Direct cosmic ray measurements at the 36th ICRC

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ICRC2019 36th International Cosmic Ray Conference - Madison, WI, USA
THE ASTROPARTICLE PHYSICS CONFERENCE

Outline of the presentation

- Some statistics
- Measurements
  - Primary Cosmic Rays (p, He, C, O)
  - Heavier nuclei
  - Secondary Cosmic Rays
  - Antimatter
  - Electrons & Positrons
  - Anisotropy
  - Solar Modulation
- Theory (very short summary …)

Cosmic-Ray Direct impact at ICRC

We can divide in 2 categories:

- CRD-Experiment
- CRD-Theory

Total number of CR contributions: 96

CR
- Highlight 3
- Oral 55
- Poster 38

CR
- EX 74
- TH 22

Many other posters shared with «Solar&Heliospheric»

Experiments presented at ICRC

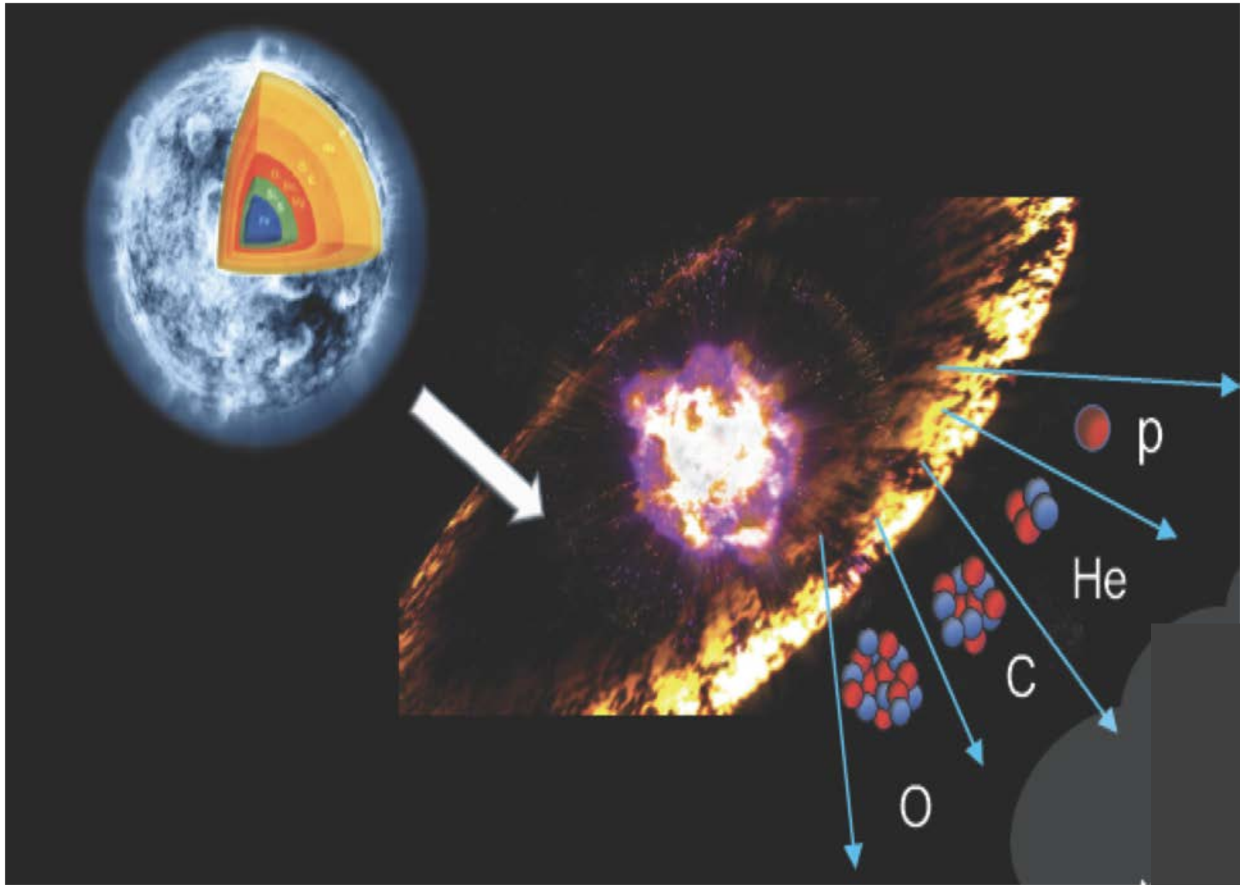
EXPERIMENT	HL	ORAL	POSTER
AMS-02	1	13	1
BESS		1	
CALET	1	5	1
CRIS		1	1
CUBE-SAT			1
DAMPE	1	7	10
FERMI		1	1
GAPS		1	2

EXPERIMENT	HL	ORAL	POSTER
HELIX		1	3
HEPD-02			1
HERD		1	3
HNX		1	1
ISS-CREAM		2	6
LISA			1
OLIVE-HERO			1
SUPER-TIGER		2	2

Wide coverage over the experimental situation

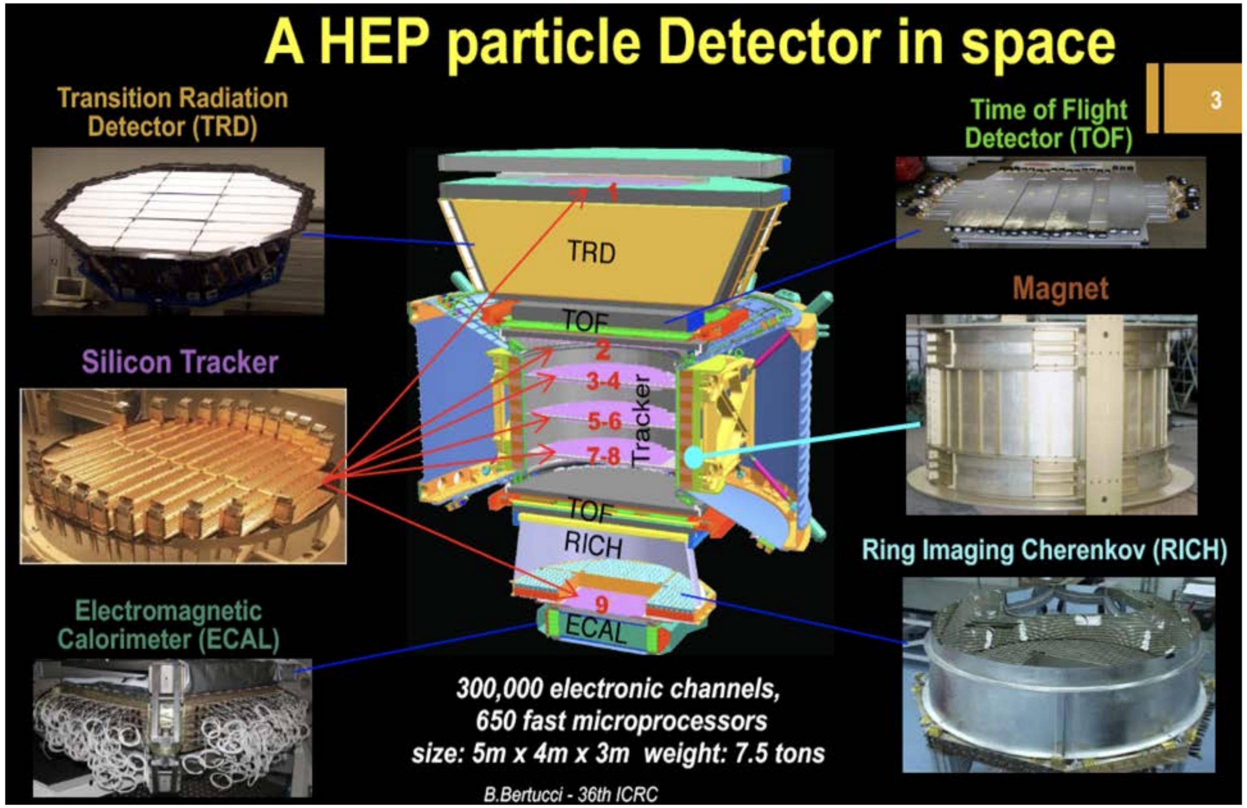
Primary cosmic rays (p, He, C, O)

CR injection and acceleration

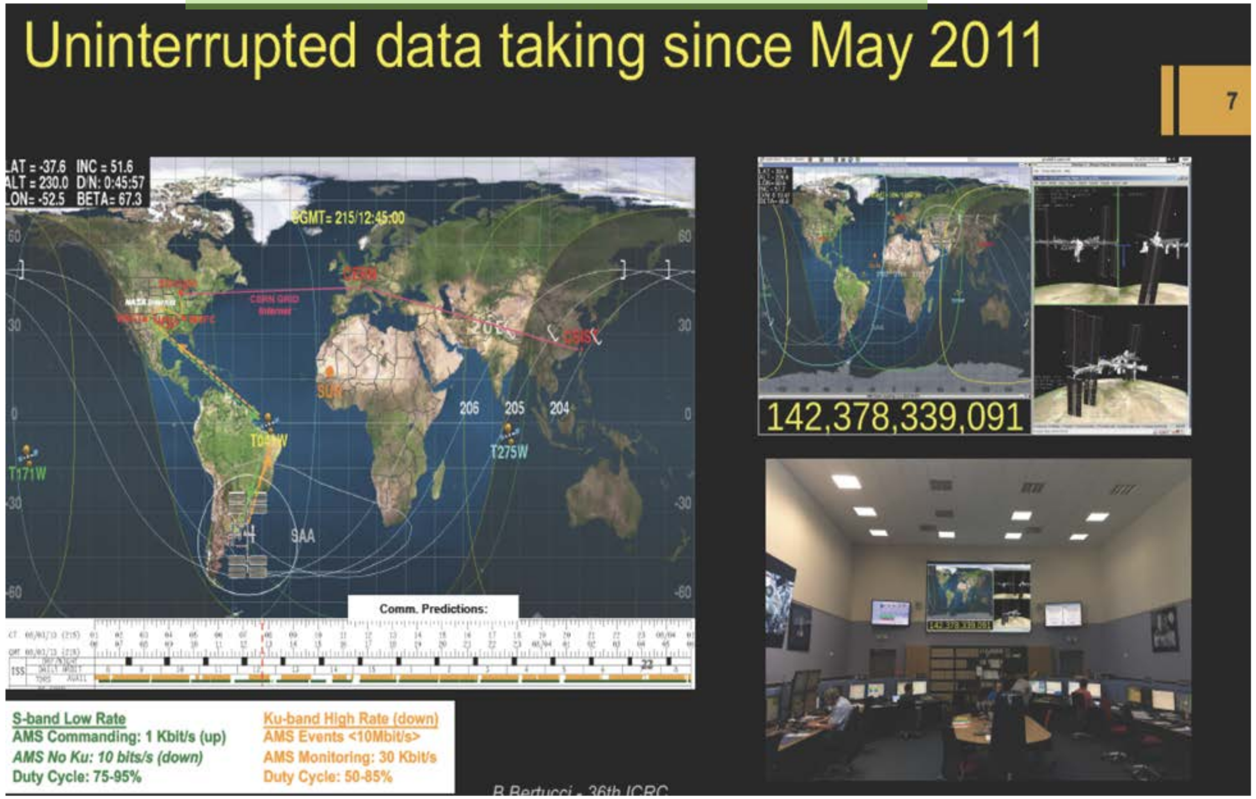


Alpha Magnetic Spectrometer AMS-02

H9:
Bruna Bertucci



Installed on ISS on 19th May 20110

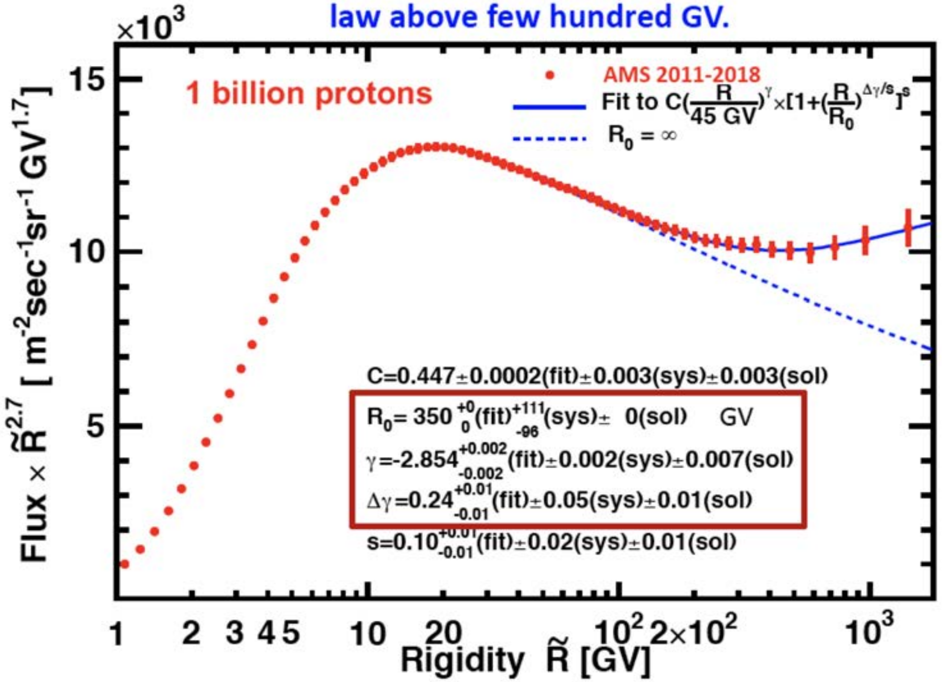


CRD8b: Qi Yan
H9: Bruna Bertucci

Proton and helium with AMS-02 (1 GV–> 2 TV)

Structure in the latest proton spectrum

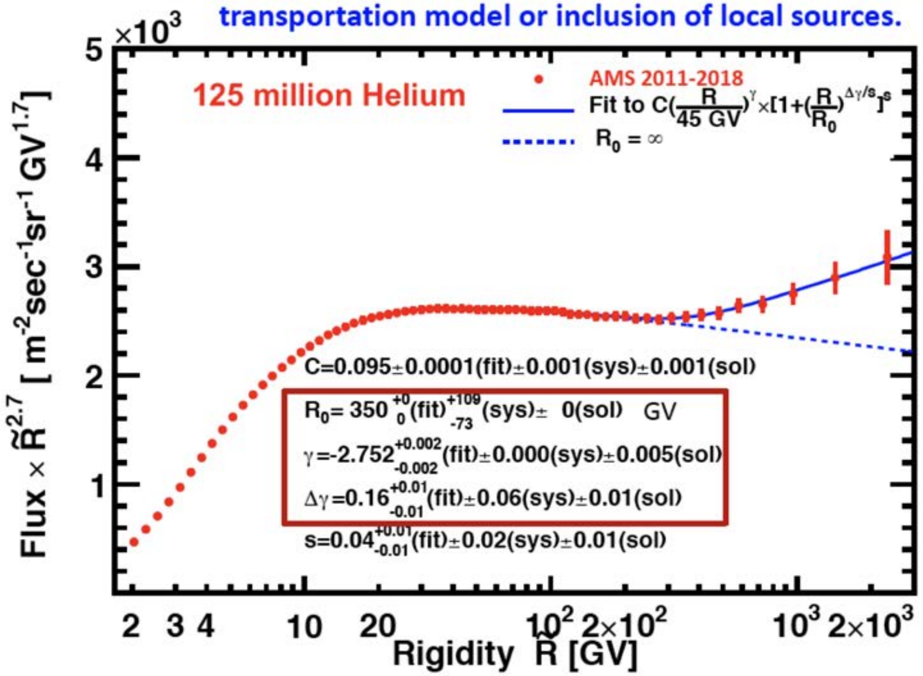
Proton spectrum measured by AMS shows a deviation from a single law above few hundred GV.



The new AMS result (2011-2018) is consistent with earlier AMS PRL result (2011-2013) "M. Aguilar *et al*., Phys. Rev. Lett., **114**, 171103 (2015)" but with improved accuracy

Origin of Structure in the latest helium spectrum

The structure in He (P) spectrum requires modification of cosmic ray transportation model or inclusion of local sources.



The new AMS result (2011-2018) is consistent with earlier AMS PRL result (2011-2016) "M. Aguilar *et al*., Phys. Rev. Lett., **119**, 251101 (2017)" but with improved accuracy

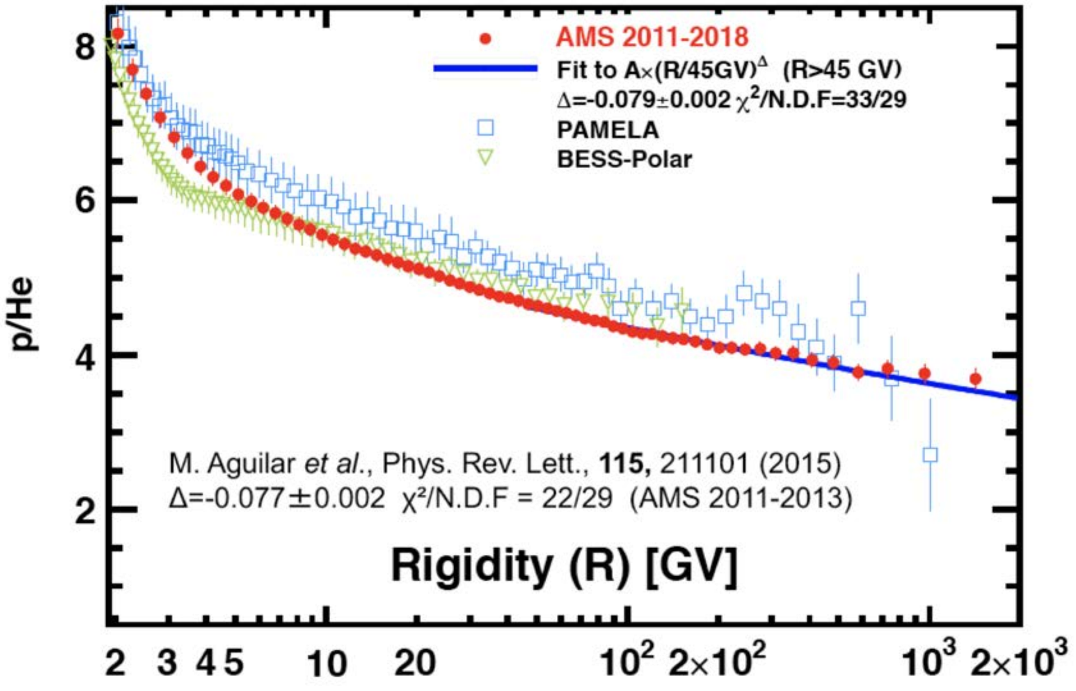
Important feature: confirmation of the deviation from a single power-law in both species at roughly 200 hundred GV

CRD8b: Qi Yan
H9: Bruna Bertucci

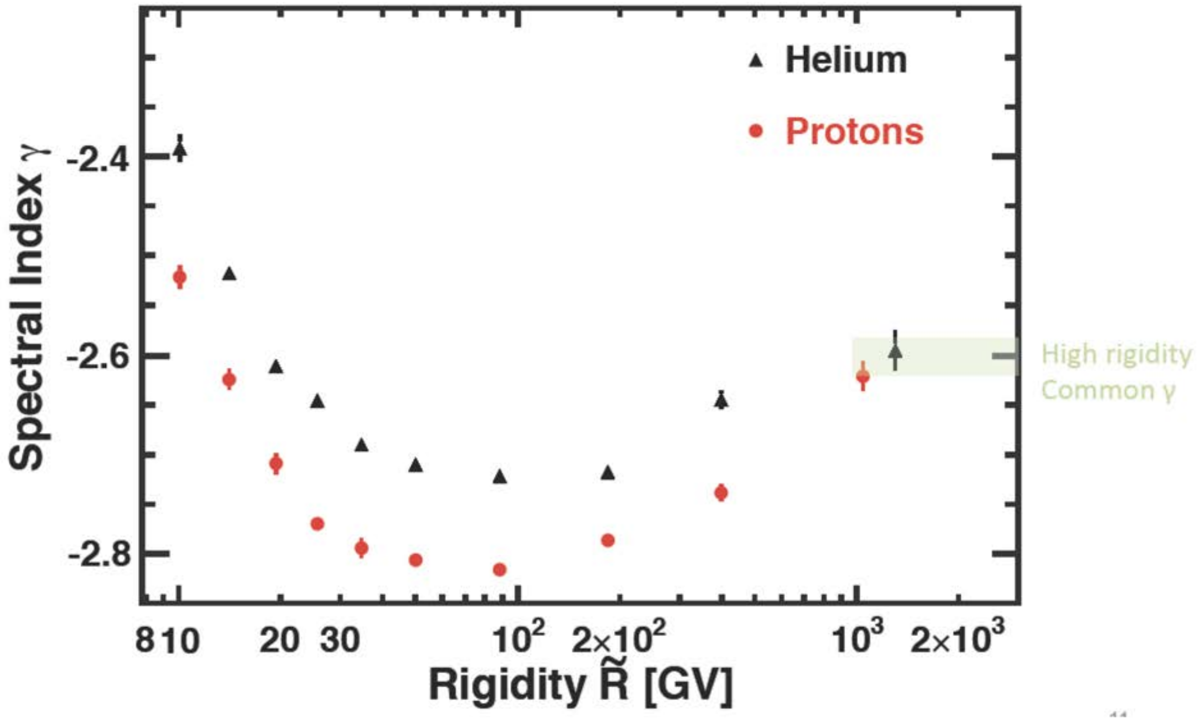
p/He ratio with AMS-02

The AMS Result on the Proton/Helium Flux Ratio

Protons and helium are both primary cosmic rays.
Traditionally, they are assumed to be produced in the same sou
so their flux ratio should be asymptotically rigidity independe



AMS Measurements of P&He Spectral Indices (2011-2018)



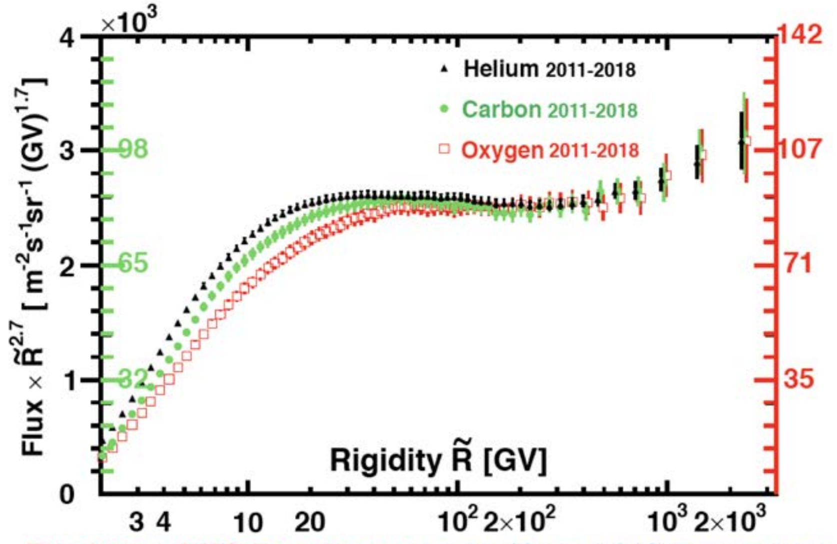
Important feature:

Confirmation that p/He not constant

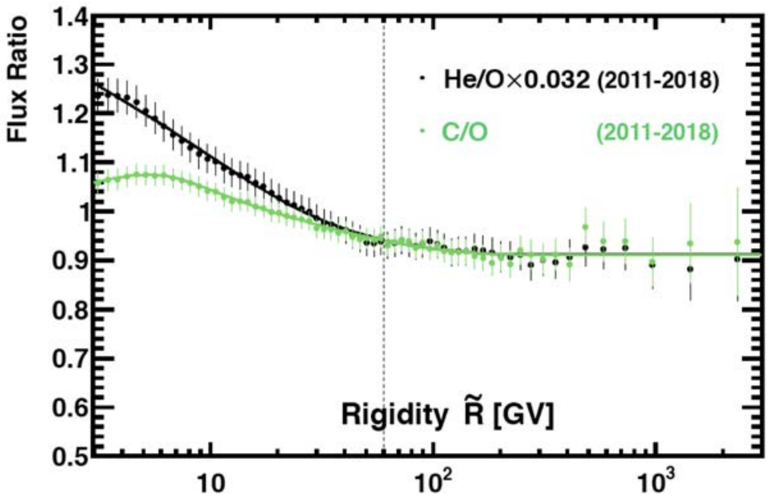
CRD8b: Qi Yan
H9: Bruna Bertucci

Carbon and Oxigen with AMS-02

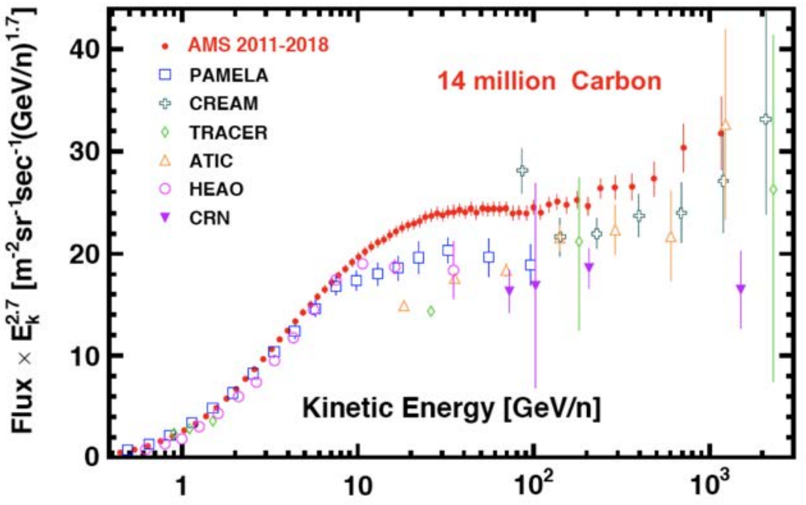
Latest AMS Measurements of He, C and O spectra



The latest AMS Results on the He/O and C/O Flux Ratios



Latest AMS Measurement of the carbon spectrum
together with earlier measurements



Important features:

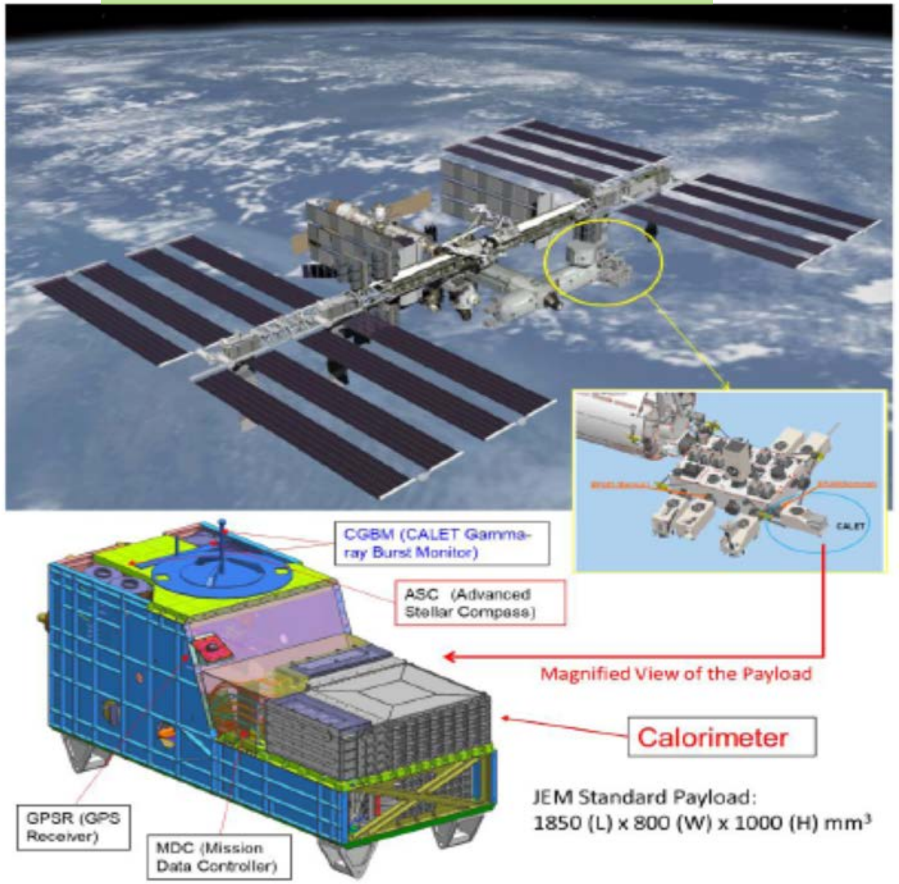
deviation from a single power-law in all species at few hundreds GV

Same spectral behavior for He, C, O above 60 GV

CALorimetric Electron Telescope CALET

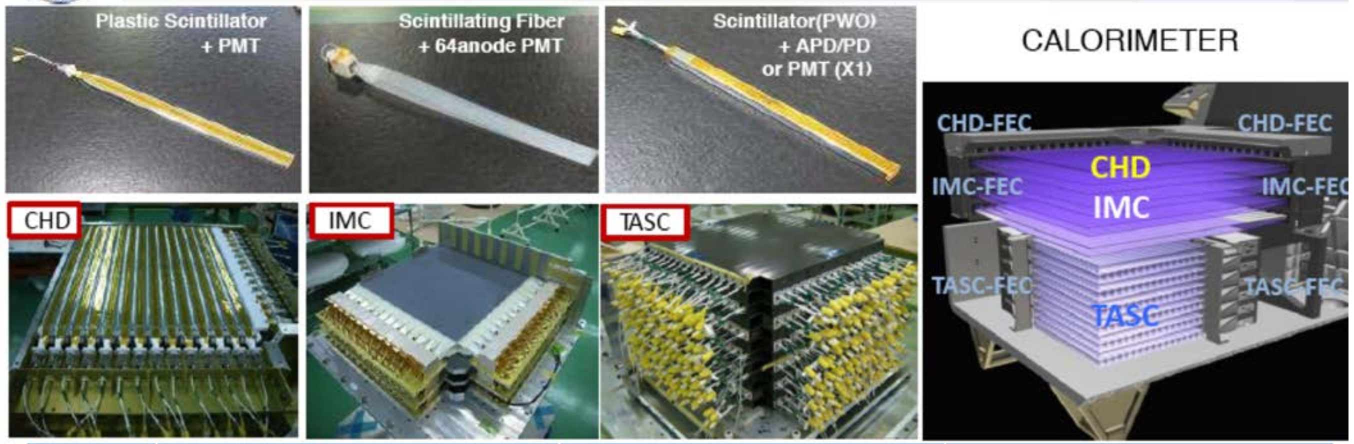
Launched August 19th, 2015

H7: Yoichi Asaoka



Continues stable observation since Oct. 13, 2015 and collected ~1.8 billion events so far.

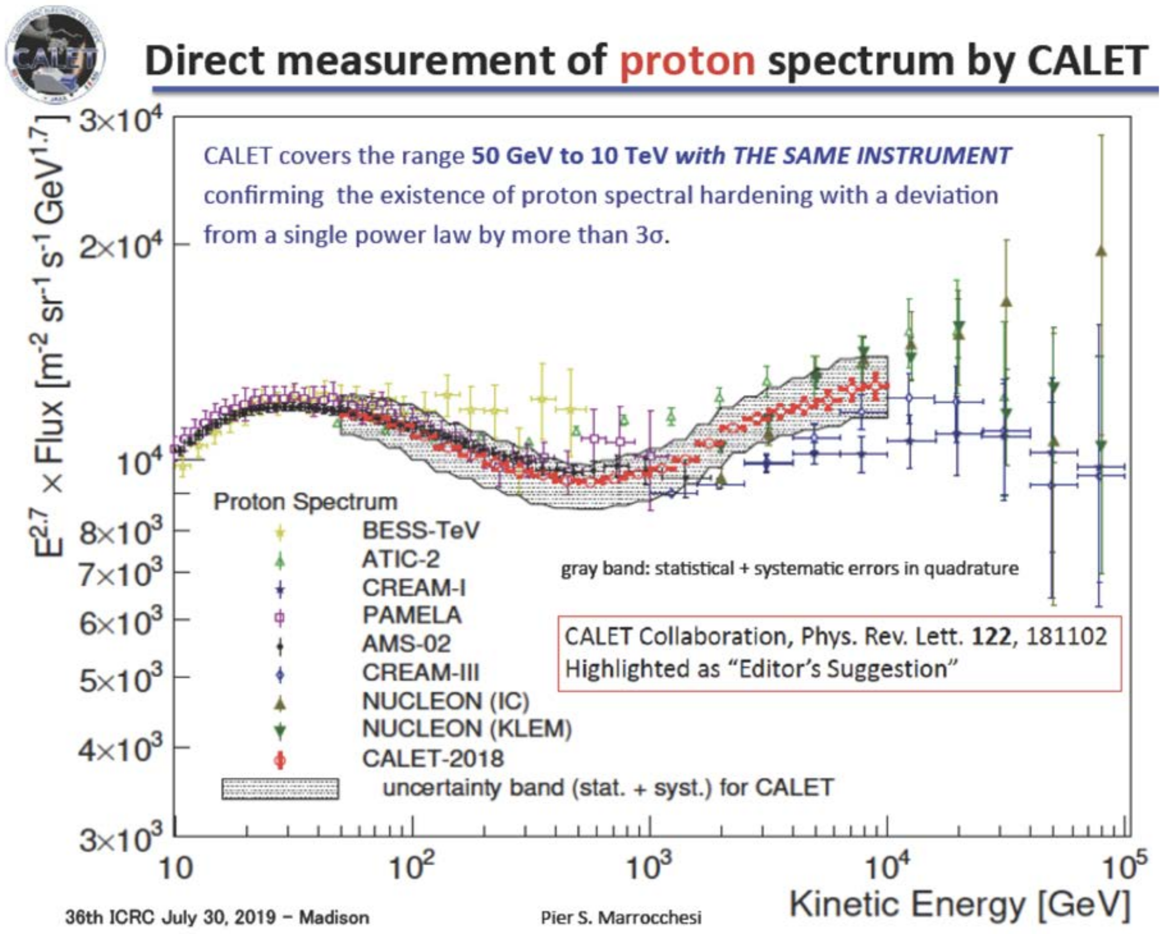
CALET Instrument

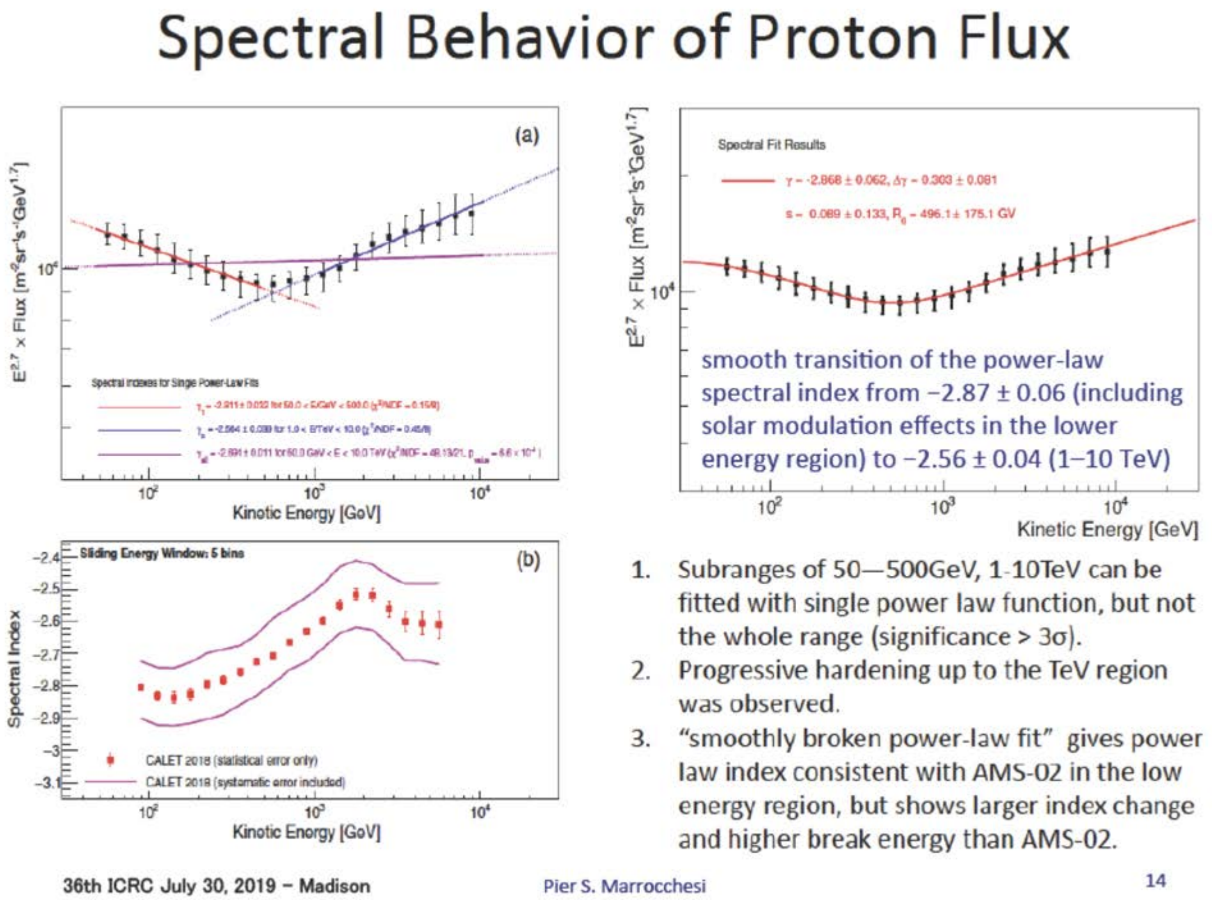


	CHD (Charge Detector)	IMC (Imaging Calorimeter)	TASC (Total Absorption Calorimeter)
Measure	Charge (Z=1-40)	Tracking , Particle ID	Energy, e/p Separation
Geometry (Material)	Plastic Scintillator 14 paddles x 2 layers (X,Y): 28 paddles Paddle Size: 32 x 10 x 450 mm³	448 Scifi x 16 layers (X,Y) : 7168 Scifi 7 W layers ($3X_0$): $0.2X_0$ x 5 + $1X_0$ x2 Scifi size : 1 x 1 x 448 mm³	16 PWO logs x 12 layers (x,y): 192 logs log size: 19 x 20 x 326 mm³ Total Thickness : 27 X_0, ~1.2 λ_I
Readout	PMT+CSA	64-anode PMT+ ASIC	APD/PD+CSA PMT+CSA (for Trigger)@top layer

H7: Yoichi Asaoka
CRD8e: PierSimone Marrocchesi

Proton flux with CALET (50 GeV – 10 TeV)

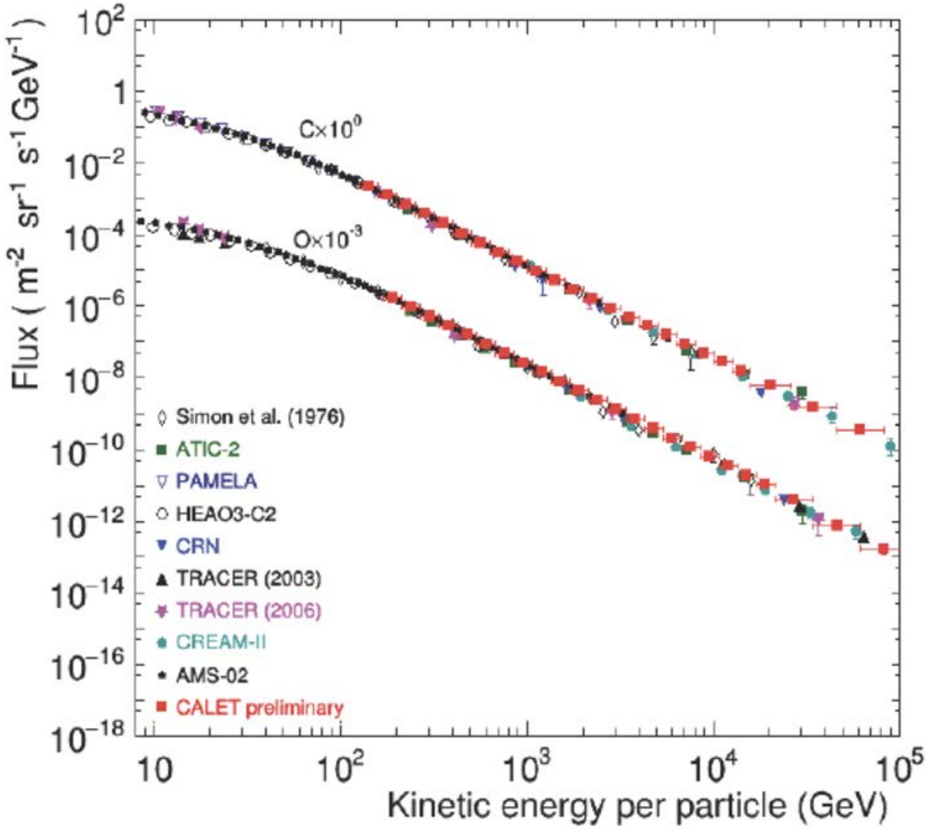


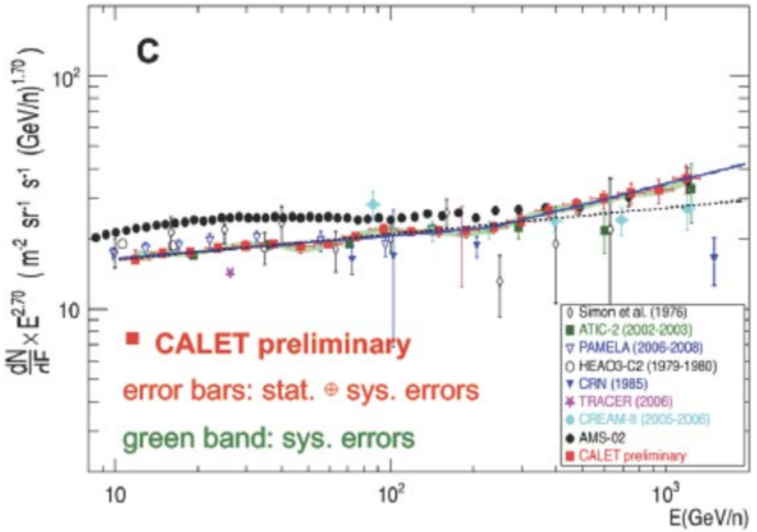


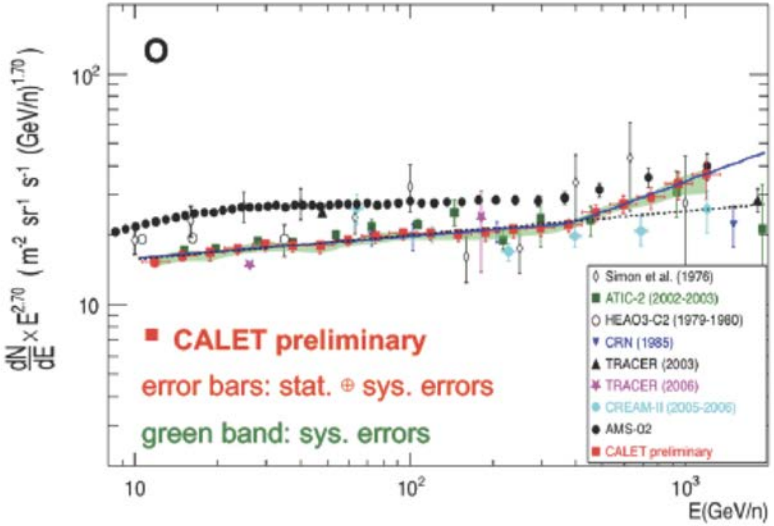
Important feature: confirmation of spectral hardening but at higher energy.
Is something happening at 10 TeV?

H7: Yoichi Asaoka
CRD8f: Paolo Maestro

Carbon and Oxygen with CALET







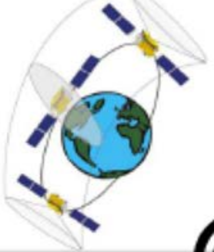
Important feature: confirmation of spectral hardening.
Some tension with AMS data (20% discrepancy)

Dark Matter Particle Explorer DAMPE

H16: Qiang Yuan

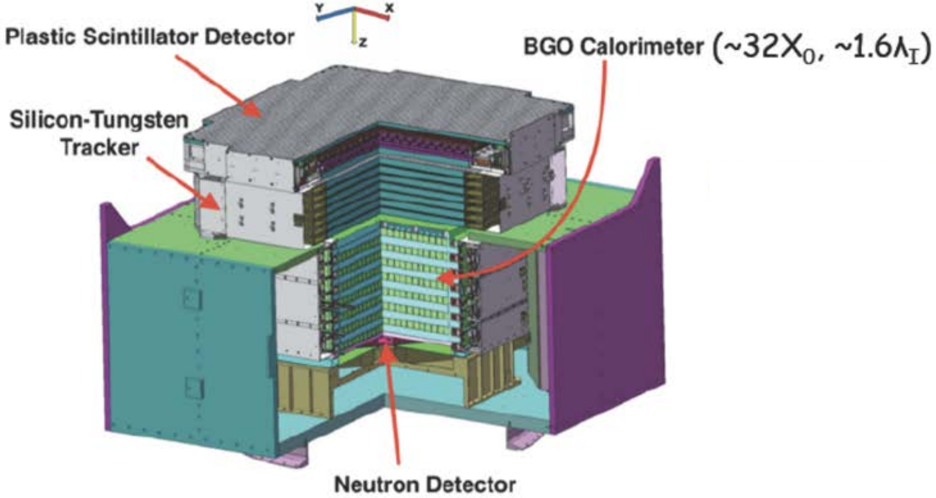
Satellite-borne particle detector, project of the *Strategic Pioneer Program on Space Science*, promoted by the *Chinese Academy of Sciences* (*CAS*).

ALTITUDE: 500 km
PERIOD: 95 minutes
ORBIT: Sun-synchronous



- *Study of Cosmic Rays composition, origin and propagation*
- *Search for Dark Matter signatures in lepton and photon spectra*
- *High Energy Gamma-Ray Astronomy*

DAMPE Instrument



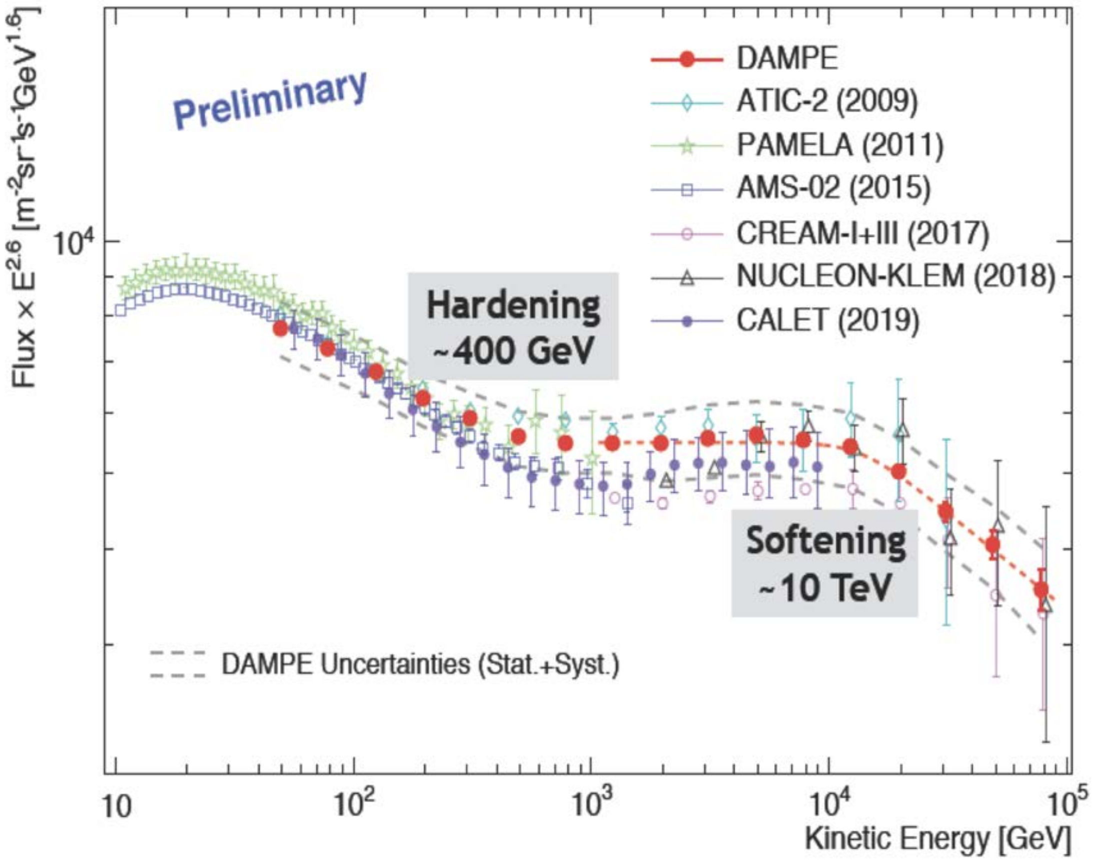
- *Charge measurement (dE/dx in PSD, STK and BGO)*
- *Gamma-ray converting and tracking (STK and BGO)*
- *Precise energy measurement (BGO Crystals)*
- *Hadron rejection (BGO and Neutron Detector)*

(Chang et al. Astropart.Phys. 95 (2017) 6–24)

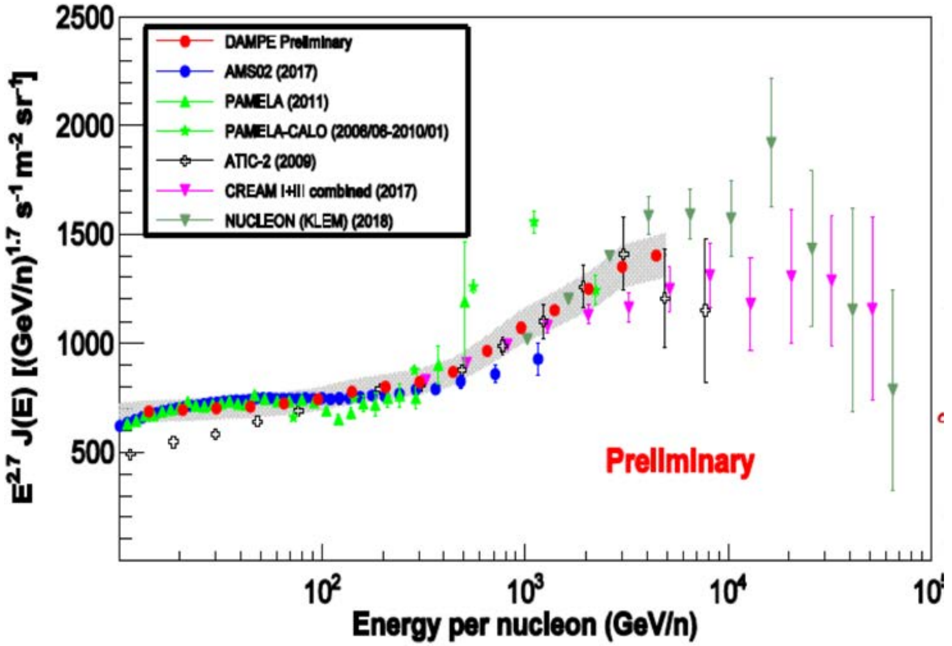
Proton and helium spectra with DAMPE

CRD8g: Chuan Yue
CRD8h: Margherita Di Santo

Prelim. proton spectrum 50 GeV → 80 TeV



Prelim. helium spectrum 10 GeV/n → 5 TeV/n



Important features for protons:

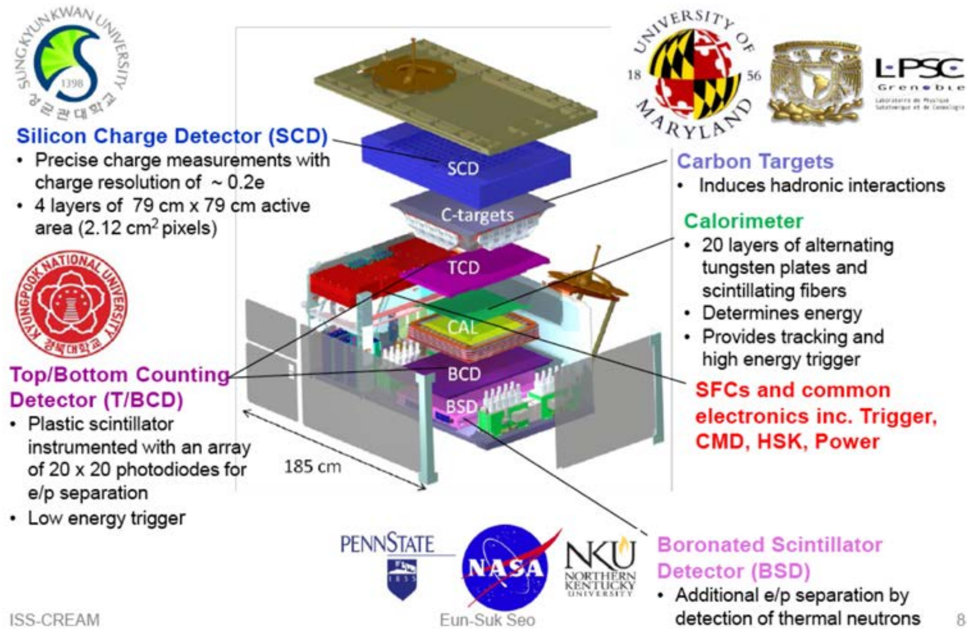
- confirmation of spectral hardening but at 400 GeV
- Softening above at 10 TeV

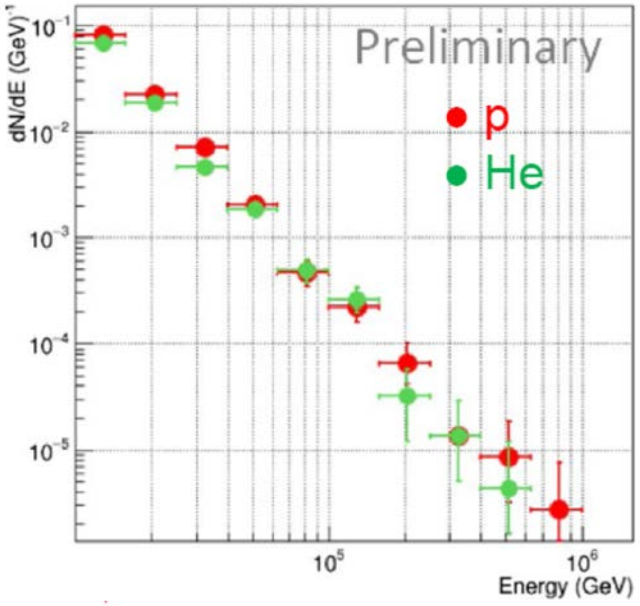
ISS-CREAM

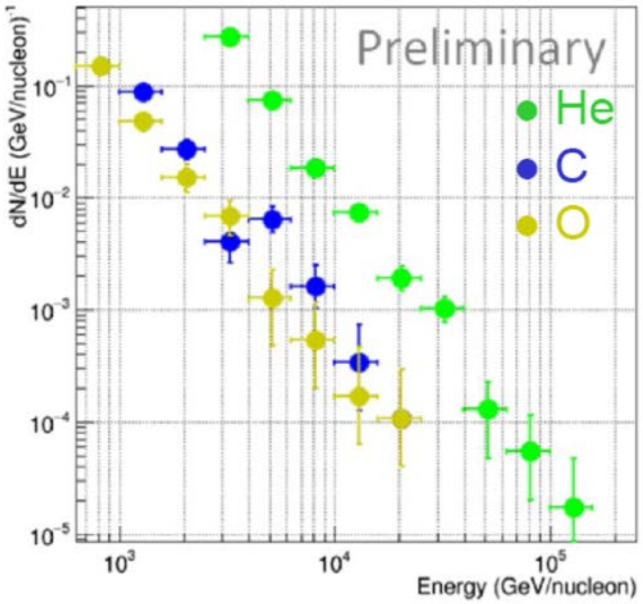
CRD7f: Eun-Suk Seo
CRD7c: Ryuiji Takeishi

ISS-CREAM launch on SpaceX-12, 8/14/17

ISS-CREAM

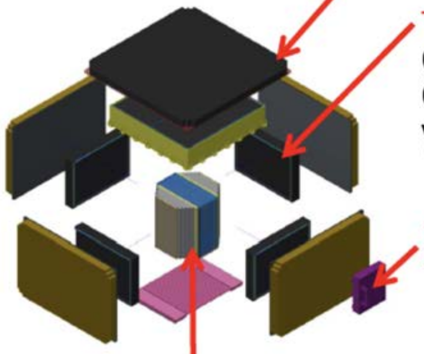






The High Energy cosmic-Radiation Detection facility HERD

- HERD, a China-led mission with a key European contribution led by Italy, is proposed by IHEP as an astronomy and particle astrophysics experiment onboard the China's Space Station, which is planned for operation starting around 2025 for about 10 years.



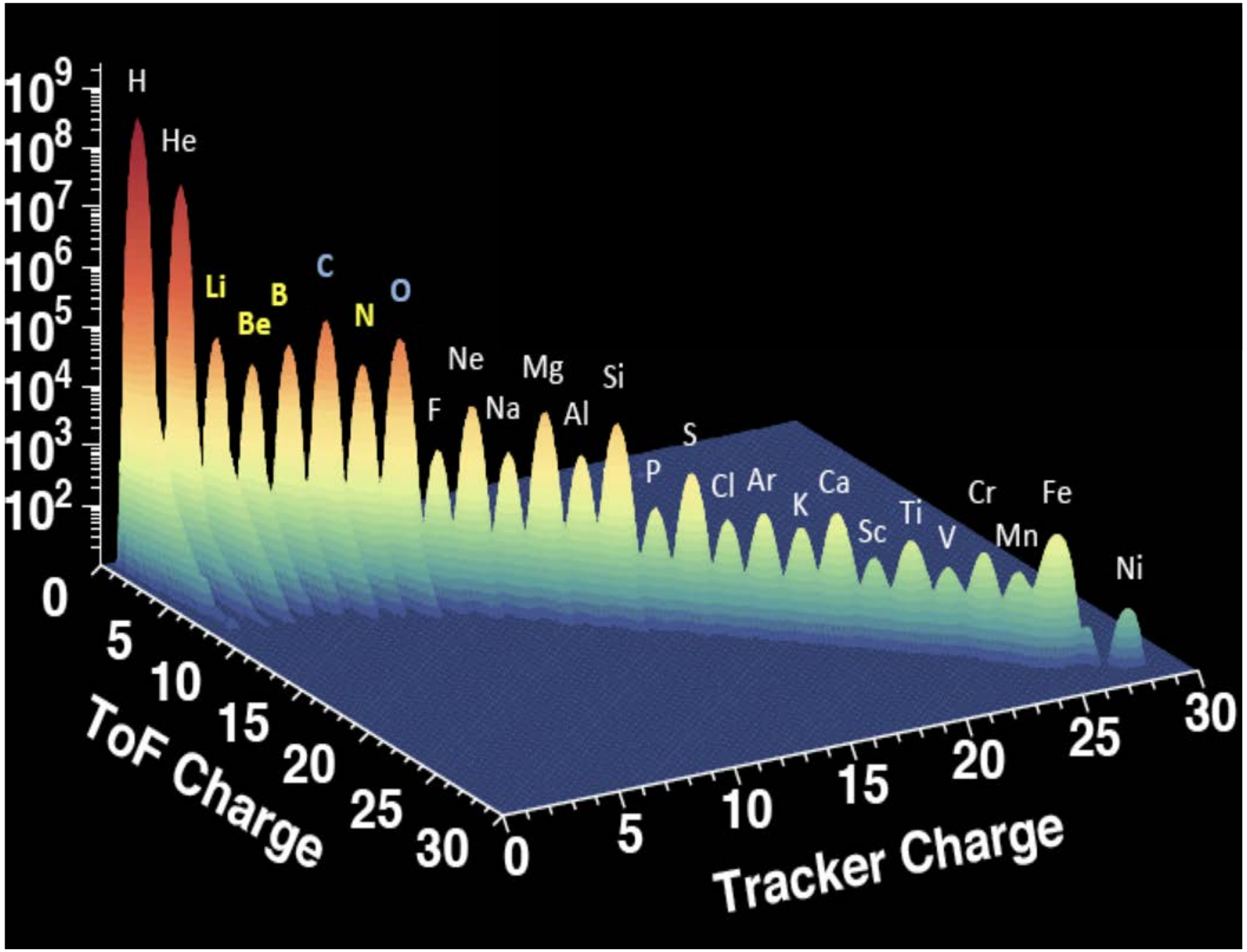
HERD specifications

Item	Value
Energy range (e/γ)	10 GeV - 100 TeV (e); 0.5 GeV-100 TeV (γ)
Energy range (CR)	30 GeV - 3 PeV
Angle resolution	0.1 deg.@10 GeV
Charge resolution	0.1-0.15 c.u
Energy resolution (e)	1%@200 GeV
Energy resolution (p)	20%@100 GeV - PeV
e/p separation	~10^{-6}
G.F. (e)	>3 m^2sr@200 GeV
G.F. (p)	>2 m^2sr@100 TeV
Field of View	+/-70 deg (targeting +/-90 deg)
Envelope (L*W*H)	~ 2300*2300*2000 mm^3
Weight	~ 4000 kg
Power Consumption	~ 1400 W

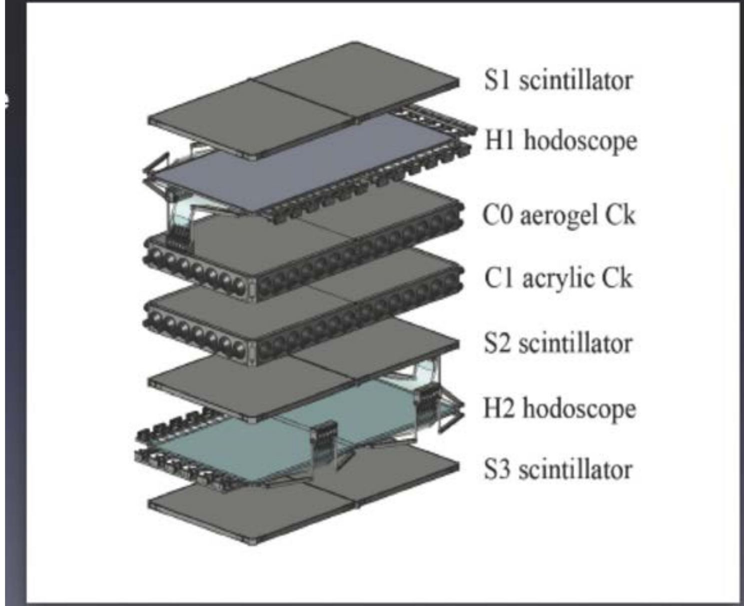
Heavier nuclei

Origin of CRs

CR acceleration

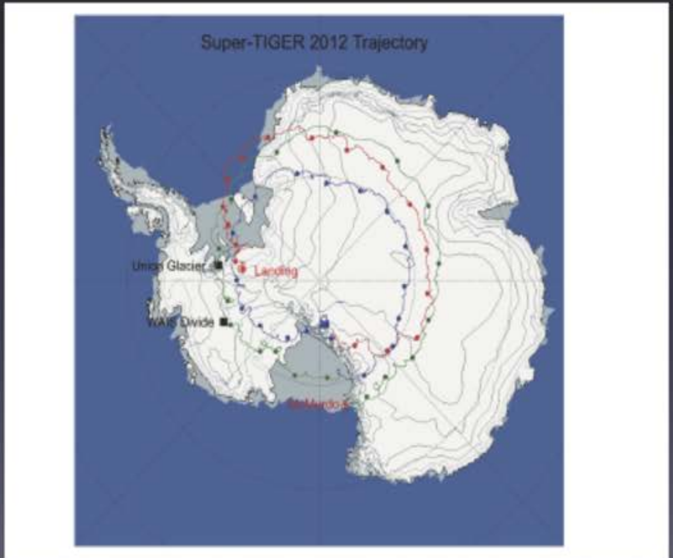


Super Trans Iron Galactic Element Recorder
Super-TIGER



2 modules (1 shown), effective geometry 3.9 m^2 sr
Plastic scintillators (for Z)
Acrylic (n=1.49) and Aerogel (n=1.043, 1.025)
Cherenkov Detectors (for Z, β)

- "Super" Trans-Iron Galactic Element Recorder
- A balloon-borne cosmic ray instrument that can measure galactic cosmic ray abundances for Z=~10–60 for energies ~0.8-10 GeV/nuc
- Primary Goals: Measure Z=30–60 abundances to test OB association models for cosmic ray origins
  - R.P. Murphy et al., ApJ 2016
  - N.E. Walsh et al., COSPAR 2018, E1.5-0040-18
  - **N.E. Walsh et al., ICRC 2019, CRD3a**
- Secondary Goals: Spectra, spectral features



December 8, 2012 — February ~2, 2013
Record 55 day flight, avg altitude 125k ft.
~5x10^6 Fe events (used to map detector responses)

Super-Tiger UH CR Z→ 41-56

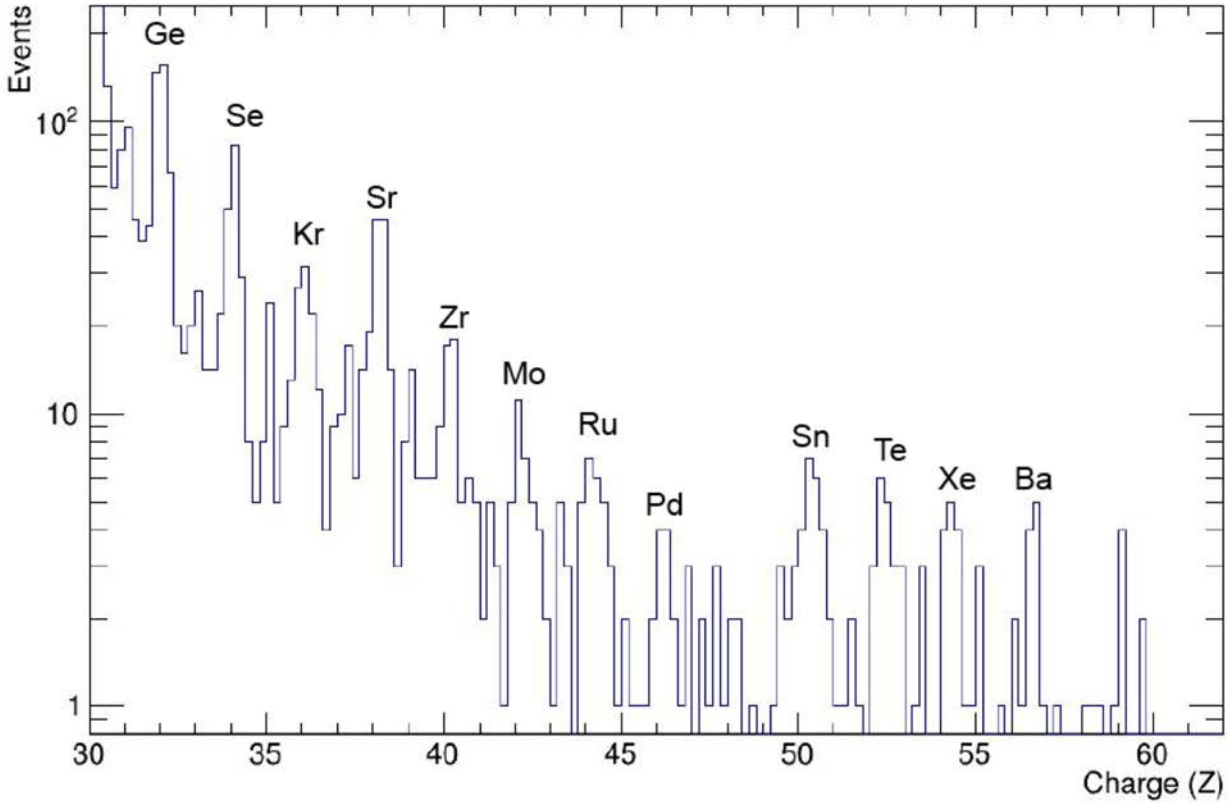
CRD3a:
Nathan Walsh

SuperTIGER measures UHGCR to test the OB association origin of cosmic rays at higher Z, in which:

1) the GCRs are **a mix of massive star material and normal ISM**
2) refractory elements that condense in dust grains are **preferentially accelerated** compared to volatile elements residing in gas.

Both supernovae in OB associations and binary neutron star mergers produce r-process nuclei.

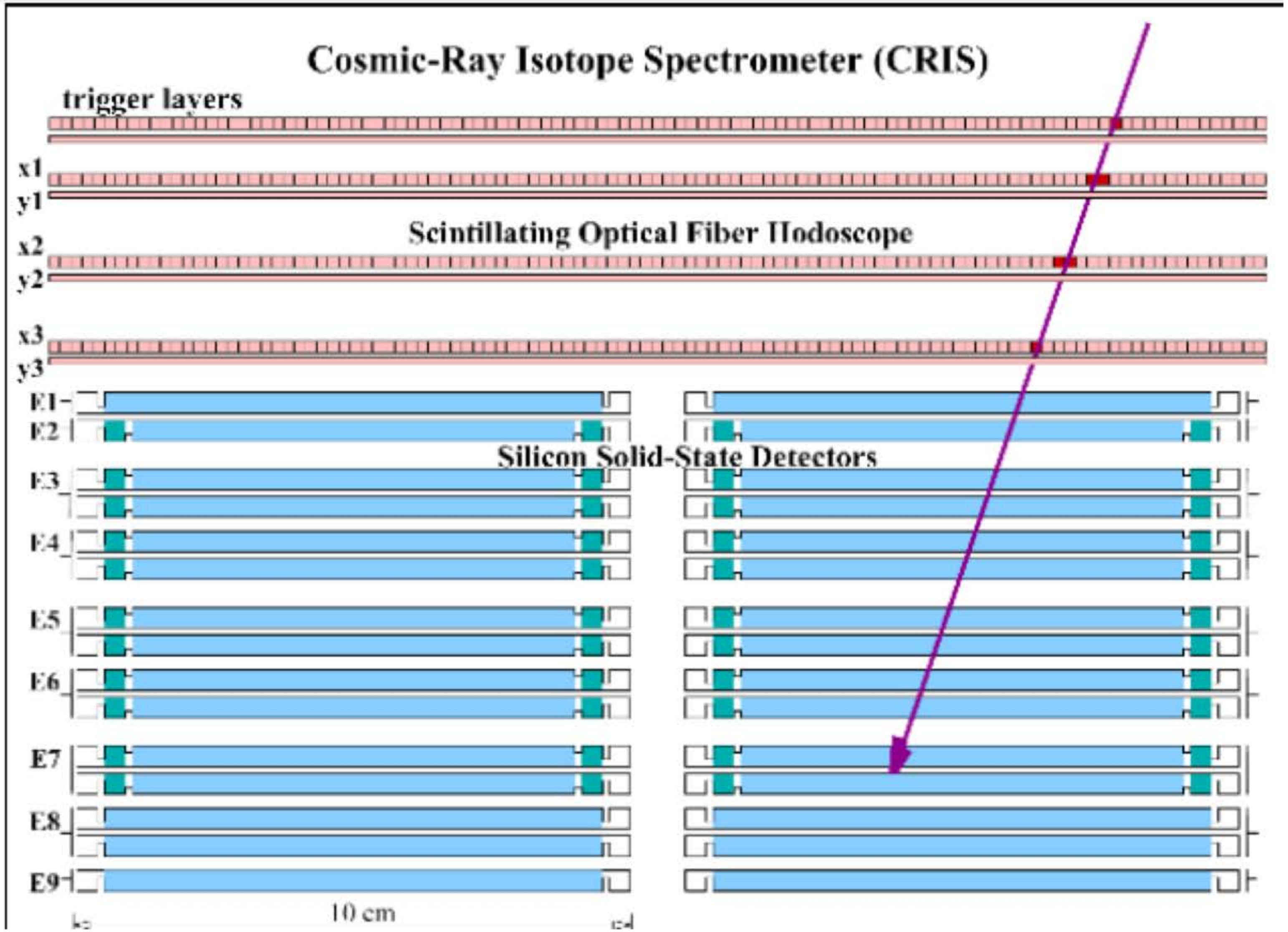
Measurements up to Barium (Z=56) will be able to put constraints on the r-process production models of SNE and BNSM.



Improve upon the SuperTIGER charge assignment analysis done in APJ, 831, 2016 in the Z=30-40 charge range.
Extend the charge assignment analysis to higher charges (up to Z=56)

CRIS Detector System on the ACE Spacecraft

- Designed to measure nuclei between $_4$Be and $_{28}$Ni that stop in the Si detector stack.
- Geometrical factor ~250 cm^2 sr
- Life-time ≥ 2 years, hopefully 5 years.
- Abundance in cosmic rays of $_{30}$Zn is ~10^{-4} of $_{26}$Fe and of heavier elements ~10^{-5} of $_{26}$Fe.
- UH measurements with CRIS made possible by long life of ACE & CRIS – still returning good data after >21 years.



Ultra-Heavy nuclei with CRIS (ACE) → 21 years !

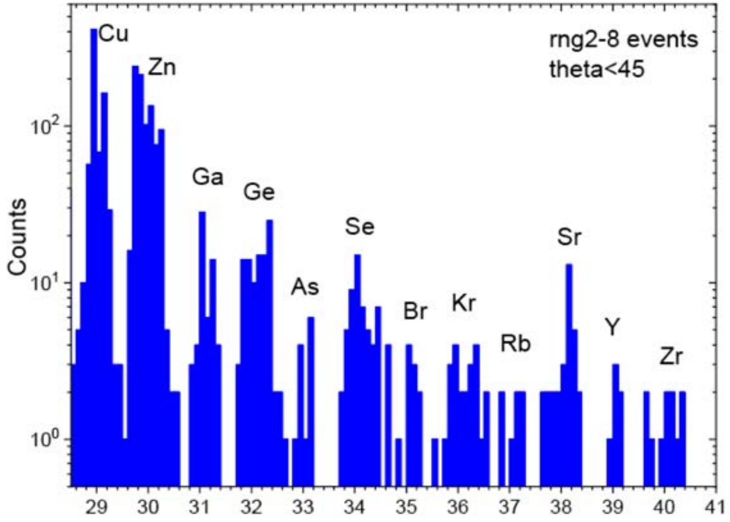
CRD3d:
Martin Israel

Data taken over time interval from Dec. 4, 1997 through Feb. 18, 2019

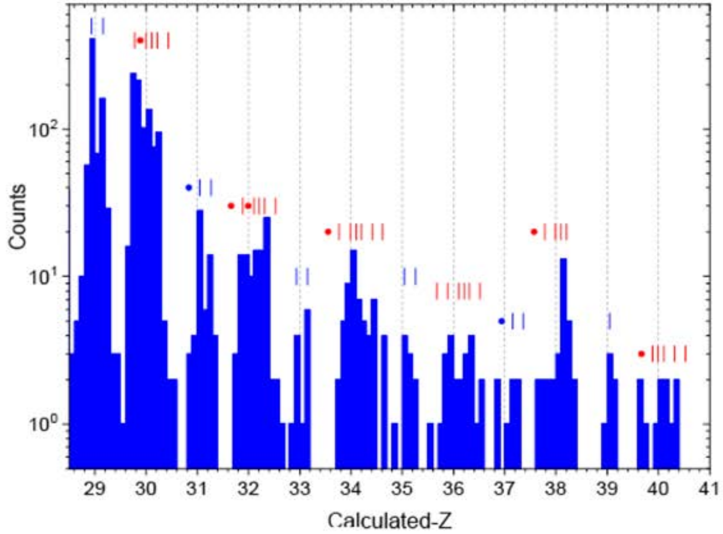
A total of 7406 days of actual data

Excellent resolution in charge for UH nuclei

Data set corresponds to 1.5 x 10^6 Fe nuclei



- Width of element distributions is primarily dependent upon the number of stable isotopes for each element.
- Red and blue lines show the calculated position of each stable isotope for an element.
- Red and blue circles show the calculated position of isotopes that can only decay by electron-capture and thus are stable when fully stripped.
- (Red lines and circles for even-Z elements, blue for odd-Z elements).



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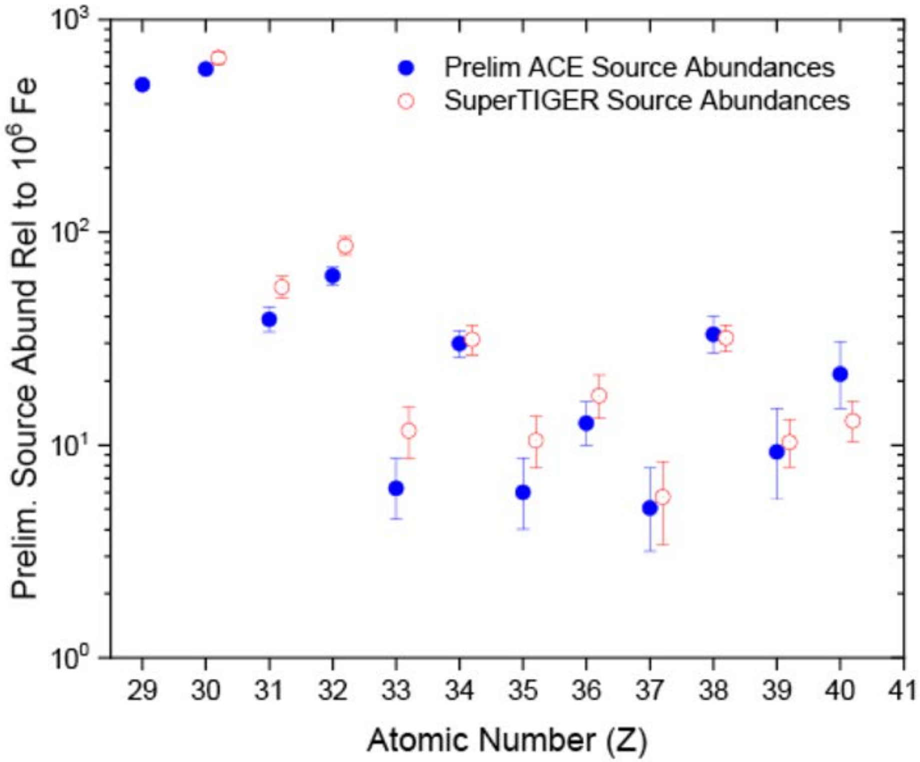
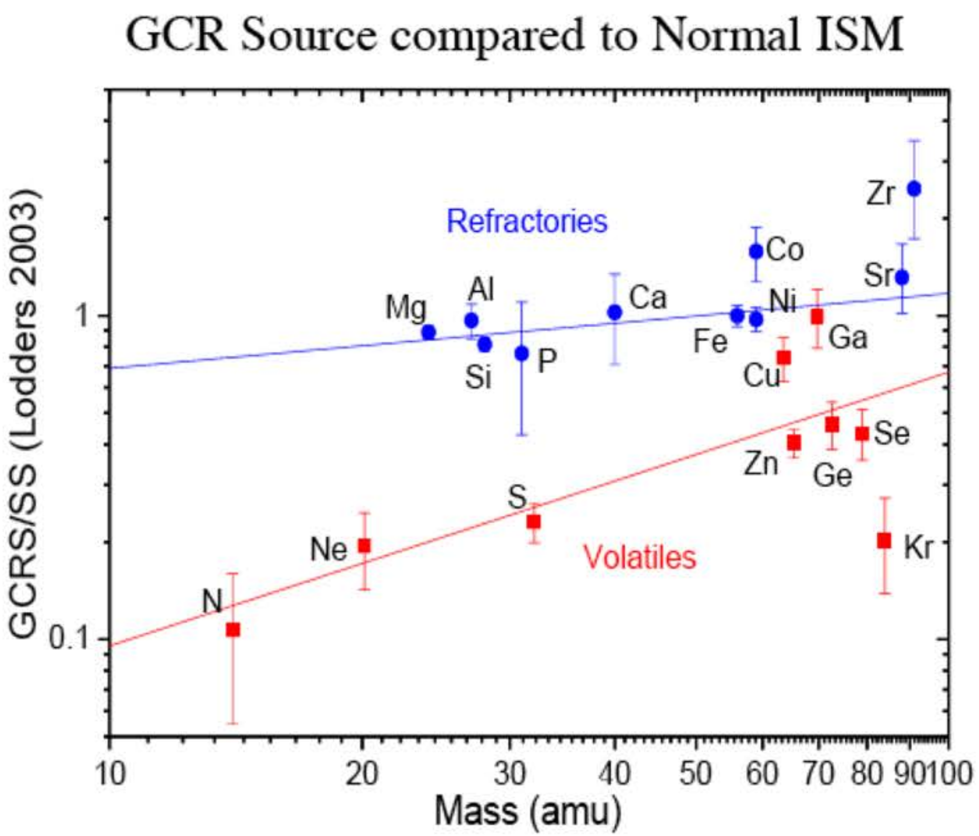
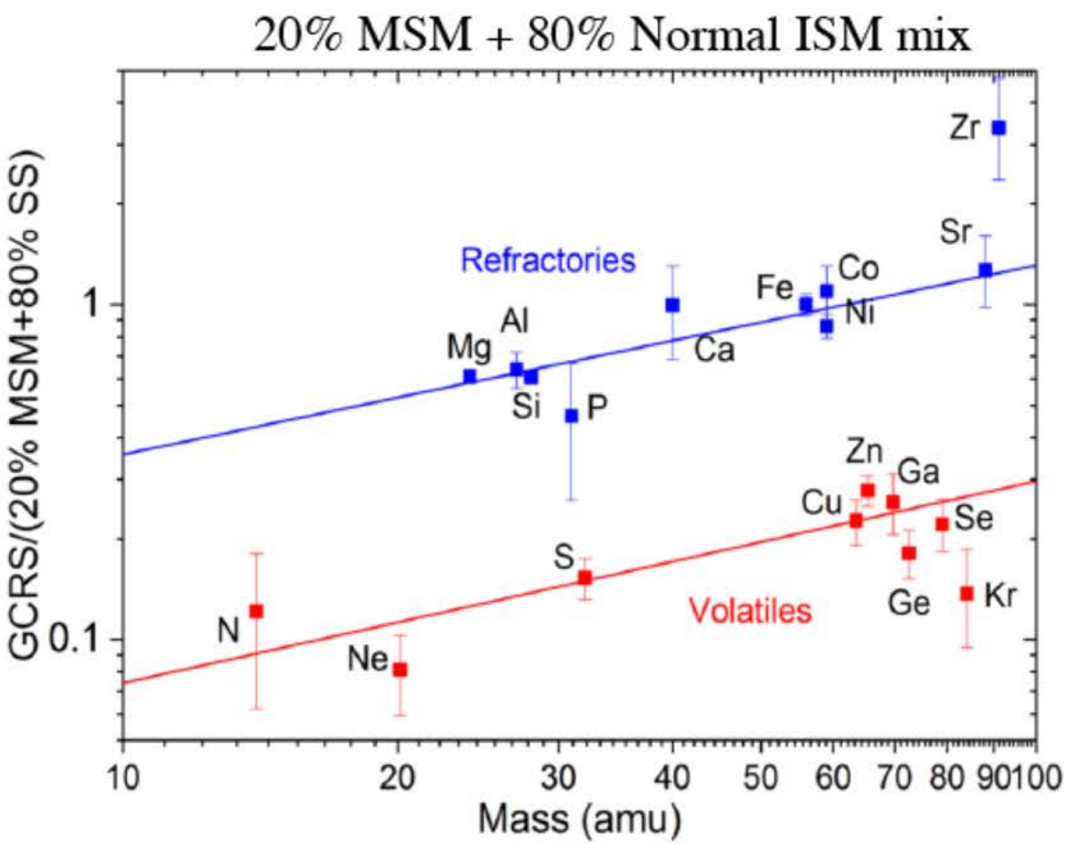


CRD3d:
Martin Israel



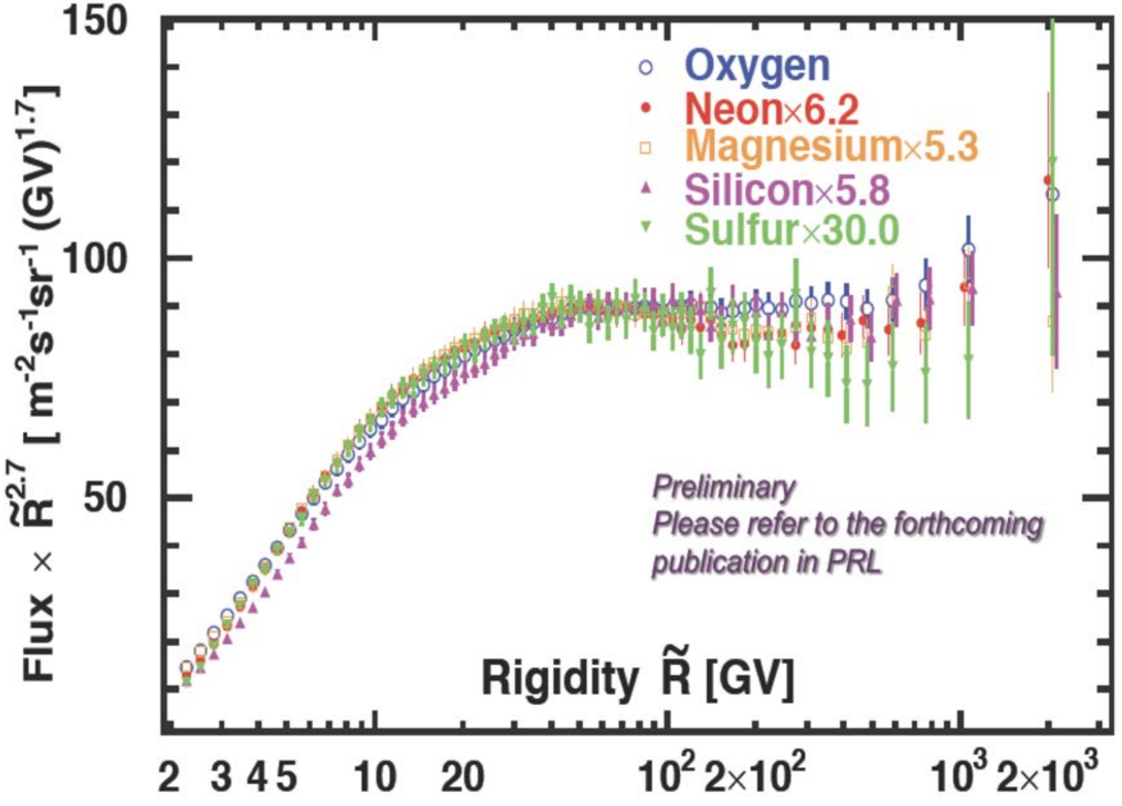


We have previously shown that when one plots the GCRS abundances relative to a mix of massive star material (MSM) and Normal ISM vs. mass instead of relative to Normal ISM only (Solar System material), the refractories and volatile elements separate nicely with similar slopes.

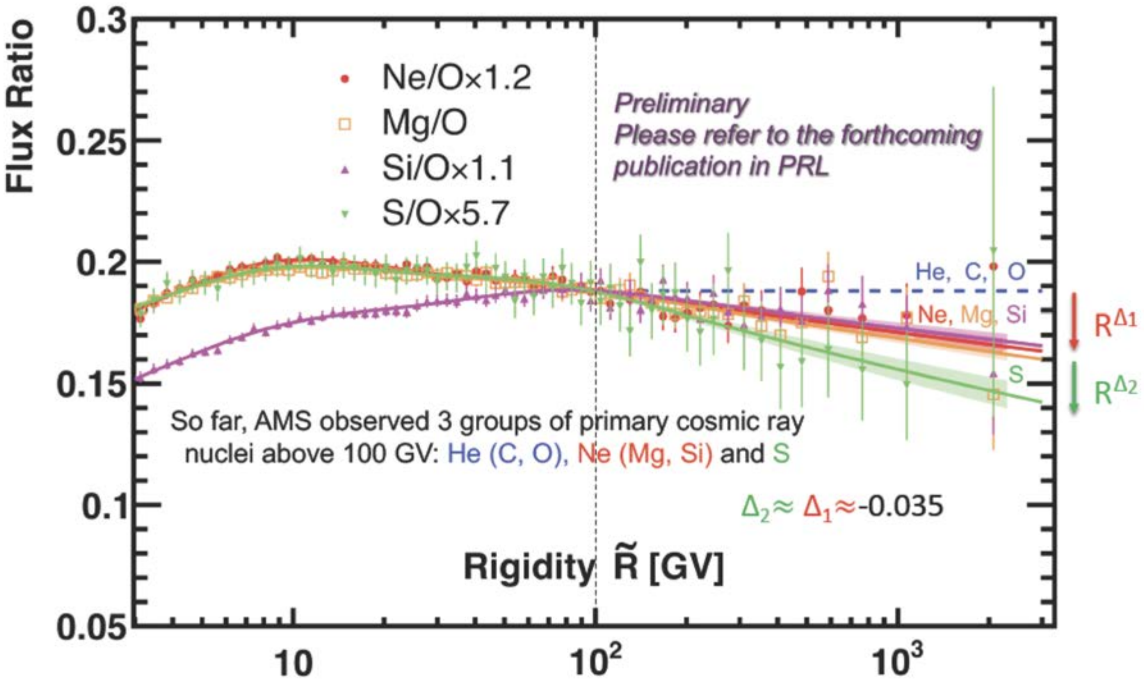
Ne, Mg, Si, S with AMS-02

CRD7a:
Qi Yan

O, Ne, Mg, Si and S Fluxes



Flux Ratio to Oxygen (Ne/O, Mg/O, Si/O and S/O)



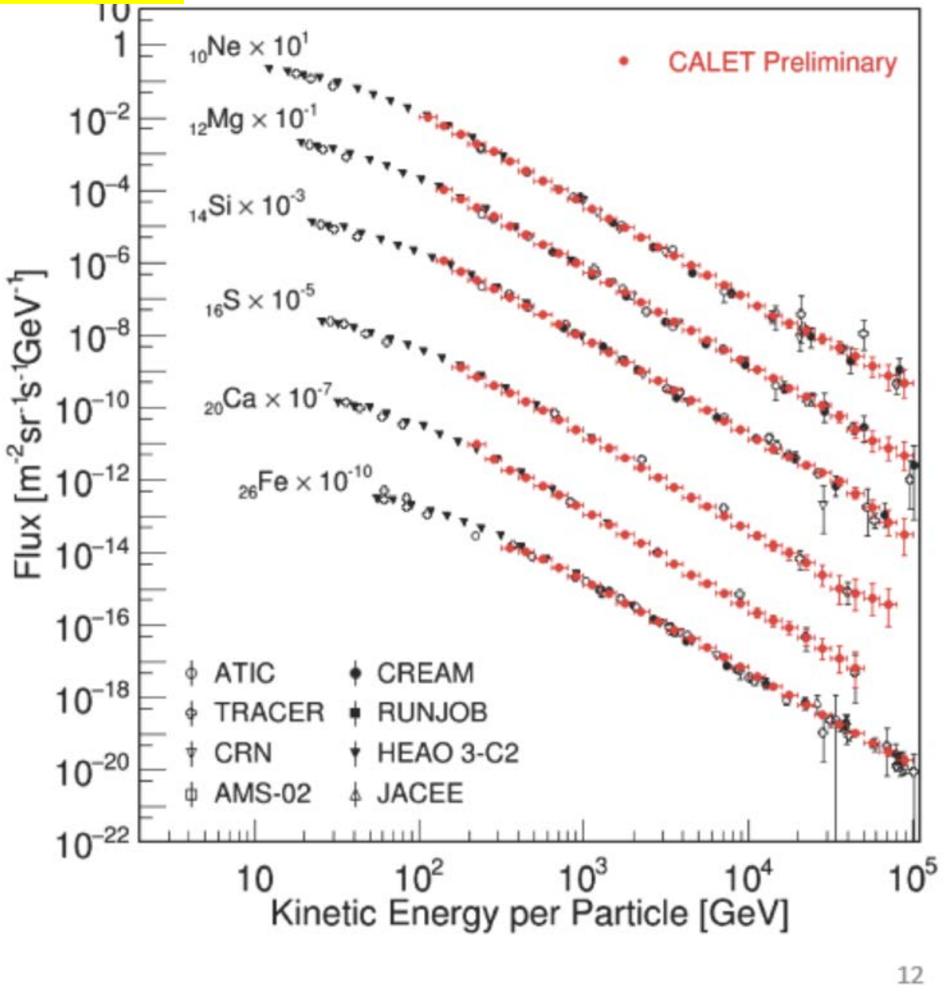
Important features:

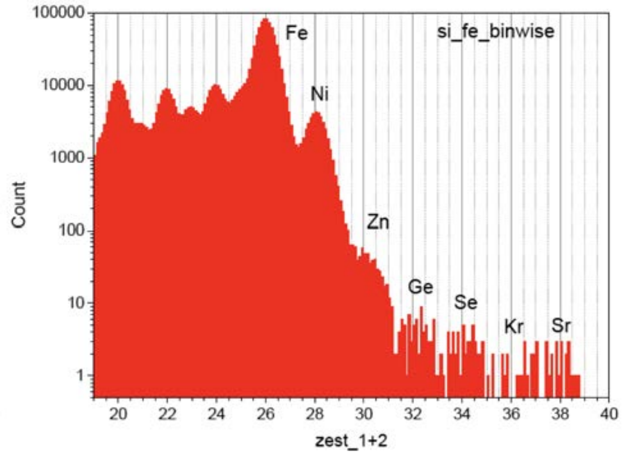
3 primary groups behaving different:
- He, C, O
- Ne, Mg, Si
- S

Ultra-Heavy nuclei with CALET: 3 years data

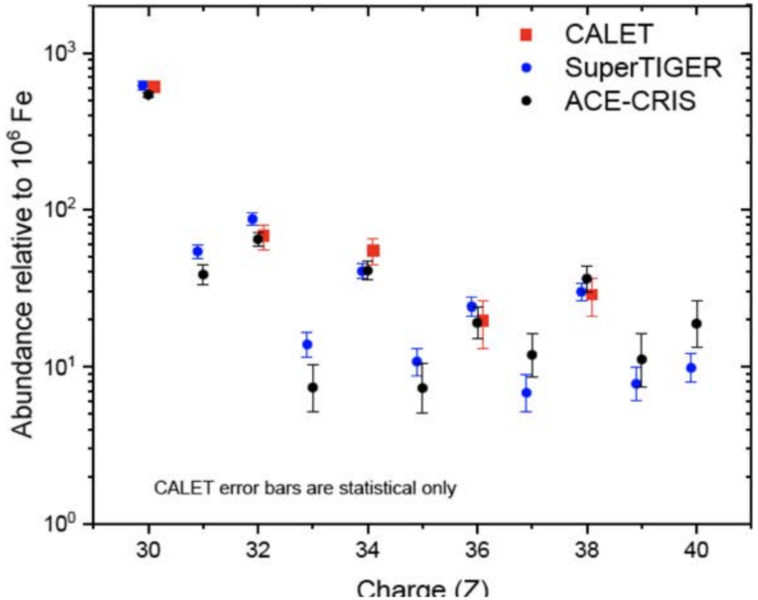
CRD3b:
Yosui Akaike

CRD3c:
Brian Rauch



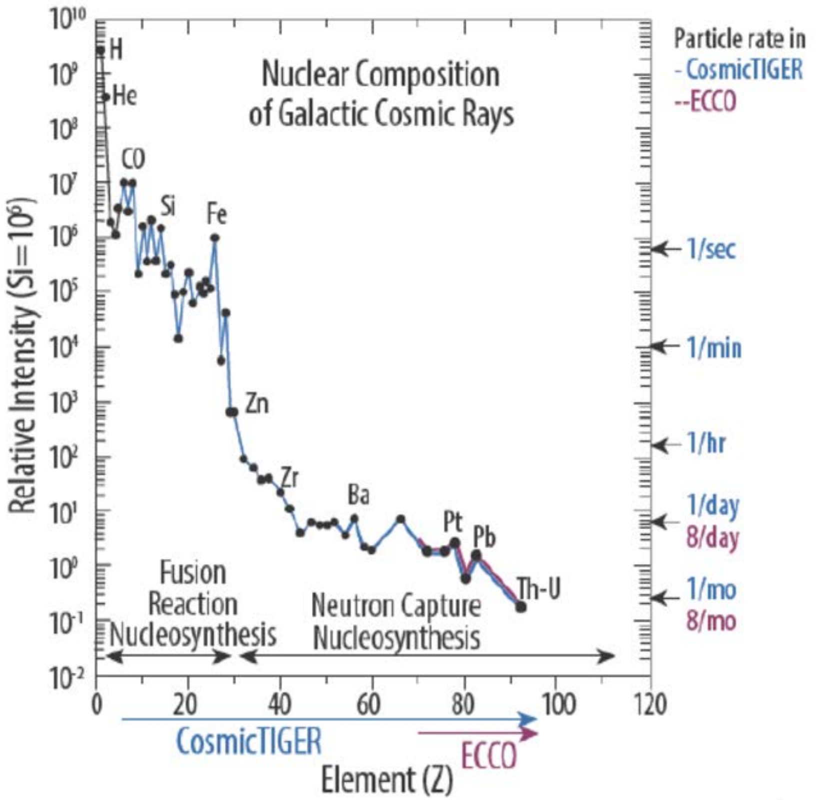


- The ACE and ST data are "in-space" abundances.
- The CALET data have not yet been corrected to the top of the instrument.
  - Those corrections will be small, so they will not change things materially.
- The agreement with ST and ACE-CRIS appears to be quite good.
- Additional data and anticipated improved resolution should result in reduced error bars.



The Heavy Nuclear eXplorer

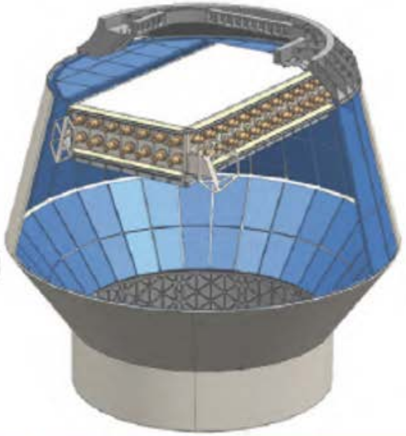
- **HNX explores to the end of the periodic table**
- Elements in the upper 2/3rds are extremely rare



HNX uses two complementary instruments to span $6 \le Z \le 96$ ($Z > 96$ if flux exists) with the needed high exposure factor and charge resolution.

ECCO (Extremely-heavy Cosmic-ray Composition Observer)

- Uses ~21 m^2 of Barium Phosphate (BP-1) glass tiles covering the walls and part of the top of the DragonLab Capsule to measure $Z \ge 70$ (Yb) nuclei
- Recovery is required for post-flight processing of glass



CosmicTIGER (Cosmic-ray Trans-Iron Galactic Element Recorder)

- 2 m^2 electronic instrument using – silicon strip detectors and Cherenkov detectors with acrylic and silica-aerogel radiators in the pressurized DragonLab Capsule

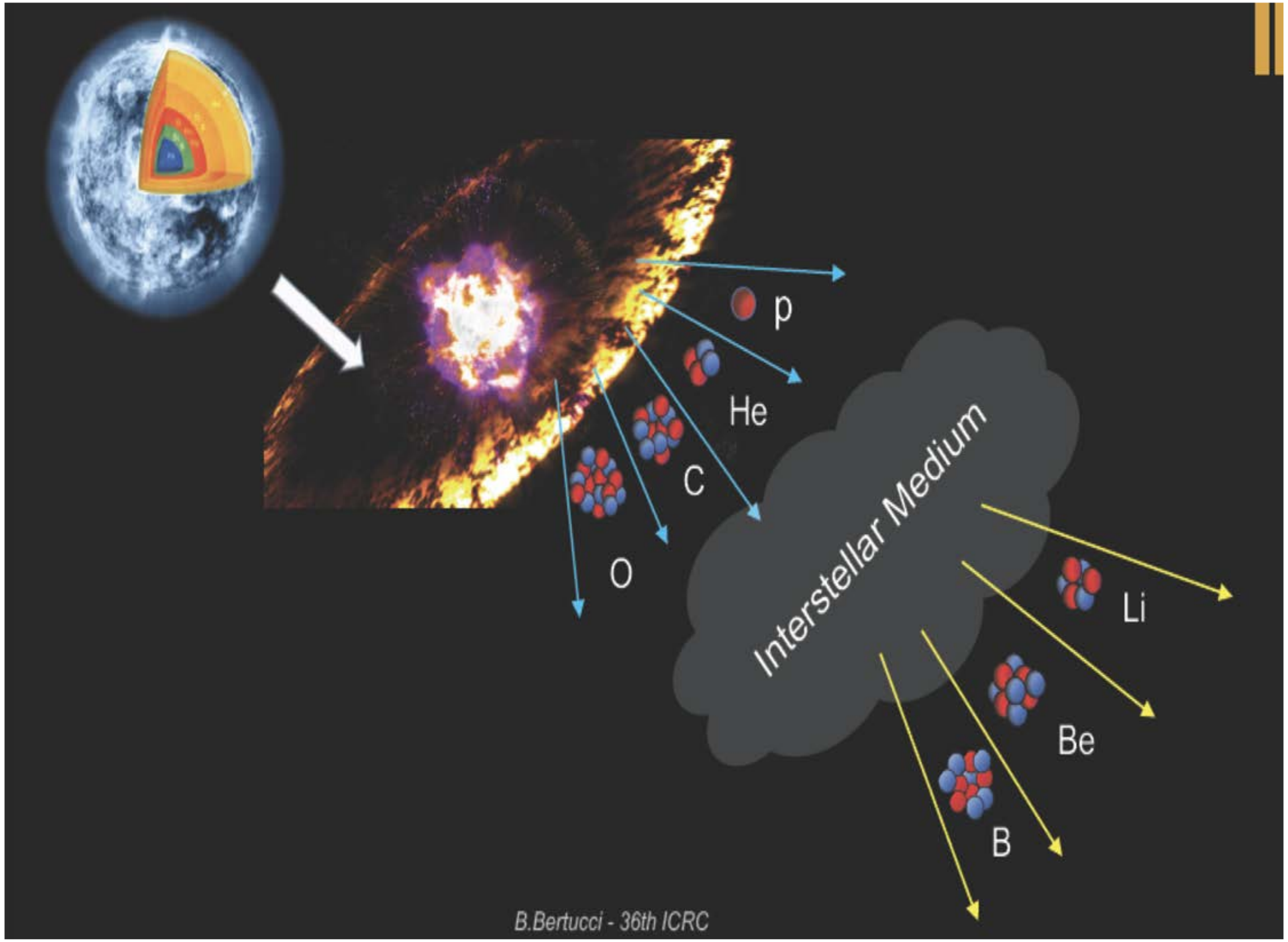
DragonLab Capsule Accommodation

- Pressurization of capsule reduces complexity of CosmicTIGER – no high-voltage potting, convective/forced air cooling and Temperature Stability for ECCO
- Mission duration baseline is 2 years, can be extended since there are no consumables

HNX was proposed to NASA in response to the 2014 Small Explorer Announcement of Opportunity, but unfortunately not selected. Developing for next SMEX AO.

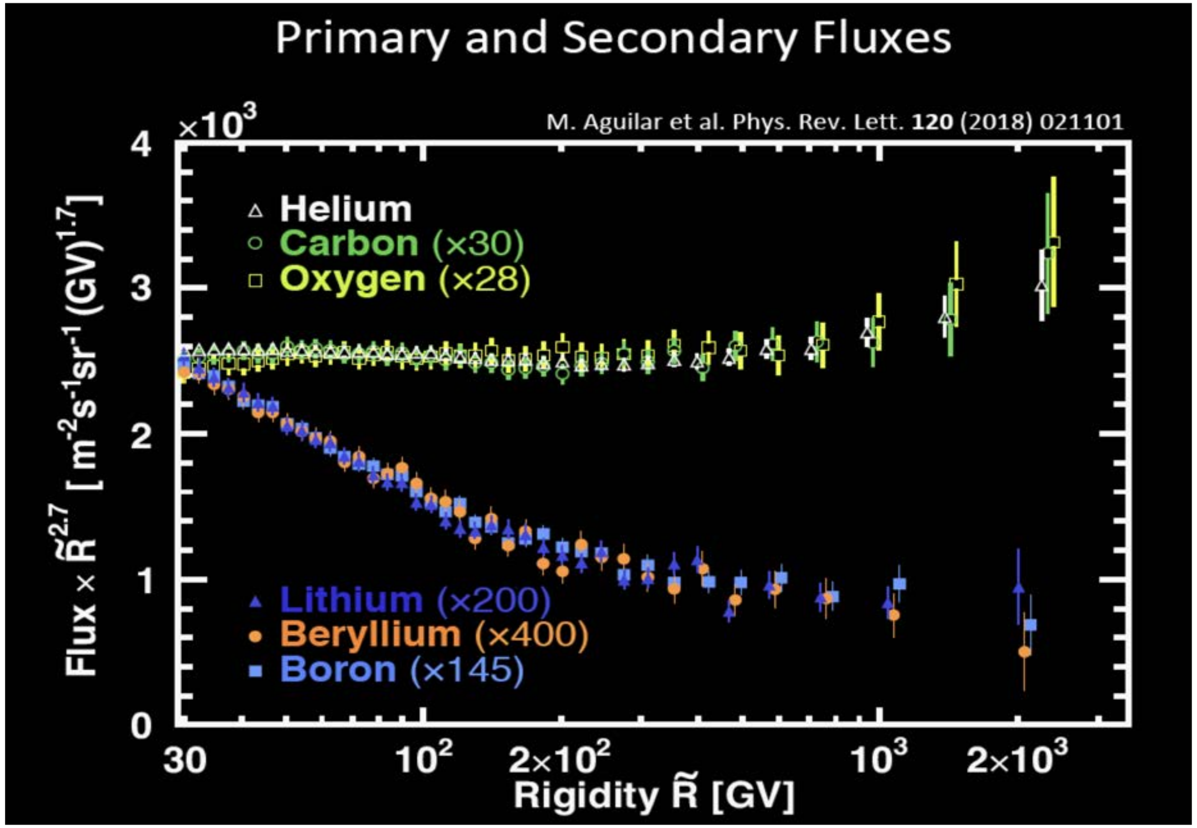
Secondary cosmic rays

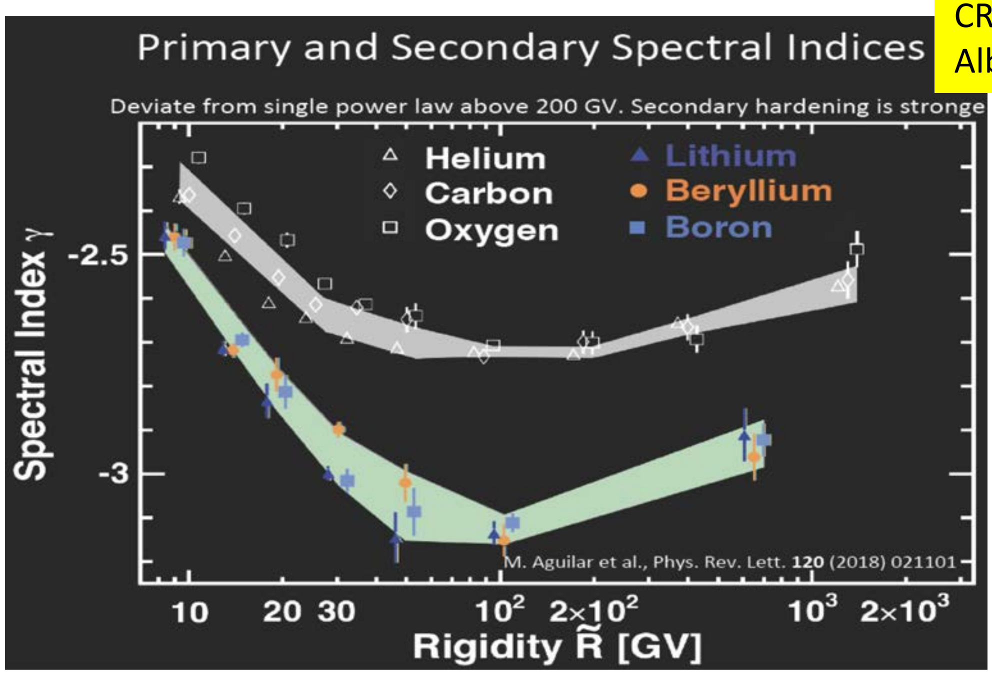
CR propagation

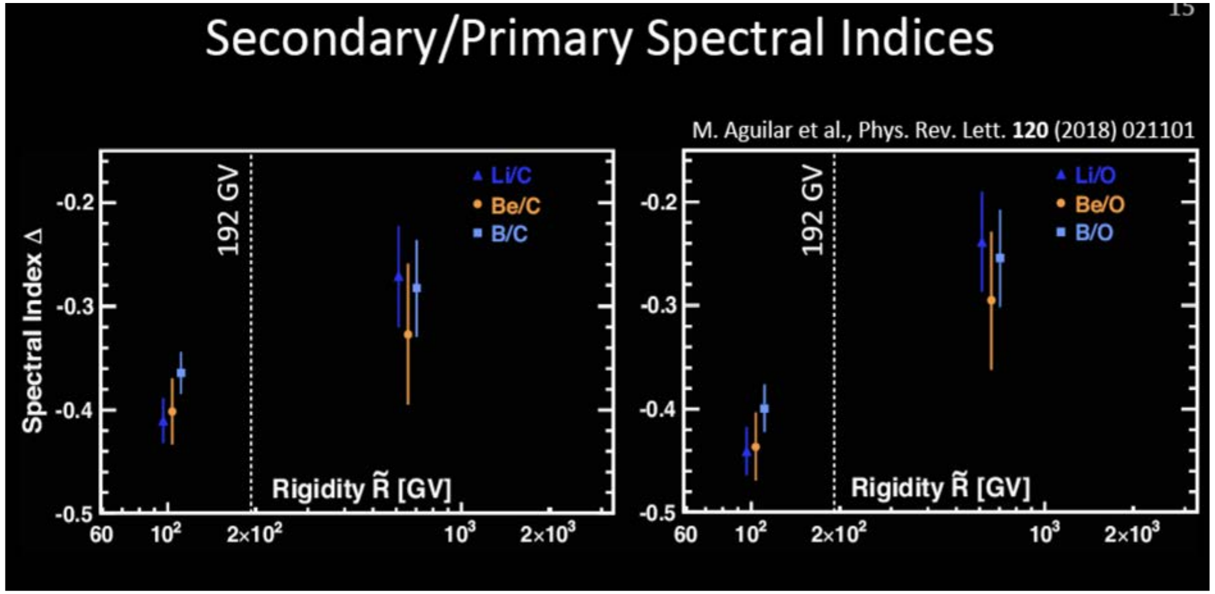


Li, Be, B with AMS-02

CRD6b:
Alberto Oliva



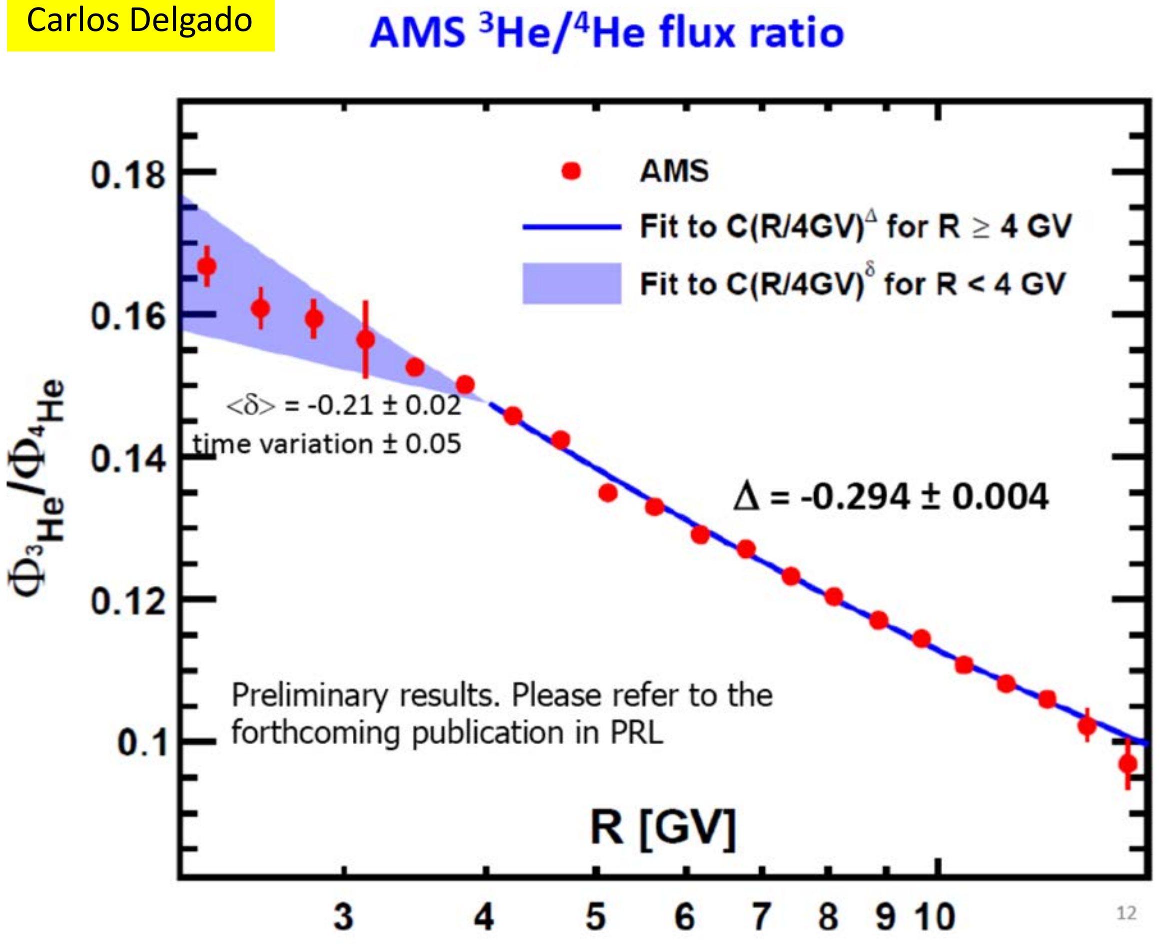




Important feature:
Secondary/primary ratios harden at 192 GV by $\Delta\gamma = 0.13$. The flux hardening seems to be a universal propagation effect.

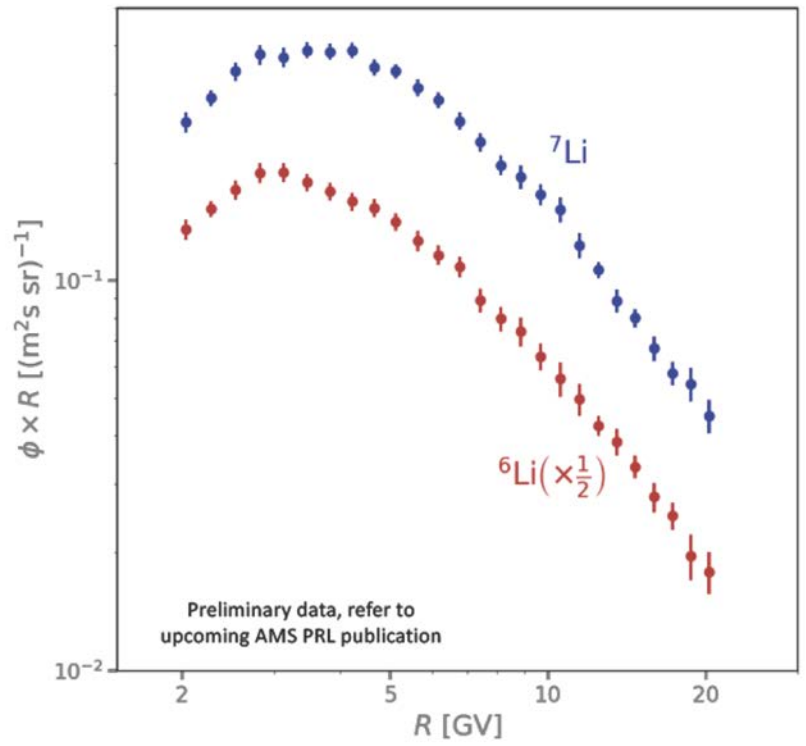
Isotopes with AMS-02

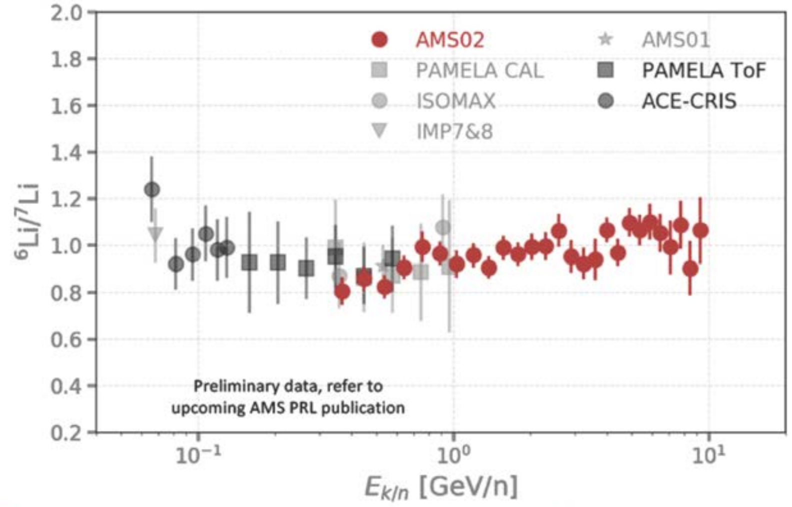
CRD6c:
Carlos Delgado



Important feature: single power-law

CRD6e:
Laurent Derome





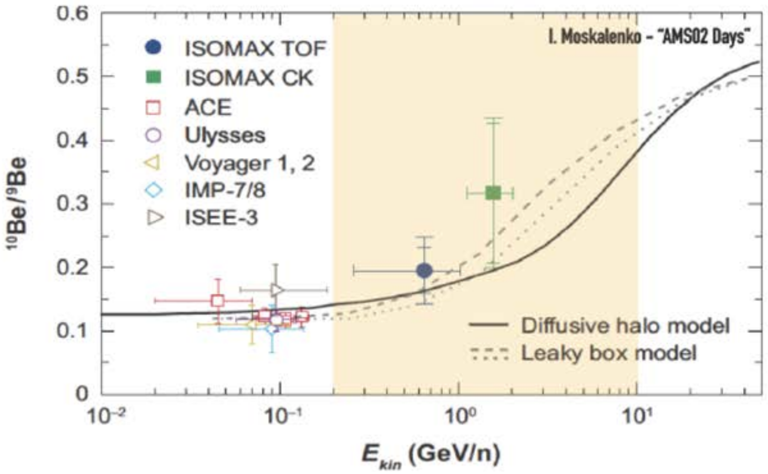
High Energy Light Isotope eXperiment HELIX

CRD6h:
Nahee Park

Propagation Clock Isotope, ^{10}Be

^{10}Be : Unstable isotope w/ known half life of 1.5×10^6 yr

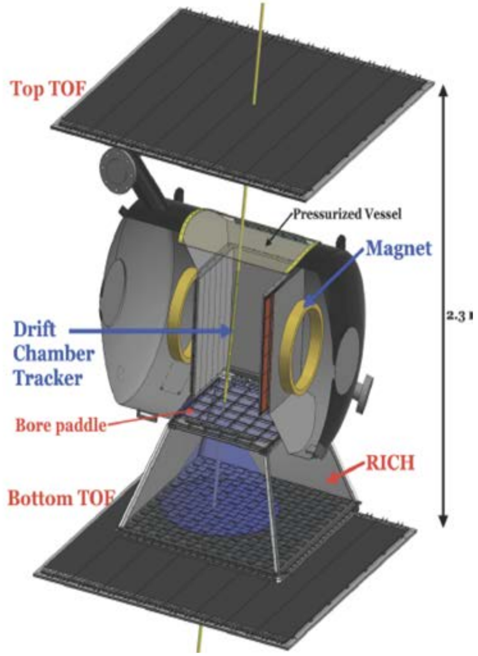
- $^{10}Be/^{9}Be$ ratio provides strong constraints for the propagation models
- Good model discriminating power around 3 GeV/nuc
- Challenging measurements
  - ☆ Several good measurements at a few hundred MeV/nuc. Above this, the ISOMAX balloon payload covers up to ~2 GeV/nuc



A new magnet spectrometer payload to measure $^{10}Be/^{9}Be$ isotope ratio up to 10 GeV/n

$$m = Ze\,R\,\frac{\sqrt{1-\beta^2}}{\beta}$$

- Two stage approach to cover wider range of energy
- Stage 1 : covers up to ~ 3 GeV/nuc, designed to have a flight in Antarctica with a long duration balloon in 2020
- Very challenging measurements
  - ☆ Mass resolution of few % up to 10 GeV/n
  - ☆ Readout within a very strong magnetic field (HEAT superconducting magnet, B field at the center ~ 1 T)
  - ☆ All SiPM readout needs good thermal design
  - ☆ Total ~ 26k channels for full configuration

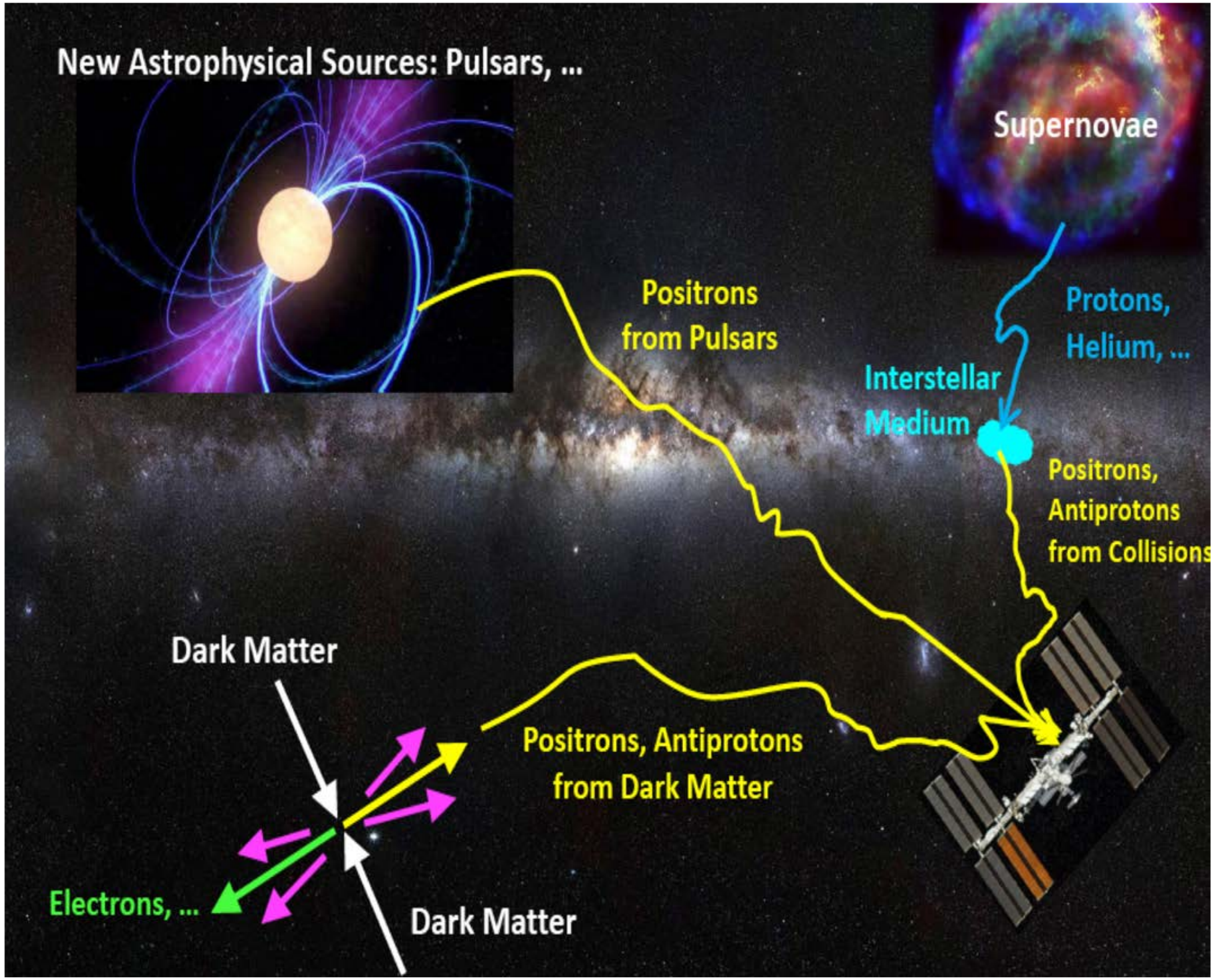


HELIX is moving forward to be ready for integration test in 2019, and an Antarctica flight in 2020!

Antimatter
(antiprotons & antideuterons)

CR propagation

New sources



Antiprotons in AMS-02

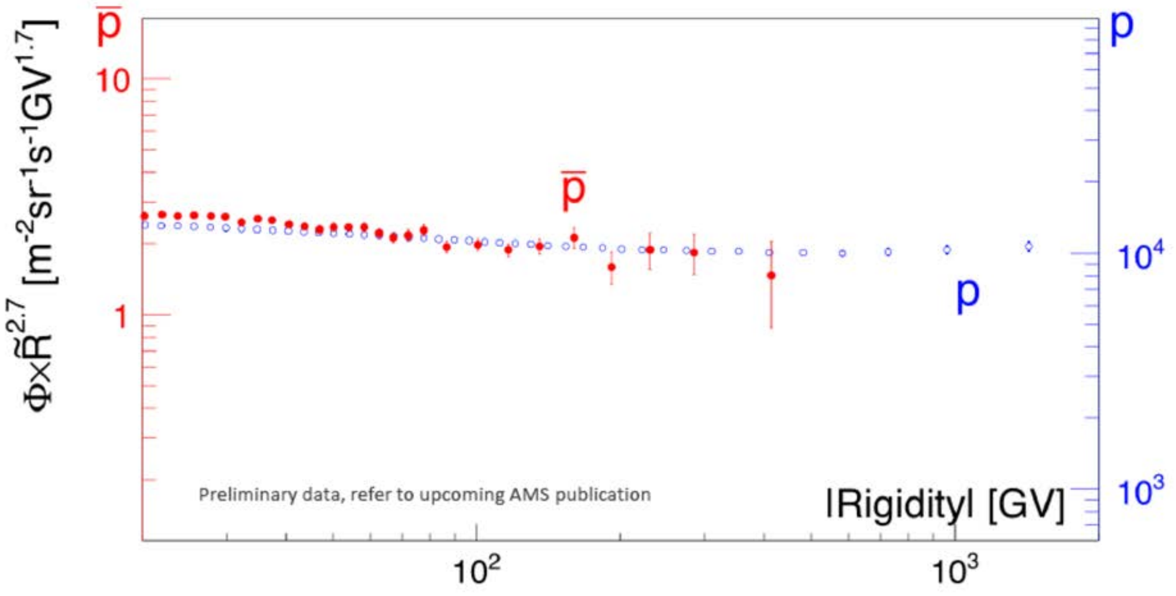
Important feature:

Antip/p flat for R>60 GeV

The Spectra of Protons and Antiprotons

If p̄ are secondaries produced in ISM, their rigidity dependence should be different than p:

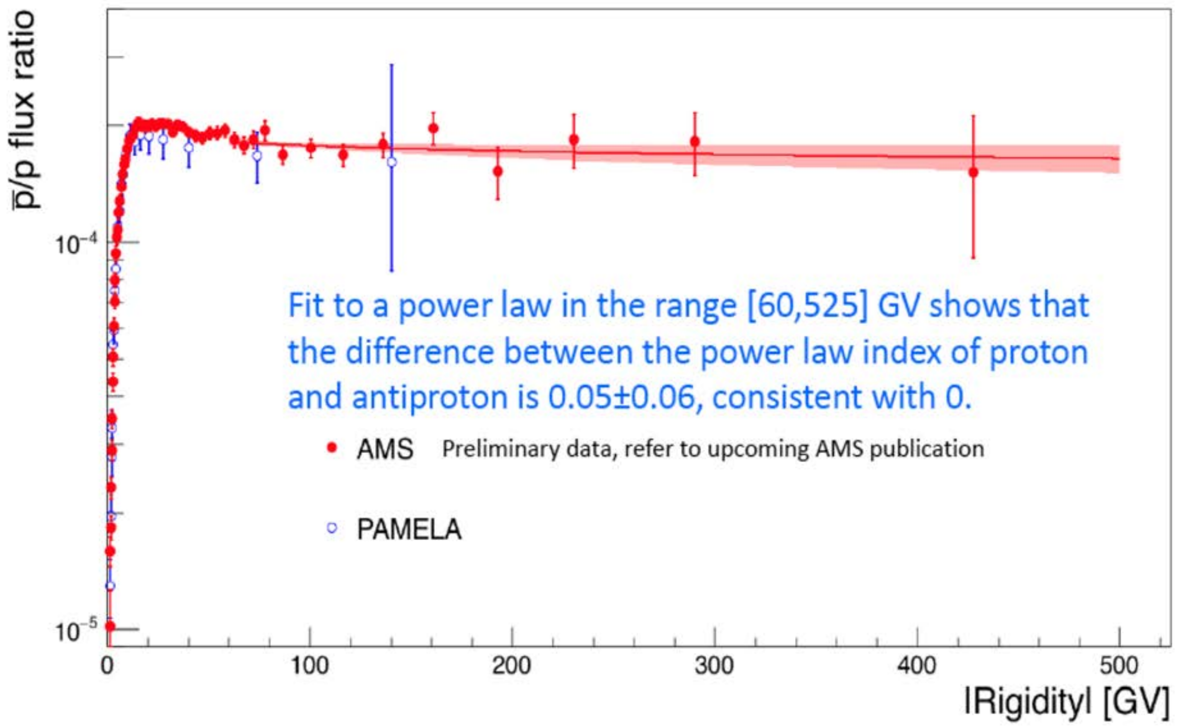
p + ISM → p̄ + ...



AMS observed for the first time that above 60 GeV, p and p̄ have identical behavior

Antiproton-to-Proton Flux Ratio

Show no rigidity dependence above 60GV



Flux from 1 to 450 GV

Partially extended wrt PRL 117, 091103 (2016)

CRD1a: Cheng Zhang
H9: Bruna Bertucci

Bess-Polar I and II

CRD1d:
Kenichi Sakai

The BESS Project

2 BESS-Polar I and II experiment

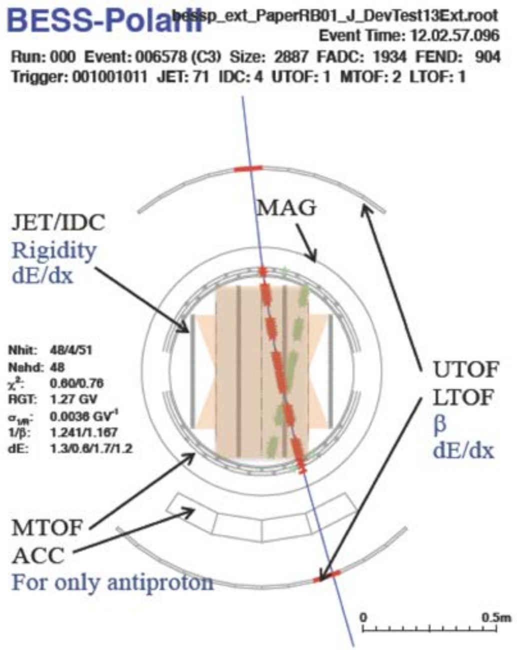
BESS-Polar I & II flights were carried out over Antarctica.

BESS-Polar I (green),
BESS-Polar II (1st :blue, 2nd :red)

	BESS-Polar I	BESS-Polar II
Launch date	Dec. 13th ,2004	Dec. 23rd , 2007
Observation time	8.5 days	24.5 days
Cosmic-ray observed	9 x 10^8 events	4.7 x 10^9 events
Flight altitude	37~39km (5~4g/cm²)	~36km (6~5g/cm²)

The BESS Project

3 BESS spectrometer



Event display with reconstructed proton track is shown.

Rigidity (MDR:200GV)

Solenoid: Uniform field (ϕ=0.9m, B=0.8T)
Thin material (2.4 g/cm²/wall)

Drift chamber: Redundant hits
(σ~150μm, 32~48+4hits)

Charge, Velocity

TOF, Chamber: dE/dx measurement
(Z = 1, 2, ...)

TOF: 1/β measurement (σ~1,2%)

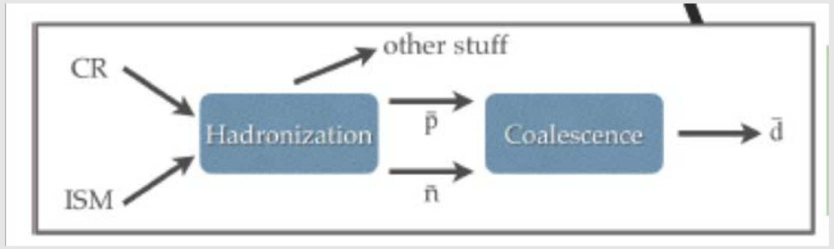
$$m = ZeR\sqrt{1/\beta^2 - 1}$$

Antideuteron searches with BESS-Polar II

CRD1d:
Kenichi Sakai

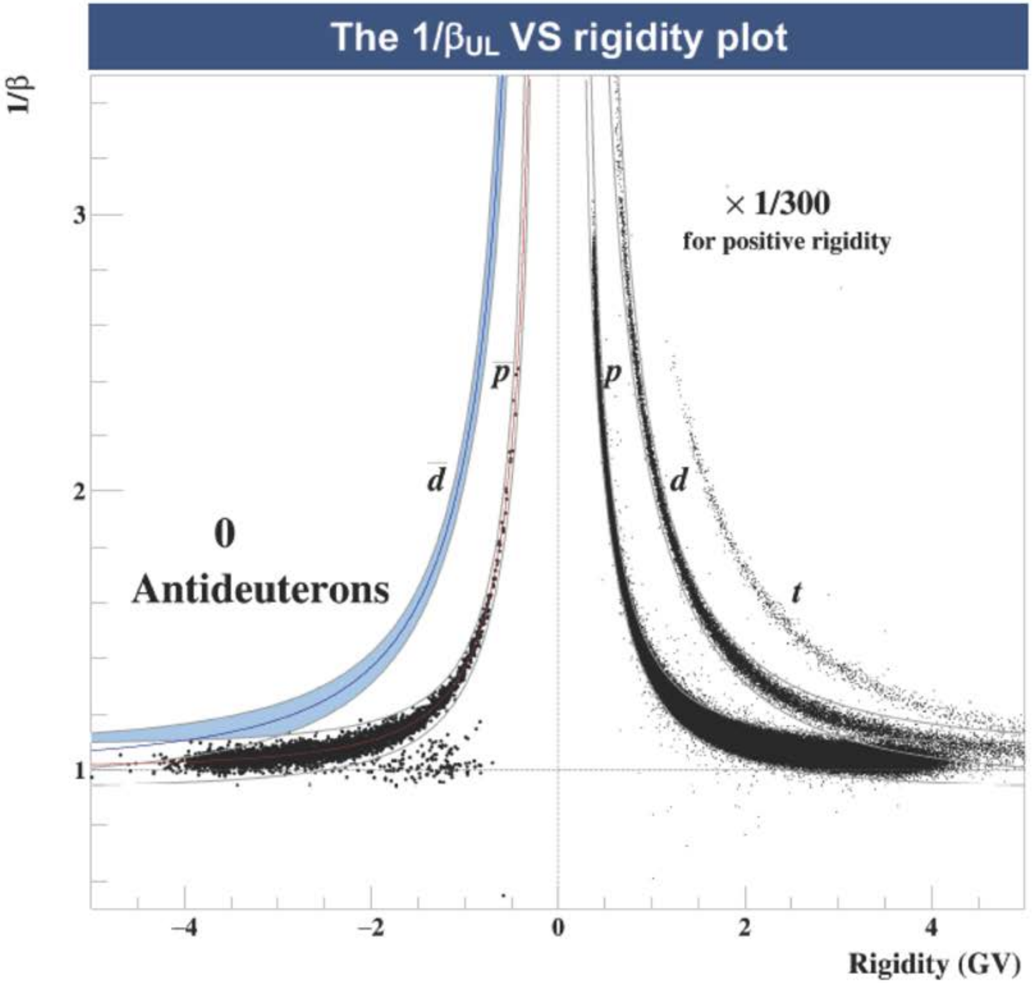
Why antideuterons ?

High Signal-to-Background ratio = good channel for search.



Low energy antinuclei are hard to produce due to kinematic effects

The $1/\beta_{UL}$ VS rigidity plot



The $1/\beta_{UL}$ VS rigidity plot and antideuteron's selection band.

- Signal region for antideuteron

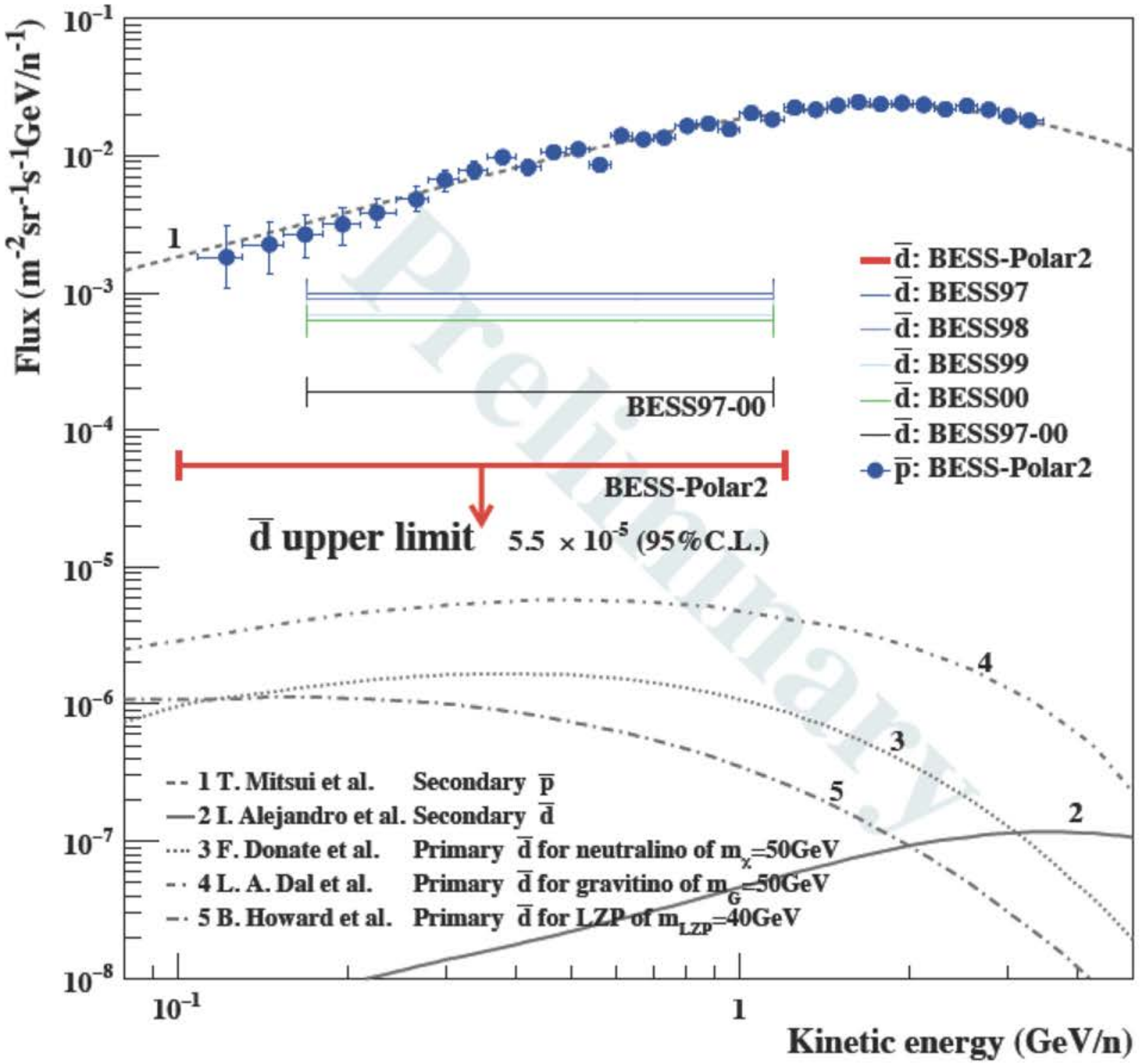
  Excluding 3.5σ region from antiproton center to prevent antiproton contamination

- No antideuteron candidate in BESS-Polar II data

11 Upperlimit of Antideuteron flux

$$\Phi_{\bar{d}}\, dE = \frac{N_{obs}}{S\Omega \cdot T_{live}} \frac{1}{\varepsilon_{single} \cdot \varepsilon_{Q-ID}} \frac{1}{\eta} \frac{1}{(1-\delta_{sys})}$$

CRD1d: Kenichi Sakai



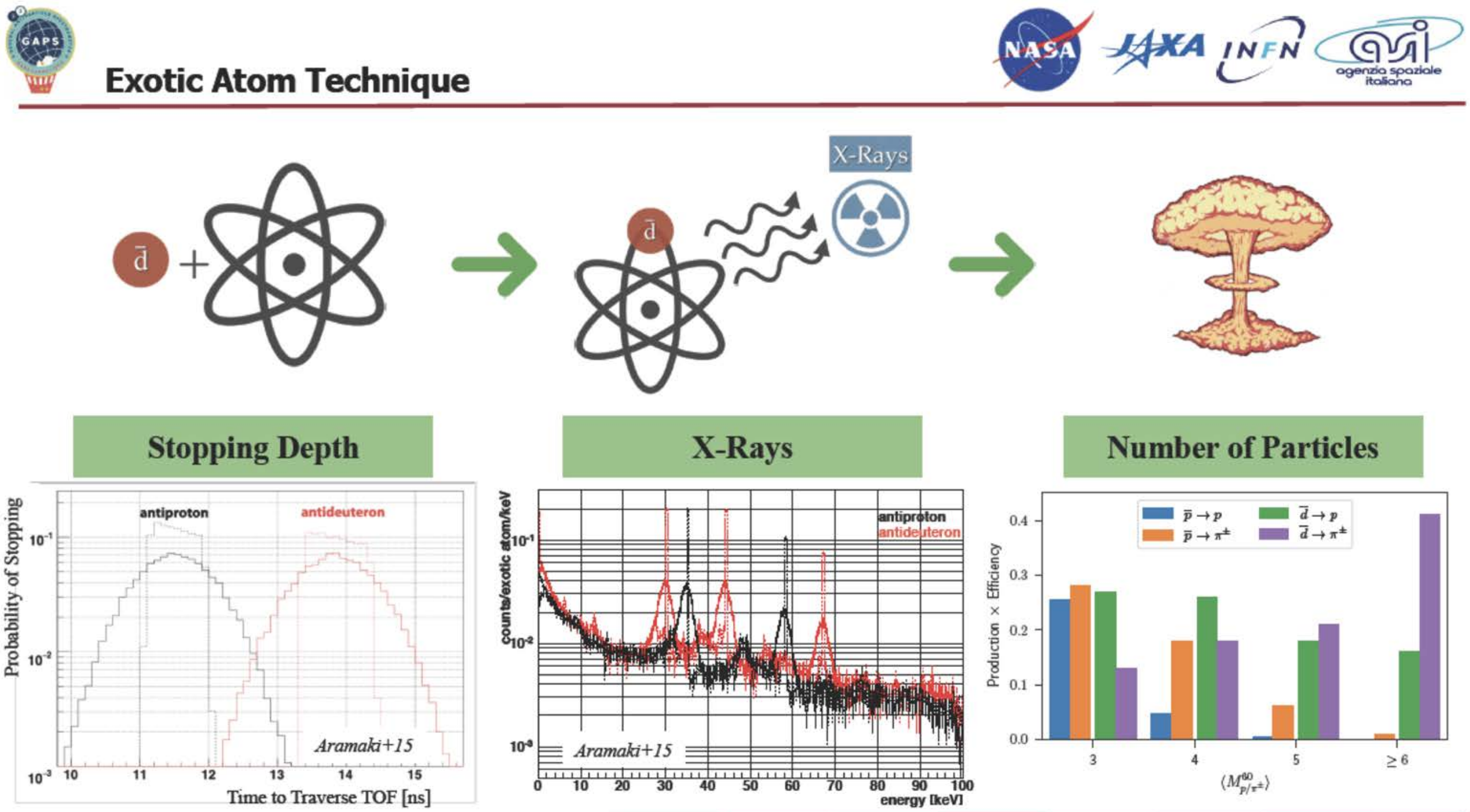
Upper limit on antideuteron flux measured by BESS-Polar II together with earlier published BESS97-00 antideuteron upper limit

$J(d) < 5.5 \times 10^{-5}$ $(m^2 sr\ sec\ GeV/n)^{-1}$ (95%C.L.)

- Compared with the data taken in the solar minimum (BESS97), order of magnitude improvement has been achieved.

Antideuterons and antiprotons with GAPS

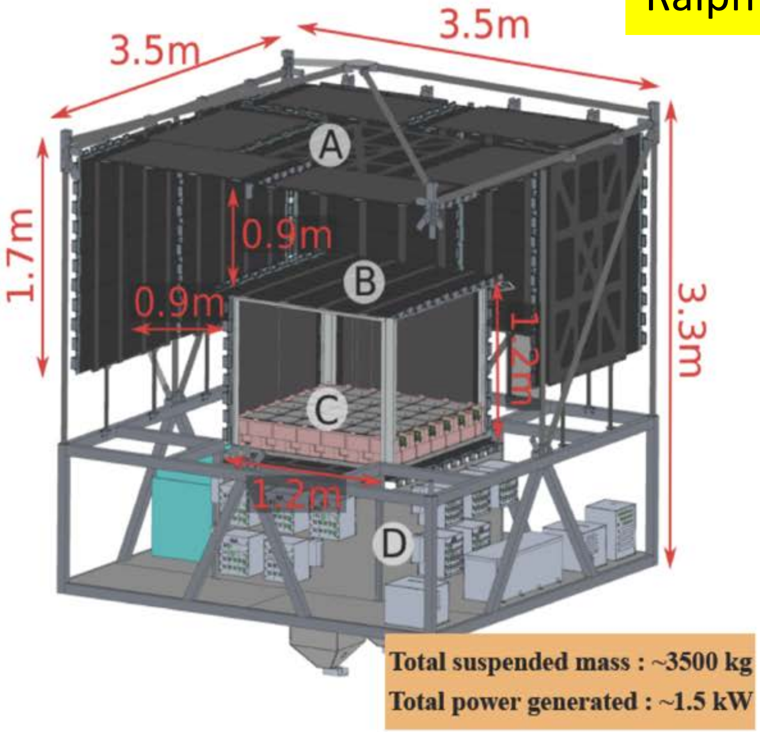
CRD1f:
Ralph Bird



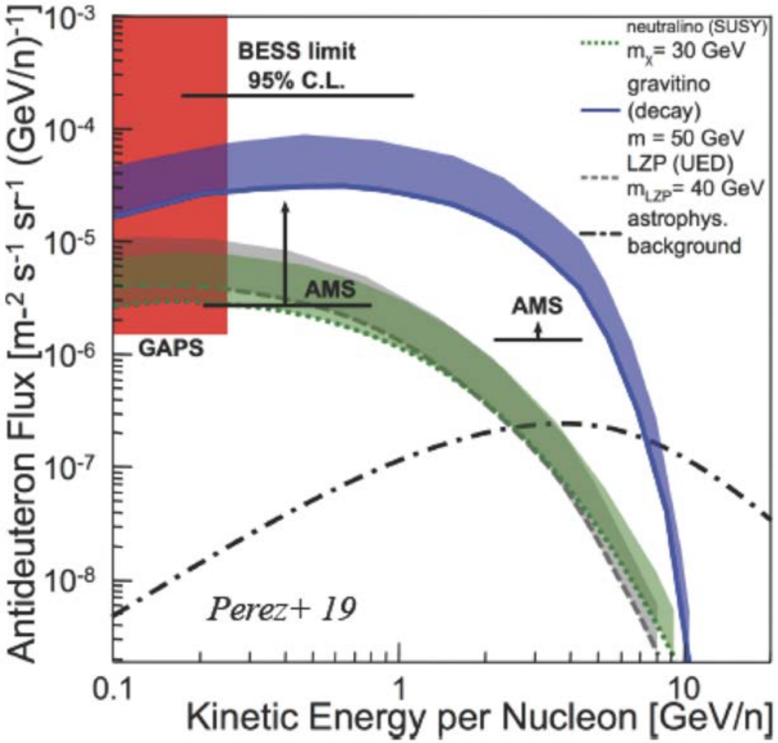
GAPS Detector – Overview

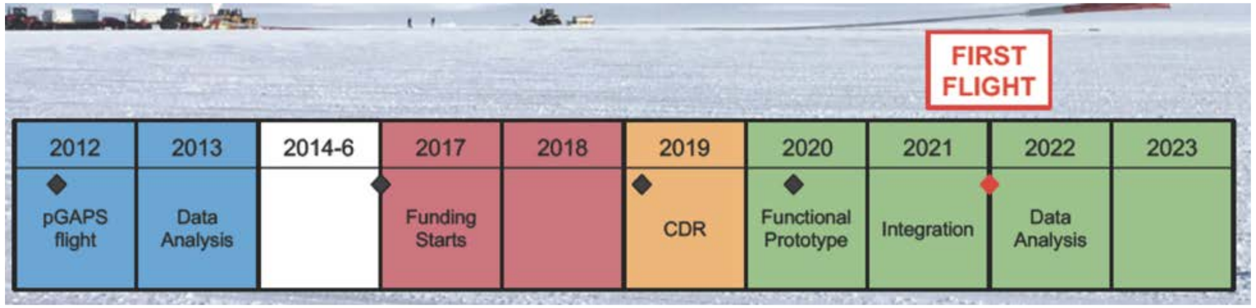
CRD1f: Ralph Bird

- The detector consists of 2 instruments.
  - Si(Li) Tracker (C):
    - 1440 10 cm-diameter Si(Li) detectors over 10 layers.
    - Stops primary, detects X-rays, tracks secondaries
  - Time-Of-Flight (A, B):
    - Two layers of plastic scintillator paddles providing near 100% coverage.
    - Characterizes primary, counts secondaries, provides trigger
- In addition:
  - Cooling, power & thermal insulation (not shown)
  - Support systems (D)



Three flights – The most sensitive low energy antideuteron search.





AMS-02 antiproton data

CRD1b:
Mathieu Boudaud

Prediction (not a fit) of the secondary antiprotons flux from the state of the art:

- Data (AMS-02)
  - CR fluxes: H, He, C, O *PRL 114 171103 (2015), PRL 119 251101 (2017)*
  - CR ratio: B/C *PRL 117 231102 (2016)*
- Models USINE code
  - CR transport in the Galaxy *Derome+(2019), Génolini+(2019)*
  - antiprotons production cross sections (XS) *Winkler(2016), Korsmeier+(2018)*

Statistical test

χ^2/dof	p-value (χ^2-test)	p-value (KS-test)
0.77	0.90	0.27

Good agreement between data and model

$\Longrightarrow$ **AMS-02 data are consistent with 'standard' secondary antiprotons**

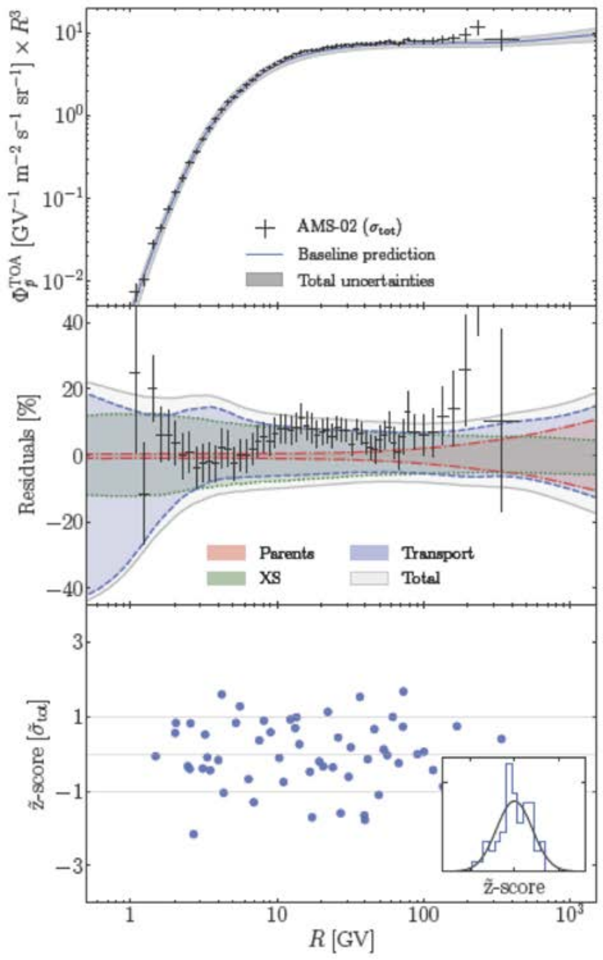
Secondary antiprotons prediction

$\Longrightarrow$ **prediction of the antiprotons flux (not a fit)**

Is there an excess?

☑ model uncertainties

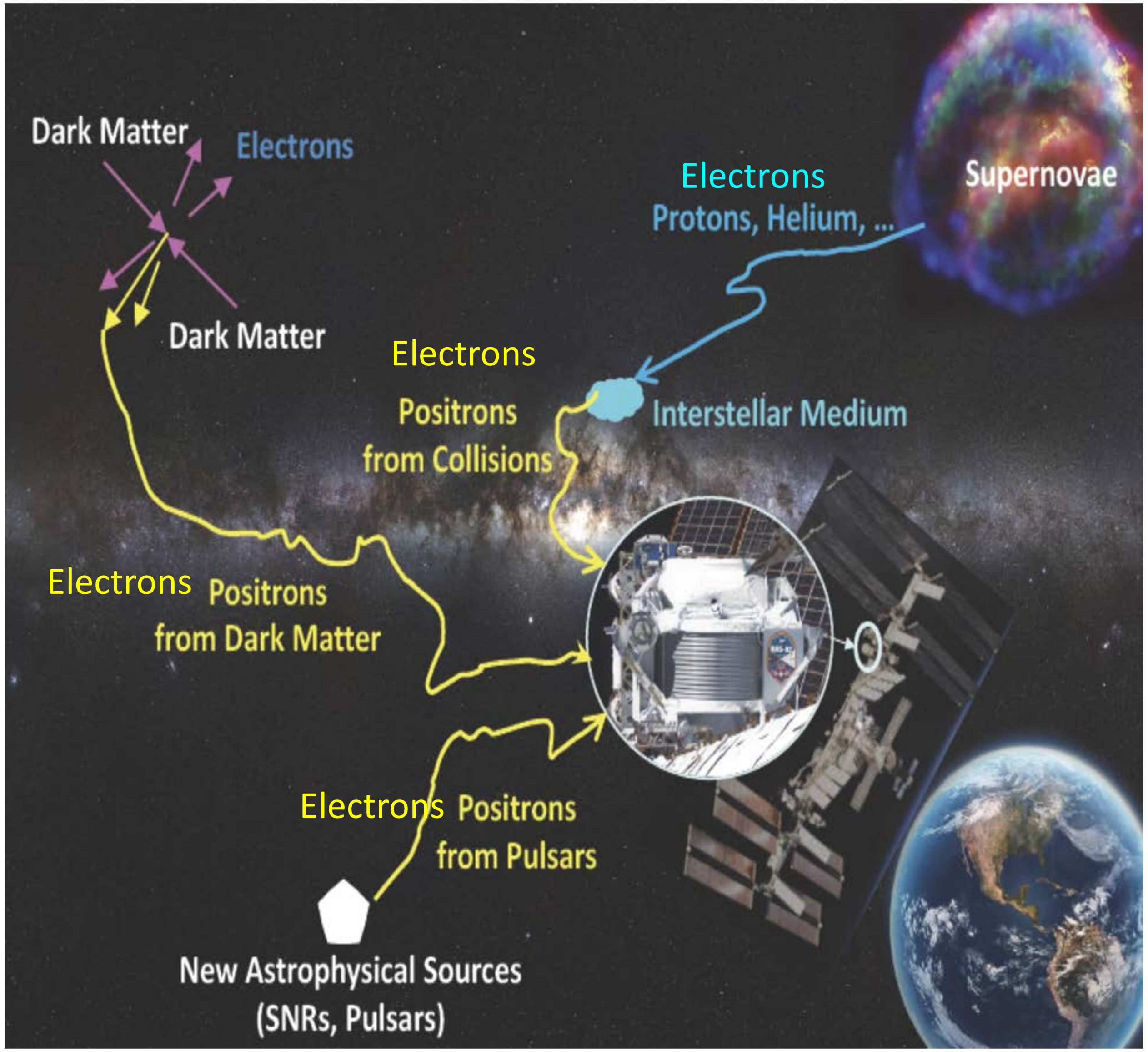
☑ correlation in AMS-02 data



Electrons and positrons

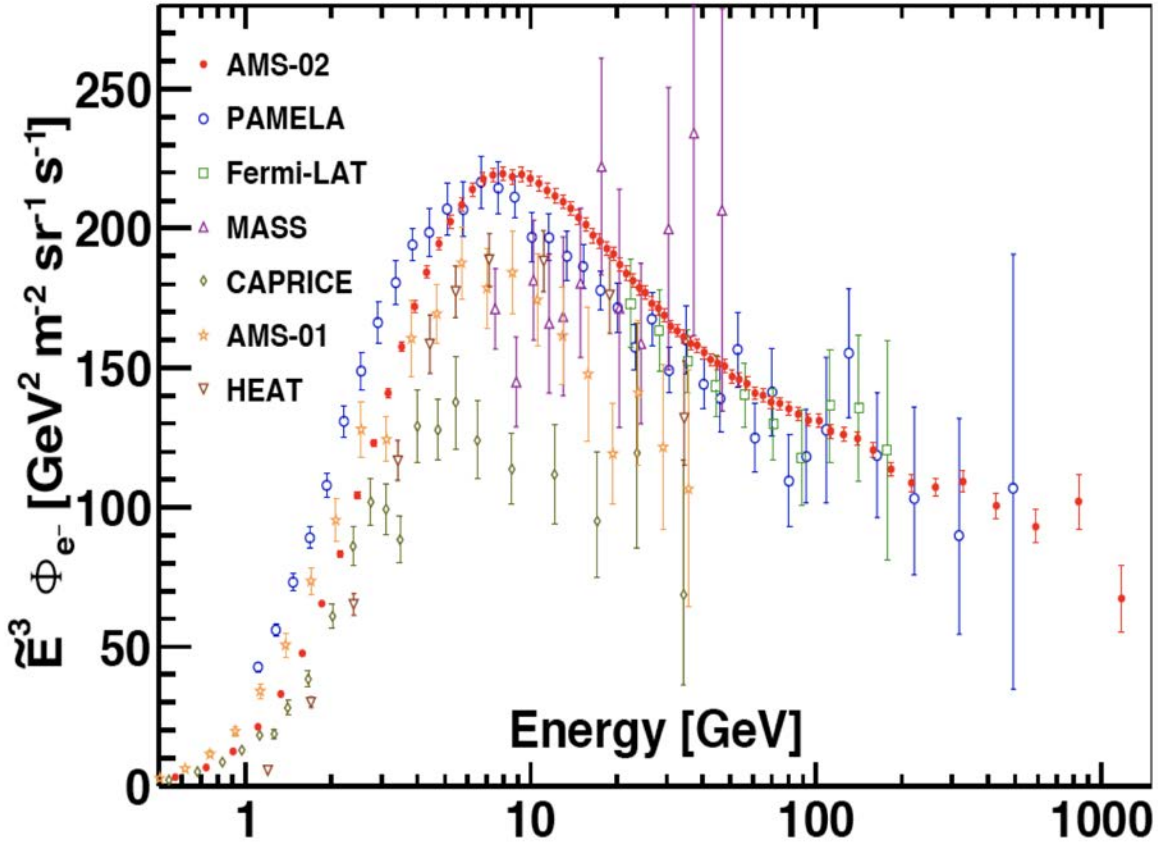
CR acceleration
CR propagation

New sources



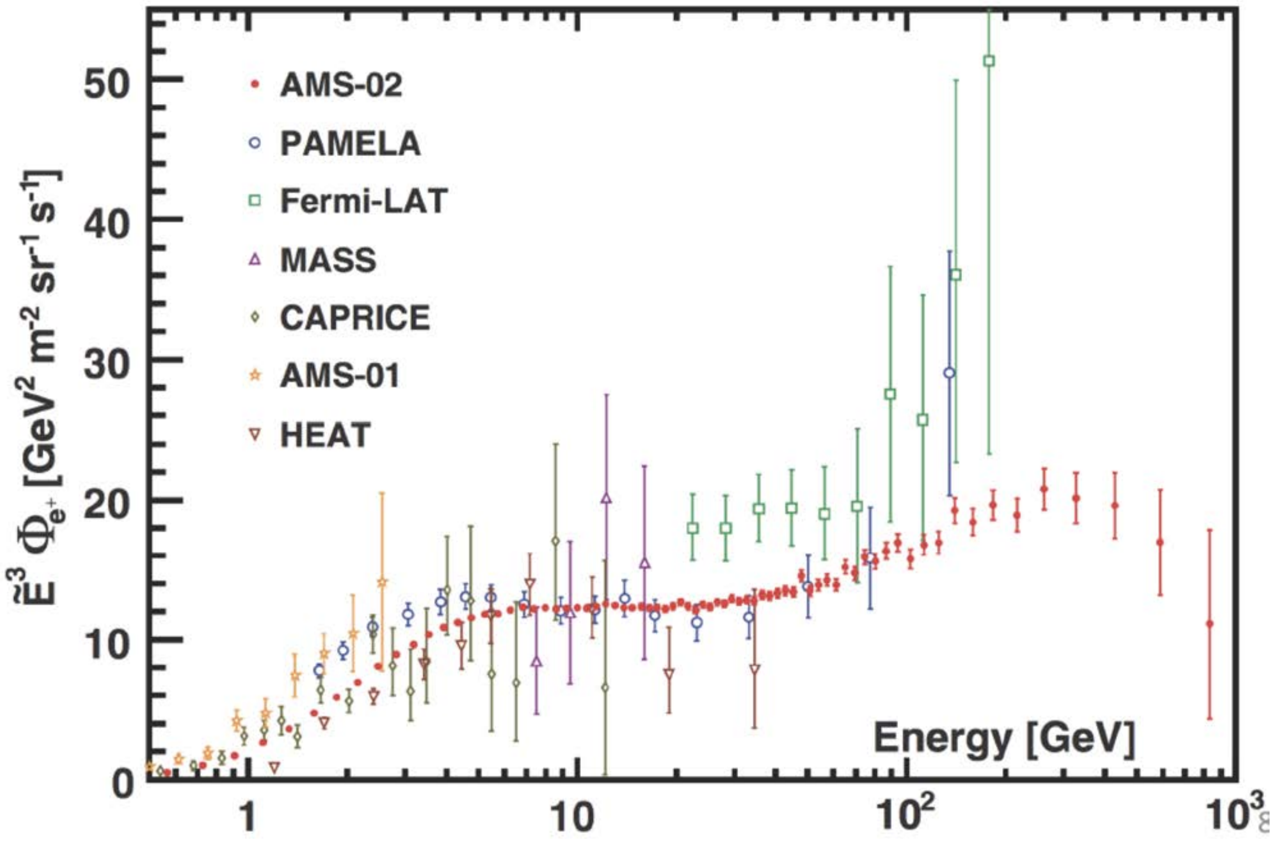
Electrons and positrons with AMS-02

Electron flux x E^3



CRD2b: Weiwei Xu
H9: Bruna Bertucci

Positron flux x E^3

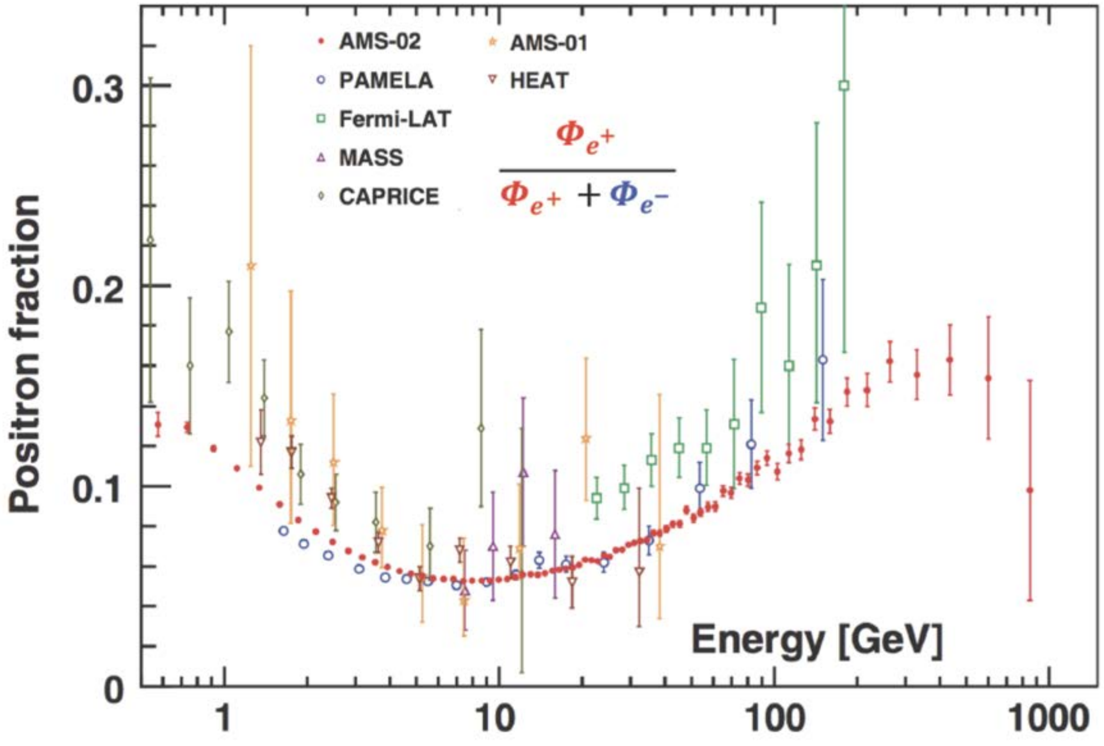


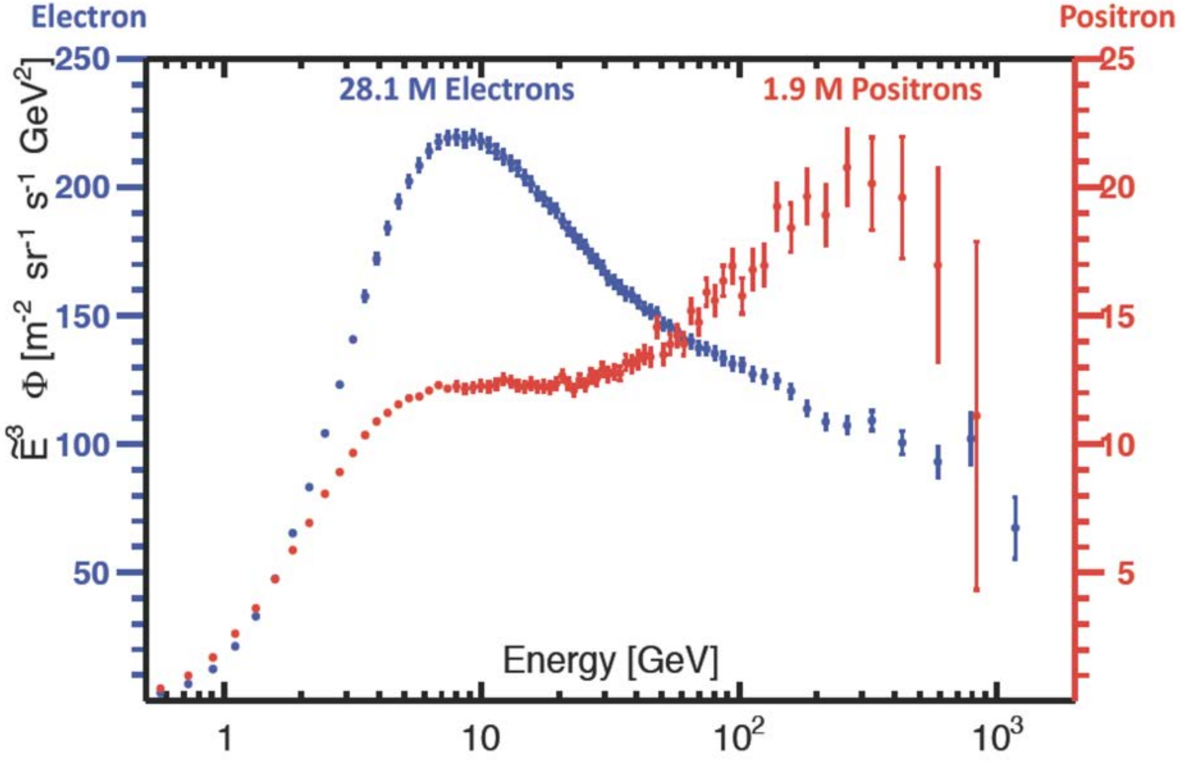
Phys. Rev. Lett. **122**, 041102 (2019)

CRD2h: Zuhao Weng
H9: Bruna Bertucci

Positron fraction

CRD2h: Zuhao Weng
H9: Bruna Bertucci

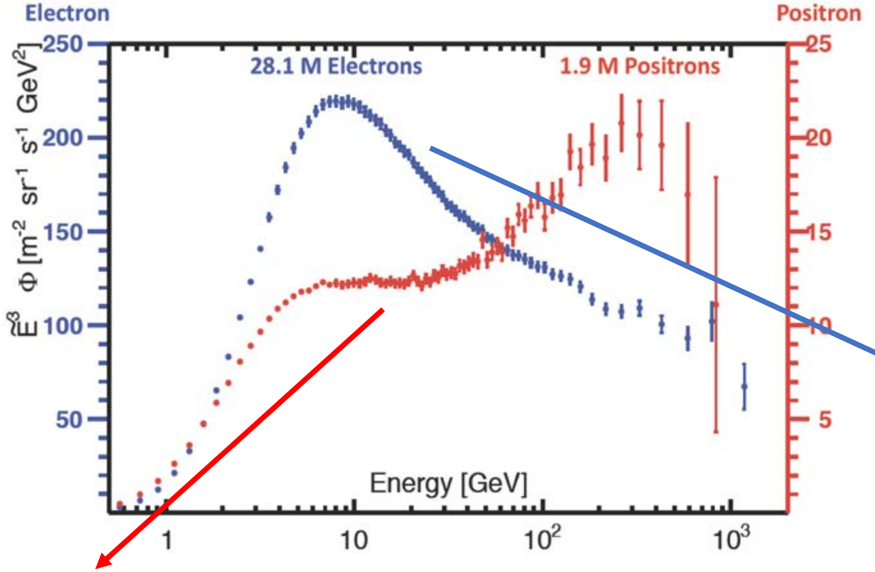




CRD2b: Weiwei Xu
H9: Bruna Bertucci

Positron and electron fluxes overimposed

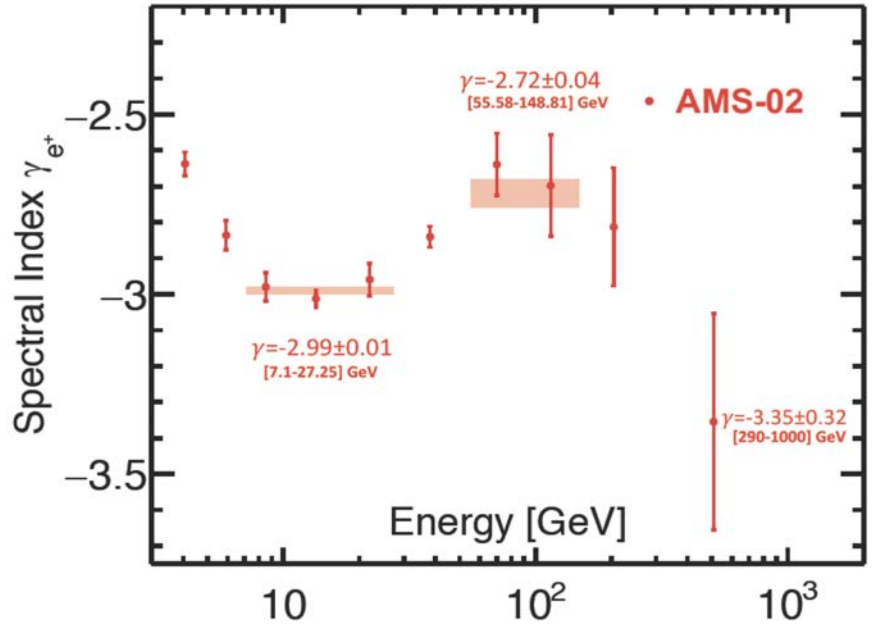
Spectral indexes



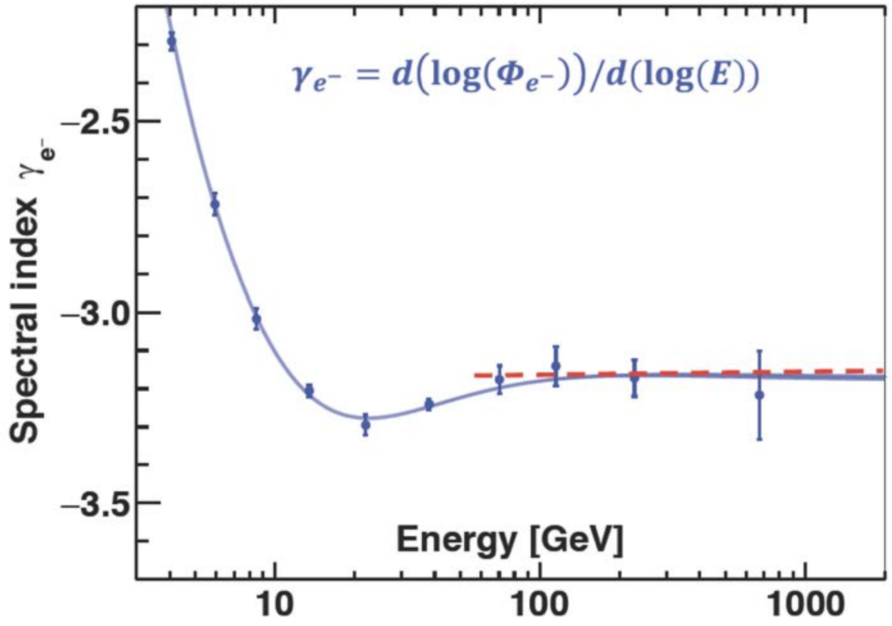
Important feature:

- New source of positrons (Pulsars, SNRs, DM)?
- Review of SND paradigm?

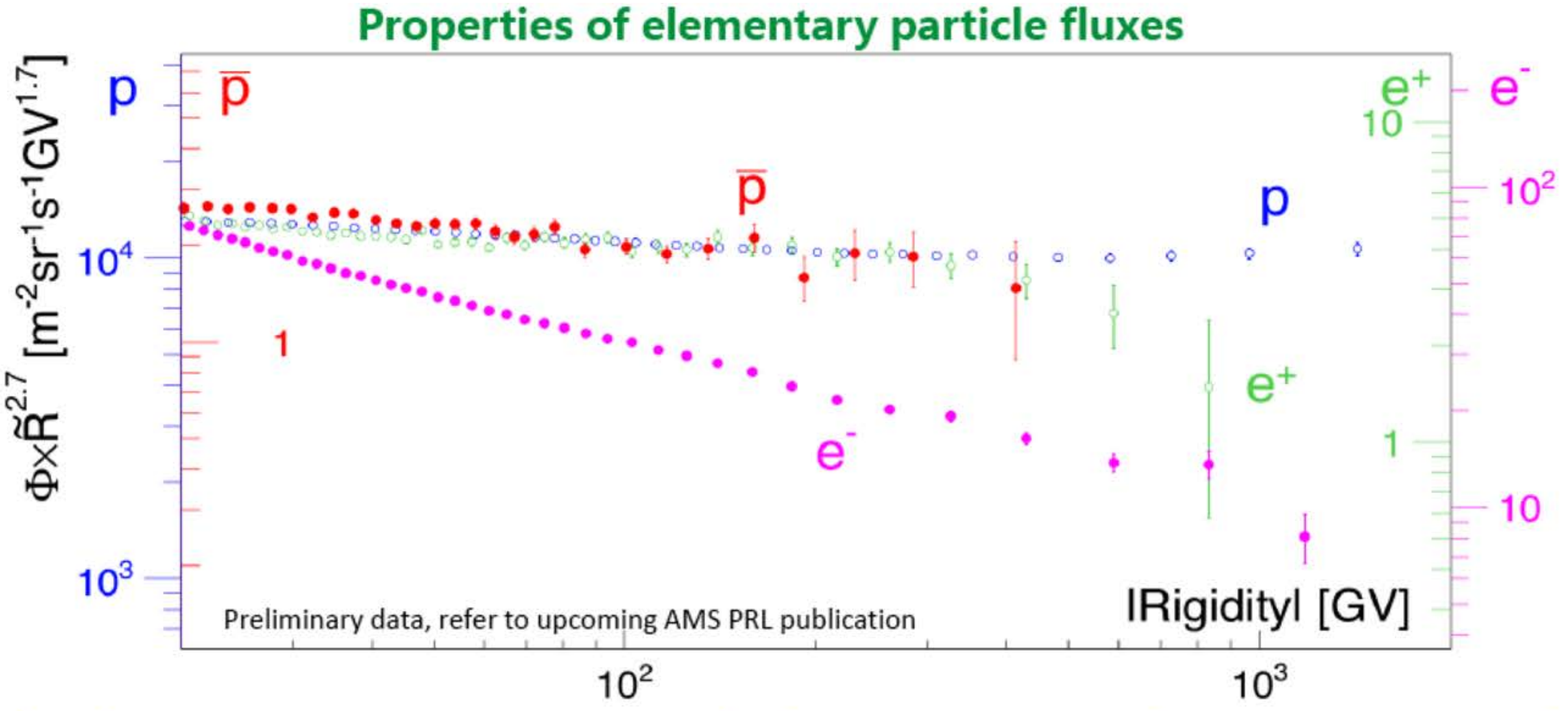
Positron flux spectral index $\gamma = d[\log(\Phi_{e^+})]/d[\log(E)]$ exhibits complex energy dependence



The spectral index of electron flux



Electron/positrons/protons/antiprotons by AMS-02

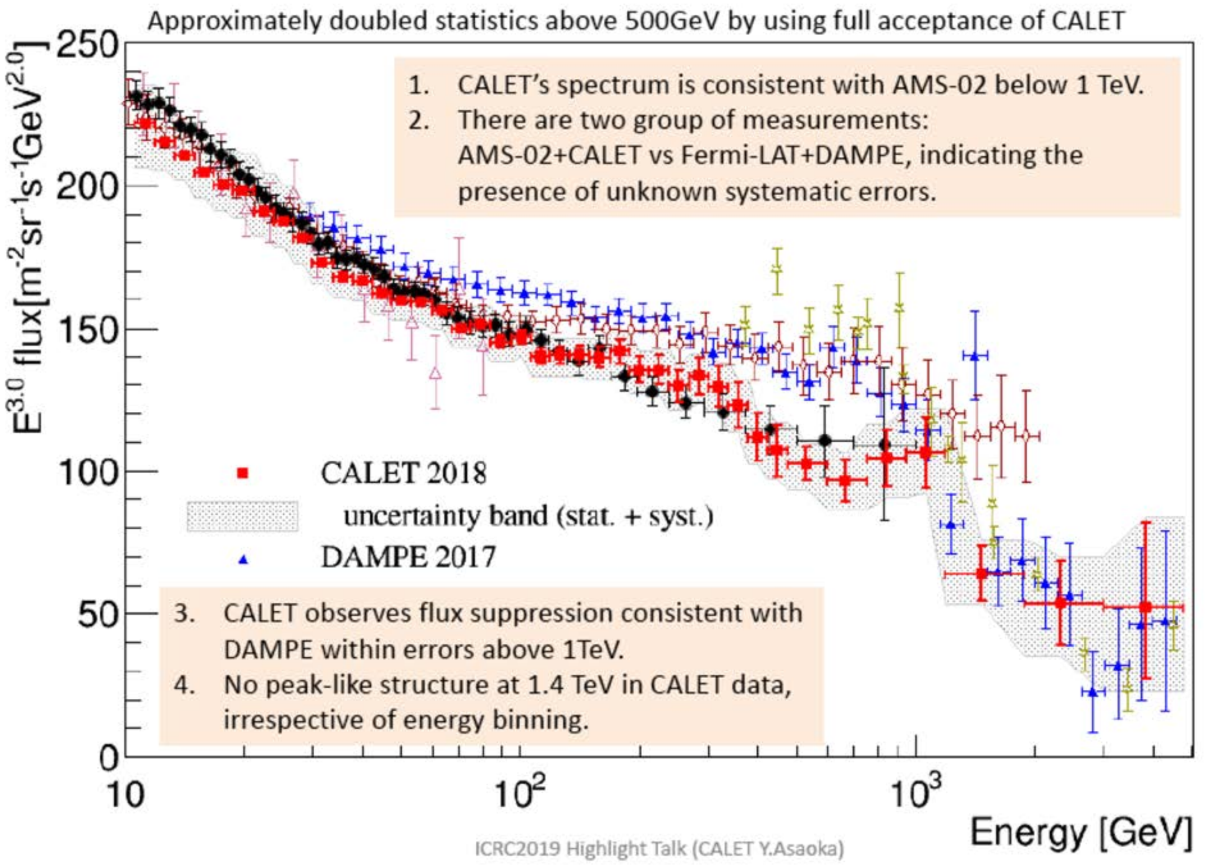


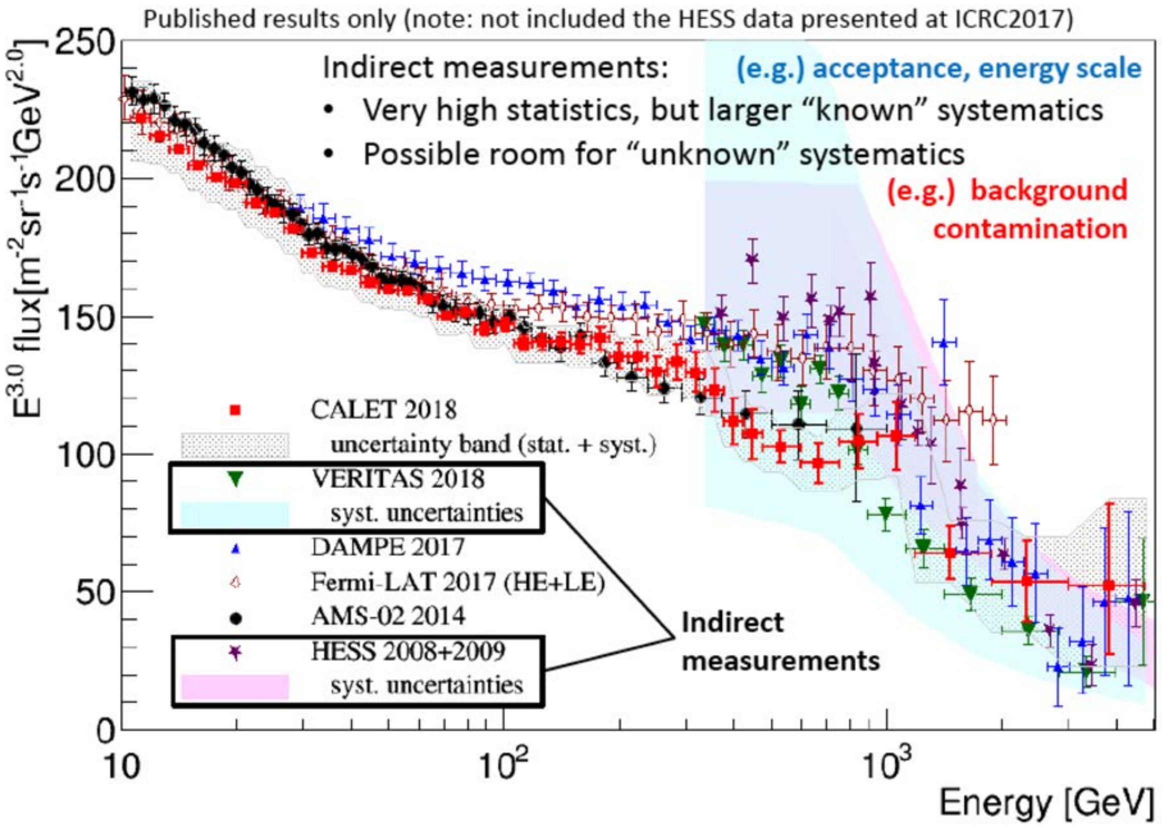
Important feature:
- Primaries and secondaries same spectral behavior?

1. The latest AMS measurement of elementary particles are presented.
2. The spectra of positrons, antiprotons, and protons are nearly identical in a large energy range and positron show drop-off at ~280GV.
3. Electron spectrum decrease faster than other three species.

CRD2c:
Shoji Torii

Electrons + positrons with CALET

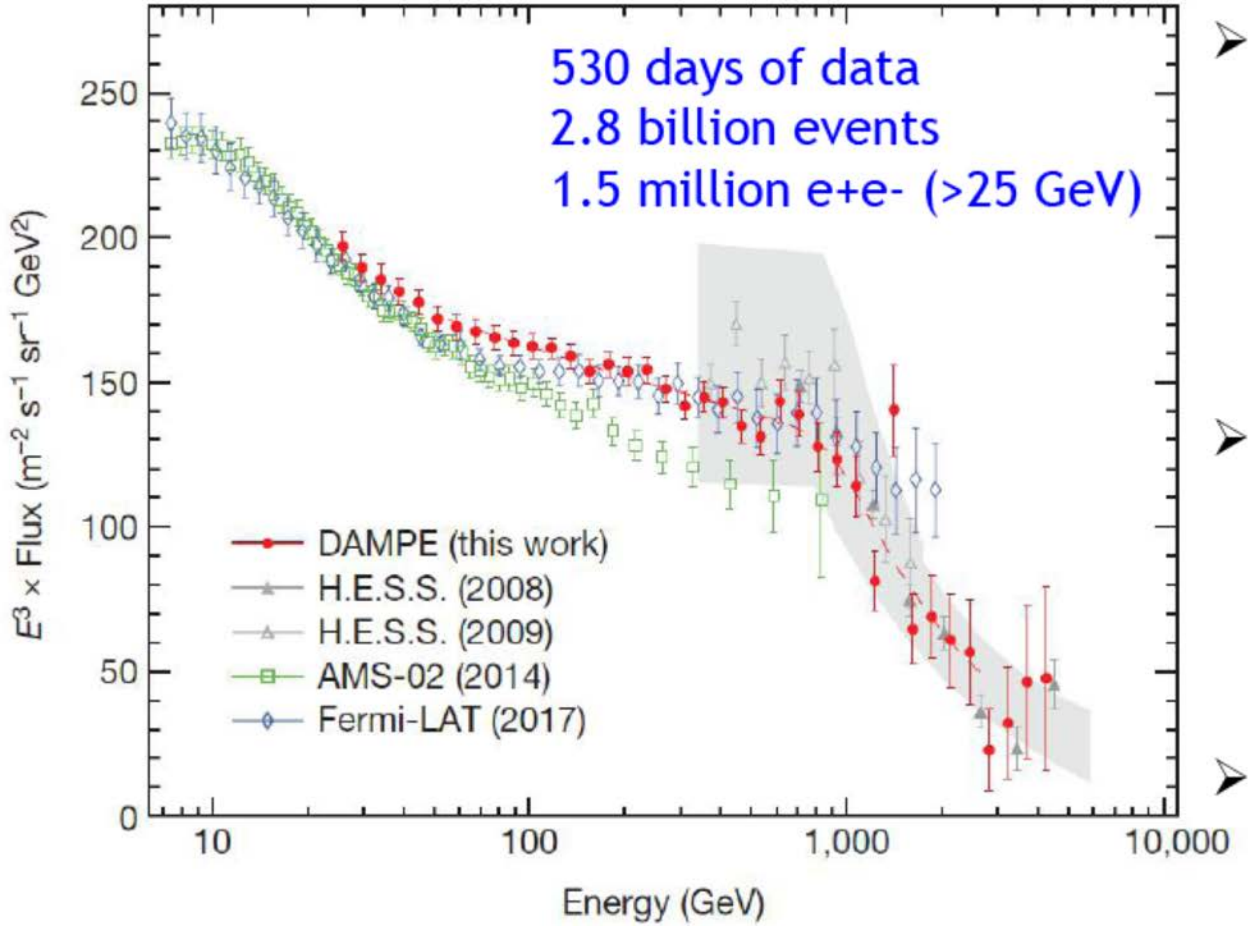




Confirmed electron flux suppression seen by grd exps at E > 1 TeV
Some tension between data (energy scale)?

H16:
Qiang Yuan

Electrons + positrons with DAMPE



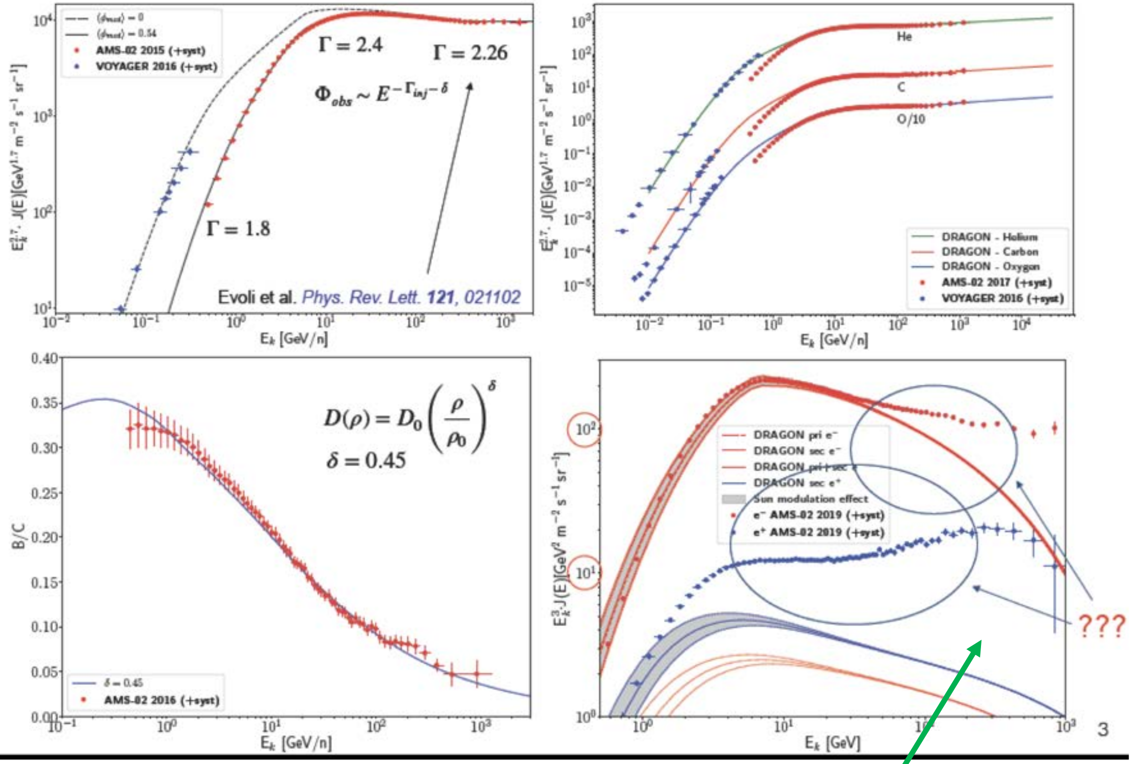
- Three different PID methods give very consistent results on event-by-event level
- Direct detection of a spectral break at ~1 TeV with 6.6σ confidence level
- Analysis with new data is on-going

Confirmed electron flux suppression seen by grd exps at E > 1 TeV
Some tension between data (energy scale)?

Lepton data and nearby cosmic accelerators

CRD1c:
Ottavio Fornieri

DRAGON **output: our best fit**

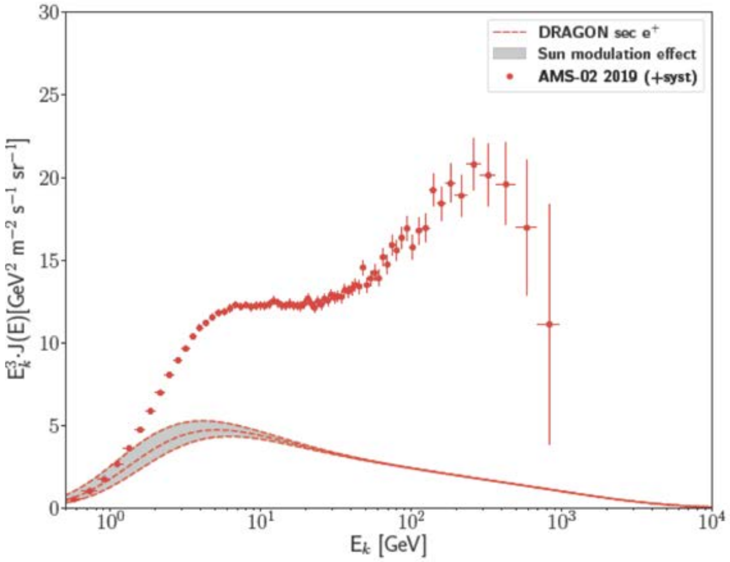


Two main features:
Positron and electrons
«excess»
not reproduced

Positron origin

$$p + X/\gamma \rightarrow \pi_0^{\pm} + Y$$
$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}$$
$$\mu^{\pm} \rightarrow e^{\pm} + \bar{\nu}_e$$

Secondary production ruled by the protons' and nuclei's flux



- The propagation paradigm has to be changed?
  (P.Lipari - *Phys. Rev. D* **99**, *043005*)
- Additional source(s) for primary positrons? (antimatter factories)

Pulsars?

Rotating neutron stars with large B-field:

Magnetic-dipole emission?

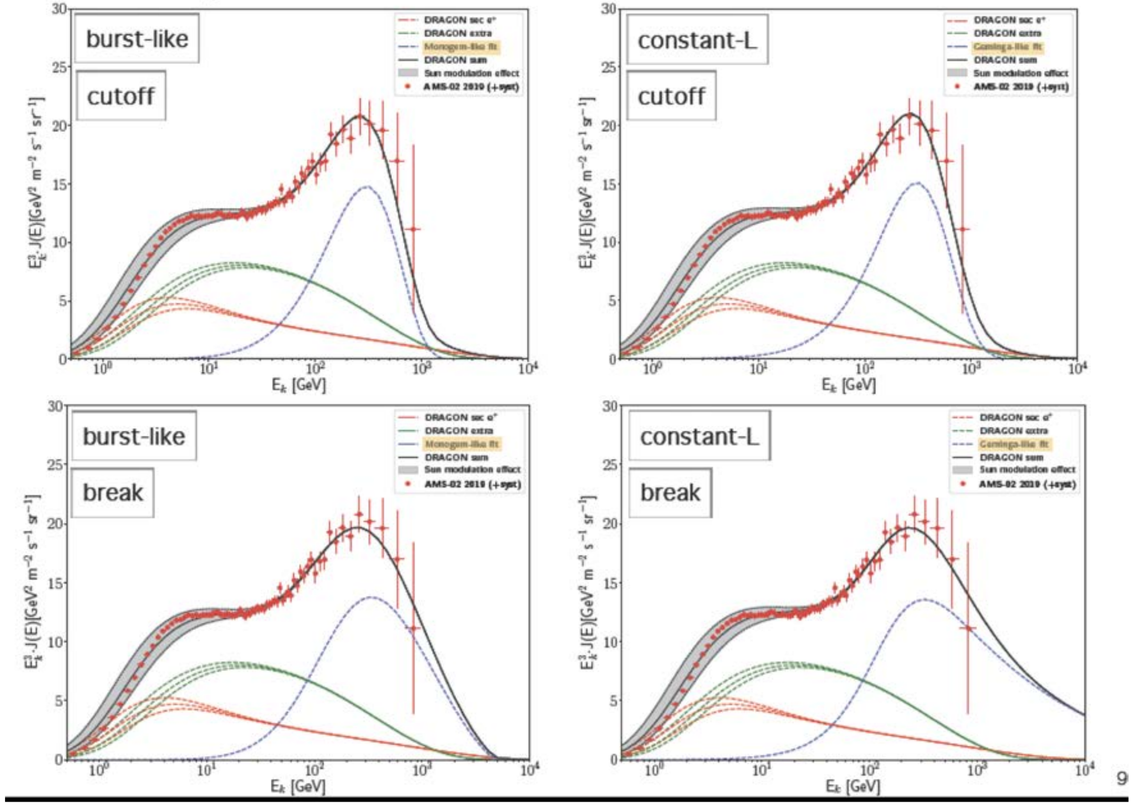
4

CRD1c:
Ottavio Fornieri

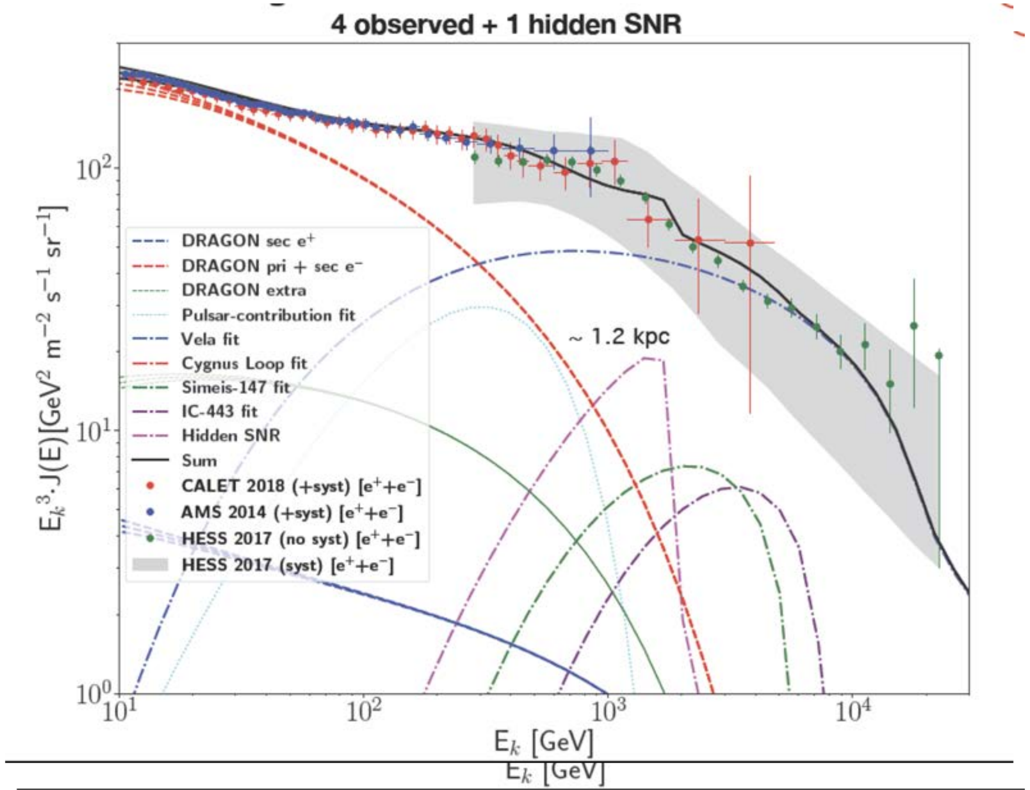
Low-energy spectrum ($E \lesssim 40$ GeV) → convolution of $\mathcal{O}(10^4)$ old ($t_{age} > 10^6$ yr) sources (7 kpc))

High-energy spectrum ($E > 40$ GeV) → One dominant nearby source with an injection feature (cutoff or break) (Monogem. Geminga, 300 pc))

Bayesian fit to Positron flux



Once «positron factories» are established, still an «electron source» is needed.



Best fit: 4 known SNR within 1000 pc + 1 hidden SNR source 600-1200 pc

Multimessenger constraints to electron data

CRD2g:
Fiorenza Donato

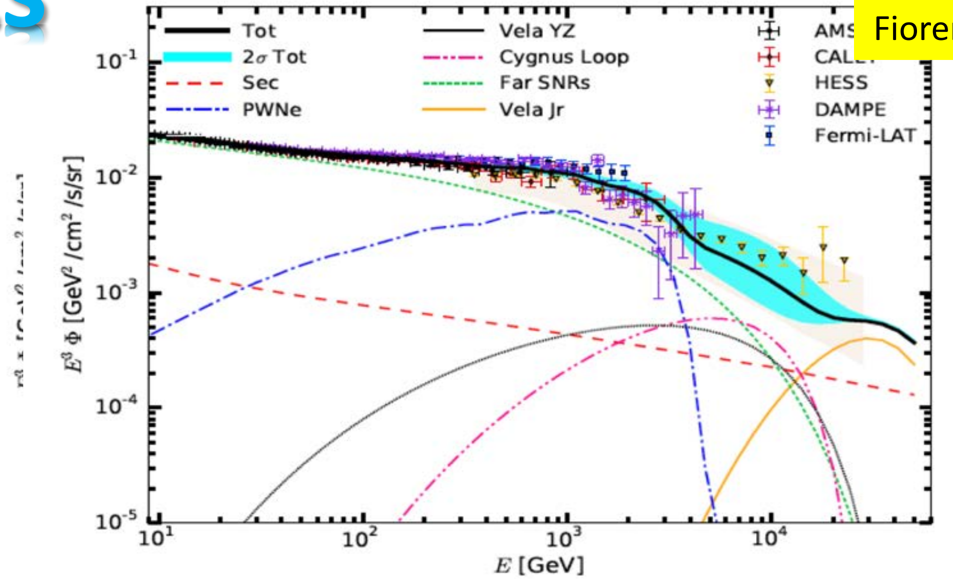
We build a model for the production and propagation of e- and e+ in the Galaxy and test it against 3 observables:

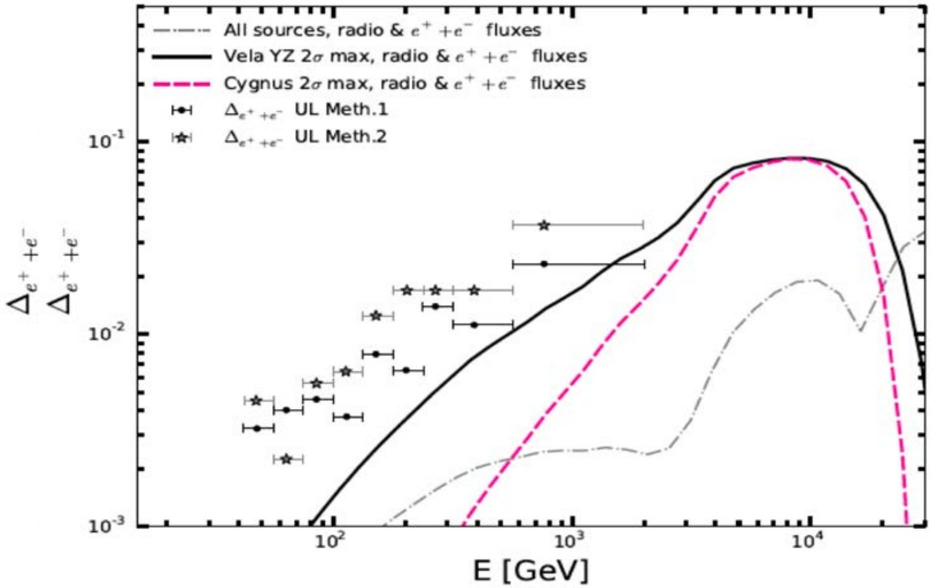
1. Radio brightness data from Vela YZ and Cygnus Loop SNRs at all frequencies. The radio emission is all synchrotron from e- accelerated by the source.

2. e+e- flux. Data from 5 experiments, e+ flux from AMS-02
   Contributors: Far and near SNRs, near SNRs and PWNe, secondaries for e+e-.
   The e+ flux constrains the PWN emission.
   e+e- data taken with their uncertainty on the energy scale.

3. e+e- dipole anisotropy upper bounds from Fermi-LAT
   Test on the power of this observable on the closest SNRs.

Authors fit the (e+ + e-) spectrum on many energy decades using Vela, Cygnus, a smooth distribution of SNRs, PWNe and secondary production.
They **find a model which is compatible with all the (e+ + e-) flux data, the radio data for Vela YZ and Cygnus Loop, and with the anisotropy upper bounds.**





Electron spectrum at SNR

CRD5h:
Rebecca Diesing

Protons and electrons are accelerated at the forward shocks of supernova remnants (SNRs) via diffusive shock acceleration (DSA).*

DSA predicts power law distributions of CRs:

$$\Phi_{\text{inj, p}} \propto E^{-q_{\text{p}}}$$

$$\Phi_{\text{inj, e}} \propto E^{-q_{\text{e}}}$$

Common assumption: $q_p = q_e$

STEEPENING THE ELECTRON SPECTRUM

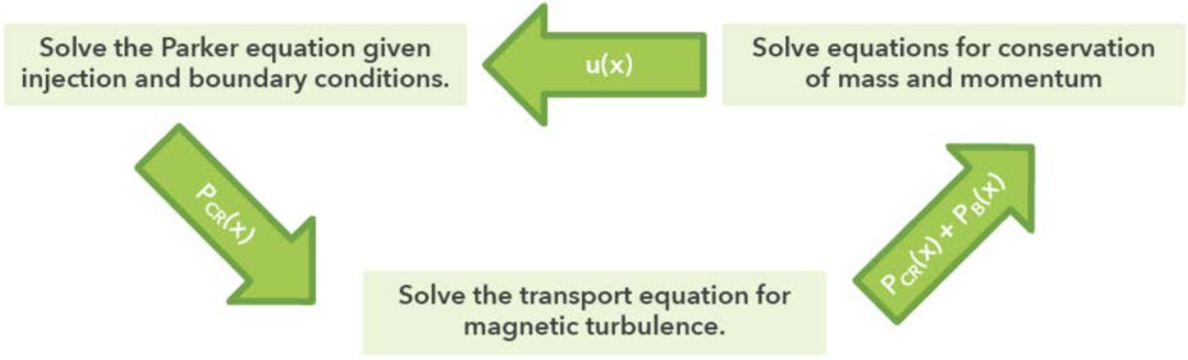
CR electrons experience synchrotron losses in the amplified magnetic fields of SNRs.

$$\tau_{\text{synch}} \simeq 7 \times 10^3 \text{ yr} \left(\frac{B}{300\ \mu\text{G}}\right)^{-2} \left(\frac{E}{10\ \text{GeV}}\right)^{-1}$$

$$\tau_{\text{SNR}} \lesssim 10^5 \text{ yr}$$

Although the life-time of a typical SNR is much shorter than the CR galactic residence time, CR acceleration leads to magnetic field amplification producing magnetic fields that are hundreds of times stronger than that of the Galaxy

Use CRAFT (method paper in prep.), a semi-analytic model of non-linear DSA which self-consistently accounts for particle acceleration and magnetic field amplification.



ELECTRON ACCELERATION

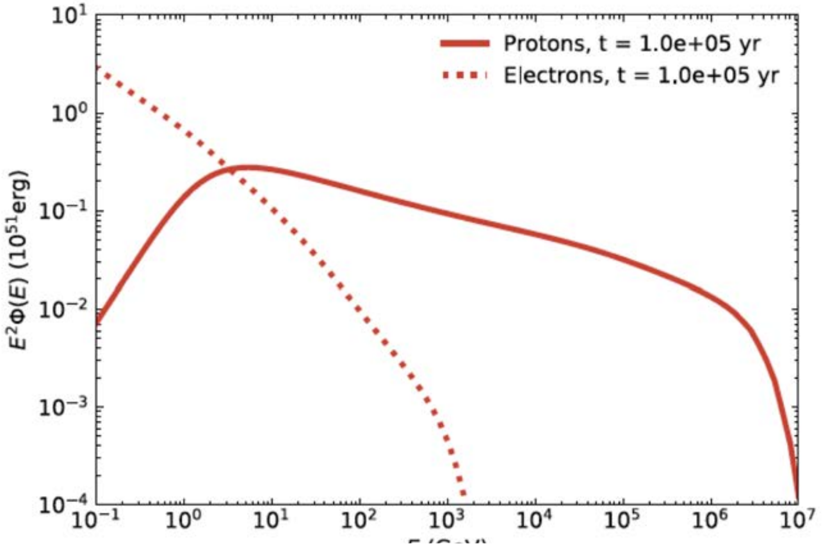
Use an analytical approximation* to go from a proton spectrum to an electron spectrum, with a cutoff determined by synchrotron losses.

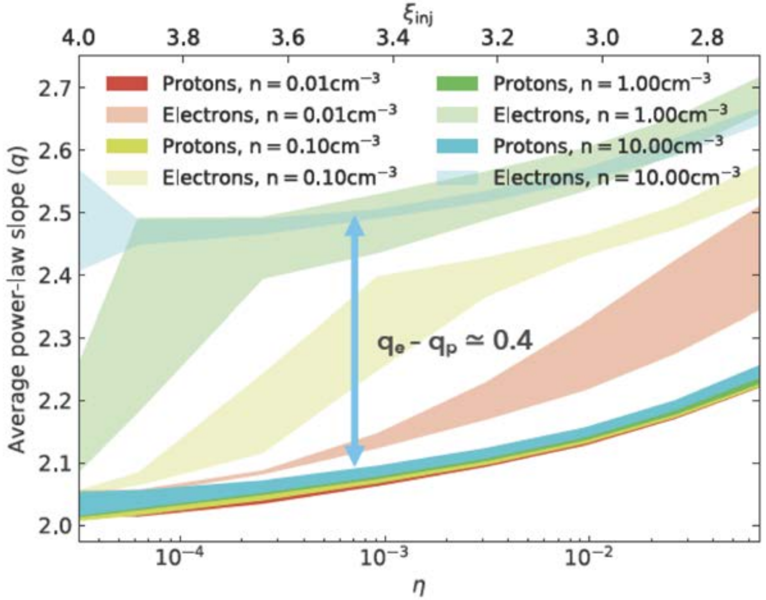
Weight the electron spectrum at each timestep to account for energy losses.

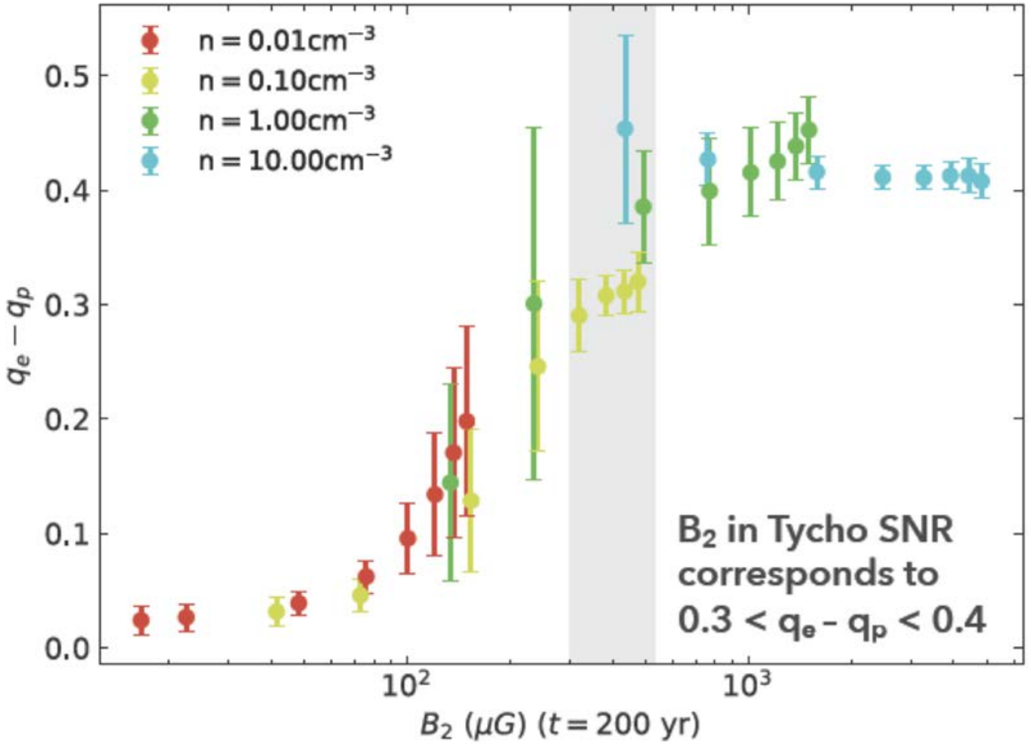
$$\frac{dE}{dt} = -\underbrace{\boxed{\frac{4}{3}\sigma_T c\left(\frac{E}{m_e c^2}\right)^2 \frac{B_2^2}{8\pi}}}_{\text{Synchrotron losses}} - \underbrace{\boxed{\frac{E}{R_{\text{sh}}}\frac{dR_{\text{sh}}}{dt}}}_{\text{Adiabatic losses}}$$

Proton and electron spectra near the end of the SNR lifetime

CRD5h:
Rebecca Diesing







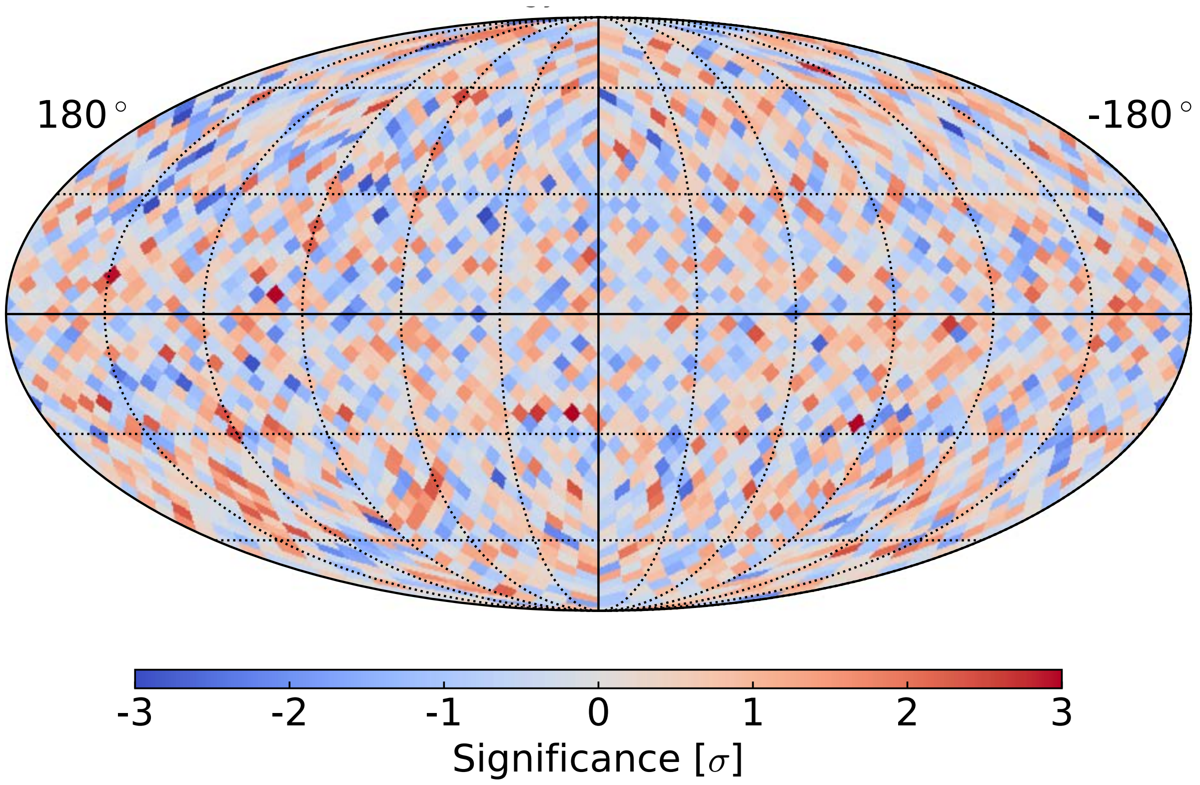
1. Electrons experience synchrotron losses in the amplified magnetic fields of SNRs, resulting in a steepening of their spectrum.

2. The steepening of the electron spectrum suggests that the positron "excess" may in part be an electron deficit.

3. Regardless of secondary production, this steepening may have significant implications for CR propagation models.
   See, e.g., Orlando 2018, which assumes $q_e - q_p \simeq 0.35$.

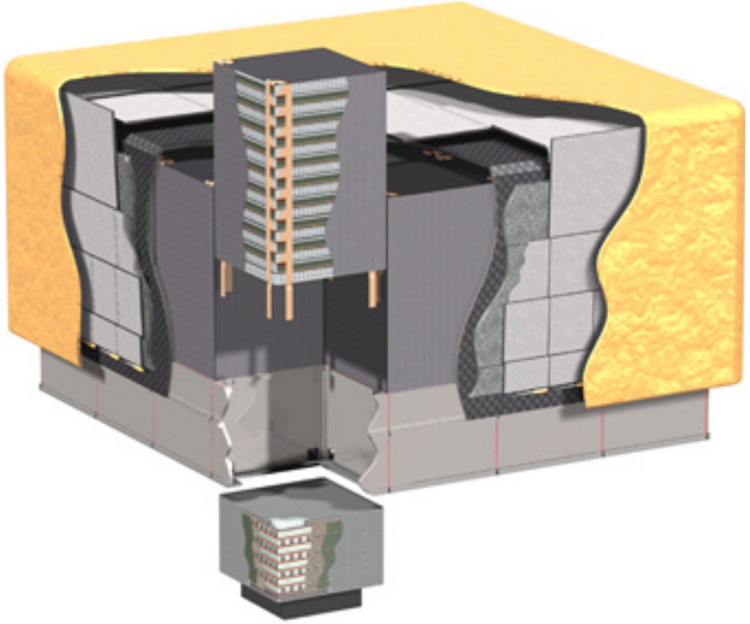
Anisotropy

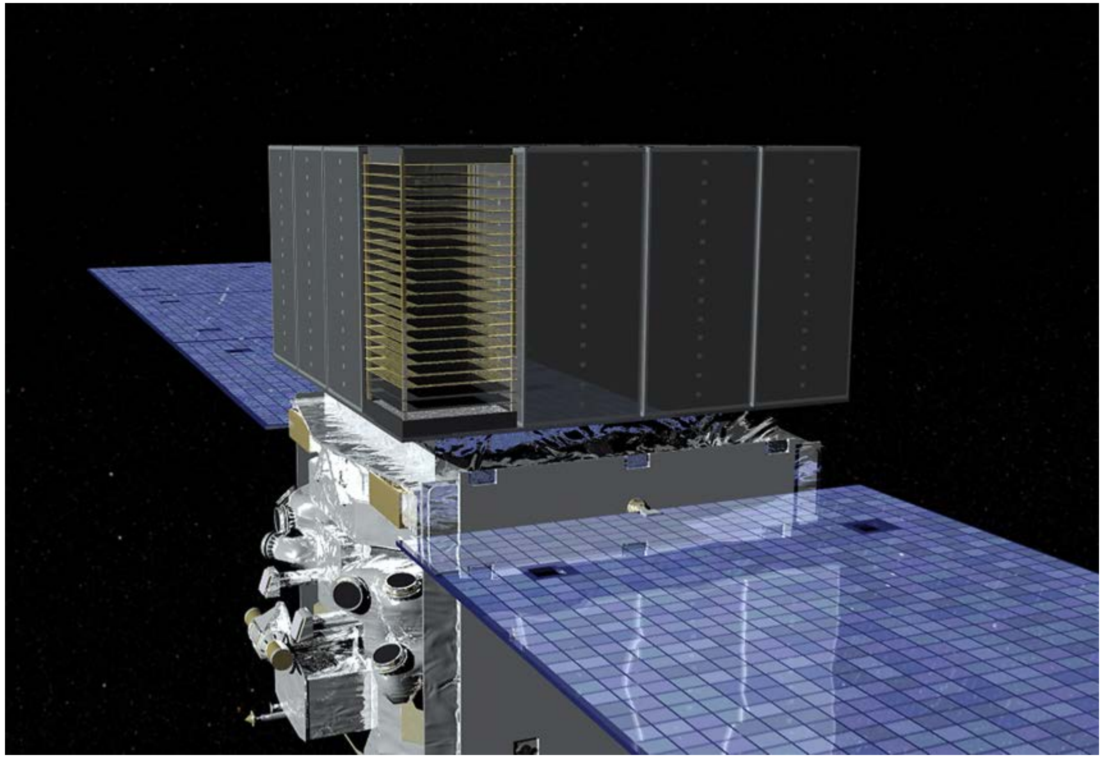
Distribution of CR sources



CRD4h:
Justin Vandenbroucke

Fermi Large Area telescope





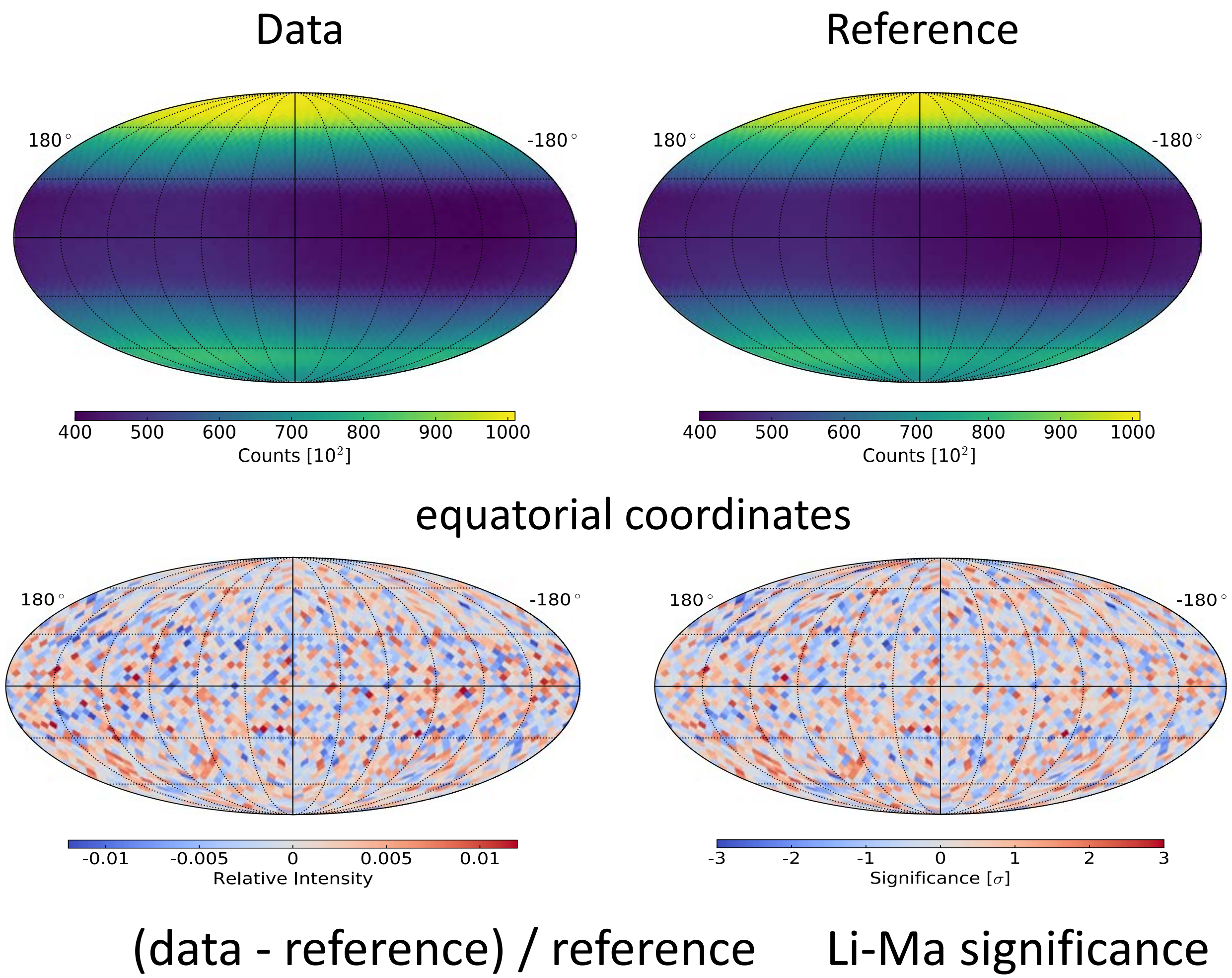
- Tracker: tungsten conversion foils + silicon strip detectors, 1.5 radiation lengths on-axis
- Calorimeter: 1536 Cesium Iodide crystals, 8.6 radiation lengths on-axis, gives 3D energy deposition distribution
- Anti-Coincidence Detector: charged particle veto surrounding Tracker, 89 plastic scintillator tiles + 8 ribbons

Flying since 11 June 2008

Dipole anisotropy with FERMI

- Cosmic-ray anisotropy has been measured from TeV to EeV scale by ground-based experiments
- Most of these experiments make 1D measurements in right ascension (insensitive to declination)
- Ground-based experiments also have limited composition resolution
- Fermi LAT has recorded the largest ever set of cosmic-ray protons at the 100 GeV scale, with excellent composition, direction, and energy resolution
- **179 million proton events above 78 GeV**

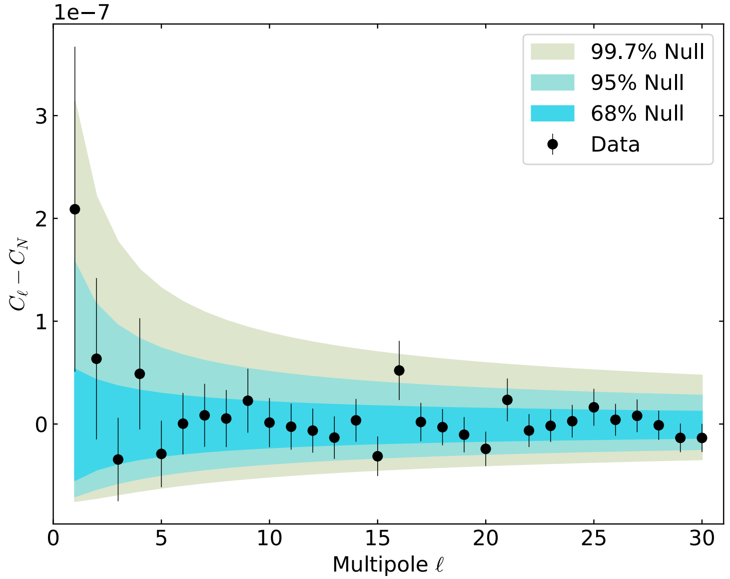
arXiv:1903.02905



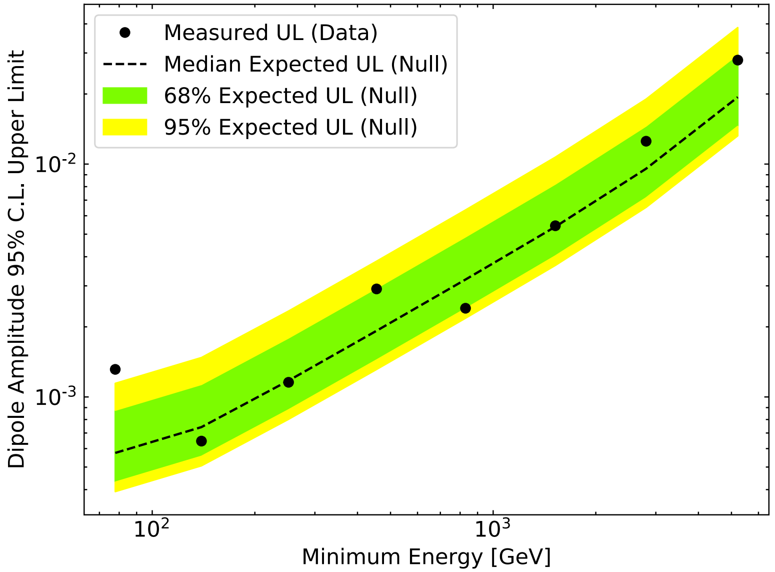
CRD4h:
Justin Vandenbroucke

Dipole anisotropy with FERMI

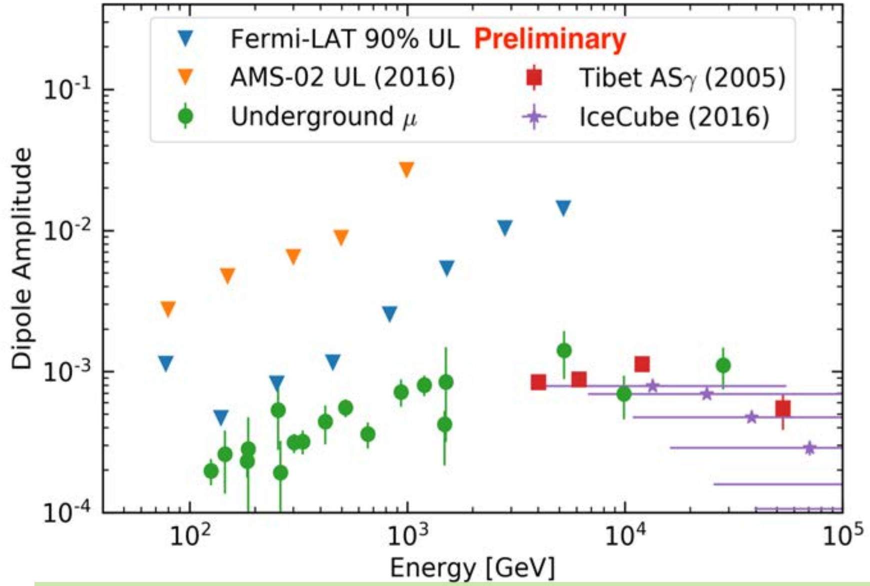
8 year angular power spectrum



Dipole amplitude upper limits vs. energy



LAT dipole results in context



- Excess power found in dipole (p = 0.01)

Note: Fermi LAT and AMS upper limits are cumulative

For all events above 78 GeV, dipole power with modest statistical significance (p = 0.01)

- Interpreted as **signal: amplitude (3.9 ± 1.5) x 10^{-4}**
- Alternatively, **set amplitude upper limit (95% CL): 1.3 x 10^{-3}**

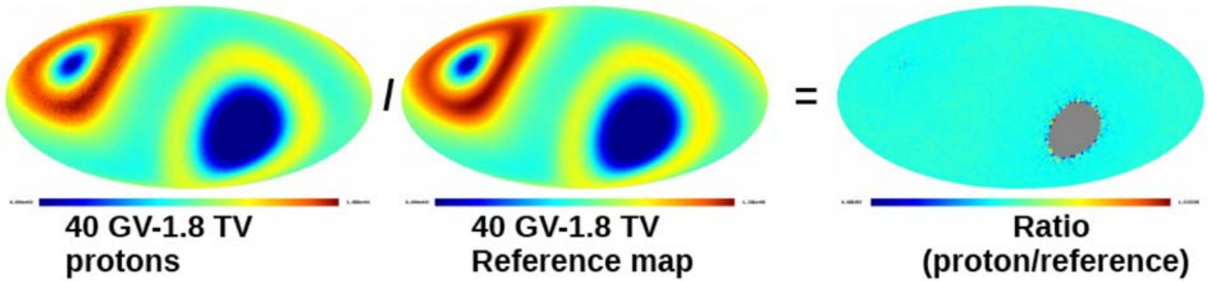
CRD4h:
Justin Vandenbroucke

Dipole anisotropy with AMS

CRD4a:
Iris Gebauer

We have searched for dipole anisotropies in the arrival directions of protons, Helium, Carbon and Oxygen.

Reference map: best guess for an image of an isotropic sky measured by AMS-02 in the respective data taking period. Any deviation from this reference map might be detected as a signal.

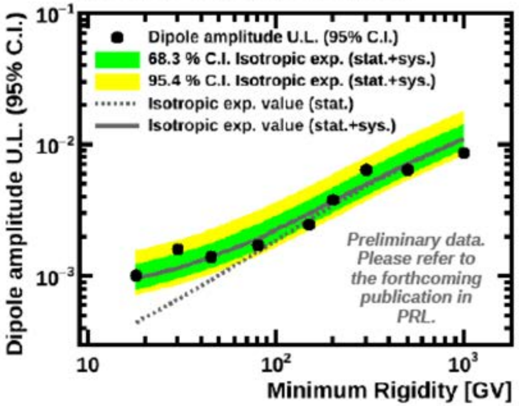


7.5 years
total exposure time: 1.72×10^{8} s

CRD4a:
Iris Gebauer

Protons

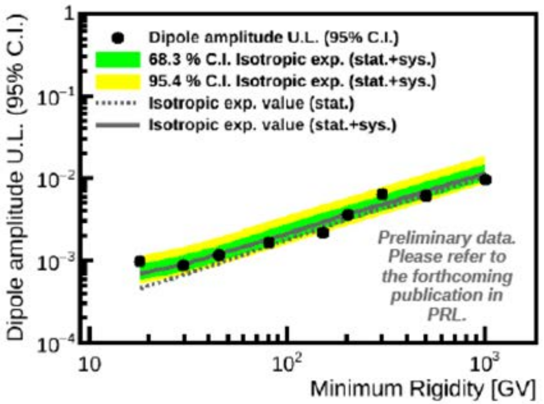
1.2 x 10^8 events, R>18 GV



Upper limit on dipole amplitude:
δ_p(>200 GV) < 0.38% at 95% C.I.

Helium

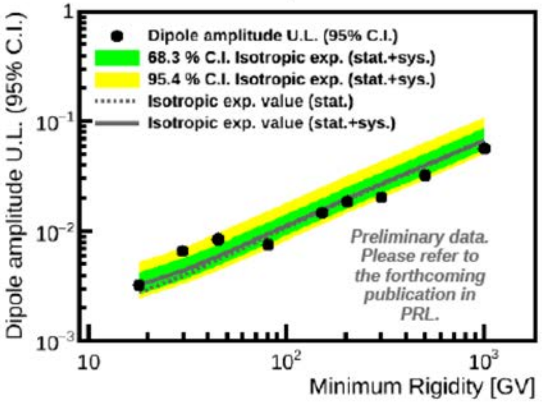
1.0 x 10^8 events, R>18 GV



Upper limit on dipole amplitude:
δ_{He}(>200 GV) < 0.36% at 95% C.I.

Carbon

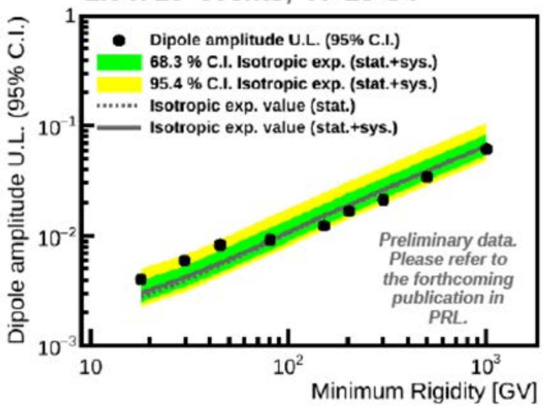
2.9 x 10^6 events, R>18 GV



Upper limit on dipole amplitude:
δ_C(>200 GV) < 1.9% at 95% C.I.

Oxygen

2.9 x 10^6 events, R>18 GV

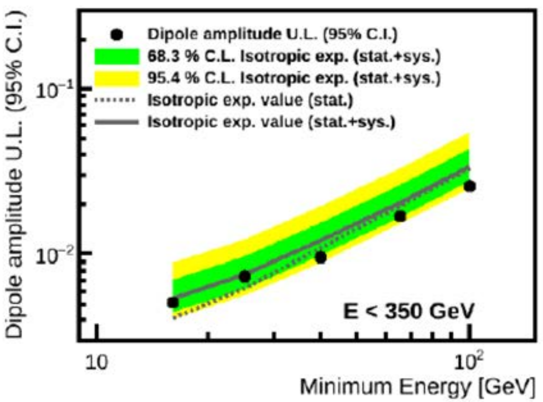


Upper limit on dipole amplitude:
δ_O(>200 GV) < 1.7% at 95% C.I.

6.5 years: total exposure time 1.48 x 10^8 s

Electrons

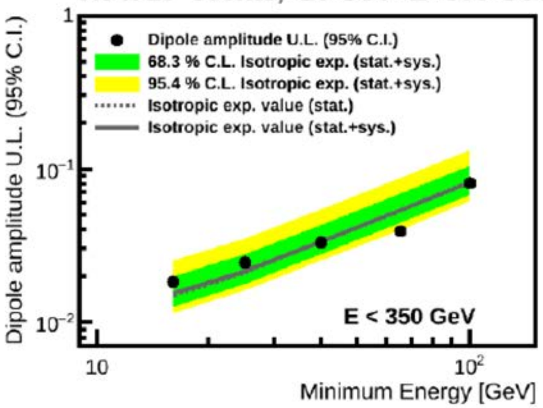
1.3 x 10^6 events, 16 GeV<E<350 GeV



Upper limit on dipole amplitude:
δ_{e-}(>16 GeV) < 0.5% at 95% C.I.
[Phys. Rev. Lett. 122, 101101]

Positrons

9.9 x 10^4 events, 16 GeV<E<350 GeV



Upper limit on dipole amplitude:
δ_{e+}(>16 GeV) < 1.9% at 95% C.I.
[Phys. Rev. Lett. 122, 041102]

No significant deviation from isotropy was observed in any observable and any coordinate system.

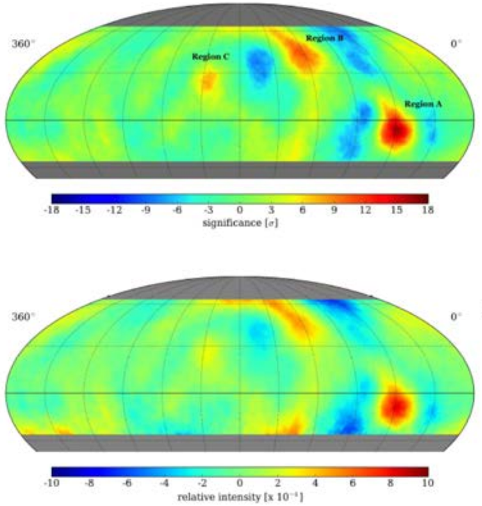
Upper limits on the 3D absolute anisotropies were set.

AMS will continue to take data until the end of ISS operation, currently 2024. By that time positron statistics will allow us to reach the 1% level expected for pulsars.

Small-scale anisotropies

CRD4g:
Philipp Mertsch

Small-scale anisotropies



- Subtract off dipole and quadrupole
- Smooth with 10° disk

→ Small-scale features

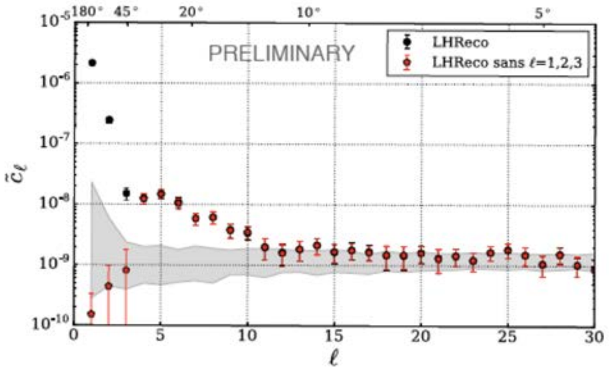
Abeysekara *et al.*, ApJ 796 (2014) 108

IceCube

Aartsen *et al.*, ApJ 826 (2016) 220

IceCube+HAWC

Daz-Vlez *et al.*, *Proc. 35th ICRC* (2017) 28

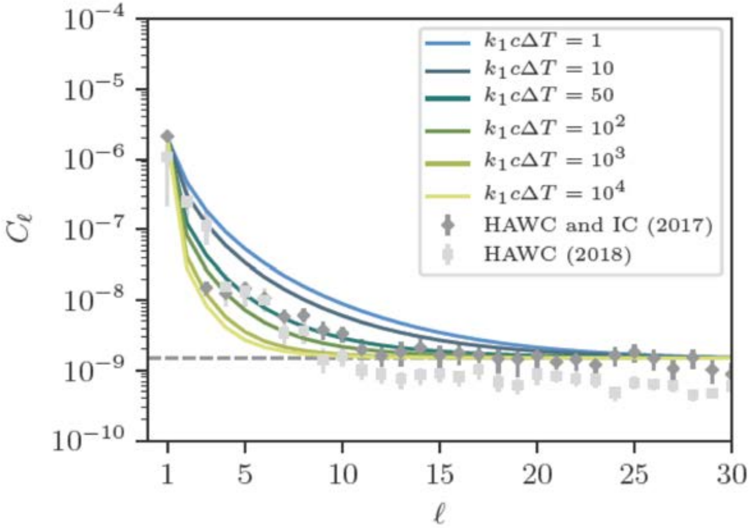


Conventional quasi-linear theory only predicts dipole!

Source of the small scale anisotropies?

Giacinti & Sigl, PRL 109 (2012) 071101

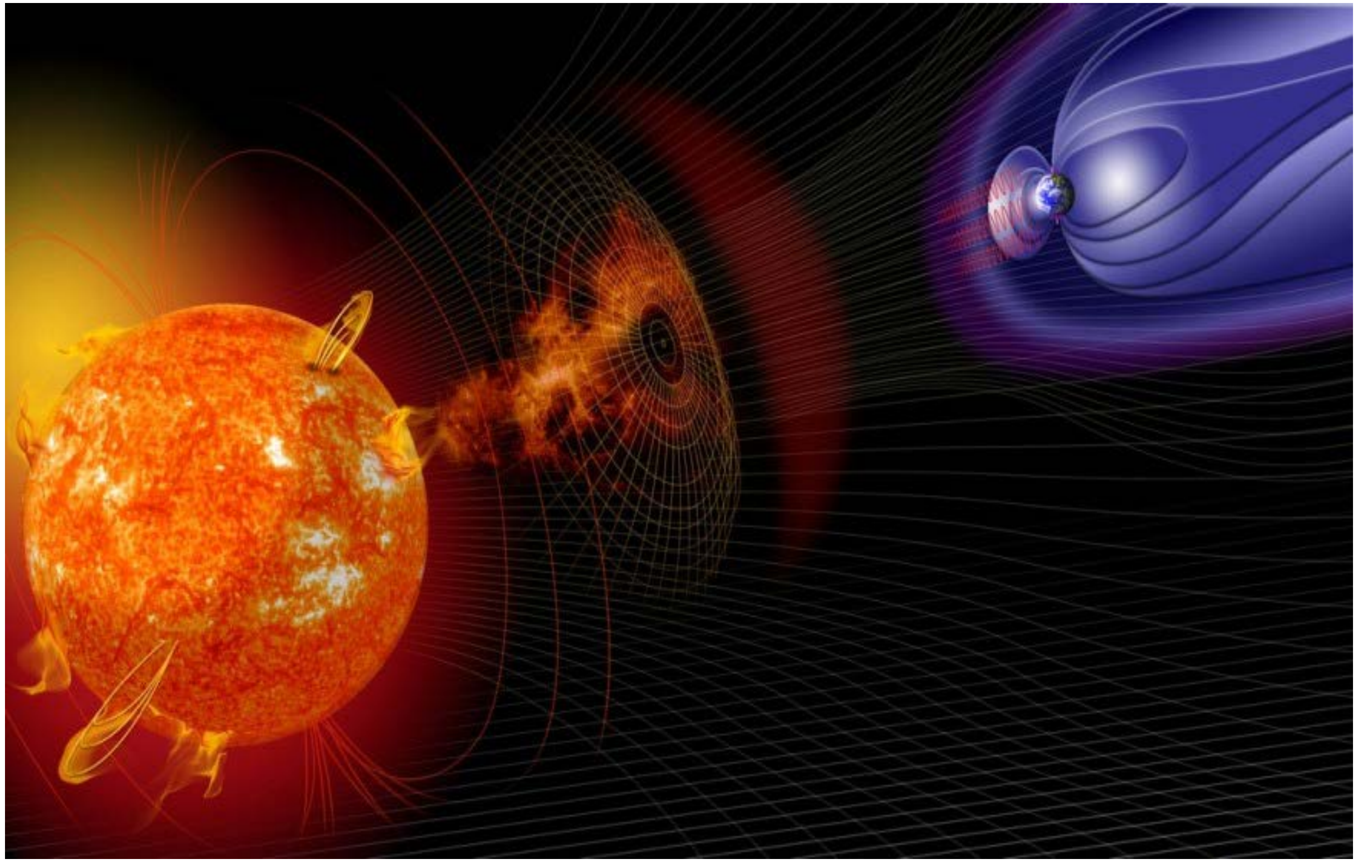
Small-scale anisotropies are a result of cosmic ray streaming in a particular realisation of the turbulent magnetic field within a few scattering lengths in our local Galactic neighbourhood.



Analitical computation that through a perturbative approach predicts the angular power spectrum.
Simple, isotropic turbulence model has remarkable agreement with the results of numerical studies.

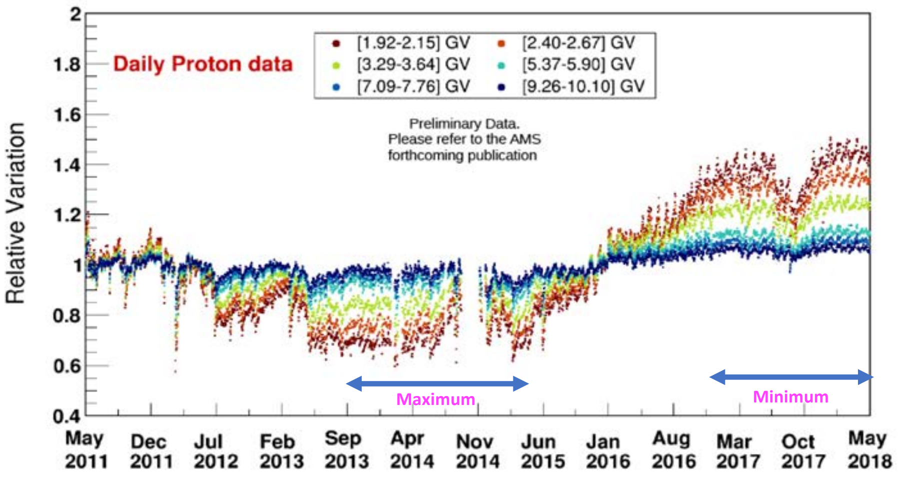
Solar Modulation

Effects of the heliosphere on CR fluxes



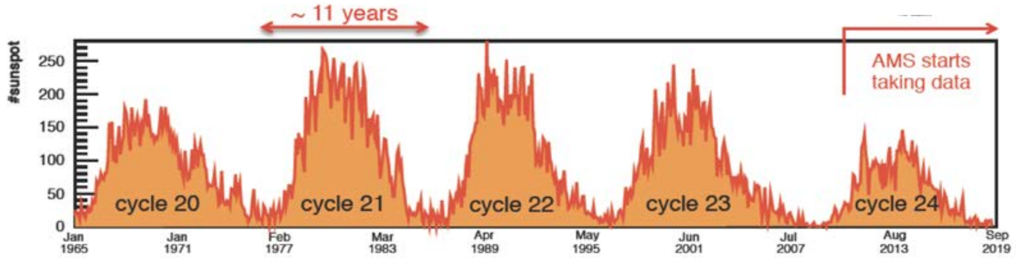
Connection with «Solar&Heliospheric»

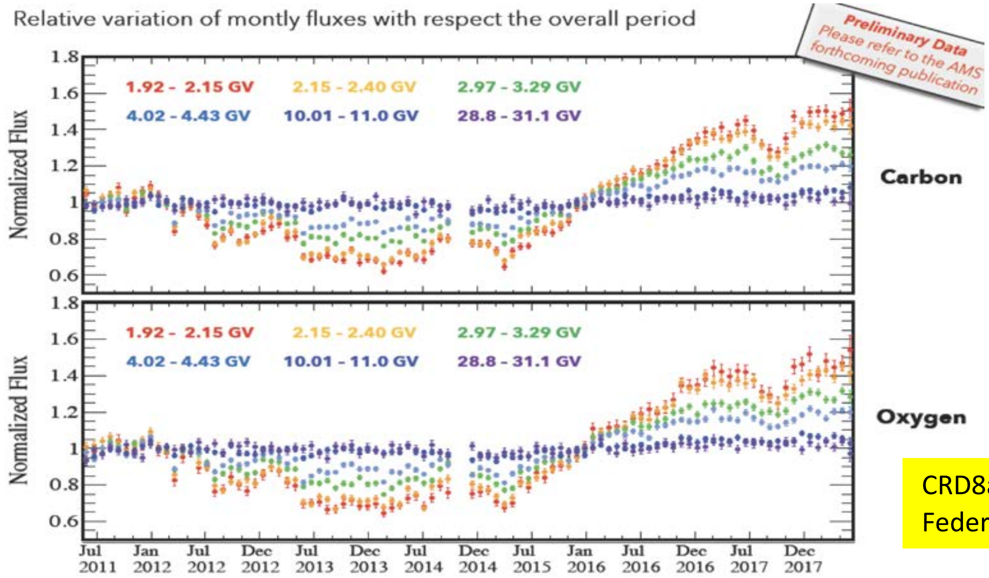
Fluxes modulation with AMS (2011-2018)



CRD8c:
Cristina Consolandi

Long-term modulation of the proton flux



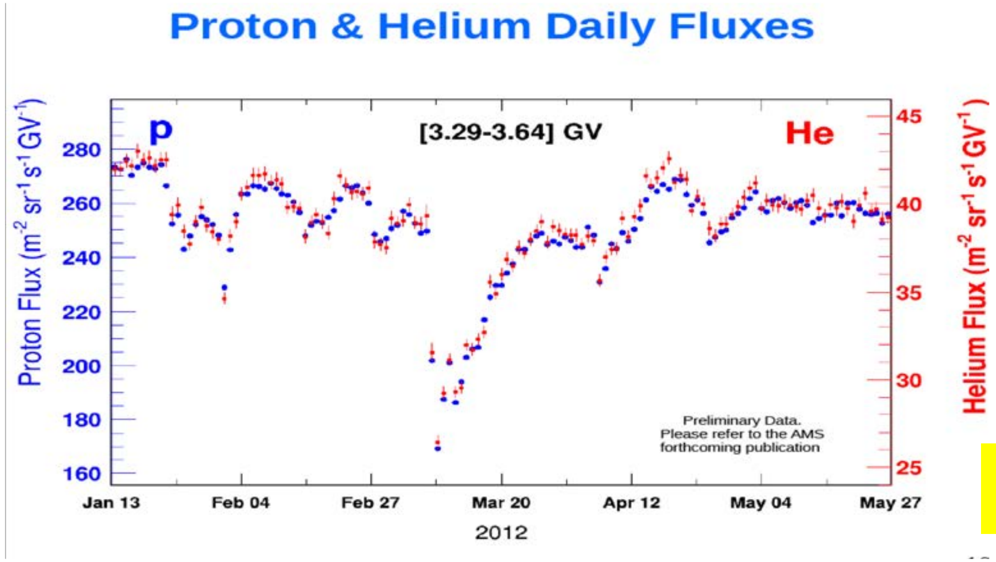


Long-term modulation of the Carbon and Oxygen flux

CRD8a:
Federico Donnini

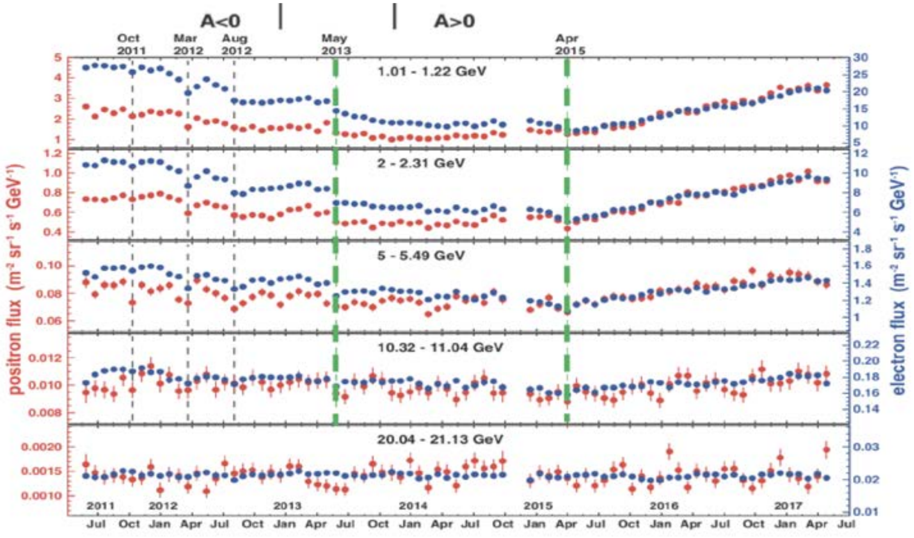
Fluxes modulation with AMS (2011-2018)

Short-term modulation of the proton and helium flux: **Forbush decrease (SEP event 7th March 2012)**



CRD8c: Cristina Consolandi

Charge-dependent modulation of the electron and positron flux

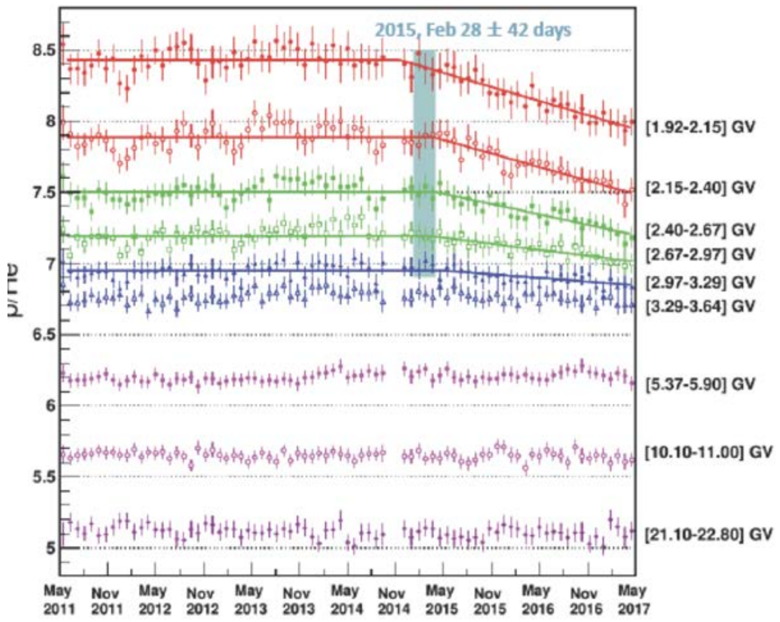


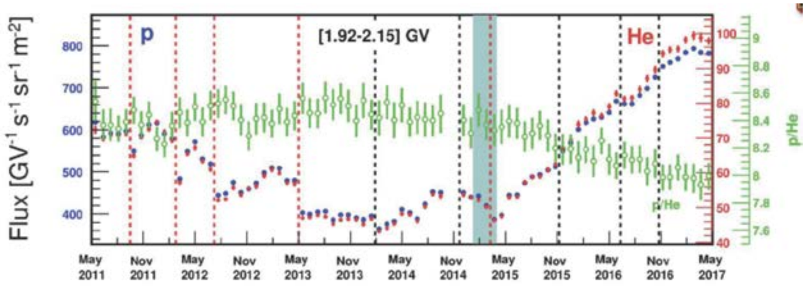
CRD2a: Matteo Duranti

p/He ratio modulated at solar minimum

CRD8d:
Nicola Tomassetti

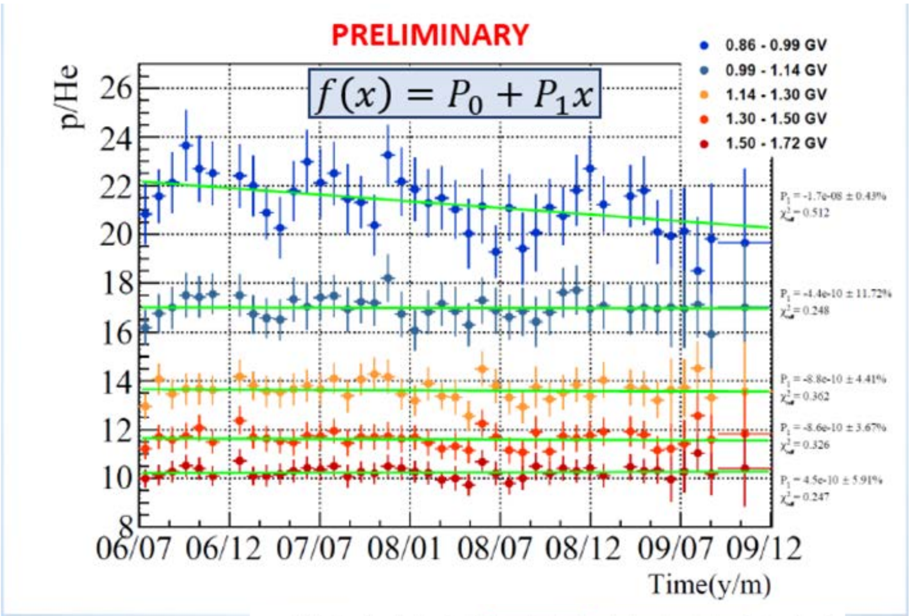
p/He AMS data

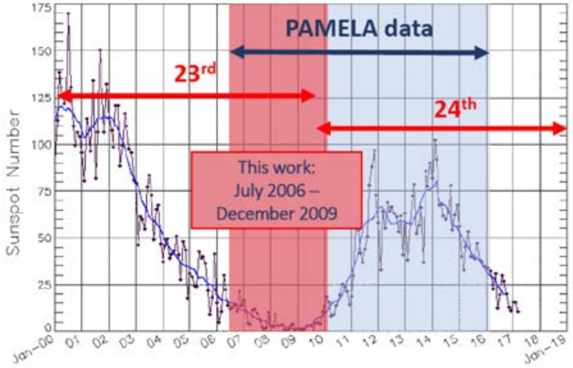




p/He PAMELA data

SH2c:
Nadir Marcelli

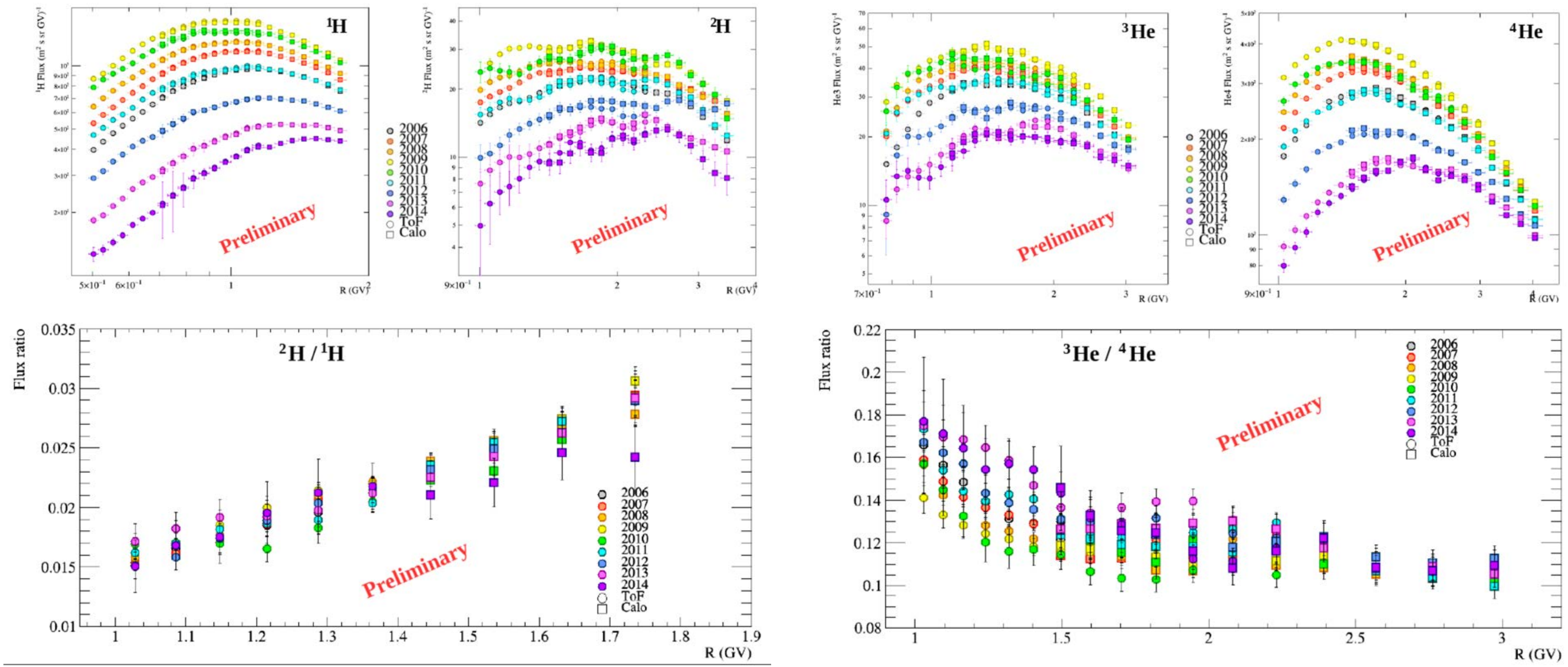




Mass/charge dependency of the diffusion mechanism or different LIS spectra

Isotope modulation with PAMELA (2006-2014)

SH2d:
Riccardo Munini



Theory

(very short summary ....)

Summary of presented talks

- **SOURCES (PEVATRONS):** Makarim Bouyahiaoui (CRD4b), Mehmet Guenduez (CRD4f), Vikram V. Dwarkadas (CRD5c)
- **MODELS OF ACCELERATION:** Benjamin J. Buckman (CRD4c), Yutaka Ohira (CRD5d), Shoma Kamijima (CRD5g), Shota Yokoyama (CRD5f)
- **MODELS OF TRANSPORT AND PROPAGATION**: Igor Moskalenko (CRD2d), Alexei Ivlev (CRD4d), Loann Brahimi (CRD5a), Hongbo Hu (CRD5b), Yoann Genolini (CDR6a), Manuela Vecchi (CRD6g)

Conclusions: set of «classical» questions

I. Which **classes of sources** contribute to the CR flux in different energy ranges?

II. Are **CR nuclei and electrons accelerated by the same sources**?

III. Which sources are capable of **reaching the highest particle energies**?

IV. Which are the relevant processes responsible for CR **confinement in the Galaxy**?

V. Where is the **transition between Galactic and extra-Galactic CRs**?

VI. What is the origin of the difference between the **chemical composition of CRs and the solar one**?

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In the last decades we developed an «accepted» scenario for CR origin, that we call «**standard paradigm**» .
In this framework, many of the classical questions have been (plausibly) answered.

Conclusions: set of «new» questions !

I. What is the origin of the **hardening observed in the spectra of CR nuclei** at a rigidity of 300 GV?

II. Why is the slope of the spectrum of CR **proton and helium different**?

III. What is the origin of the prominent break observed at a particle energy of **1 TeV in the electron spectrum**?

IV. Why do the **proton, positron, and antiproton spectra have roughly the same slope at particle energies larger than 10 GeV**?

V. What is the origin of the **rise in the positron fraction** at particle energies above 10 GeV?

VI. What is the origin of **small scale anisotropies**?

VII. ……….

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VI. What is the origin of **small scale anisotropies**?

VII. ……….

A «**new paradigm**» is needed? The following years will tell us much!

Stay tuned for 2021 ICRC Berlin