Recent Results of TeV Gamma-Ray Observation

(TeVガンマ線の最近の観測結果)

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Atmospheric Cherenkov Telescopes

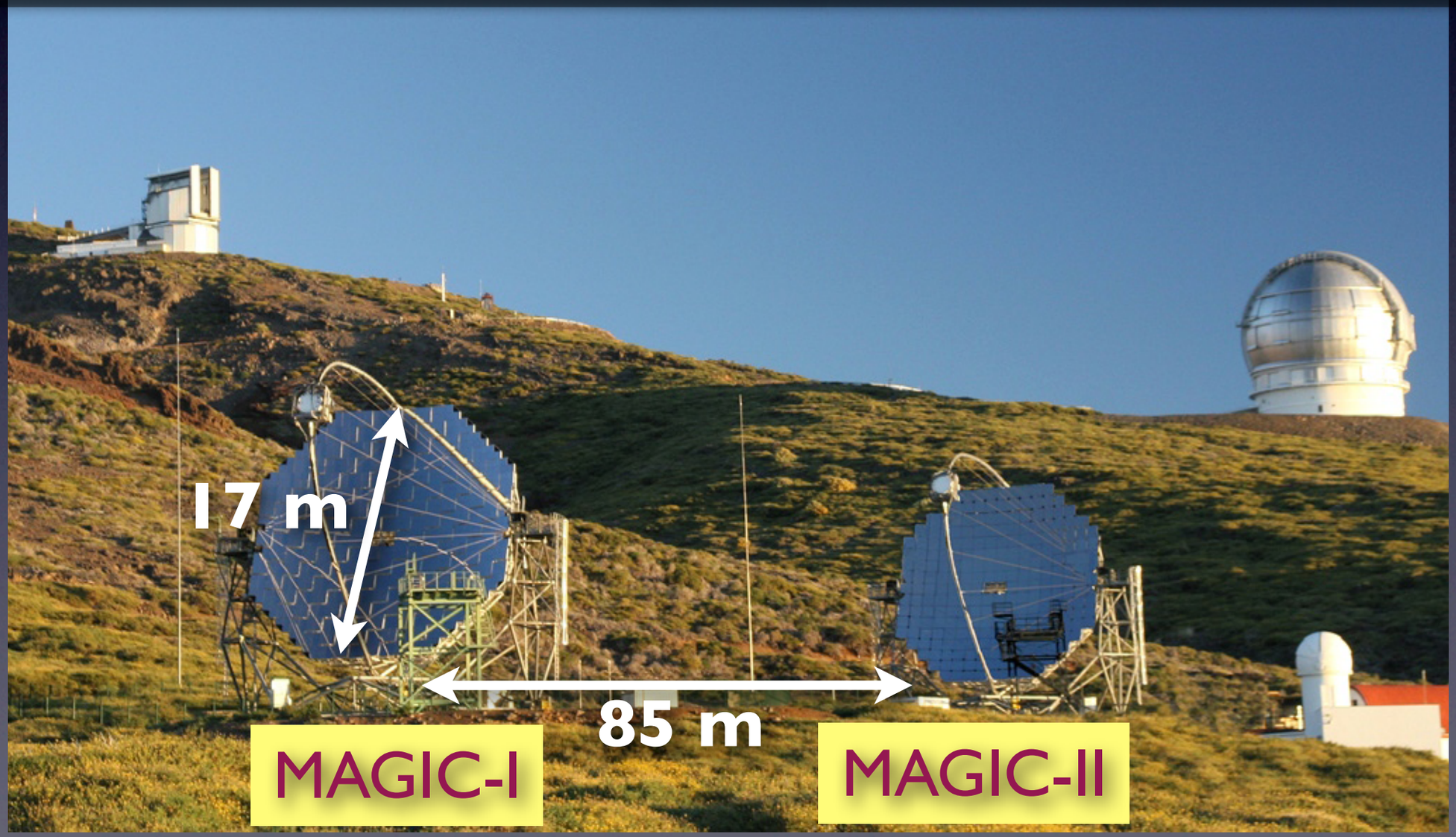
MAGIC-II

VERITAS

HESS-II

The MAGIC Project

- 170 collaborators in 10 countries
  - 12 Japanese member (as of Apr. 2014)
- Stereoscopic system of 2 telescopes with the size of 17 m diameter
- Location: La Palma in Spain (a.s.l 2231 m)



The MAGIC Telescopes

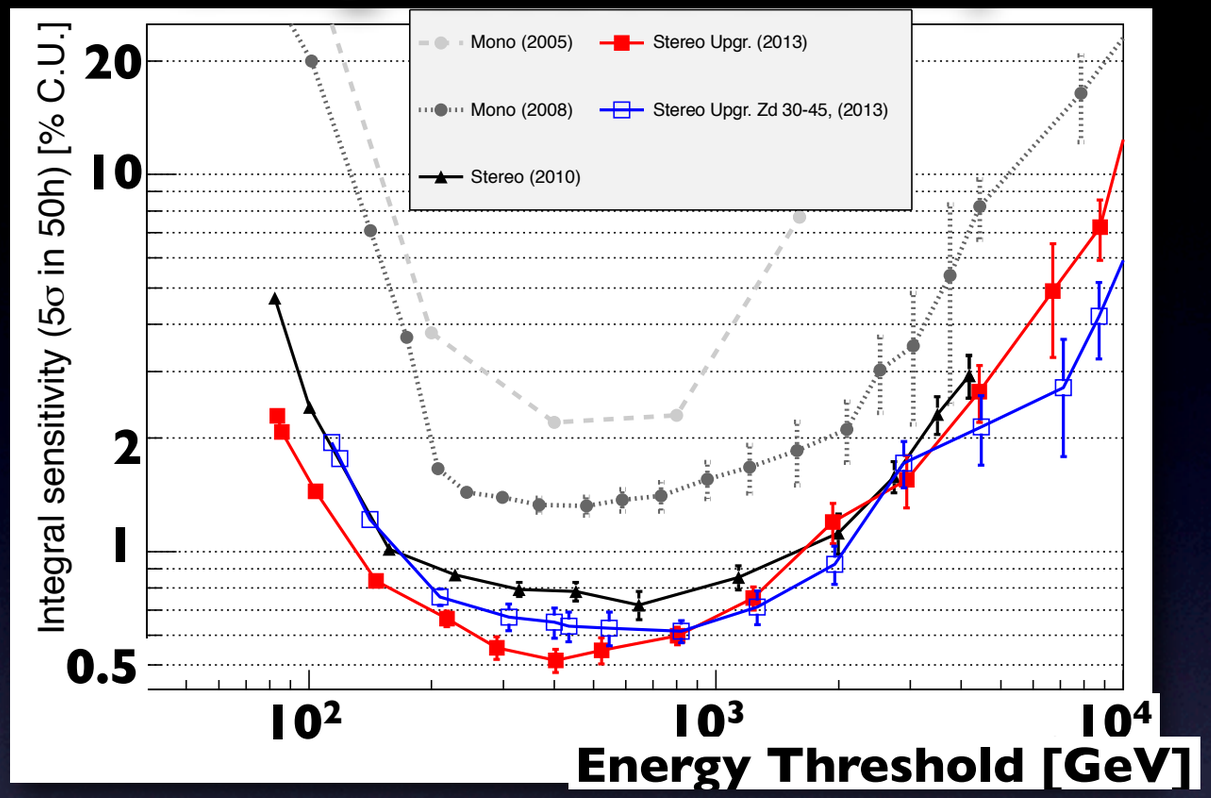
- Low energy threshold of 50 GeV. Down to 25 GeV by Sum-trigger.
- Field of view: 3.5 deg diameter
- Angular resolution: <0.07 deg (>300 GeV)
- Sensitivity: ~0.6% Crab unit for 50 hours observation.

History of Upgrade

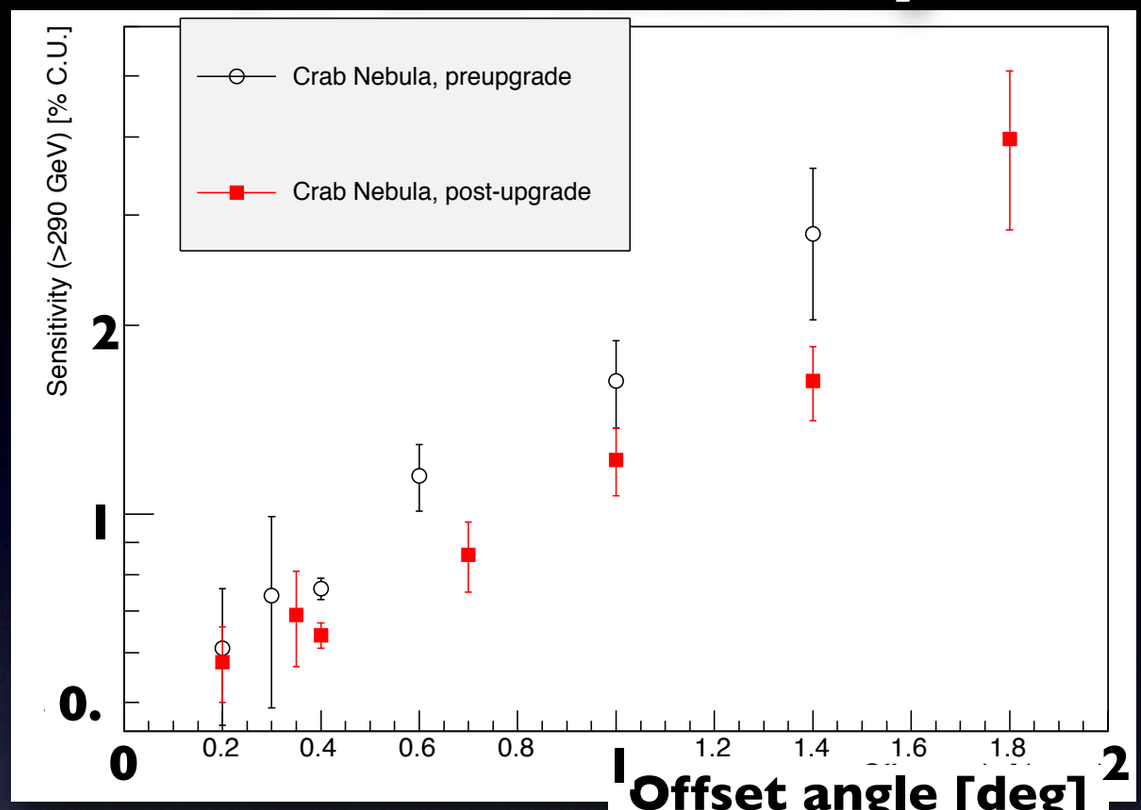
2009 Starting stereo observation
2011 Replacement of the readout electronics to DRS4
2012 Replacement of MAIC-I Camera
Change of the trigger system
2013 Sum Trigger-II installation
2014 Mirror replacement (~90 m^2)

The MAGIC Performance

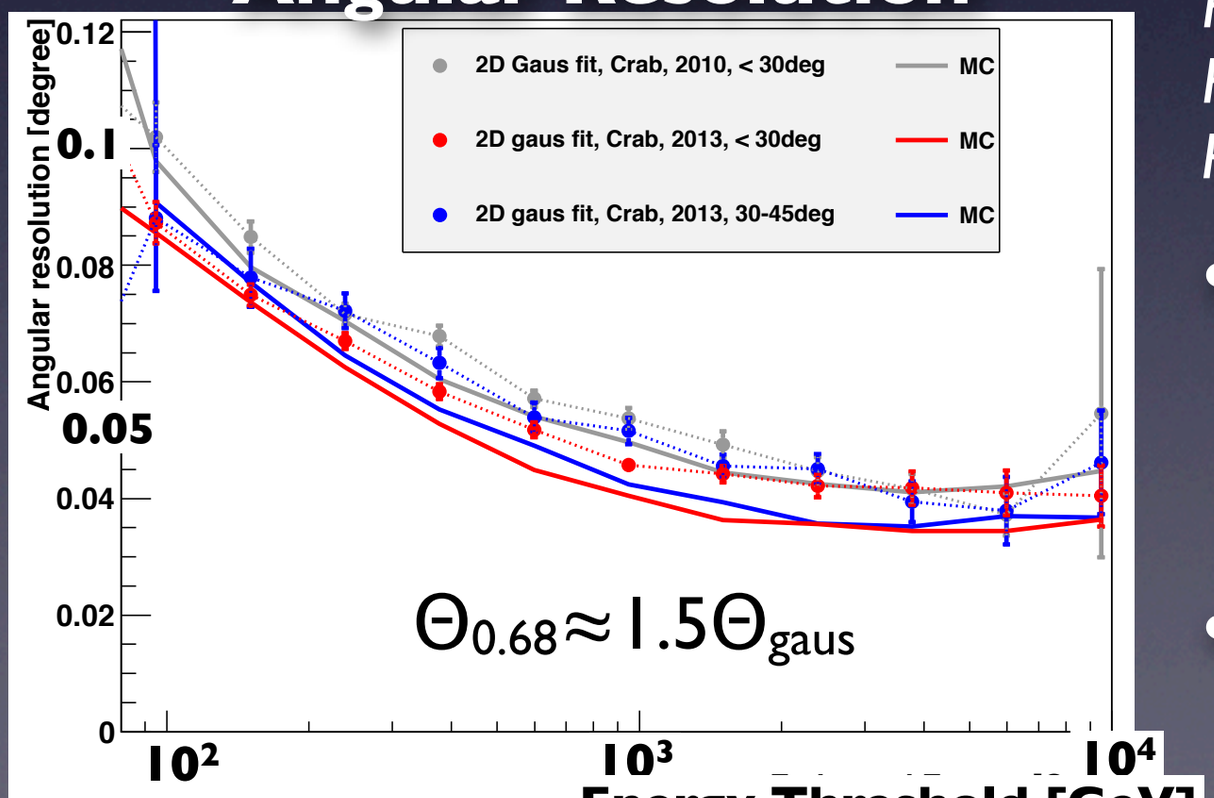
Integrated sensitivity



Off-axis sensitivity



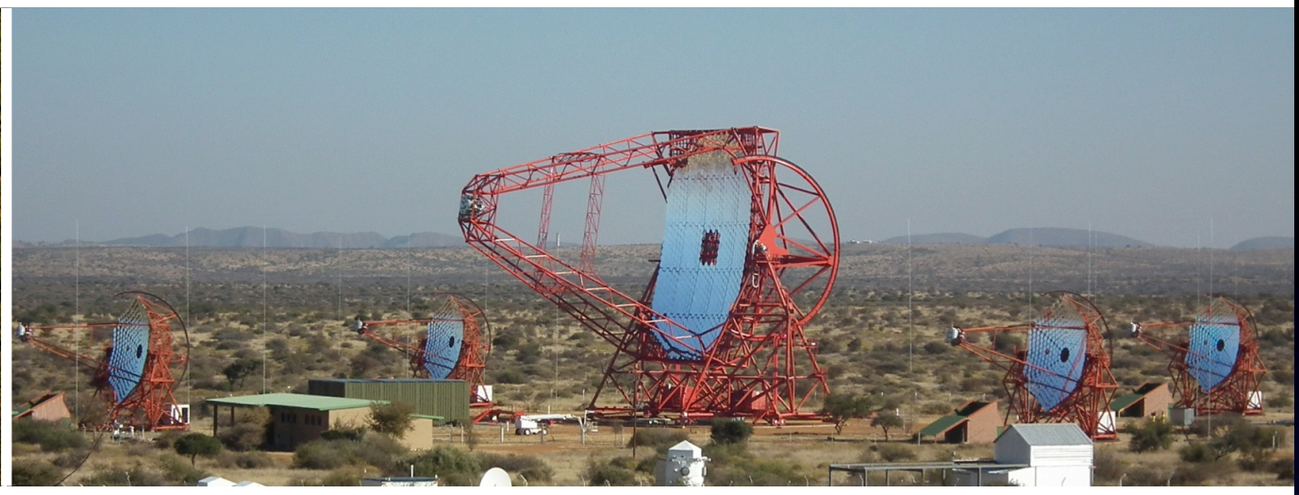
Angular Resolution



Ref.
Hardware improvement arXiv:1409.5594
Physics performance arXiv:1409.6073

- Large improvement at low energies
  - Optimization to detect distant AGN which suffers from the absorption due to EBL.
- Also improved off-axis performance
  - Further study are ongoing.

H.E.S.S.



- H.E.S.S. phase I
  - four 12m telescopes
  - FoV 5 deg
  - energy threshold 100 GeV
  - angular resolution < 0.1 deg
  - 1% Crab in 25 hours obs.

- H.E.S.S. phase II
  - four 12m telescopes
  - one 28m telescope (FoV 3.5 deg)
  - energy threshold O(30 GeV)
  - angular resolution from 0.4 deg to less than 0.1 deg

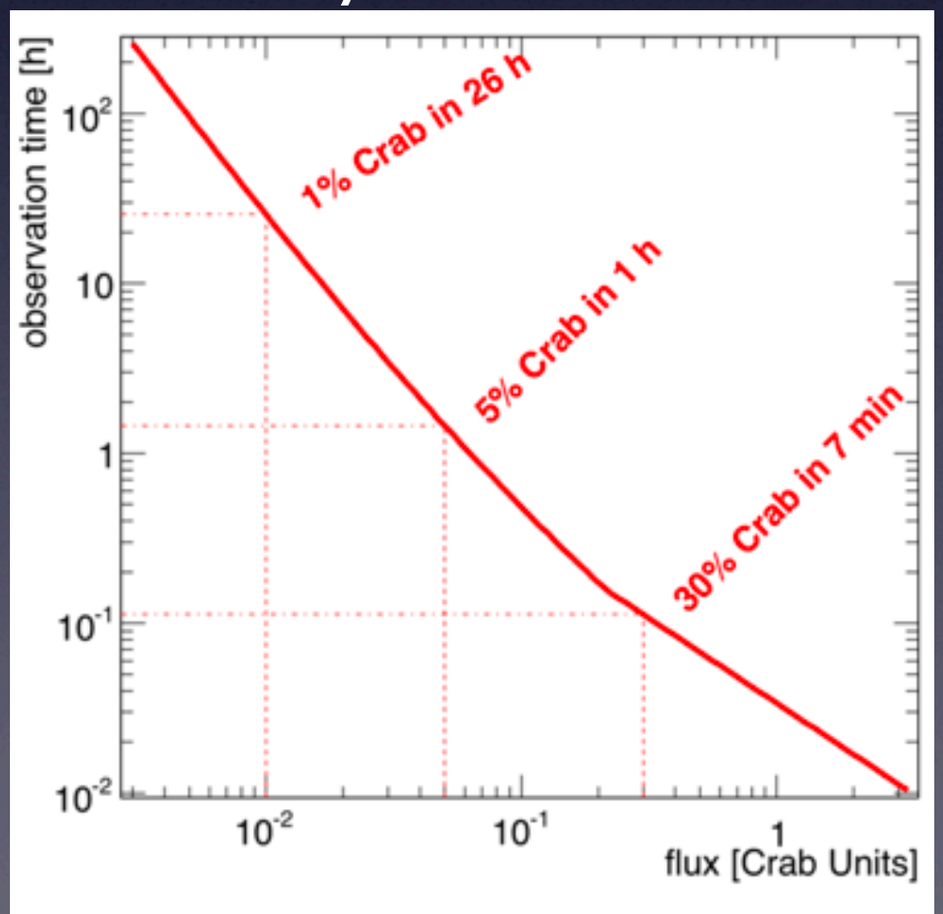
Replacement of the PMTs will be done by 2016.

H.E.S.S. phase I → H.E.S.S. phase II

C. Stegmann's talk at TeVPA2014

VERITAS

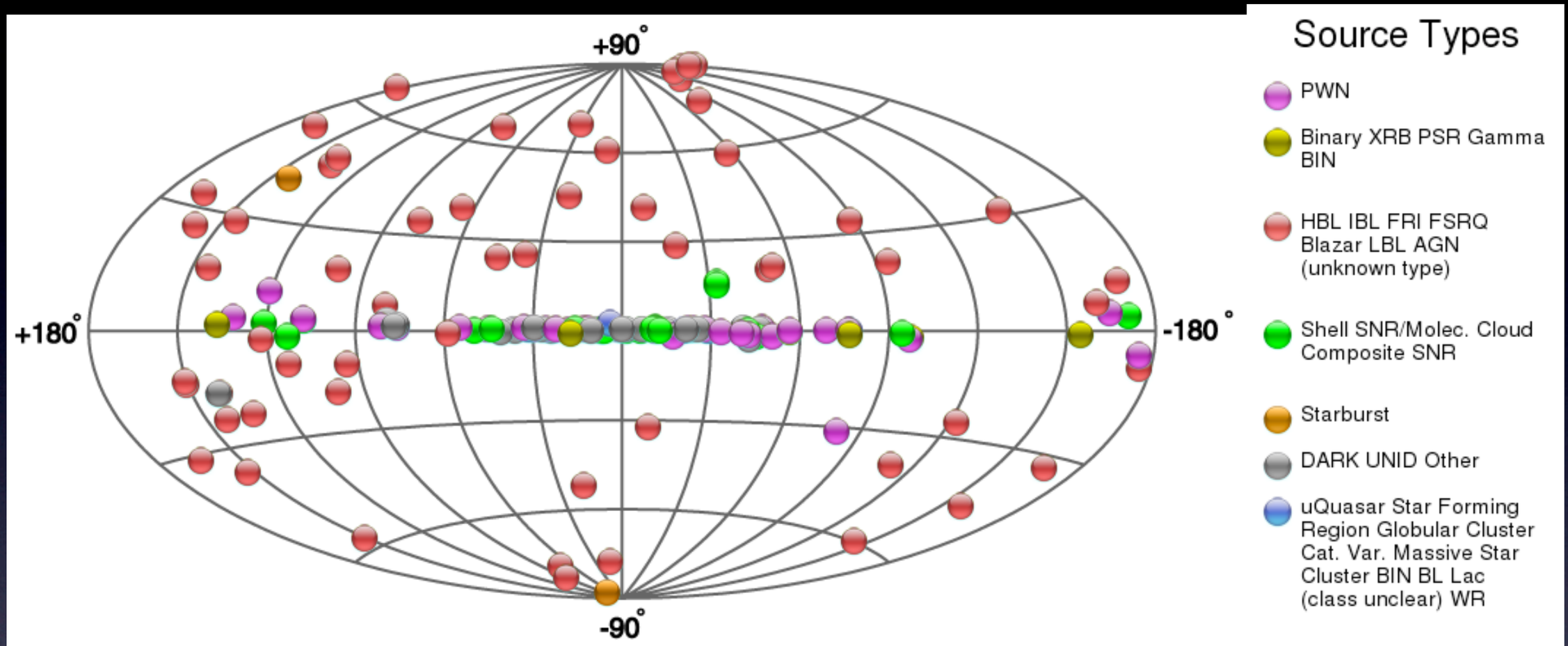
Sensitivity curve with time



Comparable performance to HESS-I.
Upgrade was done in 2012.

- Energy Range: > ~70 GeV
  ∵ High Q.E. PMTs are used.
- Sensitivity: 1% Crab in 26 hours
- Angular resolution: < 0.14 deg (>200 GeV)

TeV Gamma-Ray Sources



Sources discovered over the past year.

SNR G349.7+0.2	17 18 01	-37 26 30	SNR/Molec. Cloud	2013.07	22 kpc	Newly Announced
RBS 0723	08 47 12.9	+11 33 50	HBL	2014.01	z = 0.198	Newly Announced
RX J1136.5+6737	11 36 30.1	+67 37 04	HBL	2014.04	z = 0.1342	Newly Announced
3C 58	02 05 31	+64 51 00	PWN	2014.05	2 kpc	Default Catalog
Vela Pulsar	08 35 20.7	-45 10 35.2	PSR	2014.06	0.29 kpc	Newly Announced
S3 0218+357	02 21 05.5	+35 56 14	Blazar	2014.07	z = 0.944	Newly Announced
1-151						

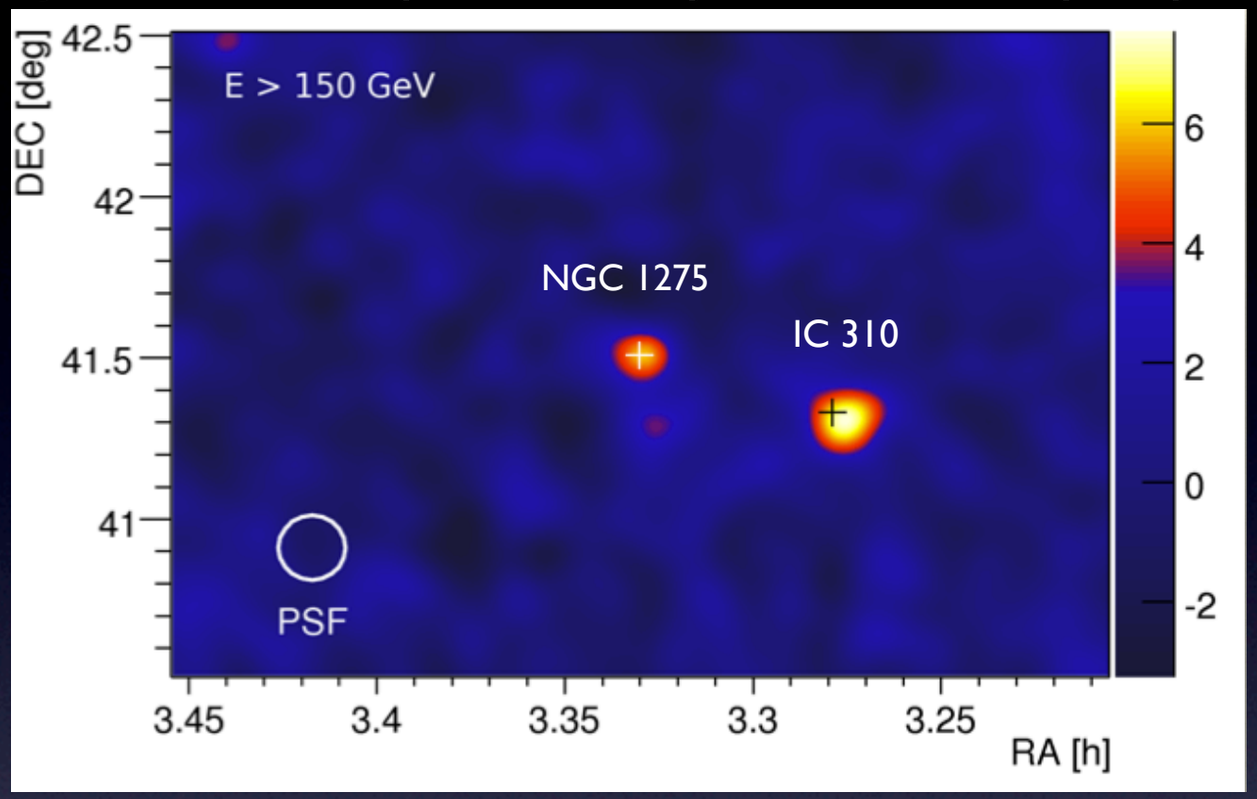
151 sources have been detected.

Recent Results

AGNs
(Mainly MAGIC Results)

IC310

J. Aleksić et al.,(MAGIC Coll.), A&A. 541, 99 (2012)

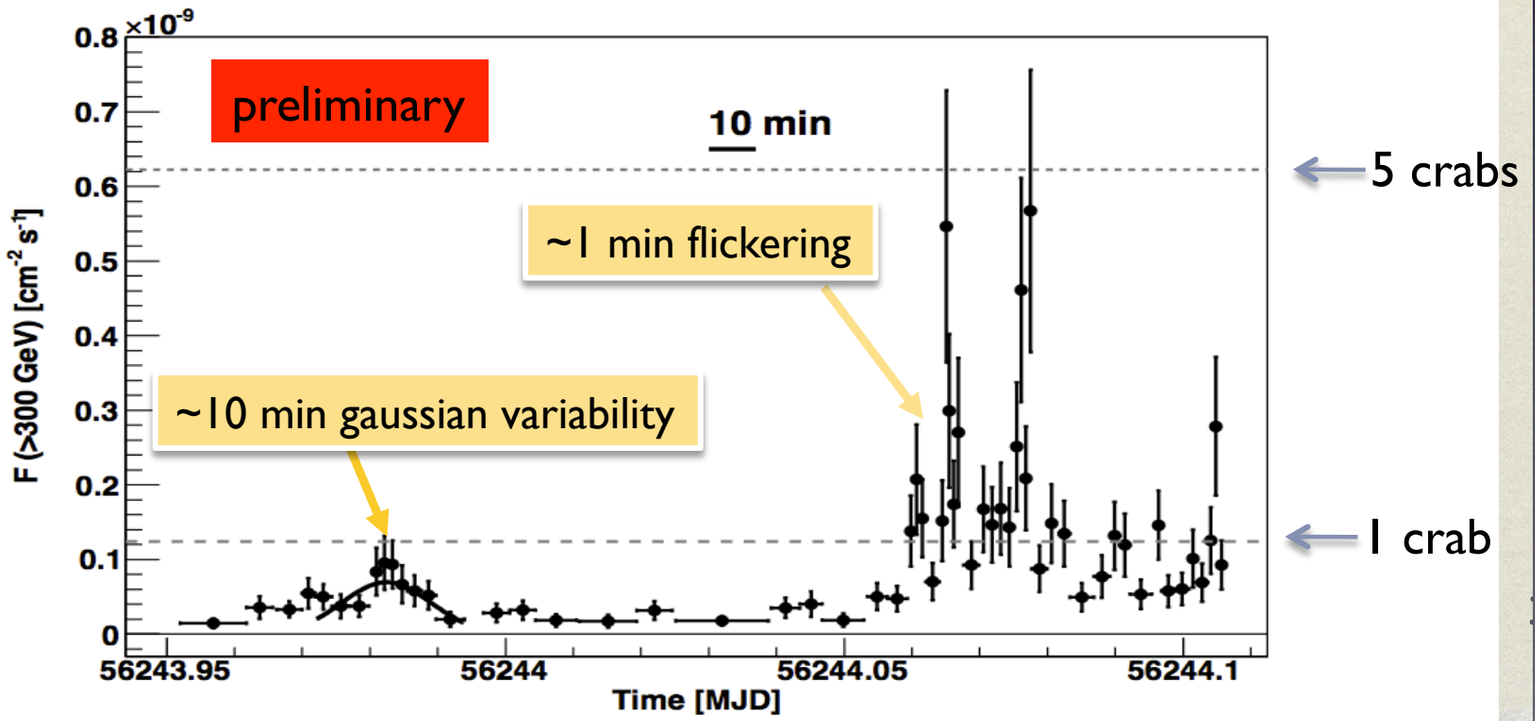


Radio Galaxy (HBL)

First serendipitously detected by Fermi (Neronov+10) and MAGIC (Aleksic+10).

Showed day to day variability in 2011 (Aleksic+11)

From Carmona's talk at TeVpar 2014

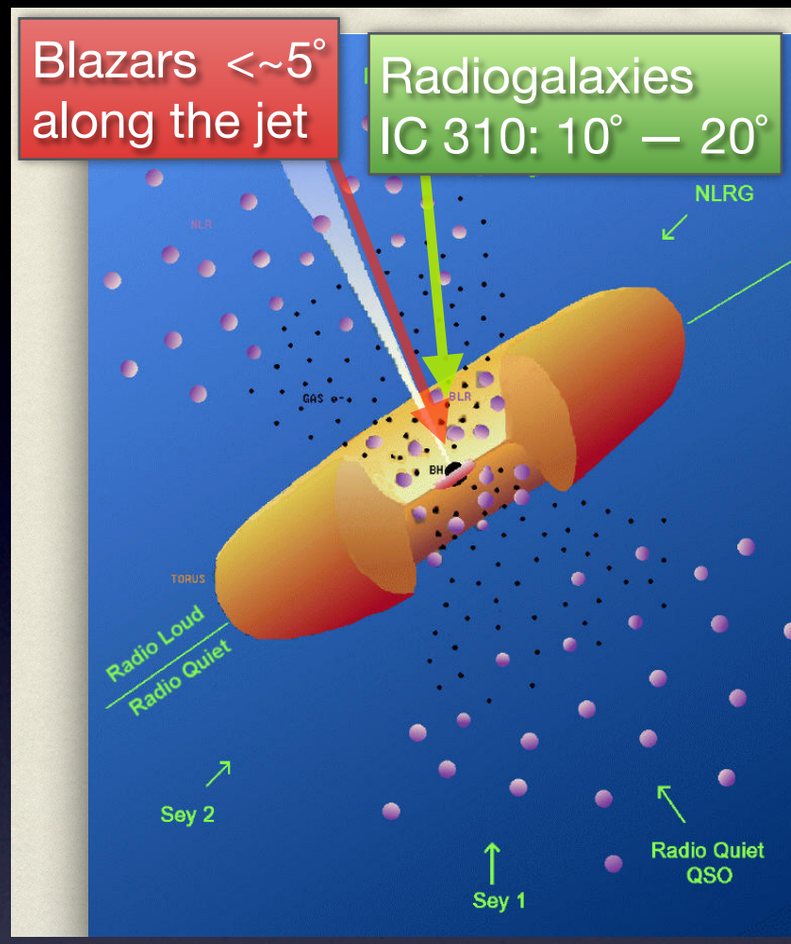


- During the flare in 2012, 10 min. variability was observed.
- Large amplitude flickering where flux was doubling in timescale of 1 min.!

Interpretation of Short Term Variability

•Assuming the mass black hole mass of 2×10^8 Mo, 1 min. time corresponds to 25% of the light-crossing-time for the event horizon.

•Mrk 501or PKS2155−304 has similar fast Variability but Doppler factors of Blazars are ~10. IC 310 could have the factor of 3-4.
→Intrinsic variability is much shorter in IC 310.



Models are hard to explain the emission feature.

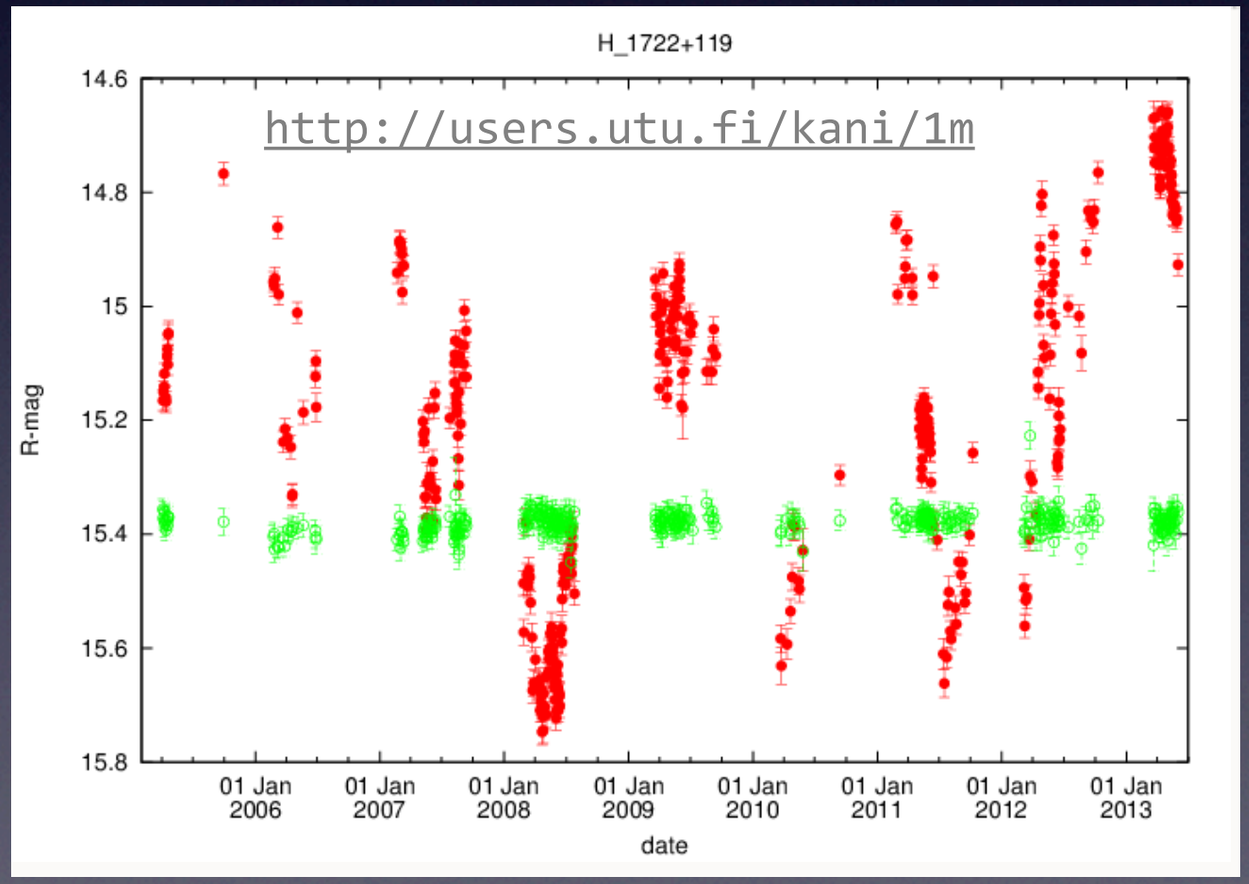
•Shocks in the jet → Difficult to explain the horizon light-crossing time.

•Minijets in the jet pointing towards the ling of sight → The luminosity of IC 310 should be huge.

•Jets crossing dense matter clouds or stars → time scale of crossing and cooling time of p-p collision is longer.

H1722+119

- BL Lac object
- Distance: z > 0.5 from the optical observation.
- Recorded the brightest R-band magnitude (14.5) in May 2013.
- MAGIC detected with 12 hours observation in ToO (ATel #5080).



Red: R-band of H1722+119
Green: Control star

Preliminary!

Multi-Wavelength Light Curve

MAGIC observation

- LAT flux was almost consistent with that in 2FGL catalog.
- LAT spectrum had the index of 1.92+/-0.06.
- No large flux variability was seen in the radio band.

Preliminary!

MAGIC Result

Daily light curve

Preliminary!

No significant variability.
Luminosity: 2.2% C.U. (>140 GeV)

Energy spectrum

Preliminary!

Γ = 3.6 +/- 0.3 (observed)
Γ = 2.6 +/- 0.6 (de-absorbed, z=0.5)

Preliminary!

← Intrinsic spectrum was assumed the extrapolation of Fermi one.

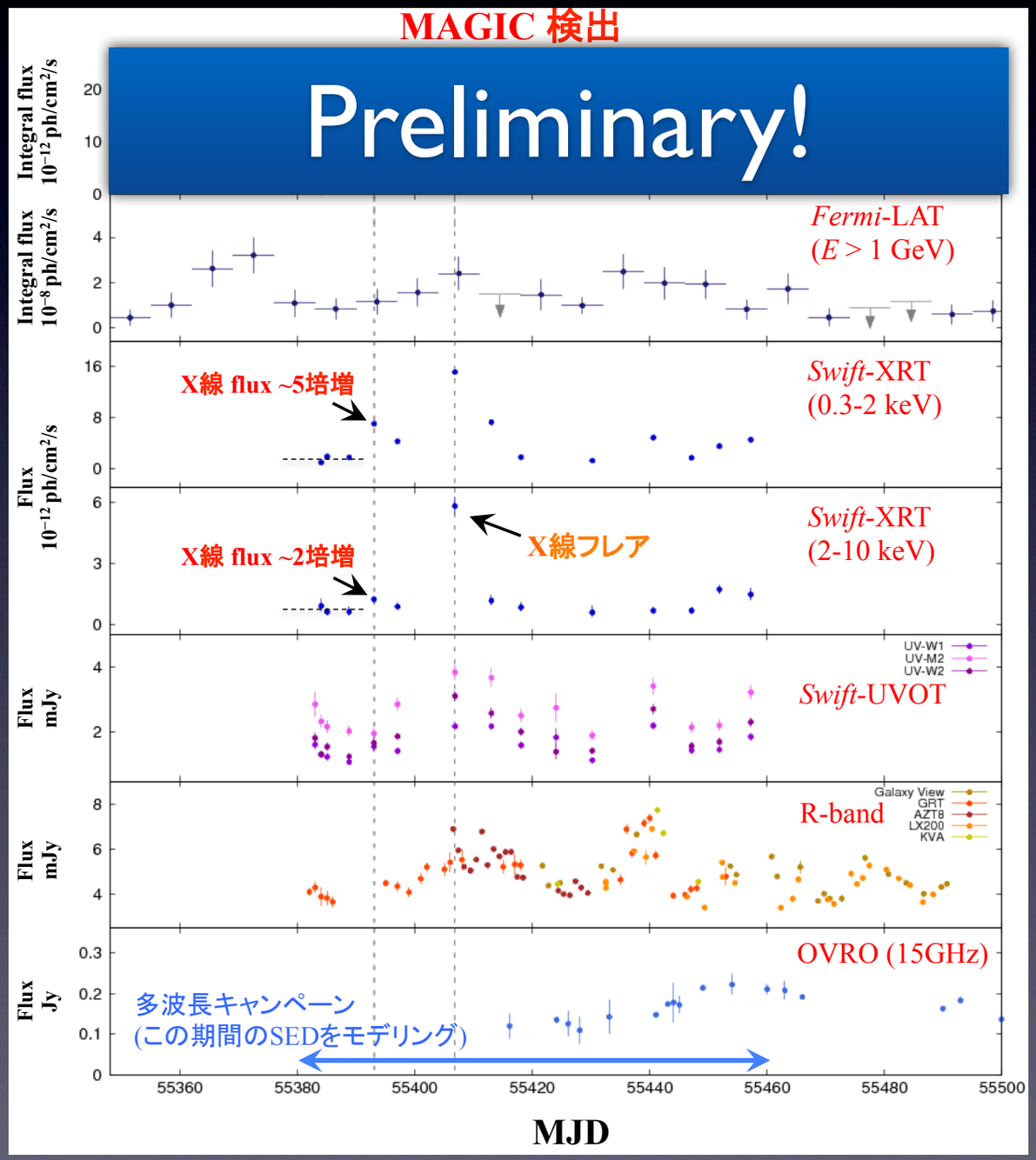
$$\tau_{\max}(E) = \log\left[\frac{F_{\rm int}(E)}{F_{\rm obs}(E) - 1.64 \cdot \Delta F(E)}\right]$$

Georganopoulos+2010, Aleksić+2011, Abramowski+2013

SED is well represented with SSC model by Takami+11.

MAGIC J2001+435

- Fermi object w/ hard spectrum: 2FGL J2001.1+4352, Γ_{LAT}=1.90+/-0.03
- Categorized as HBL object. • Red shift > 0.11 (Shaw+13)
- First VHE gamma-ray detection by MAGIC (July - Sep. in 2010, 14 hours).



- Time variabilities were seen in multi-wavelength.
- Strong variability in X-ray band.

Preliminary!

- z=0.17+-/-0.1 from z-spectral index relation (Prandini=10).
- VHE flare, X-ray flare, quiescence state can be explained by one-zone SSC model.

Other Interesting Objects

Discovery of Very High Energy Gamma-Ray Emission From Gravitationally Lensed Blazar S3 0218+357 With the MAGIC Telescopes

ATel #6349; *Razmik Mirzoyan (Max-Planck-Institute for Physics) On Behalf of the MAGIC Collaboration*
on 28 Jul 2014; 14:20 UT
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Gamma Ray, >GeV, TeV, VHE, UHE, AGN, Blazar, Cosmic Rays, Microlensing Event

The MAGIC collaboration reports the discovery of very high energy (VHE; E>100 GeV) gamma-ray emission from S3 0218+357 (RA=02h21m05.5s, DEC=+35d56m14s, J2000.0). The object was observed with the MAGIC telescopes for a total of 3.5 hours from 2014/07/23 to 2014/07/26. The preliminary analysis of these data resulted in the detection of S3 0218+357 with a statistical significance of more than 5 standard deviations. From the preliminary analysis, we estimate the VHE flux of this detection to be about 15% of the flux from the Crab Nebula in the energy range 100-200 GeV. S3 0218+357 is a gravitationally lensed blazar located at the redshift of 0.944+/-0.002 (Cohen et al., 2003, ApJ, 583, 67). Fermi-LAT observations during the flaring state of S3 0218+357 in 2012 revealed a series of flares with their counterparts after 11.46+/-0.16 days delay, interpreted as due to the gravitational lensing effect (Cheung et al. 2014, ApJ, 782, L14). On 2014 July 13 and 14 Fermi-LAT detected another flaring episode (ATel #6316). Due to the full-moon time, the MAGIC telescopes were not operational and could not observe S3 0218+357 after the original alert. However, observations scheduled at the expected time of arrival of the gravitationally lensed component led to the first significant detection of a gravitationally lensed blazar and the most distant source detected at VHE with Cherenkov telescopes to date. MAGIC observations on S3 0218+357 will continue during the next days and multiwavelength observations are encouraged. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) and J. Sitarek (jsitarek@ifae.es). MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Canary island of La Palma, Spain, and designed to perform gamma-ray astrophysics in the energy range from 50 GeV to greater than 50 TeV.

S3 0218+357

Red shift: 0.944+/-0.002!

Maybe observed the delayed component due to a gravitationally lensed component.

Detailed results are coming soon!

RBS0723 (ATel #5768)

- Extreme BL Lac
- Weak but variable

RX J1136.5+6737 (ATel #6062)

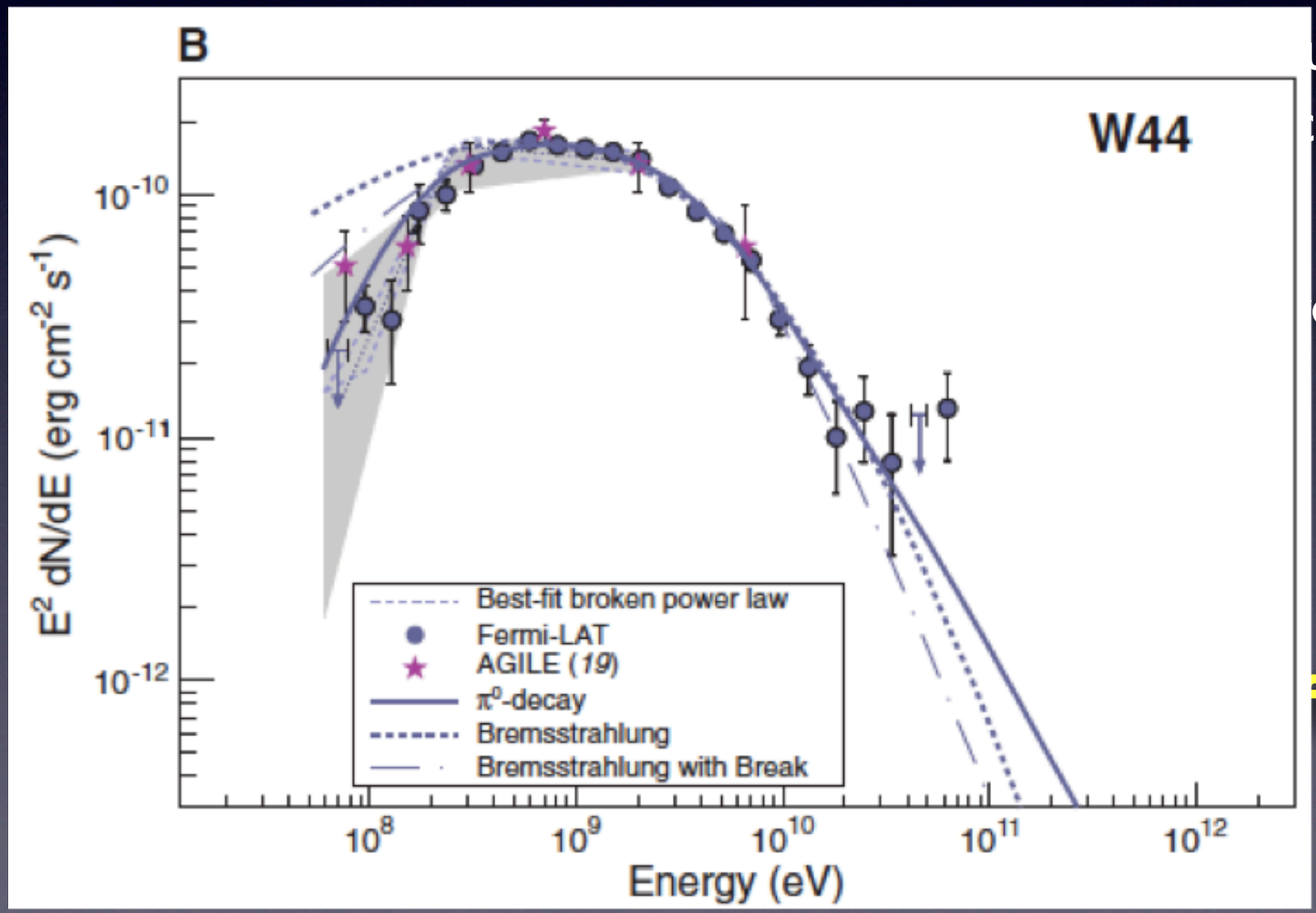
- Extreme BL Lac?

Galactic Sources

SNRs

SNR W44

- Middle-aged SNR (~2×10^4 yr)
- Surrounded by giant molecular (10^6 Mo) cloud and interacting with it



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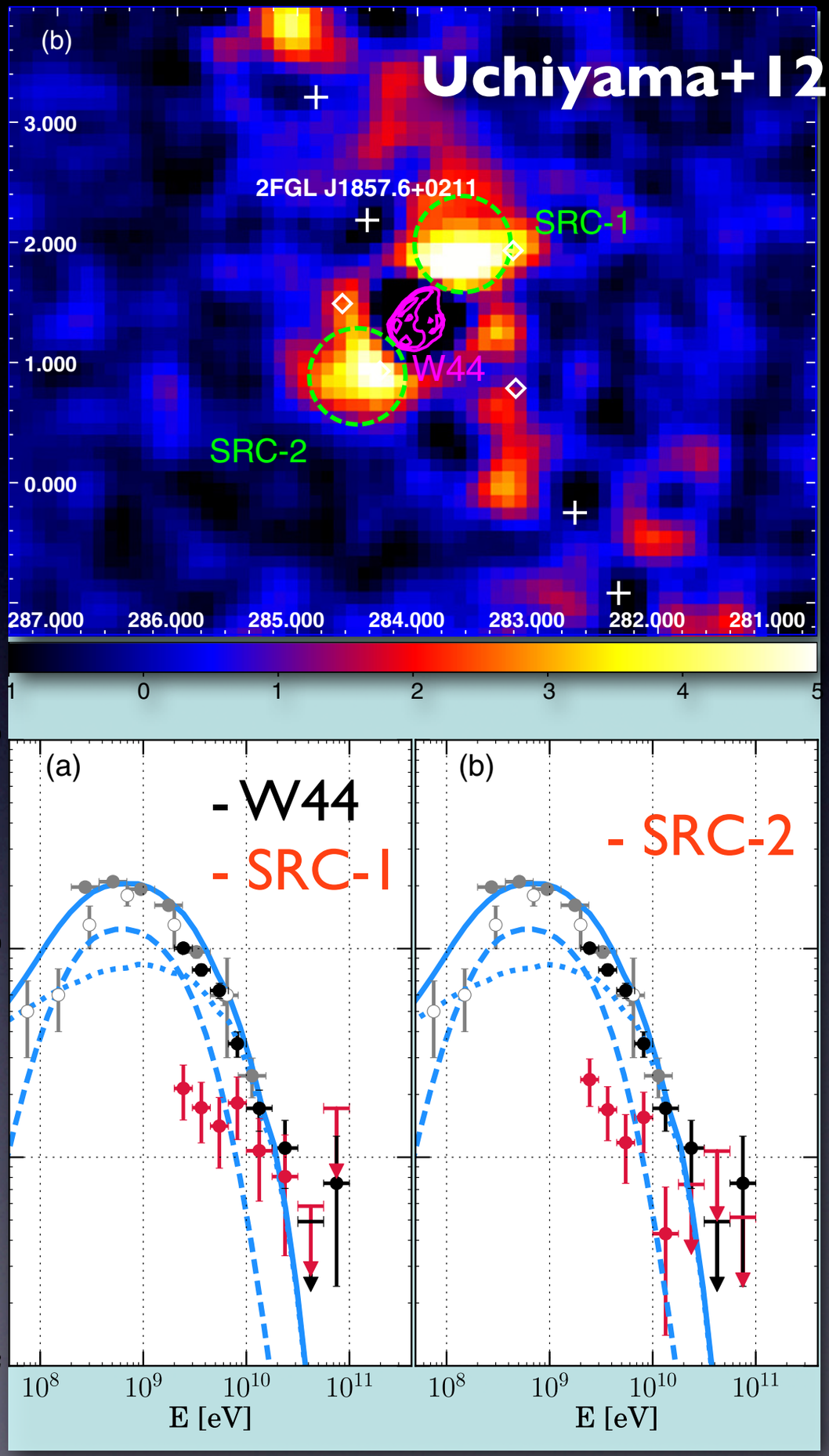


SNR W44

- Middle-aged SNR (~2×10^4 yr)
- Surrounded by giant molecular (10^6 Mo) cloud and interacting with it
- Detected the pion-decay signature from p-p collision → evidence of CR acceleration (Ackerman+13)
- Bi-polar gamma-ray emission around the SNR (Uchiyama+12).

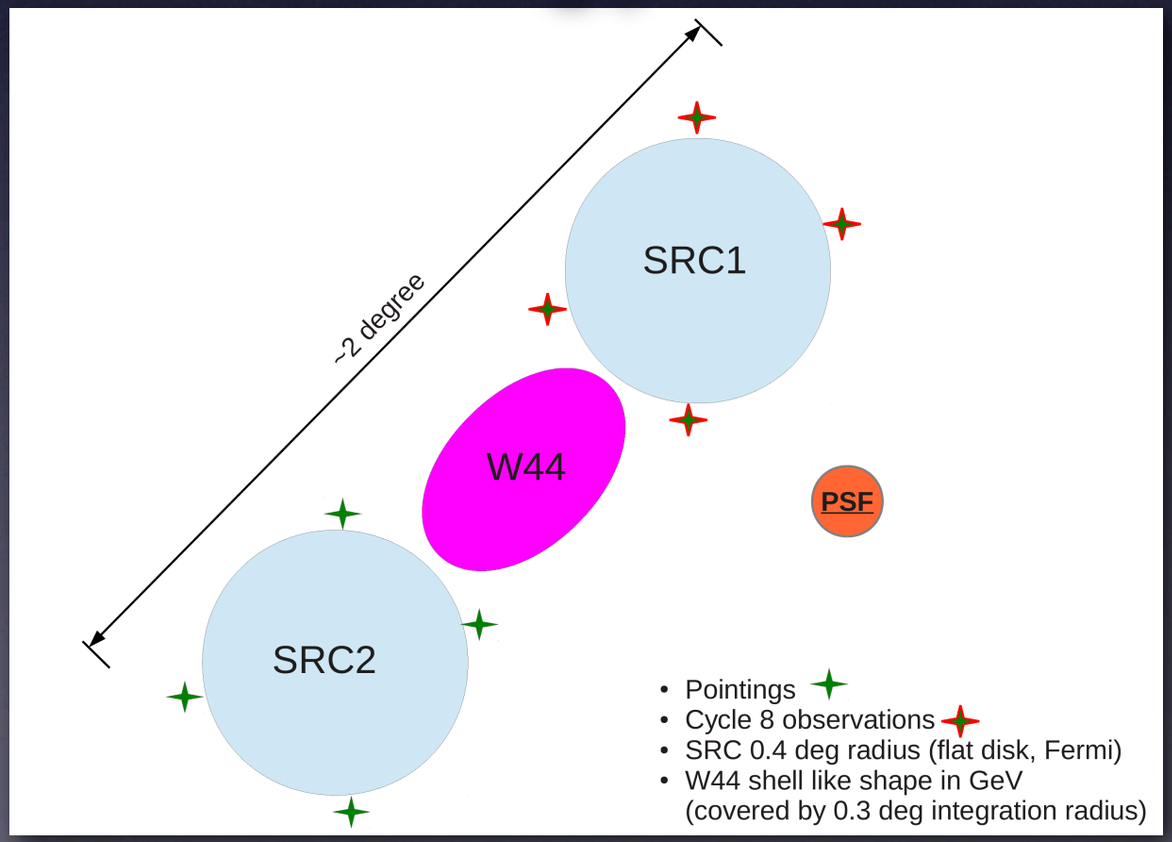
Good site for study of the CR diffusion process

Observation with MAGIC

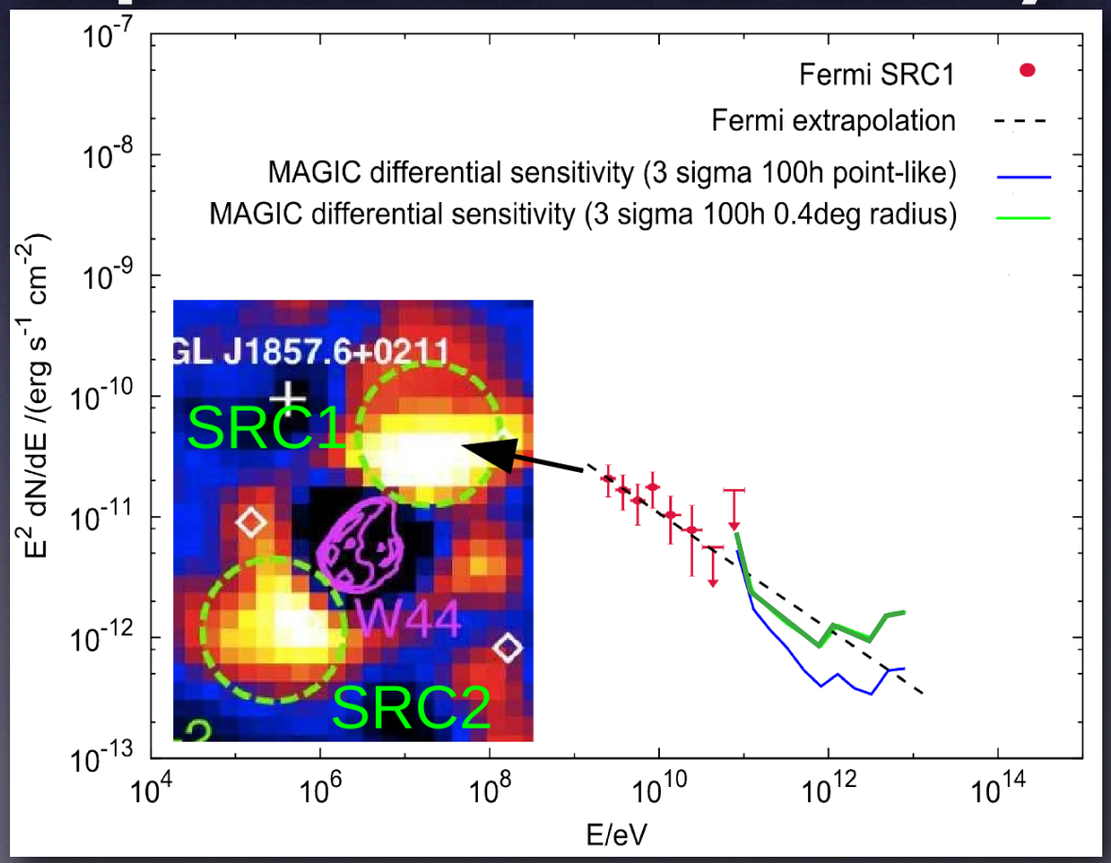
Observation of SRC-1 and SRC-2 for 100 hours (in total 200 hours) each was proposed as MAGIC KOP.

- W44 itself should be covered by the observations.
- Starting from SRC-1 because both sources have the same fluxes and spectral shapes.
- Observation of SRC-1 was completed in this summer.

Pointing positions



Expected flux vs sensitivity



Sky Map

TS value map

Preliminary!

Surviving time of ~93 hours after the data selection.

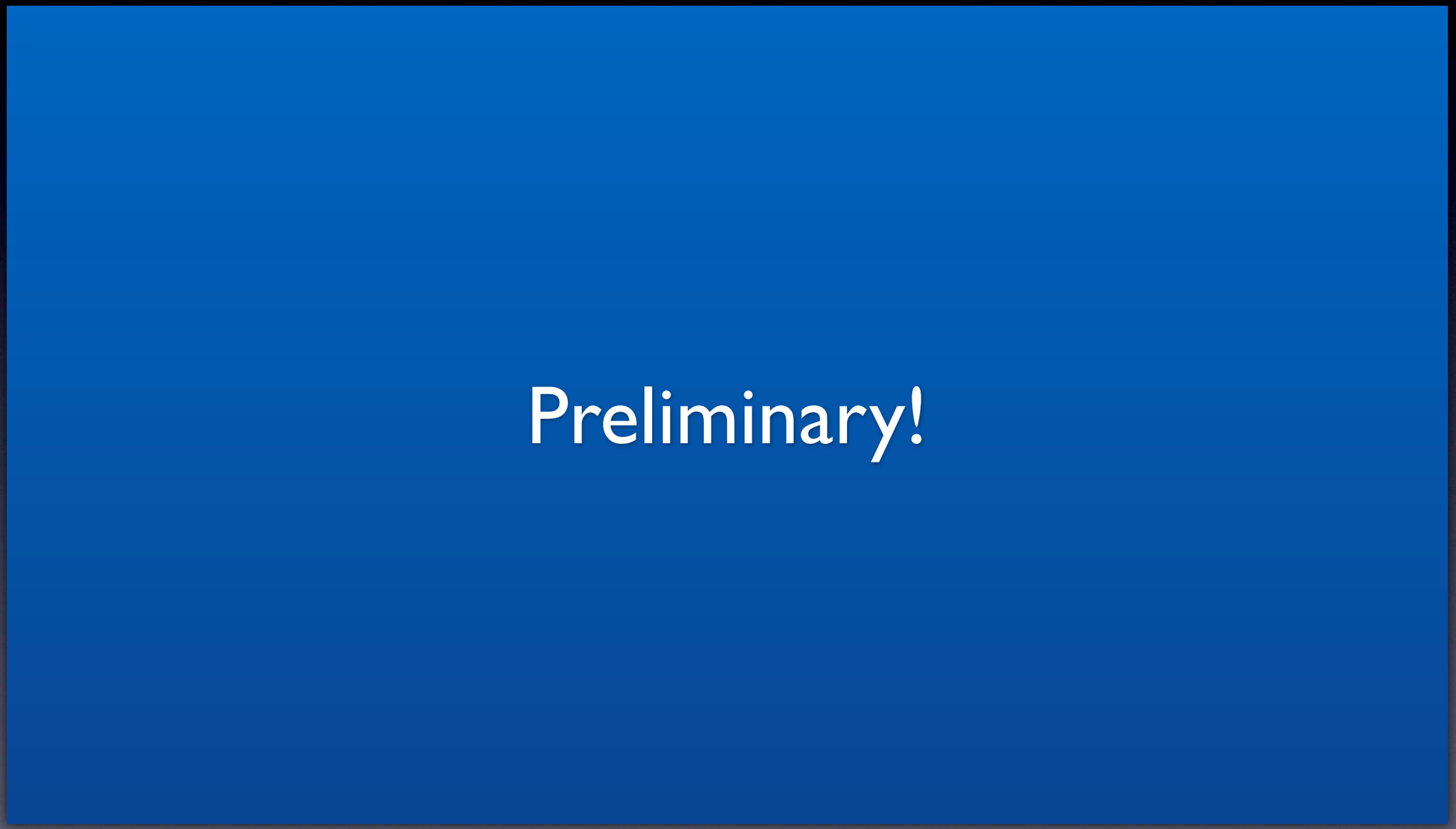
Preliminary!

- HESS J1857+026 and HESS J1858+020 (a few percent Crab) have been detected.

Preliminary!

Spectral Energy Distribution of SRC-1

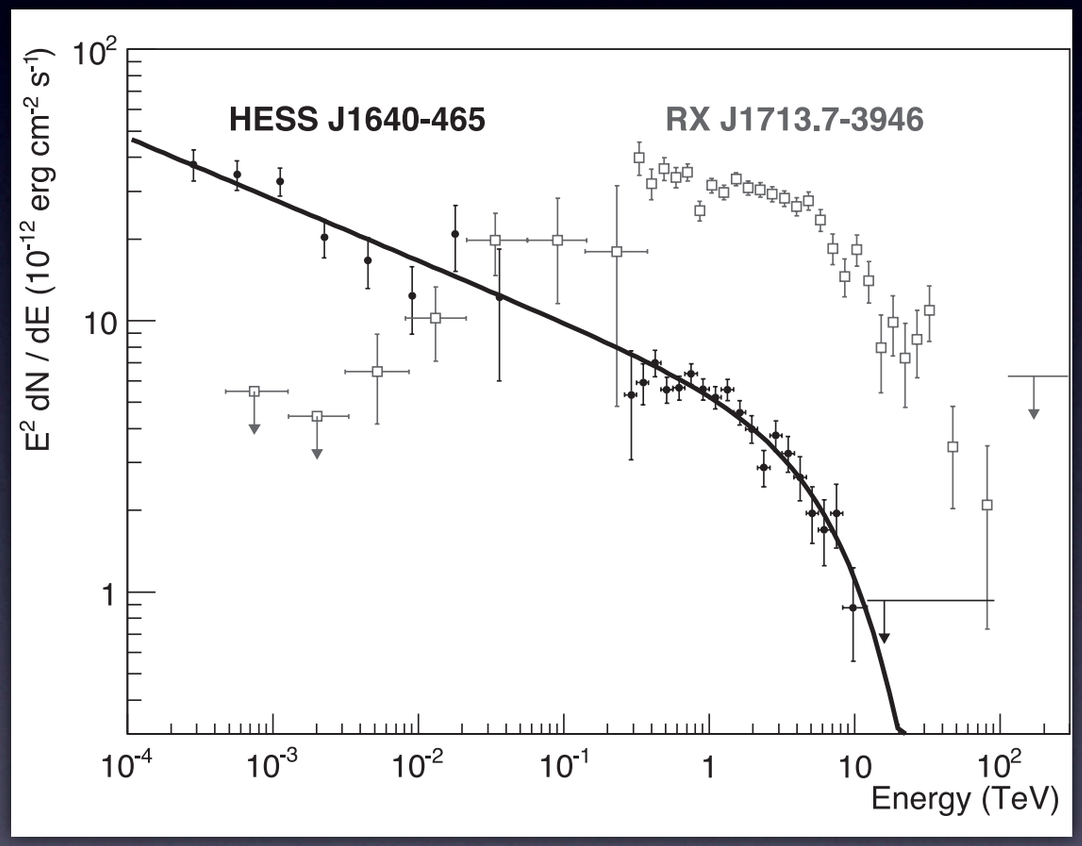
Emission region was assumed the disk with the radius of 0.4 deg from Uchiyama+12.



The analysis of W44 itself is ongoing considering the effect of off-axis.

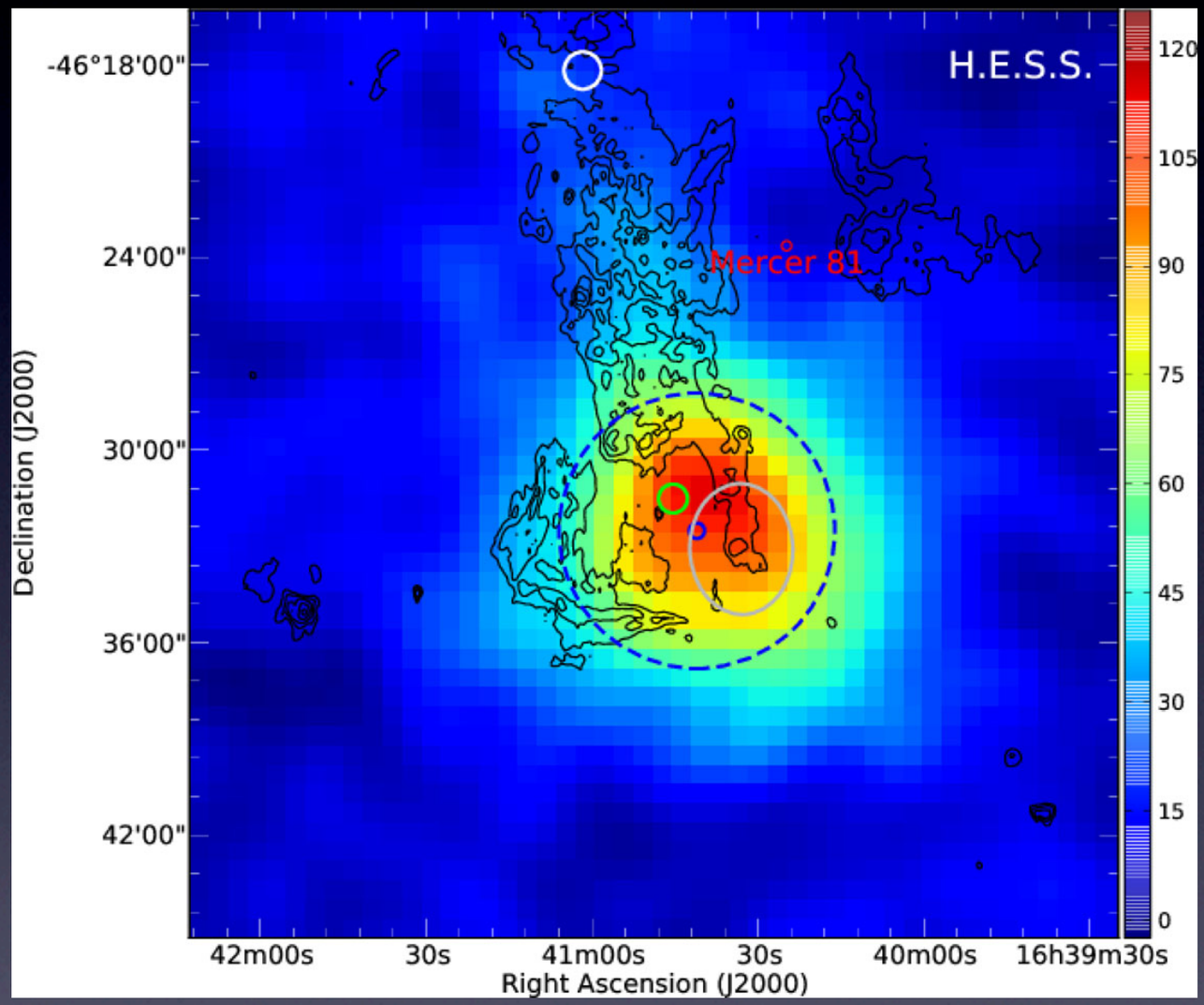
HESS J1640-465

- Discovered by HESS GPS (2005)
- Coincident with the northern shell of SNR G338.3−0.0 at 10 kpc.
- Detected by Fermi (Slane+2010)



- Well fitted with exponential cut-off power-law model.
- Index = 2.15 +/- 0.1
- E_{cut} = 7.3 +/- 2.0 TeV

Excess map (Abramowski+2014)



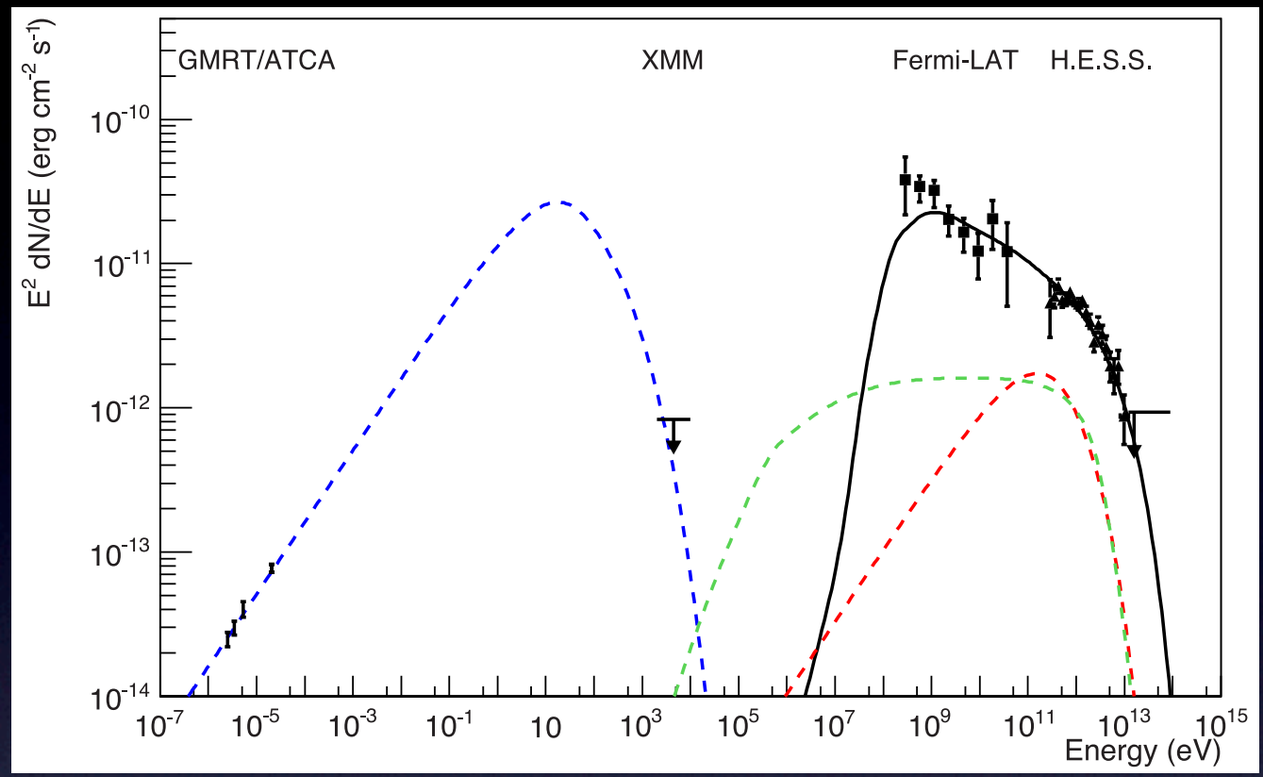
Green: PWN XMMU J16045.4-463131
Grey: 2FGL 1640.5-4633
White: HESS J1641-463
Contour: Radio 610 MHz

Extremely Bright SNR?

SNR (hadronic model)

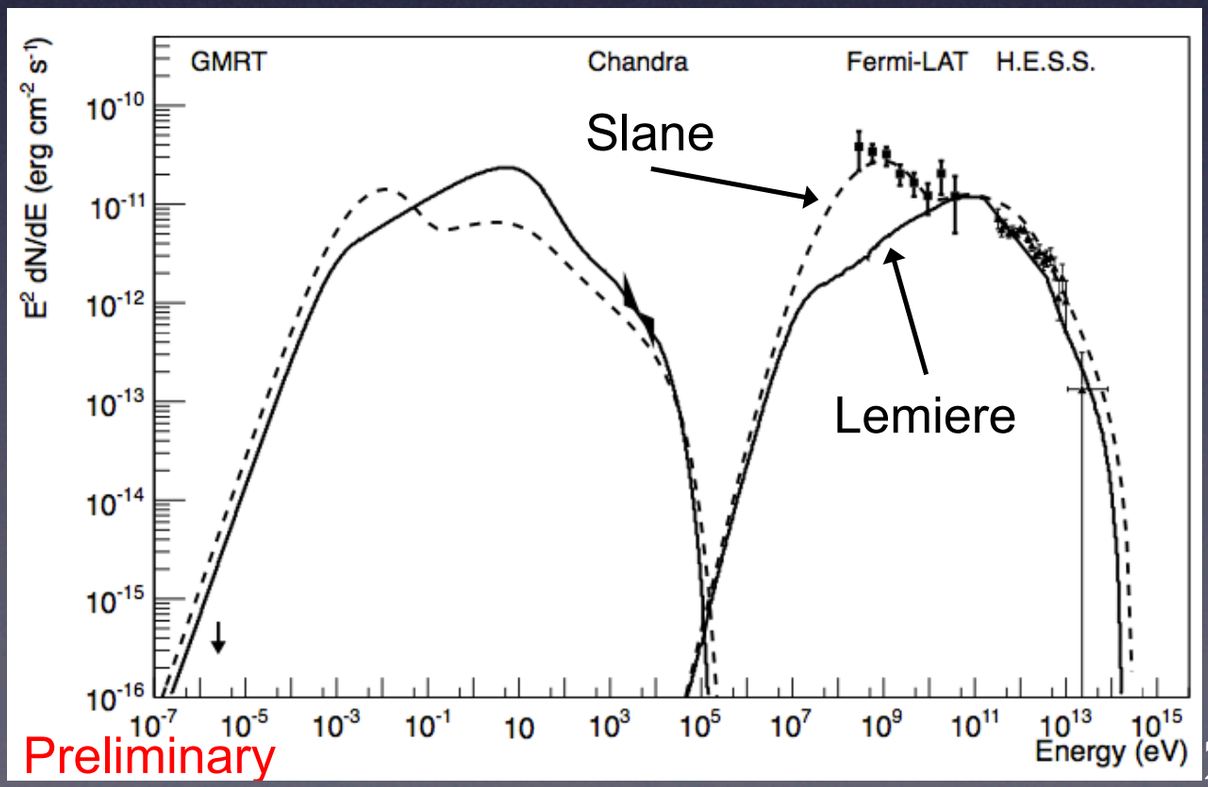
- The GeV and TeV gamma rays overlap with the gaseous.
- Hadronic model can naturally explain the gamma-ray emission.
- B=25μG, $E_{c,e}$=10 TeV, Γ=2.2
- $W_p n_H = 4 \times 10^{52}$ (d/10 kpc)^2 erg cm^{-3}

  c.f. Wp of Fermi SNR ~10^{49} erg



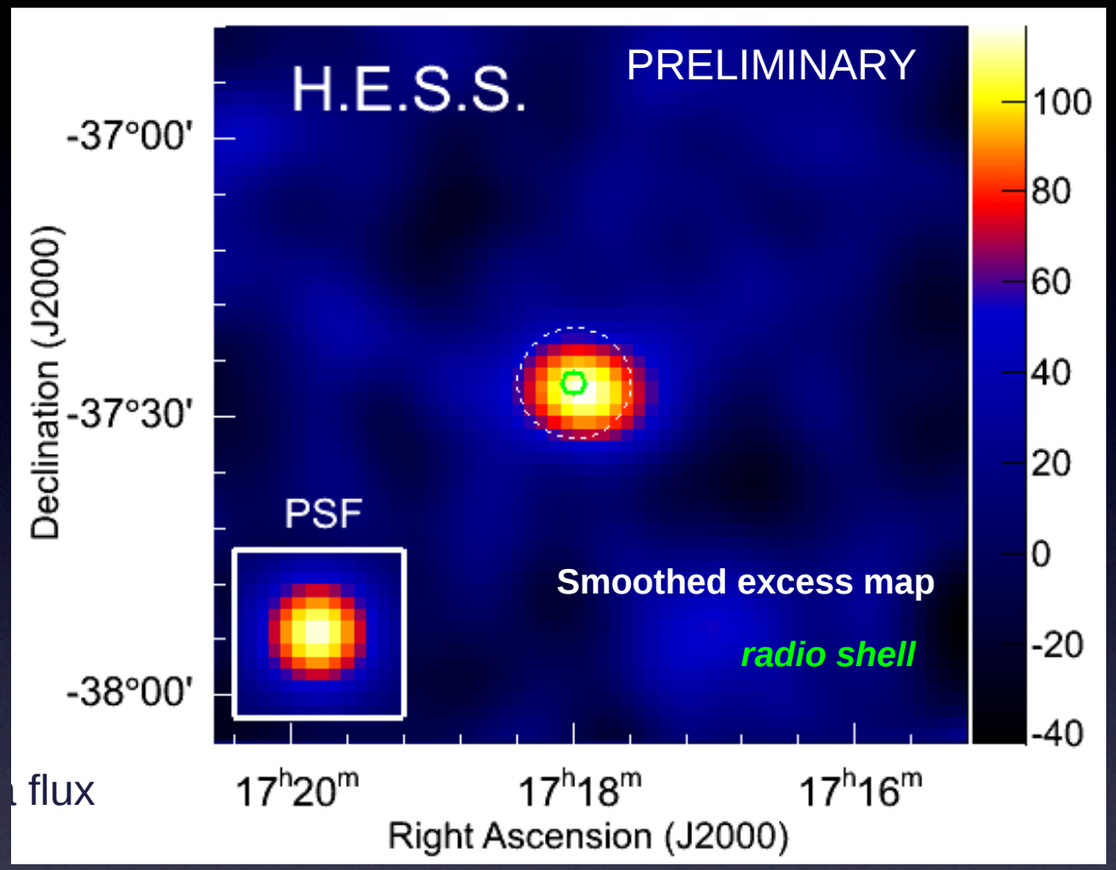
PWN (leptonic model)

- Smooth gamma-ray power-law spectrum which are not seen in other PWNe.
- TeV emission more extended than SNR (smaller extension at higher energy in PWNe).
- Observed upper limit in radio conflict with the model spectrum.



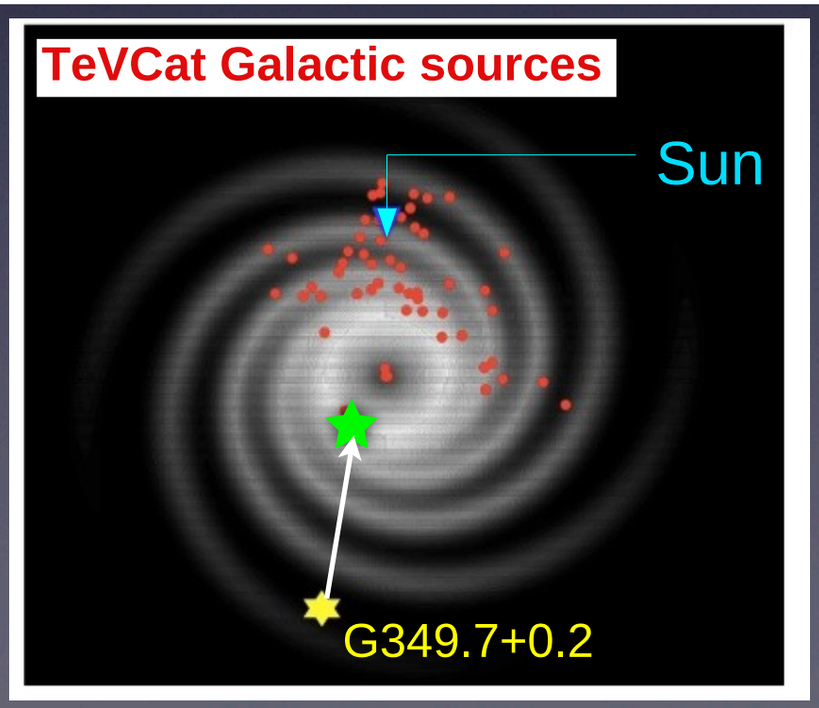
G349.7+0.2

From the talk of C. Trichard at ICRC2013



- Middle-aged 2800 yr
- Interacting with molecular cloud
- Distance:22.4 kpc?
- Detected by Fermi
  - Spectral index of 2.2+/-0.1

Detected by HESS at >5σ (post-trial) after more than 100 h obs.

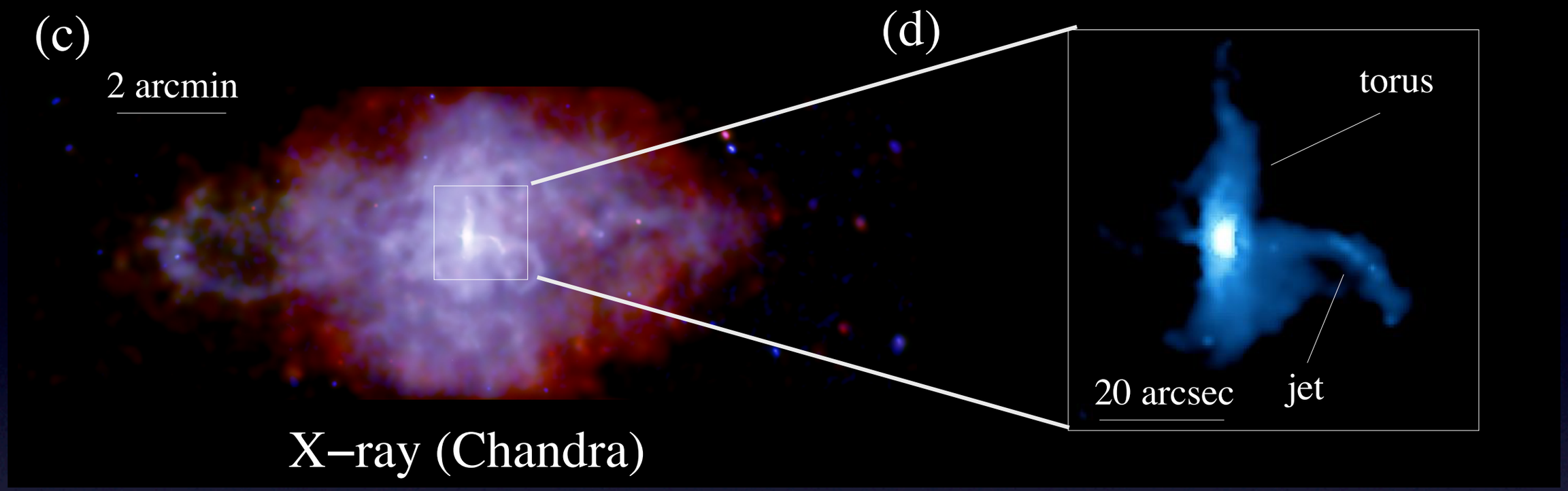


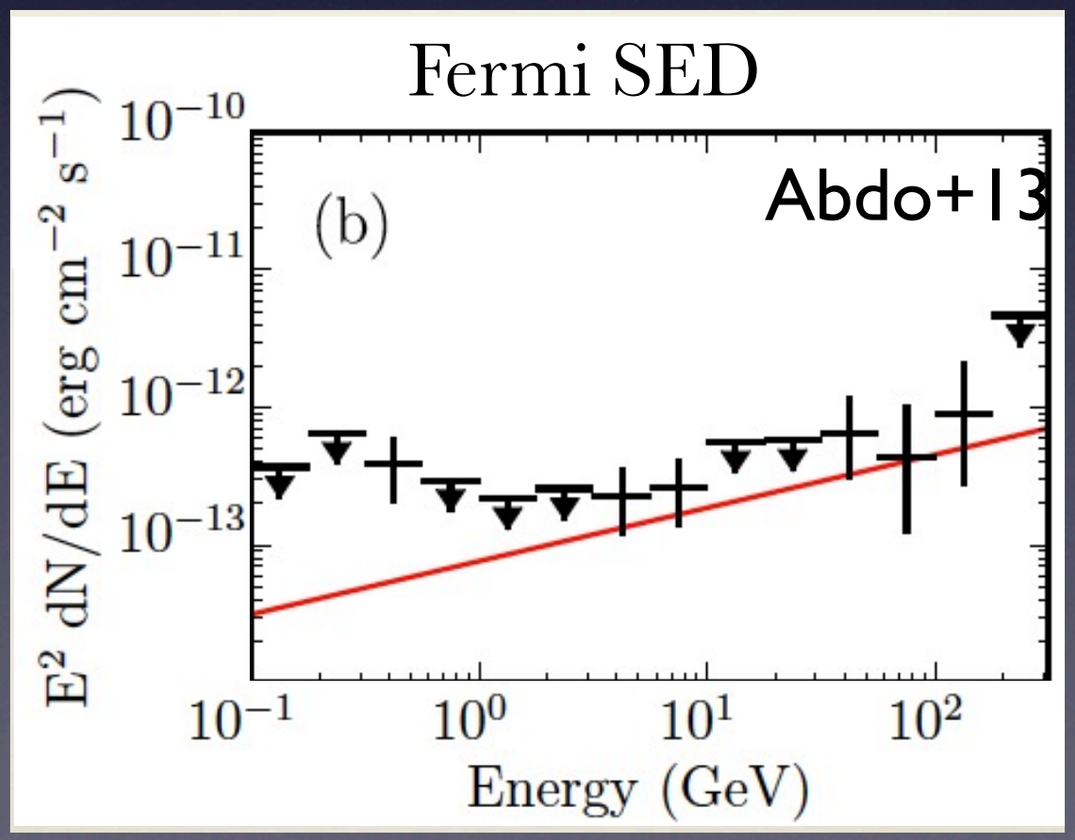
- Distance was corrected to 11.5 kpc by Tian+14.

→Explosion energy is estimated to be 2.5×10^{50} erg (typical 10^{51} erg)

Pulsars and PWNe

3C58





- PSR J0205+6449 is centered in 3C58.
  - High spin-down luminosity E_{dot}=2.7×10^{37} erg/s (5% Crab)
- Jet-torus morphology similar to Crab.
- Distance of 3 kpc (Kothes+13).
- Age of 2.5 kyr? Related to SN1181?
- Pulsar and off-pulse component detected by Fermi (Ackermann+13)
- Power-law spectrum with an index of -1.6 up to 100 GeV.

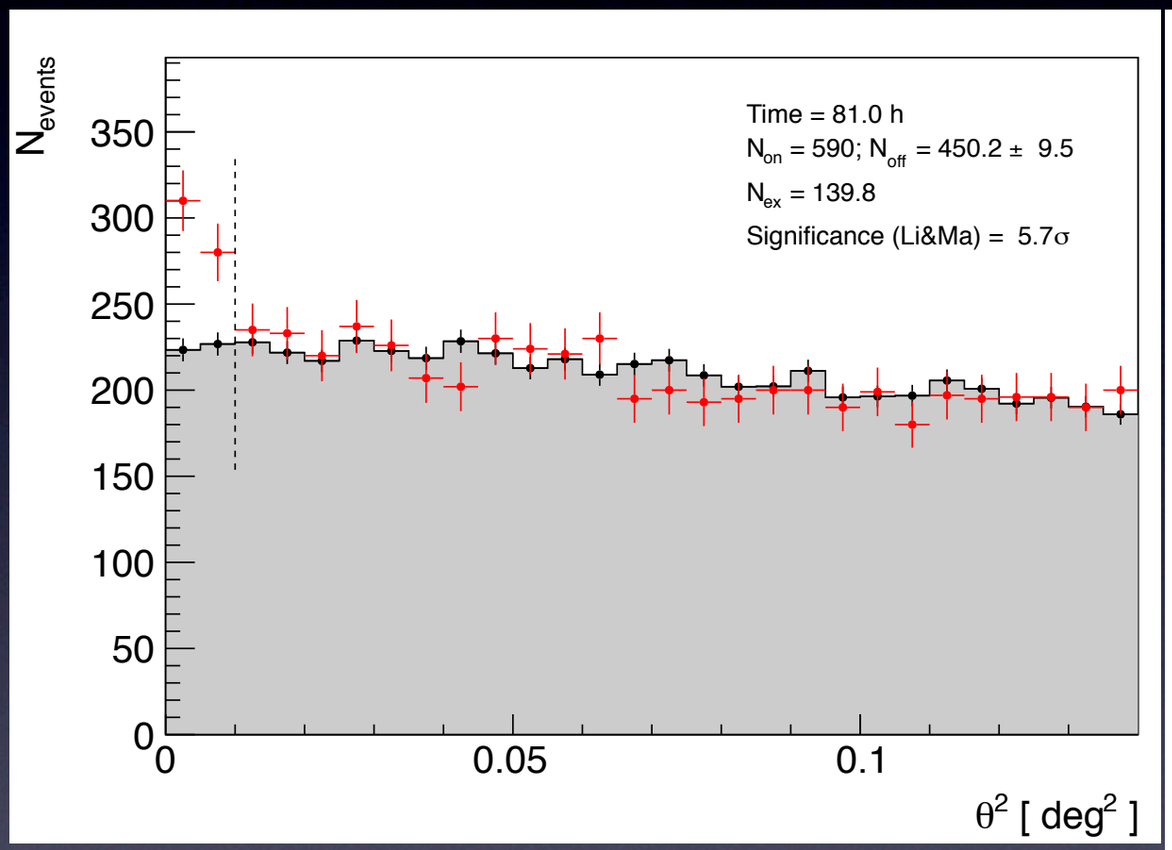
Detection of 3C58 by MAGIC

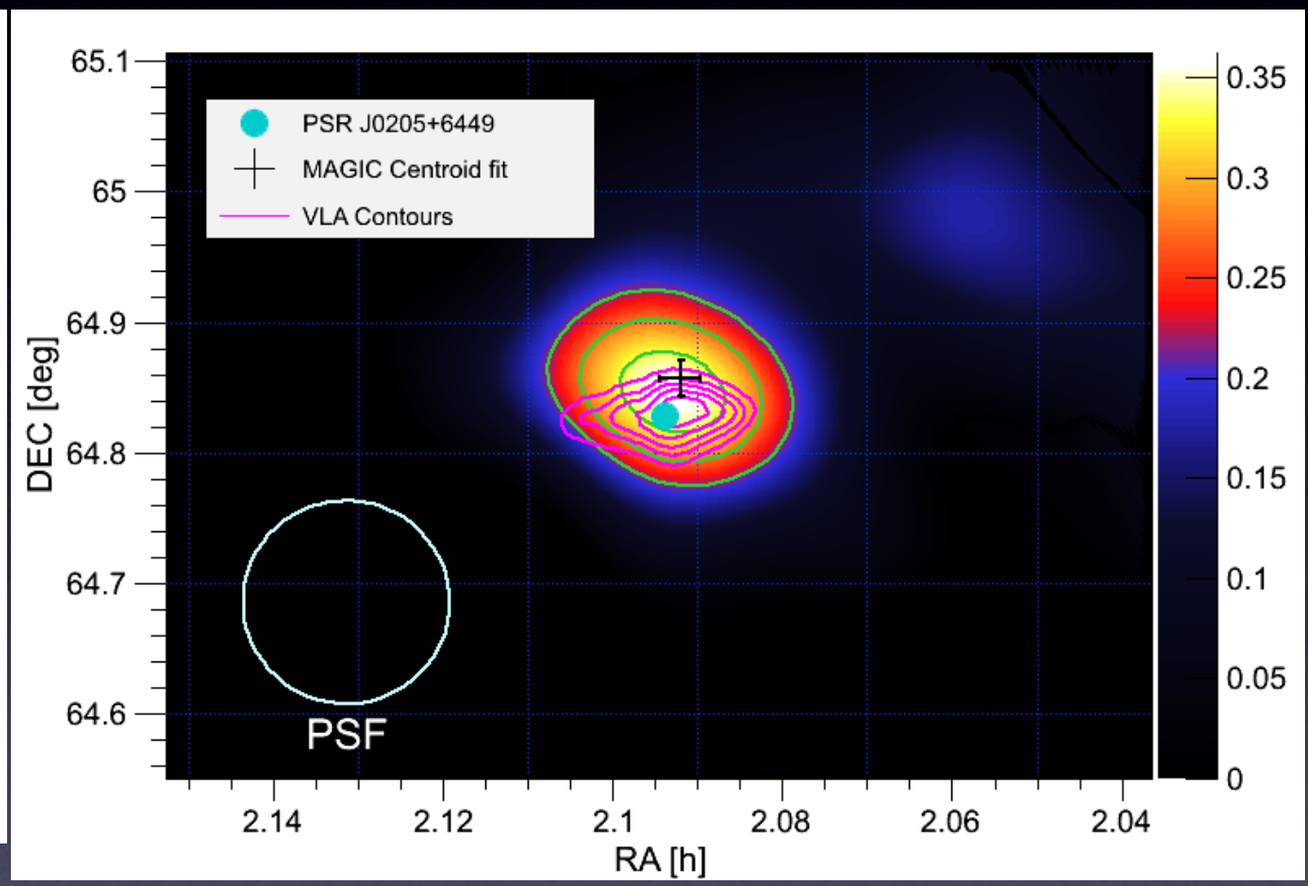
Detected at 5.7σ with 81 h data of MAGIC!

θ^2 distribution

Aleksic+12

Skymap

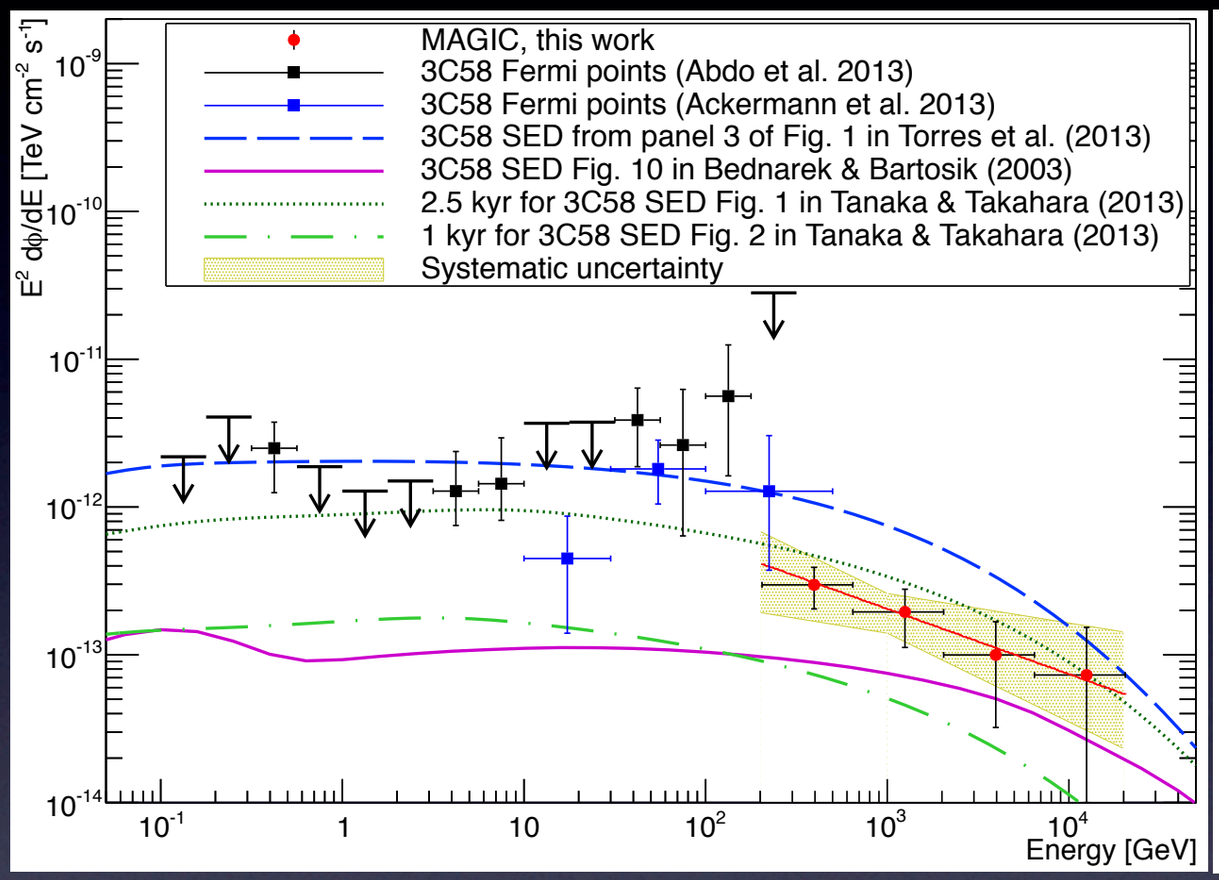


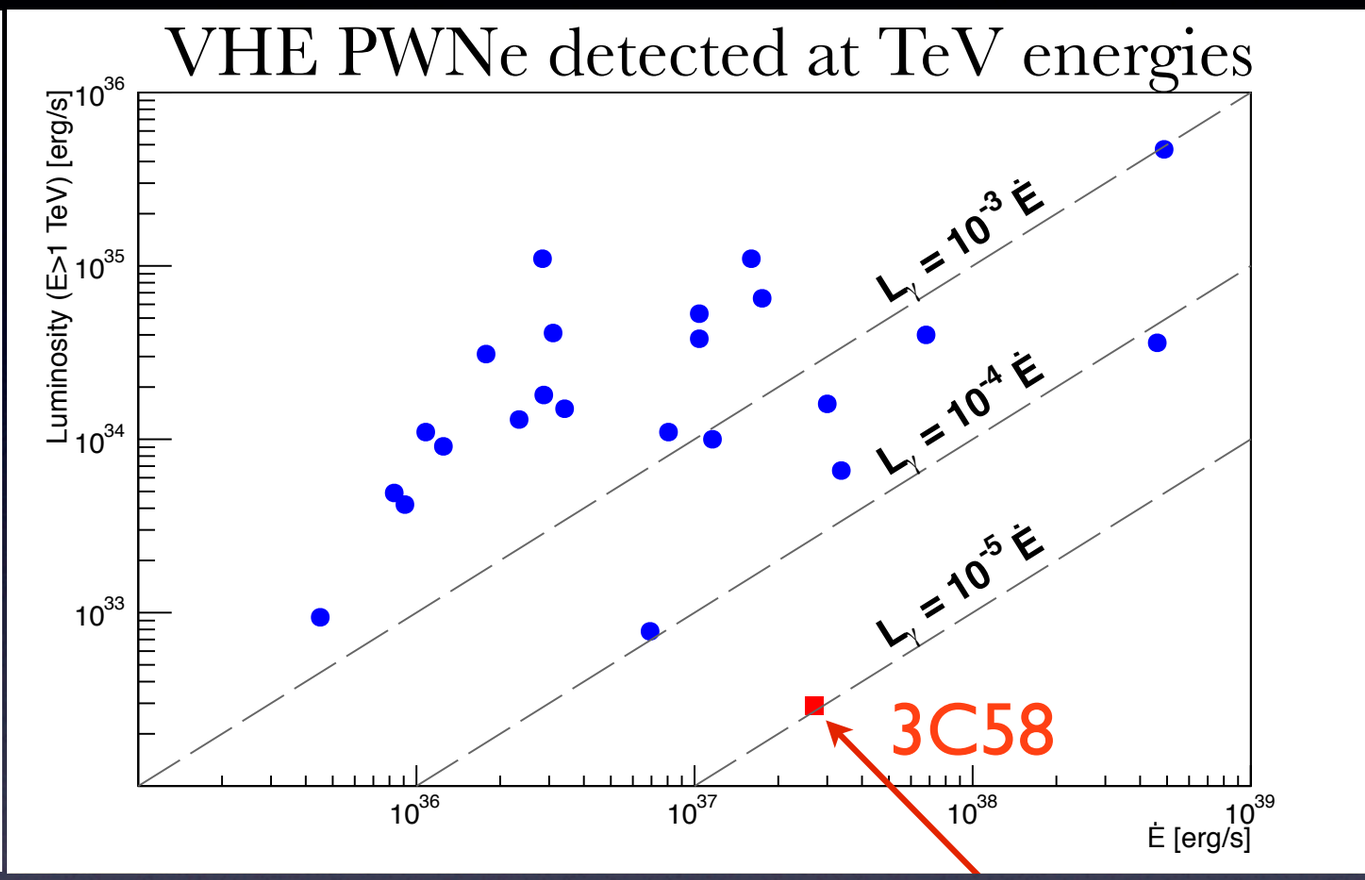


Consistent with point source.
Integral flux: 0.65% C.U. (weakest PWN detected at TeV)
Spectral index: 2.4 +/- 0.2_{stat} +/- 0.2_{sys}

Interpretation of the Result

Aleksic+12





- Considering the evolution of the PWN by solving diffusion-loss equation (Tanaka&Takahara13), the spectrum can be reproduced.
- Magnetic field strength is obtained to be ~<35μG.

➡ Very low for young PWN (c.f. Crab ~100μG), suggesting far from equipartition.

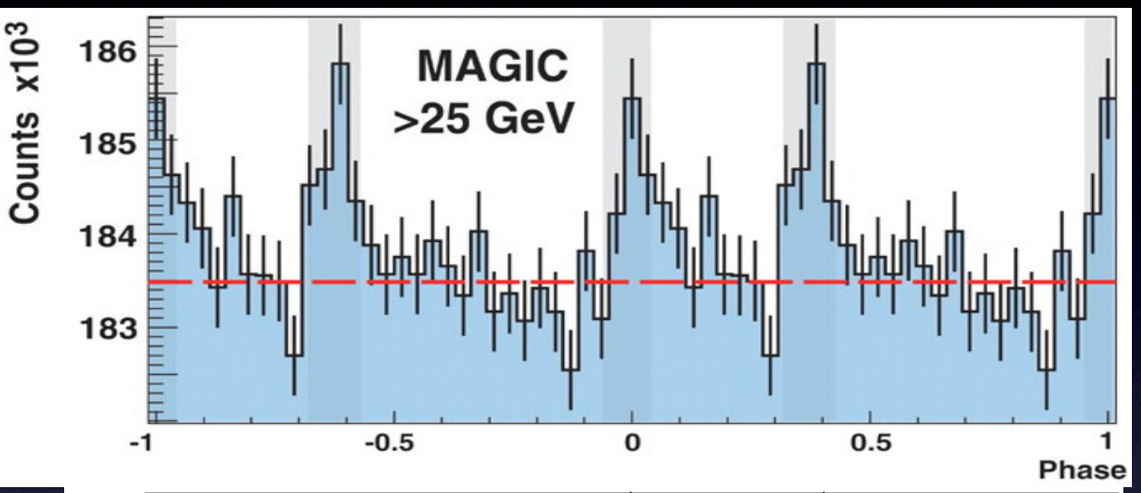
Crab

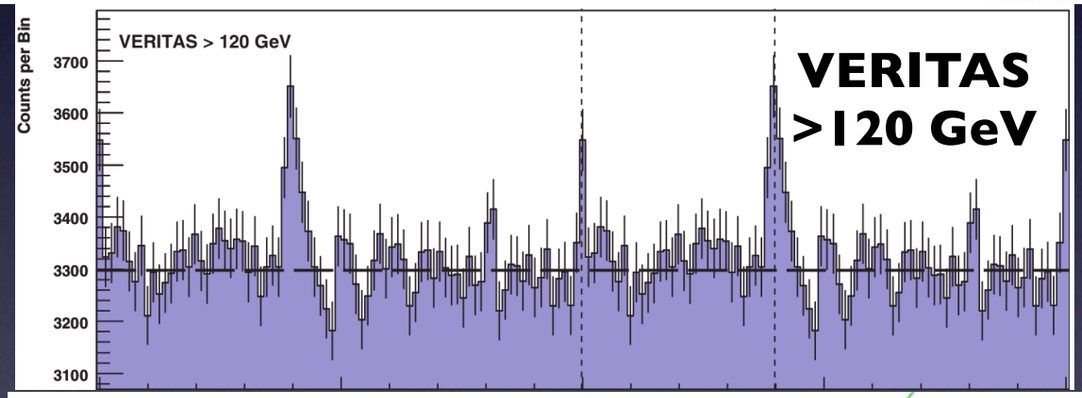
Crab is the most studied Pulsar/PWN but always gives us surprises.

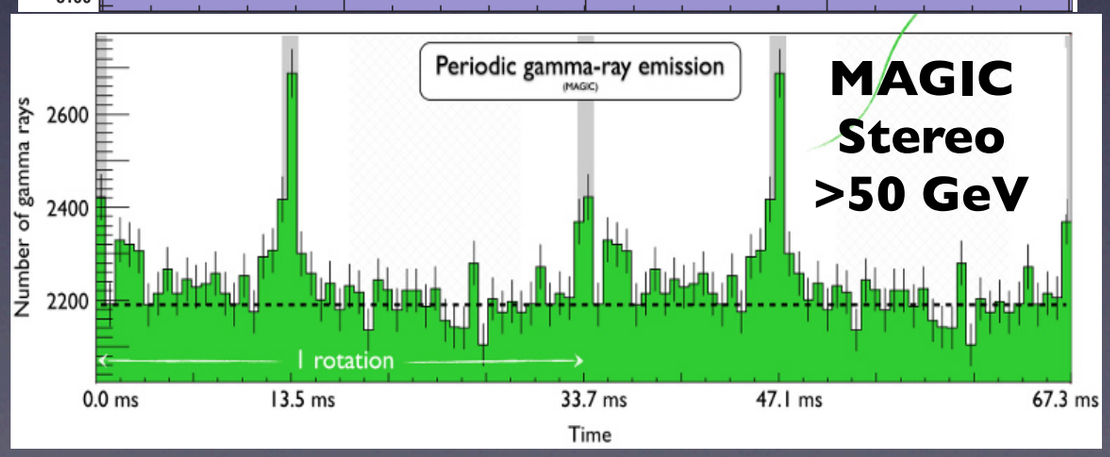
•2008 MAGIC mono discovered pulsed emission at > 25GeV (Aliu+08)

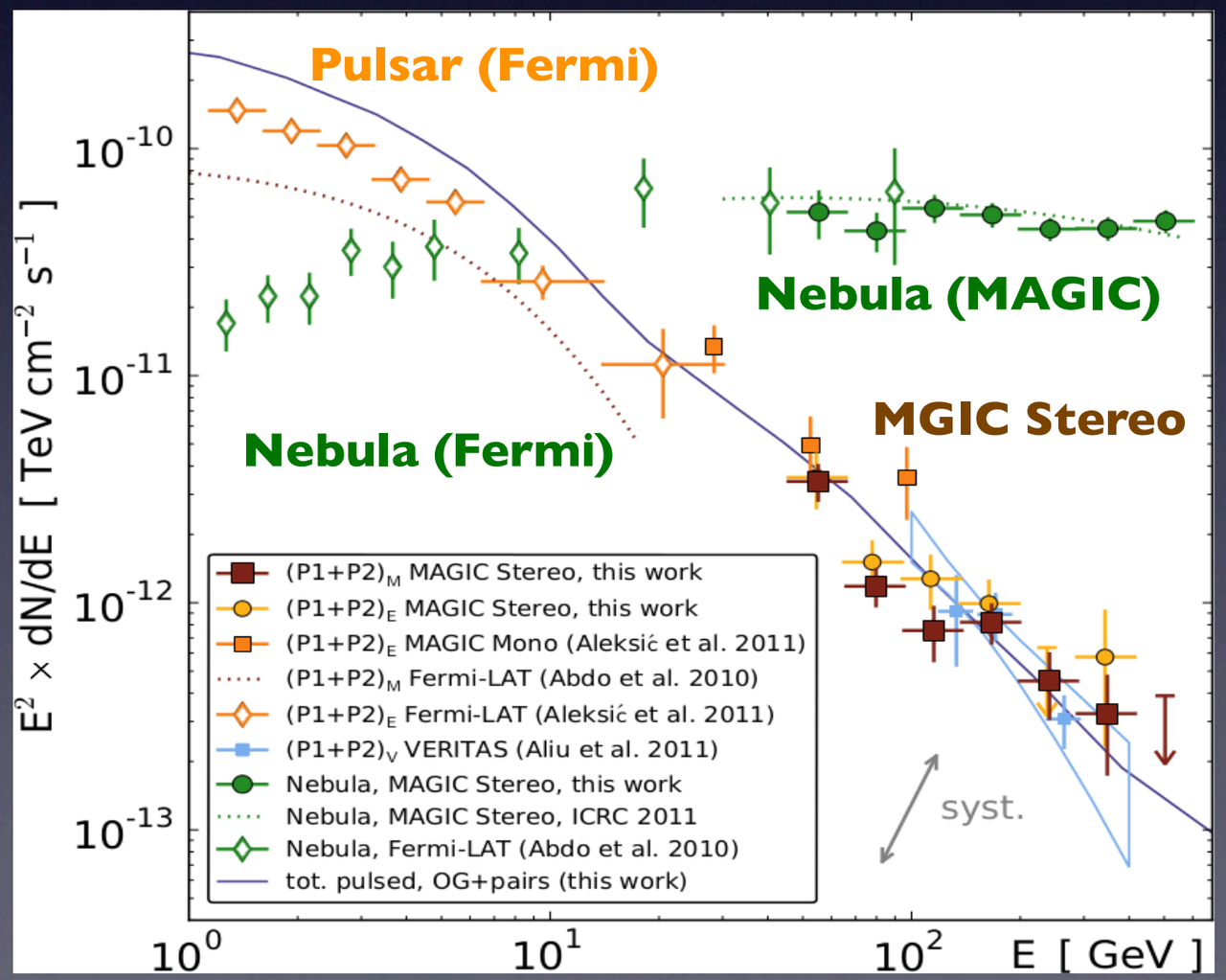
•2011-2012
VERITA reported pulsed emission at > 100 GeV (Aliu+11).

MAGIC stereo detected the pulsed component in 50 < E < 400 GeV (Aleksic+12).





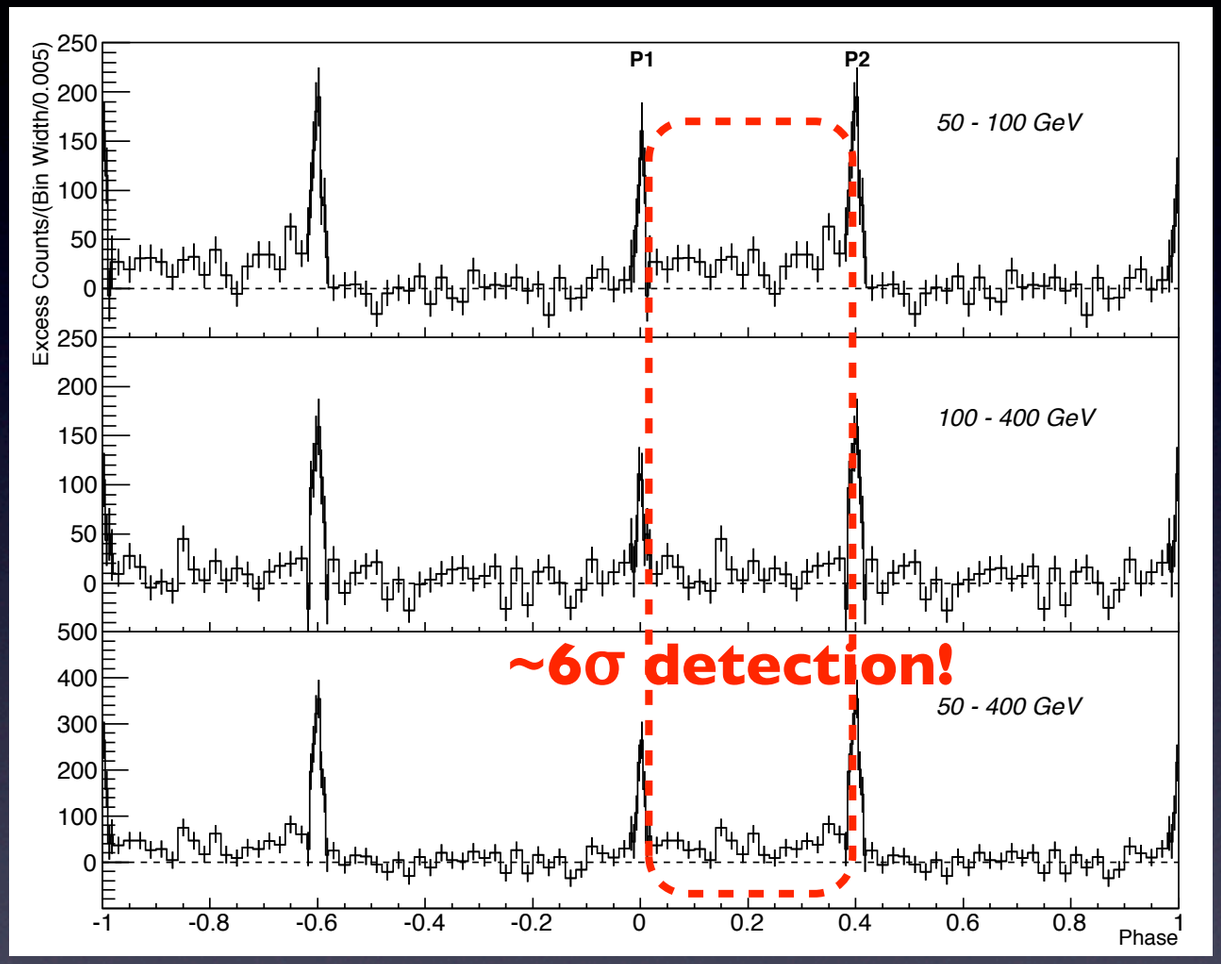


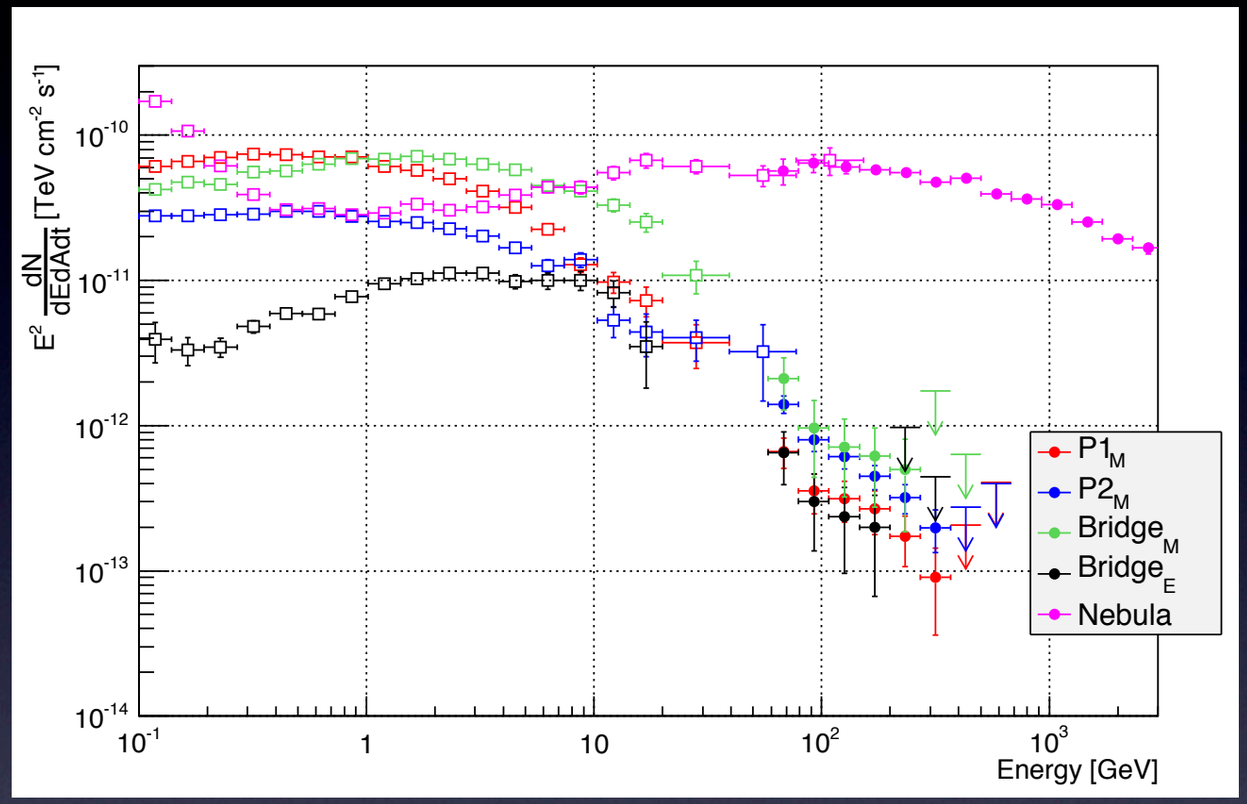


Bridge Emission

First detection of the bridge emission in the TeV energy!

Aleksic+14





Flatter spectrum in the Fermi range than those of the pulsed emission.

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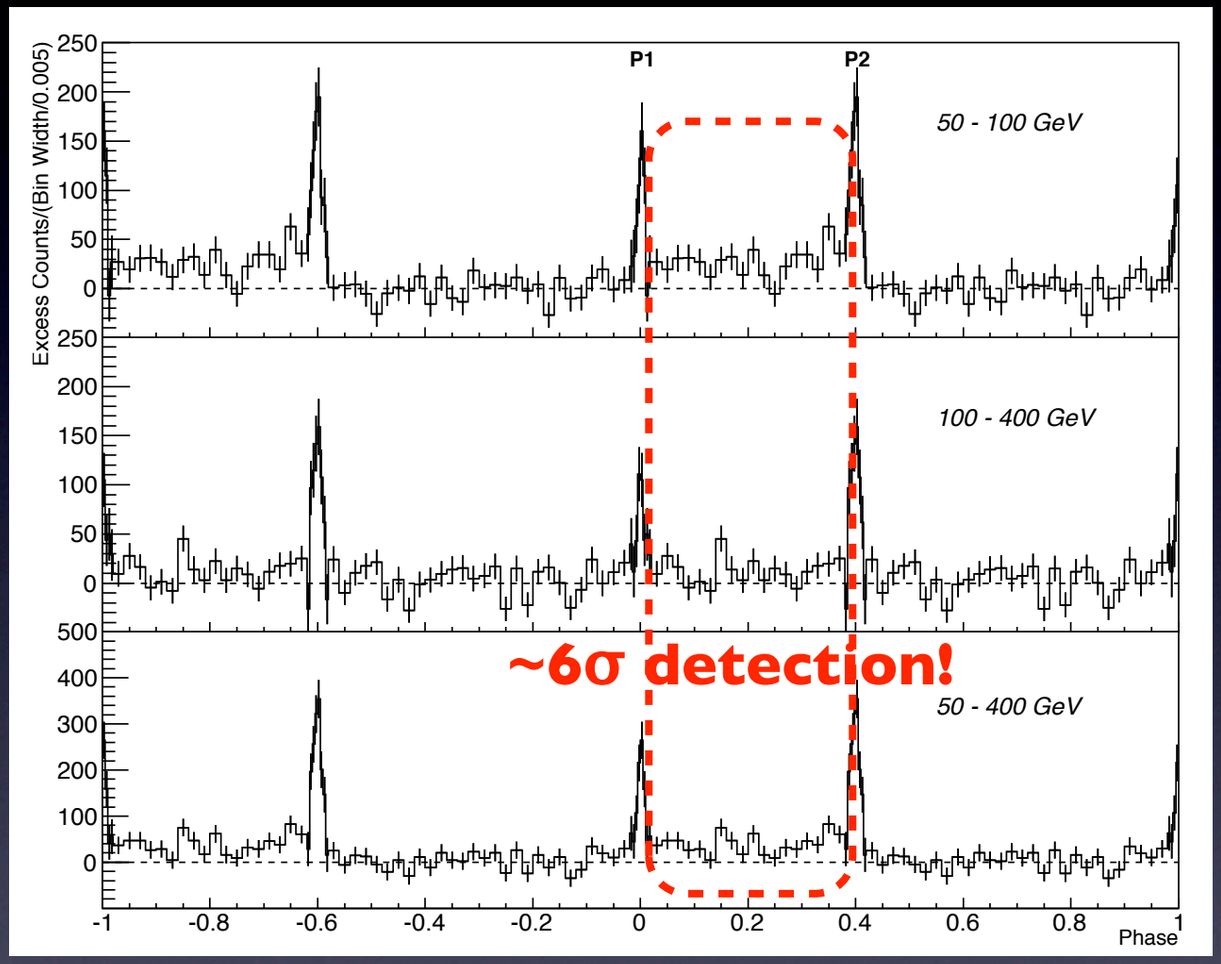

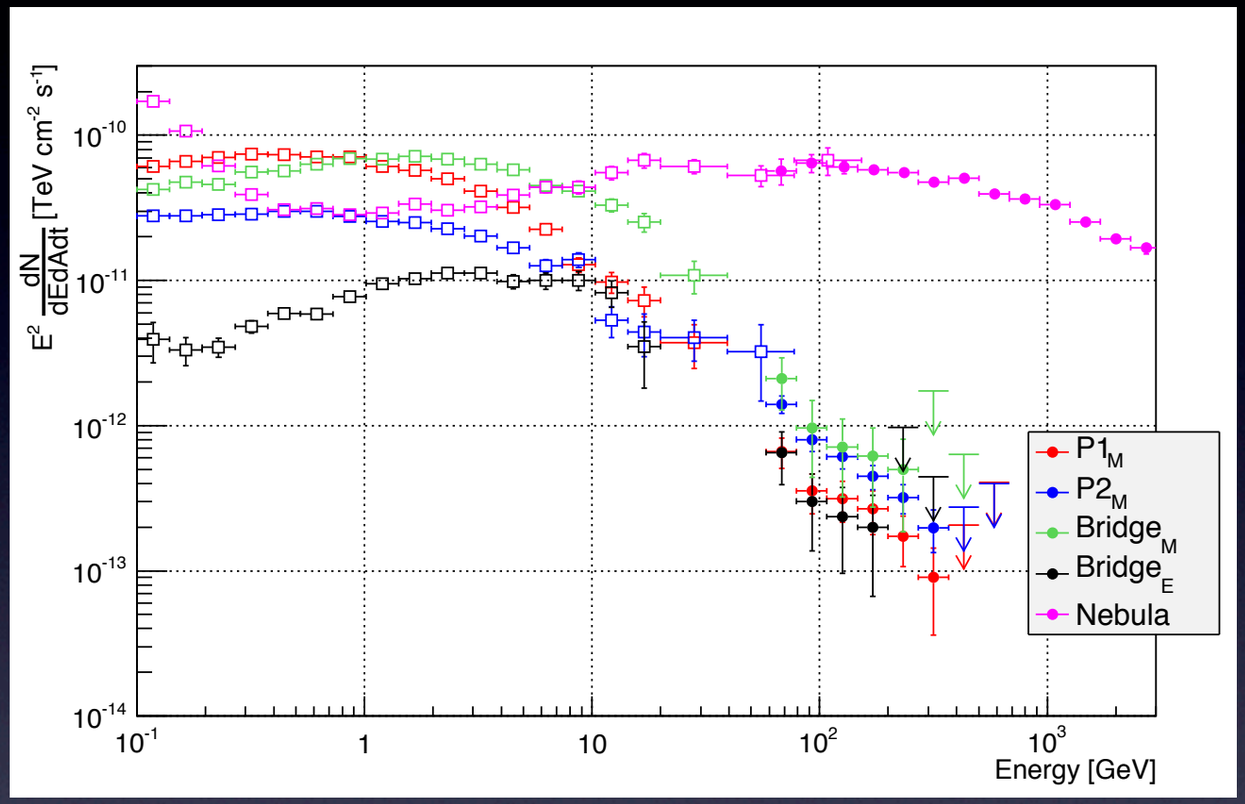

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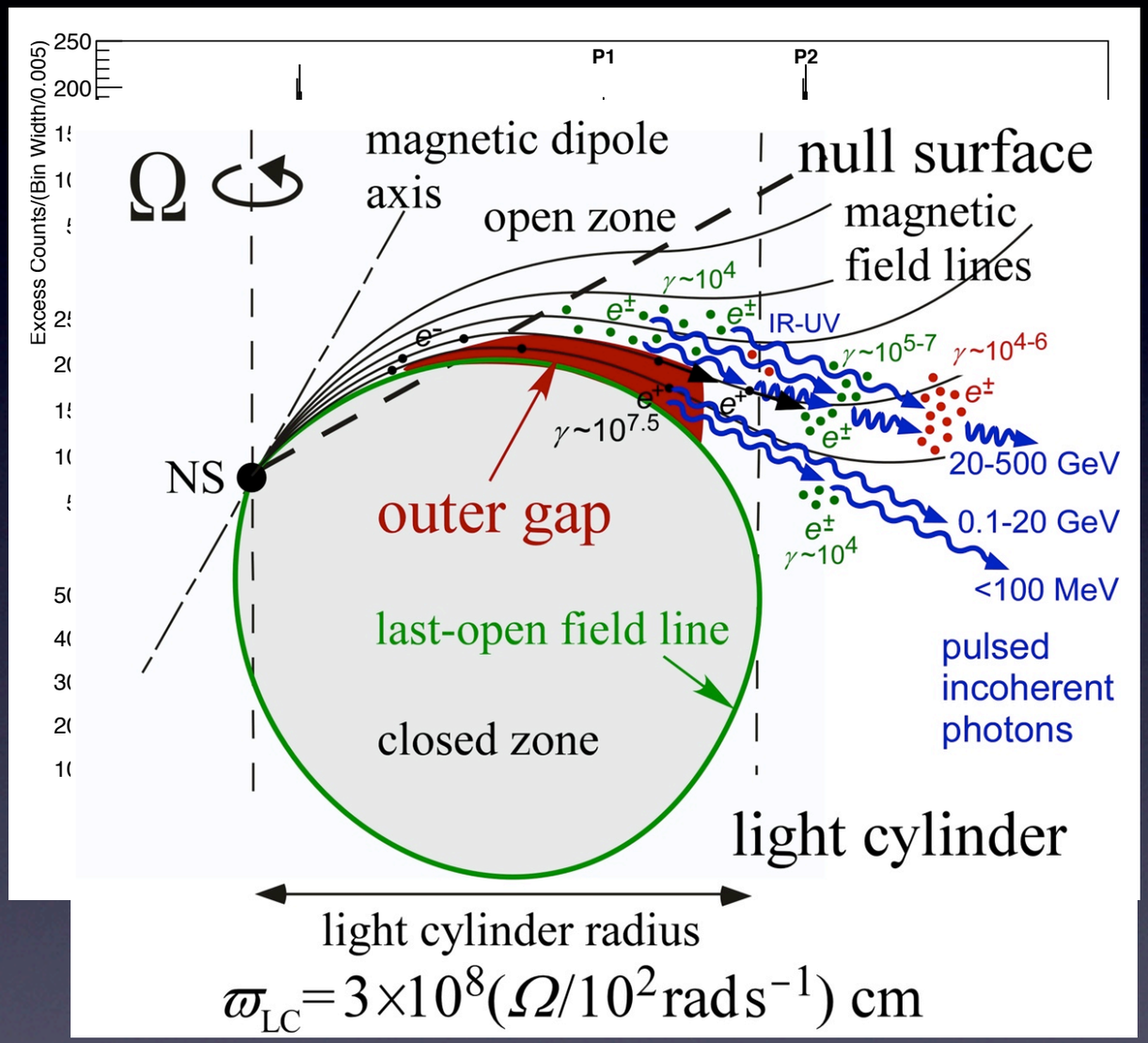

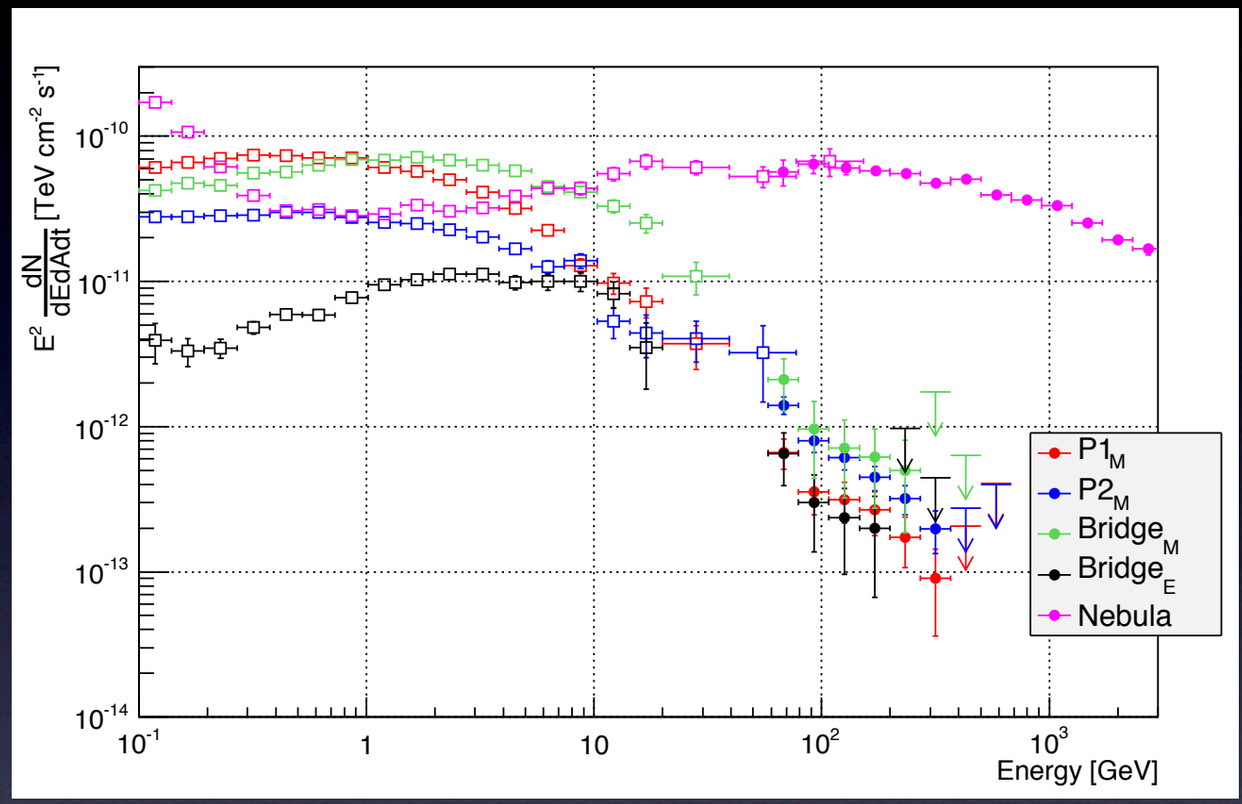

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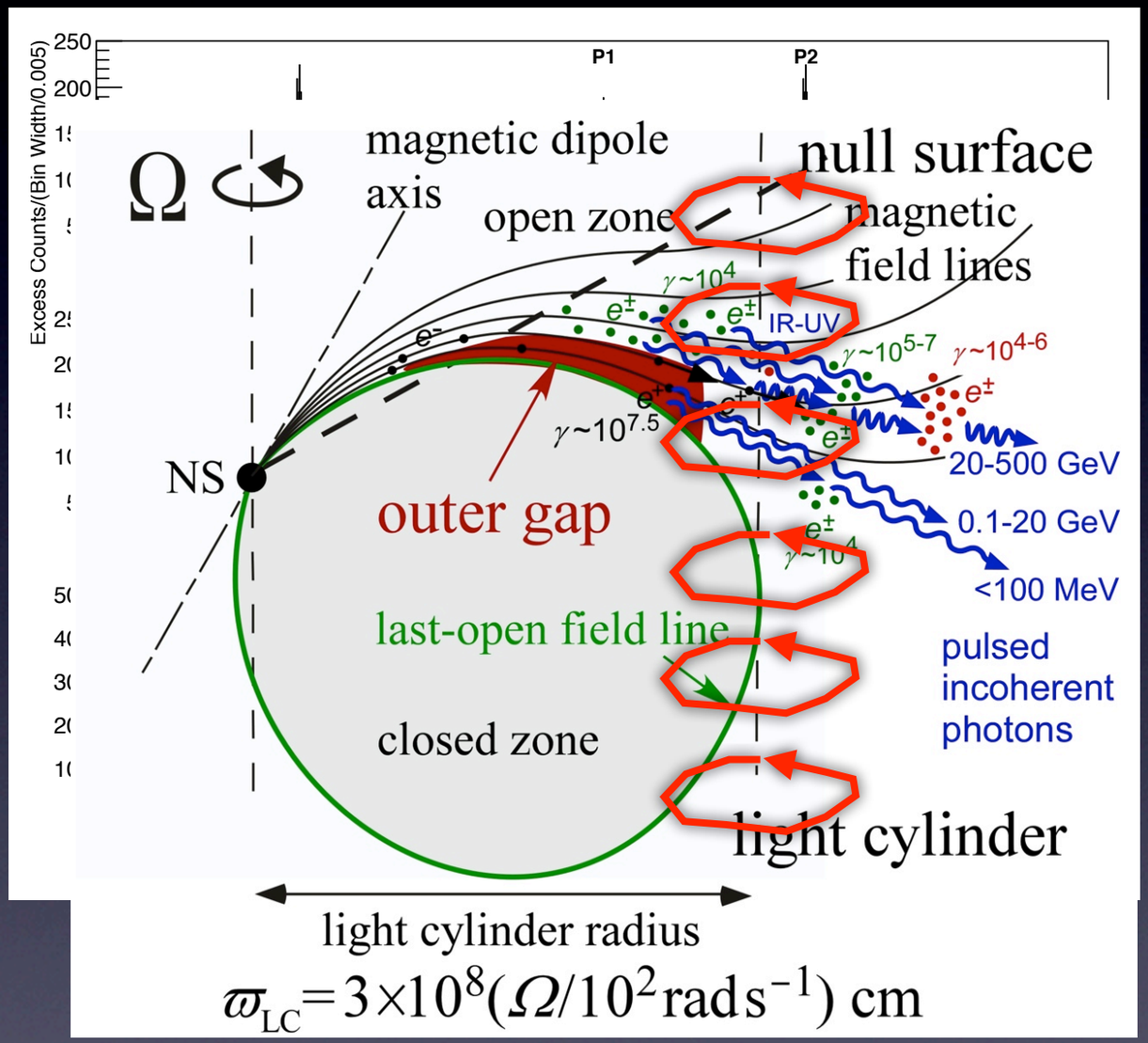

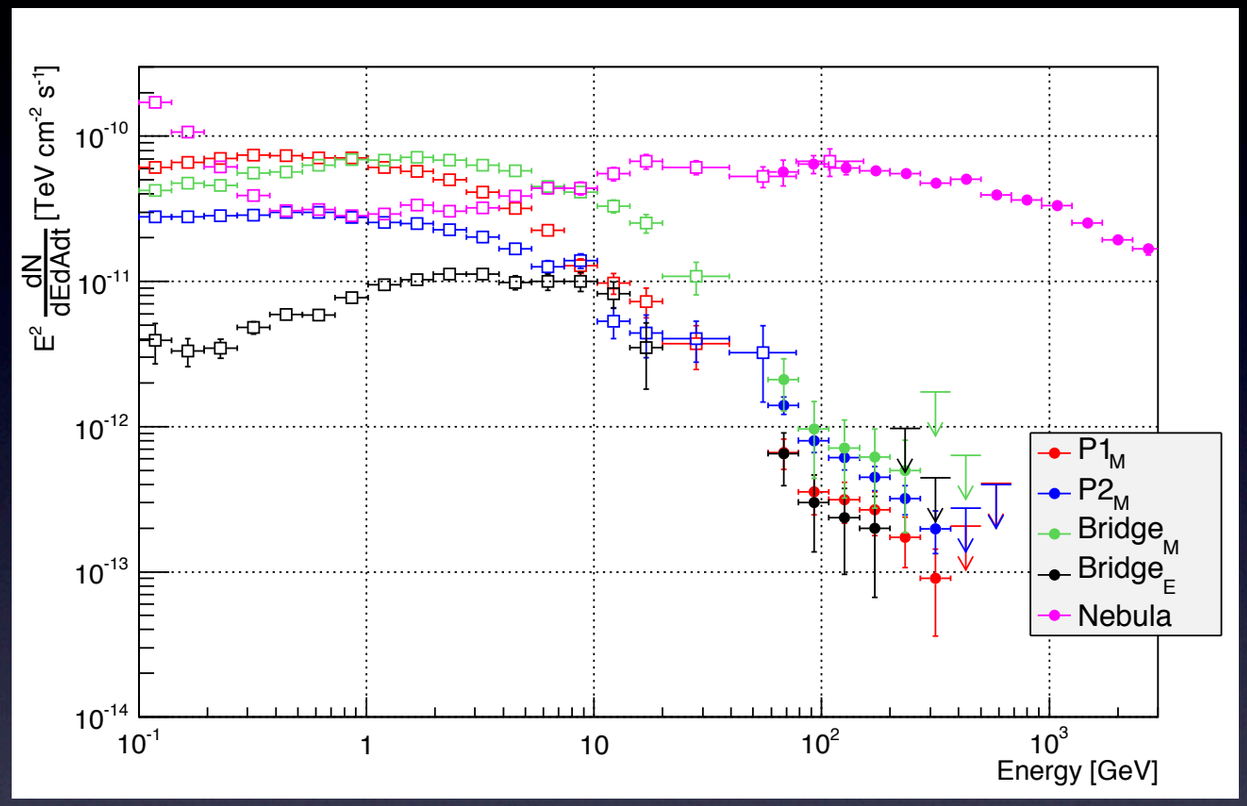

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Toroidal component of the magnetic field is expected to be enhanced around light cylinder.

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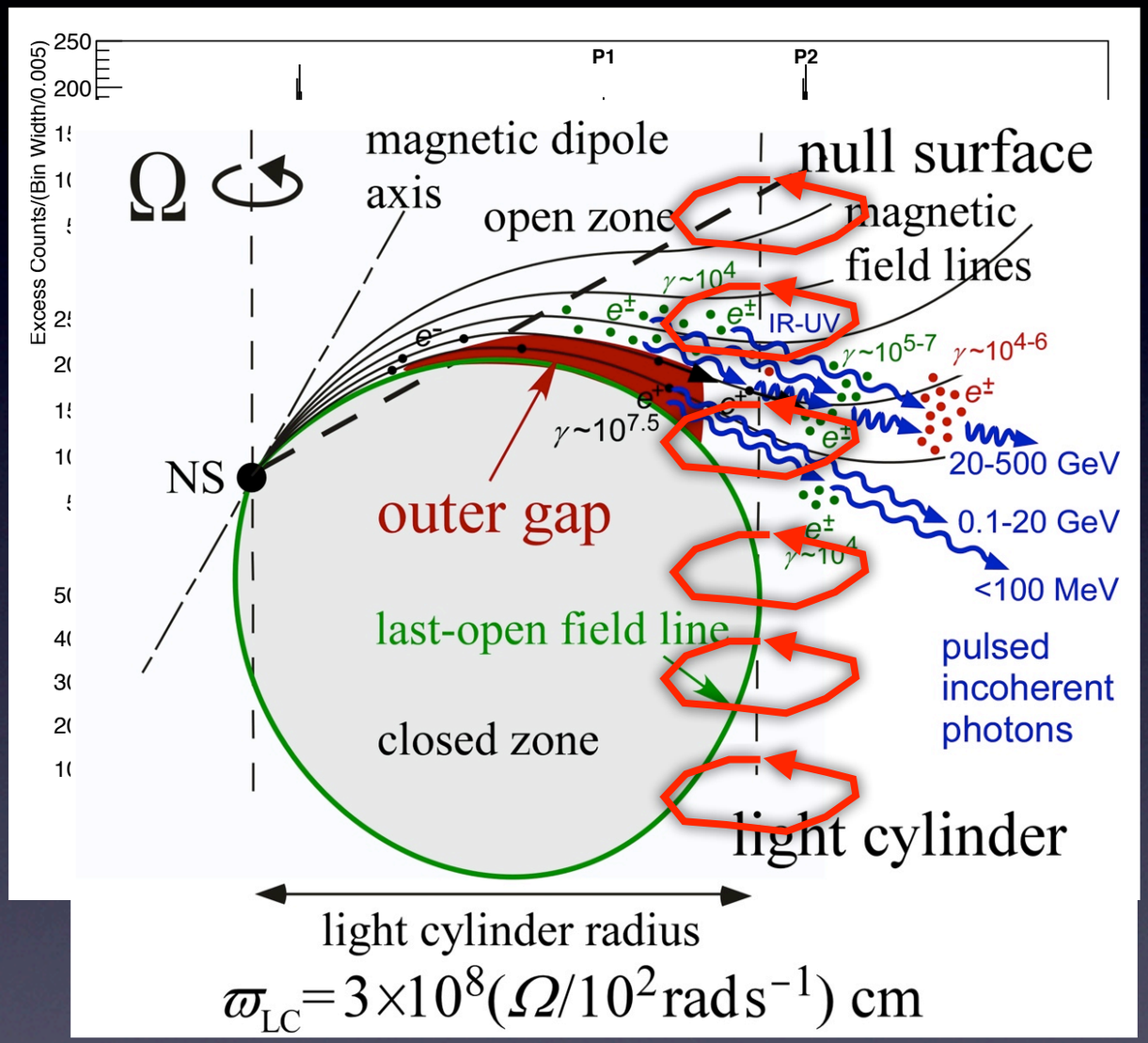
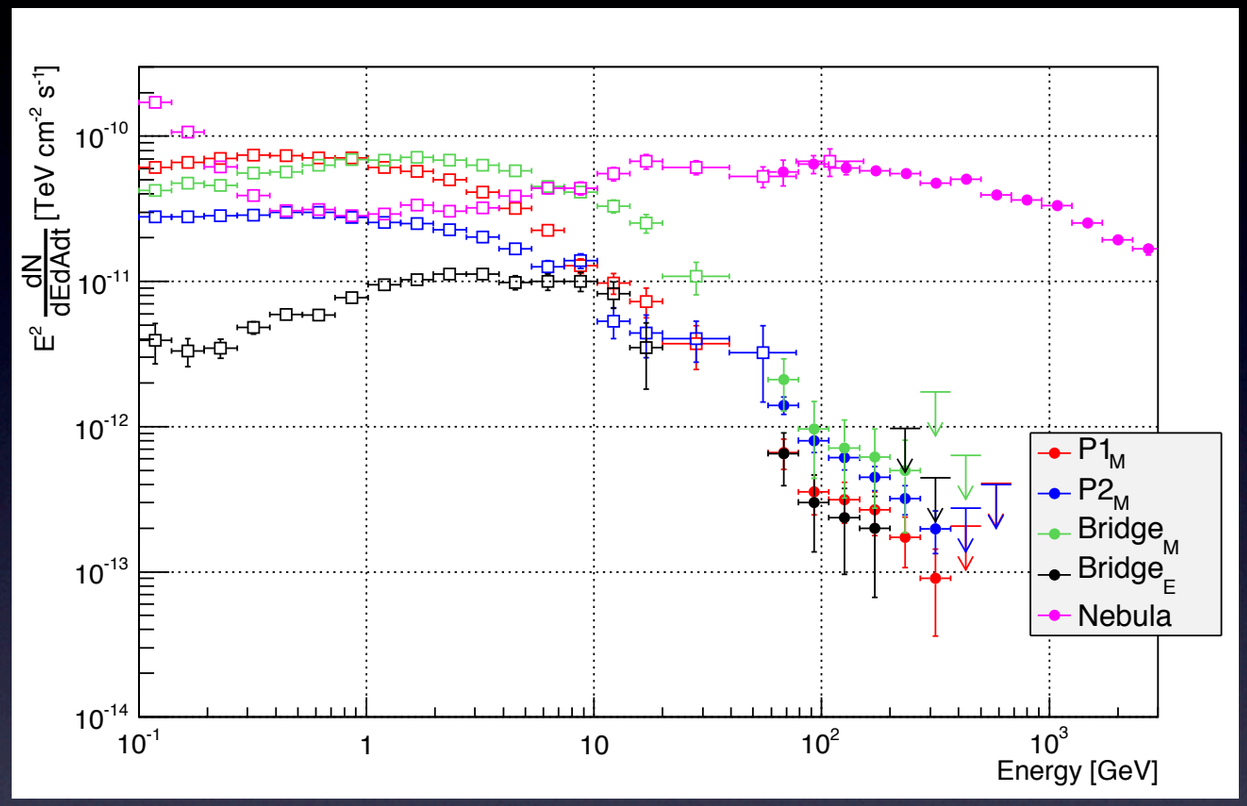


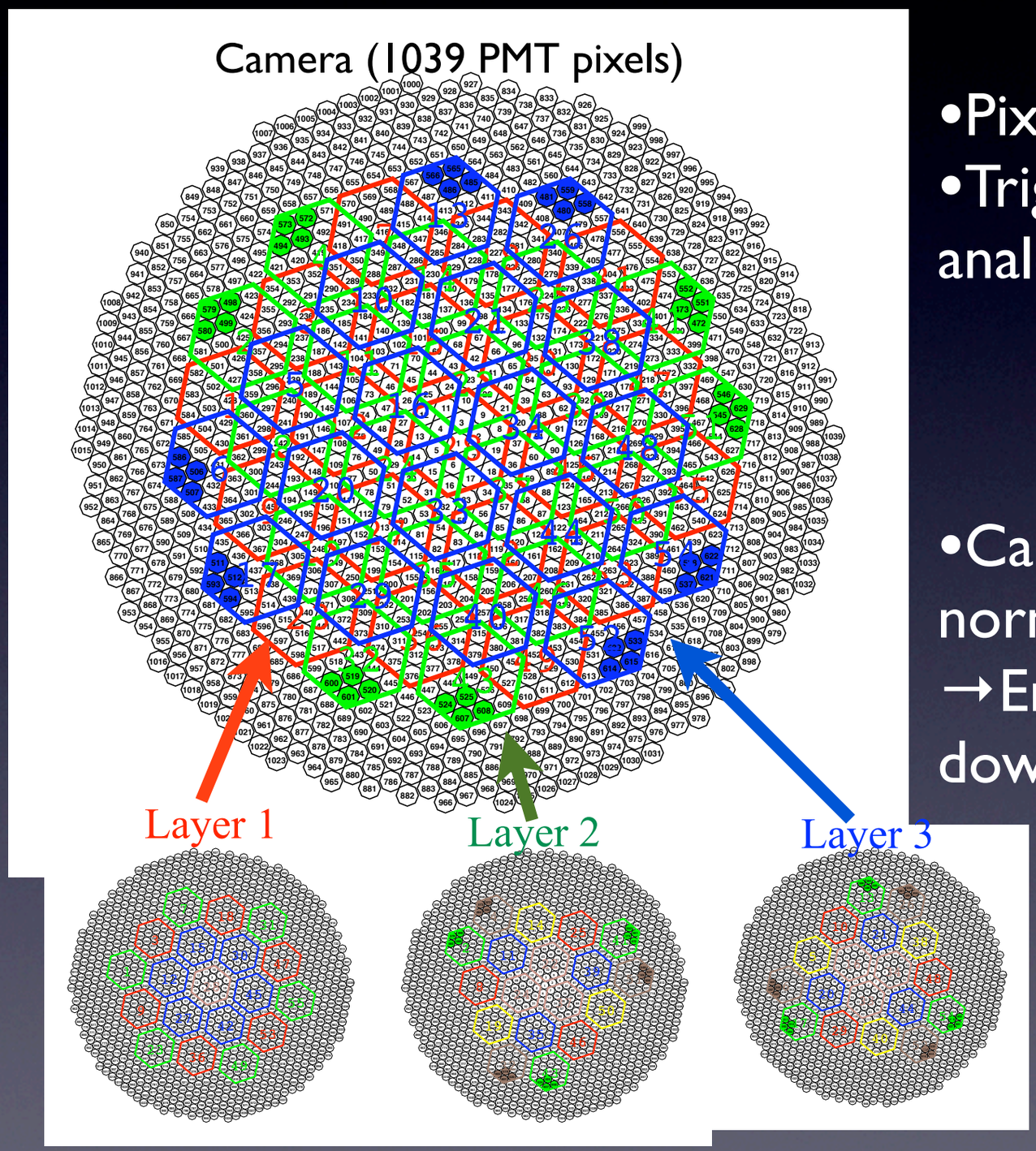


Flatter spectrum in the Fermi range than those of the pulsed emission.

Toroidal component of the magnetic field is expected to be enhanced around light cylinder.

→ No current model can explain the pulsed and bridge emission!

Searched for Tail Emission from Other Pulsars: Case of MAGIC



- Pixels are divided into 55 macro cells.
- Trigger is issued by summation of the analog signals in a macro cel.

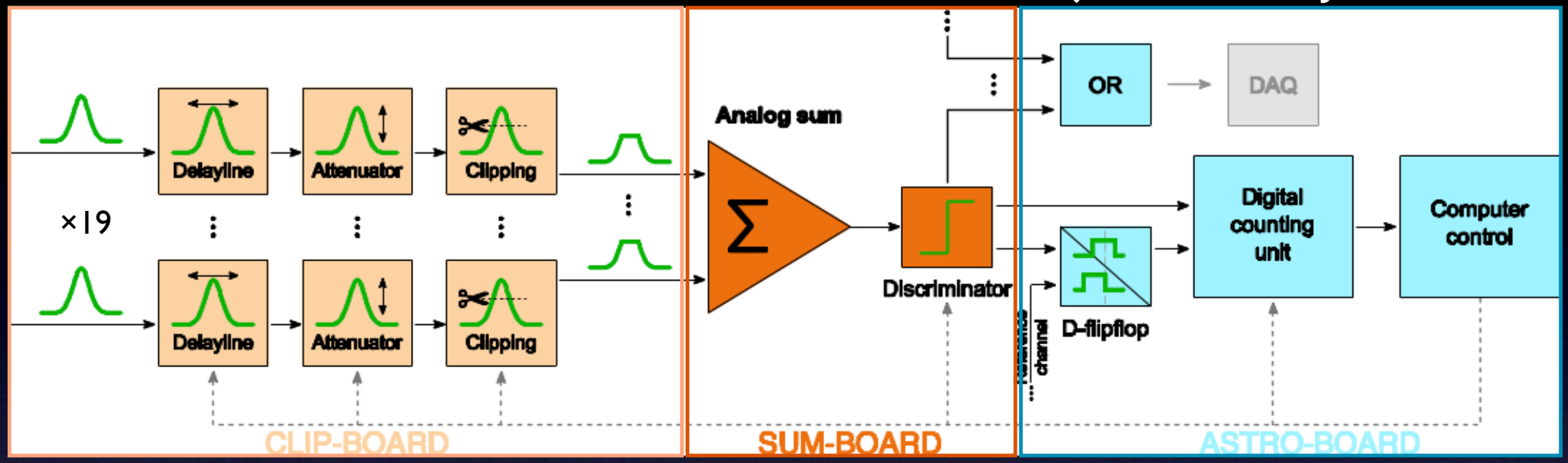
- Can trigger the even which we miss with normal trigger logic.

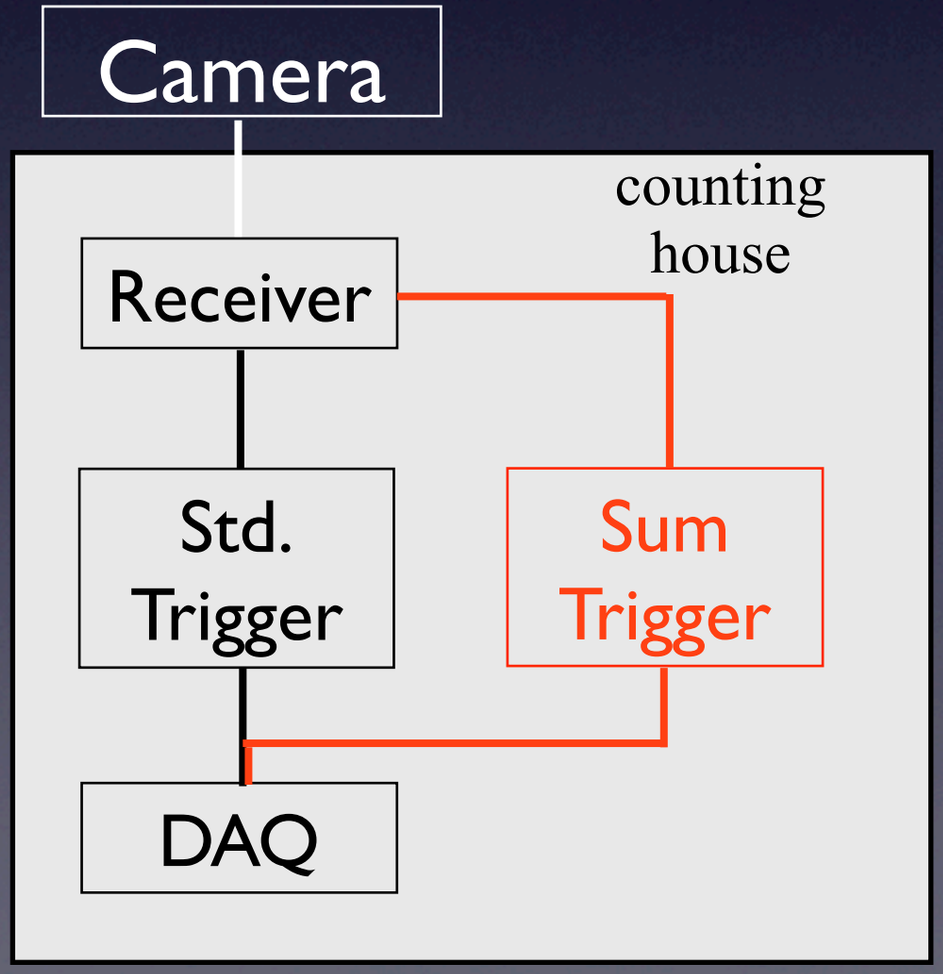
→Energy threshold is expected to go down to ~25 GeV.

LST will employ the same trigger logic.

Sum-Trigger

From D. Nakajima's talk at JPS 2014

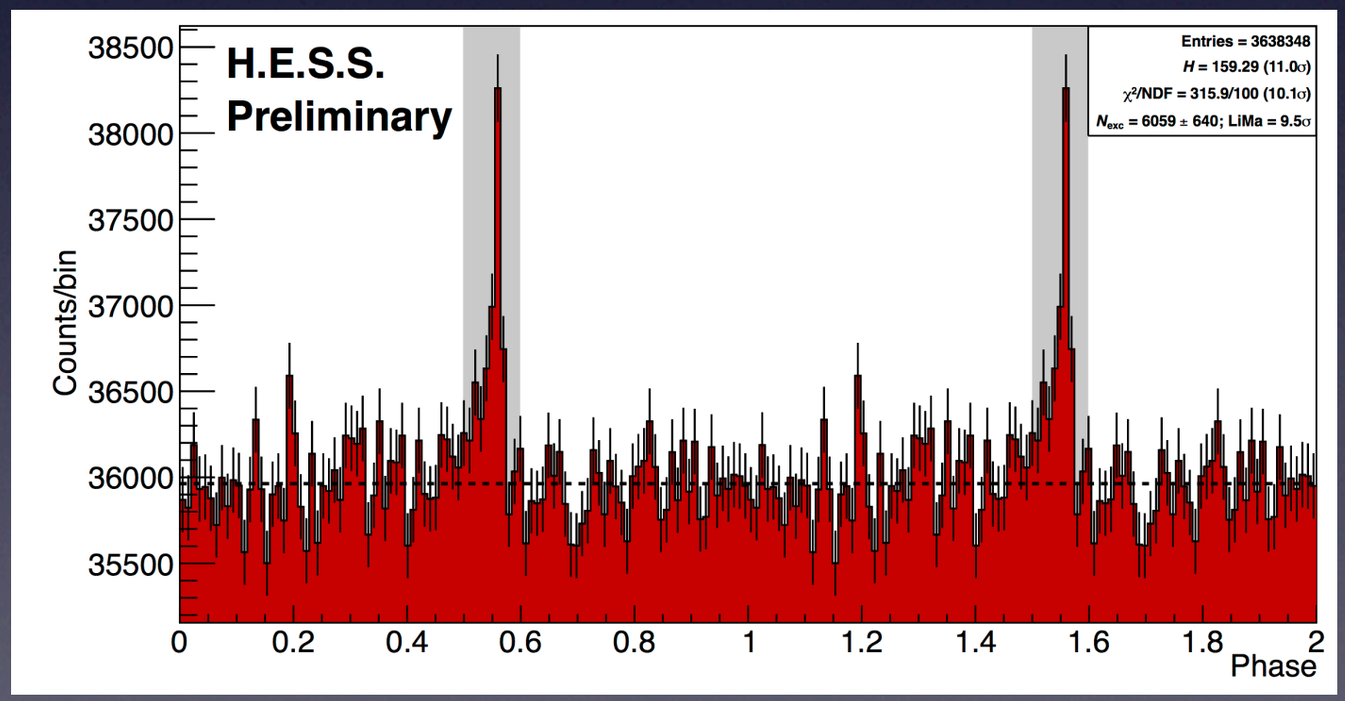


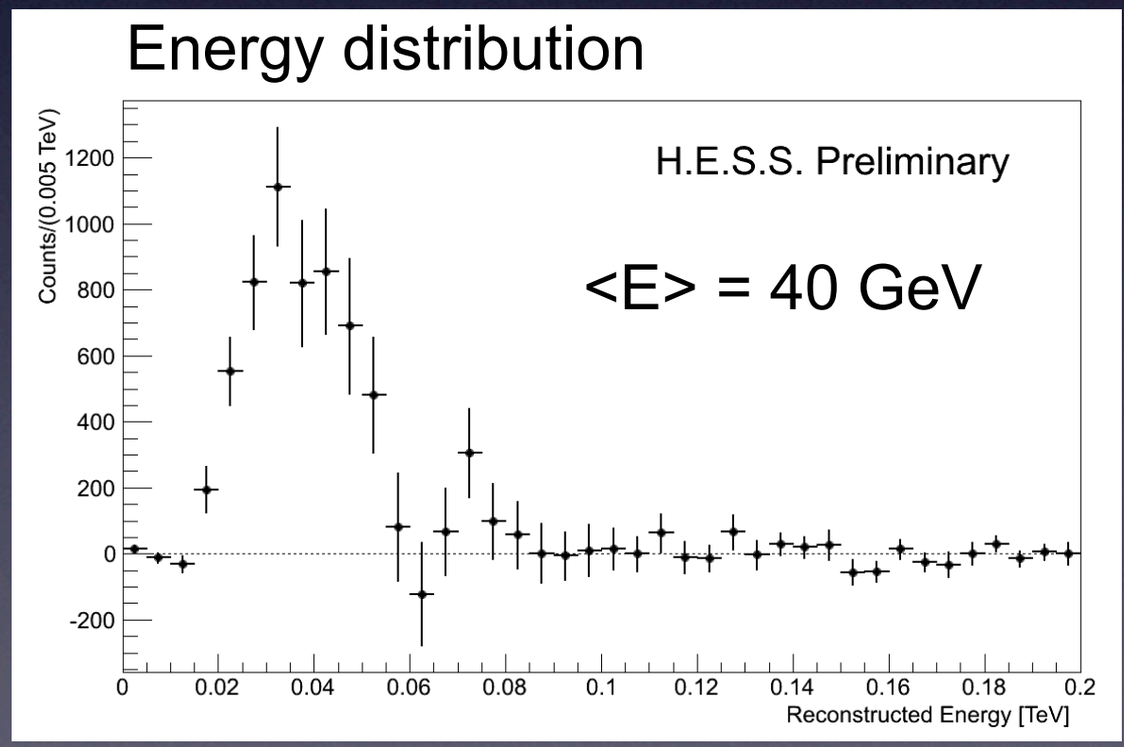


Installation was completed Nov. in 2013!!

Validation and performance check are ongoing.

Case of H.E.S.S.

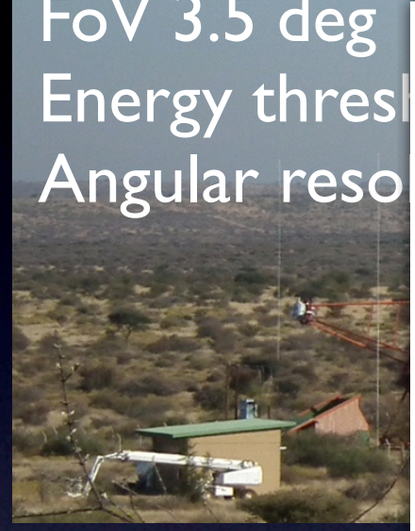


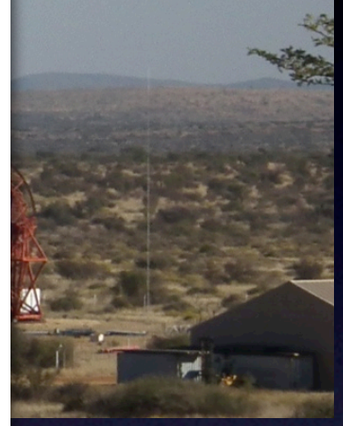


Vela pulsar was detected with 8σ.

Case of H.E.S.S.

28 m diameter telescope
FoV 3.5 deg
Energy thresh
Angular reso





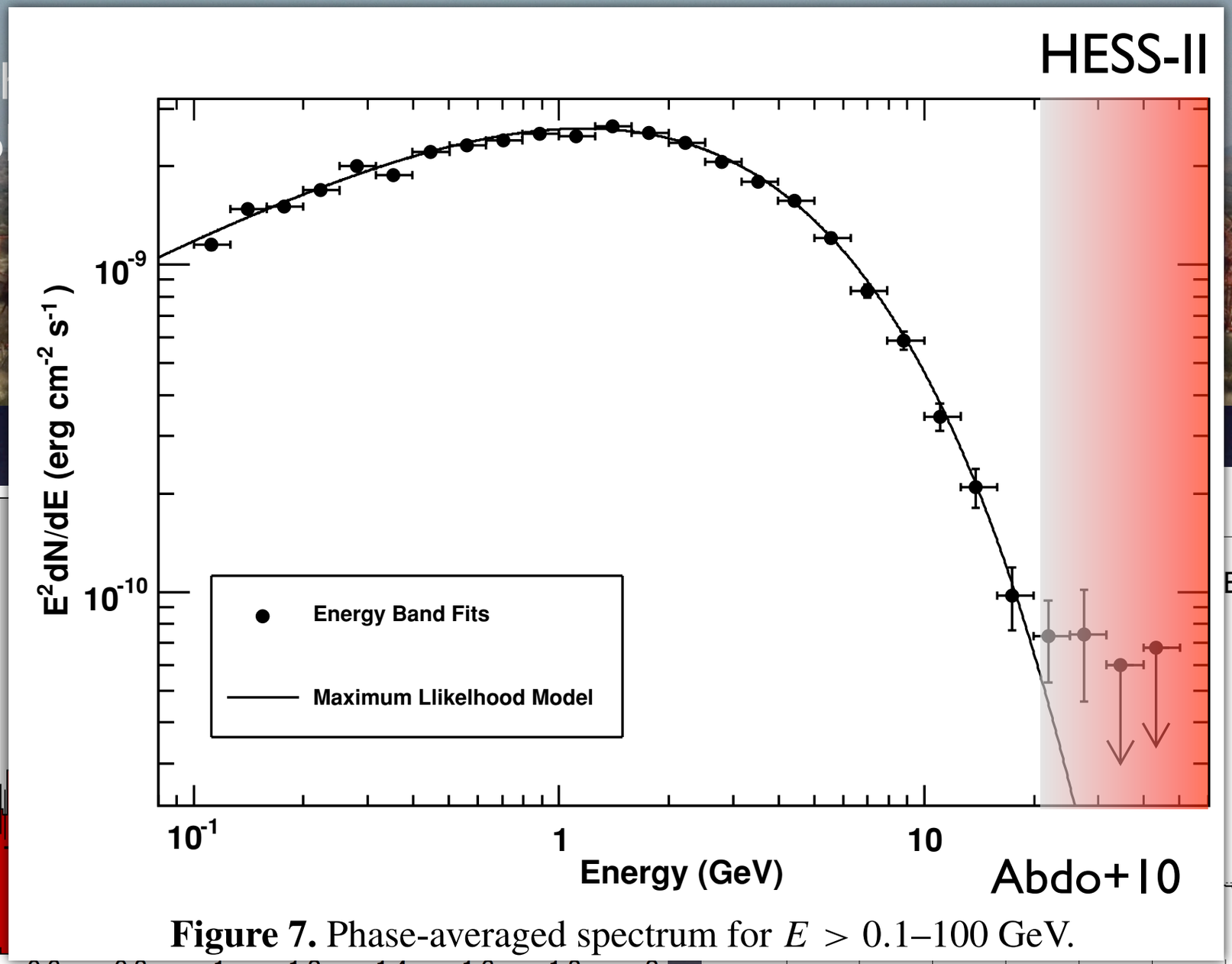


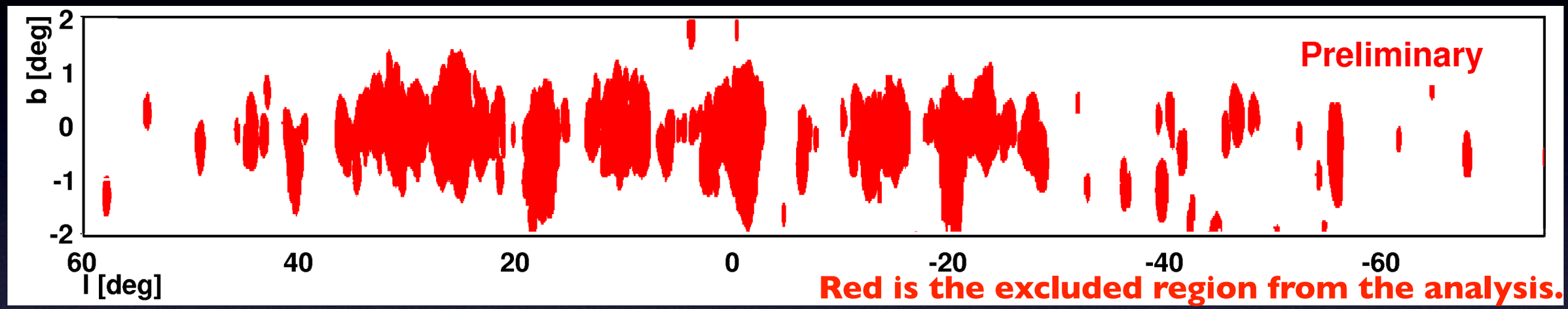
Figure 7. Phase-averaged spectrum for $E > 0.1$–100 GeV.

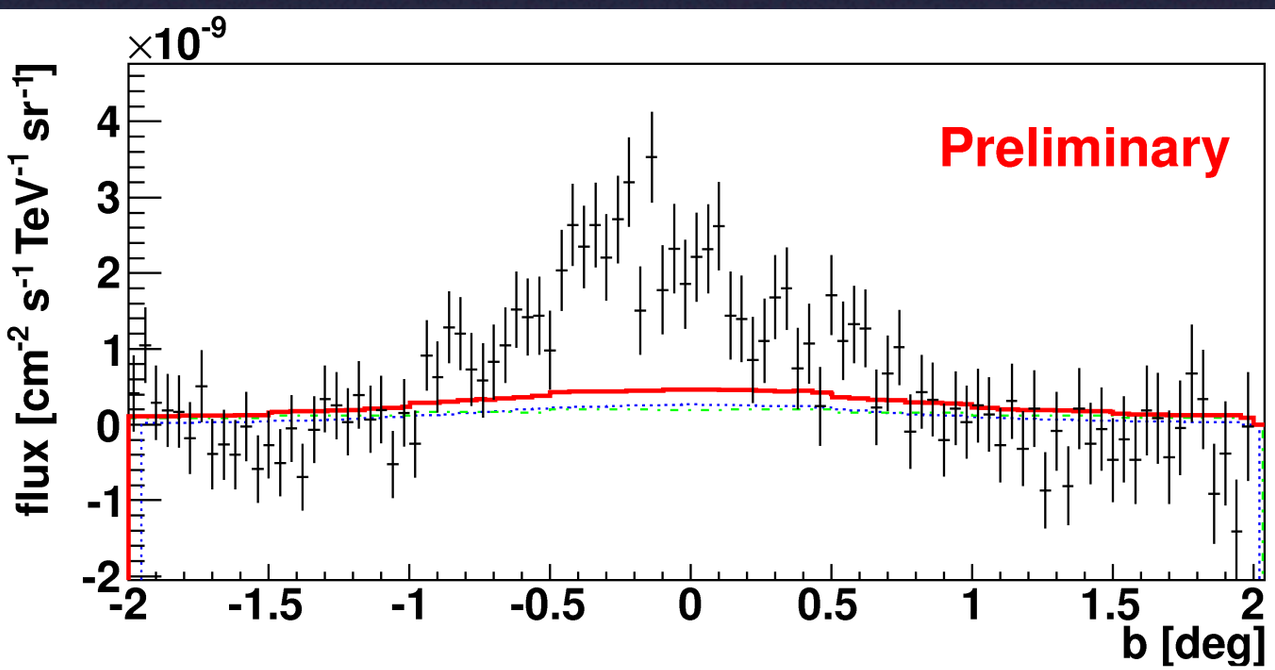
Vela pulsar was detected with 8σ.

Other News in Galactic Sources

Galactic Diffuse Emission

HESS detected the TeV gamma-ray from the diffuse emission (Egberts+14, arXiv1308.0161) ←More than 2000 h GPS data are used.





Red: Gamma-ray emission due to *p*-*p* collision assuming the CR spectrum at the Earth.

The intensity of the gamma-ray is fairly higher than predicted one assuming CR spectrum at the Earth.

↓

Contamination from unresolved sources? or due to nonlinear acceleration in SNR shocks?

Summary

- All three Cherenkov telescopes have been upgraded and realized very good performances.
- Improvement at lower energies.
- Sources with the parameters deviated from the ordinary ones have been also detected.
  - Detailed studies of unique sources is becoming possible in addition to the systematic studies.
- We can do good science even before starting the operation of CTA.