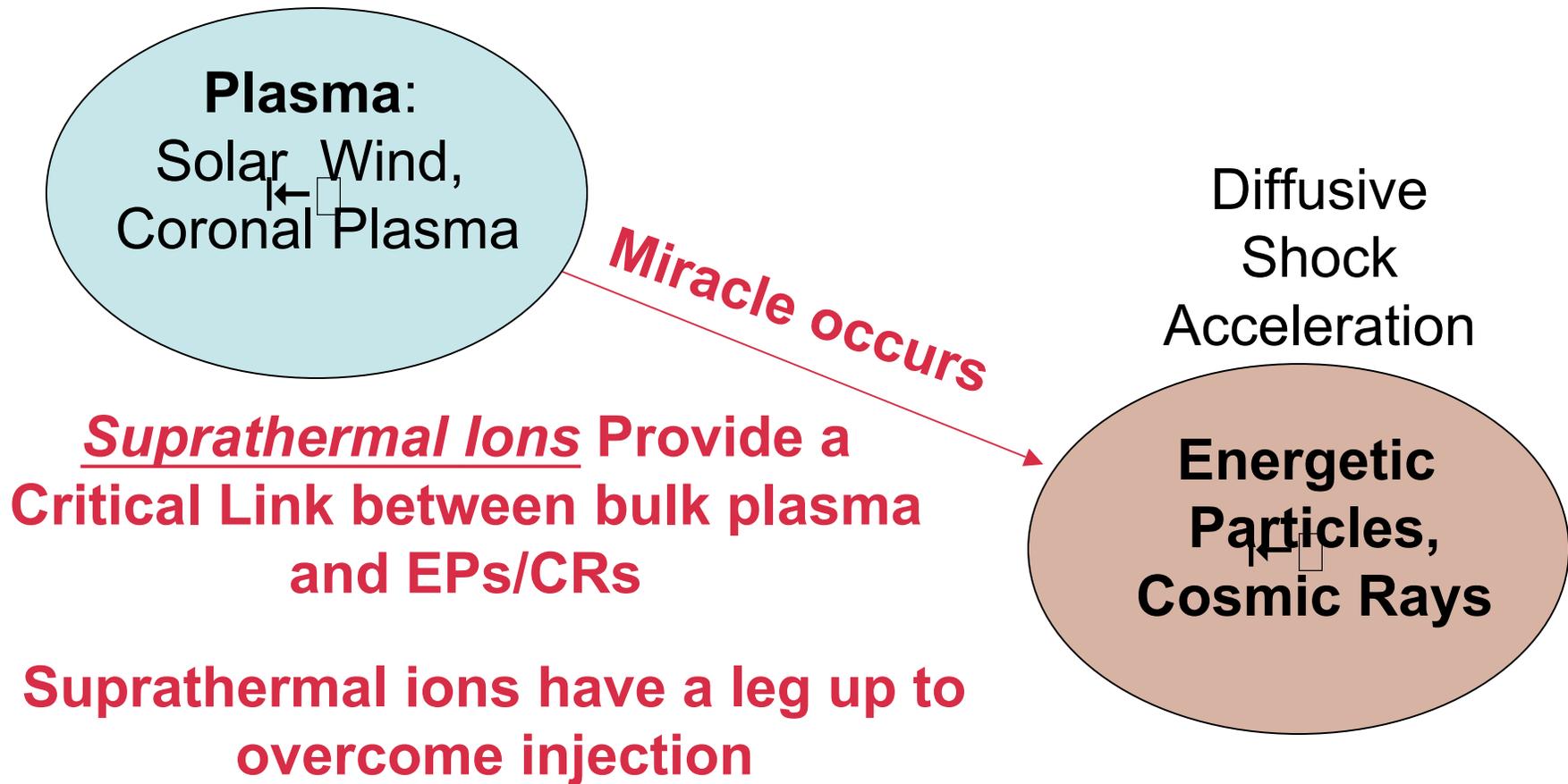


Pre-accelerated seed populations of energetic particles in the heliosphere

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Where do energetic particles and cosmic rays come from?



Is there an Injection Problem?

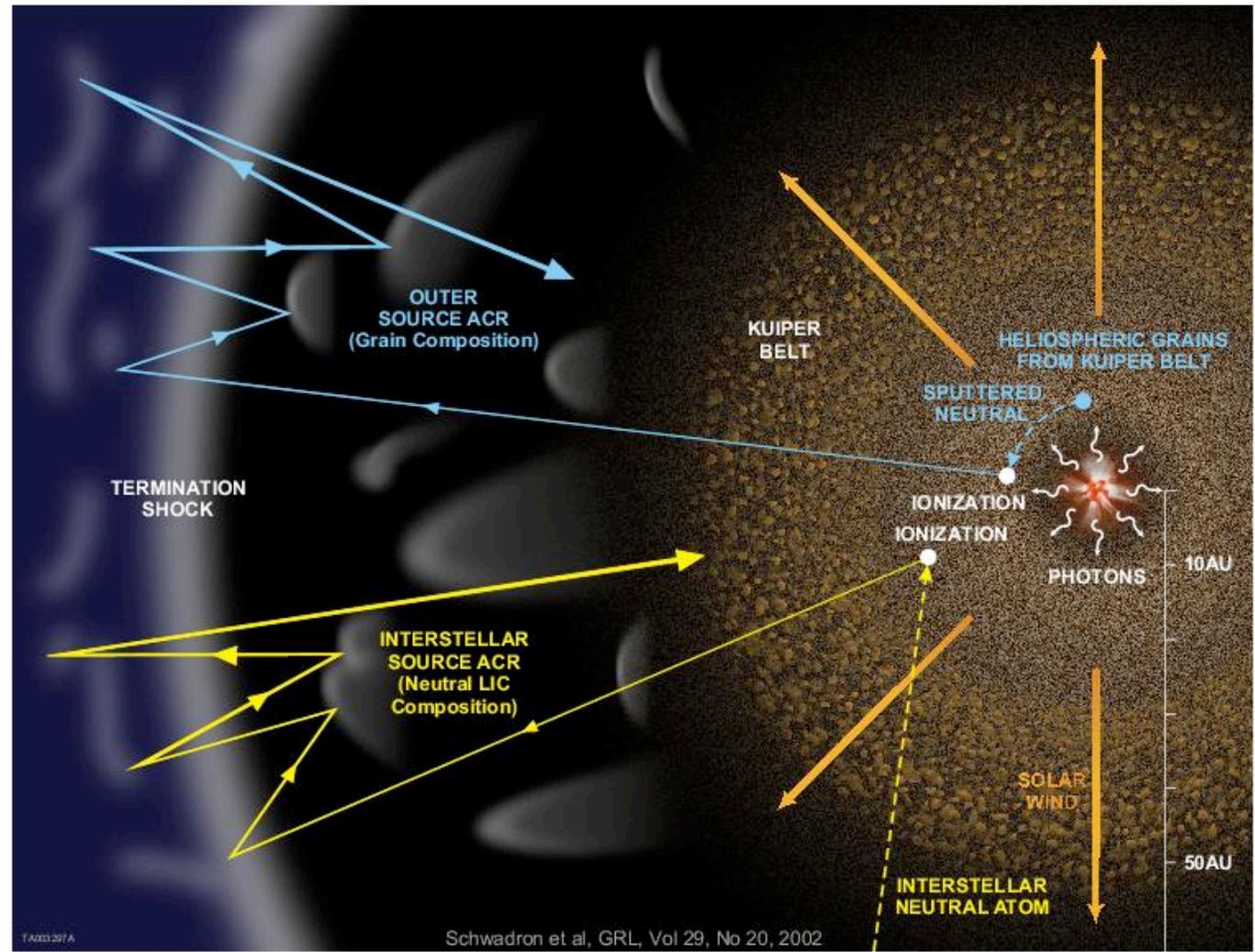
- Theorist's answer - **No**
 - Multiply Reflected Ions, Shock Surfing, $V \times B$ drift
 - Cross-field diffusion
- Observer's answer - **Yes**
 - EP composition reflects suprathermals, not bulk plasma

Example: Pickup Ions to ACRs

Pickup ions born with high energy and naturally predisposed to accel. At Termination Shock

Evidence:

1. Single-charge of ACR species
2. Composition like neutral ISM



Schwadron et al., GRL, 2002

Injection at several shock types

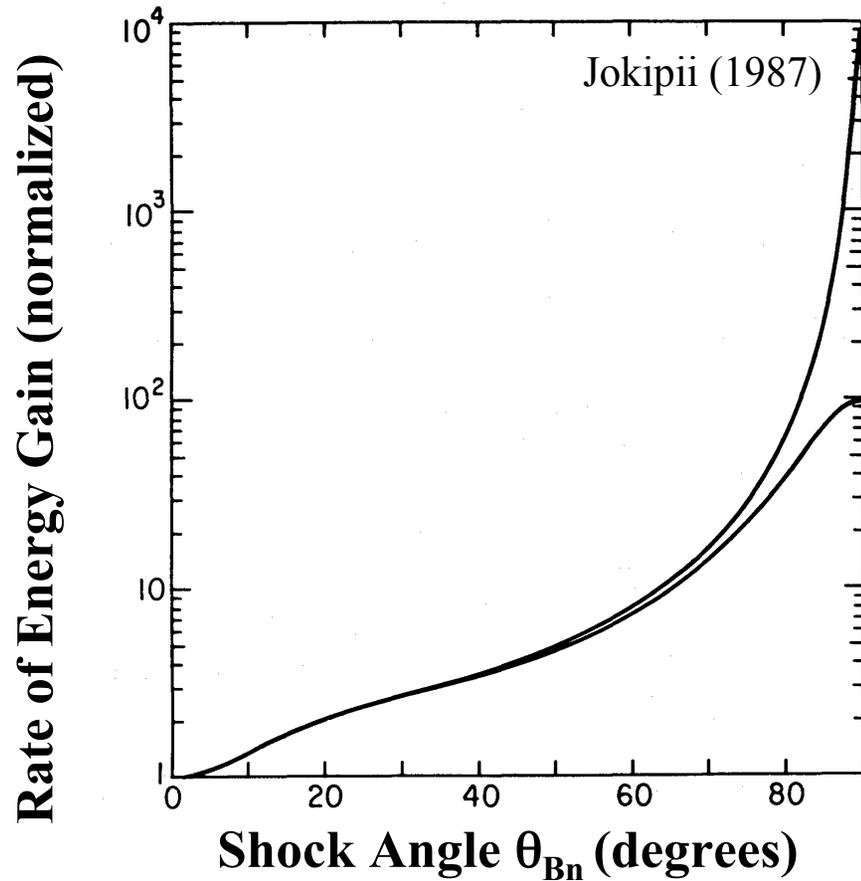
- Injection energy given by

$$- E_{inj} = v_{inj}^2/2, \quad u_{sh}/\cos(\Theta_{BN}) < v_{inj}, \text{ but } v_{inj} < \eta u_{sh}$$

$$\eta \sim \lambda_{||}/r_g \text{ (here, take } \eta \sim 30)$$

Type	Shock Speed	Θ_{BN}	$E_{inj}(\Theta_{BN})$	$E_{inj}(\eta)$
Termination Shock	300 km/s	89.93 deg	0.3 GeV	1 MeV
FALTS	300 km/s	70 deg	4 keV	1 MeV
CIRs (3 \leftarrow ◆ AU)	300 km/s	88 deg (Std) 30 deg (Fluct)	0.4 MeV 0.6 KeV	Debate (2 keV - > MeV)
Traveling IP Shocks	50 - 1000 km/s	Varies (Tylka et al., 2005)	KeV-MeV	Debate (2 keV - > MeV)

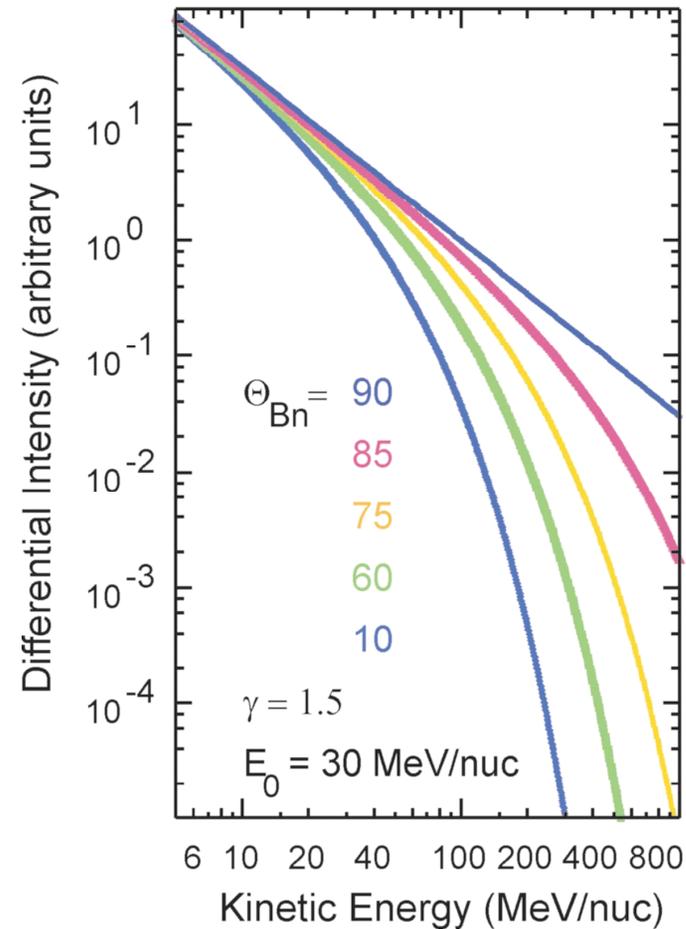
Higher rates of energy gain and harder spectra at quasi-perp shocks.



Lee (2005):

$$F(E) = E^{-\gamma} \exp(-E/E_{0X})$$

$$\text{where } E_{0X} = E_0 (\sec \Theta_{Bn})^{2/(2\gamma-1)}$$



➔ ***If a shock takes on a range of θ_{Bn} values, high-energies will be dominated by particles produced at $\theta_{Bn} \sim 90^\circ$.***

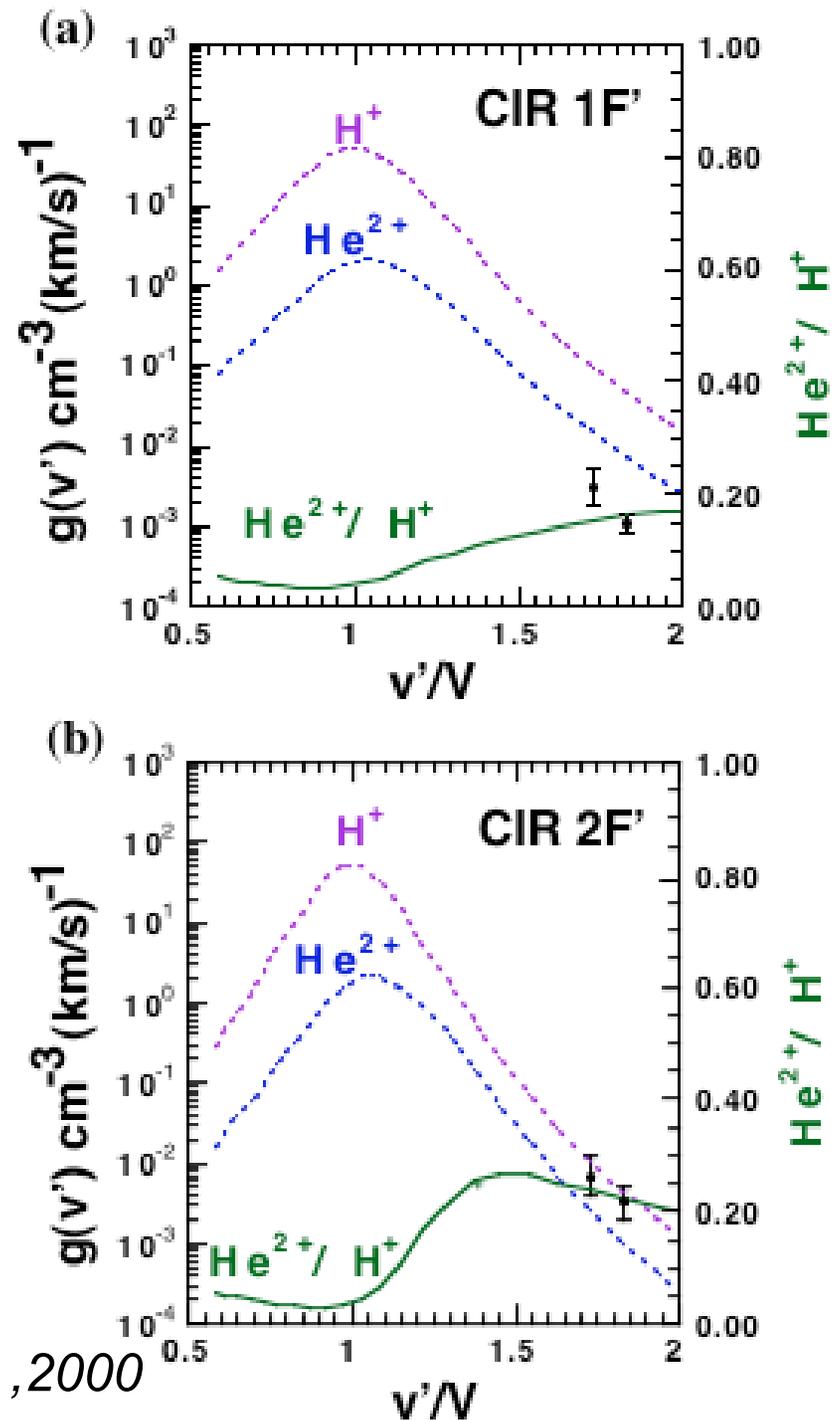
Slide from Tylka, 2005

Quasi-parallel vs. Quasi-perp Shocks?

- Quasi-parallel:
 - Lower injection threshold
 - Larger flux of injected ions
 - Longer time for acceleration to high energies
- Quasi-perp:
 - Higher injection threshold
 - Faster ion acceleration
- Most shocks, even the termination shock, cannot be classified as quasi-parallel or quasi-perp
 - Injection best where quasi-parallel
 - Higher energy acceleration where quasi-perp

Where does the injection begin?

- Composition change, beginning at suprathermal energies, marks the injection speed
- Suprathermal tail may control particle injection

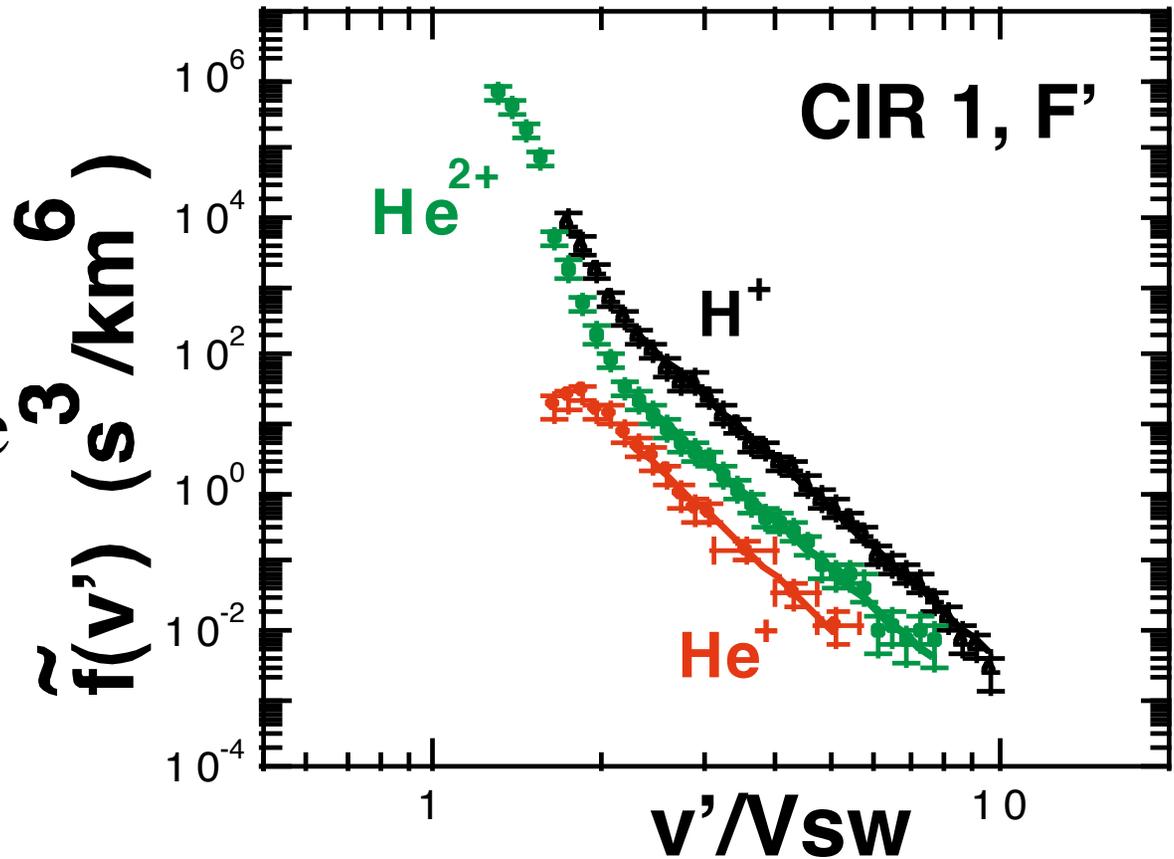


Chottoo et al., JGR, 2000

Where does the acceleration begin, what gets accelerated?

He⁺ abundance
enhanced 10³-
10⁴ times the
solar wind value
Injection appears
at ~twice solar
wind speed

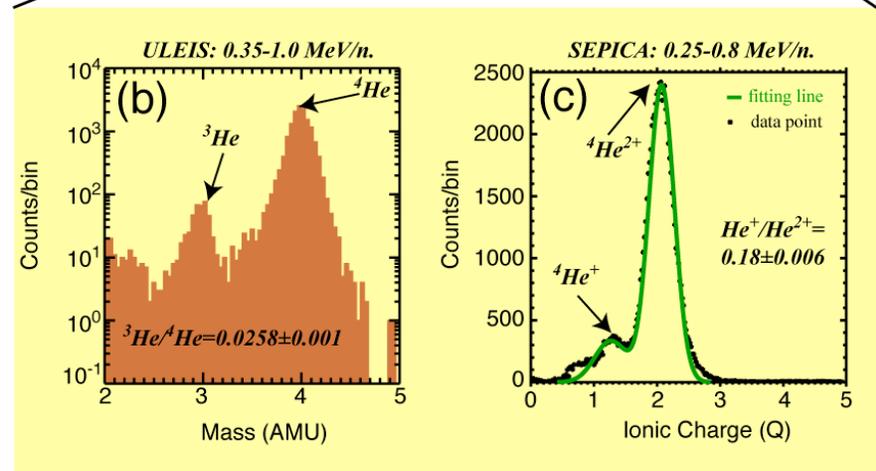
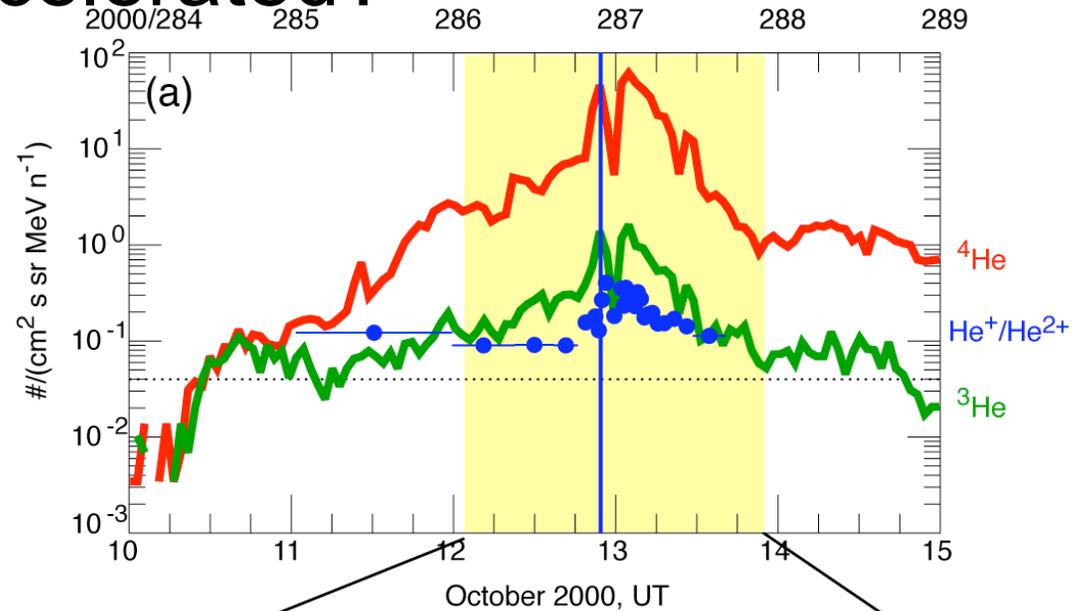
He⁺/He²⁺ ~0.17



Chotoo et al. 2000. JGR, vol. 105; 23107

Where does the acceleration begin, what gets accelerated?

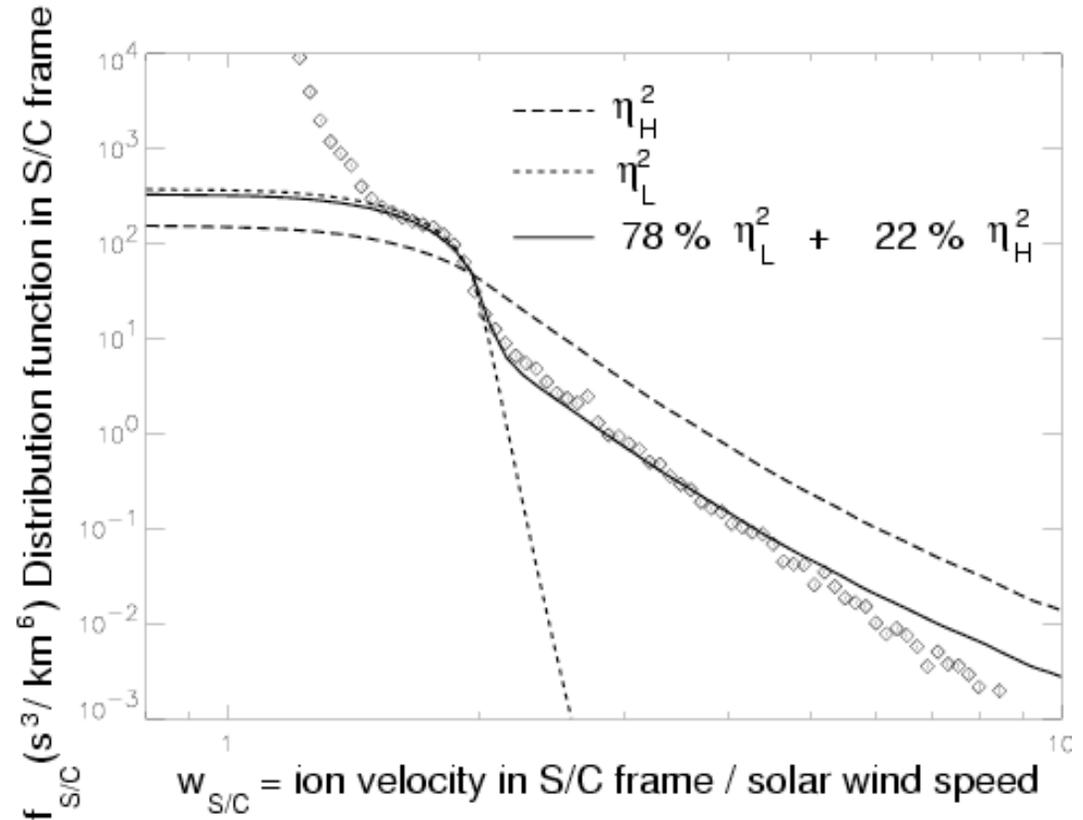
He⁺ enhancement
 from PUIs
³He from flares
 He⁺/He²⁺ ~0.18



(adapted from Desai et al., 2001 and Kucharek et al., 2003)

Statistical Acceleration in Co-rotating Interaction Regions (CIRs)

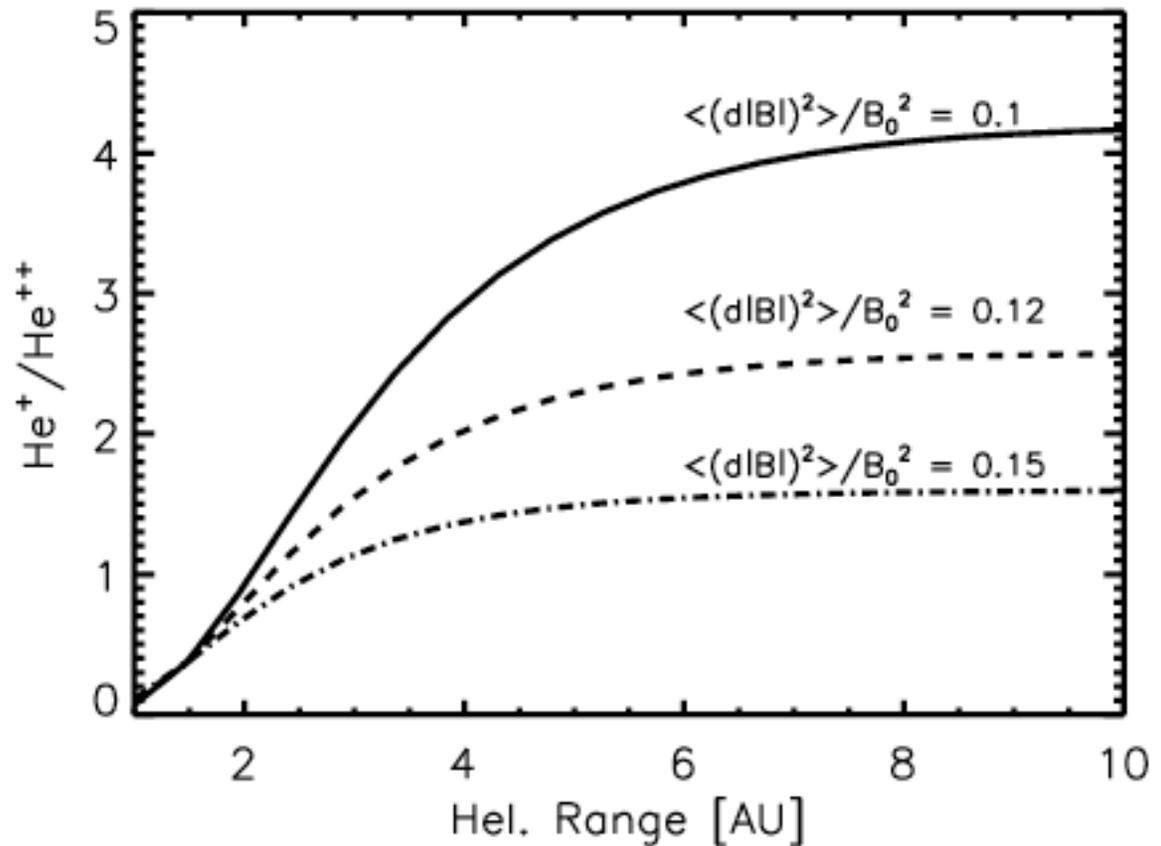
Statistical acceleration through transit time damping of magnitude field fluctuations (magnetosonic waves)



$$u \frac{\partial f_0}{\partial r} - \frac{2u}{3r} v \frac{\partial f_0}{\partial v} - \frac{1}{v^2} \frac{\partial}{\partial v} \left(v^2 D_{vv} \frac{\partial f_0}{\partial v} \right) = \beta_p \left(\frac{r_0}{r} \right)^2 \frac{n_H(r, \theta)}{4\pi u^2} \delta(v - u)$$

Where does the acceleration begin, what gets accelerated?

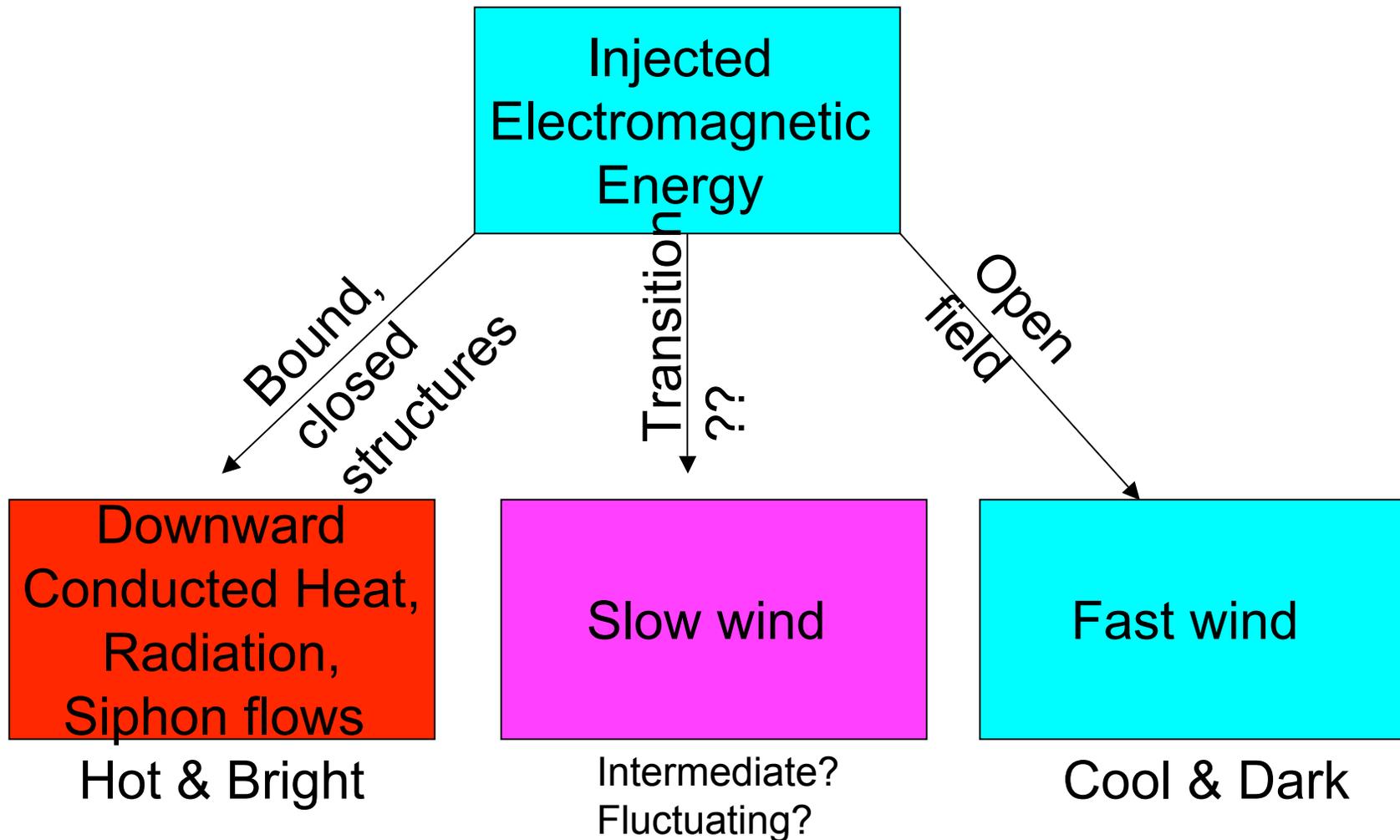
Spatial profile of $\text{He}^+/\text{He}^{++}$ provides strong constraints on the acceleration rate



Suprathermal Seed Population

- The source population of energetic particles and cosmic rays
- Pickup ions provide an important example
- What causes the suprathermal tails?
 - Stochastic acceleration (transit time damping) provides a likely explanation and explains pickup ion tails
- What causes suprathermal tails close to the Sun?
 - We see composition differences, i.e., enhancements in ^3He
 - ***What fundamentally differentiates solar wind from sources of suprathermal ions?***

Paths for Deposited Coronal Energy



$$\frac{mu_f^2}{2} = \frac{c}{4\pi} \frac{\int d\mathbf{S}_0 \cdot \langle \mathbf{E} \times \mathbf{B} \rangle_0}{\delta \dot{N}} - \frac{\int_{r_0}^{r_1} dV \langle \dot{E}_{\text{Rad}} \rangle}{\delta \dot{N}} - \frac{GM_s m}{R_s}$$

Paths of deposited Energy

- Solar Wind Scaling Law
- Electron heat conduction and radiative losses

Fast wind

Cool, Dark

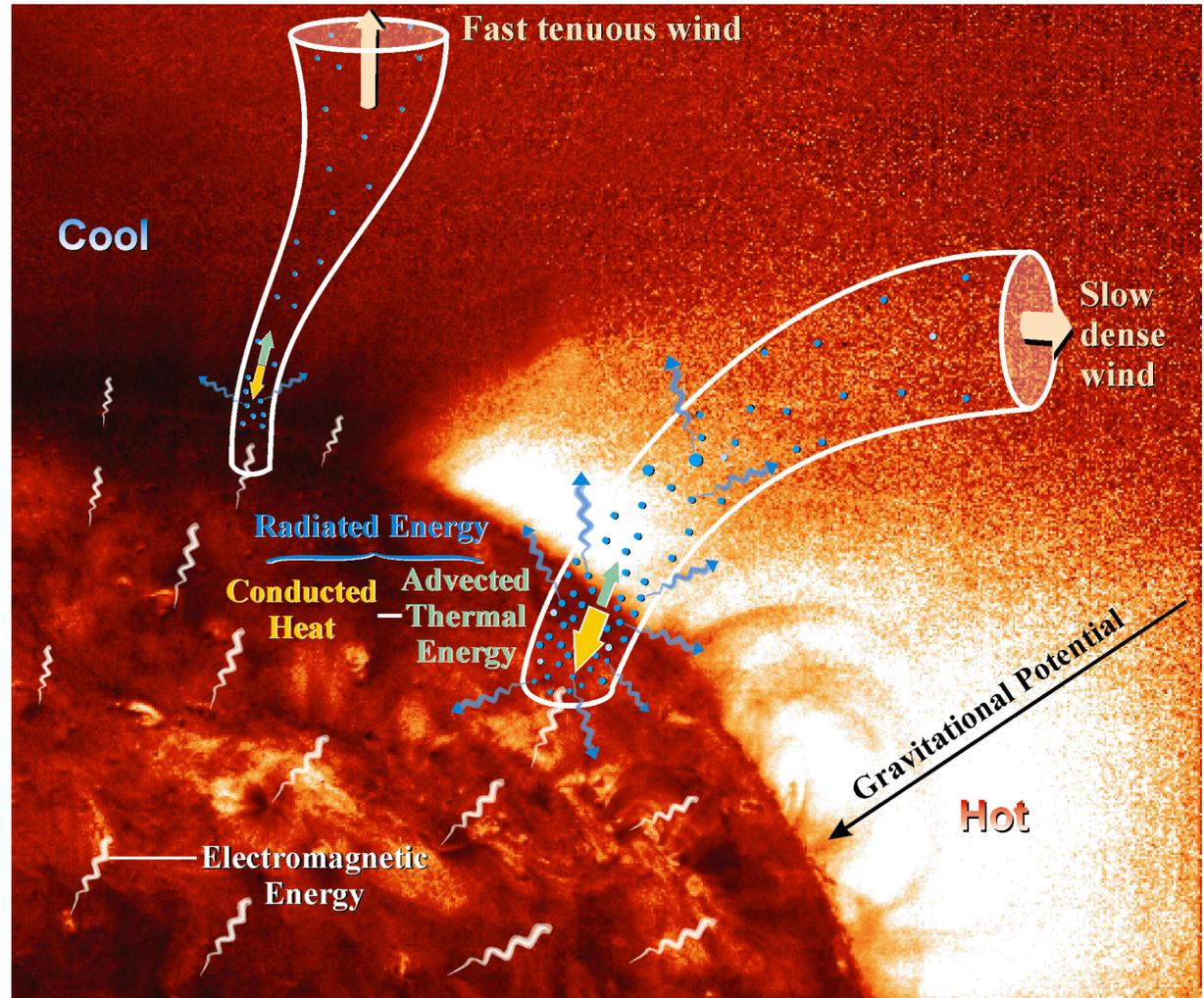
Slow wind

Warm, Brighter

Radiative Loss

Hot, Bright

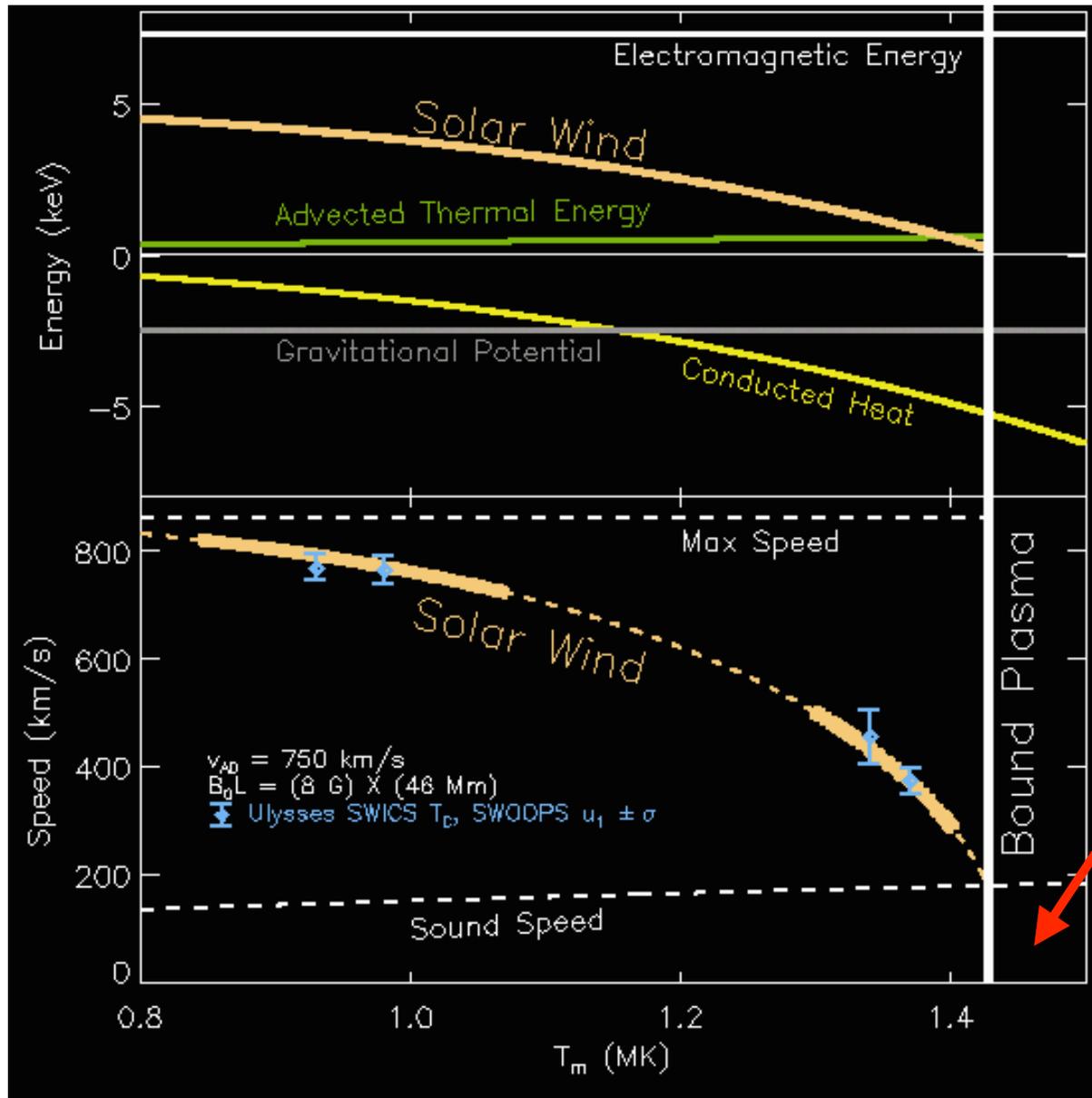
Schwadron and McComas, ApJ, 2003



Energy	Electro-magnetic Energy	-	Radiated Energy (Conducted Heat - Advected Thermal Energy)	-	Gravitational Potential	=	Wind Energy
Scaling Law	$m\bar{v}_{ad}^2$	-	$\left(C_0 \frac{K_0 T_m^{7/2}}{f_0 L} - C_1 k T_m \right)$	-	$\frac{GM_S m}{R_S}$	=	$\frac{m u_f^2}{2}$

A Constant Energy Source

Schwadron and McComas, ApJ, 2003



The suprathermal seed population: Suprathermal ions with speeds greater than escape speed from energetically bound bulk plasma

Summary

- Suprathermal Ions Seeds of energetic particles and cosmic rays
- He⁺/He⁺⁺ spatial profile .. A powerful technique for resolving acceleration rate
- Suprathermal tails from Sun show characteristic composition differences with solar wind - why?
- Possible that suprathermals escape from energetically bound bulk plasma