Prospects for Gravitational Wave Searches from PKS 2155-304

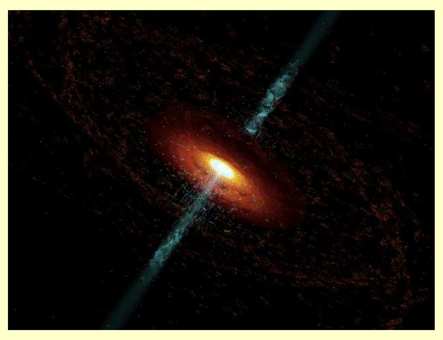
S. Desai[1], K. Hayama[2], S. Mohanty[2], M. Rakhmanov[3], T. Summerscales[4], S. Yoshida[3]

[1] *CGWP, Pennsylvania State University,* [2] *CGWA, University of Texas, Brownsville,* [3] *Southeastern Louisiana University,* [4] *Andrews University*

`PKS 2155-304` *is a blazar with redshift approximately equal to 0.12. During July 2006, the HESS atmospheric Cherenkov telescopes located in Namibia detected an outburst of TeV gamma rays from this object lasting approximately two hours with the total measured flux at least ten times larger than during quiescence. The total isotropic equivalent energy released in TeV gamma rays during this outburst is approximately* 10^{45} *ergs. During this period, the two Hanford detectors and GEO were in science mode. We propose to look for gravitational waves during this extremely energetic gamma-ray outburst with the* `RIDGE` *network analysis pipeline. Simulated detector noise is used to study the performance achievable by* `RIDGE` *for possible gravitational wave signals associated with this event.*

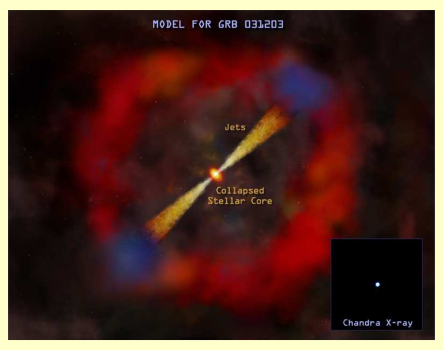
Introduction to Blazars

- Blazars are Active Galactic Nuclei(AGN) [1] powered by accretion onto supermassive black holes. They are similar to GRBs, with both of them having a central engine and a jet.



Blazar (3C120)

Image by W. Steffen, UNAM, Mexico



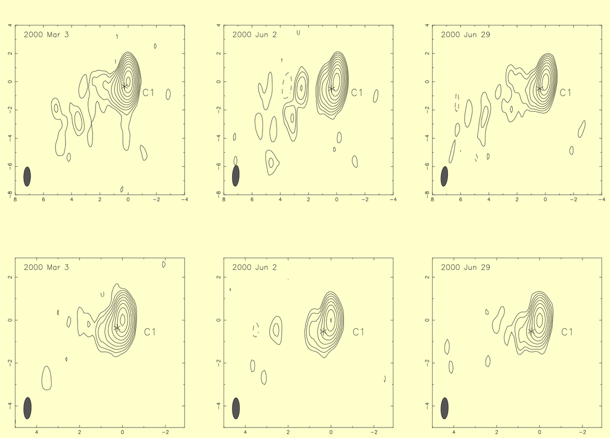
GRB 031203

Credit: Chandra observatory

- They have been observed at all wavelengths over 15 decades in frequency (from 100 MHz up to tens of TeV).
- The radio lobes from the blazar jets exhibit apparent superluminal motion and the emission is highly polarized.
- Flux variability observed on all time-scales from less than an hour to several days.
- Their central engine consists of supermassive black hole ($10^8 M_\odot$). Many of them could contain binary black holes [2].

PKS 2155-304

- `PKS 2155-304` (discovered by Parkes telescope in 1974) is located at a redshift of about 0.12 (Luminosity distance $\simeq$ 540 Mpc) and is the second most distant blazar. The nearest blazar's (`Mrk 501`) luminosity distance is about 143 Mpc.



Radio (VLBA) image of PKS 2155-304 at 15 GHz [3]

- It was first detected in X-Rays by HEAO, by EGRET (1993) from 30 MeV to 10 GeV, and in TeV gamma rays by the University of Durham Mark-6 telescope [4].

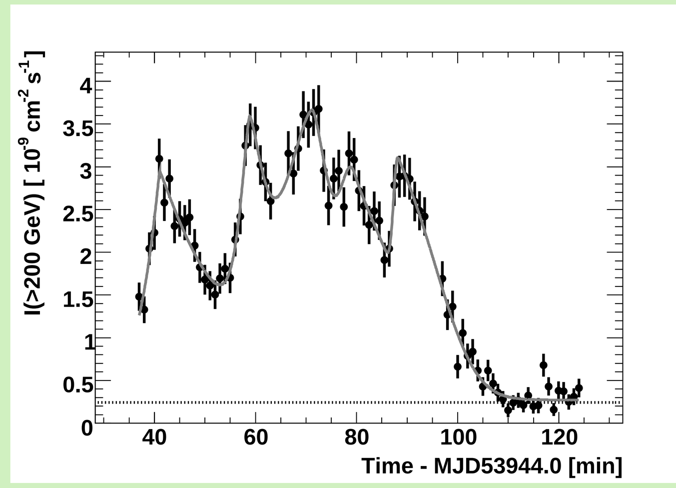
HESS Observations

- HESS stands for High Energy Stereoscopic System and consists of an array of atmospheric Cherenkov telescopes in Namibia which are sensitive to TeV gamma rays.

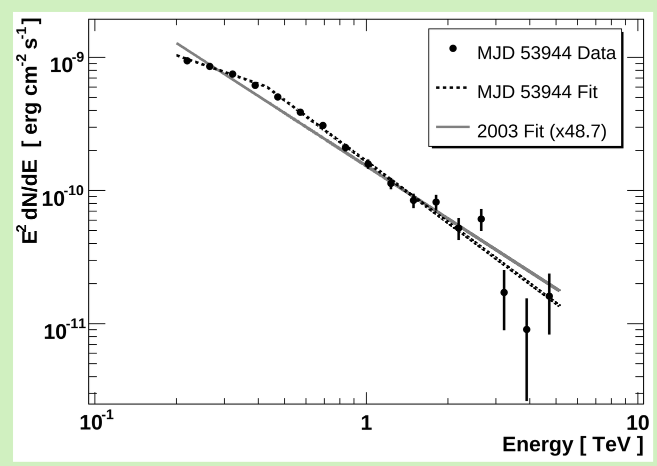
- Since 2003, HESS has been monitoring the flux from VHE blazars to look for any bright flares along with simultaneous coordinated multi-wavelength observations.

Detection of outburst during July 2006

- On 28th July 2006, HESS observed an outburst of TeV gamma rays from this object, lasting about 90 minutes, with total flux at least ten times higher then during quiescence [5]. The average integral flux above 200 GeV is given by $I \simeq 1.7 \times 10^{-9} cm^{-2} s^{-1}$.



The total integral flux above 200 GeV during the 28th July 2006 outburst [5]

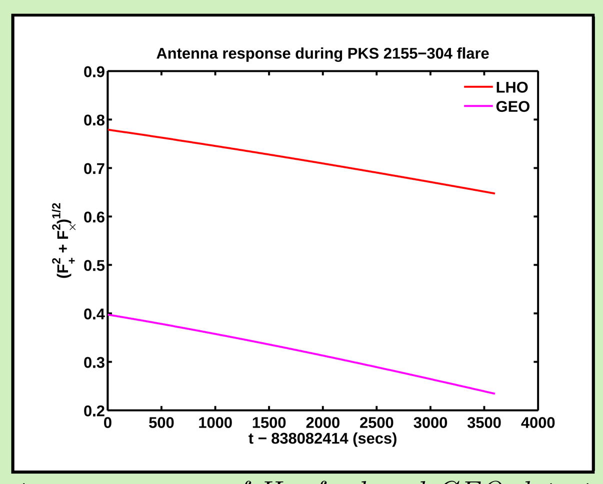


Time-averaged Energy spectrum of the above flare [5]

- The total isotropic equivalent energy released during the flare without accounting for any attenuation with cosmic infrared background is $\simeq 10^{45}$ ergs in TeV gamma rays. (The corresponding number for the SGR 1806 flare during December 2004 is $\simeq 10^{46}$ ergs)
- The exact cause of this TeV outburst is unknown. The most likely explanation is that it is caused by enhanced accretion onto the black hole due to instabilities in the accretion disc (e.g. density perturbations) and the accretion flow (*O. Elbracht, private communication*) .

Status of gravitational wave detectors

- At the time of this flare, both the LHO 4 km and 2 km detectors, and GEO were in science mode, with the sensitivity to binary inspiral of $1.4 M_\odot - 1.4 M_\odot$ neutron stars, equal to 13 Mpc, 7 Mpc, and 1.3 Mpc respectively.



Antenna response of Hanford and GEO detectors during the PKS 2155-304 flare on July 28 2006

Possible GW emission mechanisms

Although there is no theoretical prediction for g.w's during transient outbursts from blazars in LIGO band, there have been some recent proposed gravitational wave emission mechanisms from AGNs whose frequency is in the LISA band :

- Fragmentation of accretion disk in AGNs, which could give rise to bursts of gravitational waves [6]
- Formation and collapse of massive stars into stellar-mass black holes in the self-gravitating accretion disk around AGNs [6, 7]. Eventually these disk-born black holes could coalesce and merge with the central black hole.

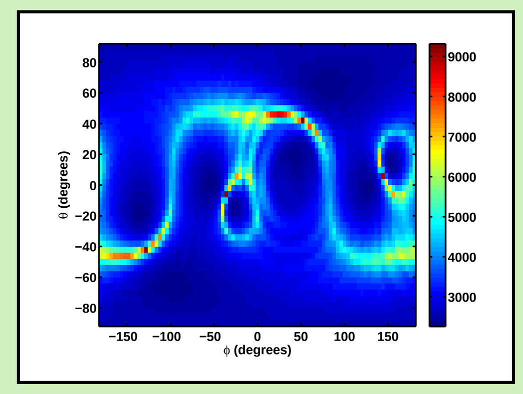
The frequency of gws from above mechanisms ranges from 10^{-4} – 10^{-1} Hz and characteristic strain amplitude from 10^{-22} to 10^{-19} and are a continuous low-frequency background for LISA. However given the rare nature of this TeV burst from `PKS 2155-304` and because its exact cause is still unknown, we would like to adopt an "eyes wide open" approach, and search for gravitational waves in coincidence with this flare.

Proposed Analysis Plans

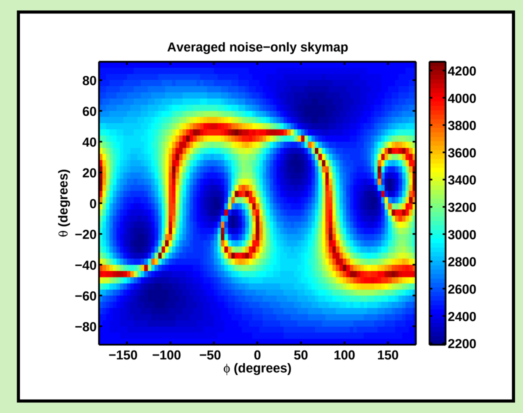
- `RIDGE` is a coherent network analysis algorithm [8] which uses `Tikhonov` regularization [9]. (*See posters by K. Hayama*)
- Data conditioning and line removal in `RIDGE` have been successfully implemented on LIGO and VIRGO [10].
- We wish to use H1, H2, and GEO data. (The quality of data from GEO near this event is under investigation and will determine its inclusion in the analysis.)

Performance with simulated data

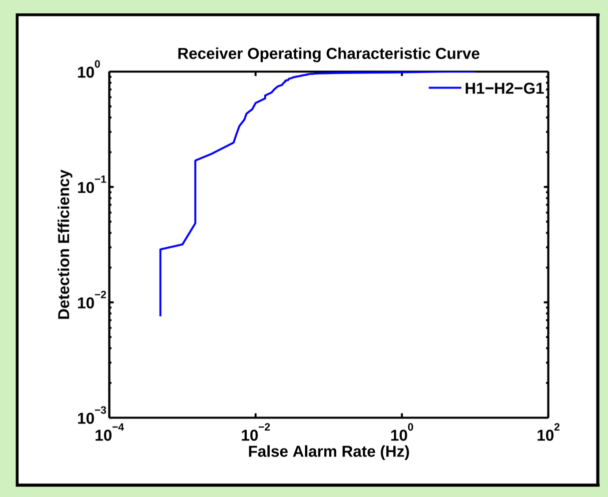
We generated 2000 seconds of simulated LHO-GEO data using design sensitivity curves for LIGO and GEO spectra from Ref. [11]. A circular polarized sine-Gaussian with *hrss* [8] equal to $1.4 \times 10^{-21}/\sqrt{Hz}$ was injected.



Likelihood statistic skymap [9] at extremum of detection statistic



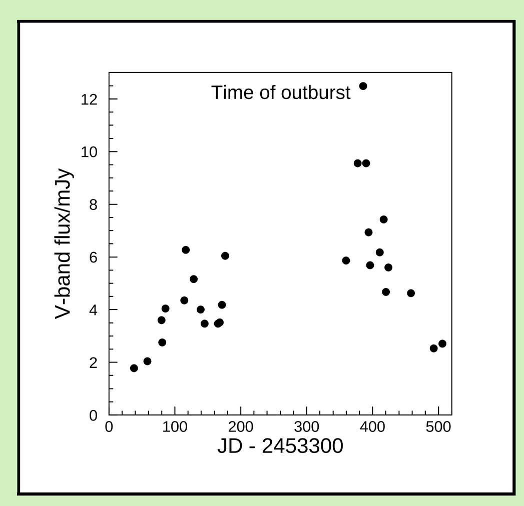
Likelihood statistic skymap [9] of off-source data with only noise



Preliminary Sensitivity curve with simulated noise during the flare

Other blazar bursts during S5

- During S5 there were 2 bursts from `OJ 287` (Luminosity distance $\simeq$ 1563 Mpc) in the optical band during Nov 2005 (just after S5 start) [12] and in Sept. 2007 (*K. Nilsson, private communication*). These are probably caused by the crossing of the accretion disk of the secondary black hole by the primary [12].



Observational data from OJ 287 during 2004-2006 [12]

References

[1] Peterson, B., 1997 An Introduction to Active Galactic Nuclei

[2] Hayasaki, K., Mineshige, K. & Sudou, H., 2006 *astro-ph/06091442*

[3] Piner, G.B. and Edwards, P.G., 2004 *ApJ* 600, 115

[4] Chadwick, P. M. et al., 1999 *ApJ* 513, 161

[5] Aharonian, F. et al., 2007 *A & A*, 664, L71

[6] Levin, Y., 2003 *astro-ph/0307084*

[7] Sigl, G., Schnittman, J., and Buonanno A., 2007 *Phys Rev* D75, 024034

[8] Thorne, K.A., 2007, *arXiv:0706.4301*

[9] Rakhmanov, M. 2006 *Class. & Quant. Grav.* 23, S673

[10] Hayama, K. et al., 2007 *Class. & Quant. Grav.* 24, S681

[11] Grischuk, L. et al., 2001 *Phys. Usp.* 44, 1

[12] Valtonen, M.J. et al., 2006 *ApJ* 643, L9

LIGO G070809-00-Z. This work is supported by NSF 428-51 29NV0 (PSU), NSF PHY 055584 and NASA NAG5-13396 (UTB), NSF PHY-0653233 (SELU), Office of Scholarly Research (Andrews)