Last time we've checked that the viscous force from "normal" gas friction is NOT efficient enough to form stars. In this lecture we'd like to resolve this problem.

Physics of star formation (continued.)

- Problem of insufficient viscosity

Recall $t_{vis} = \frac{R^2}{\nu_{vis}} \gg t_{SF} \sim 10^7 yr = 10 Myr.$

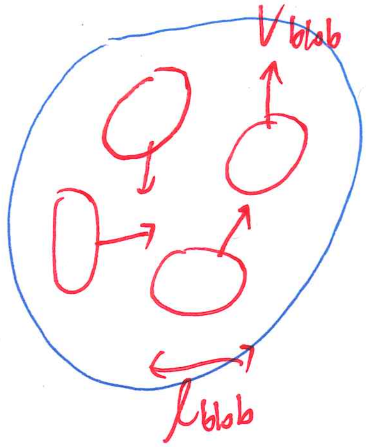
For "normal" viscosity $\nu_{vis} = \lambda_{mfp} \cdot c_s$

$\Rightarrow$ Find source of "anormalous" viscosity!

$\rightarrow$ turbulence!

Let's say we have a turbulent gas cloud. 03-29-2016

On large scale we can treat it as "blobs" of gas of size l_{blob}, moving at random velocity of V_{blob}.



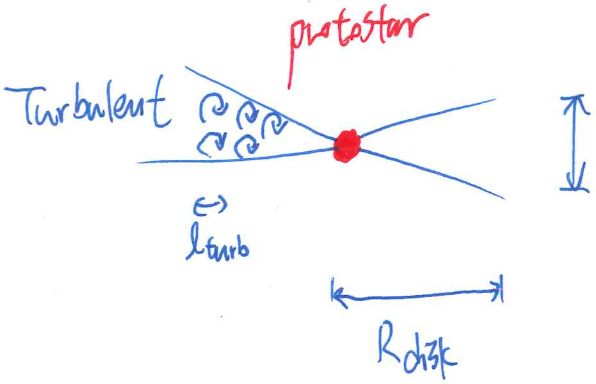
The "blobs" now act as the "particles" responsible for the random walk. We can write V_{blob} and l_{blob} assuming they are governed by turbulence:

$$V_{blob} \sim V_{turb}$$

$$l_{blob} \sim l_{turb}.$$

- Famous shortcut (for estimating "turbulent viscosity")

$\longrightarrow$ Shakura & Sunyaev (1973)



H = (pressure) scale height.

This is the mean-free path for the clouds to collide and dissolve, NOT the mean-free path for gas particle diffusion.

$$l_{turb} \simeq \text{"}\lambda_{mfp}\text{"} \lesssim H$$

$$V_{turb} \lesssim C_s$$

Then,

$$\underbrace{\nu_{vis}}_{\text{turbulent viscosity}} \lesssim C_s \cdot H \equiv \alpha \cdot C_s \cdot H$$

α = Shakura & Sunyaev parameter.

with $\alpha \leq 1$.

Quiz 11: Estimate t_{vis} for protostellar disk, assuming turbulent viscosity of $\alpha = 0.1$.

$$t_{vis} \simeq \frac{R^2}{\nu_{vis}} \quad ; \quad \nu_{vis} = \alpha C_s H.$$

With $R \sim 100\,AU$, $H \sim 10\,AU$,

$$t_{vis} \sim 10^6\,yr!!$$

Voilá, we have solved the key problem 03-29-2016
in star formation!

We will end this lecture by a case study of our own Sun:

Case Study — Formation of Solar System:

Step 1: Gravitational instability, i.e. $M \geq M_J$

$$M_J = 1 M_\odot \left(\frac{T}{10K}\right)^{3/2} \left(\frac{n}{10^5 cm^{-3}}\right)^{-\frac{1}{2}}$$

Step 2: Making of the accretion disk.

$$\dot{M}_{disk} = \frac{M_J}{t_{ff}} \sim \frac{C_s^3}{G} \sim 10^{-5} M_\odot yr^{-1}.$$

Step 3: disk gas falls onto protostar due to turbulent viscosity

$$\dot{M}_{acc} = 2\pi \nu_{vis} \cdot \Sigma \quad ; \quad \nu_{vis} = \alpha \cdot C_s \cdot H.$$

$$\Rightarrow \dot{M}_{acc} = 10^{-6} M_\odot yr^{-1}.$$

$$\therefore t_\odot = \frac{M_\odot}{\dot{M}_{acc}} \simeq 10^6 yr.$$

Formation time for the Sun.