The Local Interstellar Spectrum Beyond the Heliopause: What can be Learned from Voyager in the Inner Heliosheath?

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Outline

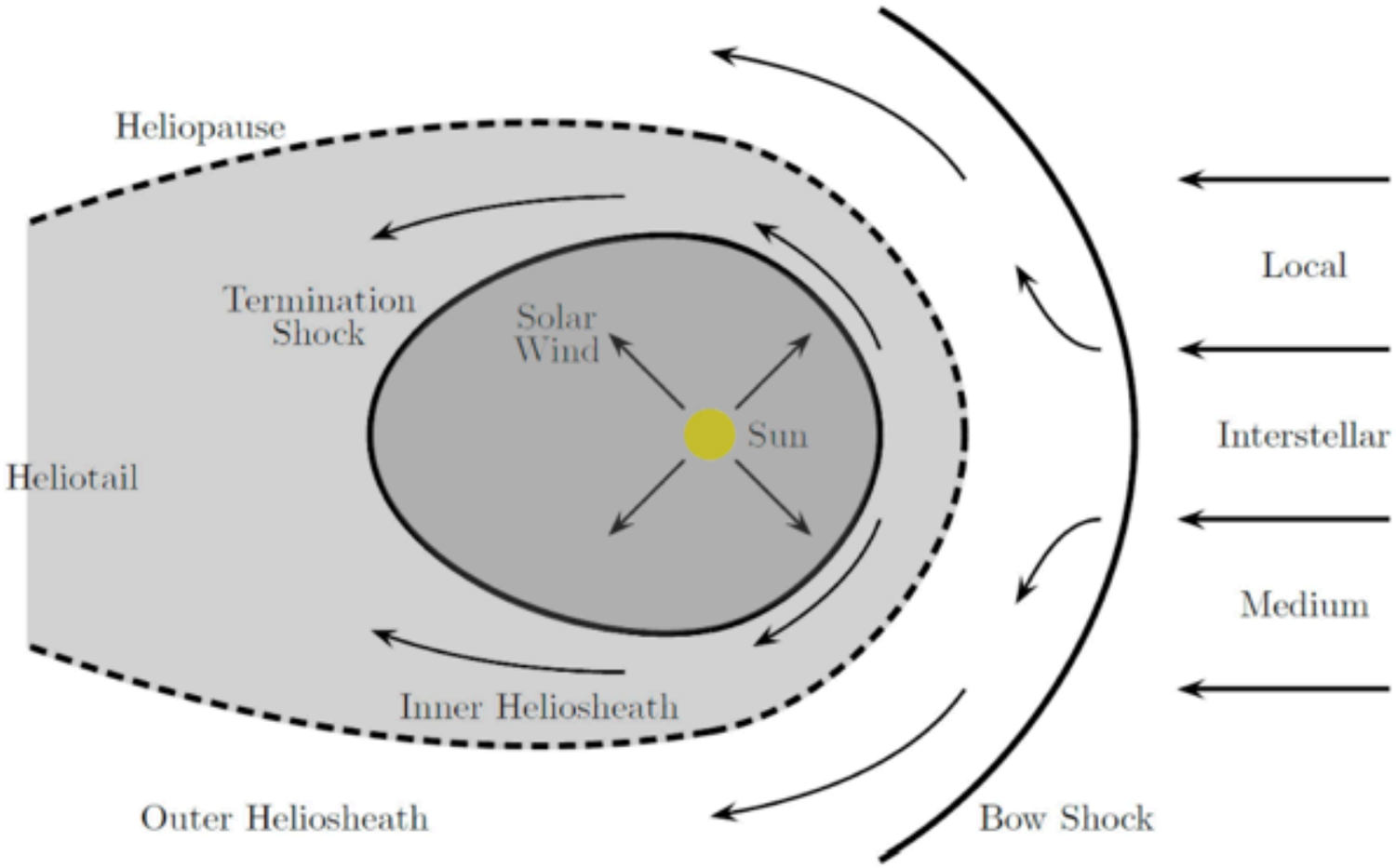
1. Background
2. The Heliopause Spectrum
3. Approximation of the results by Scherer et al. (2011)
4. From Solar Modulation Parameters to Diffusion Coefficients
5. Summary and Conclusions

1. Background

Heliospheric Transport of Charged Particles

Parker, 1965

$$\frac{\partial f}{\partial t} = -(\underbrace{\mathbf{V}}_{1} + \underbrace{\langle \mathbf{v}_D \rangle}_{2}) \cdot \nabla f + \underbrace{\nabla \cdot \left(\overleftrightarrow{\kappa} \cdot \nabla f \right)}_{3} + \underbrace{\frac{1}{3} (\nabla \cdot \mathbf{V}) \frac{\partial f}{\partial \ln R}}_{4} + \underbrace{S}_{5}$$



(adapted from Sternal (2010))

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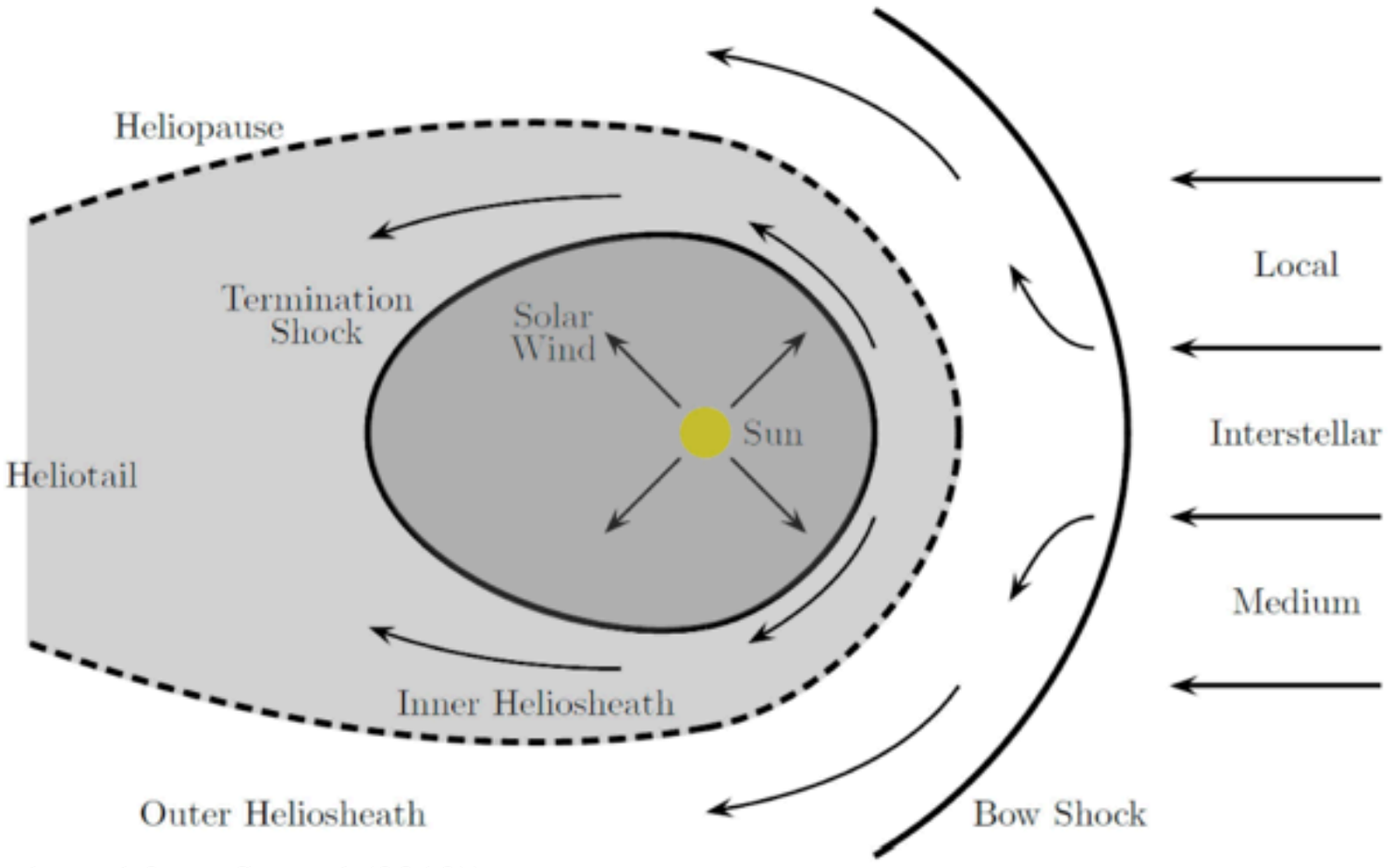
Caballero-Lopez & Moraal , 2004



(adapted from Sternal (2010))

$$\frac{\partial f}{\partial r} + \frac{vP}{3\kappa} \frac{\partial f}{\partial P} = 0$$

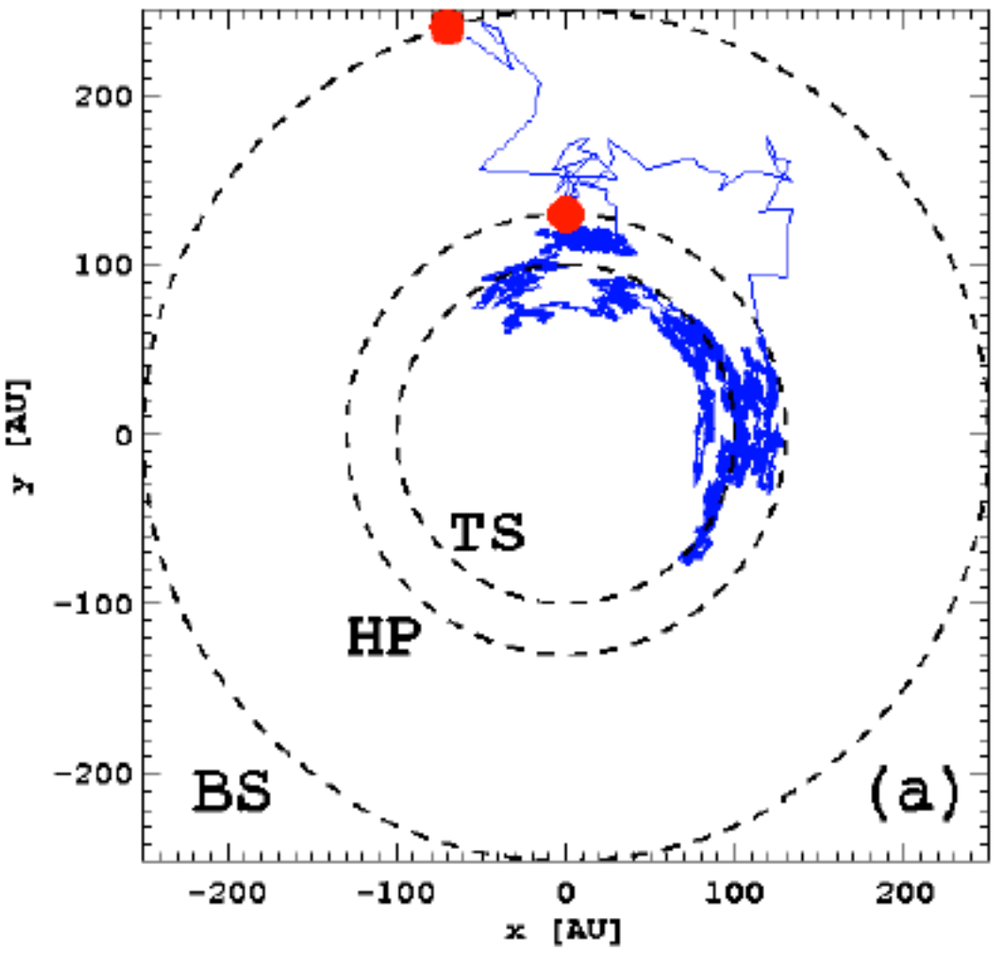
$$\phi(r) = \int_r^{r_b} \frac{v(r')}{3\kappa} dr'$$

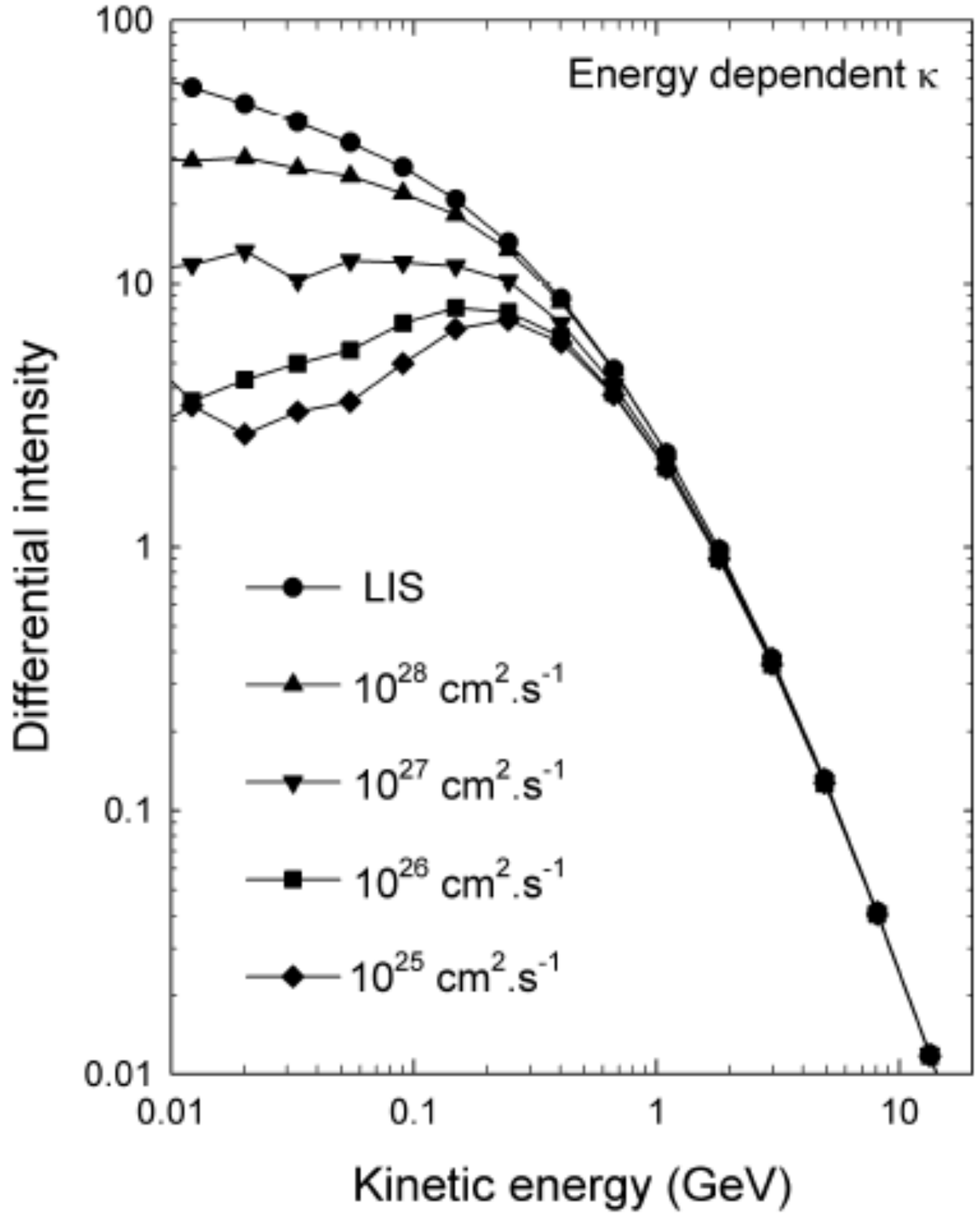
Force-Field Solution:

$$J(E, \phi) = J_{LIS}(E + \Phi) \frac{(E)(E + 2E_r)}{(E + \Phi)(E + \Phi + 2E_r)}$$

J_{LIS} ???

Results by Scherer et al., 2011





Results by Scherer et al., 2011

Idea:

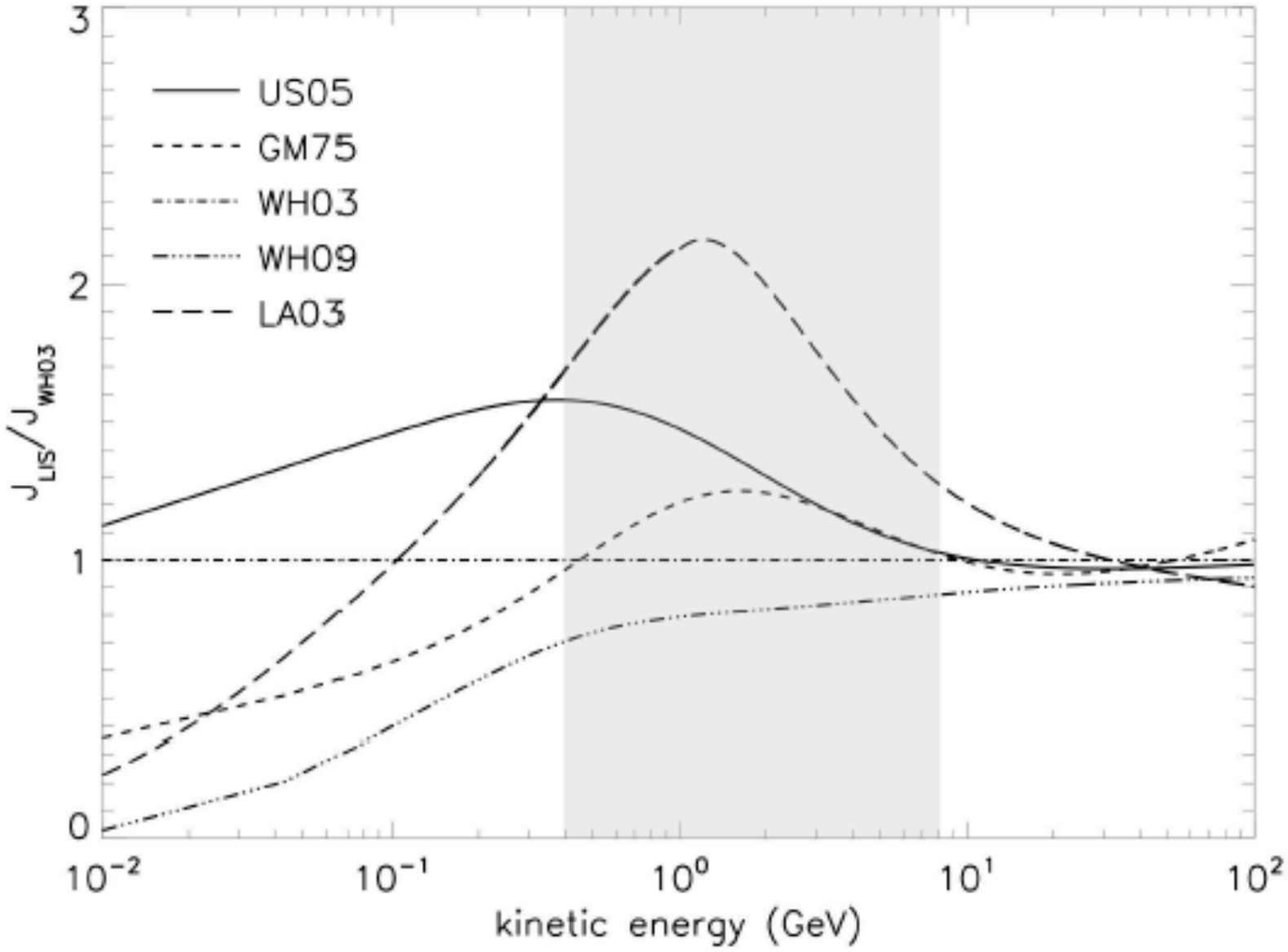
The Voyagers did not see the LIS, but the (modulated) Heliopause Spectrum (HPS)

LIS by Webber&Higbie (2009) is actually the HPS

We can use Scherer et al. (2011) to estimate the diffusion coefficient in the outer heliosphere

2. The Heliopause Spectrum

Which existing model may represent the HPS?



adapted from Herbst et al., 2010

Ratios for the Proton Spectra by

Usoskin et al., 2005 (US05)
Garcia-Munoz et al., 1975 (GM75)
Webber & Higbie, 2009 (WH09)
Langner, 2003 (LA03)

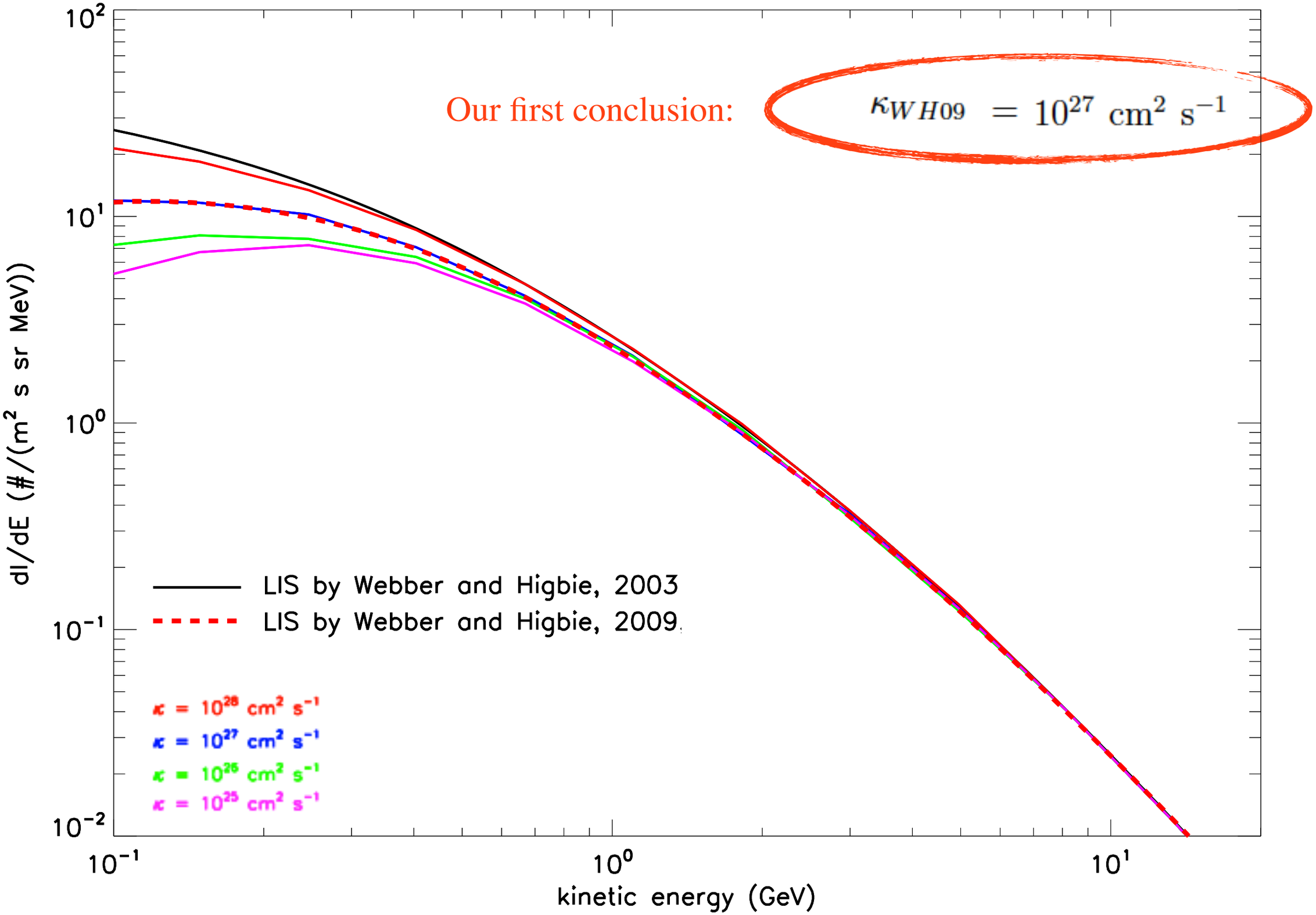
with respect to the model by Webber & Higbie, 2003 (WH03)

↓

lowest intensities by WH09

... compared to the model by Webber & Higbie, 2009 including correction

Our first conclusion: $\kappa_{WH09} = 10^{27}\ \mathrm{cm}^2\ \mathrm{s}^{-1}$

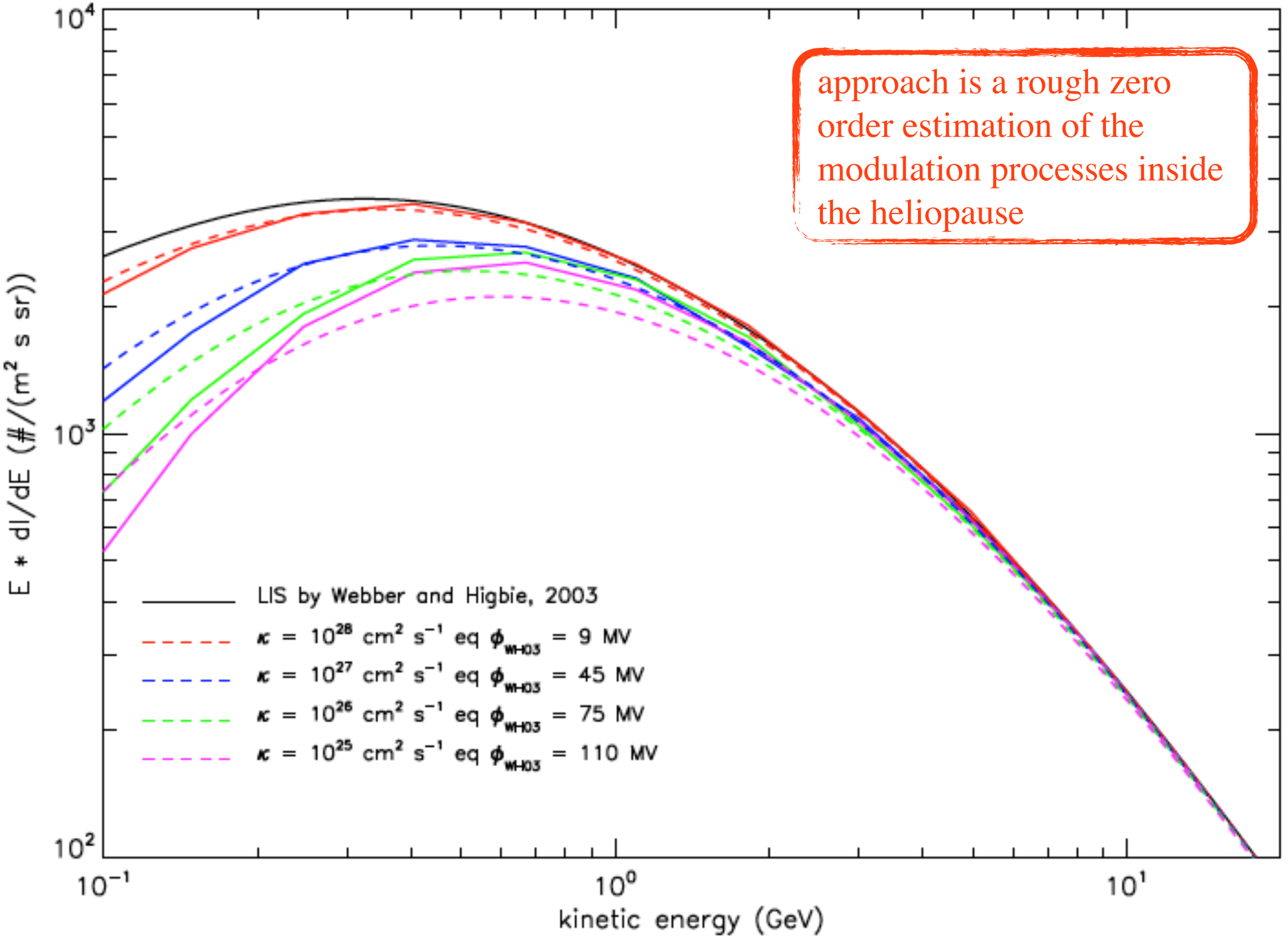


3. Approximation of the results by Scherer et al. (2011)

WH03 must not be the LIS, others are possible as well

Question:

Is there a way to estimate the diffusion coefficients without repeating the SDE simulations by Scherer et al. (2011)?

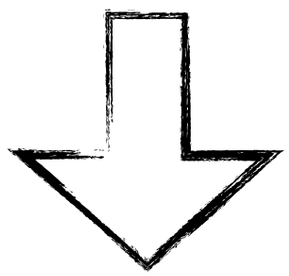

approach is a rough zero order estimation of the modulation processes inside the heliopause
E * dI/dE (#/(m² s sr))
kinetic energy (GeV)
LIS by Webber and Higbie, 2003
κ = 10²⁸ cm² s⁻¹ eq φ WH03 = 9 MV
κ = 10²⁷ cm² s⁻¹ eq φ WH03 = 45 MV
κ = 10²⁶ cm² s⁻¹ eq φ WH03 = 75 MV
κ = 10²⁵ cm² s⁻¹ eq φ WH03 = 110 MV

4. From Solar Modulation Parameters to Diffusion Coefficients

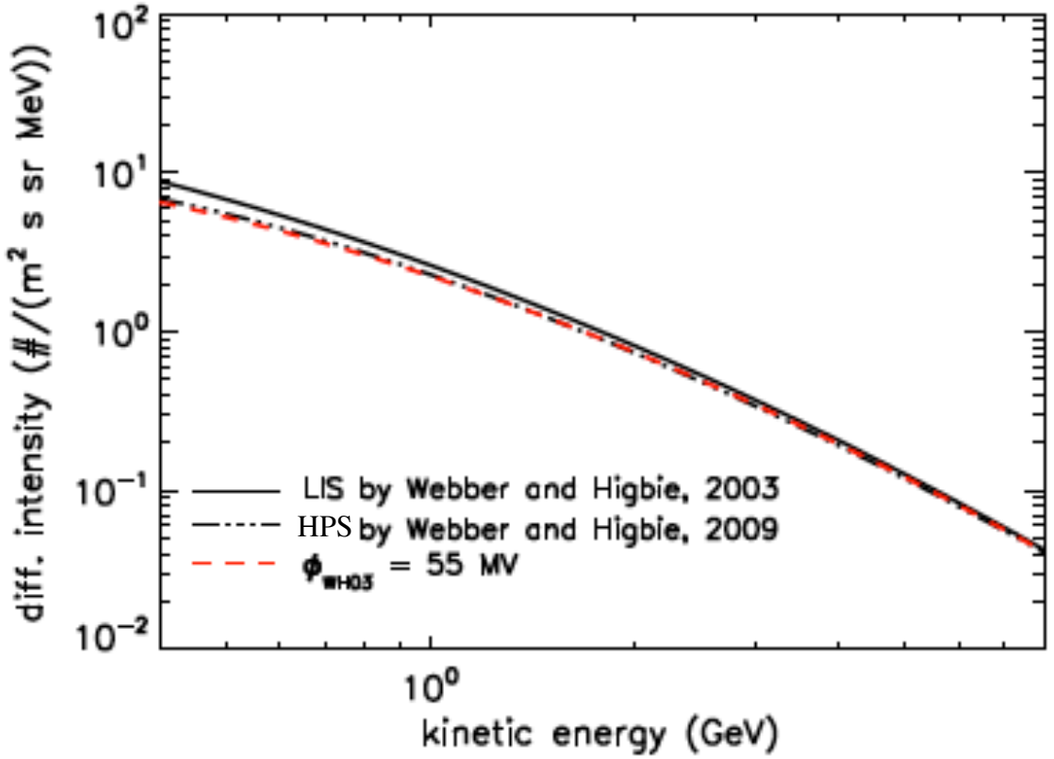
Idea: Use the Force Field solution as a rough approximation

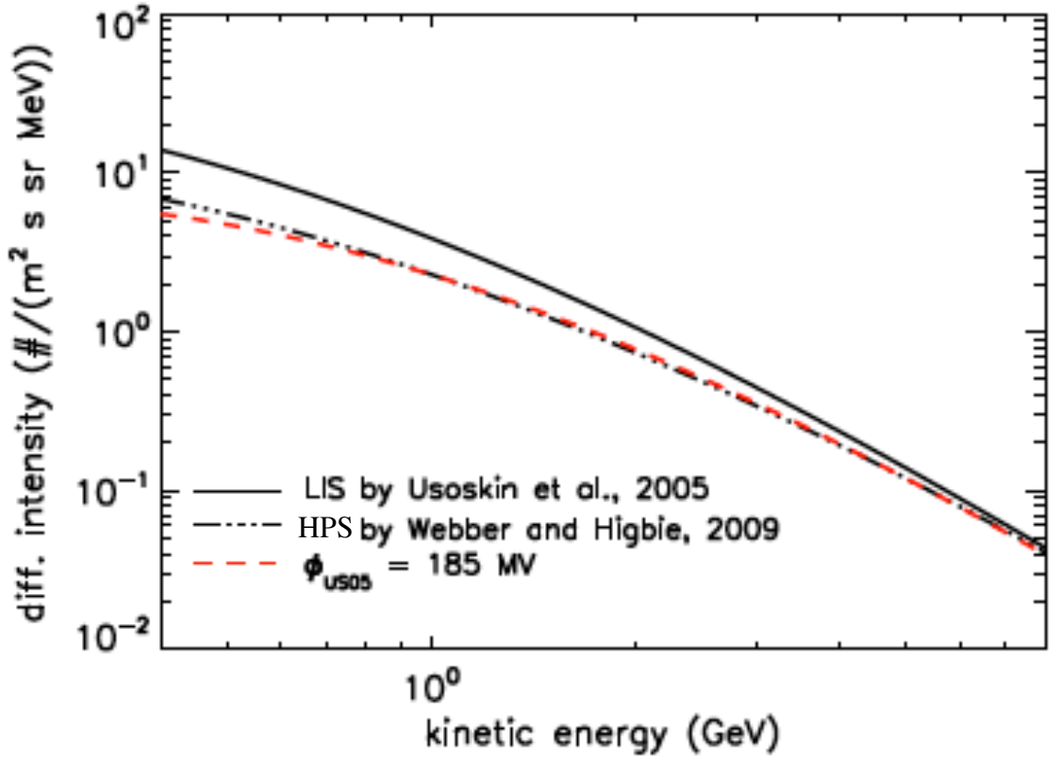
Caballero-Lopez & Moraal , 2004 : $$\phi(r) = \int_r^{r_b} \frac{v(r')}{3\kappa} dr'$$

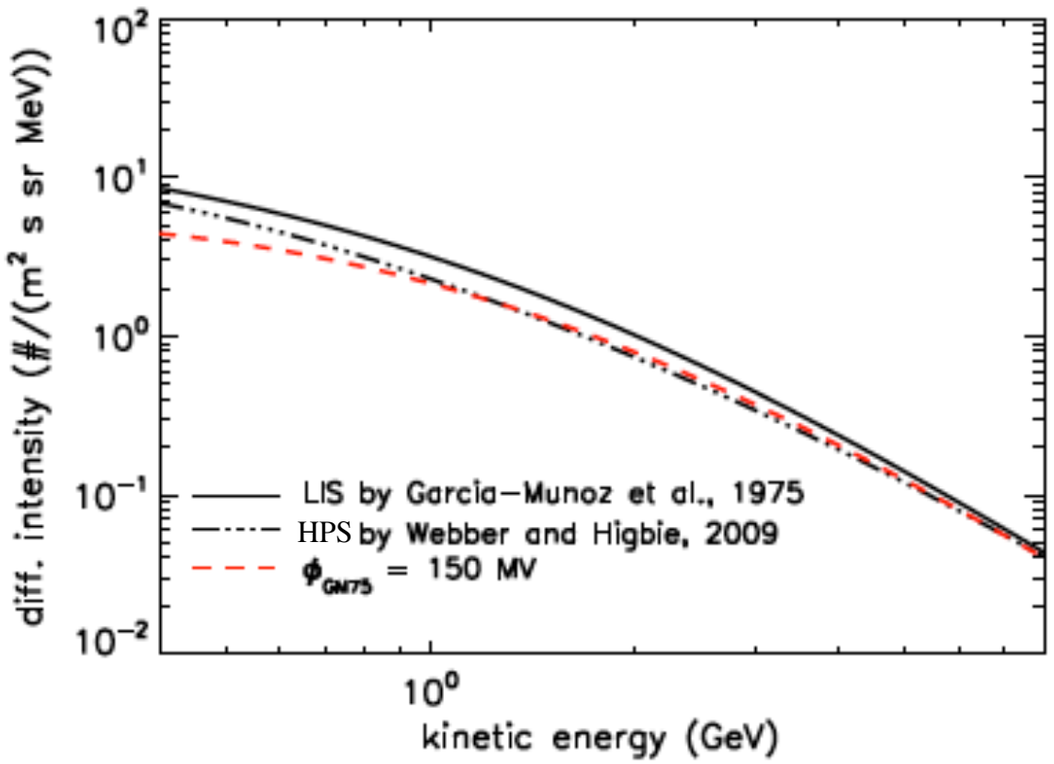
assumption: κ=const. $$\phi_{LIS} \cdot \kappa_{LIS} = \frac{1}{3} \int_r^{rB} v \ \mathrm{d}r = \mathrm{const}$$

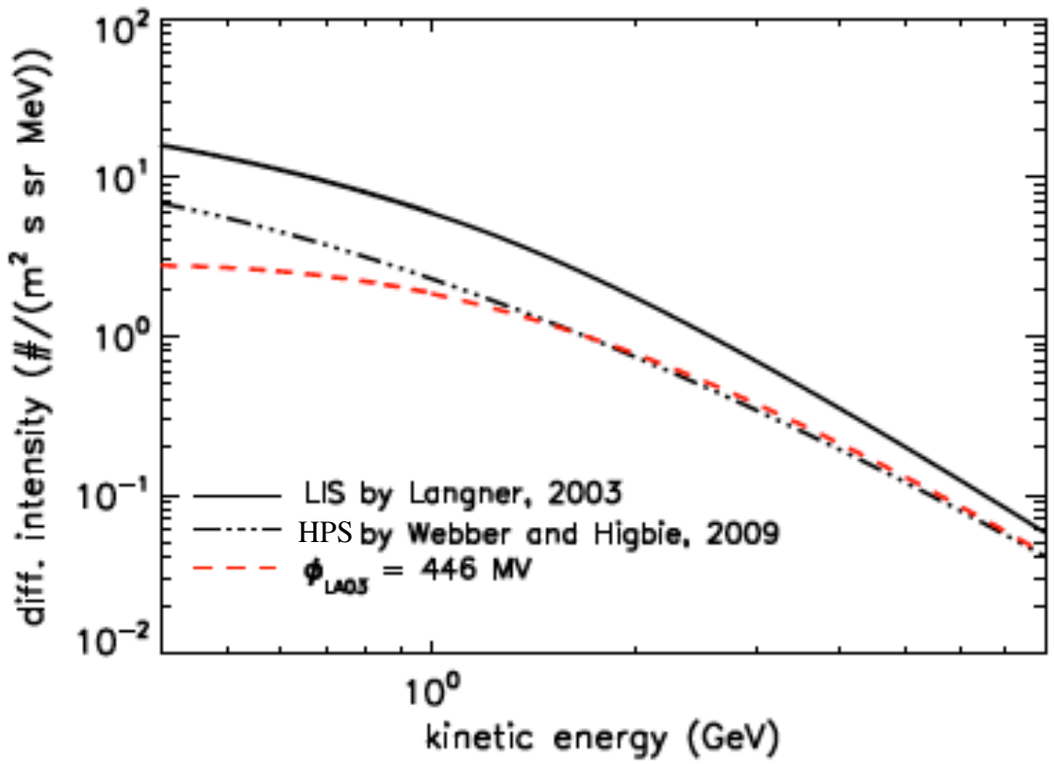


$$\kappa_{LIS} = \frac{\phi_{WH03}}{\phi_{LIS}} \cdot \kappa_{WH03}$$


diff. intensity (#/(m² s sr MeV))
kinetic energy (GeV)
LIS by Webber and Higbie, 2003
HPS by Webber and Higbie, 2009
ϕ_{WH03} = 55 MV


diff. intensity (#/(m² s sr MeV))
kinetic energy (GeV)
LIS by Usoskin et al., 2005
HPS by Webber and Higbie, 2009
ϕ_{US05} = 185 MV


diff. intensity (#/(m² s sr MeV))
kinetic energy (GeV)
LIS by Garcia−Munoz et al., 1975
HPS by Webber and Higbie, 2009
ϕ_{GM75} = 150 MV

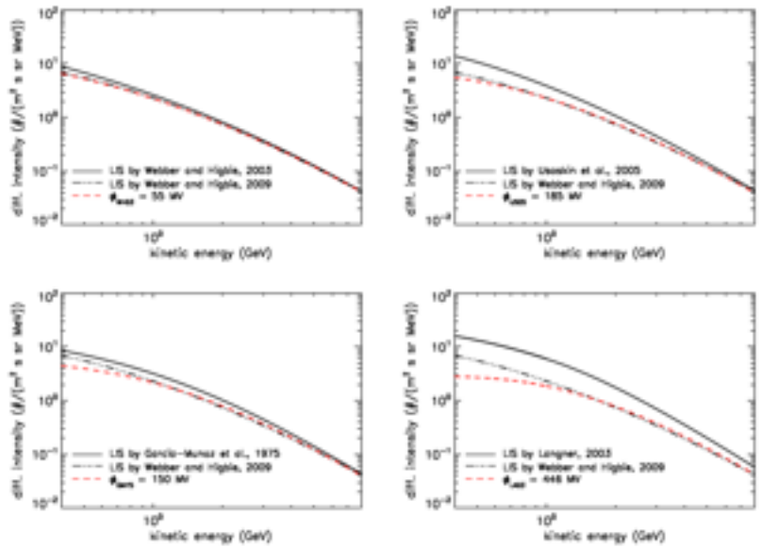

diff. intensity (#/(m² s sr MeV))
kinetic energy (GeV)
LIS by Langner, 2003
HPS by Webber and Higbie, 2009
ϕ_{LA03} = 446 MV

$$\phi(r) = \int_r^{r_b} \frac{v(r')}{3\kappa} dr'$$

$$\phi_{LIS} \cdot \kappa_{LIS} = \frac{1}{3} \int_r^{rB} v \ \mathrm{d}r = \mathrm{const}$$

$$\kappa_{LIS} = \frac{\phi_{WH03}}{\phi_{LIS}} \cdot \kappa_{WH03}$$

+



LIS model	ϕ (MV)	κ (cm^2 s^{-1})
WH03	55	$1 \cdot 10^{27}$
US05	185	$3.3 \cdot 10^{26}$
GM75	150	$5 \cdot 10^{26}$
LA03	446	$1.25 \cdot 10^{26}$

5. Summary and Conclusions

- Spectrum by Webber & Higbie (2009) = HPS
  - $\kappa_{WH09} = 10^{27}\ \mathrm{cm}^2\ \mathrm{s}^{-1}$
- Force Field solution as zero order approximation of the modulation processes in the outer heliosheath
- Estimation of the LIS-dependent diffusion coefficients κ_{LIS}
  - κ_{LIS} in the range of 10^{26} and $10^{27}\ \mathrm{cm}^2\ \mathrm{s}^{-1}$