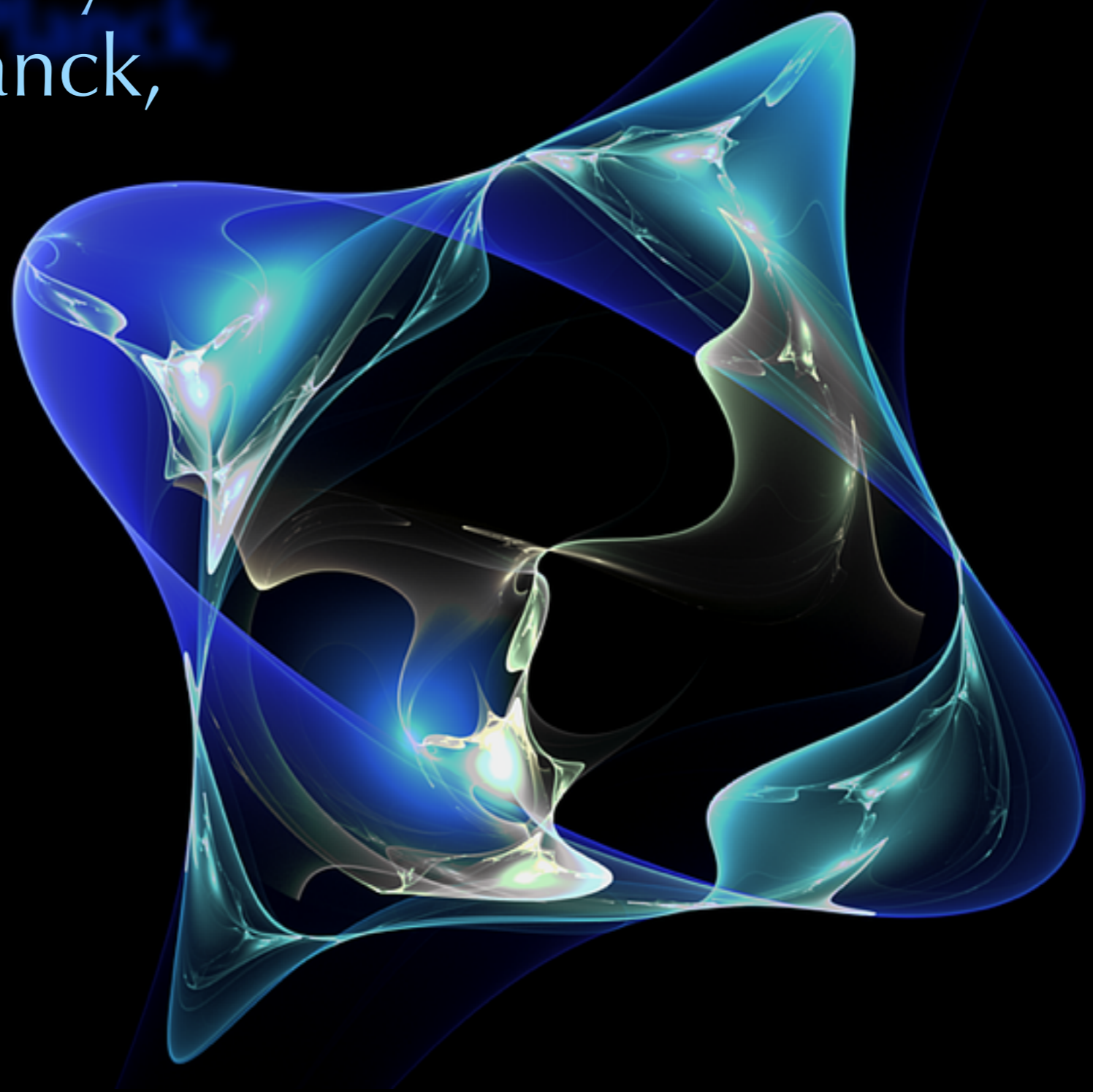


# Local Cosmic Rays with Fermi, Planck, & Voyager

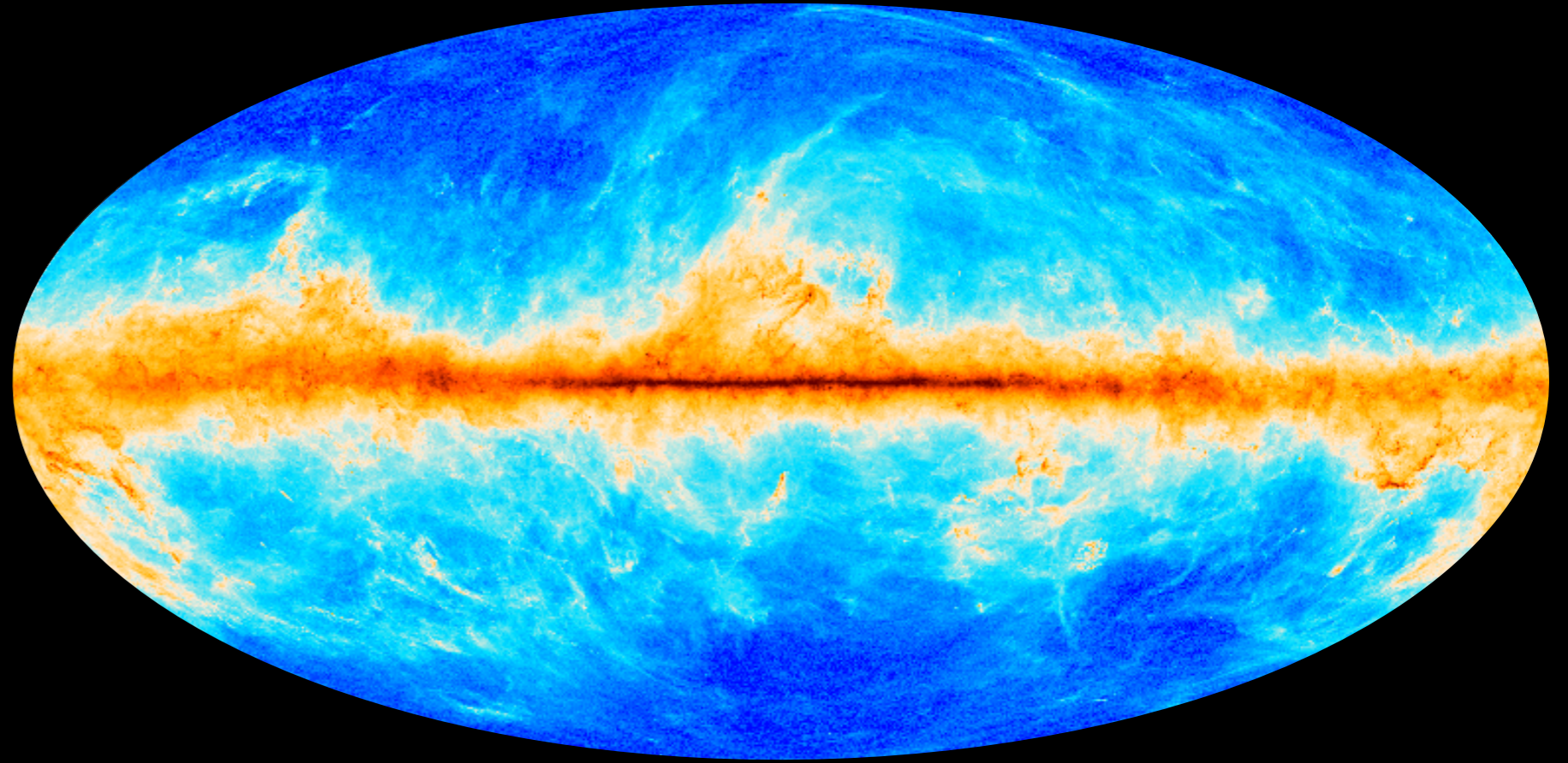
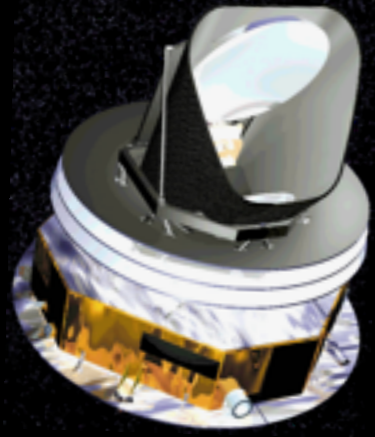


Isabelle Grenier

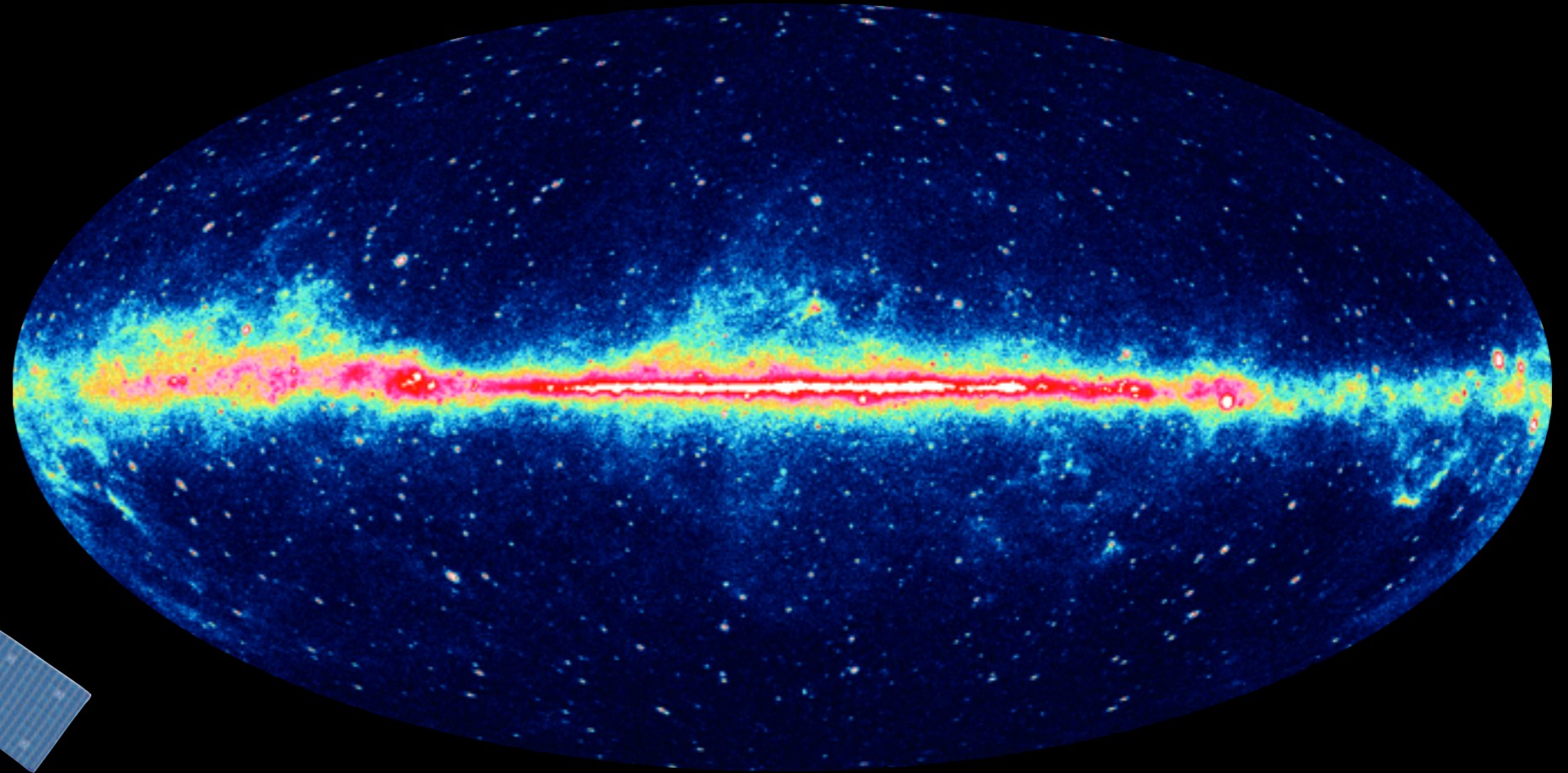
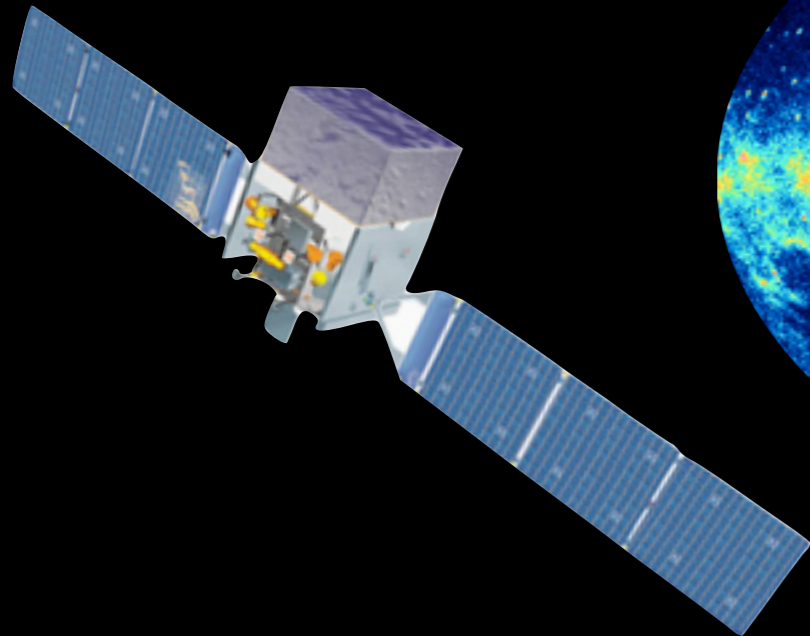
AIM, Université Paris Diderot & CEA Saclay

on behalf of the Fermi LAT and Planck Collaborations

and with Rosine Lallement, Observatoire de Paris



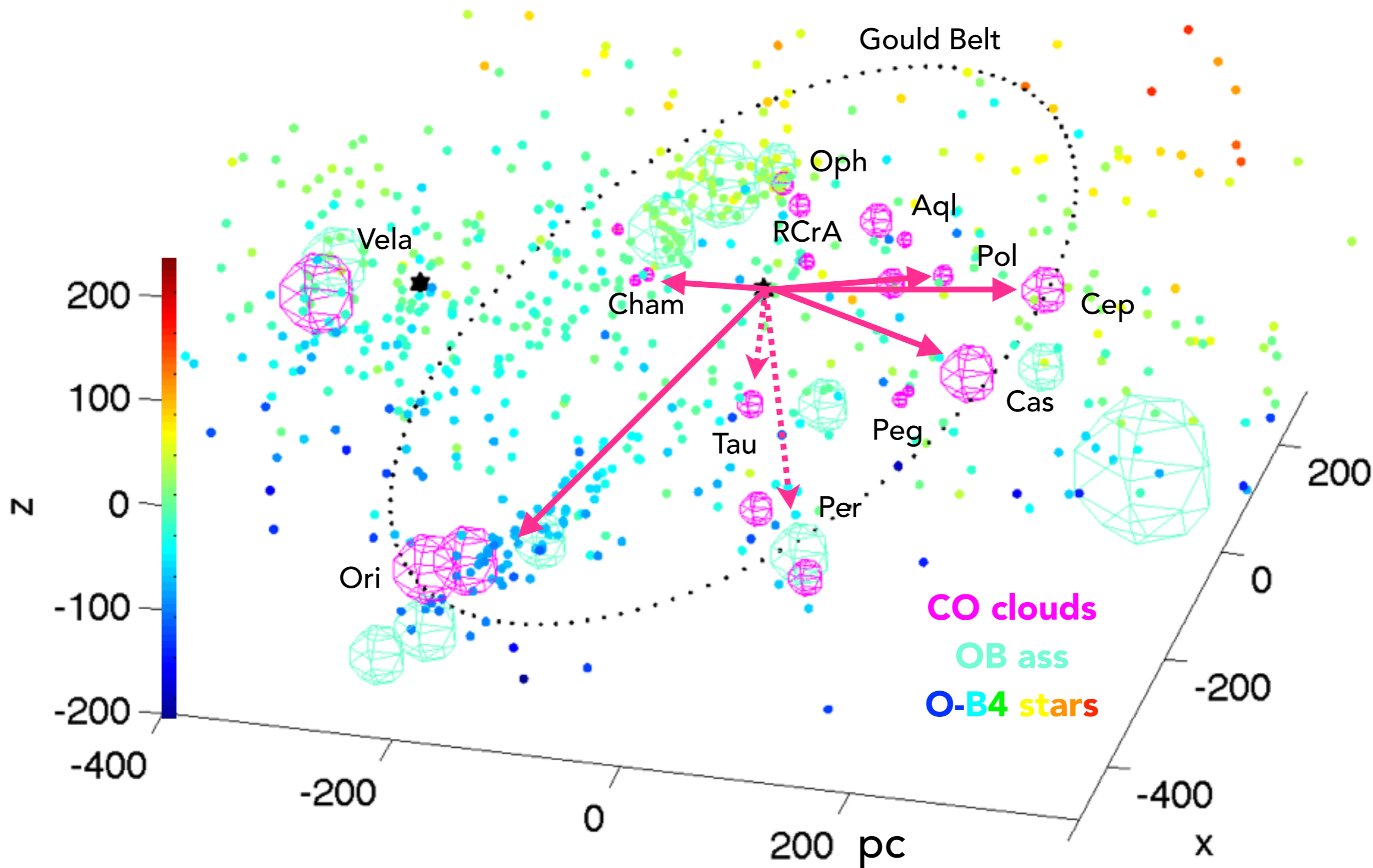
Planck et al. arXiv:1312.1300



Fermi 5 years > 1 GeV



•  $\gamma$ -ray emissivity measurements of the local gas





● since 2005:

● CRays in HI:  $N(\text{HI})$

$$\frac{dN_{\text{CR}}}{dV}$$

● CRays in  $\text{H}_2$ :

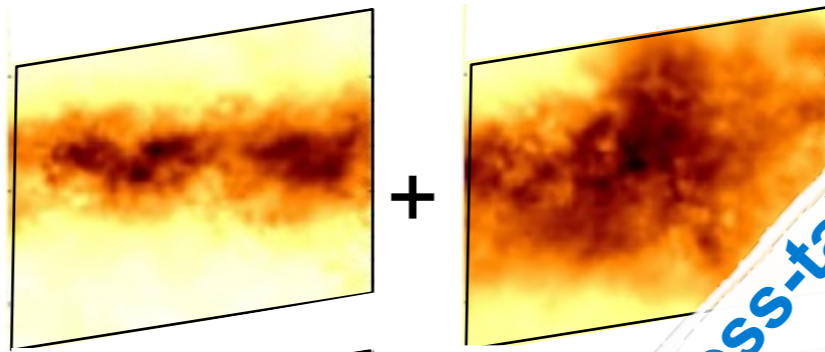
$$X_{\text{CO}} = \frac{N(\text{H}_2)}{W(\text{CO})}$$

● CRays in dark neutral gas:

$$I_\gamma = a N(\text{HI}) + b W(\text{CO})$$

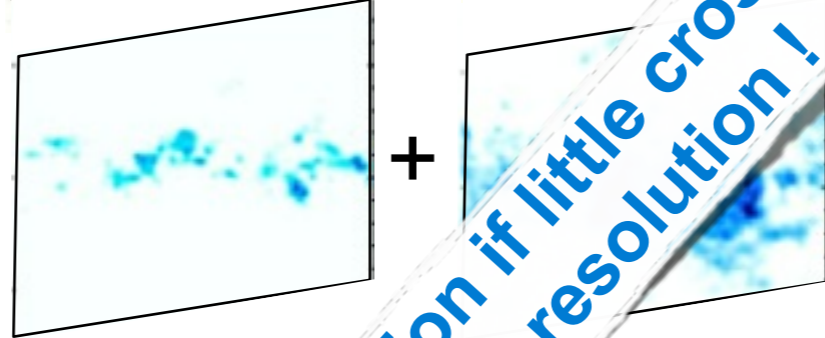
● Galactic inverse Compton

● γ-ray source



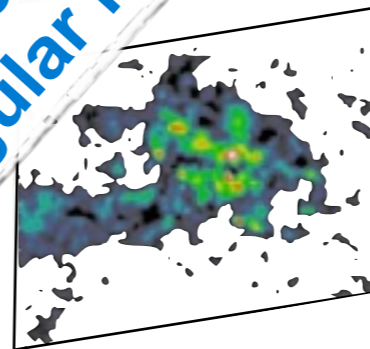
dust in HI

$$\frac{\tau_{\text{dust}}}{N\text{H}}$$



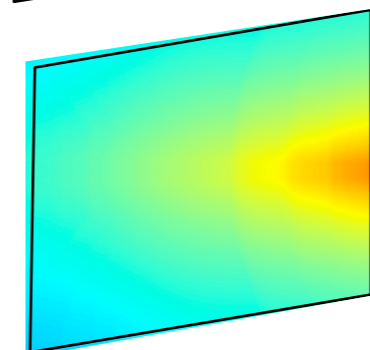
dust in  $\text{H}_2$

$$X_{\text{CO}} = \frac{N(\text{H}_2)}{W(\text{CO})}$$

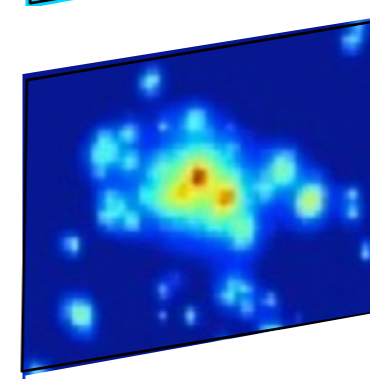


dust in dark gas

$$\tau_{\text{dust}} = a' N(\text{HI}) + b' W(\text{CO})$$



ISRF + CMB



IR sources

component separation if little cross-talk  
⇒ good angular resolution!

+ constant ?





total & ISM  $\gamma$  rays  
> 400 MeV

total dust Planck+IRAS+WISE  
 ◆ SED fits with the  
 Draine & Li model  
 + correction for ISRF bias  
 against quasar absorption

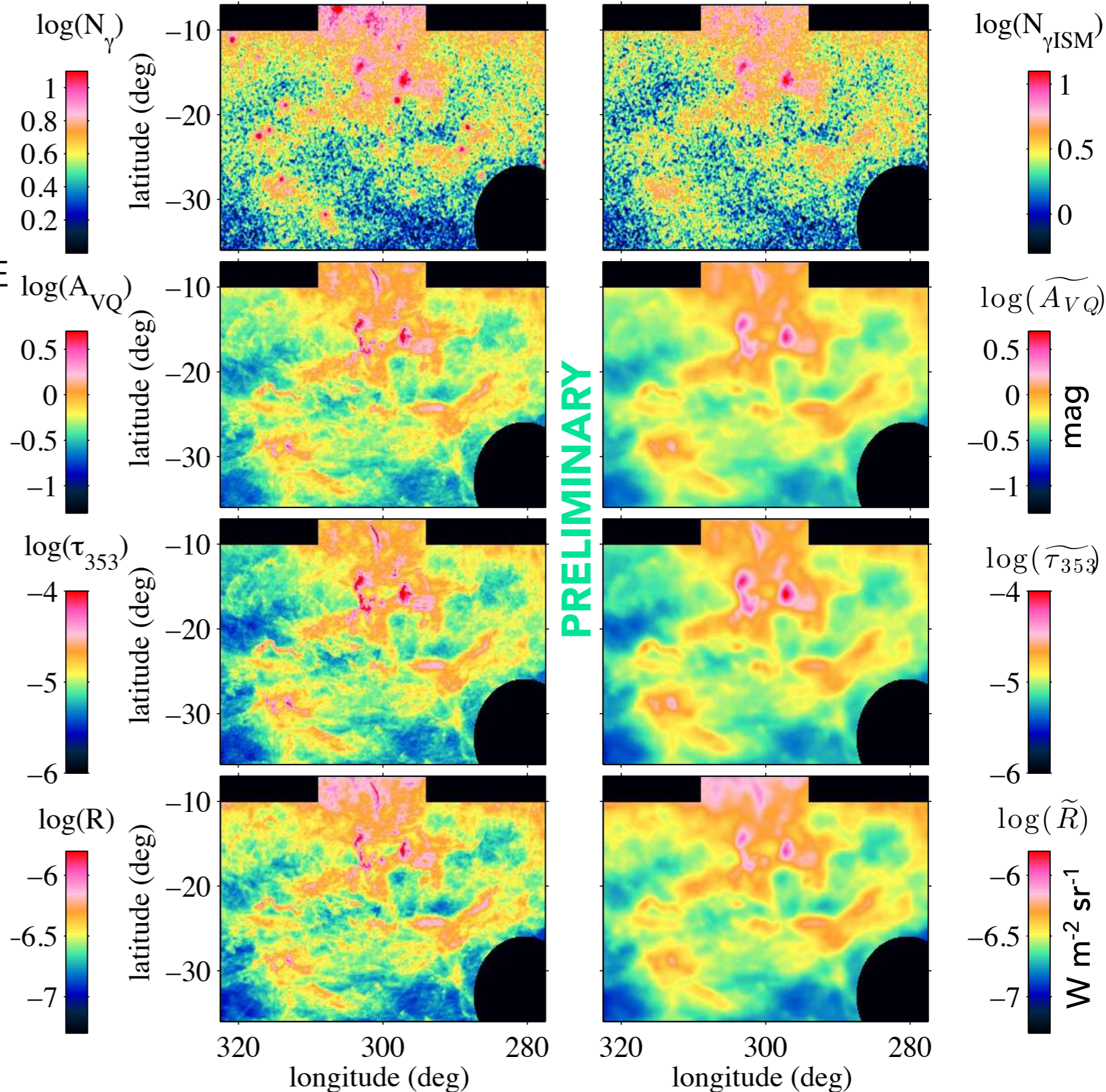
Planck+ 2014, in preparation

total dust optical depth  
 Planck+IRAS  
 ◆ SED fits with modified  
 black-body spectral fits

Planck+ 2013, arXiv:1312.1300

total dust radiance

Planck+ 2013, arXiv:1312.1300

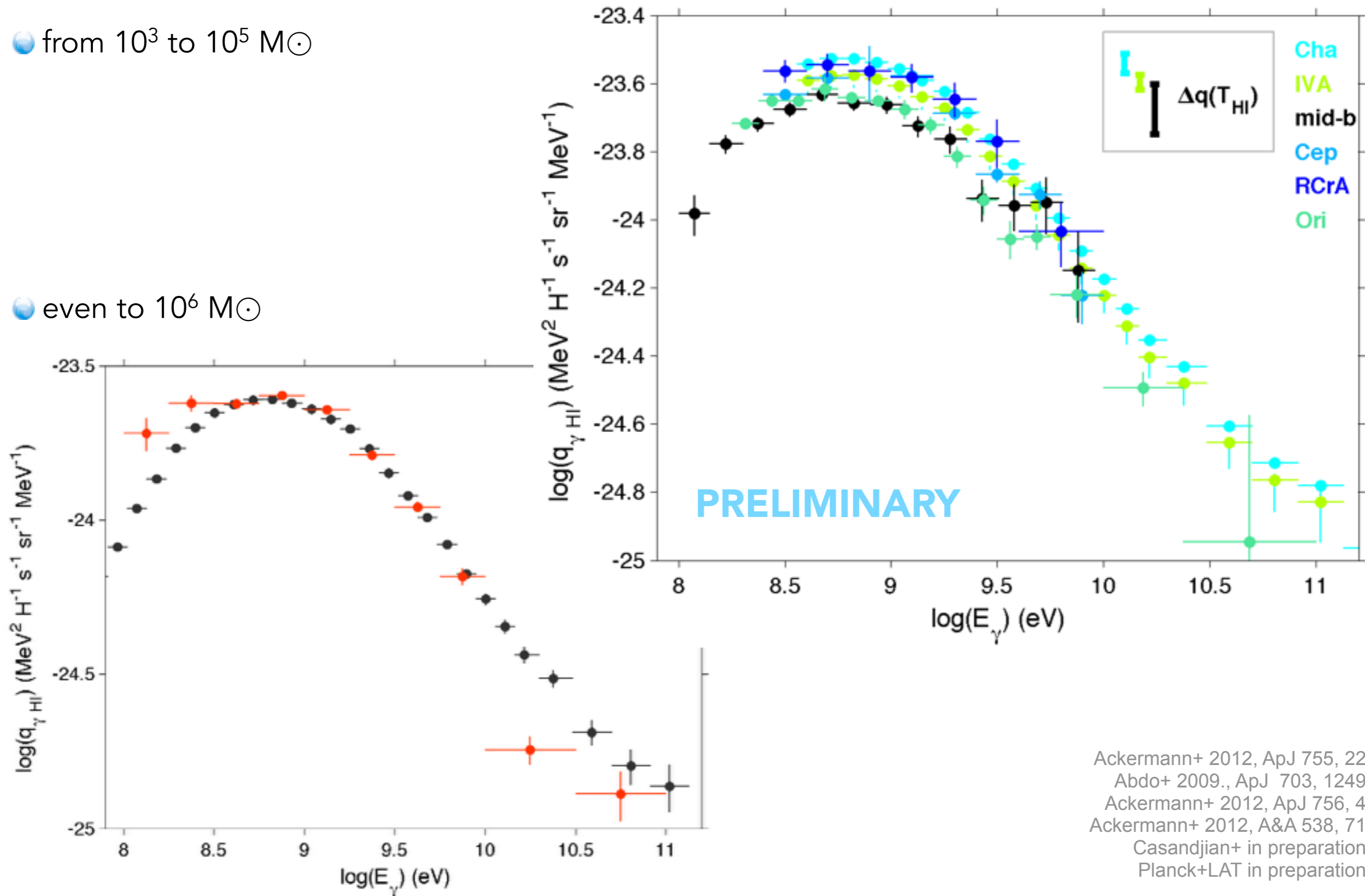




• < 30% variations compatible with uncertainties in HI spin temperature

• from  $10^3$  to  $10^5 M_\odot$

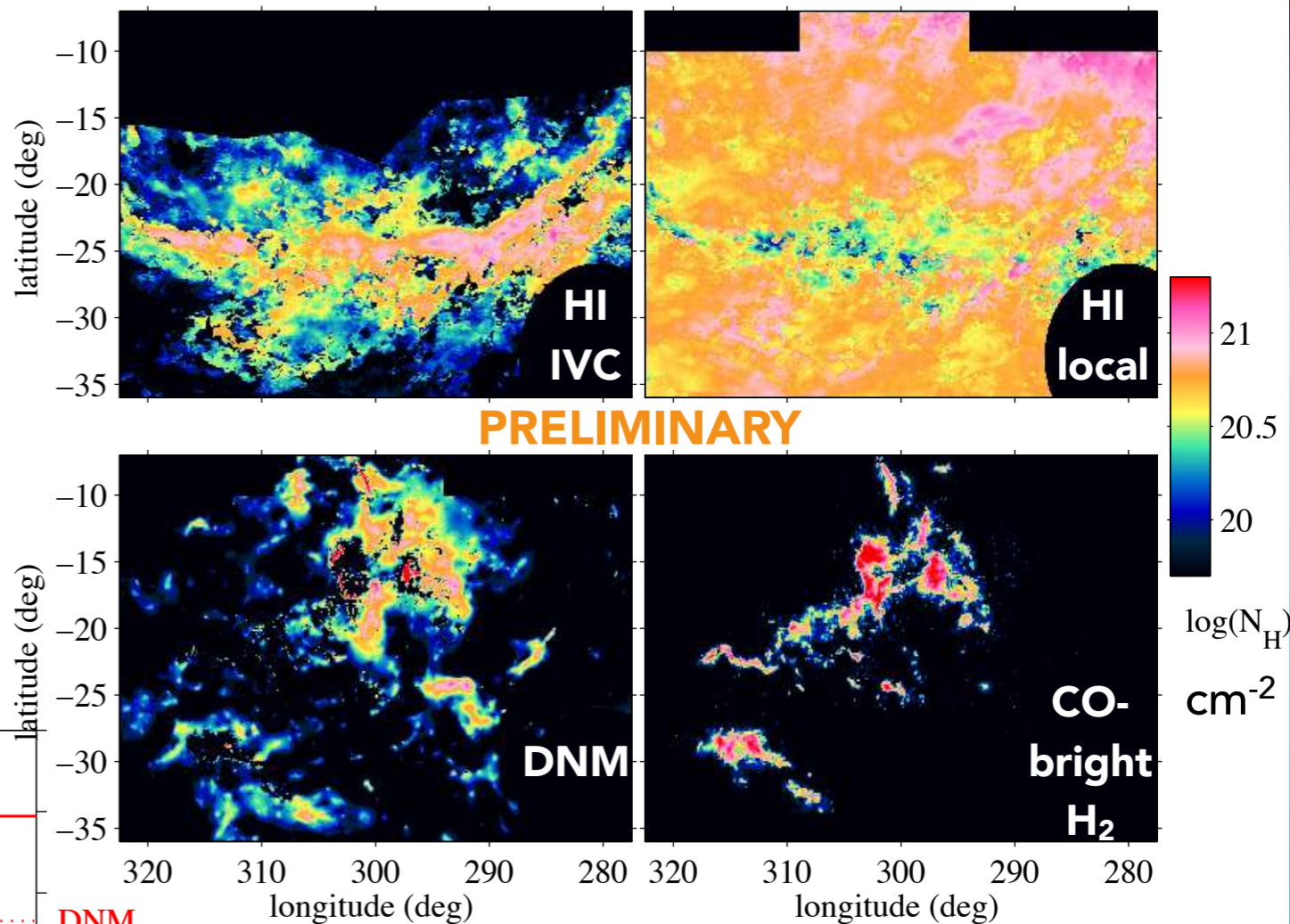
• even to  $10^6 M_\odot$



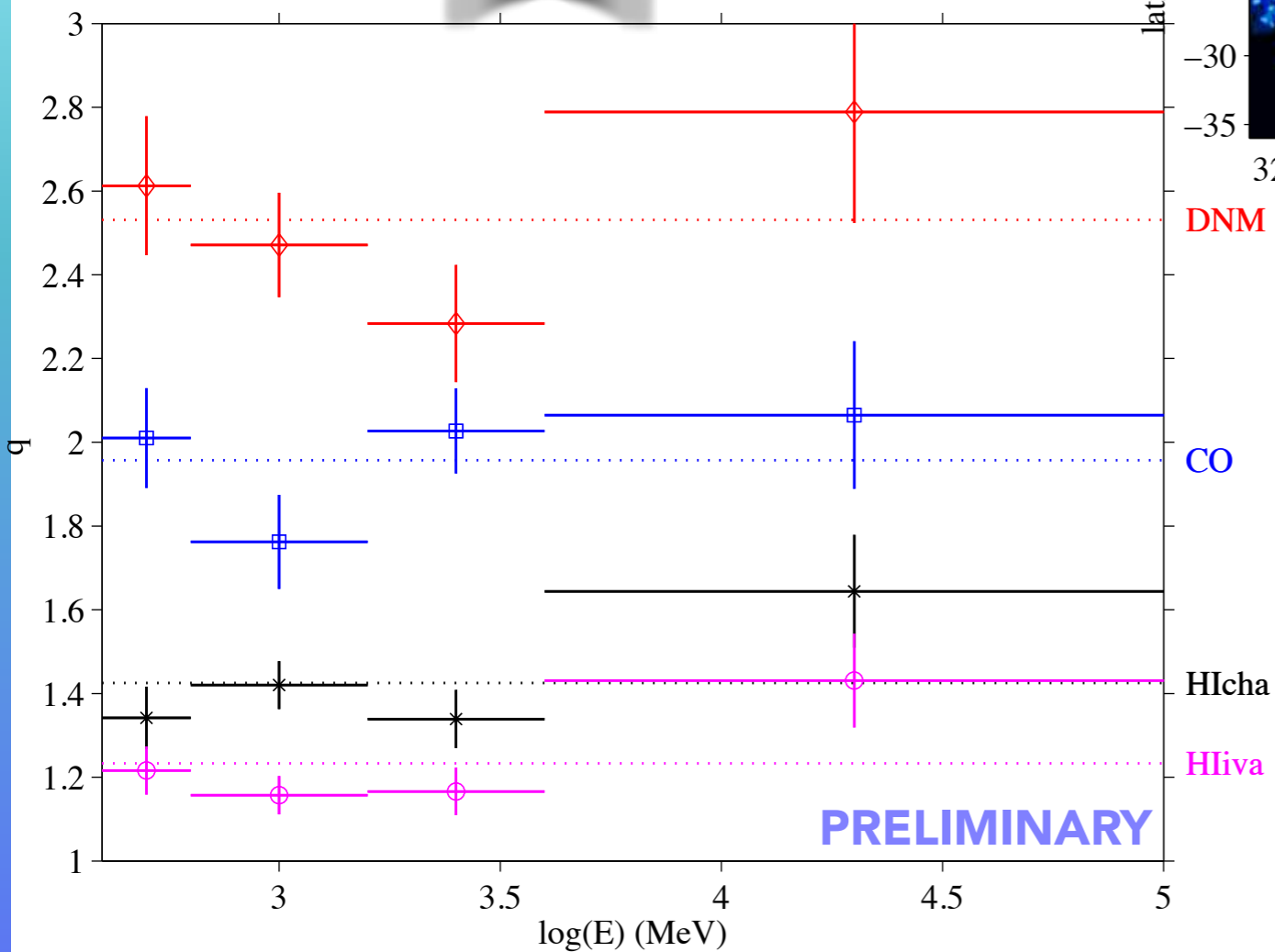
Ackermann+ 2012, ApJ 755, 22  
 Abdo+ 2009., ApJ 703, 1249  
 Ackermann+ 2012, ApJ 756, 4  
 Ackermann+ 2012, A&A 538, 71  
 Casandjian+ in preparation  
 Planck+LAT in preparation



- < 20% emissivity variation between the local HI gas and an IVC cloud
- ◆ ~ 60 pc below the Gal. plane?
- ◆ shocked gas?



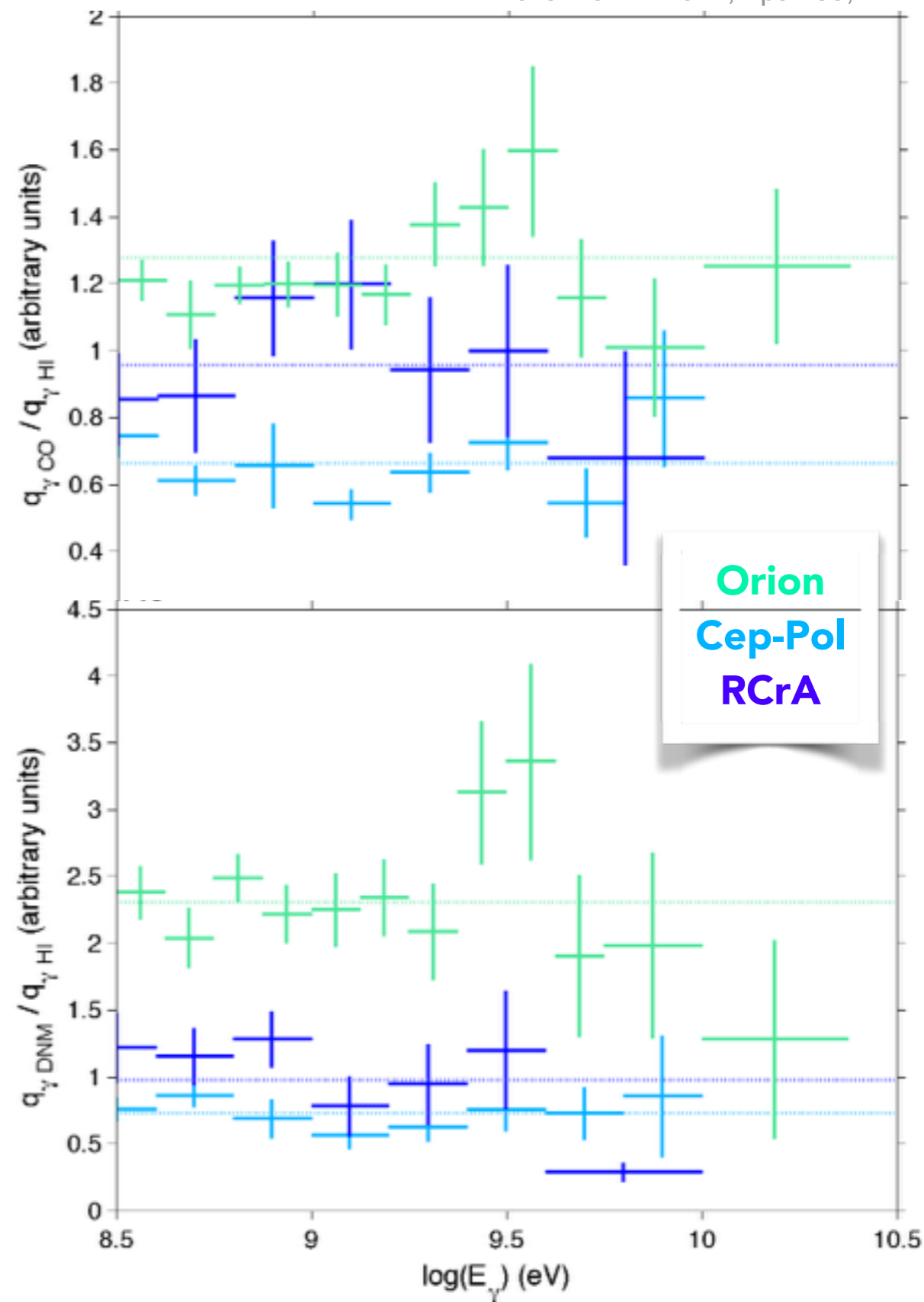
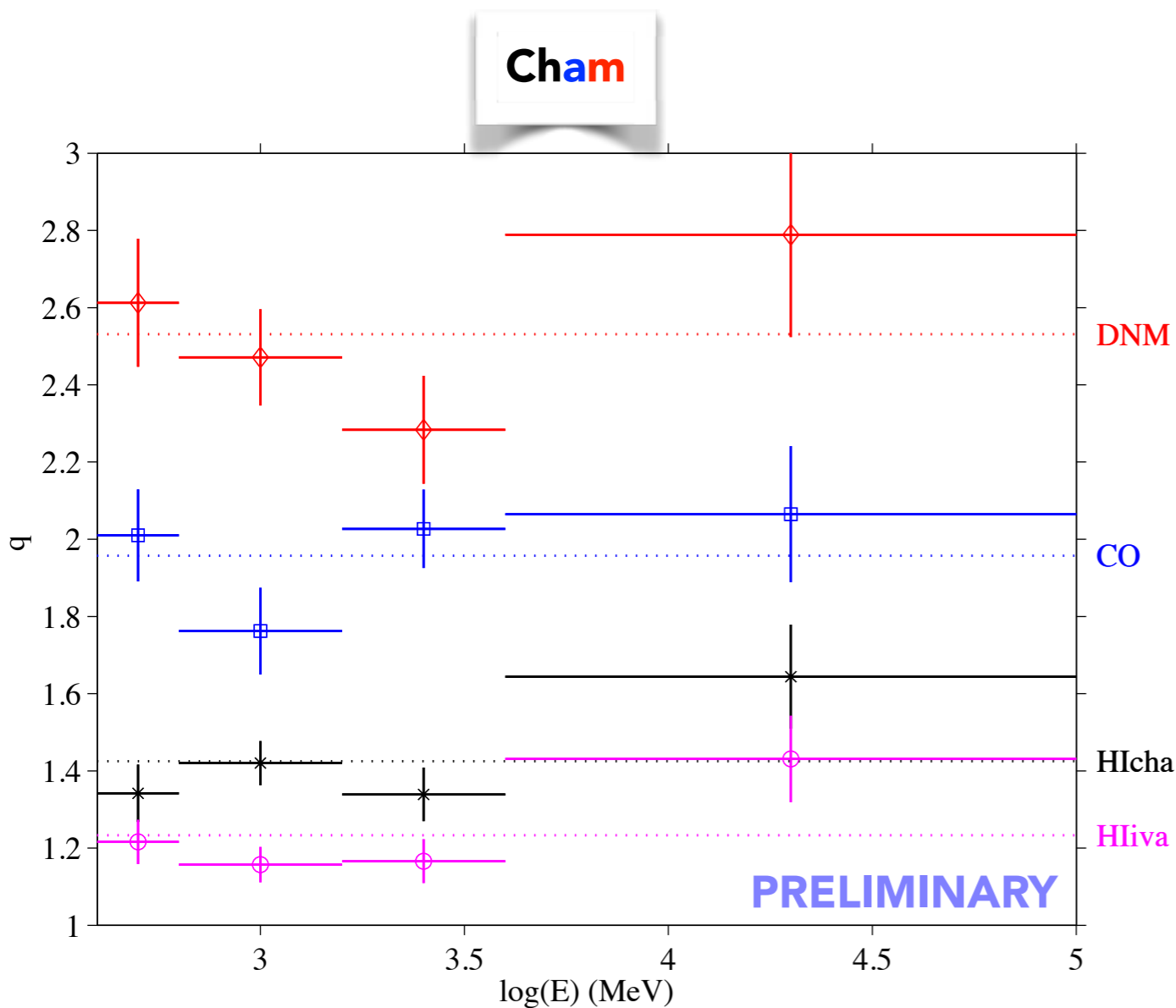
**Cham**





- no spectral deviations across the HI, DNM, and H<sub>2</sub> gas phases down to pc scale
- ≈ uniform CR penetration at the current precision

Ackermann+ 2012, ApJ 756, 4  
Ackermann+ 2012, ApJ 755, 22

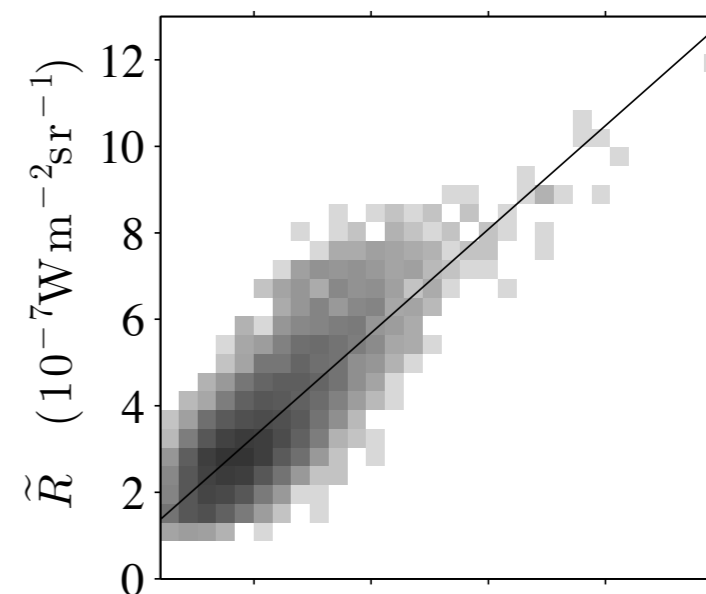
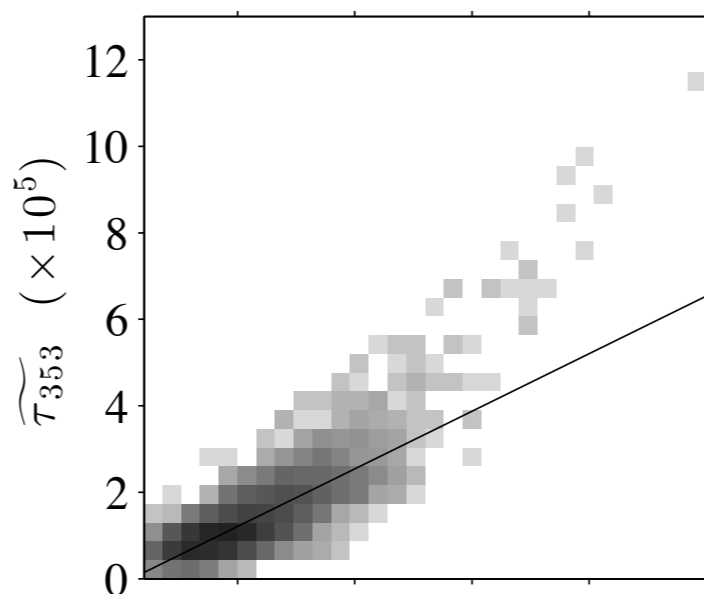
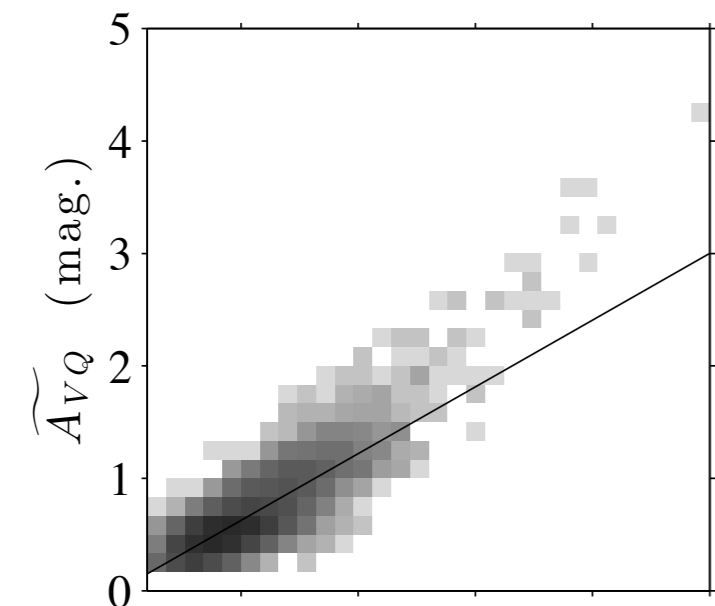




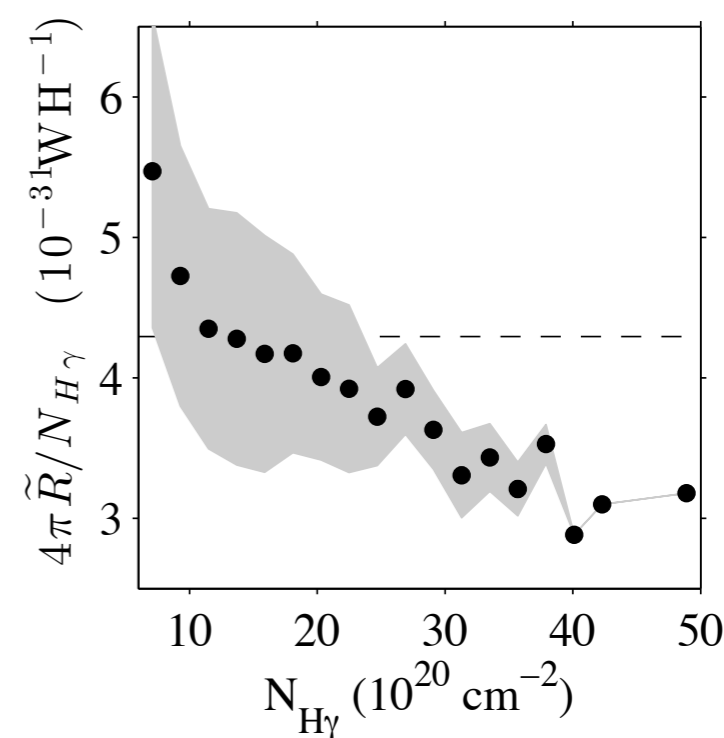
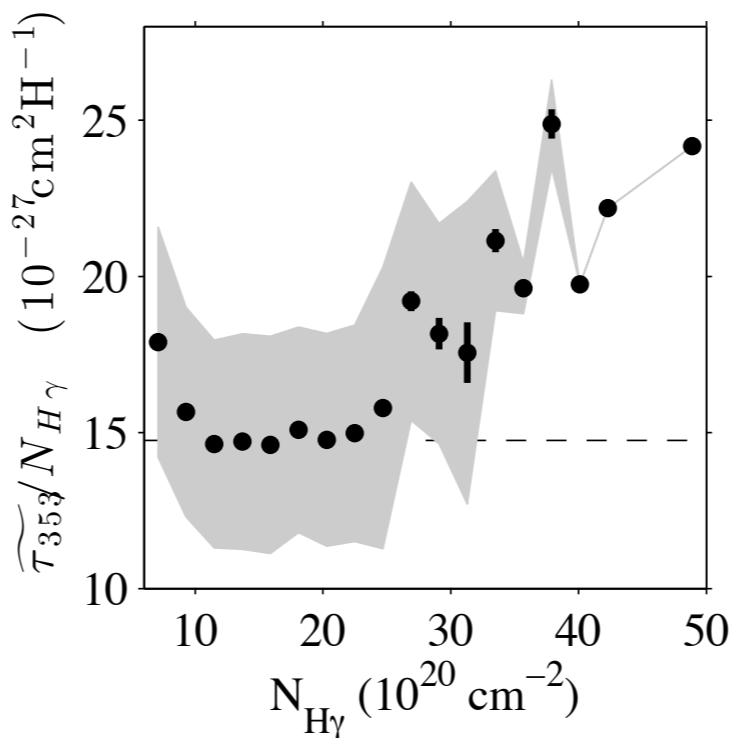
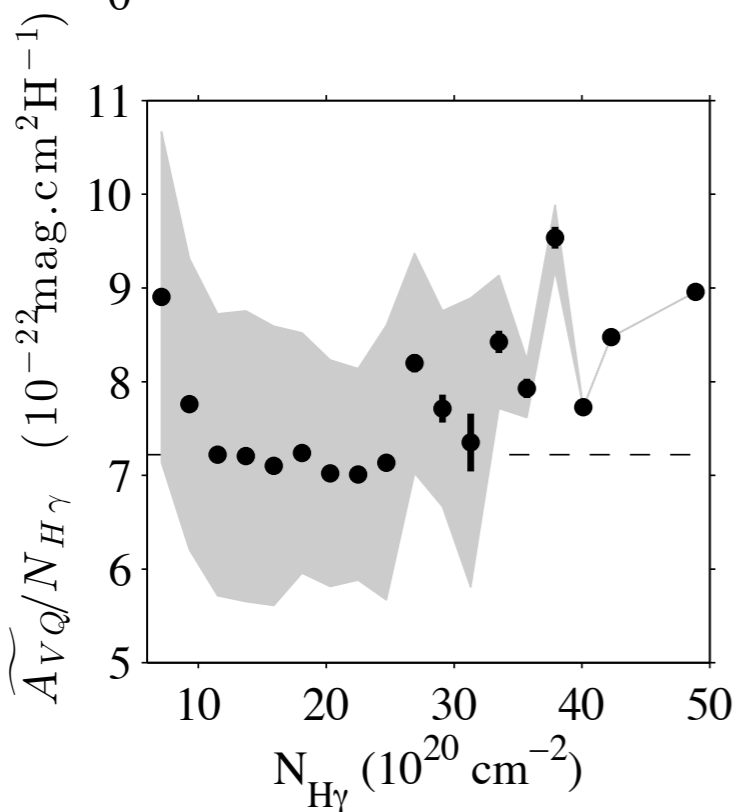


- $\bullet$   $\gamma$ -ray assumption:
  - $\blacklozenge$  uniform cosmic-ray flux

- $\bullet$  dust assumptions:
  - $\blacklozenge$  uniform dust-to-gas ratio
  - $\blacklozenge$  uniform emission mass coefficient  $\kappa_V$



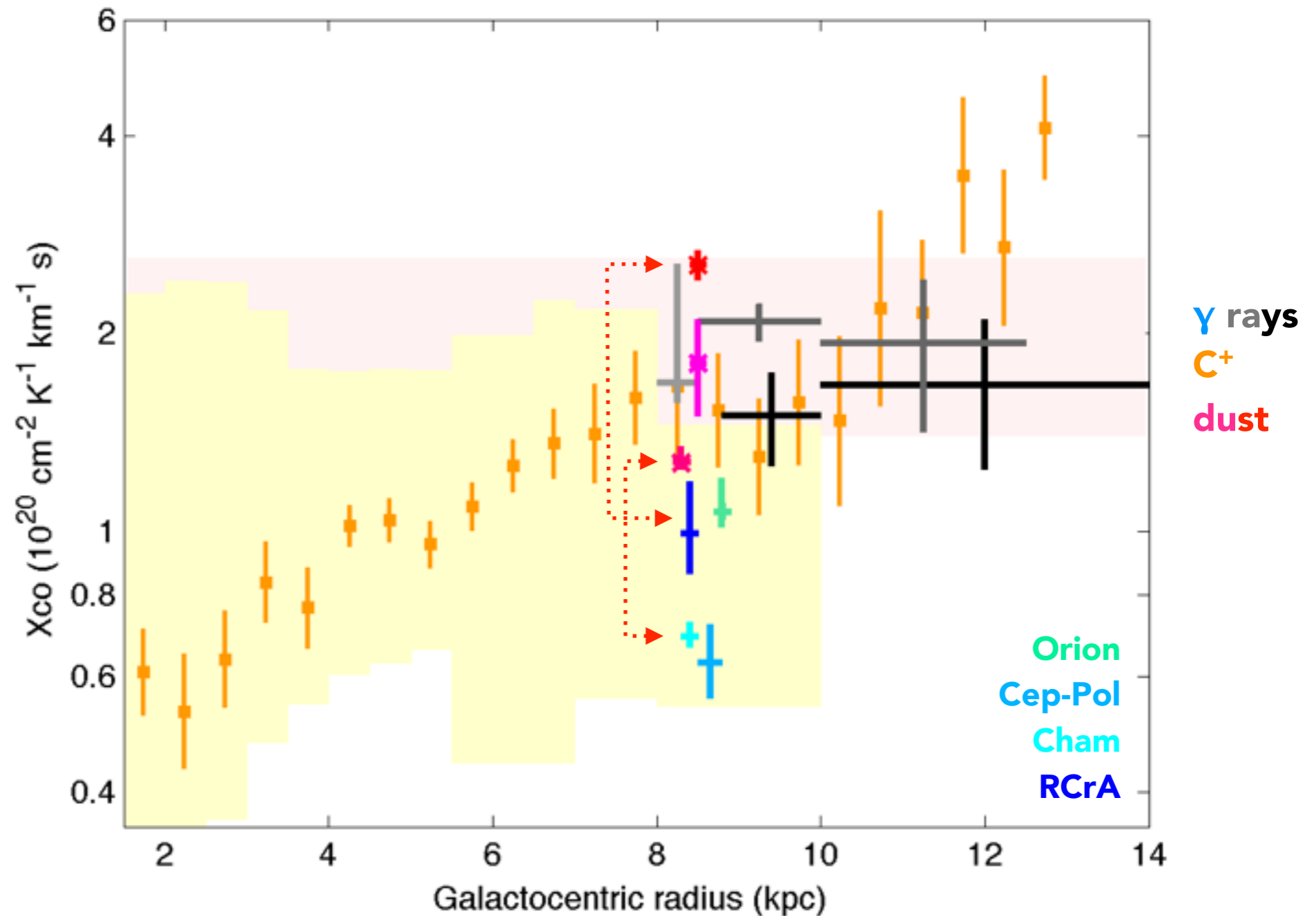
PRELIMINARY



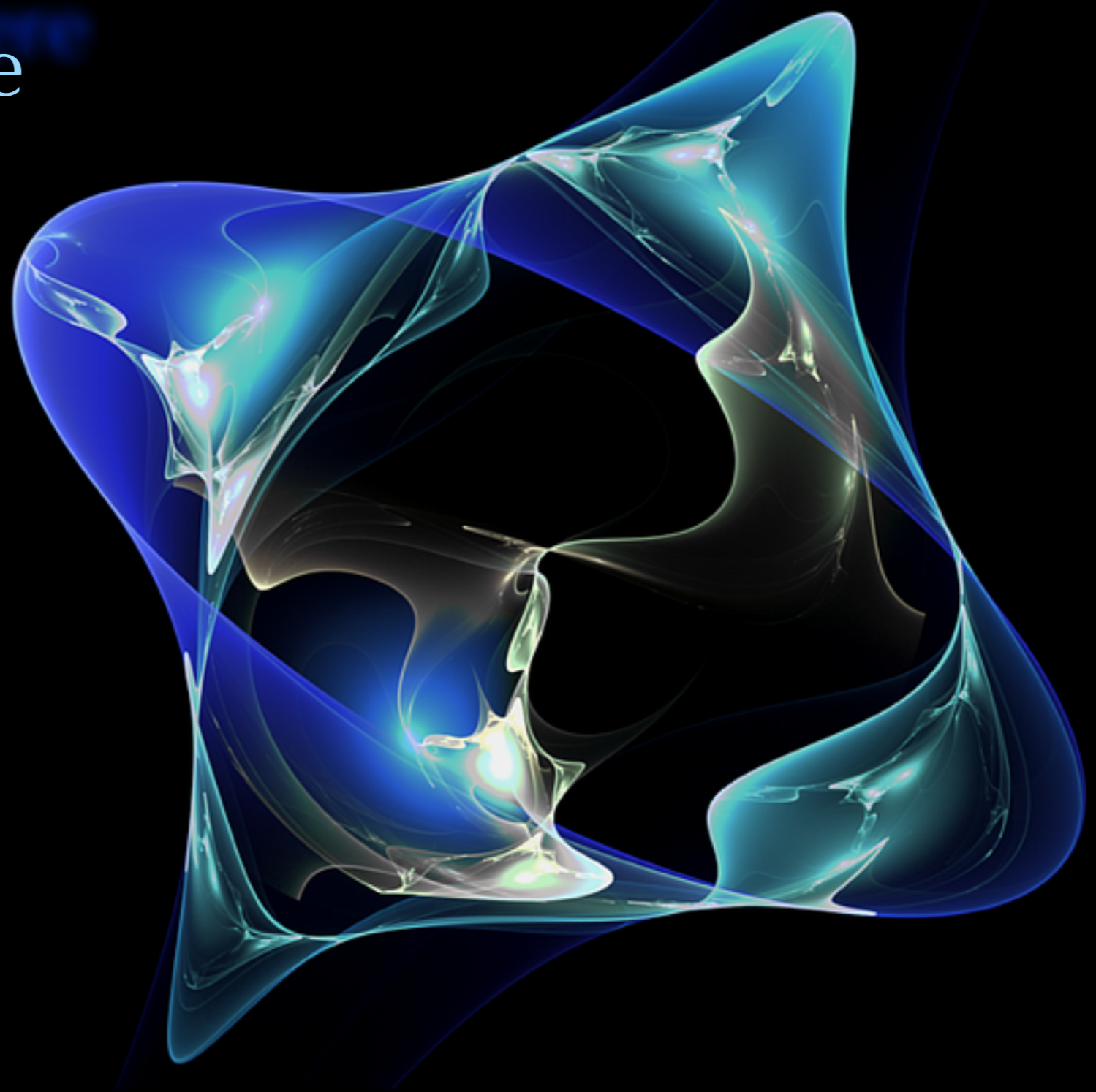


- often  $X_{\text{CO dust}} \approx 2 X_{\text{CO Y}}$ 
  - ◆ due to dust evolution rather than cosmic-ray exclusion
  
- $X_{\text{CO Y}}(\text{kpc-scale}) \approx 2 X_{\text{CO Y}}(\text{pc-scale})$  value
  - possible causes:
    - ◆ HI/CO cross-talk
    - ◆ DNM separation

Ackermann+ 2013, ApJ 772, 154  
 Abdo+ 2010., ApJ 710, 133  
 Ackermann+ 2012, A&A, 538, 71  
 Ackermann+ 2012, ApJ 755, 22  
 Abdo+ 2009., ApJ 703, 1249  
 Ackermann+ 2012, ApJ 756, 4  
 Pineda+ 2013, A&A 554, 103  
 Planck+LAT, in preparation  
 Planck+ 2011, A&A 536, A19  
 Dame+ 2001, ApJ 547, 792



peering out of  
the heliosphere





- abrupt increase of 10-300 MeV GCRs

(Stone et al, 2013, Decker et al, 2013)

- abrupt decrease of heliospheric energetic particles

(Krimigis et al 2013)

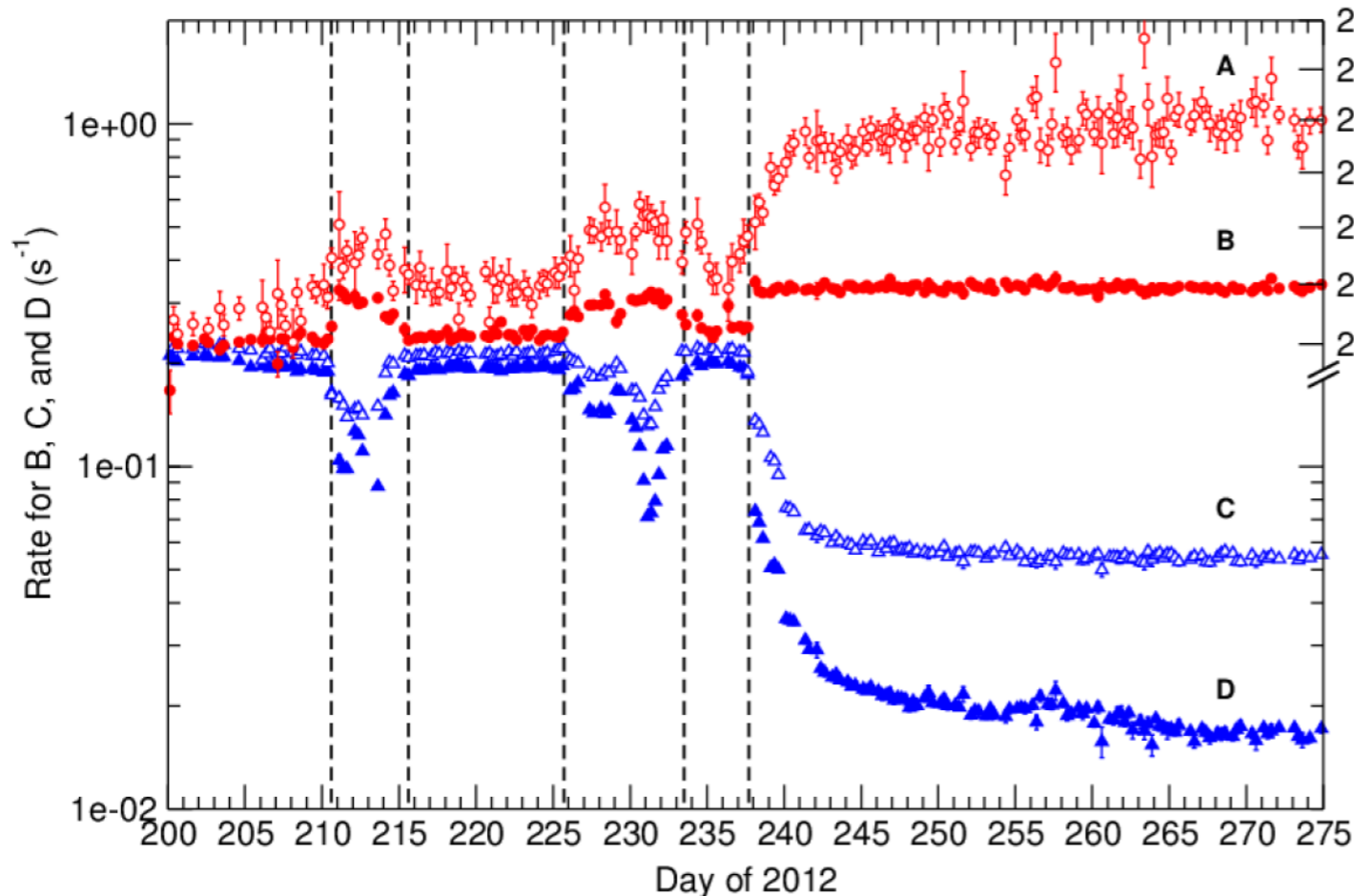
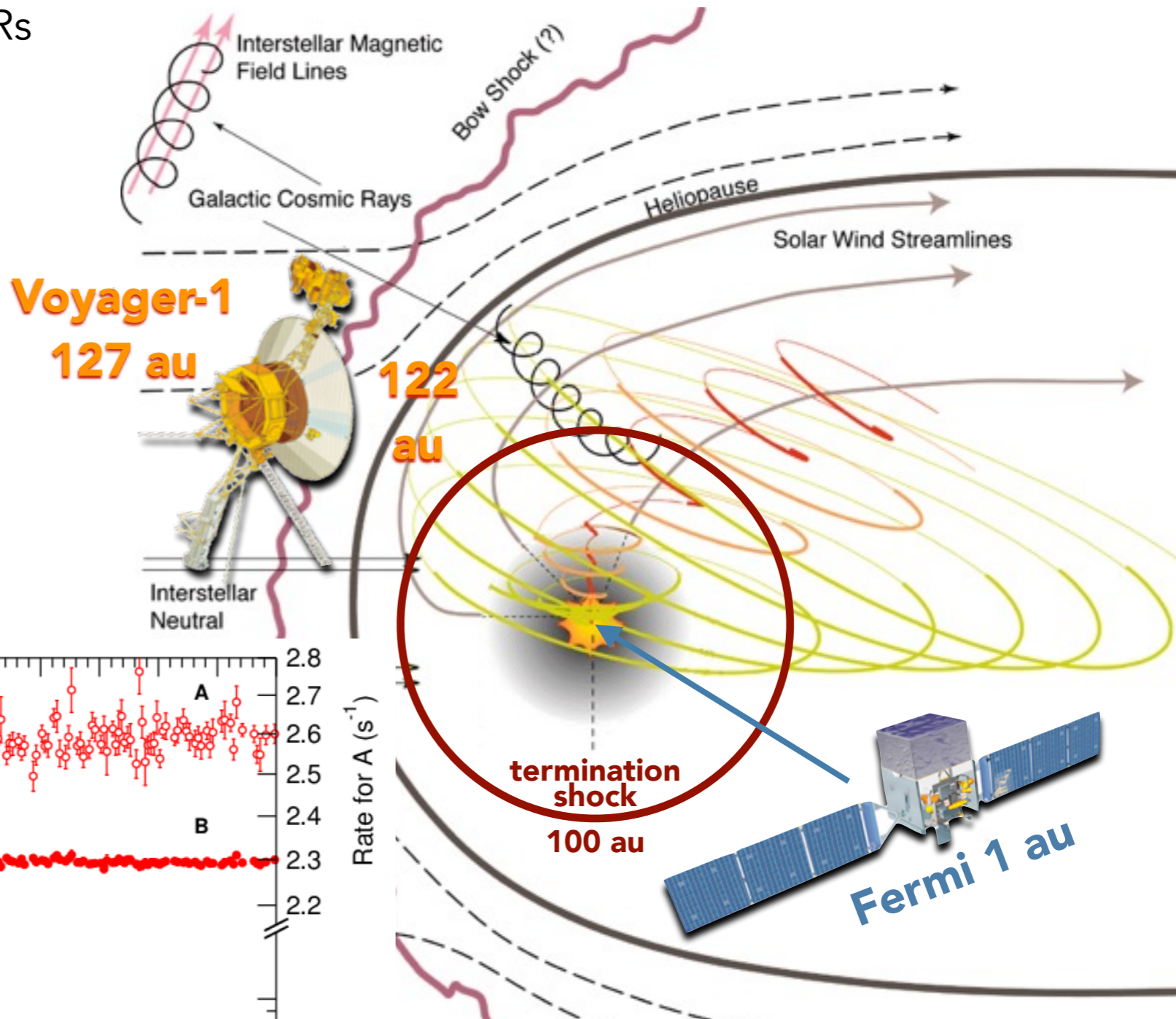
- plasma oscillations triggered by a solar wind stream => measure of the ambient electron density:

- ◆  $n(e) = 0.04-0.08 \text{ cm}^{-3}$

- ◆  $\gg n(e) \text{ solar wind}$

- ◆  $\approx \text{expected interstellar value}$

(Gurnett et al 2014)



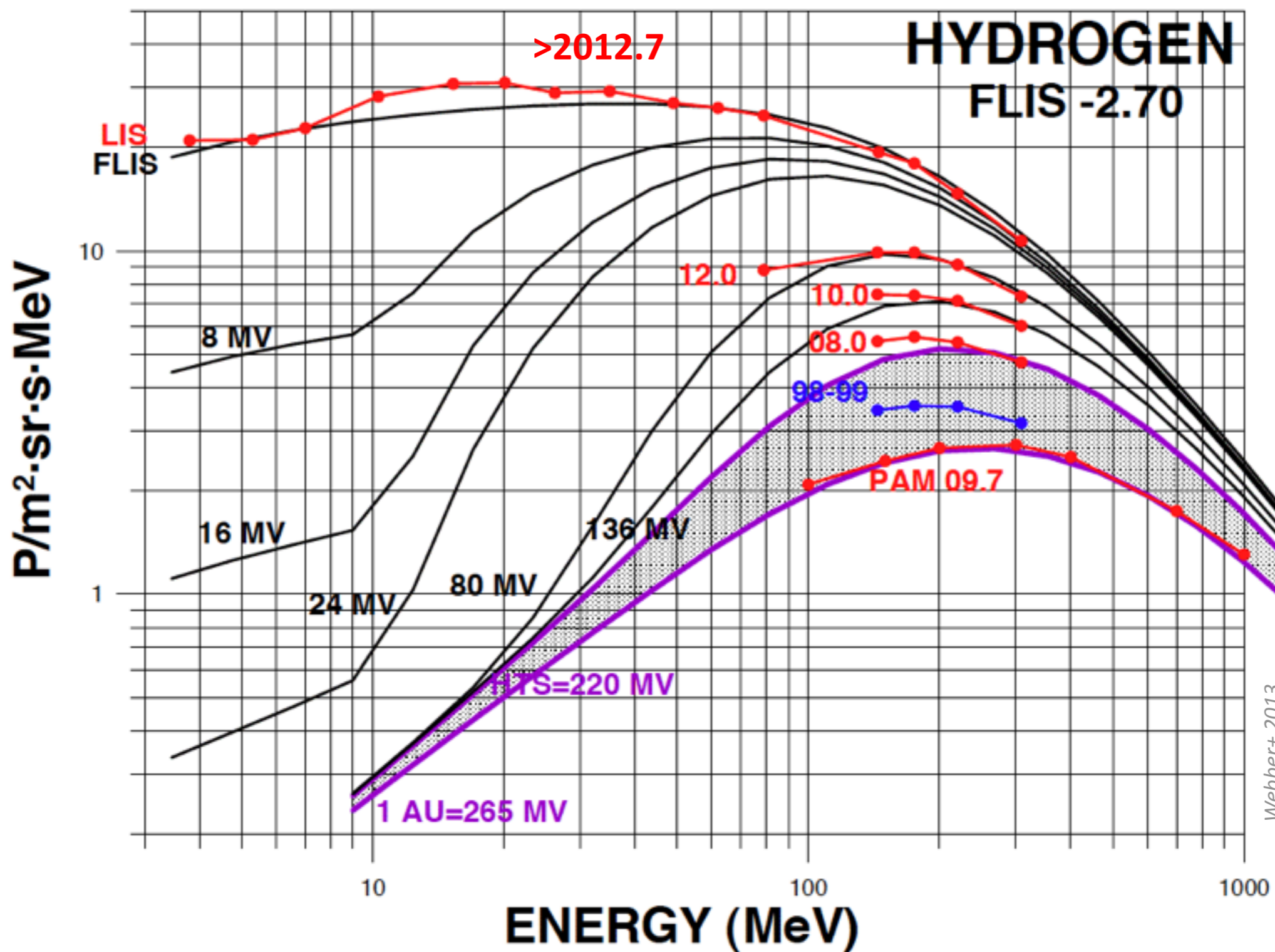
<b>from outside</b>	<b>from inside</b>
<b>CR <math>p^+ &gt; 70 \text{ MeV}</math></b>	<b>ACR <math>p^+ 7-60 \text{ MeV}</math></b>
<b>CR <math>e^- 7-100 \text{ MeV}</math></b>	<b>TSPs <math>0.5-30 \text{ MeV}</math></b>



de-modulation from 1999 to 2012

MODELS based on > 2012.7 data

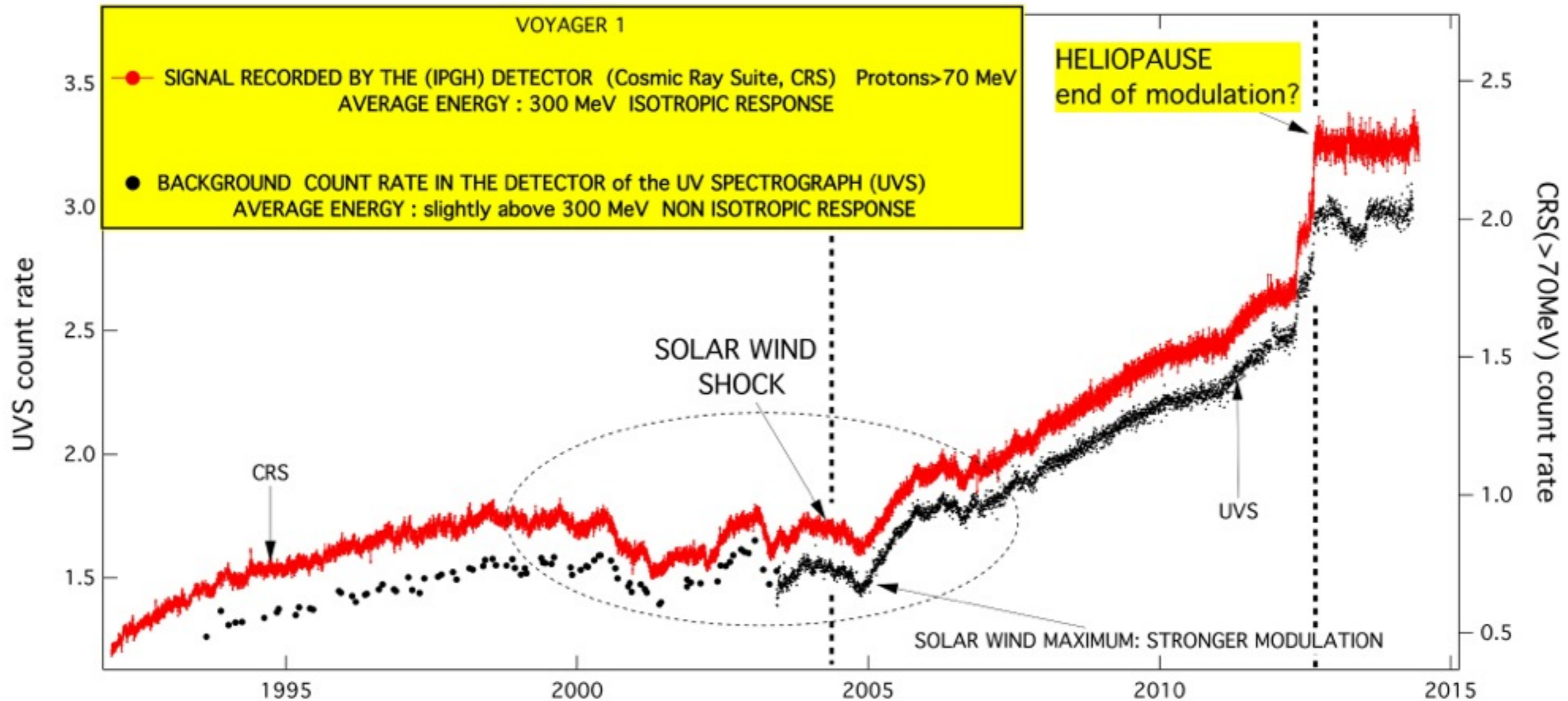
Voyager-1 data



# *fermi* independent measurements of $\sim 300$ MeV protons

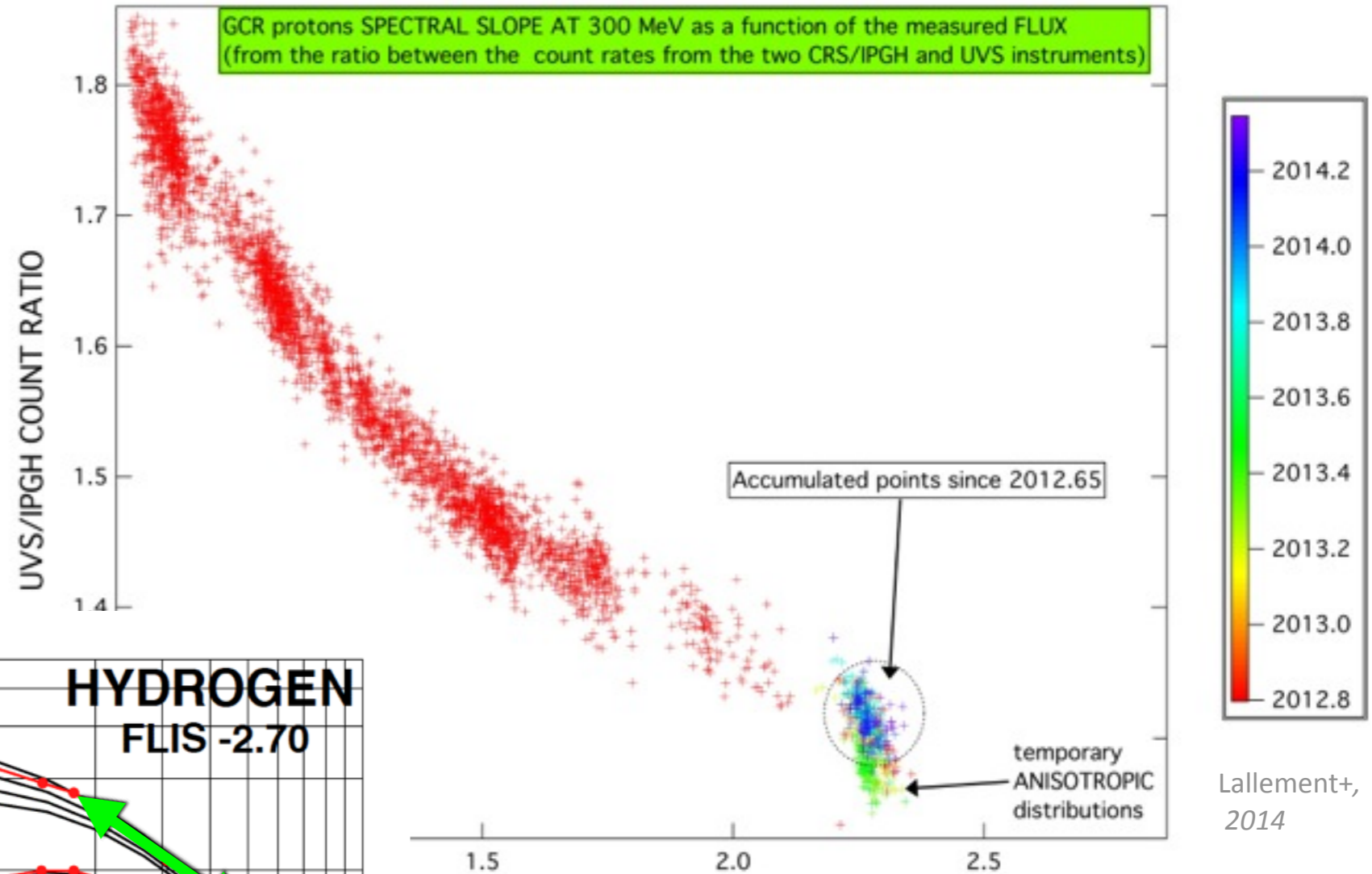


- IPGH detector (cosmic-ray suite)
- UV spectrograph
- slightly different energy response => measure of the spectral intensity gradient



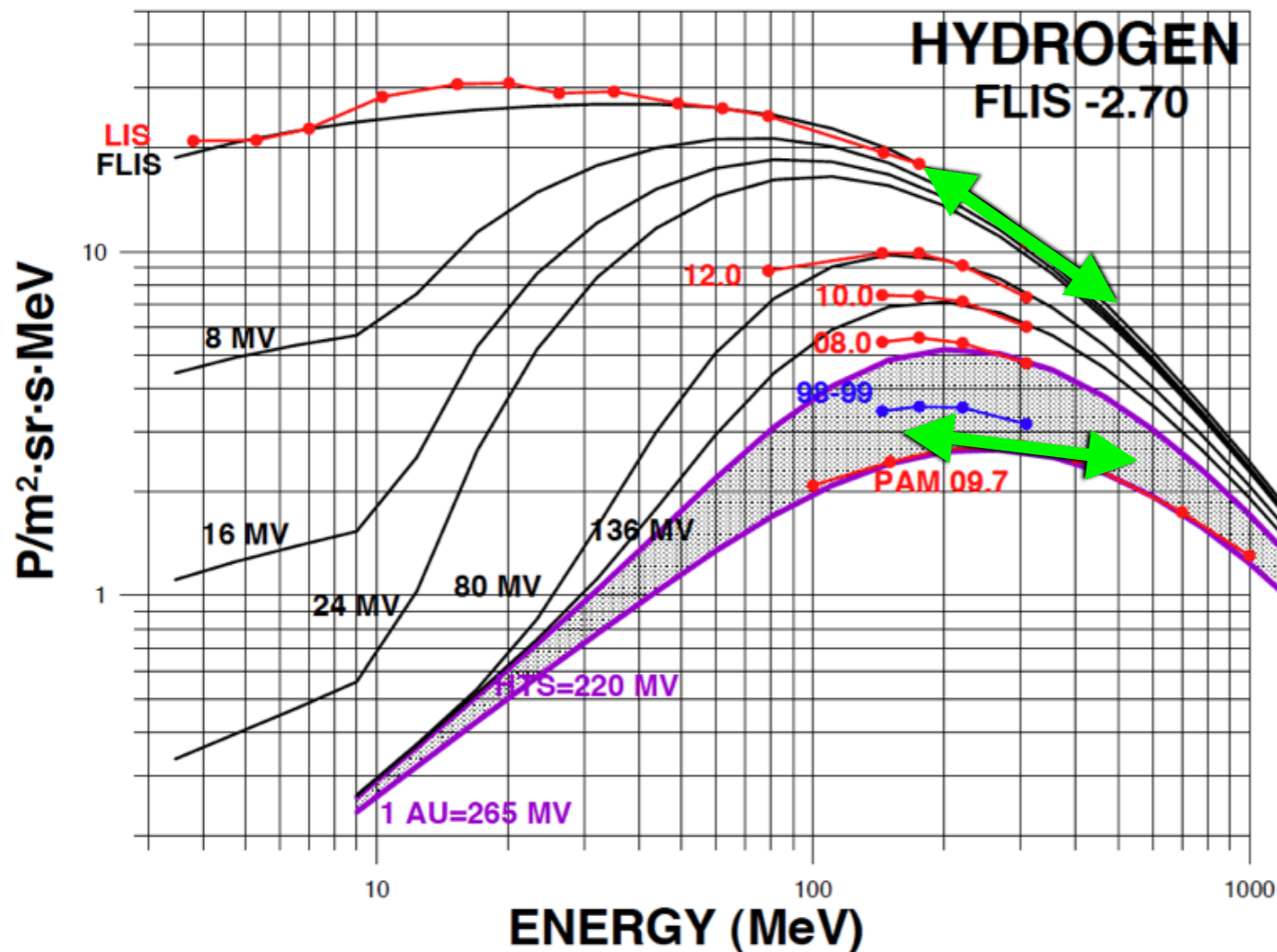


- stability of the spectral slope + strong flattening in H spectrum => likely end of modulation at 300 MeV



Lallement+, 2014

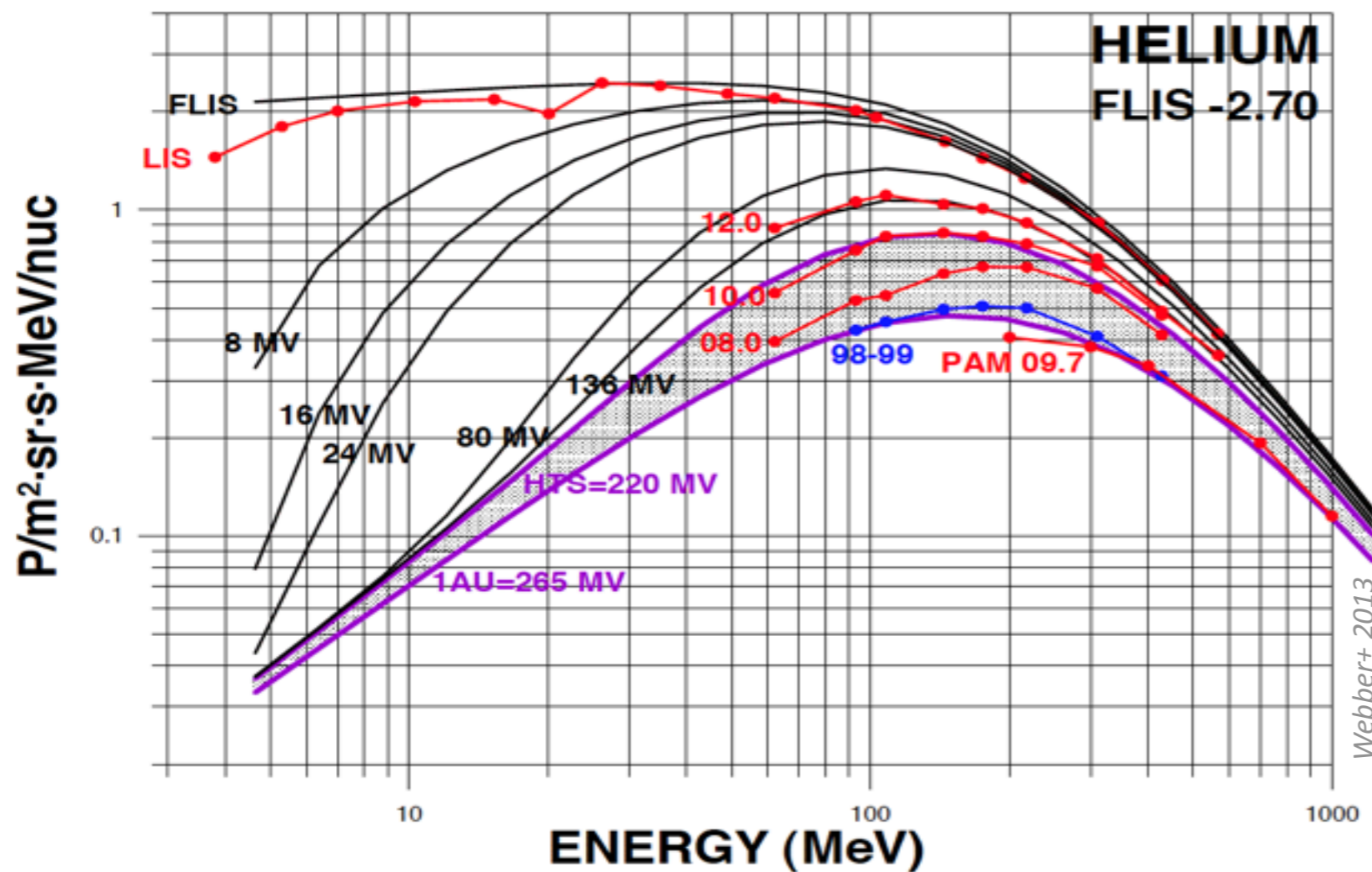
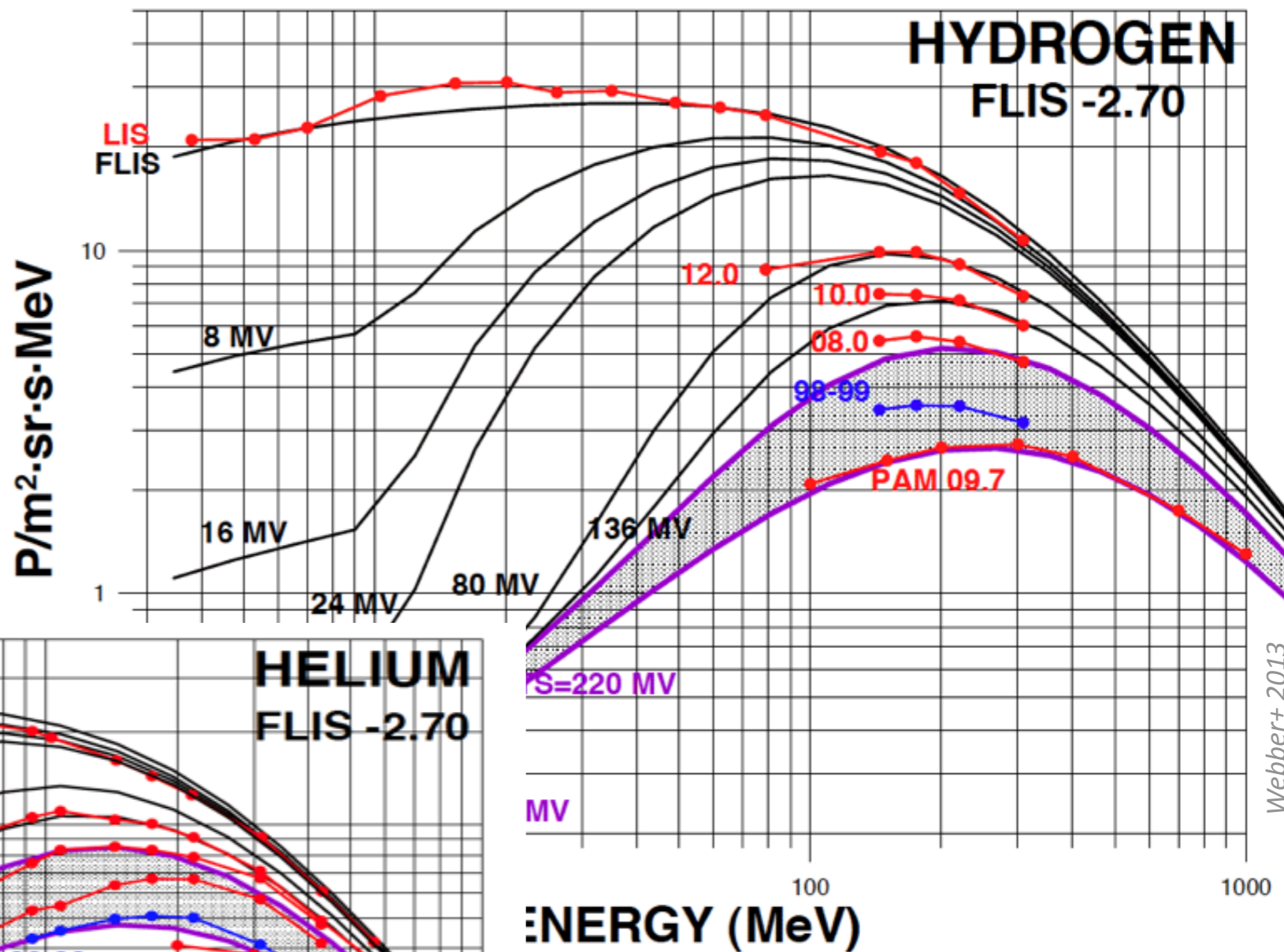
Webber+ 2013



UVS count rate



Voyager-1 in the ISM measures the local cosmic rays down to 4 MeV



Webber+ 2013

Webber+ 2013



