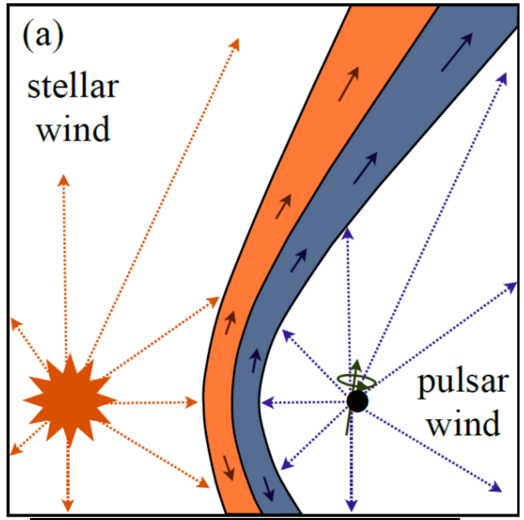
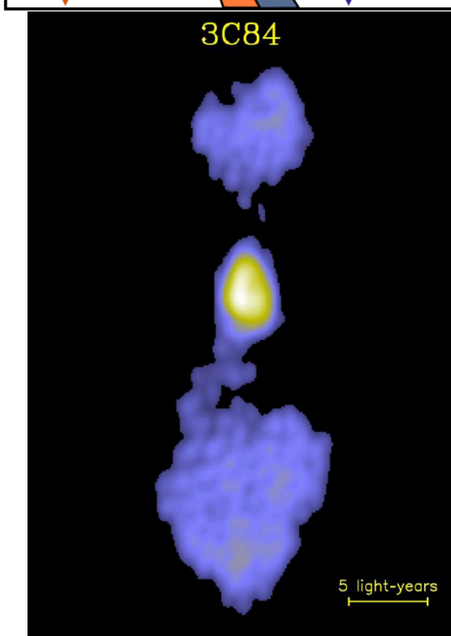
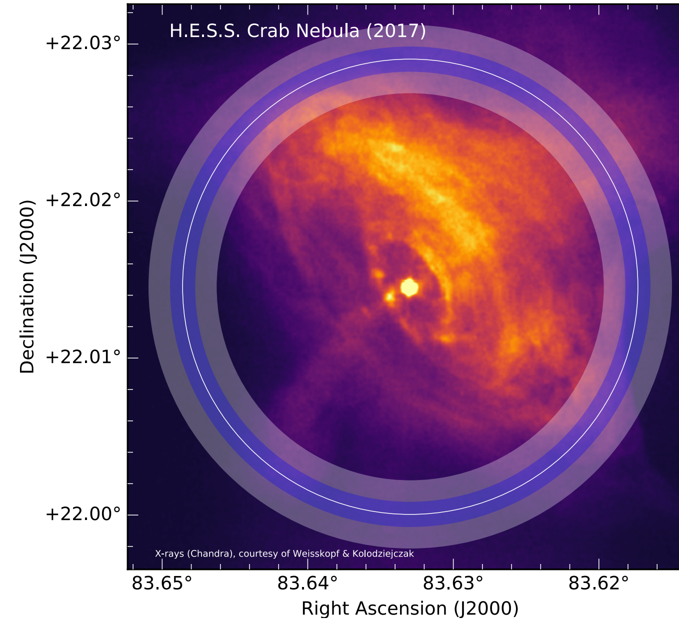
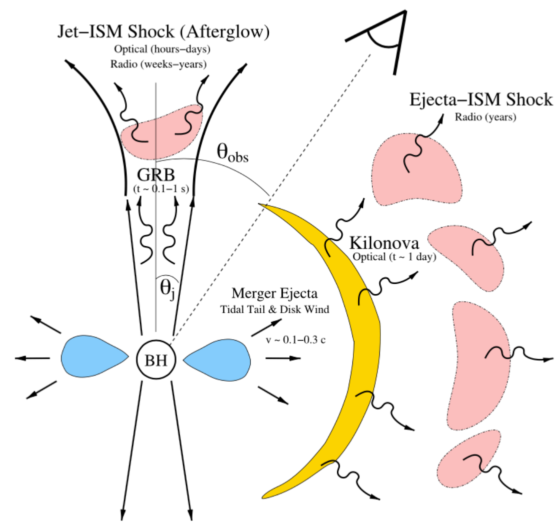
Astroparticle Physics at DESY-Zeuthen

Cosmic Labs:









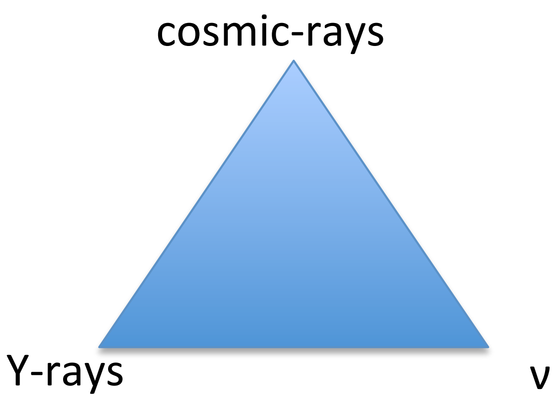
19 October 2017
Hamburg, Germany

Astropart. Physics @DESY Experiments

- Gamma-ray
  - HESS
  - MAGIC
  - VERITAS
  - TAIGA
  - CTA
  - Fermi
- Neutrino
  - IceCube

High Impact of Astropart. Groups-

ICRC 2017 (Busan, South Korea)



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Cosmic Labs

Energy Information
Temporal Information
Angular Information

- Gamma-rays: Elisa Pueschel (Highlight talk)
- Neutrinos: Jakob van Santen (Highlight talk)
  Markus Ackermann (Rapporteur talk)
- Theory: Andrew Taylor (Review talk)

Subgroups Large Impact

ICRC 2017

Coll./Consort.	Total: Talks (Cont.)	DESY: Talks (Cont.)
Fermi	16 (21)	0 (0)
HESS	21 (36)	3 (12)
MAGIC	13 (20)	0 (7)
VERITAS	12 (20)	3 (4)
CTA	11 (32)	0 (4)
TAIGA	4 (7)	1 (2)
IceCube	21 (58)	3 (6)
TOTAL	98 (194)	10 (35)

The bottom line from this table is that DESY punched well above its weight at this year's ICRC....one can of course carry out a similar comparison with other big Astroparticles phyiscs conferences such as TeVPA

Group Highlights- MAGIC

Energy Info.
Temporal Info.

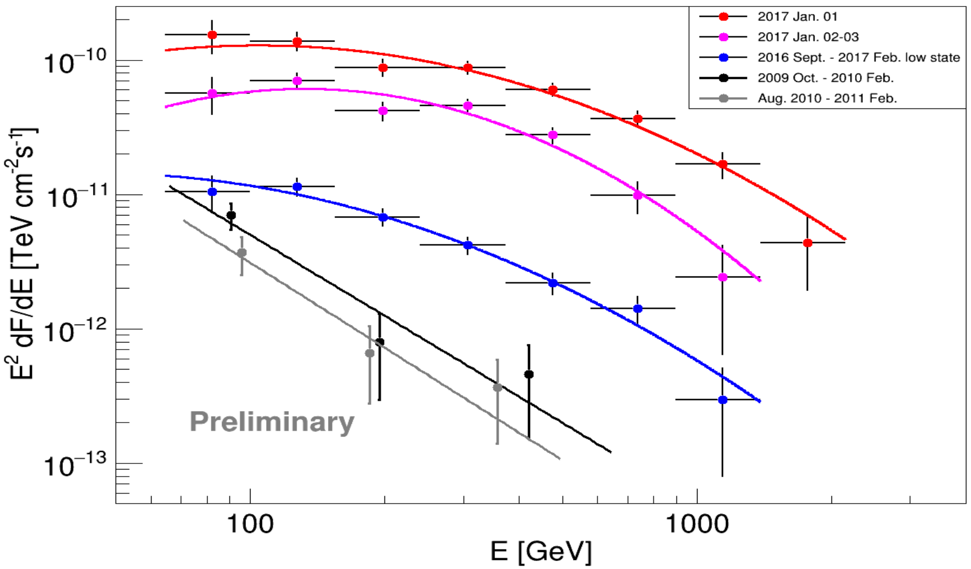
Flare of the misaligned AGN NGC1275

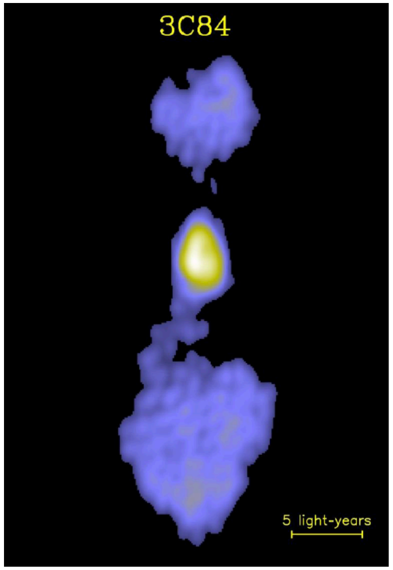
- first time TeV emission
- fast variability timescale ~1/2 day

$$t_{var} = \eta(R_{Schwarz.}/c)$$

(For $t_{var} \approx 10$ hrs $\eta \approx 20$, $M_{BH} \approx 3 \times 10^8\ M_\odot$)

- **Atels issued: ATel #9203, ATel #9929**





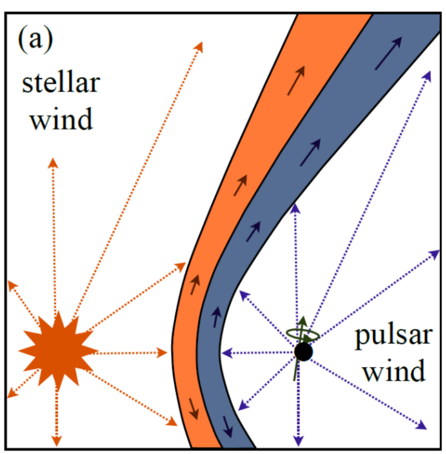
Group Highlights- VERITAS

Energy Info.
Temporal Info.

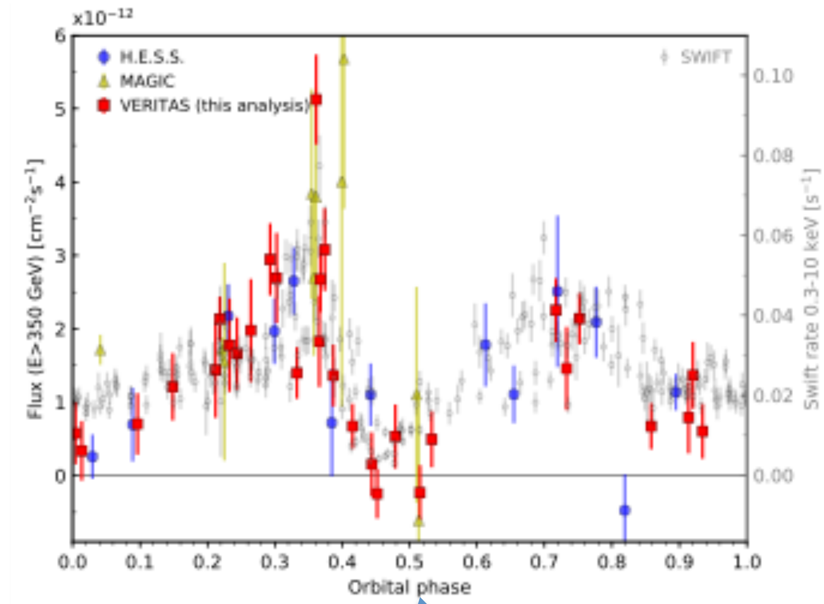
γ-ray binary, long (315±5 day) period 11 years of observations → long term study of flux/spectral variability

Long term observations key for understanding electron acceleration in this source

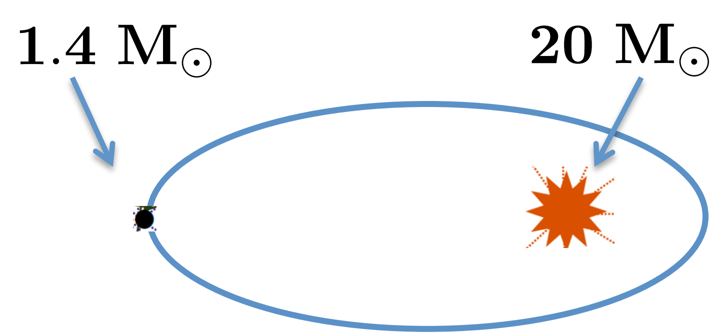
Colliding Wind Accelerator



HESS J0632+057



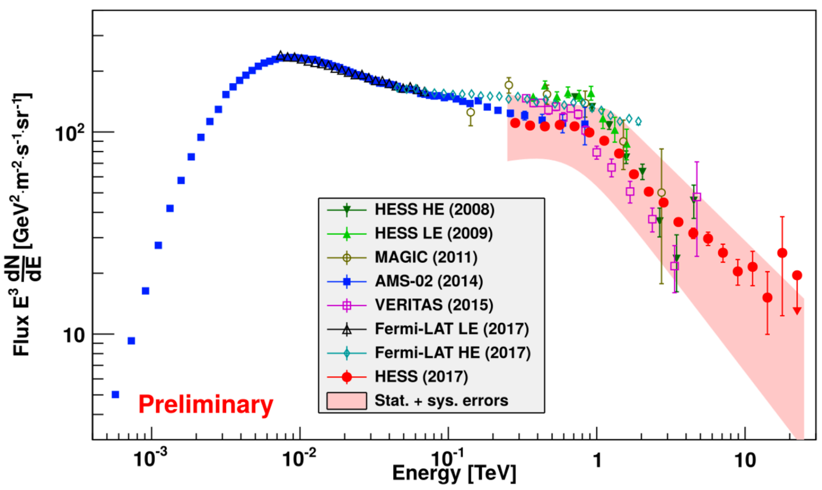
apastron



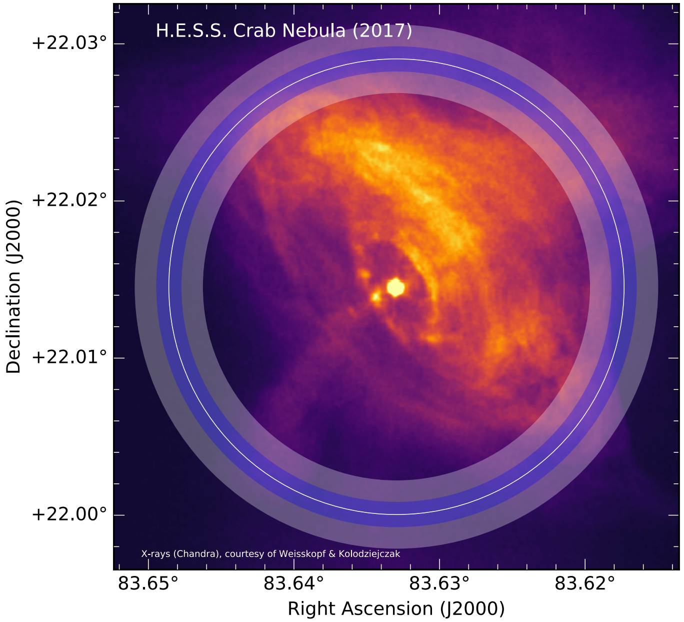
Group Highlights- HESS

Energy Info.
Temporal Info.
Angular info.

- The CR e^- spectrum up to ~20 TeV [(SOM, 09/17)](#)



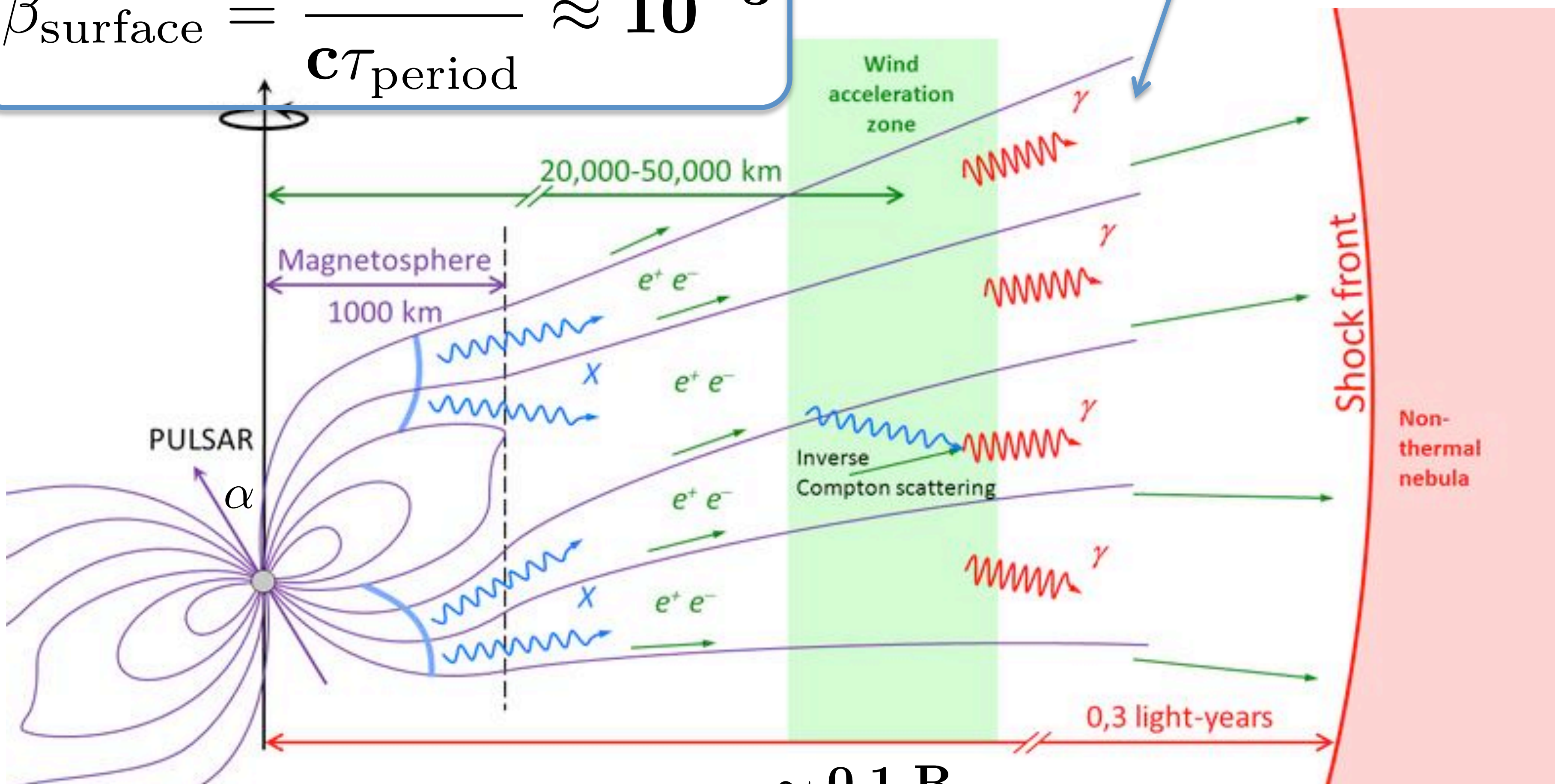
- Crab extension (a standard candle for astronomy)



The Crab Nebula: the rotational energy drain

$$\beta_{\mathrm{surface}} = \frac{2\pi \mathbf{R}_{\mathrm{NS}}}{\mathbf{c}\tau_{\mathrm{period}}} \approx \mathbf{10^{-3}}$$

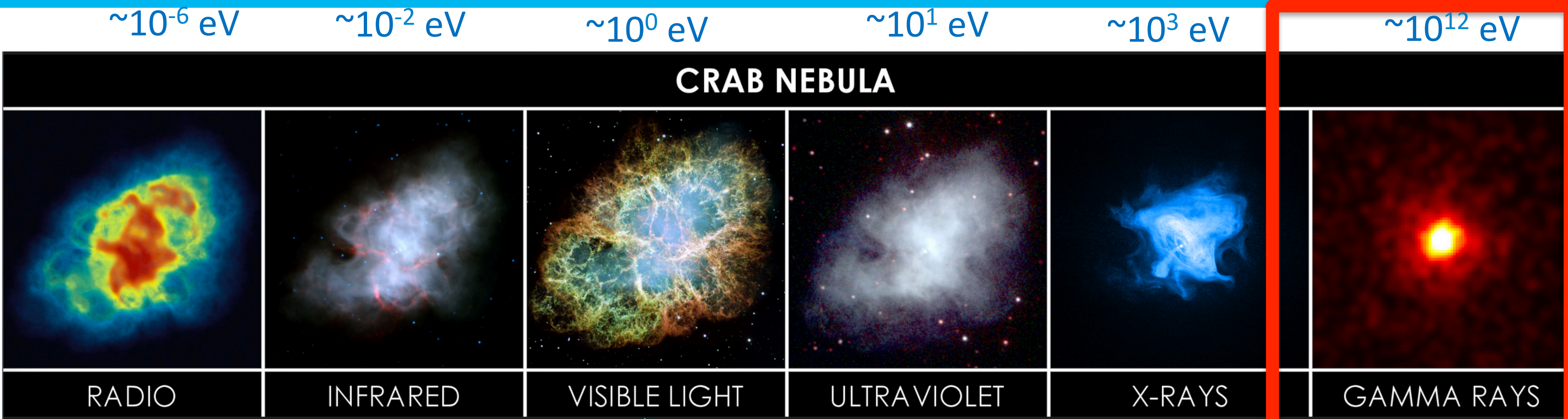
highly relativistic wind ($\mathbf{\Gamma} \sim \mathbf{10^4}$)



$\sim \mathbf{0.1\ R_\odot}$

The Crab- a True Cosmic Laboratory

Before 2017: point-like γ-ray emission



$$P_{s.d.} \approx 5 \times 10^{38} \text{ erg s}^{-1}$$

$$P_{\gamma} \approx 10^{37} \text{ erg s}^{-1}$$

Rotational Spindown

↓

Poynting Flux

↓

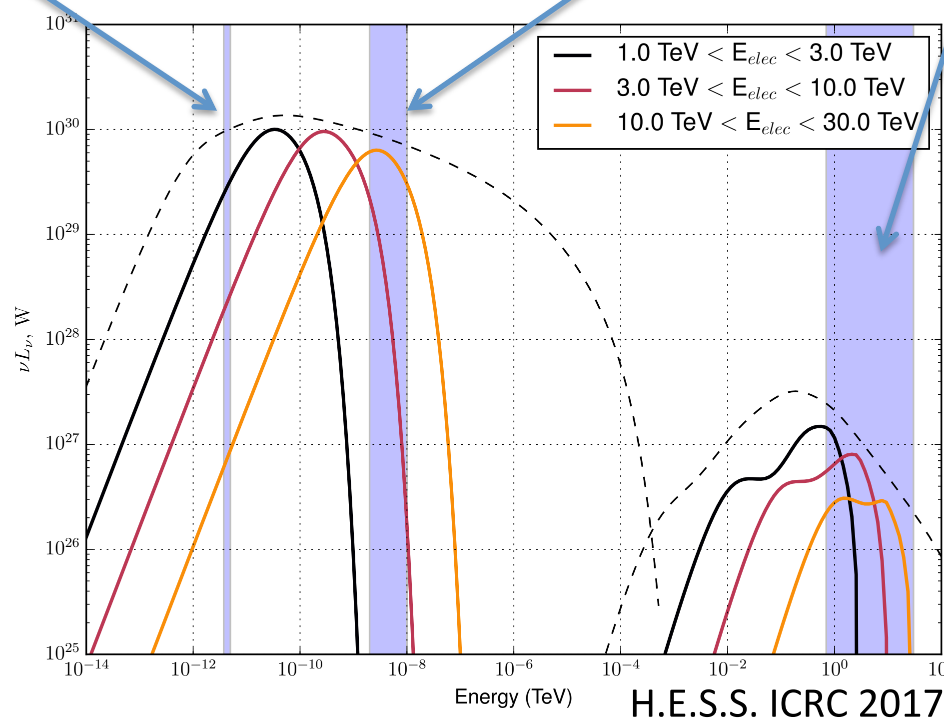
Wind

↓

Cosmic Rays

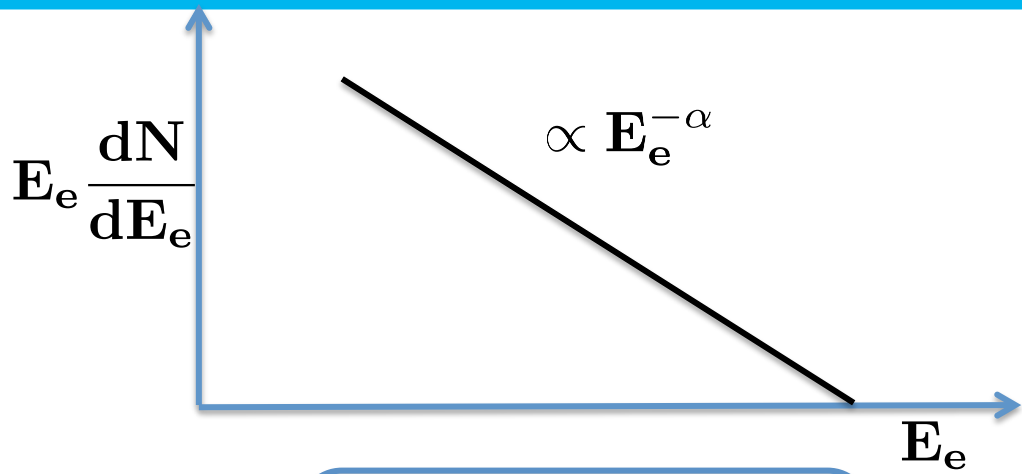
↓

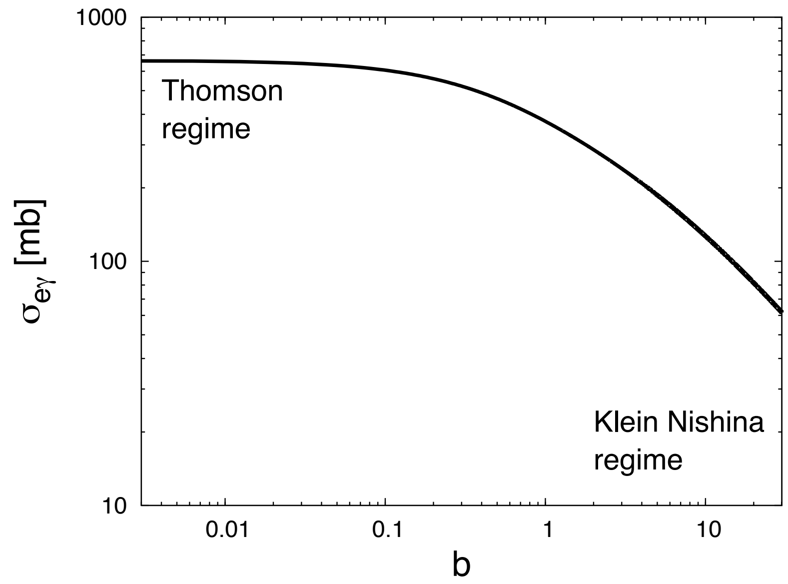
Gamma Rays



H.E.S.S. ICRC 2017

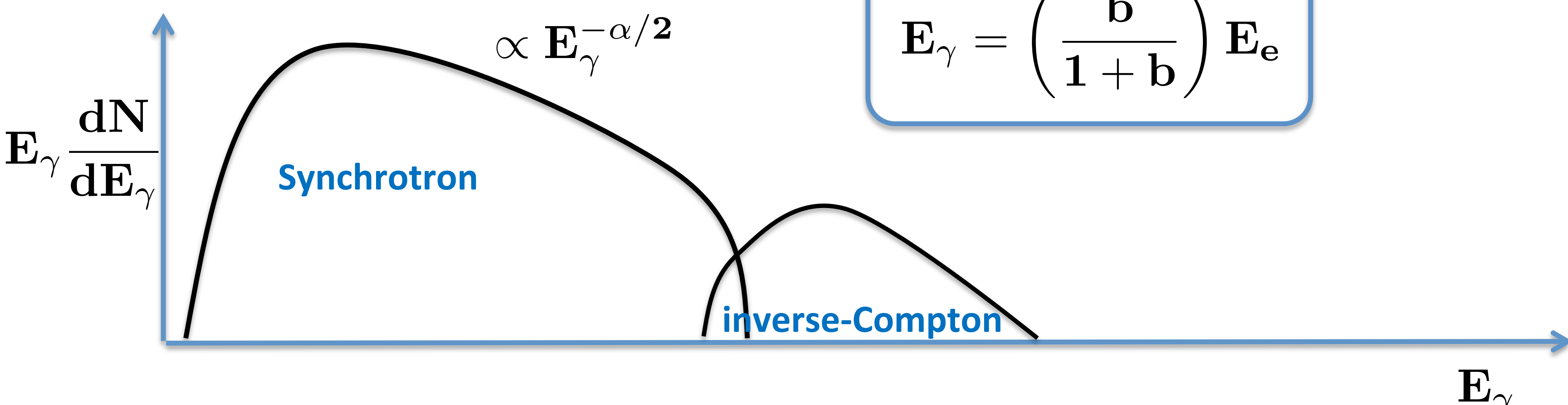
Crab Emission- Electron Cooling and Emission





$$\mathbf{E}_\gamma \approx \gamma_e^2 \left(\frac{\mathbf{B}}{\mathbf{B}_{\mathrm{crit}}} \right) \mathbf{m}_e = \mathbf{b}\mathbf{E}_e$$

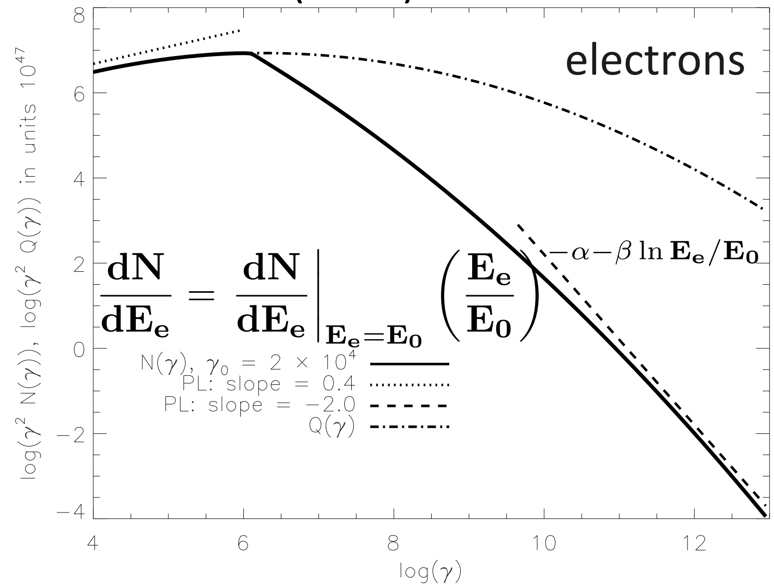
$$\mathbf{E}_\gamma = \left(\frac{\mathbf{b}}{1+\mathbf{b}} \right) \mathbf{E}_e$$

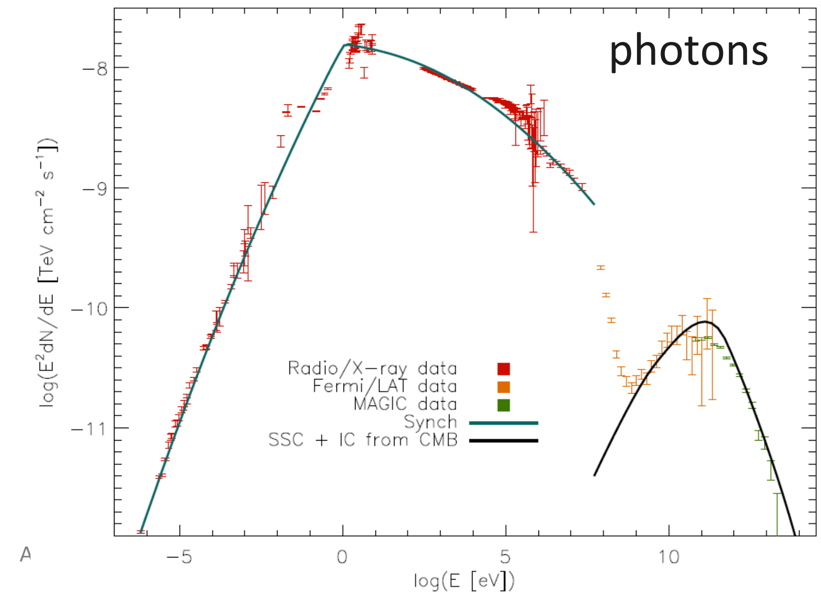


Particle Acceleration in Pulsar Wind Nebulae

- **Spectrum evolved: source, energy loss, etc.**
- **Best fit with log-parabola as source spectrum**
- **Deviation from power law**
- **Reflects details of acceleration process**

Fraschetti and Pohl (2017) **MNRAS 471 4856**





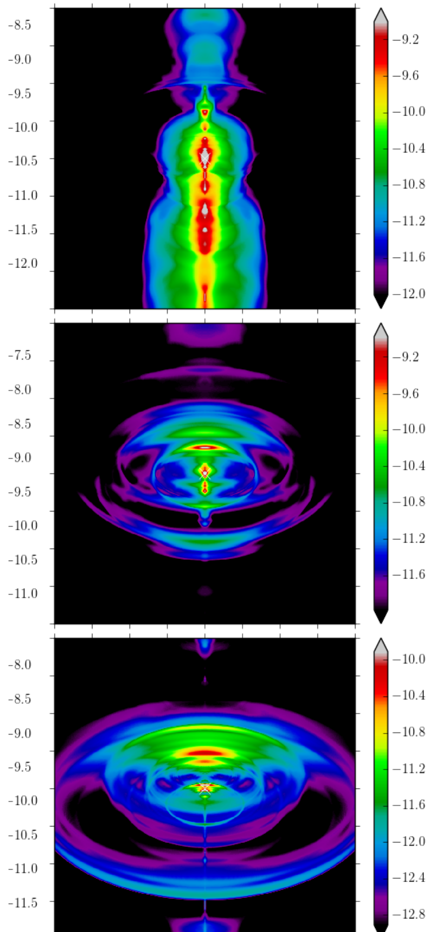
Simulations of Outflow from the Crab

Follow **turbulence** and **acceleration** over nine decades in scales:

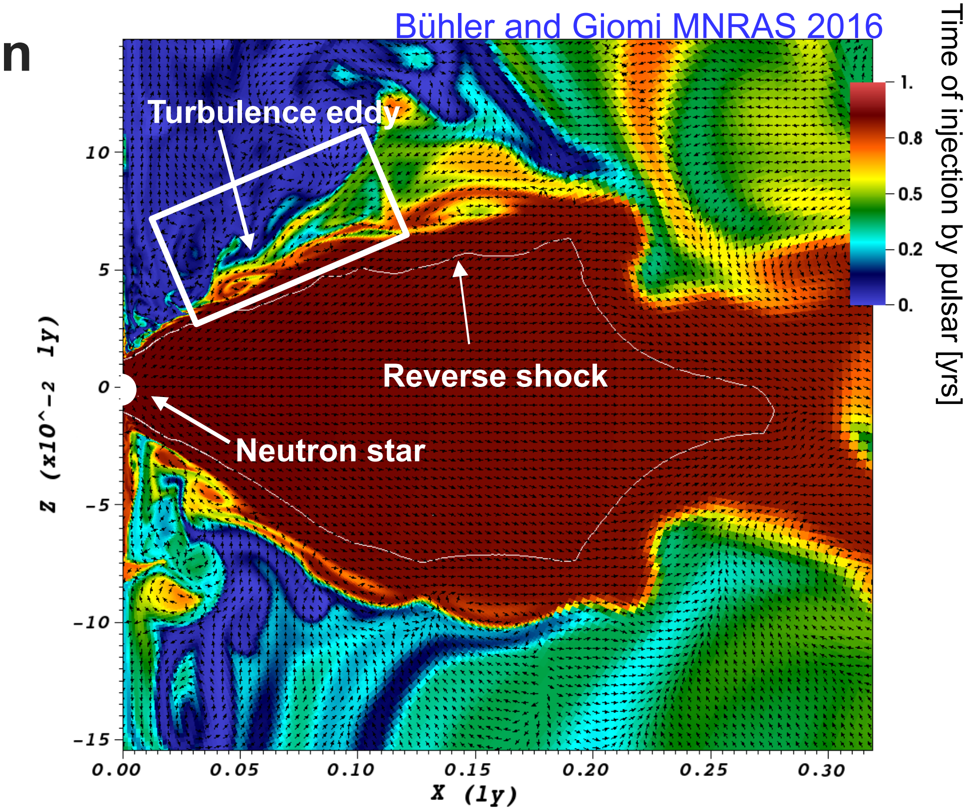
$\alpha = 10^\circ$

$\alpha = 45^\circ$

$\alpha = 80^\circ$

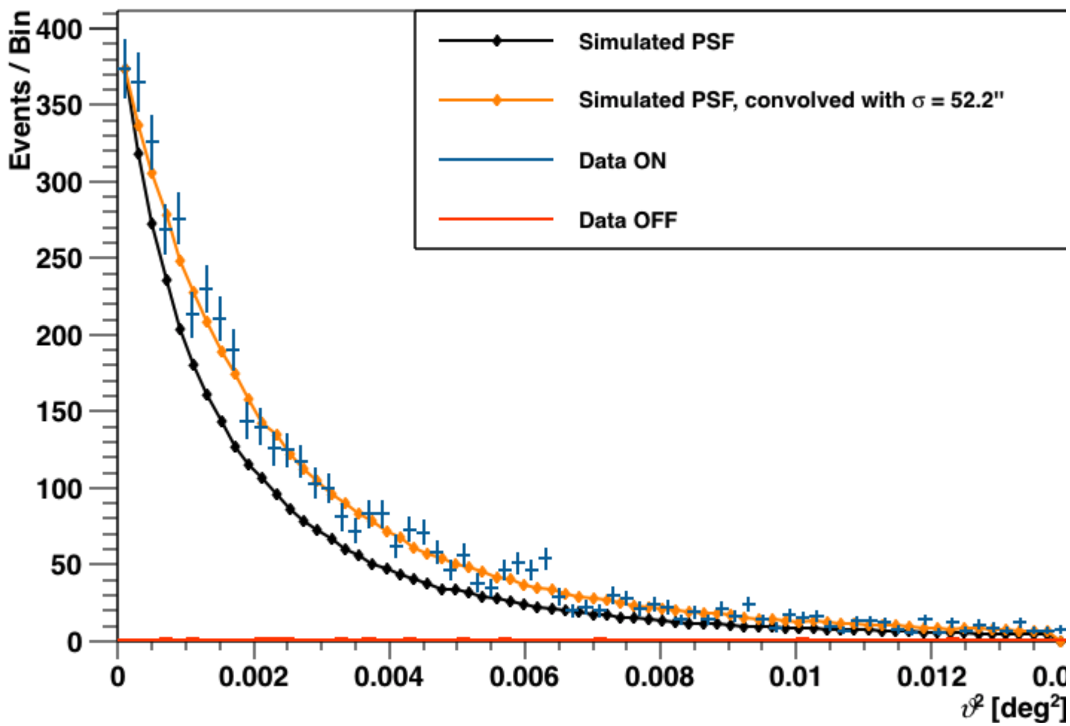


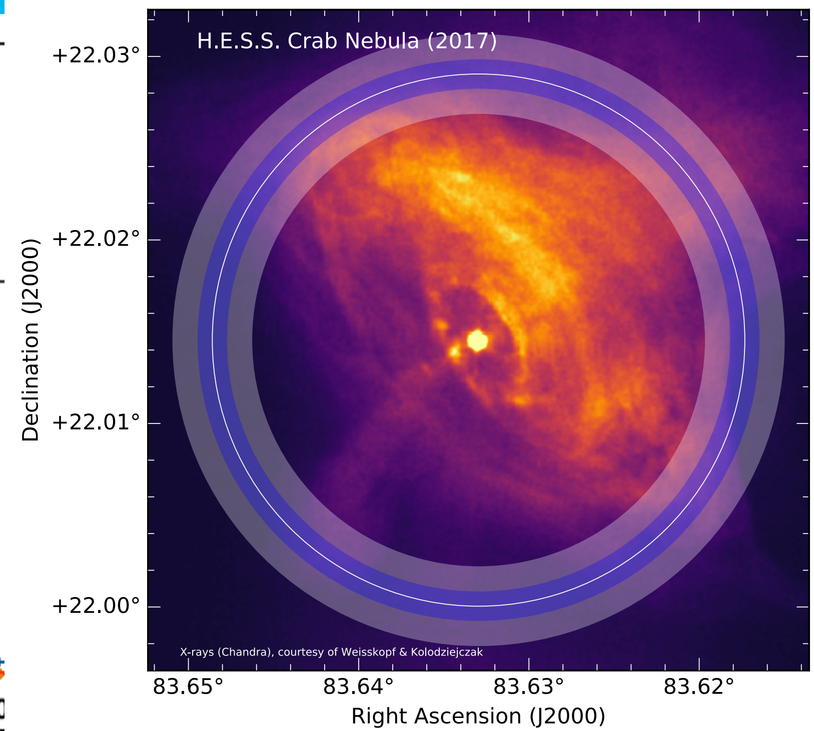
Electric current

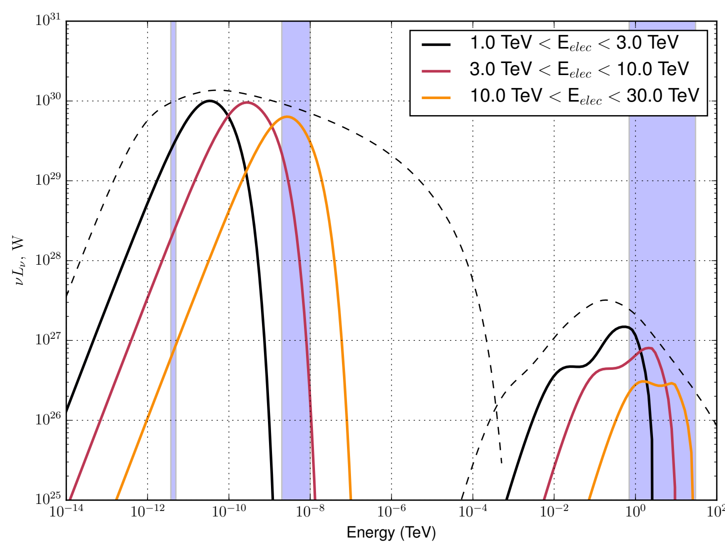


3D fluid-kinetic simulations with realistic boundaries that resolve dissipation scales.

Crab Nebula Extension Revealed at γ-ray Energies 2017



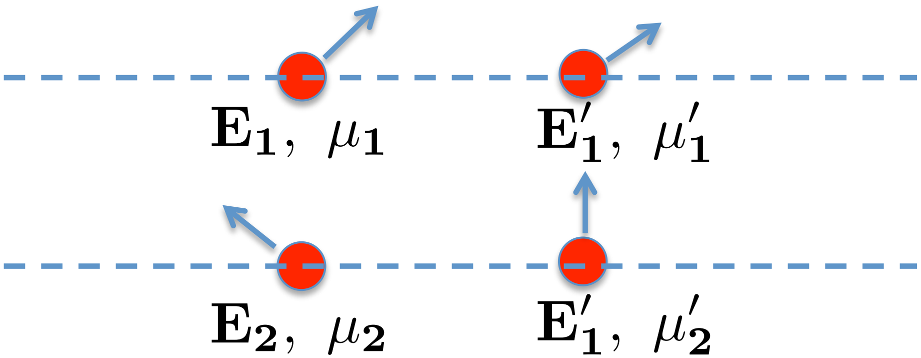




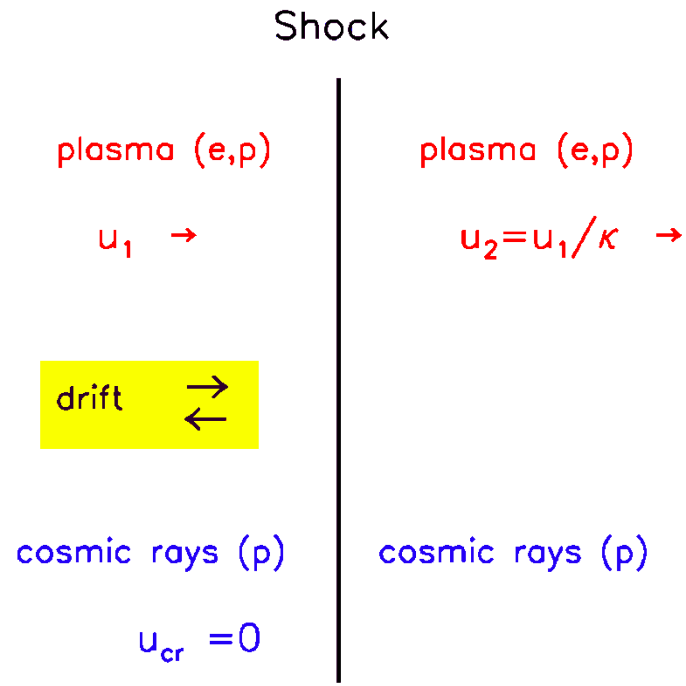
Note- the HESS Y-ray extension is larger than that seen in X-rays. On physical grounds this is well motivated when considering the different electron energies probed.

H.E.S.S. ICRC 2017, arXiv:1707.04196

Particle Acceleration and Magnetic Turbulence

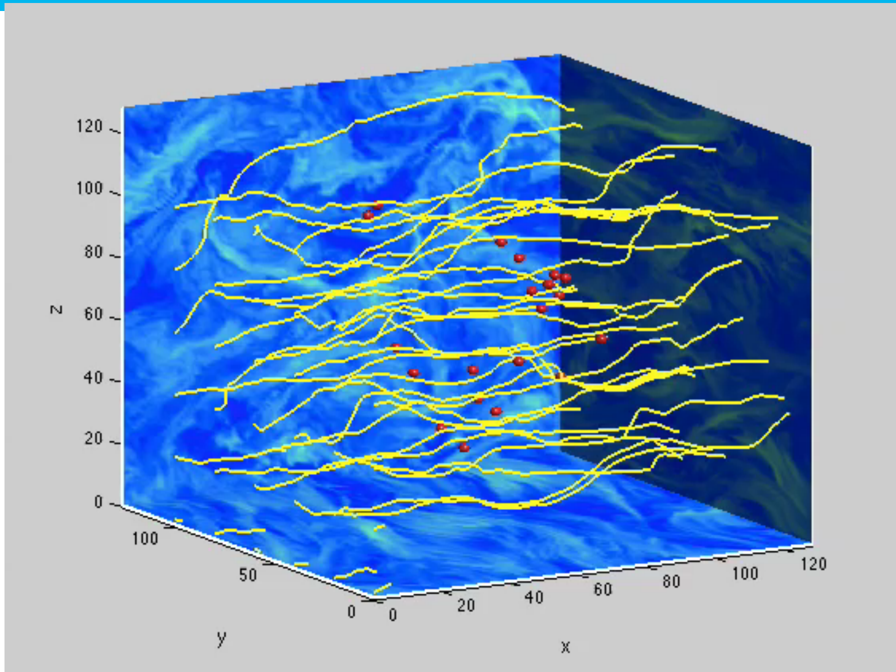


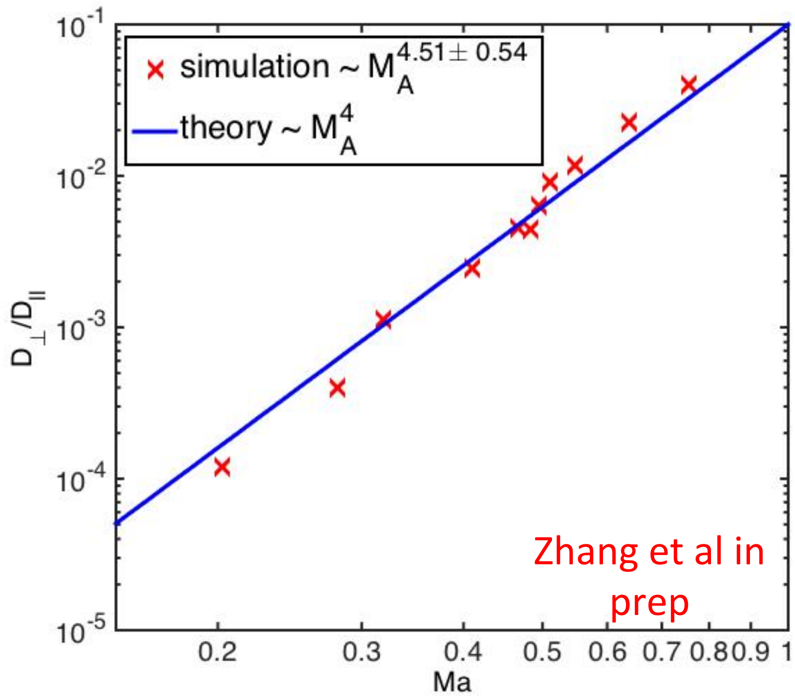
$$E_2 = E_1 \left(\frac{1 + \beta\mu_1}{1 + \beta\mu_2} \right)$$



- **Shifting of μ_1' to μ_2' is caused by magnetic turbulence**
- **What drives strong magnetic turbulence?**

Particle Transport in Space





$$\frac{\mathbf{D}_{\parallel}}{\beta} = \left\langle \frac{\mathbf{B_0^2}}{(\delta\mathbf{B}(\mathbf{k}))^2} \right\rangle \mathbf{R_L} \qquad \frac{\mathbf{D}_{\perp}}{\beta} = \left\langle \frac{(\delta\mathbf{B}(\mathbf{k}))^2}{\mathbf{B_0^2}} \right\rangle \mathbf{R_L}$$

A study of the fundamental plasma processes governing particle transport (and acceleration) in astrophysical settings, the interaction with MHD turbulence, reconnection, etc.

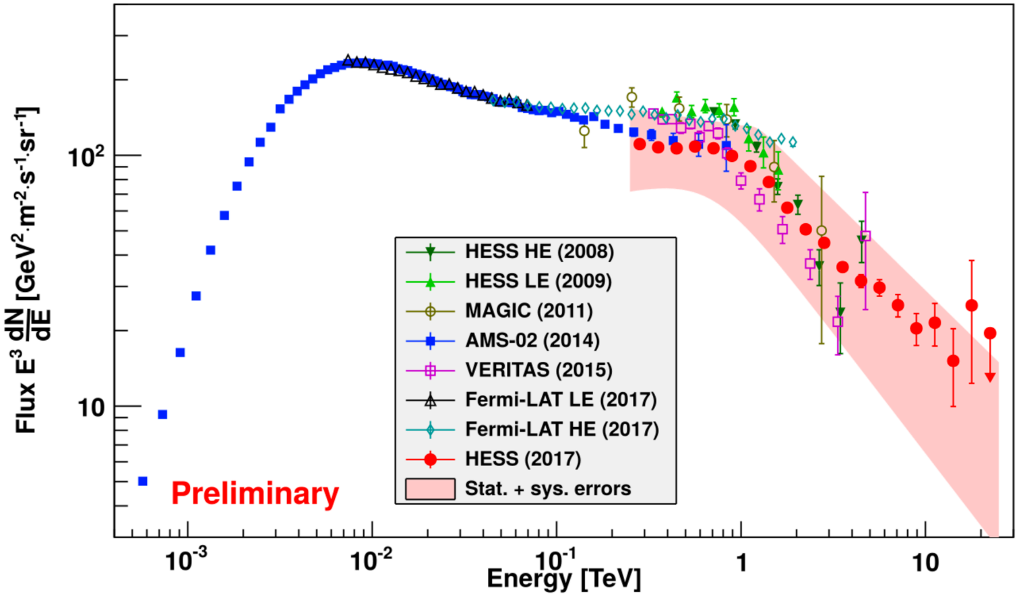
Jokipii suggested different scaling- updated understanding of MHD turbulence

Electrons from Local PWN (Source)?

$$\lambda_{\rm scat}(E_e) \approx 1 \left(\frac{10^{13}\ {\rm eV}}{E_e}\right)^{1/3} {\rm pc}$$

$$\tau_{\rm cool}(E_e) \approx 10^5 \left(\frac{10^{13}\ {\rm eV}}{E_e}\right) {\rm yrs}$$

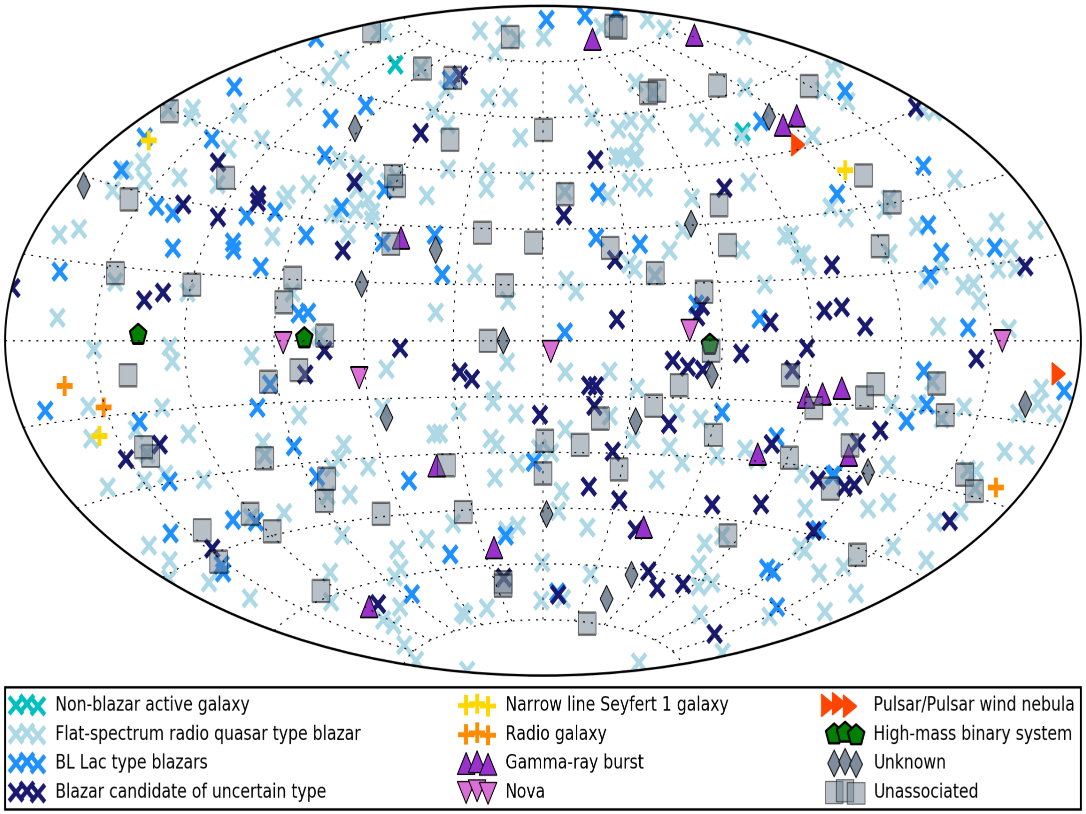
$$r_{\max}(E_e) = (\lambda_{\rm scat} c \tau_{\rm cool})^{1/2} \approx 10^{2.2} \left(\frac{10^{13}\ {\rm eV}}{E_e}\right)^{-1/3} {\rm pc}$$



Group Highlights- Fermi-LAT

Catalog for flaring gamma-ray sources and running real time monitor

https://fermi.gsfc.nasa.gov/ssc/data/access/lat/FAVA/



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DESY news 30/08/2017

2017/08/30

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Flickering in the gamma skies

Analysis reveals dozens of unknown gamma-ray sources in the universe

Researchers at DESY have compiled an extensive catalogue of variable sources of cosmic gamma radiation. For his doctoral thesis, Matteo Giomi, working at DESY in Zeuthen, analysed almost 7.5 years of observational data from NASA's "Fermi" space telescope. Over that period, the "Large Area Telescope" (LAT) on board the satellite registered a total of 4547 bursts of gamma radiation, known as flares. Thanks to improved analytical methods, Giomi was able to assign these flares to 518 variable sources. The "Fermi All-Sky Variability Analysis" (FAVA) also lists 77 unknown sources, whose identity has not yet been determined. The "Fermi" scientists are presenting their catalogue in *The Astrophysical Journal*.

Download [161KB, 1115 x 570]

The gamma-ray sky as seen by 'Fermi'. Each spot represents a localised gamma-ray flare. Credit: Fermi All-Sky Variability Analysis

"The catalogue comprises a wide range of gamma-ray sources," explains Giomi. "Most of the sources in the catalogue are eruptions in extremely distant, so-called active galactic nuclei, but we are also seeing binary star systems involving white dwarfs and black holes, neutron stars and other remnants of stellar explosions." In all cases, the recorded gamma rays are produced by subatomic particles, which are accelerated to extremely high energies by a range of mechanisms. The catalogue will make it easier for astroparticle physicists to figure out precisely how the different cosmic particle accelerators work.

"We are looking at the particles while they are in the process of being accelerated, so to speak," says DESY's Rolf Bühler, who supervised the thesis. "In steadily radiating galaxies, the acceleration can take thousands of years. In the variable sources, by contrast, the acceleration must be taking place on roughly the same timescale as the flare. This gives us some clues about the acceleration process. For example, an accelerator cannot be larger than the distance travelled by light over the duration of the flare."

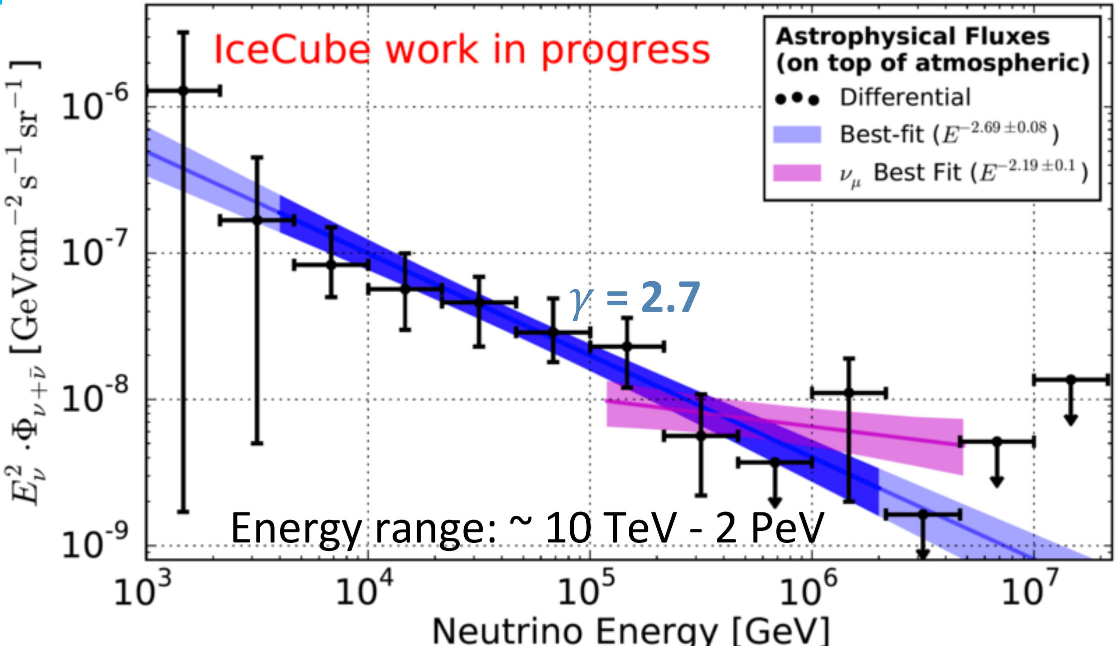
The analysis pays special attention to the 77 as yet unidentified sources. "In most cases, these will probably be active galactic nuclei as well, but they could also include representatives of entirely new classes of gamma-ray sources, which we have not come across before," says Bühler, who compiled an earlier catalogue of variable gamma-ray sources with some of his colleagues, based on just under four years of "Fermi" observations and listing 215 sources. To facilitate access to the two catalogues, as well as the latest data from "Fermi", Daniel Kocevski of NASA's Goddard Space Flight Center has written a web interface, through which research scientists can retrieve the latest observational data on variable sources: https://fermi.gsfc.nasa.gov/ssc/data/access /lat/FAVA/

Reference:

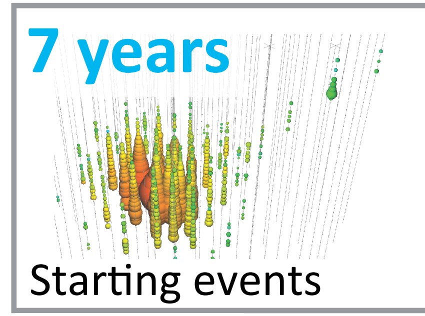
The second catalog of flaring gamma-ray sources from the Fermi All-sky Variability Analysis; S. Abdollahi et al.; *The Astrophysical Journal*, 2017; DOI: 10.3847/1538-4357/aa8092

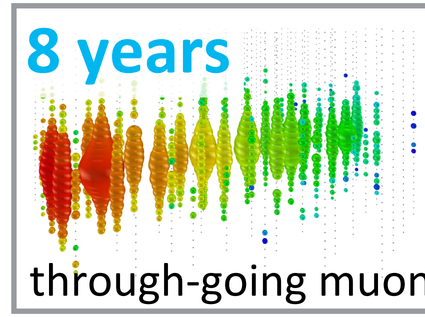
Abdollahi et al., ApJ 846 1, 2017
PhD thesis 2017 Matteo Giomi

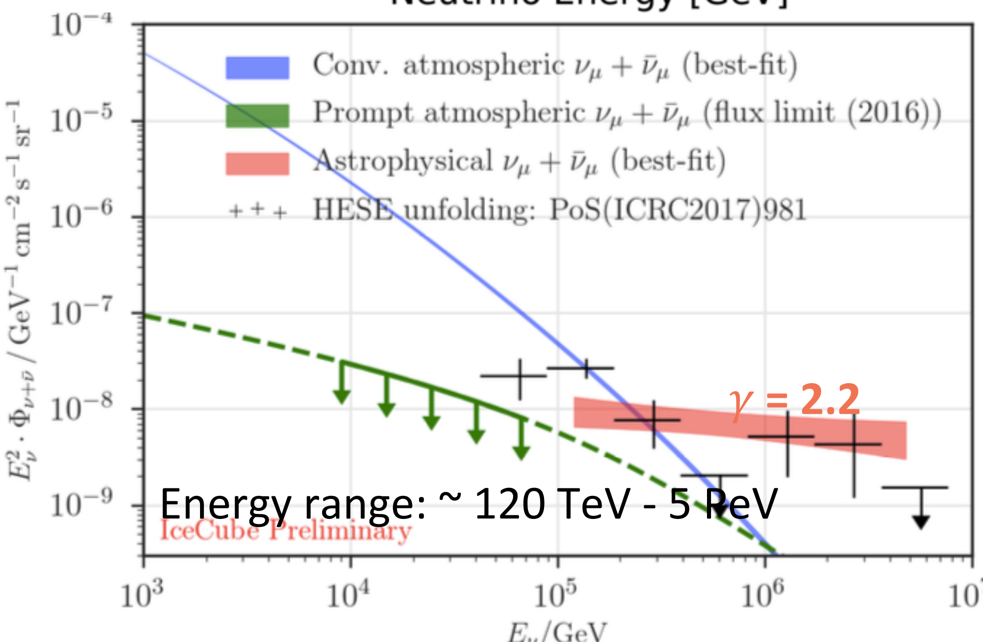
Group Highlights- IceCube



IceCube collaboration, TeVPA 2017







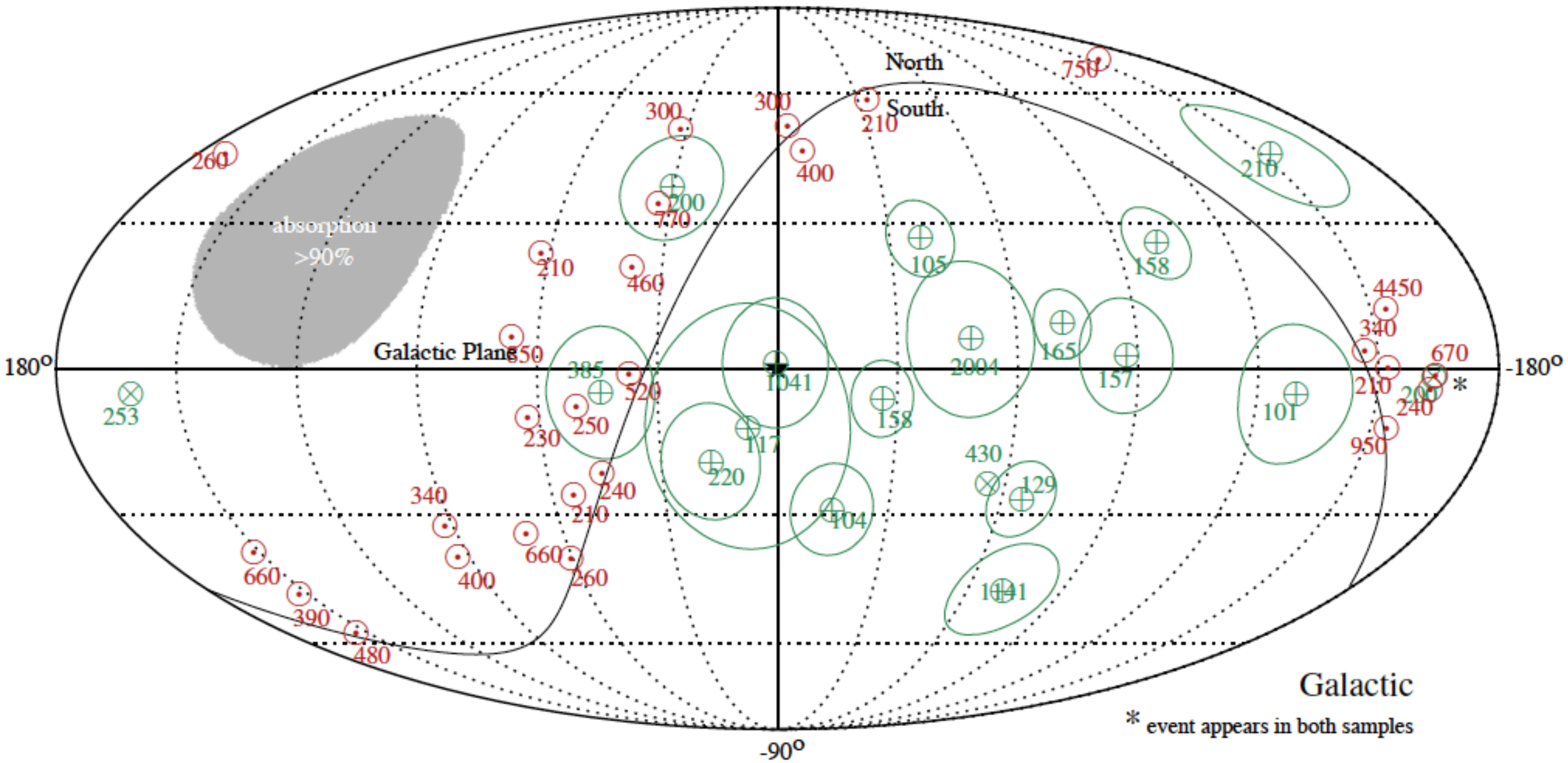
- Potential **spectral hardening** above 100 TeV

IceCube collaboration, ICRC 2017

Which Cosmic Laboratory is Being Probed?

Energy Info.

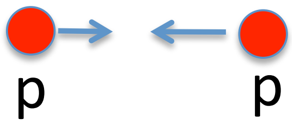
HESE 4yr with $E_{dep} > 100$ TeV (green) / Classical $\nu_\mu + \bar{\nu}_\mu$ 6yr with $E_\mu > 200$ TeV (red)



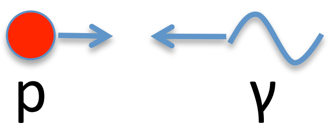
- 16 "cascade events" (circles) and 3 "tracks events" (diamonds) with $E_{dep} \gtrsim 100$ TeV
- 28(+1) up-going muon neutrino events with $E_\mu \gtrsim 200$ TeV [IceCube'15]
- ✗ no significant spatial or temporal correlation of events

Neutrino Production in Astrophysical Sources

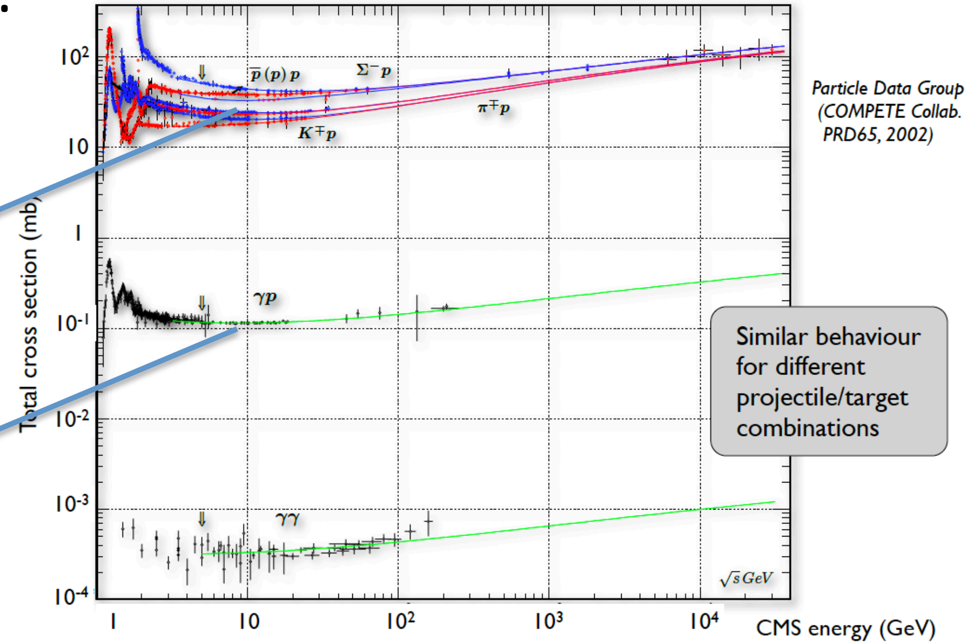
Multiple pion production channels:



$$\mathbf{s = 2m_p^2 + 2E_p m_p}$$



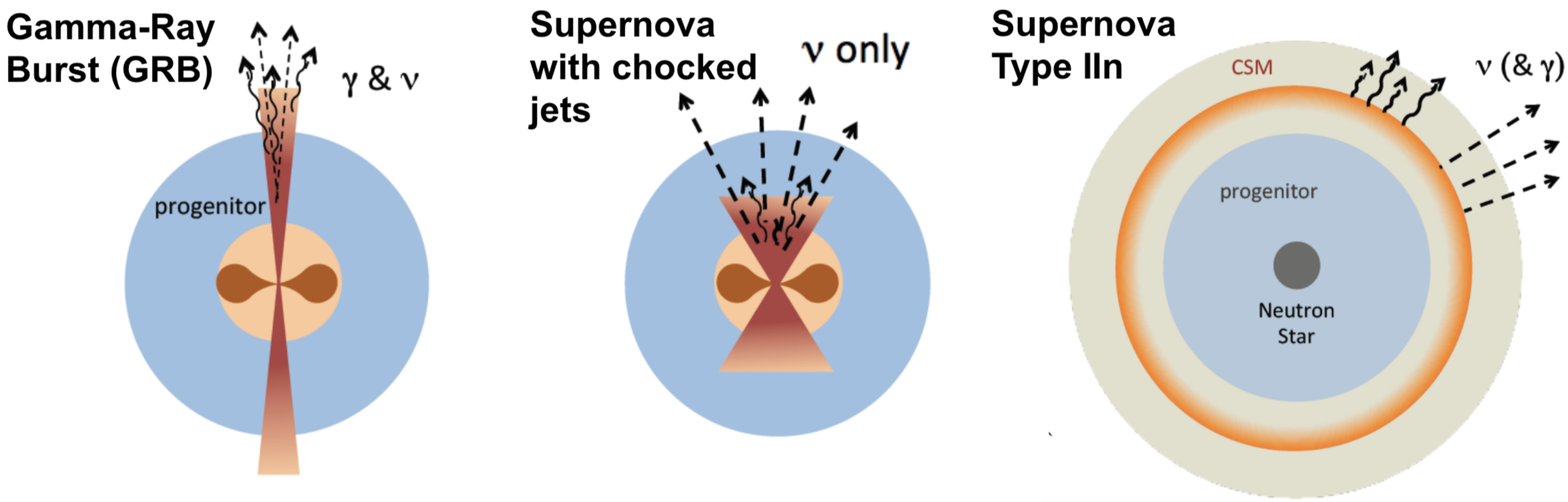
$$\mathbf{s = m_p^2 + 2(E_p + p_p)E_\gamma^{bg}}$$



For pγ interactions, a "high energy" proton threshold energy exists for pion production:

$$\mathbf{E_p^{min} \approx \frac{m_p m_\pi}{E_\gamma^{bg}}}$$

Search for Neutrinos from SNe Explosions



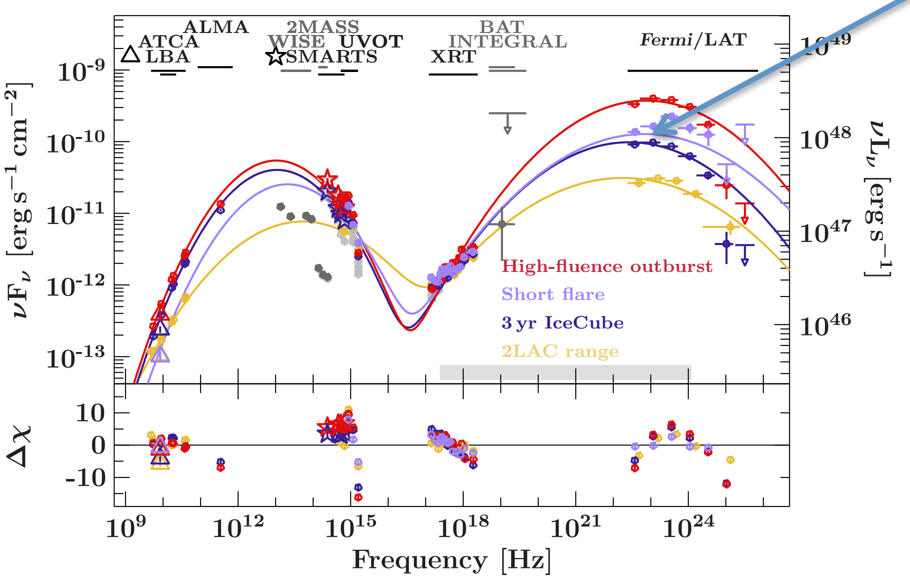
- Stacking analysis to probe origin of cosmic neutrinos from chocked-jet supernovae and SNe expoding into a massive circumstellar medium (SN IIn).
- Different time correlations / expected neutrino light curves tested.
- No correlation found stacking several hundred SNe.
- Bright SNe tested separately.

DESY

Are bright AGN the Sources of the PeV Neutrinos?

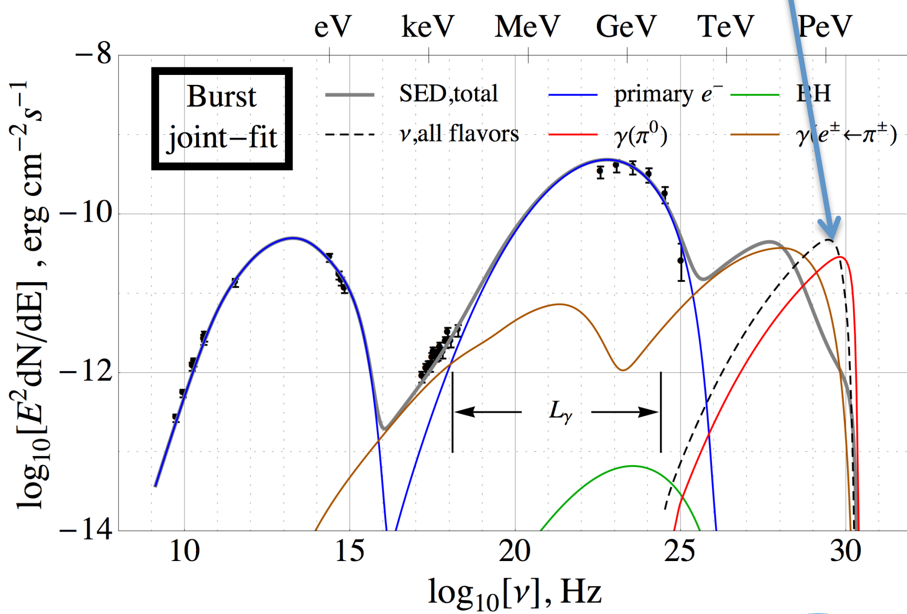
Brightness level makes it a valid candidate

Kadler et al. (2016) **Nature Physics, 12, 807**



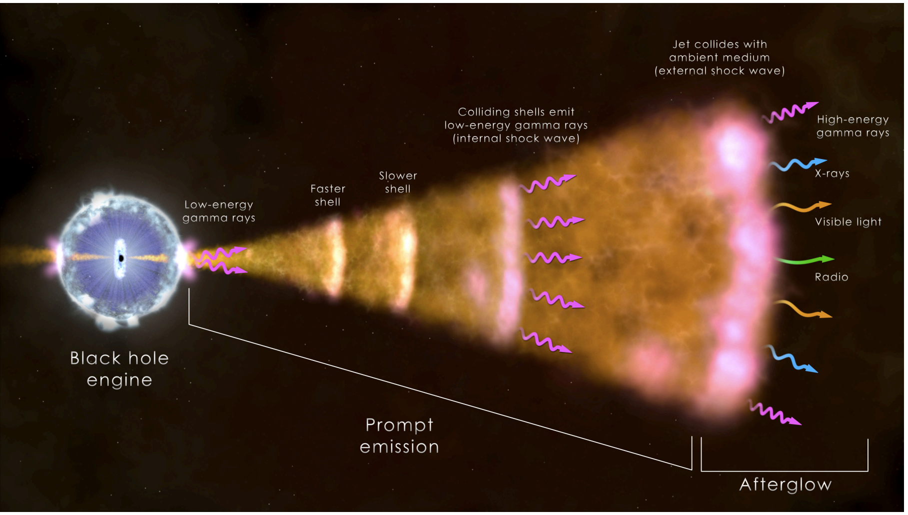
Pion spectrum reflects proton threshold energy for this channel

Gao et al. (2016) **Ap.J. 843 (2017) 109**

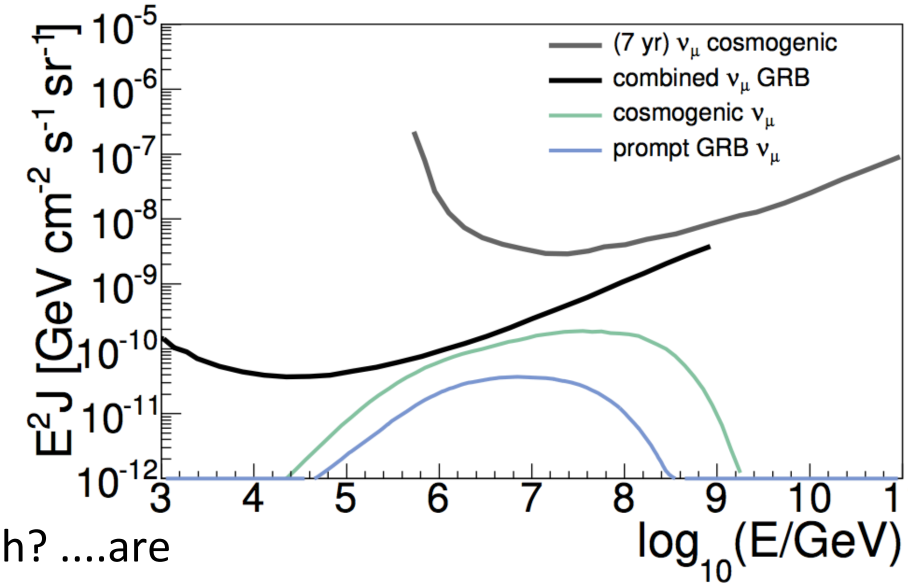


Secondary electrons in sources are however problematic, forcing pionic component to be **sub-dominant**

GRBs as Source Candidates



Boncioli et al., ICRC 2017

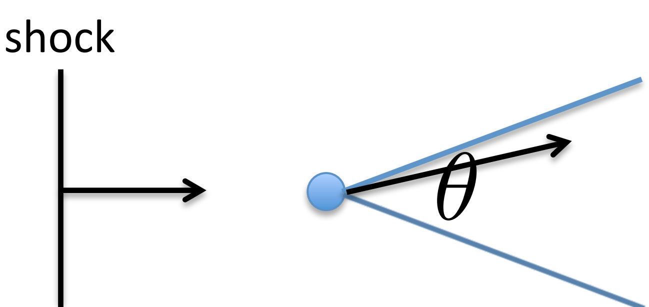


What is the maximum energy this source can reach? ....are relativistic shocks efficient accelerators?

For non-relativistic shocks: $\mathbf{E_{max} = \beta_{sh} e B R_{source}}$

For relativistic shocks the situation looks attractive, recalling that:

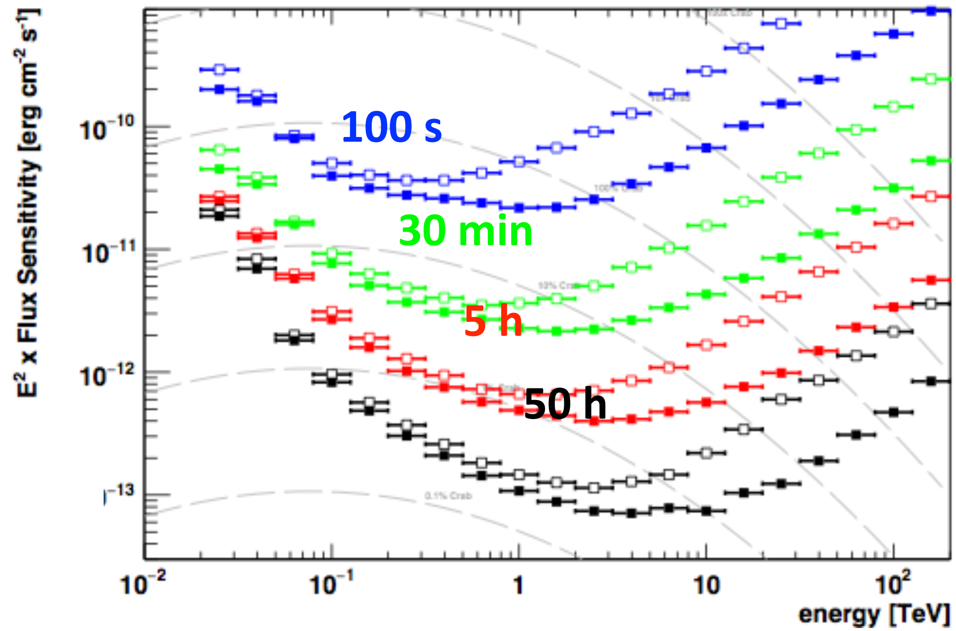
$$\mathbf{E_2 = E_1 \left(\frac{1 + \beta\mu_1}{1 + \beta\mu_2} \right)}$$

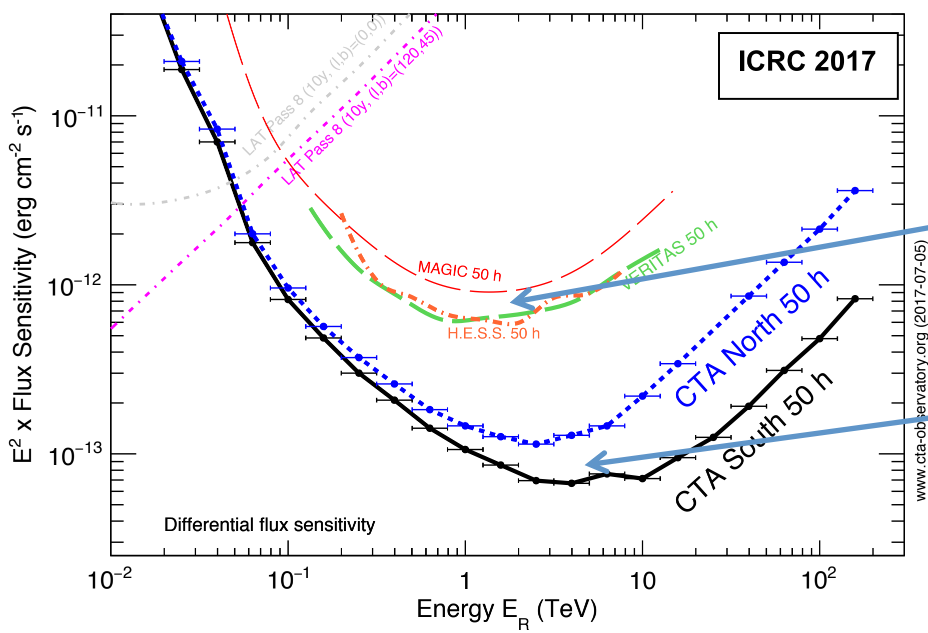


Group Highlights- CTA

- An understanding of the instrument sensitivity to transient events on different timescales
- Angular resolution studies

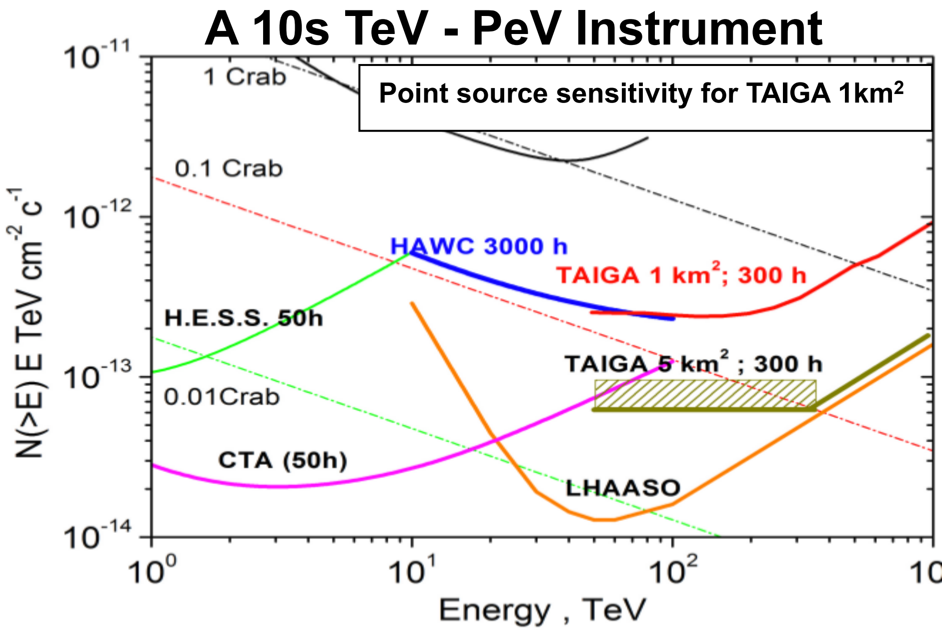
CTA South - filled (■) symbols
CTA North - open (□) symbols

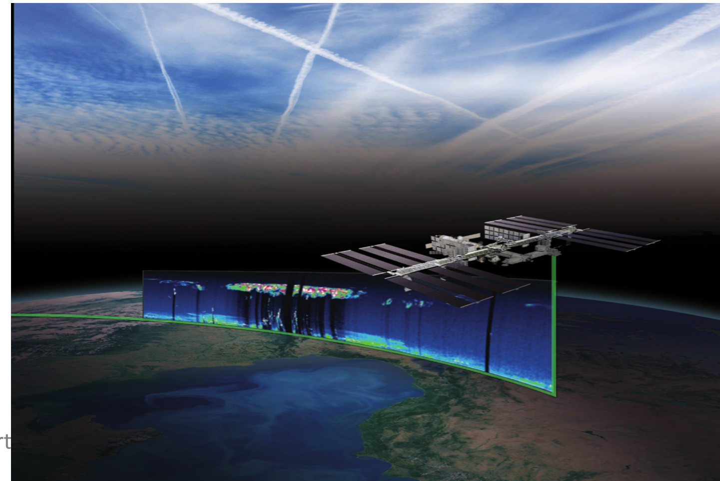




Group Highlights- TAIGA

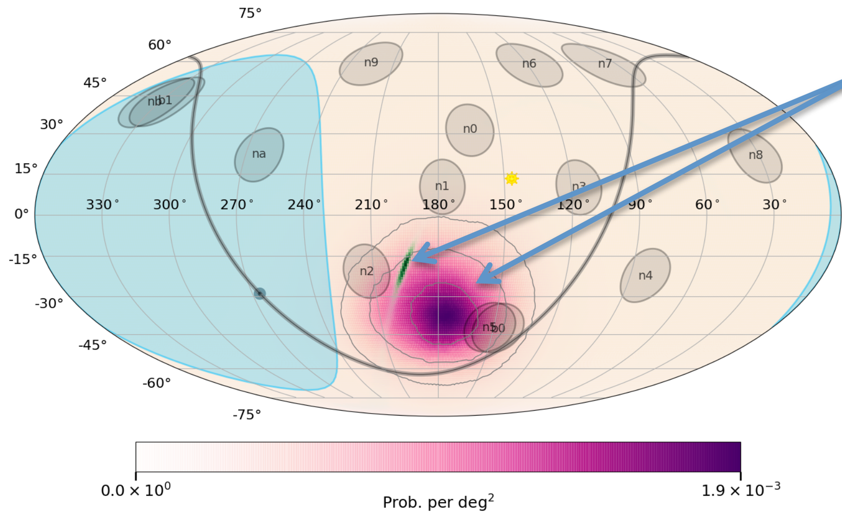
- A better understanding of the instrument sensitivity to point sources
- HiSCORE has detected the ISS – Laser. Proves to be an excellent calibration sources to test array event timing reconstruction
- Next goal is the detection of the **Crab Nebula** (low elevation angle observations)



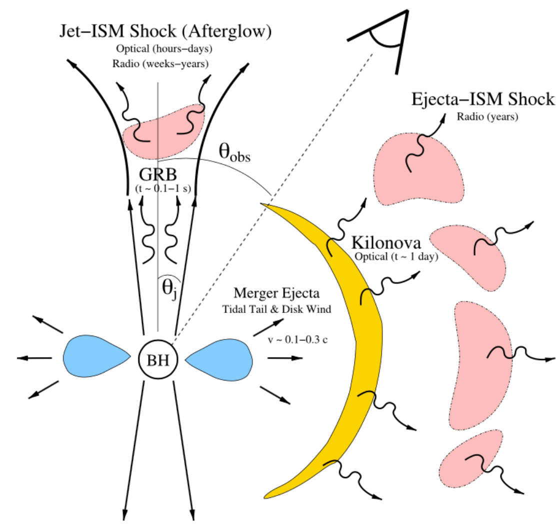


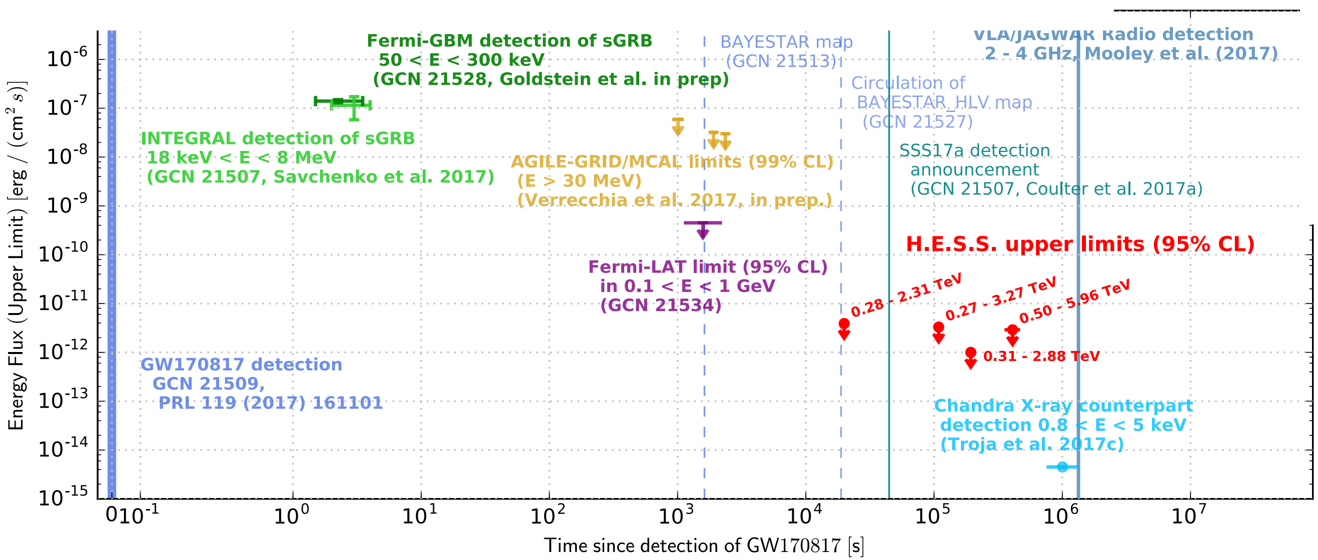
Exciting Recent Developments

First Gravitational Wave Event with an Electromagnetic Counterpart



Gravitational wave + GRB uncertainty regions





H.E.S.S. [arXiv:1710.05862](https://arxiv.org/abs/1710.05862)

…and other interesting multi-messenger observational developments are currently in pipeline!

Summary

- The field is now rich in the range of high energy astrophysical objects detected, thanks to the diverse range of energies (and messengers) covered

- A subset of these astrophysical objects demonstrate a wide variety of phenomena (ie. Operating as “Cosmic Labs”), allowing full exploitation of the information provided by their messenger particles

- A growing level of interconnectedness is starting to be revealed between these results, as these fields mature and the “discovery dust” settles

- Our theoretical understanding of these systems, in some cases, is starting to also mature

- Exciting new results appear to be revealing that a class of objects recently discovered connect gamma-ray emitters to NS-NS Gravitational wave sources