Turbulence in Molecular Clouds

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Physics 785

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Introduction

- Background and Basic Theory

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- Observational Evidence

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- Origins of Turbulence

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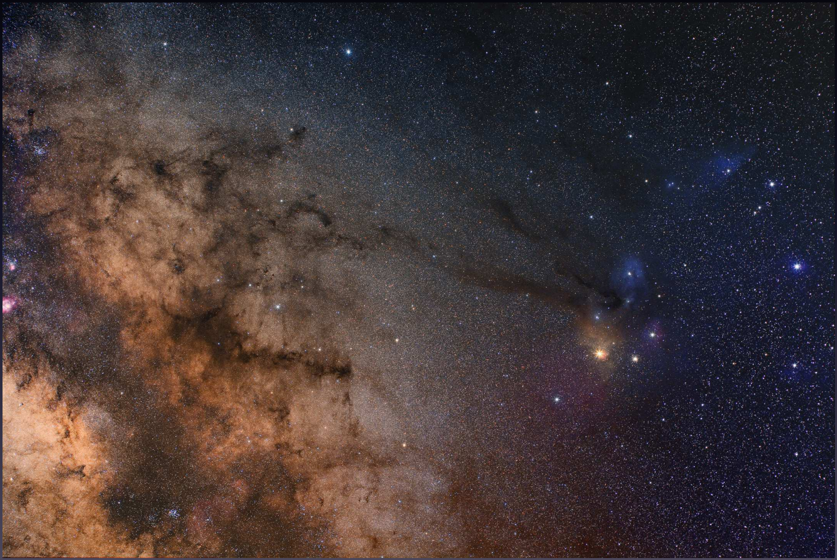
- Observational Evidence
- Origins of Turbulence
- Implications of Molecular Cloud Physics

Molecular Clouds

- Cold ($< 100K$) and dense ($> 100cm^{-3}$)
- Chemically and Structurally Complex
- Stellar Nurseries

Molecular Clouds



Kolmogorov's 1941 Theory

We begin by defining...

- Assume isotropic, homogeneous turbulence
- Two key hypotheses relating ν, ϵ

$$\eta = \nu^{3/4}\epsilon^{1/4}$$

$$\sigma = \sqrt{\nu/\epsilon}$$

- Characteristic Energy Spectrum

$$E(k) \propto \epsilon^{2/3}k^{-5/3}$$

Not the whole story...

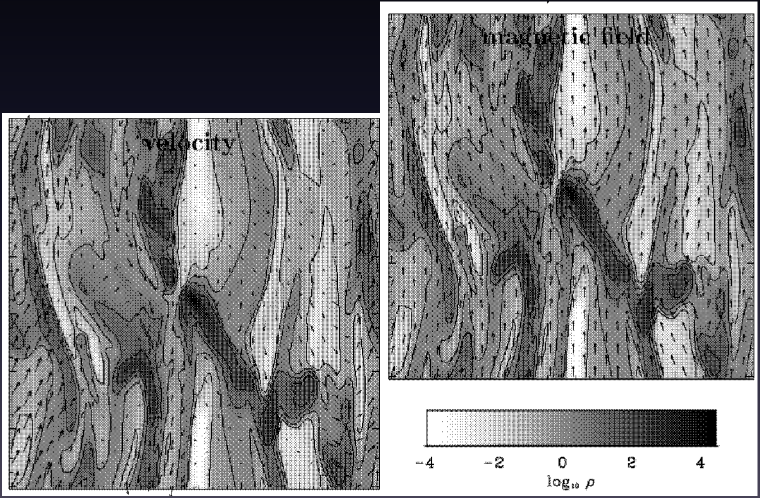
Real ISM Turbulence is...

- Compressible! (Turbulence in molecular clouds is often supersonic)
- Magnetized! (Molecular clouds have magnetic fields of a few 10s μG

MHD Turbulence

- Isotropy broken
- Power-law spectrum (-3/2 slope)
- Decays in roughly a crossing time
- Effects vs. hydrodynamic turbulence may be small

MHD Turbulence promotes filament/sheet growth



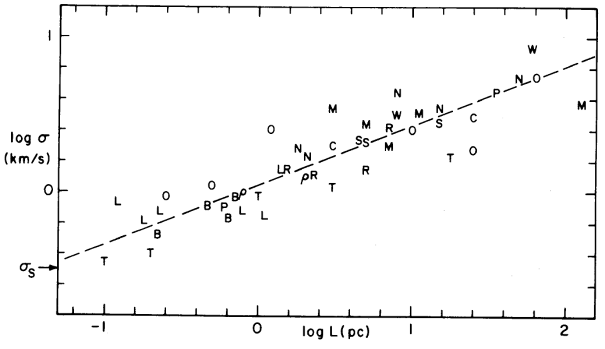
Observational Evidence of Turbulence

- Real-space Kolmogorov spectrum

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

- Power spectrum of density field
- Larson's 1979 and 1981 CO Observations

Larson's First Law



Slope of fit = 0.38

The Origins of Turbulence

- Turbulence decays in a few free-fall times
- What keeps it going?

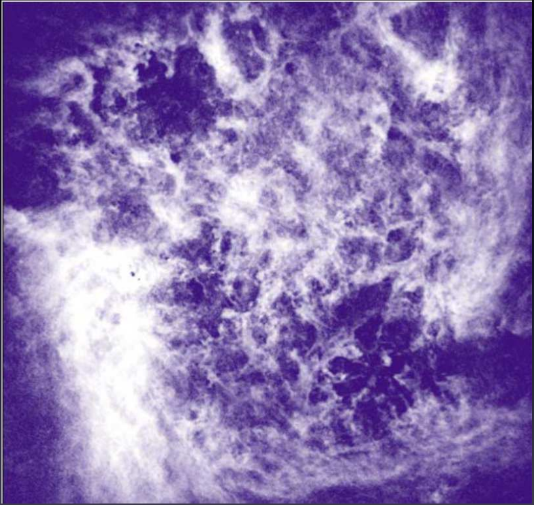
Feedback from Massive Stars

A typical supernova injects $\approx 10^{51} erg$ on a scale of $\approx 50pc$

The Effects on Clouds

- Cloud Formation
- Turbulent Support
- Chemistry
- Star formation & Cloud fragmentation

Cloud Formation



Molecular clouds can form rapidly from density perturbations in galactic-scale turbulence

Turbulent Support

- Why don't clouds just collapse?
- Chandrasekhar 1951 proposed turbulent support:

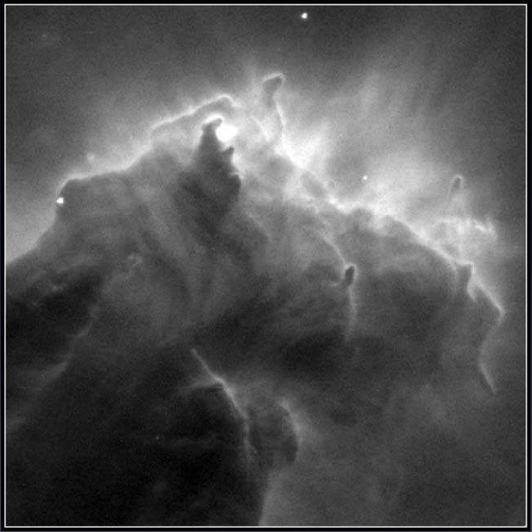
$$\lambda_J = 2\pi\sqrt{\frac{c_s^2}{4\pi G\rho}}$$

$$\lambda_{J-turbulent} = 2\pi\sqrt{\frac{c_s^2 + u^2/3}{4\pi G\rho}}$$

Cloud Chemistry

- Turbulence generates density, temperature anisotropies
- Turbulence can transport reactants and products between regions with different physical conditions

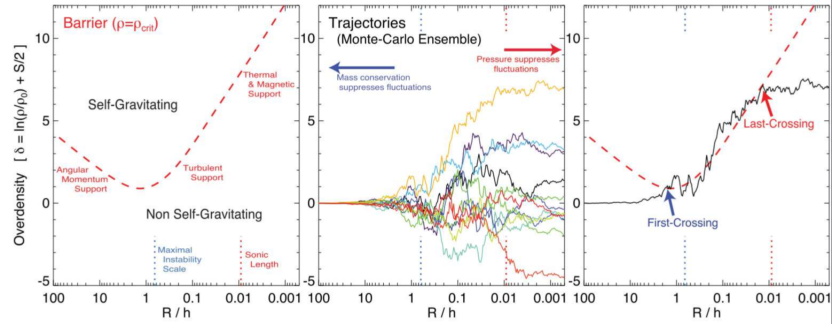
Chemical Transport



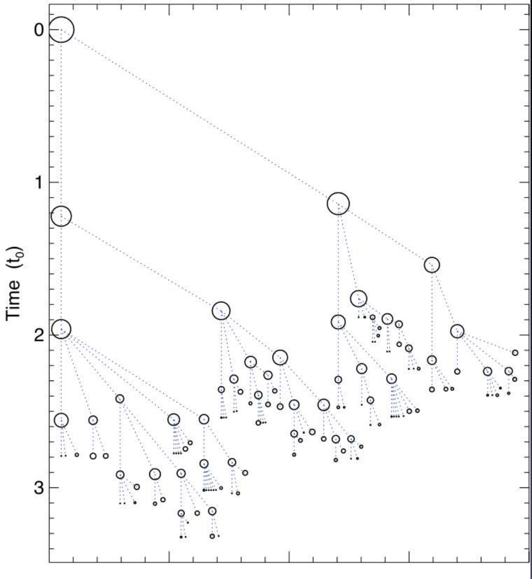
Star Formation within Clouds

- Turbulence can make sub-cloud structures just as easily as it can make clouds
- These clumps have a characteristic mass function that should be “set" by turbulence
- Hopkins 2013 has an analytic framework for generating mass functions from turbulence.

Turbulent Fragmentation



Turbulent Fragmentation



Conclusions

- Turbulence can build and destroy molecular clouds
- Turbulent pressure keeps clouds from rapidly collapsing to stars
- Turbulence promotes chemical reactions within clouds
- Turbulence may ultimately determine the mass functions for molecular clouds and the structures within them (cores and stars)

Questions?