1 Introduction

2 Model

Due that the proplyds cusp is the only part that is directly exposed to the radiation field of θ^1C this is the brigthest part of the proplyd at least in Ha and ions of high and medium ionization. The difuse radiation of the nebulae is negligible in comparation with the θ^1C in the cusp at least between $0^\circ \leq \theta \leq 60^\circ$ where the flux is reduced in 50% of the total flux. In this first step of the model we contructed a model for only the proplyd cusp with the influence of the main radiation field.

We follow the analytic model of a photoevaporated wind described in Henney & Arthur (1998).

The simplest assumpion is that there is a static spherical distribution of gas about the central lowmass star. This gas is being evaporated and ionizing by the radiation coming from θ^1C

- Ionizing radiation incident parallel to the proplyd.
- Assuming a cylindrical geometry with symmetry in the coordinate Φ
- Semi-spheric ionization front.
- The photoionized gas flows radially from the border of ionization
- The gas flow is not isotermic
- Collisional deexitation are not negligibles

We construct Cloudy models of a series of individual radial cuts from the center of the proplyd, at different angles θ from the proplyd axis. For each angle we reduce the flux by a factor of $\cos\theta$.

2.1 Geometry

Δ is the ionization front width in terms of the mean free path at 1 Rydberg. That is, $\Delta = \mathrm{W} / \mathrm{n}_0 \, \sigma_0$ where n_0 is the density at the sonic point, σ_0 is the H cross section and W is the number of the mean free paths.

For simplicity and clarity of the model we chose to use a dimenssionless radial coordinate $\mathrm{R} \, \mathrm{r} / \mathrm{r}_0$ where r is the radial coordinate in cm starting in the low-mass star inside the proplyd and r_0 is the distance between the proplyd center and the sonic point.

2.2 Radial Density Structure

As we mentioned above one way to develope models that take into account both, the radiative transfer and the hydrodinamics of the gas, is to introduce an aproximate hydrodinamics in the radiative models that are availables and such are stables. This is our case and the way to introduce the hydrodinams of the gas is using the electron density structure that is a result of the hydrodinamic teorical models.

We divide the proplyd flow into two zones:

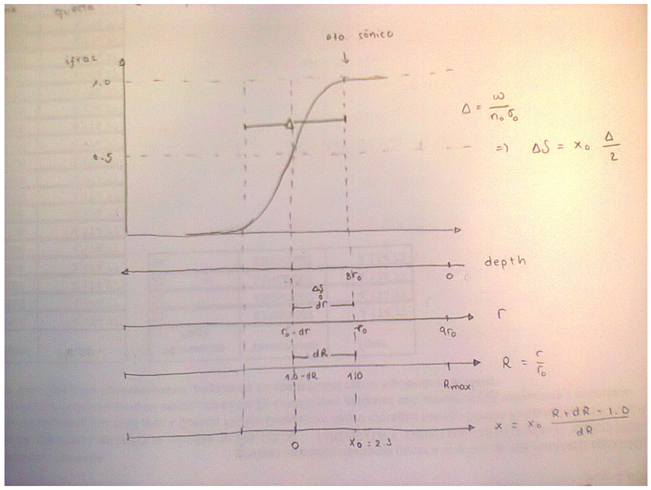

Figure 1: A sketched geometry of the 1D Cloudy modell.

- $r > r_0$: An outer, fully ionized flow.
- $r < r_0$: An inner, partially ionized flow.

This is equivalent to say that the behavior of the physical conditions are diferent in both zones. We suppose that the flow in the partially ionized zone, that correspond to the thin ionization front, is a subsonic flow. This is acelerated to be a supersonic flow in the outer fully ionized zone. The boundary between them are exactly the sonic point. The conditions there, and in every point of the proplyd, are fixed by continuity, it means that the electron density change as the gas-phase velocity change and visceversa.

$$\mathrm{n_e(X)} = \begin{cases} f_1(X) & 1 \geq X \geq 0.98 \\ f_2(X) & 0.02 \geq X \leq 0.98 \end{cases} \tag{1}$$

2.2.1 The outer zone

This is similar to what Will did in (Henney et al., 2002)

In the outer zone we assume an isothermal, supersonic, complite ionized flow. From mass conservation, in spherical geometry and In the steady state, radial velocity of the ionized gas, $v(r)$

Gas velocity is given by Dyson solution (Dyson, 1968)

$$R = U^{(-1/2)} exp\left[\frac{1}{4}\left(U^2 - 1\right)\right] \tag{2}$$

where $\mathrm{U(R)} = \mathrm{v}/\mathrm{c_0}$ with $v(R)$ is the gas velocity and c(R) is the sound speed wich is calculated *in situ* by Cloudy for each step. Due we can not have an analytic solution for U as a function of R, from this equation generate a table of values for U and R and interpolate this table for each R that is necesary in the Cloudy model.

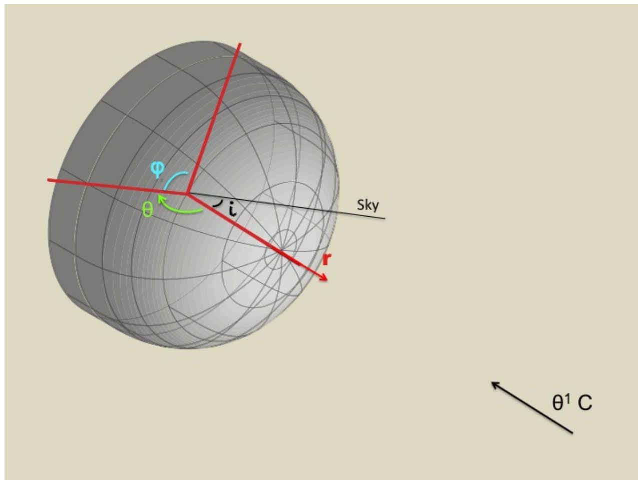

Figure 2: A sketched geometry of the semi-3D model.

At each point the density is calculated by the continuity equation:

$$\rho(R) = \rho(R_{max}) \left(\frac{U(R_{max})}{U(R)} \right) \left(\frac{R_{max}}{R} \right)^2 \tag{3}$$

2.2.2 The boundary

Because the gas velocity is the property that determines the behavior of other physical properties of the proplyd, the logical boundary between the regions is exactly the sonic point.

This point is also where the criterion of Stromgren for a density bounded region is met. That is, where the photoionization balance is broken and the recombination start to overcome the photoinization.

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$r = r_0$

$X_H \simeq 0.99$

$u = c$ by definition of the boundary

$c = c_{max}$ at least a local maximum

2.2.3 The inner zone

Partially ionized region: Density is function of sound speed

In this zone, we follow the simplified analytic model for weak–D ionization front described in Appendix of the Henney et al. (2005) paper. Even when this model is for a plane-parallel ionization front (the momentum conservation assumes plane parallel geometry) and this is not our case (we have an divergent geometry) this is an aproximation that could give us a good idea of the advection effects on the I-front.

Following the A8 equation,

$$c(X) = c_m \left[\frac{T(X)}{T_m} \frac{1 + X}{1 + X_m} \right]^{1/2} \tag{4}$$

If we see the electronic temperature behavior for the waek–D solutions, Fig.18 from Henney et al. (2005), we can see that the temperature could be assume constant in first aproximation, at least in $0.25 \leq X \leq 1.0$. This is our case, then the sound speed will be:

$$c(X) = c_m \left[\frac{1 + X}{1 + X_m} \right]^{1/2} \tag{5}$$

As in the Cloudy models the temperature is one of the physical quantities that are calculated in each zone, we can not use it for calculate the sound speed in each zone. Then, we made an aproximation for the behavior of X in the recombination zone, for calculate the sound speed. We aproximate the H ionization fraction by a function of R:

$$\text{ifrac} = 0.5(\tanh(\text{x}) + 1.0) \tag{6}$$

where $x = x_0 \frac{R+dR-1.0}{dR}$. x_0 is where the H ionization fraction is 0.99, i.e. in the sonic point where $R = 1$ ($ifrac_m = 0.5(tanh(x_0) + 1.0)$).

Making use of the Mach number $M = v/c$ and the fact of $c_m/c = \frac{1}{2}\left(M + M^{-1}\right)$. Then, once more by continuity, the electronic density in this zone is:

$$\rho = \rho_m / 1.0 - \sqrt{1.0 - \left[\frac{1 + X}{1 + X_m} \right]} \tag{7}$$

in contrast to the static case where the density is: $\rho \sim 1/c^2$

3 Results and Predictions

3.1 Physical properties

- Electron Density: It has an almost constant increase reaching the maximum value in the i-front (after the sonic point) where the H is partially ionized. In this zone, the electron density reach the critical electron density for some ions, making the collisional deexitation a process that need to take into account.
  This could be negligible in the outer parts of the flow since they are highly ionized, which means that [O III] is the dominant coolant. The critical density of this ion is about 1e6 cm-3, which is reached just near of the sonic point, that is, where the [O III] emission is less than the 10% of the total [O III] emission. (See Sect. 3.3).

- Temperature: The electron temperature is almost constant in the outer zone. As we approache to the He recombination front the Te increase reaching the maximum value just before the i-front, where the He is neutral and the H still fully ionized.

It is due for two reasons: The first one is that as the radiation field goes into the gas-phase of the proplyd, the less energy photons are absorved. This cause a hardening of the radiation field increasing the mean electron kinetic energy. That is, increasing the photoelectric heating per recombination. The second one is the electron density increase. It causes collisional deexcitation of the main cooling lines.

3.2 Ionization structure

3.3 Emissivities

All the high ionization lines are all wholly outside the sonic point.

[Ne II], Hα, [N II] and [O II] have almost the 90% of their emission in the super-sonic zone and the 10% in the sub-sonic zone.

[S II] is about 70% outside the sonic point and 30% inside.

[O I] is about 20% outside and 80% inside the sonic point.

So if we take into account the full emission of the proplyd, and the sub-sonic zone is not well modelated, the efect of this should be not very important since it is only going to affect two lines. Nevertheless, if we want to compare the model predictions with observations that takes only a little aperture of the proplyd and it is near of the center (near the i-front), the sub-sonic zone will be very important.

There are a clear separation of 3 km/s (about 15%) between the median velocity of the [O III] 5007 and 4363 lines.

Discutir tambien la diferencia que hay entre la linea auroral y la nebular de [N II] para ver la importancia de las desexitaciones colisionales. Una es mas afectada que la otra y por lo tanto conforme vamos a las zonas de mayor densidad la razon entre ellas debe ir cambiando, aumentando de hecho.

4 Conclusion

We will construct Cloudy models of a series of individual radial cuts from the center of the proplyd, at different angles θ from the proplyd axis.

References

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