Overview and Summary

Connecting high-energy astroparticle physics for origins of cosmic rays and future perspectives

Toshihiro Fujii (Kyoto Unviersity)

December 7 - 10, 2020

Connecting high-energy astroparticle physics for origins of cosmic rays and future perspectives

December 7 - 10, 2020, Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto, Japan

Invited talk (25 min + 5 min), Oral contribution (10 min + 5 min), Poster talk (5 min + on-site display)
Time-zone: Japan Standard Time

148 registrations
51 contributions

Thank you so much for your contributions and participations!

12/7 (Mon.)

13:00-14:30 Registration

14:30-15:20 Welcome coffee, Opening, Self-introduction (1 min/person) (optional)

15:30-19:00 Session1 — Chairperson: Kohta Murase

- 15:30-16:00 **Kazumasa Kawata** — **100 TeV Gamma-Ray Observation with Extensive Air Shower Arrays**
- 16:00-16:15 Sei Kato — VHE gamma-ray astronomy using the prototype array of a new extensive air-shower-array experiment ALPACA in the southern hemisphere
- 16:15-16:30 Kimura Shigeo — Gamma-ray and neutrino emission from radiatively inefficient accretion flows
- 16:30-17:00 **Foteini Oikonomou** — **High-energy neutrino emission from blazars**
- [30 minutes break]
- 17:30-18:00 **Olivier Deligny** — **The UHECR science after 15 years of operation of the Pierre Auger Observatory**
- 18:00-18:30 **Yana Zhezher** — **Overview of the Telescope Array experiment**
- 18:30-19:00 **Anatoli Fedynitch** — **Hadronic interactions in cosmic ray physics**

12/8 (Tue.)

09:00-12:30 Session2 — Chairperson: Aya Ishihara

- 09:00-09:30 **Takatomi Yano** — **Neutrino astrophysics prospect at Super-Kamiokande and Hyper-Kamiokande**
- 09:30-10:00 **Ignacio Taboada** — **Recent Astrophysical results of IceCube**
- 10:00-10:30 **Stephanie Wissel** — **Radio detection of ultrahigh-energy neutrinos: present and future**
- [30 minutes break]
- 11:00-11:30 **Nepomuk Otte** — **Trinity: An Air-Shower Imaging Instrument to detect Ultrahigh-Energy Neutrinos**
- 11:30-12:00 **Ruoyu Liu** — **The Giant Radio Array for Neutrino Detection**
- 12:00-12:15 Mahdi Bagheri — The VHE Neutrino Cherenkov telescope onboard EUSO-SPB2
- 12:15-12:30 Susumu Inoue — High-energy neutrino and gamma-ray emission from AGN-driven winds

14:30 - 15:00 Poster session (5 min / person) and coffee, Chairperson: Wataru Ishizaki

- Satoshi Takashima — GRAMS project: A MeV gamma-ray large area telescope using liquid argon and its concept study
- Susumu Inoue — The Blazar Hadronic Code Comparison Project
- Ken Matsuno — Particle acceleration by ion-acoustic solitons in plasma in a magnetic field
- Ken Ohashi — Effects of diffractive collisions on predictions of the number of muons in the air shower
- Tomohiko Oka — The time-evolution measurement of a diffusive shock acceleration using supernova remnants and local molecular clouds

15:30-19:15 Session3 — Chairperson: Hiroaki Menjo

- 15:30-16:00 **Teruaki Enoto** — **High-Energy Atmospheric Physics of Lightning and Thunderstorms Observed along the Sea of Japan**
- 16:00-16:30 **Markus Alhers** — **Cosmic-Ray Anisotropy**
- 16:30-17:00 **Roberta Colalillo** — **The Pierre Auger Observatory and the study of atmospheric electricity phenomena**
- [30 minutes break]
- 17:30-18:00 **Ioana Maris** — **Future Detectors for Measuring Ultra High Energy Cosmic Rays from the Ground**
- 18:00-18:30 **Maria Petropoulou** — **Blazar neutrinos: implications of recent IceCube observations**
- 18:30-19:00 **Walter Winter** — **Gamma-ray bursts and tidal disruption events as the sources of UHECRs and neutrinos**
- 19:00-19:15 Norita Kawanaka — Origin of Spectral Hardening of Secondary Cosmic-Ray Nuclei

12/9 (Wed.)

09:00-12:10 Session4 — Chairperson: Kunihito Ioka

- 09:00-09:30 **Yoshihiro Ueda** — **The origin of the cosmic X-ray background**
- 09:30-10:00 **Yoshiyuki Inoue** — **Future Prospects of MeV Gamma-ray Astronomy**
- 10:00-10:30 **Keith Bechtol** — **Using optical surveys to explore the origin of cosmic rays**
- [25 minutes break]
- 10:55-11:25 **Andreas Zoglauer** — **Future missions in the MeV domain: COSI & AMEGO**
- 11:25-11:55 **Atsushi Takada** — **MeV gamma-ray observations utilizing electron-tracking Compton cameras loaded on balloons**
- 11:55-12:10 Nagisa Hiroshima — Dark matter search in extended dwarf spheroidal galaxies with CTA

14:30 - 15:00 Poster session (5 min /person) and coffee, Chairperson: Wataru Ishizaki

- Yutaka Fujita — Intrusion of Cosmic-Rays into Molecular Clouds Studied by Ionization, the Neutral Iron Line, and Gamma-Rays
- Yugo Omura — NICHE detector and analysis results
- Ryo Sawada — A Consistent Modeling of Neutrino-driven Wind with Accretion Flow onto a Protoneutron Star and its Implications for 56Ni Production
- [illegible] — The Fluorescence detector Array of Single-pixel Telescopes: The next-generation cosmic ray observatory

15:30-19:00 Session5 — Chairperson: Yudai Suwa

- 15:30-16:00 **Yutaka Ohira** — **Cosmic-ray acceleration in supernova remnants**
- 16:00-16:15 Naomi Tsuji — Systematic study of acceleration efficiency in young supernova remnants
- 16:15-16:30 Hiromasa Suzuki — Observational gamma-ray and X-ray study on cosmic-ray escape from supernova remnants
- 16:30-16:45 Tomoaki Kasuga — cipher: a CubeSat-Based Hard X-ray Imaging Polarimetry Mission
- [30 minutes break]
- 17:15-17:45 **Kumiko Kotera** — **Pulsars and magnetars as high-energy cosmic particle sources**
- 17:45-18:15 **Andrew Taylor** — **Particles Acceleration in the Jets of Centaurus A**
- 18:15-18:30 Merten Lukas — Ultra-high Energy Cosmic Rays Acceleration in FR 0 Radio Galaxies
- 18:30-19:00 **Yoshiyuki Takizawa** — **Observation of ultra high energy cosmic rays from space (K-EUSO and POEMMA)**

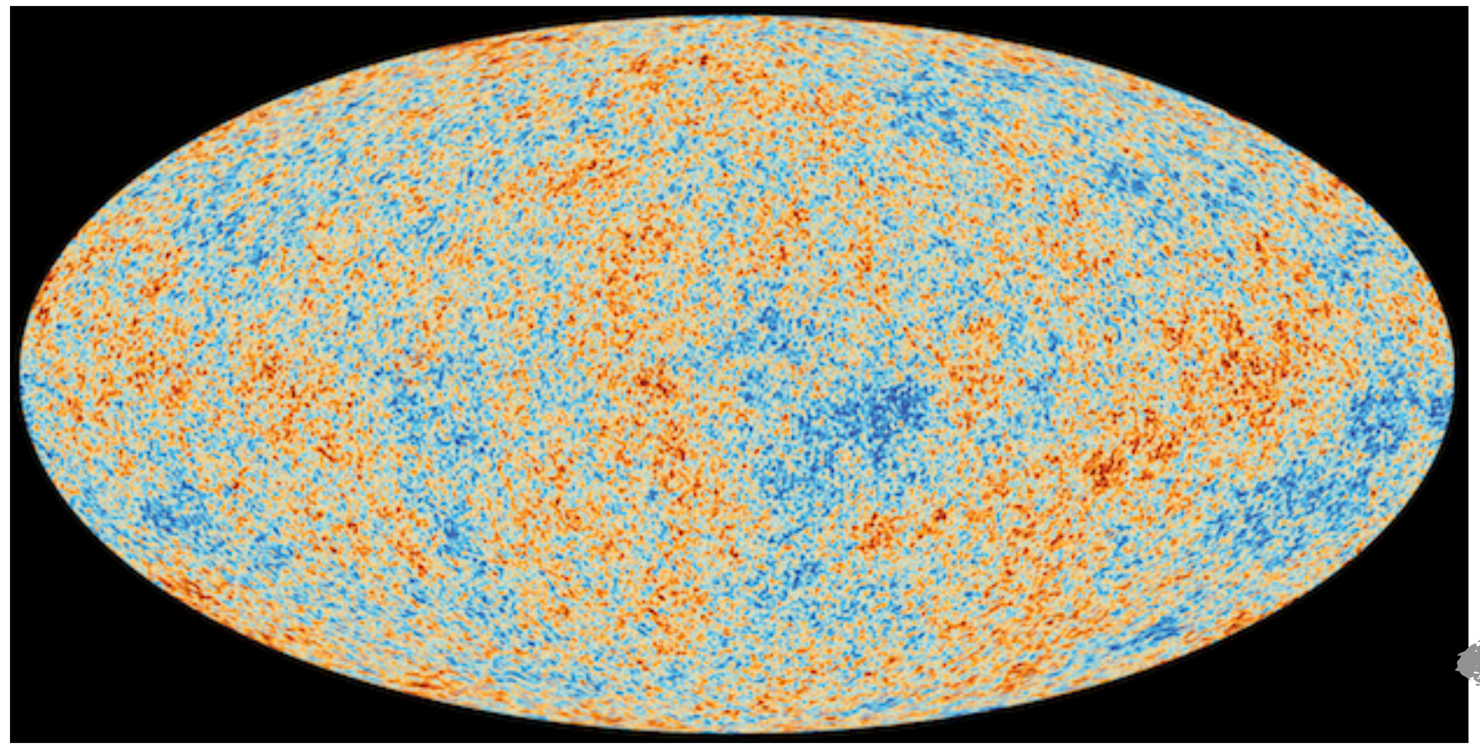
12/10 (Thu.)

09:00-12:45 Session6 — Chairperson: Tsuyoshi Nakaya

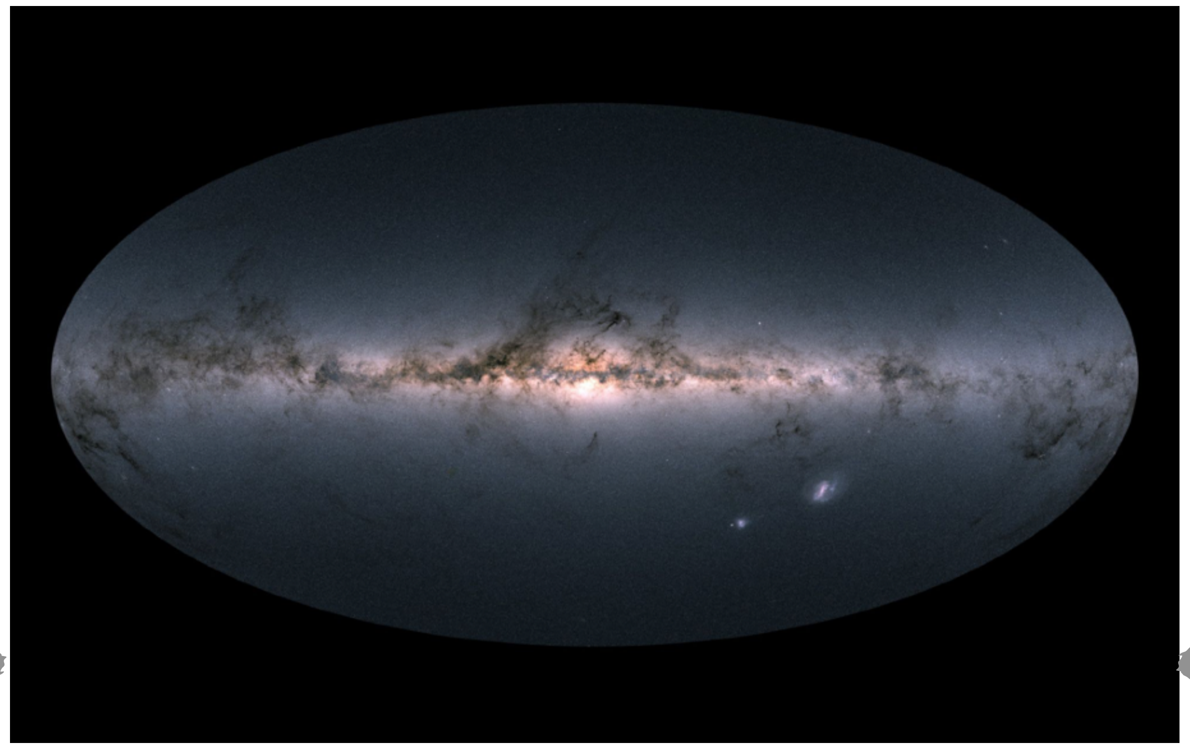
- 09:00-09:30 **Kazumi Kashiyama** — **Fast Radio Bursts: A Mystery Being Solved?**
- 09:30-09:45 Lin Haoxiang — Afterglows of neutron star mergers and fast radio bursts
- 09:45-10:15 **Imre Bartos** — **Compact object mergers as high-energy multi-messenger sources**
- 10:15-10:30 Shuta Tanaka — Stochastic acceleration model of very young pulsar wind nebula associated with SN 1986J
- [30 minutes break]
- 11:00-11:30 **Ke Fang** — **High-energy Cosmic Particles by Black-hole Jets in Galaxy Clusters**
- 11:30-12:00 **Ali Kheirandish** — **High-Energy Neutrinos as Probes of New Physics**
- 12:00-12:15 Ryo Higuchi — Effects of Galactic magnetic field on the UHECR anisotropy studies
- 12:15-12:30 On Alvina Yee Lian — Diagnosing the invisible: cosmic magnetism and the radio sky
- 12:30-12:45 Takahiro Sudoh — Millisecond Pulsars Modify the Radio-SFR Correlation

14:30 - 16:00 Summary — Chairperson: Toshihiro Fujii

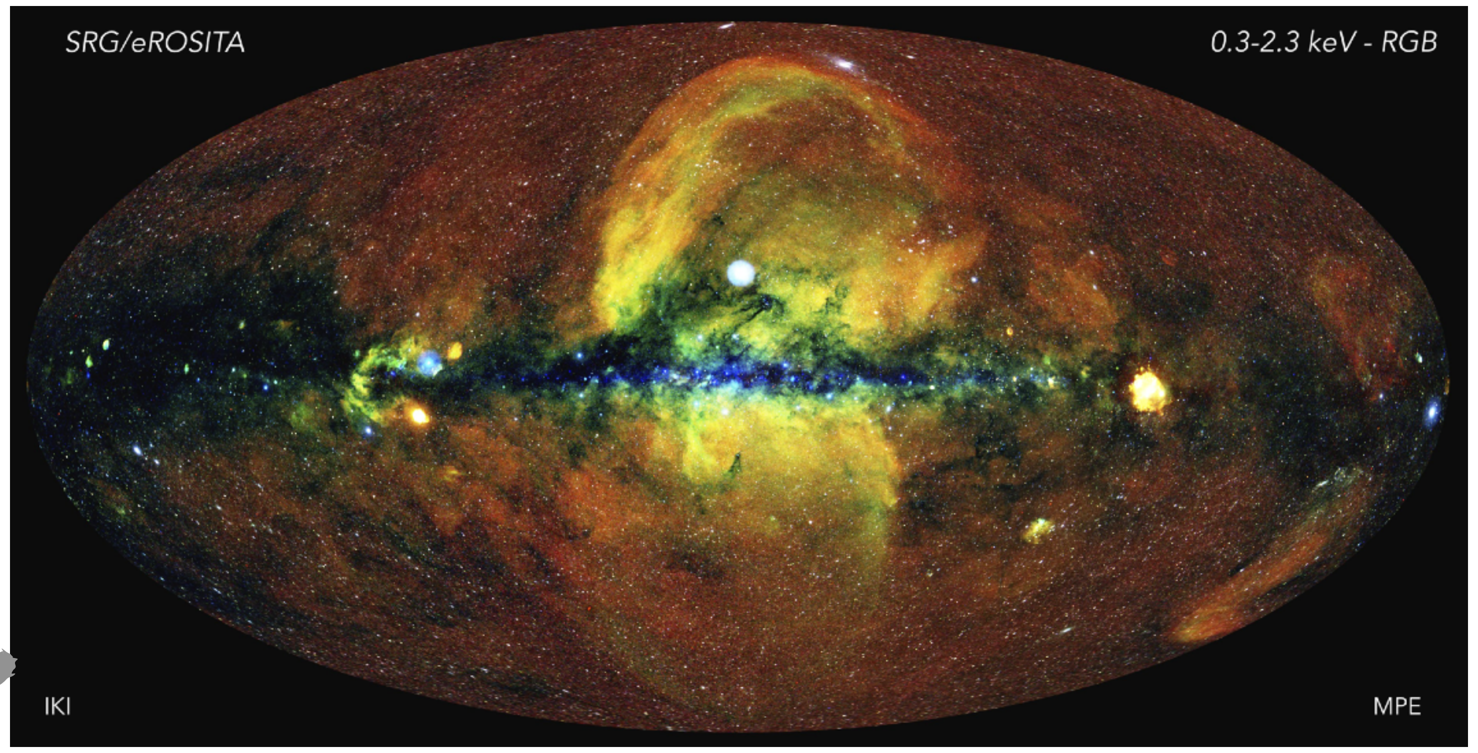
- 14:30-15:30 Overview Discussion and Summary
- 15:30-16:00 Workshop Photo and Closing



Planck Collaboration

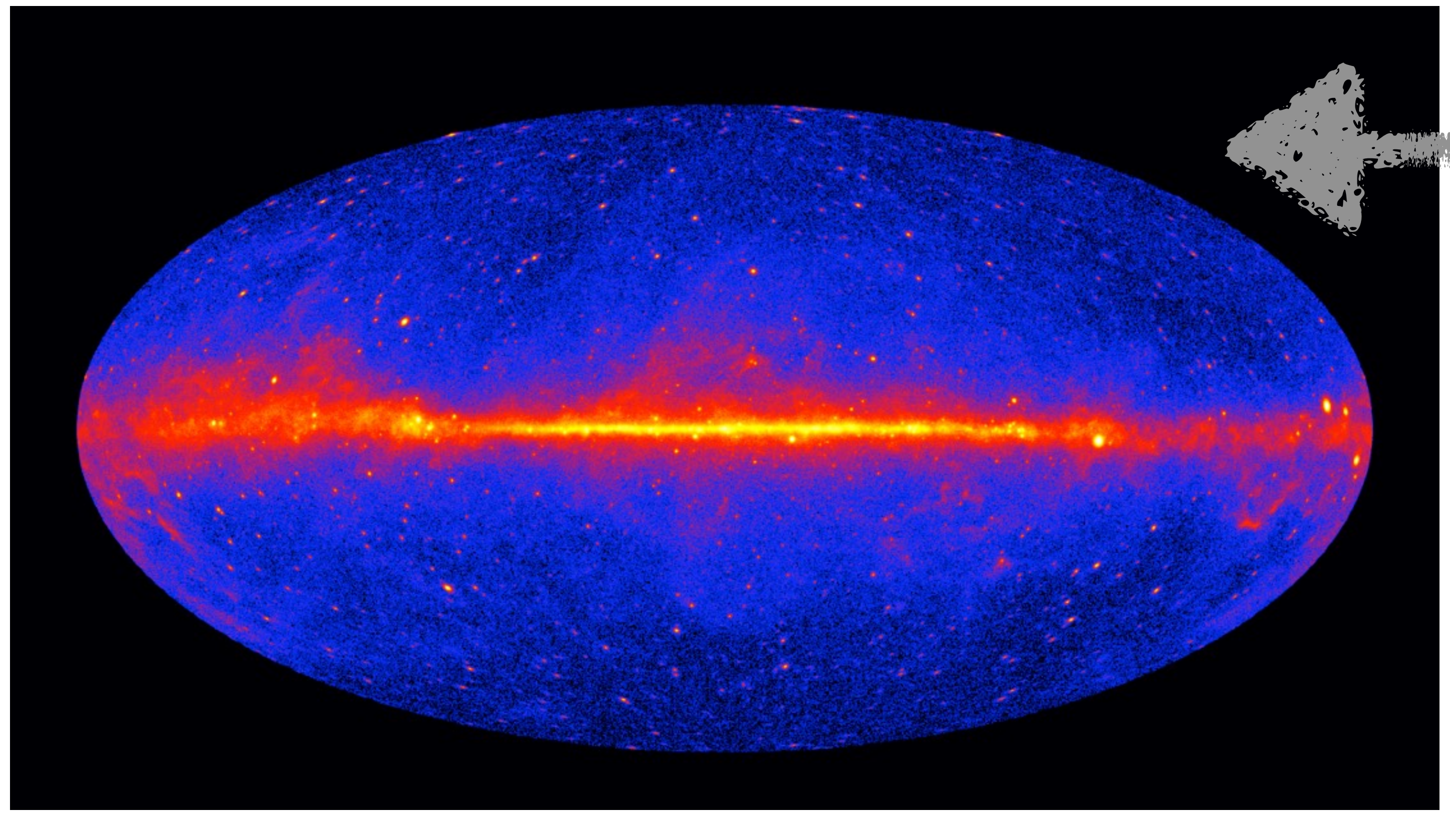


GAIA Collaboration

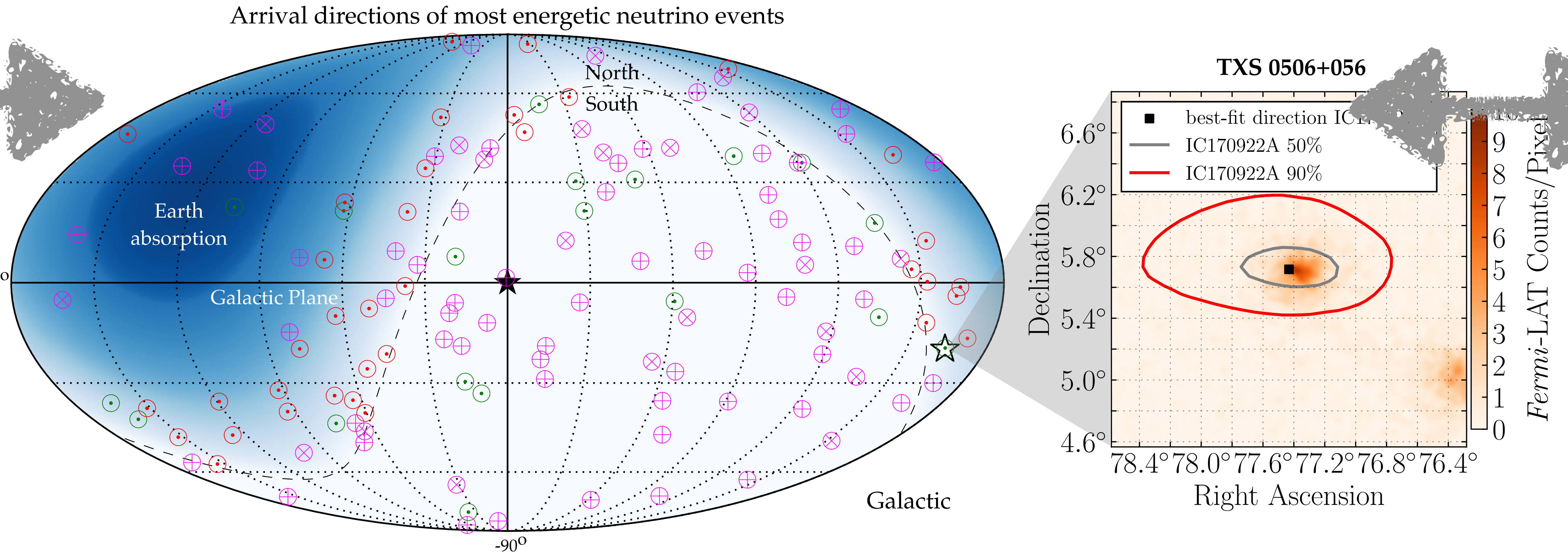


eROSITA Collaboration

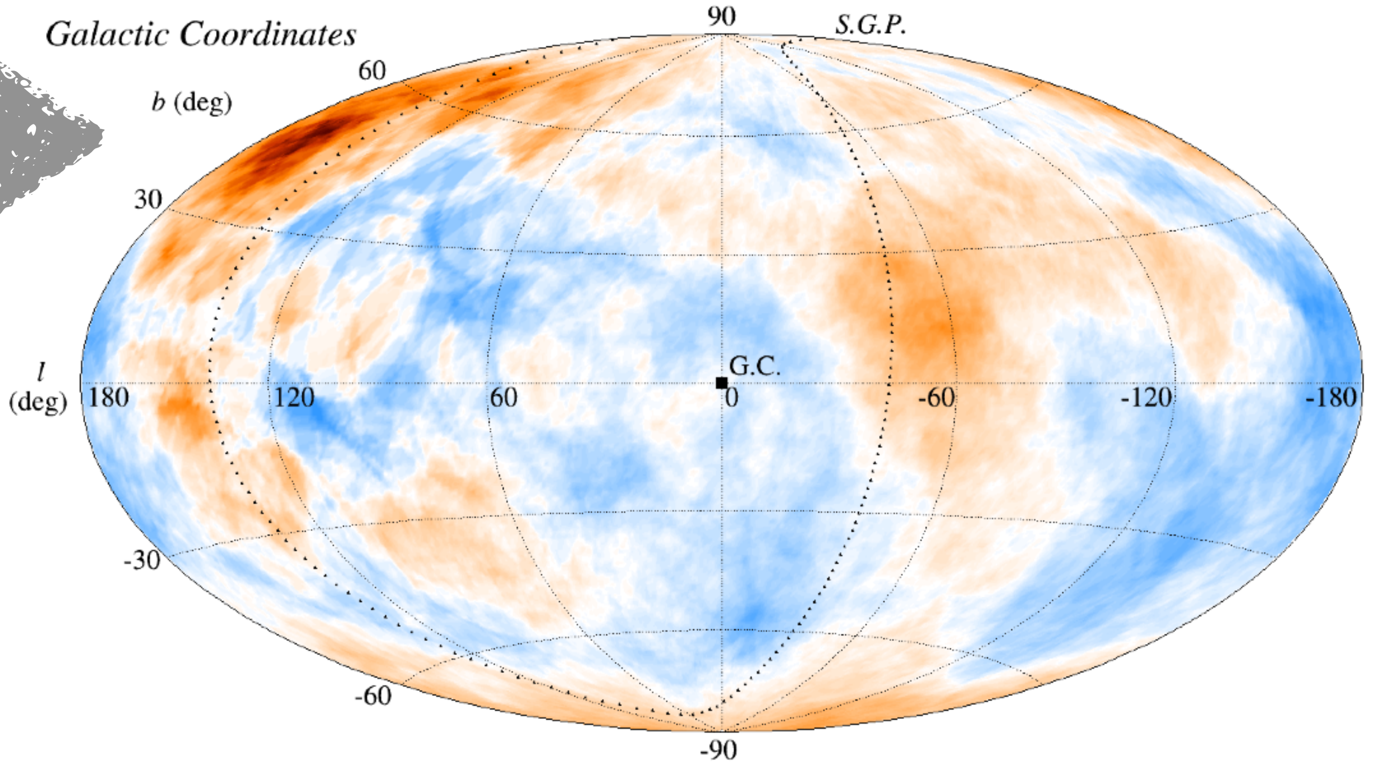
Cosmic Ray Ground Unified Theory (CR-GUT)



Fermi Collaboration



IceCube Collaboration



Auger and TA Collaborations

Connecting multi-wavelength multi-particle observations

X-ray MeV GeV - TeV

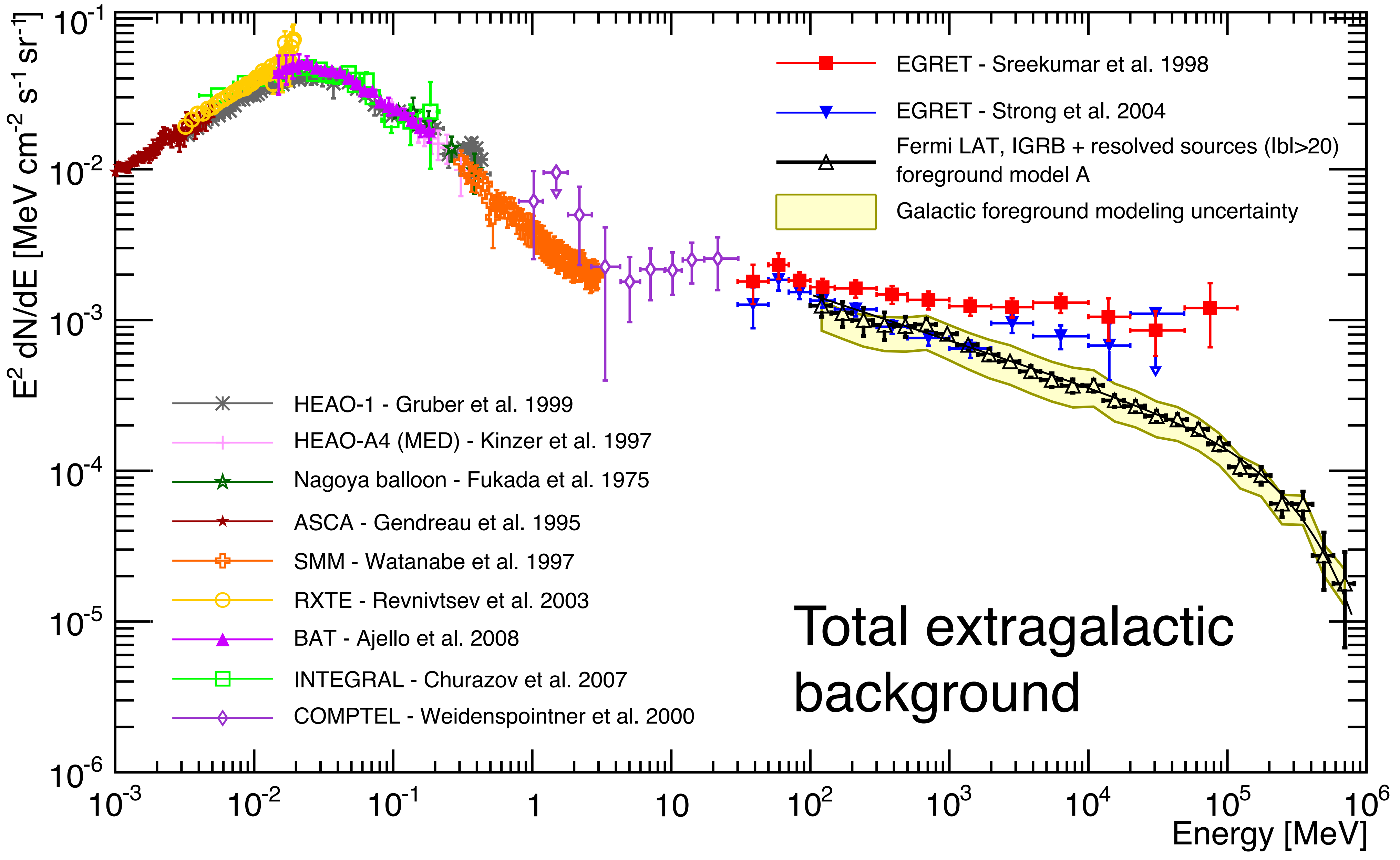
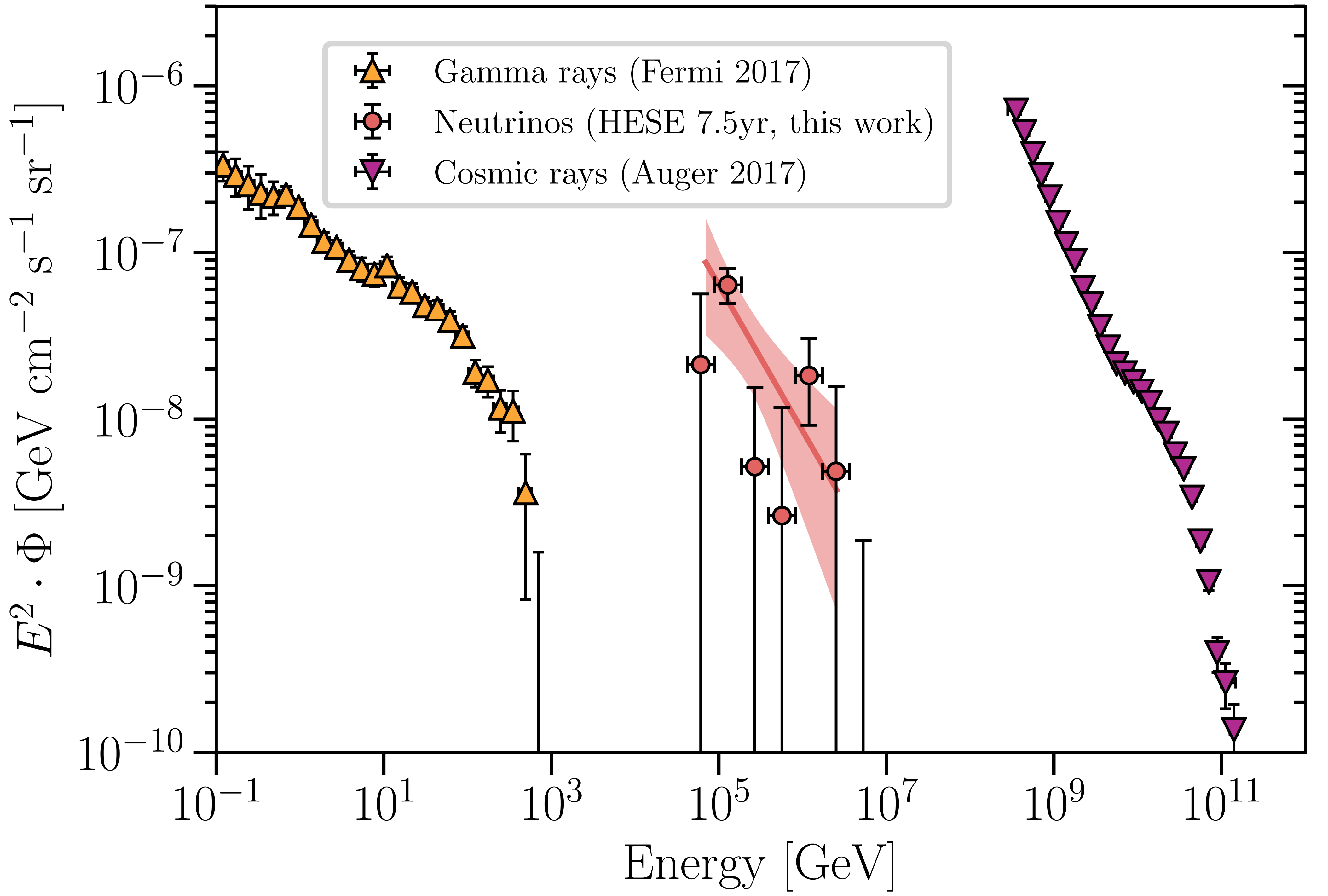


Fig. 10.— Comparison of the derived total EGB intensity (foreground model A) to other measurements of the X-ray and γ-ray background. The error bars on the LAT measurement include the statistical uncertainty and systematic uncertainties from the effective area parametrization, as well as the CR background subtraction. Statistical and systematic uncertainties have been added in quadrature. The shaded band indicates the systematic uncertainty arising from uncertainties in the Galactic foreground. (Note that the EGRET measurements shown are measurements of the IGRB. However, EGRET was more than an order of magnitude less sensitive to resolve individual sources on the sky than the *Fermi*-LAT.)

Fermi-LAT collaboration, Astrophys.J. 799 (2015) 86

γ-rays neutrinos UHECRs



IceCube Collaboration, arXiv:2011.03545

Intriguing for both theorists and experimentalists

Common sensitivity at space, south pole and desert

Who is the origin of cosmic ray?

Galaxy Cluster

FRB

New Physics

TDE

SNR

Pulser

GRB

Magnetar

AGN

Confidential image

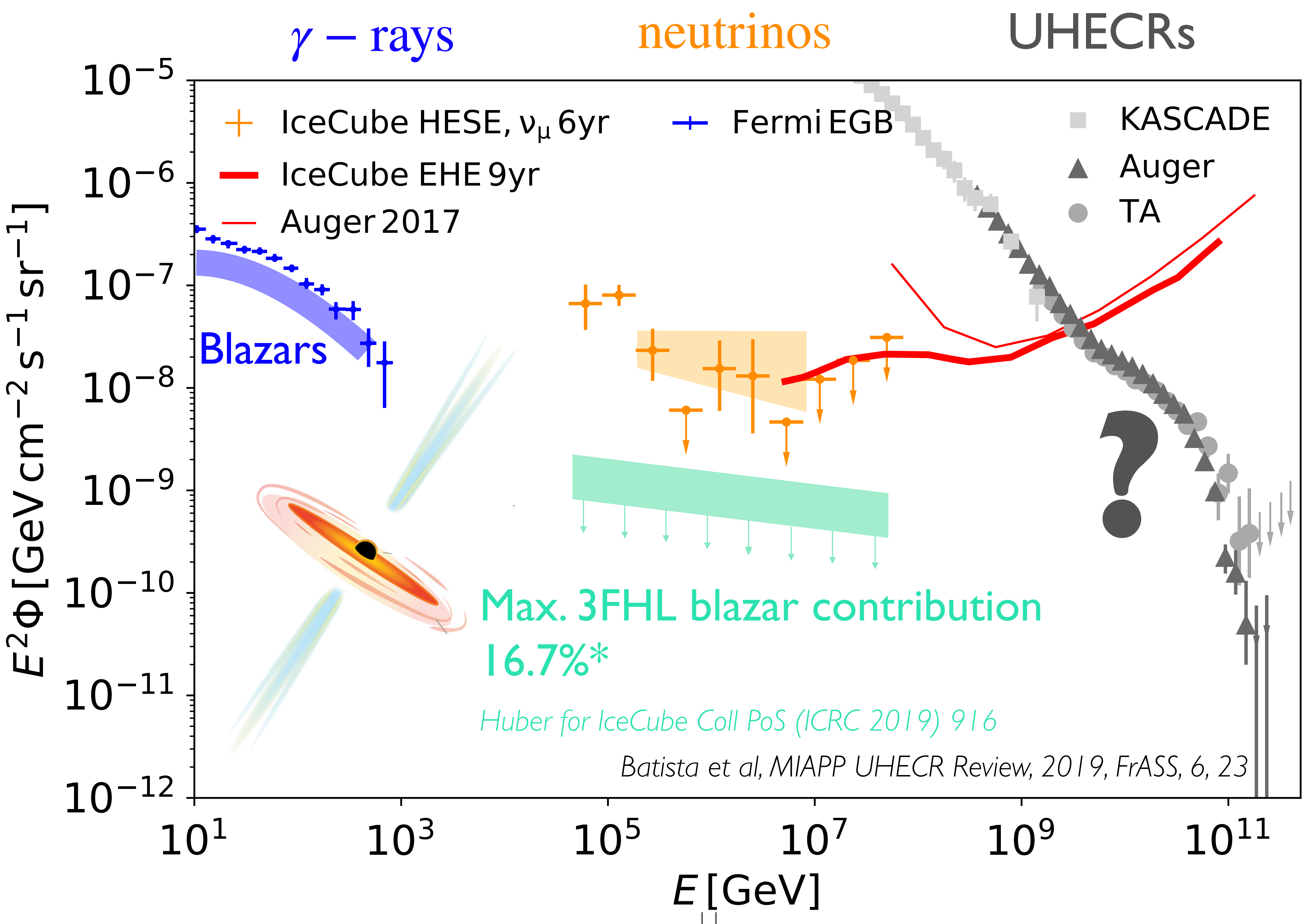
Starburst galaxy

Radio galaxy

or surviving at the end...

Multi-messenger approach (F.Oikonomou)

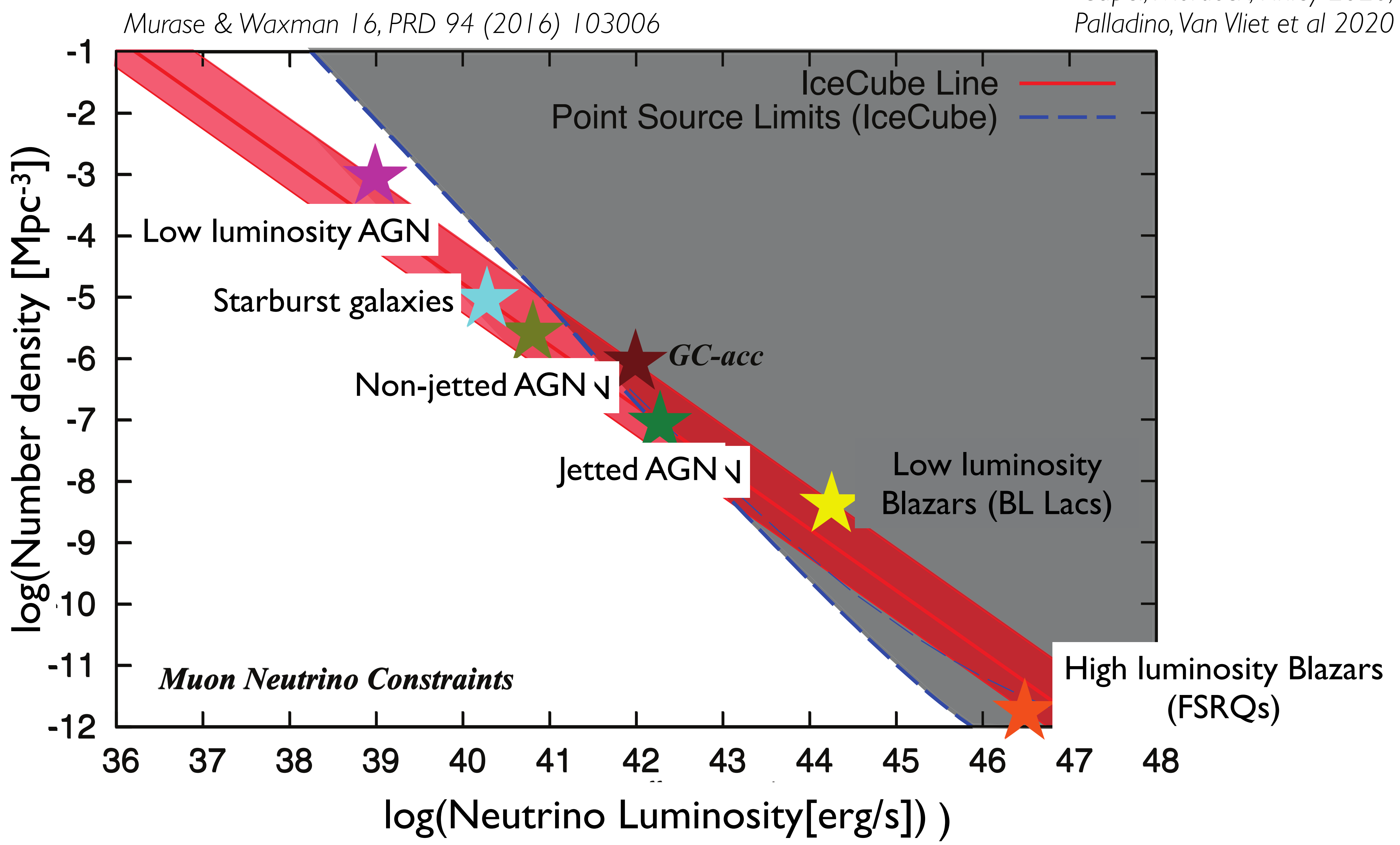
Constraints on the contribution of blazars to the diffuse neutrino flux: Stacking



* ≤27% with spectral templates: *IceCube Coll PoS (ICRC2017) 994*

Constraints on the contribution of blazars to the diffuse neutrino flux: Clustering

Lipari 2008, Ahlers & Halzen 2014, Neronov & Semikoz 2018, Ackermann, Ahlers et al. 2019, Yuan et al 2019, Capel, Mortlock, Finley 2020, Palladino, Van Vliet et al 2020



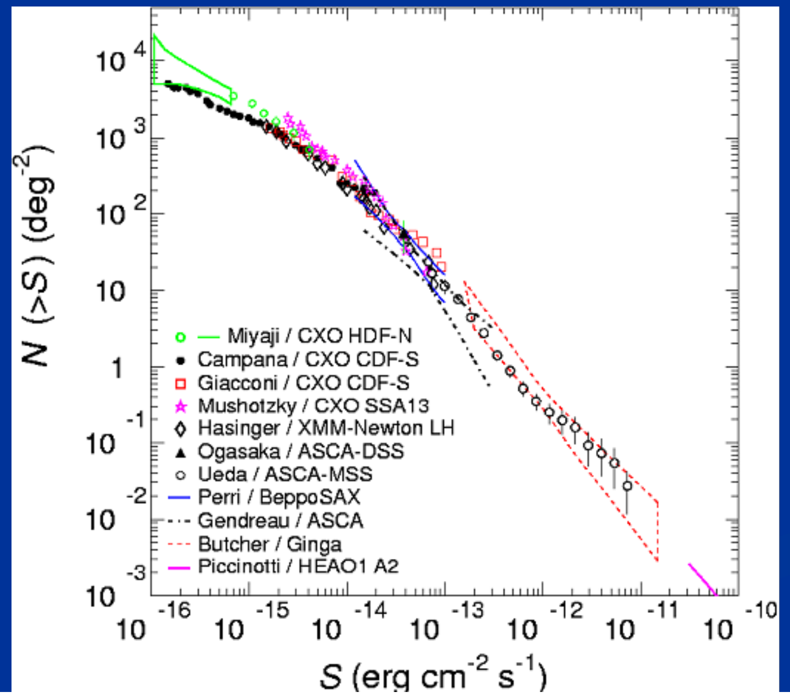
other diagnostics: cross-correlations (Padovani et al 2016, Palladino 2017, Giommi et al, 2020, Plavin et al 2020) autocorrelations (IceCube Coll 2015,17, Ando et al 2017, Dekker & Ando 2019), EHE Limits (IceCube Coll 2016,17)…

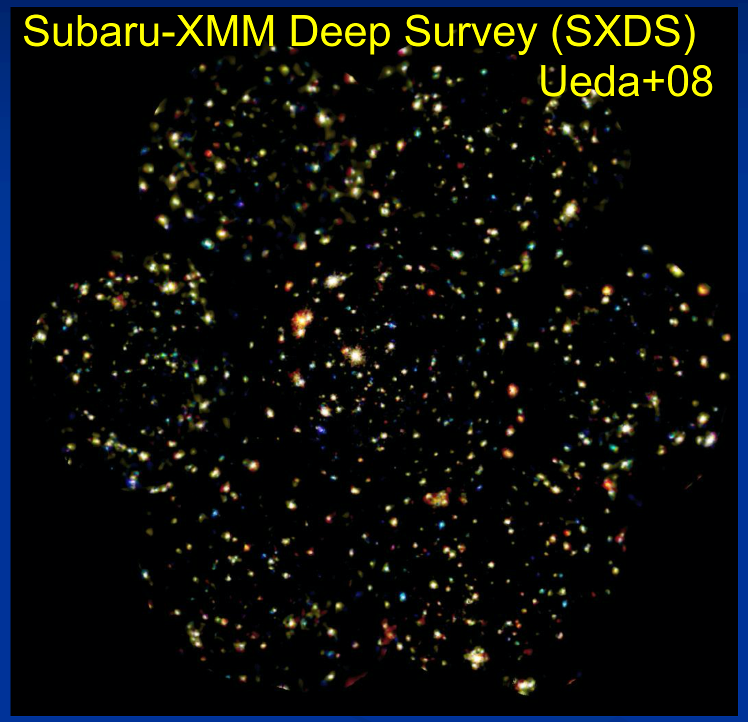
X-ray sky (Y.Ueda)

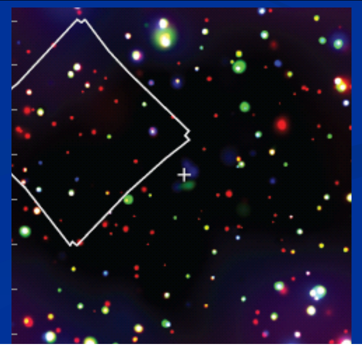
The CXB below 10 keV

- Now almost all of the CXB below ~10 keV is resolved, mostly into Compton-thin AGNs (N_H < 10^{24} cm^2) with ~10^4 deg^{-2}
- X-ray surveys are the most sensitive among those at any wavelengths

Kushino+ 02



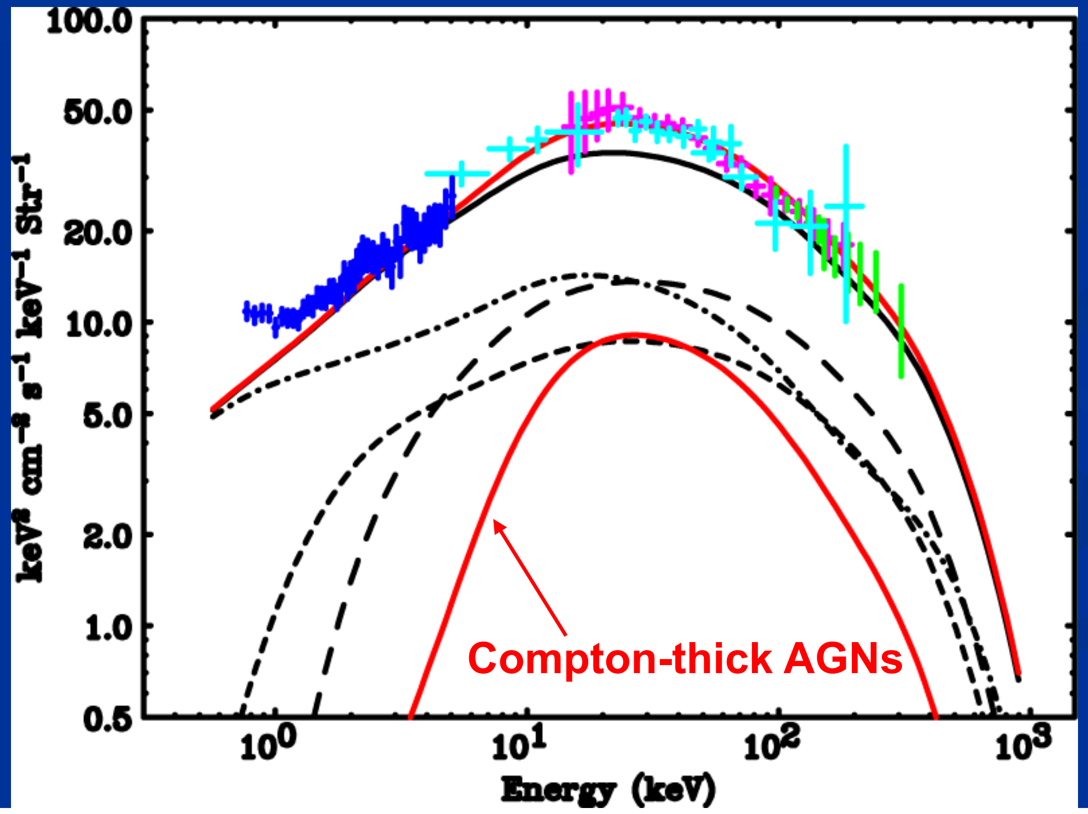




CDFS
Xue+ 11

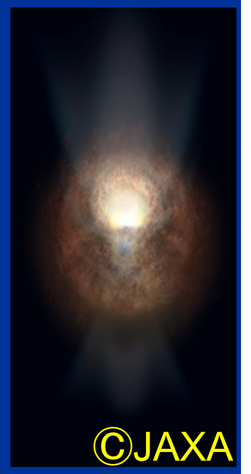
Population Synthesis Model of the CXB (Ueda+14)

- CXB = (luminosity function) × (absorption distribution)
- Assumptions
  - Broadband spectra (1-1000 keV)
  - *Compton thick AGNs* follow the same evolution as Compton thin AGNs

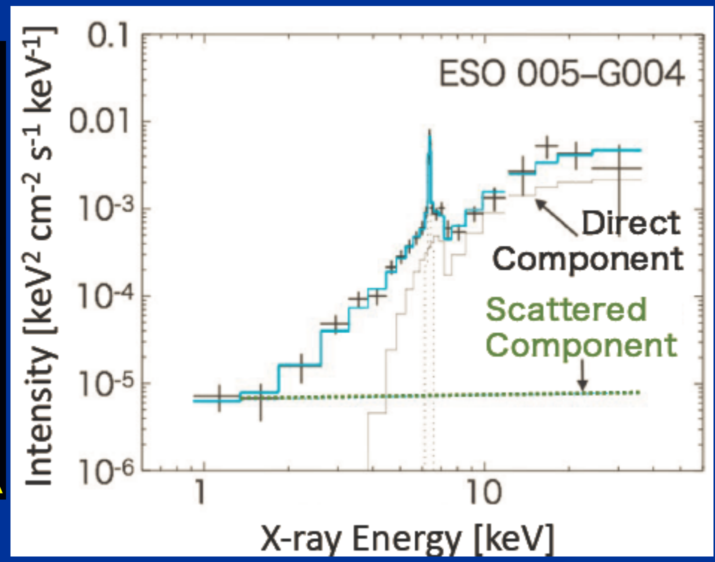


Key Population: Buried AGN

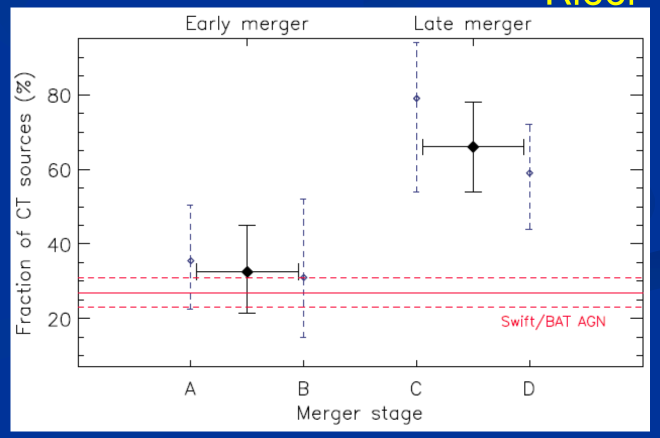
- Covered by Compton thick material with large solid angle
  - Narrow line regions are little developed because UV lights do not leak
  - Sometimes AGN can be identified only by using X-rays (ex. NGC 4945)
- Hard X-rays are the best band to catch such AGNs, thanks to
  - Strong penetrating power against obscuration
  - Little contamination from stars (cf. infrared band)



Ueda+ 07



Ricci+ 17



Remaining Issues on the CXB

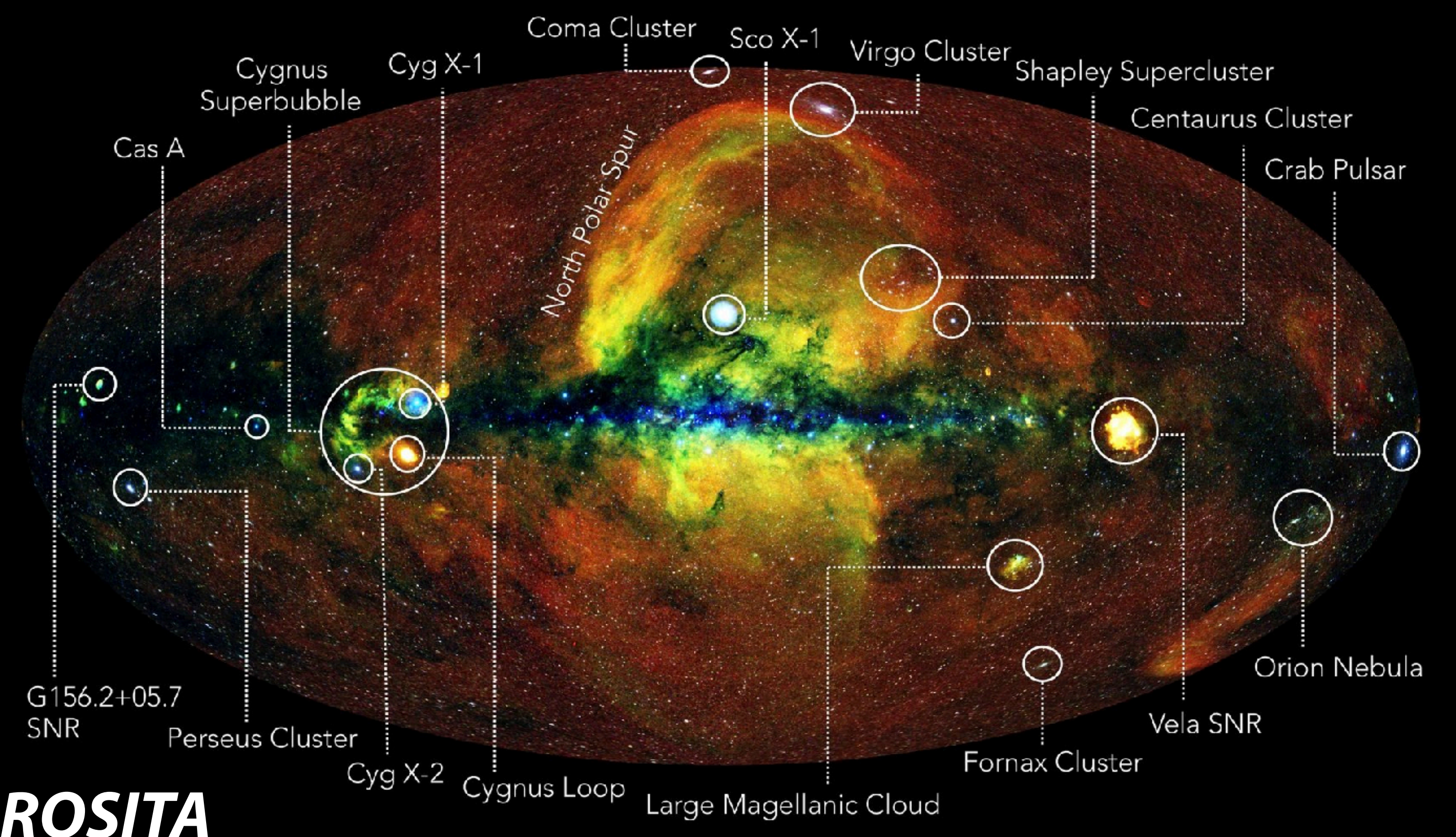
Buried AGN as key population

- Origin of the CXB above 10 keV
  - Contribution of Compton thick AGNs

- AGN evolution
  - Do they “co-evolve” with galaxies? Why/how?
  - Physical origin of cosmic downsizing

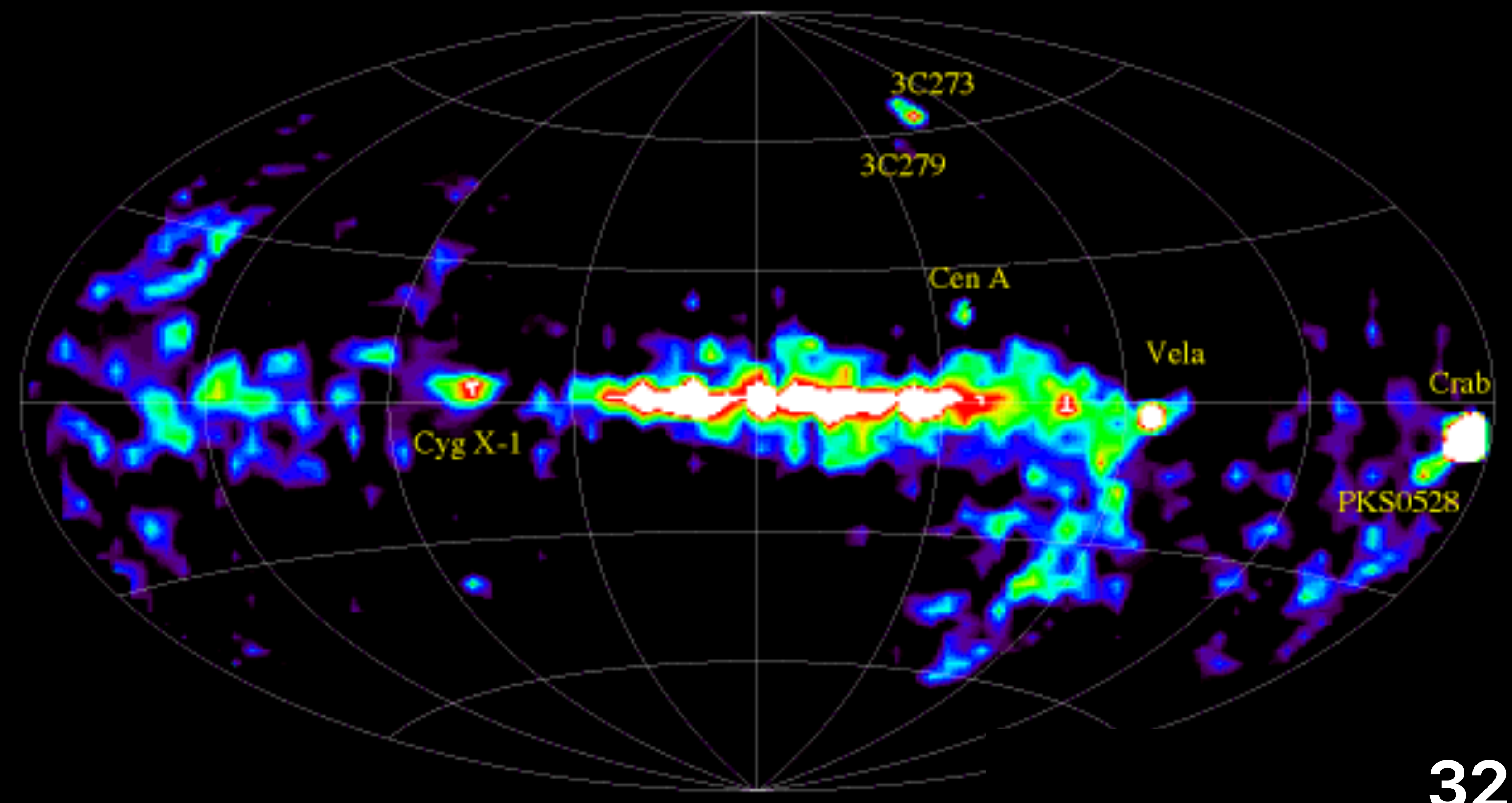
X-ray, MeV skys (Y.Inoue)

Soft X-ray Sky (0.3-2.3 keV)



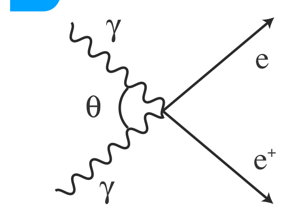
SRG/e-ROSITA 6-month survey $> 1 \times 10^{-14}$ erg/cm2/s **~10^6 objects**

MeV Gamma-ray Sky



COMPTEL $> 1 \times 10^{-10}$ erg/cm2/s **32 objects**

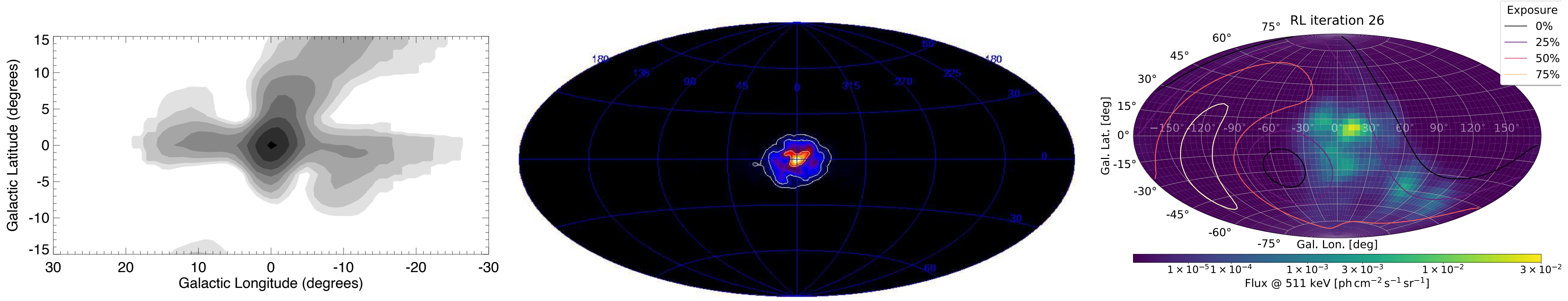
Note: >50 Candidates in GW now



Particle physics processes: Gamma-ray Lines

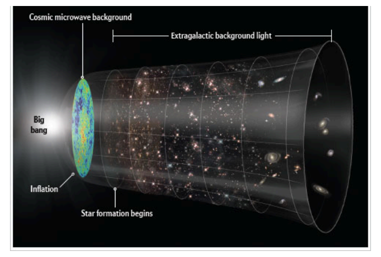
511 keV e^+e^- annihilation line from Galactic Center

OSSE | INTEGRAL | COSI



Purcell+'97 | Knödlseder+'05 | Siegert+'20

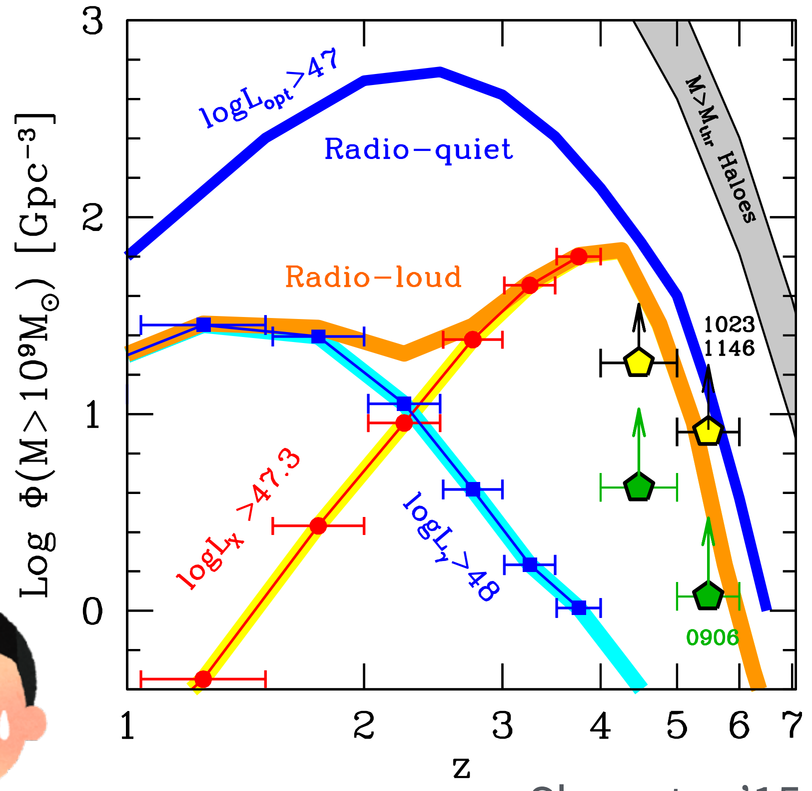
- Clear excess toward the direction of the Galactic Center
- Detailed morphology is still not clear
- Various origins are proposed
  - SNe Ia, LXMBs, Microquasars, RIAF,,,, (e.g., Prantzos '06; Guessoum+'06; Totani '06)



Evolution of Blazars

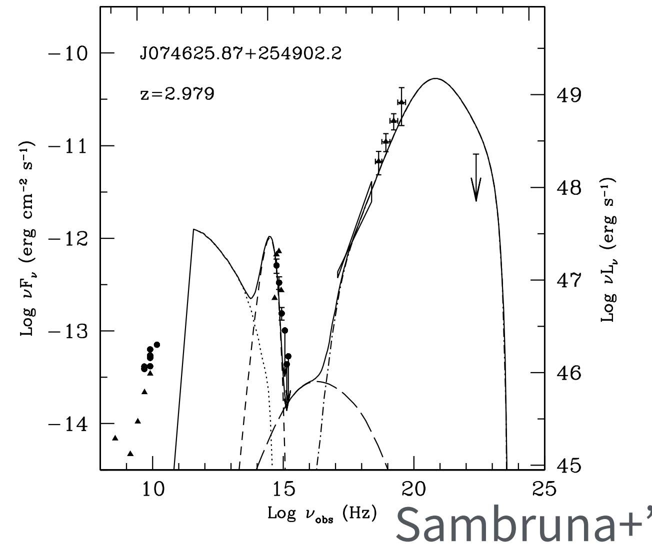
Inconsistency in X-ray and Gamma-ray?

MeV from buried AGN?



Sbarrato+'15

- Gamma-ray blazars show evolutionary peak at z~1-2 (e.g., YI & Totani'09; Ajello,YI+'15)
- But, it is at z~3-4 for X-ray blazars (Ajello+'09, see also Toda, Fukazawa, YI'20).
- More MeV blazars are needed (e.g., Blom+'96; Sambruna+'06).

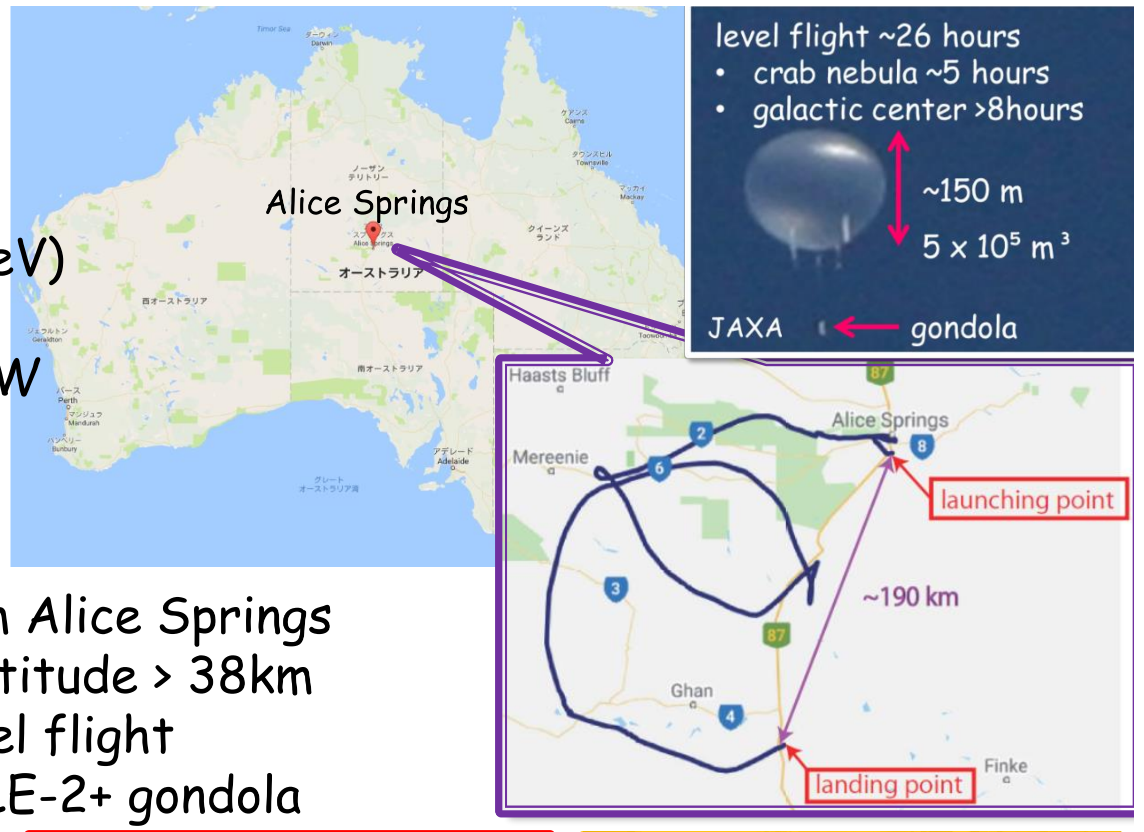


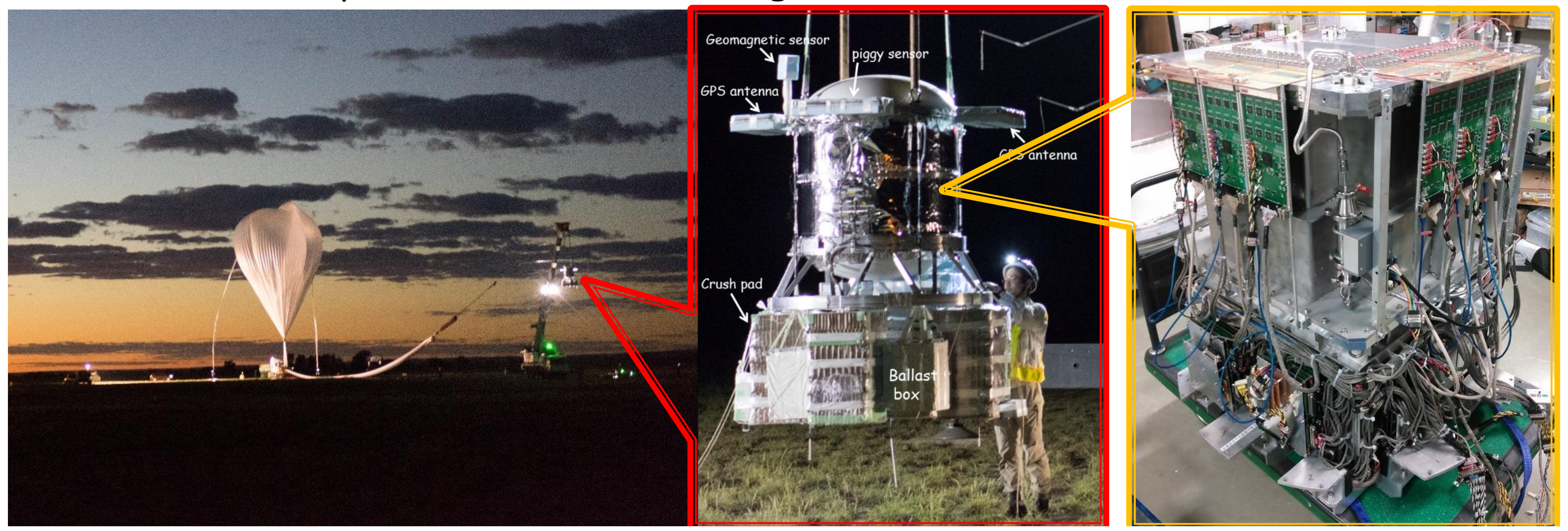
Sambruna+'06

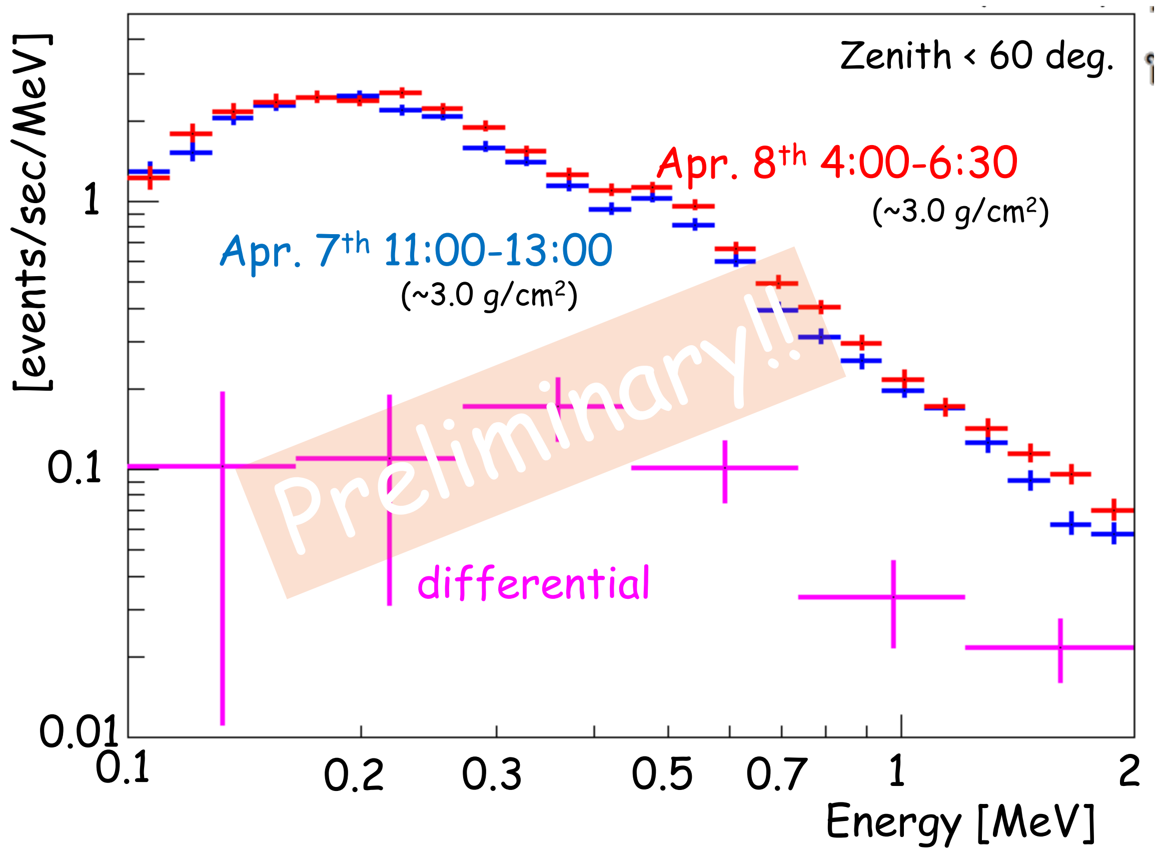
MeV window (A.Takada, A.Zoglauer)

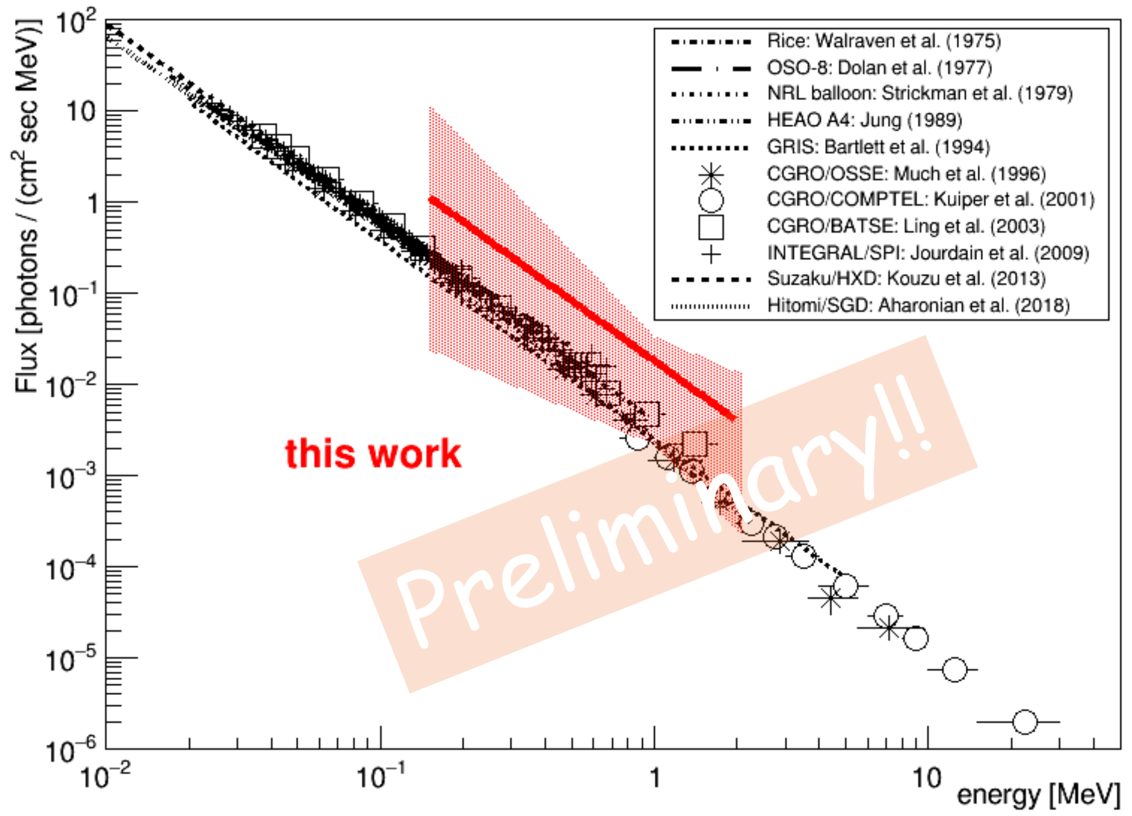
SMILE-2+

- ETCC
  - Range : 0.3~5 MeV
  - effective area : ~1 cm^2 (0.3 MeV)
  - PSF : ~20° (0.6 MeV)
  - weight : 511 kg power : ~250W
- Observation targets :
  - Galactic center region
  - Crab nebula
- Launched on April 7th, 2018, from Alice Springs
- Level flight lasted 26 hours at altitude > 38km
- System worked stably during level flight
- We successfully recovered SMILE-2+ gondola





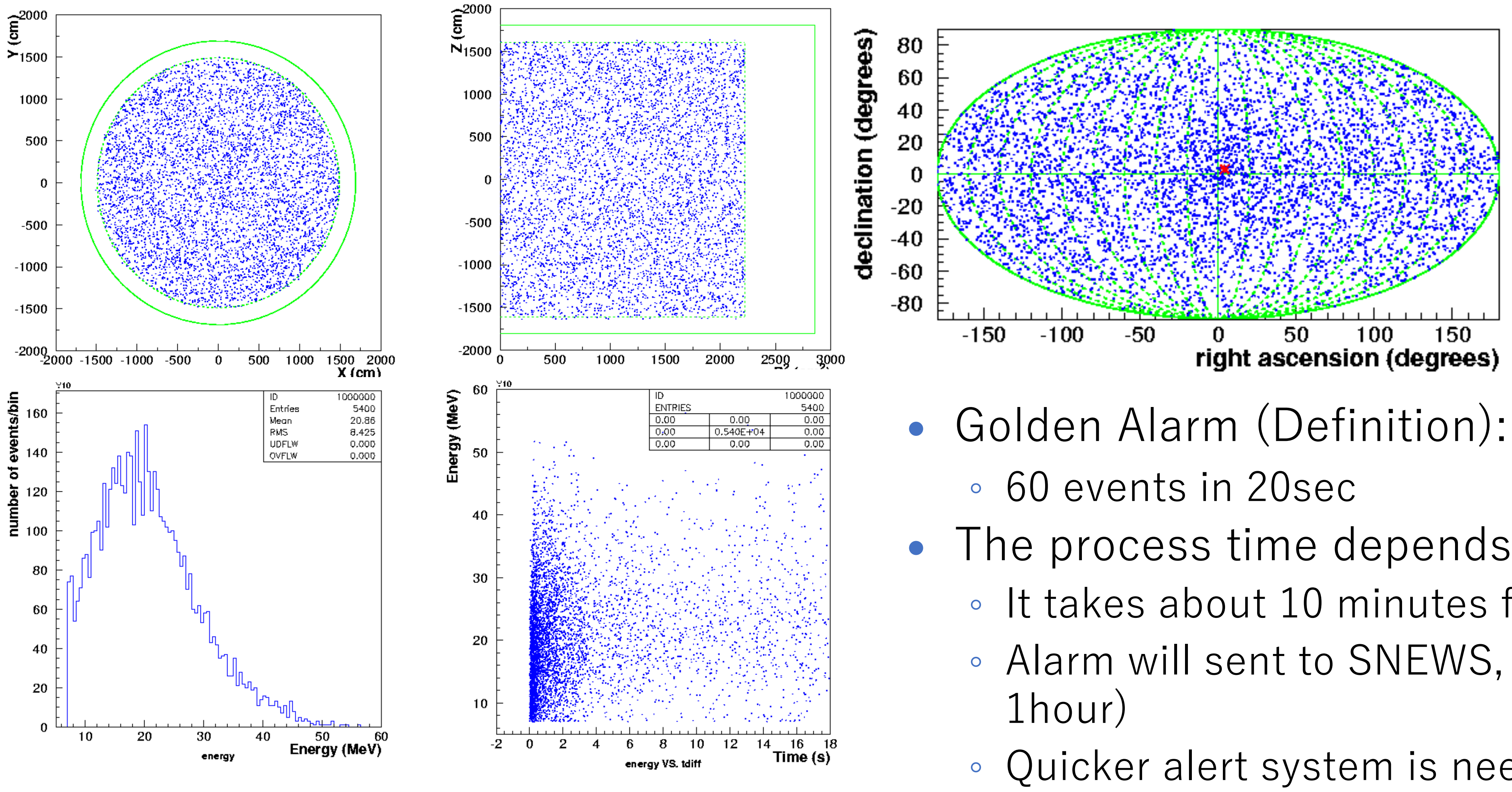




Ready to detect supernova neutrinos (T.Yano)

What if SN happens now? @Super-K

- **SK's directional information is important for optical telescopes in the multi-messenger astronomy era.**
- SNwatch: Real-time supernova neutrino burst monitor Astropart. Phys. 81(2016)39
  - In several minutes plots are generated automatically and auto-emails+ auto-phone calls follow

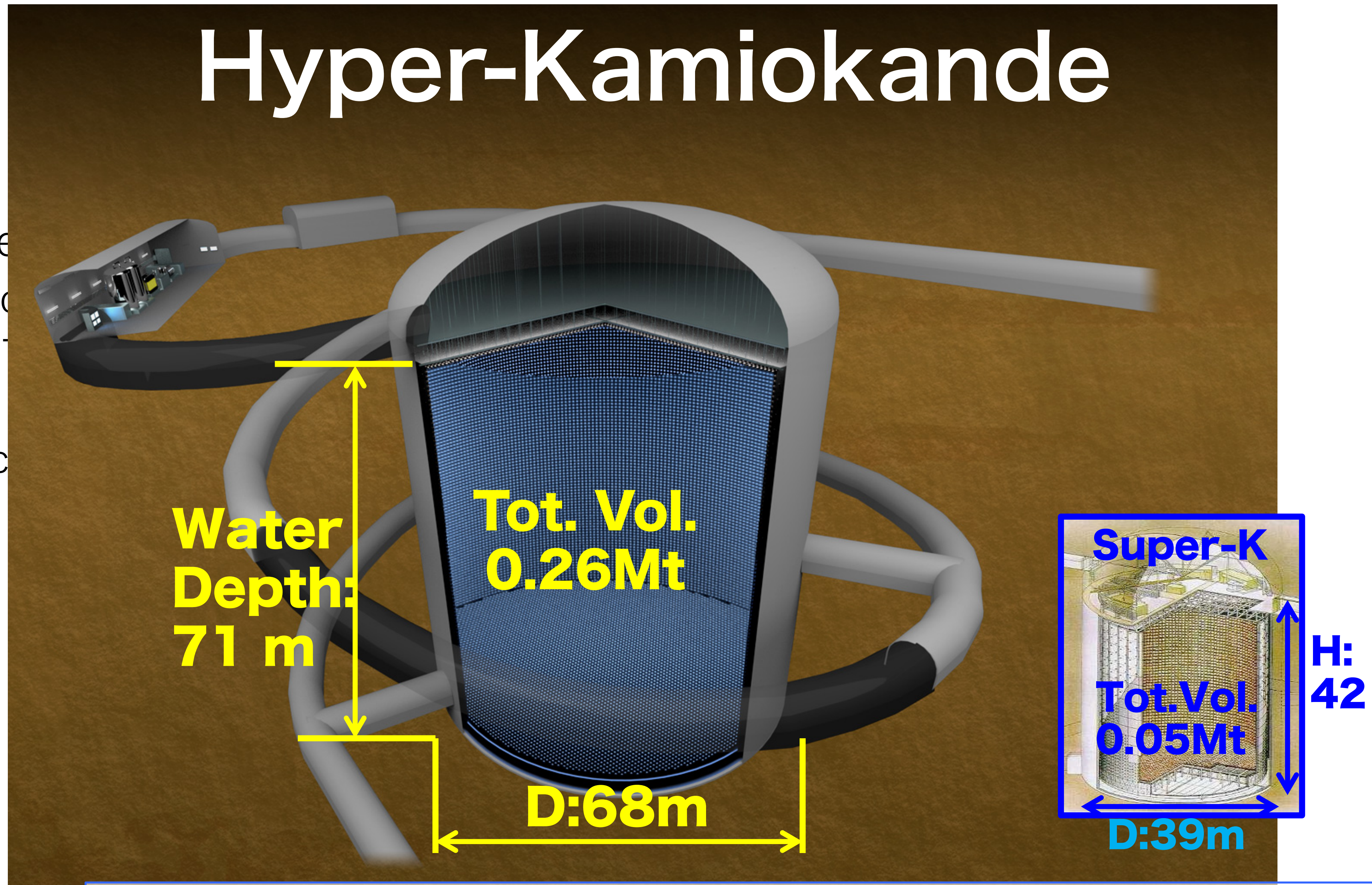


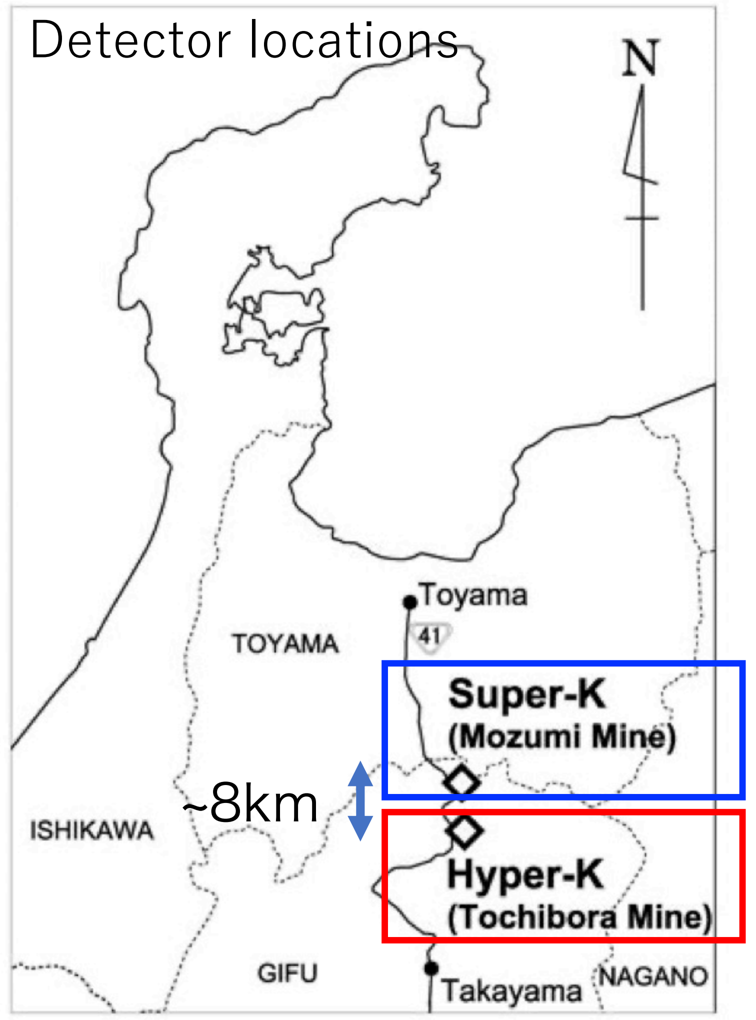
SN simulation @10kpc, Wilson (Totani1998) model

- Golden Alarm (Definition):
  - 60 events in 20sec
- The process time depends on the e
  - It takes about 10 minutes for the pro
  - Alarm will sent to SNEWS, IAU CBAT 1hour)
  - Quicker alert system is needed for c stars.

Complete upgrade to SK-Gd

Start construction of Hyper Kamiokande



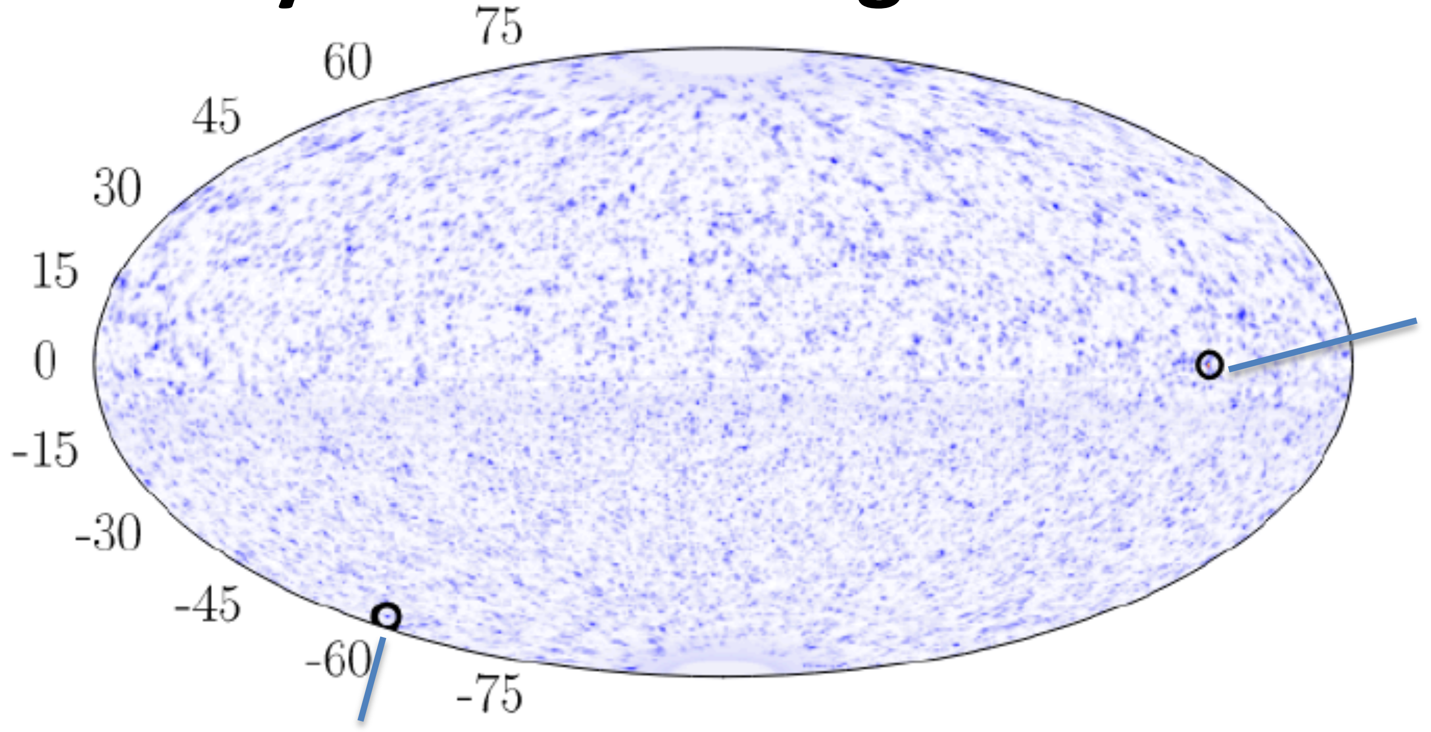


Next generation large water Cherenkov detector
- 2020 Feb: Hyper-Kamiokande is officially approved by Japanese Diet.
- 2027: Observation with Hyper-Kamiokande will be started.

19

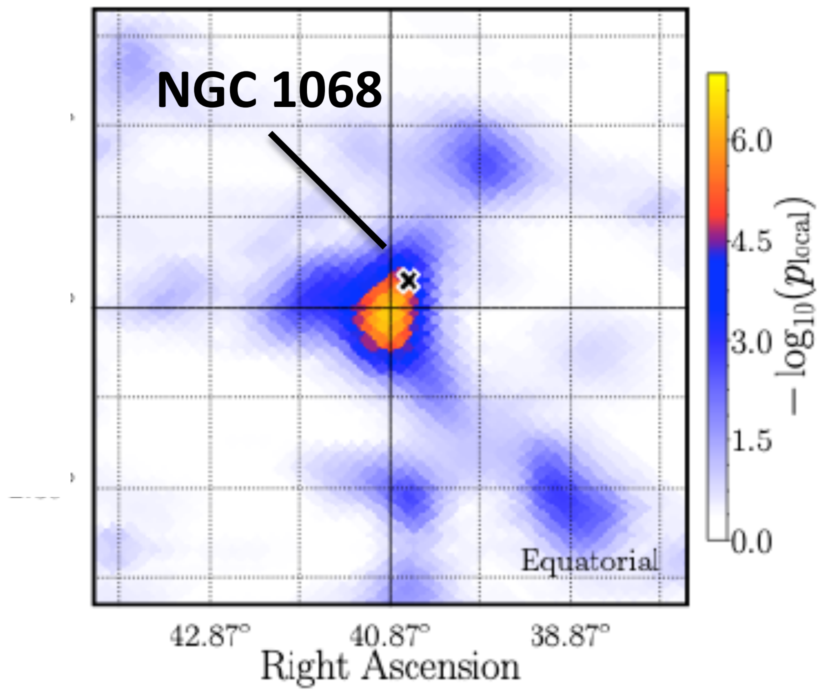
High energy neutrino sky (I.Taboada)

10-year Time Integrated Point Source Searches



Northern sky hottest spot (δ>-5°)
p-value: 0.099
γ = -3.4 n_s = 61.5

Southern sky hottest spot
RA: 350.2°, δ=-56.5° (δ>-5°)
p-value: 0.75



Source list: NGC 1068: 2.9 σ

Binomial search. 4 sources (NGC 1068, TXS 0506+056, PKS 1424+240, GB6 J1542+6129): 3.3 σ

Phys. Rev. Lett. 124, 051103 (2020)

Point sources: No – but see ahead.

Follow up by multiple instruments: TXS 0506+056 – see ahead.

GRBs (prompt < 1-3%): No   ApJL 824 (2016) 2

Any short (<100 s) transients: Probably not   PRL 122 (2019) 051102

Galactic plane: No   ApJ 849 (2017) 67

Many other usual suspects have been excluded …

IceCube's Multi-messenger program

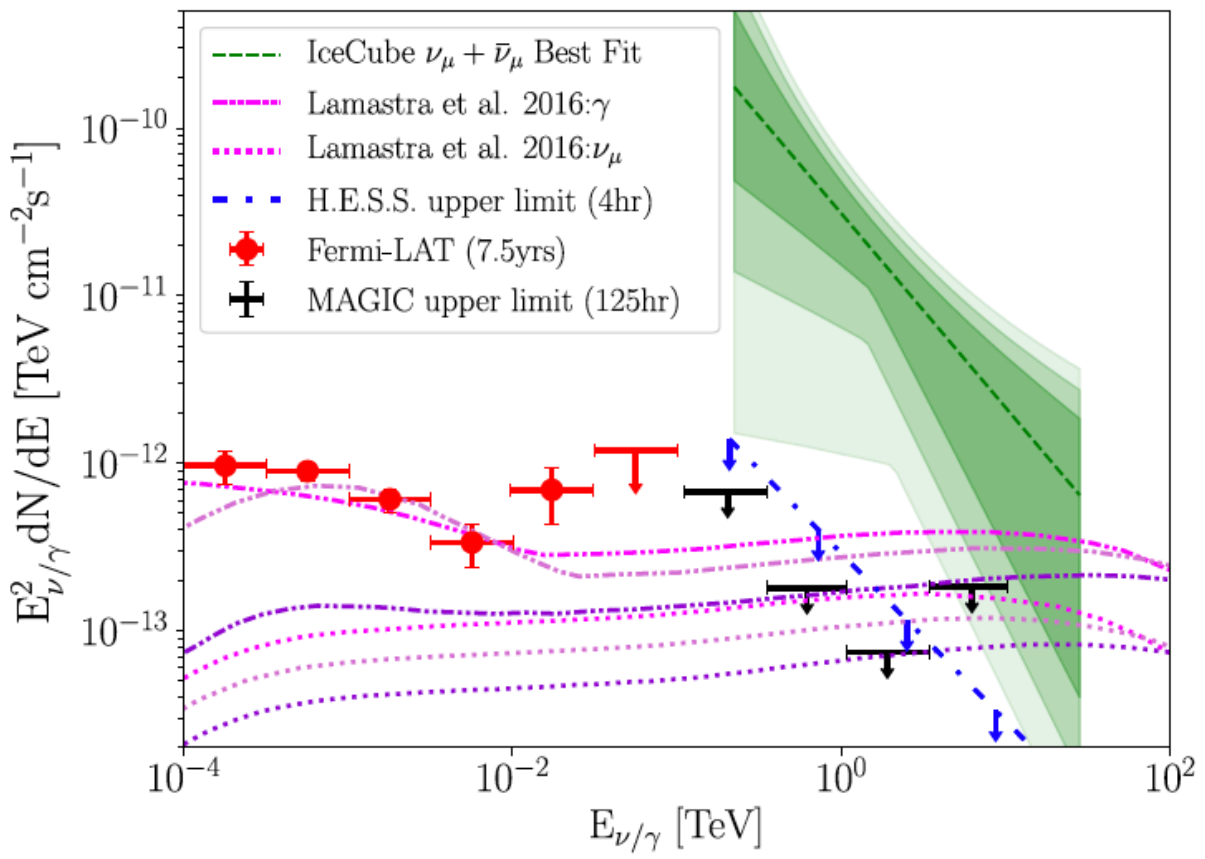
Realtime alerts V1: April 2016 – June 2019
Realtime alerts V2: June 2019 – present

10 Gold (+20 Bronze) events / year
PoS(ICRC2019)1021

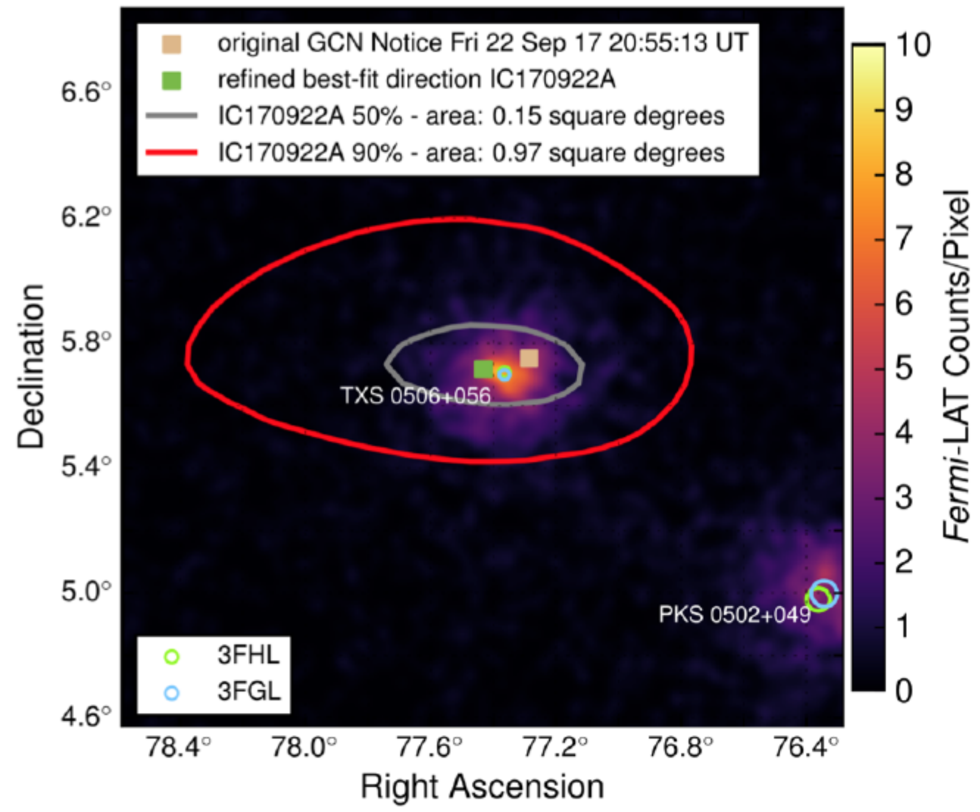
Fast Response Analysis
PoS(ICRC2019)1026

GW realtime follow-up
PoS(ICRC2019)918

Preferred hidden core model, like compton think AGN (NGC1068)

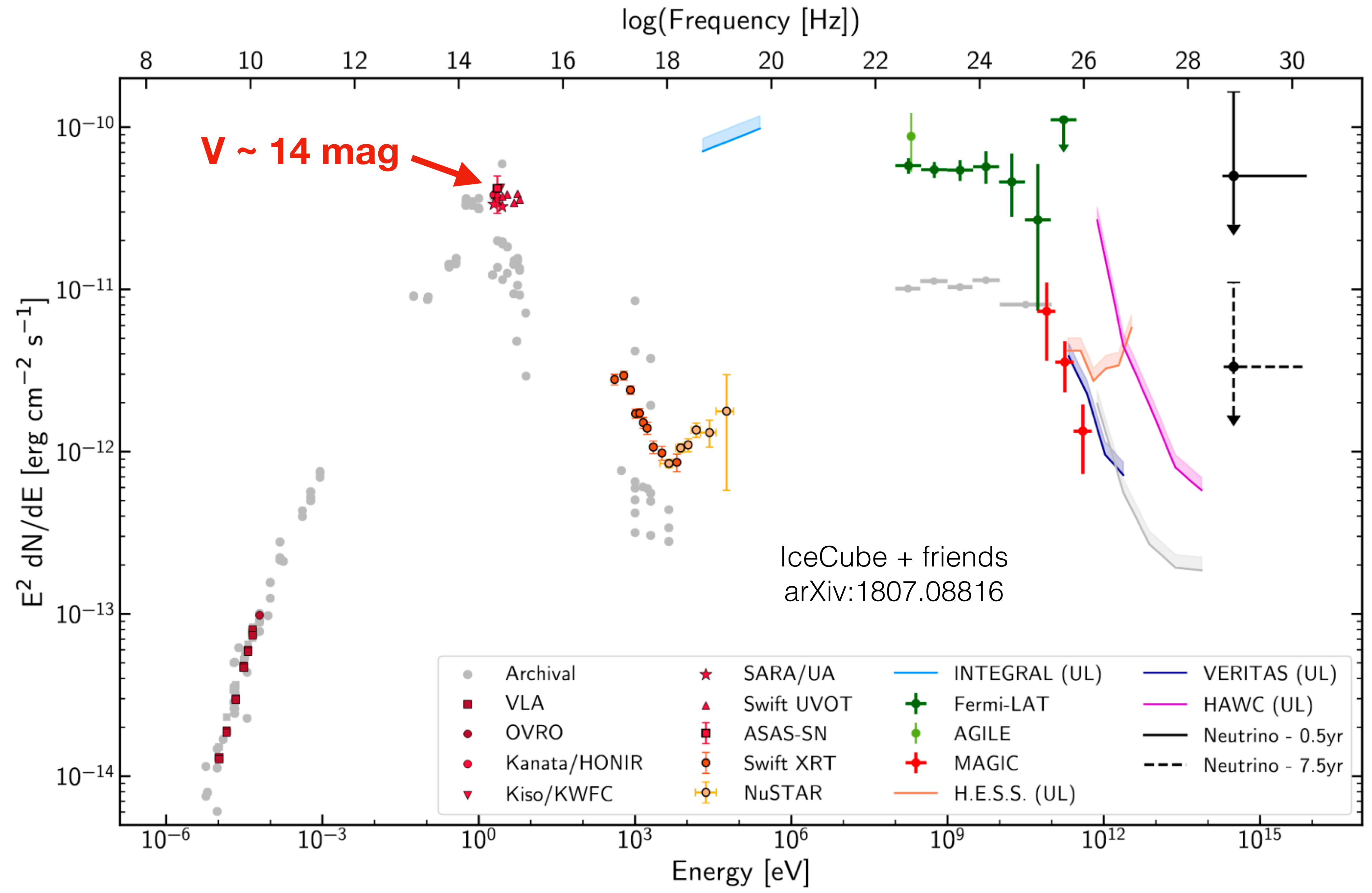


Science 361 (2018) eaat1378
Science 361 (2018) 147-151



Optical follow-up (K.Bechtol)

Multimessenger Context: IceCube-170922A / TXS 0506+056 (Blazar)

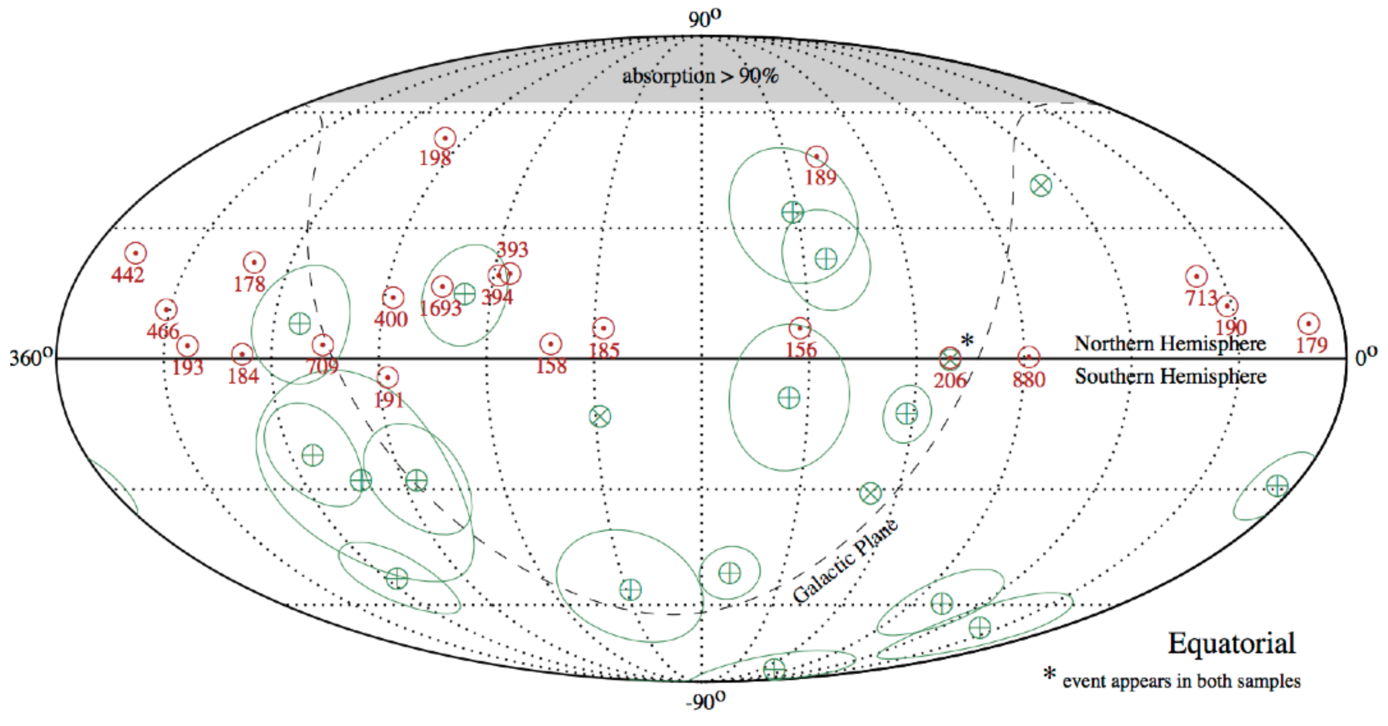


Measured with ASAS-SN. Brightened by 0.5 mag in 50 days prior to IceCube event. Brightest level in last several years.

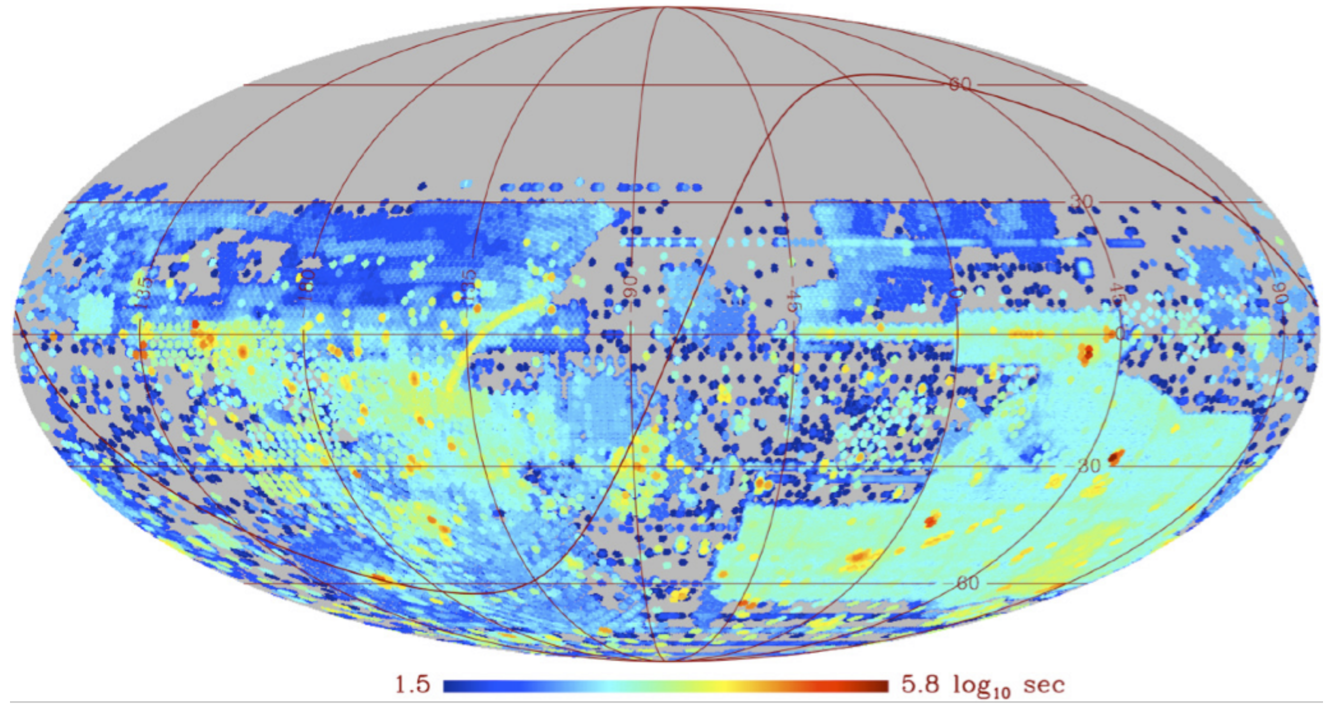
Optical Follow-up of IceCube Tracks: Access to the Southern Hemisphere

THE DARK ENERGY SURVEY

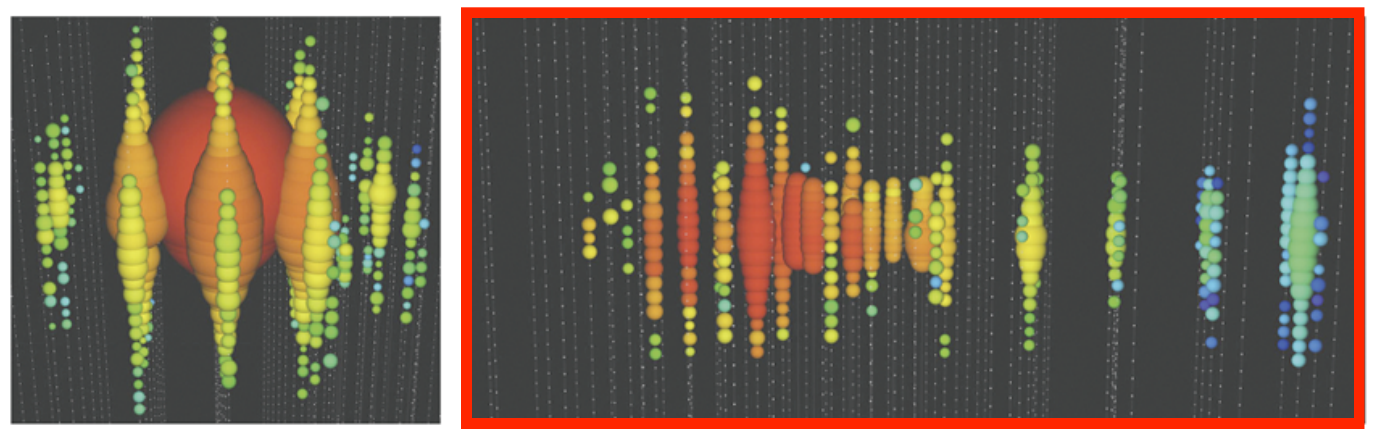
IceCube HESE (3yr) and NuMu (2y) Events



All DECam exposures up to June 2016

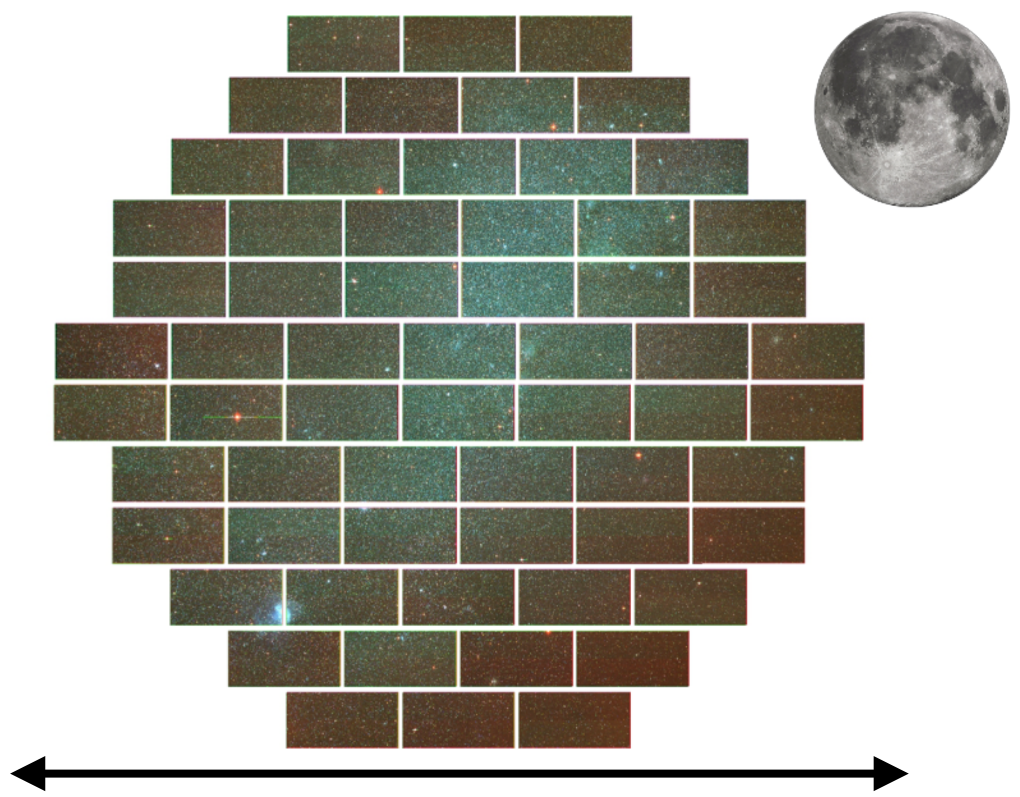


Cascade **Track**



IceCube, arXiv:1406.6757

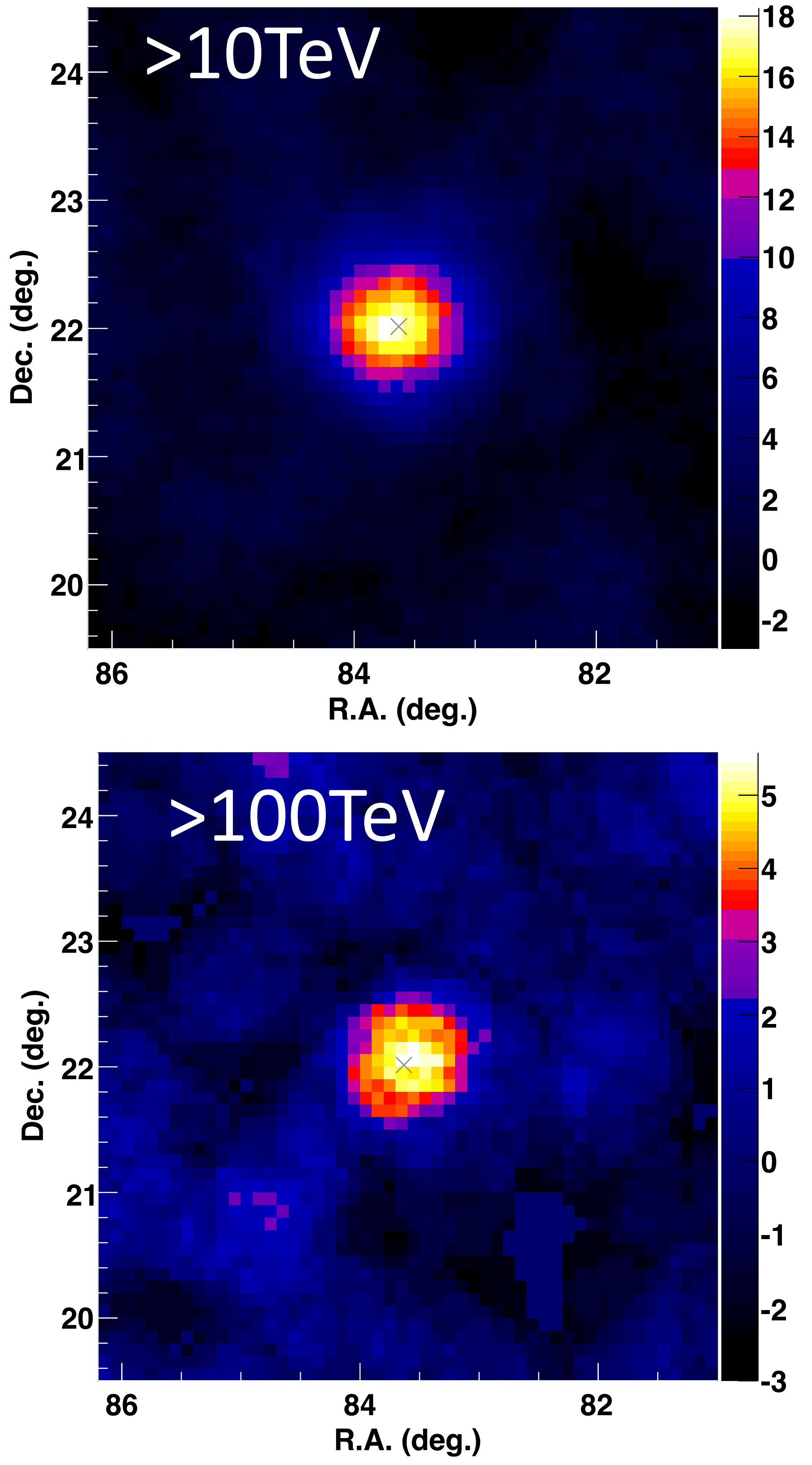
Angular Resolution	Cascade	Track
	~15 deg	~1 deg @ 1 TeV ~0.4 deg @ 100 TeV

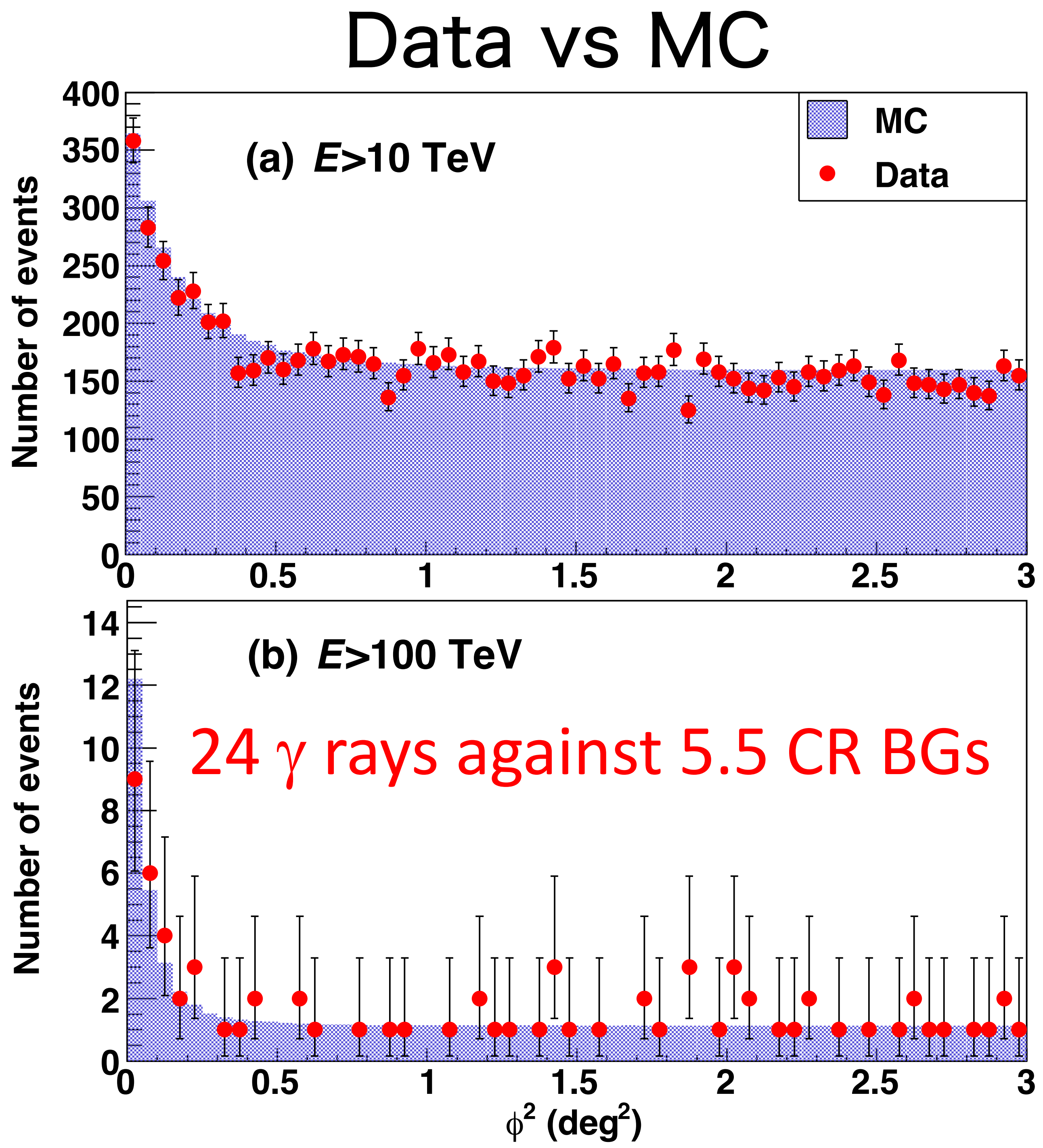


2.2 deg

100 TeV gamma-ray sky (K.Kawata)

Gamma-ray Emission from Crab





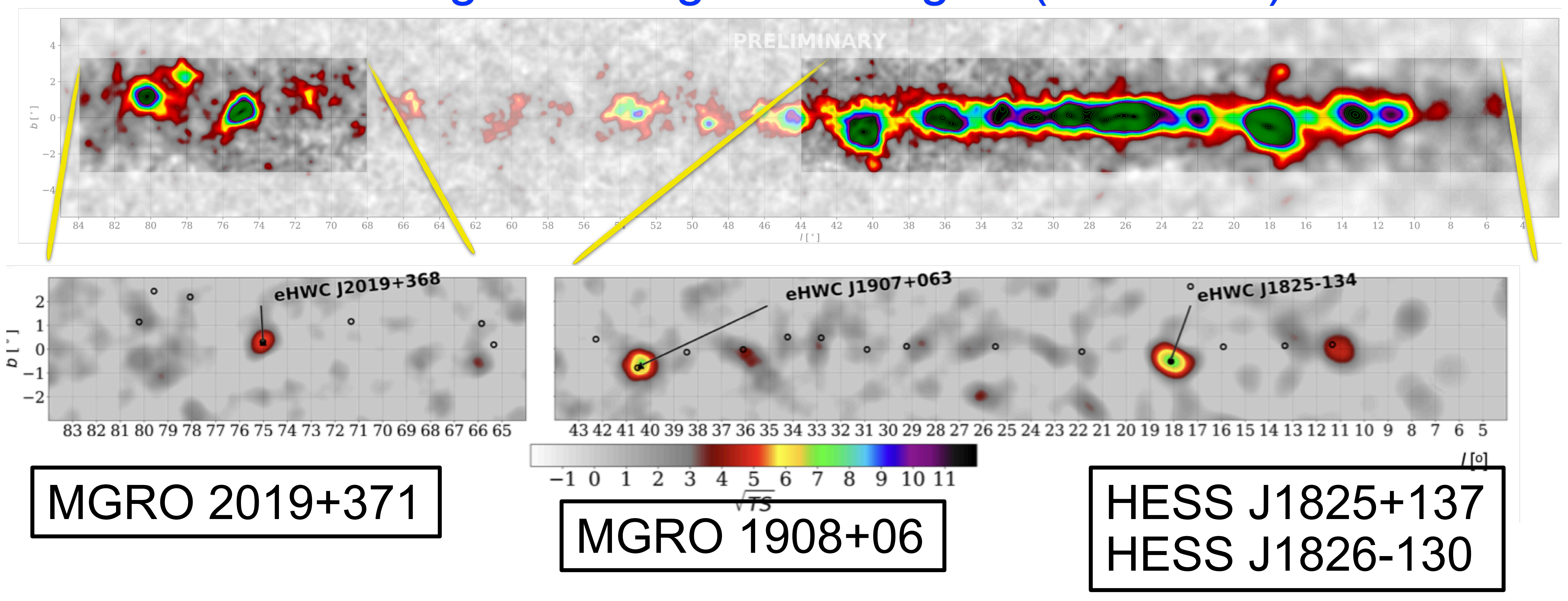
First Detection of Sub-PeV γ (5.6σ)

Amenomori et al., PRL Supplemental Material (2019)

9

100 TeV Observation with HAWC

Pushing to the highest energies (>100 TeV)



Abeysekara et al., PRL, 124, 021102 (2020)

From Slides made by S. Casanova 2020

16

Competition on 100 TeV breakthrough

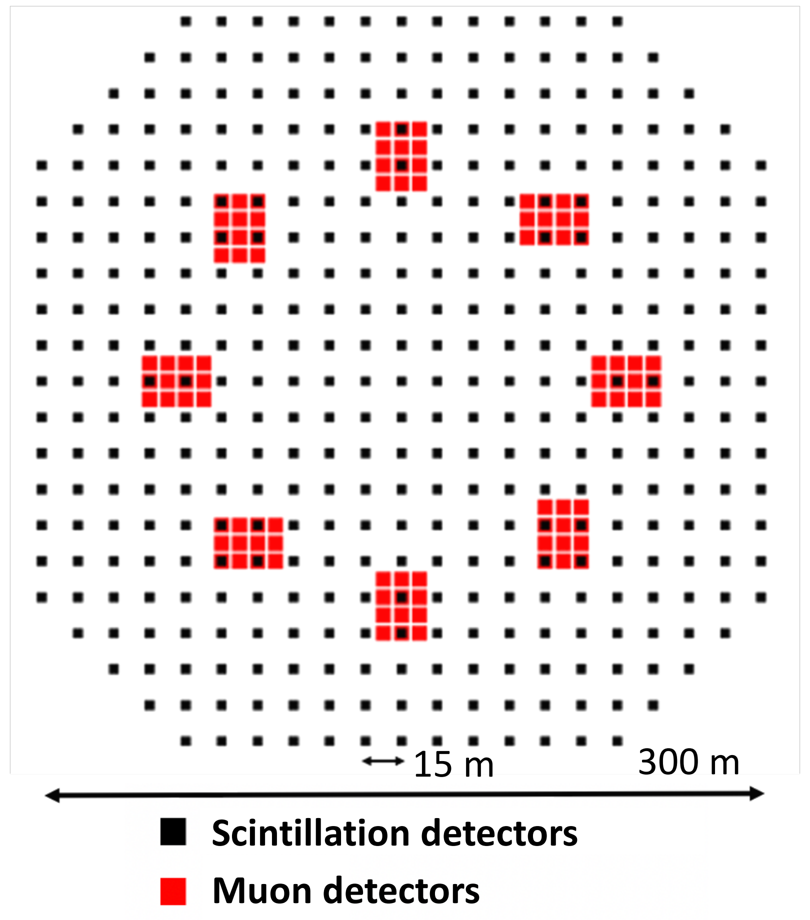
ALPACA (S.Kato)

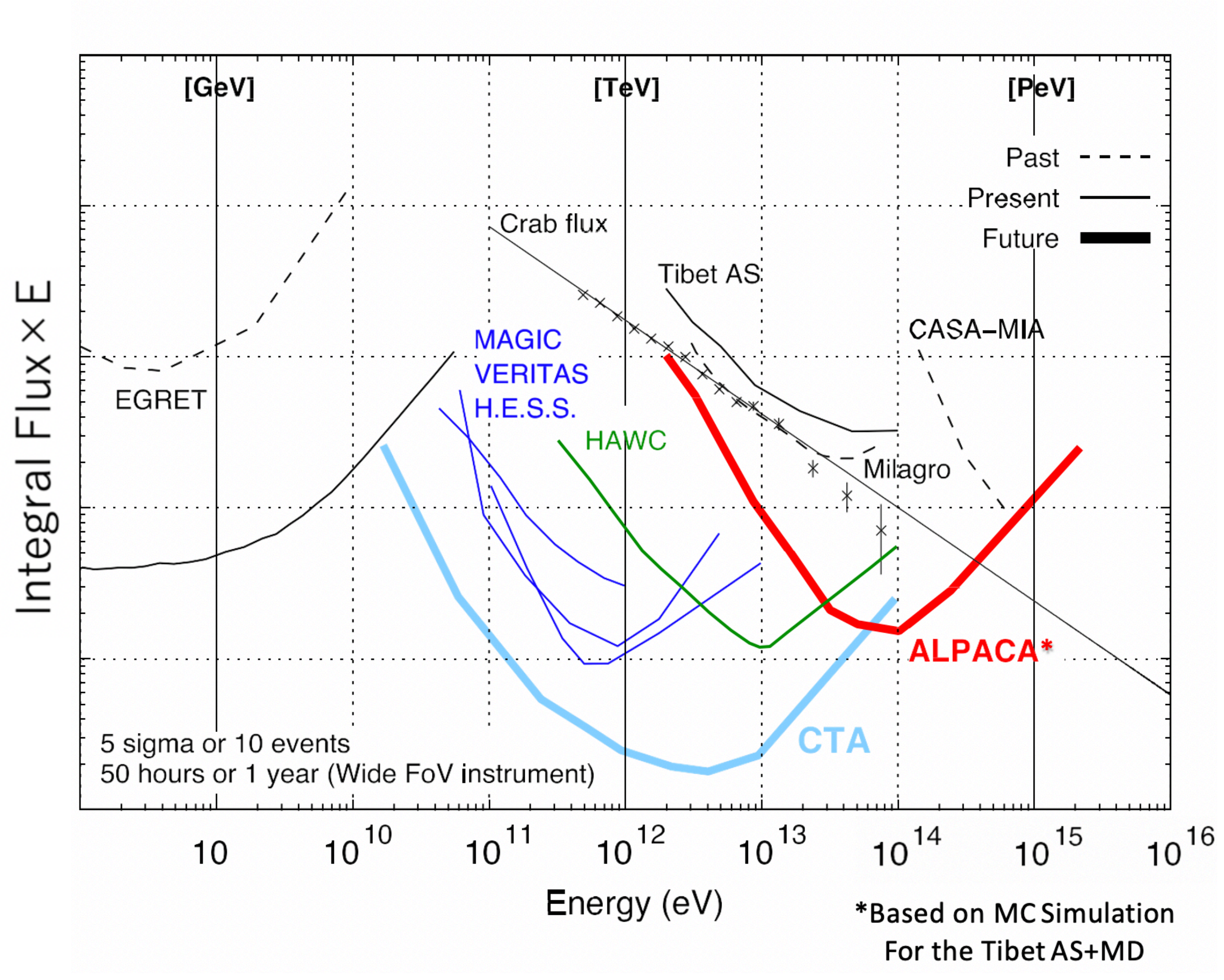
The ALPACA Experiment (Air Shower Array)

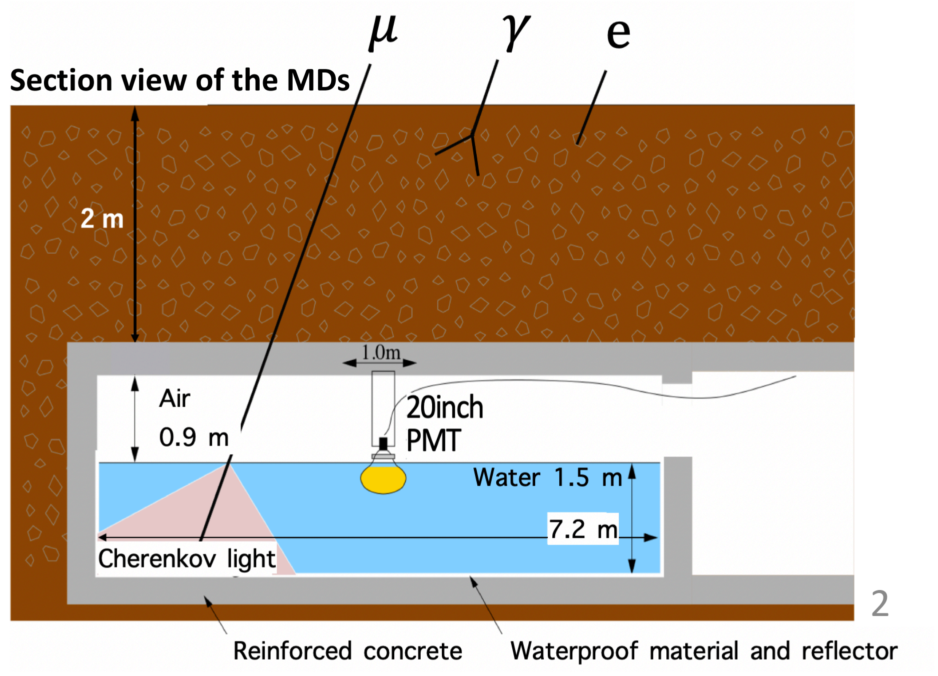
- Chacaltaya plateau (16° 23′ S, 68° 08′ W, Bolivia)
- Elevation : 4,740 m (572.4 g/cm^2)
- A surface air shower array (AS array : 83,000 m^2)

+ an u/grd. muon detector array → BGCR rejection

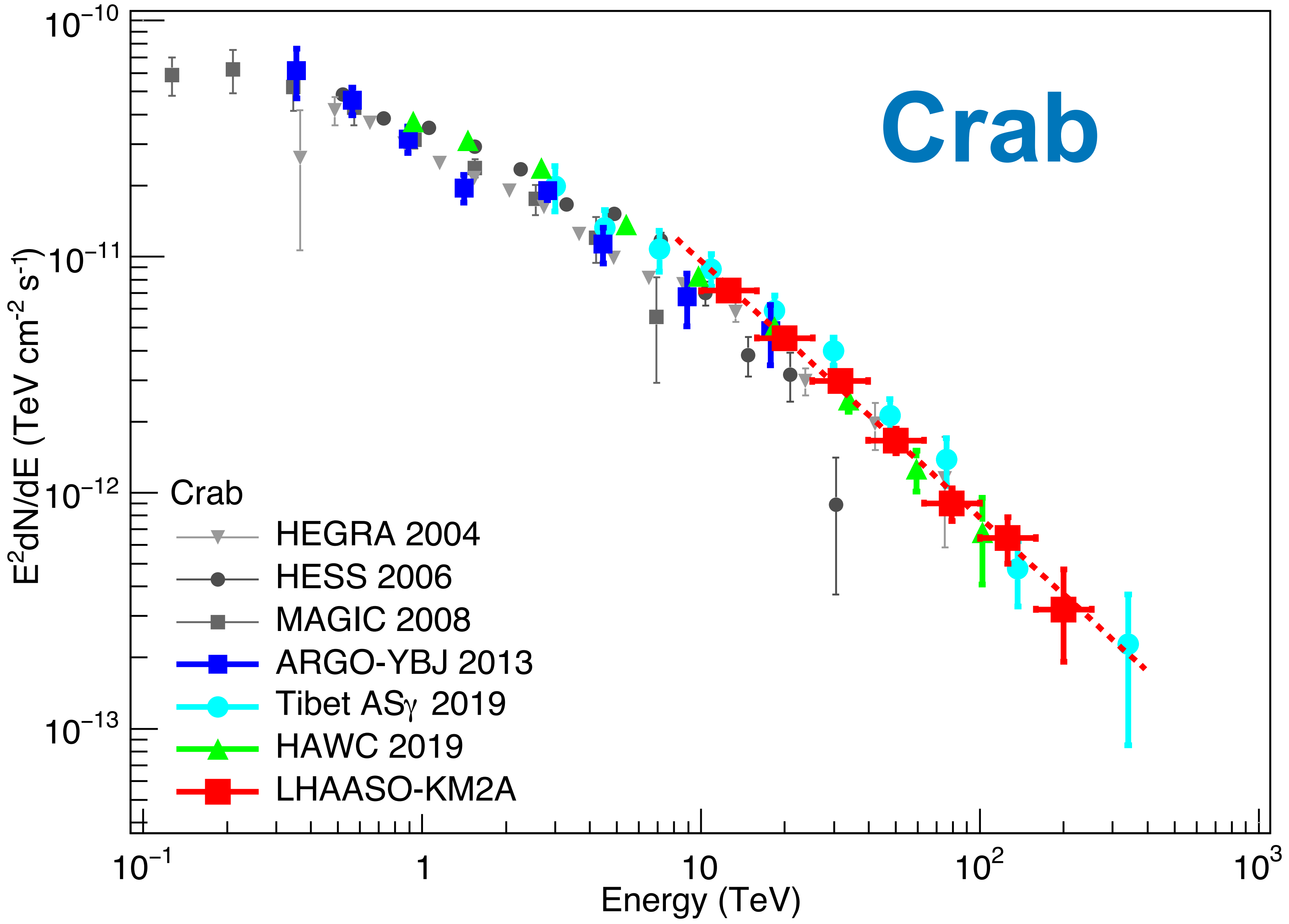
- Main motivation: Southern VHE γ-ray astronomy beyond 100 TeV





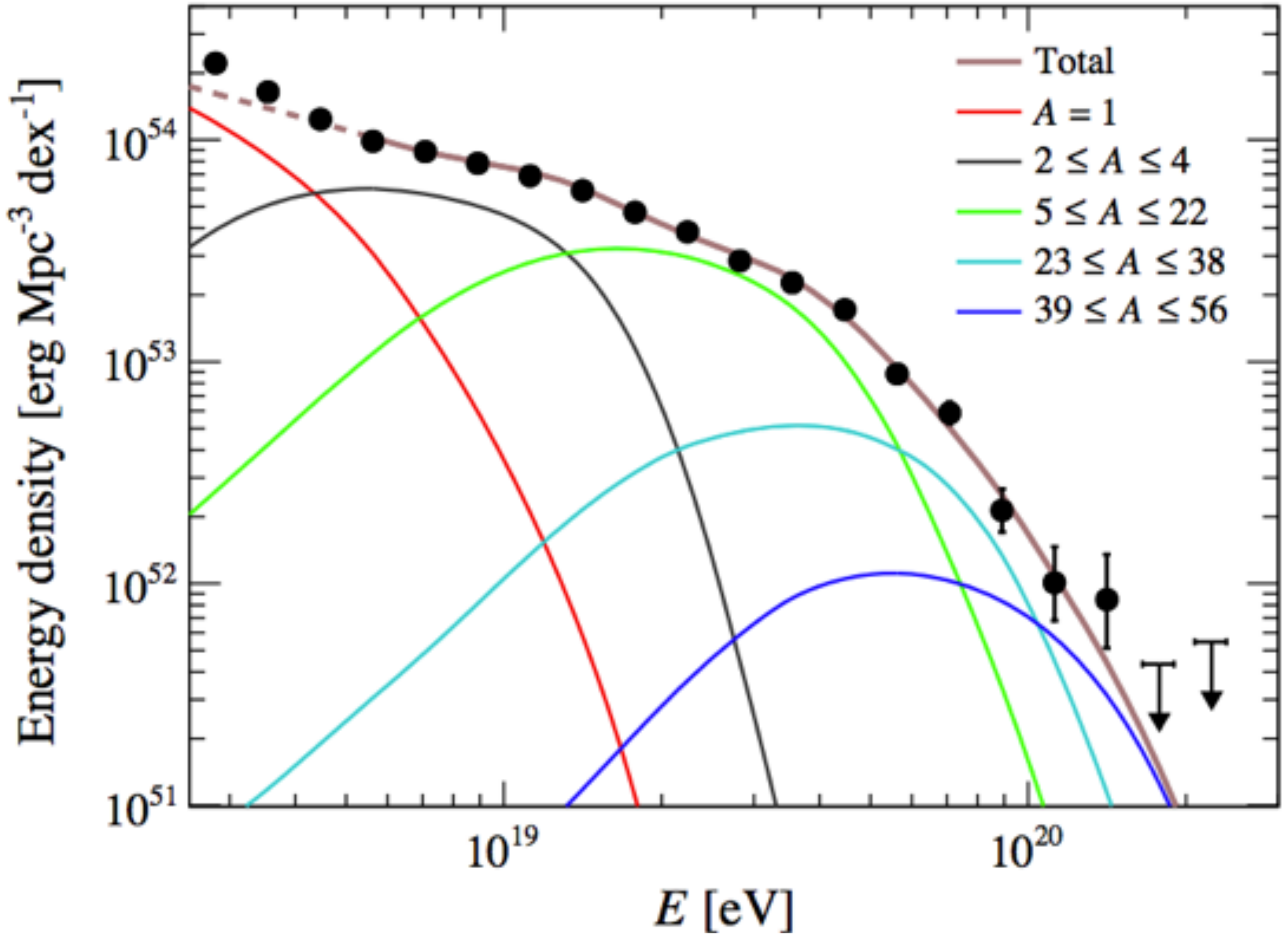


Results coming soon from LHAASO (arXiv:2010.06205)



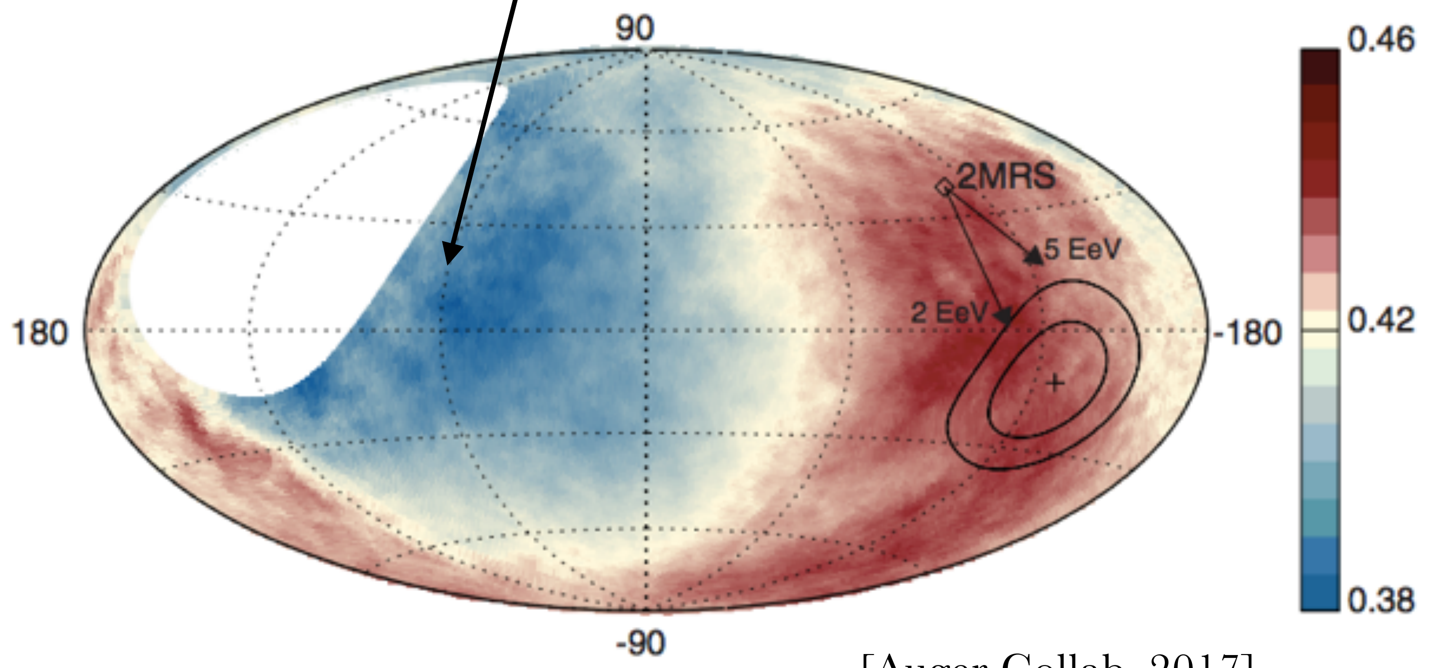
Rumor: ~1 PeV γ-ray from somewhere?

Ultrahigh-energy cosmic ray sky (O.Deligny)



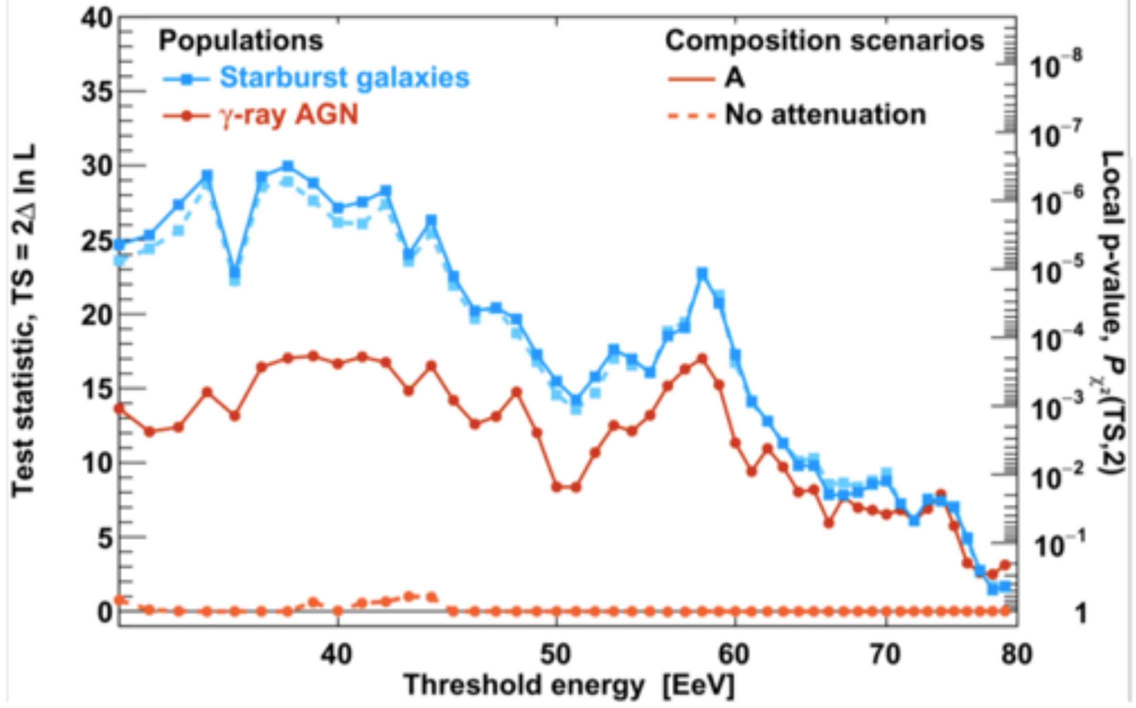
Direction of the local void

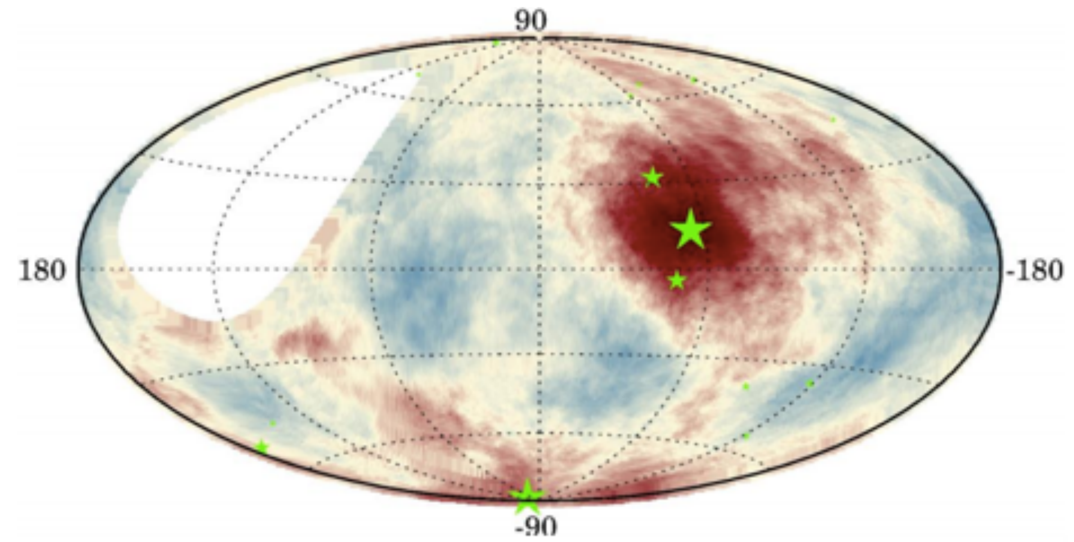
> 8 EeV



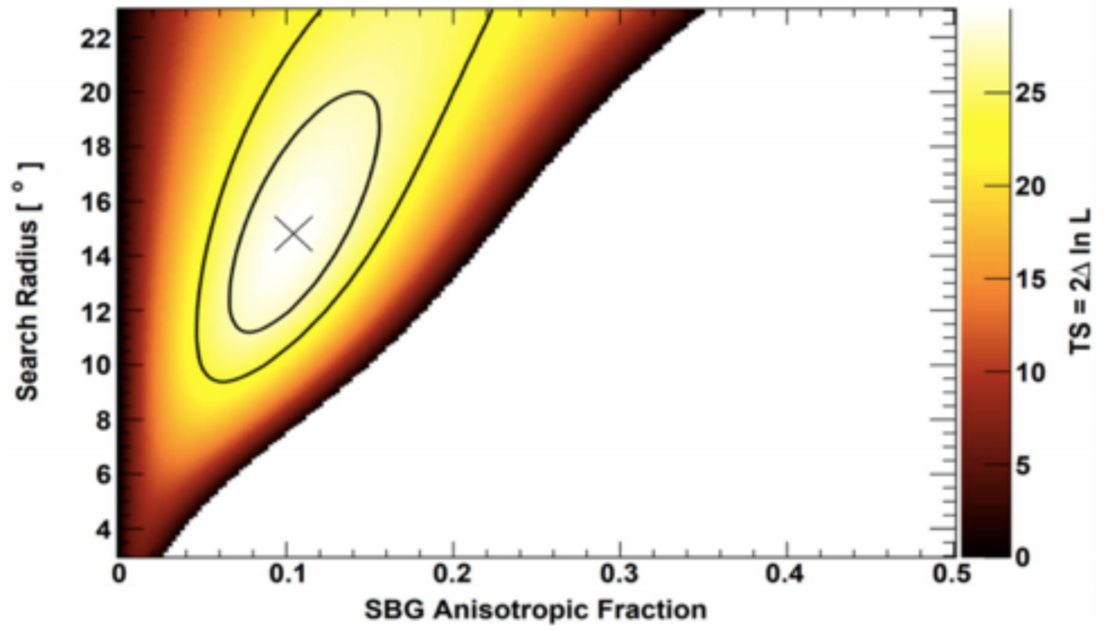
[Auger Collab. 2017]

Best matching: starburst galaxies



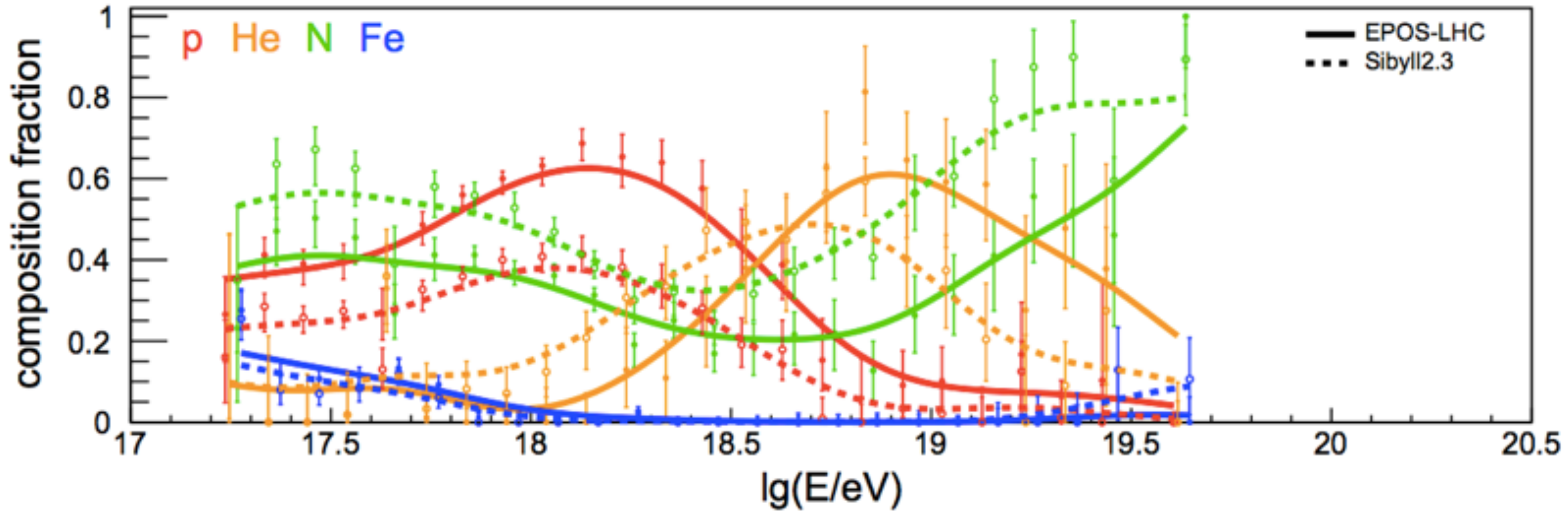


Post-trial significance: 4.5σ



- SBGs : higher rate of cataclysmic events (GRBs, hypernovas, magnetars)
- Transient sources in all galaxies, SBGs being a good tracer of the proportionality between SFR and CR production?

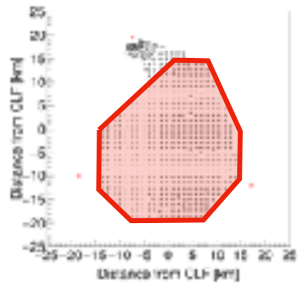
[Auger Collab. 2019]



Ultrahigh-energy cosmic ray sky (Y.Zhezher)

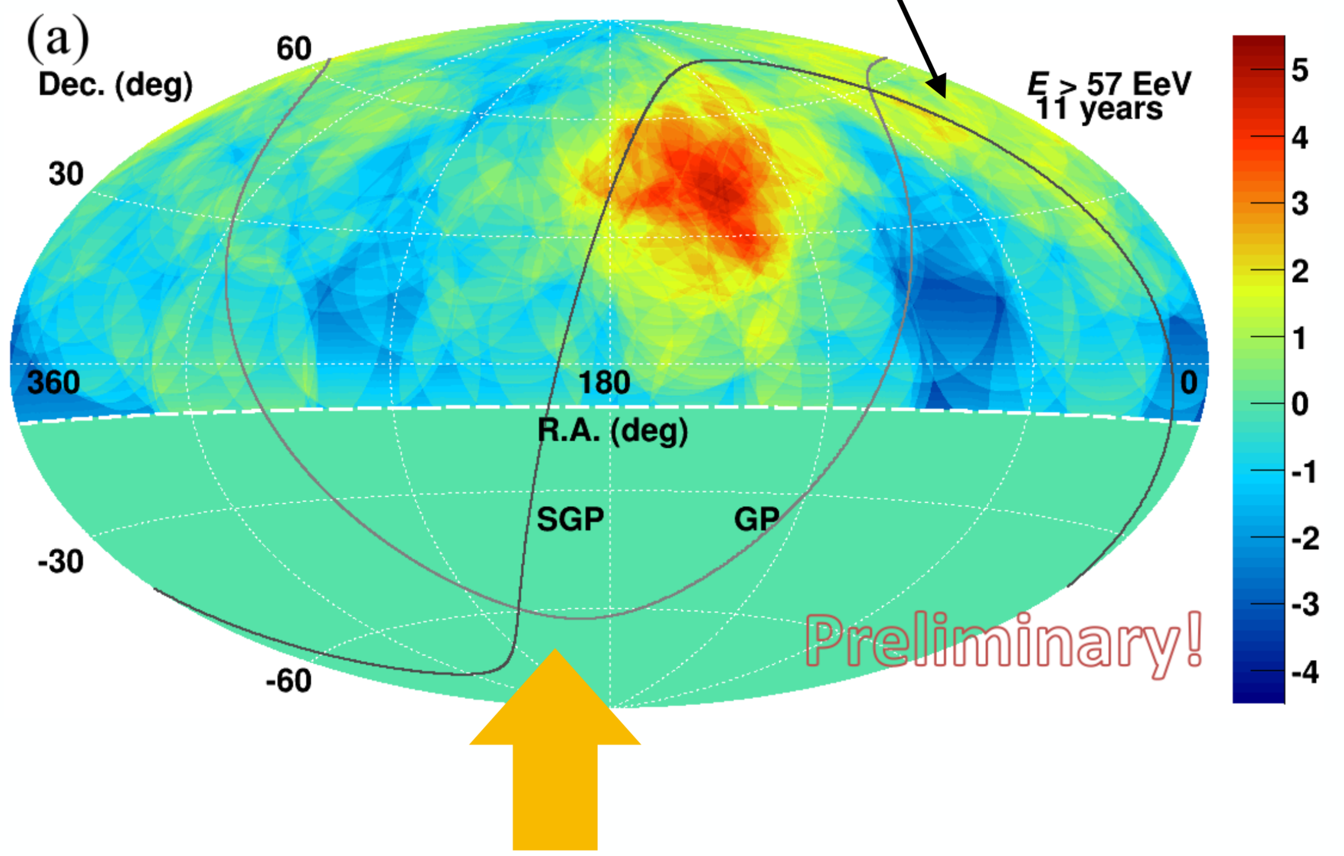
"Hotspot" update from 11 years of data

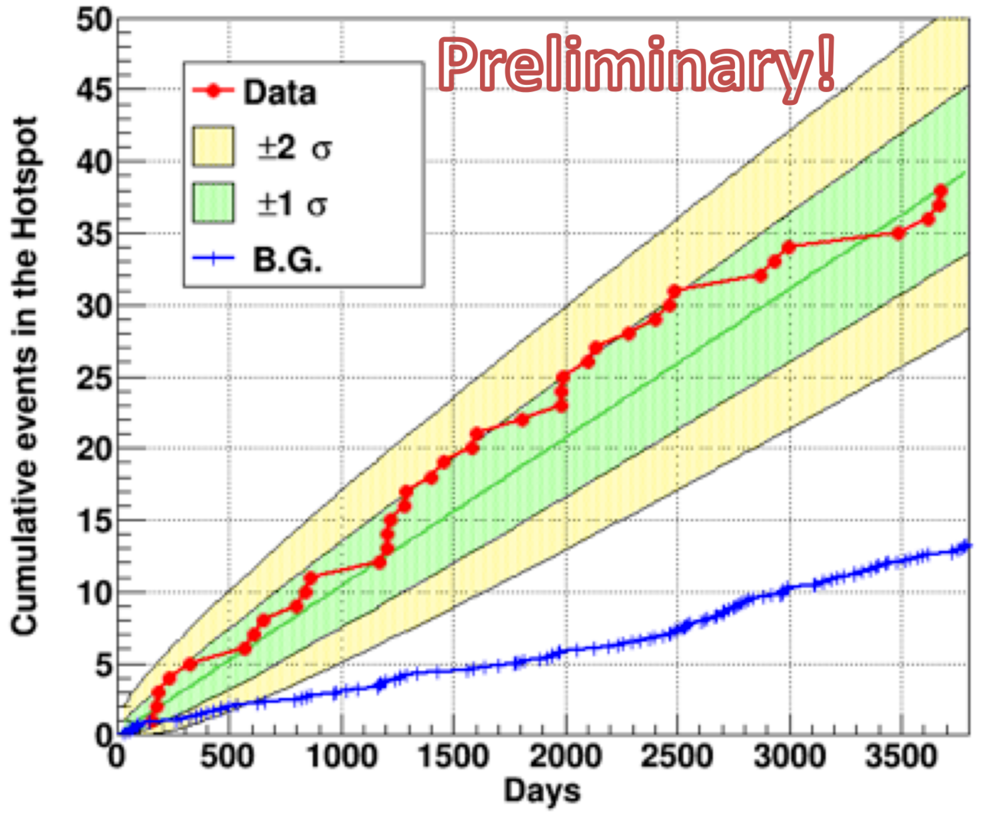
> 57 EeV



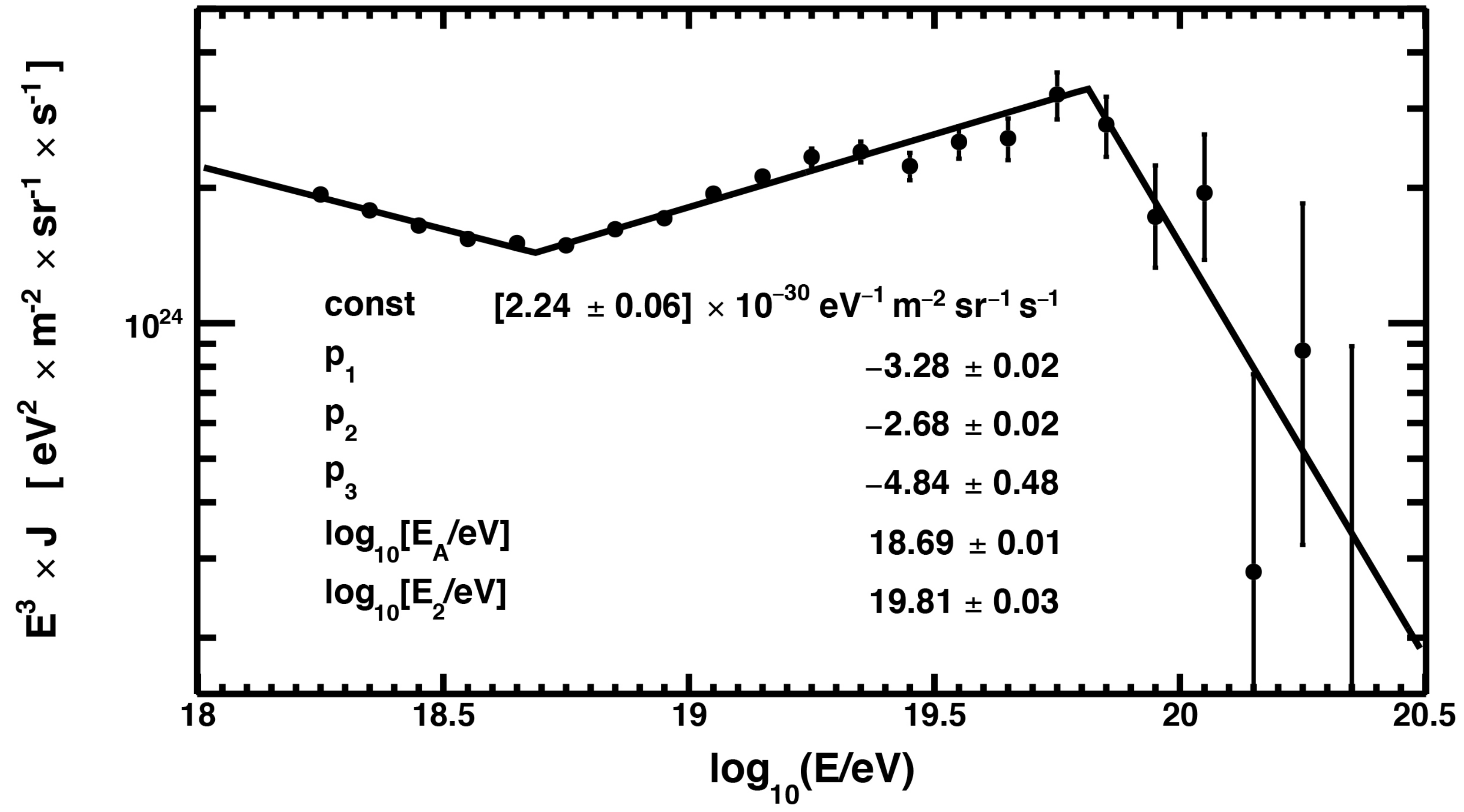
There is a marginal excess is seen along the SGP (around the Perseus-Pisces Supercluster) at the local significance of ~ 3σ

The increase rate of the events inside the hotspot circle is consistent with a constant within ±1σ fluctuation

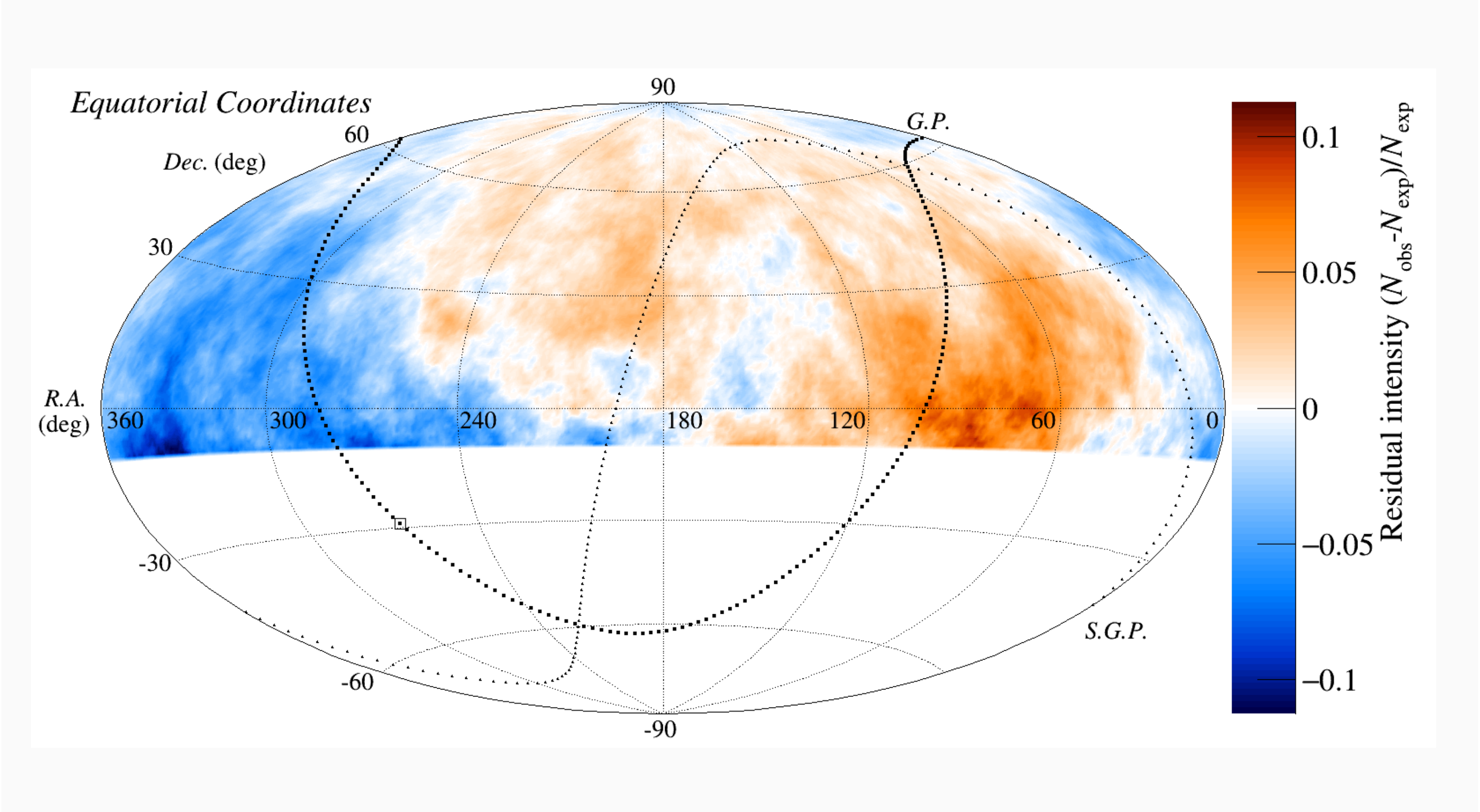




Hotspot from 11 years of TA SD data, from May 11, 2008 to May 11, 2019

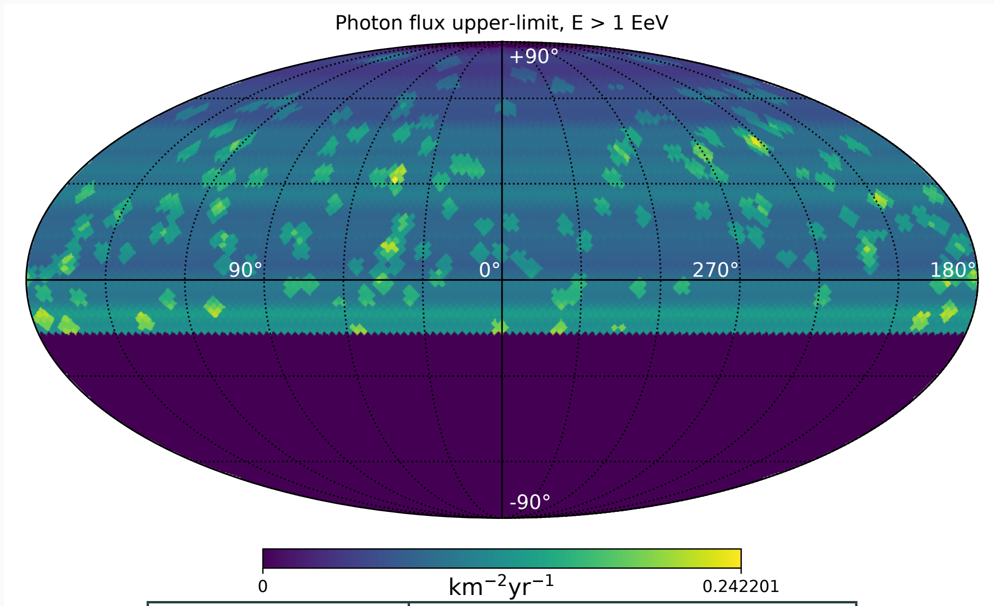


> 8.8 EeV



Results: point-source photon flux upper-limits

95% C.L.

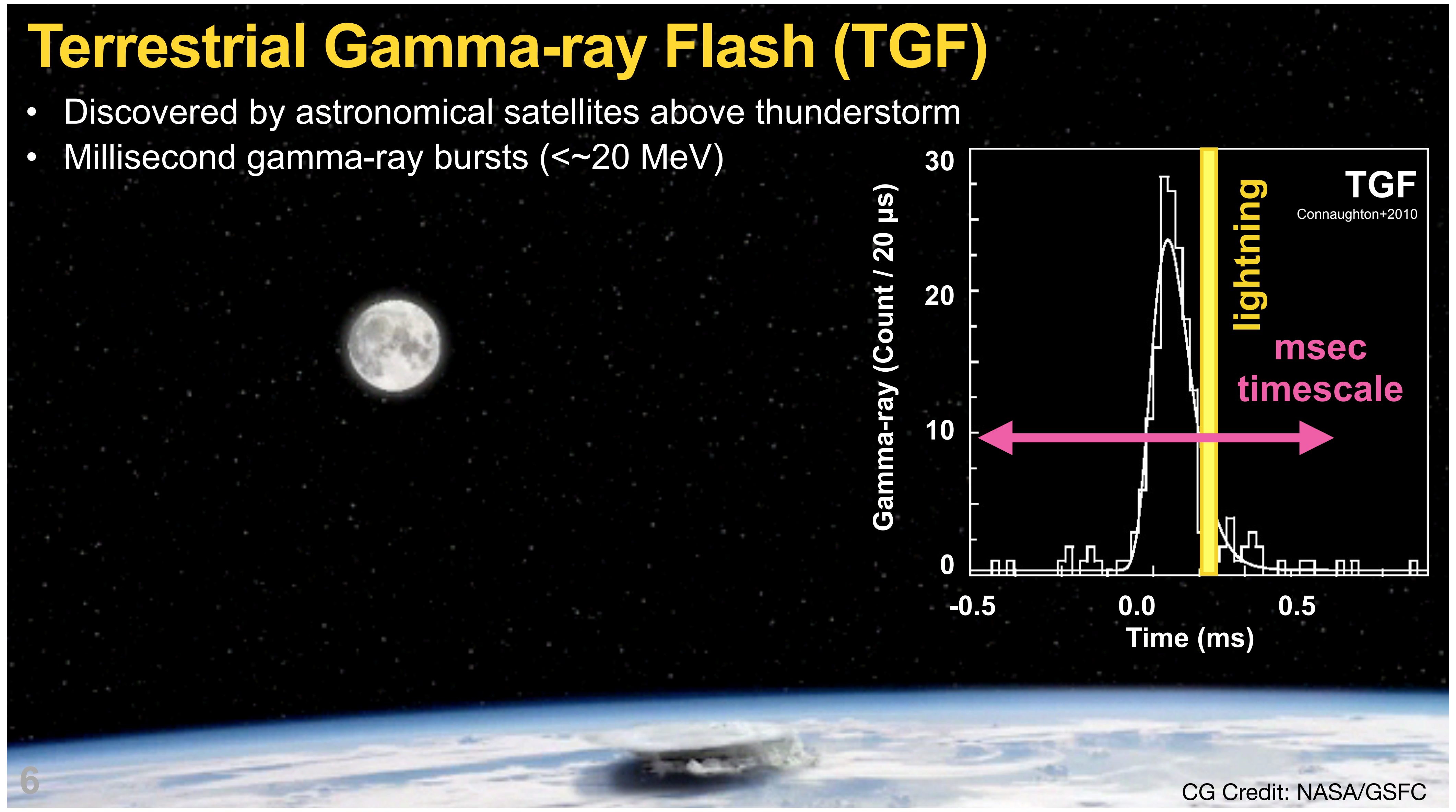


$E_\gamma \geq$, eV	$\langle F_\gamma \rangle \leq$, $km^{-2}yr^{-1}$
$10^{18.0}$	0.094
$10^{18.5}$	0.029
$10^{19.0}$	0.010
$10^{19.5}$	0.0071
$10^{20.0}$	0.0058

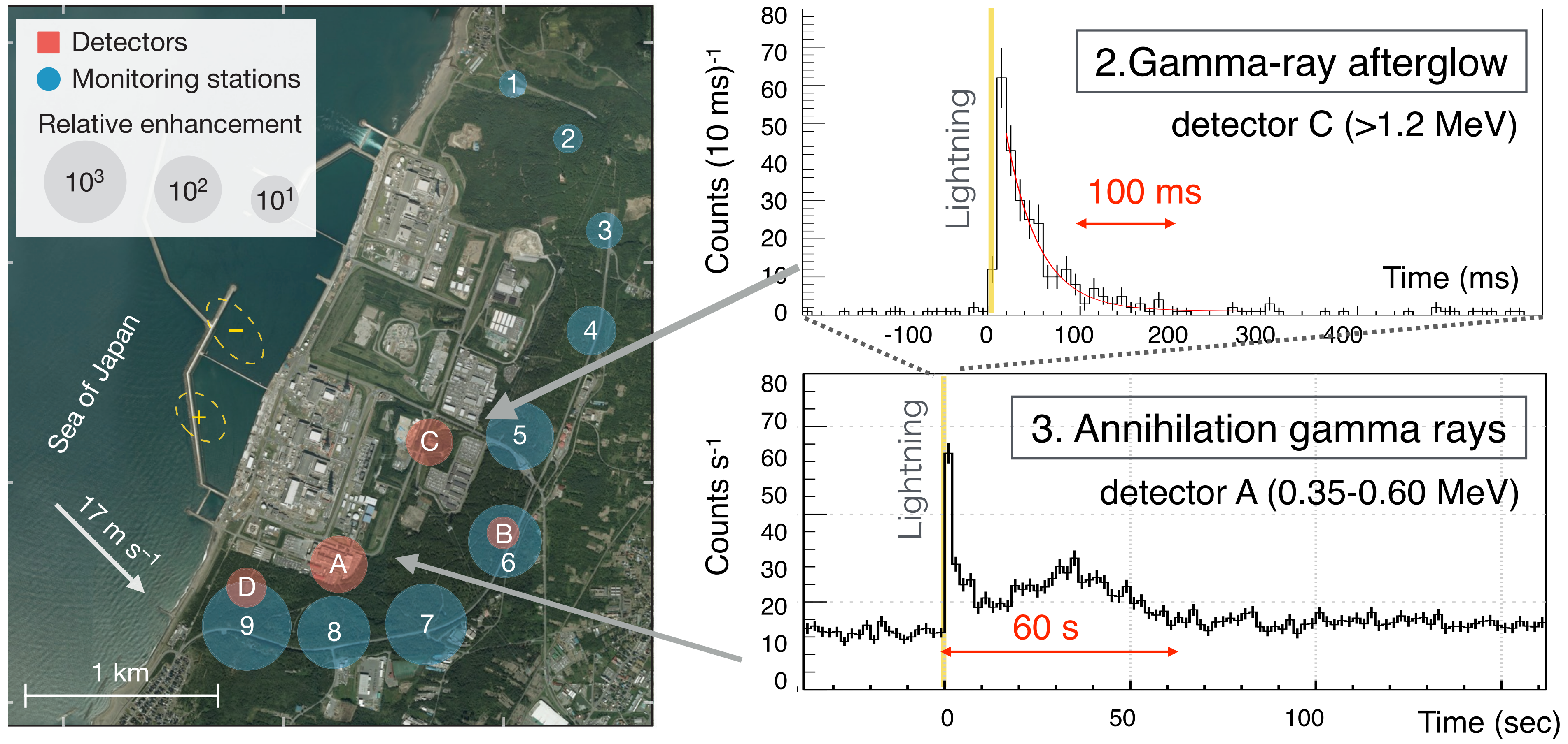
Pierre Auger: $\langle F_\gamma \rangle \leq 0.035\ km^{-2}yr^{-1}$ (1° ang.res., $10^{17.3} \leq E \leq 10^{18.5}$ eV)

TA, MNRAS 492 (2020), 3984

Connecting to Geophysics (T.Enoto)



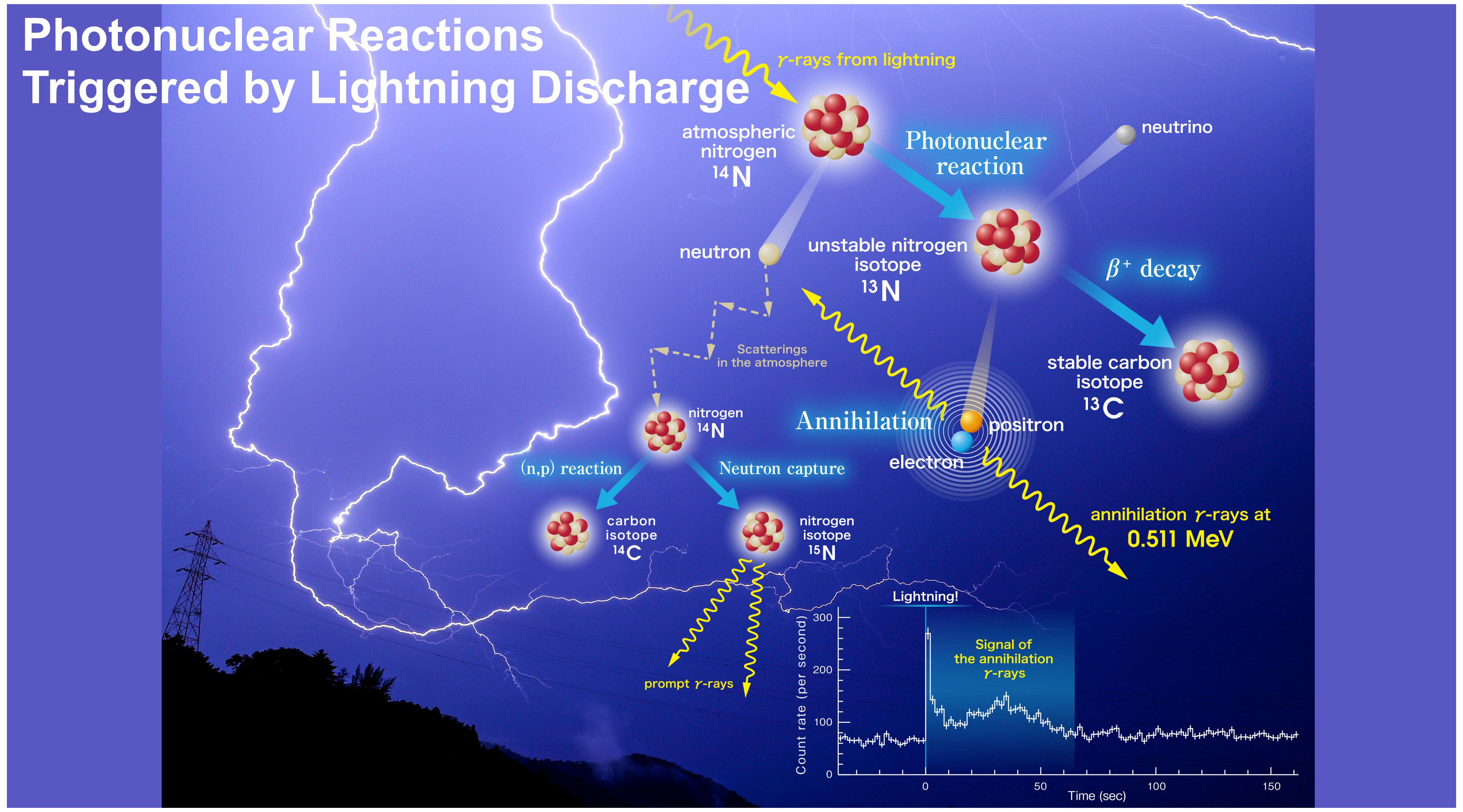
Short-duration burst associated with lightning

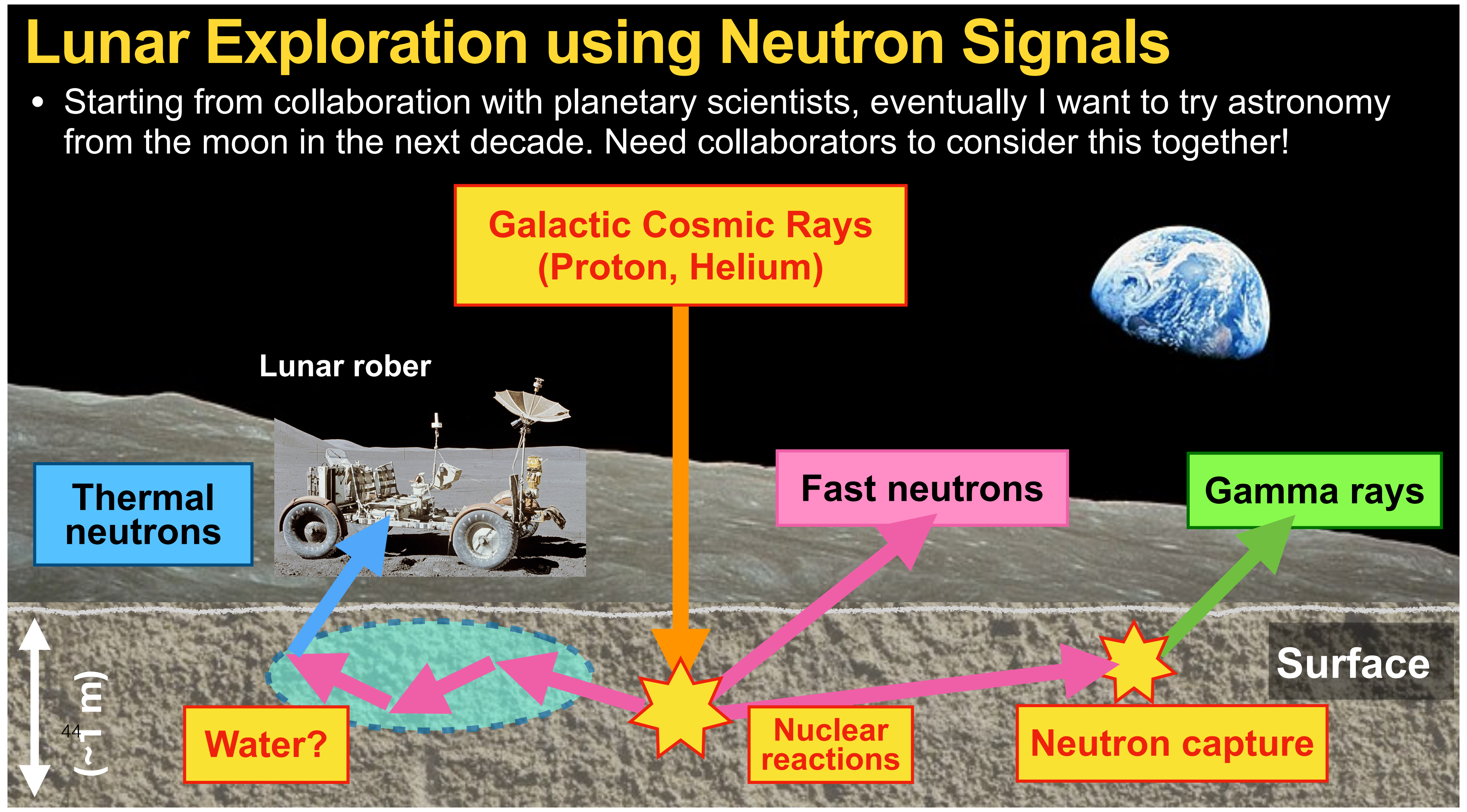


- on February 6, 2017, 17:34:06, at Kashiwazaki

1. Intensive initial spike (<~a few milliseconds, exceeds 10 MeV)
2. Gamma-ray afterglow (<~100 ms, <10 MeV)
3. Delayed annihilation gamma rays (~minute, at 0.511 MeV)

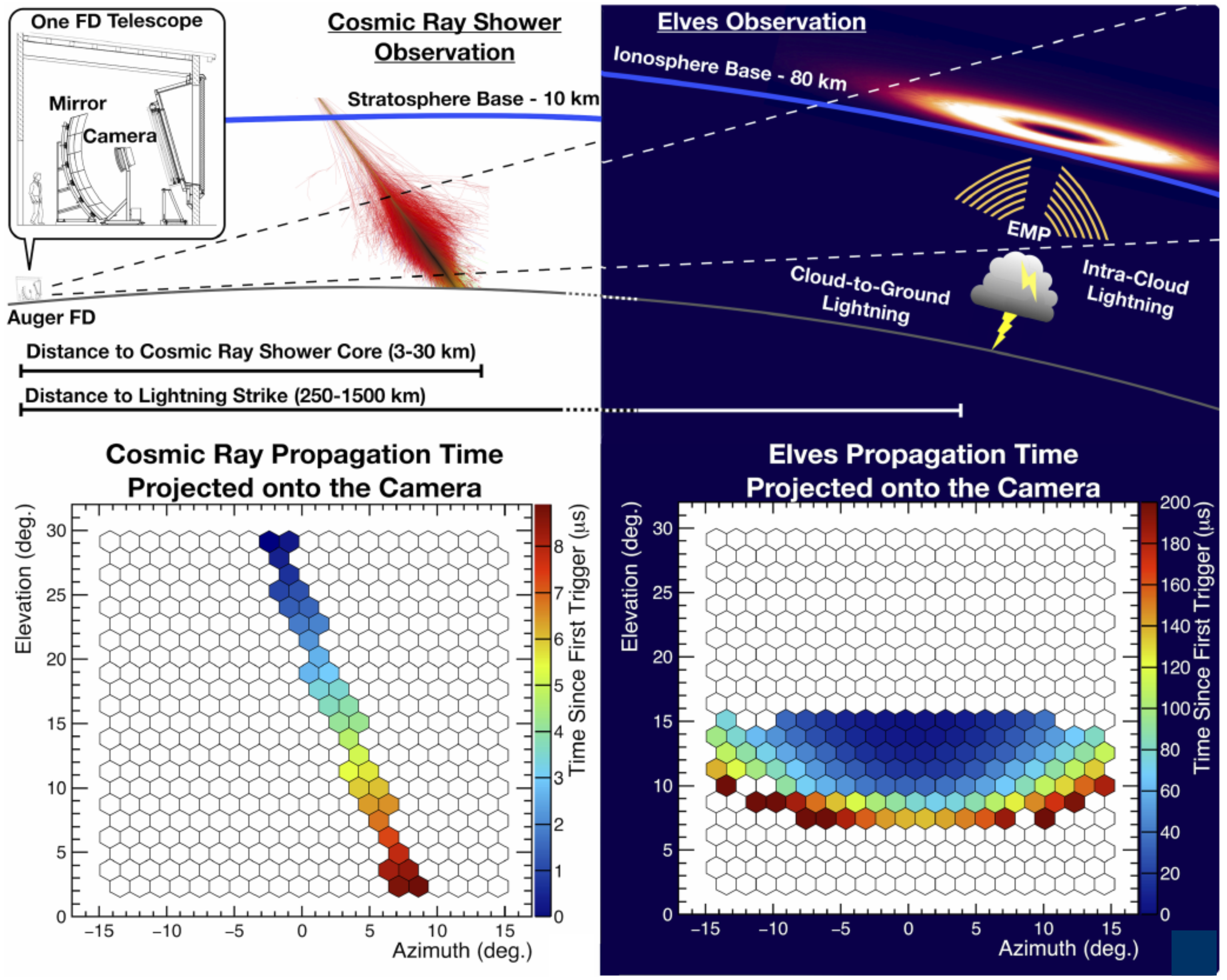
26 (Enoto, Wada et al., Nature, 2017)

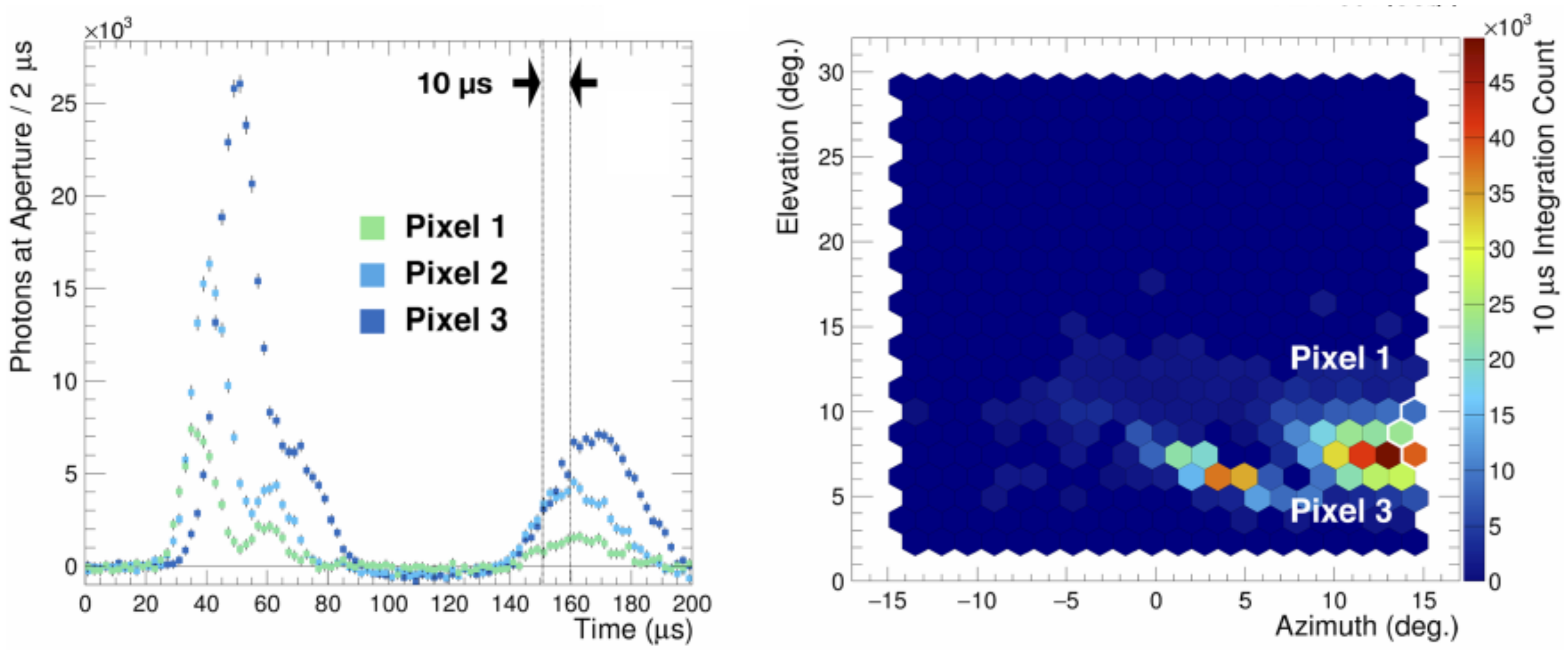




Go to the Moon!

Geophysics by cosmic ray detectors (R.Colalillo)

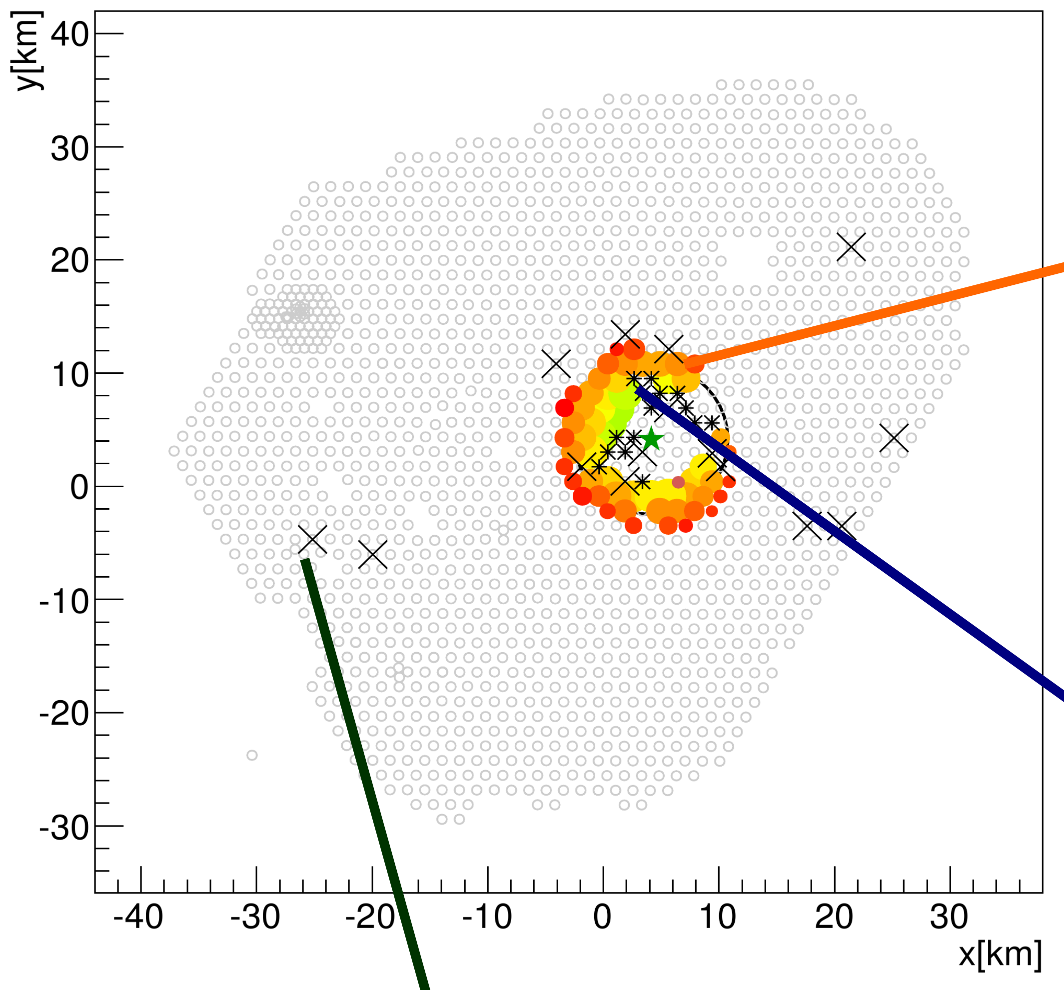


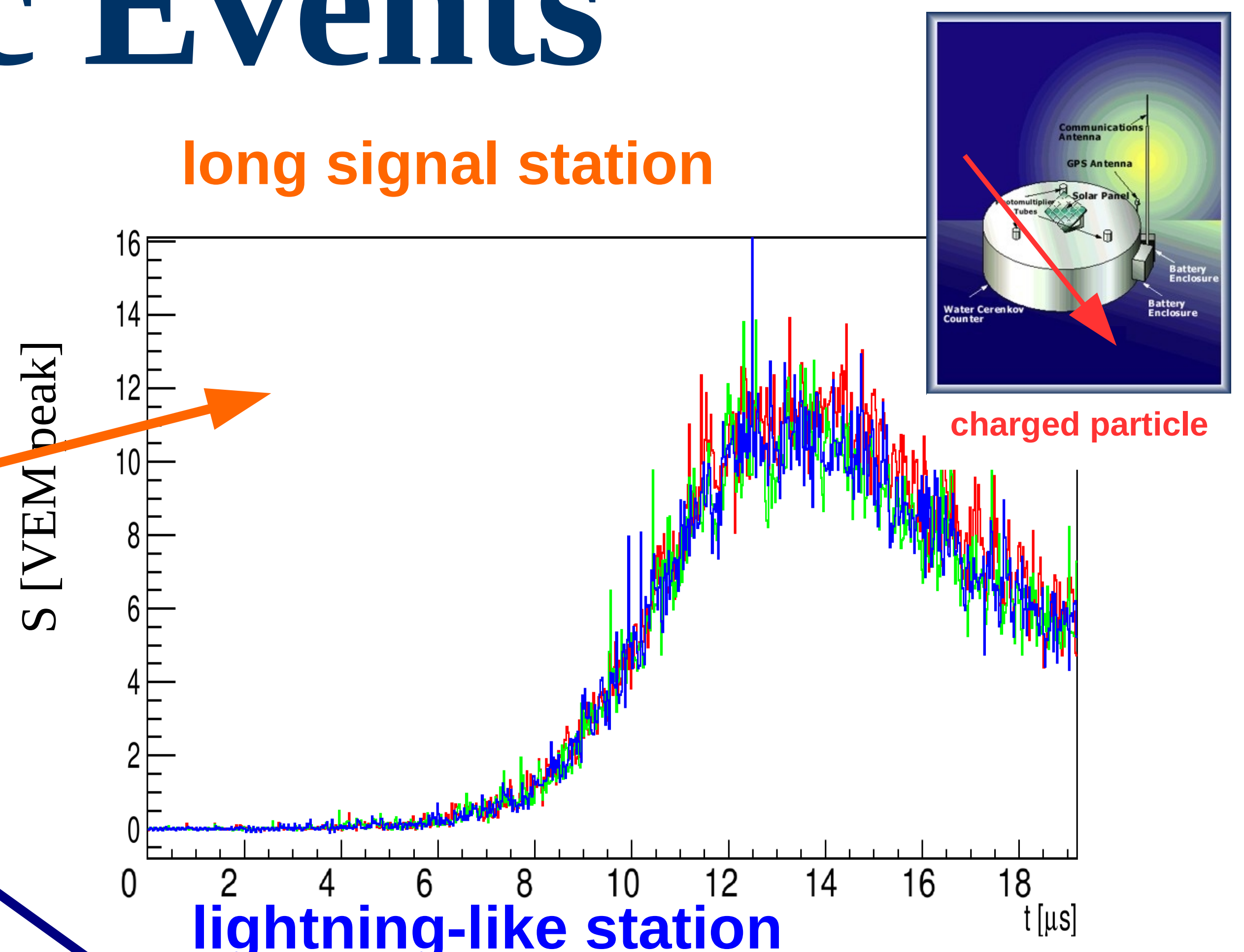


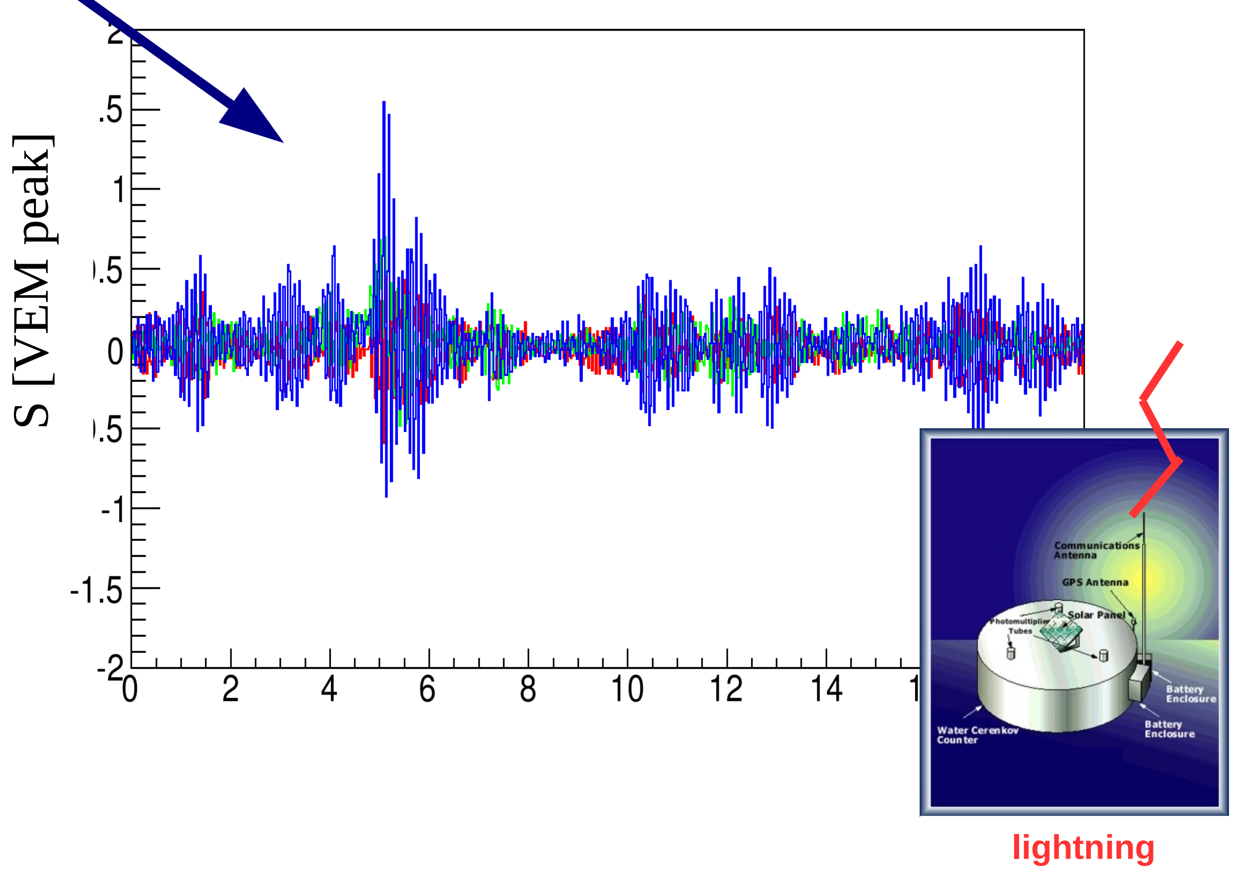
First observation of a triple elves

→ Also detected by Mini-EUSO

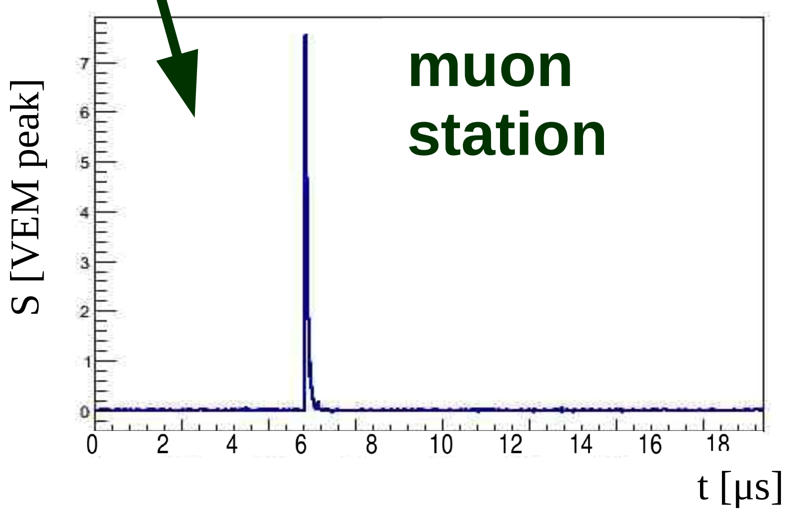
SD Exotic Events







In some these events, there are stations with a "standard" SD signal produced by a cosmic muon

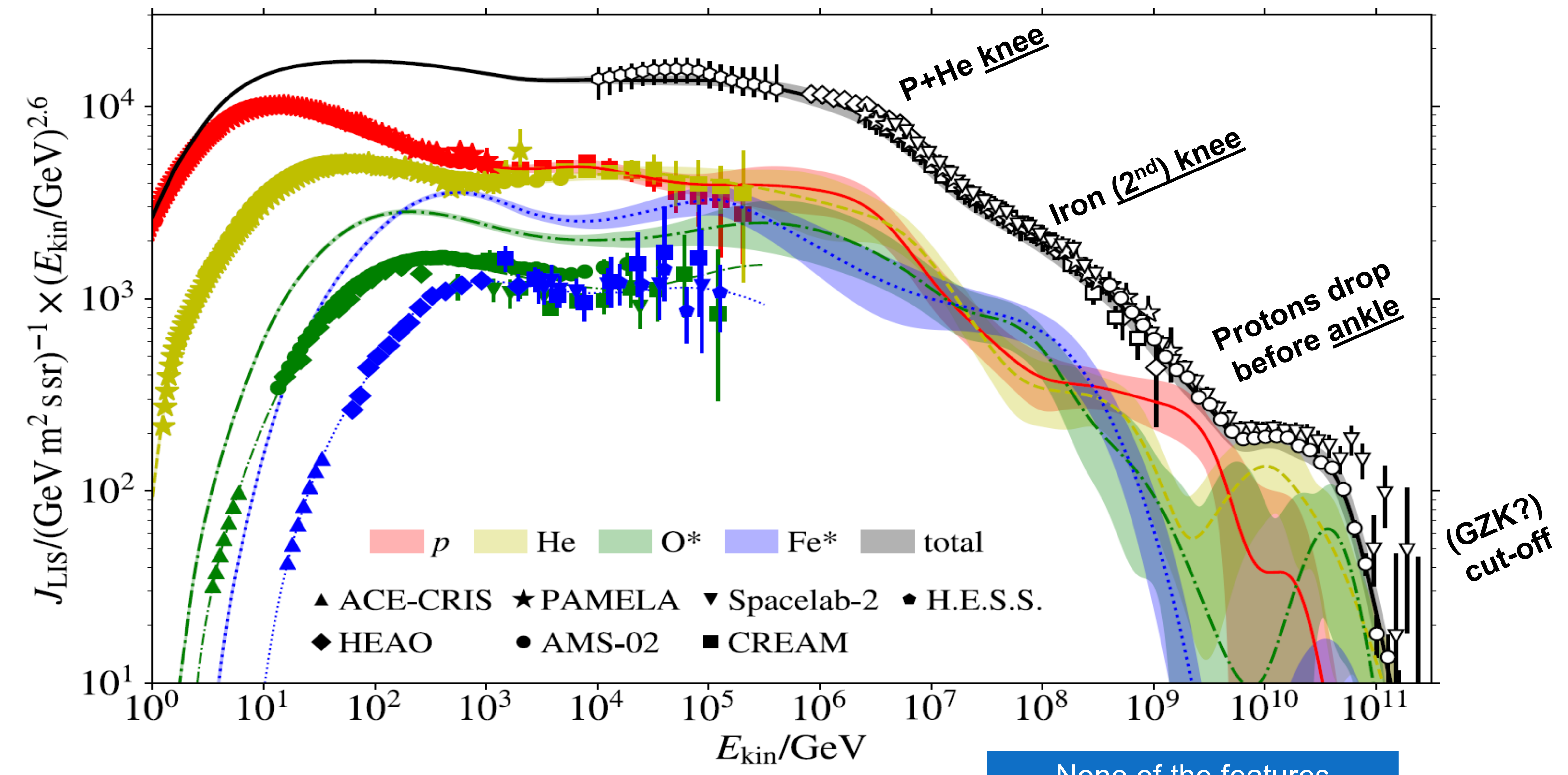


Altitude of the origin point very low, compatible with a source at ground.

Tuning interaction models for interpretation (A.Fedynitch)

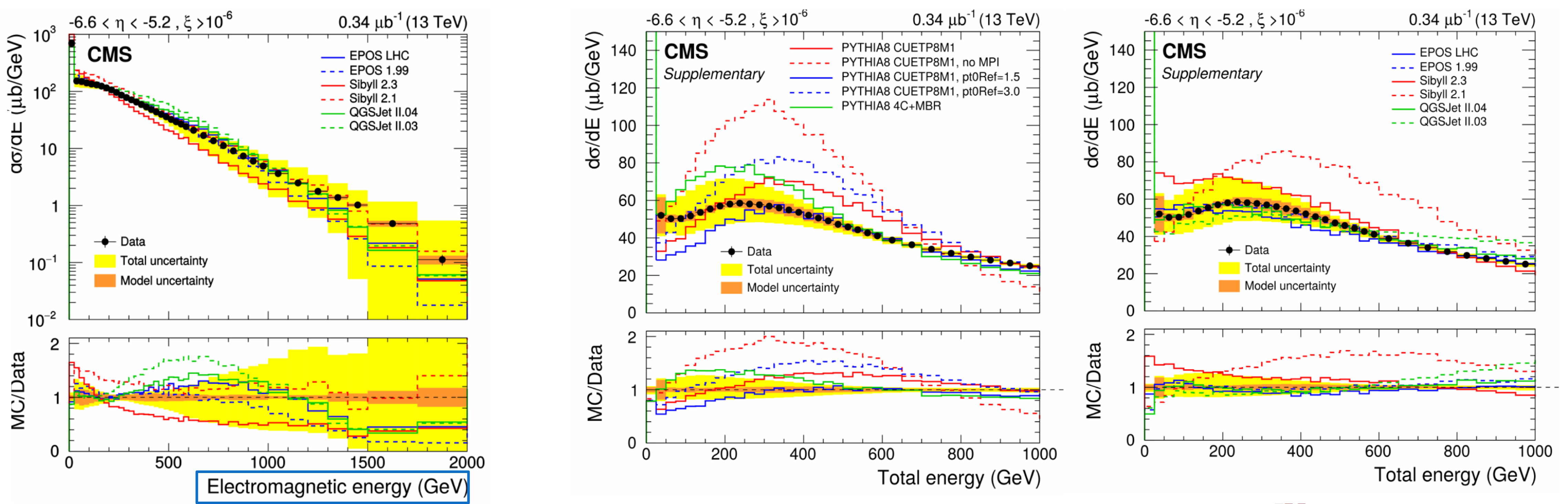
Features in cosmic ray observations

Dembinski, AF, Engel, Gaisser, Stanev
PoS(ICRC2017)533 & in prep.



None of the features unambiguously explained

Electromagnetic fraction measurement not yet in CR models



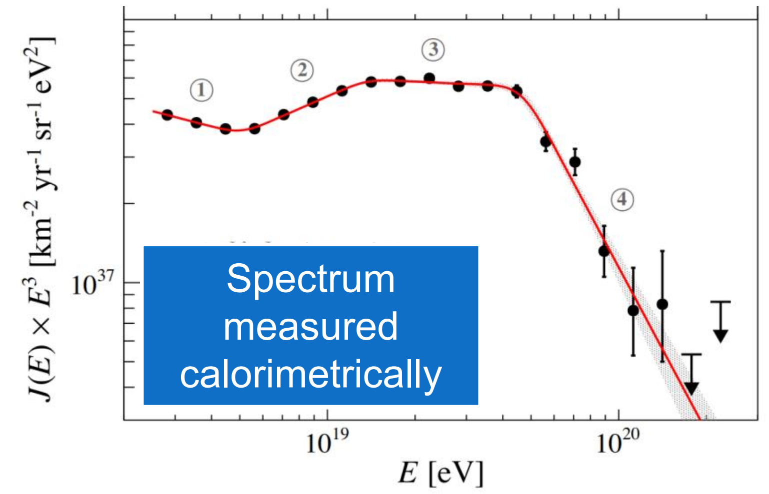
JHEP 08 (2017) 046

- Measurement constrains <~5% of total interaction energy
- EM energy fraction in SIBYLL 2.3 found to be underestimated in this limited phase space
- None of the cascade models uses these data, yet

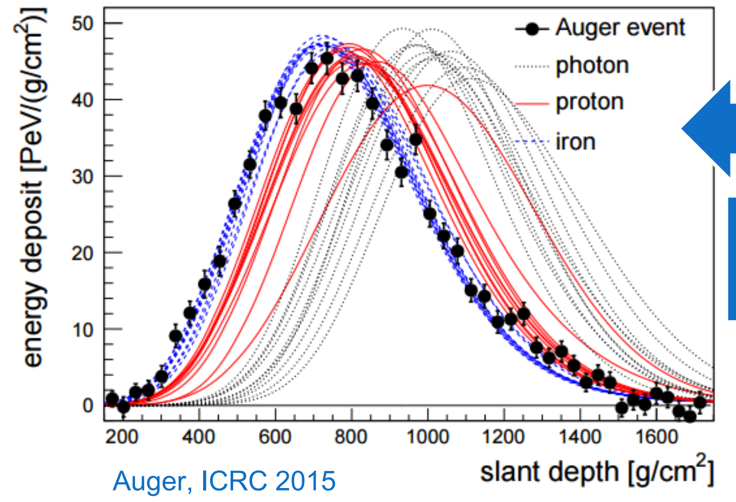
UHECR mass composition

Data

Aab et al. (PAO), PRL 2020



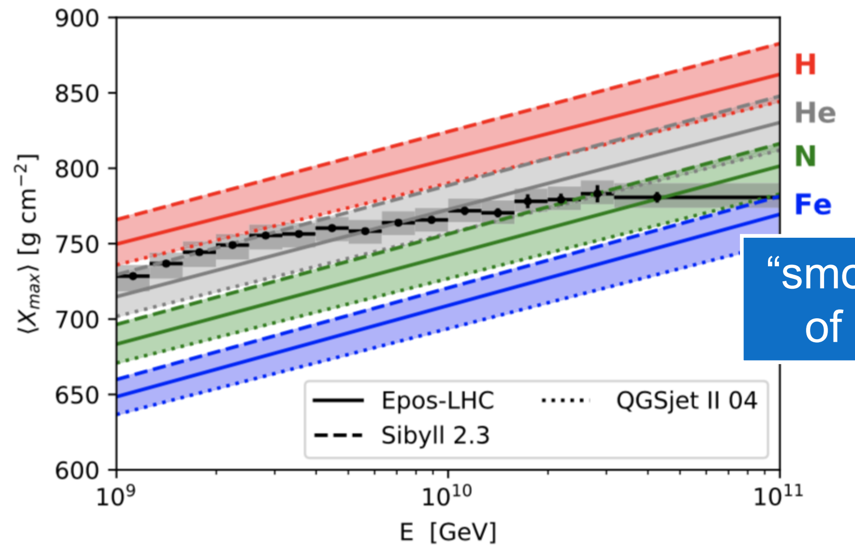
Spectrum measured calorimetrically



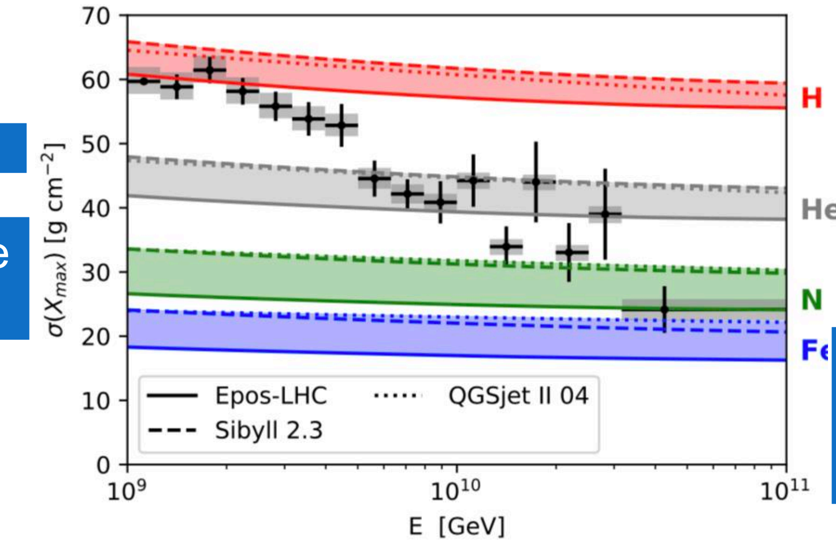
Auger, ICRC 2015

UHECR are nuclei(?)

Model territory



"smooth" increase of mean mass



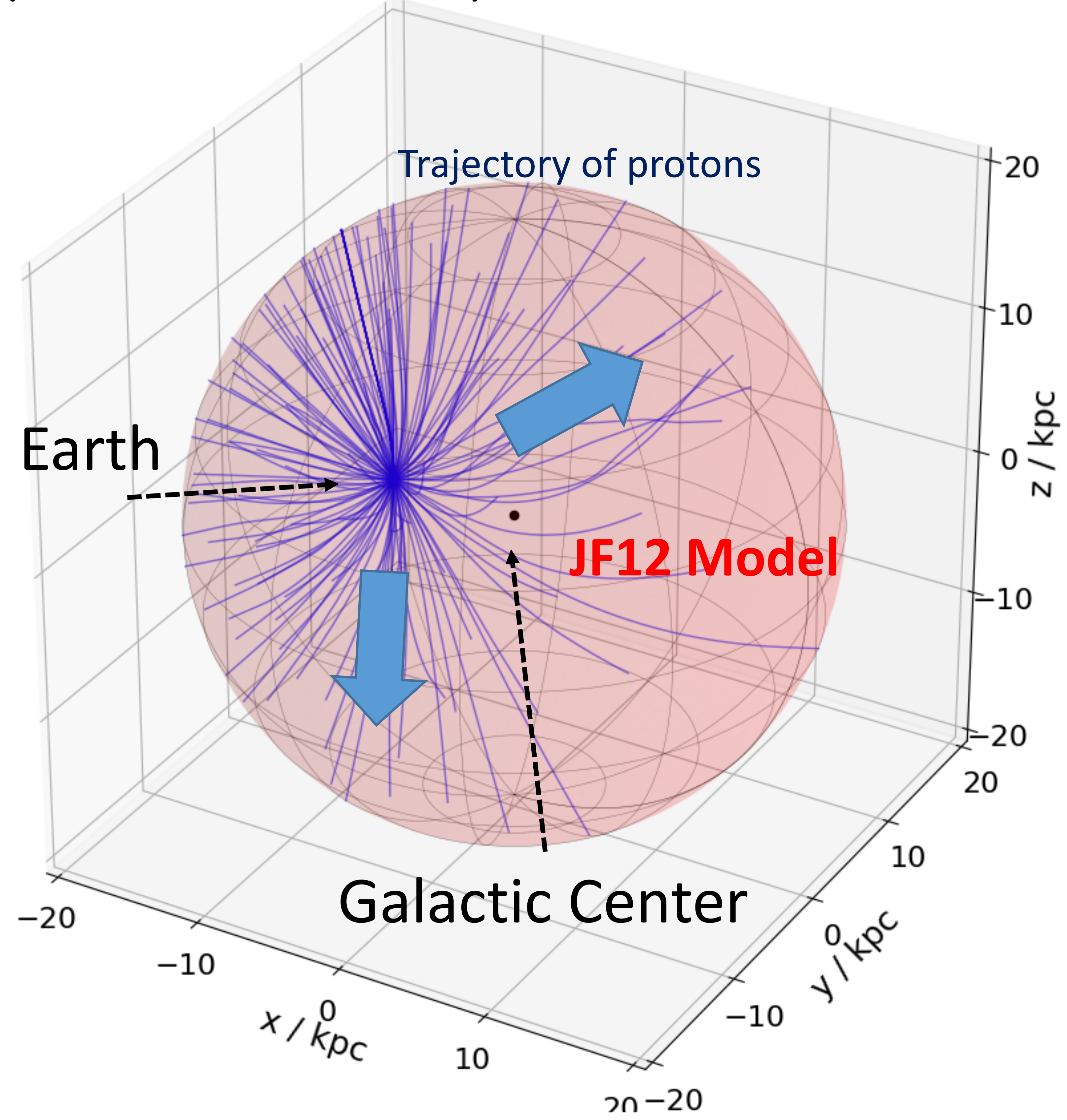
Decreasing fluctuations → mixture masses

Galactic/Extra-galactic magnetic fields

Backtracking of charged particle (R.Higuchi)

Backtracking in GMF (with CRPropa)

(JF12 Model, 10 EeV)



- **Backtracking:** inverse calculation using anti-particle from the earth
  - **particle: anti-proton**
  - back to 20 kpc from the galactic center
- Tool: CRPropa 3
  - software for UHECR propagation
  - propagation with GMF
- GMF : JF12 Model (Jansson&Farrar+12)

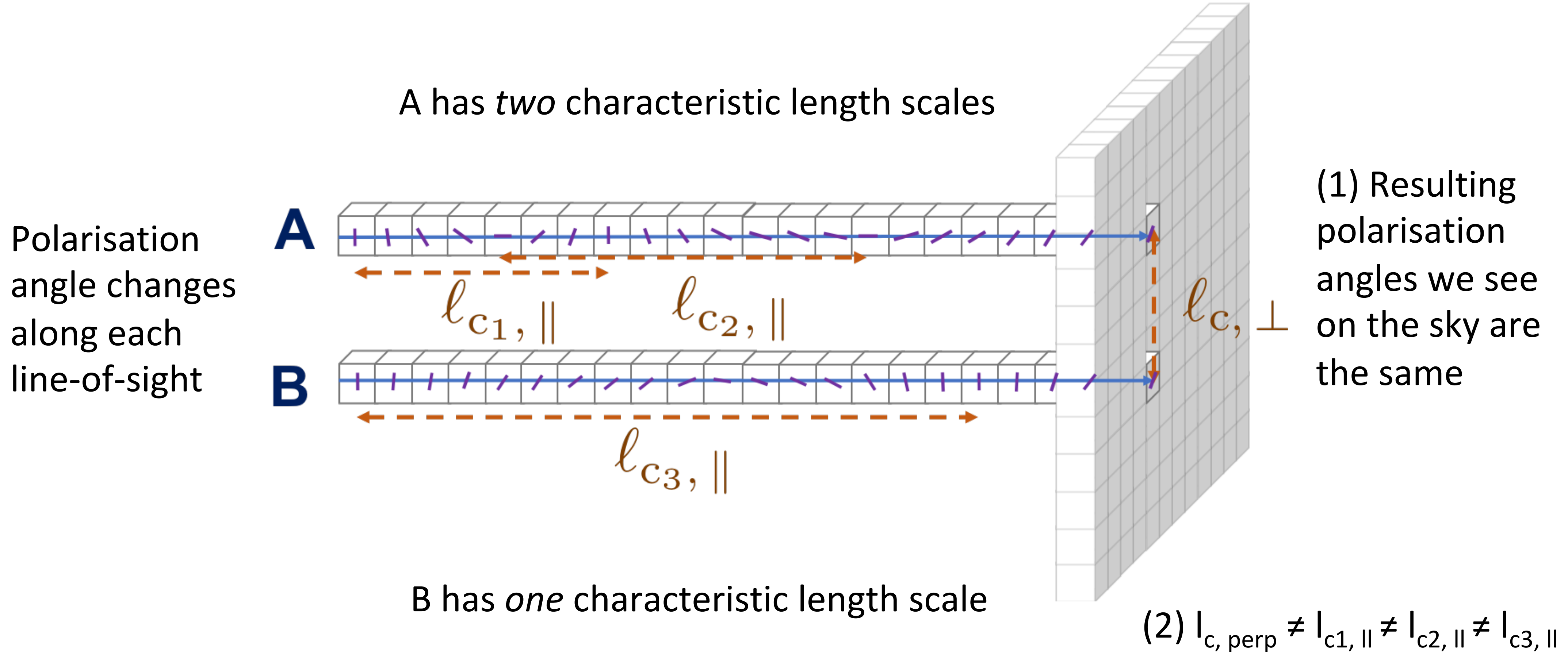
6

Faraday rotation measurement (A.Y.L. On)

YITP Workshop
December 7 – 10, 2020
Alvina Y. L. On
國立清華大學 NATIONAL TSING HUA UNIVERSITY
UCL

SUBTLETIES IN QUANTIFYING THE RMF

Fluctuations of density and magnetic fields along the line-of-sight and across the sky plane can be different

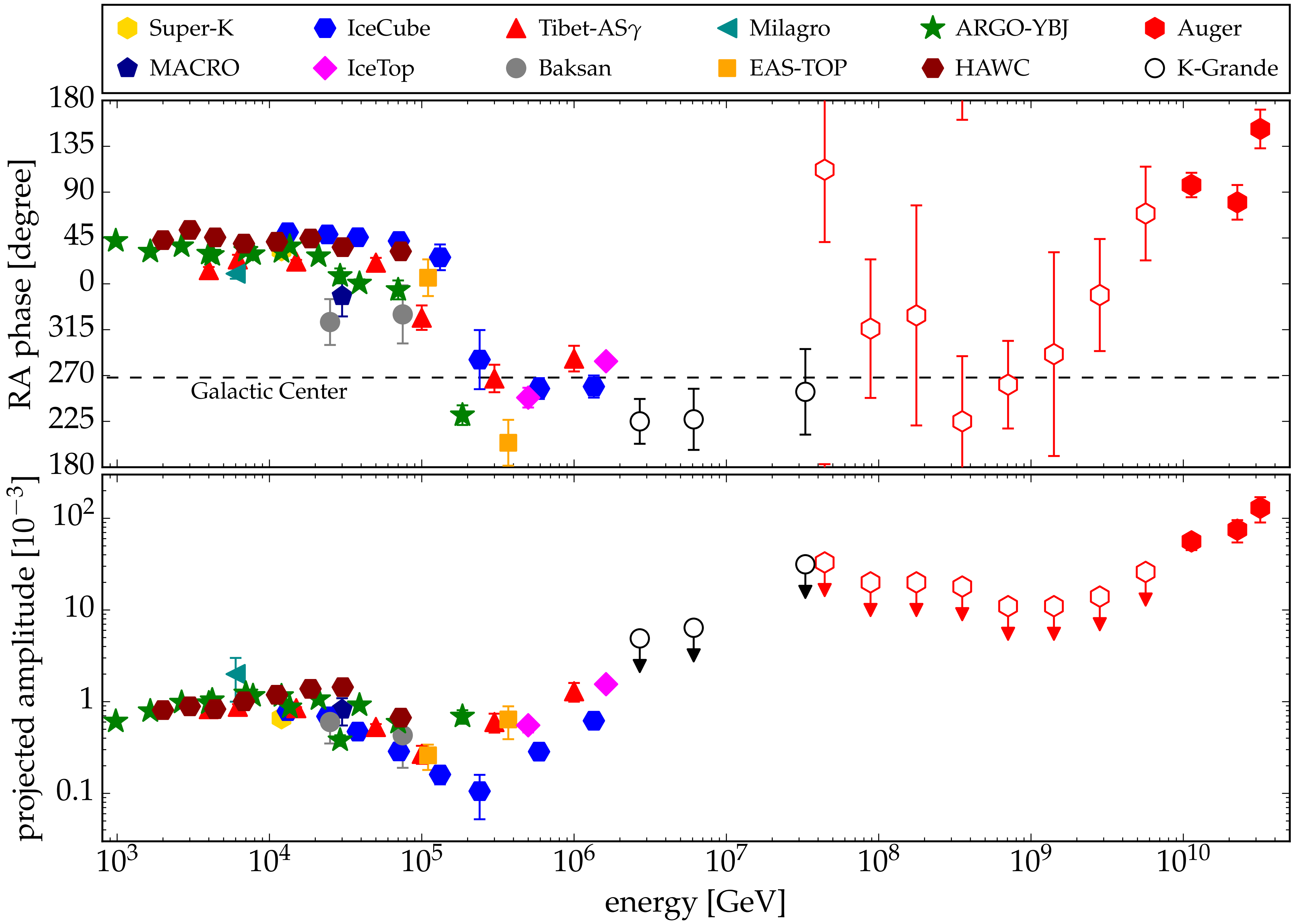


18

(Chan, Wu, **On**+ 2018; **On**+ 2019)

Cosmic ray anisotropy to investigate magnetic field (M.Alhers)

Cosmic Ray Dipole Anisotropy



Vela, as local cosmic ray origin?

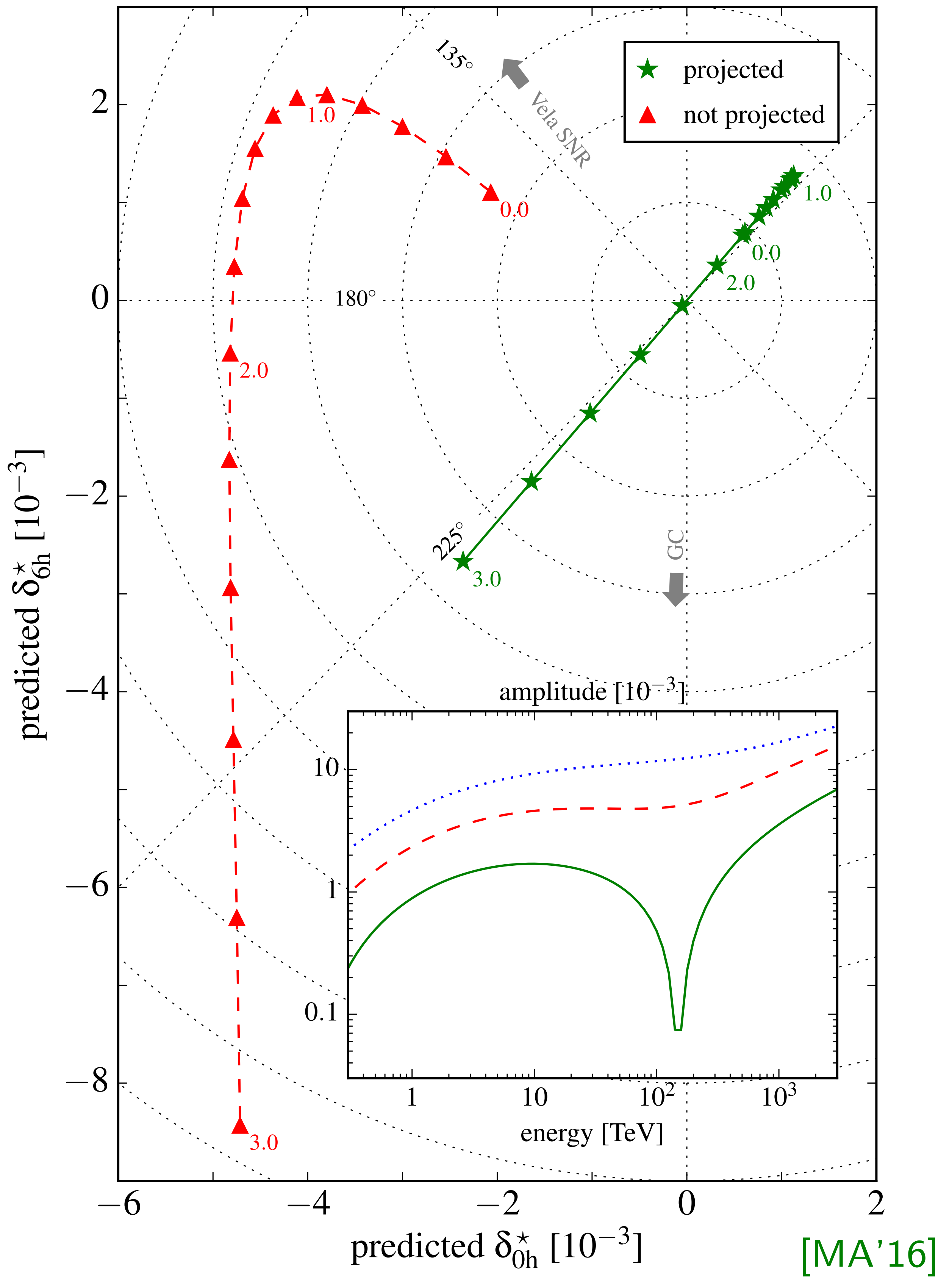
Phase-Flip by Vela SNR

- 1–100 TeV phase indicates dominance of a local source within longitudes:

$$120^\circ \lesssim l \lesssim 300^\circ$$

- **plausible scenario: Vela SNR** [MA'16]
  - *age* : $\simeq 11{,}000$ yrs
  - *distance* : $\simeq 1{,}000$ lyrs
  - *SNR rate* : $\mathcal{R}_{\rm SNR} = 1/30\,{\rm yr}^{-1}$
  - *(effective) isotropic diffusion*:

    $$K_{\rm iso} \simeq 4\times10^{28}(E/3{\rm GeV})^{1/3}{\rm cm}^2/{\rm s}$$
  - *Galactic half height* : $H \simeq 3$ kpc
  - *instantaneous CR emission* $(Q_\star)$



[MA'16]

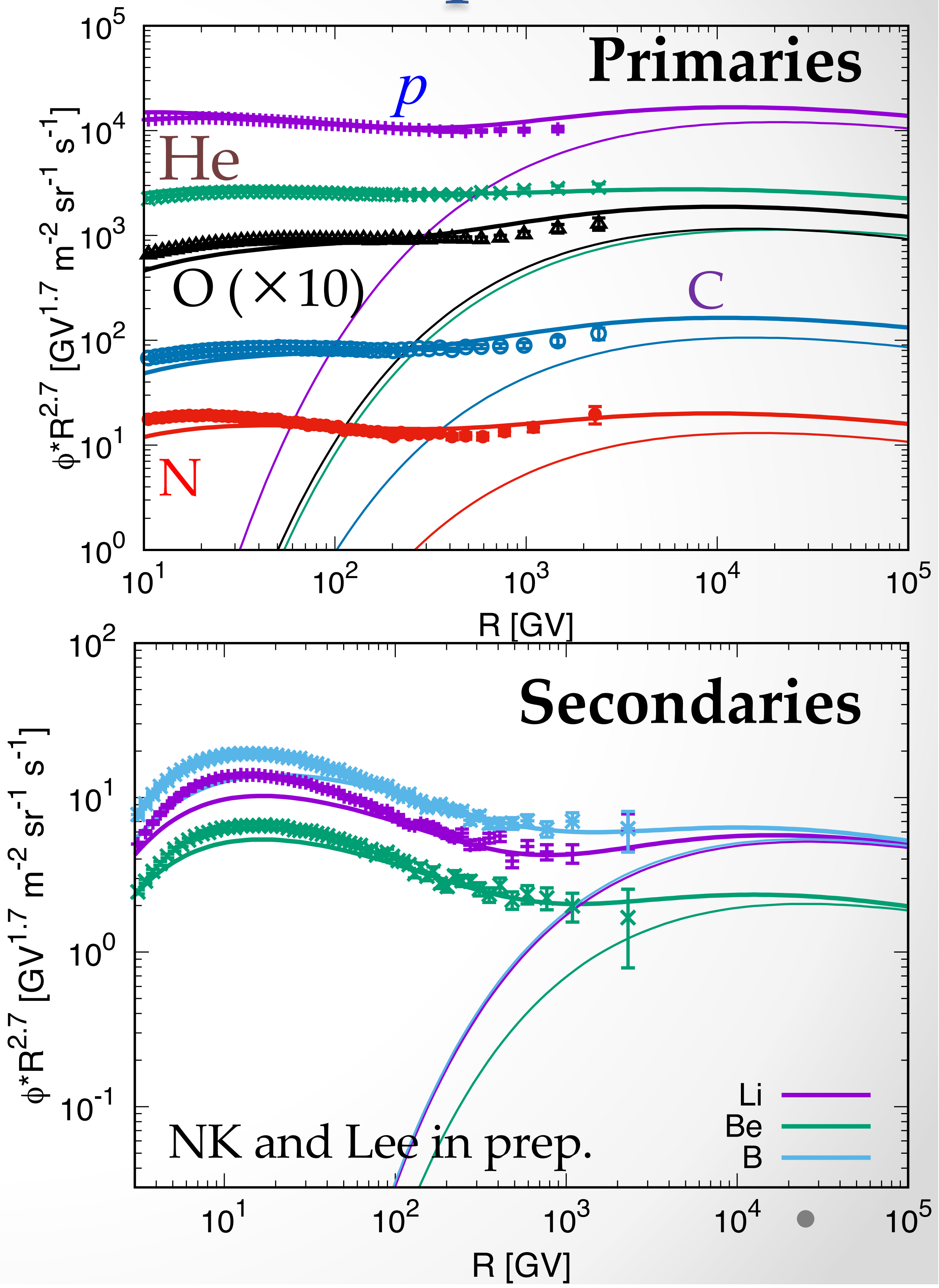
Spectrum hardening by secondary nuclei (N.Kawanaka)

Fitting to the observed CR spectra

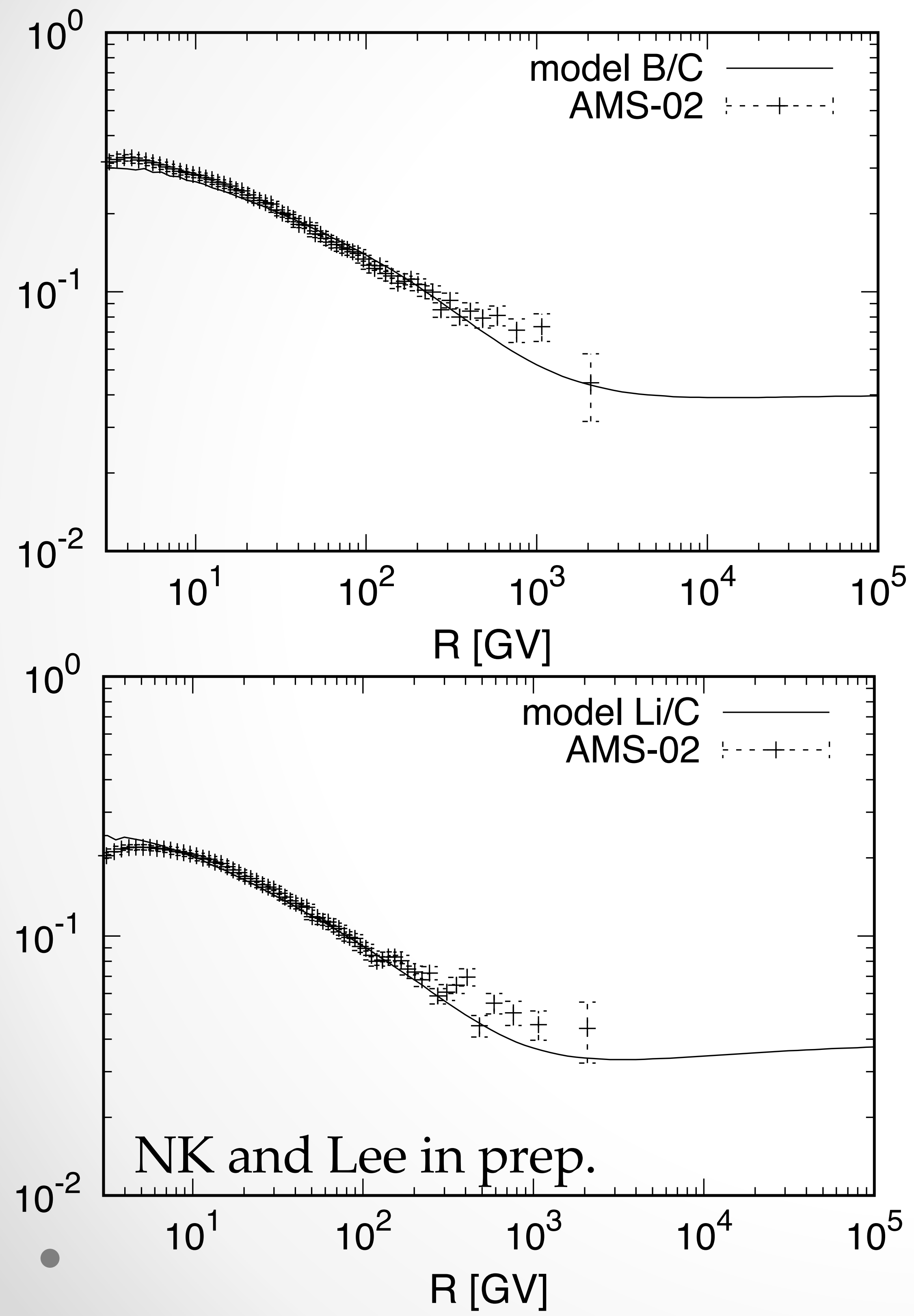
a local SNR with CSM:
(thin lines)

$$\begin{cases} \dot{M} = 1\times10^{-3} M_\odot \ \mathrm{yr}^{-1}, \\ v_w = 100 \ \mathrm{km\ s}^{-1}, \\ E_{SN} = 10^{51}\mathrm{erg}, \eta_{CR} = 0.1 \\ \text{age: } 1.5 \times 10^5 \ \mathrm{yr} \\ \text{distance: } 1.5 \ \mathrm{kpc} \end{cases}$$

Spectral hardenings of primary and secondary nuclei are reproduced simultaneously!



Prediction



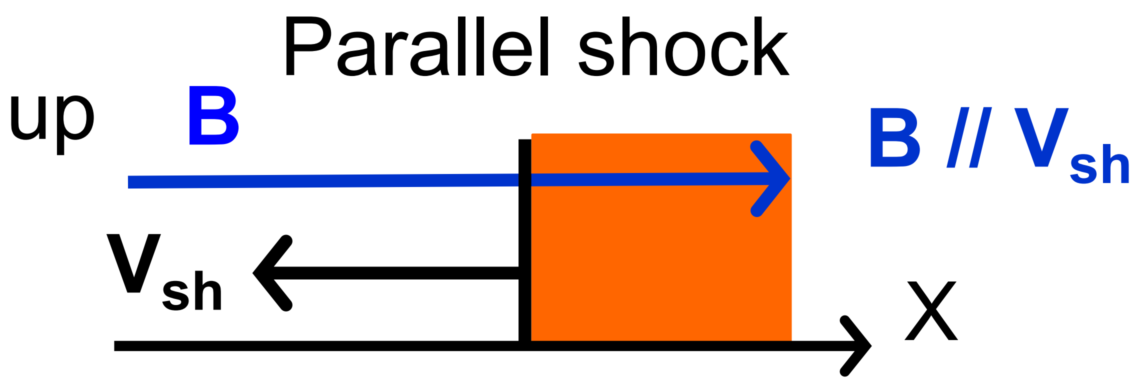
<u>background</u> ($\lesssim$ 200 GV):
Secondaries are <u>softer</u> than primaries.

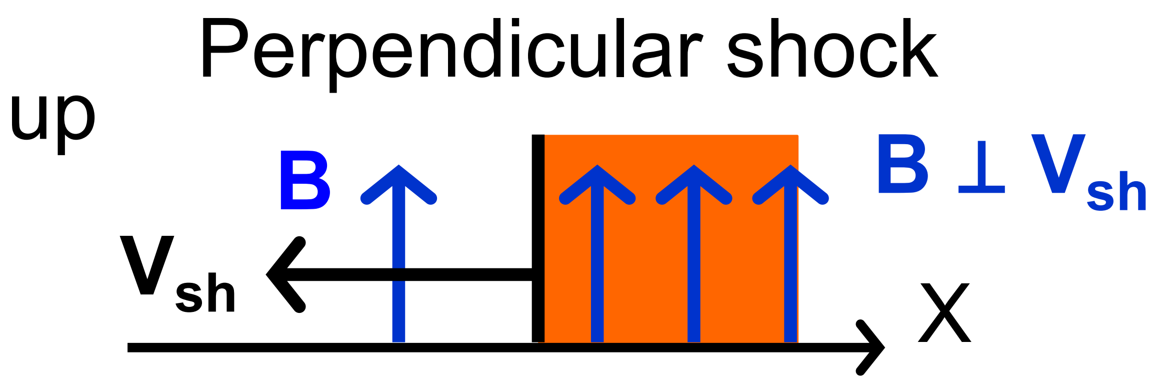
<u>a local SNR contribution</u> ($\gtrsim$ 200 GeV):
Secondaries are <u>harder</u> than primaries

Energy dependence of **secondary-to-primary ratios** would flatten at higher energies
It may rise with energy!

SNR as PeVatron (Y.Ohira)

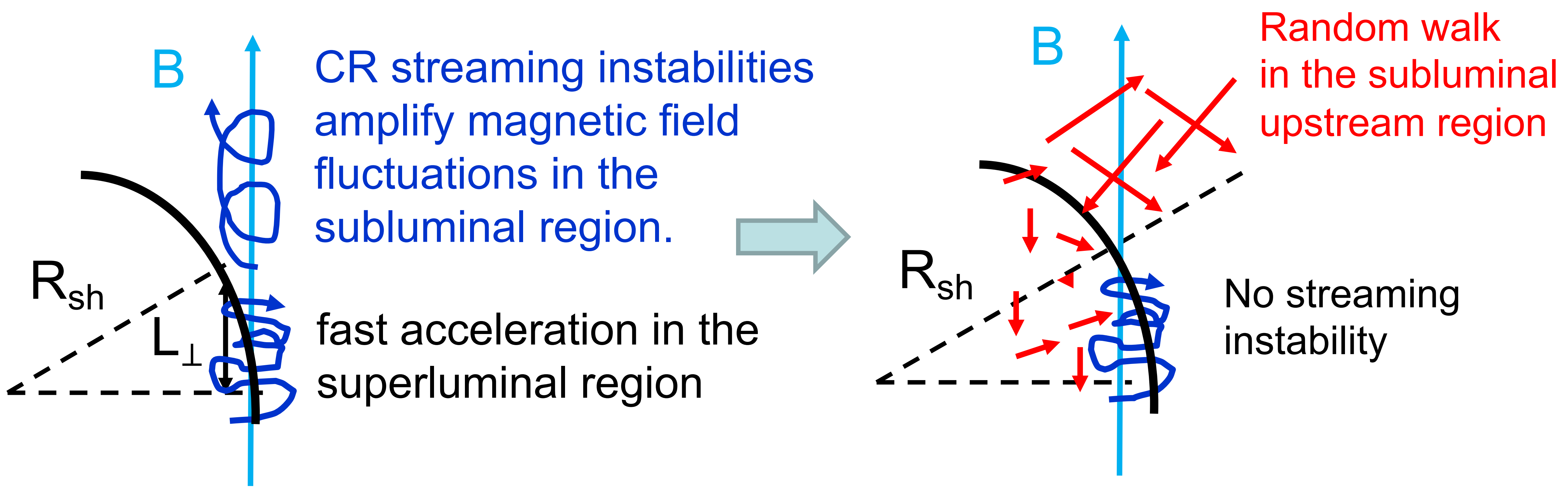
DSA at parallel and perpendicular shocks

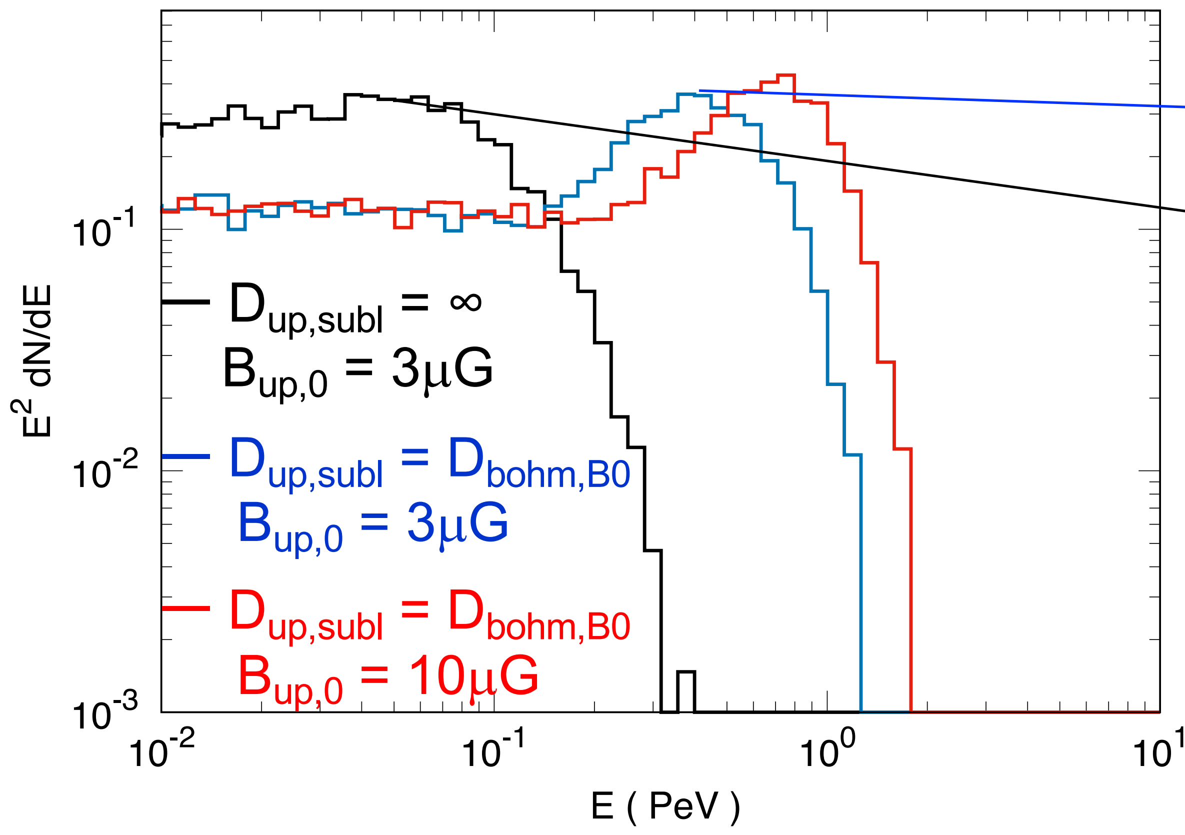


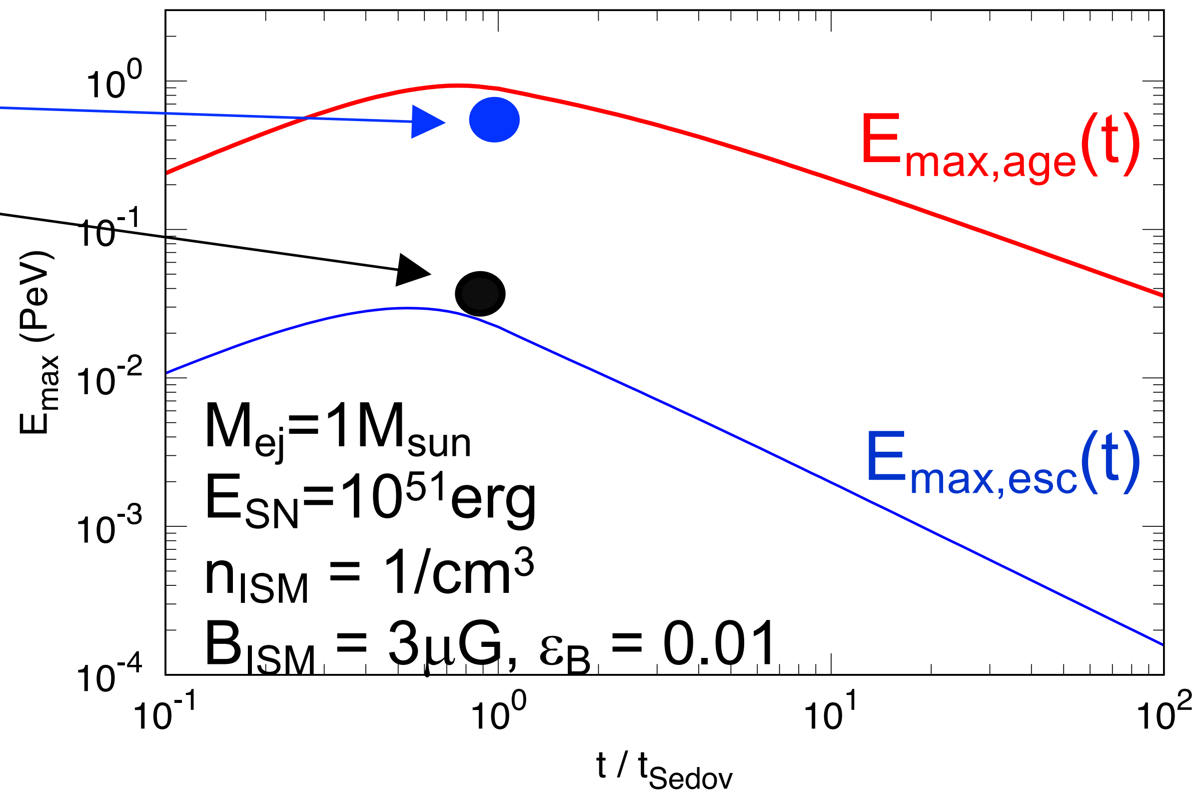


Parallel shock		Perpendicular shock
Particles can easily go back to upstream region. 👍	Injection	Low energy particles cannot go back to upstream region (Jokipii1987). 👎 H atoms help the injection. 👍 (Ohira2012,2013,2016)
For $U_{CR} << \rho V_{sh}^2$, s = 2. 👍 For U_{CR} >~ $0.1\rho V_{sh}^2$, ??? 👍👎?	Spectral index	For $\delta B_{down} << B_0$, s >> 2. 👎 (Takamoto & Kirk 2015) For $\delta B_{down} >> B_0$, s = 2. 👍 (Kamijima, Ohira, Yamazaki 2020)
For $\delta B \sim B_0 \sim 3\mu G$, $E_{max} << 1PeV$. 👎 (Lagage & Cesarsky 1983) $\delta B_{up} > 100\ \mu G$ is needed. 👍👎?	E_{max}	For $\delta B << B_0 \sim 3\mu G$, $E_{max} \sim 1PeV$. 👍 (Jokipii1987) Escape of CRs makes E_{max} small. 👎 $\delta B_{up,subluminal} \sim 10\ \mu G$ is needed. ✋ (Kamijima & Ohira, in preparation)

Self confinement by streaming instability







Detailed studies of SNRs

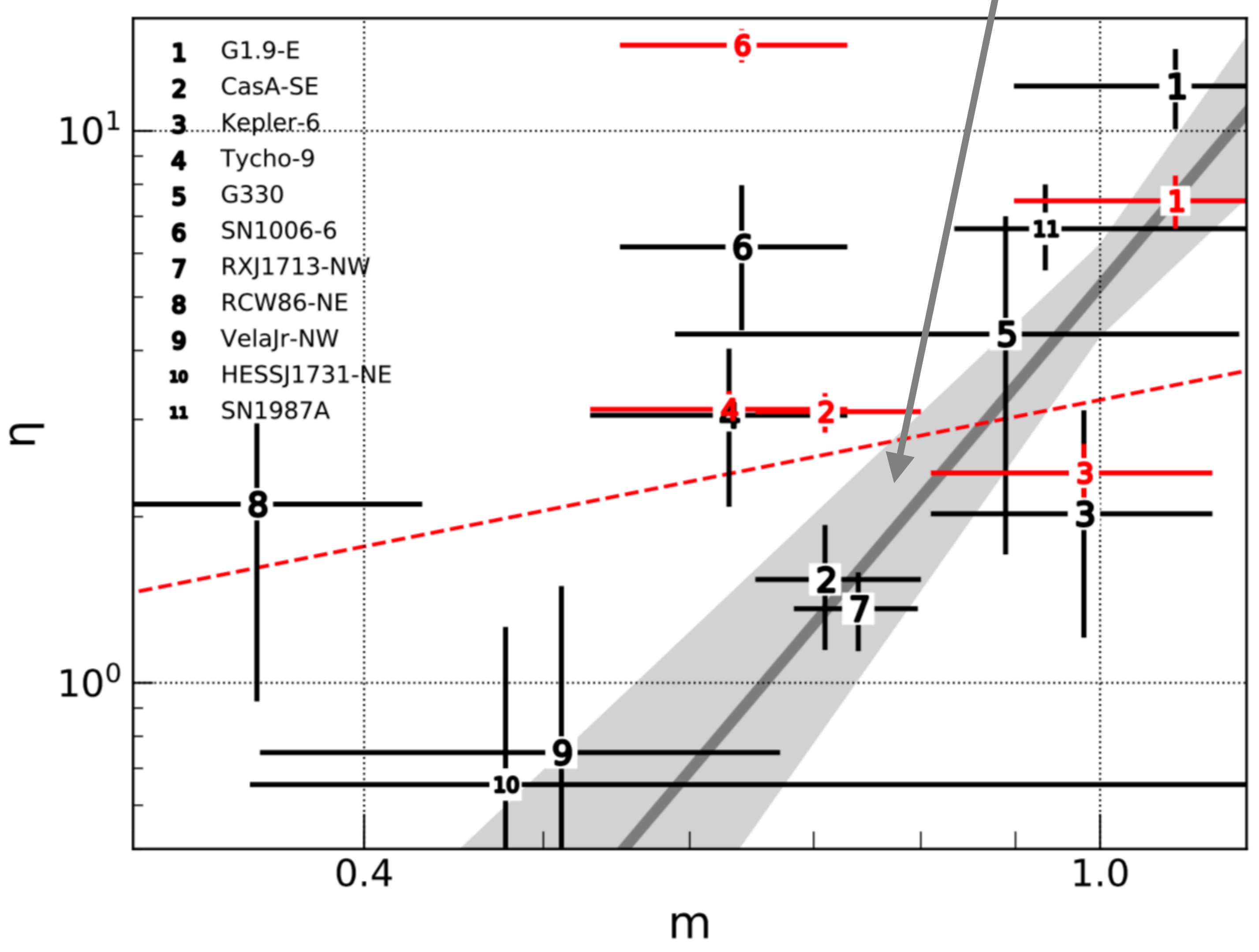
Systematic study (N.Tsuji)

Acceleration efficiency in young SNRs

※ Note: Forward-shocked max-ε_0 (max-V_{sh}) regions

$\eta = 5.2\ m^{-4}$

Turbulent level	Acceleration
weak	inefficient
strong	efficient



- Evolution of η (expansion parameter v.s. η):
  - Acceleration is more efficient (small η) in older (m~0.4) SNRs
  - could be related to turbulent production

Particle escape (H.Suzuki)

Sample selection & Analysis 1: gamma-ray spectral modeling

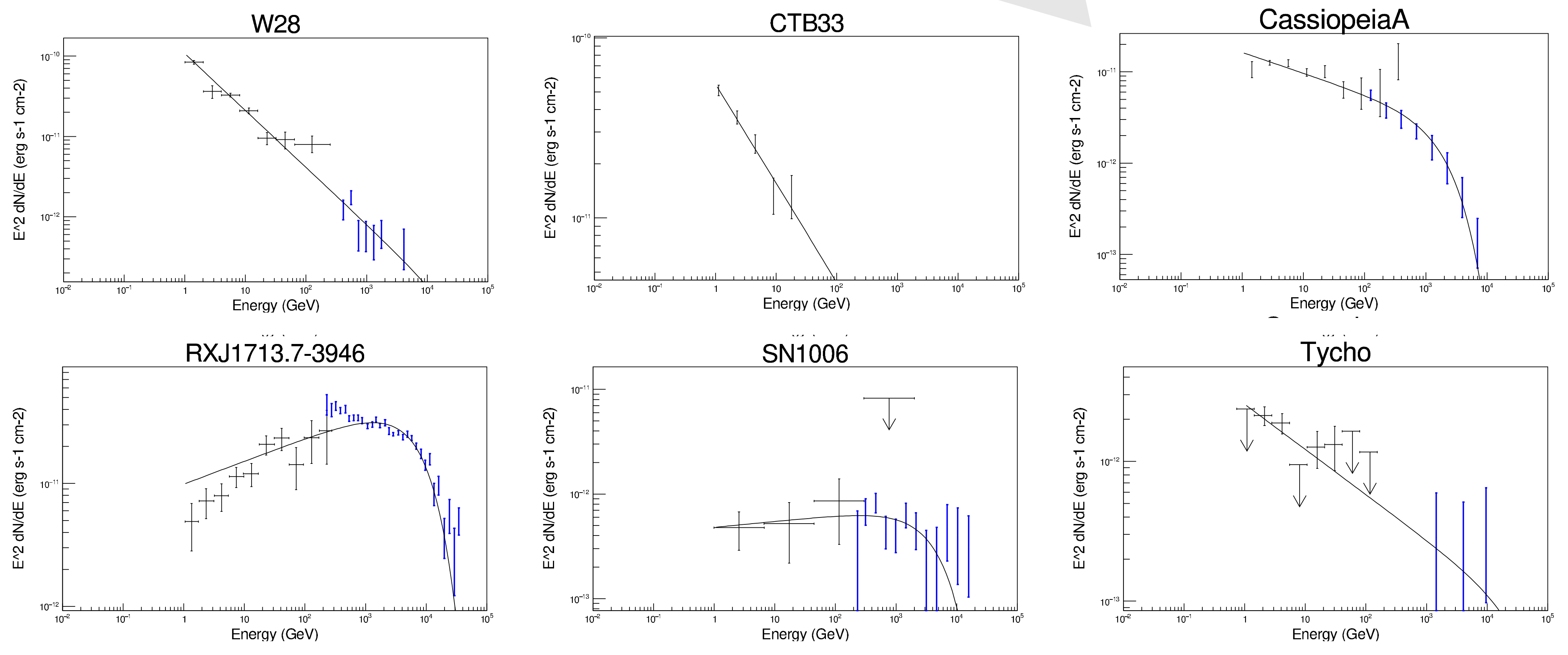
- **Sample selection**
  - From 1st Fermi SNR catalog & preceding systematic gamma-ray study : 38 SNRs (Acero+16; Zeng+19)
  - Gamma-ray spectra: our analysis on Fermi (15 SNRs) or literatures (23 SNRs) (Suzuki PhD thesis in prep.)
- **Analysis 1: Gamma-ray spectral modeling:** (Suzuki PhD thesis in prep.)
  - Markov-Chain Monte-Carlo sampling method is used (similar to Zeng+19)
  - Cutoff / Broken power-law models assumed

ex.) Cutoff power-law modeling results

Model: $(\mathrm{const.}) \times E^{-\Gamma} \exp(-E/E_{\mathrm{cut}})$

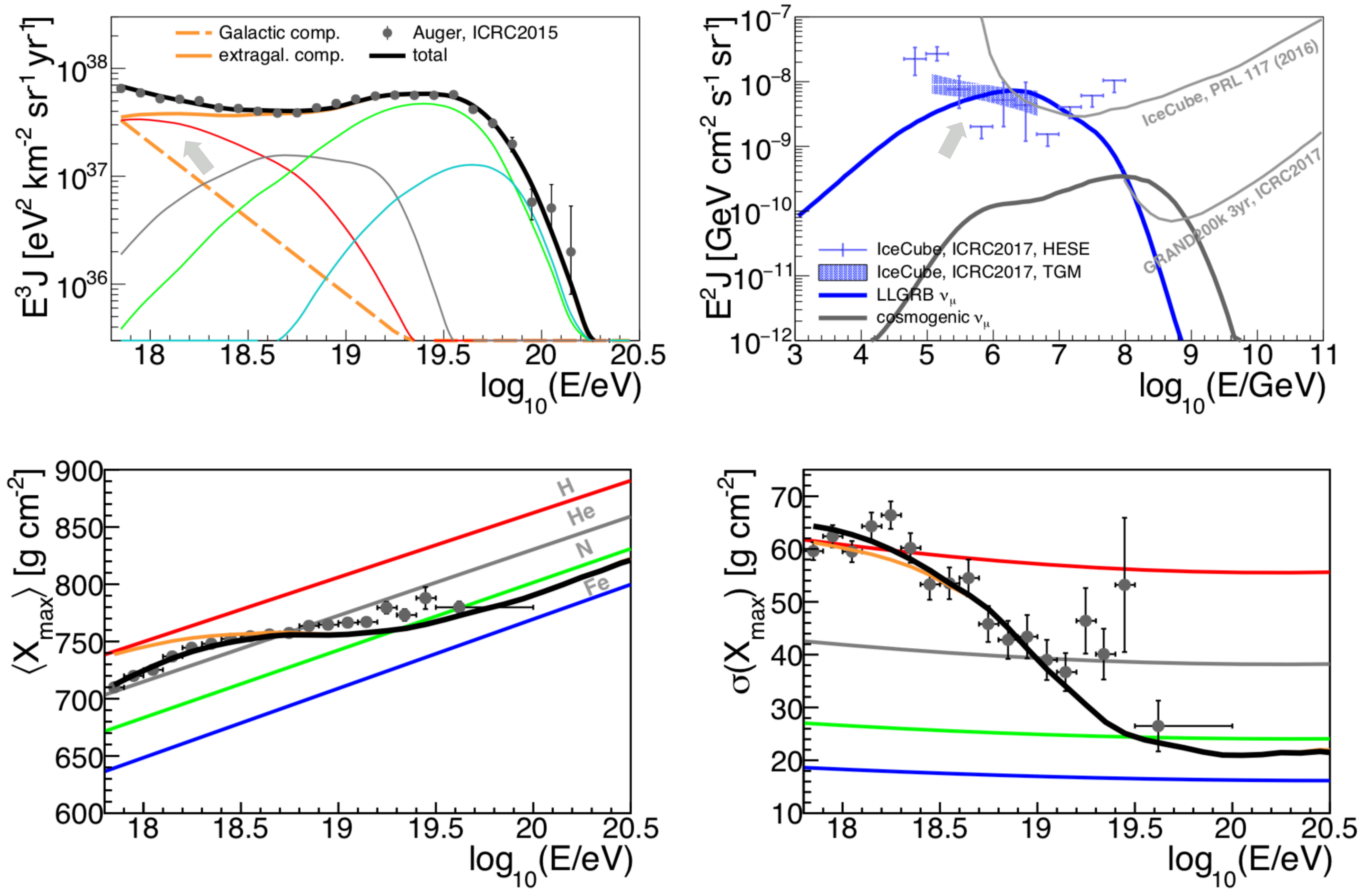
Good fit for almost all w/ this simple model

Fermi
HESS/ MAGIC/ VERITAS



HL-GRB, LL-GRB, TDE (W.Winter)

Describing UHECRs and neutrinos with LL-GRBs



Acceleration to UHE is complicated…

- Required energy per transient event to power UHECRs:

$$E_{\mathrm{CR}}^{[10^{10},10^{12}]} = 10^{53}\,\mathrm{erg}\cdot\frac{\dot{\varepsilon}_{\mathrm{CR}}^{[10^{10},10^{12}]}}{10^{44}\,\mathrm{erg\,Mpc^{-3}\,yr^{-1}}}\;\frac{\mathrm{Gpc^{-3}\,yr^{-1}}}{\dot{n}_{\mathrm{GRB}}\big|_{z=0}}$$

Required energy output per source | Fit to UHECR data | Source density

Summary

Different transient classes in the light of UHECR and neutrino observations

HL-GRBs

- Well-studied source class
- Can describe UHECR spectrum and composition X_{max}
- Multi-collision models work for a wide range of parameter sets
- Neutrino stacking limits obeyed
- Light curves may be used to further narrow down models
- Cannot describe diffuse neutrinos
- Composition variable $\sigma(X_{max})$ requires some fine-tuning
- Energetics in internal shock scenario is a challenge; more energy in afterglows than previously thought? VHE γ–rays?

LL-GRBs

- Potentially more abundant than HL-GRBs
- Can describe UHECR spectrum and composition even across the ankle
- May at the same time power the diffuse neutrino flux
- Less established/studied source class = more speculative
- Radiation modeling requires further work
- Progenitor model disputed
- UHECR+neutrino energetics point require relatively long “standard” LL-GRBs, may be challenged by population studies

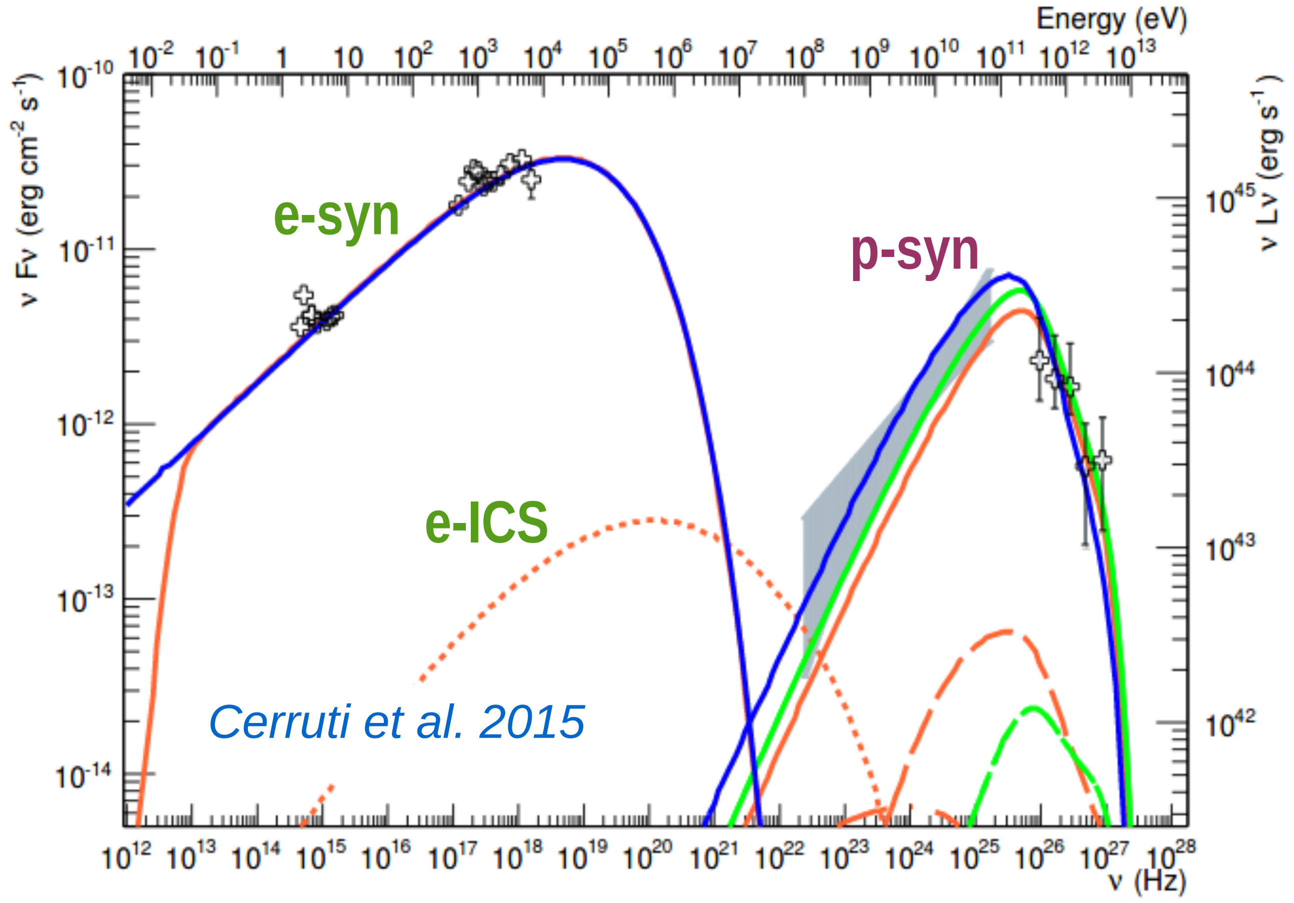
TDEs

- The only transient class from which neutrinos have been observed from → Must accelerate cosmic rays
- Have potentially negative source evolution, which helps UHECRs
- A lot of recent activity in astrophysics; many new discoveries
- Observed TDEs are very diverse
- Models have a lot of freedom
- Local rate and demographics may have to be re-evaluated
- Energetic events, such as the jetted TDE Sw J1644+57, may be rare
- Potential tension with neutrino multiplet searches if too few too energetic events

Blazer jet emission models (M.Petropoulou)

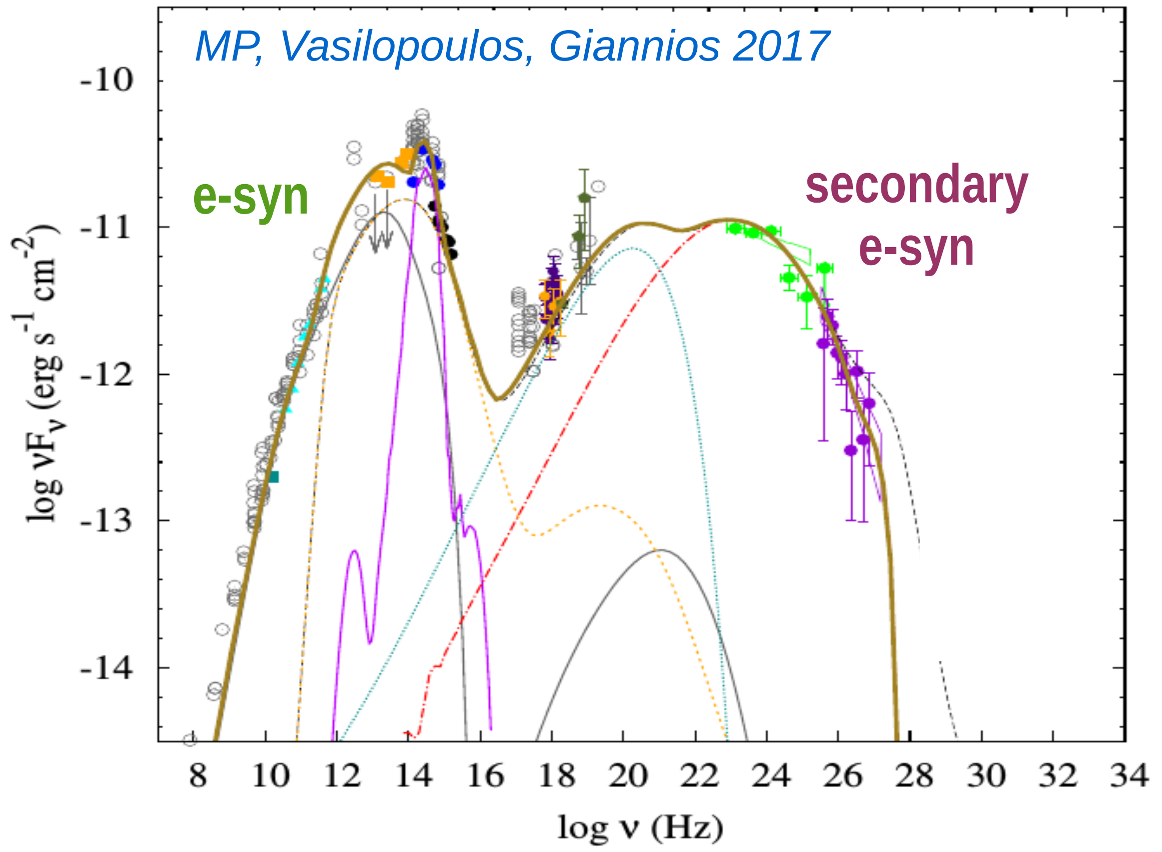
Hadronic Synchrotron Models

- **Jet plasma:** relativistic e^+e^- p + cold e,p
- **HE emission:** SYN from rel. p



Hadronic Cascade Models

- **Jet plasma:** relativistic e^+e^- p + cold e,p
- **HE emission:** ICS/SYN from secondary e^+e^-

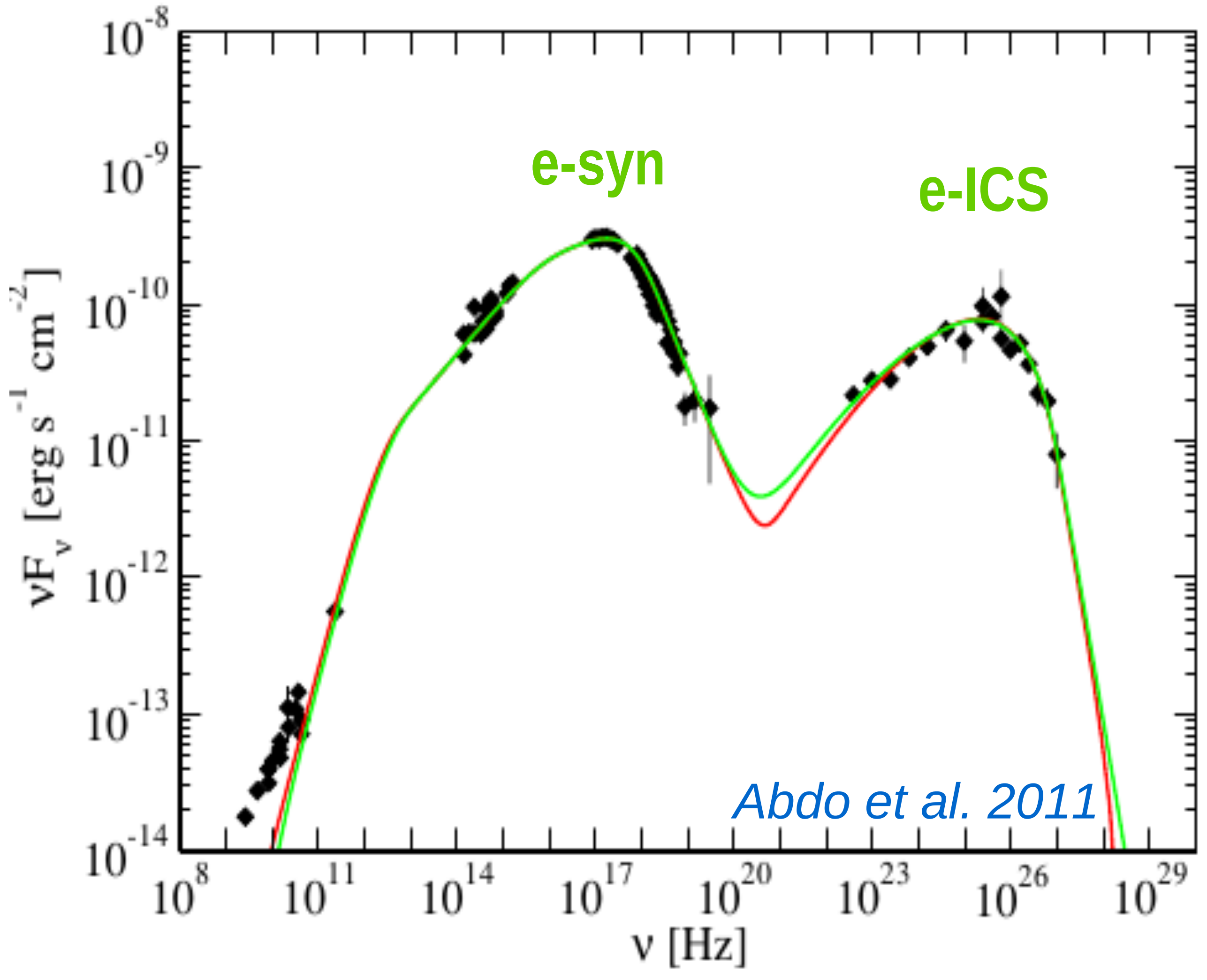


How can we tell which scenario is true?

1) High-energy neutrino observations
2) Multi-frequency temporal information
3) MeV monitoring observations (flux & polarization)

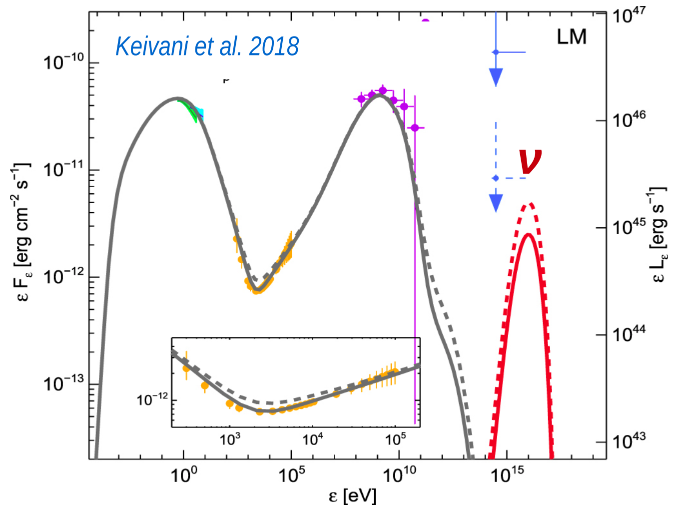
Leptonic Models

- **Jet plasma:** relativistic e^+e^- + cold e,p
- **HE emission:** ICS from rel. e^+e^-

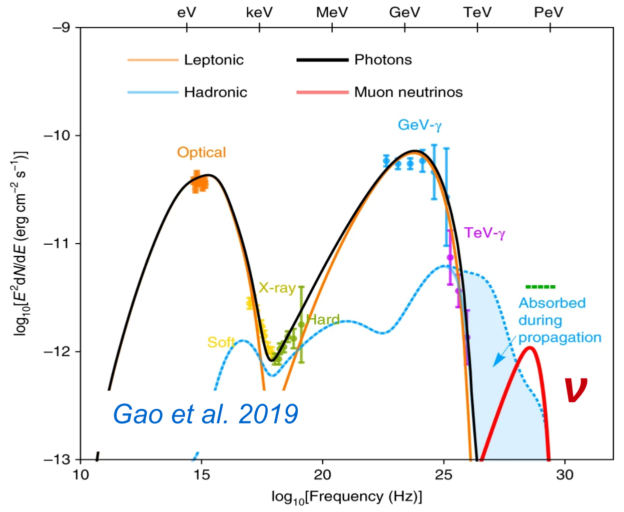


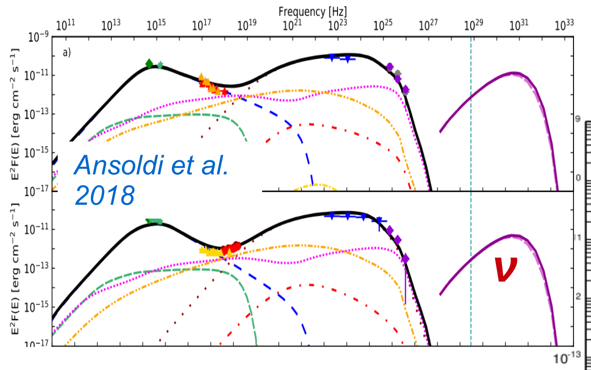
Plasma physics required

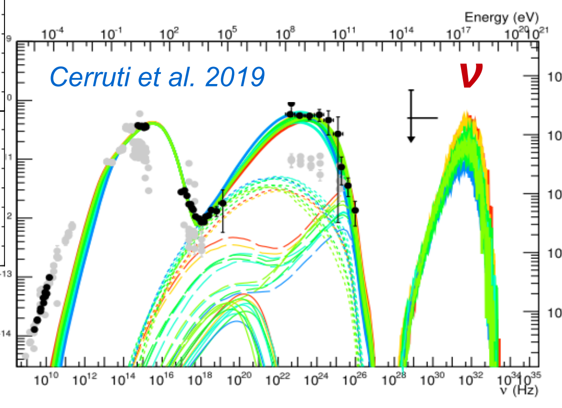
Implications from the 2017 Flare Modeling



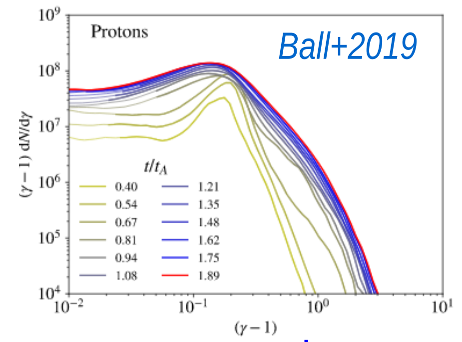
- Past studies of neutrinos from blazars predicted hadronic γ-rays. **BUT** modeling of TXS 0506+056/IC-170922A requires a **leptonic** origin of γ-rays.
- Maximum proton energies below EeV → TXS 0506+056 is **unlikely** to be an UHECR + PeV neutrino source.
- Number of muon neutrinos per yr < 1. Still, the predictions are **statistically consistent** with the detection of 1 event in 0.5 yr *(e.g. Strotjohann et al. 2019)*.

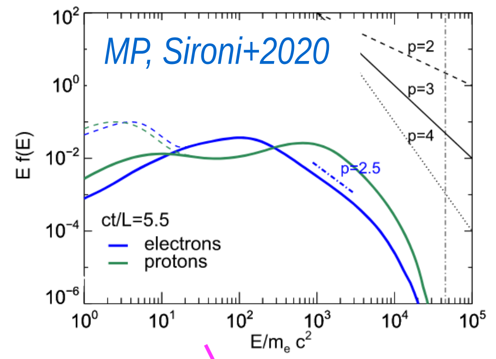


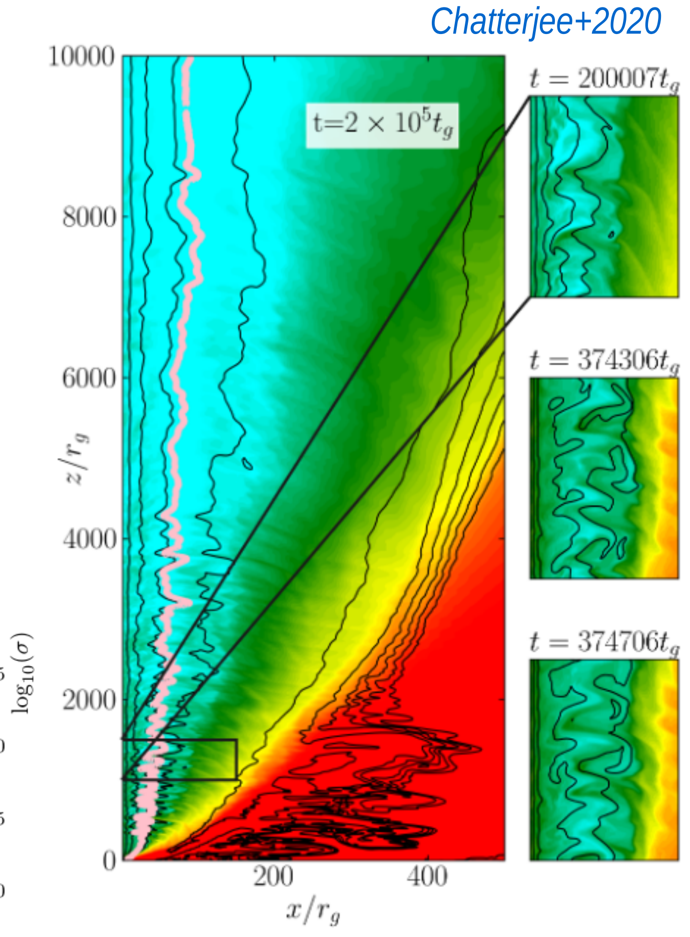


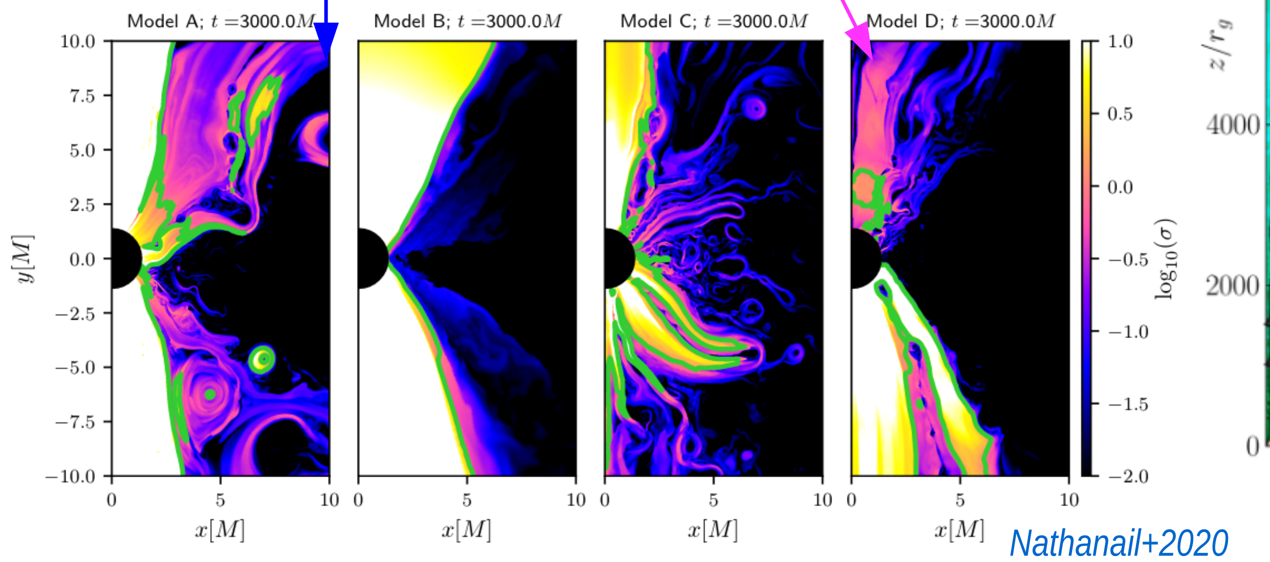


- Connect **plasma physics** (particle acceleration) with **magnetized fluid physics** (jet dynamics and acceleration) with **radiation physics** to create a physical model for multi-messenger emission in jets.





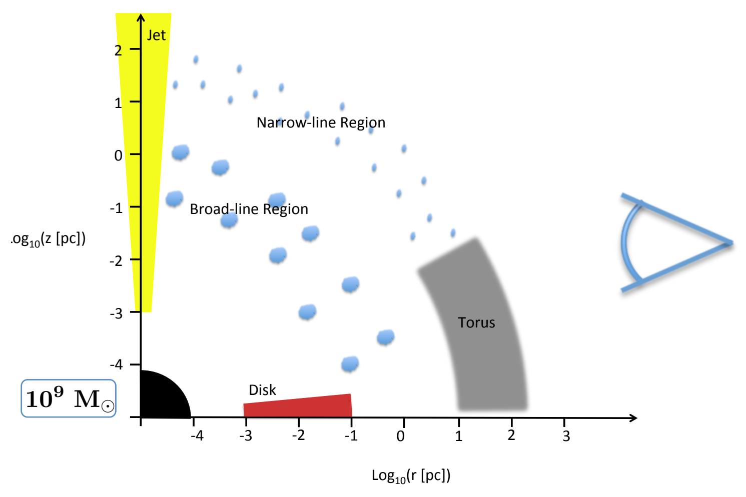


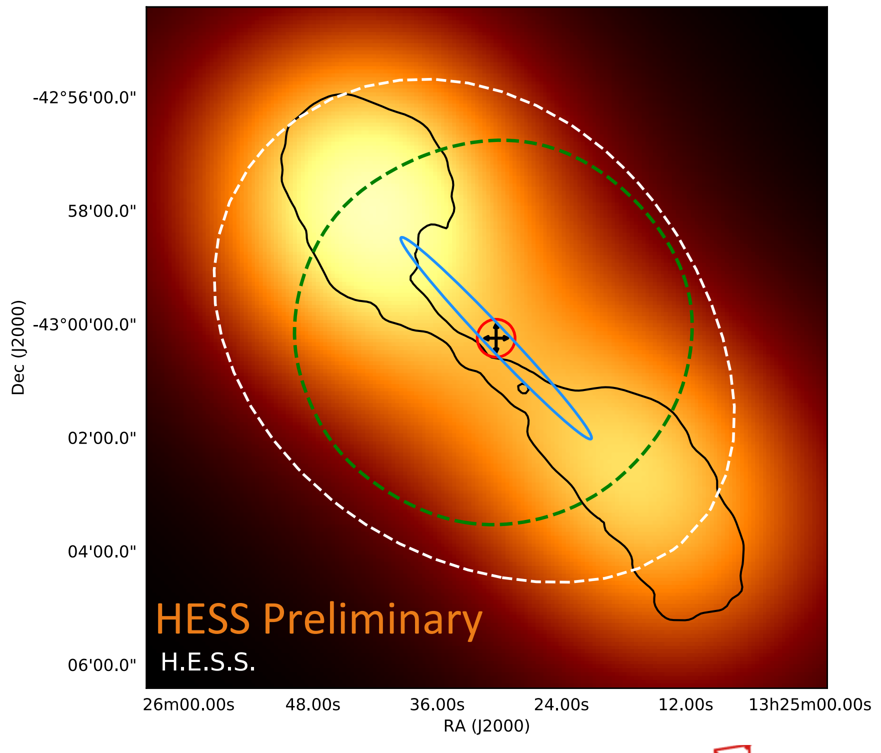


Centaurus A as UHECR source? (A.Taylor)

Centaurus A - VHE Extension

HESS Detected Extension on ~2kpc scale



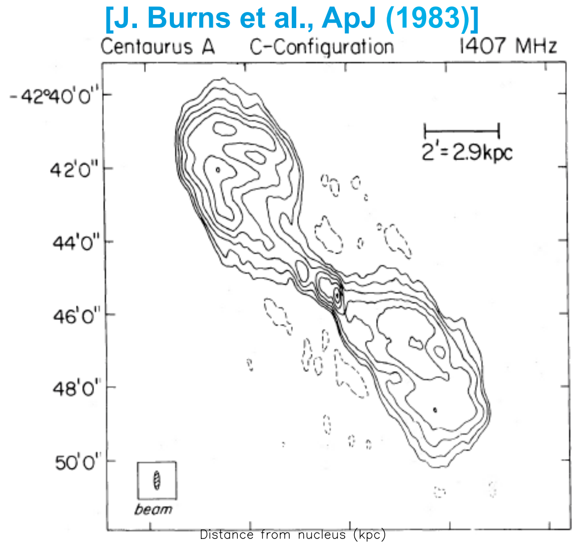


[HESS- F. Rieger, A. Taylor, et al., Nature]

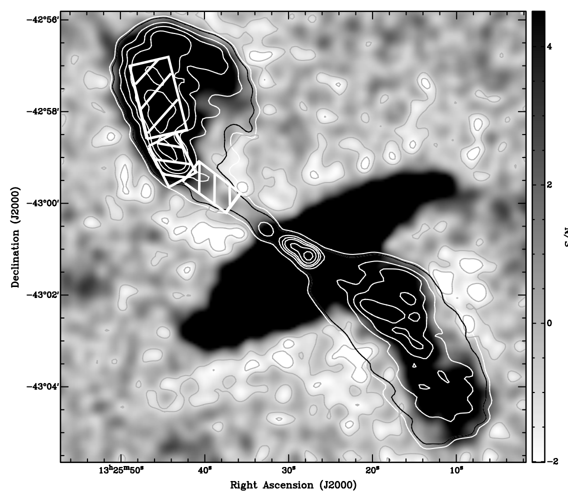
DESY. Andrew Taylor H.E.S.S.

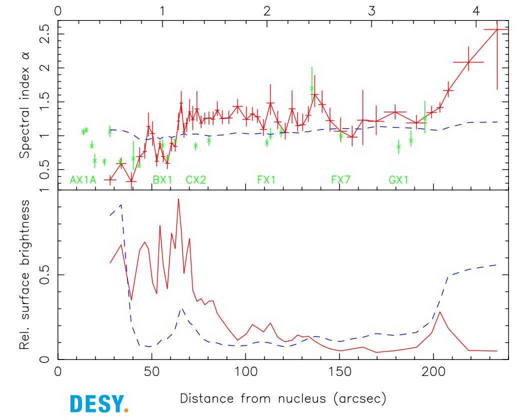
Centaurus A's Inner Jet- A Cosmic Lab

[J. Burns et al., ApJ (1983)]



[A. Weiss et al., A&A (2008)]

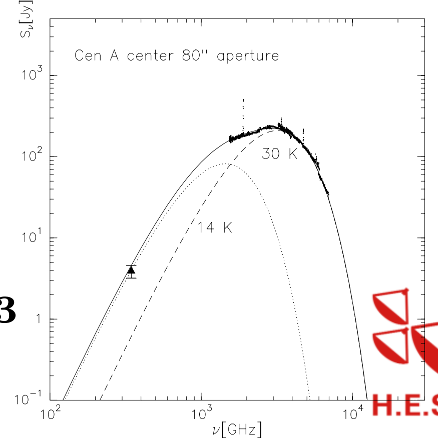




$$\mathrm{B_{eq} = 60\ \mu G}$$

$$\mathrm{U_B \approx 10\ eV\ cm^{-3}}$$

$$\mathrm{U_{IR} \approx 10\ eV\ cm^{-3}}$$



DESY. Andrew Taylor H.E.S.S. 10

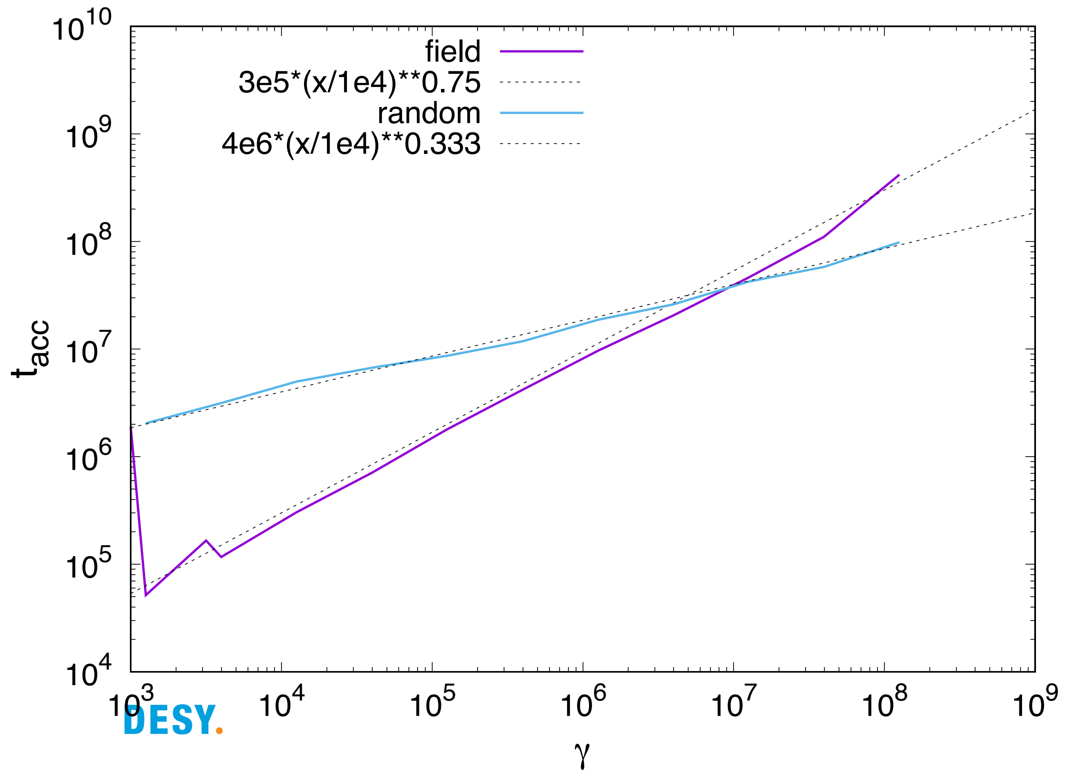
Dissecting Cen A's Acceleration Sites

Acceleration on kpc scales:

$$\mathrm{E_{max} = \beta BR/\eta}$$

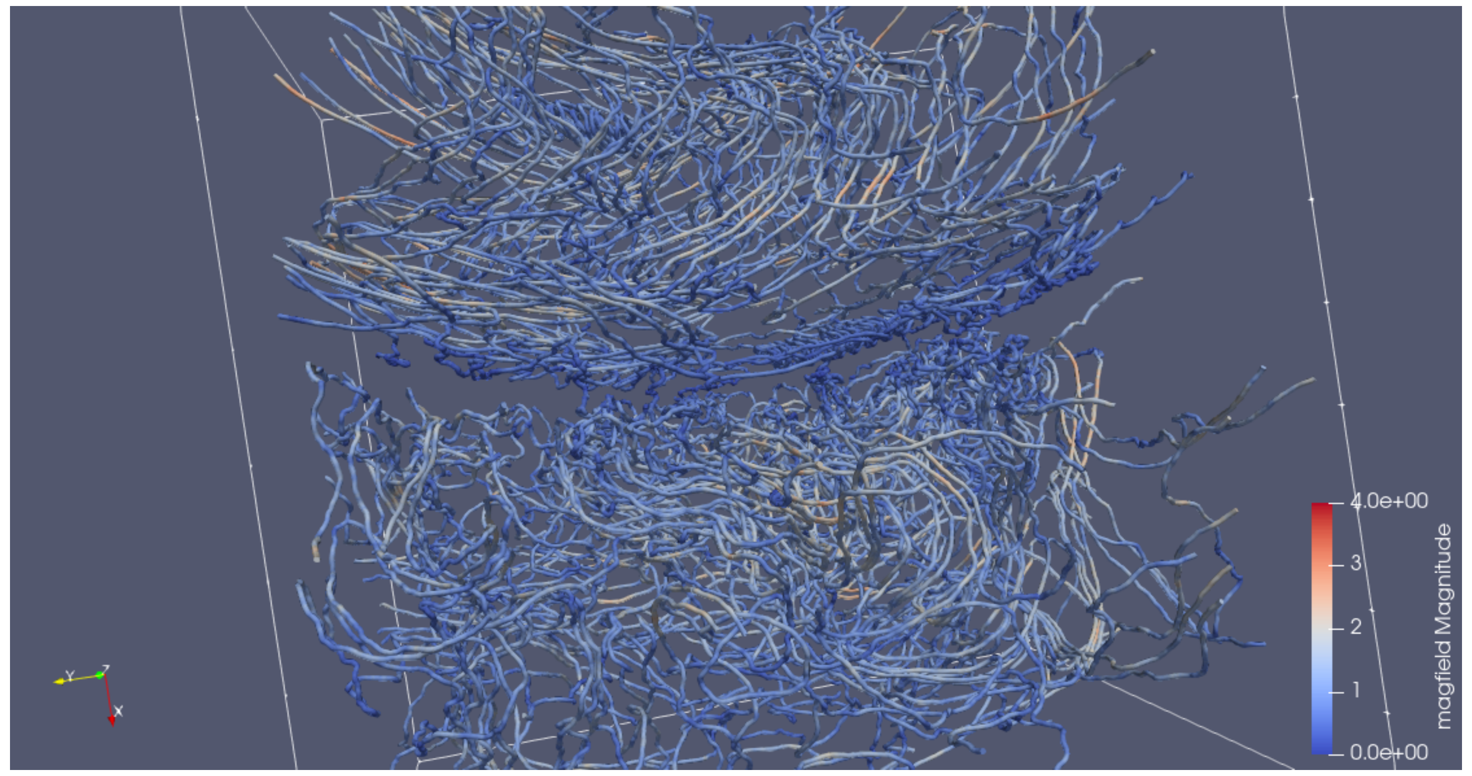
$$\beta_{\mathrm{scat.}} \approx 0.5, \quad \eta \approx 10^4$$

$$\mathrm{E_{max} \approx 10^{15} eV}$$



DESY.

Acceleration on larger scales:



[S. O'Sullivan, A. Taylor, B. Reville in prep.]

Energy dependence of acceleration time may only approach the Bohm level (η~1) at the highest energies

Andrew Taylor

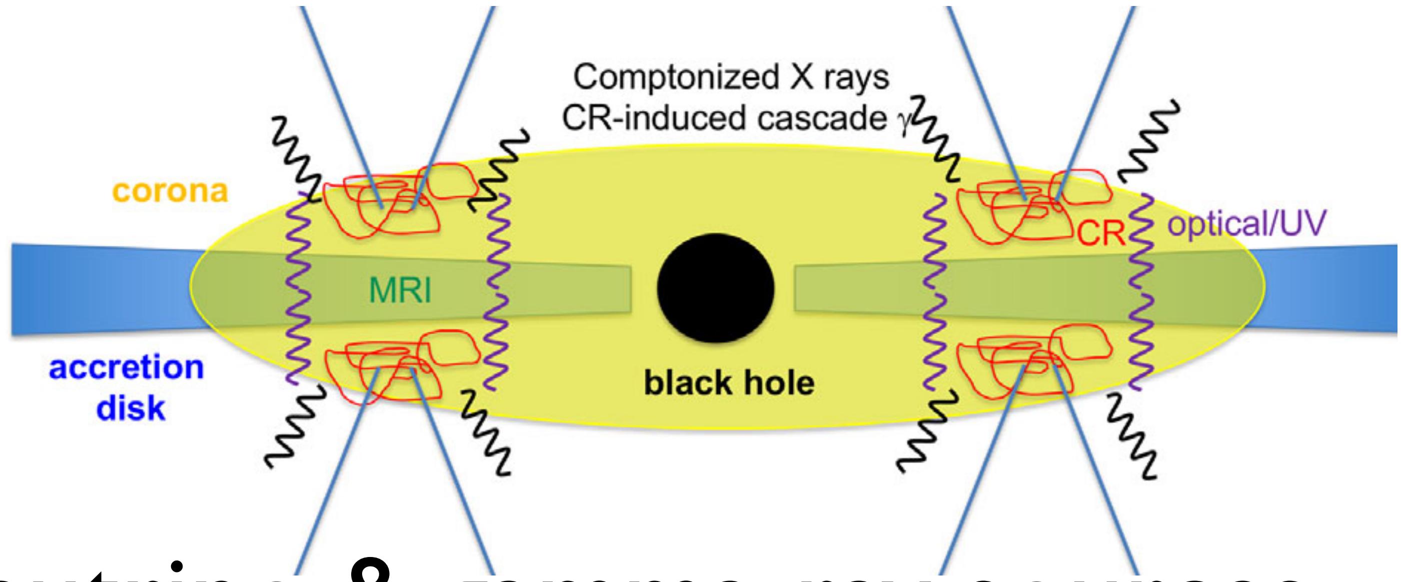
$$\mathrm{E_{max} \approx 10^{18} eV}$$

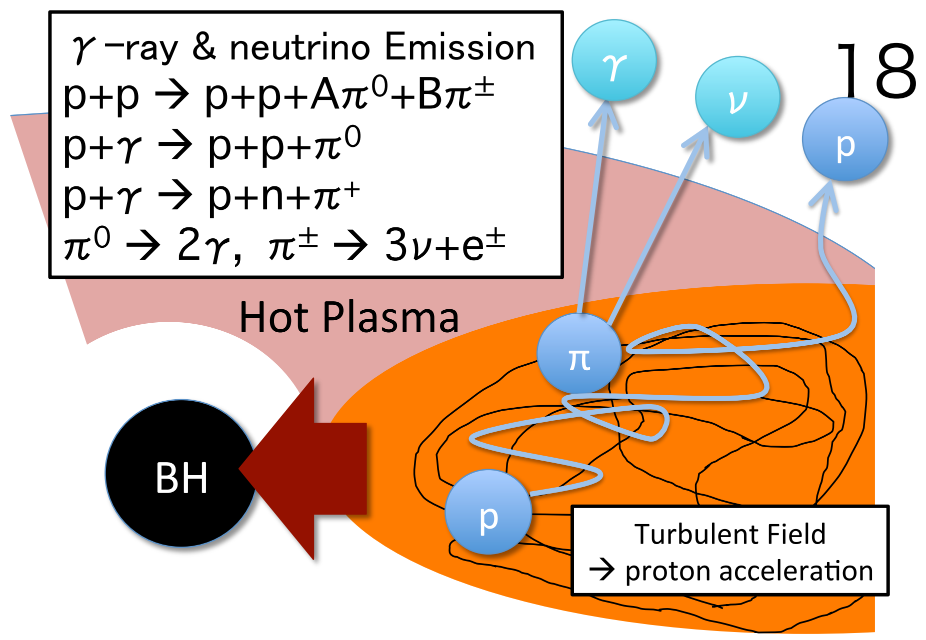
$$\mathrm{t_{acc} \approx 0.1\ Myr}$$

17

Neutrino & γ-ray emissions from buried AGN (S.Kimura)

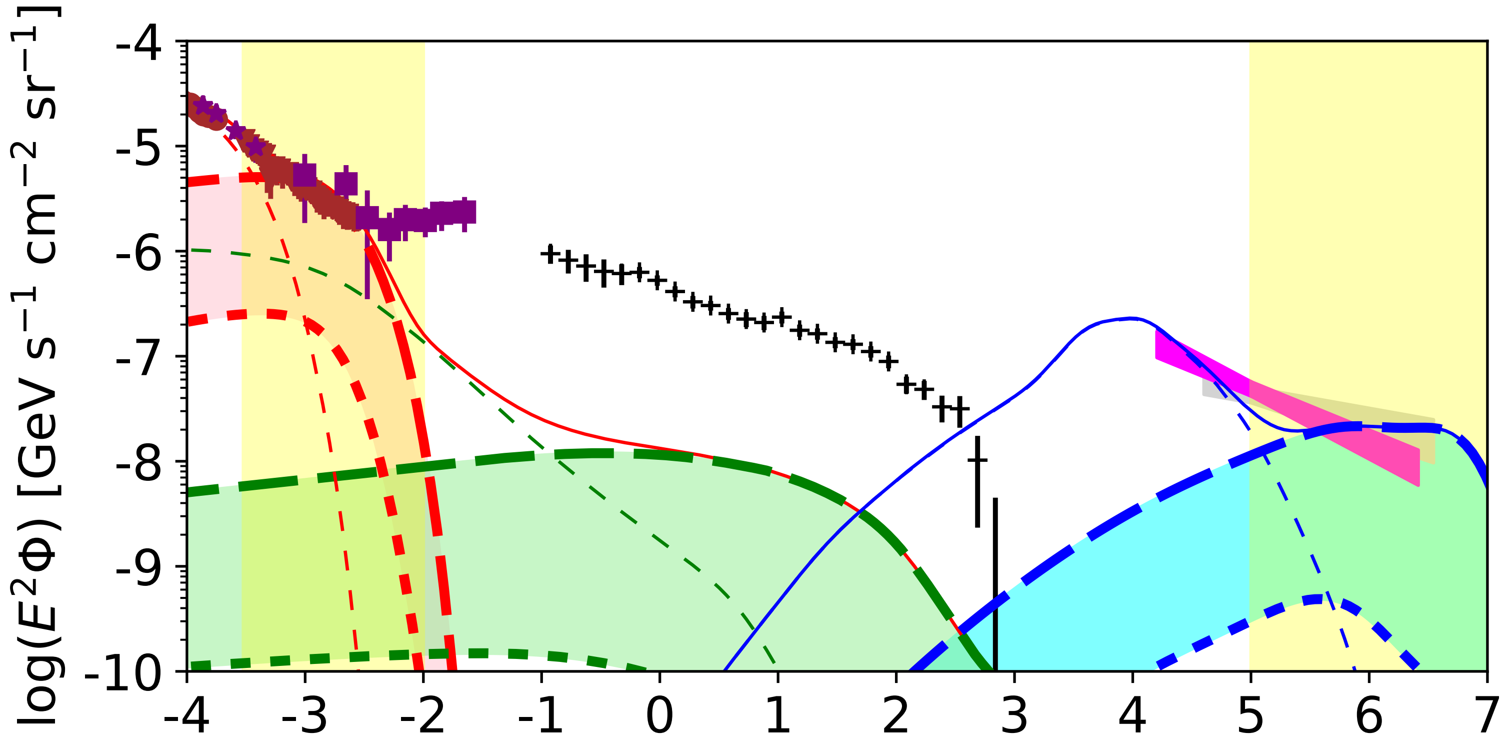
Summary

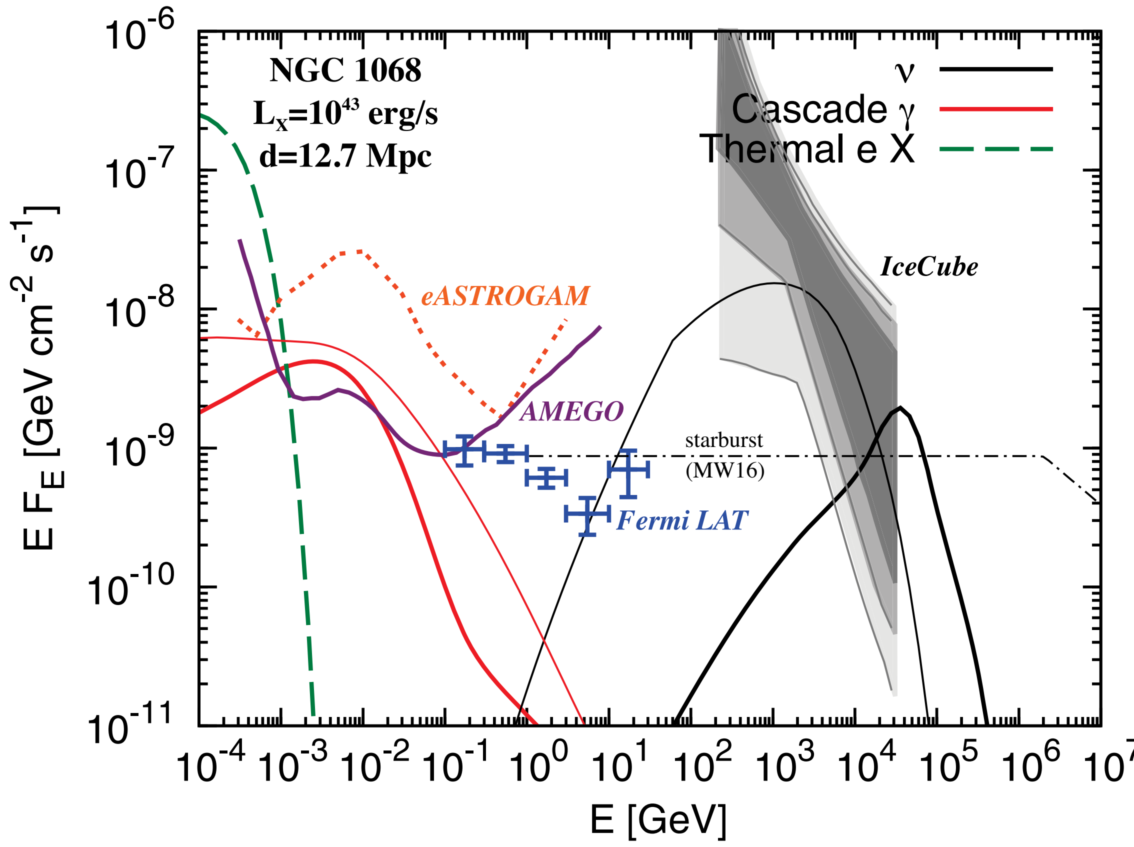


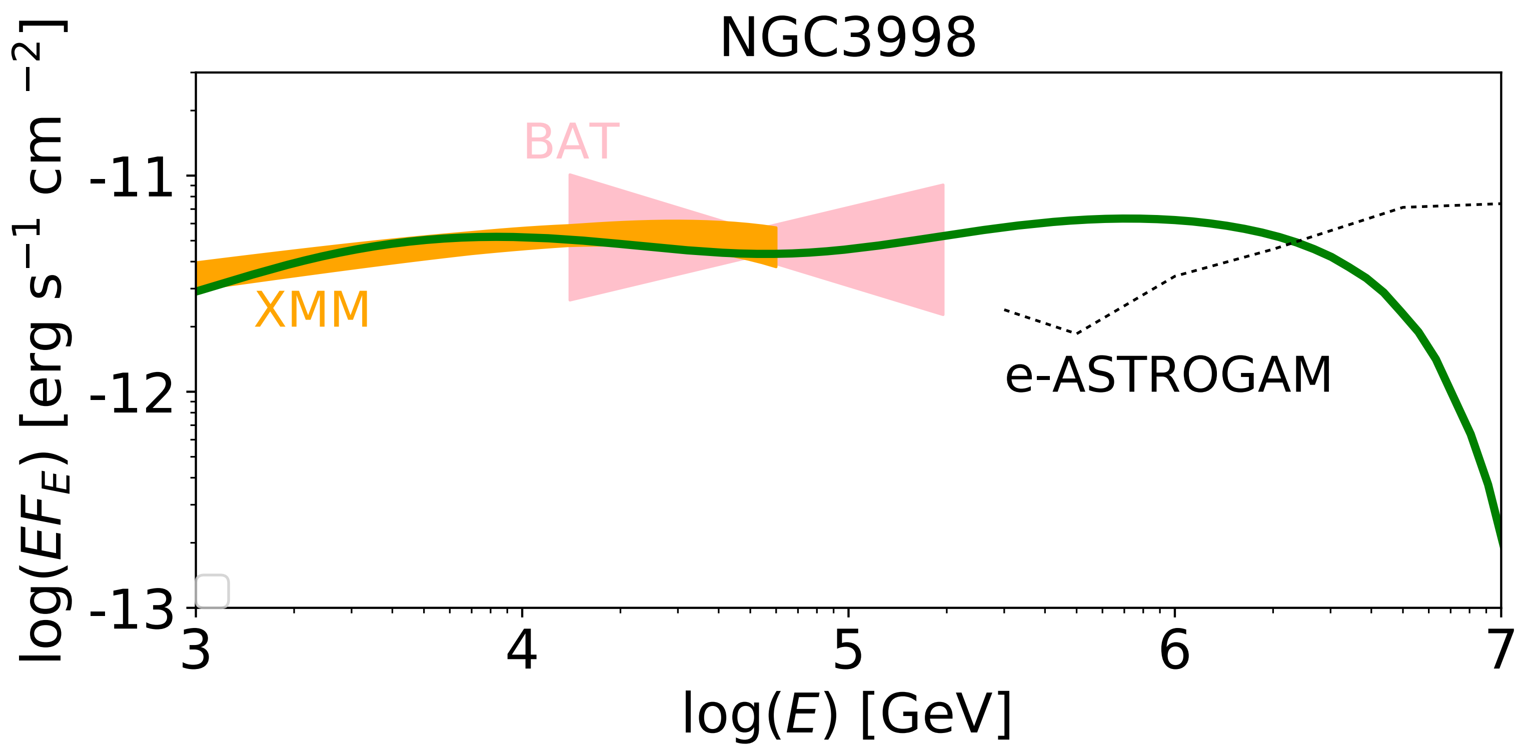


- Accretion flows in AGNs are feasible neutrino & gamma-ray sources
  - Coronae in Seyfert galaxies can reproduce X-ray & 10-100 TeV ν backgrounds
  - RIAFs in LLAGNs can explain MeV γ & PeV ν backgrounds

  → **Combining these two, AGN accretion flows can explain a wide energy range of γ & ν backgrounds**
- **Future multi-messenger observations can robustly test our models:**
  - IceCube-Gen2 can detect AGNs as point sources
  - Proposed MeV satellites can detect MeV γ rays from AGNs





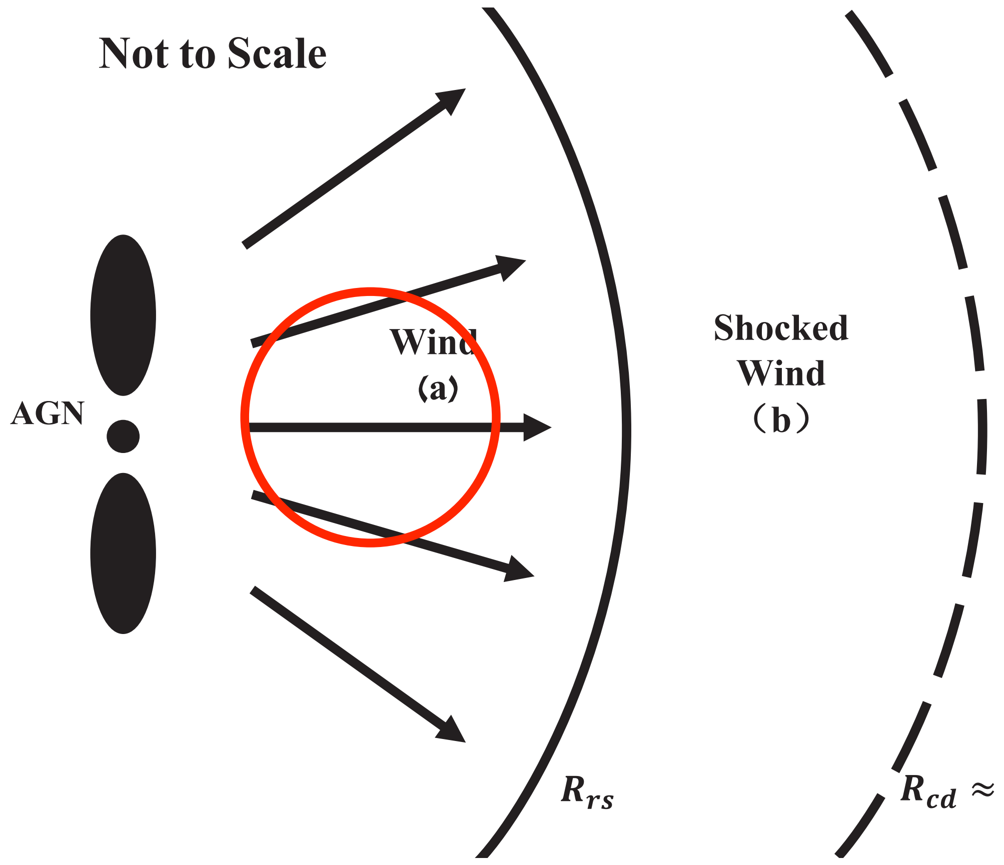


Neutrinos and gamma rays from NGC1068 (S.Inoue)

pγ ν (+ γ) from inner regions of AGN winds

potential particle acceleration via:
- internal shocks caused by highly variable wind ejection (observational evidence + theoretical support)
- "interaction" shocks with external or internal clouds/stars

pγ interactions with nuclear radiation
- neutrinos ~<10 PeV
- cascade ~<MeV-GeV



$p+\gamma \to N+\pi^0, \pi^\pm$

$\pi^0 \to 2\gamma \quad \pi^\pm \to \mu^\pm \nu \to e^\pm + 3\nu$

$\mu^\pm + B \to \mu^\pm + \gamma$ muon synchrotron

$\gamma+\gamma \to e^+e^-$

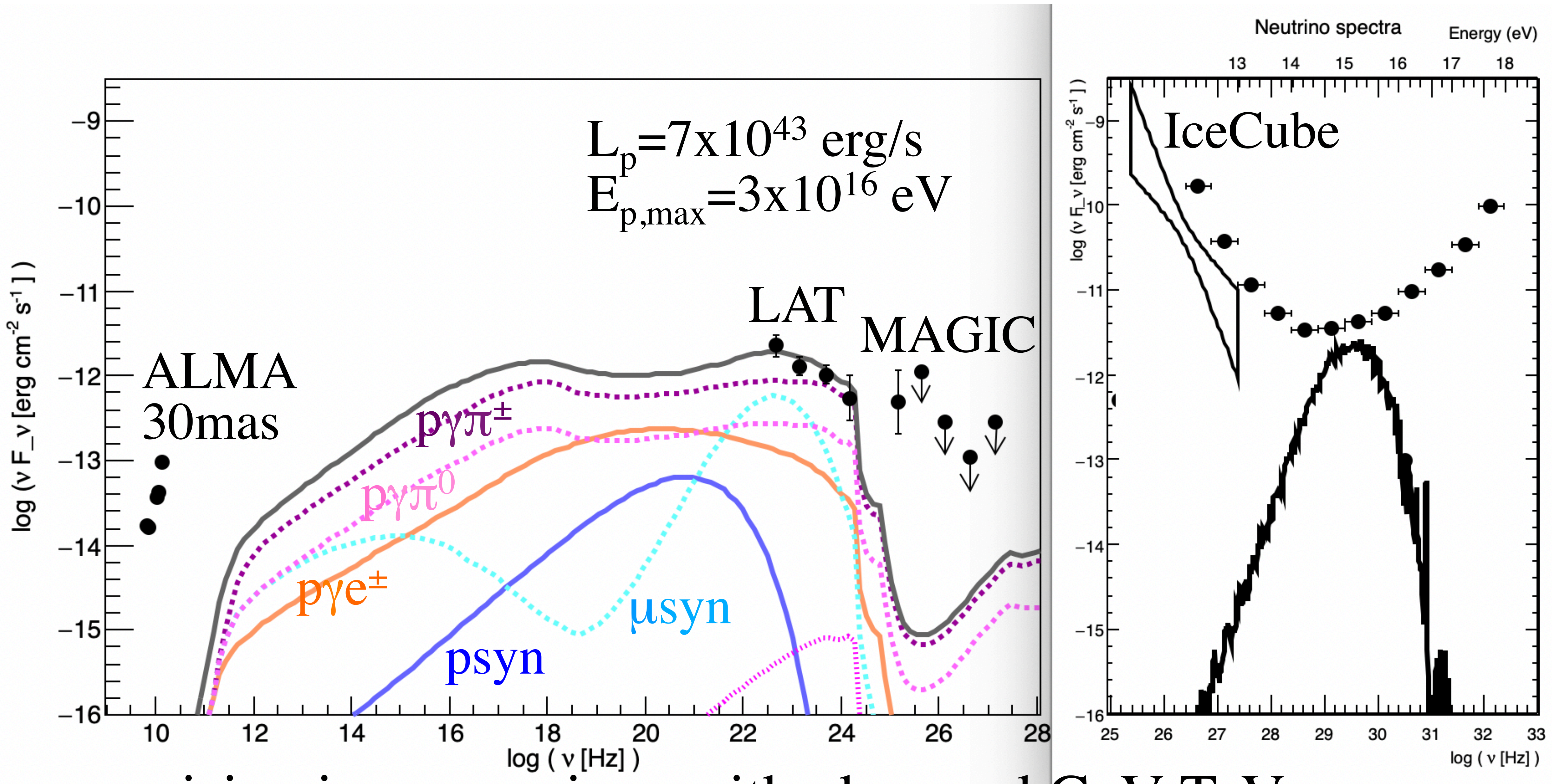
$e^+e^- + B/\gamma \to e^+e^- + \gamma$ electron-positron sync./IC cascade

$p+\gamma \to p+e^+e^-$ Bethe-Heitler pair production

$p+B \to p+\gamma$ proton synchrotron

1,000000E-03

wind internal model for NGC 1068: example



- promising in comparison with observed GeV-TeV γ, ν
  -> parameter search in progress, please stay tuned
- clear break due to γγ on disk field
- cascade spectrum: $f_\nu \propto \nu^{-1}$ @keV-GeV, $\propto \nu^{-0.5}$ <keV below observed radio/submm

Radio galaxy (L.Merten)

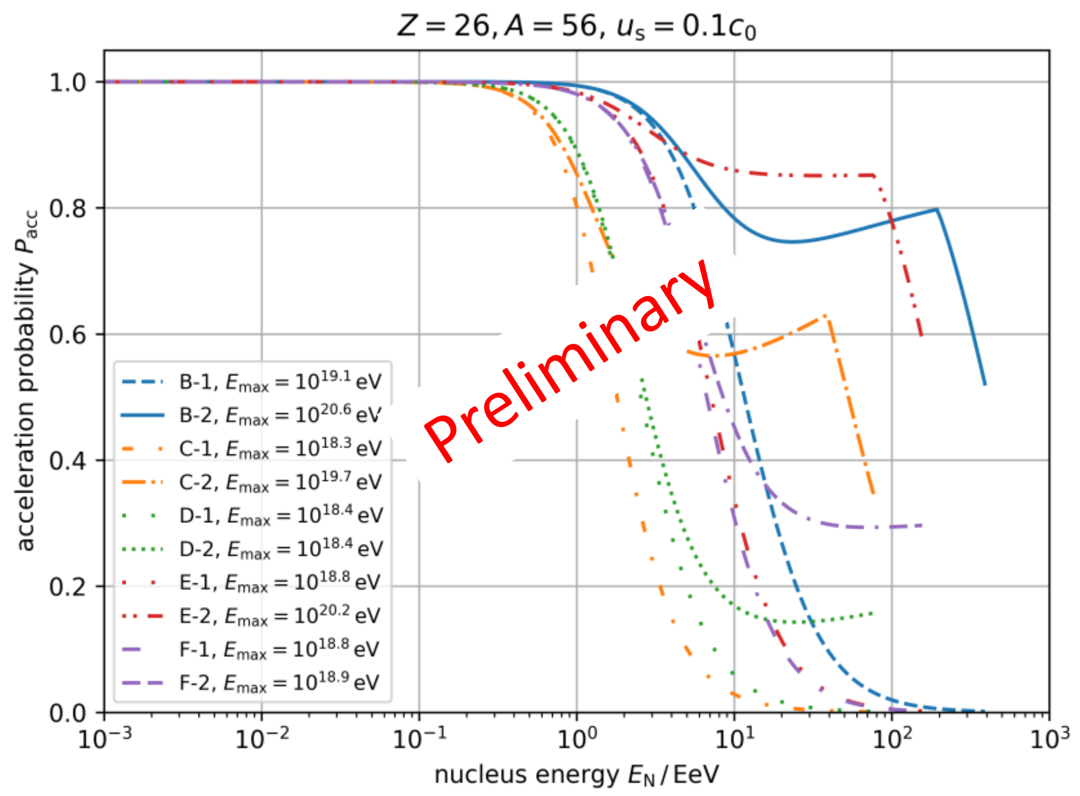
Merten et al. subm. (2020)

Acceleration Probability

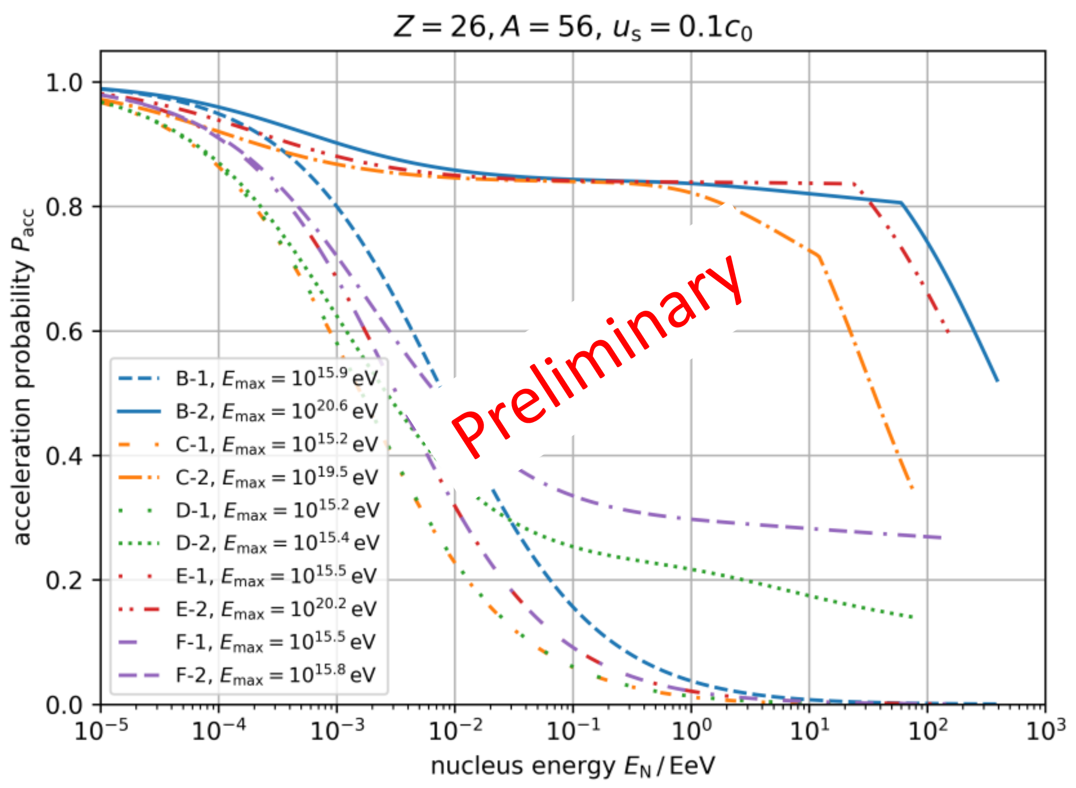
This probability is a measure for the dominance of acceleration:

$$P_{acc} := \frac{\Sigma {\tau^{i}_{acc}}^{-1}}{\Sigma {\tau^{i}_{acc}}^{-1} + \Sigma {\tau^{j}_{loss}}^{-1} + \Sigma {\tau^{k}_{esc}}^{-1}},$$ defining the maximum energy $P(E^{acc}_{max}) = 0.5$

Bohm diffusion ($\kappa \propto E$)



Kolmogorov diffusion ($\kappa \propto E^{1/3}$)



Merten et al. subm. (2020)

Maximum Energies

Hillas Energy: $E^{Hillas}_{max} = eZBR\beta c \approx 10^{21} Z \left(\frac{B}{\mathrm{G}}\right)\left(\frac{R}{\mathrm{pc}}\right)$ eV

Source Environment: $P(E^{\mathrm{acc}}_{\mathrm{max}}) = 0.5$

$\rightarrow E_{\mathrm{max}} = \min\left(E^{\mathrm{Hillas}}_{\mathrm{max}}, E^{\mathrm{acc}}_{\mathrm{max}}\right)$

Maximum energies for target photon *model E*

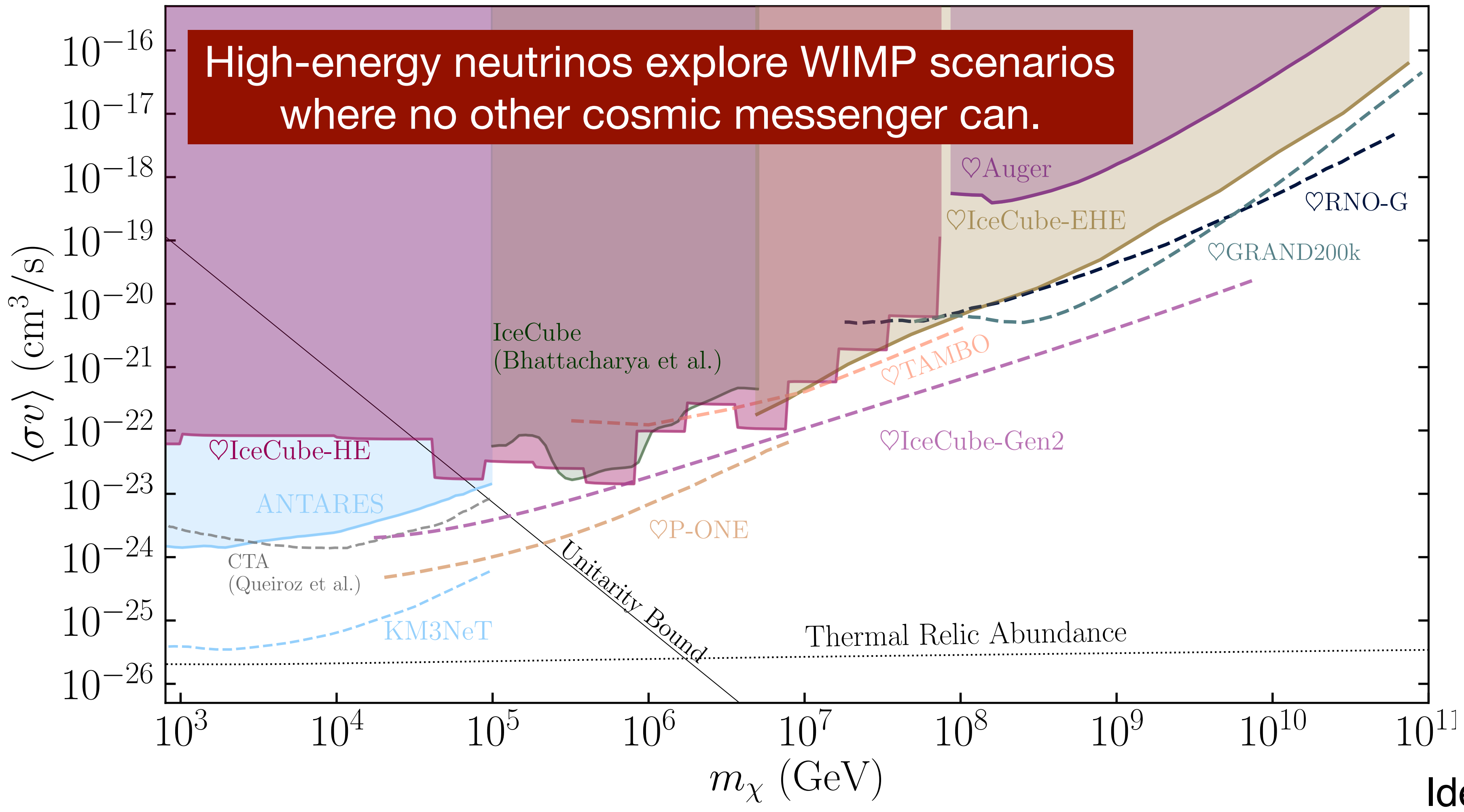
Turb.	Accel.	$\log(E/eV)$					$\langle log(R/V)\rangle$
		P	He	N	Si	Fe	
Bohm	Fermi-I	17.4	17.8	18.3	18.6	18.8	17.44±0.04
Bohm	Hybrid	18.8	19.1	19.6	19.9	20.2	18.78±0.02
Kolm.	Fermi-I	14.1	14.4	14.9	15.2	15.5	14.08±0.02
Kolm.	Hybrid	18.8	19.1	19.6	19.9	20.2	18.78±0.02

New physics (A.Kheirandish)

Neutrinos from Dar Matters

Constraining the DM parameter space

- High Mass (only accessible to neutrinos)

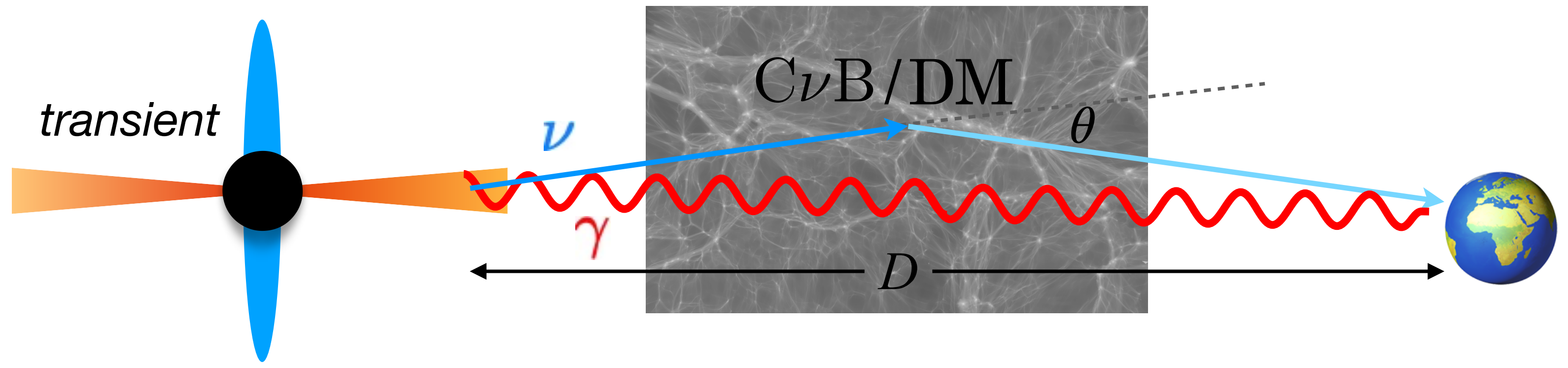


Argüelles, Diaz, **AK**, Safa, Olivares-Del-Campo, Vincent, 1912.09486

BSM induced time delay

Identification of the origin of cosmic neutrinos offer new avenues to probe for new physics.

Transients offer exploring the delay induced by neutrino secret interactions.



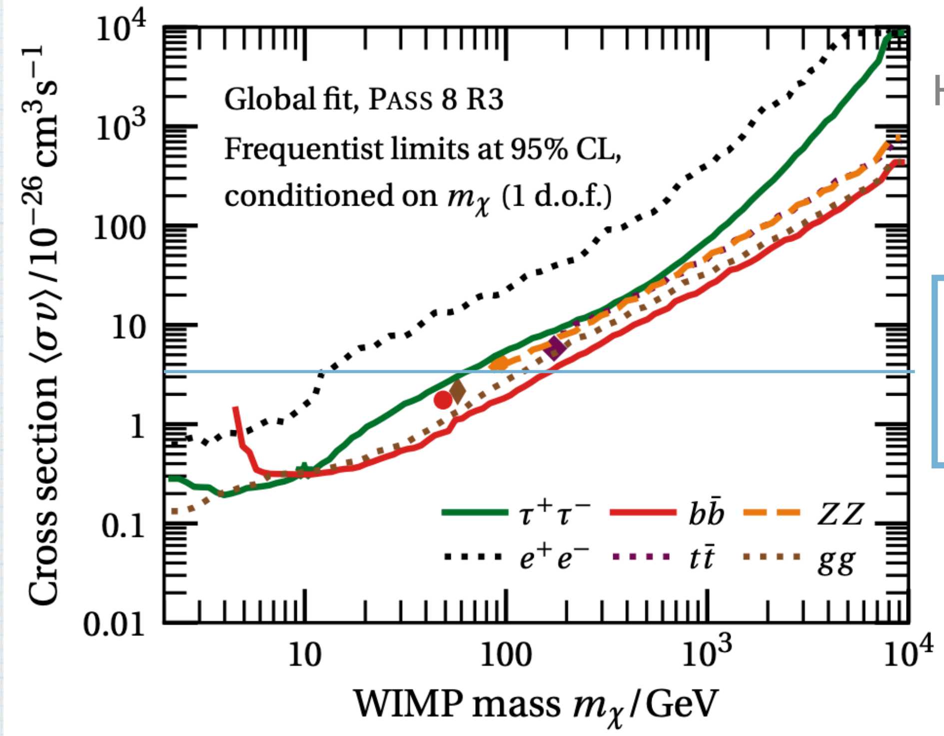
The time difference can be estimated by evaluating the extra distance neutrino has to travel.

$$t \approx \frac{1}{2}\frac{\langle\theta^2\rangle}{4} D \simeq 77\ \mathrm{s}\left(\frac{D}{3\ \mathrm{Gpc}}\right)\left(\frac{C}{0.6}\right)^2\left(\frac{m_\nu}{0.1\ \mathrm{eV}}\right)\left(\frac{0.1\ \mathrm{PeV}}{E_\nu}\right)$$

Gamma-ray from Dark Matter (N.Hiroshima)

Current constraints:

Fermi-LAT, 11y, 27 dwarf spheroidal galaxies (dSphs)



Hoof et al., 2020

canonical

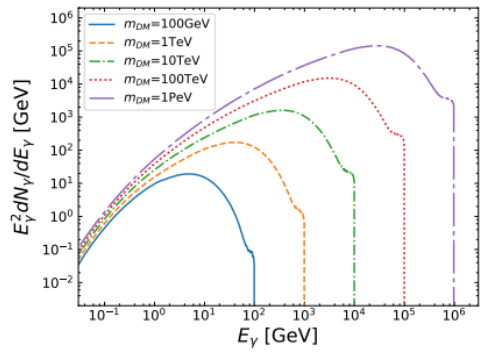
$\sim 3\times10^{-26}\mathrm{cm}^3/s$

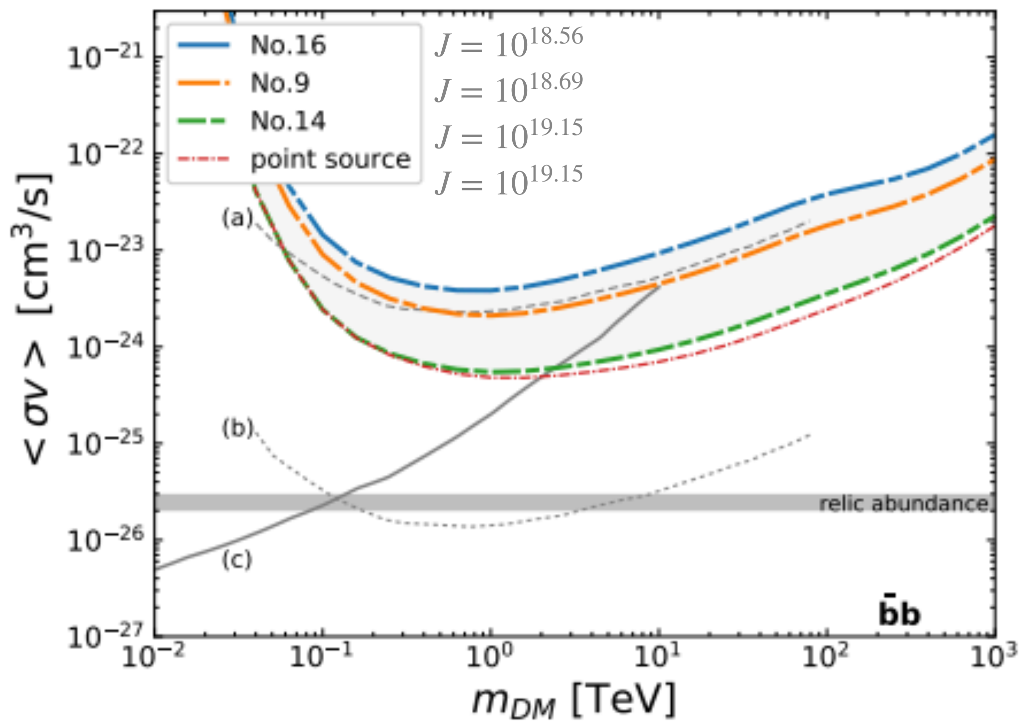
We should consider TeV WIMP seriously.

Our accessibility (1):

Hiroshima et al., 2019

95% C.L
sys. only

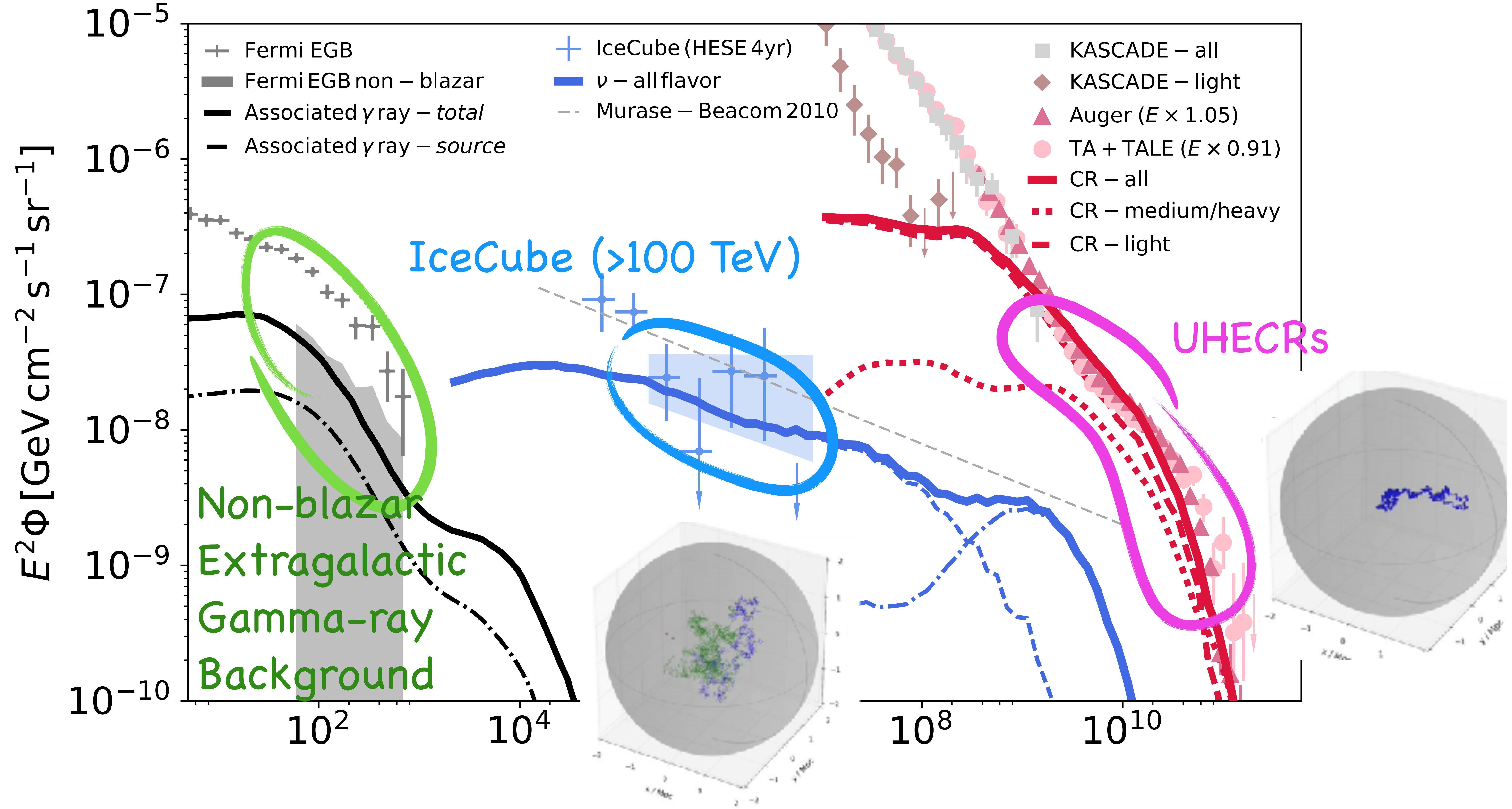




Galaxy clusters (K.Fang)

Cosmic Particles from Black Hole Jets in Galaxy Clusters

KF & Murase *Nature Physics* (2018)

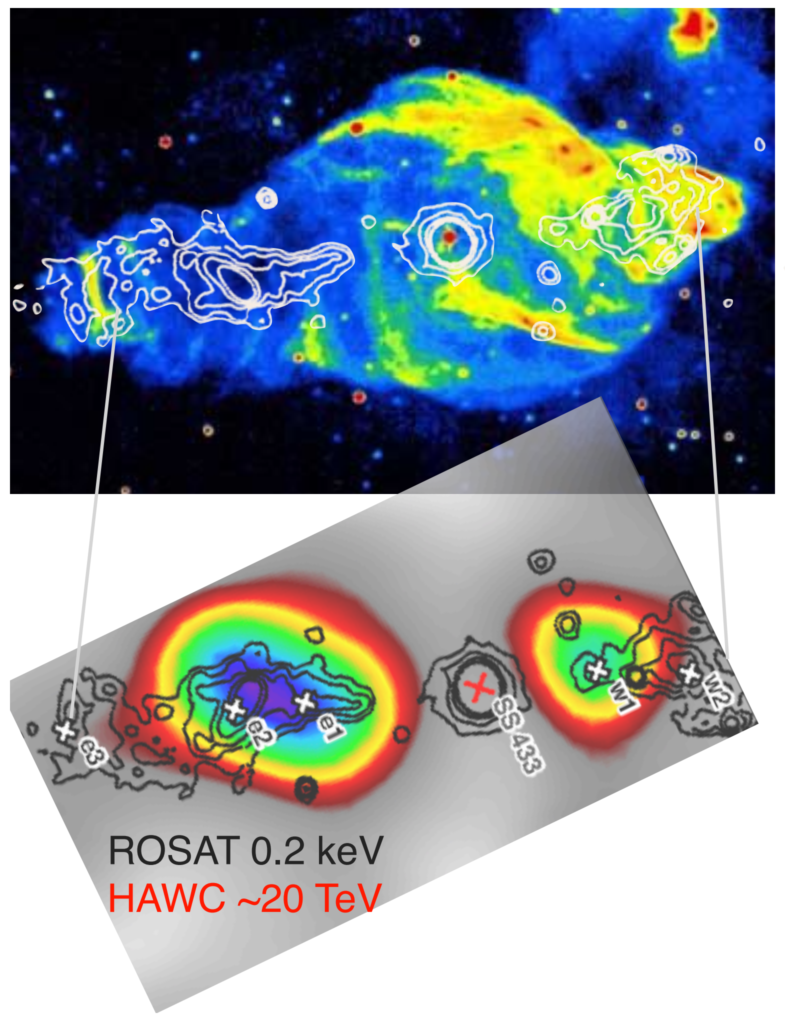


Injection Composition = Galactic CR abundance

SS 433, Cygnus cocoon

Black Hole Jets as Cosmic Accelerators

Microquasar SS 433



- "Mini AGN" in our own galaxy with extended X-ray jets
- **TeV gamma-rays in both lobes** detected by HAWC
- **GeV counterparts** identified in Fermi-LAT data

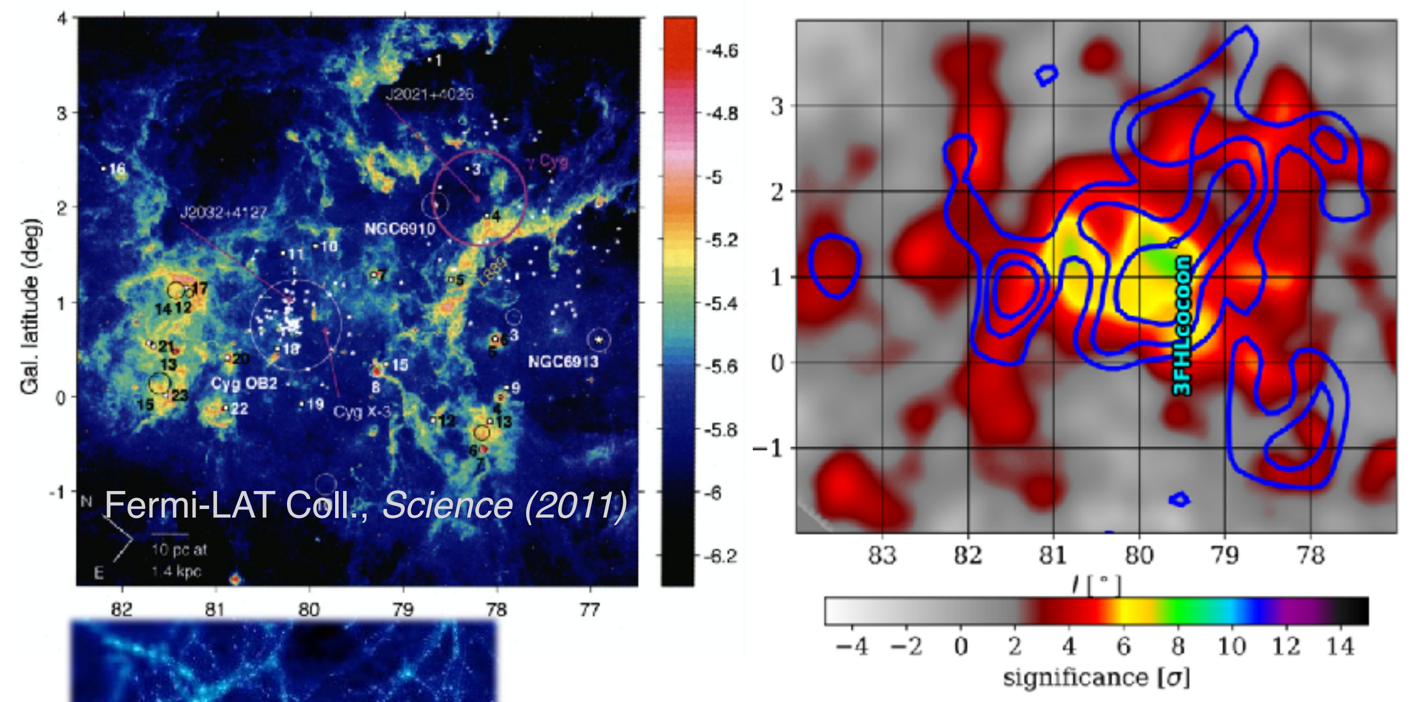
HAWC Collaboration, *Nature* (2018)
KF as a main author

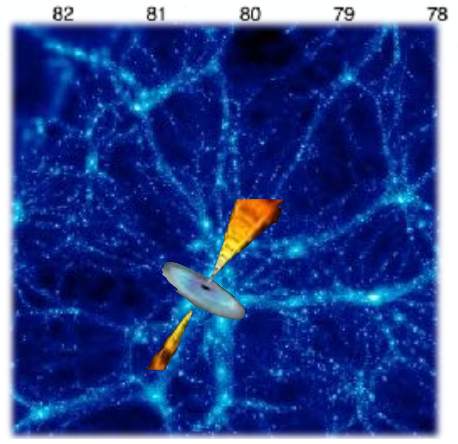
KF, Charles, Blandford, ApJL (2020)

13

Confinement of Cosmic Rays in Local Environment

Cygnus Cocoon





GeV to100 TeV gamma-rays trace infrared emission

HAWC Collaboration, *under review*
KF as a main author

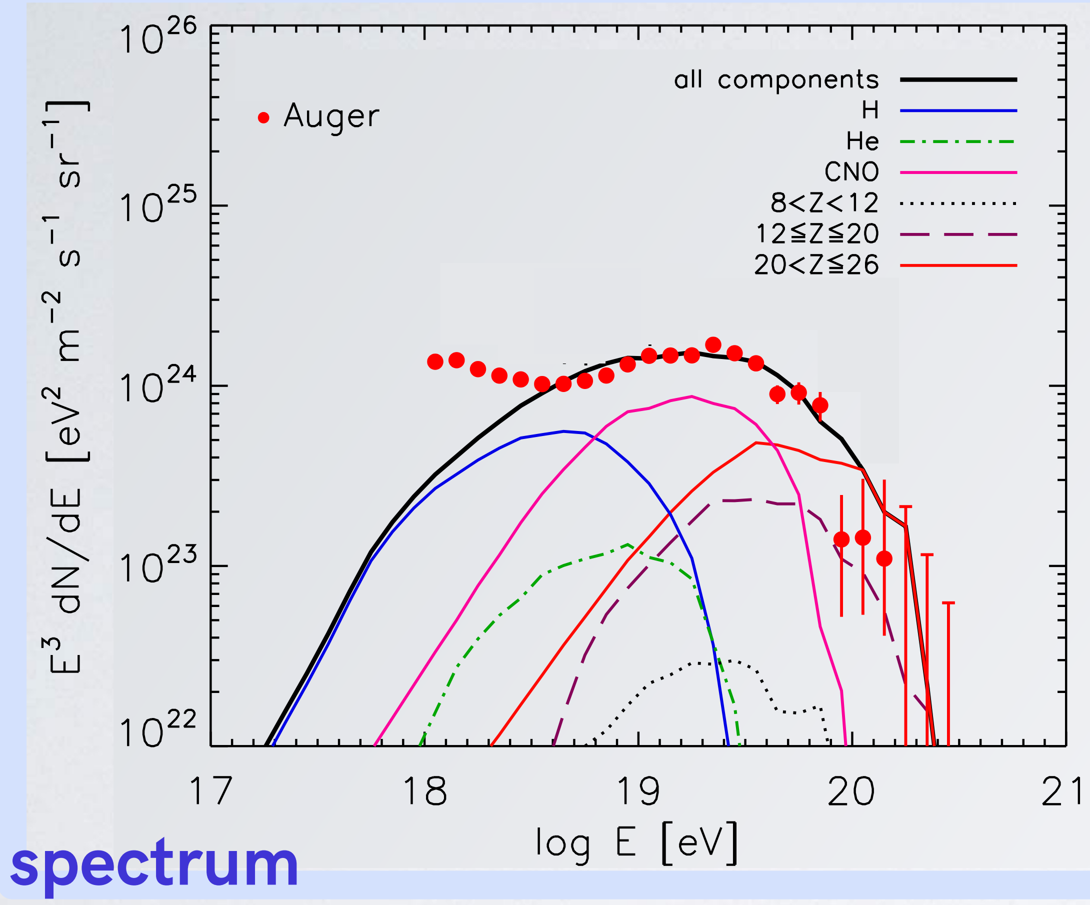
15

Pulser / magnetars (K.Kotera)

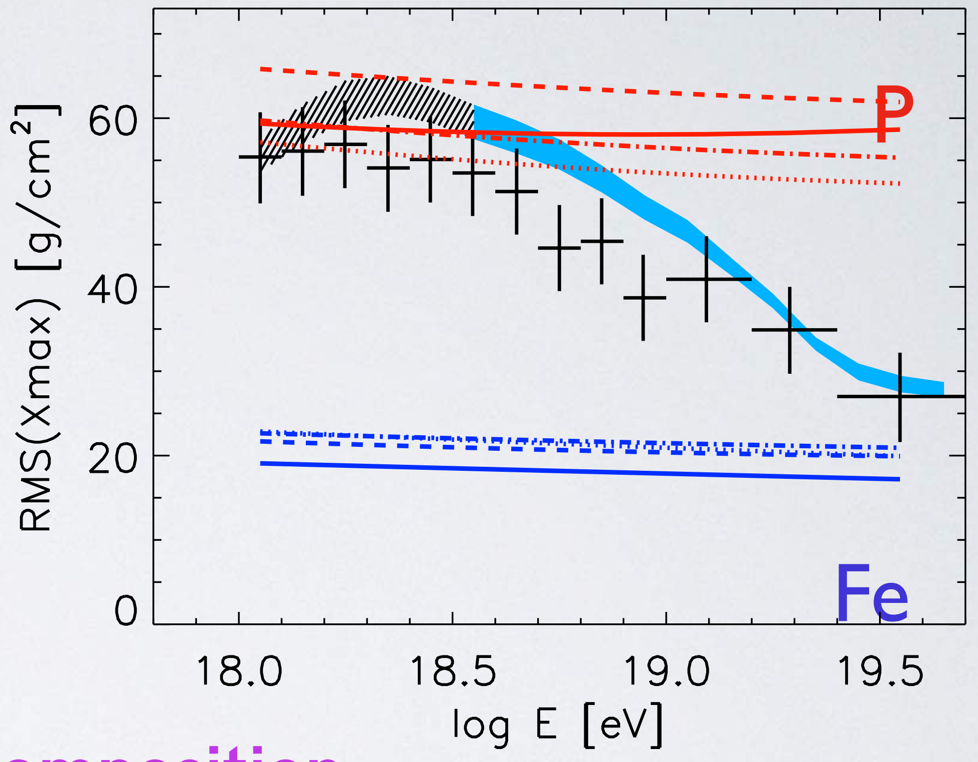
Properties of escaping UHECRs

Fang, KK, Olinto 2012
Fang, KK, Olinto, 2013
KK, Amato, Blasi 2015

after interaction on **supernova ejecta + propagation** in the intergalactic medium



spectrum

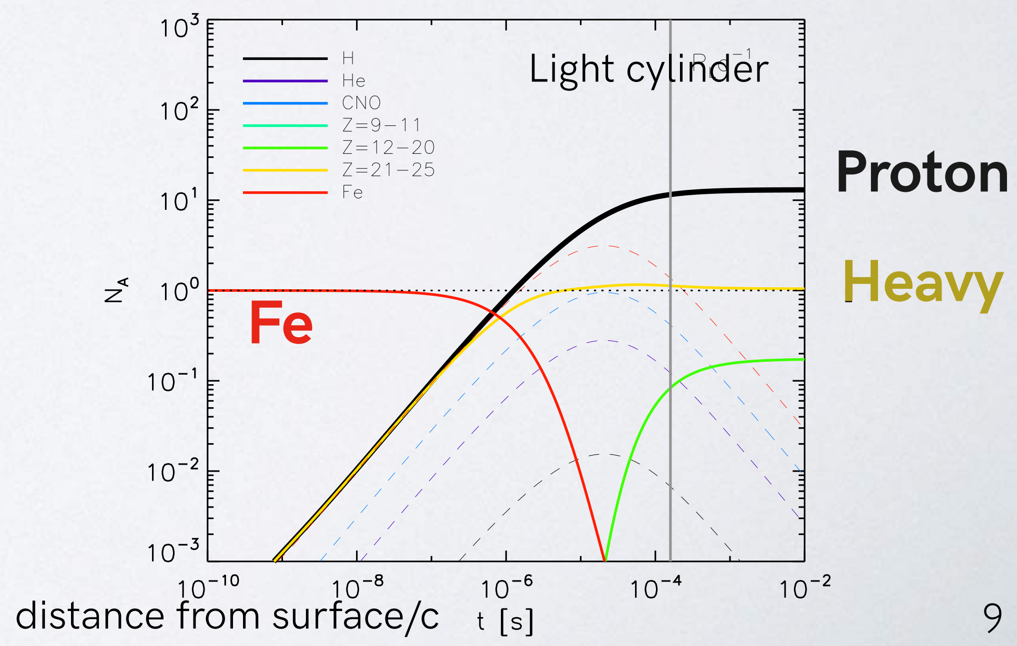


composition

uniform source emissivity evolution
accelerated: 50%P, 30%CNO, 20%Fe

100% Fe @ injection

then interaction on neutron star thermal radiation can lead to right composition *KK, Amato, Blasi 2015*

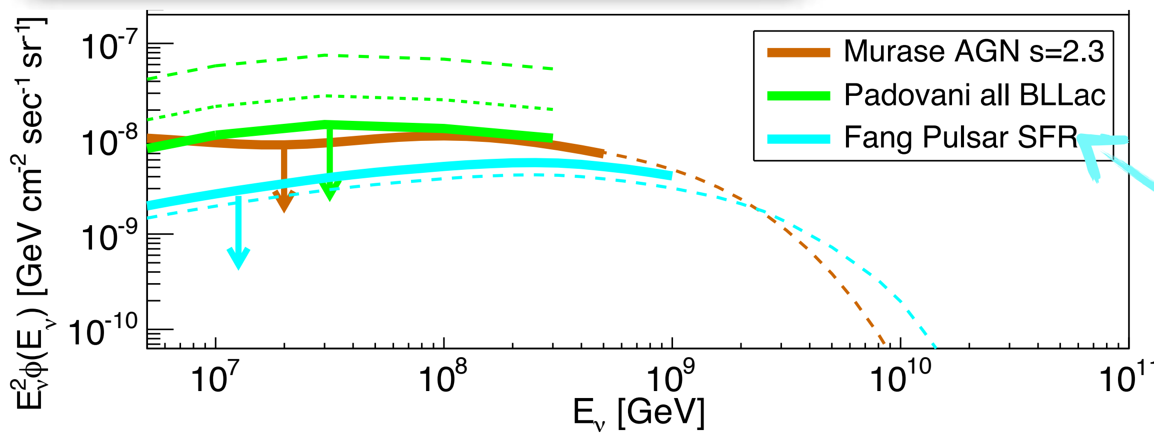


9

IceCube constraints on pulsars as sources of HECRs

model dependent 90% C.L. limits

Aartsen et al. 2016



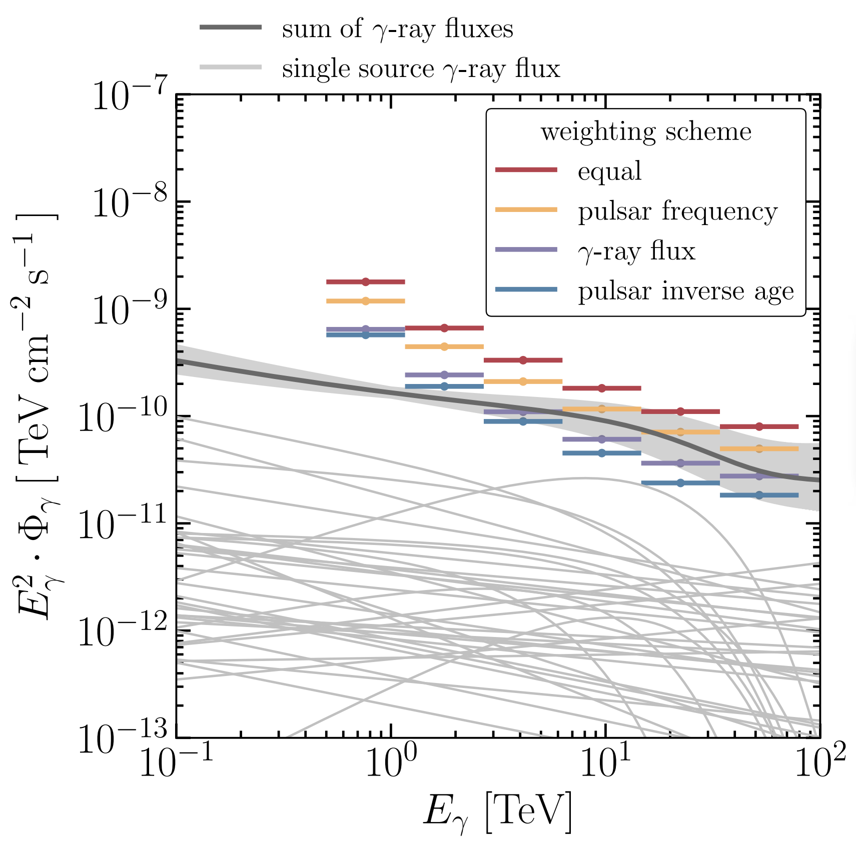
population of pulsars with realistic (P,B) distribution

ν Model	Event rate per livetime (Expected number of events in 2426 days of effective livetime)	p-value	MRF (Model Rejection Factor)
Murase *et al.* [45] $s = 2.3$, ξ_{CR}=100	$7.4^{+1.1}_{-1.8}$	$2.2^{+9.9}_{-1.4}$%	0.96 ($\xi_{CR} \leq$96)
Murase *et al.* [45] $s = 2.0$, ξ_{CR}=3	$4.5^{+0.7}_{-0.9}$	$19.9^{+20.2}_{-9.2}$%	1.66 ($\xi_{CR} \leq$5.0)
Fang *et al.* [48] SFR	$5.5^{+0.8}_{-1.1}$	$7.8^{+14.4}_{-3.7}$%	1.34
Fang *et al.* [48] uniform	$1.2^{+0.2}_{-0.2}$	$54.8^{+1.7}_{-2.7}$%	5.66
Padovani *et al.* [46] $Y_{\nu\gamma} = 0.8$	$37.8^{+5.6}_{-8.3}$	<0.1%	0.19 ($Y_{\nu\gamma} \leq$0.15)

MRF = ratio of expected average upper limit to expected signal

Population of newborn pulsars as sources of UHECRs following star formation rate excluded at 90% C.L.

Fang, KK, Murase & Olinto 2013
Aartsen et al. 2016



No significant correlation between IceCube neutrinos and PWN locations

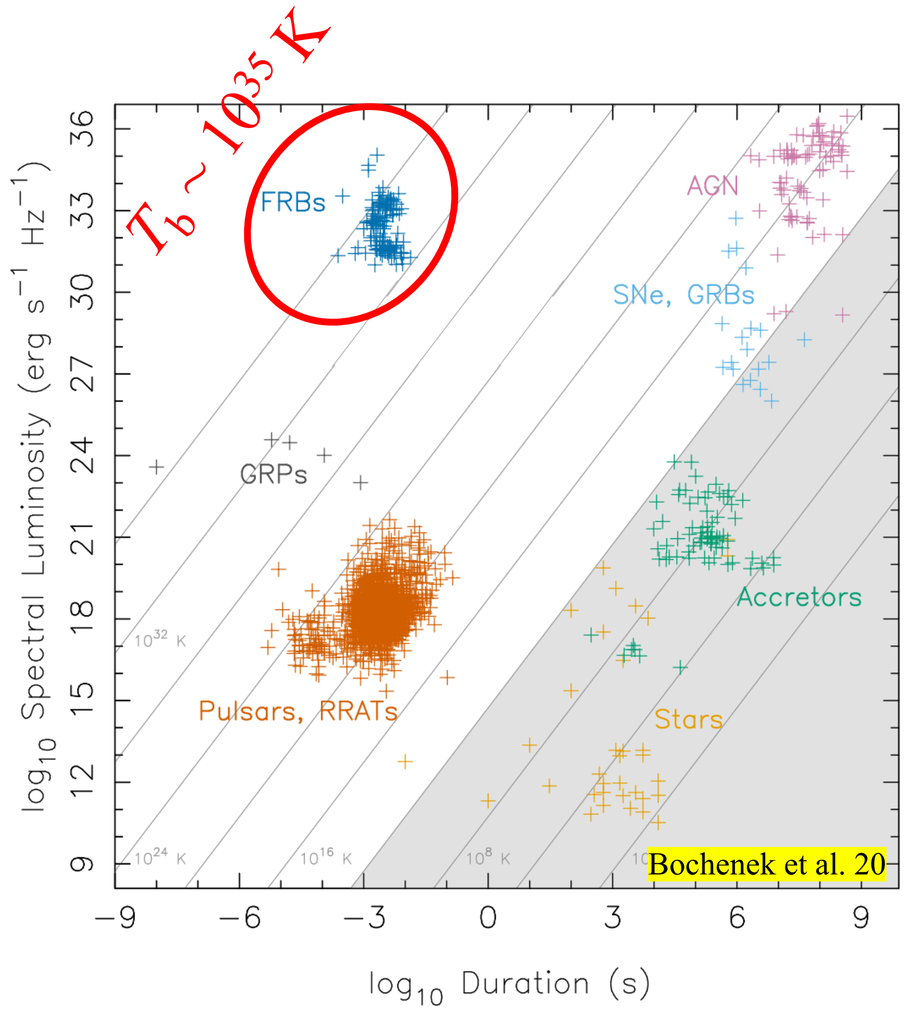
90% C.L. upper limits
on hadronic gamma-ray emission
from 35 stacked Pulsar Wind Nebulae

Aartsen et al. 2020

10

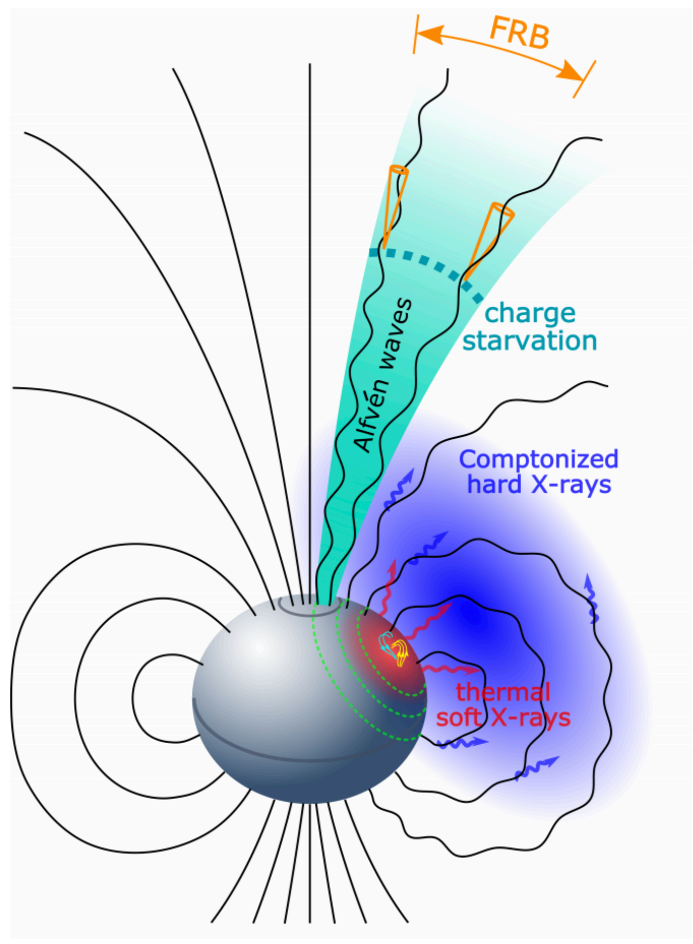
FRB (K.Kashiyama)

FRB = *The Most Powerful Coherent Emission in the Universe*



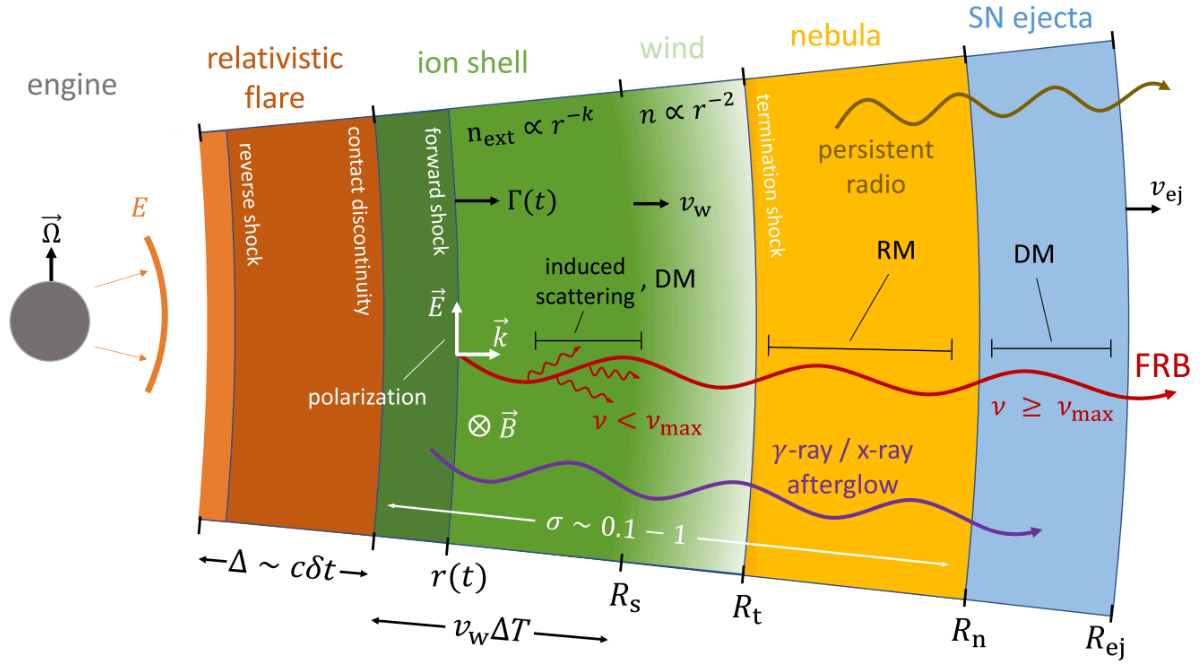
How to produce FRB with X-ray burst?

✓ Trapped fireball + coherent curvature?



Falcke & Rezzolla 13; KK et al, 13; Pen & Connor 15;
Cordes & Wasserman 16; Lyutikov et al. 16;
Kumar et al. 17; Zhang 17; Lu et al. 20; Ioka 20; …

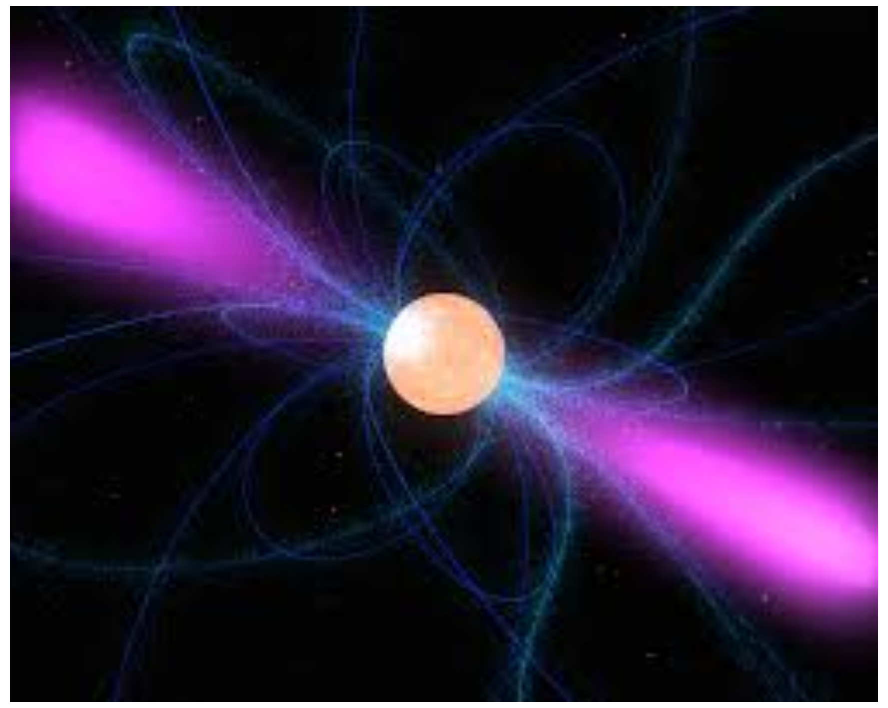
✓ shock + synchrotron maser?



Hoshino & Arons 91; Gallant, Hoshino, et al. 92
Lyubarsky 14; Murae, KK, Meszaros 16;Waxman 17;
Beloborodov 17, 19; Metzger et al. 19; Margalit et al. 20; …

The source of the electrons

spindown luminosity and/or magnetic flare



Electron/position pair dominated

The NS is born with a millisecond rotation and a sufficiently high magnetic field

✓ A superluminous supernova at its birth?

KK & Murase 17 also Kotera-san's talk Margalit+17

Ion + electron dominated?

The magnetar is less than ~100 years old, significantly more active than those in our galaxy.

✓ compatible with the synchrotron maser model

Beloborodov 17

Young pulser as a possible origin of FRB?

FRB afterglow (L.Haoxiang)

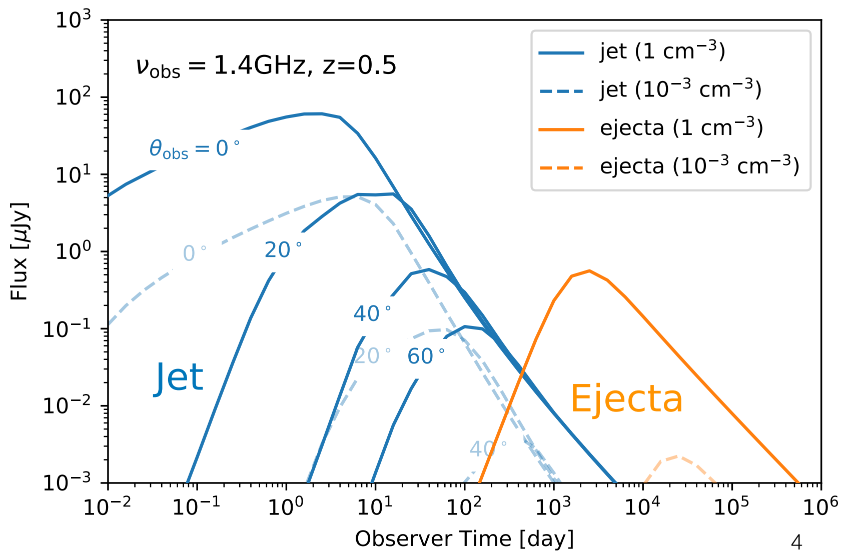
Detection probability of afterglow

We approach the question by quantifying the "detection probability" of afterglow in the following pattern:

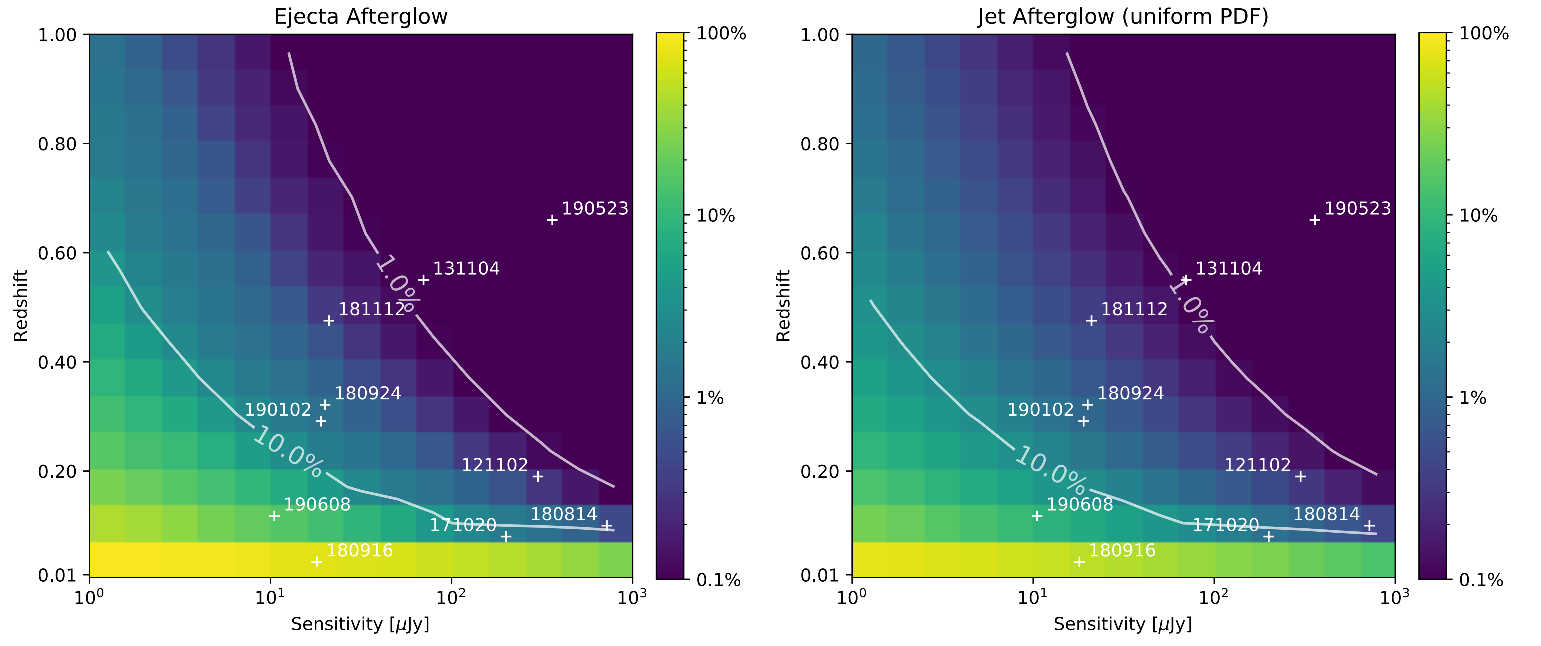
1. Start from the prior knowledge from short GRB observations: distributions of isotropic energies, ambient densities, microphysical parameters, and jet half opening angle.
2. Calculate afterglows of relativistic jet and isotropic ejecta rising from the population of mergers, with intrinsic variability prescribed by these distributions.
3. Quantify the detection probability (P_{det}) of radio afterglow as the observable fraction in the population, as a function of observed time T, source redshift z and detector sensitivity.

Parameters	Median	Standard Deviation
$\log(E_{k,iso}$ [erg])	51.2	0.83
$\log(n$ [cm^{-3}])	-1.57	1.63
θ_j [deg]	5.8	1.2
p	2.39	0.23

Table 1. Median and 1σ scatter of Gaussian fit to the parameter cumulative distributions by short GRB afterglow observation (Fong et al. 2015).



Detection probability vs FRB radio limits



- Most FRBs have only 1—10% detectable afterglows at their follow-up sensitivities.
- Considering the sample # < 10, we conclude no strong constraint on merger model.

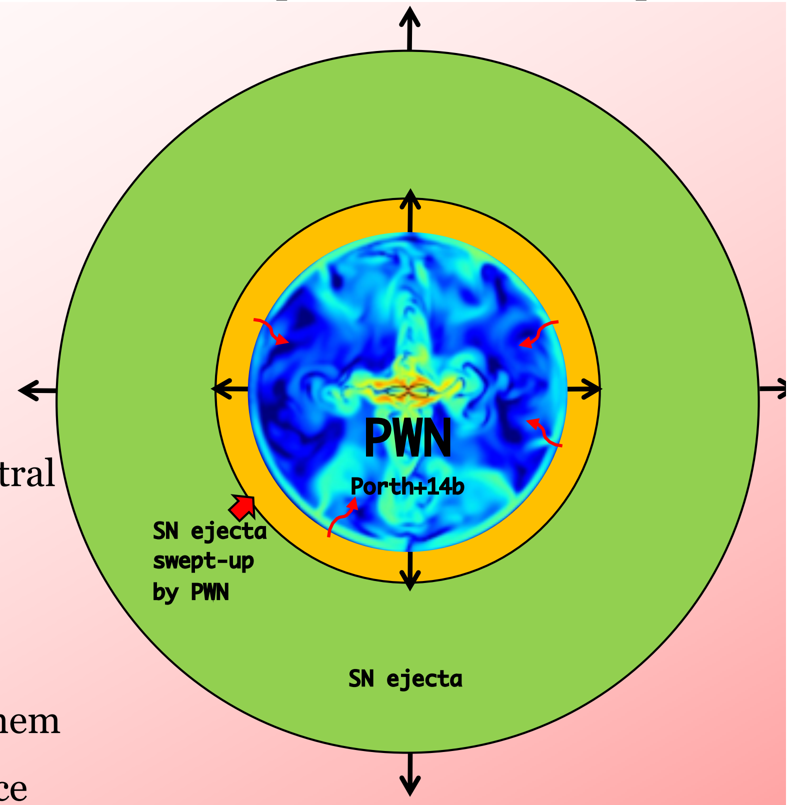
SN1986J → PWN? (S.Tanaka)

One-zone Model

One-zone approx. for PWN

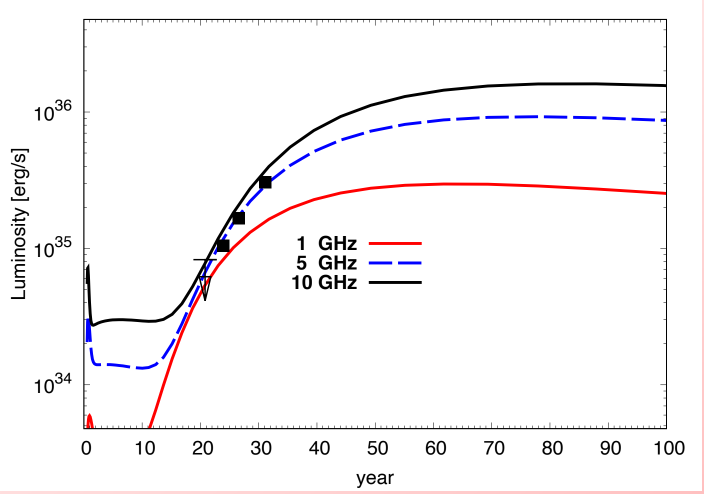
- Expanding PWN inside expanding SN ejecta e.g., Gelfand+09, Bandiera+20
- Supplying accelerated e± & B from central PSR e.g., Pacini&Salvati73, Kennel&Coroniti84
- Seeding low-energy electrons from SN ejecta and stochastically accelerating them to radio-emitting particles by turbulence Tanaka&Asano17
- B-field evolution of $\frac{4\pi}{3}R^3_{\rm PWN}(t)\frac{B^2(t)}{8\pi} = \eta_{\rm B}\int_0^t L_{\rm spin}(t')dt'$ Tanaka&Takahara10

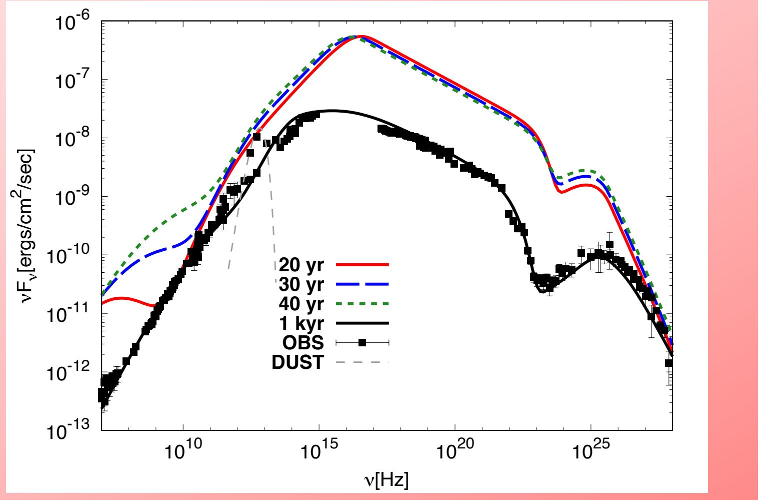
$$L_{\rm spin} = (\eta_{\rm e} + \eta_{\rm B} + \eta_{\rm turb})L_{\rm spin}$$



Results

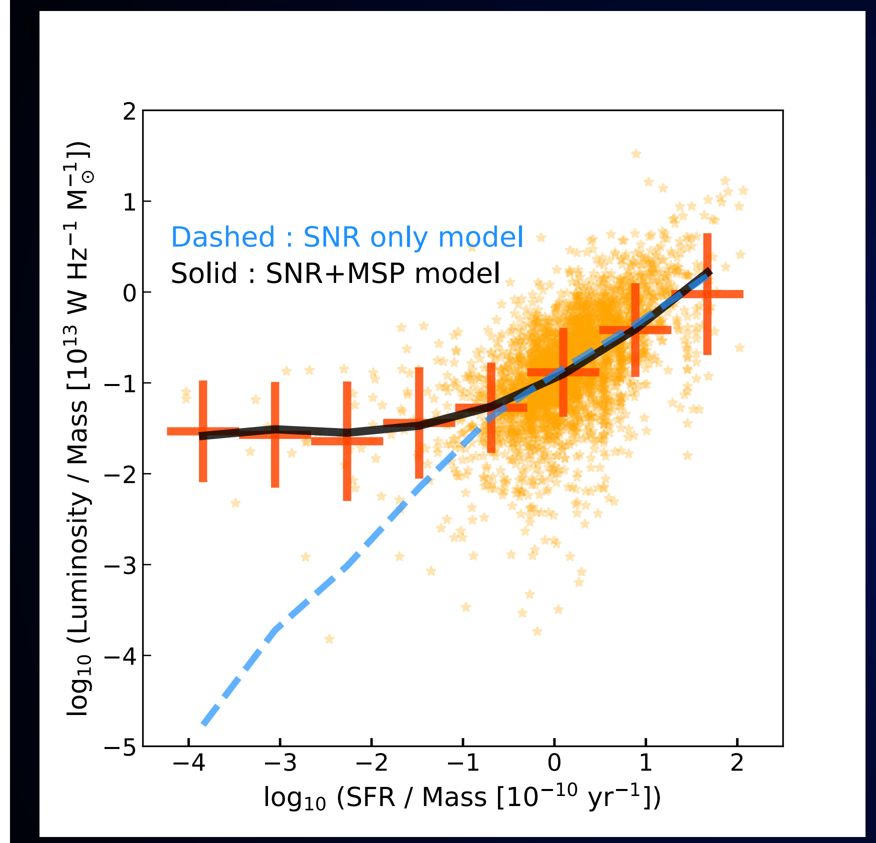
- 5 GHz light curve of SN 1986J (<30 yr) and Crab spectrum (~950 yr) can be fitted simultaneously
- Crab's spin-down evolution
- $(\eta_{\rm B}, \eta_{\rm turb})$ = (0.01, 0.5)
- $(\tau_{\rm acc,m}, \tau_{\rm turb})$ = (10, 80) yr
- $f_{\rm inj}$=3 x 10^{-5}





M31? (T.Sudoh)

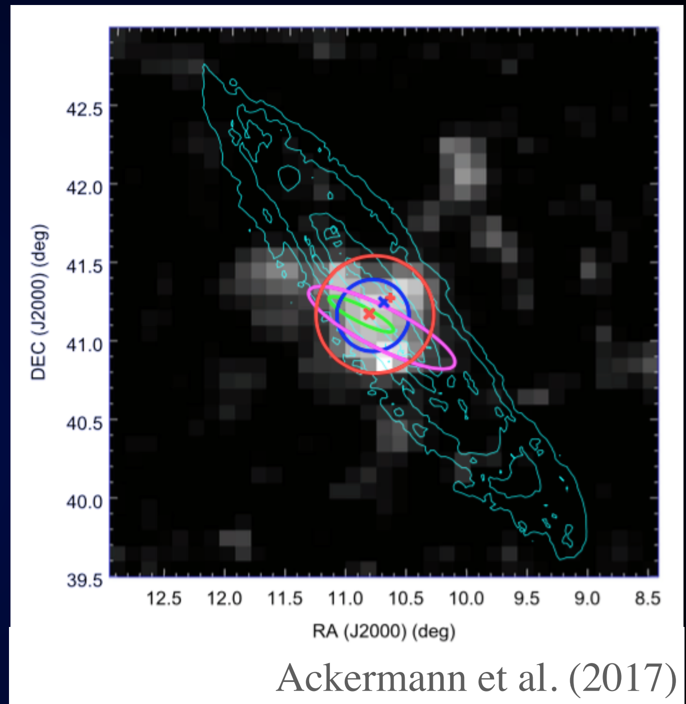
Comparison to LOFAR data



- Adding one parameter significantly improve the fit.
- The best-fit efficiency is : $\eta_e \simeq 1$
- It degenerates with a number of uncertainties and assumptions.
- MSPs may inject significant fraction of the power as cosmic-ray e+-.

Implications

- The center of Andromeda galaxy show bright radio and gamma-ray emission despite its low SFR
- Our best-fit model naturally explains the required cosmic-ray electron power
- Nearby galaxies will be good way to differentiate AGN contribution



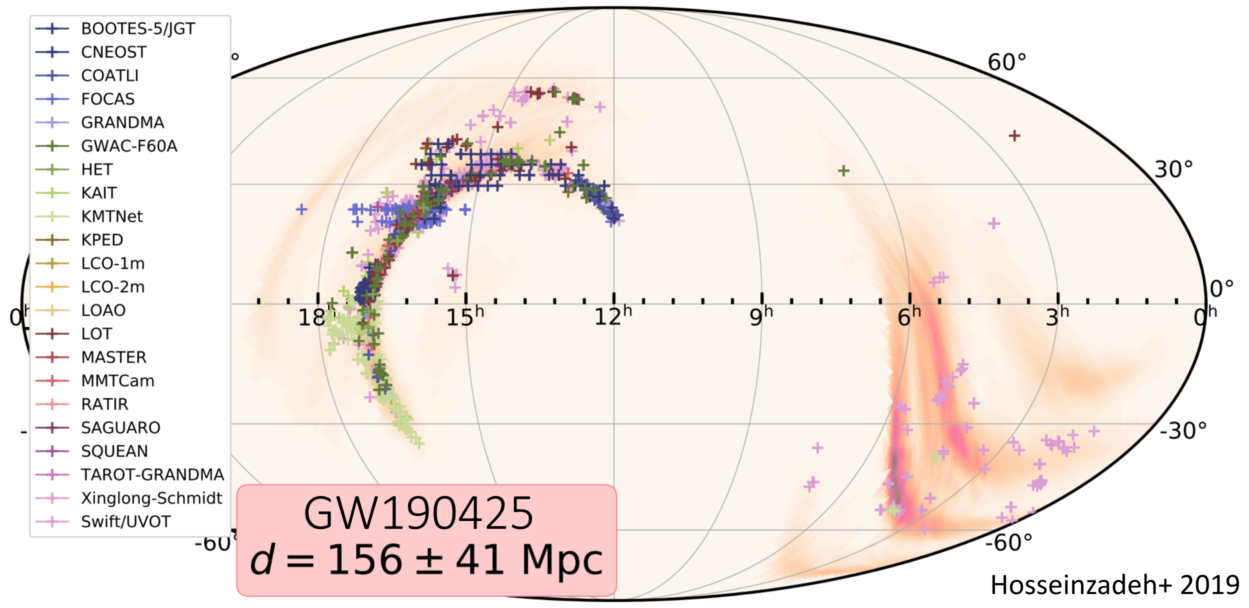
Ackermann et al. (2017)

Compact object mergers (I.Bartos)

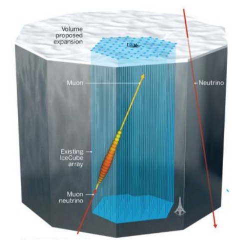
Difficulty to observe EM counterpart

Electromagnetic follow-up can be difficult

- We were spoiled by GW170817.
- No GRB / high-energy neutrino counterpart.
- Dozens of observatories, 100s of observations (>230 GCN circulars).
- Extensive observation campaign only covered ~50% of volume.
- Many false positives.
- Galaxy targeted searches --- < 1% covered.



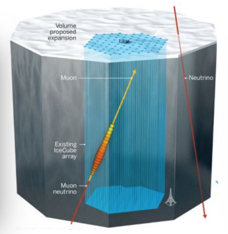
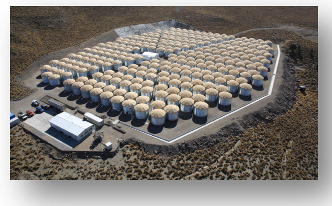
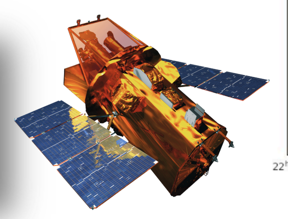
Hosseinzadeh+ 2019

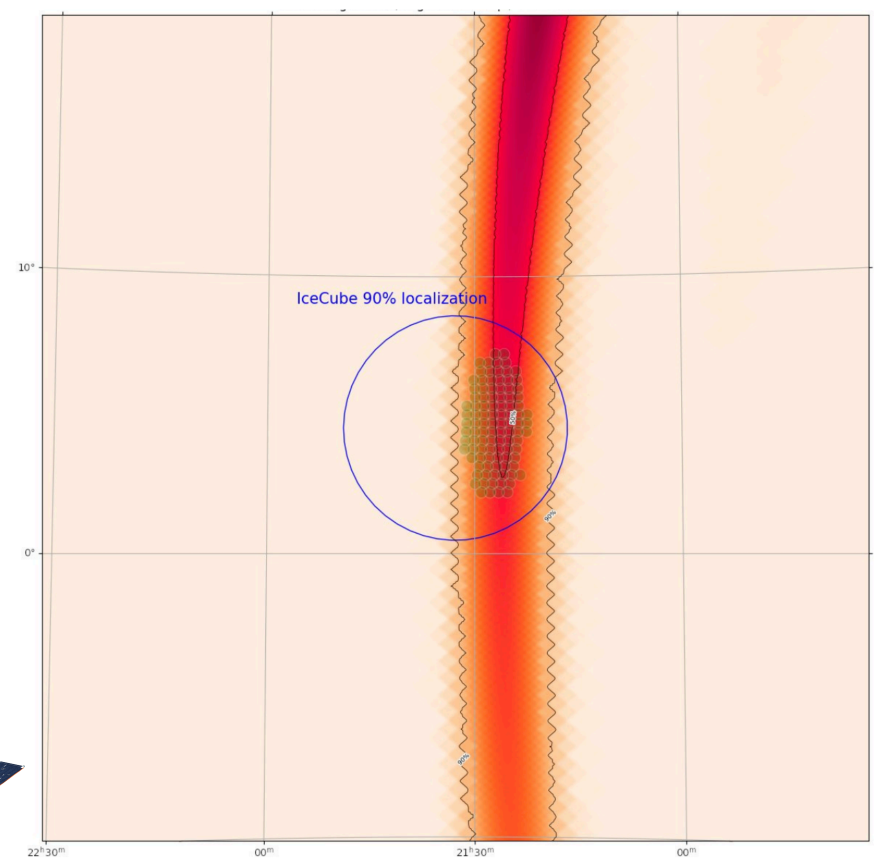


Poor localization is not a problem for neutrino follow-up.
IceCube ApJ Lett. 898:L10 2020

IceCube follow-up of gravitational-wave candidate S191216ap

- IceCube followed up all of LIGO/Virgo's publicly announced candidates.
- Low latency (mostly it was the first detector to report the results of the follow-up).
- One particularly interesting overlap: S191216ap
  - Classified as "mass gap" by LIGO/Virgo
  - Bayesian coincidence analysis (Bartos+ PRD 2019) identified overlap significance of 2.5σ.
  - Coincidence substantially shrunk the error region for follow-up observations.
  - The HAWC high-energy gamma detector identified an interesting coincident sub-threshold event.
  - The Swift satellite carried out X-ray follow-ups in the jointly found direction, but did not find any signal.



Keivani,...,Bartos+ 2020

Possibility to detect Past NS by radio?

Can we uncover past neutron star mergers in archival radio surveys?

- No radio flare has been detected from neutron star mergers.

❑ Radio flares are not detectable unless the merger is nearby.

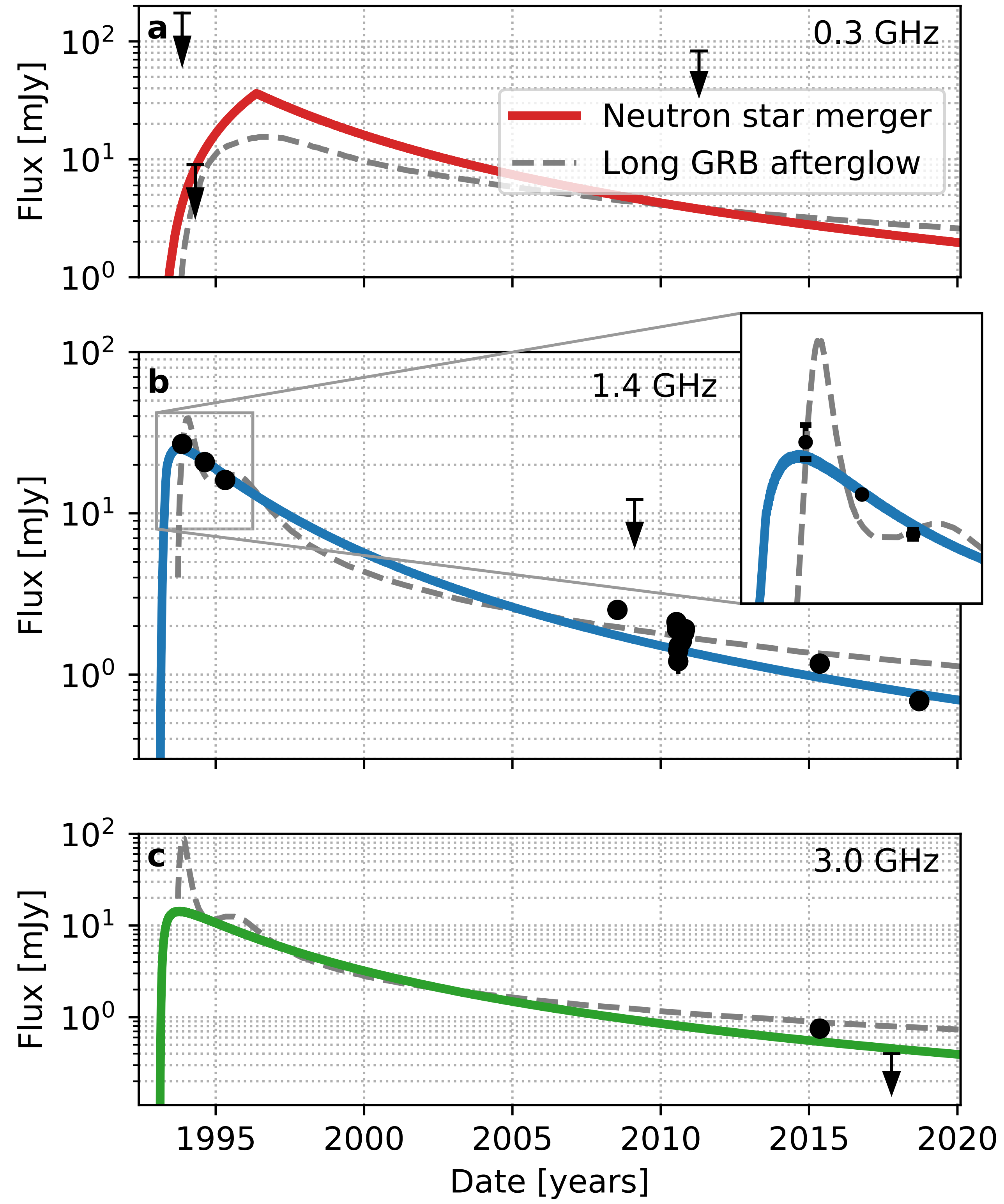
❑ The merger also needs to be in a dense interstellar medium, which is typically not expected (Metzger & Merger 2012). (e.g. GW170817 is close but is in a very sparse medium)

- But: **atypical ≠ never!**

✓ A long-term radio signal (FIRST J1419+3940) 87 Mpcs away is better explained with a merge origin than alternative explanations (afterglow).

✓ Would be first such discovery.

Lee, Bartos+ ApJ Lett 2020

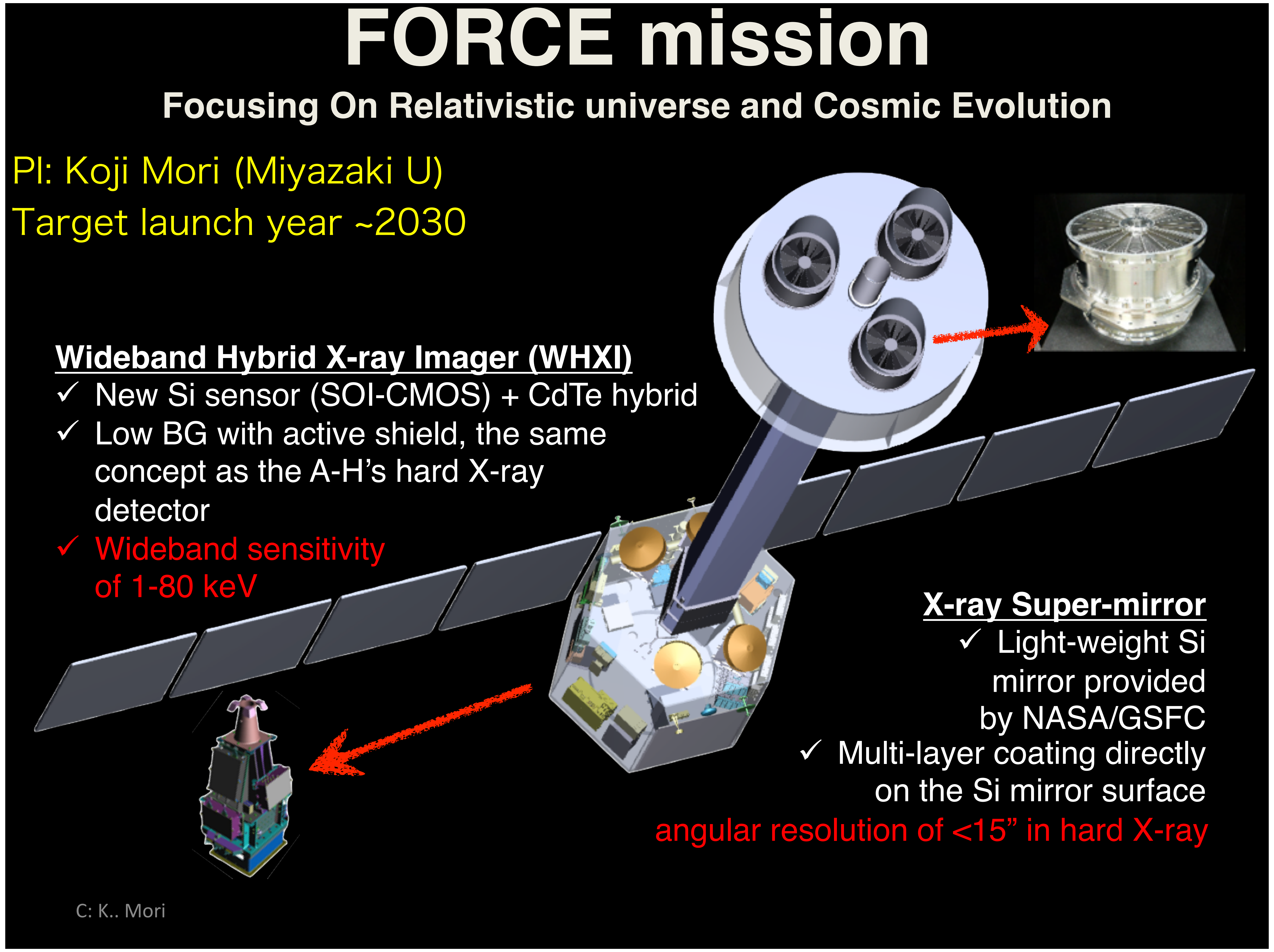


Importance to connect GW lovers...

Future observatories

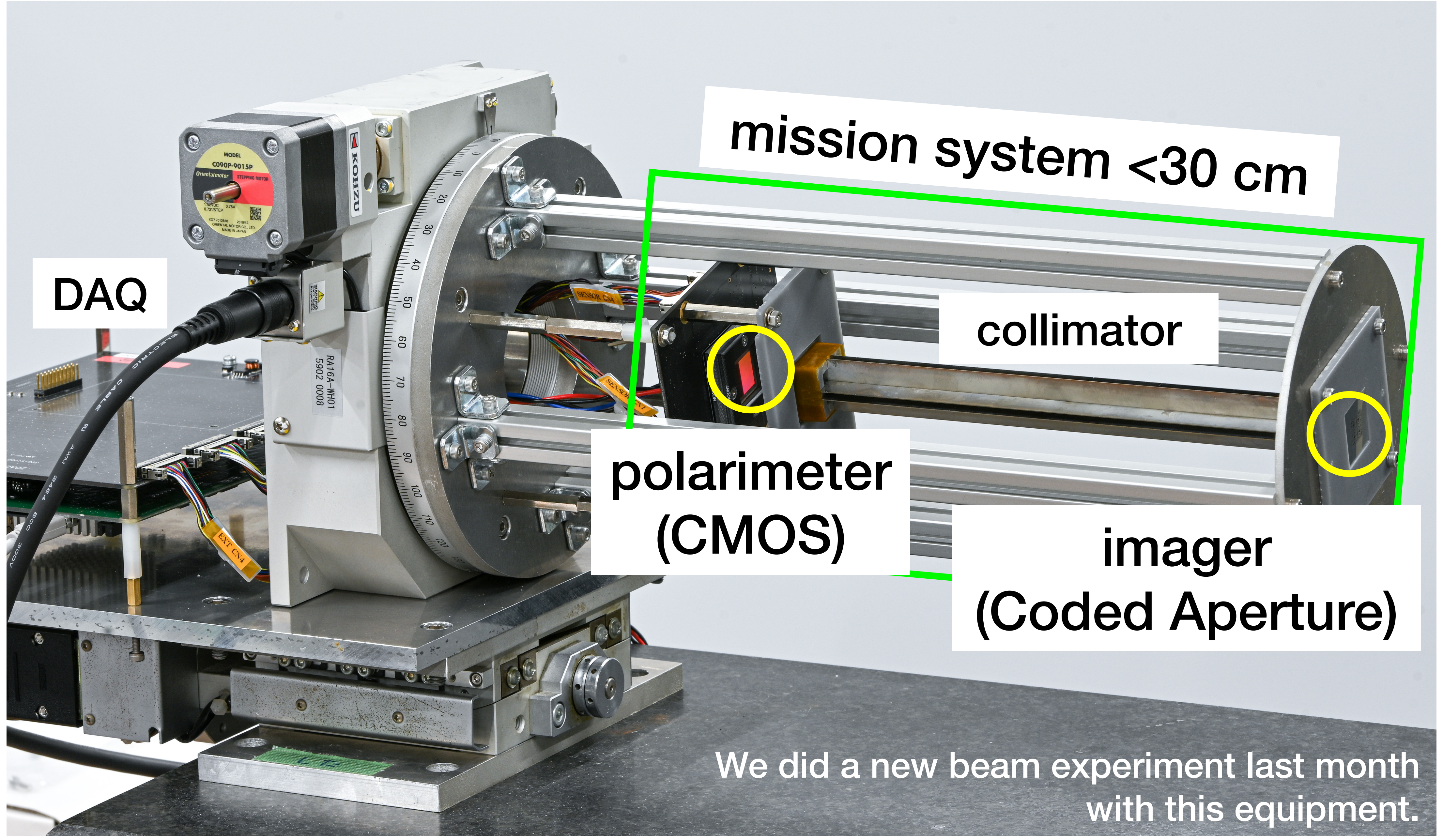
X-ray future instruments

XRISM, FORCE (Y.Ueda) and then ATHENA...



cipher: a CubeSat-Based Hard X-ray Imaging Polarimetry (T.Kasuga)

Demonstration of *cipher*



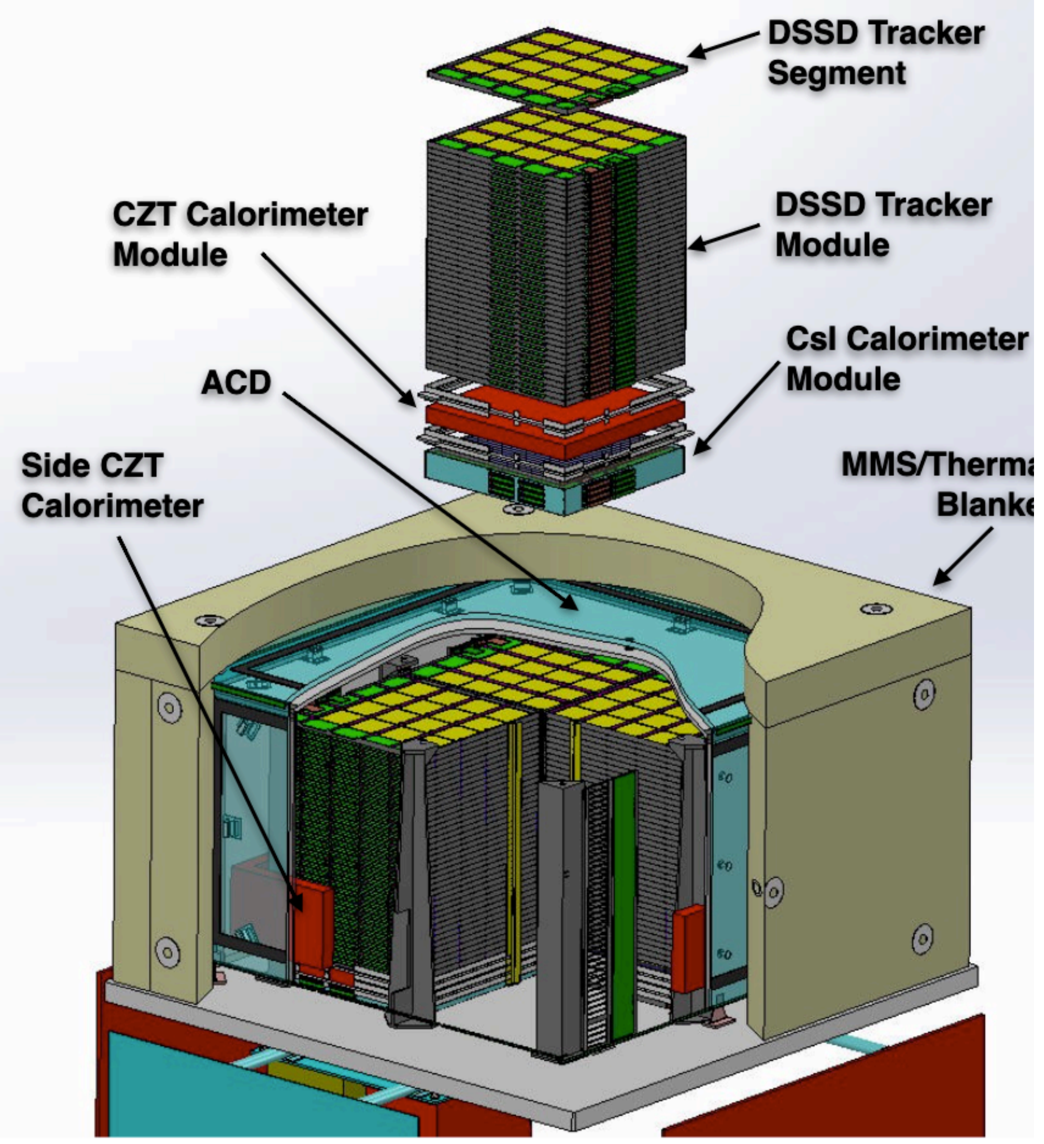
Dec. 09, 2020 Connecting high-energy astroparticle physics for origins of cosmic rays and future perspectives 11

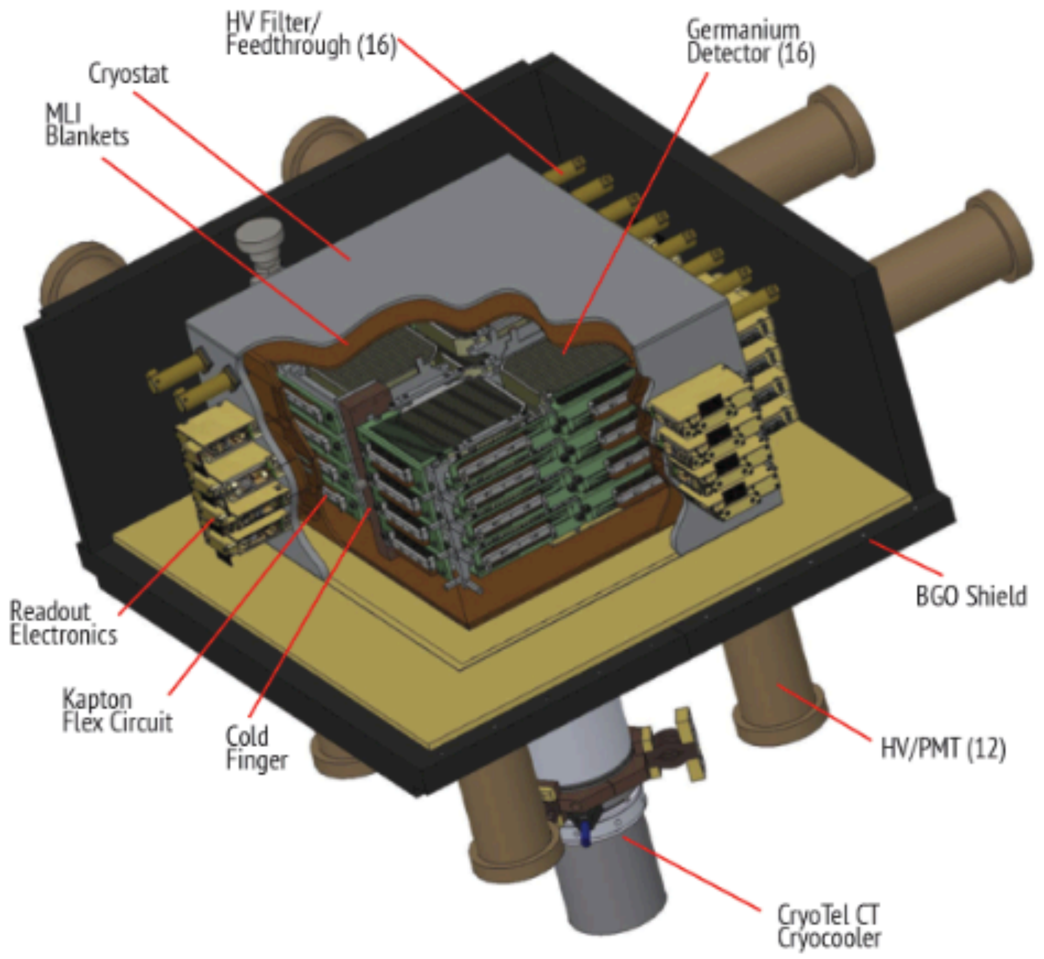
MeV missions

Proposed MeV Gamma-ray Missions

Not complete,,,,

Solid



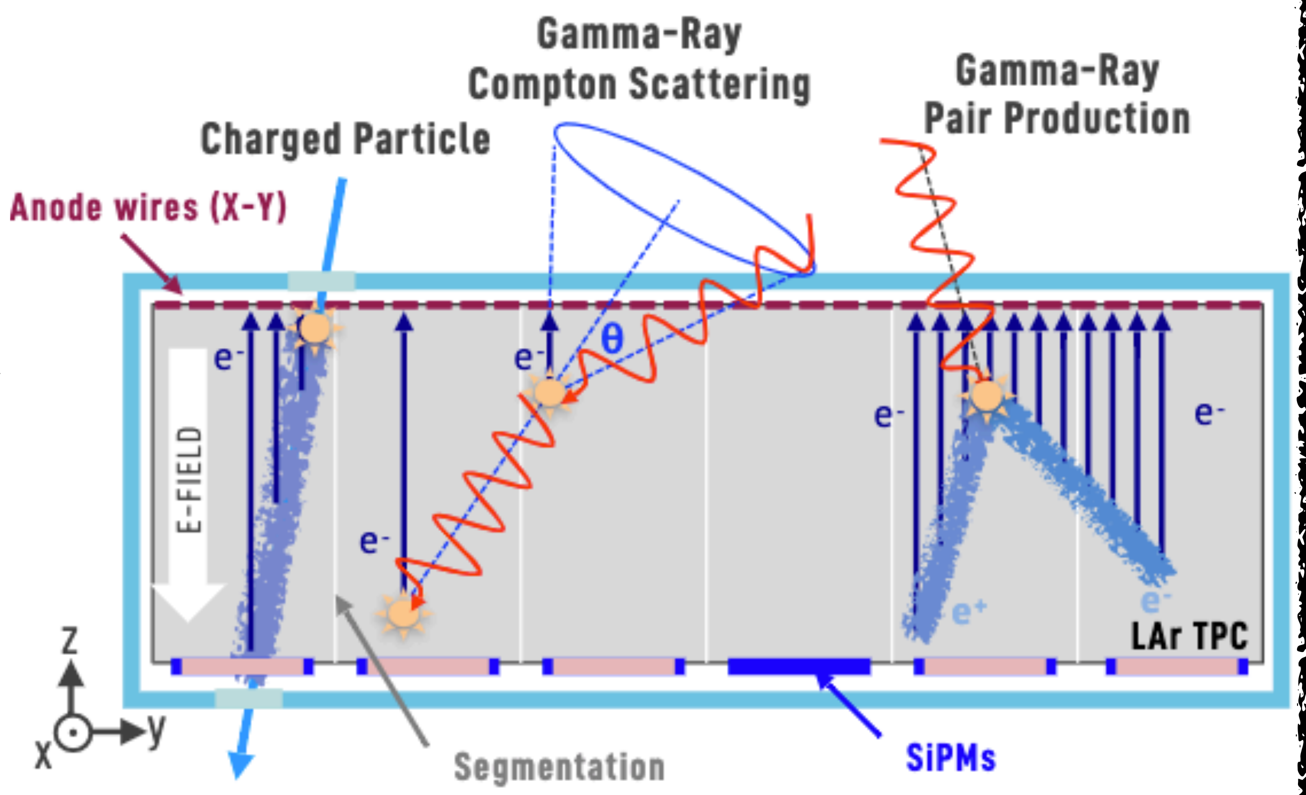


AMEGO

COSI

See talk by Zoglauer

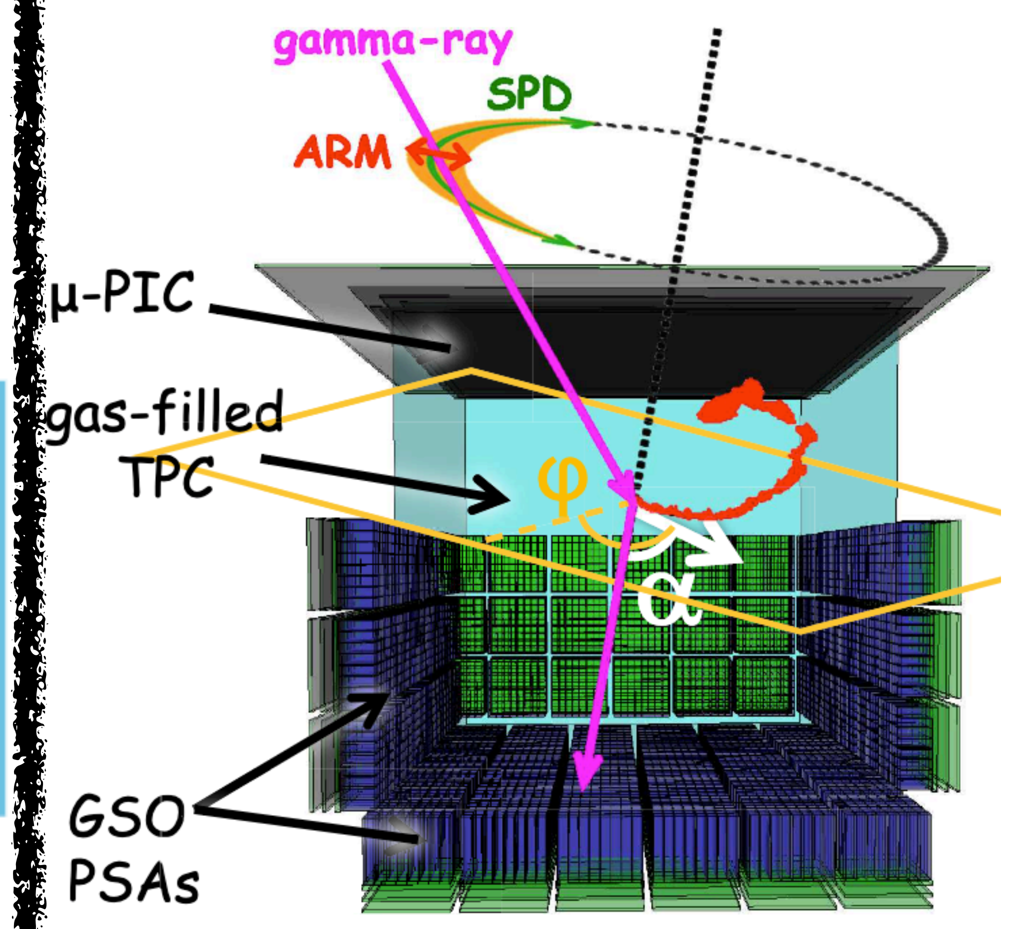
Liquid



GRAMS

See Poster by Takashima

Gas



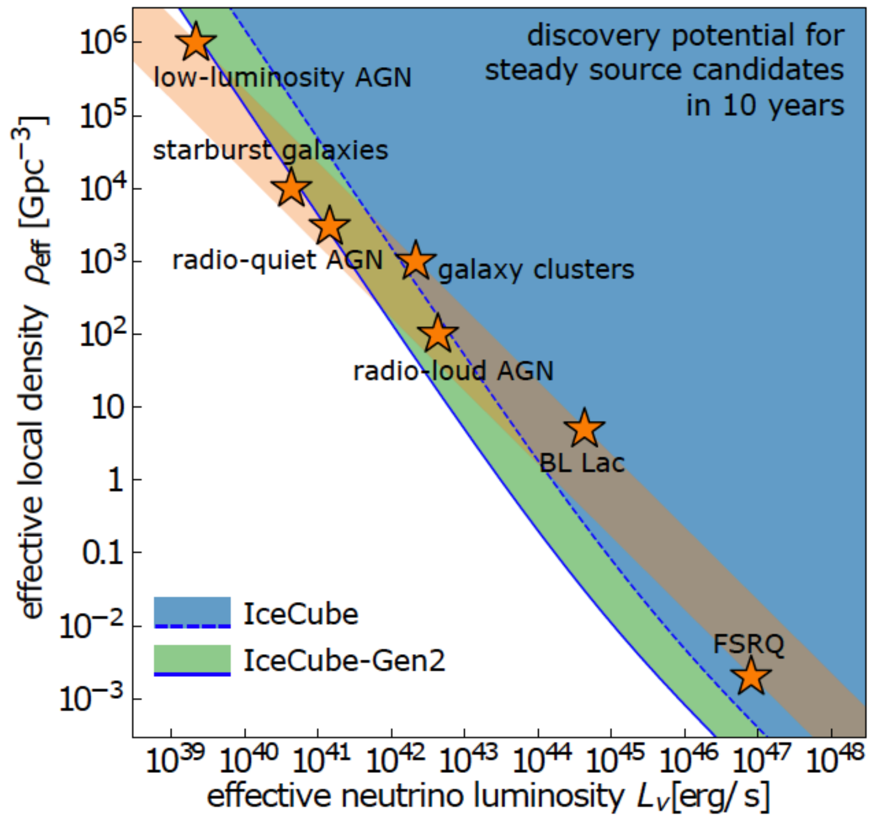
SMILE

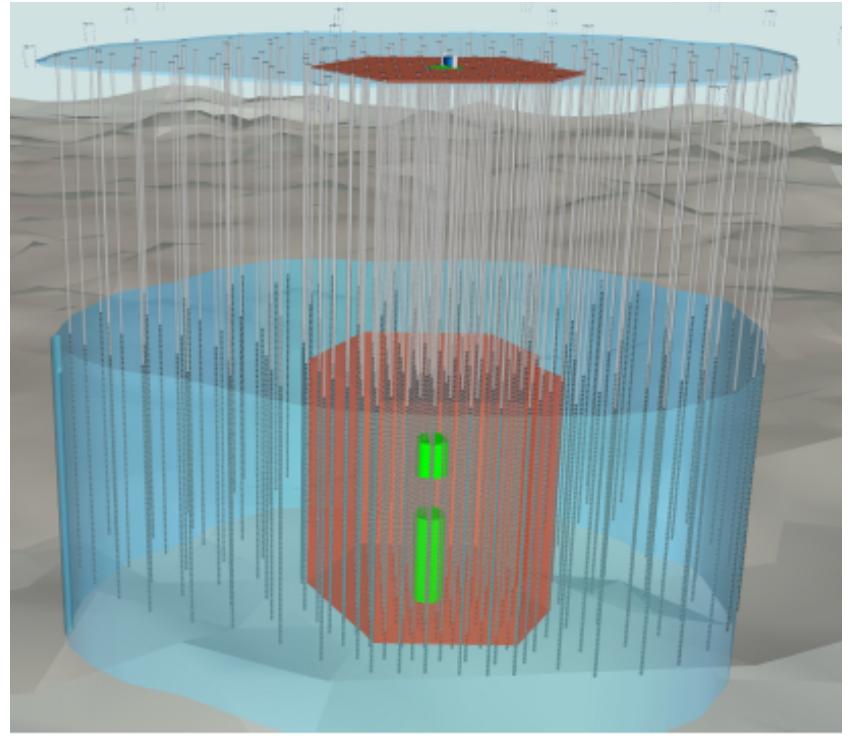
See talk by Takada

Future neutrino observatory (I.Taboada, S.Wissel)

IceCube Gen-2

8 times the instrumented (optical) volume + radio component.
5x better time-integrated point source sensitivity than IceCube (E^{-2})
Threshold is ~30 TeV (‘Standard’ IceCube’s is ~1 TeV)
Better angular resolution, specially above ~100 TeV



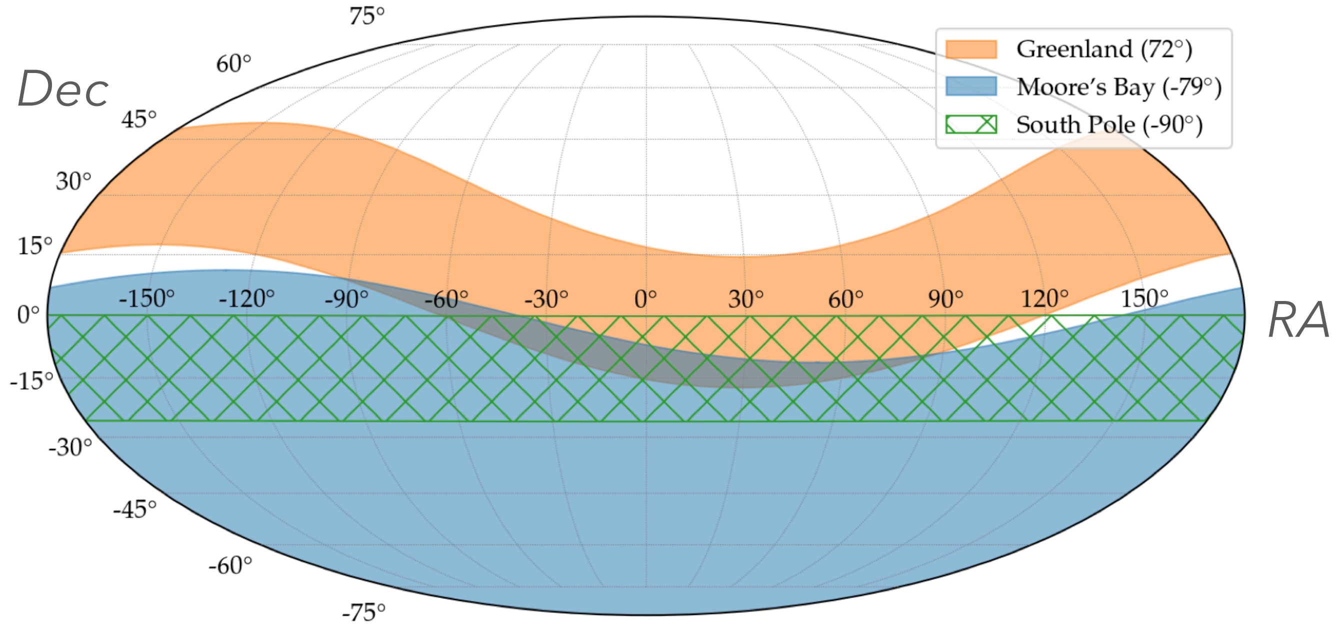


Gen2 Whitepaper: arXiv:2008.04323

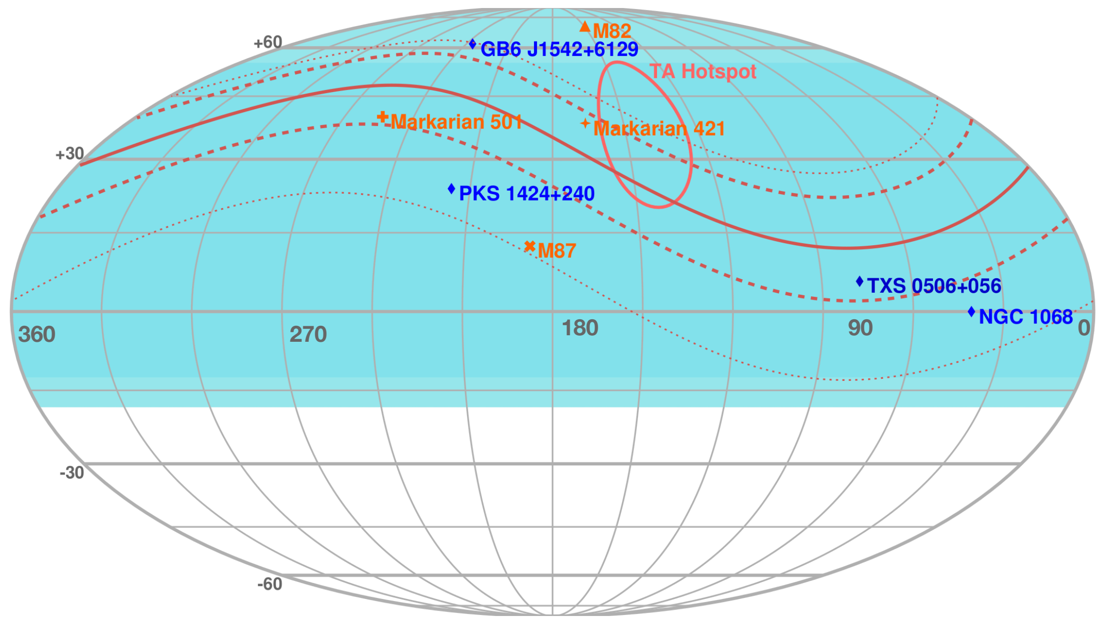
I. Taboada | Georgia Inst. of Tech.

- ➤ **South Pole** (ARA, ARIANNA-200, Gen2): Identical view of UHE neutrino sky as IceCube, deep glacial ice yields the longest attenuation lengths → largest effective volume/station
- ➤ **Moore’s Bay** (ARIANNA): Lower polar latitude + reflections off bottom surface of ice shelf yield broadest sky coverage
- ➤ **Summit Station** (RNO-G): Lower polar latitude in the North → broader sky coverage that overlaps with IceCube’s hotspots at lower energies

Radio Detector Instantaneous Sky Coverage

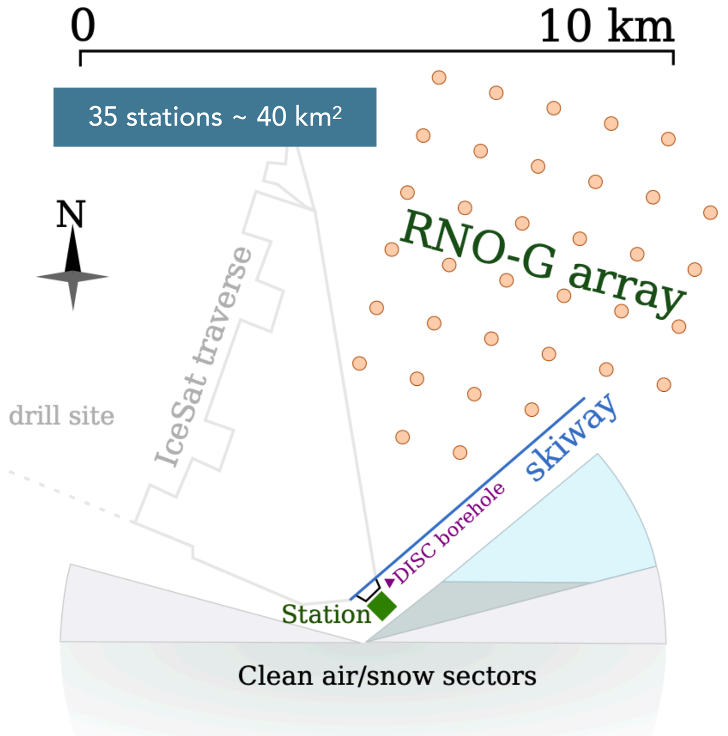


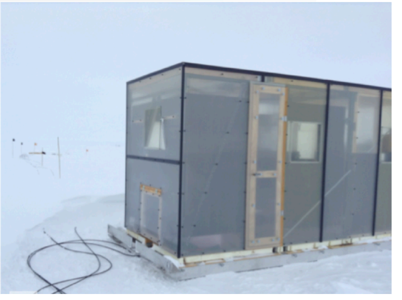
RNO-G Sky Coverage

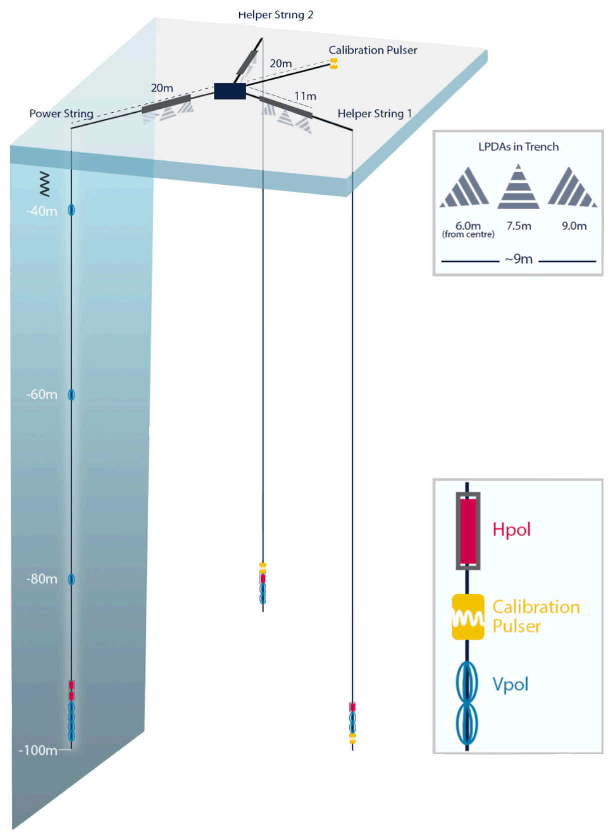


11

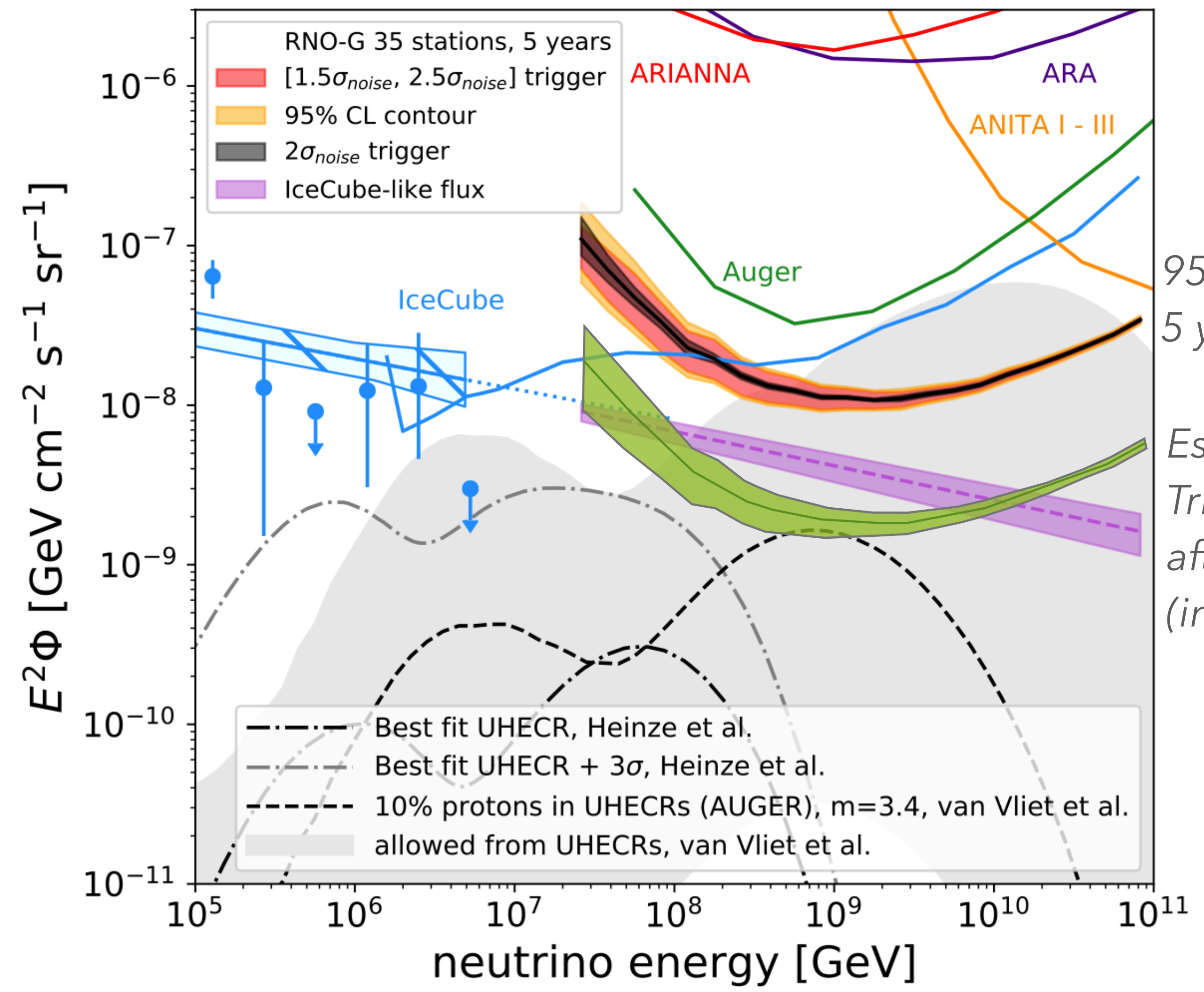
RNO-G Expected Sensitivity







Current (COVID-friendly) deployment plan:
up to 10 stations 2021, 25 stations 2022-2023



95% CL Upper limit 5 years

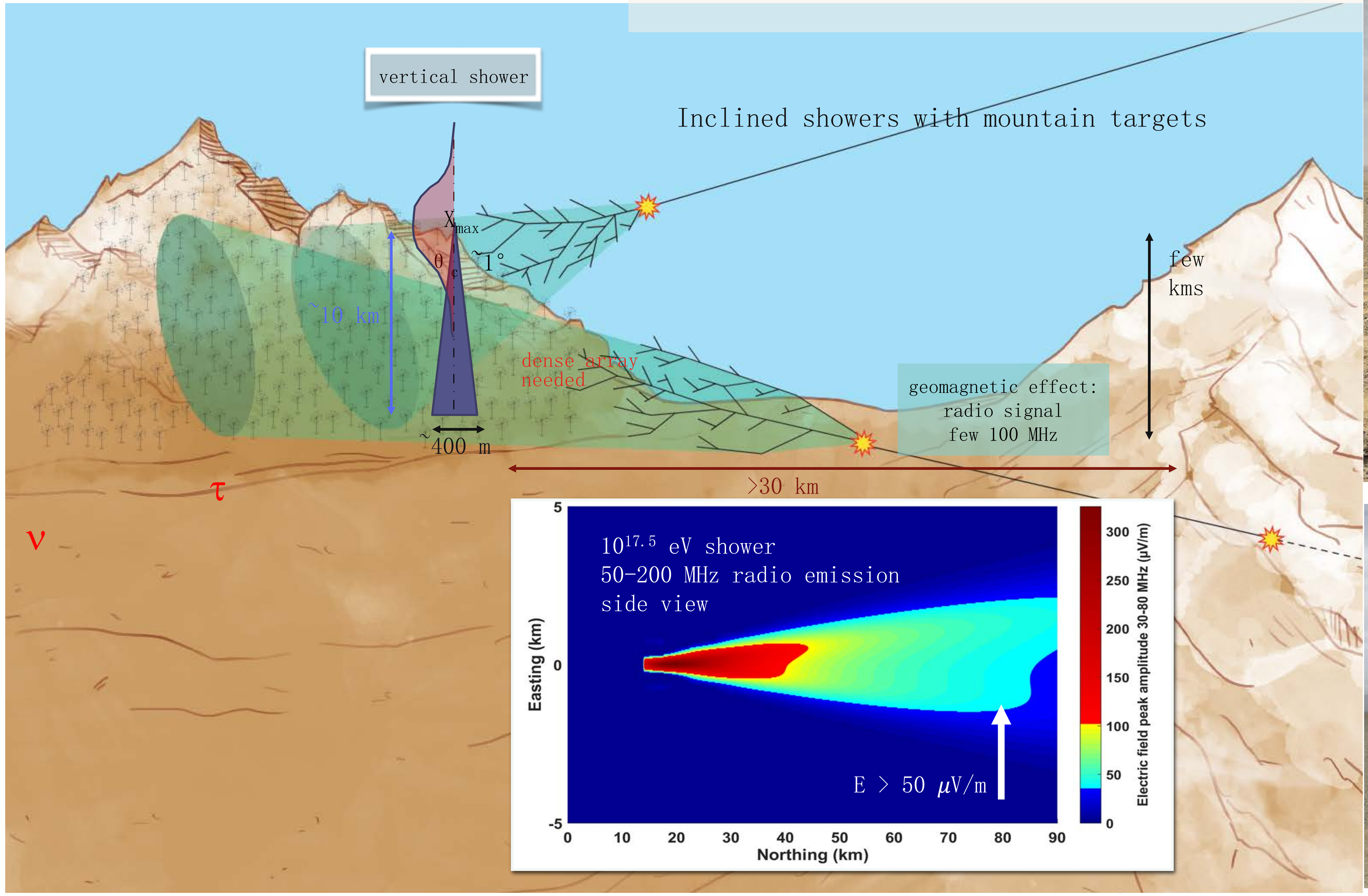
Estimate of Trigger level sensitivity after 10 years (including 70% lifetime)

GRAND at the highest energy neutrinos (R.Liu)

The GRAND Concept

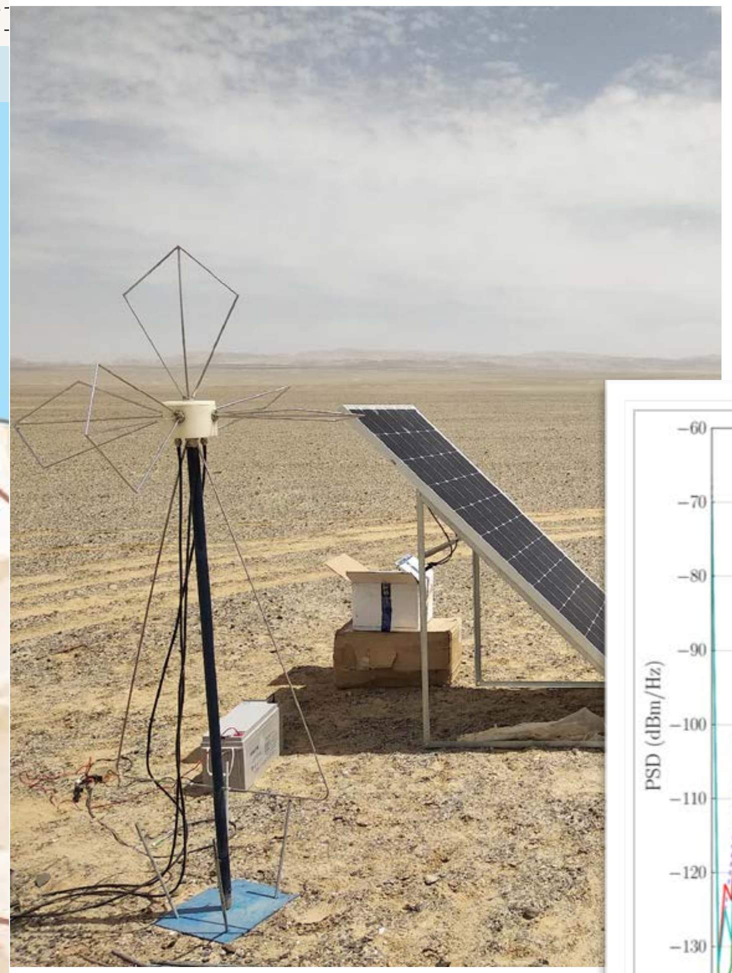
radio detection: a mature and autonomous technique
AERA, LOFAR, CODALEMA/EXTASIS, Tunka-Rex, TREND

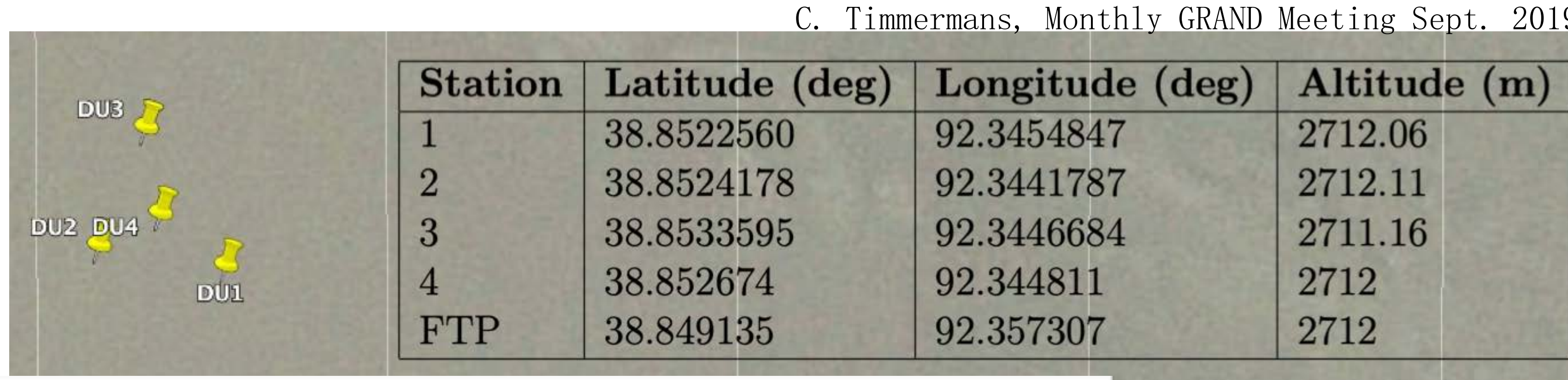
radio antennas cheap and robust: ideal for giant ar



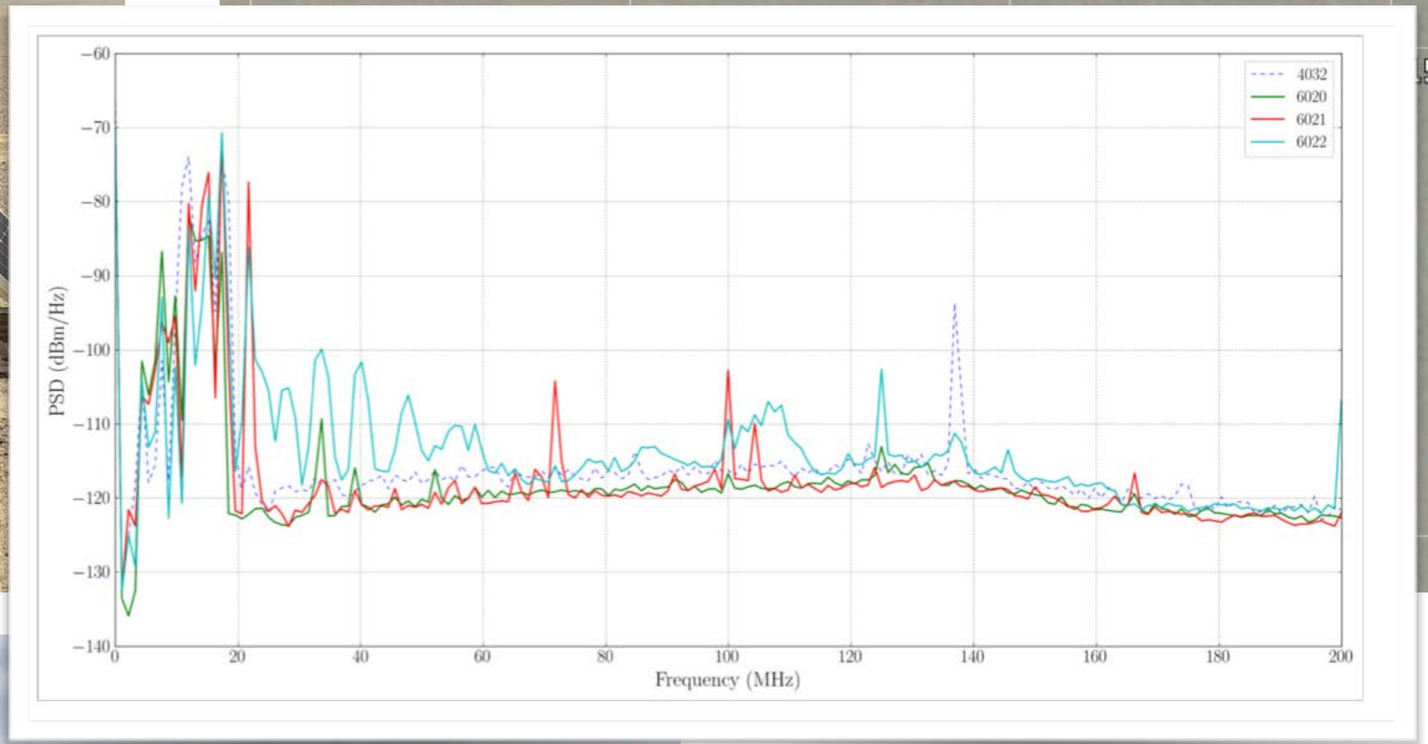
GRANDProto300 long-term monitoring: started this summer!

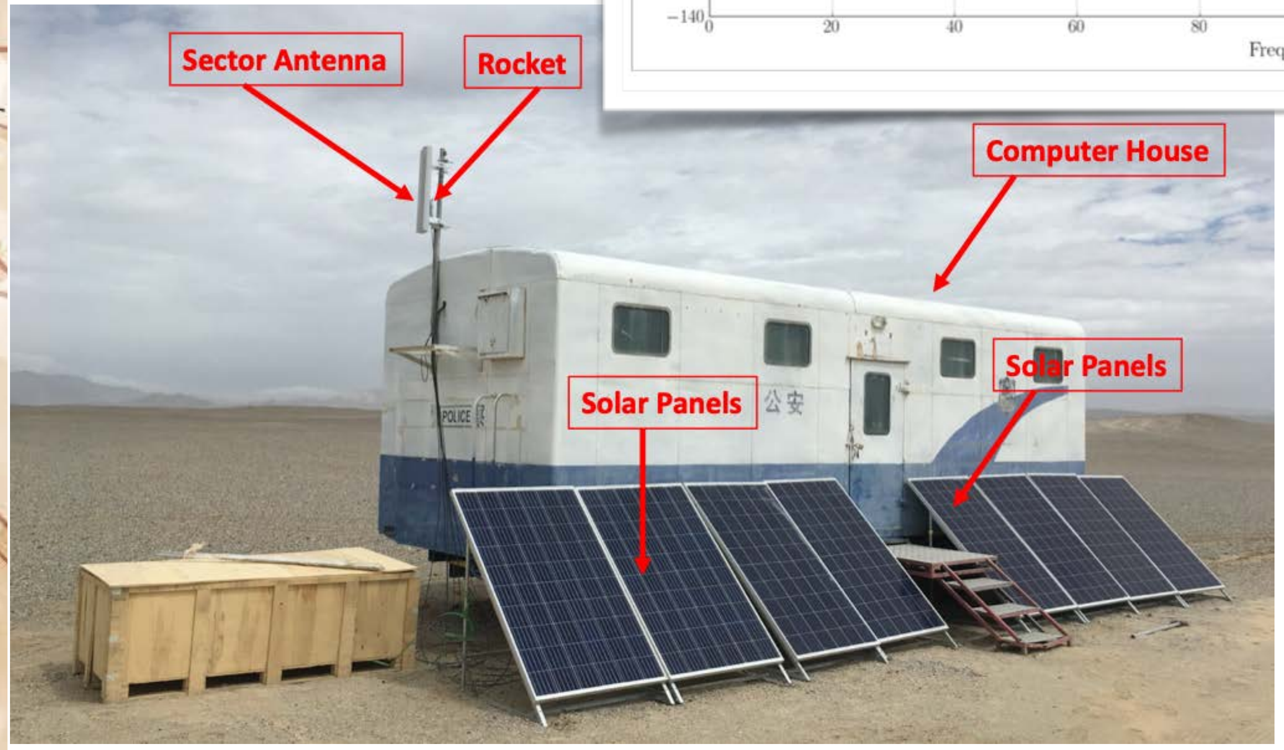
C. Timmermans, Monthly GRAND Meeting Sept. 2019





Station	Latitude (deg)	Longitude (deg)	Altitude (m)
1	38.8522560	92.3454847	2712.06
2	38.8524178	92.3441787	2712.11
3	38.8533595	92.3446684	2711.16
4	38.852674	92.344811	2712
FTP	38.849135	92.357307	2712

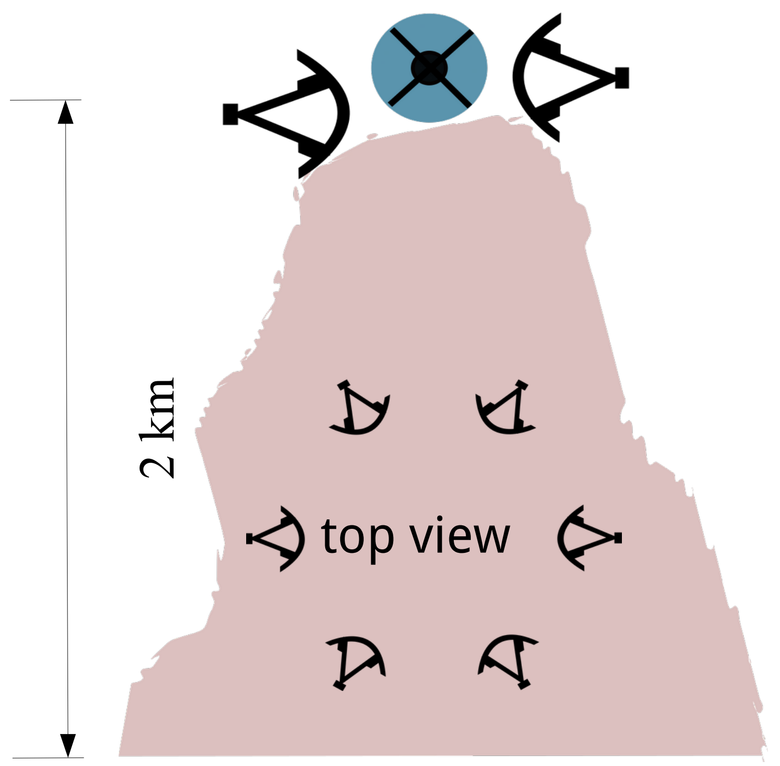




- overall excellent electromagnetic conditions
- noise rate dominated by self-induced noise
- in 24 hours: only 15 events triggered by all 3 stations
- new tests within next months with low-noise equipment

Trinity (N.Otte)

Trinity: An Optimized PeV Threshold UHE-Neutrino Detector

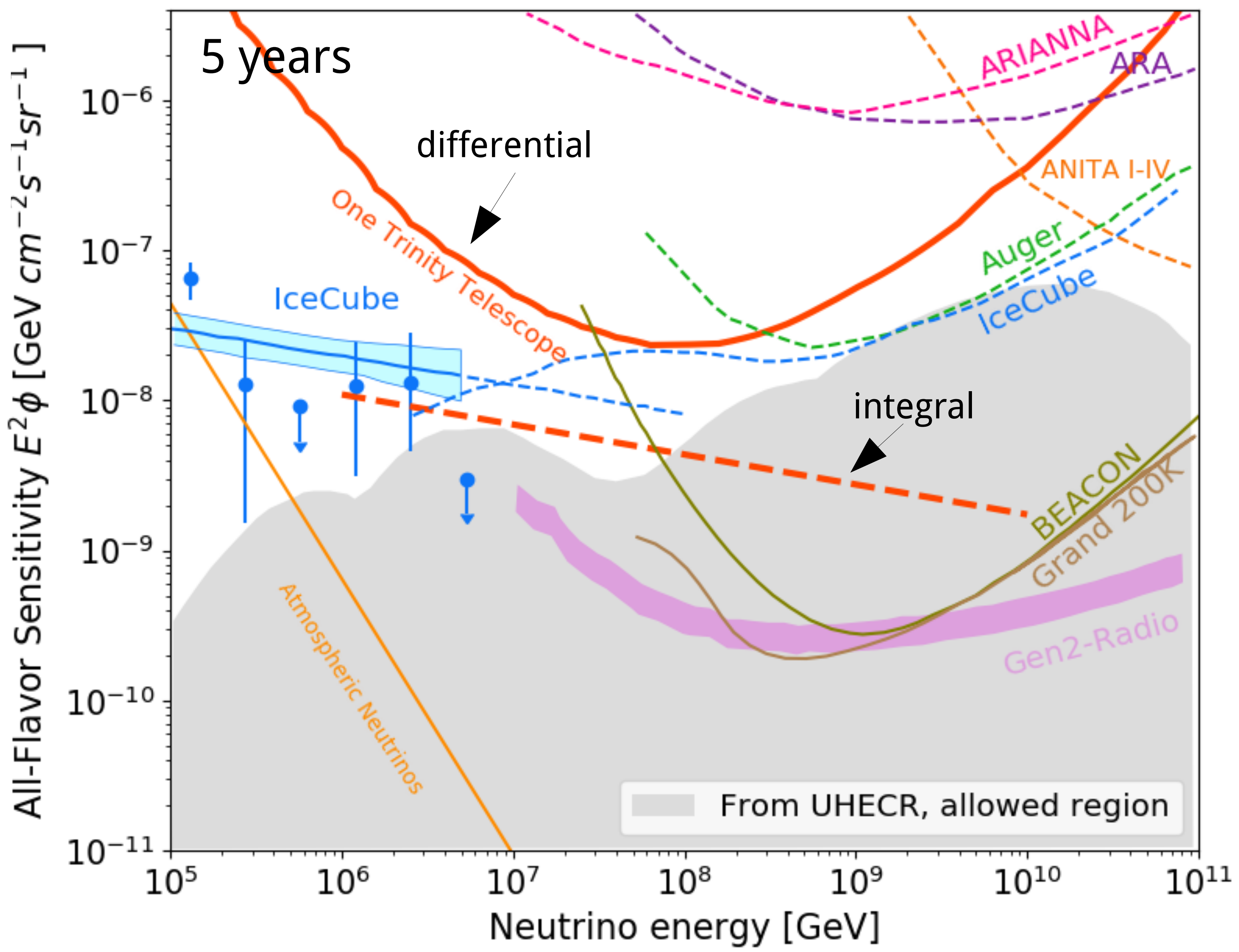


- 2 km above ground
- 360° azimuthal acceptance (six 60° FoV telescopes)
- Three sites (18 telescopes)
- 10 m^2 effective mirror area
- 3° FoV above horizon, 2° FoV below horizon
- 0.3° angular resolution
- Silicon photomultipliers instead of bialkali photomultipliers
- $15 M (telescopes + infrastructure)

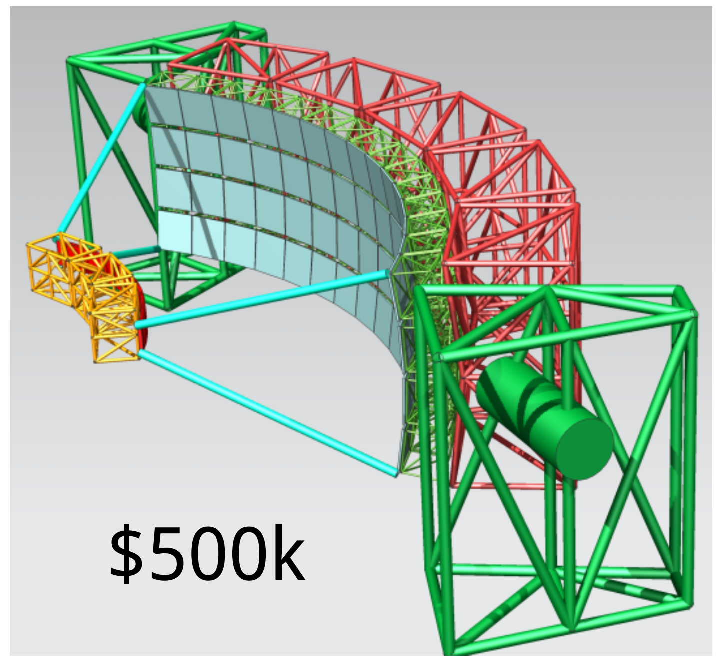
Suitable sites for Trinity with existing infrastructure:
Frisco Peak, UT; Hawaii; Canary Islands La Palma and Tenerife

Nepomuk Otte

Trinity: Single-Telescope Sensitivity



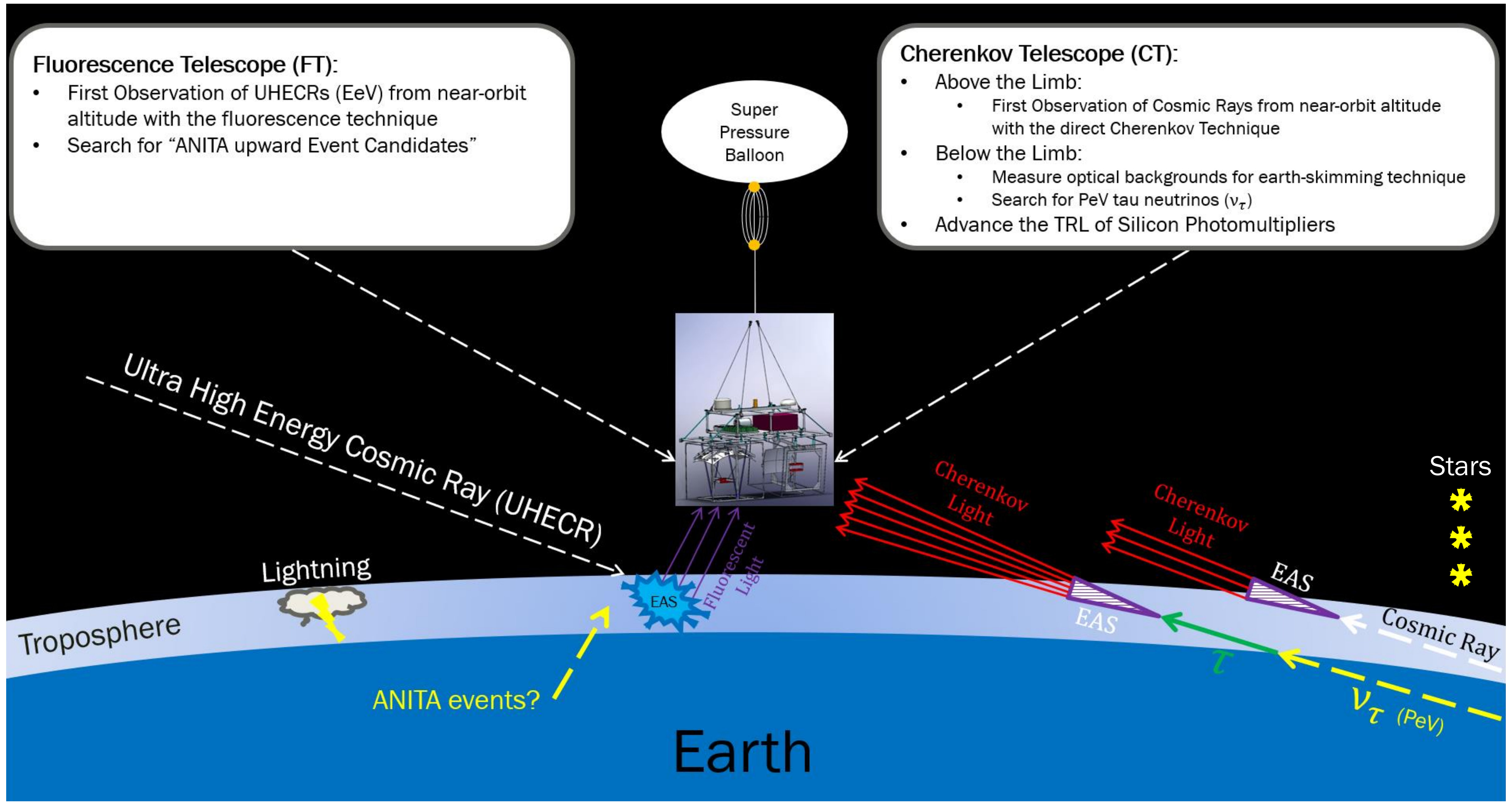
Nepomuk Otte



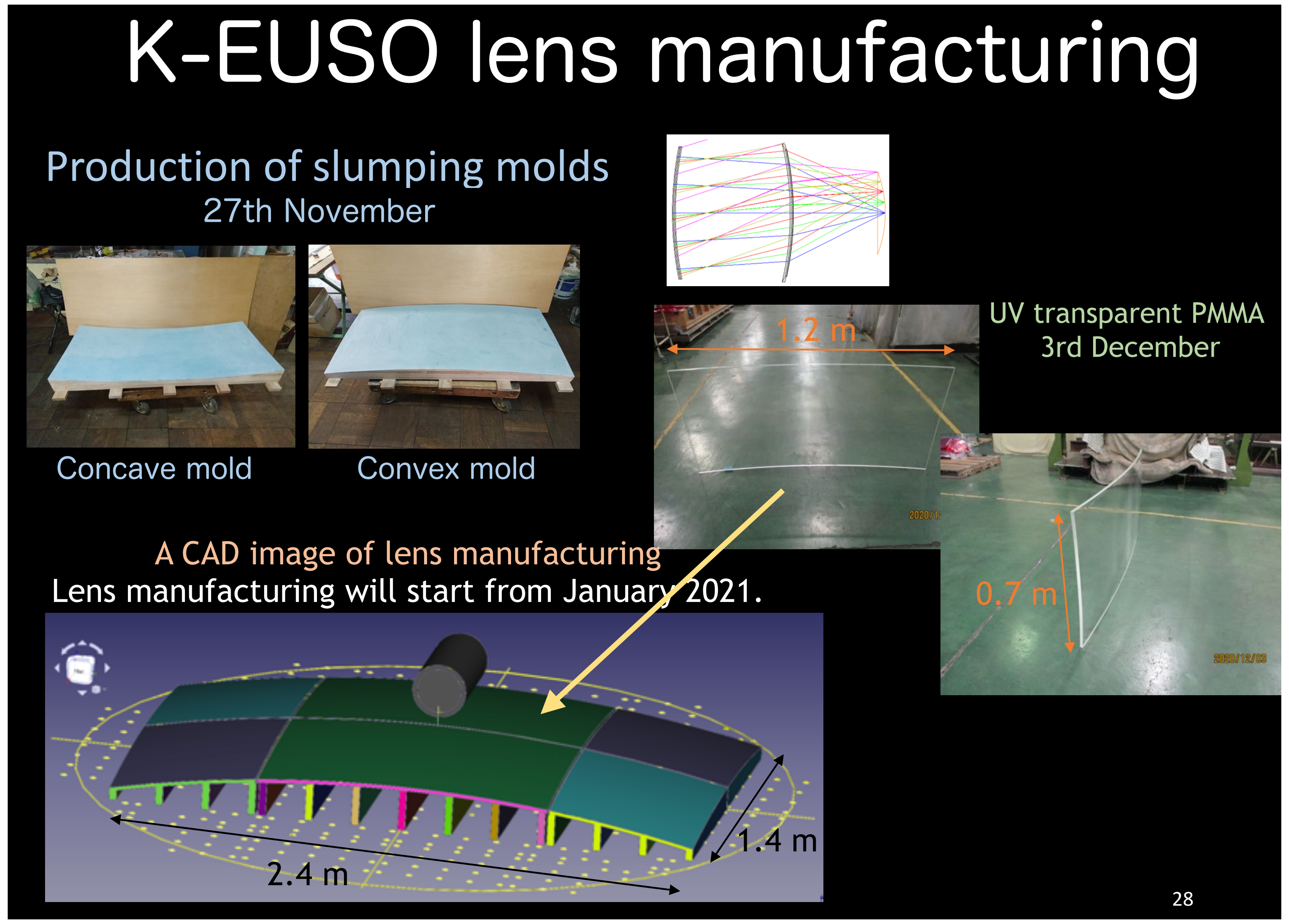
A single telescope will detect astrophysical neutrinos provided the spectrum does not cut off.

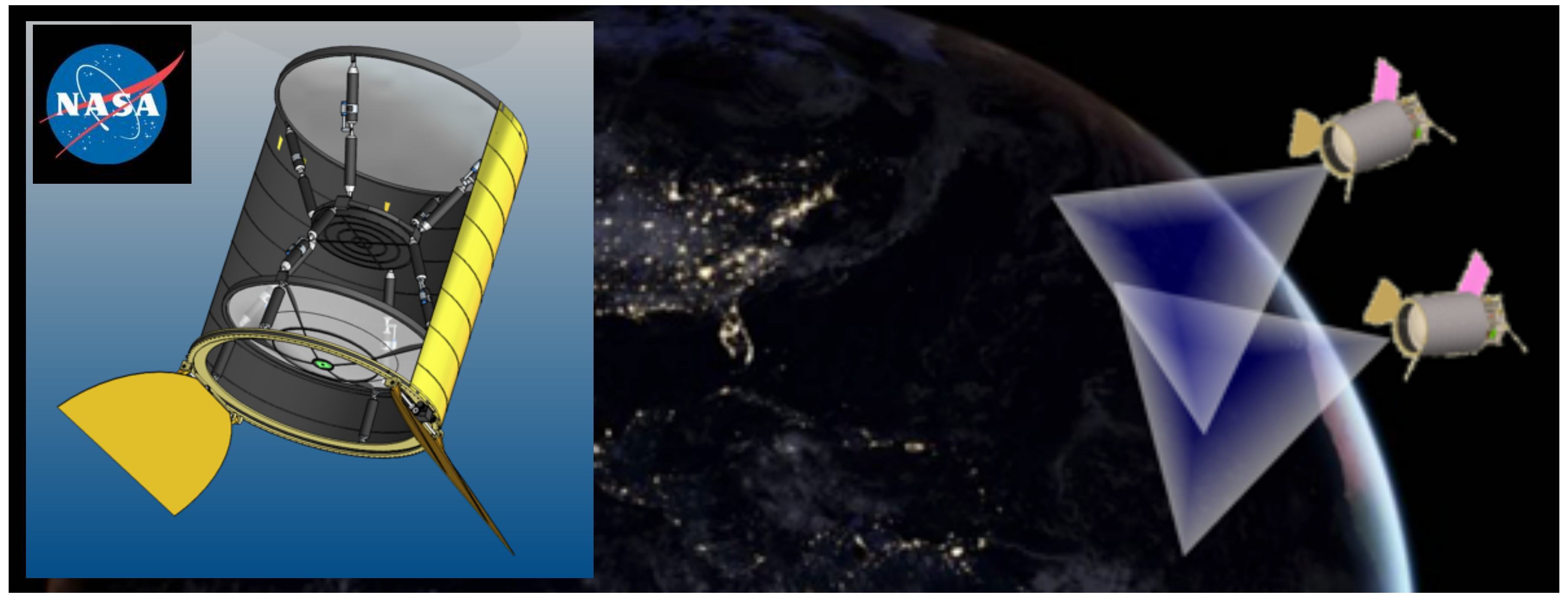
Future observatories

EUSO-SPB2 (M. Bagheri)



K-EUSO and POEMMA (Y.Takizawa)



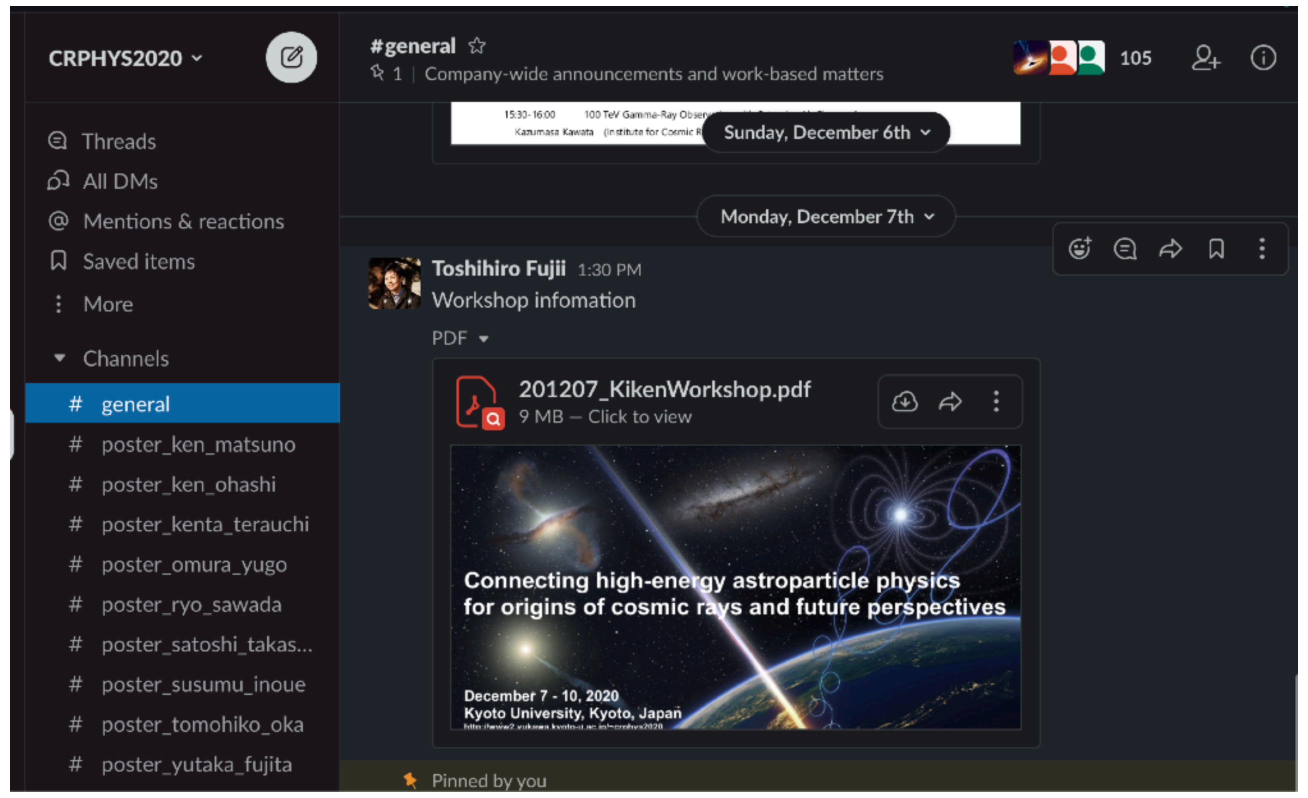


POEMMA team is working on a conceptual design for selection of the 2020 Astronomy and Astrophysics Decadal Survey .

Nice posters!

Satoshi Takashima	GRAMS project: A MeV gamma-ray large area telescope using liquid argon and its concept study
Susumu Inoue	The Blazar Hadronic Code Comparison Project
Ken Matsuno	Particle acceleration by ion-acoustic solitons in plasma in a magnetic field
Ken Ohashi	Effects of diffractive collisions on predictions of the number of muons in the air shower
Tomohiko Oka	The time-evolution measurement of a diffusive shock acceleration using supernova remnants and local molecular clouds
Yutaka Fujita	Intrusion of Cosmic-Rays into Molecular Clouds Studied by Ionization, the Neutral Iron Line, and Gamma-Rays
Yugo Omura	NICHE detector and analysis results
Ryo Sawada	A Consistent Modeling of Neutrino-driven Wind with Accretion Flow onto a Protoneutron Star and its Implications for 56Ni Production
Kenta Terauchi	The Fluorescence detector Array of Single-pixel Telescopes: The next-generation cosmic ray observatory

Productive discussions in Slack channels...



What's your targeted physics in next decades?

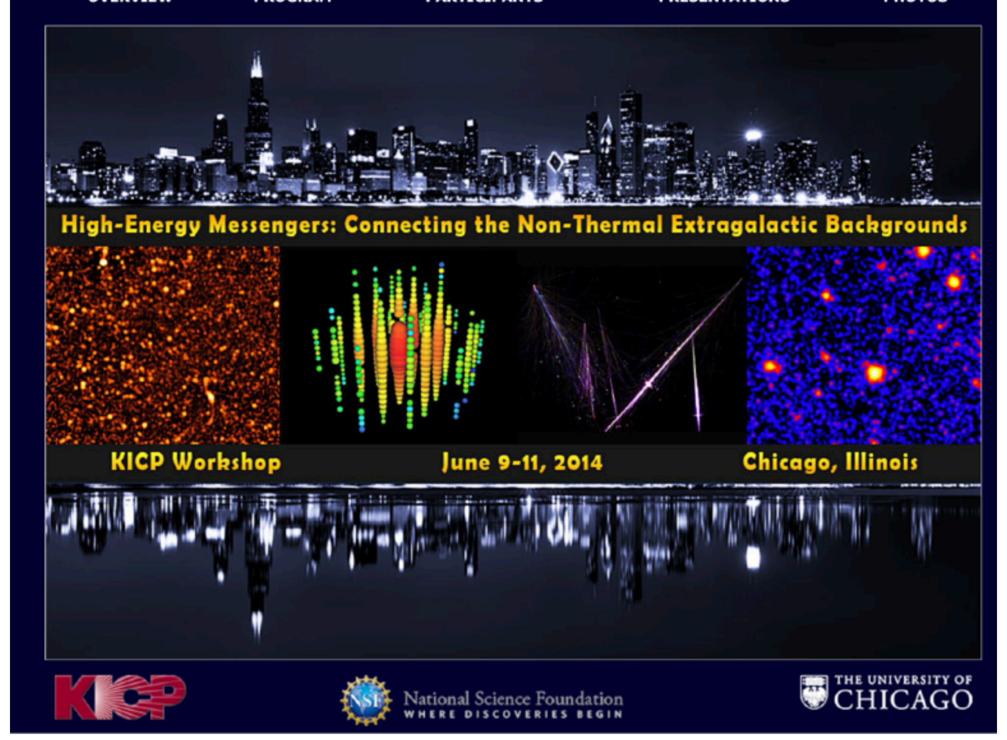
- Galactic origin cosmic rays
- Transition of Galactic/extra-Galactic
- Identifying UHECR sources
- Heavy Dark Matter search
- Physics Beyond Standard Model
- Reduce atmospheric neutrino flux uncertainty
- Understand current observables of UHECR
- Lunar exploration by neutrons
- Atmospheric electricity physics
- HL-GRB, LL-GRB, TDE
- More specific acceleration theory
- Ion acceleration in neutrino star magnetospheres
- Prove our local magnetic environment
- Origin of SMBH coevolution
- Cosmic history, Cosmic Dawn (z~20)
- Small scale anisotropy of UHECRs
- Association with UHE neutrinos GW, FRB
- More binary mergers
- HE emission from SMBH
- High energy messengers
- Cosmic Ray Grand Unified Theory

What we need to accomplish is...

- **Multi-wavelength and multi-particle observations**
- **Next generation experiments** with more sensitive and precision measurements
- **Fund, Money, Grant!!**
- **Next-generation detectors**
- "New window" at MeV
- Understanding interaction models
- Connection to GW physics
- Detailed simulations
- **Next paradigm shift**, such as GW

- **Collaborating among different experiments and observatories**
- Multi-messenger network
- Data analysis infrastructures
- UHE neutrinos
- TeV-PeV cosmic rays, 100 TeV gamma rays
- Precise measurement of SNR
- Non-GW signatures from BBH
- BH mergers contribute overall radiation in the universe?
- Small-size experiments for career of young scientist

A series of workshops…
(just my personally)

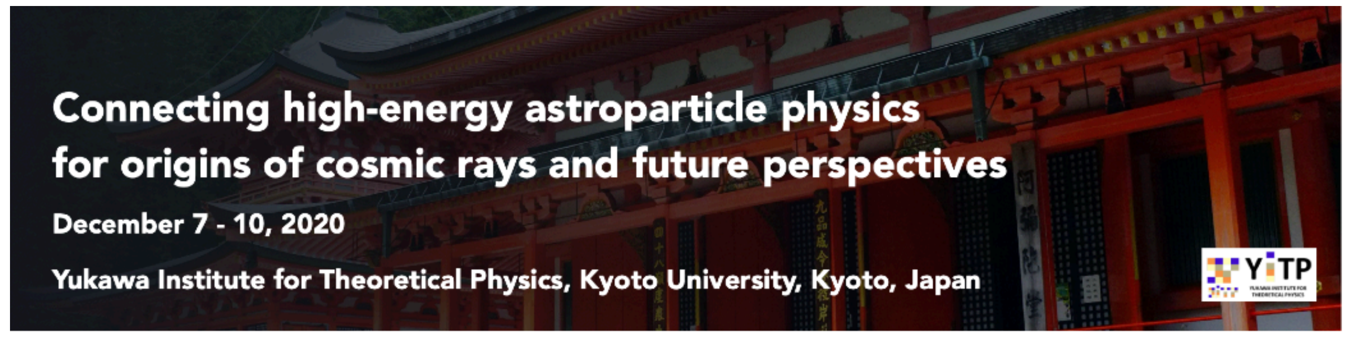


https://kicp-workshops.uchicago.edu/hem2014/

2014

2016

https://kicp-workshops.uchicago.edu/uheap2016/



2020

2023?

http://www2.yukawa.kyoto-u.ac.jp/~crphys2020/

Hope productive physics results in next decades...

Stay well and see you soon!

Backup

Hope a lot of new physics results in next decades.

Stay well and see you soon!

Join Slack

- Login Slack from the invitation link
  - **LINK:** https://join.slack.com/t/crphys2020/shared_invite/zt-jk0gk9yt-38CSaPdUo40t4UnLFcZFhA
  - Unlimited discussion during workshop
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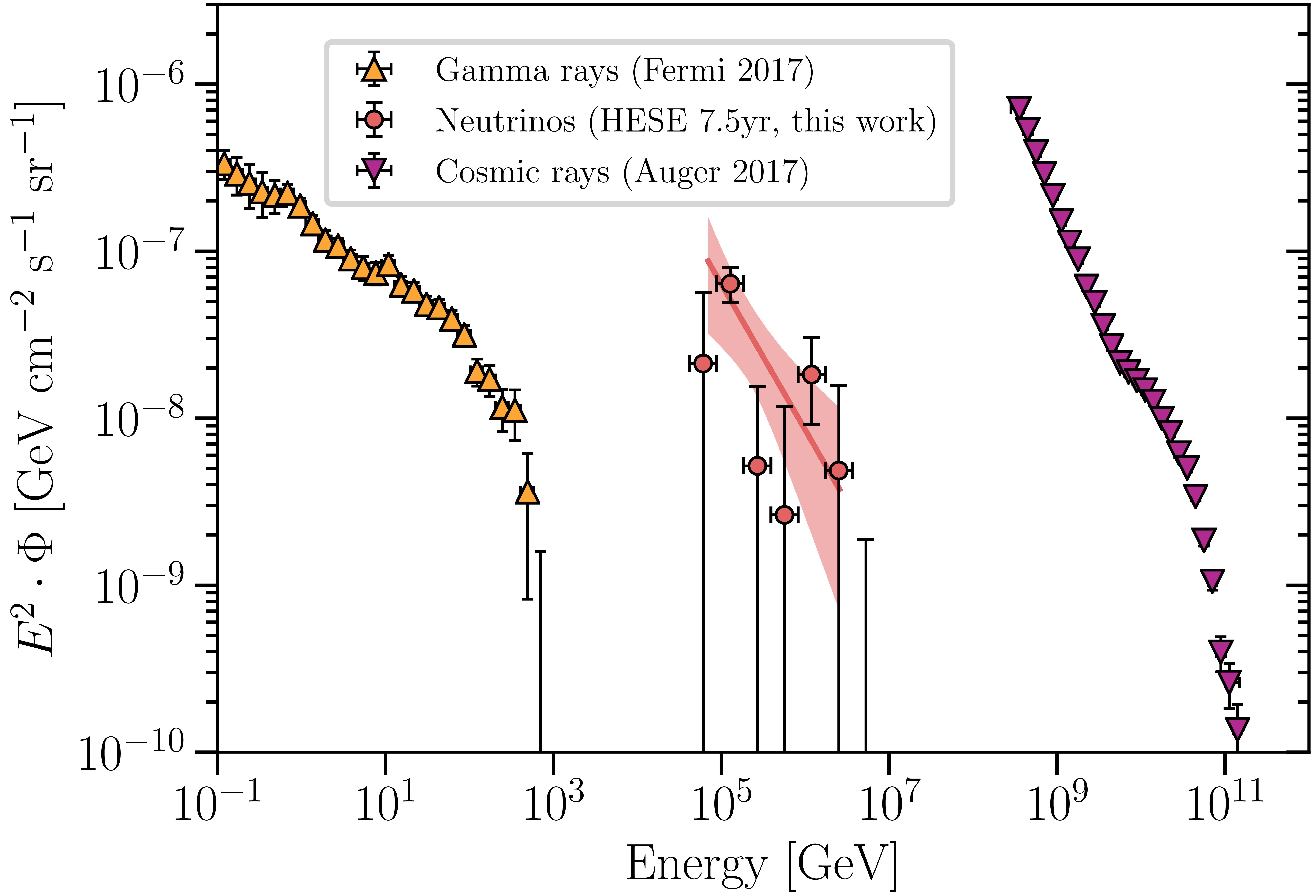
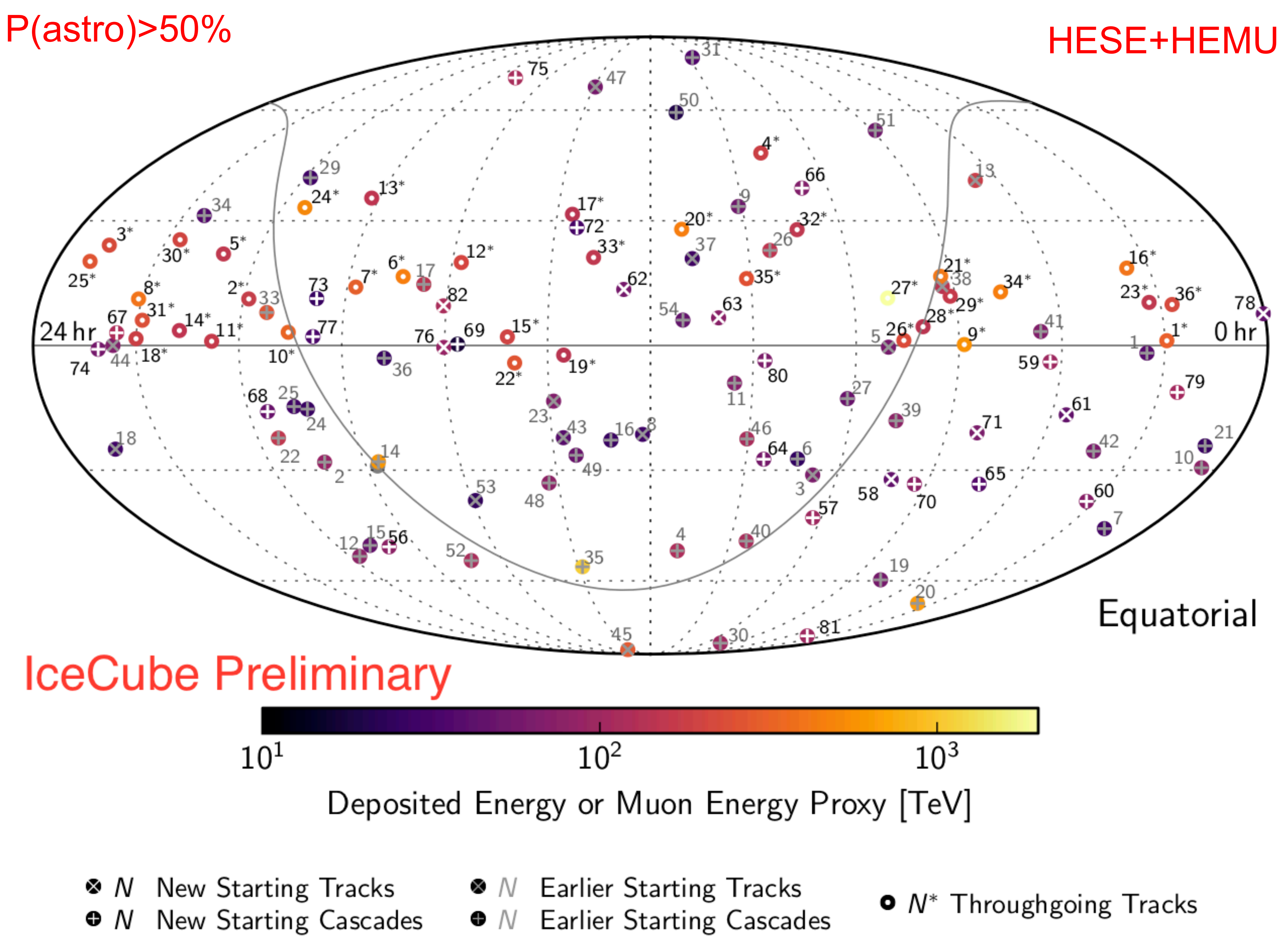
    - Alternatively, just send slide by an email to crphys2020@yukawa.kyoto-u.ac.jp
      - The slides will be shared among participants

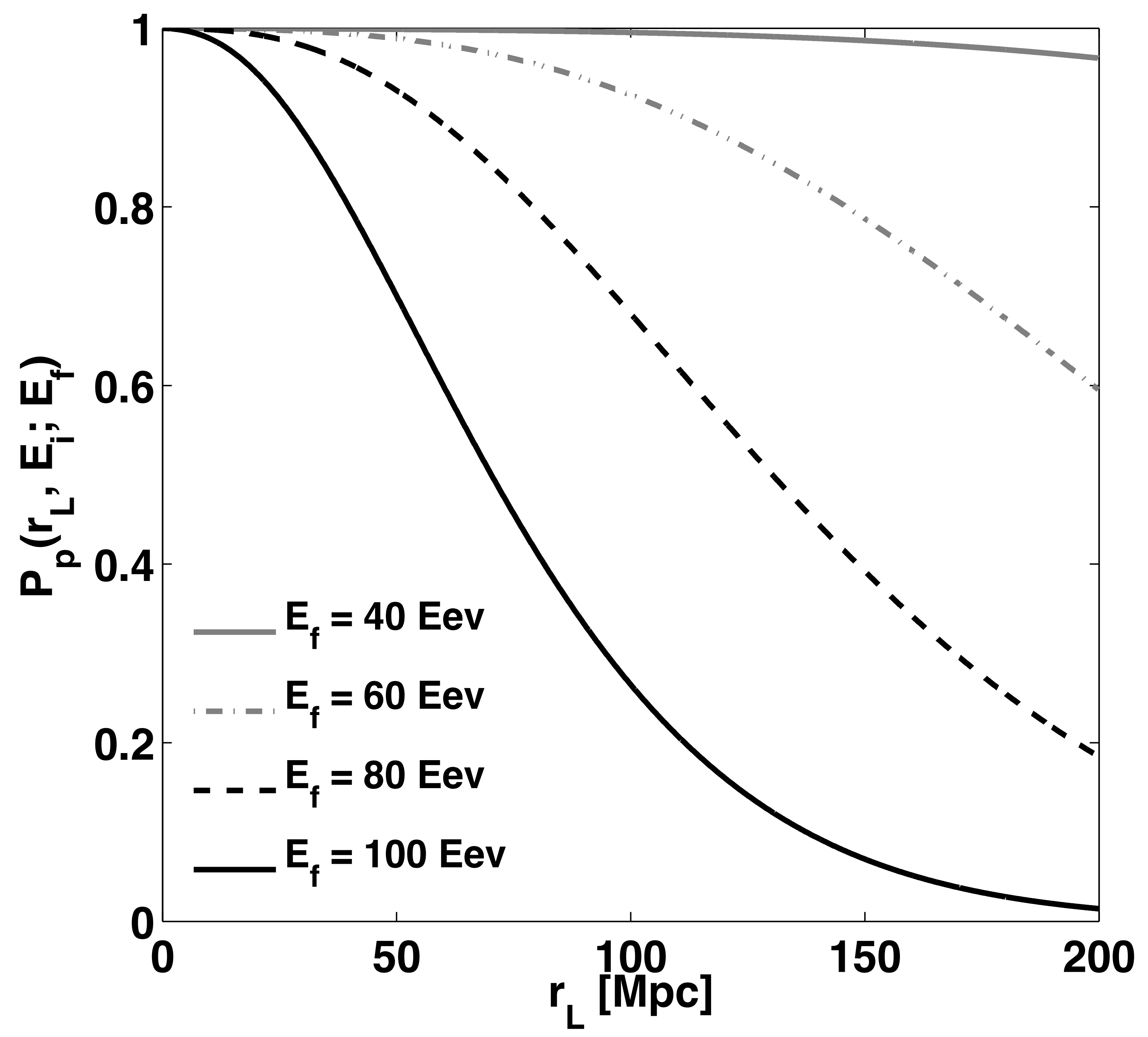
Cosmic Ray Grand Unified Theory (CR-GUT)



IceCube Collaboration, arXiv:2011.03545

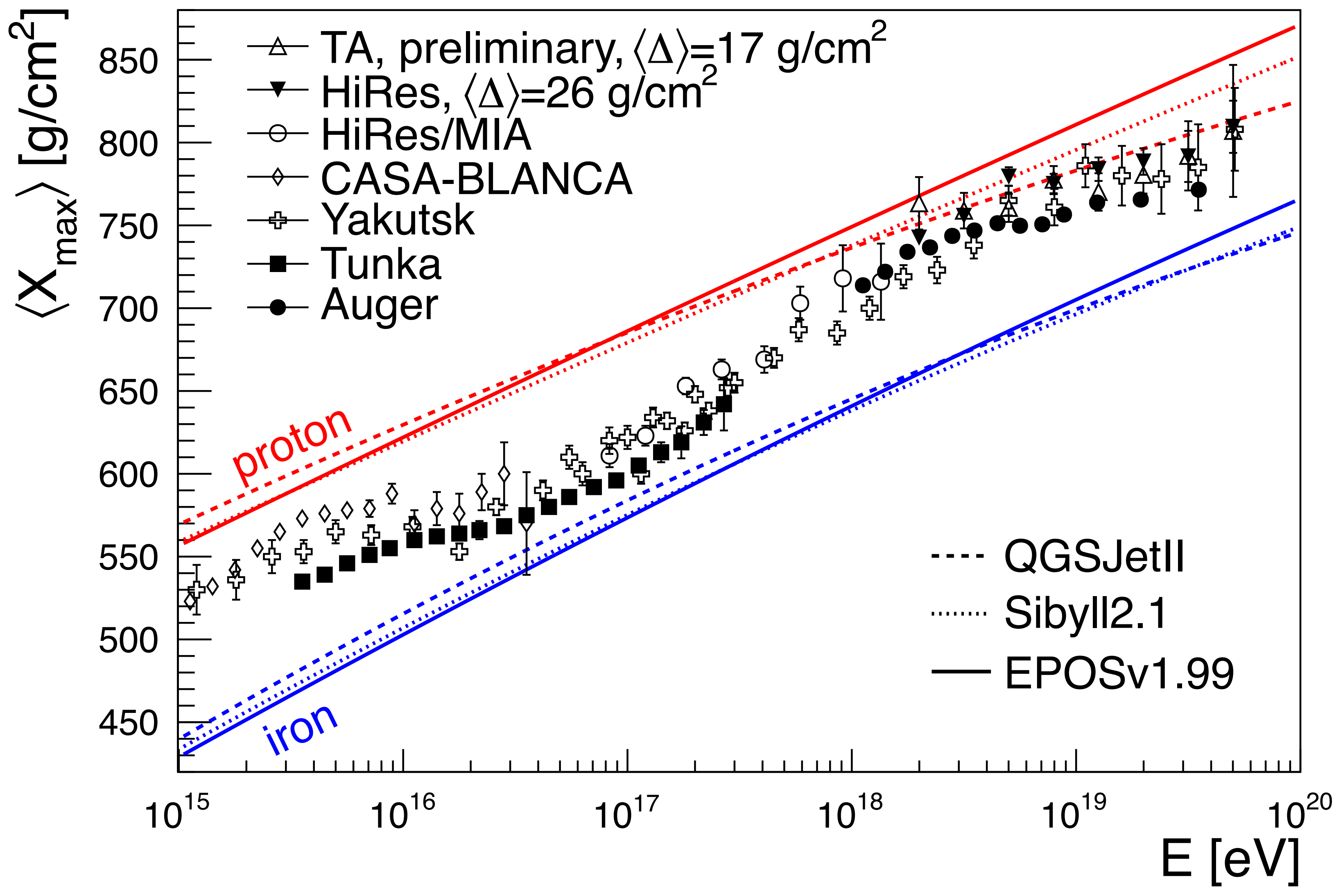
HE Neutrinos

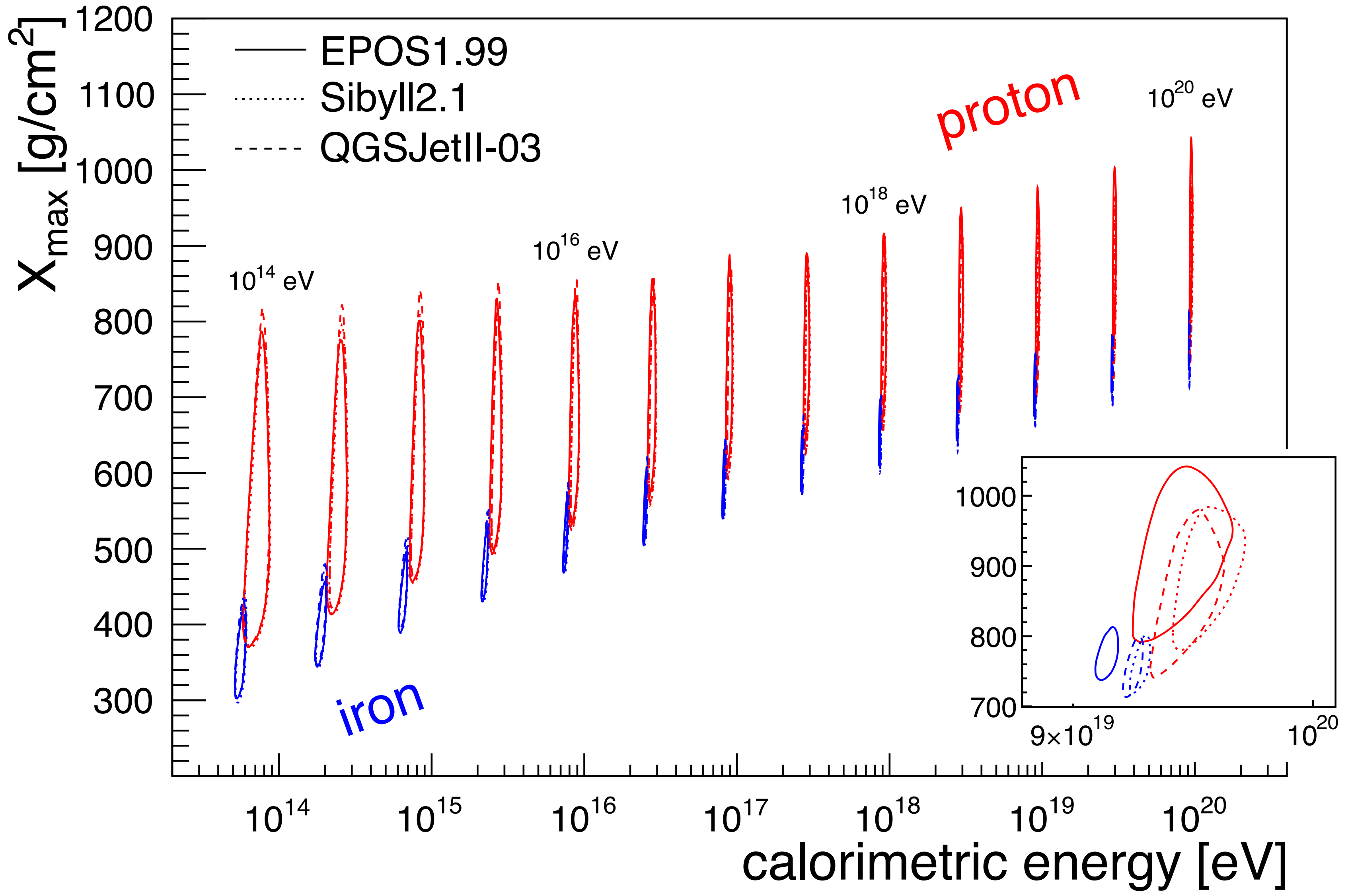


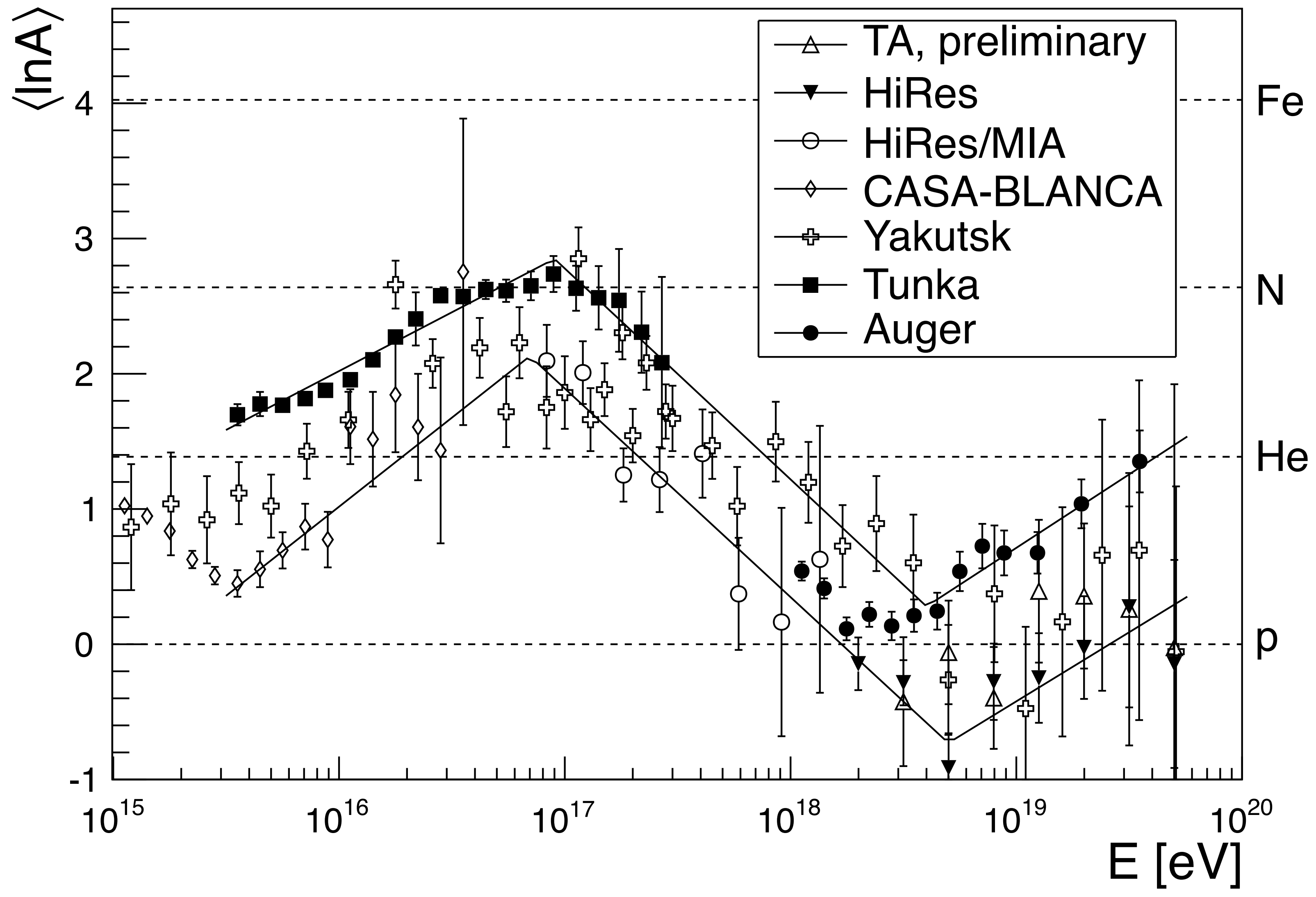


JCAP05(2013)015

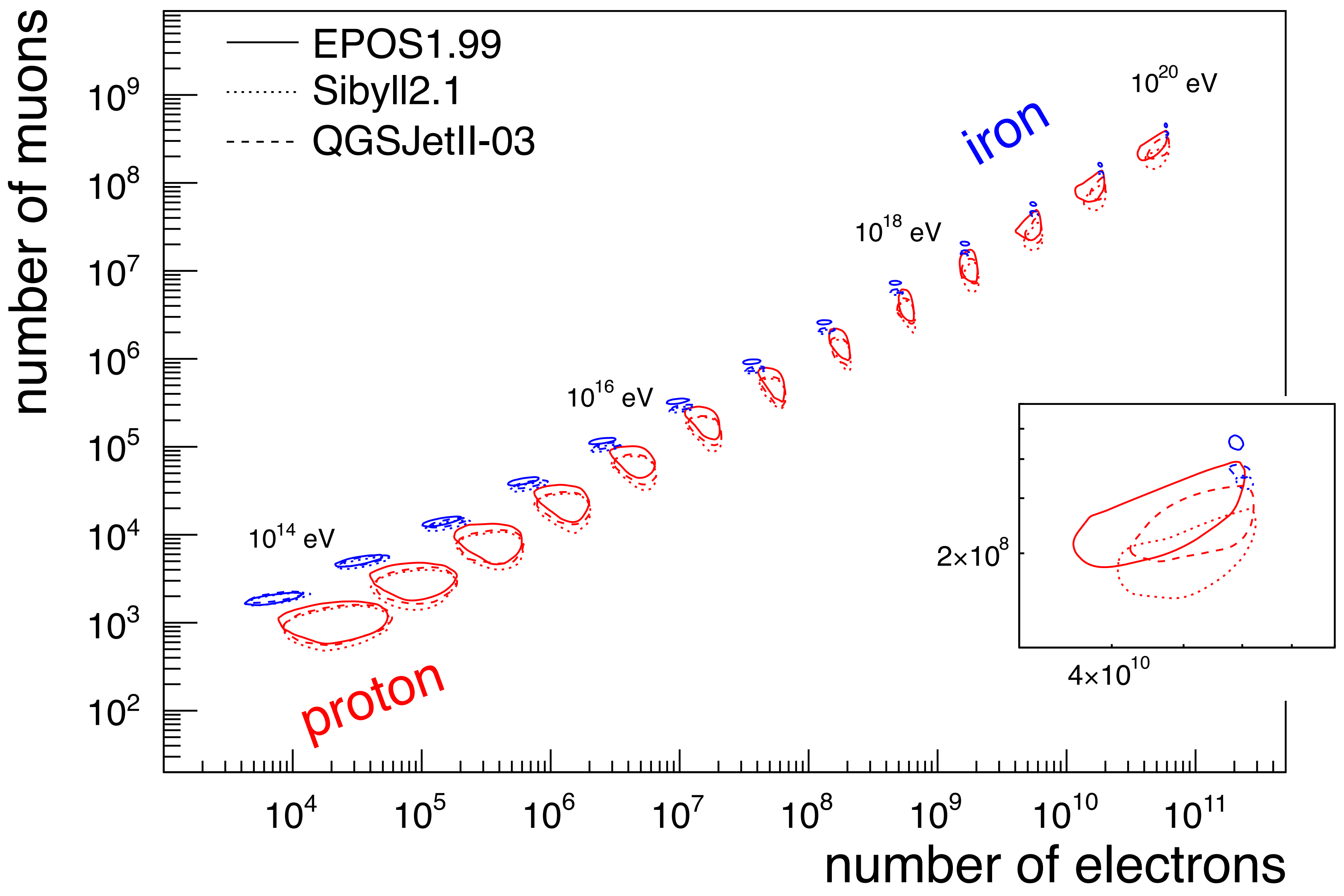
Chemical composition





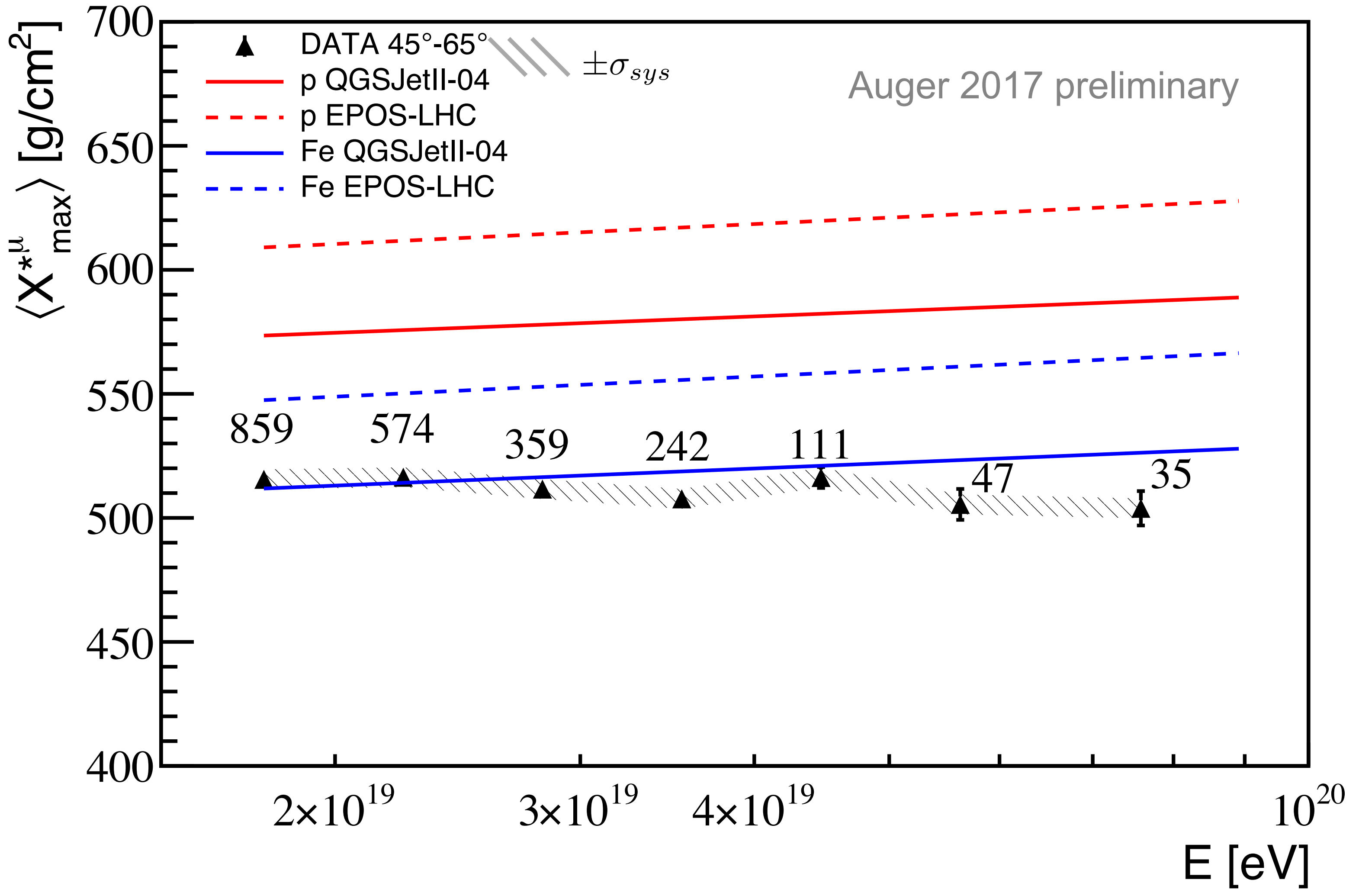


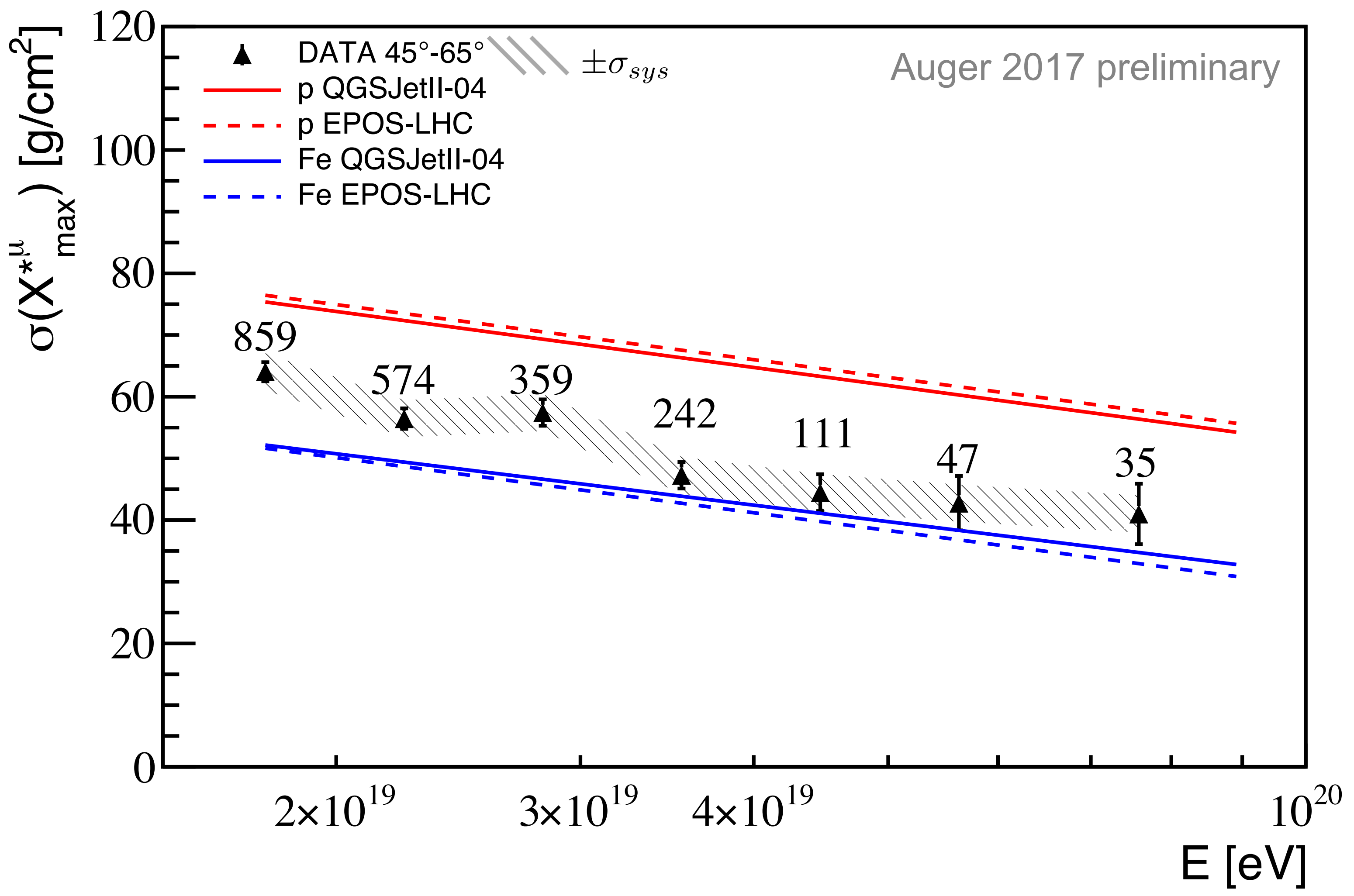
(a) QGSJet01

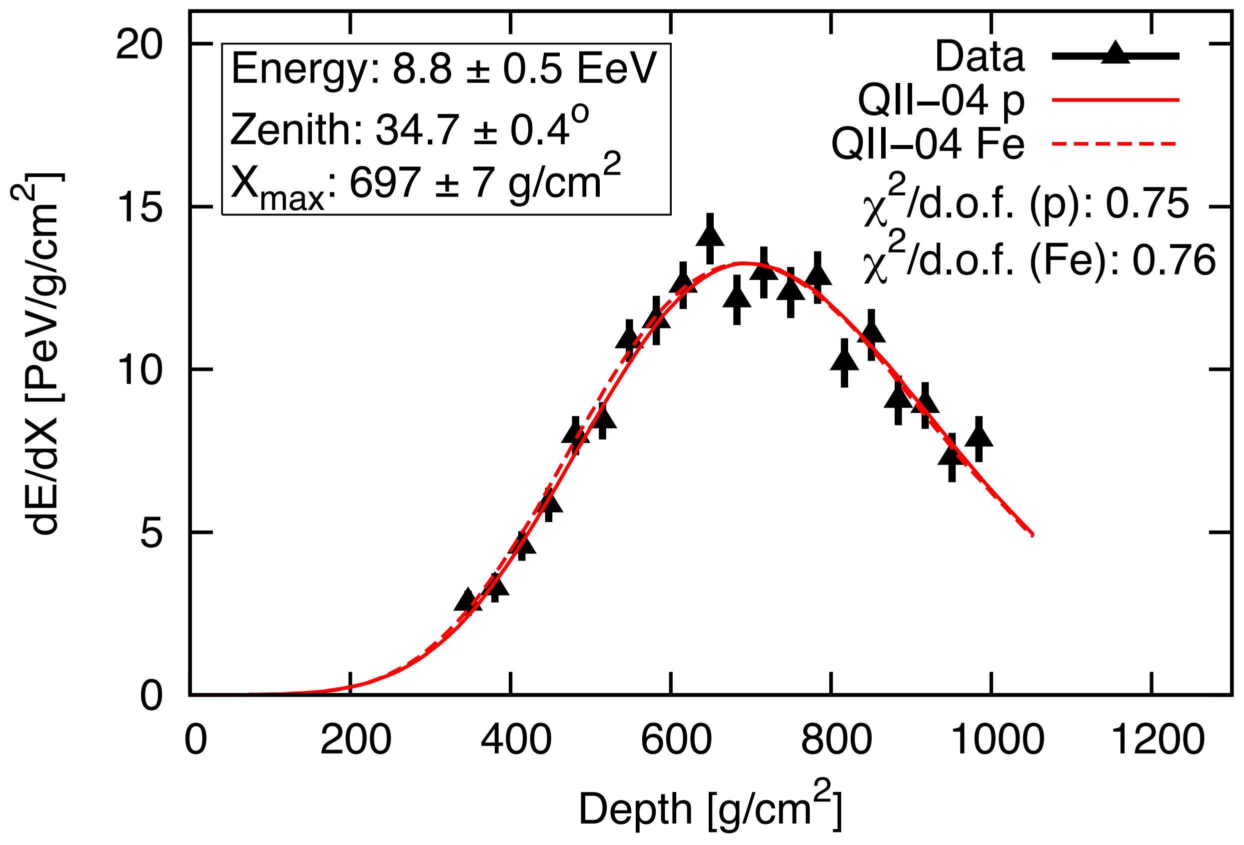


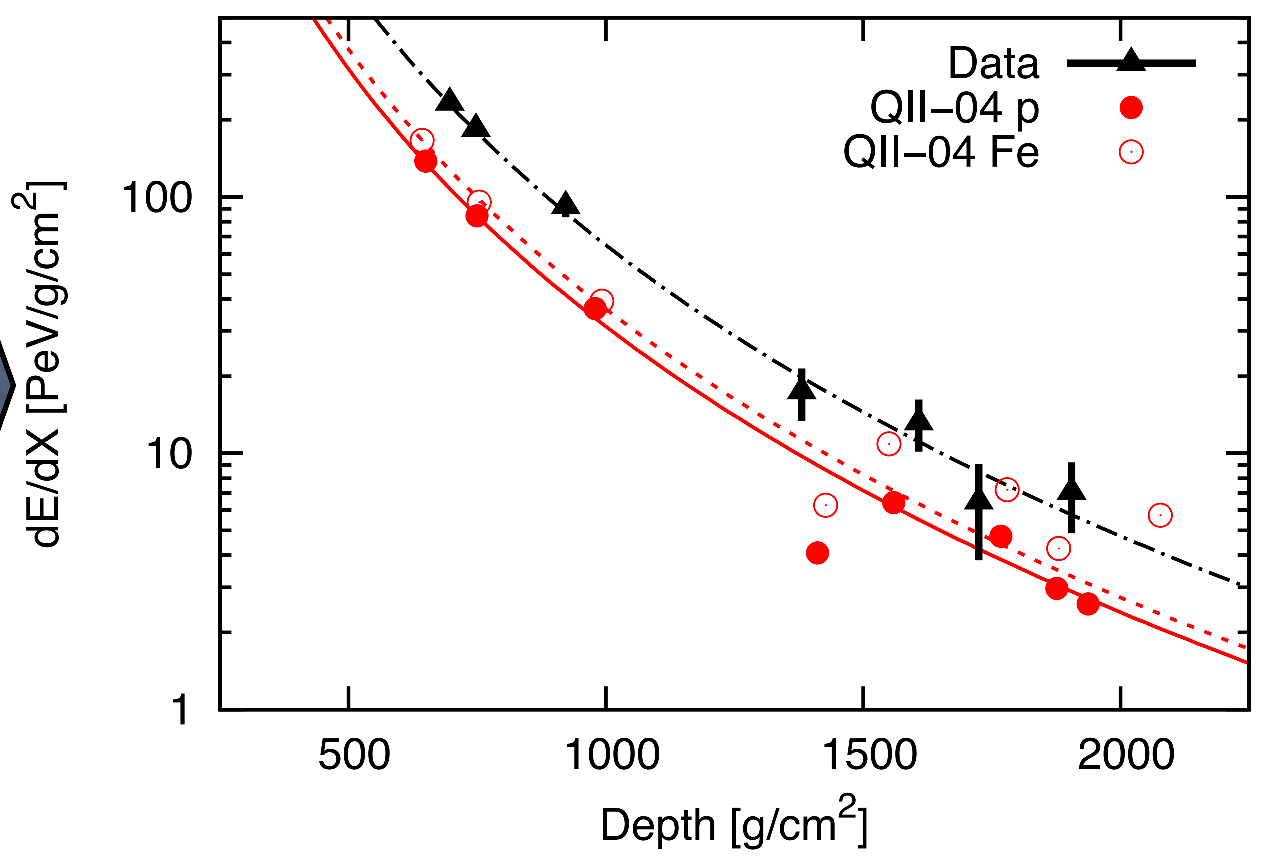
M. Unger, K. Kampert, Astropart.Phys. 35 (2012) 660-678

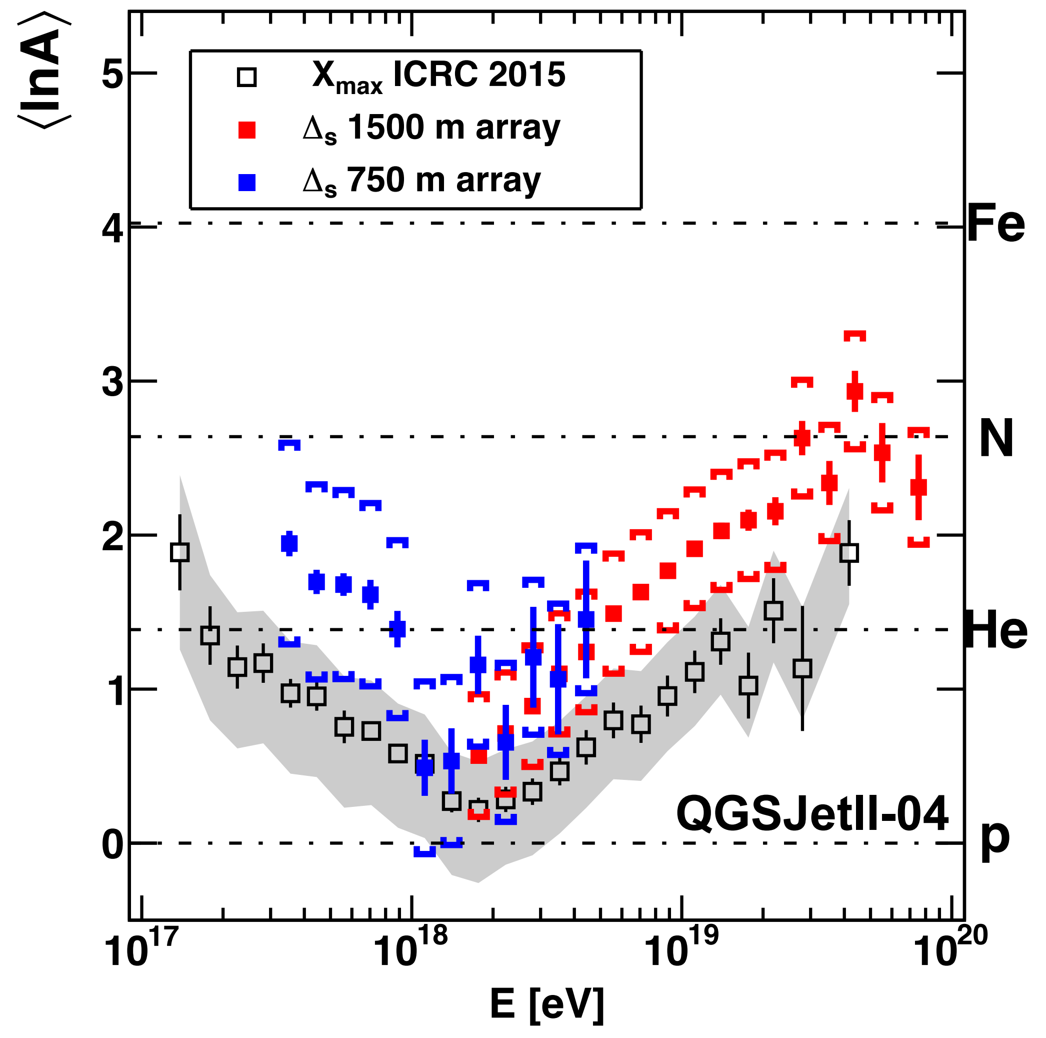
Testing hadron interaction model

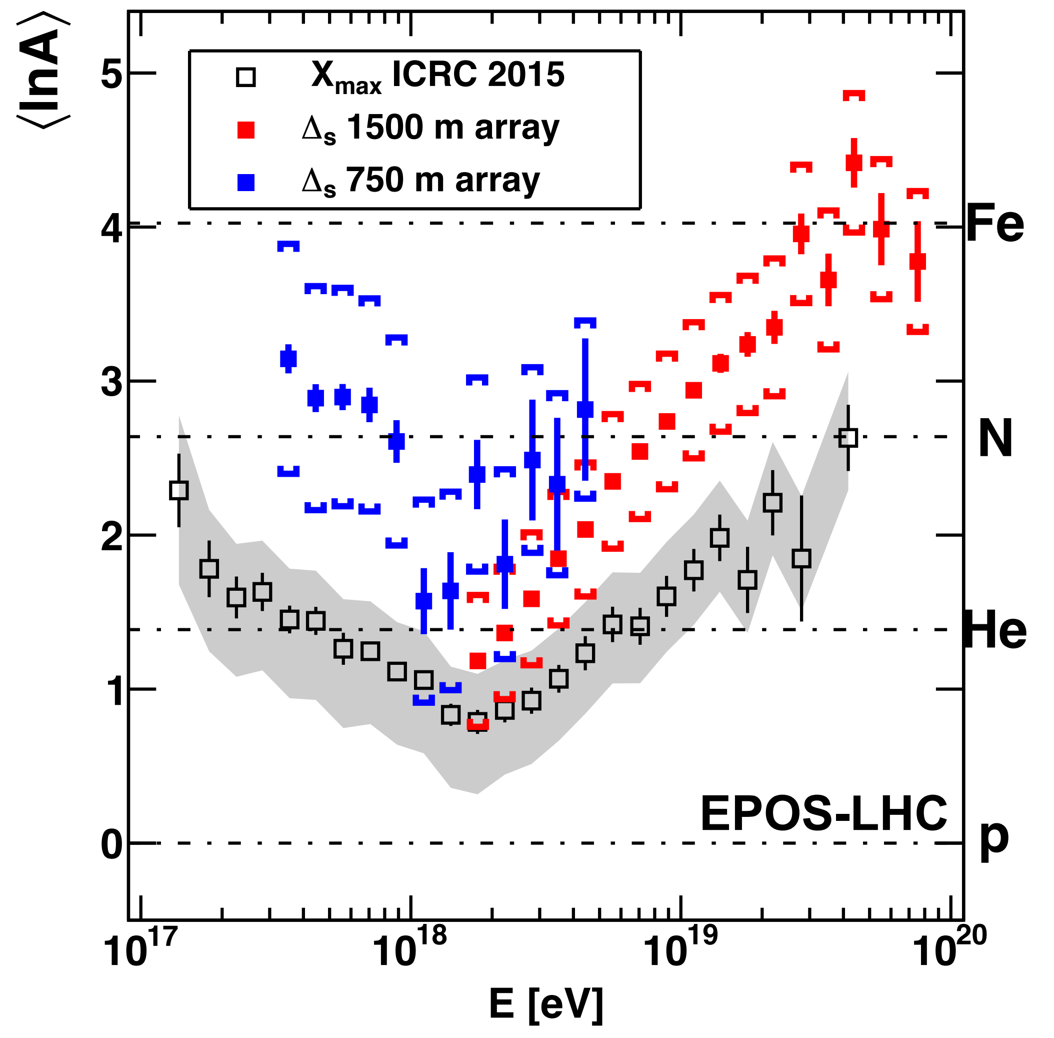












M. Mallamaci, P. Sanchez-Lucas, M. Unger, Y. Zhezher in ICRC 2017

Local source (maybe Vela) and other population?

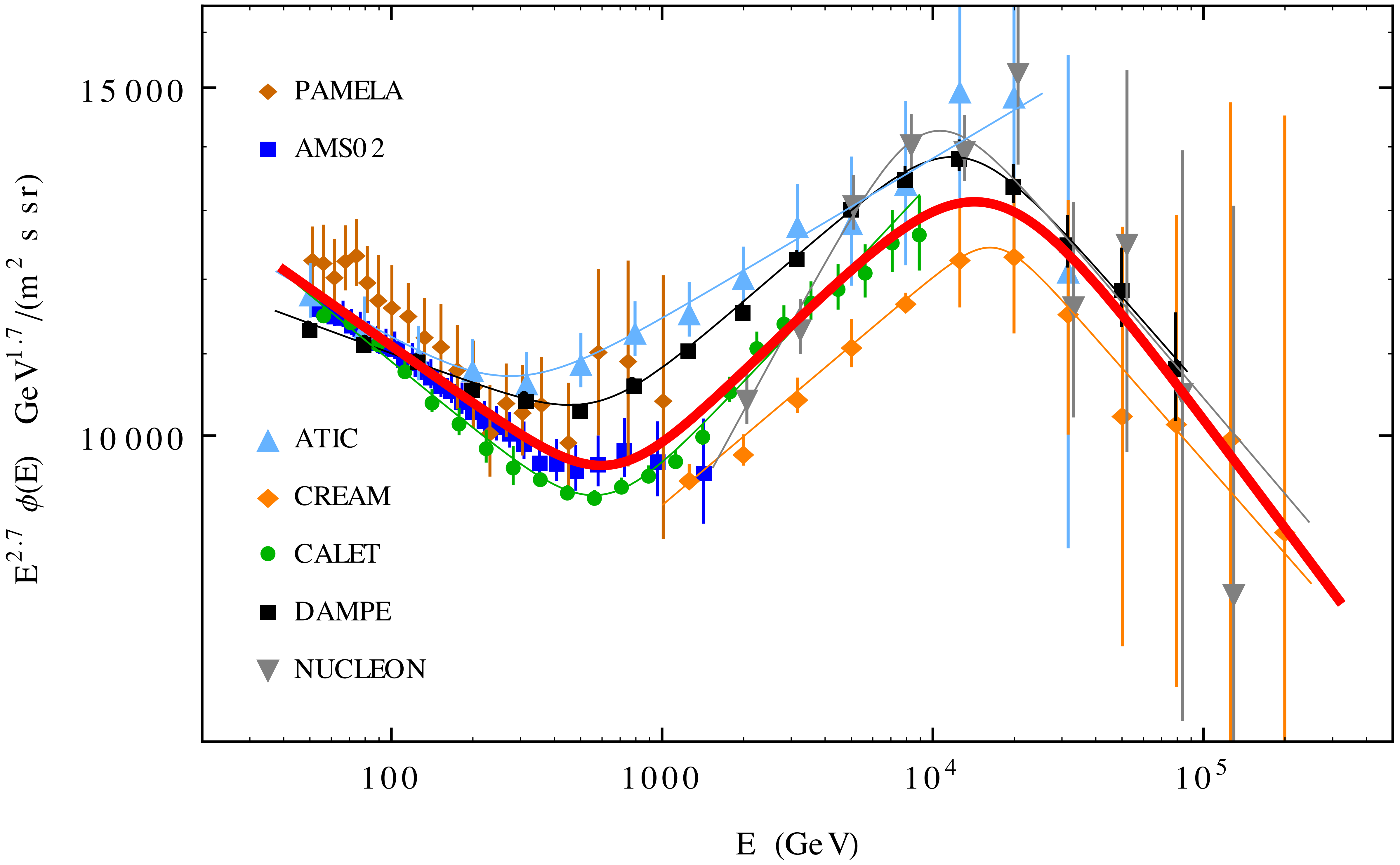


Figure 1: Direct measurements of the CR proton spectrum. The flux is shown in the form $E^{2.7}\,\phi(E)$ versus E to enhance the visibility of the spectral features. The points are the data of PAMELA [2], AMS02 [4], ATIC [5], CREAM [6], CALET [7], DAMPE [10] and NUCLEON [8]. The thick (red) solid line is a fit of the combined data of all the experiments using the two–break expression (1). The thin lines are fits of the data of individual experiments. The parameters of all fits are listed in Table 1.

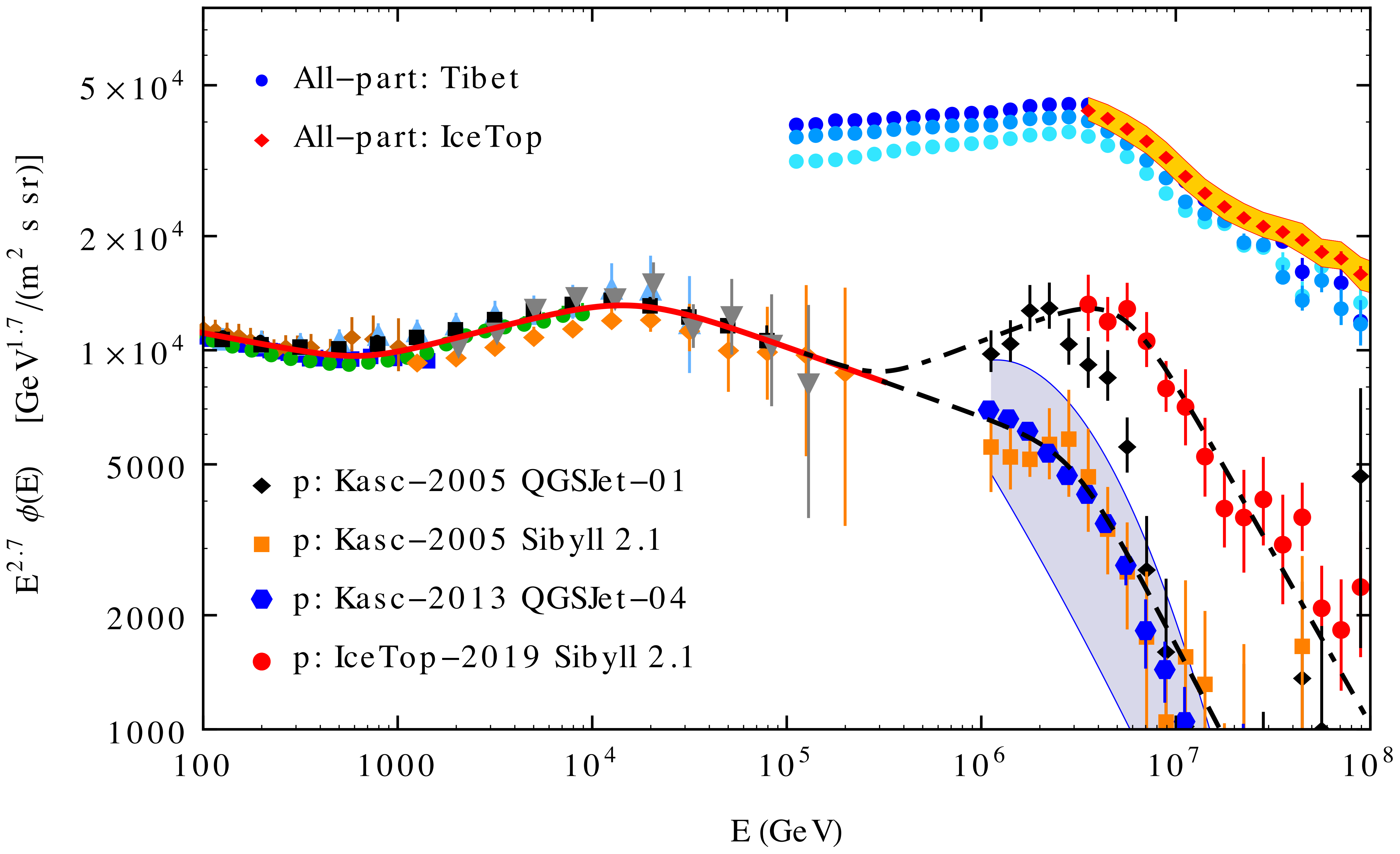


Figure 2: All–particle and proton spectra obtained by direct measurements and EAS observations. The all–particle data are by the Tibet experiment [12] (with three sets of data points obtained with different assumptions for the CR composition and shower development models), and by IceTop/IceCube [13] (with the shaded area indicating systematic uncertainties). For the proton direct measurements the symbols are identical to those in Fig. 1. The EAS proton spectra are by Kascade–2005 [15], Kascade–2013 [19] (with the shaded area indicating systematic uncertainties) and IceTop/IceCube–2019 [13]. The thick solid line is a fit to the direct measurements of the proton flux (with the parameters given in Table 1). The dashed and dot–dashed lines are extrapolations to higher energy (see main text).

Auger, IceCube, TA

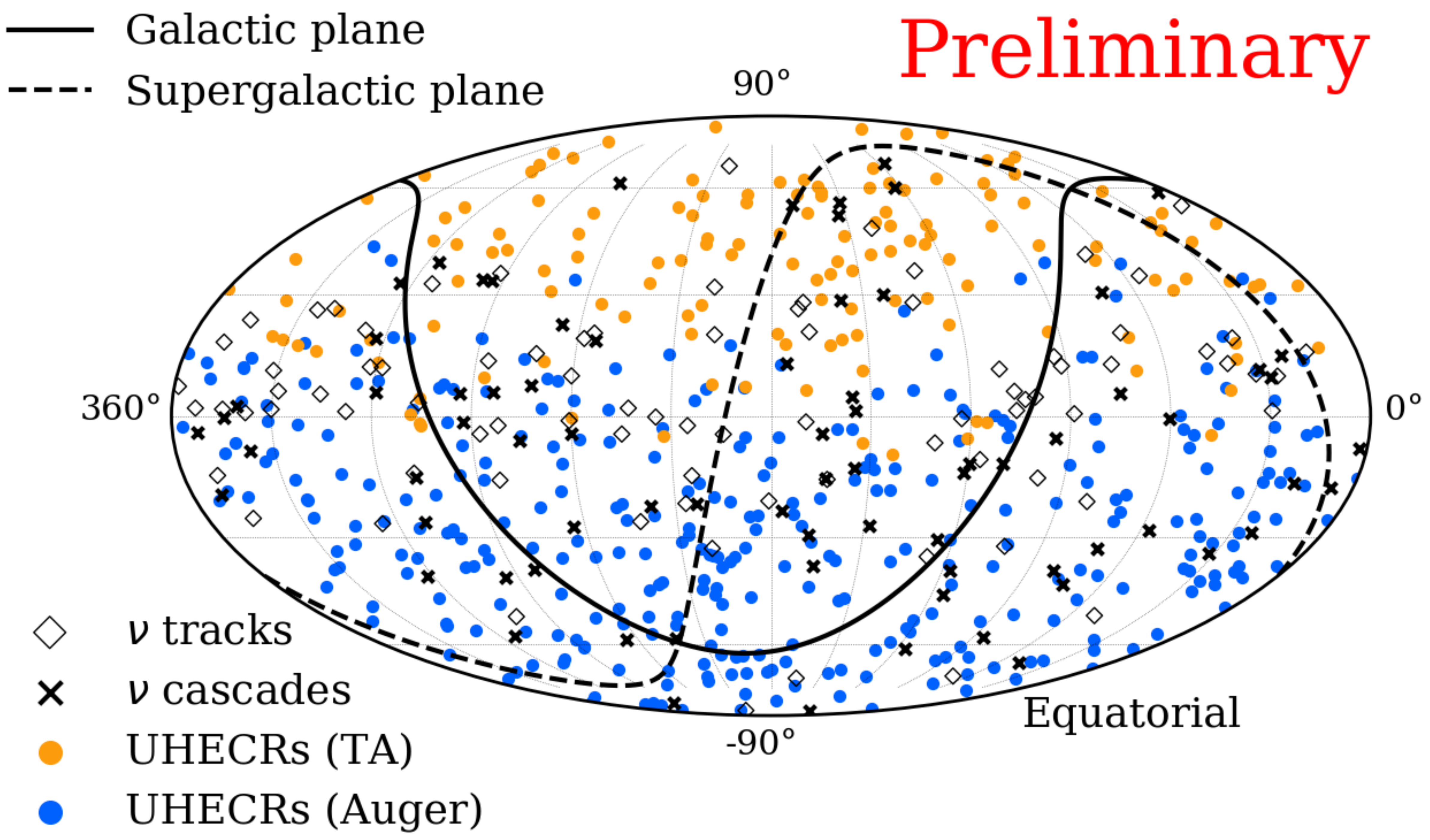


Figure 1: The UHECR events from TA and Auger are shown as orange and blue dots, respectively. The neutrino track- and cascade-like events from IceCube (HESE [10], EHE [11], 7-year through-going muons [12] samples) and ANTARES [20] are shown as black empty diamonds and crosses, respectively.

- Auger: 324 events
- TA: 142 events
  - A. Barbano et al., PoS ICRC2019 (2020) 842

Extra-galactic background

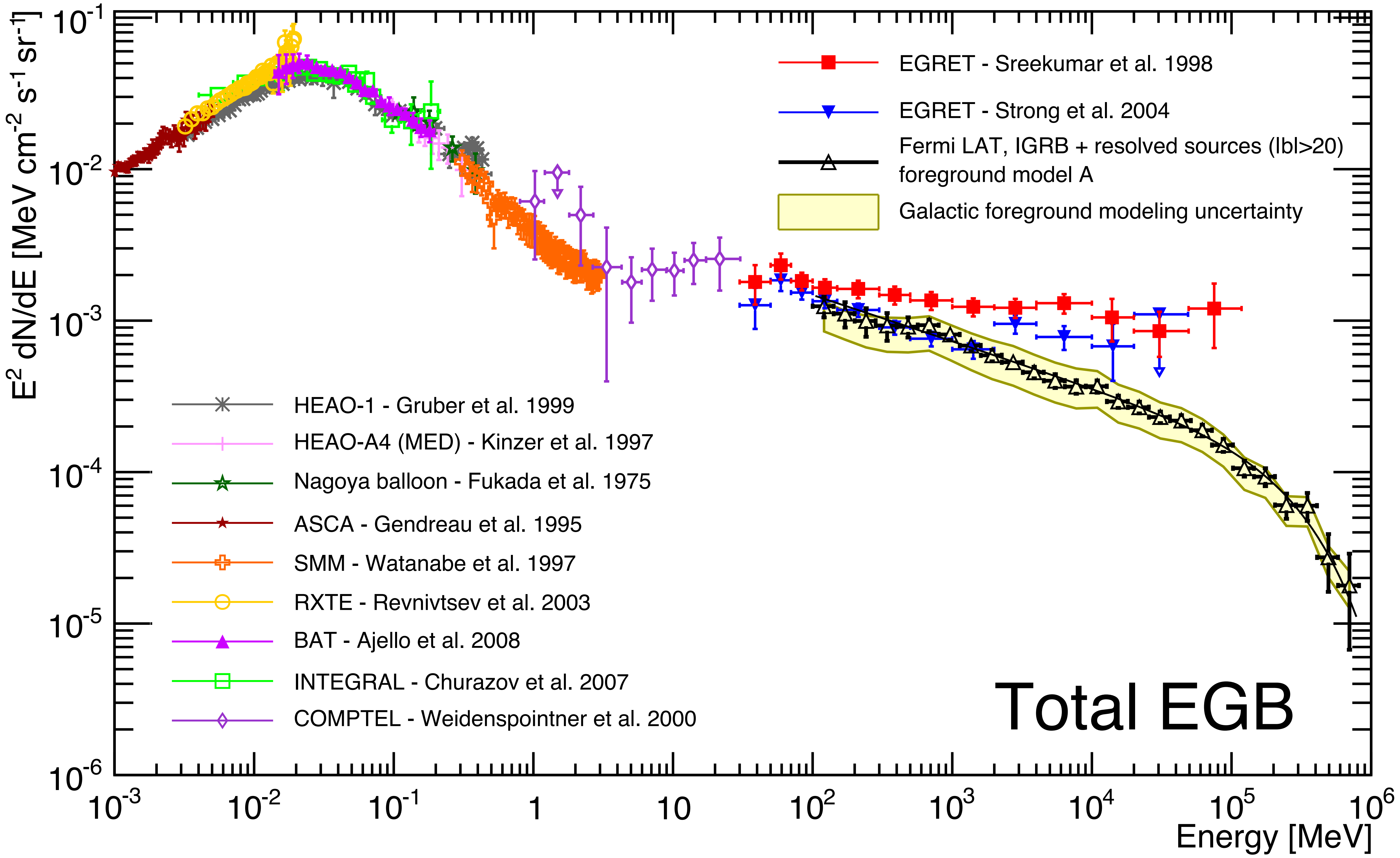


Fig. 10.— Comparison of the derived total EGB intensity (foreground model A) to other measurements of the X-ray and γ-ray background. The error bars on the LAT measurement include the statistical uncertainty and systematic uncertainties from the effective area parametrization, as well as the CR background subtraction. Statistical and systematic uncertainties have been added in quadrature. The shaded band indicates the systematic uncertainty arising from uncertainties in the Galactic foreground. (Note that the EGRET measurements shown are measurements of the IGRB. However, EGRET was more than an order of magnitude less sensitive to resolve individual sources on the sky than the *Fermi*-LAT.)

Fermi-LAT collaboration, Astrophys.J. 799 (2015) 86

Centaurus A

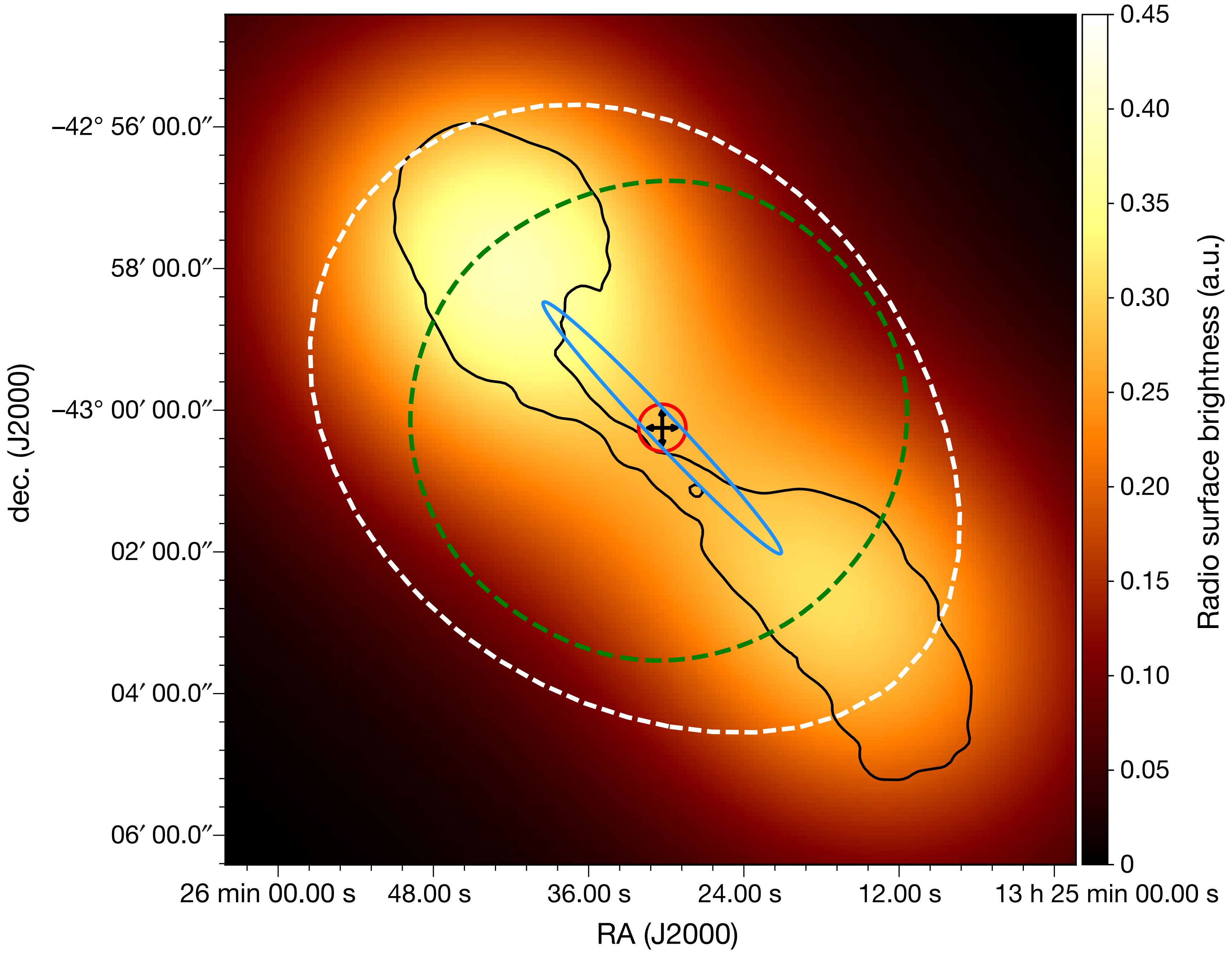


Fig. 1 | Multiwavelength image of Centaurus A. The colour map represents the radio surface brightness (21 cm wavelength) VLA map of Centaurus A[39], after convolution with the H.E.S.S. PSF and an additional oversampling with a radius of 0.05°. Contours of the unconvolved VLA map, with levels adjusted to highlight the core (corresponding to 4 Jy per beam) as well as the kiloparsec-scale jet (0.5 Jy per beam), are drawn in black. The VHE γ-ray morphology of Centaurus A is represented by a white dashed contour which is derived from the 5σ excess significance level of the H.E.S.S. sky map, also after oversampling with a radius of 0.05°. The result of the best fit of an elliptical Gaussian to the H.E.S.S. measurement is shown in blue by its 1σ contour, which corresponds to a model containment fraction of 39%. The 1σ statistical uncertainties of the fitted position are drawn as black arrows, and the estimated pointing uncertainties with a red circle. The dashed green line denotes the 68% containment contour of the H.E.S.S. PSF.

H.E.S.S. collaboration, Nature 582, 356 (2020)

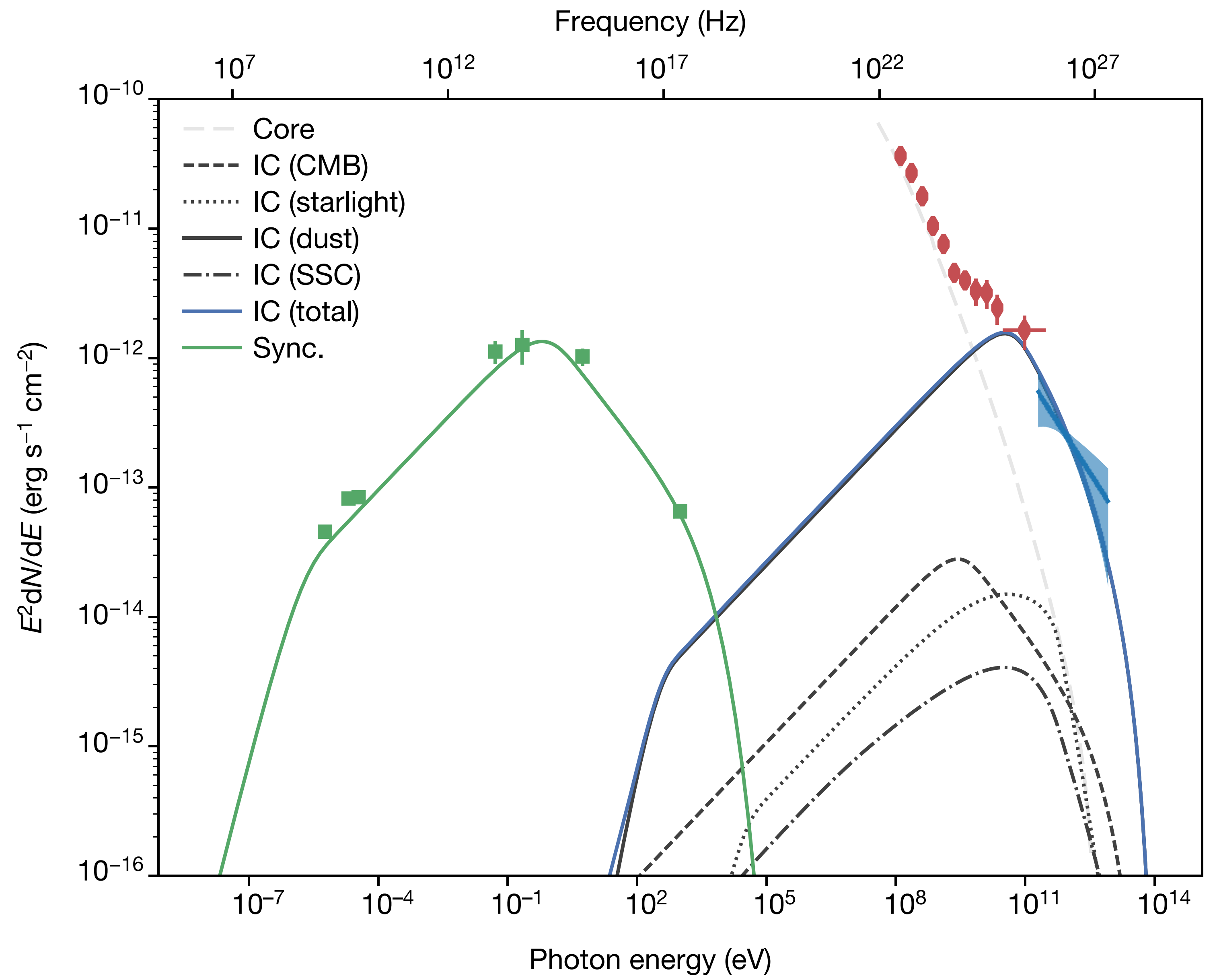


Fig. 2 | Spectral energy distribution of Centaurus A. Shown are the observed and modelled spectral energy distribution (SED) from radio to γ-ray energies for the inner, kiloparsec-scale jet of Centaurus A. The VHE emission is dominated by relativistic electrons with Lorentz factor $\gamma \geq 10^7$ inverse Compton (IC) up-scattering dust photons to high energies (solid blue curve, 'IC total'). This emission from the kiloparsec-scale jet makes a major contribution to the unexpected spectral hardening above a few GeV as seen by Fermi-LAT (red points)[16]. The lower-energy part of the γ-ray spectrum (red points) is attributed to emission from the core (grey dashed line referring to a core model fit[16]). The green curve ('Sync.') designates the synchrotron emission of the inferred broken power-law electron distribution in a magnetic field of characteristic strength $B = 23$ µG. The blue 'butterfly' corresponds to the H.E.S.S. spectra, while green data points mark radio, infrared and X-ray measurements and reported uncertainties (error bars) from the inner region of the Centaurus A jet (see Methods section 'Theoretical modelling'). A breakdown is provided of the full IC contribution, from the scattering of: the cosmic microwave background (CMB), the starlight emission of the host galaxy, infrared emission from dust, and the low-energy synchrotron jet emission (synchrotron self Compton, SSC). Data are from refs. [16,36]; see Methods section 'Theoretical modelling' for further details.

SS433

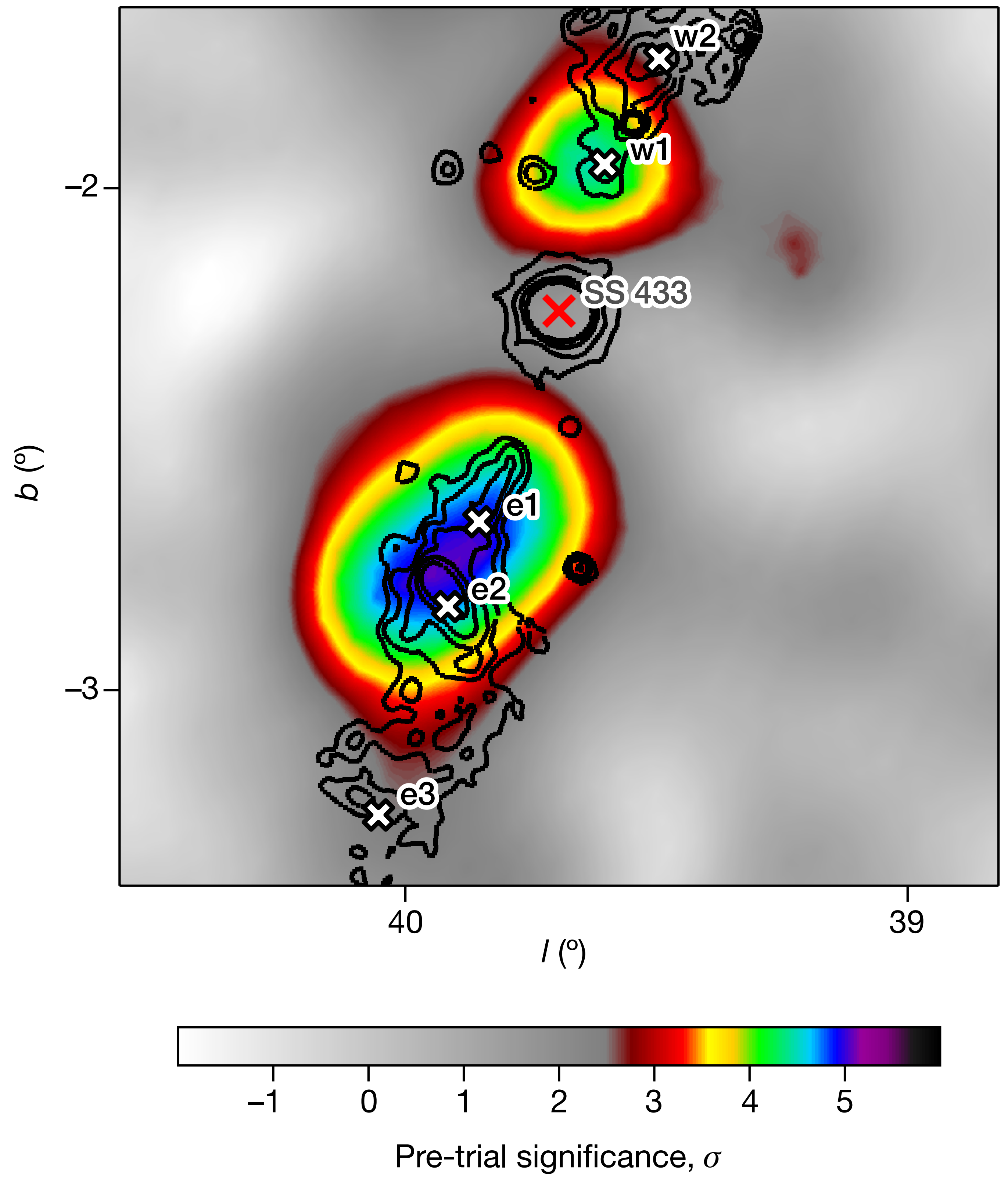


Fig. 1 | VHE γ-ray image of the SS 433/W50 region in Galactic coordinates. The colour scale indicates the statistical significance of the excess counts above the background of nearly isotropic cosmic rays before accounting for statistical trials. The figure shows the γ-ray excess measured after the fitting and subtraction of γ-rays from the spatially extended source MGRO J1908+06. The jet termination regions e1, e2, e3, w1 and w2 observed in the X-ray data are indicated, as well as the location of the central binary. The solid contours show the X-ray emission observed from this system.

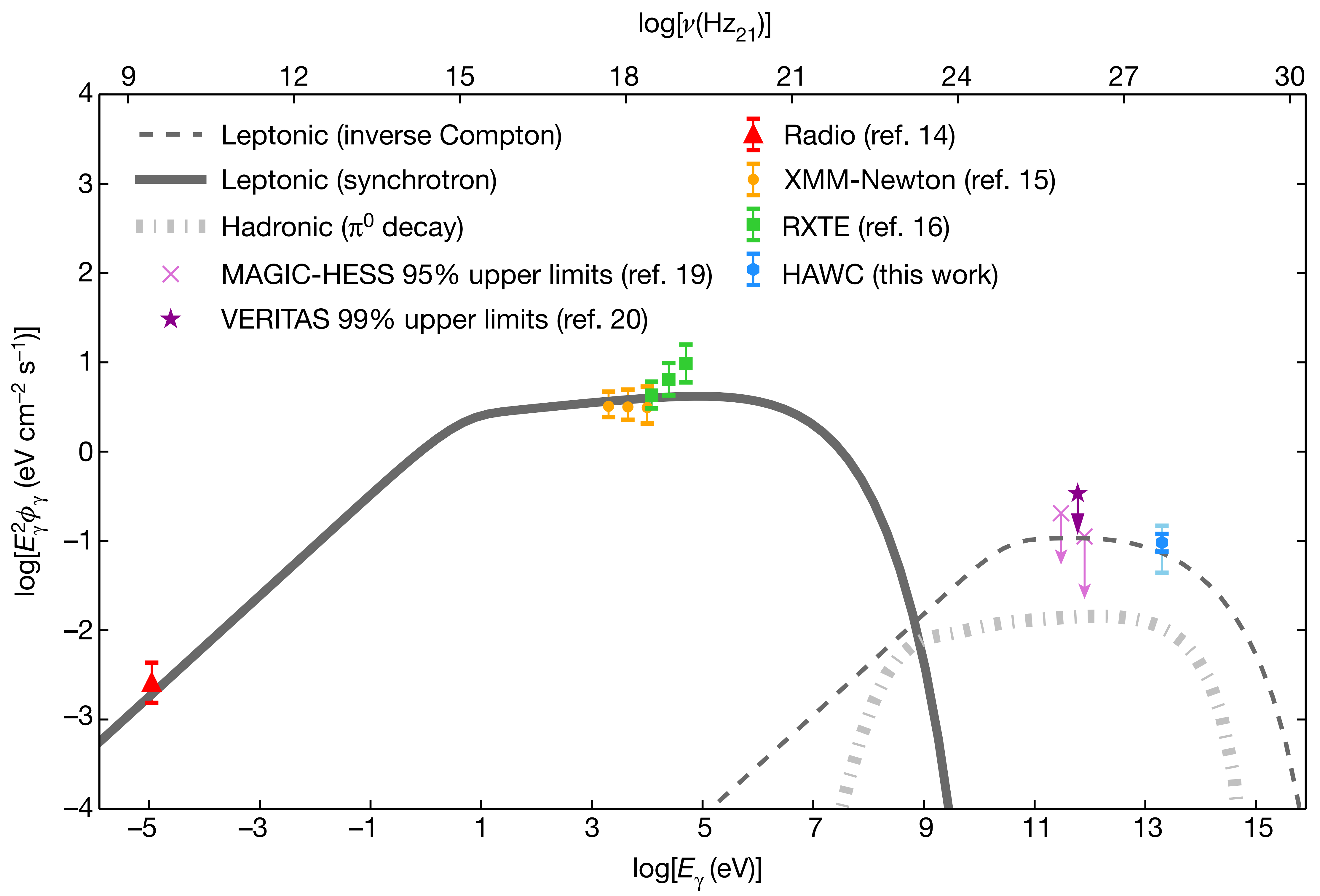
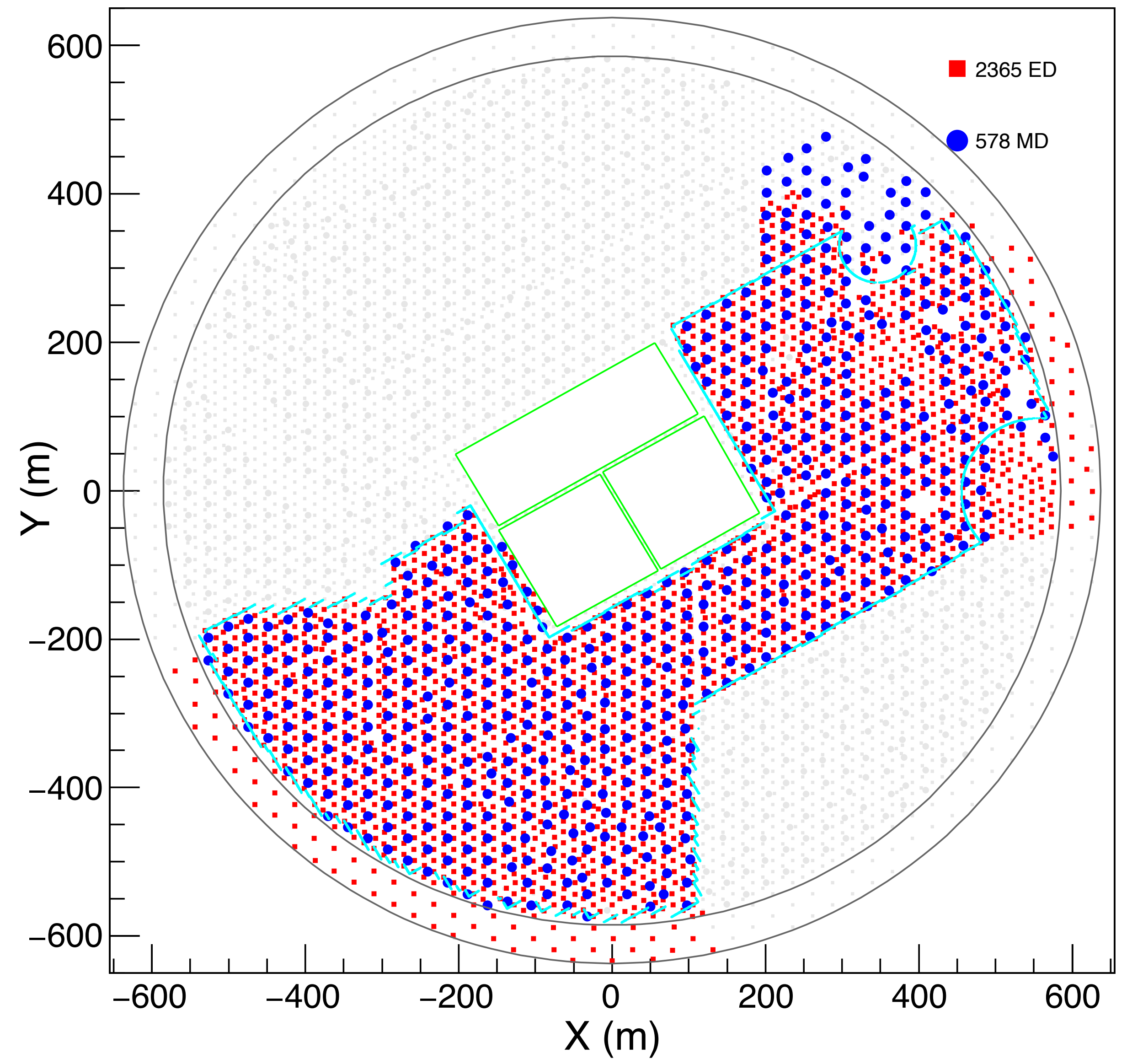
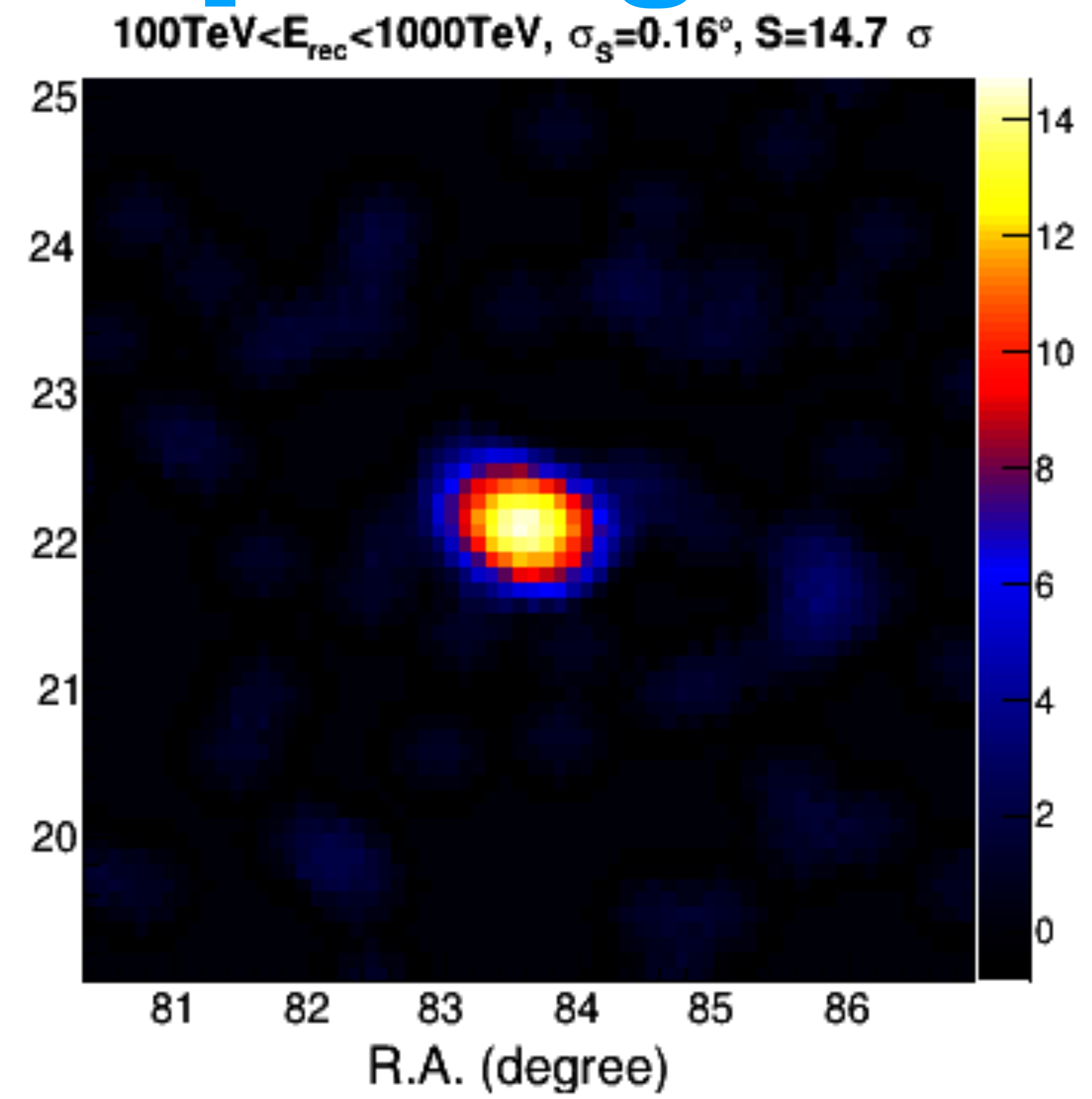


Fig. 2 | Broadband spectral energy distribution of the eastern emission region e1. The data include radio[14], soft X-ray[15], hard X-ray[16] and VHE γ-ray upper limits[19,20], and HAWC observations of e1. Error bars indicate 1σ uncertainties, with the thick (thin) errors on the HAWC flux indicating statistical (systematic) uncertainties and arrows indicating flux upper limits. The multiwavelength spectrum produced by electrons assumes a single electron population following a power-law spectrum with an exponential cutoff. The electrons produce radio to X-ray photons through synchrotron emission in a magnetic field (thick solid line) and teraelectronvolt γ rays through inverse Compton scattering of the CMB (thin dashed line). The dash-dotted line represents the radiation produced by protons, assuming that 10% of the jet kinetic energy converts into protons.

HAWC collaboration, Nature 562, 82 (2018)

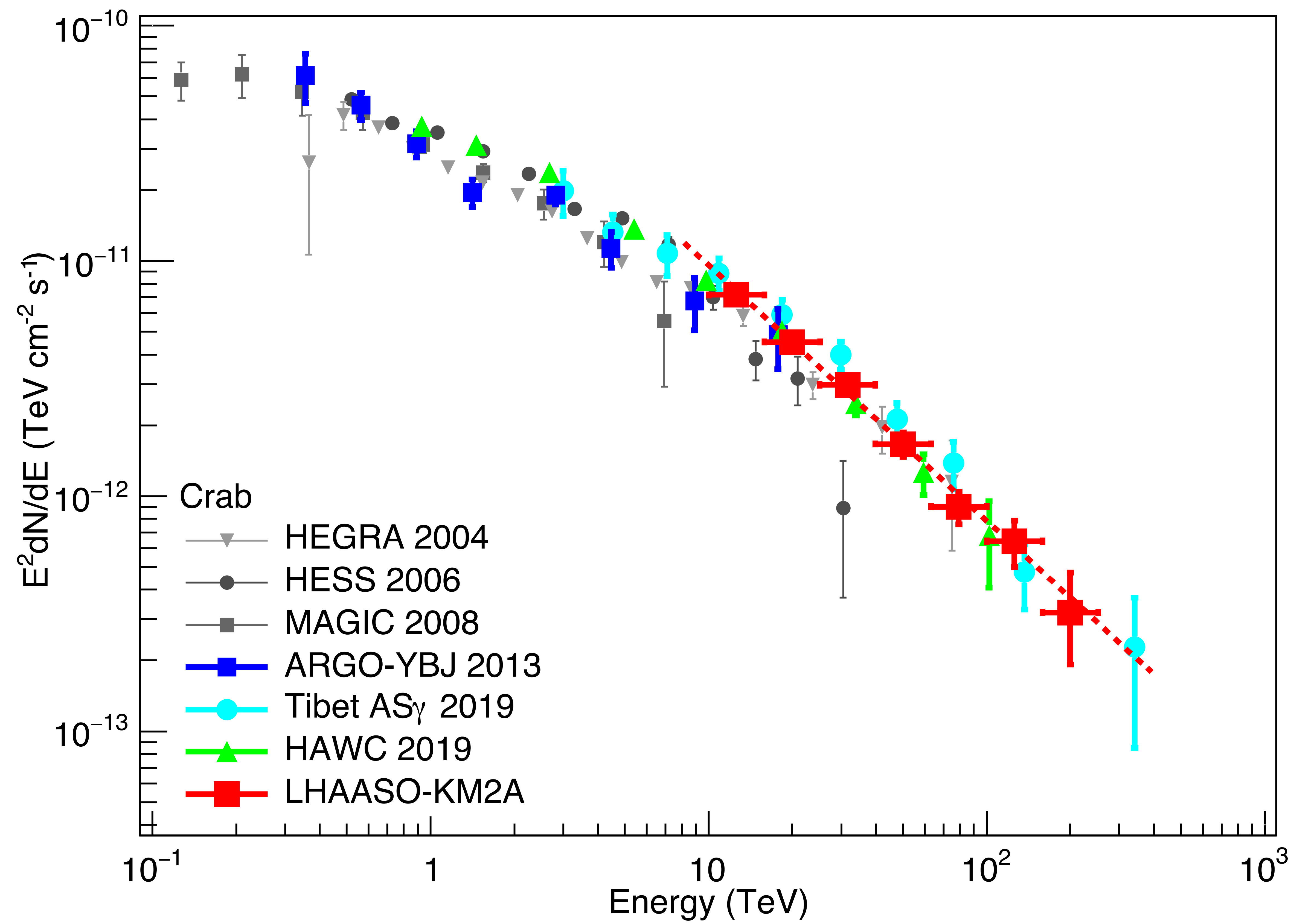
Surprising result from LHAASO

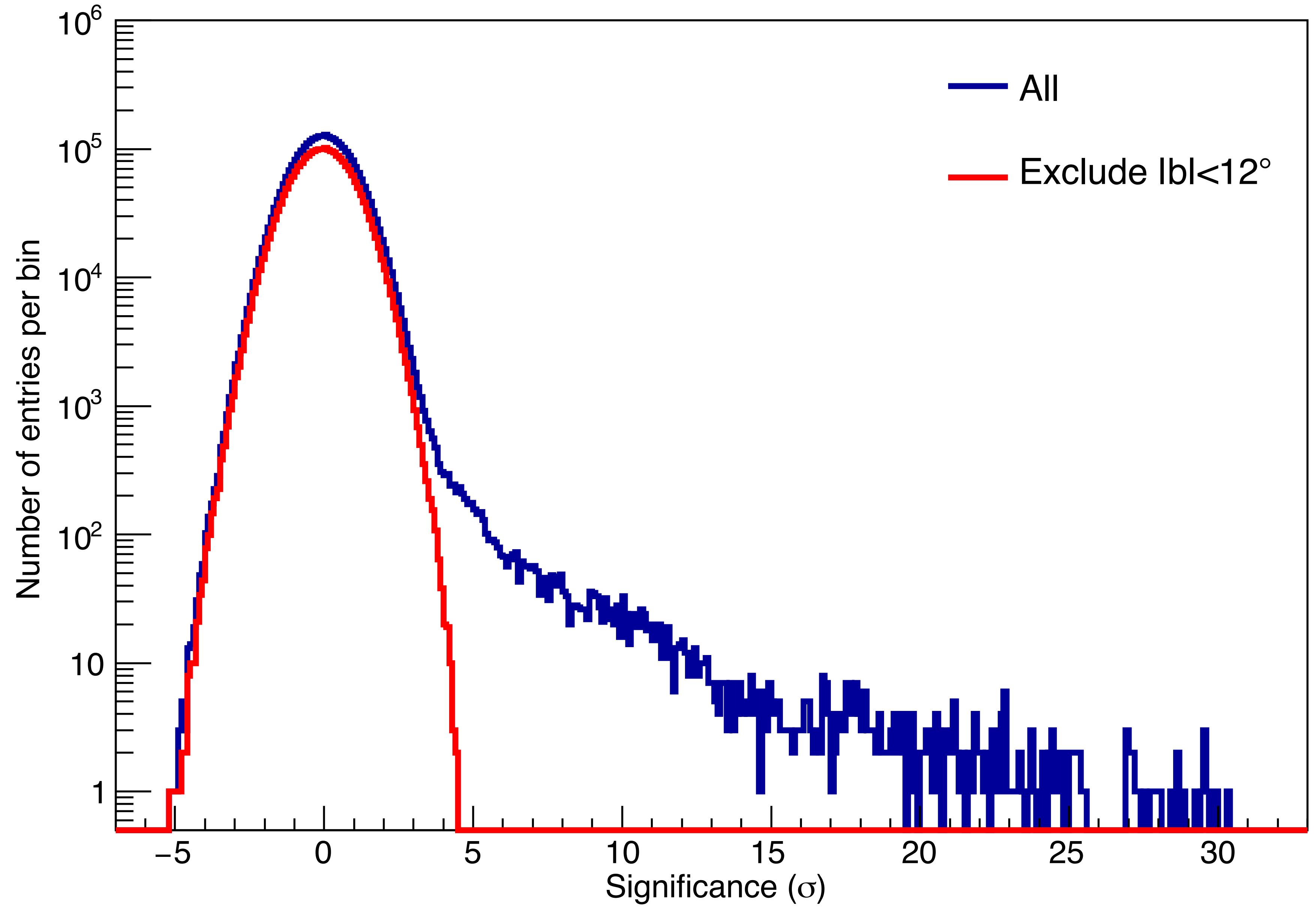




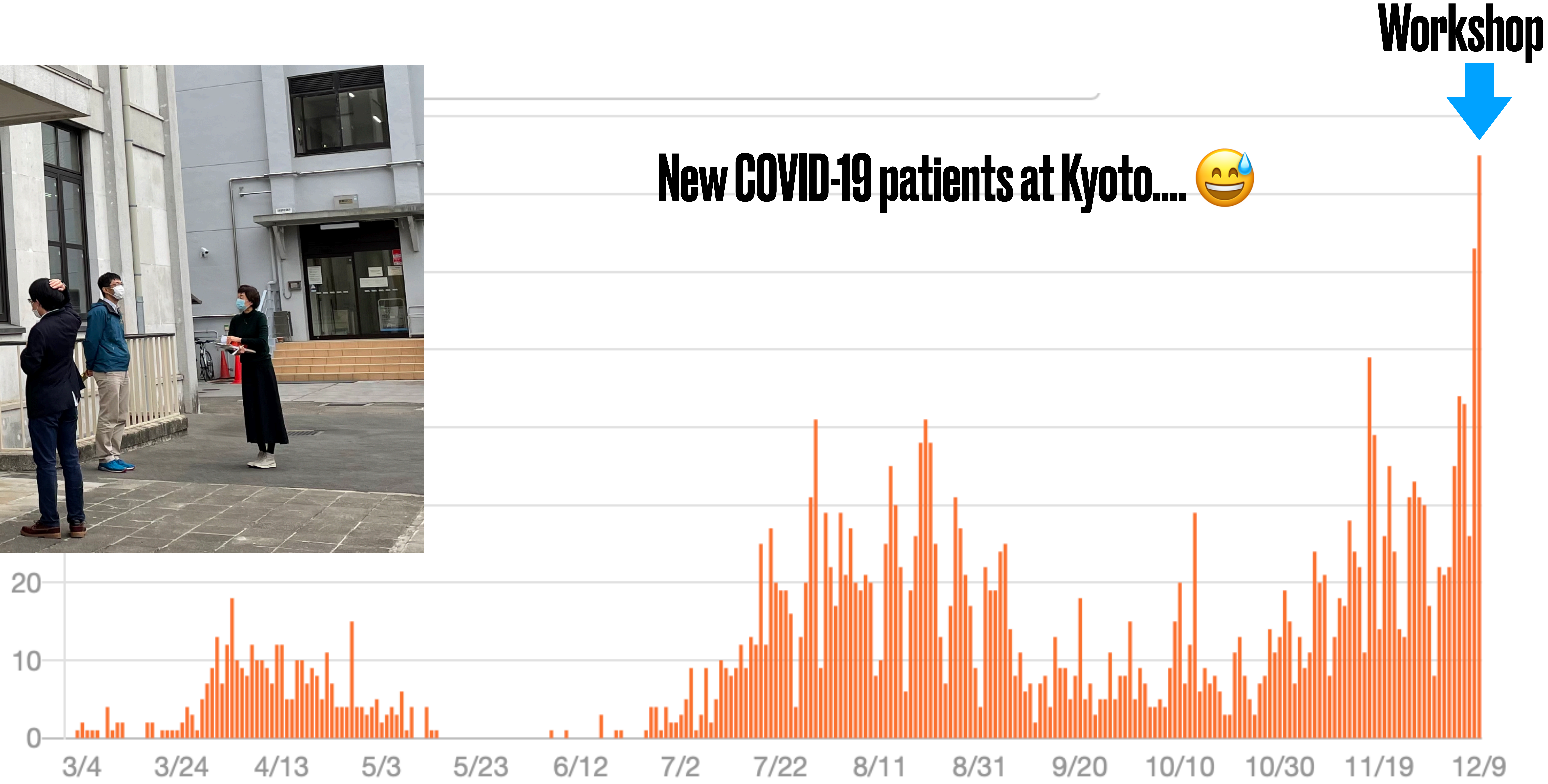
RHAASO collaboration, submitted to Chinese Physics C, arXiv: 2010.06205 (2020)

>100 TeV γ-ray detection from Crab





Masking, social network and eating sweets outside a building...



Not too cold weathers 😄