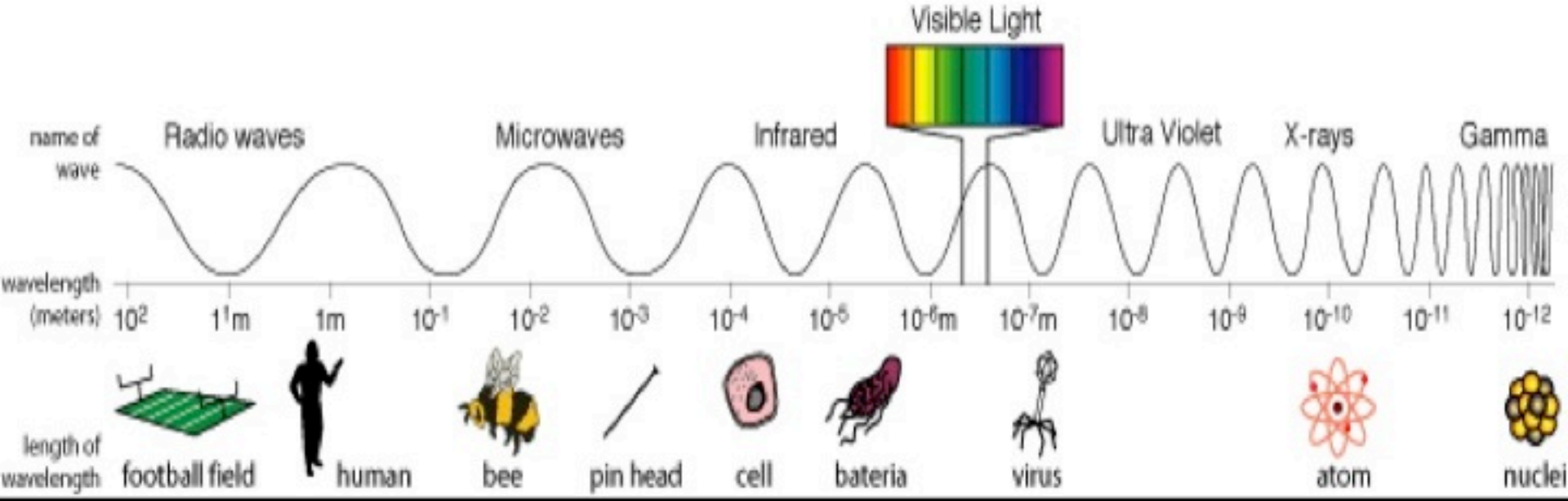
CosmicSIG Science and Plans

Cosmic Ray *Science Interest* Group

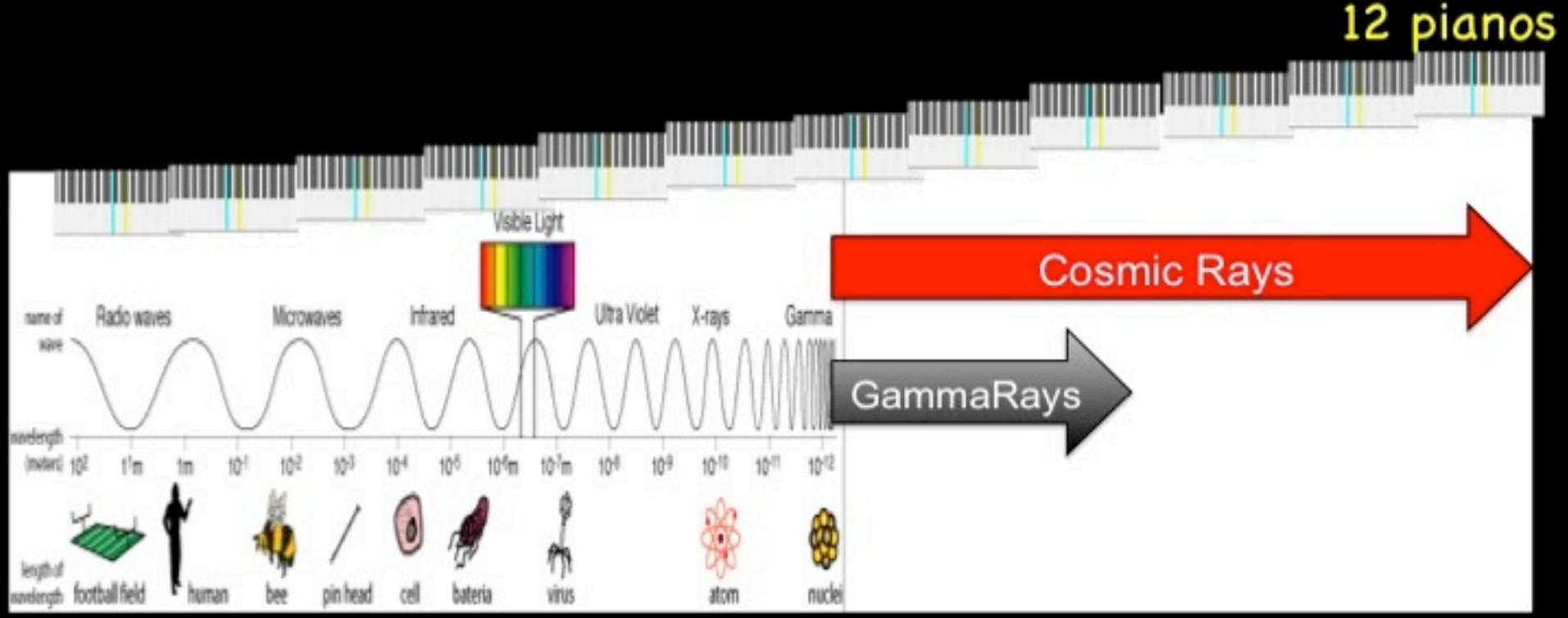
APS Meeting, April 6, 2014

Photon "energy range"



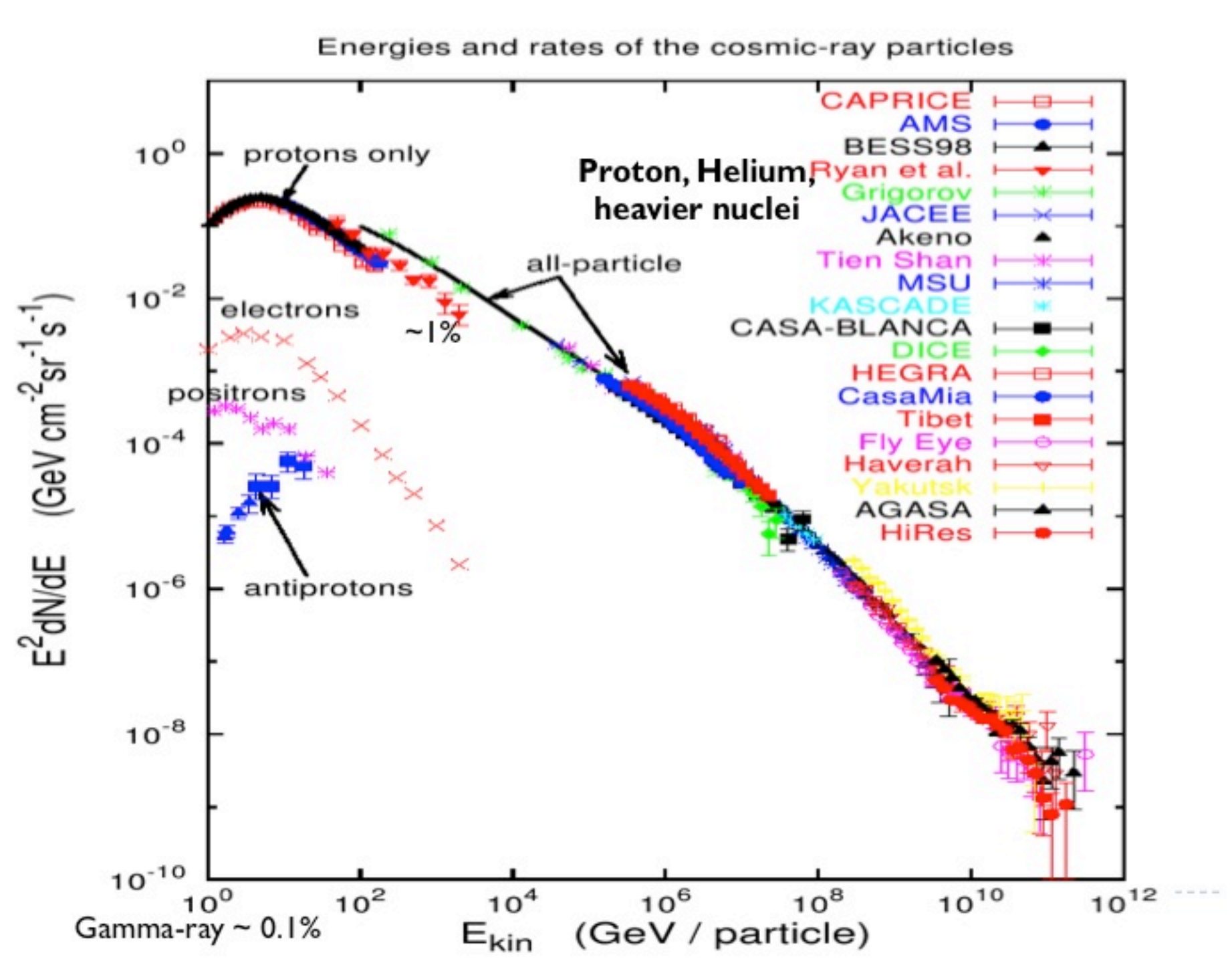
Energy range of Cosmic Rays

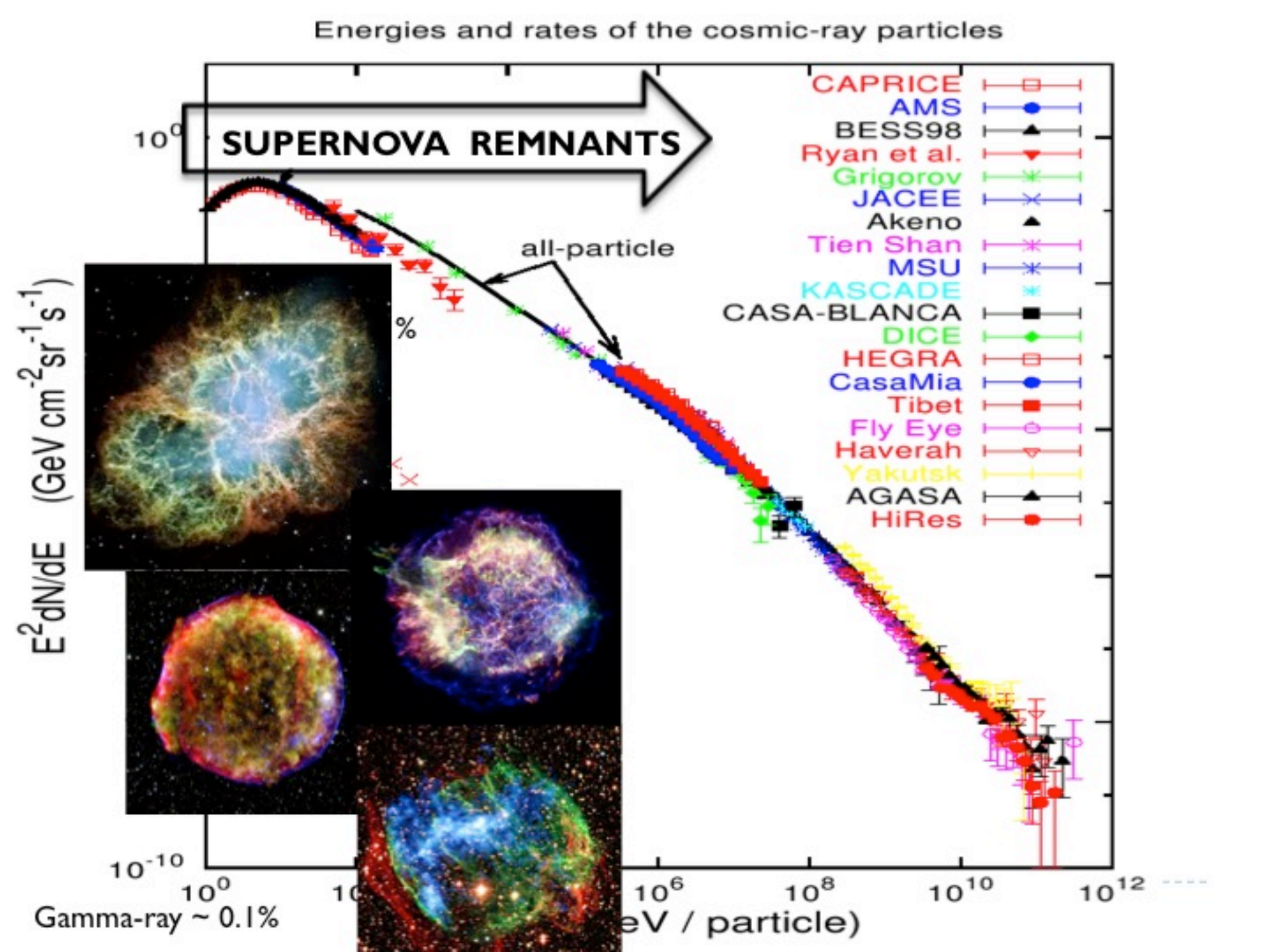
+ 12 orders of magnitude
from 0.1 GeV to 0.3 ZeV or from 10^8 to $\mathbf{10^{20}}$ **eV**



Cosmic Ray Science

- Cosmic Sessions at APS april 2014
  - **Session C4 Invited Session: Astrophysical and Cosmological Neutrinos** (Apr 5 2014 1:30PM, Saturday)
  - Session E9 Galactic Cosmic Rays
  - Session J8: Ultra-high Energy Cosmic Rays
  - Session K8 Astroparticle Observatories and Techniques
  - Session R8: Gamma-ray and Neutrino Observations
  - Session S8 Radio in Ice: UHECR Cosmic-rays and Neutrino
  - **Session U4 Invited Session: Cosmic Rays** (Apr 7 2014 3:30PM, Monday)


Energies and rates of the cosmic-ray particles
protons only
electrons
positrons
antiprotons
all-particle
~1%
Proton, Helium,
heavier nuclei
CAPRICE
AMS
BESS98
Ryan et al.
Grigorov
JACEE
Akeno
Tien Shan
MSU
KASCADE
CASA-BLANCA
DICE
HEGRA
CasaMia
Tibet
Fly Eye
Haverah
Yakutsk
AGASA
HiRes
$E^2 dN/dE$ (GeV cm^{-2}sr^{-1}s^{-1})
E_{kin} (GeV / particle)
Gamma-ray ~ 0.1%


Energies and rates of the cosmic-ray particles
SUPERNOVA REMNANTS
all-particle
CAPRICE
AMS
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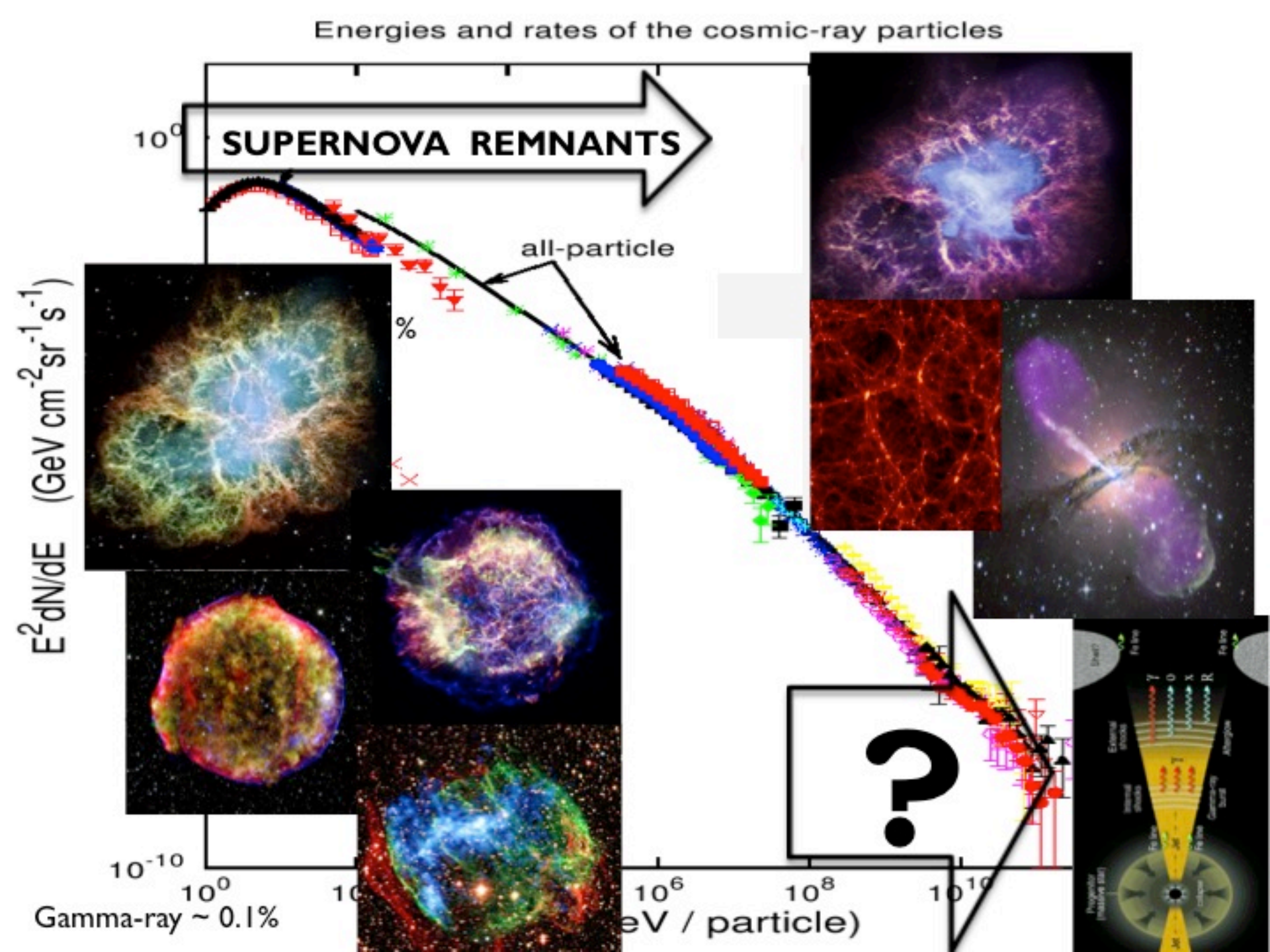
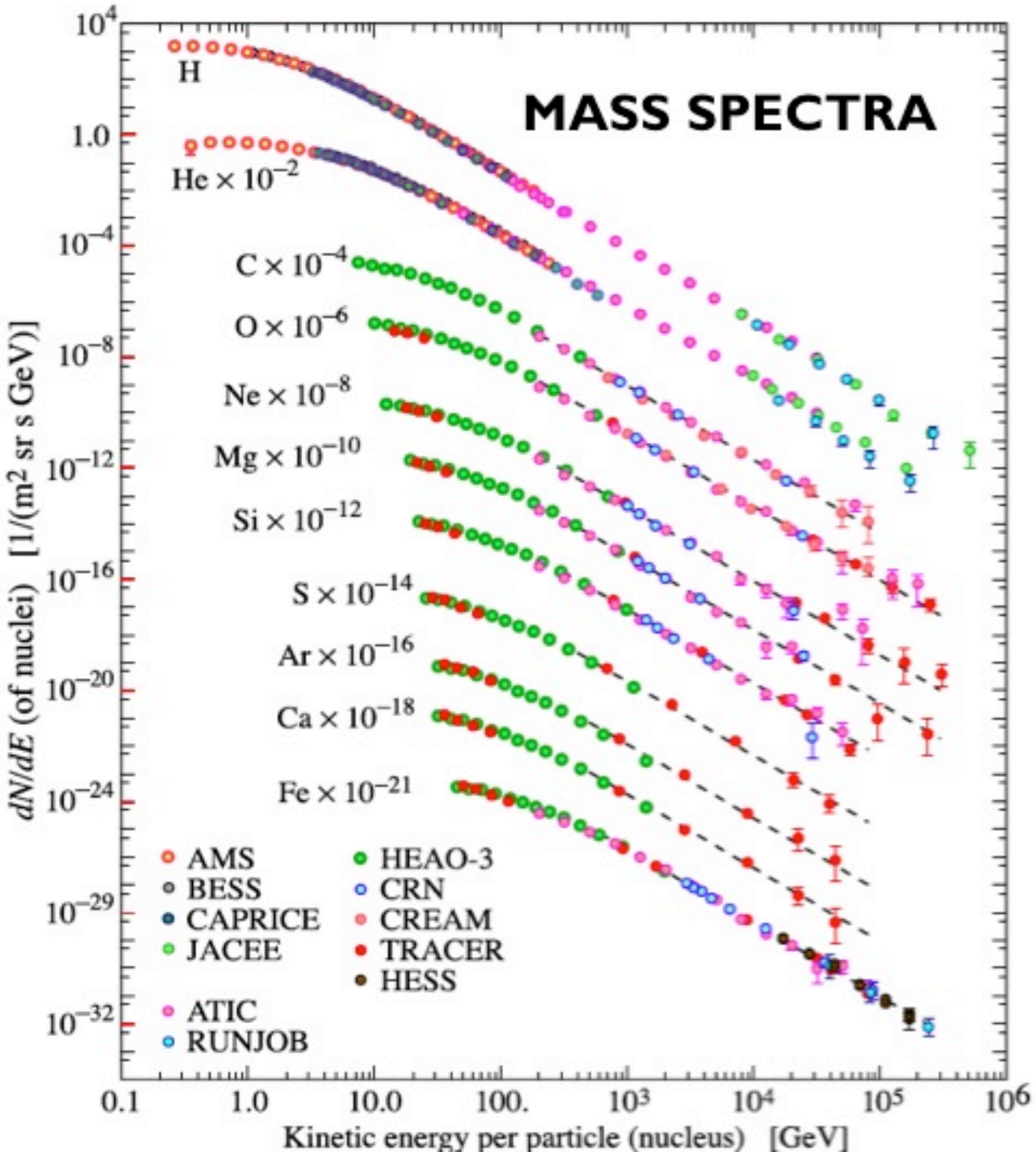
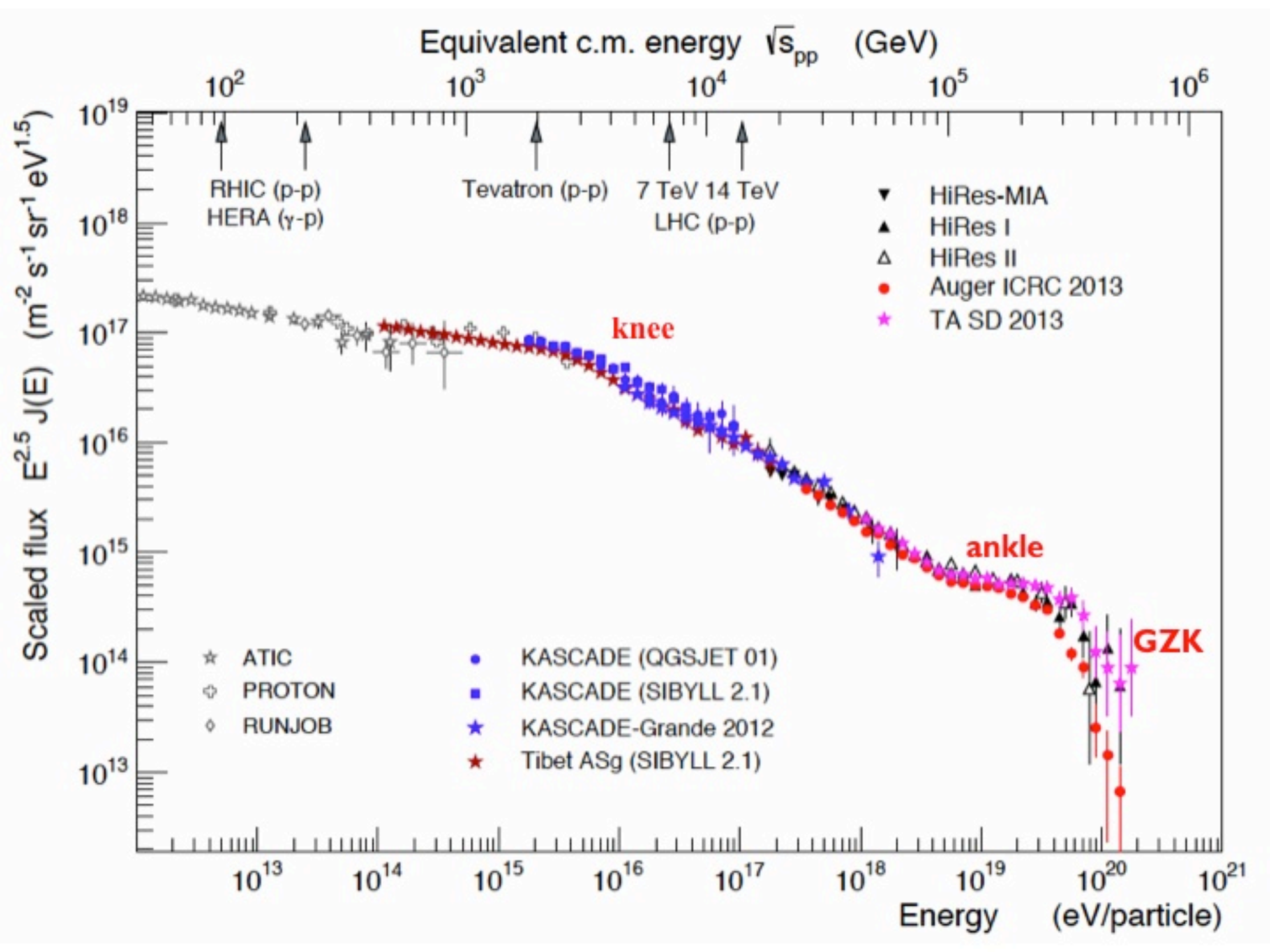
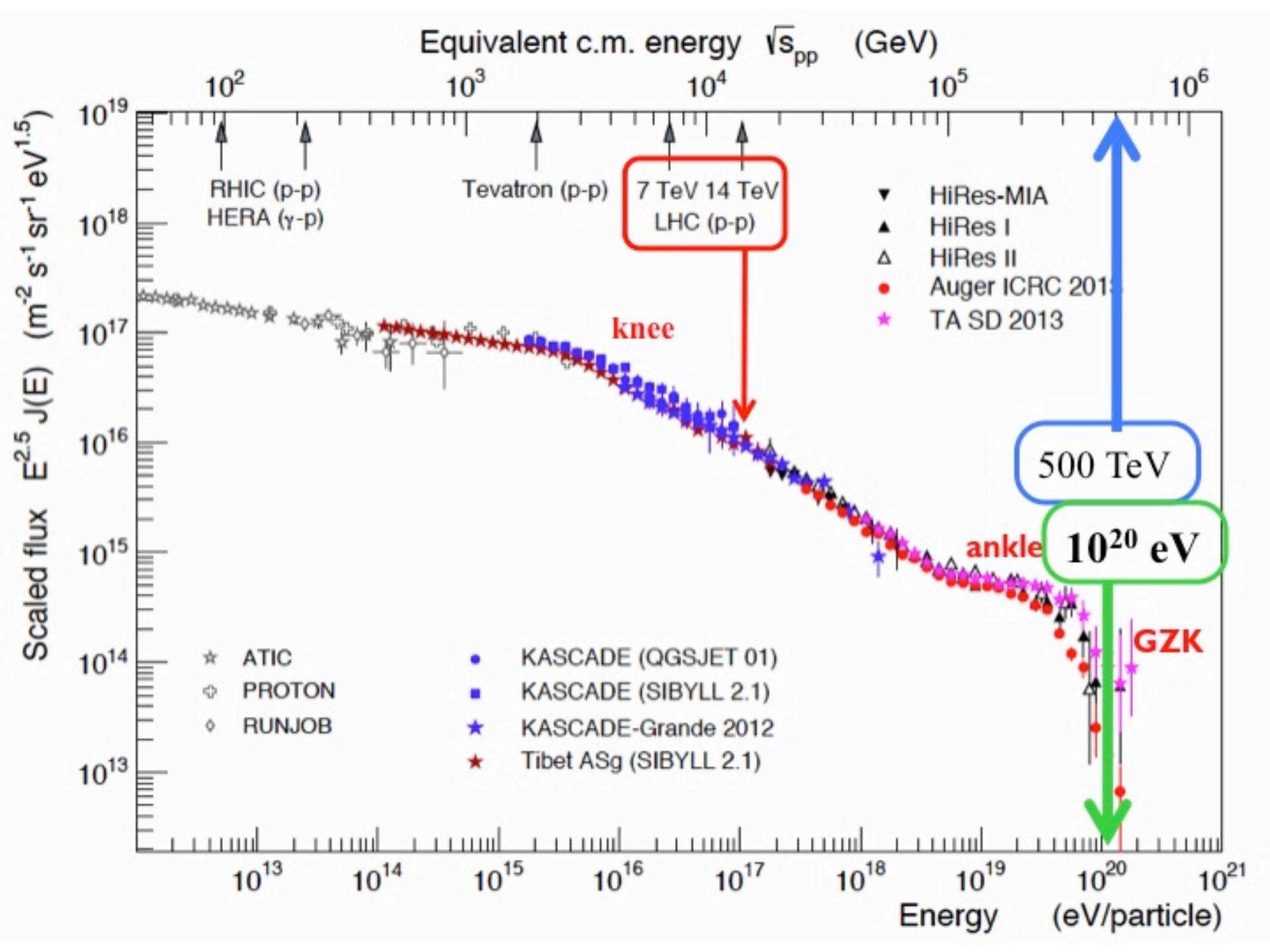
DICE
HEGRA
CasaMia
Tibet
Fly Eye
Haverah
Yakutsk
AGASA
HiRes
$E^2 dN/dE$ (GeV cm^{-2}sr^{-1}s^{-1})
10^{-10}
10^{0}
10^{6}
10^{8}
10^{10}
10^{12}
eV / particle)
Gamma-ray ~ 0.1%


Energies and rates of the cosmic-ray particles
SUPERNOVA REMNANTS
all-particle
%
?
E^2dN/dE (GeV cm^{-2}sr^{-1}s^{-1})
10^{-10}
10^{0}
10^{6}
10^{8}
10^{10}
Gamma-ray ~ 0.1%
eV / particle)


MASS SPECTRA
H
He × 10^−2
C × 10^−4
O × 10^−6
Ne × 10^−8
Mg × 10^−10
Si × 10^−12
S × 10^−14
Ar × 10^−16
Ca × 10^−18
Fe × 10^−21
AMS
BESS
CAPRICE
JACEE
ATIC
RUNJOB
HEAO-3
CRN
CREAM
TRACER
HESS
dN/dE (of nuclei) [1/(m² sr s GeV)]
Kinetic energy per particle (nucleus) [GeV]
10^4
1.0
10^−4
10^−8
10^−12
10^−16
10^−20
10^−24
10^−29
10^−32
0.1
1.0
10.0
100.
10^3
10^4
10^5
10^6


Equivalent c.m. energy √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
GZK
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2012
Tibet ASg (SIBYLL 2.1)
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
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
10^4
10^5
10^6
RHIC (p-p)
HERA (γ-p)
Tevatron (p-p)
7 TeV 14 TeV
LHC (p-p)
knee
ankle
500 TeV
10^{20} eV
GZK
HiRes-MIA
HiRes I
HiRes II
Auger ICRC 201
TA SD 2013
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
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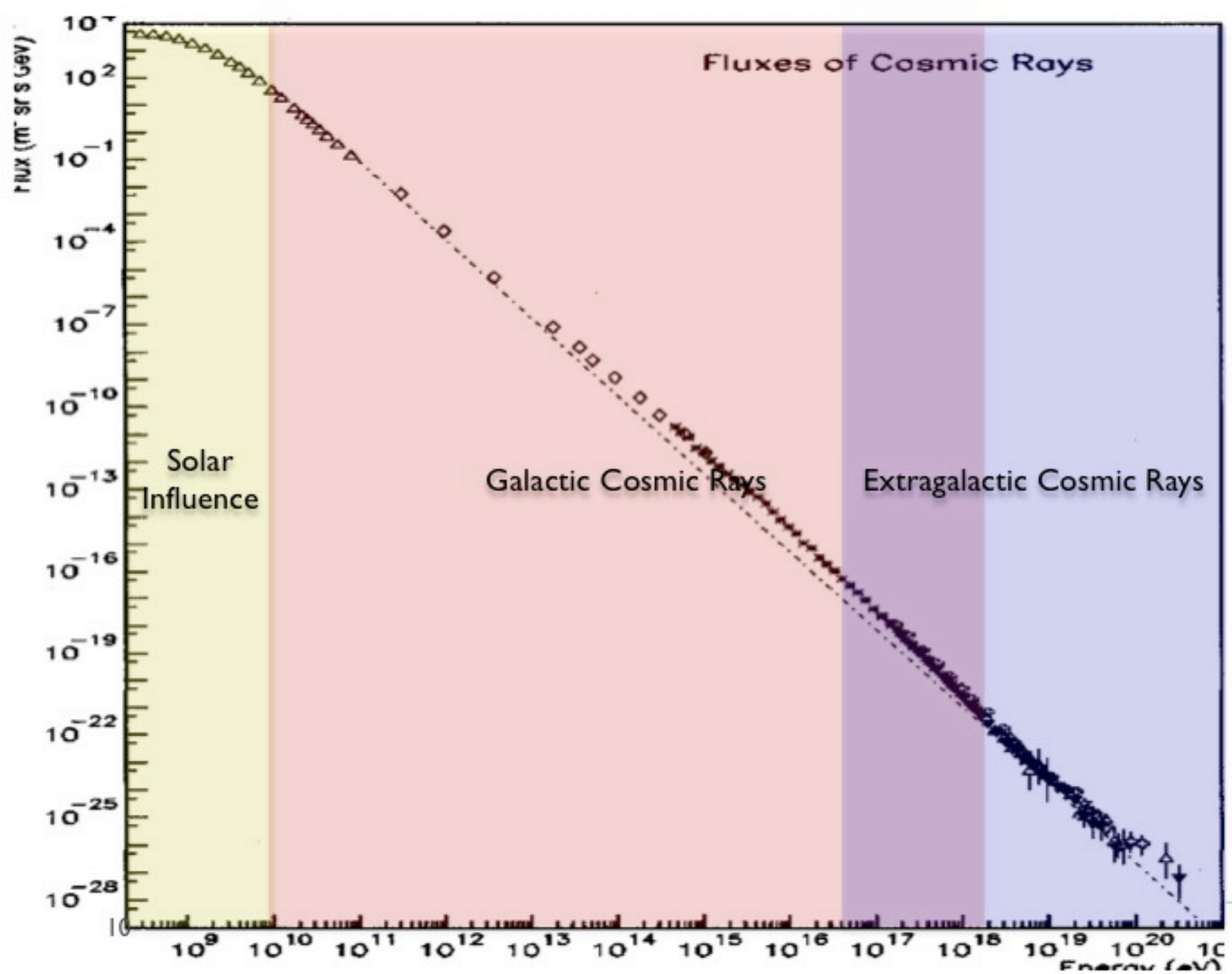
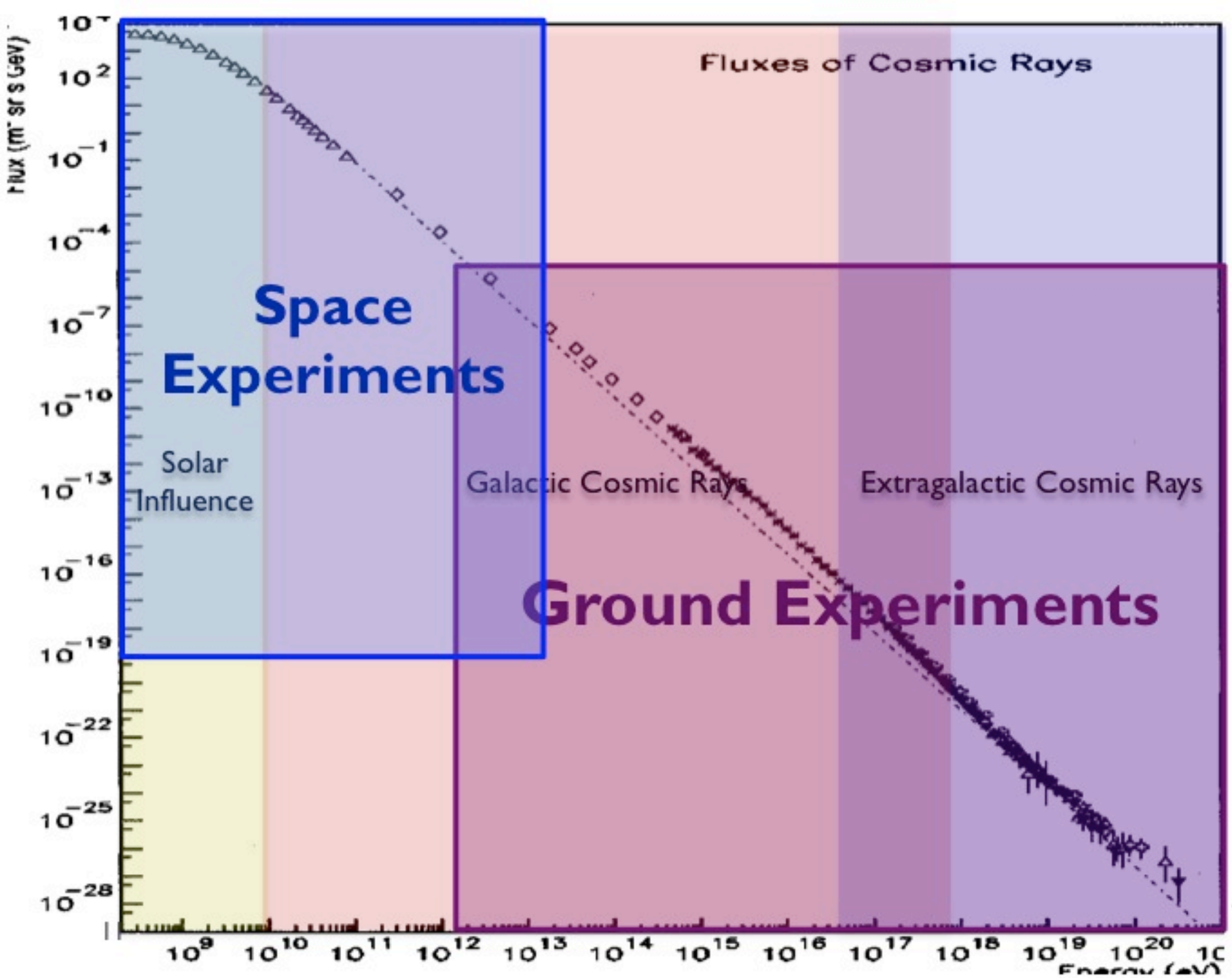
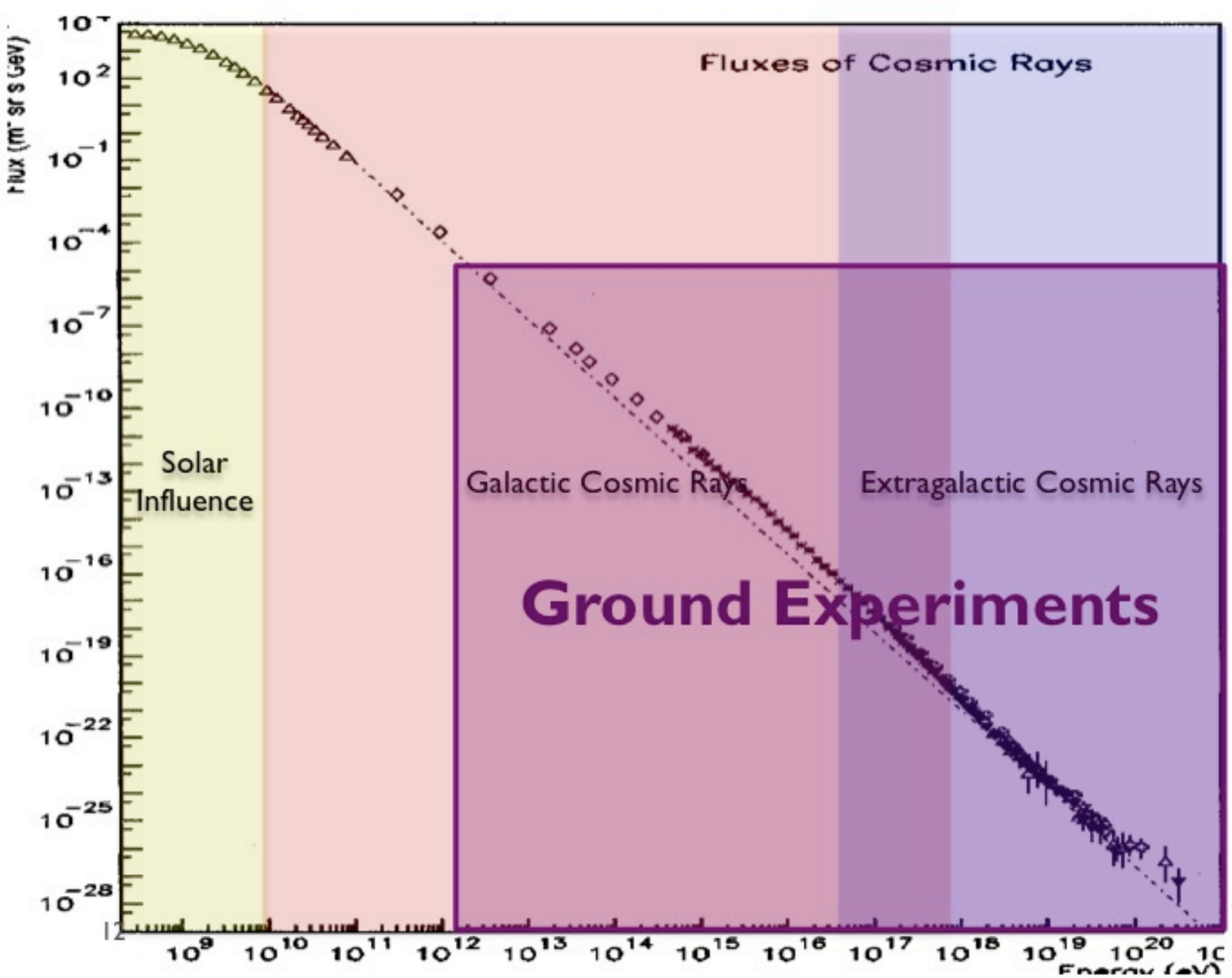
Scaled flux $E^{2.5}$ J(E) (m^{-2} s^{-1} sr^{-1} $eV^{1.5}$)
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
10^{21}
Energy (eV/particle)


Fluxes of Cosmic Rays
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays

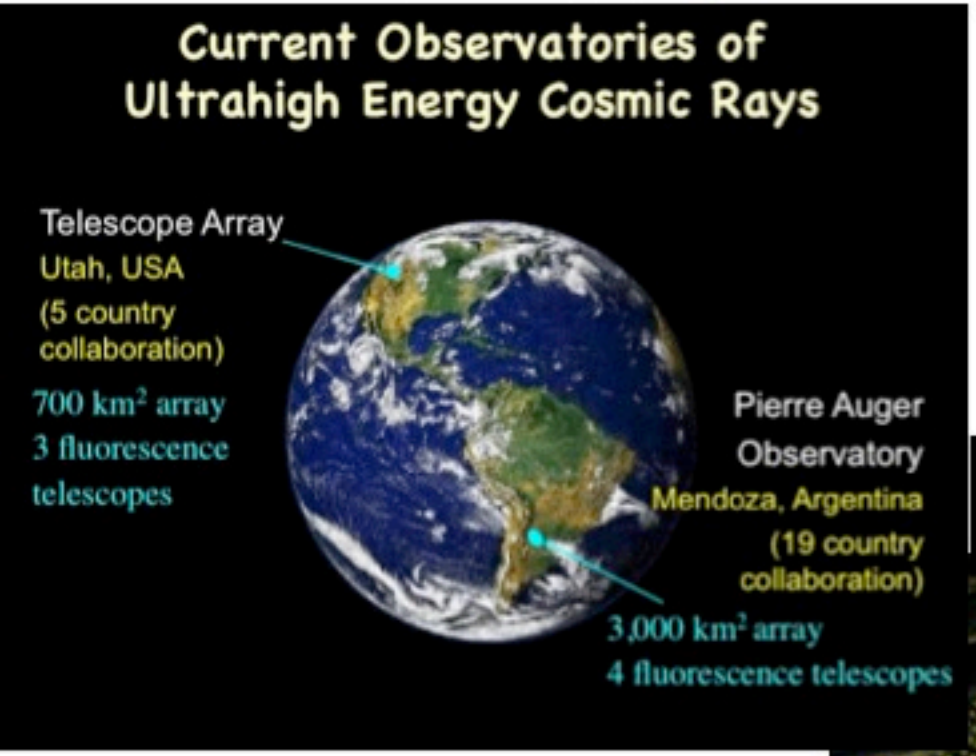

Fluxes of Cosmic Rays
Space Experiments
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Ground Experiments

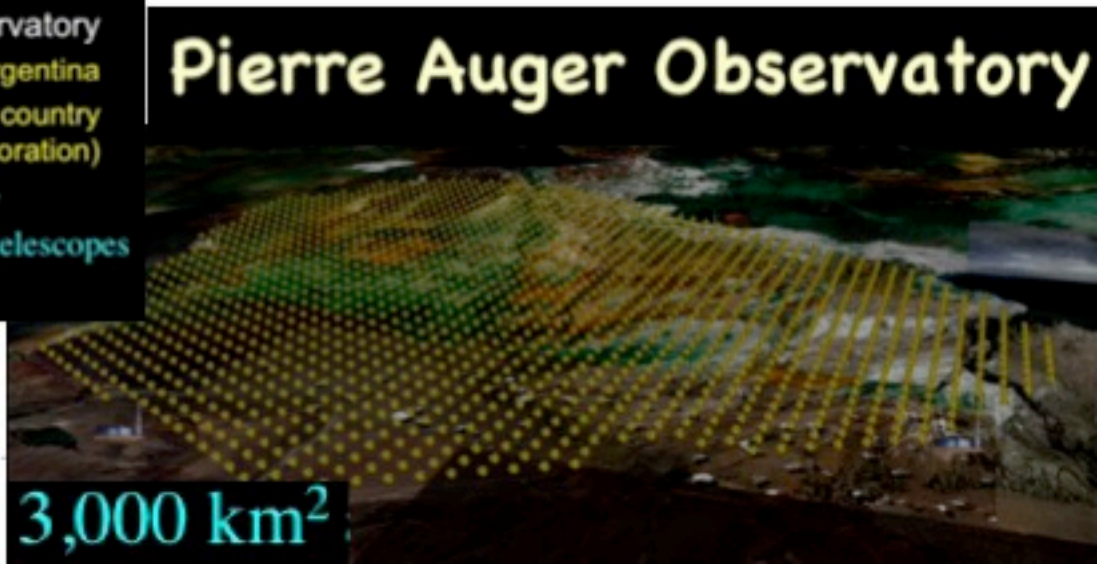

Fluxes of Cosmic Rays
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Ground Experiments

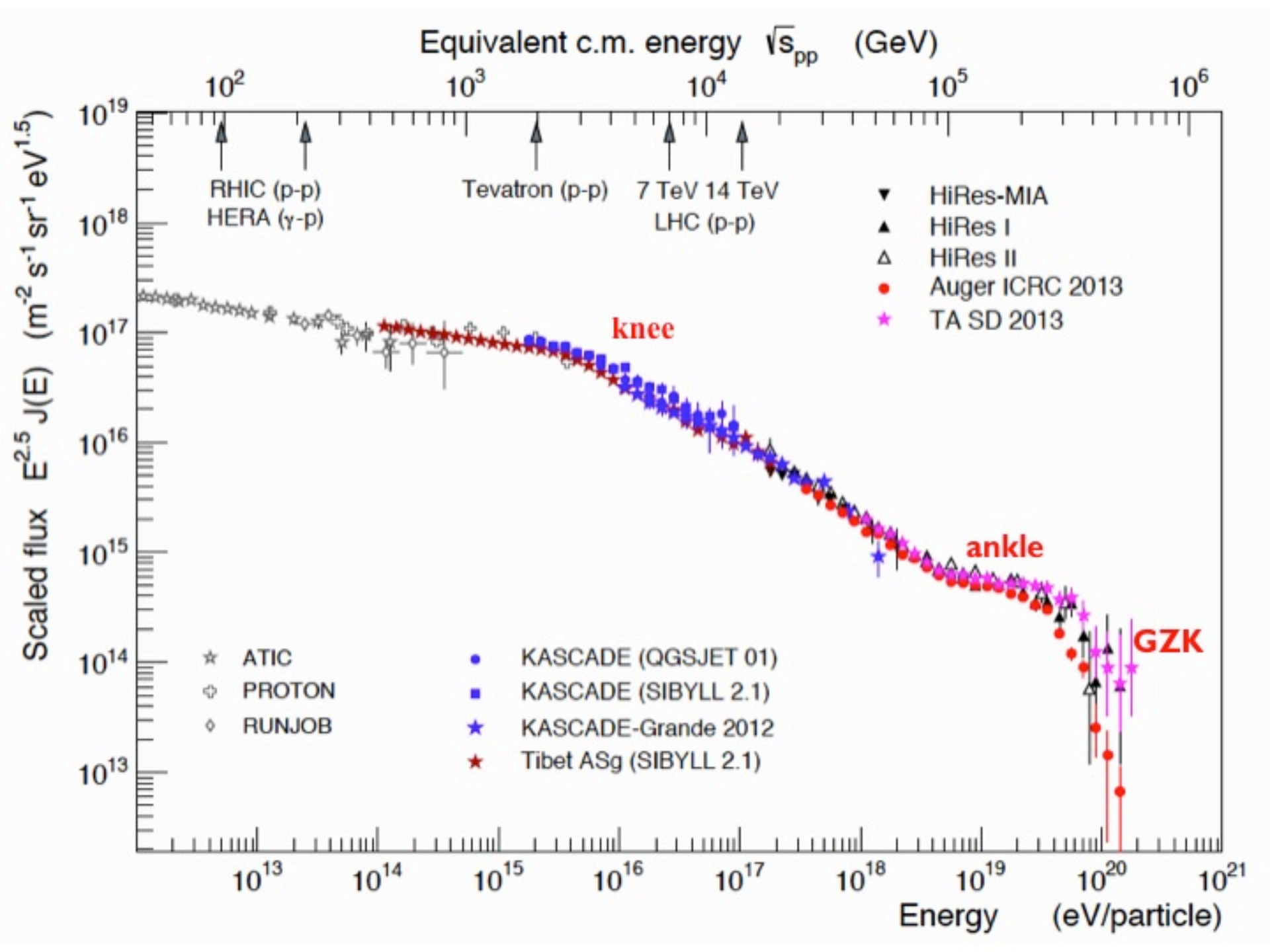
Cosmic Ray Science on the Ground

- Ground Observatories = Giant Arrays of Detectors

  Observe air-showers produced by primary cosmic rays



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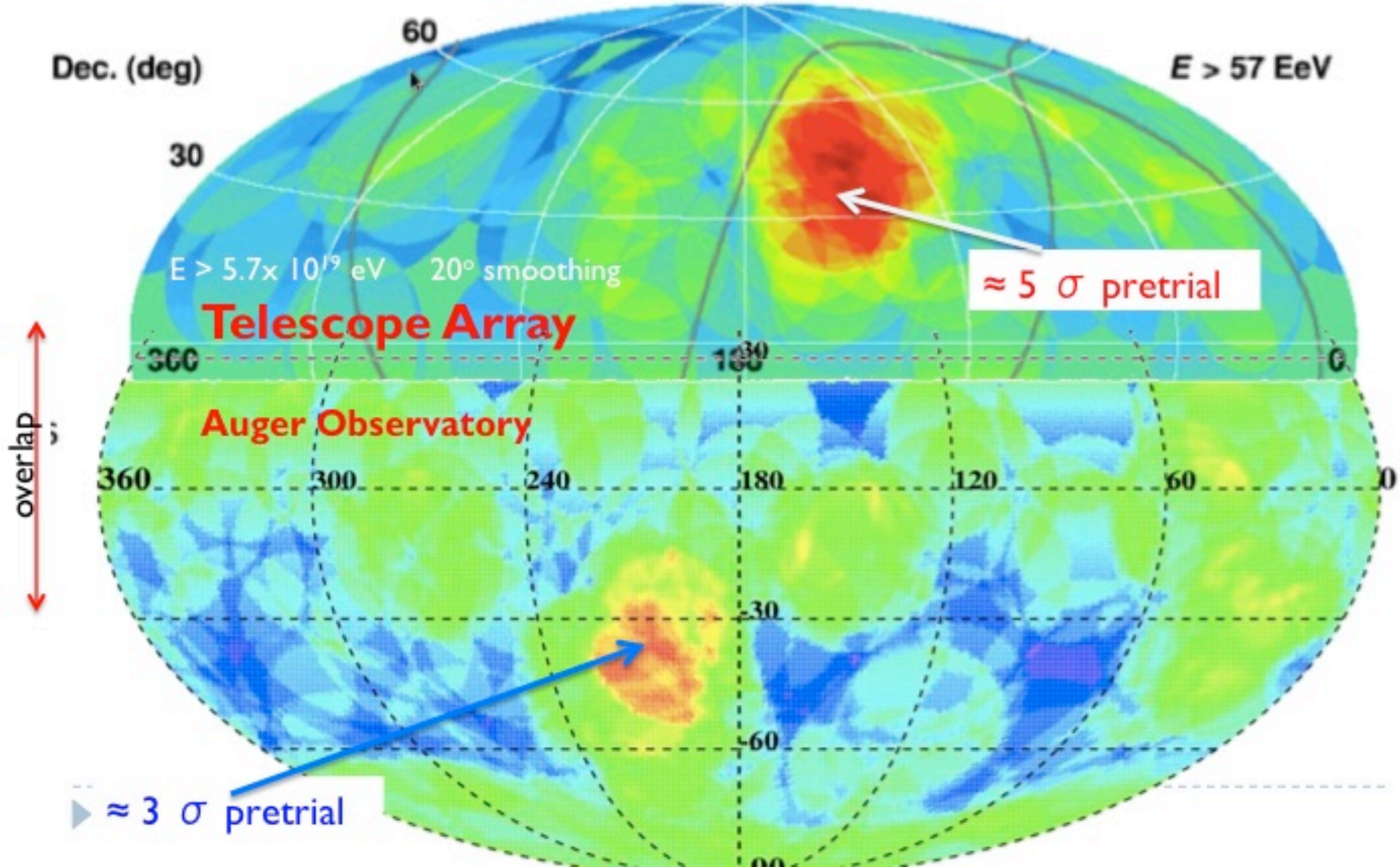
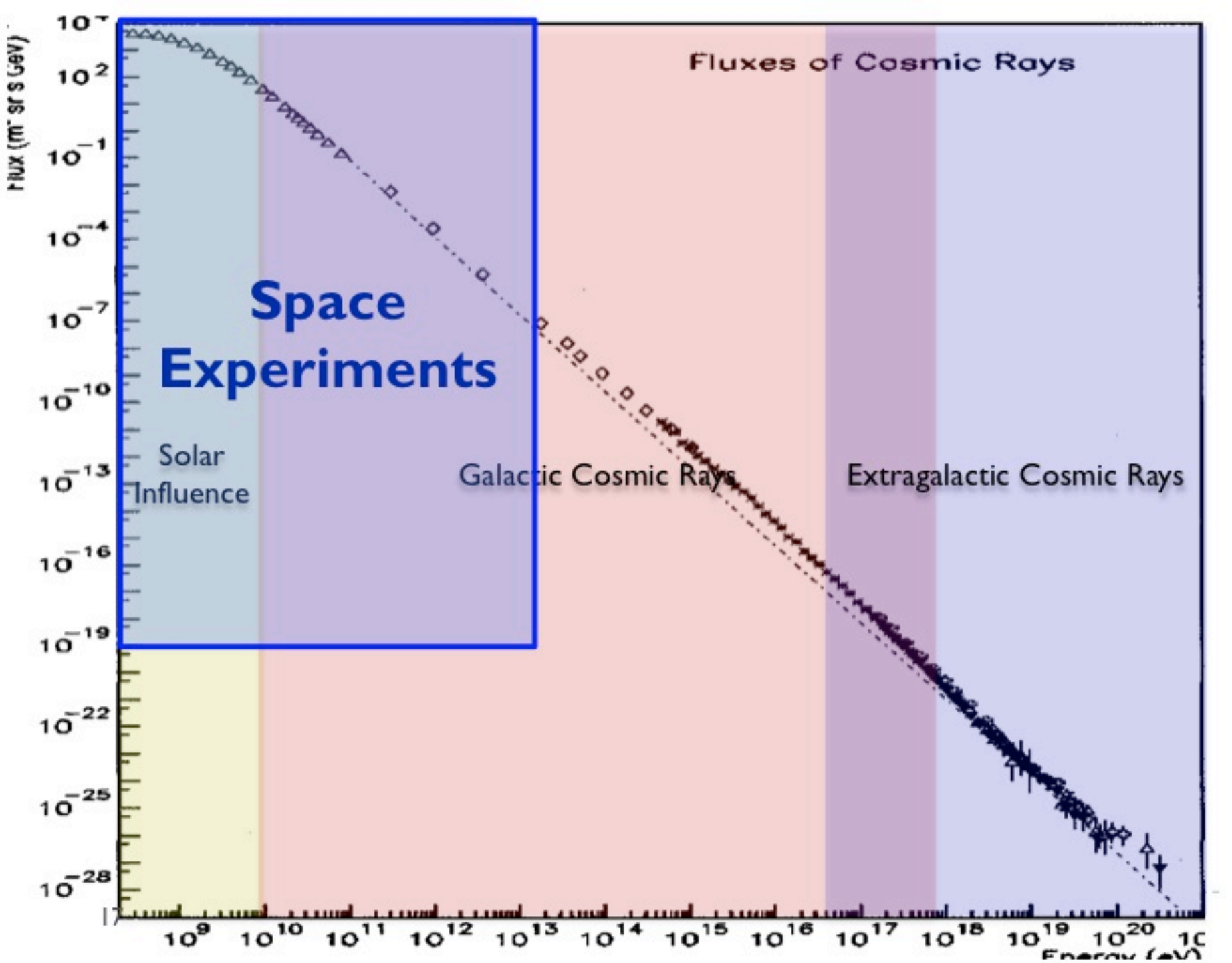
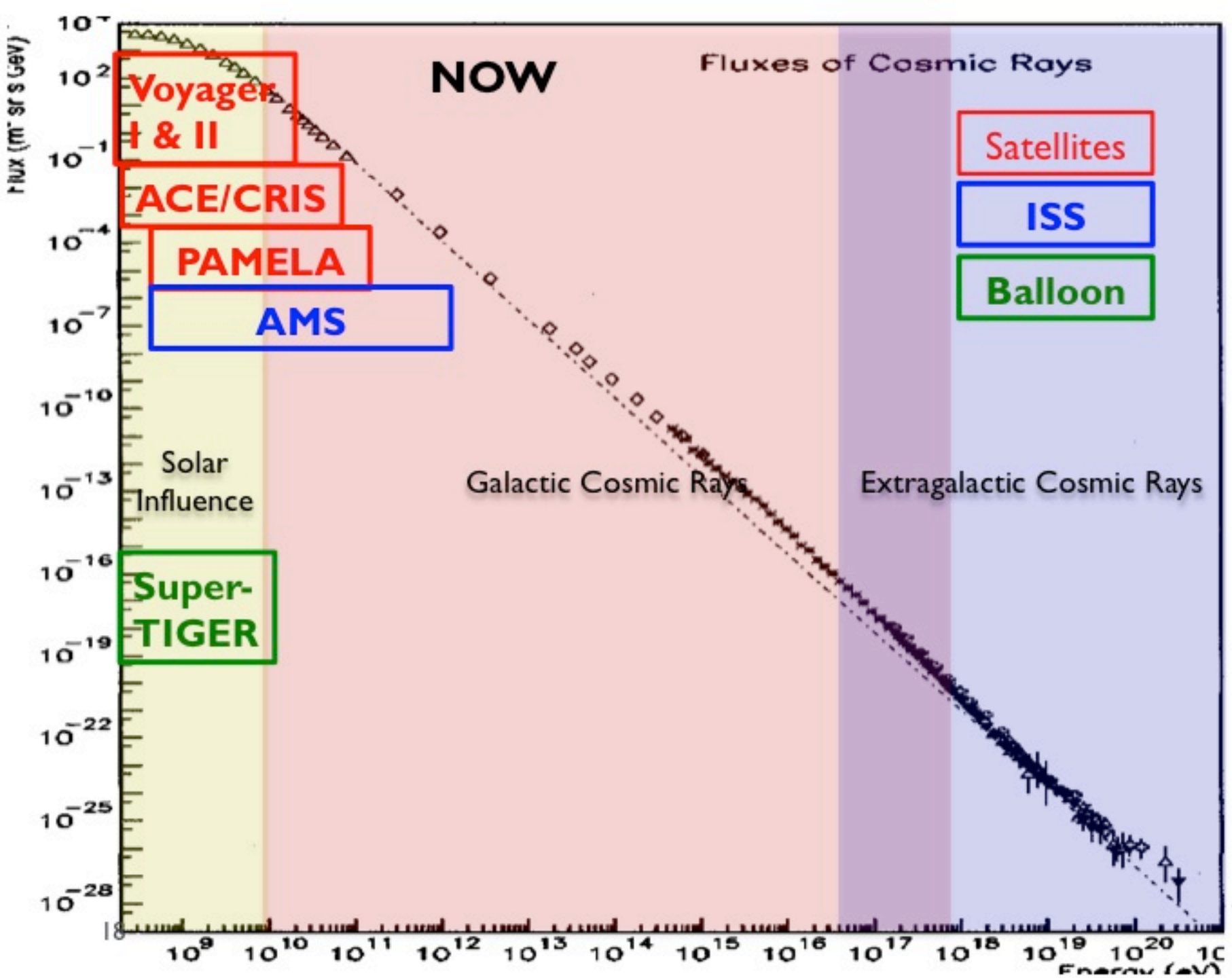
10^13
10^14
10^15
10^16
10^17
10^18
10^19
10^20
10^21
Energy (eV/particle)

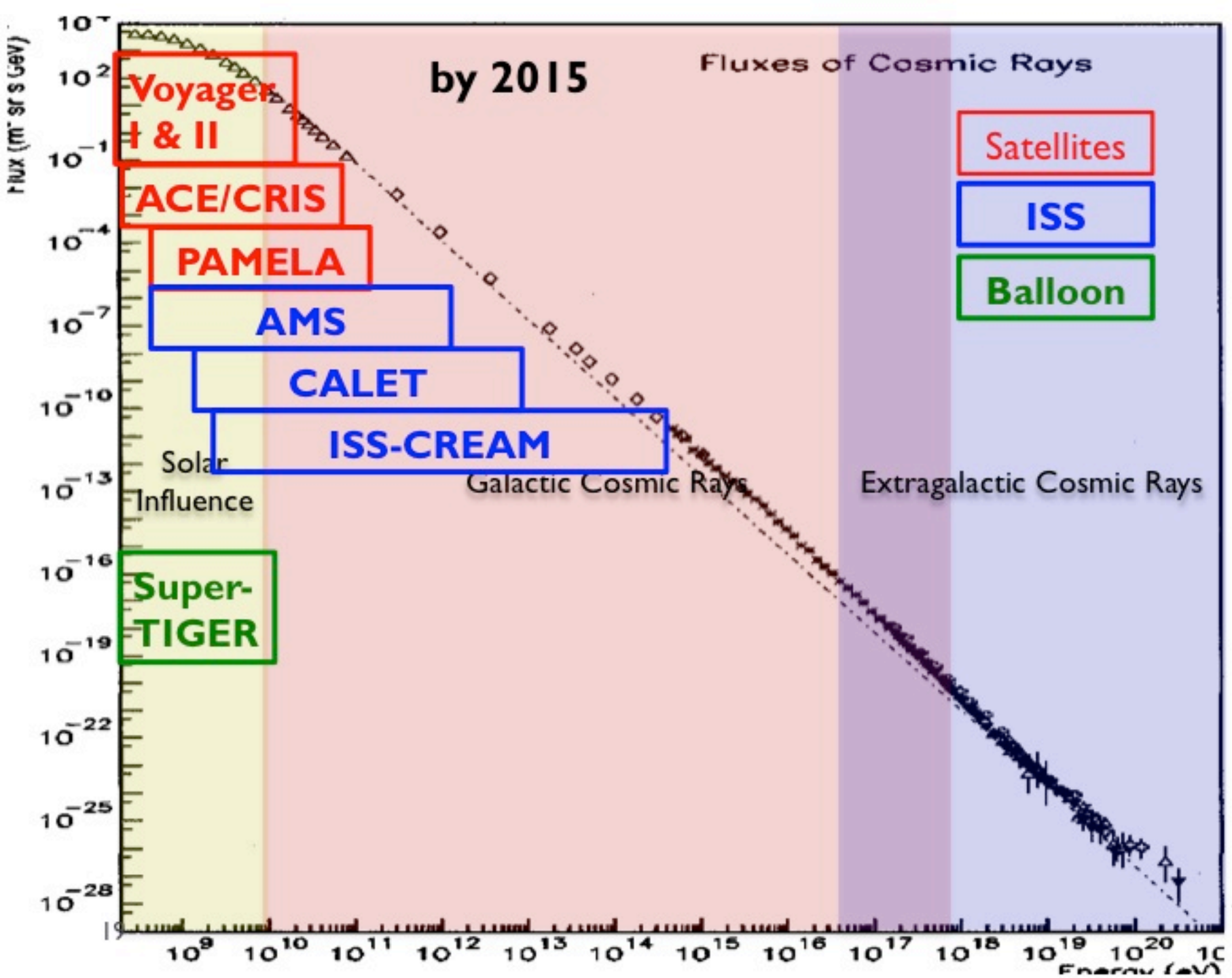
Anisotropy Hints > 6 x 10^{19} eV



Cosmic Ray Science from Space


Fluxes of Cosmic Rays
Space Experiments
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Flux (m² sr s GeV)
Energy (eV)


NOW
Fluxes of Cosmic Rays
Voyager I & II
ACE/CRIS
PAMELA
AMS
Satellites
ISS
Balloon
Super-TIGER
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays


Fluxes of Cosmic Rays
by 2015
Voyager I & II
ACE/CRIS
PAMELA
AMS
CALET
ISS-CREAM
Super-TIGER
Satellites
ISS
Balloon
Solar Influence
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Extragalactic Cosmic Rays
Flux (m² sr s GeV)
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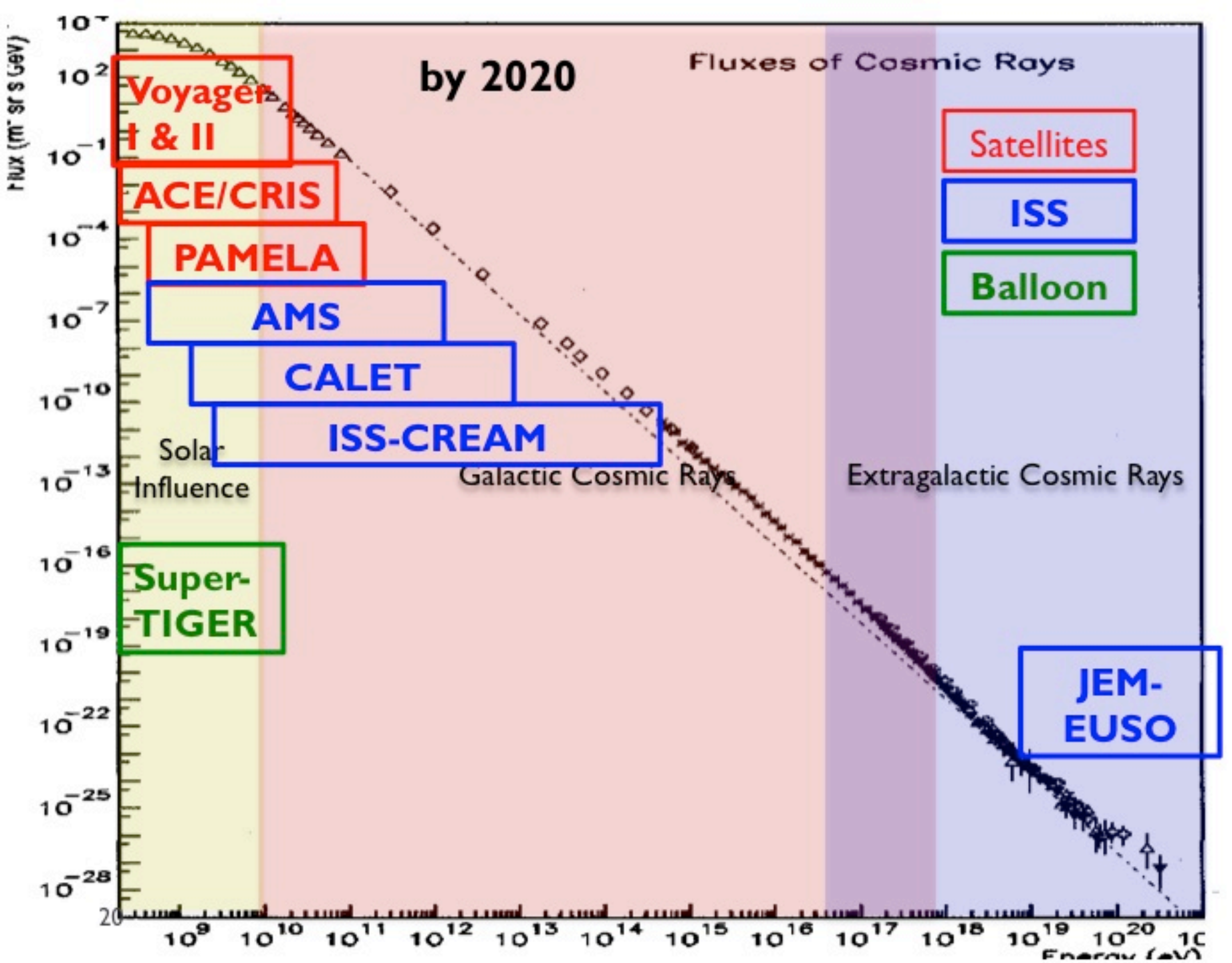

by 2020
Fluxes of Cosmic Rays
Voyager I & II
ACE/CRIS
PAMELA
AMS
CALET
ISS-CREAM
Super-TIGER
Satellites
ISS
Balloon
JEM-EUSO
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Flux (m² sr s GeV)
Energy (eV)

Open Questions in CR Science

- Origin of Galactic Cosmic Rays (GCR):
  - What are the accelerators?
  - What are they accelerating?
  - How do they propagate in the Galaxy?
  - Where is the Transition between Galactic & ExtraGalactic CRs?
- Origin of ExtraGalactic Cosmic Rays (XGCR):
  - What are the accelerators?
  - What are they accelerating?
  - How do they propagate to Earth?
  - At what Energy COSMIC RAY ASTRONOMY begins?
- How do Cosmic Rays Affect the Earth, the Solar System, the ISM, the Galaxy, other Galaxies, and the formation of Stars and Galaxies?

Open Questions in CR Science

- Origin of Galactic Cosmic Rays (GCR):
  - **What are the accelerators? (**CosmicSIG + GammaSIG)
  - What are they accelerating?
  - How do they propagate in the Galaxy?
  - Where is the Transition between Galactic & ExtraGalactic CRs?
- Origin of ExtraGalactic Cosmic Rays (XGCR):
  - What are the accelerators?
  - What are they accelerating?
  - How do they propagate to Earth?
  - At what Energy COSMIC RAY ASTRONOMY begins?
- How do Cosmic Rays Affect the Earth, the Solar System, the ISM, the Galaxy, other Galaxies, and the formation of Stars and Galaxies?

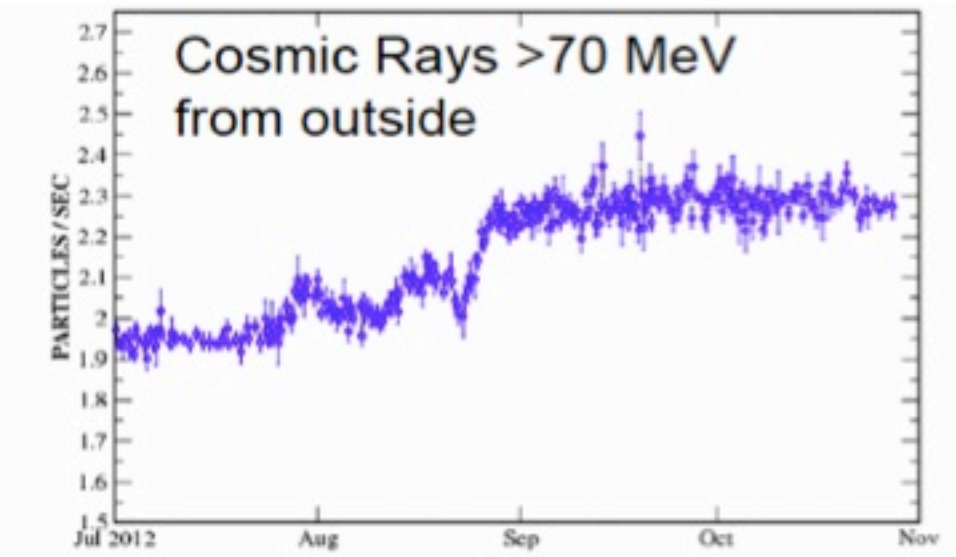
Questions Related to CR Science

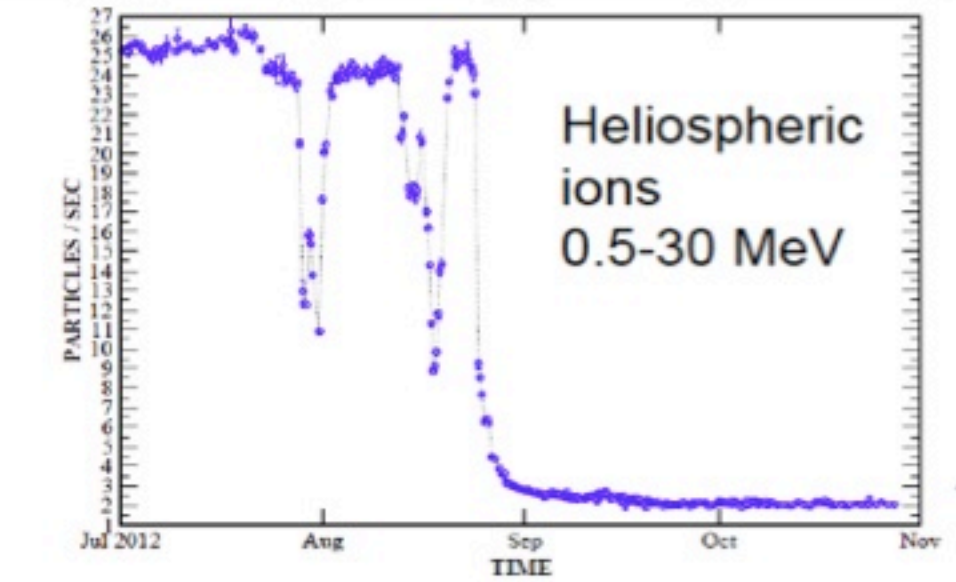
- Origin of PeV neutrinos (IceCube detections)
- Indirect Dark Matter Searches
  - WIMP in the Galactic Halo: e+, e-; p, anti-p, γ , ν ...
- Probe of Particle Interactions above LHC energies
  - Ultrahigh Energy Cosmic Rays (UHECR) E_{cm} > 100 TeV
  - Ultrahigh Energy Neutrinos
- Searches for Exotic Components of Matter:
  - Antinuclei
  - Magnetic Monopoles
  - Strangelets
  - Qballs
  - Primordial Black Holes

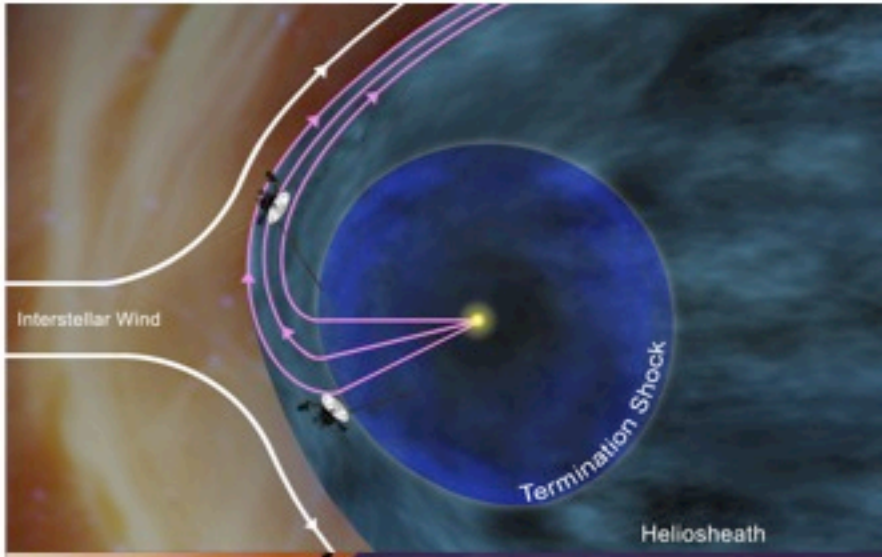
Recent Highlights

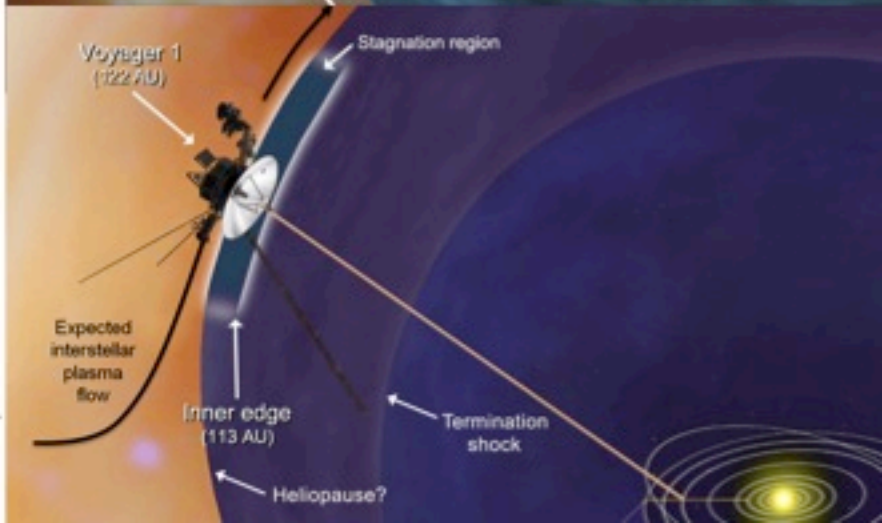
Cosmic Rays Recent Highlights

- Voyager 1 reaches Interstellar Space (Aug/Sep 2012)



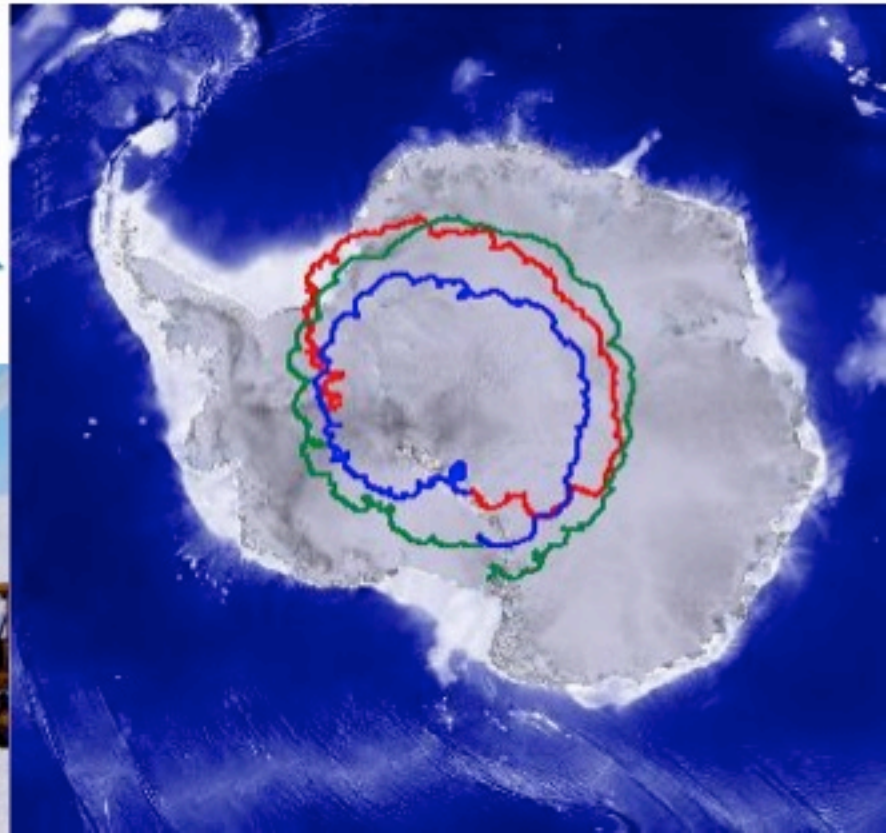






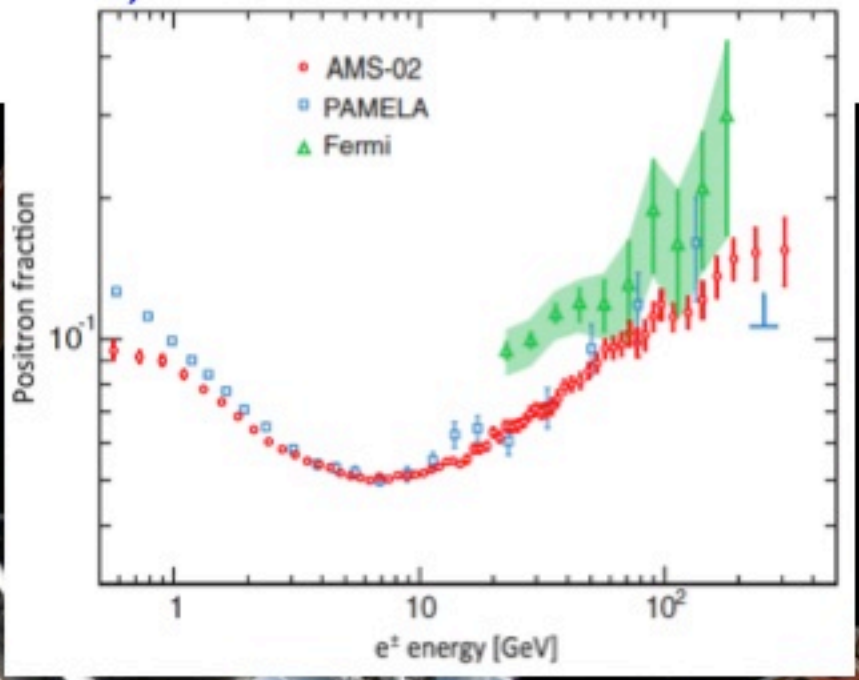
Cosmic Rays Recent Highlights

- Super-TIGER (Trans-Iron Galactic Element Recorder) breaks flight duration record: 55 days at 127,000 feet
  - Increase on UltraHeavy Nuclei data by 1 o.o.m. to study composition and origin of Galactic Cosmic Rays

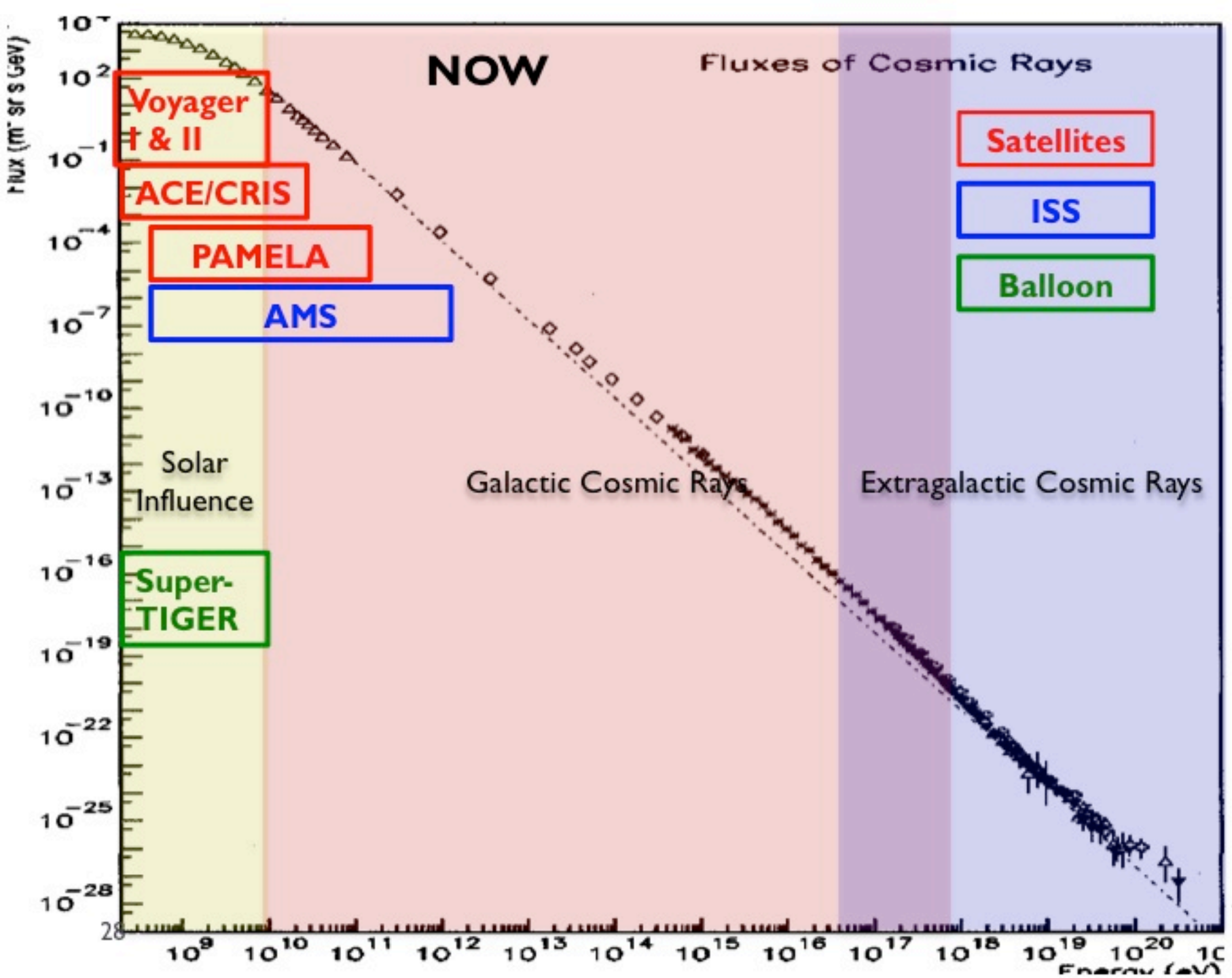


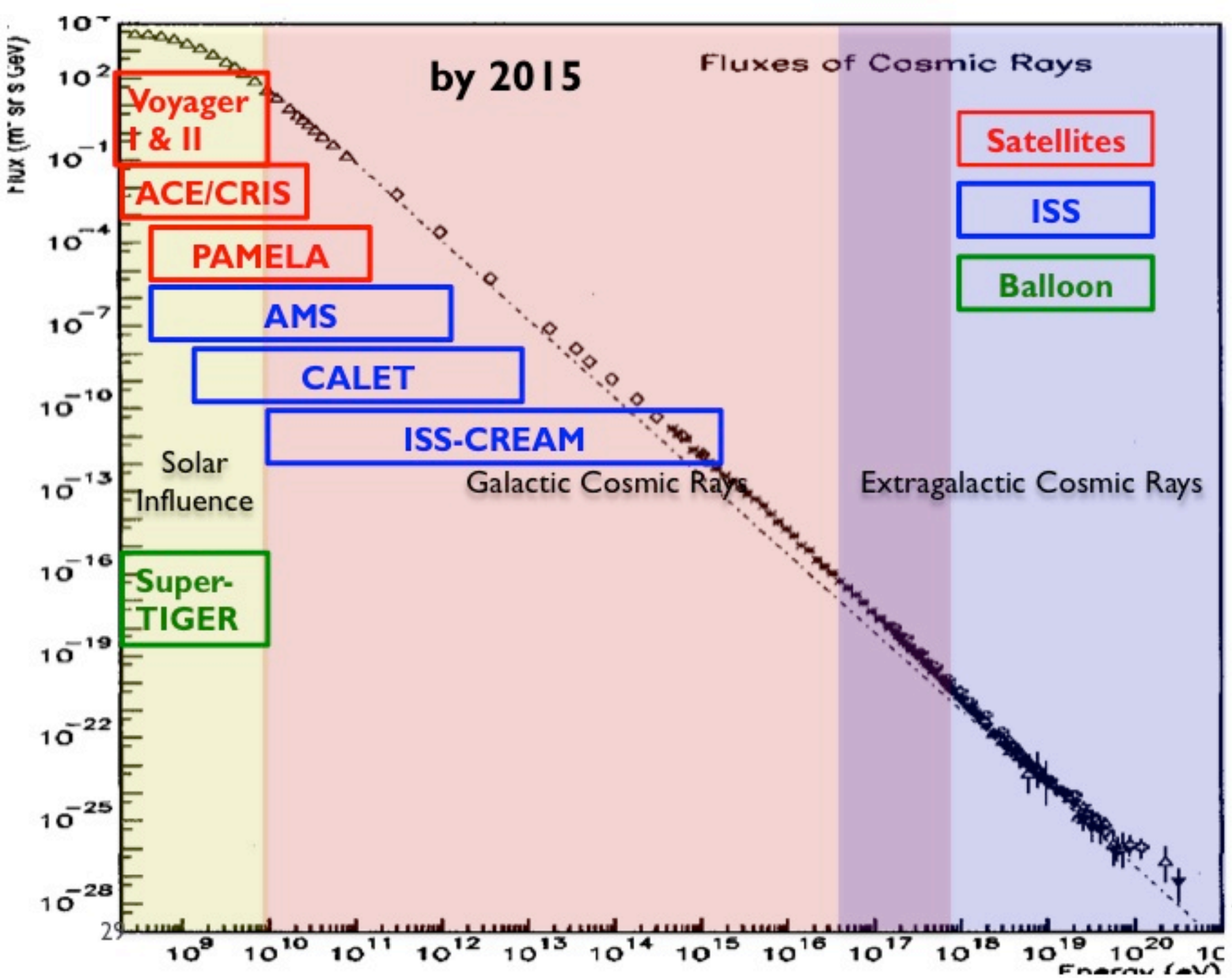
Cosmic Rays Recent Highlights

- AMS (Alpha Magnetic Spectrometer) on the ISS announces first results



Session U4 Invited Session: Cosmic Rays (Apr 7 2014 3:30PM, Monday)


NOW
Fluxes of Cosmic Rays
Voyager I & II
ACE/CRIS
PAMELA
AMS
Super-TIGER
Satellites
ISS
Balloon
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Flux (m² sr s GeV)
Energy (eV)
28


by 2015
Fluxes of Cosmic Rays
Voyager I & II
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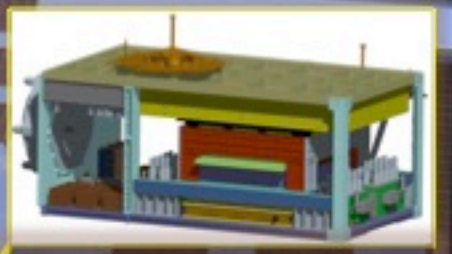
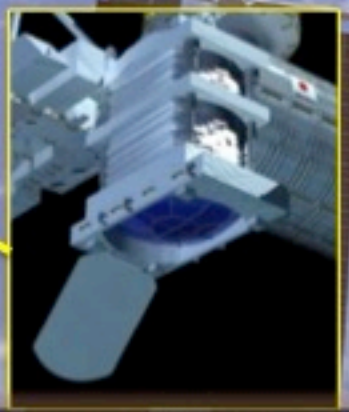
"Cosmic Ray Observatory on the ISS"

AMS Launch
May 16, 2011



ISS-CREAM
Sp-X Launch 2014

CALET on JEM
HTV Launch 2014

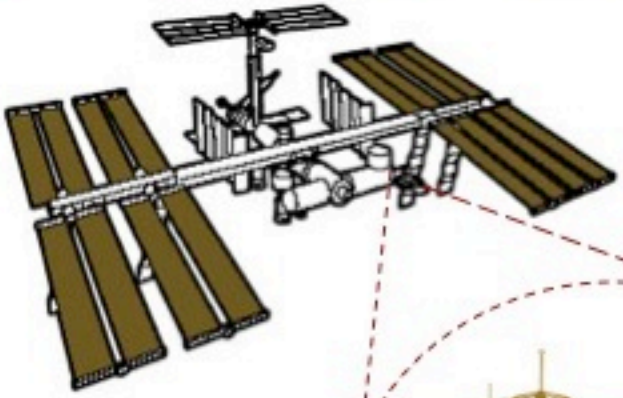


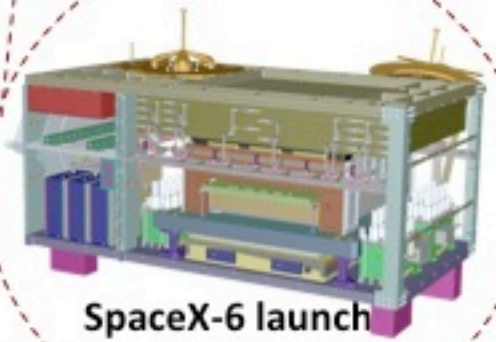
JEM-EUSO
Launch Tentatively
planned for 2017

ISS-CREAM (CREAM for the ISS)

Cosmic Ray Energetics And Mass

- The balloon-borne CREAM was flown 6 times over Antarctica with ~161 days of total flight time, the longest exposure to date for a single balloon project.
- ROSES 2010 proposal: Building on the success of the balloon flights, the payload is being transformed for accommodation on the ISS (NASA's share of JEM-EF).
- CREAM measures the energy spectra from 10^{12} to $>10^{15}$ eV over the elemental range from protons to iron.
- It extends the energy reach of direct measurements of cosmic rays to the highest energy possible to probe their origin, acceleration and propagation.





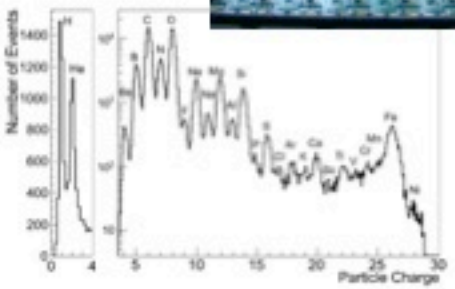
SpaceX-6 launch December 2014

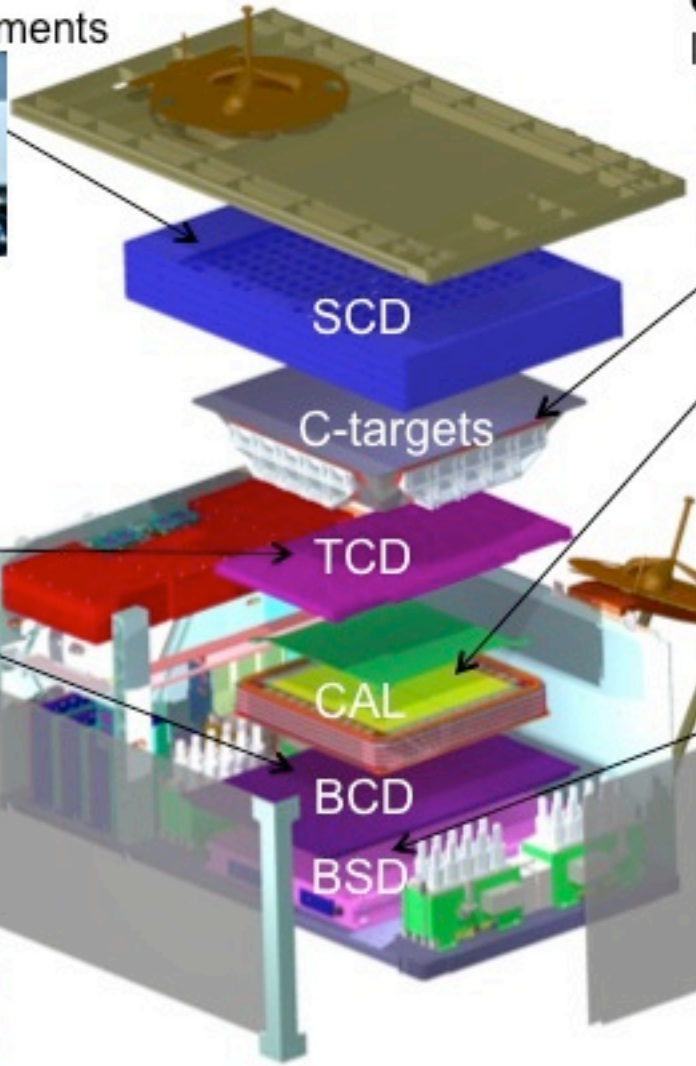
Increase the exposure by an order of magnitude

ISS-CREAM Instrument

Ahn et al., NIM A, **579**, 1034, 2007; Anderson et al., Hyun et al., Seo et al. 33rd ICRC, 2013

Silicon **C**harge **D**etector
- Precise charge measurements

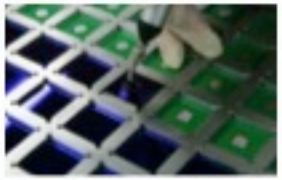




Carbon **Targets**
Induce hadronic interactions

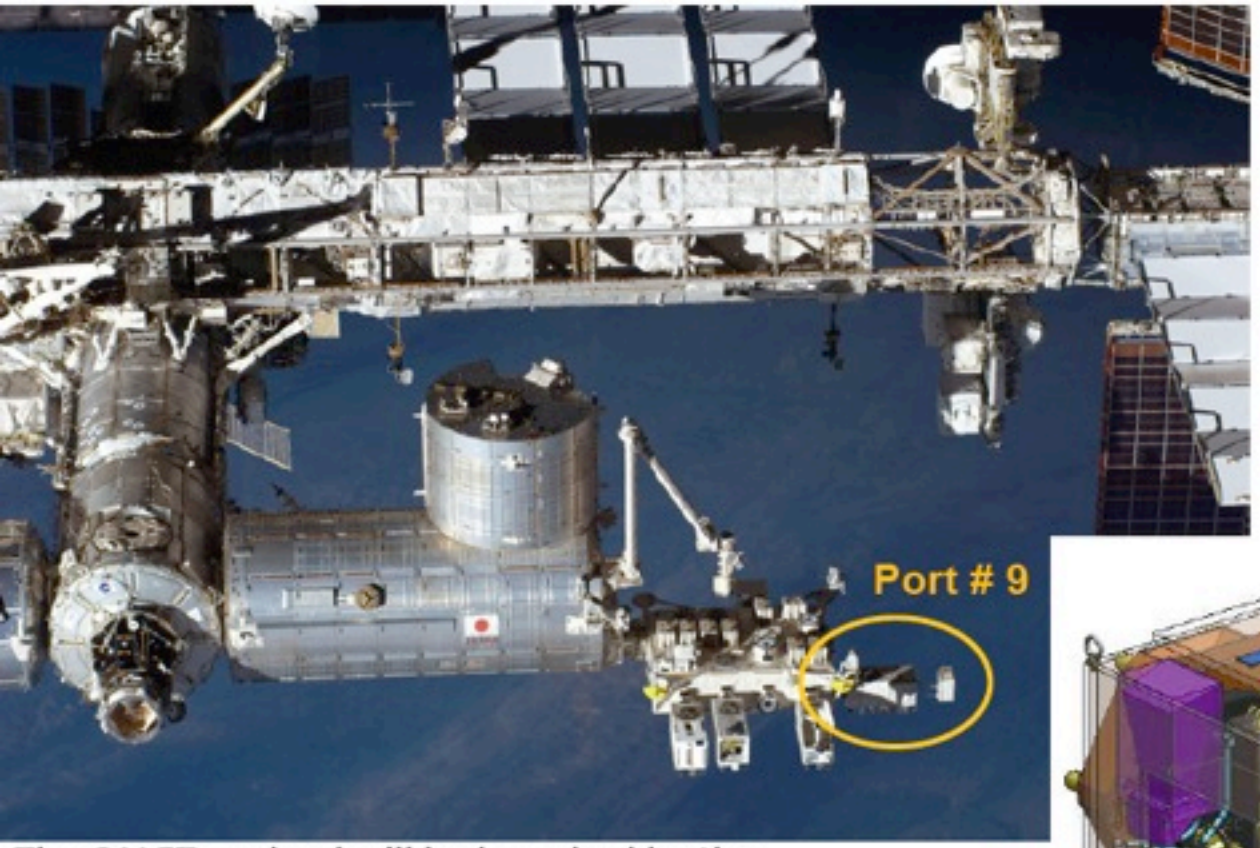
Calorimeter (20 layers W + scintillating fibers)
- Determine Energy
- Provide Trigger

Top & **B**ottom **C**ounting **D**etectors
- Each with 20 x 20 photodiodes and a plastic scintillator for e/p separation



Boronated **S**cintillator **D**etector
- Additional e/p separation

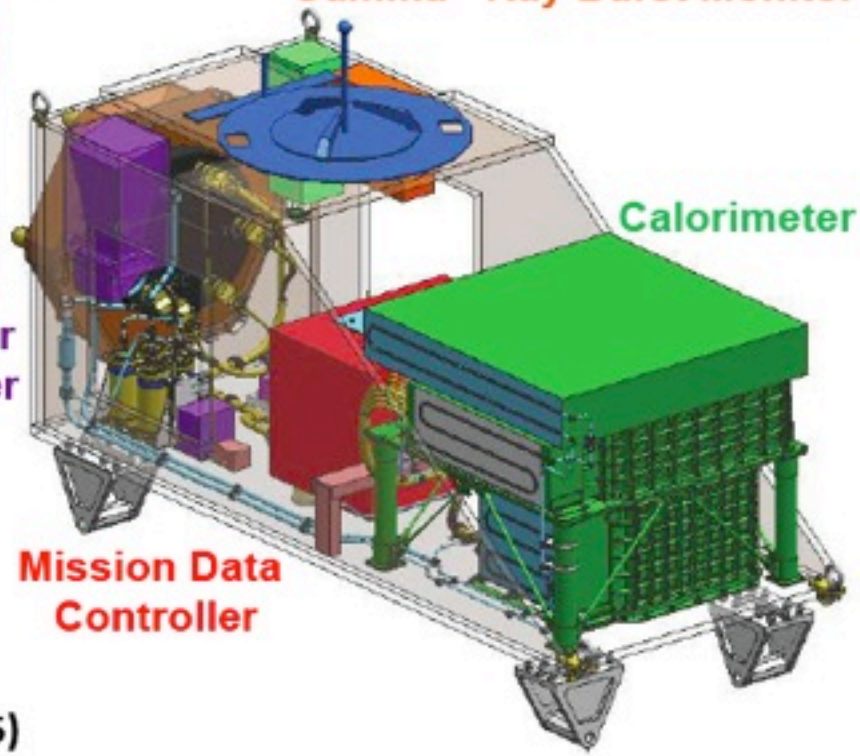
CALorimetric Electron Telescope overview

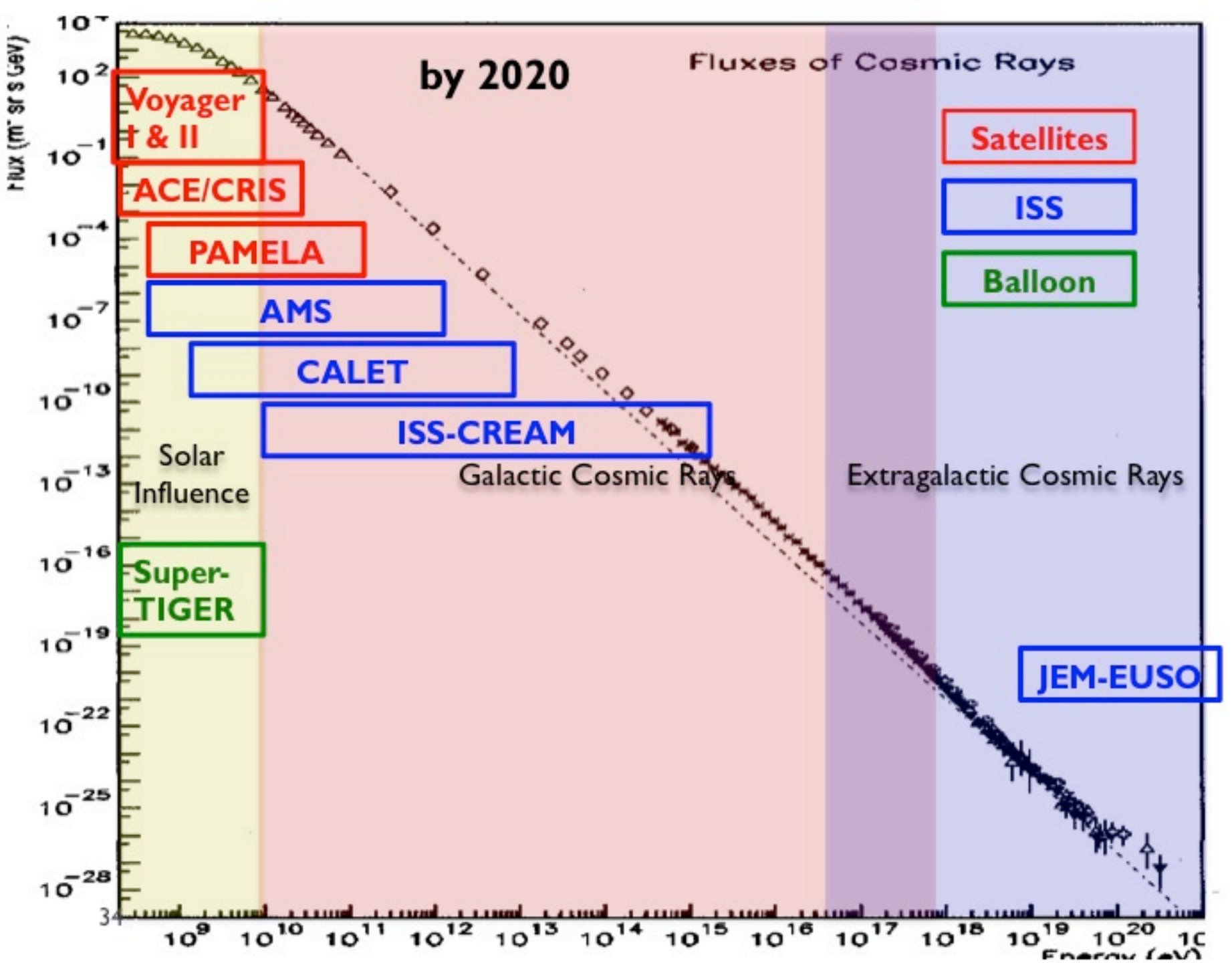


The CALET payload will be launched by the Japanese carrier, H-II Transfer Vehicle 5 (HTV), and robotically attached to the port # 9 of the Japanese Experiment Module - Exposed Facility (JEM-EF) on the International Space Station.

Weight: 650 kg
Mission Life: 5 years
Launch: by fiscal year 2014 (from April 2014 to March 2015)

CALET Payload




by 2020
Fluxes of Cosmic Rays
Voyager I & II
ACE/CRIS
PAMELA
AMS
CALET
ISS-CREAM
Super-TIGER
Satellites
ISS
Balloon
JEM-EUSO
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Flux (m² sr s GeV)
Energy (eV)

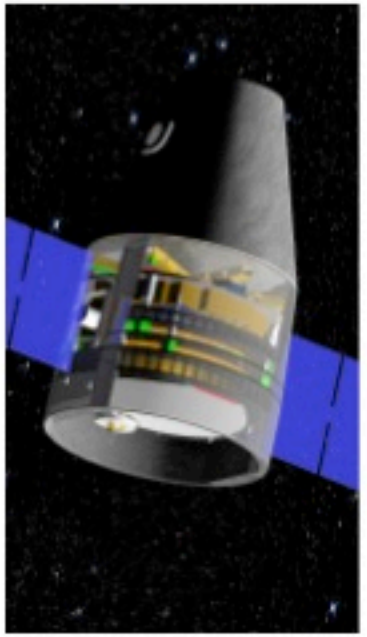
JEM-EUSO update

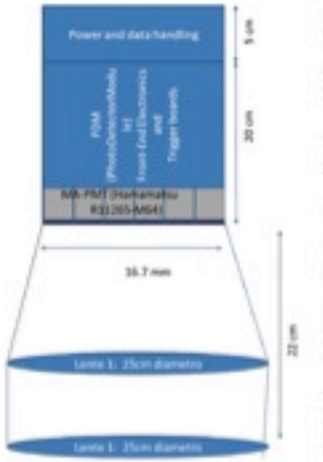
- Extreme Universe Space Observatory (EUSO)
  in the Japanese Experiment Module (JEM)
  of the International Space Station (ISS)

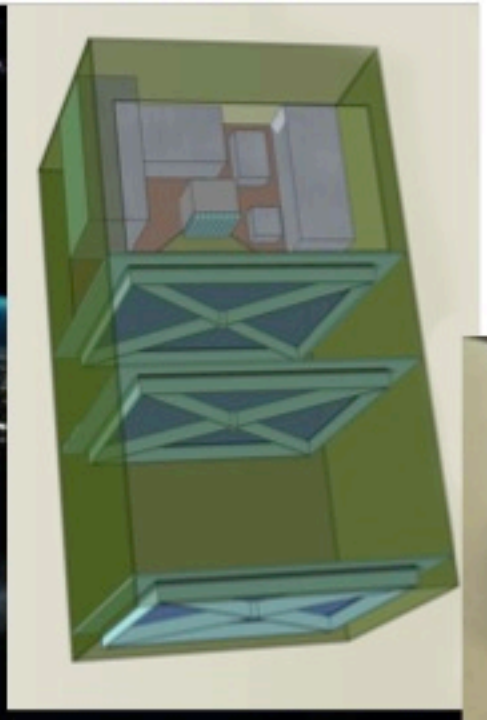
JEM-EUSO goals (EECR = Extreme Energy Cosmic Rays)
- pioneer the study of EECR from Space
- increase exposure to EECR by 1 order of magnitude
- discover the nearby sources of UHECRs

JEM-EUSO update

- Redesigned for SpaceX Dragon Delivery
- Pathfinders:
  - EUSO-Balloon first launch in 2014
  - EUSO-TA commissioning Spring 2014
  - Mini-EUSO launch 2015-16







Opportunities in Space for CR Science

- In Situ Measurements of Solar System
  - Voyager I & II
- Ultra Heavy Nuclei
  - ACE/CRIS
  - Super-TIGER
- Precise Measurements from GeV to TeV
  - PAMELA
  - AMS
  - CALET
- Galactic Cosmic Rays up to the knee
  - CREAM, TRACER
  - ISS-CREAM
- Extragalactic Cosmic Rays
  - JEM-EUSO
  - OWL/PATEL

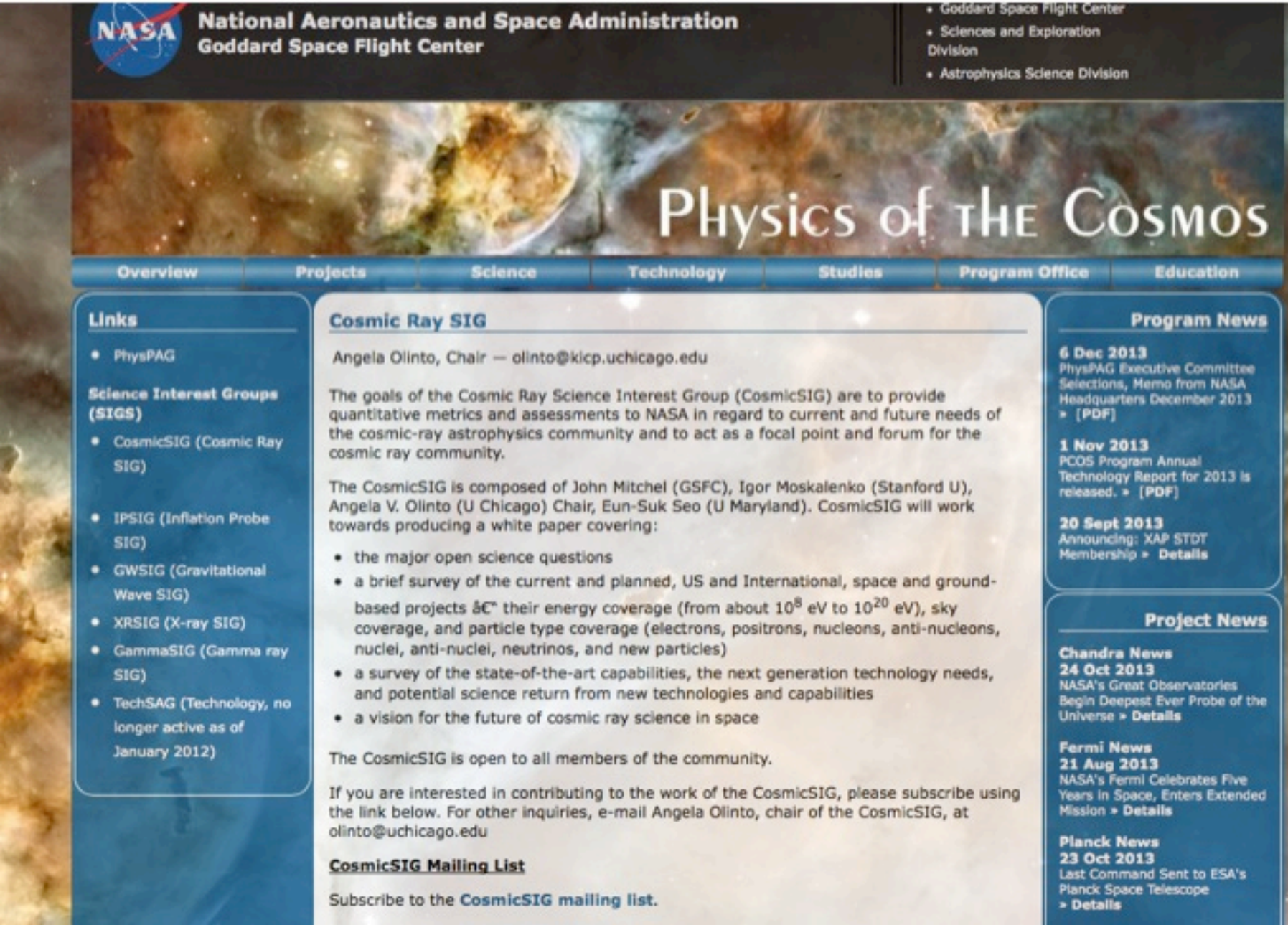
Space Opportunities for Cosmic Ray Science

AMS

CosmicSIG Activities

- Committee formed April 2013
  - John Mitchel (GSFC), Igor Moskalenko (Stanford U), Angela Olinto (U Chicago) Chair, Eun-Suk Seo (U Maryland)
- Goals of CosmicSIG
  - Provide an assessment to NASA HQ and the PCOS program office of the status and the **current and future** needs of the **cosmic-ray astrophysics** community.
  - Act as a **focal point** and forum for the cosmic ray community.
- White Paper with Cosmic Ray vision for the next decade(s)
  - **Gather input from Community**
  - Survey current and future projects and missions and their science goals and coverage
  - Survey technology development needs for future progress in the field

http://pcos.gsfc.nasa.gov/sigs/cosmicsig.php



NASA Astrophys Roadmap

Enduring Quests Daring Visions

NASA Astrophysics in the Next Three Decades

December 20, 2013

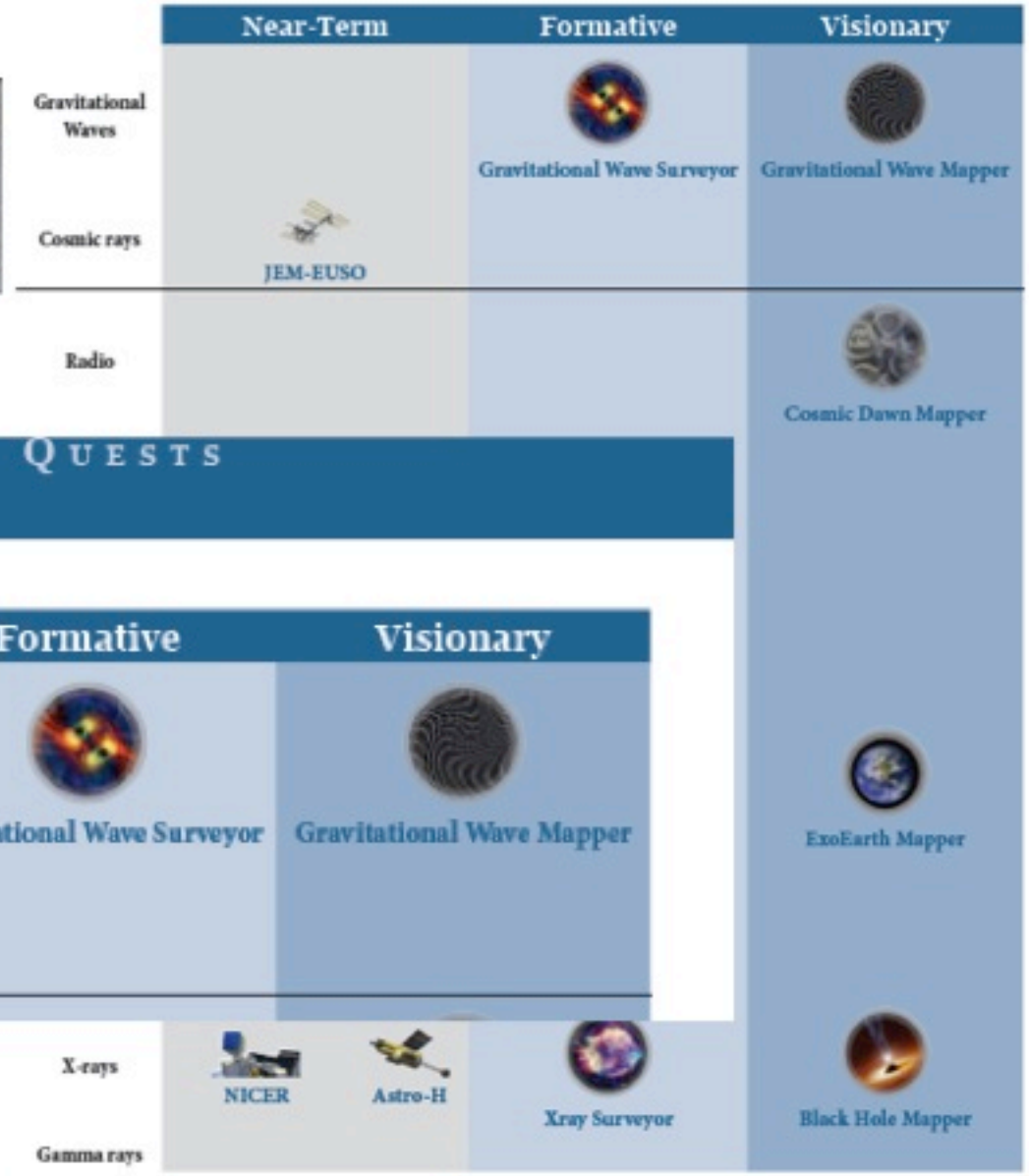


Figure 1.2 Chart of the missions currently planned for launch during the Near-Term Era and of the notional missions of this roadmap for the Formative and Visionary Eras.