The origin and magnitude of UV and Xray emission in T Tauri stars.

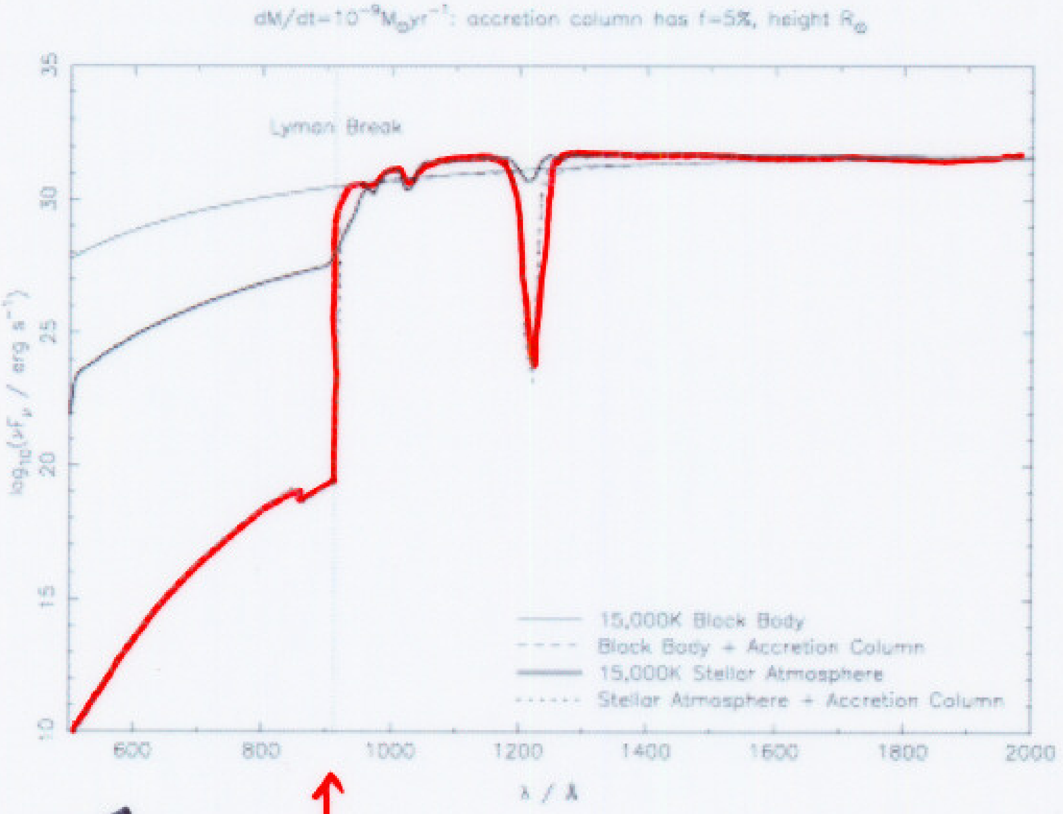
[can't be accretion if radiation is an effective dispersal agent: see Matsuyama et al 2003]

Xrays: produced by B field reconnection in corona/magnetosphere

- thermal bremstrahlung peaking at 1–2 keV (Feigelson & Montmerle 1999)
- $L_x \sim 10^{30}$ erg s^{-1} (x10 - 100 in flares) (Wolk et al 2005)
- at least as strong in Weak Line T Tauri stars (no $\dot{M}$) cf Classical TTs. (Preibisch et al 2005) ← not accretion origin for Xrays.

UV: probably contributions from an active chromosphere and accretion but any ionising photons from accretion hotspot will not escape accretion column

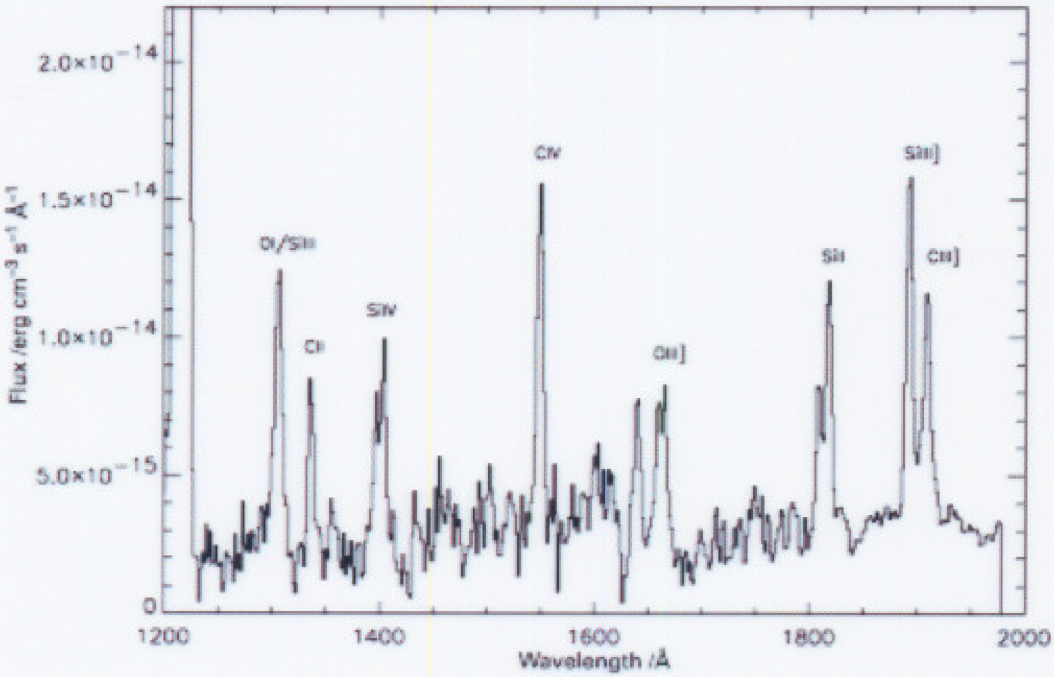
Alexander, Clarke & Pringle 2004.



Lyman limit

EUV attenuated to levels < from photosphere.

FUV spectrum of RY Tau
(Brooks et al 2001)



$$I(\lambda_{ij}) = \underset{\substack{\nearrow \\ \propto \text{ abundance}}}{Ab(X)} \int_T \underset{\substack{\nearrow \\ \text{"contribution} \\ \text{function"}}}{C(T, \lambda_{ij}, n_e)} \underbrace{n_e n_H \frac{dz}{dT}}_{\substack{\text{differential} \\ \text{emission measure}}} dT$$

$I(\lambda_{ij}) \rightarrow$ measure $n_e n_H dz$ in range $T \rightarrow T + dT$ required to reproduce observed line

fit to large number of lines to constrain $n_e n_H dz$ in each T range

4.

feed derived differential emission measures into spectral synthesis code

⇒ calculate implied Φ_{ion}

modulo reddening

Alexander, Clarke and Pringle 2005a): $\Phi_{ion} \sim 10^{42} - 10^{43}\ s^{-1}$

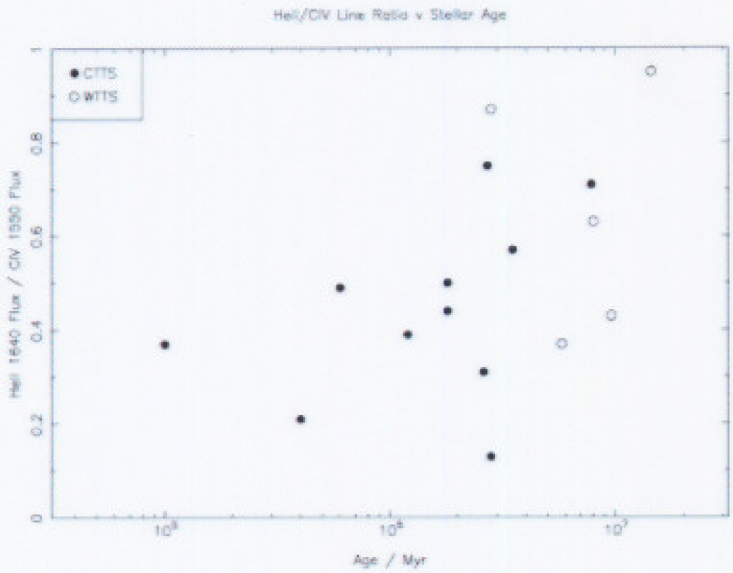
Star	He II/C IV	Power at $\lambda < 228$Å / Total power
CV Cha	0.12±0.04	0.0064
RU Lup	0.15±0.01	0.0054
BP Tau	0.50±0.01	0.0277

Table 3.2: Observed He II/C IV line ratios and derived He II-ionizing/total power ratios for the 3 objects where the power ratio is robust. Observed line ratios are taken from Valenti et al. (2000).

Star	No. of Spectra	Line Flux ($\times 10^{-14}$ erg s^{-1}cm^{-2}) C IV 1550Å	He II 1640Å	He II/C IV Ratio
T Tau	10	19.94±1.34	7.01±0.15	0.35±0.03
RY Tau	1	0.73±0.24	0.17±0.04	0.23±0.10
SU Aur	2	3.60±0.15	0.76±0.03	0.21±0.02
GW Ori	2	2.58±0.52	0.67±0.02	0.26±0.05
CO Ori	2	0.09±0.02	0.03±0.01	0.31±0.08
EZ Ori	1	0.75±0.05	0.14±0.01	0.19±0.02
V1044 Ori	1	1.58±0.09	0.26±0.02	0.16±0.02
P2441	1	0.37±0.02	0.09±0.02	0.23±0.06
RY Lup	2	11.80±0.97	1.59±0.13	0.14±0.02

Table 3.3: Line strengths obtained from *HST STIS*. Values for C IV 1550Å are the sum of the two fitted components.

also "correlation" between He II / C IV and spectral hardness



spectral hardness ratio

Age

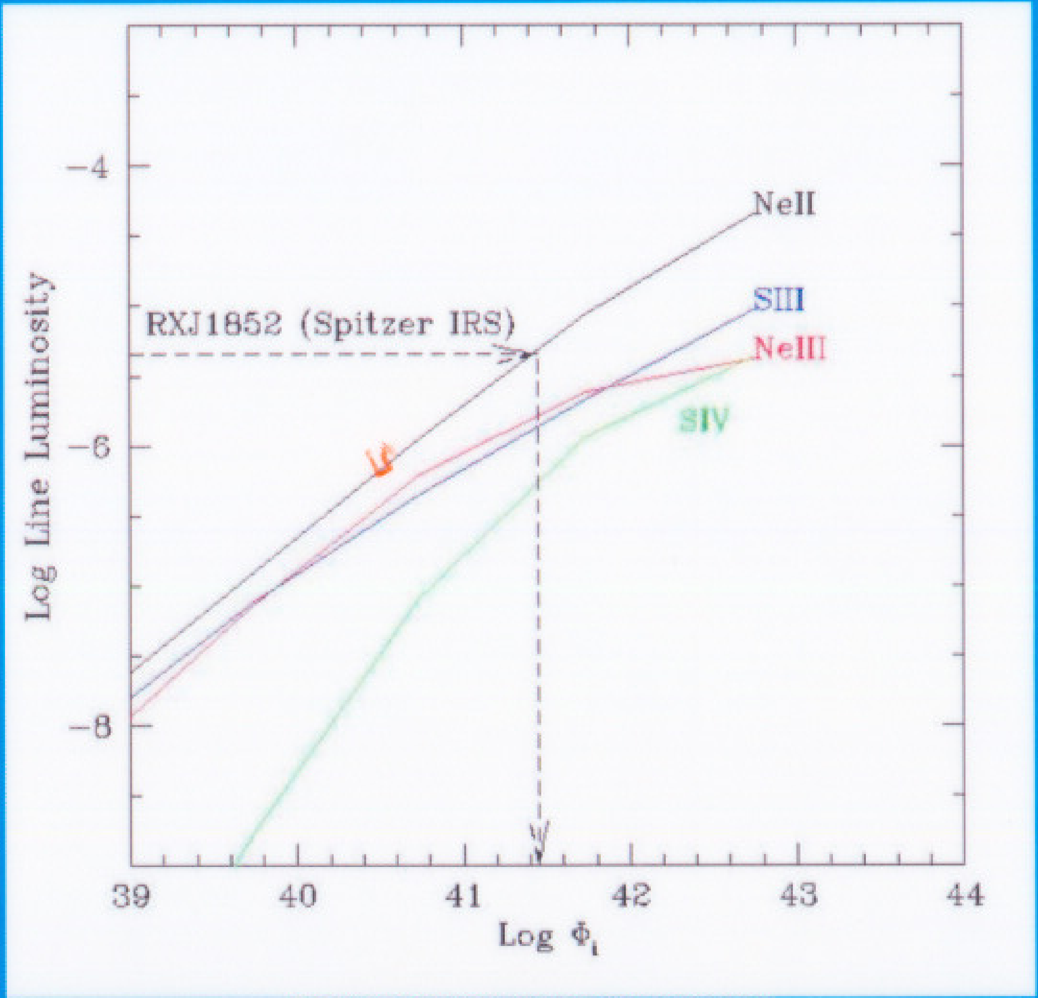
if anything, spectrum harder for older sources without accretion diagnostics

--> suggests EUV is not accretion related.

C. Photoevaporation by Central Star (EUV)

Observational Diagnostics of ionized (HII) surface

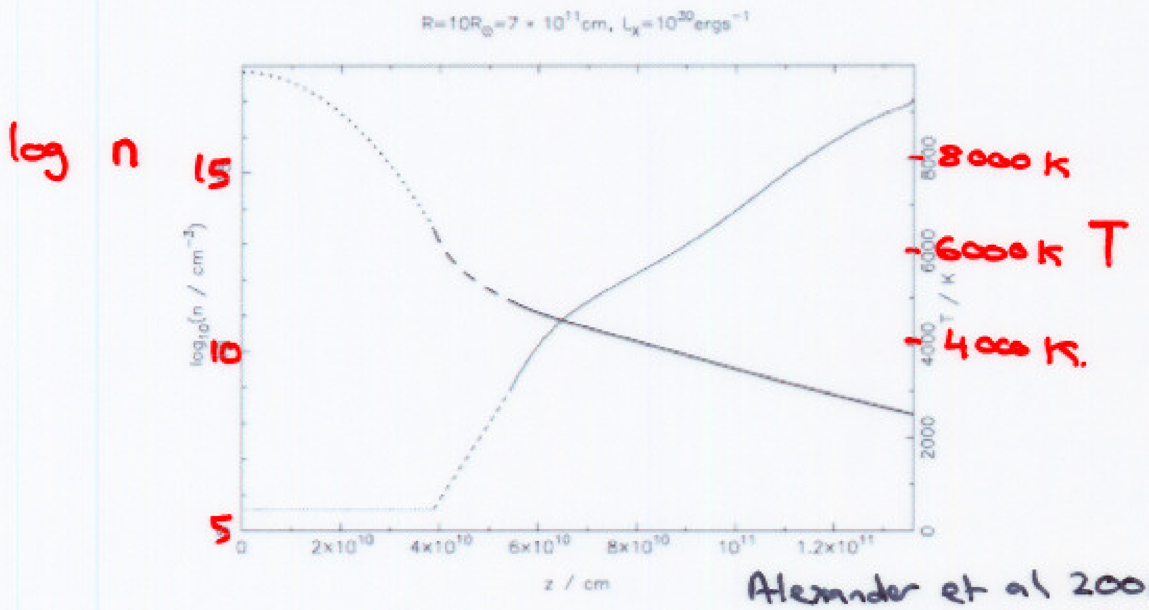
L$_\odot$



EUV photons/ s

Xrays heat surface layers to $\simeq$ 5000 K

$\Rightarrow$ could drive wind from $\sim$ 10 A.U.



Alexander et al 2004 b

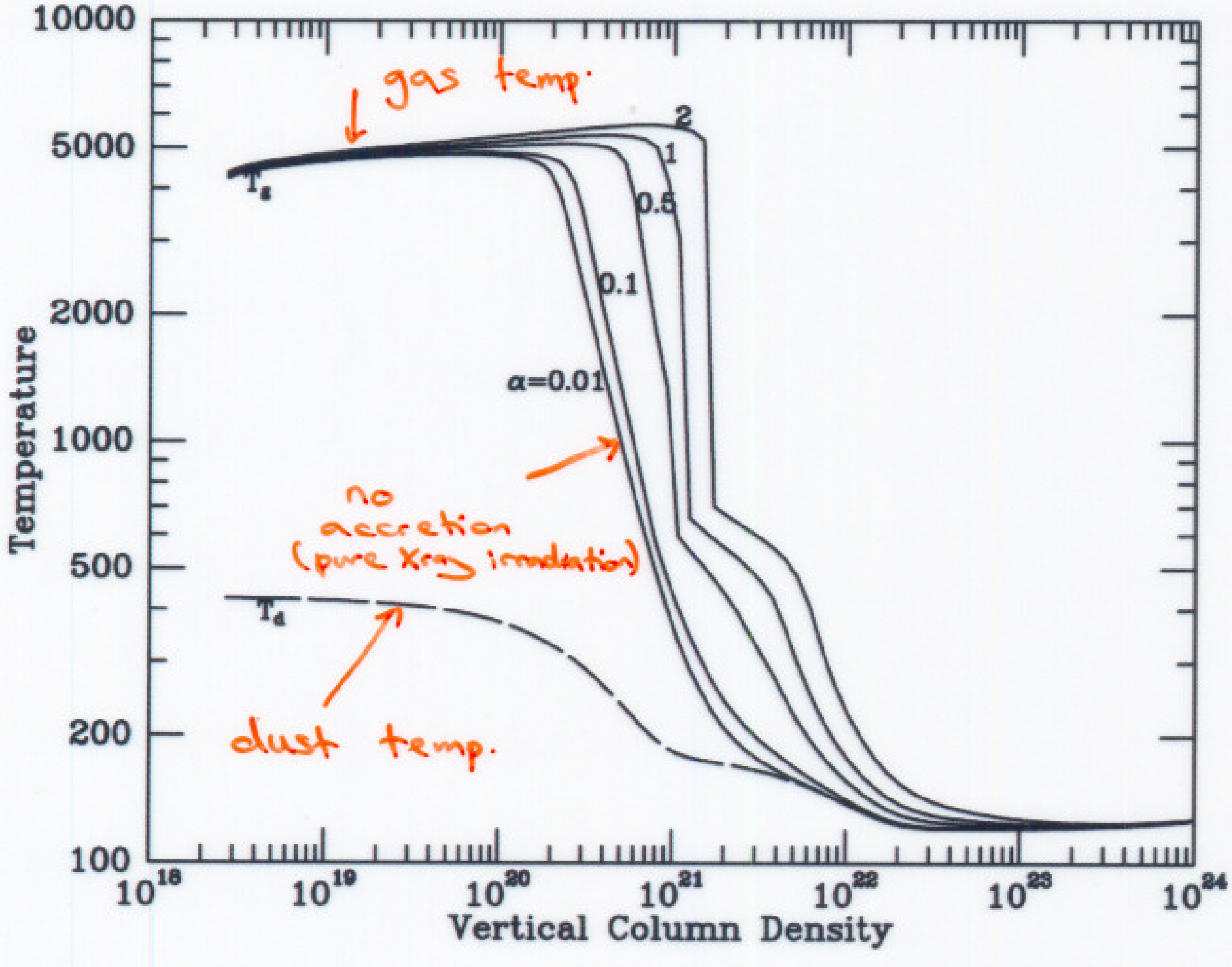
to unbind gas at 5000 K

$\Rightarrow$ need to get Xrays to $\sim$ 10 A.U.

need to solve 2D problem for Xray penetration through inner disc atmosphere

Glassgold, Najita & Igea (2004):

best for thermal chemical structure (e.g. excitation of CO bands in warm surface layer).

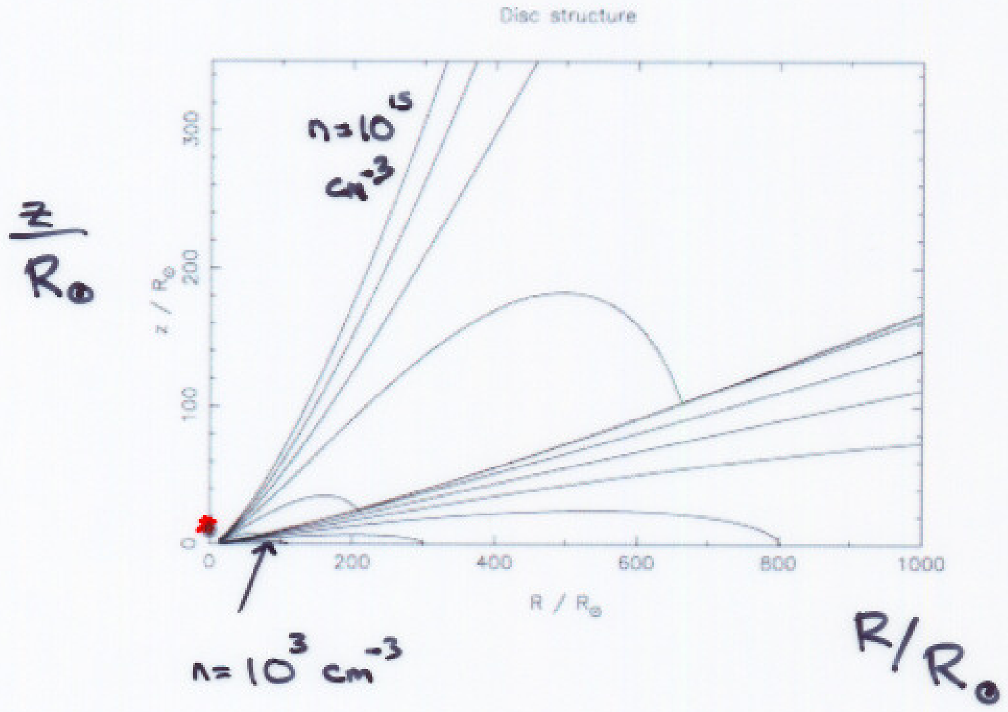


... but doesn't iterate density structure to attain hydrostatic equilibrium in inner disc

cf Alexander et al 2004 b.

Alexander et al 2004 b): compute puffing up of inner disc in response to Xray heating

→ reduces Xray penetration to large radii



$\Rightarrow \dot{M}_X < \dot{M}_{EUV}$ (see later).

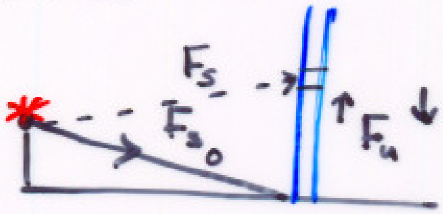
(cf Hollenbach, priv. comm.).

EUV from central source.

→ Hollenbach, Johnstone, Lizano + Shu 1994 ←

Key points:

- diffuse UV field (from recombinations to ground state) is important
- simplify problem by assuming that diffuse field is everywhere vertical



- model radiation field by "3 streams"

i) stellar field, diluted by geometrical effects + photoabsorption

$$\underline{\nabla} \cdot F_* \equiv \frac{1}{s^2} \frac{d}{ds} \left(s^2 F_*(s,\theta) \right) = n_H(r,z) \sigma F_*(s,\theta).$$

ii) upward
iii) downward

$\Big\}$ diffuse fields, diluted by photoabsorptions, replenished by recombinations to ground state

$$\frac{d}{dz} F_u = - n_H(r,z) \sigma F_u + \frac{1}{2} n_e^2(r,z) k_1$$

$$\frac{d}{dz} F_d = n_H(r,z) \sigma F_d - \frac{1}{2} n_e^2(r,z) k_1$$

+ ionisation balance $n_H(r,z) \sigma (F_* + F_u + F_d) = n_e^2(r,z) \alpha_1$

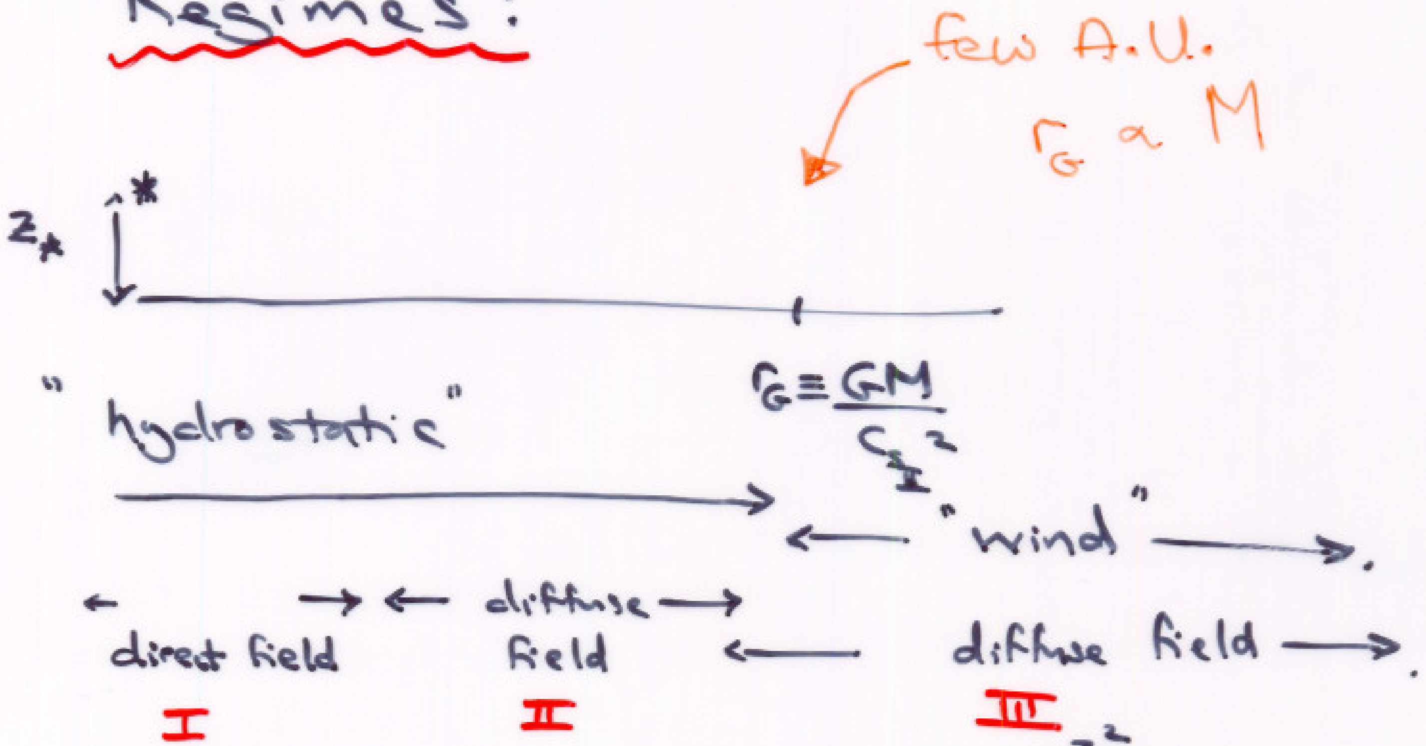
[note: this satisfies $\underline{\nabla} \cdot \underline{F} = \alpha_B n_e^2(r,z)$, as must].

then solve for $n_0(r)$ subject to

density at base of wind/ ionised region

boundary condition $F_* = F_d = F_u = 0$ at $z=0$.

Regimes:



hydrostatic $\Rightarrow$ $n(r,z) \sim n(r,0)\, e^{-\frac{z^2}{2H(r)^2}}$

wind $\Rightarrow$ $n(r,z) \sim n(r,0)$.

I direct $\Rightarrow$ $F_*\big|_z (z=0) \propto \frac{\Phi_{ion}}{r^2} \cdot \frac{z_*}{r} \propto r^{-3}$.

$$\int n^2 \, dz \propto n_0^2 H(r) \propto n_0^2 r^{3/2}$$

recombination integral

static isothermal atmosphere

$\Rightarrow n_0 \propto r^{-9/4} \Phi_{ion}^{1/2}$ ✓

II diffuse field

+ hydrostatic atmosphere

numerically $n_0 \propto r^{-3/2}\, \Phi_{ion}^{1/2}$ $\circledast$

III diffuse field

+ wind

numerically $n_0 \propto r^{-5/2}\, \Phi_{ion}^{1/2}$.

> feD A.U.

Note:
Only III → mass loss, but structure of I + II important as control penetration of ionising photons into wind driving regime.

$$\dot{M}_{wind} = \int_{r_g}^{\infty} 2\pi r\, n_0(r)\, c_s\, dr \propto r_g^2\, n_g$$

$$\Big\downarrow \circledast$$

$$r_g^{1/2}\, \Phi_{ion}^{1/2}$$

$$\propto M_*^{1/2}\, \Phi_{ion}^{1/2}$$

$$\dot{M}_{wind} \sim 4 \times 10^{-10} \left(\frac{\Phi_{ion}}{10^{41}\, s^{-1}}\right)^{1/2} \left(\frac{M_*}{M_\odot}\right)^{1/2} M_\odot\, yr^{-1}$$

... small, for low mass stars....

A few consistency issues:

- ionisation equilibrium (assumed) requires

recombination timescale < flow time

marginally satisfied in outer disc

- neglect of dust

absorption → $\dot{M}_w \downarrow$

scattering → $\dot{M}_w \uparrow$

Richling + Yorke 1997: wins.

boosts $\dot{M}$ by $\sim \times 2-3$.

- angular momentum, non-vertical flow

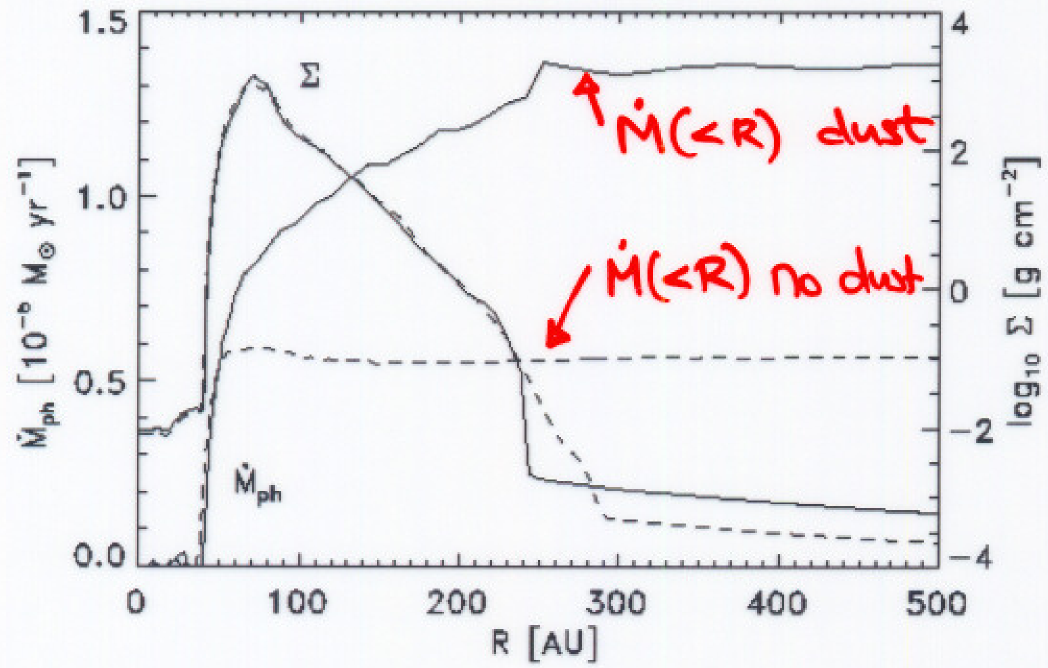
Font et al 2004

study flow with ZEUS 2D

subject to — prescribed base density

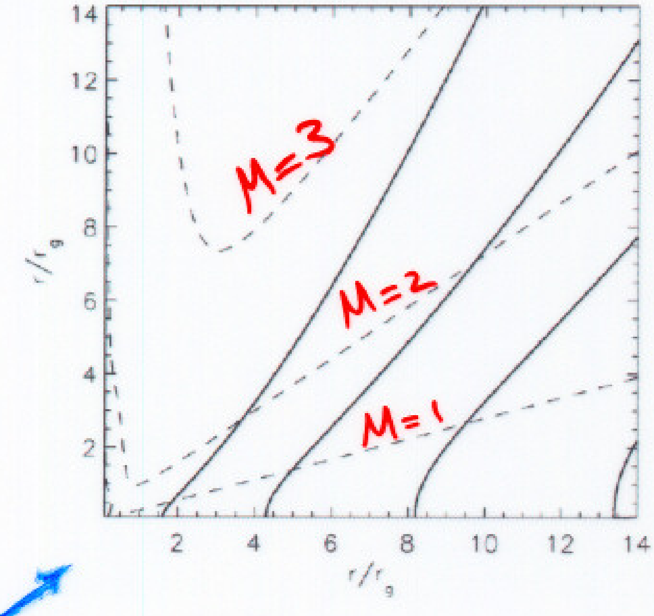
— isothermal e.o.s. ionised flow

Richling + Yorke 1997: radiation hydro. including dust

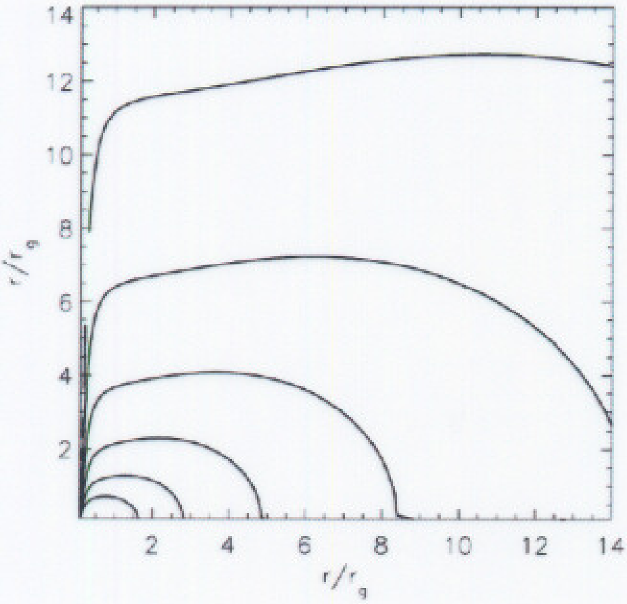


Font et al 2004:

streamlines & Mach surfaces.



isodensity contours.



$n_0 \propto r^{-1.5}$

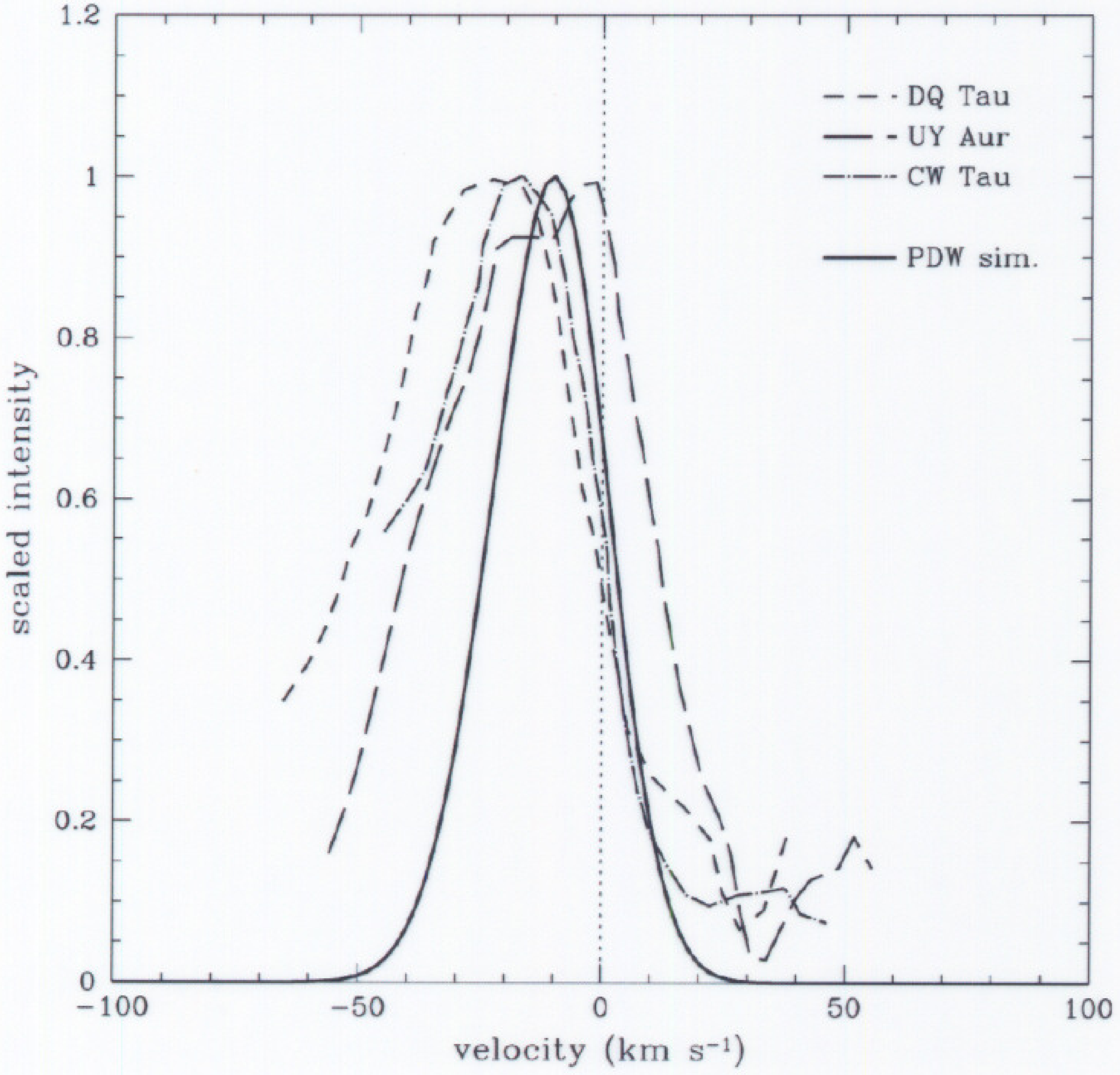
$\underline{\nabla} p$ diverts vertical flow → ~ radial.

if $n_0 \propto r^{-2.5}$

.... goes radial quicker

explain low velocity component of forbidden line emission from ionised species?

[SII] λ6731 Å



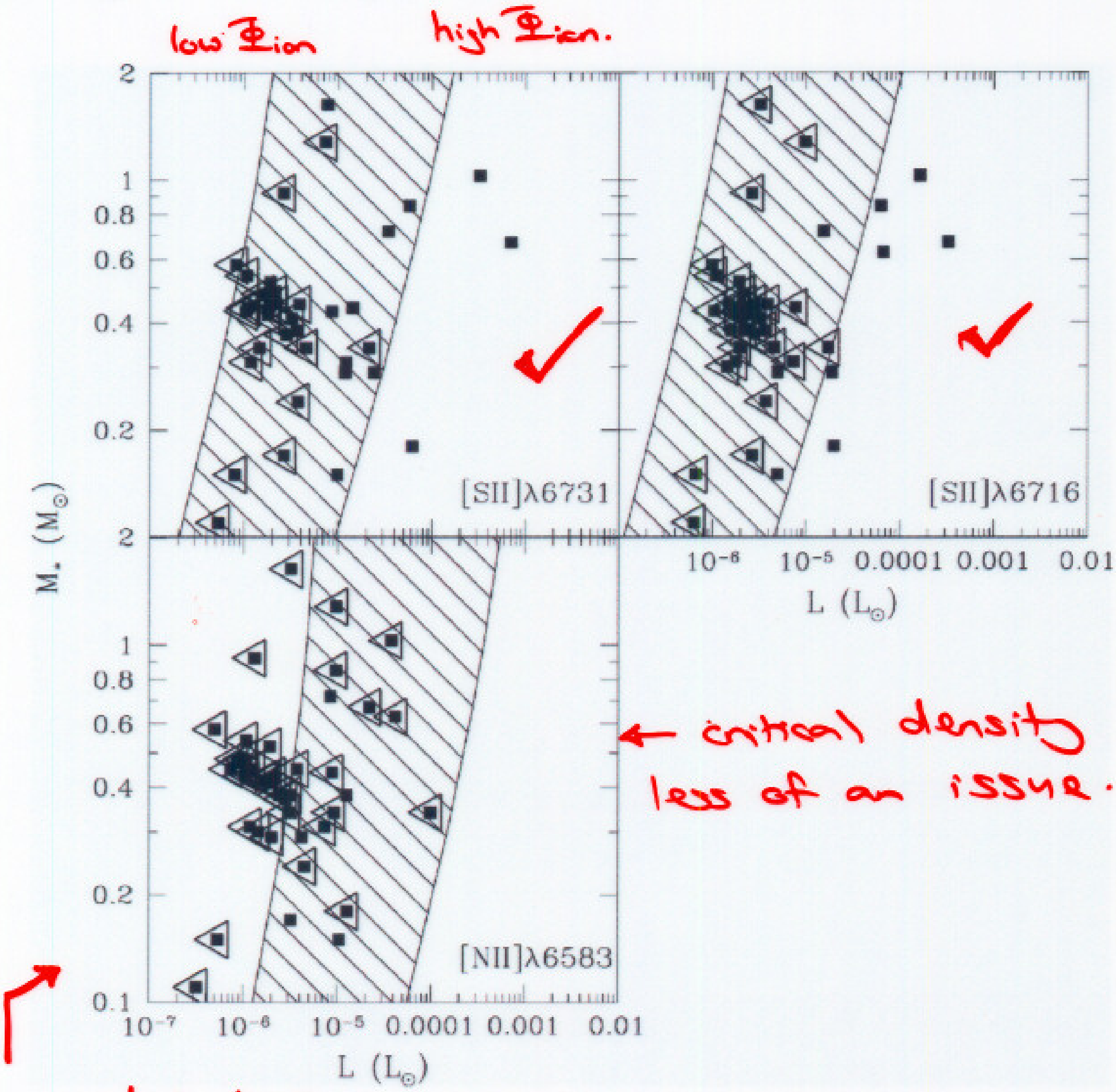
Font et al 2004

- if no collisional de-excitation:

$$L_{\rm line} \propto n^2 dr^3 \propto n_g^2 r_g^3 \propto \Phi_{\rm ion}$$

no explicit mass dependence.

- accounting for $n_{\rm crit}$: lose emission from high density regions: suppresses emission for low M_*



← critical density less of an issue....

model a bit high ....

- can't reproduce [OI] 6300 this way
- in ionised wind ... O isn't neutral!
- column of neutral O penetrated by ionising photons [needed to excite line] not enough to → observed $L_{\rm line}$.

The next stage in studying radiation feedback in discs:

Gorti + Hollenbach in prep.

Xrays } already know answer.
EUV
FUV

+ iterations on $n(r, z)$.

- Hard! simplifications: • ignore scattered FUV i.e attenuate along path to star • prescribe grain size distn. as fn (z).
  - chemical networks
  - radiative transfer

..... involves rezoning to capture important processes

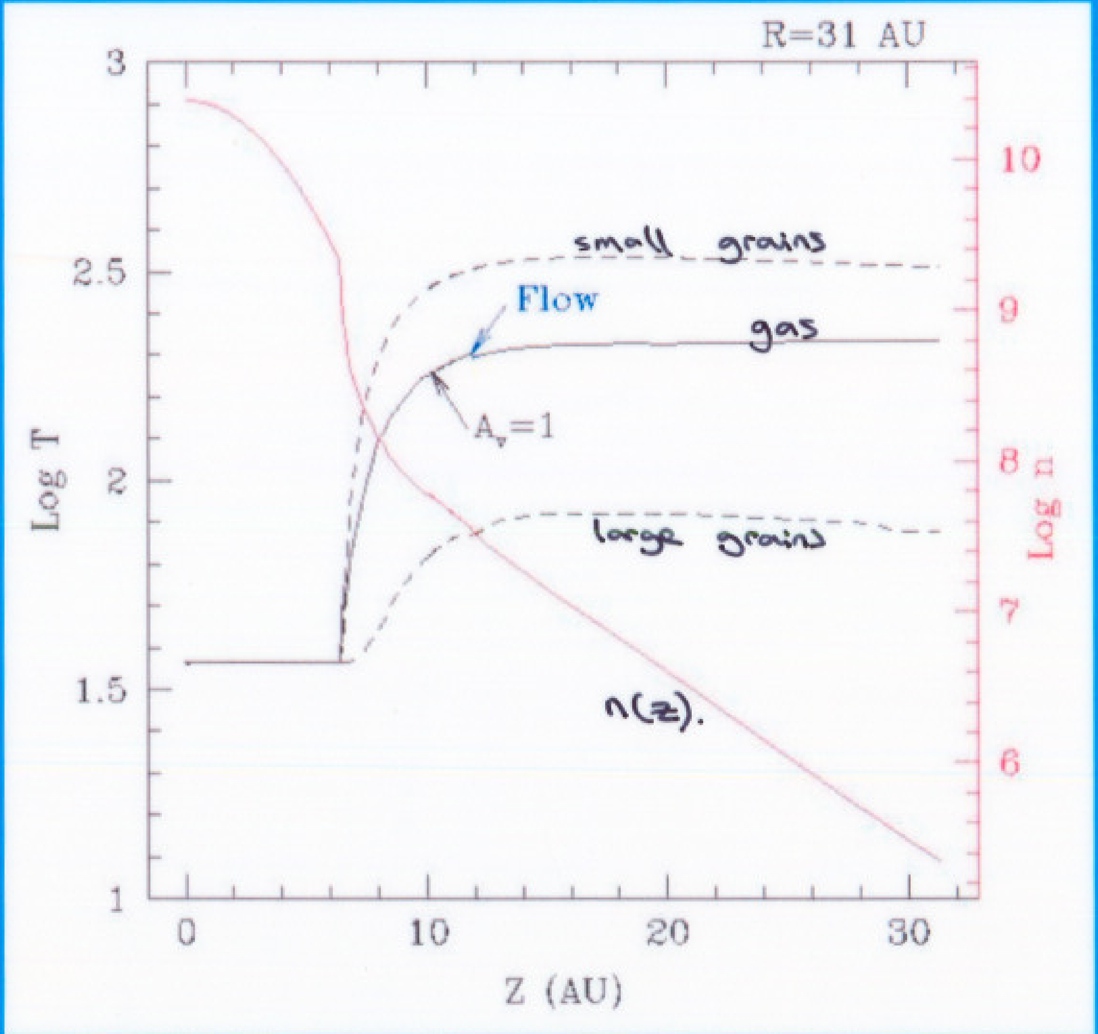
.... convergence can be difficult.

- ... even harder:

using $n(r, z)$ to estimate $\dot{M}$!

C. Photoevaporation by Central Star (FUV, EUV+Xrays)

$M_* = 1\ M_\odot$, $L_* = 2.3\ L_\odot$, $L_X = 6\times10^{-4}\ L_\odot$, $L_{FUV} = 0.28\ L_\odot$



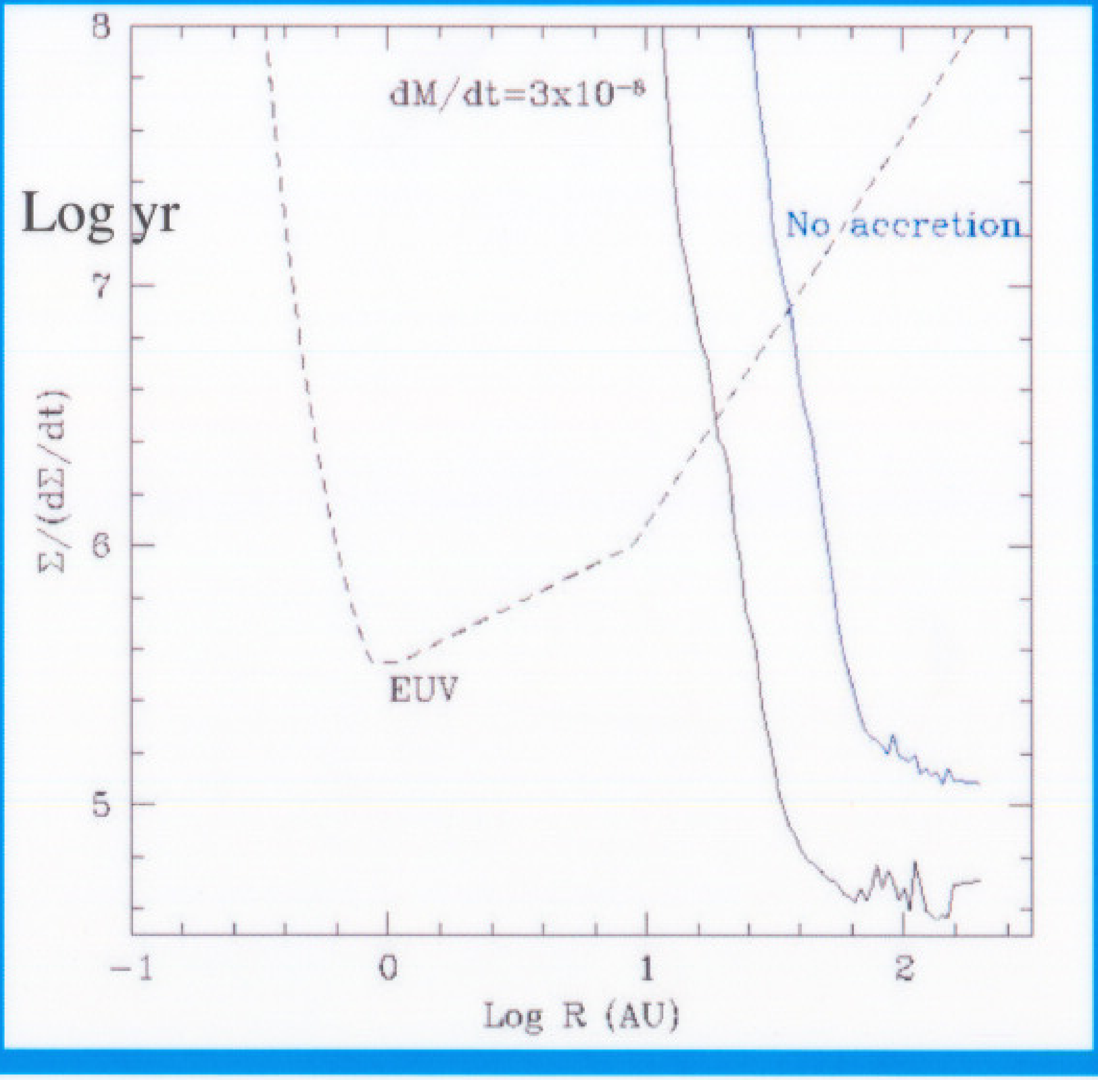
Gorti & Hollenbach in prep.

Gorti and Hollenbach in prep.

C. Photoevaporation by Central Star (FUV, EUV+Xrays)

$M_* = 1\ M_\odot$, $M_d = 0.03\ M_\odot$, $L_* = 2.3\ L_\odot$, $L_X = 6\times10^{-4}\ L_\odot$,

provisional results!



$L_{FUV} = 0.28\ L_\odot$ (accreting)

$L_{FUV} = 1.2\times10^{-3}\ L_\odot$ (non-accreting)

Grains have 0.1 of UV/optical opacity Of ISM grains.