A brief overview of VHEPU 2018

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14th Rencontres du Vietnam. 12-18 August 2018. ICISE. Quy Nhon, Vietnam

Some numbers

- 5 days, ~80 talks
- 77 participants from 16 countries (4 continents)
- US (17), Germany (13), France (12), Italy (8), Spain (6), and Japan (5) were the most represented

All slides available at:
http://vietnam.in2p3.fr/2018/vhepu/program.php

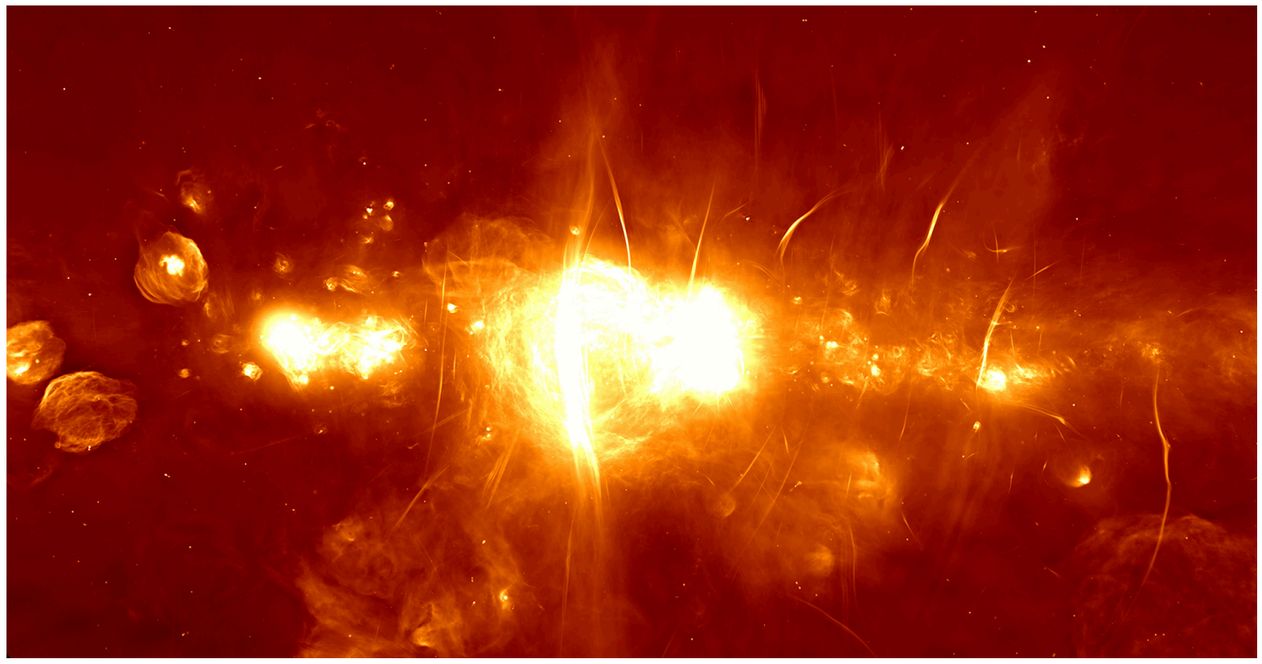
(Some of) what the conference covered

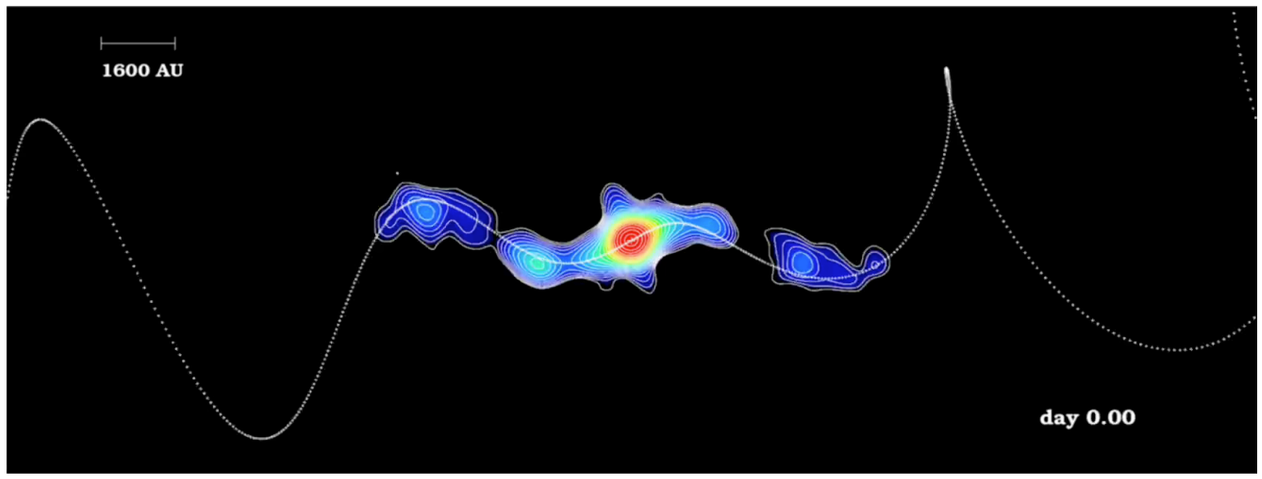
NS, Pulsars, PWNe, SNRs
Galactic Center, AGN
GRBs, AGN, FRBs, …

VERITAS, MAGIC, HESS,
Fermi LAT
Auger, TA
LIGO/Virgo
Antares, Ice Cube

Gamma rays,
Cosmic rays,
gravitational waves,
neutrinos

Extreme Particle Astrophysics

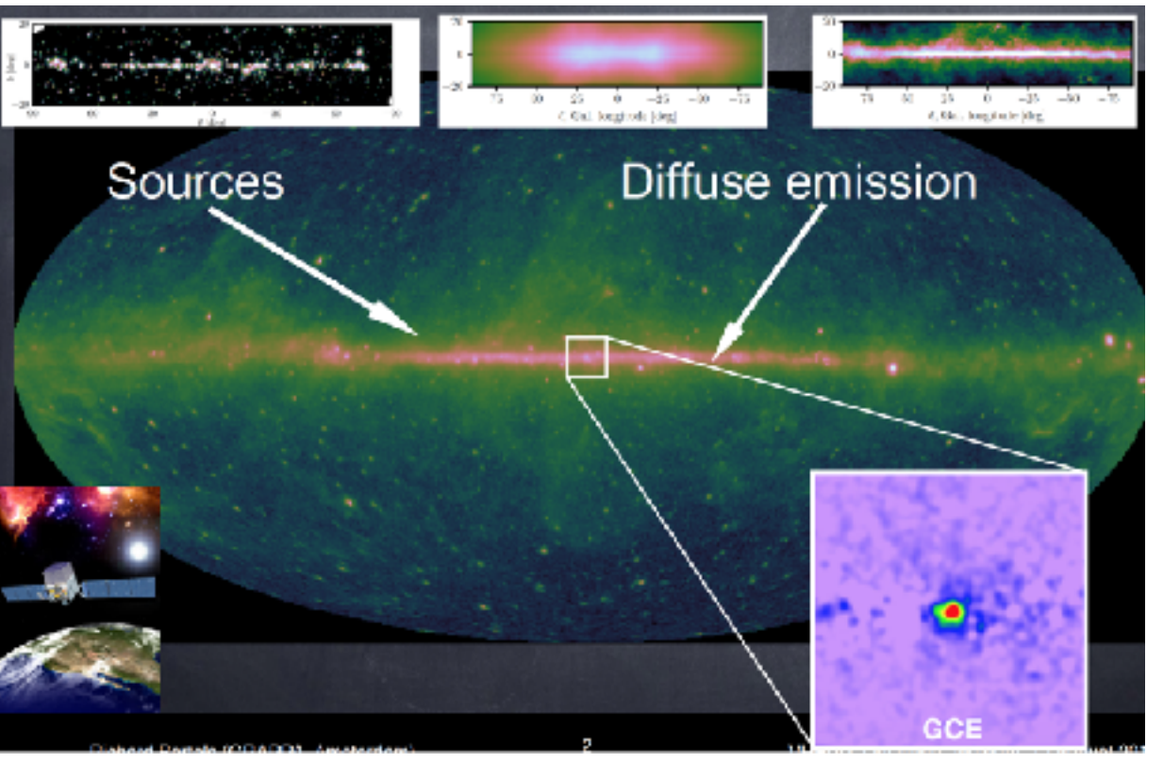




Roger Blandford

What is hyperluminal motion?
What are the Galactic center filaments?
What is the "lamppost"?
How are jets made?
How are jets confined?
How do electromagnetic flows dissipate?
Are jets powerful neutrino sources?
How does SS433 work?
How and when do accretion disks radiate and vary?
What is the provenance of stellar binary black holes
What makes a Gamma Ray Burst?
How do pulsars shine?
Neutron star physics
Are there millisecond magnetars?
How much more relativity can we extract from binaries?
Is GW 170817 a short Gamma Ray Burst?
NS merger discovery space
What is a Fast Radio Burst?

The Galactic Center Excess



Candidate	Spectrum	Morphology
Dark Matter	✅	✅
MSPs	✅	✅
Transient event	?	?
CR source	?	?
Molecular clouds	✅	✗*

The current status

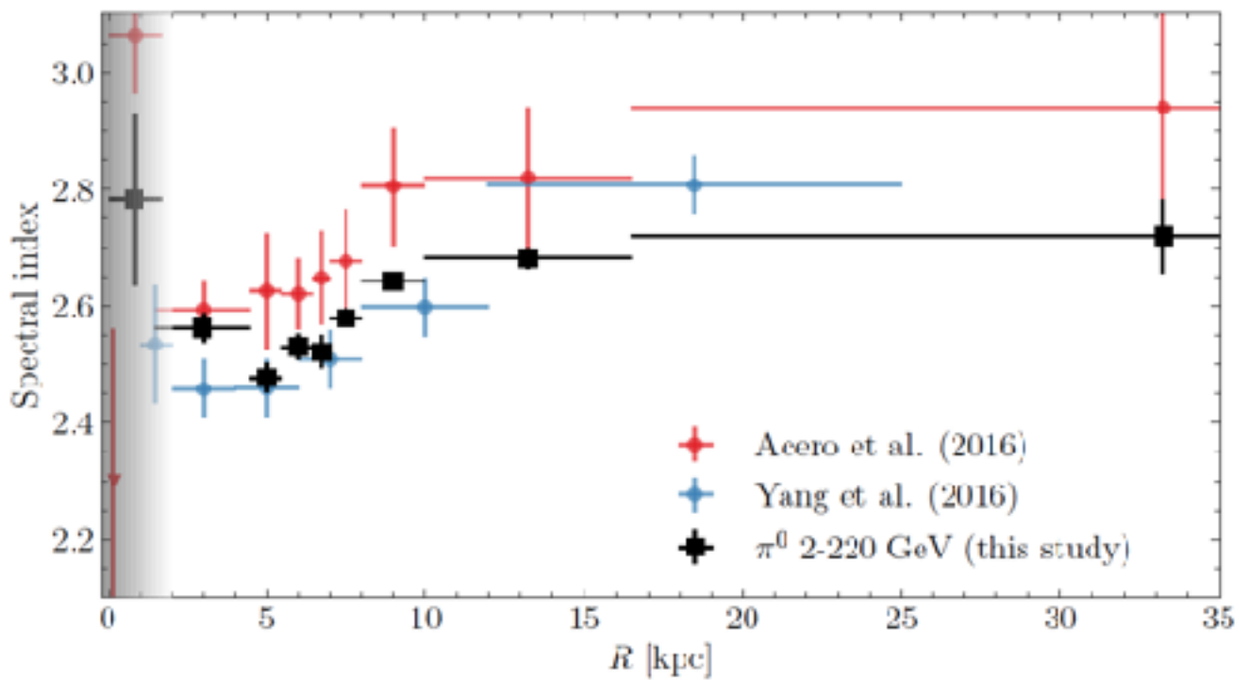
- The GCE is a significant feature that so-far stood the test of time (9 years) despite ever improving background models.
- Although its characteristics have been altered. No longer preference for NFW with γ~1.26
- ~50 GeV DM and bulge MSPs look very similar…
- Evidence in favour of MSPs is slowly accumulating
- Improved γ-ray analyses can maybe teach us a little more, but radio will probably be the next breakthrough.

Richard Bartels

The spectral index gradient problem

Prothast, Gaggero, Strom, Weniger, 2018

proton spectral index
using SkyFact: *adaptable* template fitting tool [*Storm, Veniger & Calore 2017*]



Clear evidence of a progressive hardening in the inner Galaxy towards the GC
Large uncertainty in the GC region !

ed on spatial dependent diffusion

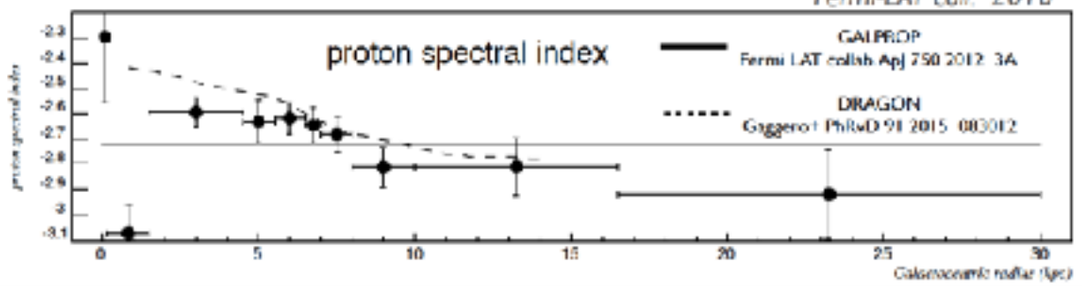
Gaggero, Urbano, Valli & Ullio, PRD 2015

The CR spectral index gradient problem is interpreted as a consequence of the radial dependence of the diffusion coefficient
This was implemented in the **DRAGON code**.

Evoli, Gaggero, DG. & Maccione 2008
Evoli, Gaggero, Di Mauro, Vittino, Mazziotta & DG 2017,18

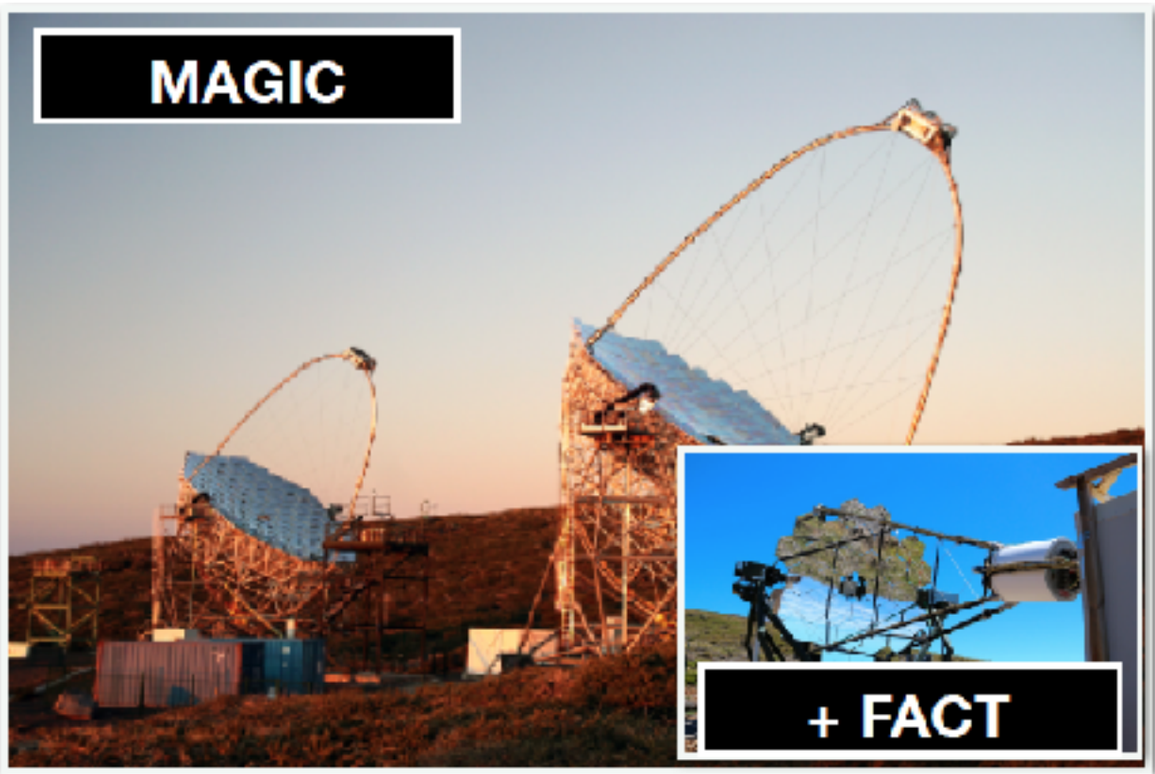
$D(E) = D_0 (E/E_0)^{\delta(r)}$ with $\delta(r) = A\,r + B$ for $r < 11$ kpc
so that $\Gamma(r) = \Gamma_{source} + \delta(r)$ "KRAγ model"

Fermi-LAT coll. 2016



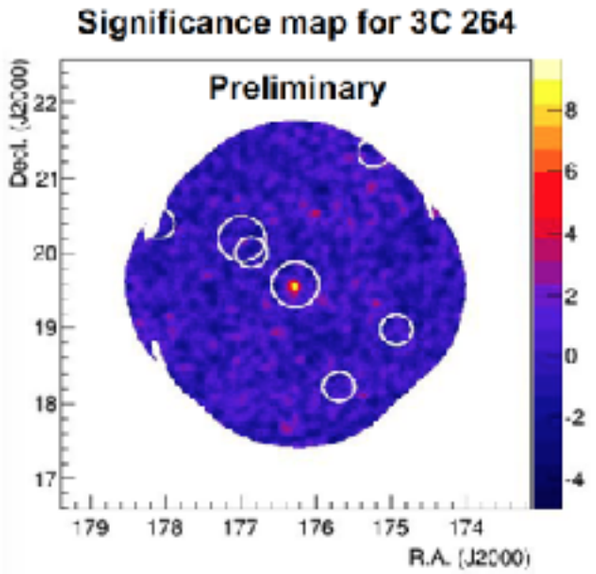
Dario Grasso

Current VHE telescopes



Credit: Stefan Funk

New VERITAS discoveries



VERITAS discovery of VHE emission from the FRI radio galaxy 3C 264

ATel #11436; *Reshmi Mukherjee (Barnard College) for the VERITAS Collaboration*
on 17 Mar 2018; 06:25 UT
Credential Certification: Reshmi Mukherjee (mukh@astro.columbia.edu)

Subjects: Gamma Ray, TeV, VHE, Request for Observations, AGN, Blazar

We report the VERITAS discovery of very-high-energy emission (VHE; >100 GeV) from the FRI radio galaxy 3C 264, also known as NGC 3862. Nearly 12 hours of quality selected data, collected by VERITAS between 09 February 2018 and 16 March 2018 (UTC), were analyzed. Preliminary results yield an excess of 80 gamma ray events above background at the position of the source, corresponding to a statistical significance of 8.4 standard deviations. The preliminary flux estimate (E>300 GeV) is (1.3 ± 0.2)e-12 cm^-2 s^-1, or approximately 1% of the Crab Nebula flux above the same threshold. The Fermi-LAT 3FHL catalog (Ackermann et al. 2017 ApJS 232, 18) lists a photon index of 1.95 ± 0.33 for 3C 264 which, when extrapolated to the VHE band, is consistent with the VERITAS detection. At a redshift of 0.0217, 3C 264 is a more distant analog to M87, with supermassive mass of ~8e (Meyer et al. 2015, Nature 521, 495) detected in its kpc-scale optical jet. With this discovery, 3C 264 is the most distant radio galaxy detected at VHE so far. VERITAS will continue to observe 3C 264; multi-wavelength observations are encouraged. Questions regarding the VERITAS observations should be directed to Reshmi Mukherjee (rm34@columbia.edu). Contemporaneous target of opportunity observations with the Swift satellite have also been scheduled. VERITAS (Very Energetic Radiation Imaging Telescope Array System) is located at the Fred Lawrence Whipple Observatory in southern Arizona, USA, and is most sensitive to gamma rays between 85 GeV and 30 TeV (http://veritas.sao.arizona.edu).

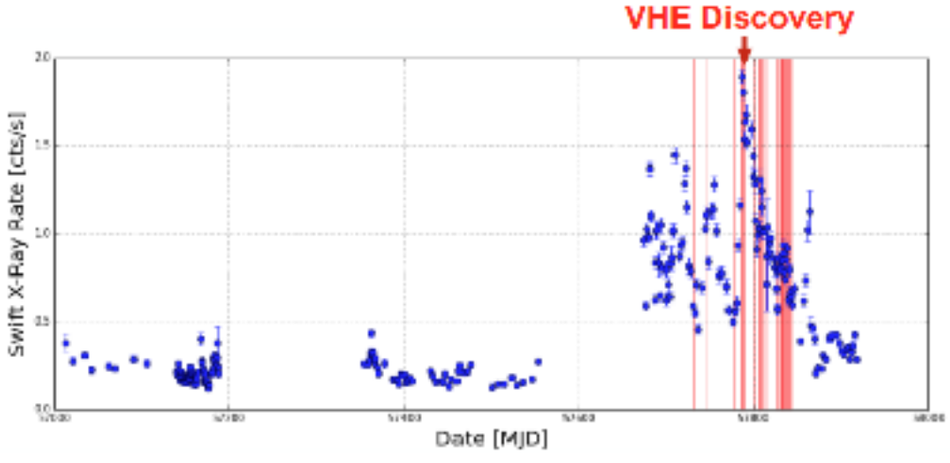
- Strong, hard-spectrum detection: ~8σ in ~44 h; Γ ~ 2.3
- Low, weakly variable VHE flux: ~0.5% Crab; ~Month-scale variations
- Major VERITAS + MWL effort: Radio (e.g. VLBA), Optical (HST, ground-based), X-ray (Chandra + Swift), Fermi-LAT => No major activity in knot sub-structure

- Probing connection between radio knot structure and AGN activity
  – Multiwavelength observations can help pinpoint location of TeV emission
  – BL Lac: Fast g-ray flare coincident with emergence of a radio knot
  – 3C 264: New TeV-detected radio galaxy with no strong activity from the radio knot or core

- VERITAS is running very well & is funded to operate until at least 2019
  – Source catalog is now at 63 sources from 8 classes
  – Exploring the possibility of further operations (e.g. until ~2022)

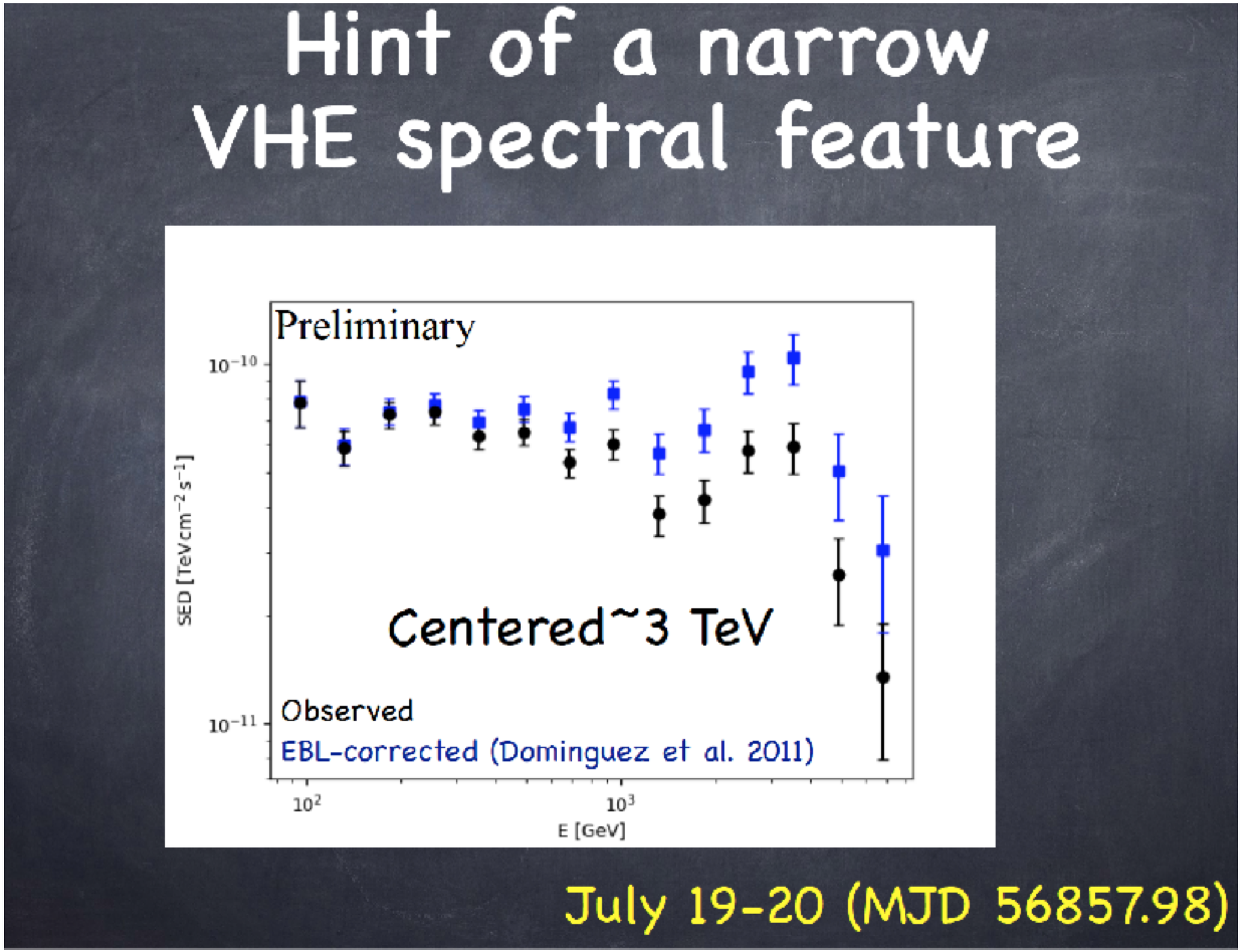
OJ 287: VERITAS VHE Discovery

- Optically bright blazar @ z = 0.306
  – Classification uncertain
  – TeV candidate: Costamante & Ghisellini 2002
- "Periodic" optical behavior: T ~ 12 yr
  – Binary black hole system? Helical jet?
  – Next optical outburst in 2019



David Williams

MAGIC view of Mrk 501

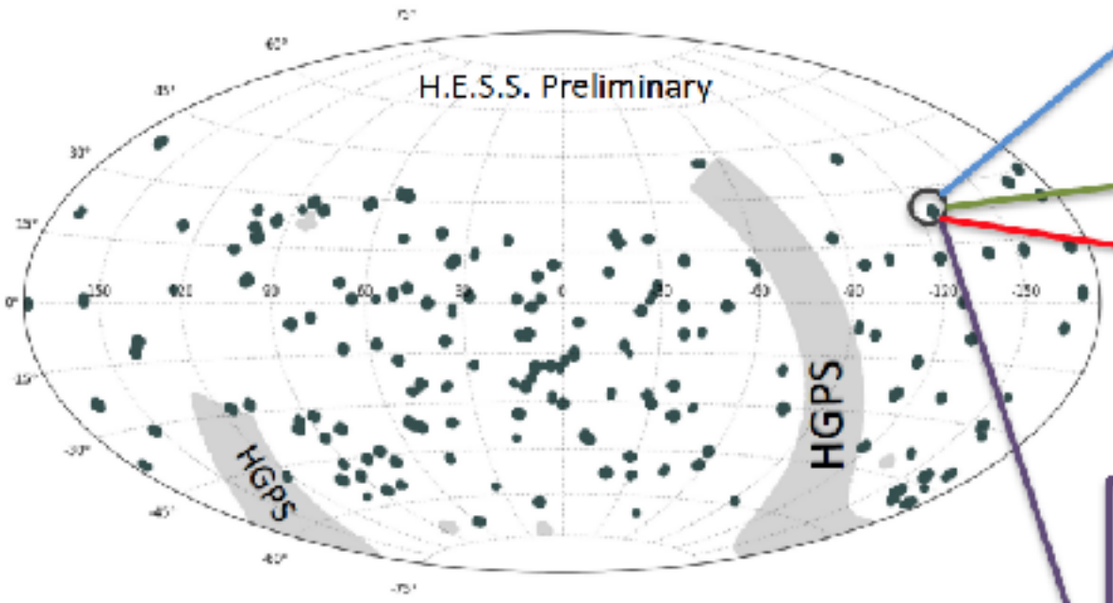


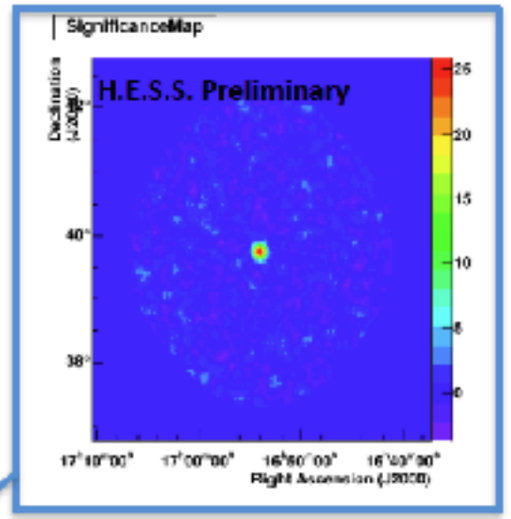
HESS extra-Galactic survey

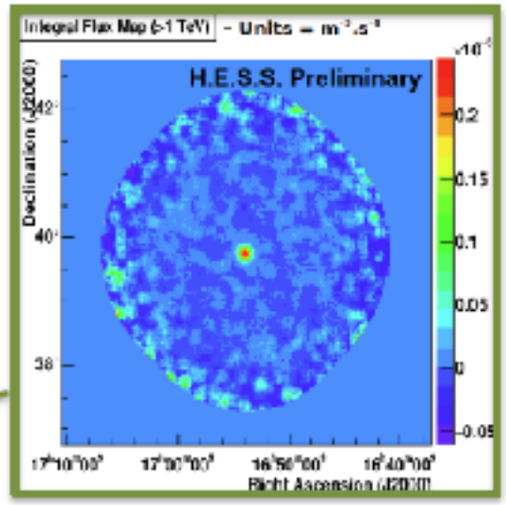
Release products

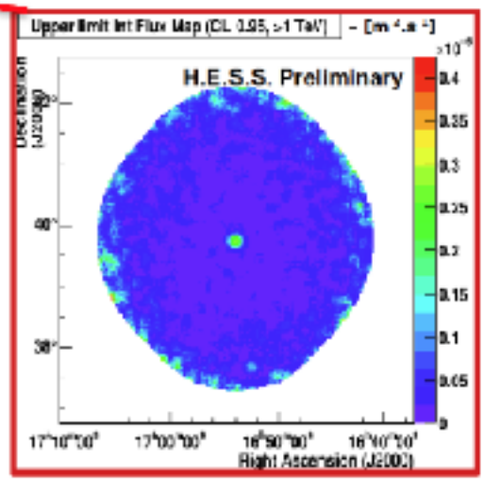
Example of the analysis products for Mrk 501

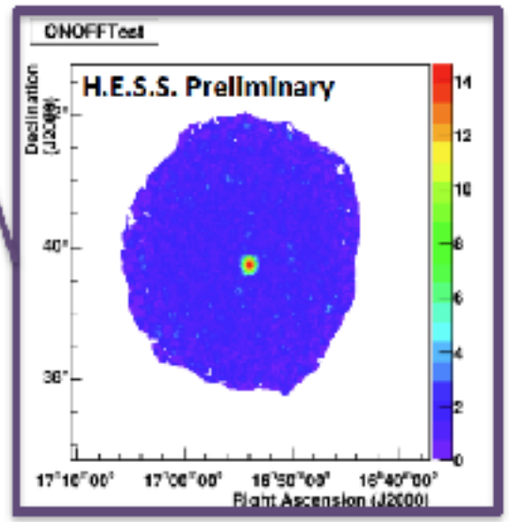
- Significance map;
- Flux map;
- Upper-limits map;
- Variability map;





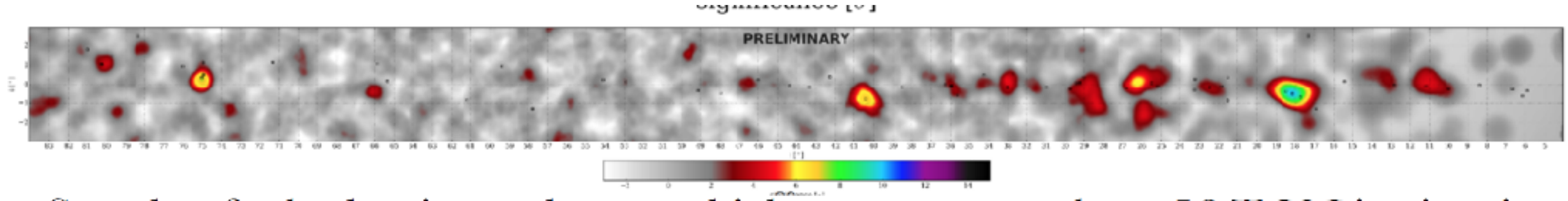






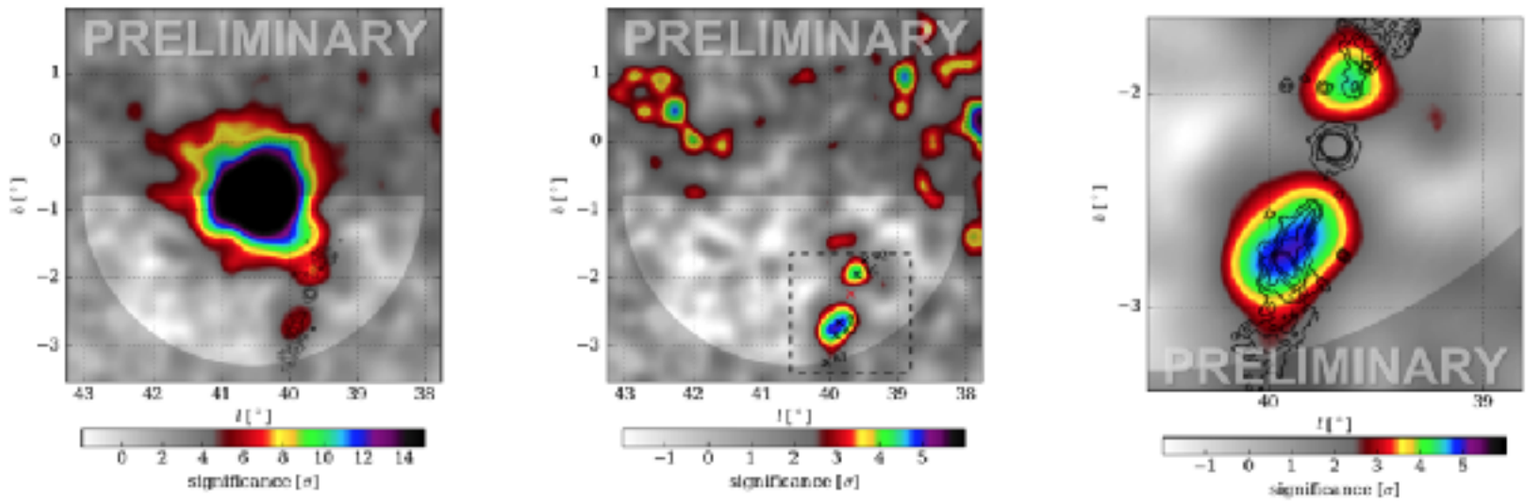
- We also intend to release maps for all the RunClusters in FITS format.

HAWC results



Searches for hadronic accelerators: high-energy maps above 56 TeV. Livetime is 911.3 days. Using new energy estimator under development.
If you go to TeVPA, look for Kelly Malone.

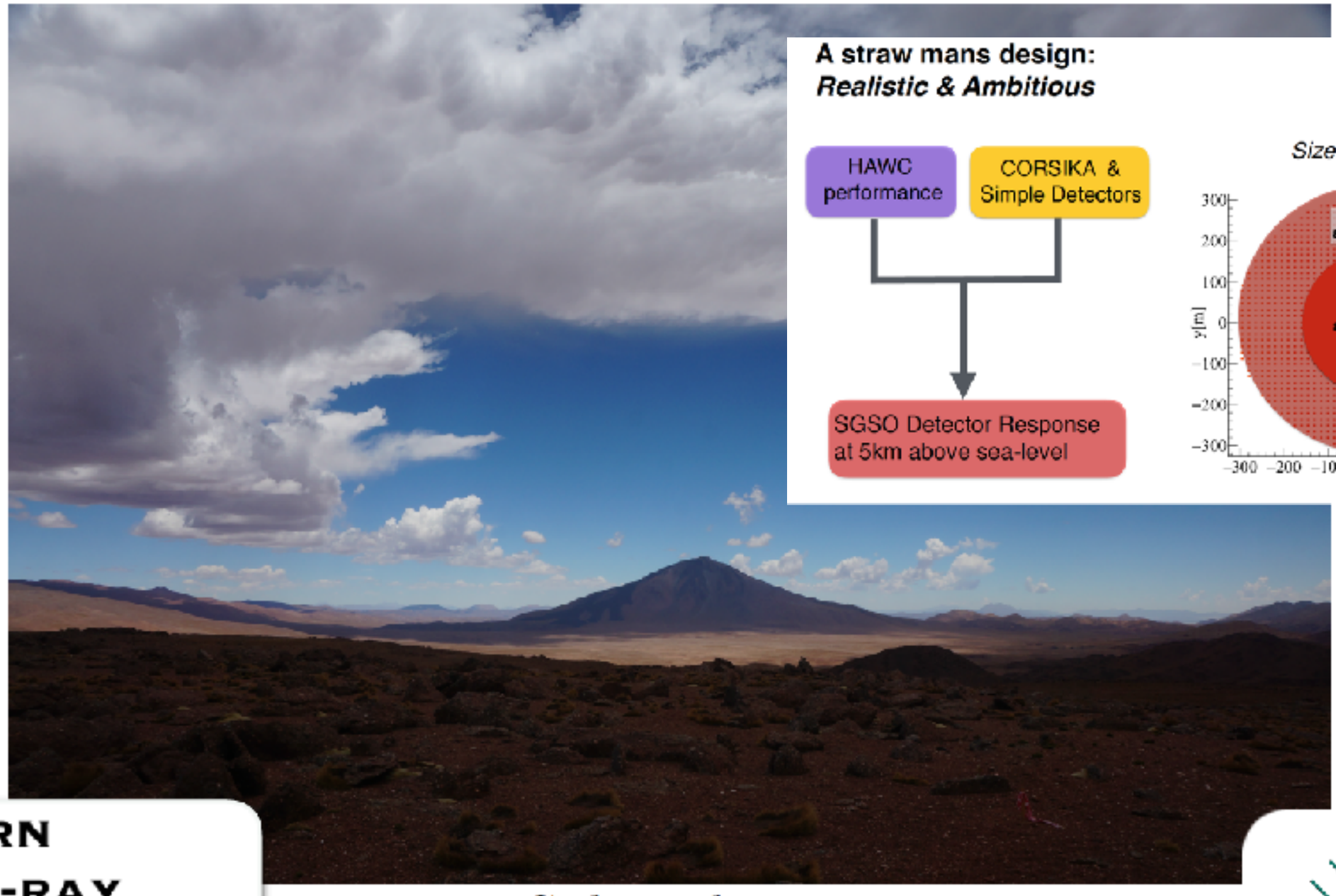
Observations from the galactic microquasar SS 433 below MGRO1908.
HAWC observes TeV emission coincident with the lobes of the jets.



Publication was just accepted in Nature. Be alert for when it gets published.
If going to TeVPA, look for Chang Rho

Hugo Ayala Solares

The Science Case for a Southern Gamma-ray Survey observatory



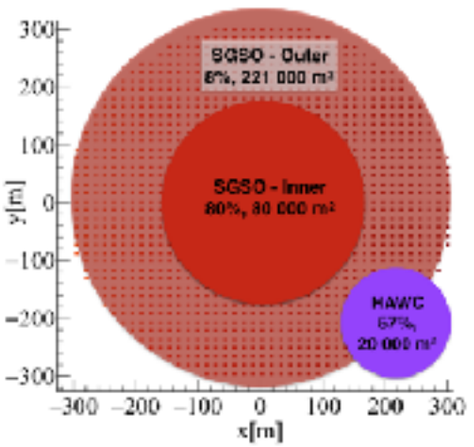
A straw mans design:
Realistic & Ambitious

HAWC performance

CORSIKA & Simple Detectors

SGSO Detector Response at 5km above sea-level

Size & Fill factor



SOUTHERN GAMMA-RAY SURVEY OBSERVATORY

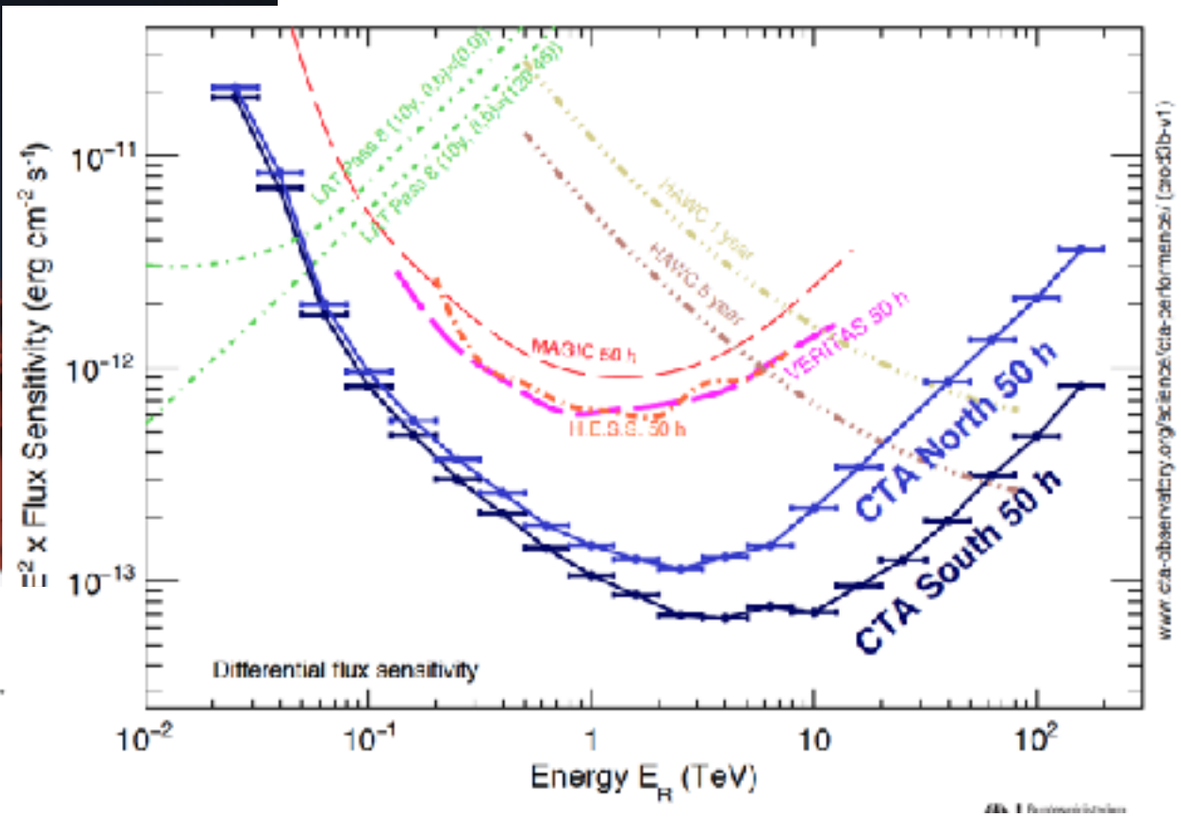
Harm Schoorlemmer,
on behalf of the SGSO-alliance

MAX PLANCK INSTITUT FÜR KERNPHYSIK

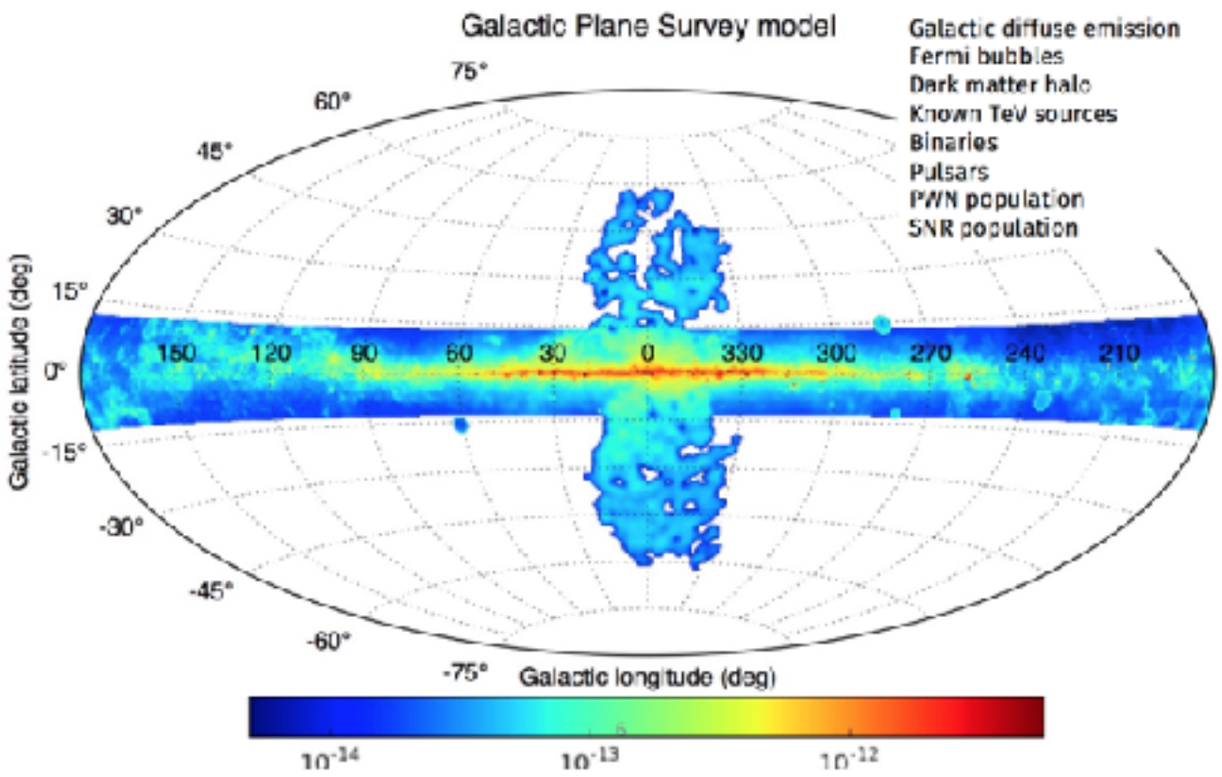
www.sgso-alliance.org

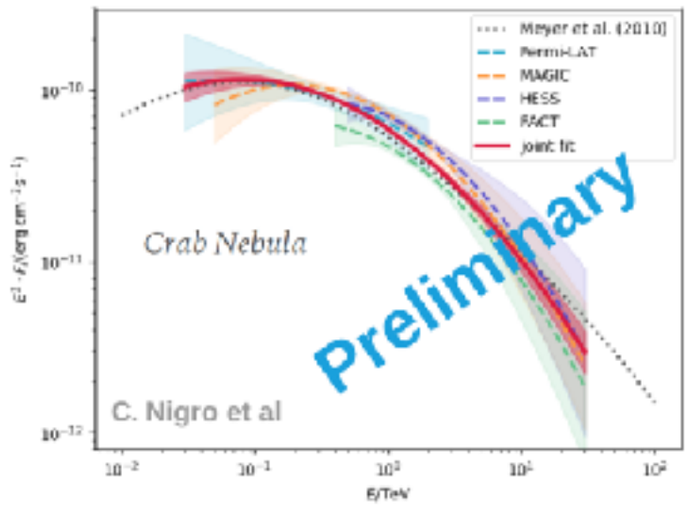
Future VHE telescope(s): CTA

Stefan Funk



FIRST CTA DATA CHALLENGE – FERMI-LAT +IACT INPUT

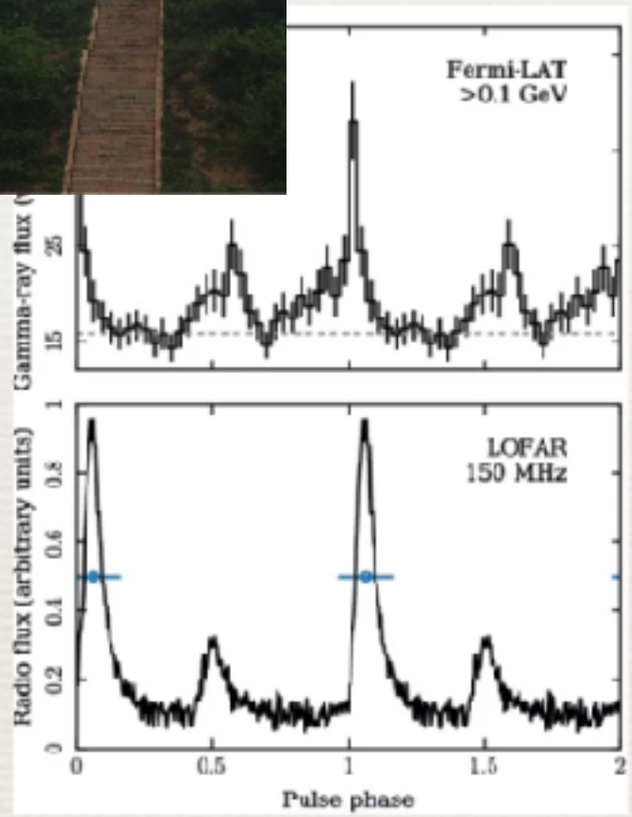




- Teams are starting to cooperate on joint analyses of sources, combining data sets from different instruments

Fermi LAT gamma-ray pulsars

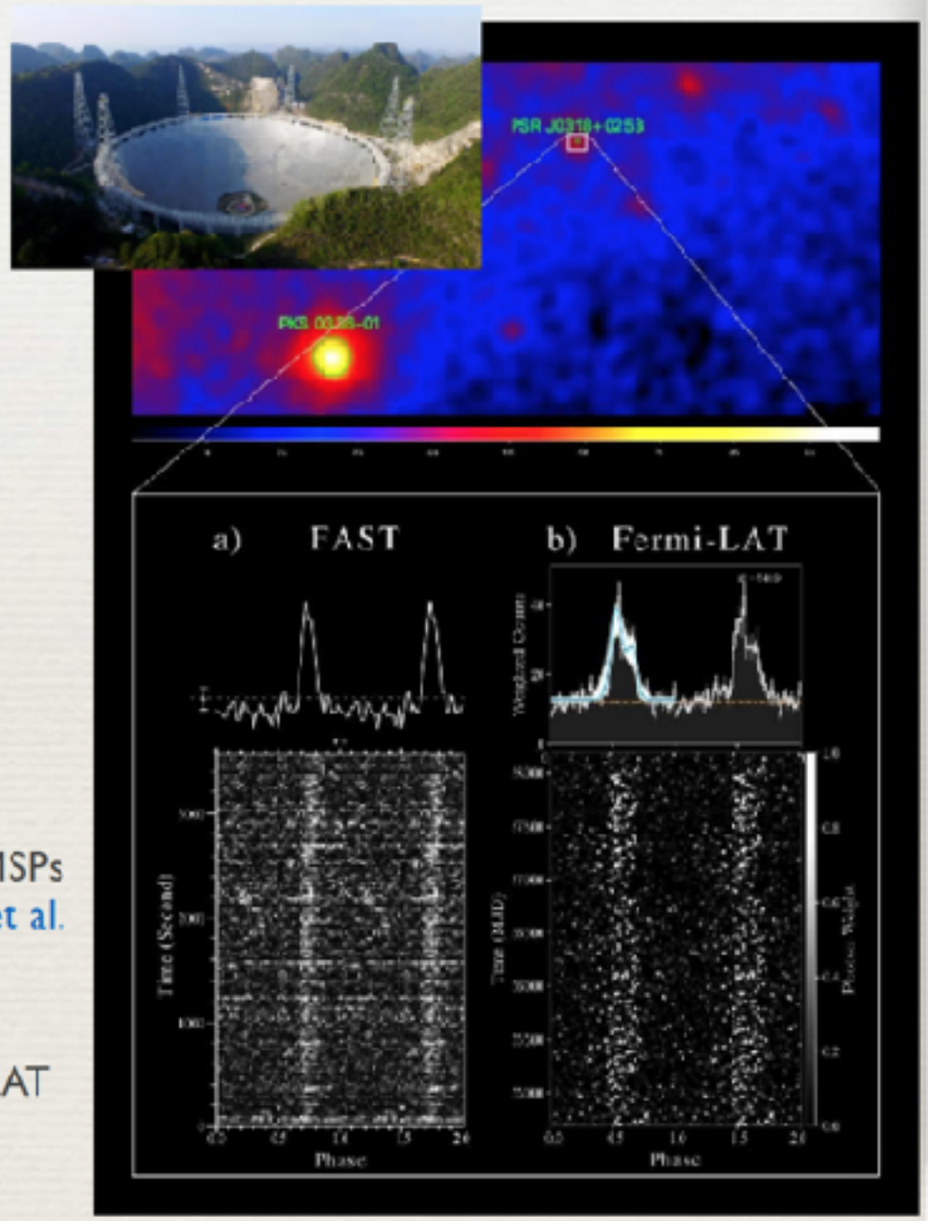
Some recent highlights

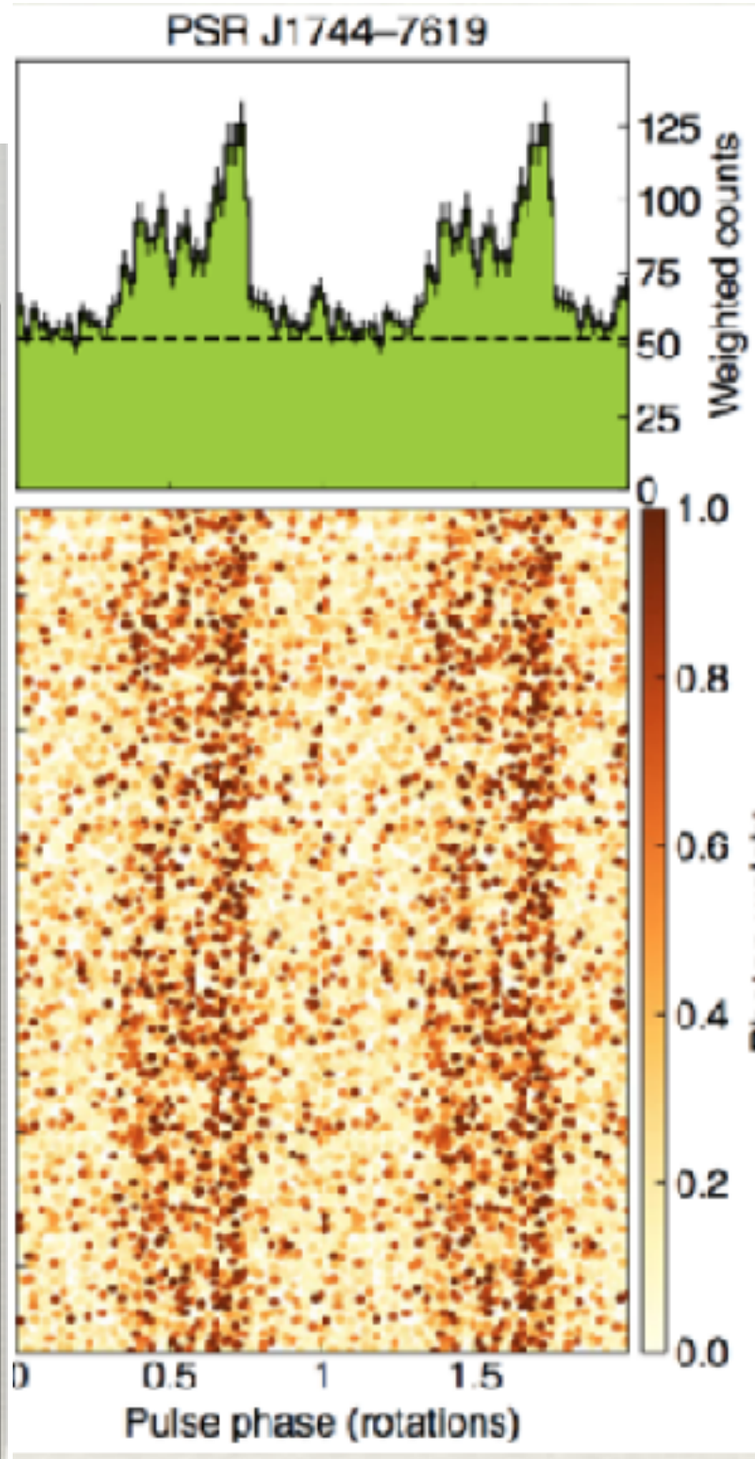


J1552+5437 (above). J0952-0607 & J0652+47: 3 MSPs discovered by LOFAR at 150 MHz! (see Pleunis et al. 2017 & Bassa et al. 2017)

J0318+0253: first MSP discovered by FAST, in a LAT source! (Wang et al., ATEL11584).

L. Guillemot, 13/08/18

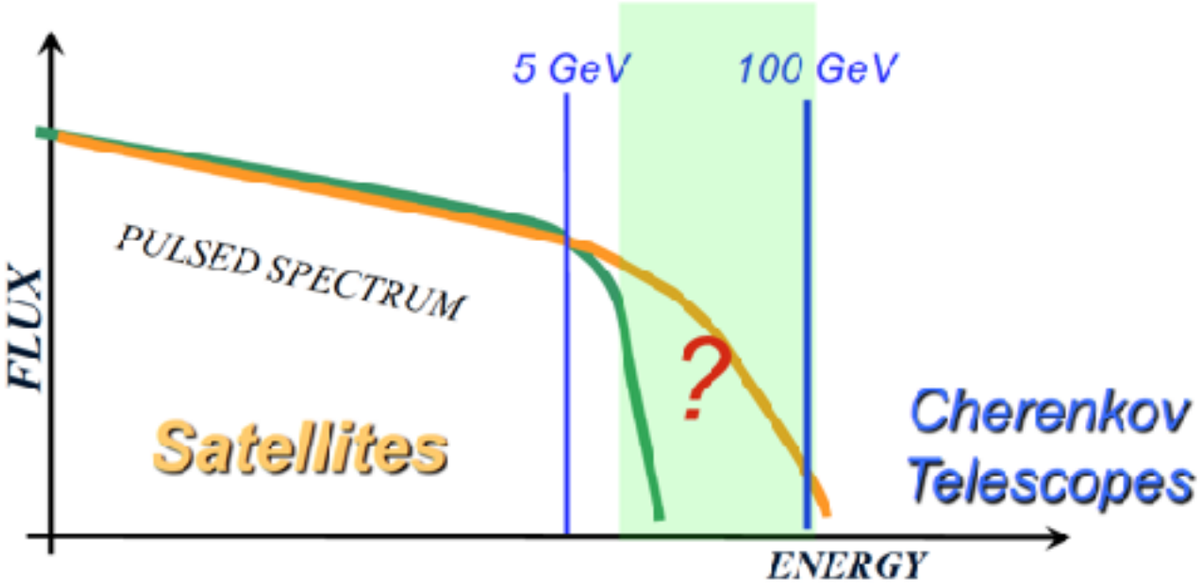




Clark et al., Sci Adv. 2018.

Lucas Guillemot

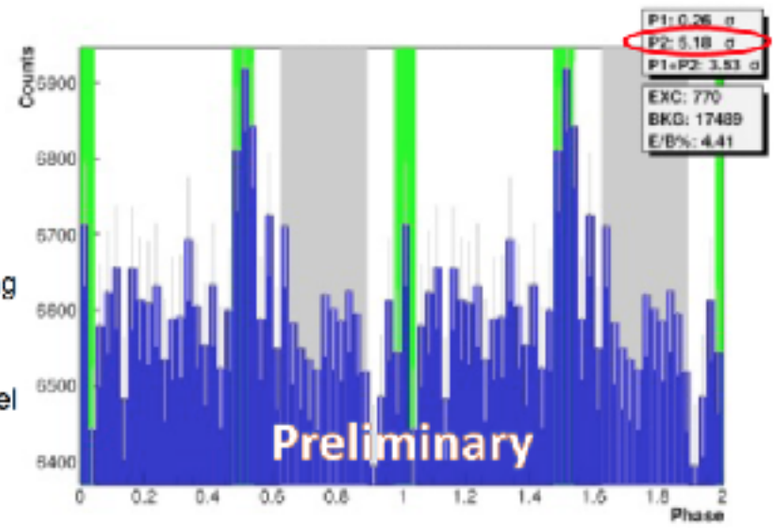
Pulsars at VHE



Highlight: MAGIC detects Geminga pulsar

Observations with MAGIC SumTrigger-II

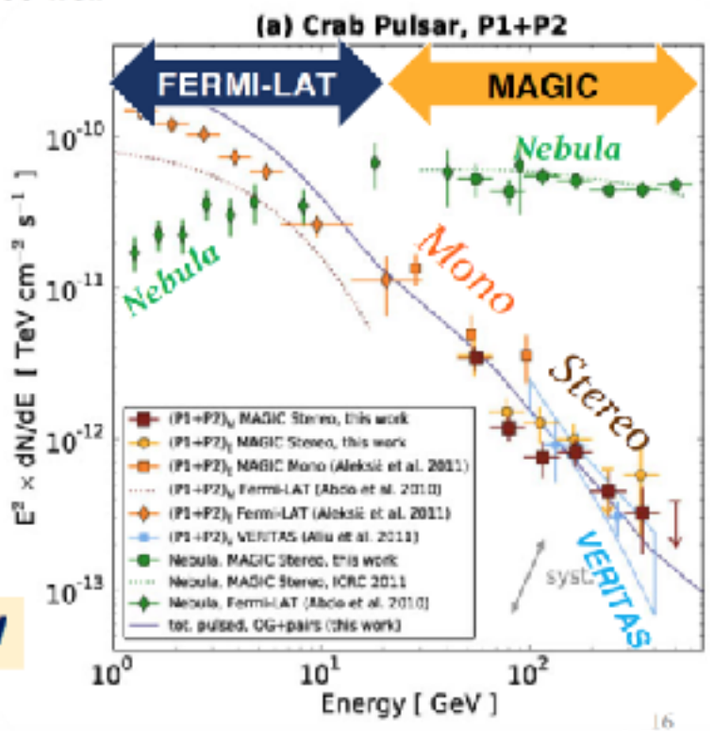
- ~30 h in 2017
- Two independent analysis chains:
  - Std. cleaning
  - Special SumT cleaning
- Clear detection:
  - P2 detected at 5σ level
  - P1 not visible



2nd VHE pulsar detected in the Northern Sky

Phase-resolved spectra up to 400 GeV

- MAGIC Mono & Stereo spectra agree well
- Agreement also with VERITAS



Spectral Indexes

P1+P2 : Γ = -3.6 ± 0.3

P1 : Γ = -4.0 ±0.8

P2 : Γ = -3.4 ±0.3

Aleksic et al, A&A 540, A69, 2012

Challenges Outer Gap model

Marcos López Moya

Long period Gamma-ray binaries with Fermi

- PSR B1259-63 continues to provide surprises
  - Three periastron passages, three different light curve
  - 2017 event showed the fastest variability seen in LAT data (excluding GRBs and solar flares)

- Gamma-ray luminosity suggests Doppler boosted emission
  - Disfavors inverse Compton emission
  - Estimate a maximum Doppler factor D ~ 3
  - ~1.5 minute variability → emission region radius $\lesssim$ 8e7 km (~30 - 40% of the distance to the Be star)

- No flare from PSR J2032+4127 near periastron
  - Geometry? Energetics?

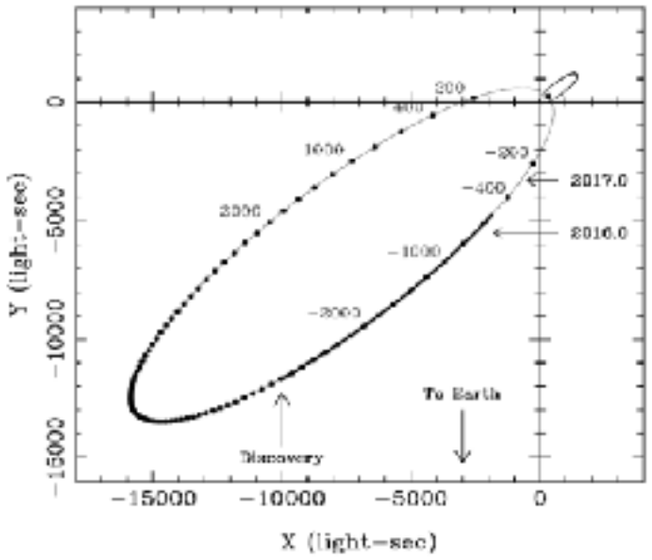
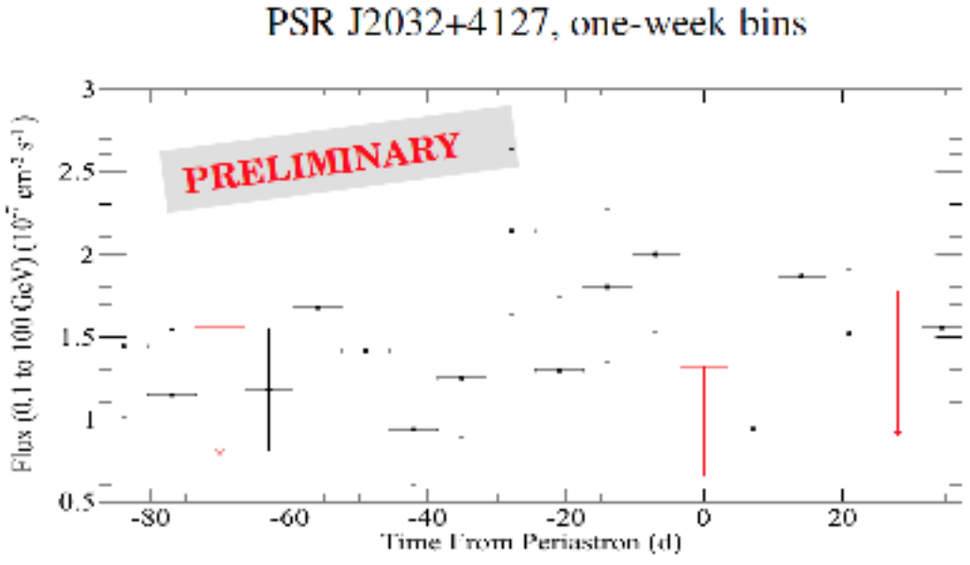


Figure 1. Schematic diagram illustrating the approximate orbital motion of PSR J2032+4127 and its Be-star companion MT91 213 about their common

Ho et al. (2017)

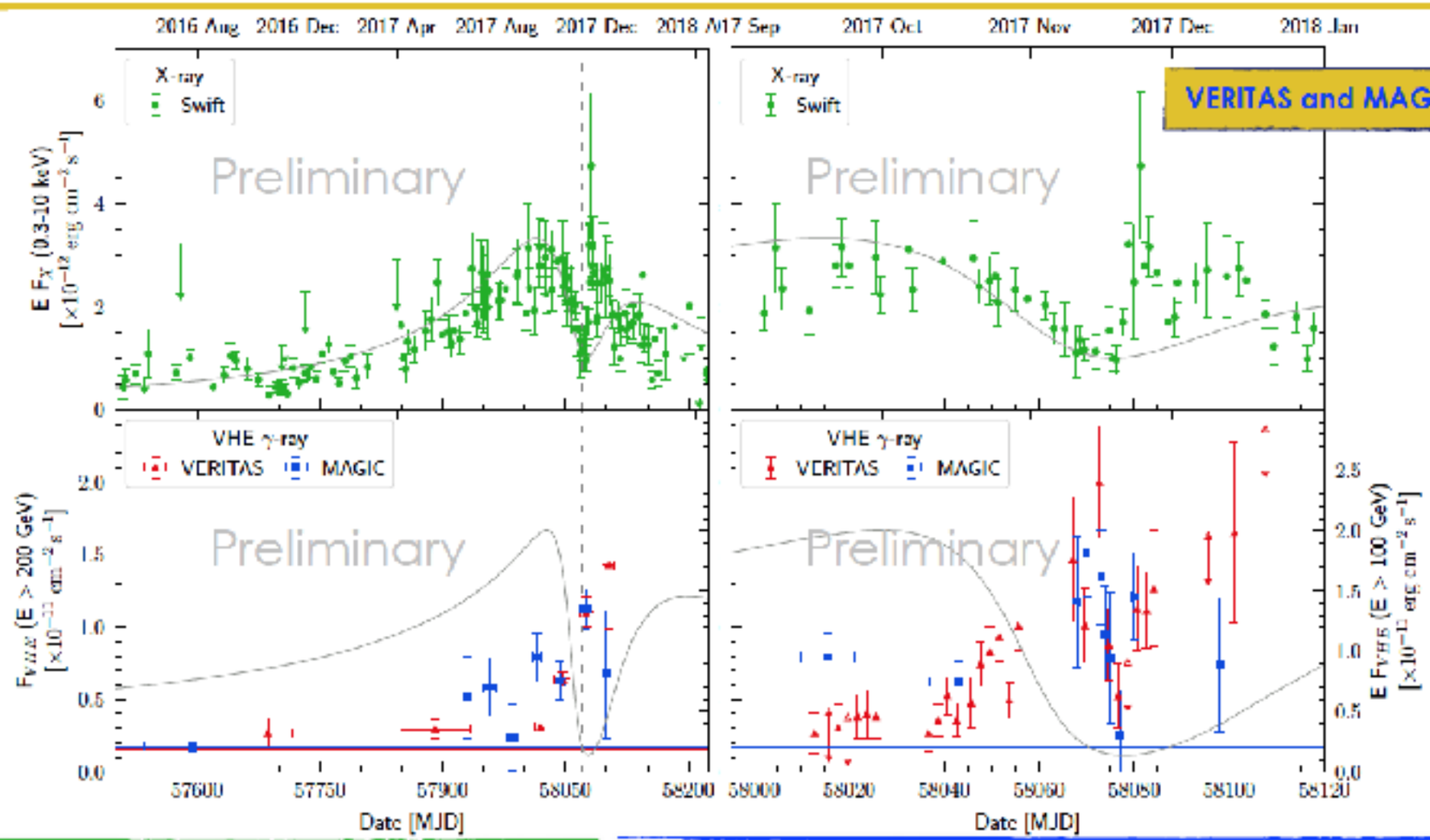
- Continued timing revealed binary orbit (Lyne et al. 2015 & Ho et al. 2017).
  - Orbital period ~50 years
  - Eccentricity ~ 0.96
  - Periastron 13 November 2017

- Another B1259?
  - Spin-down power of J2032 is 20% that of B1259
  - J2032 is closer at 1.4 kpc



Tyrel Johnson

VHE emission from **PSR J2032 +4107**



VERITAS and MAGIC. In prep

X-rays **Swift LC**:

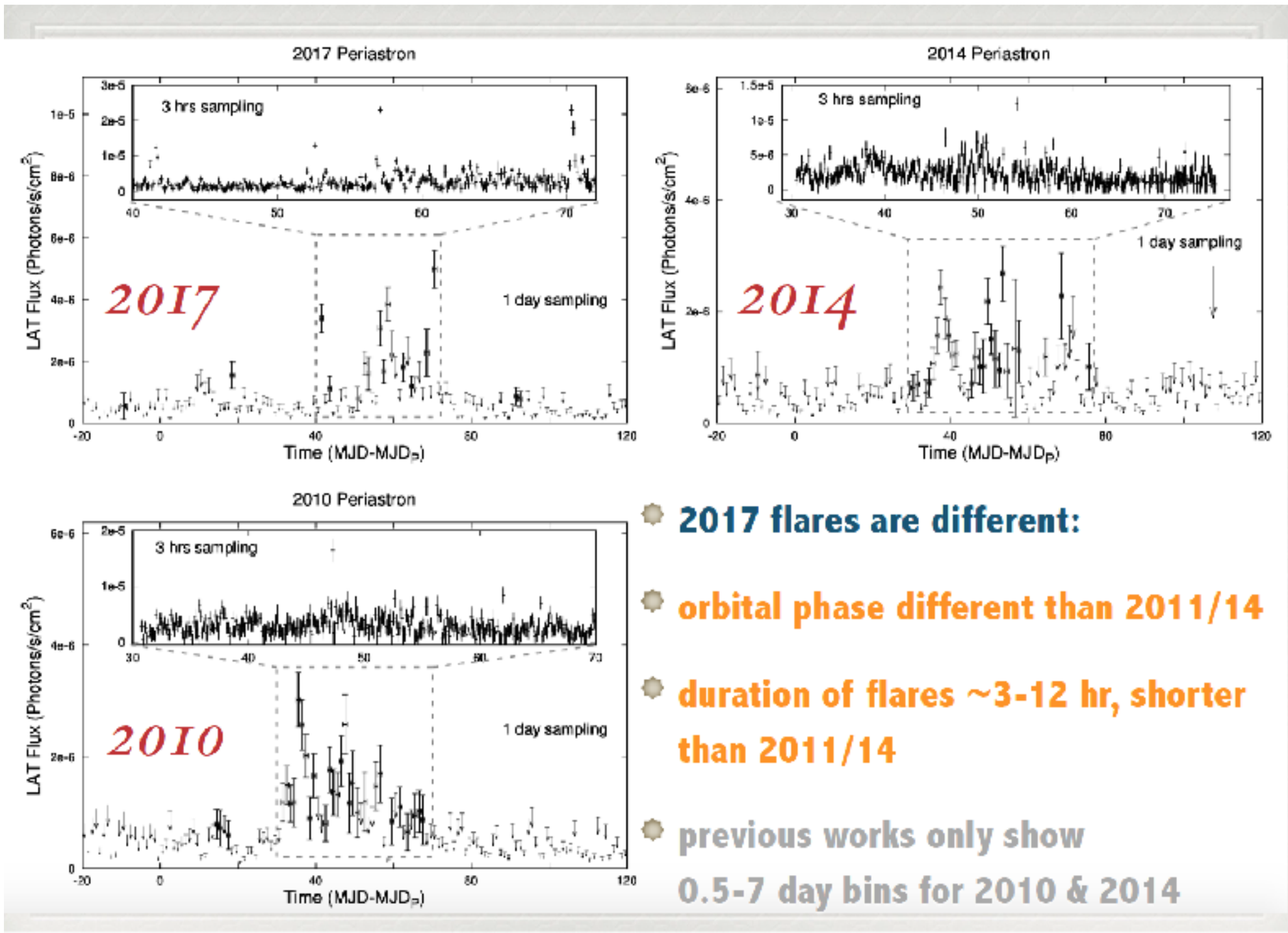
- **Peaked** about **30 days before periastron**
- Gradually decreasing, **minimum at periastron**
- **Recovery** over the next 30 days (**punctual flare** 15 days after periastron)

VHE LC:

- Flux **peaked at periastron**
- **7 days after periastron: sharp decrease** of the flux compatible with the baseline emission. Flux **recovered** to periastron level few days later
- Sharp **dip after periastron likely caused by γ-γ absorption**

Alicia López Oramas,
David Williams

PSR B1259-63 (P~3.4 yr)

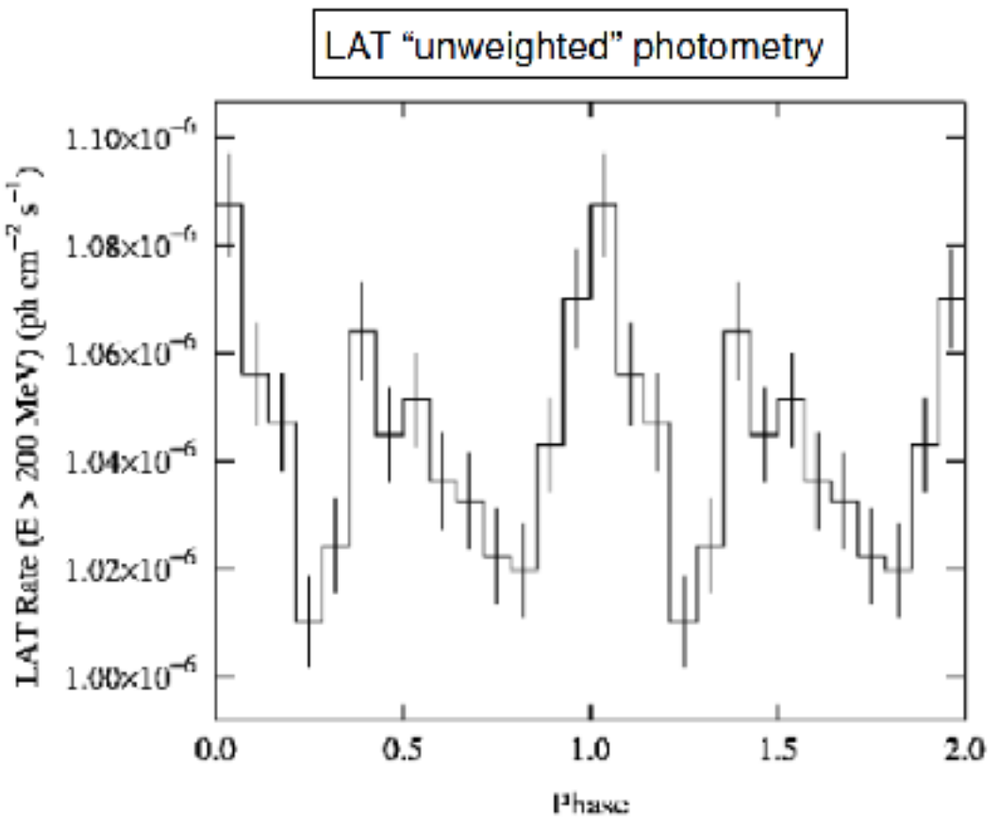


- **2017 flares are different:**
- **orbital phase different than 2011/14**
- **duration of flares ~3-12 hr, shorter than 2011/14**
- **previous works only show 0.5-7 day bins for 2010 & 2014**

Pak Hin Tam

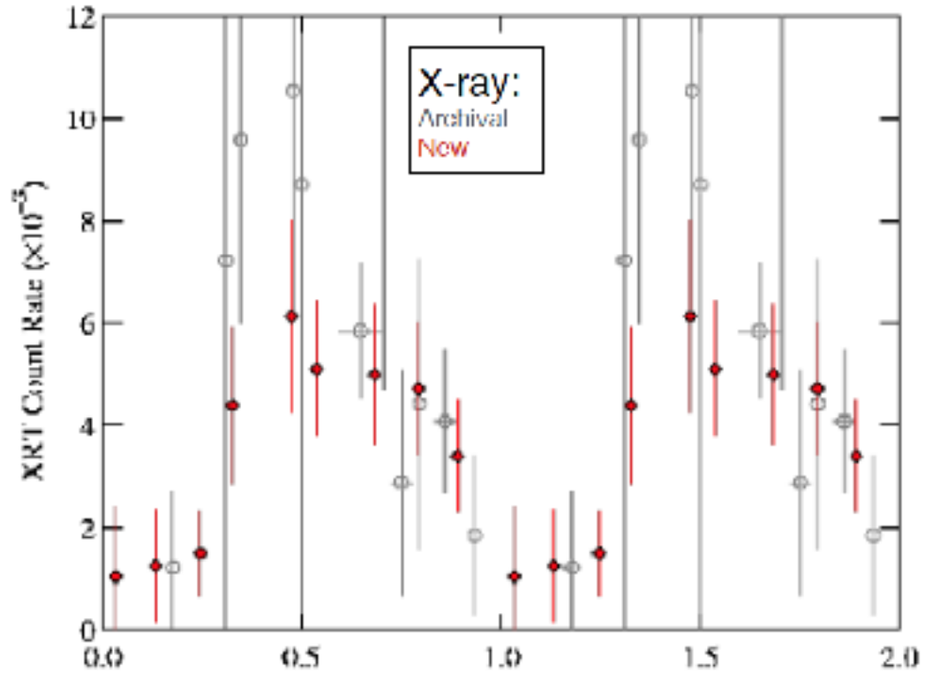
A new gamma-ray binary

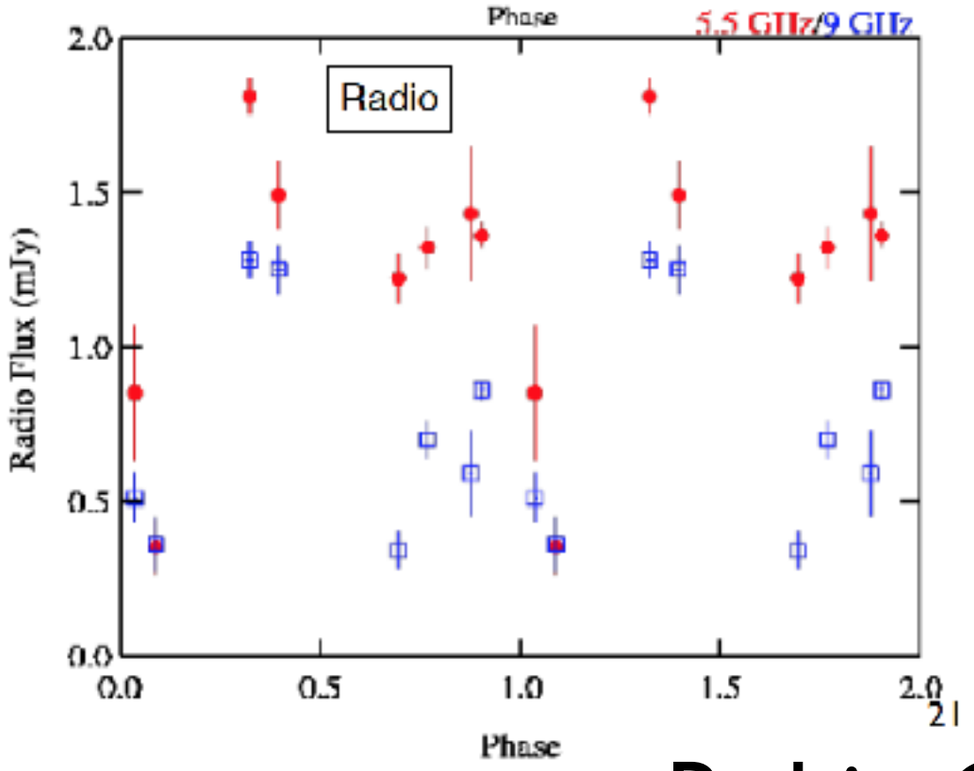
X-ray and Radio Support for New Source



- "Conventional" LAT aperture photometry shows double-peaked profile on ~14 d period.
- *Secondary* γ-ray peak is *softer*.

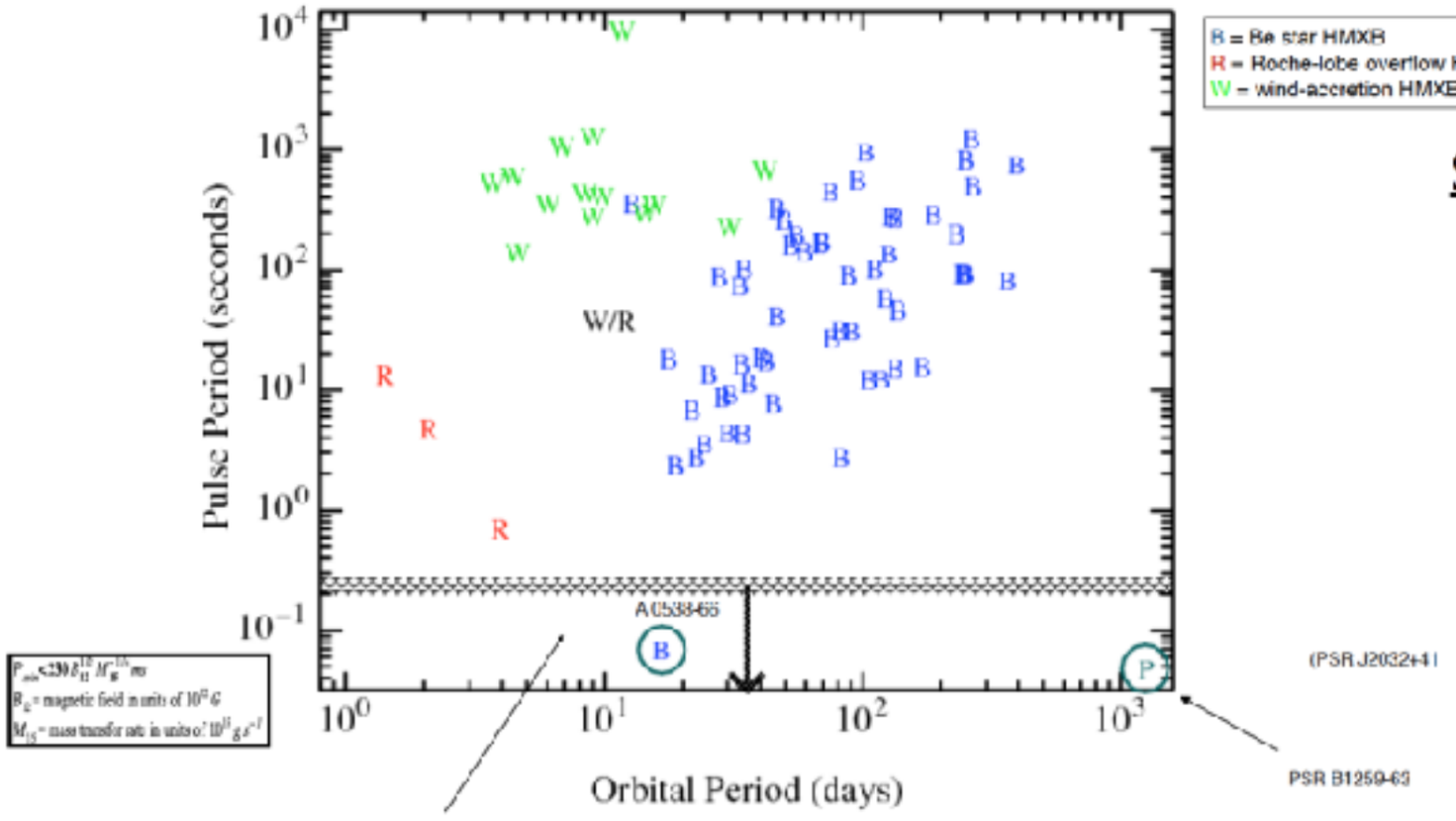
- X-ray and radio appear modulated with *soft* peak.





Gamma-ray binaries

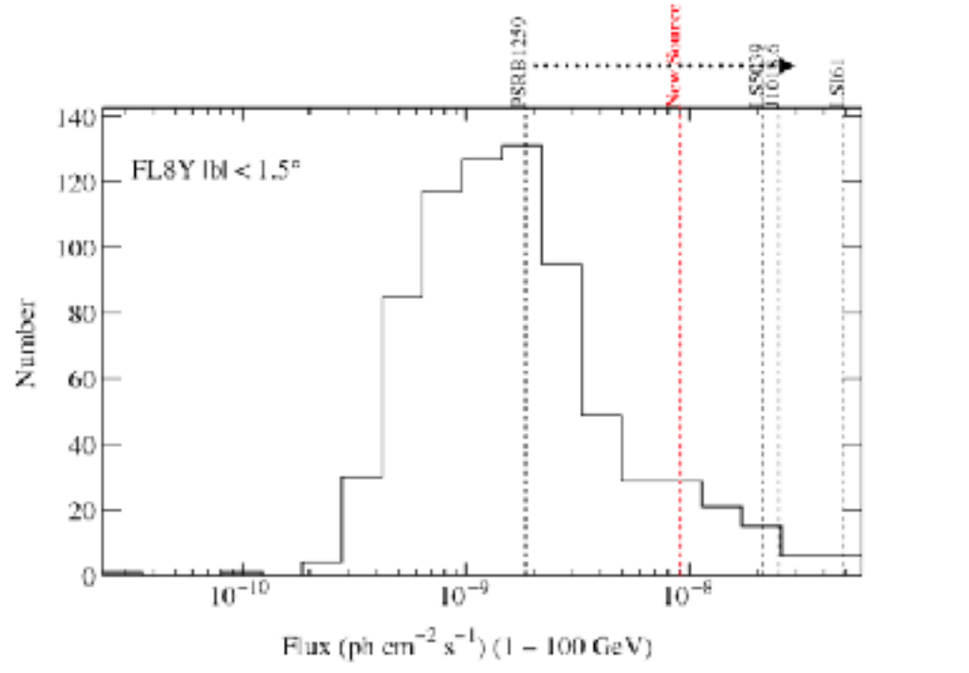
X-ray Binaries Born as Gamma-ray Binaries



HMXBs containing neutron stars may begin as gamma-ray binaries with rapidly rotating neutron stars before spinning down. (Later become neutron star/neutron star binaries.)

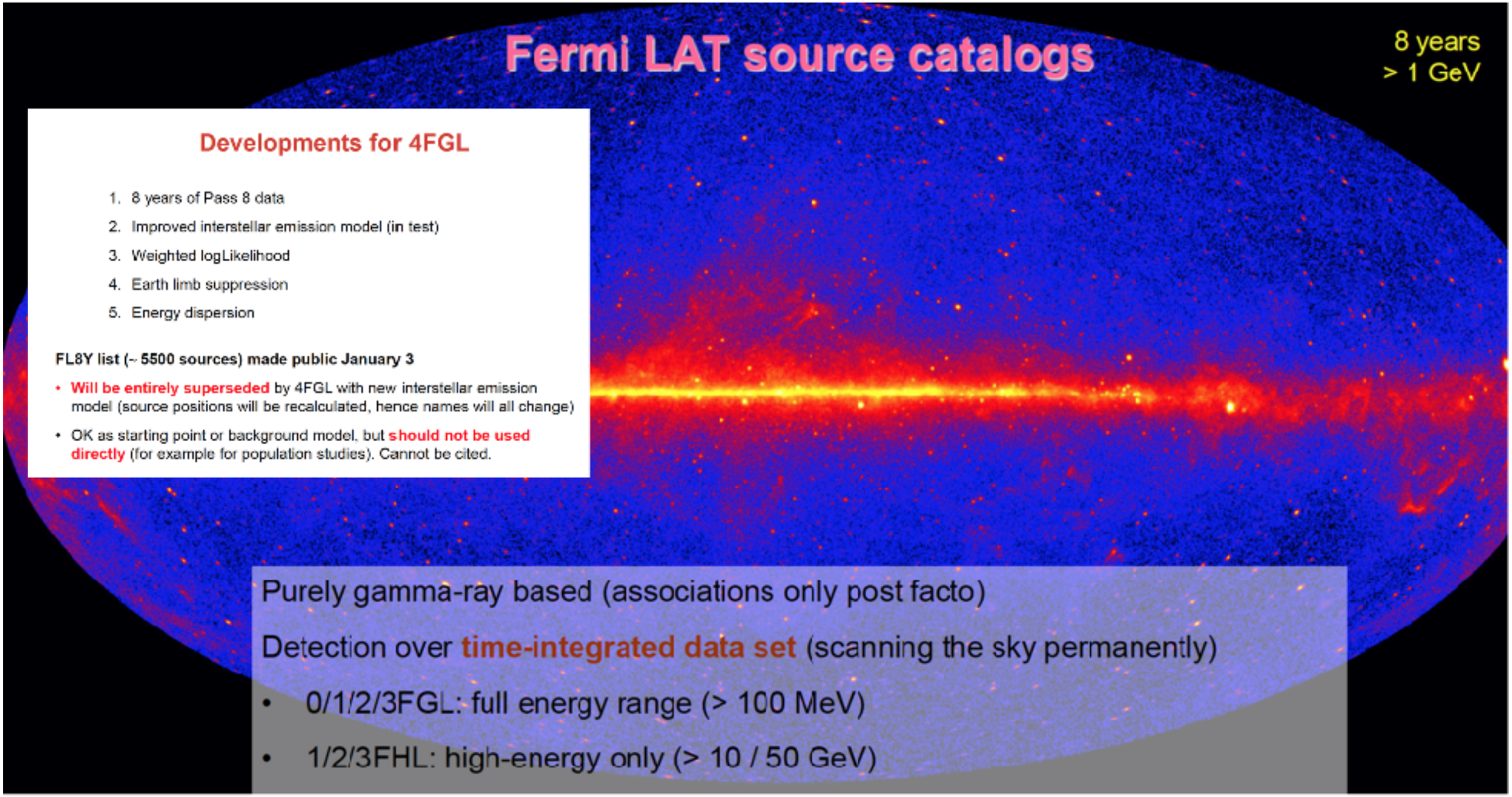
4

Still Only Seeing the Tip of the (Flux) Iceberg?



Robin Corbet

Fermi LAT 4FGL Catalog …

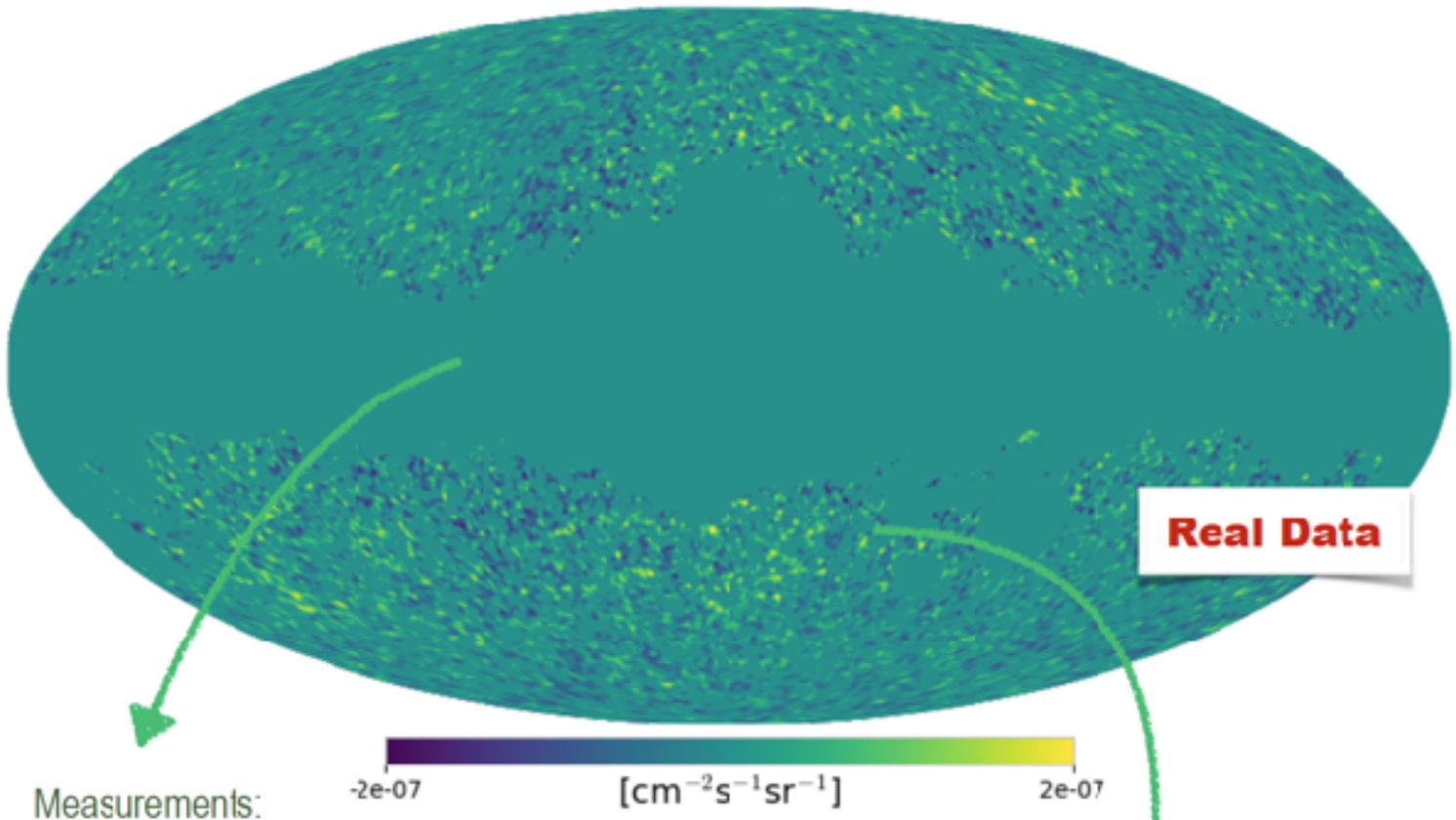


Each generation has used **improved data/calibration**: P6 → P7 → P7Rep → P8

Jean Ballet

The UGRB

- How to study -



Measurements:

- Mean intensity flux
- Intensity fluctuations amplitude
- Photon statistics

Characterization:

- Cross-correlation technique

11

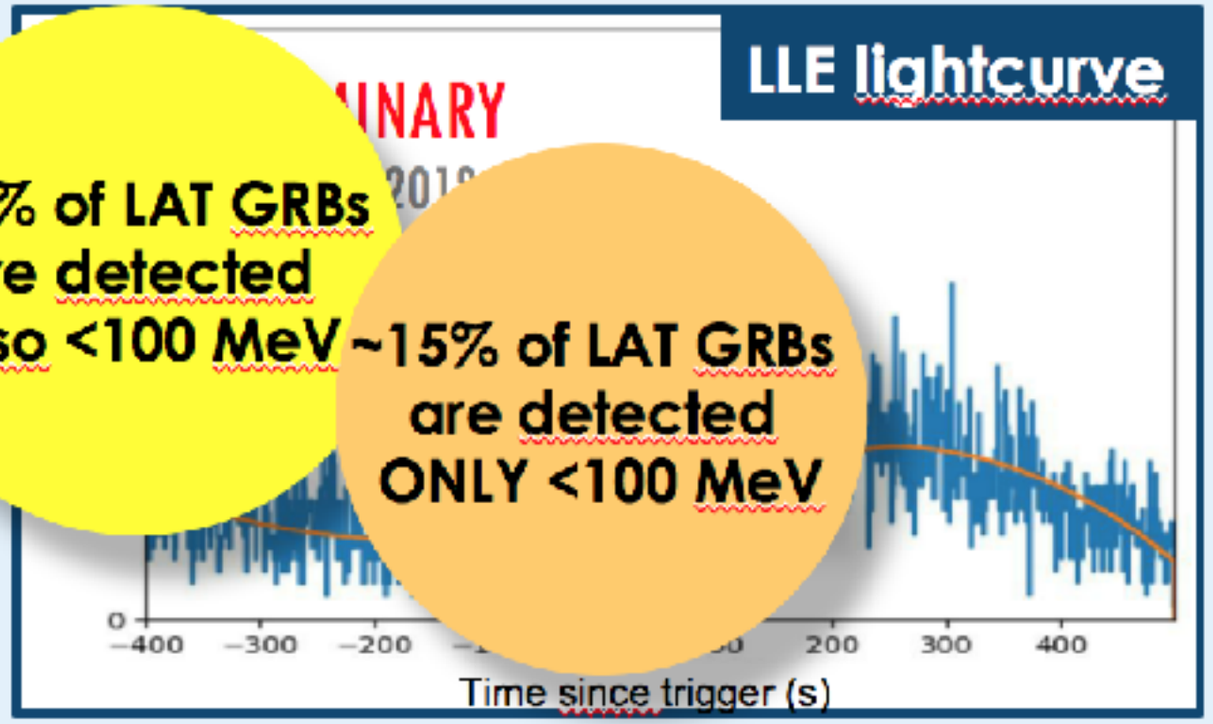
Beyond the resolved components
Time and analysis-dependent
Mostly extragalactic
Likely unresolved point sources (astrophysical or exotic)

Michela Negro

Towards the 2nd LAT catalog

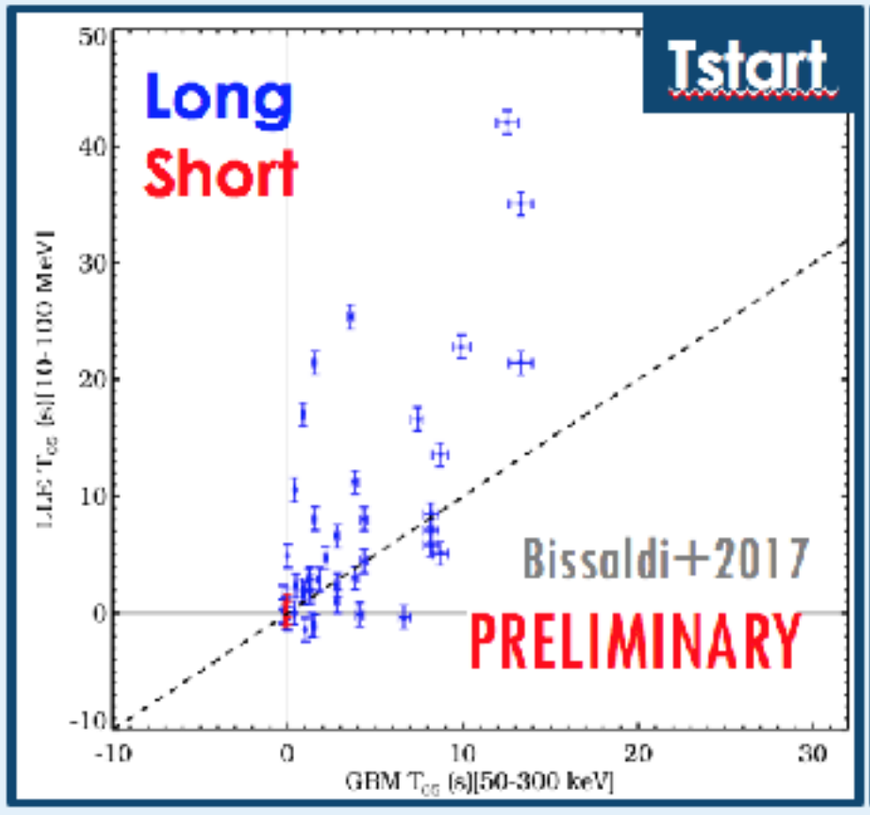
- **Studying GRBs at energies <100 MeV with the LLE class**

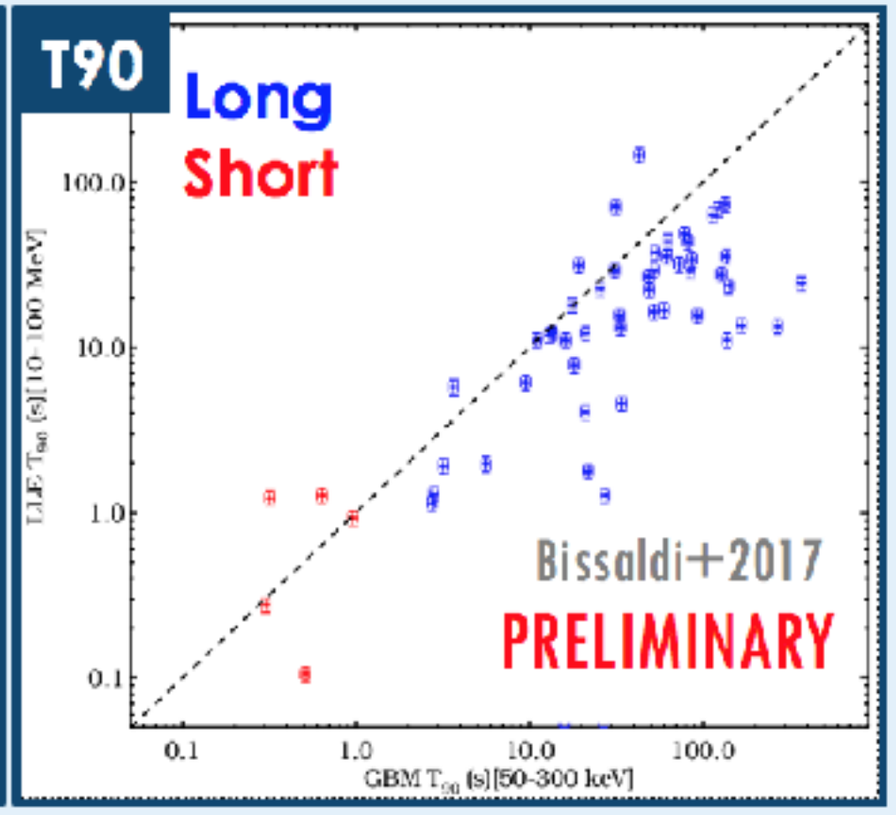
  - looser selection criteria
  - higher acceptance
  - larger effective area at lower energies and at larger off-axis angles (>60°)
  - Bayesian blocks analysis in presence of time-varying background



- **Catalog analysis:**

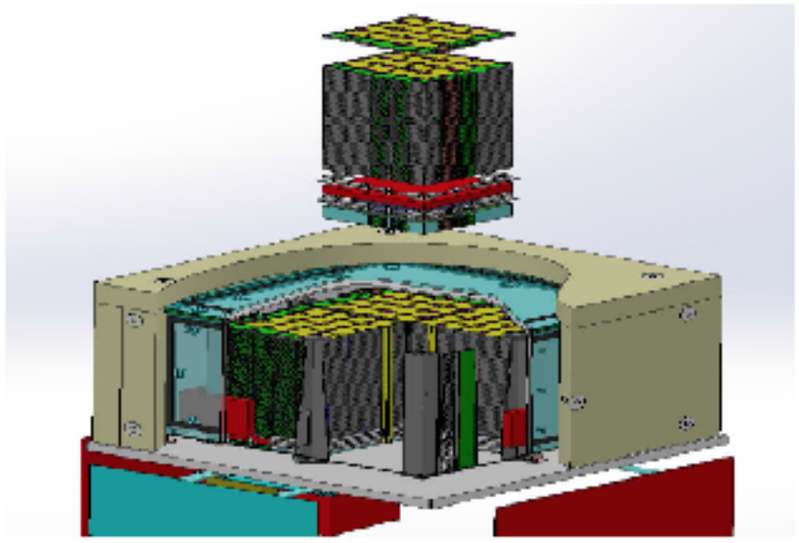
  - LLE data used for **source detection** and **duration** measurement

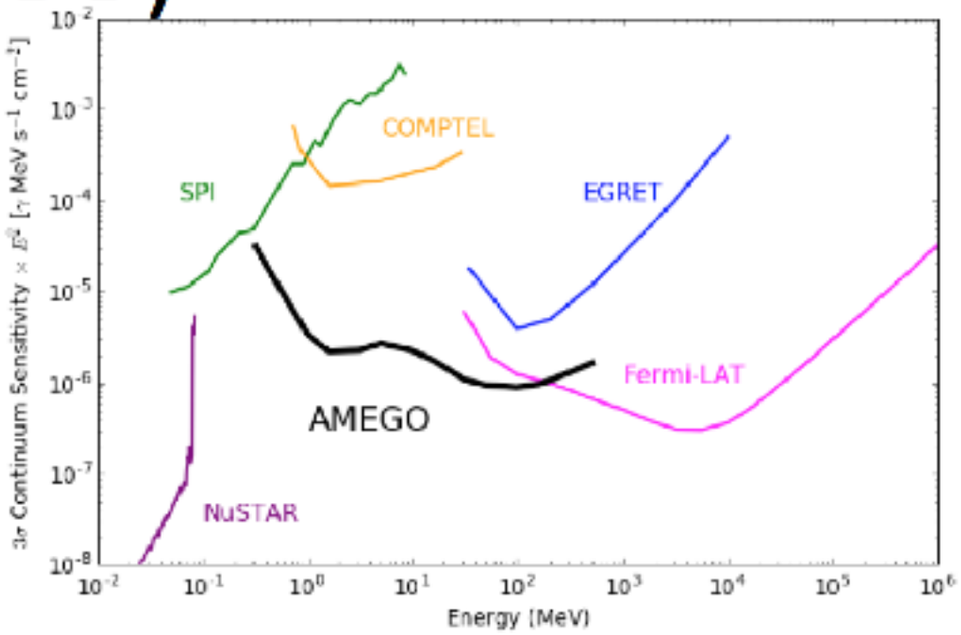




Future MeV telescope

All Sky Medium Energy Gamma-ray Observatory (AMEGO)

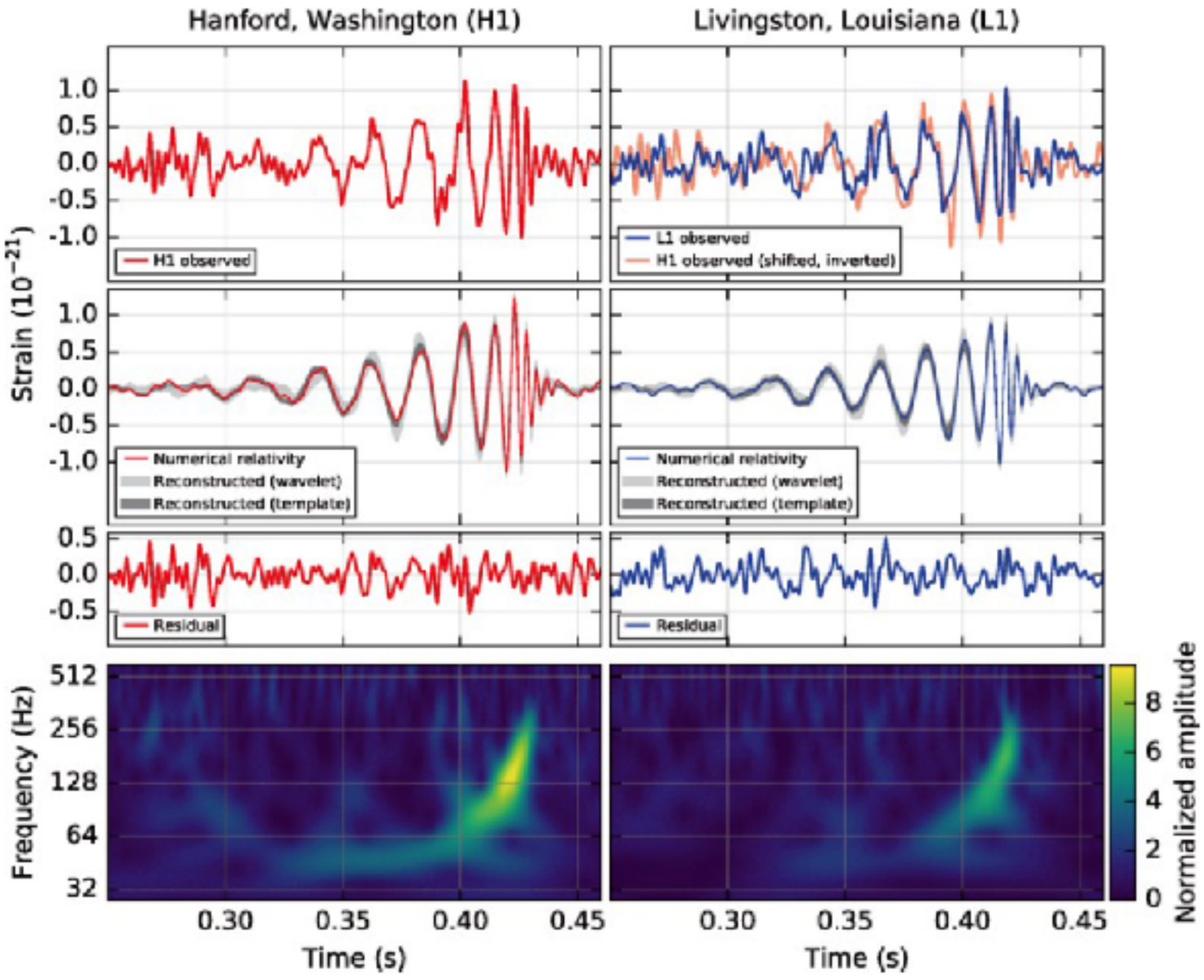




- Energy range: 200 keV – >10 GeV; <2% energy resolution below 5 MeV
- Angular resolution: 3° (1 MeV), 10° (10 MeV), 1.5° (100 MeV)
- Field of View: ~2.5 sr
- Survey mode, view 80% of the sky per orbit – Explore the time domain!
- Sensitivity to polarization and nuclear lines

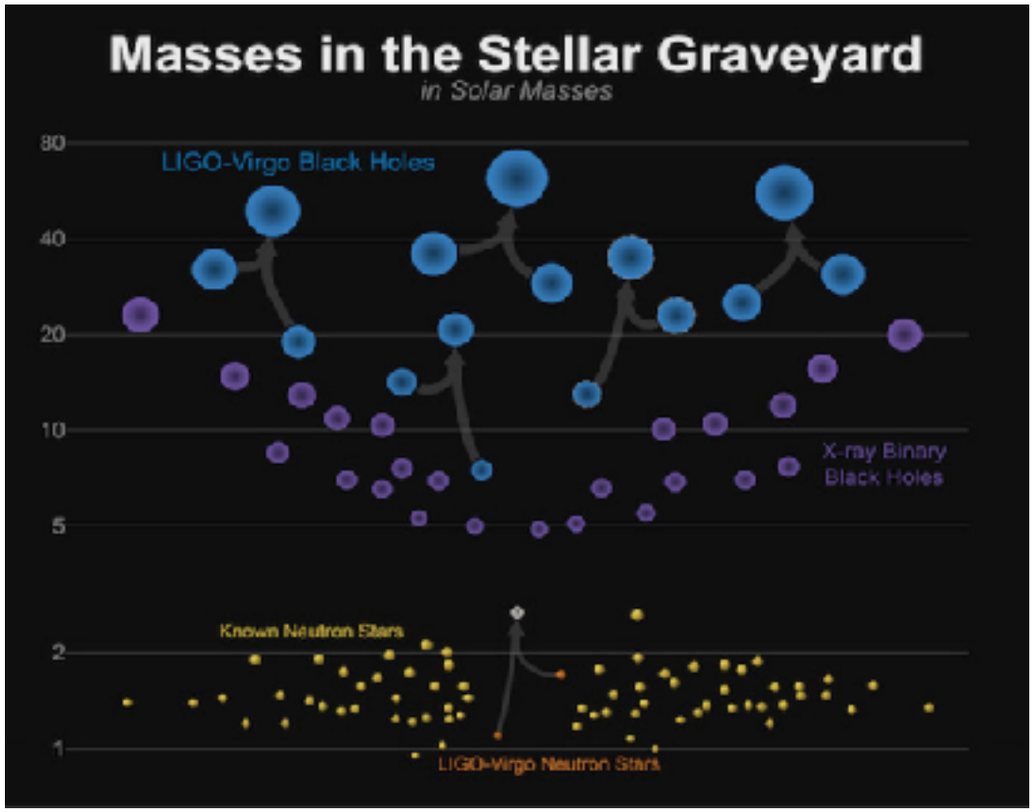
Julie McEnery

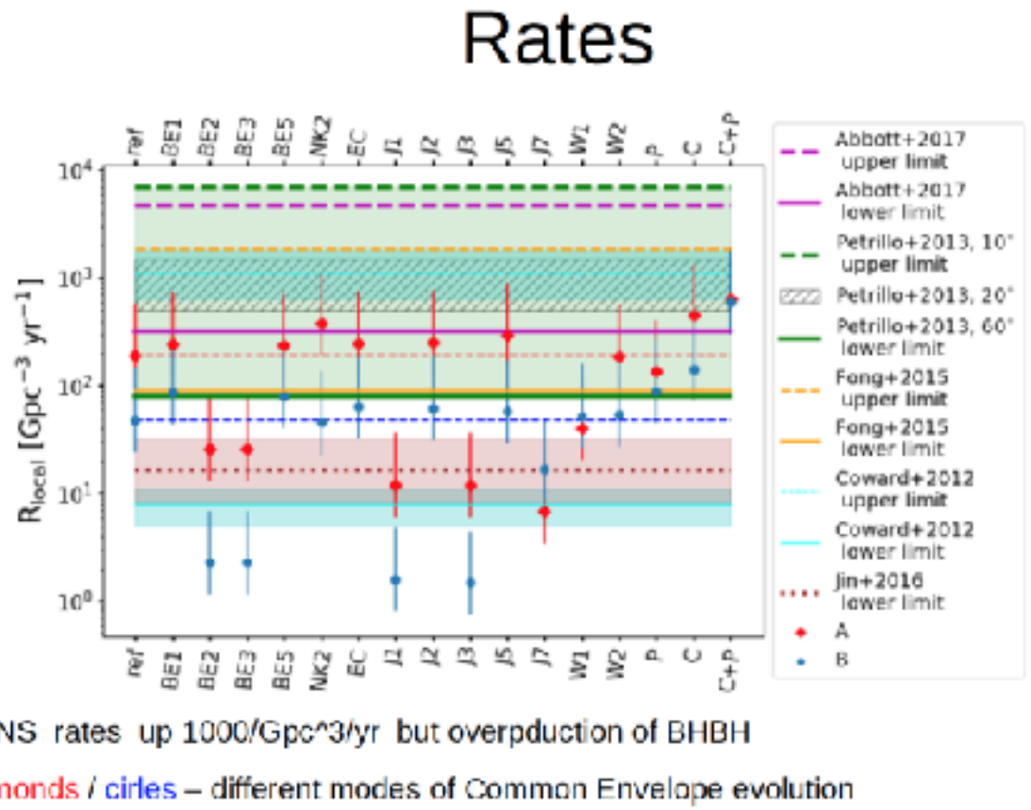
LIGO detected Gravitational Waves



GW signal from two merging 30 solar mass BHs

The origin of the coalescing binaries





NS-NS rates up 1000/Gpc^3/yr but overpduction of BHBH

Diamonds / cirles – different modes of Common Envelope evolution

The merger rate densities

- BBH estimate 12-213 Gpc^{-3}yr^{-1}
- BNS estimate $R = 1540^{+3200}_{-1220}\mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$
- The local supernova rate ~10^5Gpc^{-3}yr^{-1}
- The BH formation rate is ~10^4Gpc^{-3}yr^{-1}
- About 1 black hole in a 100 ends up in a merging binary
- Similarily NS: 1 in 100 is in a merging binary!

Open issues

- Place the scenarios within astrophysical landscape
- Rates seem to be high
  - There are models that are marginally consistent with the rates
  - Globular cluster origin – tough to reconcile with all observations
  - Many paths may contribute
- Value of BH spins
  - Are spins small? - binary evolution origin
  - Do they have random orientations? - GC origin
- How exceptional was GW170817?
  - Long delay time
  - Unusual GRB

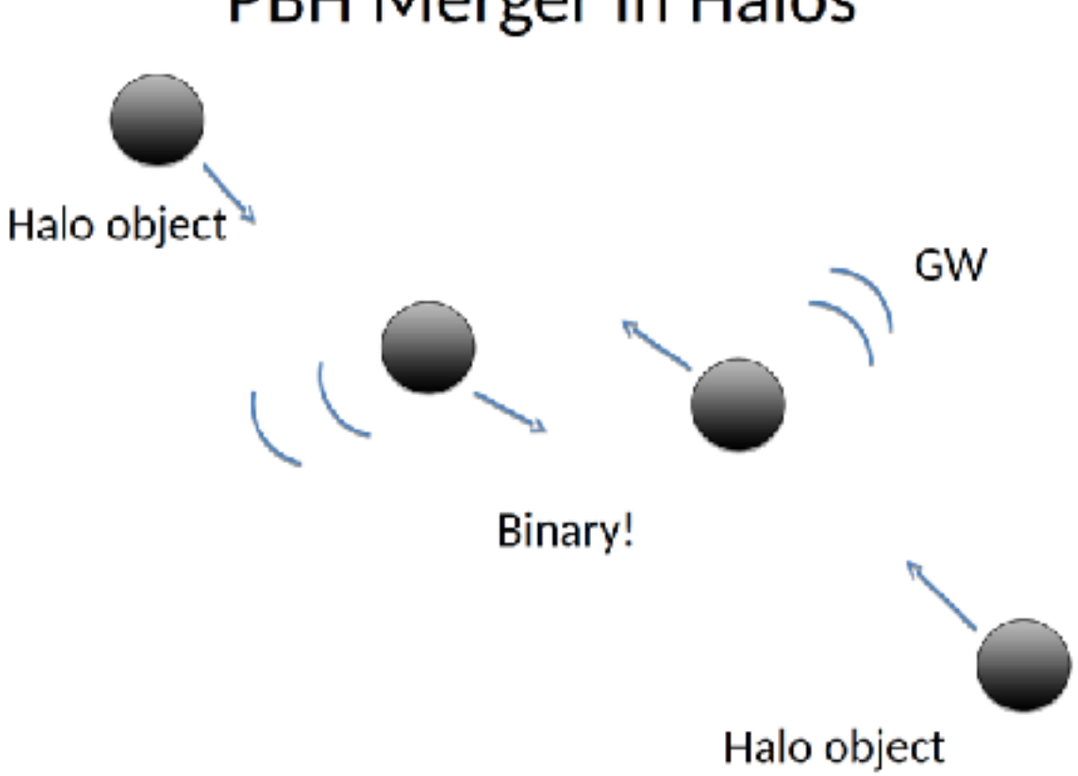
Tomasz Bulik

How did the Black Holes form?

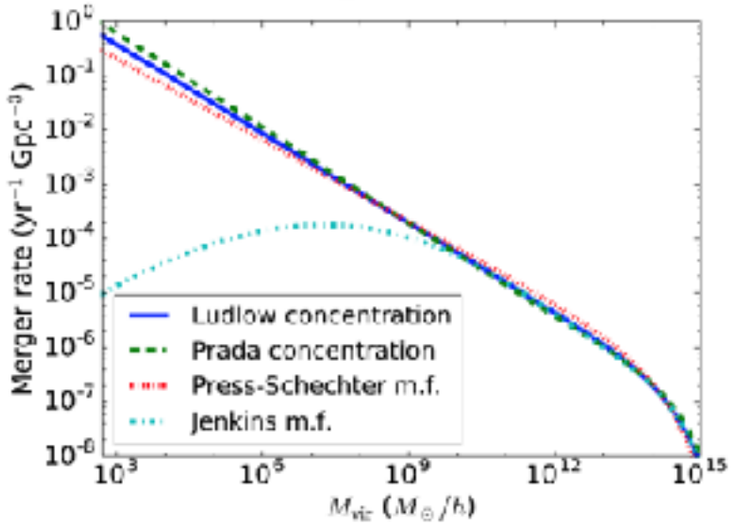
Are some of them

Primordial Black Hole Dark Matter

PBH Merger in Halos



Merger Rate

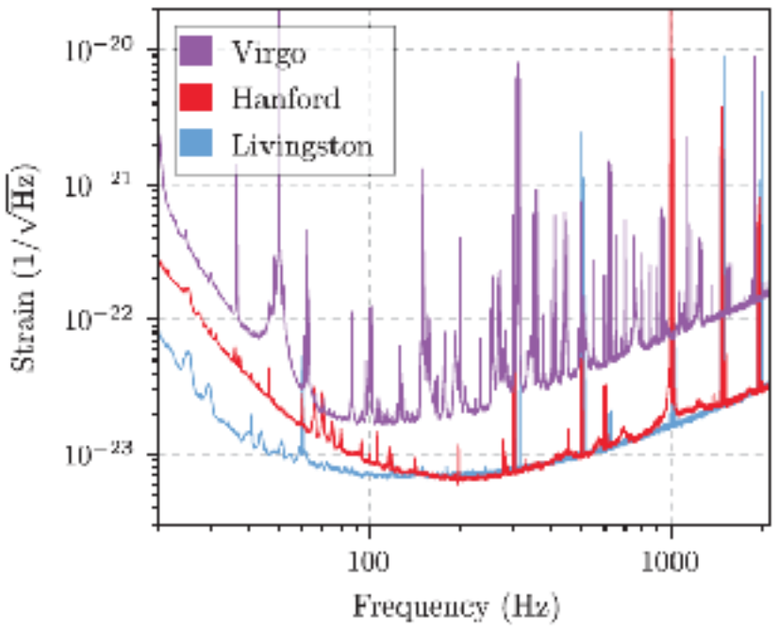


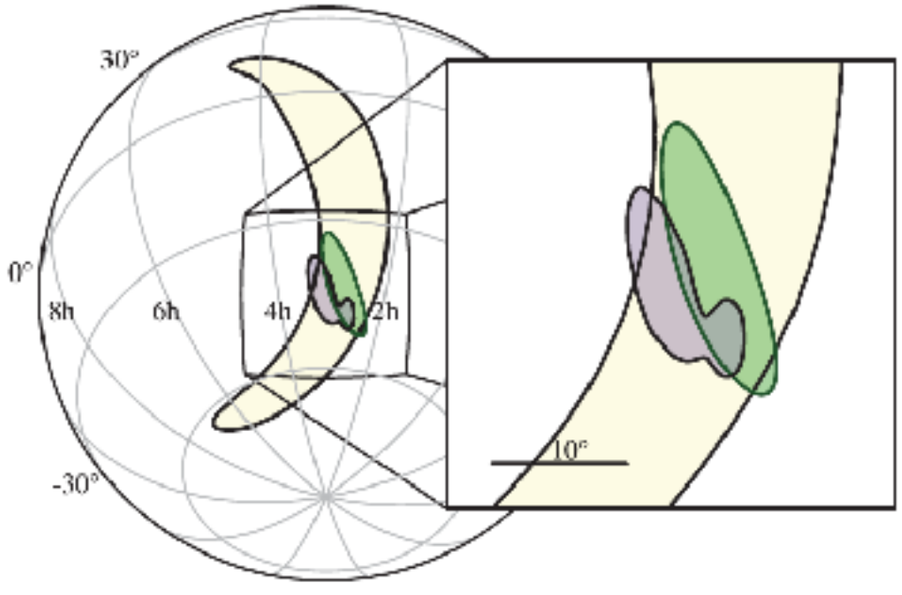
- Integrated: $2\ \mathrm{yr}^{-1}\mathrm{Gpc}^{-3}$
- LIGO: ~~$2 - 53\ \mathrm{yr}^{-1}\mathrm{Gpc}^{-3}$~~
  $0.5 - 12\ \mathrm{yr}^{-1}\mathrm{Gpc}^{-3}$

GW detections becoming routine

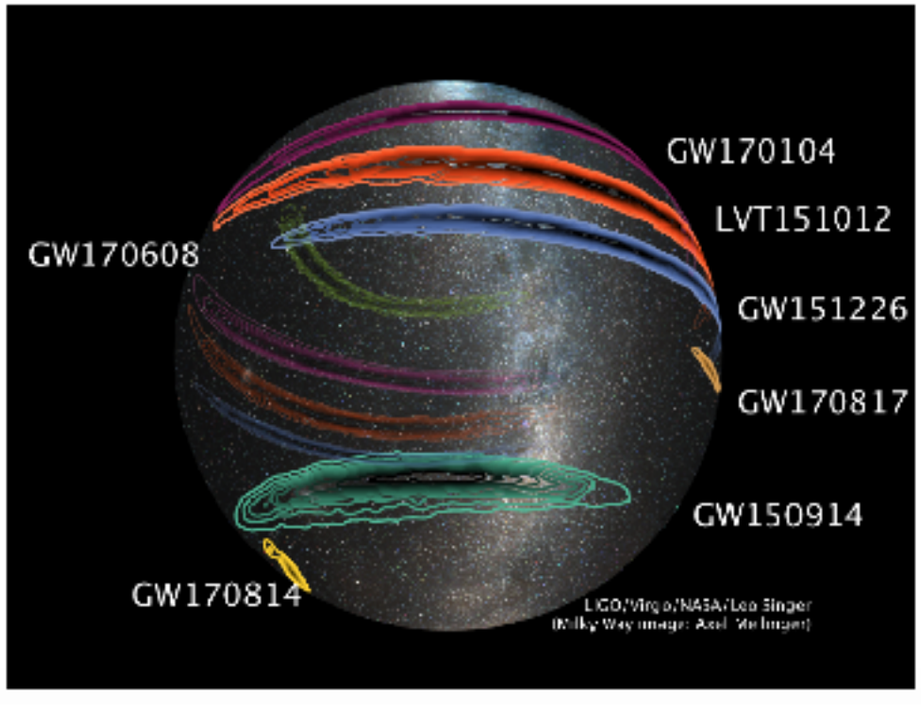
GW170814: The first HLV binary

- 3-detector network SNR ~18
- The addition of Advanced Virgo allows for much tighter sky localisation
  - 1160 deg^2 to ~60 deg^2

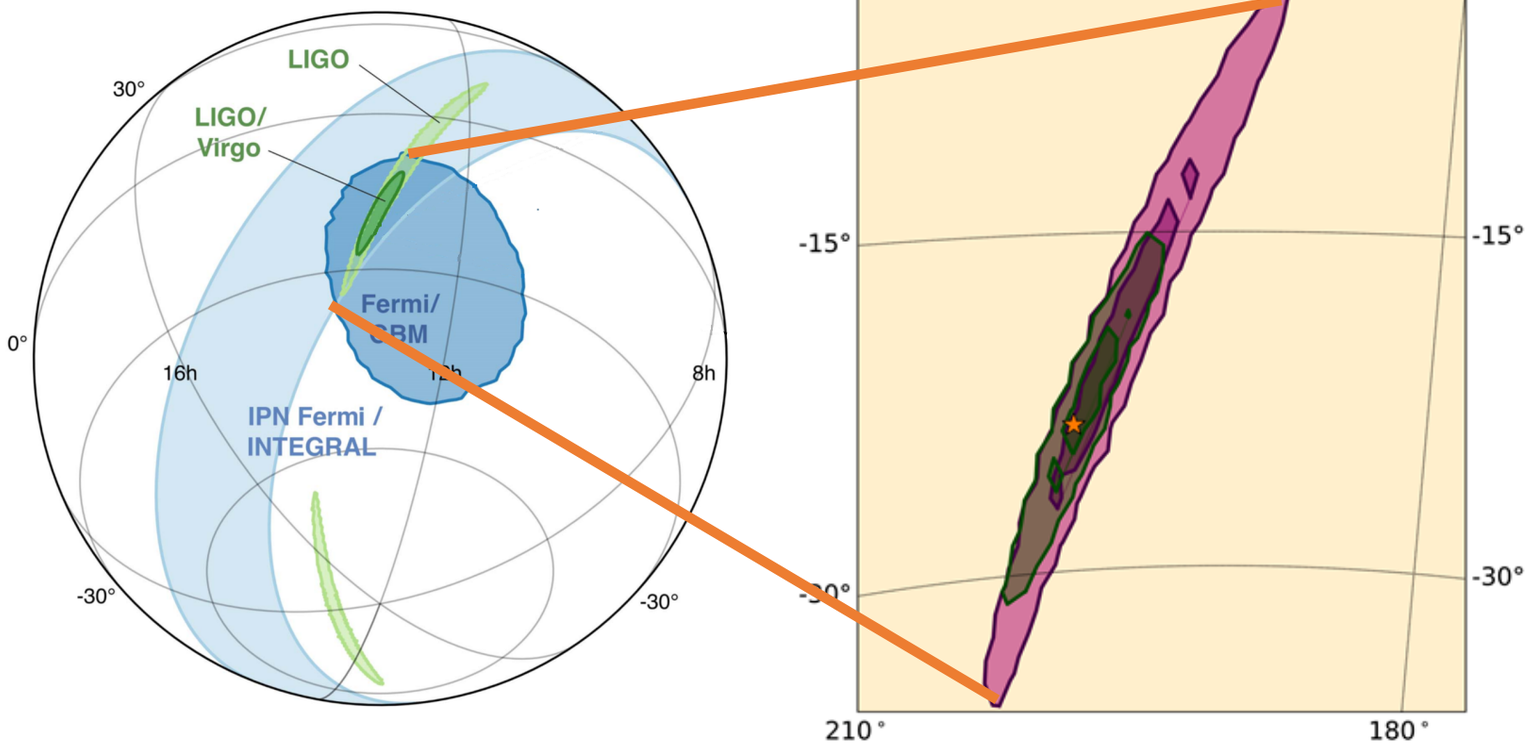


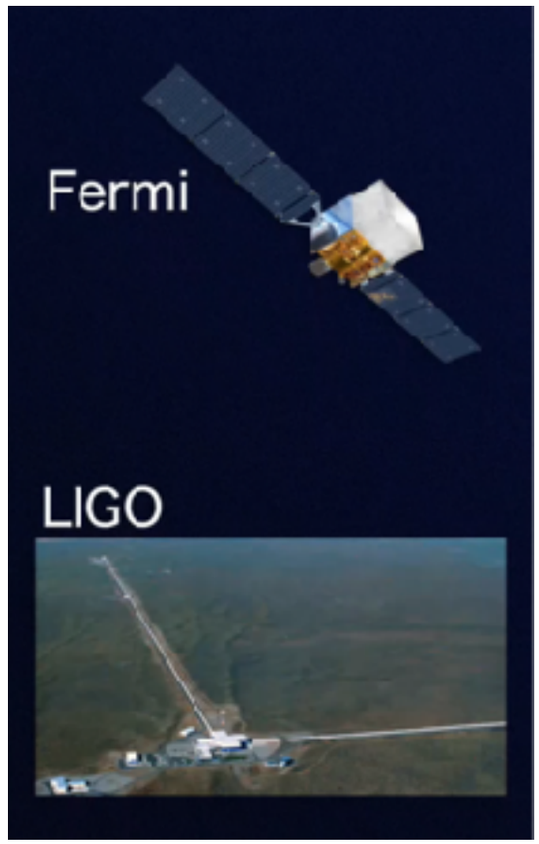


PRL, 119, 141101 (2017)



Gamma-ray observations of NS mergers

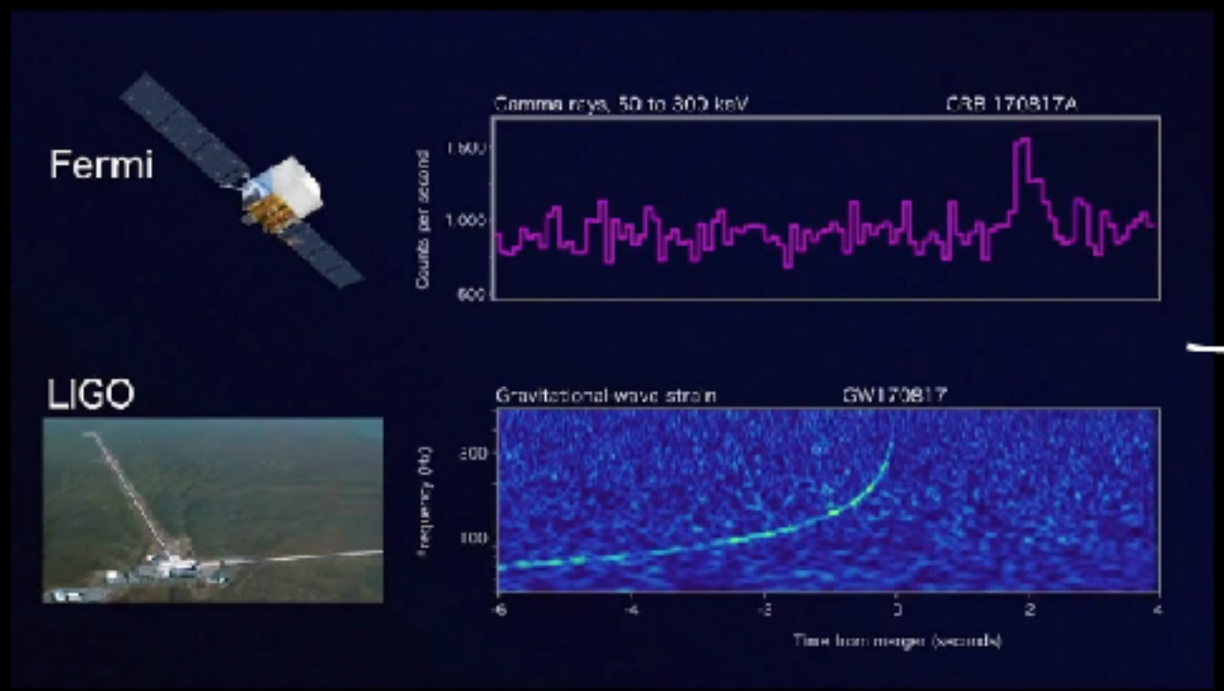


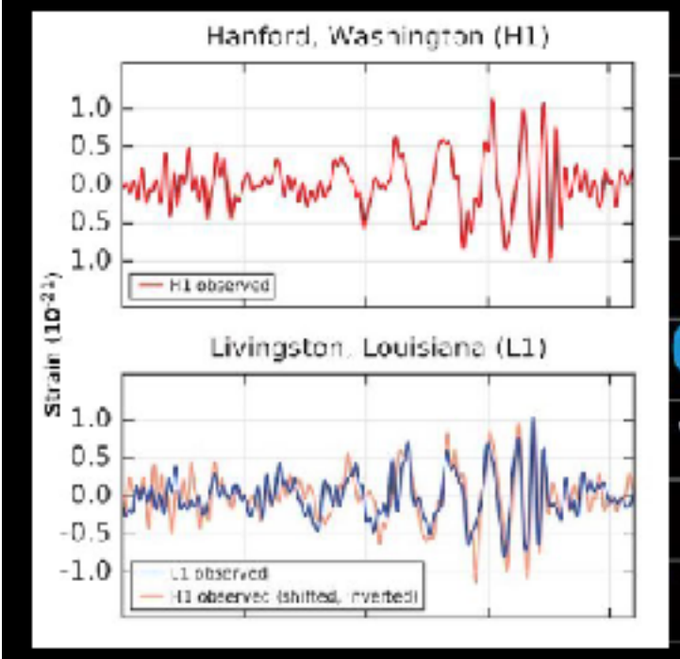


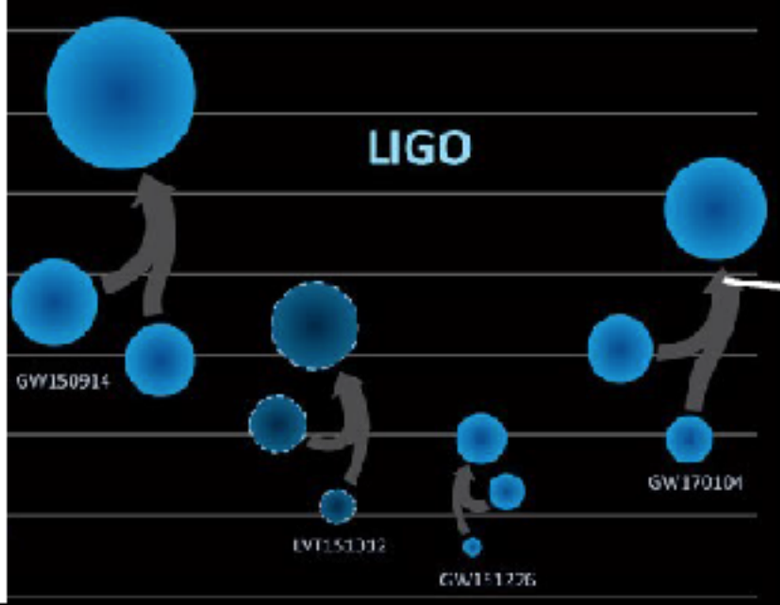
Eric Burns

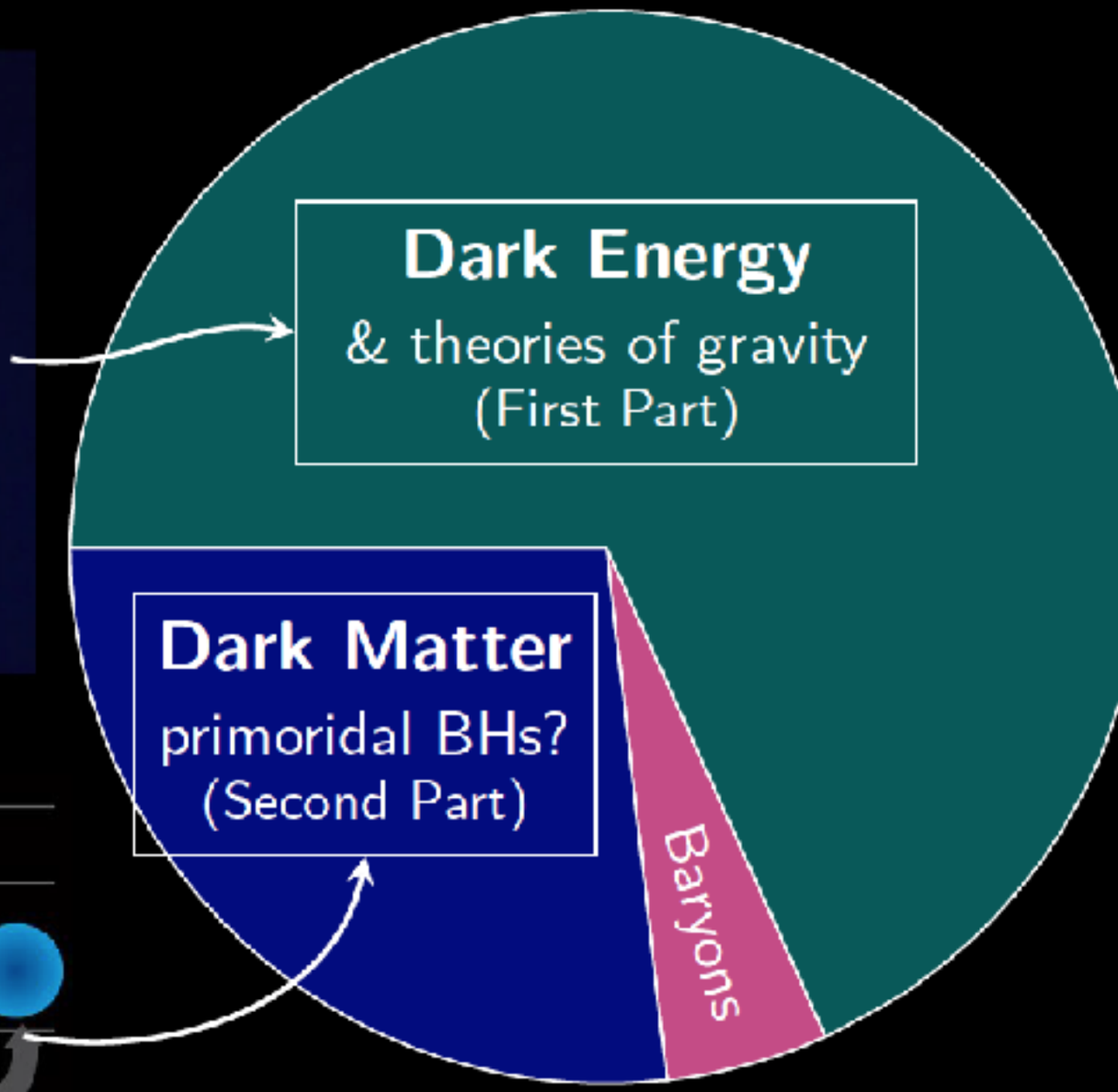
Generat	Tim	Interferometers	BNS	BNS	NSBH
Gen 2	O2	LIGO (HL),	47-96, 26	1	0
	O3	LIGO (HL),	120-150,	1-17	0-4
	2020	LIGO (HLI),	173,	3-51	0-11
Gen 2.5	2024	LIGO A+	325	20-330	0-70
	2028	LIGO Voyager	1100	1000-12	2-2500
Gen 3	2035	Einstein	All BNS to	2000000	4000-70
		Cosmic Explorer	Up to z=6	-300000	00000

Gravitational Waves vs ΛCDM





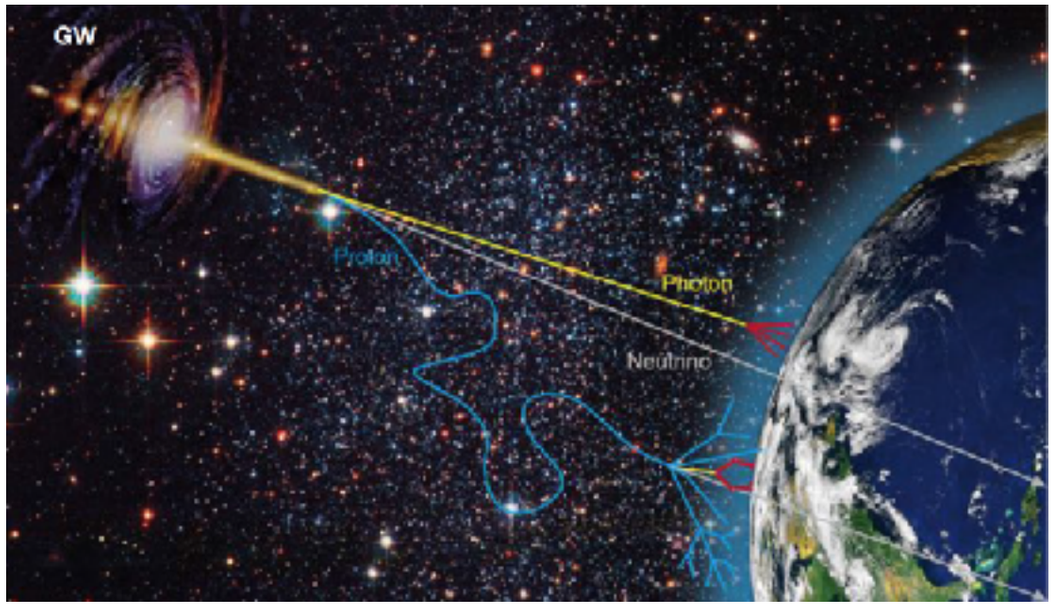


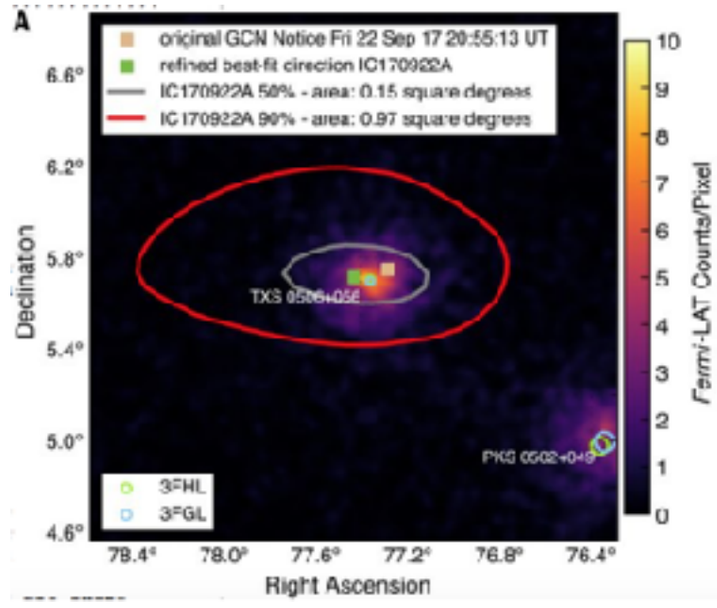


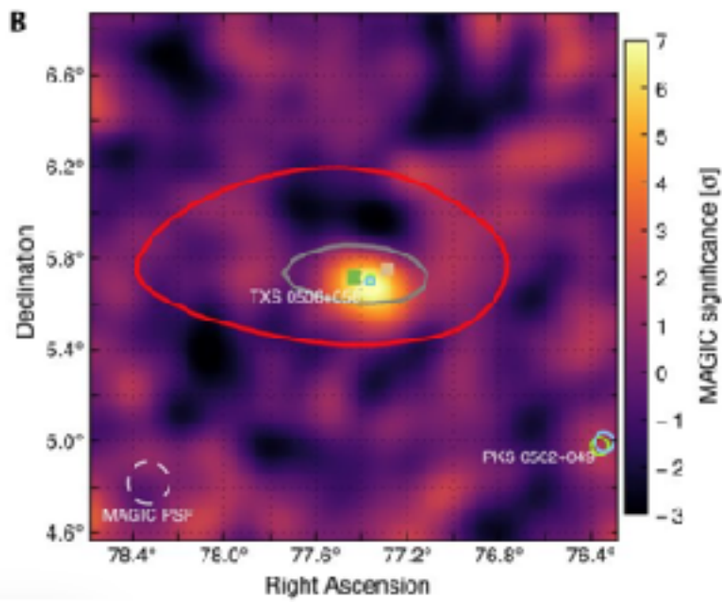
$$
\begin{aligned}
100\Omega_b h^2 &= 2.222 \pm 0.023\ (1.0\%) \\
\Omega_c h^2 &= 0.1197 \pm 0.0022\ (1.8\%) \\
\Omega_\Lambda &= 0.685 \pm 0.013\ (1.9\%)
\end{aligned}
$$

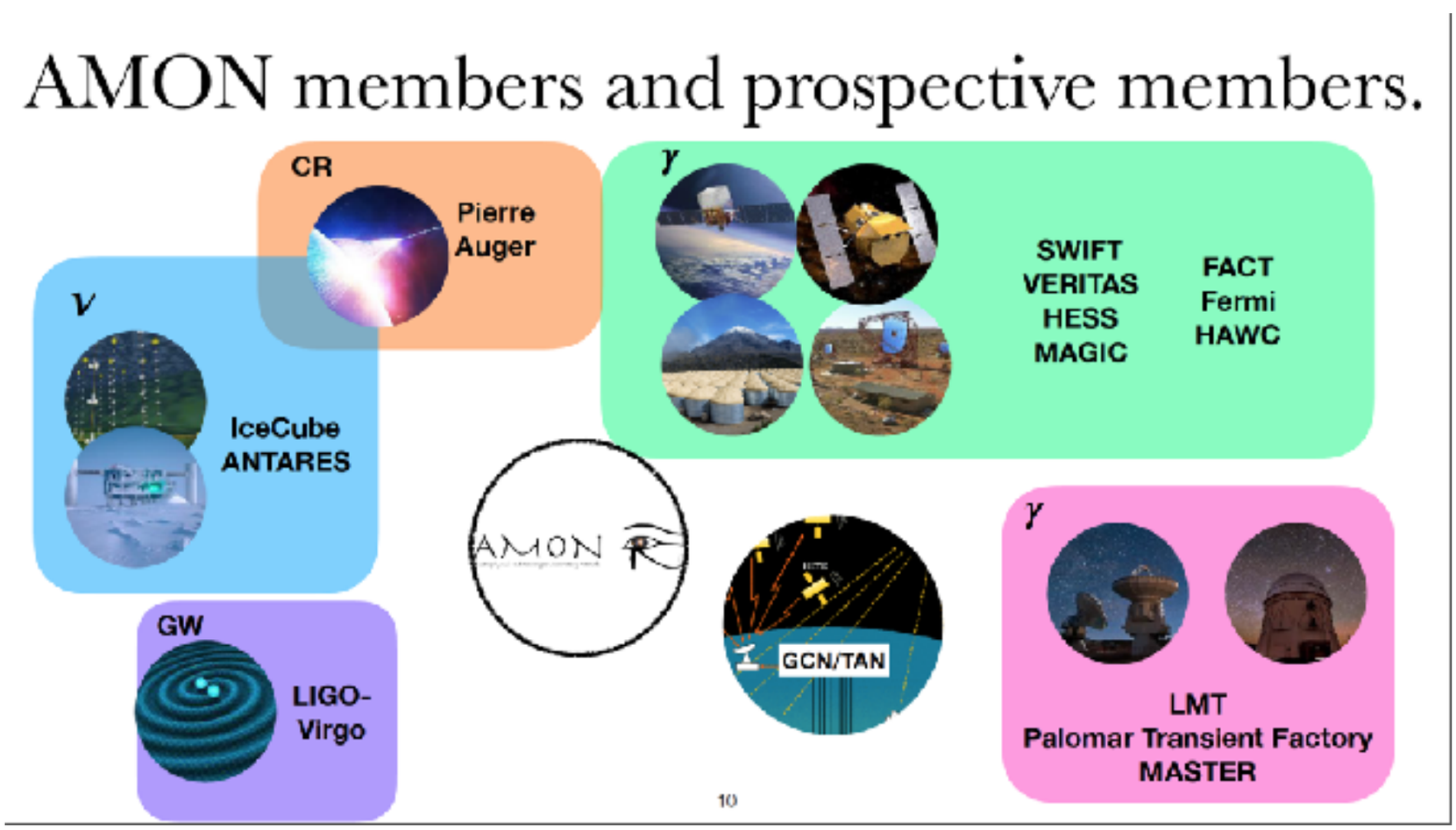
Planck '15 (T+lowP only!)

Multi-messenger astronomy is here!







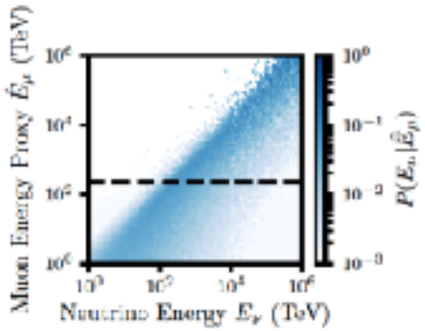


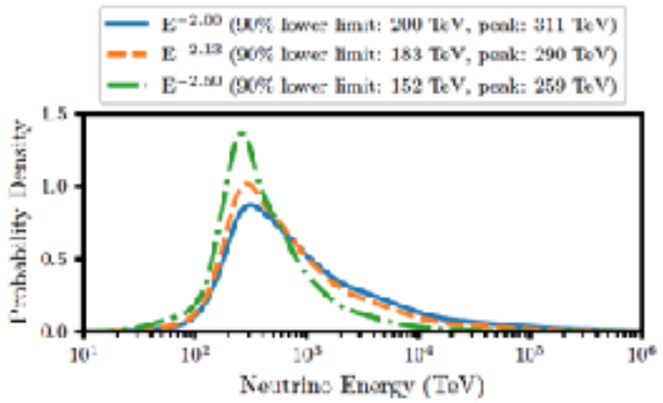
AMON receives sub-threshold data events and send alerts to GCN/ TAN which then is distributed to partner observatories/public

Hugo Ayala Solares

IceCube-170922A: Signal Probability

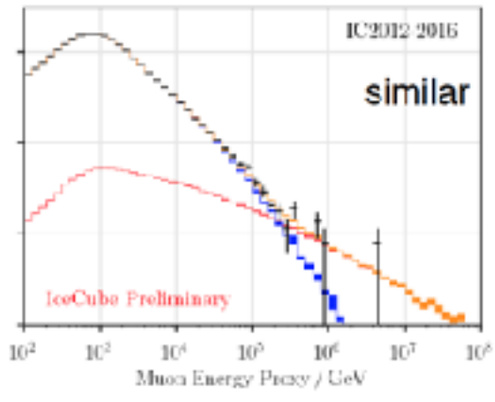
- Energy estimate:
  - 5785 PE deposited (22 TeV)
  - 170 TeV muon energy at the detector
  - Most probable ν energy: 290 TeV





- Estimating "signalness", given declination (5.7 deg) and energy
  - Signalness = S / (S+B)
  - Signal assumption: diffuse astrophysical flux ($E^{-2.13}$)
  - Dominant background: atmospheric neutrinos

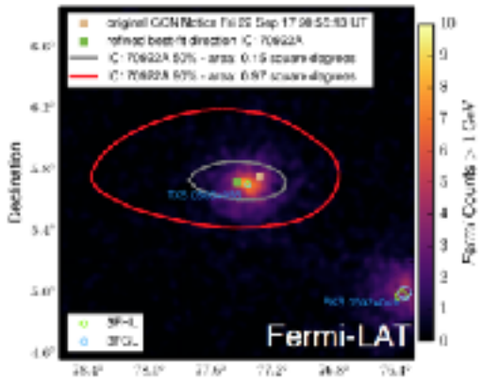
- Probability for event to be of astrophysical origin: 56%

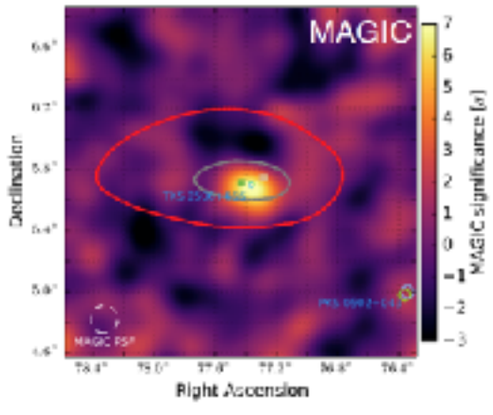


IceCube-170922A: Origin?

- 3FHL source in the error circle: the blazar TXS 0506+056
- Fermi-LAT report of gamma-ray flare → plenty of follow-up observations
- MAGIC: VHE gamma-ray detection at 6.2σ (80 GeV — 400 GeV)

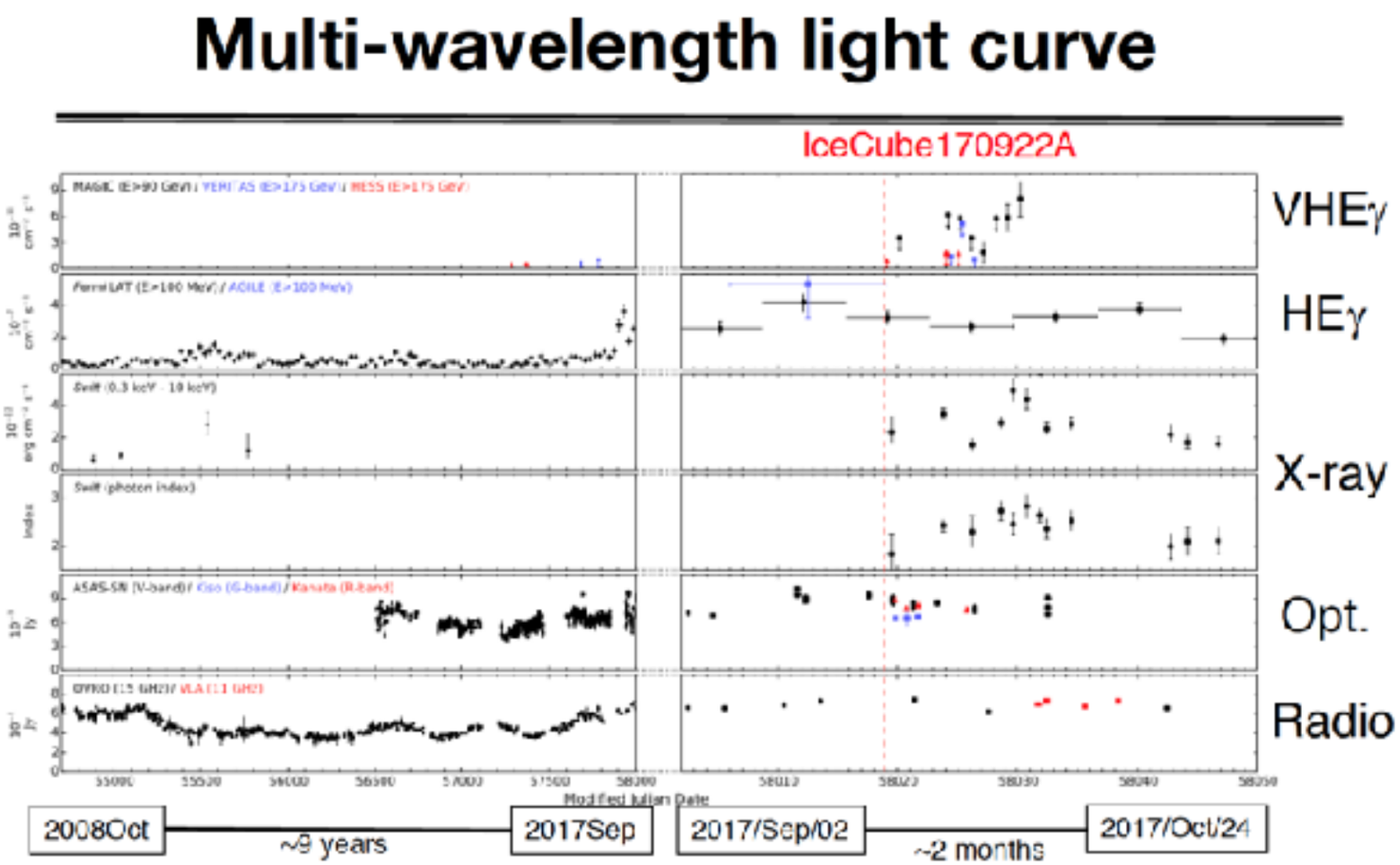
- Chance coincidence? Disfavored at 3σ, in each scenario where…
  - … ν flux correlated to high energy γ-ray flux
  - … ν flux correlated to high energy γ-ray flux variations
  - … ν flux correlated to VHE γ-ray flux
  - Note: a-posteriori significance
  - Details on the calculation in M. Hayashida's talk

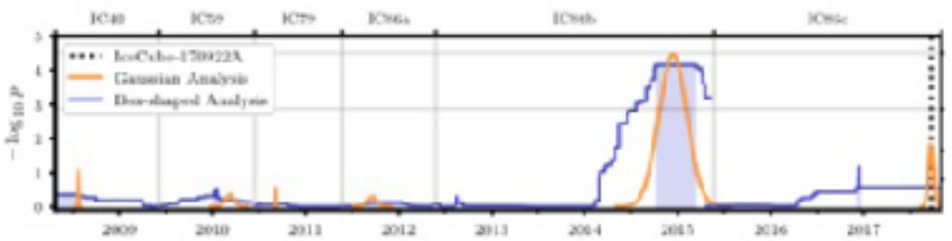


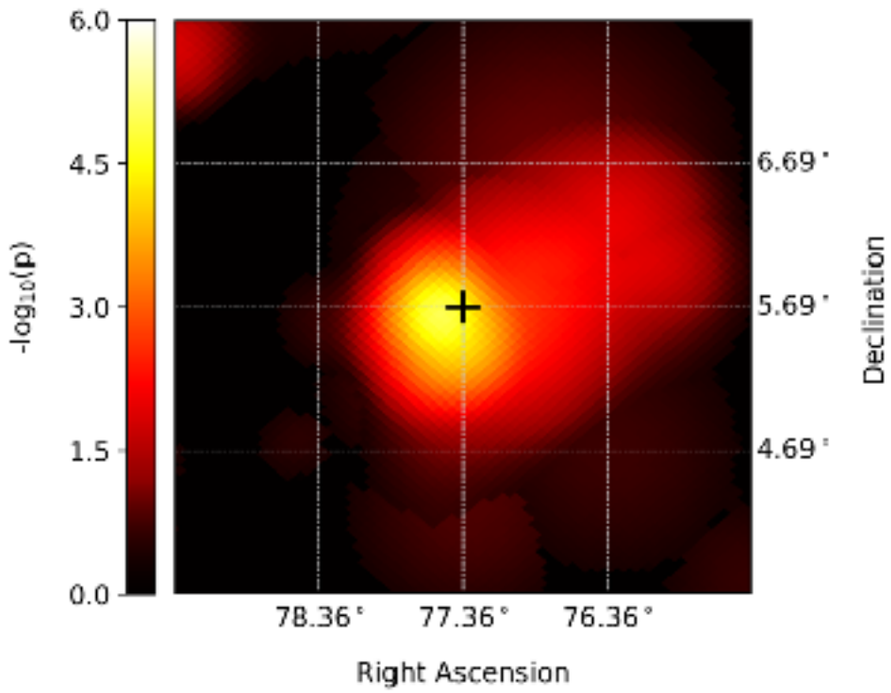


Thomas Kintscher

IceCube-170922A and TXS 0506+056



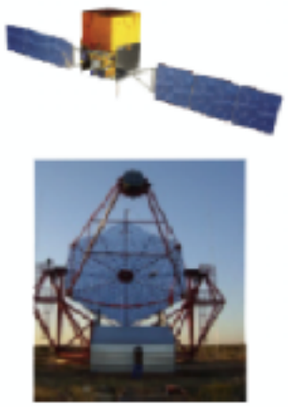


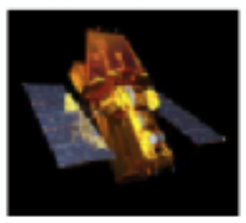


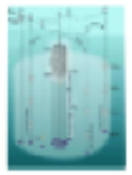
Masaaki Hayashida

ANTARES observations

Multi-messenger programs







neutrinos
IceCube, GVD, SNEWS

GeV-TeV γ-rays
Fermi, HESS, HAWC, CTA

UHECR
Auger, TA

only spatial coincidence

ANTARES

Receive alerts
Generate alerts

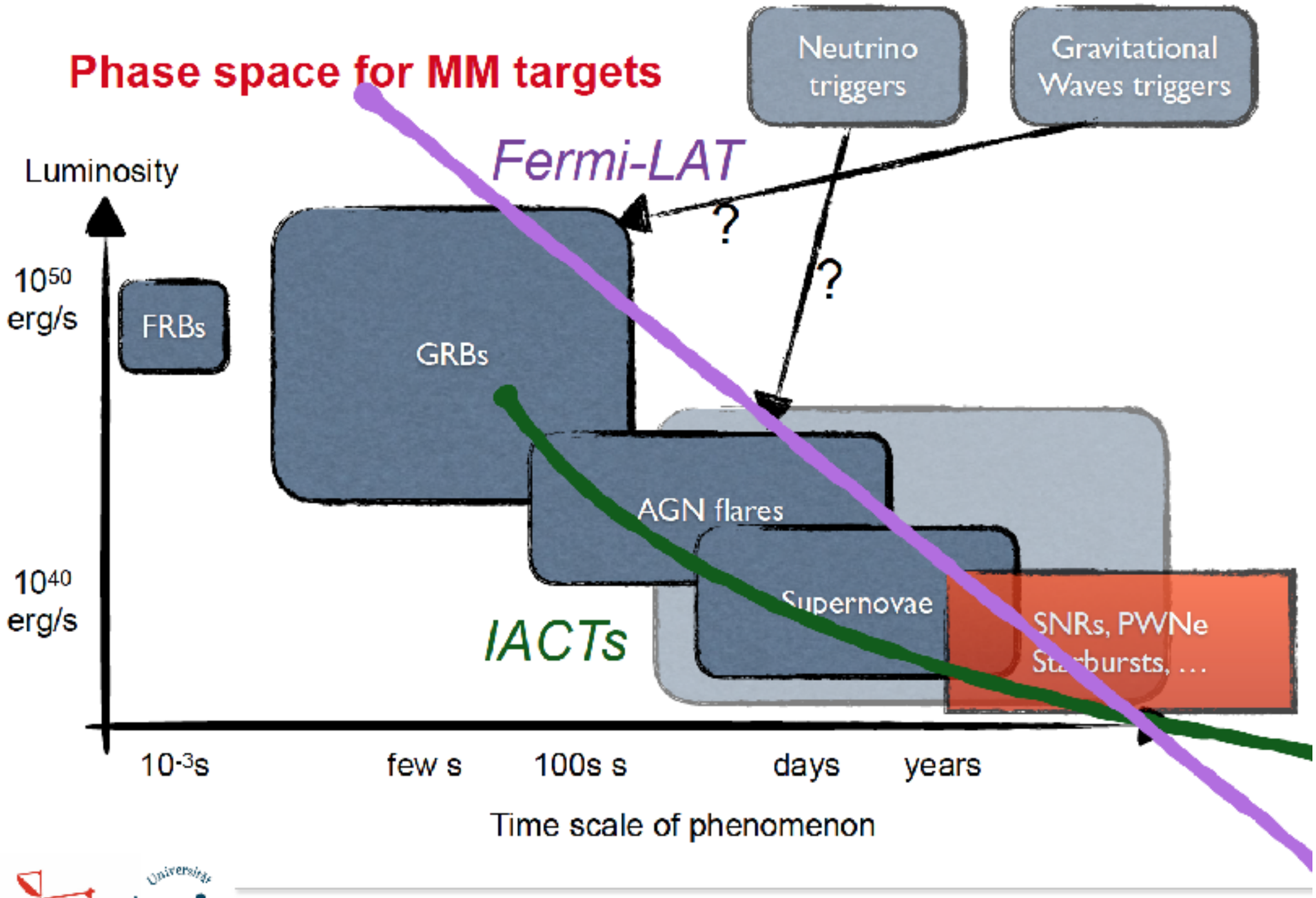
Radio/Optic /X-ray
TAROT, MASTER, Swift, INTEGRAL, MWA

Gravitational Waves
VIRGO, LIGO

\+ AMON
Astrophysical Multimessenger Observatory Network

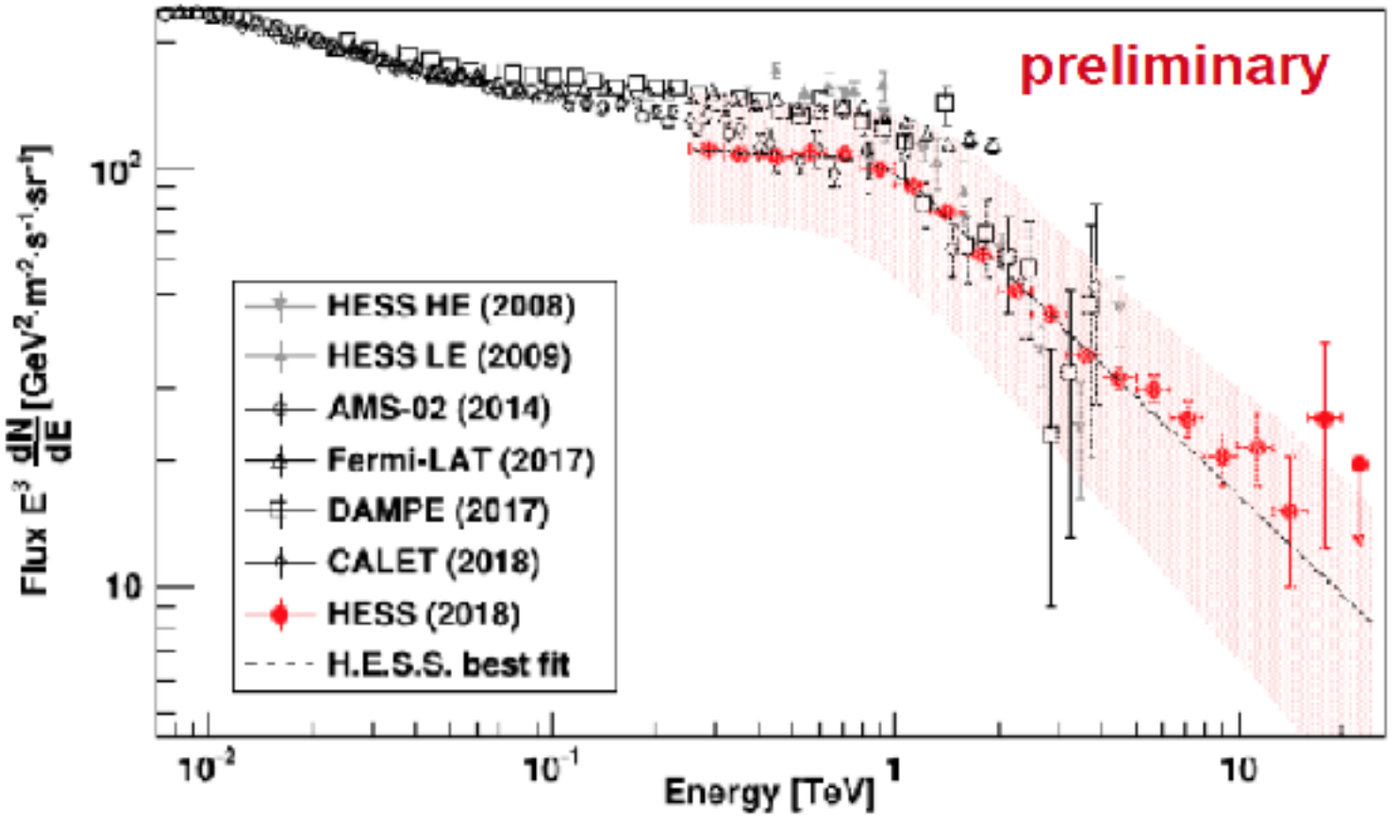
Damien Dormic

Multi-messenger follow-up with ACTs



Clemens Hoischen

Cosmic ray electron spectrum

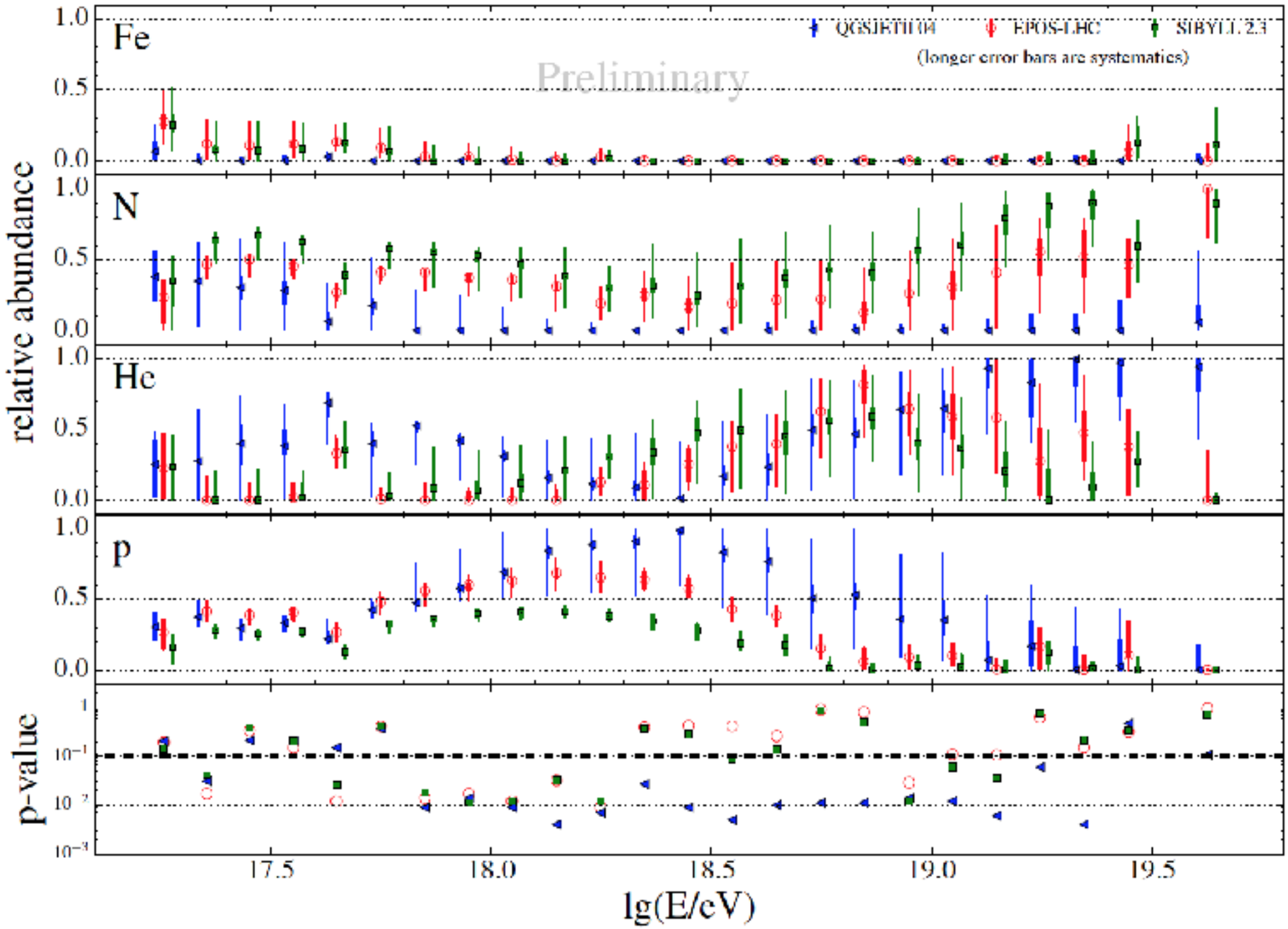


- Recent measurements made a giant step in both, accuracy and energy coverage
- Despite some discrepancy between measurements yet to be resolved, the data seems to indicate that the one major feature of the CR $e^- + e^+$ spectrum is a break at ~1 TeV
- We are approaching the end of the CR $e^- + e^+$ spectrum
  - measurements still awaiting full scientific exploitation

Kathrin Egberts

Cosmic ray abundances with Auger

Mass fractions



Bruce Dawson

Thank you to Prof. Jean Trân Thanh Vân, the members of the Scientific Program Committee, the Conference Secretariat, and all the conference attendees for such an enjoyable and scientifically productive meeting.