ISM 02-12-2019 lecture 12

Extragalactic ISM and last gaps of intragalactic

Molecular clouds are self-gravitating.

Larsons laws

- size-linewidth relation

$$\sigma_v \approx 1.1 \left(\frac{\text{size}}{\text{pc}}\right)^{\gamma} \text{ km s}^{-1} \qquad \gamma \approx 0.5$$

so velocity dispersion scales sublinear with the size of the cloud

- For large clouds (100 pc), $\sigma_v \approx 11 \text{ km s}^{-1} \gg c_s$ thus we have strong, supersonic shocks.
- Clouds are in virial equilibrium.

$$M = X \frac{\sigma_v^2 L}{G}, \quad X \sim 1 \text{ (shape, density profile, etc)}.$$

Virial equilibrium between self-gravity and random motions. So gravity counterbalance is provided by non-thermal random motions : turbulent cells.

- Average ~~column~~ surface density of cloud is always close to

$$\Sigma = 100 \, M_\odot \, pc^{-2}$$

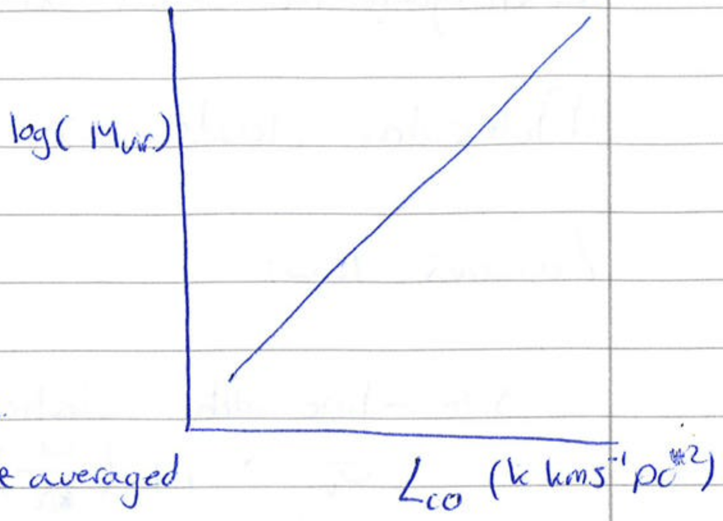
3rd and 1st rule combine to 2nd !

$$M = \Sigma A = \Sigma \underset{\substack{\uparrow \\ \text{size}}}{L}^2 = \Sigma L \sigma_v^2$$

We will use the virial equilibrium law a lot

ng Virial Theorem we can find relation
en CO luminosity and H_2 mass

y are M_{vir} and L_{co}
strongly coupled?



$$\sigma_v = \sqrt{\frac{GM}{5R}}$$

in pretend 2 level system.

$\bar{n}_\gamma$ direction ~~are~~ averaged
radiation field.

could go from optically thin to thick case

escape probability

$$A_{10} \rightarrow \cancel{A} \; \beta A_{10}$$
$$\bar{n}_\gamma \rightarrow \bar{n}_\gamma^{\,0}$$
1 = external radiation field.

$$\beta = \frac{1}{1 + \frac{1}{2}\tau_0}$$

$$\tau_0 = \frac{g_1}{g_2}\frac{A_{10}\lambda_{10}^3}{4(2\pi)^{3/2}\sigma_v} n_0 R\left(1 - \frac{n_1 g_0}{n_0 g_1}\right)$$

peak optical depth assuming
Gaussian profile

$$\tau_0 \propto \frac{M}{\sigma_v}, \quad M \propto \int \tau_v \, dv \propto \tau_0 \sigma_v$$

two $\int \tau_v dv$ are the same, their column
hes are the same.

$$\tau_0 = \frac{g_1}{g_2} \frac{A_{10} \lambda_{10}^3}{8\pi} \left(\frac{5}{2\pi G}\right)^{1/2} \frac{n_0 R^{3/2}}{M^{1/2}} \left(1 - \frac{g_0 n_1}{g_1 n_0}\right)$$

!

Now we calculate the ~~emissit~~ emissivity, we'd expect

$$I_\nu^{\text{op. thin}} = \int n_1 A_{10} \frac{h\nu}{4\pi} \phi_\nu \, dS = n_1 A_{10} \frac{h\nu}{4\pi} \phi_\nu$$

$$I_\nu^{\text{op thick}} = \int n_1 \beta A_{10} \frac{h\nu}{4\pi} \phi_\nu \, dS = n_1 A_{10} \frac{h\nu}{4\pi} \phi_\nu \frac{1}{1+0.5\tau_0}$$

$$\overset{\tau \gg 1}{\approx} n_1 A_{10} \frac{h\nu}{2\pi} \frac{\phi_\nu}{\tau_0}$$

Insert τ_0 equation

(...)

$$I_\nu = \frac{2k\nu^2}{c^2} T_B$$

$\int_B T \, d\nu$ [K km s^{-1}]

$$= \sqrt{\frac{2}{15}} \, 4\pi \frac{nc}{h} \left(\frac{G m_H \mu}{n_{H_2}}\right) \frac{N_{H_2}}{\exp(h\nu/kT) - 1}$$

$$\mu = \frac{\langle m \rangle}{m_{H_2}} \approx 2.8 \text{ in average mol. cloud.}$$

So indeed signal $\propto$ column density

Dependence on:

- column density
- temperature
- $X_{CO} = \cancel{X_{CO}(\rho, T)}\ X_{CO}(n_{H_2}, T_{ex})$

This works if every cloud has on average ~~the~~ about the same structure.

can understand that T roughly constant
side radiation sets it. Every ~~do~~ cloud ~~at thus~~ ~~as~~ has their own T, ~~it~~ Th temperature

omline : we can use CO as H_2 ~~m~~ mass
~~g~~ ~~esty~~ estimate. } sleepy

~~comparable way~~ de...
can also derive mass using dust
ion. thus both CO (1-0) + dust. ~~m~~

agalactic ISM
trongly star forming regions
- stars form in molecular clouds
- virial equilibrium
- if not, would collapse in freefall time
with no support : $SFR|_{milkyway} \sim 1300 \, M_\odot \, yr^{-1}$
actually $SFR \sim 3 \, M_\odot \, yr^{-1}$
support (random motion) need to be updated
continuously because quickly go down.
eg ULIRGS have SFR of 100's $M_\odot \, yr^{-1}$

$$\text{IRGs} : \left\langle \frac{L_{FIR}}{M_{H_2}} \right\rangle = 100 \, L_\odot \, M_\odot^{-1}$$

$$\text{lky Way} : \quad " \quad " \quad = 1.5 \, L_\odot \, M_\odot^{-1}$$

$$\text{on} : \quad " \quad " \quad = 400 \, L_\odot \, M_\odot^{-1}$$

ULIRGs form stars with ~~efficeen~~ efficiency of
but then for whole galaxy!

WISE : PAH
↓
small dust grains
↓
IRAS dust

ULIRG power source
Most lines obscured due to dust. Need to go to millimeter lines. → mostly molecular lines.

Star formation : radiation mostly in UV
→ ~~PDR~~ PDR (photon dominated)
AGN: radiation is mostly x-ray
→ XDR
Observational differences
- presence / absence high excitation ~~lo~~ fine structure lines
- " " " " CO "

AGN galaxy : [SIX], [NeV] etc, very high excitation lines

X-rays penetrate much deeper than UV. Dust heating is much more efficient in PDRs than in XDRs.
*Gas heating is much more efficient in XDRs compared to PDRs (10 - 50 % vs <1 %).

Photo-electron effect : most energy ~~se~~ goes into dust grain, only little into gas on dust grain

OR : much higher CO lines. Warmer CO and
e of it.