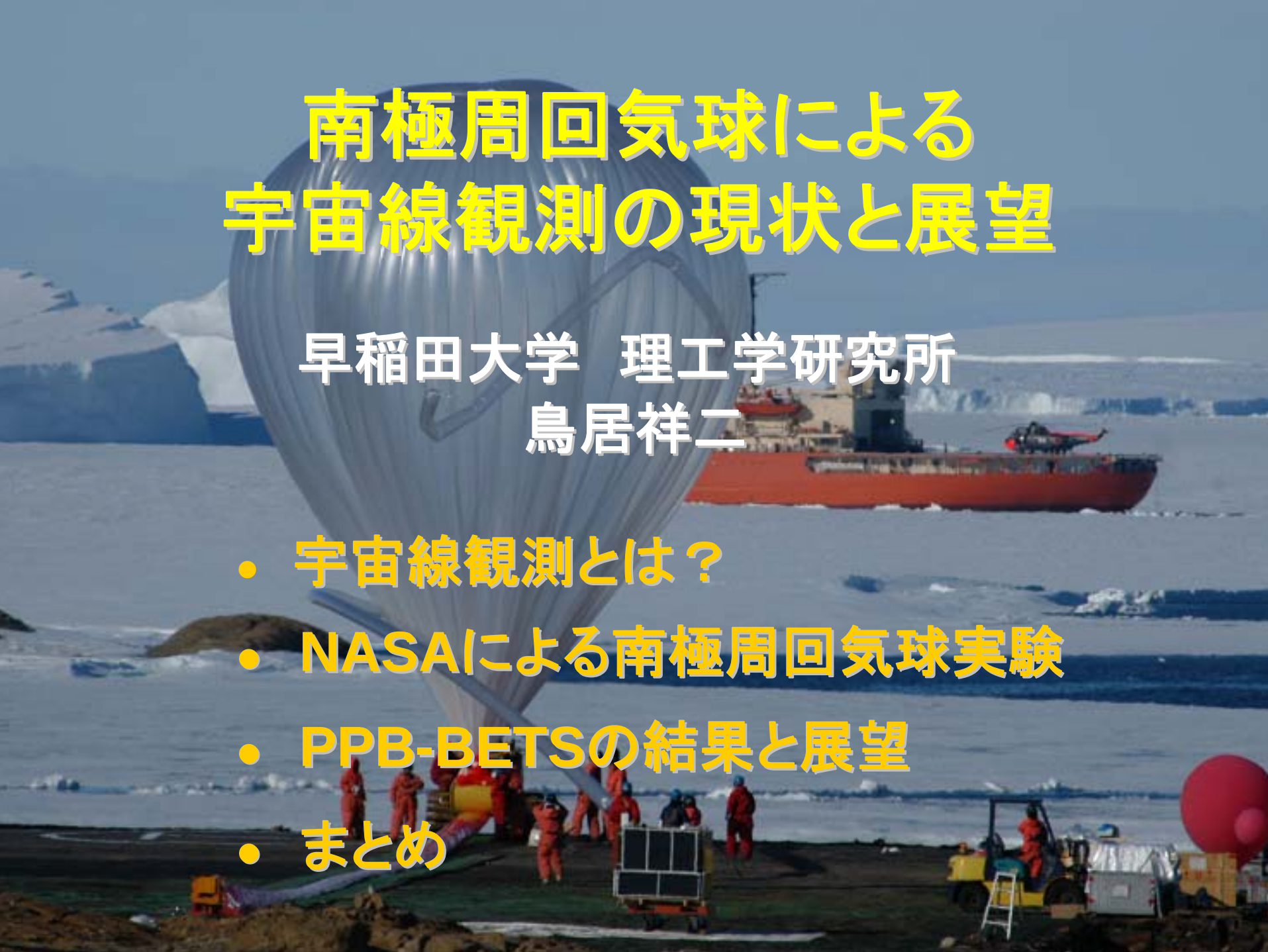
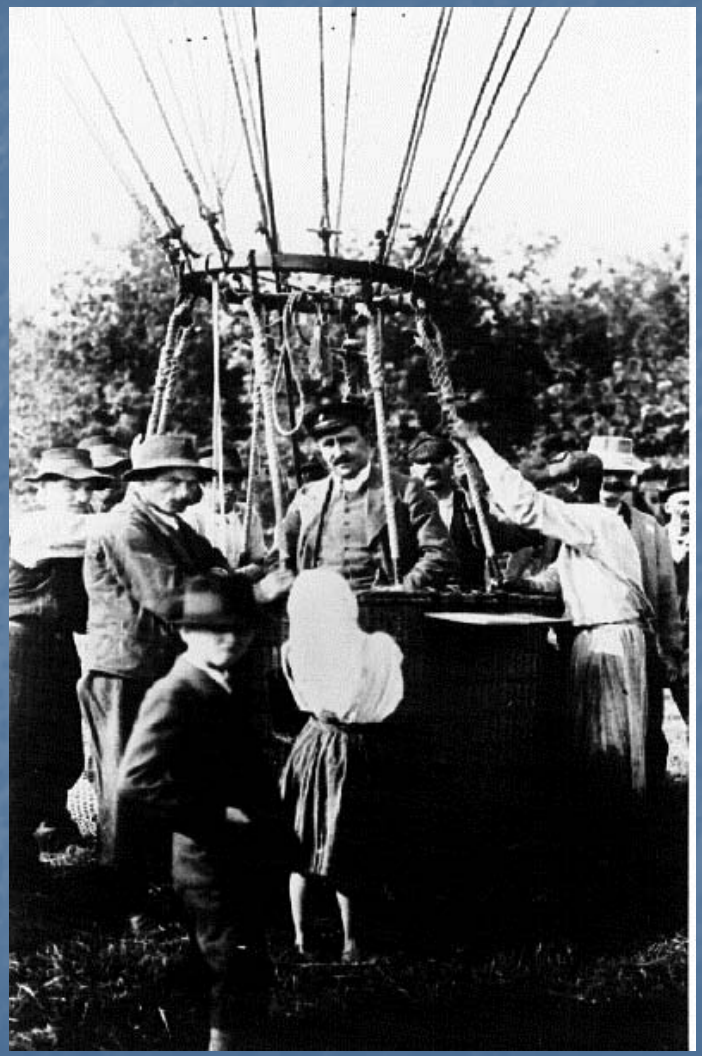


南極周回気球による宇宙線観測の現状と展望

早稲田大学　理工学研究所
鳥居祥二

- 宇宙線観測とは？
- NASAによる南極周回気球実験
- PPB-BETSの結果と展望
- まとめ

宇宙線観測は気球で始まった!!!

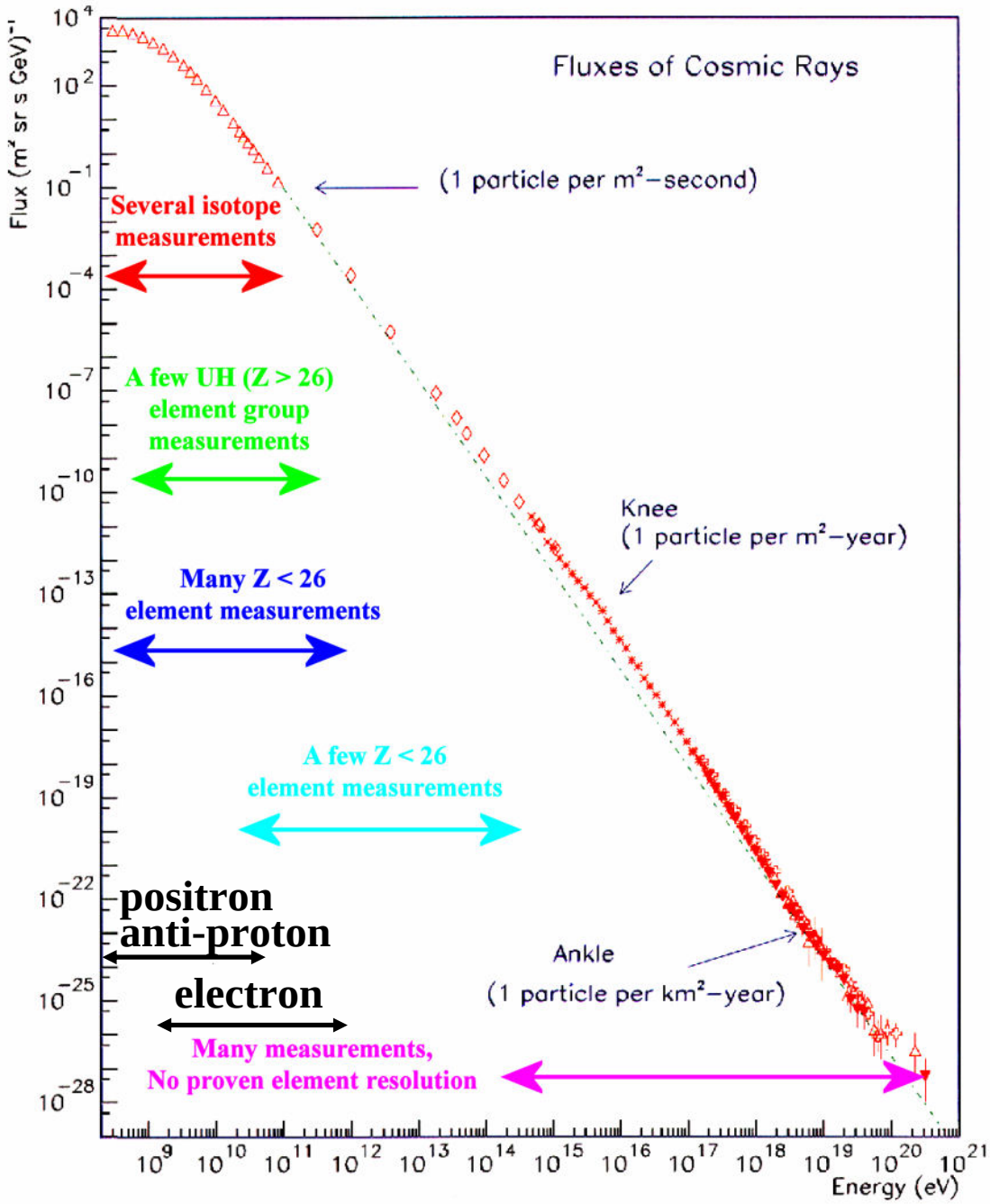


1912年
HESS　による宇宙から飛来する放射線の発見

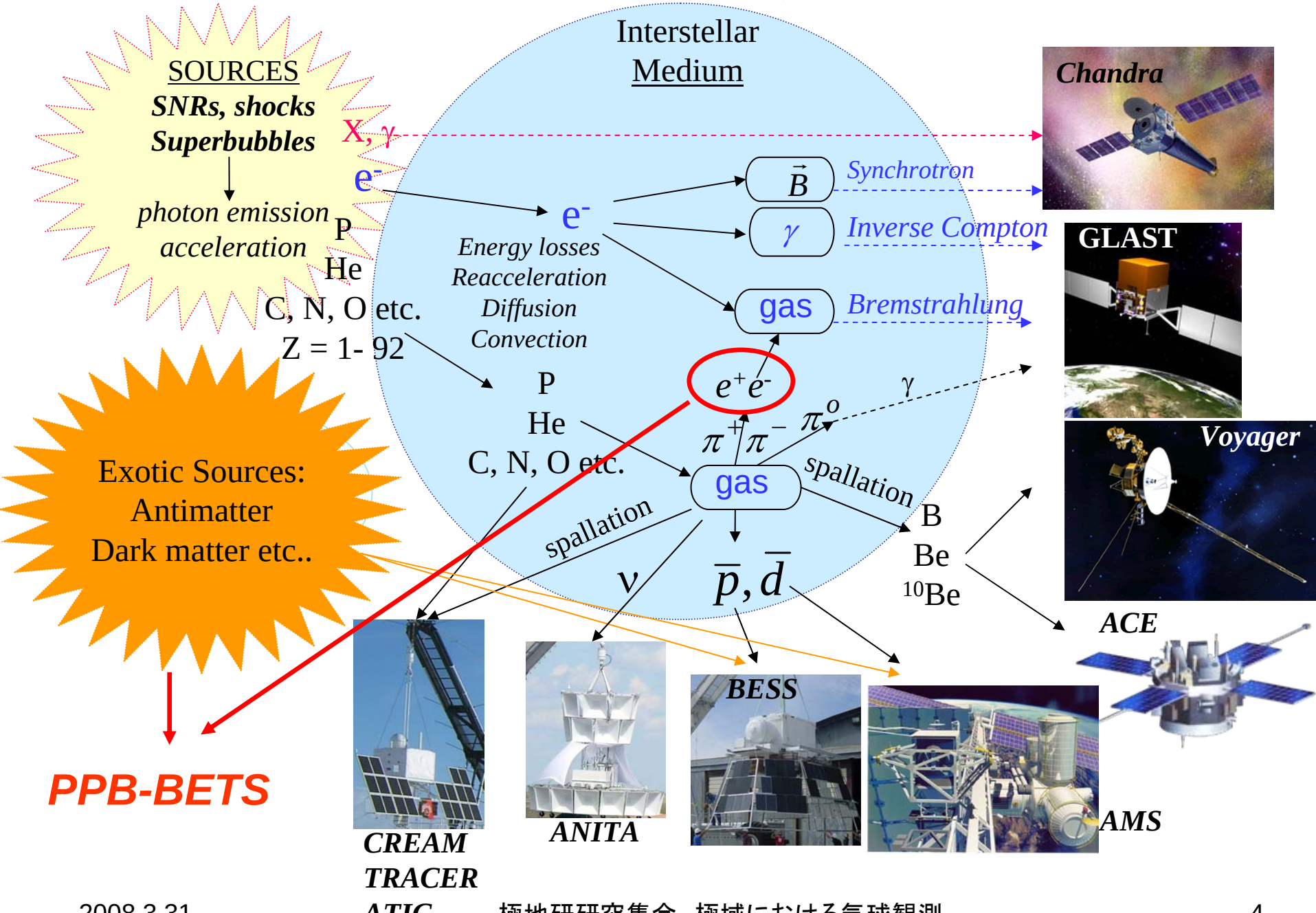
発見以来約1世紀が経過した今もまだ宇宙線の起源は謎に包まれている

Energy Spectrum

- Covers more than 20 orders of magnitude
- Flux varies by more than 30 orders of magnitude
- Required detector size varies greatly over this range
  - Satellites limited to low energy (< 100 GeV)
- Balloons can approach the "knee" (~ 1 PeV)
  - Air shower measurements for highest energy
- Most detailed measurements are at low energy
- Little composition knowledge above 1 PeV



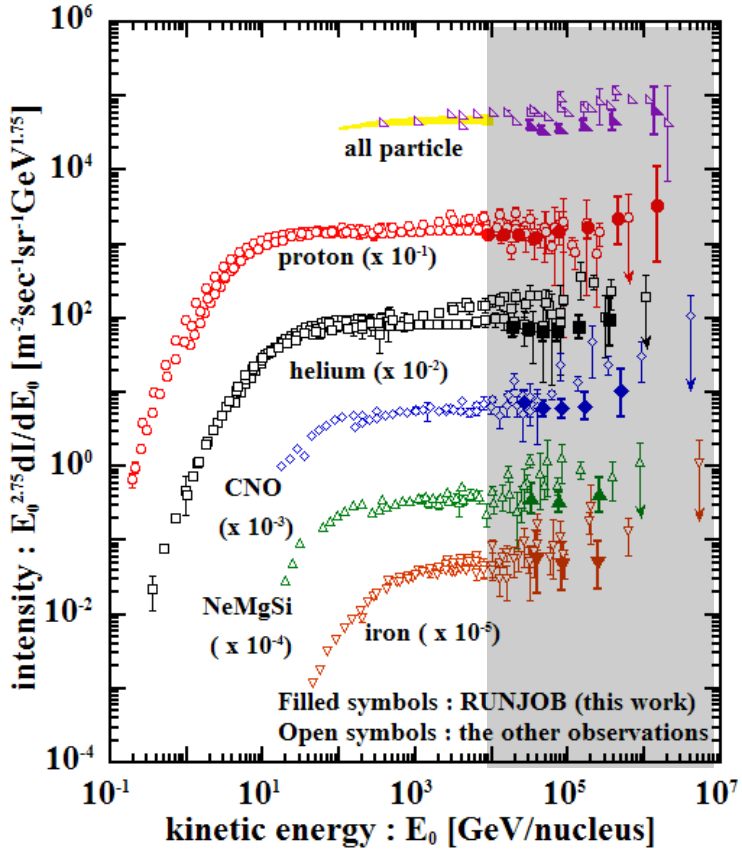
Schematic Context of Particle Astrophysics *(NASA Strategy by V.Jones)*



Proton & Nucleus Observation before 2000

"Supernova remnant paradigm"

- **Cosmic Rays are accelerated by Fermi acceleration at SNR shocks**
- **Power laws of the type $E^{-\gamma}$ are usually assumed to be generated naturally, with slope around $\gamma = 2$**
- **The spectra observed at the Earth are modified by diffusive propagation in the Galaxy**



Due to poor statistics, it is difficult to know details of energy spectra of each component over 10 TeV/ nucleus.

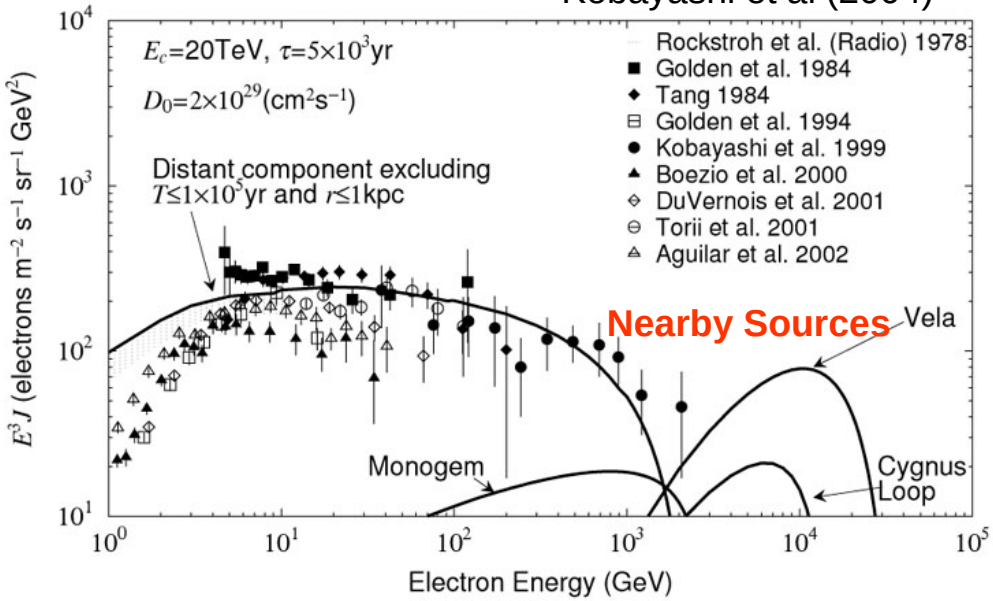
Need more observation with Large Scale and Long Duration for accurate measurement of the spectra and abundances of elements in cosmic rays

Electrons can provide additional information about the GCR source

- High energy electrons have a high energy loss rate $\propto E^2$
  - Lifetime of ~10^5 years for >1 TeV electrons
- Transport of GCR through interstellar space is a diffusive process
  - Implies that source of high energy electrons are < 1 kpc away

- Electrons <u>are</u> accelerated in SNR
- Only a handful of SNR meet the lifetime & distance criteria

Kobayashi et al (2004)



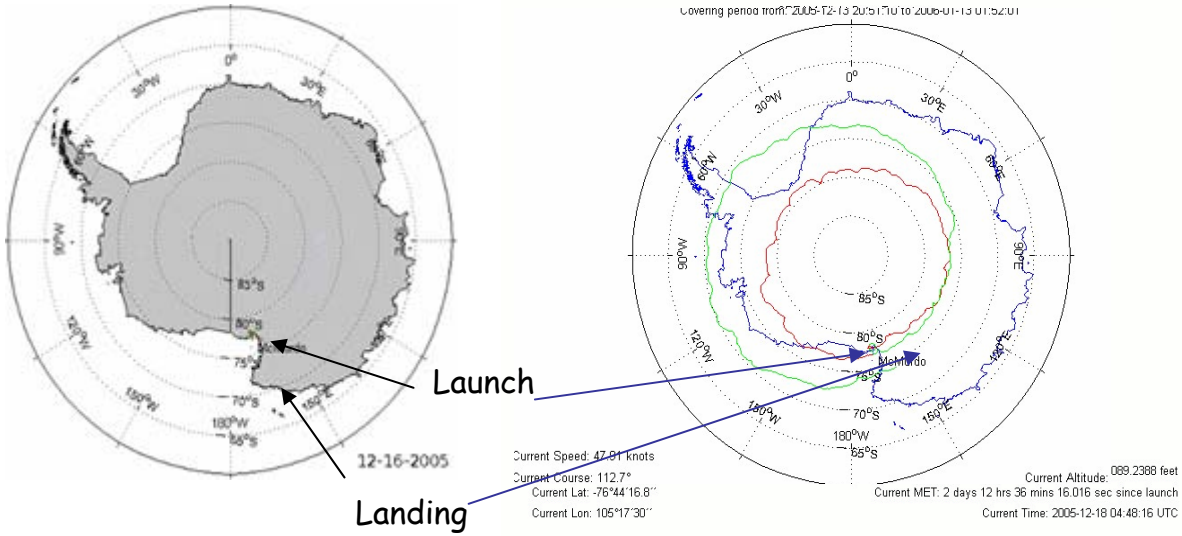
New Technology and Long Duration Ballooning for Precise Measurments

70 days of flight from 2 launches,
as of 2006

- CREAM
- ATIC
- Tracer
- TIGER
- BESS-Polar
- PPB-BETS

CREAM-I
12/16/04 – 1/27/05
Record breaking 42 days

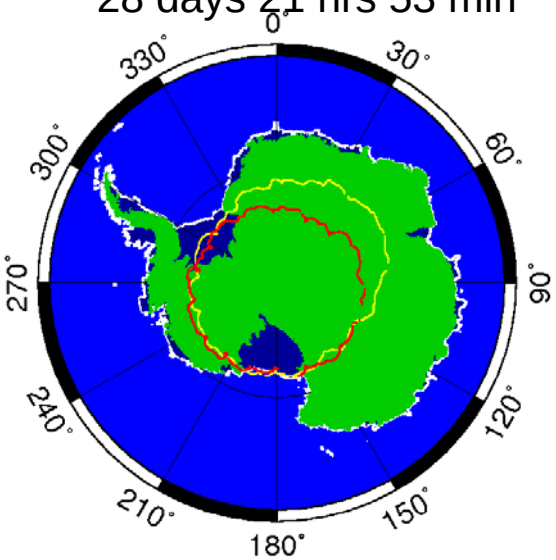
CREAM-II
12/16/05-1/13/06
28 days



Three Long-Duration Balloon (LDB) Flights in FY-08

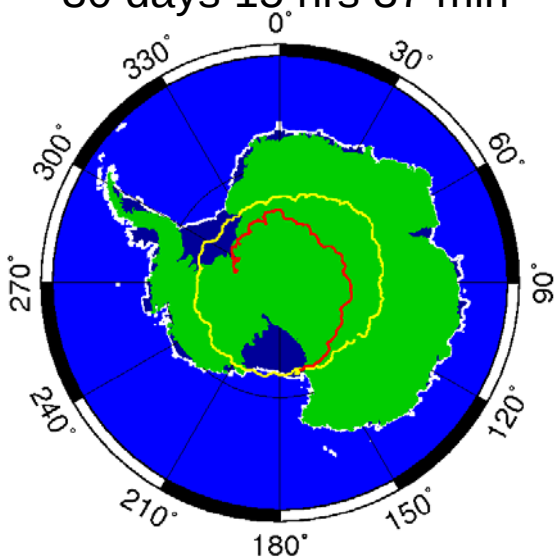
- Three LDB payloads were launched within 7-1/2 days in December 2007
- All three completed their flights successfully: ~79 days of total flight
  - CREAM: 2 circumnavigations in ~29 days / ~29 days data
  - BESS: 1-1/2 circumnavigations in ~30 days / ~24.5 days data
  - ATIC: 1-1/2 circumnavigations in ~19 days / ~14.5 days data
- Longer flight of CREAM was precluded by lack of air assets for recovery

CREAM-III **(~100 days in total)**
12/19/07 - 1/17/08
28 days 21 hrs 53 min



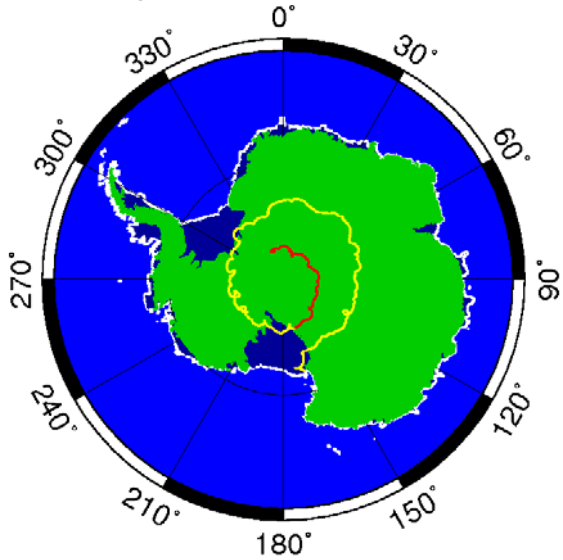
GMT 2008 Jan 23 22:00:10 LDB_Antarctica_2007-2008_CREAM

BESS-II
12/22/07 - 1/22/08
30 days 15 hrs 37 min



GMT 2008 Jan 23 22:00:05 LDB_Antarctica_2007-2008_BESS

ATIC-III
12/26/07 - 1/15/08
19 days 10 hrs 43 min



GMT 2008 Jan 15 14:30:00 LDB_Antarctica_2007-2008_ATIC

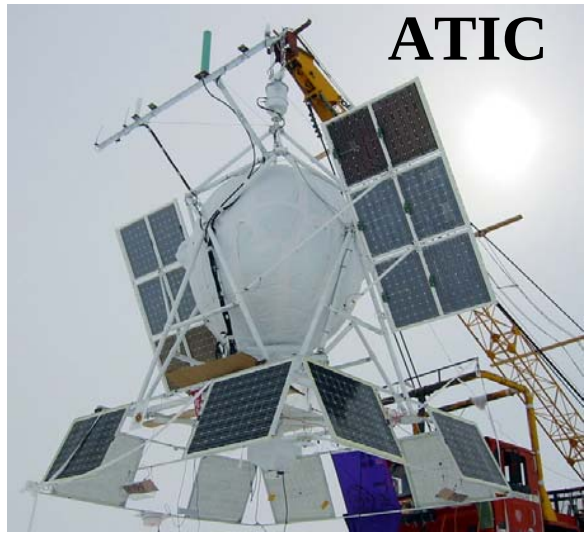
Cosmic ray balloon payloads (1)

Cosmic Ray Energetics and Mass (CREAM)

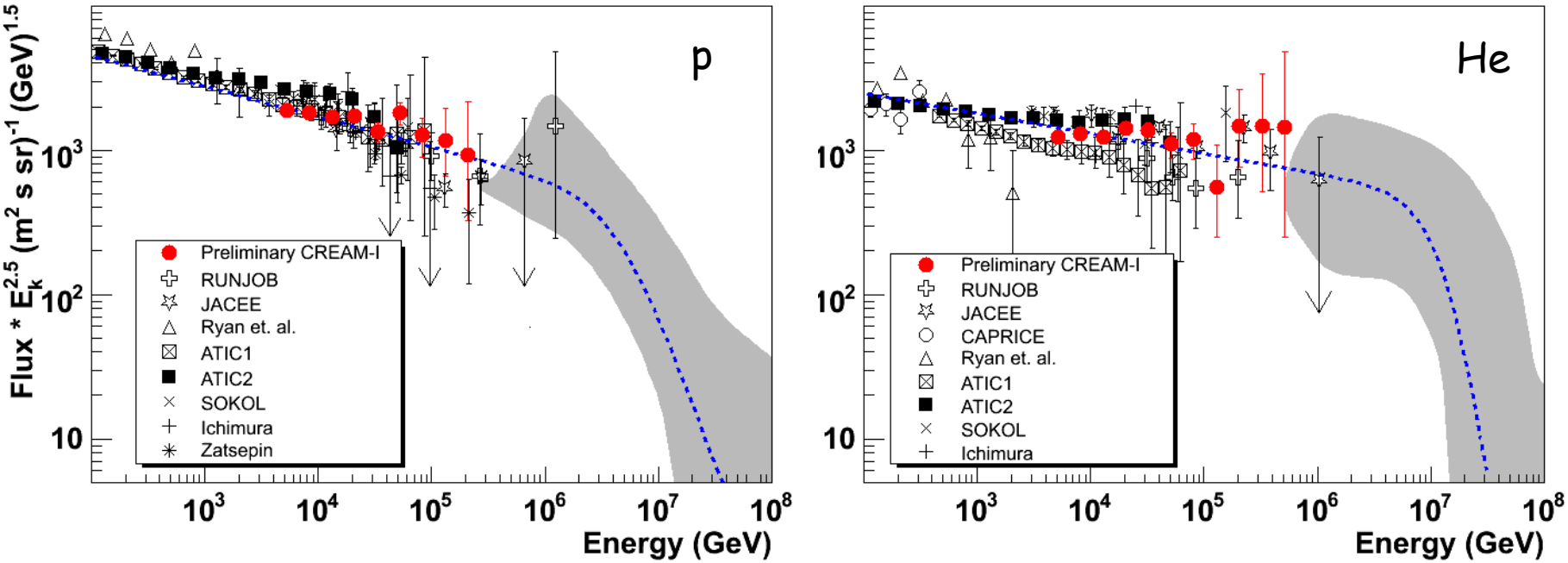
- GCR nuclei from H to Fe for energies from ~1 TeV to ~500 TeV
- 1141 kg (2526 lbs)
- Flights in 2004 , 2005 and 2007(~100 days)
- Anticipated flight in 2008

Advanced Thin Ionization Calorimeter (ATIC)

- GCR nuclei from H to Fe from 50 GeV to ~100 TeV; GCR electrons from ~20 GeV to several TeV
- 1636 kg (3600 lbs)
- Flights in 2000, 2002 (30 days), launch failure in 2005
- Flight in 2007

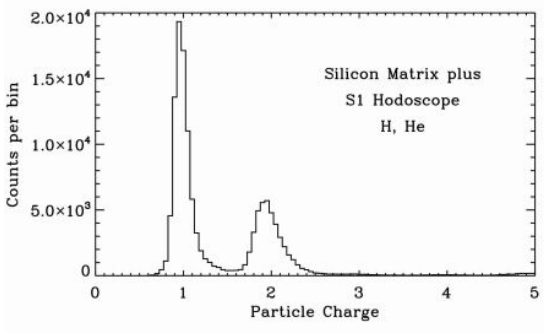


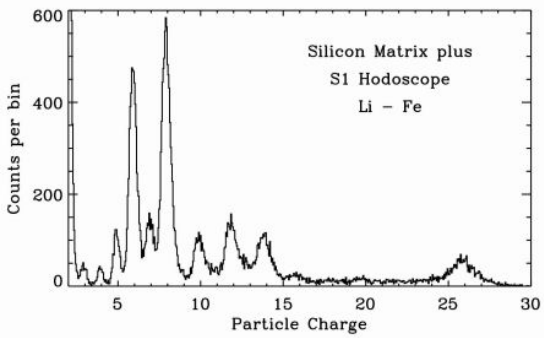
Approaching the "knee" (CREAM)

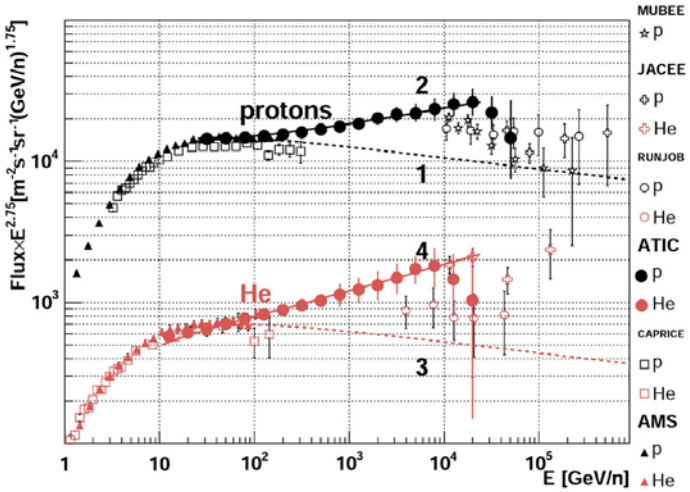


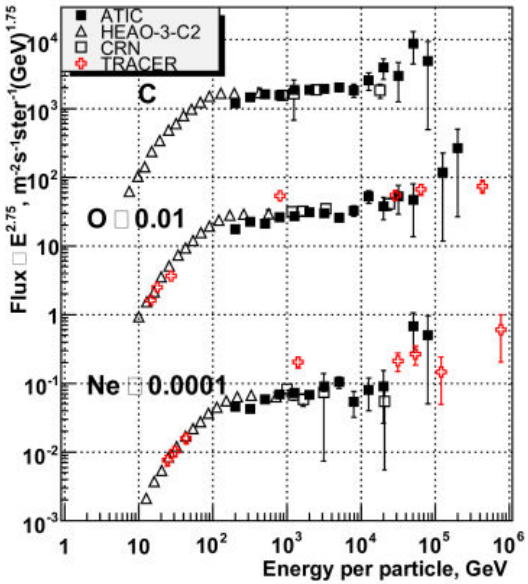
- The proton spectrum follows a power law with little change up to ~ 100 TeV.
- The He spectrum seems harder than the proton spectrum.
  - If this continues, the "knee" composition could be dominated by He
  - He/p ratio is about a factor of 2 higher at ~10TeV/n than 10-100 GeV/n
- Future flights will extend the CREAM energy reach to higher energies and distinguish hadronic interaction models such as QGSJET and SIBYLL used for ground based data.

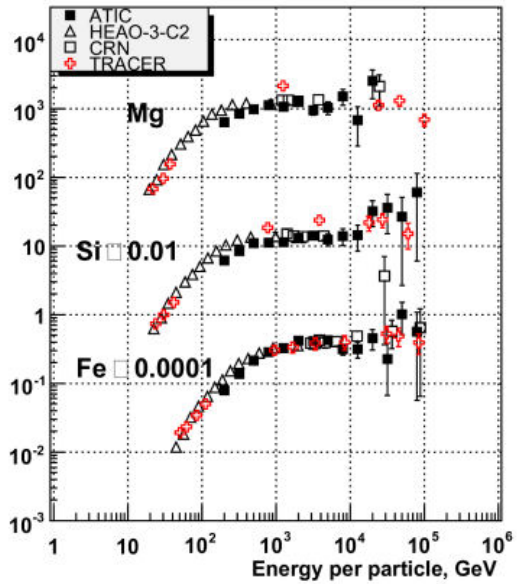
Preliminary ATIC-2 Results

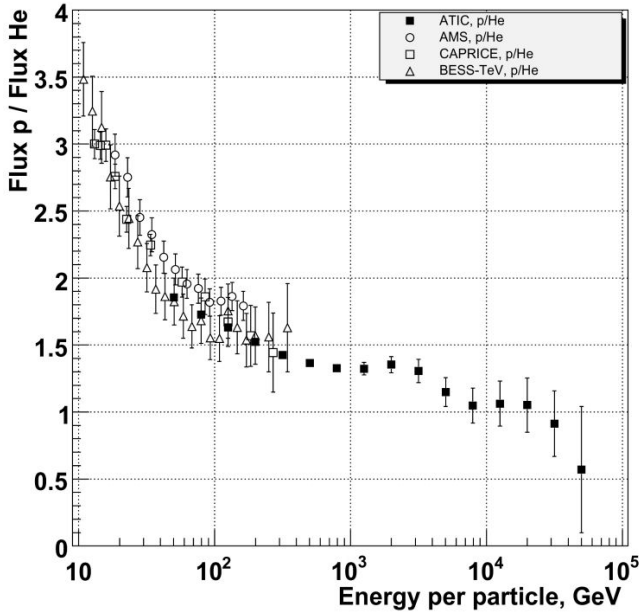












Cosmic ray balloon payloads(2)

Transition Radiation Array for Cosmic Energetic Radiation (TRACER)

- Direct measurements of O to Fe from ~50 GeV to several 100 TeV; 5 m^2 sr
- 1614 kg (3550 lbs)
- Flights in 2003, 2006 (14 days)
- Proposing for more flights

Trans-Iron Galactic Element Recorder (TIGER)

- GCR nuclei heaver than iron (26 < Z < 40) for energies ranging from 0.3 to ~100 GeV/nucleon
- 700 kg (1543 lbs)
- Flights in 2001 and 2003 (50 days)
- Unrecovered after 2003 flight

TRACER Results

The TRACER results, extending to about 10^{14} eV per particle, represent the highest energy cosmic-ray data currently available with single element resolution.

The data can be described by a simple propagation model with

δ : 0.6 *energy dependent path length*

α : 2.3 *power law source index*

Λ_0 :0.1 g/cm^2 *residual path length*

The TRACER data indicate a common origin and mode of propagation for all species. They are consistent with predictions of commonly accepted shock acceleration models.

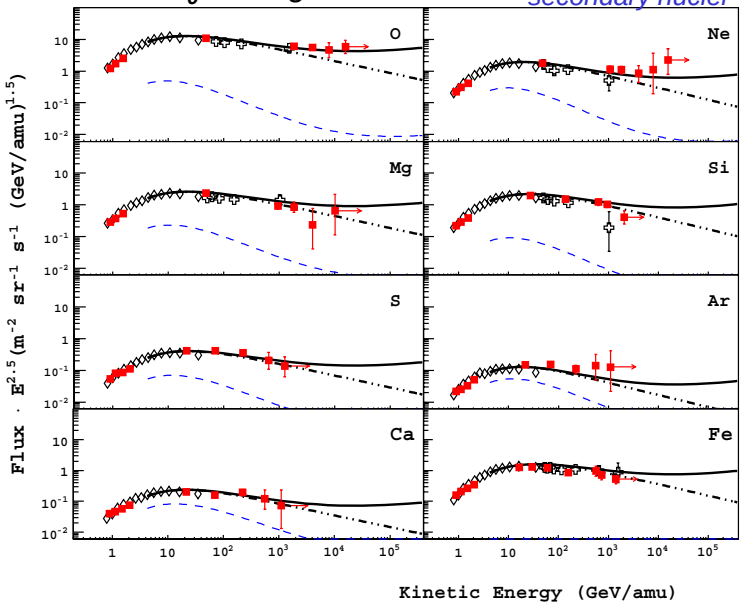
The relative source abundances of cosmic rays confirm the anti-correlation with the first ionization potential, or volatility at high energy.

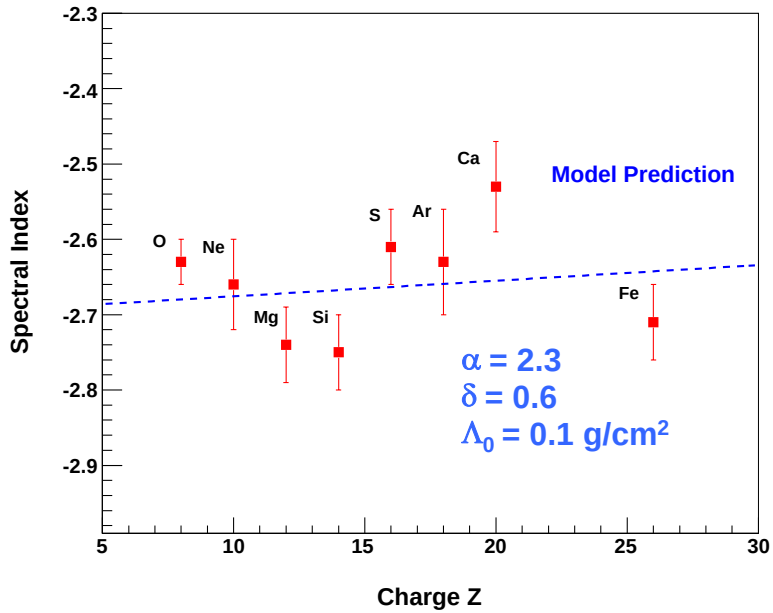
TRACER + Propagation Model

α = 2.3

Λ_0 = 0.1 g/cm^2

Dashed Line
Contribution from secondary nuclei

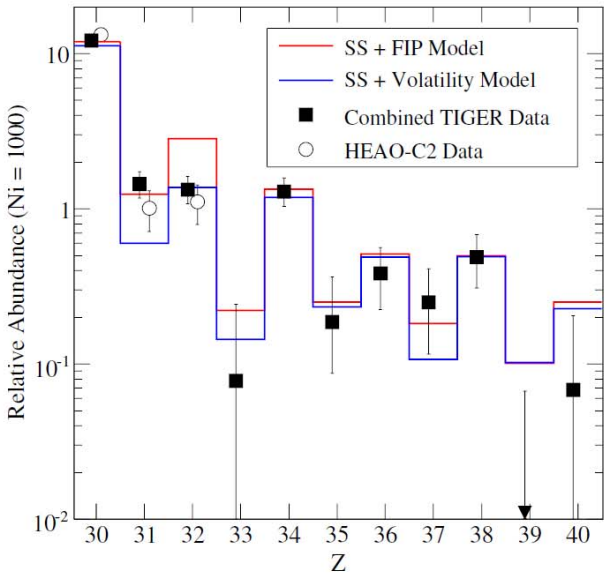




TIGER Results

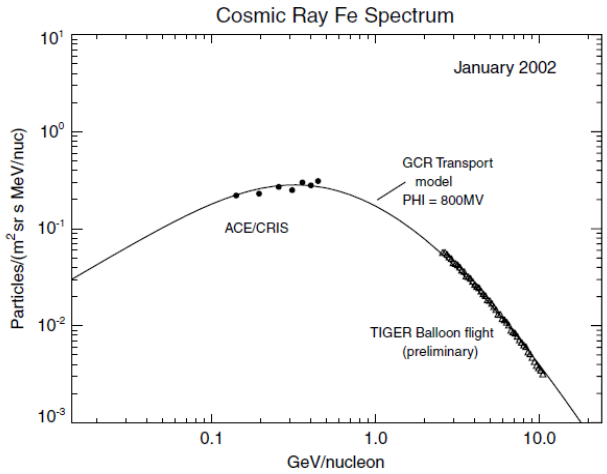
Volatility or FIP Fractionation or ??

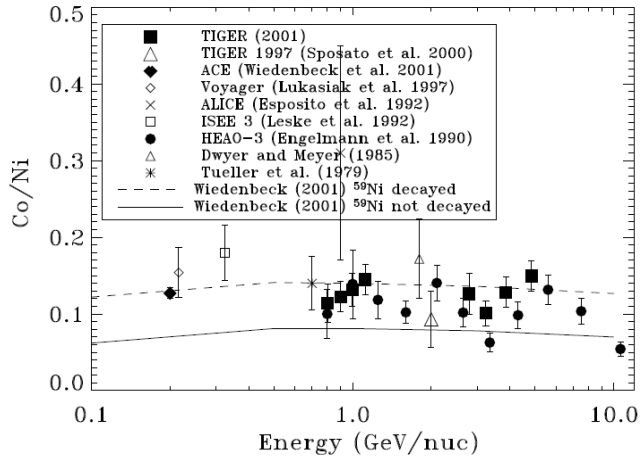
Top-of-atmosphere abundances



- $_{31}$Ga agrees with SS+FIP.
- $_{32}$Ge agrees with SS+Volatility.
- The disagreement suggests that the source abundances are not SS.
- TIGER results for Ga and Ge are consistent with HEAO-C2.

ACE/CRIS & TIGER

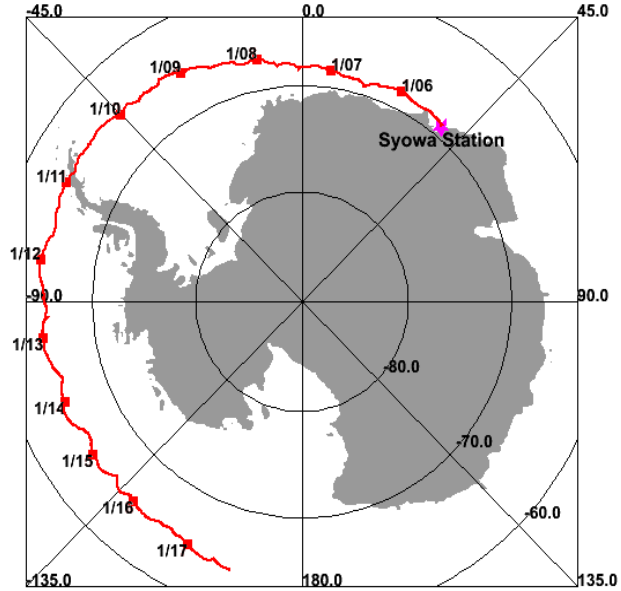


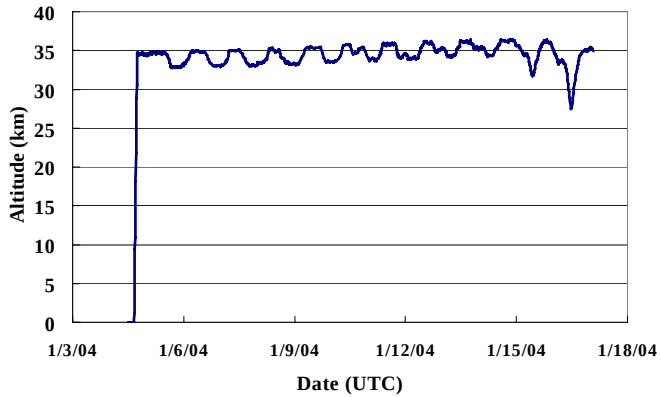


PPB-BETS Flight

- **Launched at the Syowa Station, Antarctica**
- **Level Altitude ~34.6 km**
- **13 days flight**
  (Jan. 4, 2004 to Jan. 17)
  HE (>100 GeV)
  ～5700 events, (0.02 Hz)
  LE(>10GeV)
  ～22000 events, (3 Hz)

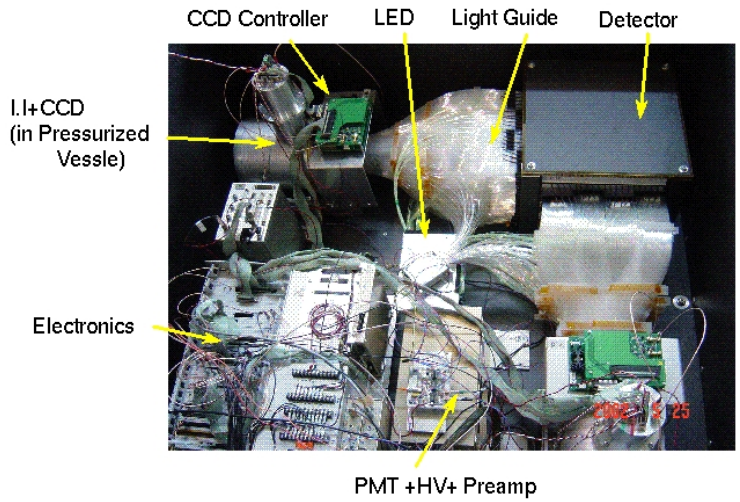
More than 20 times larger than previous flights at Sanriku





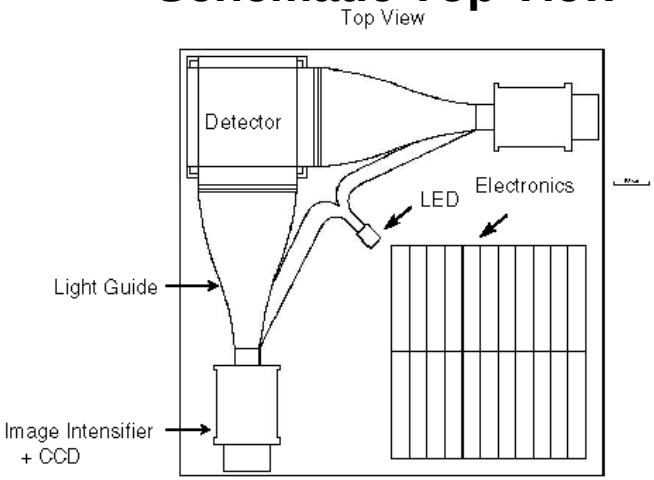
Instrument and Flight in Antarctica

View of PPB-BETS



Payload in Antarctica

Schematic Top View



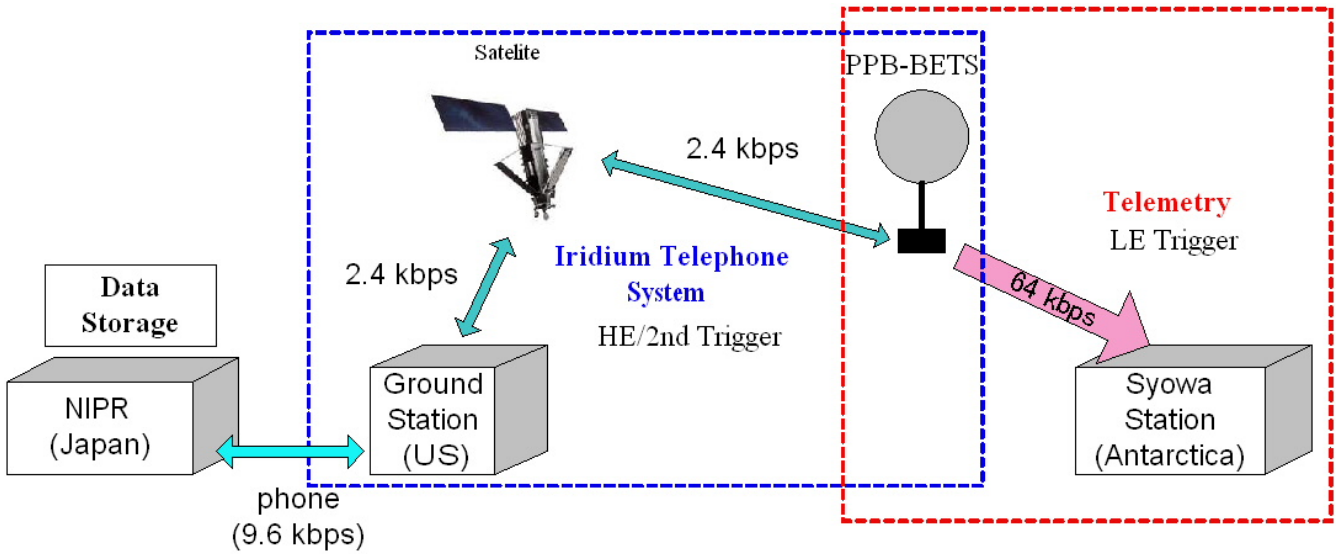
Trigger and Data Transfer System

- Low Energy (LE) Trigger
  - 10 GeV – 100 GeV
  - 10 hours from launching
- High Energy (HE) Trigger
  - 100 GeV – 1 TeV
- 2nd Trigger
  - Software trigger selected from HE

Direct telemetry to Syowa Station

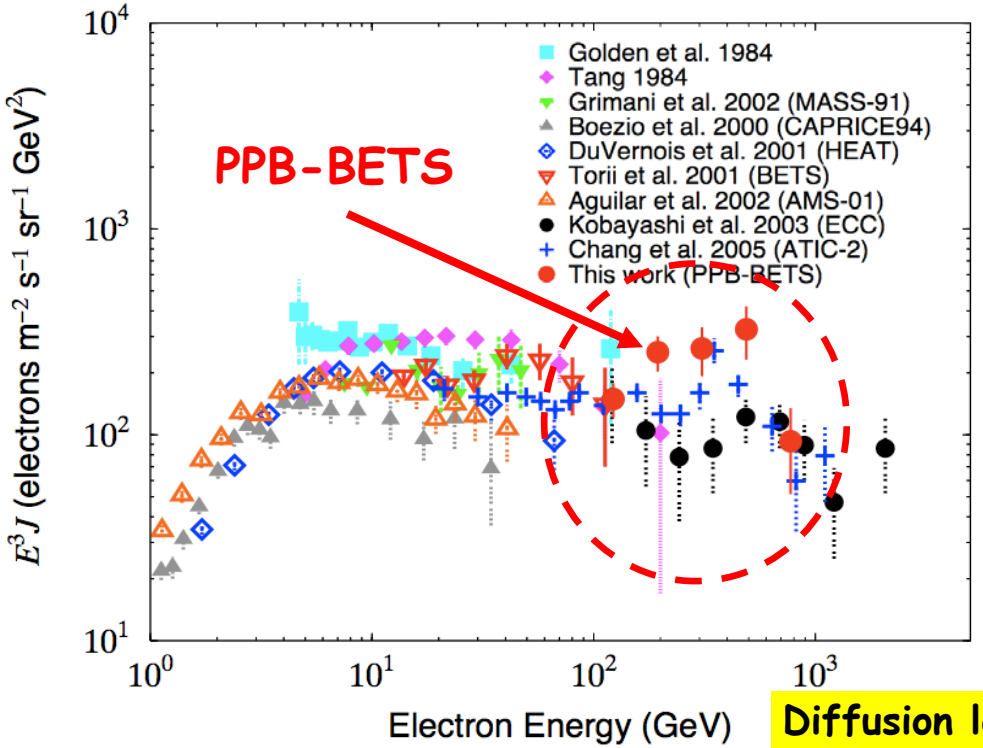
Storage to on-board disk

Iridium satellite telephone

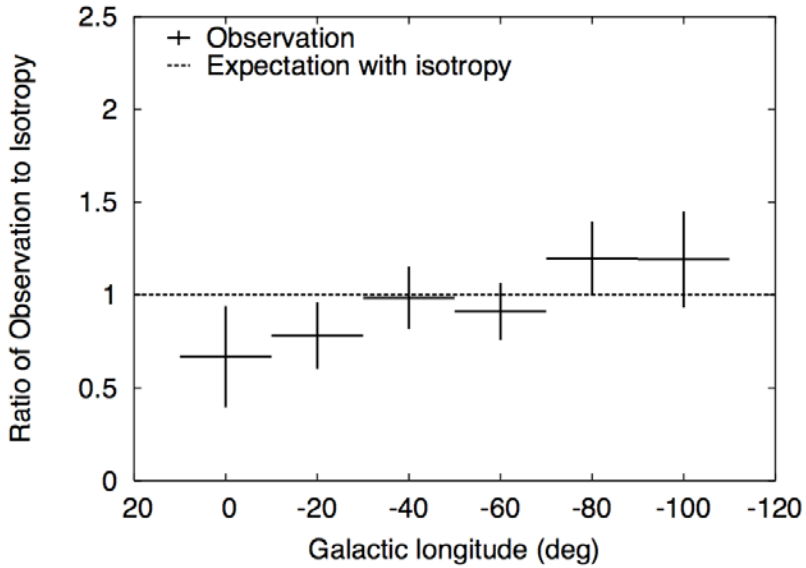


PPB-BETS Results

Energy spectrum of electrons in the energy range of 100GeV to ~1TeV



Ratio of observation to isotropic distribution along Galactic longitude

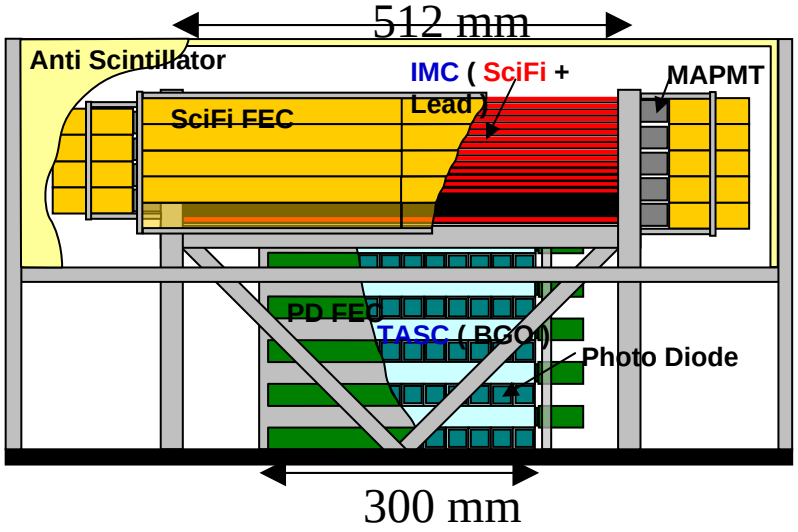


(Expected anisotropy by a model: ~1% >200GeV)

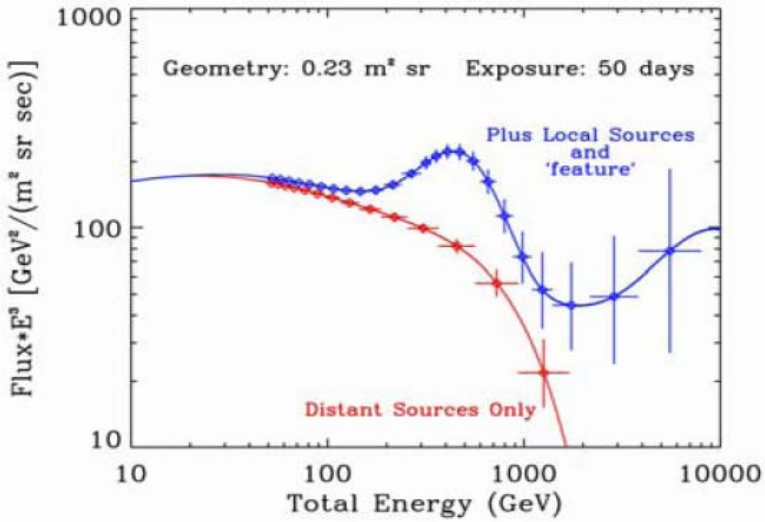
Diffusion length during the loss Time: $[4D(E)T_{loss}]^{1/2}$=1-2 kpc

Possible bump at 300 – 800 GeV seen by both ATIC and PPB-BETS may be a source signature?

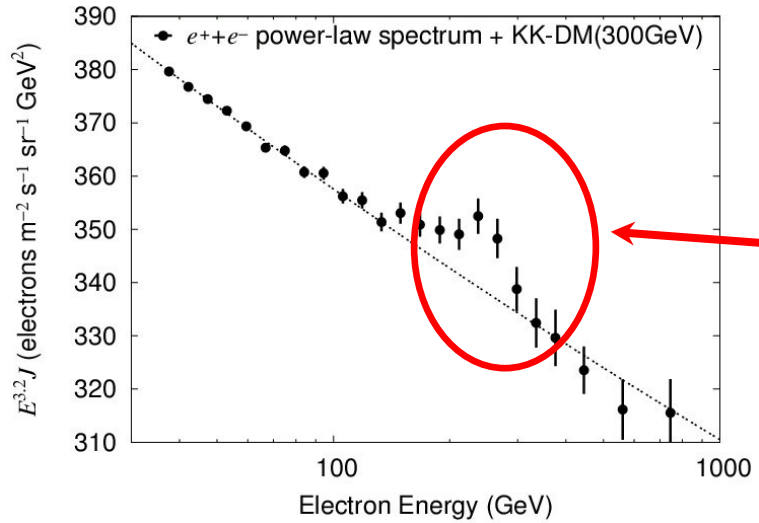
Future Electron Observation by PPB BETS-II



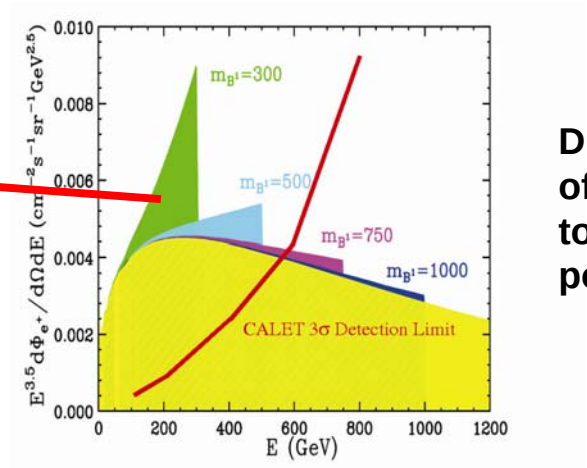
Expected Observation of Electron Energy Spectrum up to a few TeV



Expected Flux for SΩT~ 1000 m2 sr day



Nearby Sources and/or Dark Matter Signature !!



Direct decay of K-K Dark Matter to electron and positron

まとめと今後の展望

- 2000年以降の南極周回気球実験によって宇宙線観測は質的な飛躍を伴う目覚しい進展をとげている。

- NASAはこのような観測計画を戦略的に進めており、南極周回気球の約80%は宇宙線関連の観測に利用されており、今後もこの方針を堅持する予定である。

- 我々は、国内実験の経験を生かして電子観測による宇宙線加速源の検出をおこなうという極めてユニークな観測を昭和基地において実施し、世界に先駆けてTeV領域にいたるエネルギースペクトルの観測に成功した。

- 南極における長期間気球実験は、宇宙線研究にとって不可欠であり、暗黒物質の探索など宇宙物理学の新局面を開拓する可能性が高い。

- 国際ネットワークの実現により、米国マクマード基地をはじめとする諸外国との共同により、放球機会の確保とデータ受信、装置回収などの効率化を実現できることが期待される。

PPB-BETSの観測に対する極地研の全面的支援に感謝するとともに、今後においてもさらなる観測の実現に向けてご支援をお願いします。