Gauging Low-metallicity Turbulence in the Small

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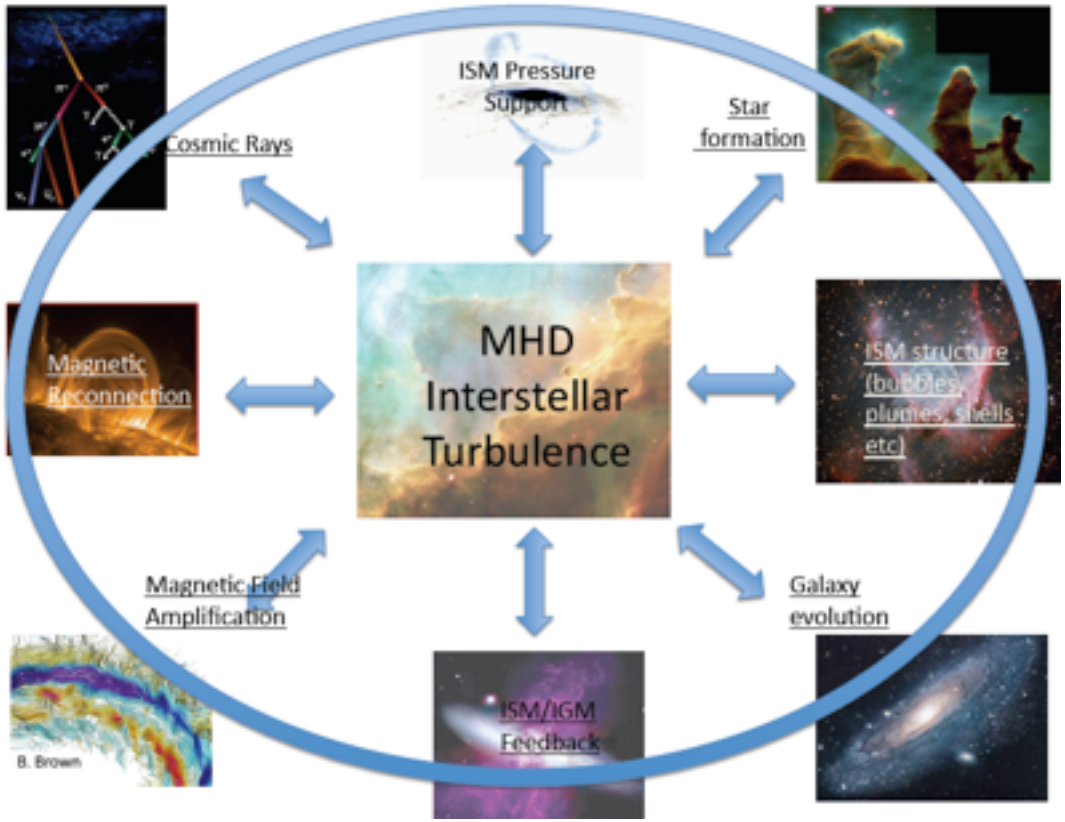
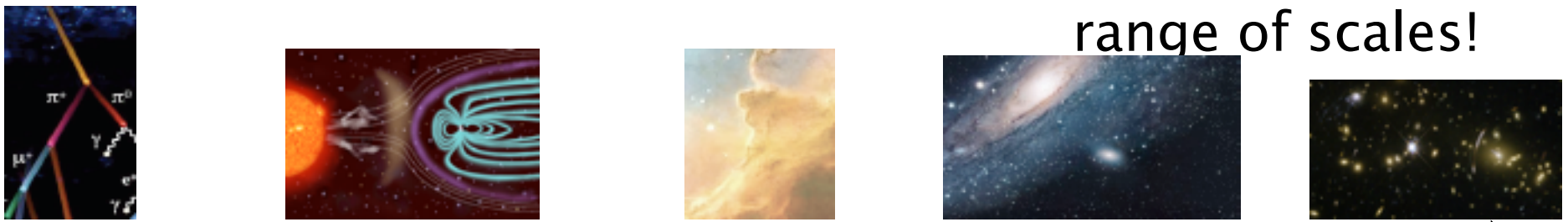


Magnetic fields & turbulence are critically important for many astrophysical processes in low and high metallicity regions....

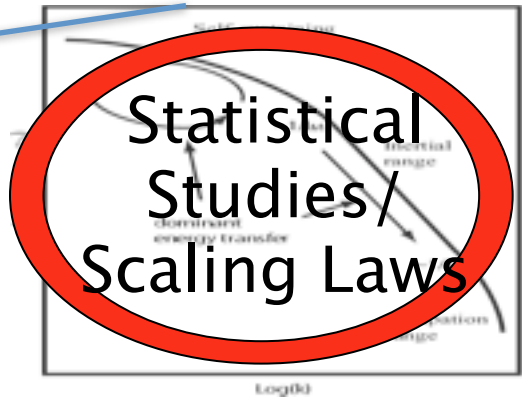
...and connect a wide range of scales!

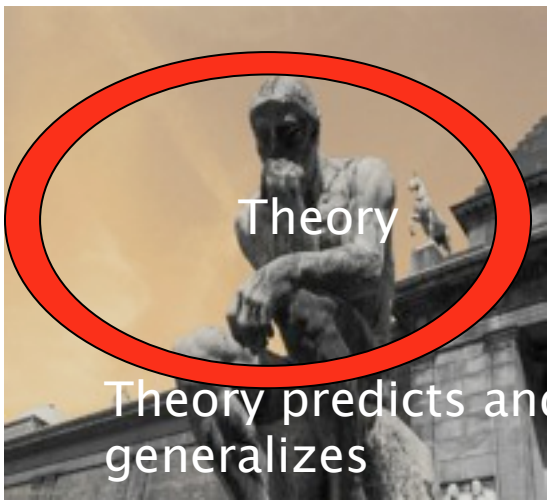


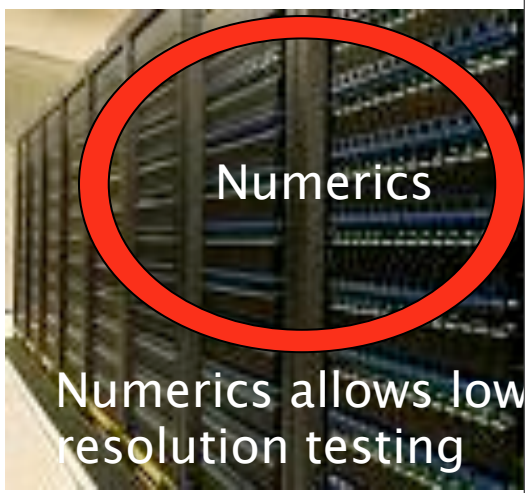
Sub AU AU Pc Kpc Mpc

The story of this talk: How to Study Turbulence From the Observations?

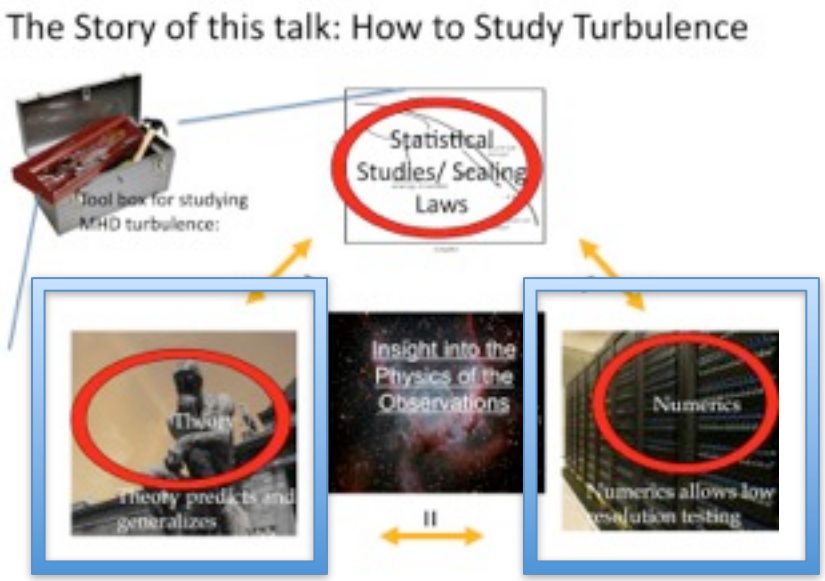
Tool box for studying MHD turbulence:



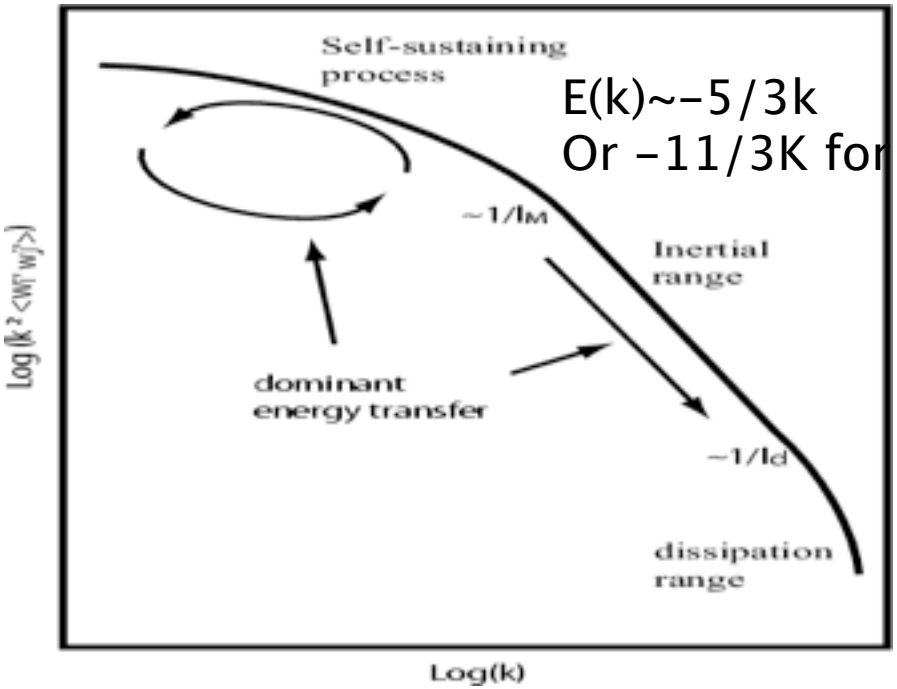




Q. What Information do we need to study turbulence?



Ultimately….we need the cascade!

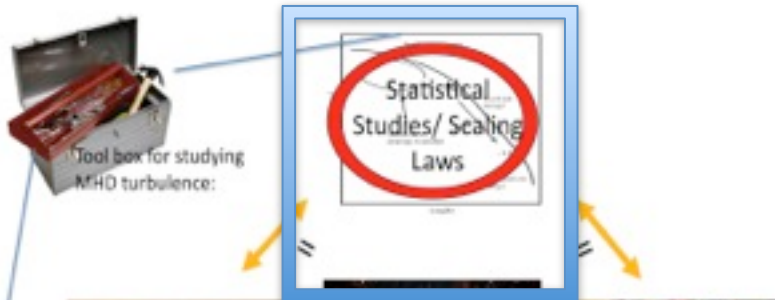


Inertial range slope gives the cascading rate and depends on the compressibility and (to a lesser
extent) the magnetization.

Question: How to obtain sonic Mach number, power spectrum, and magnetization in ISM observations?

Q. How to Obtain Information on MHD Turbulence?

The Story of this talk: How to Study Turbulence



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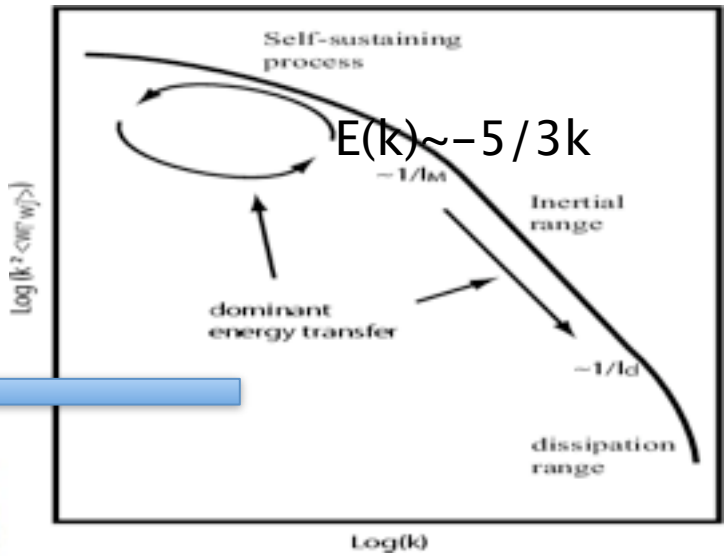
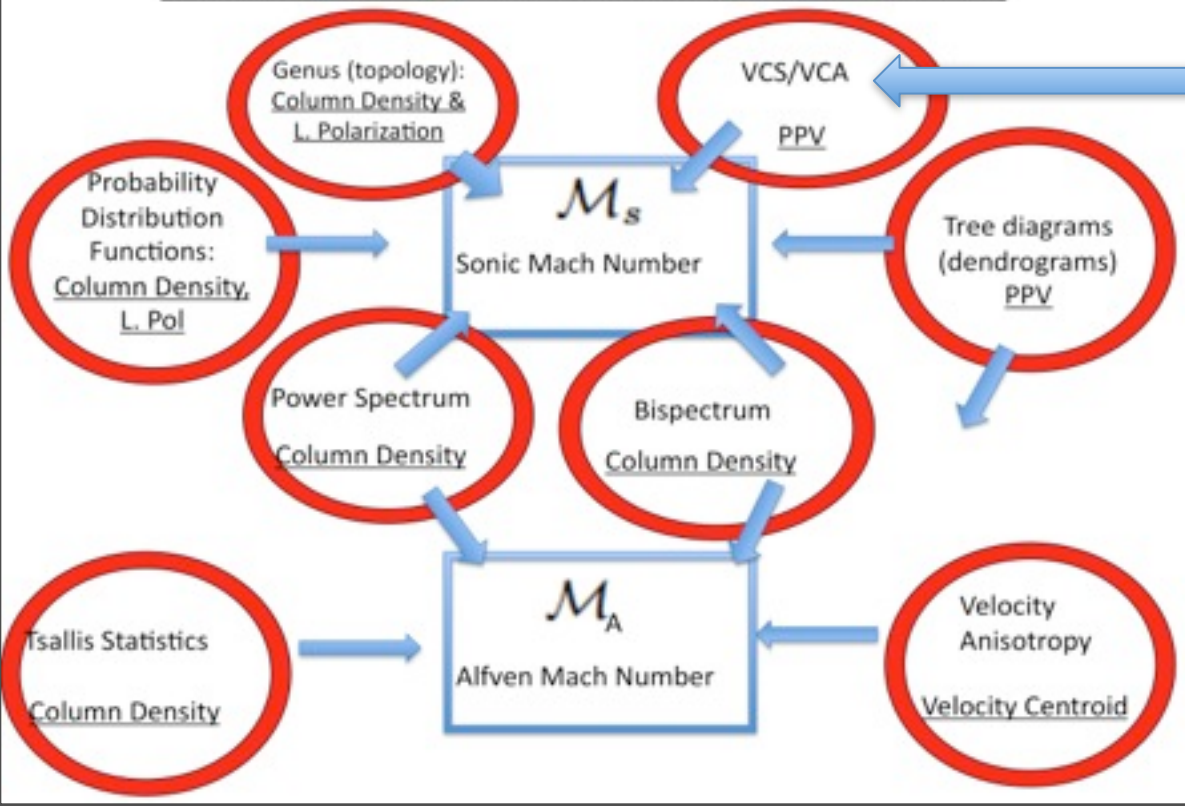
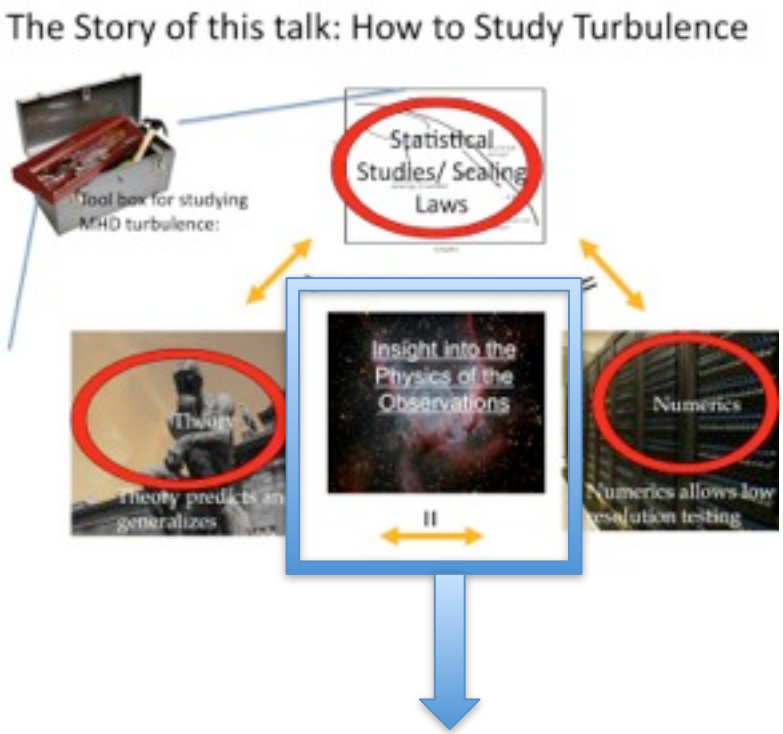
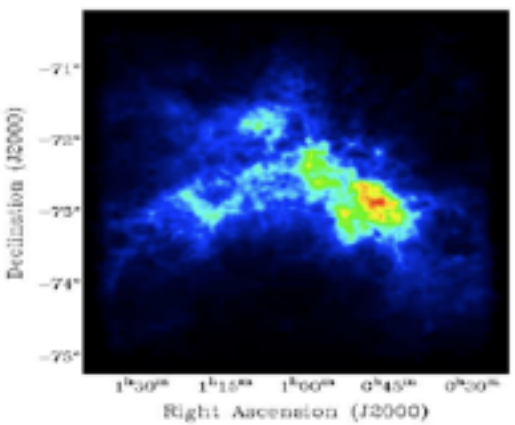


Turbulence Statistics and their Dependencies



Observational Tests Case: The SMC





SMC is the ideal observational candidate for a study of low metallicity turbulence :

1) At 60kpc away it is close and we ignore distance confusion that exists in MW.
2) Heavy element abundance is ~10 lower then MW.
3) Well studied dwarf galaxy in many wavelengths of emission/absorption with magnetic field information….

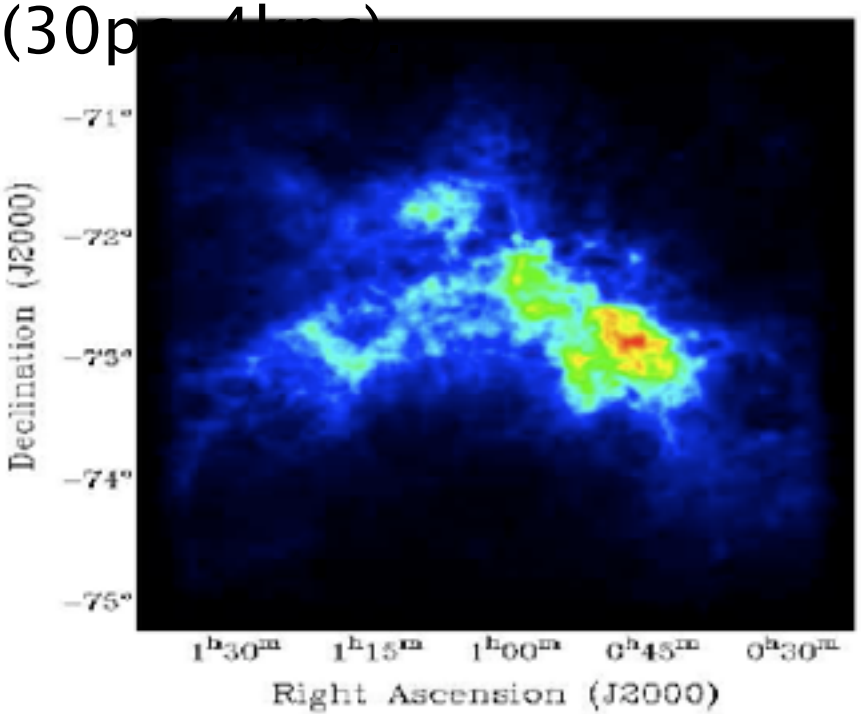
Outline

- The SMC in 21 cm emission
- Obtaining Velocity and Density Spectrum in the SMC via HI radio data and comparison with simulations
- Obtaining the compressibility (sonic Mach number) of the SMC via spin/kinetic temperatures and Probability Distribution Function moments and comparison with simulations
- Issues of large scale driving as traced by PDFs

SMC in 21 cm emission

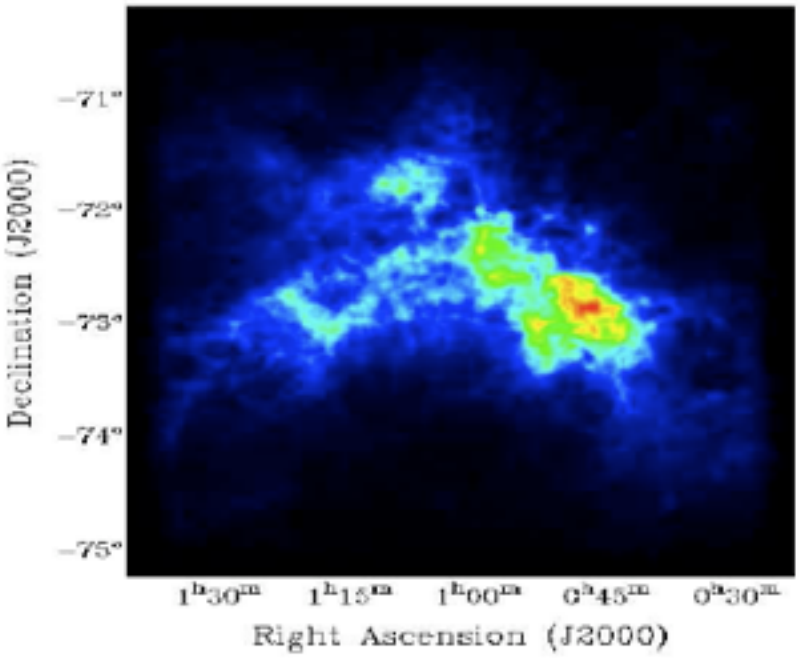
Radio data is ideal for studies of turbulence because it contains information about turbulence velocity along the LOS

Stanimirovic et al. 1999 data set has good spatial (98") and spectral resolution (1.65kms^{-1}) and contains both single dish (Parkes Telescope) and interferometer (ATCA telescope) data (30p



Determining the Velocity/Density Spectrum of Turbulence in t SMC

Turbulence broadens emission and absorption lines and this can be used to study turbulence with VCA techniques



Developed in Lazarian & Pogosyan

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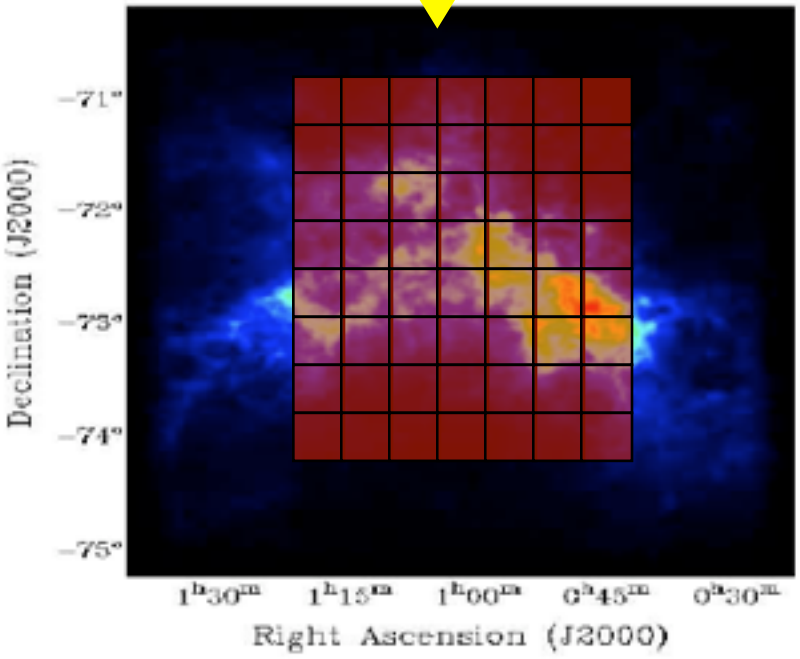

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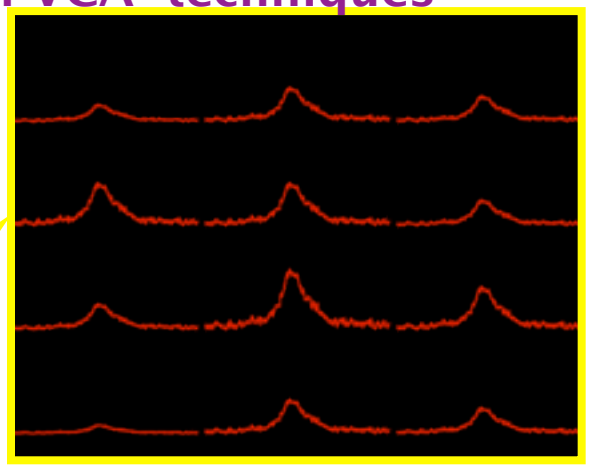

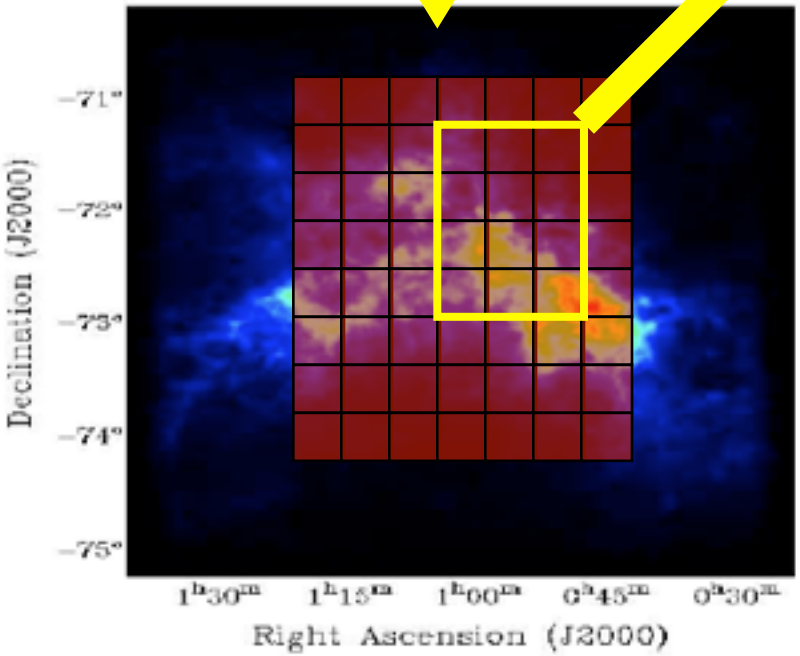

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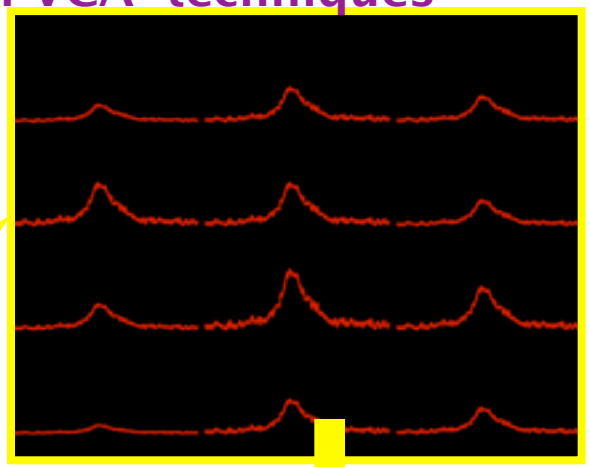

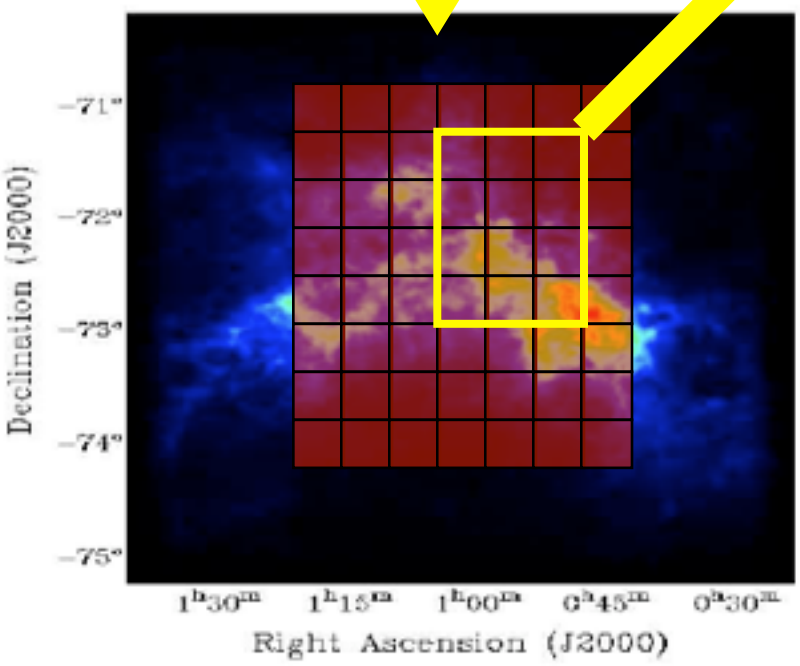

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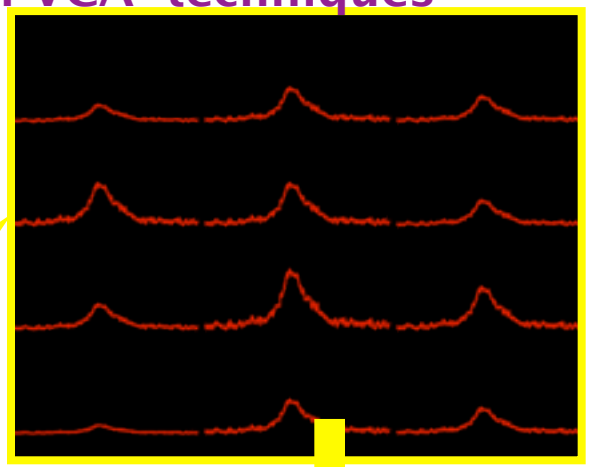
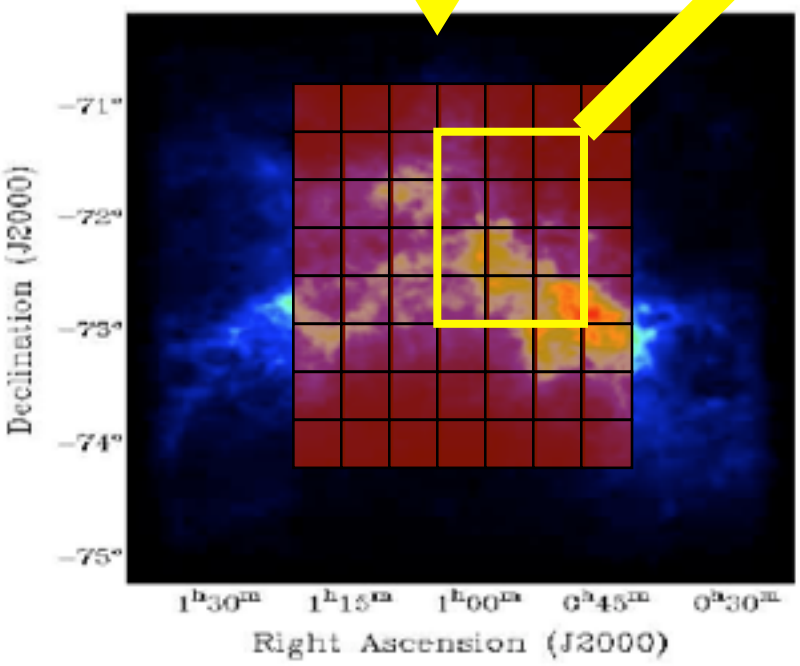
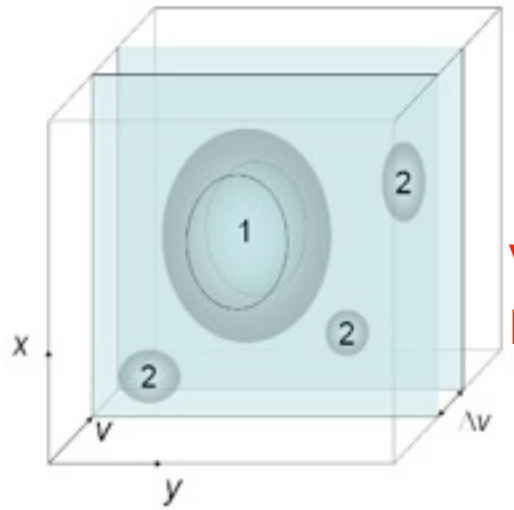




PPV Cube



VCA procedure

Developed in Lazarian & Pogosyan

Velocity/Density Power Spectrum in the SMC

Application of VCA to SMC from Stanimirovic & Lazarian 2001

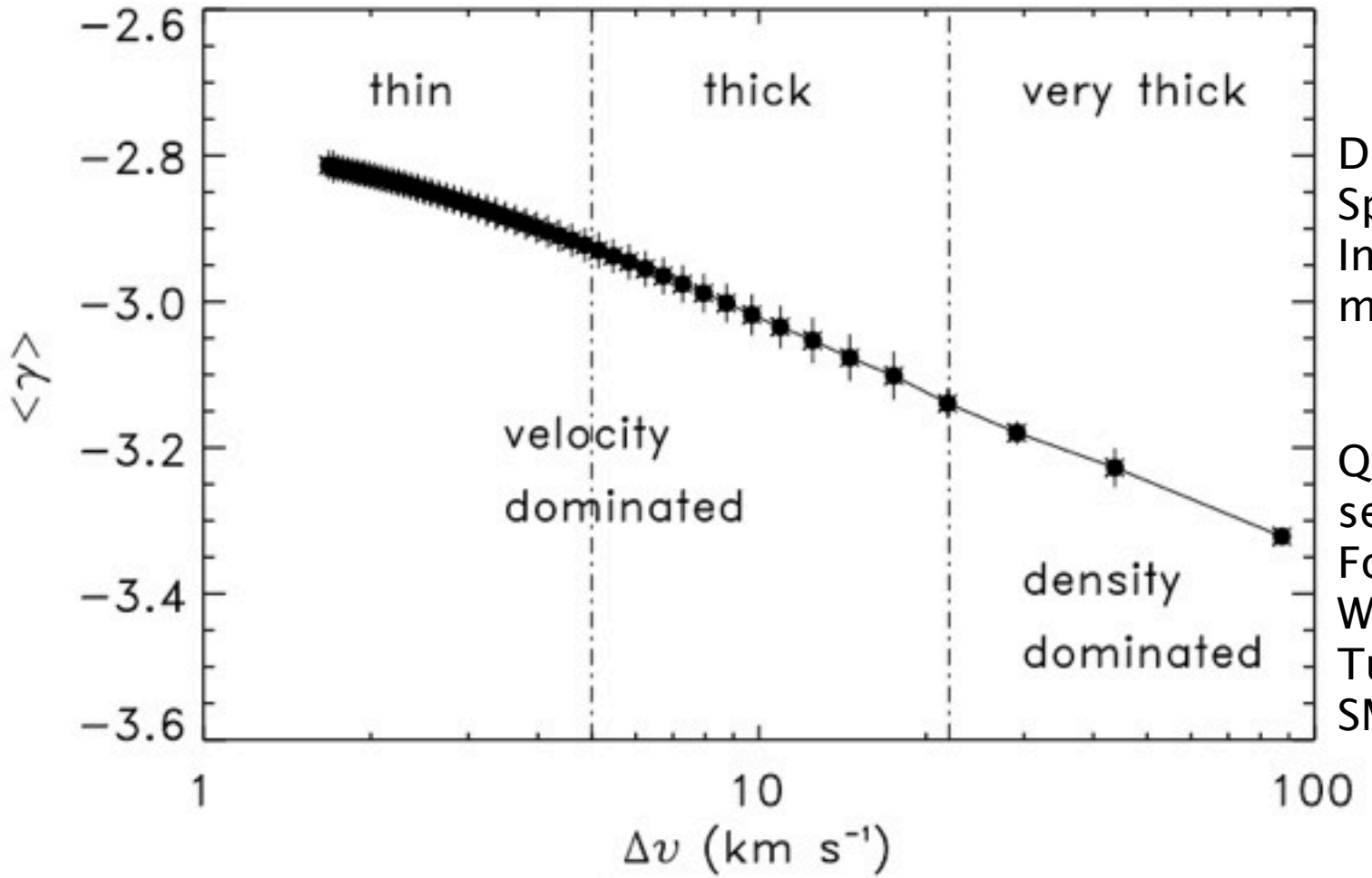


FIG. 1.— The variation of the 2-D HI power spectrum slope ⟨γ⟩ with the velocity slice thickness Δv. The dot-dashed lines distinguish thin, thick and very thick slice regimes.

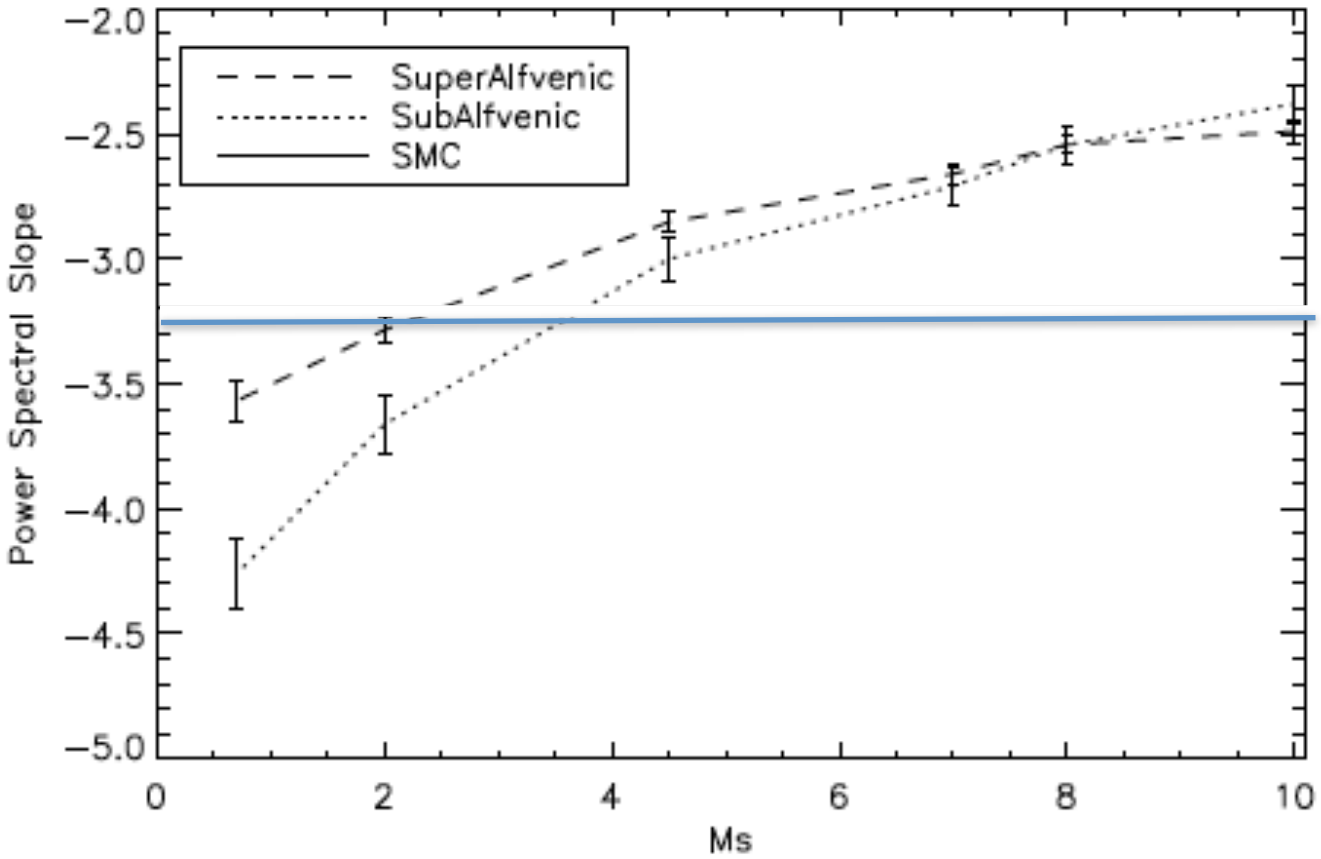
Density
Spectral slope -3.
Indicates superso
motions.

Q: Power law seen
For all scales….
What drives Turbulence in the SMC?

Density Spectrum Compared with 3D MHD Simulations

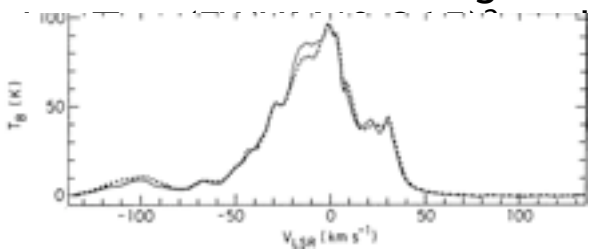
Density spectral index=-3.3 for SMC

From Burkhart et al.



Sonic Mach Number

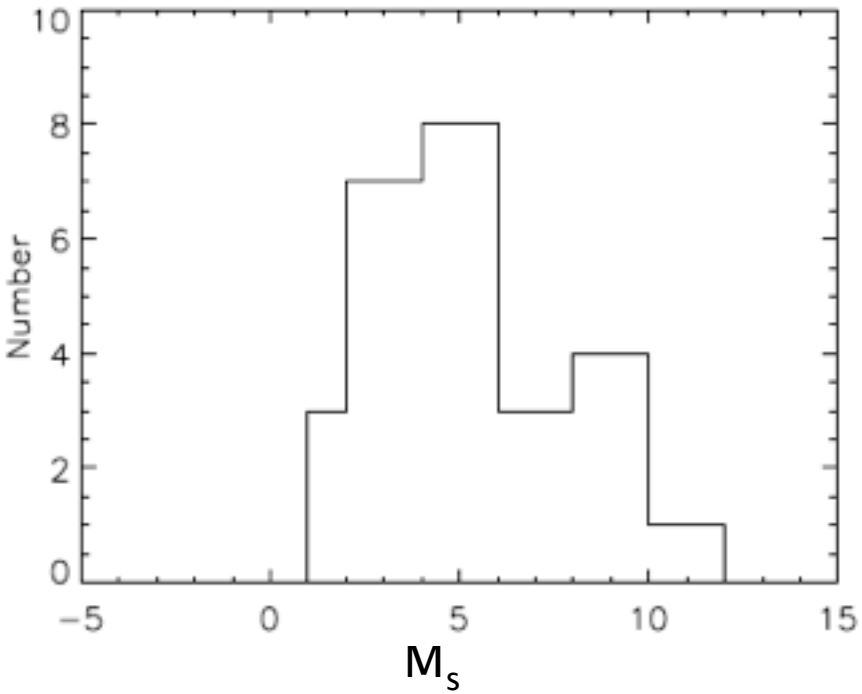
- Heiles and Troland (2003) showed that the Mach number can be related to the ratio of upper limit of the kinetic temperature (T_k) and the spin temperature (T_s).
- Using absorption sources from 29 strong radio continuum sources (Dickey et al. 2000) we de[illegible] use Dickey et al. (2000) values for T_s. →



$$\frac{N_1}{N_0} \equiv \frac{g_1}{g_0} \exp\left(-\frac{h\nu_{10}}{kT_s}\right)$$

$$T_{k,\max} = (\mathrm{FWHM}/0.215)^2$$

$$\sigma_{\rm obs} = \left(\sigma_{\rm th}^2 + \sigma_{\rm nt}^2\right)^{1/2}$$



$$C_s = \sqrt{kT_s/\mu m_H}.$$

$$V_{t,1\mathrm{D}}^2 = \frac{kT_s}{m_H}\left(\frac{T_{k,\max}}{T_s} - 1\right)$$

$$\mathcal{M}_s{}^2 = \frac{V_{t,3\mathrm{D}}{}^2}{C_s{}^2} = 3.7\left(\frac{T_{k,\max}}{T_s} - 1\right)$$

Sonic Mach Number from PDFs

Long time tool of studies of turbulence of column density data for WNM/CNM and Molecular Clouds

$$\sigma^2_{\rho/\rho_0} = b^2\mathcal{M}_s^2$$

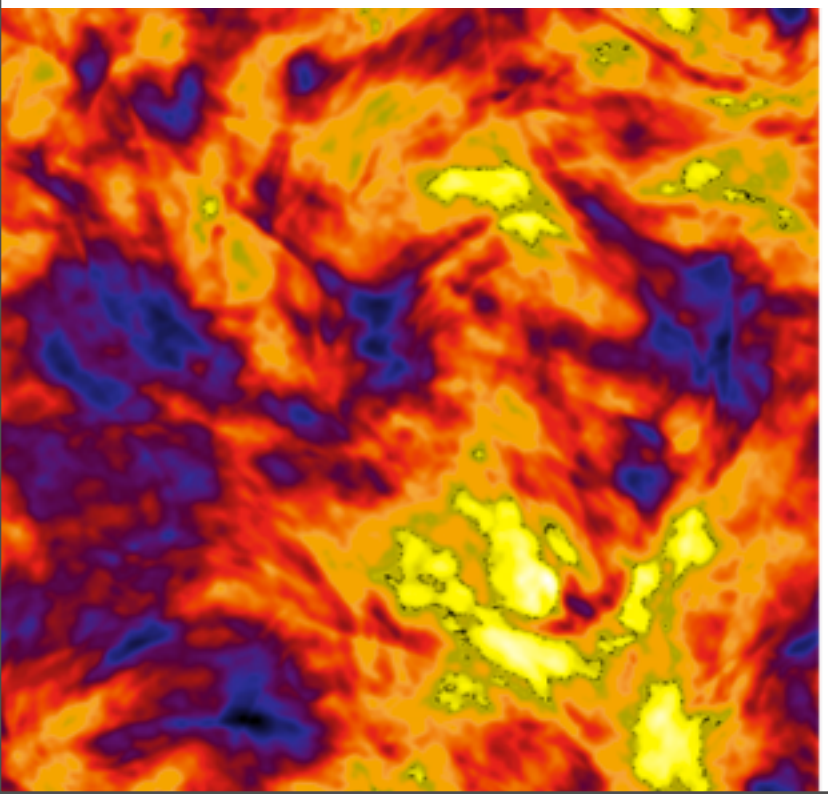
$$\sigma_s^2 = ln(1 + b^2\mathcal{M}_s^2)$$

2nd moment: Variance (σ^2 linear and log PDF) vs. M_s

3rd moment: Skewness(linear PDF) vs. M_s $S = A*M_s + b$

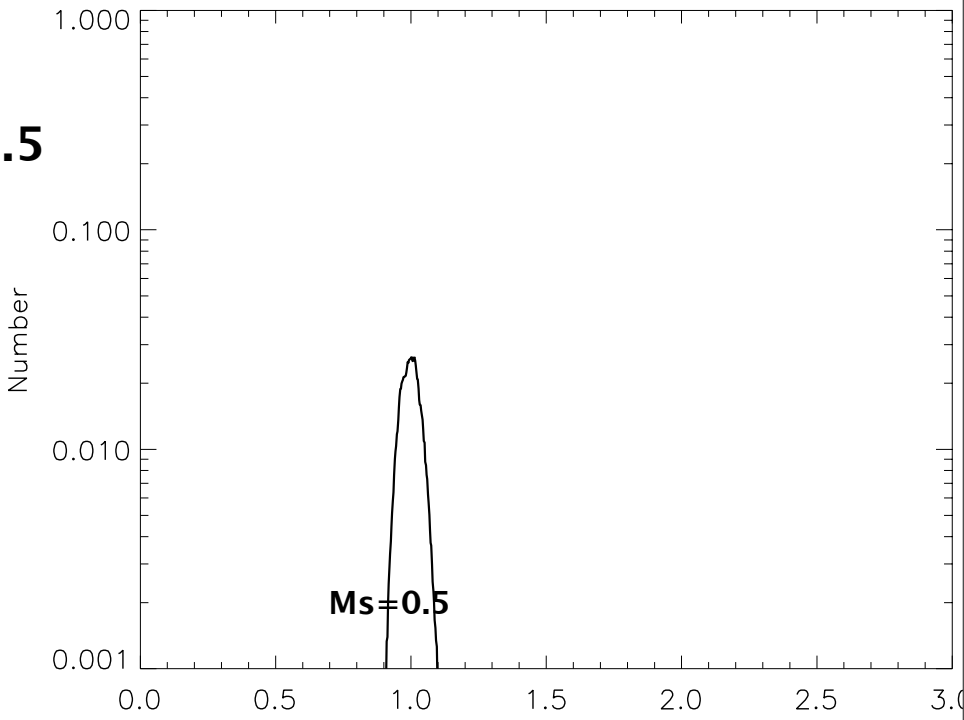
4th moment: Kurtosis(linear PDF) vs M_s $K = A*M_s + b$

See papers by: Kowal, Burkhart, Federrath, Colins, Padoan, Vazquez-Semadeni, Molina ...



$M_s = 0.5$

Linear Column Density PDF



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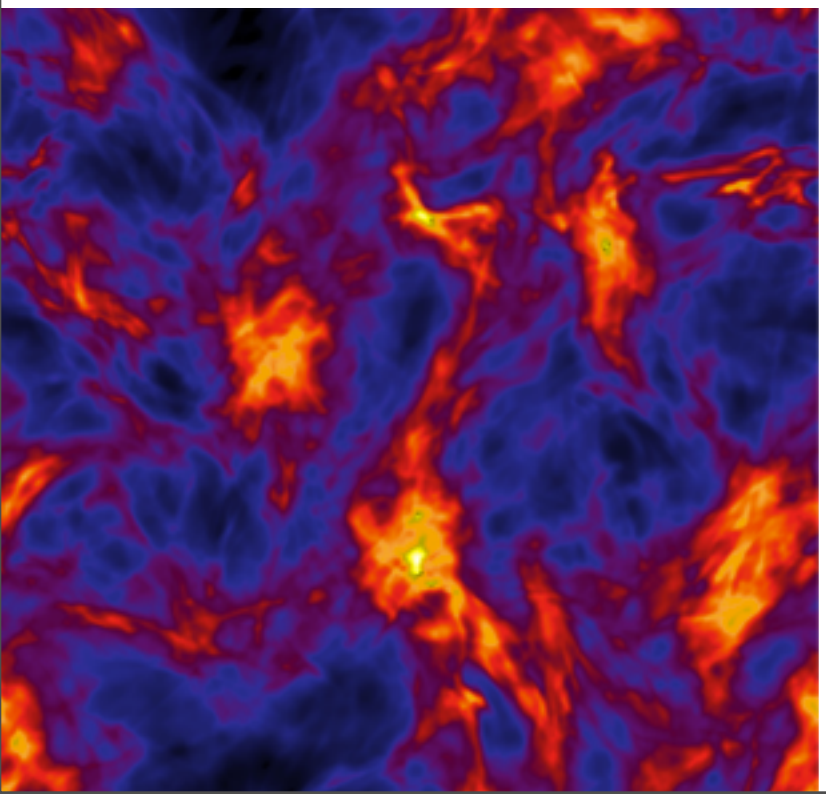
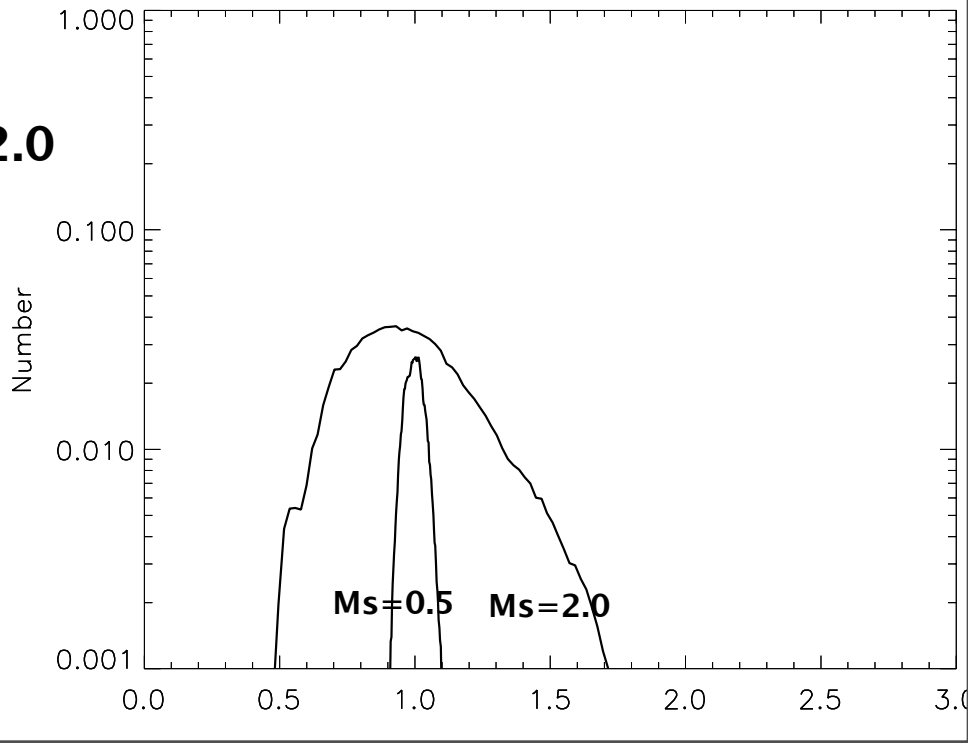


$M_s = 2.0$

Linear Column Density PDF



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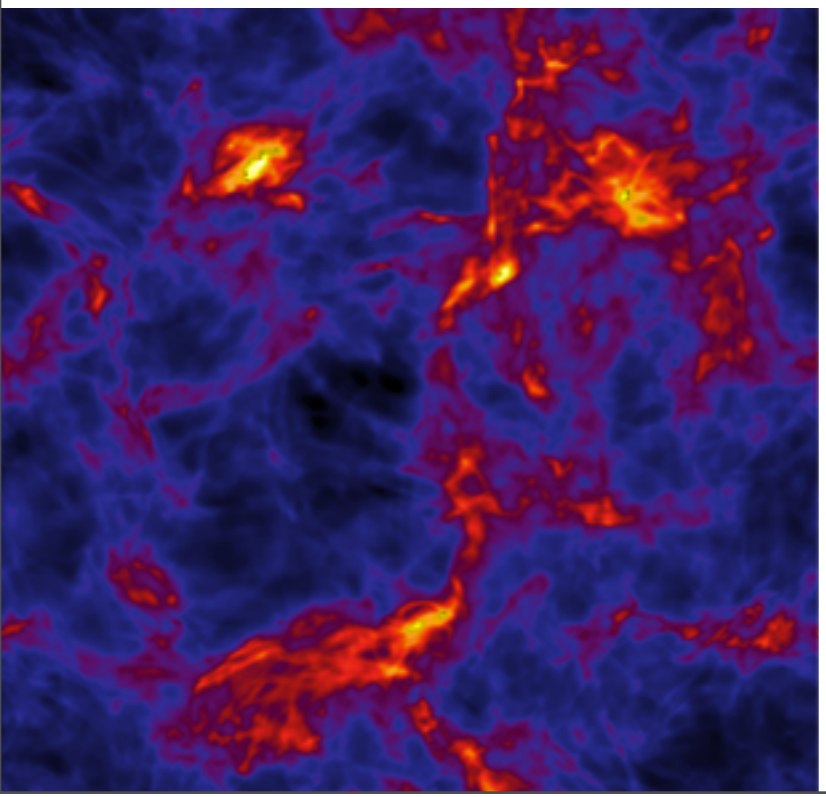
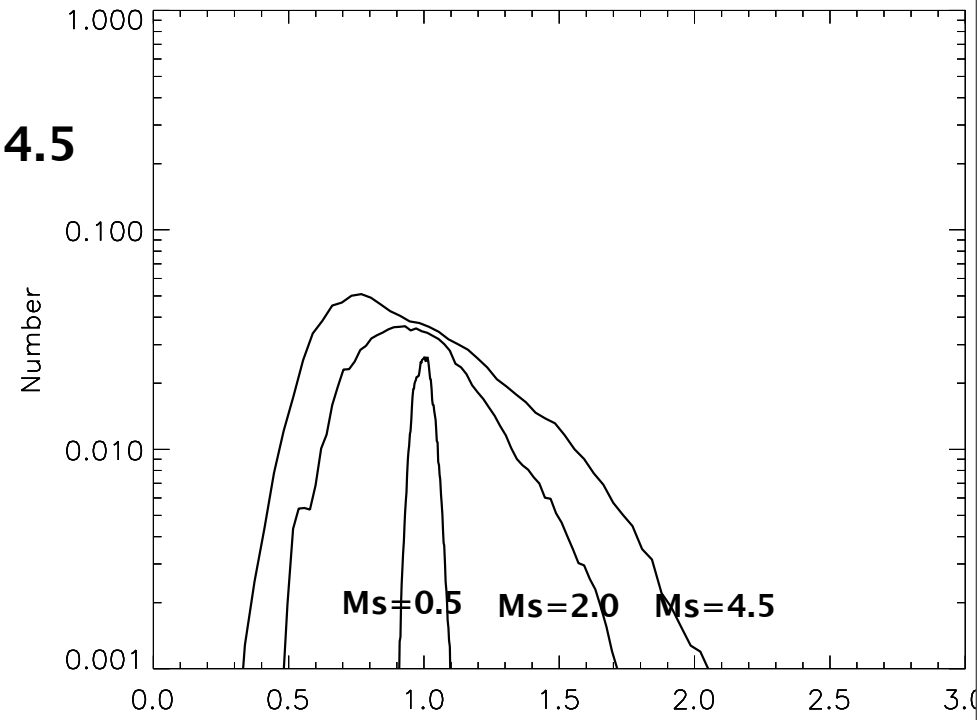


$M_s = 4.5$

Linear Column Density PDF



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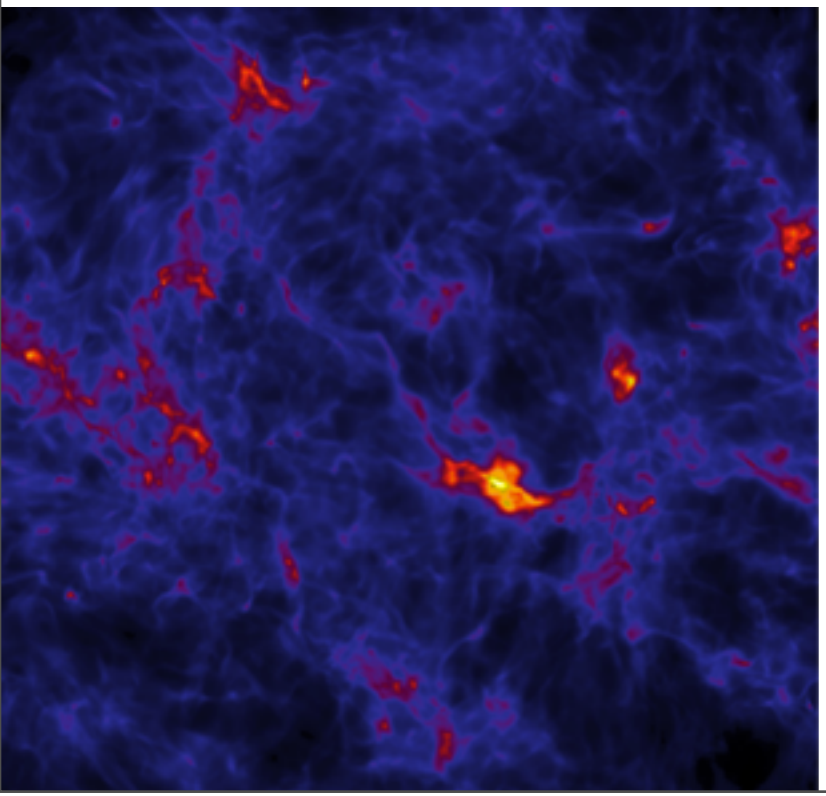
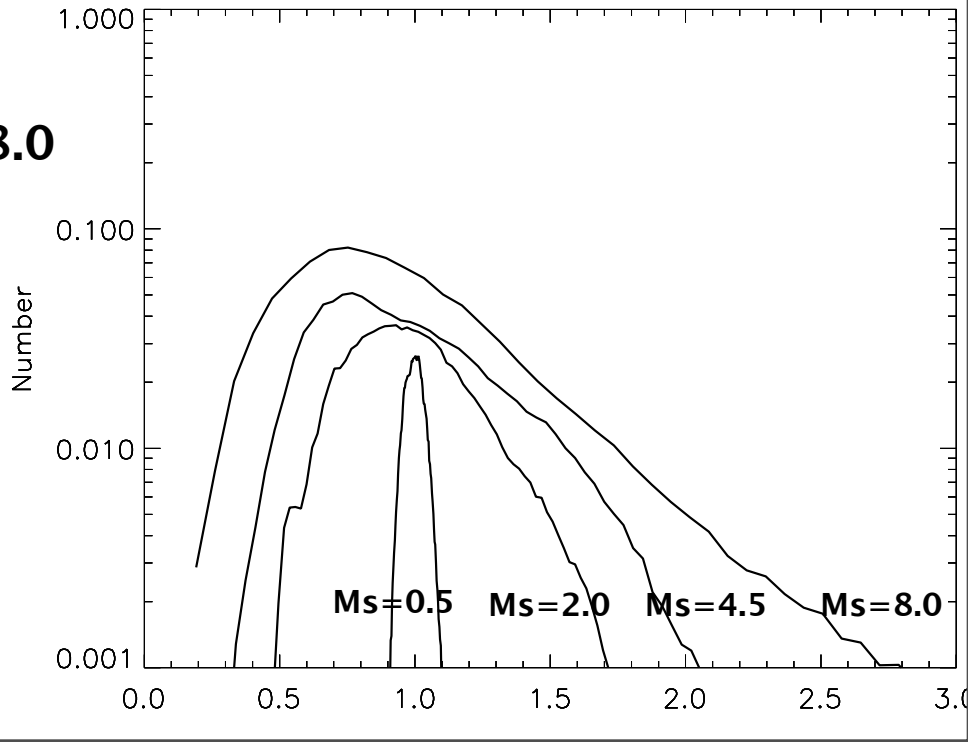
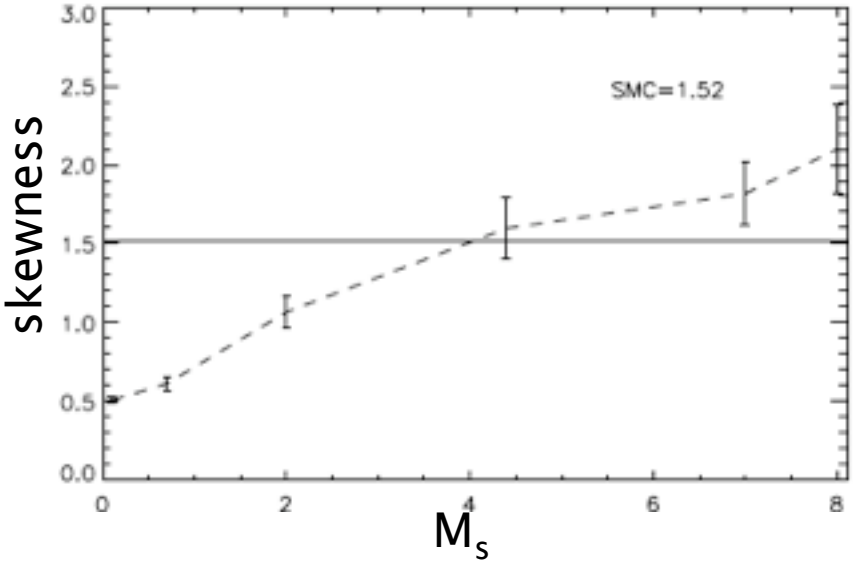


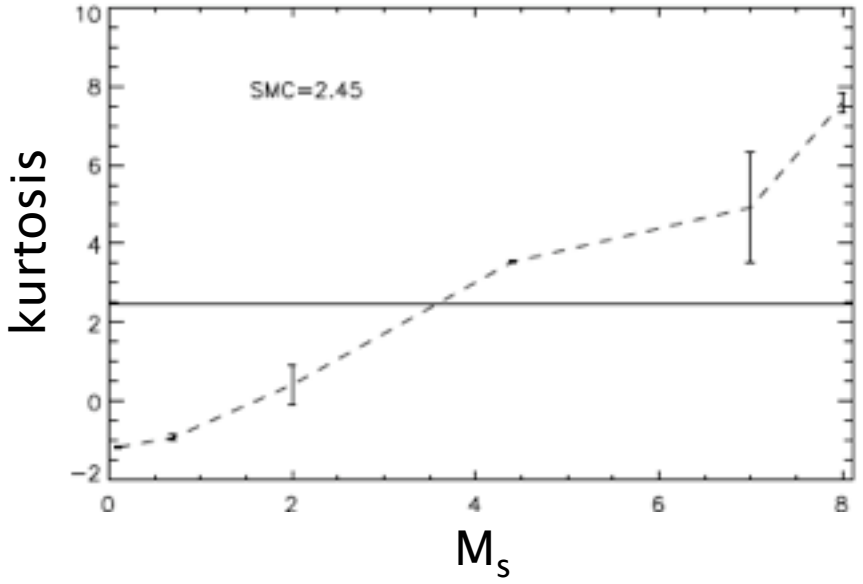
$M_s=8.0$

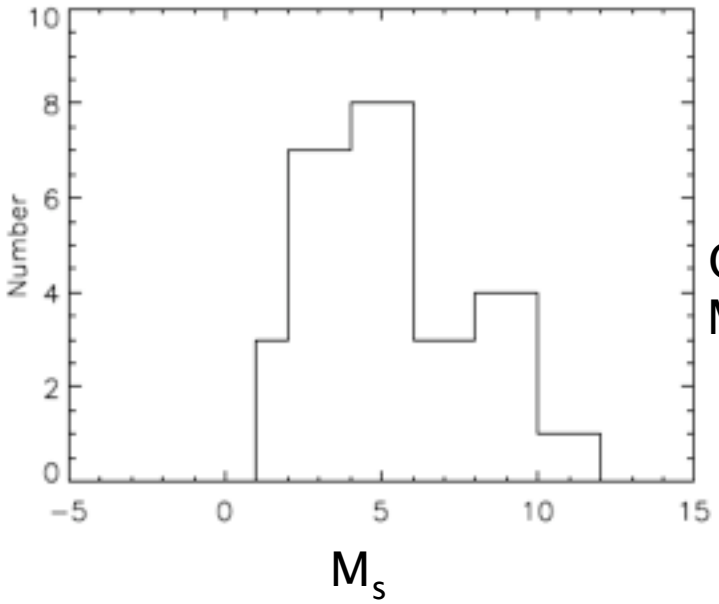
Linear Column Density PDF



Sonic Mach Number: PDF vs.







Observational Method for Cold Neutral SMC Mach Numbers

$$\mathcal{M}_s{}^2 = \frac{V_{t,3\mathrm{D}}{}^2}{C_s{}^2} = 3.7\left(\frac{T_{k,\max}}{T_s} - 1\right)$$

GASKAP (PI: Dickey)**:** MW plane + Magellanic System

5000+ HI absorption spectra → build 2d images of CNM temperature and fraction

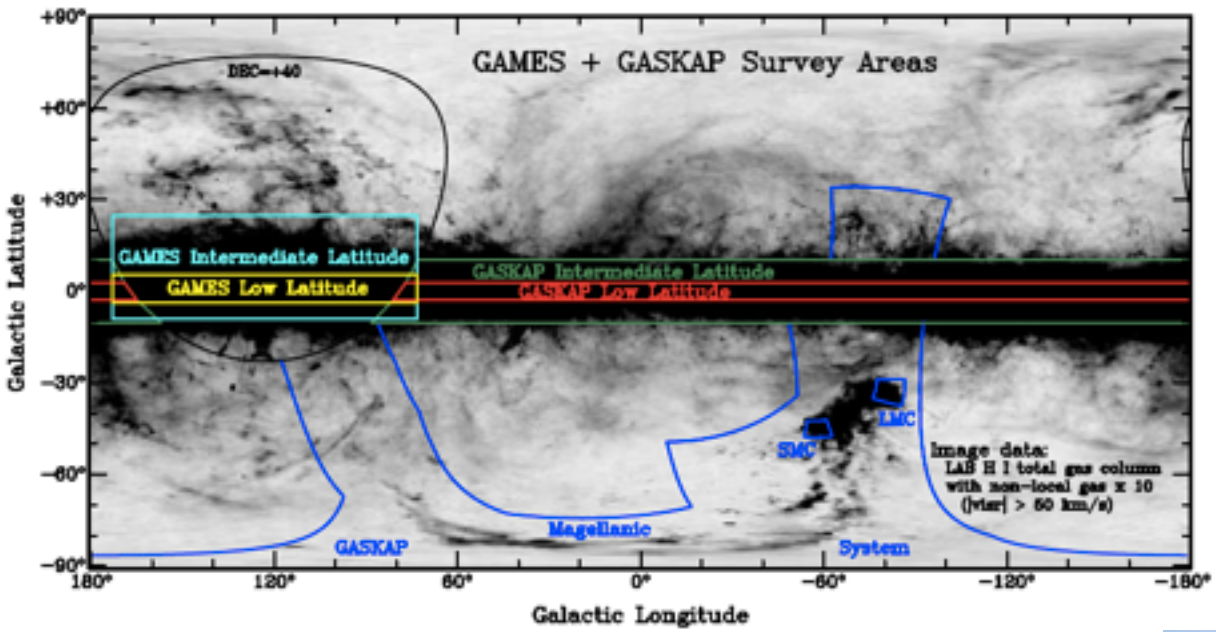
HI+OH emission → turbulent properties and atomic/molecular transition

GAMES with WSRT

(northern sister survey, PI: McClure-Griffiths):

HI absorption + HI/OH emission

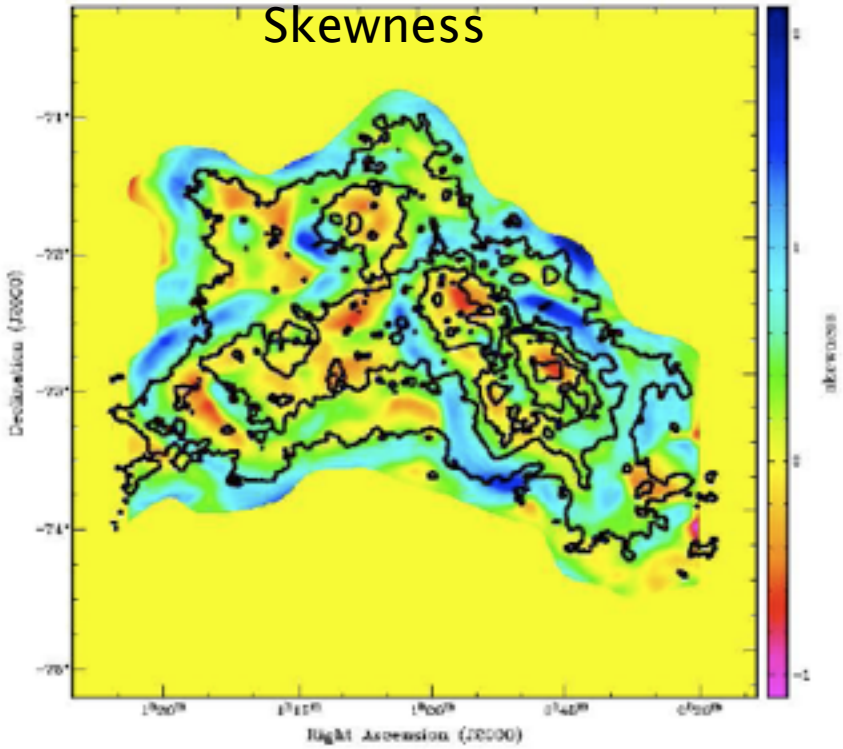
Together, measure how CNM properties vary with interstellar environments (MW, LMC, SMC).



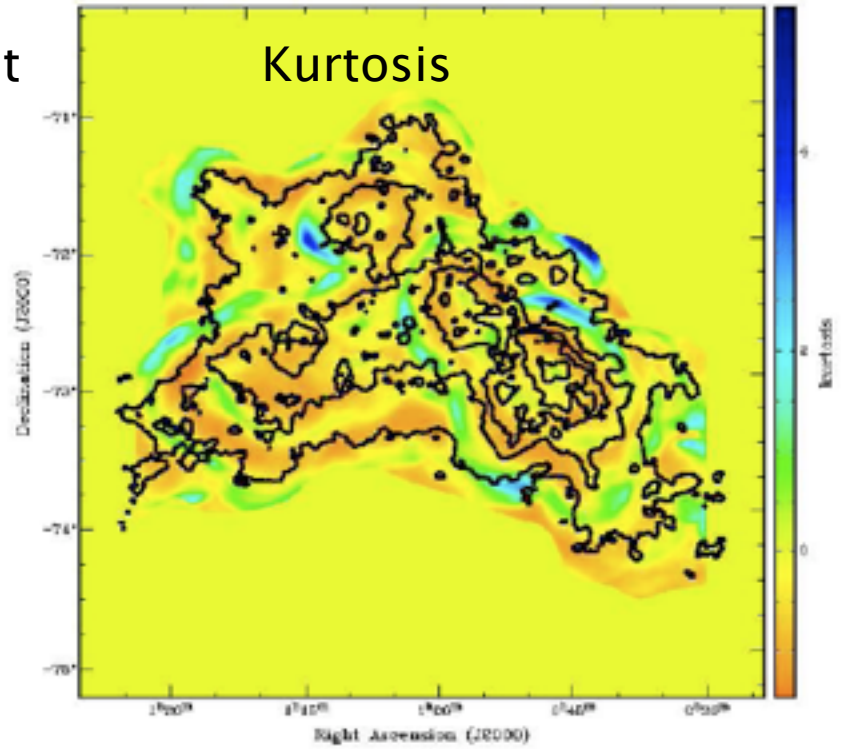
Dickey et al. (2012)

https://sites.google.com/site/gaskapproject/

Q. What is the driving scale?



"Moment Maps"



Several regions in the SMC indicate very quiescent environments, most of them unfortunately have a size close to our angular resolution (30' after the kernal is applied).

Regions with the highest sonic Mach number via PDF analysis are found around the bar and correspond to compressed HI contours.

Most high M_s regions seem to trace shear flows. Several are near LMC

Summary

1) HI gas in the SMC density/velocity spectrum corresponds to mildly supersonic turbulence

2) Spectrum shows no evidence of a turn over!

3) Spin-Kinetic temperatures show the SMC to be generally supersonic which agrees with PDF analysis predicted by MHD simulations

4) Evidence for large scale external driving in SMC

PDFs – Burkhart et al., 09, ApJ, 693, 250; Kowal et al. 07, ApJ, 658, 423

Velocity Power Spectrum (VCS/VCA)- Lazarian & Pogosyan,08, ApJ, 686, 350;

Stanimirovic & Lazarian, 2001, ApJ, 551, 53

Chepurnov, Burkhart & Lazarian, in prep

What about the magnetic fields!??

Magnetic Fields in the Universe IV: From Laboratory and Stars to the Primordial Universe

Mayan Riviera, Mexico. February 4-8, 2013.

You are here: Home

Overview

This is the webpage for the fourth edition of the ***"Magnetic Fields in the Universe: from Laboratory and Stars to Primordial Structures"***.

The three previous editions, MFU I, MFU II, and MFU III, were held on Angra dos Reis (Brazil, 2004), Cozumel (Mexico, 2008), and Zacopane (Poland, 2011).

In the fourth edition, the conference returns to the Mexican Caribbean, this time to the ***Mayan Riviera, on February 4-8 of 2013.***

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Thermal instability…