Constraining the Properties of Kilonovae Based on Zwicky Transient Facility Searches for 13 Neutron Star Mergers

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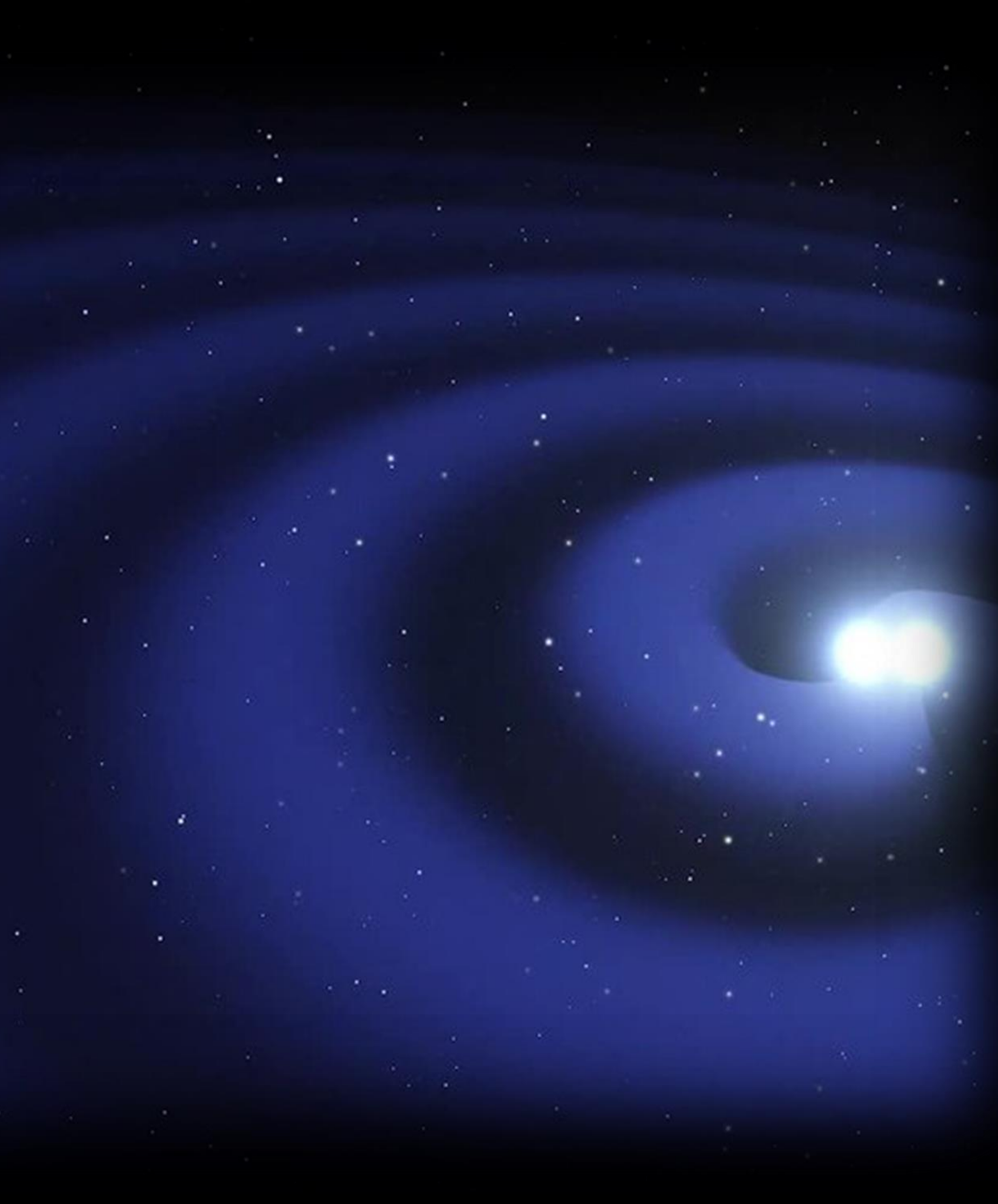
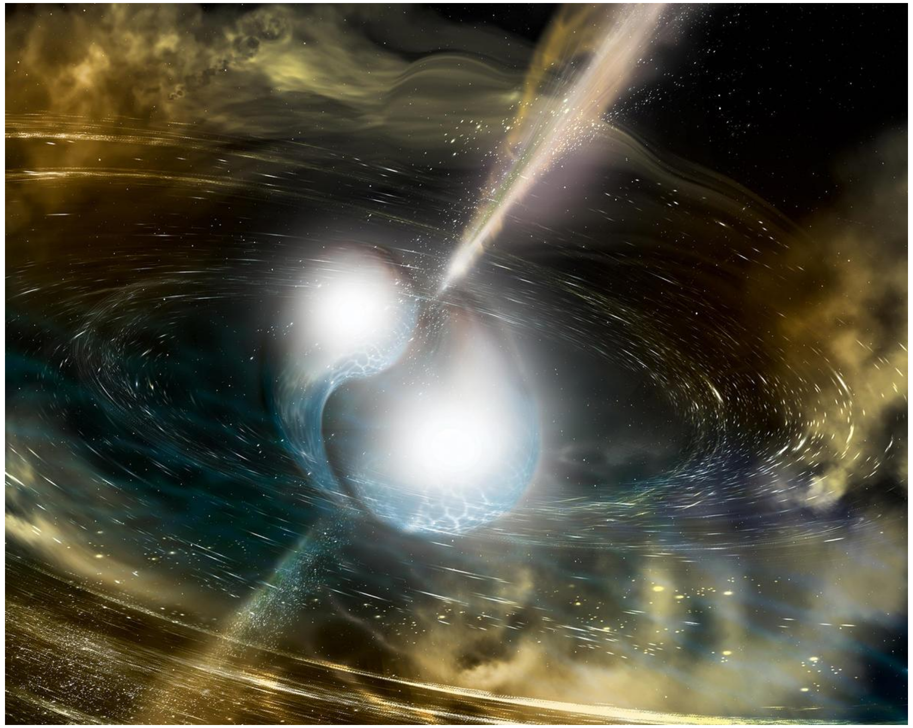
Mentor: Shreya Anand



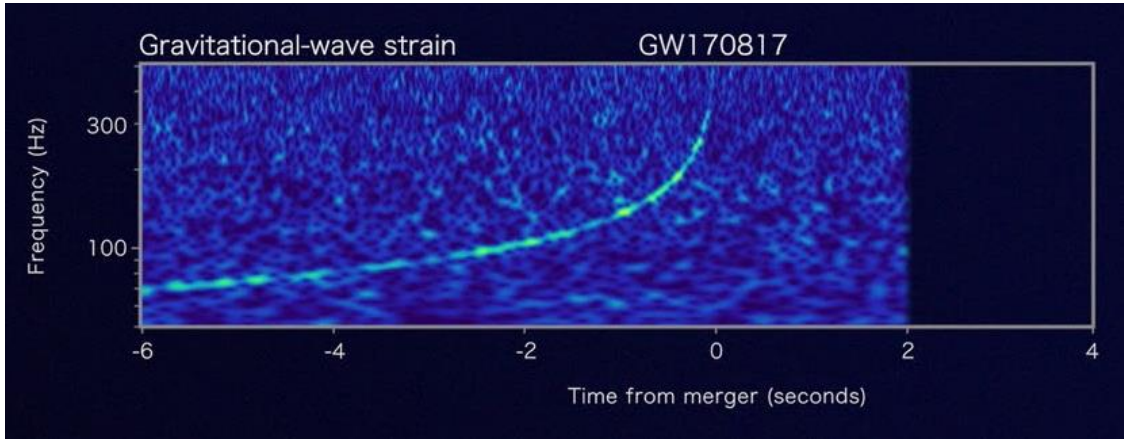
Caltech | GROWTH
Global Relay of Observatories Watching Transients Happen

Electromagnetic (EM) Counterpart to GW Events

GW170817

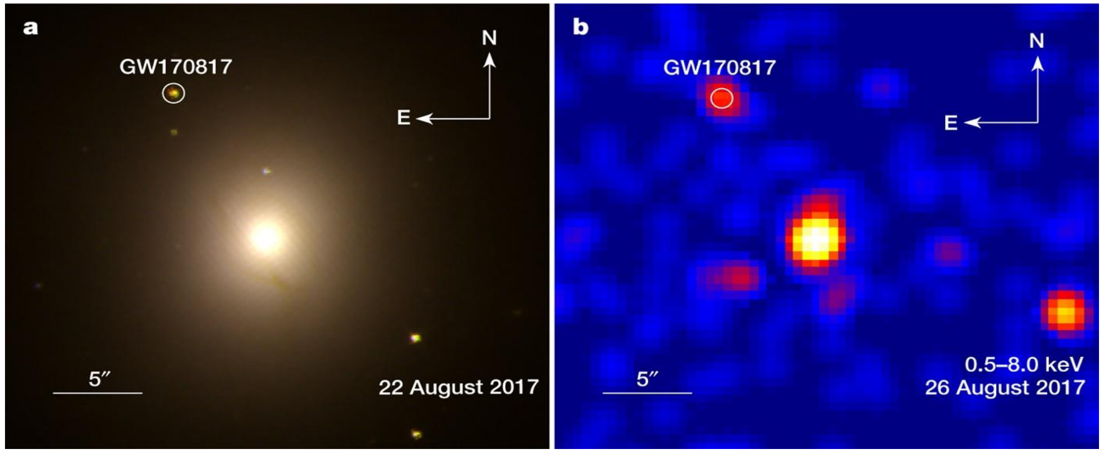


Credit: National Science Foundation/LIGO/Sonoma State University/A. Simonnet



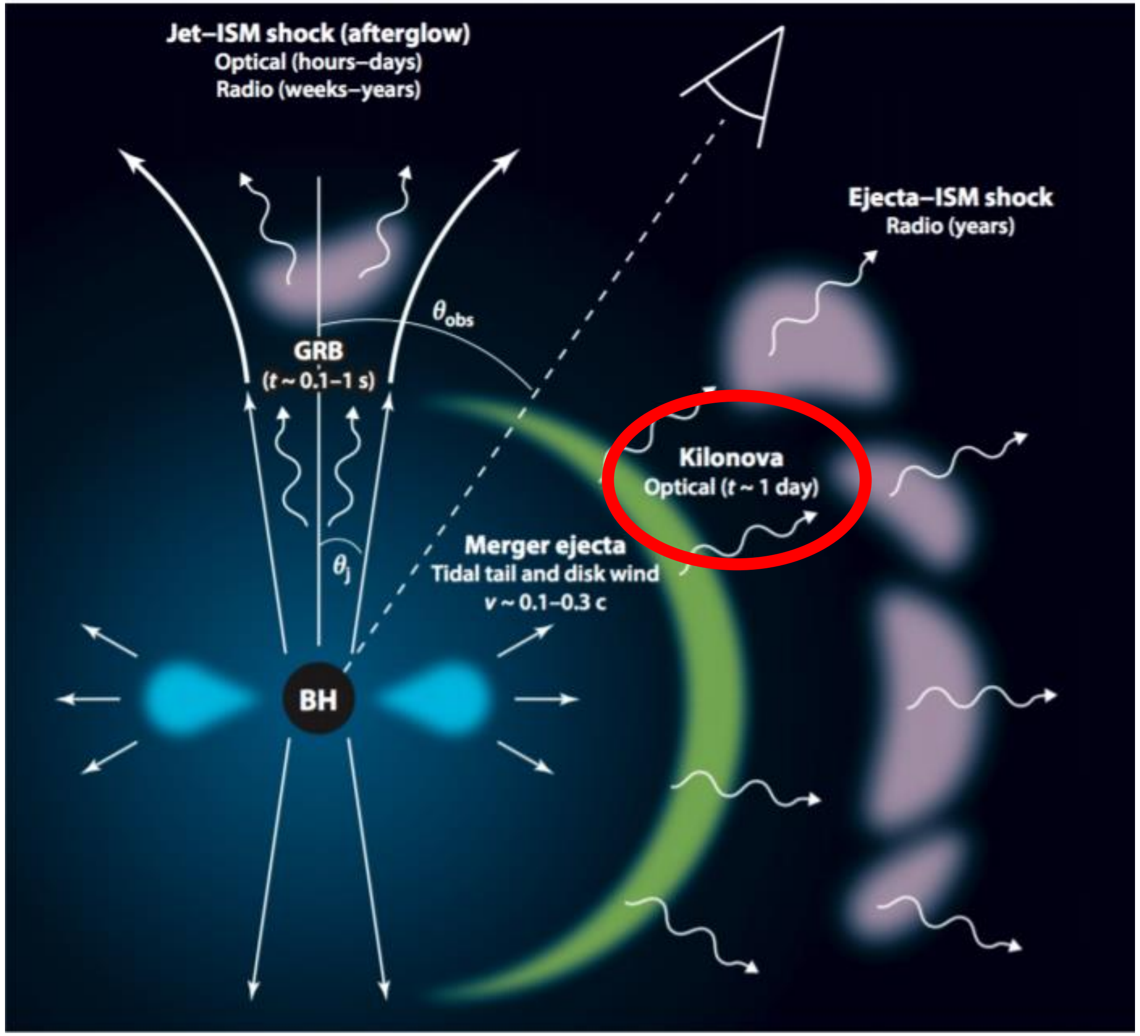
Credit: Caltech/MIT/LIGO Lab

Optical/Infrared and X-ray image of the counterpart of GW170817

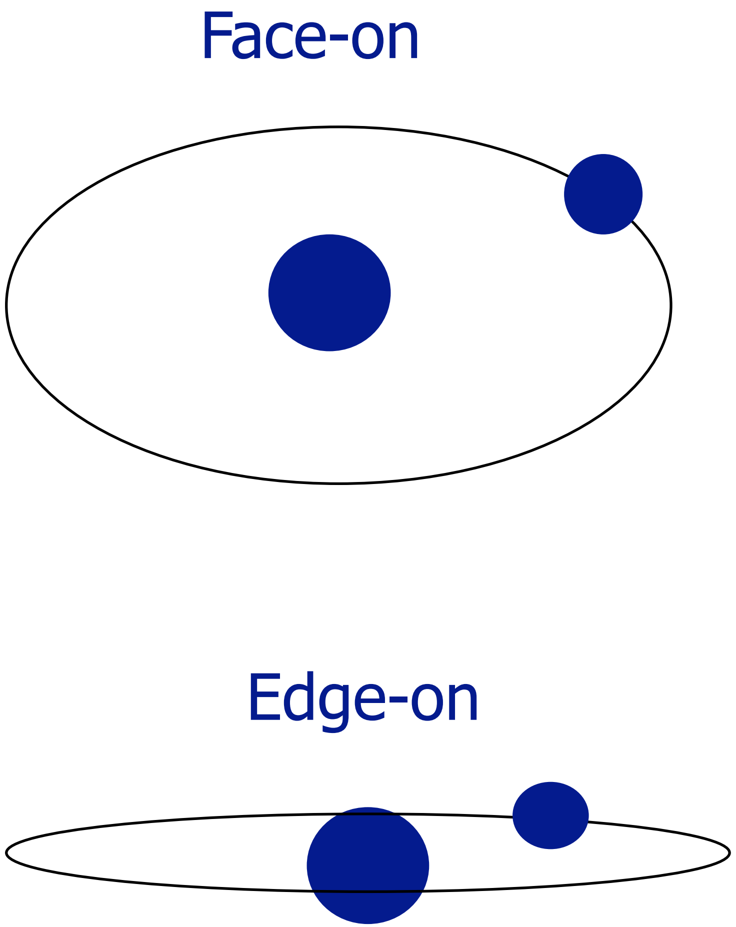


Troja+2017

Kilonova - the most promising EM Counterpart of a Compact Binary Merger

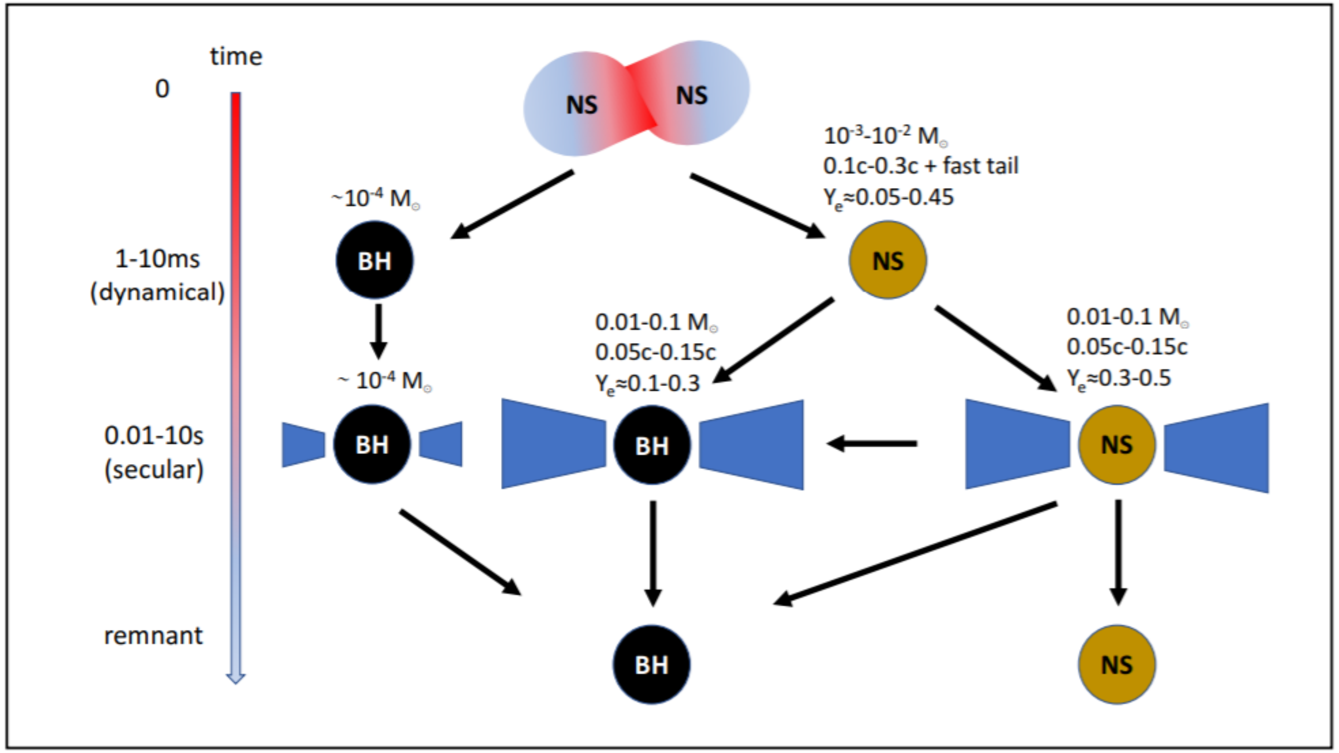


Metzger+2019

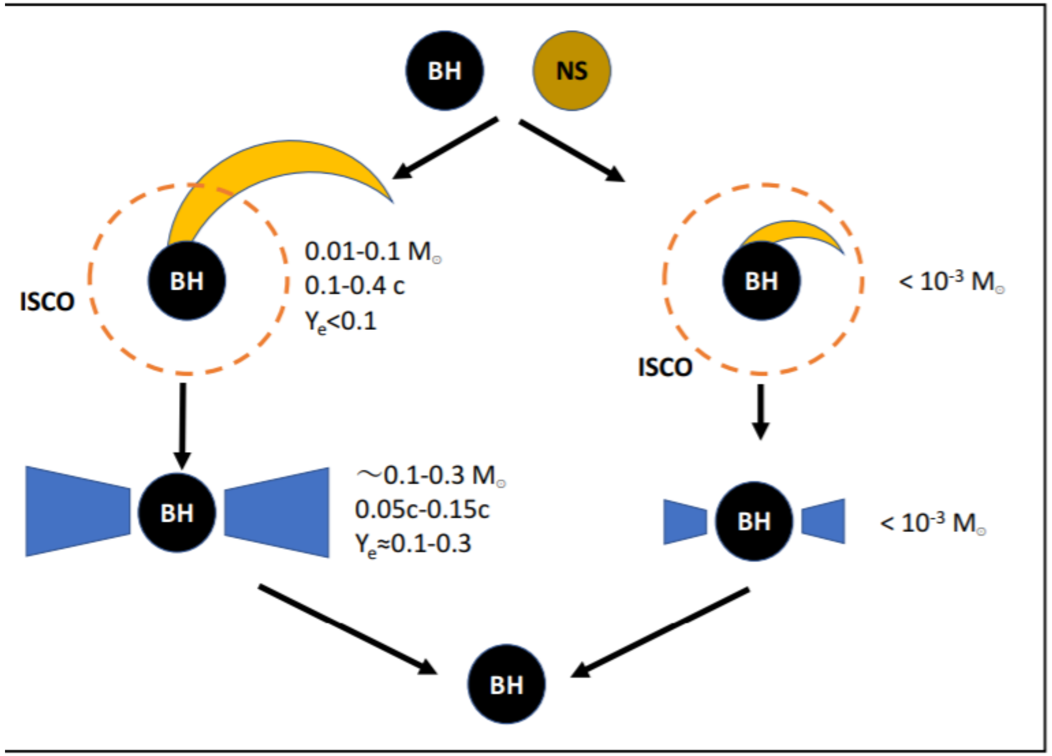


Variety in Ejecta Properties

BNS



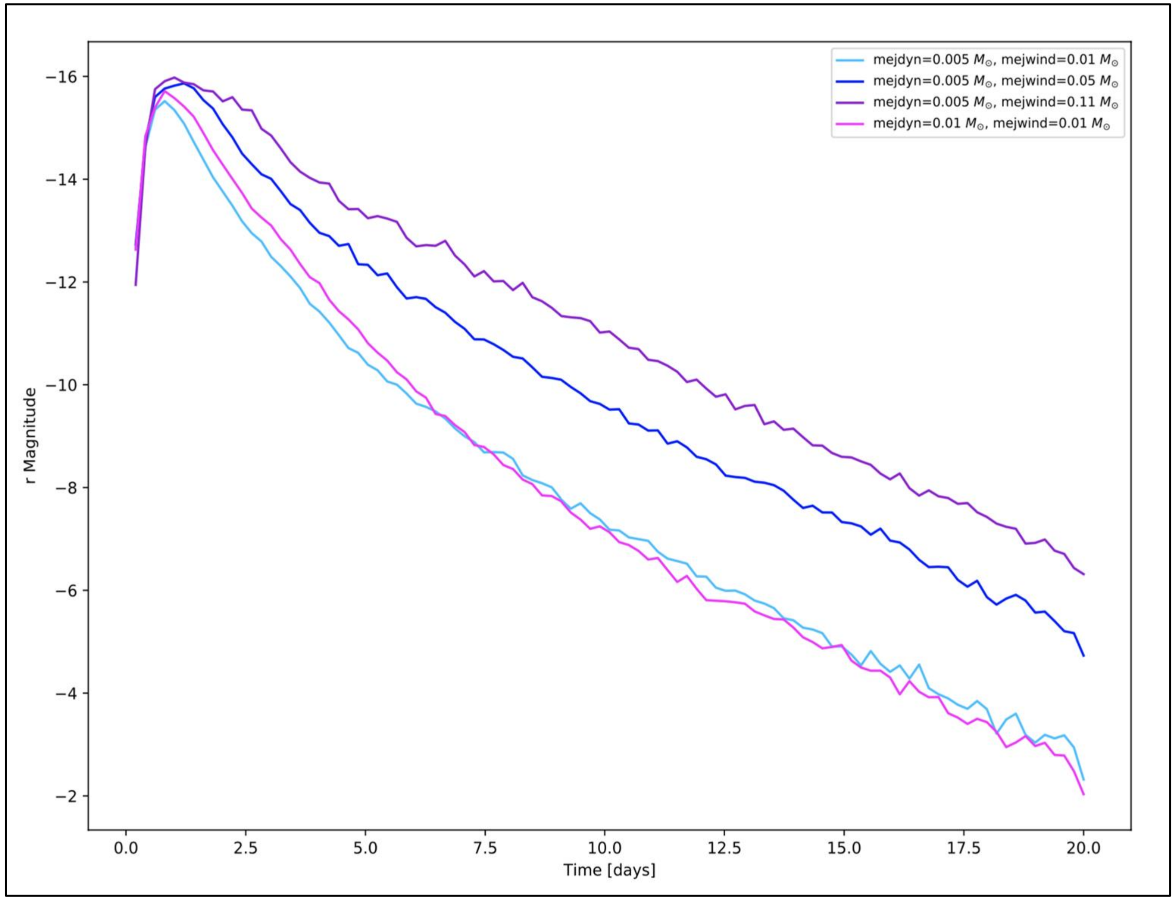
NSBH



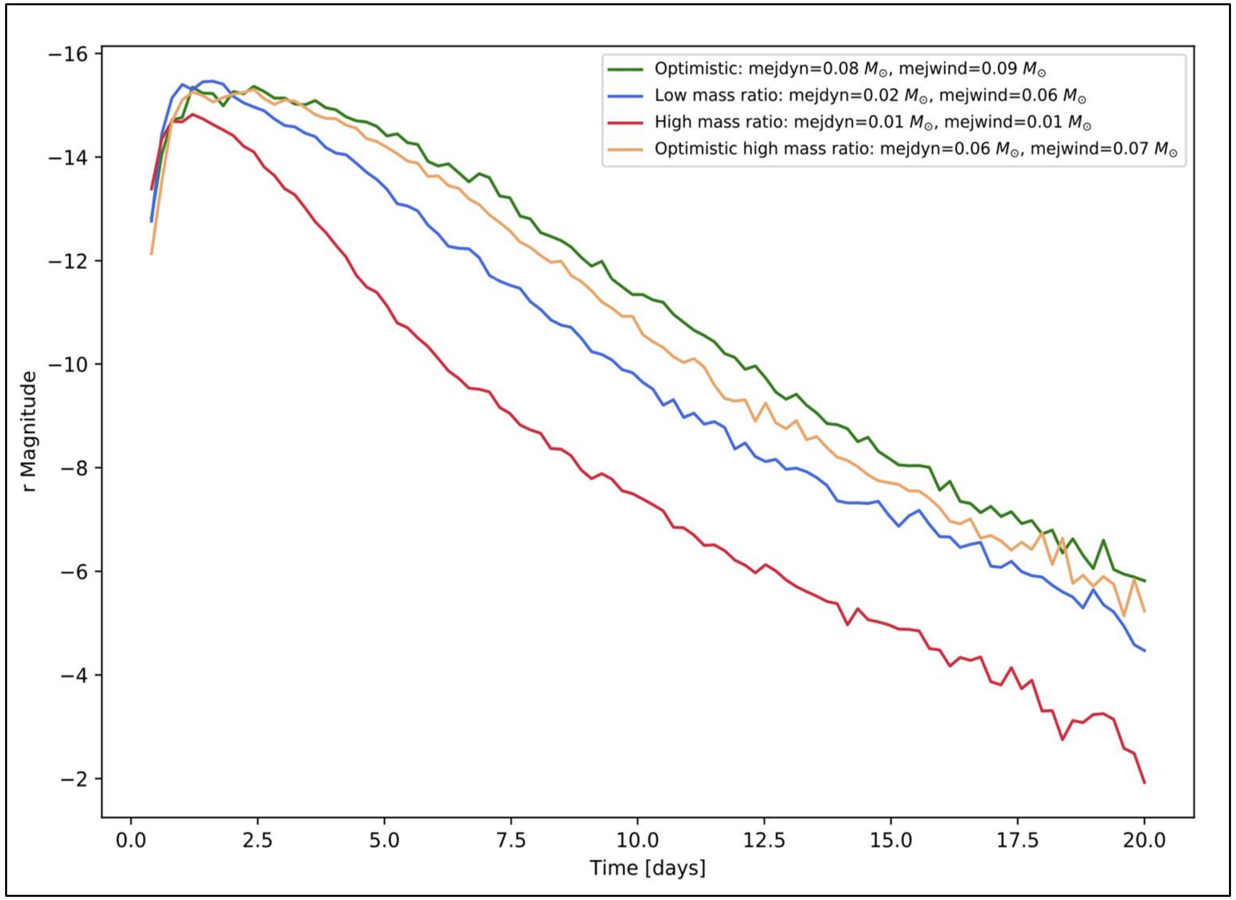
Nakar+2020

BNS vs NSBH Light Curves

BNS

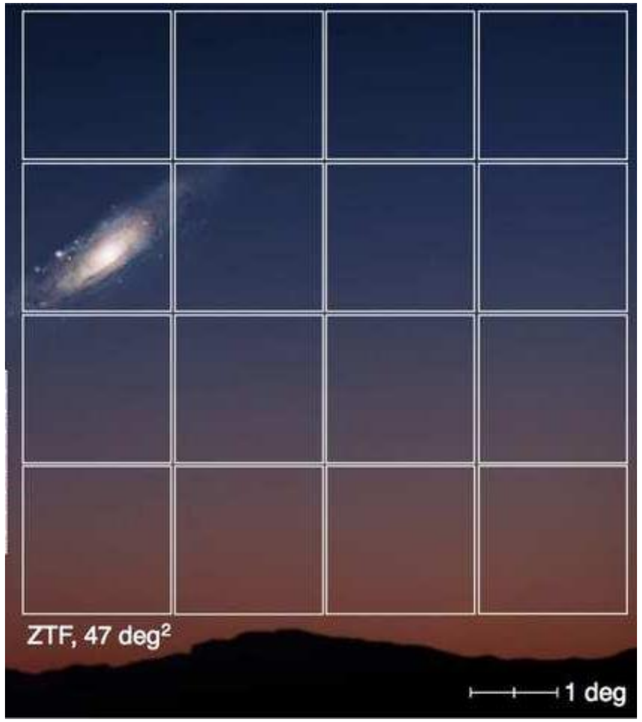


NSBH

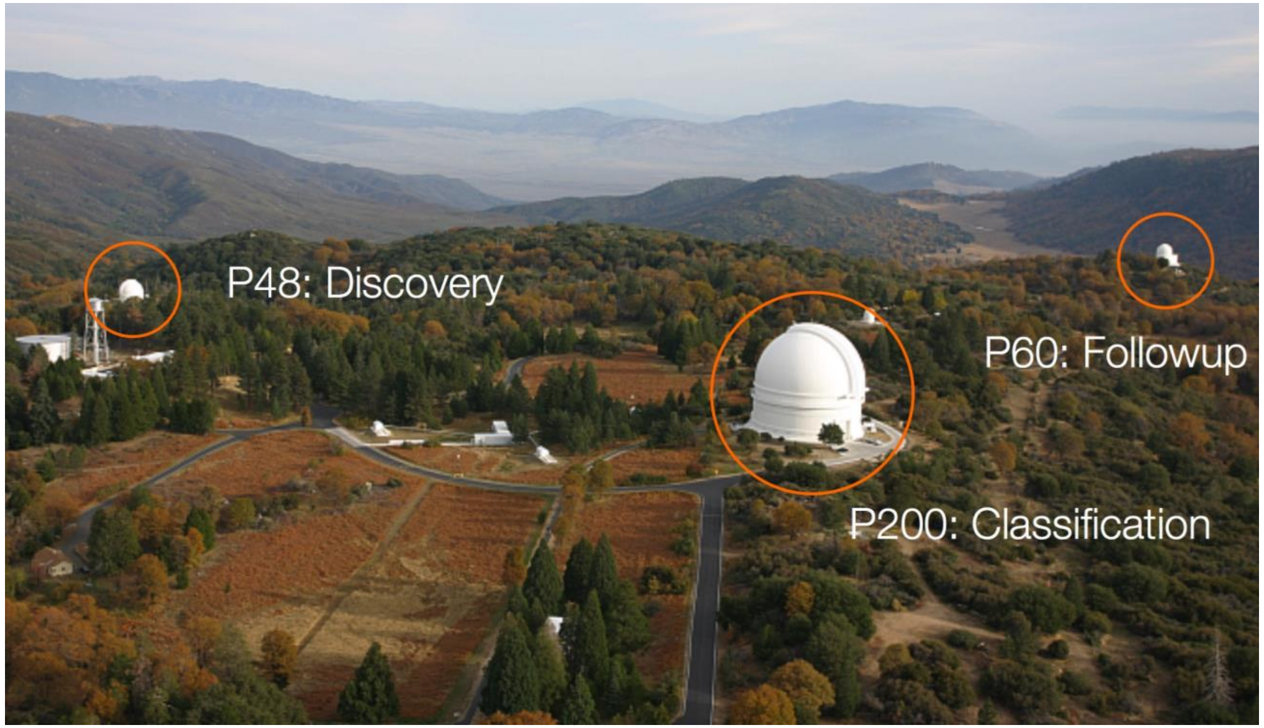


Credit: Polina Petrov

The Zwicky Transient Facility



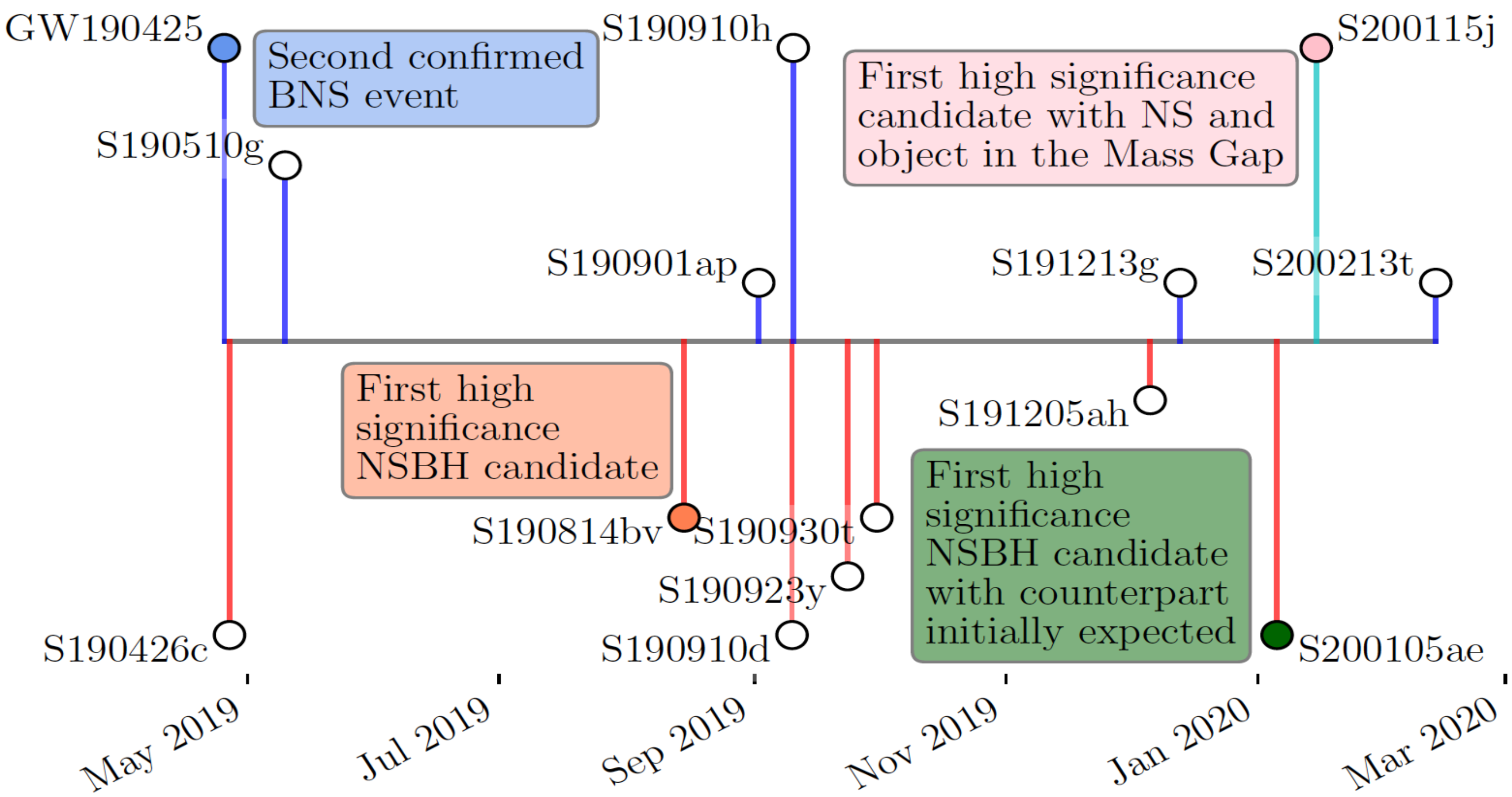
Laher+2017



Credit: IPAC/Caltech

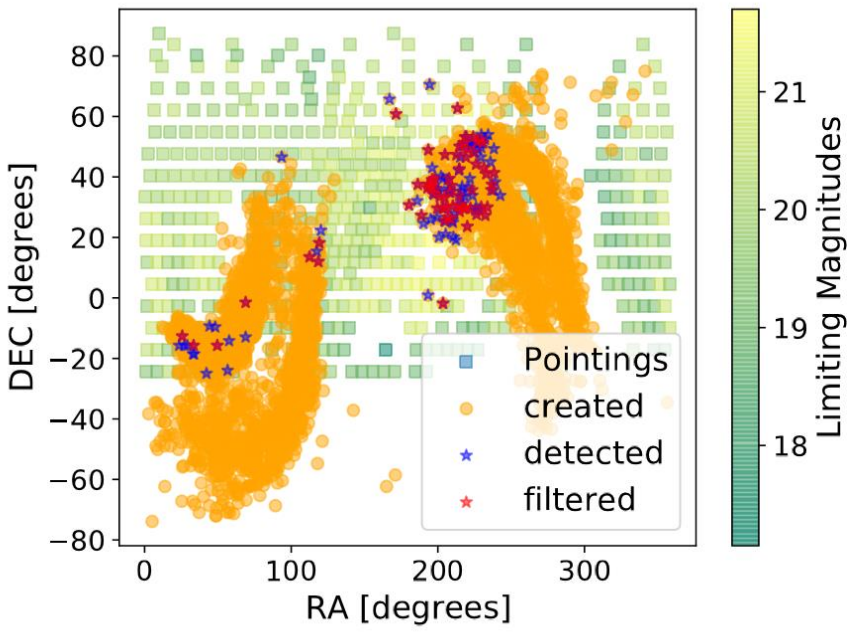
- Optical survey on Samuel Oschin 48in telescope
- Site: Palomar, CA, USA
- Field of View: 47 sq.deg.
- 3750 sq. deg. / hour
- Median depth: r = 20.5 mag

Searching for Kilonovae using ZTF



Credit: Michael Coughlin

Simsurvey - simulation software



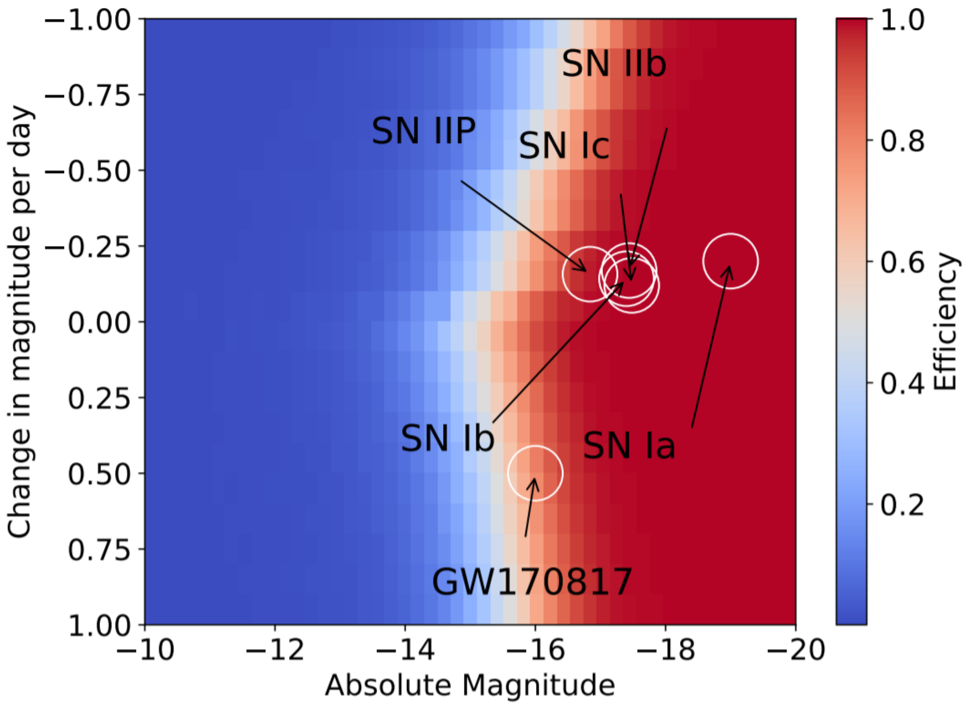
Input Parameters:

- 3-D GW sky map
- ZTF observational log

Detection Criteria:

- One 5sigma detection
- KN falling with observed area

Detection Efficiencies



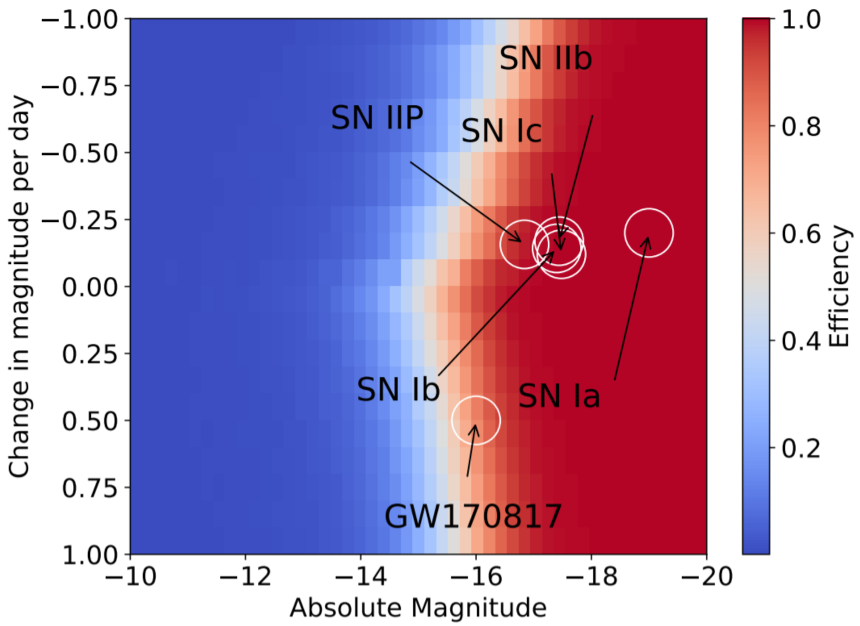
Kasliwal+2020

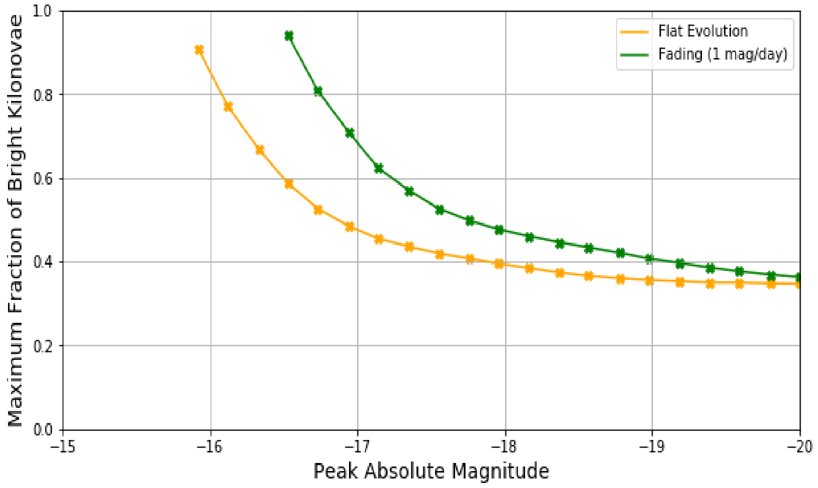
Kilonovae Luminosity Function

$$(1 - CL) = \prod_{i=1}^{N} (1 - f_b * p_i)$$

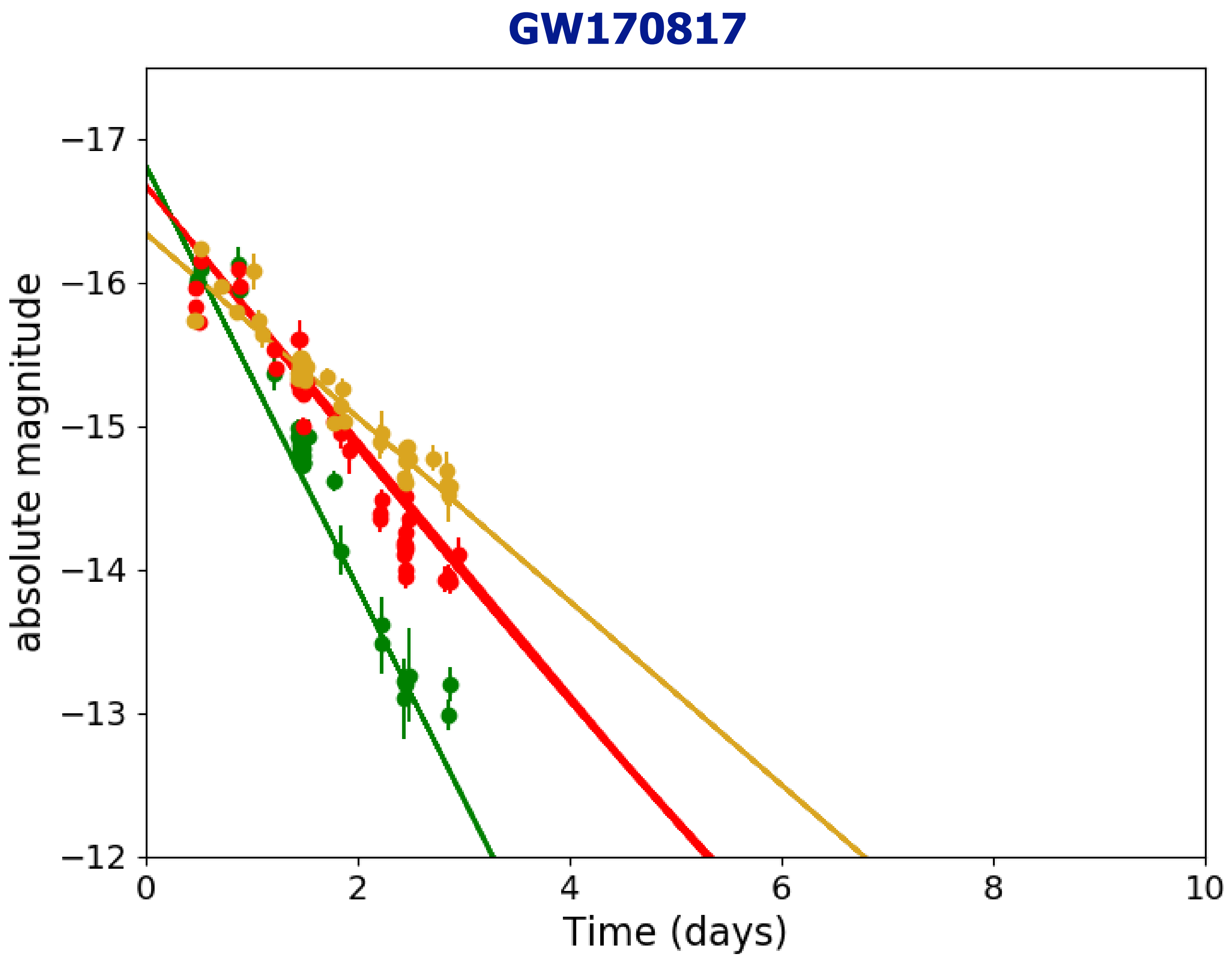
- f_b – fraction of kilonovae brighter than a given absolute magnitude.
- p_i – the recovery fraction from the simsurvey injections
- CL – confidence Level

According to Kasliwal+2020, for flat evolution, no more than 34% of kilonovae could be brighter than – 20 mag.





Color Evolution of Kilonovae



Project Goal

1. Detection efficiencies for each band

2. Weighted Efficiencies

$$P(det|\Lambda) = p(det|\theta)\, p(\theta\,|\Lambda)$$

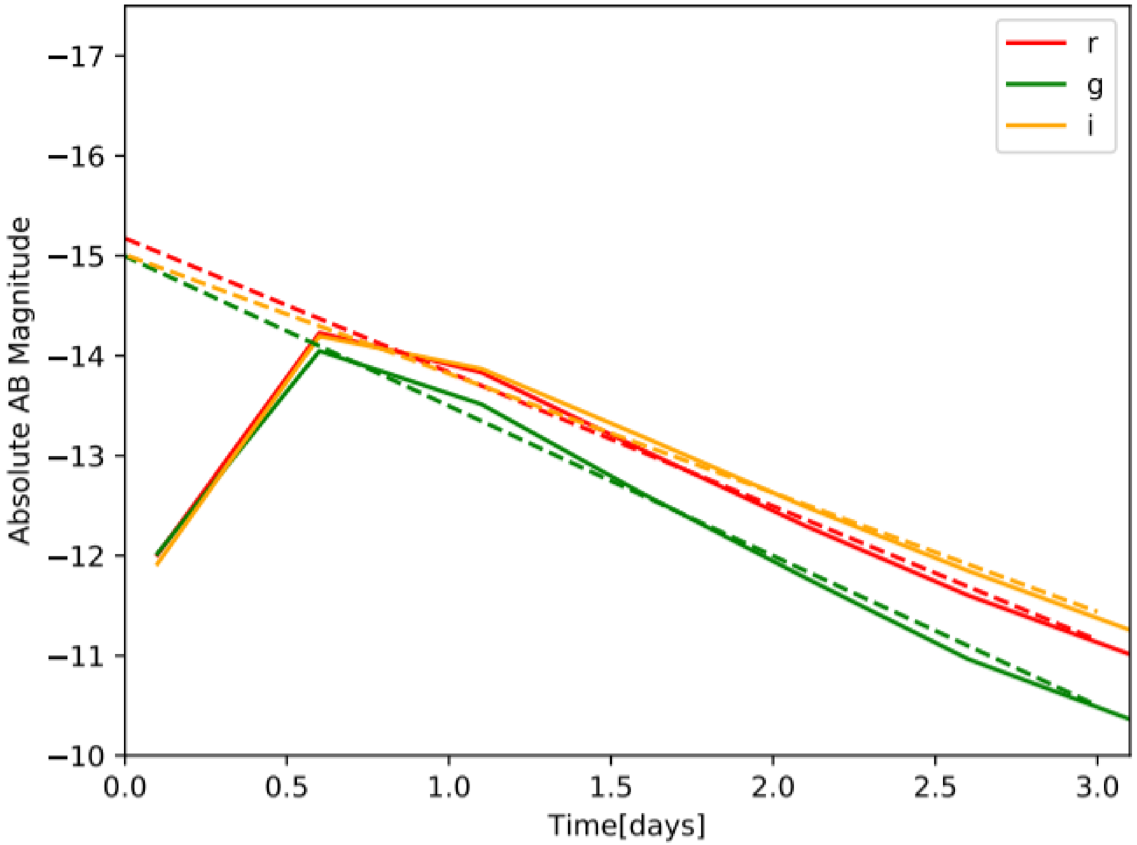
3. Constraints on kilonovae source parameters

GOAL 1 & 2

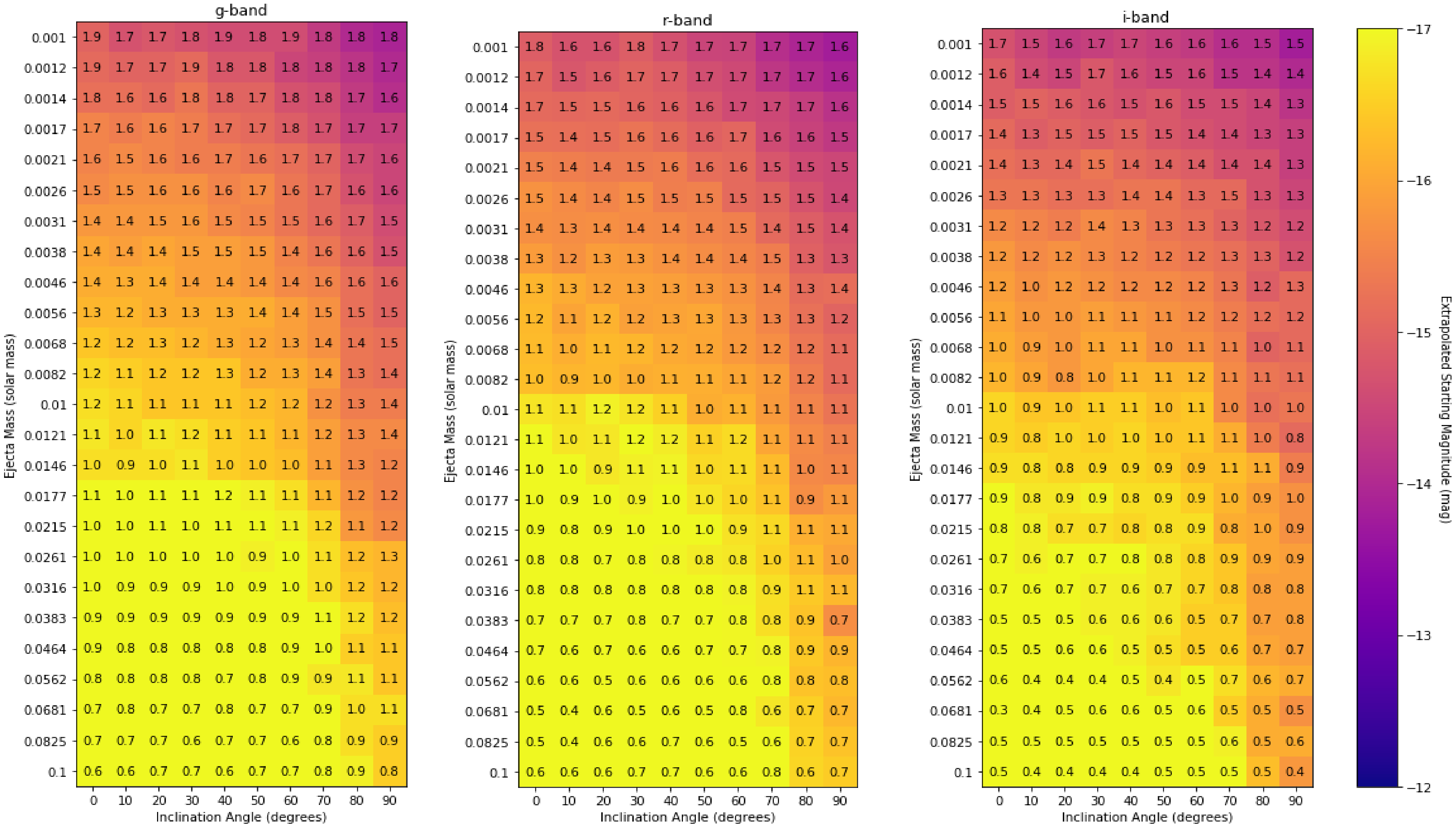
Linear Model of Kilonovae

$$M(t) = M_0 + \alpha t$$

M_0 → Extrapolated Peak Magnitude; α → Decay Rate



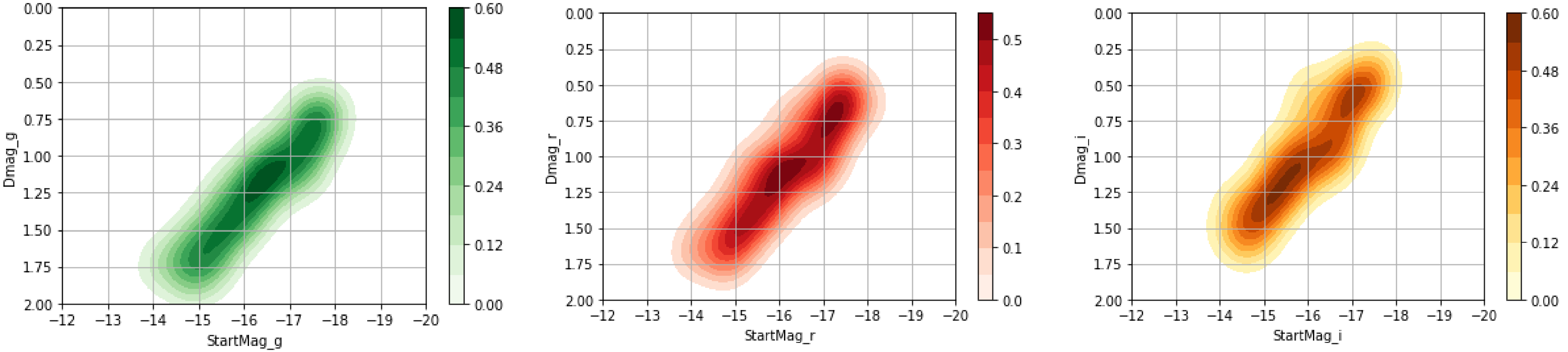
BNS Models



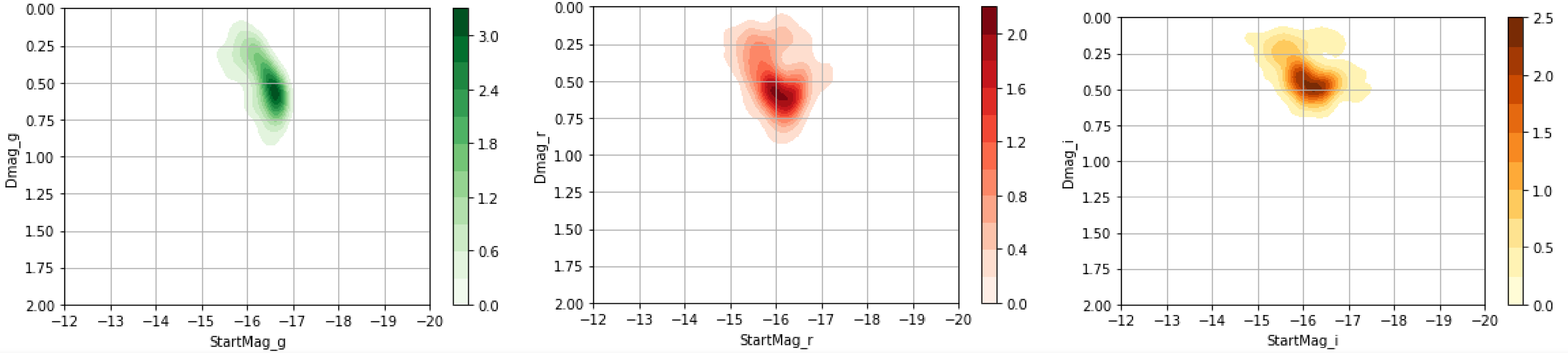
Annotations → Decay Rate (mag per day)

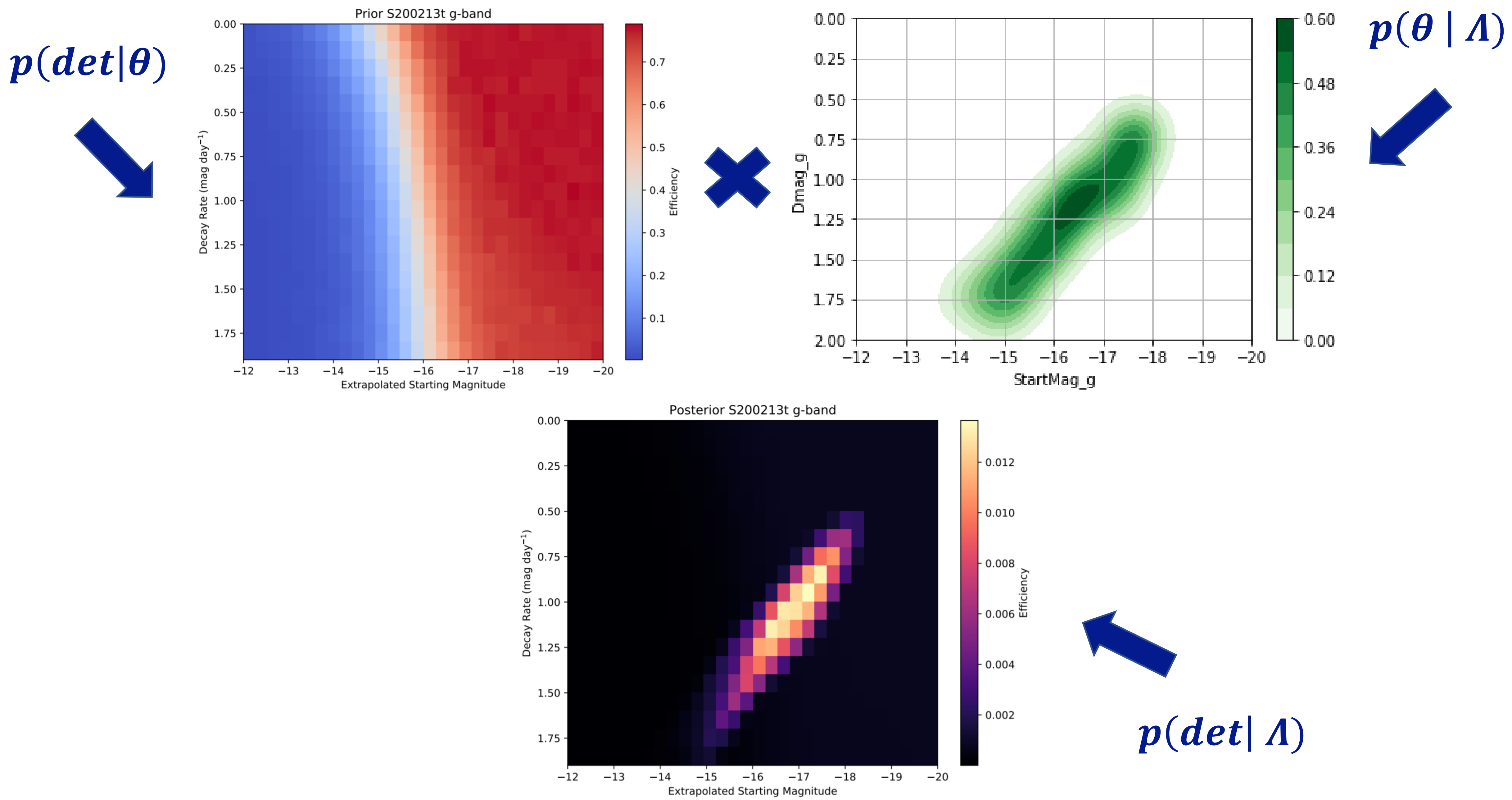
$p(\theta \mid \Lambda)$

BNS



NSBH

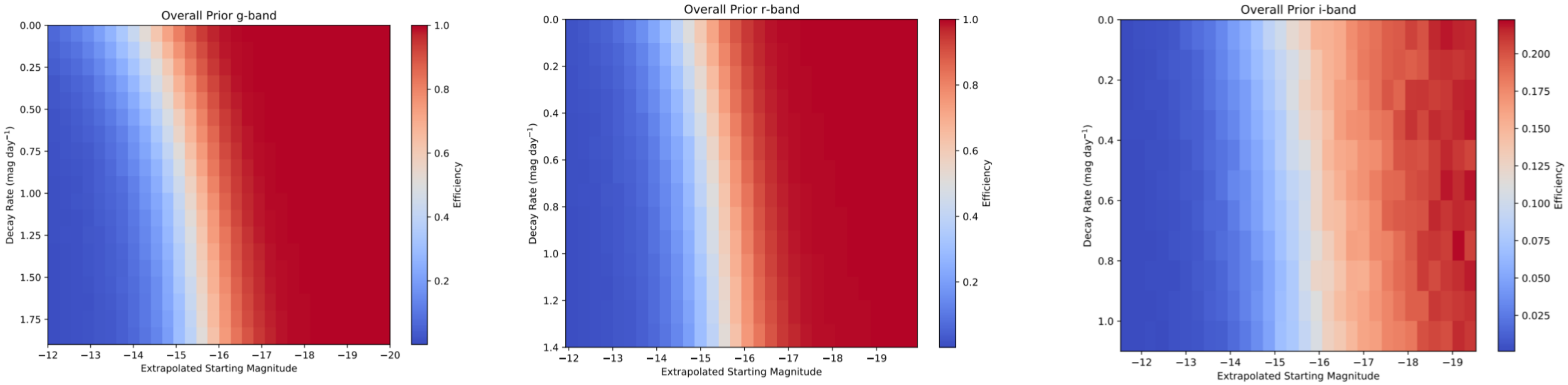




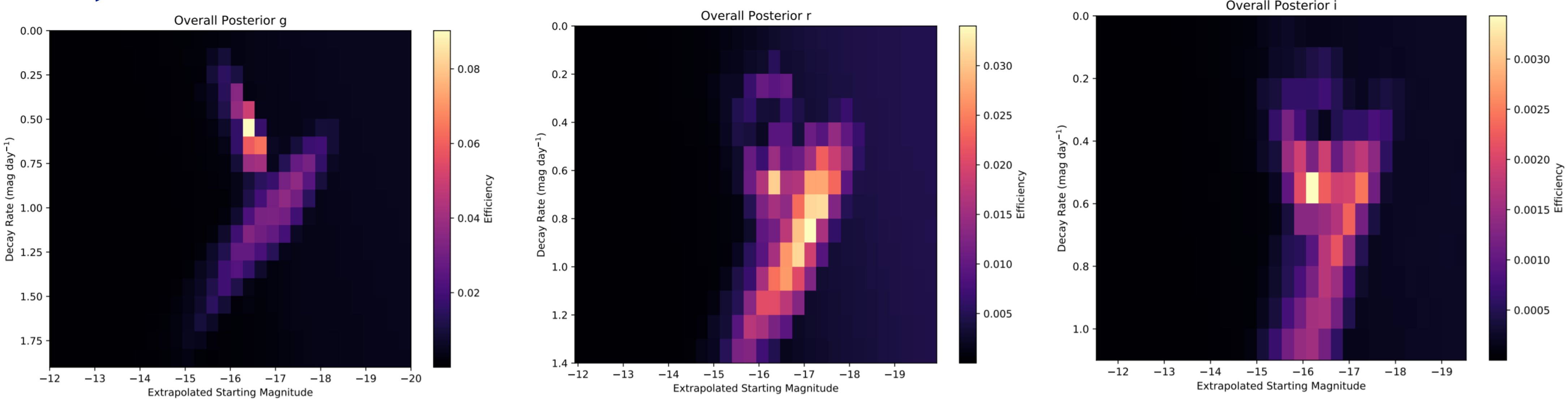
$p(det|\theta)$
Prior S200213t g-band
Decay Rate (mag day^{-1})
Extrapolated Starting Magnitude
Efficiency
Dmag_g
StartMag_g
$p(\theta \mid \Lambda)$
Posterior S200213t g-band
Decay Rate (mag day^{-1})
Extrapolated Starting Magnitude
Efficiency
$p(det|\,\Lambda)$

Composite Efficiency Map

$p(det|\theta)$

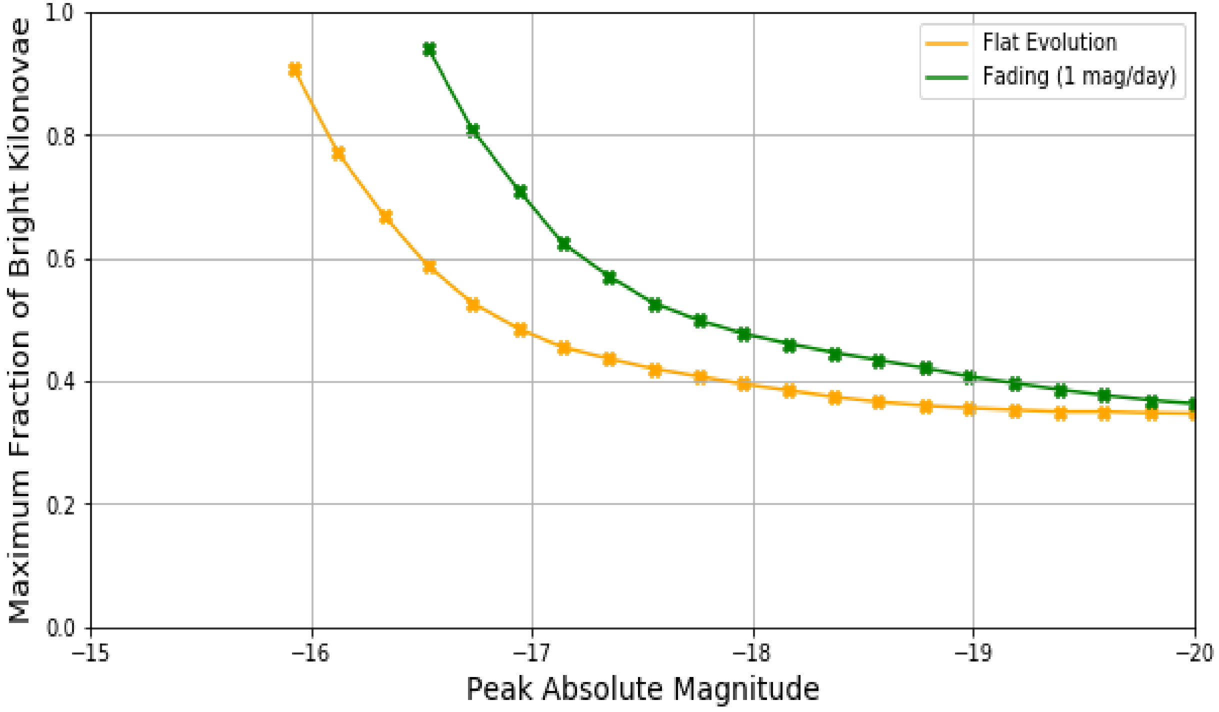


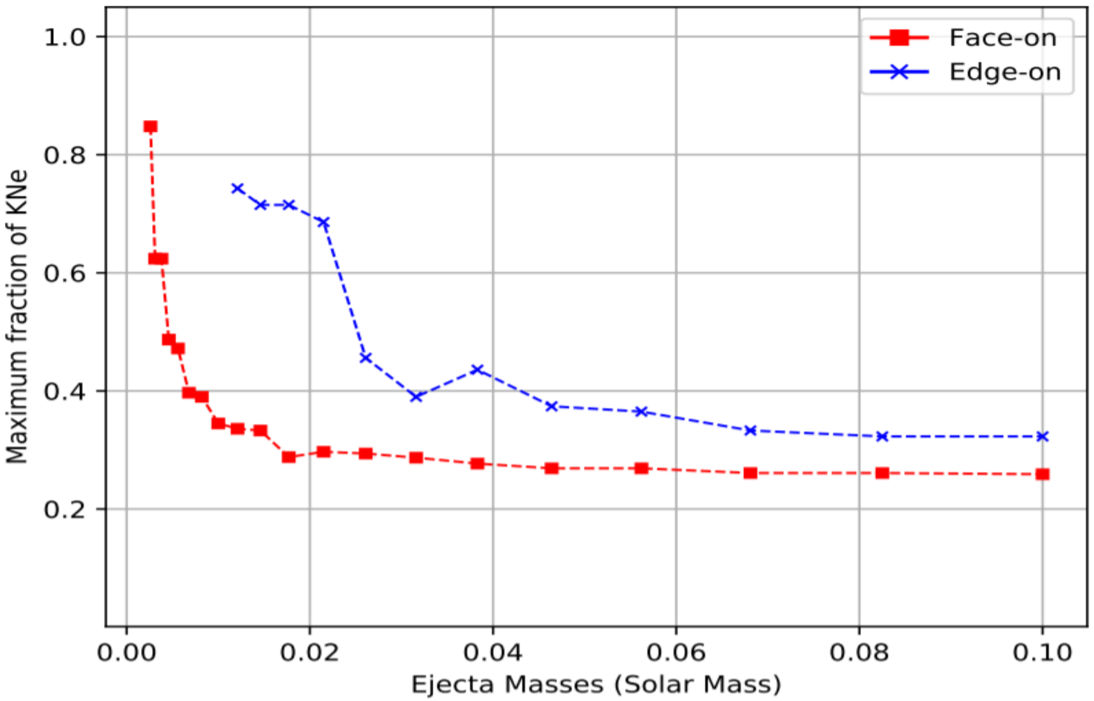
$p(det \mid \Lambda)$



GOAL 2

Constraints on Kilonova Source Properties





Conclusion and Future Work

1. **GOAL 1:**

   With more events and better sensitivity, the weighted efficiencies can be used to place tighter constraints on kilonova luminosity function.

   a. Relax the assumptions made in the analysis.
   b. Use other theoretical models and compare the results.

2. **GOAL 2:**

   We can use the non-detection of kilonovae to place constraints on the kilonova source properties.

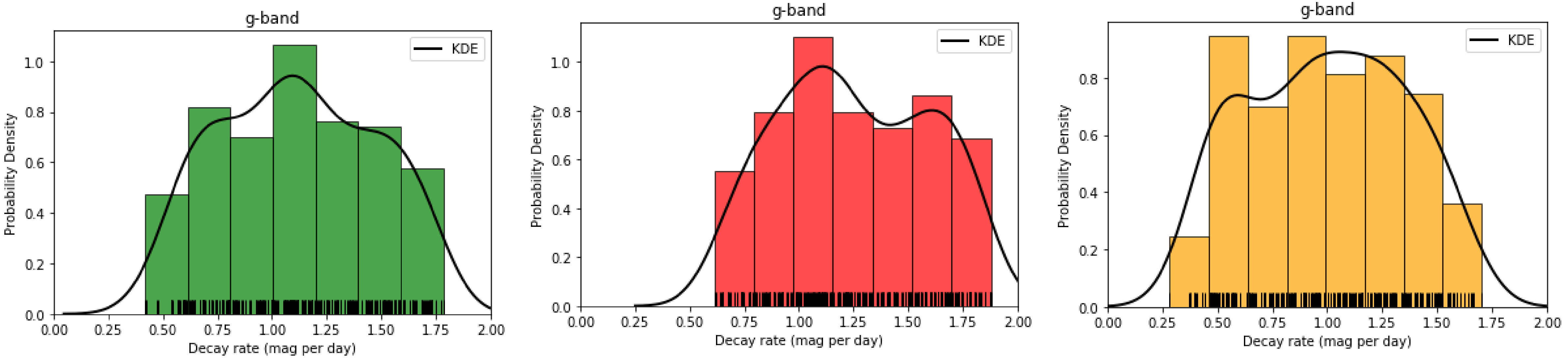
   a. Potentially translate even to constraints on the component masses or chirp mass
   b. Perform the same analysis for constraining the NSBH kilonova source properties

Acknowledgements

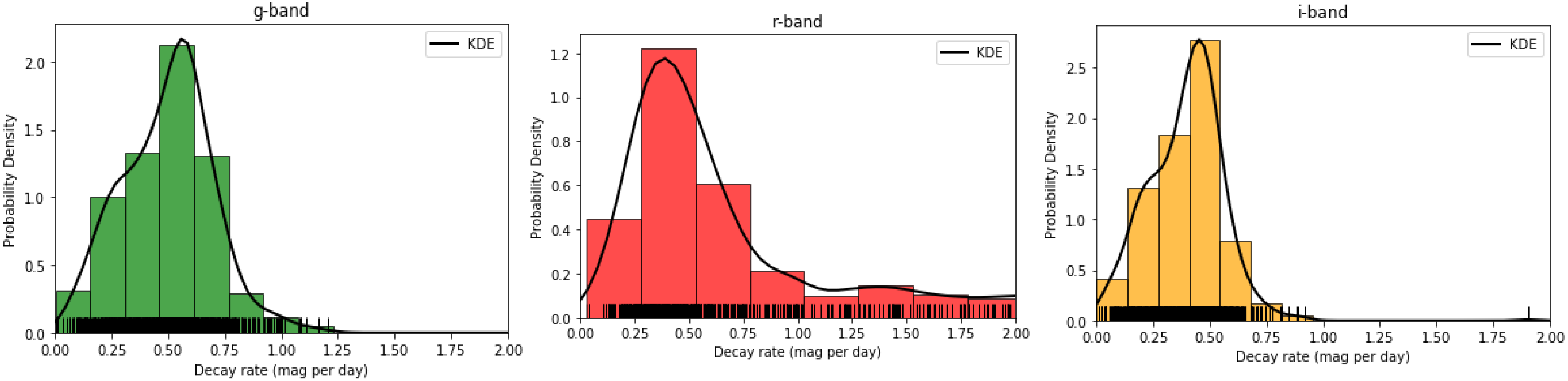
- Shreya Anand (Mentor)
- Michael Coughlin
- Colm Talbot
- Jack Heinzel
- Alan Weinstein
- Everyone in LIGO Data Analysis Group

Thank you for listening and for a great summer!

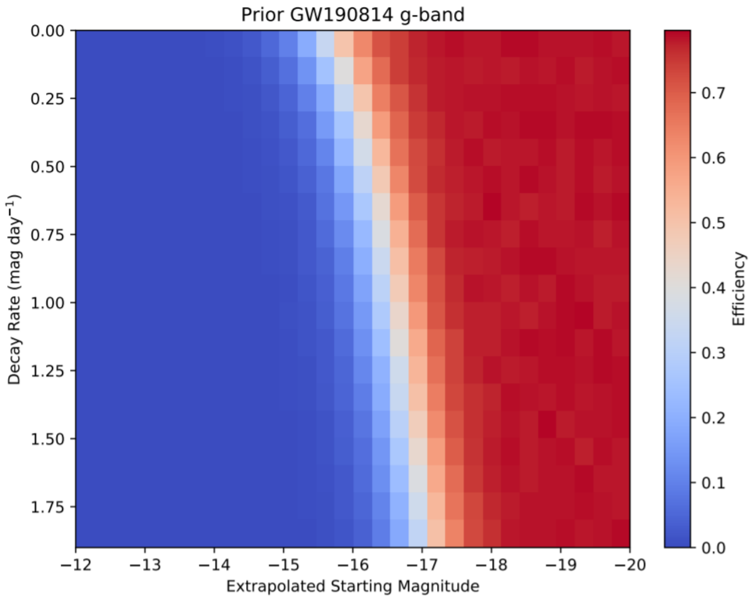
BNS Decay Rate Distribution

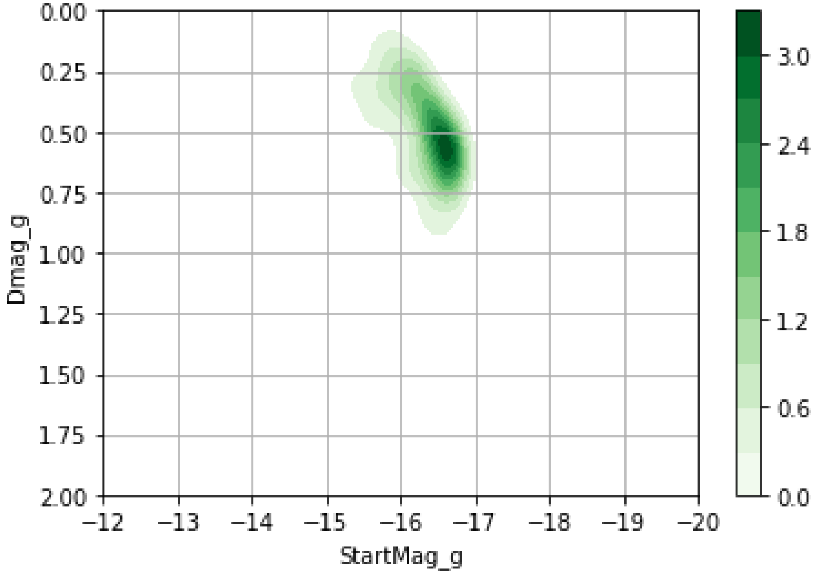


NSBH Decay Rate Distribution

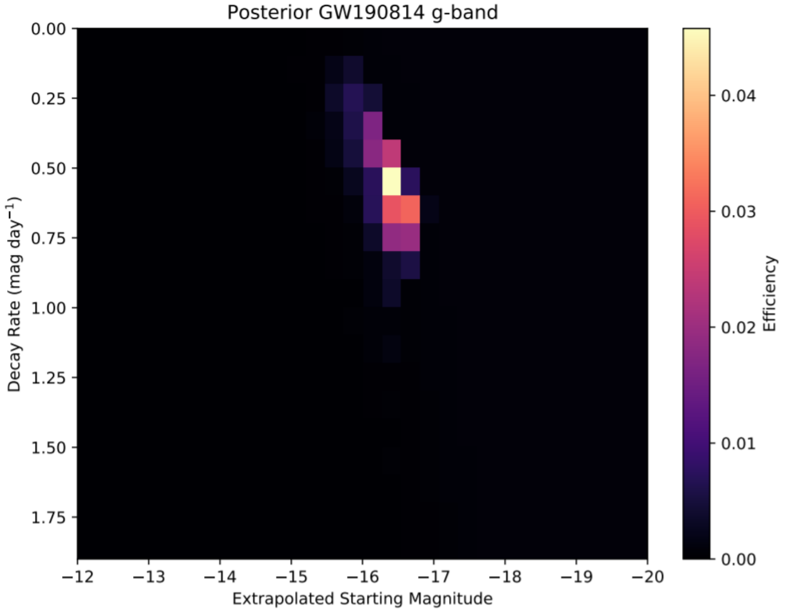


$p(det|\theta)$





$p(\theta \mid \Lambda)$



$p(det| \Lambda)$