### Direct detection of Cosmic Rays L. Derome (LPSC Grenoble)

CRISM, june 2009

# Plan I will focus on: Recent (<3 years) measurements of e<sup>-</sup>/e<sup>+</sup> fluxes and positron fraction. > Recent (<3 years) measurements of cosmicray nuclei fluxes.

Future experiments and prospects

#### e<sup>+</sup>- e<sup>-</sup> Measurements

#### **Experimental challenge**

- ➢ Rare signal → large acceptance
  Note: A = A = A = A
  - $\rightarrow$  long exposure time
- Huge background from p component e<sup>-</sup>/p ~1% @ 1 GeV, ~0.1% @ 1 TeV, e<sup>+</sup>/e<sup>-</sup> ~0.1
  - $\rightarrow$  optimal e/p separation
  - $\rightarrow$  charge sign measurement

#### **Experimental measurements**

- All electron spectrum (e<sup>+</sup> + e<sup>-</sup>) → e/p rejection
- Positron fraction (e<sup>+</sup>/e<sup>-</sup>+e<sup>+</sup>) → e/p rejection, charge identification
- Absolute fluxes e<sup>+</sup>, e<sup>-</sup> → e/p, charge identification.

### ATIC Instrument

- Balloon experiment
- 3 Antarctic flights

12/28/00 - 1/13/01 (ATIC 1) 12/29/02 - 1/18-03 (ATIC 2) 12/27/07 - 1/15/08 (ATIC 4)

#### How are electrons measured ?

- Silicon matrix identifies charge
- Excellent energy resolution ±2% (Deep BGO Calorimeter)
  - $\rightarrow$  Key for identifying spectral features
- Key issue: Separating protons and electrons
  - Use interactions in the target
  - Energy deposited in the calorimeter
  - Shower longitudinal and transverse profile
     →Reject all but 1 in 5000 protons





### ATIC Bump

## The ATIC e<sup>-</sup>+e<sup>+</sup> results exhibit a "feature":

- Sum of data from both ATIC 1 and ATIC 2 flights
- "Feature" at about 300 800 GeV
- Significance is about 3.8 sigma
- Also seen by PPB-BETS



### ATIC Bump



ATIC-4 with 10 BGO layers has improved e ,p separation.

"Bump" is seen in all three flights.

Significance for ATIC1+2+4 is 5.1 sigma

### HESS

- Ground based atmospheric Cherenkov telescope array for gamma-ray astronomy
- for e<sup>-</sup>+e<sup>+</sup>:
  - Observes off-source regions of sky.
  - Separates proton background by 'random forest' approach using simulations
    - $\rightarrow$  Systematic uncertainty
  - Huge collecting area
     → High statistic results
  - Energy resolution ~ 15 %
  - Energy threshold > 100 GeV



### High Energy ( > TV) HESS Analysis



 $\rightarrow$  Shows a rapid fall off in the spectrum beyond TeV energies.

L. Derome, CRISM, June 2011

#### Low Energy (0.34 – 0.7 TeV) HESS Results

Astronomy and Astrophysics, 508, 561, December 2009



→ Considering the systematic, statistical uncertainties and the HESS energy threshold, HESS and ATIC results are not clearly incompatible.

#### Fermi-LAT

FERMI-LAT: Gamma-Ray Space Telescope

- Anti-Coincidence
   Detector
- Tracker
- Calorimeter

Measuring  $(e^++e^+)$  in FERMI-LAT:

- Energy resolution: ~20%
- Large acceptance: 2 m<sup>2</sup>sr at 300 GeV
- p/e rejection factor: ~10<sup>3</sup>
- Hadronic contamination: up to 20 % at high energy.



Launch 11. jun 2008 Nominal operations: Aug 4 2008

#### Fermi-LAT e<sup>+</sup>+e<sup>-</sup> flux



- High statistics  $\rightarrow$  errors dominated by systematic uncertainties
- Fermi data do not confirm the ATIC Bump
- Still indicates an excess above 100 GeV

### PAMELA

 PAMELA installed on Russian satellite Resurs-DK1, inside a pressurized container.



- Mission started on June 2006, extended to 5 years total lifetime.
- Magnetic spectrometer
   → e<sup>+</sup>/e<sup>-</sup>, anti-p/p identification
- Calorimeter+Neutron Detector e/p rejection



#### PAMELA cosmic-ray e<sup>-</sup> Flux



### PAMELA positron fraction

At low energies, results are systematically lower than data collected in 1990's:
→This is interpreted as the effect of charge-sign dependent solar modulation.

•At high energies data show a significant increase with energy.



#### **PAMELA** positron ratio





But the increase with energy not explained by standard (steadystate) models of secondary production of cosmic rays.



#### Pamela Antiproton

#### PAMELA observation of the antiproton flux



### Short summary of data

 In e<sup>+</sup>/(e<sup>-</sup>+e<sup>+</sup>) ratio and e<sup>+</sup>+e<sup>-</sup> flux: excess in addition to the background model.

(Some experimental results still not compatible)

- Antiproton flux compatible with a pure secondary component.
- $\rightarrow$  need for e<sup>+</sup>/e<sup>-</sup> additional source
  - Dark Matter annihilation: simplest dark matter scenarios are strained:
    - Need for a strong boost factor.
    - Leptophilic channel to not overproduce antiproton.
    - TeV and higher mass favored.
  - Nearby pulsars: natural sources of e<sup>-</sup>/e<sup>+</sup>, readily reproduce the data.

#### Pulsar scenario



•Each gray line corresponds to a randomly chosen set of pulsar parameters

 $\rightarrow$  Both the PAMELA positron excess and the Fermi-LAT data are naturally explained in this scenario.

## Cosmic-ray nuclei measurements

#### The CREAM experiment

**CREAM (Cosmic Ray Energetics and Mass):** 

Balloon borne experiment, dedicated to high energy cosmic ray measurements between 1 TeV – 1000 TeV

- 6 LDB flights achieved: CREAM I-VI
   >100 days of cumulative exposure
- > Instrument:
  - Energy measurement: Tungsten-Calorimeter
  - Charge identification:
    - -Silicon detectors
    - -Imaging Cherenkov Camera
  - No e/p separation



CREAM Coll. : US, Korea, Italie, Mexico, France

#### Nuclei spectra from Cream

- Proton spectra harder than Helium spectra?
  - → Coming from different type of sources/acceleration sites?

Indication of a hardening of the spectra above ~200 GeV/n
 →Nearby sources?
 →Propagation effect?



#### Proton and Helium fluxes from Pamela



• Tend to confirm a spectral hardening at high energy



#### Summary of the data

 Many new data in the recent years, which may imply something new:

The hardening of CR nuclei spectra may challenge the conventional understanding of the acceleration and propagation of CR particles.

- → In the forthcoming years, new experiments should confirm (or not) these results with:
  - Improved statistics
  - Reduced systematic
  - Extended energy range

### AMS02

#### **Magnetic Spectrometer on ISS**

AMS experiment is to perform accurate, high statistics, long duration (>10 y) measurements in space of:

- Energetic (0.1 GV few TV) charged CR
- Energetic (>1 GeV) gamma rays.
  - > Measurements of particle:
    - Rigidity: Silicon Tracker in permanent magnet
    - e-γ energy: Electromagnetic Calorimeter (ECAL)
    - (e/p) rejection: TRD & ECAL
    - Charge: TOF, Tracker, RICH, TRD
    - Velocity: TOF, RICH



#### AMS on ISS

AMS is running in nominal condition since May 19.

More than 10<sup>9</sup> triggers registered

#### AMS02: e<sup>+</sup> and e<sup>-</sup>

>AMS02 will provide precise absolute flux for:

- e<sup>+</sup> up to 300 GeV
- e<sup>-</sup> up to 1 TeV

High confidence level ( $e^+/p$  rejection factor > 10<sup>5</sup> up to 300 GeV)



+Simultaneous measurement of p and search d

L. Derome, CRISM, June 2011

### AMS02: Elemental flux and ratio

AMS02: charge identification from:

TOF, Silicon Tracker (Energy deposit) and RICH (Cherenkov light)



- High-precision absolute flux measurement for all elements up to Z~30 and for 200 MeV/n < E < 1 TeV/n</p>
  - $\rightarrow$  Study of individual spectra
  - $\rightarrow$  Complete set of data to constrain propagation models

#### **CALET: CALorimetric Electron Telescope**

#### **CALET Mission Concept**

Instrument: High Energy Electron and Gamma-Ray Telescope Consisted of

- Imaging Calorimeter (IMC)
- Total Absorption Calorimeter (TASC)

Launch: HTV: H-IIA Transfer Vehicle

 Attach Point on the ISS: Exposed Facility of Japanese
 Experiment Module (JEM-EF)

Life Time: >3 years

Mission Status Launch around 2013 in Plan



**CALET Payload:** 

- ➤ 1 GeV ~ 10 TeV for (e<sup>+</sup>+e<sup>-</sup>)
- > 20 MeV ~ TeV for gamma-rays
- Several 10 GeV ~ 1000 TeV for nuclei
- Geometrical Factor: 1 m<sup>2</sup>sr

Japan/USA/Italie/China (PPB-BETS coll.)

#### **CALET: All electron flux**

- > All electron ( $e^- + e^+$ ) flux up to 20 TeV
- Precise flux from GeV to TeV range
- Above 1 TeV, sensitive probe of nearby accelerating sources.

Measurement of the anisotropy in electron arrival directions due to local source



#### **CALET: Elemental flux**



#### Future of Balloon flights: ULDB

NASA Balloon Program is developing a Super Pressure Balloon.
 Sealed and pressurized to maintain constant altitude night and day
 0.6 million m<sup>3</sup> balloon able to carry a one-ton instrument for 100 days

Test flight during the Antarctica campaign 08-09
>0.2 million m<sup>3</sup> balloon (scale 1/3 model)
> Sets new flight record of 54 days

![](_page_31_Picture_3.jpeg)

Image of the SPB taken through a telescope

![](_page_31_Picture_5.jpeg)

First ULDB scientific flight in forthcoming years

For the future this could allow long duration mission for balloon borne experiments like CREAM.

L. Derome, CRBM, June 2011

#### Conclusions

> Current and future experiments in the forthcoming years:

- Space experiments: PAMELA FERMI AMS02 CALET
- Balloon experiments: CREAM

 $\rightarrow$  ULDB: research platform for the future

- > They will provide new measurement with:
  - More statistics
  - Extended energy range

> These new data should confirm (or not) the  $e^+$  and  $e^-$  excess and allow to investigate their origin.

- > New nuclei precise flux measurements:
  - Confirmation and detailed study of the hardening of nuclei spectra.
  - Very important to understand source & propagation mechanisms:
    - Better constrains on propagation models.
    - Better estimation of primary, secondary and exotic e<sup>+</sup> and e<sup>-</sup> flux.