# Models of cosmic ray modulation in light of new data from AMS-02

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## **Galactic cosmic rays in the Heliosphere**

Eliopause

Voyager 1

Eliosheat

Eliosphere

Termination shock

> Space scientists Aimed at evaluations or predictions for space missions

#### **Solar physicists** Aimed at understanding CR transport in heliosphere.

#### **GCR/DM** physicists

Aimed at unveiling IS fluxes of particles and antiparticles

**GCRs** 

## **Il fenomeno della modulazione solare**

Voyager-1 2012, primi dati dallo spazio interstellare Voyager-2: dicembre 2018 nello spazio interstellare



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10<sup>2</sup>

10<sup>1</sup>

Voyager-1

INTERSTELLAR

104

# **Basic phenomenology**



#### $\rightarrow$ Connection with Sun's magnetic activity $\rightarrow$ Need of multichannel & time-resolved data



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10

1997

GeV<sup>-1</sup>

r.s

10

Voyager

## **Basic phenomenology**



A.D. 1308

[2.15 - 2.40] GV

Jan Jul

Jul

Jan

2013

**Light Nuclei** 

0.07

0.06

Jul

2011 2012







Jan Jul

2014

Jan Jul

2015

С

>> talk V. Formato

Jan Jul

2017

>> talk M. Graziani

Jan Jul

2016

Particle-resolved
Time-resolved
Energy-resolved
Space resolved



>> Updates in F. Donnini's talk

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PAMELA: Adriani et al. PRL 241105 (2016); AMS-02: Aguilar et al. PRL 120 (2018) 051102

>> talk by M. Graziani

## **Solar Modulation Calculations**



#### SDE or numerical integration methods

SDE: the solution is obtained by sampling, with the MC simulation of many particle trajectories.



#### CR transport parameters

Free parameters that regulate the processes of CR tranport in heliosphere, e.g. diffusion and drift.



#### Heliospheric input parameters

Proxies for the average condition of the •

- heliospheric plasma (the medium where •
- CRs move throught) at a given epoch
- IMF intensity
- IMF polarity
- IMF Tilt Angle

# Heliospheric input Parameters: IMF



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## **Solar Modulation Calculations**

Fiandrini et al. Phys. Rev. D 104, 023012 (2021)

Parallel component of the diffusion tensor



## Insights from protons: time lag beween CR and SSN



## Insights from the p/He ratio: diffusion

The p/He long-term behavior is a signature of *universality* of the CR mean free path  $\lambda(R)$ 



## Insights from antimatter/matter ratios: drift



Aguilar et al. PRL 120 (2018) 051102



## Insights from antimatter/matter ratios: drift



## **Predictions for the carbon flux**



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## Conclusions

### **Golden age for cosmic ray measurements**

- Data from space: Voyager-1, PAMELA, AMS-02, CRIS/ACE
- Multi-channel approach: protons, nuclei, antiparticles

## New insights to CR physics

- Proton data -> evidence for a time-lag -> timescale of CR modulation
- P/He & nuclei data -> test for low-energy diffusion of CRs in heliosphere
- Antimatter/matter -> test for charge-sign dependent effects

## From multi-channel & long-term data to space physics

- Establishment of predictive model with *forecast* capabilities
- Improve risk assessment in manned exploration missions