AST393F **Spring 2007**
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Class 9 Notes

Explain how H_2 dissociation heating works (Figure 3.5)

$$n\Gamma_{pd} \propto n(H_2)\ k_{pump}$$

$$k_{pump} = \beta(\tau) \quad G_0\ e^{-2.6Av}$$

$\beta(\tau)$ is the "self-shielding" term.

<u>Question:</u> What is the exponential term there for?

Competition between gas and dust.

Only 10% of UV excitations leads to dissociation. 90% of the excitations decay to a bound but vibrationally excited state.

At very high densities ($n > 10^4\ cm^{-3}$), this can lead to gas heating.

<u>Question:</u> Why only when n is large?

(Competition between radiative and collisional decay).

<u>Question:</u> How can you tell *observationally* that you are in this regime?

In the low density limit, populations are determined by the selection rules in the downward cascade.

<u>Efficiency of vibrational de-excitation</u>

$$\varepsilon(H_2) \sim \underline{\left(\frac{E_{vib}}{h\nu}\right)}\ f_{H_2} \simeq 0.17\ f_{H_2}$$

f_{H_2} is the fraction of FUV photon flux pumping H_2 –competition between gas and dust.

$G_0/n < 4 \times 10^{-2} cm^3$ Why this dependence? H_2 forms is closer to the edge at high density.

Two level system 2eV

$$n\Gamma_{H_2} \propto n\gamma\, n_2^*$$

$$n_2^* = \frac{n(H_2)k_{pump}}{\gamma\, n_H + A + k_{pump}}$$

Question: Why do they start talking here about formation rates?

Chemical equilibrium – 10% destruction.
We can replace $n(H_2)\ k_{pump}$ with 9 $nn_H R$
It can dominate over PE at high density.

Formation heating and how this works –
Turns out to be most relevant behind dissociative shocks – where you get a temperature plateau from this effect.

Dust – gas heating

$$n\,\Gamma_{g\text{-}d} = nn_d\sigma_d \left(\tfrac{8kT}{\pi m}\right)^{\frac{1}{2}} (2kT_d - 2kT)\alpha_a$$

α_a = accommodation coefficient
= 1 ⇒ how gas adjusts to T_d

Question: Why is this not always a heating mechanism?

Question: What happens when densities get large?

Question: Where is this mechanism most relevant?

CR Heating

Question: What's the scenario?
The energy in the primary electron is ~ 35 eV
Elastic collisions or secondary ionization

Question: Why is it primarily low-E CR's that produce the heating?
More of them, larger cross-section.

Question: Why can't we measure their flux directly. How do we determine it?

Question: Where is this mechanism relevant and important?

$$n\Gamma_{cr} = n\zeta_{cr}\, E_h\, (E, x_e)$$ no attenuation term

X-ray heating

$$n\zeta_{xr} = 4\pi n \int \mathcal{N}_{xr}(\nu)\, e^{-\sigma(\nu)N} \sigma(\nu) d\nu$$

Question: Where do the x-rays come from?

Question: Where is this mechanism likely to be important?

Fig 3.6 Harder photons go further so why do the curves rise? E^3 in y axis.

Turbulent heating
The ISM is highly turbulent. Energy is injected into gas motions on large scales by supernovae and stellar and protostellar winds, cascades down to smaller scales where it is dissipated

Energy flows through the system

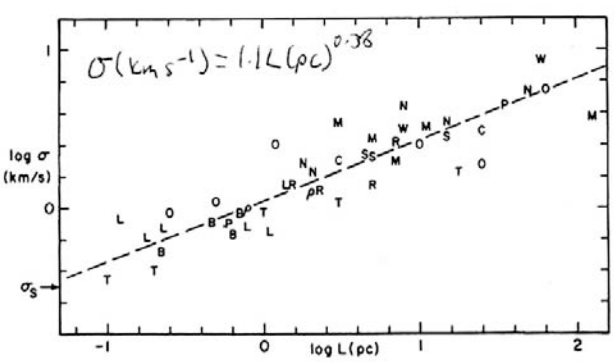
$$\dot{\varepsilon} = \underbrace{v^2}_{\text{kinetic energy}}/\underbrace{(\ell/v)}_{\text{crossing time}} = \text{constant}$$

Energy density at scale $k = 2\pi/\ell$ is dv^2/dk

$$E(k)\, dk = \tfrac{2}{3} (2\pi\dot{\varepsilon})^{\frac{2}{3}} k^{-\frac{5}{3}} dk$$

Kolmogorov spectrum

If you assume this holds and you have constant energy flow, you can measure on one scale and know what the dissipation rate is.



The three-dimensional internal velocity dispersion σ plotted versus the maximum linear dimension L of molecular clouds and condensations, based on data from Table 1; the symbols are identified in Table 1. The dashed line represents equation (1), and σ_s is the thermal velocity dispersion.

Kolmogorov predicts $\sigma \propto L^{1/3}$

Larson gets $\sigma \propto L^{0.37}$

Ambipolar diffusion – critical ingredient of star formation.

- clouds partly supported by magnetic pressure – ions hold the field in place. It is significant and scales up as density rises.

Field lines push apart (slowly) and drag the ions with them.

Question: Why is this a heating mechanism?
Where is the energy coming from?

$$n\Gamma_{ad} = n_e n_n \; m \left\langle \sigma v \right\rangle v_d^2 \;\; \text{cm/sec}.$$

v_d is the drift velocity $\simeq 5 \times 10^3$ cm/s in molecular cores $\simeq$ 100 mph.

Gravitational Heating

My favorite example is skiing – you pay $50 bucks for a lift ticket, go wait in line for two hours, and get frostbite and add CO2 to the atmosphere to get higher in gravitational potential. You drop down through this potential, trying not to break a leg.

Question: Where does the potential energy go? Into the melting snow.

$$n\Gamma_{\text{gravity}} = \tfrac{5}{2}\; kT \; v \left|\tfrac{dn}{dr}\right| = \tfrac{15}{4}\; kT \; \tfrac{n}{\tau_{ff}}$$ is just work done during collapse

$$\tau_{ff} = \left(\frac{3\pi}{32 G n m_H}\right)^{\frac{1}{2}} \qquad \propto n^{-\frac{1}{2}}$$ independent of n.