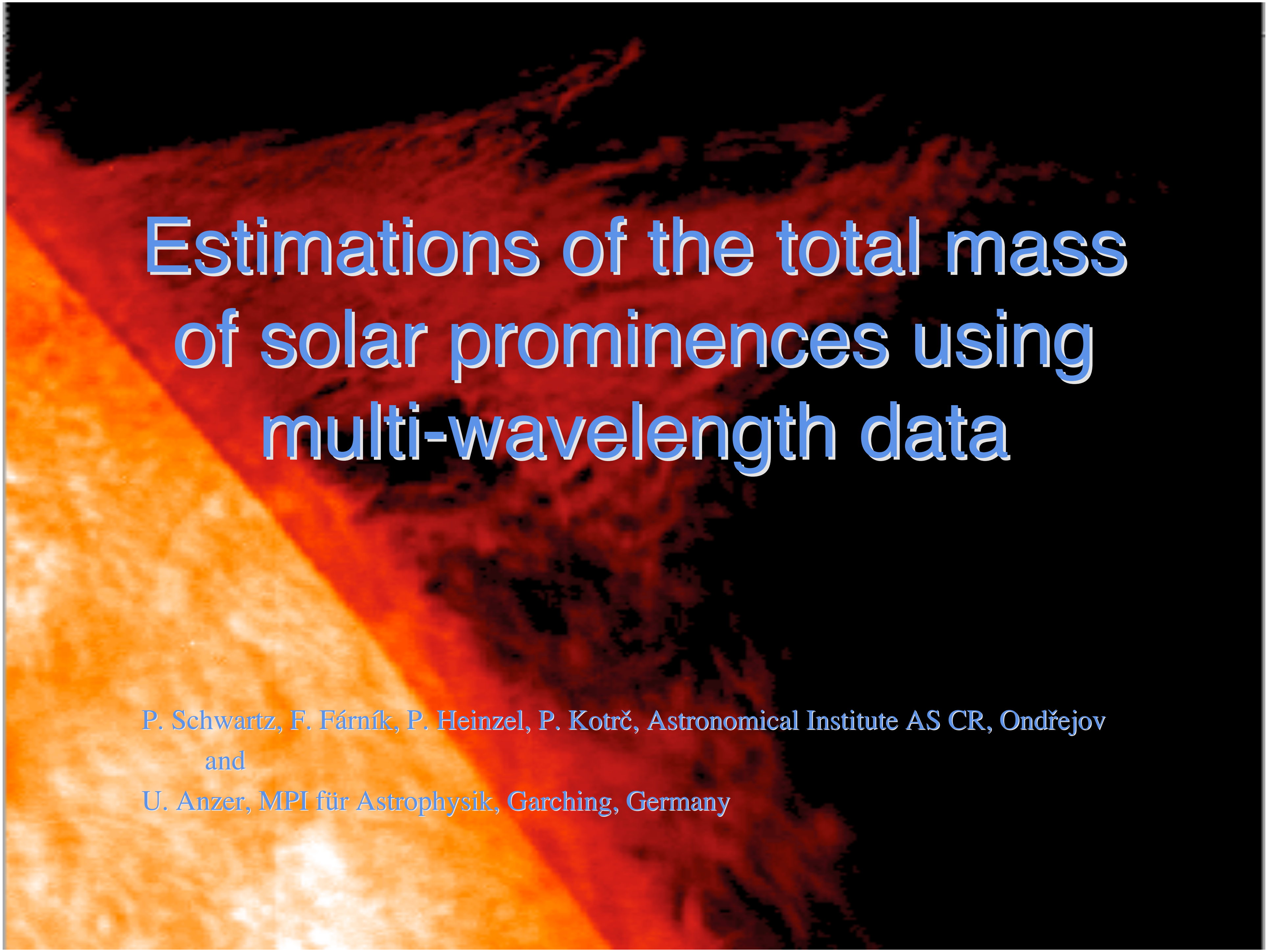


Estimations of the total mass of solar prominences using multi-wavelength data

P. Schwartz, F. Fárník, P. Heinzel, P. Kotrč, Astronomical Institute AS CR, Ondřejov
and
U. Anzer, MPI für Astrophysik, Garching, Germany

Prominence visibility

- in emission:

  chromospheric lines (Balmer lines - esp. Hα, He lines -
  e.g. HeI 584 Å, HeII 304 Å, Ca lines, H Lyman lines)
  many TR lines formed in PCTR (e.g. OV 629 Å)

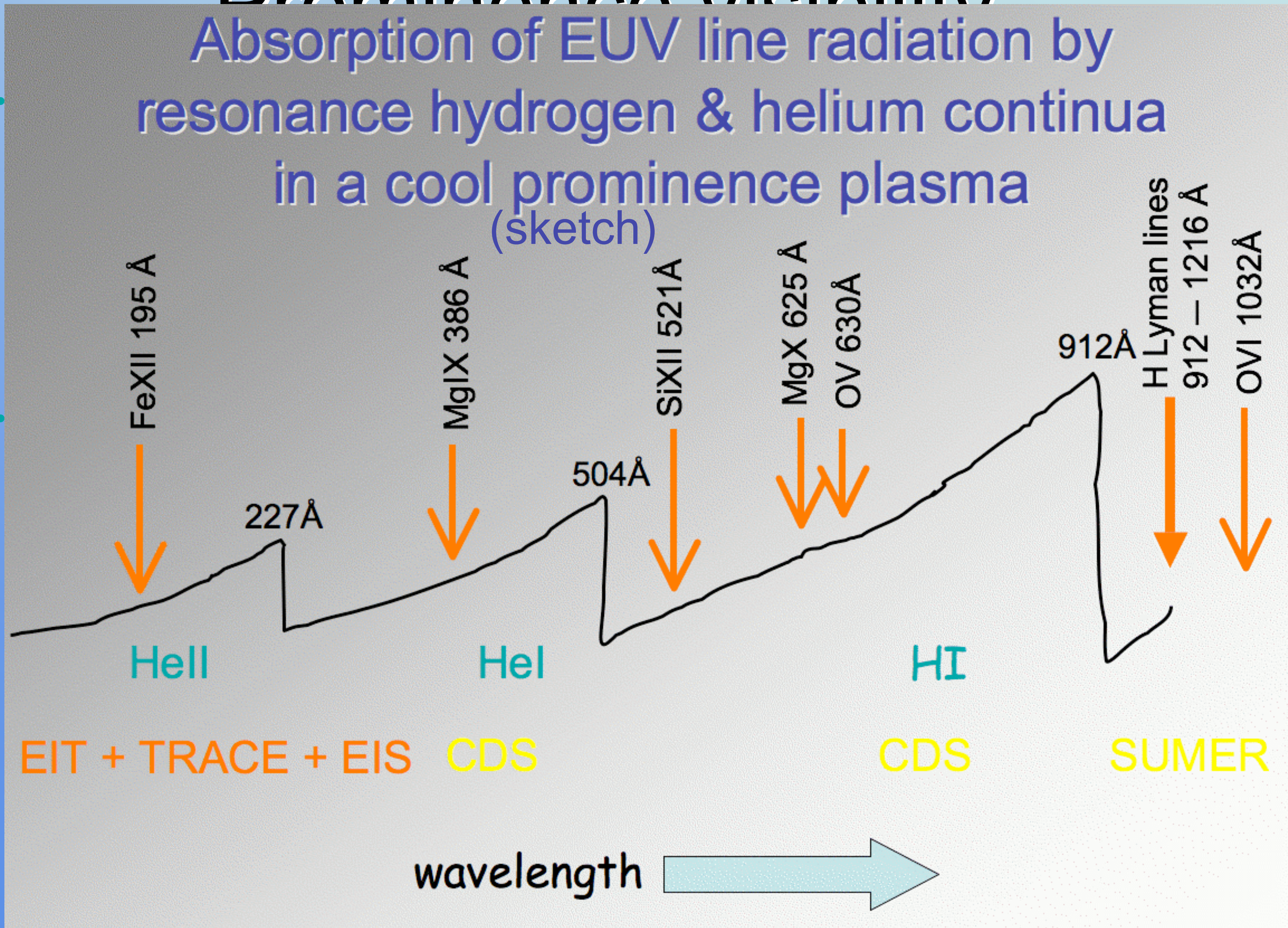
  mechanism: scattering

- as dark structure in:

  coronal EUV lines, e.g. MgX 625 Å, MgIX 368 Å,
  FeXII 195 Å, FeIX 171 Å

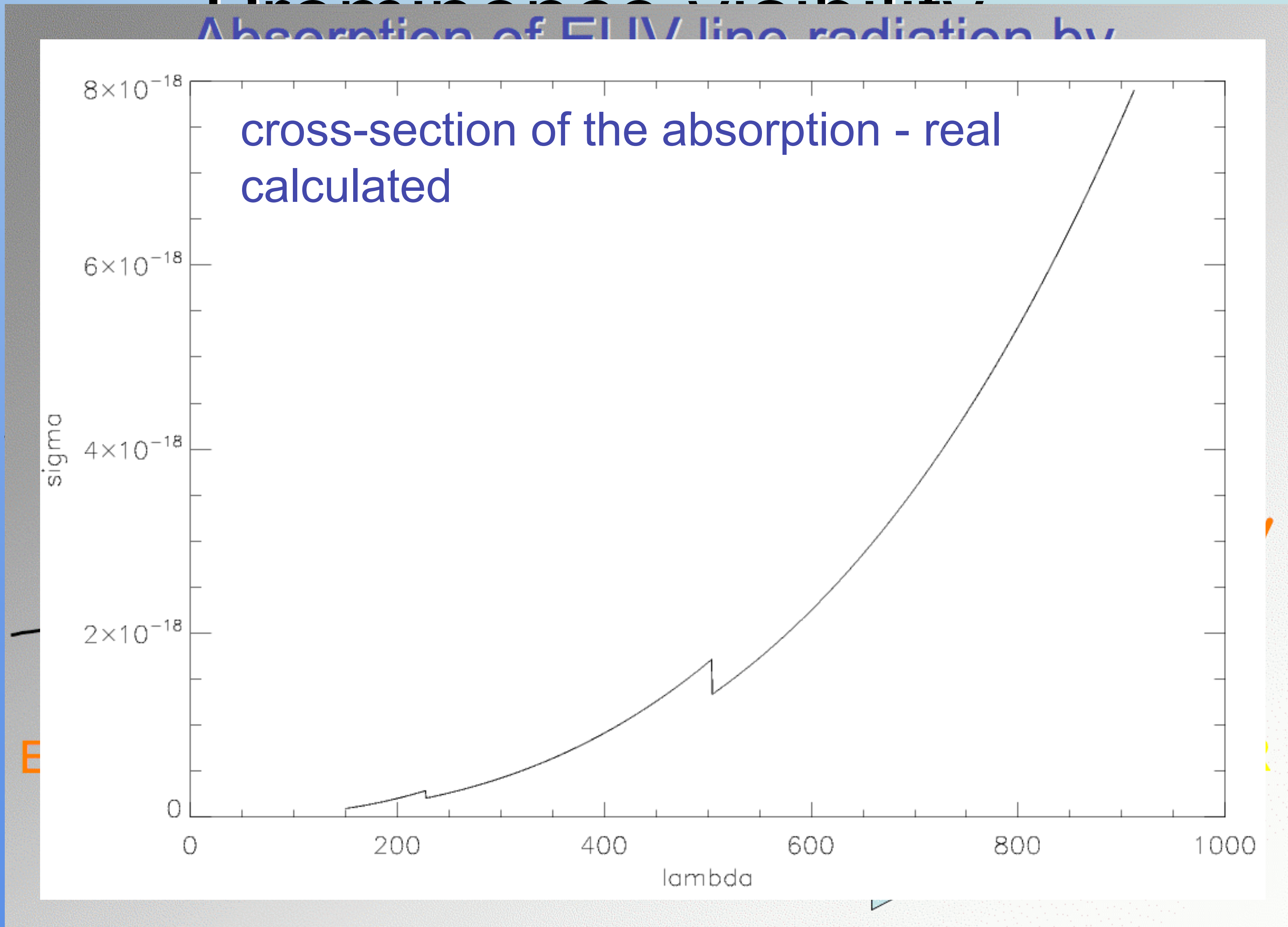
  mechanisms: absorption by cool material of the prominence
  (Daw et al. 1995; Kucera et al. 1998)
  by resonance continua of HI, HeI and HeII
  (Anzer & Heinzel, 2005)
  coronal emissivity blocking
  (Kucera et 1998, Schmieder 1999, Anzer & Heinzel, 2005)

Prominence visibility



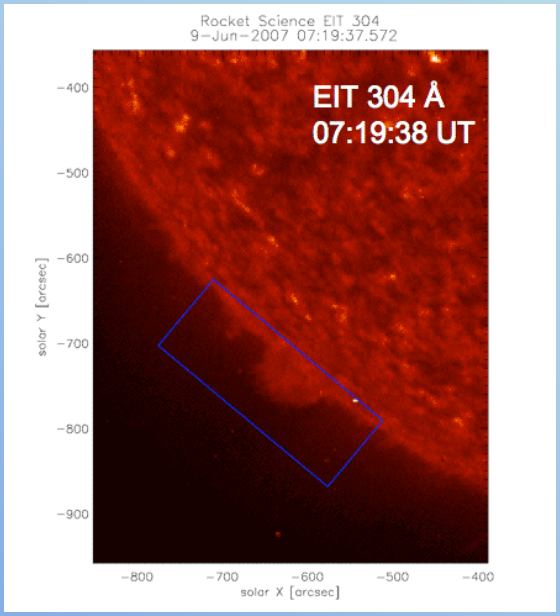
Prominence visibility

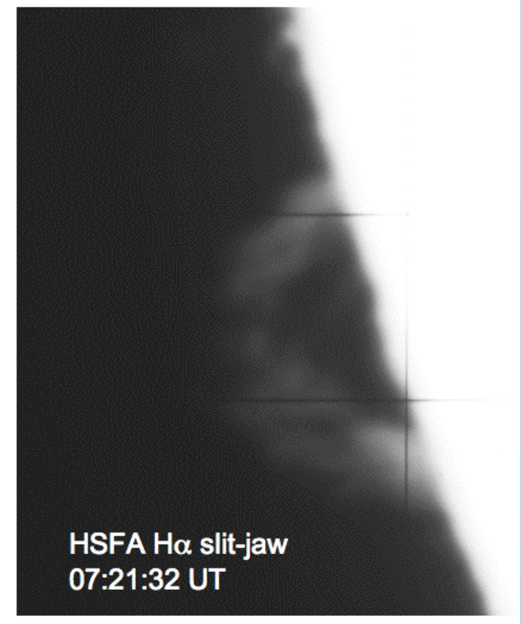
Absorption of EUV line radiation by



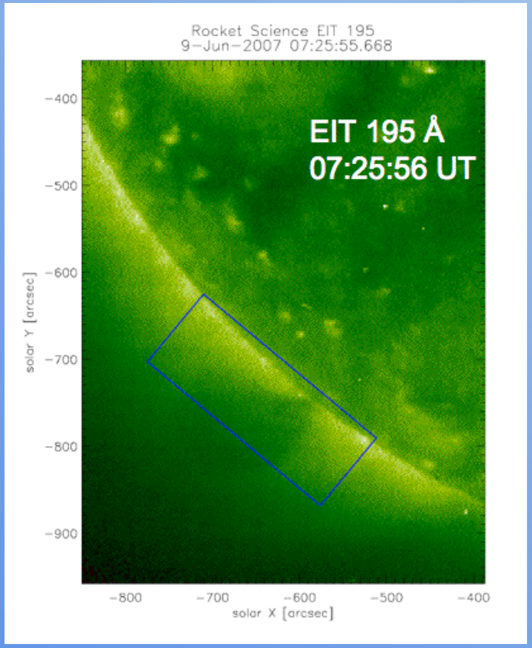
Prominence seen in emission and absorption

in emission:





in absorption:



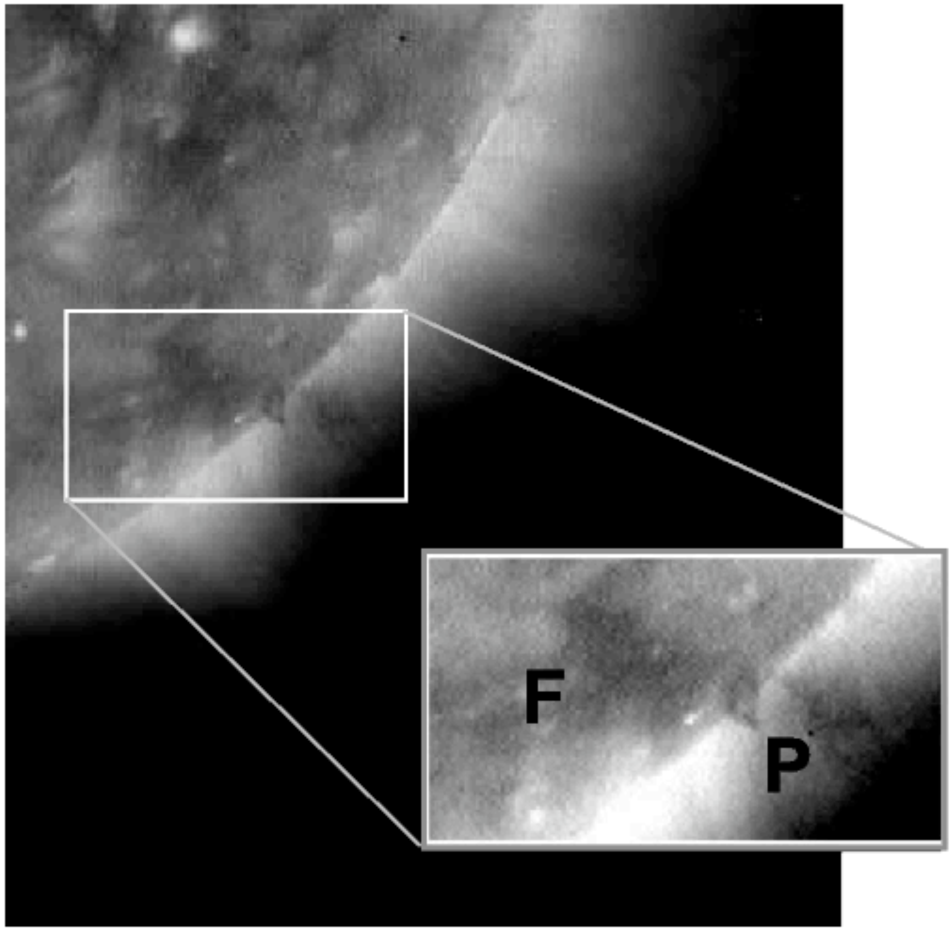


FIG. 1.—Example of dark EUV structures as observed by *SOHO*/EIT at a wavelength of 195 Å on 1997 July 4 at 07:12:30 UT. In this case a filament F is crossing the solar limb, and part of it is seen as a prominence P above the limb. Note also the iron-line corona at 195 Å with its radially decreasing brightness.

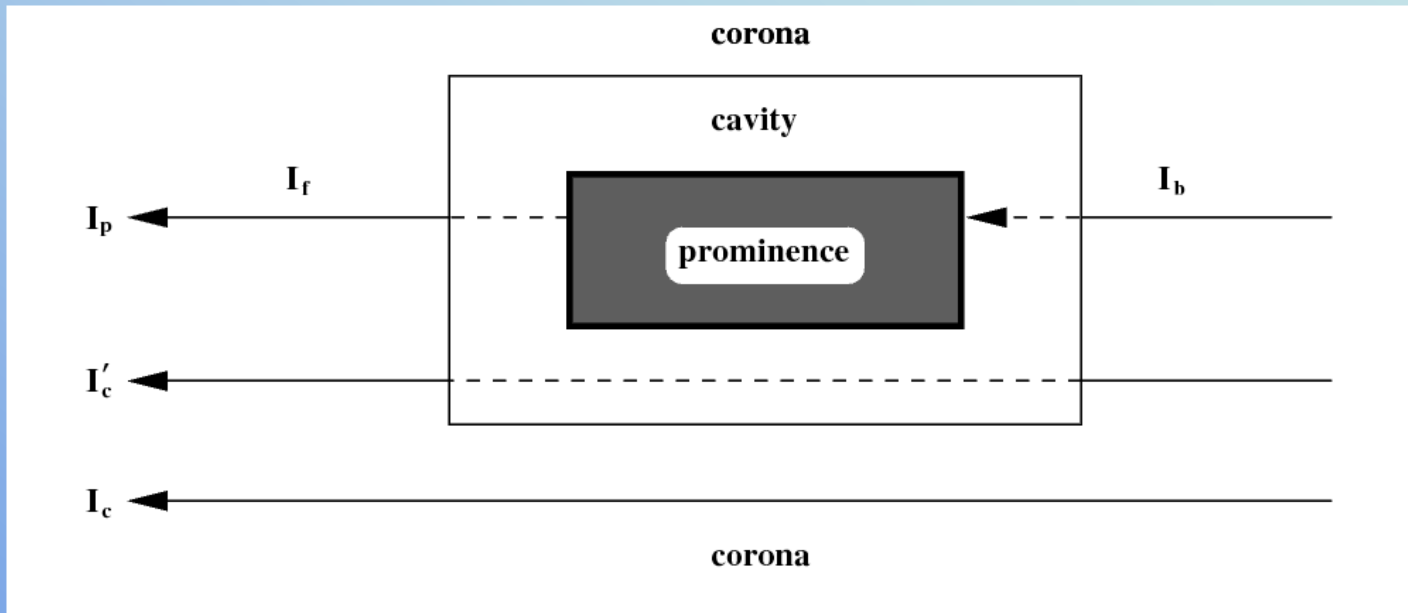
Anzer & Heinzel, 2005

How to distinguish effects of absorption and emissivity blocking?

in X-rays the absorption by a cool prominence plasma is negligible (Anzer et al. 2007)

⇓

multi-wavelength simultaneous observations in EUV lines with wavelengths below 912 Å and in X-rays are suitable for analysis taking into account both absorption and emissivity blocking



symmetrical corona:

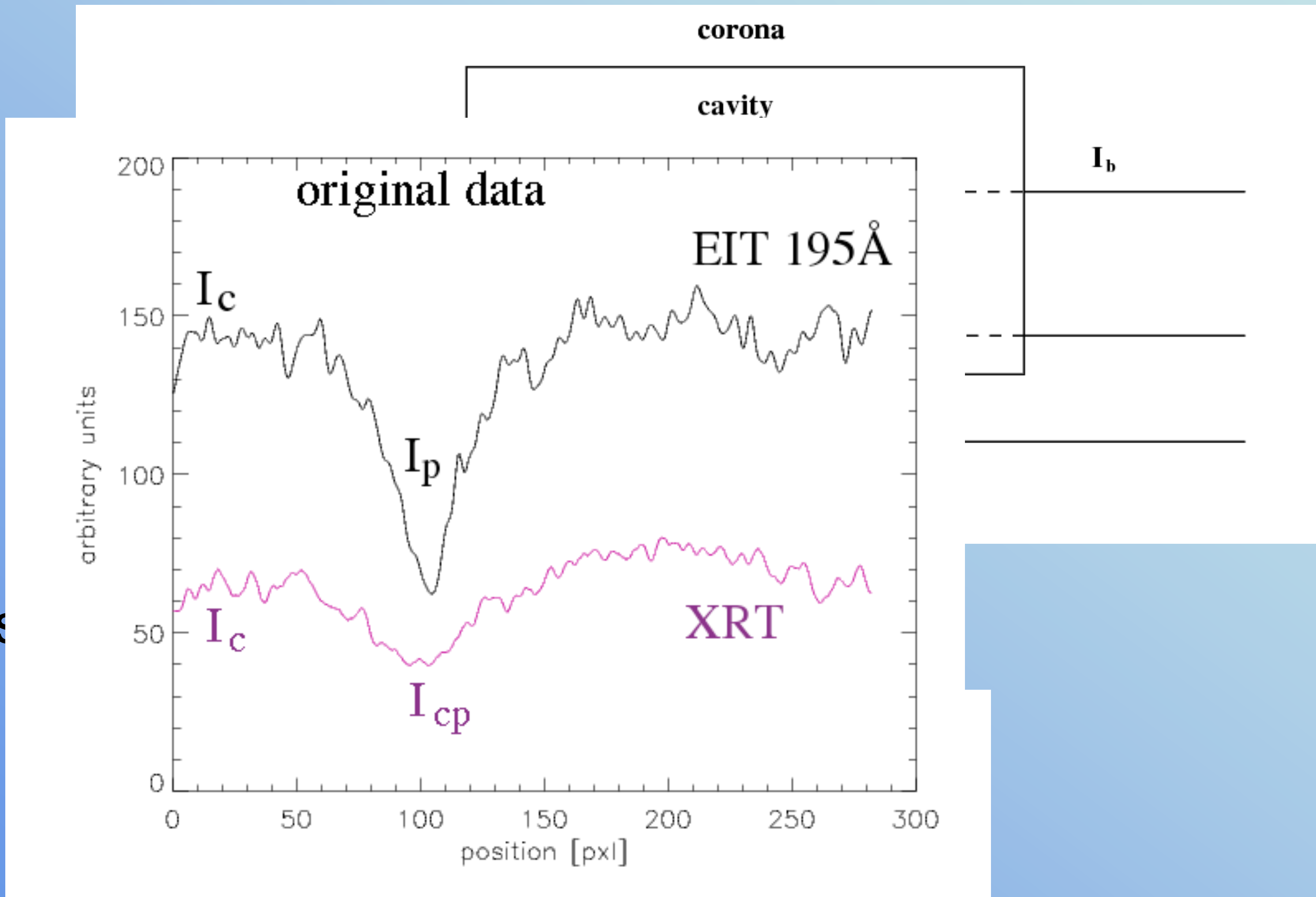
$$r = \frac{1}{2}\left(1 + \mathrm{e}^{-\tau}\right) r_\mathrm{b}$$

$$r = \frac{I_\mathrm{p}^{195\,\text{Å}}}{I_\mathrm{c}^{195\,\text{Å}}} = \frac{1}{2}\left(1 + \mathrm{e}^{-\tau}\right) \frac{I_\mathrm{cp}^{\mathrm{XRT}}}{I_\mathrm{c}^{\mathrm{XRT}}}$$

$$r' = \frac{I_\mathrm{p}}{I_\mathrm{cp}} = \frac{1}{2}\left(1 + \mathrm{e}^{-\tau}\right)$$

$$\tau = -\ln\left(2\,r' - 1\right)$$

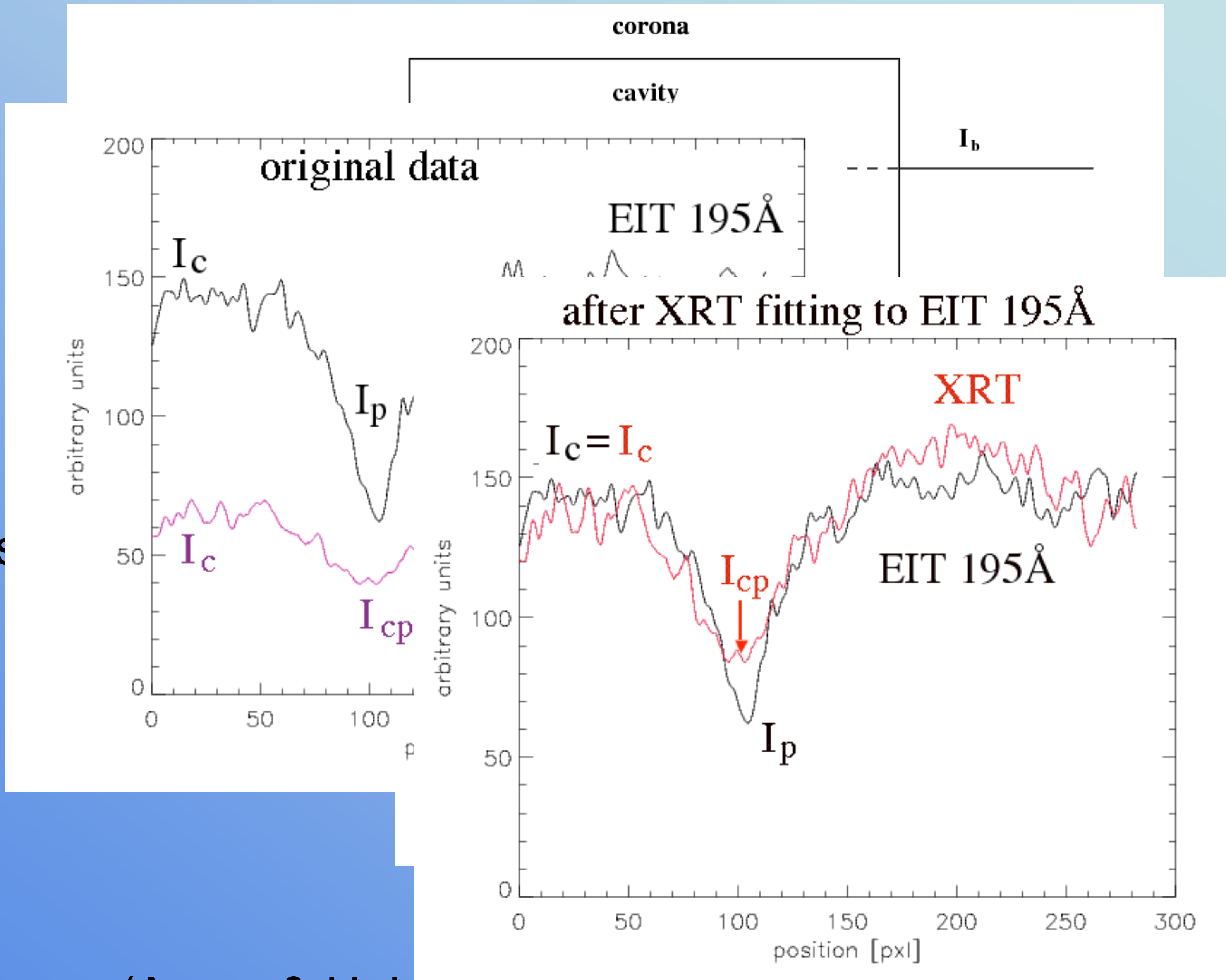
(Anzer & Heinzel 2005; Heinzel et al 2008)



$$r' = \frac{I_p}{I_{cp}} = \frac{1}{2}\left(1 + e^{-\tau}\right)$$

$$\tau = -\ln\left(2\,r' - 1\right)$$

(Anzer & Heinzel 2005; Heinzel et al 2008)



(Anzer & Heinzel 2005; Heinzel et al 2008)

EIT observations:

FeXII 195 Å channel .... sensitive to temperatures $\log(T) \approx 6.2$

FeIX 171 Å channel ..... sensitive to temperatures $\log(T) \approx 6.1$

Hinode/XRT X-ray observations:

sensitive to range of temperatures log(T) 6.1 – 7.5

asymmetrical corona:

$$I_b = \alpha\, I_{cp} \qquad I_f = (1-\alpha)\, I_{cp}$$

$$I_{\rm p} = I_{\rm f} + I_{\rm b}\, {\rm e}^{-\tau} \qquad I_{\rm cp} = I_{\rm f} + I_{\rm b}$$

$$r' = \frac{I_{\rm p}}{I_{\rm cp}}$$

$$\tau = -\ln\left(\frac{r'}{\alpha} - \beta\right)$$

$$\beta = (1-\alpha)/\alpha$$

Estimation of a parameter of the asymmetrical distribution of coronal emissivity

for $\lambda \leq 227\,\text{Å}$ (Anzer&Heinzel 2005):

$$\tau_\lambda = N(\mathrm{H})\left\{(1-i)\,\sigma_{\mathrm{H}}(\lambda) + r_{\mathrm{He}}\left[(1-j_1-j_2)\,\sigma_{\mathrm{HeI}}(\lambda) + j_1\,\sigma_{\mathrm{HeII}}(\lambda)\right]\right\}$$

where helium abundance in solar atmosphere: $r_{\mathrm{He}} = 0.1$

$\sigma_{\mathrm{H}}(\lambda)$, $\sigma_{\mathrm{HeI}}(\lambda)$, $\sigma_{\mathrm{HeII}}(\lambda)$ – cross-sections of absorption by resonance continua of H, HeI and HeII

i, j_1, j_2 – ionization degrees of H, HeI and HeII, respectivelly.

Then α parameter is estimated from a comparison of ratio τ_{195} / τ_{171} obtained from observations with a theoretical one $\tau_{195} / \tau_{171} \approx 1.4$

Prominence mass

for $\lambda \leq 227\,\text{Å}$:

$$\tau_\lambda = N(\mathrm{H})\,\{(1-i)\,\sigma_{\mathrm{H}}(\lambda) + r_{\mathrm{He}}\,[(1-j_1-j_2)\,\sigma_{\mathrm{HeI}}(\lambda) + j_1\,\sigma_{\mathrm{HeII}}(\lambda)]\}$$

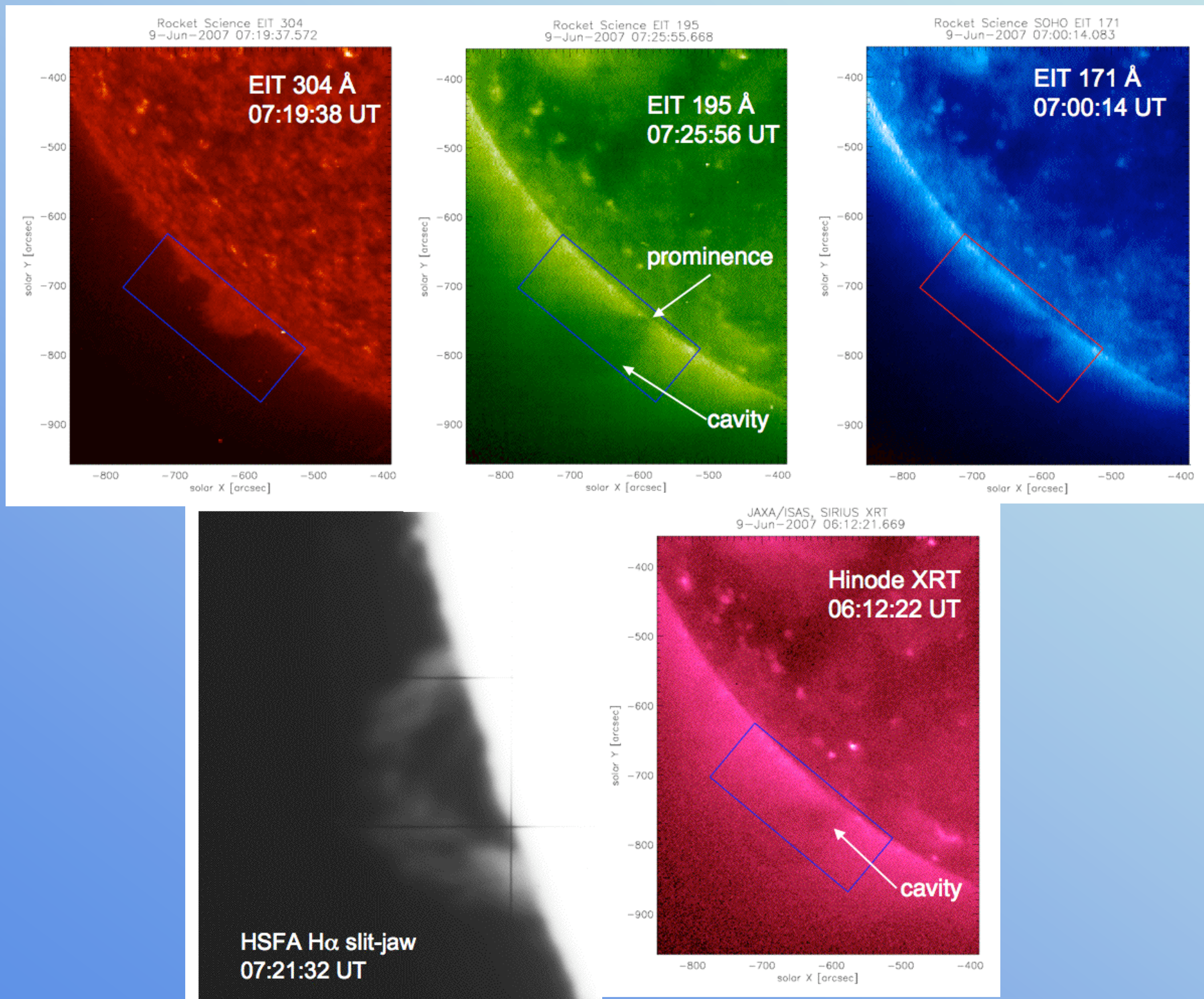
hydrogen column density:

$$N(\mathrm{H}) = \frac{\tau_{195}}{(1-i)\,\sigma_{\mathrm{H}}(195\,\text{Å}) + r_{\mathrm{He}}\left[(1-j_1-j_2)\,\sigma_{\mathrm{HeI}}(195\,\text{Å}) + j_1\,\sigma_{\mathrm{HeII}}(195\,\text{Å})\right]}$$

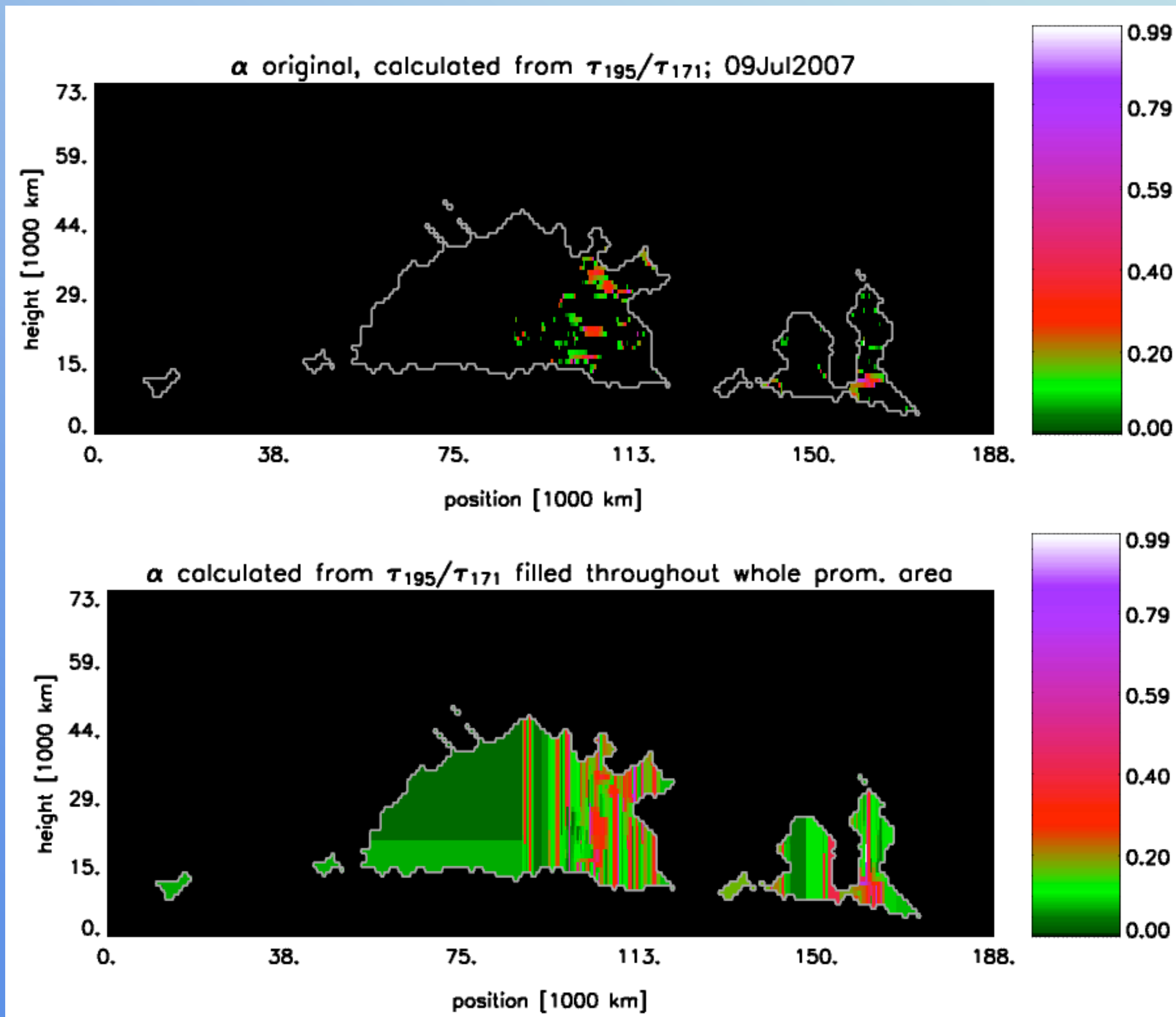
column mass: $m = N(\mathrm{H})\;(m_{\mathrm{H}} + r_{\mathrm{He}}\,m_{\mathrm{He}})$

The total prominence mass: $M = \int_{\mathrm{PA}} m\,dS$, where PA is a prominence area.

June 9, 2007 – small, well visible prominence



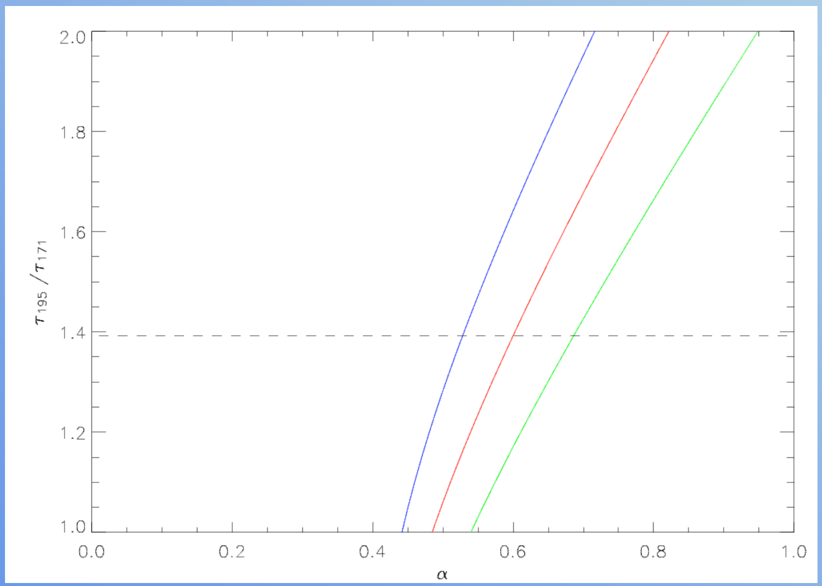
α calculated using ratio τ_{195} / τ_{171} for the prominence observed on June 9, 2007

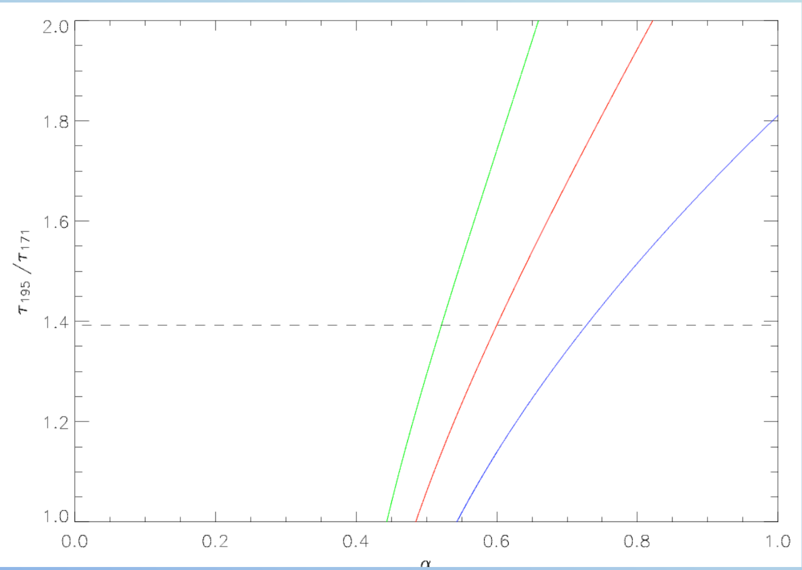


avg α=0.13

Testing the stability of solution for α estimation (the first attempts)

$i = 0.6,\ j_1 = 0.5,\ j_2 = 0,\ r'_{195} = 0.7,\ \alpha = 0.6$

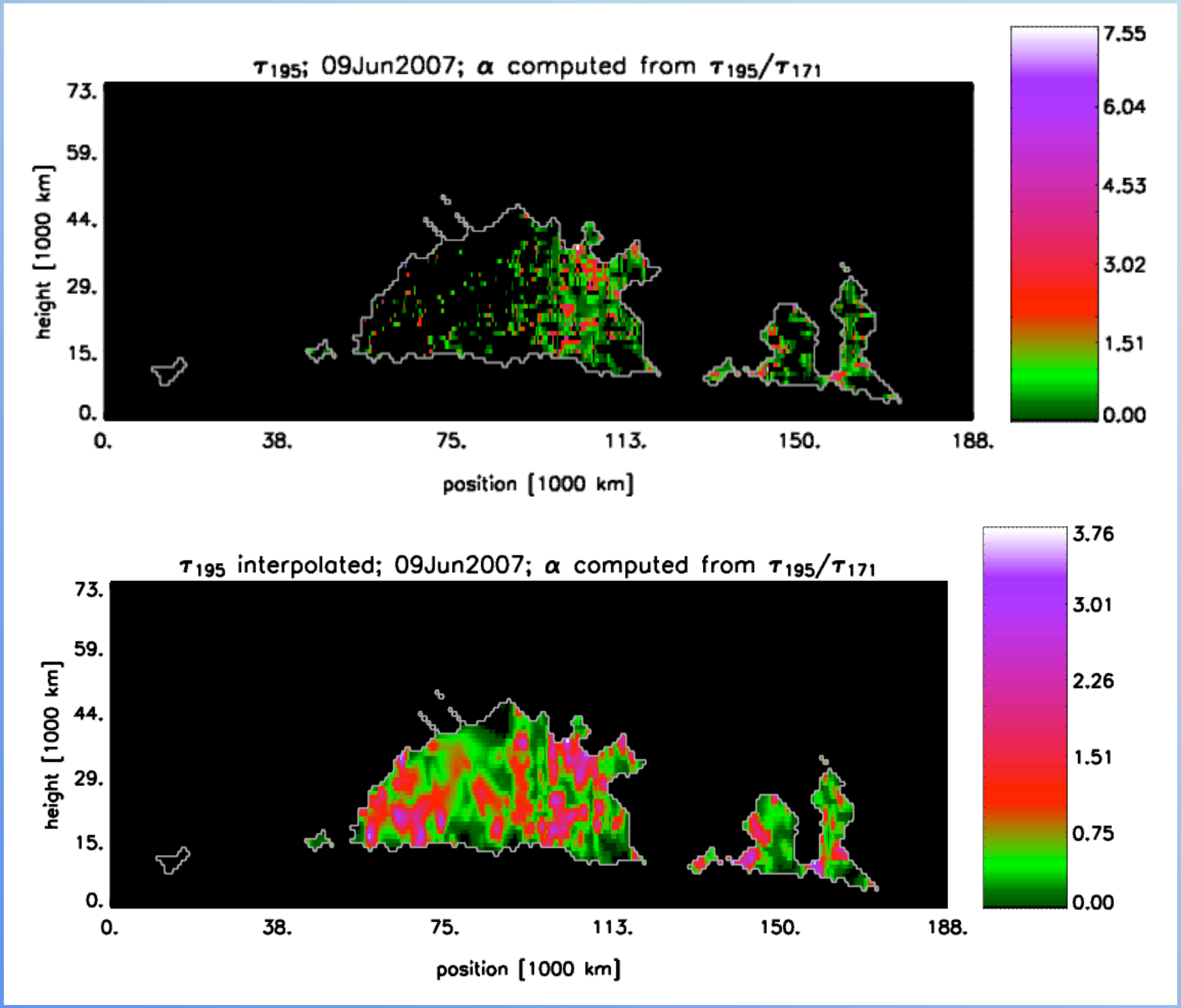




r'_{195}: -5%, 0%, +5%

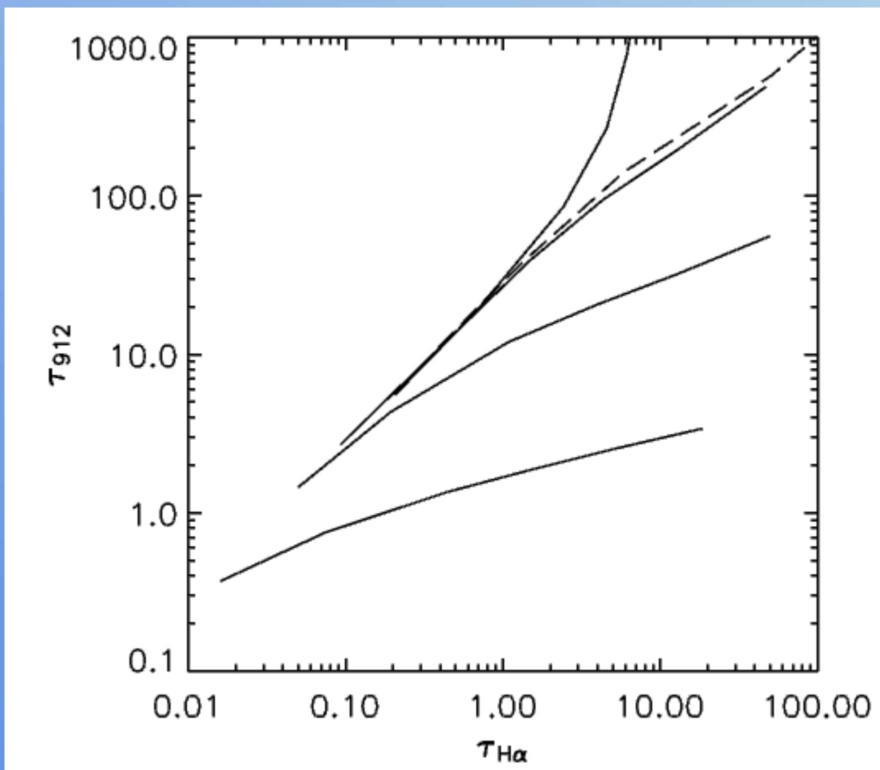
r'_{171}: -5%, 0%, +5%

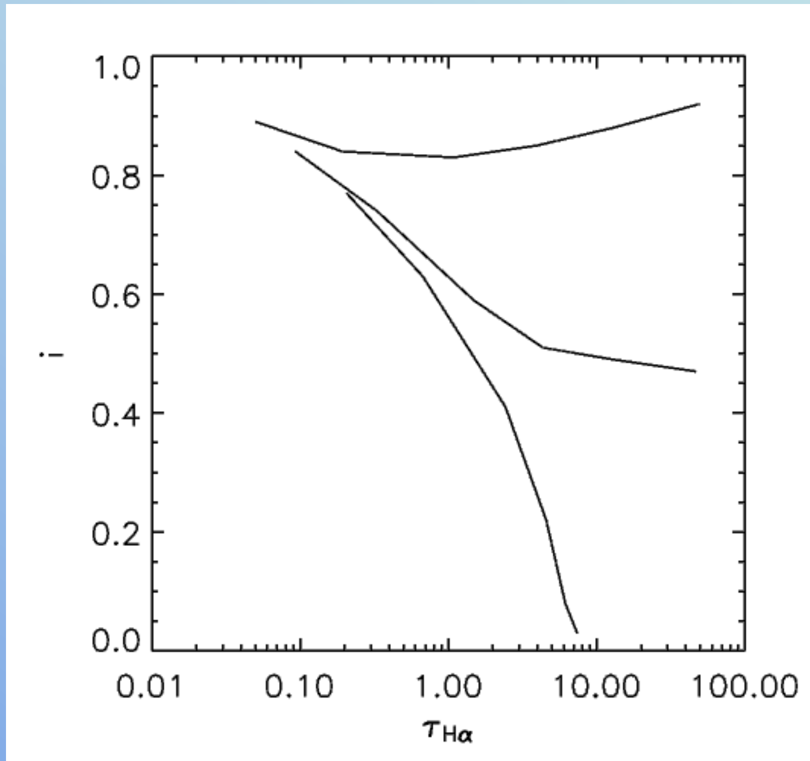
Maps of τ_{195} of prominence observed on June 9, 2007



Optical thickness estimated from the Hα profiles

$\tau_o(H\alpha)$ estimated from deviation of the Hα profiles from the Gaussian





computed using 1D isothermal models with PRD by Anzer & Heinzel (2005)

α estimation from $\tau_o(H\alpha)$ and r'_{195}

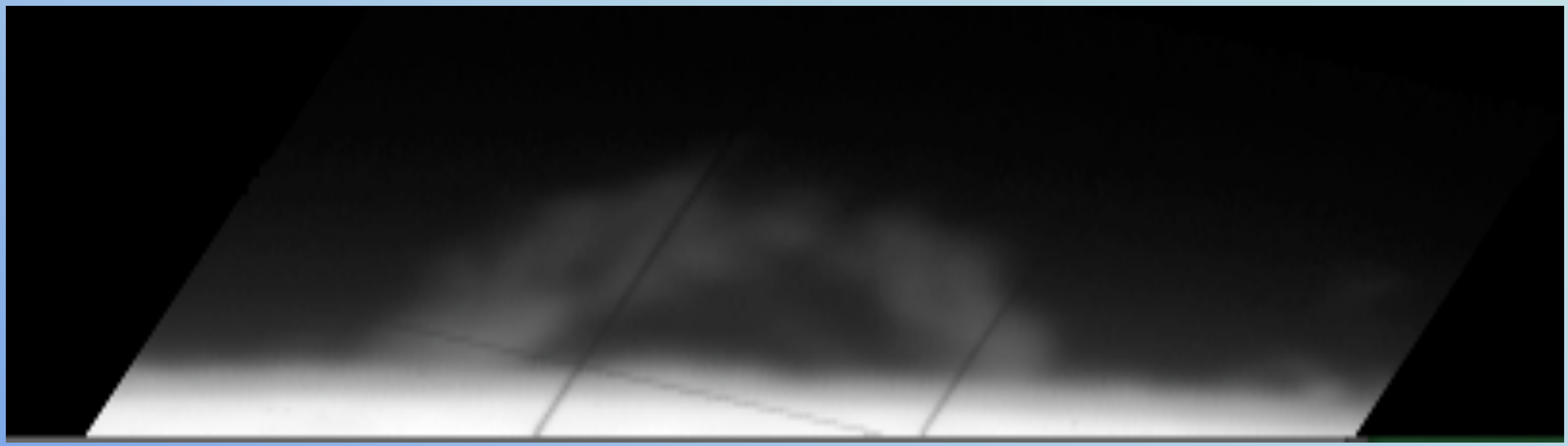
$$\tau_\lambda = N(\mathrm{H})\,\{(1-i)\,\sigma_{\mathrm{H}}(\lambda) + r_{\mathrm{He}}\,[(1-j_1-j_2)\,\sigma_{\mathrm{HeI}}(\lambda) + j_1\,\sigma_{\mathrm{HeII}}(\lambda)]\}$$

$$\tau_{195}/\tau_{912} \simeq 12.09\times10^{-3} + 1.93\times10^{-2} f(i)$$

$$f(i) = \frac{1}{1-i}$$

$$\alpha = \frac{1-r'_{195}}{1-\exp(-\tau_{195})}$$

Co-aligned Hα slit-jaw of prominence of June 9, 2007



unfortunately only one slit-position

$\tau_o(H\alpha) = 1.2$ and $i \simeq 0.6 \Rightarrow \tau_{195} = 1.9 \Rightarrow \alpha = 0.13$

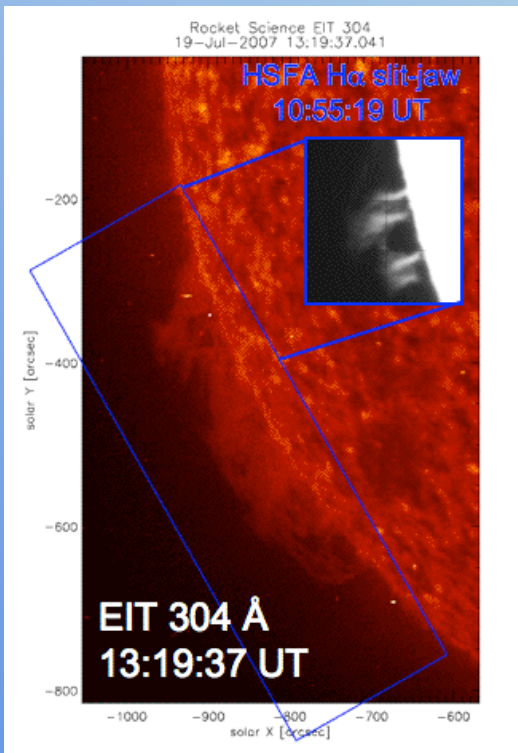
The same as avg α estimated from the τ_{195} / τ_{171} ratio

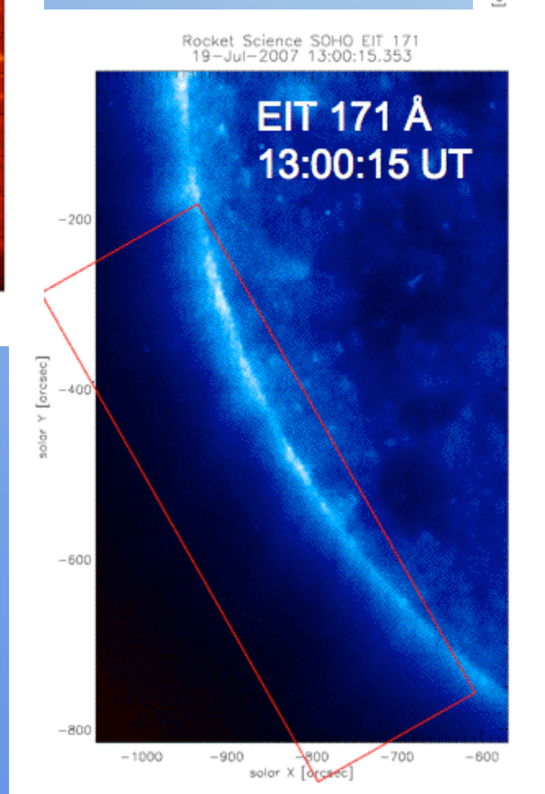
Also value of τ_{195} is the same as the one estimated from EIT 195 Å and XRT X-ray observations

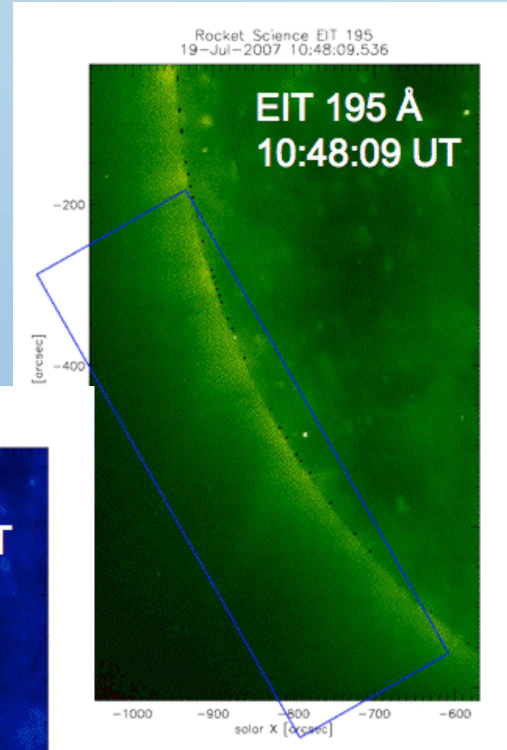
Total mass estimated for the prominence observed on June 9, 2007

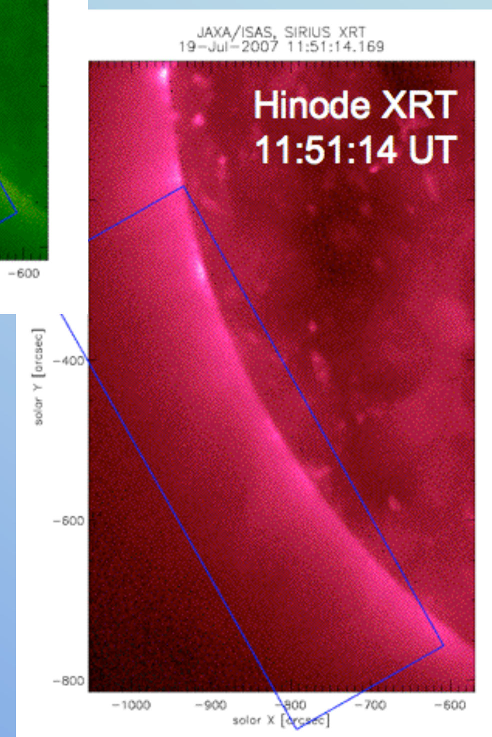
- average value of $\tau_o(H\alpha) = 1.19$ estimated from deviation of the Hα profiles from the Gaussian (Anzer&Heinzel 2005). It corresponds to $i \simeq 0.6$ at T = 8000 K.
- i = 0.6, j_1= 0.5 and j_2= 0 ... the total mass of 2.27×10^{11} kg
- for T = 6000 – 10000 K ... i = 0.5 – 0.8 ... the total mass from interval 2.23×10^{11}(-2%) – 2.27×10^{11} kg (+13%) can be estimated
- for i = 0.6, j_1 = 0.1 – 0.95 and j_2 close to zero (Labrosse et al. 2004) ... values of the total mass from interval between 1.67×10^{11}(-26%) and 3.12×10^{11} kg (+37%) can be estimated

July 19, 2007 – faint extended prominence, absorption structure almost invisible, faint cavity

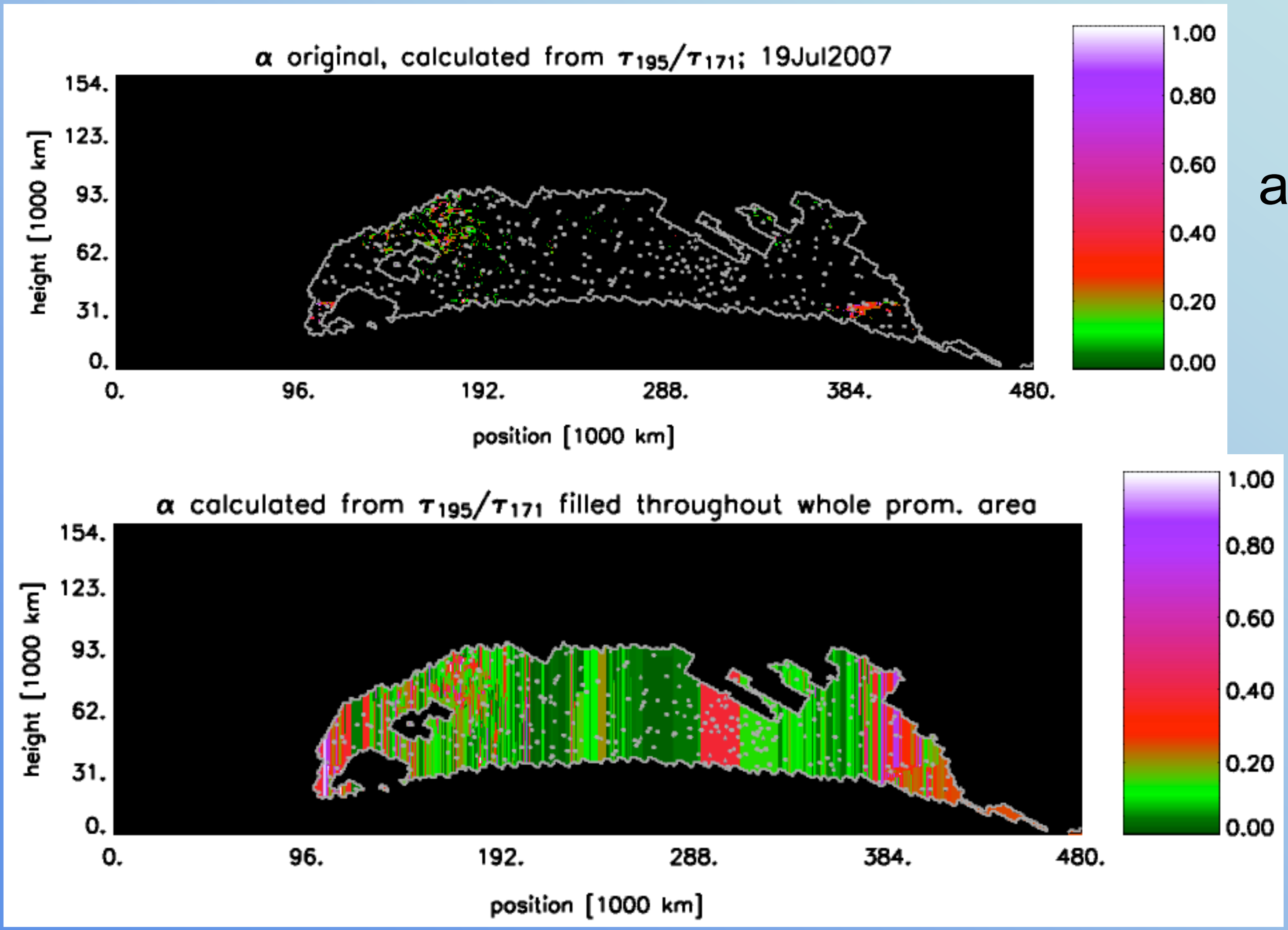






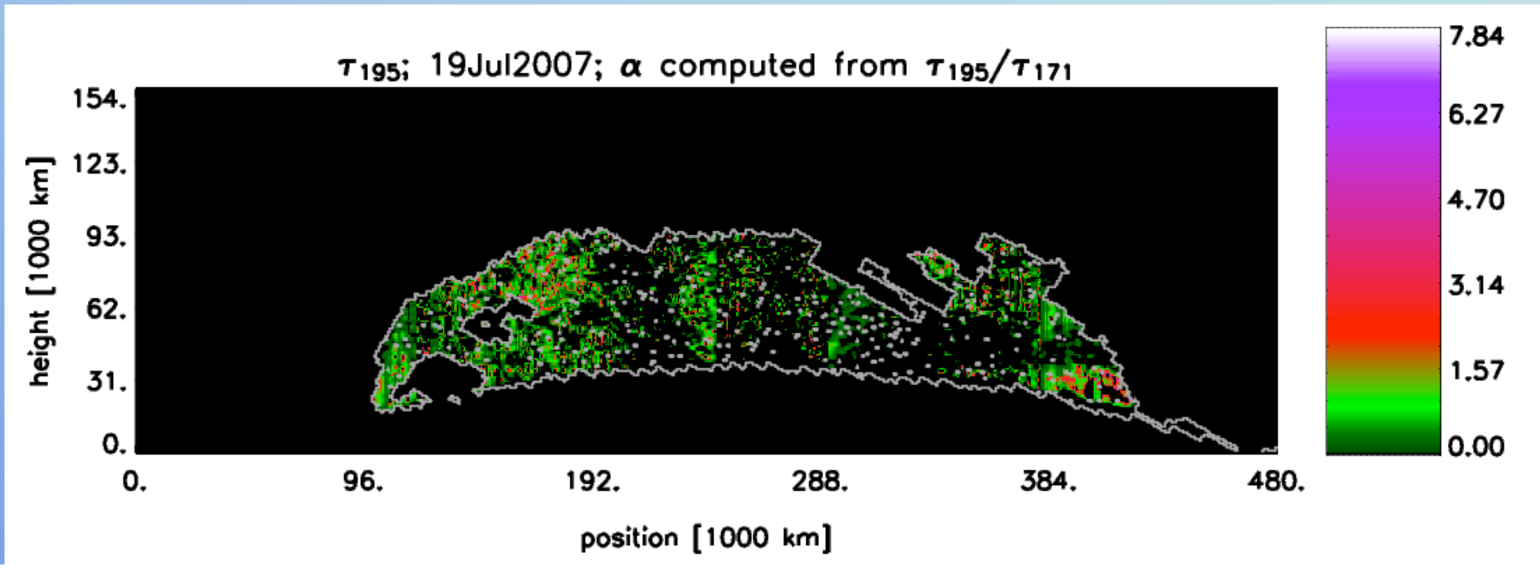


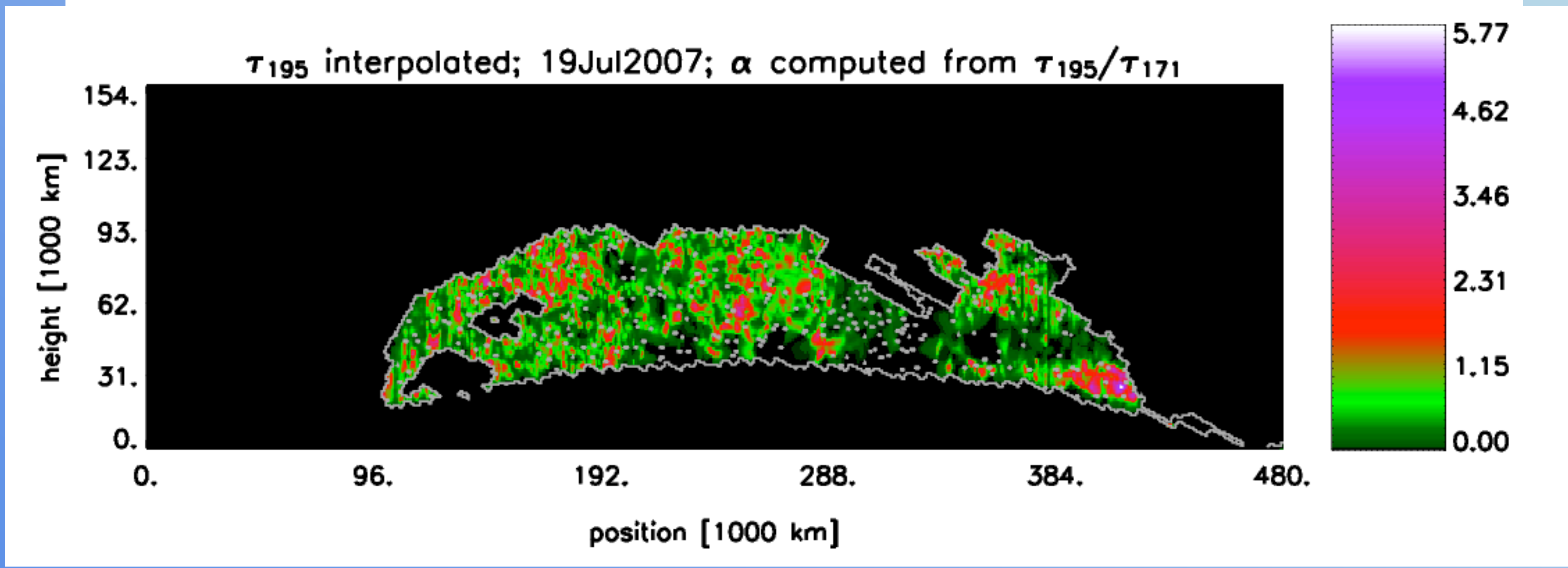
calculated using ratio τ_{195} / τ_{171} for the prominence observed on July 19, 2007



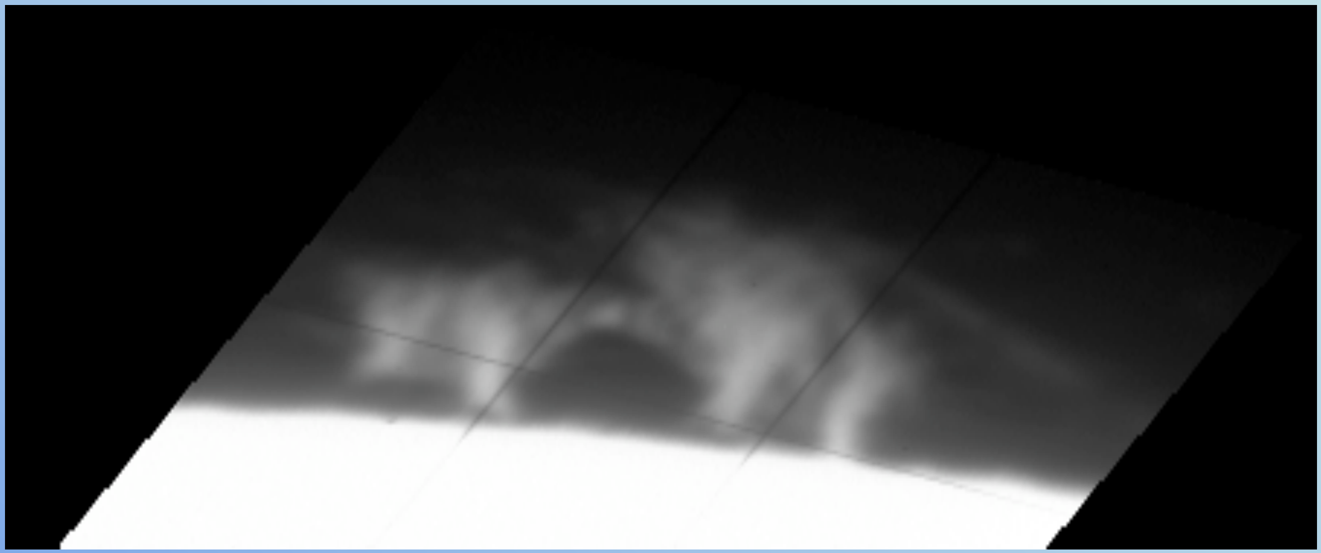
avg α=0.17

Maps of τ_{195} of prominence observed on July 19, 2007





Co-aligned Hα slit-jaw of prominence of July 19, 2007



5 slit-positions

$\tau_o(H\alpha) = 1.3 - 1.5$ and $i \simeq 0.6 \Rightarrow \tau_{195}=2 - 2.3$
$\Rightarrow \alpha=0.05 - 0.24$ (avg $\alpha=0.1$)
Close to the avg value 0.17 of α estimated from the τ_{195} / τ_{171} ratio. Also values of τ_{195} are close to those estimated from observations of EIT in 195 Å channel and XRT X-ray observations

Total mass estimated for the prominence observed on July 19, 2007

- $\tau_o(H\alpha) = 1.3 - 1.5$; it corresponds to $i \simeq 0.6$ at $T = 8000$ K.
- $i = 0.6$, $j_1 = 0.5$ and $j_2 = 0$ ... the total mass 1.34×10^{12} kg
- for T=6000 – 10000 K ... $i = 0.5 - 0.8$ ... the total mass from interval 1.29×10^{12}(-4%) – 1.58×10^{12} kg (+18%) can be estimated
- for $i = 0.6$, $j_1 = 0.1 - 0.95$ and j_2 close to zero, values of the total mass from interval between 1.26×10^{12}(-6%) and 1.80×10^{12} kg (+34%) can be estimated

CONCLUSIONS:

Values 2.27×10^{11} and 1.34×10^{12} kg of the total mass estimated in this work for the two studied prominences are comparable with values 7.4×10^{11} and 6×10^{11} kg estimated for a different prominence by Gilbert et al. (2005). They are also close to values 8.6×10^{11} – 3×10^{12} kg estimated for an EUV filament by Heinzel et al. (2003).

SUMMARY:

- **prominence of June 9, 2007**

– $\tau_o(H\alpha) = 1.19$ estimated $\Rightarrow i \simeq 0.6$ at T = 8000 K.
– for i = 0.6, j_1= 0.5 and j_2= 0 ... the total mass of 2.27×10^{11} kg
– because of uncertainties in ionization degrees of H and He, uncertainty in the total mass from -26% to +37%

- **prominence of July 19, 2007**

– $\tau_o(H\alpha) = 1.3 – 1.5$ and $i \simeq 0.6$ it corresponds to $i \simeq 0.6$ at T = 8000 K.
– for $i = 0.6$, $j_1 = 0.5$ and $j_2 = 0$ ... the total mass 1.34×10^{12} kg
– because of uncertainties in ionization degrees of H and He, uncertainty in the total mass from -6% to +34%

The values of the total mass calculated for both prominences are reasonable and close to values estimated by other authors

THANK YOU FOR
YOUR ATTENTION