Draft version April 2, 2026
Typeset using LaTeX **twocolumn** style in AASTeX631

Narrowband searches for continuous gravitational waves from known pulsars in the first two parts of the fourth LIGO–Virgo–KAGRA observing run

A. G. Abac,[1] I. Abouelfettouh,[2] F. Acernese,[3,4] K. Ackley,[5] A. Adam,[6] C. Adamcewicz,[7] S. Adhicary,[8]
D. Adhikari,[9,10] N. Adhikari,[11] R. X. Adhikari,[12] V. K. Adkins,[13] S. Afroz,[14] A. Agapito,[15] D. Agarwal,[16]
M. Agathos,[17] N. Aggarwal,[18] S. Aggarwal,[19] O. D. Aguiar,[20] I.-L. Ahrend,[21] L. Aiello,[22,23] A. Ain,[24] P. Ajith,[25]
T. Akutsu,[26,27] S. Albanesi,[28,29] L. Albers,[30] W. Ali,[31,32] S. Al-Kershi,[9,10] C. Alléné,[33] A. Allocca,[34,4]
S. Al-Shammari,[35] P. A. Altin,[36] S. Alvarez-Lopez,[37] W. Amar,[33] O. Amarasinghe,[35] A. Amato,[38,39]
F. Amicucci,[40,41] C. Amra,[42] C. Anand,[7] A. Ananyeva,[12] S. B. Anderson,[12] W. G. Anderson,[12] M. Andia,[43]
M. Ando,[44,45] M. Andrés-Carcasona,[37] J. L. Andrey,[46] T. Andrić,[47,48] J. Anglin,[49] J. Anna,[50] S. Ansoldi,[51,52]
J. M. Antelis,[53] S. Antier,[43] M. Aoumi,[54] E. Z. Appavuravther,[55,56] S. Appert,[12] S. K. Apple,[57] K. Arai,[12]
A. Araya,[58] M. C. Araya,[12] M. Arca Sedda,[47,48] F. Arciprete,[22,23] J. S. Areeda,[59] N. Aritomi,[2] F. Armato,[31,32]
S. Armstrong,[60] N. Arnaud,[61] M. Arogeti,[62] S. M. Aronson,[49] G. Ashton,[63] Y. Aso,[54,64] L. Asprea,[29]
M. Assiduo,[65,66] S. Assis de Souza Melo,[67] S. M. Aston,[68] P. Astone,[40] F. Attadio,[41,40] F. Aubin,[69]
K. AultONeal,[50] G. Avallone,[70] E. A. Avila,[53] S. Babak,[21] C. Badger,[71] S. Bae,[72] S. Bagnasco,[29] L. Baiotti,[73]
R. Bajpai,[74] T. Baka,[75,39] K. A. Baker,[6] T. Baker,[76] G. Balbi,[77] G. Baldi,[78,79] N. Baldicchi,[80,55] M. Ball,[81]
G. Ballardin,[67] S. W. Ballmer,[82] S. Banagiri,[7] B. Banerjee,[47] D. Bankar,[83] T. M. Baptiste,[13] P. Baral,[11]
M. Baratti,[84,85] J. C. Barayoga,[12] K. Baric,[12] B. C. Barish,[12] D. Barker,[2] N. Barman,[83] P. Barneo,[86,87,88]
F. Barone,[89,4] B. Barr,[90] M. Barrios,[91] L. Barsotti,[37] M. Barsuglia,[21] D. Barta,[92] M. A. Barton,[90] I. Bartos,[49]
A. Basalaev,[9,10] R. Bassiri,[93] A. Basti,[85,84] M. Bawaj,[80,55] P. Baxi,[94] J. C. Bayley,[90] A. C. Baylor,[11]
P. A. Baynard II,[62] M. Bazzan,[95,96] V. M. Bedakihale,[97] F. Beirnaert,[98] M. Bejger,[99] D. Belardinelli,[23]
A. S. Bell,[90] C. Bellani,[100] L. Bellizzi,[84,85] D. Beltran-Martinez,[101] W. Benoit,[19] I. Bentara,[61] M. Ben Yaala,[60]
S. Bera,[102] F. Bergamin,[35] B. K. Berger,[93] S. Bernuzzi,[28] M. Beroiz,[12] I. Berry,[103] D. Bersanetti,[31]
T. Bertheas,[104] A. Bertolini,[39,38] J. Betzwieser,[68] D. Beveridge,[6] G. Bevilacqua,[105] N. Bevins,[106]
R. Bhandare,[107] R. Bhatt,[12] A. Bhattacharjee,[108] D. Bhattacharjee,[109,110] S. Bhattacharyya,[111] S. Bhaumik,[49]
V. Biancalana,[105] A. Bianchi,[39,112] F. Bianchi,[55] I. A. Bilenko,[113] G. Billingsley,[12] A. Binetti,[100] S. Bini,[78,79,12]
C. Binu,[114] S. Biot,[115] O. Birnholtz,[116] S. Biscoveanu,[117] A. Bisht,[10] M. Bitossi,[67,84] M.-A. Bizouard,[118]
S. Blaber,[119] J. K. Blackburn,[12] L. A. Blagg,[81] C. D. Blair,[6,68] D. G. Blair,[6] N. Bode,[9,10] N. Boettner,[30]
P. Bogdan,[120] G. Boileau,[118] M. Boldrini,[40] G. N. Bolingbroke,[121] A. Bolliand,[122,42] L. D. Bonavena,[49]
R. Bondarescu,[86] F. Bondu,[123] V. A. Bonhomme,[37] E. Bonilla,[93] M. S. Bonilla,[59] A. Bonino,[124] R. Bonnand,[33,122]
A. Borchers,[9,10] N. Borghi,[125,77] V. Boschi,[84] S. Bose,[126] V. Bossilkov,[68] Y. Bothra,[39,112] A. Boudon,[61]
M. Boyle,[127] A. Bozzi,[67] C. Bradaschia,[84] M. J. Brady,[128] P. R. Brady,[11] A. Branch,[68] M. Branchesi,[47,48]
T. Briant,[129] A. Brillet,[118,*] M. Brinkmann,[9,10] P. Brockill,[11] E. Brockmueller,[9,10] A. F. Brooks,[12]
B. C. Brown,[49] D. D. Brown,[121] M. L. Brozzetti,[80,55] S. Brunett,[12] G. Bruno,[16] R. Bruntz,[120] J. Bryant,[124]
Y. Bu,[130] F. Bucci,[66] J. Buchanan,[120] O. Bulashenko,[86,87] T. Bulik,[131] H. J. Bulten,[39] A. Buonanno,[132,1]
K. Burtnyk,[2] R. Buscicchio,[133,134] D. Buskulic,[33] C. Buy,[104] R. L. Byer,[93] R. Cabrita,[16] V. Cáceres-Barbosa,[8]
L. Cadonati,[62] G. Cagnoli,[135] C. Cahillane,[82] A. Calafat,[136] T. A. Callister,[137] E. Calloni,[34,4] S. R. Callos,[81]
G. Caneva Santoro,[138] K. C. Cannon,[45] H. Cao,[37] L. A. Capistran,[139] E. Capocasa,[21] G. Capoccia,[55] E. Capote,[2]
G. Capurri,[85,84] G. Carapella,[70,140] F. Carbognani,[67] K. J. Cardona-Martínez,[13] M. Carlassara,[9,10]
J. B. Carlin,[130] T. K. Carlson,[141] M. F. Carney,[109] M. Carpinelli,[133,67] G. Carrillo,[81] J. J. Carter,[9,10]
G. Carullo,[124] A. Casallas-Lagos,[142] J. Casanueva Diaz,[67] C. Casentini,[143,23] S. Caudill,[141] M. Cavaglià,[110]
R. Cavalieri,[67] G. Cella,[84] S. Cepic,[125] P. Cerdá-Durán,[144,145] E. Cesarini,[23] N. Chabbra,[36] W. Chaibi,[118]
A. Chakraborty,[14] P. Chakraborty,[9,10] S. Chakraborty,[107] S. Chalathadka Subrahmanya,[30] R. Chalmers,[76]
C. Chan,[146] J. C. L. Chan,[147] M. Chan,[119] K. Chang,[148] P. Charlton,[149] E. Chassande-Mottin,[21] C. Chatterjee,[150]
Debarati Chatterjee,[83] Deep Chatterjee,[37] M. Chaturvedi,[107] S. Chaty,[21] A. Chen,[151] A. H.-Y. Chen,[152]
D. Chen,[153] H. Chen,[154] H. Y. Chen,[155] S. Chen,[150] Y. Chen,[156] G. Cheng,[151] H. P. Cheng,[103] P. Chessa,[80,55]
T. Cheunchitra,[130] H. T. Cheung,[94] S. Y. Cheung,[7] F. Chiadini,[157,140] G. Chiarini,[9,10] A. Chiba,[158] A. Chincarini,[31]
D. Chintala,[109] M. L. Chiofalo,[85,84] A. Chiummo,[4,67] C. Chou,[159] S. Choudhary,[6] N. Christensen,[118,160]
S. S. Y. Chua,[36] G. Ciani,[78,79] P. Ciecielag,[99] M. Cieślar,[131] M. Cifaldi,[23] B. Cirok,[161] F. Clara,[2] J. A. Clark,[12,62]
T. A. Clarke,[7] P. Clearwater,[146] S. Clesse,[115] F. Cleva,[118] S. M. Clyne,[128] E. Coccia,[47,48,138] E. Codazzo,[162]
P.-F. Cohadon,[129] D. E. Cohen,[9,10] S. Colace,[32] E. Colangeli,[76] O. Cole,[146] M. Colleoni,[136] C. G. Collette,[163]
J. Collins,[68] S. Colloms,[90] A. Colombo,[164,134] C. M. Compton,[2] G. Connolly,[81] L. Conti,[96] T. R. Corbitt,[13]
I. Cordero-Carrión,[165] S. Corezzi,[80,55] N. J. Cornish,[166] I. Coronado,[167] A. Corsi,[168] L. A. Corubolo,[22,23]
L. Cotnoir,[120] R. Cottingham,[68] M. W. Coughlin,[19] P. Couvares,[12,62] D. M. Coward,[6] D. C. Coyne,[12] R. Coyne,[128]
A. Cozzumbo,[47] J. D. E. Creighton,[11] T. D. Creighton,[169] S. Crook,[68] R. Crouch,[2] J. Csizmazia,[2] J. R. Cudell,[170]
T. J. Cullen,[12] A. Cumming,[90] E. Cuoco,[125,77] M. Cusinato,[144] L. V. Da Conceição,[171] T. Dal Canton,[43]
S. Dall'Osso,[172,77] S. Dal Pra,[173] G. Dálya,[104] O. Dan,[116] Y. Dang,[8] B. D'Angelo,[31] S. Danilishin,[38,39]
S. D'Antonio,[40] K. Danzmann,[9,10] K. E. Darroch,[120] L. P. Dartez,[68] R. Das,[111] A. Dasgupta,[97] V. Dattilo,[67]

A. Daumas,[21] I. Dave,[107] A. Davenport,[174] M. Davier,[43] T. F. Davies,[6] D. Davis,[12] L. Davis,[6] M. C. Davis,[19]
P. Davis,[175,176] E. J. Daw,[177] M. Dax,[1] J. De Bolle,[98] M. Deenadayalan,[83] J. Degallaix,[178] M. De Laurentis,[34,4]
C. J. Delgado Mendez,[101] F. De Lillo,[24] S. Della Torre,[134] W. Del Pozzo,[85,84] O. M. del Rio,[179] A. Demagny,[33]
F. De Marco,[41,40] G. Demasi,[180,66] F. De Matteis,[22,23] N. Demos,[37] T. Dent,[181] A. Depasse,[16] N. DePergola,[106]
R. De Pietri,[182,183] R. De Rosa,[34,4] C. De Rossi,[67] M. Desai,[37] V. Deshmukh,[90] R. De Simone,[157,140] S. Determan,[184]
A. Dhani,[1] R. Dhurkunde,[76] R. Diab,[49] C. Diaz,[101] M. C. Díaz,[169] M. Di Cesare,[34,4] G. Dideron,[185] T. Dietrich,[1]
L. Di Fiore,[4] C. Di Fronzo,[6] M. Di Giovanni,[186,84] T. Di Girolamo,[34,4] D. Diksha,[39,38] J. Ding,[37,21,187]
S. Di Pace,[41,40] I. Di Palma,[41,40] D. Di Piero,[188,52] F. Di Renzo,[66,180] Divyajyoti,[35] A. Dmitriev,[124]
J. P. Docherty,[90] Z. Doctor,[117] N. Doerksen,[171] E. Dohmen,[2] A. Doke,[141] A. Domiciano De Souza,[189]
L. D'Onofrio,[4] F. Donovan,[37] K. L. Dooley,[35] T. Dooney,[75] S. Doravari,[83] O. Dorosh,[190] F. Dosopoulou,[35]
W. J. D. Doyle,[120] M. Drago,[41,40] J. C. Driggers,[2] M. Dubois,[104] R. R. Dumbreck,[35] L. Dunn,[130] U. Dupletsa,[47]
D. D'Urso,[191,162] P. Dutta Roy,[49] H. Duval,[192] P.-A. Duverne,[21] S. E. Dwyer,[2] C. Eassa,[2] M. Eberhardt,[184]
M. Ebersold,[193,33] T. Eckhardt,[30] G. Eddolls,[82] A. Effler,[68] J. Eichholz,[36] H. Einsle,[118] M. Eisenmann,[26]
R. A. Eisenstein,[37] M. Emma,[63] K. Endo,[158] R. Enficiaud,[1] L. Errico,[34,4] R. Espinosa,[169] M. Esposito,[4,34]
R. C. Essick,[194] H. Estellés,[1] T. Etzel,[12] M. Evans,[37] T. Evstafyeva,[185] B. E. Ewing,[8] J. M. Ezquiaga,[147]
F. Fabrizi,[65,66] V. Fafone,[22,23] S. Fairhurst,[35] X. Fan,[151] A. M. Farah,[137] B. Farr,[81] W. M. Farr,[195,196]
M. Favata,[197] M. Fays,[170] M. Fazio,[60] J. Feicht,[12] M. M. Fejer,[93] J.-N. Feldhusen,[30] E. Fenyvesi,[92,198]
J. Fernandes,[199] T. Fernandes,[200,144] D. Fernando,[114] S. Ferraiuolo,[201,41,40] T. A. Ferreira,[13] M. Ferrer,[136]
F. Fidecaro,[85,84] P. Figura,[99] A. Fiori,[84,85] I. Fiori,[67] M. Fishbach,[194] R. P. Fisher,[120] R. Fittipaldi,[202,140]
V. Fiumara,[203,140] R. Flaminio,[33] S. M. Fleischer,[179] L. S. Fleming,[204] E. Floden,[19] H. Fong,[119] J. A. Font,[144,145]
F. Fontinele-Nunes,[19] C. Foo,[1] B. Fornal,[205] P. W. F. Forsyth,[36] K. Franceschetti,[182] A. Franco-Ordovas,[12]
F. Frappez,[33] S. Frasca,[41,40] F. Frasconi,[84] J. P. Freed,[50] Z. Frei,[206] A. Freise,[39,112] O. Freitas,[200,144] R. Frey,[81]
W. Frischhertz,[68] P. Fritschel,[37] V. V. Frolov,[68] M. Fuentes-Garcia,[12] S. Fujii,[207] T. Fujimori,[208] P. Fulda,[49]
M. Fyffe,[68] B. Gadre,[75] J. R. Gair,[1] S. Galaudage,[189] V. Galdi,[209] R. Gamba,[8] A. Gamboa,[1] S. Gamoji,[210]
A. Ganguly,[83] B. Garaventa,[31] P. García Abia,[101] J. García-Bellido,[211] C. García-Quirós,[193] J. W. Gardner,[36]
S. Garg,[45] J. Gargiulo,[67] X. Garrido,[43] A. Garron,[136] F. Garufi,[34,4] P. A. Garver,[93] C. Gasbarra,[212,23]
B. Gateley,[2] F. Gautier,[213] V. Gayathri,[11] T. Gayer,[82] G. Gemme,[31] A. Gennai,[84] V. Gennari,[104] J. George,[107]
R. George,[155] O. Gerberding,[30] L. Gergely,[161] Archisman Ghosh,[98] Sayantan Ghosh,[199] Shaon Ghosh,[197]
Shrobana Ghosh,[9,10] Suprovo Ghosh,[214] Tathagata Ghosh,[83] J. A. Giaime,[13,68] K. D. Giardina,[68] D. R. Gibson,[204]
C. Gier,[60] S. Gkaitatzis,[85,84] J. Glanzer,[12] F. Glotin,[43] J. Godfrey,[81] R. V. Godley,[9,10] P. Godwin,[12]
A. S. Goettel,[35] E. Goetz,[119] J. Golomb,[12] S. Gomez Lopez,[41,40] G. González,[13] P. Goodarzi,[46] S. Goode,[7]
A. Goodwin-Jones,[16] M. Gosselin,[67] C. Gostiaux,[69] R. Gouaty,[33] D. W. Gould,[36] K. Govorkova,[37] A. Grado,[80,55]
A. E. Granados,[19] M. Granata,[178] V. Granata,[215,140] S. Gras,[37] P. Grassia,[12] C. Gray,[2] R. Gray,[90] G. Greco,[55]
A. C. Green,[39,112] L. Green,[216] S. M. Green,[76] S. R. Green,[217] A. M. Gretarsson,[50] E. M. Gretarsson,[50]
H. K. Griffin,[19] D. Griffith,[12] H. L. Griggs,[62] G. Grignani,[80,55] C. Grimaud,[33] H. Grote,[35] S. Grunewald,[1]
D. Guerra,[144] A. G. Guerrero,[137] D. Guetta,[218] G. M. Guidi,[65,66] T. Guidry,[2] H. K. Gulati,[97] F. Gulminelli,[175,176]
A. M. Gunny,[37] H. Guo,[151] W. Guo,[6] Y. Guo,[39,38] Anuradha Gupta,[219] I. Gupta,[8] N. C. Gupta,[97] S. K. Gupta,[49]
V. Gupta,[19] N. Gupte,[1] J. Gurs,[30] N. Gutierrez,[178] N. Guttman,[7] F. Guzman,[139] D. Haba,[220] M. Haberland,[1]
S. Haino,[221] E. D. Hall,[37] E. Z. Hamilton,[136] G. Hammond,[90] M. Haney,[39] J. Hanks,[2] C. Hanna,[8] M. D. Hannam,[35]
O. A. Hannuksela,[222] H. Hansen,[2] J. Hanson,[68] R. Harada,[45] A. R. Hardison,[184] S. Harikumar,[99] K. Haris,[223]
I. Harley-Trochimczyk,[139] T. Harmark,[224] J. Harms,[47,48] G. M. Harry,[225] I. W. Harry,[76] J. Hart,[109]
M. T. Hartman,[21] B. Haskell,[99,226,227] C.-J. Haster,[216] K. Haughian,[90] H. Hayakawa,[54] K. Hayama,[228]
A. Heffernan,[136] D. Hegde,[16] M. C. Heintze,[68] J. Heinze,[124] J. Heinzel,[37] H. Heitmann,[118] F. Hellman,[91]
A. F. Helmling-Cornell,[81] G. Hemming,[67] O. Henderson-Sapir,[121] M. Hendry,[90] I. S. Heng,[90] M. H. Hennig,[90]
C. Henshaw,[62] M. Heurs,[9,10] A. L. Hewitt,[229,230] J. Heynen,[16] J. Heyns,[37] S. Higginbotham,[35] S. Hild,[38,39] S. Hill,[90]
Y. Himemoto,[231] N. Hirata,[26] C. Hirose,[232] W. C. G. Ho,[233] D. Hofman,[178] B. E. Hogan,[50] N. A. Holland,[39,112]
K. Holley-Bockelmann,[150] I. J. Hollows,[177] D. E. Holz,[137] L. Honet,[115] K. M. Hoops,[210] M. E. Hoque,[234]
D. J. Horton-Bailey,[91] J. Hough,[90] S. Hourihane,[12] N. T. Howard,[150] E. J. Howell,[6] C. G. Hoy,[76]
C. A. Hrishikesh,[22] P. Hsi,[37] H.-F. Hsieh,[154] H.-Y. Hsieh,[154] C. Hsiung,[235] S.-H. Hsu,[236] W.-F. Hsu,[100] Q. Hu,[90]
H. Y. Huang,[148] Y. Huang,[8] Y. T. Huang,[82] A. D. Huddart,[237] B. Hughey,[50] V. Hui,[33] S. Husa,[136] L. Iampieri,[41,40]
G. A. Iandolo,[38] M. Ianni,[23,22] G. Iannone,[140] J. Iascau,[81] K. Ide,[238] R. Iden,[220] A. Ierardi,[47,48] S. Ikeda,[153]
H. Imafuku,[45] Y. Inoue,[148] G. Iorio,[95] P. Iosif,[188,52] J. Irwin,[90] R. Ishikawa,[238] T. Ishikawa,[239] M. Isi,[196]
K. S. Isleif,[240] Y. Itoh,[208,241] S. Iwaguchi,[239] M. Iwaya,[207] B. R. Iyer,[25] C. D. Jackson,[49] C. Jacquet,[104]
P.-E. Jacquet,[129] T. Jacquot,[43] S. J. Jadhav,[242] S. P. Jadhav,[146] M. Jain,[141] T. Jain,[229] A. L. James,[12] K. Jani,[150]
J. Janquart,[16] N. N. Janthalur,[242] S. Jaraba,[243] P. Jaranowski,[244] R. Jaume,[136] W. Javed,[35] M. Jensen,[2] W. Jia,[37]
J. Jiang,[103] H.-B. Jin,[245,246] G. R. Johns,[120] N. A. Johnson,[49] R. Johnston,[90] N. Johny,[9,10] D. H. Jones,[36]
D. I. Jones,[214] R. Jones,[90] H. E. Jose,[81] P. Joshi,[62] S. K. Joshi,[83] G. Joubert,[61] J. Ju,[247] L. Ju,[6]
I. L. Juarez-Reyes,[81] K. Jung,[248] J. Junker,[36] V. Juste,[115] H. B. Kabagoz,[37] T. Kajita,[207] I. Kaku,[208]
V. Kalogera,[117] M. Kalomenopoulos,[216] M. Kamiizumi,[54] N. Kanda,[241,208] S. Kandhasamy,[83] G. Kang,[249]
J. B. Kanner,[12] S. A. KantiMahanty,[19] S. J. Kapadia,[83] D. P. Kapasi,[59] M. Karthikeyan,[141] M. Kasprzack,[12]
H. Kato,[158] T. Kato,[207] E. Katsavounidis,[37] W. Katzman,[68] R. Kaushik,[107] K. Kawabe,[2] R. Kawamoto,[208]
D. Keitel,[136] S. A. Kemper,[57] L. J. Kemperman,[121] J. Kennington,[8] F. A. Kerkow,[19] R. Kesharwani,[83] J. S. Key,[250]

R. Khadela,[9,10] S. Khadka,[93] S. S. Khadkikar,[8] F. Y. Khalili,[113] F. Khan,[9,10] T. Khanam,[168] M. Khursheed,[107]
N. M. Khusid,[195,196] W. Kiendrebeogo,[118,251] N. Kijbunchoo,[121] C. Kim,[252] J. C. Kim,[253] K. Kim,[254] M. H. Kim,[247]
S. Kim,[255] Y.-M. Kim,[254] C. Kimball,[117] K. Kimes,[59] M. Kinnear,[35] J. S. Kissel,[2] S. Klimenko,[49] A. M. Knee,[119]
E. J. Knox,[81] N. Knust,[9,10] K. Kobayashi,[207] S. M. Koehlenbeck,[93] G. Koekoek,[39,38] K. Kohri,[256]
K. Kokeyama,[35,239] S. Koley,[47,170] P. Kolitsidou,[124] A. E. Koloniari,[257] K. Komori,[44,45] K. Kompanets,[19]
A. K. H. Kong,[154] A. Kontos,[258] K. Kopczuk,[109] L. M. Koponen,[124] M. Korobko,[30] X. Kou,[19] A. Koushik,[24]
N. Kouvatsos,[71] M. Kovalam,[6] T. Koyama,[158] D. B. Kozak,[12] E. Kraja,[67] S. L. Kranzhoff,[38,39] V. Kringel,[9,10]
N. V. Krishnendu,[124] S. Kroker,[259] A. Królak,[260,190] K. Kruska,[9,10] J. Kubisz,[261] G. Kuehn,[9,10]
A. Kulur Ramamohan,[36] Achal Kumar,[49] Anil Kumar,[242] Praveen Kumar,[181] Prayush Kumar,[25] Rahul Kumar,[2]
Rakesh Kumar,[97] J. Kume,[262,263,45] K. Kuns,[37] N. Kuntimaddi,[35] S. Kuroyanagi,[264,265] S. Kuwahara,[45] K. Kwak,[248]
K. Kwan,[36] S. Kwon,[45] G. Lacaille,[90] D. Laghi,[193] A. H. Laity,[128] A. Lakhal,[129] E. Lalande,[266] M. Lalleman,[24]
S. Lalvani,[117] M. Landry,[2] R. N. Lang,[37] J. Lange,[155] R. Langgin,[216] B. Lantz,[93] I. La Rosa,[136]
A. Lartaux-Vollard,[43] P. D. Lasky,[7] L. Lavezzi,[29] J. Lawrence,[169] M. Laxen,[68] C. Lazarte,[144] A. Lazzarini,[12]
C. Lazzaro,[267,162] P. Leaci,[41,40] L. Leali,[19] Y. K. Lecoeuche,[119] H. W. Lee,[268] J. Lee,[82] K. Lee,[247] R.-K. Lee,[154]
R. Lee,[37] Sungho Lee,[269] Sunjae Lee,[247] Y. Lee,[148] I. N. Legred,[12] J. Lehmann,[9,10] L. Lehner,[185] M. Le Jean,[178,122]
A. Lemaître,[270] M. Lenti,[66,180] M. Leonardi,[78,79,271] M. Lequime,[42] N. Leroy,[43] M. Lesovsky,[12] N. Letendre,[33]
M. Lethuillier,[61] S. E. Levin,[46] Y. Levin,[7] S. Lexmond,[112] K. Leyde,[76] K. L. Li,[272] T. G. F. Li,[100] X. Li,[156] Y. Li,[117]
Z. Li,[90] Q. Liang,[151] A. Lihos,[120] E. T. Lin,[154] F. Lin,[148] L. C.-C. Lin,[272] Y.-C. Lin,[154] C. Lindsay,[204] S. D. Linker,[210]
A. Liu,[222] G. C. Liu,[235] Jian Liu,[6] S. Liu,[151] F. Llamas Villarreal,[169] J. Llobera-Querol,[136] R. K. L. Lo,[147]
J.-P. Locquet,[100] S. C. G. Loggins,[273] M. R. Loizou,[141] L. T. London,[71,37] A. Longo,[65,66] D. Lopez,[170]
M. Lopez Portilla,[75] A. Lorenzo-Medina,[181] V. Loriette,[43] M. Lormand,[68] G. Losurdo,[186,84] E. Lotti,[141]
T. P. Lott IV,[62] J. D. Lough,[9,10] H. A. Loughlin,[37] C. O. Lousto,[114] N. K. Y Low,[130] N. Lu,[36] L. Lucchesi,[84]
H. Lück,[9,10] O. Lukina,[37] D. Lumaca,[23] A. P. Lundgren,[274,275] L. Lunghini,[67,34,4] A. W. Lussier,[266] X. Ma,[46]
D. M. Macleod,[35] I. A. O. MacMillan,[12] A. Macquet,[43] S. S. Madekar,[138] K. Maeda,[158] S. Maenaut,[100]
S. S. Magare,[83] R. M. Magee,[12] E. Maggio,[1] R. Maggiore,[39,112] M. Magnozzi,[31,32] P. Mahapatra,[35] M. Mahesh,[30]
S. Majhi,[83] E. Majorana,[41,40] C. N. Makarem,[12] E. Makelele,[109] D. Malakar,[110] J. A. Malaquias-Reis,[20]
U. Mali,[194] S. Maliakal,[12] A. Malik,[107] L. Mallick,[171,194] A.-K. Malz,[63] N. Man,[118] M. Mancarella,[102]
V. Mandic,[19] V. Mangano,[191,162] B. Mannix,[81] G. L. Mansell,[82,37] M. Manske,[11] M. Mantovani,[67]
M. Mapelli,[95,96,276] S. Marchetti,[95,96] C. Marinelli,[105] F. Marion,[33] A. S. Markosyan,[93] A. Markowitz,[12]
E. Maros,[12] S. Marsat,[104] F. Martelli,[65,66] I. W. Martin,[90] R. M. Martin,[197] B. B. Martinez,[139] D. A. Martinez,[59]
M. Martinez,[138,277] V. Martinez,[135] A. Martini,[78,79] J. C. Martins,[20] D. V. Martynov,[124] E. J. Marx,[37]
L. Massaro,[38,39] A. Masserot,[33] M. Masso-Reid,[90] T. Masters,[109] S. Mastrogiovanni,[40] G. Mastropasqua,[77]
T. Matcovich,[55] M. Matiushechkina,[9,10] A. Matte-Landry,[266] L. Maurin,[213] N. Mavalvala,[37] N. Maxwell,[2]
G. McCarrol,[68] R. McCarthy,[2] D. E. McClelland,[36] S. McCormick,[68] L. McCuller,[12] L. I. McDermott,[126]
S. McEachin,[120] C. McElhenny,[120] G. I. McGhee,[90] K. B. M. McGowan,[150] J. McIver,[119] A. McLeod,[6] T. McRae,[36]
R. McTeague,[90] D. Meacher,[11] B. N. Meagher,[82] R. Mechum,[114] Q. Meijer,[75] A. Melatos,[130] C. S. Menoni,[174]
F. Mera,[2] R. A. Mercer,[11] L. Mereni,[178] K. Merfeld,[168] E. L. Merilh,[68] G. Merino,[101] J. R. Mérou,[136]
J. D. Merritt,[81] M. Merzougui,[118] C. Messick,[11] B. Mestichelli,[47] M. Meyer-Conde,[278] F. Meylahn,[9,10]
A. Mhaske,[83] A. Miani,[78,79] H. Miao,[279] I. Michaloliakos,[49] C. Michel,[178] Y. Michimura,[12,45] H. Middleton,[124]
D. P. Mihaylov,[109] S. J. Miller,[12] M. Millhouse,[62] E. Milotti,[188,52] V. Milotti,[95] Y. Minenkov,[23] E. M. Minihan,[50]
Ll. M. Mir,[138] L. Mirasola,[162,267] C.-A. Miritescu,[138] A. Mishra,[25] C. Mishra,[111] T. Mishra,[49] A. L. Mitchell,[39,112]
J. G. Mitchell,[50] O. Mitchem,[81] S. Mitra,[83] V. P. Mitrofanov,[113] K. Mitsuhashi,[26] R. Mittleman,[37]
O. Miyakawa,[54] S. Miyoki,[54] G. Mo,[37] L. Mobilia,[65,66] S. R. P. Mohapatra,[12] S. R. Mohite,[8] M. Molina-Ruiz,[91]
M. Mondin,[210] M. Montani,[65,66] C. J. Moore,[229] D. Moraru,[2] A. More,[83] S. More,[83] C. Moreno,[280]
E. A. Moreno,[37] G. Moreno,[2] A. Moreso Serra,[86] C. Morgan,[35] S. Morisaki,[207] Y. Moriwaki,[158] G. Morras,[211]
A. Moscatello,[95] M. Mould,[37] B. Mours,[69] C. M. Mow-Lowry,[39,112] L. Muccillo,[180,66] F. Muciaccia,[41,40]
Arunava Mukherjee,[234] D. Mukherjee,[124] Samanwaya Mukherjee,[25] Soma Mukherjee,[169] Subroto Mukherjee,[97]
Suvodip Mukherjee,[14] N. Mukund,[37] A. Mullavey,[68] C. L. Mungioli,[6] M. Murakoshi,[238] P. G. Murray,[90]
D. Nabari,[78,79] S. L. Nadji,[9,10] S. Nadji,[178] A. Nagar,[29,281] N. Nagarajan,[90] K. Nakagaki,[54] K. Nakamura,[26]
H. Nakano,[282] M. Nakano,[12] D. Nanadoumgar-Lacroze,[138] D. Nandi,[13] V. Napolano,[67] S. U. Naqvi,[111]
P. Narayan,[219] I. Nardecchia,[23] T. Narikawa,[207] H. Narola,[75] L. Naticchioni,[283,40] R. K. Nayak,[284] J. Neeson,[35]
L. Negri,[75] A. Nela,[90] C. Nelle,[81] A. Nelson,[139] T. J. N. Nelson,[68] A. Nemmani,[99] M. Nery,[9,10] A. Neunzert,[2]
M. Newell,[17] S. Ng,[59] L. Nguyen Quynh,[285] A. B. Nielsen,[286] Y. Nishino,[26,287] A. Nishizawa,[288] S. Nissanke,[289,39]
W. Niu,[8] F. Nocera,[67] J. Noller,[290] M. Norman,[35] C. North,[35] J. Novak,[243,291] R. Nowicki,[150] J. F. Nuño Siles,[211]
G. Nurbek,[169] L. K. Nuttall,[76] K. Obayashi,[238] J. Oberling,[2] C. E. Ochoa,[46] J. O'Dell,[237] M. Oertel,[243,291]
G. Oganesyan,[47,48] T. O'Hanlon,[68] M. Ohashi,[54,278] F. Ohme,[9,10] I. Oke,[60] R. Omer,[19] B. O'Neal,[120] M. Onishi,[158]
K. Oohara,[292,293] B. O'Reilly,[68] M. Orselli,[55,80] R. O'Shaughnessy,[114] S. Oshino,[54] C. Osthelder,[12] I. Ota,[13]
G. Othman,[240] D. J. Ottaway,[121] A. Ouzriat,[61] H. Overmier,[68] B. J. Owen,[108] R. Ozaki,[238] A. E. Pace,[8]
R. Pagano,[13] M. A. Page,[26] A. Pai,[199] L. Paiella,[47] A. Pal,[294] S. Pal,[284] M. A. Palaia,[84,85] M. Pálfi,[206]
P. P. Palma,[41,22,23] C. Palomba,[40] P. Palud,[21] H. Pan,[154] J. Pan,[6] K.-C. Pan,[154,154] P. K. Panda,[242]
Shiksha Pandey,[8] Swadha Pandey,[37] P. T. H. Pang,[39,75] F. Pannarale,[41,40] K. A. Pannone,[59] B. C. Pant,[107]
F. H. Panther,[6] M. Panzeri,[65,66] F. Paoletti,[84] A. Paolone,[40,295] A. Papadopoulos,[90] E. E. Papalexakis,[46]

L. Papalini,[84, 85] G. Papigkiotis,[257] A. Paquis,[43] A. Parisi,[80, 55] B.-J. Park,[269] J. Park,[296] W. Parker,[68]
G. Pascale,[9, 10] D. Pascucci,[98] A. Pasqualetti,[67] R. Passaquieti,[85, 84] L. Passenger,[7] D. Passuello,[84] O. Patane,[2]
A. V. Patel,[148] D. Pathak,[83] A. Patra,[35] B. Patricelli,[85, 84] B. G. Patterson,[35] K. Paul,[111] S. Paul,[81] E. Payne,[12]
T. Pearce,[35] M. Pedraza,[12] A. Pele,[12] F. E. Peña Arellano,[297] X. Peng,[124] Y. Peng,[62] S. Penn,[298, 82]
M. D. Penuliar,[59] A. Perego,[78, 79] Z. Pereira,[141] C. Périgois,[299, 96, 95] G. Perna,[95] A. Perreca,[47, 48] J. Perret,[21]
S. Perriès,[61] J. W. Perry,[39, 112] S. Peters,[170] S. Petracca,[209] C. Petrillo,[80] H. P. Pfeiffer,[1] H. Pham,[68]
K. A. Pham,[19] K. S. Phukon,[124] H. Phurailatpam,[222] M. Piarulli,[104] L. Piccari,[41, 40] O. J. Piccinni,[36] M. Pichot,[118]
A. Pied,[90] M. Piendibene,[85, 84] F. Piergiovanni,[65, 66] L. Pierini,[40] G. Pierra,[40] V. Pierro,[300, 140] M. Pietrzak,[99]
M. Pillas,[301] L. Pinard,[178] I. M. Pinto,[300, 140, 302, 34] M. Pinto,[67] B. J. Piotrzkowski,[11] M. Pirello,[2]
M. D. Pitkin,[229, 90] A. Placidi,[55] E. Placidi,[41, 40] M. L. Planas,[136] W. Plastino,[215, 23] C. Plunkett,[37]
R. Poggiani,[85, 84] E. Polini,[118] J. Pomper,[84, 85] L. Pompili,[1] J. Poon,[222] E. Porcelli,[39] A. S. Porter,[108]
E. K. Porter,[21] C. Posnansky,[8] R. Poulton,[67] J. Powell,[146] G. S. Prabhu,[83] M. Pracchia,[170] B. K. Pradhan,[83]
T. Pradier,[69] A. K. Prajapati,[97] K. Prasai,[303] R. Prasanna,[242] P. Prasia,[304] G. Pratten,[124] A. Praveen,[194]
G. Principe,[188, 52] G. A. Prodi,[78, 79] P. Prosperi,[84] P. Prosposito,[22, 23] A. Puecher,[1] J. Pullin,[13] P. Puppo,[40]
M. Pürrer,[128] H. Qi,[17] M. Qiao,[151] J. Qin,[36] G. Quéméner,[176, 122] V. Quetschke,[169] P. J. Quinonez,[50] R. Rading,[240]
I. Rainho,[144] S. Raja,[107] C. Rajan,[107] B. Rajbhandari,[114] K. E. Ramirez,[68] F. A. Ramis Vidal,[136]
M. Ramos Arevalo,[169] A. Ramos-Buades,[136, 39] S. Ranjan,[62] M. Ranjbar,[46] K. Ransom,[68] P. Rapagnani,[41, 40]
B. Ratto,[50] A. Ravichandran,[141] A. Ray,[117] V. Raymond,[35] M. Razzano,[85, 84] J. Read,[59] J. Regan,[216] T. Regimbau,[33]
T. Reichardt,[146] S. Reid,[60] C. Reissel,[37] D. H. Reitze,[12] A. I. Renzini,[12, 133, 134] B. Revenu,[305, 43] A. Revilla Peña,[86]
L. Ricca,[16] F. Ricci,[41, 40] M. Ricci,[40, 41] A. Ricciardone,[85, 84] J. Rice,[82] J. W. Richardson,[46] M. L. Richardson,[121]
A. Rijal,[50] K. Riles,[94] H. K. Riley,[35] S. Rinaldi,[276] J. Rittmeyer,[30] C. Robertson,[237] F. Robinet,[43] M. Robinson,[2]
A. Rocchi,[23] L. Rolland,[33] J. G. Rollins,[12] A. E. Romano,[306] R. Romano,[3, 4] A. Romero-Rodríguez,[33]
I. M. Romero-Shaw,[229] J. H. Romie,[68] S. Ronchini,[8] T. J. Roocke,[121] L. Rosa,[4, 34] T. J. Rosauer,[46] C. A. Rose,[62]
D. Rosińska,[131] M. P. Ross,[57] M. Rossello-Sastre,[136] S. Rowan,[90] K. Rowlands,[184] S. K. Roy,[195, 196] S. Roy,[16]
D. Rozza,[133, 134] P. Ruggi,[67] N. Ruhama,[248] G. H. Ruiz,[273] E. Ruiz Morales,[307, 211] K. Ruiz-Rocha,[150] V. Russ,[179]
S. Sachdev,[62] T. Sadecki,[2] P. Saffarieh,[39, 112] S. Safi-Harb,[171] M. R. Sah,[14] S. Saha,[154] T. Sainrat,[69]
S. Sajith Menon,[218, 41, 40] K. Sakai,[308] Y. Sakai,[278] M. Sakellariadou,[71] S. Sakon,[8] O. S. Salafia,[164, 134, 133]
F. Salces-Carcoba,[12] L. Salconi,[67] M. Saleem,[155] F. Salemi,[41, 40] M. Sallé,[39] S. U. Salunkhe,[83] S. Salvador,[176, 175]
A. Salvarese,[155] A. Samajdar,[75, 39] A. Sanchez,[2] E. J. Sanchez,[12] N. Sanchis-Gual,[144] J. R. Sanders,[184]
E. M. Sänger,[1] F. Santoliquido,[47, 48] F. Sarandrea,[29] T. R. Saravanan,[83] N. Sarin,[7] P. Sarkar,[9, 10] A. Sasli,[19, 257]
P. Sassi,[55, 80] B. Sassolas,[178] R. Sato,[232] S. Sato,[158] Yukino Sato,[158] Yu Sato,[158] O. Sauter,[49] R. L. Savage,[2]
T. Sawada,[54] H. L. Sawant,[83] S. Sayah,[178] V. Scacco,[22, 23] D. Schaetzl,[12] M. Scheel,[156] A. Schiebelbein,[194]
M. G. Schiworski,[82] P. Schmidt,[124] S. Schmidt,[75] R. Schnabel,[30] M. Schneewind,[9, 10] R. M. S. Schofield,[81, 2]
K. Schouteden,[100] B. W. Schulte,[9, 10] M. Schulz,[47, 48] B. F. Schutz,[35, 9, 10] E. Schwartz,[309] M. Scialpi,[310] J. Scott,[90]
S. M. Scott,[36] R. M. Sedas,[68] T. C. Seetharamu,[90] M. Seglar-Arroyo,[138] Y. Sekiguchi,[311] D. Sellers,[68]
N. Sembo,[208] A. S. Sengupta,[312] E. G. Seo,[90] J. W. Seo,[100] V. Sequino,[34, 4] M. Serra,[40] A. Sevrin,[192] T. Shaffer,[2]
U. S. Shah,[62] M. A. Shaikh,[313] L. Shao,[314] J. Sharkey,[90] A. K. Sharma,[136] Preeti Sharma,[13] Priyanka Sharma,[107]
Ritwik Sharma,[19] Sushant Sharma-Chaudhary,[19] P. Shawhan,[132] N. S. Shcheblanov,[315, 270] E. Sheridan,[150]
Z.-H. Shi,[154] R. Shimomura,[316] H. Shinkai,[316] S. Shirke,[83] D. H. Shoemaker,[37] D. M. Shoemaker,[155] R. W. Short,[2]
S. ShyamSundar,[107] A. Sider,[163] H. Siegel,[195, 196] V. Sierra,[280] D. Sigg,[2] L. Silenzi,[38, 39] L. Silvestri,[41, 173]
M. Simmonds,[121] L. P. Singer,[317] Amitesh Singh,[219] Anika Singh,[12] D. Singh,[91] M. K. Singh,[35] N. Singh,[136]
S. Singh,[220, 26] A. M. Sintes,[136] V. Sipala,[191, 162] V. Skliris,[35] B. J. J. Slagmolen,[36] T. J. Slaven-Blair,[6]
J. Smetana,[124] D. A. Smith,[68] J. R. Smith,[59] L. Smith,[188, 52] R. J. E. Smith,[7] W. J. Smith,[150]
S. Soares de Albuquerque Filho,[65] K. Somiya,[220] I. Song,[154] S. Soni,[37] V. Sordini,[61] F. Sorrentino,[31] H. Sotani,[318]
F. Spada,[84] V. Spagnuolo,[39] A. P. Spencer,[90] P. Spinicelli,[67] A. K. Srivastava,[97] F. Stachurski,[90] C. J. Stark,[120]
D. A. Steer,[319] N. Steinle,[171] J. Steinlechner,[38, 39] S. Steinlechner,[38, 39] N. Stergioulas,[257] P. Stevens,[43]
M. StPierre,[128] M. D. Strong,[13] A. Strunk,[2] A. L. Stuver,[106, †] M. Suchenek,[99] S. Sudhagar,[99] Y. Sudo,[238]
N. Sueltmann,[30] L. Suleiman,[59] K. D. Sullivan,[13] J. Sun,[253, 249] L. Sun,[36] S. Sunil,[97] J. Suresh,[118] B. J. Sutton,[71]
P. J. Sutton,[35] K. Suzuki,[220] M. Suzuki,[207] A. Svizzeretto,[80] B. L. Swinkels,[39] A. Syx,[122] M. J. Szczepańczyk,[142]
P. Szewczyk,[131] M. Tacca,[39] M. Tagliazucchi,[125, 77] H. Tagoshi,[207] S. C. Tait,[12] K. Takada,[207] H. Takahashi,[278]
R. Takahashi,[26] A. Takamori,[58] S. Takano,[9, 10] H. Takeda,[320, 321] K. Takeshita,[220] I. Takimoto Schmiegelow,[47, 48]
M. Takou-Ayaoh,[82] C. Talbot,[137] M. Tamaki,[207] N. Tamanini,[104] D. Tanabe,[148] K. Tanaka,[54] S. J. Tanaka,[238]
S. Tanioka,[35] D. B. Tanner,[49] W. Tanner,[9, 10] L. Tao,[46] R. D. Tapia,[8] E. N. Tapia San Martín,[39] C. Taranto,[22, 23]
A. Taruya,[322] J. D. Tasson,[160] J. G. Tau,[114] A. Tejera,[168] R. Tenorio,[136] H. Themann,[210] A. Theodoropoulos,[144]
M. P. Thirugnanasambandam,[83] L. M. Thomas,[12] M. Thomas,[68] P. Thomas,[2] J. E. Thompson,[214] S. R. Thondapu,[107]
K. A. Thorne,[68] E. Thrane,[7] J. Tissino,[47, 48] A. Tiwari,[83] Pawan Tiwari,[47] Praveer Tiwari,[199] S. Tiwari,[193]
V. Tiwari,[124] M. R. Todd,[82] E. Tofani,[40] M. Toffano,[95] A. M. Toivonen,[19] K. Toland,[90] A. E. Tolley,[76]
T. Tomaru,[26] V. Tommasini,[12] T. Tomura,[54] H. Tong,[7] C. Tong-Yu,[148] A. Torres-Forné,[144, 145] C. I. Torrie,[12]
I. Tosta e Melo,[323] E. Tournefier,[33] M. Trad Nery,[118] A. Trapananti,[56, 55] R. Travaglini,[77] F. Travasso,[56, 55]
G. Traylor,[68] M. Trevor,[132] M. C. Tringali,[67] A. Tripathee,[94] G. Troian,[188, 52] A. Trovato,[188, 52] L. Trozzo,[4]
R. J. Trudeau,[12] T. Tsang,[35] S. Tsuchida,[324] K. Tsuji,[239] L. Tsukada,[216] K. Turbang,[192, 24] M. Turconi,[118]
C. Turski,[98] H. Ubach,[86, 87] A. S. Ubhi,[124] T. Uchiyama,[54] R. P. Udall,[119] T. Uehara,[325] K. Ueno,[45] V. Undheim,[286]

L. E. Uronen,[222] T. Ushiba,[54] M. Vacatello,[84,85] H. Vahlbruch,[9,10] G. Vajente,[12] J. Valencia,[136]
M. Valentini,[112,39] E. Vallejo-Pagès,[138] S. A. Vallejo-Peña,[306] S. Vallero,[29] M. van Dael,[39,326]
E. Van den Bossche,[192] J. F. J. van den Brand,[38,112,39] C. Van Den Broeck,[75,39] M. van der Kolk,[112]
M. van der Sluys,[39,75] A. Van de Walle,[43] J. van Dongen,[39] K. Vandra,[106] M. VanDyke,[126] H. van Haevermaet,[24]
J. V. van Heijningen,[39,112] P. Van Hove,[69] J. Vanier,[266] J. Vanosky,[2] N. van Remortel,[24] M. Vardaro,[38,39]
A. F. Vargas,[130] V. Varma,[141] A. Vecchio,[124] G. Vedovato,[96] J. Veitch,[90] P. J. Veitch,[121] S. Venikoudis,[16]
J. Venneberg,[37] R. C. Venterea,[19] P. Verdier,[61] M. Vereecken,[16] D. Verkindt,[33] B. Verma,[141] Y. Verma,[107]
S. M. Vermeulen,[12] F. Vetrano,[65] A. Veutro,[40,41] A. Viceré,[65,66] S. Vidyant,[82] A. D. Viets,[327] A. Vijaykumar,[194]
A. Vilkha,[114] N. Villanueva Espinosa,[144] V. Villa-Ortega,[181] E. T. Vincent,[62] J.-Y. Vinet,[118] S. Viret,[61]
S. Vitale,[37] A. Vives,[81] L. Vizmeg,[179] H. Vocca,[80,55] D. Voigt,[30] E. R. G. von Reis,[2] J. S. A. von Wrangel,[9,10]
W. E. Vossius,[240] L. Vujeva,[147] S. P. Vyatchanin,[113] J. Wack,[12] L. E. Wade,[109] M. Wade,[109] K. J. Wagner,[114]
L. Wallace,[12] E. J. Wang,[93] H. Wang,[220] W. H. Wang,[169] Y. F. Wang,[1] Z. Wang,[151] G. Waratkar,[199] R. L. Ward,[36]
J. Warner,[2] M. Was,[33] T. Washimi,[26] N. Y. Washington,[12] B. Weaver,[2] S. A. Webster,[90] N. L. Weickhardt,[30]
M. Weinert,[9,10] A. J. Weinstein,[12] R. Weiss,[37,‡] L. Wen,[6] K. Wette,[36] C. Wheeler,[68] J. T. Whelan,[114]
B. F. Whiting,[49] E. G. Wickens,[76] D. Wilken,[9,10] B. M. Williams,[126] D. Williams,[90] M. J. Williams,[76]
N. S. Williams,[1] J. L. Willis,[12] B. Willke,[9,10] M. Wils,[100] L. Wilson,[109] C. W. Winborn,[110] J. Winterflood,[6]
C. C. Wipf,[12] G. Woan,[90] J. Woehler,[38,39] N. E. Wolfe,[37] H. T. Wong,[148] I. C. F. Wong,[100] K. Wong,[194]
T. Wouters,[75,39] J. L. Wright,[2] M. Wright,[90,75] B. Wu,[82] C. Wu,[154] D. S. Wu,[9,10] H. Wu,[154] K. Wu,[126] Q. Wu,[57]
Z. Wu,[104] E. Wuchner,[59] D. M. Wysocki,[11] V. A. Xu,[91] Y. Xu,[136] N. Yadav,[29] H. Yamamoto,[12] K. Yamamoto,[158]
T. S. Yamamoto,[45] T. Yamamoto,[54] R. Yamazaki,[238] T. Yan,[124] H. Yang,[279] K. Z. Yang,[19] Y. Yang,[159]
Z. Yarbrough,[13] J. Yebana,[136] S.-W. Yeh,[154] A. B. Yelikar,[150] X. Yin,[37] J. Yokoyama,[328,45,44] T. Yokozawa,[54]
S. Yuan,[6] H. Yuzurihara,[54] M. Zanolin,[50] M. Zeeshan,[114] T. Zelenova,[67] J.-P. Zendri,[96] M. Zeoli,[16] M. Zerrad,[42]
M. Zevin,[117] H. Zhang,[151] L. Zhang,[12] N. Zhang,[62] R. Zhang,[103] T. Zhang,[124] C. Zhao,[6] Yue Zhao,[167]
Yuhang Zhao,[21] Z.-C. Zhao,[329] Y. Zheng,[110] H. Zhong,[19] H. Zhou,[82] H. O. Zhu,[6] Z.-H. Zhu,[329,330] Z. Zhu,[114]
A. B. Zimmerman,[155] L. Zimmermann,[61] M. E. Zucker,[37,12]

The LIGO Scientific Collaboration, the Virgo Collaboration, and the KAGRA Collaboration

S.B. Araujo Furlan,[331] Z. Arzoumanian,[332] E. Carli,[333,334] I. Cognard,[335,336] M. Curyło,[337,334]
S. del Palacio,[331,338] C. M. Espinoza,[339,340] E. Fonseca,[341,342] G. Gancio,[331] F. García,[331,343] K. C. Gendreau,[332]
L. Guillemot,[335,336] S. Guillot,[344,345] M. J. Keith,[346] L. Kuiper,[347] A. G. Lyne,[346] B. W. Meyers,[348,349]
M. T. Miles,[350,334] J. L. Palfreyman,[351] A. B. Pearlman,[352,353] D. J. Reardon,[333,334] G. E. Romero,[331,343]
R. M. Shannon,[333,334] B. Shaw,[346] I. H. Stairs,[354] B. W. Stappers,[346] G. Theureau,[335,336] P. Weltevrede,[346]
E. Zubieta,[331,343]

[1] *Max Planck Institute for Gravitational Physics (Albert Einstein Institute), D-14476 Potsdam, Germany*
[2] *LIGO Hanford Observatory, Richland, WA 99352, USA*
[3] *Dipartimento di Farmacia, Università di Salerno, I-84084 Fisciano, Salerno, Italy*
[4] *INFN, Sezione di Napoli, I-80126 Napoli, Italy*
[5] *University of Warwick, Coventry CV4 7AL, United Kingdom*
[6] *OzGrav, University of Western Australia, Crawley, Western Australia 6009, Australia*
[7] *OzGrav, School of Physics & Astronomy, Monash University, Clayton 3800, Victoria, Australia*
[8] *The Pennsylvania State University, University Park, PA 16802, USA*
[9] *Max Planck Institute for Gravitational Physics (Albert Einstein Institute), D-30167 Hannover, Germany*
[10] *Leibniz Universität Hannover, D-30167 Hannover, Germany*
[11] *University of Wisconsin-Milwaukee, Milwaukee, WI 53201, USA*
[12] *LIGO Laboratory, California Institute of Technology, Pasadena, CA 91125, USA*
[13] *Louisiana State University, Baton Rouge, LA 70803, USA*
[14] *Tata Institute of Fundamental Research, Mumbai 400005, India*
[15] *Centre de Physique Théorique, Aix-Marseille Université, Campus de Luminy, 163 Av. de Luminy, 13009 Marseille, France*
[16] *Université catholique de Louvain, B-1348 Louvain-la-Neuve, Belgium*
[17] *Queen Mary University of London, London E1 4NS, United Kingdom*
[18] *University of California, Davis, Davis, CA 95616, USA*
[19] *University of Minnesota, Minneapolis, MN 55455, USA*
[20] *Instituto Nacional de Pesquisas Espaciais, 12227-010 São José dos Campos, São Paulo, Brazil*
[21] *Université Paris Cité, CNRS, Astroparticule et Cosmologie, F-75013 Paris, France*
[22] *Università di Roma Tor Vergata, I-00133 Roma, Italy*
[23] *INFN, Sezione di Roma Tor Vergata, I-00133 Roma, Italy*
[24] *Universiteit Antwerpen, 2000 Antwerpen, Belgium*
[25] *International Centre for Theoretical Sciences, Tata Institute of Fundamental Research, Bengaluru 560089, India*
[26] *Gravitational Wave Science Project, National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka City, Tokyo 181-8588, Japan*

[27]Advanced Technology Center, National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka City, Tokyo 181-8588, Japan
[28]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena, D-07743 Jena, Germany
[29]INFN Sezione di Torino, I-10125 Torino, Italy
[30]Universität Hamburg, D-22761 Hamburg, Germany
[31]INFN, Sezione di Genova, I-16146 Genova, Italy
[32]Dipartimento di Fisica, Università degli Studi di Genova, I-16146 Genova, Italy
[33]Univ. Savoie Mont Blanc, CNRS, Laboratoire d'Annecy de Physique des Particules - IN2P3, F-74000 Annecy, France
[34]Università di Napoli "Federico II", I-80126 Napoli, Italy
[35]Cardiff University, Cardiff CF24 3AA, United Kingdom
[36]OzGrav, Australian National University, Canberra, Australian Capital Territory 0200, Australia
[37]LIGO Laboratory, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
[38]Maastricht University, 6200 MD Maastricht, Netherlands
[39]Nikhef, 1098 XG Amsterdam, Netherlands
[40]INFN, Sezione di Roma, I-00185 Roma, Italy
[41]Università di Roma "La Sapienza", I-00185 Roma, Italy
[42]Aix Marseille Univ, CNRS, Centrale Med, Institut Fresnel, F-13013 Marseille, France
[43]Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France
[44]Department of Physics, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan
[45]Research Center for the Early Universe (RESCEU), The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan
[46]University of California, Riverside, Riverside, CA 92521, USA
[47]Gran Sasso Science Institute (GSSI), I-67100 L'Aquila, Italy
[48]INFN, Laboratori Nazionali del Gran Sasso, I-67100 Assergi, Italy
[49]University of Florida, Gainesville, FL 32611, USA
[50]Embry-Riddle Aeronautical University, Prescott, AZ 86301, USA
[51]Dipartimento di Scienze Matematiche, Informatiche e Fisiche, Università di Udine, I-33100 Udine, Italy
[52]INFN, Sezione di Trieste, I-34127 Trieste, Italy
[53]Tecnologico de Monterrey, Escuela de Ingeniería y Ciencias, 64849 Monterrey, Nuevo León, Mexico
[54]Institute for Cosmic Ray Research, KAGRA Observatory, The University of Tokyo, 238 Higashi-Mozumi, Kamioka-cho, Hida City, Gifu 506-1205, Japan
[55]INFN, Sezione di Perugia, I-06123 Perugia, Italy
[56]Università di Camerino, I-62032 Camerino, Italy
[57]University of Washington, Seattle, WA 98195, USA
[58]Earthquake Research Institute, The University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo 113-0032, Japan
[59]California State University Fullerton, Fullerton, CA 92831, USA
[60]SUPA, University of Strathclyde, Glasgow G1 1XQ, United Kingdom
[61]Université Claude Bernard Lyon 1, CNRS, IP2I Lyon / IN2P3, UMR 5822, F-69622 Villeurbanne, France
[62]Georgia Institute of Technology, Atlanta, GA 30332, USA
[63]Royal Holloway, University of London, London TW20 0EX, United Kingdom
[64]Department of Astronomical Science, The Graduate University for Advanced Studies (SOKENDAI), 2-21-1 Osawa, Mitaka City, Tokyo 181-8588, Japan
[65]Università degli Studi di Urbino "Carlo Bo", I-61029 Urbino, Italy
[66]INFN, Sezione di Firenze, I-50019 Sesto Fiorentino, Firenze, Italy
[67]European Gravitational Observatory (EGO), I-56021 Cascina, Pisa, Italy
[68]LIGO Livingston Observatory, Livingston, LA 70754, USA
[69]Université de Strasbourg, CNRS, IPHC UMR 7178, F-67000 Strasbourg, France
[70]Dipartimento di Fisica "E.R. Caianiello", Università di Salerno, I-84084 Fisciano, Salerno, Italy
[71]King's College London, University of London, London WC2R 2LS, United Kingdom
[72]Korea Institute of Science and Technology Information, Daejeon 34141, Republic of Korea
[73]International College, Osaka University, 1-1 Machikaneyama-cho, Toyonaka City, Osaka 560-0043, Japan
[74]Accelerator Laboratory, High Energy Accelerator Research Organization (KEK), 1-1 Oho, Tsukuba City, Ibaraki 305-0801, Japan
[75]Institute for Gravitational and Subatomic Physics (GRASP), Utrecht University, 3584 CC Utrecht, Netherlands
[76]University of Portsmouth, Portsmouth, PO1 3FX, United Kingdom
[77]Istituto Nazionale Di Fisica Nucleare - Sezione di Bologna, viale Carlo Berti Pichat 6/2 - 40127 Bologna, Italy
[78]Università di Trento, Dipartimento di Fisica, I-38123 Povo, Trento, Italy
[79]INFN, Trento Institute for Fundamental Physics and Applications, I-38123 Povo, Trento, Italy
[80]Università di Perugia, I-06123 Perugia, Italy
[81]University of Oregon, Eugene, OR 97403, USA

[82]Syracuse University, Syracuse, NY 13244, USA
[83]Inter-University Centre for Astronomy and Astrophysics, Pune 411007, India
[84]INFN, Sezione di Pisa, I-56127 Pisa, Italy
[85]Università di Pisa, I-56127 Pisa, Italy
[86]Institut de Ciències del Cosmos (ICCUB), Universitat de Barcelona (UB), c. Martí i Franquès, 1, 08028 Barcelona, Spain
[87]Departament de Física Quàntica i Astrofísica (FQA), Universitat de Barcelona (UB), c. Martí i Franqués, 1, 08028 Barcelona, Spain
[88]Institut d'Estudis Espacials de Catalunya, c. Gran Capità, 2-4, 08034 Barcelona, Spain
[89]Dipartimento di Medicina, Chirurgia e Odontoiatria "Scuola Medica Salernitana", Università di Salerno, I-84081 Baronissi, Salerno, Italy
[90]IGR, University of Glasgow, Glasgow G12 8QQ, United Kingdom
[91]University of California, Berkeley, CA 94720, USA
[92]HUN-REN Wigner Research Centre for Physics, H-1121 Budapest, Hungary
[93]Stanford University, Stanford, CA 94305, USA
[94]University of Michigan, Ann Arbor, MI 48109, USA
[95]Università di Padova, Dipartimento di Fisica e Astronomia, I-35131 Padova, Italy
[96]INFN, Sezione di Padova, I-35131 Padova, Italy
[97]Institute for Plasma Research, Bhat, Gandhinagar 382428, India
[98]Universiteit Gent, B-9000 Gent, Belgium
[99]Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences, 00-716, Warsaw, Poland
[100]Katholieke Universiteit Leuven, Oude Markt 13, 3000 Leuven, Belgium
[101]Centro de Investigaciones Energéticas Medioambientales y Tecnológicas, Avda. Complutense 40, 28040, Madrid, Spain
[102]Aix-Marseille Université, Université de Toulon, CNRS, CPT, Marseille, France
[103]Northeastern University, Boston, MA 02115, USA
[104]Laboratoire des 2 Infinis - Toulouse (L2IT-IN2P3), F-31062 Toulouse Cedex 9, France
[105]Università di Siena, Dipartimento di Scienze Fisiche, della Terra e dell'Ambiente, I-53100 Siena, Italy
[106]Villanova University, Villanova, PA 19085, USA
[107]RRCAT, Indore, Madhya Pradesh 452013, India
[108]University of Maryland, Baltimore County, Baltimore, MD 21250, USA
[109]Kenyon College, Gambier, OH 43022, USA
[110]Missouri University of Science and Technology, Rolla, MO 65409, USA
[111]Indian Institute of Technology Madras, Chennai 600036, India
[112]Department of Physics and Astronomy, Vrije Universiteit Amsterdam, 1081 HV Amsterdam, Netherlands
[113]Lomonosov Moscow State University, Moscow 119991, Russia
[114]Rochester Institute of Technology, Rochester, NY 14623, USA
[115]Université libre de Bruxelles, 1050 Bruxelles, Belgium
[116]Bar-Ilan University, Ramat Gan, 5290002, Israel
[117]Northwestern University, Evanston, IL 60208, USA
[118]Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Artemis, F-06304 Nice, France
[119]University of British Columbia, Vancouver, BC V6T 1Z4, Canada
[120]Christopher Newport University, Newport News, VA 23606, USA
[121]OzGrav, University of Adelaide, Adelaide, South Australia 5005, Australia
[122]Centre national de la recherche scientifique, 75016 Paris, France
[123]Univ Rennes, CNRS, Institut FOTON - UMR 6082, F-35000 Rennes, France
[124]University of Birmingham, Birmingham B15 2TT, United Kingdom
[125]DIFA- Alma Mater Studiorum Università di Bologna, Via Zamboni, 33 - 40126 Bologna, Italy
[126]Washington State University, Pullman, WA 99164, USA
[127]Cornell University, Ithaca, NY 14850, USA
[128]University of Rhode Island, Kingston, RI 02881, USA
[129]Laboratoire Kastler Brossel, Sorbonne Université, CNRS, ENS-Université PSL, Collège de France, F-75005 Paris, France
[130]OzGrav, University of Melbourne, Parkville, Victoria 3010, Australia
[131]Astronomical Observatory, University of Warsaw, 00-478 Warsaw, Poland
[132]University of Maryland, College Park, MD 20742, USA
[133]Università degli Studi di Milano-Bicocca, I-20126 Milano, Italy
[134]INFN, Sezione di Milano-Bicocca, I-20126 Milano, Italy
[135]Université de Lyon, Université Claude Bernard Lyon 1, CNRS, Institut Lumière Matière, F-69622 Villeurbanne, France
[136]IAC3–IEEC, Universitat de les Illes Balears, E-07122 Palma de Mallorca, Spain
[137]University of Chicago, Chicago, IL 60637, USA

[138] *Institut de Física d'Altes Energies (IFAE), The Barcelona Institute of Science and Technology, Campus UAB, E-08193 Bellaterra (Barcelona), Spain*
[139] *University of Arizona, Tucson, AZ 85721, USA*
[140] *INFN, Sezione di Napoli, Gruppo Collegato di Salerno, I-80126 Napoli, Italy*
[141] *University of Massachusetts Dartmouth, North Dartmouth, MA 02747, USA*
[142] *Faculty of Physics, University of Warsaw, Ludwika Pasteura 5, 02-093 Warszawa, Poland*
[143] *Istituto di Astrofisica e Planetologia Spaziali di Roma, 00133 Roma, Italy*
[144] *Departamento de Astronomía y Astrofísica, Universitat de València, E-46100 Burjassot, València, Spain*
[145] *Observatori Astronòmic, Universitat de València, E-46980 Paterna, València, Spain*
[146] *OzGrav, Swinburne University of Technology, Hawthorn VIC 3122, Australia*
[147] *Niels Bohr Institute, University of Copenhagen, 2100 Kóbenhavn, Denmark*
[148] *National Central University, Taoyuan City 320317, Taiwan*
[149] *OzGrav, Charles Sturt University, Wagga Wagga, New South Wales 2678, Australia*
[150] *Vanderbilt University, Nashville, TN 37235, USA*
[151] *University of Chinese Academy of Sciences / International Centre for Theoretical Physics Asia-Pacific, Bejing 100190, China*
[152] *Institute of Physics, National Yang Ming Chiao Tung University, 101 Univ. Street, Hsinchu, Taiwan*
[153] *Kamioka Branch, National Astronomical Observatory of Japan, 238 Higashi-Mozumi, Kamioka-cho, Hida City, Gifu 506-1205, Japan*
[154] *National Tsing Hua University, Hsinchu City 30013, Taiwan*
[155] *University of Texas, Austin, TX 78712, USA*
[156] *CaRT, California Institute of Technology, Pasadena, CA 91125, USA*
[157] *Dipartimento di Ingegneria Industriale (DIIN), Università di Salerno, I-84084 Fisciano, Salerno, Italy*
[158] *Faculty of Science, University of Toyama, 3190 Gofuku, Toyama City, Toyama 930-8555, Japan*
[159] *School of Physical Science and Technology, ShanghaiTech University, 393 Middle Huaxia Road, Pudong, Shanghai, 201210, China*
[160] *Carleton College, Northfield, MN 55057, USA*
[161] *University of Szeged, Dóm tér 9, Szeged 6720, Hungary*
[162] *INFN Cagliari, Physics Department, Università degli Studi di Cagliari, Cagliari 09042, Italy*
[163] *Université Libre de Bruxelles, Brussels 1050, Belgium*
[164] *INAF, Osservatorio Astronomico di Brera sede di Merate, I-23807 Merate, Lecco, Italy*
[165] *Departamento de Matemáticas, Universitat de València, E-46100 Burjassot, València, Spain*
[166] *Montana State University, Bozeman, MT 59717, USA*
[167] *The University of Utah, Salt Lake City, UT 84112, USA*
[168] *Johns Hopkins University, Baltimore, MD 21218, USA*
[169] *The University of Texas Rio Grande Valley, Brownsville, TX 78520, USA*
[170] *Université de Liège, B-4000 Liège, Belgium*
[171] *University of Manitoba, Winnipeg, MB R3T 2N2, Canada*
[172] *INAF, Osservatorio di Astrofisica e Scienza dello Spazio, I-40129 Bologna, Italy*
[173] *INFN-CNAF - Bologna, Viale Carlo Berti Pichat, 6/2, 40127 Bologna BO, Italy*
[174] *Colorado State University, Fort Collins, CO 80523, USA*
[175] *Université de Normandie, ENSICAEN, UNICAEN, CNRS/IN2P3, LPC Caen, F-14000 Caen, France*
[176] *Laboratoire de Physique Corpusculaire Caen, 6 boulevard du maréchal Juin, F-14050 Caen, France*
[177] *The University of Sheffield, Sheffield S10 2TN, United Kingdom*
[178] *Université Claude Bernard Lyon 1, CNRS, Laboratoire des Matériaux Avancés (LMA), IP2I Lyon / IN2P3, UMR 5822, F-69622 Villeurbanne, France*
[179] *Western Washington University, Bellingham, WA 98225, USA*
[180] *Università di Firenze, Sesto Fiorentino I-50019, Italy*
[181] *IGFAE, Universidade de Santiago de Compostela, E-15782 Santiago de Compostela, Spain*
[182] *Dipartimento di Scienze Matematiche, Fisiche e Informatiche, Università di Parma, I-43124 Parma, Italy*
[183] *INFN, Sezione di Milano Bicocca, Gruppo Collegato di Parma, I-43124 Parma, Italy*
[184] *Marquette University, Milwaukee, WI 53233, USA*
[185] *Perimeter Institute, Waterloo, ON N2L 2Y5, Canada*
[186] *Scuola Normale Superiore, I-56126 Pisa, Italy*
[187] *Corps des Mines, Mines Paris, Université PSL, 60 Bd Saint-Michel, 75272 Paris, France*
[188] *Dipartimento di Fisica, Università di Trieste, I-34127 Trieste, Italy*
[189] *Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Lagrange, F-06304 Nice, France*
[190] *National Center for Nuclear Research, 05-400 Świerk-Otwock, Poland*
[191] *Università degli Studi di Sassari, I-07100 Sassari, Italy*
[192] *Vrije Universiteit Brussel, 1050 Brussel, Belgium*

[193]*University of Zurich, Winterthurerstrasse 190, 8057 Zurich, Switzerland*
[194]*Canadian Institute for Theoretical Astrophysics, University of Toronto, Toronto, ON M5S 3H8, Canada*
[195]*Stony Brook University, Stony Brook, NY 11794, USA*
[196]*Center for Computational Astrophysics, Flatiron Institute, New York, NY 10010, USA*
[197]*Montclair State University, Montclair, NJ 07043, USA*
[198]*HUN-REN Institute for Nuclear Research, H-4026 Debrecen, Hungary*
[199]*Indian Institute of Technology Bombay, Powai, Mumbai 400 076, India*
[200]*Centro de Física das Universidades do Minho e do Porto, Universidade do Minho, PT-4710-057 Braga, Portugal*
[201]*Aix Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France*
[202]*CNR-SPIN, I-84084 Fisciano, Salerno, Italy*
[203]*Dipartimento di Ingegneria, Università della Basilicata, I-85100 Potenza, Italy*
[204]*SUPA, University of the West of Scotland, Paisley PA1 2BE, United Kingdom*
[205]*Barry University, Miami Shores, FL 33168, USA*
[206]*Eötvös University, Budapest 1117, Hungary*
[207]*Institute for Cosmic Ray Research, KAGRA Observatory, The University of Tokyo, 5-1-5 Kashiwa-no-Ha, Kashiwa City, Chiba 277-8582, Japan*
[208]*Department of Physics, Graduate School of Science, Osaka Metropolitan University, 3-3-138 Sugimoto-cho, Sumiyoshi-ku, Osaka City, Osaka 558-8585, Japan*
[209]*University of Sannio at Benevento, I-82100 Benevento, Italy and INFN, Sezione di Napoli, I-80100 Napoli, Italy*
[210]*California State University, Los Angeles, Los Angeles, CA 90032, USA*
[211]*Instituto de Fisica Teorica UAM-CSIC, Universidad Autonoma de Madrid, 28049 Madrid, Spain*
[212]*Istituto Nazionale di Astrofisica - Osservatorio di Roma, Viale del Parco Mellini 84 - 00136 Roma, Italy*
[213]*Laboratoire d'Acoustique de l'Université du Mans, UMR CNRS 6613, F-72085 Le Mans, France*
[214]*University of Southampton, Southampton SO17 1BJ, United Kingdom*
[215]*Dipartimento di Ingegneria Industriale, Elettronica e Meccanica, Università degli Studi Roma Tre, I-00146 Roma, Italy*
[216]*University of Nevada, Las Vegas, Las Vegas, NV 89154, USA*
[217]*University of Nottingham NG7 2RD, UK*
[218]*Ariel University, Ramat HaGolan St 65, Ari'el, Israel*
[219]*The University of Mississippi, University, MS 38677, USA*
[220]*Graduate School of Science, Institute of Science Tokyo, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8551, Japan*
[221]*Institute of Physics, Academia Sinica, 128 Sec. 2, Academia Rd., Nankang, Taipei 11529, Taiwan*
[222]*The Chinese University of Hong Kong, Shatin, NT, Hong Kong*
[223]*Nirula Institute of Technology, Kolkata, West Bengal 700109, India*
[224]*Niels Bohr Institute, Copenhagen University, 2100 København, Denmark*
[225]*American University, Washington, DC 20016, USA*
[226]*Dipartimento di Fisica, Università degli studi di Milano, Via Celoria 16, I-20133, Milano, Italy*
[227]*INFN, sezione di Milano, Via Celoria 16, I-20133, Milano, Italy*
[228]*Department of Applied Physics, Fukuoka University, 8-19-1 Nanakuma, Jonan, Fukuoka City, Fukuoka 814-0180, Japan*
[229]*University of Cambridge, Cambridge CB2 1TN, United Kingdom*
[230]*University of Lancaster, Lancaster LA1 4YW, United Kingdom*
[231]*College of Industrial Technology, Nihon University, 1-2-1 Izumi, Narashino City, Chiba 275-8575, Japan*
[232]*Faculty of Engineering, Niigata University, 8050 Ikarashi-2-no-cho, Nishi-ku, Niigata City, Niigata 950-2181, Japan*
[233]*Department of Physics and Astronomy, Haverford College, 370 Lancaster Avenue, Haverford, PA 19041, USA*
[234]*Saha Institute of Nuclear Physics, Bidhannagar, West Bengal 700064, India*
[235]*Department of Physics, Tamkang University, No. 151, Yingzhuan Rd., Danshui Dist., New Taipei City 25137, Taiwan*
[236]*Department of Electrophysics, National Yang Ming Chiao Tung University, 101 Univ. Street, Hsinchu, Taiwan*
[237]*Rutherford Appleton Laboratory, Didcot OX11 0DE, United Kingdom*
[238]*Department of Physical Sciences, Aoyama Gakuin University, 5-10-1 Fuchinobe, Sagamihara City, Kanagawa 252-5258, Japan*
[239]*Nagoya University, Nagoya, 464-8601, Japan*
[240]*Helmut Schmidt University, D-22043 Hamburg, Germany*
[241]*Nambu Yoichiro Institute of Theoretical and Experimental Physics (NITEP), Osaka Metropolitan University, 3-3-138 Sugimoto-cho, Sumiyoshi-ku, Osaka City, Osaka 558-8585, Japan*
[242]*Directorate of Construction, Services & Estate Management, Mumbai 400094, India*
[243]*Observatoire Astronomique de Strasbourg, Université de Strasbourg, CNRS, 11 rue de l'Université, 67000 Strasbourg, France*
[244]*Faculty of Physics, University of Białystok, 15-245 Białystok, Poland*
[245]*National Astronomical Observatories, Chinese Academy of Sciences, 20A Datun Road, Chaoyang District, Beijing, China*

[246]*School of Astronomy and Space Science, University of Chinese Academy of Sciences, 20A Datun Road, Chaoyang District, Beijing, China*
[247]*Sungkyunkwan University, Seoul 03063, Republic of Korea*
[248]*Department of Physics, Ulsan National Institute of Science and Technology (UNIST), 50 UNIST-gil, Ulju-gun, Ulsan 44919, Republic of Korea*
[249]*Chung-Ang University, Seoul 06974, Republic of Korea*
[250]*University of Washington Bothell, Bothell, WA 98011, USA*
[251]*Laboratoire de Physique et de Chimie de l'Environnement, Université Joseph KI-ZERBO, 9GH2+3V5, Ouagadougou, Burkina Faso*
[252]*Ewha Womans University, Seoul 03760, Republic of Korea*
[253]*National Institute for Mathematical Sciences, Daejeon 34047, Republic of Korea*
[254]*Korea Astronomy and Space Science Institute, Daejeon 34055, Republic of Korea*
[255]*Department of Astronomy and Space Science, Chungnam National University, 9 Daehak-ro, Yuseong-gu, Daejeon 34134, Republic of Korea*
[256]*Division of Science, National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka City, Tokyo 181-8588, Japan*
[257]*Department of Physics, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece*
[258]*Bard College, Annandale-On-Hudson, NY 12504, USA*
[259]*Technical University of Braunschweig, D-38106 Braunschweig, Germany*
[260]*Institute of Mathematics, Polish Academy of Sciences, 00656 Warsaw, Poland*
[261]*Astronomical Observatory, Jagiellonian University, 31-007 Cracow, Poland*
[262]*Department of Physics and Astronomy, University of Padova, Via Marzolo, 8-35151 Padova, Italy*
[263]*Sezione di Padova, Istituto Nazionale di Fisica Nucleare (INFN), Via Marzolo, 8-35131 Padova, Italy*
[264]*Instituto de Fisica Teorica UAM-CSIC, Universidad Autonoma de Madrid, 28049 Madrid, Spain*
[265]*Department of Physics, Nagoya University, ES building, Furocho, Chikusa-ku, Nagoya, Aichi 464-8602, Japan*
[266]*Université de Montréal/Polytechnique, Montreal, Quebec H3T 1J4, Canada*
[267]*Università degli Studi di Cagliari, Via Università 40, 09124 Cagliari, Italy*
[268]*Department of Computer Simulation, Inje University, 197 Inje-ro, Gimhae, Gyeongsangnam-do 50834, Republic of Korea*
[269]*Korea Astronomy and Space Science Institute (KASI), 776 Daedeokdae-ro, Yuseong-gu, Daejeon 34055, Republic of Korea*
[270]*NAVIER, École des Ponts, Univ Gustave Eiffel, CNRS, Marne-la-Vallée, France*
[271]*Gravitational Wave Science Project, National Astronomical Observatory of Japan (NAOJ), Mitaka City, Tokyo 181-8588, Japan*
[272]*Department of Physics, National Cheng Kung University, No.1, University Road, Tainan City 701, Taiwan*
[273]*St. Thomas University, Miami Gardens, FL 33054, USA*
[274]*Institució Catalana de Recerca i Estudis Avançats, E-08010 Barcelona, Spain*
[275]*Institut de Física d'Altes Energies, E-08193 Barcelona, Spain*
[276]*Institut fuer Theoretische Astrophysik, Zentrum fuer Astronomie Heidelberg, Universitaet Heidelberg, Albert Ueberle Str. 2, 69120 Heidelberg, Germany*
[277]*Institucio Catalana de Recerca i Estudis Avançats (ICREA), Passeig de Lluís Companys, 23, 08010 Barcelona, Spain*
[278]*Research Center for Space Science, Advanced Research Laboratories, Tokyo City University, 3-3-1 Ushikubo-Nishi, Tsuzuki-Ku, Yokohama, Kanagawa 224-8551, Japan*
[279]*Tsinghua University, Beijing 100084, China*
[280]*Universidad de Guadalajara, 44430 Guadalajara, Jalisco, Mexico*
[281]*Institut des Hautes Etudes Scientifiques, F-91440 Bures-sur-Yvette, France*
[282]*Faculty of Law, Ryukoku University, 67 Fukakusa Tsukamoto-cho, Fushimi-ku, Kyoto City, Kyoto 612-8577, Japan*
[283]*Istituto Nazionale di Fisica Nucleare (INFN), Universita di Roma "La Sapienza", P.le A. Moro 2, 00185 Roma, Italy*
[284]*Indian Institute of Science Education and Research, Kolkata, Mohanpur, West Bengal 741252, India*
[285]*Phenikaa Institute for Advanced Study (PIAS), Phenikaa University, Yen Nghia, Ha Dong, Hanoi, Vietnam*
[286]*University of Stavanger, 4021 Stavanger, Norway*
[287]*Department of Astronomy, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan*
[288]*Physics Program, Graduate School of Advanced Science and Engineering, Hiroshima University, 1-3-1 Kagamiyama, Higashihiroshima City, Hiroshima 739-8526, Japan*
[289]*GRAPPA, Anton Pannekoek Institute for Astronomy and Institute for High-Energy Physics, University of Amsterdam, 1098 XH Amsterdam, Netherlands*
[290]*University College London, London WC1E 6BT, United Kingdom*
[291]*Observatoire de Paris, 75014 Paris, France*
[292]*Graduate School of Science and Technology, Niigata University, 8050 Ikarashi-2-no-cho, Nishi-ku, Niigata City, Niigata 950-2181, Japan*
[293]*Niigata Study Center, The Open University of Japan, 754 Ichibancho, Asahimachi-dori, Chuo-ku, Niigata City, Niigata 951-8122, Japan*
[294]*CSIR-Central Glass and Ceramic Research Institute, Kolkata, West Bengal 700032, India*

[295] *Consiglio Nazionale delle Ricerche - Istituto dei Sistemi Complessi, I-00185 Roma, Italy*
[296] *Department of Astronomy, Yonsei University, 50 Yonsei-Ro, Seodaemun-Gu, Seoul 03722, Republic of Korea*
[297] *Department of Physics, University of Guadalajara, Av. Revolucion 1500, Colonia Olimpica C.P. 44430, Guadalajara, Jalisco, Mexico*
[298] *Hobart and William Smith Colleges, Geneva, NY 14456, USA*
[299] *INAF, Osservatorio Astronomico di Padova, I-35122 Padova, Italy*
[300] *Dipartimento di Ingegneria, Università del Sannio, I-82100 Benevento, Italy*
[301] *Institut d'Astrophysique de Paris, Sorbonne Université, CNRS, UMR 7095, 75014 Paris, France*
[302] *Museo Storico della Fisica e Centro Studi e Ricerche "Enrico Fermi", I-00184 Roma, Italy*
[303] *Kennesaw State University, Kennesaw, GA 30144, USA*
[304] *Government Victoria College, Palakkad, Kerala 678001, India*
[305] *Subatech, CNRS/IN2P3 - IMT Atlantique - Nantes Université, 4 rue Alfred Kastler BP 20722 44307 Nantes CÉDEX 03, France*
[306] *Universidad de Antioquia, Medellín, Colombia*
[307] *Departamento de Física - ETSIDI, Universidad Politécnica de Madrid, 28012 Madrid, Spain*
[308] *Department of Electronic Control Engineering, National Institute of Technology, Nagaoka College, 888 Nishikatakai, Nagaoka City, Niigata 940-8532, Japan*
[309] *Trinity College, Hartford, CT 06106, USA*
[310] *Dipartimento di Fisica e Scienze della Terra, Università Degli Studi di Ferrara, Via Saragat, 1, 44121 Ferrara FE, Italy*
[311] *Faculty of Science, Toho University, 2-2-1 Miyama, Funabashi City, Chiba 274-8510, Japan*
[312] *Indian Institute of Technology, Palaj, Gandhinagar, Gujarat 382355, India*
[313] *Seoul National University, Seoul 08826, Republic of Korea*
[314] *Kavli Institute for Astronomy and Astrophysics, Peking University, Yiheyuan Road 5, Haidian District, Beijing 100871, China*
[315] *Laboratoire MSME, Cité Descartes, 5 Boulevard Descartes, Champs-sur-Marne, 77454 Marne-la-Vallée Cedex 2, France*
[316] *Faculty of Information Science and Technology, Osaka Institute of Technology, 1-79-1 Kitayama, Hirakata City, Osaka 573-0196, Japan*
[317] *NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA*
[318] *Faculty of Science and Technology, Kochi University, 2-5-1 Akebono-cho, Kochi-shi, Kochi 780-8520, Japan*
[319] *Laboratoire de Physique de l'École Normale Supérieure, ENS, (CNRS, Université PSL, Sorbonne Université, Université Paris Cité), F-75005 Paris, France*
[320] *The Hakubi Center for Advanced Research, Kyoto University, Yoshida-honmachi, Sakyou-ku, Kyoto City, Kyoto 606-8501, Japan*
[321] *Department of Physics, Kyoto University, Kita-Shirakawa Oiwake-cho, Sakyou-ku, Kyoto City, Kyoto 606-8502, Japan*
[322] *Yukawa Institute for Theoretical Physics (YITP), Kyoto University, Kita-Shirakawa Oiwake-cho, Sakyou-ku, Kyoto City, Kyoto 606-8502, Japan*
[323] *University of Catania, Department of Physics and Astronomy, Via S. Sofia, 64, 95123 Catania CT, Italy*
[324] *National Institute of Technology, Fukui College, Geshi-cho, Sabae-shi, Fukui 916-8507, Japan*
[325] *Department of Communications Engineering, National Defense Academy of Japan, 1-10-20 Hashirimizu, Yokosuka City, Kanagawa 239-8686, Japan*
[326] *Eindhoven University of Technology, 5600 MB Eindhoven, Netherlands*
[327] *Concordia University Wisconsin, Mequon, WI 53097, USA*
[328] *Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU), WPI, The University of Tokyo, 5-1-5 Kashiwa-no-Ha, Kashiwa City, Chiba 277-8583, Japan*
[329] *Department of Astronomy, Beijing Normal University, Xinjiekouwai Street 19, Haidian District, Beijing 100875, China*
[330] *School of Physics and Technology, Wuhan University, Bayi Road 299, Wuchang District, Wuhan, Hubei, 430072, China*
[331] *Instituto Argentino de Radioastronomía (CCT La Plata, CONICET; CICPBA; UNLP), C.C.5, (1894) Villa Elisa, Buenos Aires, Argentina*
[332] *X-Ray Astrophysics Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD, 20771, USA*
[333] *Centre for Astrophysics and Supercomputing, Swinburne University of Technology, Hawthorn, VIC 3122, Australia*
[334] *ARC Center of Excellence for Gravitational Wave Discovery (OzGrav), Swinburne University of Technology, VIC 3122, Australia*
[335] *LPC2E, OSUC, Univ Orleans, CNRS, CNES, Observatoire de Paris, F-45071 Orleans, France*
[336] *ORN, Observatoire de Paris, Université PSL, Univ Orléans, CNRS, 18330 Nançay, France*
[337] *School of Physics and Astronomy, Monash University, Clayton VIC 3800, Australia*
[338] *Department of Space, Earth and Environment, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden*
[339] *Departamento de Física, Universidad de Santiago de Chile (USACH), Av. Víctor Jara 3493, Estación Central, Chile*
[340] *Center for Interdisciplinary Research in Astrophysics and Space Sciences (CIRAS), Universidad de Santiago de Chile, Santiago, Chile*
[341] *Department of Physics and Astronomy, West Virginia University, PO Box 6315, Morgantown, WV 26506, USA*
[342] *Center for Gravitational Waves and Cosmology, West Virginia University, Chestnut Ridge Research Building, Morgantown, WV 26505, USA*
[343] *Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Paseo del Bosque, B1900FWA La Plata, Argentina*
[344] *IRAP, CNRS, 9 avenue du Colonel Roche, BP 44346, 31028 Toulouse Cedex 4, France*

[345]*Université de Toulouse, CNES, UPS-OMP, 31028 Toulouse, France*
[346]*Jodrell Bank Centre for Astrophysics, School of Physics and Astronomy, University of Manchester, Manchester, UK, M13 9PL*
[347]*Space Research Organisation Netherlands, Niels Bohrweg 4, 2333 CA, Leiden, Netherlands*
[348]*International Centre for Radio Astronomy Research, Curtin University, Bentley, WA, Australia*
[349]*Australian SKA Regional Centre (AusSRC), Curtin University, Bentley, WA, Australia*
[350]*Department of Physics and Astronomy, Vanderbilt University, 2301 Vanderbilt Place, Nashville, TN 37235, USA*
[351]*School of Natural Sciences, University of Tasmania, Hobart, Australia*
[352]*Department of Physics, McGill University, 3600 rue University, Montréal, QC H3A 2T8, Canada*
[353]*Trottier Space Institute, McGill University, 3550 rue University, Montréal, QC H3A 2A7, Canada*
[354]*Department of Physics and Astronomy, University of British Columbia, 6224 Agricultural Road, Vancouver, BC V6T 1Z1, Canada*

ABSTRACT

Rotating non-axisymmetric neutron stars (NSs) are promising sources for continuous gravitational waves (CWs). Such CWs can, if detected, inform us about the internal structure and equation of state of NSs. Here, we present a narrowband search for CWs from known pulsars, for which an efficient and sensitive matched-filter search can be applied. Narrowband searches are designed to be robust to mismatches between the electromagnetic (EM) and gravitational emissions, in contrast to fully targeted searches where the CW emission is assumed to be phase-locked to the EM one. In this work, we search for the CW counterparts emitted by 34 pulsars using data from the first and second parts of the fourth LIGO–Virgo–KAGRA observing run. This is the largest number of pulsars so far targeted for narrowband searches in the advanced detector era. We use the 5n-vector narrowband pipeline, which applies frequency-domain matched filtering. In previous searches, it covered a narrow range in the frequency – frequency time derivative ($f - \dot{f}$) space. Here, we also explore a range in the second time derivative of the frequency $\ddot{f}$ around the value indicated by EM observations. Additionally, for the first time, we target sources in a binary system with this kind of search. We find no evidence for CWs and therefore set upper limits on the strain amplitude emitted by each pulsar, using simulated signals added in real data. For 20 analyses, we report an upper limit below the theoretical spin-down limit. The tightest constraint is for pulsar PSR J0534+2200 (the Crab pulsar), for which our strain upper limit on the CW amplitude is $\lesssim 2\%$ of its spin-down limit, corresponding to less than 0.04% of the spin-down power being radiated in the CW channel.

1. INTRODUCTION

Continuous gravitational waves (CWs) represent one of the most elusive and scientifically rich targets in gravitational wave (GW) astronomy. Unlike transient signals produced by cataclysmic events such as binary mergers of black holes and/or neutron stars (NSs), CWs are expected to be persistent and nearly monochromatic signals potentially emitted by rapidly rotating NSs with a non-symmetric mass distribution with respect to the rotation axis (K. Riles 2023).

The mass-distribution asymmetries, such as "mountains" on the crust (F. Gittins 2024) or internal deformations supported by strong magnetic fields (S. Bonazzola & E. Gourgoulhon 1996; C. Cutler 2002) or exotic matter (B. J. Owen 2005), can cause the star to emit gravitational radiation steadily over timescales of months to years. In the literature (see K. Riles 2023; K. Wette 2023; B. Haskell & M. Bejger 2023), different emission models are generally considered; the single harmonic model predicts an emission at exactly twice the spin frequency, while the dual harmonic model has emission at both one and two times the spin frequency (D. I. Jones 2010). Additional mechanisms may also contribute to CW emission, such as free precession or internal fluid oscillation modes (e.g., r-modes) (N. Andersson 1998; J. L. Friedman & S. M. Morsink 1998). The search for CWs is motivated by their potential to unveil fundamental information about the structure and composition of NSs (B. Haskell & M. Bejger 2023; B. J. Owen 2025). A detection would provide direct evidence of non-axisymmetric deformations, offer insight into the dense-matter physics of the NS interior (see e.g., A. Idrisy et al. 2015; S. Ghosh et al. 2023; S. Ghosh 2023), and allow tests of gravitational theories in the strong-field regime (M. Isi et al. 2017; B. P. Abbott et al. 2019a).

However, CW signals are expected to be extremely weak and much weaker than the transient signals detected so far by the LIGO–Virgo–KAGRA (LVK) Collaboration (see A. G. Abac et al. (2025) for the latest

---

[*] Deceased, March 2026.
[†] Deceased, September 2024.
[‡] Deceased, August 2025.

catalogue of GW detections, and J. Aasi et al. (2015); F. Acernese et al. (2015); T. Akutsu et al. (2021) for more information on LVK detectors). This low amplitude necessitates long observation times and sensitive data analysis techniques capable of extracting faint, long-duration signals from detector noise. Searches for CWs must also account for intrinsic decrease in the NS's spin frequency (the so-called spin-down), and the Doppler modulation caused by Earth's motion and by the orbital motion for sources in binary systems.

To address these challenges, different types of CW search strategies have been developed (K. Riles 2023; K. Wette 2023), each optimised for different assumptions about the signal and the level of prior information available about the source. Known pulsars for which we have accurate measurements of their sky positions and rotation parameters from electromagnetic (EM) observations can be targeted using fully coherent searches. The most sensitive CW searches assume that the GW phase evolution is locked to the EM phase evolution and remains consistent throughout the entire observation time.

Coherent narrowband searches, the focus of this paper, are used when the source position is known, but the signal frequency is uncertain or may have shifted from electromagnetic predictions (e.g., B. Abbott et al. 2008; J. Aasi et al. 2015; B. P. Abbott et al. 2017, 2019b; R. Abbott et al. 2022; A. Ashok et al. 2021; A. G. Abac et al. 2025a). This could happen due to timing noise, glitches, or mismatches between gravitational and EM emission mechanisms (G. Ashton et al. 2017; M. Antonelli et al. 2025). Narrowband searches extend the targeted approach by scanning a small frequency band and a limited range of spin-down parameters, achieving improved robustness while maintaining relatively high sensitivity. Pulsars, NSs possessing powerful magnetic fields that emit beams of EM waves across different frequency bands (radio, X-rays, gamma-rays), are the primary candidates for CW targeted and fully-coherent narrowband searches.

In this work, we present a narrowband CW search using data from the recent LVK O4 observing run, considering the first two parts, namely O4a and O4b data from the LIGO Livingston (L1) and LIGO Hanford detectors (H1). We study 34 pulsars, with ephemerides provided by a set of gamma-ray, radio, and X-ray observatories, representing the largest set of targets ever considered for a narrowband search. For the first time, we consider sources in binary systems and explore templates in the second-order spin-down ($\ddot{f}$) dimension, enlarging the science scope of this work.

The paper is organized as follows: Section 2 describes the EM and GW data used in the analysis. Section 3 outlines the astrophysical motivations and characteristics of the expected signals and describes the analysis method. The results are presented and discussed in Section 4. Our conclusions are given in Section 5.

2. DATASETS

2.1. *EM data*

We used EM data to obtain pulsar timing solutions that were used as inputs for the GW search. A gamma-ray timing solution was obtained for one target from Fermi-Large Area Telescope (W. B. Atwood et al. 2009, LAT). Radio data for multiple pulsars were collected from the Nancay Radio Telescope (NRT, Guillemot, L. et al. 2023), the 42 ft and Lovell telescopes at Jodrell Bank Observatory (JBO), the Argentine Institute of Radio astronomy (IAR, G. Gancio et al. 2020), the Canadian Hydrogen Intensity Mapping Experiment (CHIME, M. Amiri et al. 2021), the MeerKAT radio telescope (J. Jonas & MeerKAT Team 2016) and the Mount Pleasant Radio Observatory[1] (J. L. Palfreyman et al. 2011). The MeerKAT timing solutions were derived from observations over 6 years, collected for the MeerKAT Pulsar Timing Array (MPTA). These data were processed following the methods used for the first two data releases of the MPTA (M. T. Miles et al. 2023, 2025). X-ray timing solutions were obtained from Chandra (M. C. Weisskopf et al. 2002) and the Neutron Star Interior Composition Explorer (NICER, K. C. Gendreau et al. 2016).

For processing the EM observations, we used PSRCHIVE (W. van Straten et al. 2012) or PRESTO (S. M. Ransom et al. 2002; S. Ransom 2011) packages, Chandra Interactive Analysis of Observations (CIAO) package and Calibration Database (CALDB) (A. Fruscione et al. 2006), the NICER software in HEASoft (Nasa High Energy Astrophysics Science Archive Research Center (Heasarc) 2014), and for the gamma-ray data we used the procedures detailed in L. Kuiper & W. Hermsen (2009). We first cleaned the data for noise/radio frequency interference, when applicable. Next, we folded the observations and obtained the Time of Arrival (ToA) by cross-correlating the folded profiles with a template with high signal-to-noise ratio. We selected the ToAs during the O4ab run and used TEMPO2 (R. T. Edwards et al. 2006; G. B. Hobbs et al. 2006; G. Hobbs et al. 2009) or PINT (J. Luo et al. 2019, 2021) to characterize the rotation of each pulsar by fitting the

---

[1] Due to some mechanical issues in mid 2023, this observatory was not able to provide ephemerides entirely covering the O4ab run.

ToAs with a Taylor expansion of the rotational phase

$$\phi(t) = \phi_0 + f_{\rm rot}(t-t_0) + \frac{1}{2}\dot{f}_{\rm rot}(t-t_0)^2 + \frac{1}{6}\ddot{f}_{\rm rot}(t-t_0)^3 + \dots . \tag{1}$$

Here, $f_{\rm rot}$, $\dot{f}_{\rm rot}$, and $\ddot{f}_{\rm rot}$ are the rotation frequency of the pulsar, and its first and second derivatives, respectively. Their reference epoch is t_0, and ϕ_0 is the phase at t_0. Higher-order derivatives can be included if necessary.

2.1.1. *Glitches*

Pulsars are known for their extremely stable rotation; however, some of them present *glitches*. Glitches are abrupt changes in the rotational frequency of the pulsar, and they have been observed in over 200 pulsars (C. M. Espinoza et al. 2011; M. Yu et al. 2013; A. Basu et al. 2022). Most glitches are likely a consequence of the interaction between the superfluid interiors of NSs and their solid crusts. However, their dynamics and the mechanism that may trigger them are not well understood (S. Zhou et al. 2022; D. Antonopoulou et al. 2022).

The additional phase in pulsar rotation induced by glitches is included in the timing model as (P. M. McCulloch et al. 1987):

$$\phi_{\rm g}(t) = \Delta\phi + \Delta f_{\rm rot}(t-t_{\rm g}) + \frac{1}{2}\Delta\dot{f}_{\rm rot}(t-t_{\rm g})^2 + \frac{1}{6}\Delta\ddot{f}_{\rm rot}(t-t_{\rm g})^3 + \sum_i \left[1 - \exp\left(-\frac{t-t_{\rm g}}{\tau^i_{\rm d}}\right)\right]\Delta f^{i,d}_{\rm rot}\,\tau^i_{\rm d}, \tag{2}$$

where $t_{\rm g}$ is the glitch epoch and $\Delta\phi$ is used to counteract its uncertainty. $\Delta f_{\rm rot}$, $\Delta\dot{f}_{\rm rot}$, and $\Delta\ddot{f}_{\rm rot}$ are the step changes in $f_{\rm rot}$, $\dot{f}_{\rm rot}$, and $\ddot{f}_{\rm rot}$ at $t_{\rm g}$, respectively. Finally, $\Delta f^{d,i}_{\rm rot}$ represent temporary increases in frequency that recover in $\tau_{\rm d,i}$ days. Detected timescales for well-monitored pulsars can range from minutes (R. G. Dodson et al. 2002; J. Palfreyman et al. 2018; G. Ashton et al. 2019; E. Zubieta et al. 2025) to ∼ 500 d (E. Zubieta et al. 2024).

For some pulsars, we consider data even before the beginning of the run to improve the parameter estimation. This results in the modeling of some pre-O4 glitches listed in Table 1, together with the others that occurred during the run. Details of glitching pulsar analyses will be provided in Section 3.

2.2. *GW data*

We considered data from the first (O4a) and second (O4b) parts of the fourth observing run, known as O4ab, of the LIGO Livingston (L1) and LIGO Hanford (H1) detectors. The first part of the run (A. G. Abac et al. 2025b) took place between May 24, 2023 15:00:00 UTC (MJD 60088) and ended January 16, 2024 16:00:00 UTC (MJD 60325). The duty factors for L1 and H1 were 69.0% and 67.5%, respectively. Detectors resumed the observing mode for O4b on April 10, 2024, at 15:00 UTC (MJD 60410) and ended on January 28, 2025, at 17:00:00 UTC (MJD 60703). Here, the duty factors for L1 and H1 were 68.1% and 48.6%, respectively. As a result, we here consider ∼ 360 days (∼ 300 days) for L1 (H1) of effective observing time.

PSR	$t_{\rm g}$ [MJD]
J0058−7218	60291
J0537−6910	60223, 60379, 60611
J0540−6919	60105, 60170
J0835−4510	60430
J1809−1917	60071
J1813−1246	60247
J2021+3651	60289
J2022+3842	60540
J2229+6114	60065

Table 1. Pulsar glitches incorporated in the O4ab narrowband search. Details of the two PSR J0540−6919 timing events are given in C. M. Espinoza et al. (2024). We truncated the analysis to MJD 60510 for PSR J2022+3842 due to a lack of observations to narrow down the post-glitch parameters. PSR J1809-1917 and PSR J2229+6114 glitched before the beginning of the run.

We use L1:GDS–CALIB_STRAIN_CLEAN_AR and H1:GDS–CALIB_STRAIN_CLEAN_AR frame channels with CAT1 vetoes (D. Davis et al. 2019) for L1 and H1, respectively following E. Goetz & K. Riles (2024). For the PSR J0534+2200 search only, we substitute data from September 3 to November 11, 2024, with L1:DCS-CALIB_STRAIN_CLEAN_C01 and H1:DCS-CALIB_STRAIN_CLEAN_C01 channels since the 60 Hz line subtraction was not working well during this period in the online calibration, requiring an improved "C01" version (J. R. Merou et al. 2024).

A general description of the LIGO detectors' performance throughout O4ab is given in D. Ganapathy et al. (2023); W. Jia et al. (2024); E. Capote et al. (2025); S. Soni et al. (2025). For the O4ab data used in this analysis, the worst 1σ calibration uncertainty is within $\lesssim 10\%$ in amplitude, and $\lesssim 10$ degrees in phase, over the range 10–2000 Hz (M. Wade et al. 2025). The uncertainty at specific frequencies or times can be significantly smaller. Two hours of H1 data with large calibration uncertainties ($\lesssim 25\%$ in amplitude and $\lesssim 15$ degrees in phase, over the range 10–2000 Hz) (L. Dartez et al. 2024) were inadvertently included in the analysis. This data represents ∼ 0.03% of the effective observing time analyzed from the O4 run. We have confirmed, using spot checks of the hardware injections[2] (P. Baxi et al. 2026), that including this data has a $< 0.5\%$ effect on our results.

The Virgo and KAGRA detectors have not been considered since they joined the O4 run only in the second and third parts, respectively. For a description of the upgrades to the Advanced LIGO (E. Capote et al. 2025), Advanced Virgo (V. Collaboration 2025), and KAGRA detectors in preparation for the O4 run, we refer to Appendix A in A. G. Abac et al. (2024).

3. SIGNAL MODEL AND SEARCH METHOD

In this section, we will briefly discuss the expected signal (K. Riles 2023) and the narrowband search method based on the 5-vector formalism (P. Astone et al. 2010; S. Mastrogiovanni et al. 2017) as implemented in the Snag framework (S. Frasca et al. 2022). We will focus on the single harmonic emission model since the narrowband searches are performed around $f_{\rm gw} = 2f_{\rm rot}$, where $f_{\rm gw}$ is the GW frequency. For a triaxial star, the amplitude h_0 can be expressed as

$$h_0 = \frac{16\pi^2 G}{c^4}\frac{I_{zz}\varepsilon f_{\rm rot}^2}{d}\,, \tag{3}$$

where d is the distance of the source, and ε the equatorial ellipticity defined as

$$\varepsilon \equiv \frac{|I_{xx} - I_{yy}|}{I_{zz}}\,, \tag{4}$$

where I_{xx}, I_{yy}, and I_{zz} are the source's principal moments of inertia, with the star rotating about the z-axis.

The spin-down limit $h_0^{\rm sd}$ quantifies the maximum CW amplitude assuming all the lost rotational energy is converted into GW emission. It is calculated as

$$h_0^{\rm sd} = \frac{1}{d}\left(\frac{5GI_{zz}}{2c^3}\frac{|\dot{f}_{\rm rot}|}{f_{\rm rot}}\right)^{1/2}\,. \tag{5}$$

By constraining the CW emission, we can set upper bounds on the fraction of energy emitted through the gravitational channel.

The relative motion of Earth and the source modulates the signal received at the detector (K. Wette 2023). It depends on the source's sky location (Earth motion) and, where needed, on up to five Keplerian parameters for the binary orbit (source motion). After we correct the data for spin-down and Doppler effects (induced by the Earth's revolution and by the source binary motion), the expected CW signal is modulated in amplitude by the Earth's rotation and can be expressed as the real part of the following complex expression (P. Astone et al. 2010)

$$h(t) = H_0\left(H_+\mathbf{A}^+ + H_\times\mathbf{A}^\times\right)\cdot\mathbf{W}\,e^{i(\omega_{\rm gw}t+\phi)}, \tag{6}$$

where $\omega_{\rm gw} = 2\pi f_{\rm gw}$, and boldface symbols denote 5-vectors (arrays with five complex components). The $\mathbf{A}^{+/\times}$ represent the 5-vectors of the single-detector response to the two GW polarizations, and $\mathbf{W} = e^{ik\Theta}$ encodes sidereal modulation, with $k = \{0, \pm1, \pm2\}$ and Θ the local sidereal time (see Section 4 of P. Astone et al. 2010 for more information).

The amplitude H_0 is related to the standard GW amplitude h_0 (P. Jaranowski et al. 1998) as

$$H_0 = h_0\sqrt{\frac{1+6\cos^2\iota+\cos^4\iota}{4}}\,, \tag{7}$$

with ι being the angle between rotation axis and line of sight. The polarization coefficients are given by

$$H_+ = \frac{\cos(2\psi) - i\eta\sin(2\psi)}{\sqrt{1+\eta^2}},\; H_\times = \frac{\sin(2\psi) + i\eta\cos(2\psi)}{\sqrt{1+\eta^2}}, \tag{8}$$

being ψ the CW polarization angle, and

$$\eta = -\frac{2\cos\iota}{1+\cos^2\iota}\,. \tag{9}$$

The matched filters $\hat{H}_{+/\times}$ are computed in the frequency domain as

$$\hat{H}_{+/\times} = \frac{\mathbf{X}\cdot\mathbf{A}^{+/\times}}{|\mathbf{A}^{+/\times}|^2}, \tag{10}$$

where $\mathbf{X}$ is the data 5-vector

$$\mathbf{X} = \int_{T_{\rm obs}} x(t)\,e^{-i\mathbf{k}\Theta}\,e^{-i\omega_{\rm gw}t}dt. \tag{11}$$

Finally, the detection statistic is

$$S = |\mathbf{A}^+|^4|\hat{H}_+|^2 + |\mathbf{A}^\times|^4|\hat{H}_\times|^2\,, \tag{12}$$

as defined in P. Astone et al. (2014a). Note that recent works on the 5-vector formalism (L. D'Onofrio et al. 2024; R. Prix 2025) have described the equivalence with the usual $\mathcal{F}$-statistic.

In this work, we focus on a narrowband approach where we search for CWs allowing for a small mismatch between the EM emission described by Equation 1 and the gravitational one. We use the 5n-vector narrowband pipeline, widely used in several CW searches (e.g. R. Abbott et al. 2022; B. P. Abbott et al. 2017, 2019b; J. Aasi et al. 2015; L. Mirasola et al. 2025; A. G. Abac et al. 2025a). We explore a narrow frequency and spin-down range around twice the best-fit values from the pulsar

---

[2] Simulated CW signals injected through the detector hardware for testing purposes.

ephemeris, to allow for a small mismatch between the EM and CW emissions, namely

$$f \in 2f_{\rm rot}[1-\delta,\, 1+\delta] \qquad (13)$$

generally setting $\delta = 10^{-3}$ (R. Abbott et al. 2022), and a similar equation for $\dot{f}$ using the same value. As a novelty of this work, we explore a corresponding additional range of values in the $\ddot{f}$ space. During the implementation of this feature, we identified a bug in the spin-down correction of this pipeline used in A. G. Abac et al. (2025a). After rerunning the analyses in A. G. Abac et al. (2025a), we find no additional candidates, and upper limits are unchanged. Moreover, the results of A. G. Abac et al. (2025a) are now superseded by those reported in Section 4.

The method makes use of the Short Fourier Data Base (SFDB, P. Astone et al. 2005), which is a collection of short-duration (here we use 2048 s ones) fast Fourier transforms overlapped by half. For each pulsar, we then extract a narrow frequency band from the SFDBs around the region of interest that is then inverse-Fourier transformed to the time domain.

For every target, data are Doppler-corrected in the time domain using a non-uniform resampling method that is independent of the CW frequency, and then they are subsampled at a rate of 1 Hz. For the first time, the pipeline can now target sources in binary systems, accounting for orbital modulation, following A. Singhal et al. (2019); F. Amicucci et al. (2025).

At this point, the time series are Fourier transformed and matched-filtered (using Equation 10) to estimate the two CW polarizations using a template bank in the $f - \dot{f} - \ddot{f}$ space. The template grid consists of all the resolved parameter-space points within the region of interest, spaced by the corresponding resolution calculated as (P. Astone et al. 2014b)

$$\delta f = \frac{1}{T_{\rm obs}}\,, \qquad \delta \dot{f} = \frac{1}{T_{\rm obs}^2}\,, \qquad \delta \ddot{f} = \frac{2}{T_{\rm obs}^3}\,, \qquad (14)$$

with $T_{\rm obs}$ the data timespan. Note that these resolutions neglect correlations among parameters, resulting in more templates than needed (K. Wette et al. 2008), though the overall impact on the computing cost is not significant. Higher-order spin-down terms, if provided in the ephemerides, are fixed at twice the best-fit values to track the GW frequency evolution over time, without exploring any additional template (P. Astone et al. 2014a). When we consider a glitching pulsar, we split the data into two segments that exclude from the analysis the period around $[\, t_{\rm g}{-}1\ {\rm d},\, t_{\rm g}{+}2\ {\rm d}\,]$, with $t_{\rm g}$ the glitch epoch. The segments are then analyzed independently. If the pulsar glitched more than once, this process is repeated until we cover the entire observing time.

The matched filter results from different detectors are coherently combined following S. Mastrogiovanni et al. (2017) to evaluate the detection statistic in Equation 12. Then, marginalization over the spin-downs is performed by sorting the detection statistic values along the frequency axis and selecting the maximum in every 10^{-4} Hz band. All templates with detection statistic above a certain threshold, set by fixing the false-alarm probability ($p_{\rm fa}$) at 1% after taking into account the number of explored grid points, are followed up. The noise-only distribution, used to set the threshold, is inferred with an exponential fit from the tail of the histogram of all statistic values which have not been selected as local maxima (A. Singhal et al. 2019).

If no CW-related outlier is found, we calculate the 95% confidence level (CL) upper limits (ULs) $h_0^{95\%}$ by injecting simulated signals in real data (R. Abbott et al. 2022).

4. SEARCH DETAILS AND RESULTS

In this section, we present and discuss our results using LIGO O4ab data. We do not report a detection. The search identified a set of outliers for PSRs J0117+5914 and J1826−1334, for which we reject an astrophysical origin, as justified below. We first describe the target selection procedure and search setup in Section 4.1. Then, we detail our results in Section 4.2 that are then interpreted in terms of astrophysical constraints in Section 4.3.

4.1. *Target selection and search setup*

The O4ab narrowband search selected all the targets from the set presented in Section 2.1. We focus on those pulsars with $h_0^{\rm sd}$ above or within a factor of four below the expected sensitivity calculated as (P. Astone et al. 2014a; L. D'Onofrio et al. 2024)

$$h_0^{\rm sens} \approx \mathcal{C} \sqrt{\left(\sum_{i=1}^{n} \frac{\mu^i\, T_{\rm obs}^i}{S_i} \right)^{-1}}\,, \qquad (15)$$

where μ^i and S_i are respectively the duty cycle and the harmonic average power spectral density (PSD) for the i-th detector. The prefactor $\mathcal{C}$ in Equation 15 mildly depends on the number of explored templates $N_{\rm templ}$ for each target (P. Astone et al. 2014a; L. D'Onofrio et al. 2024). In our plots, we consider $\mathcal{C} \in [20, 26.5]$ which roughly corresponds to $N_{\rm templ} \in [10^3,\, 10^9]$.

Of the 39 targets within this range, 7 isolated targets glitched within the O4ab period[3] (see Section 2.1.1), and

---

[3] Note that Table 1 reports 9 glitching pulsars, but 2 glitched *before* the beginning of the run, therefore we do not have to perform separate pre- and post-glitch analyses.

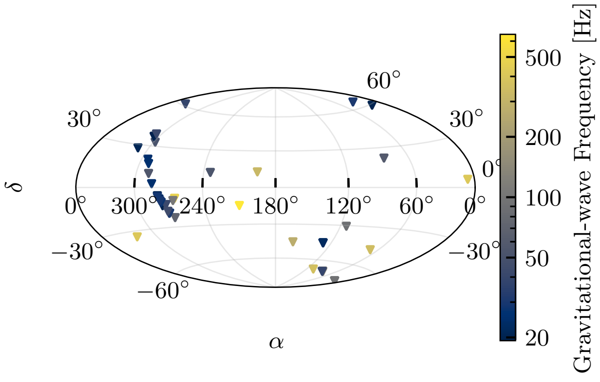

Figure 1. Sky location in equatorial coordinates of the selected targets. The color scale indicates the target's $f_{\rm gw}$.

10 are in a binary system. Figure 1 shows the sky location of the pulsars targeted in this work.

For PSR J0540−6919, we analyzed data only after the second timing event, since both are very close to the beginning of the run (C. M. Espinoza et al. 2024).

Following L. Mirasola et al. (2024), we discard one pulsar, PSR J1231−1411, in a binary system for which the ephemeris does not provide all the Keplerian parameters needed to correct for the source's orbital motion. For each of the other targets in binary systems, we calculate the longest considerable time span ($T_{\rm obs}^{\rm max}$) within which a single fully-coherent search can be applied without needing to account for uncertainties on orbital parameters (L. Mirasola et al. 2024). For four of the pulsars, PSRs J0437−4715, J1045−4509, J1737−0811 and J1745−0952, this calculation returns segments much shorter ($1\ \text{day} \lesssim T_{\rm obs}^{\rm max} \lesssim 90\ \text{days}$) than $T_{\rm obs}^{\rm O4ab} \approx 610$ days. We exclude these four targets since the 5n-vector narrowband pipeline does not cover orbital uncertainties. On the other hand, we have split $T_{\rm obs}$ into three separate segments for pulsar J1400−1431, since $T_{\rm obs}^{\rm max} \sim 200$ days. We have not considered the second segment, as it includes the commissioning break, and the $\mu\, T_{\rm obs}$ would not be enough to perform the analysis. For the other pulsars in a binary system, we have analyzed the entire dataset coherently.
Due to storage limitations, we had to restrict the analysis to $\delta = 10^{-4}$ for PSRs J0534+2200 (Crab pulsar), J0540−6919, J0205+6449, and J2229+6114.

As a result, we present in the following section the search for CWs emitted by 34 selected targets.

4.2. *Outliers and upper limits*

Only for two targets we report outliers (i.e., inferred p-value $< 1\%$ after accounting for $N_{\rm templ}$): 1 for PSR J0117+5914 and 8 for PSR J1826−1334. The two pulsars have a similar rotational frequency (~ 19.7 Hz) that does not overlap with known line-like features reported in E. Goetz et al. (2026), though L1 data are affected by a known transient noise reported (T. Ohanlon & A. Effler 2023), which happens to cross the outliers' band. The noise is related to a $\sim$3.4 Hz line which interacted with the $\sim$16.3 Hz calibration line. The interaction lost strength on August 3rd, 2023 (MJD 60159). This transient behavior, reported in T. Ohanlon & A. Effler (2023), is readily shown in Figure 2, where we display the spectrogram for the L1 detector along the run built with segments of 2048 seconds. For comparison, we superimpose the outliers' frequency tracks encompassing Doppler and spin-down effects as (B. Krishnan et al. 2004)

$$f(t) = \left[f_0 + \dot{f}_0\,(t - t_0) + \frac{1}{2}\ddot{f}_0\,(t - t_0)^2\right]\left(1 + \frac{\vec{v}_{\rm det}\cdot\vec{n}}{c}\right), \tag{16}$$

with the parameters f_0, $\dot{f}_0$, $\ddot{f}_0$ as those of the outliers, t the time at the detector, $\vec{v}_{\rm det}$ the detector's velocity in the solar system barycentre, and $\vec{n}$ the source sky location.

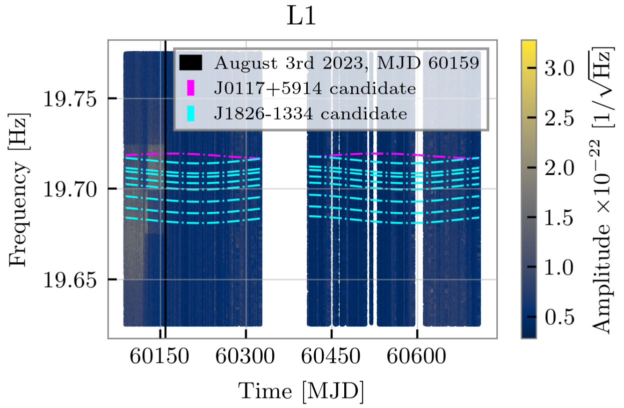

Figure 2. L1 spectrogram computed each 2048 seconds over the O4ab run. The PSRs J0117+5914 and J1826−1334 outlier tracks, calculated with Equation 16, are displayed in fuchsia and cyan, respectively. During the first part of the dataset, the spectrum is affected by a known noise transient reported in T. Ohanlon & A. Effler (2023) whose strength reduces after the MJD 60159 (vertical black line), see text for more details.

Since all the tracks are crossing the polluted band, their astrophysical origin is discarded.

As a result, we have calculated ULs at the 95% CL for each of the analyzed pulsars. In Table 2 we report the per-pulsar ULs, and in Figure 3 we compare $h_0^{95\%}$ with the expected sensitivity estimated through Equation 15.

For PSR J0835−4510 (the Vela pulsar), one of our most interesting targets, we performed an independent

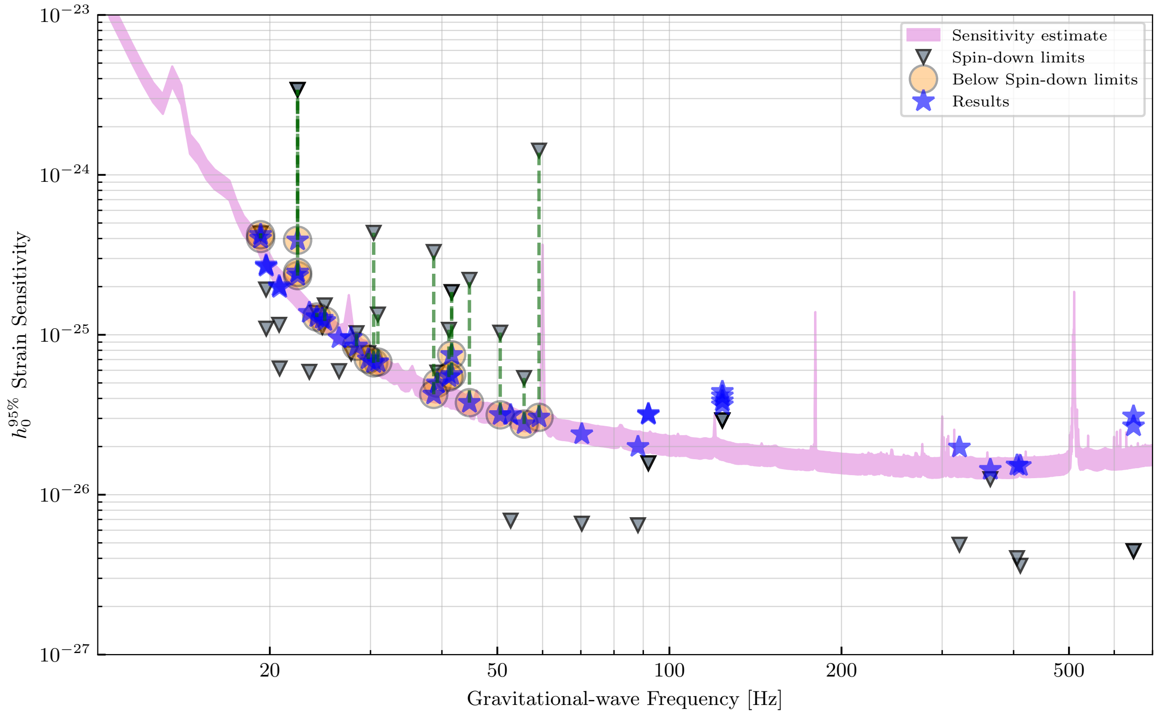

Figure 3. Expected sensitivity of the narrowband search using O4ab (shaded pink region) dataset from the two LIGO detectors. The curve is compared with the spin-down limits (triangles) and the 95% CL ULs (stars) averaged over all the 10^{-4} Hz bands for each source. ULs below the spin-down limit are highlighted with orange circles. Superimposed blue stars correspond to the multiple analyses of glitching pulsars.

post-glitch cross-check analysis with a Mount Pleasant ephemeris covering $T_{\rm obs} \sim 117$ days of O4b. After correcting for the shorter $T_{\rm obs}$ compared with $T_{\rm obs} \sim 270$ days for the IAR ephemeris and the corresponding number of templates, the two results are in agreement. See Table 2 for numerical values. Constraints on GW emission from this target using O4 data have also been presented in A. G. Abac et al. (2025), which searched for post-glitch transient signals. Results for signals lasting the full 120 days considered in that paper are in broad agreement with the Mount Pleasant ephemeris upper limit reported here. However, the two analyses considered different time evolution of the signal and different template banks, so there is no exact correspondence.

We also compare $h_0^{95\%}$ with the spin-down limit $h_0^{\rm sd}$ of each source using a moment of inertia $I_{zz} = 10^{38}$ kg m^2 in Equation 5. In this work, we have surpassed the spin-down limit in 20 analyses (counting pre- and post-glitch searches as separate analyses), with our most stringent constraint being a ratio of $\sim 2\%$ between our UL and Crab's $h_0^{\rm sd}$.

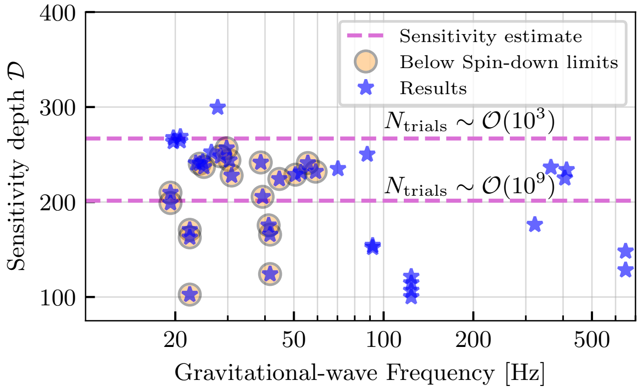

Figure 4. Sensitivity depths calculated with Equation 17 using the results in Figure 3. The two horizontal dotted lines highlight the theoretical sensitivity for the reported number of explored templates, calculated with Equations 15 and 17.

From the ULs in Figure 3, we calculate the dimensionless sensitivity depth $\mathcal{D}$ (B. Behnke et al. 2015; C. Dreissigacker et al. 2018; K. Wette 2023) as

$$\mathcal{D} = \frac{\sqrt{S_h \cdot \mathrm{Hz}}}{h_0^{95\%}} \tag{17}$$

here, S_h is the power spectral density, harmonic-averaged over time and detectors. See B. Behnke et al. (2015); C. Dreissigacker et al. (2018) for additional references on the sensitivity depth. In this work, we reached a median depth of $\mathcal{D} \approx 230$ (not including glitching pulsar analyses), in agreement with previous searches (K. Wette 2020). Note that the distribution of $\mathcal{D}$ in Figure 4, where we report the per-pulsar depths, can be tracked back to either $N_{\rm templ}$ or a glitching pulsar analysis (i.e., where we split the dataset into shorter segments).

In this work, we improve our previous constraints on the CW emission for all the considered non-glitching targets, as shown in Figure 5. If we compare with O4a (A. G. Abac et al. 2025a) and O3 (R. Abbott et al. 2022) analyses, which have a comparable sensitivity (A. G. Abac et al. 2025a), we see an improvement of about $\sim 1/\sqrt{2}$ related to the doubled $T_{\rm obs}$ (see Equation 15). If we compare with O2 (B. P. Abbott et al. 2019b) and O1 (B. P. Abbott et al. 2017), the improvement is even larger thanks to the detectors' upgrades and a longer run.

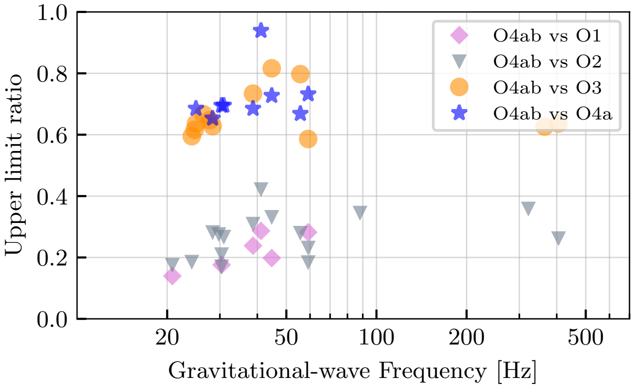

Figure 5. ULs in Figure 3 of non-glitching pulsars divided by previous 5n-vector narrowband upper limits. More specifically, blue stars compare with the O4a-only analysis of A. G. Abac et al. (2025a), orange circles with O3 (R. Abbott et al. 2022), grey triangles with O2 (B. P. Abbott et al. 2019b), and O1 purple squares from B. P. Abbott et al. (2017). Note that multiple analyses might have targeted the same pulsar; we show all the comparisons to highlight the significant improvements from one observing run to the other.

4.3. *Astrophysical interpretation*

In Figure 6 we re-cast our results as ULs on ellipticities, as defined in Equation 4; these are also reported in Table 2. In the Figure, we also show lines of constant characteristic age $\tau = f/4|\dot{f}|$, as would be relevant if spin-down were driven entirely by GW emission from a constant mass quadrupole. This plot provides a natural place to interpret the astrophysical significance of our results. The ULs naturally divide into two subclasses.

For the younger pulsars, with $f \lesssim 100$ Hz, the ellipticity limits lie mainly in the range $10^{-3} \lesssim \varepsilon \lesssim 10^{-5}$, with a few ULs of a few times 10^{-6}. All of the pulsars for which we have beaten the energy-based spin-down limit belong to this class. The limit is surpassed by the greatest margin for the Crab pulsar (J0534+2200), for which we find $h_0^{95\%}/h_0^{\rm sd} \approx 0.02$, corresponding to no more than $0.02^2 \approx 0.04\%$ of its spin-down energy budget being radiated in the GW channel.

For the older millisecond pulsars, with $f \gtrsim 100$ Hz, our upper limits on h_0 lead to upper bounds on ellipticity lying roughly in the range $10^{-8} \lesssim \varepsilon \lesssim 10^{-7}$. While smaller than the ellipticity constraints quoted above for the young pulsars, we do *not* beat the spin-down upper limits for any of the millisecond pulsars, and thus their ellipticity constraints are not physically informative. The closest to the spin-down limit was PSR J0711−6830, for which we report $h_0^{95\%}/h_0^{\rm sd} \approx 1.15$. Note, however, our calculations of the spin-down limits assume a canonical moment of inertia $I_{zz} = 10^{38}$ kg m^2. For realistic NS masses and equations of state, values as large as $I_{zz} \approx 3 \times 10^{38}$ kg m^2 are possible (A. Worley et al. 2008). In this case, the spin-down limits in $h_0^{\rm sd}$ are decreased by a factor $\sqrt{3}$ (see Equation 5), bringing this millisecond pulsar into the range of potential detectability, a significant achievement for a narrowband search.

To place our ULs in further context, theoretical estimates of maximum ellipticities supported by strains in NS crusts are around 10^{-6}, somewhat below our best ULs for young pulsars; see e.g. M. Pitkin (2011); N. K. Johnson-McDaniel & B. J. Owen (2013); G. Ushomirsky et al. (2000); F. Gittins & N. Andersson (2021); J. A. Morales & C. J. Horowitz (2022). Theoretical estimates of the ellipticities produced by magnetic fields depend upon the poorly constrained geometry and strength of the *internal* magnetic field $B_{\rm int}$, with an estimate of $\varepsilon \sim 10^{-8} (B_{\rm int}/10^{12}\ {\rm G})$ for a superconducting interior (see R. Abbott et al. (2020) for discussion and references). For such magnetic mountains to reach the level of our ULs for the young pulsars, the internal field strength would have to be several orders of magnitude greater than the external field strength $\sim 10^{12}$ G typical of such pulsars (A. Lyne & F. Graham-Smith 2012).

However, mountains supported by less conventional matter phases, e.g. solid quark phases or the colour-flavour-locked (CFL) phase, can be as large as $\sim 10^{-3}$; see e.g. B. J. Owen (2005); K. Glampedakis et al. (2012). While exotic, such stars are potentially particularly relevant to narrowband searches, where a possible emission mechanism is from a non-axisymmetric solid core, whose rotation is not perfectly coupled to that of the crust, allowing for a GW emission offset slightly from (twice) the radio pulsation frequency (B. Abbott et al. 2008). By this measure, all of our ULs that are tighter than the spin-down limits are of astrophysical interest, but not directly comparable with those set by targeted searches (e.g., A. G. Abac et al. (2025a)) due to the intrinsic assumptions on the CW emission being mis-

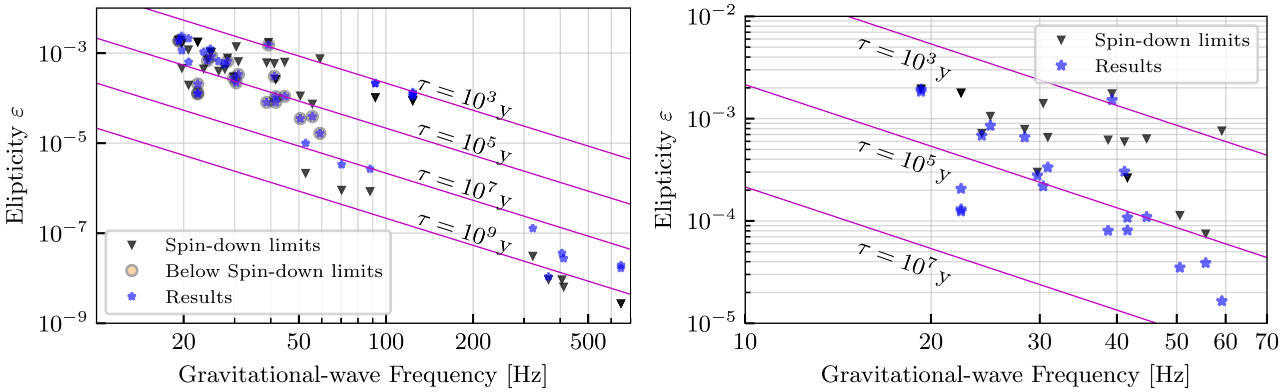

Figure 6. ULs on the star's ellipticity ε compared with the spin-down limits. While the left panel shows our results for all the pulsars, the right panel focuses only on those for which the observational UL is stricter than the spin-down limit (i.e., physically constraining the fraction of rotational energy emitted through the CW channel). The values are compared with contour lines of equal characteristic age $\tau = f/4|\dot{f}|$, assuming that GW emission alone is causing the spin-down.

matched (narrowband) or locked (targeted) to the EM emission.

5. CONCLUSIONS

In this work, we present a search for CW signals from a set of 34 known pulsars using O4ab data from the two LIGO detectors, allowing for a mismatch between the EM and GW emissions. This is the largest set of targets ever considered for a narrowband search.

We performed the CW search using the 5n-vector narrowband pipeline, based on matched filtering in the frequency domain. Narrowband searches allow a small mismatch between the EM and CW emissions, unlike targeted searches (e.g. A. G. Abac et al. 2025a). This implies that the results presented here are more robust in cases where the two signals are not phase-locked, e.g., for glitching pulsars, which are likely to have a superfluid interior flow.

For the first time, we study pulsars in binary systems in a narrowband search. Thanks to other improvements of the 5n-vector pipeline, it can now explore an additional range of values in the $\ddot{f}$ space.

We do not report a detection as all statistically significant outliers were associated with instrumental disturbances and vetoed. Therefore, we set ULs on the GW strain amplitude and ellipticity from each target. For 20 analyses, we report an UL below the theoretical spin-down limit. Overall, we improve our constraints on the CW emission from all the targets as shown in Figure 5. Our tightest constraint is for the Crab pulsar, for which our upper limit on the CW amplitude is $\lesssim 2\%$ of its spin-down limit, corresponding to no more than $\sim 0.04\%$ of its spin-down energy budget being radiated in the GW channel.

Data products associated with this work are collected in the LIGO-DCC document T2600052.

ACKNOWLEDGEMENTS

This material is based upon work supported by NSF's LIGO Laboratory, which is a major facility fully funded by the National Science Foundation. The authors also gratefully acknowledge the support of the Science and Technology Facilities Council (STFC) of the United Kingdom, the Max-Planck-Society (MPS), and the State of Niedersachsen/Germany for support of the construction of Advanced LIGO and construction and operation of the GEO 600 detector. Additional support for Advanced LIGO was provided by the Australian Research Council. The authors gratefully acknowledge the Italian Istituto Nazionale di Fisica Nucleare (INFN), the French Centre National de la Recherche Scientifique (CNRS) and the Netherlands Organization for Scientific Research (NWO) for the construction and operation of the Virgo detector and the creation and support of the EGO consortium. The authors also gratefully acknowledge research support from these agencies as well as by the Council of Scientific and Industrial Research of India, the Department of Science and Technology, India, the Science & Engineering Research Board (SERB), India, the Ministry of Human Resource Development, India, the Spanish Agencia Estatal de Investigación (AEI), the Spanish Ministerio de Ciencia, Innovación y Universidades, the European Union NextGenerationEU/PRTR (PRTR-C17.I1), the ICSC - CentroNazionale di Ricerca in High Performance Computing, Big Data and Quantum Computing, funded by the European Union NextGenerationEU, the Comunitat Autonòma de les Illes Balears through the Conselleria d'Educació i Universitats, the Conselleria d'Innovació, Universitats, Ciència i Societat Digital de la Generalitat Valenciana and the CERCA Programme Generalitat de Catalunya, Spain, the Polish National Agency for Academic Exchange, the National Science Centre of Poland and the European Union - European Regional Development Fund; the Foundation for Polish Science (FNP), the Polish Ministry of Science and Higher Education, the Swiss National Science Foundation (SNSF), the Russian Science Foundation, the European Commission, the European Social Funds (ESF), the European Regional Development Funds (ERDF), the Royal Society, the Scottish Funding Council, the Scottish Universities Physics Alliance, the Hungarian Scientific Research Fund (OTKA), the French Lyon Institute of Origins (LIO), the Belgian Fonds de la Recherche Scientifique (FRS-FNRS), Actions de Recherche Concertées (ARC) and Fonds Wetenschappelijk Onderzoek - Vlaanderen (FWO), Belgium, the Paris Île-de-France Region, the National Research, Development and Innovation Office of Hungary (NKFIH), the National Research Foundation of Korea, the Natural Sciences and Engineering Research Council of Canada (NSERC), the Canadian Foundation for Innovation (CFI), the Brazilian Ministry of Science, Technology, and Innovations, the International Center for Theoretical Physics South American Institute for Fundamental Research (ICTP-SAIFR), the Research Grants Council of Hong Kong, the National Natural Science Foundation of China (NSFC), the Israel Science Foundation (ISF), the US-Israel Binational Science Fund (BSF), the Leverhulme Trust, the Research Corporation, the National Science and Technology Council (NSTC), Taiwan, the United States Department of Energy, and the Kavli Foundation. The authors gratefully acknowledge the support of the NSF, STFC, INFN and CNRS for provision of computational resources.

This work was supported by MEXT, the JSPS Leading-edge Research Infrastructure Program, JSPS Grant-in-Aid for Specially Promoted Research 26000005, JSPS Grant-in-Aid for Scientific Research on Innovative Areas 2402: 24103006, 24103005, and 2905: JP17H06358, JP17H06361 and JP17H06364, JSPS Core-to-Core Program A. Advanced Research Networks, JSPS Grants-in-Aid for Scientific Research (S) 17H06133 and 20H05639, JSPS Grant-in-Aid for Transformative Research Areas (A) 20A203: JP20H05854, the joint research program of the Institute for Cosmic Ray Research, University of Tokyo, the National Research Foundation (NRF), the Computing Infrastructure Project of the Global Science experimental Data hub Center (GSDC) at KISTI, the Korea Astronomy and Space Science Institute (KASI), the Ministry of Science and ICT (MSIT) in Korea, Academia Sinica (AS), the AS Grid Center (ASGC) and the National Science and Technology Council (NSTC) in Taiwan under grants including the Science Vanguard Research Program, the Advanced Technology Center (ATC) of NAOJ, and the Mechanical Engineering Center of KEK.

Additional acknowledgements for support of individual authors may be found in the following document: `https://dcc.ligo.org/LIGO-M2300033/public`. For the purpose of open access, the authors have applied a Creative Commons Attribution (CC BY) license to any Author Accepted Manuscript version arising. We request that citations to this article use 'A. G. Abac *et al.* (LIGO-Virgo-KAGRA Collaboration), ...' or similar phrasing, depending on journal convention.

The MeerKAT telescope is operated by the South African Radio Astronomy Observatory (SARAO), which is a facility of the National Research Foundation, an agency of the Department of Science and Innovation. SARAO acknowledges the ongoing advice and calibration of GPS systems by the National Metrology Institute of South Africa (NMISA) and the time space reference systems department of the Paris Observatory.

Parts of this work were supported by the Australian Research Council Centre of Excellence for Gravitational Wave Discovery (OzGrav) through grants CE170100004 and CE230100016.

MM acknowledges support from the NANOGrav Collaboration's National Science Foundation (NSF) Physics Frontiers Center award numbers 1430284 and 2020265.

C.M.E. acknowledges support from ANID/FONDECYT, grant 1211964. S.G. acknowledges the support of the CNES. W.C.G.H. acknowledges support through grants 80NSSC22K1305 and 80NSSC24K1195 from NASA and Chandra award SAO GO4-25038X. Chandra grants are issued by the Chandra X-ray Center (CXC), which is operated by the Smithsonian Astrophysical Observatory for and on behalf of NASA under contract NAS8-03060. This research made use of data obtained from the Chandra Data Archive and the Chandra Source Catalog, and software provided by the Chandra X-ray Center (CXC) in the application packages CIAO and Sherpa. This work is supported by NASA through the NICER mission and the Astrophysics Explorers Program and uses data and software provided by the High Energy Astrophysics Science Archive Research Center (HEASARC), which is a service of the Astrophysics Science Division at NASA/GSFC and High Energy Astrophysics Division of the Smithsonian Astrophysical Observatory.

S.B.A.F., S.D.P., G.G., F.G., G.E.R. and E.Z. are grateful to the staff of the IAR for technical support and assistance during the observations. The activities at the Instituto Argentino de Radioastronomia (IAR) are supported by the national agency CONICET, the

Province of Buenos Aires agency CIC, and the National University of La Plata (UNLP).

E.F. is supported by the National Science Foundation under grant AST-2407399.

Pulsar research at UBC is supported by an NSERC Discovery Grant and the Canadian Institute for Advanced Research.

A.B.P. is a Banting Fellow, a McGill Space Institute (MSI) Fellow, and a Fonds de Recherche du Quebec – Nature et Technologies (FRQNT) postdoctoral fellow.

This document has been given the LIGO-DCC number P2500612.

Software: The 5-vector method is based on the SFDB framework (P. Astone et al. 2005), and on the Virgo Rome Snag software (S. Frasca et al. 2022). Plots are produced using `matplotlib` (J. D. Hunter 2007). Many pulsar ephemerides are produced with `TEMPO` (D. Nice et al. 2015), `TEMPO2` (G. B. Hobbs et al. 2006). The pulsar selection has been handled through `CWInPy` (M. Pitkin 2022) and `psrqpy` (M. Pitkin 2018).

Table 2. Results table obtained with the method described in Section 3. The nomenclature "pg" identifies the post-glitch analyses, "pgMt" identifies the second post-glitch Vela analysis using the Mount Pleasant ephemeris; more information is given in the text. Starred pulsars have been analysed using $\delta = 10^{-4}$. The marker † identifies pulsars in a binary system. Frequencies and spin-down parameters are referred to the starting day of the run.

Pulsar Name	$f_{\rm rot}$	$\dot{f}_{\rm rot}$	$\ddot{f}_{\rm rot}$	d	$h_0^{95\%}$	$h_0^{95\%}/h_0^{sd}$	$\mathcal{D}$	$\varepsilon^{95\%}$	$\mathrm{N_{trials}}$	Distance Ref.
J2000	Hz	Hz/s	Hz/s^2	kpc	$\times 10^{-26}$				$\times 10^6$	
J0030+0451$^{\rho}$	205.53	-4.3×10^{-16}	-	0.32	1.52	4.21	233.8	2.7×10^{-8}	46	A. N. Lommen et al. (2000)
J0058$-$7218$^{\beta}$	45.94	-6.2×10^{-11}	6.6×10^{-21}	59.70	3.16	2.01	154.2	2.1×10^{-4}	701	C. Maitra et al. (2021)
J0058$-$7218 pg$^{\beta}$	45.94	-6.2×10^{-11}	4.9×10^{-21}	59.70	3.21	2.04	152.0	2.1×10^{-4}	6047	C. Maitra et al. (2021)
J0117+5914$^{\gamma}$	9.86	-5.7×10^{-13}	-8.4×10^{-24}	1.77	26.69	2.44	267.5	1.1×10^{-3}	55	J. M. Yao et al. (2017)
J0205+6449$^{*\gamma}$	15.19	-4.5×10^{-11}	1.7×10^{-20}	3.20	6.67	0.15	244.0	2.2×10^{-4}	50	S. S. Murray et al. (2002)
J0534+2200$^{*\gamma}$	29.57	-3.7×10^{-10}	1.8×10^{-20}	2.00	3.05	0.02	232.0	1.6×10^{-5}	753	A. R. Walker (2012)
J0537$-$6910$^{\beta}$	61.89	-2.0×10^{-10}	5.8×10^{-21}	49.70	3.63	1.25	121.5	1.1×10^{-4}	896	F. E. Marshall et al. (1998)
J0537$-$6910 pg1$^{\beta}$	61.89	-2.0×10^{-10}	5.8×10^{-21}	49.70	4.13	1.42	106.8	1.3×10^{-4}	1447	F. E. Marshall et al. (1998)
J0537$-$6910 pg2$^{\beta}$	61.89	-2.0×10^{-10}	1.4×10^{-20}	49.70	3.85	1.32	114.7	1.2×10^{-4}	4057	F. E. Marshall et al. (1998)
J0537$-$6910 pg3$^{\beta}$	61.89	-2.0×10^{-10}	9.0×10^{-21}	49.70	4.41	1.51	100.1	1.4×10^{-4}	252	F. E. Marshall et al. (1998)
J0540$-$6919$^{*\beta}$	19.64	-2.5×10^{-10}	4.7×10^{-21}	49.70	4.99	0.86	205.5	1.5×10^{-3}	226	M. Geyer et al. (2021)
J0711$-$6830$^{\nu}$	182.12	-4.9×10^{-16}	-	0.11	1.43	1.15	236.5	1.1×10^{-8}	83	J. M. Yao et al. (2017)
J0737-3039A$^{\dagger\gamma}$	44.05	-3.4×10^{-15}	-	1.10	2.00	3.09	250.2	2.7×10^{-6}	27	M. Burgay et al. (2003)
J0835$-$4510$^{\delta}$	11.18	-1.6×10^{-11}	2.0×10^{-22}	0.28	23.44	0.07	170.7	1.2×10^{-4}	213	J. P. W. Verbiest et al. (2012)
J0835$-$4510 pg$^{\delta}$	11.18	-1.6×10^{-11}	2.0×10^{-22}	0.28	24.58	0.07	162.8	1.3×10^{-4}	107	J. P. W. Verbiest et al. (2012)
J0835$-$4510 pgMt$^{\epsilon}$	11.18	-1.6×10^{-11}	-2.3×10^{-21}	0.28	39.02	0.11	102.6	2.1×10^{-4}	11	J. P. W. Verbiest et al. (2012)
J1300+1240$^{\dagger\alpha}$	160.81	-3.0×10^{-15}	-	0.71	1.98	4.06	176.2	1.3×10^{-7}	101	A. Wolszczan et al. (2000)
J1400$-$1431\_1$^{\dagger\alpha}$	324.23	-7.6×10^{-16}	-	0.28	2.68	6.04	148.1	1.7×10^{-8}	48	R. Rosen et al. (2013)
J1400-1431_2$^{\dagger\alpha}$	324.23	-7.6×10^{-16}	-	0.28	3.10	6.96	128.4	1.9×10^{-8}	48	R. Rosen et al. (2013)
J1537+1155$^{\dagger\gamma}$	26.38	-1.7×10^{-15}	6.2×10^{-29}	0.93	3.15	4.57	231.3	1.0×10^{-5}	49	E. Fonseca et al. (2014)
J1756-2251$^{\dagger\gamma}$	35.14	-1.3×10^{-15}	3.0×10^{-27}	0.73	2.39	3.63	235.0	3.3×10^{-6}	22	A. J. Faulkner et al. (2004)
J1809$-$1917$^{\gamma}$	12.08	-3.7×10^{-12}	6.2×10^{-23}	3.27	12.91	0.94	240.4	6.8×10^{-4}	326	J. M. Yao et al. (2017)
J1811$-$1925$^{\beta}$	15.45	-1.1×10^{-11}	1.8×10^{-22}	5.00	6.75	0.50	227.9	3.3×10^{-4}	1175	K. Torii et al. (1997)
J1813$-$1246$^{\zeta}$	20.80	-7.6×10^{-12}	2.6×10^{-22}	2.63	7.49	0.40	124.2	1.1×10^{-4}	472	A. A. Abdo et al. (2009)
J1813$-$1246 pg$^{\zeta}$	20.80	-7.6×10^{-12}	2.6×10^{-22}	2.63	5.61	0.30	165.7	8.1×10^{-5}	472	A. A. Abdo et al. (2009)
J1813$-$1749$^{\eta}$	22.34	-6.3×10^{-11}	-	6.15	3.76	0.17	224.3	1.1×10^{-4}	3312	J. M. Yao et al. (2017)
J1826$-$1334$^{\gamma}$	9.85	-7.3×10^{-12}	2.1×10^{-22}	3.61	27.22	1.42	263.4	2.4×10^{-3}	513	J. M. Yao et al. (2017)
J1828$-$1101$^{\gamma}$	13.88	-2.8×10^{-12}	-3.9×10^{-23}	4.77	9.58	1.25	299.6	5.6×10^{-4}	95	J. M. Yao et al. (2017)
J1831$-$0952$^{\gamma}$	14.86	-1.8×10^{-12}	7.9×10^{-24}	3.68	7.04	0.92	256.6	2.8×10^{-4}	71	J. M. Yao et al. (2017)
J1833$-$0827$^{\gamma}$	11.72	-1.3×10^{-12}	-1.7×10^{-24}	4.50	13.75	2.34	240.9	1.1×10^{-3}	125	P. Esposito et al. (2011)
J1837$-$0604$^{\gamma}$	10.38	-4.9×10^{-12}	3.5×10^{-22}	4.78	20.16	1.74	264.2	2.1×10^{-3}	123	J. M. Yao et al. (2017)
J1838$-$0655$^{\beta}$	14.18	-1.0×10^{-11}	3.0×10^{-22}	6.60	8.48	0.83	248.1	6.6×10^{-4}	335	E. V. Gotthelf & J. P. Halpern (2008)

Table 2 *continued*

Table 2 *(continued)*

Pulsar Name J2000	$f_{\rm rot}$ Hz	$\dot{f}_{\rm rot}$ Hz/s	$\ddot{f}_{\rm rot}$ Hz/s^2	d kpc	$h_0^{95\%}$ $\times 10^{-26}$	$h_0^{95\%}/h_0^{sd}$	$\mathcal{D}$	$\varepsilon^{95\%}$	N$_{\rm trials}$ $\times 10^6$	Distance Ref.
J1856+0245$^{\gamma}$	12.36	-9.5×10^{-12}	1.8×10^{-22}	6.32	12.63	1.13	242.3	1.2×10^{-3}	276	J. M. Yao et al. (2017)
J1913+1011$^{\gamma}$	27.85	-2.6×10^{-12}	-1.7×10^{-23}	4.61	2.77	0.51	241.1	3.9×10^{-5}	180	J. M. Yao et al. (2017)
J1925+1720$^{\gamma}$	13.22	-1.8×10^{-12}	1.8×10^{-23}	5.06	9.53	1.61	252.4	6.5×10^{-4}	63	J. M. Yao et al. (2017)
J1935+2025$^{\gamma}$	12.48	-9.5×10^{-12}	2.9×10^{-22}	4.59	12.22	0.80	236.9	8.5×10^{-4}	278	J. M. Yao et al. (2017)
J1952+3252$^{\gamma}$	25.29	-3.7×10^{-12}	9.2×10^{-22}	3.00	3.16	0.31	228.8	3.5×10^{-5}	684	B. R. Zeiger et al. (2008)
J2021+3651$^{\gamma}$	9.64	-8.9×10^{-12}	-2.5×10^{-22}	1.80	40.04	0.93	209.8	1.8×10^{-3}	25	M. S. E. Roberts et al. (2002)
J2021+3651 pg$^{\gamma}$	9.64	-8.9×10^{-12}	-2.5×10^{-22}	1.80	42.24	0.98	199.0	1.9×10^{-3}	190	M. S. E. Roberts et al. (2002)
J2022+3842$^{\beta}$	20.57	-3.7×10^{-11}	6.5×10^{-21}	10.00	5.44	0.51	175.5	3.0×10^{-4}	1757	Z. Arzoumanian et al. (2011)
J2043+2740$^{\gamma}$	10.40	-1.3×10^{-13}	3.1×10^{-23}	1.48	19.67	3.19	268.8	6.4×10^{-4}	6	J. M. Yao et al. (2017)
J2124−3358$^{\nu}$	202.79	-8.5×10^{-16}	-	0.41	1.53	3.80	225.1	3.6×10^{-8}	127	D. J. Reardon et al. (2016)
J2229+6114$^{*\gamma}$	19.35	-2.9×10^{-11}	2.7×10^{-21}	3.00	4.24	0.13	241.6	8.0×10^{-5}	41	J. P. Halpern et al. (2001)

References—The following is a list of references for pulsar ephemeris data used in this analysis: Nancay: α, NICER: β, JBO: γ, IAR: δ, MeerKAT: ν, CHIME: ρ, Fermi-LAT: ζ, Chandra: η, Mount Pleasant: ϵ.

References—The last column lists references for pulsar distances, and they should be consulted for information on their associated uncertainty.

REFERENCES

Aasi, J., Abbott, B. P., Abbott, R., et al. 2015, Advanced LIGO, CQGra, 32, 074001, doi: 10.1088/0264-9381/32/7/074001

Aasi, J., et al. 2015, Narrow-band search of continuous gravitational-wave signals from Crab and Vela pulsars in Virgo VSR4 data, Phys. Rev. D, 91, 022004, doi: 10.1103/PhysRevD.91.022004

Aasi, J., Abbott, B. P., Abbott, R., et al. 2015, Narrow-band search of continuous gravitational-wave signals from Crab and Vela pulsars in Virgo VSR4 data, PhRvD, 91, 022004, doi: https://doi.org/10.1103/PhysRevD.91.022004

Abac, A. G., Abbott, R., Abouelfettouh, I., et al. 2024, Observation of Gravitational Waves from the Coalescence of a 2.5–4.5 M Compact Object and a Neutron Star, The Astrophysical Journal Letters, 970, L34, doi: 10.3847/2041-8213/ad5beb

Abac, A. G., Abouelfettouh, I., Acernese, F., et al. 2025, GWTC-4.0: Updating the Gravitational-Wave Transient Catalog with Observations from the First Part of the Fourth LIGO-Virgo-KAGRA Observing Run, arXiv e-prints, arXiv:2508.18082, doi: 10.48550/arXiv.2508.18082

Abac, A. G., Abbott, R., Abouelfettouh, I., et al. 2025a, Search for Continuous Gravitational Waves from Known Pulsars in the First Part of the Fourth LIGO-Virgo-KAGRA Observing Run, Astrophys. J., 983, 99, doi: 10.3847/1538-4357/adb3a0

Abac, A. G., et al. 2025b, Open Data from LIGO, Virgo, and KAGRA through the First Part of the Fourth Observing Run, https://arxiv.org/abs/2508.18079

Abac, A. G., Abouelfettouh, I., Acernese, F., et al. 2025, Constraints on gravitational waves from the 2024 Vela pulsar glitch, https://arxiv.org/abs/2512.17990

Abbott, B., Abbott, R., Adhikari, R., et al. 2008, Beating the Spin-Down Limit on Gravitational Wave Emission from the Crab Pulsar, The Astrophysical Journal Letters, 683, L45, doi: 10.1086/591526

Abbott, B. P., Abbott, R., Abbott, T. D., et al. 2017, First narrow-band search for continuous gravitational waves from known pulsars in advanced detector data, PhRvD, 96, 122006, doi: 10.1103/PhysRevD.96.122006

Abbott, B. P., Abbott, R., Abbott, T. D., et al. 2019a, Tests of general relativity with the binary black hole signals from the LIGO-Virgo catalog GWTC-1, PhRvD, 100, 104036, doi: 10.1103/PhysRevD.100.104036

Abbott, B. P., Abbott, R., Abbott, T. D., et al. 2019b, Narrow-band search for gravitational waves from known pulsars using the second LIGO observing run, PhRvD, 99, 122002, doi: 10.1103/PhysRevD.99.122002

Abbott, R., Abbott, T. D., Abraham, S., et al. 2020, Gravitational-wave Constraints on the Equatorial Ellipticity of Millisecond Pulsars, The Astrophysical Journal Letters, 902, L21, doi: 10.3847/2041-8213/abb655

Abbott, R., Abbott, T. D., Acernese, F., et al. 2022, Narrowband Searches for Continuous and Long-duration Transient Gravitational Waves from Known Pulsars in the LIGO-Virgo Third Observing Run, Astrophys. J., 932, 133, doi: 10.3847/1538-4357/ac6ad0

Abdo, A. A., Ackermann, M., Ajello, M., et al. 2009, Detection of 16 Gamma-Ray Pulsars Through Blind Frequency Searches Using the Fermi LAT, Science, 325, 840, doi: 10.1126/science.1175558

Acernese, F., Agathos, M., Agatsuma, K., et al. 2015, Advanced Virgo: a second-generation interferometric gravitational wave detector, CQGra, 32, 024001, doi: 10.1088/0264-9381/32/2/024001

Akutsu, T., et al. 2021, Overview of KAGRA: Detector design and construction history, PTEP, 2021, 05A101, doi: 10.1093/ptep/ptaa125

Amicucci, F., et al. 2025, A directed continuous-wave search from Scorpius X-1 with the five-vector resampling technique, Class. Quant. Grav., 42, 145008, doi: 10.1088/1361-6382/adecd7

Amiri, M., Bandura, K. M., Boyle, P. J., et al. 2021, The CHIME Pulsar Project: System Overview, ApJS, 255, 5, doi: 10.3847/1538-4365/abfdcb

Andersson, N. 1998, A New Class of Unstable Modes of Rotating Relativistic Stars, ApJ, 502, 708, doi: 10.1086/305919

Antonelli, M., Basu, A., & Haskell, B. 2025, Gravitational pulsars: Correlations between the electromagnetic and the continuous gravitational wave signal, PASA, 42, e118, doi: 10.1017/pasa.2025.10086

Antonopoulou, D., Haskell, B., & Espinoza, C. M. 2022, Pulsar glitches: observations and physical interpretation, Rept. Prog. Phys., 85, 126901, doi: 10.1088/1361-6633/ac9ced

Arzoumanian, Z., Gotthelf, E. V., Ransom, S. M., et al. 2011, Discovery of an Energetic Pulsar Associated with SNR G76.9+1.0, ApJ, 739, 39, doi: 10.1088/0004-637X/739/1/39

Ashok, A., Beheshtipour, B., Papa, M. A., et al. 2021, New Searches for Continuous Gravitational Waves from Seven Fast Pulsars, Astrophys. J., 923, 85, doi: 10.3847/1538-4357/ac2582

Ashton, G., Lasky, P. D., Graber, V., & Palfreyman, J. 2019, Rotational evolution of the Vela pulsar during the 2016 glitch, Nature Astronomy, 3, 1143, doi: 10.1038/s41550-019-0844-6

Ashton, G., Prix, R., & Jones, D. I. 2017, Statistical characterization of pulsar glitches and their potential impact on searches for continuous gravitational waves, Phys. Rev. D, 96, 063004, doi: 10.1103/PhysRevD.96.063004

Astone, P., Colla, A., D'Antonio, S., et al. 2014a, Method for narrow-band search of continuous gravitational wave signals, Phys. Rev. D, 89, 062008, doi: 10.1103/PhysRevD.89.062008

Astone, P., Colla, A., D'Antonio, S., et al. 2014b, Method for narrow-band search of continuous gravitational wave signals, Phys. Rev. D, 89, 062008, doi: 10.1103/PhysRevD.89.062008

Astone, P., D'Antonio, S., Frasca, S., & Palomba, C. 2010, A method for detection of known sources of continuous gravitational wave signals in non-stationary data, CQGra, 27, 194016, doi: 10.1088/0264-9381/27/19/194016

Astone, P., Frasca, S., & Palomba, C. 2005, The short FFT database and the peak map for the hierarchical search of periodic sources, Class. Quant. Grav., 22, S1197, doi: 10.1088/0264-9381/22/18/S34

Atwood, W. B., Abdo, A. A., Ackermann, M., et al. 2009, The Large Area Telescope on the Fermi Gamma-Ray Space Telescope Mission, ApJ, 697, 1071, doi: 10.1088/0004-637X/697/2/1071

Basu, A., Shaw, B., Antonopoulou, D., et al. 2022, The Jodrell bank glitch catalogue: 106 new rotational glitches in 70 pulsars, MNRAS, 510, 4049, doi: 10.1093/mnras/stab3336

Baxi, P., Leviton, J., Morag, E., Pitkin, M., & Riles, K. 2026, Monitoring of Continuous-Wave Hardware Injections in LIGO Interferometers during the O4 Observing Run, https://arxiv.org/abs/2601.09918

Behnke, B., Papa, M. A., & Prix, R. 2015, Postprocessing methods used in the search for continuous gravitational-wave signals from the Galactic Center, Phys. Rev. D, 91, 064007, doi: 10.1103/PhysRevD.91.064007

Bonazzola, S., & Gourgoulhon, E. 1996, Gravitational waves from pulsars: emission by the magnetic-field-induced distortion., Astronomy & Astrophysics, 312, 675

Burgay, M., et al. 2003, An Increased estimate of the merger rate of double neutron stars from observations of a highly relativistic system, Nature, 426, 531, doi: 10.1038/nature02124

Capote, E., et al. 2025, Advanced LIGO detector performance in the fourth observing run, Phys. Rev. D, 111, 062002, doi: 10.1103/PhysRevD.111.062002

Collaboration, V. 2025, Optical characterization of the Advanced Virgo gravitational wave detector for the O4 observing run, Appl. Opt., 64, 4710, doi: 10.1364/AO.555312

Cutler, C. 2002, Gravitational waves from neutron stars with large toroidal B fields, PhRvD, 66, 084025, doi: 10.1103/PhysRevD.66.084025

Dartez, L., et al. 2024, Procedural issues in LHO Calibration,, Tech. rep., LIGO Laboratory. https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=86547

Davis, D., Massinger, T. J., Lundgren, A. P., et al. 2019, Improving the Sensitivity of Advanced LIGO Using Noise Subtraction, CQGra, 36, 055011, doi: 10.1088/1361-6382/ab01c5

Dodson, R. G., McCulloch, P. M., & Lewis, D. R. 2002, High Time Resolution Observations of the January 2000 Glitch in the Vela Pulsar, The Astrophysical Journal Letters, 564, L85, doi: 10.1086/339068

Dreissigacker, C., Prix, R., & Wette, K. 2018, Fast and Accurate Sensitivity Estimation for Continuous-Gravitational-Wave Searches, Phys. Rev. D, 98, 084058, doi: 10.1103/PhysRevD.98.084058

D'Onofrio, L., Astone, P., Pra, S. D., et al. 2024, Two sides of the same coin: the $\mathcal{F}$-statistic and the 5-vector method, Classical and Quantum Gravity, 42, 015005, doi: 10.1088/1361-6382/ad94c5

Edwards, R. T., Hobbs, G. B., & Manchester, R. N. 2006, TEMPO2, a new pulsar timing package - II. The timing model and precision estimates, MNRAS, 372, 1549, doi: 10.1111/j.1365-2966.2006.10870.x

Espinoza, C. M., Kuiper, L., Ho, W. C. G., et al. 2024, A Growing Braking Index and Spin-down Swings for the Pulsar PSR B0540–69, Astrophys. J. Lett., 973, L39, doi: 10.3847/2041-8213/ad778c

Espinoza, C. M., Lyne, A. G., Stappers, B. W., & Kramer, M. 2011, A study of 315 glitches in the rotation of 102 pulsars, MNRAS, 414, 1679, doi: 10.1111/j.1365-2966.2011.18503.x

Esposito, P., Israel, G. L., Turolla, R., et al. 2011, Long-term spectral and timing properties of the soft gamma-ray repeater SGR 1833-0832 and detection of extended X-ray emission around the radio pulsar PSR B1830-08, Monthly Notices of the Royal Astronomical Society, 416, 205, doi: 10.1111/j.1365-2966.2011.19022.x

Faulkner, A. J., Stairs, I. H., Kramer, M., et al. 2004, The Parkes Multibeam Pulsar Survey - V. Finding binary and millisecond pulsars, MNRAS, 355, 147, doi: 10.1111/j.1365-2966.2004.08310.x

Fonseca, E., Stairs, I. H., & Thorsett, S. E. 2014, A Comprehensive Study of Relativistic Gravity Using PSR B1534+12, The Astrophysical Journal, 787, 82, doi: 10.1088/0004-637X/787/1/82

Frasca, S., et al. 2022 https://www.sergiofrasca.net/wp-content/wwwContent/_Phys/snag.htm

Friedman, J. L., & Morsink, S. M. 1998, Axial Instability of Rotating Relativistic Stars, ApJ, 502, 714, doi: 10.1086/305920

Fruscione, A., McDowell, J. C., Allen, G. E., et al. 2006, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 6270, Observatory Operations: Strategies, Processes, and Systems, ed. D. R. Silva & R. E. Doxsey, 62701V, doi: 10.1117/12.671760

Ganapathy, D., et al. 2023, Broadband Quantum Enhancement of the LIGO Detectors with Frequency-Dependent Squeezing, Phys. Rev. X, 13, 041021, doi: 10.1103/PhysRevX.13.041021

Gancio, G., Lousto, C. O., Combi, L., et al. 2020, Upgraded antennas for pulsar observations in the Argentine Institute of Radio astronomy, Astronomy & Astrophysics, 633, A84, doi: 10.1051/0004-6361/201936525

Gendreau, K. C., Arzoumanian, Z., Adkins, P., et al. 2016, The Neutron star Interior Composition Explorer (NICER): design and development, SPIE Proceedings, 9905, 420, doi: 10.1117/12.2231304

Geyer, M., Serylak, M., Abbate, F., et al. 2021, The Thousand-Pulsar-Array programme on MeerKAT – III. Giant pulse characteristics of PSR J0540-6919, Monthly Notices of the Royal Astronomical Society, 505, 4468, doi: 10.1093/mnras/stab1501

Ghosh, S. 2023, Universal relations to measure neutron star properties from targeted r-mode searches, Monthly Notices of the Royal Astronomical Society, 525, 448, doi: 10.1093/mnras/stad2355

Ghosh, S., Pathak, D., & Chatterjee, D. 2023, Relativistic Correction to the r-mode Frequency in Light of Multimessenger Constraints, The Astrophysical Journal, 944, 53, doi: 10.3847/1538-4357/acb0d3

Gittins, F. 2024, Gravitational waves from neutron-star mountains, Classical and Quantum Gravity, 41, 043001, doi: 10.1088/1361-6382/ad1c35

Gittins, F., & Andersson, N. 2021, Modelling neutron star mountains in relativity, MNRAS, 507, 116, doi: 10.1093/mnras/stab2048

Glampedakis, K., Jones, D. I., & Samuelsson, L. 2012, Gravitational Waves from Color-Magnetic "Mountains" in Neutron Stars, PhRvL, 109, 081103, doi: 10.1103/PhysRevLett.109.081103

Goetz, E., Ansel, N., Alan, K., et al. 2026, O4ab lines and combs in found in self-gated C00 cleaned data,, Tech. Rep. LIGO-T2500212-v1, LIGO Laboratory. https://dcc.ligo.org/LIGO-T2500212-v1/public

Goetz, E., & Riles, K. 2024, Segments used for creating standard SFTs in O4 data,, Tech. Rep. LIGO-T2400058-v4, LIGO Laboratory. https://dcc.ligo.org/T2400058-v4/public

Gotthelf, E. V., & Halpern, J. P. 2008, Discovery of a Young, Energetic 70.5 ms Pulsar Associated with the TeV Gamma-ray Source HESS J1837-069, Astrophys. J., 681, 515, doi: 10.1086/588779

Guillemot, L., Cognard, I., van Straten, W., Theureau, G., & Gérard, E. 2023, Improving pulsar polarization and timing measurements with the Nançay Radio Telescope, A&A, 678, A79, doi: 10.1051/0004-6361/202347018

Halpern, J. P., Camilo, F., Gotthelf, E. V., et al. 2001, PSR J2229+6114: Discovery of an Energetic Young Pulsar in the Error Box of the EGRET Source 3EG J2227+6122, The Astrophysical Journal Letters, 552, L125, doi: 10.1086/320347

Haskell, B., & Bejger, M. 2023, Astrophysics with continuous gravitational waves, Nature Astron., 7, 1160, doi: 10.1038/s41550-023-02059-w

Hobbs, G., Jenet, F., Lee, K. J., et al. 2009, TEMPO2: a new pulsar timing package - III. Gravitational wave simulation, MNRAS, 394, 1945, doi: 10.1111/j.1365-2966.2009.14391.x

Hobbs, G. B., Edwards, R. T., & Manchester, R. N. 2006, TEMPO2, a new pulsar-timing package - I. An overview, MNRAS, 369, 655, doi: 10.1111/j.1365-2966.2006.10302.x

Hunter, J. D. 2007, Matplotlib: A 2D Graphics Environment, CSE, 9, 90, doi: 10.1109/MCSE.2007.55

Idrisy, A., Owen, B. J., & Jones, D. I. 2015, *R*-mode frequencies of slowly rotating relativistic neutron stars with realistic equations of state, Phys. Rev. D, 91, 024001, doi: 10.1103/PhysRevD.91.024001

Isi, M., Pitkin, M., & Weinstein, A. J. 2017, Probing dynamical gravity with the polarization of continuous gravitational waves, PhRvD, 96, 042001, doi: 10.1103/PhysRevD.96.042001

Jaranowski, P., Królak, A., & Schutz, B. F. 1998, Data analysis of gravitational-wave signals from spinning neutron stars: The signal and its detection, PhRvD, 58, 063001, doi: 10.1103/PhysRevD.58.063001

Jia, W., et al. 2024, Squeezing the quantum noise of a gravitational-wave detector below the standard quantum limit, Science, 385, 1318, doi: 10.1126/science.ado8069

Johnson-McDaniel, N. K., & Owen, B. J. 2013, Maximum elastic deformations of relativistic stars, Phys. Rev. D, 88, 044004, doi: 10.1103/PhysRevD.88.044004

Jonas, J., & MeerKAT Team. 2016, in MeerKAT Science: On the Pathway to the SKA, 1, doi: 10.22323/1.277.0001

Jones, D. I. 2010, Gravitational wave emission from rotating superfluid neutron stars, MNRAS, 402, 2503, doi: 10.1111/j.1365-2966.2009.16059.x

Krishnan, B., Sintes, A. M., Papa, M. A., et al. 2004, The Hough transform search for continuous gravitational waves, Phys. Rev. D, 70, 082001, doi: 10.1103/PhysRevD.70.082001

Kuiper, L., & Hermsen, W. 2009, High-energy characteristics of the schizophrenic pulsar PSR J1846-0258 in Kes 75, Astron. Astrophys., 501, 1031, doi: 10.1051/0004-6361/200811580

Lommen, A. N., Zepka, A., Backer, D. C., et al. 2000, New pulsars from an arecibo drift scan search, Astrophys. J., 545, 1007, doi: 10.1086/317841

Luo, J., Ransom, S., Demorest, P., et al. 2019, PINT: High-precision pulsar timing analysis package,, Astrophysics Source Code Library, record ascl:1902.007

Luo, J., Ransom, S., Demorest, P., et al. 2021, PINT: A Modern Software Package for Pulsar Timing, ApJ, 911, 45, doi: 10.3847/1538-4357/abe62f

Lyne, A., & Graham-Smith, F. 2012, Pulsar Astronomy (Cambridge University Press)

Maitra, C., Esposito, P., Tiengo, A., et al. 2021, IKT 16 aka PSR J0058-7218: discovery of a 22 ms energetic rotation-powered pulsar in the Small Magellanic Cloud, MNRAS, 507, L1, doi: 10.1093/mnrasl/slab050

Marshall, F. E., Gotthelf, E. V., Zhang, W., Middleditch, J., & Wang, Q. D. 1998, Discovery of an Ultrafast X-Ray Pulsar in the Supernova Remnant N157B, The Astrophysical Journal Letters, 499, L179, doi: 10.1086/311381

Mastrogiovanni, S., Astone, P., D'Antonio, S., et al. 2017, An improved algorithm for narrow-band searches of continuous gravitational waves, Class. Quant. Grav., 34, 135007, doi: 10.1088/1361-6382/aa744f

McCulloch, P. M., Klekociuk, A. R., Hamilton, P. A., & Royle, G. W. R. 1987, Daily observations of three period jumps of the VELA pulsar., Australian Journal of Physics, 40, 725, doi: 10.1071/PH870725

Merou, J. R., et al. 2024, Source of broadening of 60 Hz shoulders in L1 strain channel, https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=73549

Miles, M. T., Shannon, R. M., Bailes, M., et al. 2023, The MeerKAT Pulsar Timing Array: first data release, MNRAS, 519, 3976, doi: 10.1093/mnras/stac3644

Miles, M. T., Shannon, R. M., Reardon, D. J., et al. 2025, The MeerKAT Pulsar Timing Array: the 4.5-yr data release and the noise and stochastic signals of the millisecond pulsar population, MNRAS, 536, 1467, doi: 10.1093/mnras/stae2572

Mirasola, L., et al. 2024, New semicoherent targeted search for continuous gravitational waves from pulsars in binary systems, Phys. Rev. D, 110, 123043, doi: 10.1103/PhysRevD.110.123043

Mirasola, L., et al. 2025, Search for continuous gravitational wave signals from luminous dark photon superradiance clouds with LVK O3 observations, Phys. Rev. D, 111, 084032, doi: 10.1103/PhysRevD.111.084032

Morales, J. A., & Horowitz, C. J. 2022, Neutron star crust can support a large ellipticity, MNRAS, 517, 5610, doi: 10.1093/mnras/stac3058

Murray, S. S., Slane, P. O., Seward, F. D., Ransom, S. M., & Gaensler, B. M. 2002, Discovery of X-Ray Pulsations from the Compact Central Source in the Supernova Remnant 3C 58, ApJ, 568, 226, doi: 10.1086/338766

Nasa High Energy Astrophysics Science Archive Research Center (Heasarc). 2014, HEAsoft: Unified Release of FTOOLS and XANADU,, Astrophysics Source Code Library, record ascl:1408.004 http://ascl.net/1408.004

Nice, D., Demorest, P., Stairs, I., et al. 2015, Tempo: Pulsar timing data analysis,, Astrophysics Source Code Library, record ascl:1509.002

Ohanlon, T., & Effler, A. 2023, Calibration Lines Showing up in DARM and shifted up 3.4 Hz in DARM, https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=66597

Owen, B. J. 2005, Maximum Elastic Deformations of Compact Stars with Exotic Equations of State, Physical Review Letters, 95, 211101, doi: 10.1103/PhysRevLett.95.211101

Owen, B. J. 2025, Colloquium: Multimessenger astronomy with continuous gravitational waves and future detectors, https://arxiv.org/abs/2512.22945

Palfreyman, J., Dickey, J. M., Hotan, A., Ellingsen, S., & van Straten, W. 2018, Alteration of the magnetosphere of the Vela pulsar during a glitch, Natur, 556, 219, doi: 10.1038/s41586-018-0001-x

Palfreyman, J. L., Hotan, A. W., Dickey, J. M., Young, T. G., & Hotan, C. E. 2011, Consecutive Bright Pulses in the Vela Pulsar, Astrophys. J. Lett., 735, L17, doi: 10.1088/2041-8205/735/1/L17

Pitkin, M. 2011, Prospects of observing continuous gravitational waves from known pulsars, Mon. Not. Roy. Astron. Soc., 415, 1849, doi: 10.1111/j.1365-2966.2011.18818.x

Pitkin, M. 2018, psrqpy: a python interface for querying the ATNF pulsar catalogue, Journal of Open Source Software, 3, 538, doi: 10.21105/joss.00538

Pitkin, M. 2022, CWInPy: A Python package for inference with continuous gravitational-wave signals from pulsars, Journal of Open Source Software, 7, 4568, doi: 10.21105/joss.04568

Prix, R. 2025, Analytic weak-signal approximation of the Bayes factor for continuous gravitational waves, Class. Quant. Grav., 42, 065006, doi: 10.1088/1361-6382/adb097

Ransom, S. 2011, PRESTO: PulsaR Exploration and Search TOolkit,, Astrophysics Source Code Library, record ascl:1107.017

Ransom, S. M., Eikenberry, S. S., & Middleditch, J. 2002, Fourier Techniques for Very Long Astrophysical Time-Series Analysis, AJ, 124, 1788, doi: 10.1086/342285

Reardon, D. J., Hobbs, G., Coles, W., et al. 2016, Timing analysis for 20 millisecond pulsars in the Parkes Pulsar Timing Array, MNRAS, 455, 1751, doi: 10.1093/mnras/stv2395

Riles, K. 2023, Searches for continuous-wave gravitational radiation, Living Reviews in Relativity, 26, 3, doi: 10.1007/s41114-023-00044-3

Roberts, M. S. E., Hessels, J. W. T., Ransom, S. M., et al. 2002, PSR J2021+3651: A Young Radio Pulsar Coincident with an Unidentified EGRET gamma-Ray Source, The Astrophysical Journal Letters, 577, L19, doi: 10.1086/344082

Rosen, R., Swiggum, J., McLaughlin, M. A., et al. 2013, The Pulsar Search Collaboratory: Discovery and Timing of Five New Pulsars, ApJ, 768, 85, doi: 10.1088/0004-637X/768/1/85

Singhal, A., Leaci, P., Astone, P., et al. 2019, A resampling algorithm to detect continuous gravitational-wave signals from neutron stars in binary systems, Classical and Quantum Gravity, 36, 205015, doi: 10.1088/1361-6382/ab4367

Soni, S., et al. 2025, LIGO Detector Characterization in the first half of the fourth Observing run, Class. Quant. Grav., 42, 085016, doi: 10.1088/1361-6382/adc4b6

Torii, K., Tsunemi, H., Dotani, T., & Mitsuda, K. 1997, Discovery of a 65 Millisecond Pulsar in the Supernova Remnant G11.2-0.3 with ASCA, The Astrophysical Journal Letters, 489, L145, doi: 10.1086/316798

Ushomirsky, G., Cutler, C., & Bildsten, L. 2000, Deformations of accreting neutron star crusts and gravitational wave emission, MNRAS, 319, 902, doi: 10.1046/j.1365-8711.2000.03938.x

van Straten, W., Demorest, P., & Oslowski, S. 2012, Pulsar Data Analysis with PSRCHIVE, Astronomical Research and Technology, 9, 237, doi: 10.48550/arXiv.1205.6276

Verbiest, J. P. W., Weisberg, J. M., Chael, A. A., Lee, K. J., & Lorimer, D. R. 2012, On Pulsar Distance Measurements and Their Uncertainties, ApJ, 755, 39, doi: 10.1088/0004-637X/755/1/39

Wade, M., et al. 2025, Toward low-latency, high-fidelity calibration of the LIGO detectors with enhanced monitoring tools, Class. Quant. Grav., 42, 215016, doi: 10.1088/1361-6382/ae1095

Walker, A. R. 2012, The Large Magellanic Cloud and the distance scale, Ap&SS, 341, 43, doi: 10.1007/s10509-011-0961-x

Weisskopf, M. C., Brinkman, B., Canizares, C., et al. 2002, An Overview of the Performance and Scientific Results from the Chandra X-Ray Observatory, PASP, 114, 1, doi: 10.1086/338108

Wette, K. 2020, SWIGLAL: Python and Octave interfaces to the LALSuite gravitational-wave data analysis libraries, SoftwareX, 12, 100634, doi: 10.1016/j.softx.2020.100634

Wette, K. 2023, Searches for continuous gravitational waves from neutron stars: A twenty-year retrospective, Astroparticle Physics, 153, 102880, doi: https://doi.org/10.1016/j.astropartphys.2023.102880

Wette, K., et al. 2008, Searching for gravitational waves from Cassiopeia A with LIGO, Class. Quant. Grav., 25, 235011, doi: 10.1088/0264-9381/25/23/235011

Wolszczan, A., Doroshenko, O., Konacki, M., et al. 2000, Timing Observations of Four Millisecond Pulsars with the Arecibo and Effelsberg Radio Telescopes, The Astrophysical Journal, 528, 907, doi: 10.1086/308206

Worley, A., Krastev, P. G., & Li, B.-A. 2008, Nuclear Constraints on the Moments of Inertia of Neutron Stars, ApJ, 685, 390, doi: 10.1086/589823

Yao, J. M., Manchester, R. N., & Wang, N. 2017, A New Electron-density Model for Estimation of Pulsar and FRB Distances, ApJ, 835, 29, doi: 10.3847/1538-4357/835/1/29

Yu, M., Manchester, R. N., Hobbs, G., et al. 2013, Detection of 107 glitches in 36 southern pulsars, MNRAS, 429, 688, doi: 10.1093/mnras/sts366

Zeiger, B. R., Brisken, W. F., Chatterjee, S., & Goss, W. M. 2008, Proper Motions of PSRs B1757–24 and B1951+32: Implications for Ages and Associations, The Astrophysical Journal, 674, 271, doi: 10.1086/525276

Zhou, S., Gügercinoğlu, E., Yuan, J., Ge, M., & Yu, C. 2022, Pulsar Glitches: A Review, Universe, 8, 641, doi: 10.3390/universe8120641

Zubieta, E., García, F., del Palacio, S., et al. 2024, Timing irregularities and glitches from the pulsar monitoring campaign at IAR, Astronomy & Astrophysics, 689, A191, doi: 10.1051/0004-6361/202450441

Zubieta, E., Missel, R., Araujo Furlan, S. B., et al. 2025, Study of the 2024 major Vela glitch at the Argentine Institute of Radioastronomy, Astronomy & Astrophysics, 698, A72, doi: 10.1051/0004-6361/202554098