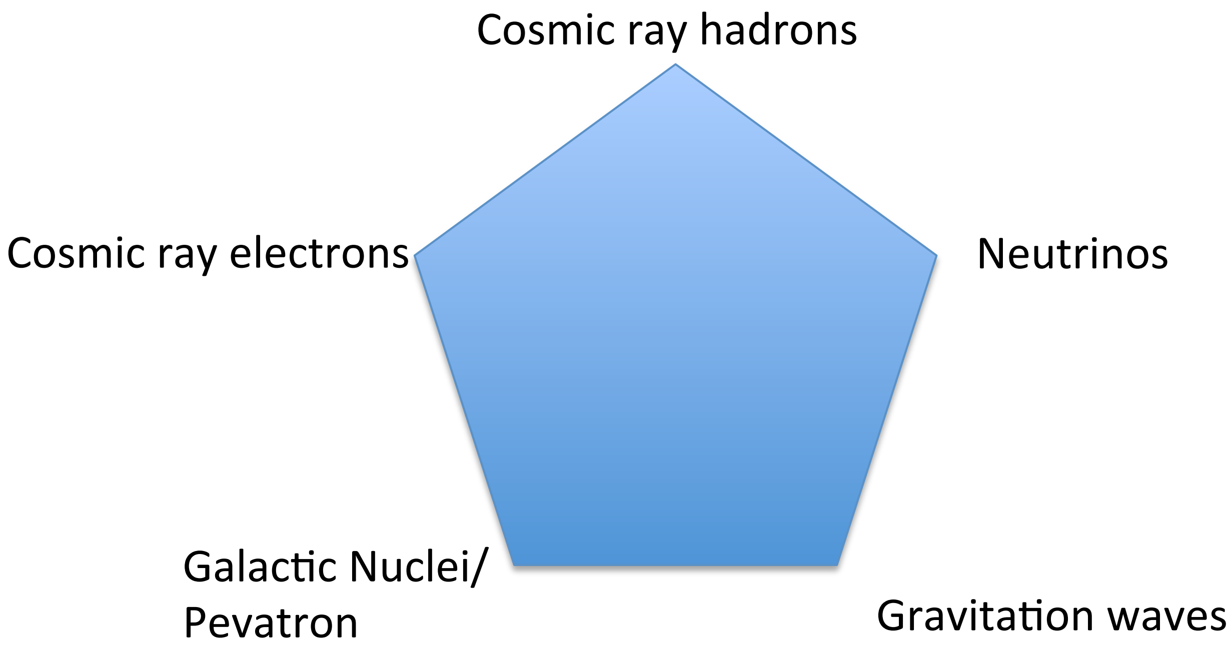
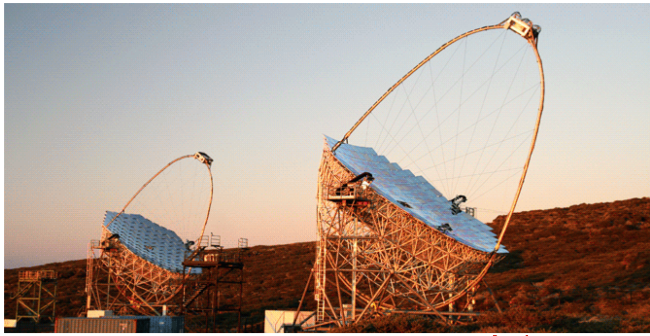
# Multi-Messenger Observations with IACTs



# Multi-Messenger Observations with IACTs

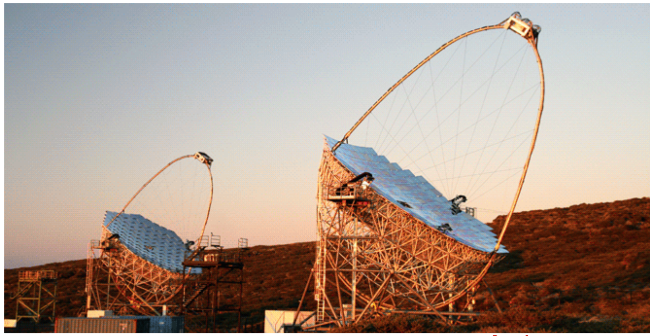
Cosmic ray hadrons (2007)

Cosmic ray electrons (2008, 2017)

Neutrinos (2017)

Galactic Nuclei/ Pevatron (2016)

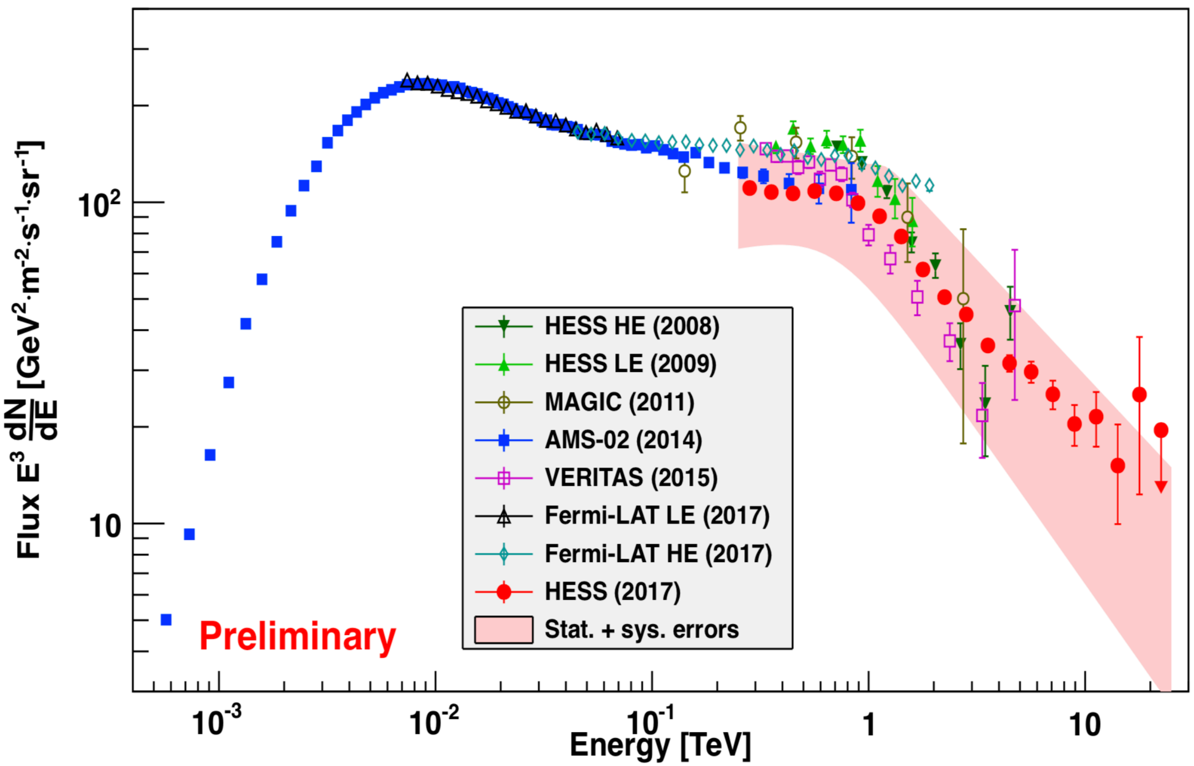
Gravitation waves (2017)



# The Latest CR Electron Spectrum

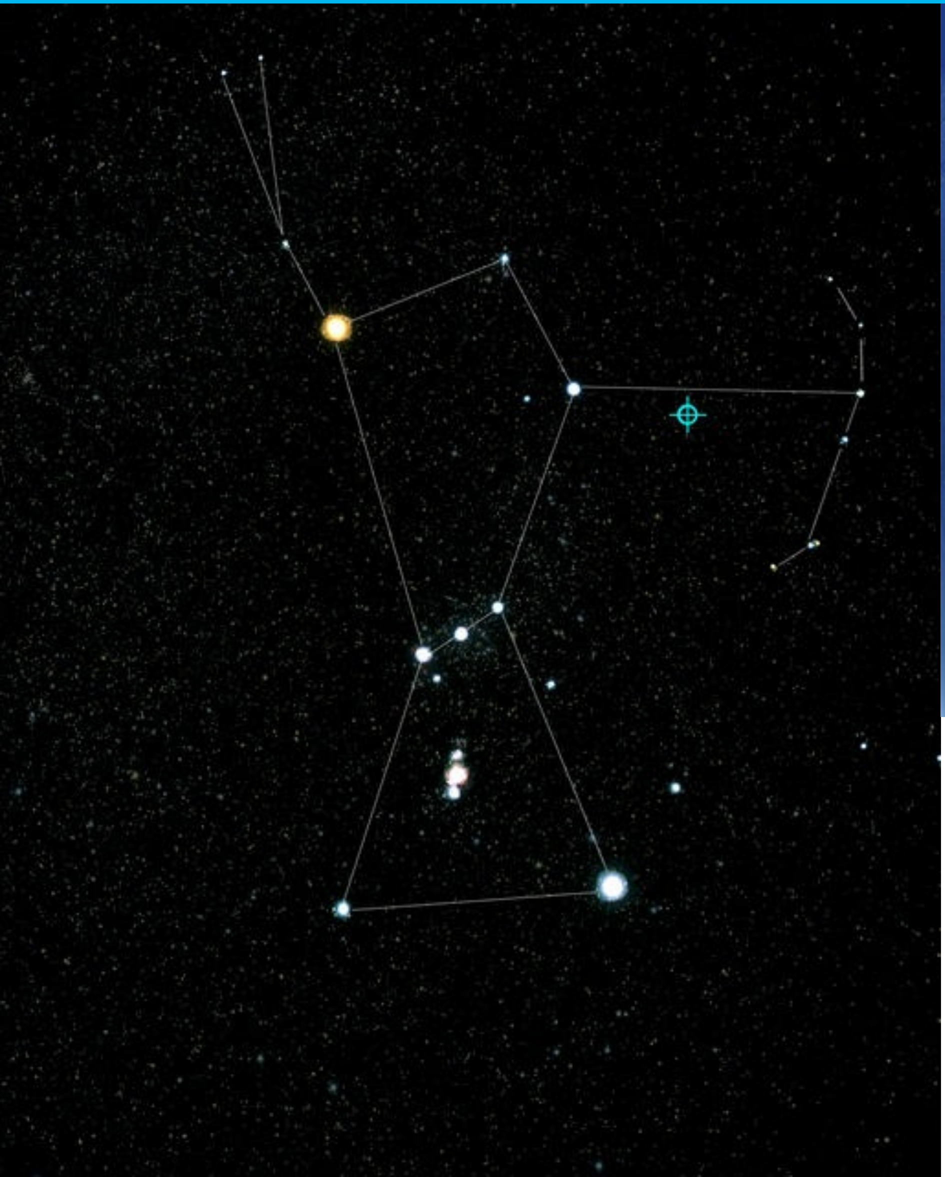
**HESS ICRC, 2017**

- Electron spectrum measured from 250 GeV to ~ 20 TeV. Electron spectrum fitted with a smooth broken power law:
- No features is seen in the electron spectrum up to the highest energies which allow us to exclude models that describe prominent features from nearby sources such as Vela.



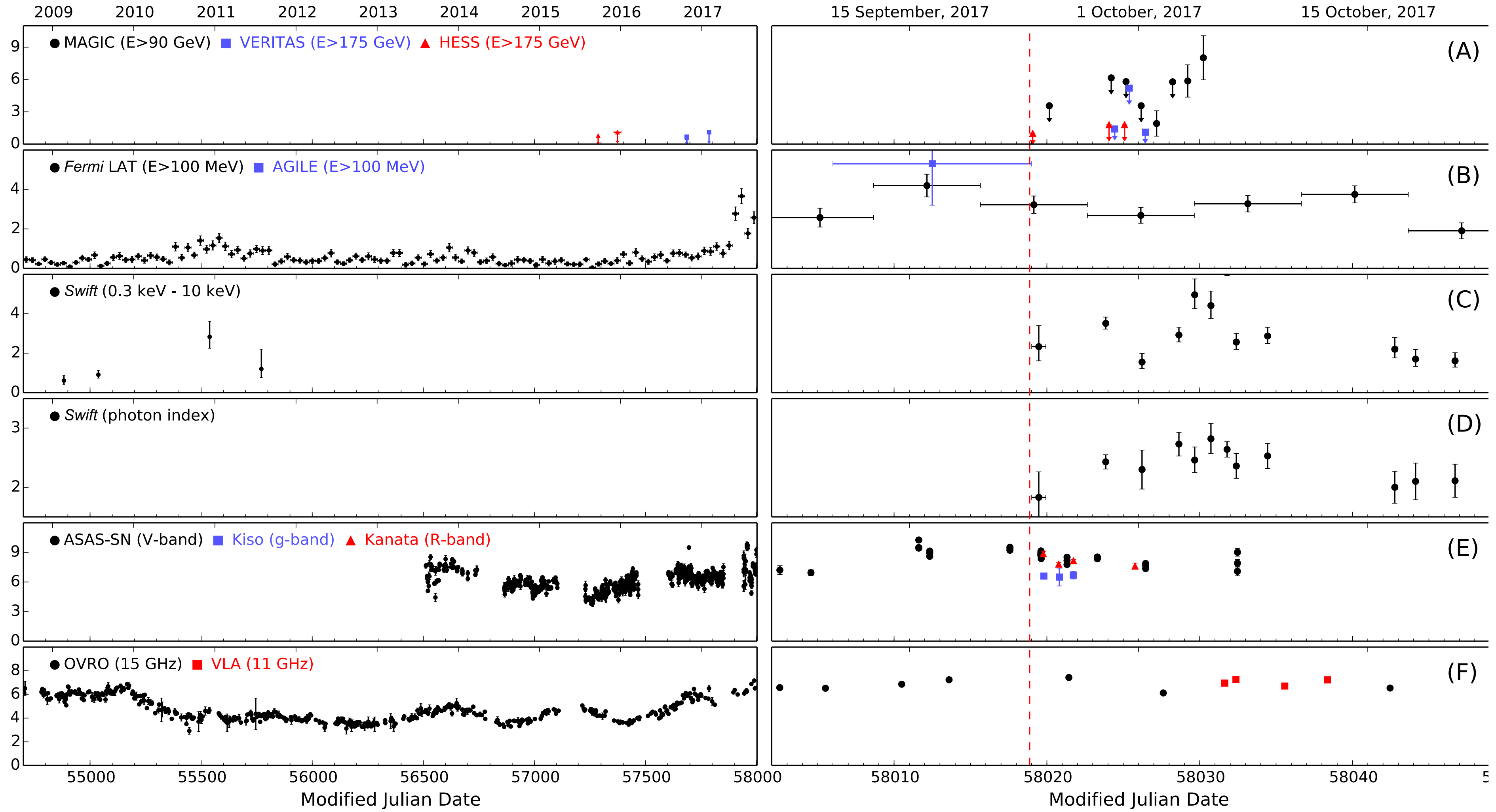

$$\Gamma_1 = 3.04 \pm 0.01 \text{ (stat)} {}^{+0.10}_{-0.18} \text{ (sys)}$$
$$\Gamma_2 = 3.78 \pm 0.02 \text{ (stat)} {}^{+0.17}_{-0.06} \text{ (sys)}$$
$$E_b = 0.94 \pm 0.02 \text{ (stat)} {}^{+0.29}_{-0.26} \text{ (sys) TeV}$$
$$N_0 = 104 \pm 1 \text{ (stat)} {}^{+27}_{-16} \text{ (sys) GeV}^2\cdot\text{m}^{-2}\cdot\text{sr}^{-1}\cdot\text{s}^{-1}$$
$$\alpha = 0.12 \pm 0.01 \text{ (stat)} {}^{+0.19}_{-0.05} \text{ (sys)}$$

# Neutrino Event from TXS 0506

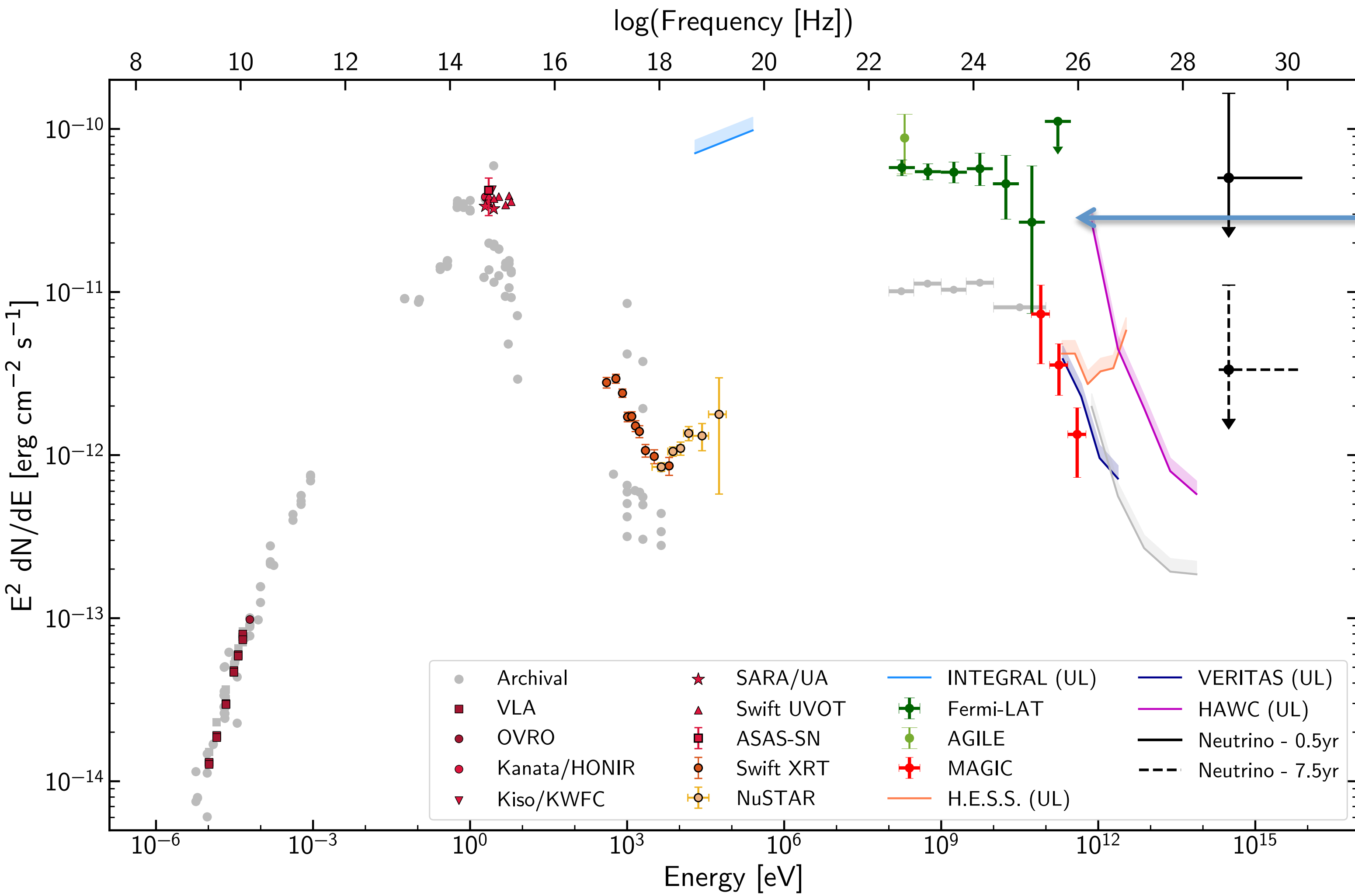


https://multimessenger.desy.de/

# Neutrino Event from TXS 0506



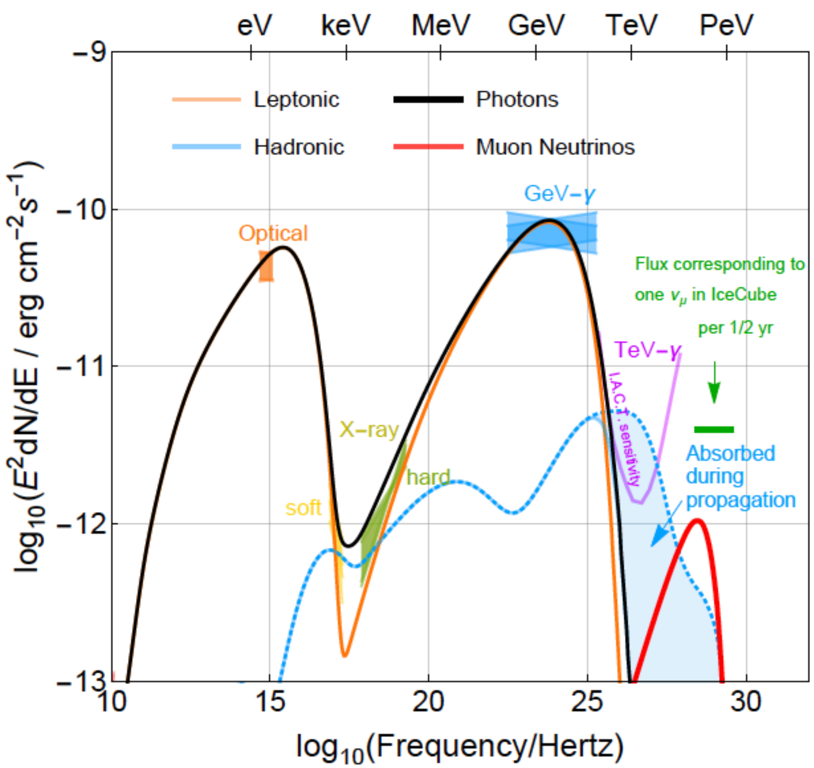
# TXS 0506: Spectral Energy Distribution




"Crab" level energy flux @1TeV

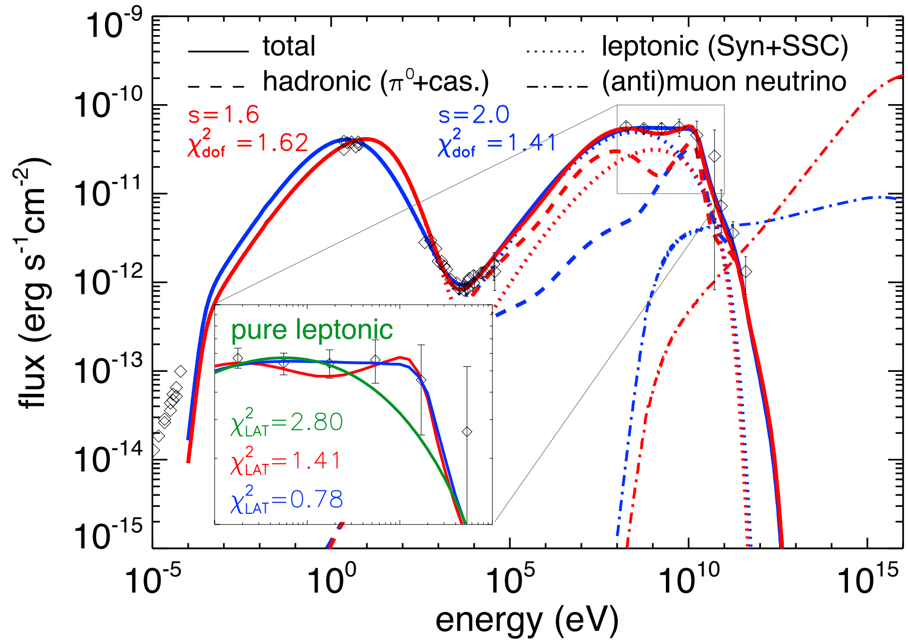
# TXS 0506: Spectral Energy Distribution

Gao et al. 2018, 1807.04275




pγ scenario

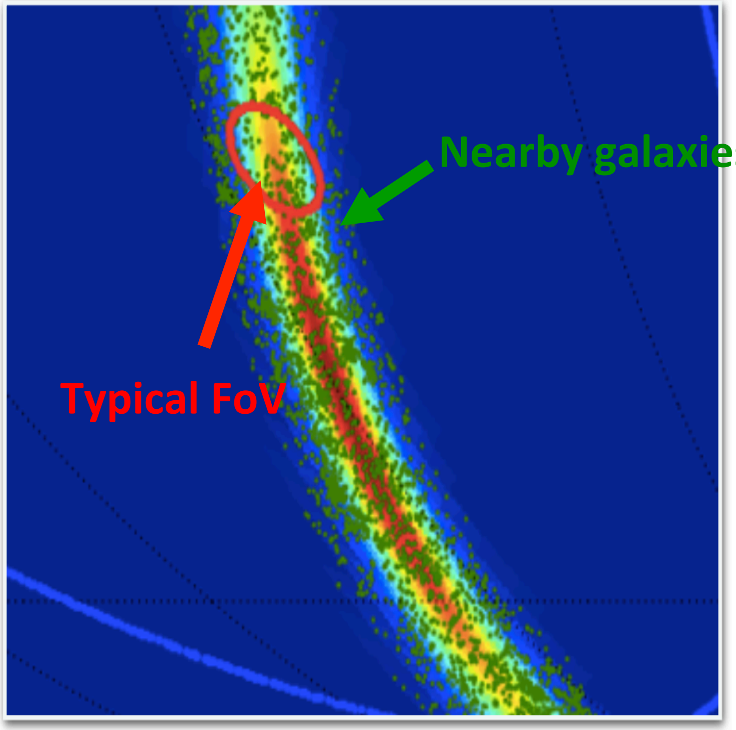
Liu et al. 2018, 1807.05113




pp scenario

# VHE gamma-ray emission from binary NS mergers?

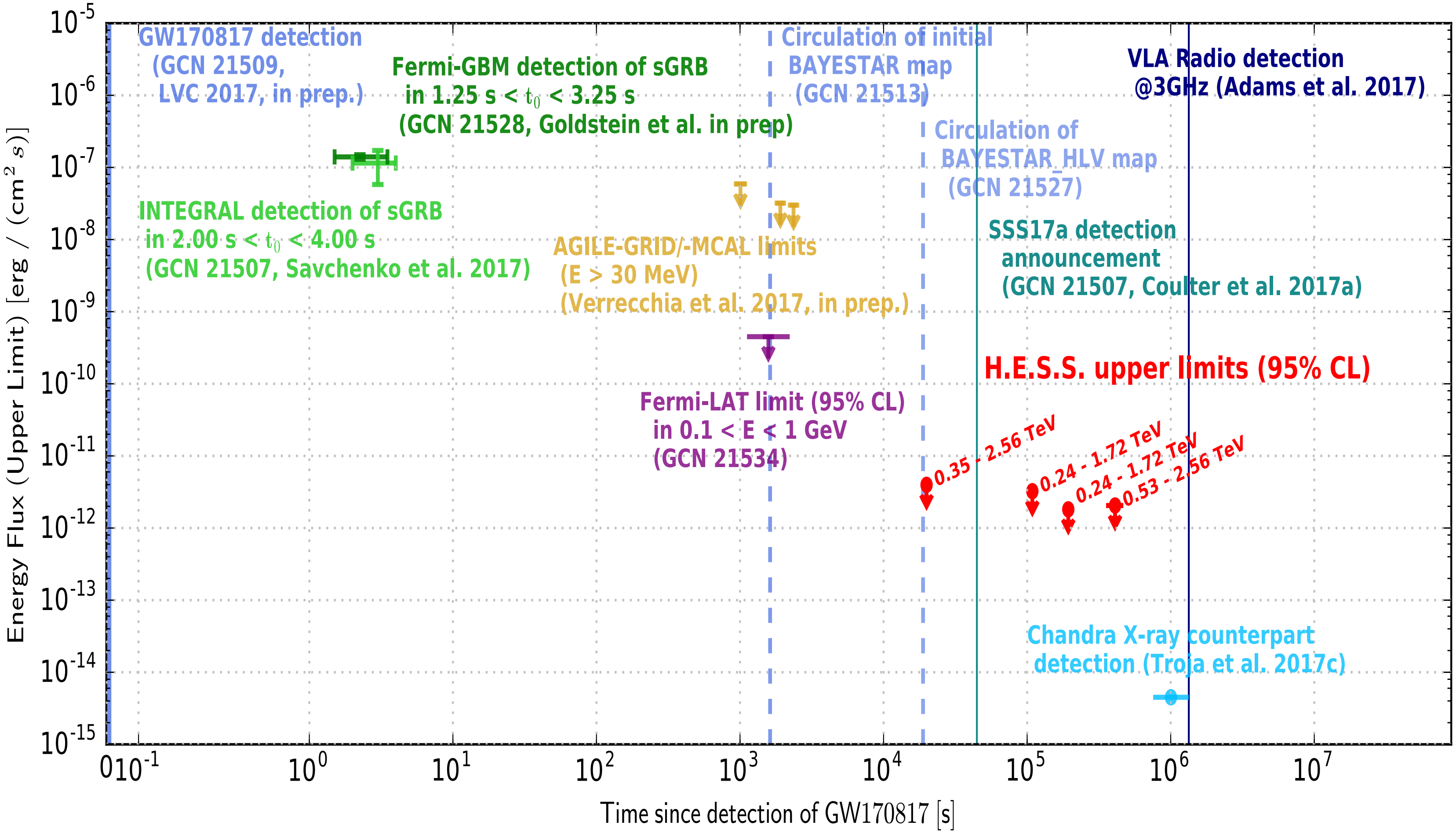
- All IACTs are part of EM GW follow-up efforts
- Large uncertainty regions make follow-up challenging
- Advantages of IACTs
  - rapid slewing
  - large FoV
- Dedicated algorithms to determine optimized scheduling
  - 3D-correlation with galaxy catalog (GLADE) vs. 2D coverage of GW uncertainty region
- Can run in fully automated fashion within transient system




M. Seglar-Arroyo + F. Schussler
arXiv: 1705.10138

# The EM follow-up of GW/EM170817

## History of Observations

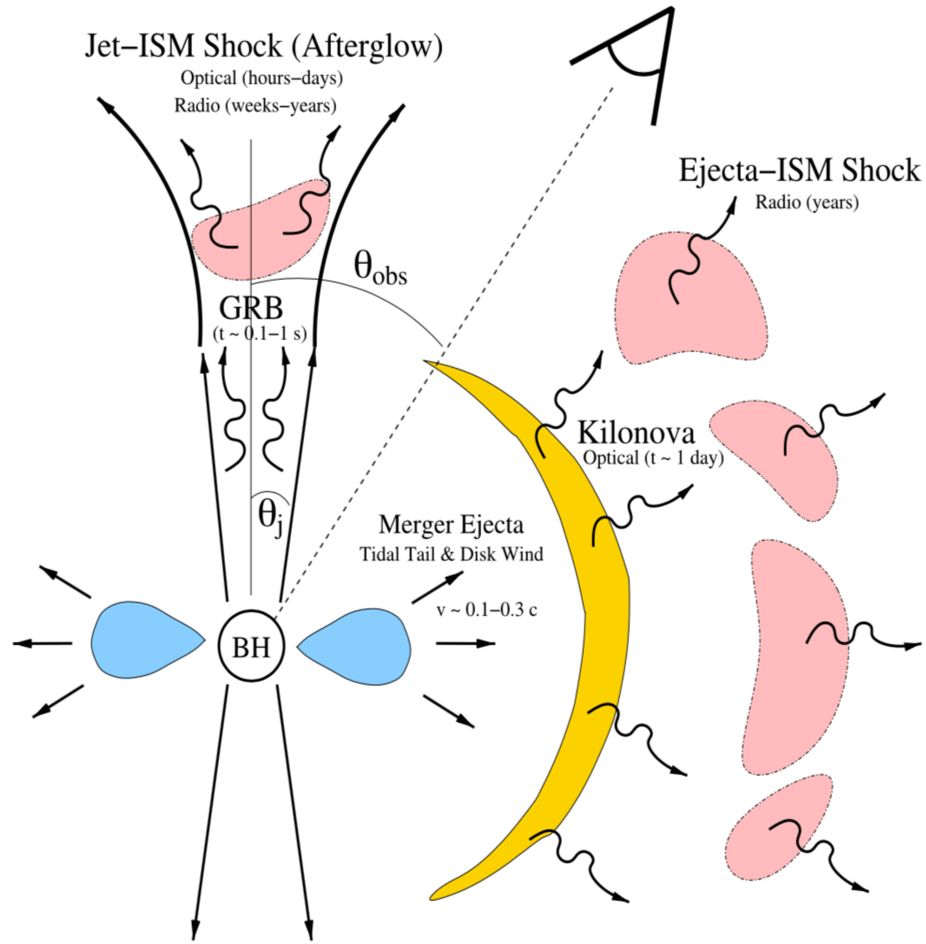



[H.E.S.S. paper on GW170817]

# Binary neutron-star mergers

## Expected electromagnetic emission

- Evidence that Binary NS mergers are progenitors of short GRBs
- Prompt phase
  - Internal shocks in jet
  
    → particle acceleration
  - Hard X-ray and soft gamma-ray production
  - Timescales of (0.1 – 2) seconds




Baiotti & Rezzolla (2017, pre-GW170817)

# The 'late-time' follow-up of GW/EM170817

## What can we learn from MWL measurements

Absence of break in synchrotron emission spectrum up to X-ray energies

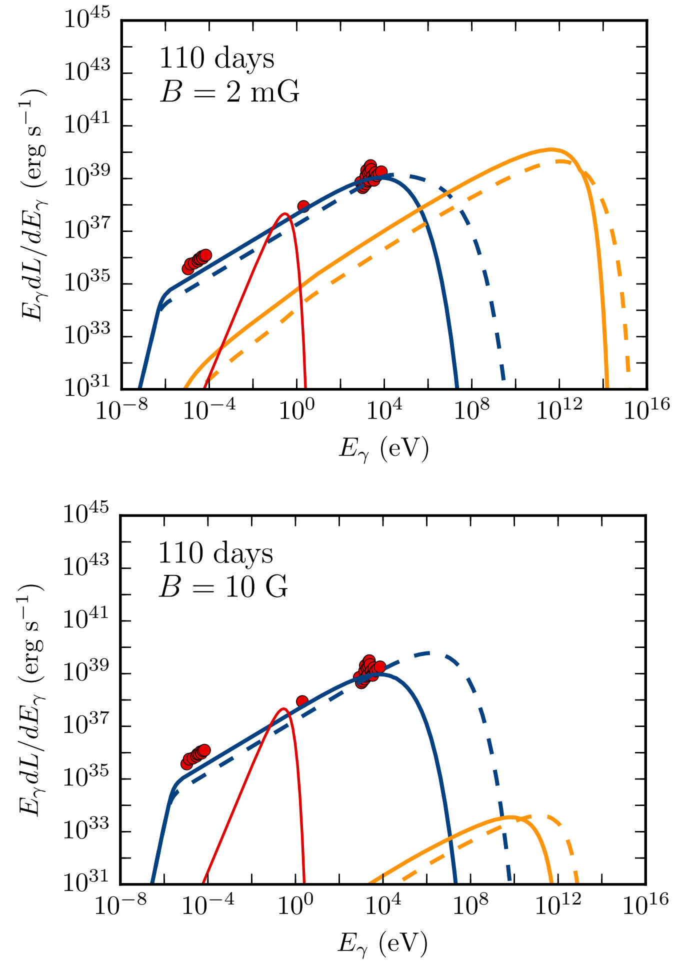
$\mathbf{B < 2\ mG}$

Acceleration within remnant timescale

$\mathbf{B > 0.1\ mG}$

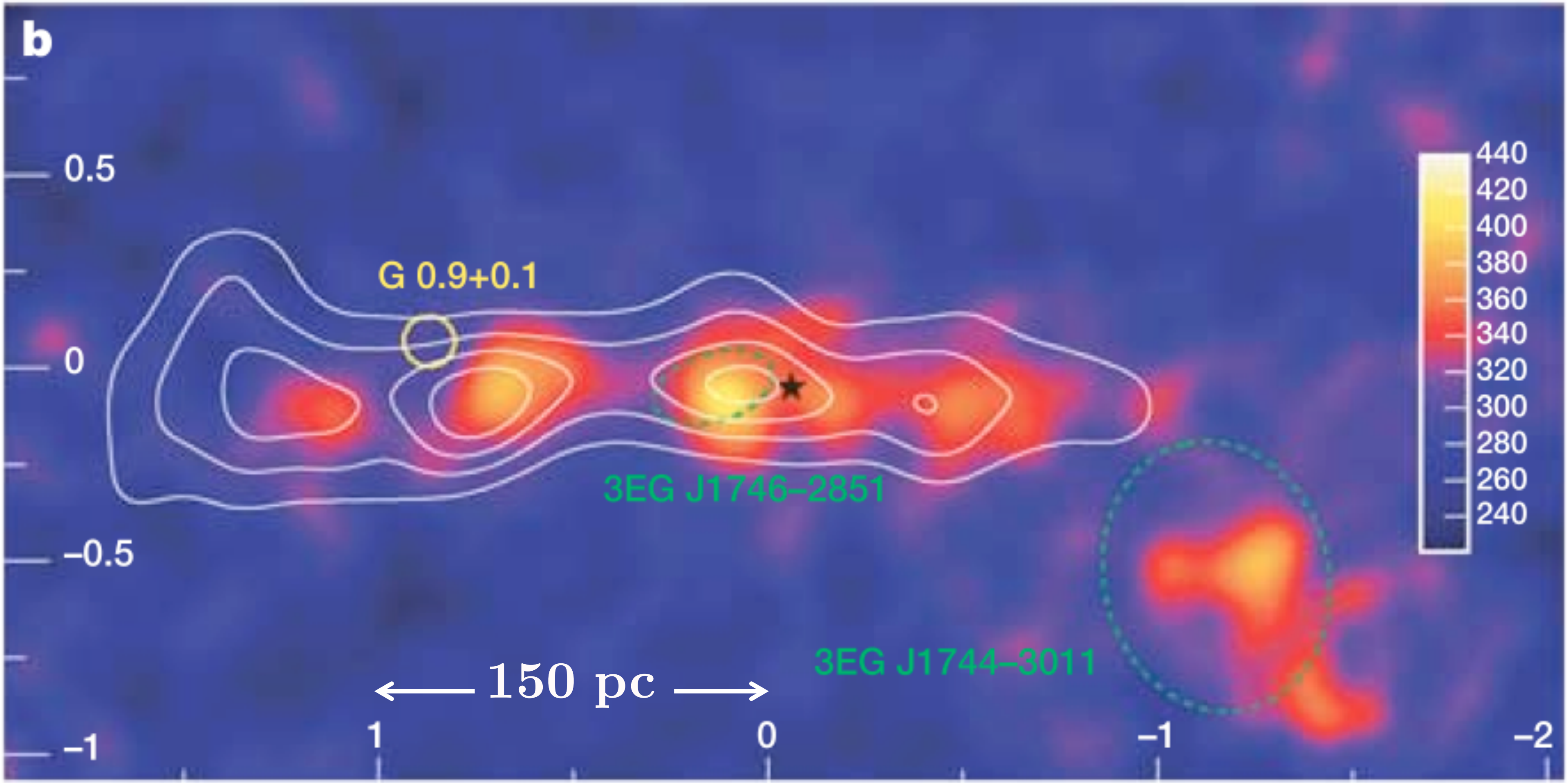
→ Radio, X-ray + γ-ray can break ambiguity, constrain magnetic field

Example non-thermal SEDs




Rogrigues et al. 2018, 1806.01624

# Milky Way- Galactic Center  Outflow

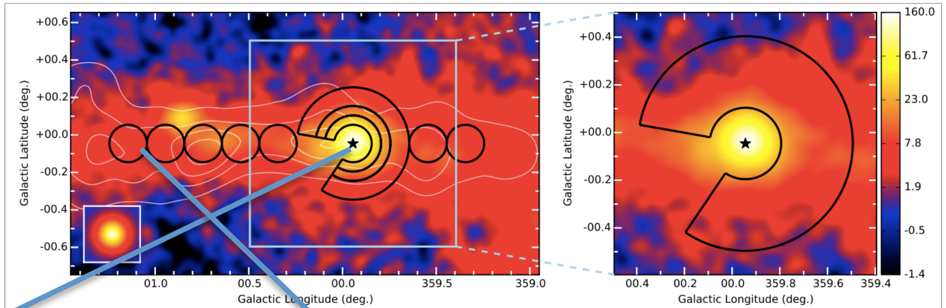


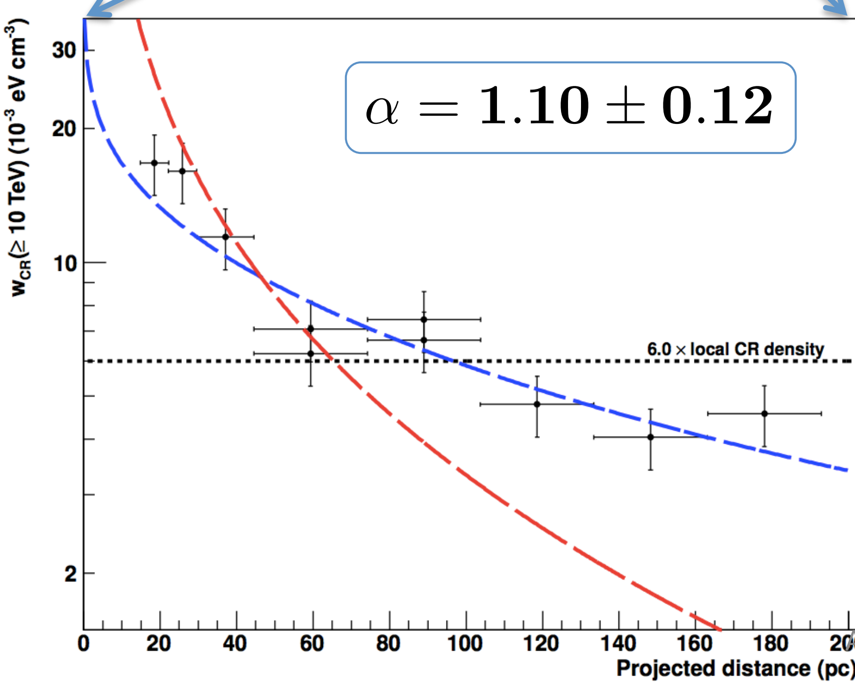

$\mathbf{L_\gamma(1\ TeV) \approx 5 \times 10^{34}\ erg\ s^{-1}}$ $\mathbf{L_\gamma^{IR} \approx 10^{42}\ erg\ s^{-1}}$

$\mathbf{\dot{M} \approx 0.1\ M_\odot\ s^{-1}}$

Aharonian+, Nature, 439, 695 (2006)

# Galactic Center Pevatron




Recall that the diffusive propagator is

$$\mathbf{G(r,t) \propto \frac{e^{(-r^2/(4Dt))}}{(4\pi Dt)^{3/2}}}$$

Steady State Spectrum Flux from Source is

$$\mathbf{n \propto 1/Dr}$$



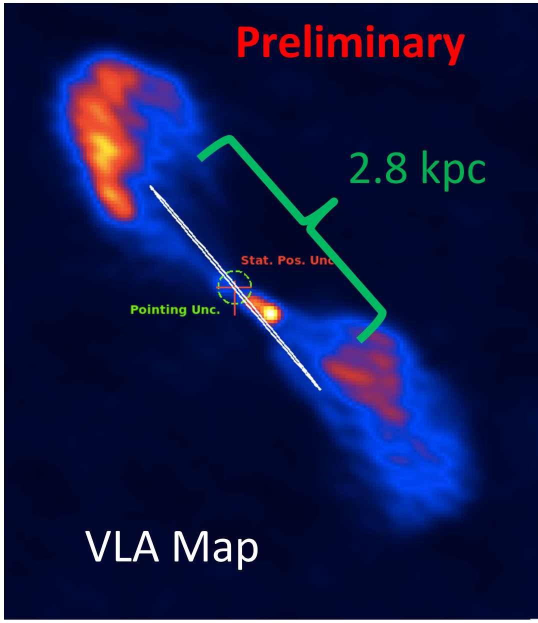
Abramowski+, Nature 531 476 (2016)

H.E.S.S.

# New Results from Centaurus A

| Symm. Gauss vs. Point-Like | Elliptic. Gauss vs. Point-Like | Elliptic. vs. Symm. Gauss |
|---|---|---|
| 3.54σ | 5.15σ *(5.47σ)* | 4.18σ *(4.56σ)* |

PRELIMINARY




Source not point-like
**First extragalactic extended source in the TeV range!**

- Gaussian width of semi-major axis: (0.0435 + 0.0122 - 0.0116)°
- Point-Like in the transvers direction
- Aligned with radio jets

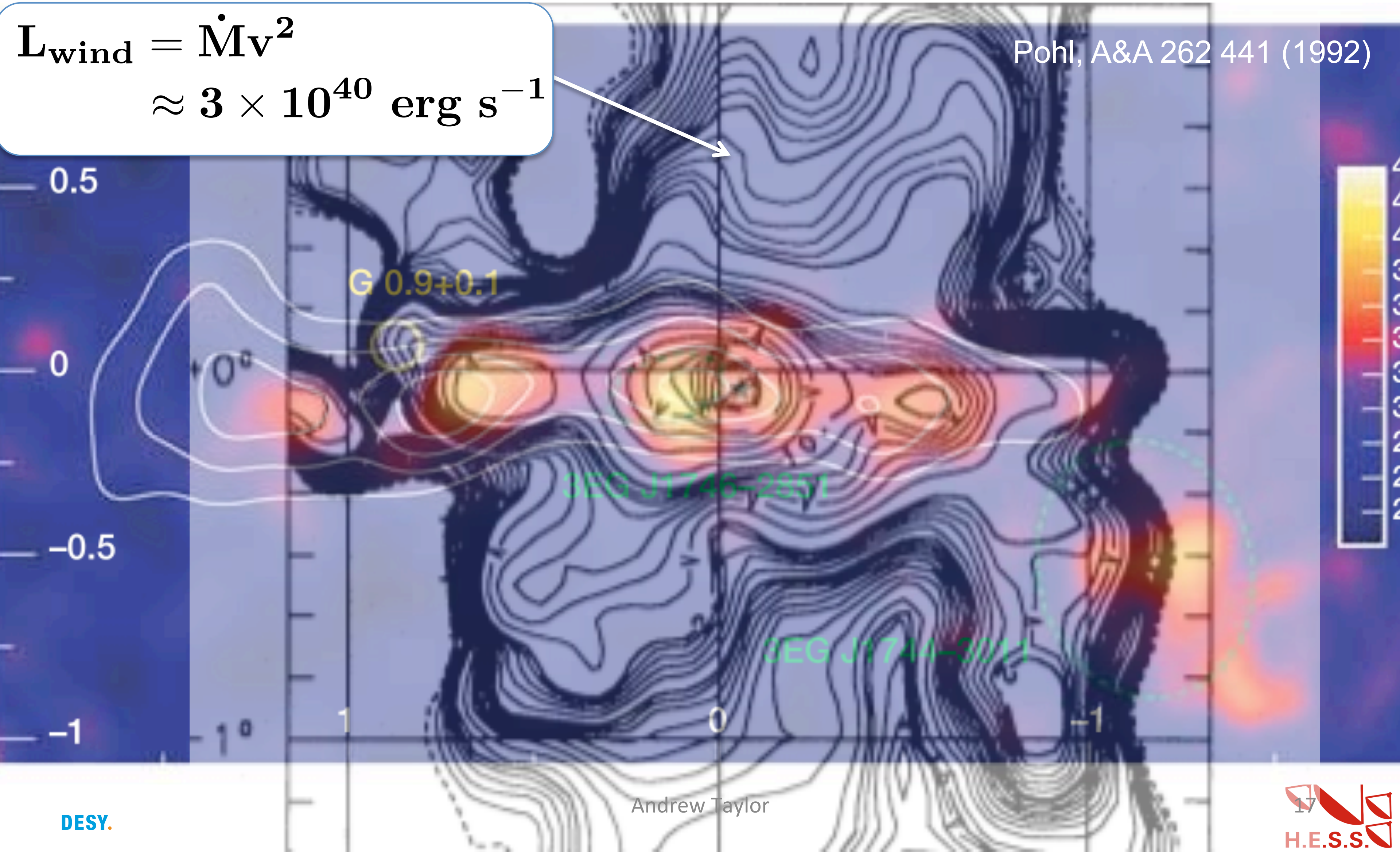
# Conclusions

- IACTs instruments have a huge role to play in the multi-messenger domain
- Observation programs of existing instruments are in place to cover a range of potential candidate messengers
- New surprises continue to come through on "well studied" (A)GN- eg. Sgr A* and Cen A
- Exciting results are also turning up through multi-messenger follow-up observations (eg. TXS 0506 gamma-ray neutrino correlation)

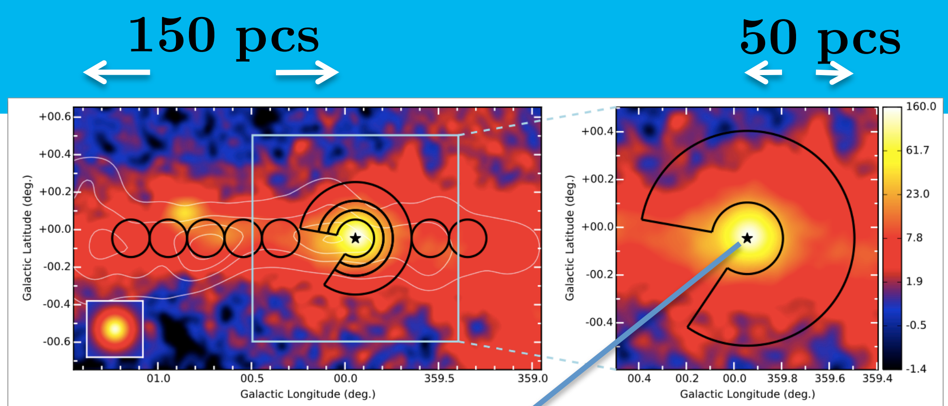
# Extra Slides

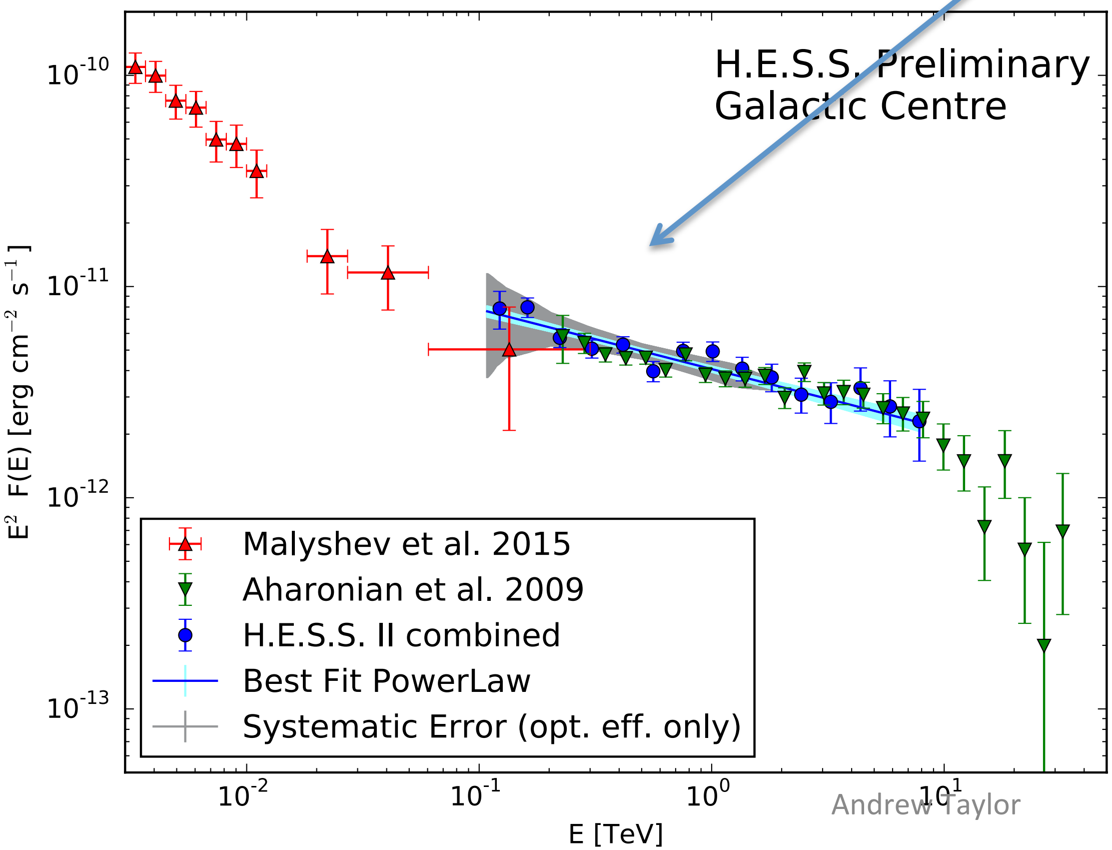
# Milky Way- Galactic Center  Outflow

$$\mathbf{L_{wind}} = \mathbf{\dot{M}v^2} \approx \mathbf{3 \times 10^{40}\ erg\ s^{-1}}$$



# Galactic Center Pevatron




- Analysis of Sgr A* 'point source' at Galactic center
- Inflection evident in spectrum around 100 GeV revealing presence of new hard component



H.E.S.S.

# Cosmic Ray (Hadron) Spectrum Measurement with IACTs