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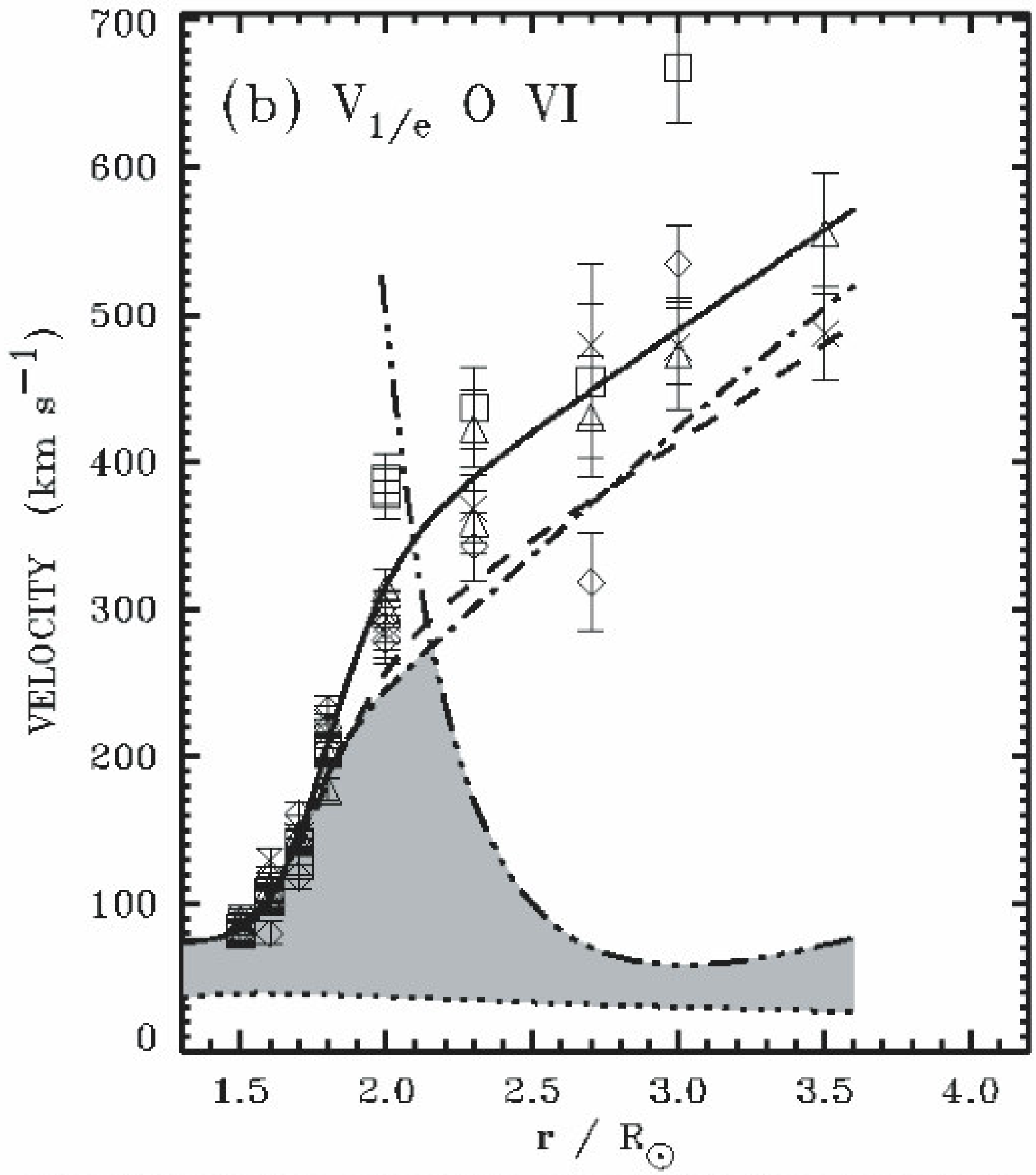
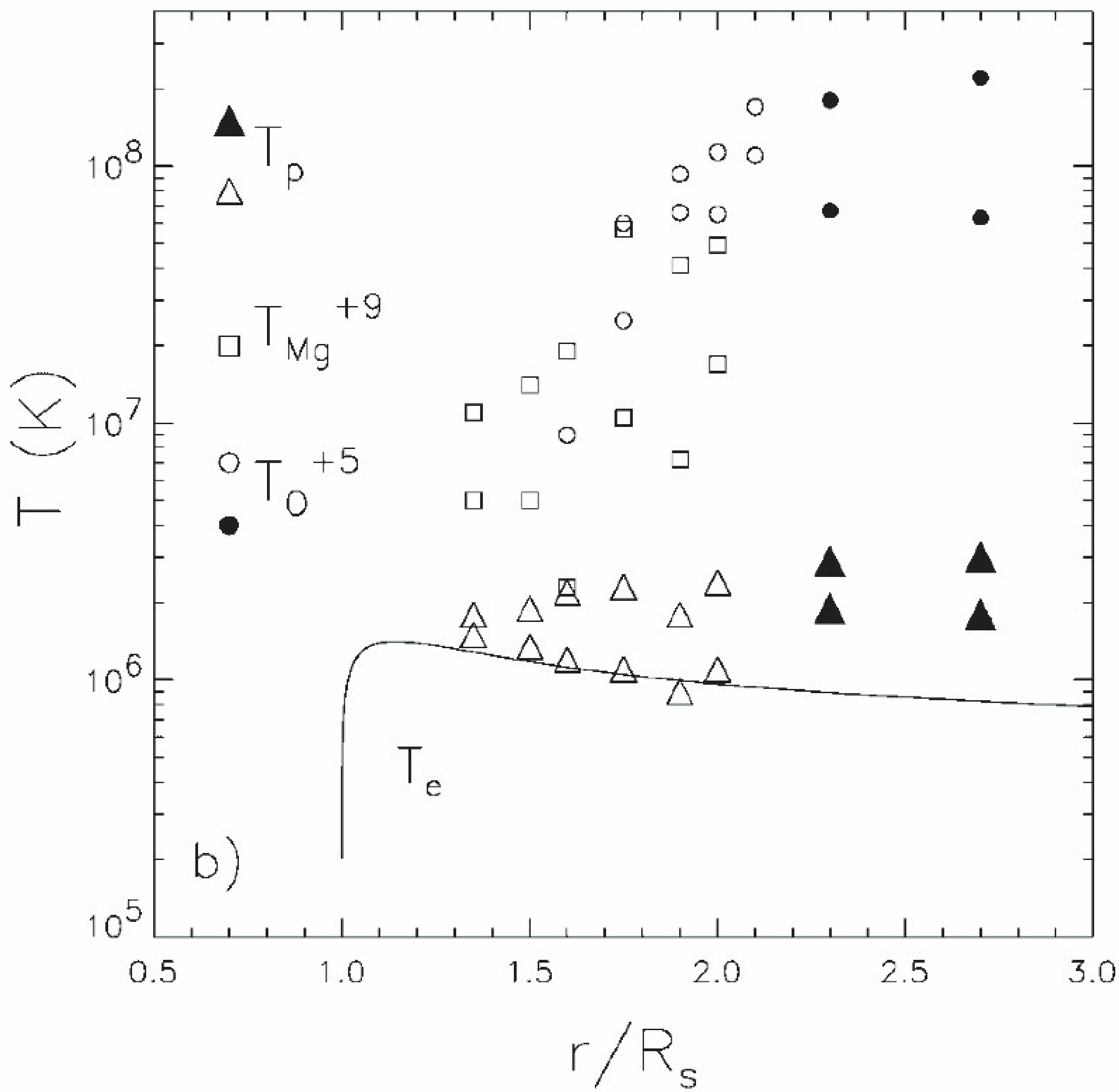
Intermittent Coronal Heating by Heat Flux Generated Ion Cyclotron Waves

UVCS / SOHO DATA FROM KOHL ET AL. (1998)

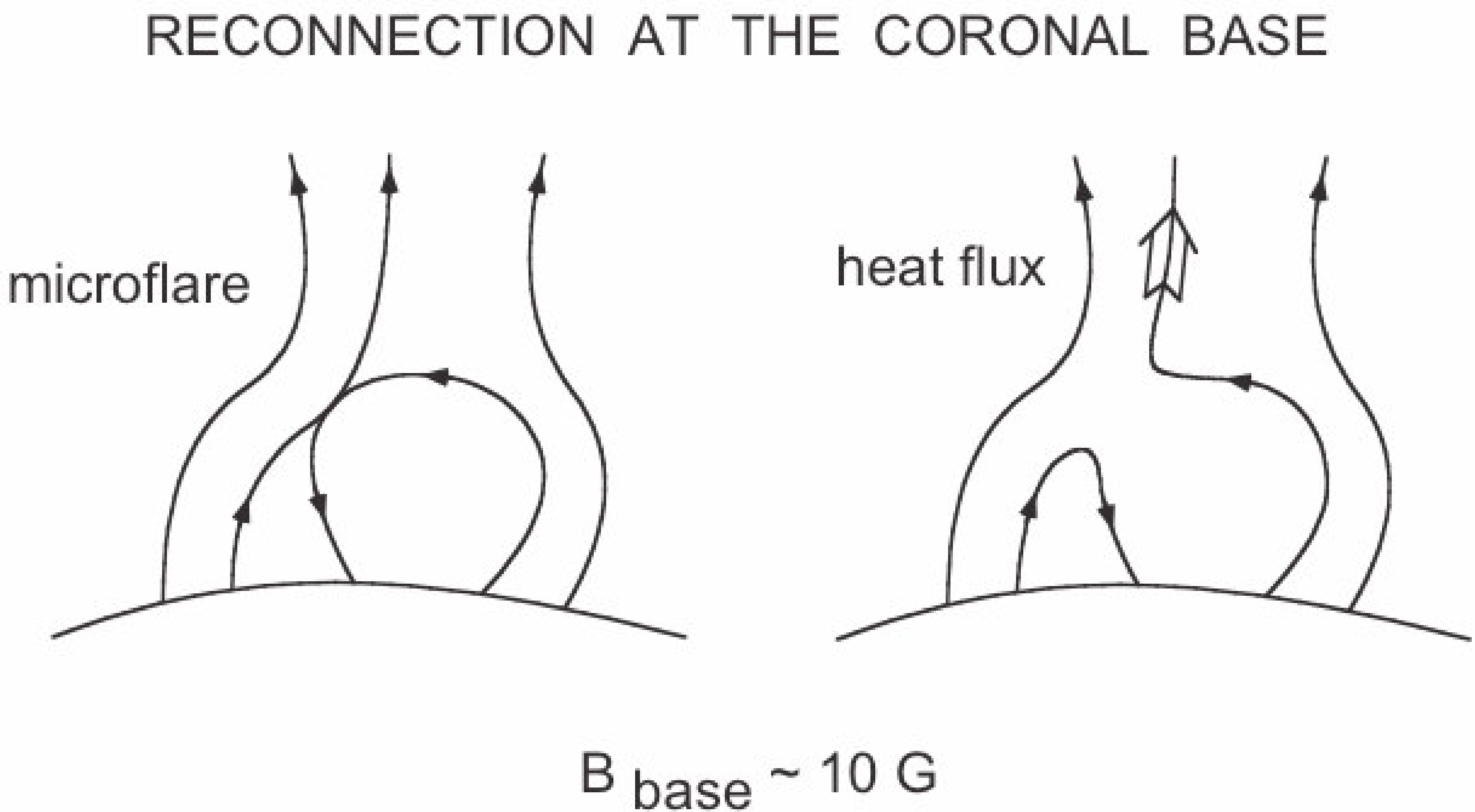


Most probable speed is greater in the direction perpendicular to the magnetic field

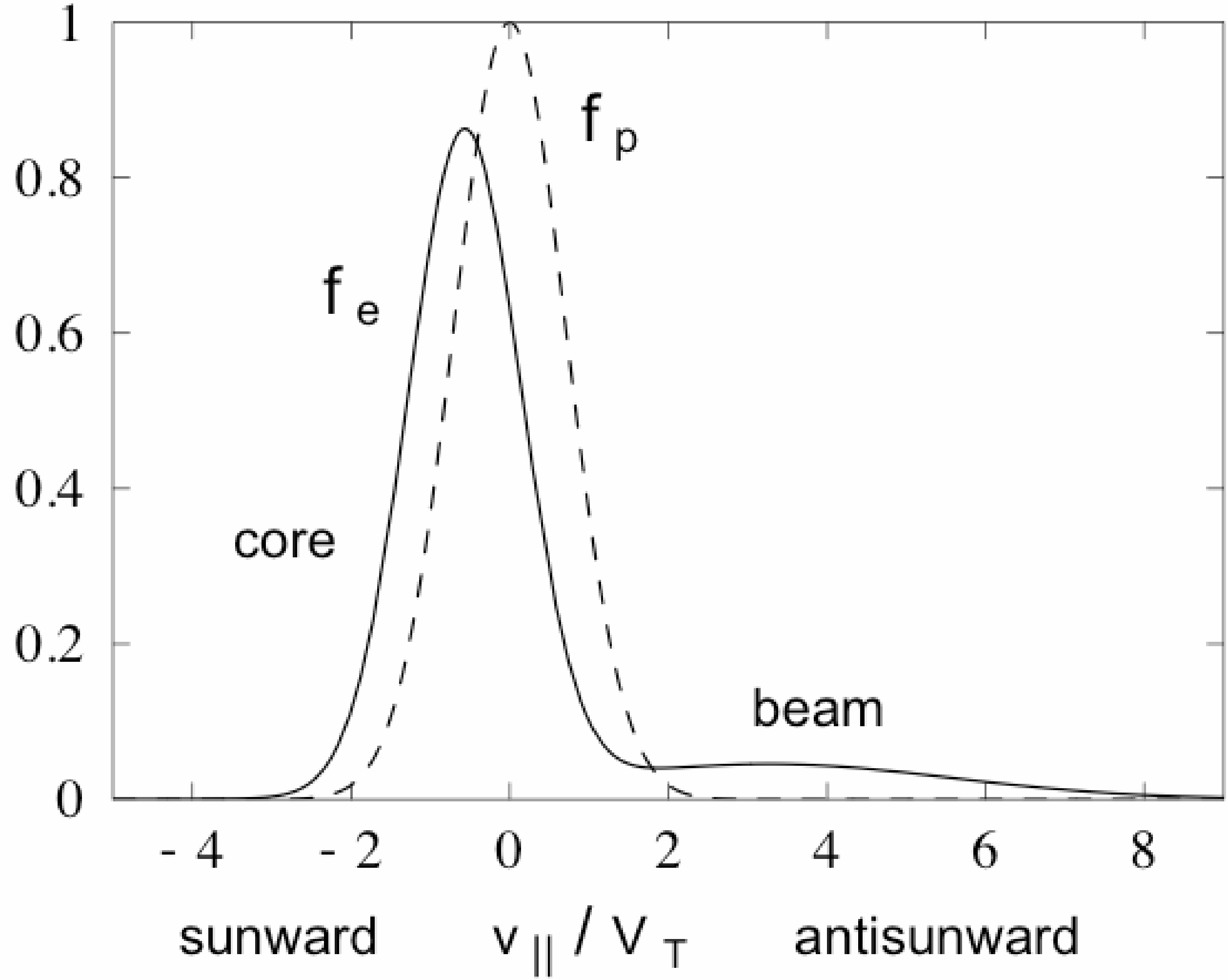
UVCS / SOHO DATA FROM ESSER ET AL. (1999)



The heating efficiency is different for different ions


RECONNECTION AT THE CORONAL BASE
microflare
heat flux
B base ~ 10 G

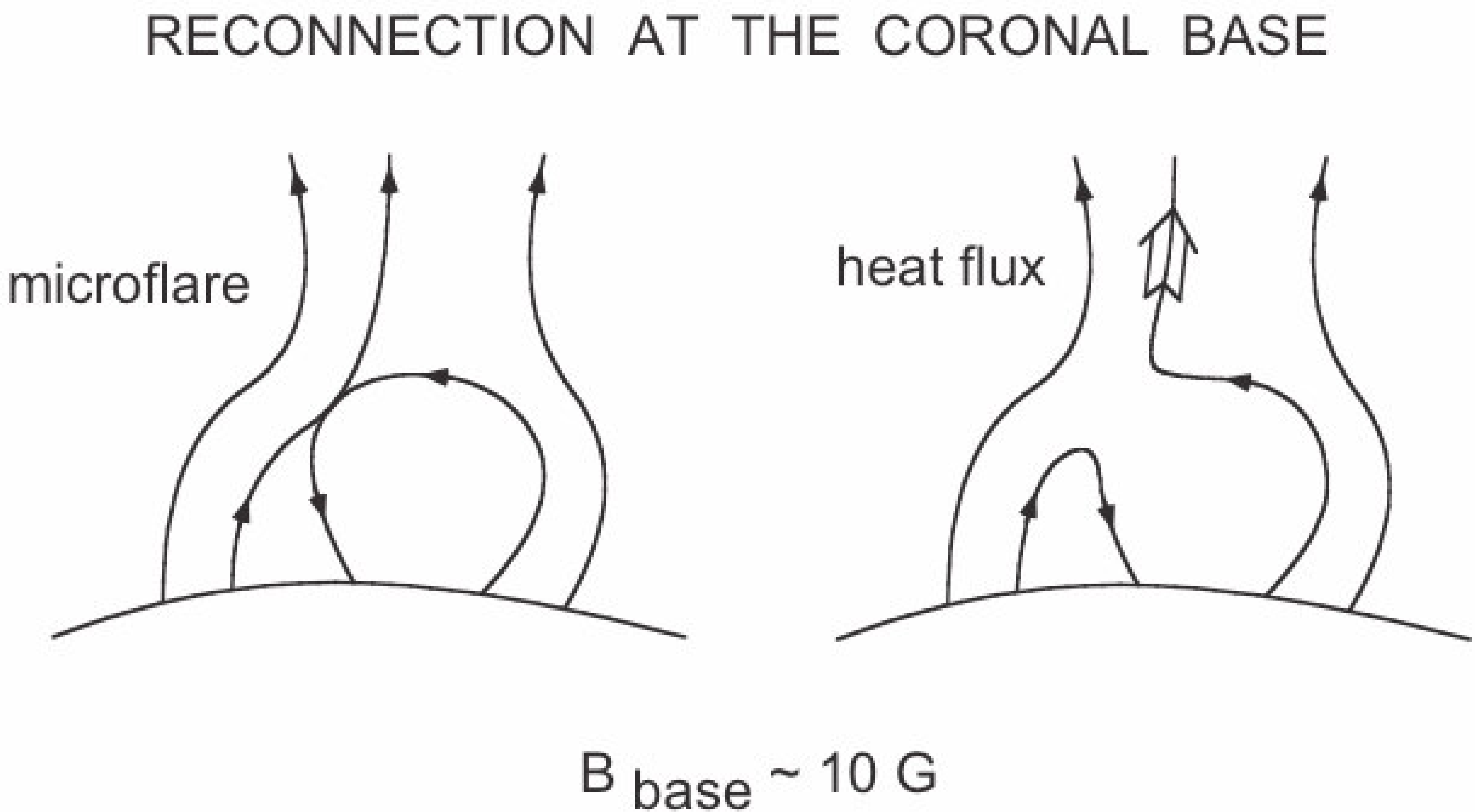
ELECTRON DISTRIBUTION



$T_{BG} \sim 10^{6}$ K $T_{HF} \sim 10^{7}$ K $T_{REC} \sim 10^{8}$ K

The net current is zero

The proton/core drift excites the instability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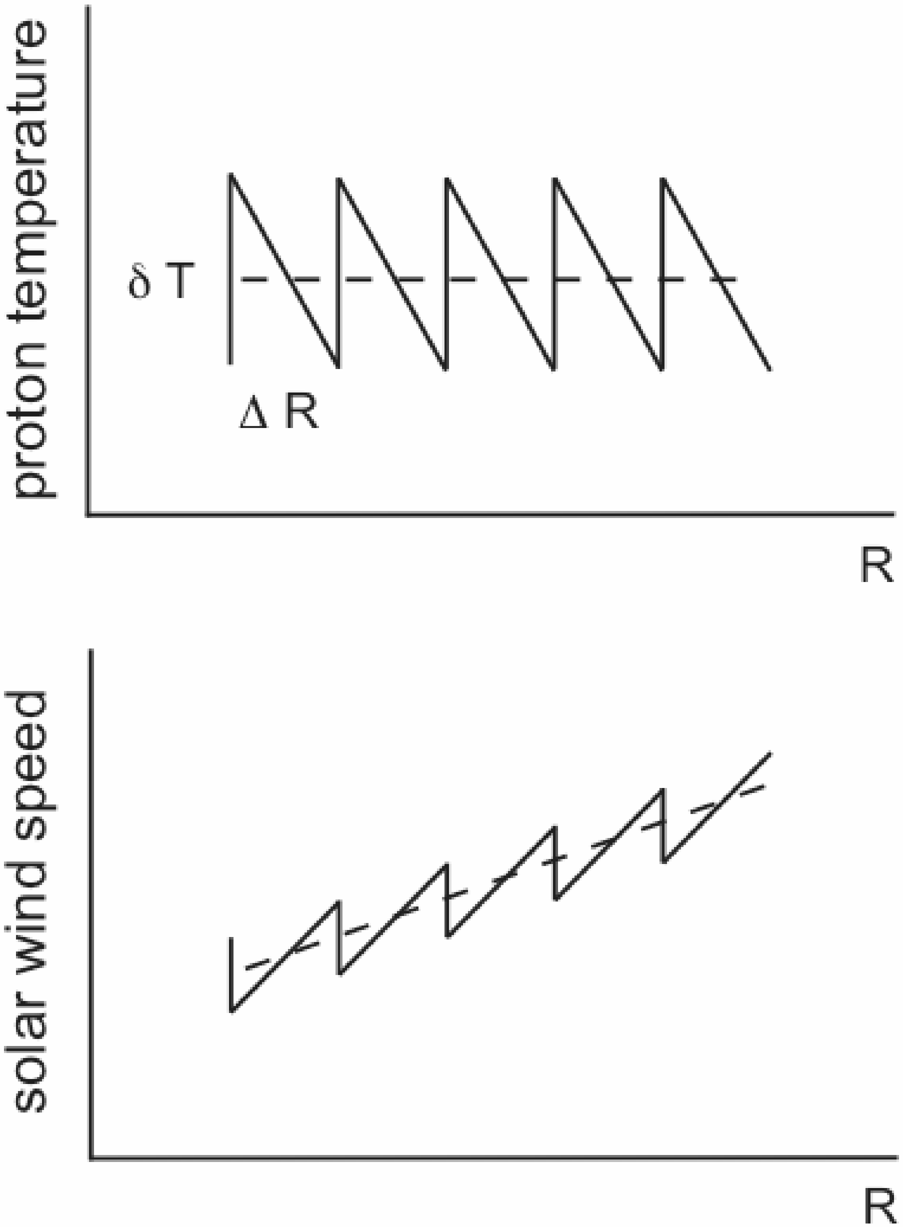
INTERMITTENT PARAMETERS OF A FLUID ELEMENT MOVING WITH THE SOLAR WIND



Time-average parameters (dashed lines) are described by fluid equations

FLUID EQUATIONS

$$\frac{\partial n}{\partial t} + \frac{1}{A}\frac{\partial}{\partial r}\left(nVA\right) = 0$$

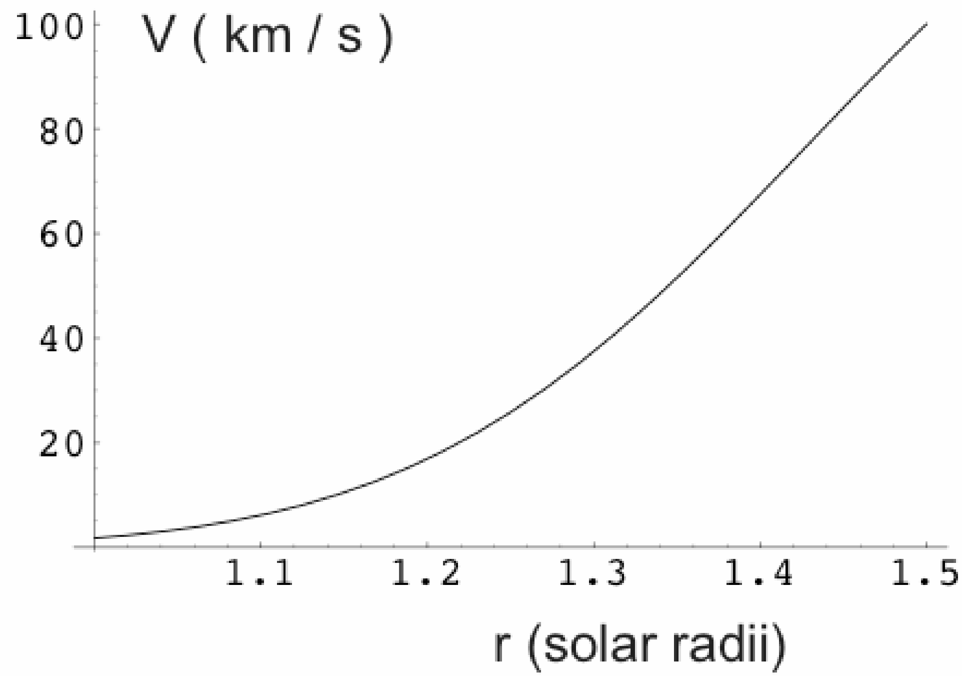
$$\frac{\partial V}{\partial t} + V\frac{\partial V}{\partial r} = -\frac{1}{\rho}\frac{\partial p}{\partial r} - \frac{GM_{sun}}{r^2} + D$$

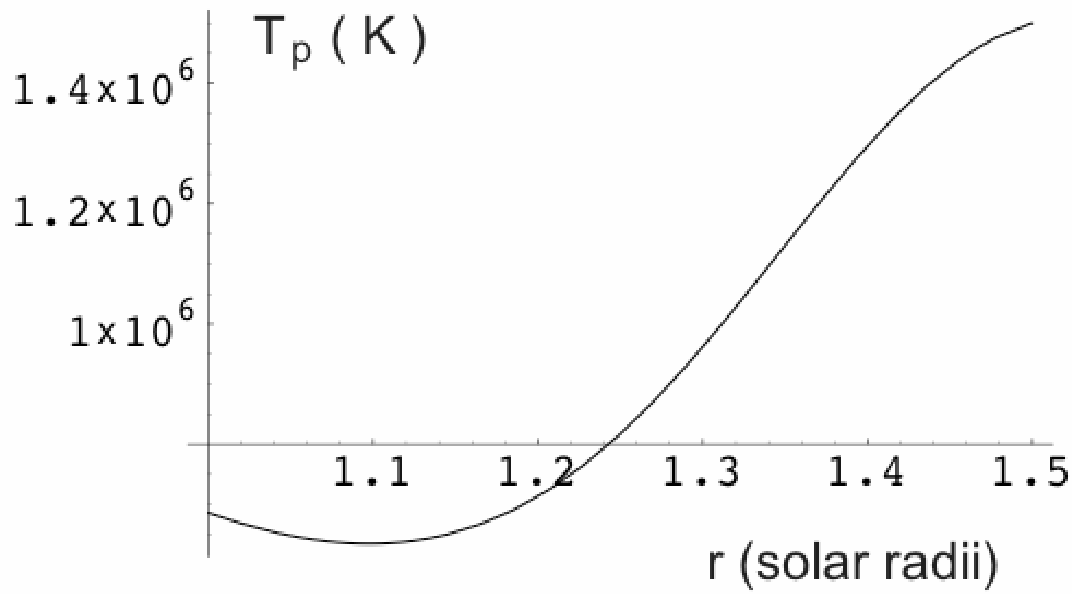
$$\frac{\partial T_p}{\partial t} + V\frac{\partial T_p}{\partial r} = -\frac{T_p}{A}\frac{\partial (VA)}{\partial r} + Q$$

The fluid models cannot describe the source of the heating

The heating and momentum addition produced by the instability are related in a certain way

NUMERICAL SOLUTION OF FLUID EQUATIONS

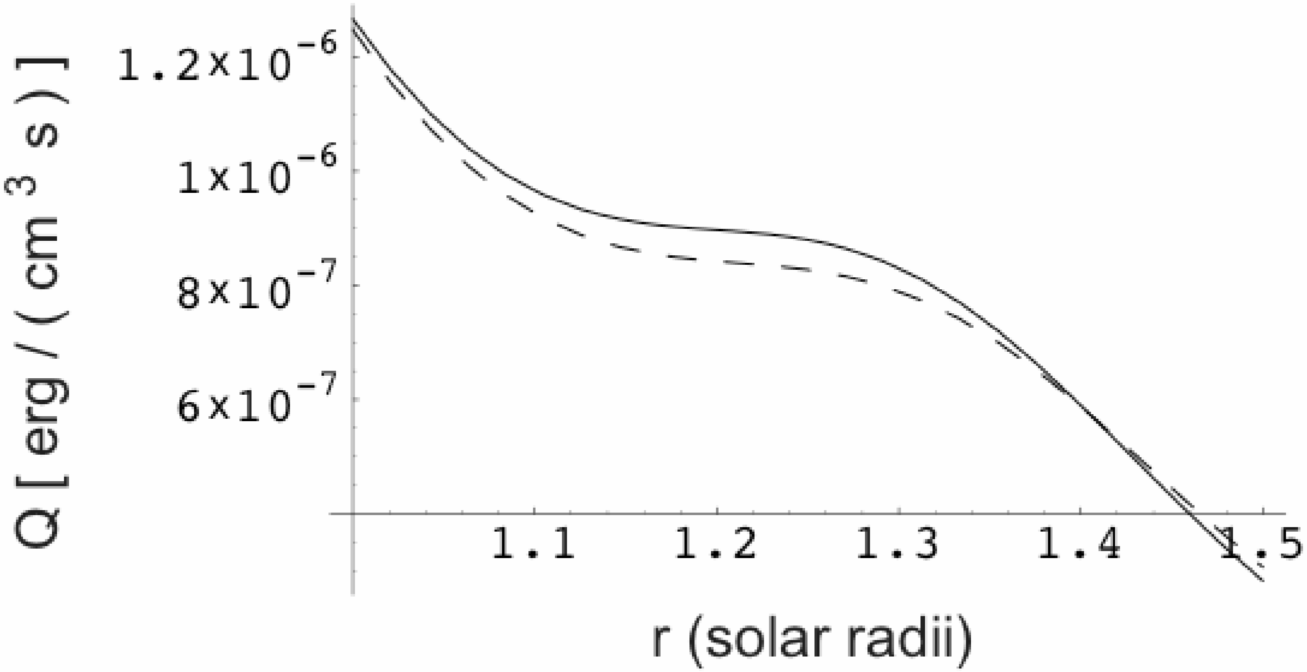




The solution reproduces the observed parameters

HEATING FUNCTION

calculated from the fluid equations

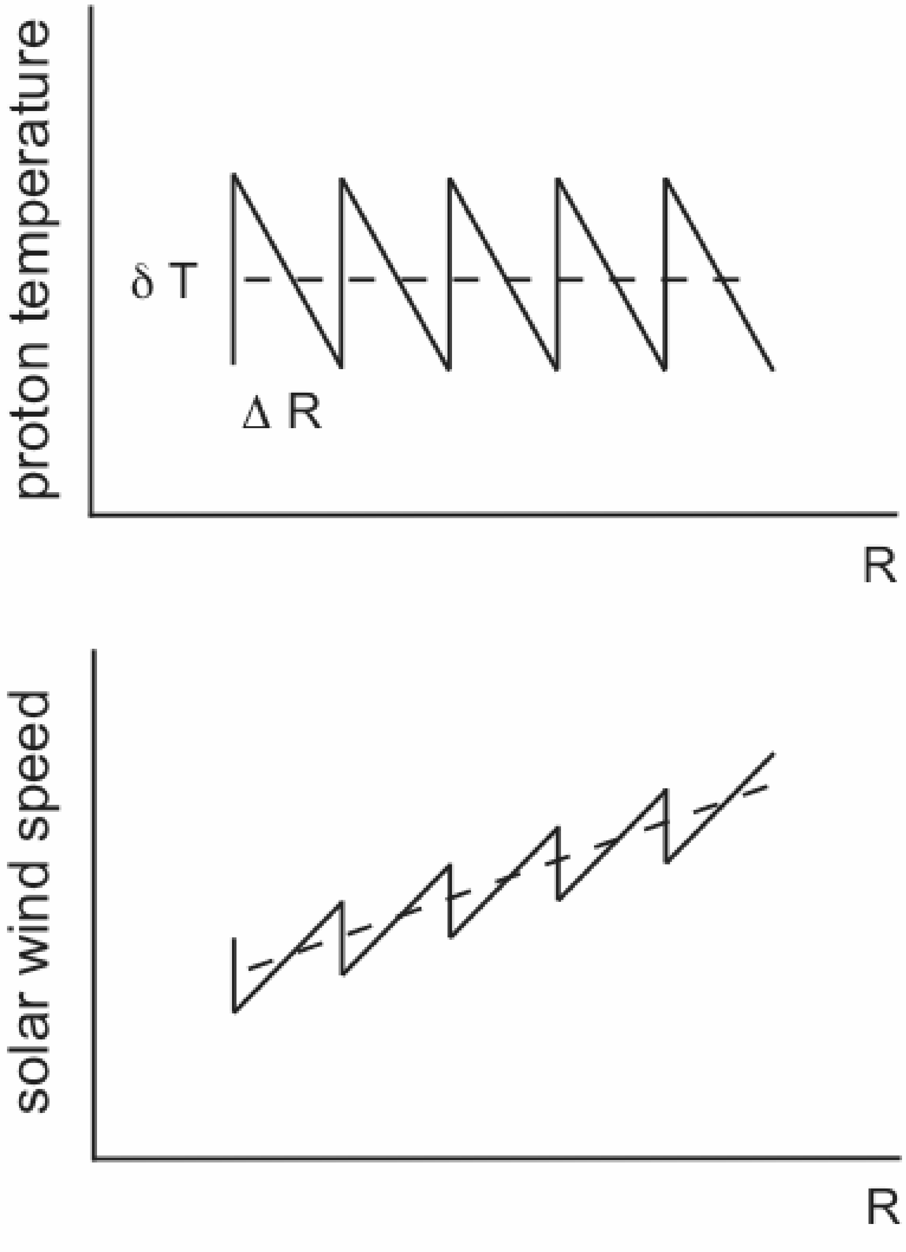


The contribution of each burst is small

The heating function is related to the parameters of a single burst by the formula

$$Q \approx \frac{3}{2} \frac{n\, k\, \delta T_p}{\Delta t}, \quad \Delta t = \frac{\Delta R}{V_{SW}}$$

INTERMITTENT PARAMETERS OF A FLUID ELEMENT MOVING WITH THE SOLAR WIND



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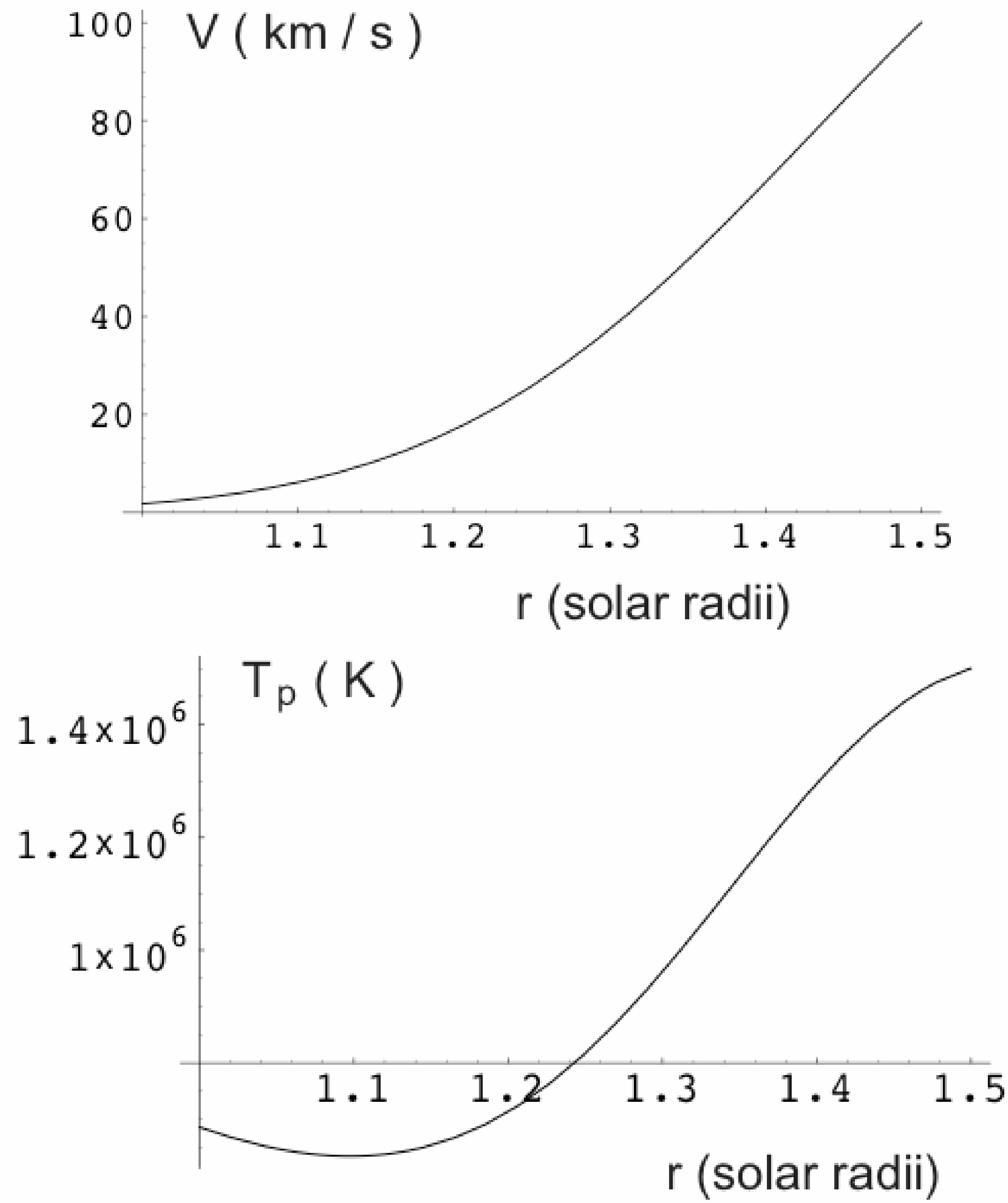

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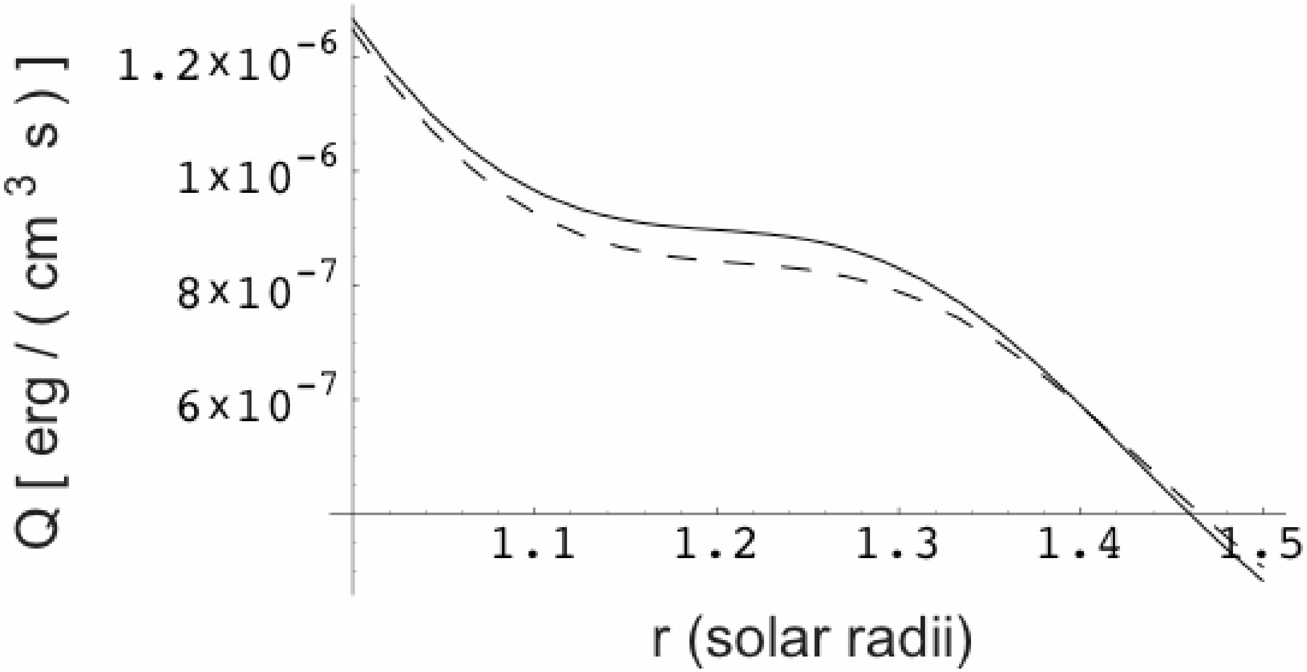

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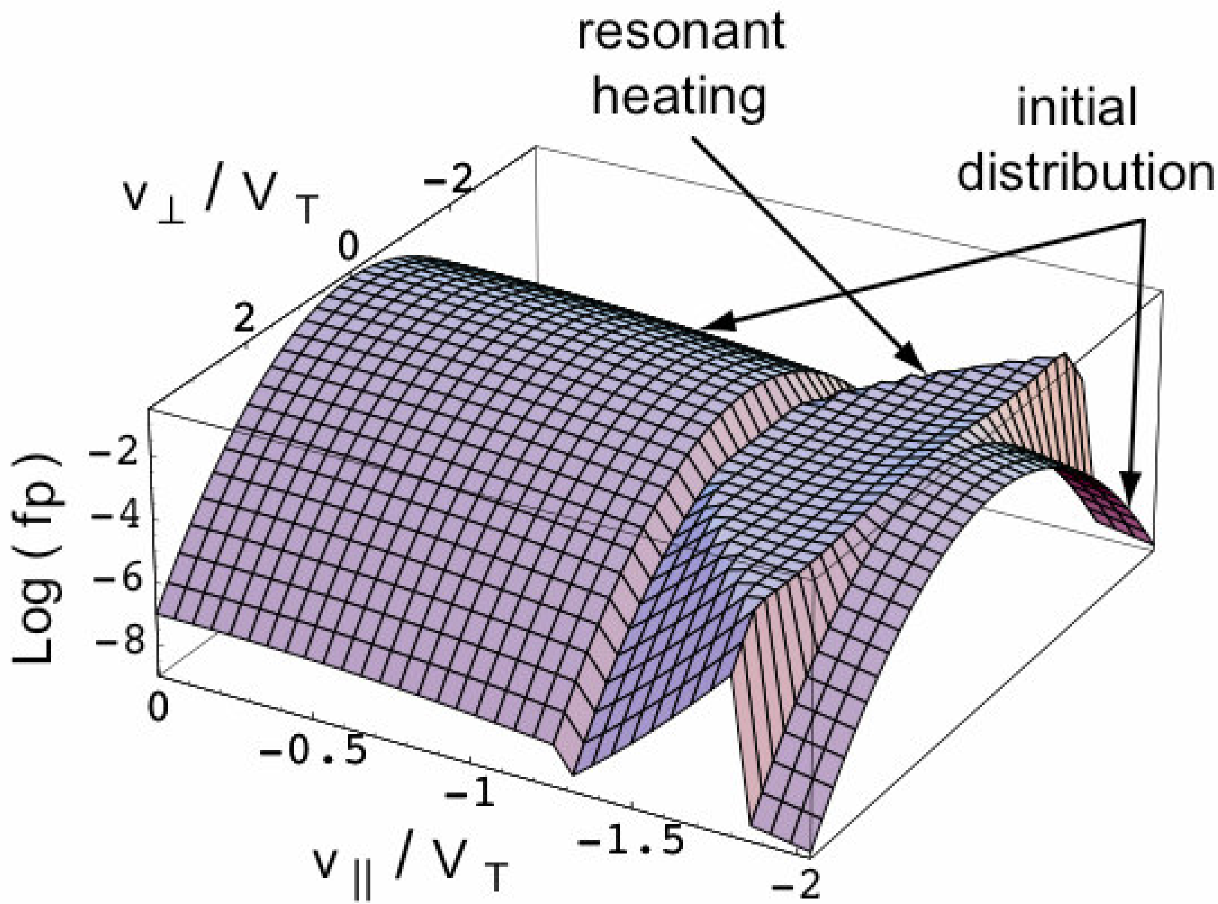
SUMMARY

- Microflares at the coronal base generate intermittent heat flux going up into the corona
- The heat flux excites an ion cyclotron instability that results in ion heating
- The heating during the sporadic heat flux bursts can be calculated without solving the diffusion equations
- The overall heating is a summed effect of the heat flux bursts and adiabatic cooling between the bursts
- The intermittent mechanism is efficient enough to provide the heating and acceleration of the solar wind consistent with the observations

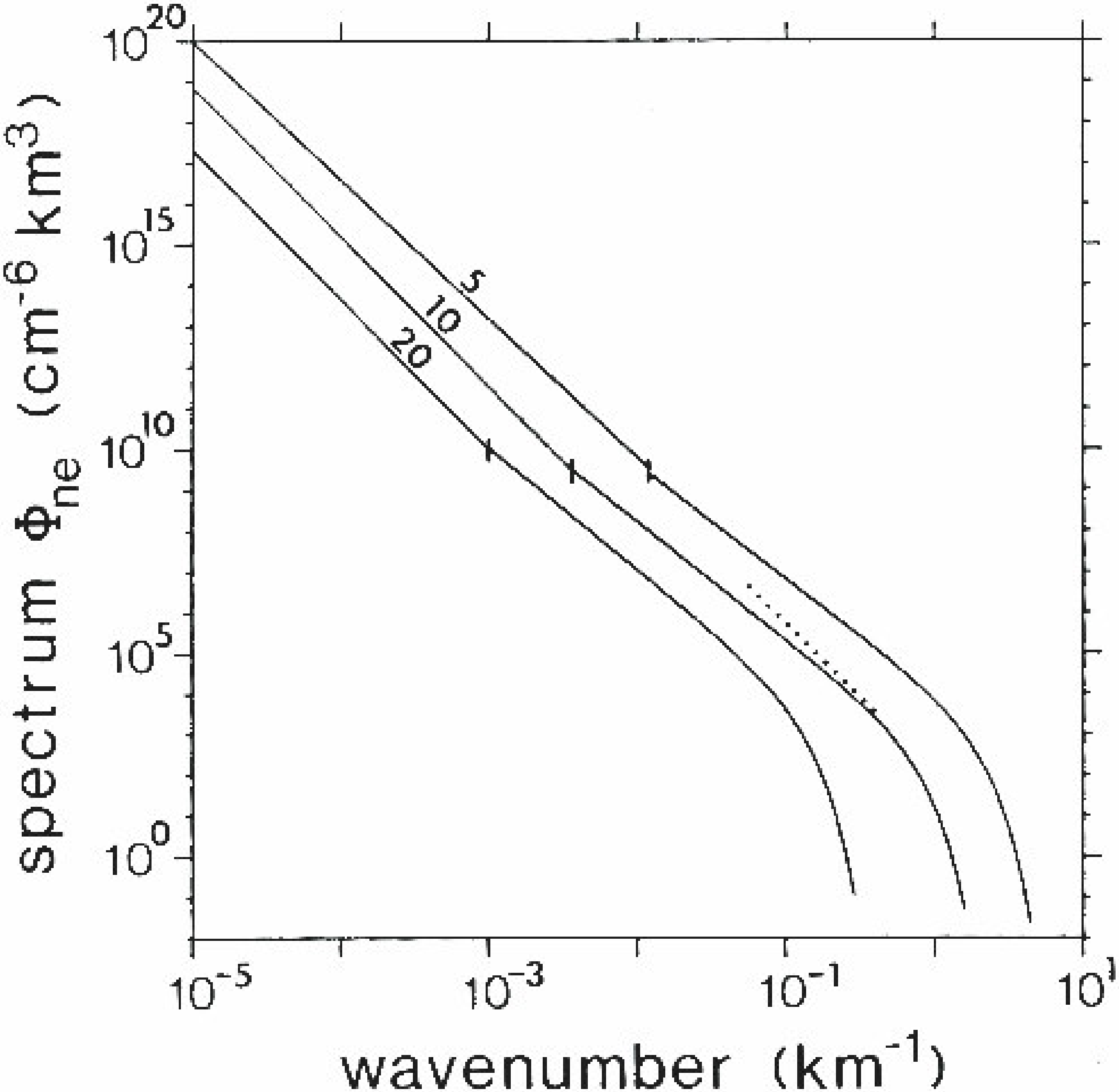
3D PLOT OF THE SUNWARD PROTON DISTRIBUTION RESULTING FROM THE HEATING



The particles have diffused to a greater $v_\perp$

The antisunward distribution is not affected by the wave-particle interactions

DENSITY FLUCTUATIONS SPECTRUM FROM RADIO SCINTILLATION OBSERVATIONS (COLES & HARMON, 1989)



observations at
5 solar radii

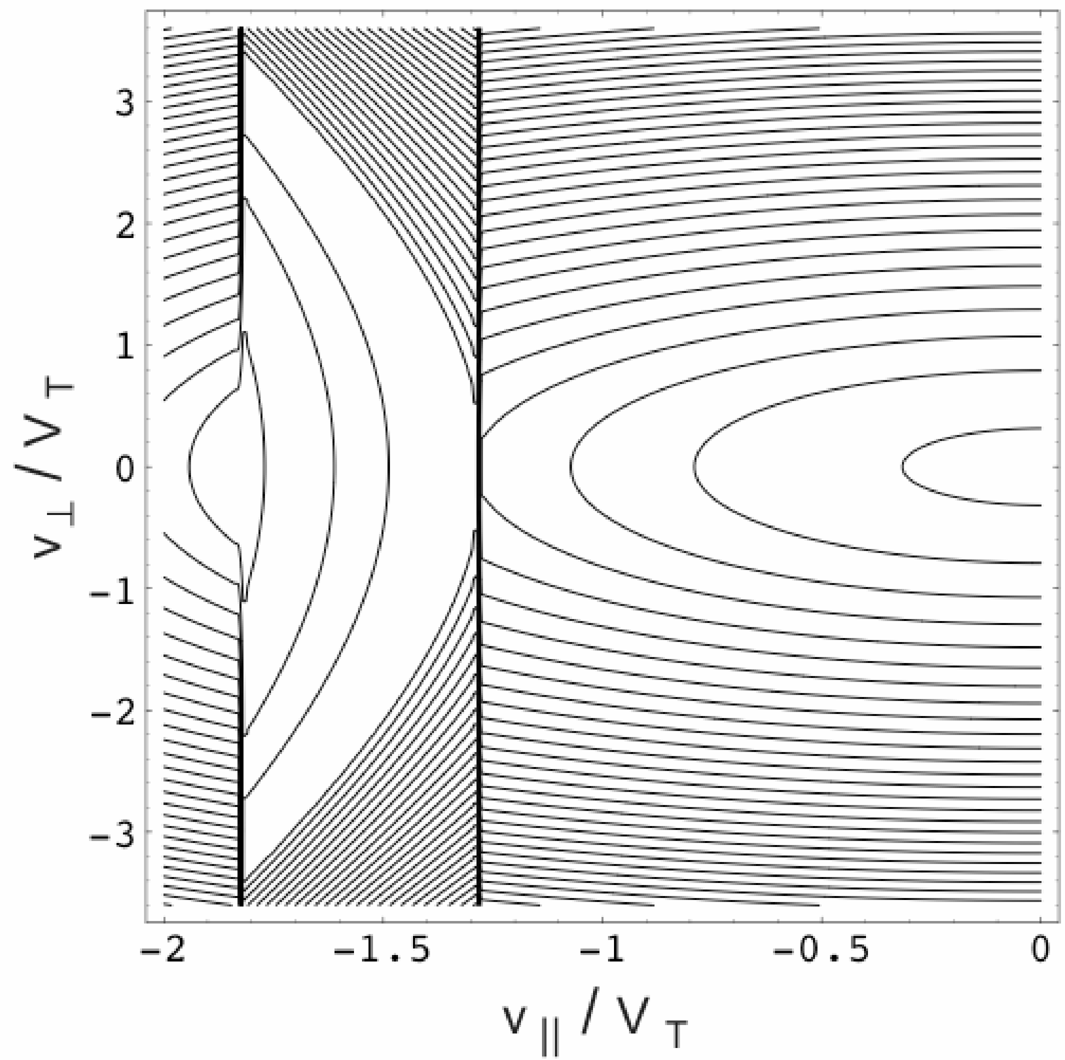
$(\delta n / n)^2 \sim 2 \times 10$

theory at 1 – 1.5
solar radii

$W / n T \sim 2 \times 10$

EQUATION DESCRIBING 1D DIFFUSION PATHS

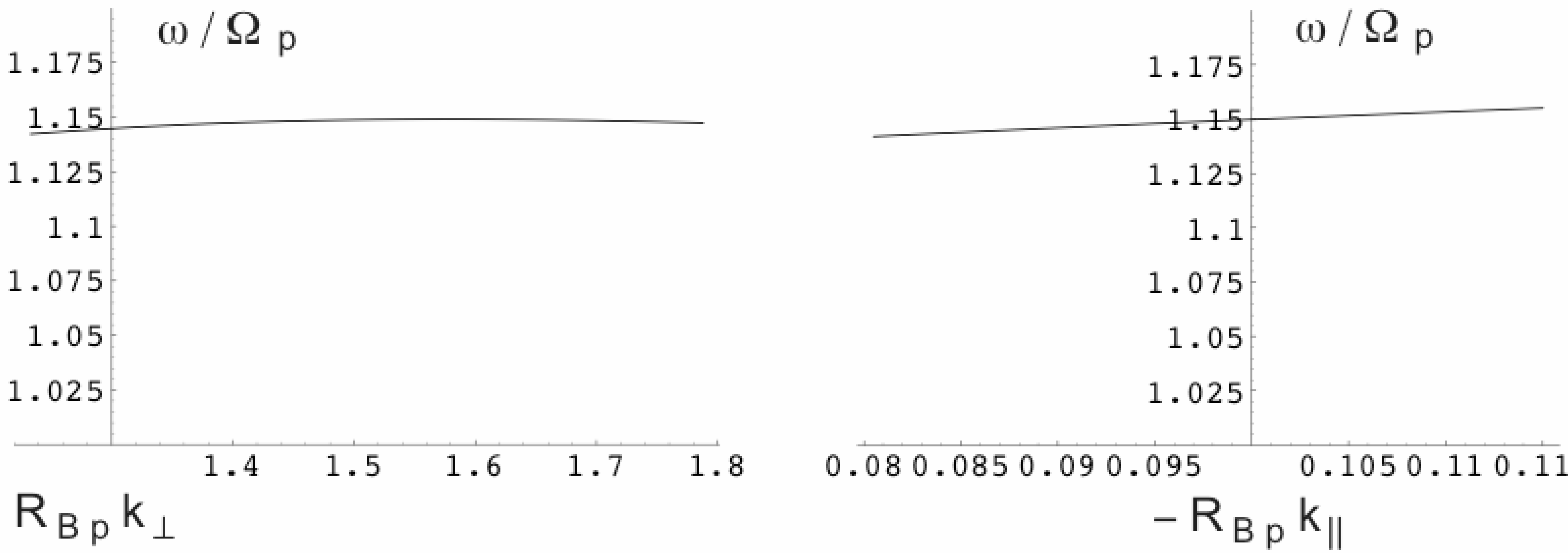
$$v_\perp^2 - \Omega/(\omega-\Omega)\, v_\parallel^2 = \eta = const$$



RESONANCE CONDITION

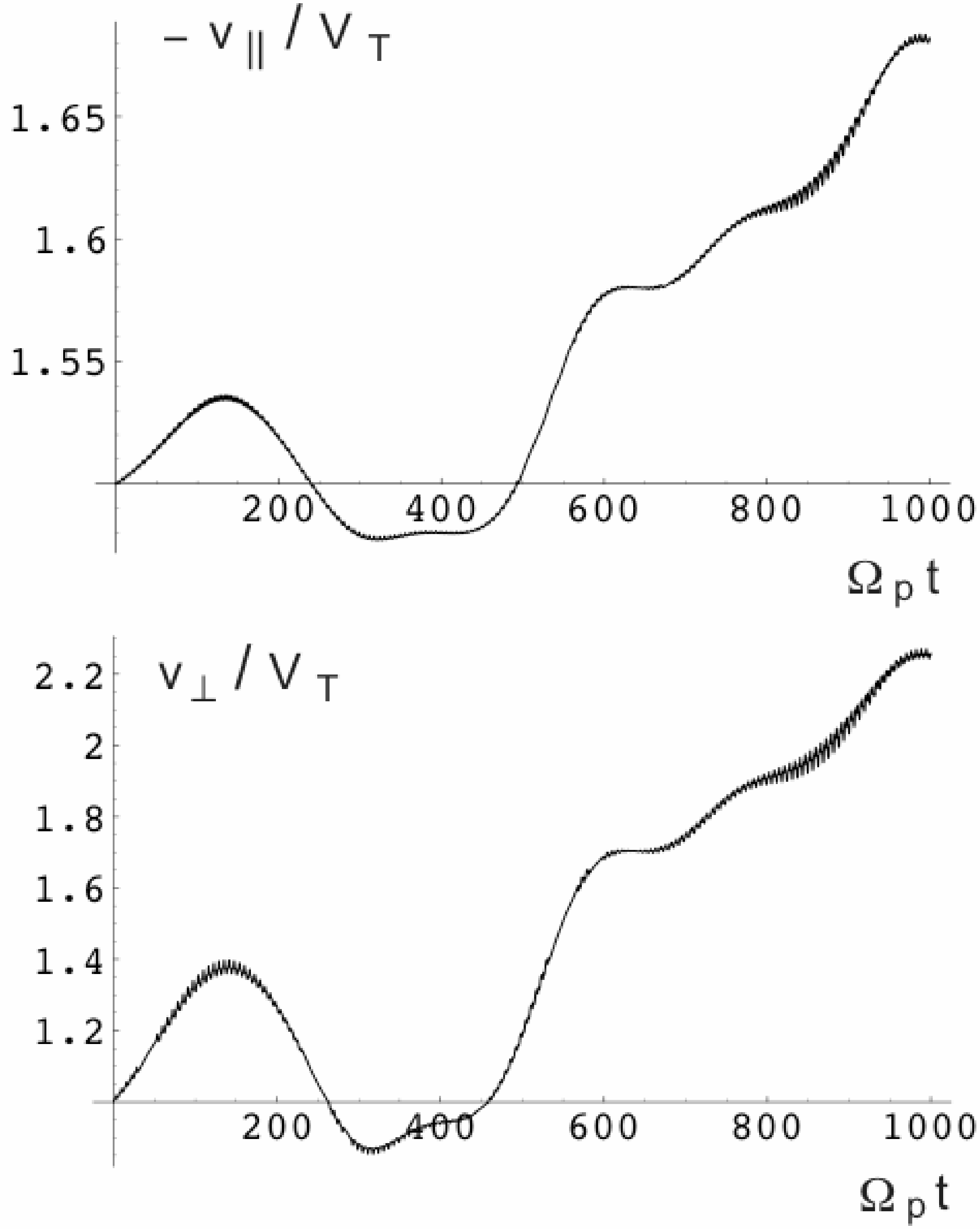
$$\omega - n\,\Omega = v_\parallel k_\parallel$$

DISPERSION CURVES OF ELECTROSTATIC ION CYCLOTRON WAVES



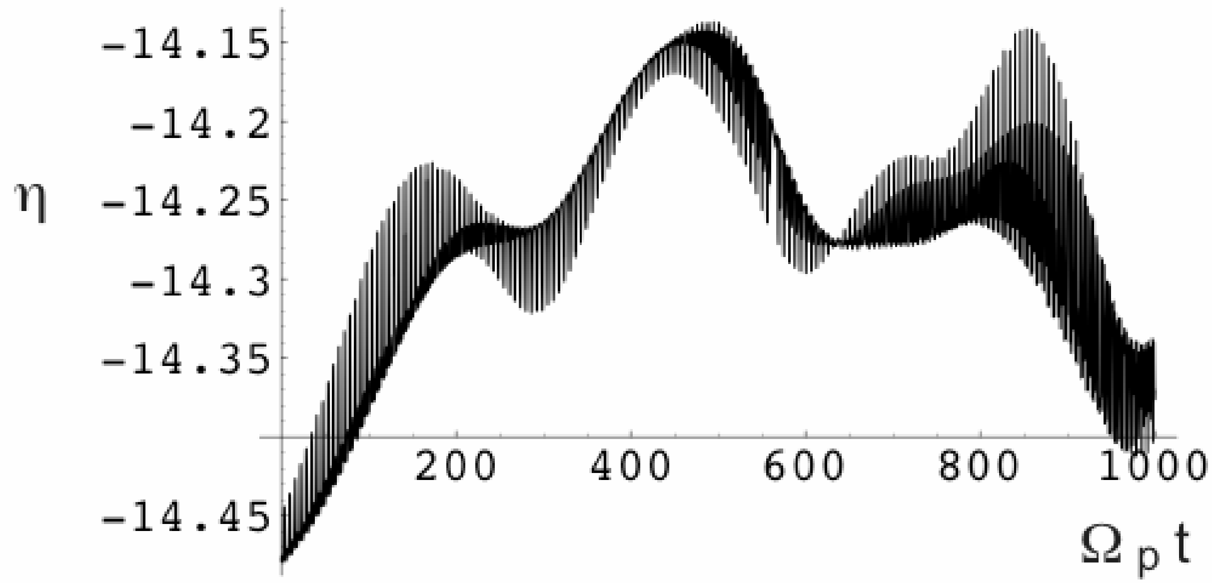
The frequency is almost constant

TEST PARTICLE VELOCITIES IN THE FIELD OF 100 WAVES



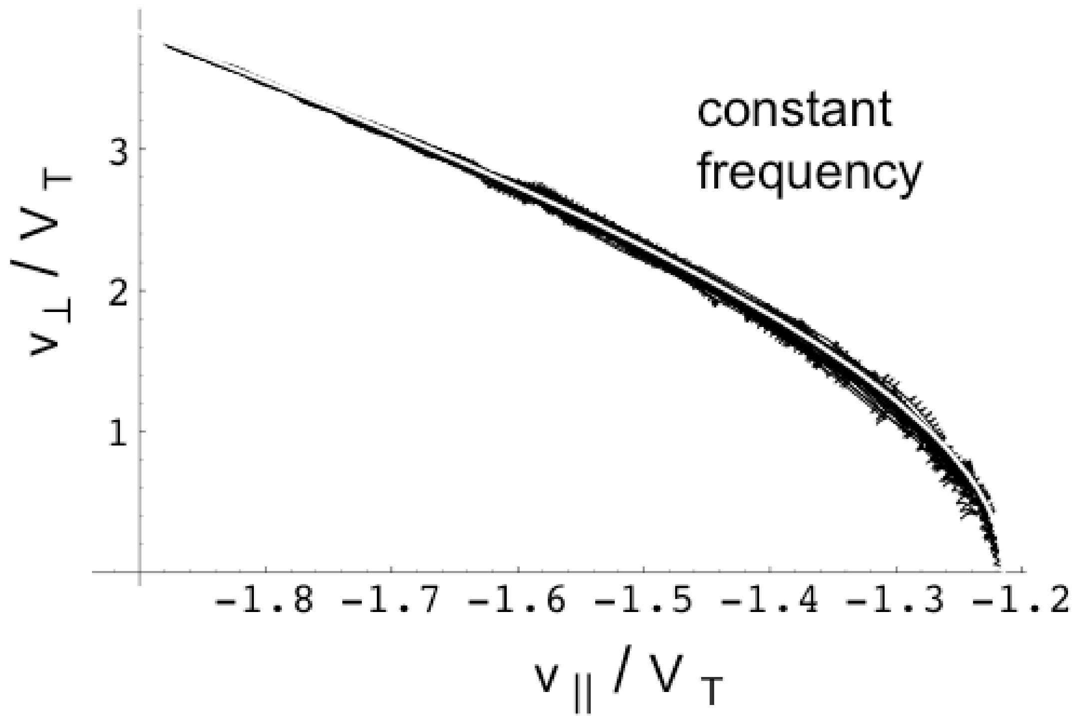
The velocities are highly correlated

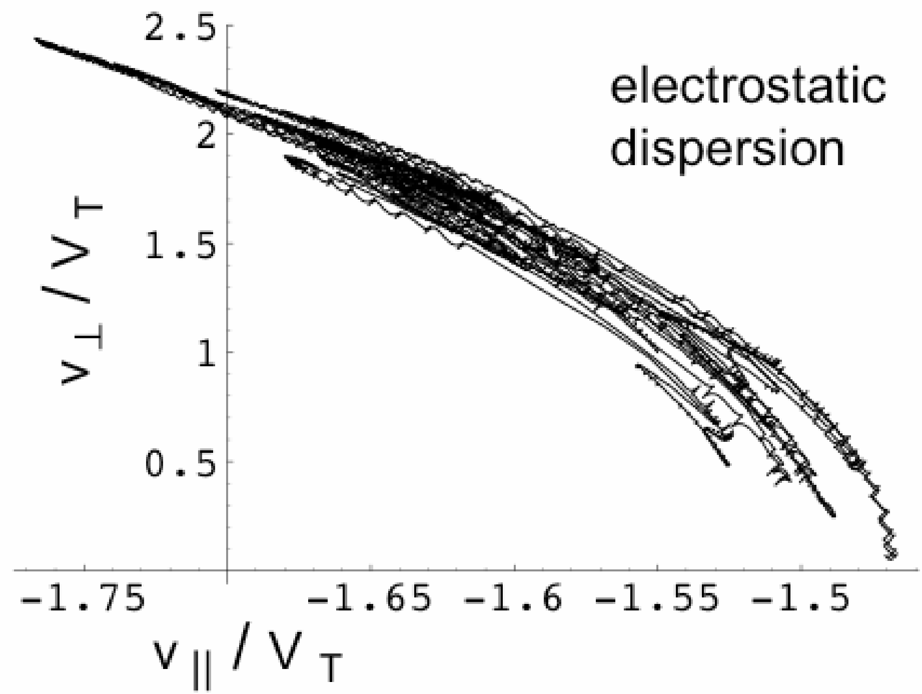
THE QUANTITY η LABELING DIFFUSION PATHS



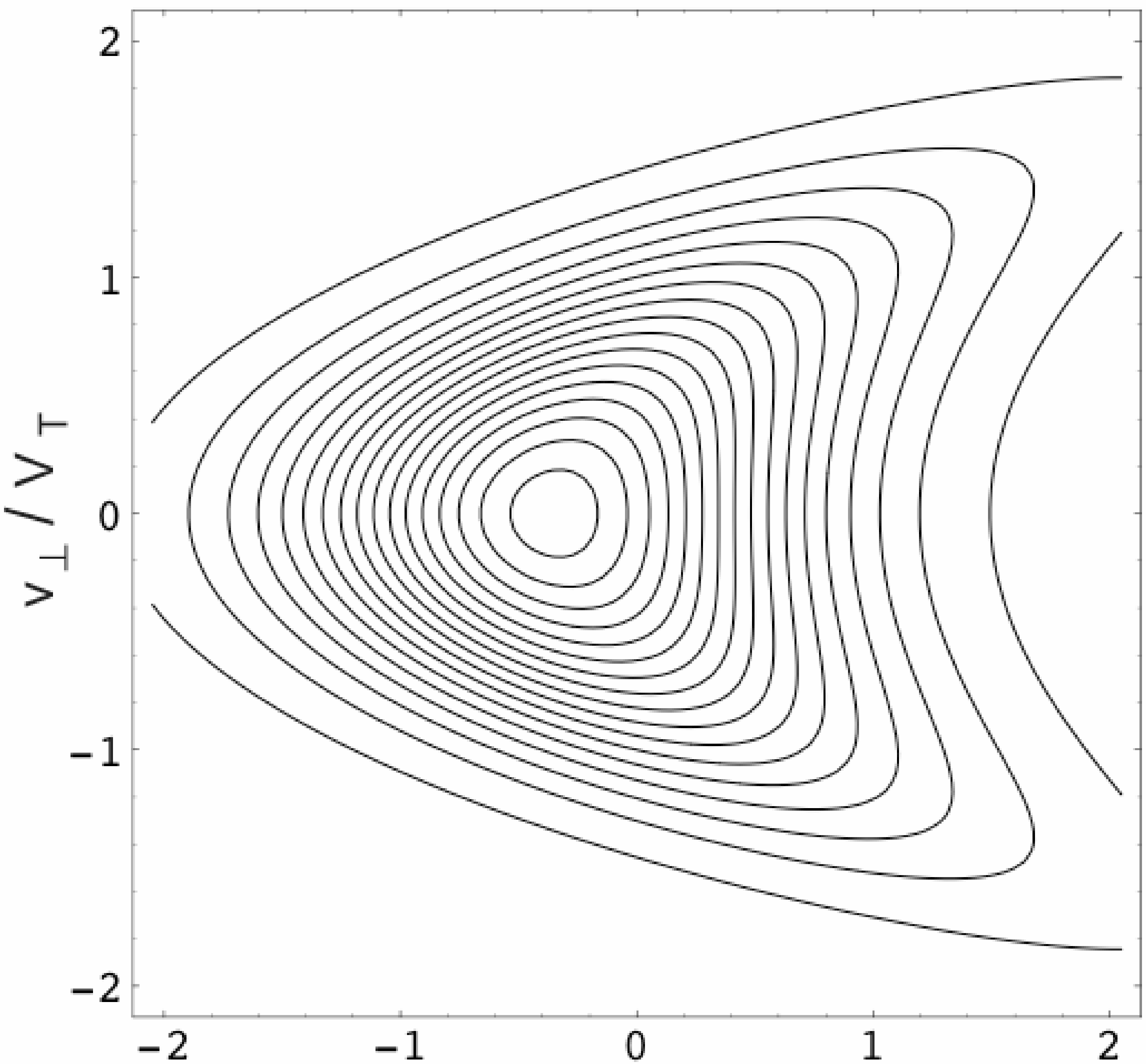
η is conserved with high accuracy

CALCULATED DIFFUSION PATHS



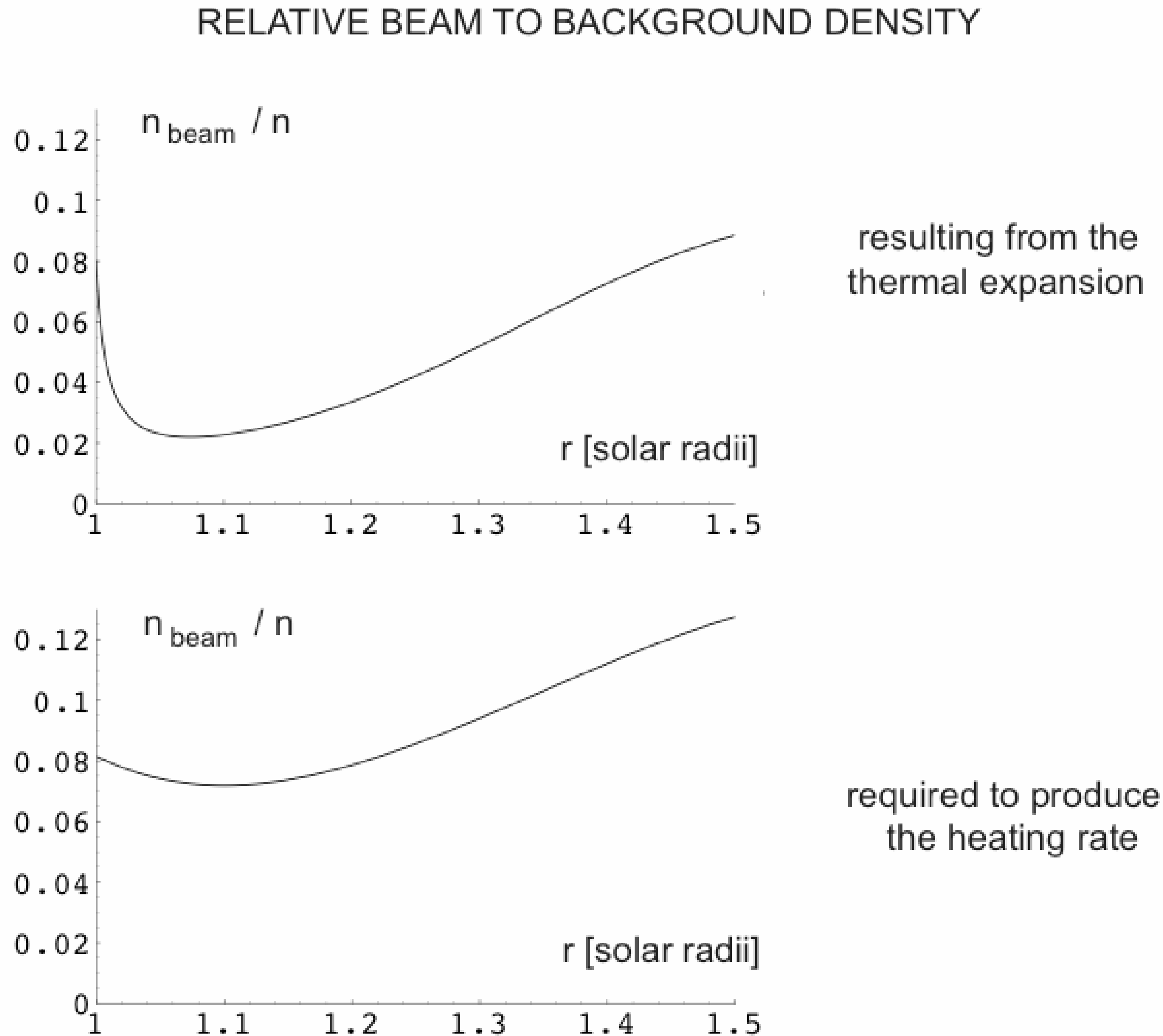


MAXWELLIAN DISTRIBUTION DISTORTED BY THE MIRROR FORCE

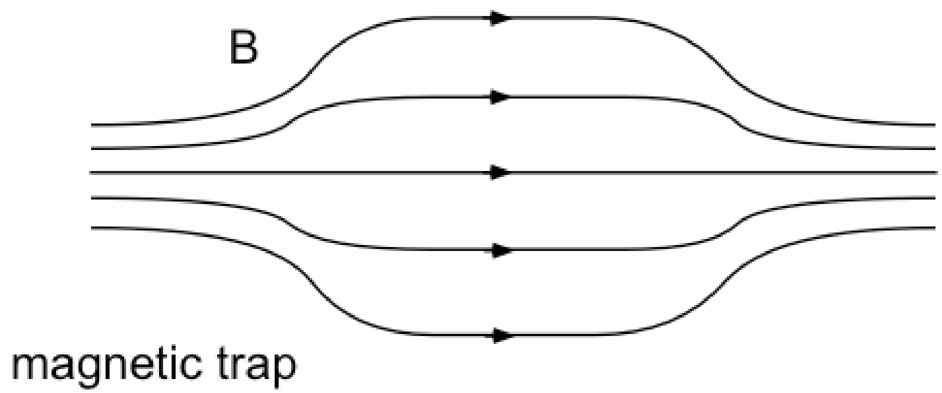


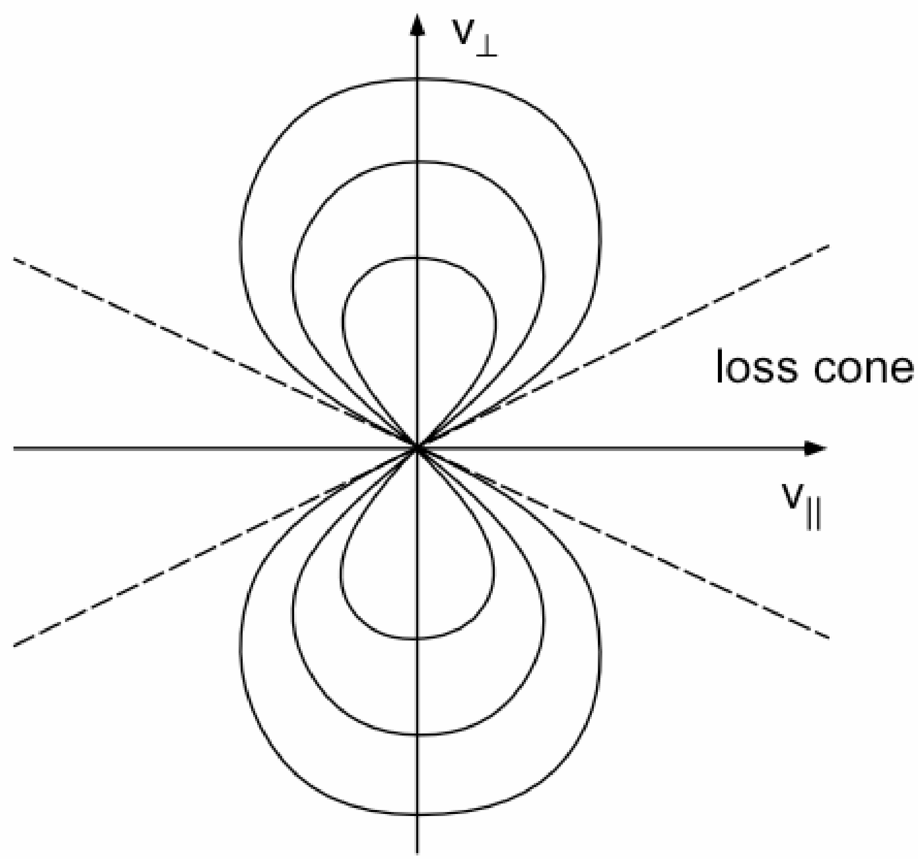
sunward $v_{||} / V_T$ antisunward

Particles with a greater $v_\perp$ are pushed more strongly

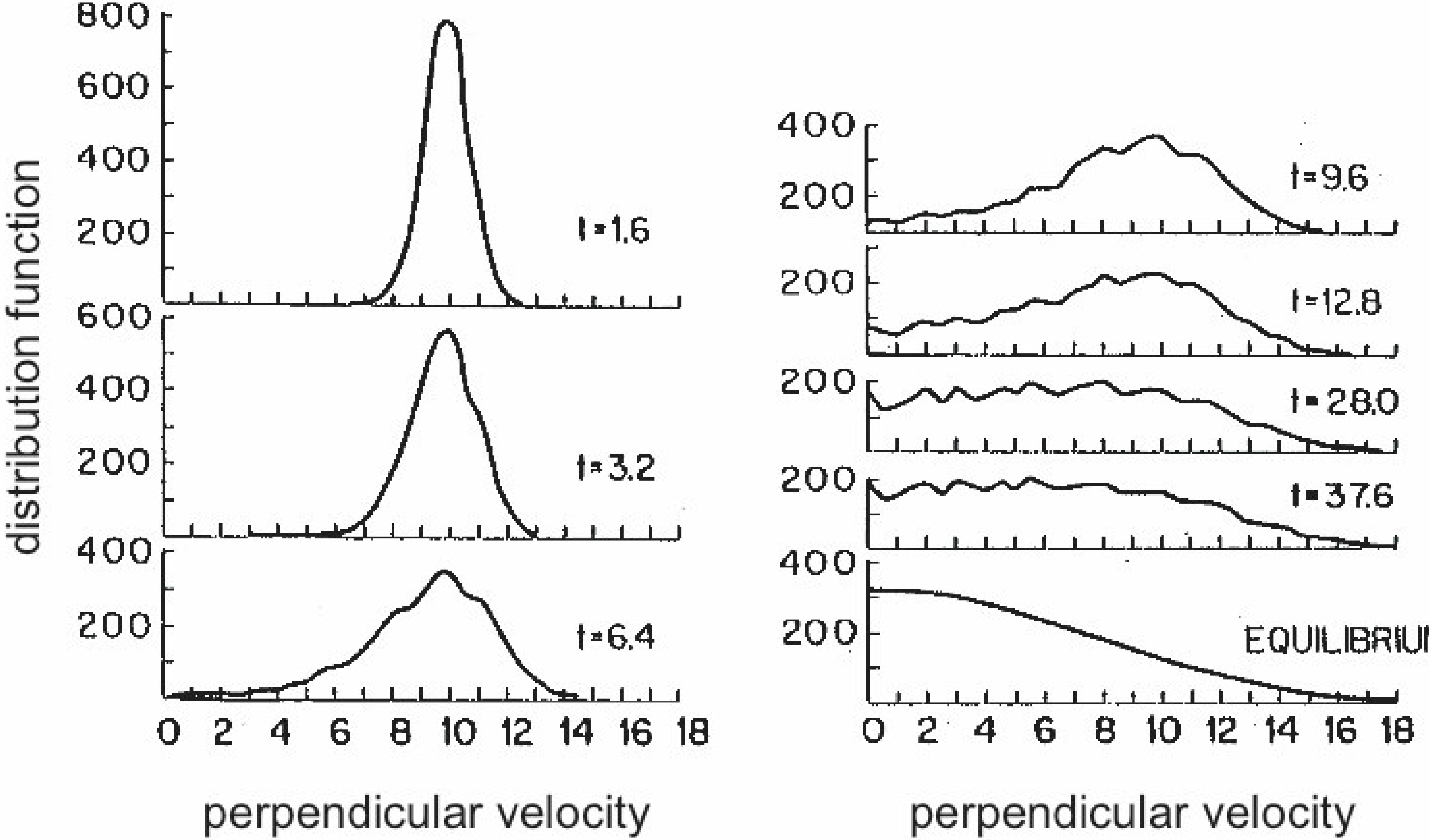

RELATIVE BEAM TO BACKGROUND DENSITY
n beam / n
0.12
0.1
0.08
0.06
0.04
0.02
0
1
1.1
1.2
1.3
1.4
1.5
r [solar radii]
resulting from the thermal expansion
n beam / n
0.12
0.1
0.08
0.06
0.04
0.02
0
1
1.1
1.2
1.3
1.4
1.5
r [solar radii]
required to produce the heating rate

LOSS-CONE DISTRIBUTION

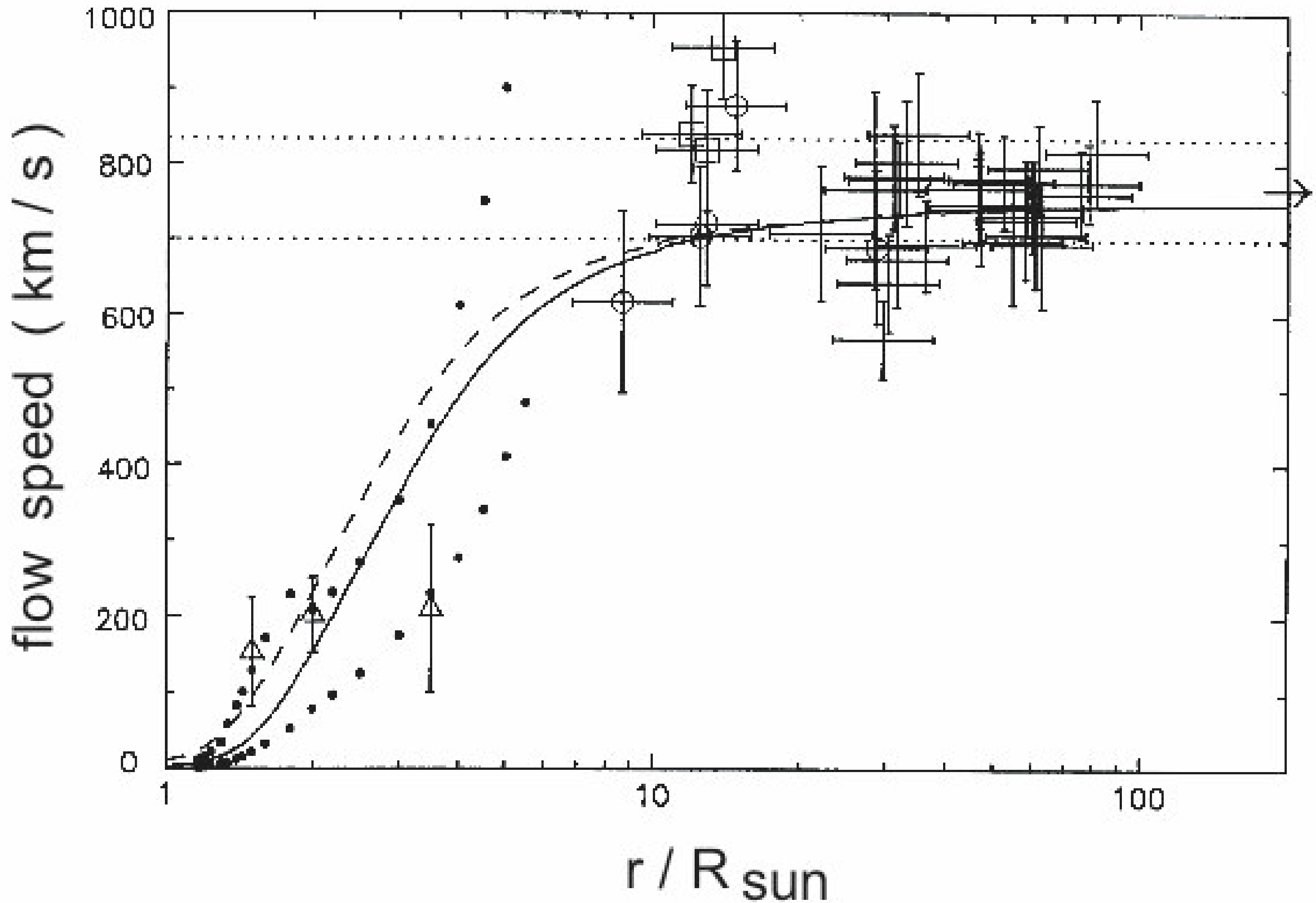




PARTICLE DIFFUSION AS A RESULT OF THE LOSS-CONE INSTABILITY (SWIFT, 1981)

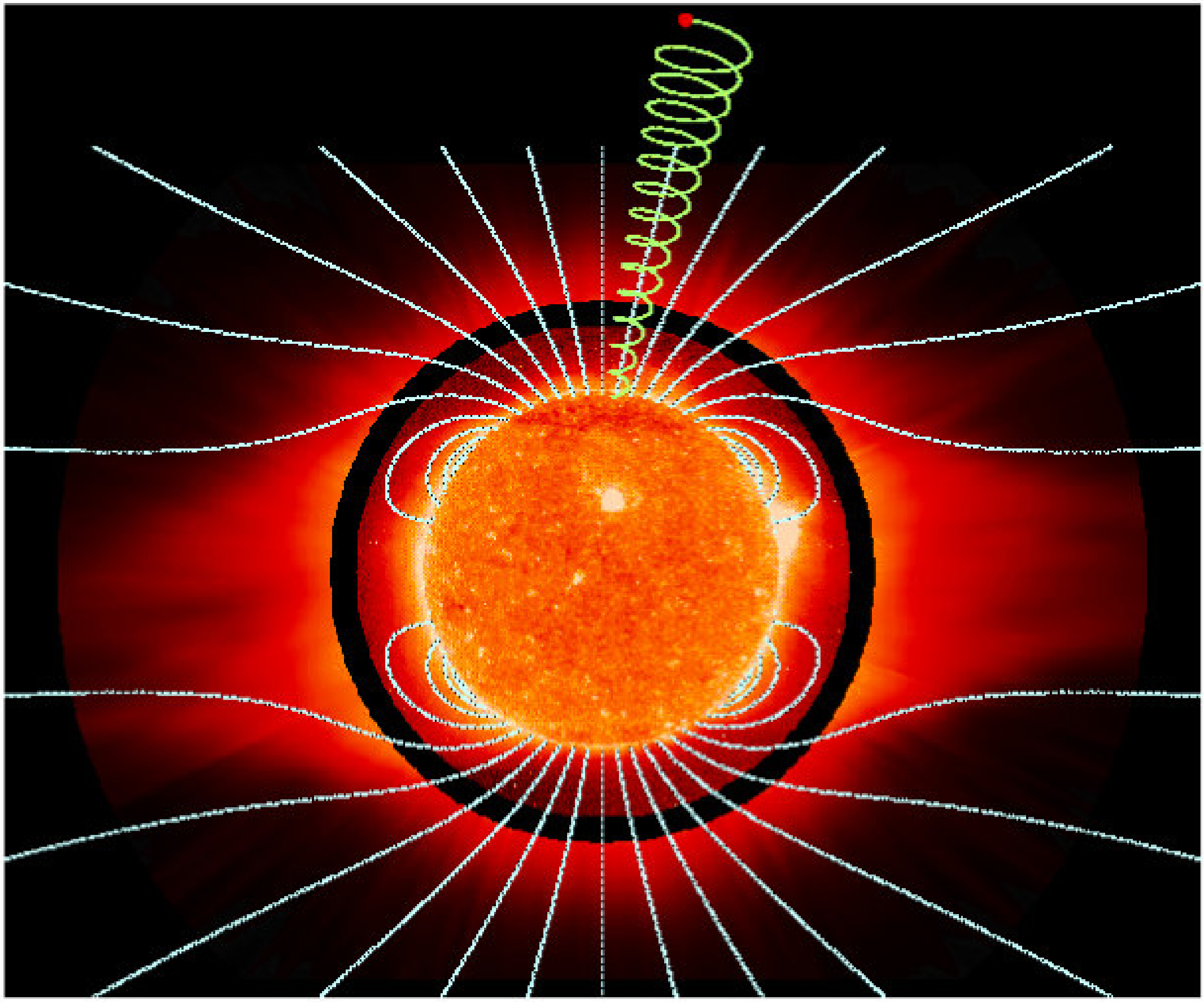


SOLAR WIND SPEED FROM OBSERVATIONS AND FLUID MODELS (ESSER ET AL., 1997)



Rapid acceleration takes place close to the Sun

COMBINED IMAGES FROM EIT & UVCS INSTRUMENTS
ON SOHO (ESA & NASA)



The color represents the total UV intensity emitted by O VI atoms in the corona.
The magnetic field model is created by Banaszkiewicz et al. (1998).