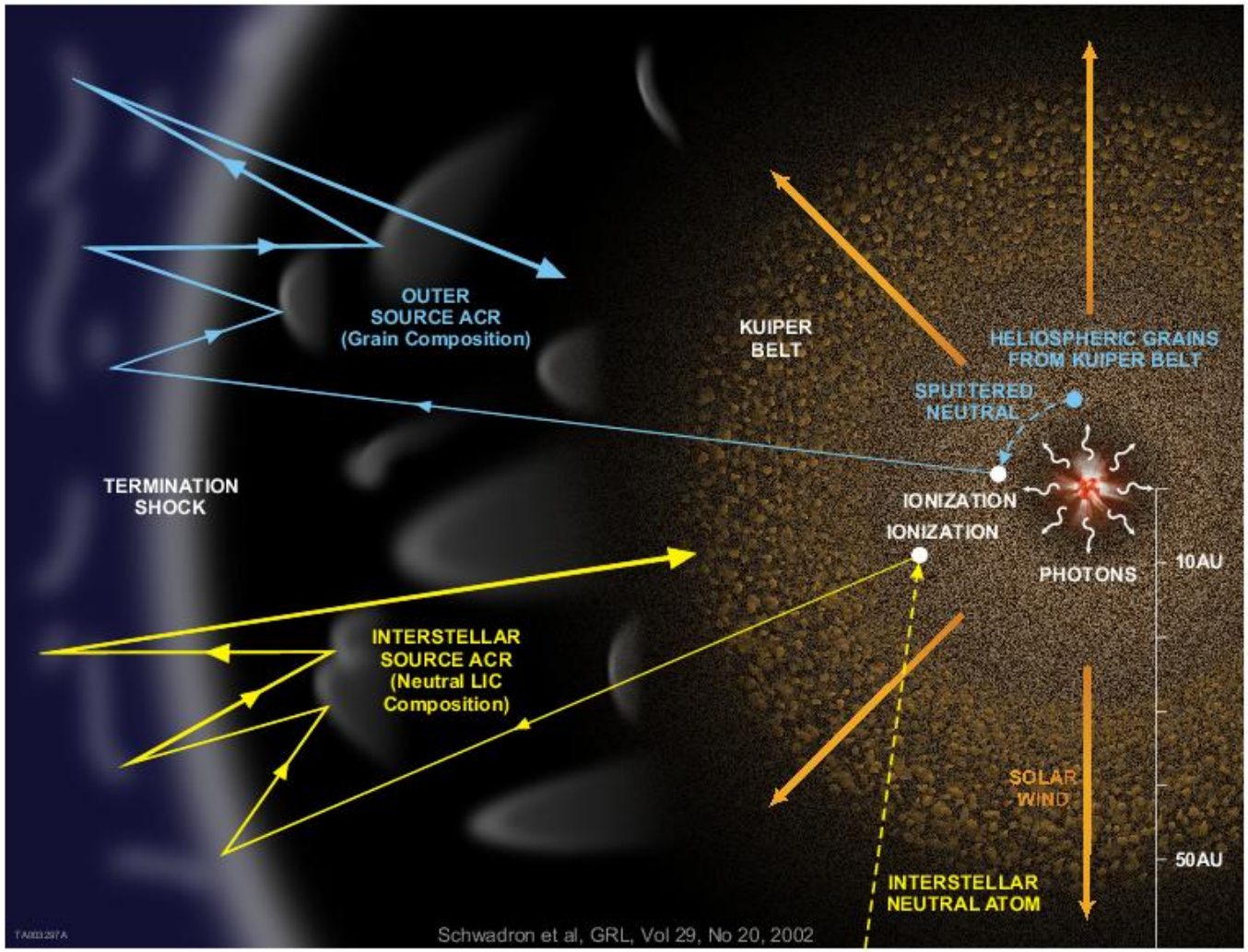
Possible evidence for shock acceleration at the termination shock

Du Toit Strauss[1]
Marius Potgieter[1], Stefan Ferreira[1]

[1]Centre for Space Research, North-West University
Potchefstroom, South Africa

Bochum workshop

Classic ACR paradigm



Classic ACR paradigm

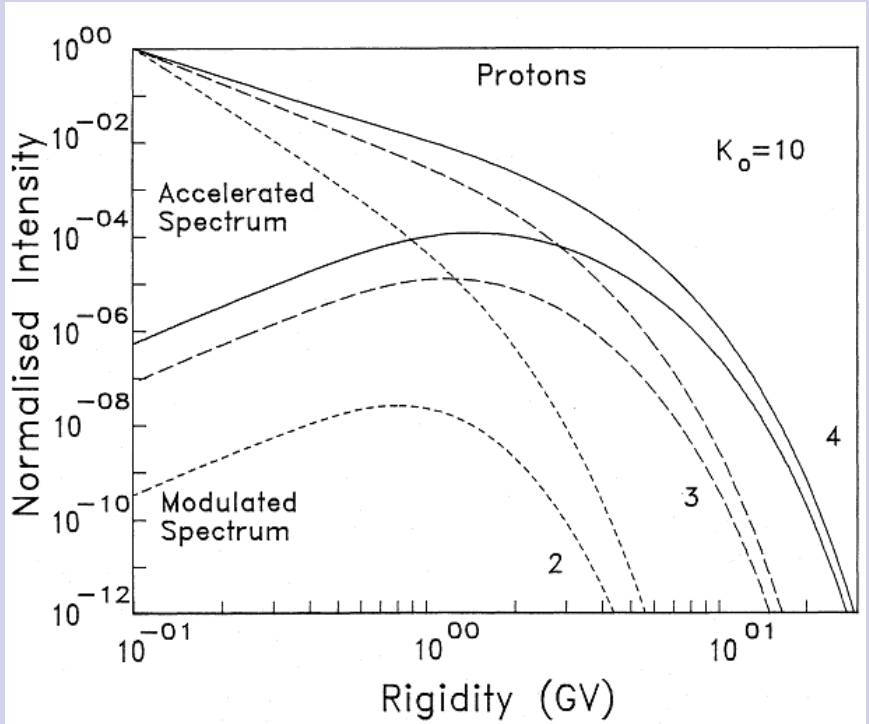
- First order Fermi acceleration
- 1D solution – spectra:

$$j \propto E^{\frac{-\gamma+2}{2}},$$

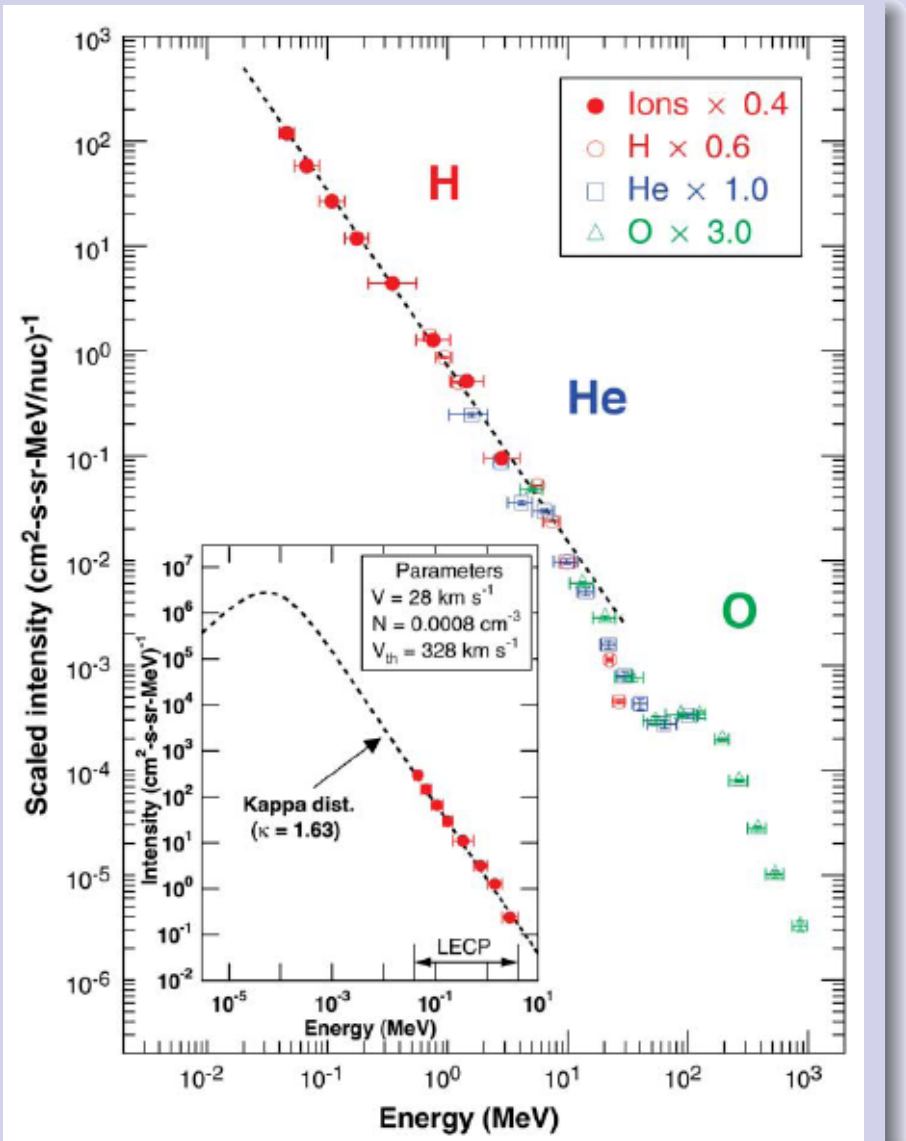
$$\gamma \equiv \frac{3s}{s-1},$$

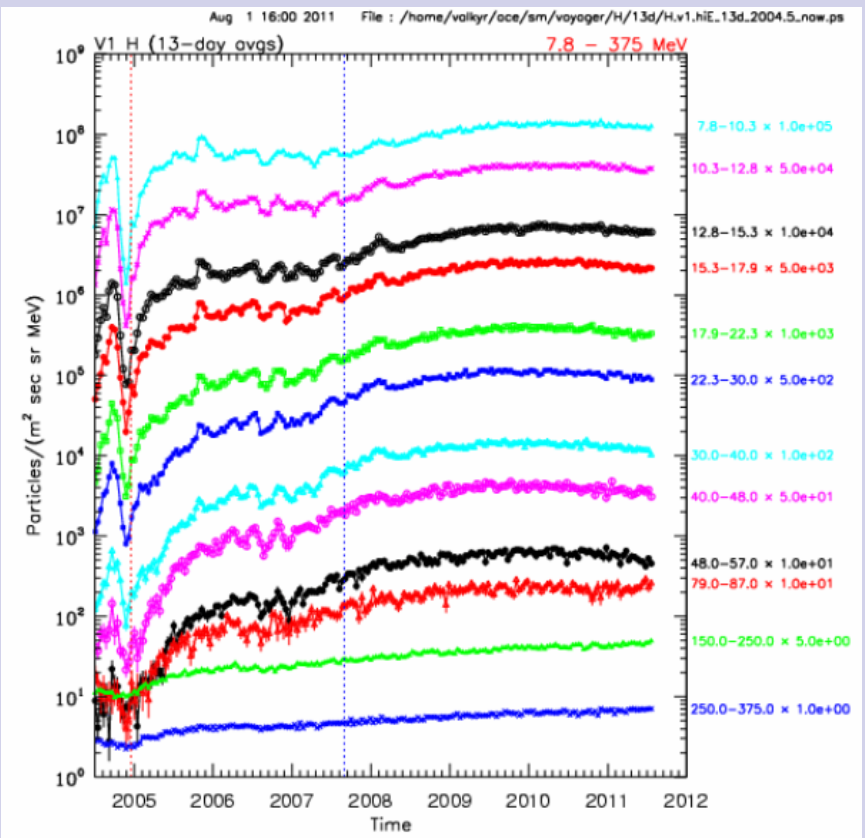
- 1D solution – times:

$$t_{p_0 \to p} = \frac{3}{V_1 - V_2} \int_{p_0}^{p} \left[\frac{\kappa_1}{V_1} + \frac{\kappa_2}{V_2} \right] \frac{dp}{p},$$



Voyager observations …



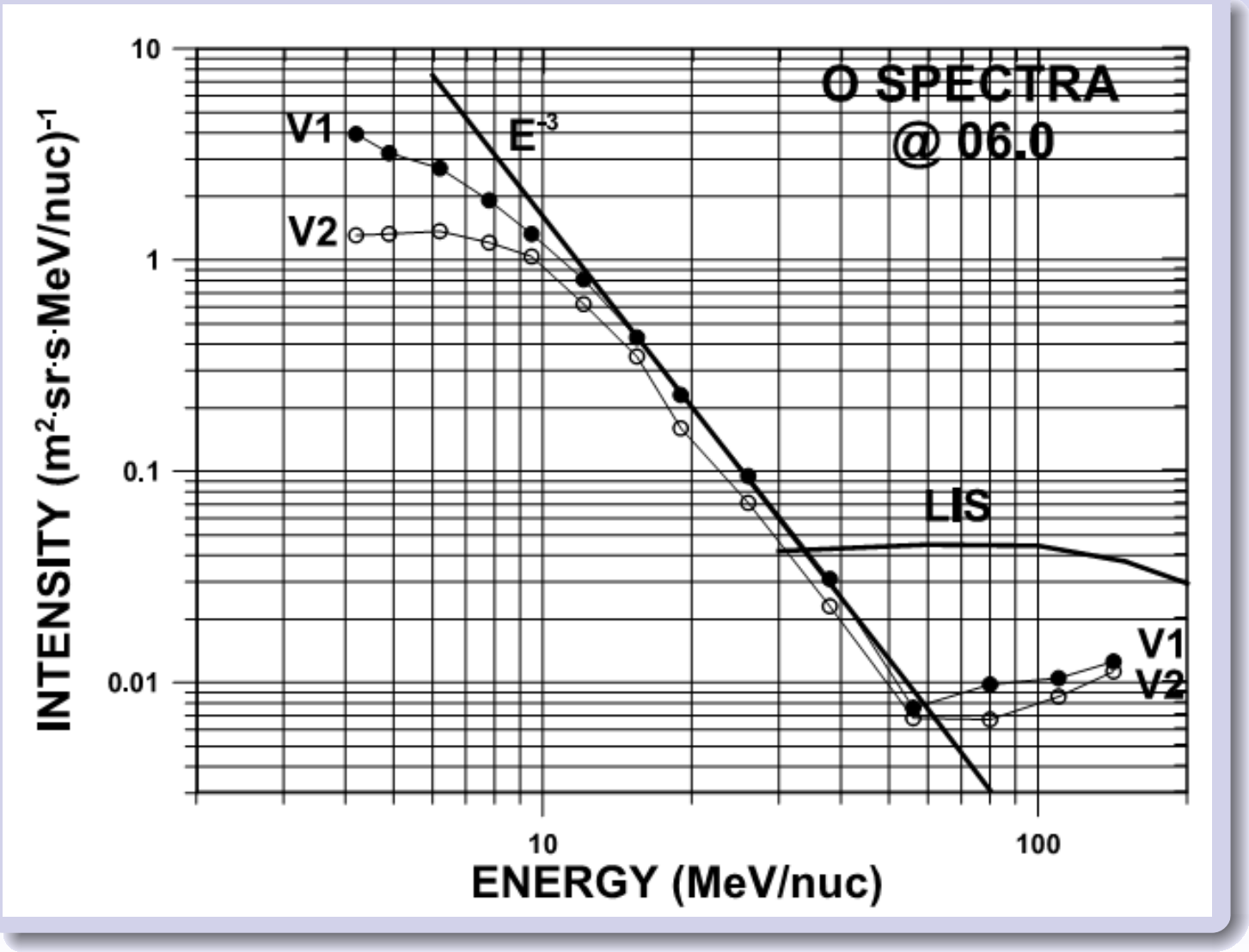


New theories emerge

- Transient event
- Preferred (Fermi I) acceleration
- Stochastic acceleration
- Momentum diffusion (Fermi II)
- Magnetic reconnection

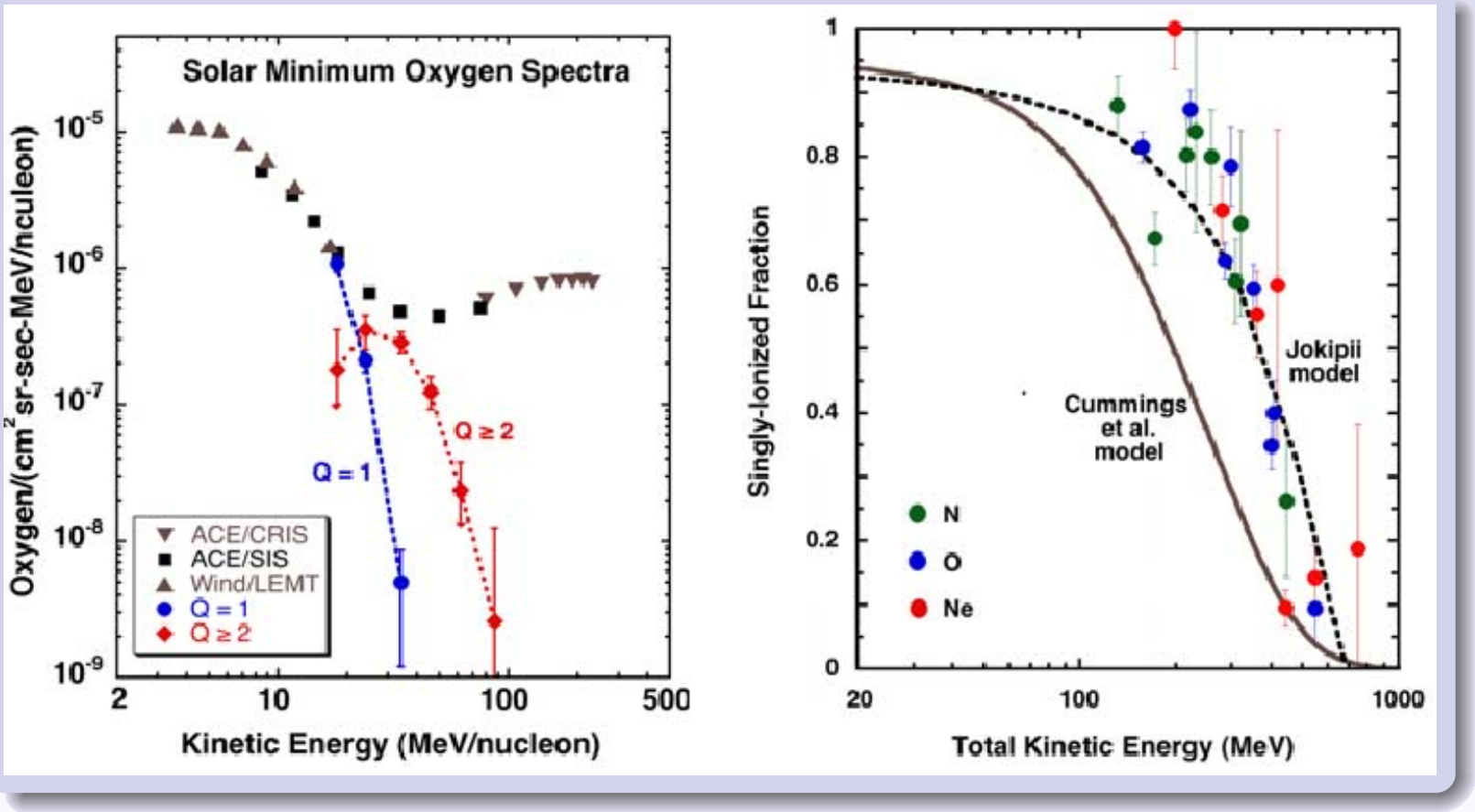
Some of these theories completely abandoned Fermi I!

A high energy power law



. . . and ACR Oxygen is not singly ionized

Charge states of $Q = 1, 2, 3, 8$ (Best fit) for Oxygen



Multiple charged ACRs – theory

- PUIs the seed population of ACRs
- PUIs mostly singly ionized
- During acceleration, ACRs spend a lot of time at the TS
- They may become additionally ionized by the interaction

$$O^{+q} + p \rightarrow O^{+(q+1)} + H$$

- The higher charge states are accelerated more efficiently, and also faster

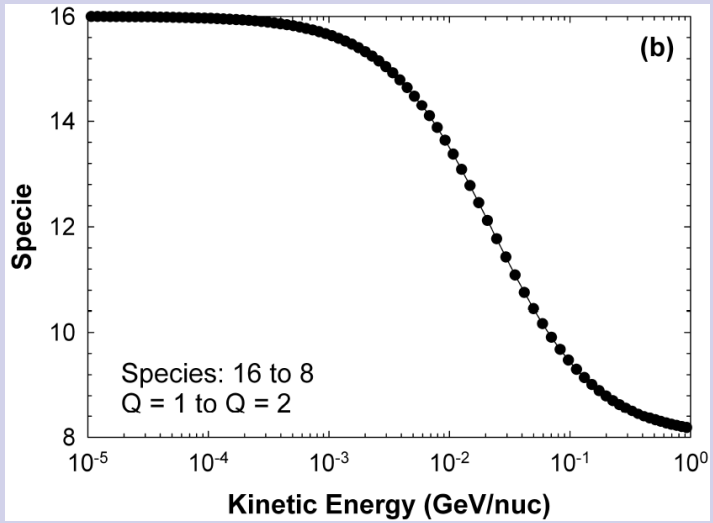
$$\Delta E \propto q$$

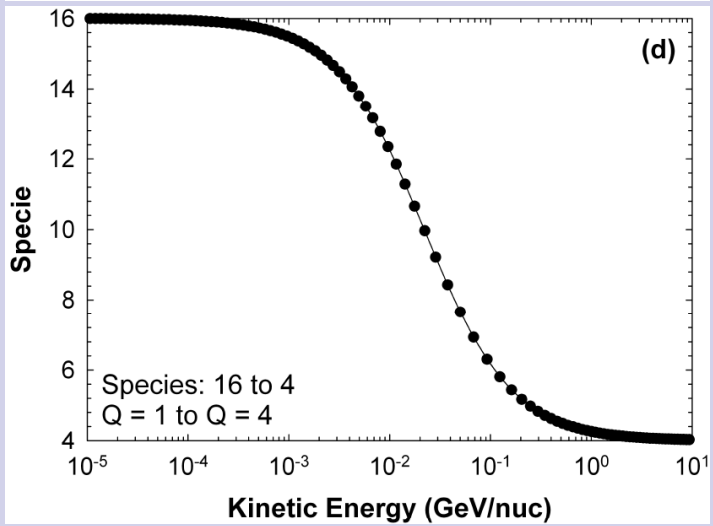
Our modelling approach …

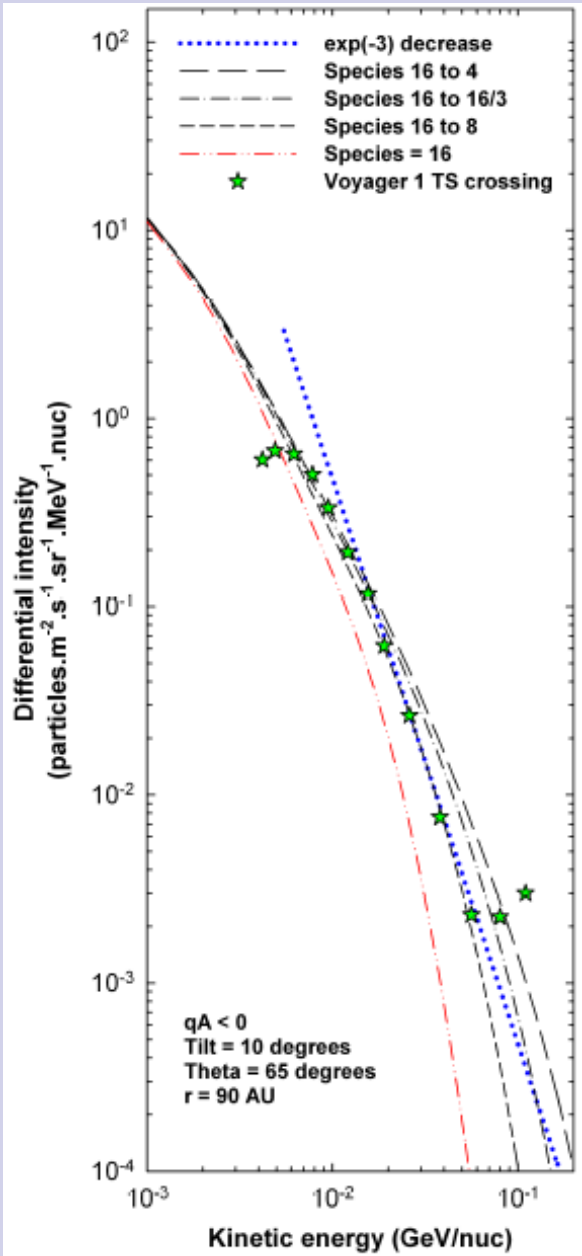
- Change the ACR's *average charge* energy dependently
- This is done via the *species* value:

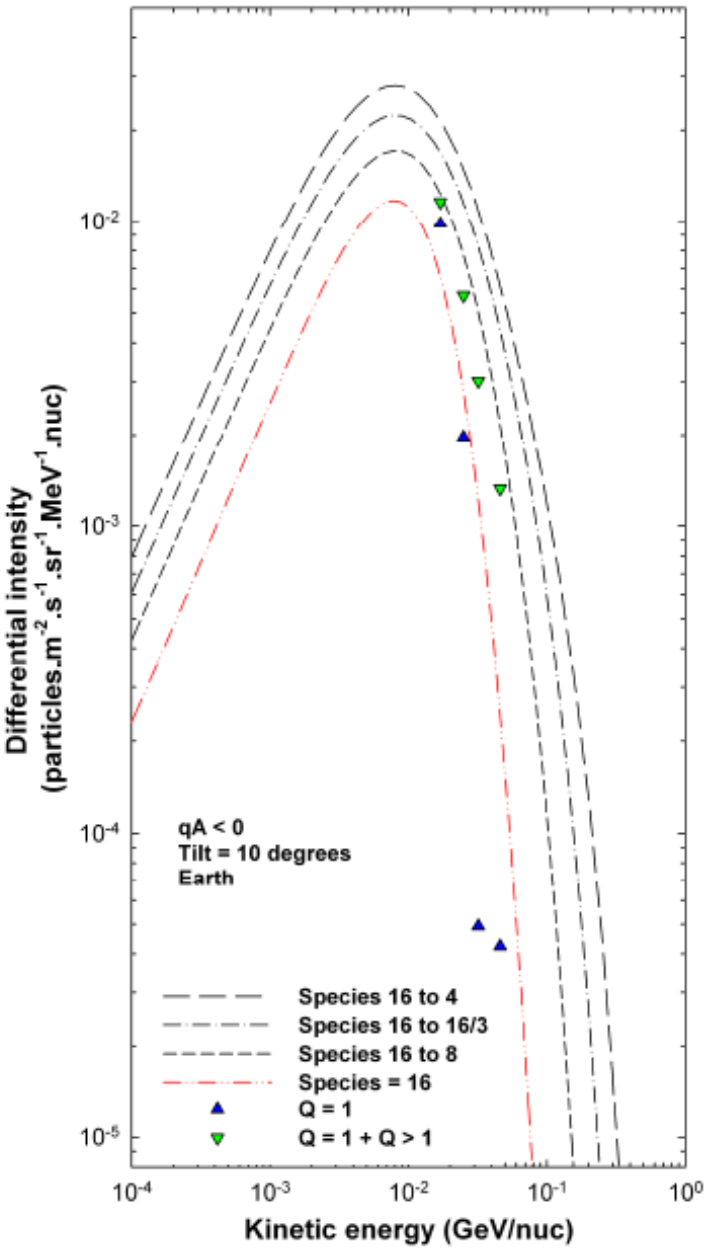
$$\Theta(E) = \frac{A}{Q(E)}$$

- $Q = 1 \Rightarrow \Theta = 16$
- $Q = 4 \Rightarrow \Theta = 4$ (extreme case)
- The resulting distribution is accelerated at the TS by diffusive shock (Fermi I) acceleration



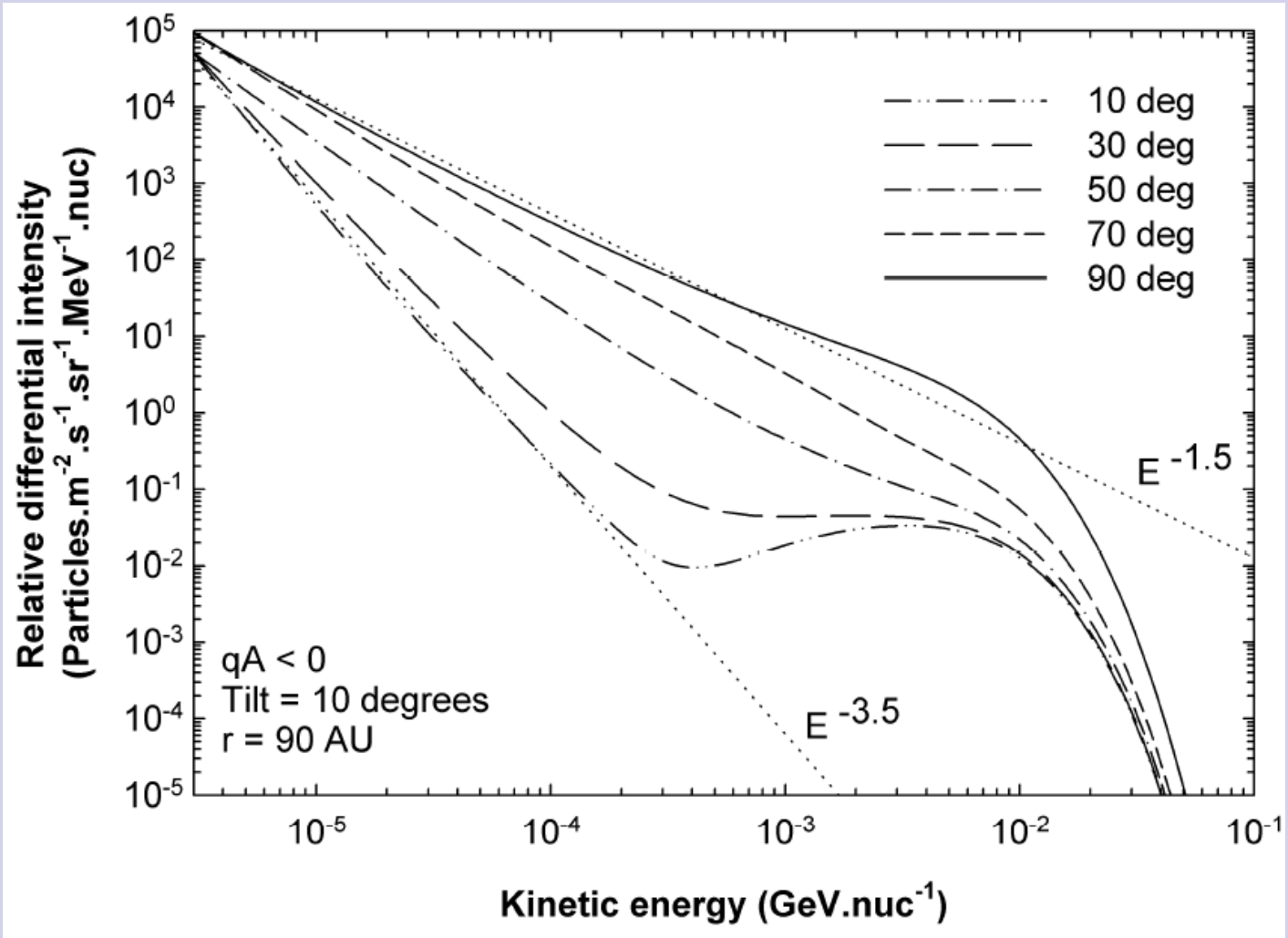



exp(-3) decrease
Species 16 to 4
Species 16 to 16/3
Species 16 to 8
Species = 16
Voyager 1 TS crossing
qA < 0
Tilt = 10 degrees
Theta = 65 degrees
r = 90 AU
Differential intensity
(particles.m-2.s-1.sr-1.MeV-1.nuc)
Kinetic energy (GeV/nuc)

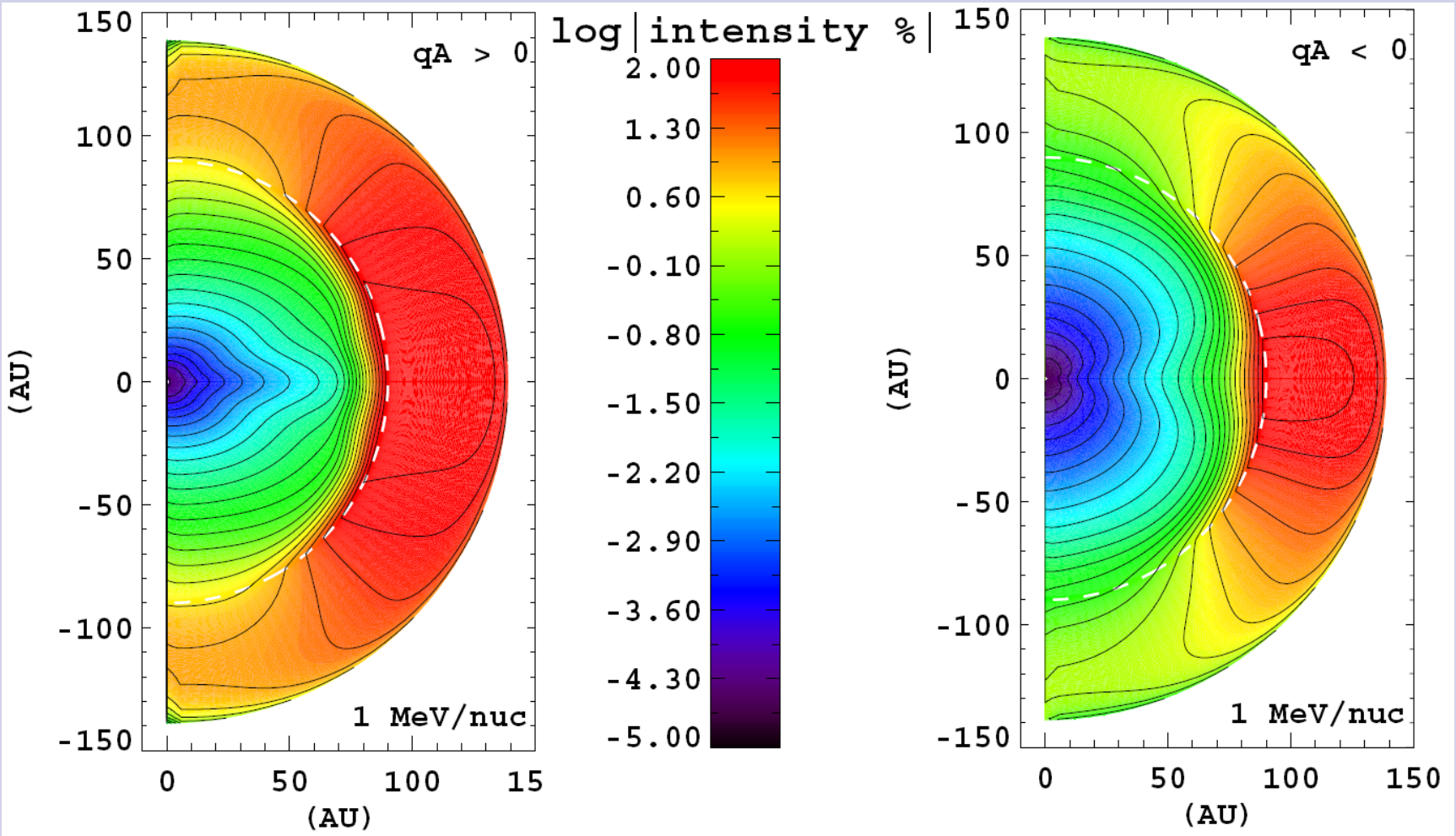

qA < 0
Tilt = 10 degrees
Earth
Species 16 to 4
Species 16 to 16/3
Species 16 to 8
Species = 16
Q = 1
Q = 1 + Q > 1
Differential intensity
(particles.m-2.s-1.sr-1.MeV-1.nuc)
Kinetic energy (GeV/nuc)

- Diffusive shock acceleration should (must) thus occur at the TS
- Can Fermi I explain the Voyager observations?
- Maybe through preferred acceleration at some position along the TS.

Energy spectra?



Increasing intensities?



Re-acceleration might be needed . . .