

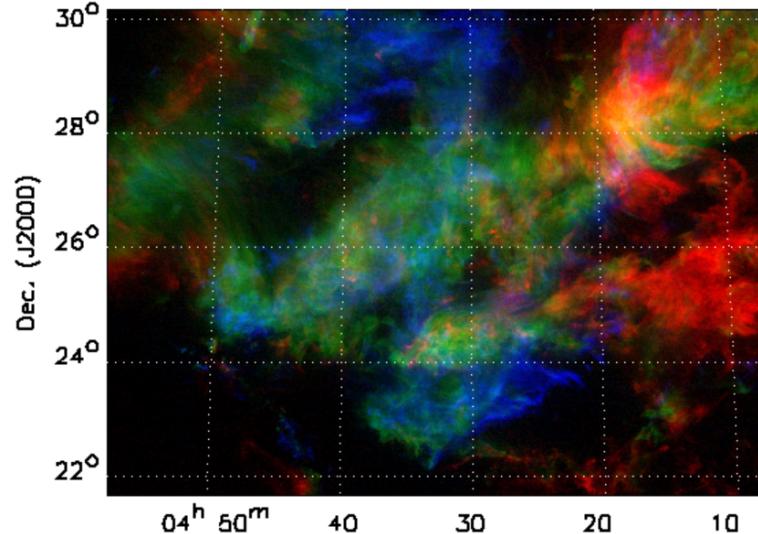
Velocity Anisotropy in ISM

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Advised by Blakesley Burkhart

Measuring anisotropy: A tale of two astrostatistics

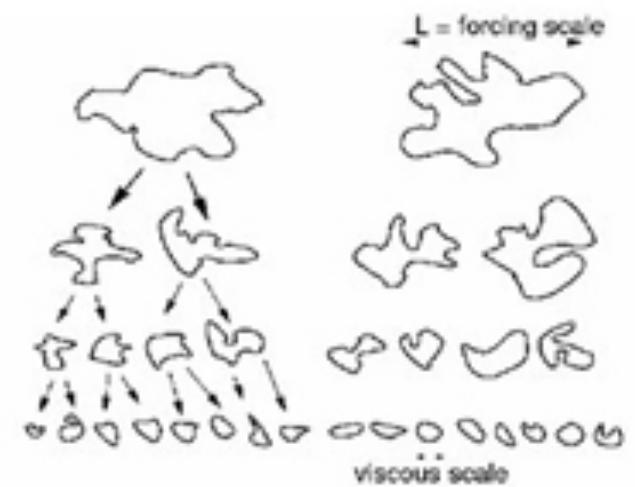
- Anisotropy is a result of MHD turbulence in a strong magnetic field
- Provides an indirect measure to the role of magnetic fields on gas
- Star formation

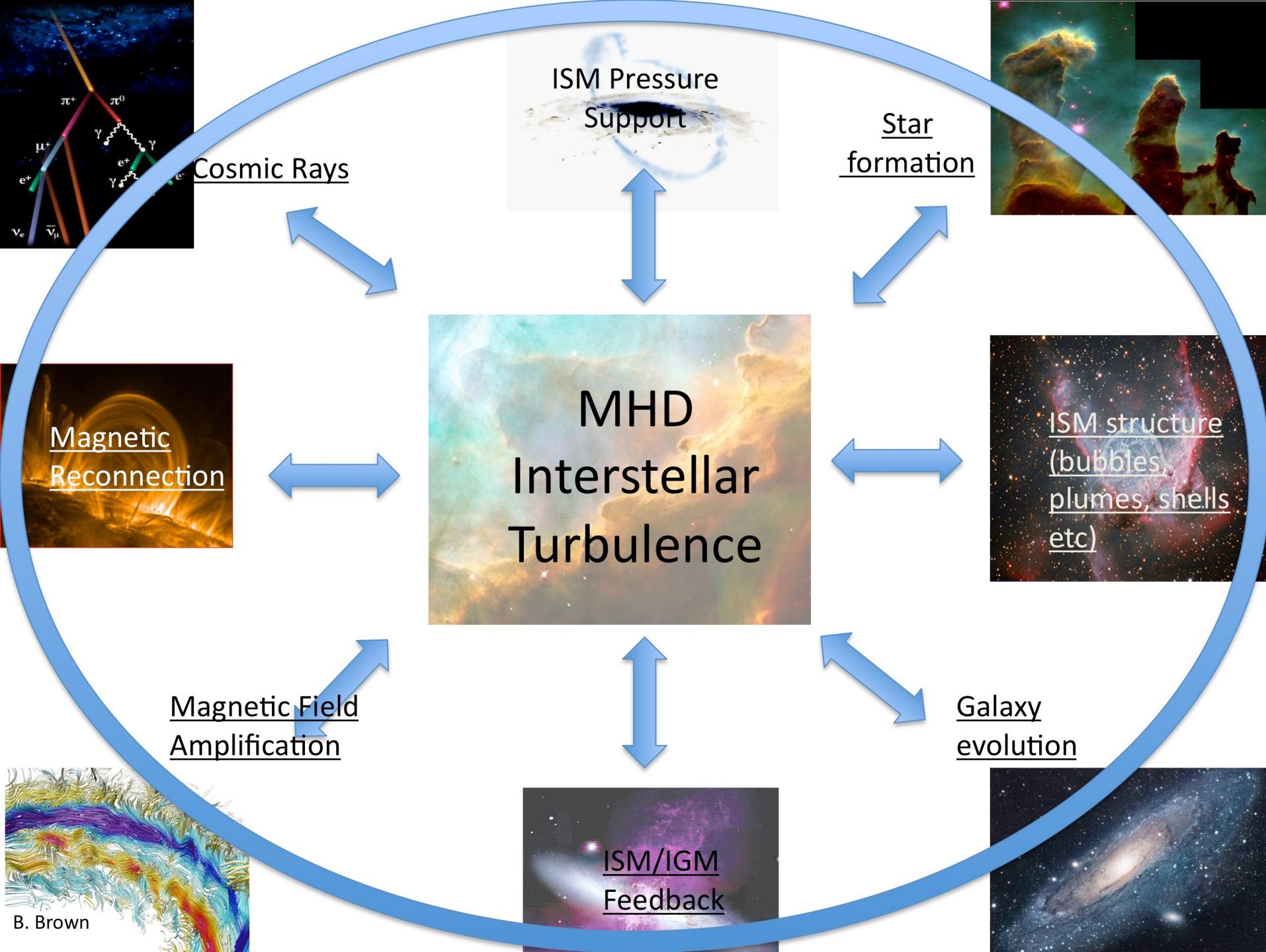


<http://www.astro.umass.edu/~heyer/taurus.html>

What is Turbulence?

Turbulence is not just 'chaos'. It has specific statistical properties which can be seen when averaged over time and space.





Observing Magnetic Fields

1. Polarization Emission
2. Zeeman Effect
3. Goldreich-Kylafis Effect

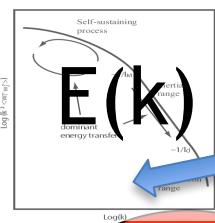
All require thousands of hours of telescope time

Is there an easier way?

Turbulence Statistics and their Dependencies

Burkhart et al. 2013b, c
Burkhart & Lazarian 2012
Burkhart Lazarian Gaensler 2012
Gaensler et al. 2011
Jacobelli et al. 2014

Probability Distribution Functions:
Column Density, L. Pol



Tsallis Statistics
Column Density

Tofflemire et al. 2011

Genus (topology):
Column Density & L. Polarization

Sonic Mach Number
 M_s

Power Spectrum (Structure function)
Column Density

M_A

Alfven Mach Number

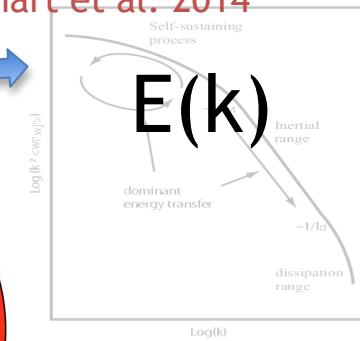
Phase Coherence

VCS/VCA
PPV

Bispectrum
Column Density

Velocity Anisotropy
Velocity Centroid

Chepurnov, Burkhart et al. 2014



Burkhart et al. 2013a

Burkhart et al. 2010a
Burkhart et al. 2009

Burkhart et al. 2013b, c
Burkhart Collins Lazarian 2014

Burkhart et al. 2014
Esquivel & Lazarian 2011

Burkhart & Lazarian in prep.

Alfvén Mach Number

- Measure of strength of a magnetic field

$$v_A = \frac{\langle B \rangle}{(4\pi\rho)^{1/2}}$$

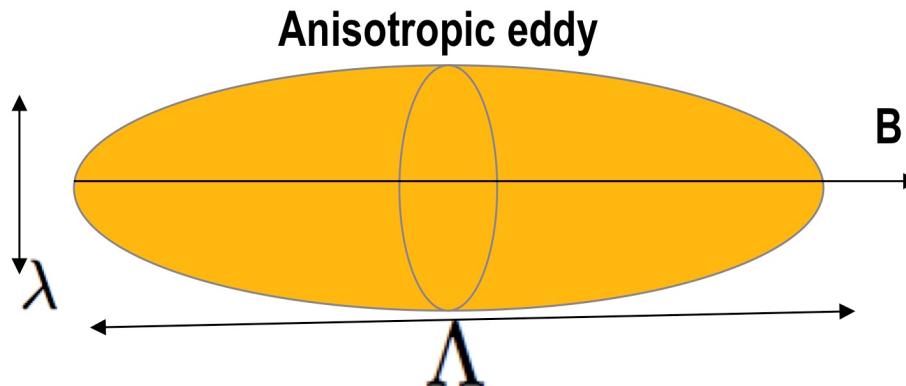
- Sub-Alfvénic if < 1
 - B field lines shape the plasma
 - strong magnetic field
- Super-Alfvénic if > 1
 - B field lines do not shape the plasma
 - weak magnetic field
 - leads to turbulent fragmentations & density seeds on which stars may condense

Velocity Anisotropy

- Eddies are elongated along the mean magnetic field creating anisotropy in turbulent flows

Structure function: a statistic describing this effect

$$SF(r) = \langle [f(x) - f(x + r)]^2 \rangle$$



<https://www.youtube.com/watch?v=fJ-MXqdOX1Y>

left B is aligned horizontally, right B is aligned along our line of sight
left we see elongation, right we don't

First Steps

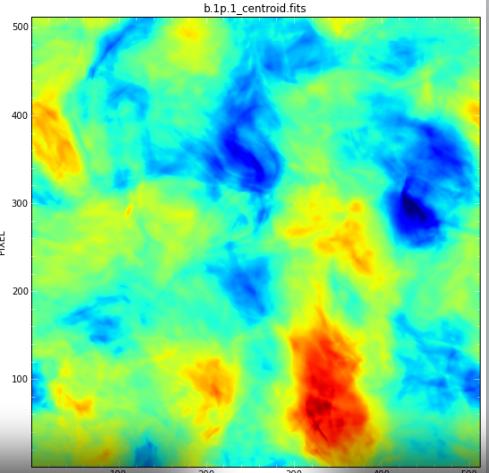
Investigate velocity anisotropy of computational simulations with varying degrees of magnetic field strength and Alfvénic Mach number

- Calculate the first moment/velocity centroid of the simulation data
- Calculate the structure function and display the results in contour maps
- Find the ellipticity of these contours as a measure of anisotropy index
- Compare anisotropy index with Mach number

Simulations

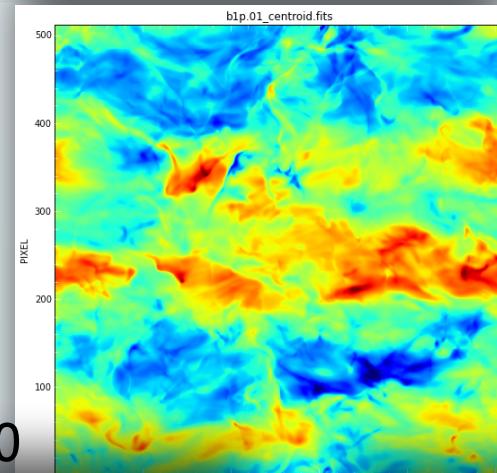
No radiative transfer

dn8000



$b=0.1,$
 $p=0.01$

dn8000

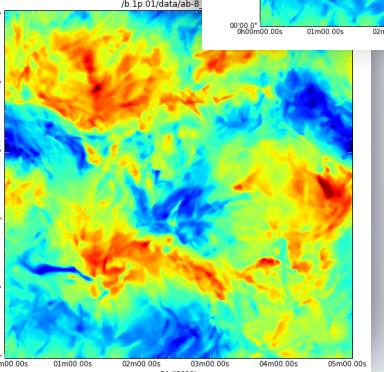


$b=1,$
 $p=0.01$

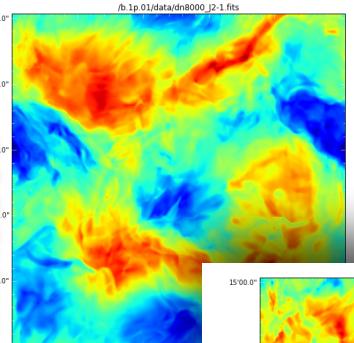
dn275

Radiative transfer included

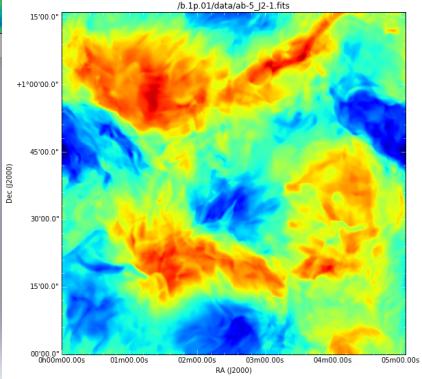
ab-8



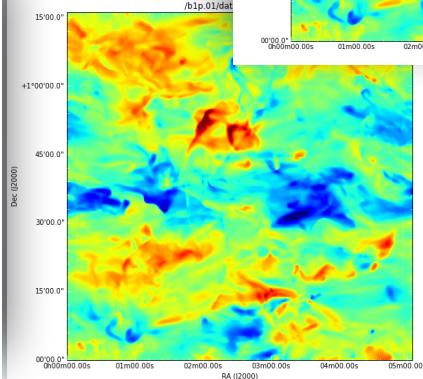
dn9



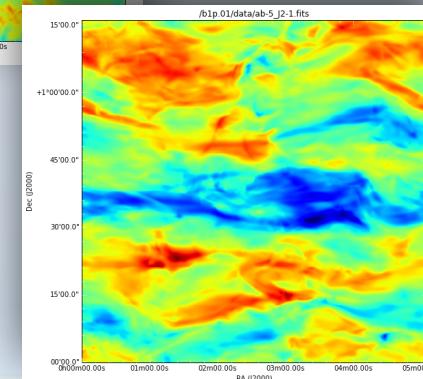
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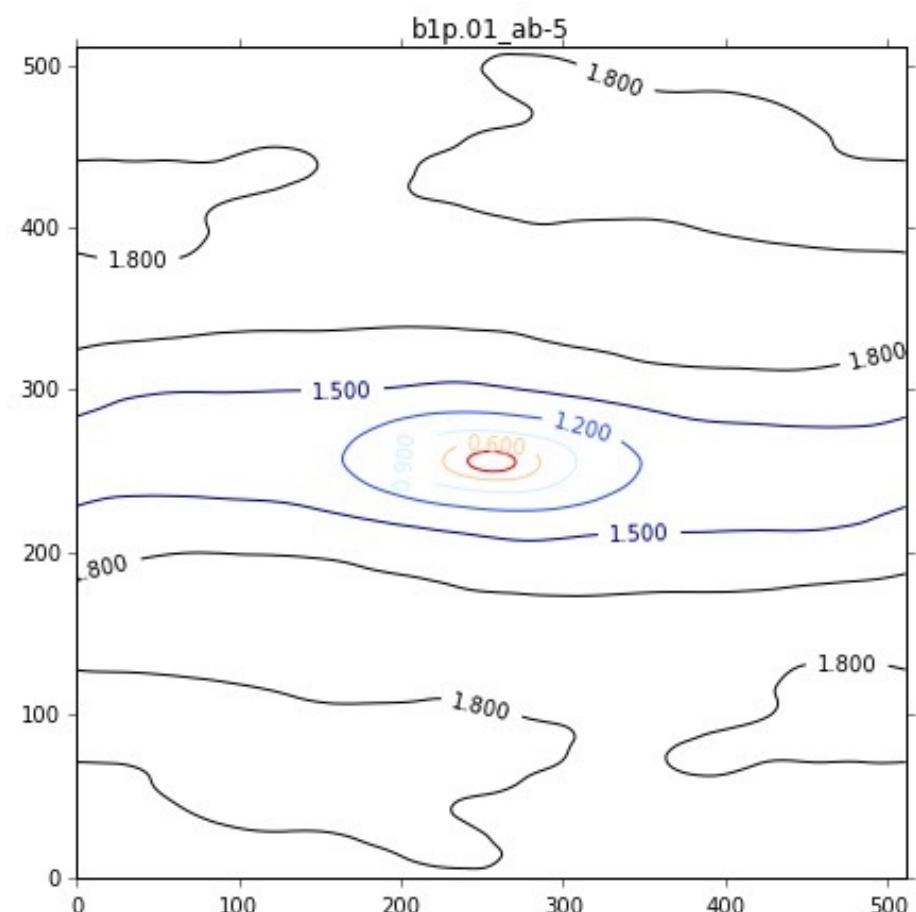
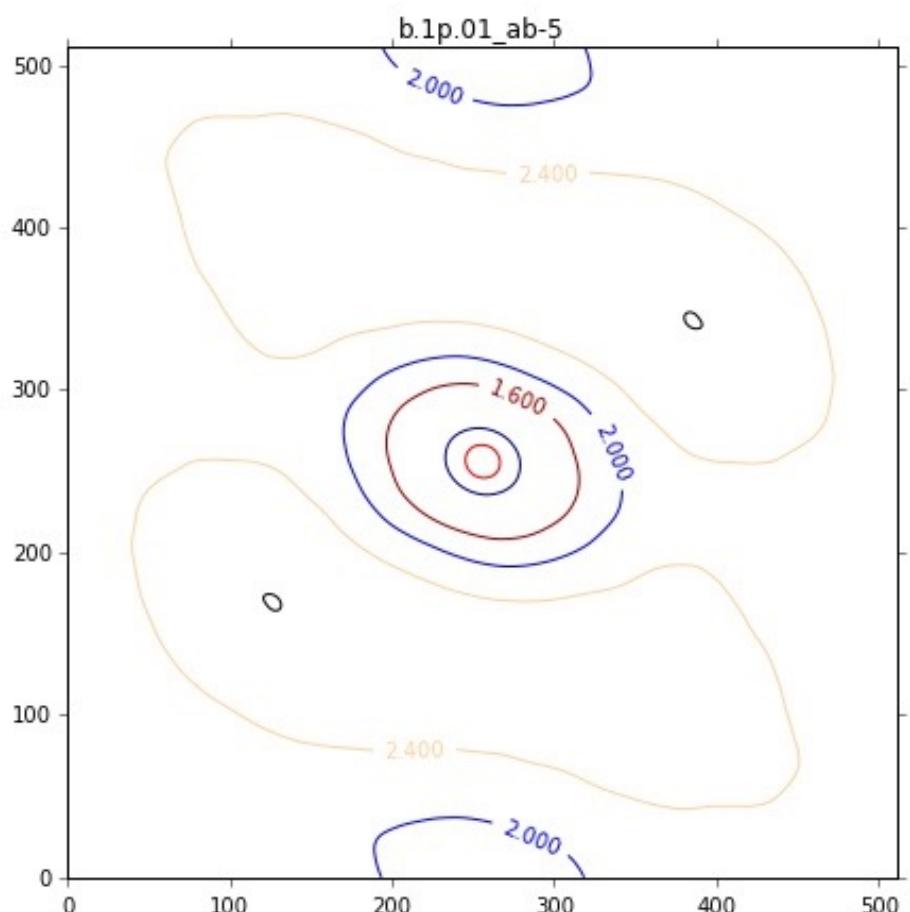


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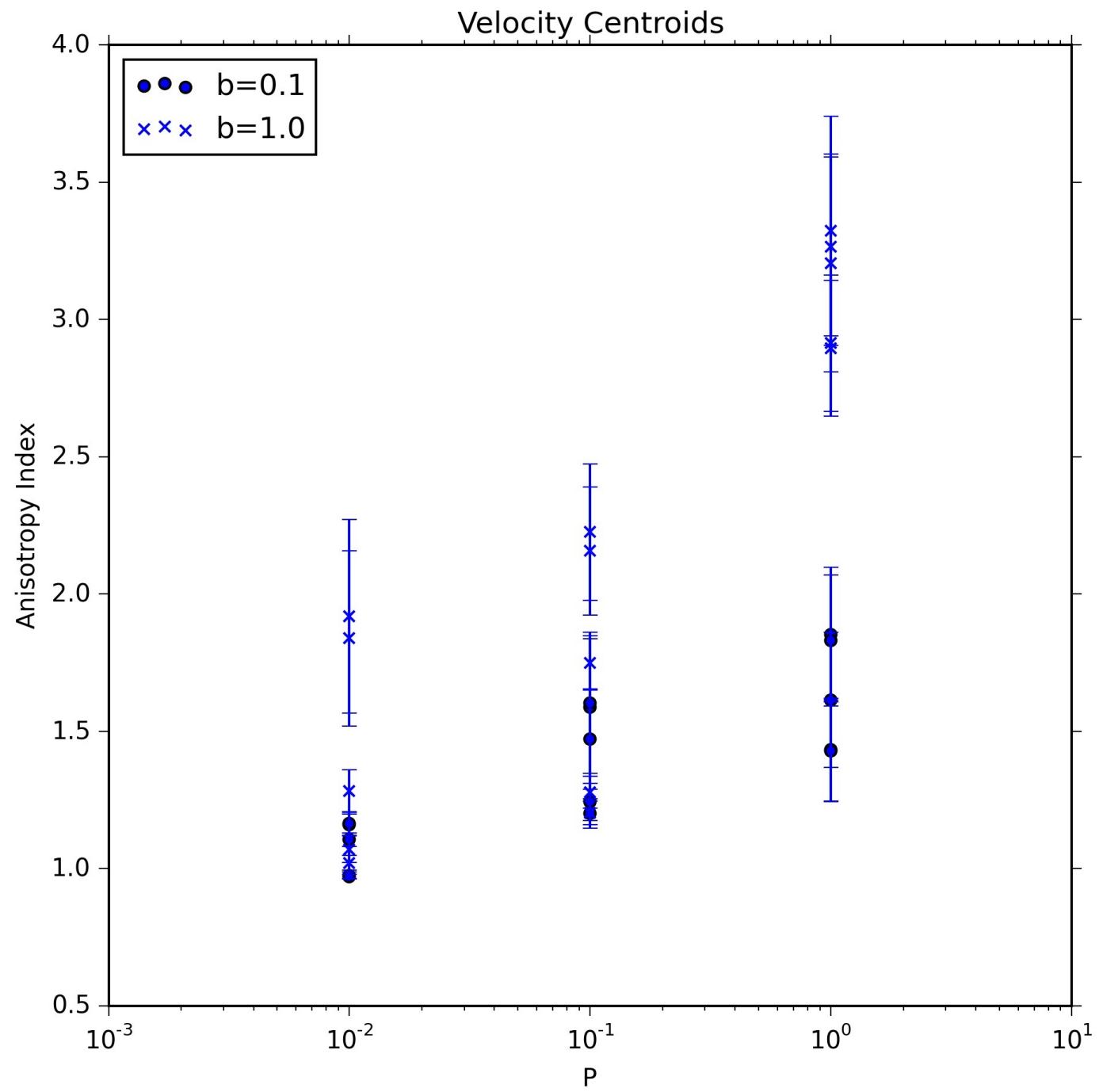


Structure Function Contours

Contour SF



Anisotropy Index vs Mach number



Next Steps

- Apply process to Taurus molecular cloud wide field spectroscopic imaging of ^{12}CO and ^{13}CO $j=1-0$ emission
- Heyer and Brunt 2012
- Optical polarization has been observed
- Will compare statistical results to observed polarization
- Check for correlation of SFR and magnetic field