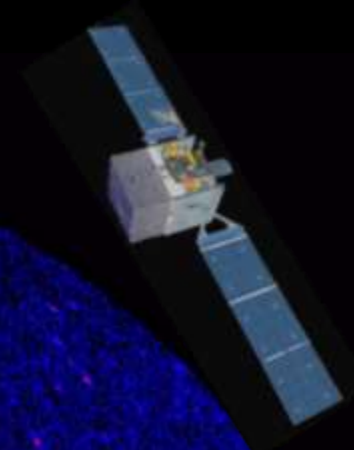
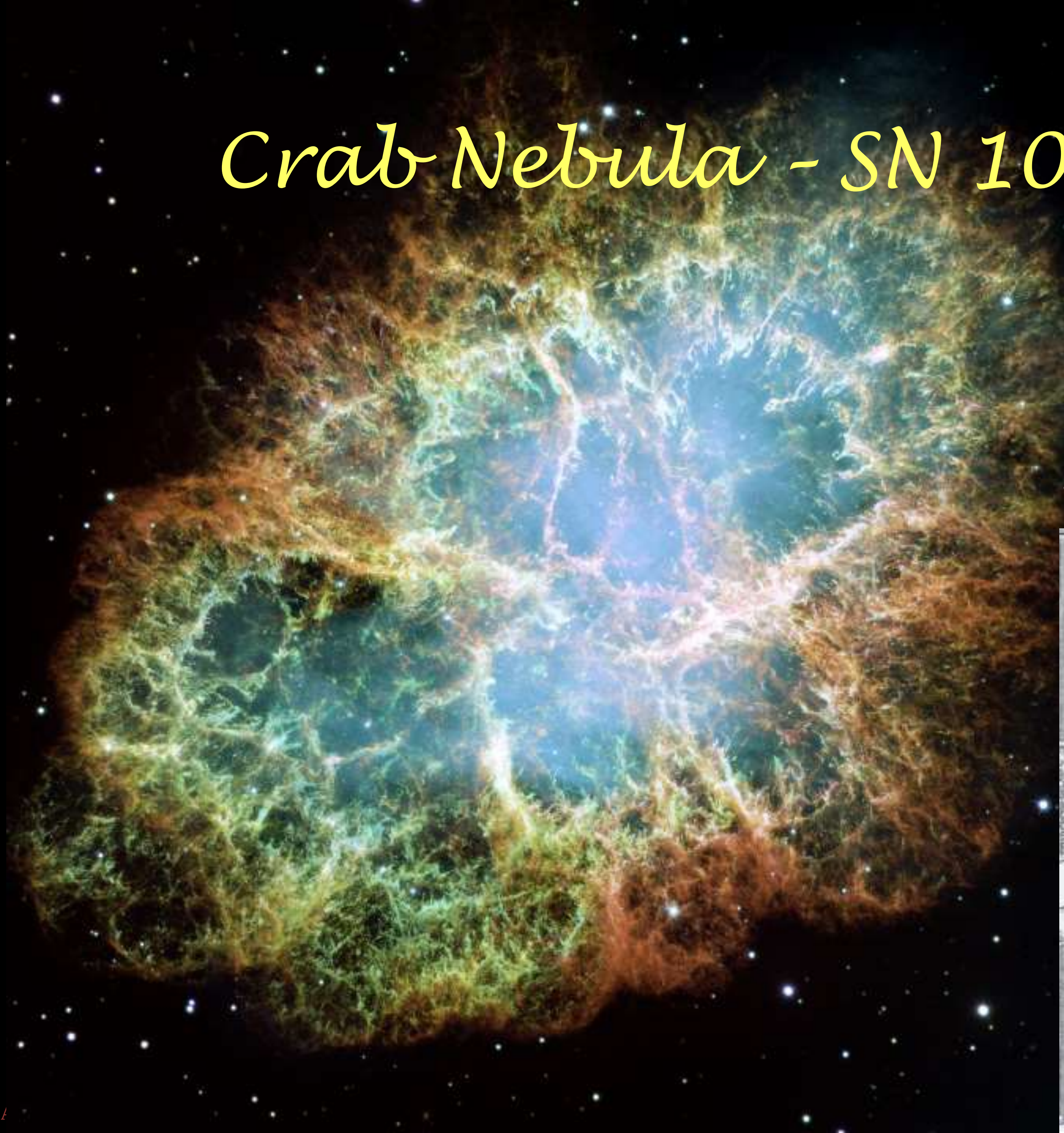


RECENT DISCOVERIES AND ANTICIPATIONS IN

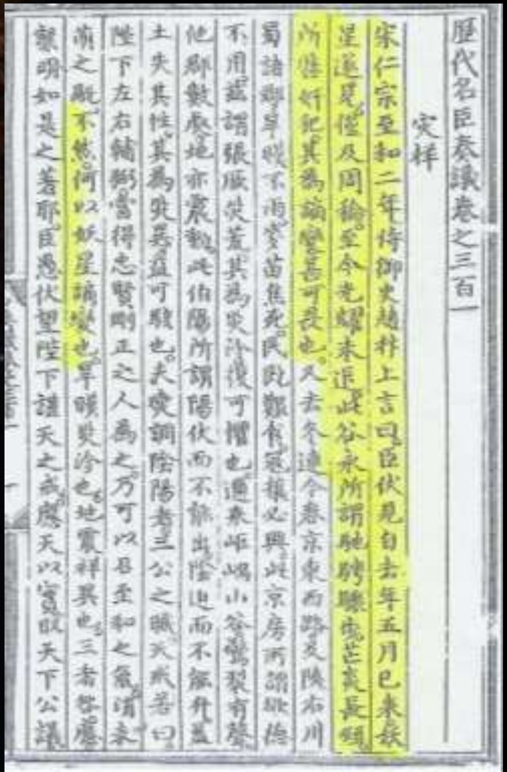
ASTROPHYSICS OF COSMIC RAYS AND GAMMA-RAYS

IGOR V MOSKALENKO – STANFORD

Crab Nebula - SN 1054



"Guest star" – in Chinese records

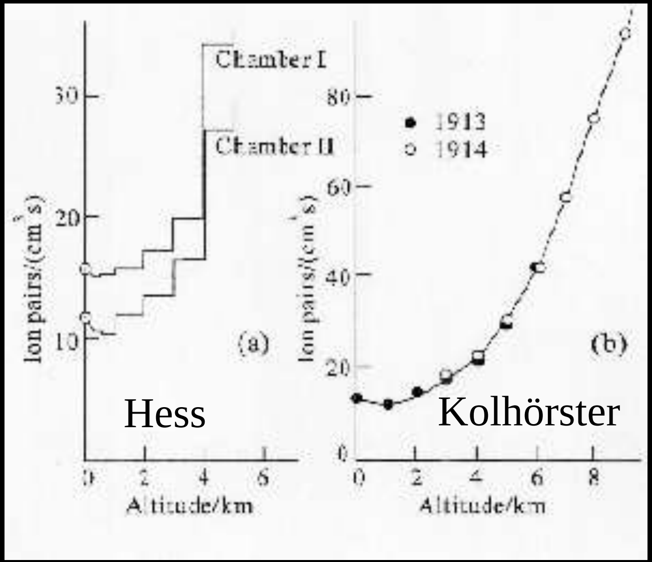


歷代名臣奏議卷之三百一

災祥

宋仁宗至和二年侍御史趙抃上言曰臣伏見自去年五月已來妖星遂見偃及周歲至今光耀未退此谷永所謂[illegible]其芒炎長[illegible]所[illegible]紀其為禍譴甚可畏也又去冬逮今春京東西路及陝府川蜀諸郡旱暵不雨麥苗焦死民既艱食寇攘必興此京房所謂與陰不用[illegible]謂張威伐害其為災於後可懼也邇來[illegible][illegible]小谷鑿裂有聲他郡數奏地亦震動此伯陽所謂陽伏而不能出陰迫而不能升蒸土失其性其為災甚可駭也夫燮調陰陽者三公之職天戒若曰陛下左右輔弼當得忠賢剛正之人為之方可以召至和之氣消來[illegible]之[illegible]不然何以妖星謫變也旱暵災沴也地震祥異也三者皆屢[illegible]明如是之著耶臣愚伏望陛下謹天之戒應天以實取天下公議

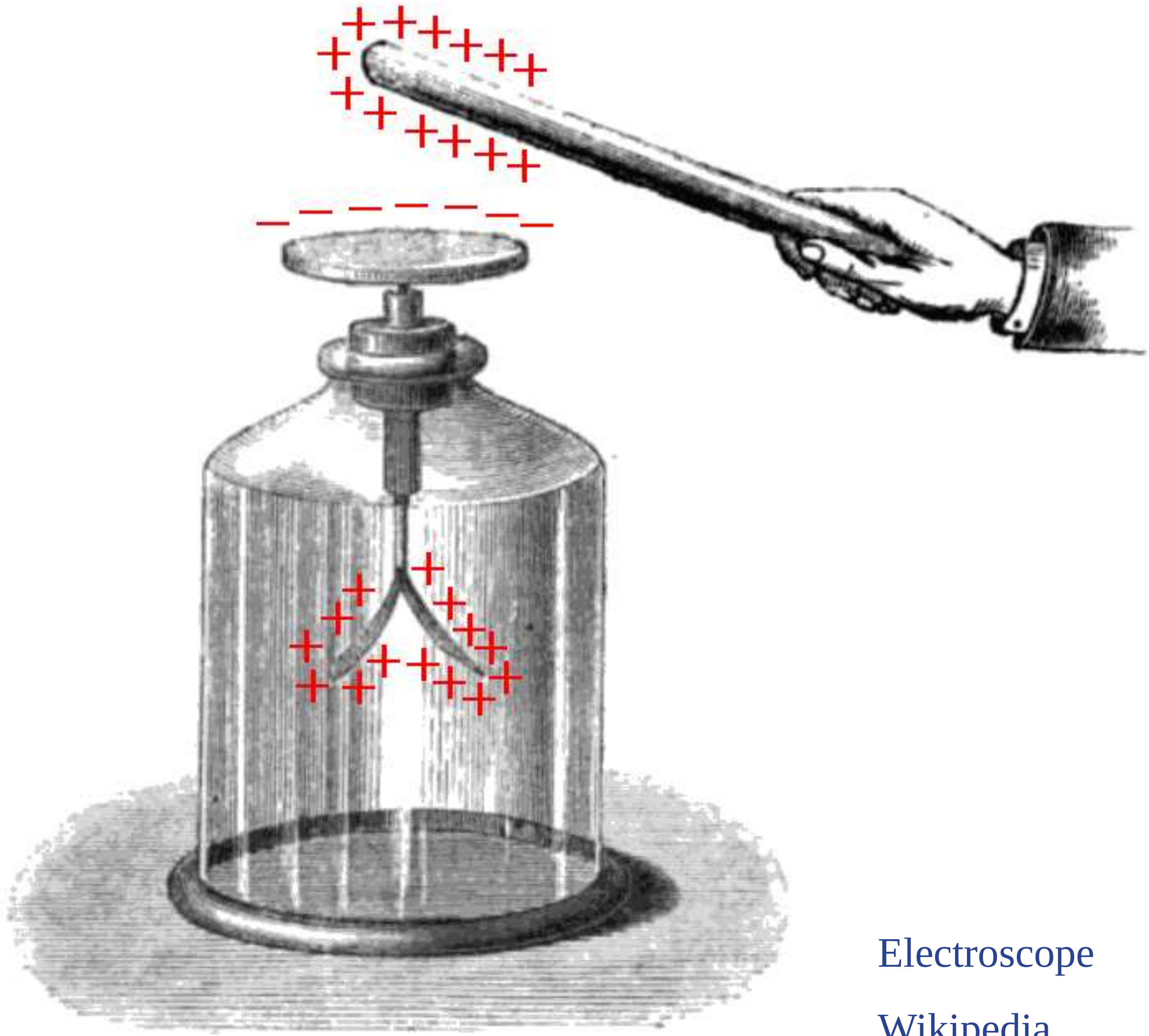
The discovery of cosmic rays



Victor Hess flight on August 7, 1912

Nobel Prize: 1936

- Victor Hess, an Austrian scientist, took a radiation counter (a simple electroscope) on a balloon flight
- He rose to 5200 m (without oxygen) and measured that the amount of radiation increases as the balloon climbed
- Hess correctly concluded that the ionization was caused by highly penetrating radiation coming from outside the atmosphere
- The results by Hess were later confirmed by the Kolhörster in a number of flights up to 9200 m

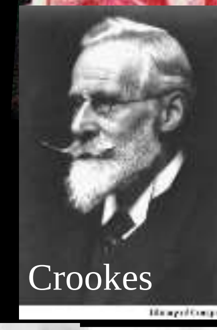


Electroscope

Wikipedia

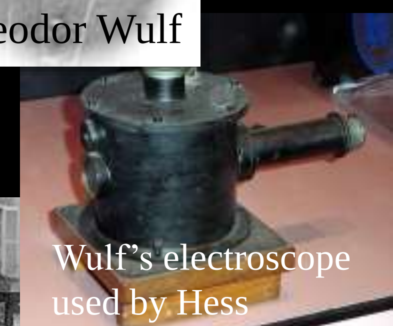
Long before that day…

- 1785 – de Coulomb noticed a spontaneous discharge of electroscopes
- 1879 – Crookes observed that speed of discharge depends on the air pressure
- 1900 – Wilson noticed continuous atmospheric ionization and appearance of drops in the cloud chamber
- 1902-03 – Linke made several balloon flights. He noticed an increase in the ionization at an altitude of 5 km , but thought of measurement uncertainties
- 1909 – Priest Wulf designed an improved electroscope
- 1910 – Wulf measured the ionization rate at the top of the Eifel Tower and found that it was significantly larger than expected if its source is at the ground
- 1910-11 – Pacini measured ionization rate on sea and under water. He concluded the source of ionization is in the atmosphere


Crookes

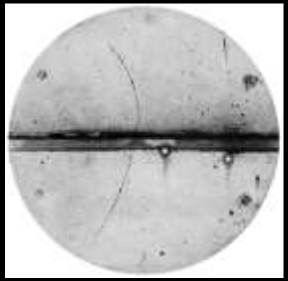

Wilson


Theodor Wulf


Wulf's electroscope used by Hess

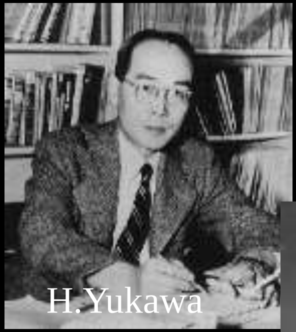

Domenico Pacini

At the same time…



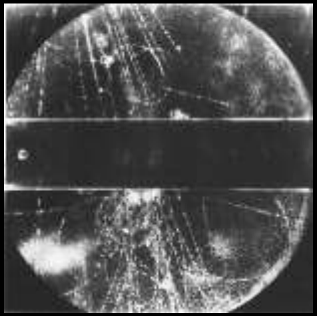
1932 – Anderson discovered positron

1936 – a discovery of muon by Neddermeyer & Anderson and simultaneously by Street & Stevenson



1947 – pions predicted by Yukawa (1935) to explain the nuclear force were discovered by Powell et al.

1947 – Rochester & Butler discovered kaons



1951-52 – Manchester group found Λ- and Ξ-hyperons

1953 – Milan group discovered Σ-hyperon

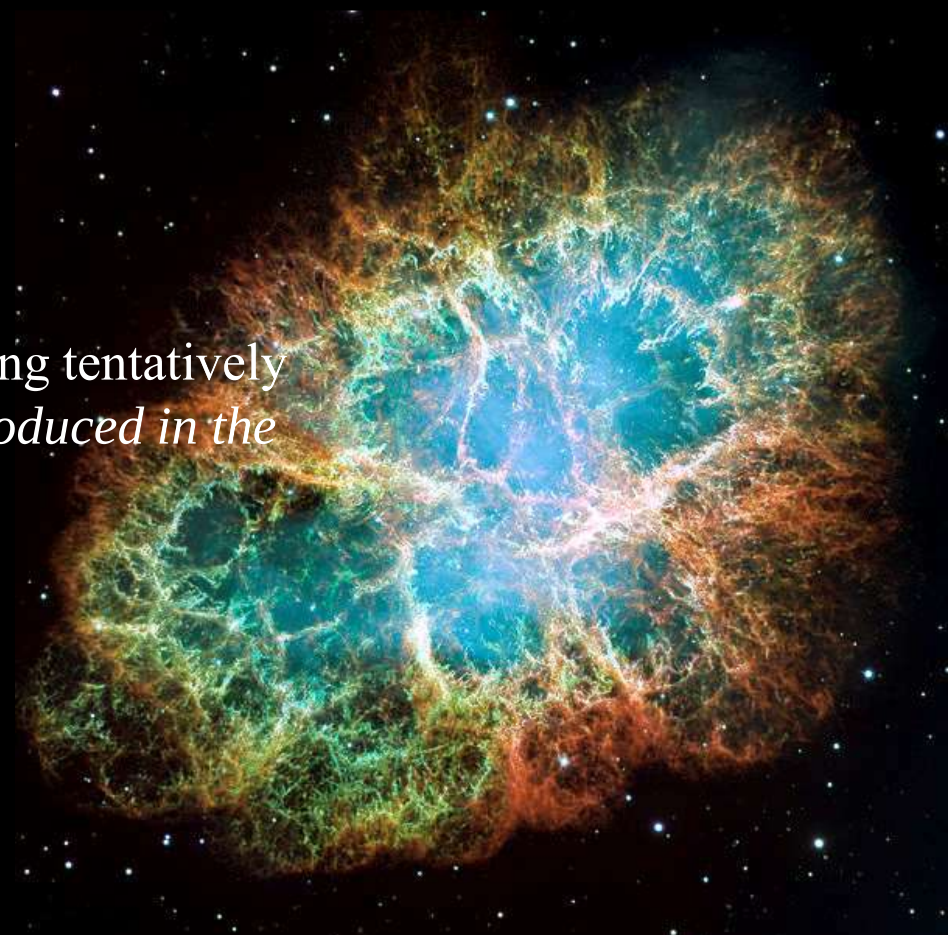
Cosmic rays from supernova remnants?

COSMIC RAYS FROM SUPER-NOVAE

BY W. BAADE AND F. ZWICKY

MOUNT WILSON OBSERVATORY, CARNEGIE INSTITUTION OF WASHINGTON, AND CALIFORNIA INSTITUTE OF TECHNOLOGY, PASADENA

Communicated March 19, 1934



"We therefore feel justified in advancing tentatively the hypothesis that *cosmic rays are produced in the super-nova process…"*

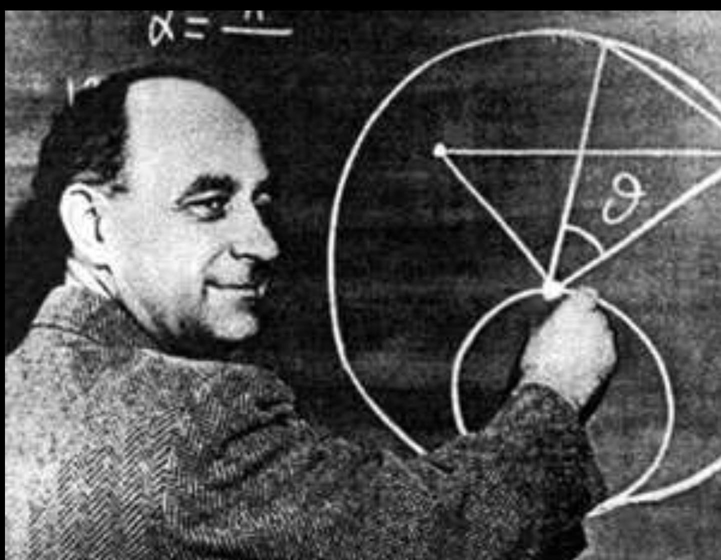
Baade & Zwicky 1934

PHYSICAL REVIEW VOLUME 75, NUMBER 8 APRIL 15, 1949

On the Origin of the Cosmic Radiation

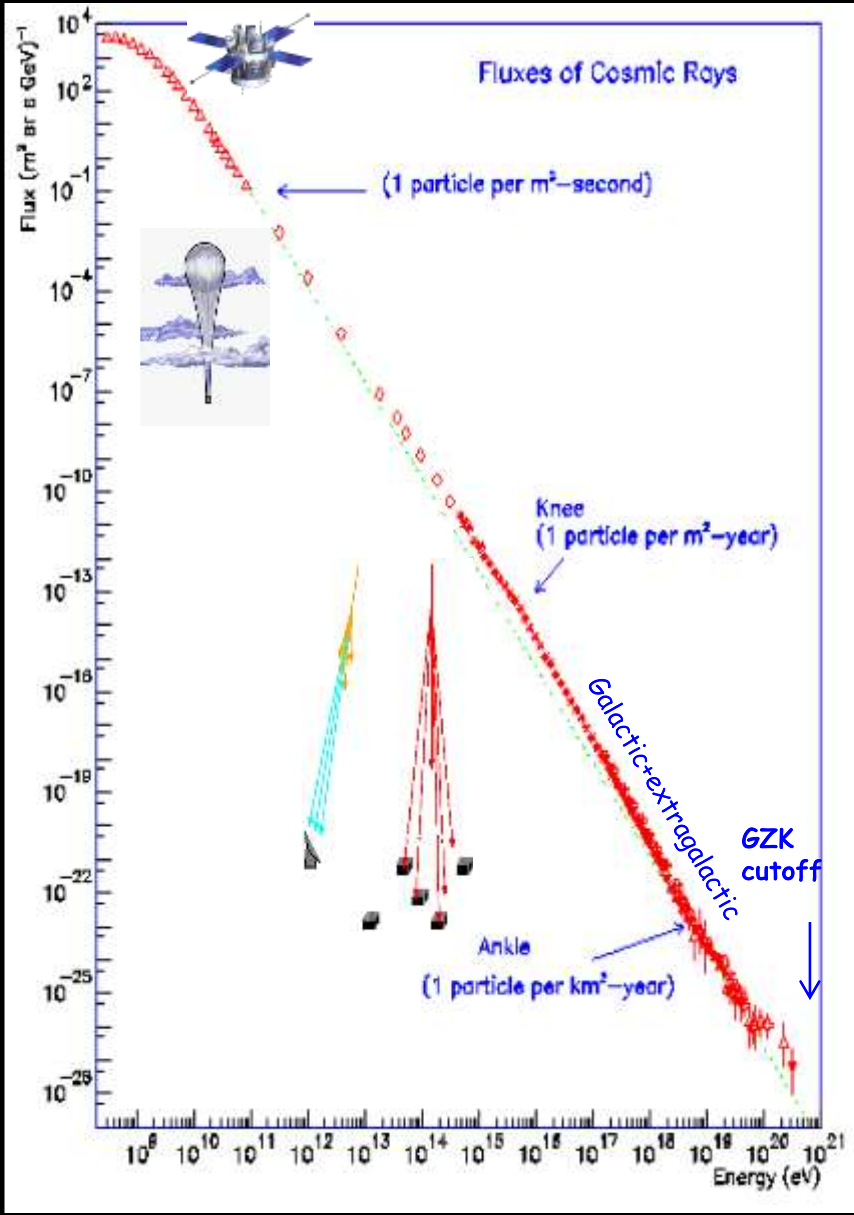
ENRICO FERMI
Institute for Nuclear Studies, University of Chicago, Chicago, Illinois
(Received January 3, 1949)

A theory of the origin of cosmic radiation is proposed according to which cosmic rays are originated and accelerated primarily in the interstellar space of the galaxy by collisions against moving magnetic fields. One of the features of the theory is that it yields naturally an inverse power law for the spectral distribution of the cosmic rays. The chief difficulty is that it fails to explain in a straightforward way the heavy nuclei observed in the primary radiation.

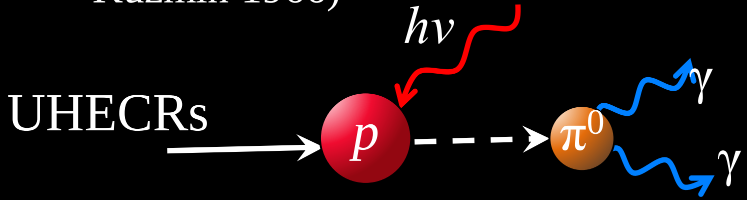


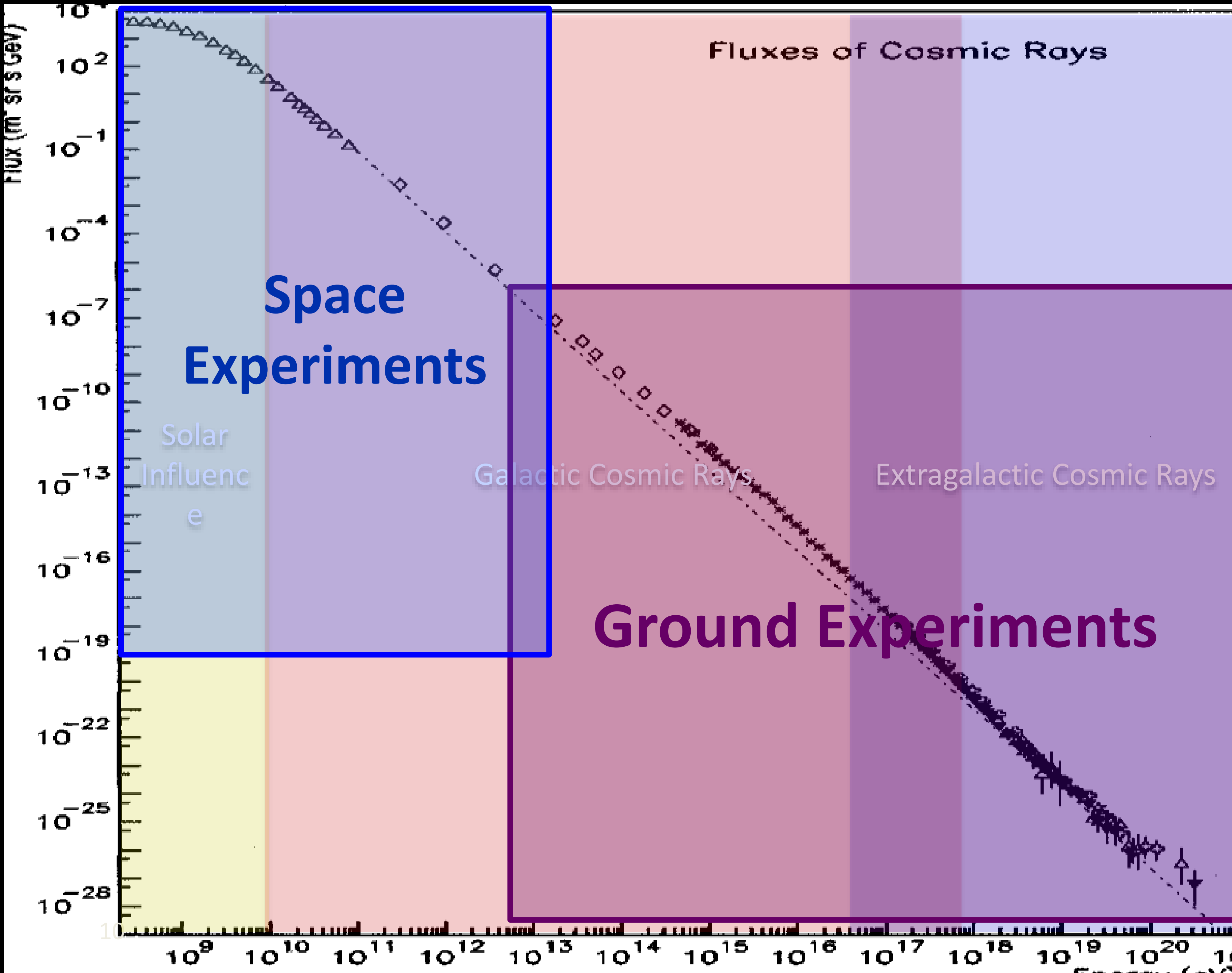
…if the mirror is moving towards the incident particle, the particle gains energy upon reflection, just as does a tennis ball pushed by a racket…

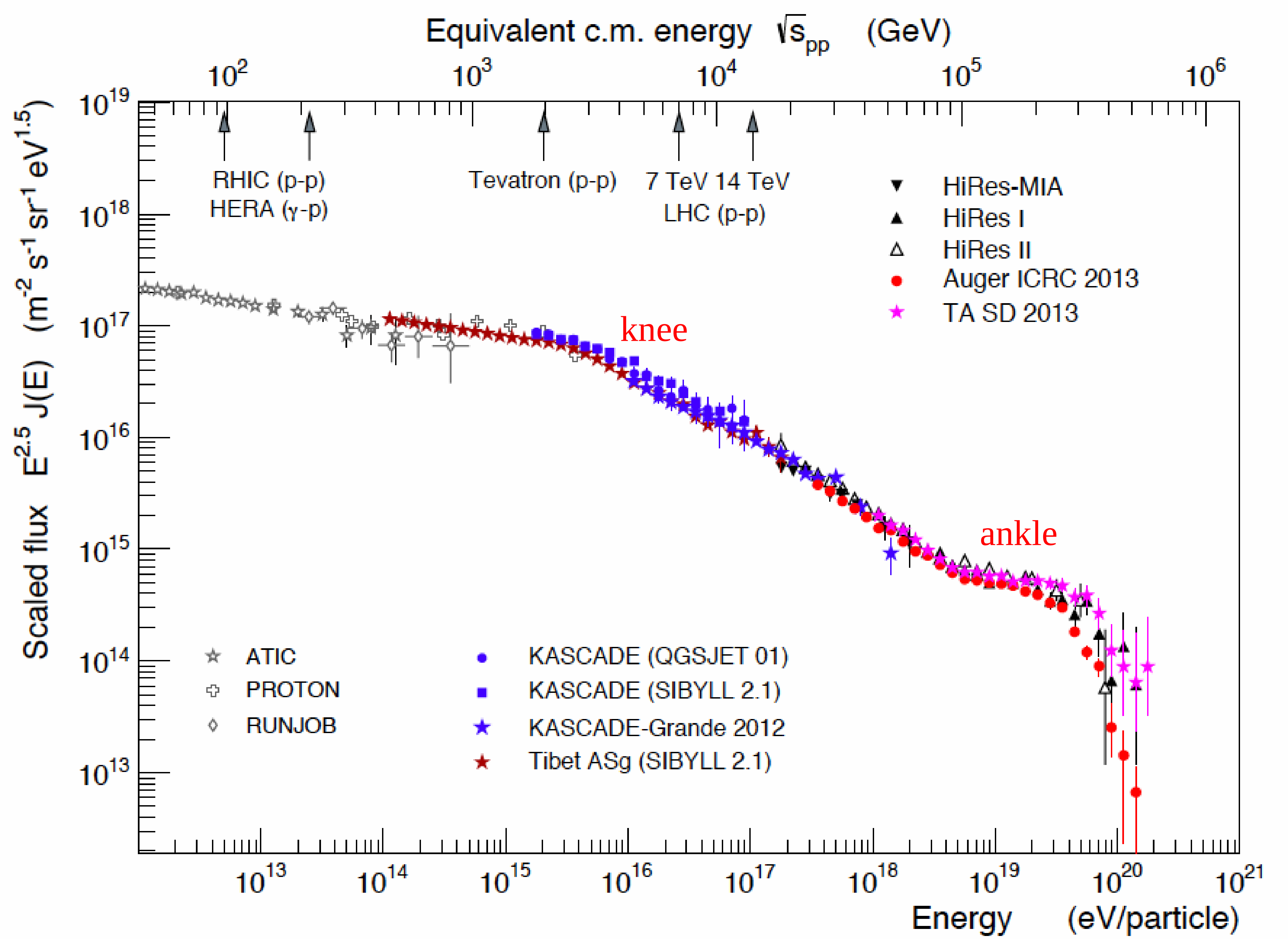
Spectrum of Cosmic Rays



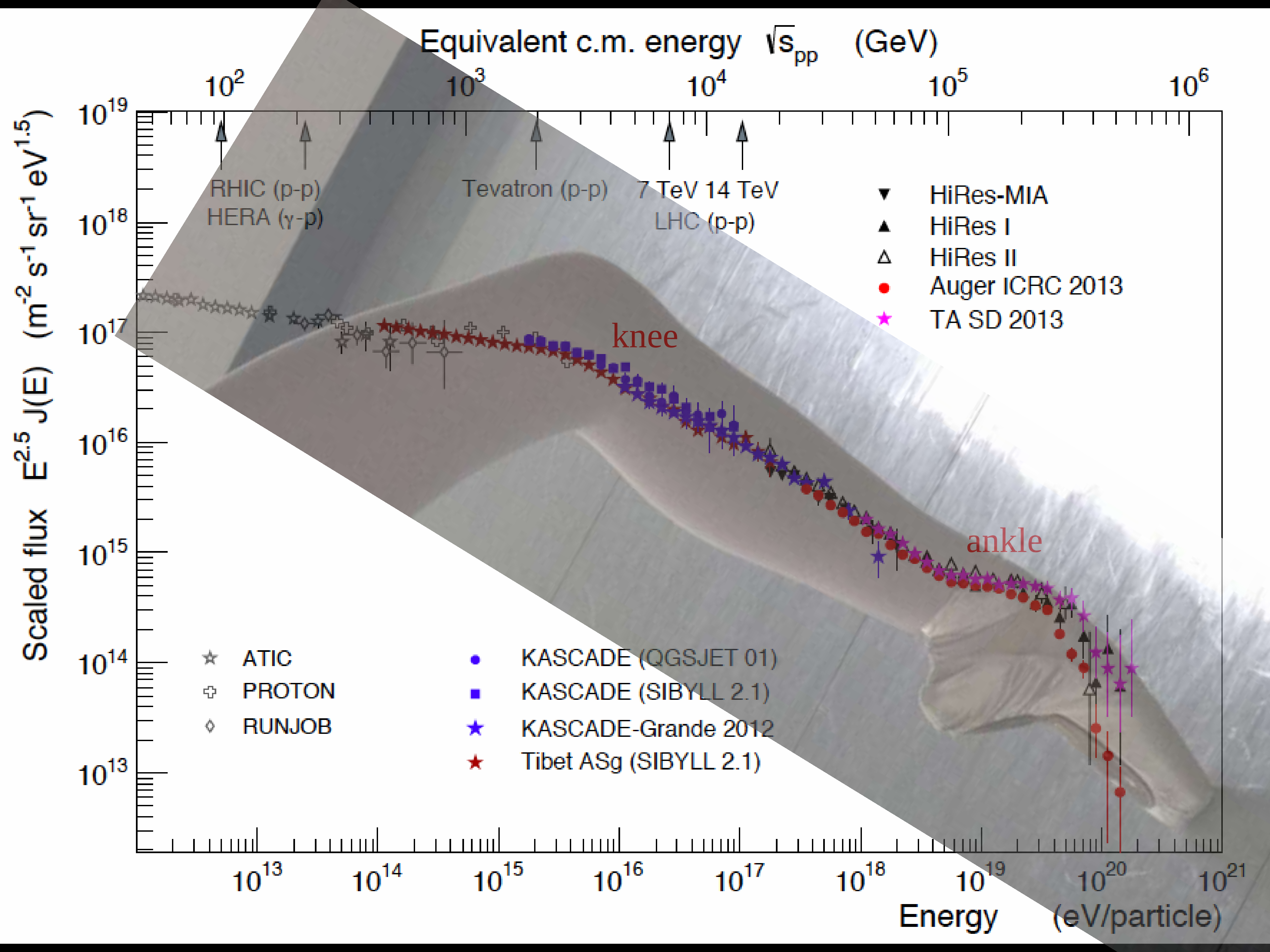
- ✧ Groundbreaking work
- ✧ Development of ideas and theoretical models that we use now
- ✧ All particle CR spectrum:
  - ✦ the knee (Kulikov & Christiansen 1958)
  - ✦ the ankle (Linsley 1963, Fly's eye 1990s)
  - ✦ GZK cutoff (predicted Greisen-Zatsepin-Kuzmin 1966)




Fluxes of Cosmic Rays
Space Experiments
Ground Experiments
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Flux (m² sr s GeV)⁻¹
Energy (eV)
10^{9} 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20}
10^{2} 10^{-1} 10^{-4} 10^{-7} 10^{-10} 10^{-13} 10^{-16} 10^{-19} 10^{-22} 10^{-25} 10^{-28}



Equivalent c.m. energy $\sqrt{s}_{pp}$ (GeV)
10^2
10^3
10^4
10^5
10^6
RHIC (p-p)
HERA (γ-p)
Tevatron (p-p)
7 TeV 14 TeV
LHC (p-p)
HiRes-MIA
HiRes I
HiRes II
Auger ICRC 2013
TA SD 2013
knee
ankle
Scaled flux $E^{2.5}$ J(E) ($m^{-2}s^{-1}sr^{-1}eV^{1.5}$)
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2012
Tibet ASg (SIBYLL 2.1)
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
10^{21}
Energy (eV/particle)



Equivalent c.m. energy $\sqrt{s}_{pp}$ (GeV)
10^2
10^3
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RHIC (p-p)
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Scaled flux $E^{2.5}$ J(E) ($m^{-2}s^{-1}sr^{-1}eV^{1.5}$)
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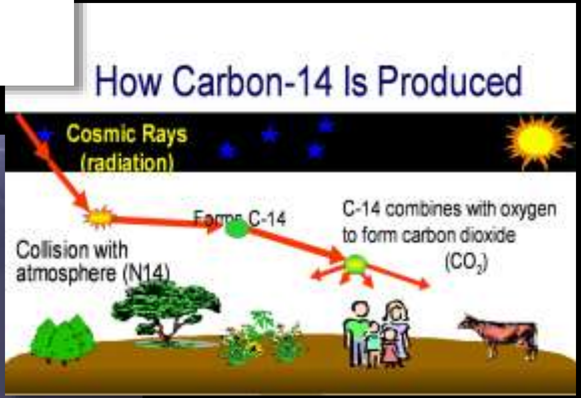
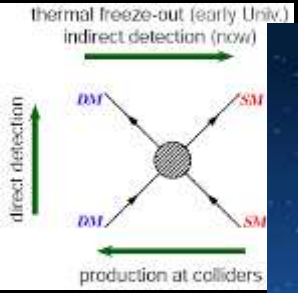
10^{14}
10^{13}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
10^{21}
Energy (eV/particle)

Why Cosmic Rays?

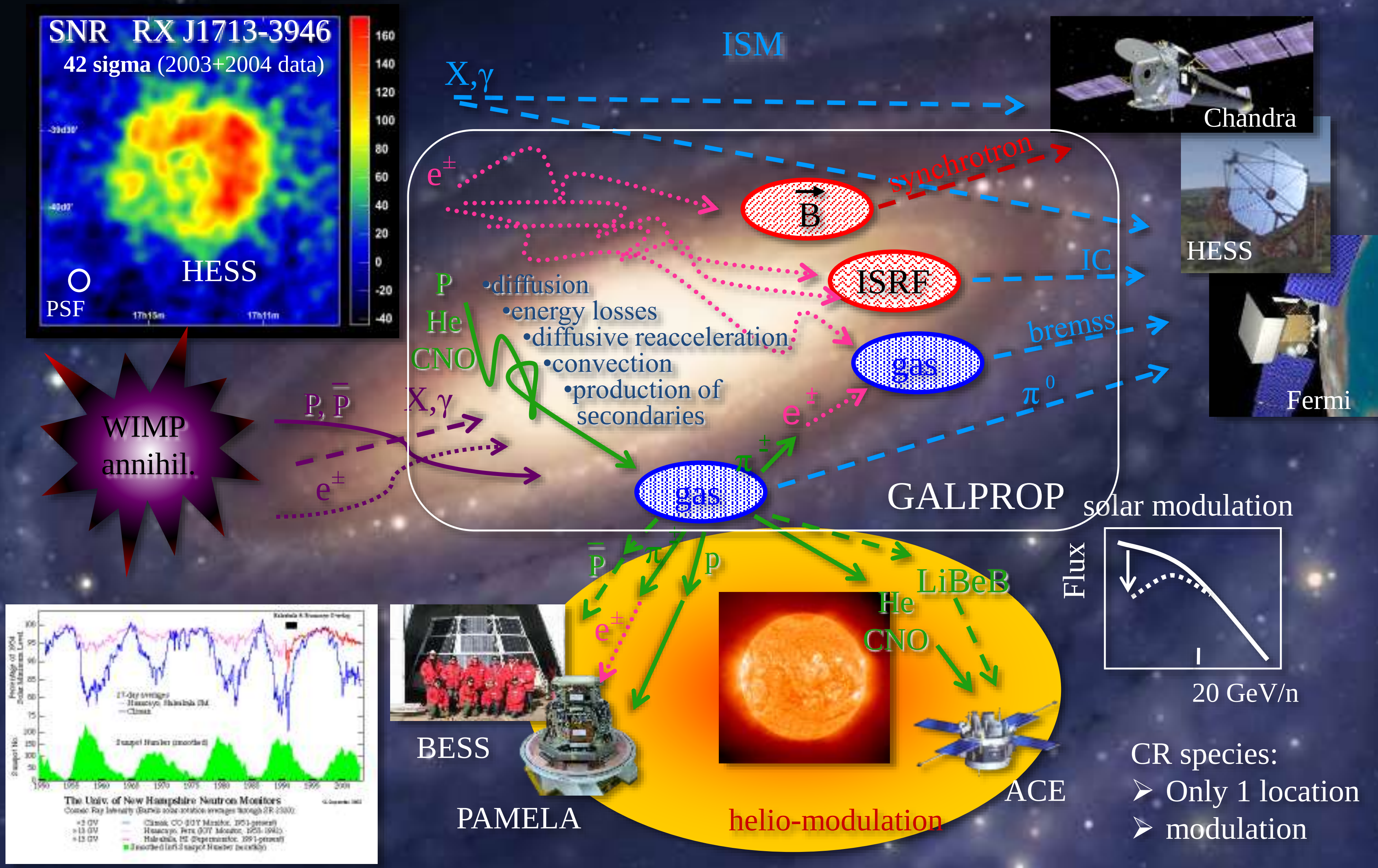
- Energy density of CRs is ~1 eV/cc, comparable to that of the interstellar radiation field, magnetic field, and turbulent motions of the gas
- The only pieces of matter that come to us from Galactic & extragalactic distances
- Nucleosynthesis: Li, Be, B are all produced by CRs
- Radiation environment for space flight
- Production of cosmogenic nuclides
- T-storm lightning flashes
- Evolution of life on Earth (ionization)
- Mass extinctions
- Signatures of new and exotic physics



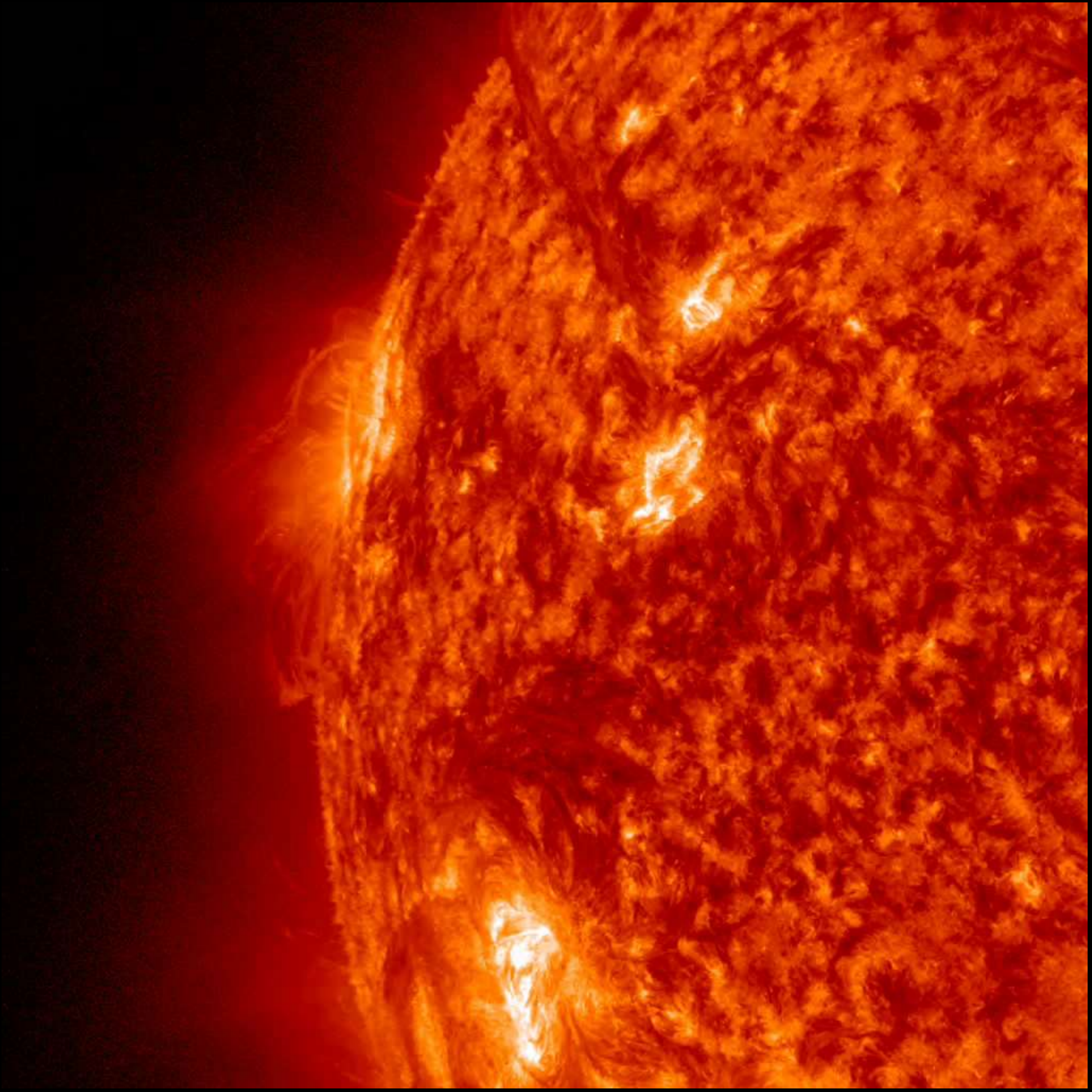



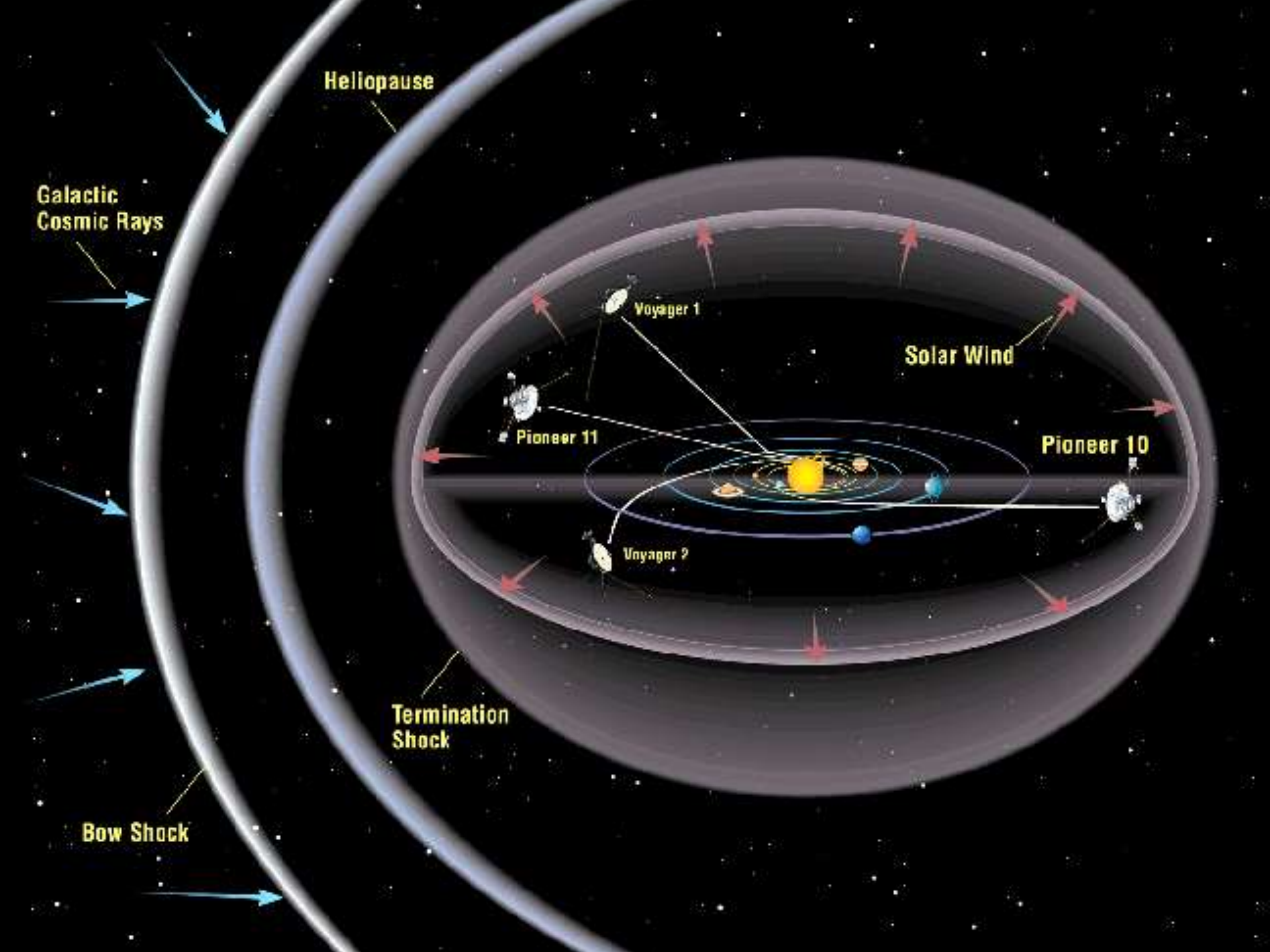




CRs in the interstellar medium

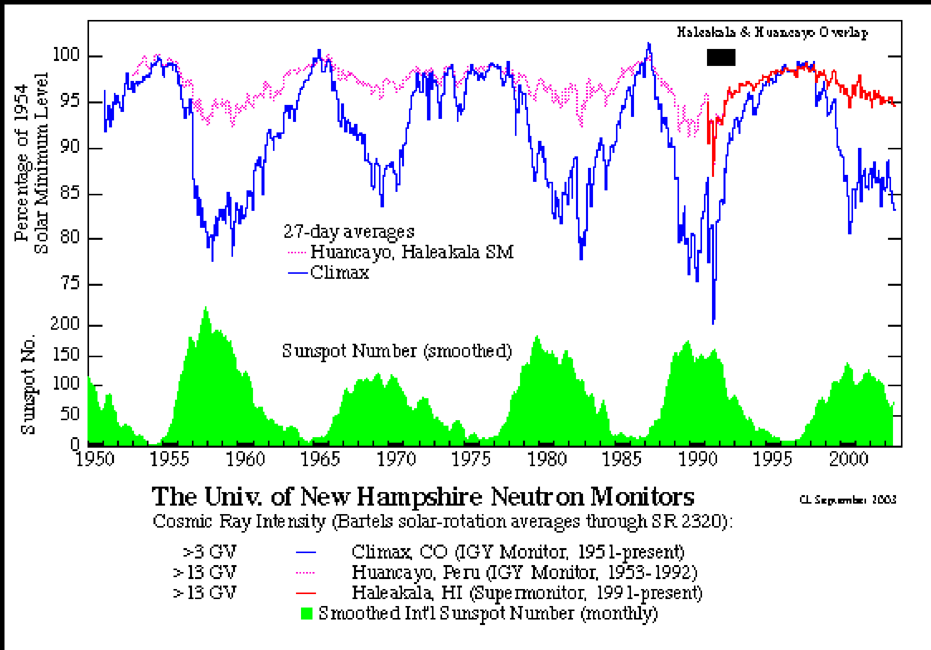


Our Star



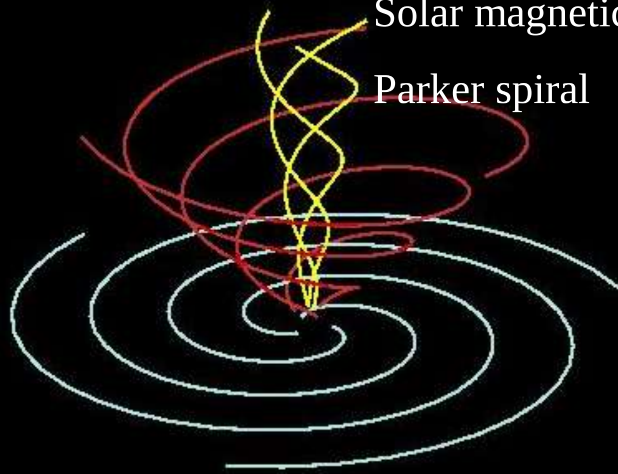

Heliopause
Galactic
Cosmic Rays
Voyager 1
Solar Wind
Pioneer 11
Pioneer 10
Voyager 2
Termination
Shock
Bow Shock

Heliospheric propagation

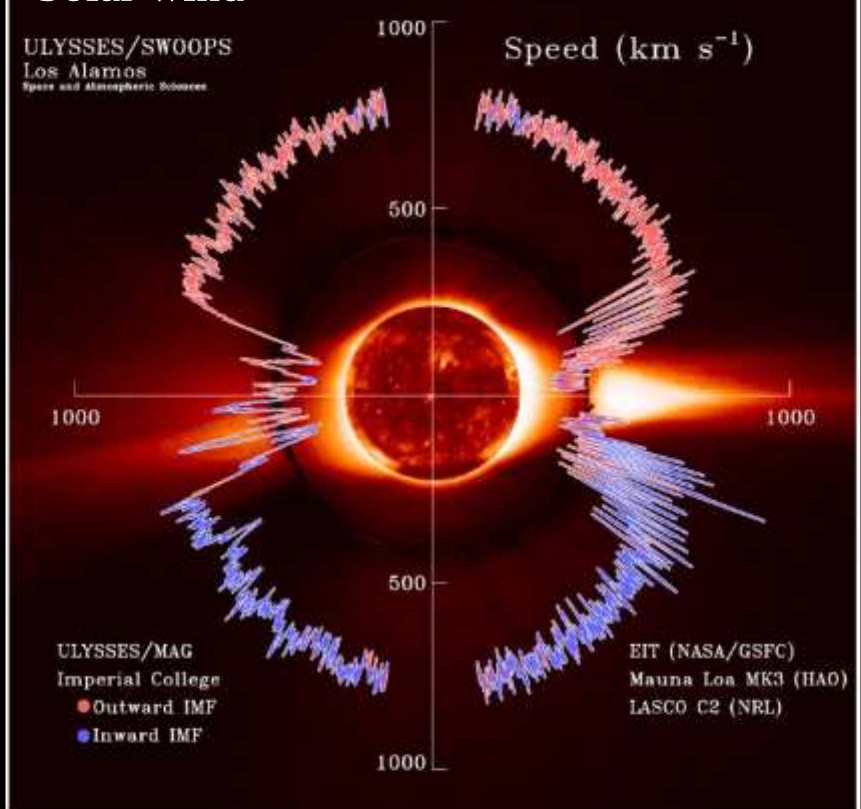


Solar magnetic field

Parker spiral



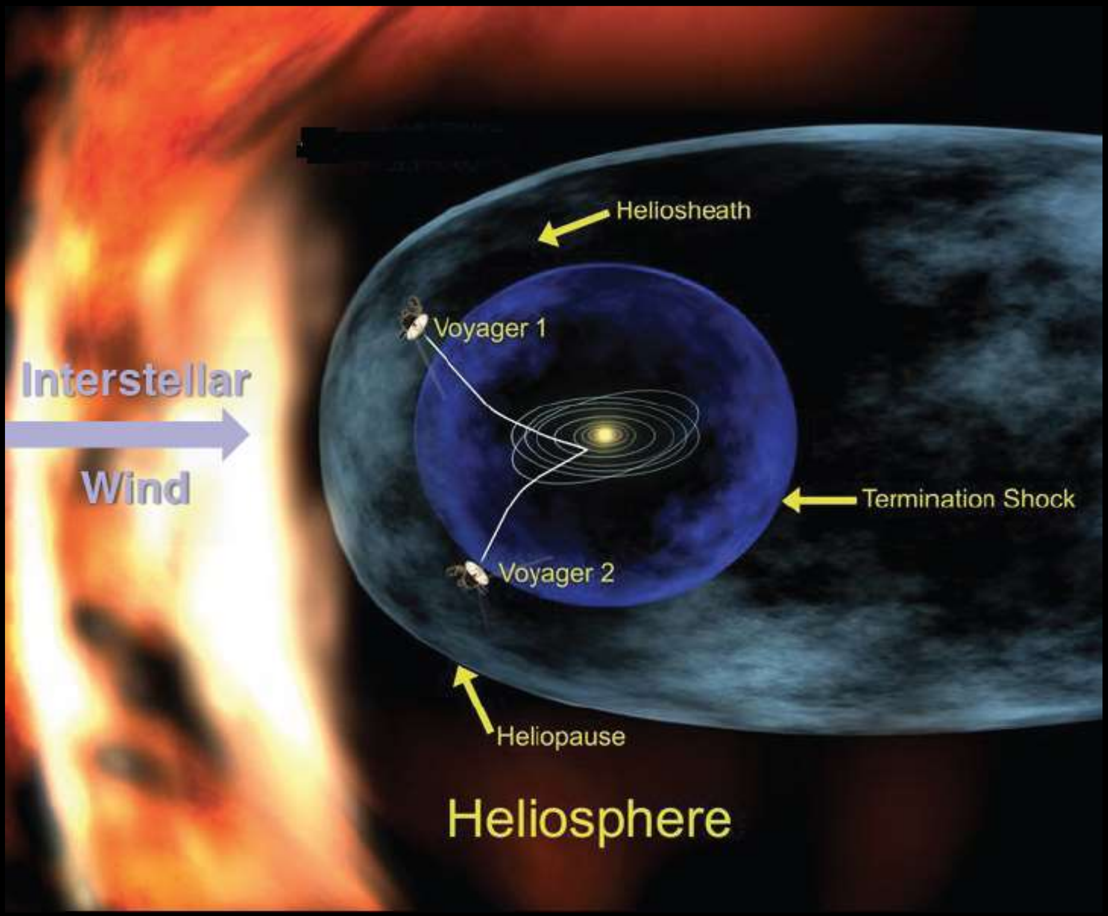
Solar wind



Main factor affecting propagation of CRs

- ✧ Solar magnetic field
- ✧ Solar wind
- ✧ Changes every 11 years, but true period is 22 years
- ✧ Size of the heliosphere

Voyager 1 in the interstellar space



Voyager 1 131.0 AU

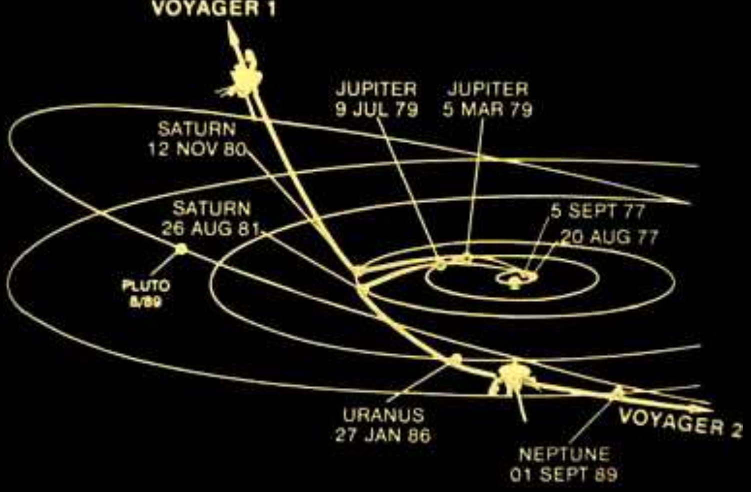
19.7 billion km

Voyager 2   107.7 AU

16.2 billion km

~2 years to interstellar space?

Launched in 1977!

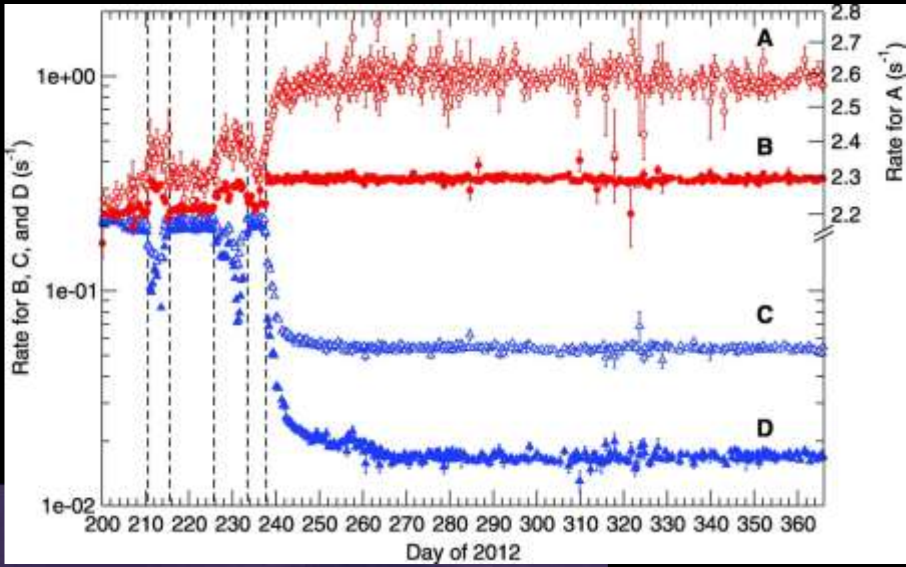


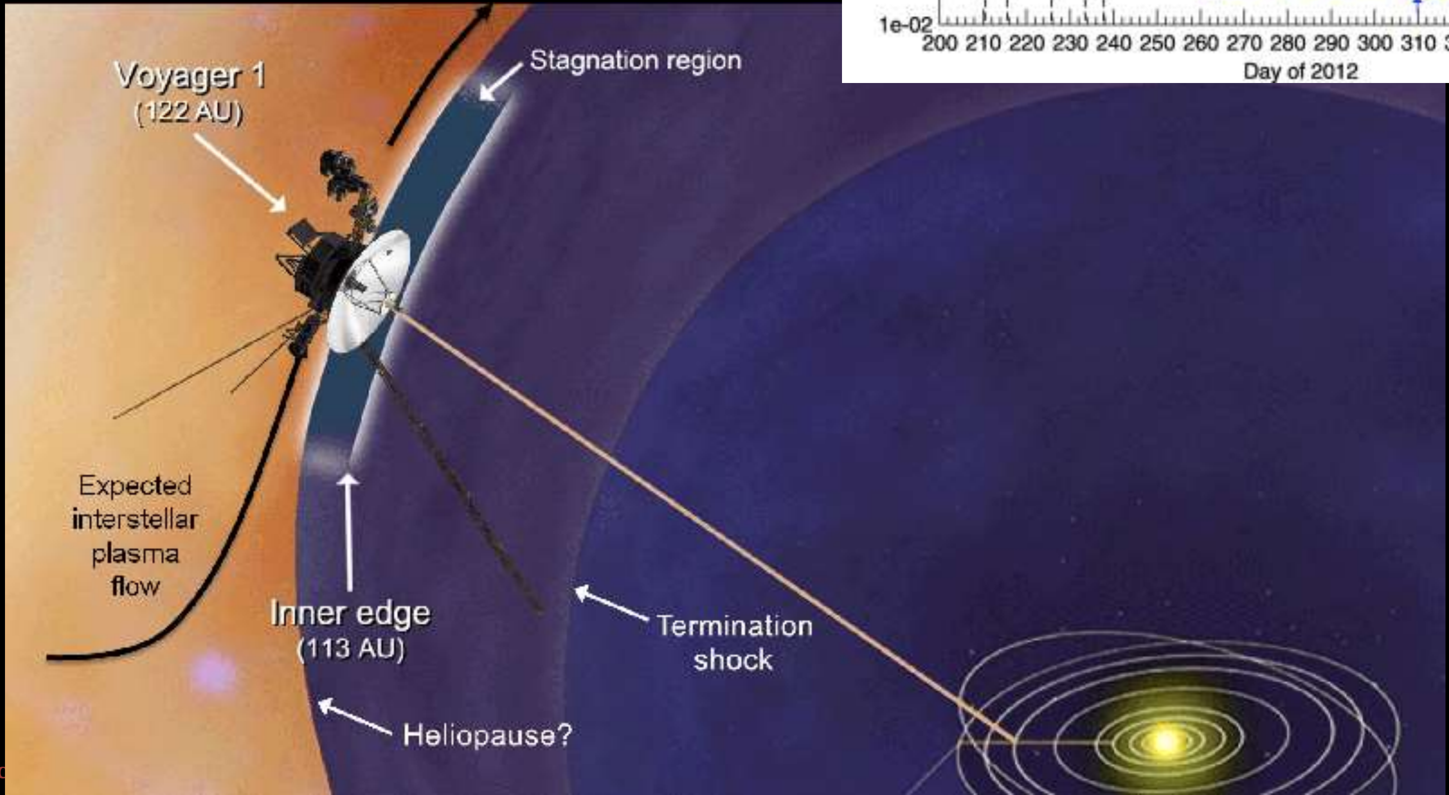
E. Stone 2015

Kitchen experiment

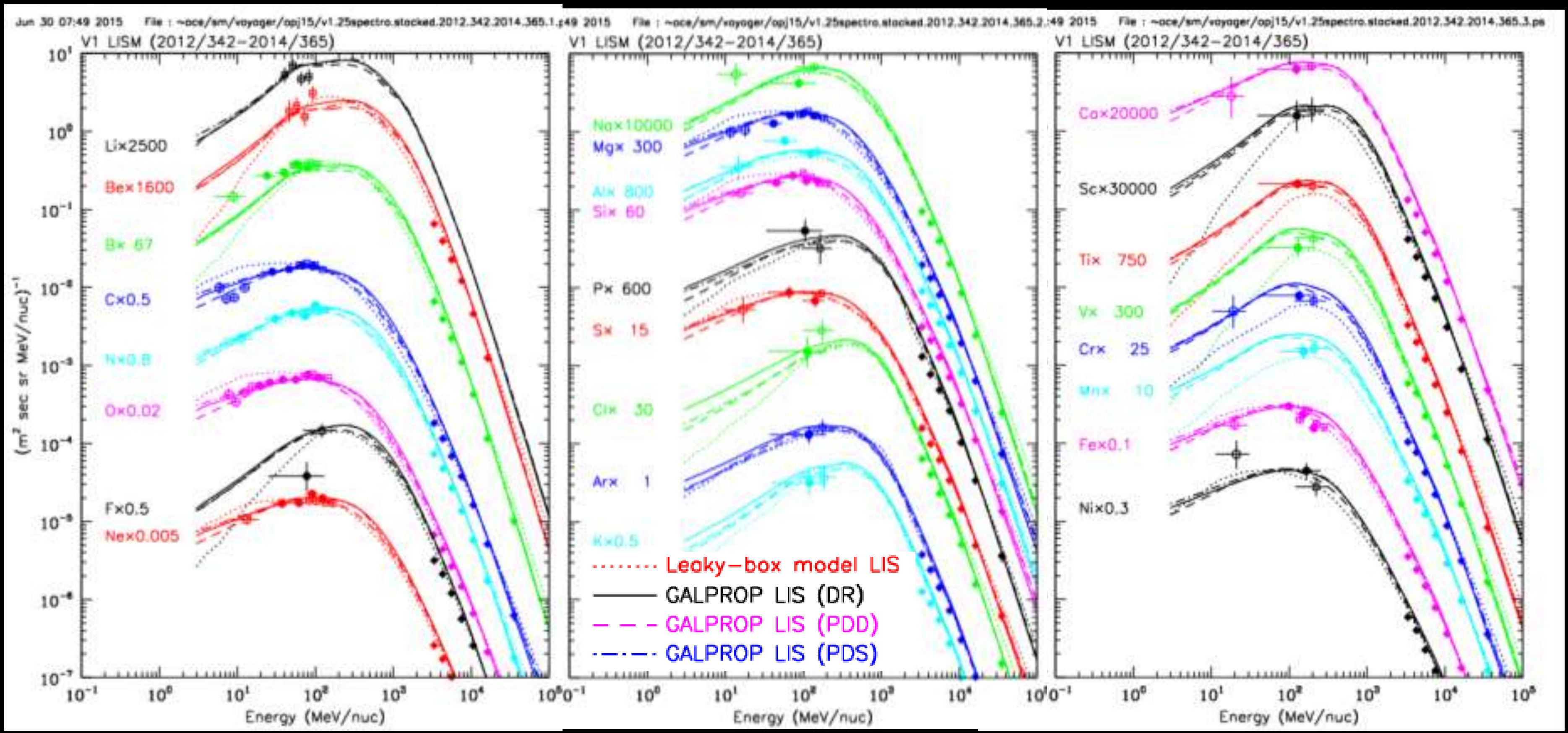
Interstellar probe – Voyager 1

- (A) (y axis on right) GCR nuclei (E > 70 MeV) at the High Energy Telescope 1
- (B) (y axis on left) GCR electrons (6-100 MeV) observed by the Electron Telescope
- (C) (y axis on left) Protons with 7 to 60 MeV stopping in HET 1 are mainly anomalous cosmic rays before 2012/238 (25 August) and galactic cosmic rays after that
- (D) (y axis on left) Low-energy particles mainly protons with 0.5 to ~30 MeV accelerated at the termination shock and in the heliosheath



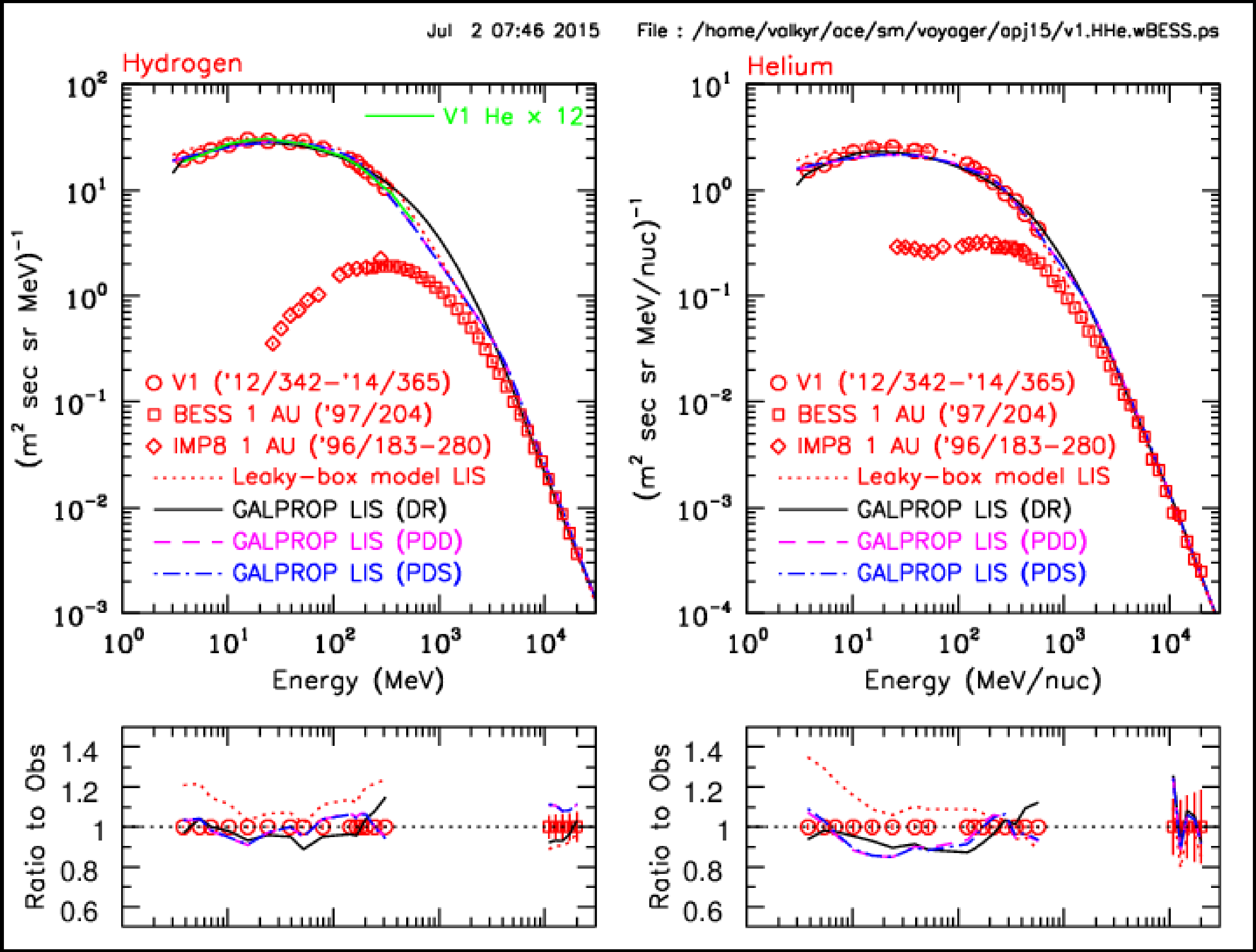


Voyager 1 spectra for 2012/342-2014/365

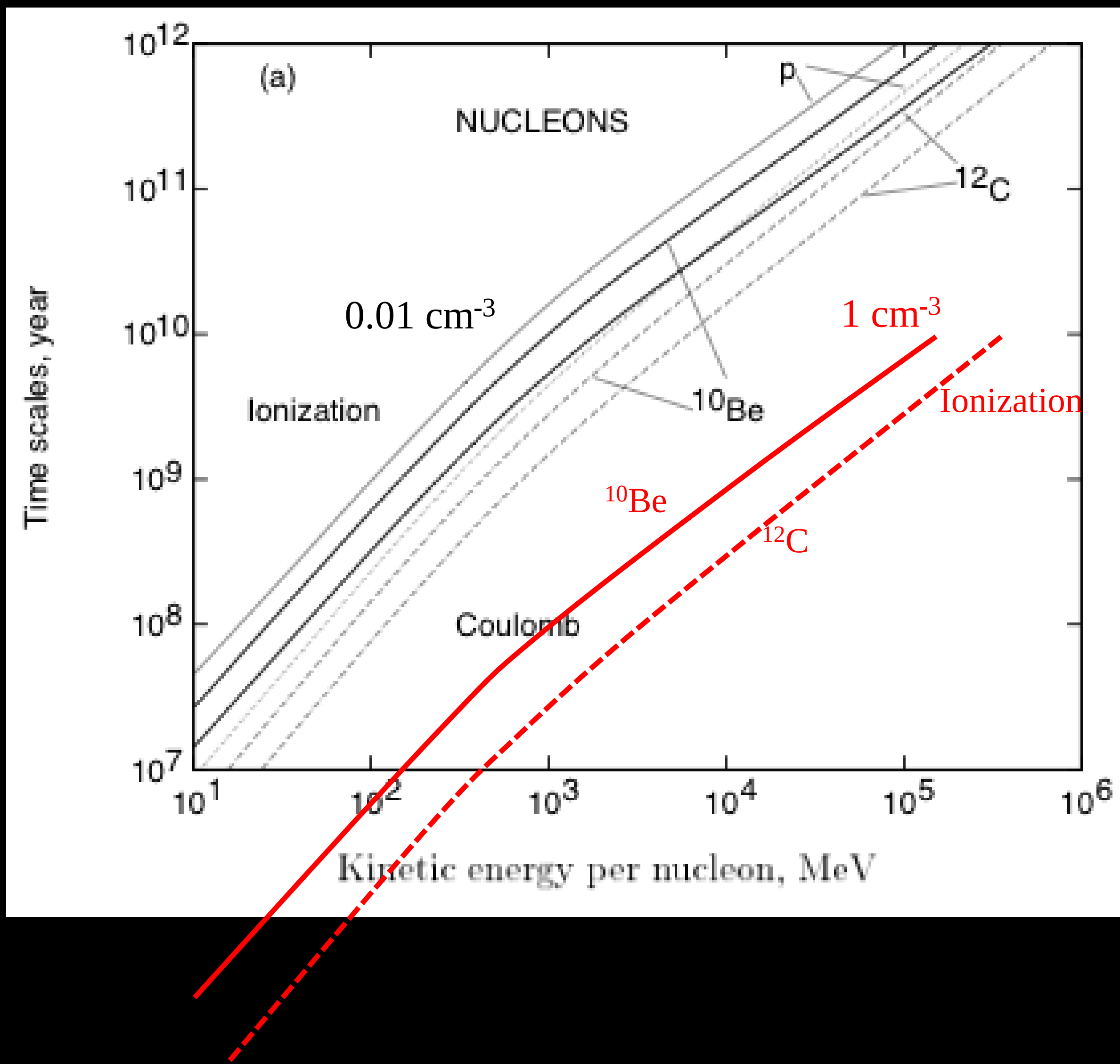


Li – Ni :

Voyager 1 – H and He spectra



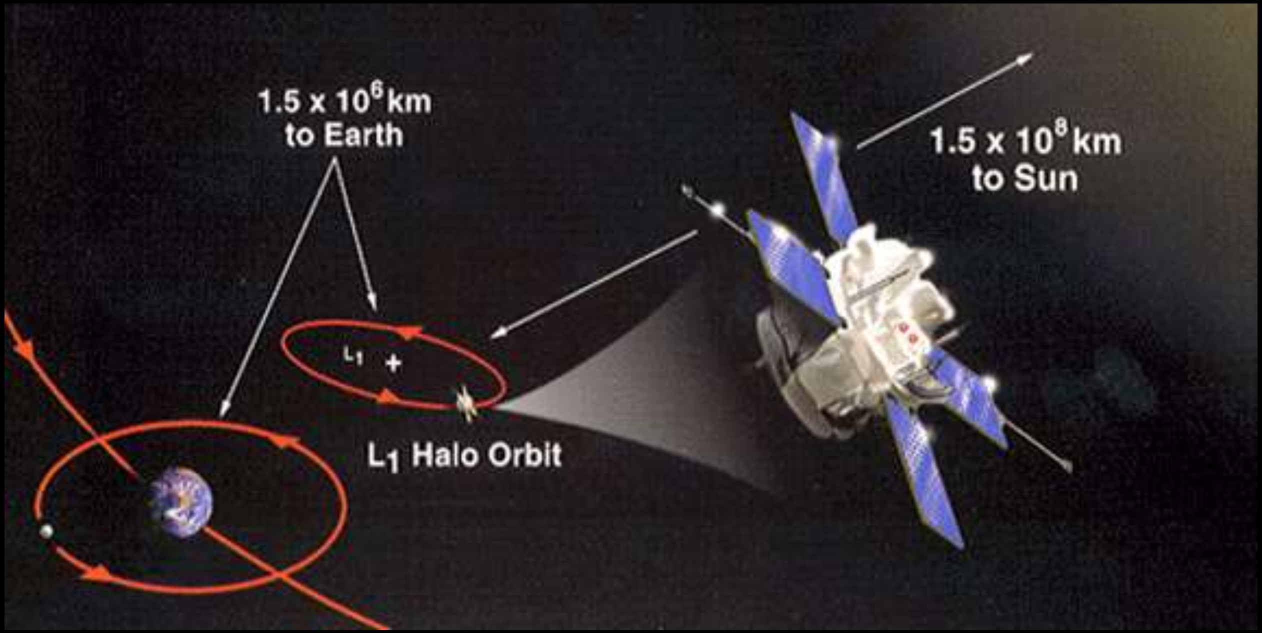
Energy losses of nucleons

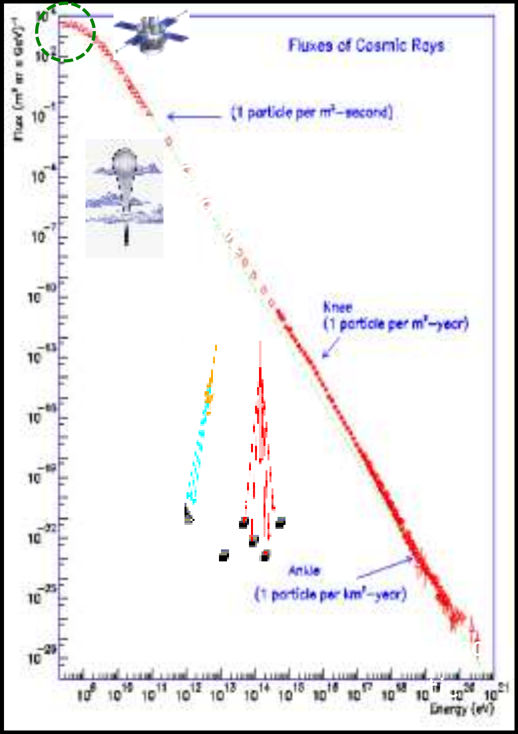


- The ionization and Coulomb losses are calculated for the gas number density 0.01 cm^{-3} & 1 cm^{-3}
- Carbon at 10 MeV/n (nH ~1 cm^{-3}):

  $\tau \sim 30$ kyr
- The energy losses by nucleons can be neglected above ~1 GeV
- Nuclear interactions are more important

Advanced Composition Explorer (ACE)

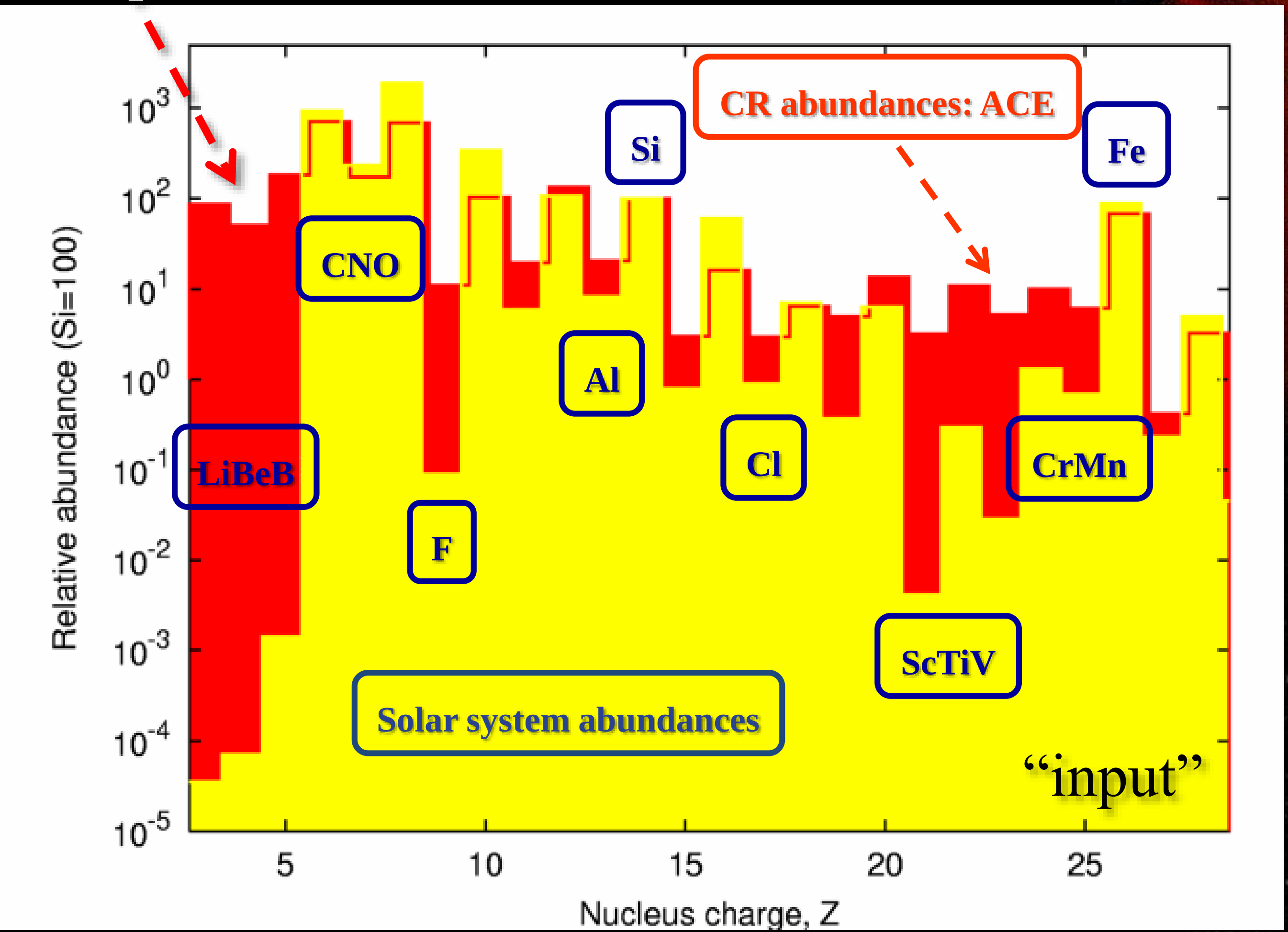


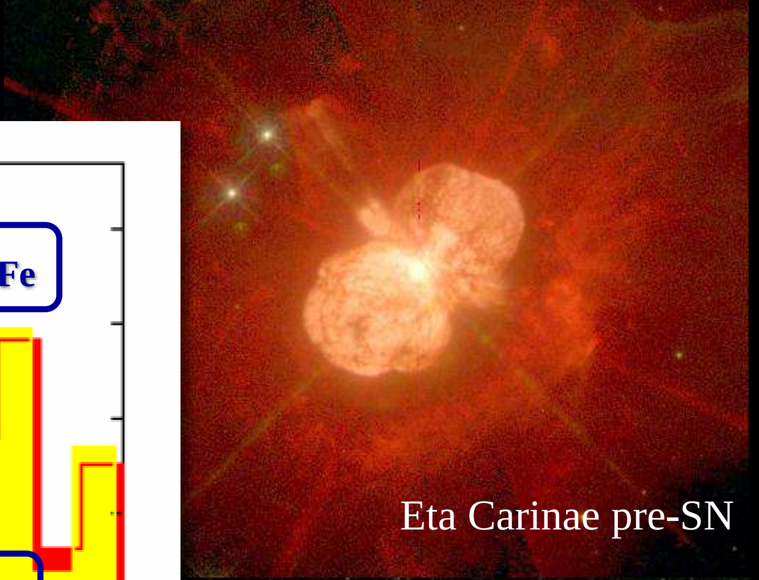


- ✧ Launched on August 25, 1997
- ✧ Energy range 100 eV/nucleon (solar wind) – 500 MeV/nucleon (Galactic CRs)
- ✧ Measures isotopic abundances of Hydrogen to Zinc (Z=1-30)
- ✧ 1.6 m across × 1 m high
- ✧ 785 kg at launch

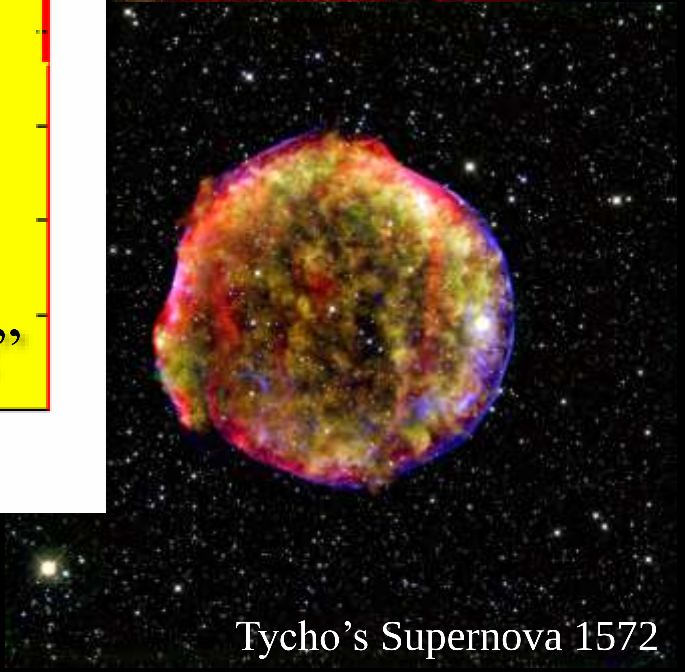
Composition of cosmic rays and interstellar medium

"output"





Eta Carinae pre-SN

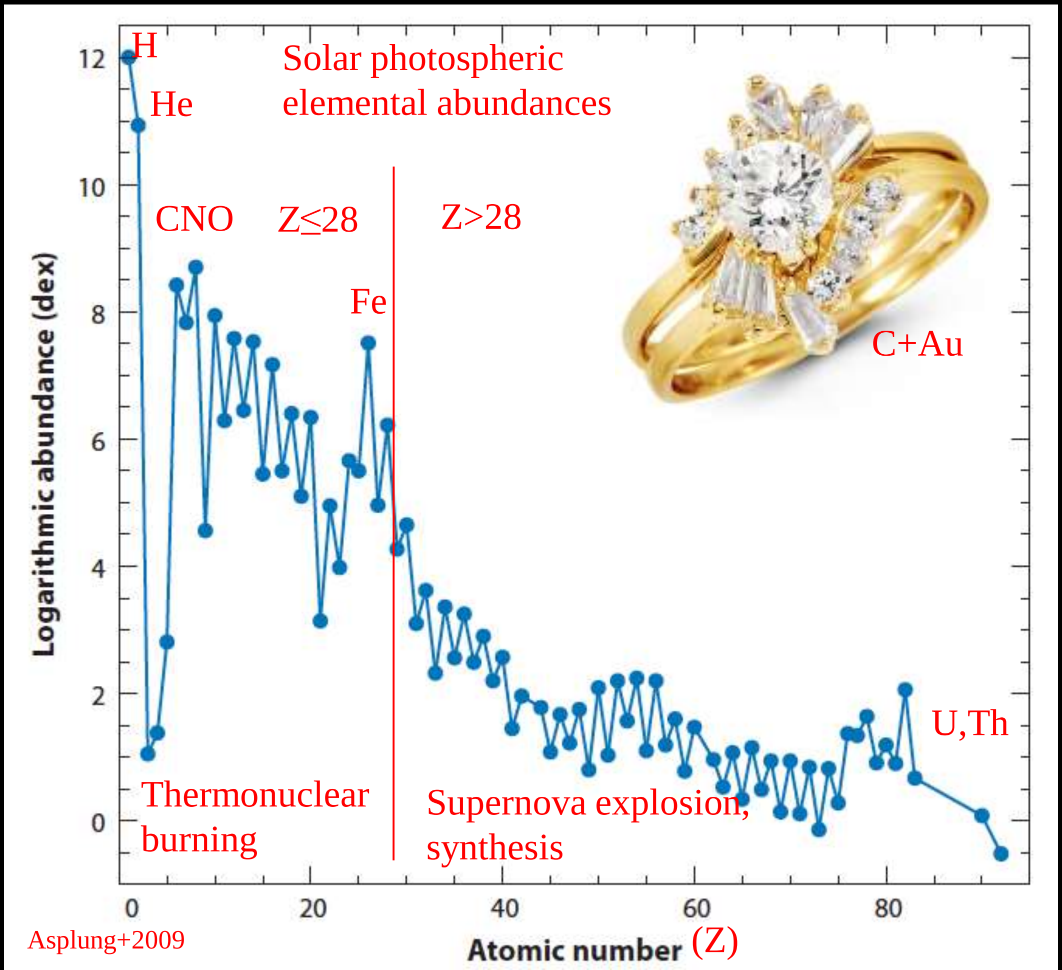


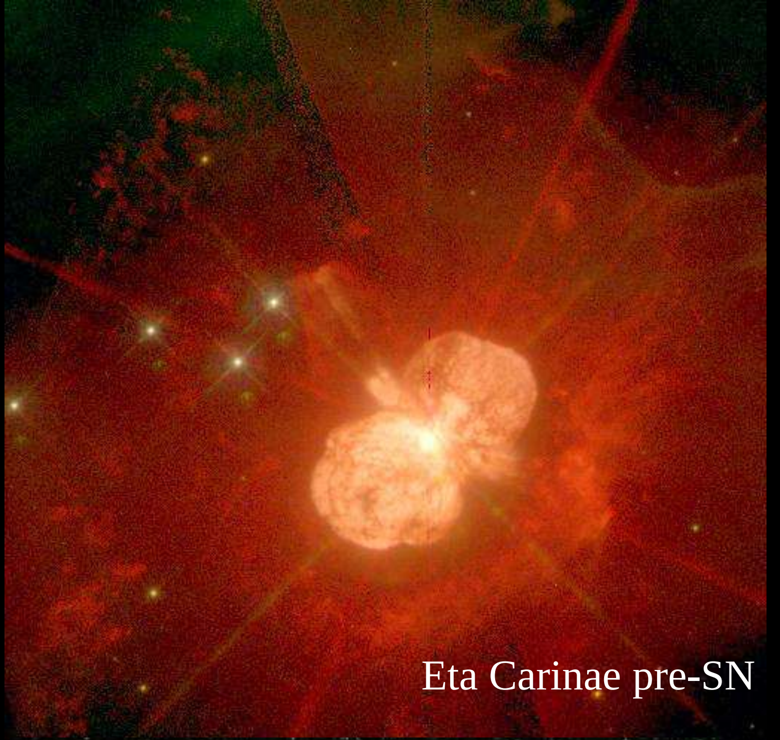
Tycho's Supernova 1572

Origin of elements

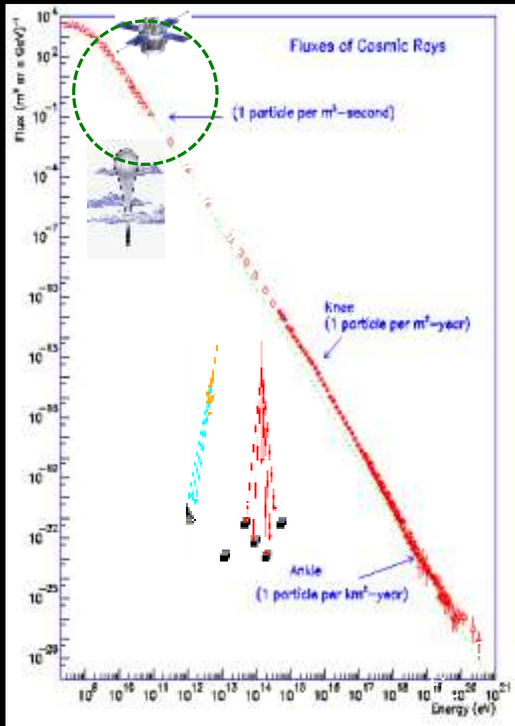
What can we get "burning" diamonds (Carbon)?

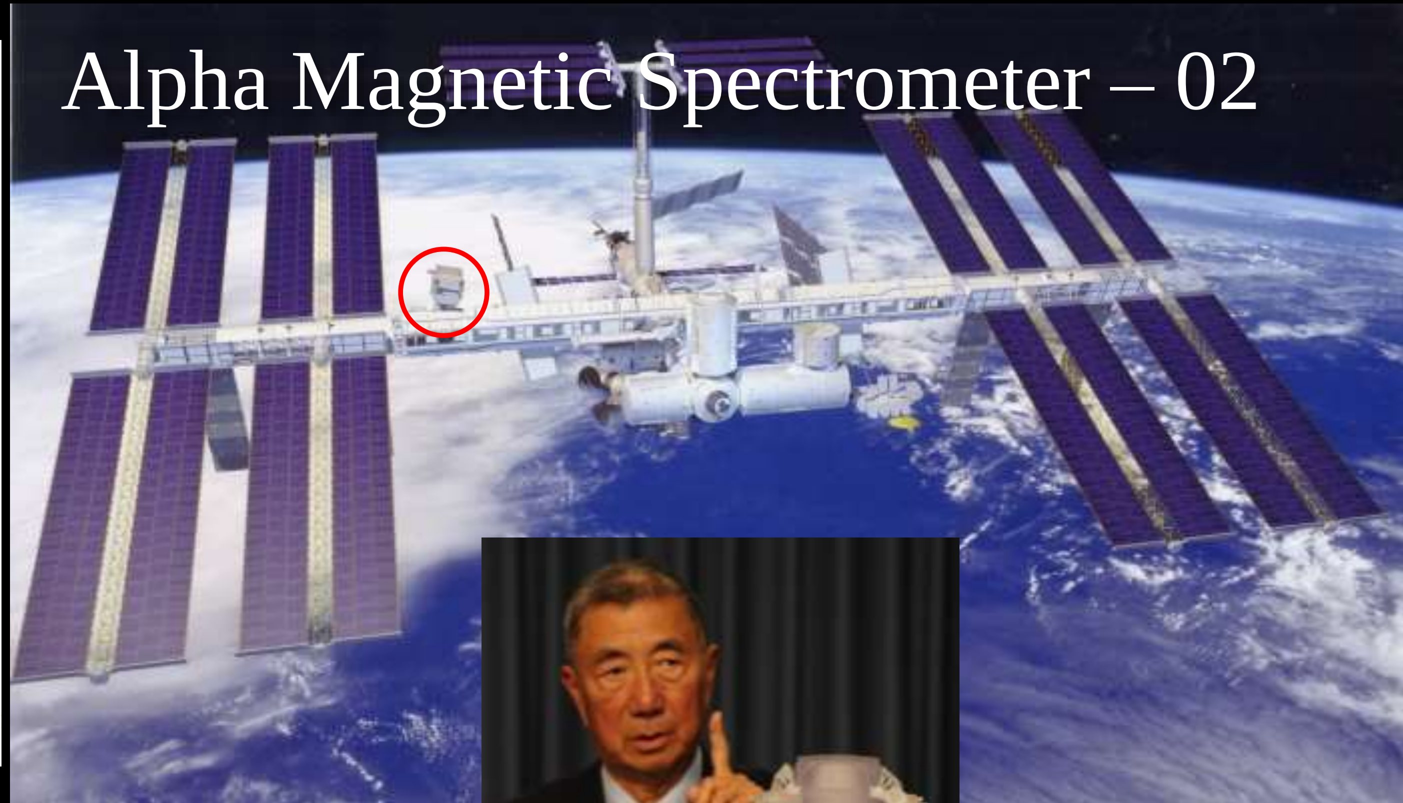
The final product is Iron!





Alpha Magnetic Spectrometer – 02





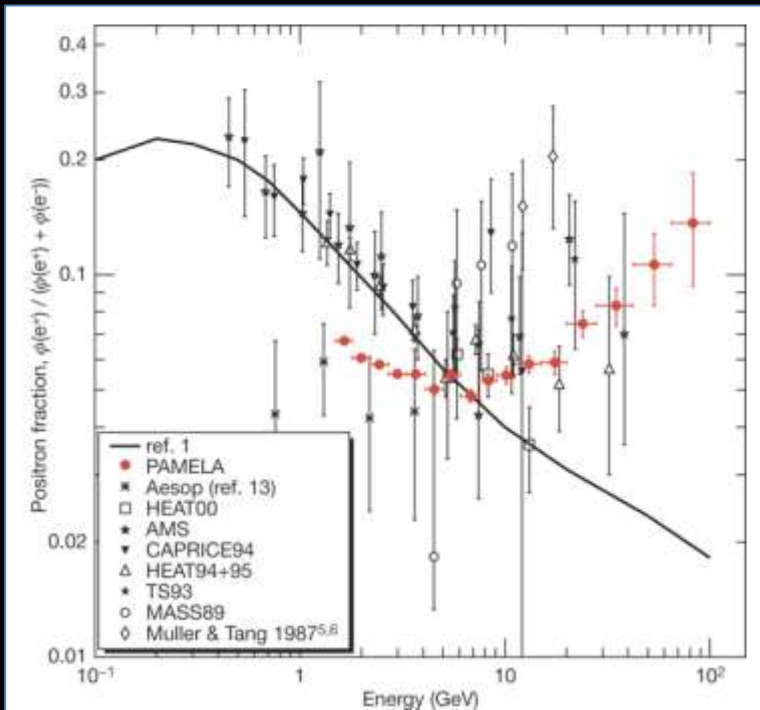
Samuel Ting (MIT)

- ✧ Launched on May 16, 2011
- ✧ Cost \$1.5 Billion
- ✧ Mass 7 ton
- ✧ Magnetic field 0.15 Tesla
- ✧ Energy range ~1 GeV – TeV

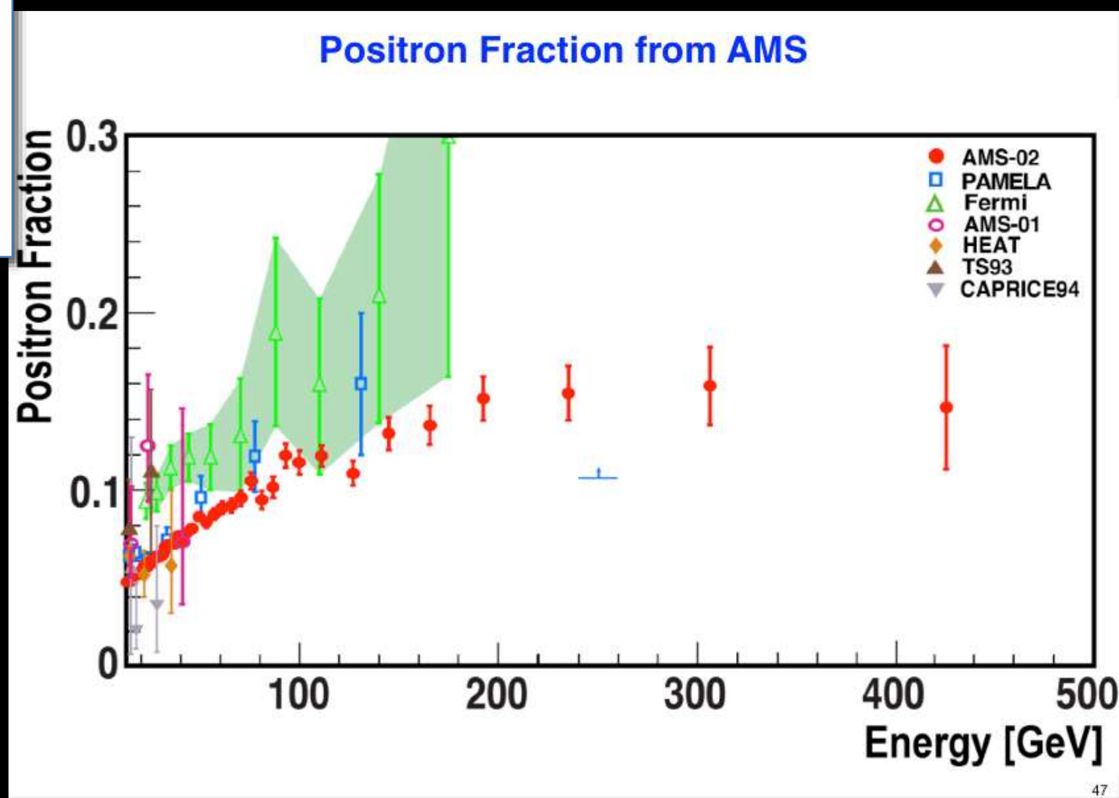
May 16, 2011

CERN Director General visits KSC, April 4, 2011

Rising positron fraction

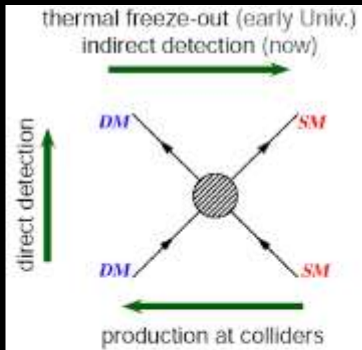


- ✧ PAMELA team reported a rise in the positron fraction compared to the "standard" model predictions
- ✧ "Standard" model:
  - ✦ Secondary production
  - ✦ Steady state
  - ✦ Smooth CR source distribution

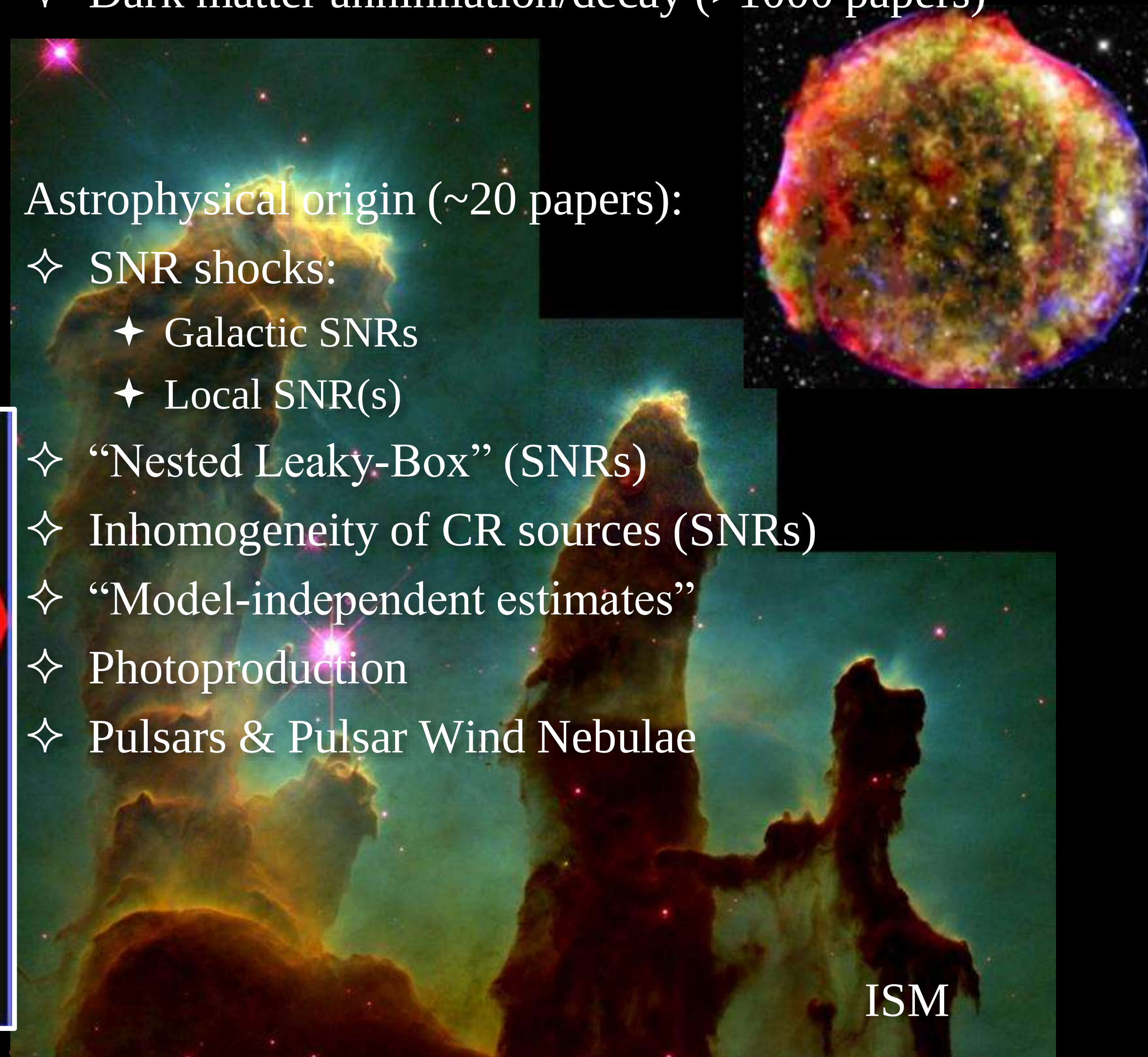


- ✧ Fermi-LAT and AMS-02 confirmed the excess and extended the measurements to higher energies

Interpretations



✧ Dark matter annihilation/decay (>1000 papers)



Astrophysical origin (~20 papers):

✧ SNR shocks:
  ✦ Galactic SNRs
  ✦ Local SNR(s)

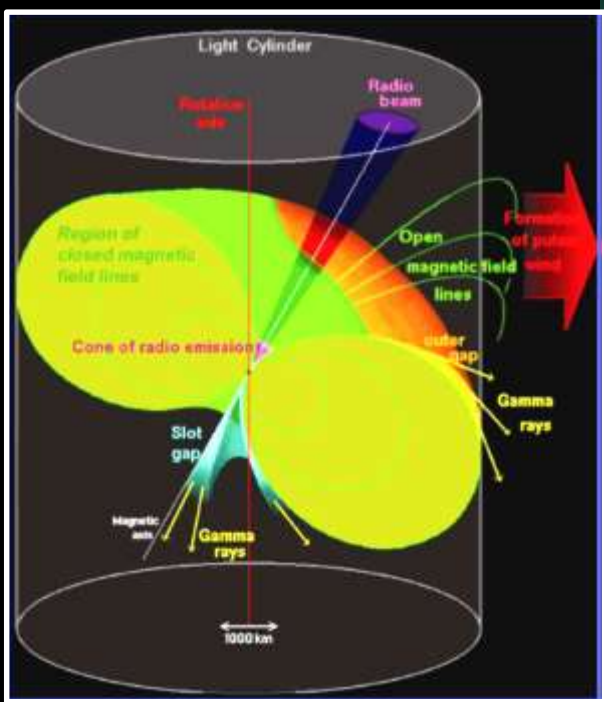
✧ "Nested Leaky-Box" (SNRs)

✧ Inhomogeneity of CR sources (SNRs)

✧ "Model-independent estimates"

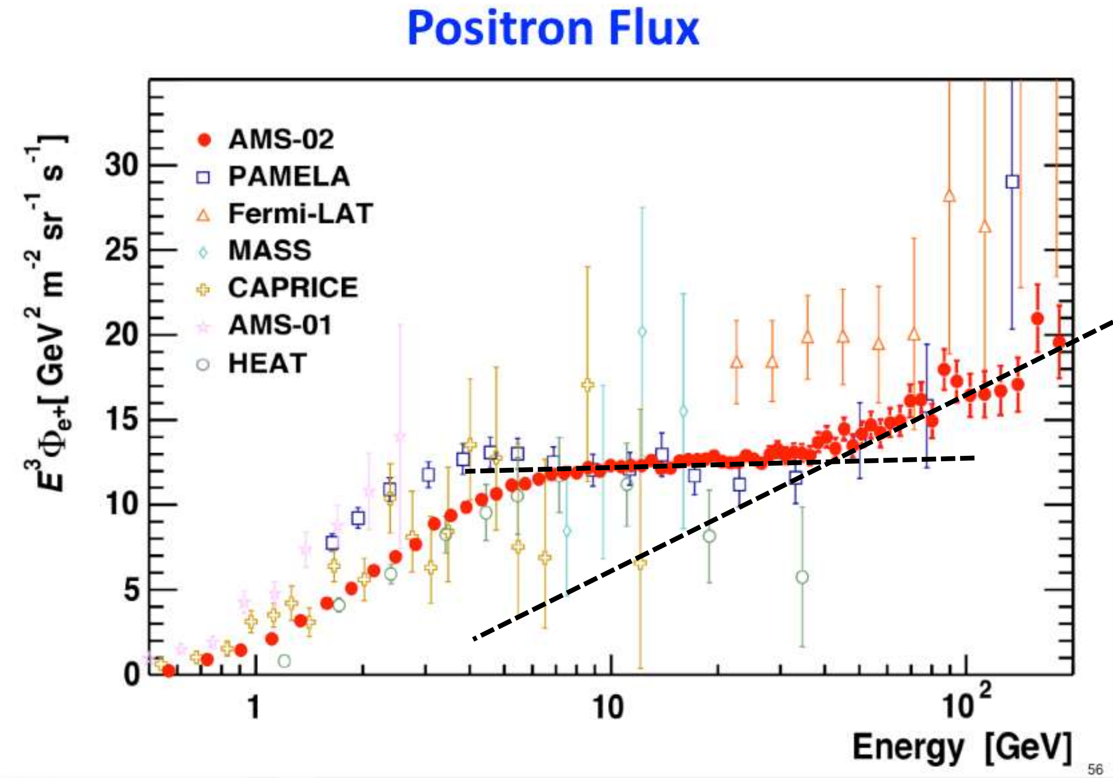
✧ Photoproduction

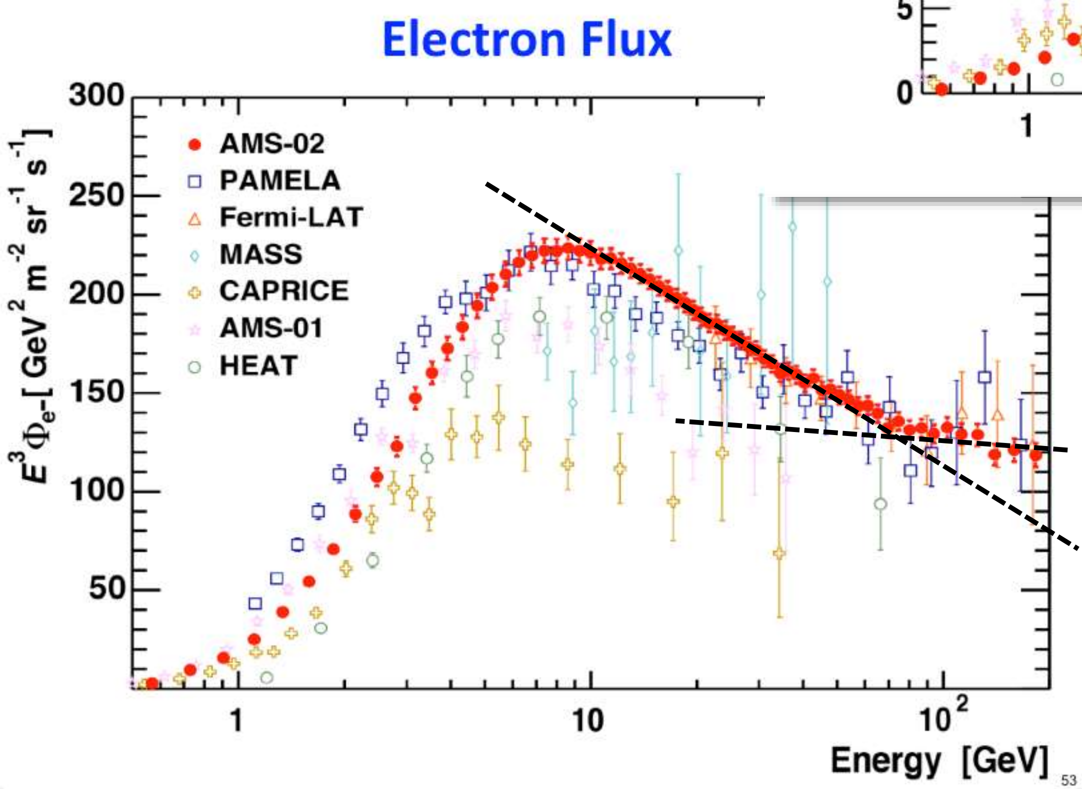
✧ Pulsars & Pulsar Wind Nebulae



AMS-02 e^+ & e^-

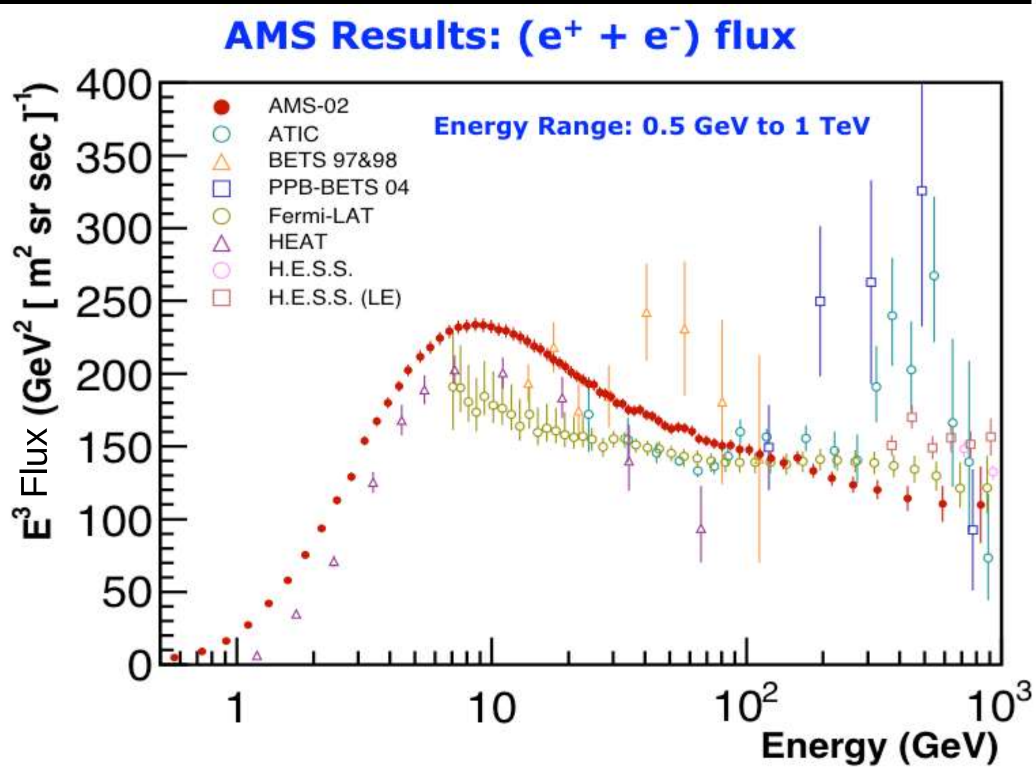
- ✧ One should look at the fluxes of e^+ & e^-, not the positron fraction

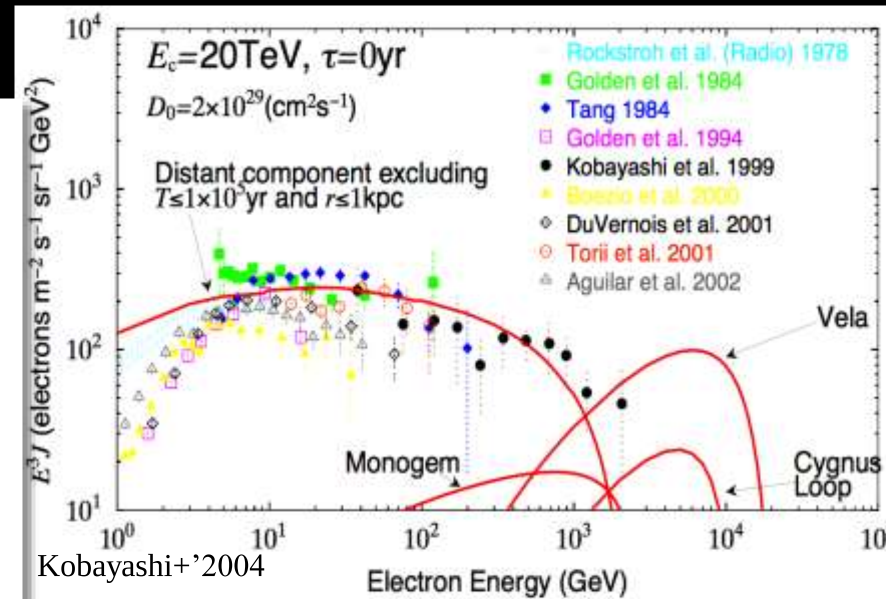




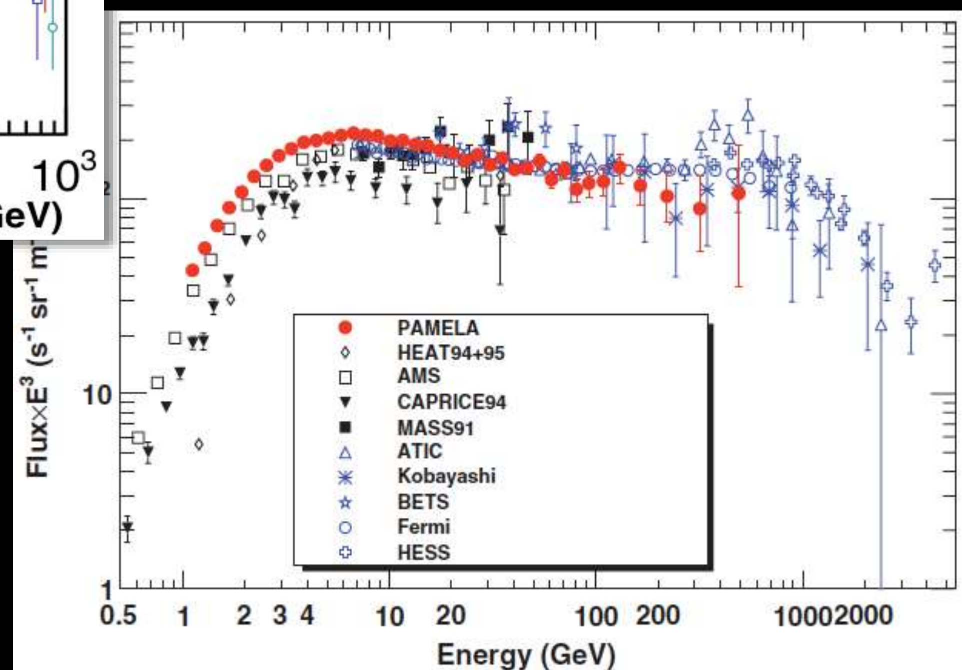
- ✧ Noticeable is a concave shape in both cases, a clear indication of an additional component >30 GeV

All-electron spectrum



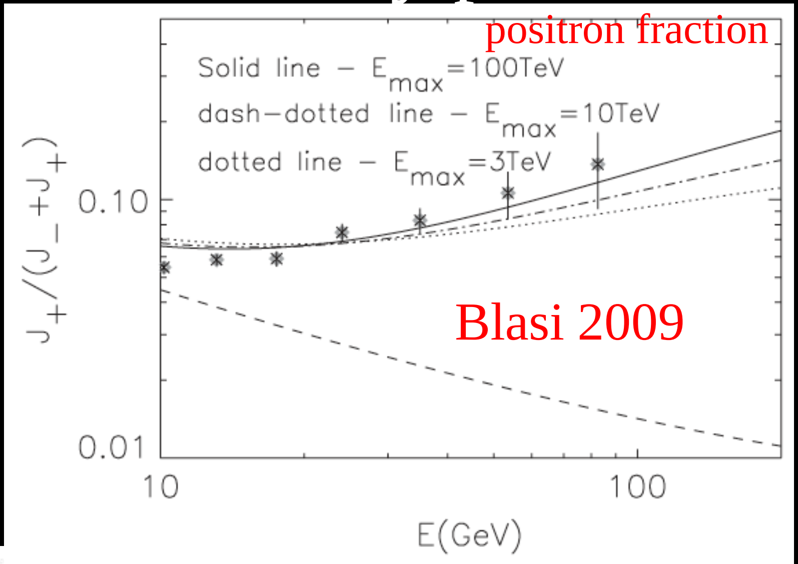


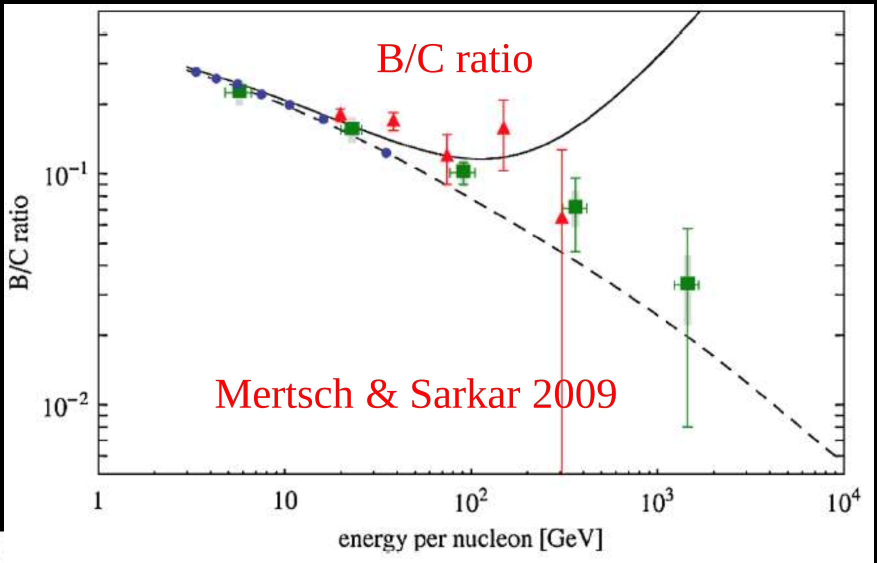
Kobayashi+'2004

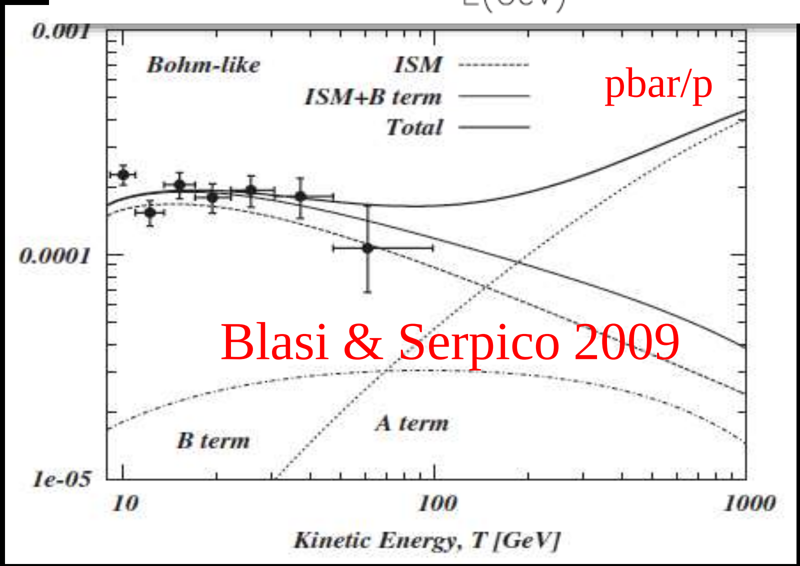


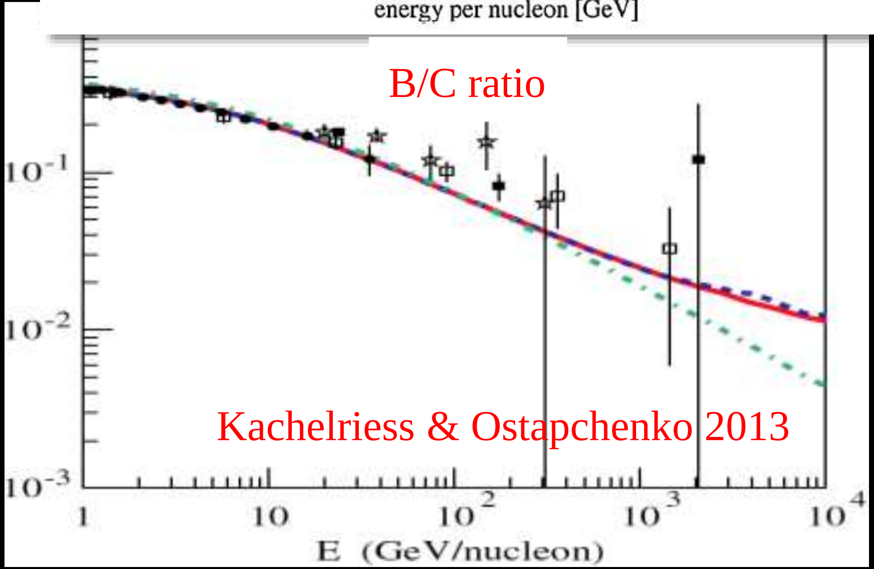
- ✧ Flatter than extrapolated from low energies
- ✧ Sharp cutoff at 1 TeV (HESS)
- ✧ Cannot be reproduced with a single power-law injection spectrum
- ✧ Monogem SNR: 86 kyr-old, at ~300 pc
- ✧ Need precise measurement and extension beyond TeV energies

Secondary production in a SNR shock



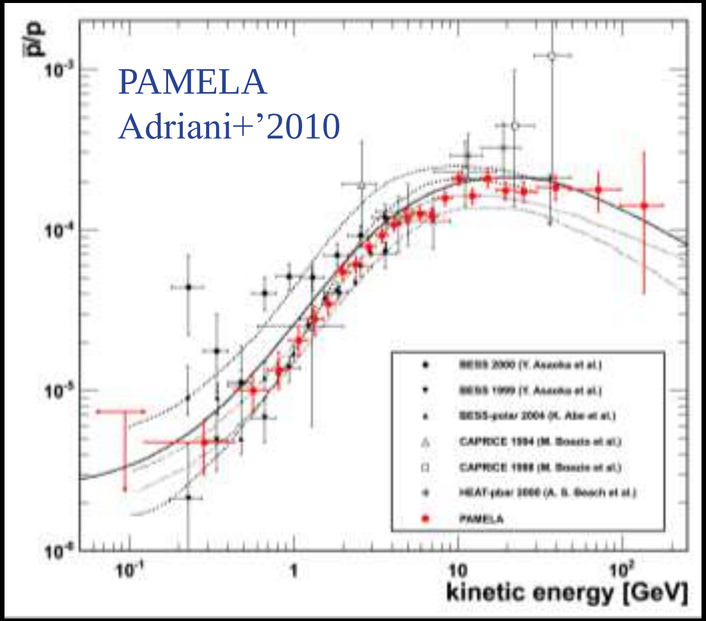


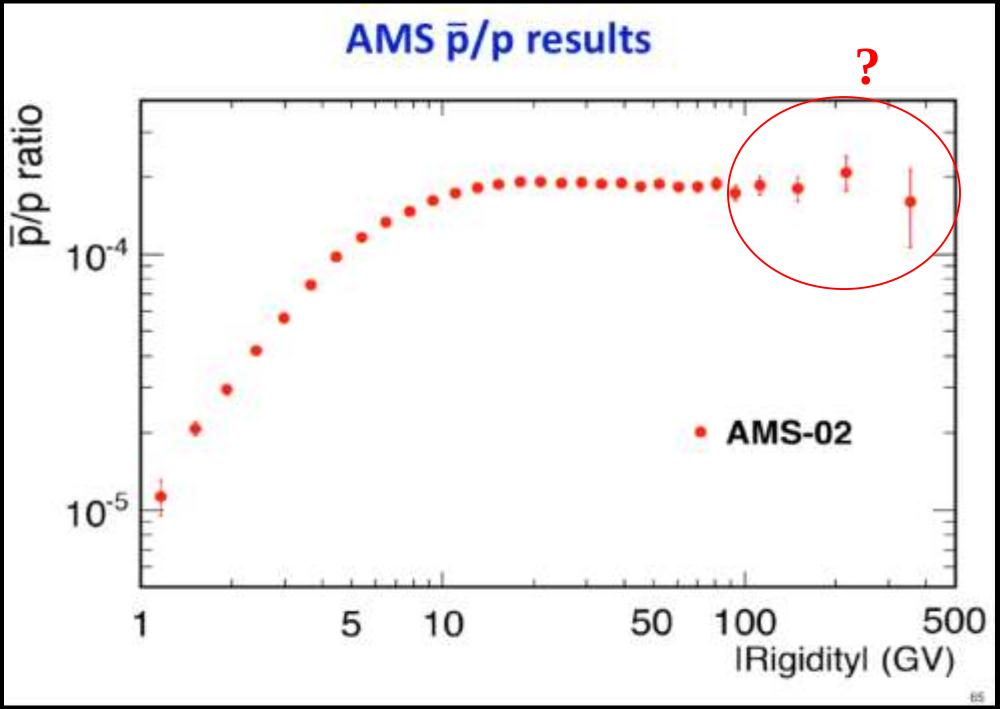


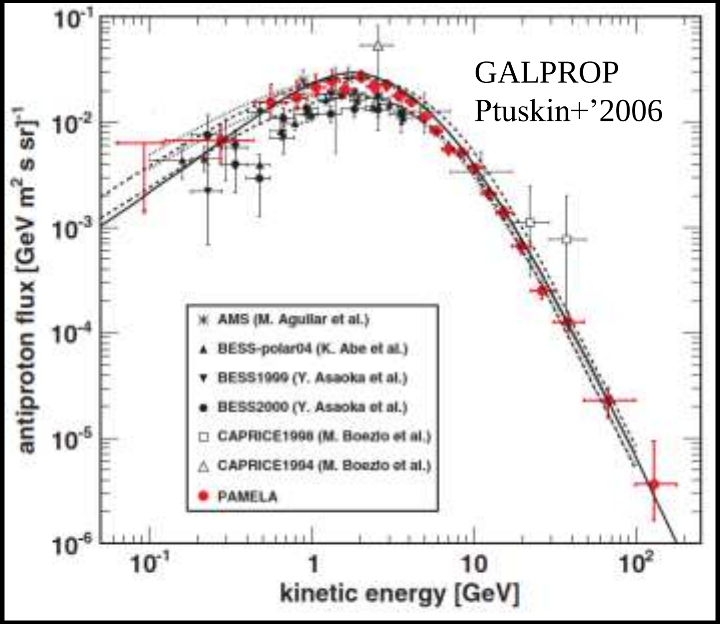


✧ The model assumptions are somewhat different, but all models predict a rise in the secondary products

AMS pbar/p ratio



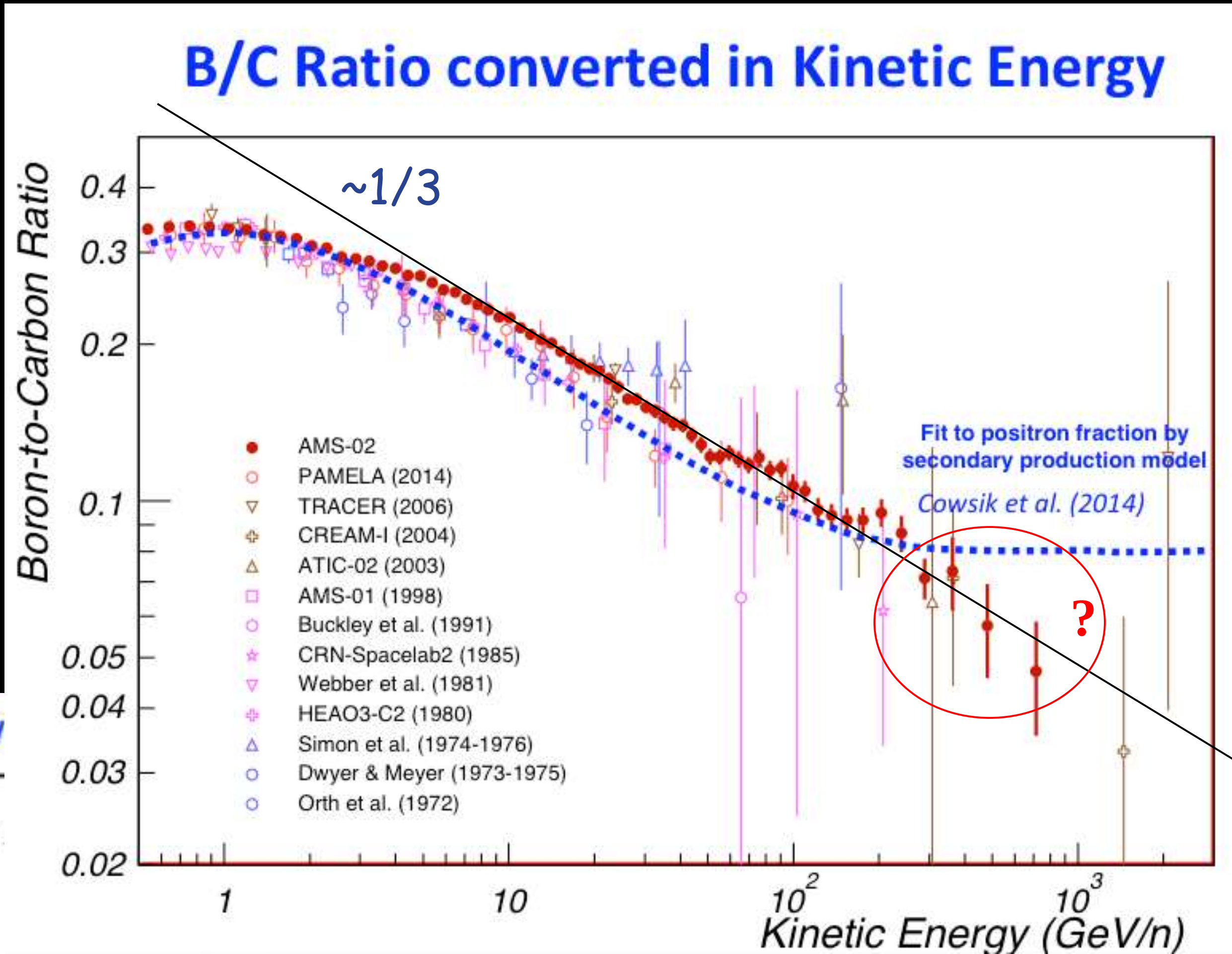


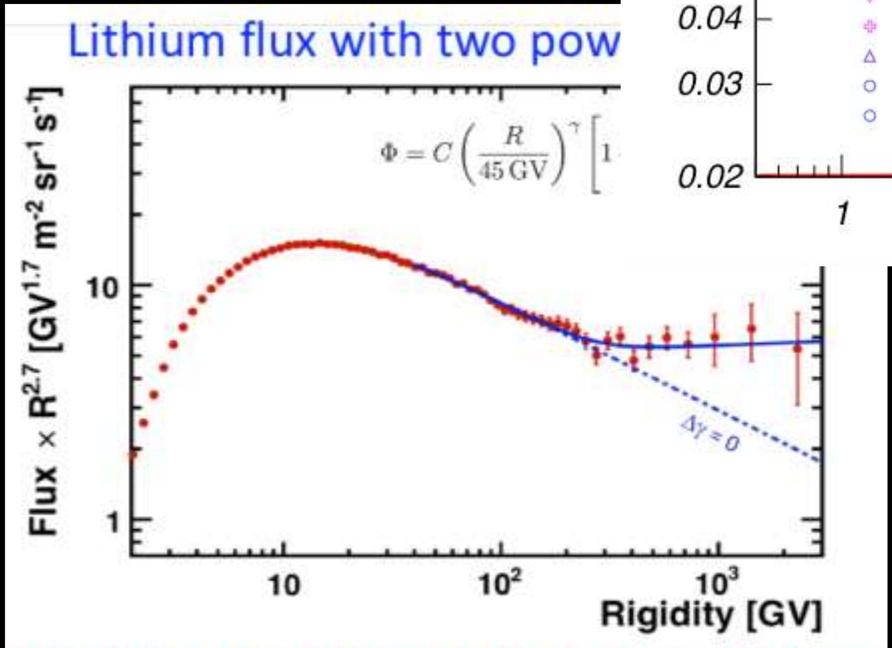


- ✧ The calculations were done in Ptuskin+'2006 with the CR p and He spectra without breaks and flattening above ~200 GV, so expect a bit of flattening in pbars >50 GeV
- ✧ New pbar production cross section is implemented in GALPROP (Kachelriess, IM, Ostapchenko'2015), which provides more pbars at HE, so stay tuned

AMS B/C ratio

- No significant change in the slope of the B/C ratio
- Rules out Cowsik+ model
- The slope >7 GeV/n is ~1/3 – clearly supports Kolmogorov reacceleration model

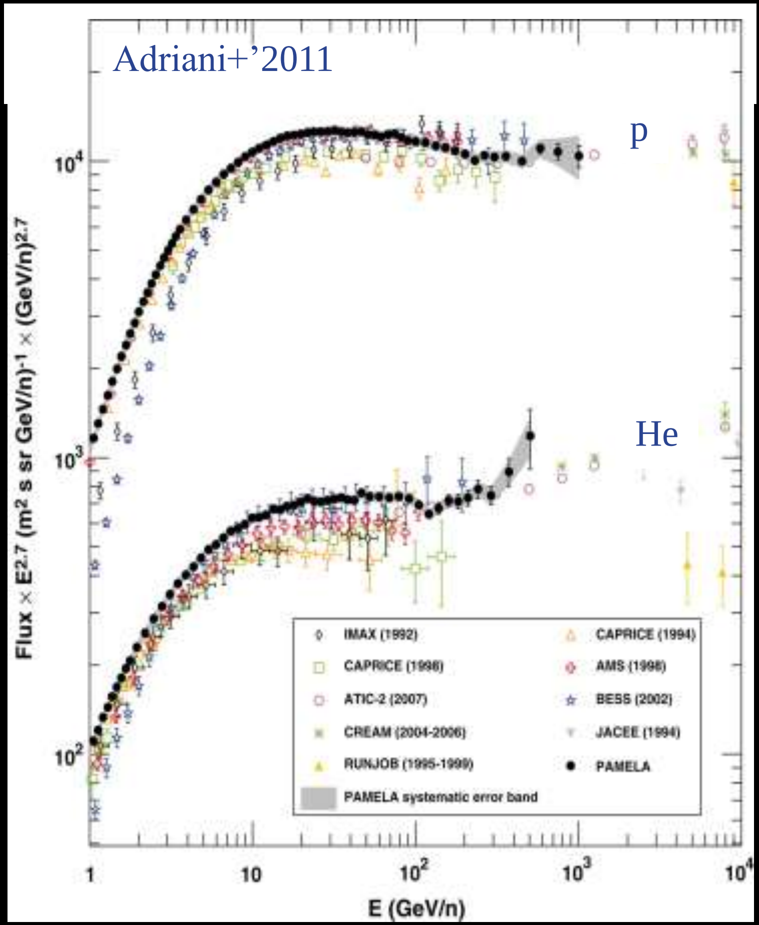


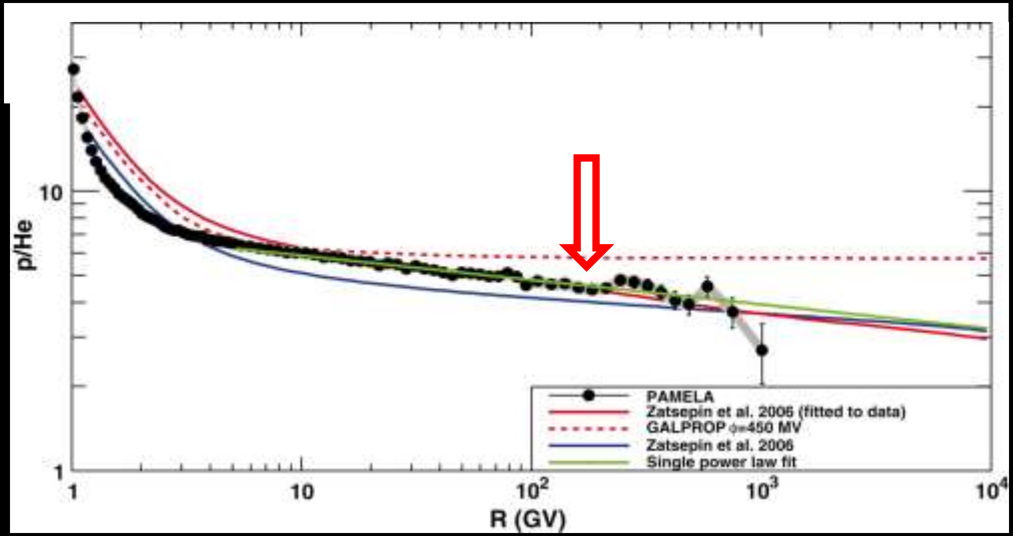


Slope changes at about the same rigidity as for protons and helium

- Interestingly, a break in the Li spectrum is found – similar to p & He
- No break reported in Carbon spectrum

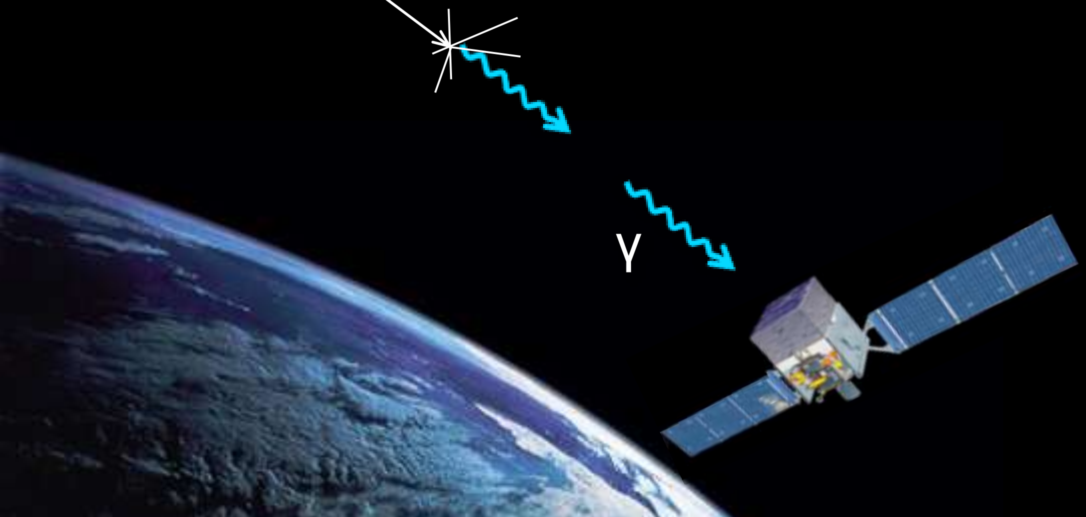
Break in the CR p and He absolute fluxes

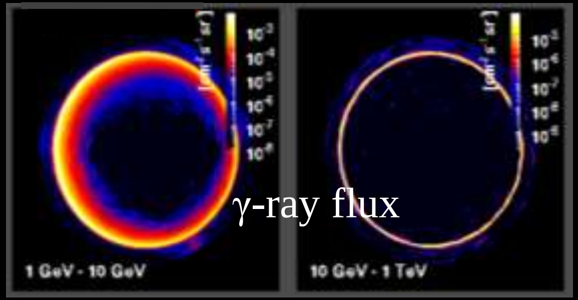


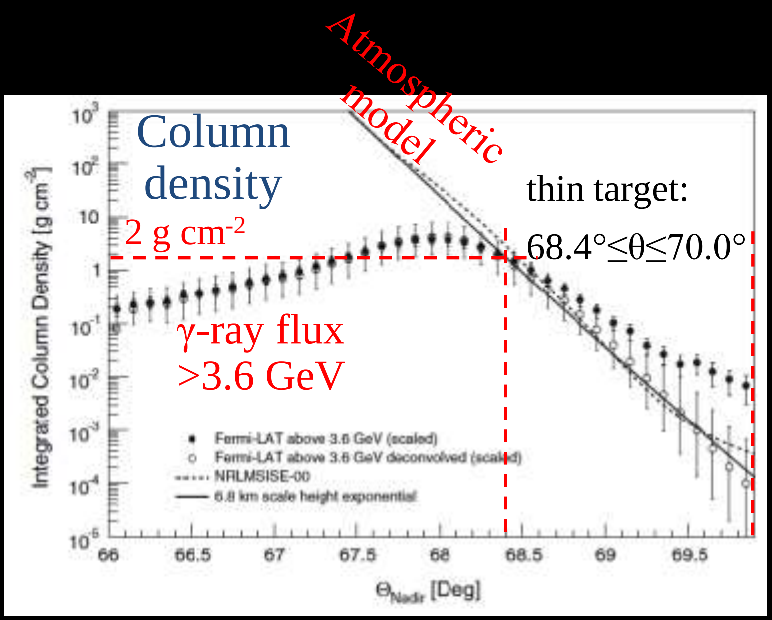


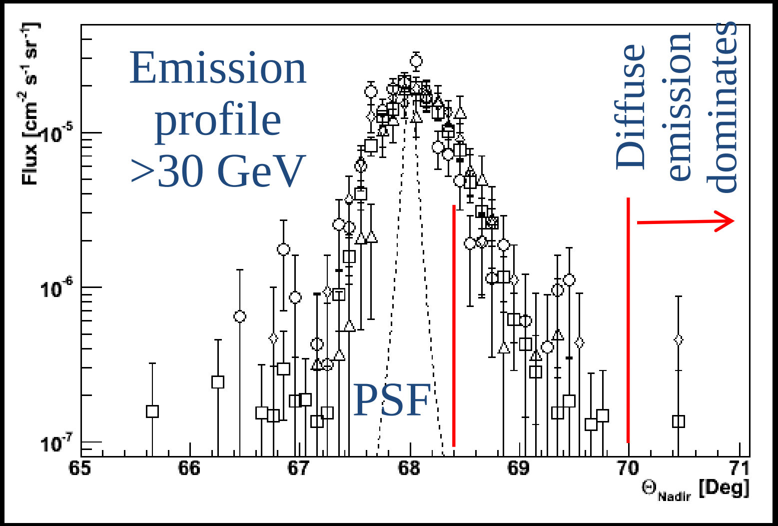
- ✧ Data from several experiments (BESS, AMS-01, ATIC'2009, CREAM'2010, PAMELA'2011) are all consistent and indicate spectral hardening above ~100 GeV/nucleon
- ✧ p/He ratio vs. rigidity R is smooth
- ✧ He spectrum is flatter than proton spectrum
- ✧ Heavier nuclei seem to share the same trend
- ✧ New data may provide us with a hint to the origin of high energy CRs

Fermi-LAT observations of the Earth's limb



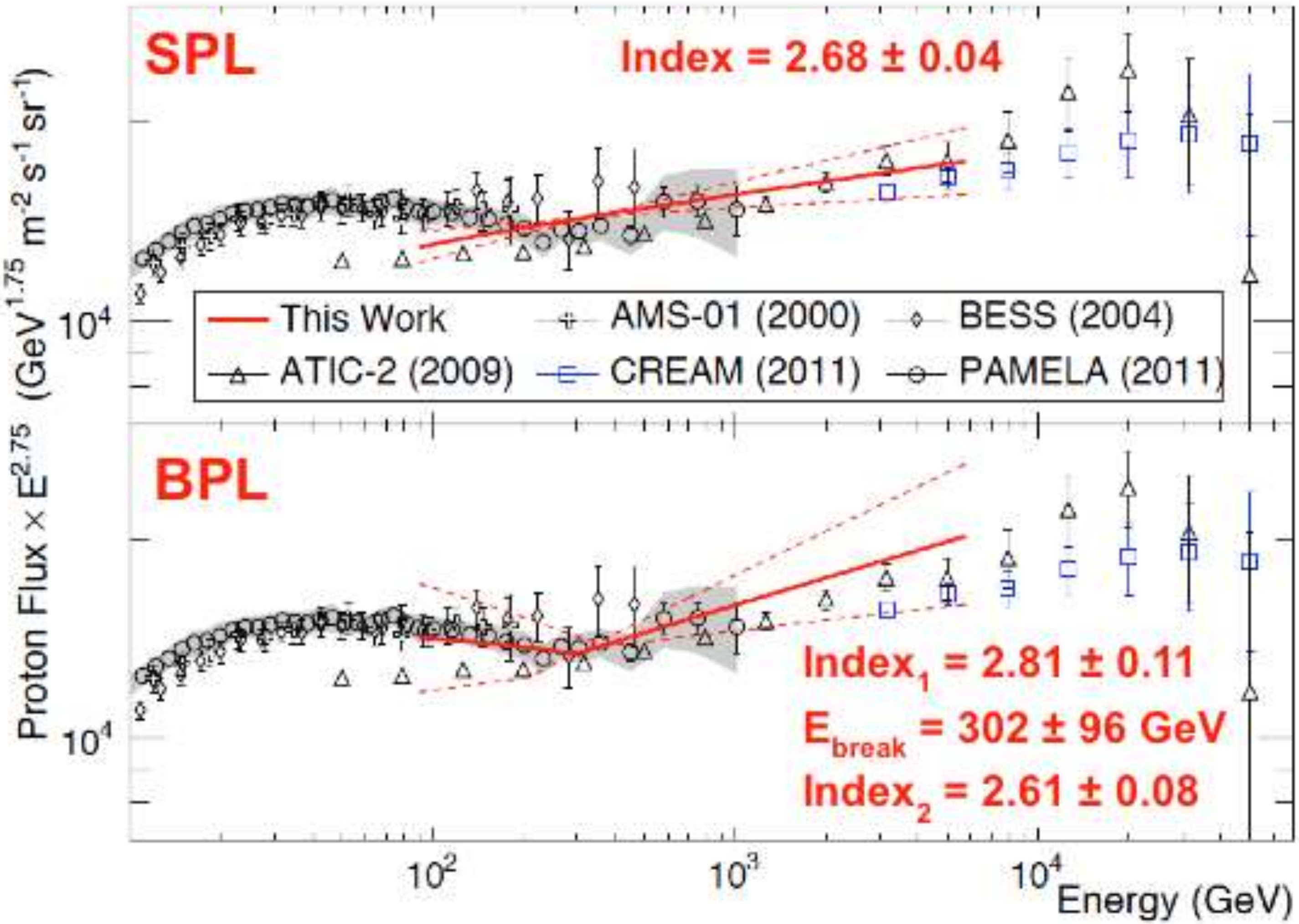






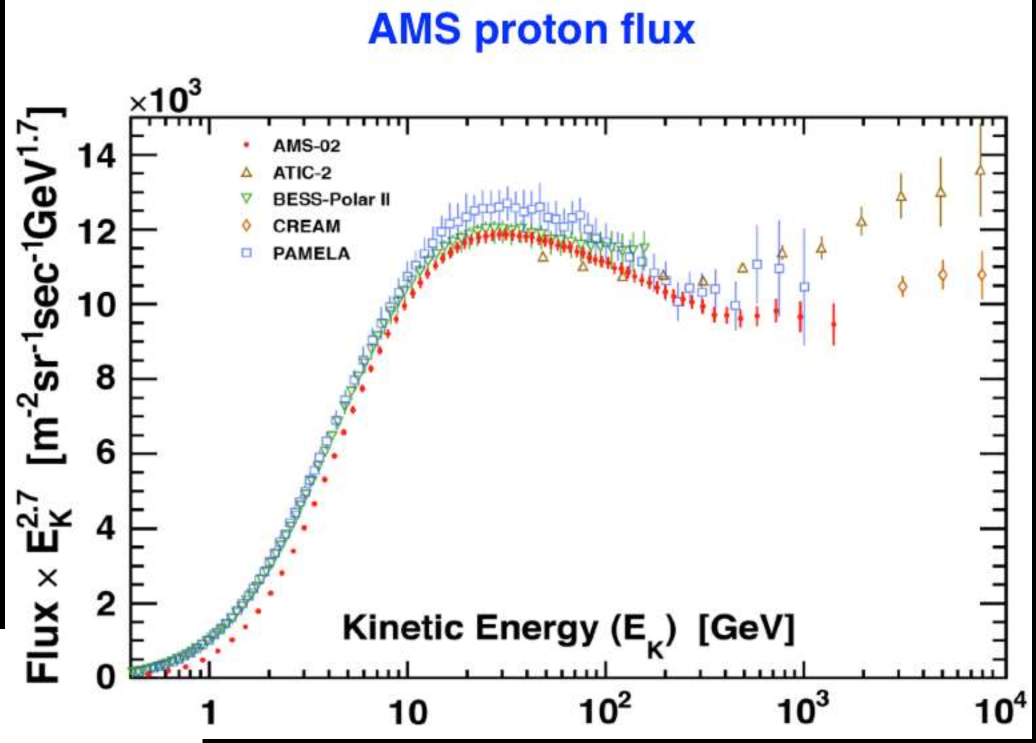
- ✧ Due to its proximity, the Earth is the brightest γ-ray source on the sky
- ✧ The emission is produced by the CR cascades in the atmosphere
- ✧ Most energetic γ-rays are produced by CRs hitting the top of the atmosphere at tangential directions (thin target)

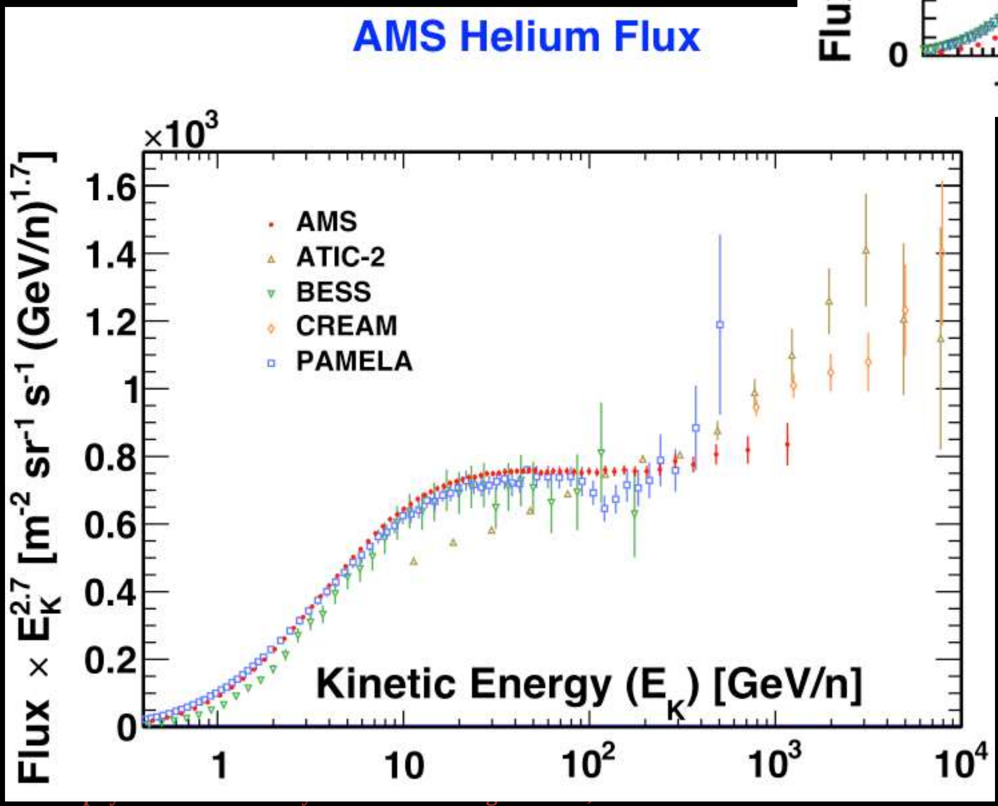
Inferred CR Proton Spectrum from *pp* Model by Kachelrieß & Ostapchenko (2012)

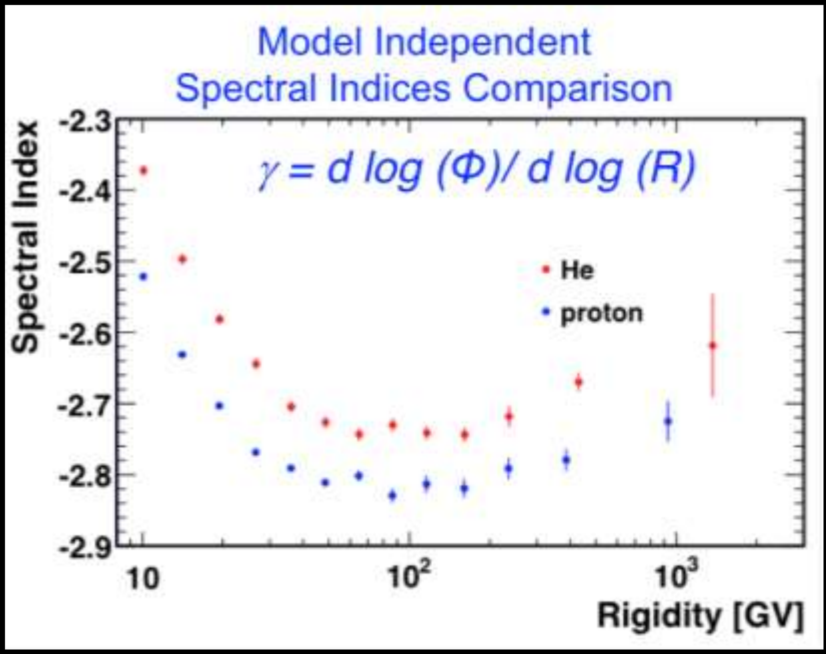


AMS p & He

- ✧ The indices of p and He spectra differ by ~0.1 in a wide energy range.
- ✧ Expansion of the SNR into the stellar wind enriched with heavy elements?

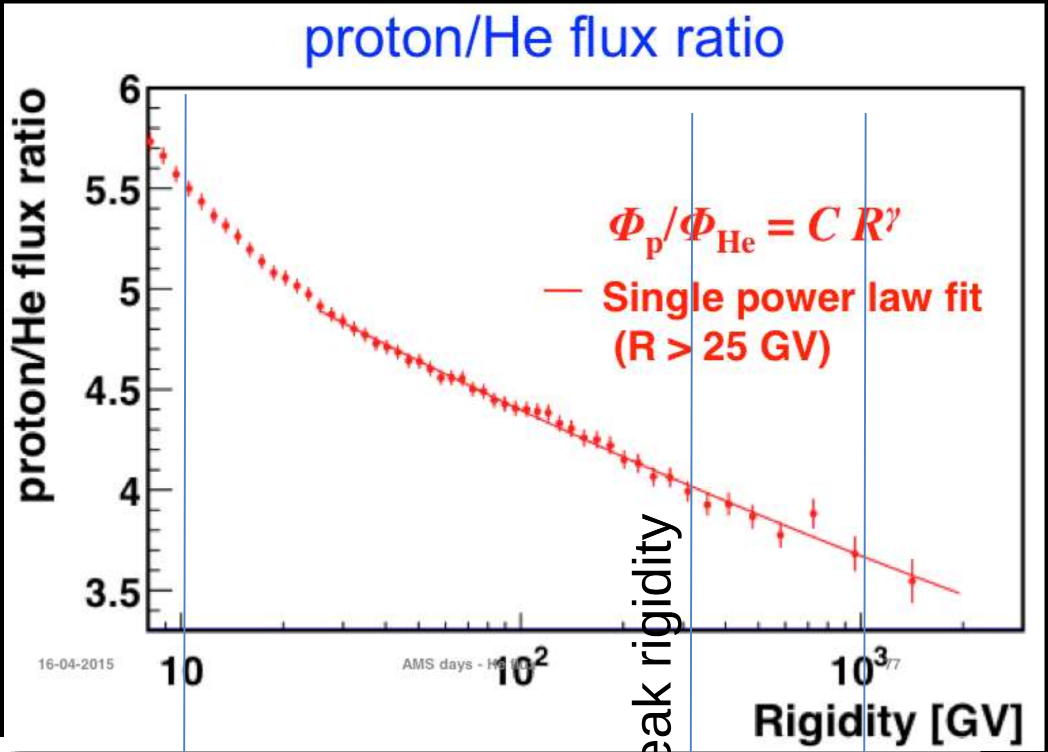


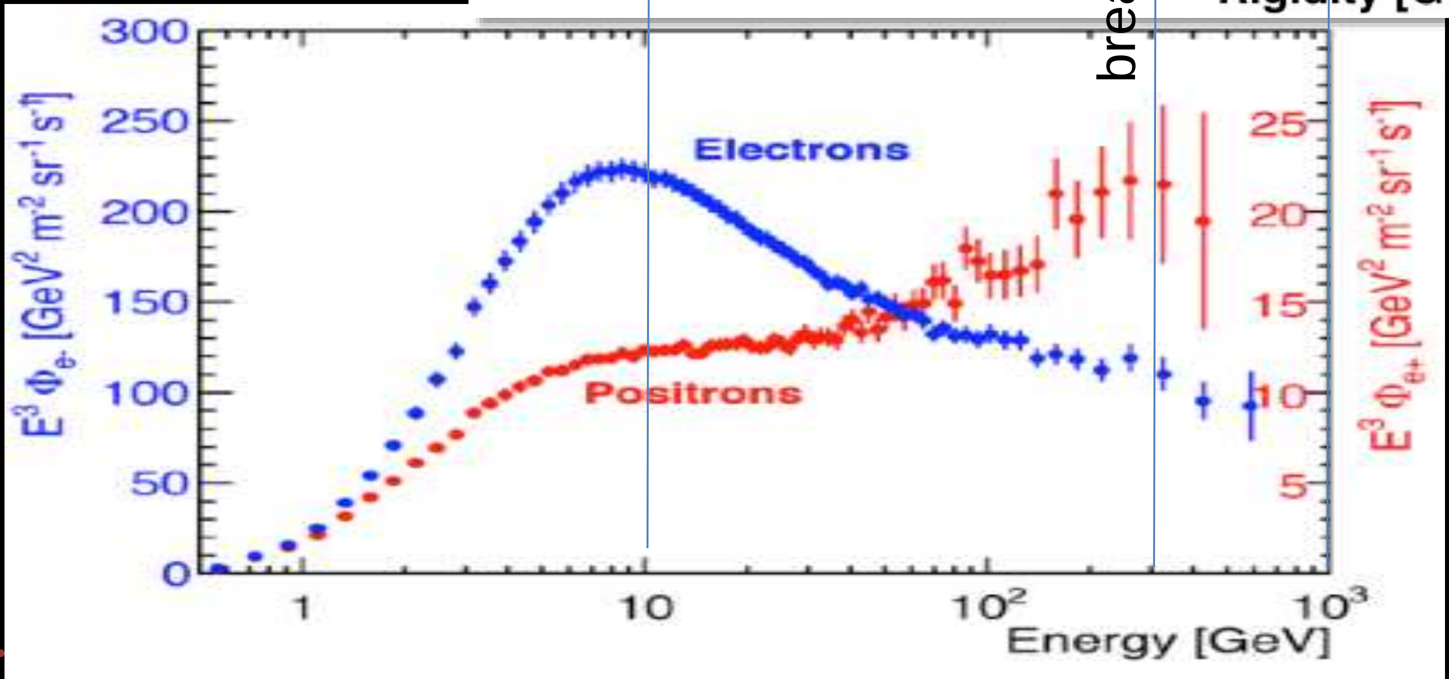




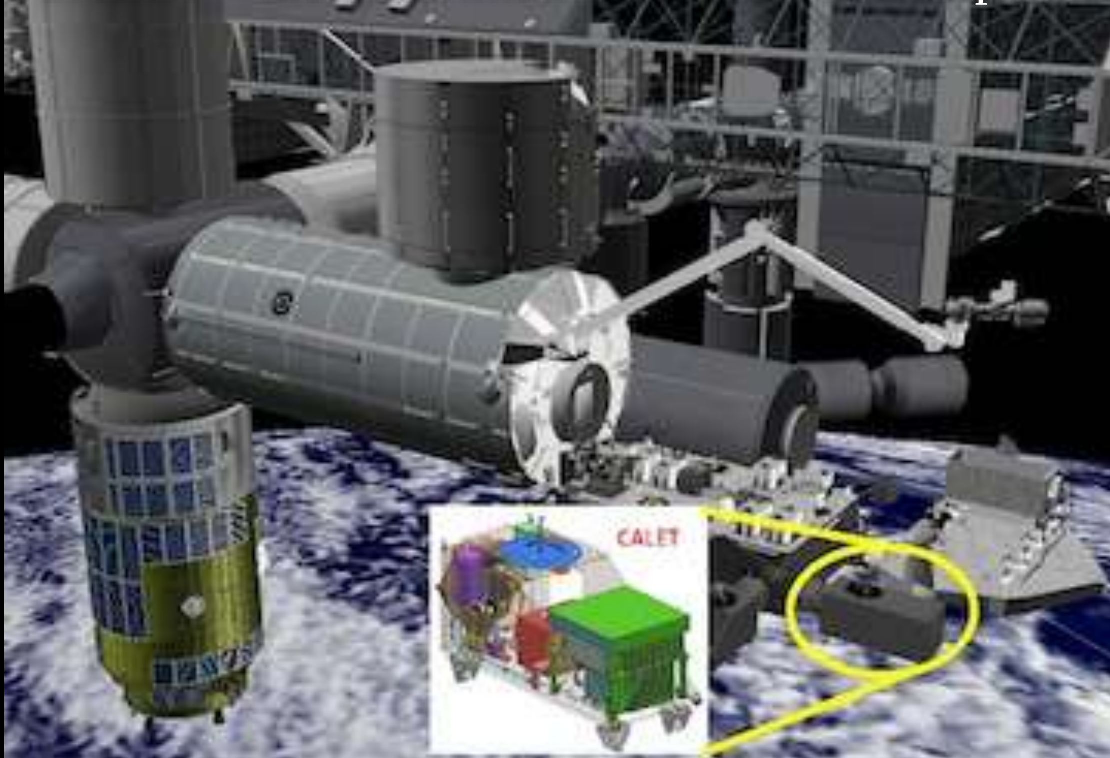
AMS p/He ratio

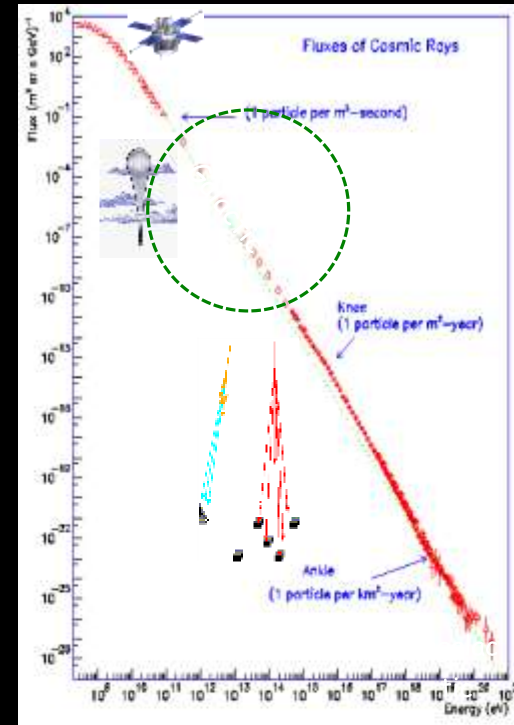
- ✧ The ratio is featureless
- ✧ Indicates that the same (unknown) mechanism works for p, He, and possibly heavier elements
- ✧ What’s about electrons and/or positrons
- ✧ More statistics is necessary





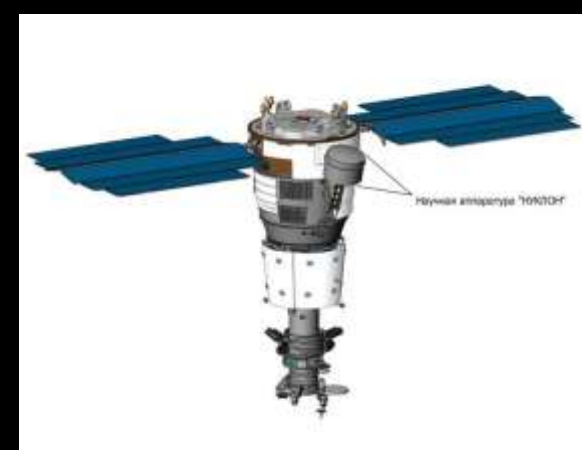
CALET – the Calorimetric Electron Telescope





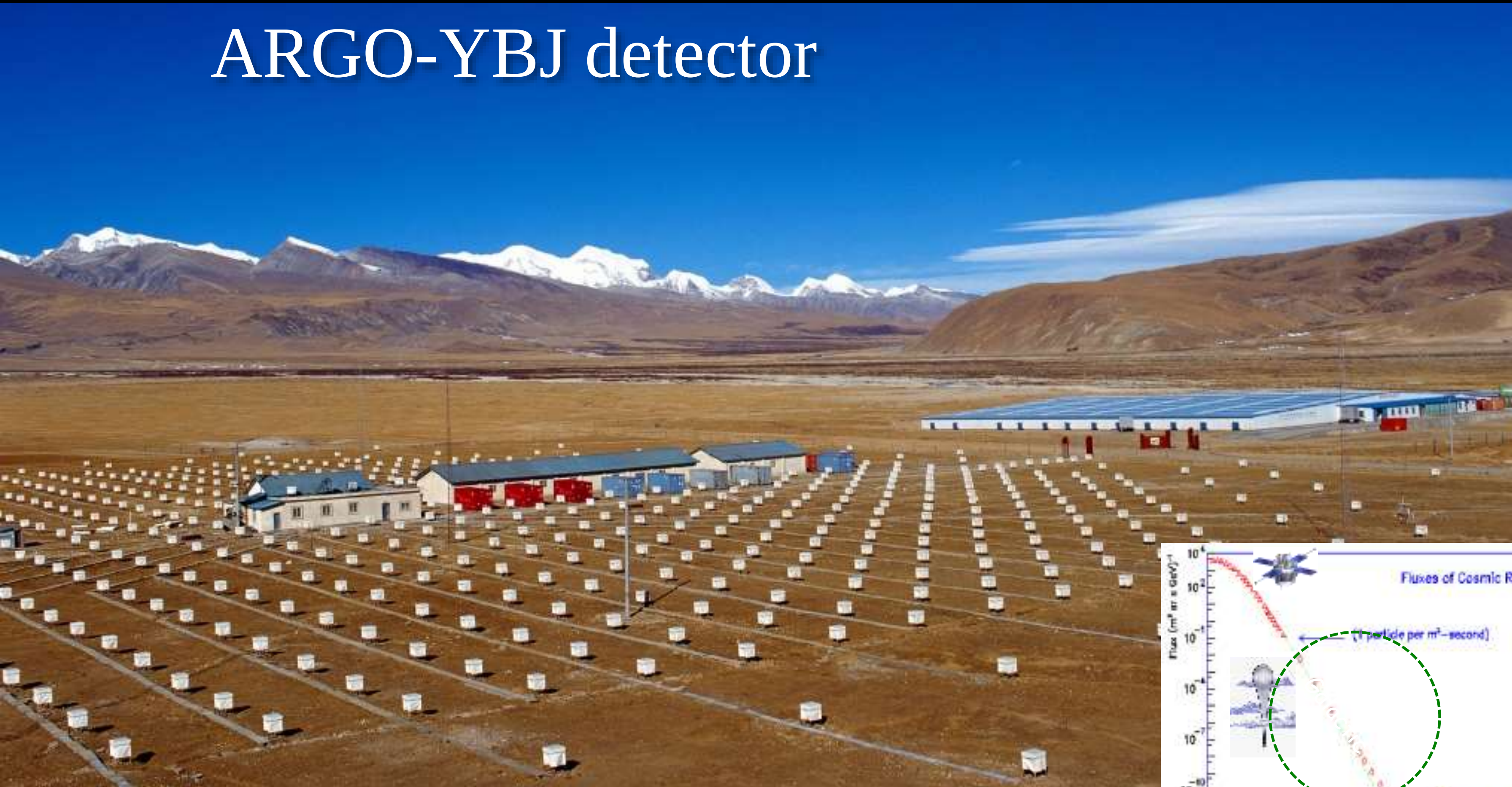
- ✧ Launched: Aug 16, 2015
- ✧ Energy range: $<10^{15}$ eV (p,He), $<10^{13}$ eV (electrons)
- ✧ Lifetime: ~5 years

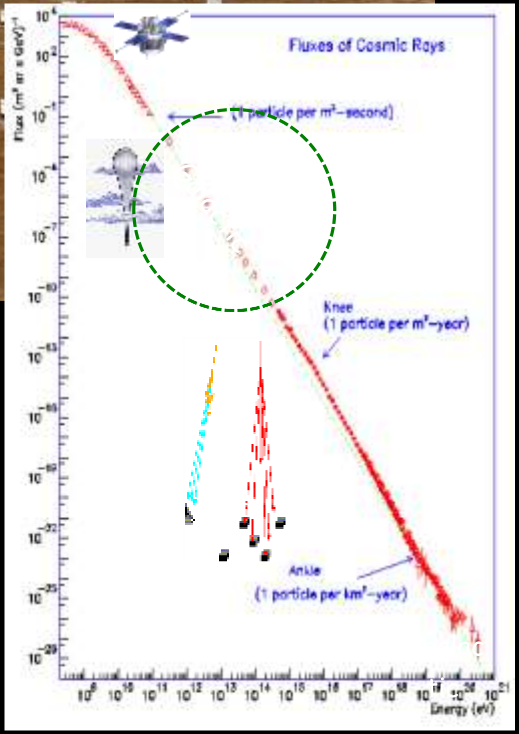
NUCLEON-Resource



- ✧ Launched Dec. 26, 2014
- ✧ $10^{11} - 10^{15}$ eV (100 GeV – 1 PeV)
- ✧ Mass: 300 kg
- ✧ Micro-calorimeter & kinematic method

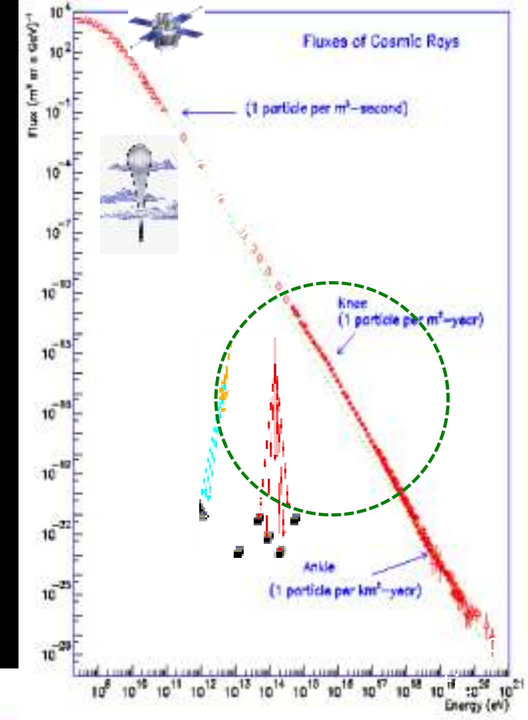
ARGO-YBJ detector



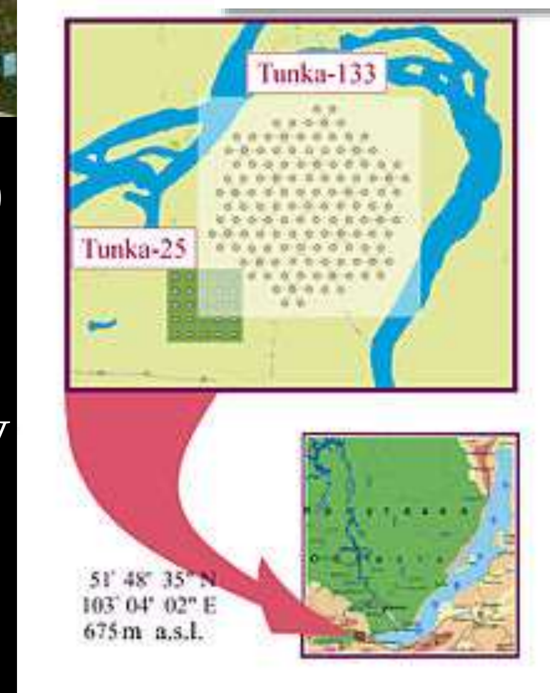


- ✧ Yangbajing in Tibet (4300 m above sea level
- ✧ $10^{12} - 10^{16}$ eV (1 TeV – 10 PeV)
- ✧ Area ~6700 m^2

CASCADE-Grande detector

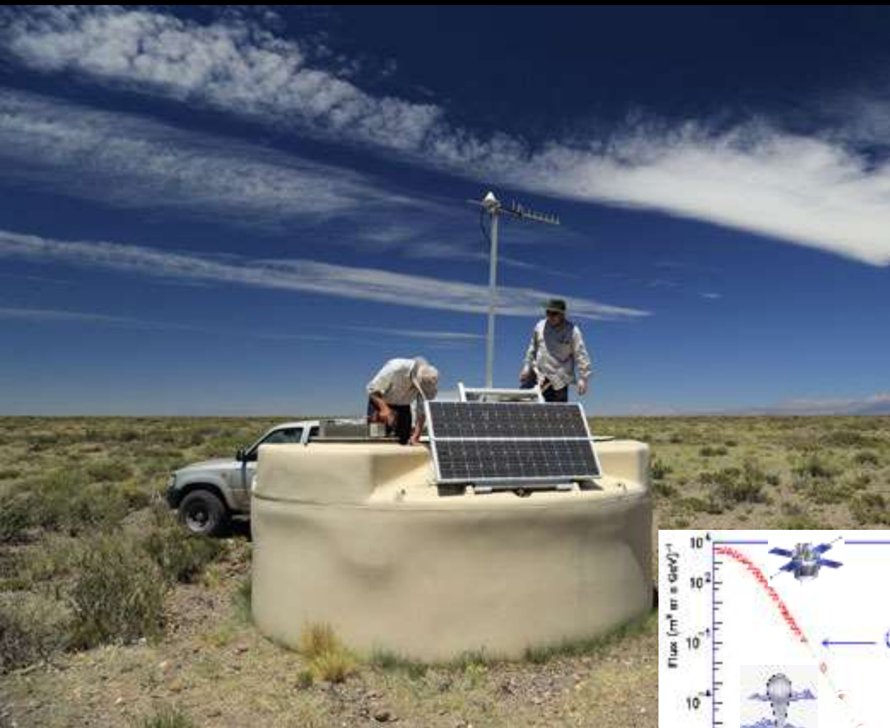


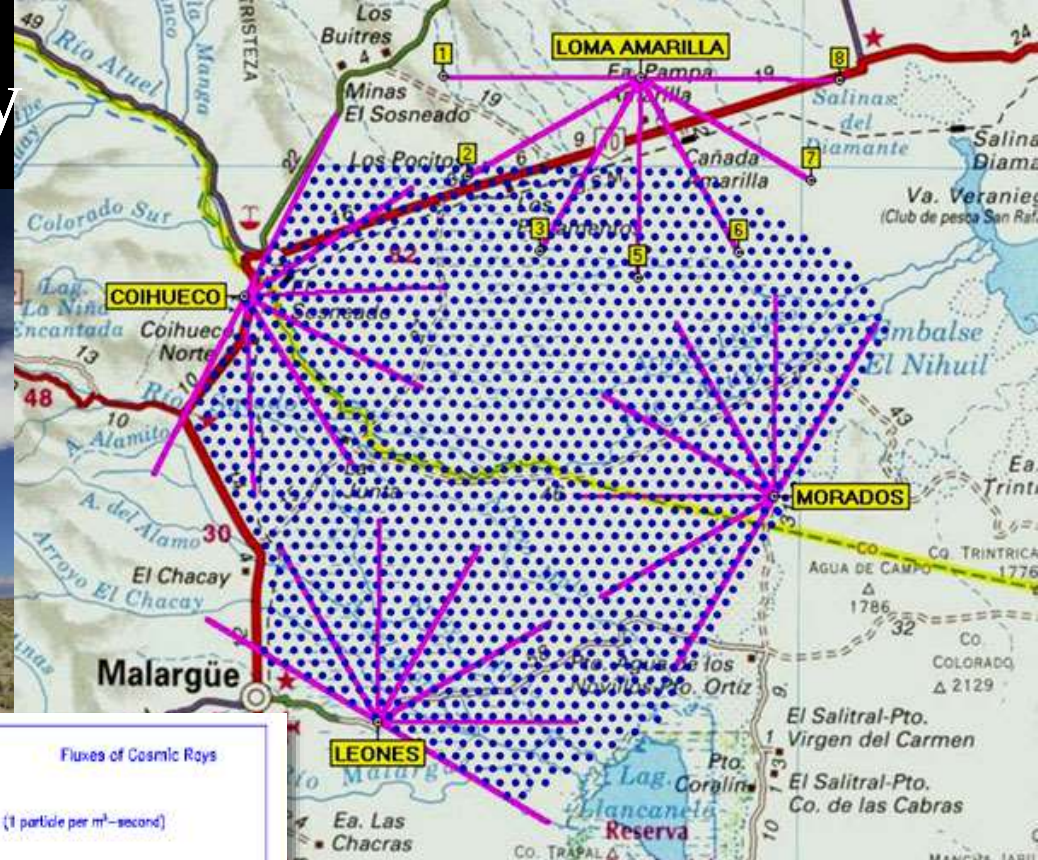
- ✧ Energy 10^{16} eV – 2×10^{18} eV (10 PeV – 2 EeV)
- ✧ Area ~1 km^2
- ✧ Closed

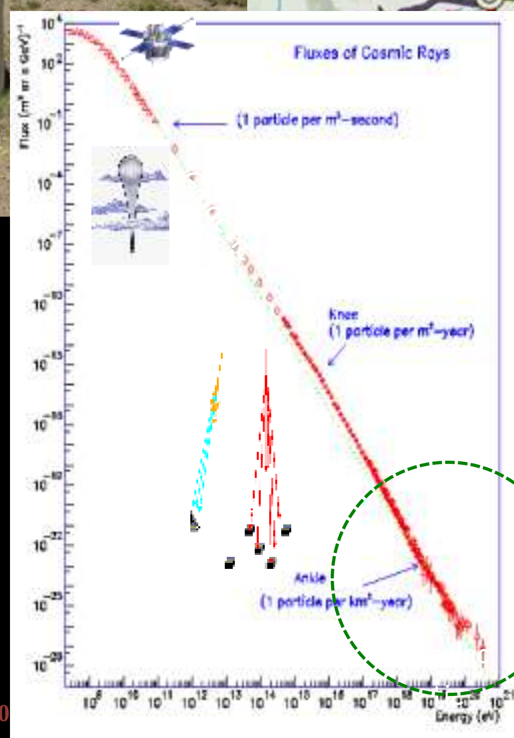


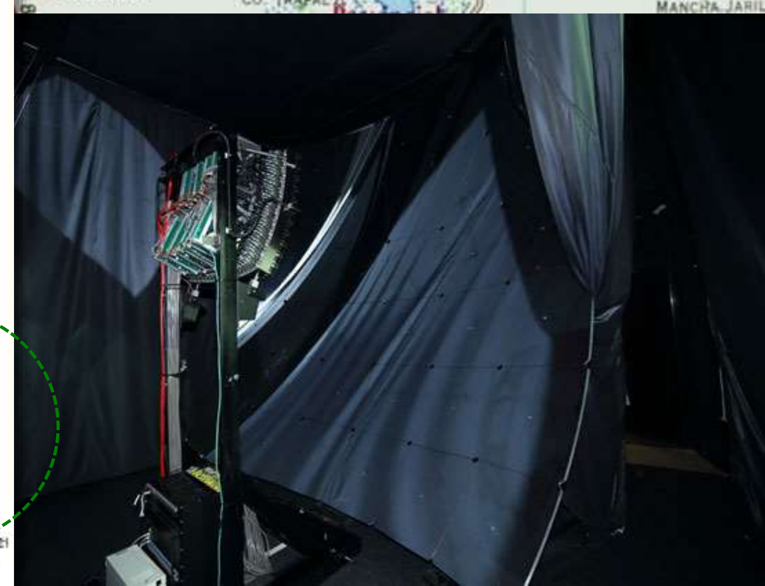
- ✧ Energy ~10^{16} eV – 1×10^{18} eV (10 PeV – 1 EeV)
- ✧ Area ~1 km^2

Pierre Auger Observatory



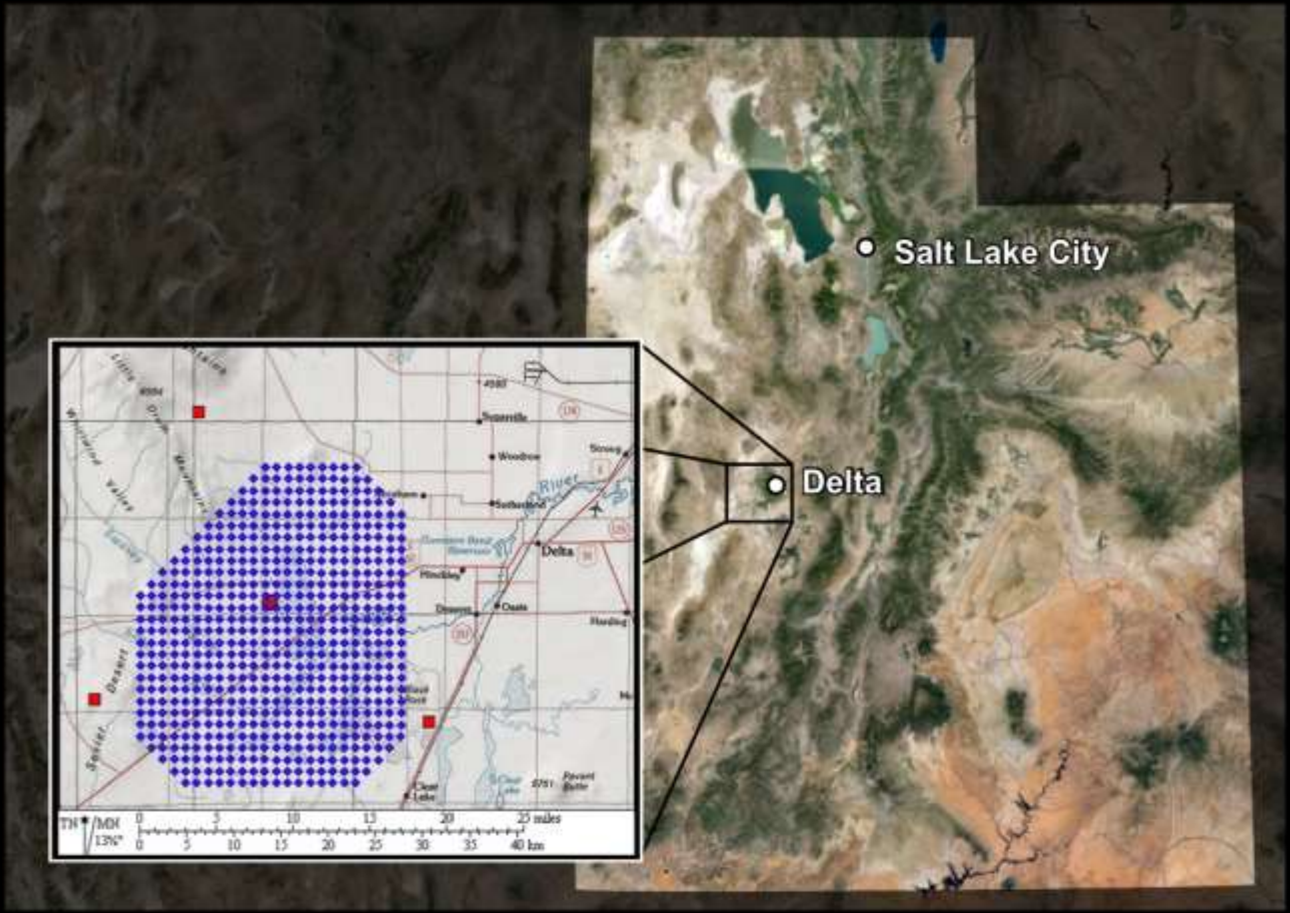






- ✧ $10^{17} – 10^{21}$ eV (0.1 – 10^3 EeV)
- ✧ 1600 water tanks
- ✧ Area: 3000 km^2 (size of Rhode Island)
- ✧ Hybrid: surface + fluorescence detectors

Telescope Array



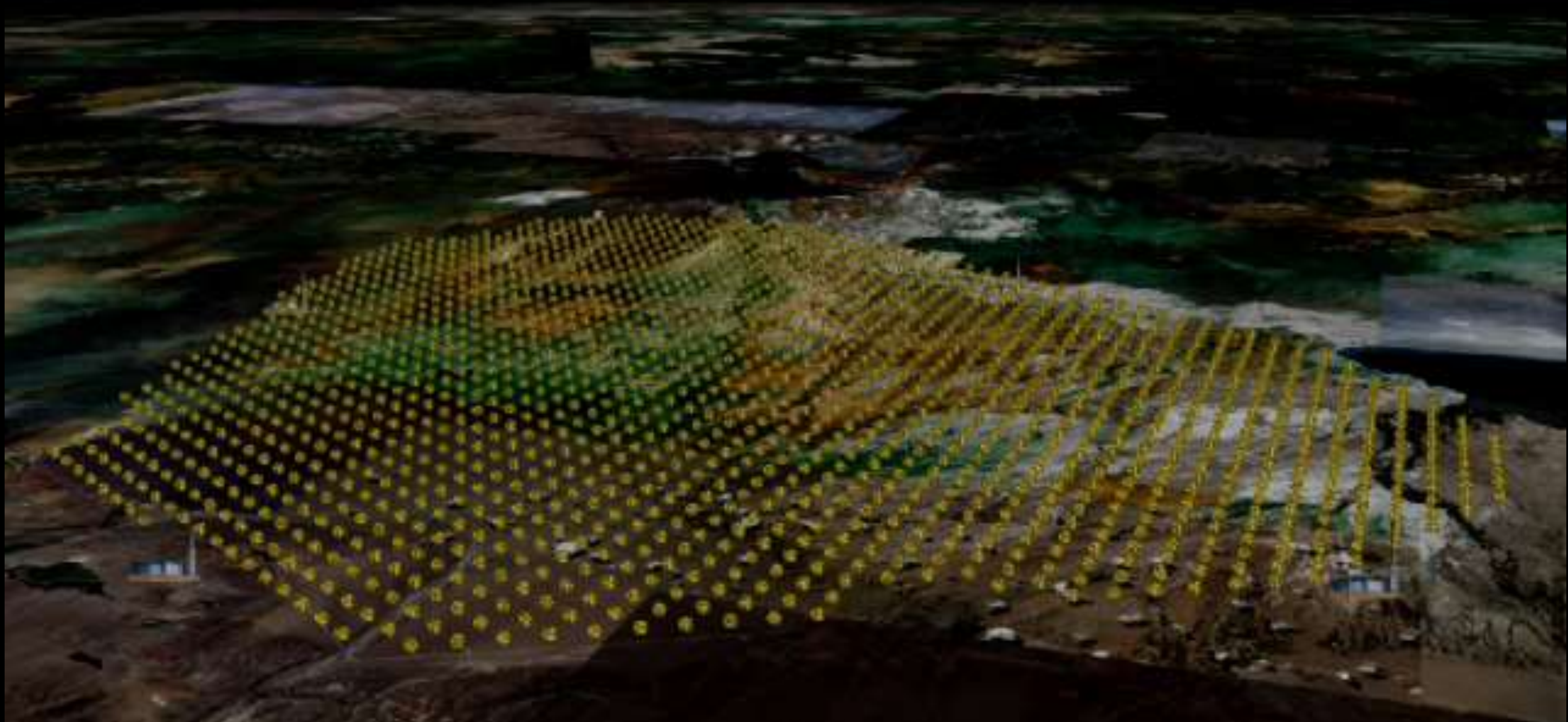
- $10^{17} – 10^{21}$ eV ($0.1 – 10^3$ EeV)
- 507 water tanks
- Area: 762 km^2
- Hybrid: surface + fluorescence detectors

Pierre Auger Observatory

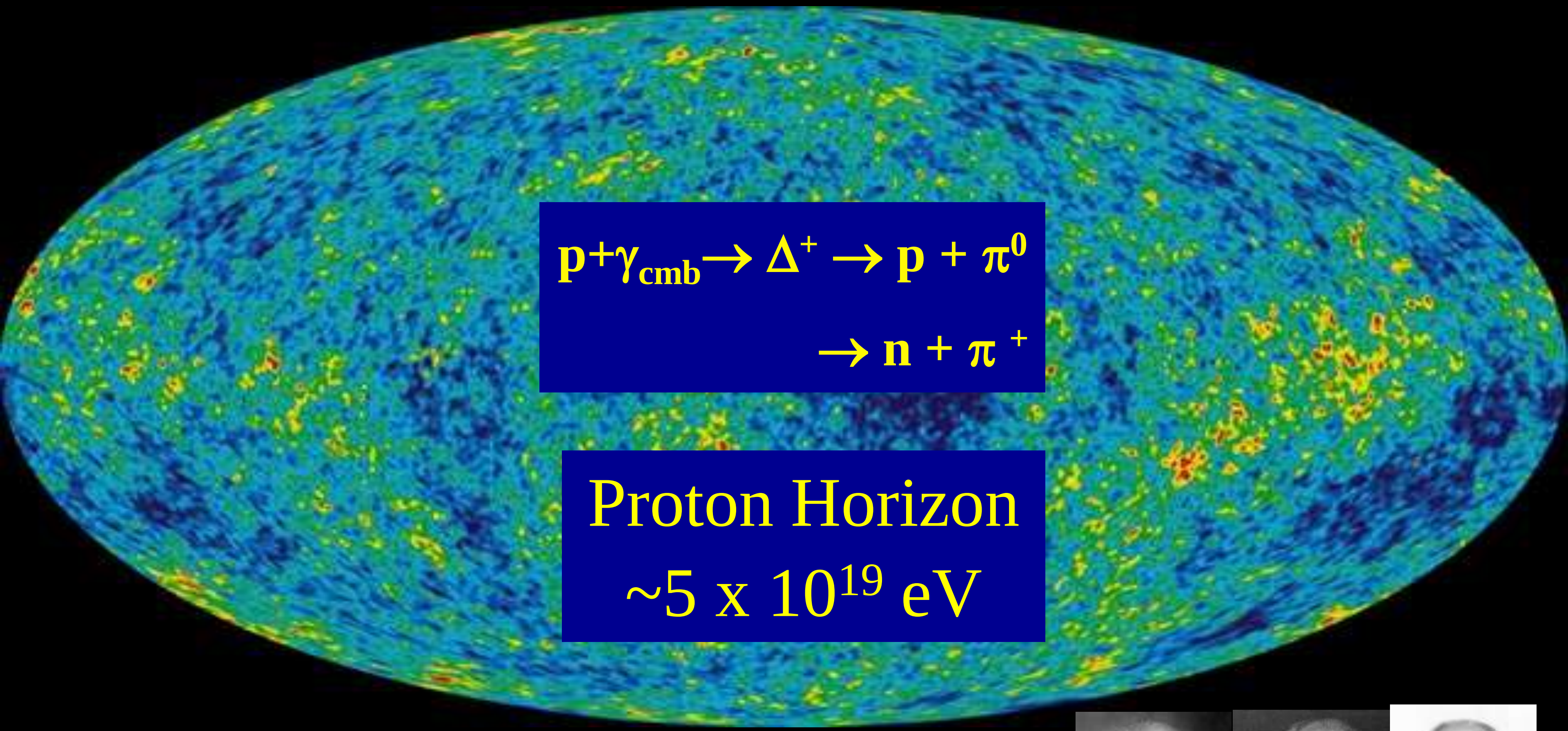
3,000 km^2 water cherenkov detectors array

4 fluorescence Telescopes, Malargue, Argentina

~ 500 Scientists, 19 Countries



“Cosmologically Meaningful Termination”



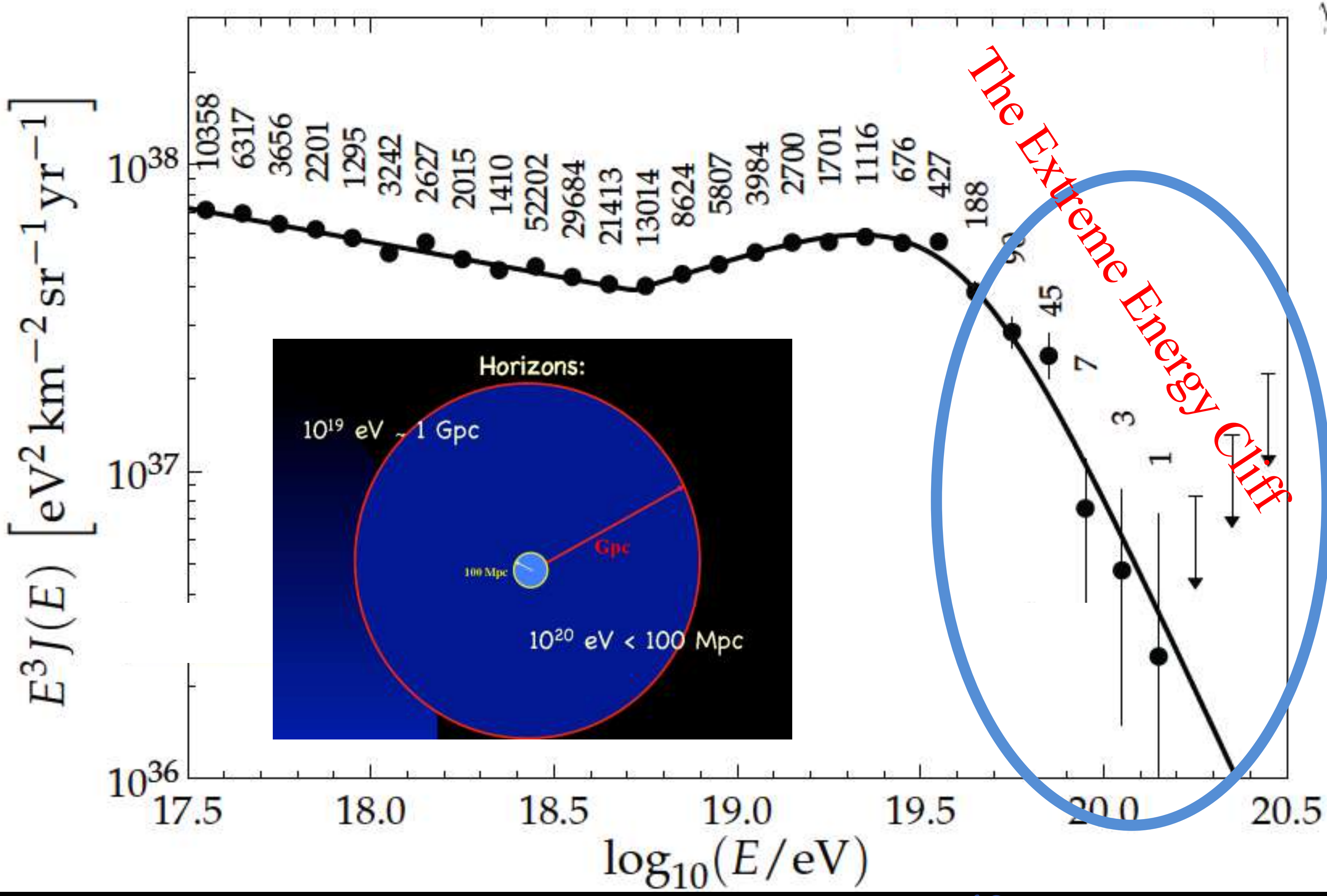
$$p+\gamma_{cmb} \rightarrow \Delta^{+} \rightarrow p + \pi^{0}$$
$$\rightarrow n + \pi^{+}$$

Proton Horizon

~5 x 10^{19} eV

GZK Cutoff:

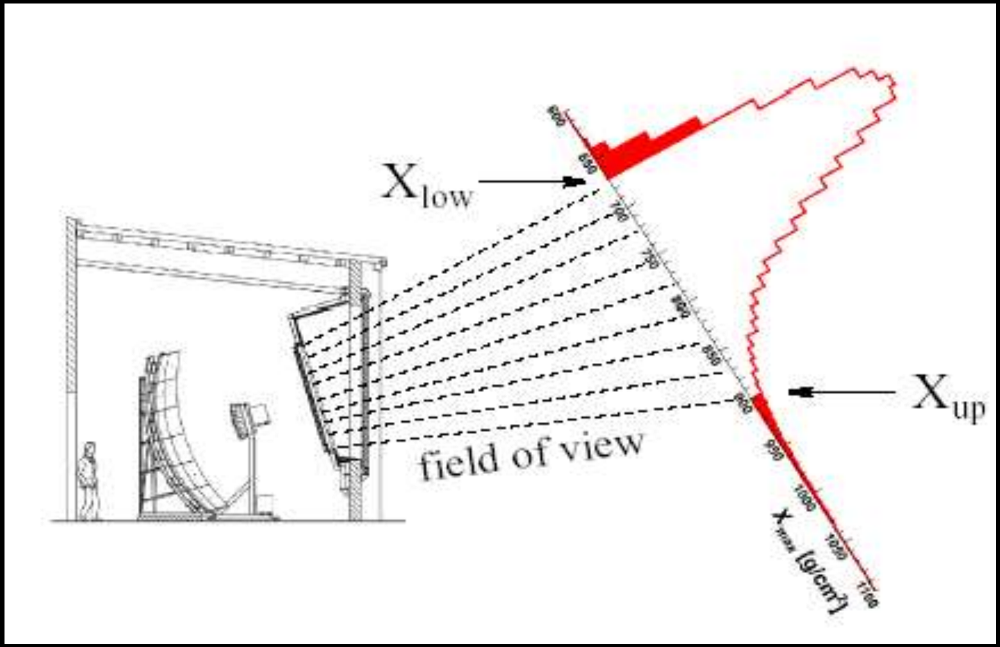
Greisen, Zatsepin, Kuzmin 1966

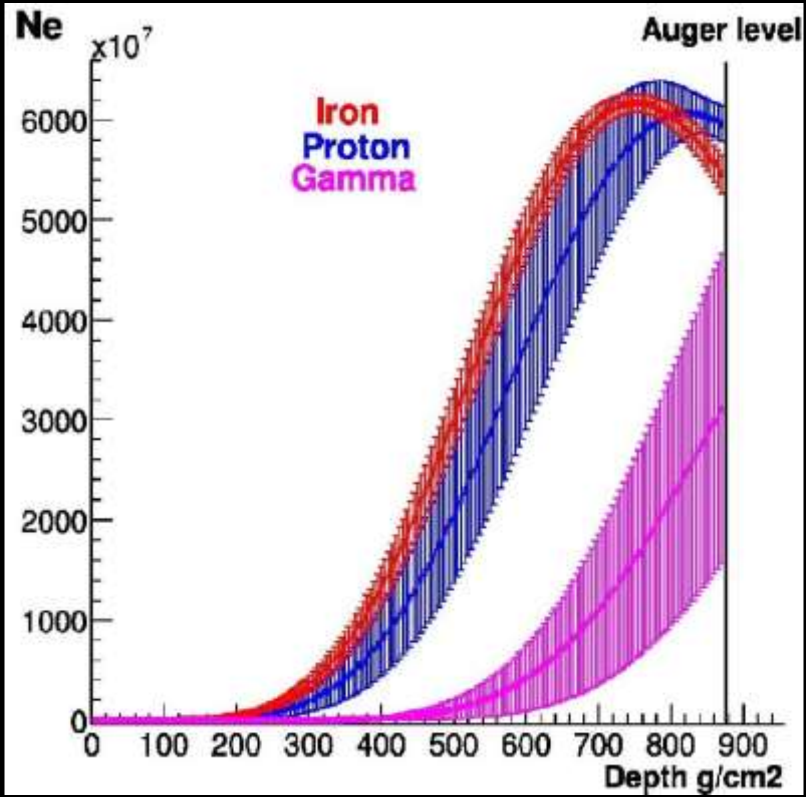


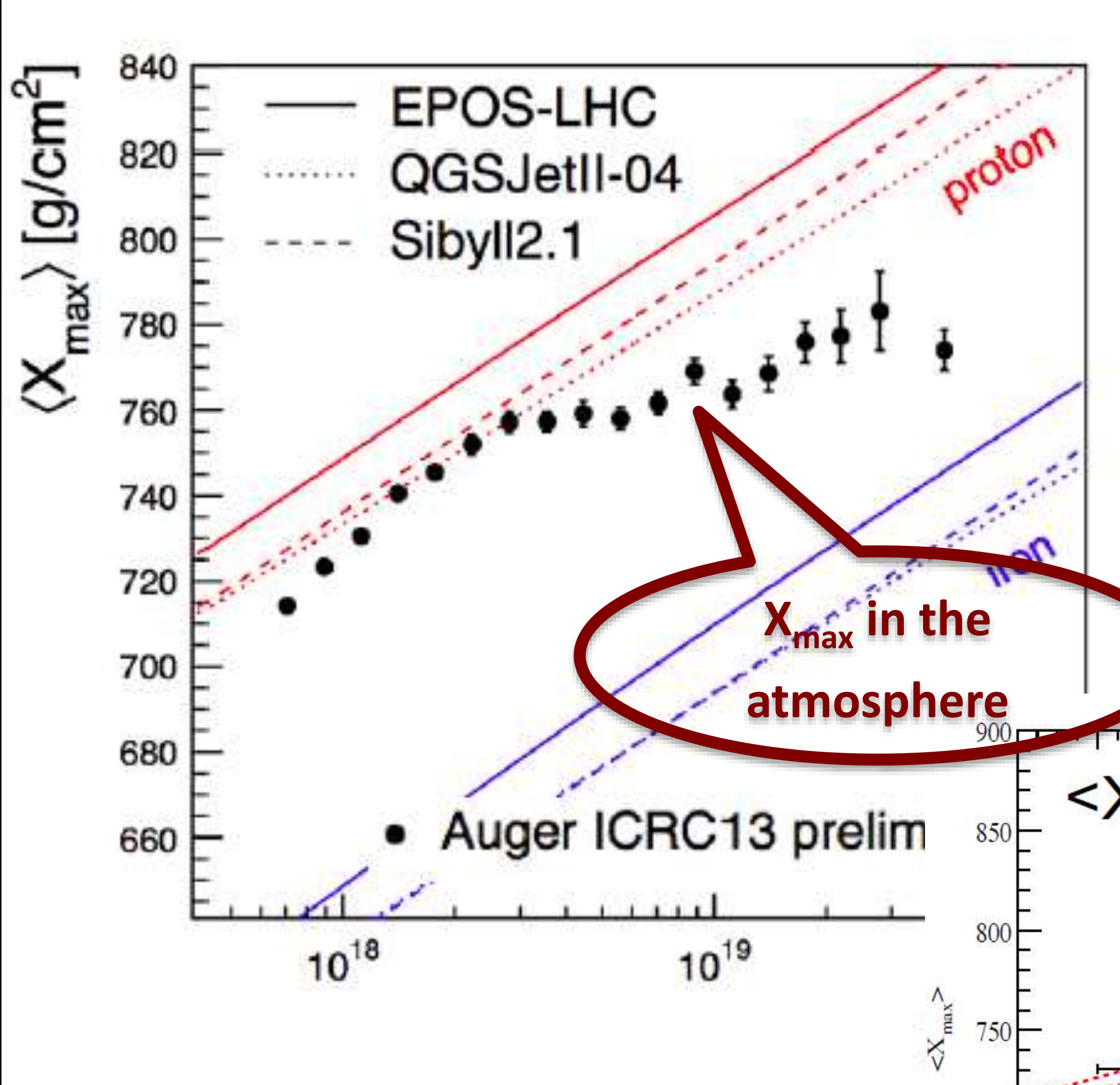
The Extreme Energy Cliff
Horizons:
10^19 eV ~ 1 Gpc
Gpc
100 Mpc
10^20 eV < 100 Mpc
10358 6317 3656 2201 1295 3242 2627 2015 1410 52202 29684 21413 13014 8624 5807 3984 2700 1701 1116 676 427 188 45 7 3 1
10^38
10^37
10^36
17.5 18.0 18.5 19.0 19.5 20.0 20.5
log10(E/eV)
E^3 J(E) [eV^2 km^-2 sr^-1 yr^-1]

48

Composition observable:
shower maximum average and fluctuations





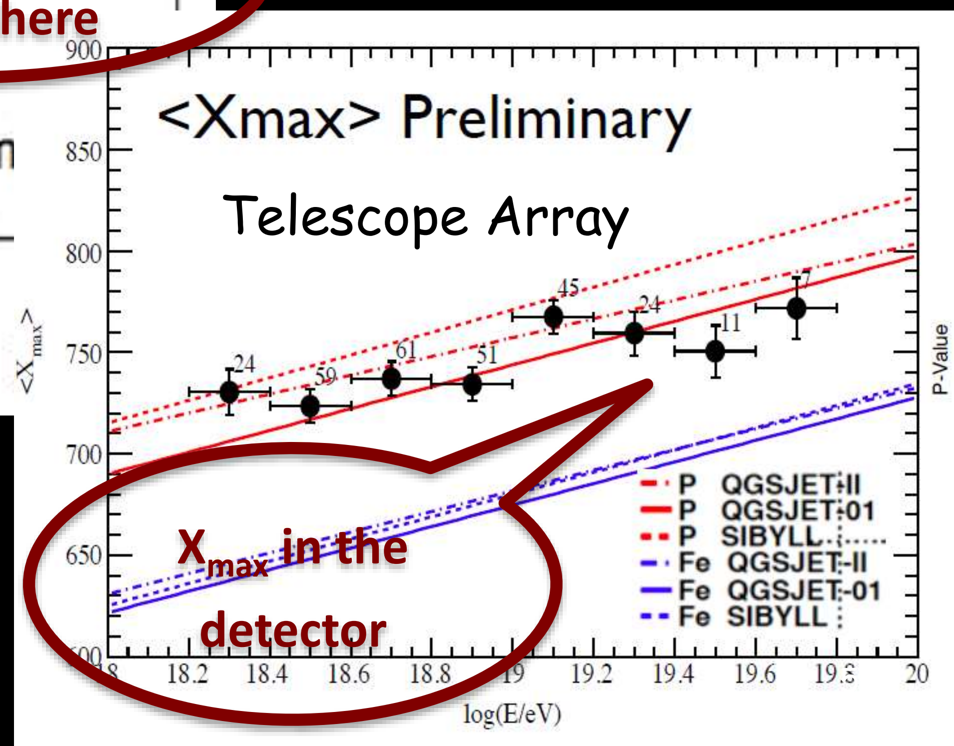


Auger sees change slope:

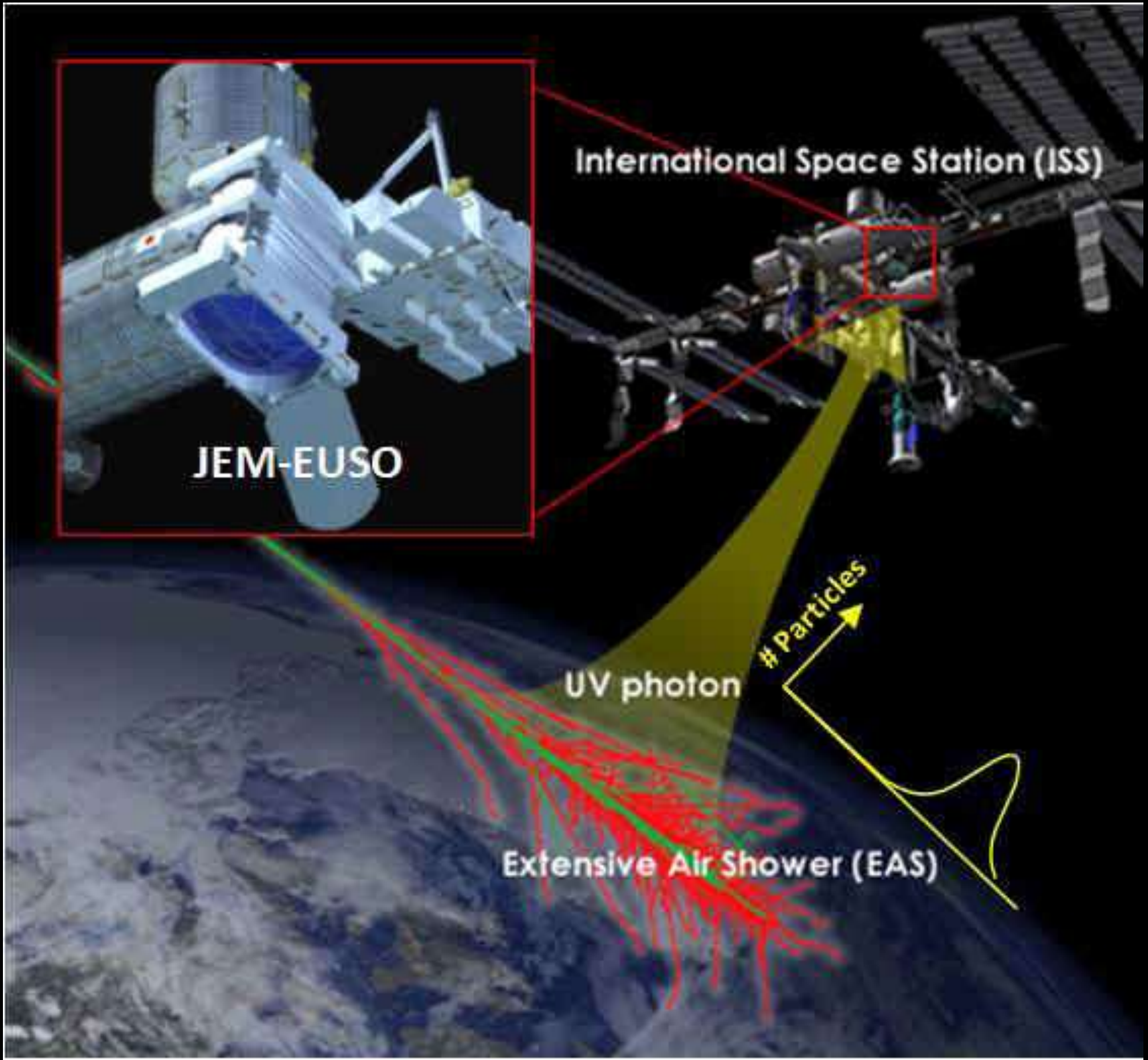
Change in Composition

or interactions

TA: not confirmed yet



JEM-EUSO – Extreme Universe Space Observatory

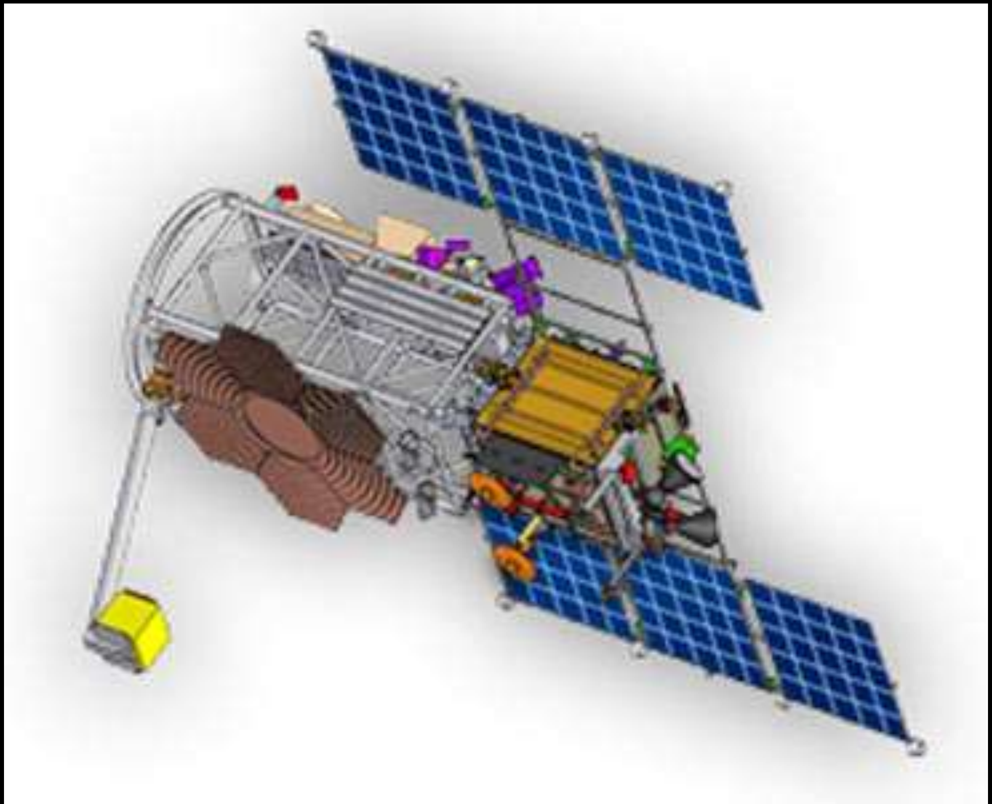


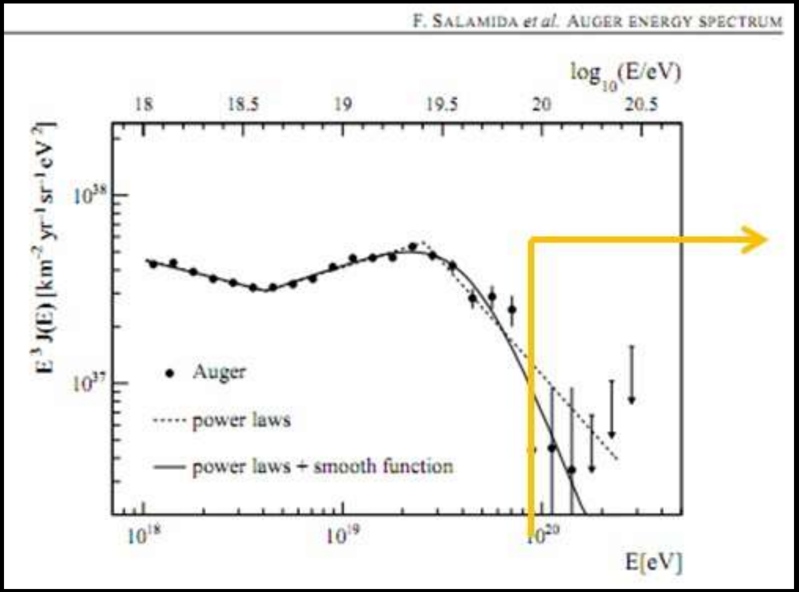
- Energy >10^{19} eV
- Observes UV photons from UHECR EAS in the atmosphere
- Area: factor of 50-250 larger than Pierre Auger Observatory
- FoV: $\pm 30^{\circ}$
- Status unknown

Collaboration:

- Japan
- USA
- France
- Germany
- Italy
- Mexico
- S.Korea
- Russia
- Switzerland
- Spain
- Poland
- Slovakia
- Bulgaria
- Sweden
- Algeria
- Romania

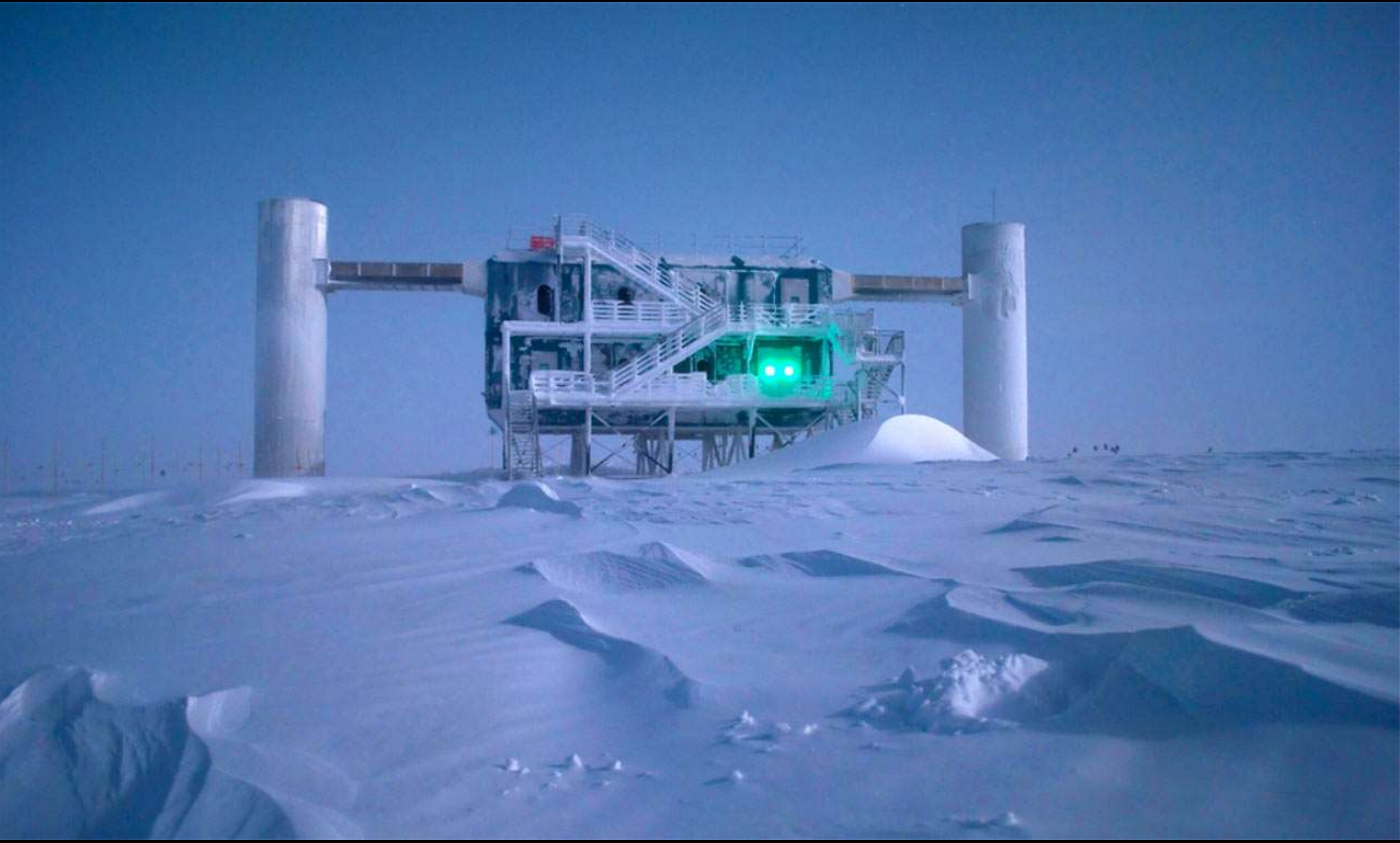
Lomonosov Satellite – UHECR pilot mission



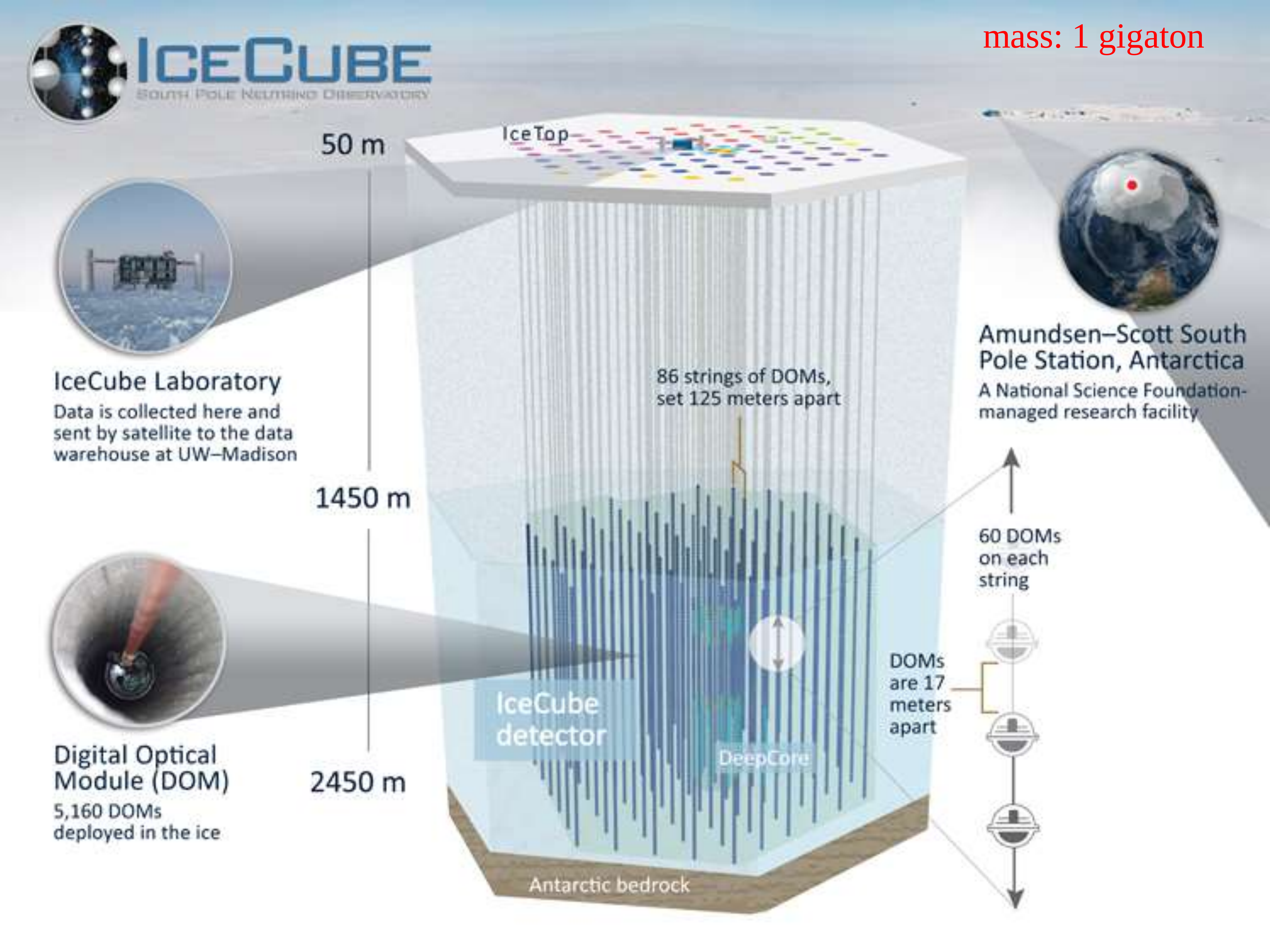


- ✧ Launch – 2106
- ✧ Mass: <60 kg
- ✧ FoV: $\pm 4.5^\circ$
- ✧ Mirror: 1.8 m^2

Which planet is this?



mass: 1 gigaton



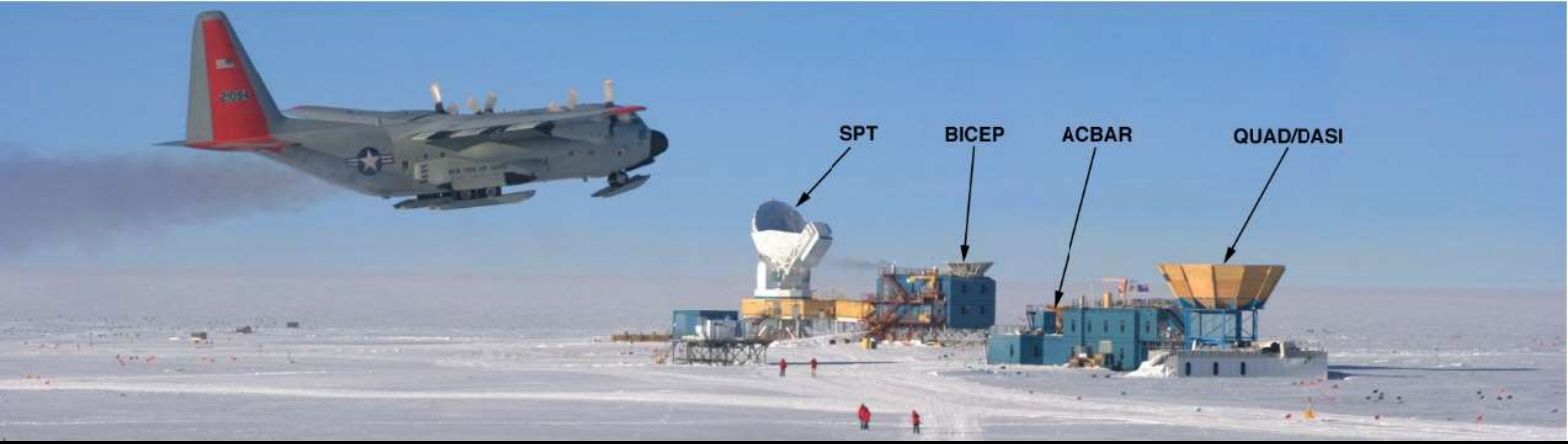
Moisei Markov

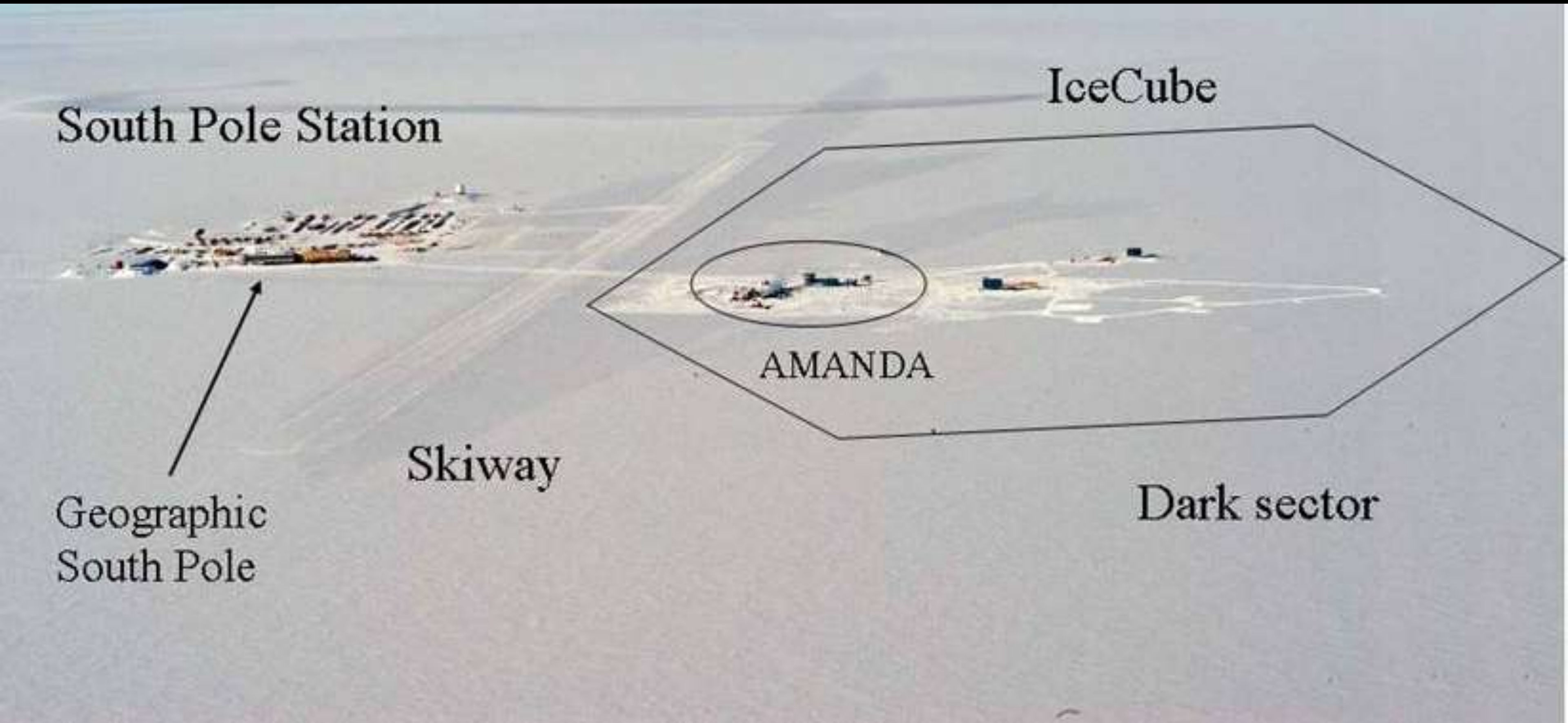
1960

Bruno Pontecorvo

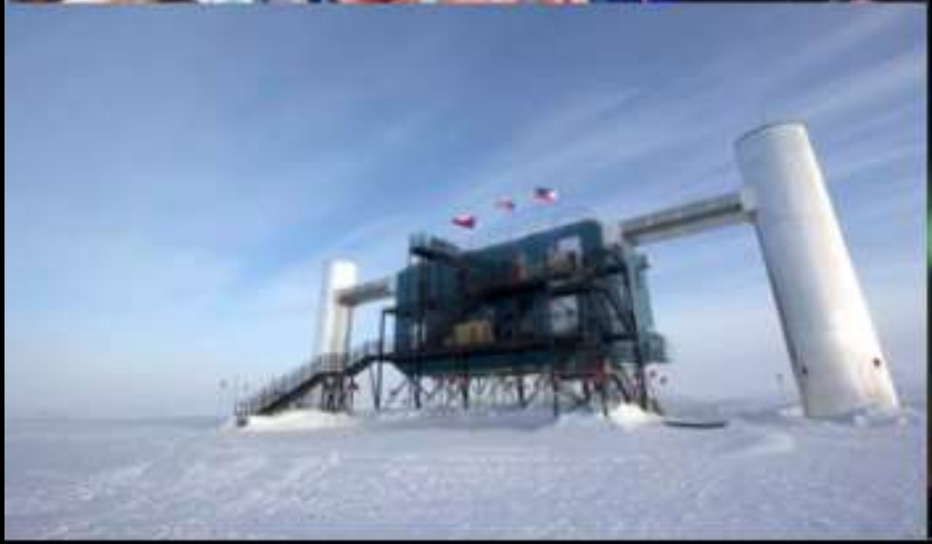
M.Markov :
we propose to install detectors deep in a lake or in the sea and to determine the direction of charged particles with the help of Cherenkov radiation.

Amudsen-Scott South Pole Station

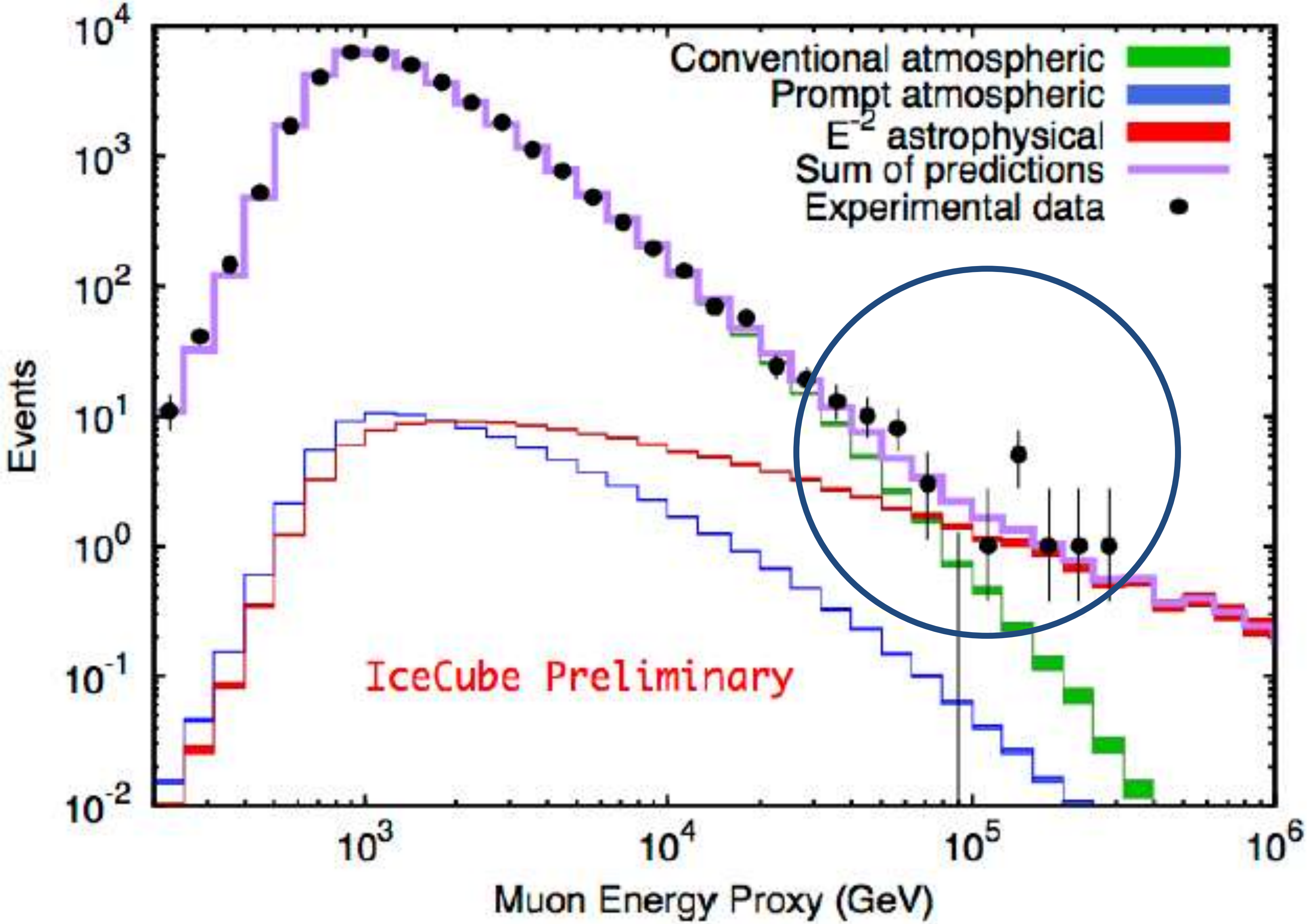

SPT
BICEP
ACBAR
QUAD/DASI


IceCube
South Pole Station
AMANDA
Skiway
Geographic
South Pole
Dark sector

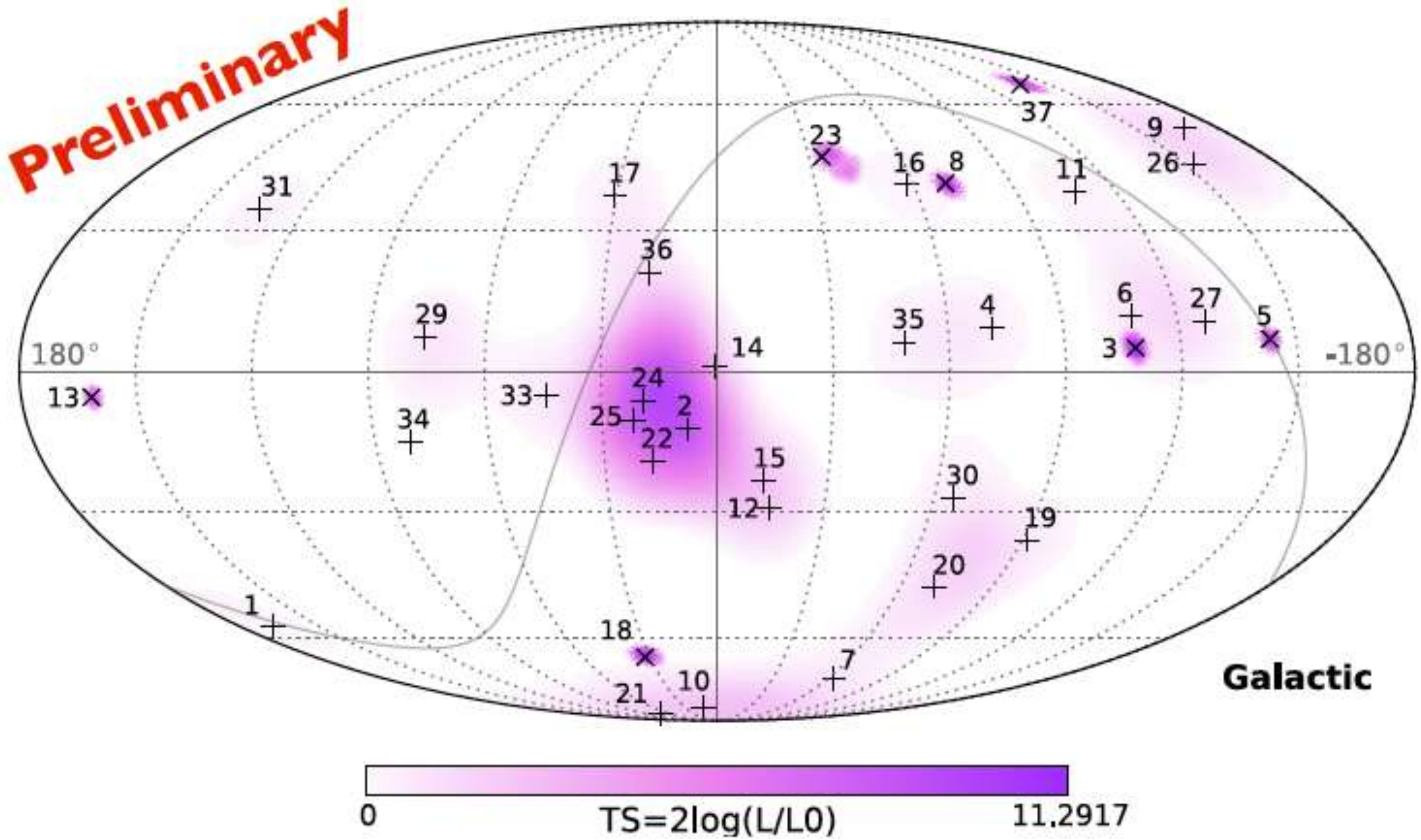
The Location



cosmic neutrinos in 2 years of data at 3.7 sigma

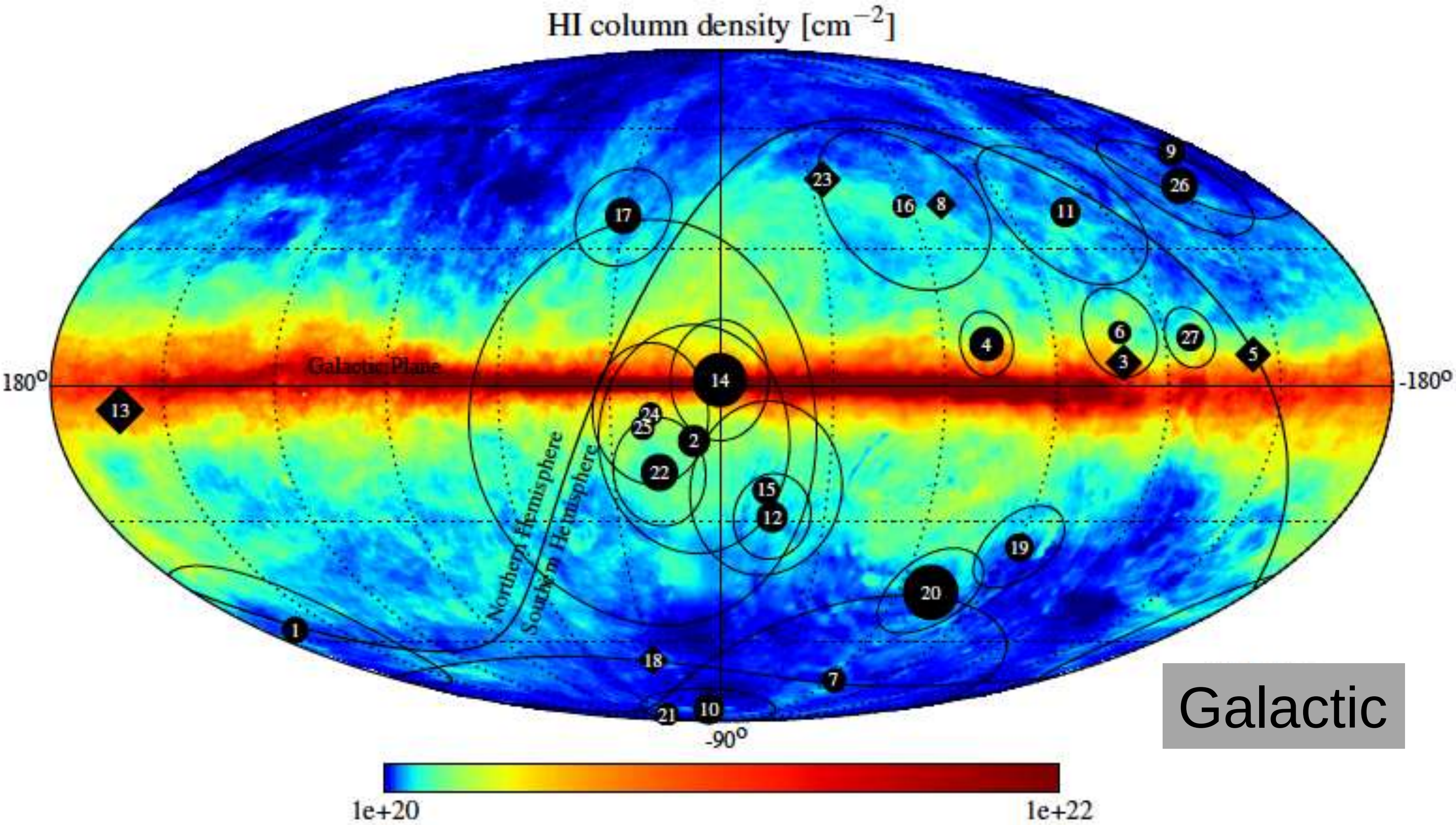


where do they come from (3 year data)?

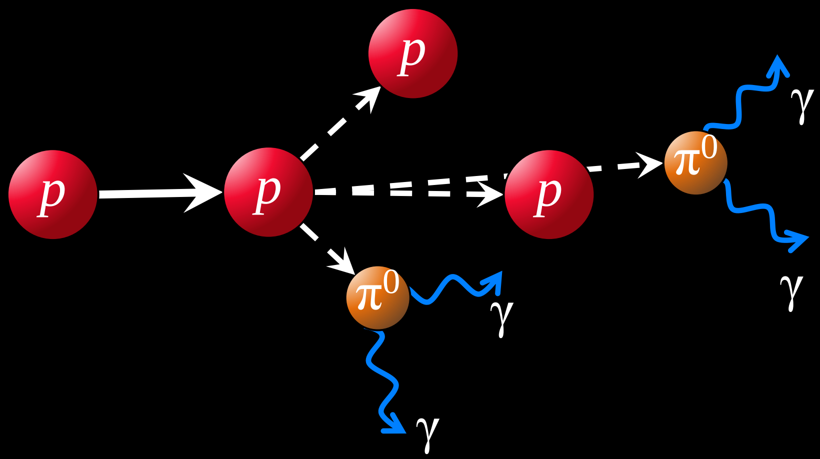


hottest spot 7.2%: consistent with diffuse flux with fllavor 1:1:1?

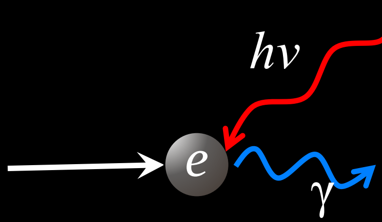
correlation with Galactic plane: TS of 2.8% for a width of 7.5 deg



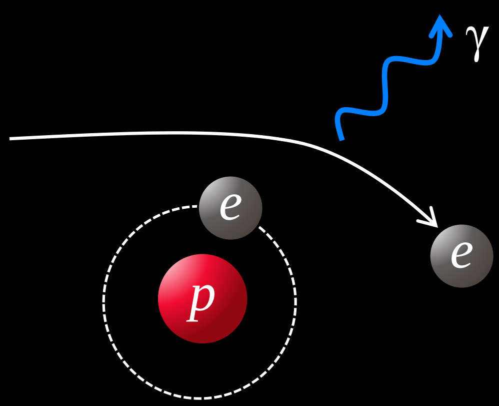
High energy gamma-ray emission processes



✧ $pp \rightarrow \pi^0(2\gamma)+X$ – neutral pion production and decay

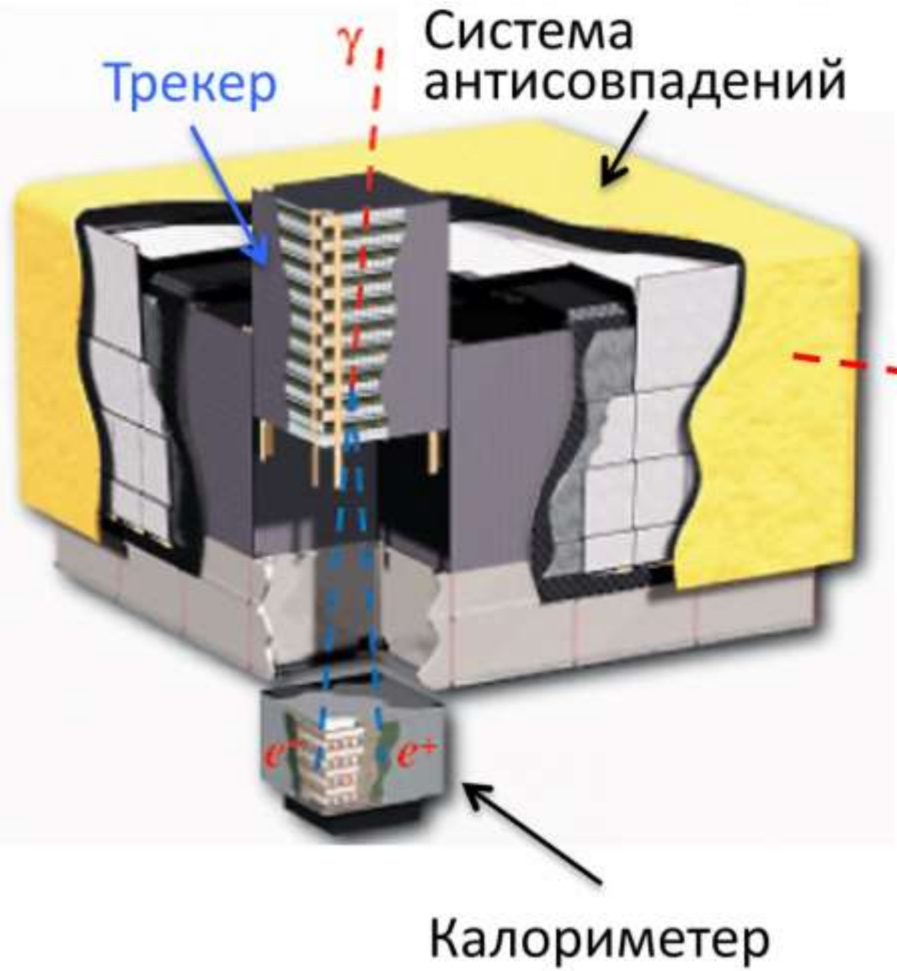


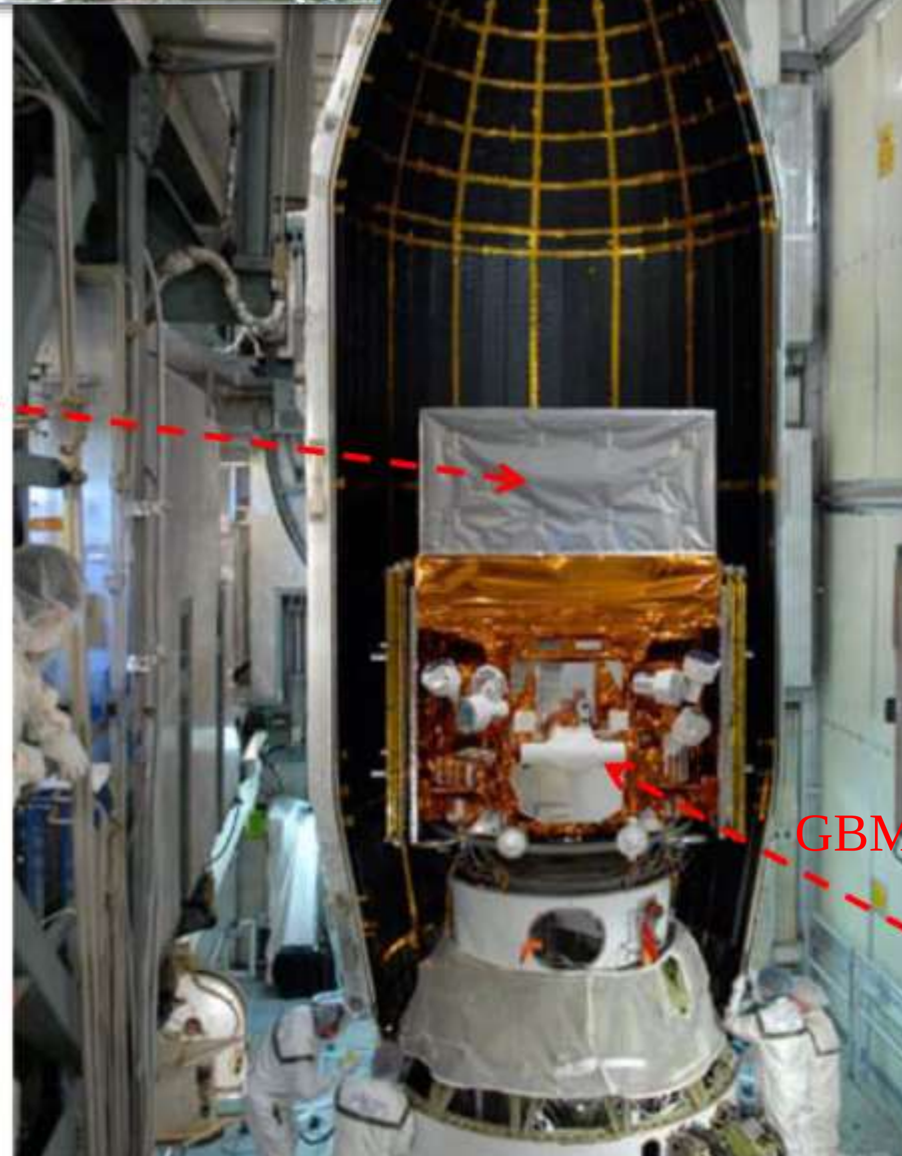
✧ Inverse Compton scattering



✧ Bremsstrahlung

GLAST/Fermi-LAT





The final check of ignition…

Launch of GLAST/ Fermi-LAT

June 11, 2008

12:05 pm (EDT)

GLAST = Gamma-Ray Large Area Space Telescope

Fermi-LAT = Fermi Large Area Telescope

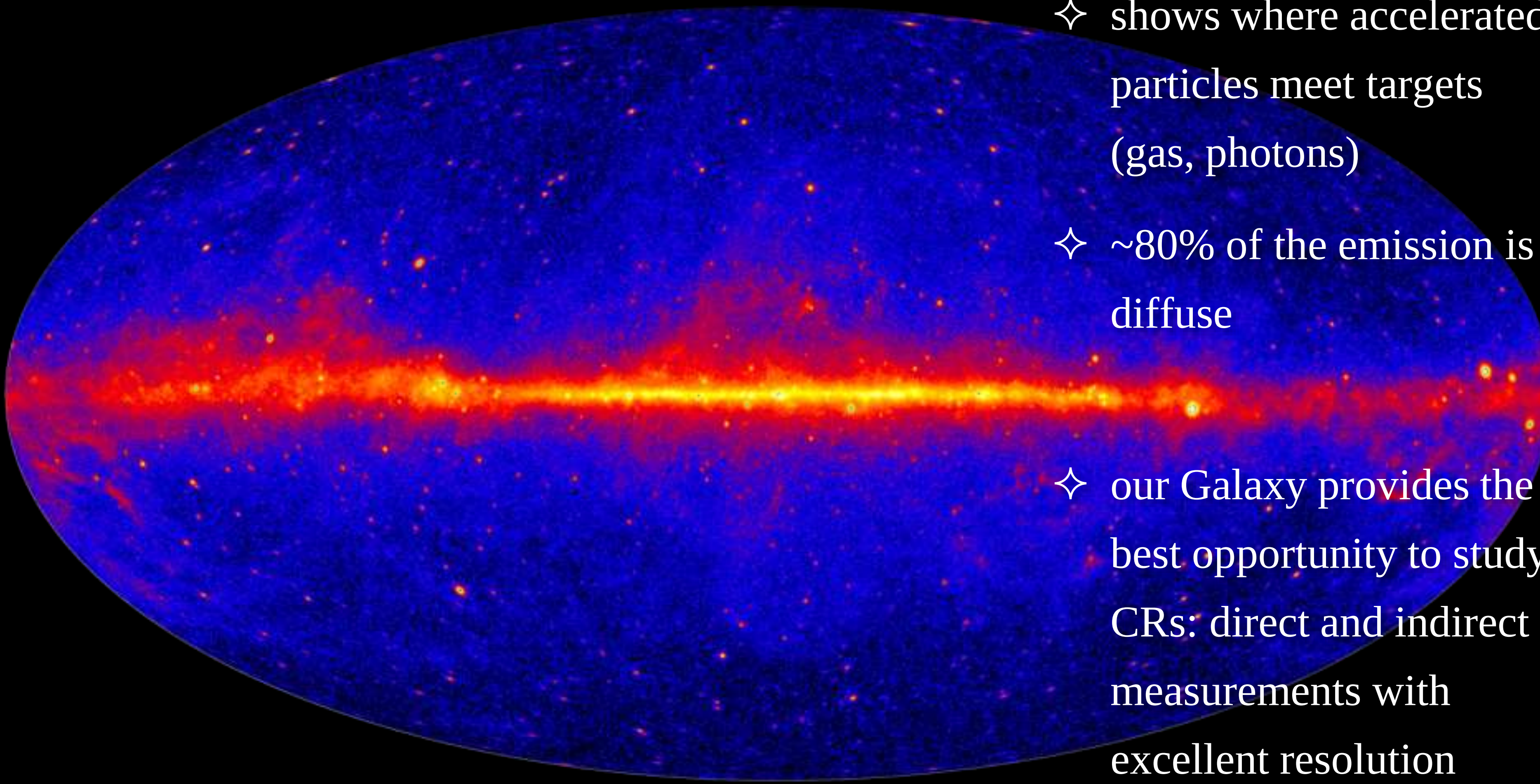
GLAST launch on June 11, 2008

Circular orbit at 565 km

Inclination 25.6°

Lifetime >5 years

Fermi-LAT skymap >1 GeV, 48 months

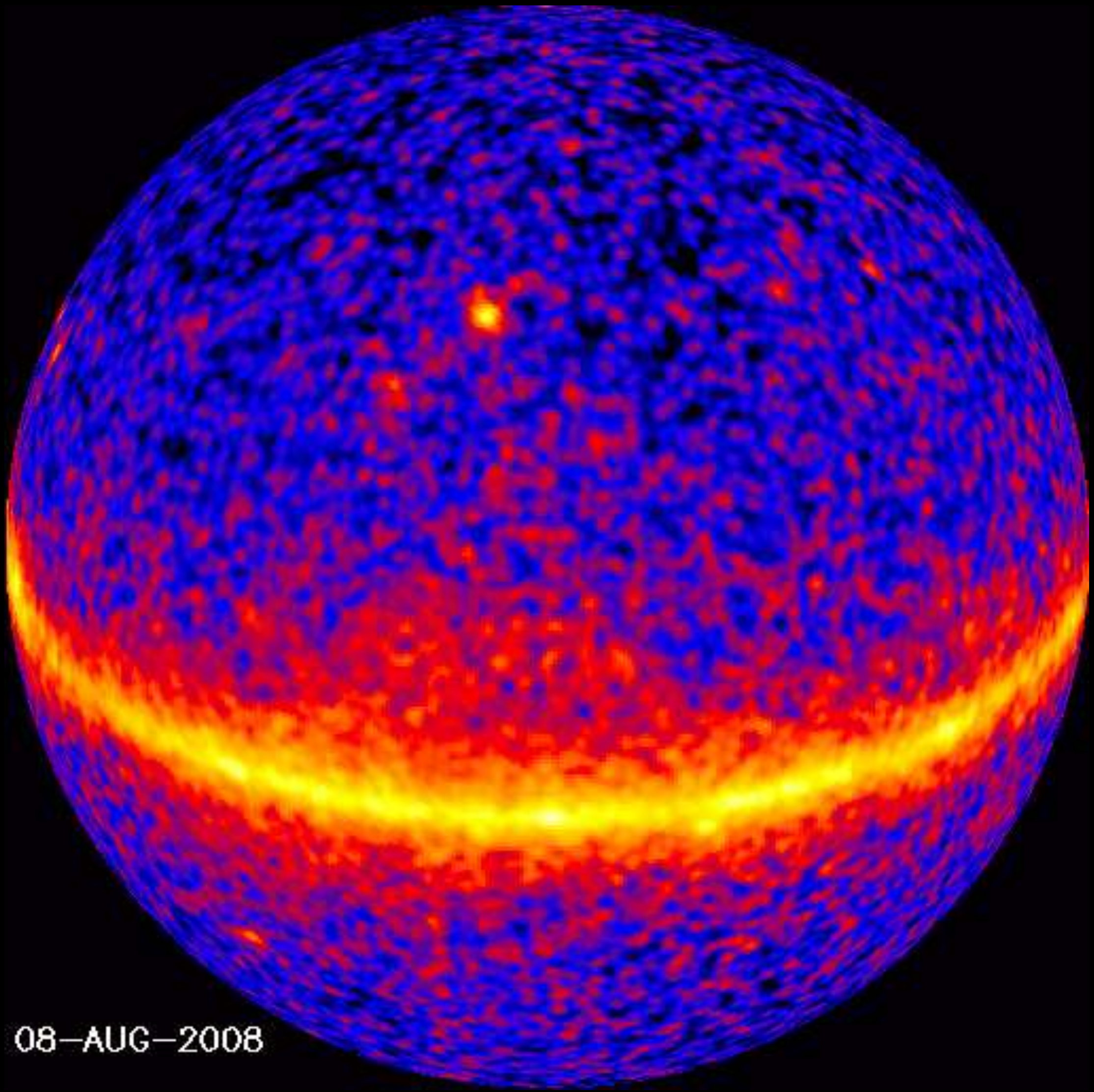


- ✧ shows where accelerated particles meet targets (gas, photons)
- ✧ ~80% of the emission is diffuse
- ✧ our Galaxy provides the best opportunity to study CRs: direct and indirect measurements with excellent resolution

4-year sky map, >1 GeV, front converting (best psf) (4.52M events)

- ✧ LAT: ~275B triggers, 225M Source class events
- ✧ GBM: >1000 GRBs

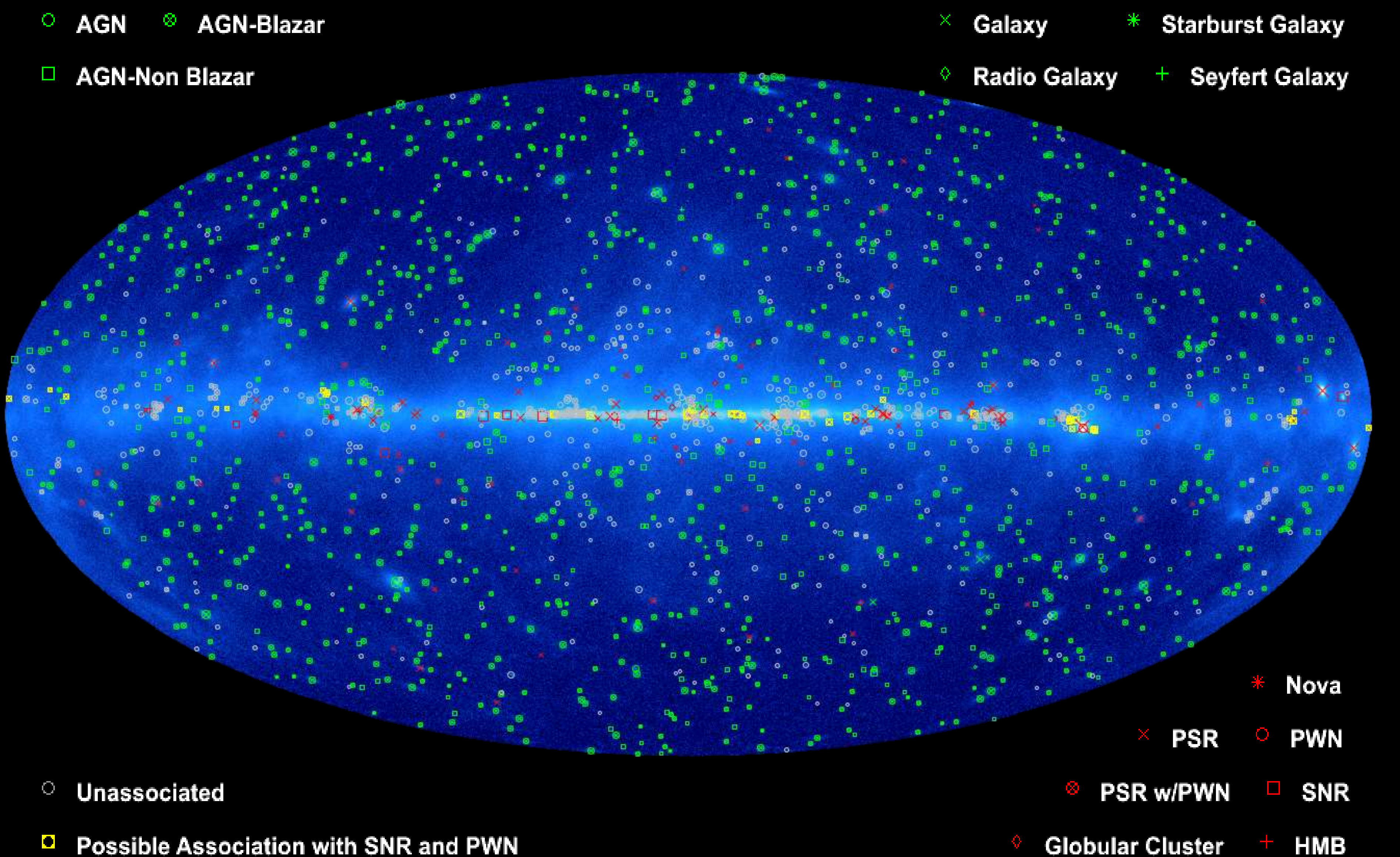
Fermi's skymap of particle interactions in real time



- ✧ >100 MeV, 36 months
- ✧ A lot of transients
- ✧ our Galaxy provides the best opportunity to study CRs: direct and indirect measurements with excellent resolution

2FGL Catalog – 1873 src

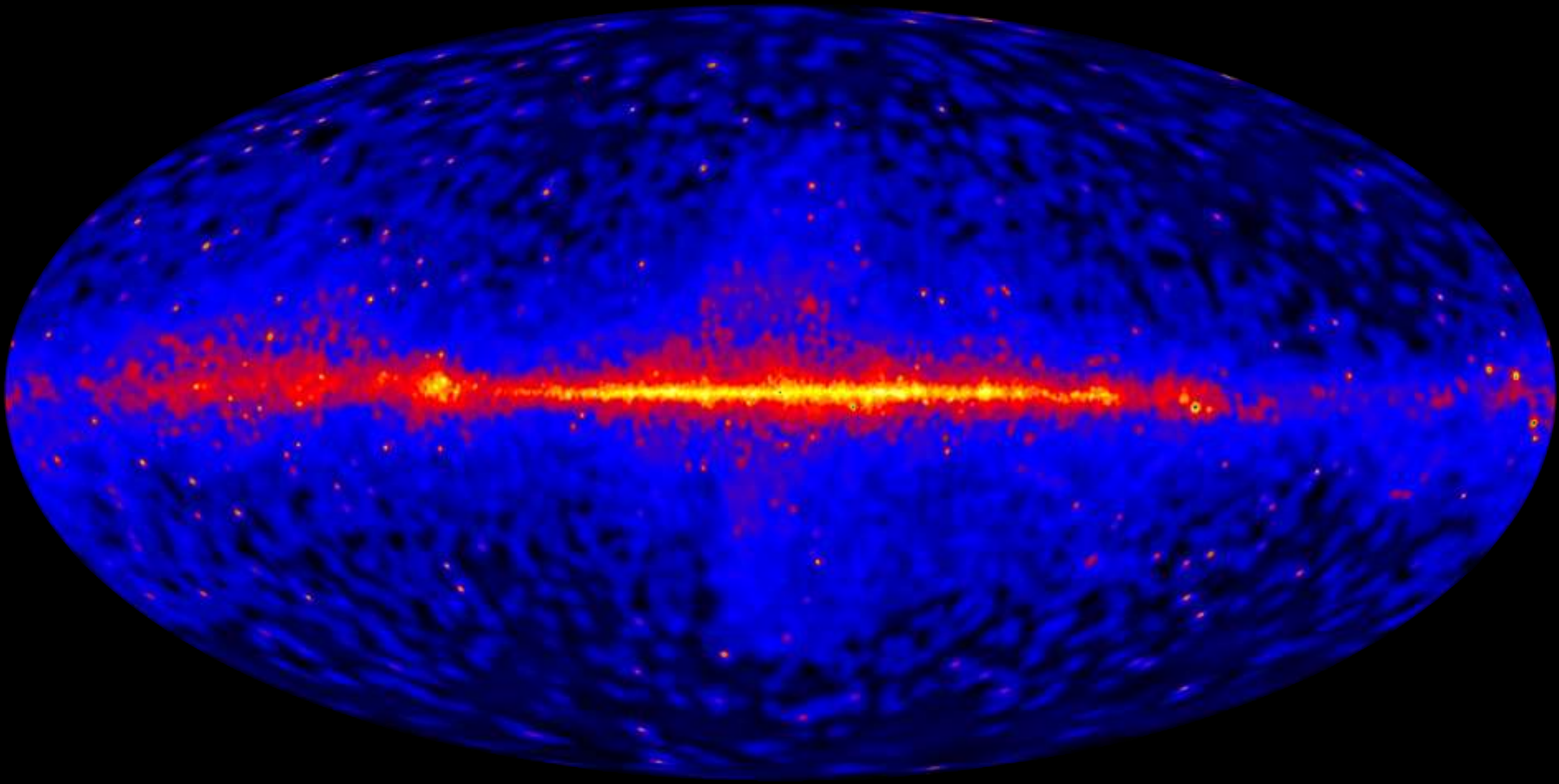
Based on integrated exposure (100 MeV to 100 GeV) from August 4, 2008, to July 31, 2010. TS > 25



3FGL, 4 years – 3033 sources! (100 MeV – 300 GeV)

Credit: Fermi Large Area Telescope Collaboration

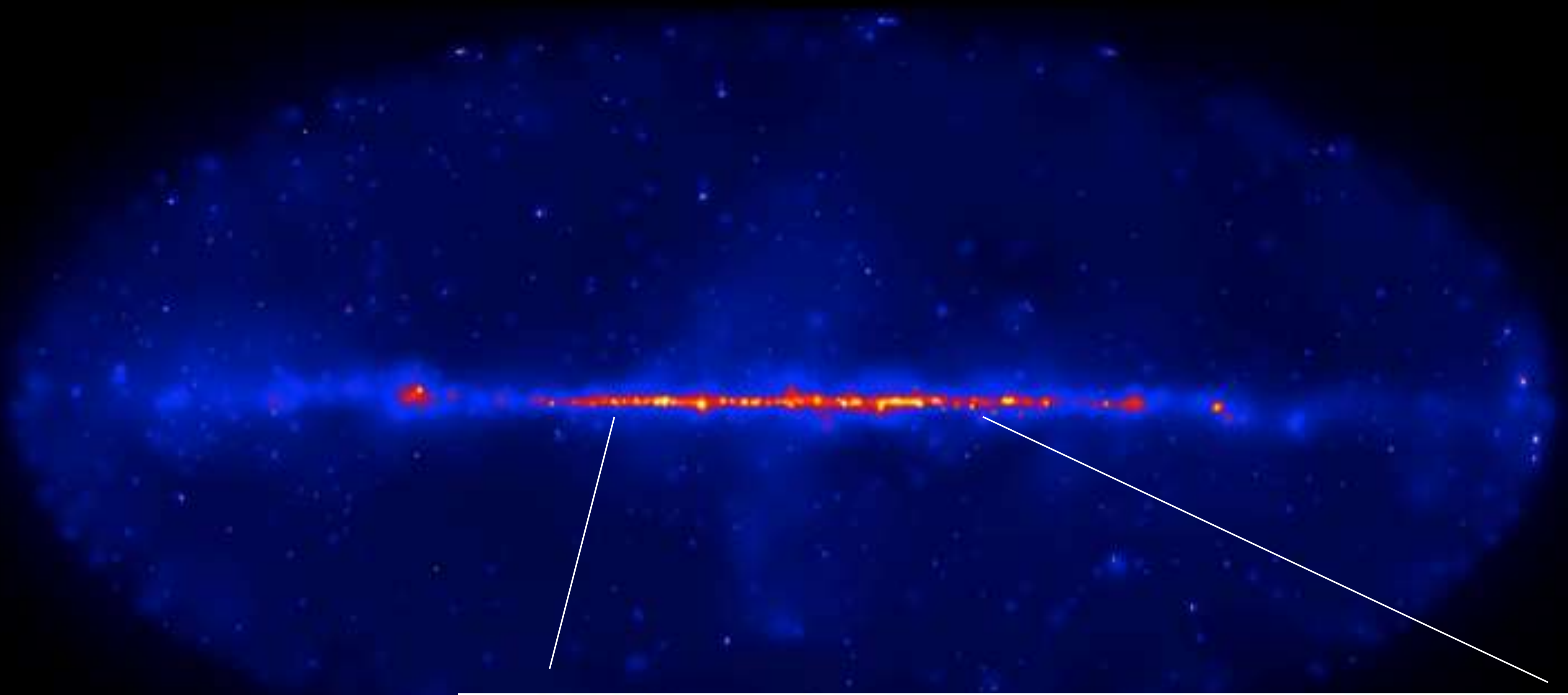
Fermi-LAT skymap >10 GeV



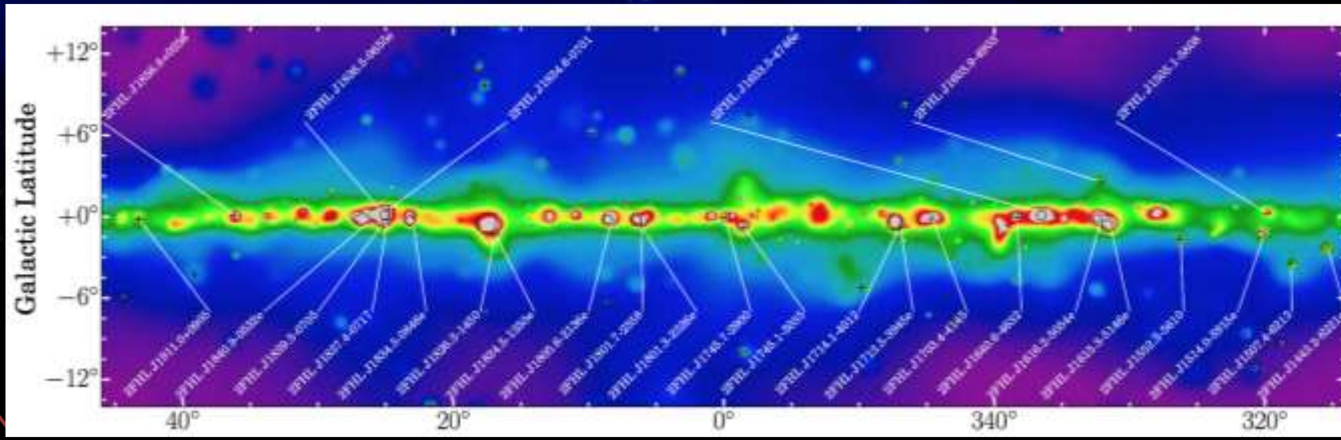
✧ Less diffuse emission

✧ Fewer but more powerful sources at high energies

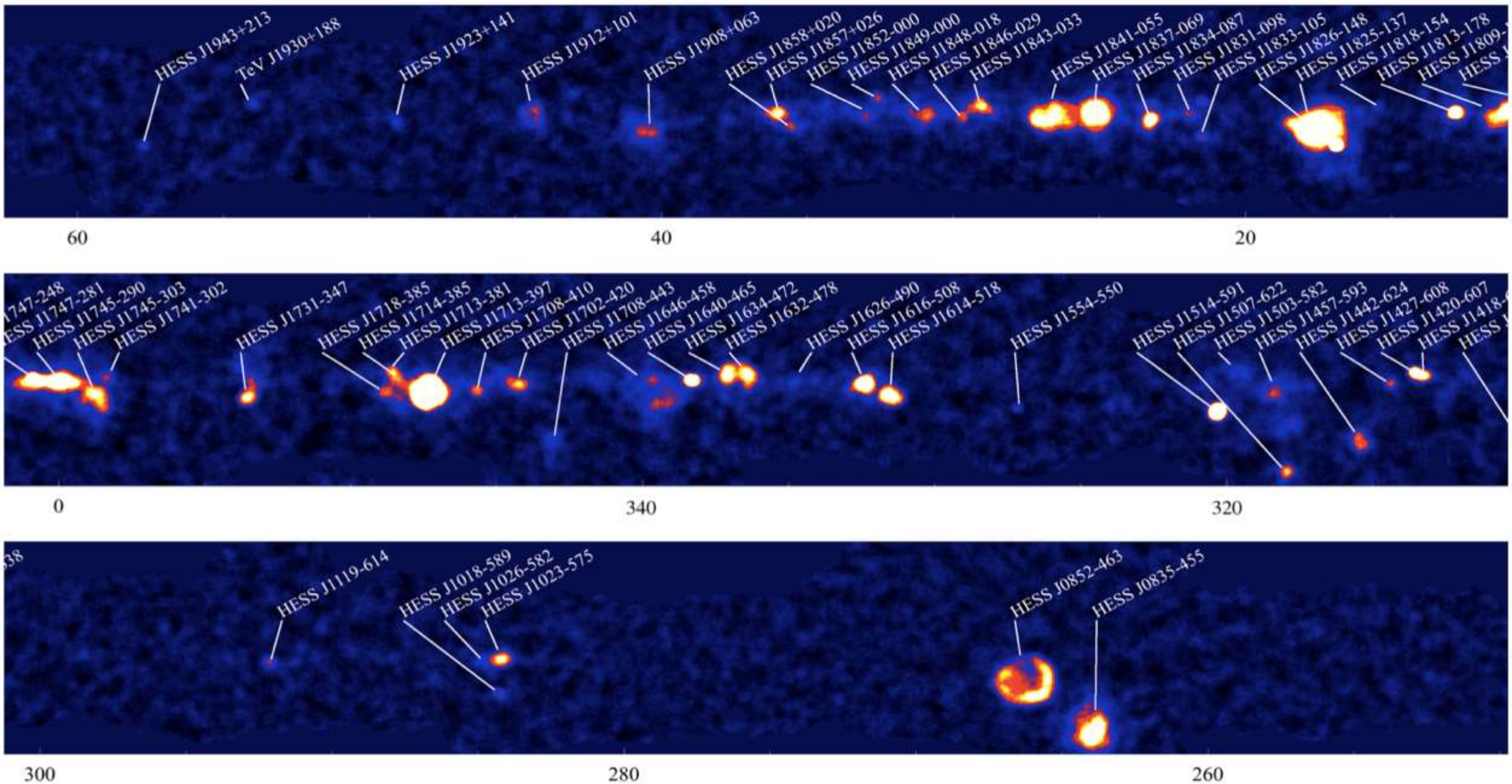
“TeVatron map” – Fermi Sky >50 GeV



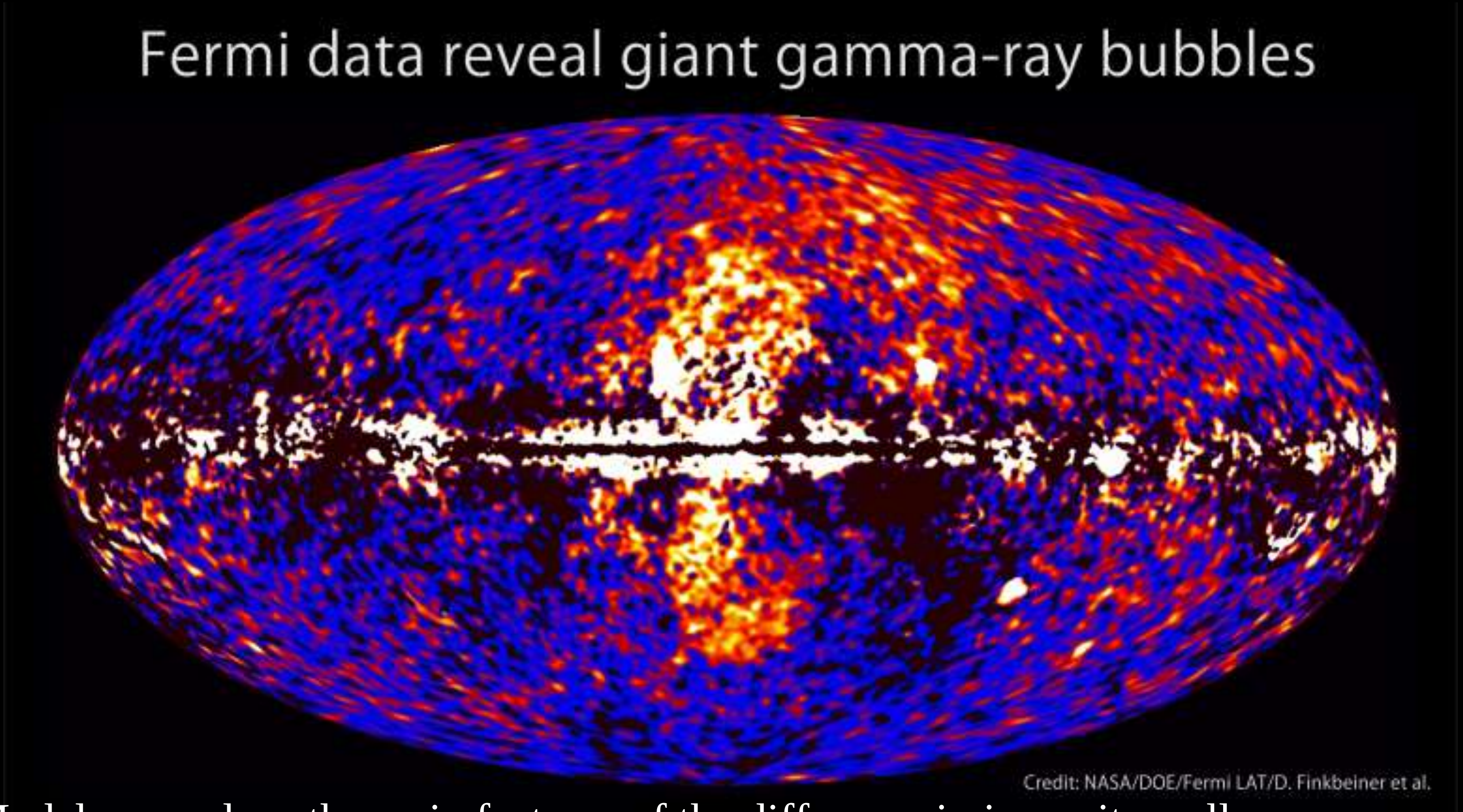
51,000 photons E >   50 GeV
18,000 photons E > 100 GeV
2,000 photons E > 500 GeV



HESS Galactic Plane Survey – TeV energies

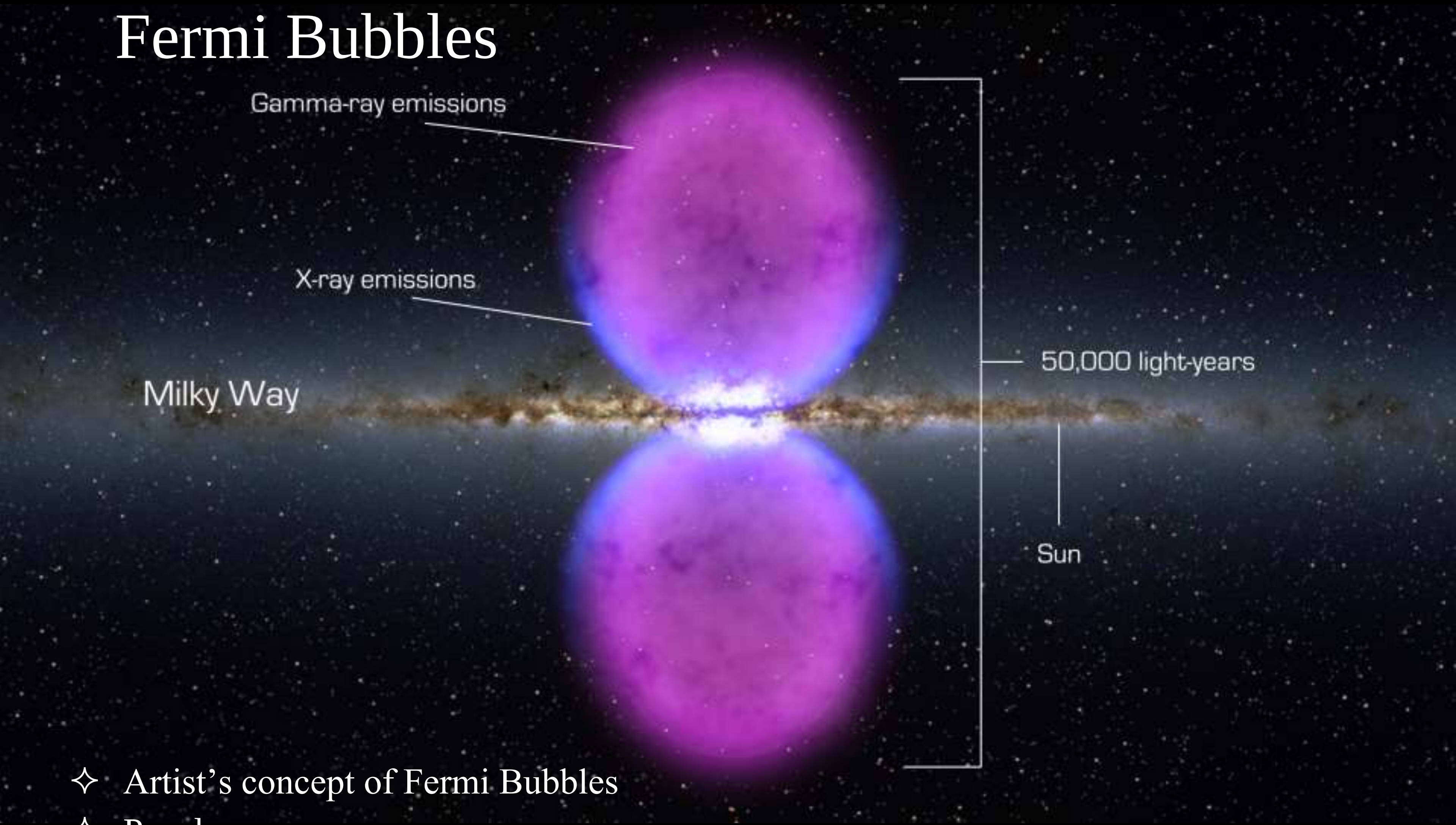


NASA press release



- ✧ Models reproduce the main features of the diffuse emission quite well
- ✧ Discrepancies between the physical model and high-resolution data (residuals) are the gold mines of new phenomena!
- ✧ Every extended source and/or process that is not included into the model pops up and exposes itself as a residual

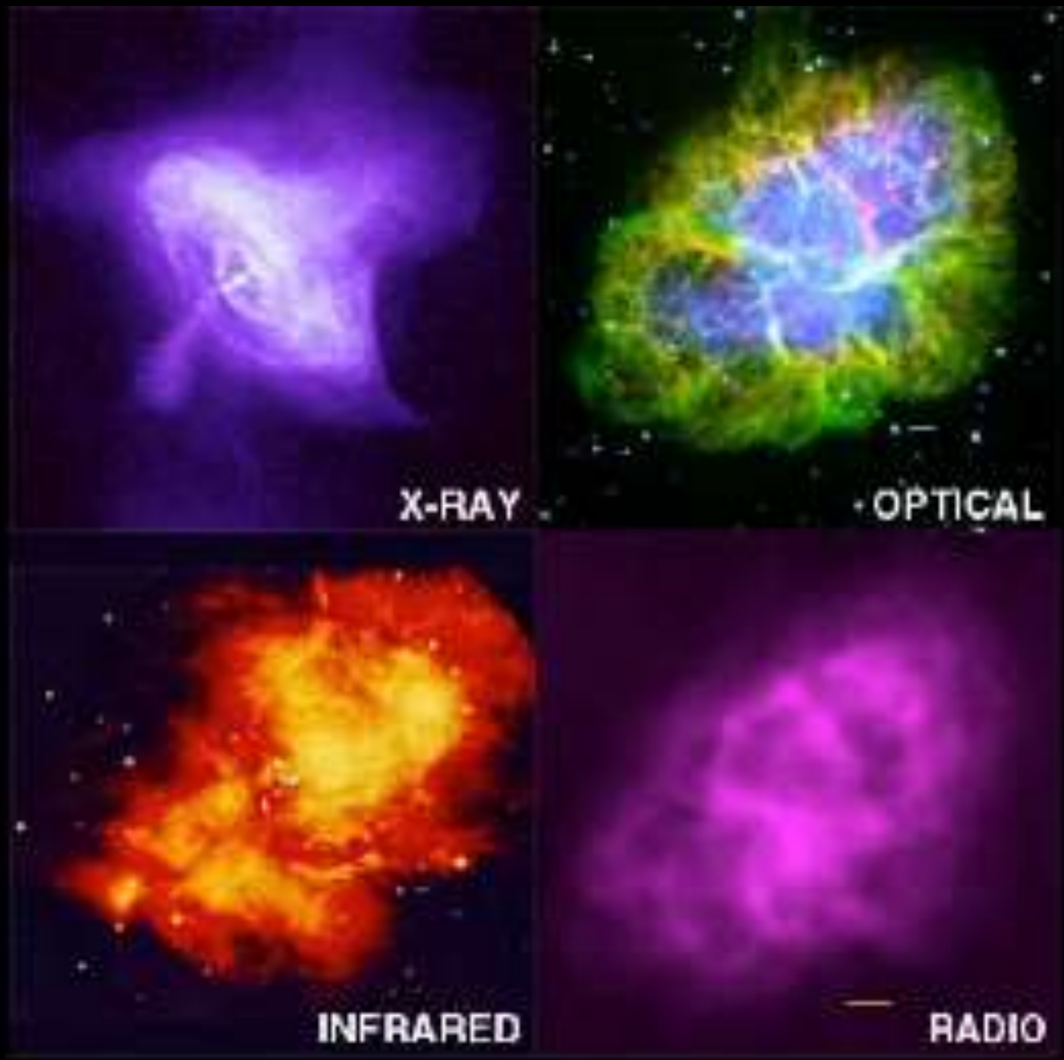
Fermi Bubbles



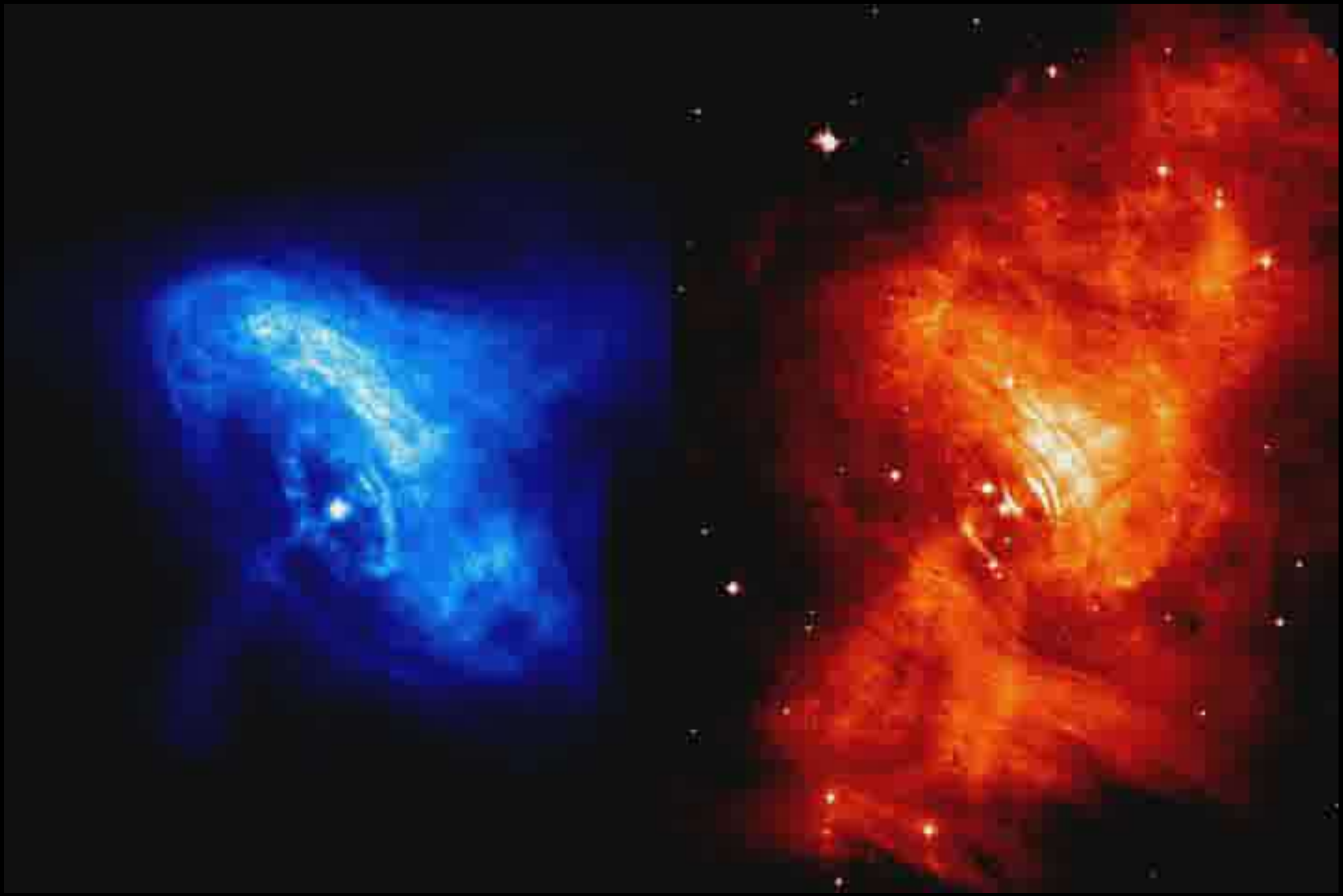
- ✧ Artist's concept of Fermi Bubbles
- ✧ Puzzles:
- ✧ The spectrum is "flat" (ongoing acceleration!)
- ✧ The spectrum is uniform over these huge structures! (what is the mechanism?)

The Crab Nebula, the brightest VHE γ-ray source

- ✧ The brightest VHE galactic “steady” source observed at different wavelengths
- ✧ Electrons accelerated up to ~10^{15} eV
- ✧ Synchrotron <500 MeV, inverse Compton scattering above

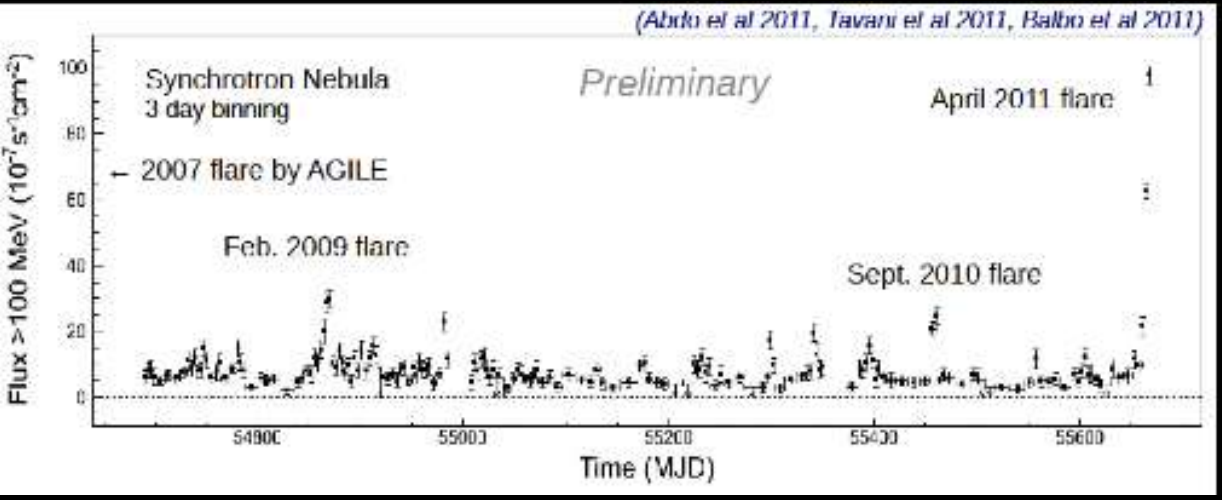


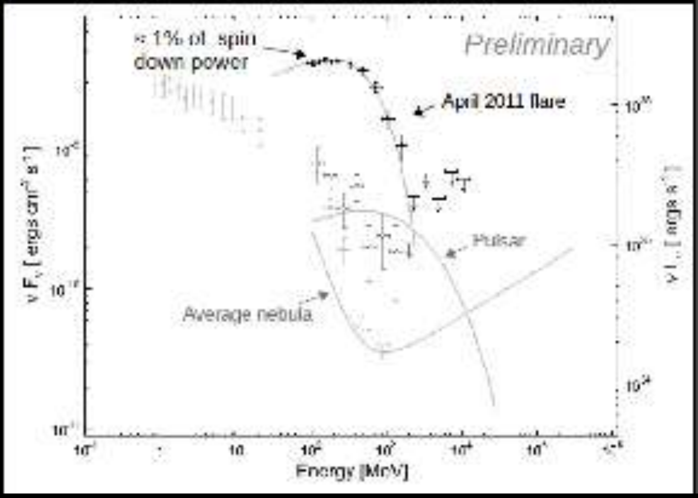
Crab pulsar: Chandra (X-rays) & Hubble (IR)



Recent flares of the synchrotron component

- Average flux ~6 × 10^{-7} photons/cm^2/sec above 100 MeV
- Two flares with flux increase by a factor of ~5 (2009, 2010)
- A flare with flux increase by a factor of ~30 (2011)
- Compact emission region <0.0004 pc



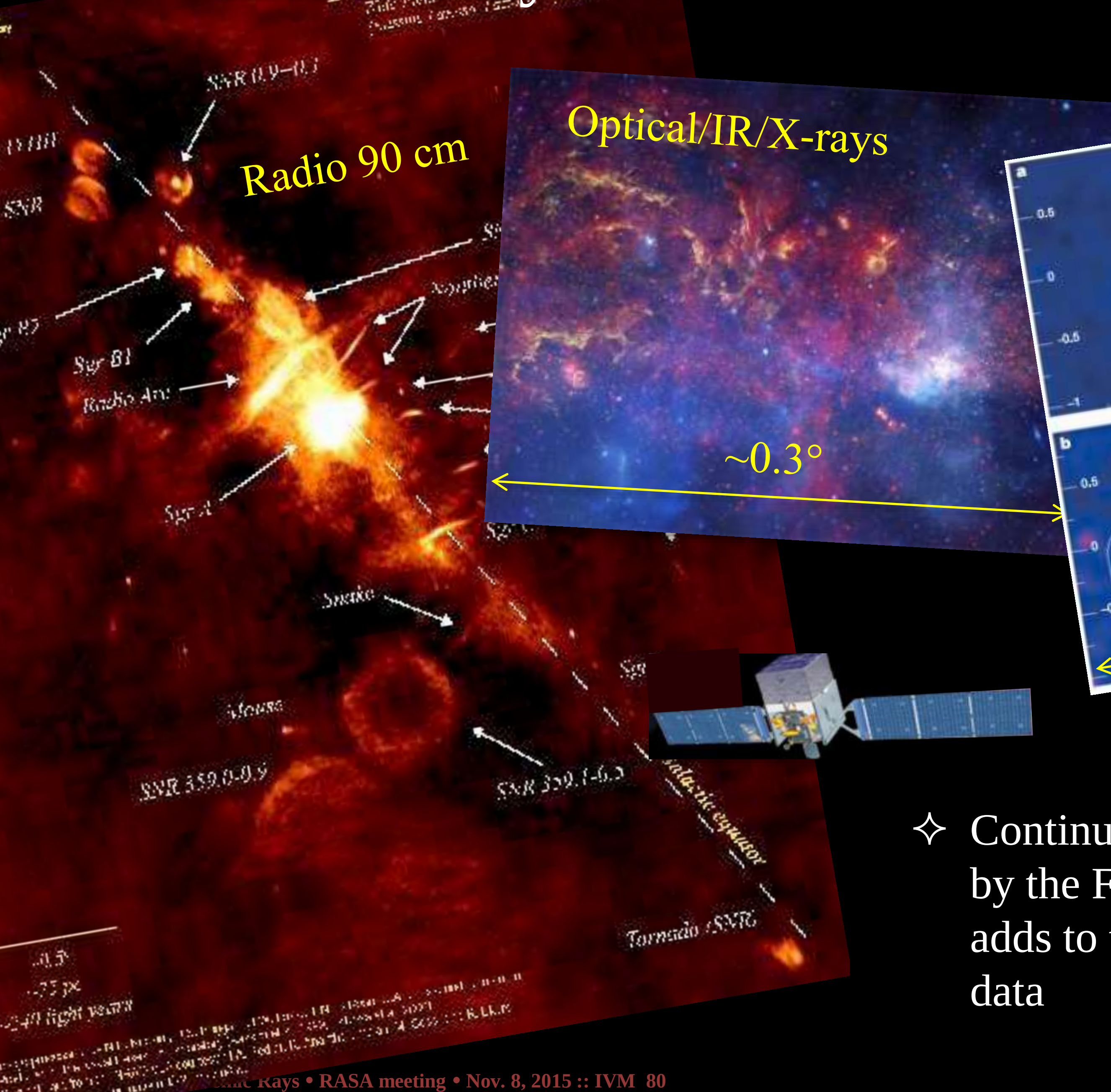


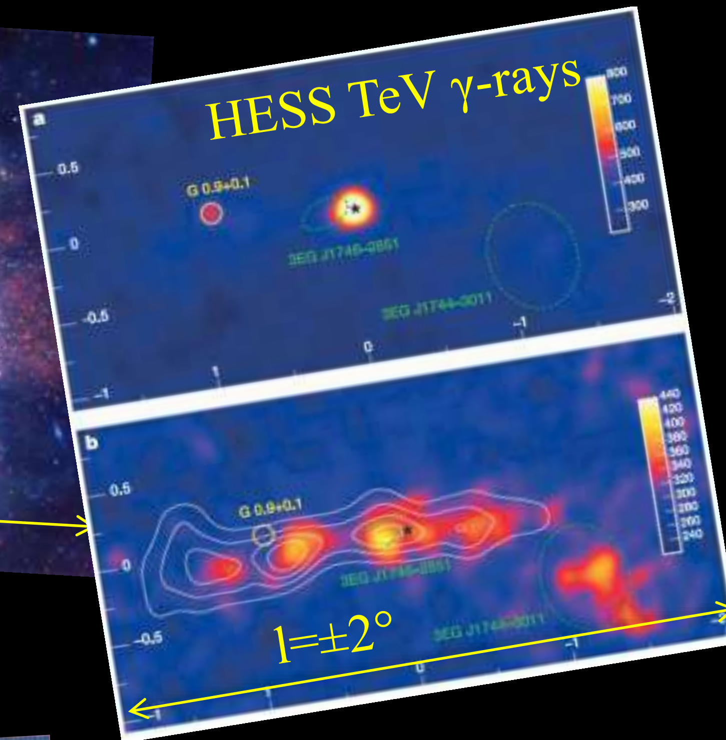
Gamma-ray emission from the inner Galaxy

"The region may be much more crowded than we think" – Andrea Ghez

Fermi-LAT analysis

Inner Galaxy at different wavelengths





✧ Continuous collection of data by the Fermi-LAT significantly adds to the available multi-λ data

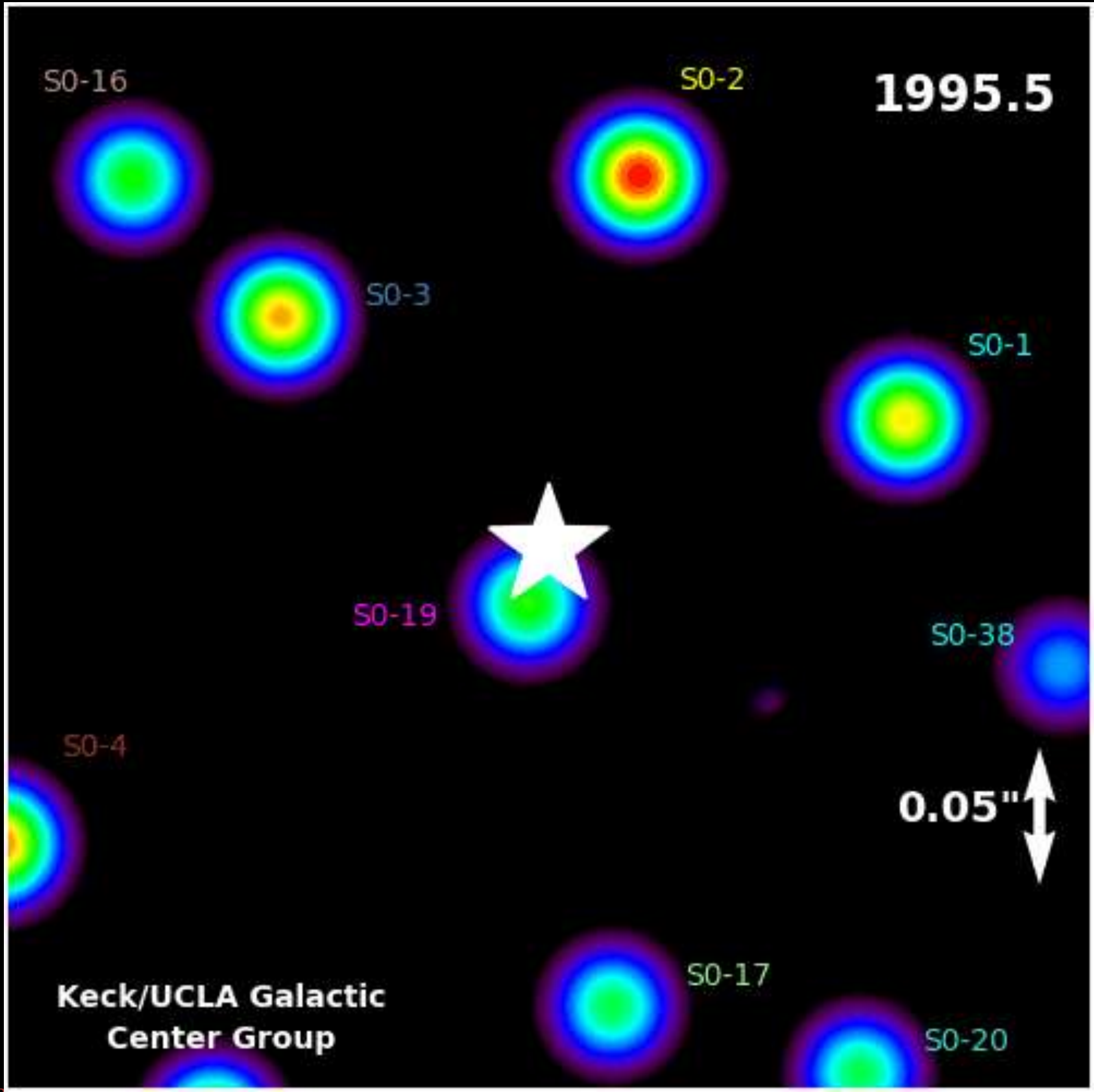
What is the inner Galaxy?

- ✧ Harbors a SMBH ~$4 \times 10^6\ M_\odot$
- ✧ Flaring activity of SMBH: large flare ~100 years ago, and faint flares
- ✧ Huge over-density of dark matter
- ✧ 1000s of stars in the innermost parsec
- ✧ Large concentration of binary systems and compact objects
- ✧ "Paradox of youth" − old (?) stars look like young
- ✧ "Fermi Bubbles" (Finkbeiner+'2010)

- ✧ Guaranteed new physics results!

Galactic center in the IR

- A 2.2 micron animation of the stellar orbits in the central 0.5 arcsec
- Images taken from the years 1995 through 2013
- Stars orbiting the black hole of 4 millions of the solar masses at the center of the Galaxy



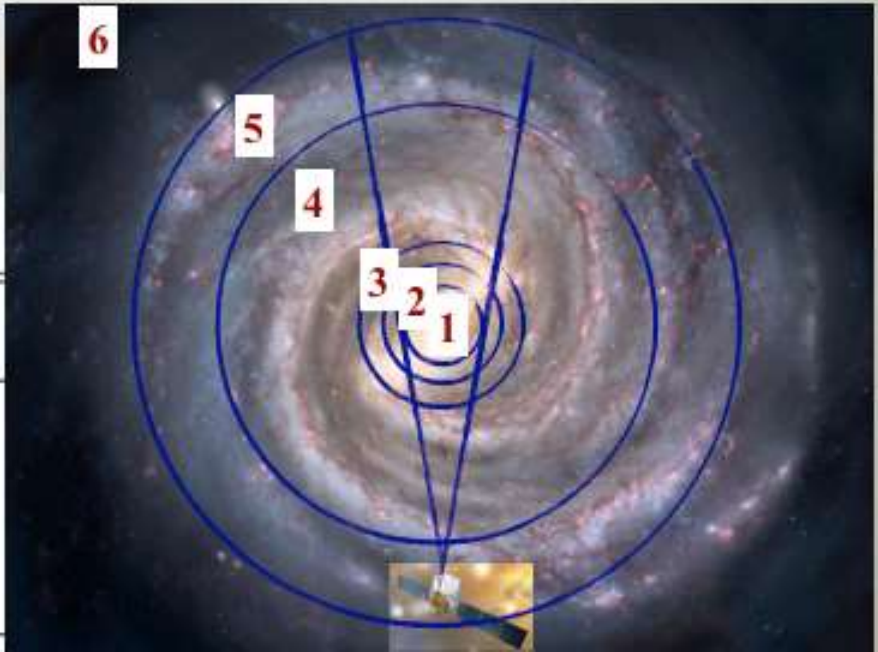
Fermi-LAT Study of the Inner Galaxy

Scaling Procedure

- Determine intensity for π^0 (from HI and H_2 gas) and IC contributions in galactocentric rings,
  - IC component divided in rings (dev. version of GALPROP), same boundaries as the gas: these additional degrees of freedom can compensate for uncertainies in the GALPROP model of the electron spectrum or ISRF used to calculate the IC templates
- Isotropic and Loop I (*Wolleben, 2007, ApJ 664*) emissions also fitted to the data
- Different sky regions are employed based on where the components that are fitted dominate. Point source locations and spectra taken from the preliminary 3FGL.

Galactocentric ring boundaries.

Ring #	$R_{\rm min}$ [kpc]	$R_{\rm max}$ [kpc]	Longitude Range (Full)
1	0	1.5	$-10° \le l \le 10°$
2	1.5	2.5	$-17° \le l \le 17°$
3	2.5	3.5	$-24° \le l \le 24°$
4	3.5	8.0	$-70° \le l \le 70°$
5	8.0	10.0	$-180 \le l \le 180°$
6	10.0	50.0	$-180 \le l \le 180°$

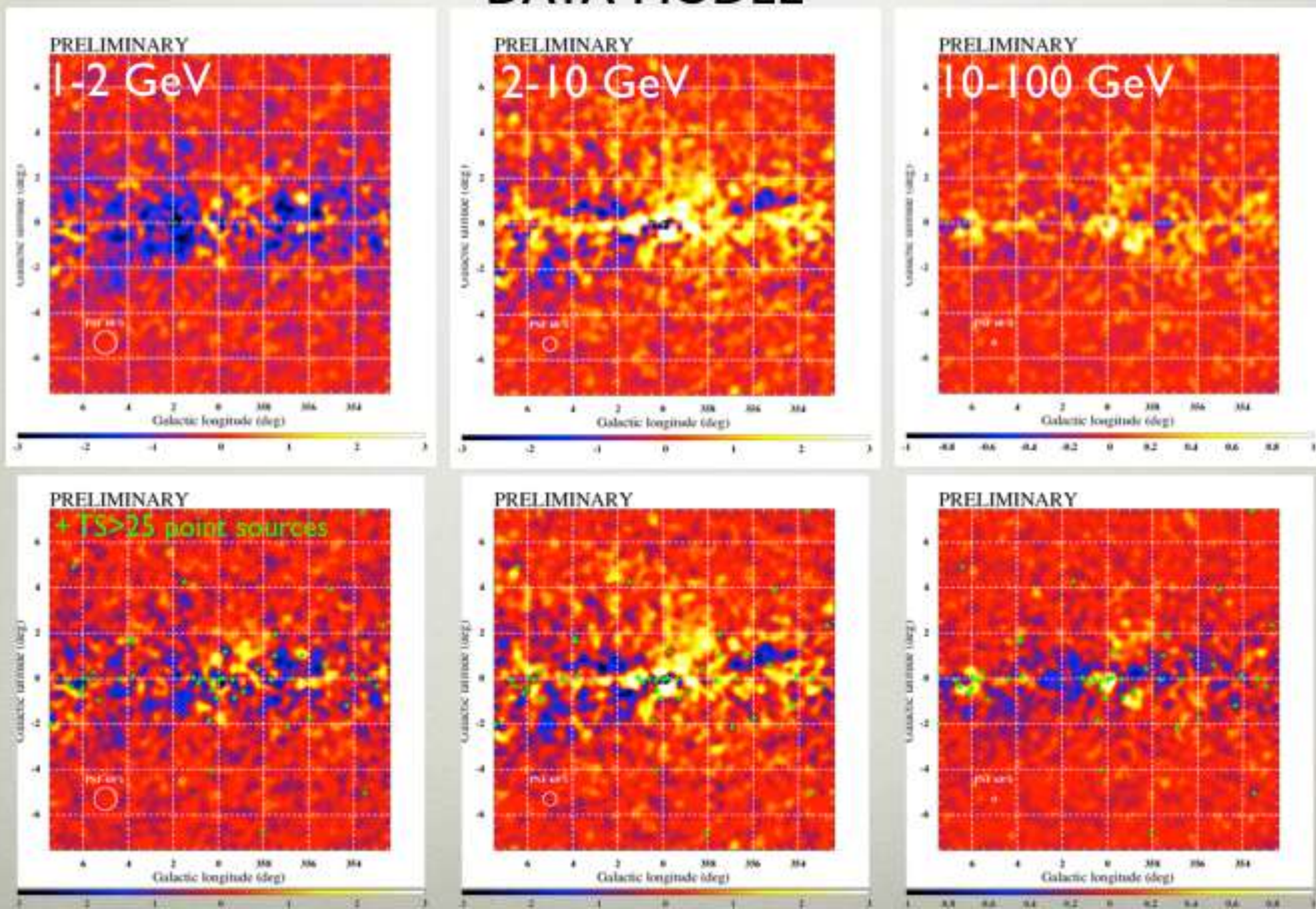


Results - Residual Maps

DATA-MODEL

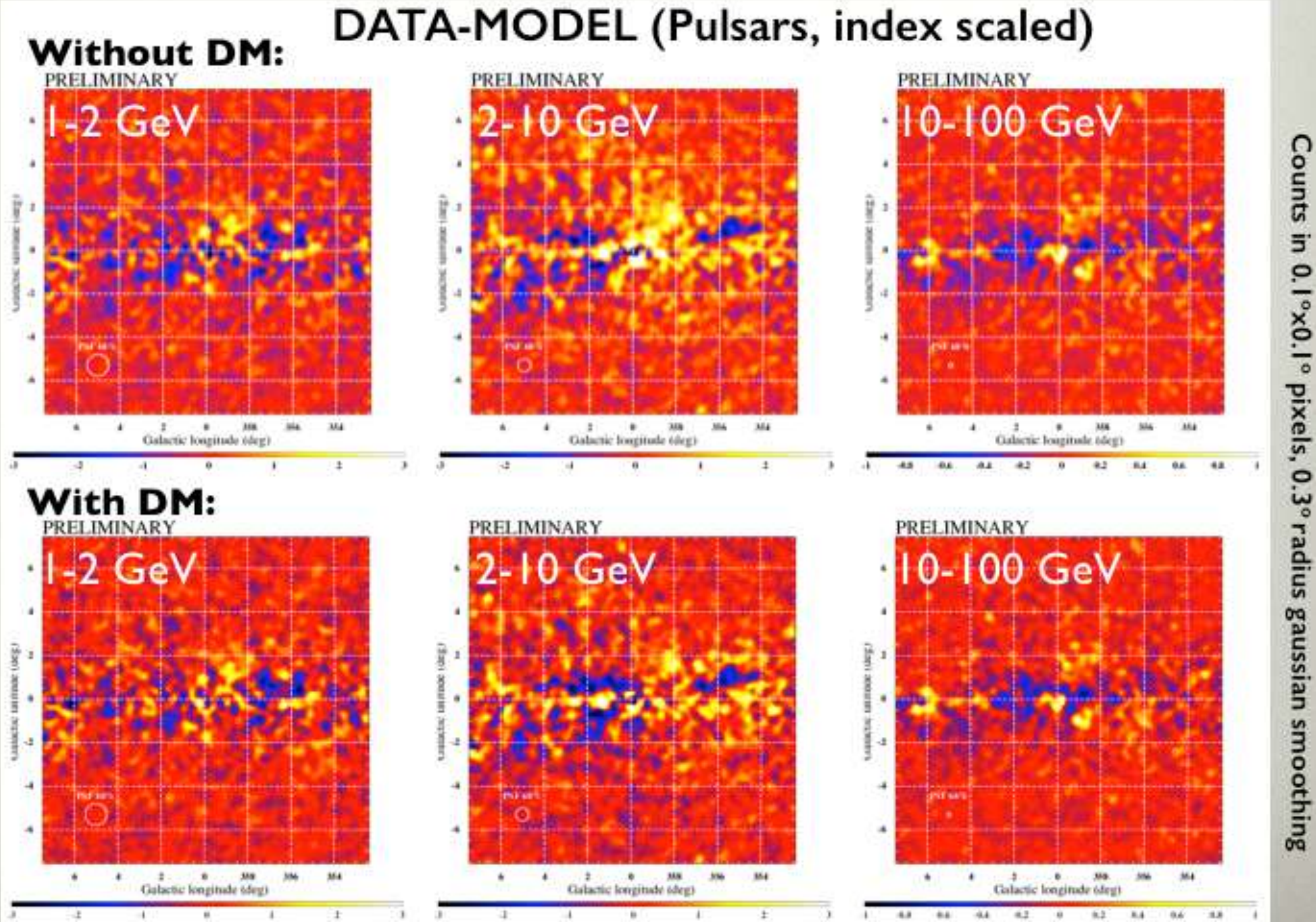
Pulsars, tuned-intensity

Pulsars, tuned-index



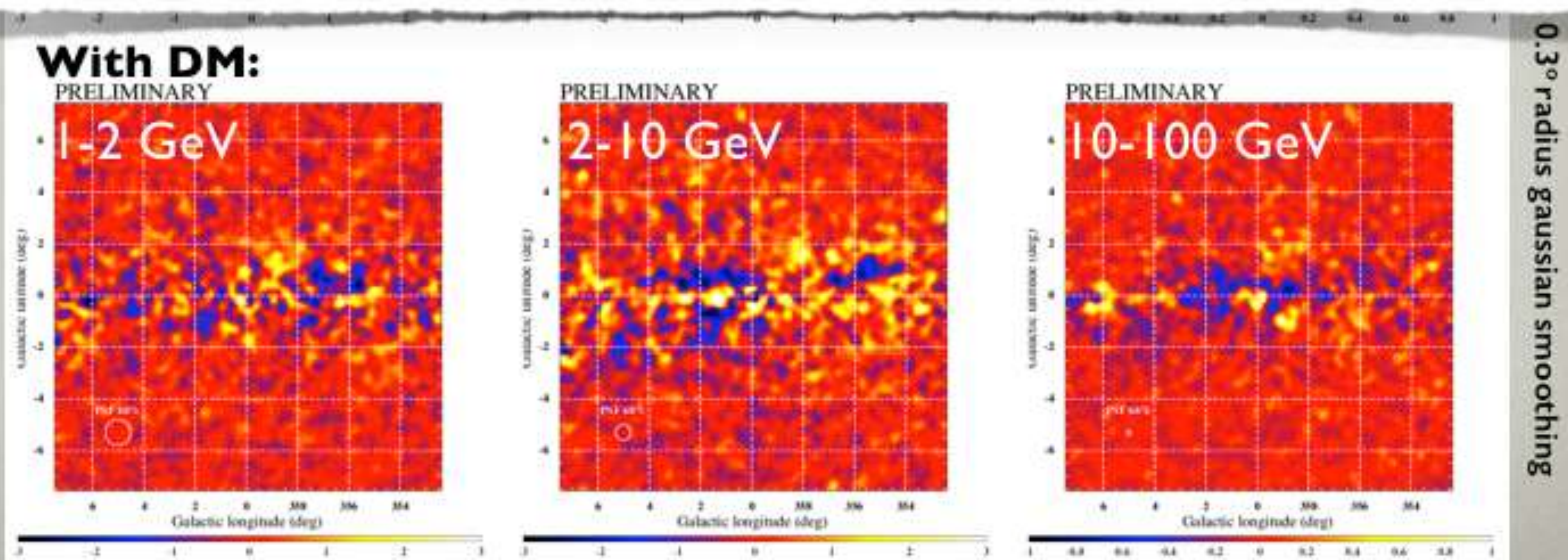
Counts in 0.1°x0.1° pixels, 0.3° radius gaussian smoothing

Results - Dark Matter



- There is a positive residual in the 15°x15° region which persists for all IEMs we used
- A DM template improves the agreement with the data and its spectral properties vary widely depending on the IEM, however:
  - Some discrepancies remain and might be due to mismodeling of the IEM
  - There are limitations in the IEMs, e.g. the gas distribution, cylindrical symmetry, as well as interplay between the interstellar emission and point sources.

    Understanding these issues is crucial to confirm the presence and properties of additional components, DM or otherwise



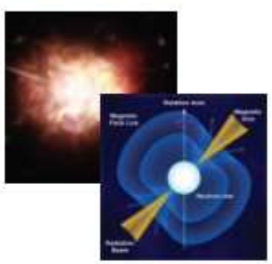
The origin of the EGB in the LAT energy range.

Unresolved sources

[Blazars](#)
Dominant class of LAT extra-galactic sources. Many estimates in literature. EGB contribution ranging from 20% - 100%.

Non-blazar active galaxies
27 sources resolved in 2FGL
~ 25% contribution of radio galaxies to EGB expected. (e.g. Inoue 2011)

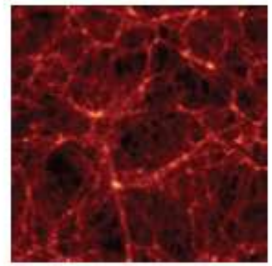
Star-forming galaxies
Several galaxies outside the local group resolved by LAT. Significant contribution to EGB expected. (e.g. Pavlidou & Fields, 2002, Ackermann et al. 2012)



GRBs
High-latitude pulsars
small contributions expected. (e.g. Dermer 2007, Siegal-Gaskins et al. 2010)

Diffuse processes

Intergalactic shocks
widely varying predictions of EGB contribution ranging from 1% to 100% (e.g. Loeb & Waxman 2000, Gabici & Blasi 2003)



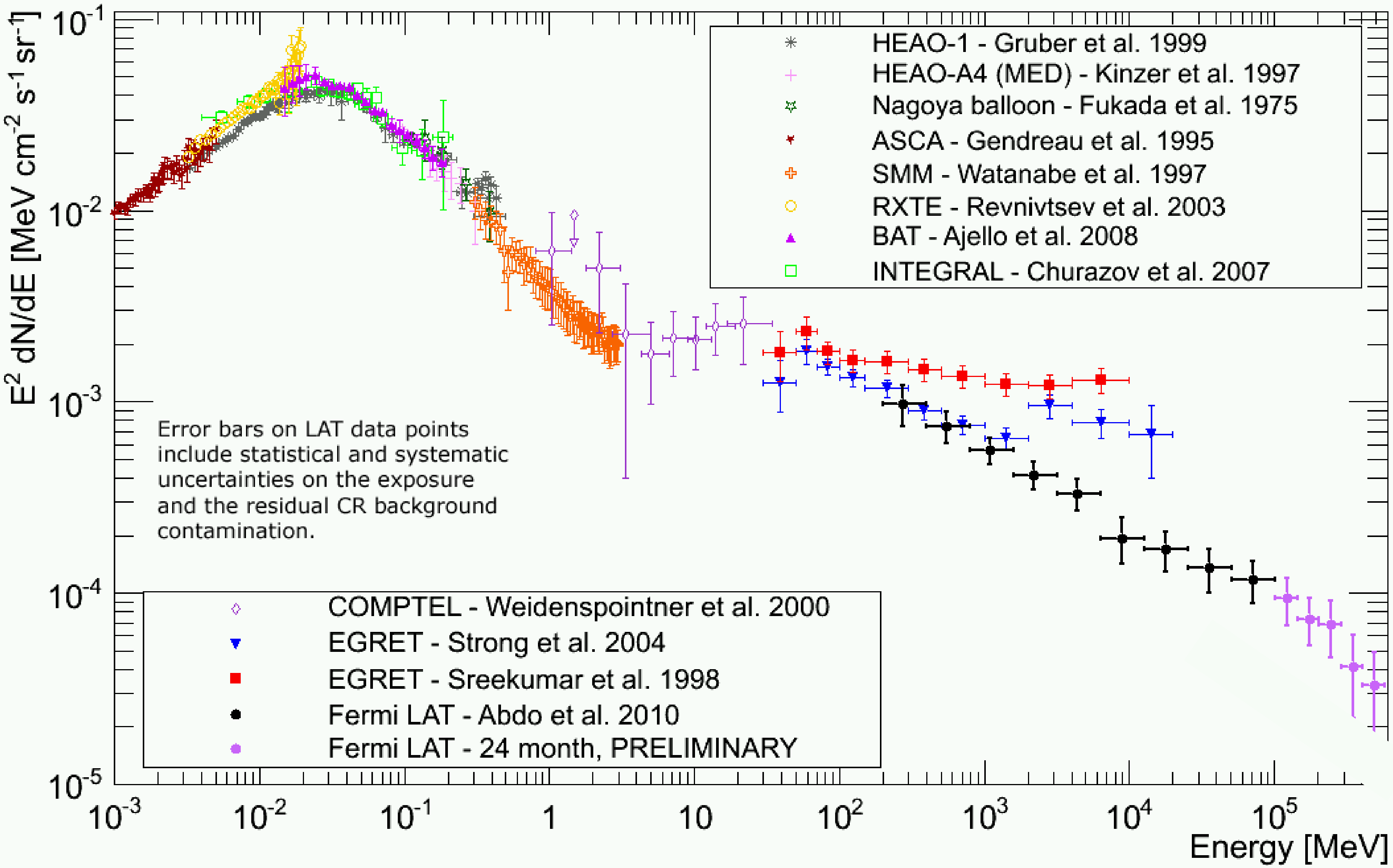
Dark matter annihilation
Potential signal dependent on nature of DM, cross-section and structure of DM distribution (e.g. Ullio et al. 2002)

Interactions of UHE cosmic rays with the EBL
dependent on evolution of CR sources, predictions varying from 1% to 100 % (e.g. Kalashev et al. 2009)

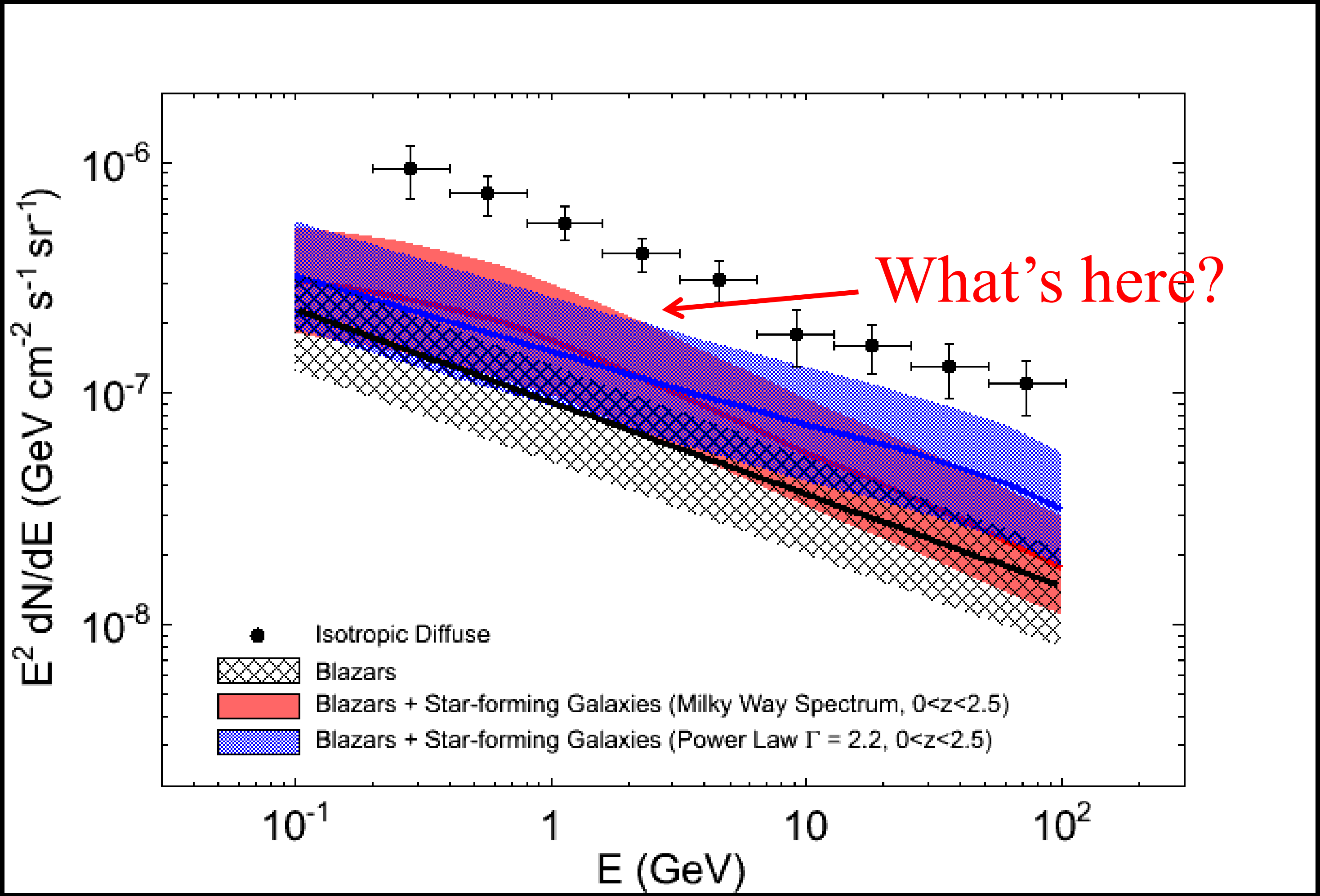
Extremely large galactic electron halo (Keshet et al. 2004)

CR interaction in small solar system bodys (Moskalenko & Porter 2009)

Spectrum and Origin of the Isotropic Background



Contribution of normal galaxies and blazars



A Zoo of Small Solar System Bodies

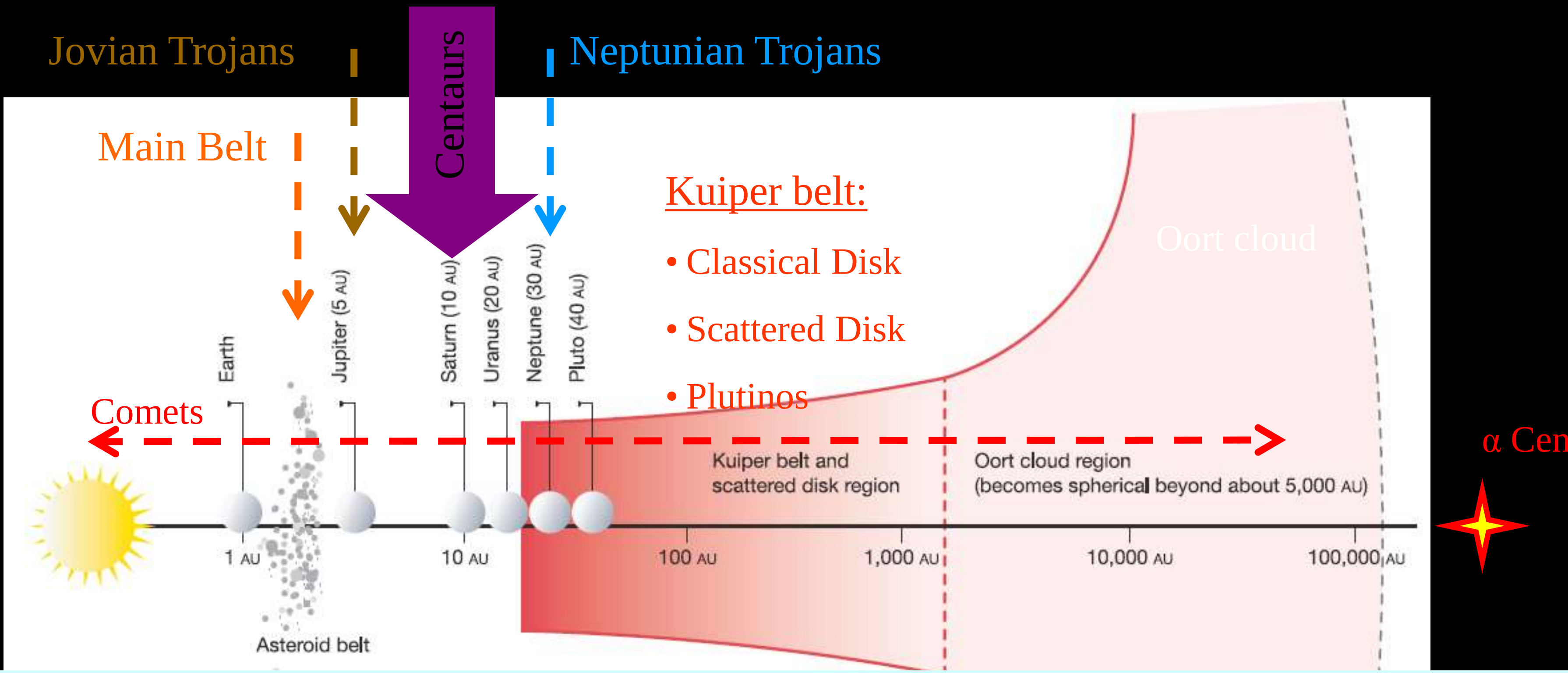


Table 1 **The primary cometary reservoirs of the Solar System**

	Kuiper belt	Oort cloud
Shape	Disk-like	Spheroidal
Distance range	30–1,000 AU	1×10^3–1×10^5 AU
Comet population	~5–10 × 10^9	1×10^{11}–5×10^{12}
Estimated mass (including smaller debris)	~0.1 $M_\oplus$	1–50 $M_\oplus$
Ambient surface temperatures	30–60 K	5–6 K
Origin	Largely *in situ*	Ejected material from the Kuiper belt and outer-planets zone
Return mechanism from the reservoir	Dynamical chaos due to planetary perturbations and collisions	Perturbations due to passing stars, galactic tides and molecular clouds

Stern'03

Small Bodies: Size Distributions (Dohnanyi'1969)

2. SMALL SOLAR SYSTEM BODIES

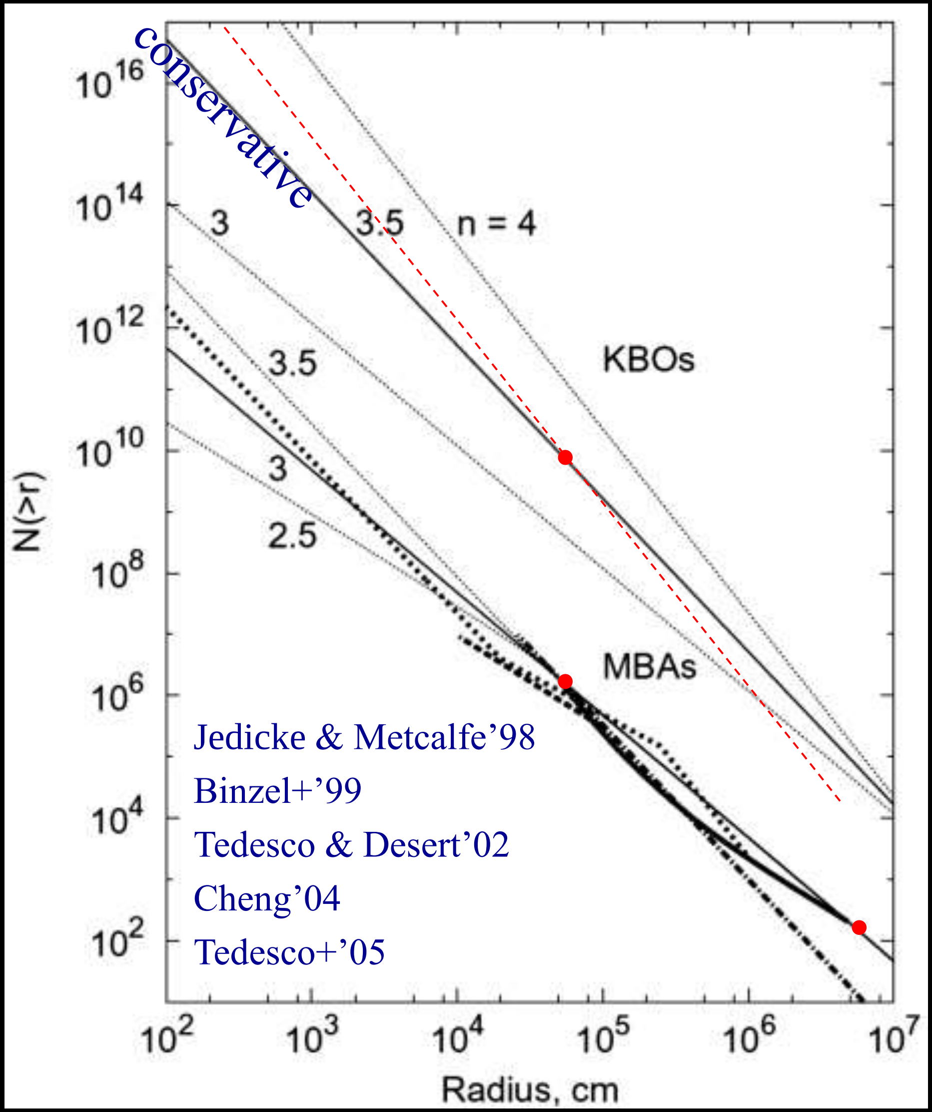
The asteroid mass and size distributions are thought to be governed by collisional evolution and accretion. Collisions between asteroids give rise to a cascade of fragments, shifting mass toward smaller sizes, while a small body impact with a much larger asteroid leads to the growth of the latter. The first comprehensive analytical description of such a collisional cascade is given by Dohnanyi (1969). Under the assumptions of scaling of the collisional response parameters and an upper cutoff in mass, the relaxed size and mass distributions approach power-laws:

$$dN = am^{-k}dm \qquad (1)$$

$$dN = br^{-n}dr, \qquad (2)$$

where m is the asteroid mass, r is the asteroid radius, and a, b, k, n are constants. These equilibrium distributions extend over all size and mass ranges of the population except near its high-mass end. The constants in eqs. (1),

- ✧ Collisional evolution & accretion
- ✧ Relaxed size distribution n=3.5 (assuming scaling of collisional response parameters)
- ✧ Scaling breaks…



HAWC – High Altitude Water Cherenkov Observatory

- ✧ 300 water tanks
- ✧ FoV ~ all sky above

HESS II – High Energy Stereoscopic System

- ✧ HESS I – 12 m dishes
- ✧ HESS II – 28 m dish
- ✧ FoV ~ 5°

CTA – Cherenkov Telescope Array (future)