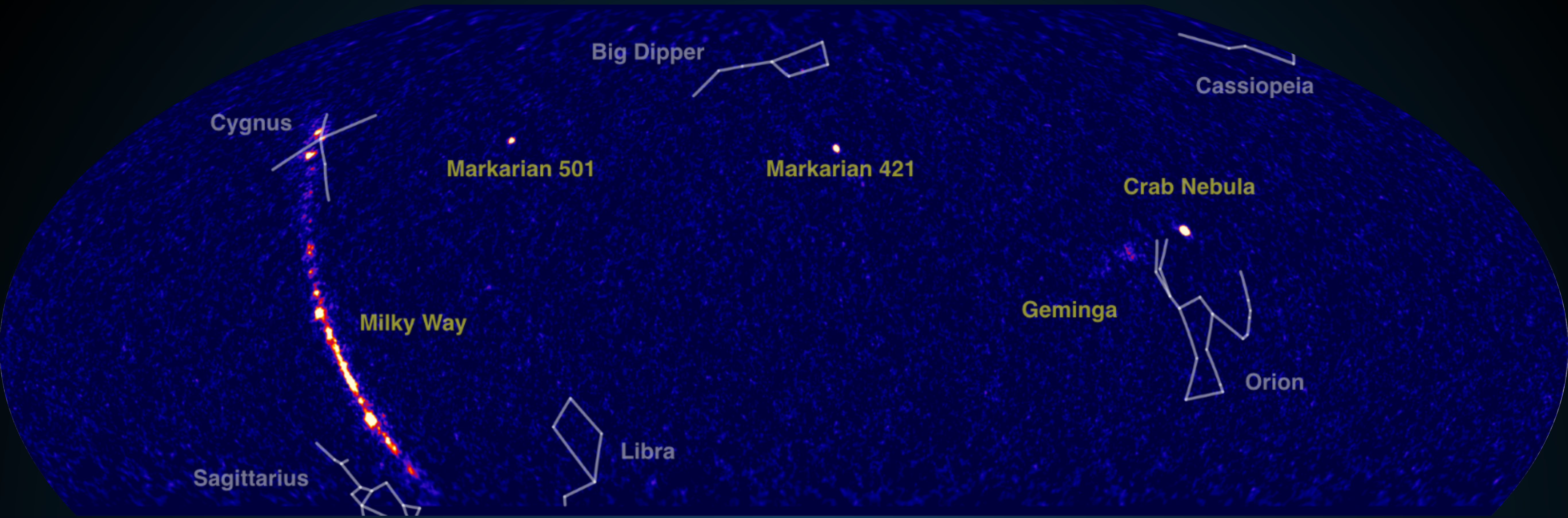


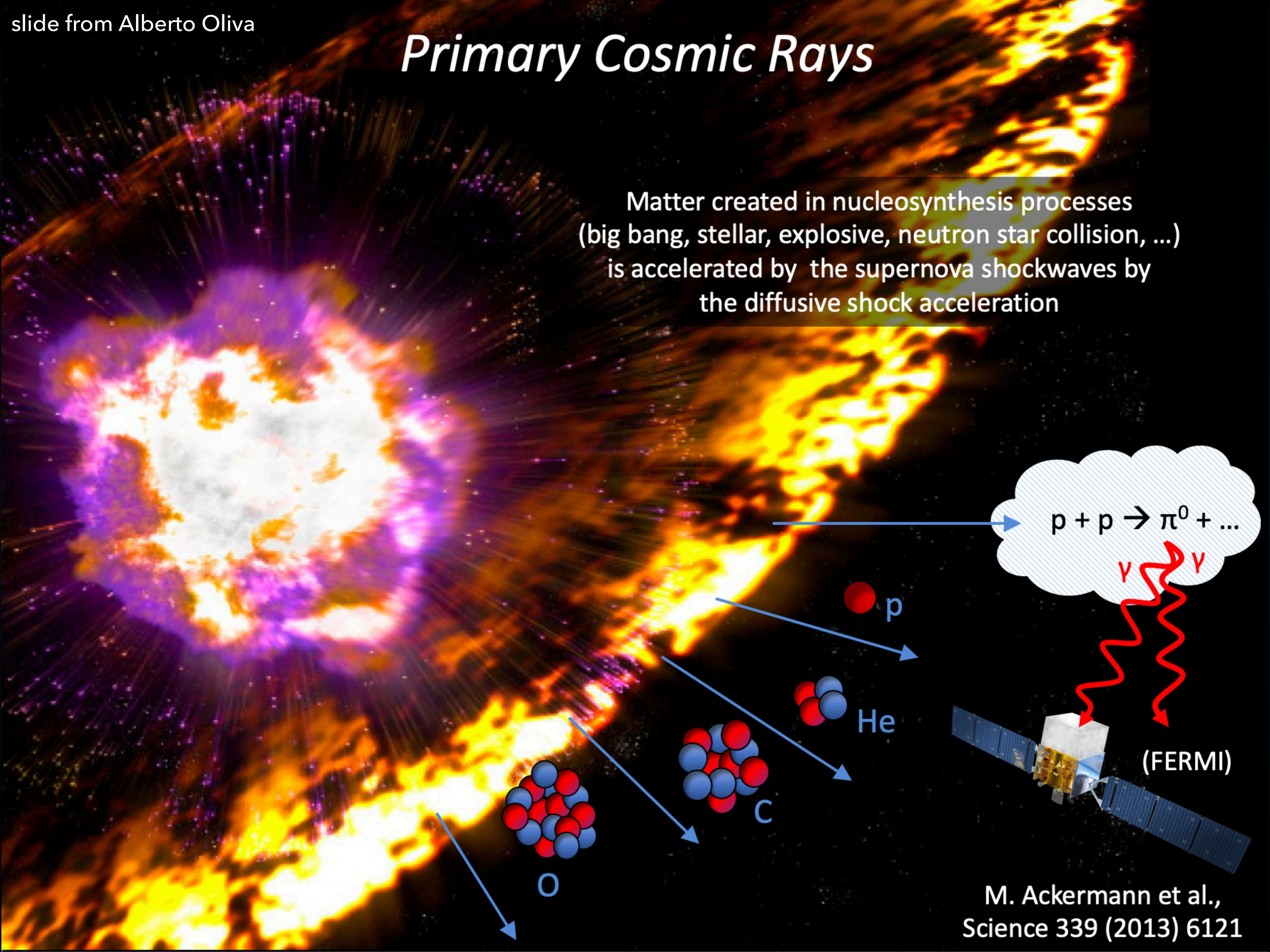
THE LIGHT LEFT BEHIND

TEV GAMMA-RAYS FROM GALACTIC AND EXTRAGALACTIC ACCELERATORS

TIM LINDEN

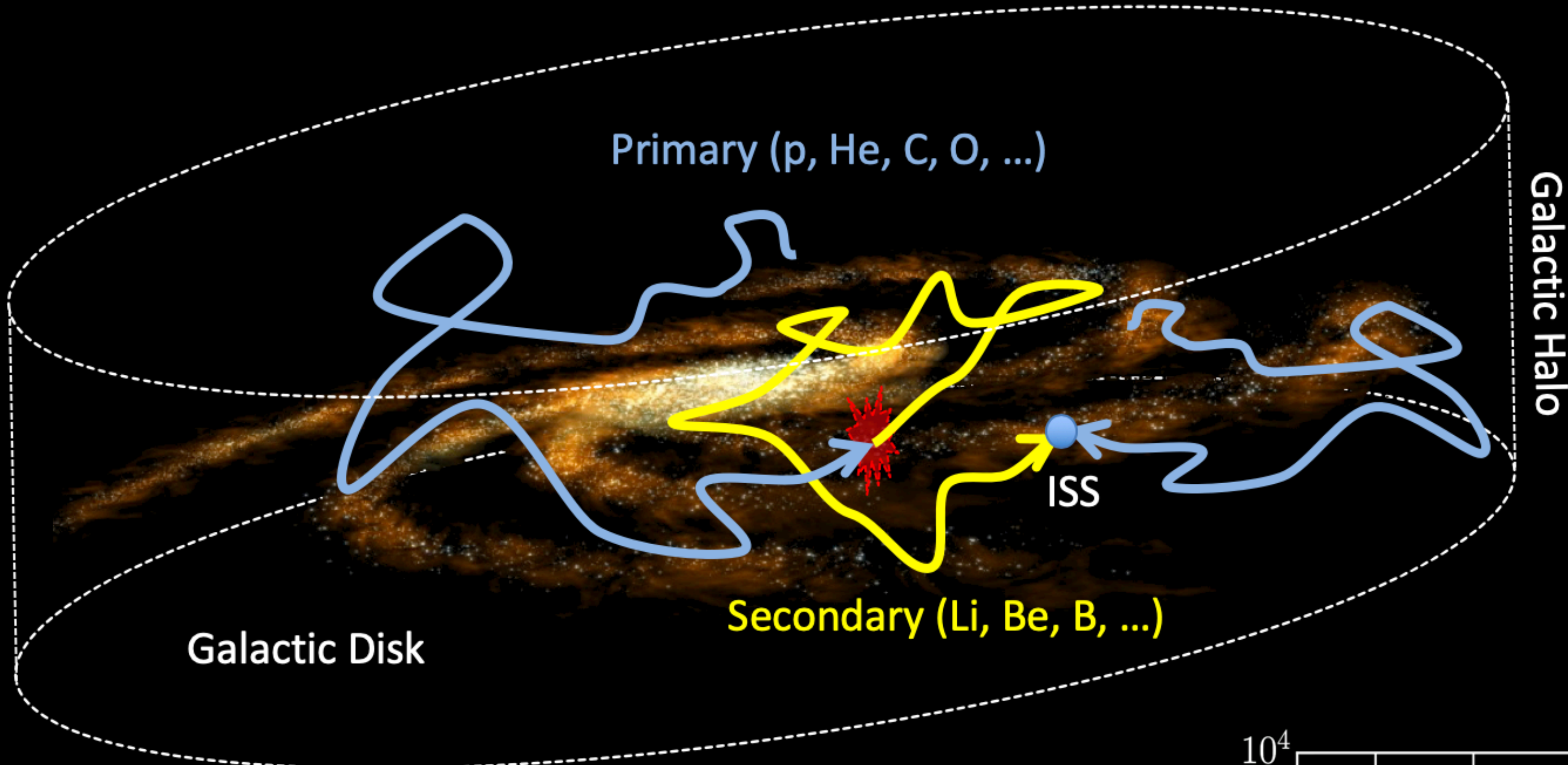
IGC @ 25
Pennsylvania State University
June 24, 2019

THE OHIO STATE UNIVERSITY
CENTER FOR COSMOLOGY AND ASTROPARTICLE PHYSICS


slide from Alberto Oliva
Primary Cosmic Rays
Matter created in nucleosynthesis processes
(big bang, stellar, explosive, neutron star collision, ...)
is accelerated by the supernova shockwaves by
the diffusive shock acceleration
p + p → π0 + ...
γ
γ
p
He
C
O
(FERMI)
M. Ackermann et al.,
Science 339 (2013) 6121

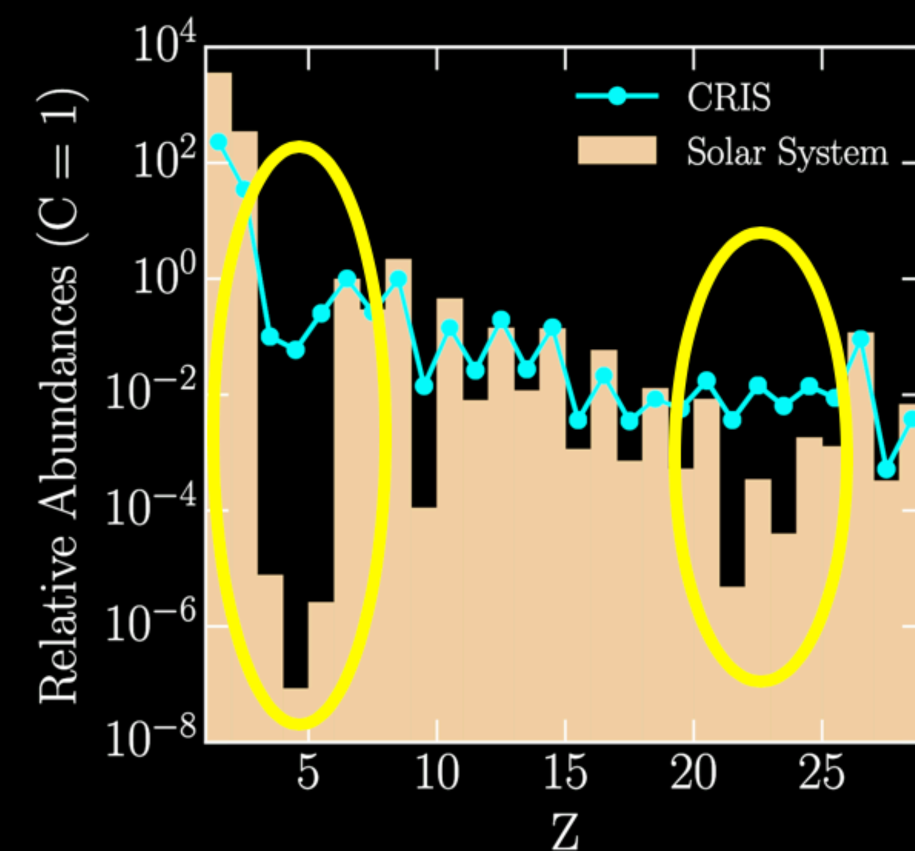
slide from Alberto Oliva

Secondary Cosmic Rays

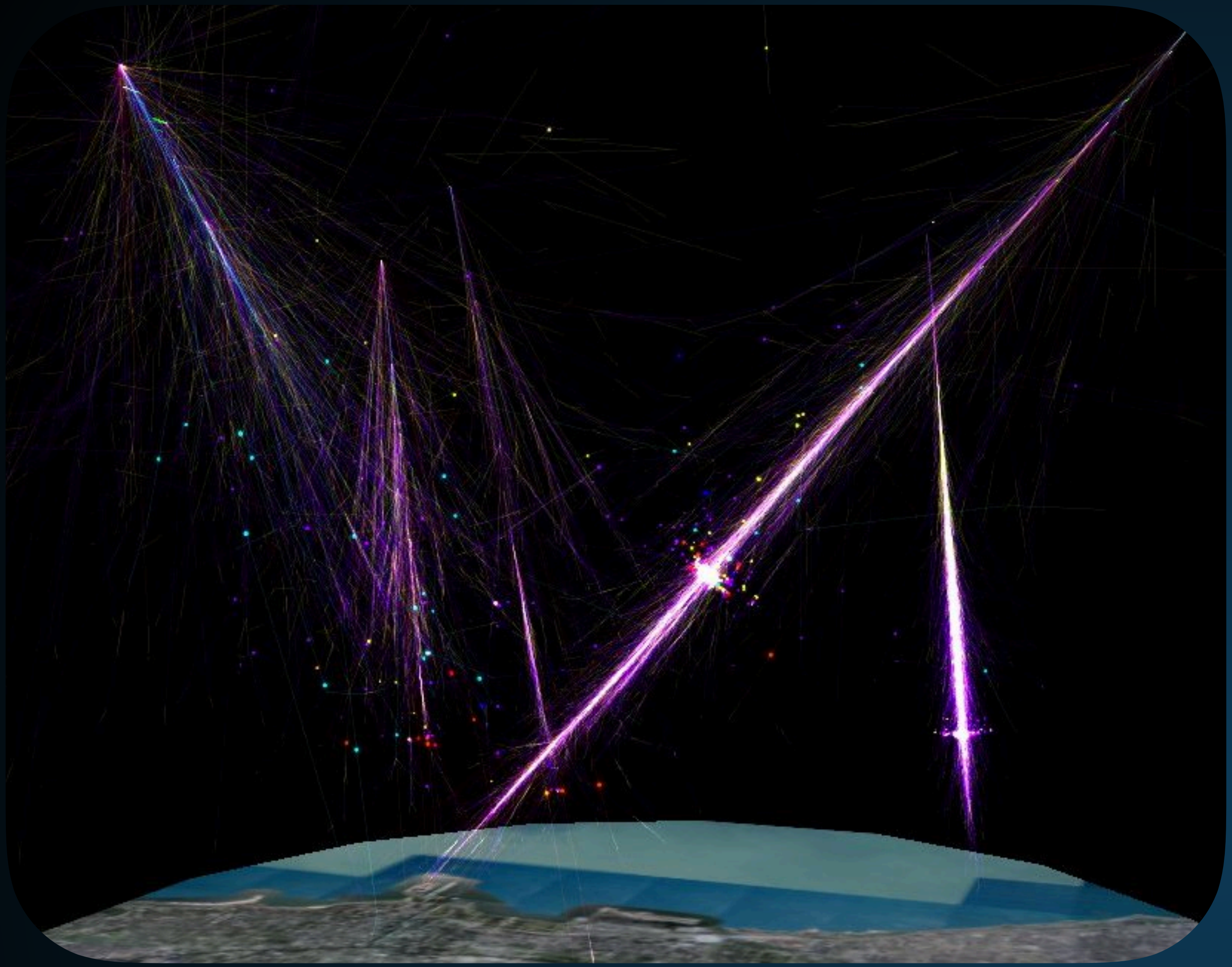


Cosmic rays **primaries** are produced at astrophysical sources (ex. p, He, C, O, …),

Secondaries (ex. Li, Be, B, …) are produced by the collision of cosmic rays with the ISM.



WELL-STUDIED PARTICLE PHYSICS



Hadronic Interactions:

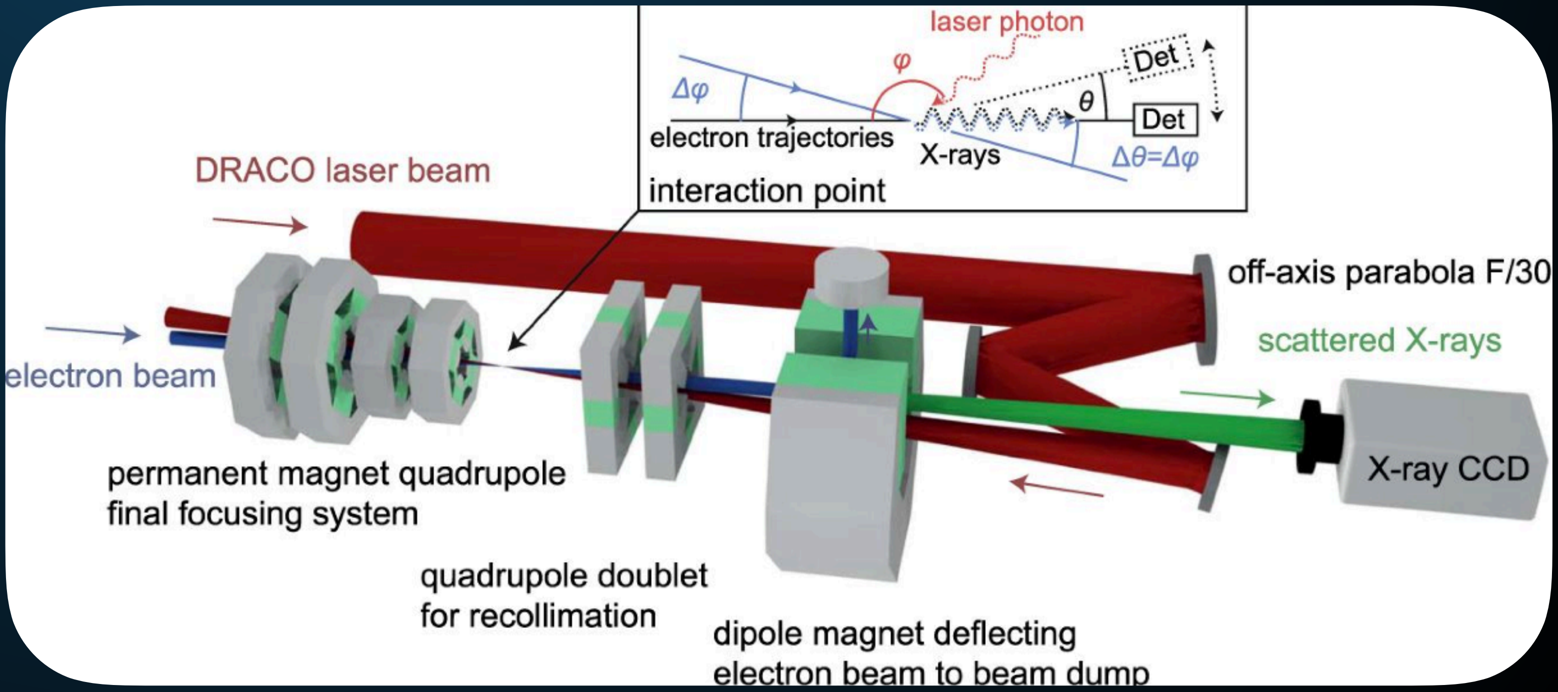
Colliders

Cosmic-Ray Showers

Inverse Compton:

Laser Experiments

Analytically Solved

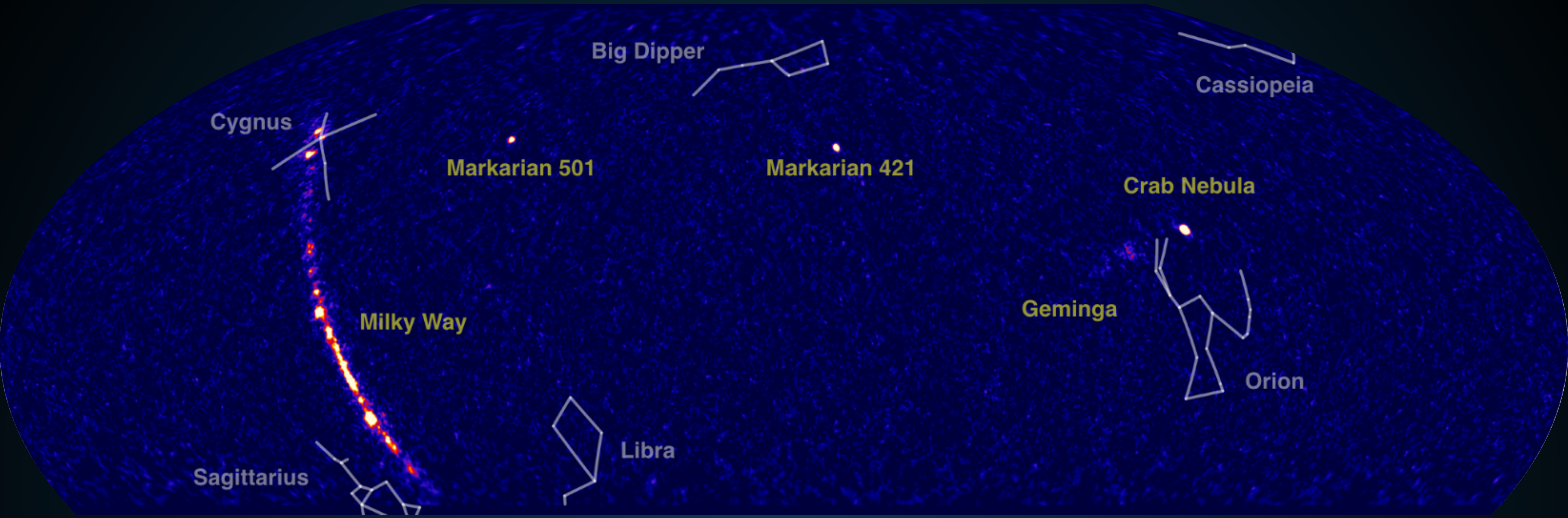


BACKGROUND-FREE

Fermi Acceleration is one of the only mechanism to produce high-energy particles, including high-energy gamma-rays

SOURCES VS. DIFFUSE EMISSION

HAWC Collaboration



TeV Emission Stems from Sources and Diffuse Emission:

- Can separate components due to morphological features.
- TeV e^+e^- lose energy quickly, can scan local environments.

TWO INSTRUMENTAL TECHNIQUES

Atmospheric Cherenkov

H.E.S.S. / VERITAS / (CTA)

Large Effective Area (50000 m^2)

Excellent Angular Resolution ($<0.1^{\circ}$)

Point Source Optimized

Water Cherenkov

HAWC / LHASSO

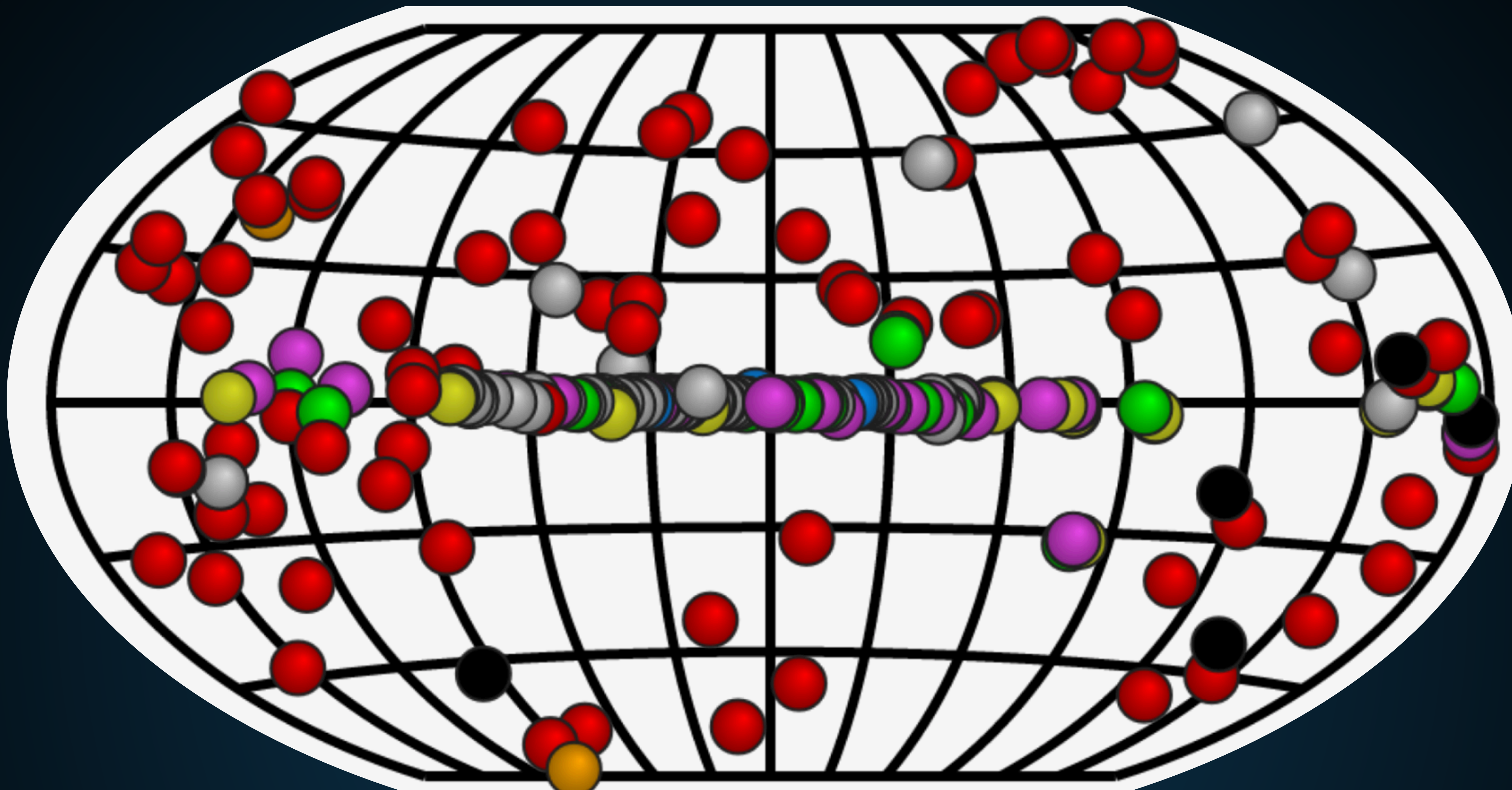
Large Angular Acceptance (30°)

Nearly Constant Observations

Diffuse Optimized

SOURCES

TeVCAT 2.0 (http://tevcat2.uchicago.edu/)

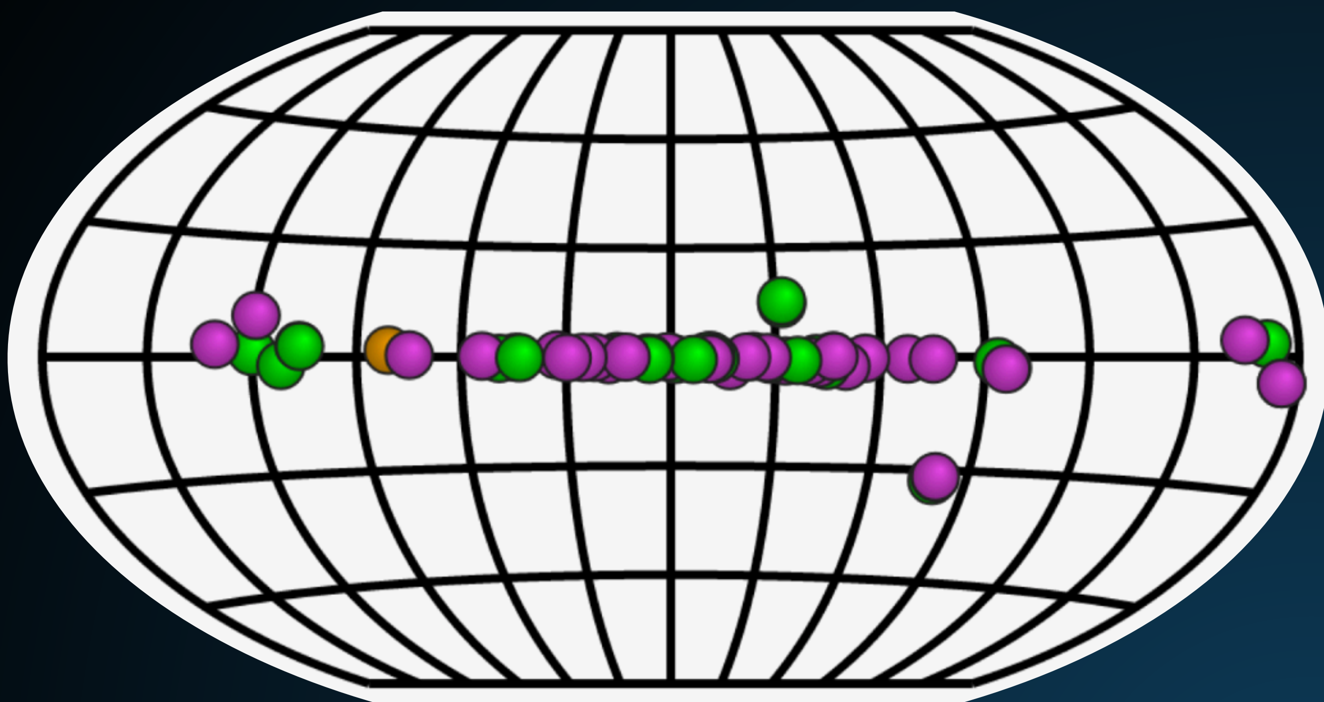


Currently 224 Sources!

Galactic

Extragalactic

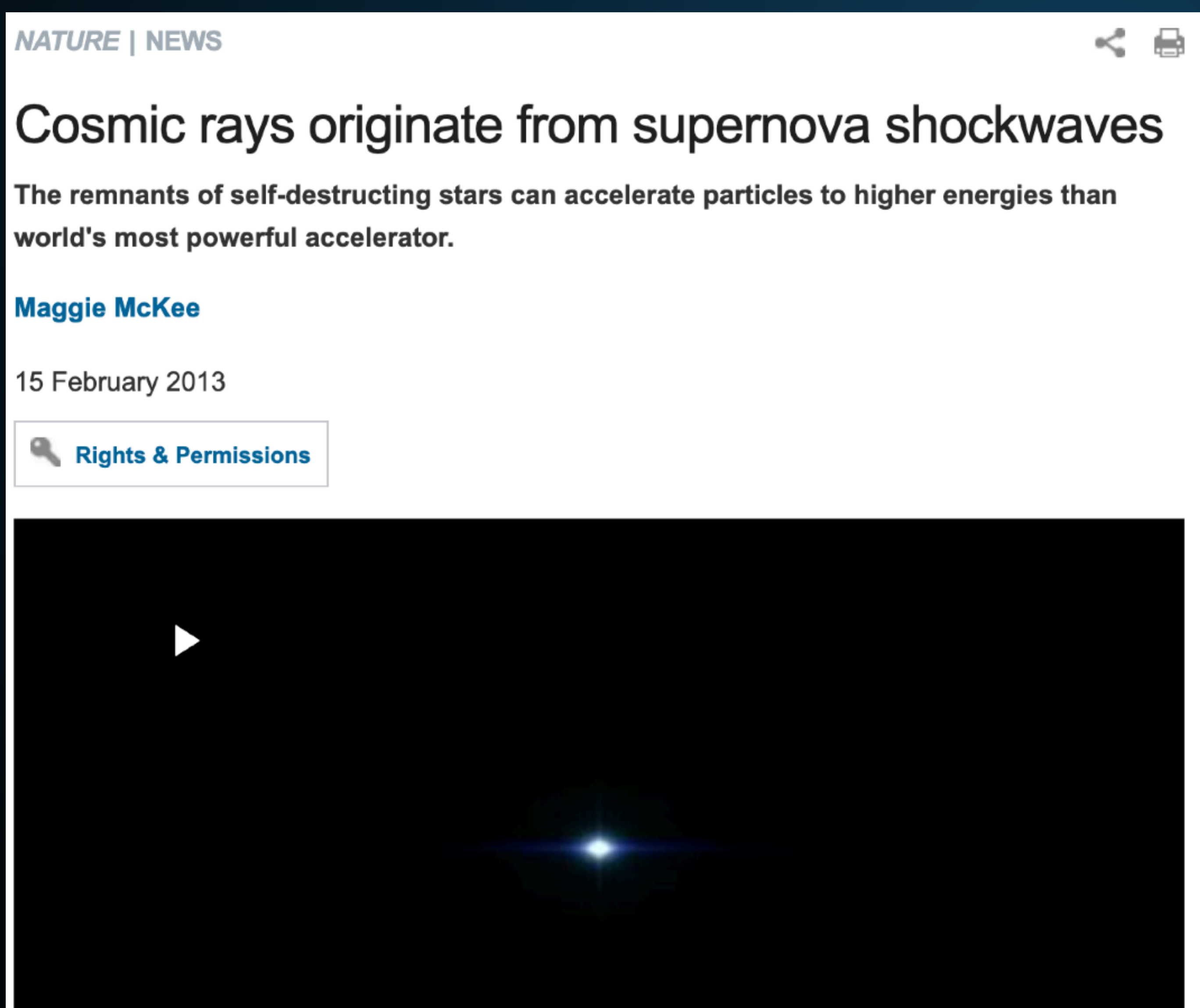
GALACTIC SOURCES: SUPERNOVA REMNANTS



Supernova Remnants:

59 Sources

Hadronic



NATURE | NEWS

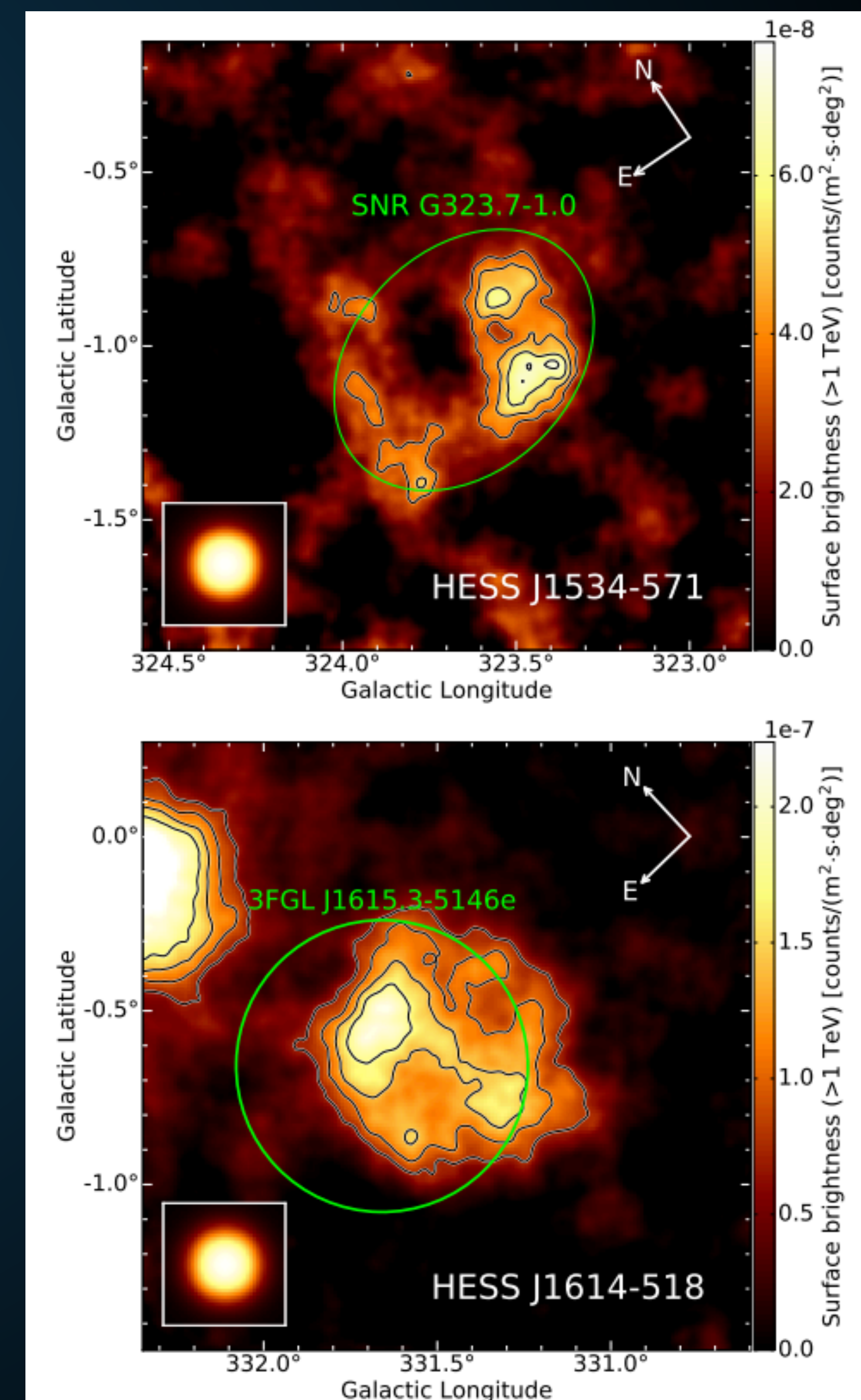
Cosmic rays originate from supernova shockwaves

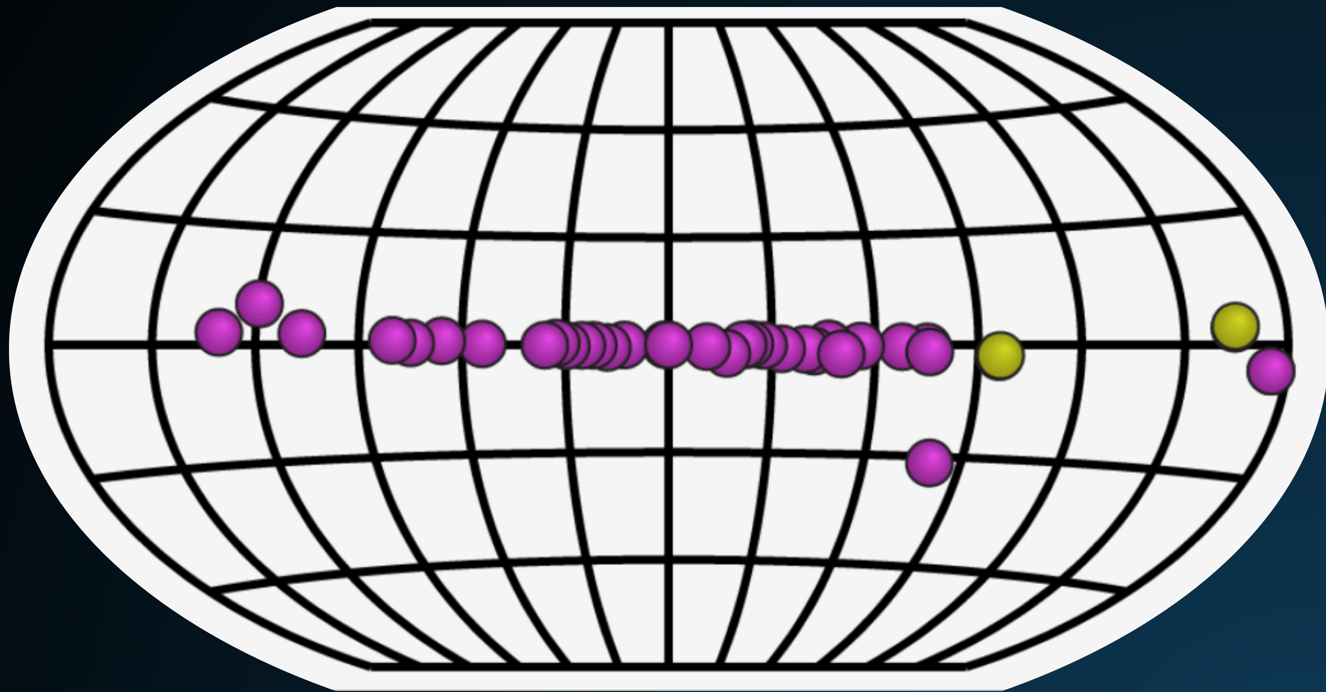
The remnants of self-destructing stars can accelerate particles to higher energies than world's most powerful accelerator.

Maggie McKee

15 February 2013

Rights & Permissions



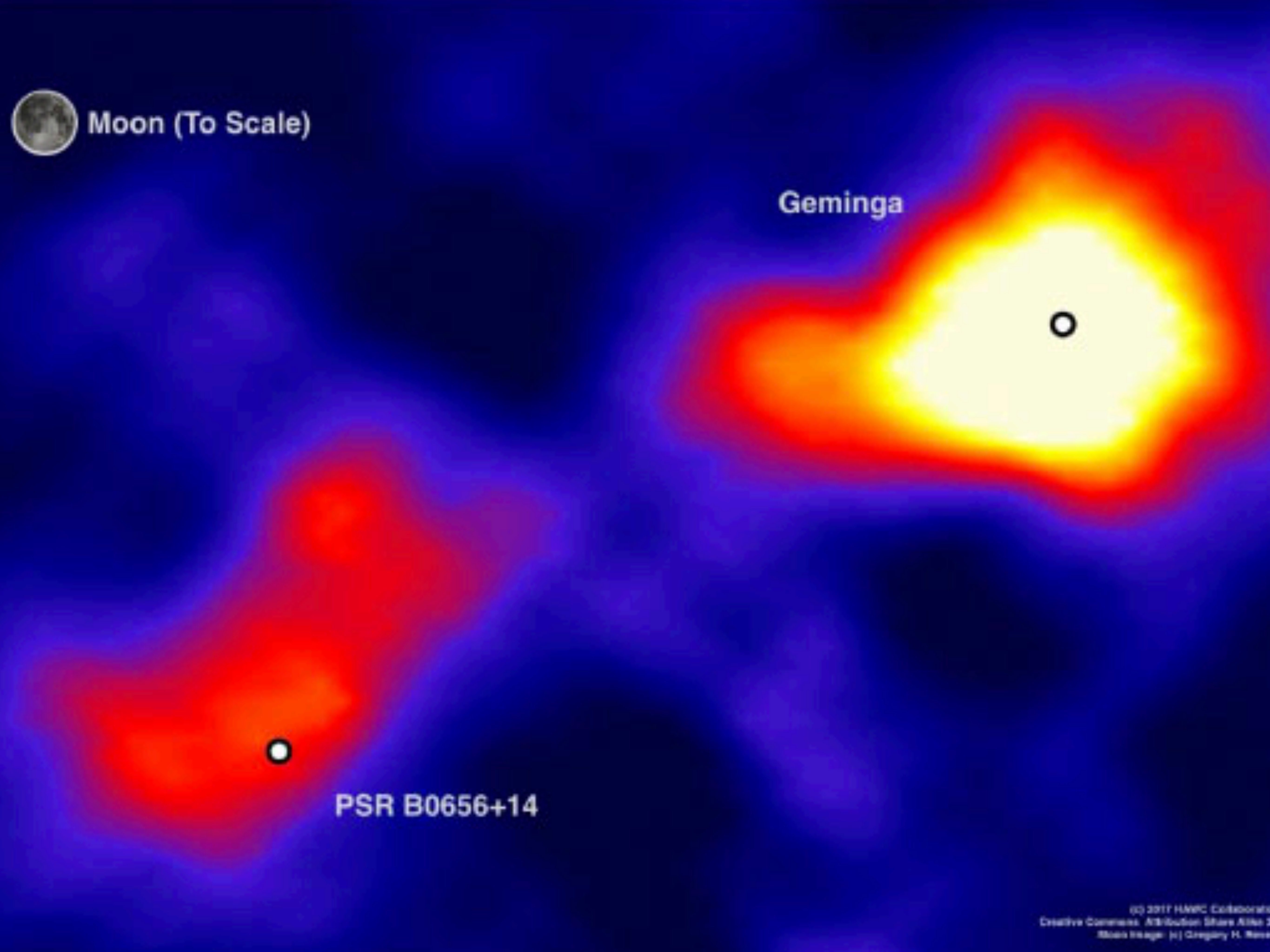


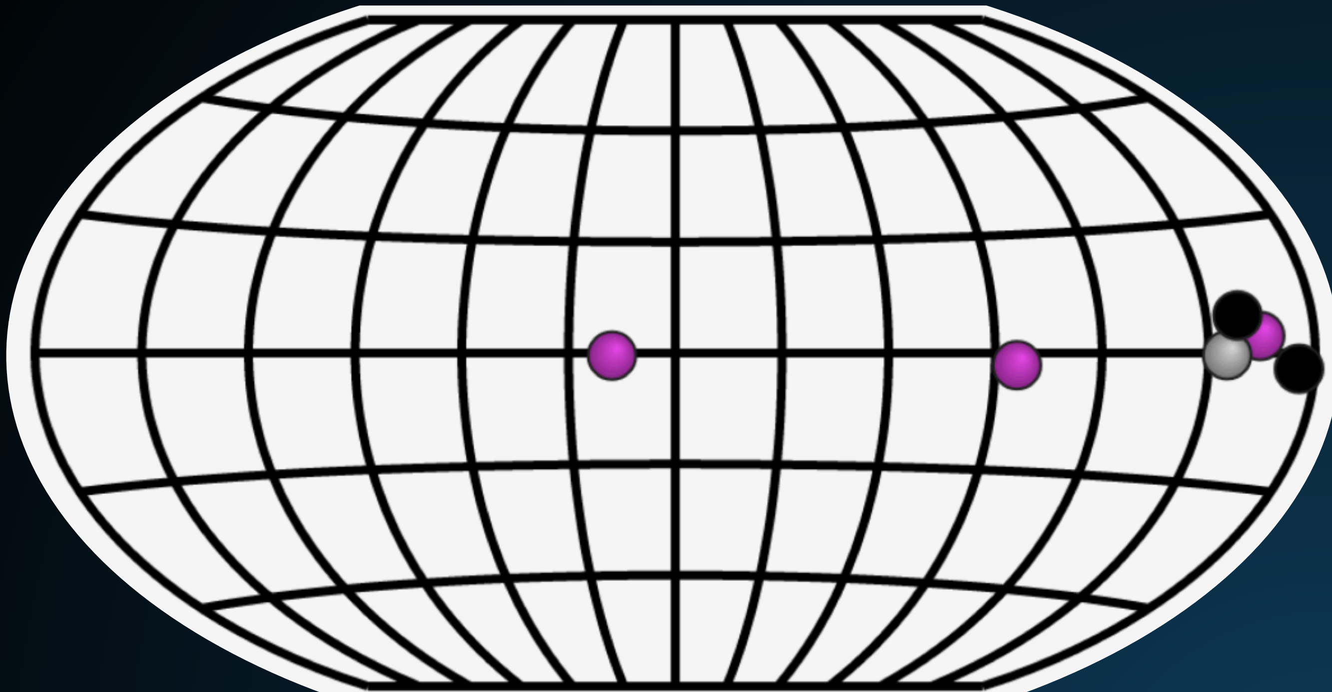
Pulsar Wind Nebulae

38 Sources

Leptonic Origin

Huge Voltage Drop (30 PV!) at PWN termination shock accelerates e^+e^-, produces synchrotron and ICS.


Moon (To Scale)
Geminga
PSR B0656+14



TeV Halos

6 Sources

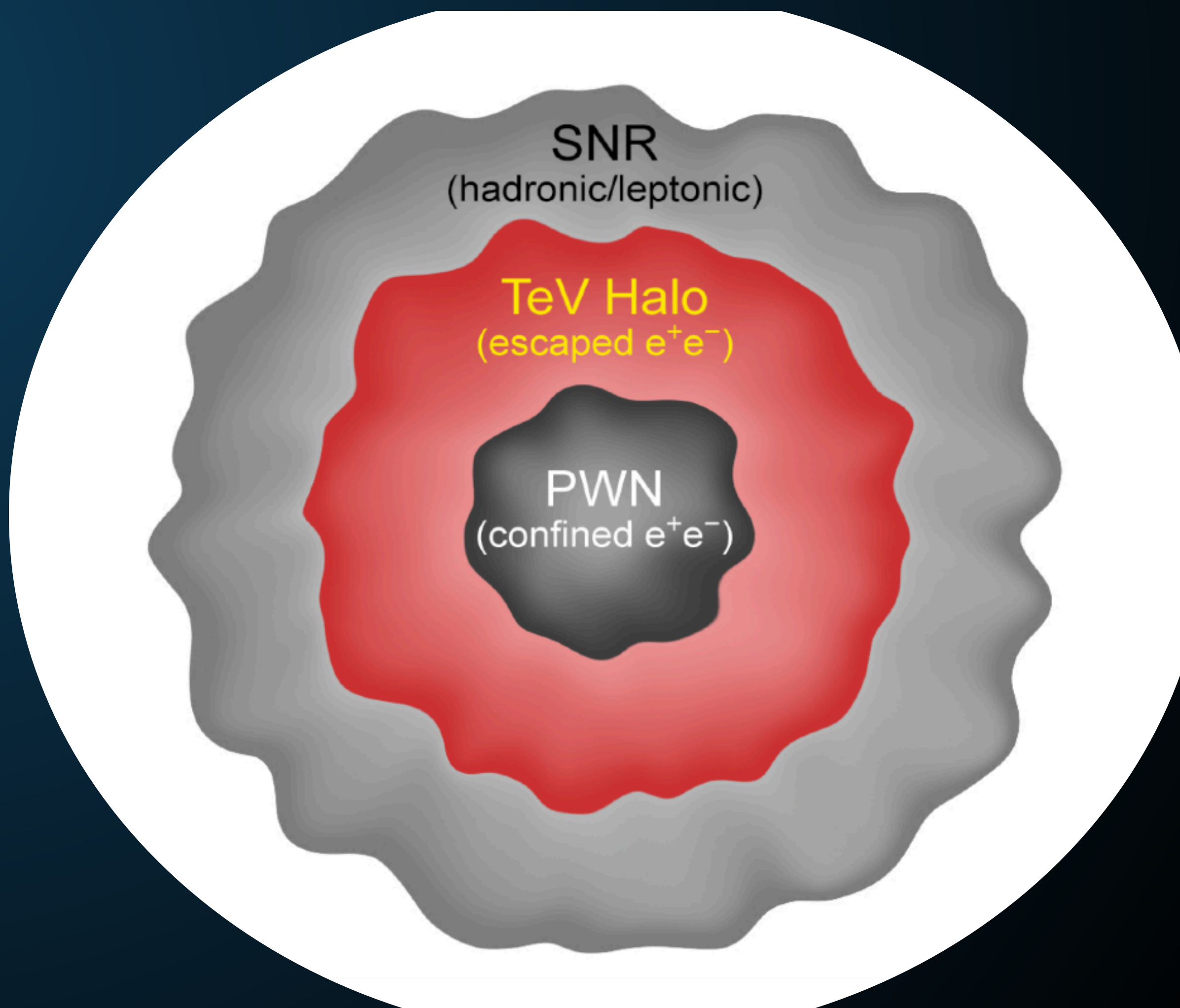
~20 tentative sources

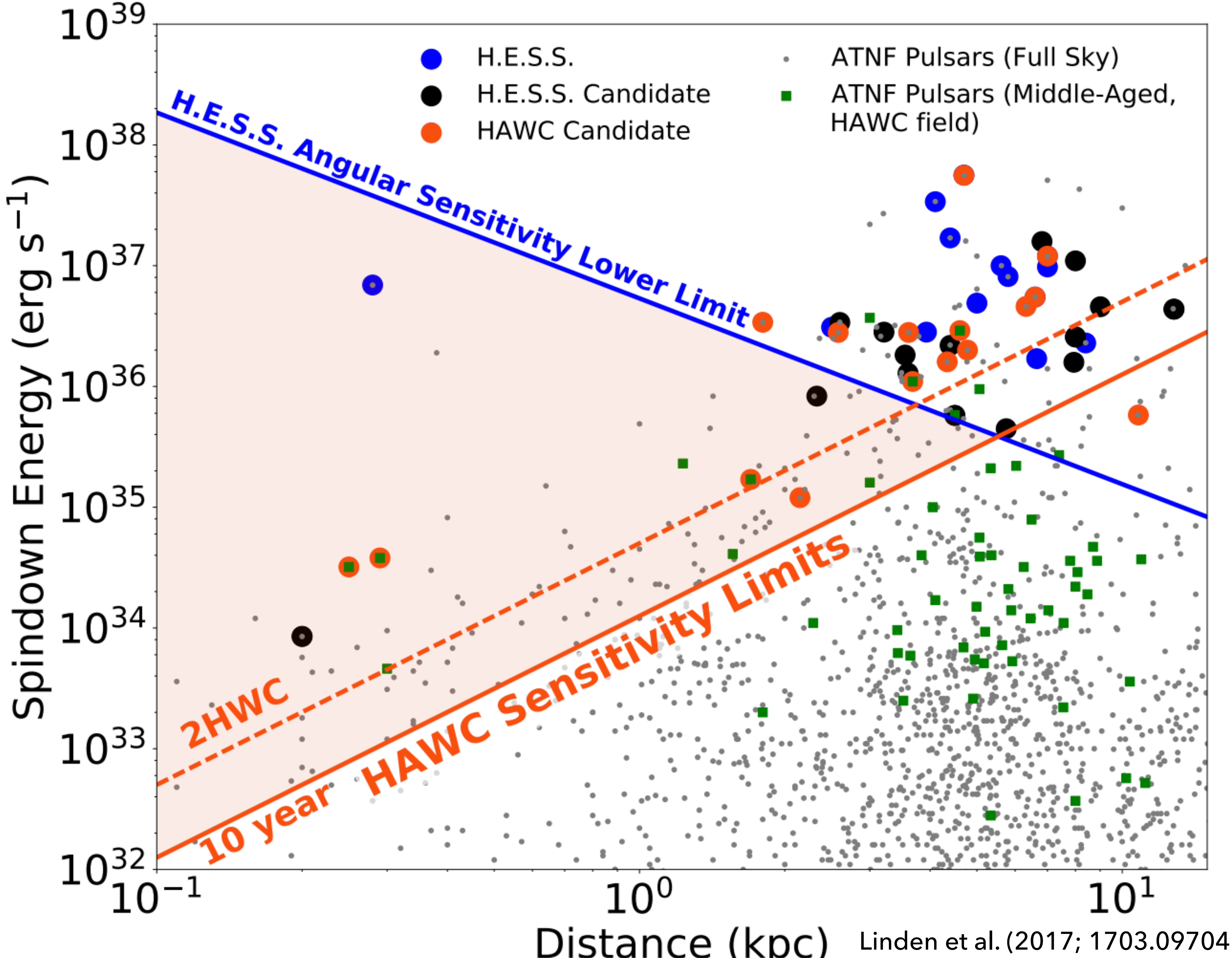
What is a TeV Halo?

e^+e^- accelerated inside PWN, but escape into ISM.

Connection between sources and diffuse emission.

Likely many composite sources

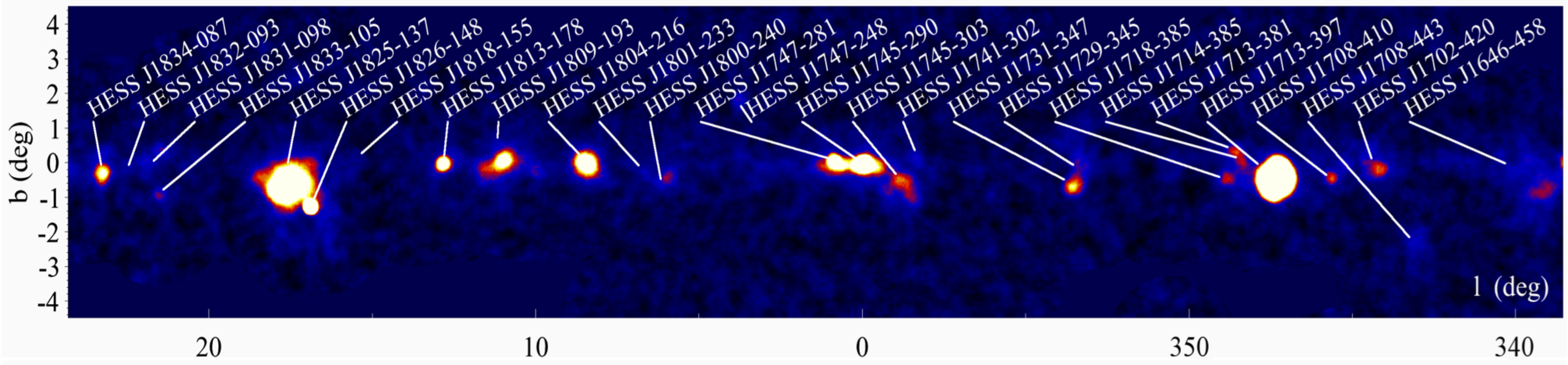


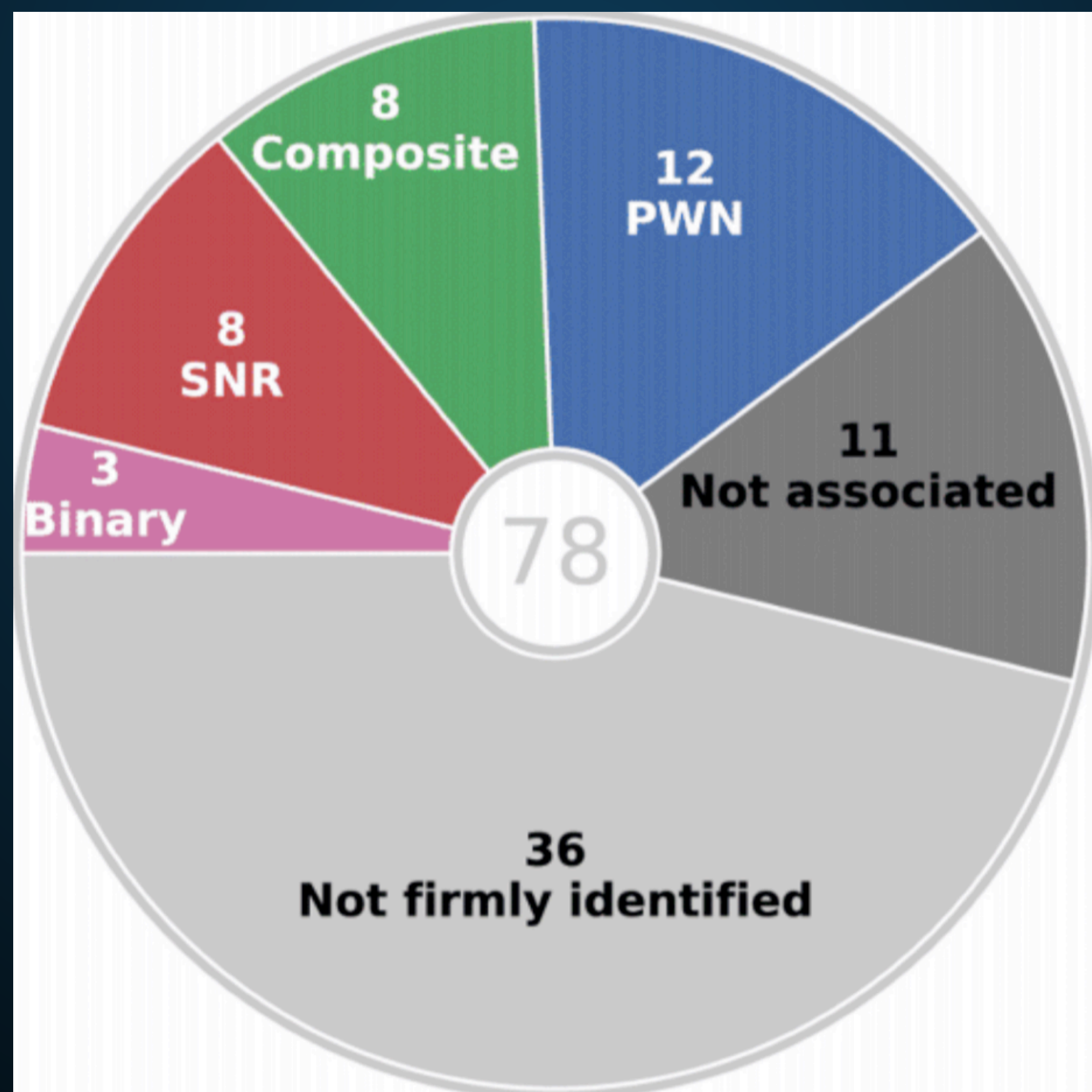


Linden et al. (2017; 1703.09704)

EVIDENCE FOR COMPOSITE OBJECTS

HESS Collaboration 2018





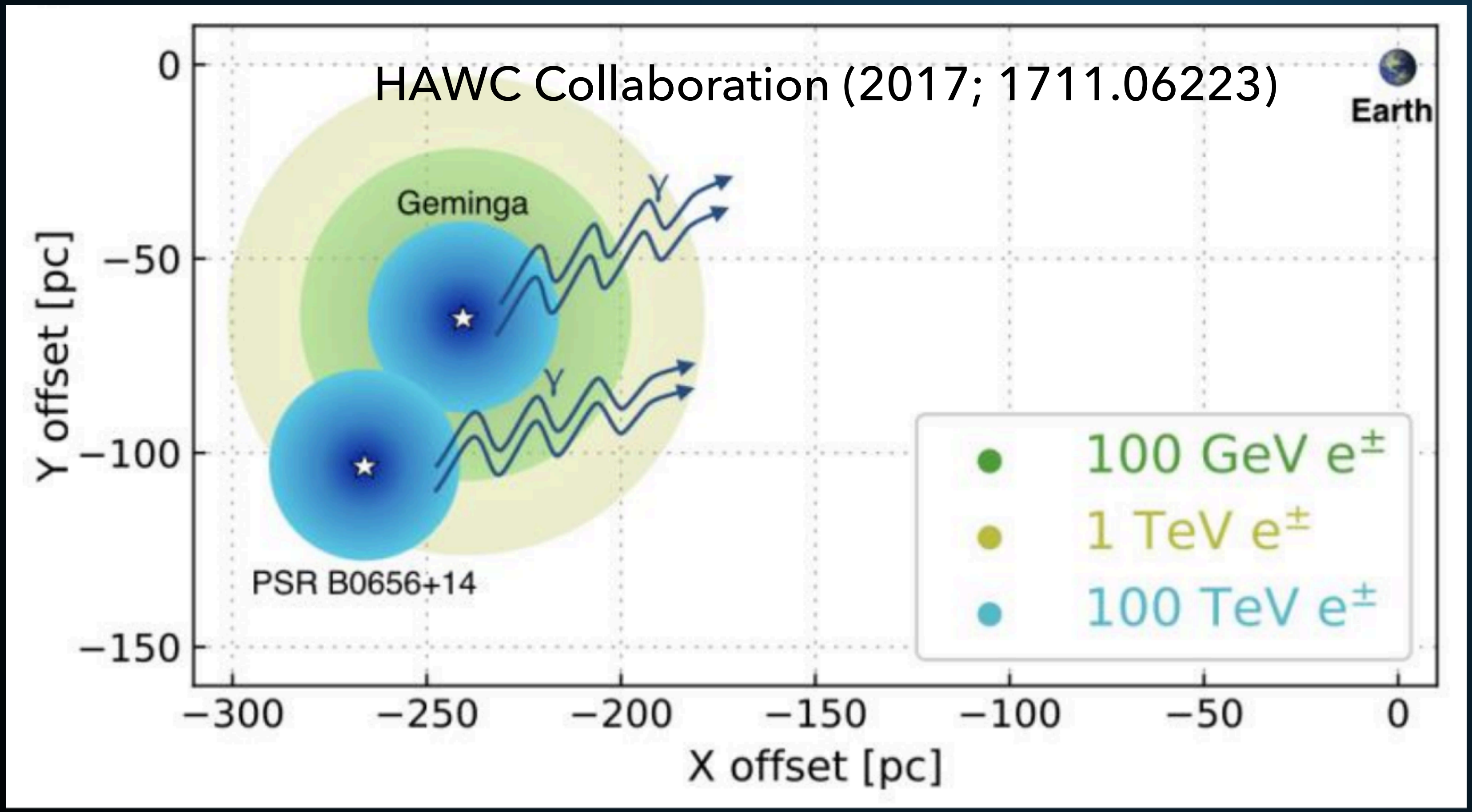
Evoli, TL, Morlino (2018;1807.09263)

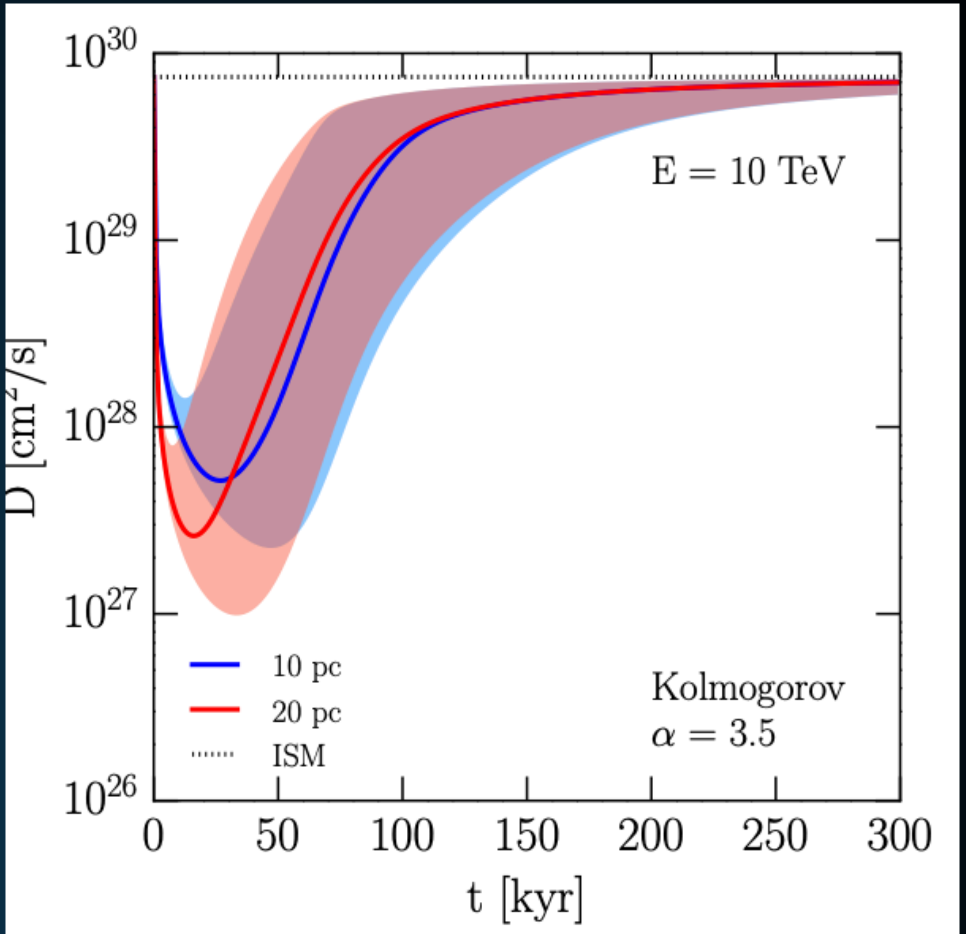
TeV Electrons Are Special:

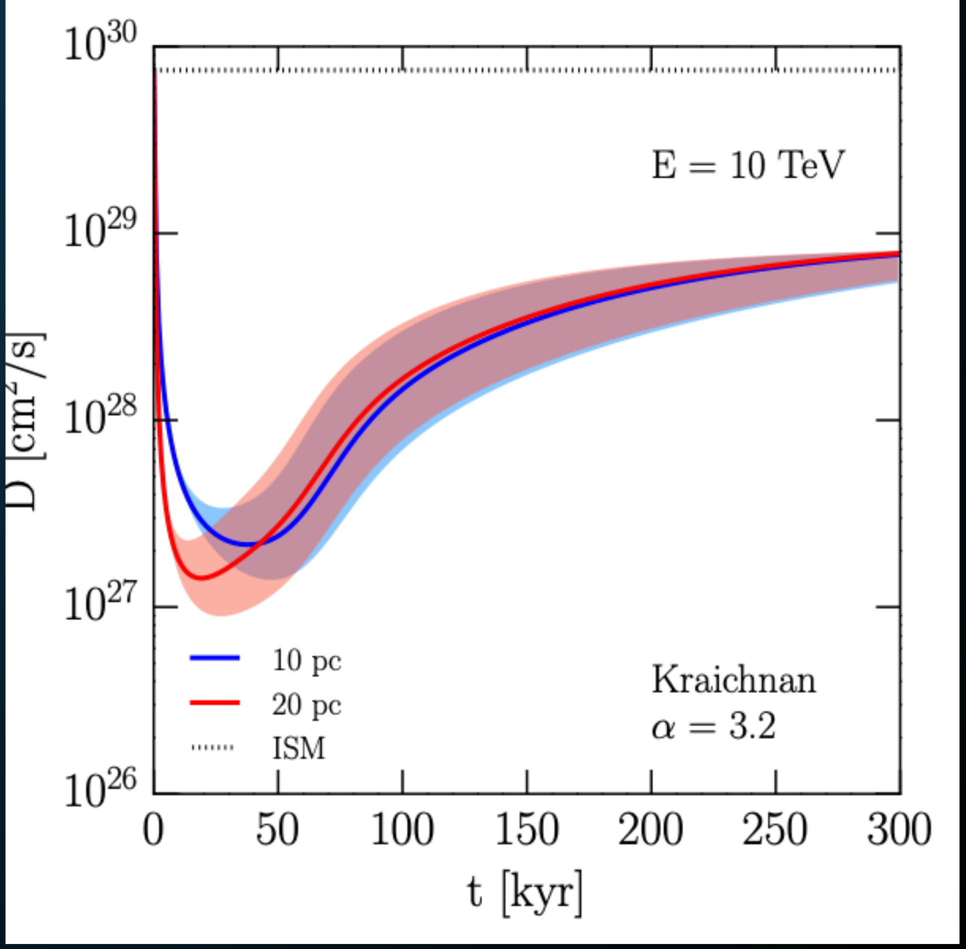
Cool Rapidly

Cooling is strongly energy Dependent

Emission Morphology Dominated by Electron Morphology

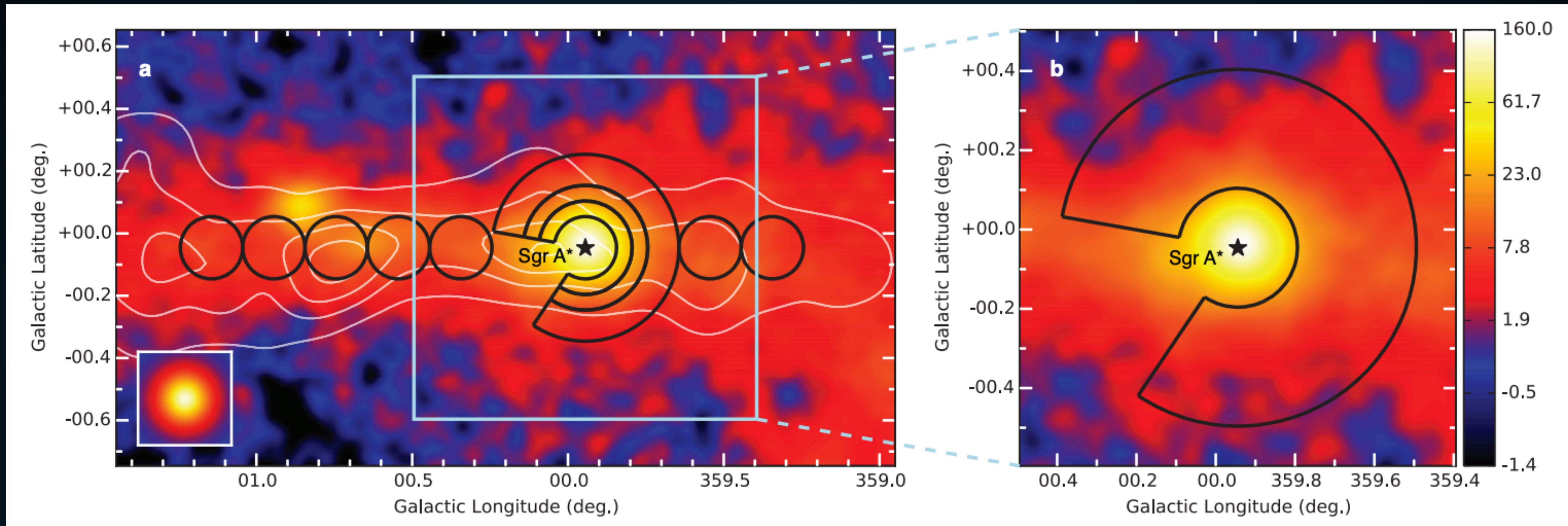






COMPLEMENTARITY WITH COSMIC-RAY OBSERVATIONS

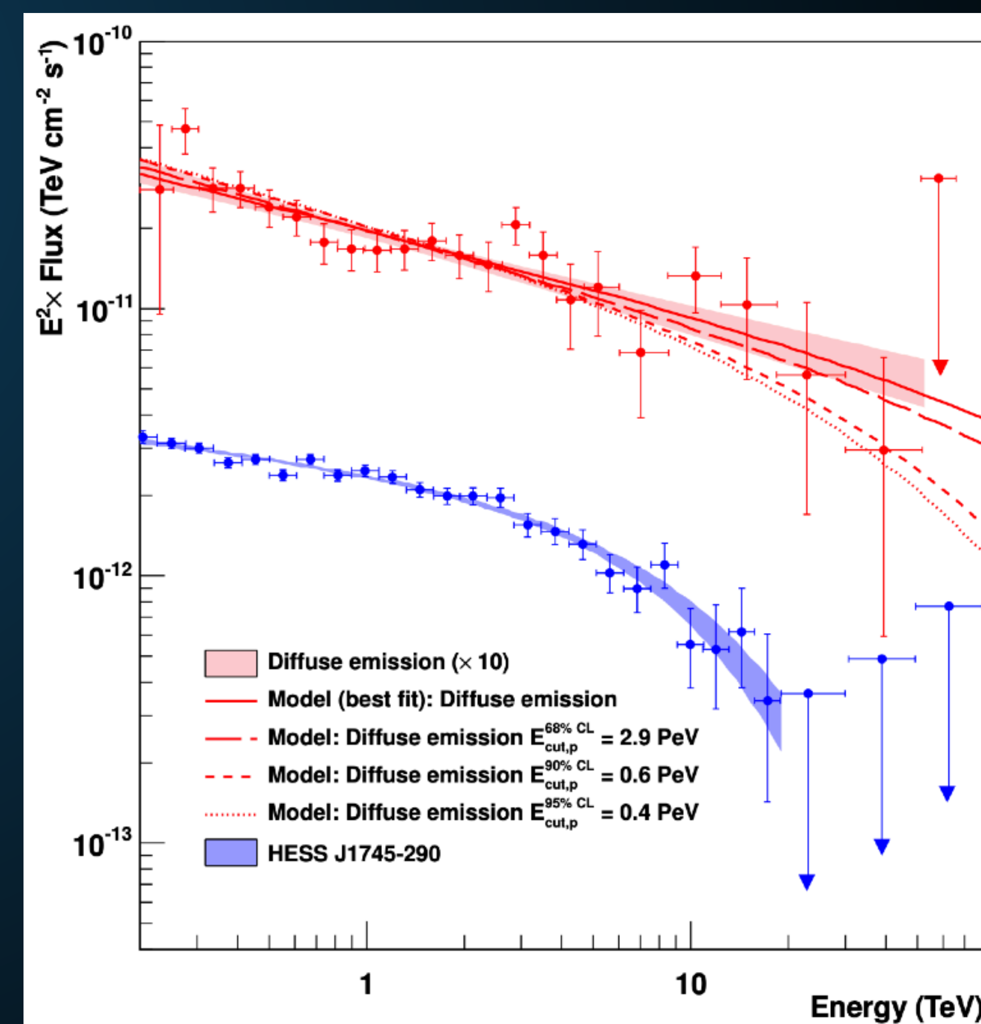
USING GAMMA-RAY INFORMATION: THE GALACTIC CENTER PEVATRON



Where do PeV CRs Come From?

Detection of 100 TeV diffuse Gamma-Ray Emission Near Galactic Center.

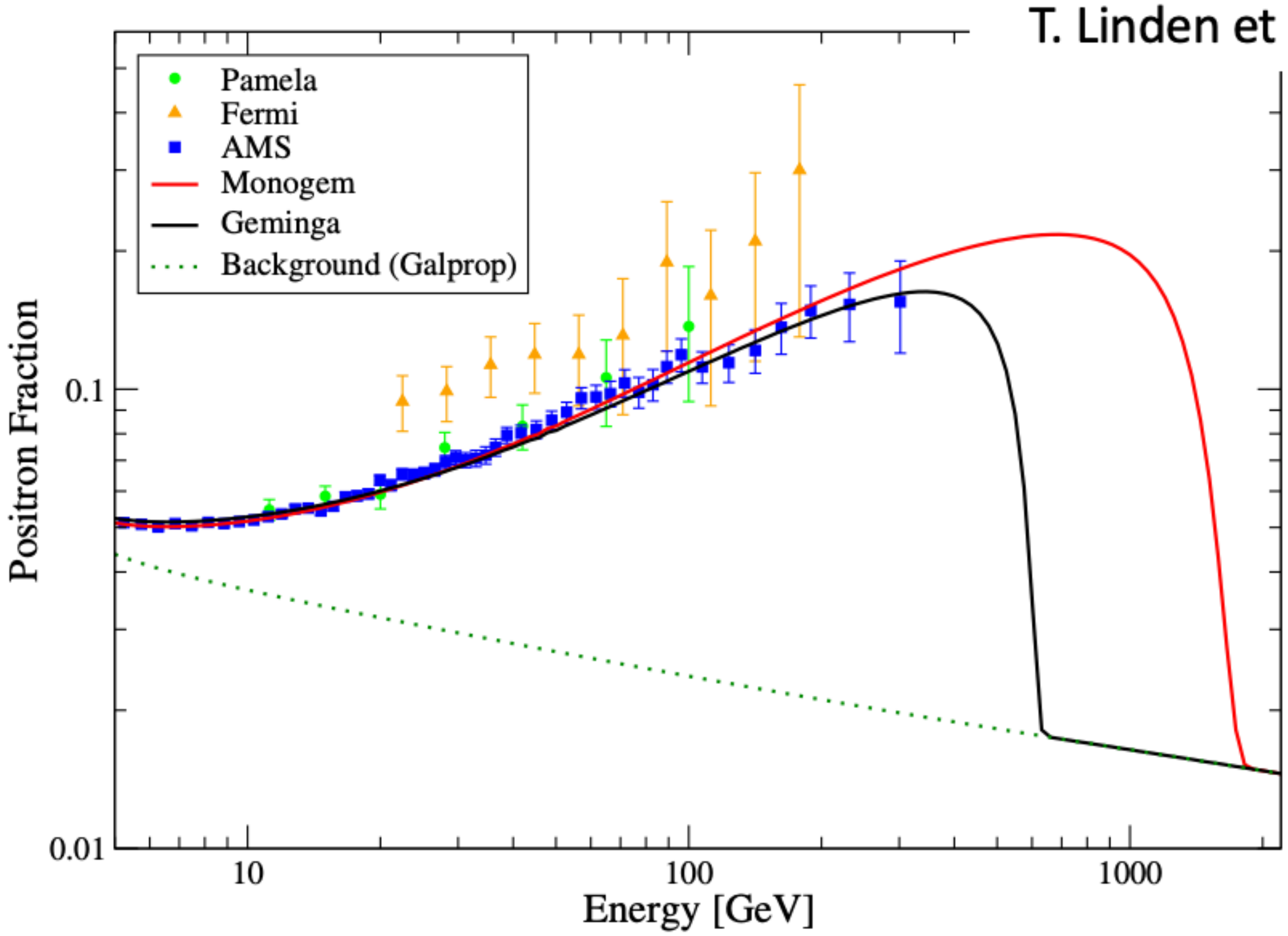
If Hadronic - Direct evidence of PeV CR acceleration in Milky Way.

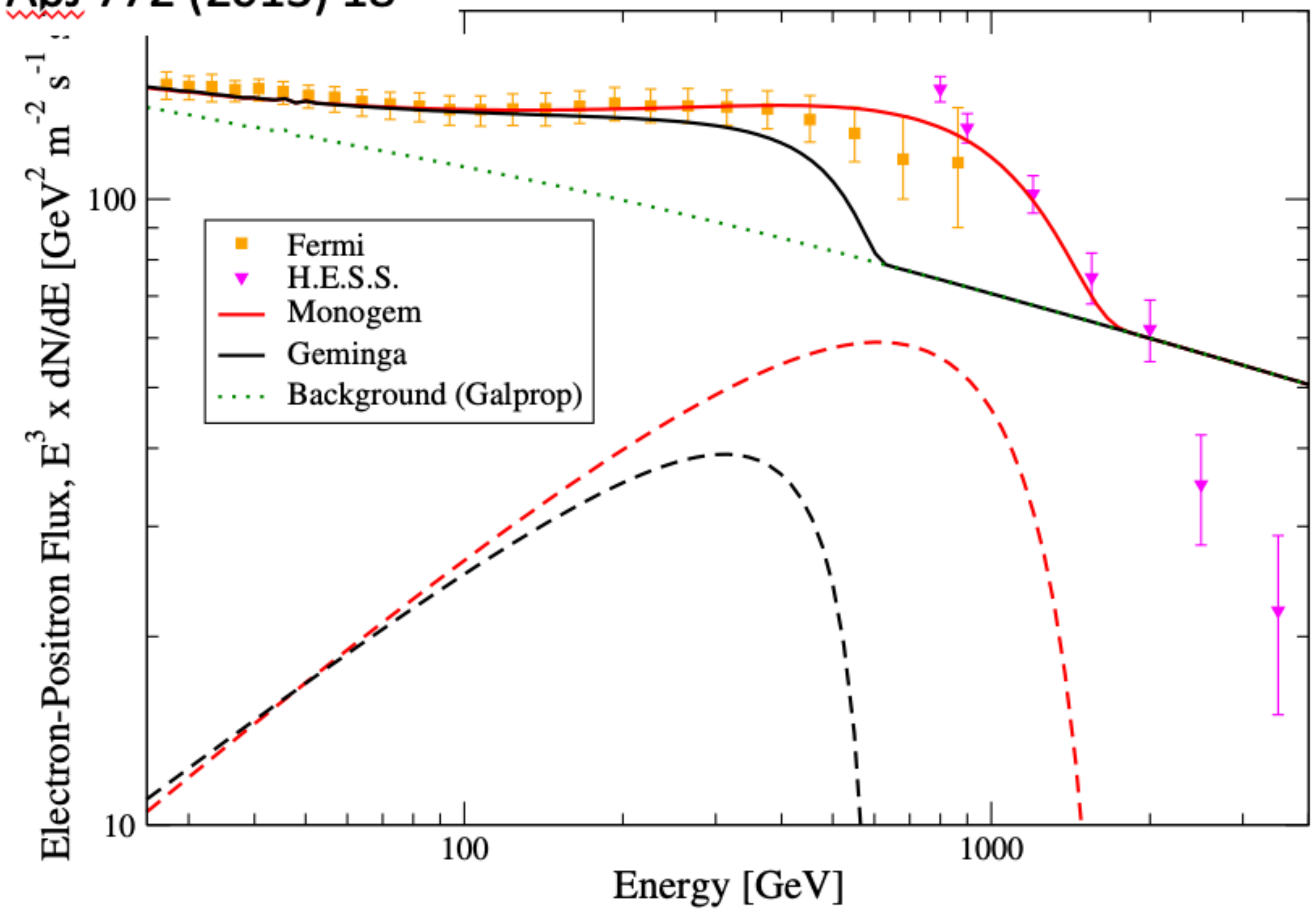


H.E.S.S. Collaboration (1603.07730)

Positron Excess from Pulsar

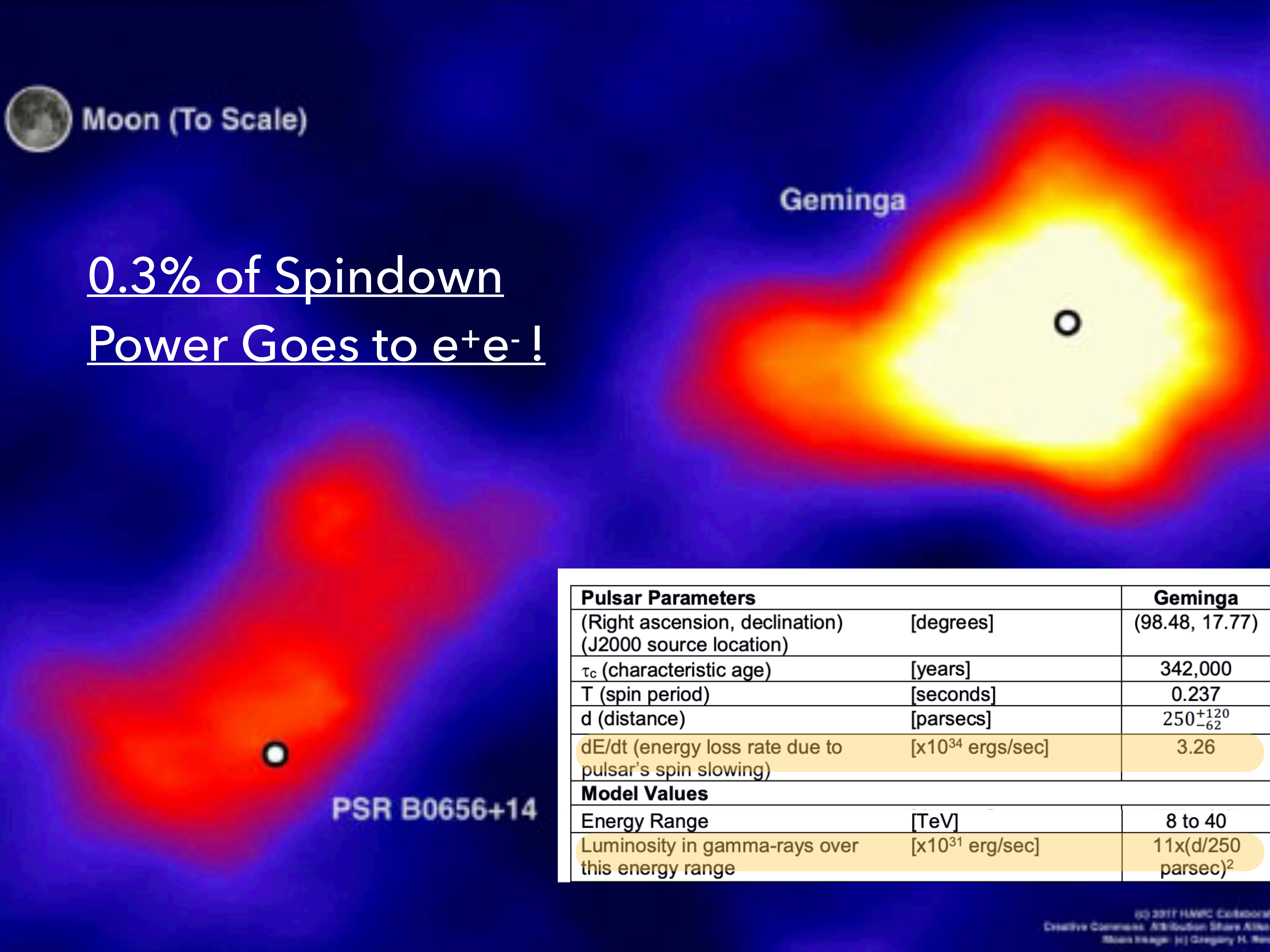
T. Linden et al., ApJ 772 (2013) 18





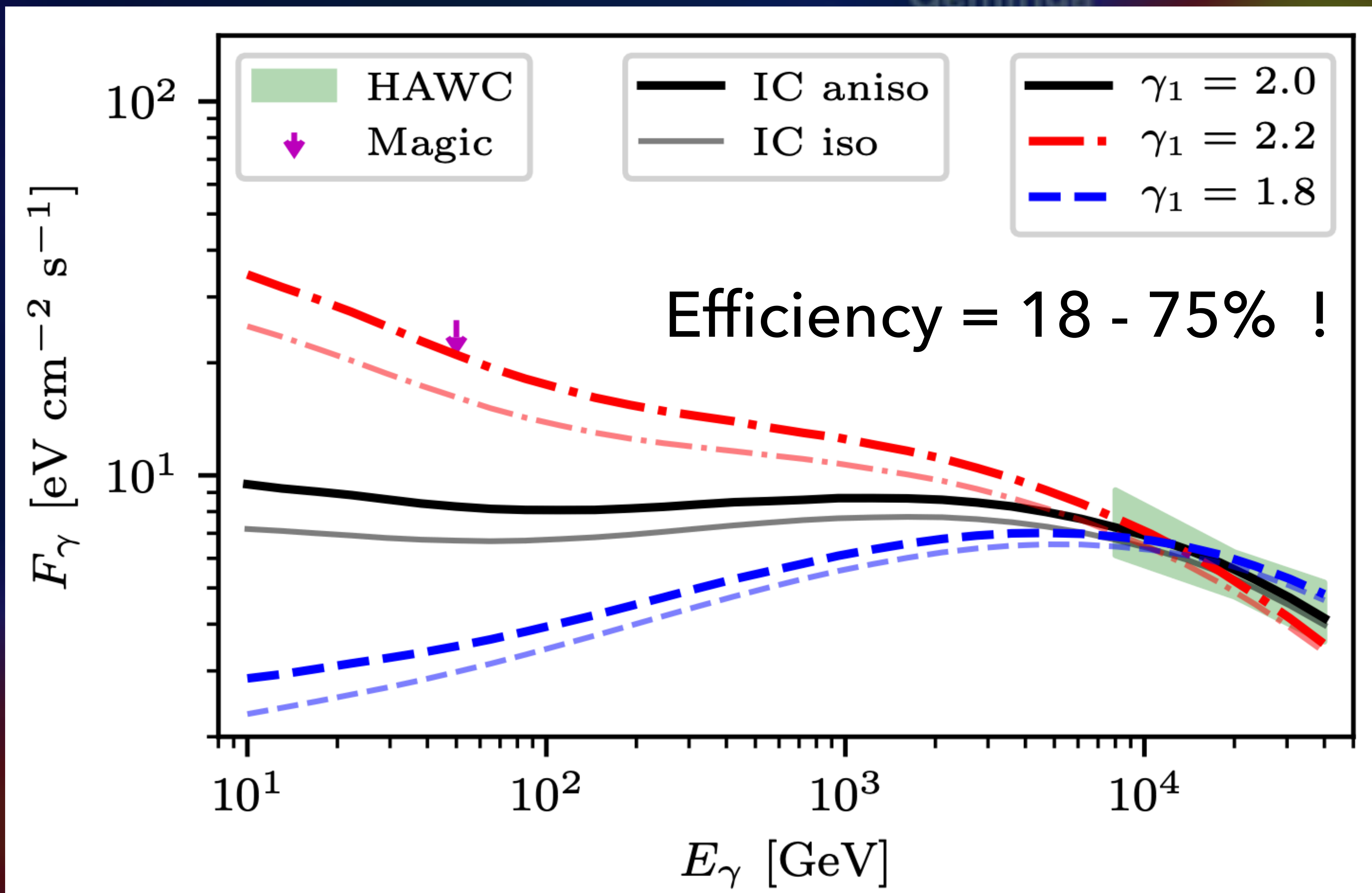
%. A quantitative discussion of plausible values for $f_{e^\pm}$ was recently given in Ref. [38]. We shall not review their discussion here, but Ref. [38] argues (see in particular their very informative App. B and C) that in the context of a standard model for the pulsar wind nebulae, a reasonable range for $f_{e^\pm}$ falls between 1% and 30%.

Profumo (0812.4457); Malyshev et al. (0903.1310)



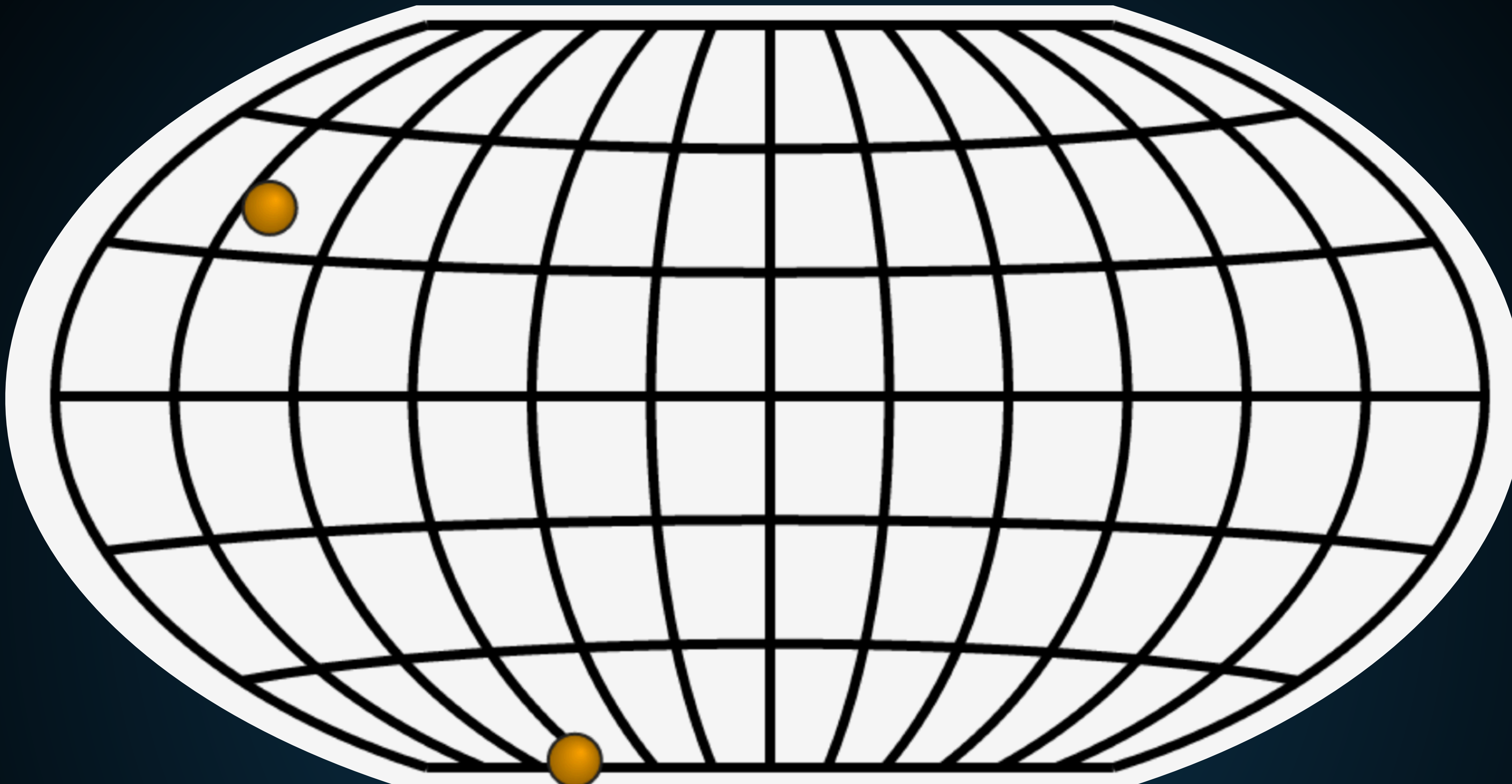
0.3% of Spindown Power Goes to e^+e^- !

Pulsar Parameters		Geminga
(Right ascension, declination) (J2000 source location)	[degrees]	(98.48, 17.77)
τ_c (characteristic age)	[years]	342,000
T (spin period)	[seconds]	0.237
d (distance)	[parsecs]	250^{+120}_{-62}
dE/dt (energy loss rate due to pulsar's spin slowing)	[x10^{34} ergs/sec]	3.26
Model Values		
Energy Range	[TeV]	8 to 40
Luminosity in gamma-rays over this energy range	[x10^{31} erg/sec]	11x(d/250 parsec)^2



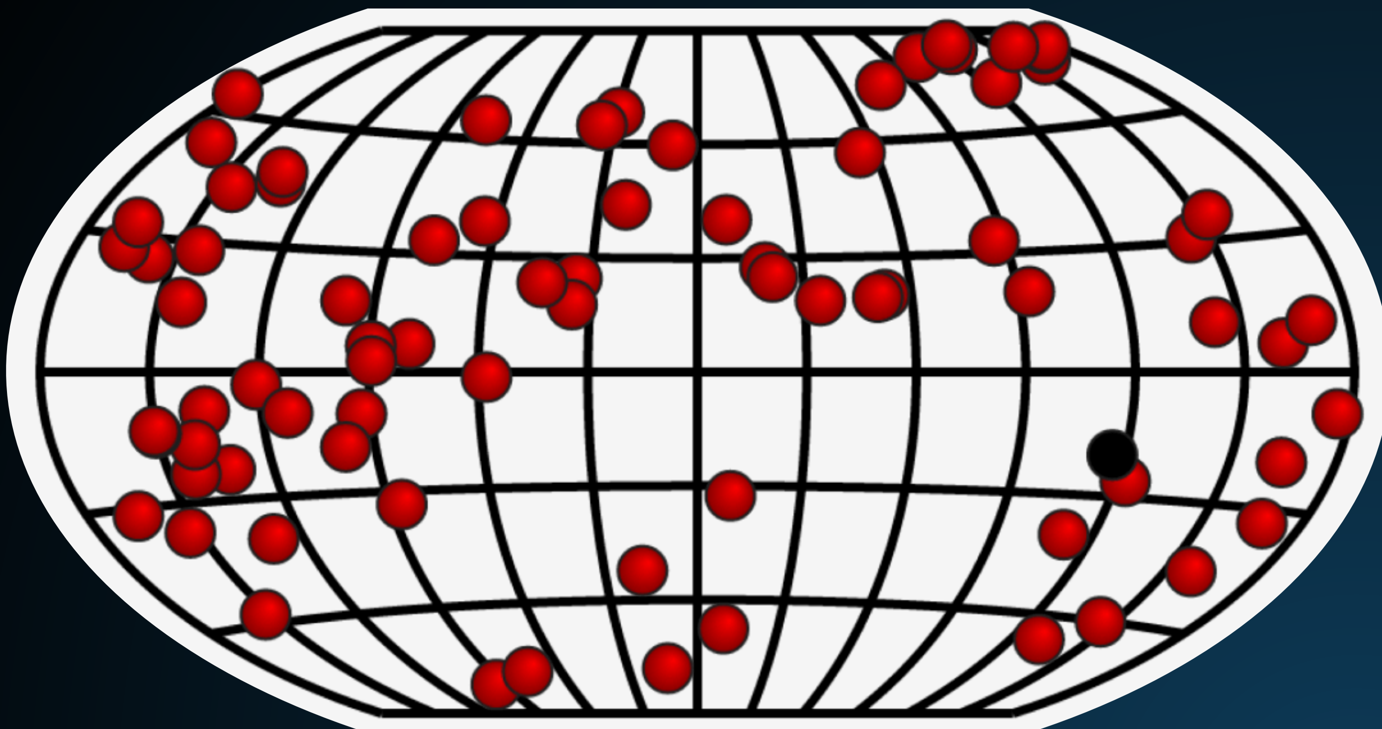
Jóhannesson et al. (1903.05509)

EXTRAGALACTIC SOURCES: ENSEMBLES OF LOCAL ACCELERATORS?



Are Extragalactic Sources Like the Milky Way?

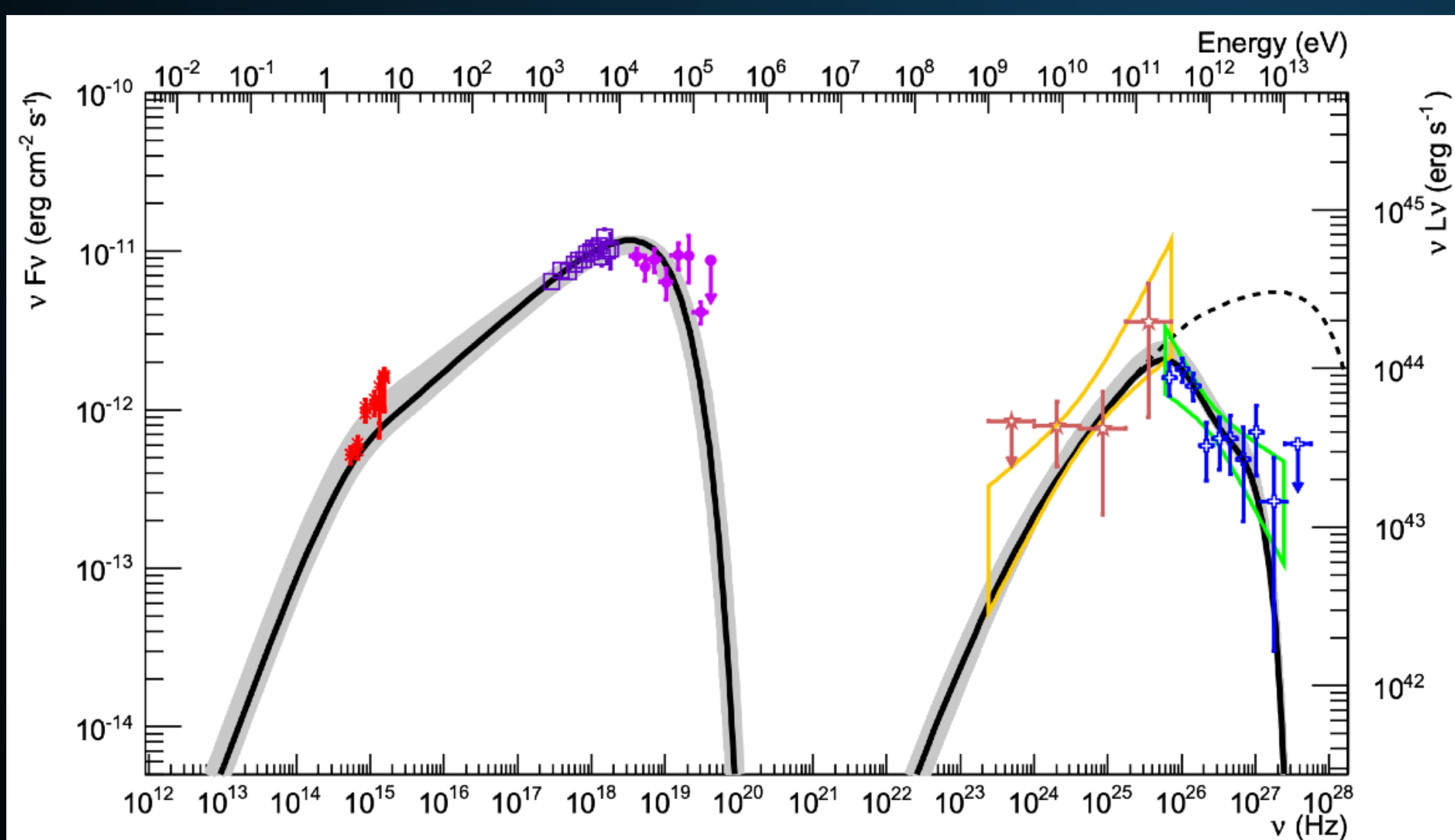
No!



Active Galactic Nuclei

78 Sources

FSRQ, BL Lac, FR-I, FR-2



VERITAS Collaboration (2013; 1312.6592)

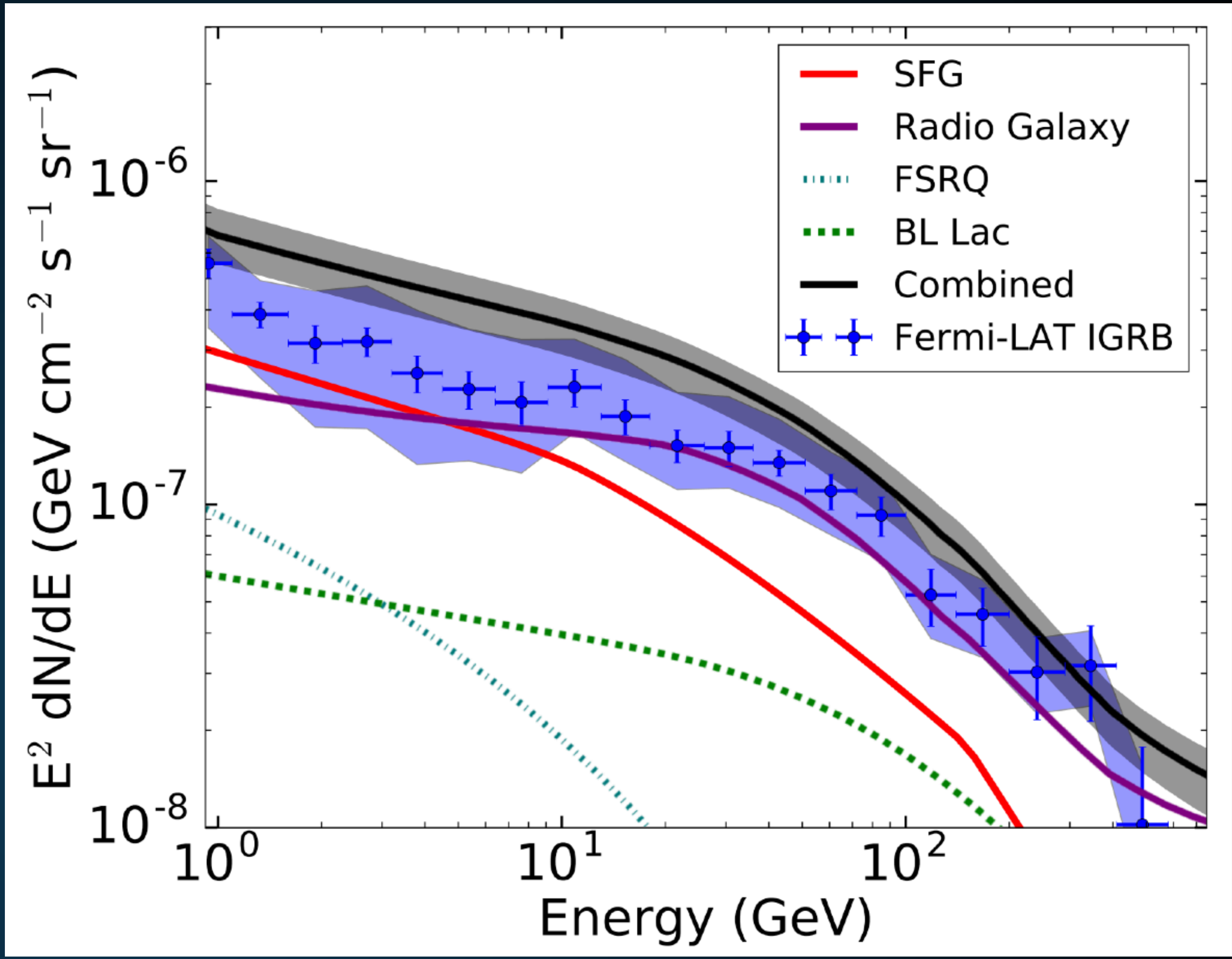
BUT WHAT ABOUT THE SUB-THRESHOLD SOURCES?

Linden (2017; 1612.03175)

Do blazars also make up the isotropic gamma-ray background?

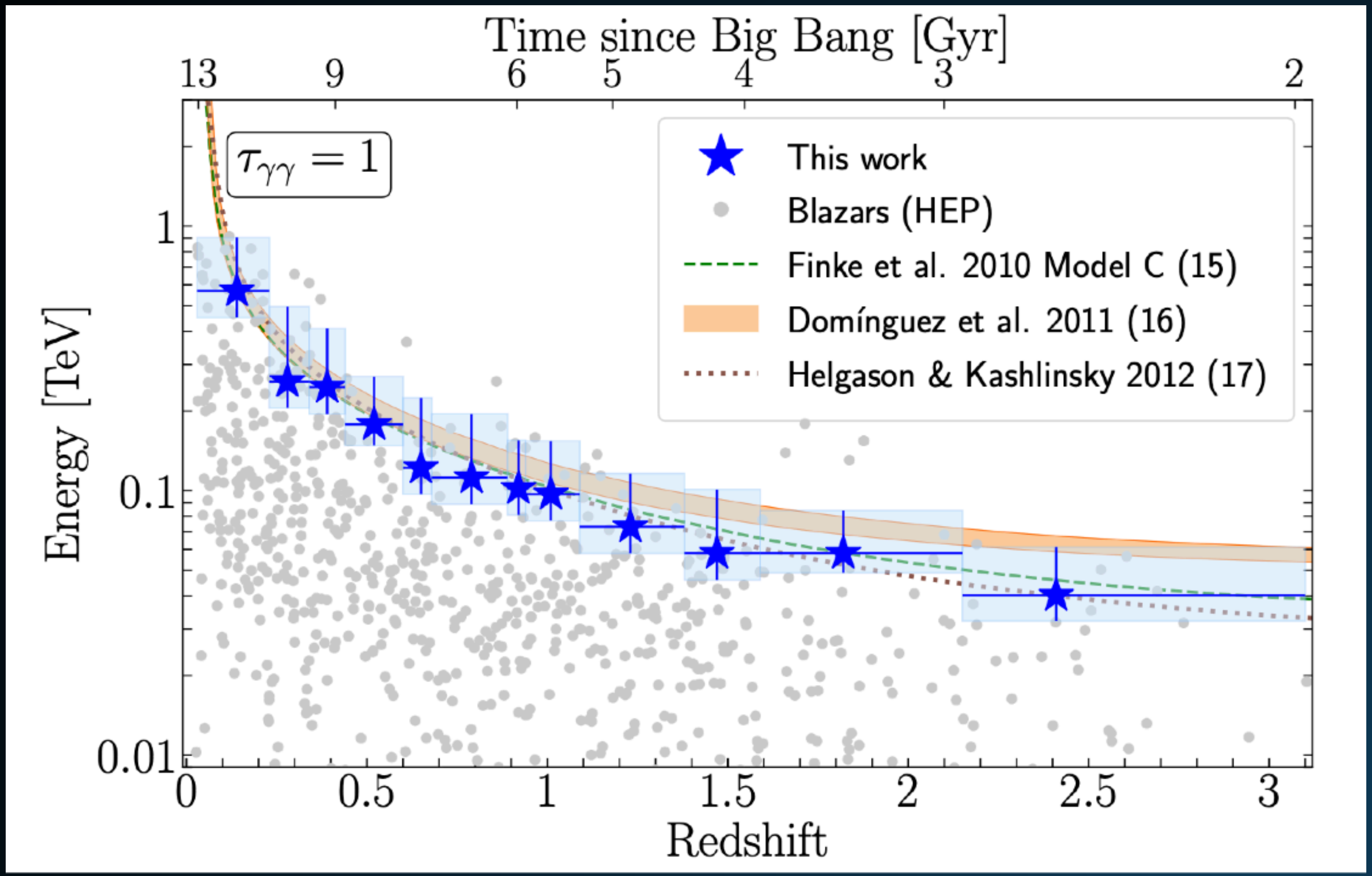
No!

Anisotropy constraints indicate that blazars are subdominant.



Instead Star Forming Galaxies and misaligned AGN appear to produce a similar contribution at GeV energies (with different spectra).

Fermi-LAT Collaboration (2018; 1812.01031)

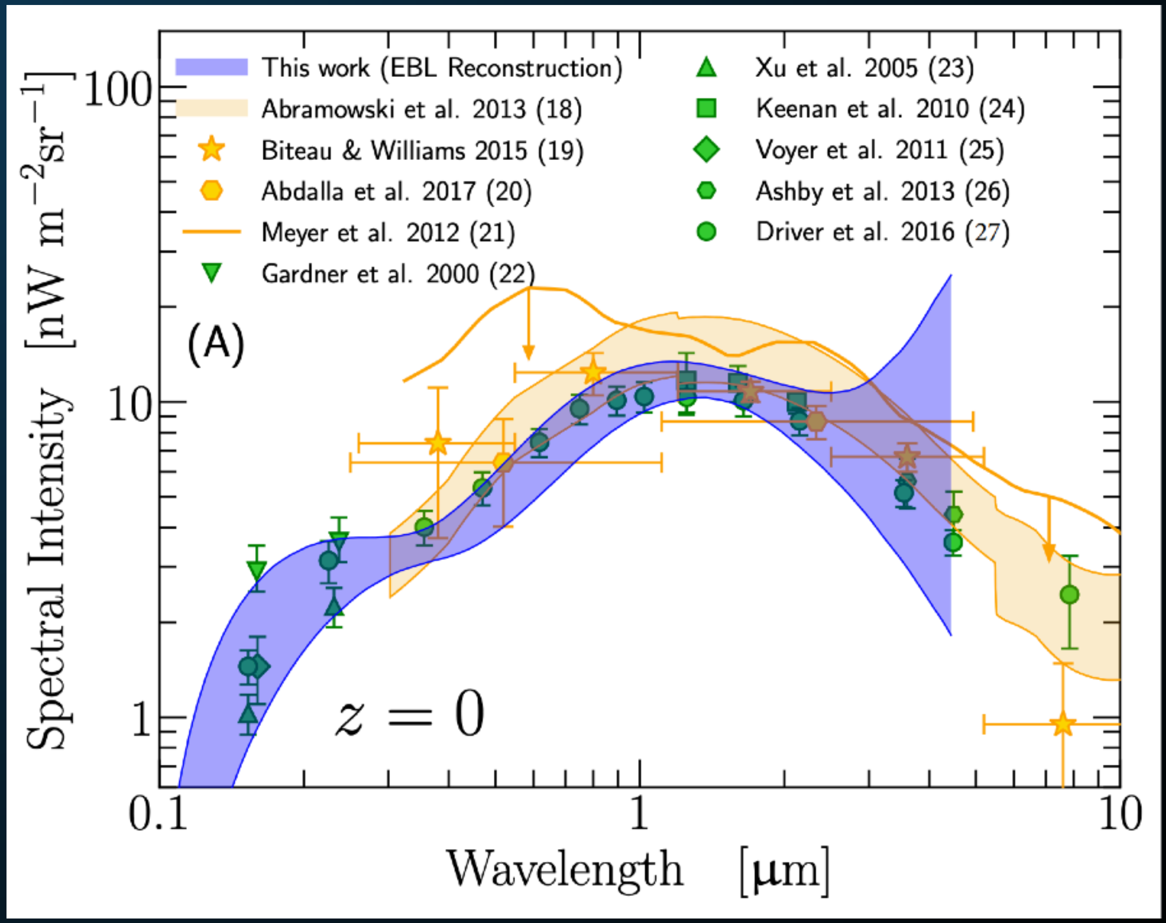


EBL Absorption!

Complementary to direct techniques.

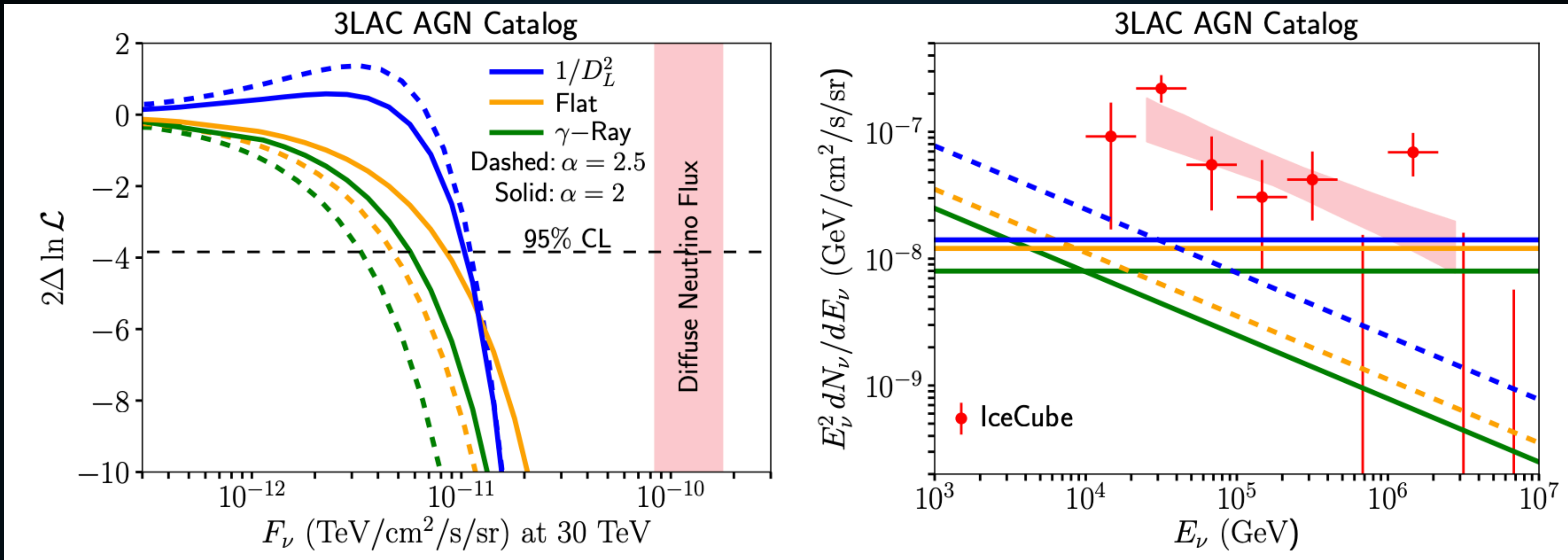
Reduced systematics (zodiacal light)

4 x 10^{84} visible photons in the universe!



SOURCE OF ICECUBE NEUTRINOS

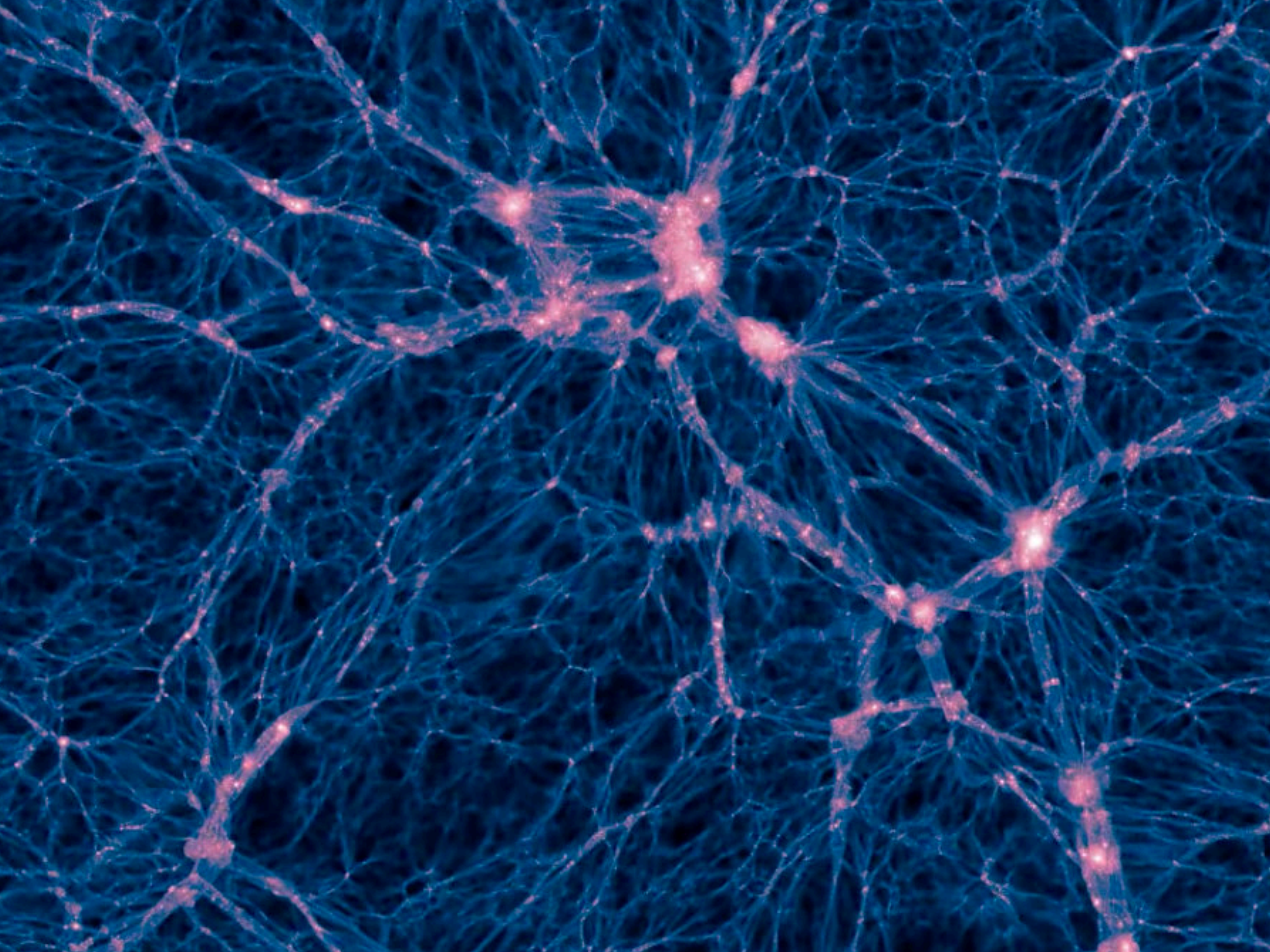
Hooper, TL, Vieregg (2018; 1810.02823)



The sources of IceCube neutrinos?

IceCube neutrinos do not appear to overlap FSRQ and BL Lac objects observed by Fermi.

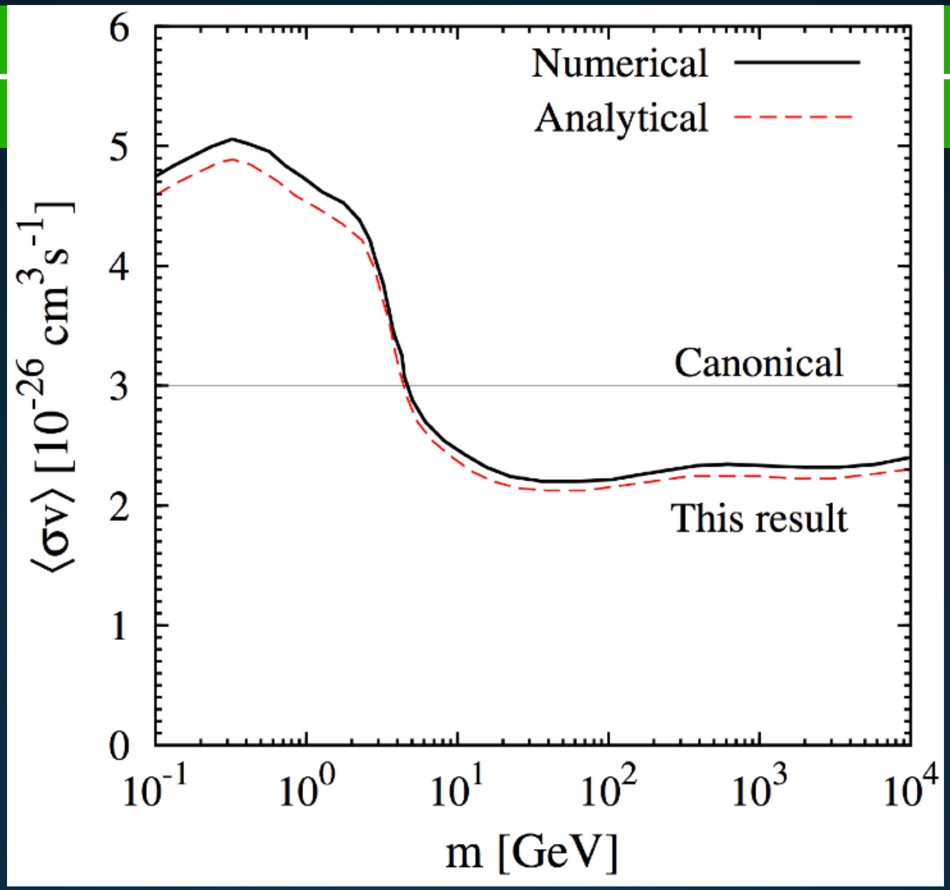
Any correlation must be more complex.



EXPECTED DARK MATTER SIGNAL IS MORE LOCAL

N_{eff}

>3 MeV



Steigman et al. (1204.3622)

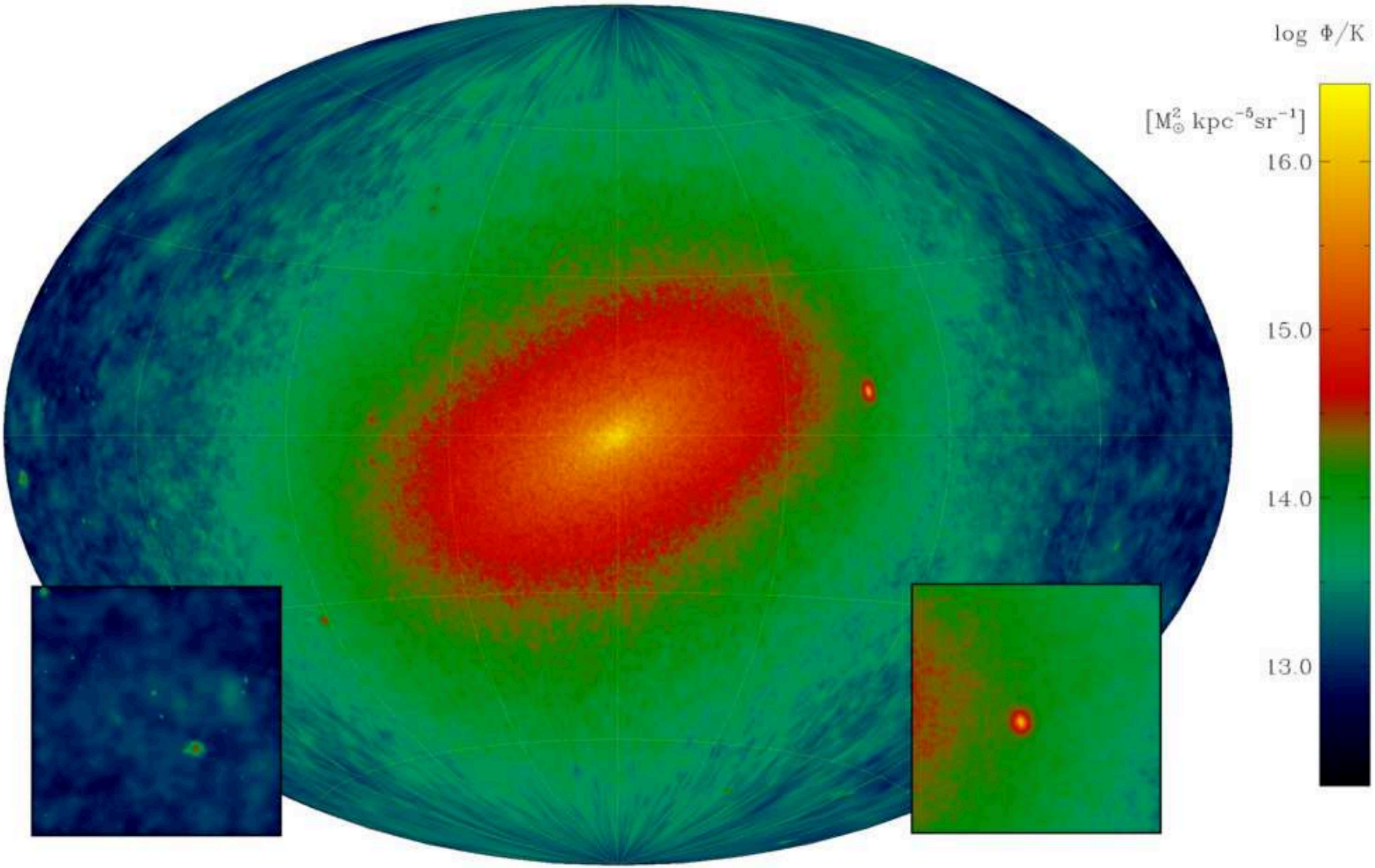
Unitarity

< 124 TeV

The simplest dark matter model is thermal – predicts a specific cross-section in a mass range from ~3 MeV – 100 TeV.

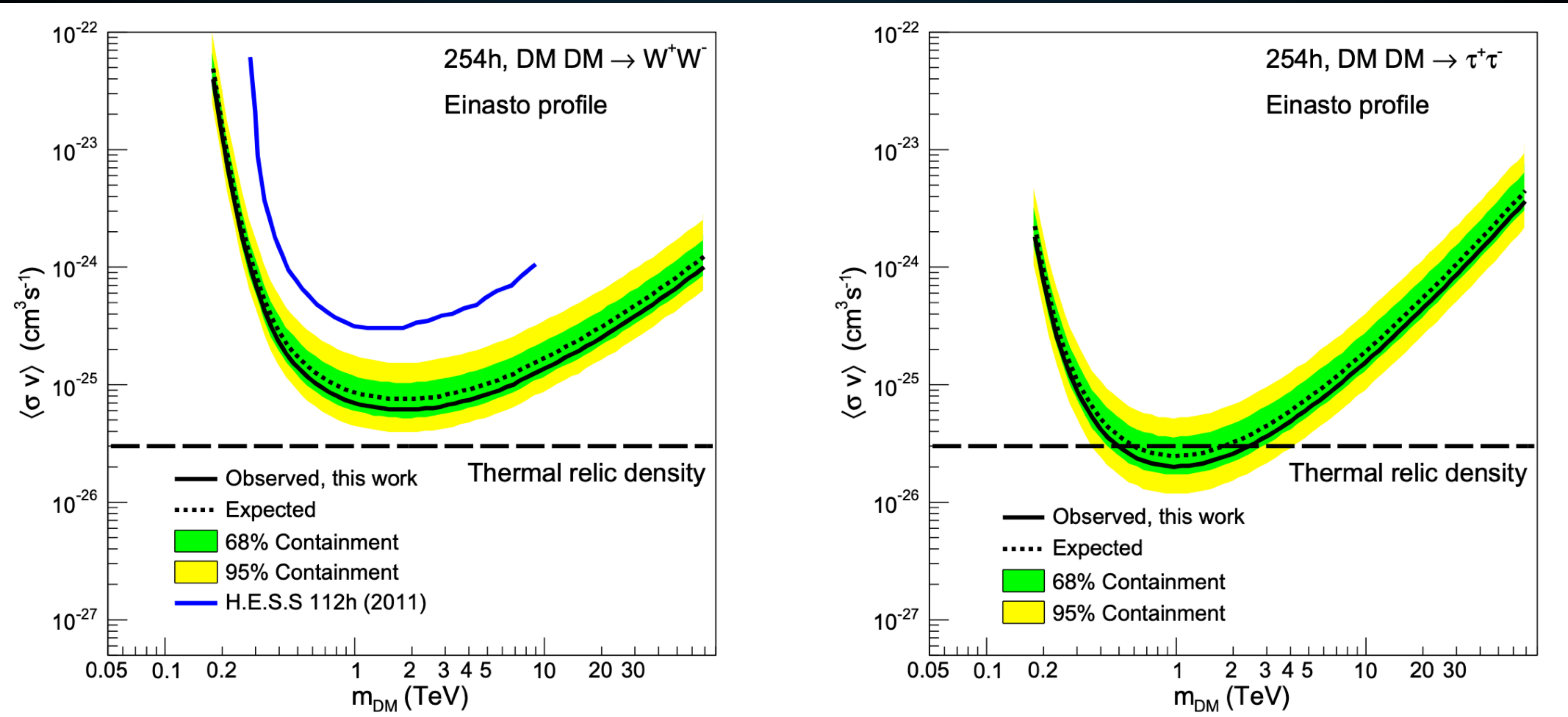
Ruling out this model only leaves more interesting possibilities!

EXPECTED DARK MATTER SIGNAL IS MORE LOCAL



GALACTIC CENTER CONSTRAINTS

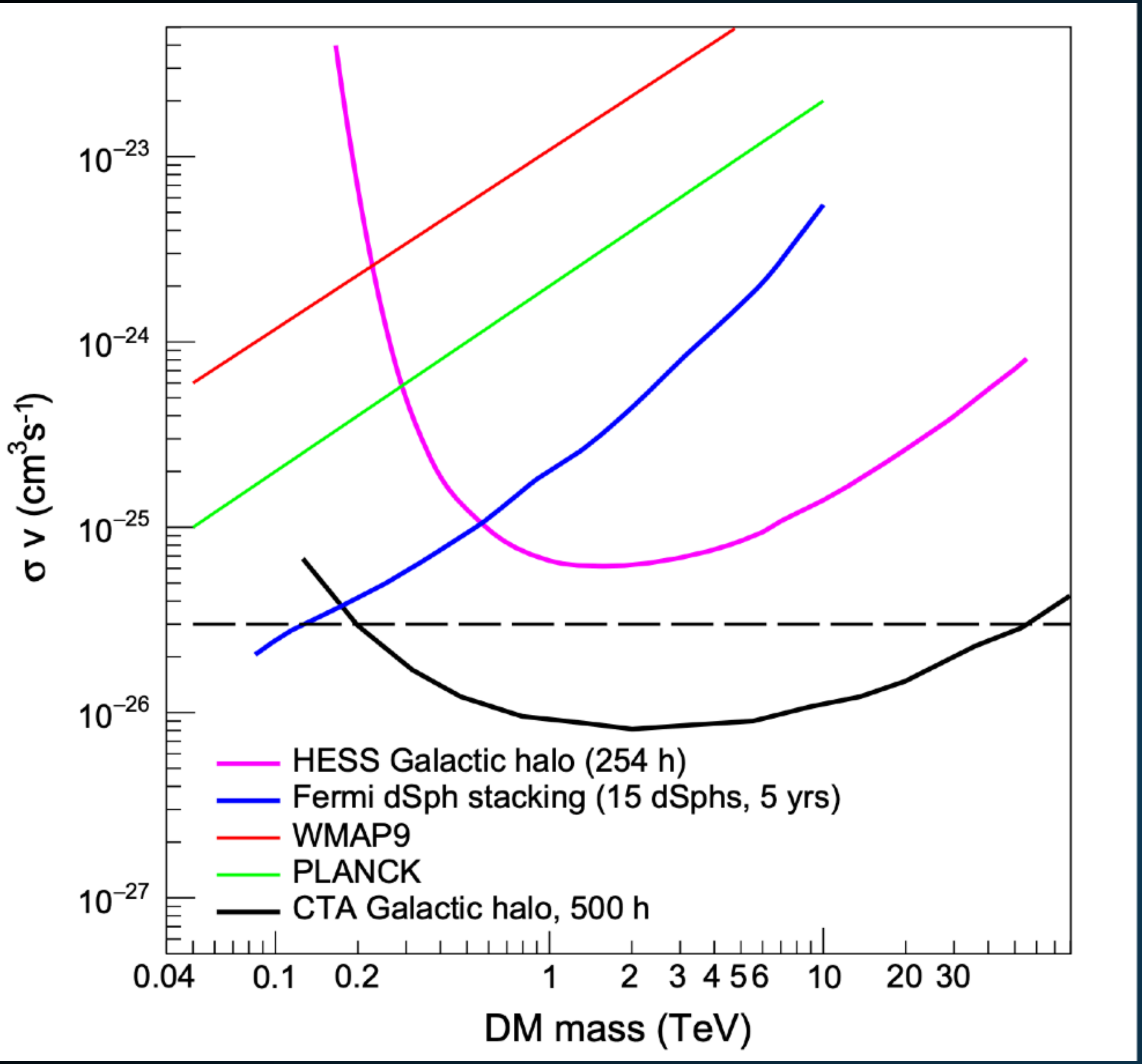
H.E.S.S. Collaboration (2016; 1607.08142)

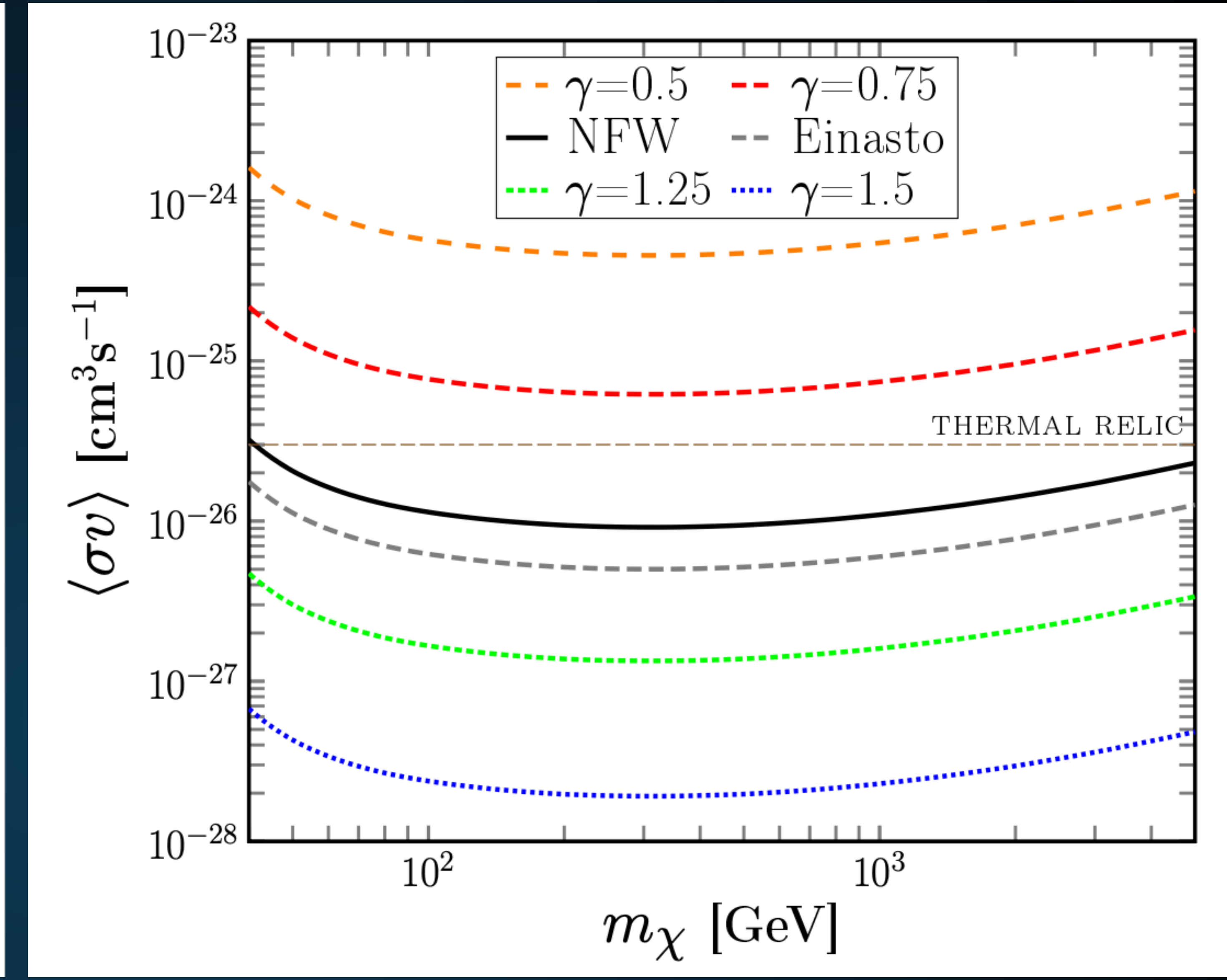


H.E.S.S. Observations have made the first push into the thermal cross-section in the TeV mass range (for specific profiles and final states).

EXPECTED DARK MATTER SIGNAL IS MORE LOCAL

Morselli (2017; 1709.01483)
Pierre et al. (2014; 1401.7330)



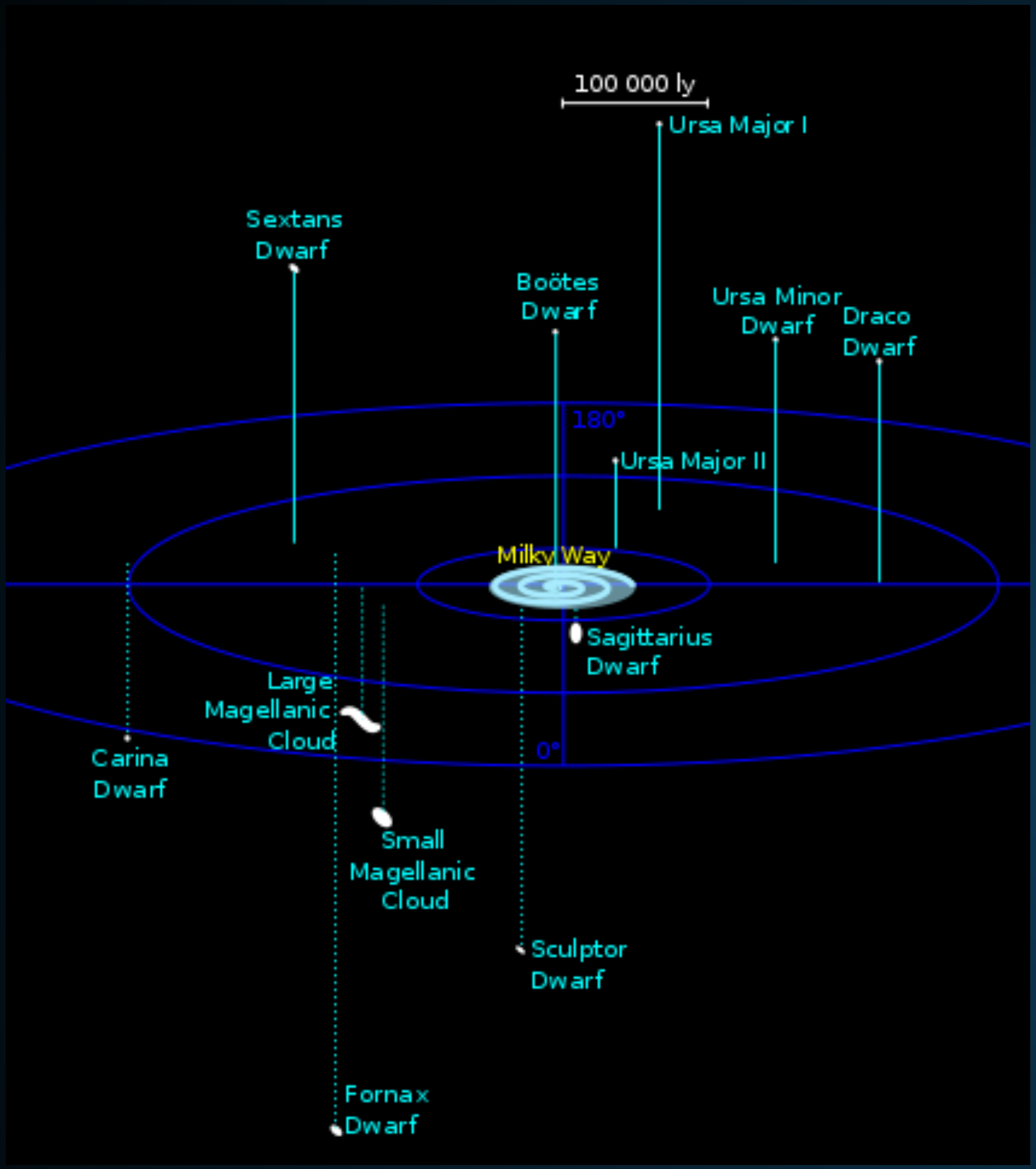


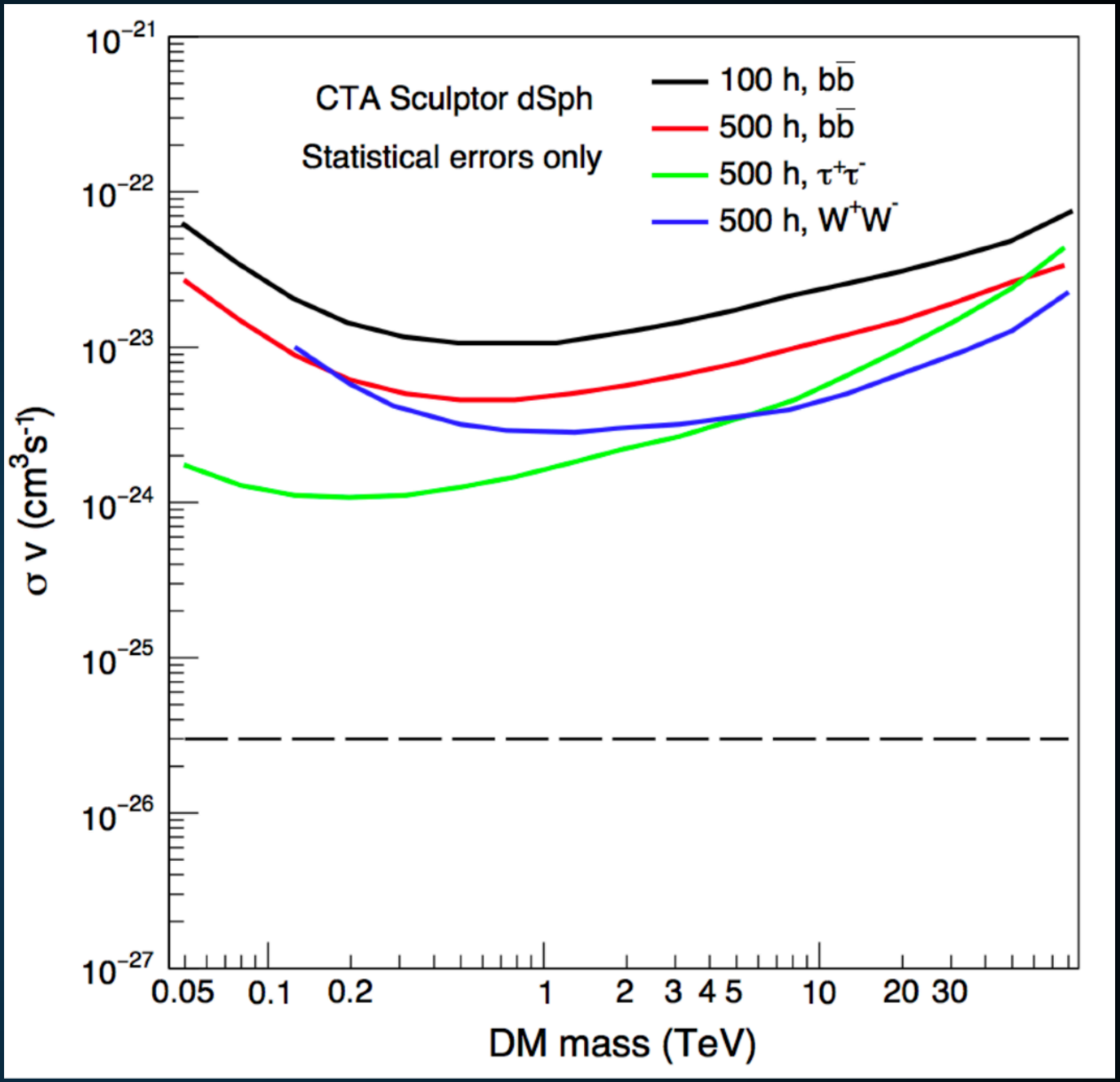
CTA can potentially rule out the TeV parameter space.

Results strongly depend on the Galactic center dark matter density profile.

EXPECTED DARK MATTER SIGNAL IS MORE LOCAL

Morselli (2017; 1709.01483)





Can still search in Milky Way dwarfs, but less promising:

Nearby Dwarfs

Sommerfeld Enhancements

Intermediate Mass Black Holes

CONCLUSIONS