

Class 15  $\rightarrow$

3/12/20

other mechanisms for turbulence

Photoevaporation

Disk winds

What is going on in disks:

Turbulence  
and Winds  
Evaporation

Conclusion: we don't know  
Show evidence

$$\text{Work out } \beta = \frac{P_{\text{thermal}}}{P_{\text{magnetic}}} = \frac{\rho c_s^2}{B^2/8\pi} = 2 \frac{c_s^2}{B^2/4\pi\rho} = 2 \frac{c_s^2}{v_A^2}$$

$$= \frac{n k T}{B^2/8\pi} = \frac{\rho}{m_H} \frac{k T}{B^2/8\pi} = 8\pi \frac{k}{m_H} \frac{\rho T}{B^2}$$

$$= \frac{8\pi \times 10^{-16}}{10^{-24}} \frac{\rho T}{B^2}$$

$$= 24 \times 10^8 \frac{\rho T}{B^2}$$

$$\approx 5 \times 10^9 \frac{\rho T}{2 B^2} \quad (\text{order of mag})$$

Turbulence  $\rightarrow$  Gravitational turbulence

at some point above, atmosphere becomes magnetically dominated  
 must have  $\nabla \times B \neq 0$  so that acceleration is finite. The field becomes free-free.

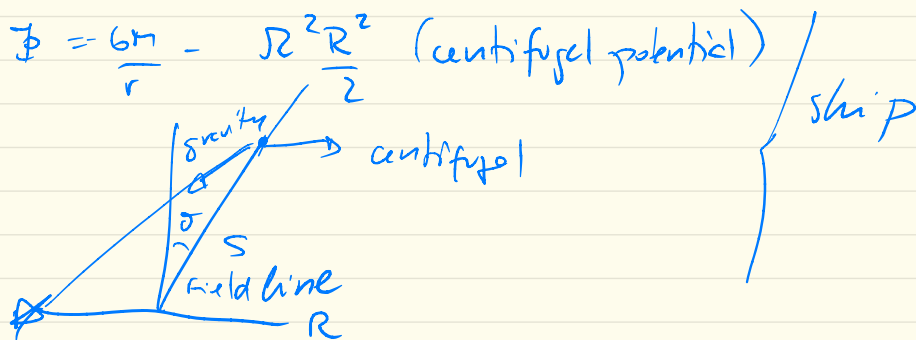
$\nabla \times B \approx 0$  as  $\rho$  decreases to keep acceleration finite

$$\frac{\nabla \times B}{\rho c} ; \quad \nabla = \frac{c}{4\pi} \nabla \times B$$

"force-free" above atm  $\rightarrow$  field straight to ensure the magnetic tension is small.

$$\rho v^2 = \frac{B^2}{8\pi} \quad \text{mag energy} = \text{kinetic energy (Alfven surface)}$$

Beyond Alfvén surface gas inertia bends lines, rotate in spiral.

$$\Phi = \frac{GM}{r} - \frac{\Omega^2 R^2}{2} \quad (\text{centrifugal potential})$$


The diagram illustrates a rotating system. A horizontal line represents the axis of rotation. A vertical line represents the field line. A curved line represents the centrifugal force vector, labeled 'centrifugal'. The distance from the axis to the field line is labeled 'R'. The distance from the axis to the centrifugal force vector is labeled 'S'. The angle between the field line and the centrifugal force vector is labeled 'α'. The angle between the field line and the axis is labeled 'θ'. A bracket on the right side of the diagram is labeled 'ship'.

## self gravity

$$t_{\text{free fall}} < \begin{cases} t_{\text{sound}} = \frac{2R}{c_s^2} \\ t_{\text{shear}} = \frac{2}{\Omega} \end{cases}$$

$$t_{\text{ff}} = \sqrt{\frac{3\pi}{32\rho}} = \sqrt{\frac{3\pi}{32} \cdot \frac{4\pi R^3}{32 \cdot G \cdot \rho M}} \approx \pi \sqrt{\frac{R^3}{86M}}$$

$$\pi \sqrt{\frac{R^3}{86M}} < \frac{2R}{c_s^2} \cdot \frac{2}{\Omega}$$

$$Q = \frac{c_s \Omega R}{\Sigma G T} \lesssim 1$$

## Photoevaporation