Jet-Front Speed and the Origin of Jets
in
Polar Coronal Holes

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Abstract

The area-average strength of the open magnetic field in the polar coronal holes can be estimated from the radial component of the magnetic field measured by *Ulysses* in the solar wind, the fraction of the solar sphere covered by the polar coronal holes, and the fraction of the heliosphere filled by the fast solar wind from the polar coronal holes. For the present minimum phase of the solar cycle, the estimated strength is ~10 G. Using this strength for the ambient open field in the standard reconnection model for jets in coronal holes, we obtain for any given jet-front speed a lower bound on the initial temperature of the expanding jet-front plasma, and an upper bound on the ambient plasma density at the reconnection site. These two bounds indicate the following. For jet-front speeds ~ 1000 km/s, (1) the reconnection site has to be in the low corona or upper transition region (n_e <~ 10^9 cm^{-3}), not in the lower transition region or chromosphere, (2) the jet-front plasma is initially heated to T >~ 10^7 K, and (3) hence a compact X-ray flare is produced at the base of the jet. For jet-front speeds <~ 100 km/s, (1) the jet can be produced by reconnection in the lower transition region or upper chromosphere (10^{10} <~ ne <~ 10^{12} cm^{-3}), (2) the initial temperature of the jet-front plasma can be less than 10^6 K, and (3) hence some EUV and Hα jet-type macrospicules may be produced with no detectable X-ray emission.

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Main Points

- We adopt the standard scenario for the production of polar jets by reconnection between open and closed magnetic fields.

- The speed of the jet front then gives:
  - A lower bound on the temperature at the base of the jet outflow, and
  - A lower bound on the Alfven speed in the reconnection inflow.

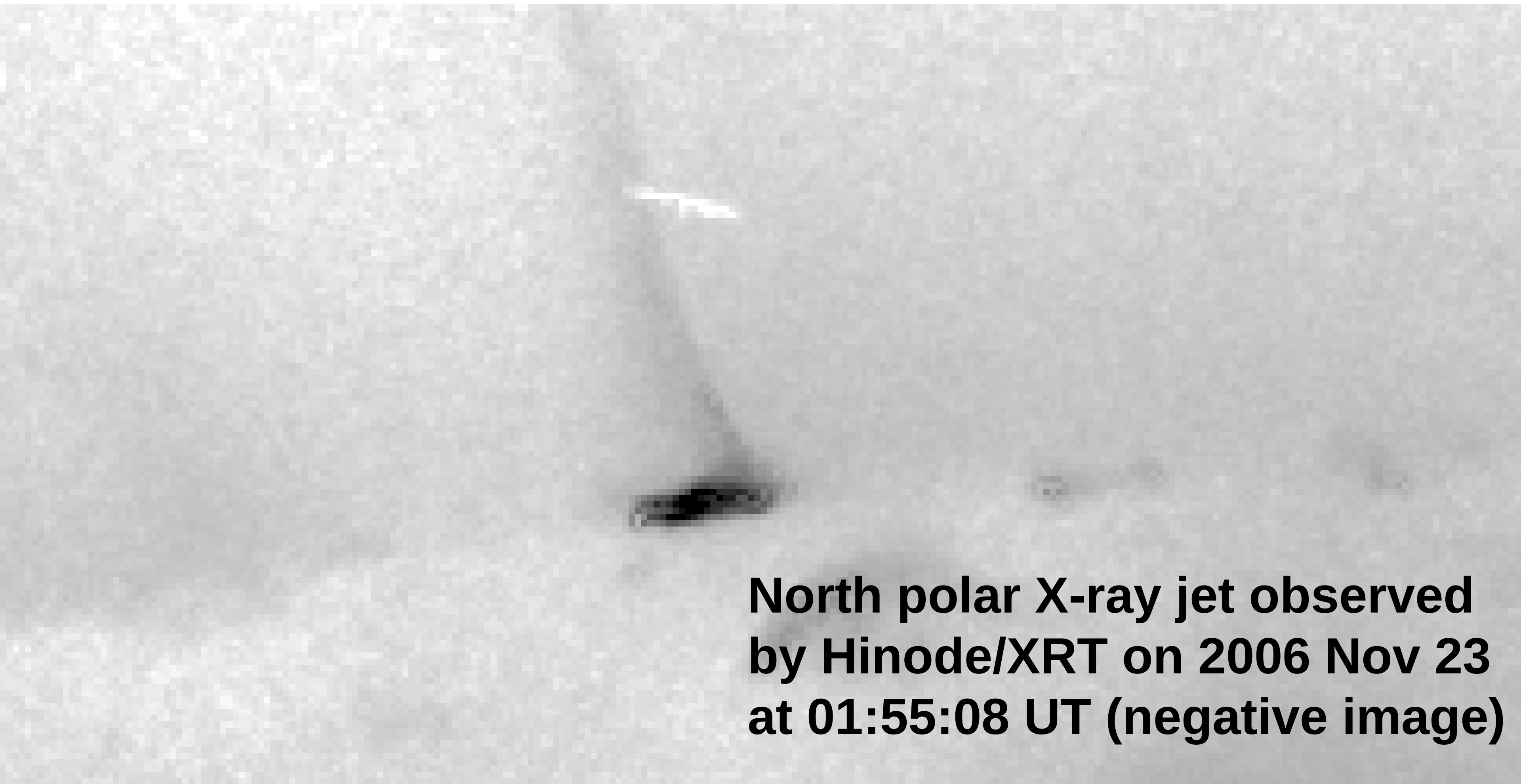
- For jets in the polar coronal holes of the current solar minimum (2006-2008), the strength of the reconnecting field is ~10 G.

- For this field strength:
  - A polar X-ray jet (jet plasma temperature > 10^6 K, jet-front speed 400-800 km/s) is produced when the reconnection sits above the lower transition region (inflow plasma density <~10^9 cm^{-3}).
  - A polar EUV or Hα jet-type macrospicule (jet plasma temperature < 10^6 K, jet-front speed 20-100 km/s) is produced when the reconnection sits in the lower transition region or upper chromosphere (10^{10} <~ inflow plasma density <~ 10^{12} cm^{-3}).

Polar X-ray Jets:

Jet plasma temperatures > 10^6 K

Range of jet-front speeds: 400-800 km/s



North polar X-ray jet observed by Hinode/XRT on 2006 Nov 23 at 01:55:08 UT (negative image)

Jet-type EUV Polar Macrospicules:

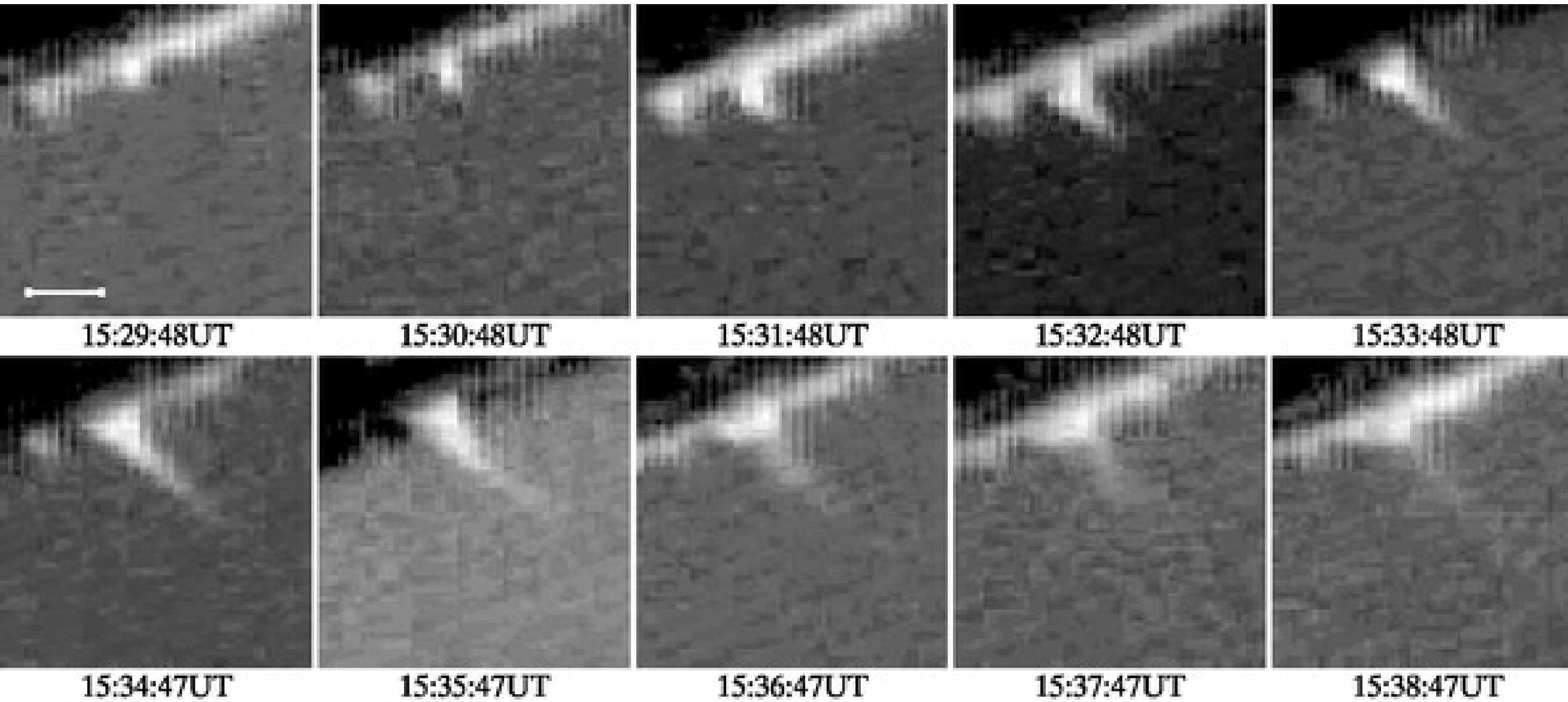
Jet plasma temperatures ~ 10^5 K
Range of jet-front speeds: 20-100 km/s


North polar EUV jet macrospicule observed in He II 304 Å emission by STEREO B EUVI on 2007 Jan 1 at 11:15:52 UT (negative image)

Jet-type Hα Polar Macrospicules:

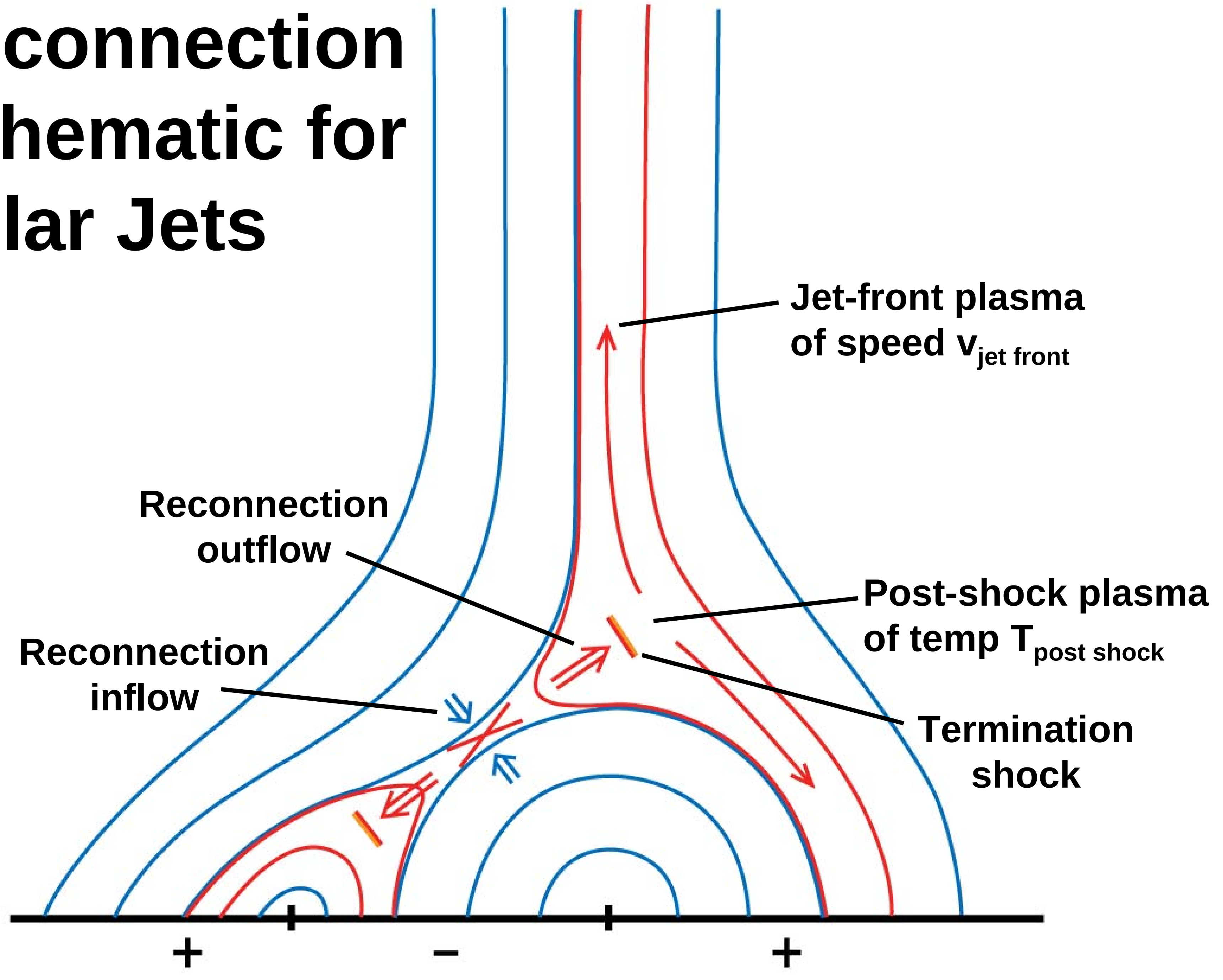
Jet plasma temperatures ~ 10^4 K

Range of jet-front speeds: 20-100 km/s



South polar Hα jet macrospicule observed in BBSO full-disk Hα images on 1997 May 7 (from Yamauchi et al 2004, ApJ, 605, 511)

Reconnection Schematic for Polar Jets



Energy Chain in Reconnection Model for Polar Jets

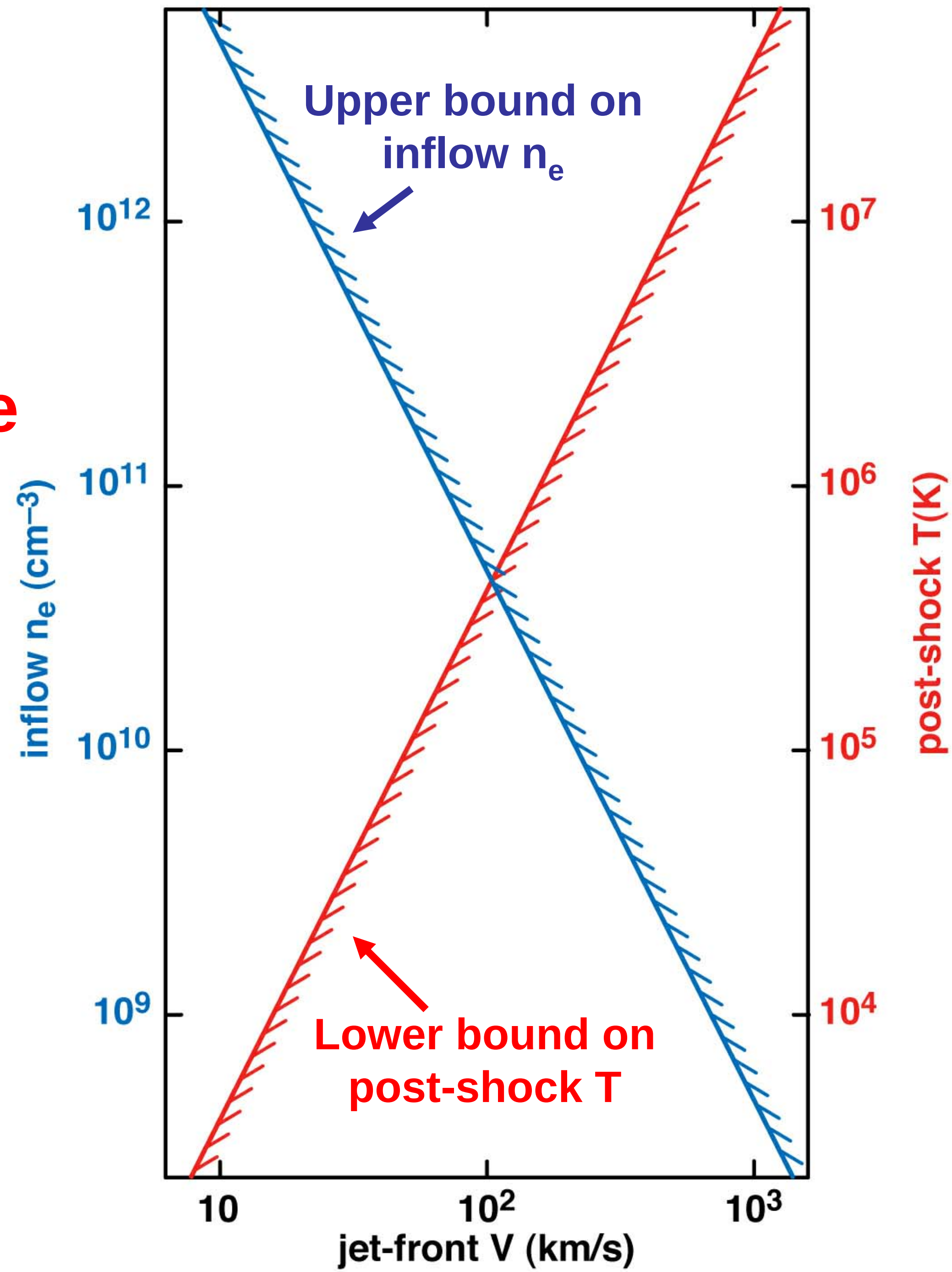
magnetic energy per proton in reconnection inflow	>	kinetic energy per proton in reconnection outflow	~	post-shock thermal energy per proton	>~	jet-front kinetic energy per proton

$$(B^2/8\pi n_p)_{\text{inflow}} > (m_p/2)v^2_{\text{outflow}} \sim (3/2)kT_{\text{post shock}} \gtrsim (m_p/2)v^2_{\text{jet front}}$$

Thus, the jet-front speed (1) gives a lower bound on the plasma temperature produced by the termination shock, and (2) together with the strength of the ambient magnetic field at the reconnection site, gives an upper bound on the ambient plasma density at the reconnection site.

Upper Bound on Inflow Plasma Density
and
Lower Bound on Post-Shock Temperature
Set by Jet-Front Speed

For B_{inflow} = 10 G:



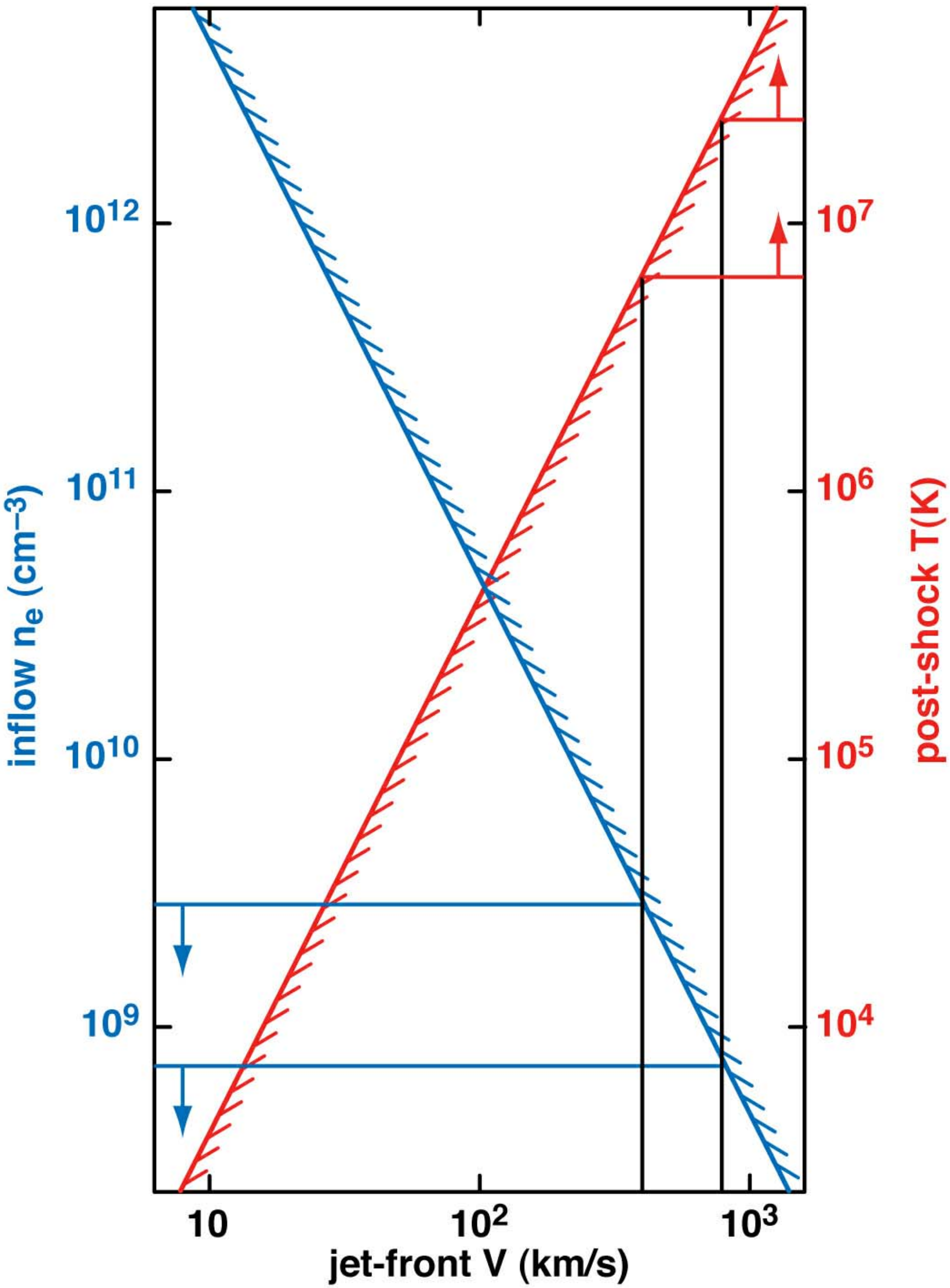
Polar X-Ray Jets

Inflow Plasma Density
and
Post-Shock Temperature
Required by
Observed Jet-Front Speeds
of
400-800 km/s:

For inflow B ≈ 10 G,

inflow n_e <~ 10^9 cm^{-3}

post-shock T >~ 10^7K



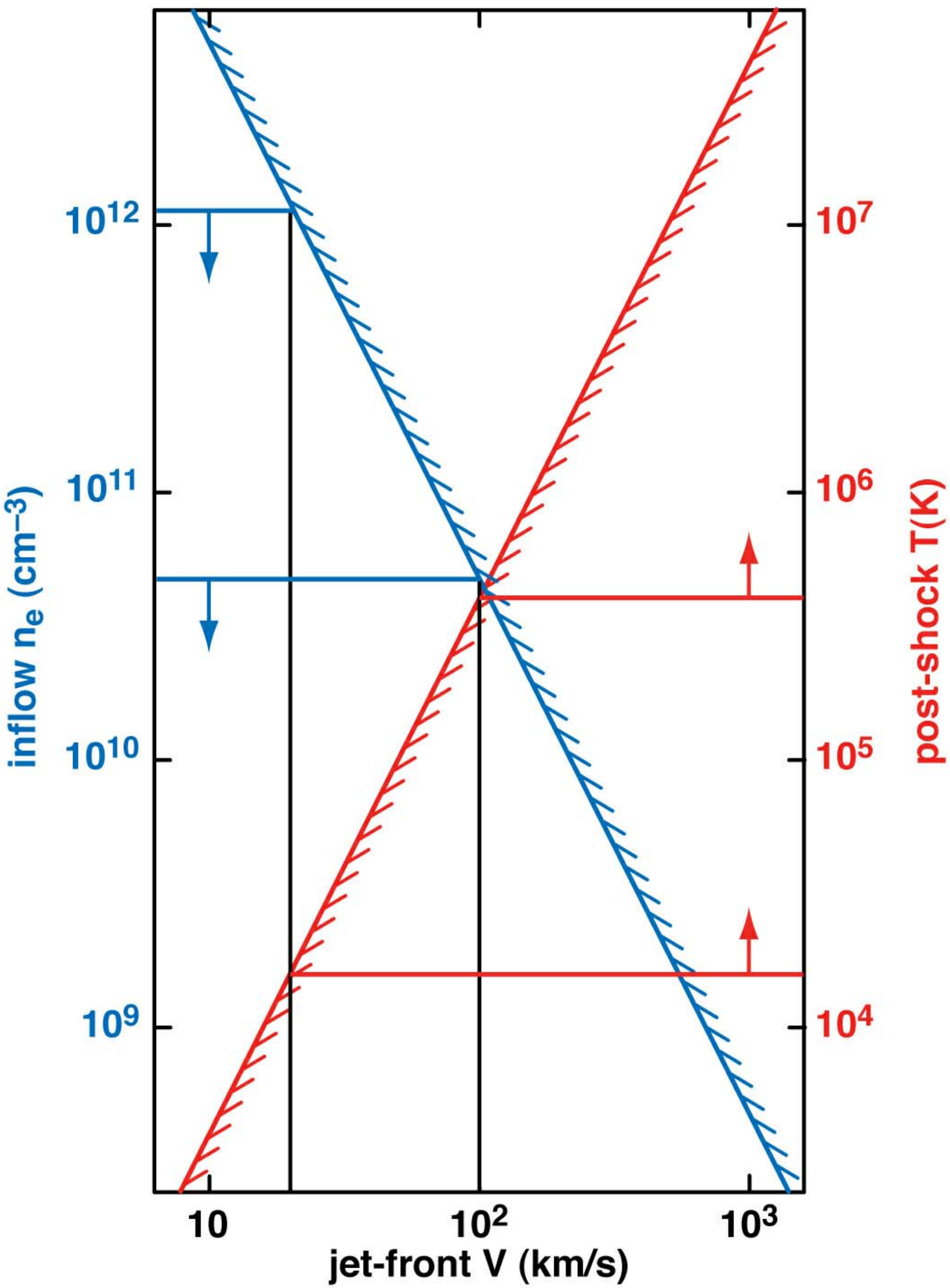
EUV and Hα Jet Macrospicules

Inflow Plasma Density
and
Post-Shock Temperature
Required by
Observed Jet-Front Speeds
of
20-100 km/s:

For inflow B ≈ 10 G,

inflow n_e <~ 10^{12}-10^{10} cm^{-3}

post-shock T >~ 10^4-10^6 K



Empirical Estimate of Magnetic Field Strength $B_{polar\ hole}$ at Bottom of Polar Coronal Holes

By conservation of radial magnetic flux in steady solar wind,

$$B_{polar\ hole} = f_{fast\ wind} B^*,$$

where B^* is interplanetary field's radial component extrapolated radially inward to solar surface, and $f_{fast\ wind}$ is areal expansion factor of fast solar wind from polar coronal hole.

$$f_{fast\ wind} = (1-\sin\theta_{fast\ wind})/(1-\sin\theta_{polar\ hole}),$$

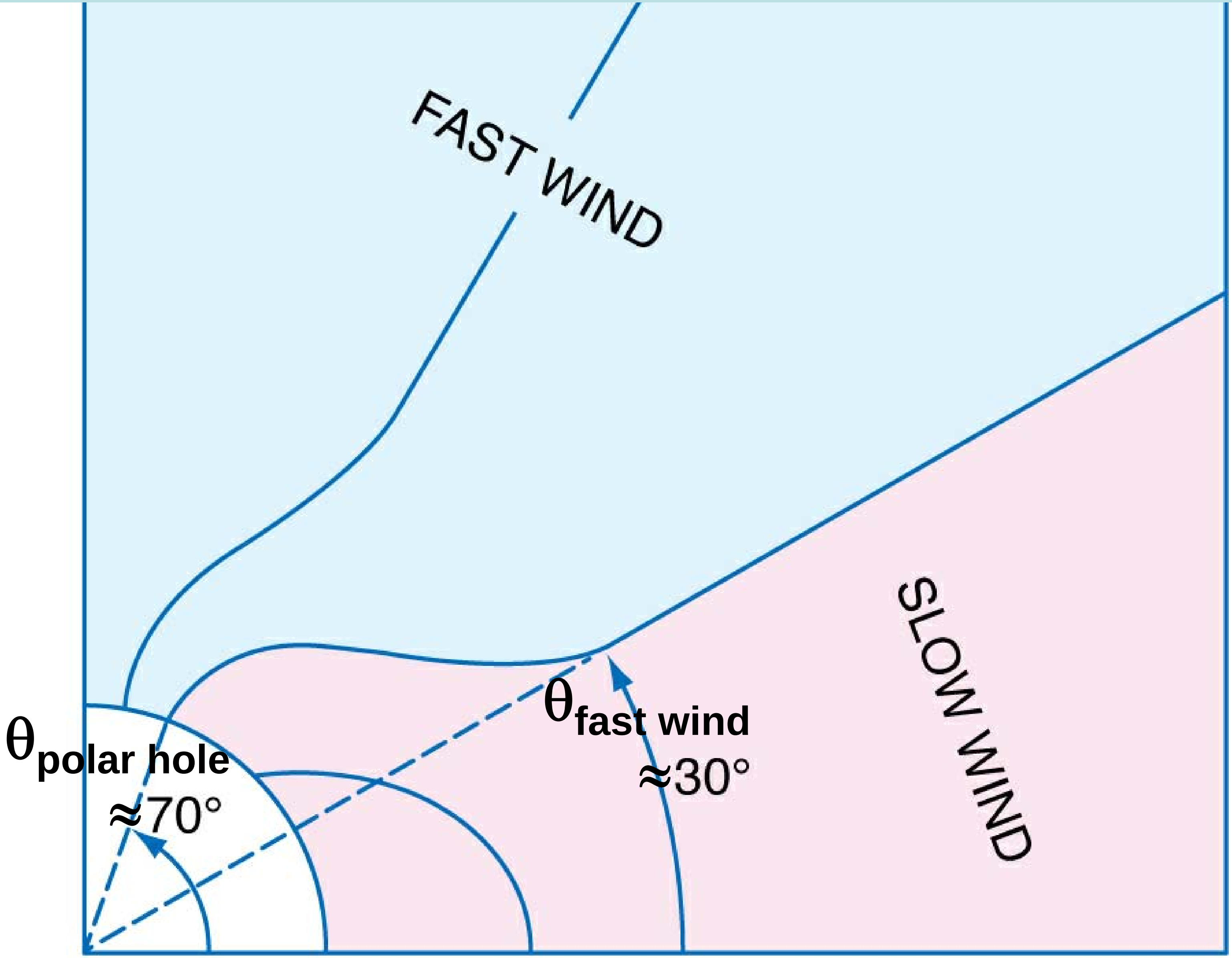
where $\theta_{fast\ wind}$ is latitude of radial edge of interplanetary fast wind, and $\theta_{polar\ hole}$ is latitude of edge of polar coronal hole.

During 2006-2008 solar minimum, from solar wind speed and magnetic field measured by Ulysses and angular width of polar coronal holes observed by SOHO/EIT and STEREO/EUVI,

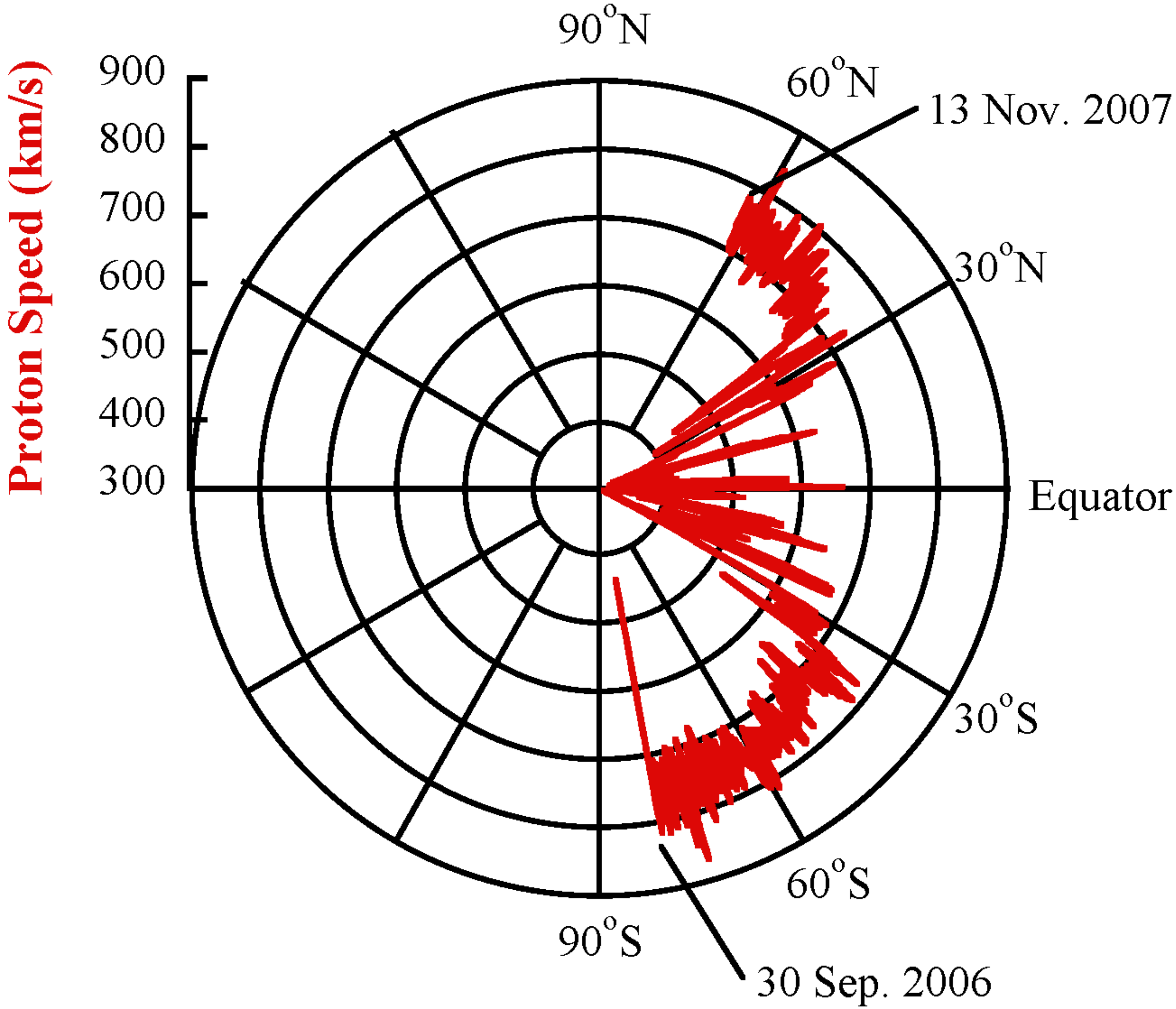
$B^* \approx 1.1$ G, $\theta_{fast\ wind} \approx 30°$, $\theta_{polar\ hole} \approx 70°$, giving:

$$B_{polar\ hole} \approx 10\ \text{G}$$

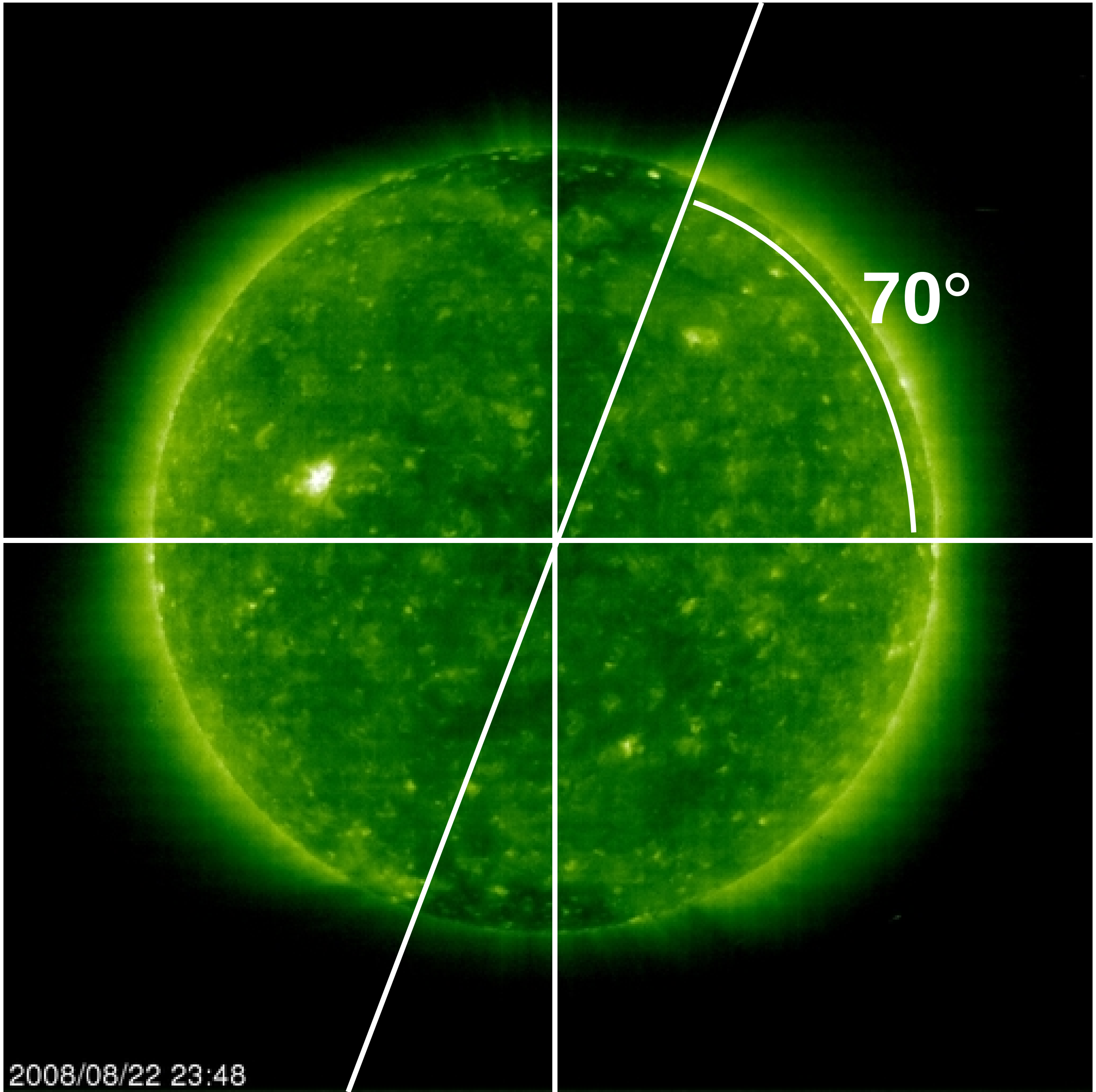
Angular Extents of Fast Solar Wind and Polar Coronal Holes in Present Solar Minimum



Latitude Dependence of Solar Wind Speed Observed by Ulysses in Present Solar Minimum



Polar Coronal Holes Observed in the Fe XII 195 Å Corona by SOHO/EIT on 2008 Aug 22



$$\frac{B^2}{8\pi} = \frac{1}{2}\rho V_A^2$$