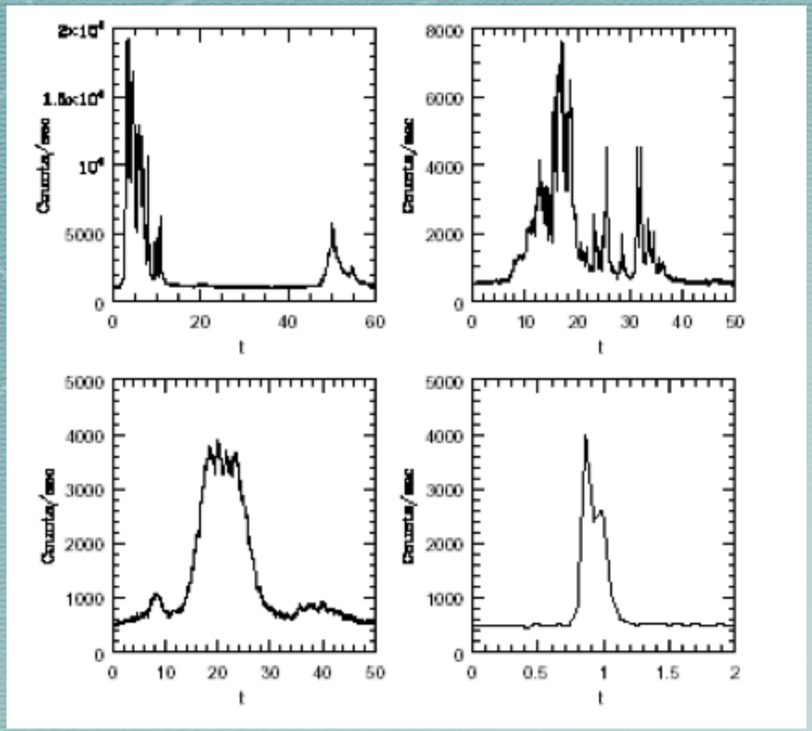
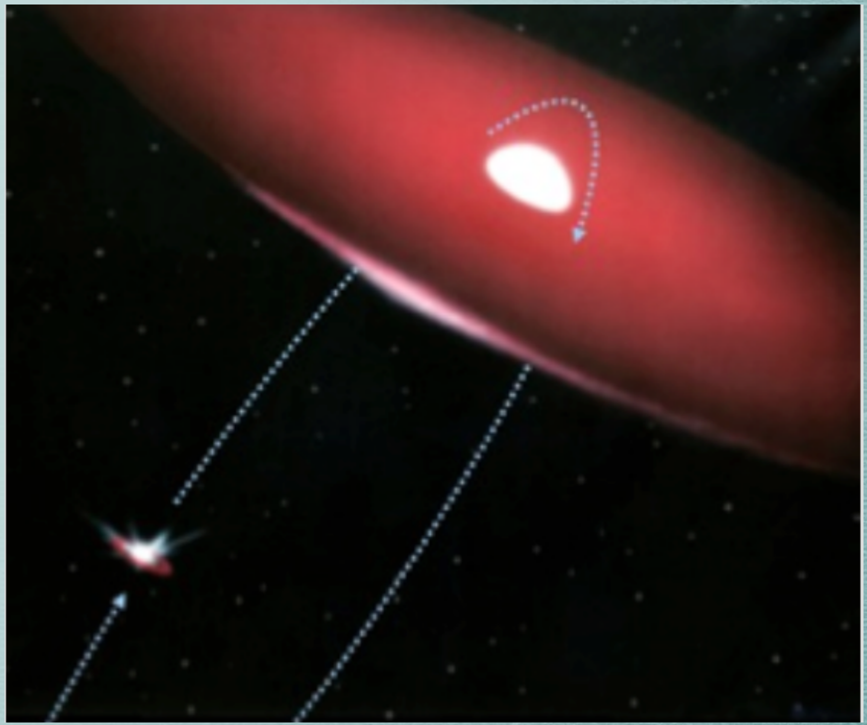



# 1. GAMMA-RAY BURSTS
# &
# 2. GAMMA-RAY BINARIES

## AT THE VERY HIGH ENERGY GAMMA-RAYS



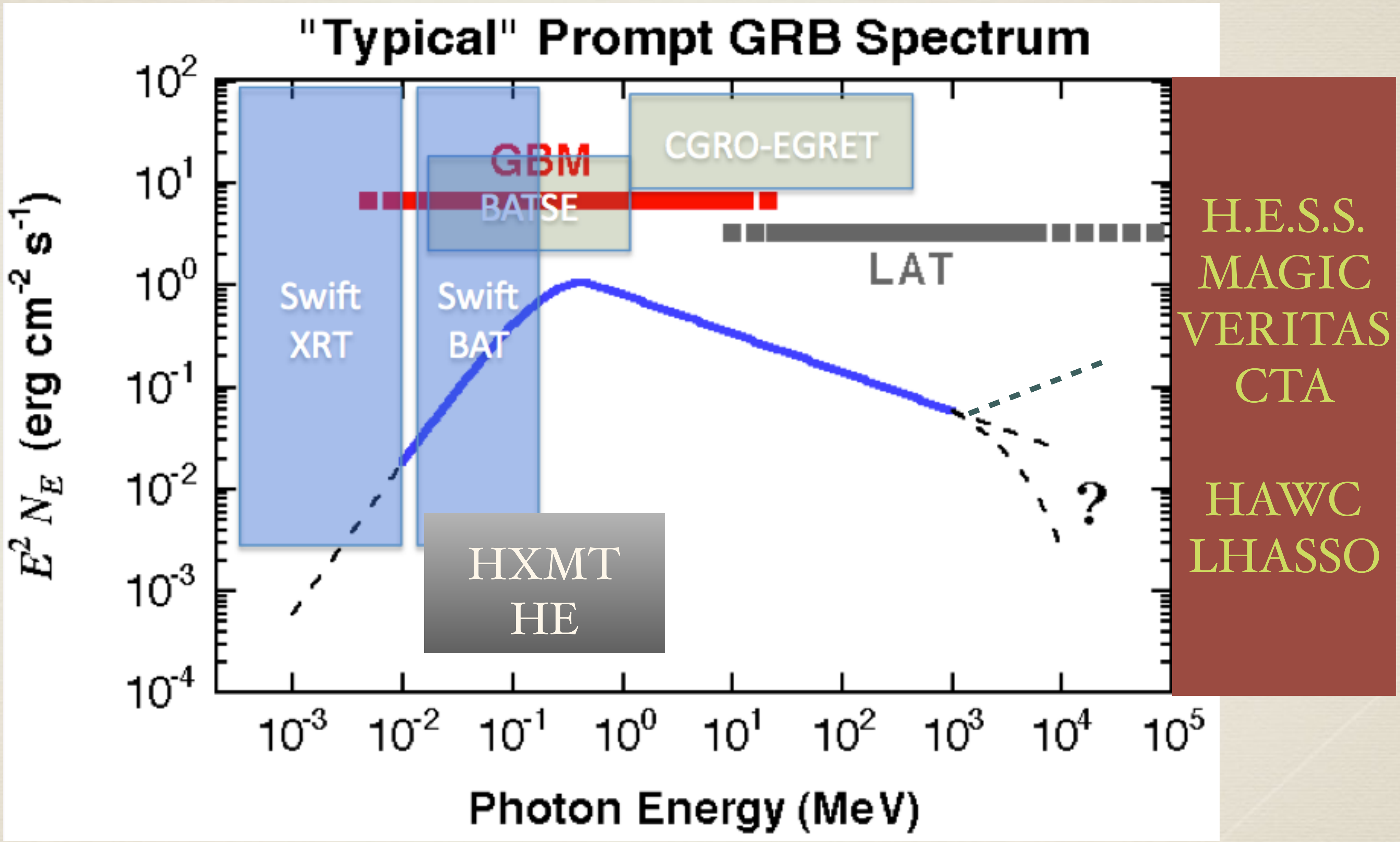
TAM, Pak Hin (Sun Yat-sen University)

# GAMMA-RAY BURST OBSERVATIONS AT 100 GEV: LESSONS LEARNT FROM FERMI/LAT

TAM, Pak Hin (Sun Yat-sen University)

collaborator: XiangYu Wang (NJU)

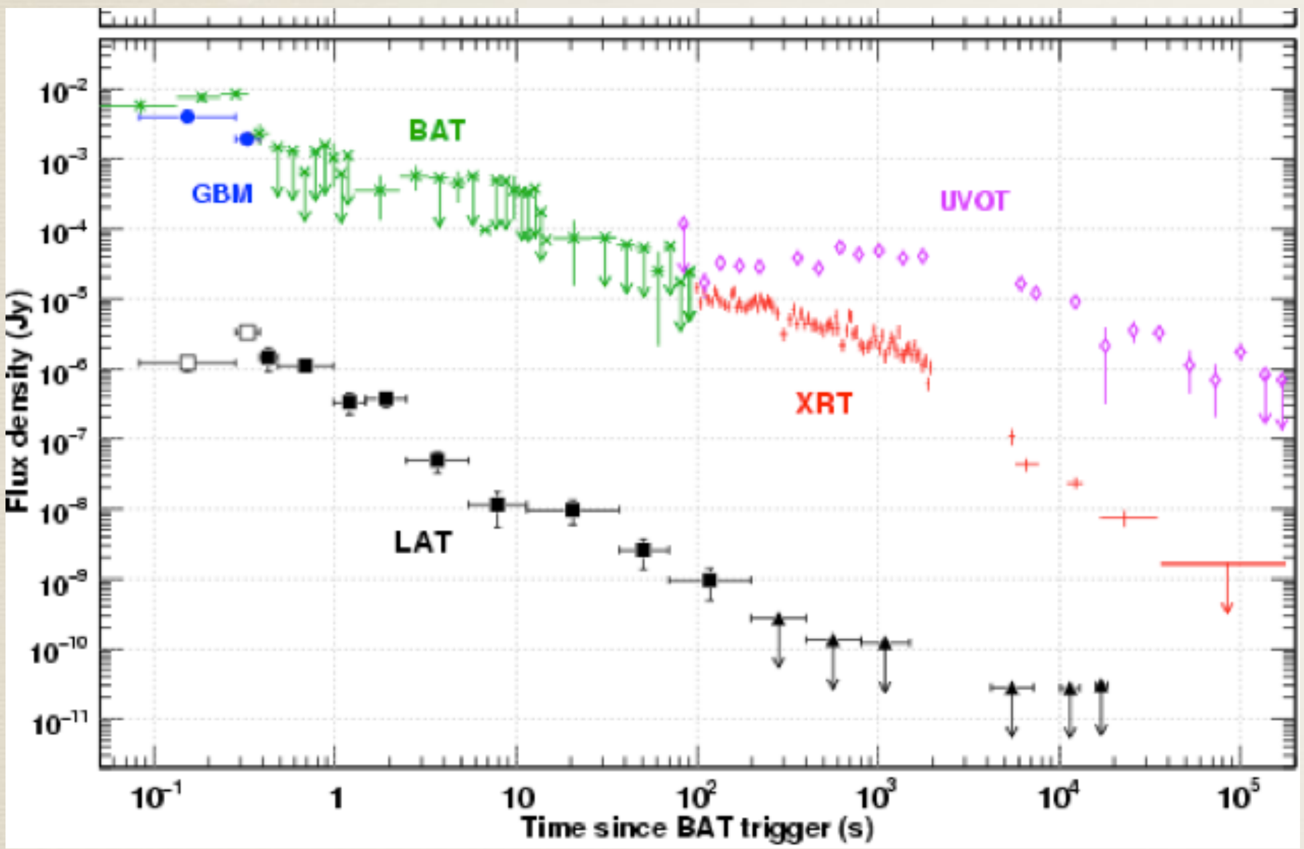
Torino, Italy
1/12/2016



"Typical" Prompt GRB Spectrum
$E^2 N_E$ (erg cm$^{-2}$ s$^{-1}$)
Photon Energy (MeV)
Swift XRT
Swift BAT
GBM
BATSE
CGRO-EGRET
LAT
HXMT HE
?
H.E.S.S.
MAGIC
VERITAS
CTA
HAWC
LHASSO

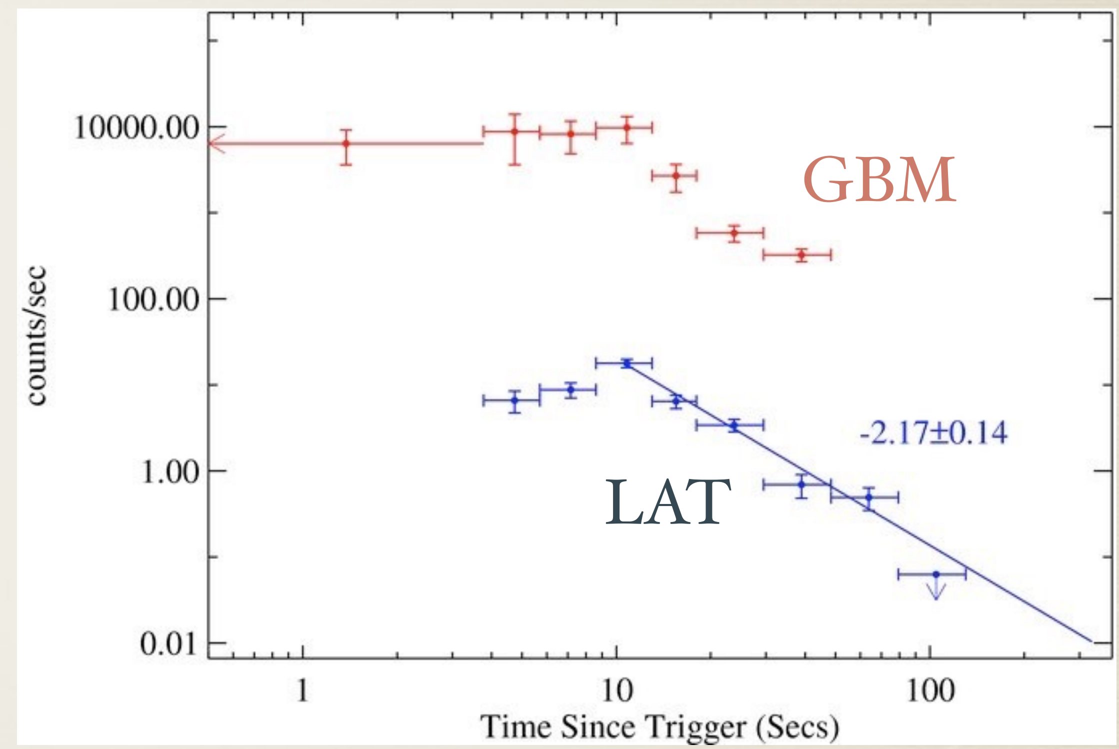
# MWL/GeV photons during GRB afterglow

GRB 090510




Abdo et al. (2010)

GRB 090926A

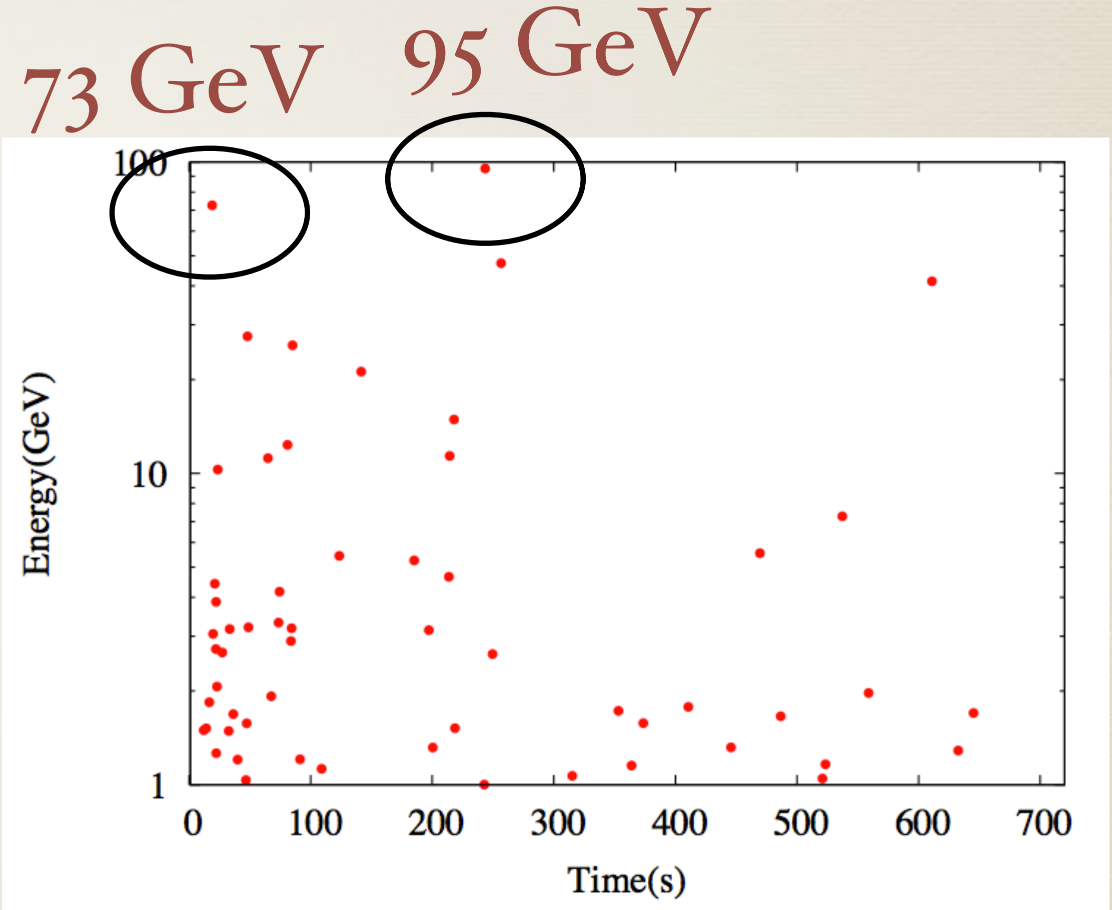



Swenson et al. (2010)

# Very bright GRB 130427A

GRB 130427A emits many high-energy gamma-rays during the prompt & afterglow period, $T_{90}$~138s

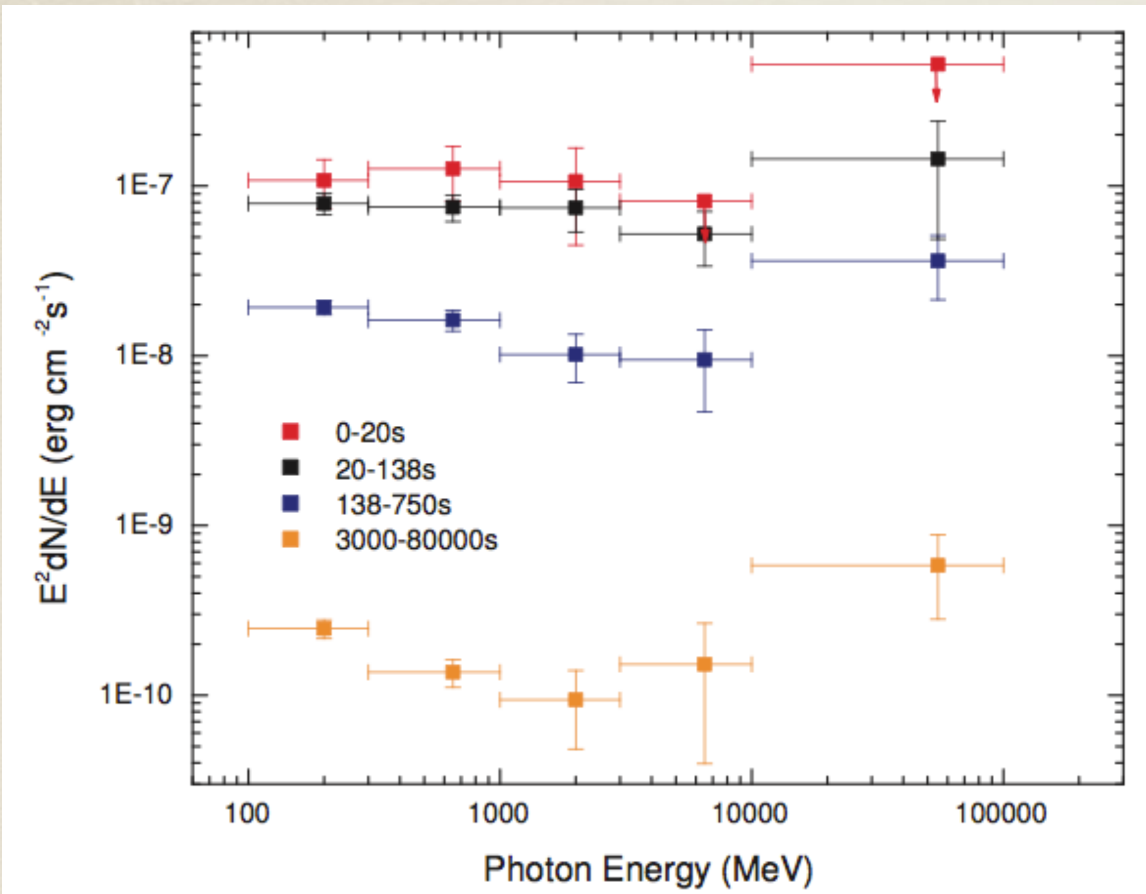
| arrival time (since $T_0$, in sec) | energy (GeV) |
|---|---|
| 18.4 | 72.6 |
| 22.9 | 10.3 |
| 47.3 | 27.5 |
| 64.2 | 11.2 |
| 80.2 | 12.3 |
| 84.5 | 25.8 |
| 140.8 | 21.2 |
| 213.7 | 11.4 |
| 217.2 | 14.9 |
| 242.8 | 95.3 |
| 256.0 | 47.3 |
| 610.3 | 41.4 |
| 3409.6 | 38.5 |
| 6062.3 | 18.6 |
| 34365.9 | 32.0 |

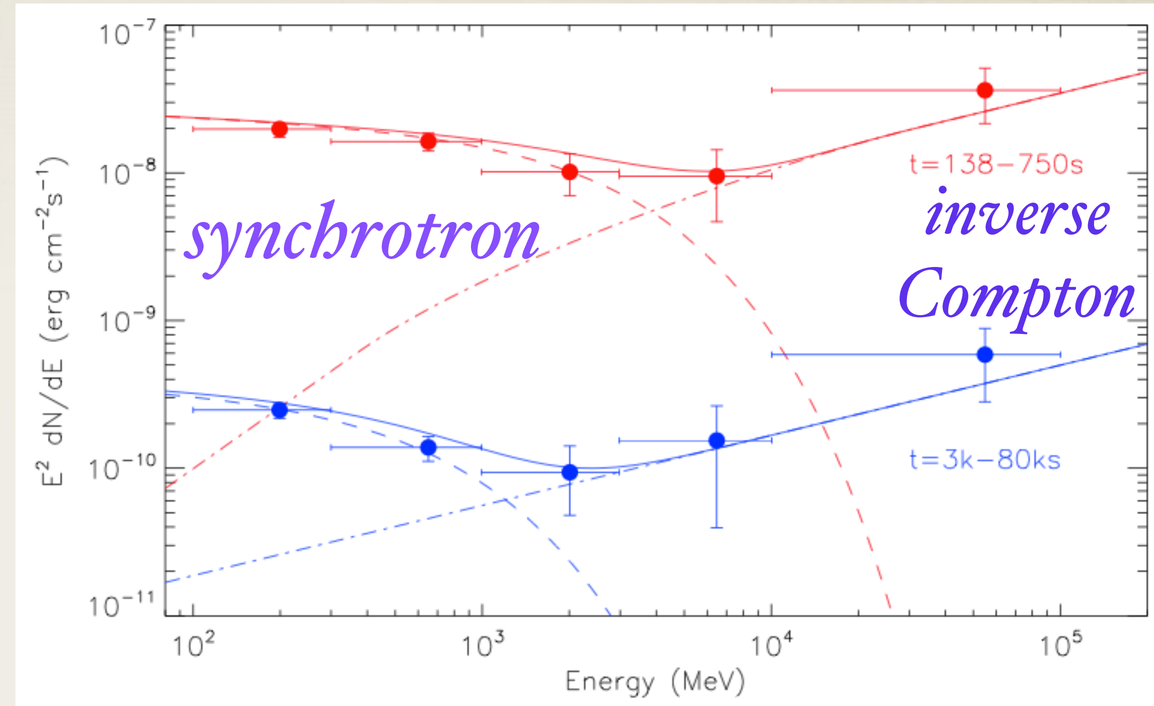



a 95 GeV photon arrived at To + 243s, corresponding to an intrinsic photon energy 128 GeV at z=0.34

Fan, Tam, et al. (2013)

# Spectral evolution




Liu et al. (2013)

| $t - T_0$ (sec) | Power Law (PL) $\Gamma$ | Broken Power Law (BPL) $\Gamma_1$ $(E < E_b)$ | $\Gamma_2$ $(E > E_b)$ | $E_b$ (GeV) | Improvement of BPL over PL[a] ($\sigma$) |
|---|---|---|---|---|---|
| 0–20 | −2.0±0.2 | | ... | | ... |
| 20–138 | −1.9±0.1 | | ... | | ... |
| 138–750 | −2.1±0.1 | −2.2±0.1 | −1.4±0.2 | 4.3±2.0 | 2.5 |
| 3000–80,000 | −2.1±0.1 | −2.6±0.7 | −1.4±0.2 | 1.1±0.9 | 2.9 |
| 138–80,000 | −2.1±0.1 | −2.3±0.2 | −1.4±0.1 | 2.5±1.1 | 3.5 |

[a] calculated as $\sqrt{2 \times [\log(\mathcal{L}_{BPL}) - \log(\mathcal{L}_{PL})]}$

Power law index doesn't change!

Significance of broken power law over power law

Tam et al. (2013)

# What did we learn from GRB 130427A?

* Many very high-energy photons come from the afterglow phase,
* and the 95 GeV photon was detected at 243s after the trigger,
* So, afterglow 100 GeV photons are there.
* **However, is there any ~100 GeV during the prompt emission?**

**YES!!!**

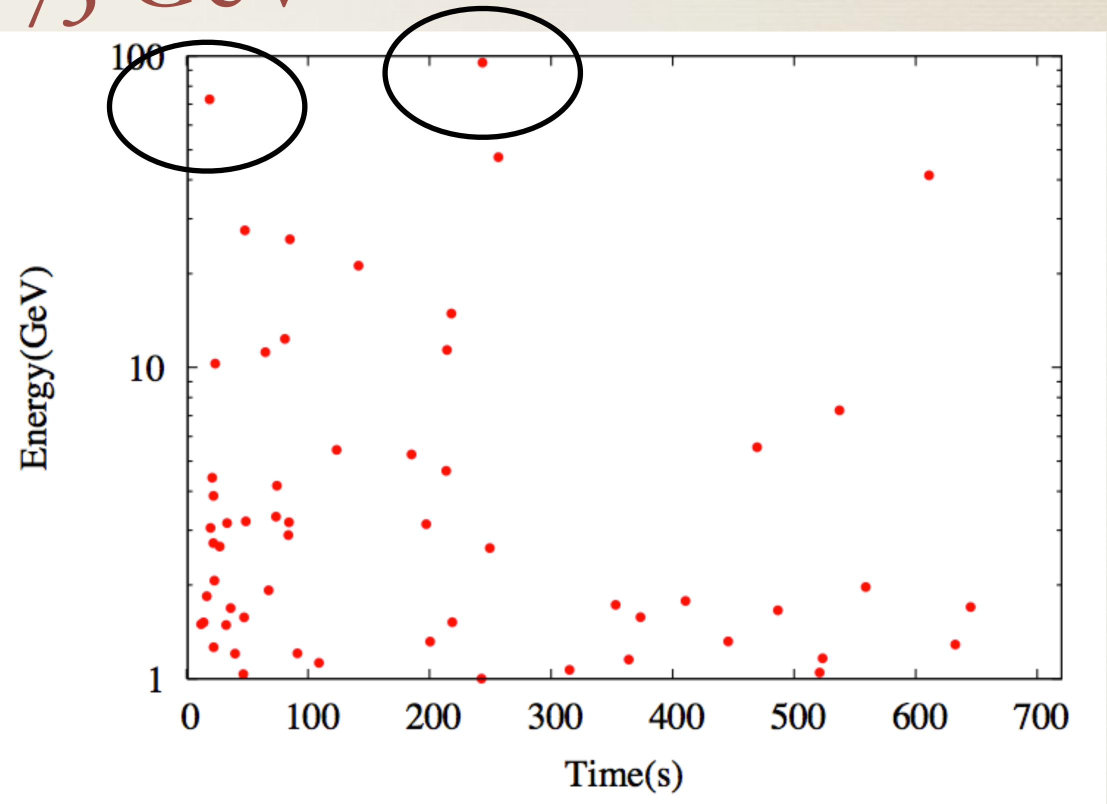
# Very bright GRB 130427A

GRB 130427A emits many high-energy gamma-rays during the prompt & afterglow period, $T_{90}$~138s

73 GeV *(1+z)=97 GeV

| arrival time (since $T_0$, in sec) | energy (GeV) |
|---|---|
| 18.4 | 72.6 |
| 22.9 | 10.3 |
| 47.3 | 27.5 |
| 64.2 | 11.2 |
| 80.2 | 12.3 |
| 84.5 | 25.8 |
| 140.8 | 21.2 |
| 213.7 | 11.4 |
| 217.2 | 14.9 |
| 242.8 | 95.3 |
| 256.0 | 47.3 |
| 610.3 | 41.4 |
| 3409.6 | 38.5 |
| 6062.3 | 18.6 |
| 34365.9 | 32.0 |

73 GeV 95 GeV

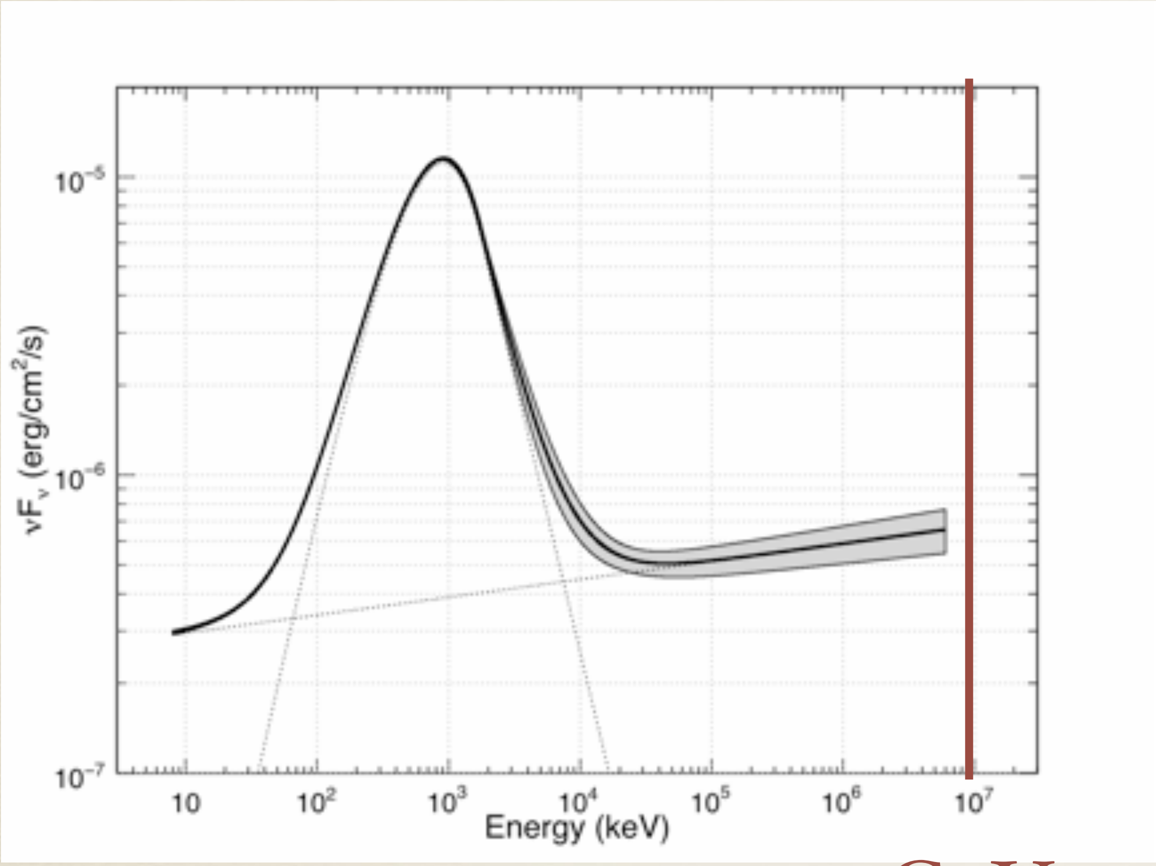



a 95 GeV photon arrived at To + 243s, corresponding to an intrinsic photon energy 128 GeV at z=0.34

Fan, Tam, et al. (2013)

# Second component during prompt phase

GRB 090902B

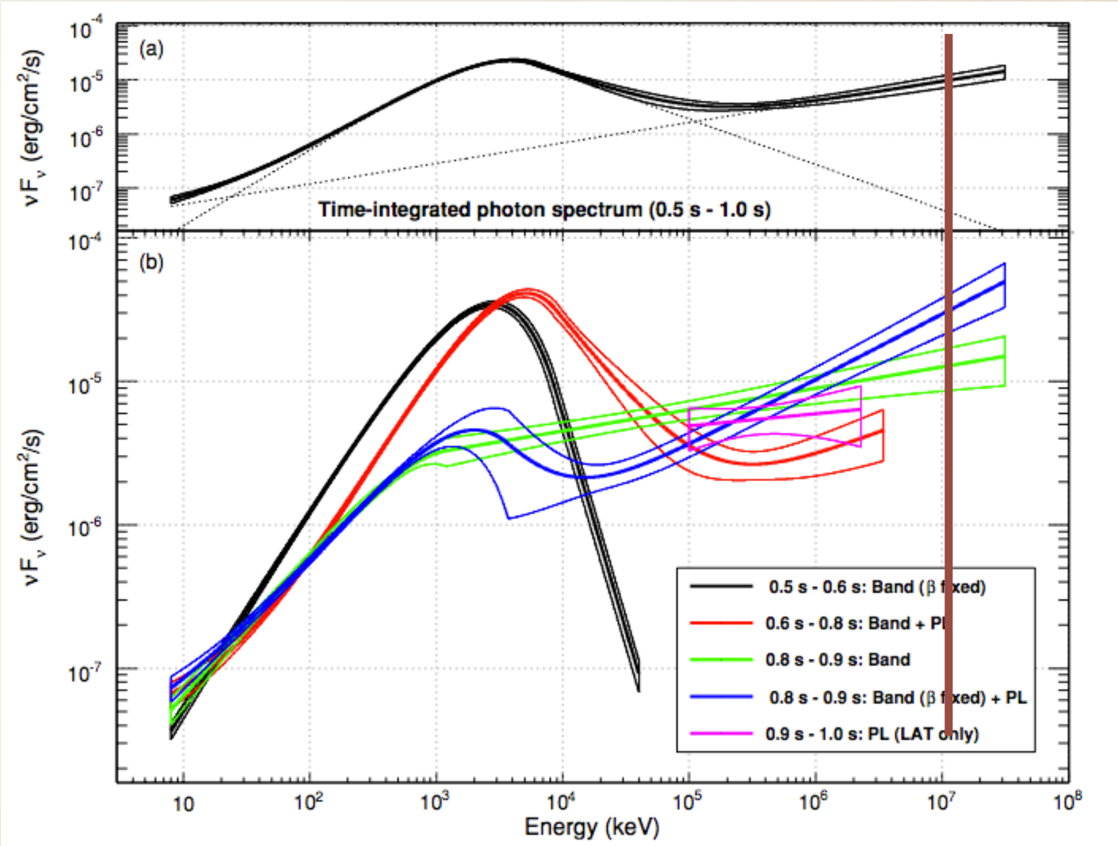



~10 GeV

Abdo et al. (2009)

~10 sec after trigger

GRB 090510




10 GeV

Ackermann, et al. 2010

~1 sec after trigger

# Why bother the very high-energy photons of GRBs?

* The radiation mechanism is still under debate
* The energy band where extragalactic background light (EBL) attenuation starts to modify the intrinsic spectra of the sources (e.g., AGN, GRBs)
* At these energies, GRBs can be seen at distances further than those of AGN, because of the EBL

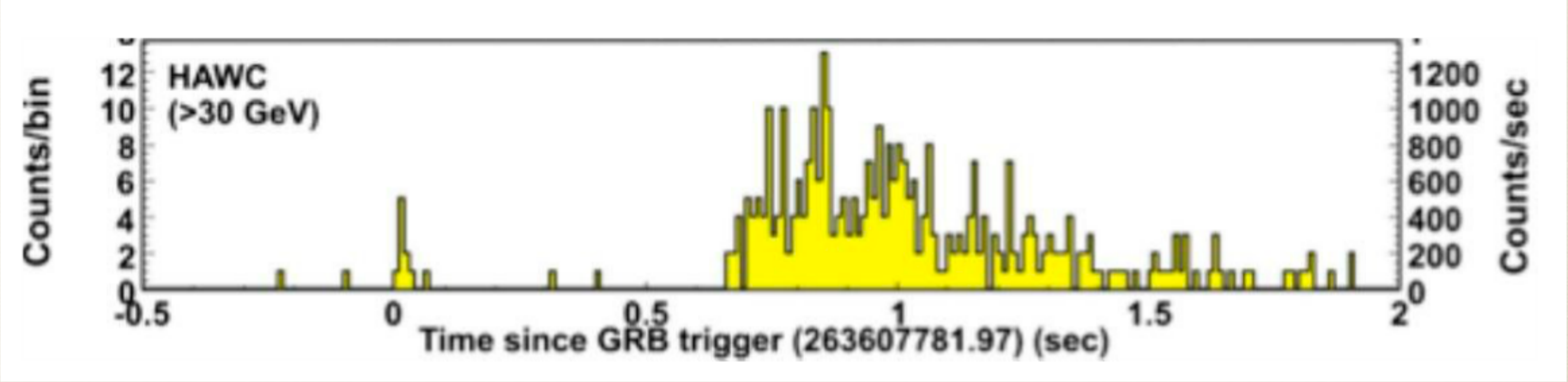
# Historical observations of GRBs

- Over the last twenty years or so, ground-based telescopes have not detected GRBs at significantly high confidence
- Some early claims:
  GRB 970417A by MILAGRITO （2.7σ）,
  GRB 991208 by Tibet-ASγ （1.88σ, z=0.706）steep fall-off of optical flash like GRB 990123 was also seen
- Not even MAGIC II/H.E.S.S. II/VERITAS/HAWC (yet)
- High energy threshold (thus absorbed by the Extragalactic Background Light, EBL) is a major reason, other reasons include low sensitivity, time delay, etc. (see, e.g., Xue, Tam, et al., 2009).

# HAWC is observing GRBs

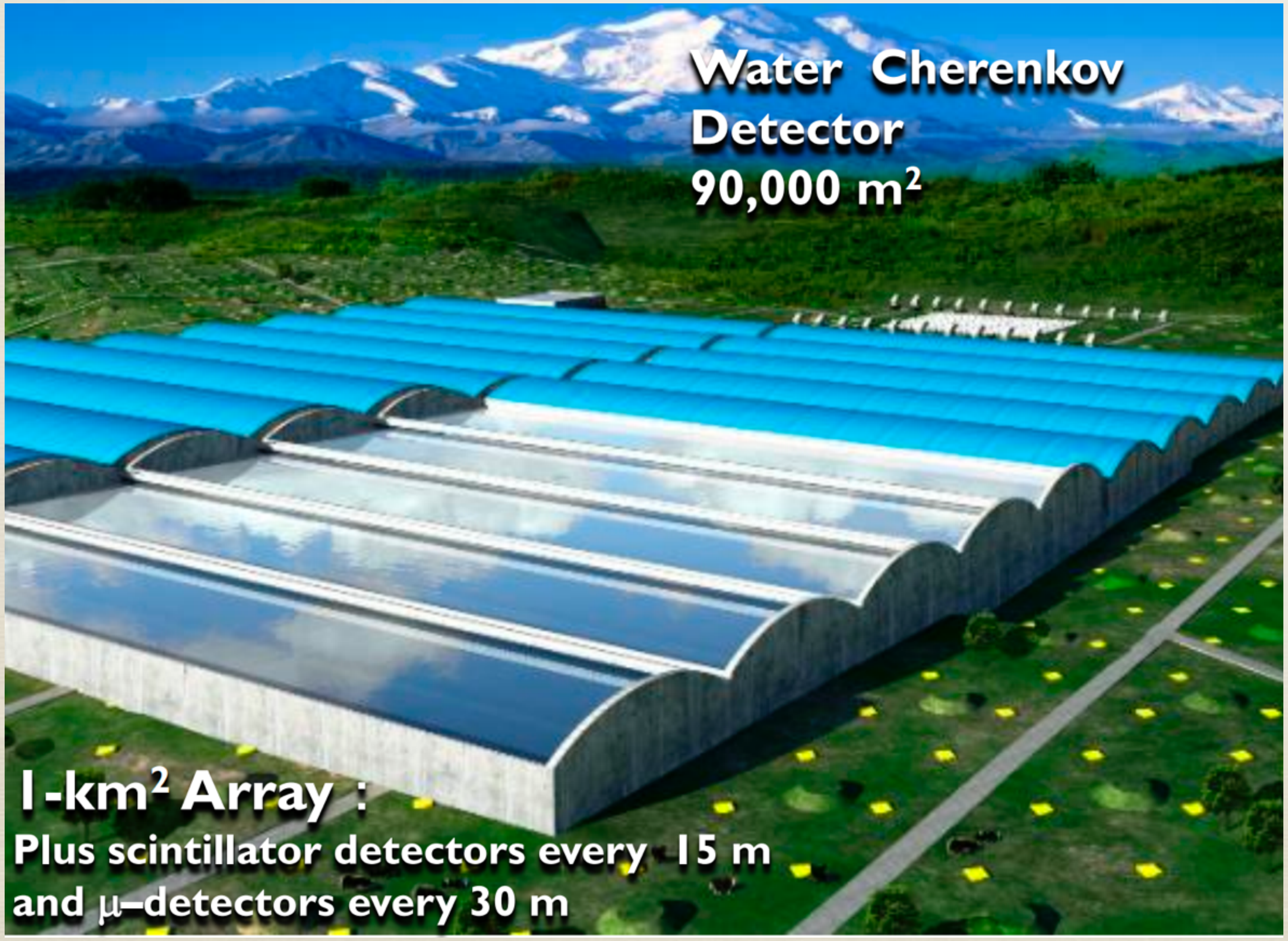
* With less than 1/3 of the array active, the HAWC observatory obtained limits for GRB 130702A, which is at a close redshift of z = 0.145, and a limit for GRB 130427A

* Simulated HAWC light curve of GRB 090510



# LHAASO opportunities

* Best instrument to observe GRB prompt emission at above ~100 GeV




Maybe a good early science project

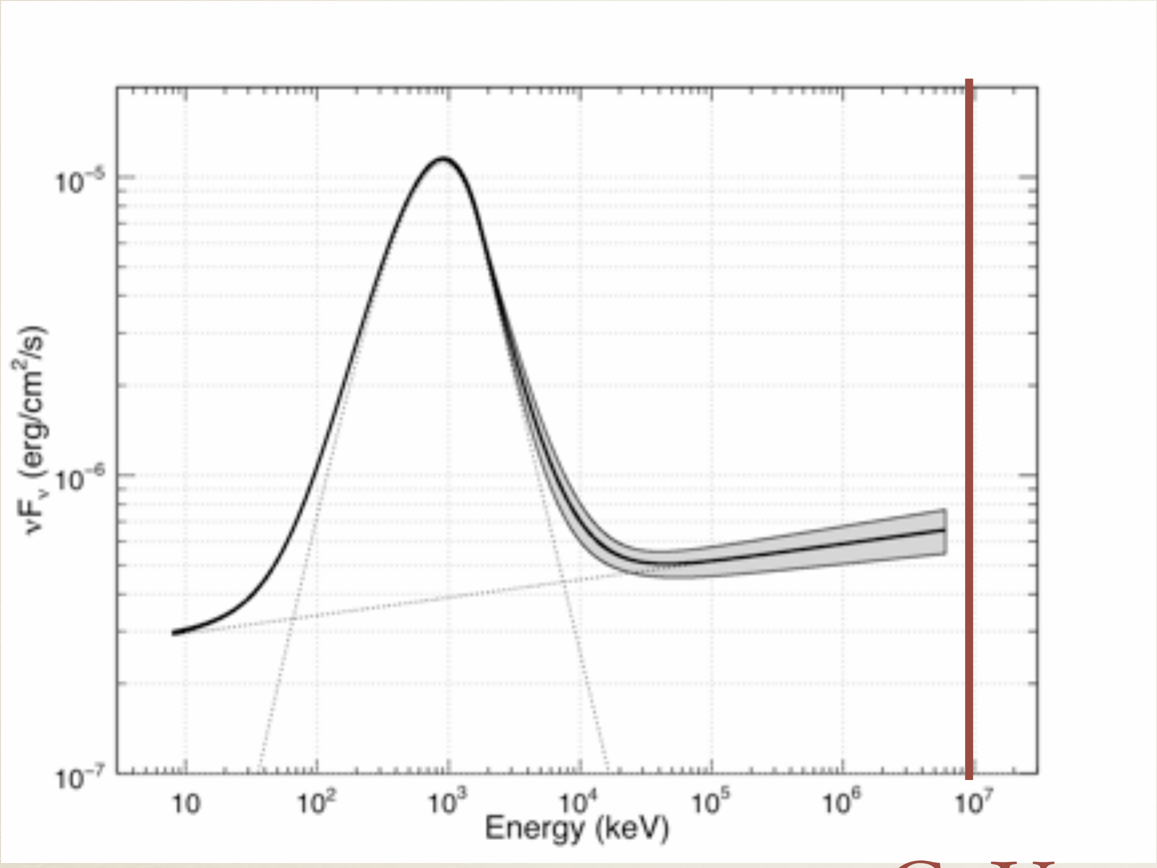
# GRB observing modes by LHAASO-WCDA

* Shower mode, high threshold ~100 GeV
* Low multiplicity trigger mode can increase the sensitivity by a factor of a few, and lower the energy threshold to ~10 GeV, but background is huge
* Single particle (scaler) mode, lowest energy threshold at ~1 GeV, but loose directional information

c.f. based on slides by Wu, H. given in Tianjin, LHAASO collaboration meeting@August 2016

# Second component during prompt phase

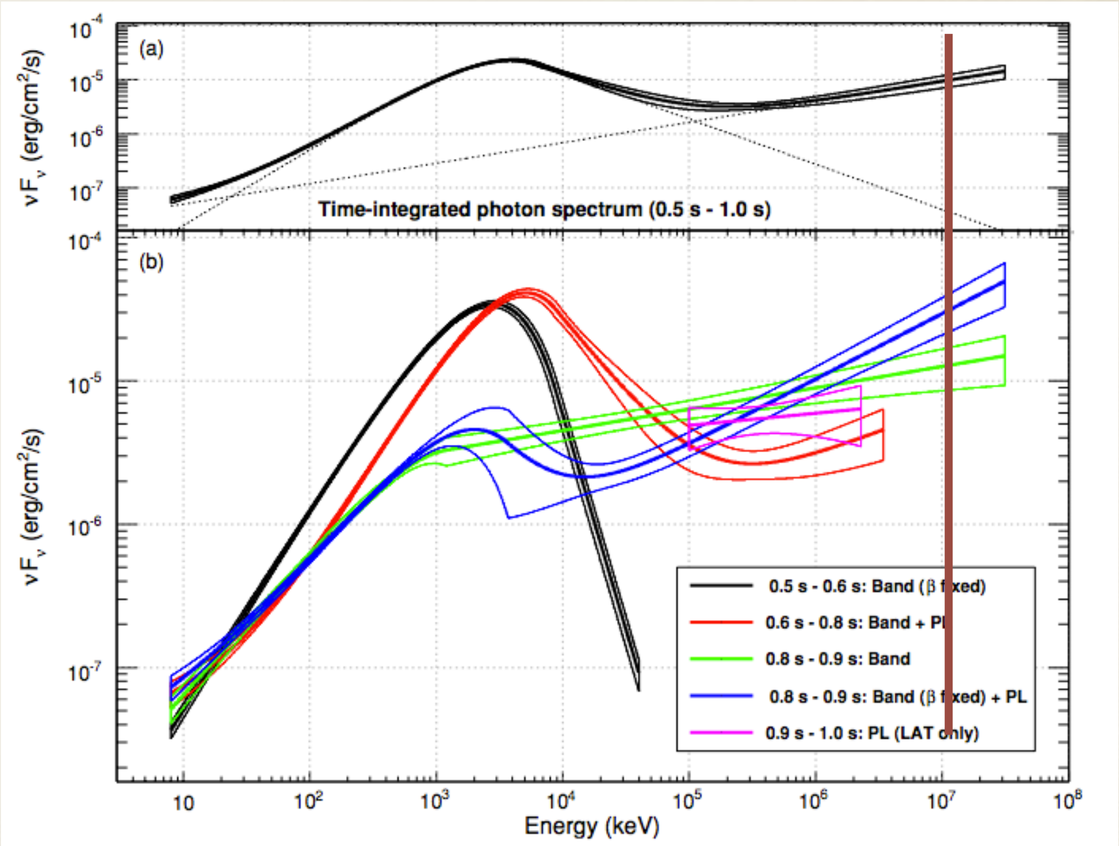
GRB 090902B




~10 GeV

Abdo et al. (2009)

GRB 090510




10 GeV

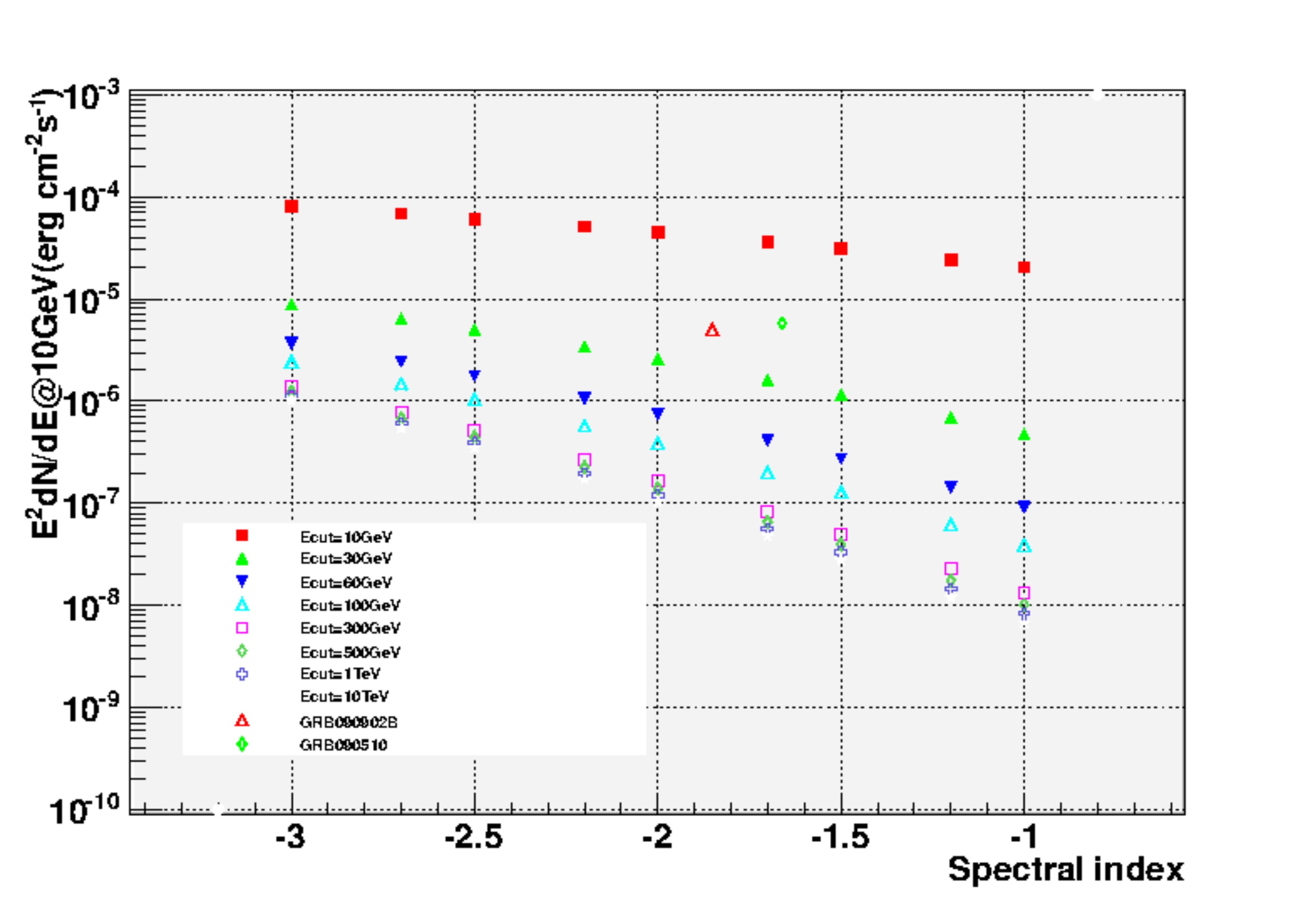
Ackermann, et al. 2010

~10 sec after trigger

~1 sec after trigger

# Sensitivity to GRBs in the WCDA shower mode

* If the high-energy cutoff is above 30GeV, WCDA can significantly detect bright GRBs, e.g., GRB090902B, GRB090510



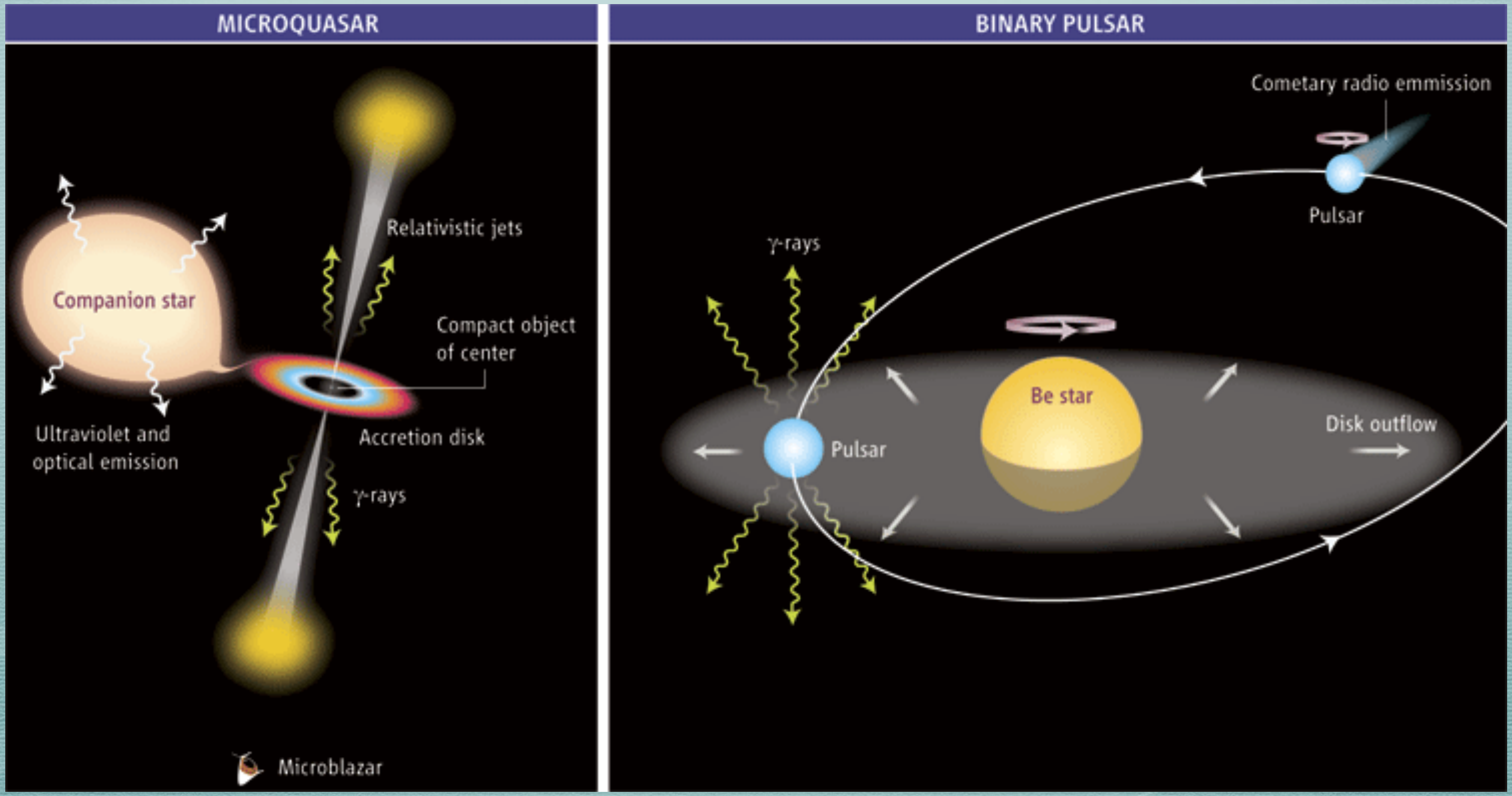

c.f. based on slides by Wu, H. given in Tianjin, LHAASO collaboration meeting@August 2016

# GAMMA-RAY BINARIES OBSERVATIONS AT TEV ENERGIES

TAM Pak Hin (Sun Yat-sen University)

on behalf of the Galactic Science group of LHAASO: CHEN Yang, HU HB, MA XH, WANG ZX, HOU X, etc.

# GAMMA-RAY BINARIES



# Currently known high-mass gamma-ray binaries (only 7 are known)

| name | binary components | | $P_{orb}$ (d) | HE | VHE | refs (⋆) | notes |
|---|---|---|---|---|---|---|---|
| (high-mass) gamma-ray binaries | | | | | | | |
| PSR B1259-63 | pulsar | Be | 1236.7 | ✓ | ✓ | [12, 13] | 47.7 ms |
| HESS J0632+057 | ? | Be | 315 | | ✓ | [14, 15] | |
| LS I +61°303 | ? | Be | 26.5 | ✓ | ✓ | [16, 17] | magnetar ? |
| 1FGL J1018.6-5856 | ? | O | 16.6 | ✓ | ✓ | [18, 19] | |
| LS 5039 | ? | O | 3.9 | ✓ | ✓ | [20, 21] | |

*Dubus (2015)*

*New comers:*

LMC P3(O star, $P_{orb}$ 10 days)

PSR J2032+4127 (Be star, $P_{orb}$ 50 years)

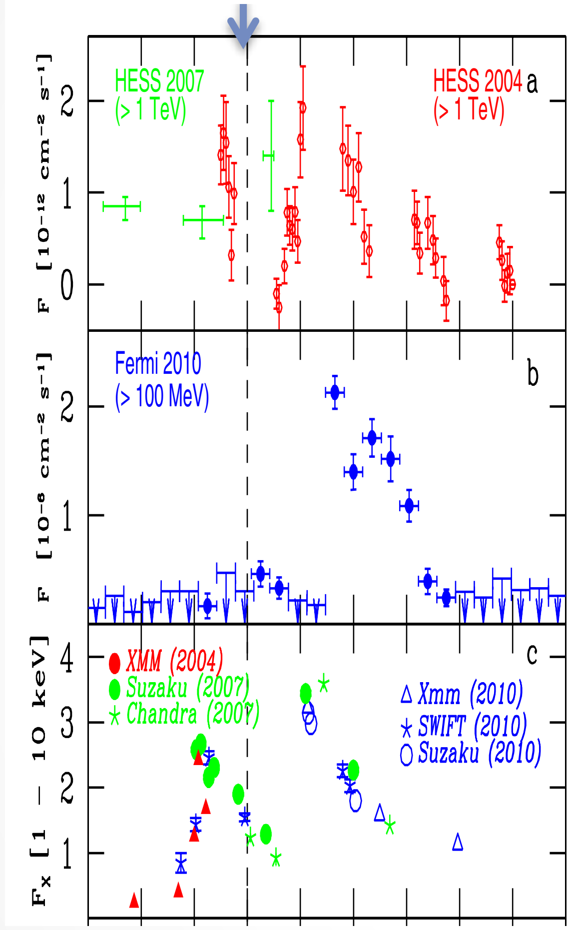
# Orbital modulation

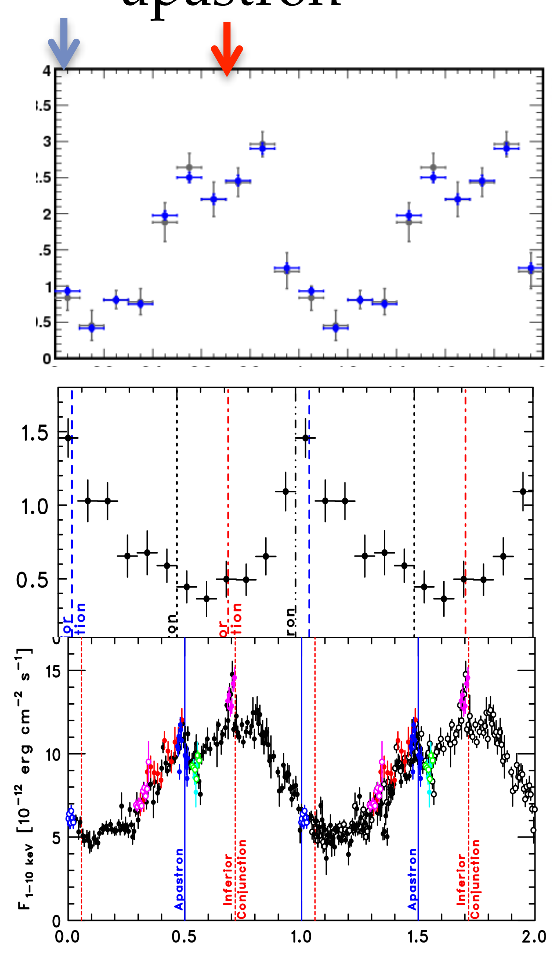
| PSR B1259-63 | LS5039 | HESS J0632 |
|---|---|---|
| periastron | apastron | |

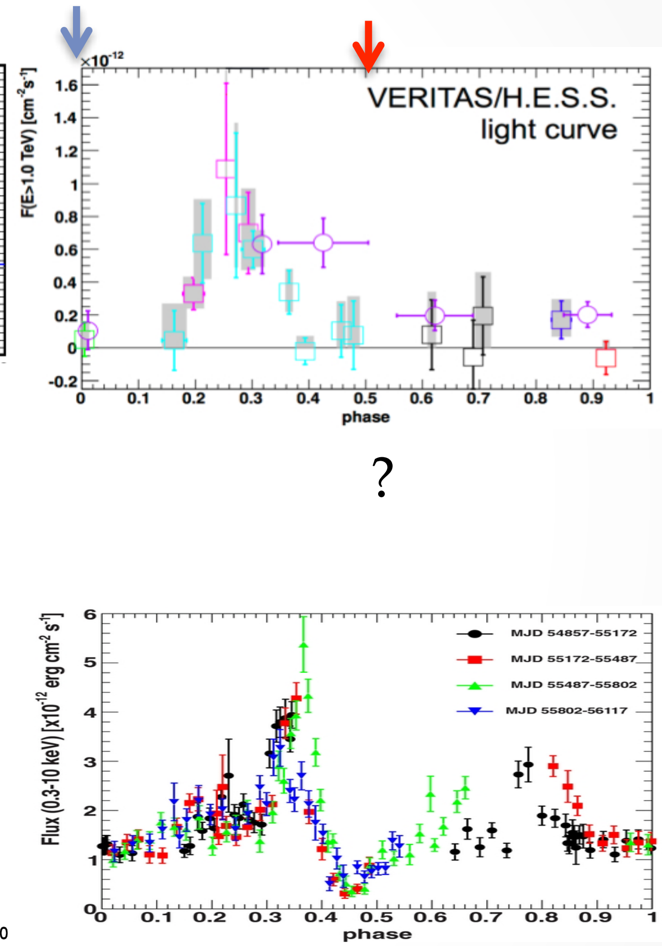
TeV

GeV

X-ray



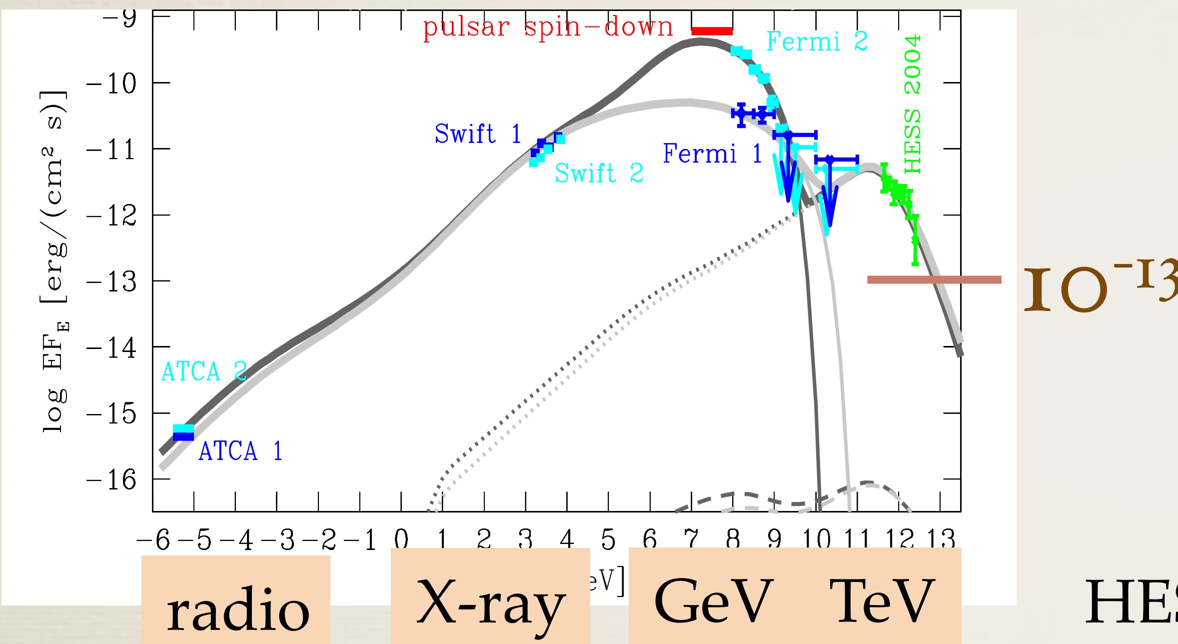

?

| ~ 0.5 orbit | 2 orbit | 1 orbit |
|---|---|---|

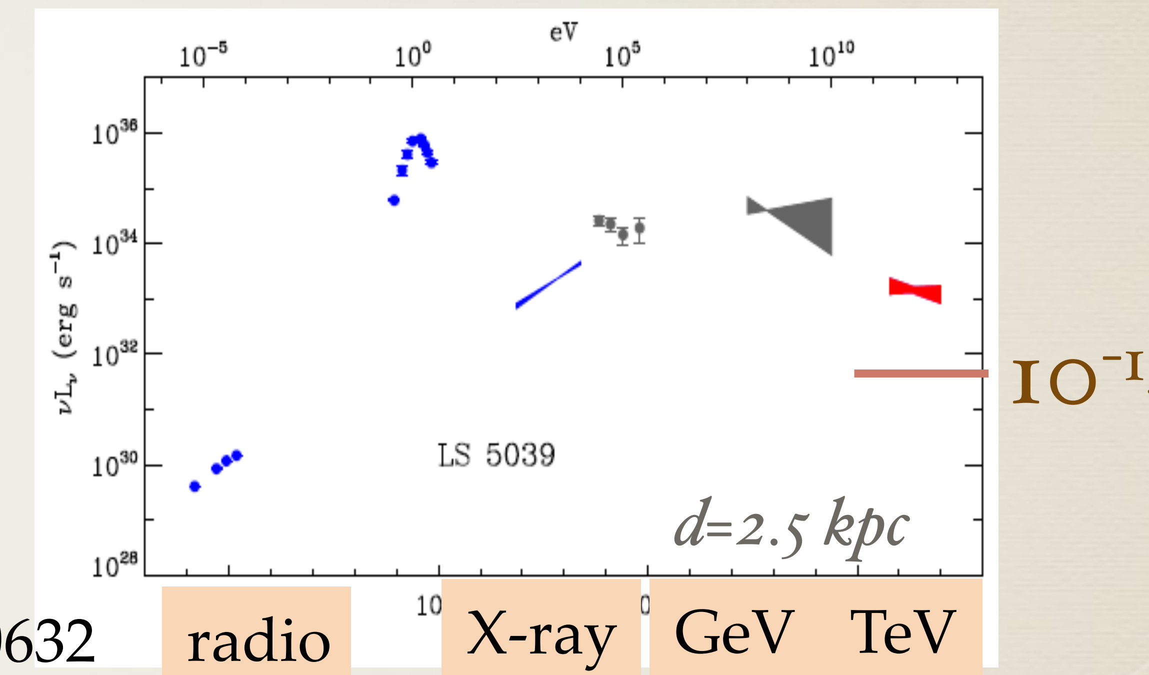
Gamma-ray binary with Be star shows more complicated orbital modulation.

# Gamma-ray binaries : Gamma-ray loud

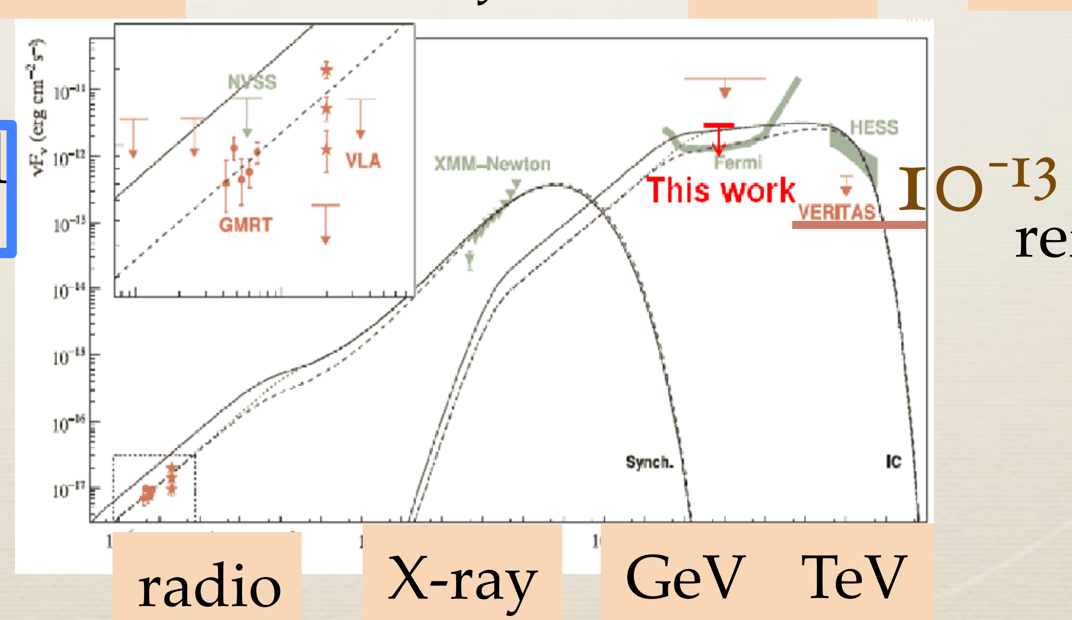
PSR B1259-63




LS5039



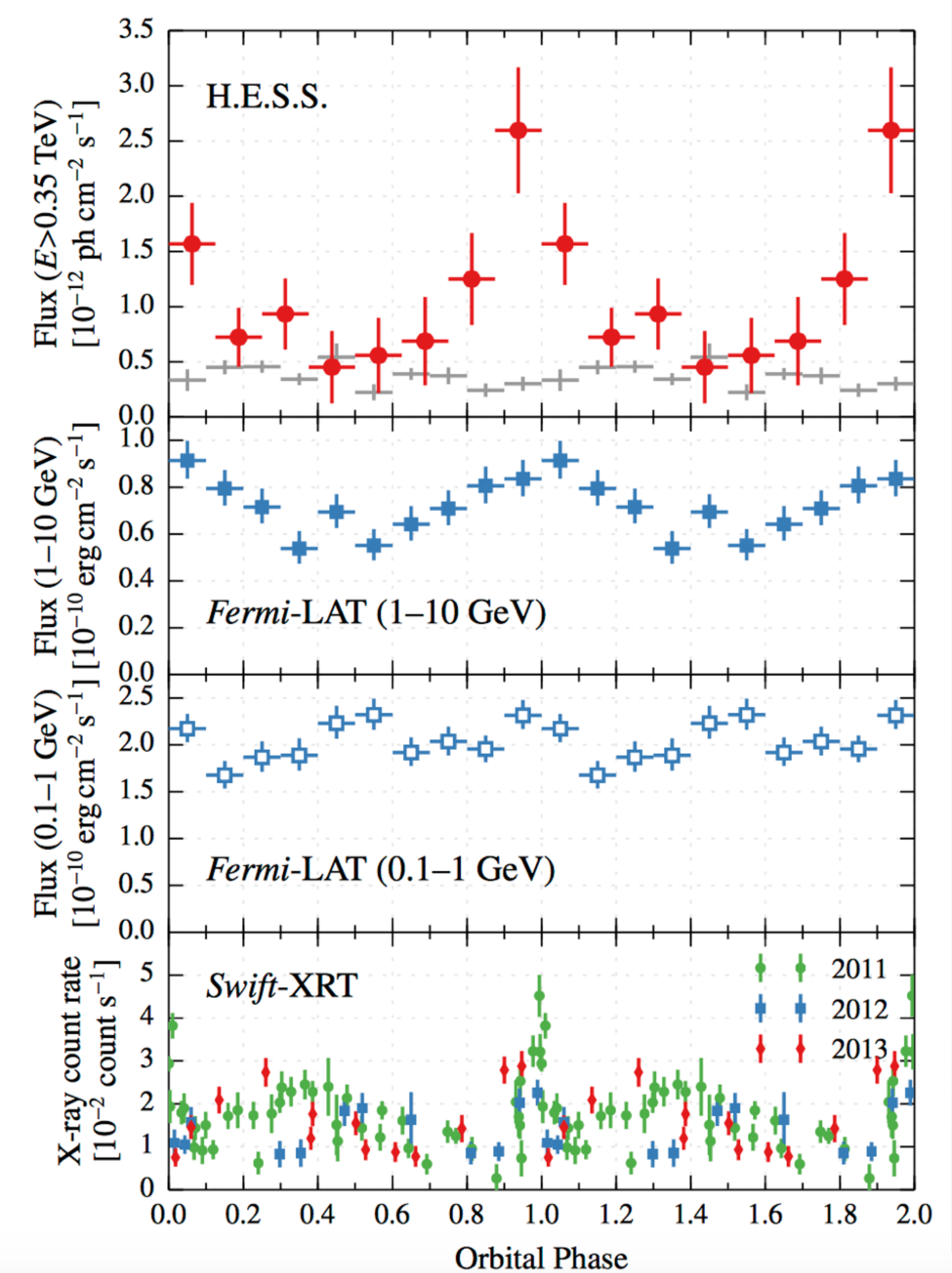

HESS J0632

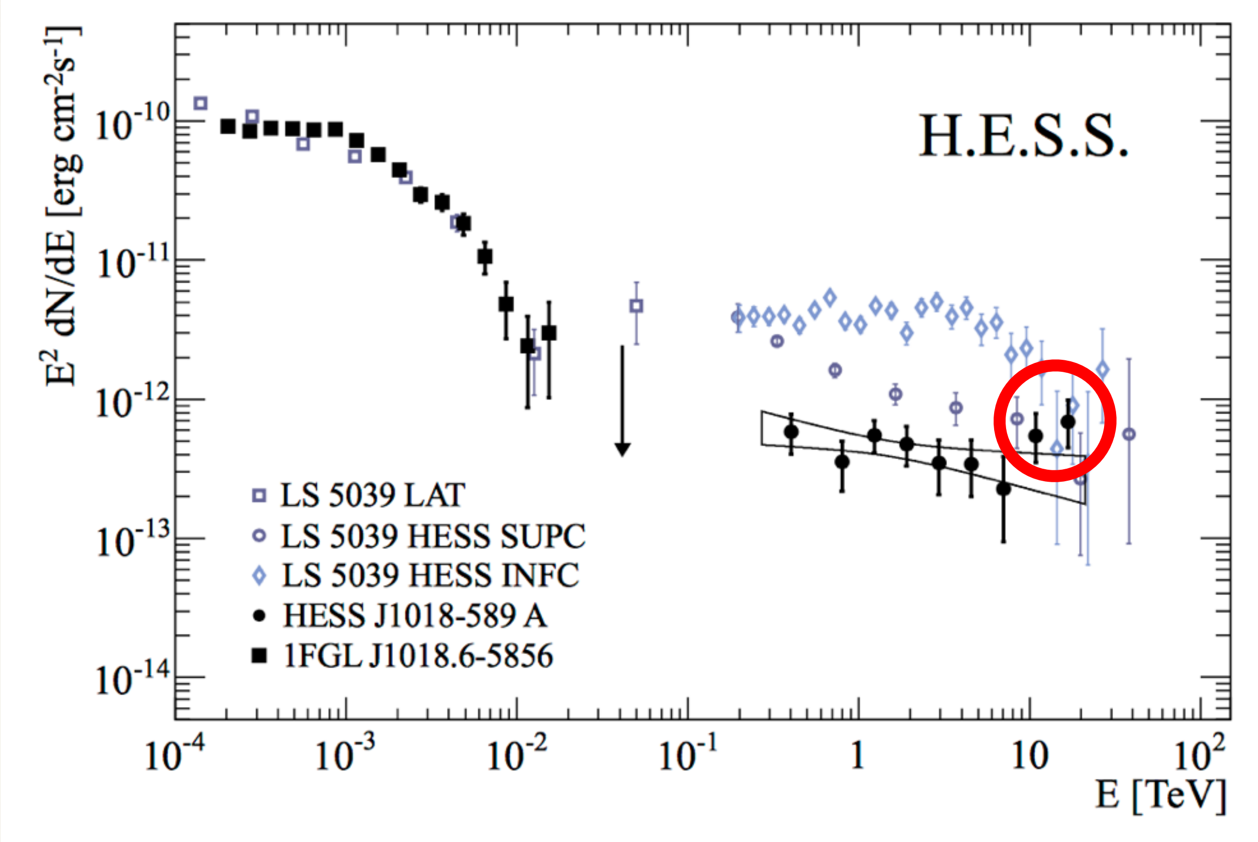



$\text{Luminosity} \sim 10^{35-36} \text{erg s}^{-1}$

ref. Dubus 2013

# 1FGL J1018-5856



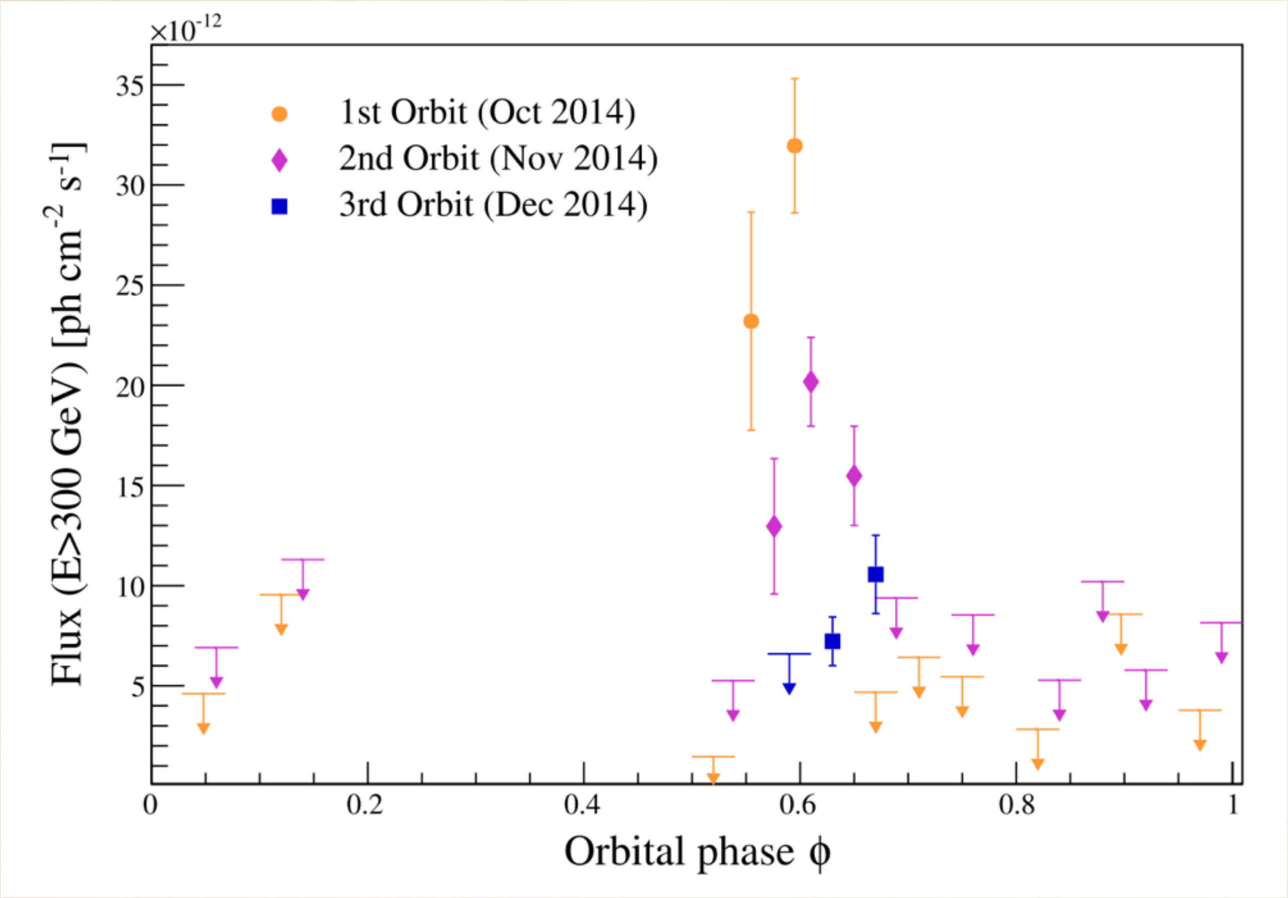



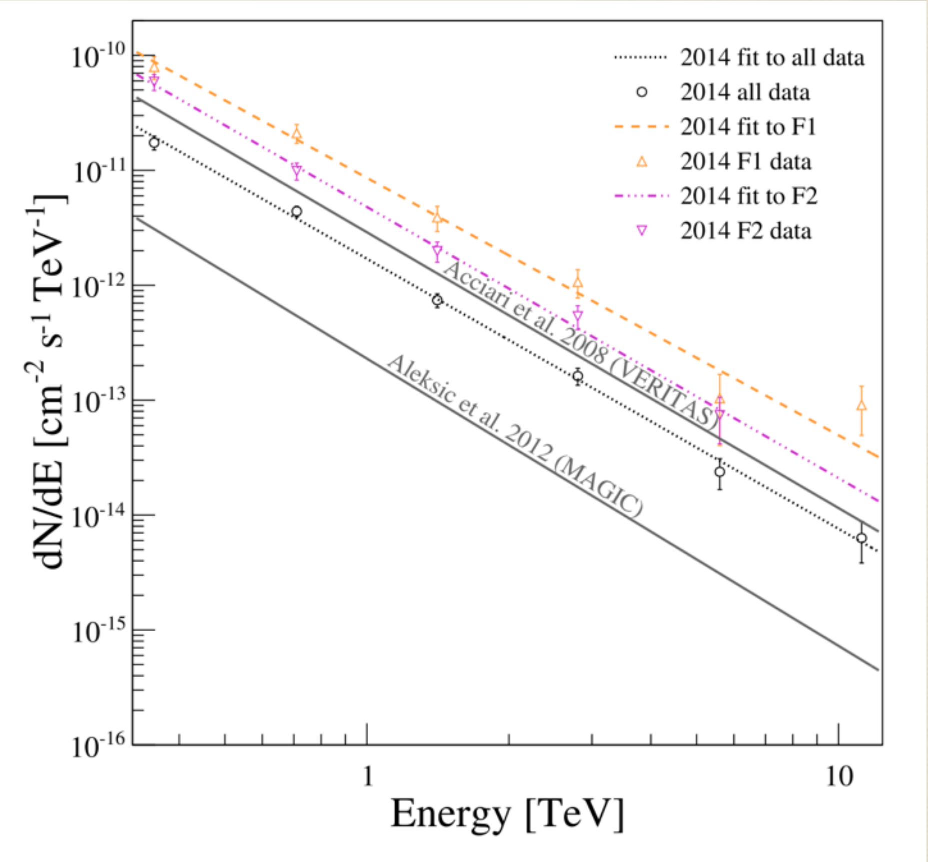

H.E.S.S. Collaboration (2015)

In general, low photon statistics at >10 TeV energies by current IACTs

# Transient emission/flares in GeV/TeV from gamma-ray binaries

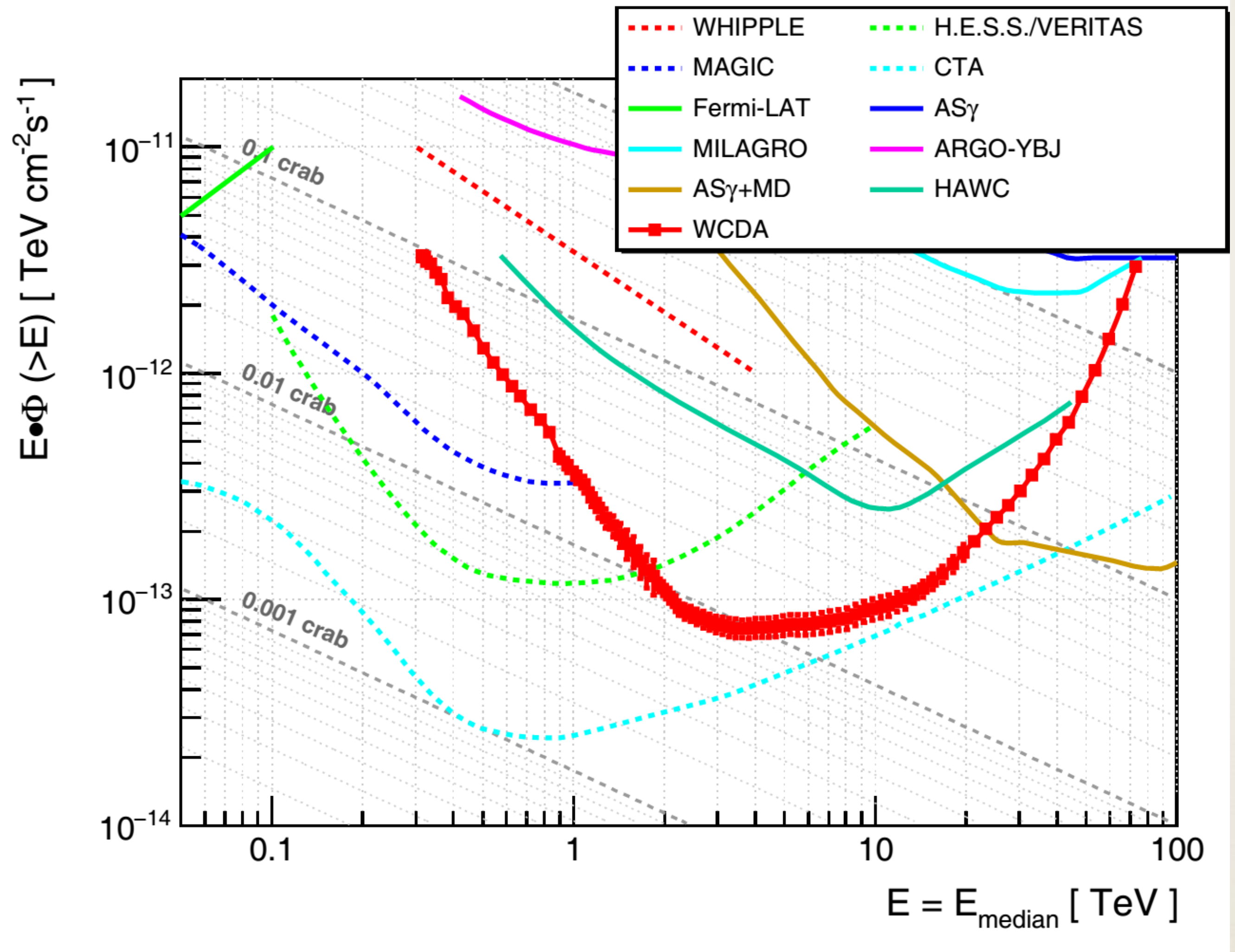
# Bright TeV flares from LS I 61 303

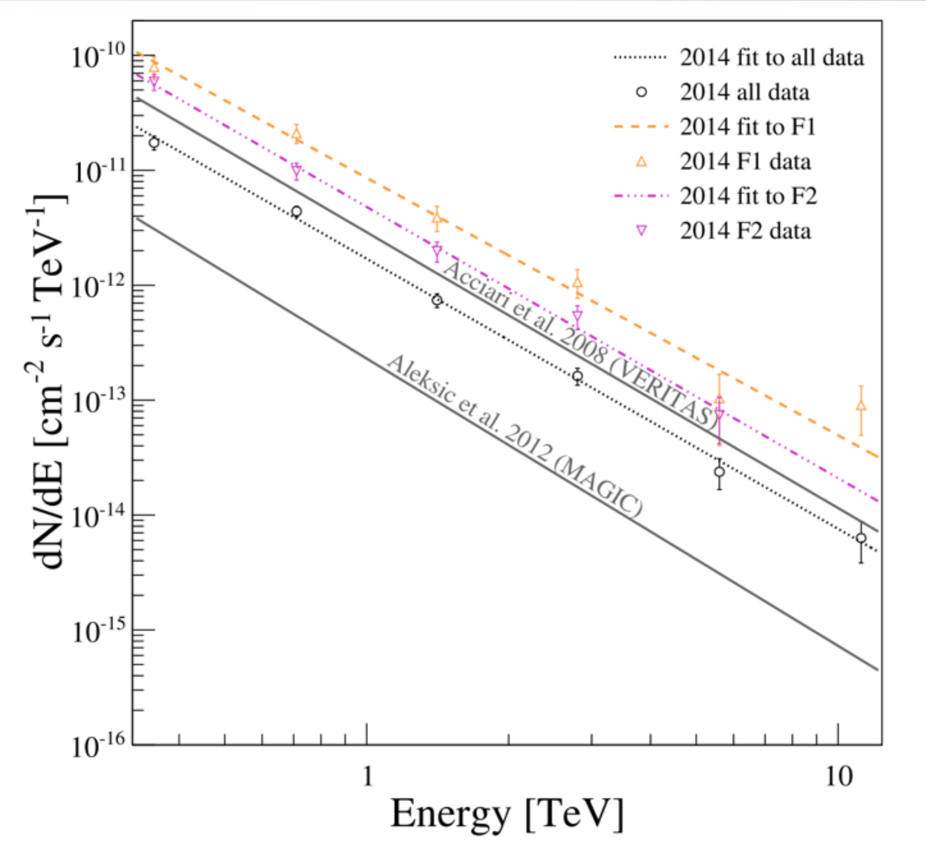



A. O'Faoláin de Bhróithe et al. (ICRC 2015)

# Bright TeV flares from LS I 61 303

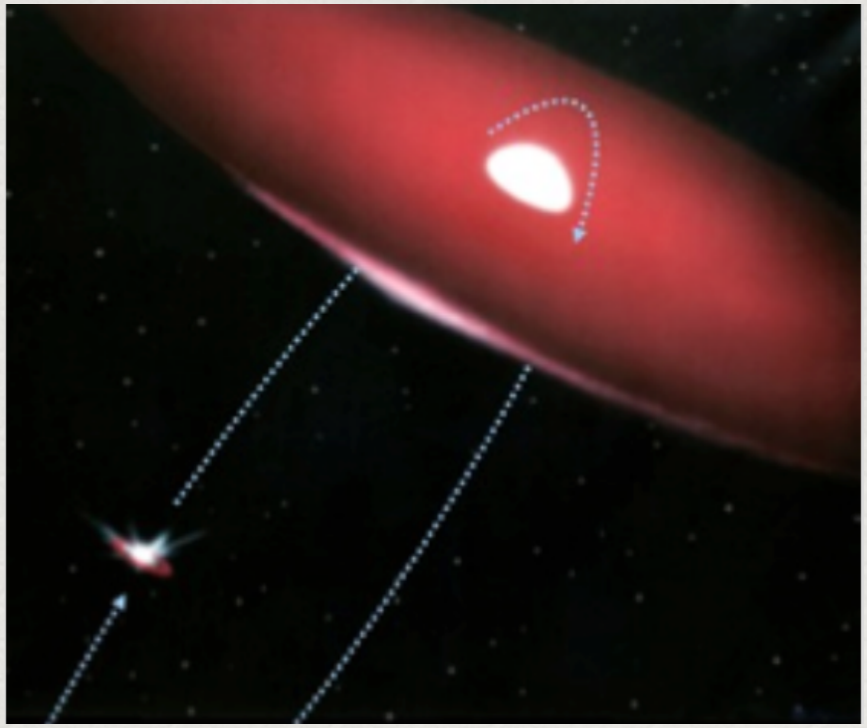


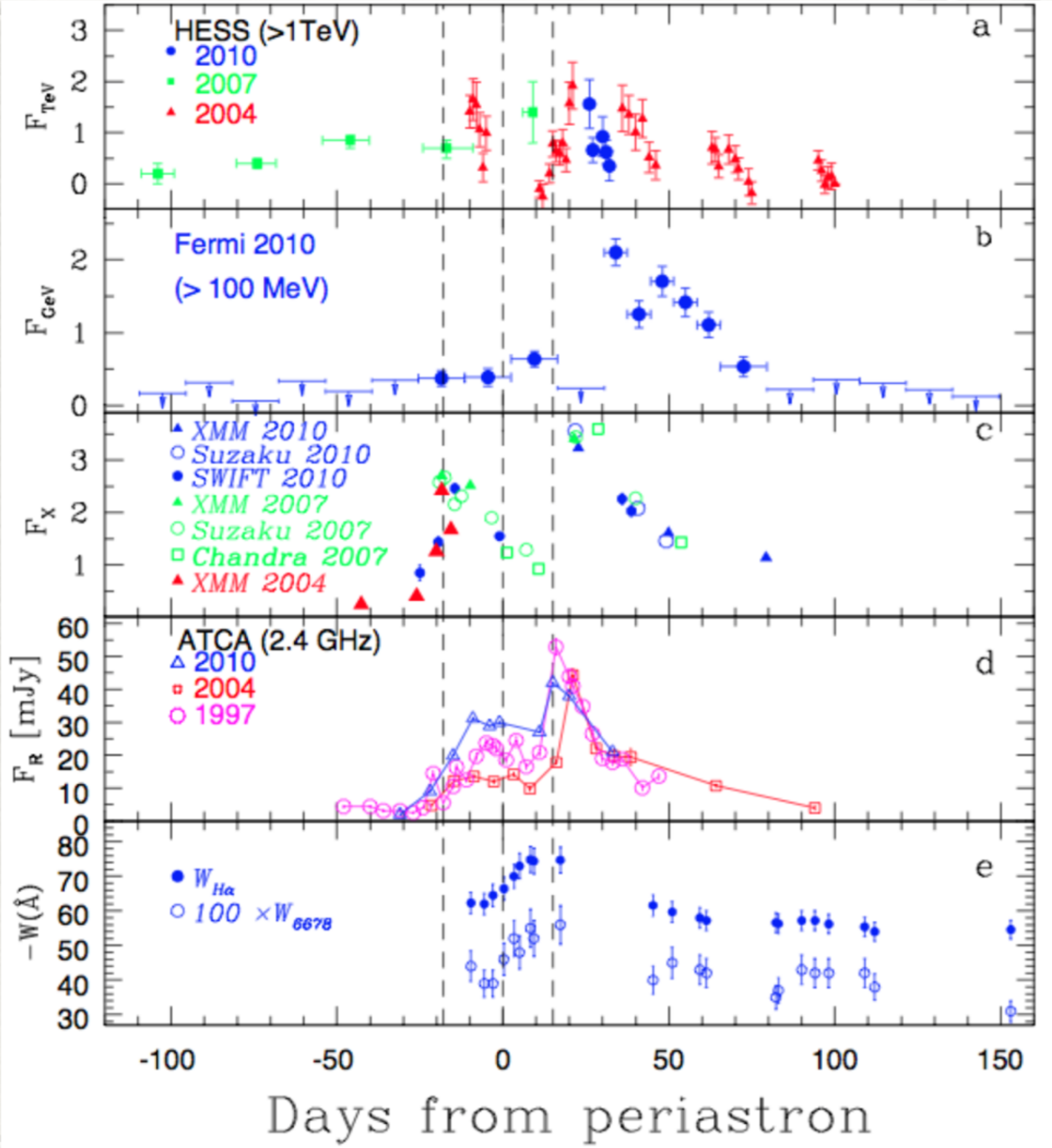

A. O'Faoláin de Bhróithe et al. (ICRC 2015)

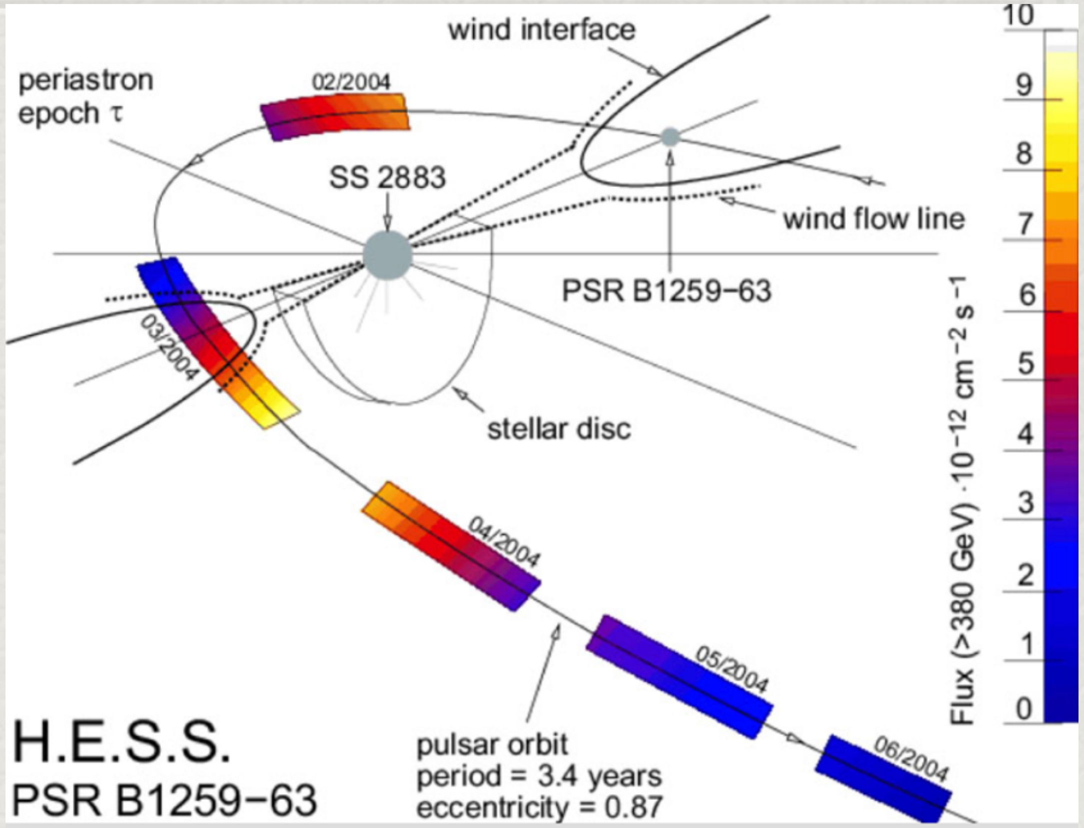
# PSR B1259-63/LS 2883

- *comprising of a pulsar and an Oe star, at d~2.3 kpc*
- *orbital period: 3.4 years*
- *Interaction between the stellar wind/disk and the pulsar wind => non-thermal radiation close to periastron*



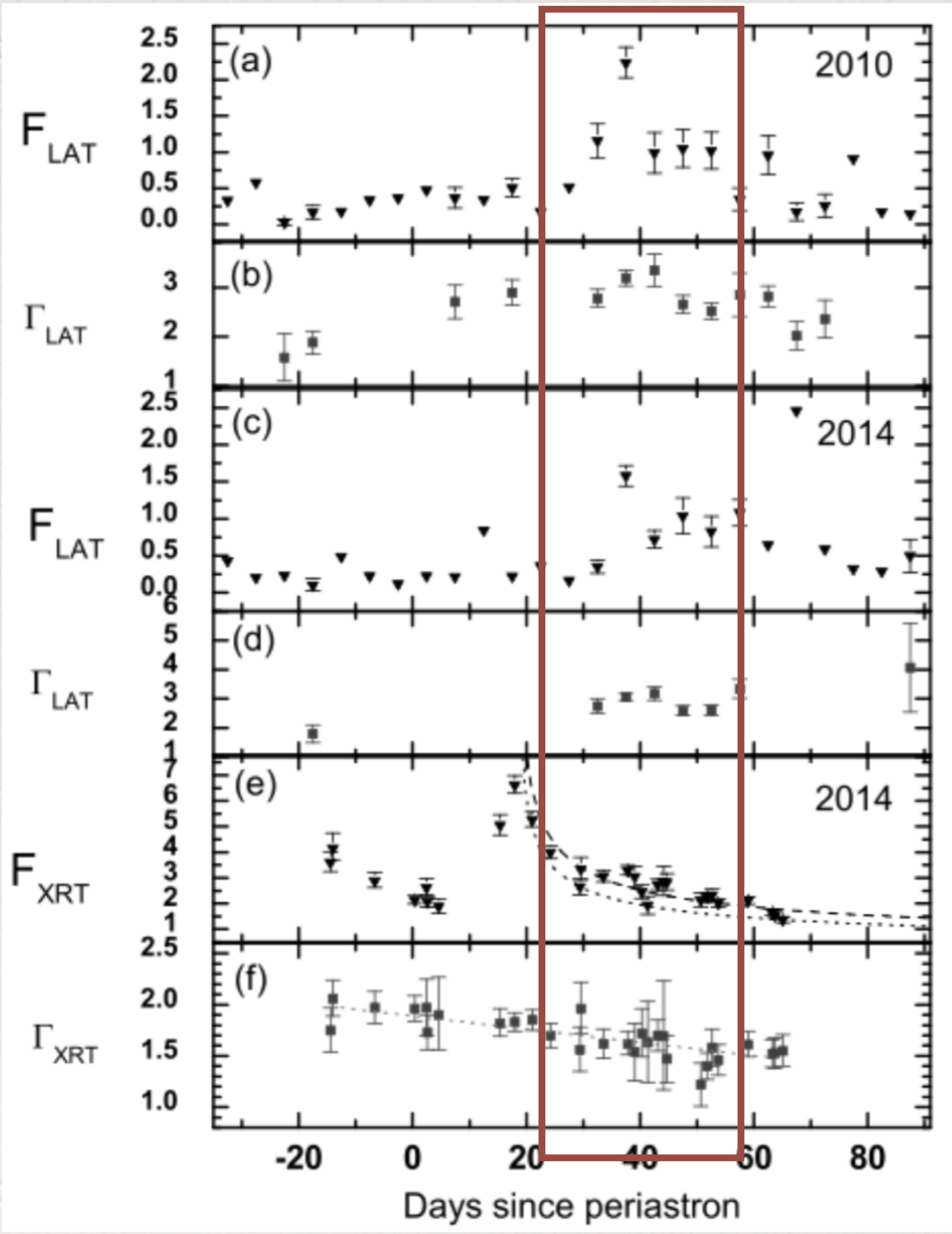
# Radio to TeV Enhancement over periastron passages




*Chernyakova et al. (2014)*

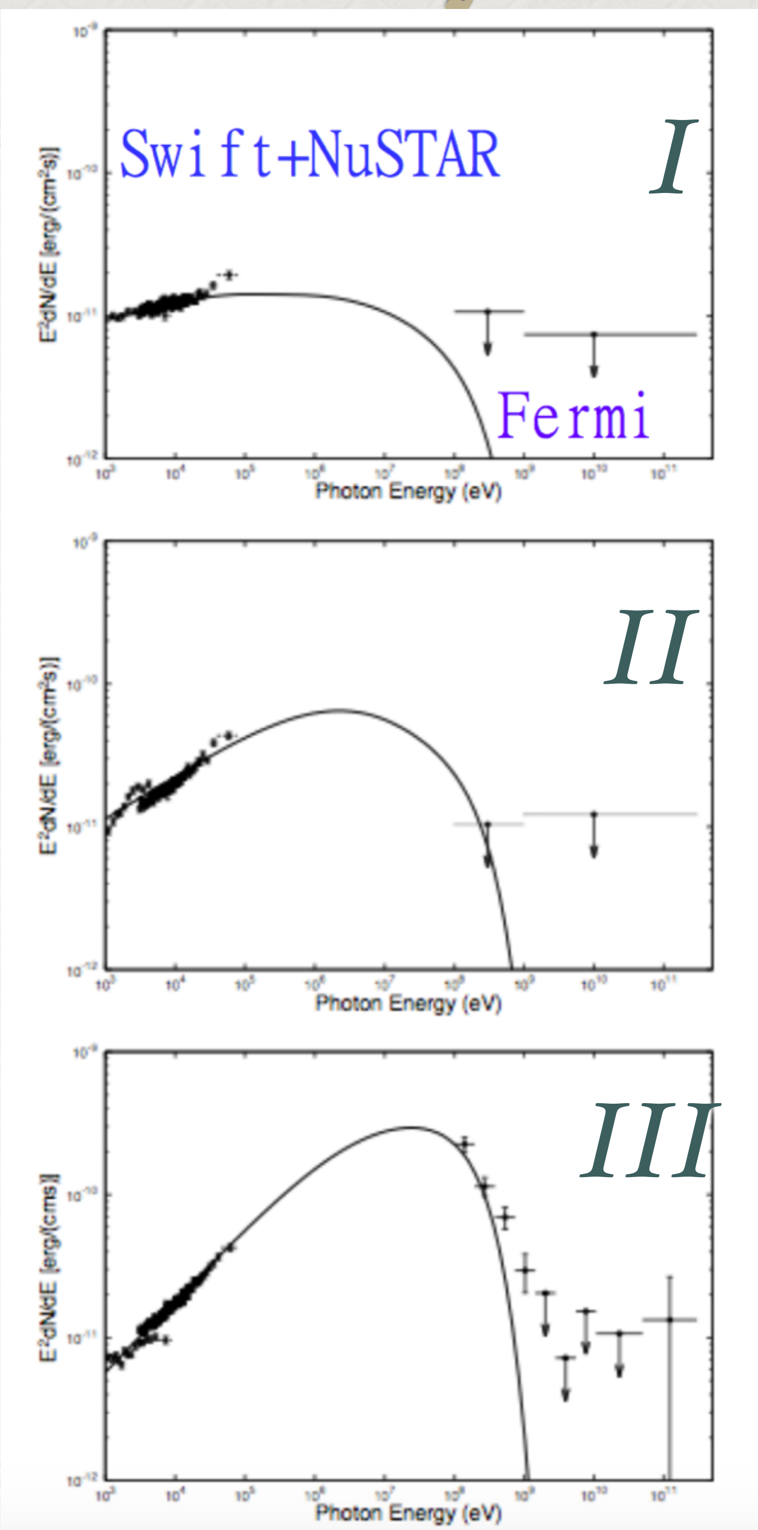
# GeV flares in 2011 & 2014!

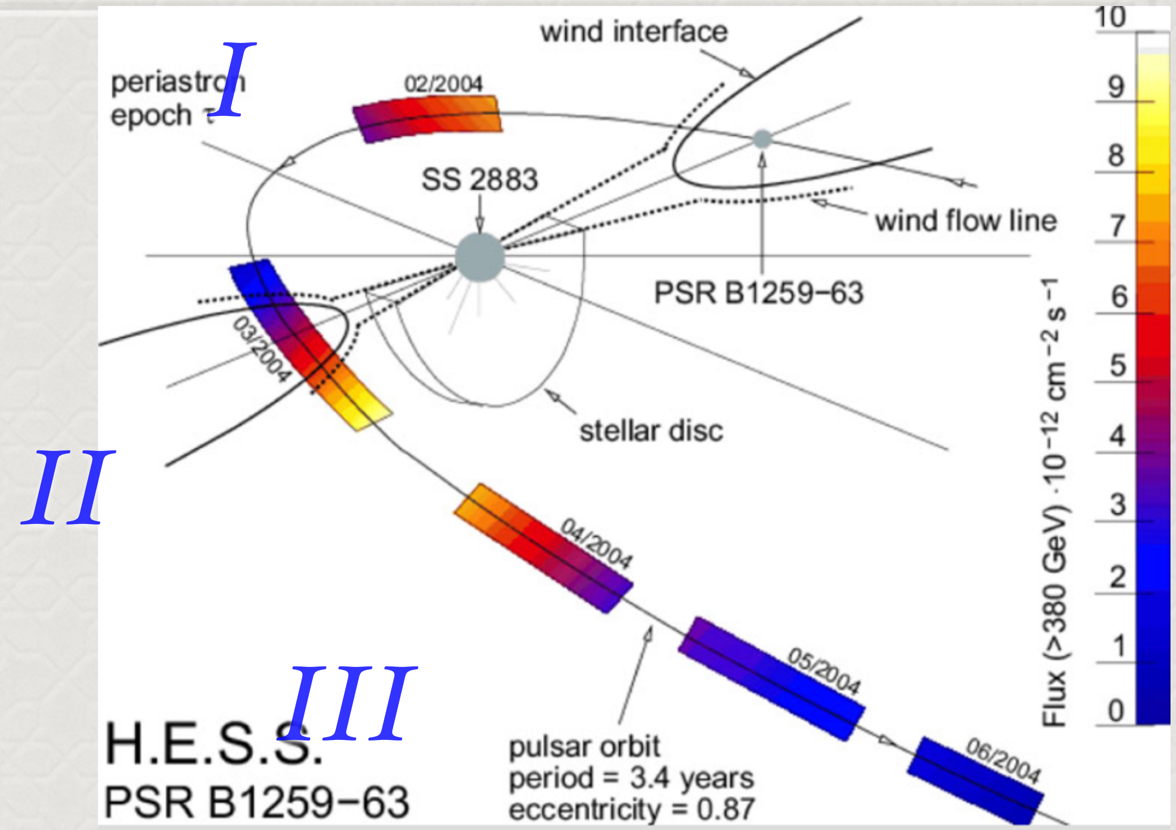



*Tam et al. (2011, 2015)*

*also see, e.g., Caliandro et al.(2015)*

# X-ray/GeV connection?

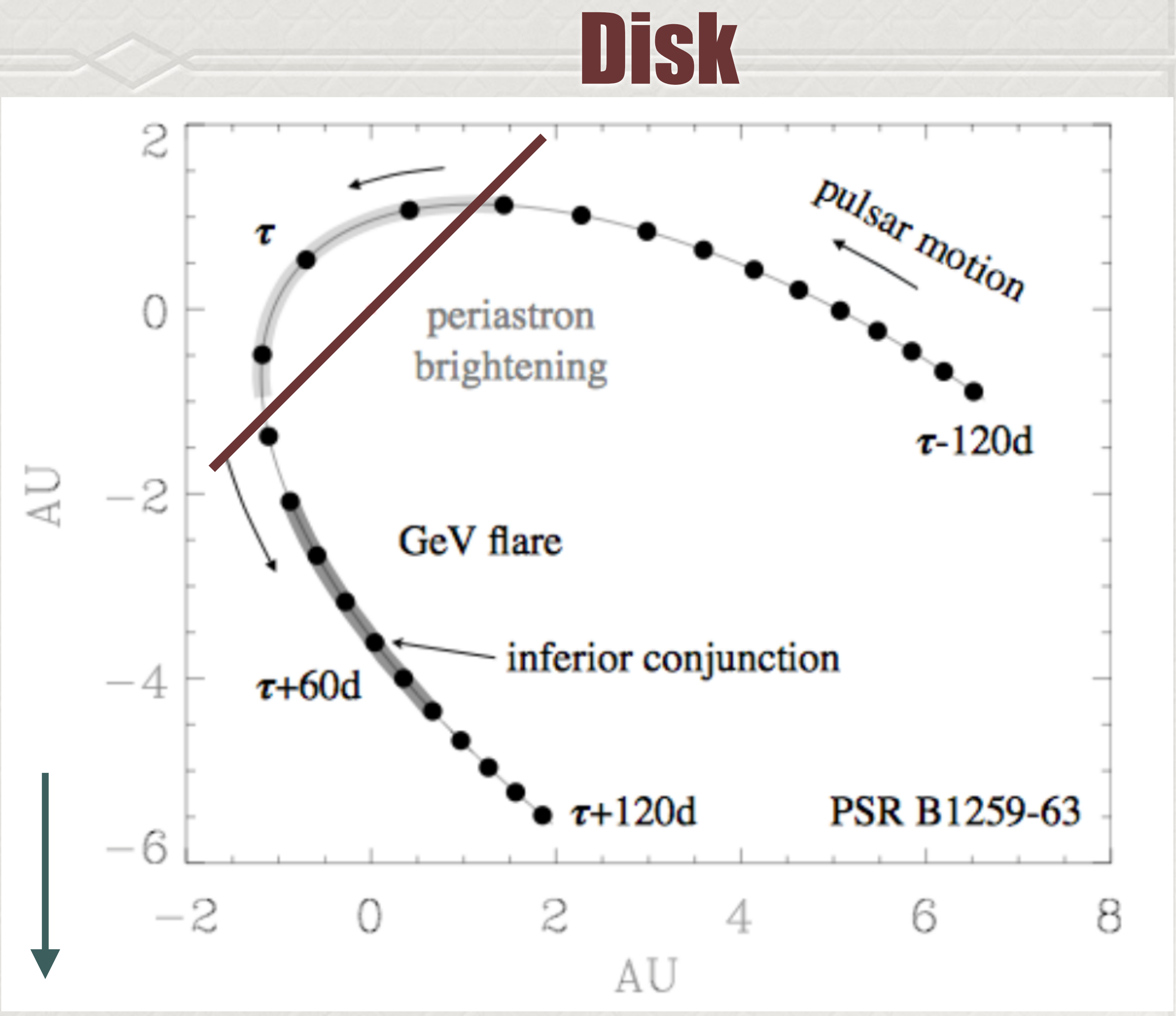



Tam et al. (2015)

# Mysterious GeV flares

- *Doppler boosting?*
- *next periastron passage at 2017*




*Dubus (2013)*

# PSR J2032+4127/MT91 213

- *A young, gamma-ray pulsar.*
- *Pulsed emission in Radio/GeV*

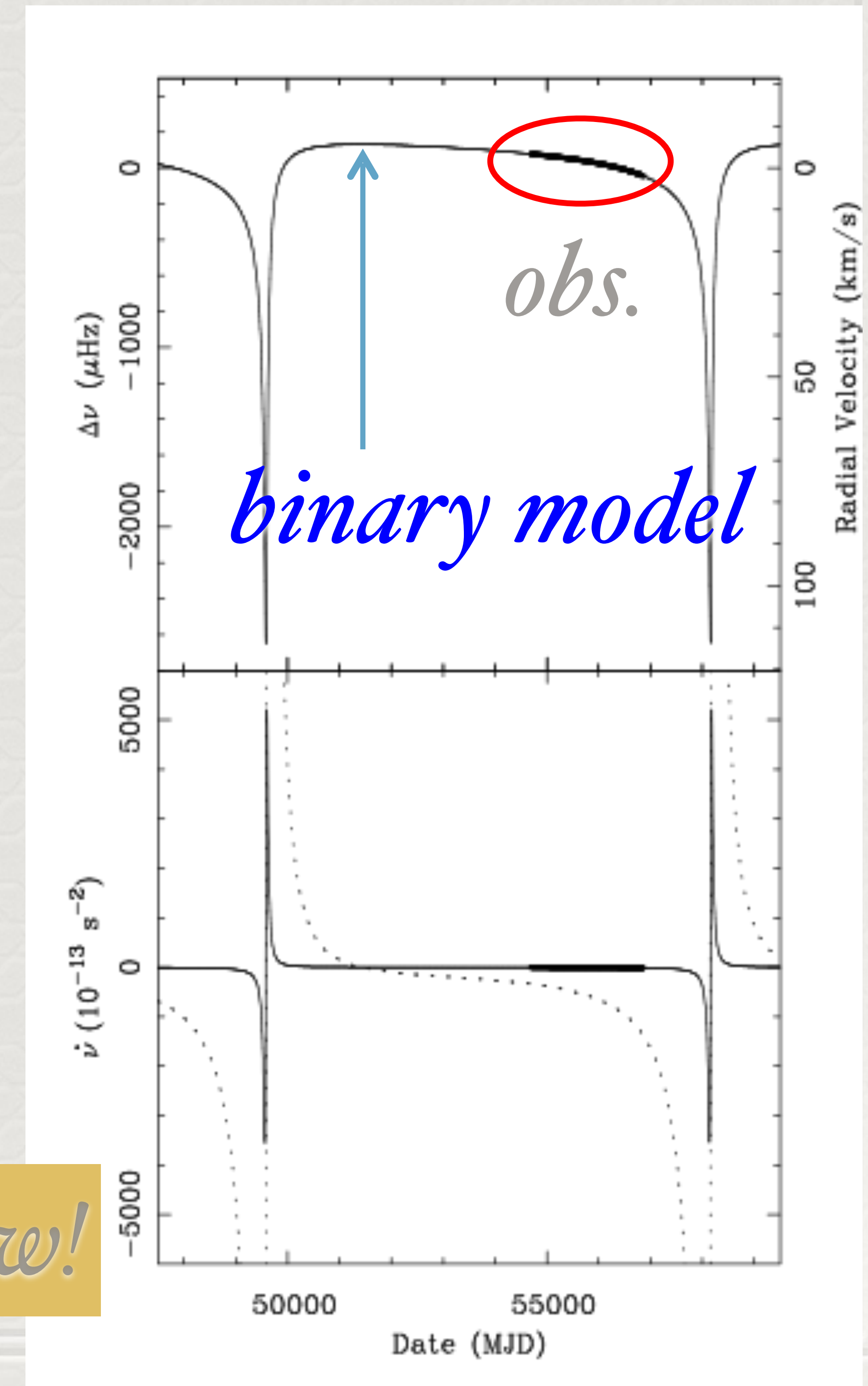
$$P \simeq 143\ \mathrm{ms} \quad L_{sd} \simeq 1.7\times 10^{35}\ \mathrm{erg/s}$$

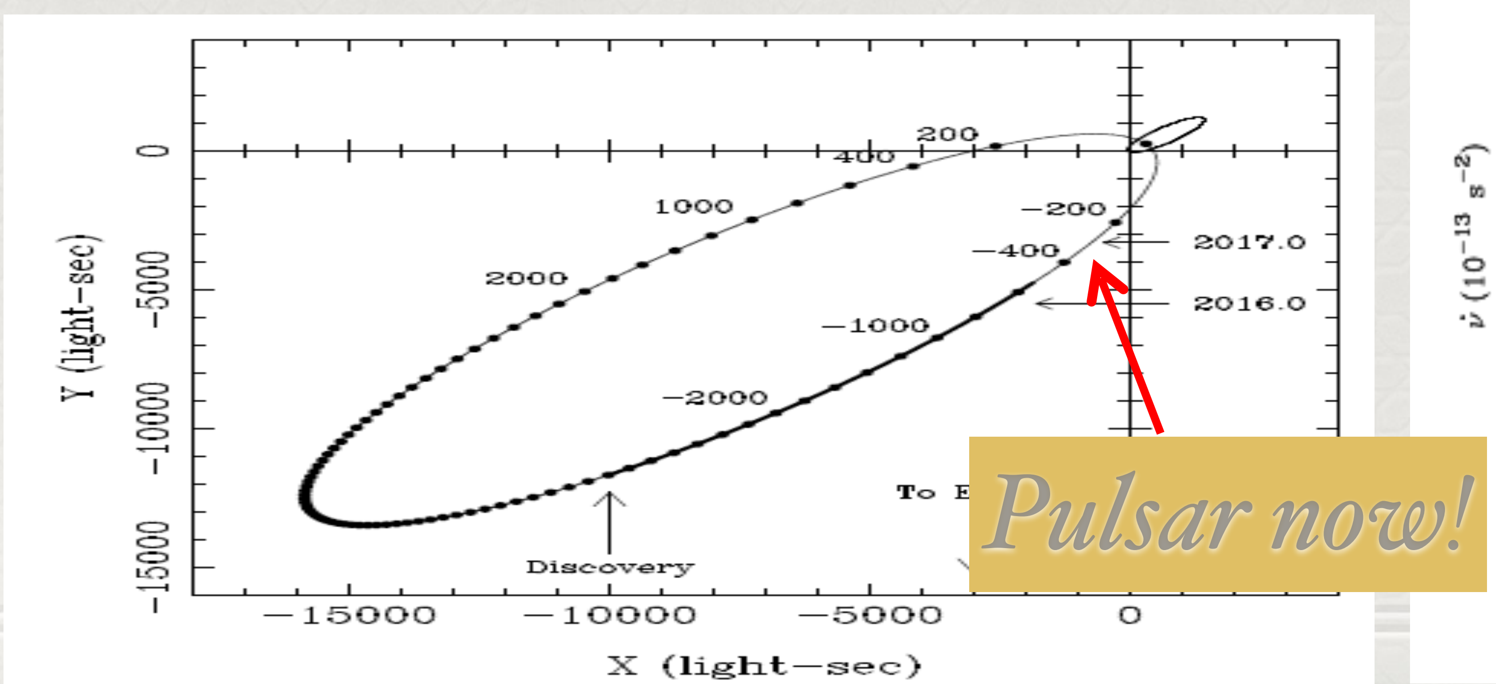
- *Very long orbit binary: Po~50 years.*

*(Lyne et al. 2015: Ho et al. 2016)*

- *Next periastron passage in late 2017.*

*pulsar's timing parameter*



# X-ray/GeV data

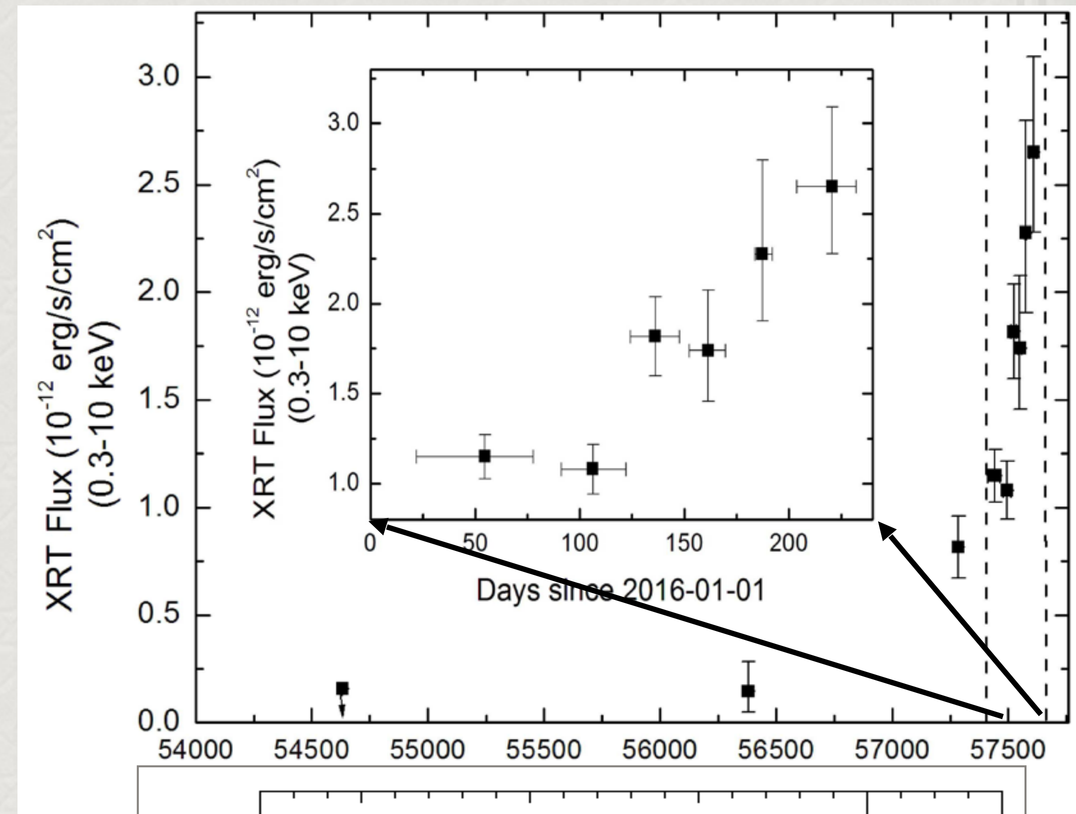
*(Takata, Tam, et al. submitted)*

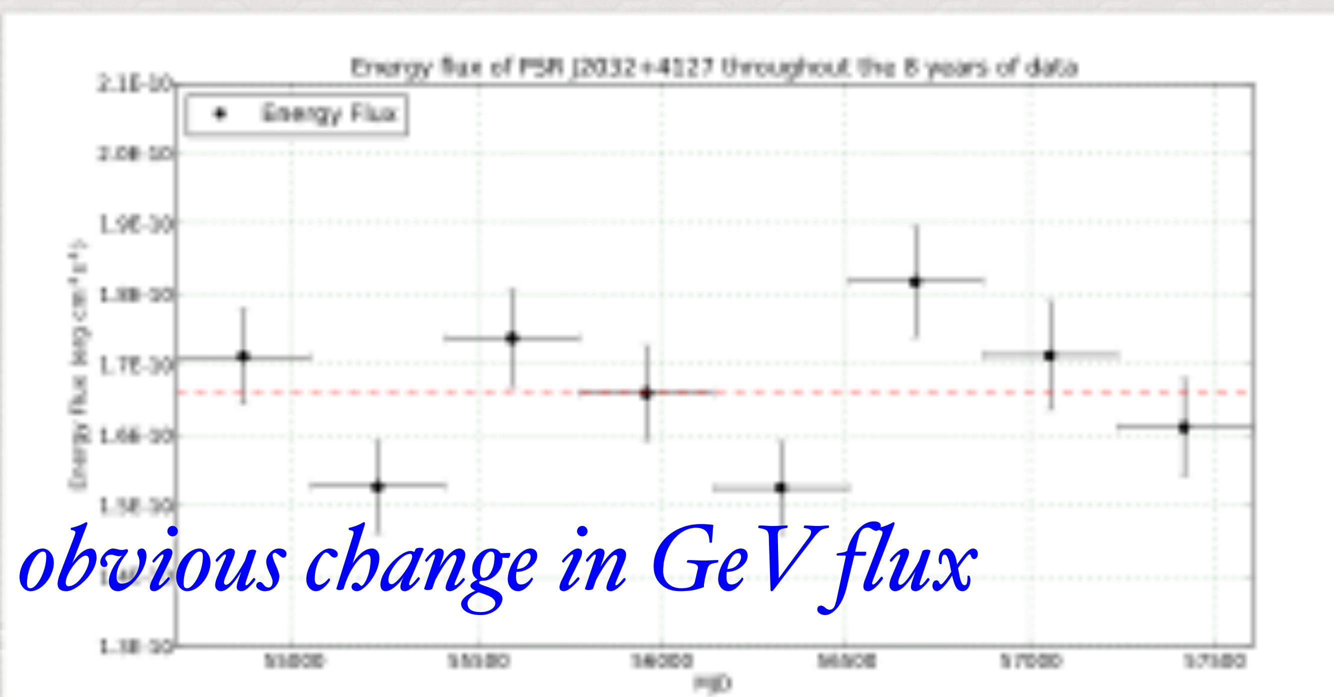
- *X-ray flux is increasing now.*

→ *about factor of ten in last ~3 years*

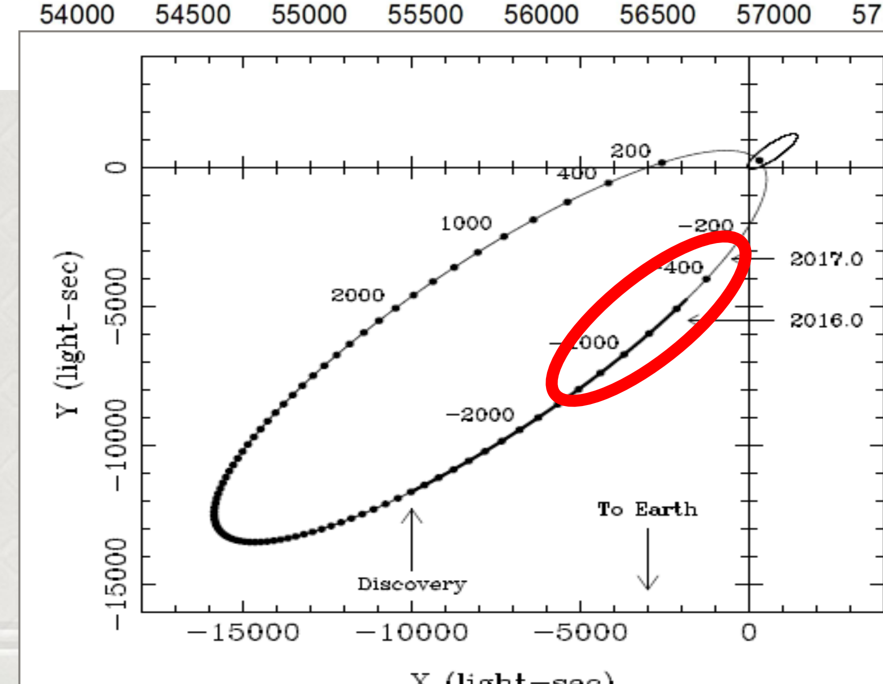
*(see also Ho et al 2016)* .

***What cause the increase of X-rays? Shock?***




*No obvious change in GeV flux*



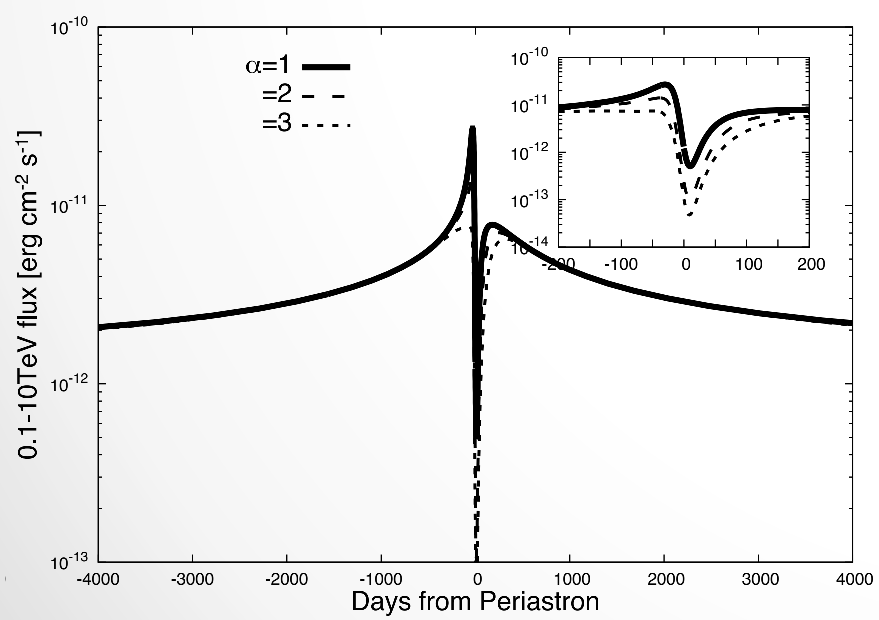
# Future perspective

- TeV

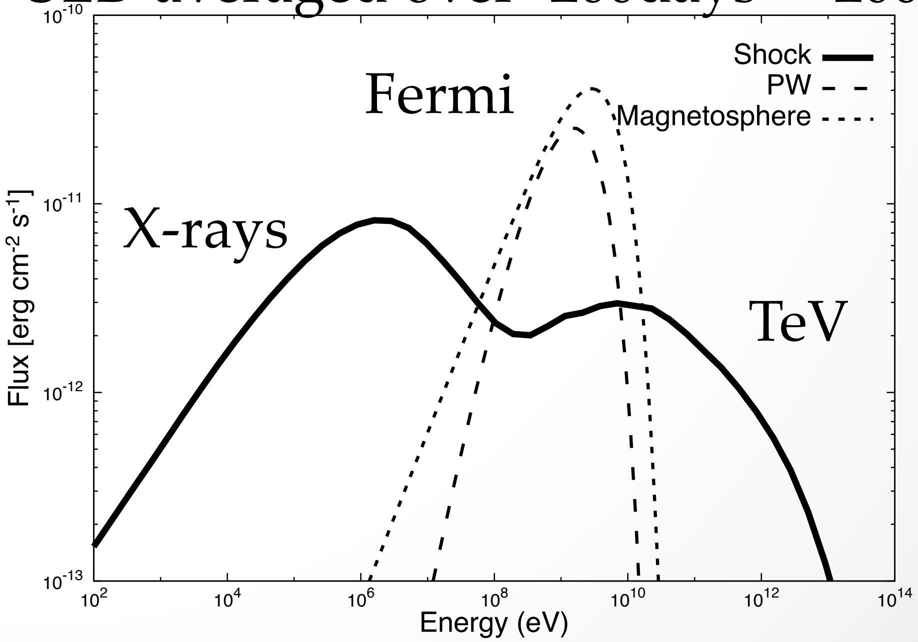
-- I.C. scattering

-- Absorption by the pair-creation.

--Good target for Cherenkov telescope.



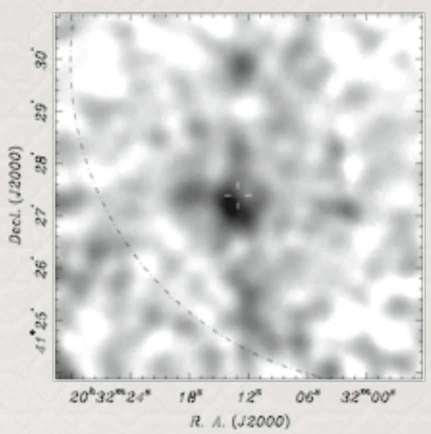

SED averaged over -200days - +200days

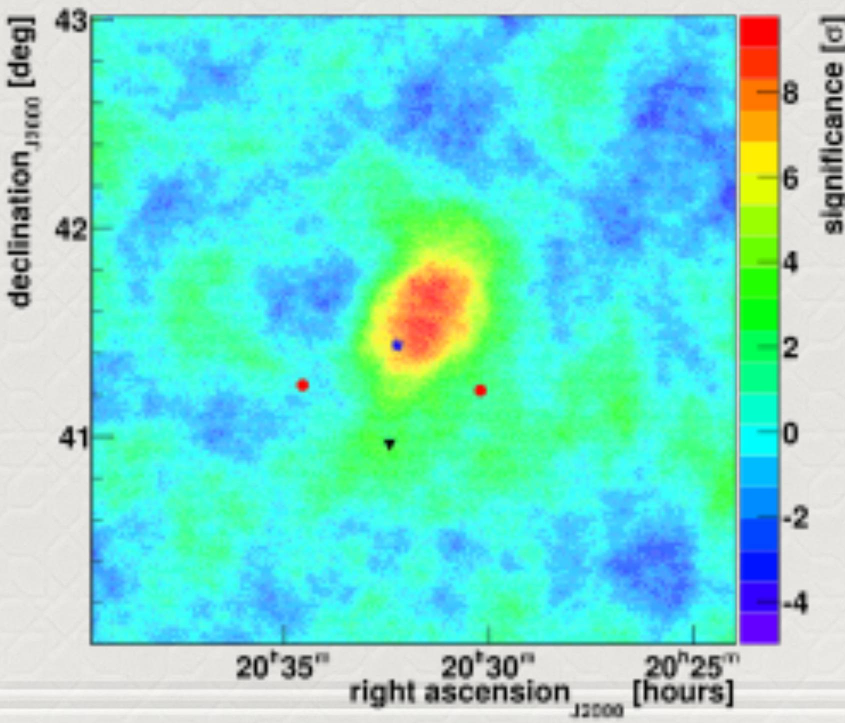


# PSR J2032+4127

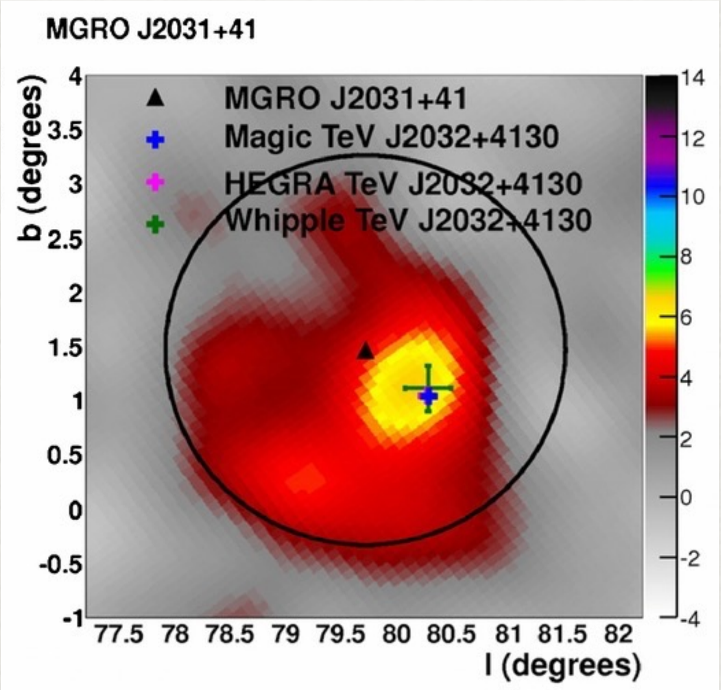
- *But it sits inside a strong TeV source TeV J2032+4130*
- *TeV and X-ray counterparts (PWN? combinations of sources?)*

*7 arcmin*




*3 degrees*




TeV J2032+4130

# Particle acceleration in gamma-ray binaries

* Persistent emission: How high can gamma-ray binaries accelerate particles persistently?
* Transient emission: What produces GeV/TeV flares?
* TeV gamma-ray observations may help to answer some of these. Wide field-of-view instruments are complimentary to pointed, deep observations, e.g., by CTA, given the unpredicted nature of enhanced emission/flares.
* Also, for long period (years or above) gamma-ray binaries, pointed observations find it hard to cover the whole orbit, not to mention orbit-to-orbit difference.

# Summary

- **GRBs**: I have presented the prospects of GRB observations using wide-field detectors at ~100 GeV, from what we know from Fermi/LAT observations
- **Gamma-ray binaries**: they are rare but important particle accelerators. Whilst observations at >10 TeV are limited, there are rooms to explore with high-altitude photon detectors.