

## Measurement of Plasma Ion Temperature and Flow Velocity from Chord-Averaged Emission Line Profile

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**Abstract.** The distinction between Doppler broadening and Doppler shift has been analysed, the differences between Gaussian fitting and the distribution of chord-integral line shape have also been discussed. Local ion temperature and flow velocity have been derived from the chord-averaged emission line profile by a chosen-point Gaussian fitting technique.

**Key words.** Plasma—Doppler broadening—Doppler shift—Gaussian fitting.

### 1. Doppler broadening and Doppler shift

Doppler broadening locally result from the distribution of velocities of the emitting particles, the line width gives the information on temperature of the emitting particles (William *et al.* 1990). For a Maxwell distribution of particles, the line profile function is:

$$f(\omega) = \frac{c}{v_{th}\omega_0\sqrt{\pi}} \exp\left[-\left(\frac{c(\omega_0 - \omega)}{\omega_0 v_{th}}\right)^2\right]. \quad (1)$$

The FWHM is given in terms of the Doppler broadening and particle temperature by:

$$\Delta\omega_{FWHM} = 2(\ln 2)^{1/2} \Delta\omega_D = 2\frac{\omega_0}{c} \left(\frac{2kT}{m} \ln 2\right)^{1/2};$$

$$\Delta\lambda_{FWHM} = 2(\ln 2)^{1/2} \Delta\lambda_D = 2\frac{\lambda_0}{c} \left(\frac{2kT}{m} \ln 2\right)^{1/2},$$

and the Doppler shift results when the emitting particles have bulk non random flow velocity in a particular direction, the drift of central wavelength gives information on the flow velocity of the emitting particles:

$$n(\vec{v} - \vec{v}_0)d\vec{v} = N \left(\frac{1}{\pi v_{th}^2}\right)^{1/2} \exp\left[-\frac{(\vec{v} - \vec{v}_0) \bullet (\vec{v} - \vec{v}_0)}{v_{th}^2}\right],$$

where  $v_0$  is the flow velocity vector. The uniform flow in the absence of any other mechanism is delta function (Xu 2003):

$$f(\lambda) = \delta \left[ \lambda - \lambda_c \left( 1 - \frac{v_0}{c} \cos \theta \right) \right] = \delta \left[ \Delta x + \lambda_c \frac{v_0}{c} \cos \theta \right],$$

where  $\Delta x = \lambda - \lambda_c$ . The line profile due to Doppler broadening and Doppler shift is the convolution of the two profile functions:

$$\begin{aligned} f(\Delta y) &= \int_{-\infty}^{+\infty} f_1(\Delta x) f_2(\Delta y - \Delta x) d\Delta x \\ &= \int_{-\infty}^{+\infty} \frac{1}{\sqrt{\pi} \Delta \lambda_D} \exp \left[ -\frac{\Delta x^2}{\Delta \lambda_D^2} \right] \cdot \delta \left[ \Delta y - \Delta x + \lambda_c \frac{v_0}{c} \cos \theta \right] d\Delta x. \end{aligned}$$

Replacing  $\Delta y = \lambda - \lambda_c$ ,

$$f(\lambda - \lambda_c) = \frac{1}{\sqrt{\pi} \Delta \lambda_D} \exp \left[ -\frac{(\lambda - \lambda_c (1 - \frac{v_0}{c} \cos \theta))^2}{\Delta \lambda_D^2} \right].$$

The Doppler shift only drifts the profile of line without changing the width.

## 2. Chord-averaged line profile and Gaussian fitting

For circular surface, chord-averaged line profile is given by (Xu *et al.* 1997):

$$I(\lambda, r_T) = \int_{-\sqrt{a^2 - x_T^2}}^{\sqrt{a^2 - x_T^2}} \frac{\epsilon(r)}{\sqrt{\pi} \Delta \lambda_D(r)} \exp \left[ -\frac{[\lambda - \lambda_c (1 - \frac{v(r)}{c} \cos \alpha(r, r_T))]^2}{\Delta \lambda_D^2(r)} \right] dl, \quad (2)$$

where  $\epsilon(r)$  is the emission coefficient. The Gaussian fitting to the chord line profile is of the form (Xu *et al.* 1997):

$$I(\lambda, r_T) = b(r_T) \exp \left[ -\frac{[\lambda - \lambda_c(r_T)]^2}{\Delta \lambda_D^2(r_T)} \right] = b(r_T) \exp \left[ -\frac{[\lambda - \lambda_c (1 - \frac{\langle v(r_T) \rangle}{c})]^2}{\Delta \lambda_D^2(r_T)} \right], \quad (3)$$

where  $b(r_T)$  is the brightness. Comparing equations (2) and (3), the picture gets very complicated, but it is not necessary to solve the equation. The flow velocity and temperature is just derived from the  $\Delta \lambda_D$  and  $\lambda - \lambda_c$  by the Gaussian fitting. We can derive the local temperature and the flow velocity from the chord-averaged line profile.

## 3. Chosen-point Gaussian fitting technique and summary

The local temperature and flow velocity can be derived from the chord-averaged line profile by the chosen-point Gaussian fitting technique. This annuli fitting technique's

basic idea is that the plasma is divided into several annuli, the chord through the annuli is more weighted, and constitutes two wings of the line distribution, the outer annuli with much lower temperature constitutes the peak of the line distribution. Thus we can orderly abandon some data points from the peak of the line distribution. With the data point increasing, the temperature derived from the fitting gets more and more higher, and finally, the temperature derived from fitting remains unchanged. This time, the temperature and flow velocity derived from the Gaussian fitting is the local temperature and flow velocity. The chosen-point Gaussian fitting technique suits the plasma of the highest temperature at the center. It is also necessary for the fitting technique that the resolution of the line distribution is as high as possible. The results of the fitting do not interfere with each other, and are credible.

### References

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