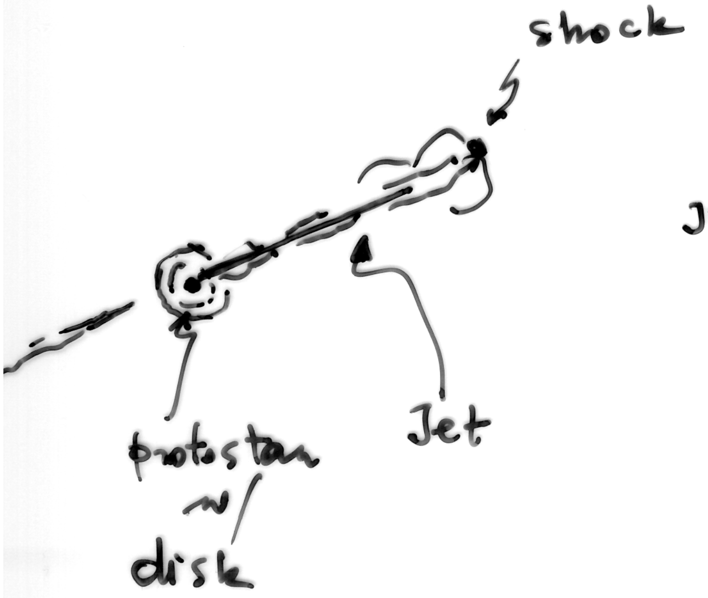


JETS FROM PROTOSTARS

MASS CONSERV

$$\frac{\partial \rho}{\partial t} + \mathrm{div}(\rho \vec{v}) = 0$$

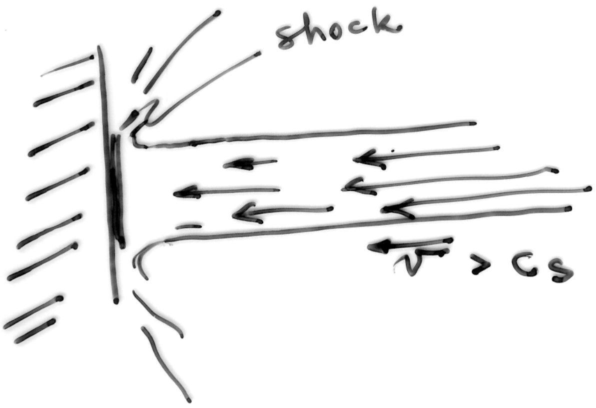
MOMENTUM CONS

$$\frac{\partial \rho \vec{v}}{\partial t} + \mathrm{div}(\rho \vec{v}\vec{v}) = -\nabla p \quad \left(+ \rho \vec{g} + \text{viscosity etc}\right)$$

if needed

$$\frac{\partial}{\partial t}\left(\rho\left(\epsilon + \frac{1}{2}v^2\right)\right) + \mathrm{div}\left(\rho\left(\epsilon + \frac{1}{2}v^2\right)\vec{v}\right) = -\mathrm{div}(p\vec{v})$$

ENERGY CONS



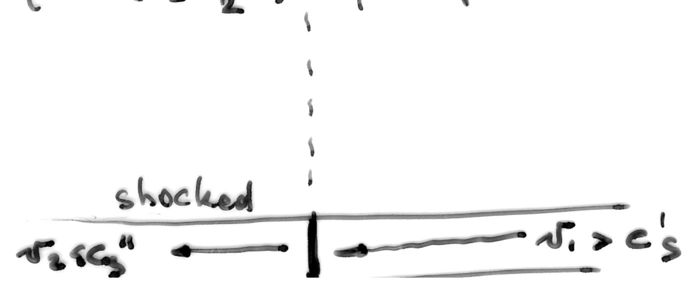
THOSE EQUATIONS BECOME

RANKINE-HUGONIOT EQUATIONS

$$\rho_2 v_2 = \rho_1 v_1$$

$$p_2 + \rho_2 v_2^2 = p_1 + \rho_1 v_1^2$$

$$p_2 v_2 + \rho_2 v_2\left(\epsilon_2 + \frac{1}{2}v_2^2\right) = p_1 v_1 + \rho_1 v_1\left(\epsilon_1 + \frac{1}{2}v_1^2\right)$$



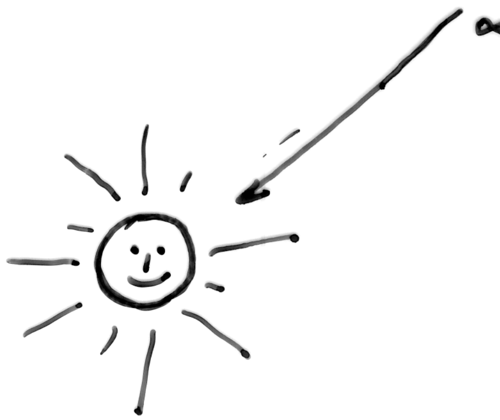
Very strong shock $\Rightarrow$ $\rho_2/\rho_1 = 4$ (max value!)

i.e. $v_2/v_1 = \frac{1}{4}$

i.e. kinetic energy per particle (per unit mass) $= 1/16$

$T_2 >> T_1$; $T_2 \sim \frac{3}{16} \frac{\langle m \rangle v_1^2}{k_B}$

if matter falls from ∞ onto the Sun?



$K = + \frac{G M_\odot}{R}$

$\frac{1}{2} v^2 = + \frac{G M_\odot}{R}$

$T_2 \sim \frac{3}{16} \frac{\langle m \rangle}{k_B} \cdot \frac{2 G M_\odot}{R_\odot}$

in a more general case

$T_2 \sim \left(\frac{3}{16} \frac{\langle m \rangle}{k_B} \frac{2 G M_\odot}{R_\odot} \right) \frac{M'}{R'}$ with M', R' in solar units

$\langle m \rangle \sim 2 \times 10^{+24}$ gm

$k_B \sim 1.4 \times 10^{-16}$ erg/°K

$G \sim 6.67 \times 10^{-8}$

$M \sim 2 \times 10^{+33}$ g

$R \sim 7 \times 10^{+10}$ cm

$T_2 \sim 10^{7}\,°K \dfrac{M'}{R'}$

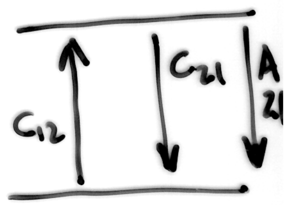
so it is very easy to achieve a few 10^6 falling onto a star

if you do not fall from ∞ but from the inner rim of an accretion disk and the star is larger (bigger R) than the Sun then T will be a few 10^6 just behind the shock

Material behind the shock will conduct & radiate so lower T (see presentations by Sacco) by R. Curran

METASTABLE LEVELS AND DENSITY-SENSITIVE LINES

FOR METASTABLE LEVELS SPONTANEOUS EMISSION IS RELATIVELY INEFFECTIVE

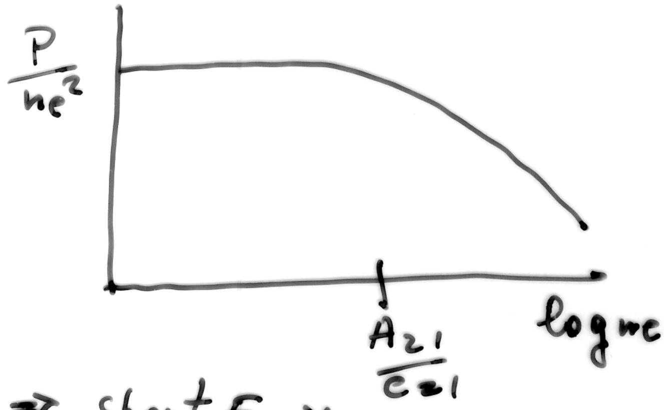


$$n_e \, n_1 \, C_{12} = n_2 \, n_e \, C_{21} + n_2 \, A_{21}$$

collisional excit — collisional deex — spontaneous emission

$$= n_2 A_{21} \left(1 + \frac{n_e C_2}{A_{21}} \right)$$

$$n_2 A_{21} = \frac{n_e \, n_1 \, C_{12}}{1 + \frac{n_e C_2}{A_{21}}}$$



low density ⇒ few collisions ⇒ spont Emission

high density ⇒ many collision ⇒ <u>no emission</u>

several lines

He-like Triplets

OVII ~ 10^6

Ne IX

Mg XI

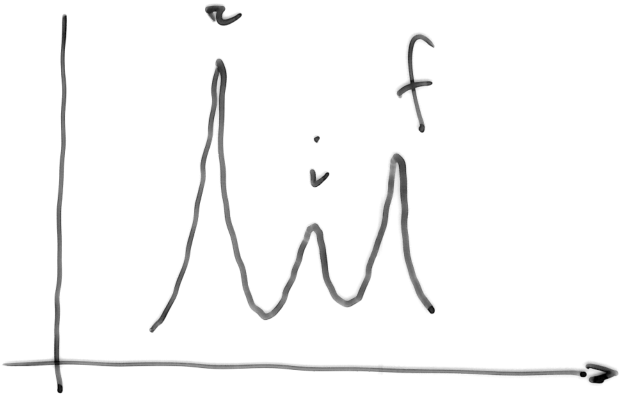
Si XIII

S XV

Ca XIX

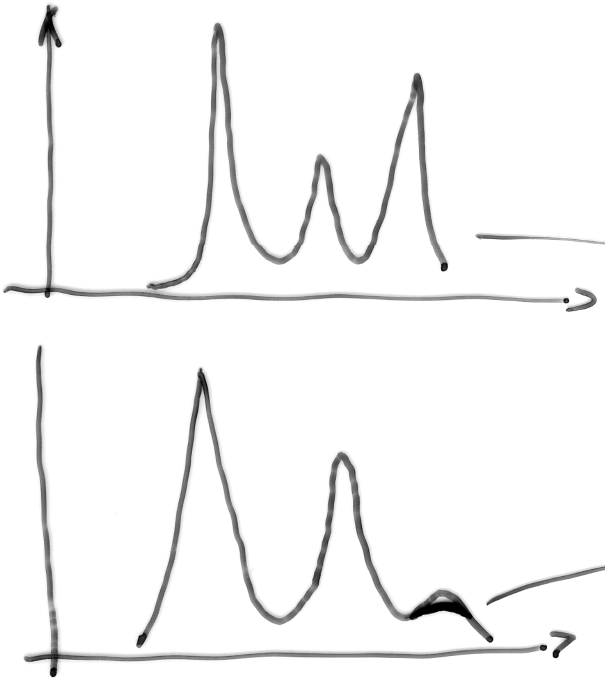
Fe XXV

(Si XIII to Ca XIX, arrow down:) Too high density

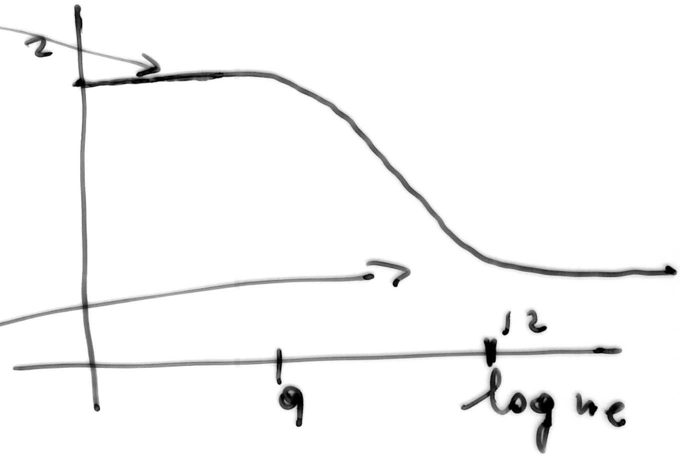


Take OVII triplet, forms at ~ 10^6
perfect for accretion shocks

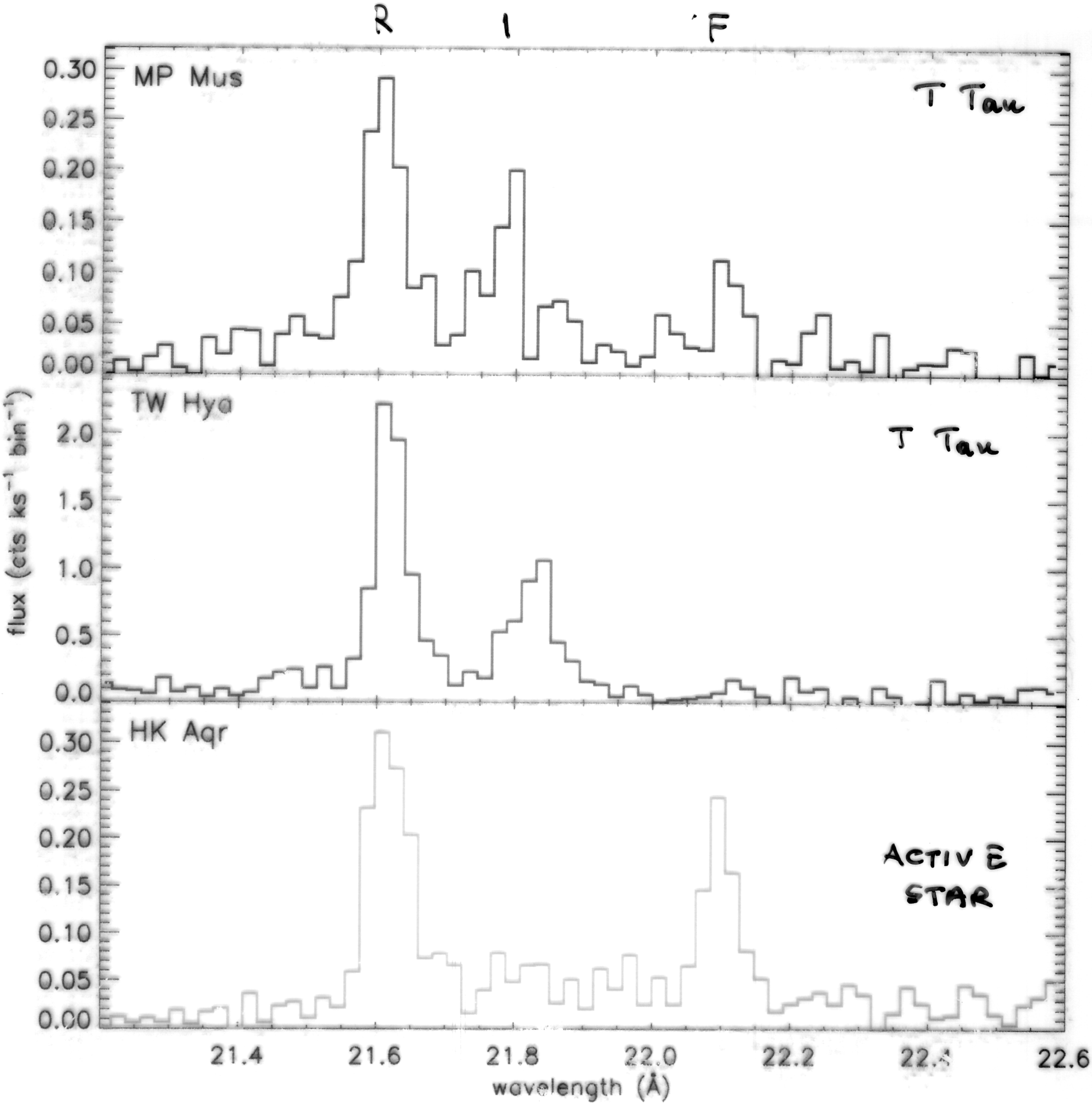
As (densityal) collisions increase the metastable level is de-populated in favour of other levels



the f/i ratio is density sensitive



But beware of UV field...



Almost in all (but one) stars w/accretion

ONLY in " " "

JETS

A FAST JET (FEW 10^2 km/s) WILL IMPACT ONTO THE CIRCUMSTELLAR GAS

$$T \sim \frac{3}{16} \frac{\langle m_0 \rangle v^2}{k}$$

$v \sim 200$ km/s enough for $T \sim 10^6$ relative to the shock

however the exact model is far from obvious

exact predictions require a hydro model with radiative losses and thermal conduction

<u>Bonito presentation</u>

- proper motion of the shock ≡ X-ray source
- hot cocoon not visible because of <u>self-opacity</u>!
- to fit observations, $\rho_{Jet} < \rho_{environ.}$ in most cases

X-ray emission from Young Stars

Several facets of physics come into play

- radiative phenomena
- non-thermal heating - (coronae)
- mechanical heating - (jets)

They inter-play often in a complex way

some are non-linear phenomena

May require complex radiation codes

" MHD "