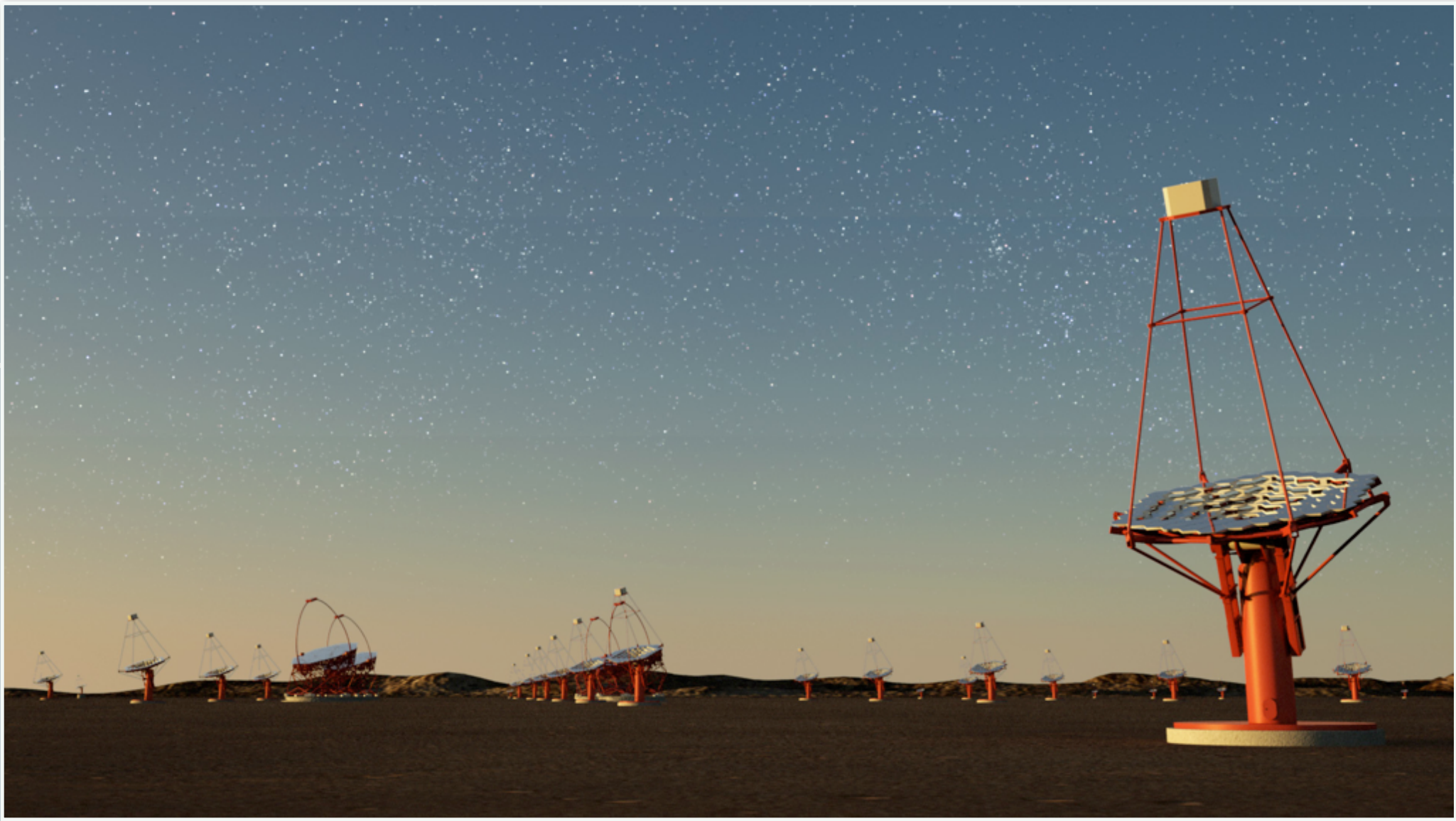


VHE SCIENCE AFTER 10 YEARS OF CTA



VHE SCIENCE AFTER 10 YEARS OF CTA

What will have learned after 10 years?

What will we do in years 10-30 of CTA operation?

10 YEARS AGO ...



LEPTON-PHOTON 2007

XXIII International Symposium on Lepton and Photon Interactions
at High Energy Aug 13-18, Daegu, Korea

Gamma-ray astrophysics

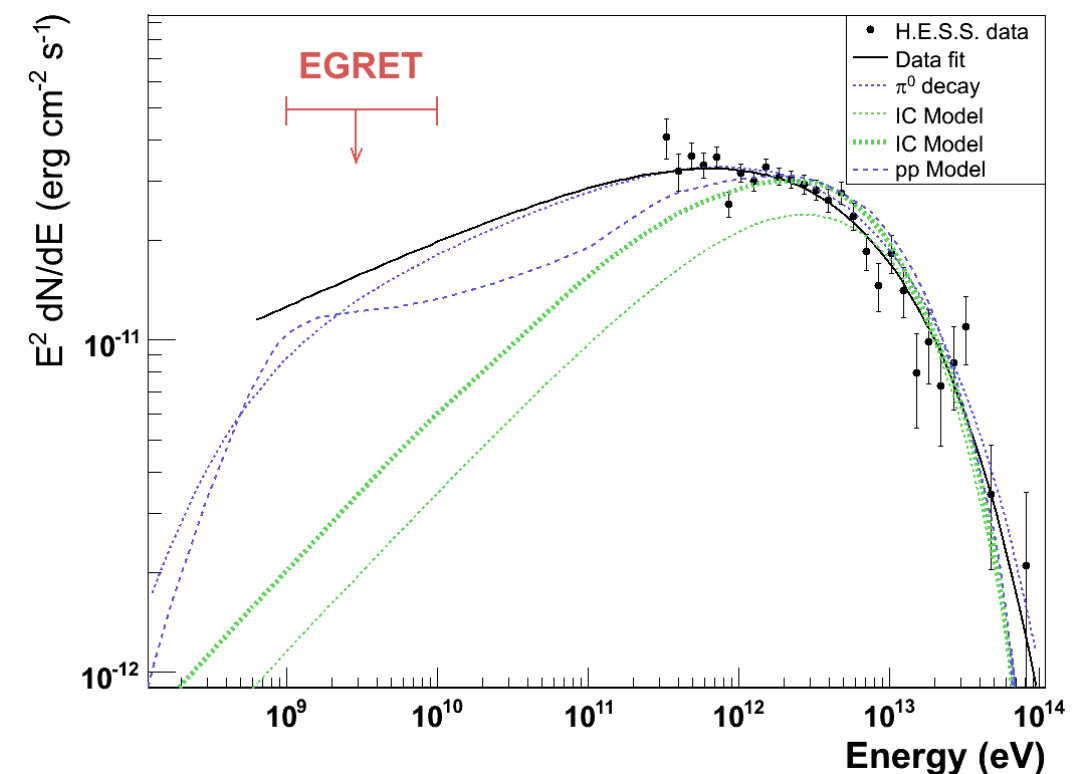
... or the end of the astrophysical
photon spectrum

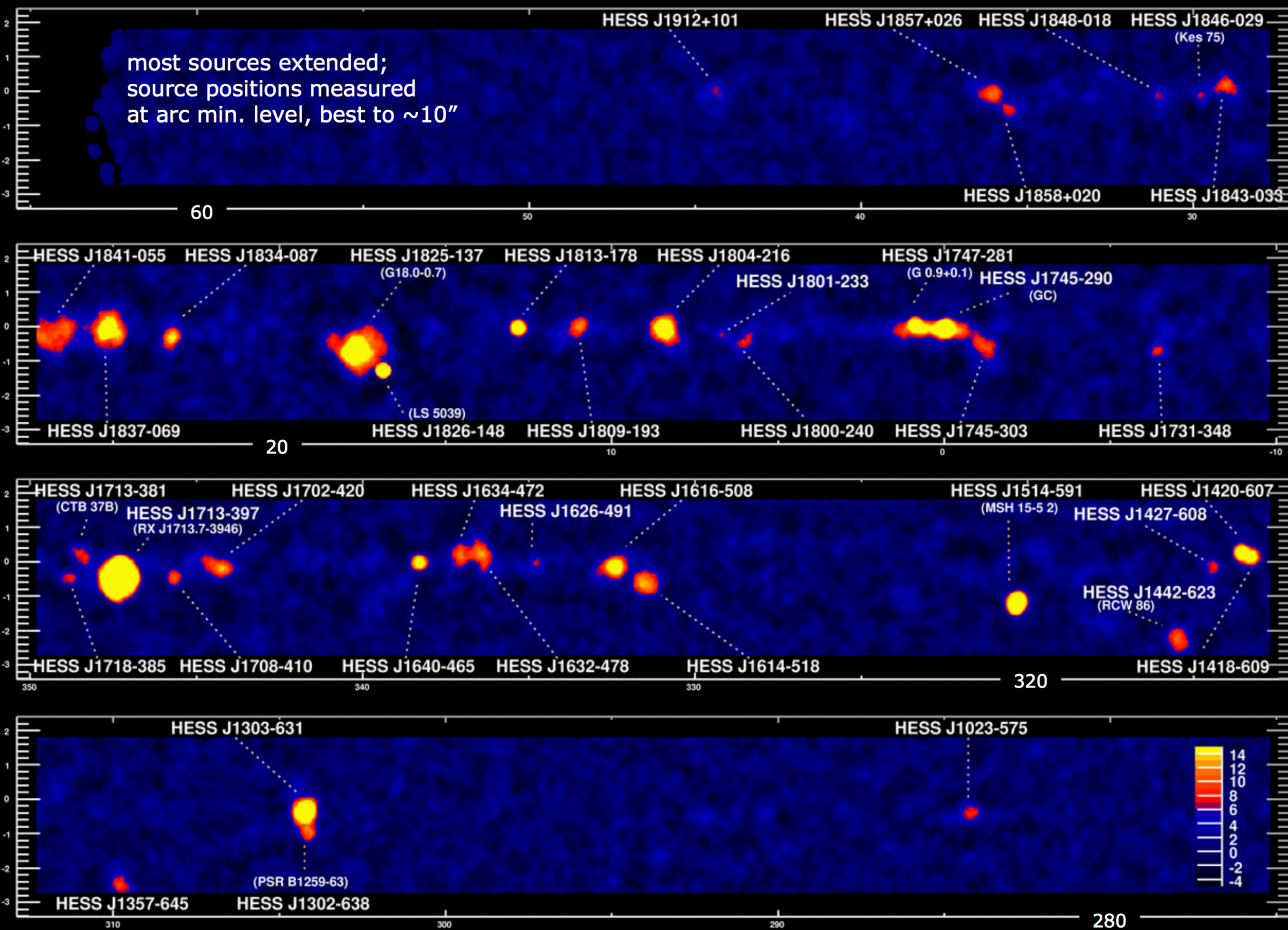
Acknowledgements to members of all these collaborations ...



... and the usual apology to everybody else I do not mention

Stefan Funk, Stanford/SLAC





10 YEARS AGO ...



LEPTON-PHOTON 2007

XXIII International Symposium on Lepton and Photon Interactions
at High Energy Aug 13-18, Daegu, Korea

Gamma-ray astrophysics

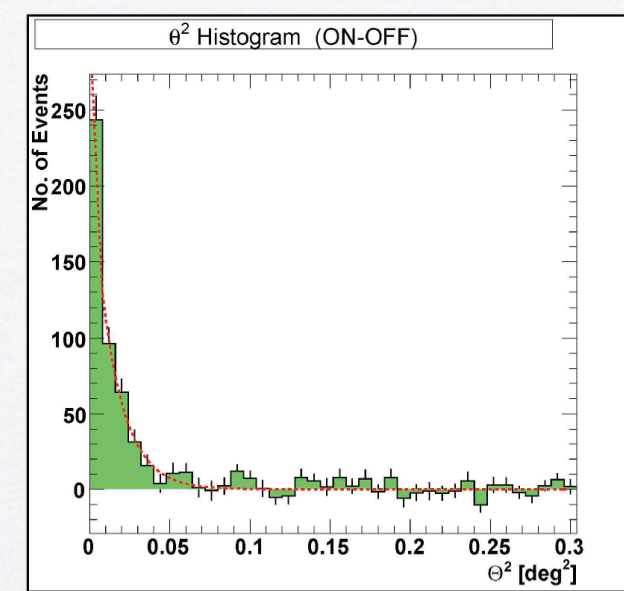
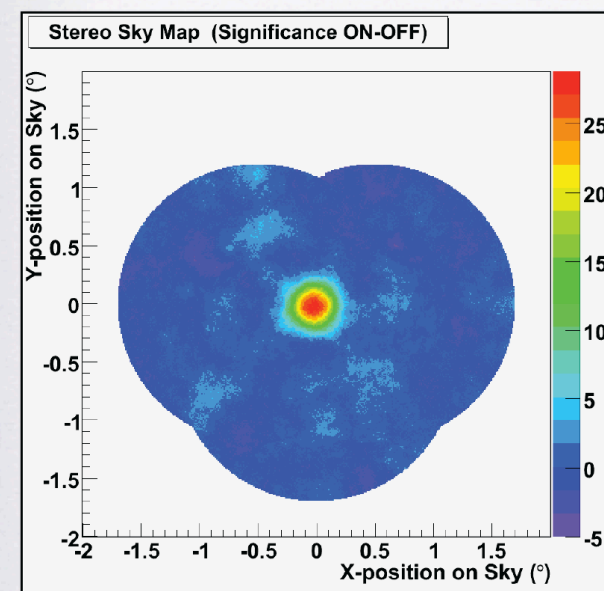
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photon spectrum

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10 YEARS AGO ...



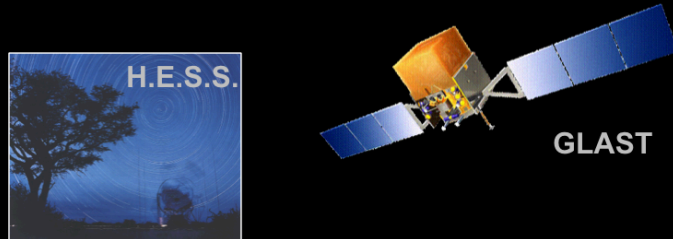
LEPTON-PHOTON 2007

XXIII International Symposium on Lepton and Photon Interactions
at High Energy Aug 13-18, Daegu, Korea

Gamma-ray astrophysics

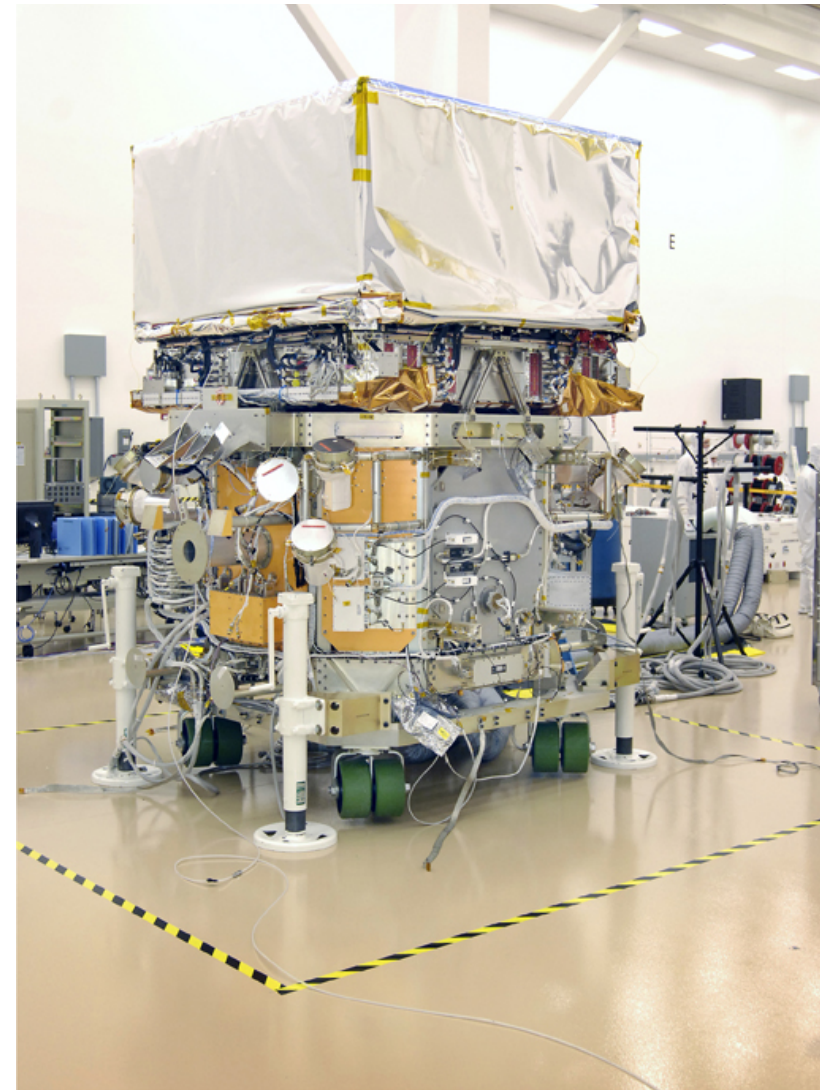
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photon spectrum

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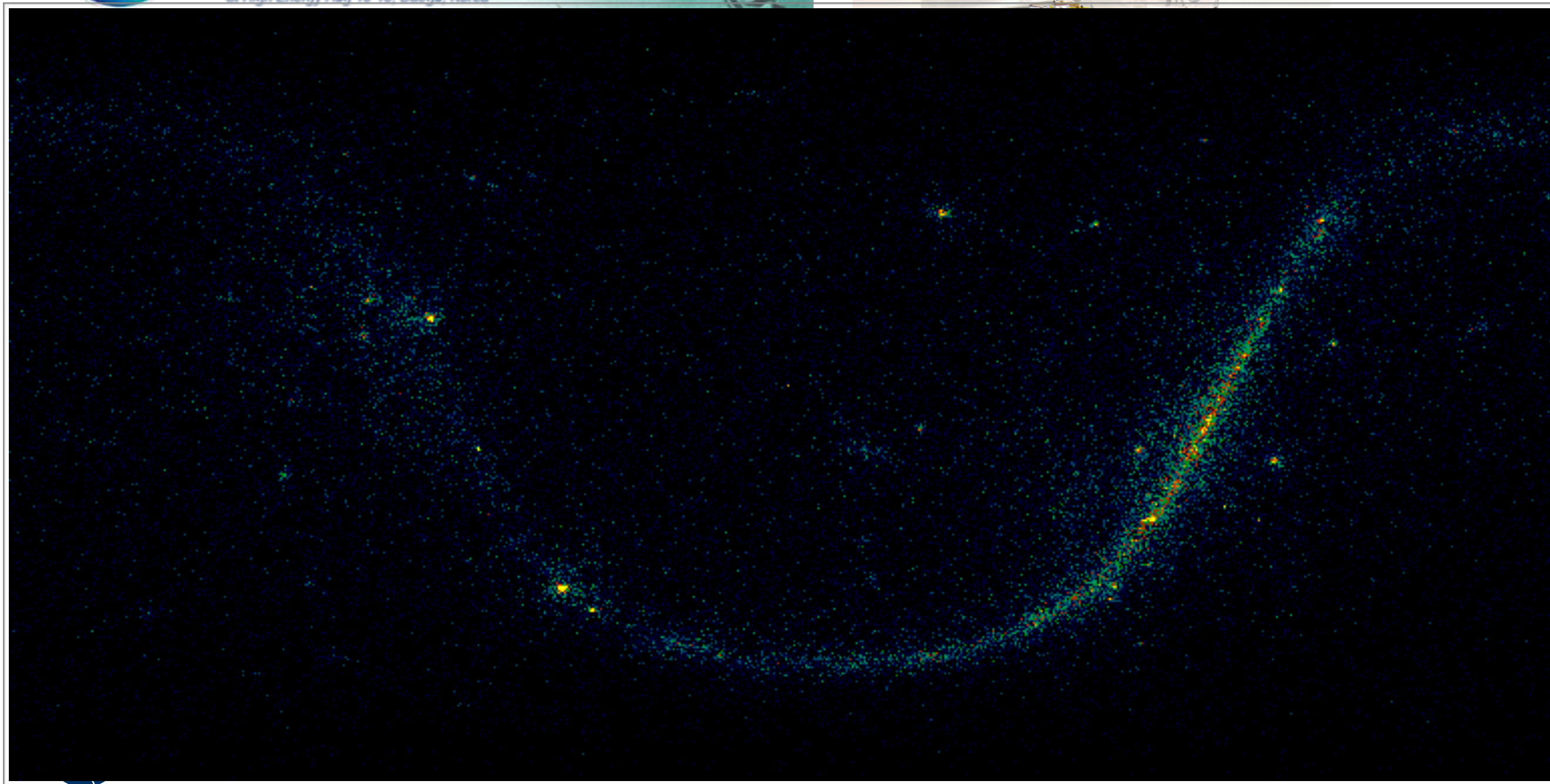


10 YEARS AGO ...

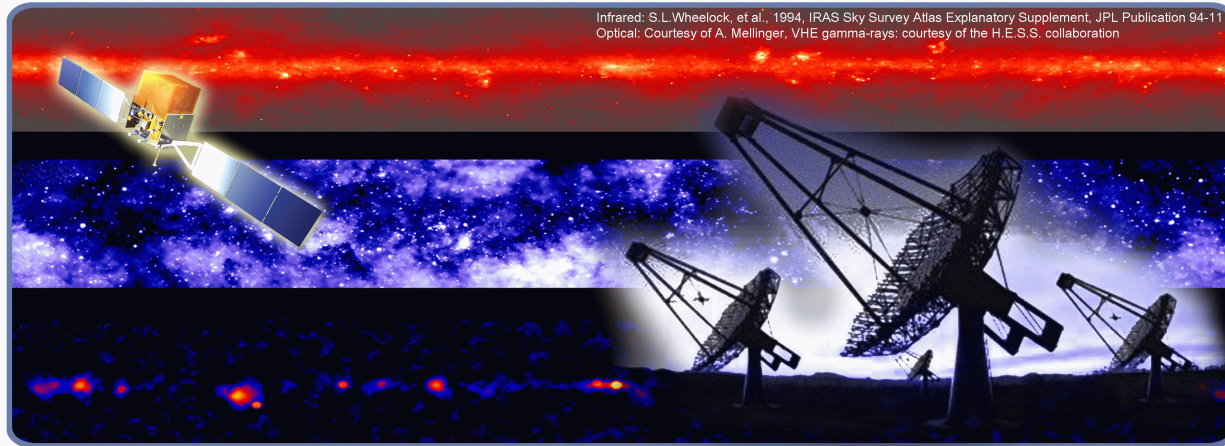


LEPTON-PHOTON 2007

XXIII International Symposium on Lepton and Photon Interactions
at High Energy Aug 13-18, Daegu, Korea



10 YEARS AGO ...

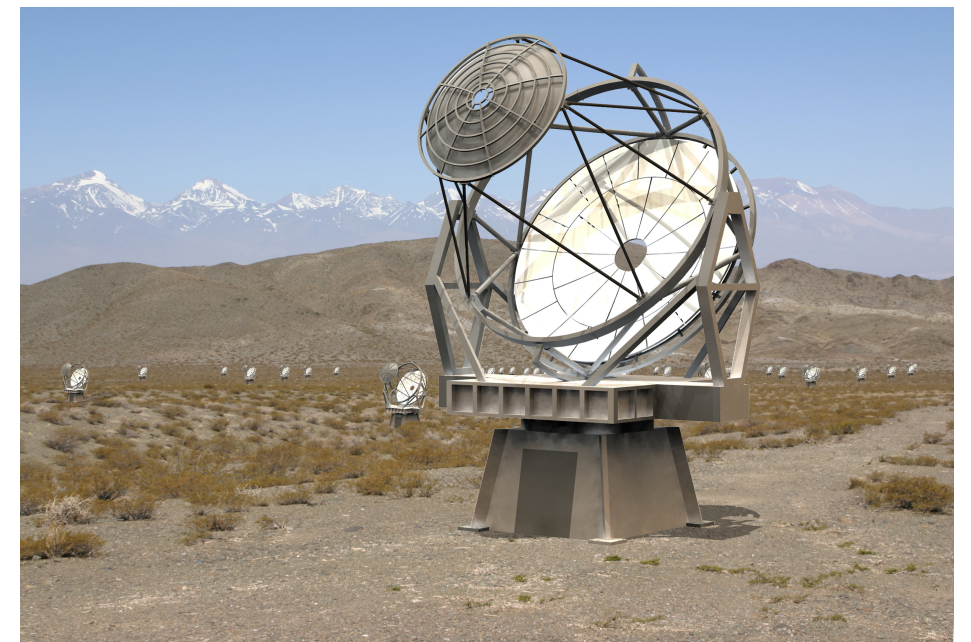
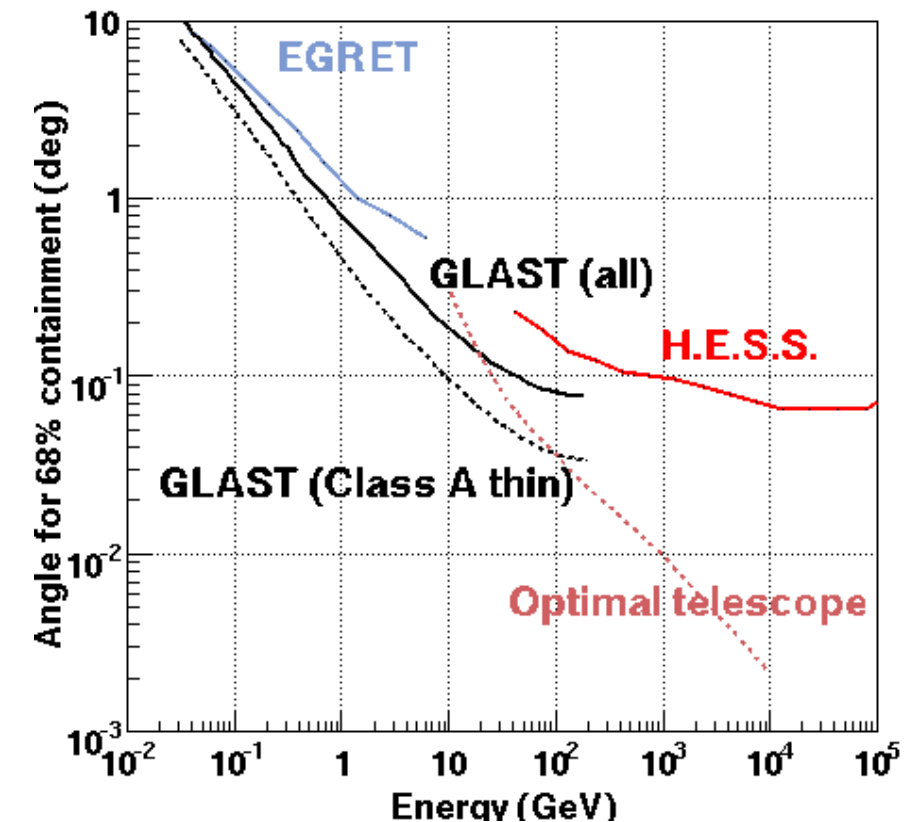


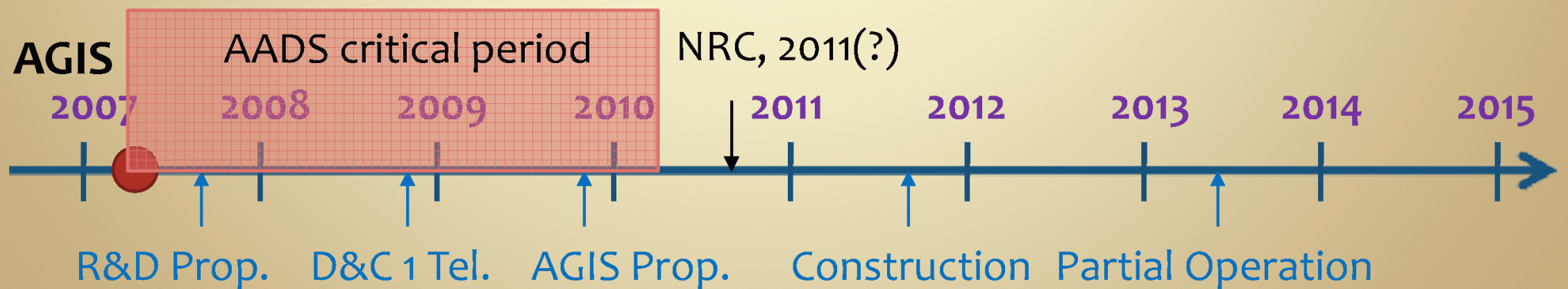
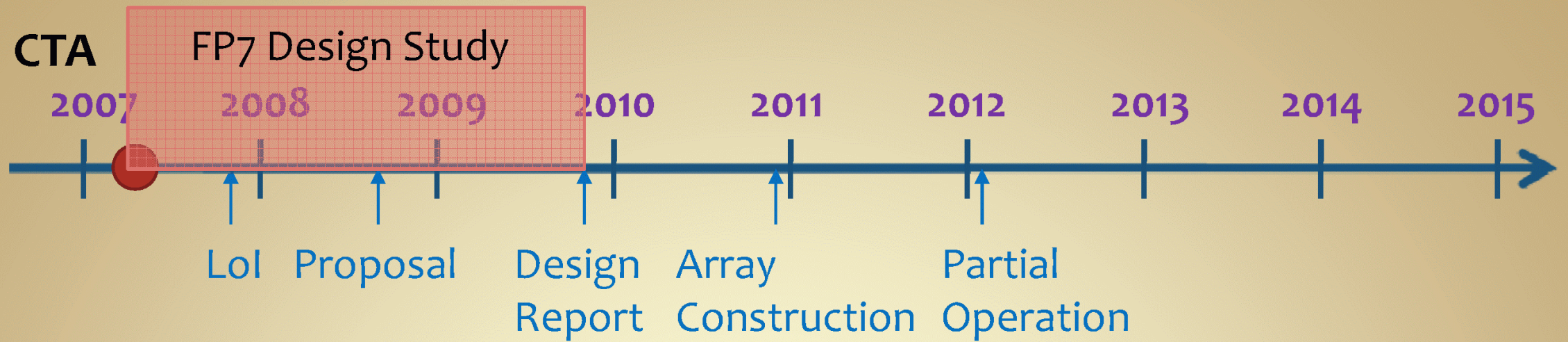
Toward the Future of Very High Energy Gamma-ray Astronomy

November 8 - 9, 2007

Kavli Auditorium, Building 51, SLAC

- Factor 10 in sensitivity with a factor 10 in cost (challenging!)







Conclusions

The future is bright!

Luke Dury, The future of ground-based gamma-ray astronomy, TeVPA, Venice 2007

The future, according to some scientists, will be exactly like the past, only far more expensive.

John Sladek

Problems are political and organisational,
not technical....

Luky Drury

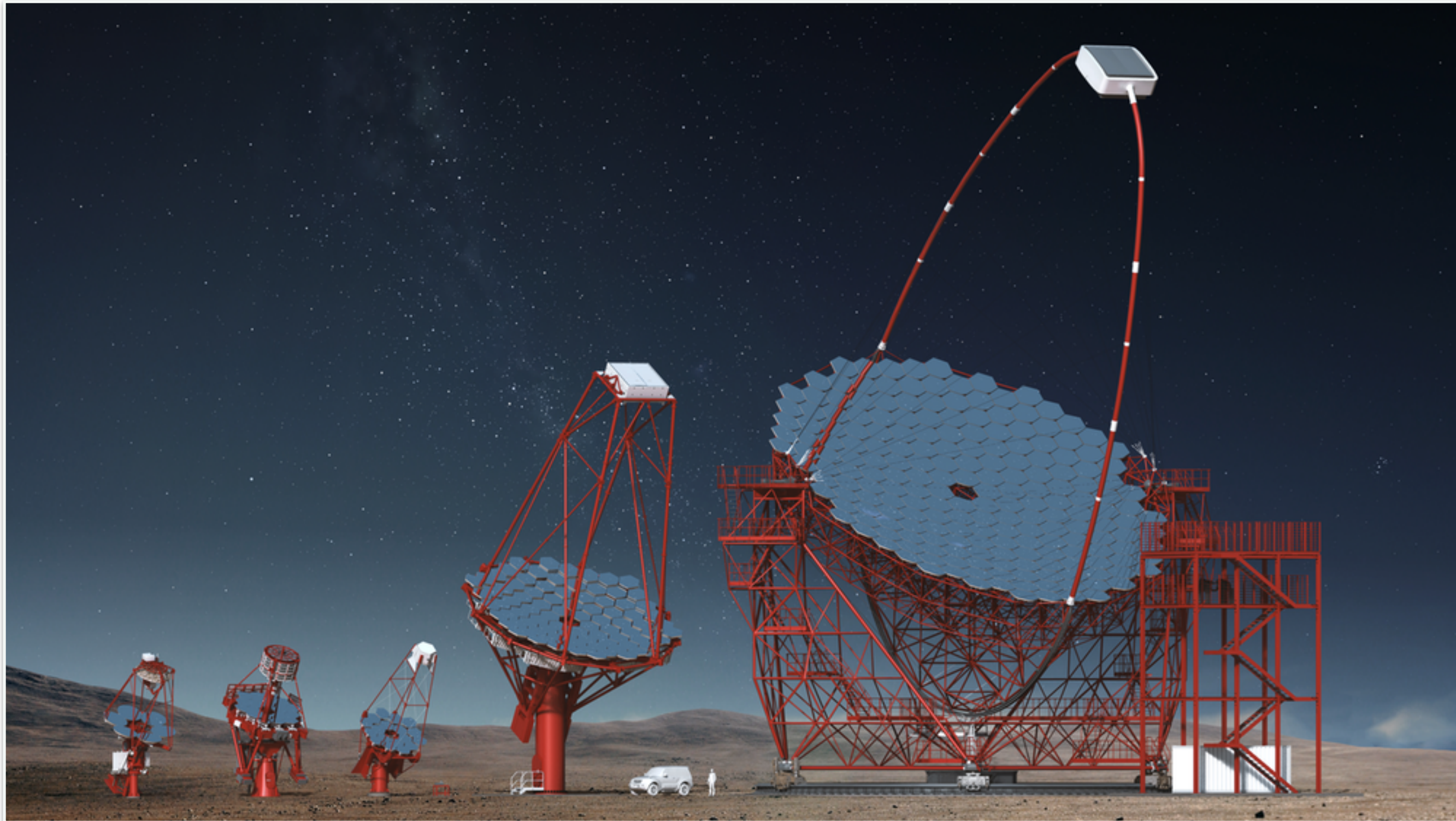
Let's try to attack these problems together!

Werner Hofmann

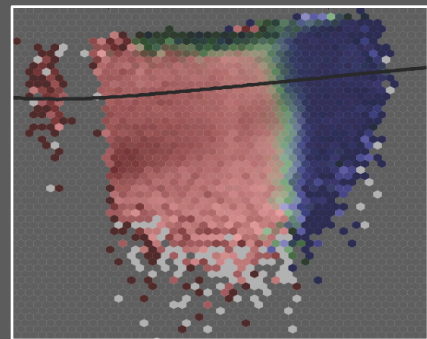


CHERENKOV TELESCOPE ARRAY

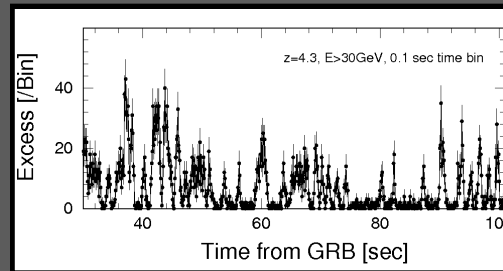
.....



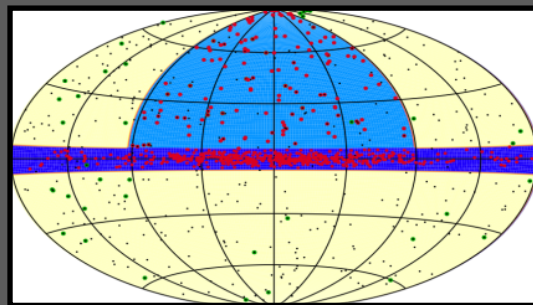
KEY SCIENCE PROGRAM



Dark Matter Programme

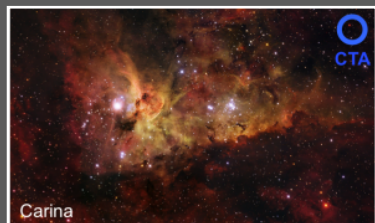
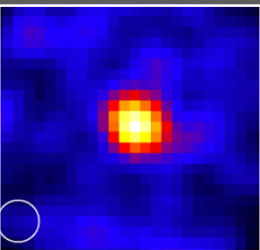


Transients



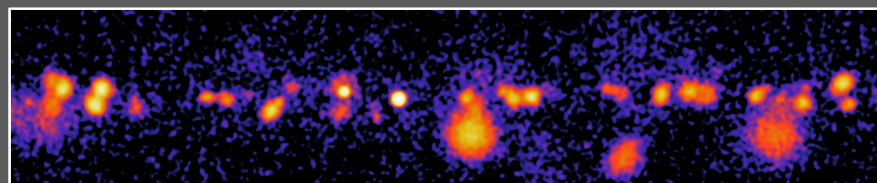
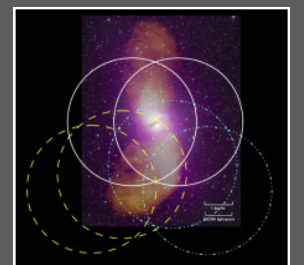
ExGal Survey

Galaxy Clusters



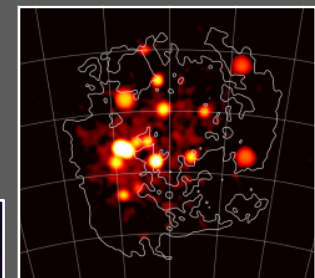
Star Forming Systems

AGN



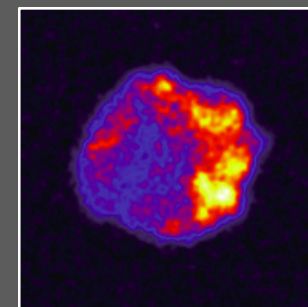
Galactic Plane Survey

LMC Survey

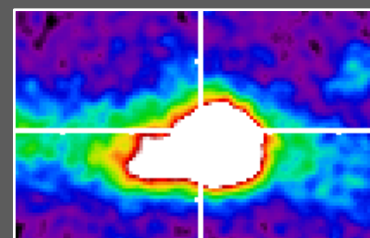


Galactic

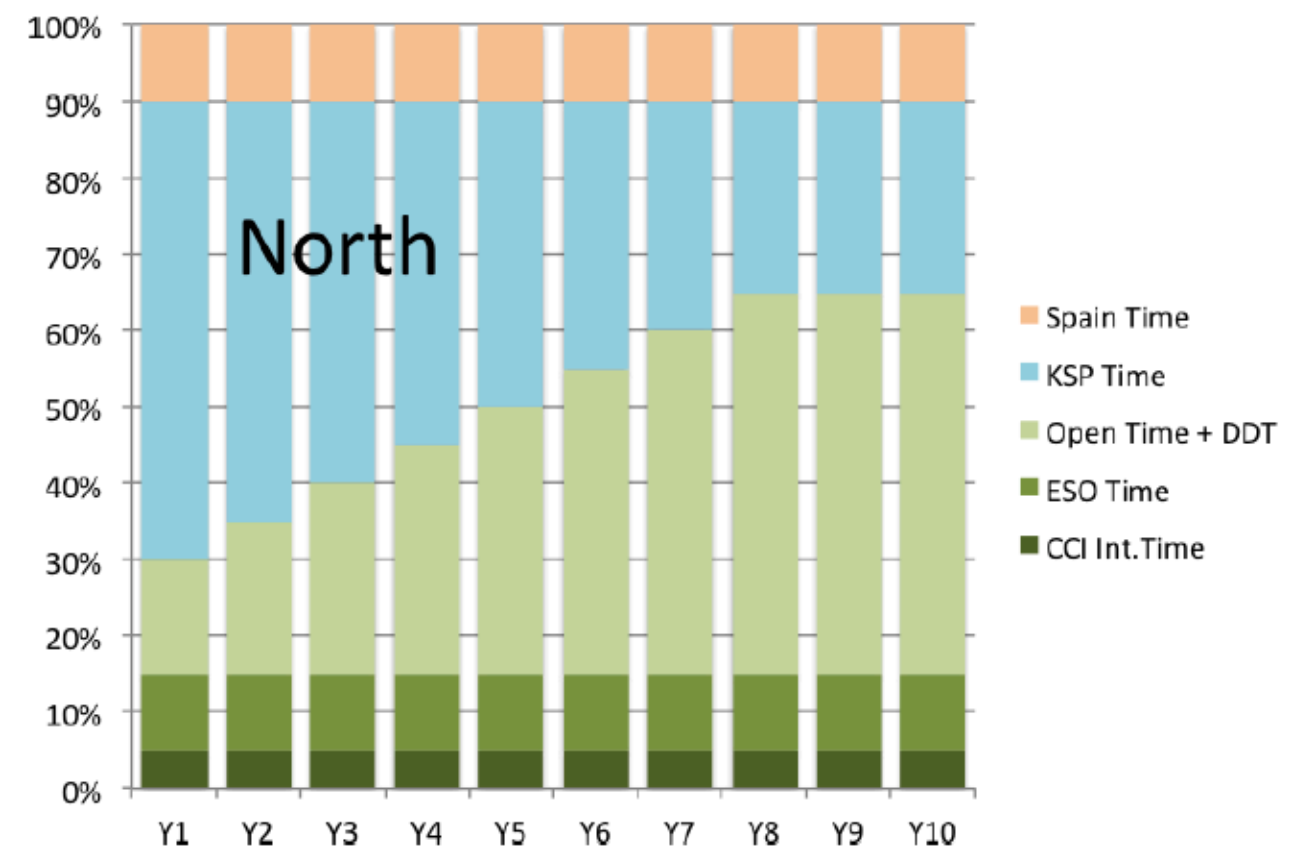
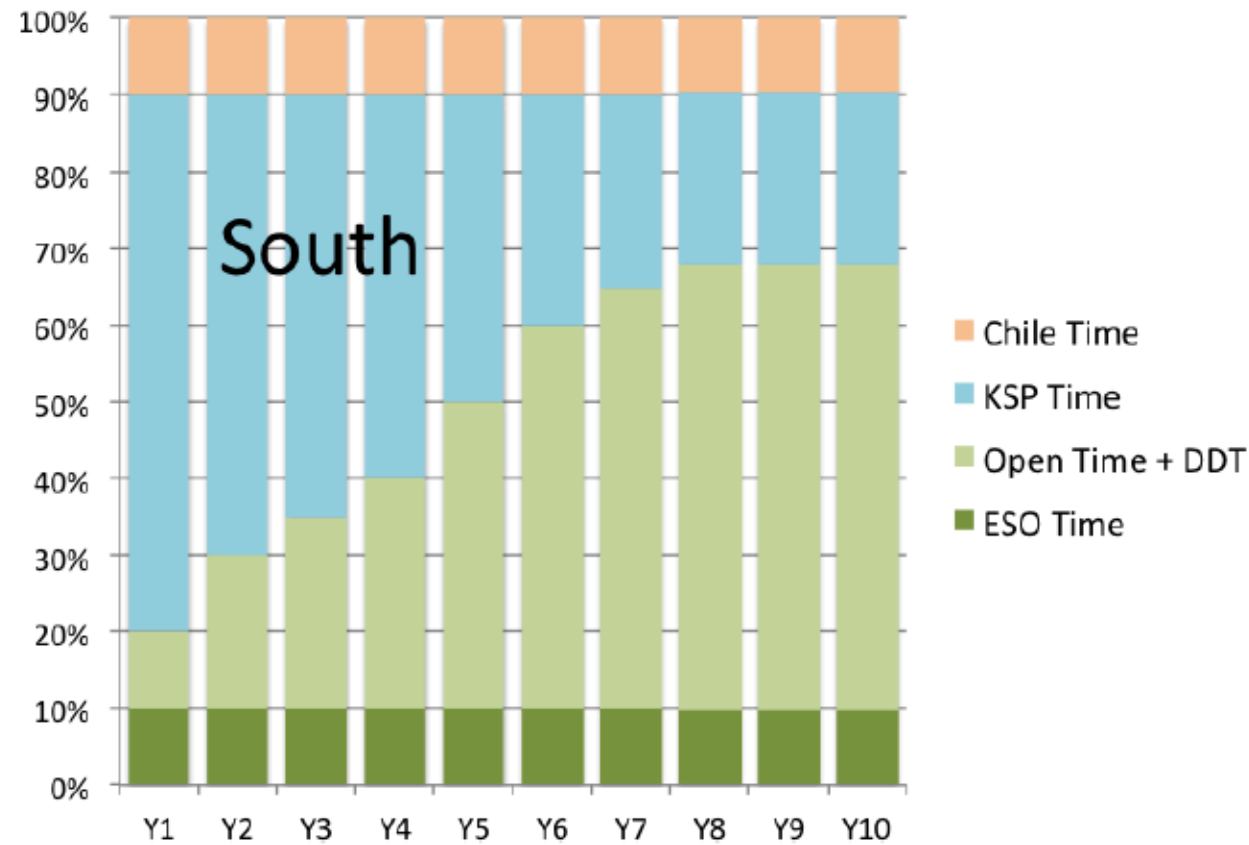
PeVatrons



Galactic Centre



OBSERVATION TIMES



Total moonless:
Available*:

CTA South

1646

1328 h/year

CTA North

1522

1015 h/year

40% over 10y:

5312 h

4060 h



cherenkov
telescope
array

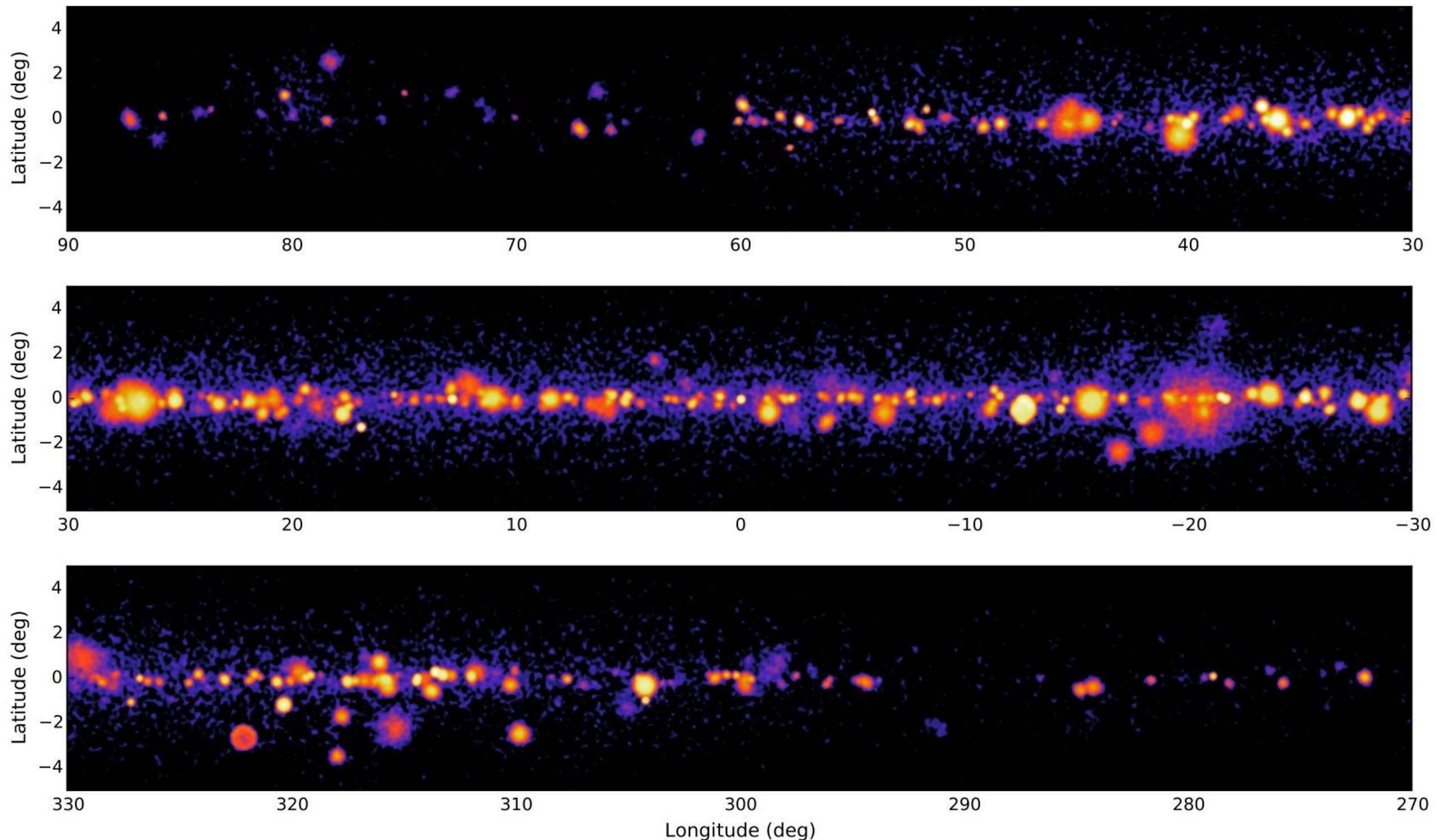
Science with the Cherenkov Telescope Array

SCIENCE WITH CTA

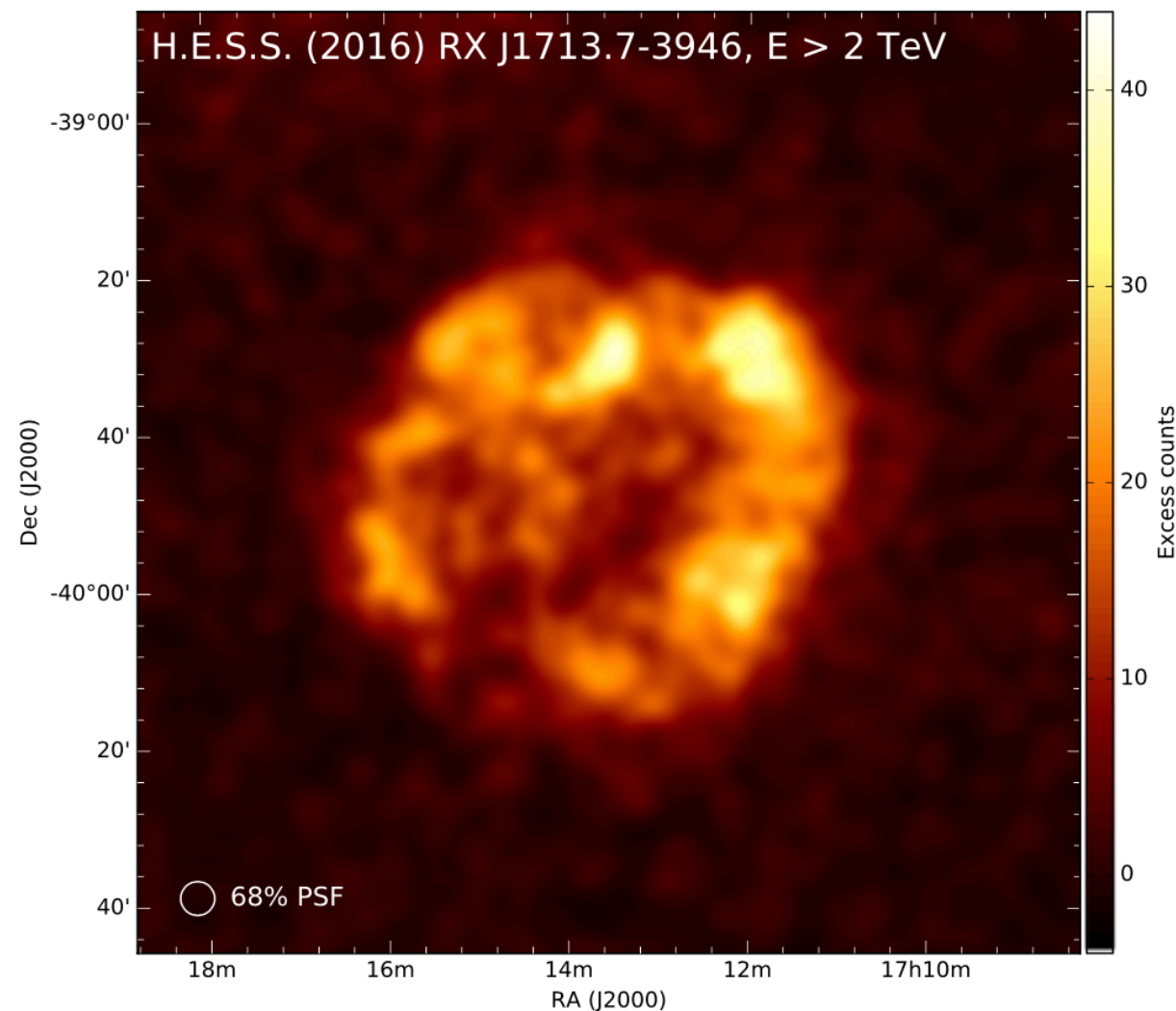
- 200 page document describing core CTA science
- Will soon be put on arXiv and become a regular book

THERE ARE KNOWN KNOWN
THERE ARE THINGS THAT WE KNOW THAT WE KNOW, THERE ARE
KNOWN UNKNOWN
THAT IS TO SAY, THERE ARE
THINGS THAT WE NOW KNOW WE DON'T KNOW
BUT THERE ARE ALSO
UNKNOWN UNKNOWN
THERE ARE THINGS
WE DO NOT KNOW
WE DON'T KNOW
AND EACH YEAR WE DISCOVER
A FEW MORE OF THOSE
UNKNOWN
UNKNOWN

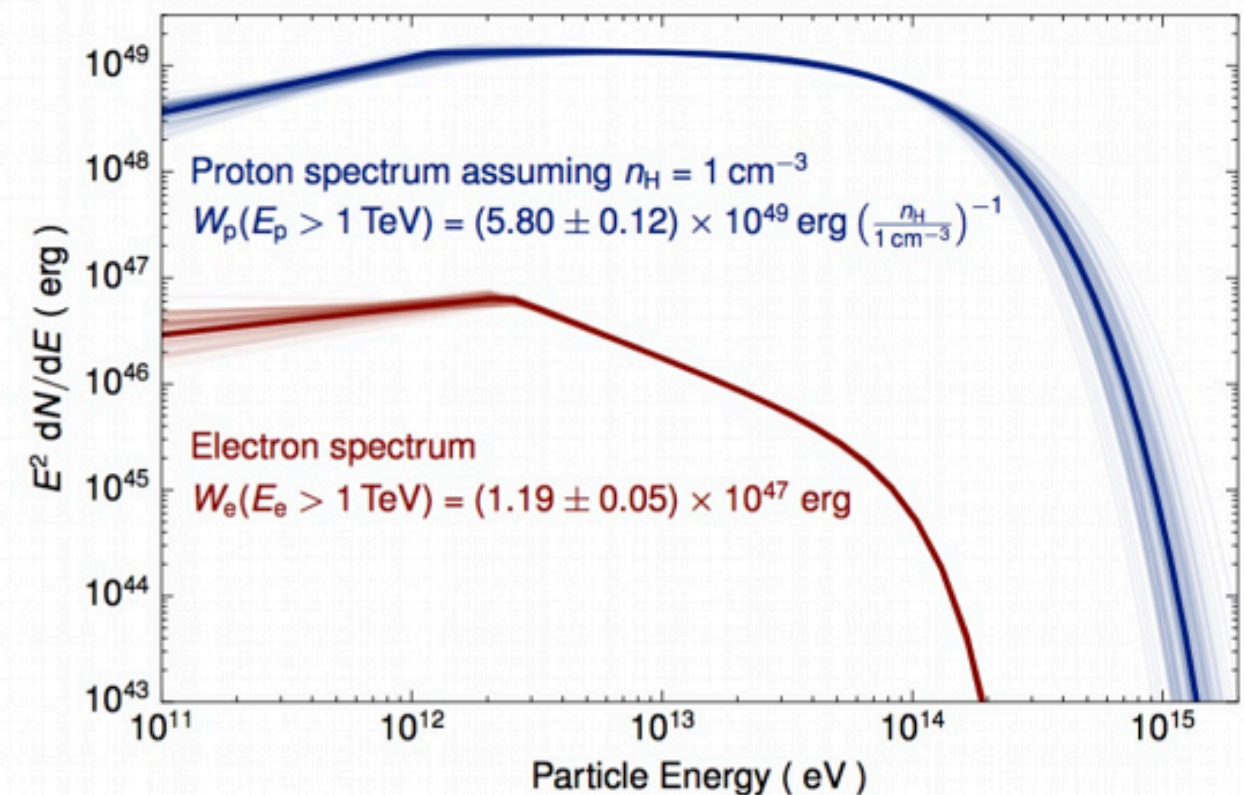
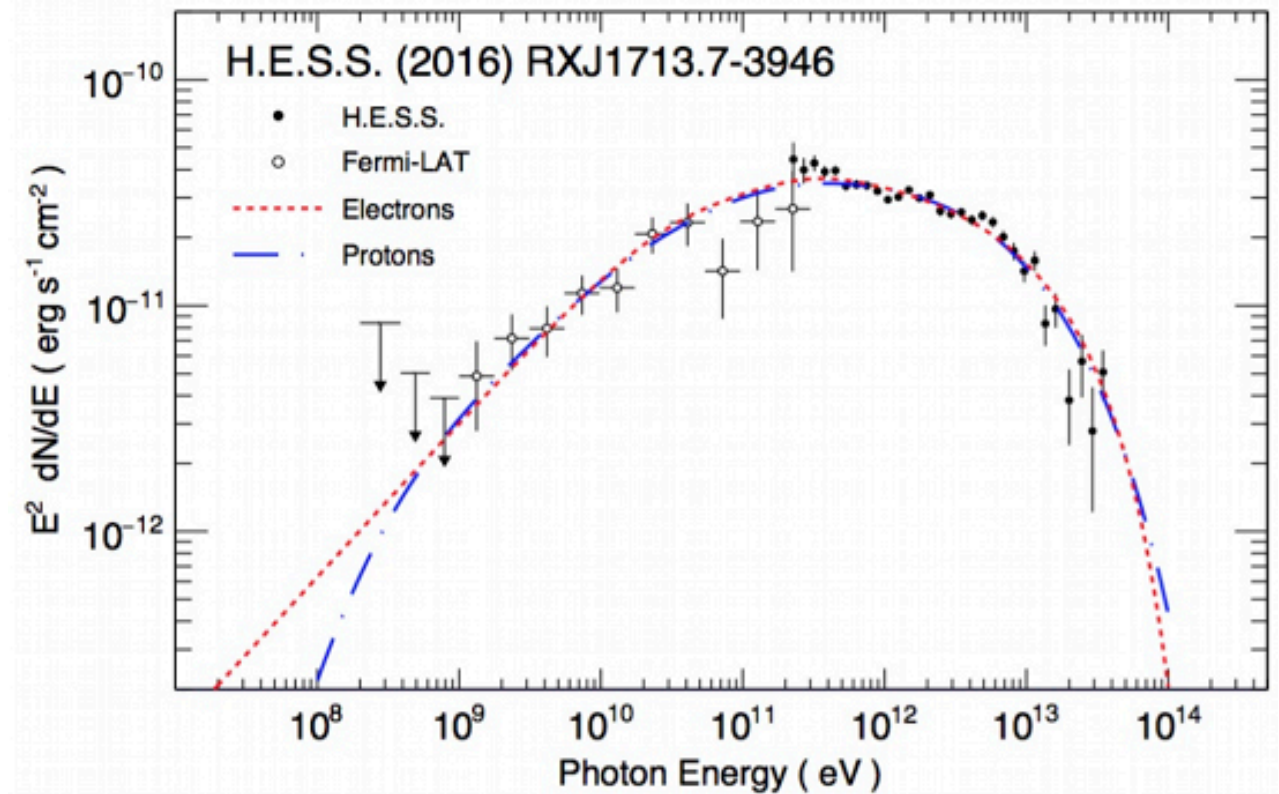
CENSUS OF HIGH-ENERGY EMITTERS TO THE MCRAB FLUX LEVEL



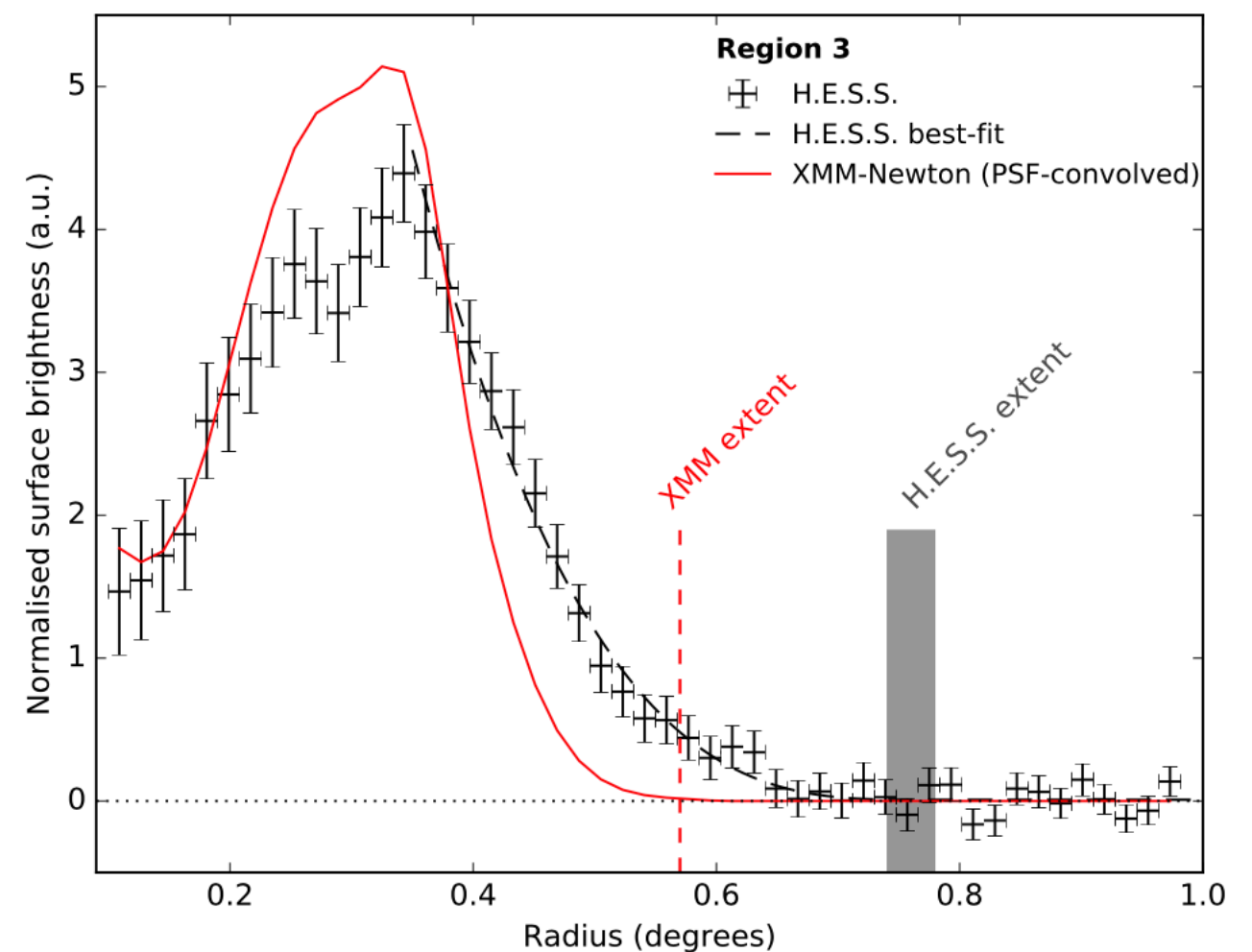
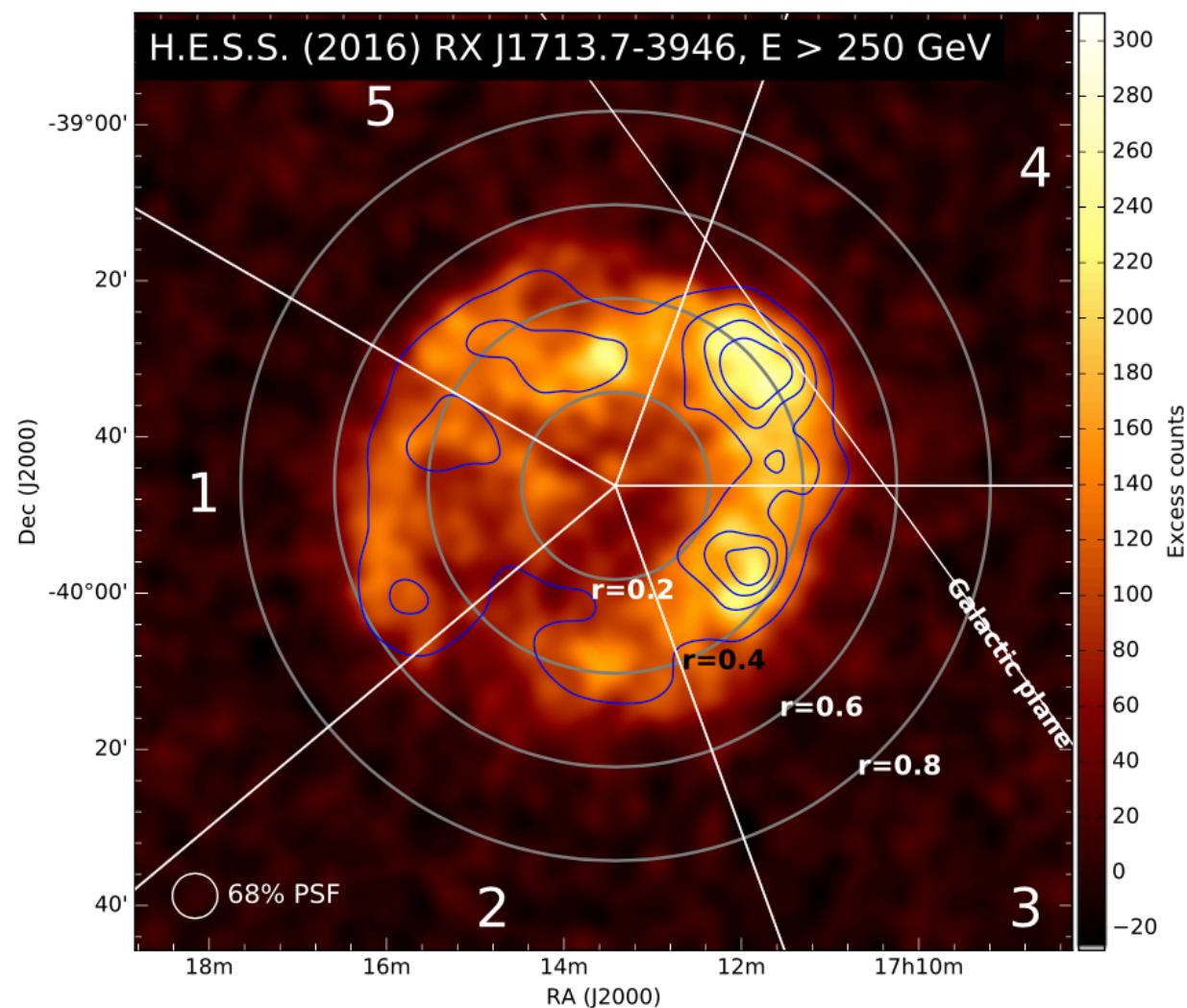
UNDERSTANDING PARTICLE ACCELERATION AND ESCAPE IN SUPERNOVA REMNANTS



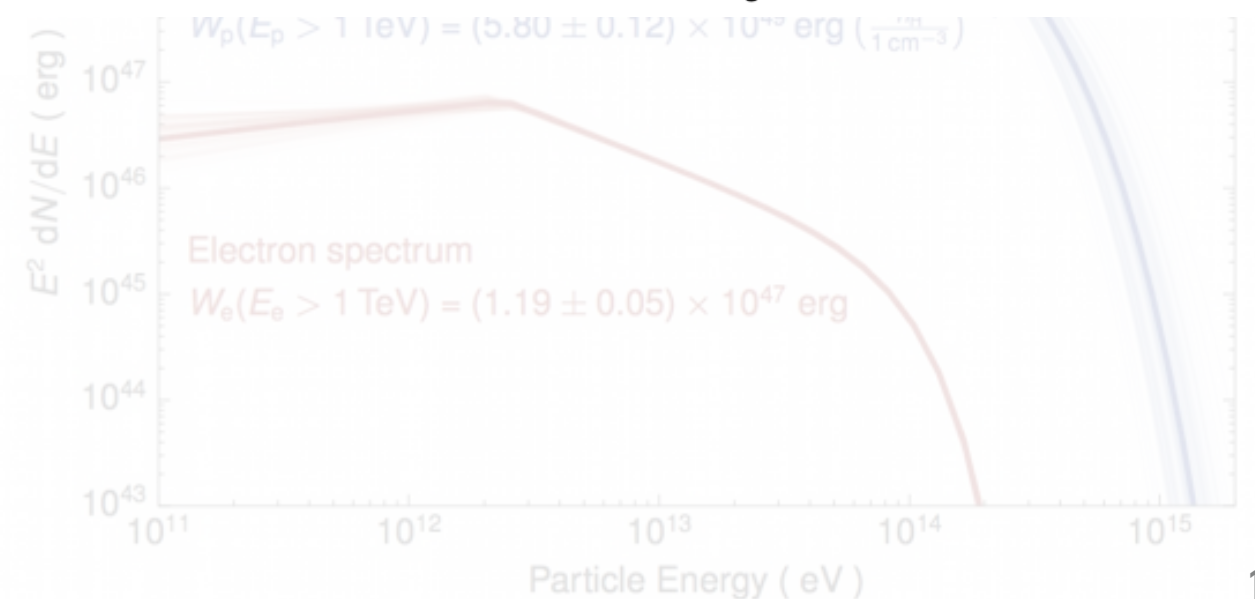
HESS observations (Abdalla et al. 2016)
<https://arxiv.org/pdf/1609.08671.pdf>



UNDERSTANDING PARTICLE ACCELERATION AND ESCAPE IN SUPERNOVA REMNANTS

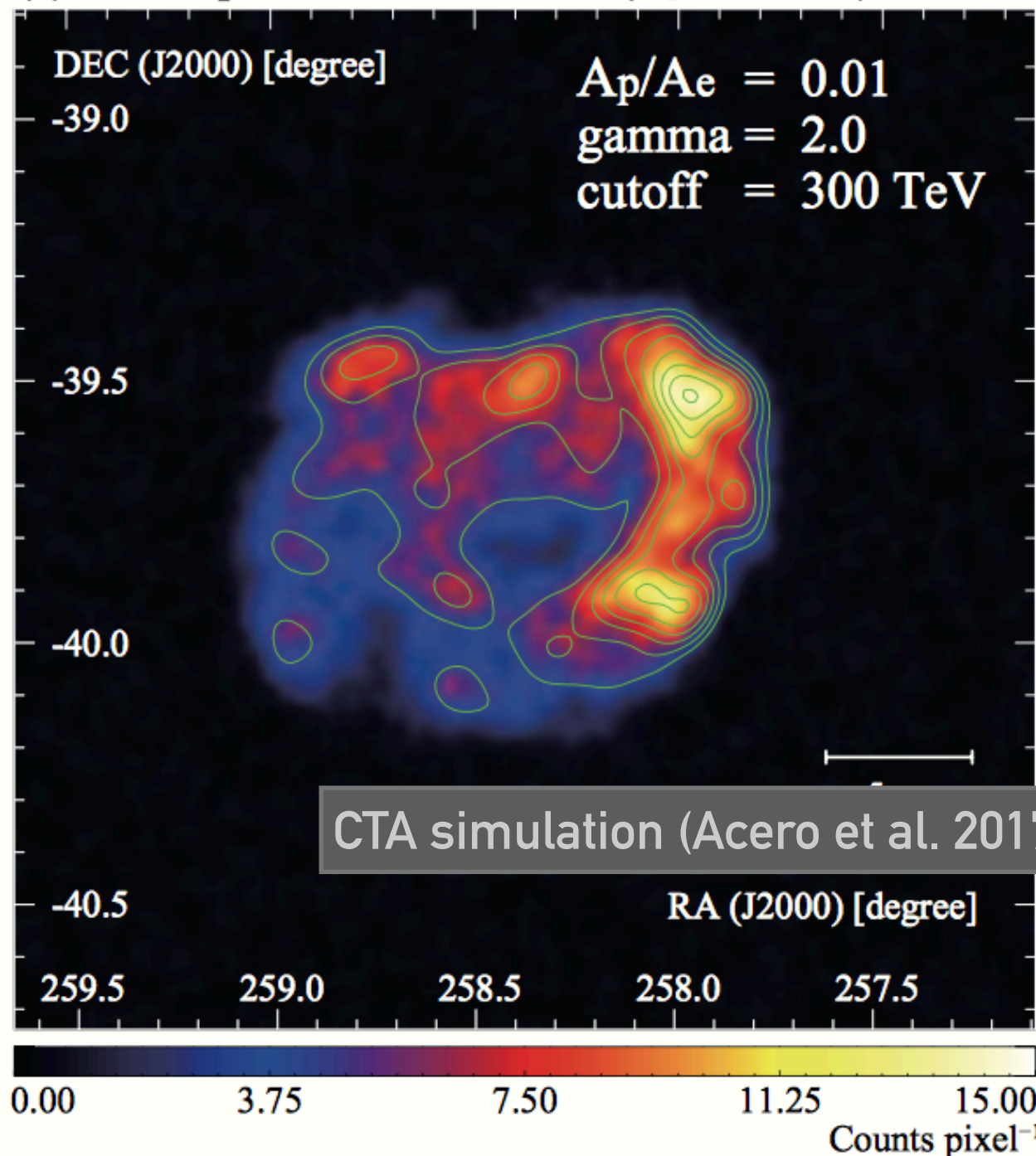


HESS observations (Abdalla et al. 2016)
<https://arxiv.org/pdf/1609.08671.pdf>

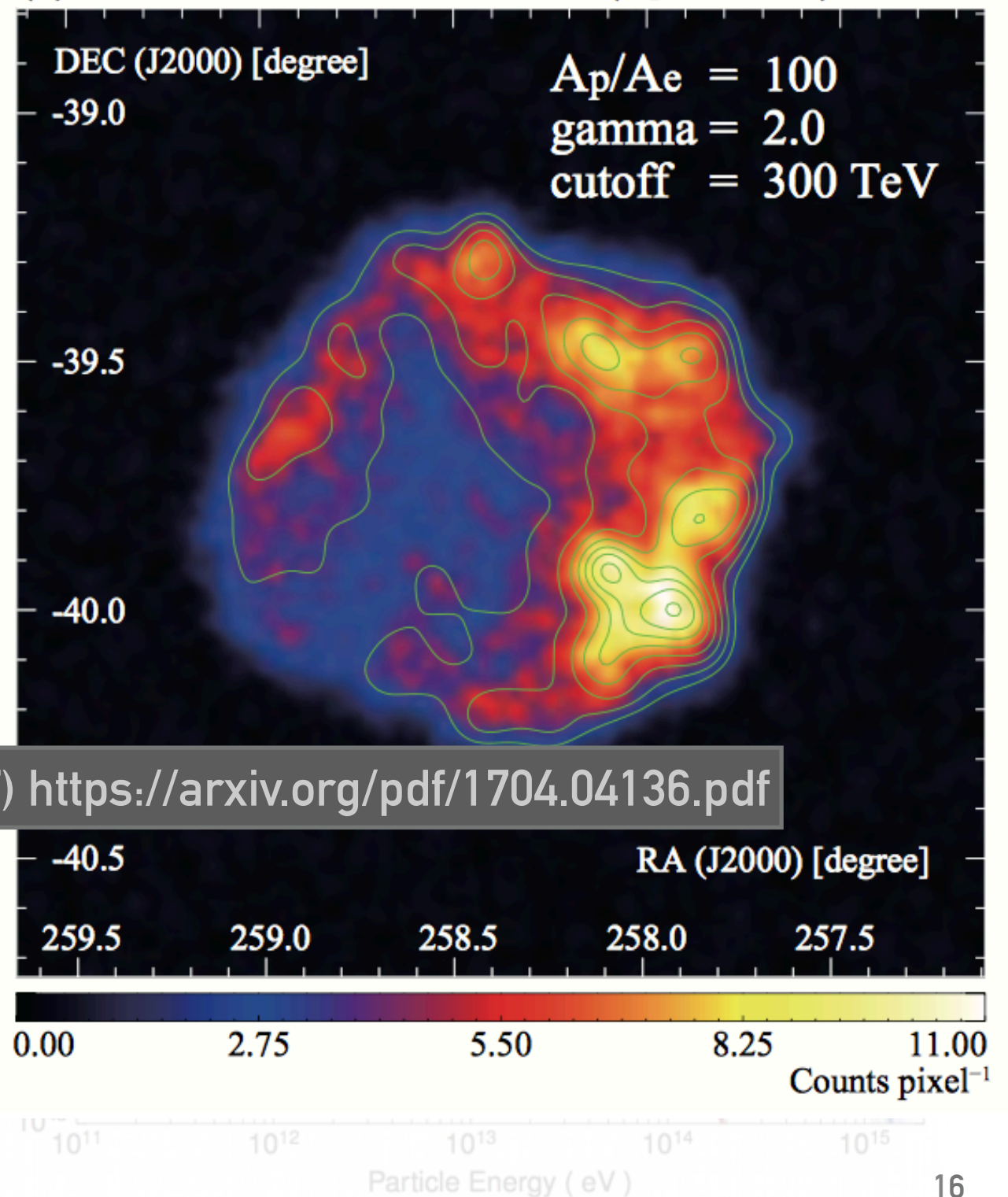


UNDERSTANDING PARTICLE ACCELERATION AND ESCAPE IN SUPERNOVA REMNANTS

(a) CTA lepton-dominated case ($A_p/A_e=0.01$)

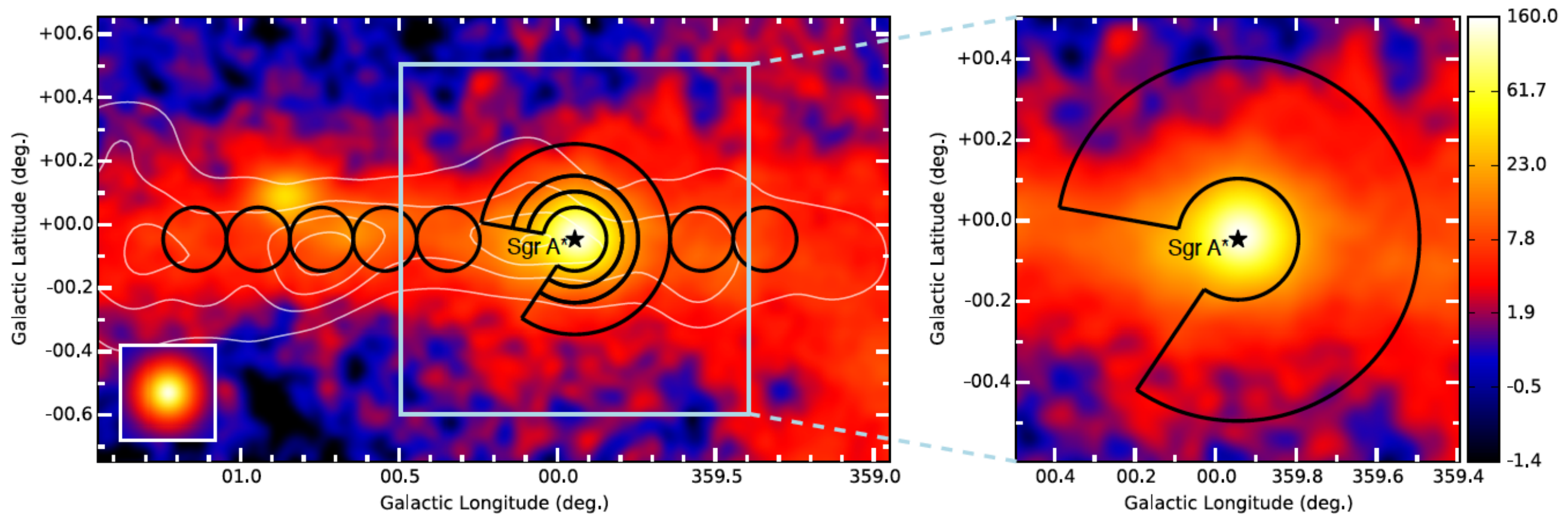
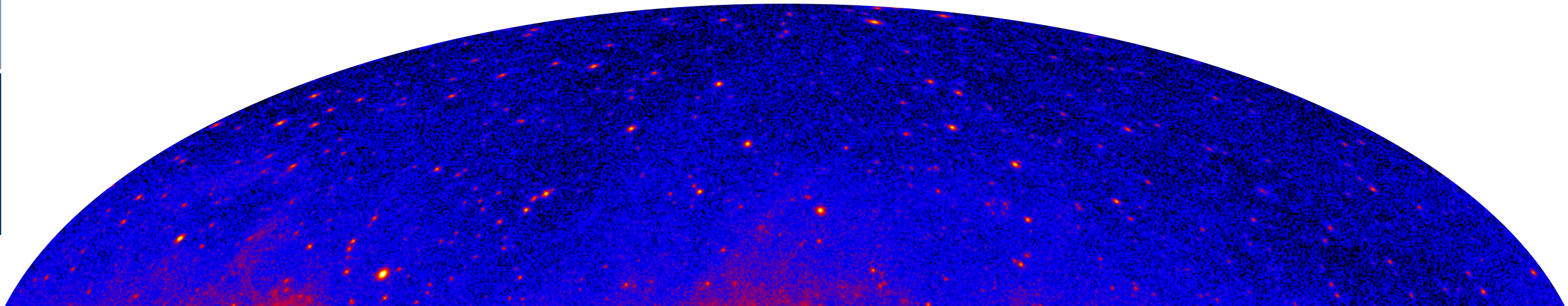


(b) CTA hadron-dominated case ($A_p/A_e=100$)

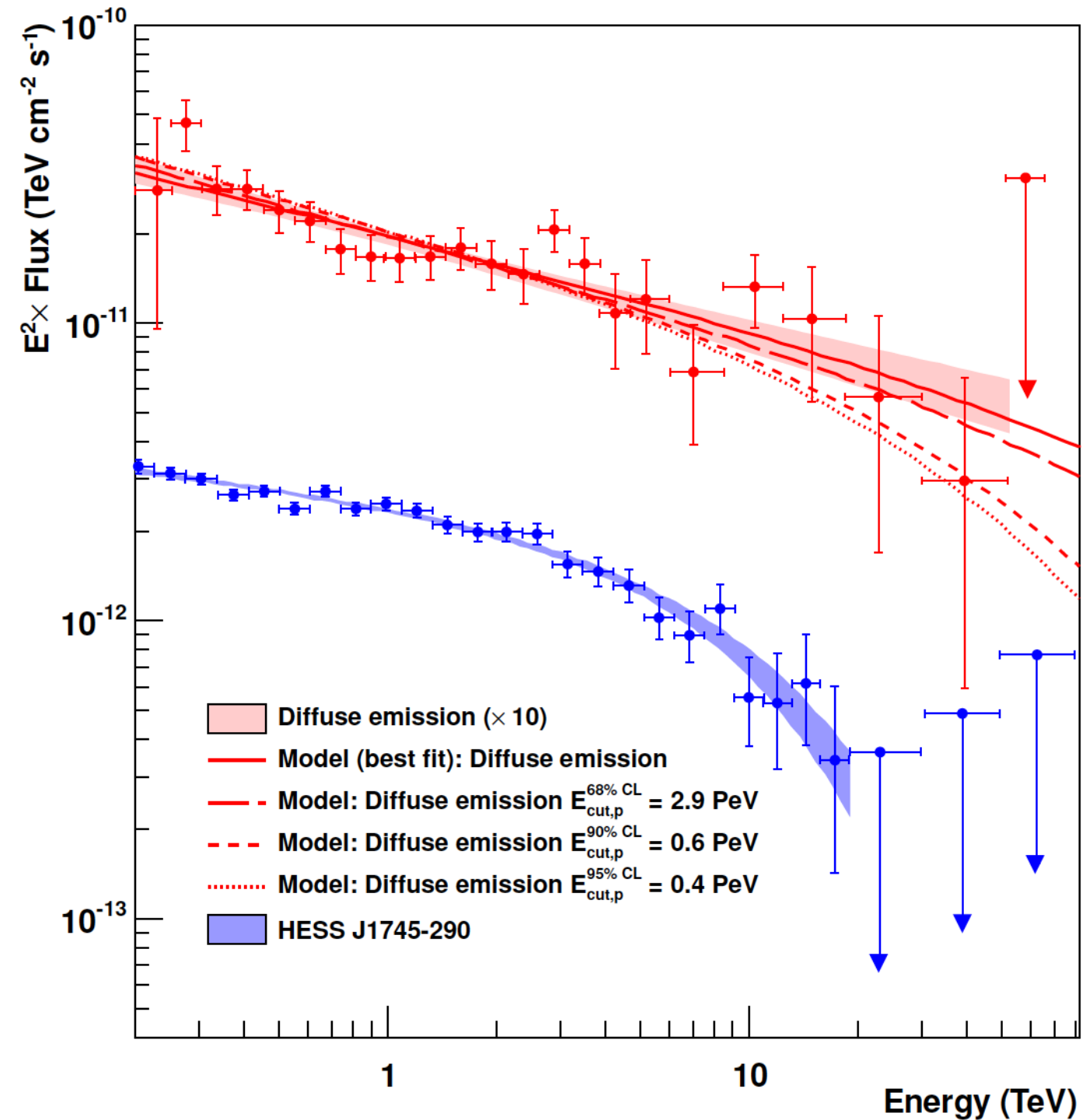
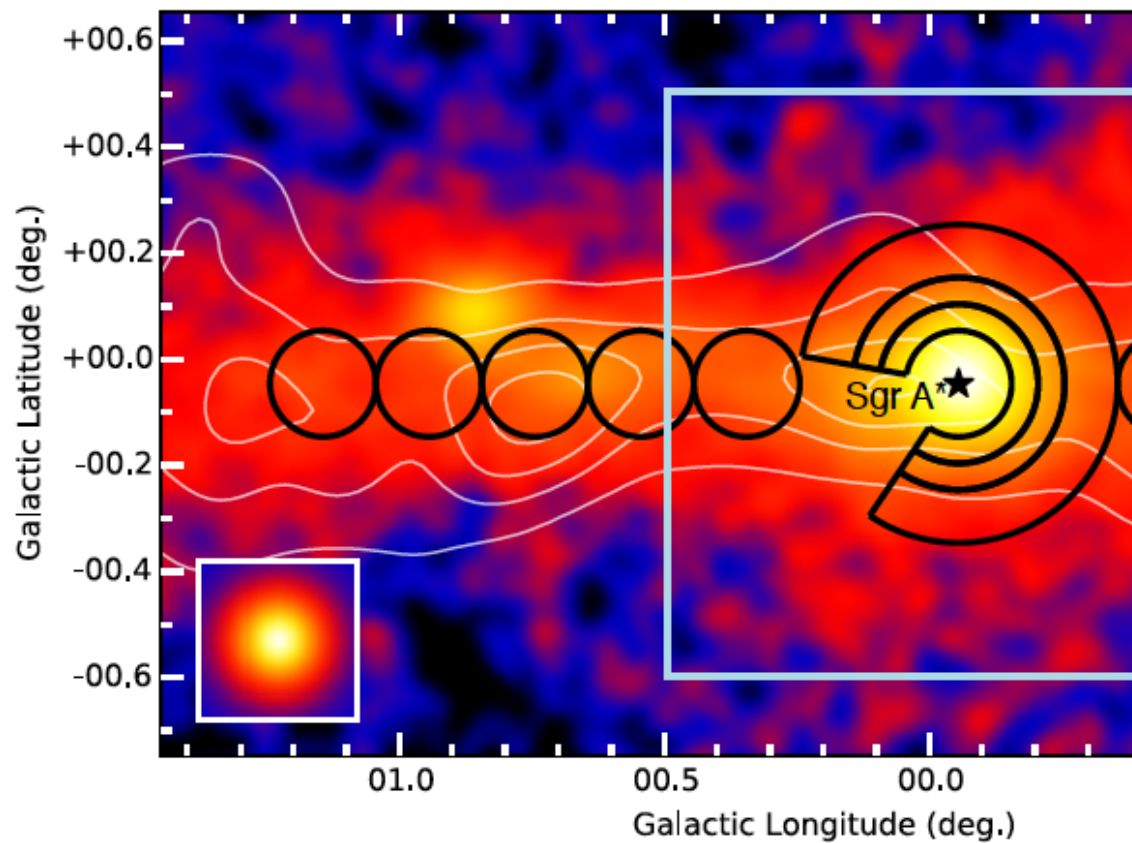
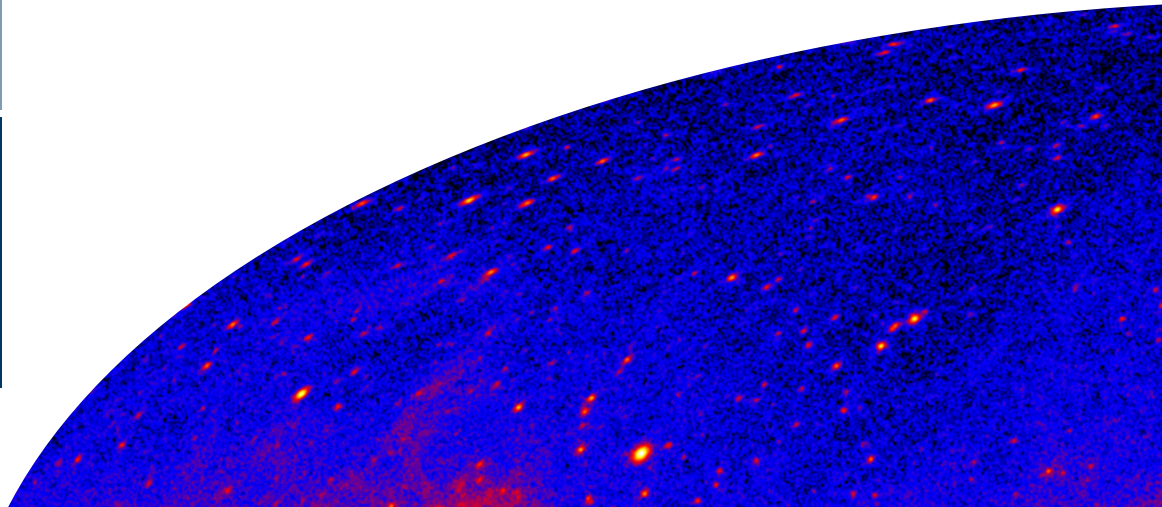


CTA simulation (Acero et al. 2017) <https://arxiv.org/pdf/1704.04136.pdf>

ALSO IN THE GALACTIC CENTER

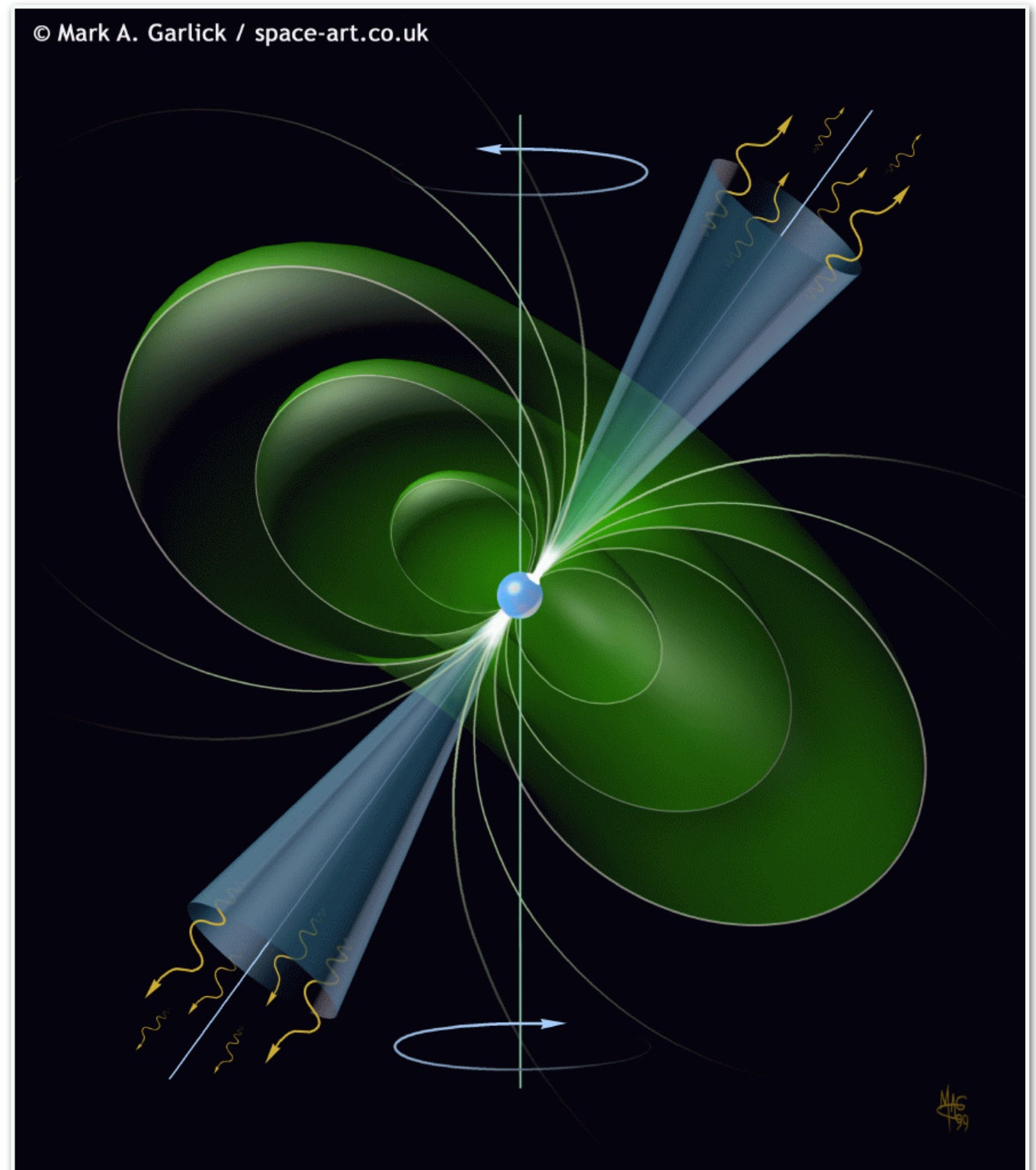


ALSO IN THE GALACTIC CENTER



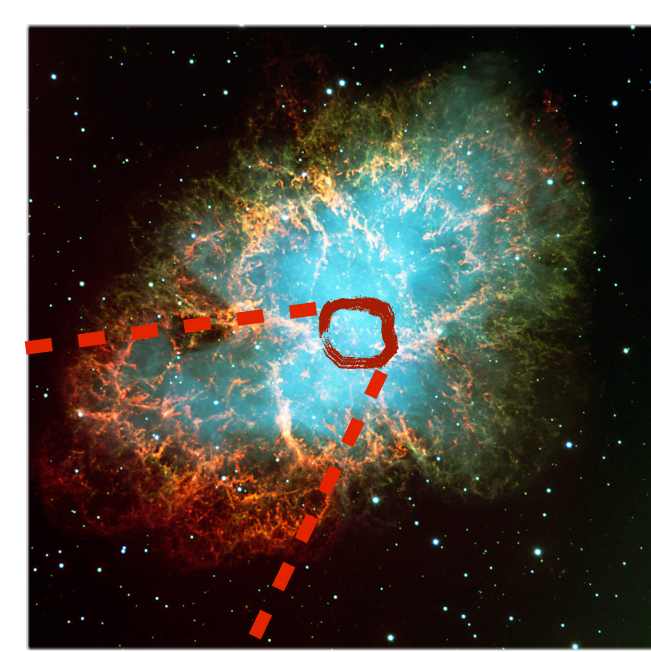
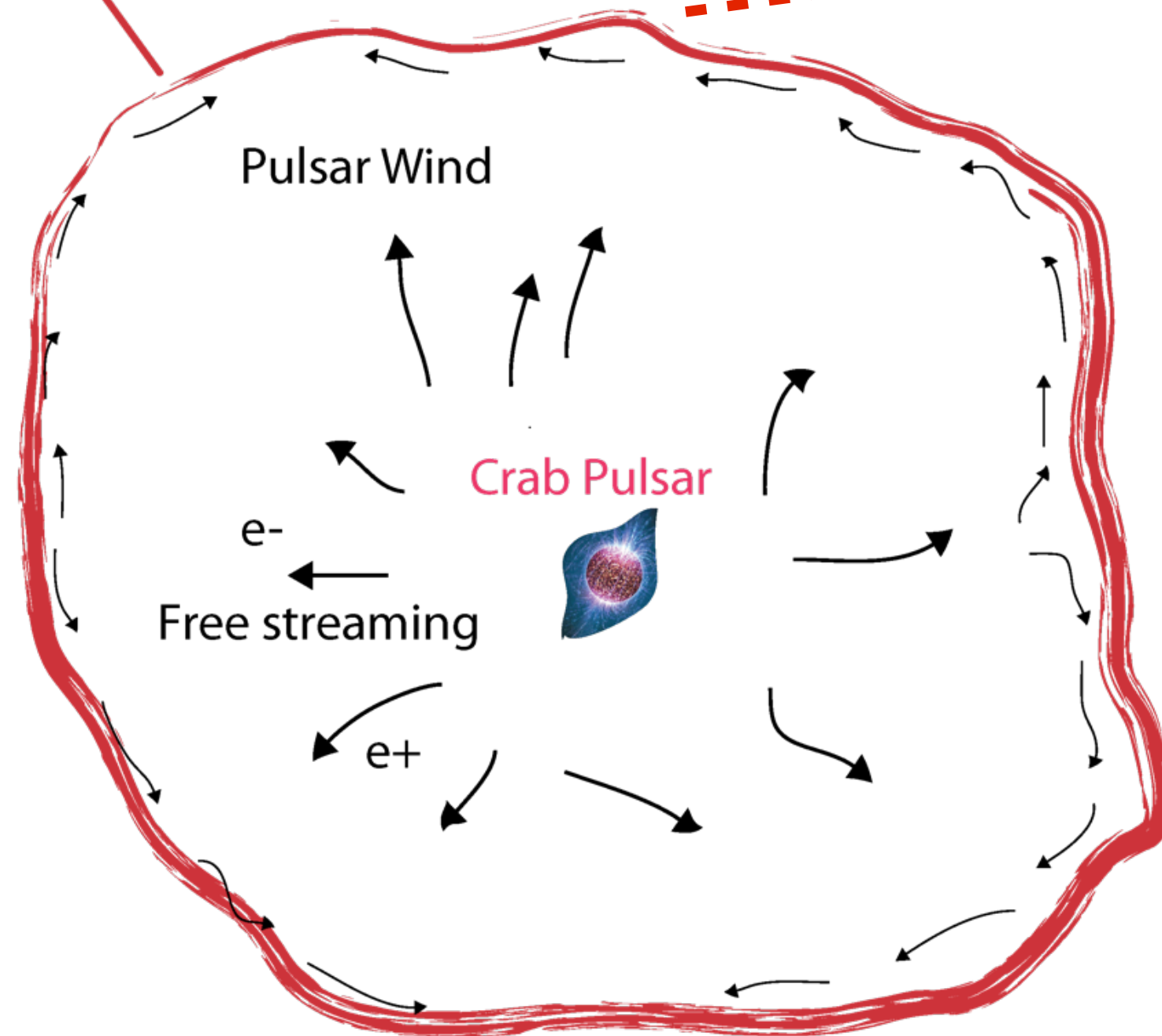
PULSARS: ROTATING NEUTRON STARS

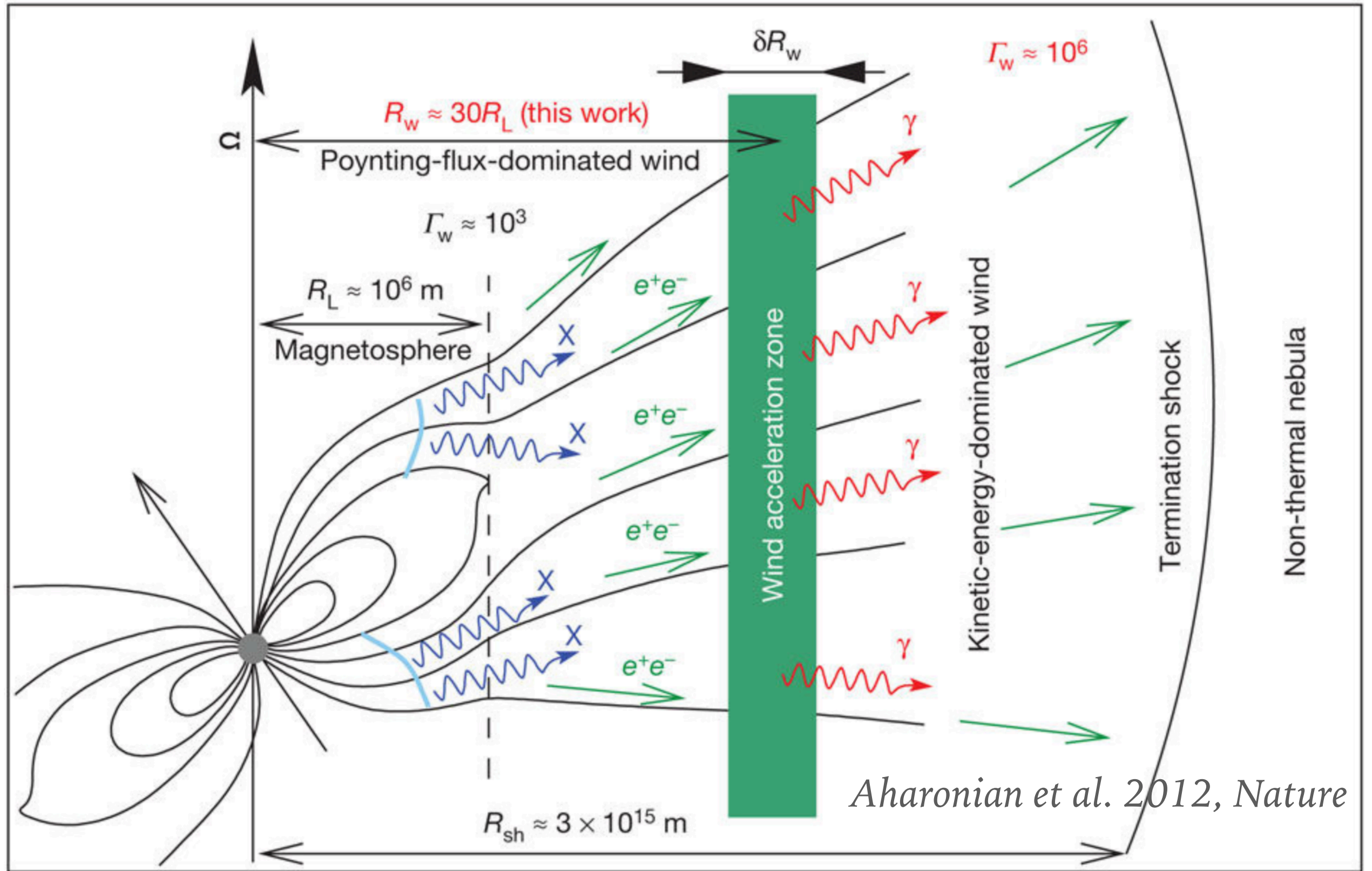
- Ultra-strong gravity (10^8 times Earth's)
- Ultra-strong B-Fields (10^{13} times Earth's)
- Ultra-ultra strong E-fields (up to 10^{18} V)



Termination shock

Reacceleration of particles at termination shock



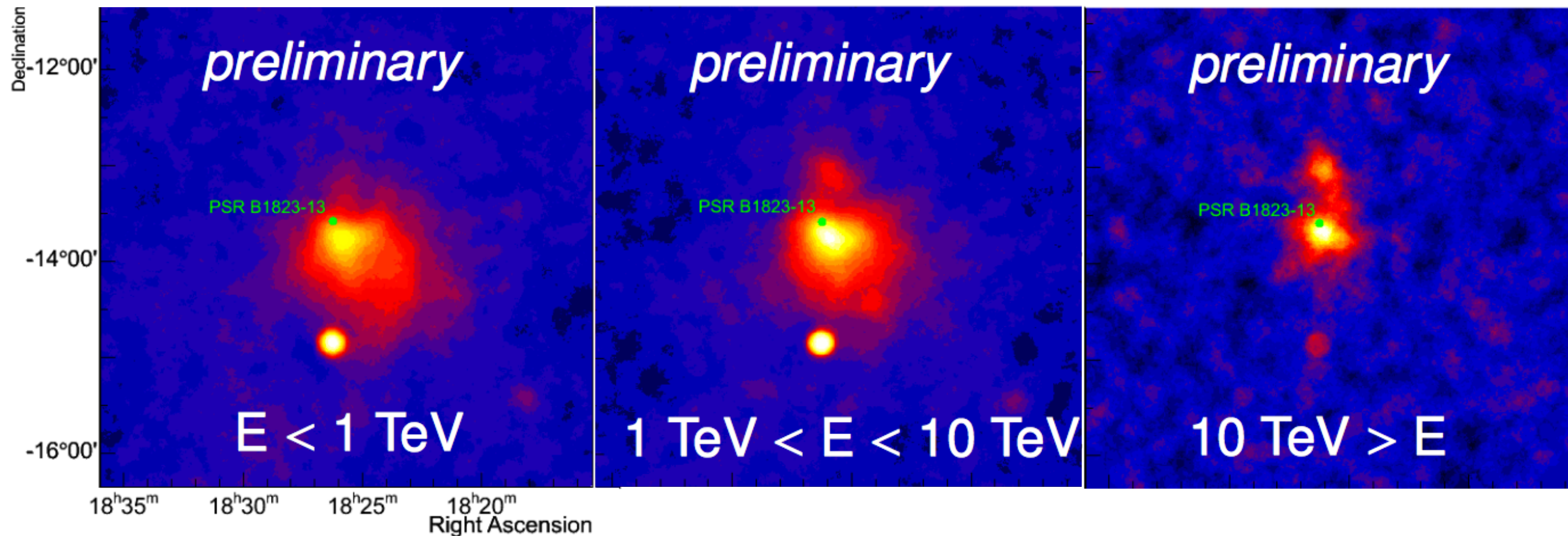


Aharonian et al. 2012, Nature



$\sim 0.1 \text{ pc}$

DETAILED UNDERSTANDING OF ELECTRON POPULATIONS IN PULSAR WIND NEBULAE



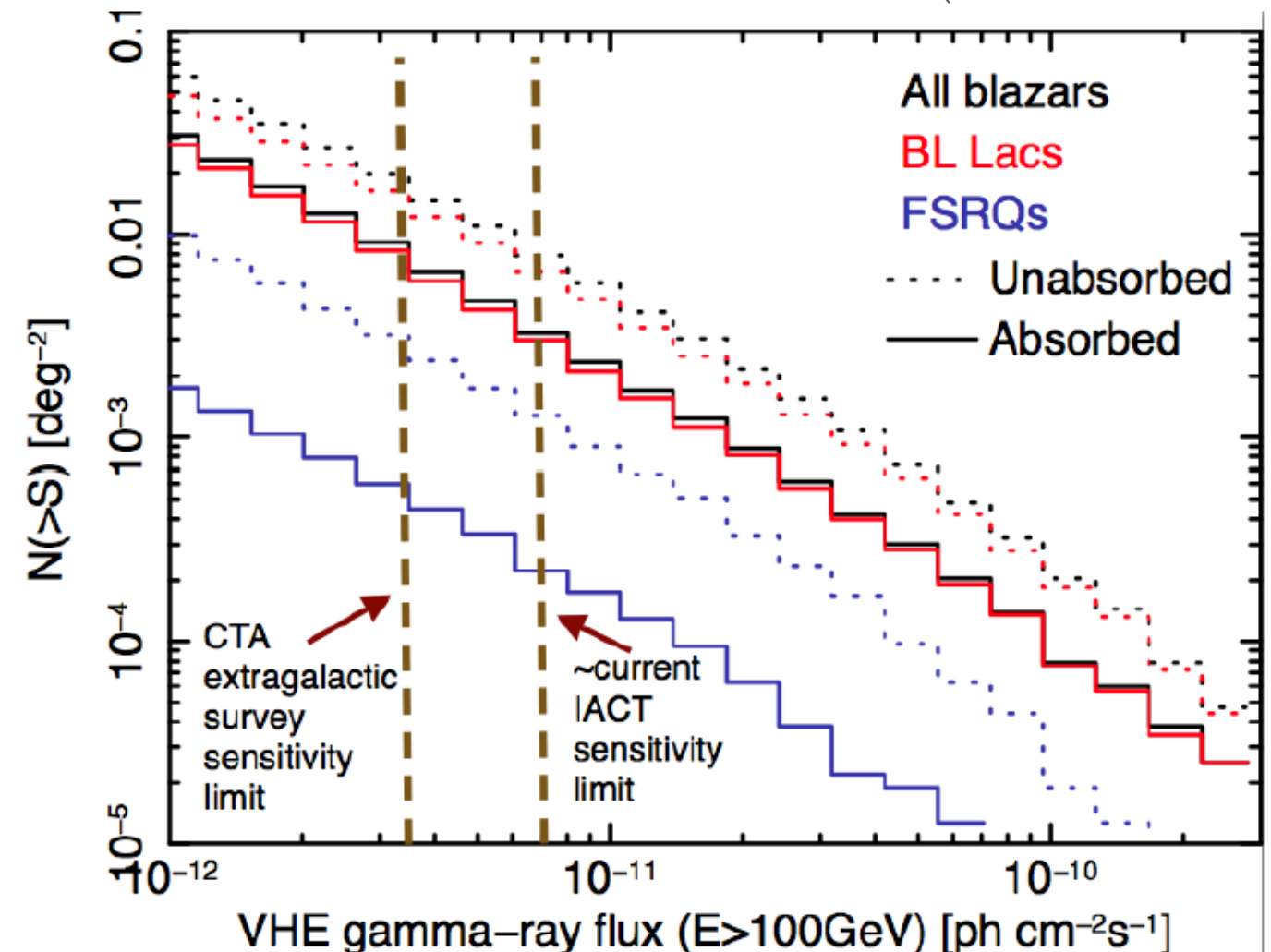
e.g. HESS Observations, Mitchell et al. (2016) <https://arxiv.org/pdf/1610.08894.pdf>

- Understand relation between pulsar geometry and magnetosphere, the wind and the nebula in detail
- HAWC and PWNe?

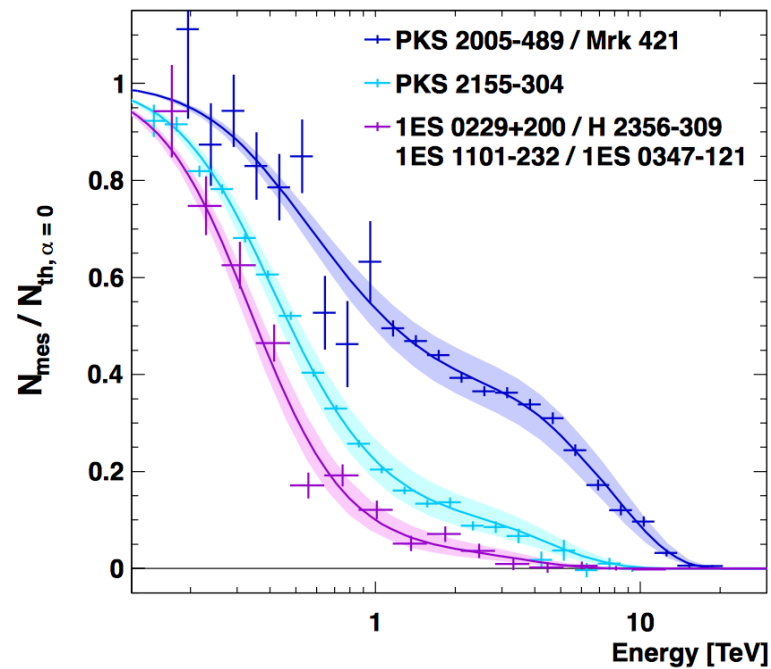
EXTRAGALACTIC SURVEY

- Combination of HAWC, Fermi-LAT at highest energies + CTA extragalactic survey
- unbiased way to determine $\text{Log } N / \text{Log } S$
- Lots of discovery potential

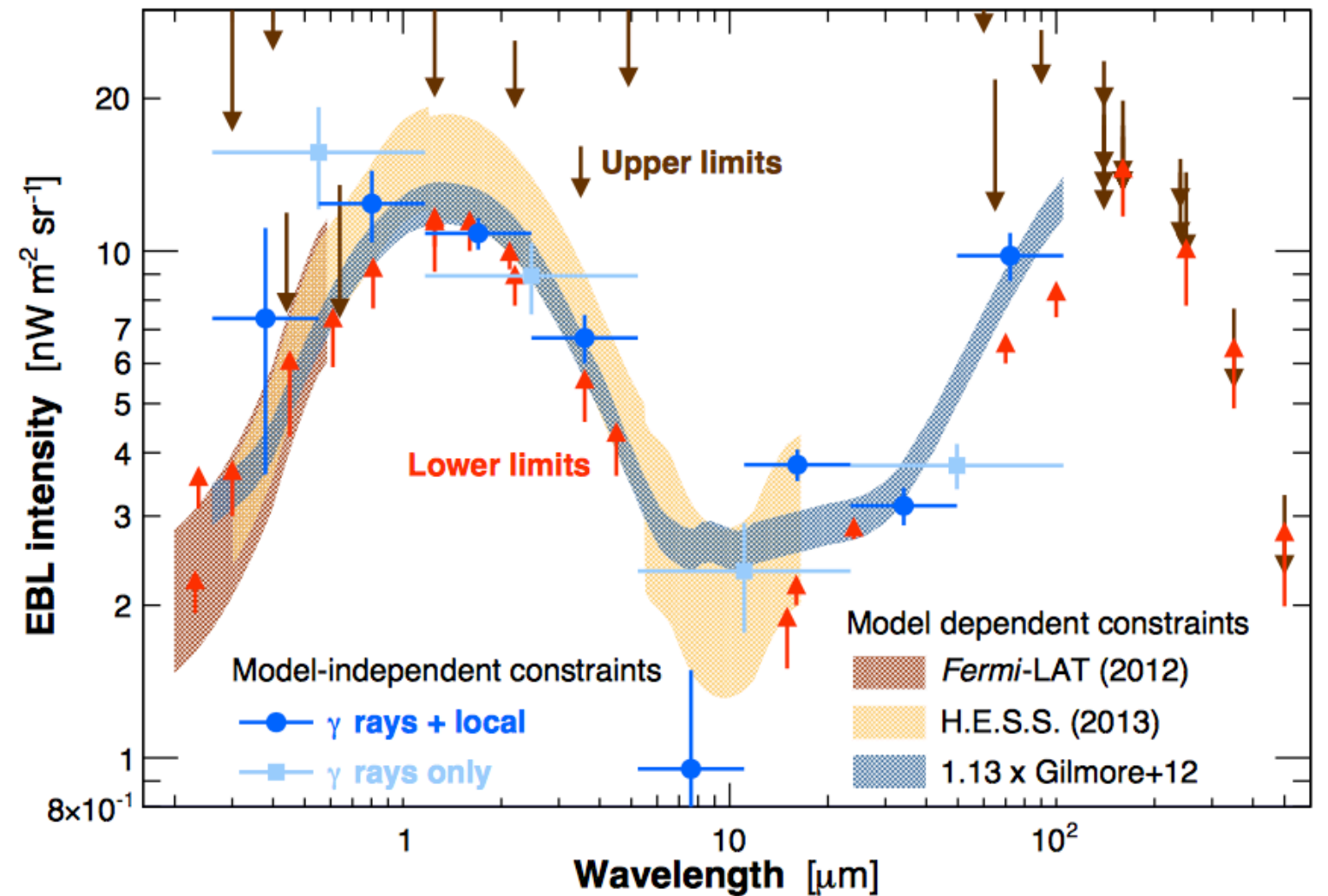
Padovani P. & Giommi P. (2015)



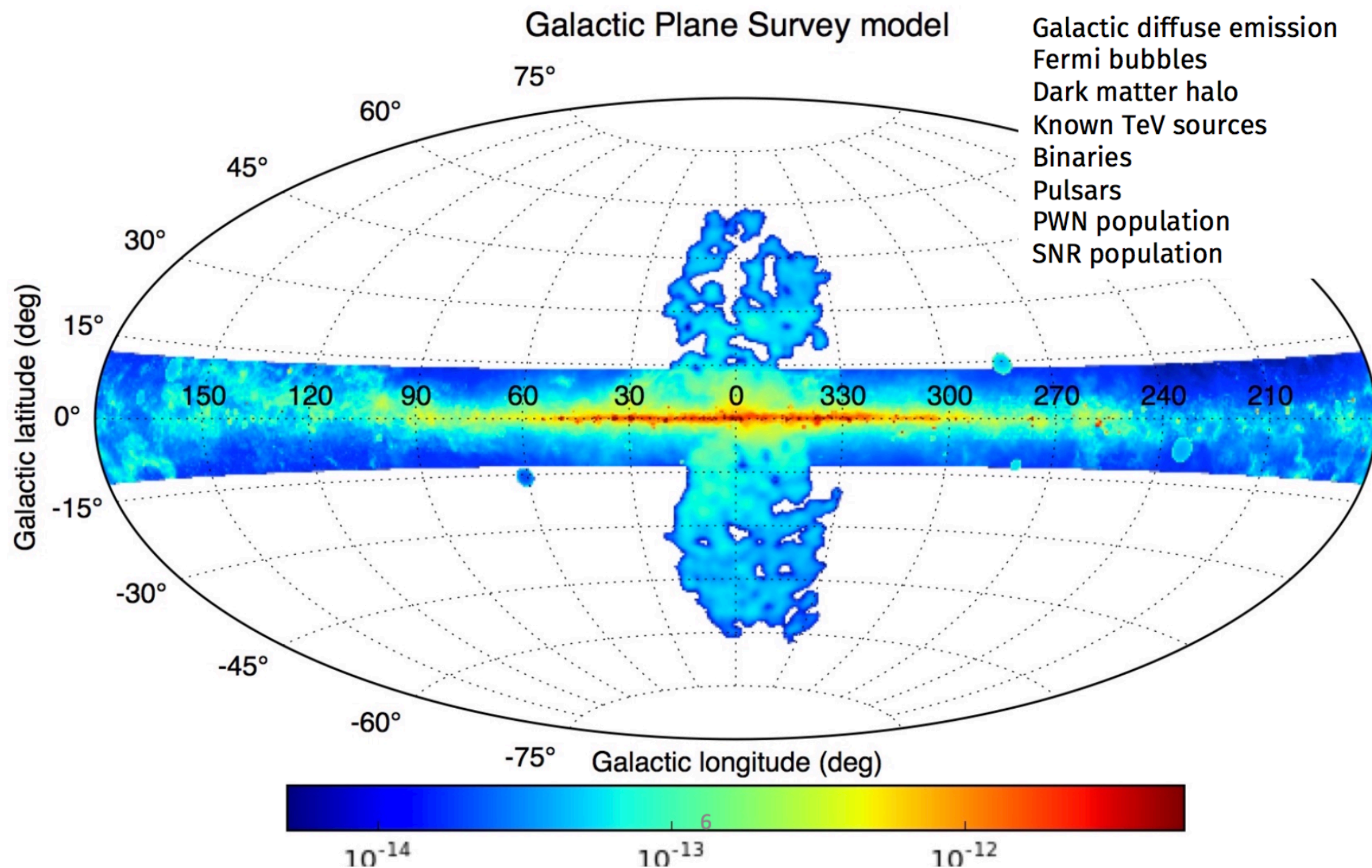
PRECISION MEASUREMENT OF EBL



Biteau & Williams 2015

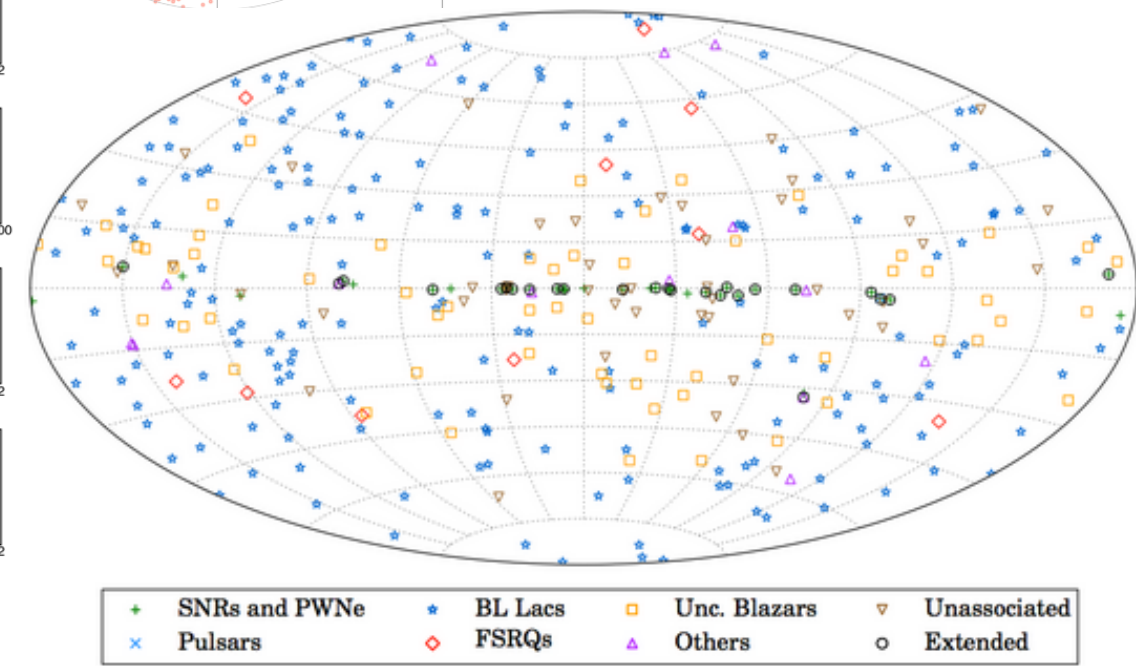
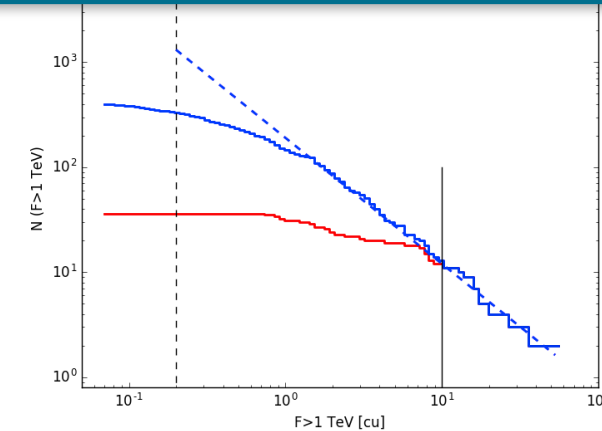
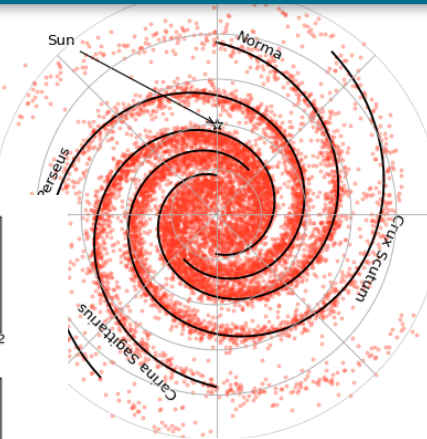
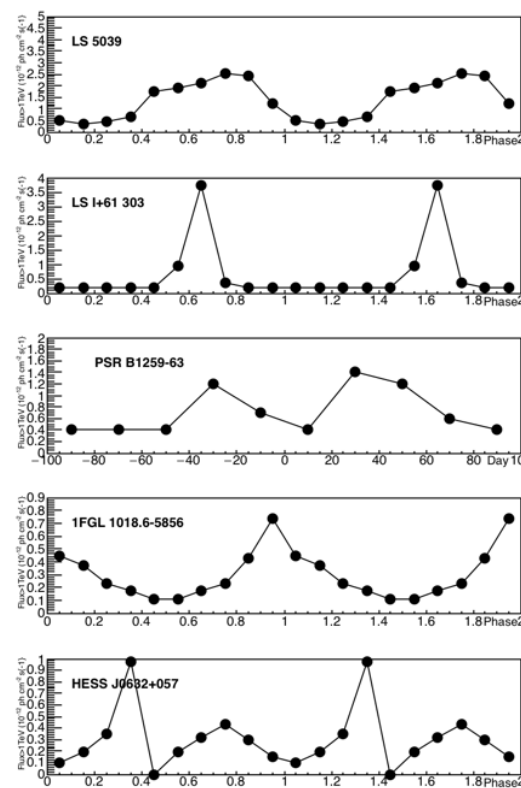
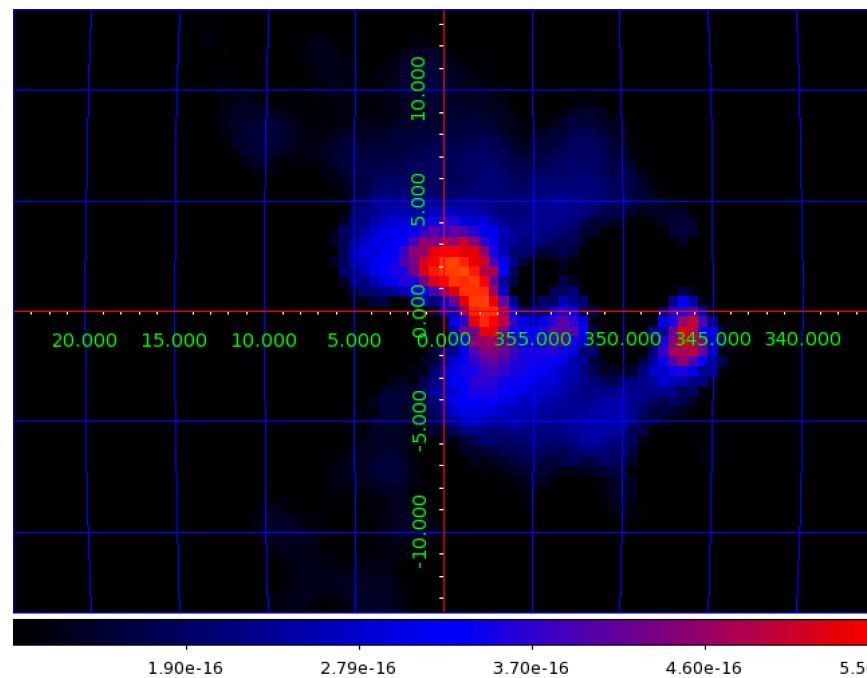
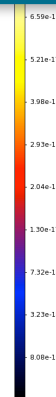
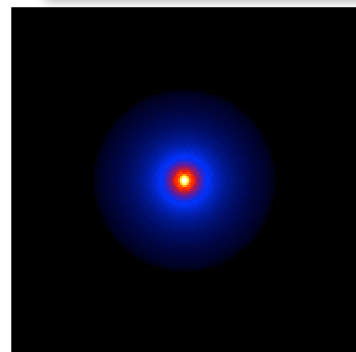


DATA CHALLENGE

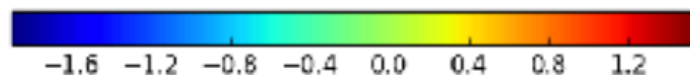
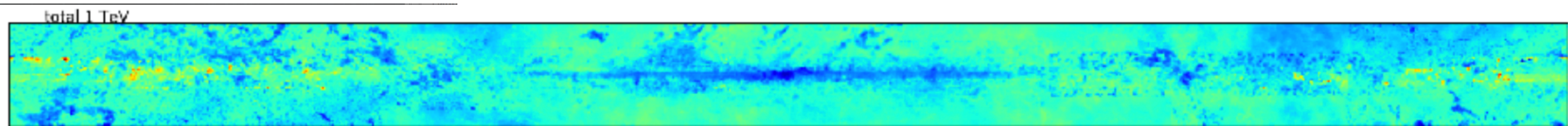


DATA CHALLENGE – PHYSICS SKY MODELS

Lots of nice work by the science working groups to get models ready
(<https://cta.cta-observatory.org/indico/conferenceTimeTable.py?confId=1300#20170306>)

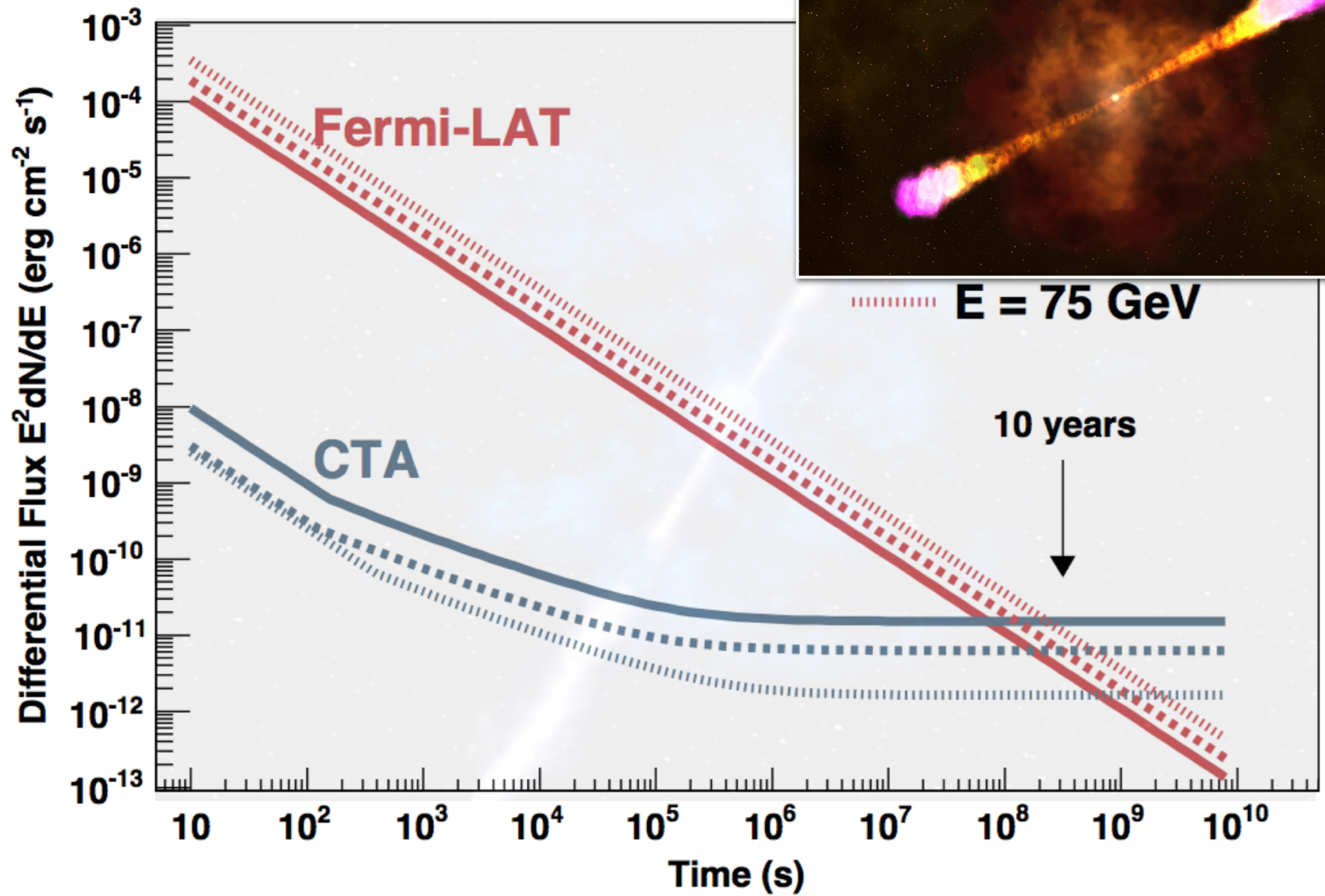


- SNRs and PWNe
- BL Lacs
- Unc. Blazars
- Unassociated
- Pulsars
- FSRQs
- Others
- Extended

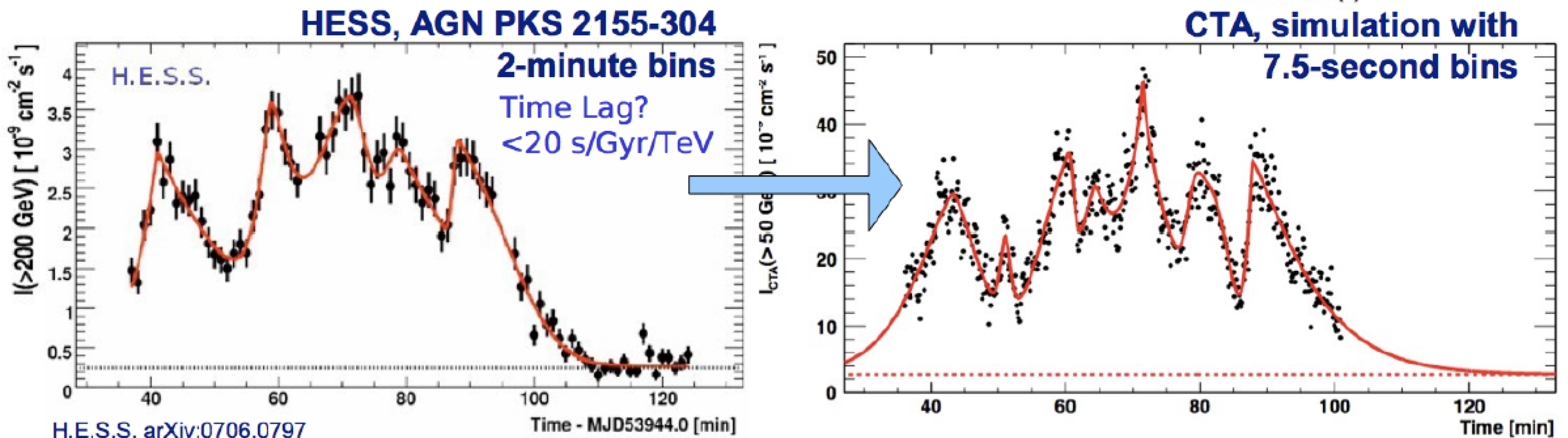
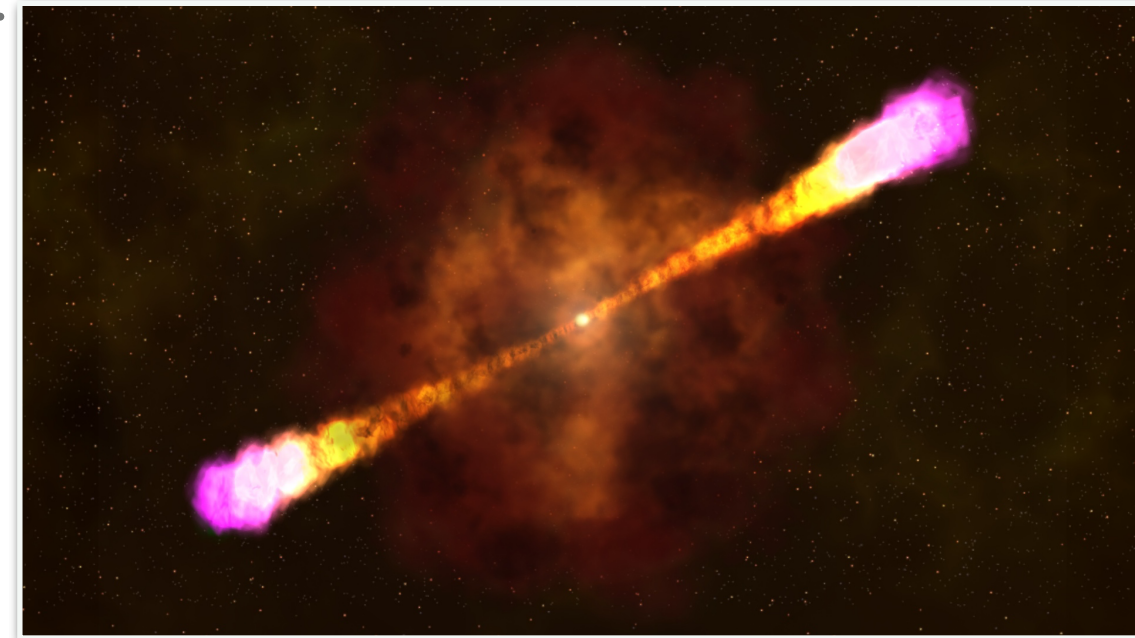


THERE ARE KNOWN KNOWN
THERE ARE THINGS THAT WE KNOW THAT WE KNOW, THERE ARE
KNOWN UNKNOWN
THAT IS TO SAY, THERE ARE
THINGS THAT WE NOW KNOW WE DON'T KNOW
BUT THERE ARE ALSO
UNKNOWN UNKNOWN
THERE ARE THINGS
WE DO NOT KNOW
WE DON'T KNOW
AND EACH YEAR WE DISCOVER
A FEW MORE OF THOSE
UNKNOWN
UNKNOWN

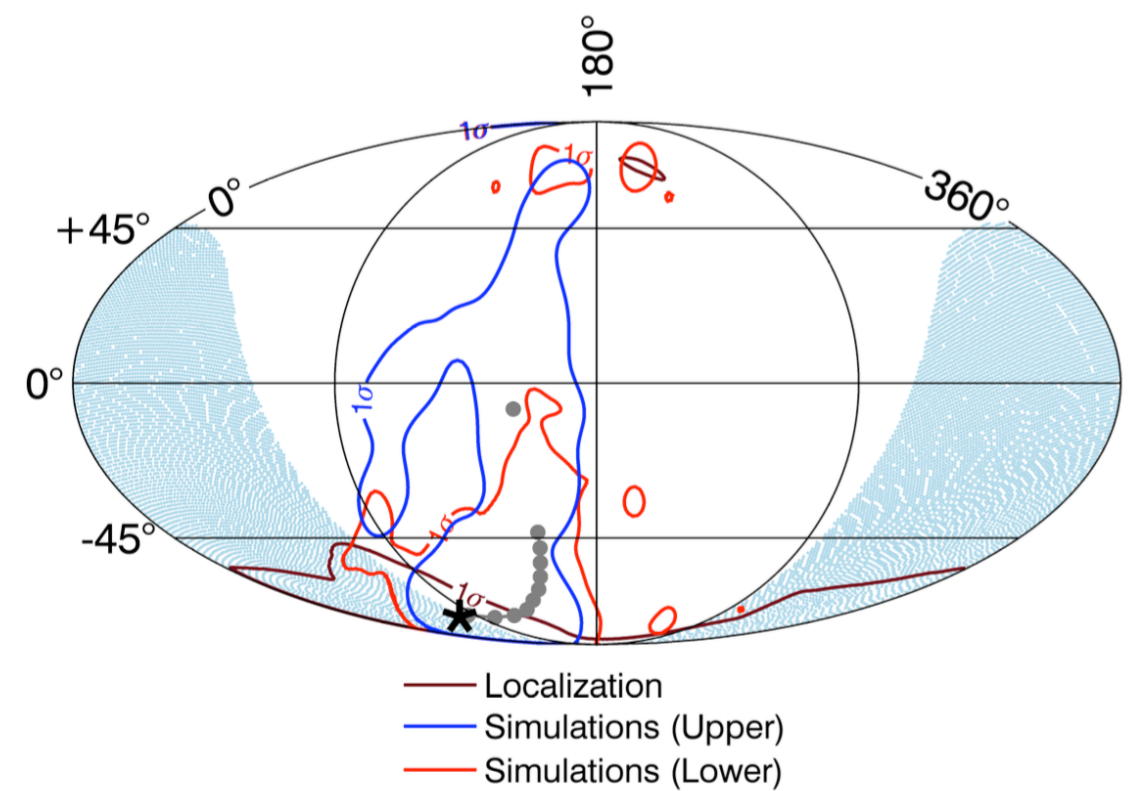
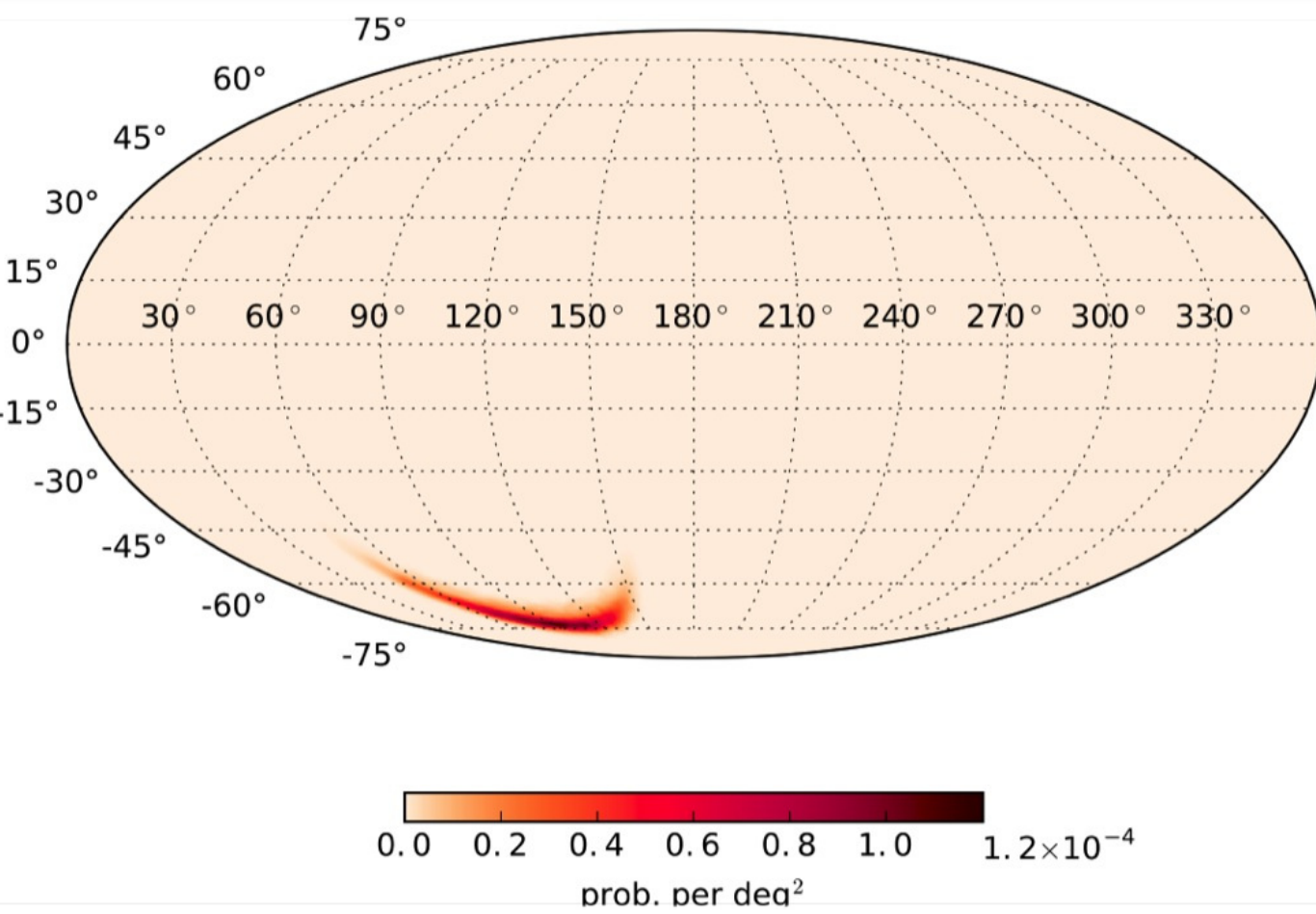
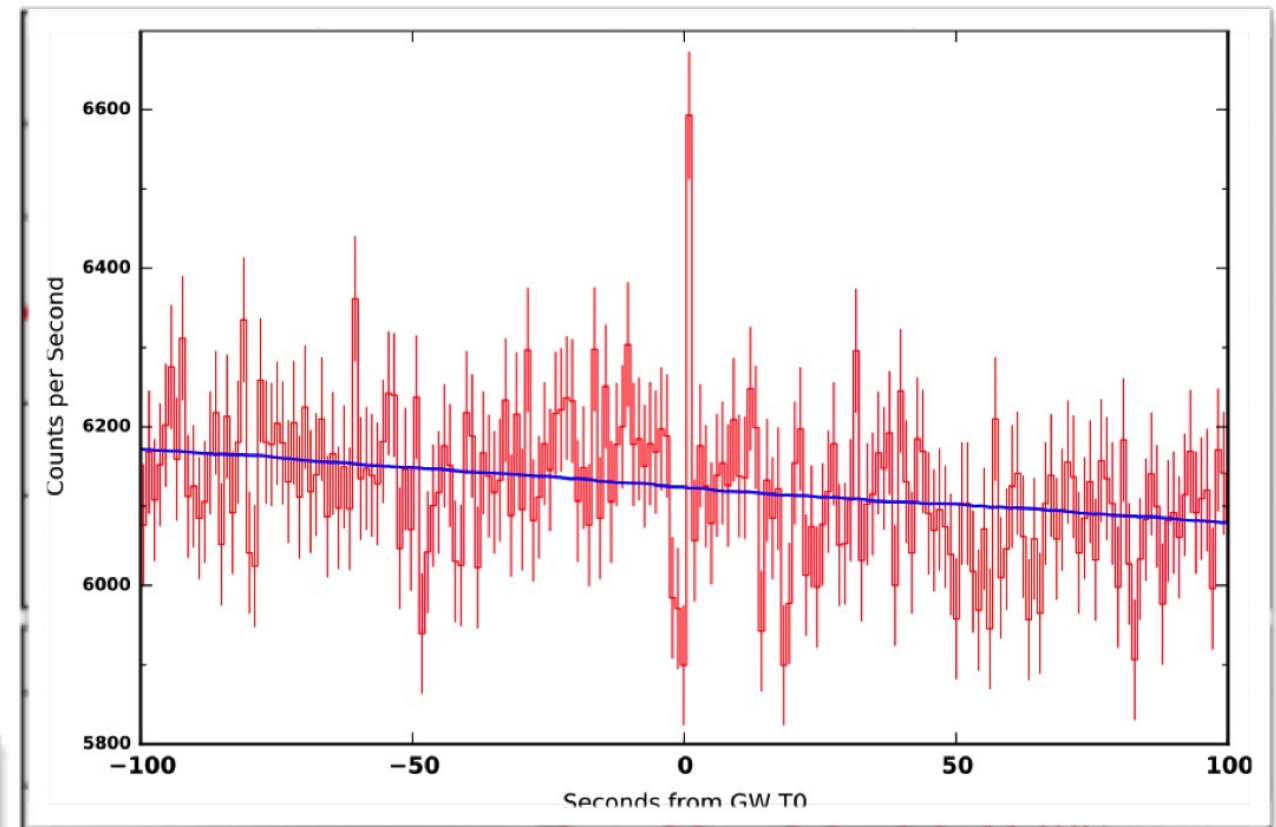
OPEN UP THE TRANSIENT TEV SKY



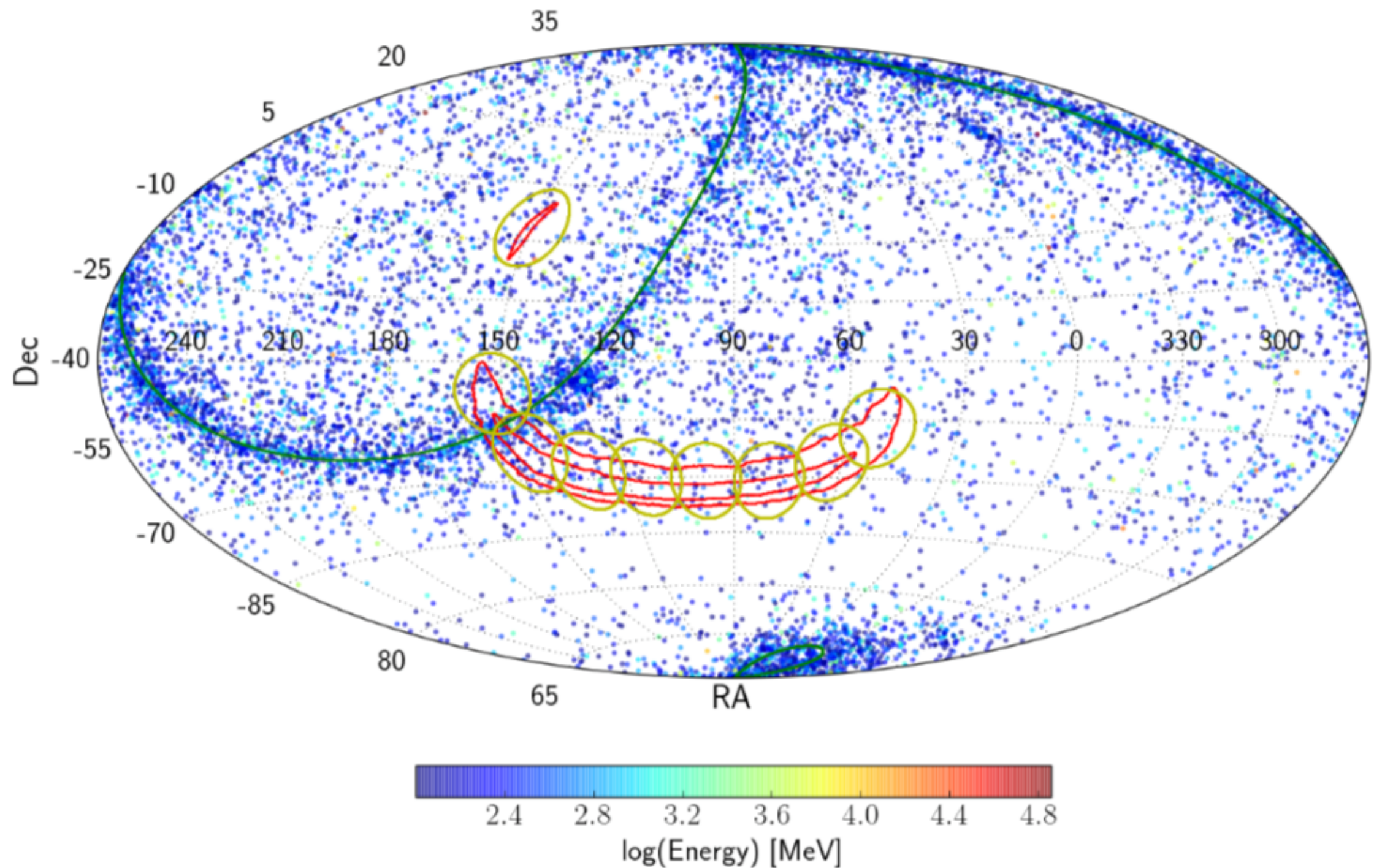
OPEN UP THE TRANSIENT TEV SKY

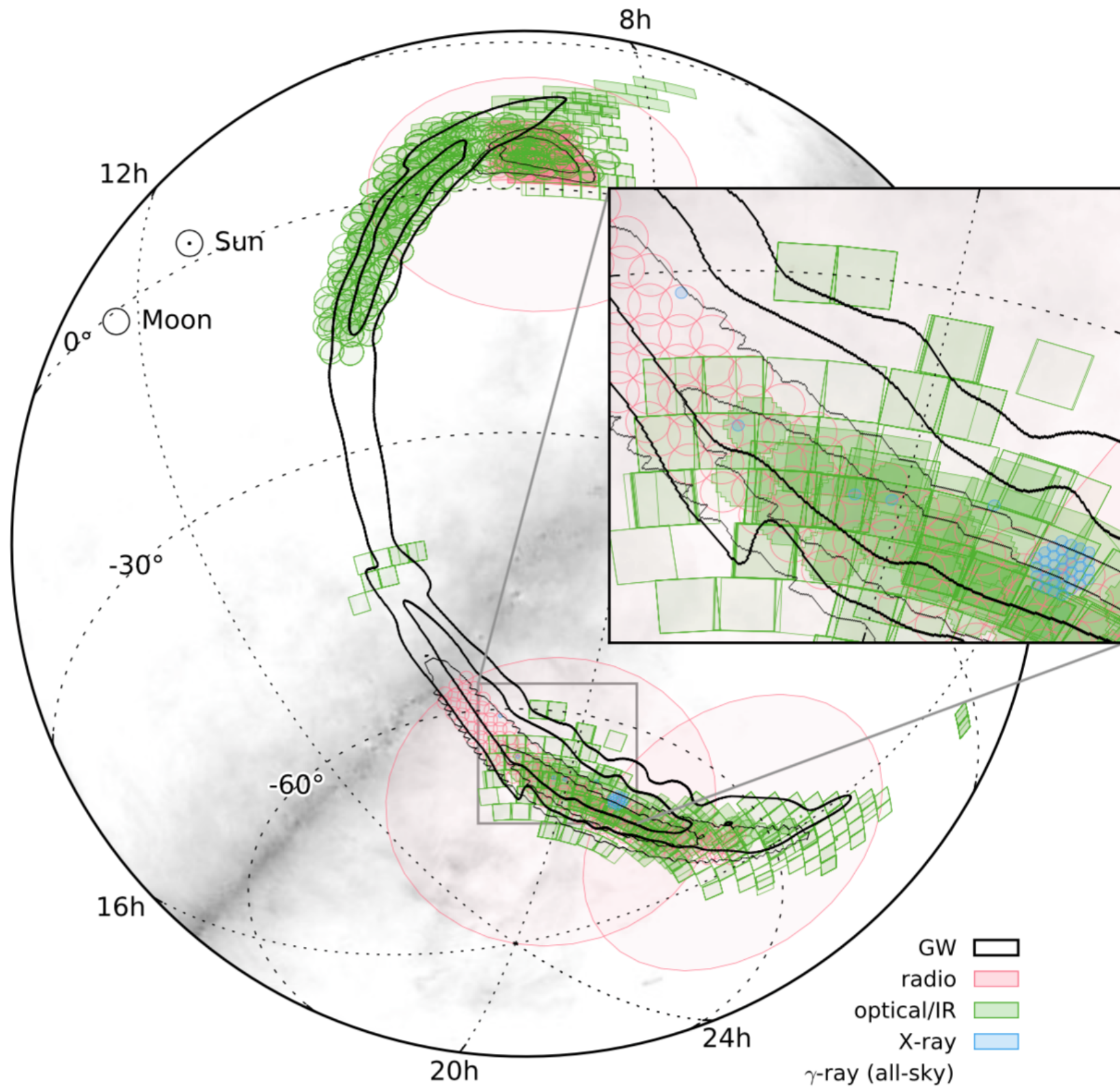


MULTI-MESSENGER OBSERVATIONS OF INSPIRALING MASSIVE OBJECTS



MULTI-MESSENGER OBSERVATIONS OF INSPIRALING MASSIVE OBJECTS



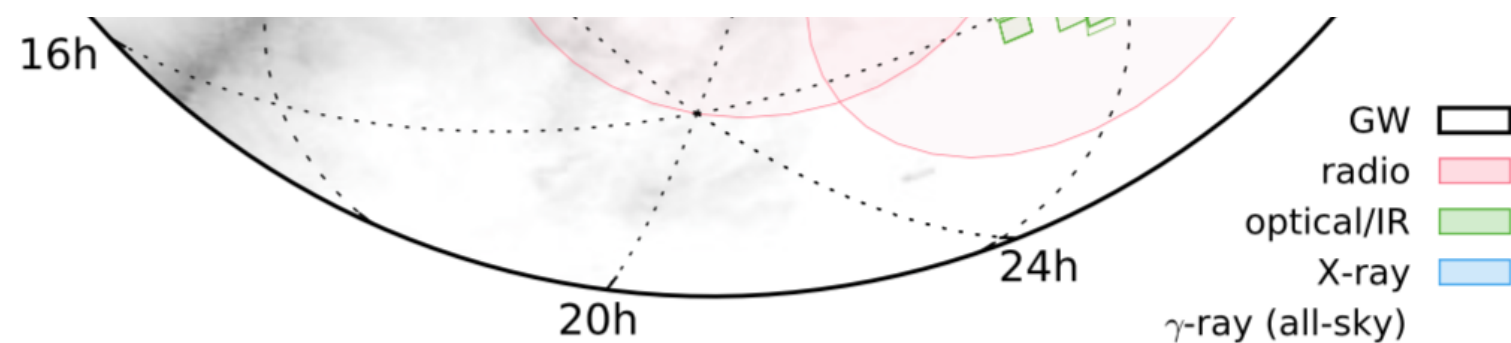


Localization and broadband follow-up of the gravitational-wave transient GW150914

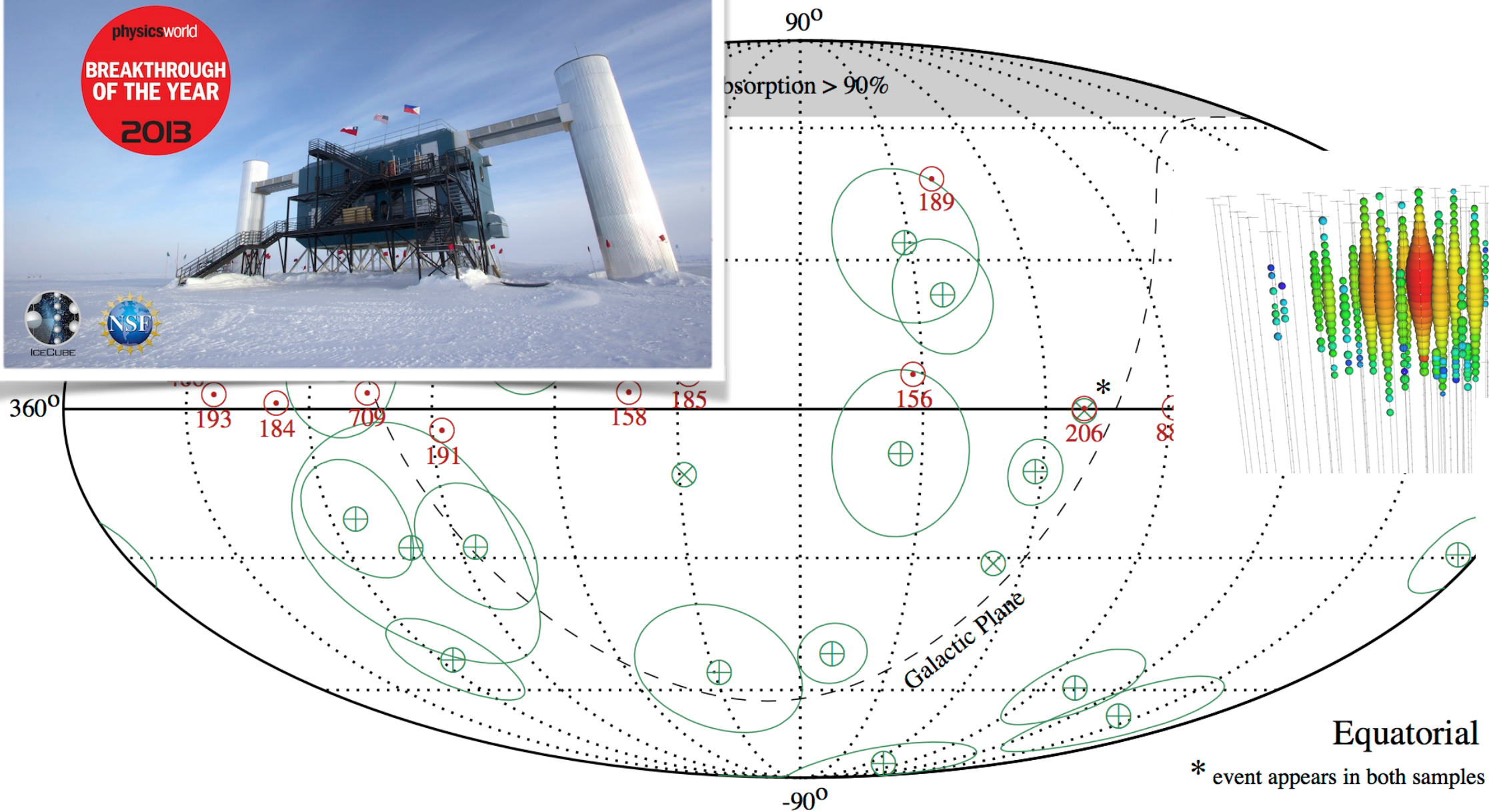
B. P. Abbott, R. Abbott, T. D. Abbott, M. R. Abernathy, F. Acernese, K. Ackley, C. Adams, T. Adams, P. Addesso, R. X. Adhikari, V. B. Adya, C. Affeldt, M. Agathos, K. Agatsuma, N. Aggarwal, O. D. Aguiar, L. Aiello, A. Ain, P. Ajith, B. Allen, A. Allocca, P. A. Altin, S. B. Anderson, W. G. Anderson, K. Arai, M. C. Araya, C. C. Arceneaux, J. S. Areeda, N. Arnaud, K. G. Arun, S. Ascenzi, G. Ashton, M. Ast, S. M. Aston, P. Astone, P. Aufmuth, C. Aulbert, S. Babak, P. Bacon, M. K. M. Bader, P. T. Baker, F. Baldaccini, G. Ballardin, S. W. Ballmer, J. C. Barayoga, S. E. Barclay, B. C. Barish, D. Barker, F. Barone, B. Barr, L. Barsotti, M. Barsuglia, D. Barta, S. Barthelmy, J. Bartlett, I. Bartos, R. Bassiri, A. Basti, J. C. Batch, C. Baune, V. Bavigadda, M. Bazzan, B. Behnke, M. Bejger, A. S. Bell, et al. (1497 additional authors not shown)

(Submitted on 26 Feb 2016)

A gravitational-wave transient was identified in data recorded by the Advanced LIGO detectors on 2015 September 14. The event candidate, initially designated G184098 and later given the name GW150914, is described in detail elsewhere. By prior arrangement, preliminary estimates of the time, significance, and sky location of the event were shared with 63 teams of observers covering radio, optical, near-infrared, X-ray, and gamma-ray wavelengths with ground- and space-based facilities. In this Letter we describe the low-latency analysis of the gravitational wave data and present the sky localization of the first observed compact binary merger. We summarize the follow-up observations reported by 25 teams via private Gamma-ray Coordinates Network Circulars, giving an overview of the participating facilities, the gravitational wave sky localization coverage, the timeline and depth of the observations. As this event turned out to be a binary black hole merger, there is little expectation of a detectable electromagnetic signature. Nevertheless, this first broadband campaign to search for a counterpart of an Advanced LIGO source represents a milestone and highlights the broad capabilities of the transient astronomy community and the observing strategies that have been developed to pursue neutron star binary merger events. Detailed investigations of the electromagnetic data and results of the electromagnetic follow-up campaign will be disseminated in the papers of the individual teams.

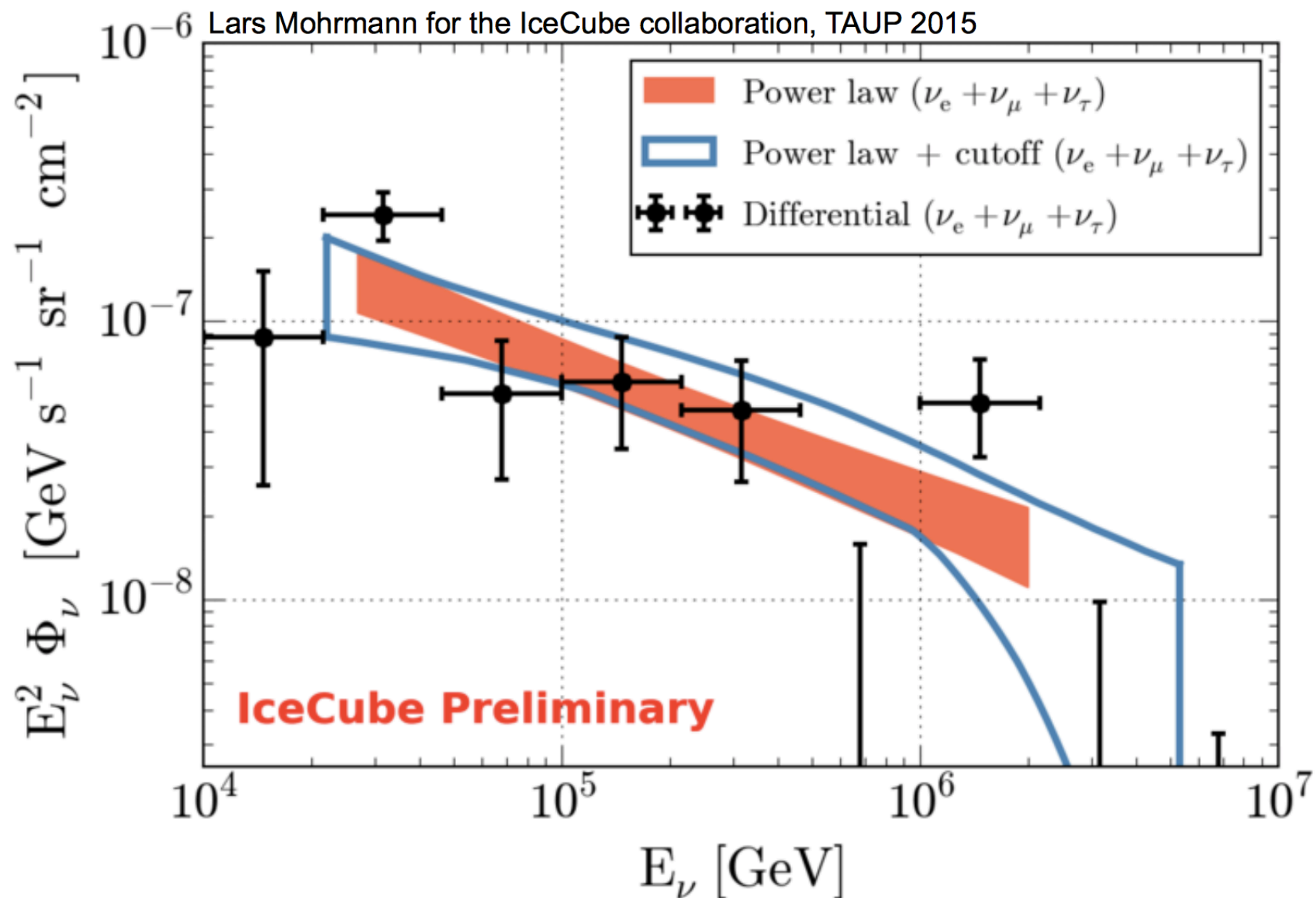
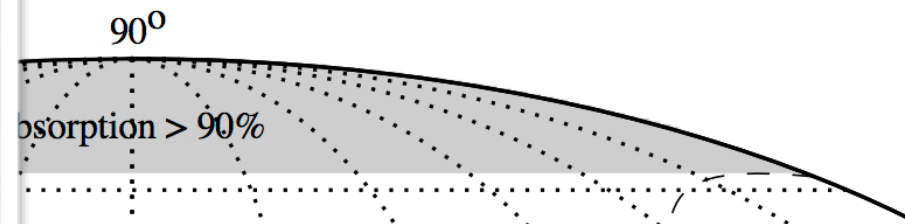
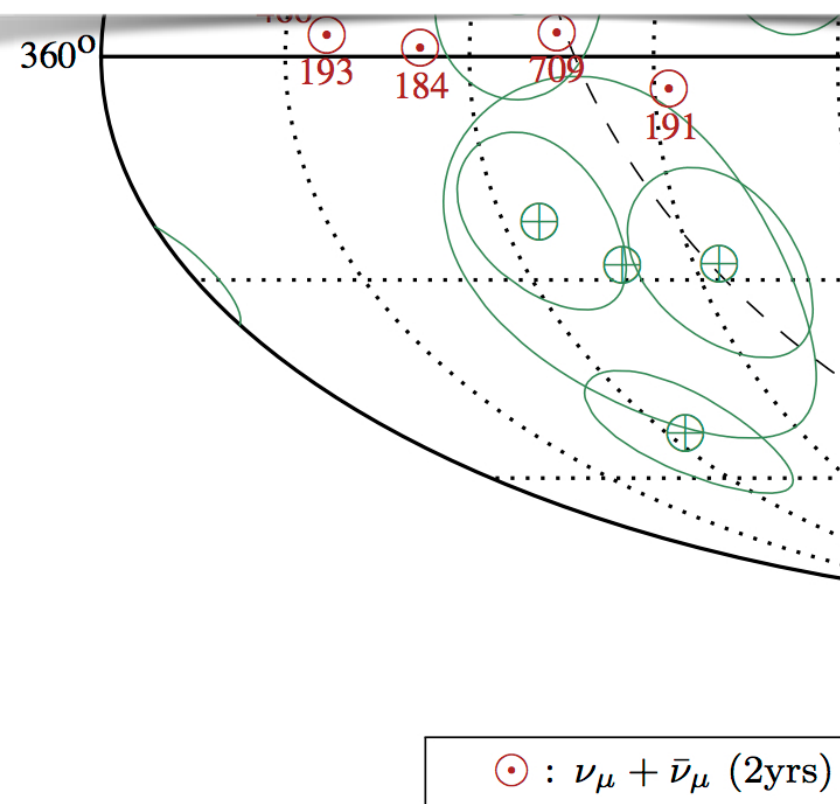


THE ORIGIN OF HIGH-ENERGY NEUTRINOS

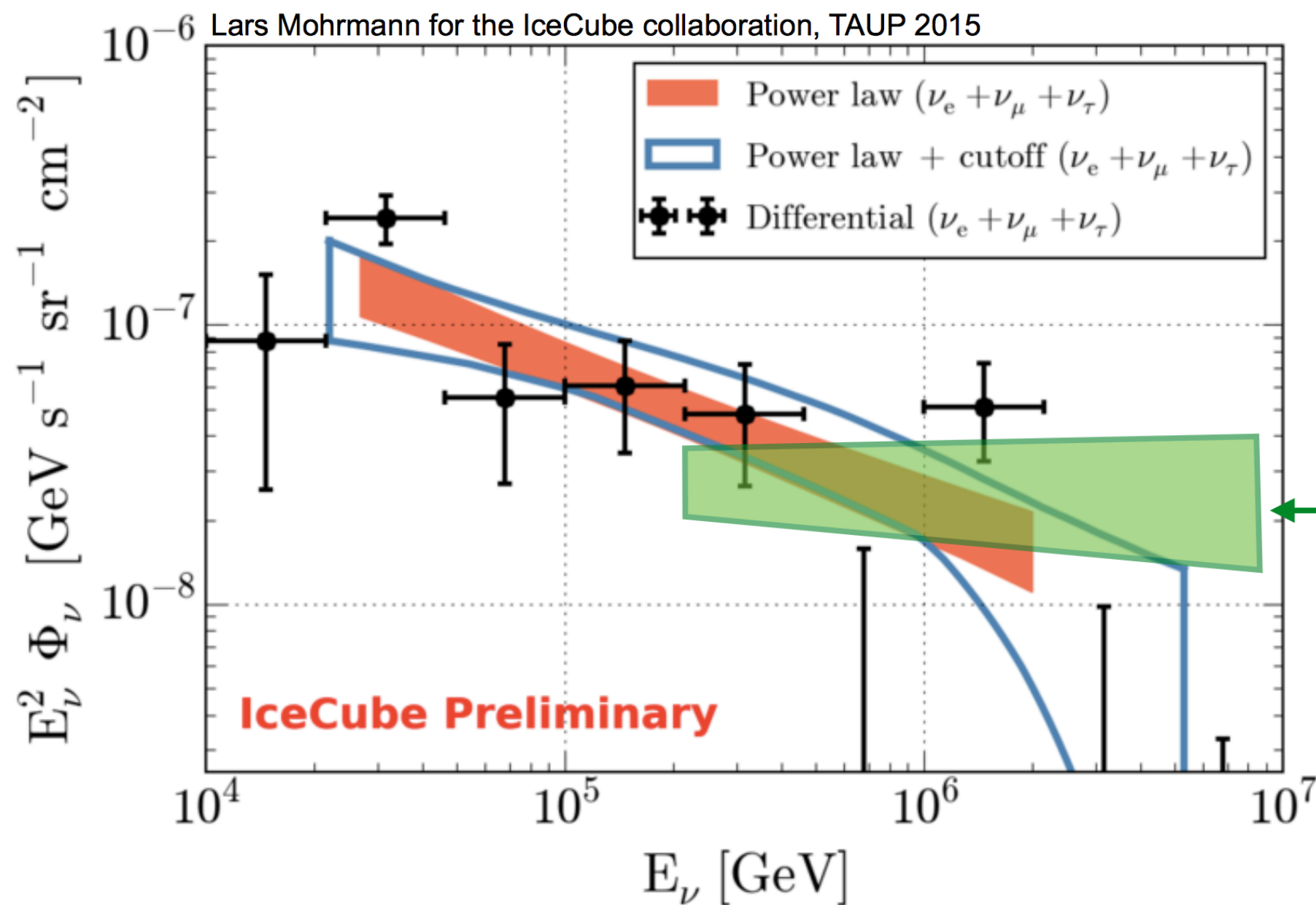
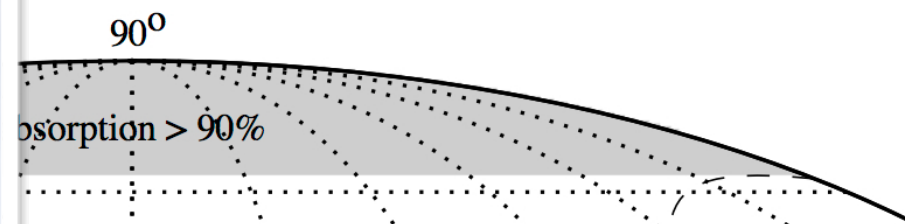
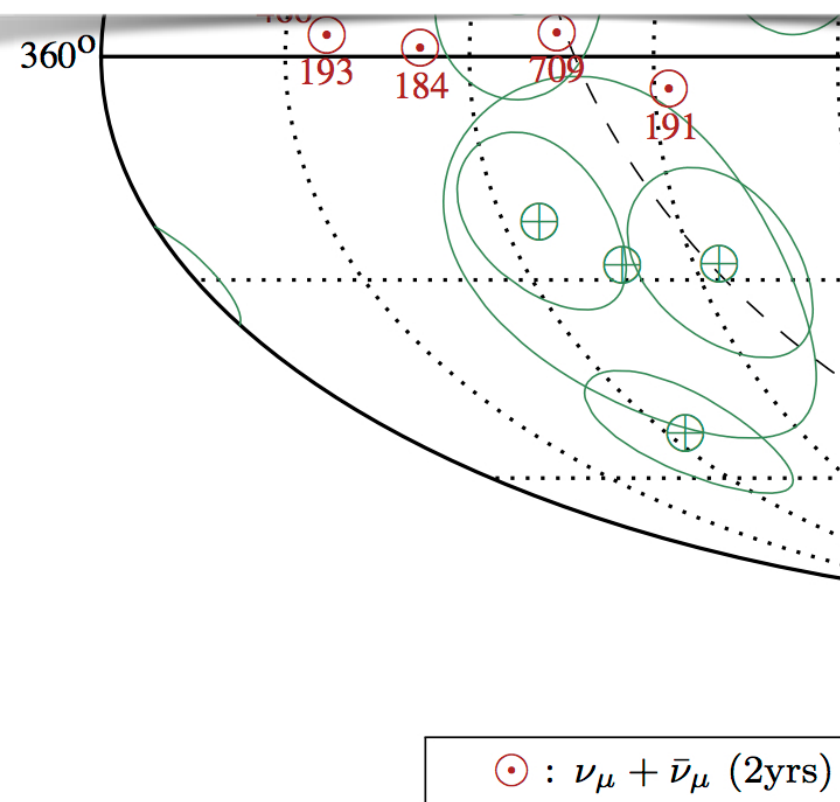


\odot : $\nu_\mu + \bar{\nu}_\mu$ (2yrs)
 \otimes : HESE track (3yrs)
 \oplus : HESE cascade (3yrs)

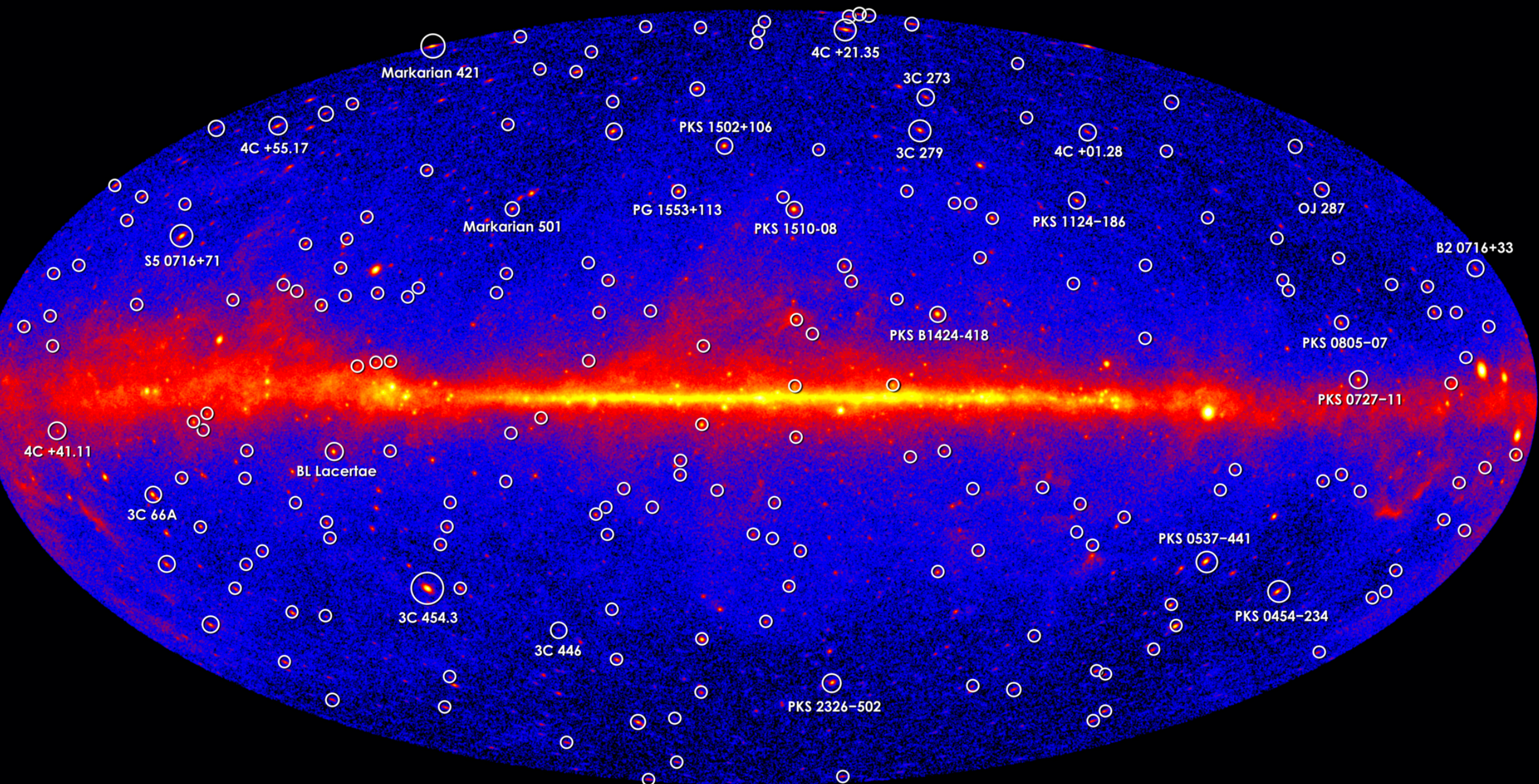
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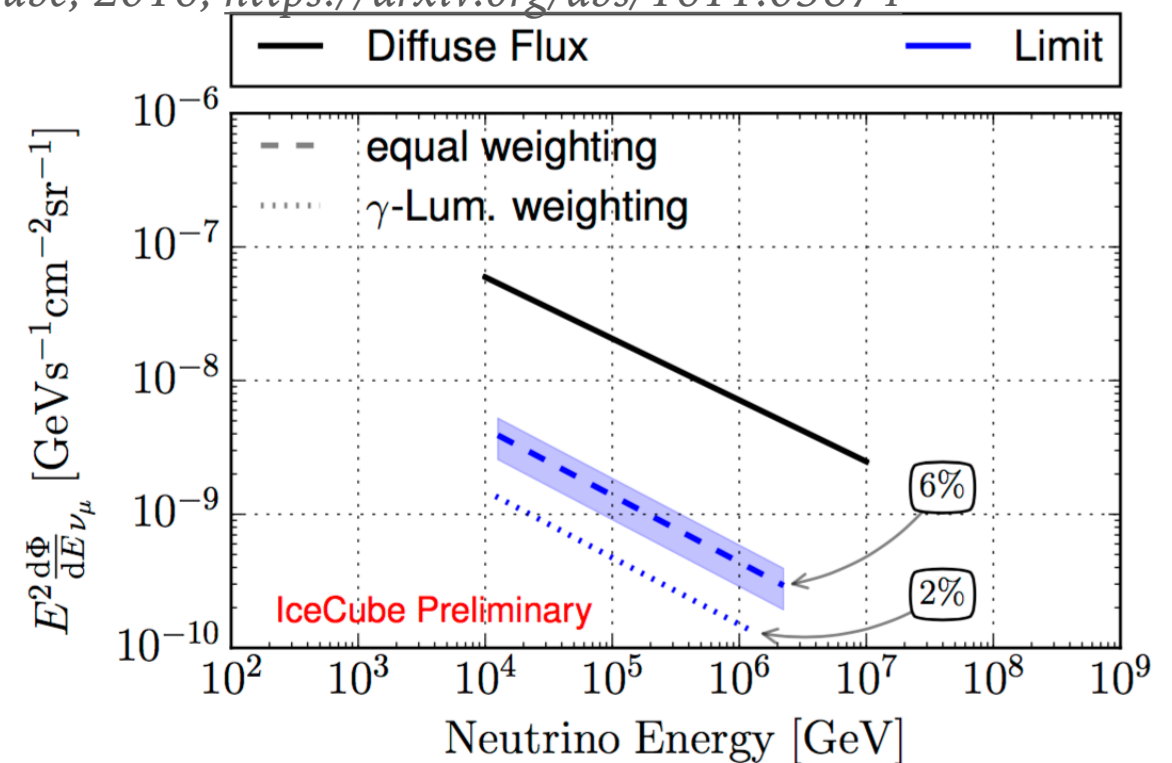
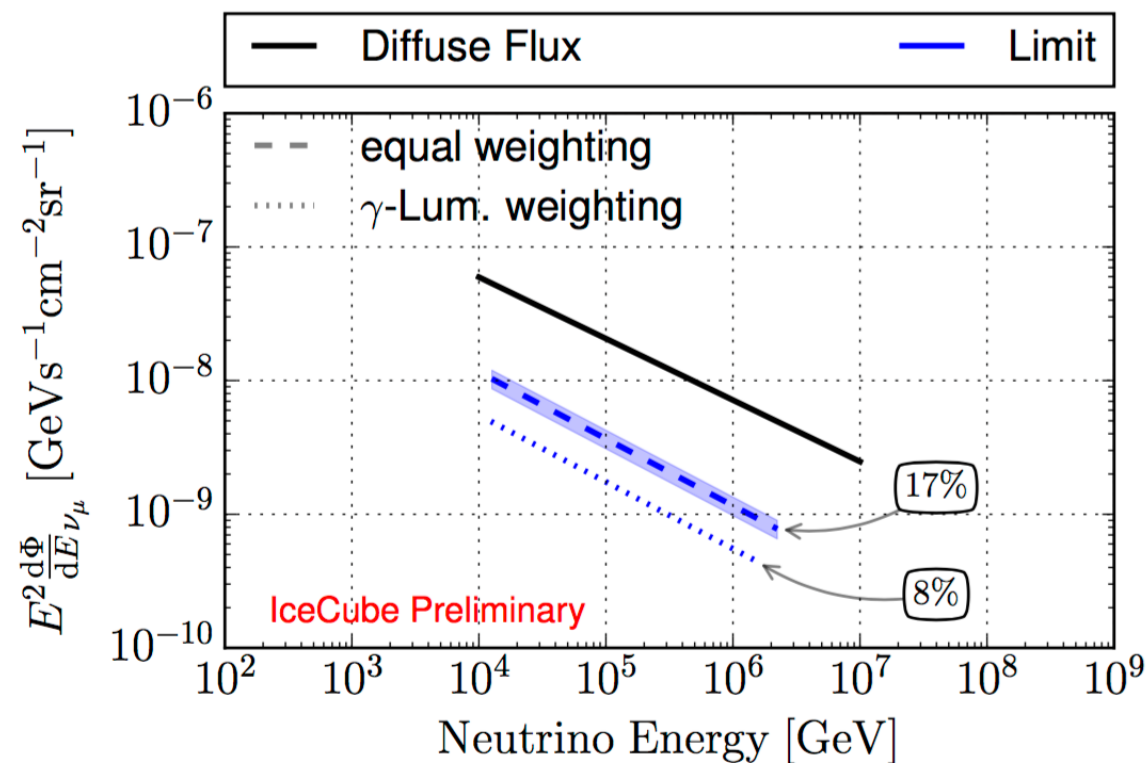


GAMMA-RAY BRIGHT ACTIVE GALACTIC NUCLEI

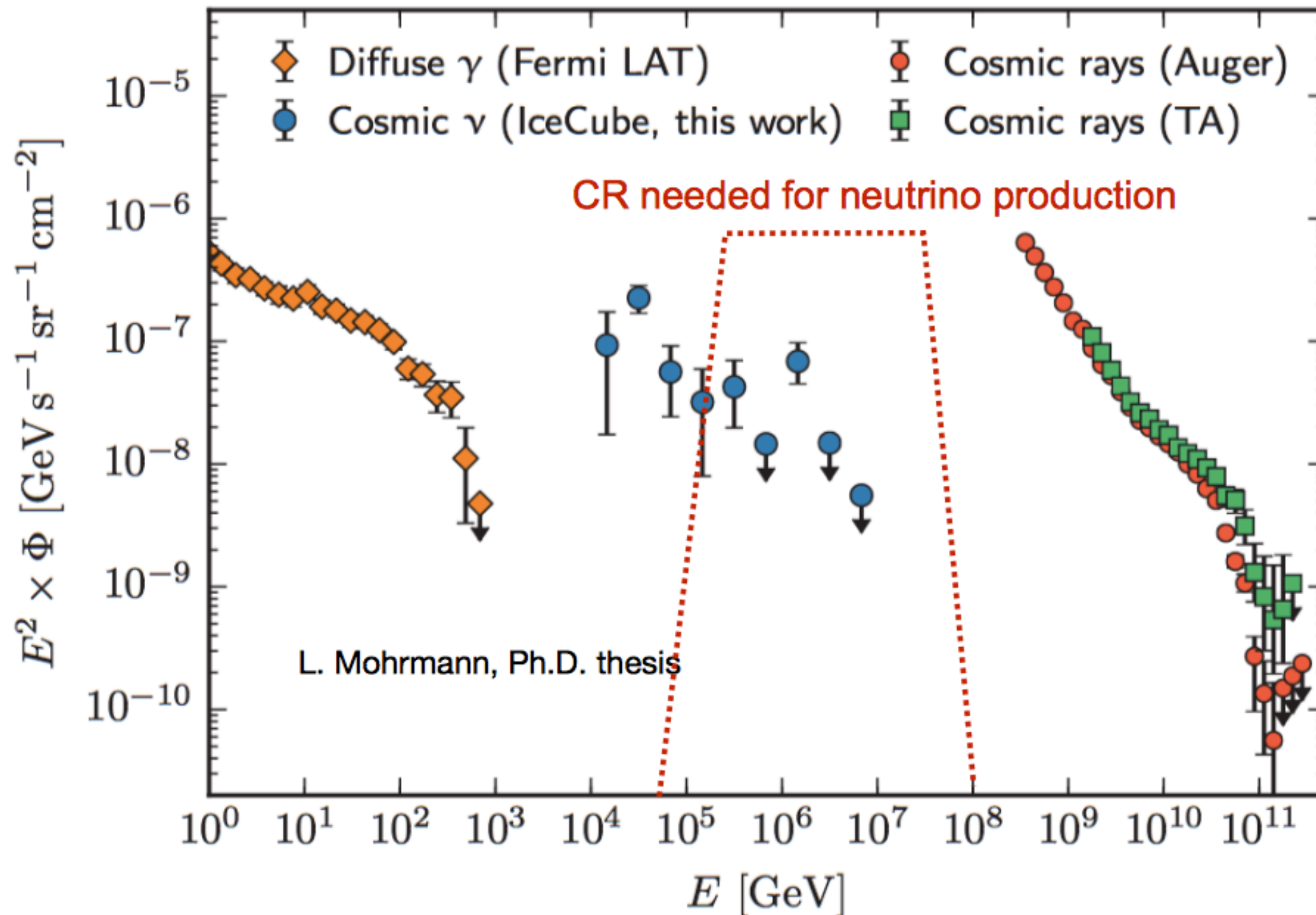


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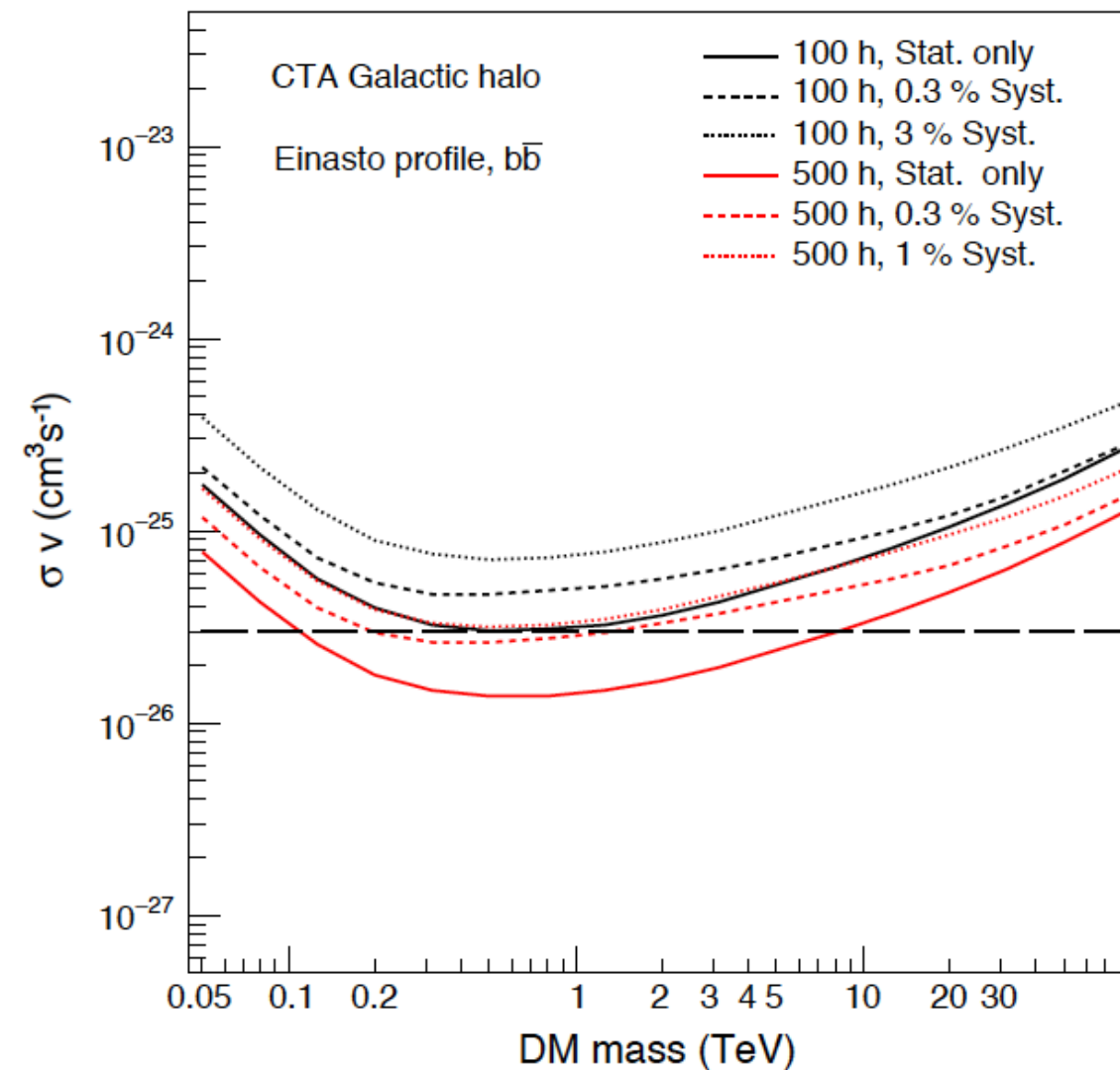
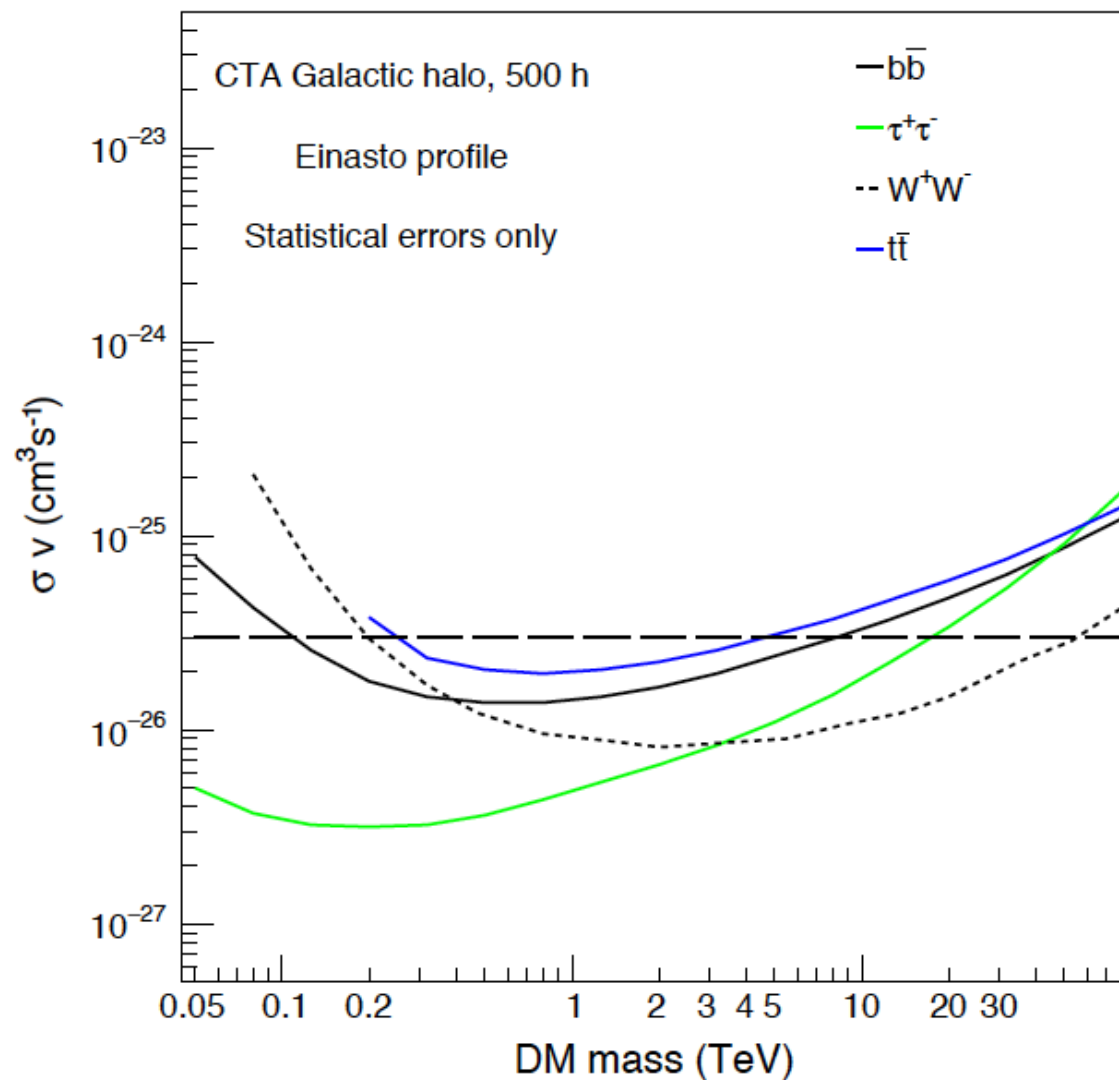
IceCube, 2016, <https://arxiv.org/abs/1611.03874>



RELATIONS STILL TO BE UNDERSTOOD

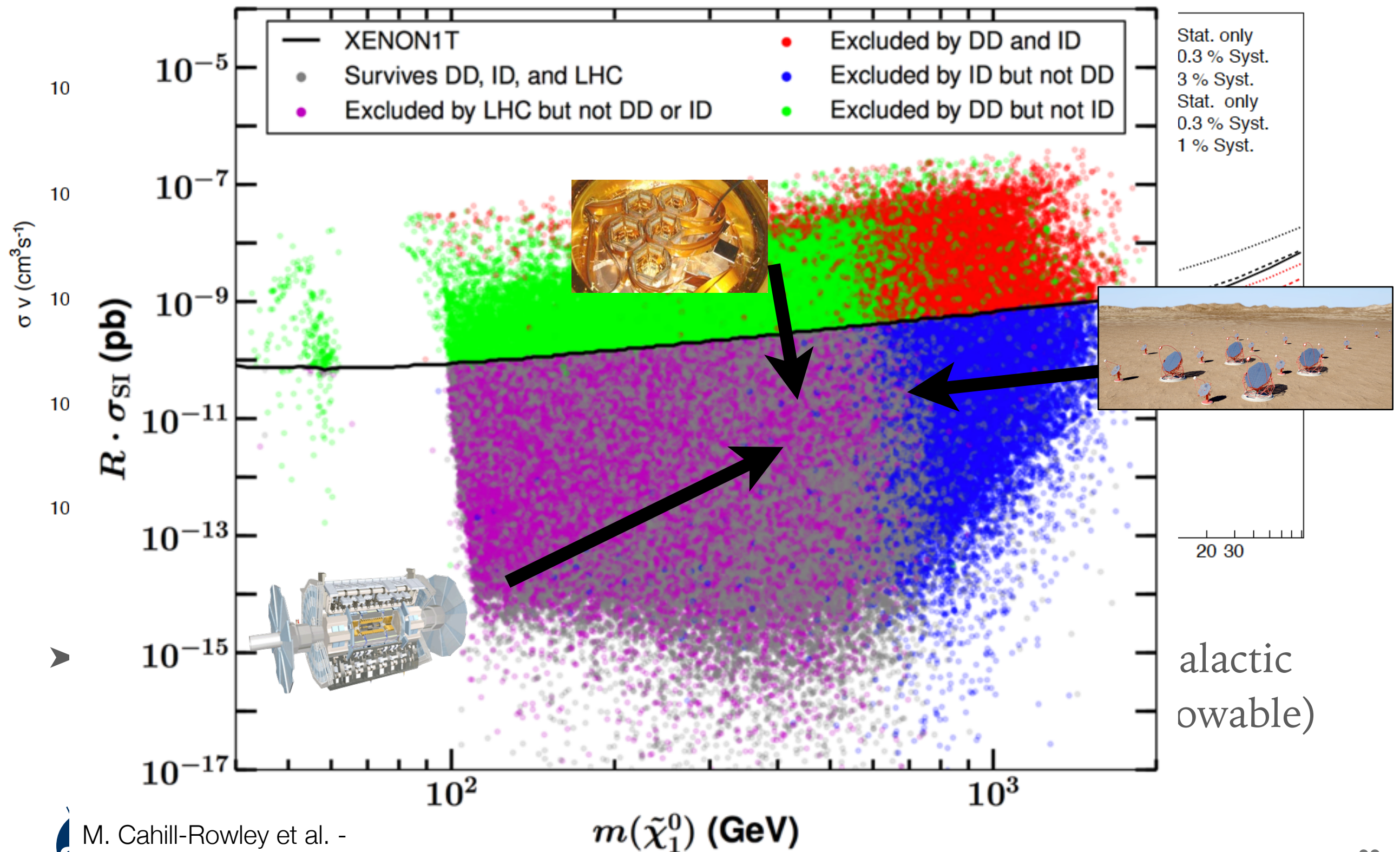


DARK MATTER

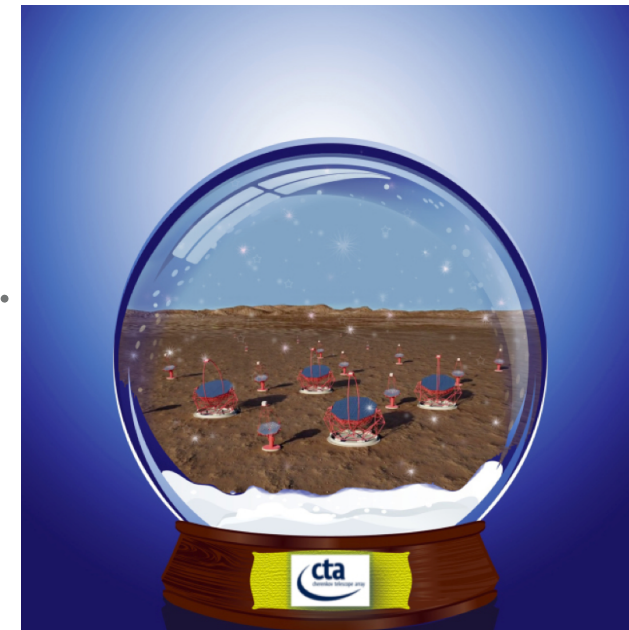


- Significant reach for high-mass dark matter models in the Galactic center. But depends on profile (which is not well known/knowable)

DARK MATTER

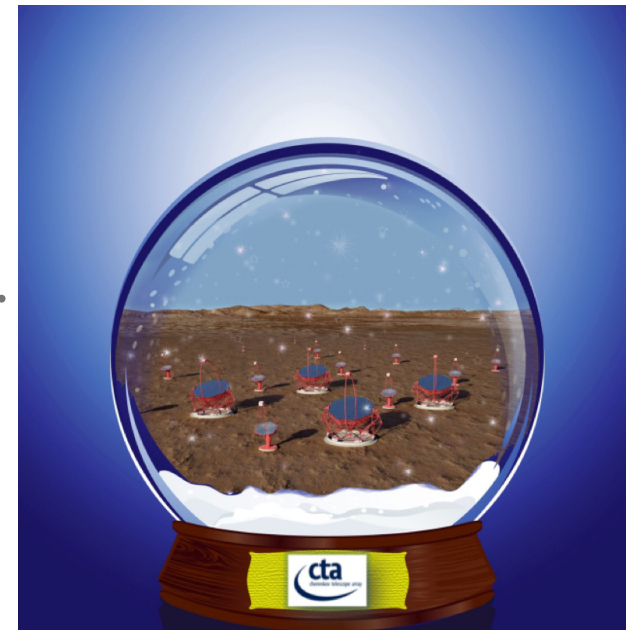


THE STATUS OF GAMMA-RAY ASTRONOMY IN 2027



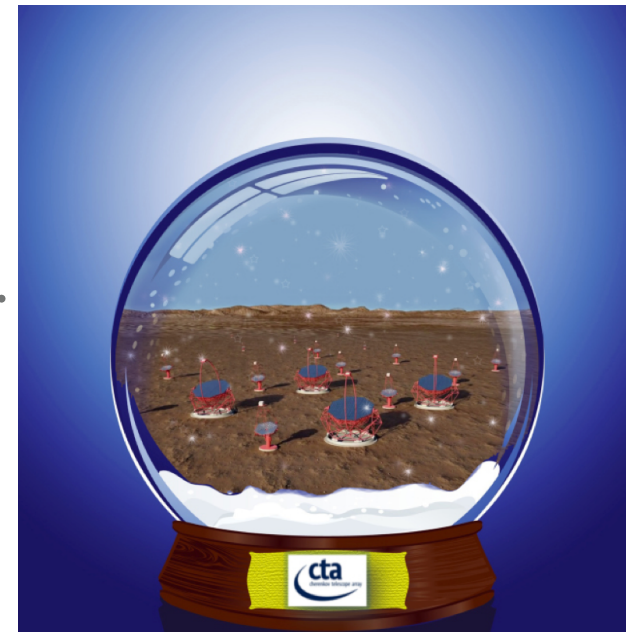
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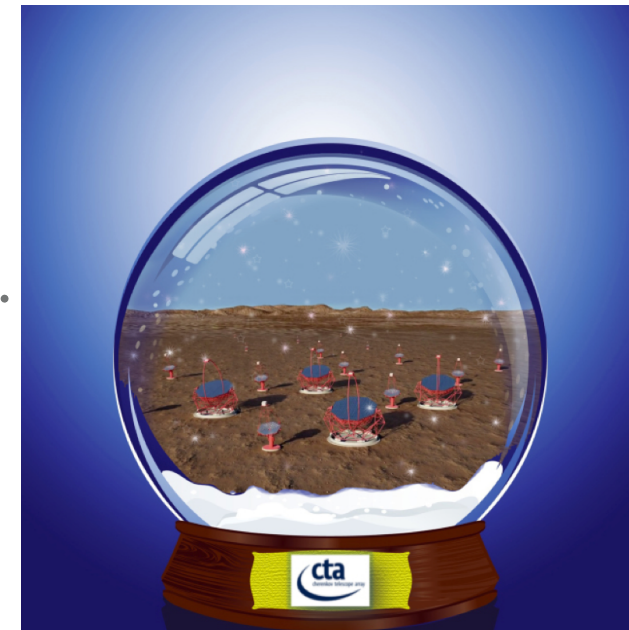
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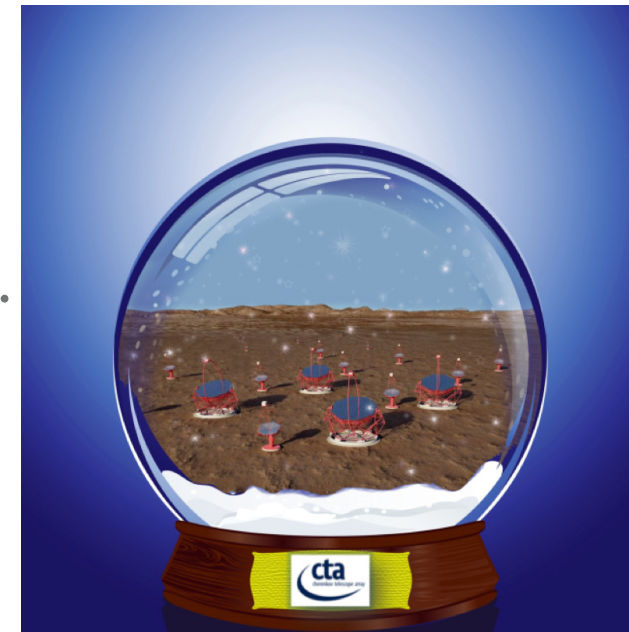
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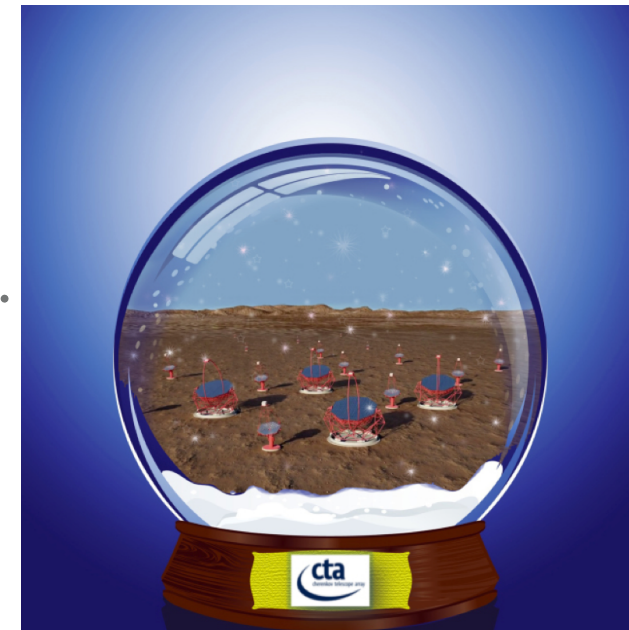
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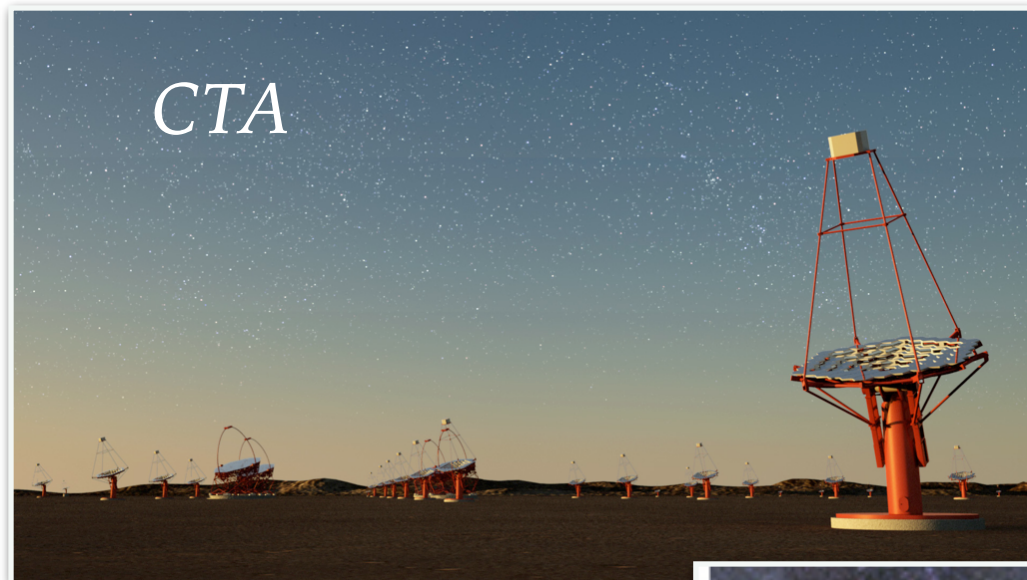


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- A student at the 7th Sexten Summer School on CTA discovers a similar signal in an ultrafaint dwarph spheroidal ...



THE FUTURE IS BRIGHT FOR MULTI-MESSENGER ASTRONOMY



Fermi-LAT

