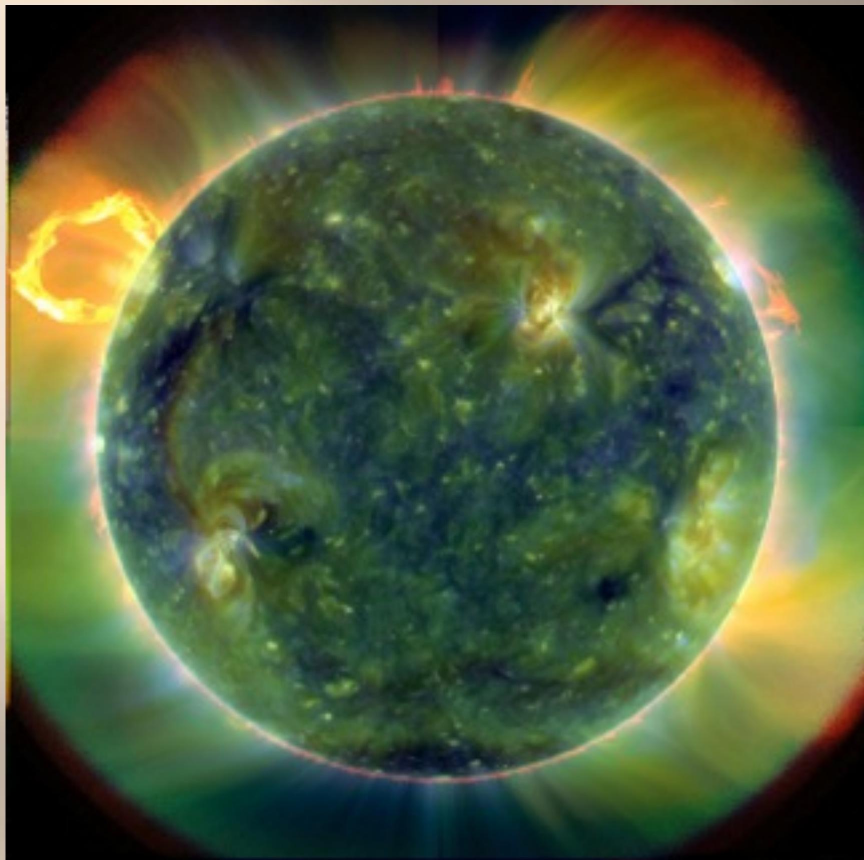
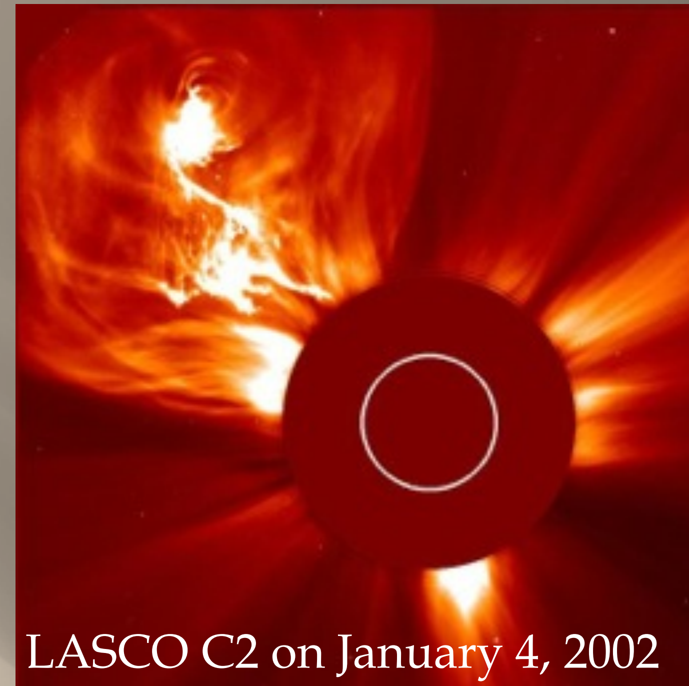
Ion-neutral Coupling in Prominences

Motivation:

- Observations of vertical flows: do ion-neutral interactions play a role?
- By understanding the coupling what can we infer about the magnetic structure?



SDO AIA composite made from three of the AIA wavelength bands, corresponding to temperatures from .7 to 2 million degrees (hotter = red, cooler = blue).

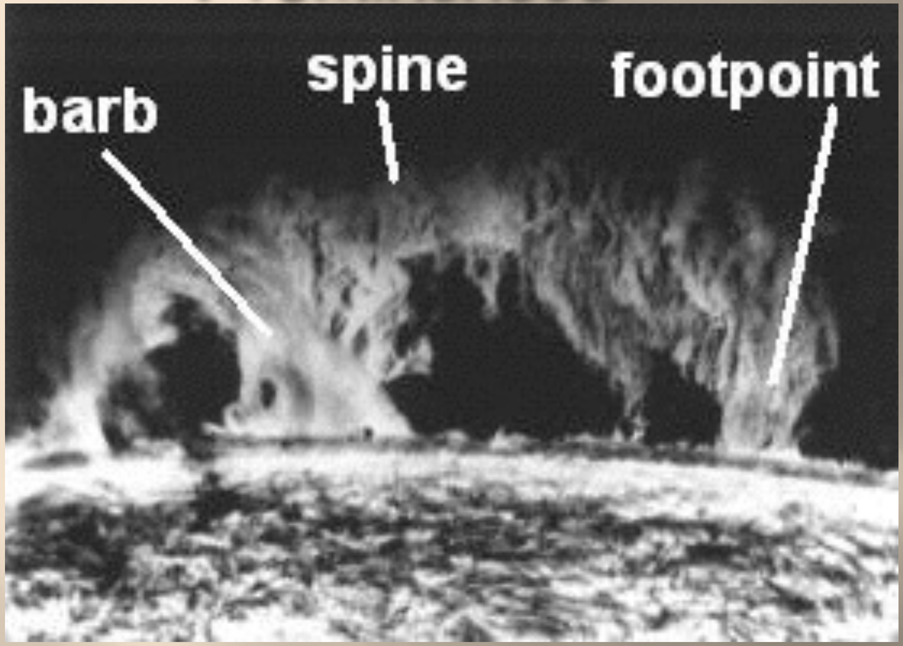


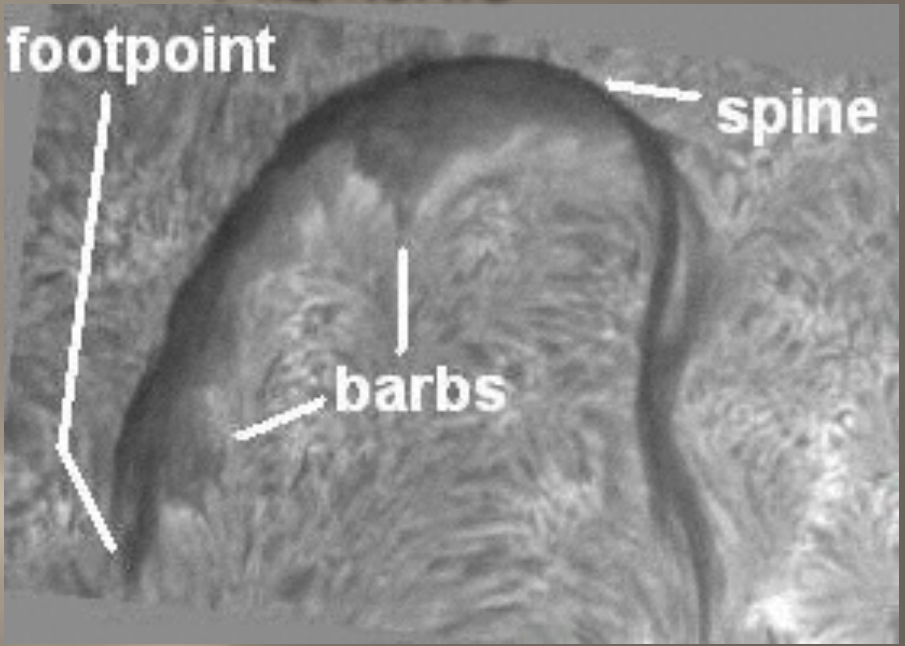
LASCO C2 on January 4, 2002

Extreme ultraviolet Imaging Telescope (EIT) 304Å on February 2, 2001

Prominences

Filaments





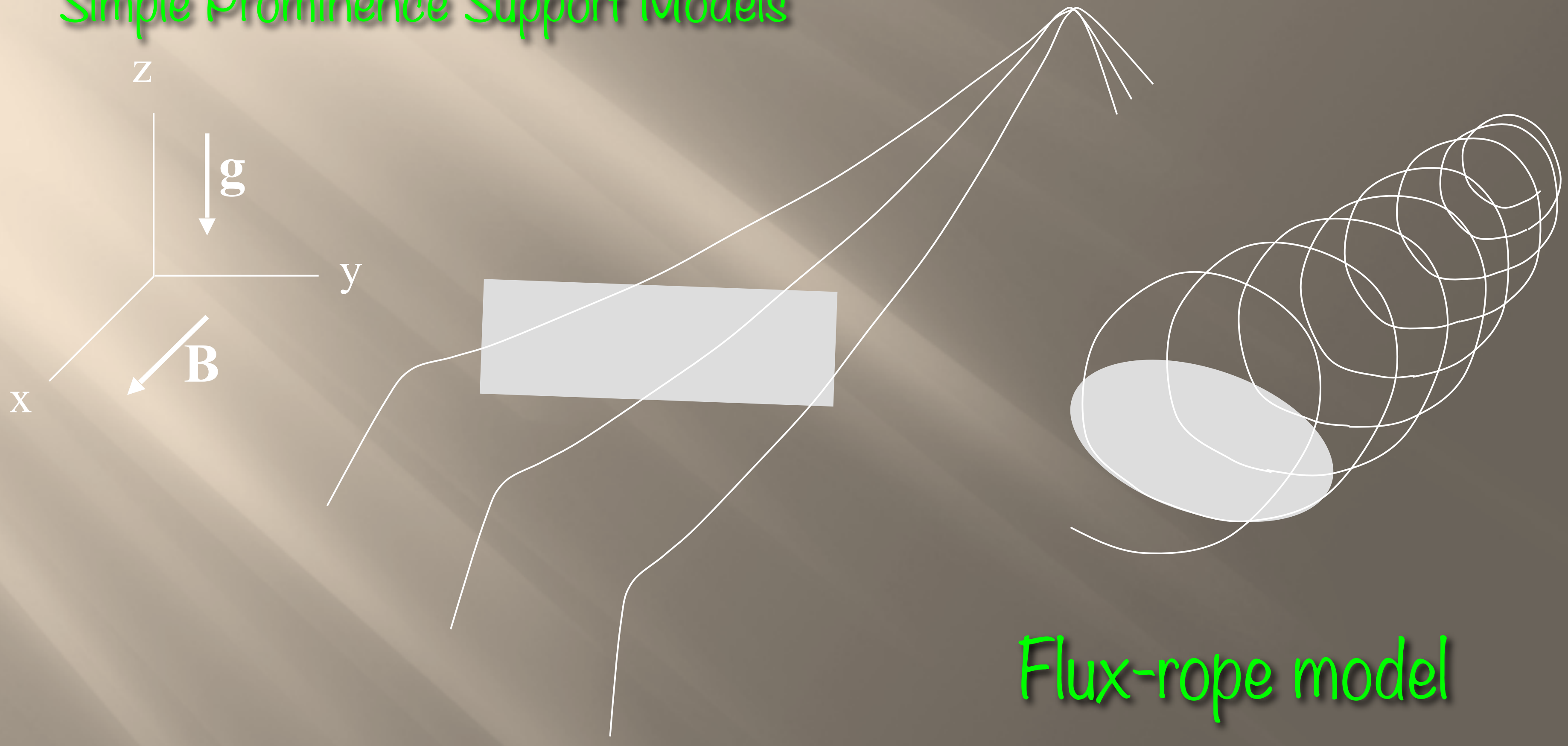
- Length ~ 10 - 1000 Mm, Height ~ 1 - 100 Mm, Width ~ 1 - 10 Mm *(1 Mm = 1000 km = 10^8 cm)*
- Lifetime ~ hours - months
- $T < 10^4$ K, $N \sim 10^{10}$ cm^{-3}, $M \sim 10^{15}$ gm
- $V \sim 5 - 100$ km s^{-1}

Approach

- Determine whether cross-field diffusion of neutrals is important-- initial calculation of Gilbert et al. (2002)
- Look to observations to support findings (2007, 2010)
  - Study spatial and temporal variation of mass in different lines
- Determine relative importance of mechanisms responsible for mass variation
- Work with modelers to further assess the importance of

Mass loss via. Cross field diffusion? (Gilbert et al. 2002; 2007)

Simple Prominence Support Models



Flux-rope model

Dip Model

Force Balance in a Multi-Constituent Prominence Plasma

General Momentum Balance Equation (j^{th} particle species)

$$\frac{\partial}{\partial t}\left(\rho_j \mathbf{u}_j\right) + \nabla \cdot \left(\rho_j \mathbf{u}_j \mathbf{u}_j\right) = -\nabla p_j - \nabla \cdot \overleftrightarrow{\tau}_j + n_j e Z_j \left(\mathbf{E} + \mathbf{u}_j \times \mathbf{B}\right) - \rho_j \frac{G M_\odot}{r^2} \hat{\mathbf{e}}_r$$

$$+ \rho_j \sum_k \nu_{jk} \left(\mathbf{u}_k - \mathbf{u}_j\right) + F_{Rj} + F_{Tj} + m_j \left[\sum_k P_{jk} \mathbf{u}_k - L_j \mathbf{u}_j\right]$$

Other assumptions:

- Neglect flows along the magnetic field
- Constant density and temperature throughout system
- Collision frequencies appropriate for subsonic flow speeds (our calculated flow speeds are less than 0.1 km s^{-1})
- Local magnetic field is exactly horizontal to the (locally flat) solar surface

EXAMPLE: Proton Force Balance

z-component: $$u_{py} = -g/\Omega_p + \Omega_p^{-1}\left[\nu_{pe}\left(u_{ez} - u_{pz}\right) + \nu_{pH}\left(u_{Hz} - u_{pz}\right) + \nu_{pHe}\left(u_{Hez} - u_{pz}\right) + \nu_{pHe^+}\left(u_{He^+z} - u_{pz}\right)\right]$$

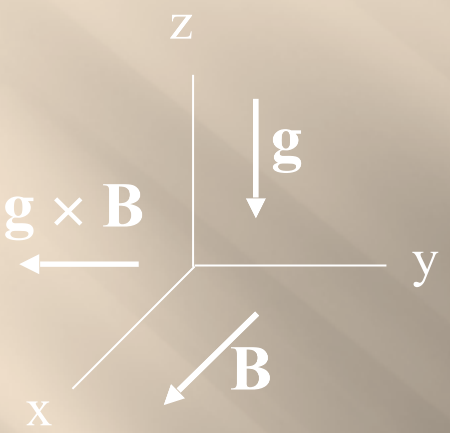
y-component: $$u_{pz} = \Omega_p^{-1}\left[\nu_{pe}\left(u_{ey} - u_{py}\right) + \nu_{pH}\left(u_{Hy} - u_{py}\right) + \nu_{pHe}\left(u_{Hey} - u_{py}\right) + \nu_{pHe^+}\left(u_{He^+y} - u_{py}\right)\right]$$

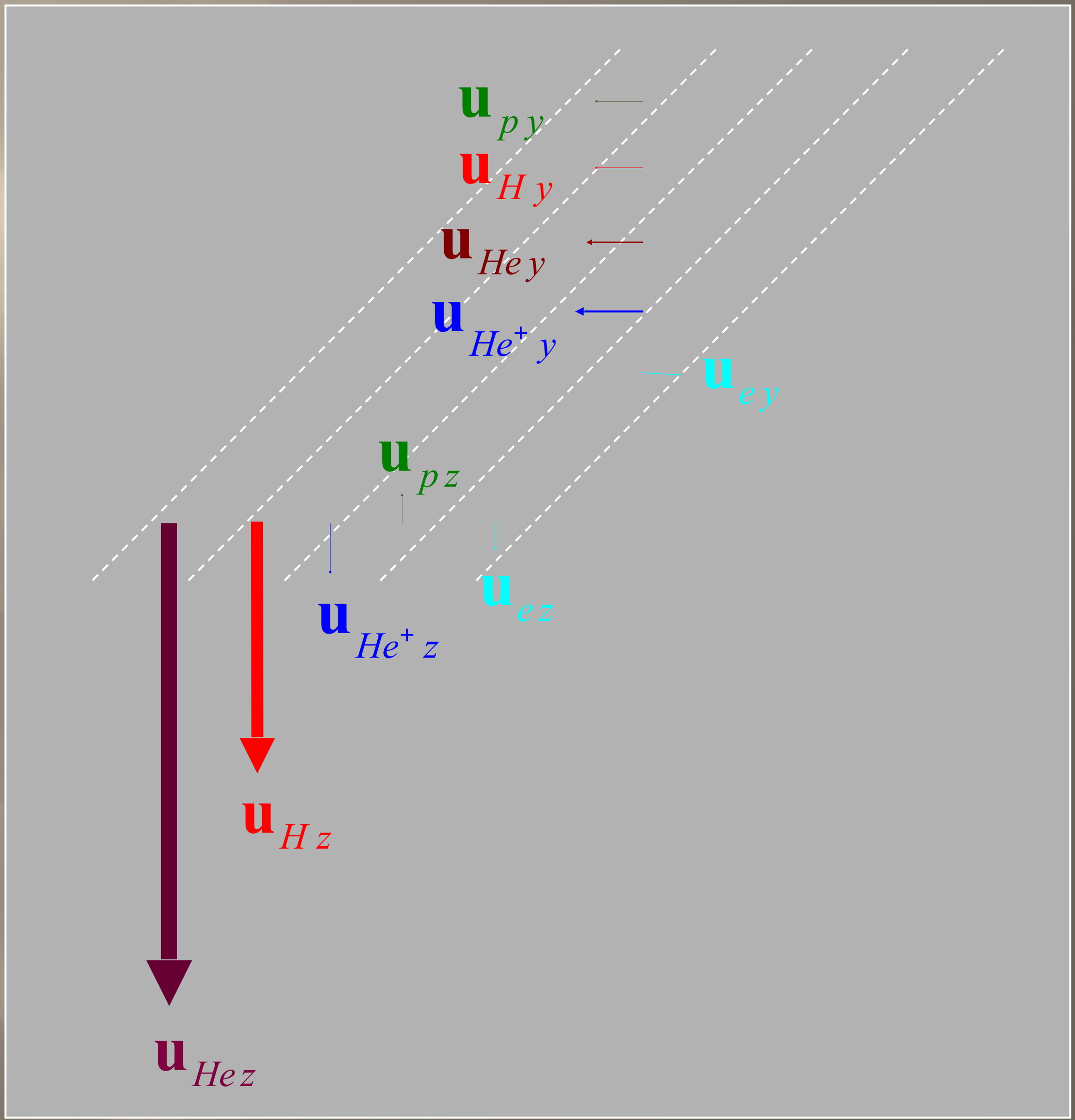
$\mathbf{B} = B\hat{\mathbf{e}}_\mathbf{x}$

$\mathbf{g} = -\hat{\mathbf{e}}_\mathbf{z} GM/r^2$

$\boldsymbol{\Omega}_j = Z_j\, eB/m_j$

Perpendicular Flow in a H-He Prominence Plasma

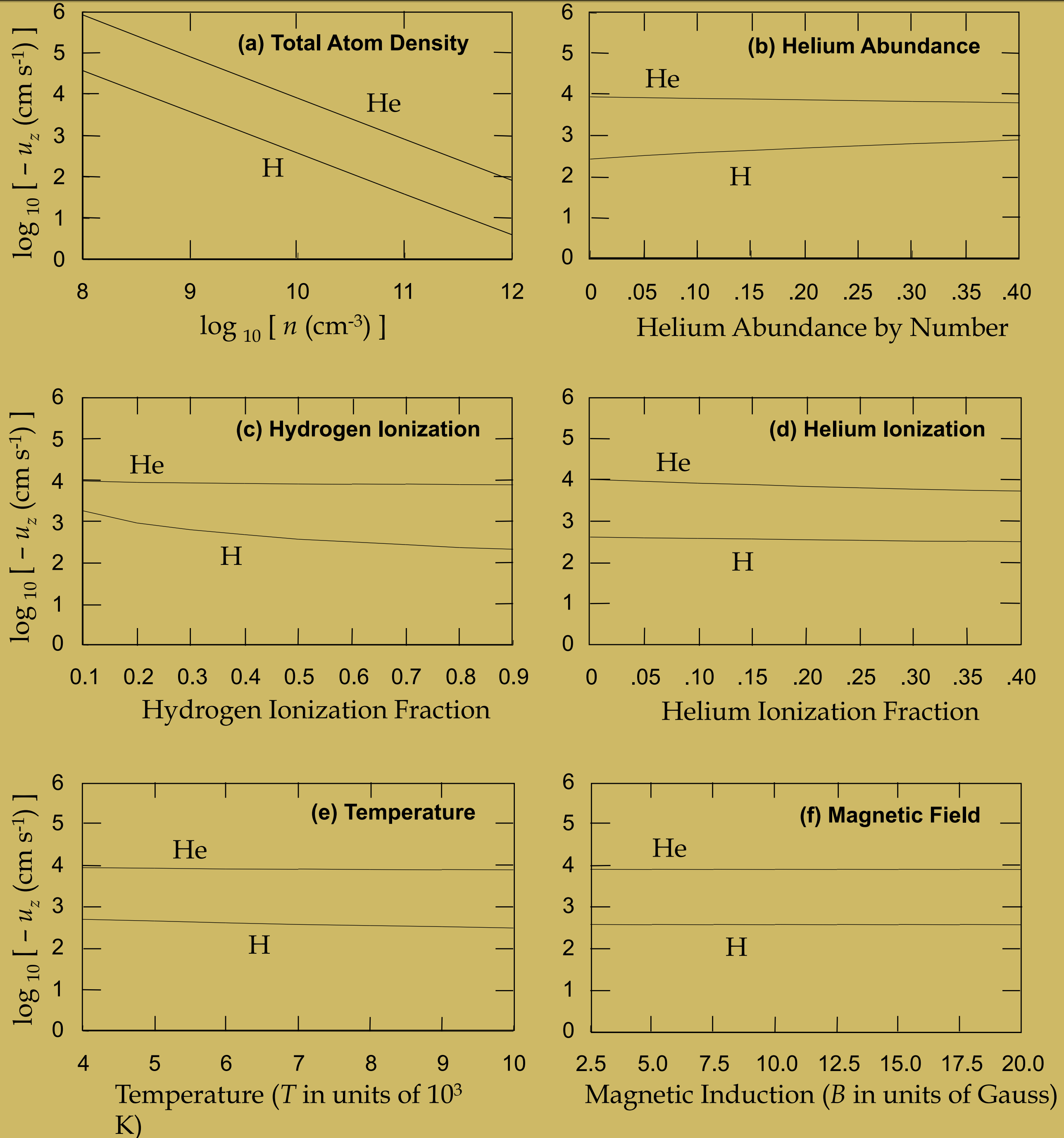




Parameter Study

Considered dependence of particle velocities on variation of several parameters (reference values in parentheses):

- Total atom density (10^{10} cm^{-3})
- Helium abundance by number (0.1)
- H and He ionization fractions (0.5 and 0.1)
- Temperature (7×10^{3} K)
- Magnetic field (10 G)


(a) Total Atom Density
He
H
log 10 [– u_z (cm s^{-1})]
log 10 [n (cm^{-3})]
(b) Helium Abundance
Helium Abundance by Number
(c) Hydrogen Ionization
Hydrogen Ionization Fraction
(d) Helium Ionization
Helium Ionization Fraction
(e) Temperature
Temperature (T in units of 10^3 K)
(f) Magnetic Field
Magnetic Induction (B in units of Gauss)

Time Scales for Neutral Atom Loss

(h_{prom} = vertical prominence dimension)

General Relations

$$\tau_{He} \approx h_{prom} / |u_{He}|$$

$$\tau_{H} \approx h_{prom} / |u_{H}|$$

$$|u_{He}| \approx 10^4 \left[\frac{10^{10}\,\mathrm{cm}^{-3}}{n\left(\mathrm{cm}^{-3}\right)}\right] \mathrm{cm\ s}^{-1}$$

$$|u_{H}| \approx 5\times10^2 \left[\frac{10^{10}\,\mathrm{cm}^{-3}}{n\left(\mathrm{cm}^{-3}\right)}\right] \mathrm{cm\ s}^{-1}$$

Loss Times for Helium and Hydrogen

Helium:

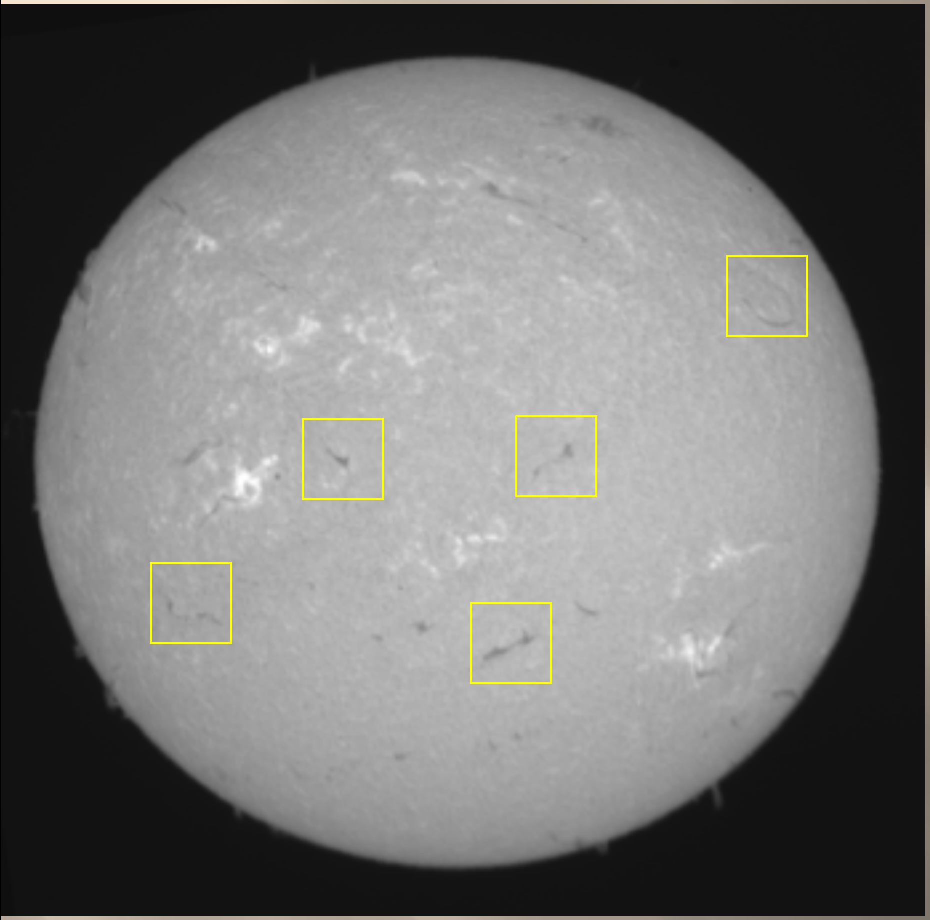
$$\tau_{He} \approx 24 \left[\frac{h_{prom}\left(\mathrm{R_{sun}}\right)}{0.01\ \mathrm{R_{sun}}}\right]\left[\frac{n\left(\mathrm{cm}^{-3}\right)}{10^{10}\,\mathrm{cm}^{-3}}\right] \text{hours}$$

= 1 day

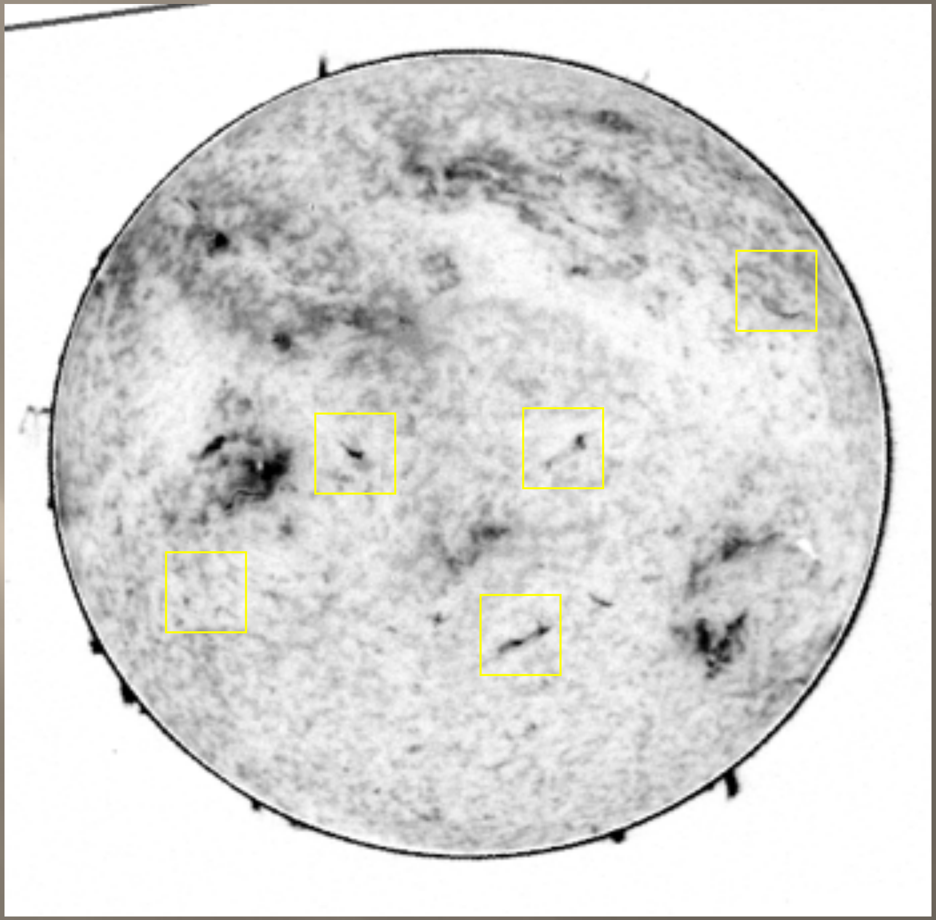
Hydrogen:

$$\tau_{H} \approx 520 \left[\frac{h_{prom}\left(\mathrm{R_{sun}}\right)}{0.01\ \mathrm{R_{sun}}}\right]\left[\frac{n\left(\mathrm{cm}^{-3}\right)}{10^{10}\,\mathrm{cm}^{-3}}\right] \text{hours}$$

~ 22 days



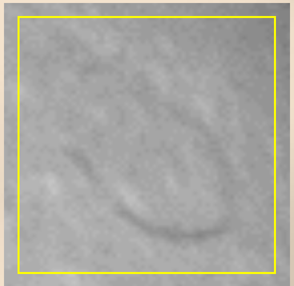
Hα (λ=656 nm)
January 30, 2000, 20:11:22 UT



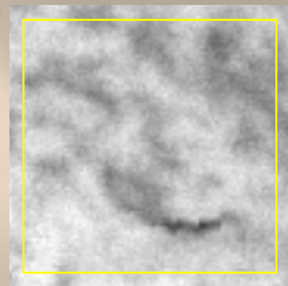
He I (λ=1083 nm)
January 30, 2000, 20:10:15 UT

Both Images from the HAO Mauna Loa Solar Observatory

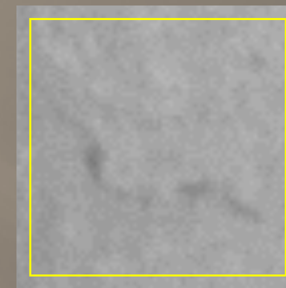
Initial Comparison of H and He Observations



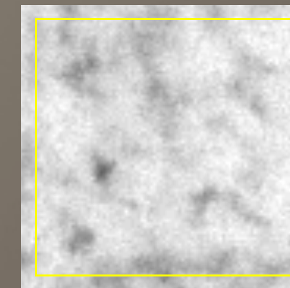
$H\alpha$ (λ=656 nm)



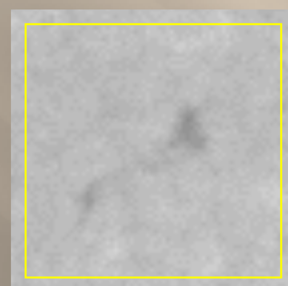
He I (λ=1083 nm)



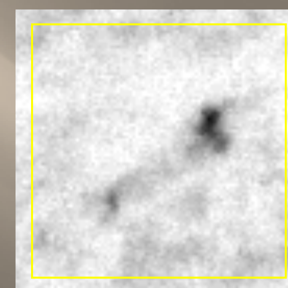
$H\alpha$ (λ=656 nm)



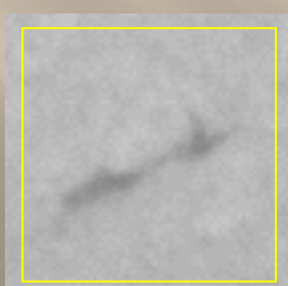
He I (λ=1083 nm)



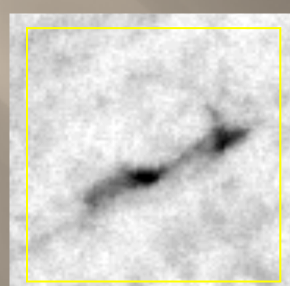
$H\alpha$ (λ=656 nm)



He I (λ=1083 nm)

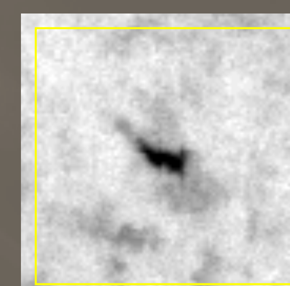


$H\alpha$ (λ=656 nm)

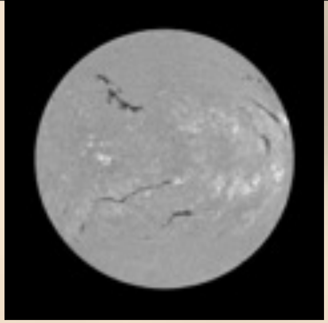


He I (λ=1083 nm)

$H\alpha$ (λ=656 nm)

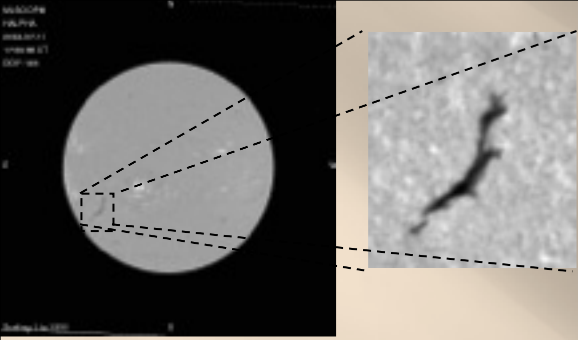


He I (λ=1083 nm)



Quantitative Analysis

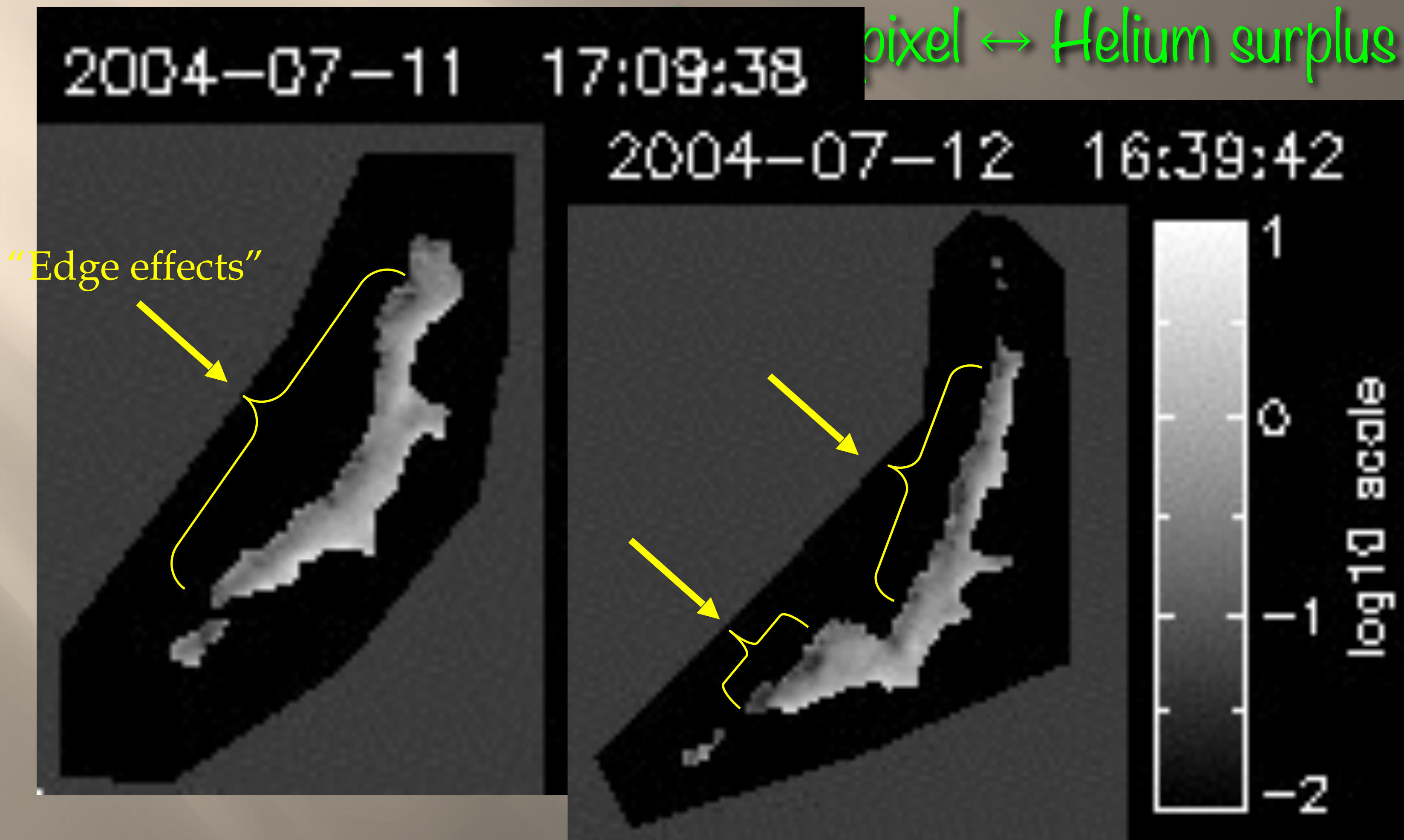
- Study temporal and spatial Changes in the relative H and He in filaments via the absorption and He I / Hα absorption ratio
  - Chose large/stable and small/stable filaments that could be followed across the solar disk
- Used co-temporal Hα (6563 Å) and He I (10830 Å) images from the Mauna Loa Solar Observatory in 2004
- Kilper (Master's thesis) Developed an IDL code that scales and aligns each pair of images, selects the filament, and calculates the absorption ratio at every pixel

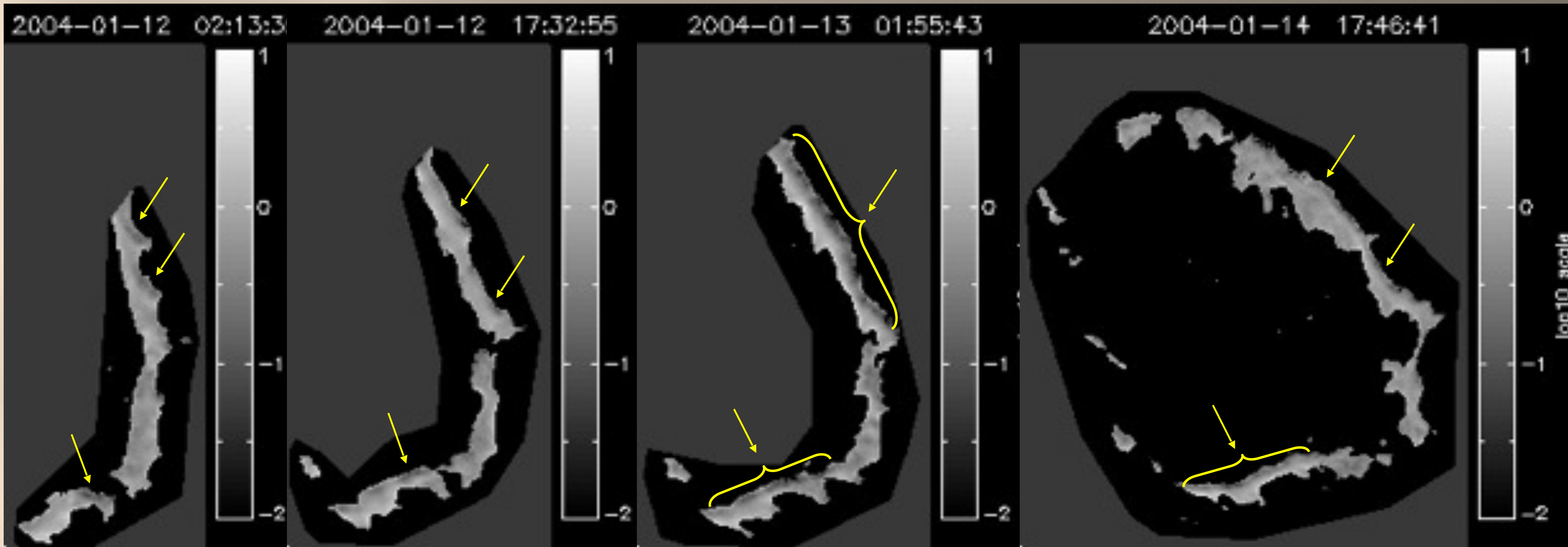


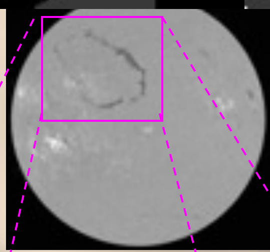
He/H absorption

Darker pixel ↔ Helium deficit

pixel ↔ Helium surplus

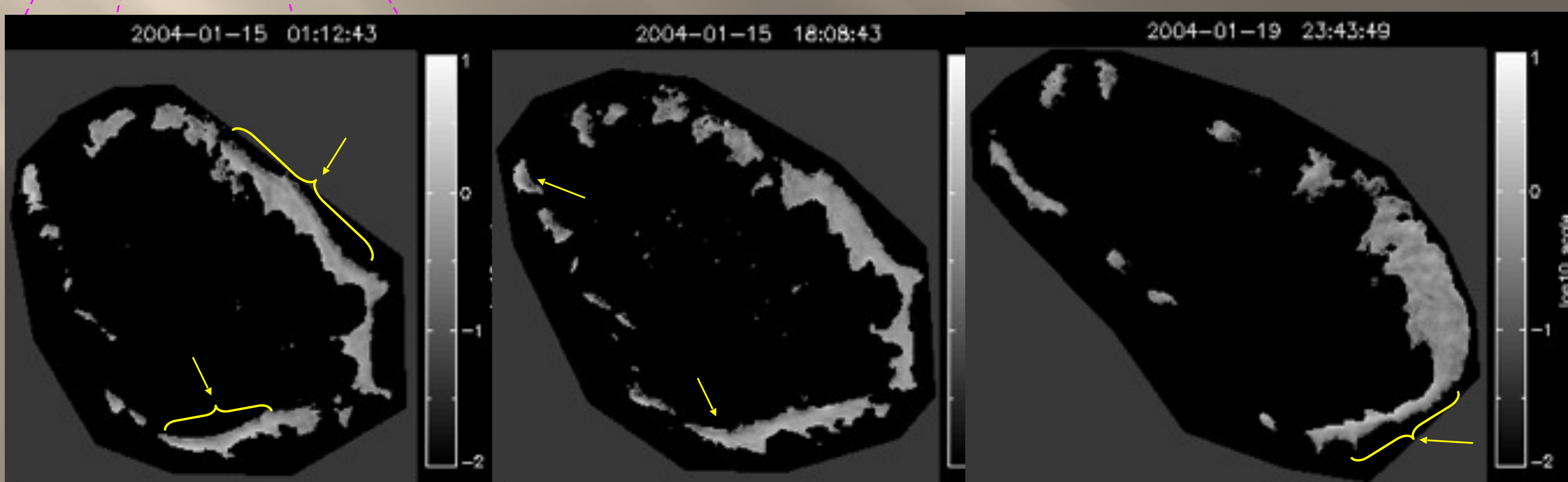




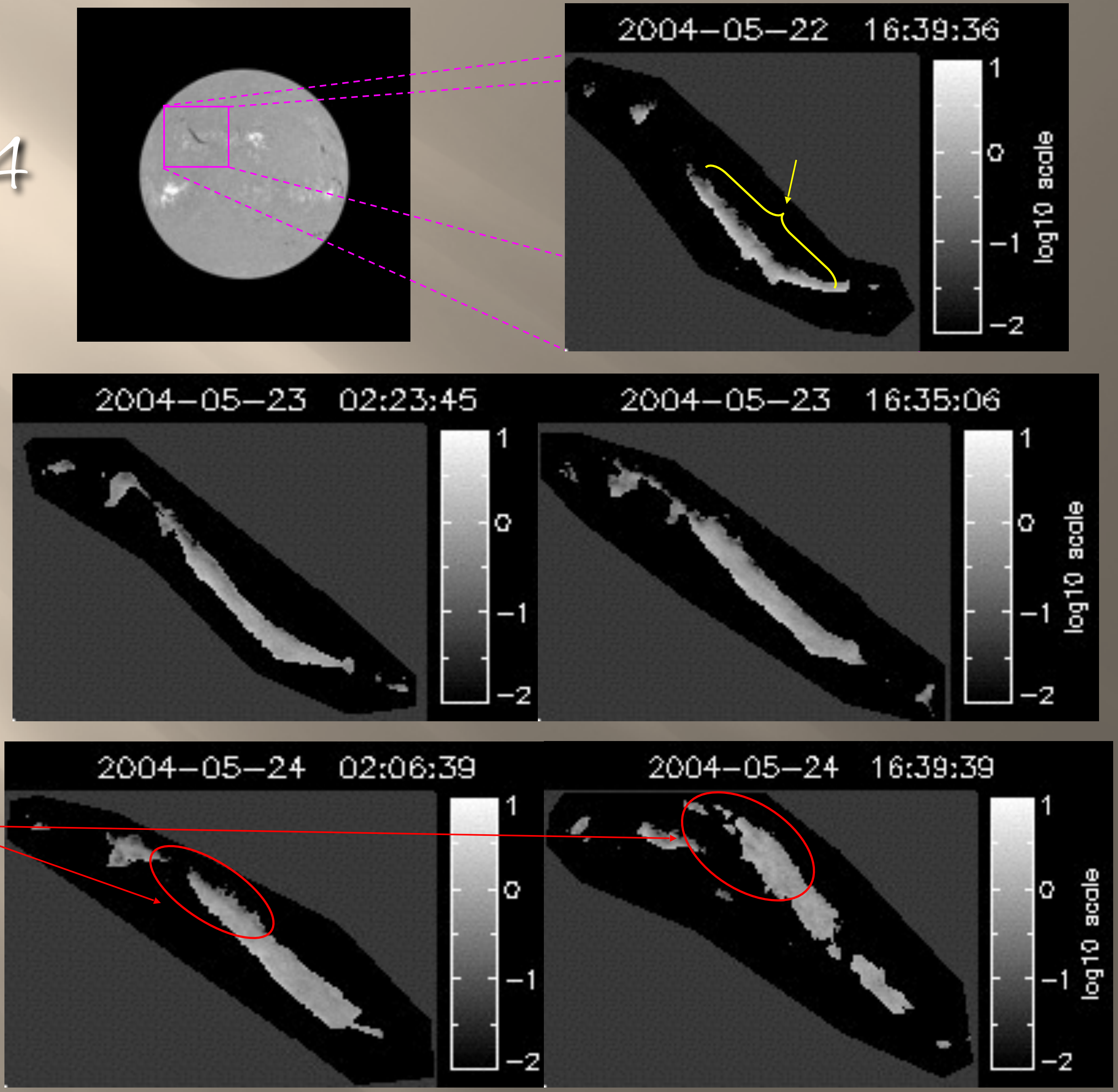


January 2004

“Large & stable”



May 2004



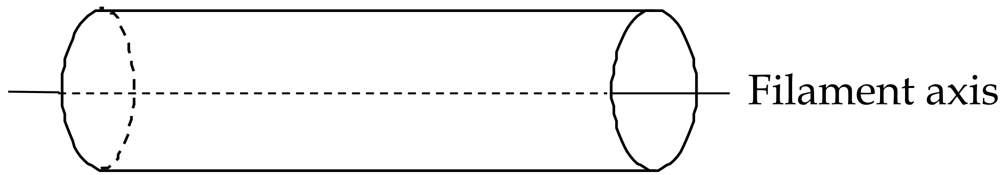
Partial eruption:

Absence of “edge

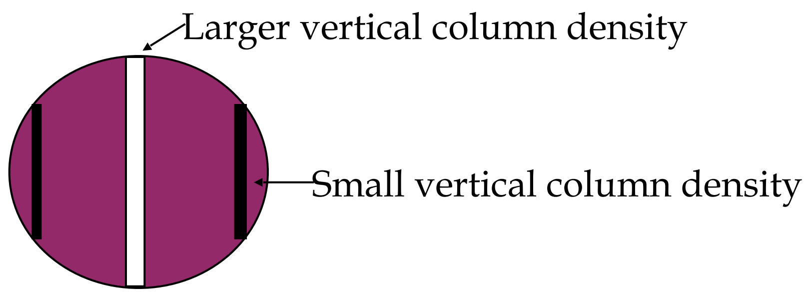
What do we expect??

Geometrical considerations: the simplest picture

Cylindrical representation of a filament



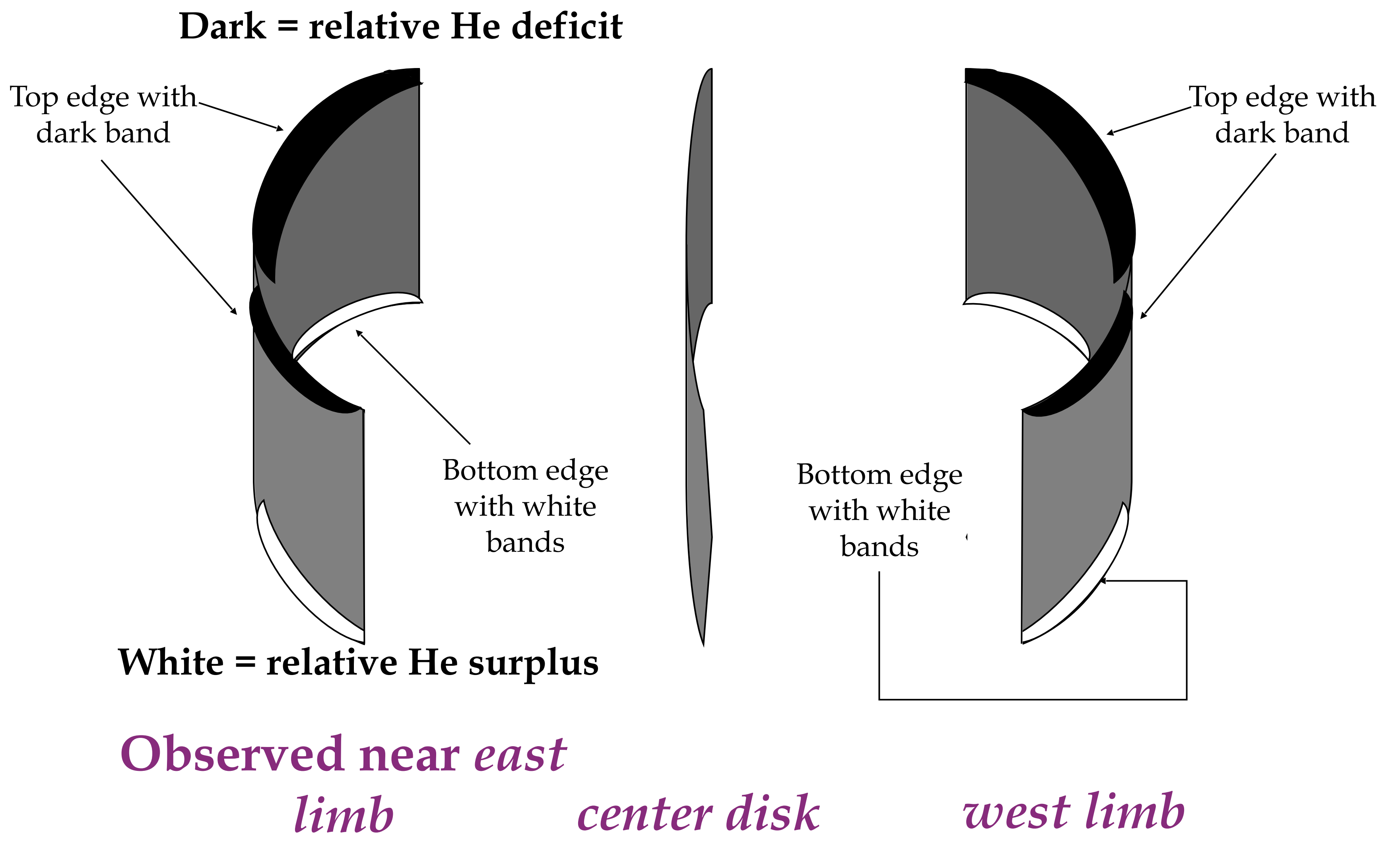
View along filament axis



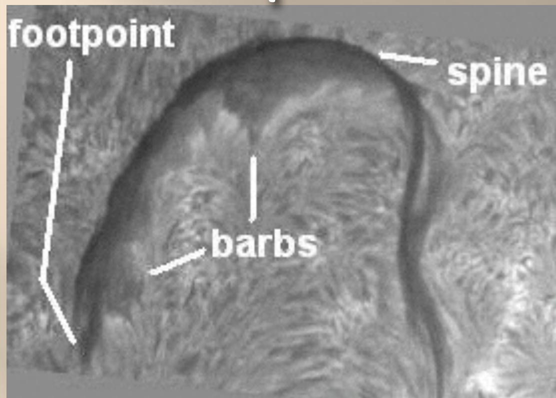
Dark = relative He deficit

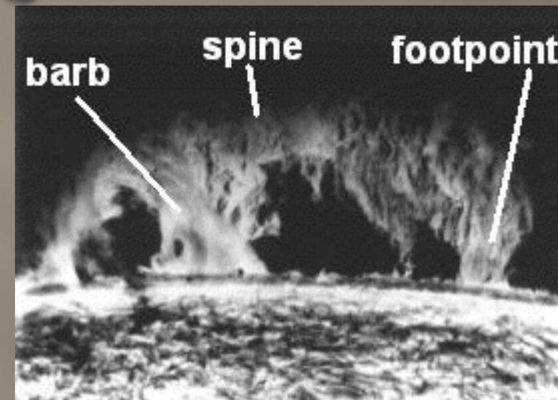
Top view at disk center

Somewhat more realistic geometry



Interpretation of "Edge effects"





- Far from disk center, one edge is at the top, and one at the bottom (where the barbs appear)
- In a relatively stable filament, He drains out of the top rapidly (relative He deficit)
- He draining out of bottom is replaced by He draining down from above (no relative He deficit)

Diffusion timescales In the context of filament threads…..

Coronal plasma can readily ionize neutral material draining into it

$$\tau_{He} \approx 24 \left[\frac{h_{prom}\left(\mathrm{R}_{sun}\right)}{0.01\ \mathrm{R}_{sun}} \right] \left[\frac{n\left(\mathrm{cm}^{-3}\right)}{10^{10}\ \mathrm{cm}^{-3}} \right] \text{ hours}$$

$$\tau_{H} \approx 520 \left[\frac{h_{prom}\left(\mathrm{R}_{sun}\right)}{0.01\ \mathrm{R}_{sun}} \right] \left[\frac{n\left(\mathrm{cm}^{-3}\right)}{10^{10}\ \mathrm{cm}^{-3}} \right] \text{ hours}$$

Expect very short draining timescales (for threads with small vertical neutral atom column density)