

Low energy cosmic rays: regulators of the interstellar medium



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Stefano Gabici

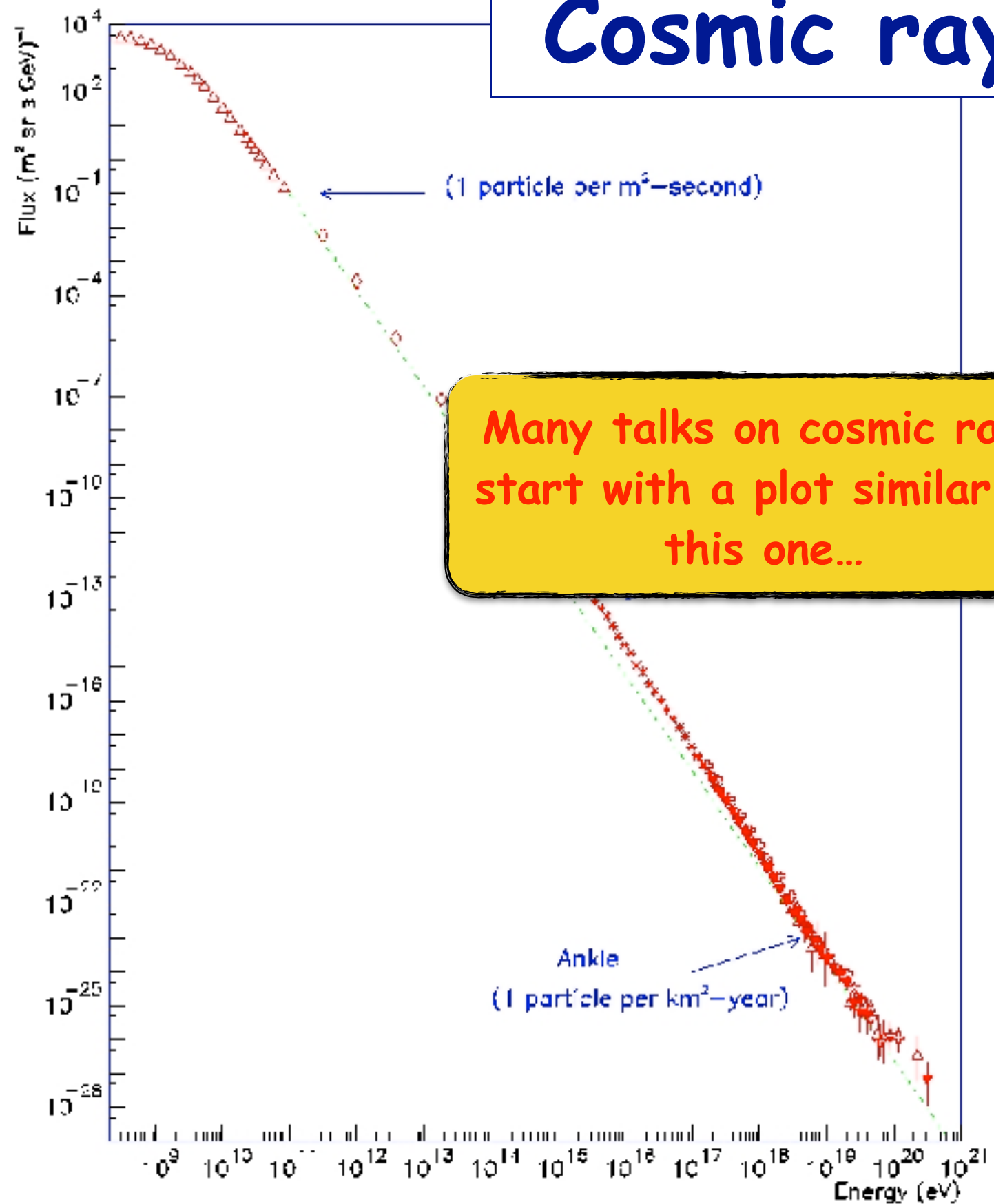
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Co-authors: F. Casse (APC), A. Coleiro (APC), A. Goldwurm (APC), A. Marcowith (LUPM), E. Parizot (APC), V. Tatischeff (IJCLab), R. Terrier (APC)

Cosmic rays

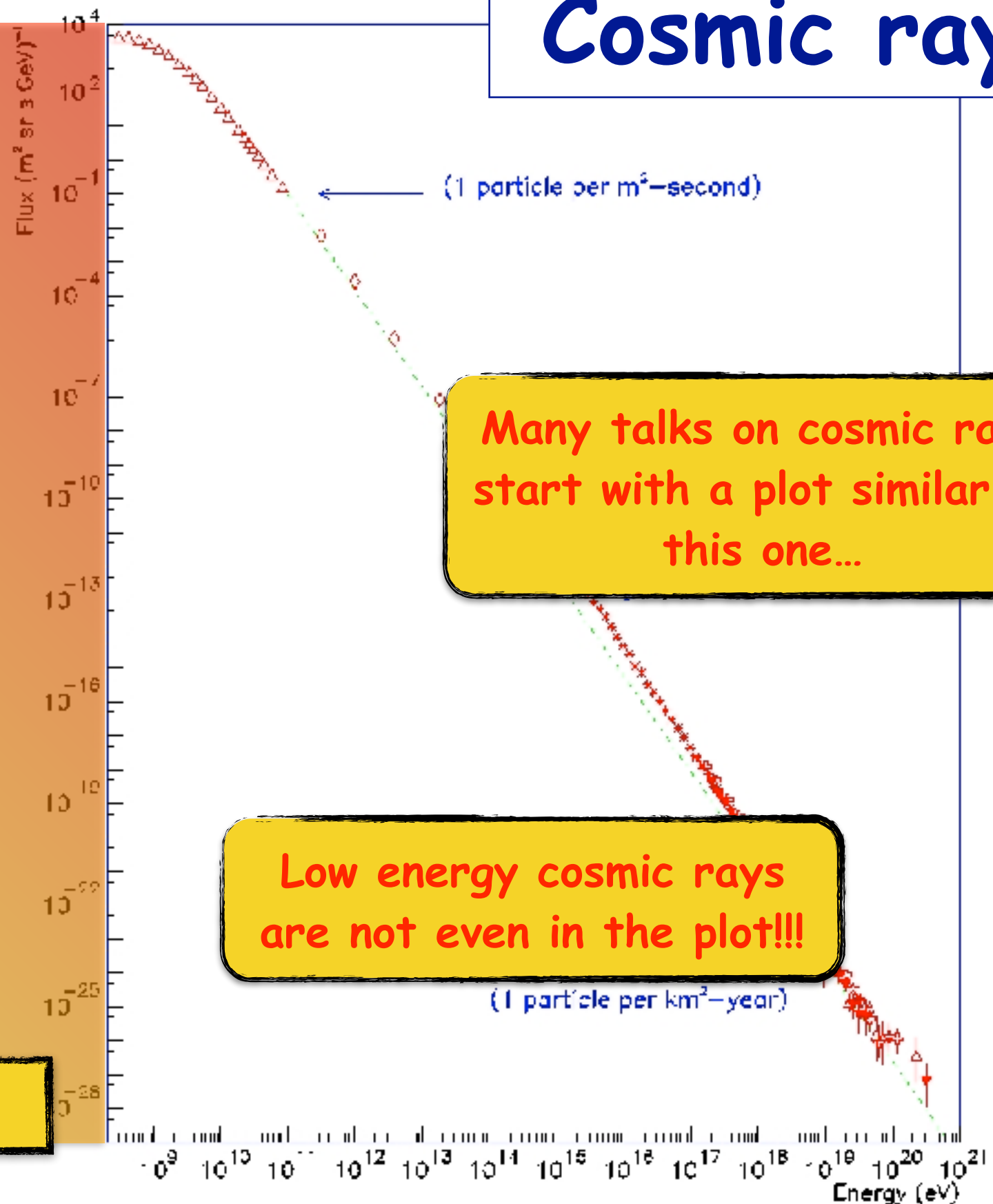


Cosmic rays

Low energy cosmic rays

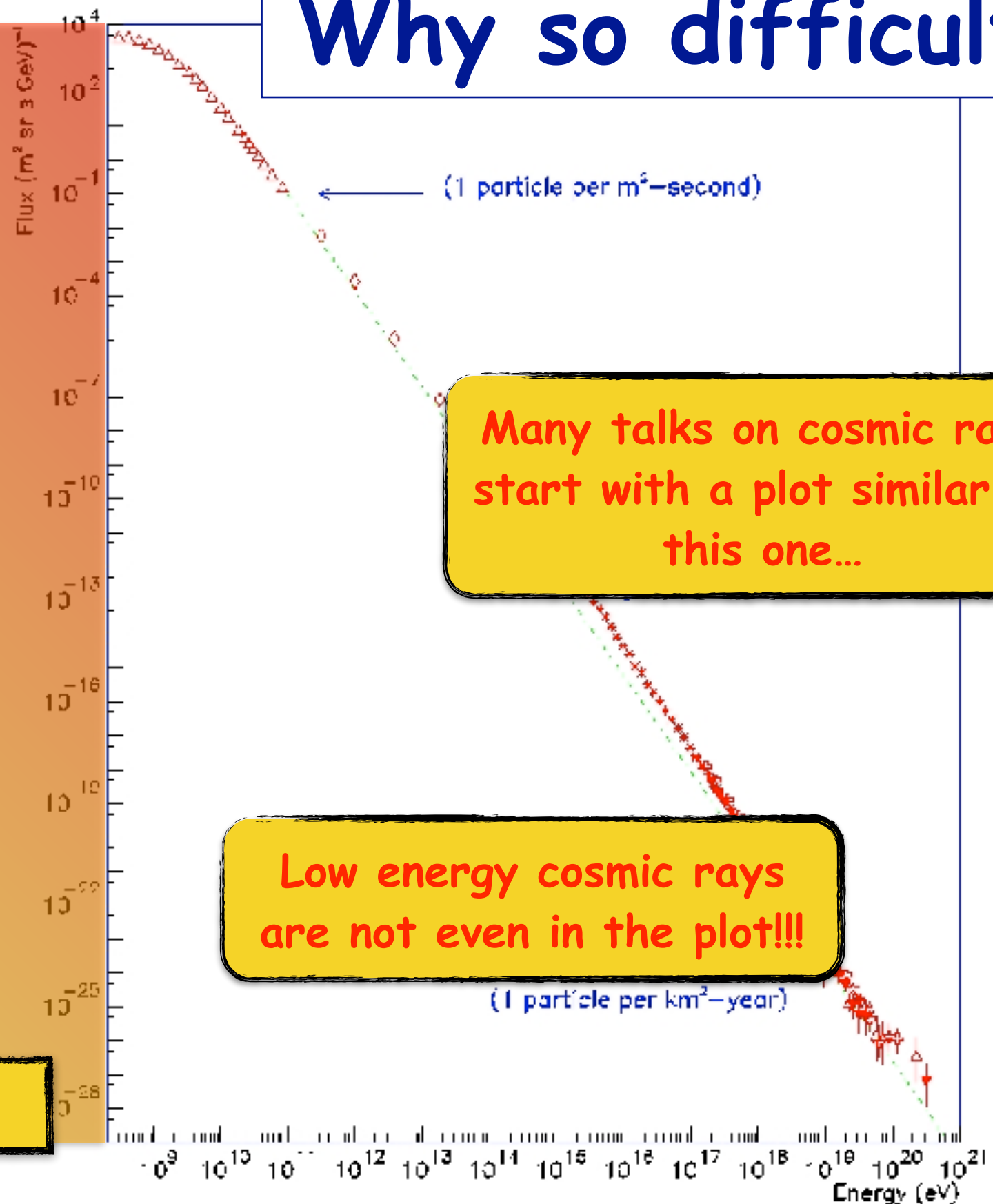
keV

MeV



Why so difficult?

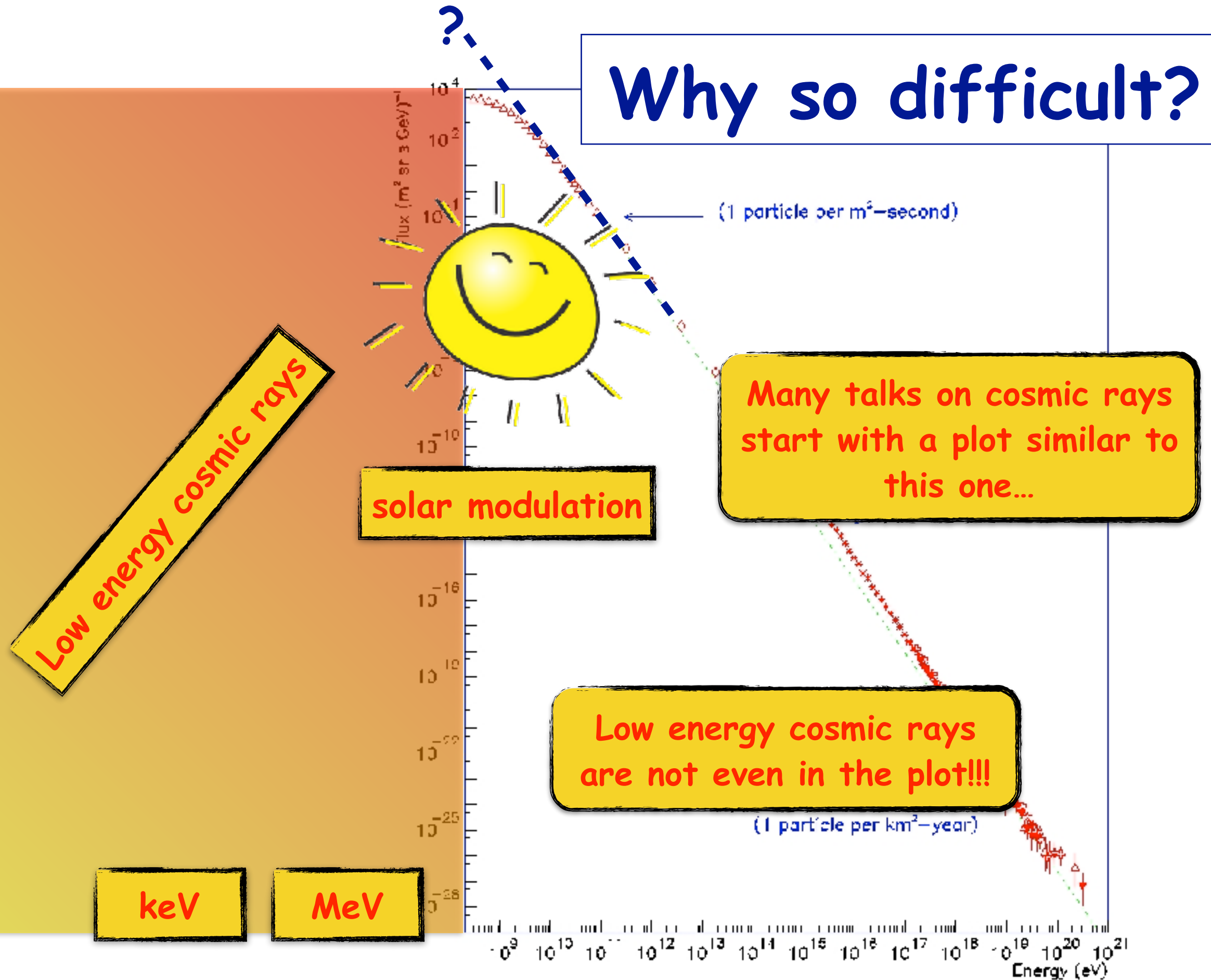
Low energy cosmic rays



keV

MeV

Why so difficult?



Why should we care?

ionisation

heating

spallative
nucleosynthesis

pressure
gradients?

CR lepto/
hadronic
interactions

PARTICLE ENERGY



Why should we care?



IR/mm lines

radio

gammas

LiBeB

coupling B-gas

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PARTICLE ENERGY

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Astrochemistry

Formation of stars & planets

Nuclear astrophysics

Formation & evolution of MCs

PARTICLE ENERGY



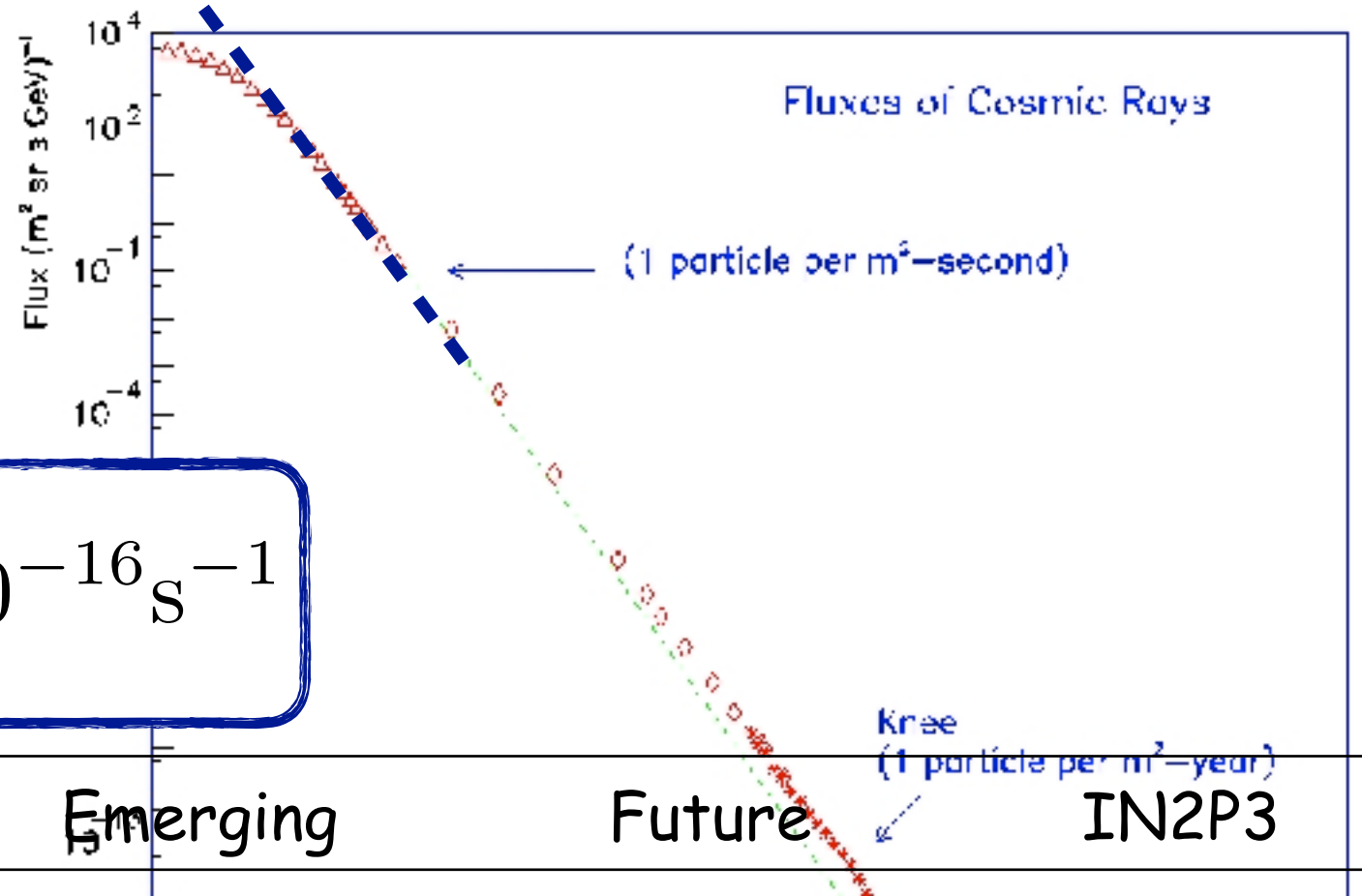
Pioneering studies

energy
losses

$\propto E$

10 MeV

100 MeV



Hayakawa+ 1961 $\rightarrow \zeta_{CR}^H \gtrsim 4 \times 10^{-16} \text{S}^{-1}$

Intro

Past/present

Emerging

Future

IN2P3

Pioneering studies

energy
losses

$$\propto E$$

10 MeV

0.85 GeV

Spitzer&Tomasko 1968
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10⁴
10²

Fluxes of Cosmic Rays

(1 particle per m²-second)

Krae
(1 particle per m²-year)

Intro

Past/present

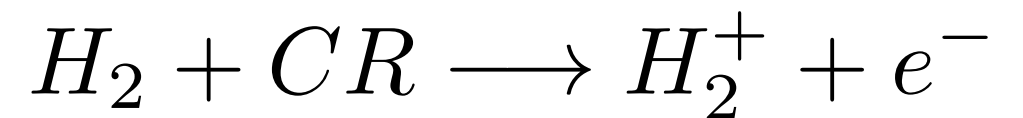
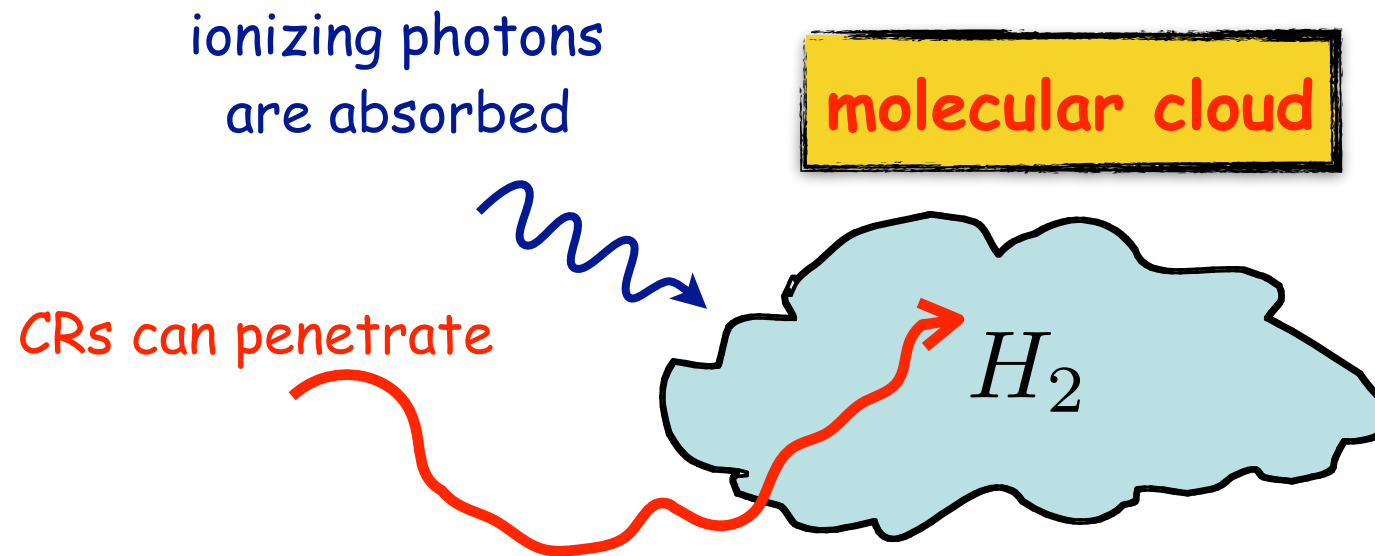
Emerging

Future

IN2P3

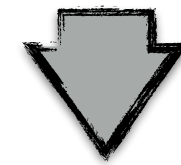
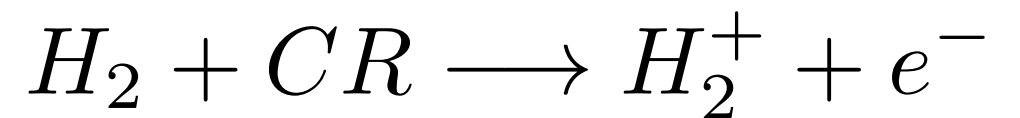
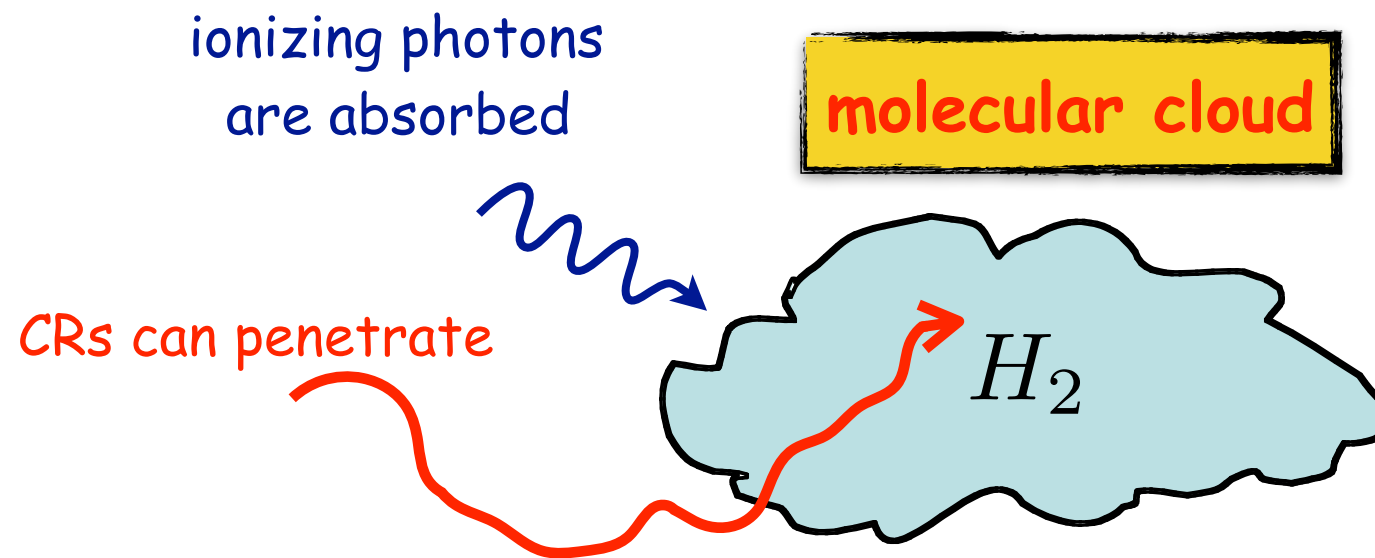
IR/mm \rightarrow CR ionisation rate

(see Padovani et al. 2009 for a recent review)

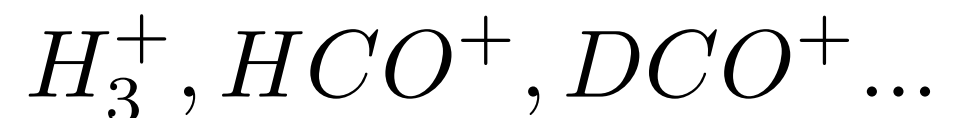
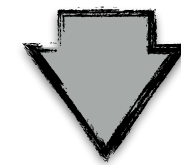


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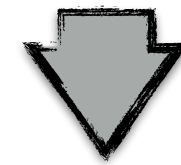
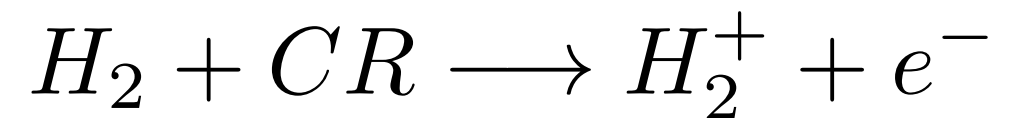
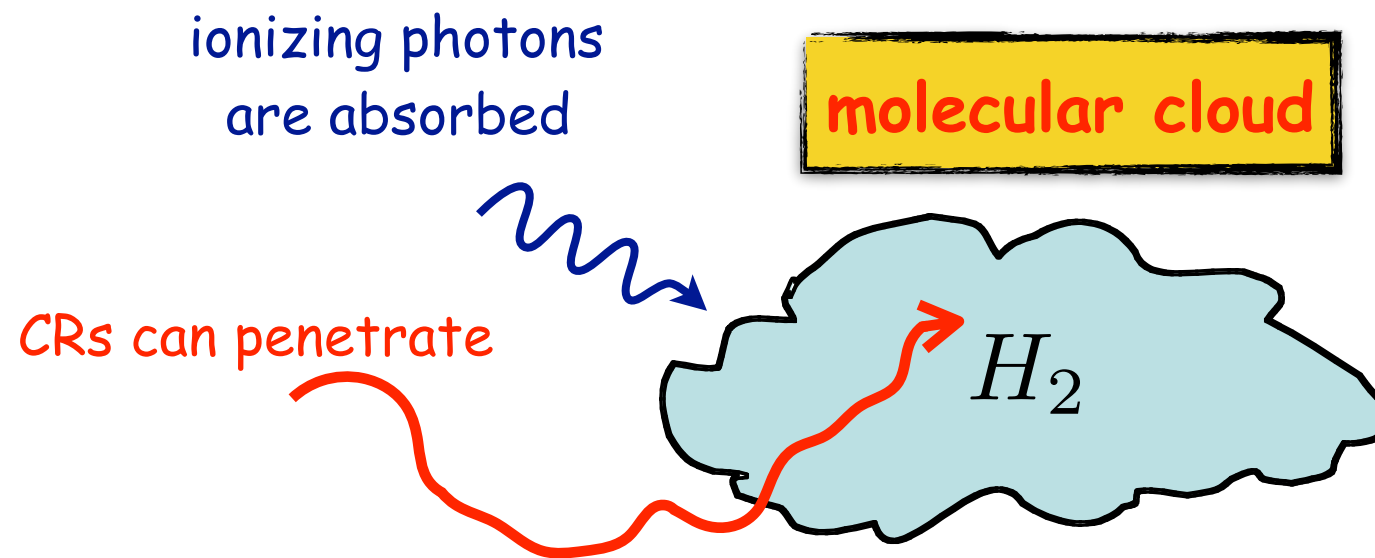
chemistry



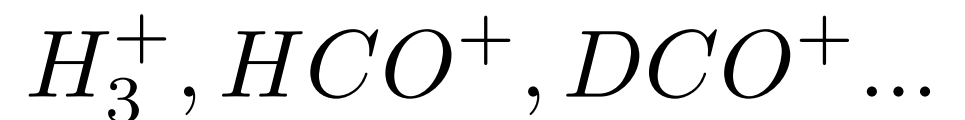
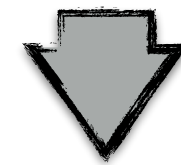
see papers by McCall, Indriolo,
Ceccarelli, Vaupré ...

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chemistry

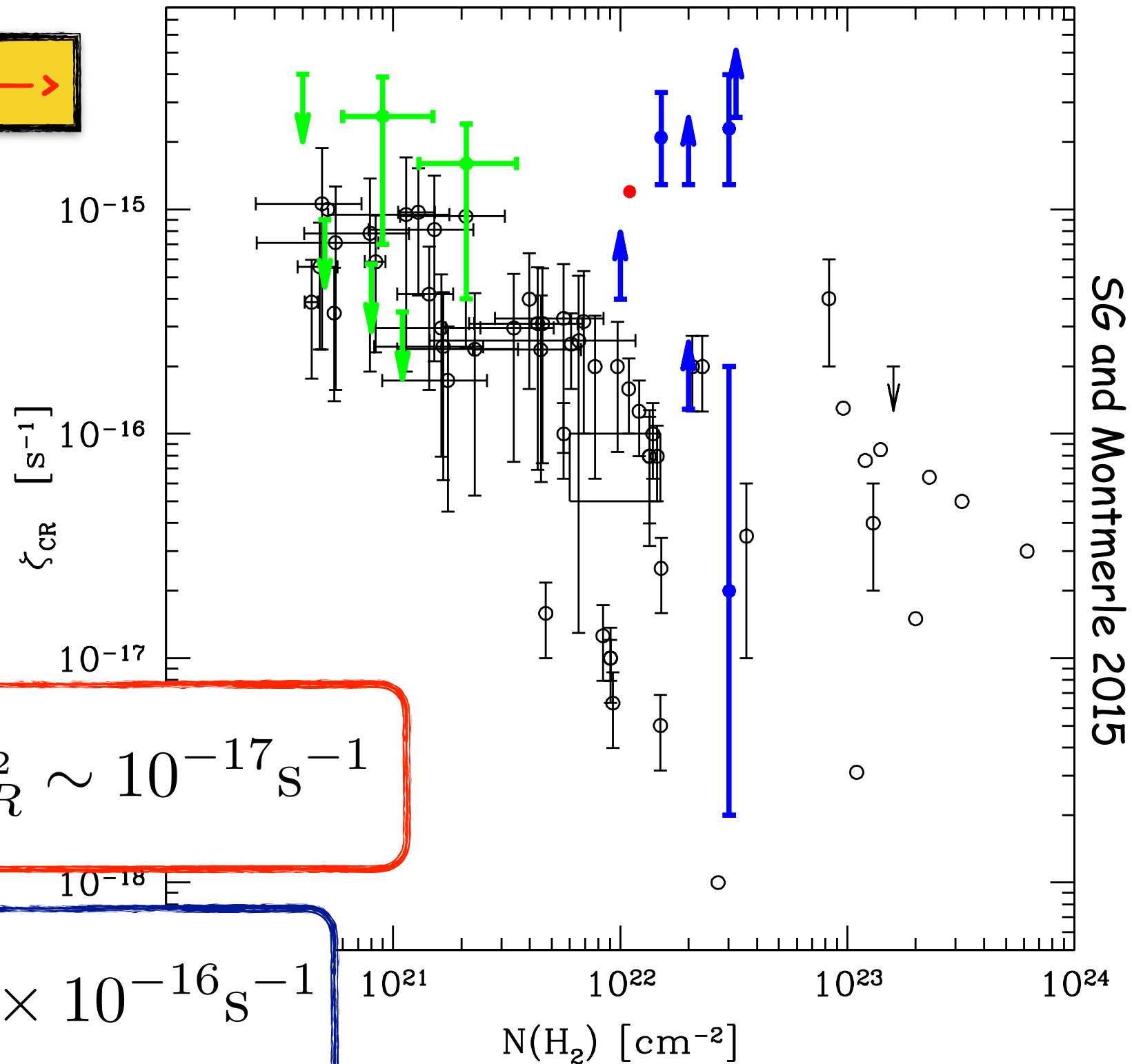


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CR ionisation rate

ion. rates observed in MCs →

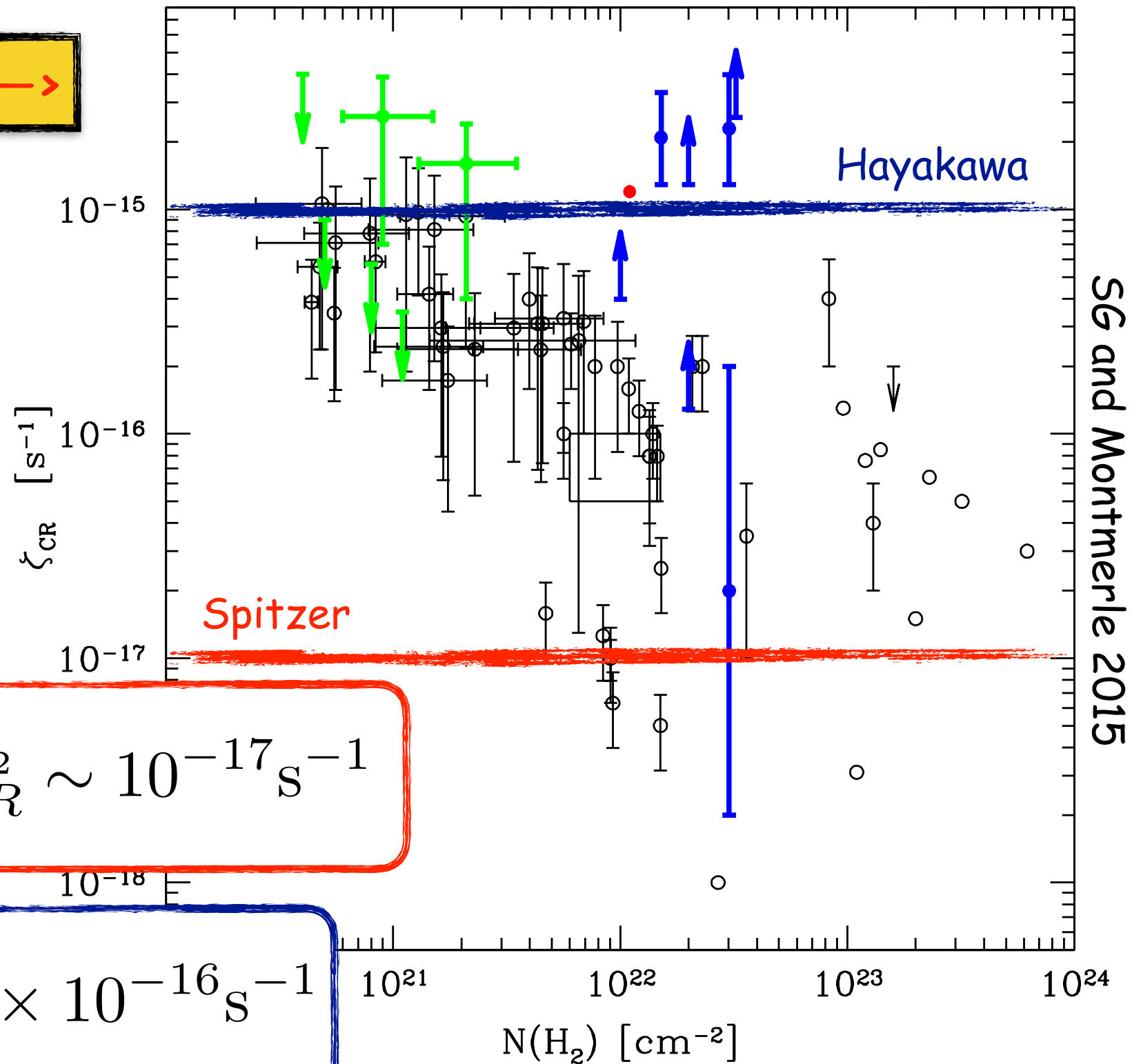


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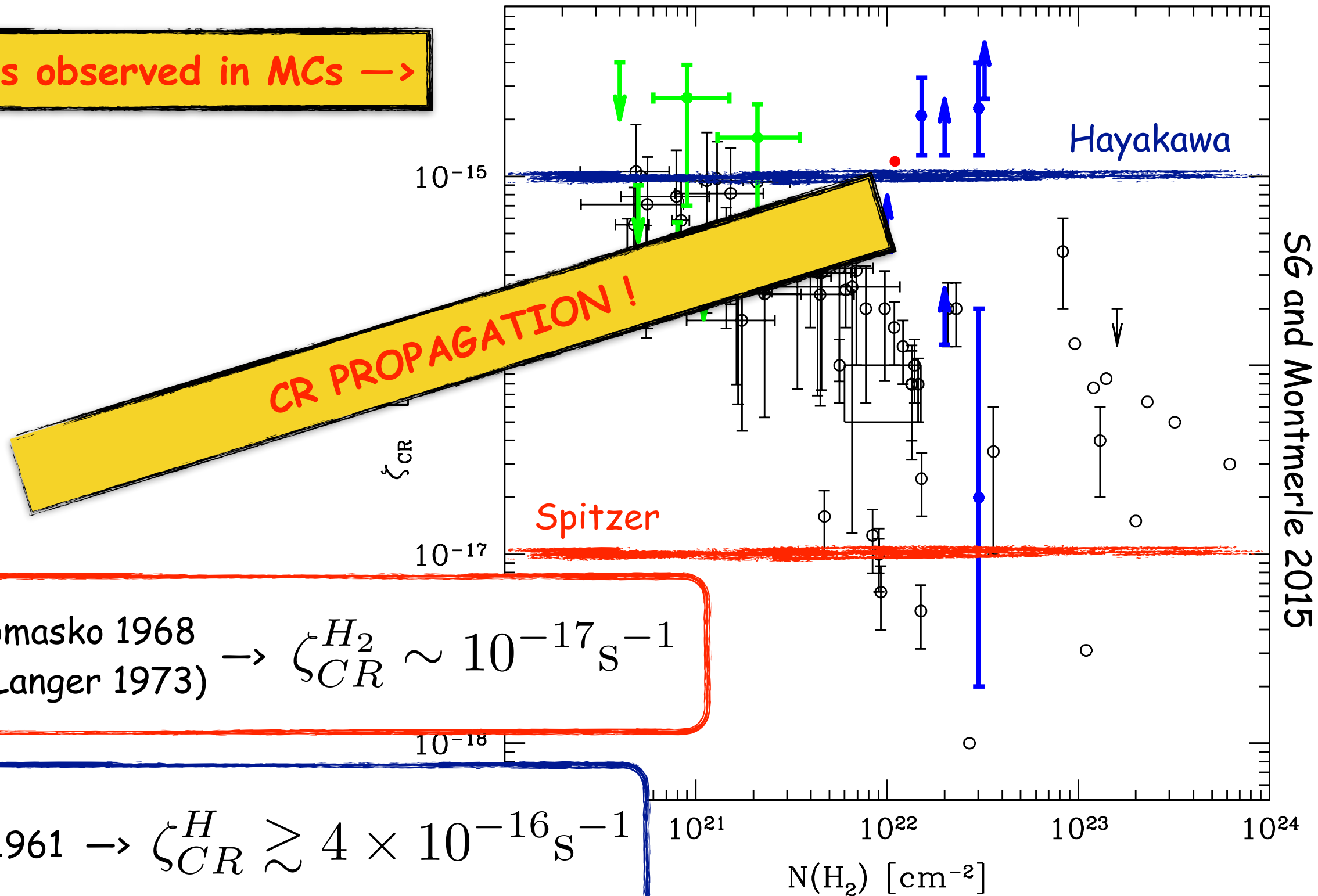


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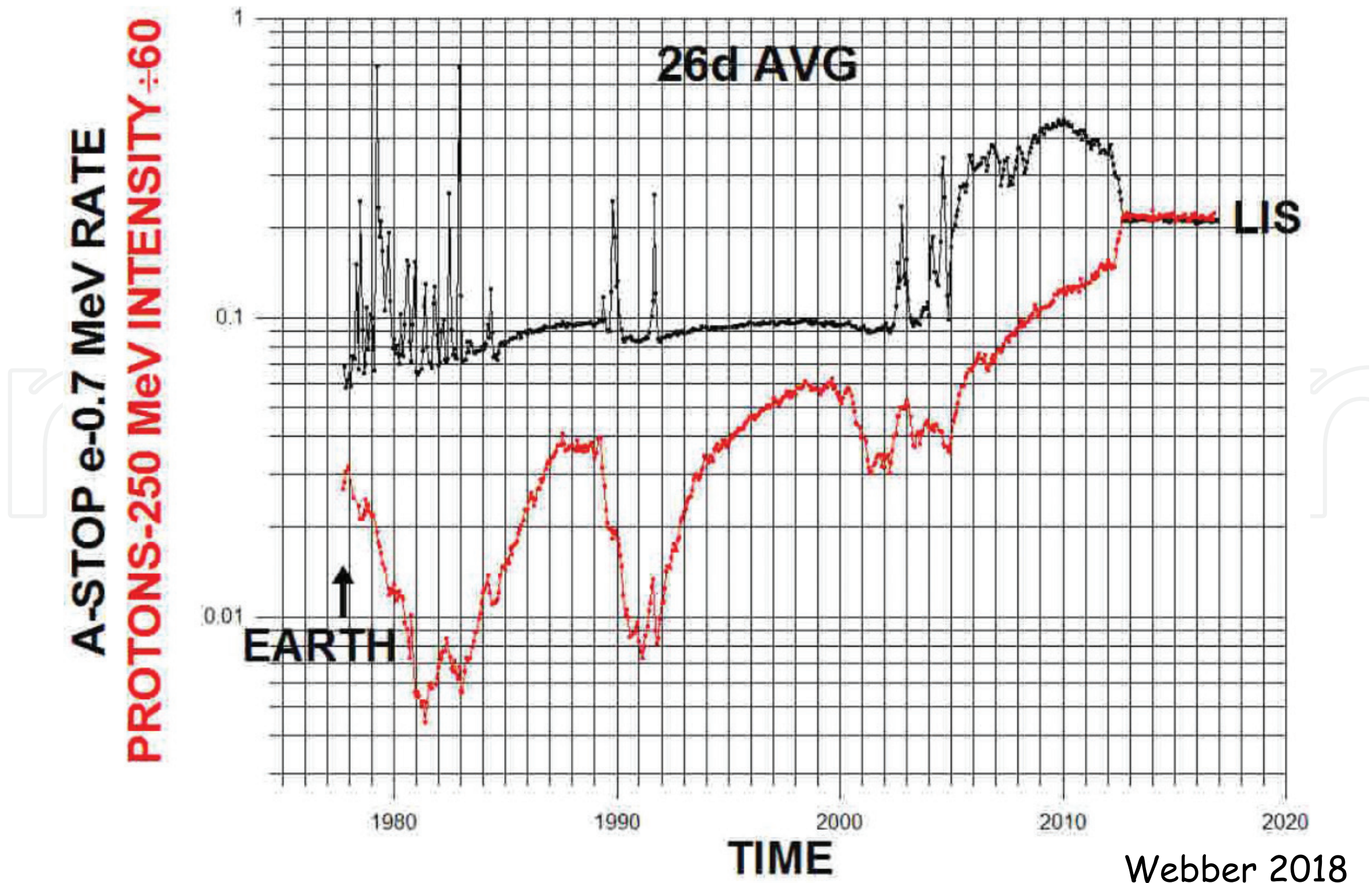
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Voyager probes

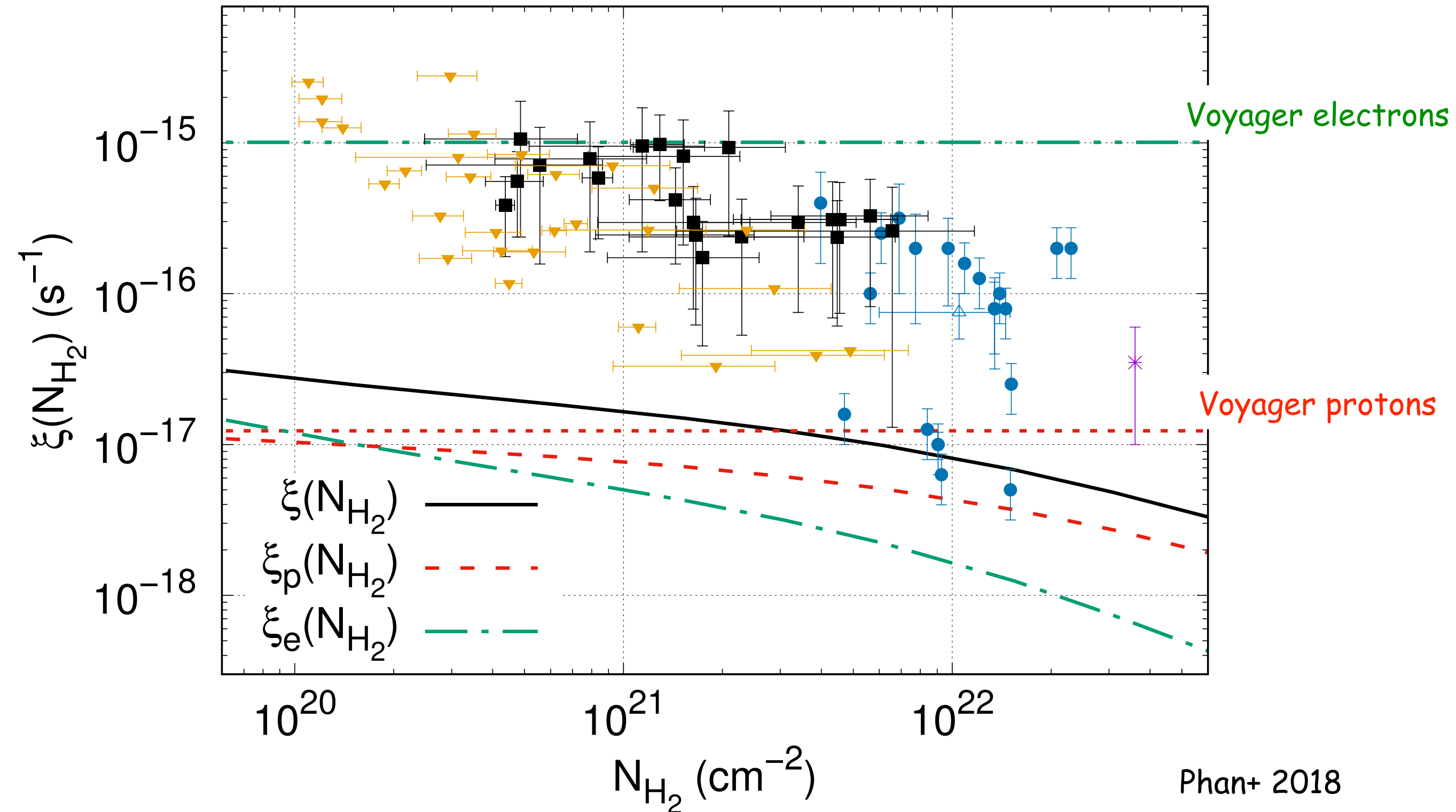
September 5 1977
the launch of Voyager 1



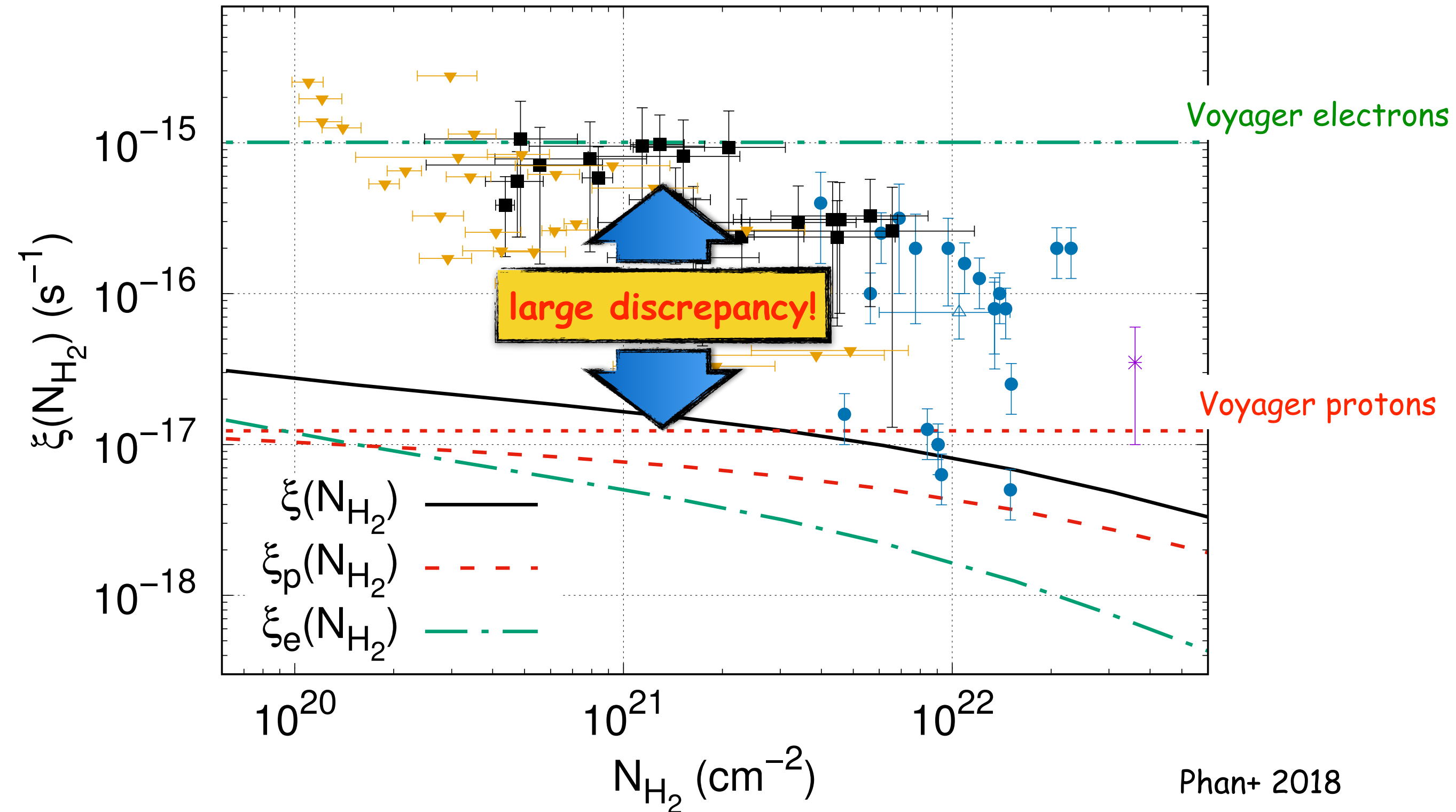
An epic journey



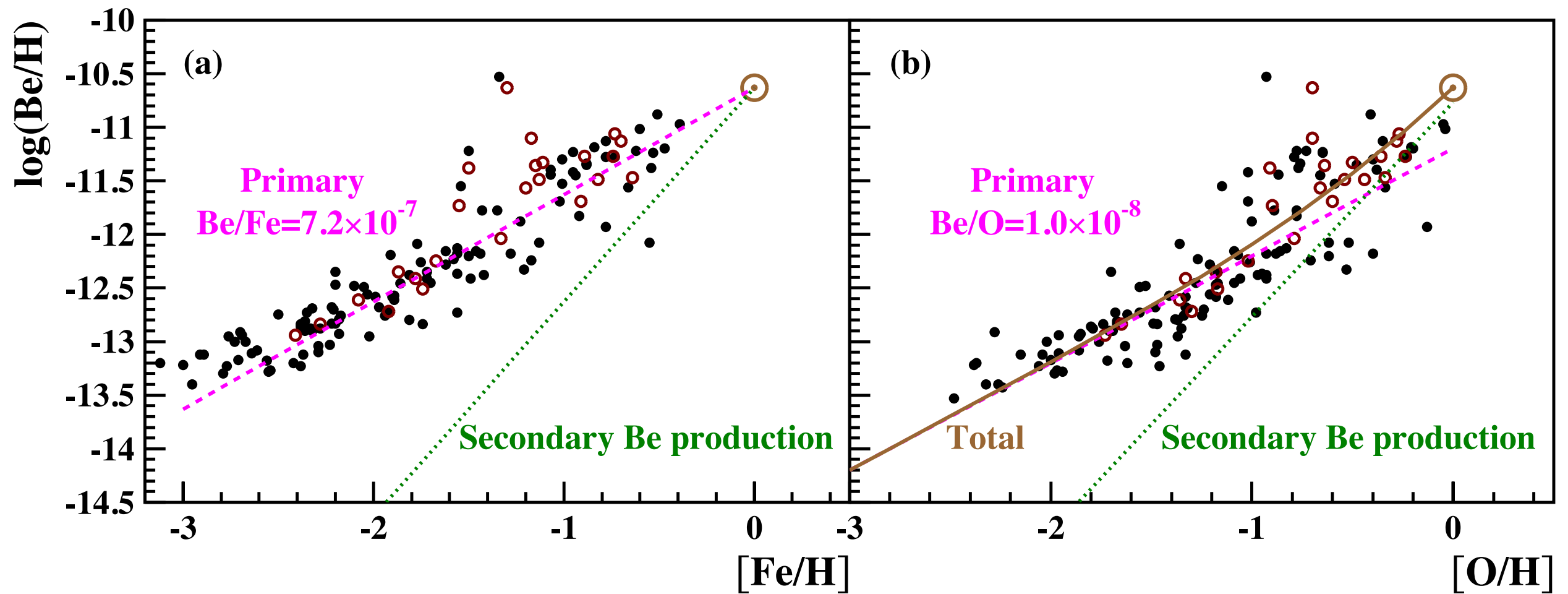
Comparison with data (???)



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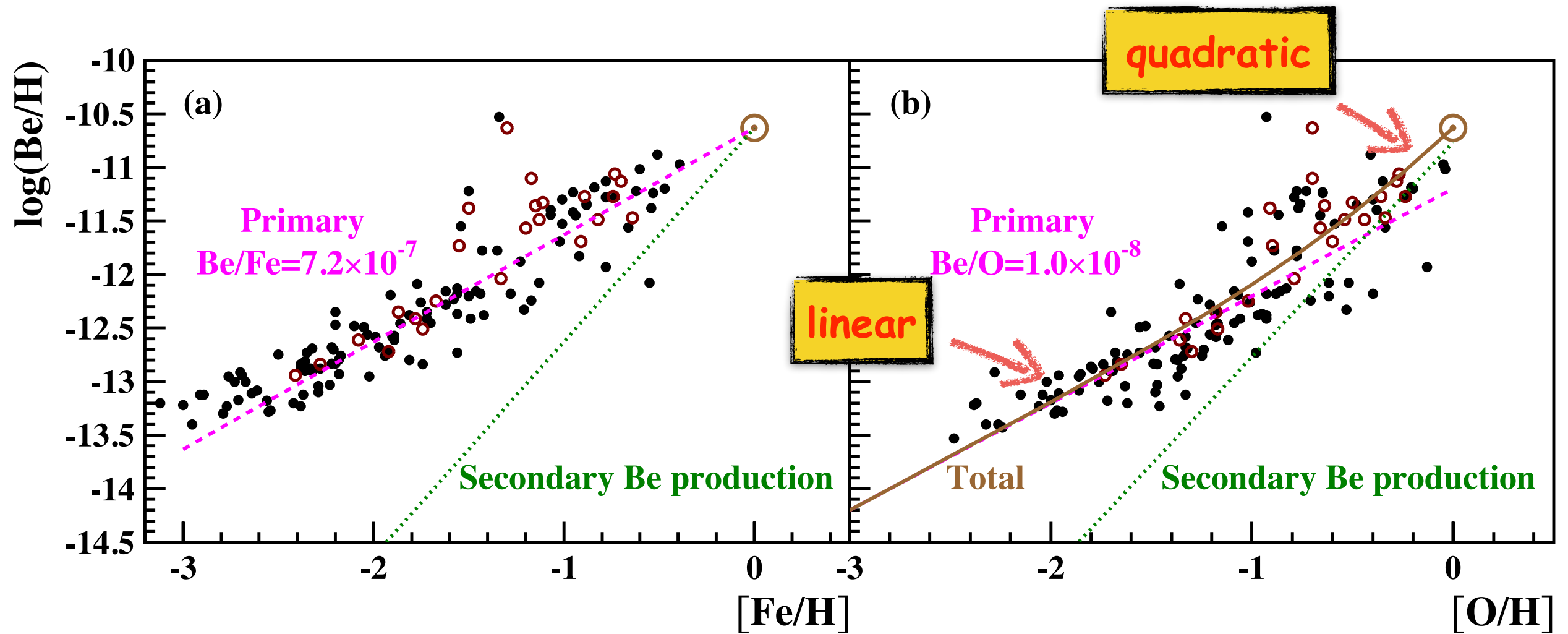


Spallogenic nucleosynthesis of Li-Be-B



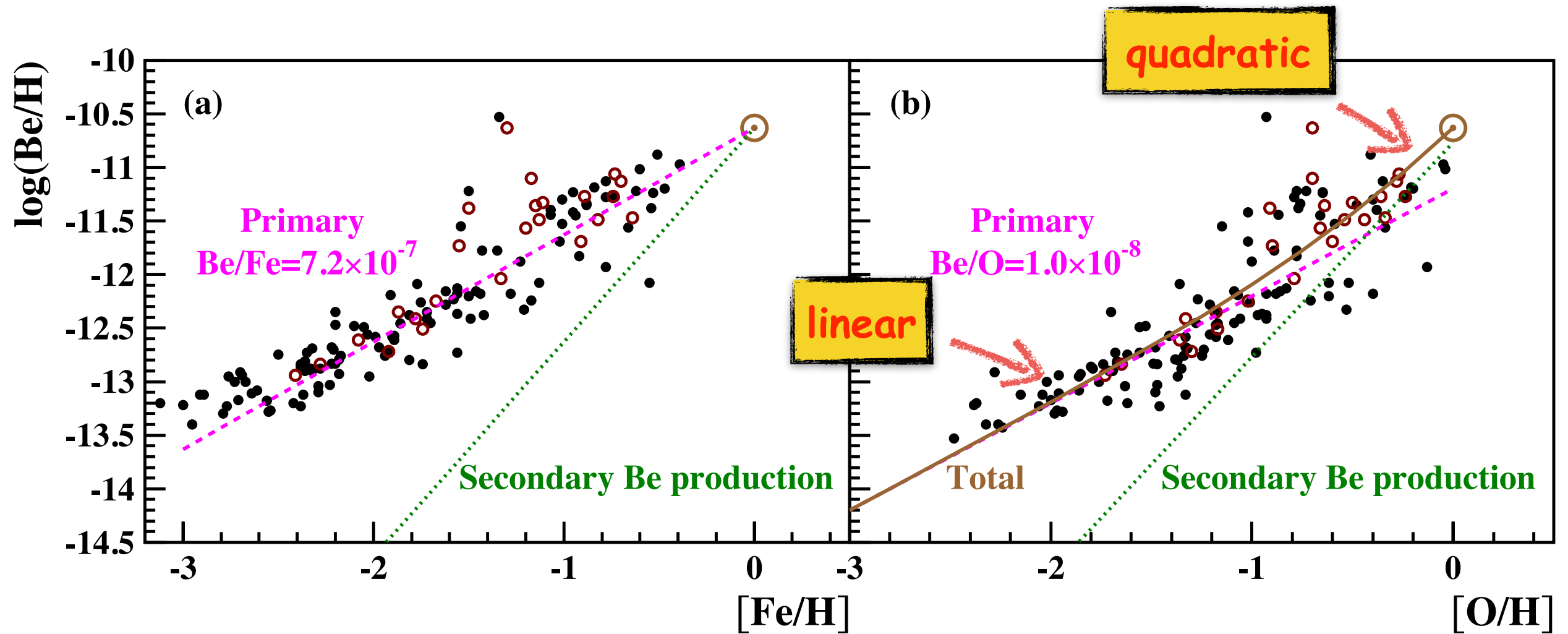
e.g. Parizot 2000, for a review see Tatischeff&Gabici 2018

Spallogenic nucleosynthesis of Li-Be-B



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Spallogenic nucleosynthesis of Li-Be-B



superbubbles -> CRs are accelerated from an enriched ISM
(X_{CR} closer to constant rather than X_{ISM})

e.g. Parizot 2000, for a review see Tatischeff&Gabici 2018

Emerging activities

- Impact on molecular clouds/star formation
- Accretion/ejection processes in young stellar objects
- Formation and evolution of protoplanetary disks
- CRs from astrospheres
- Impact on planetary atmospheres
- Appearance of life

Future perspectives

- LECR-induced gamma-ray nuclear lines → MeV mission (eASTROGAM)
- X-ray tracers such as neutral iron line @6.4 keV → ATHENA!
- Low energy astronomical observations are constantly improving

Priorités/questions scientifiques

- Origin of observed ionisation rates
- Origin and transport of LECRs
- Impact on star/planet formation
- (Light) elements nucleosynthesis
- Impact on (origin of) life

Positionnement de l'IN2P3

- Problem: scattered community (goes beyond the boundaries of IN2P3)
- Expertise is available, as well as international recognition. We just need people to speak to each other more often and start interdisciplinary collaborations

Besoins

- Support initiatives aimed at building a community (intra-institute)
- Help in defining a clear and identifiable profile for young researcher
- Recruitment: where? (too low energy for the high energy community? Too high energy for astronomical community? Not enough plasma-oriented for plasma physicists? etc.)
- Support future missions relevant for this topic: Athena (link with INSU), eASTROGAM, ...