The First Results from the HERITAGE
(Herschel Survey of the Magellanic Clouds)

Cold Dust Clumps in Dynamically Hot Gas

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Aims: Study of Physical & Statistical Properties of Dust Clumps from Herschel Observations & HI Clumps from ATCA+Parkes Survey.

Dynamically Hot Gas

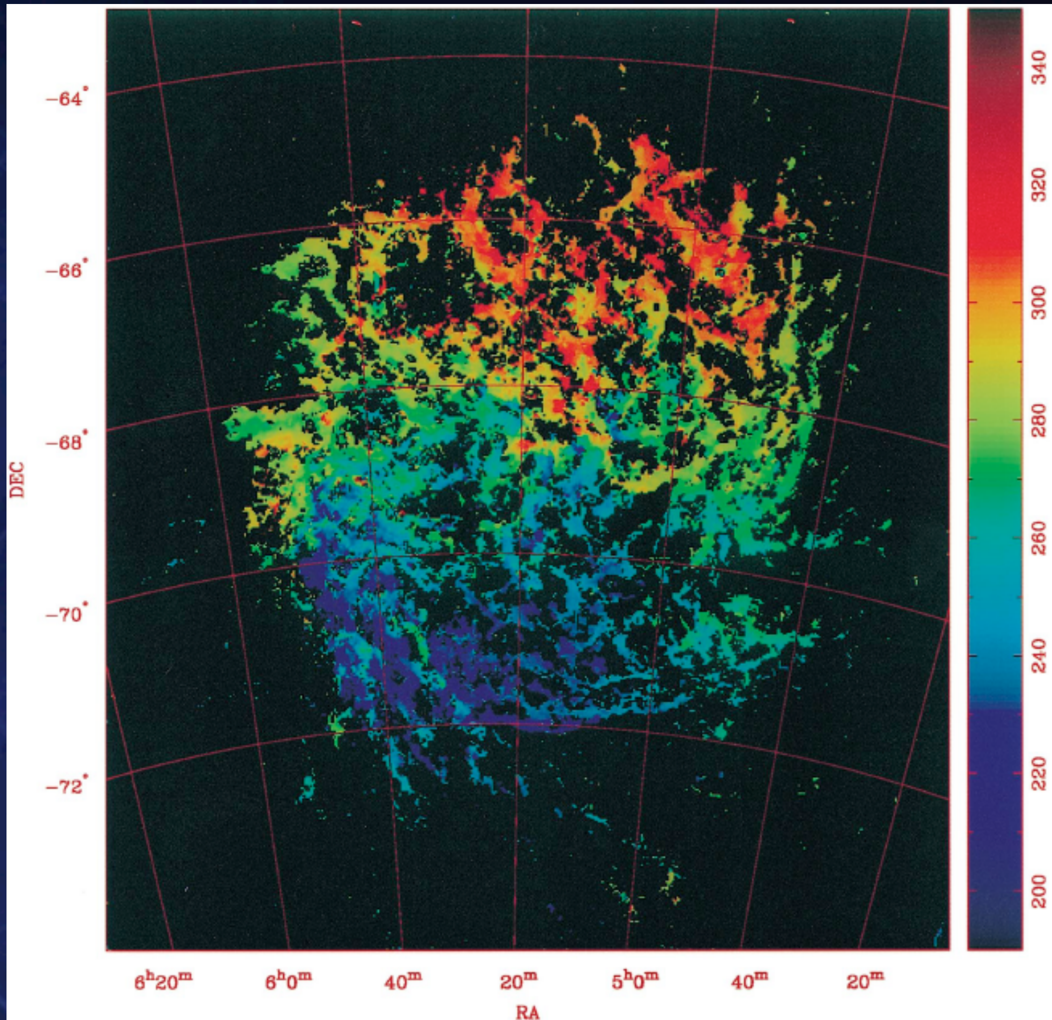

Australia Telescope Compact Array (ATCA)
The combined configuration has 40 independent baselines ranging from 30 to 750 m, with a baseline increment of 15.3m; this results in an angular resolution of 55” for the data presented here.

HI Aperture Synthesis Mosaic Survey of the Large Magellanic Cloud

HI Aperture Synthesis Mosaic Survey : Australia Telescope Compact Array (ATCA)
(Kim, Staveley-Smith, Dopita, Sault, Freeman, Kesteven, McConnell 1998)

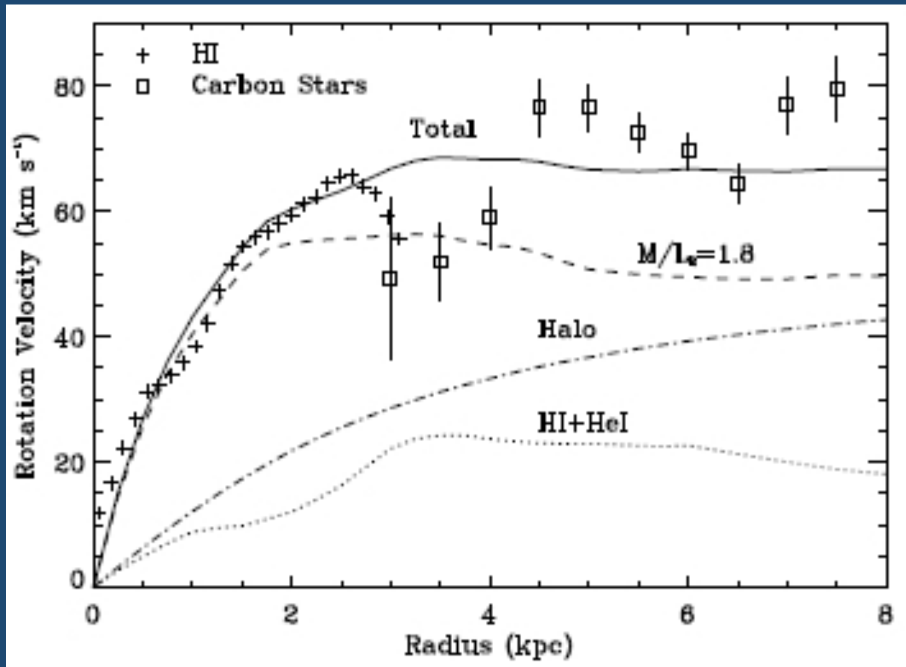
Characteristics	Combined survey
Survey area	11°.1x12°.4
Spatial resolution	55” (12-14 pc)
Velocity coverage	-33 to +627 km/s
Velocity resolution	1.649 km/s
Pointing centers	1344

HI is flocculent and turbulent in nature; it clearly shows spiral features with a flat rotation curve, v=70 km/s.



Kim, Staveley-Smith, Dopita, Sault, Freeman, Kesteven, McConnell 1998

Deprojected Rotation Curve



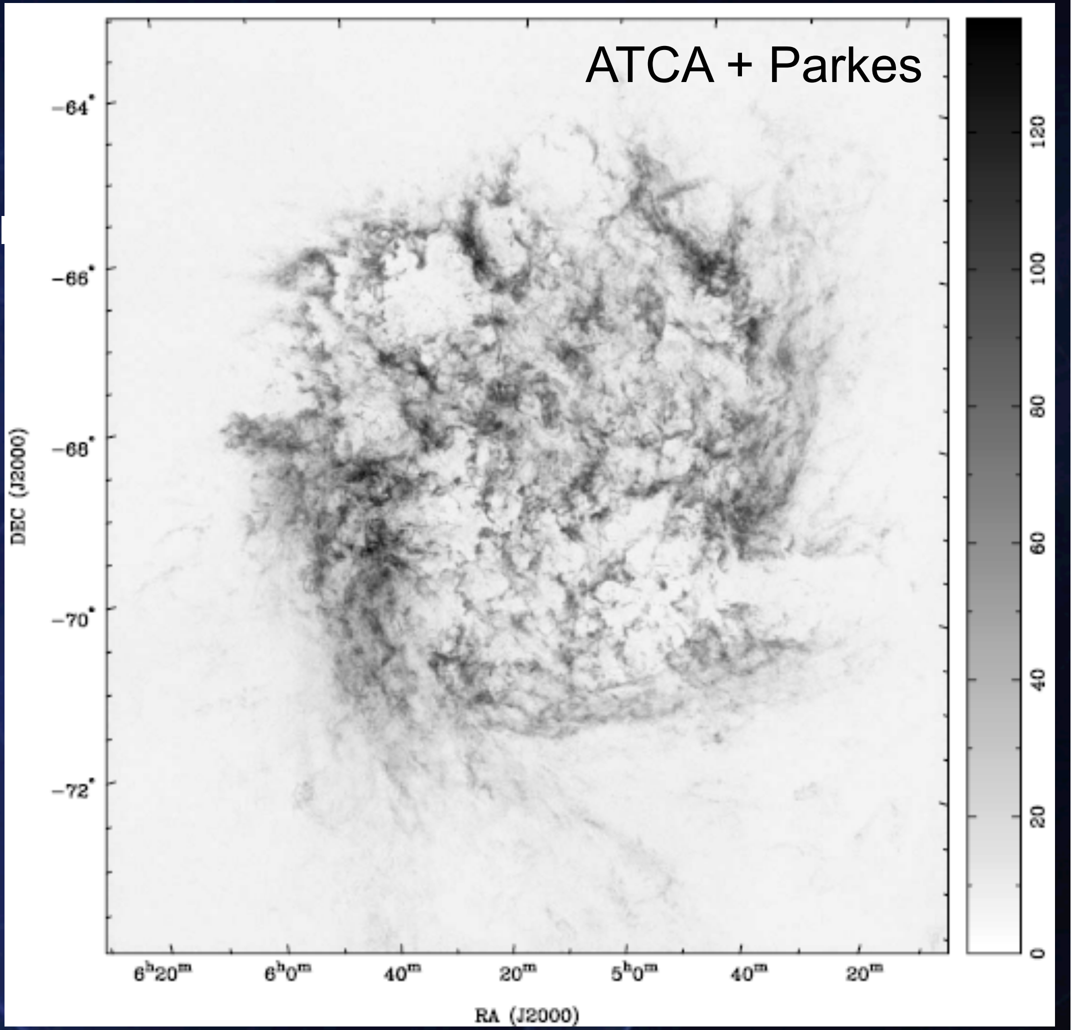
Deprojected rotation curve for the LMC based on the median smoothed HI first moment map and the carbon star data of Ku nkel et al. (1997) and assuming an inclination of 33 degree. Total predicted rotation curve (Solid line) constructed from the 1) HI mass distribution, based on the data of Luks & Rohlfs (1992) and a 30% He I contribution (dotted line).
R stellar light distribution, based on the data of de Vaucouleurs (1958) and M/L_R =1.8 (dashed line). Pseudo-isothermal dark halo with core radius 2.5 kpc and central density 0.009 M_{sun} /pc^{-3} .

HI Aperture Synthesis Mosaic of the Large Magellanic Cloud

HI Aperture Synthesis Mosaic Survey

: Australia Telescope Compact Array (Kim et al. 1998) + Parkes (Staveley-Smith et al. 2003)

Characteristics	Combined survey
Survey area	11°.1x12°.4
Spatial resolution	55” (12-14 pc)♪
Velocity coverage	-33 to +627 km/s
Velocity resolution	1.649 km/s
Pointing centers	1344



The Fourier transformed Parkes images were added to the final images with no weighting.

Kim, Staveley-Smith, Dopita, Sault, Freeman, Lee, & Chu 2003

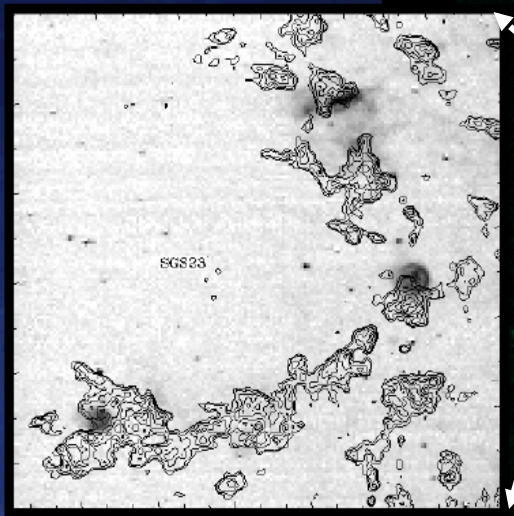
Structure in Turbulent Gas → 1) Shells,

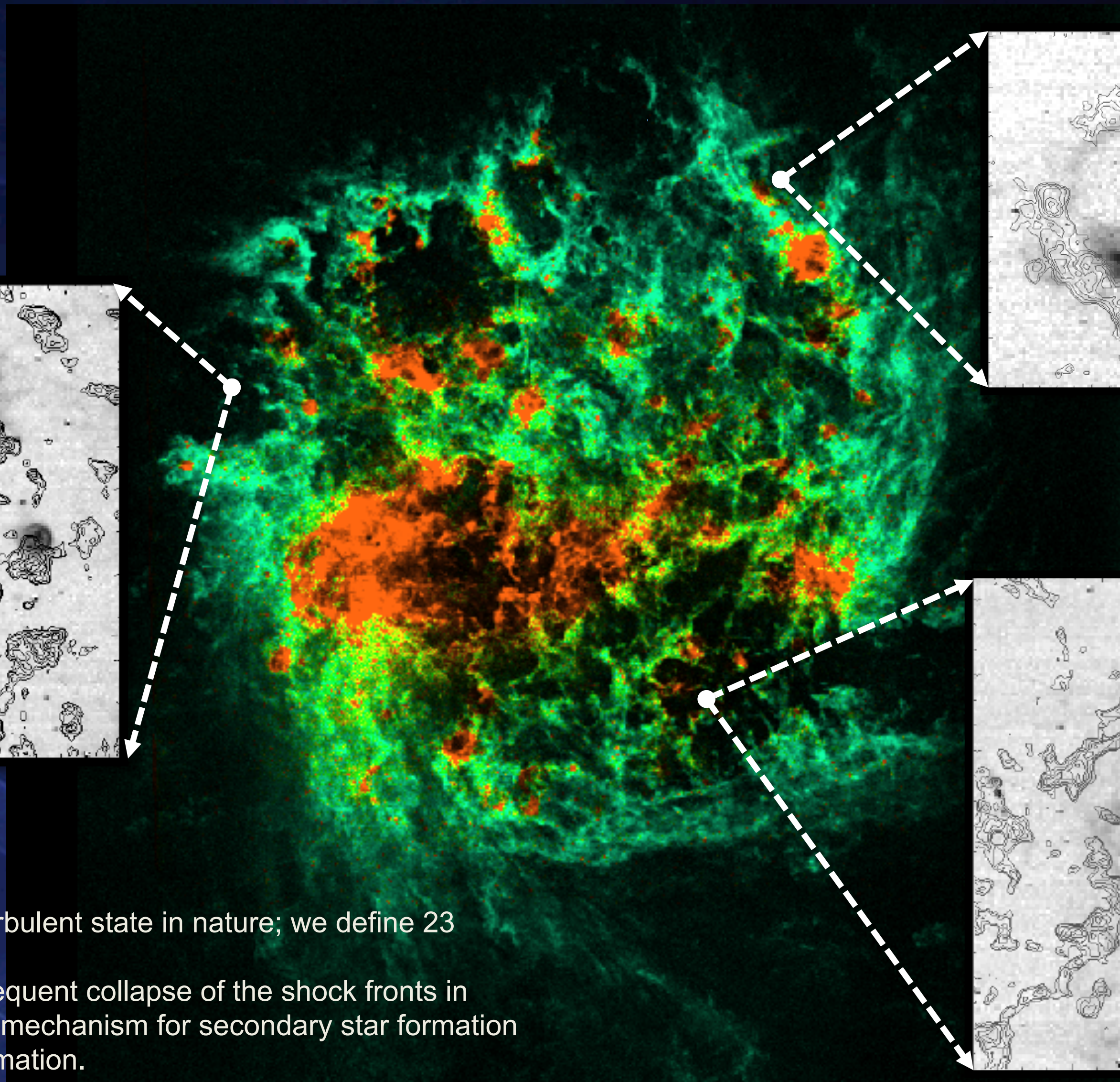
2) Clumps -- Kolmogorov

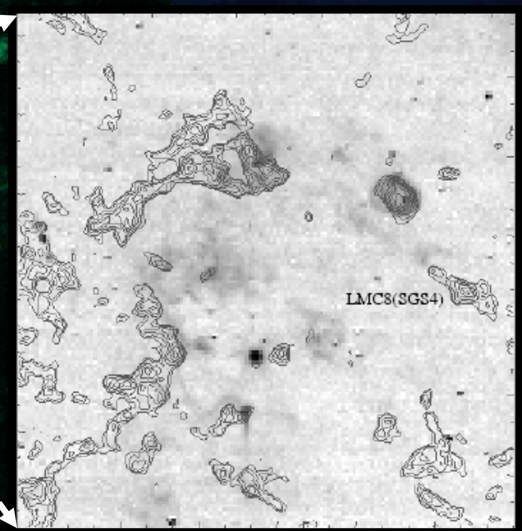
Shells

HI Shells in the Large Magellanic Cloud

Kim, Dopita, Staveley-Smith, & Bessell 1999



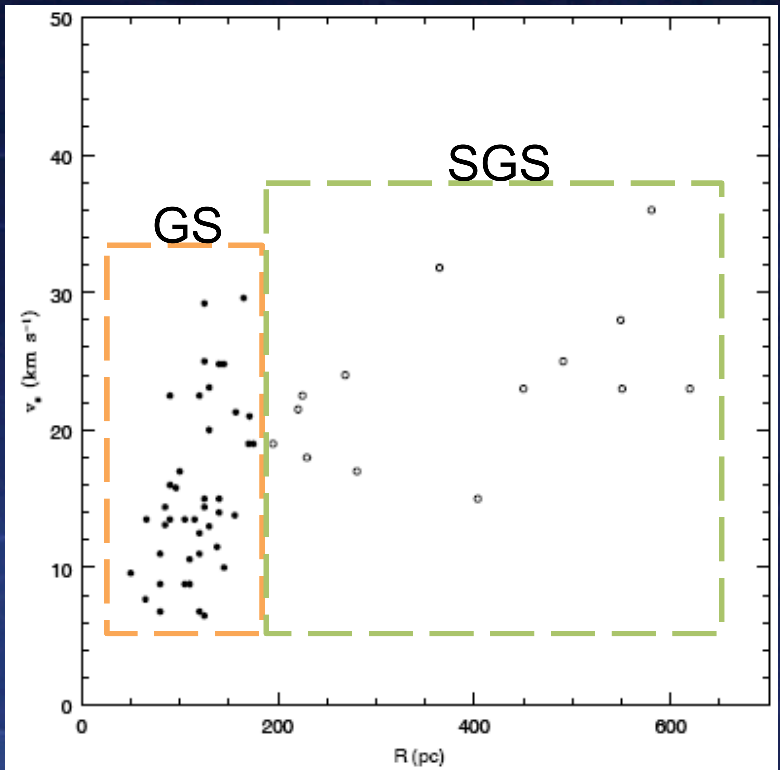




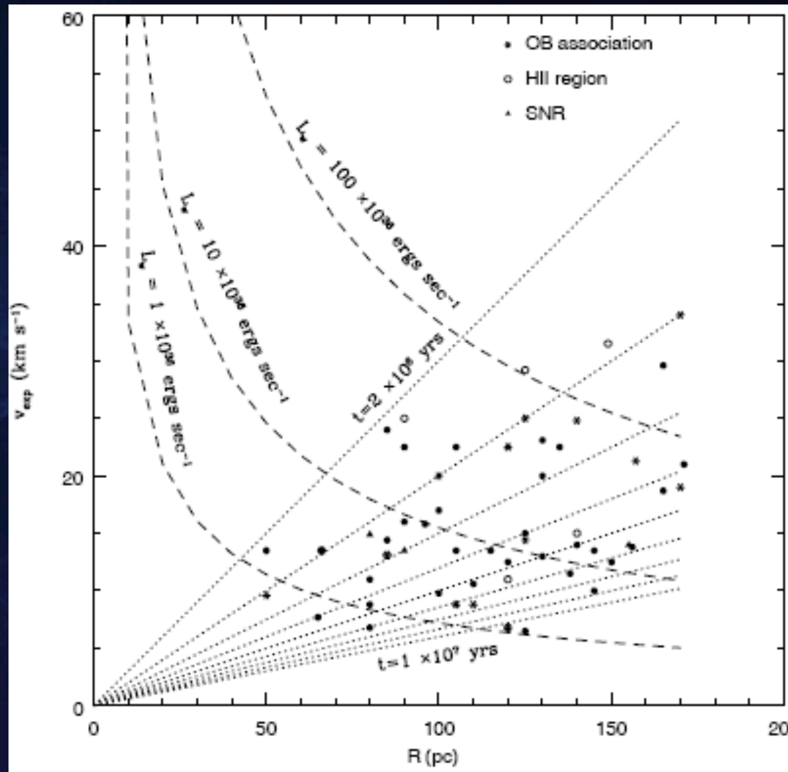
The LMC HI gas is in very turbulent state in nature; we define 23 SGS, 103GS.
The fragmentation and subsequent collapse of the shock fronts in Expanding shells be a major mechanism for secondary star formation and self-propagating star formation.

HI surface brightness map *(green)* with overlaid Hα image *(red)*

HI Shells in the Large Magellanic Cloud



Distribution of the expansion velocities vs. radius of all HI shells in the LMC.



Plot of expansion velocity vs. radius of giant shell candidates.

The expansion velocity shows a very clear correlation with the radius of the shell. The giant shells are being accelerated by the energy input from the stars within them, but supergiant shells have lost their driving pressure and are being in a momentum conserving phase.

Kim, Dopita, Staveley-Smith, & Bessell 1999

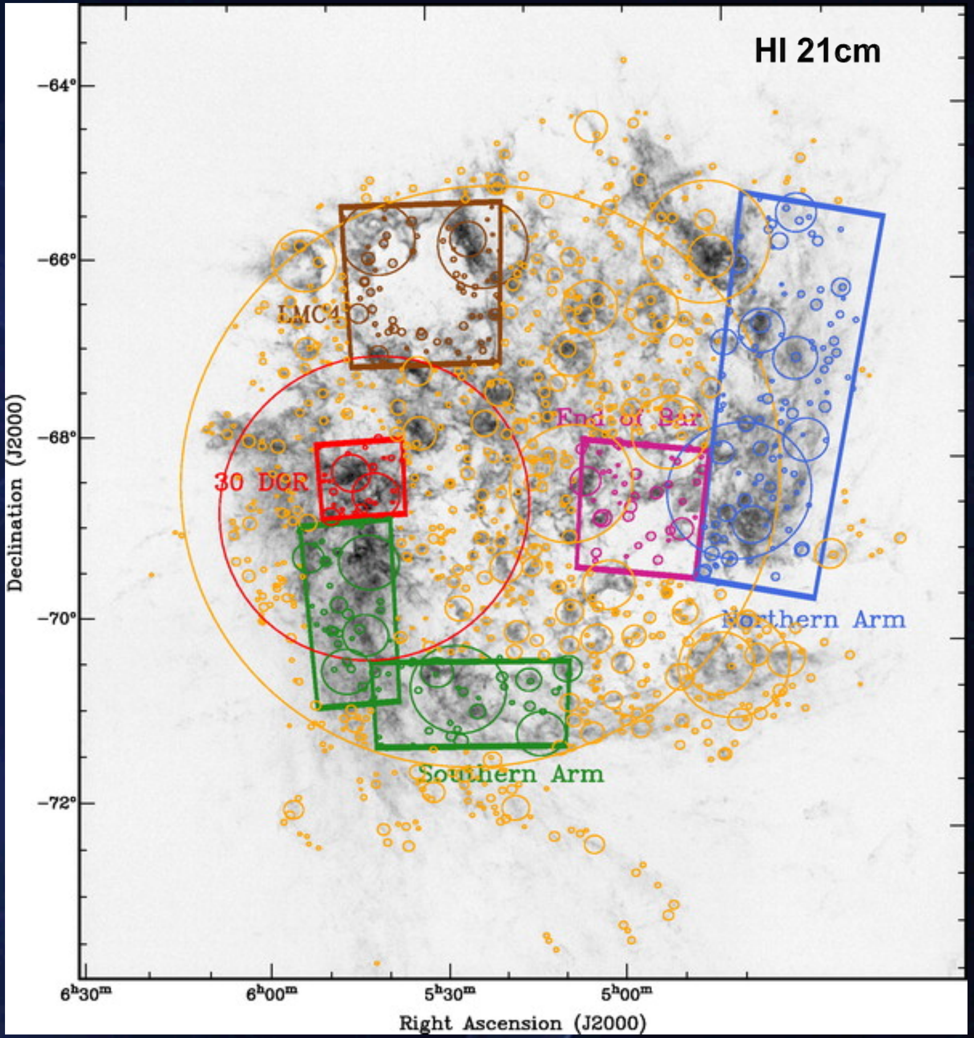
Clouds, Clumps

Catalog of HI Clouds in the Large Magellanic Cloud

HI Aperture Synthesis Mosaic Survey
: Australia Telescope Compact Array (Kim et al. 1998) + Parkes (Staveley-Smith et al. 2003)

T_{thresh}	N_{clouds}	L_{total}
16 K	468	37%
32 K	406	19%
64 K	195	3%

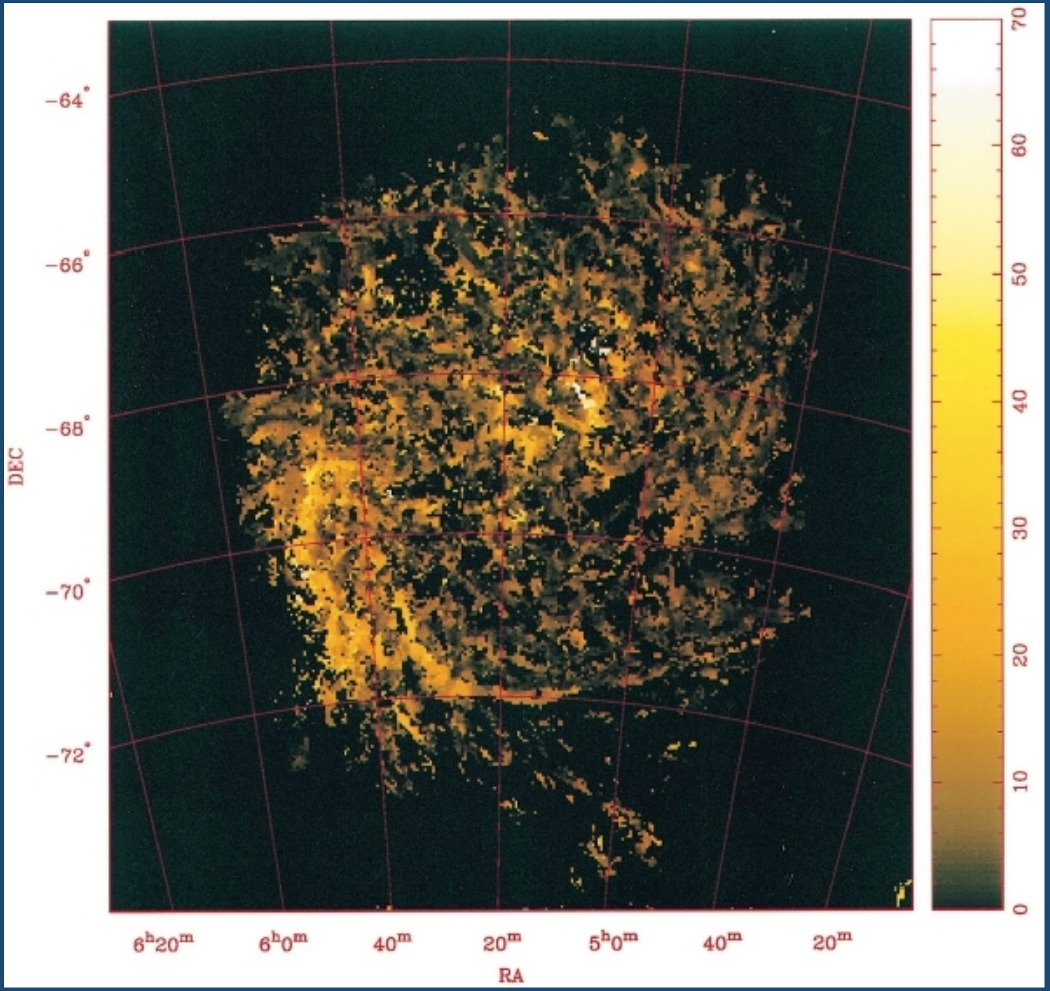
Boxes: Dynamically Hot Regions

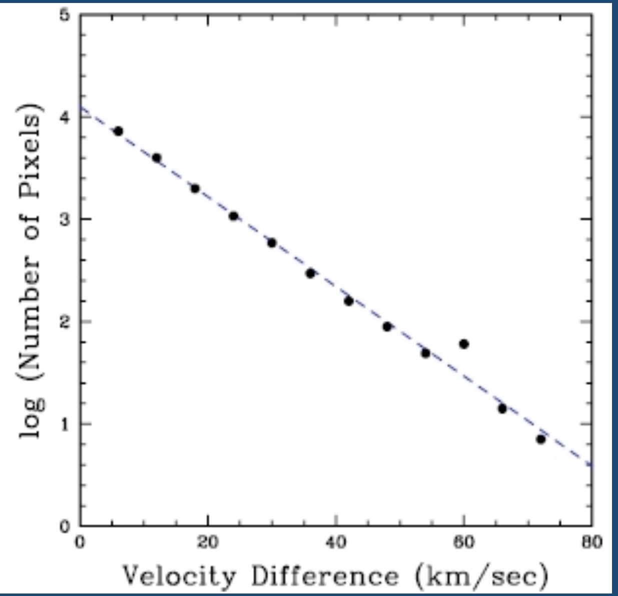


Kim, Rosolowsky, Lee, Kim, Dopita et al. 2007

While HI shows clumpy nature in their structure.

Velocity Difference Map

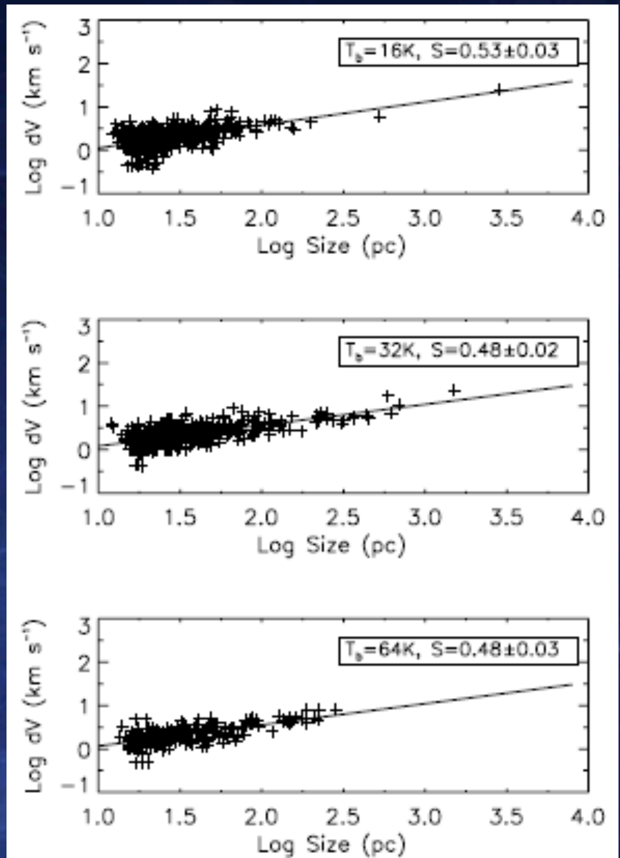




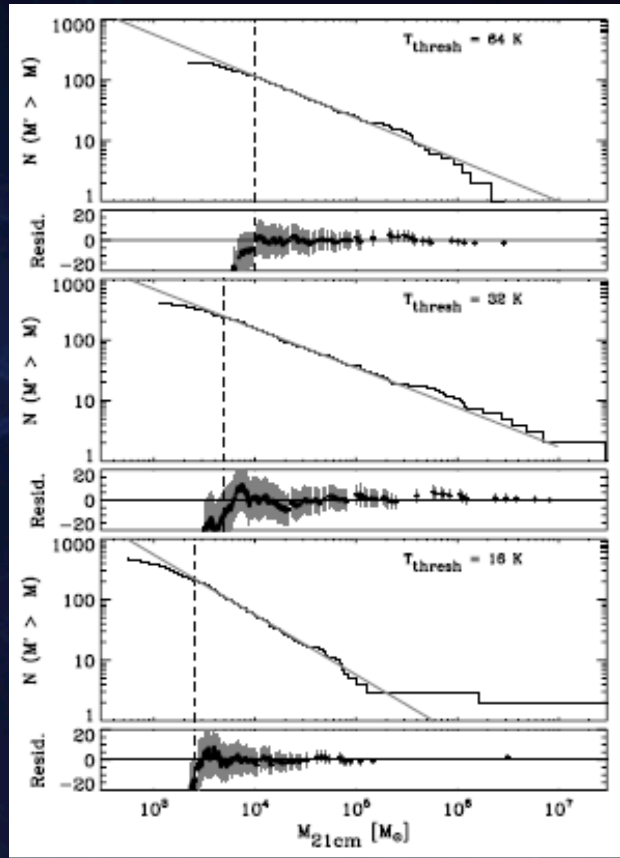
❖Histogram of modulus of the velocity difference of individual clouds from the mean local velocity field of the ensemble for the whole of the LMC.

❖The data are fitted to an exponential function across the full velocity range. This demonstrates in a startling manner the stochastic nature of the turbulent motions in the z-direction.

Catalog of HI Clouds in the Large Magellanic Cloud



Size-line width relation of the HI clouds in the entire region of the LMC for a given brightness temperature threshold



Cumulative mass distribution based on 21 cm luminosity for T_{thresh} = 64, 32, 16K.

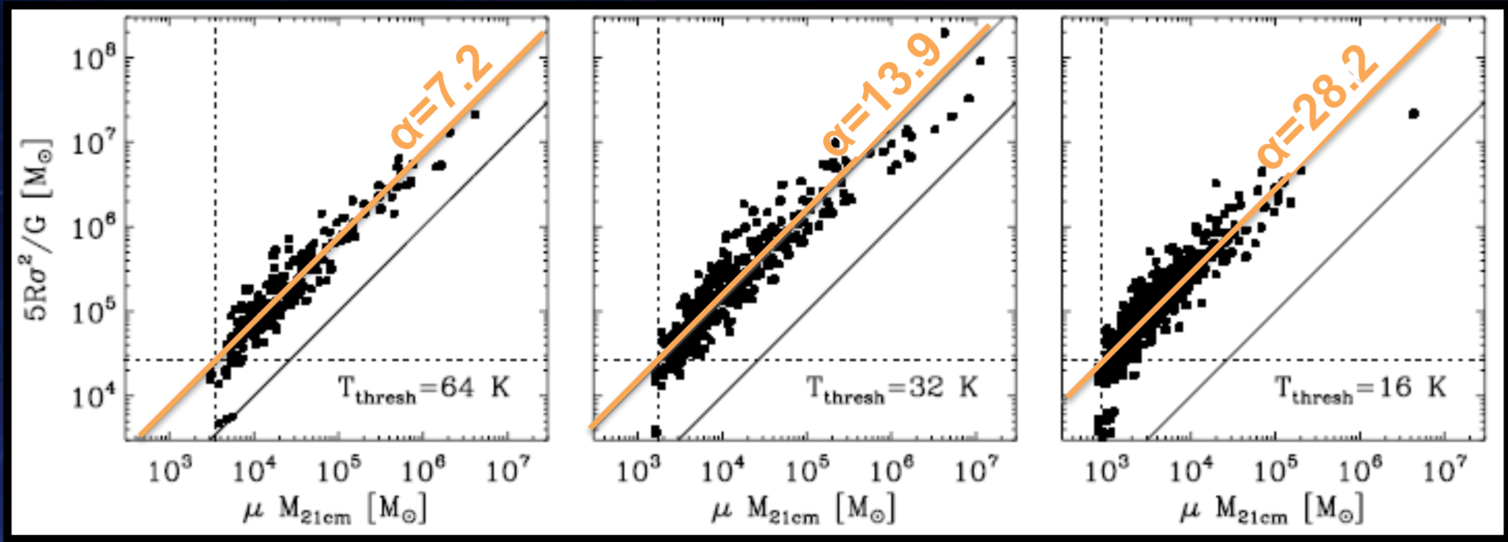
$$\sigma_v \propto R^{0.5}$$

T_{thresh} — 64 K / -1.68±0.04; 32 K / -1.65±0.04; 16 K / -1.99±0.04 — γ

Each catalog of HI cloud candidates shows a power law relationship betw een the sizes and the velocity dispersions of the clouds, following the Lar son scaling, with steeper indices associated with dynamically hot regions.

Catalog of HI Clouds in the Large Magellanic Cloud

The values of the virial parameter are significantly larger than unity, showing that turbulent motions dominate gravity in these clouds.



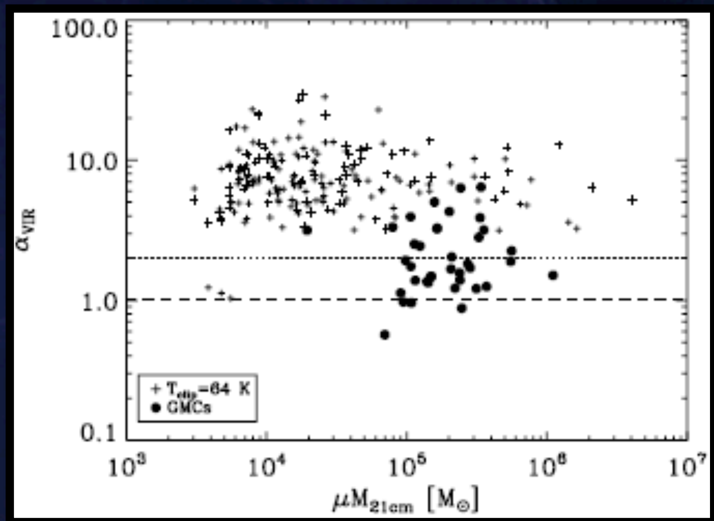
Comparison of luminous and dynamical mass estimates for clouds in each of the catalogs.

Dynamical mass

$$M_{VT} = \frac{5R\sigma_v^2}{\alpha G}$$

(α : virial parameter)

Kim, Rosolowsky, et al. 2007



Virial parameter as a function of luminous mass for HI clouds and GMCs.

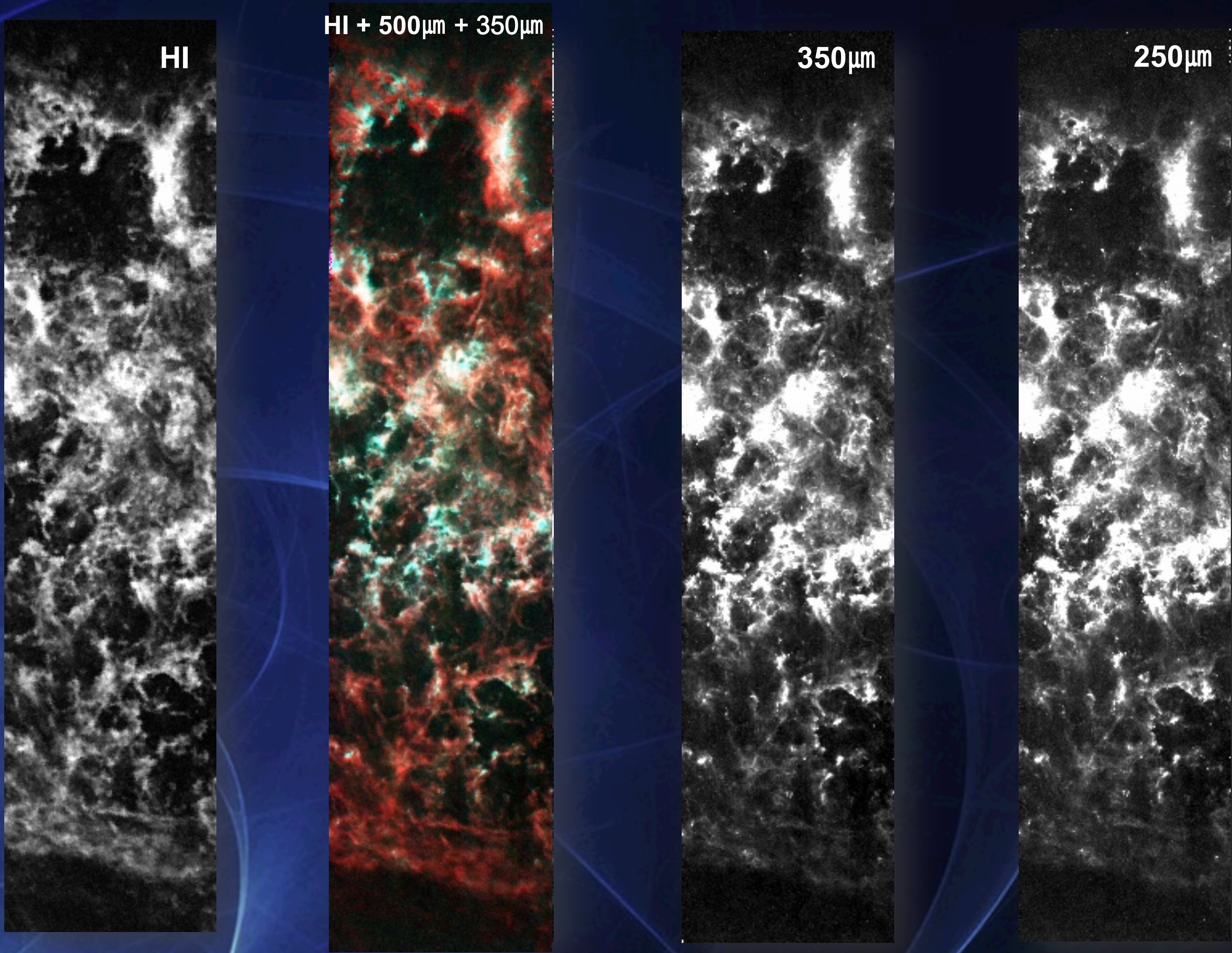
The clouds in each catalog have roughly constant virial parameters as a function of mass, suggesting that the clouds are all in roughly the same dynamical state.

Herschel Observations of the LMC

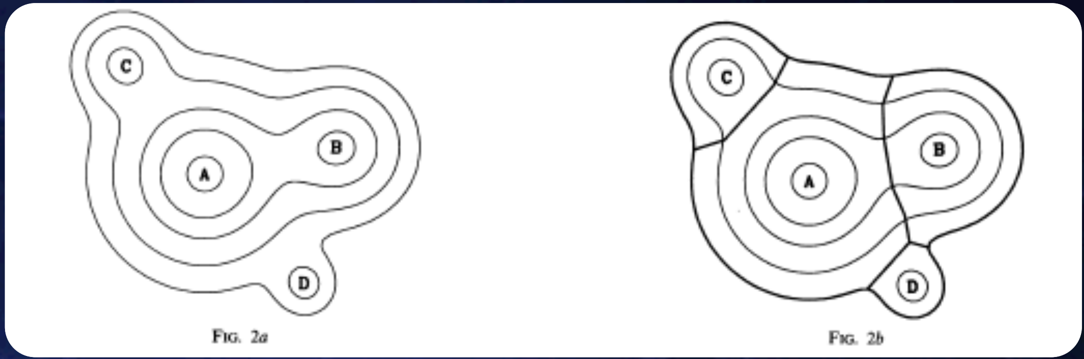
Cold Dust Clumps

Heating of Neutral Clouds are dominated by photo-electric heating by dust grains and PAH molecules, we must study the dust properties in order to understand the gas behavior.

SPIRE Observations from HERITAGE SDP (Meixner et al. 2010)



Cold Dust Clumps in Dynamically Hot Gas



Williams, De Geus & Blitz 1994

Clump-finding Algorithm

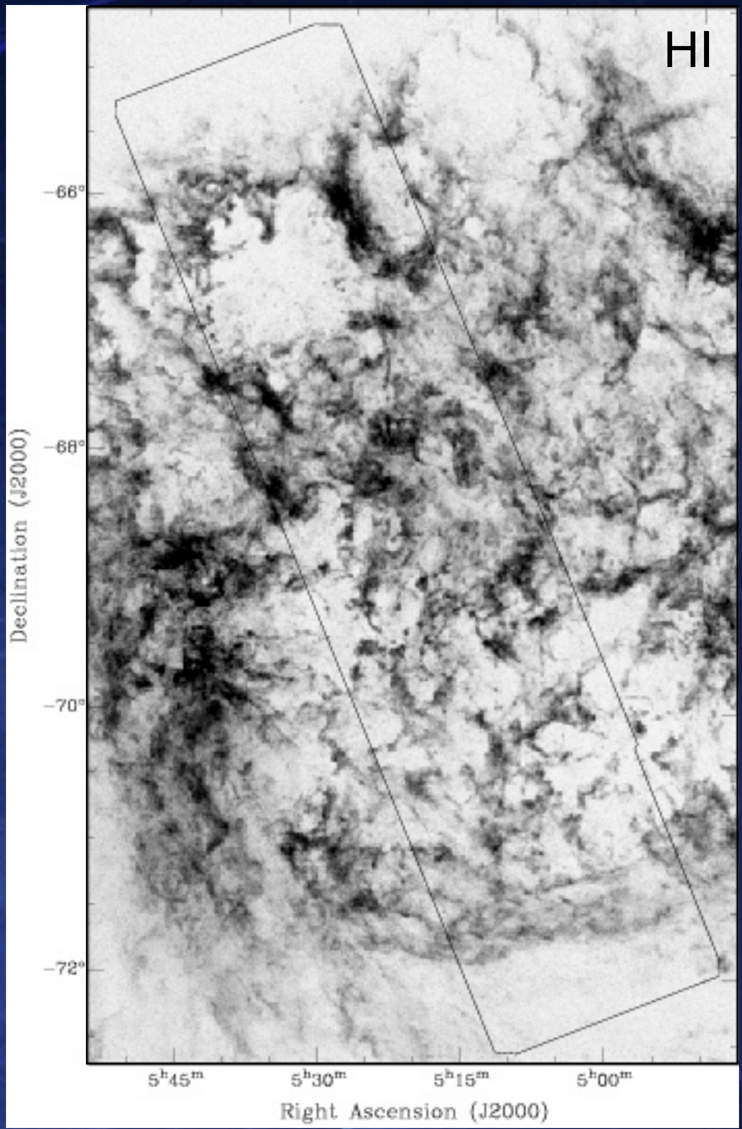
$$\sigma_x = [\frac{\Sigma x^2 I}{\Sigma I} - (\frac{\Sigma x I}{\Sigma I})^2]$$

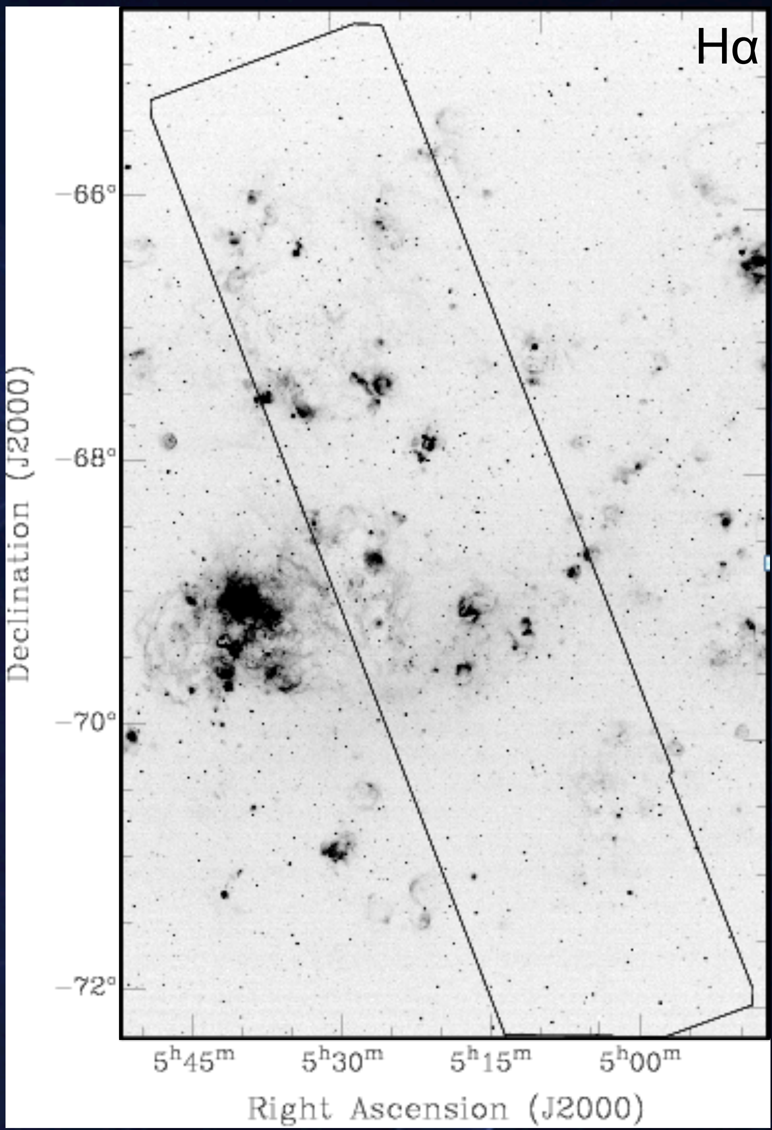
: Clump size

$$\Delta R = (A/\pi)^{1/2}$$

: Circular radius of clump size

Cold Dust Clumps in Dynamically Hot Gas





Dust clouds seen in the SPIRE 500µm image (left) and 350µm image (right)

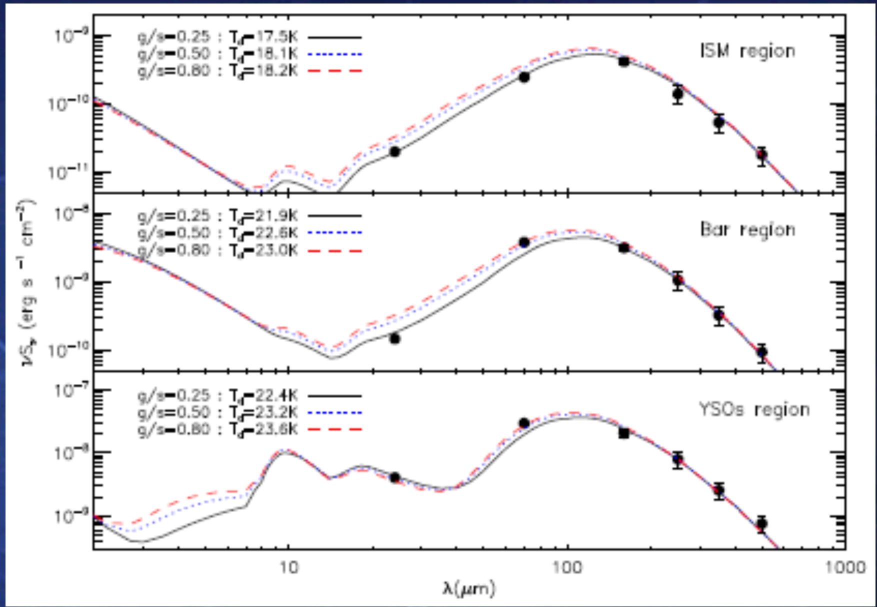
Cumulative Mass Spectrum

Cold Dust Clumps in Dynamically Hot Gas in the LMC

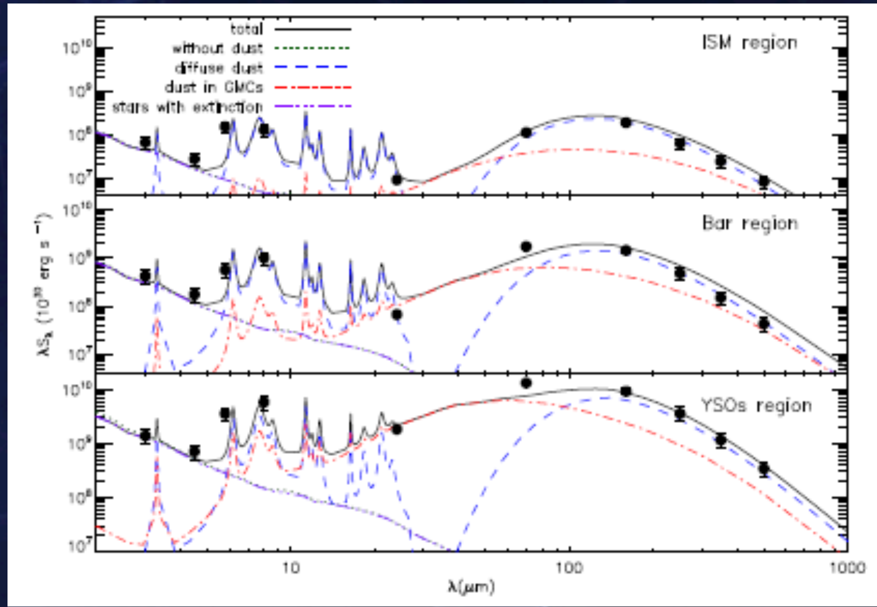
Dust clump mass

$$M_d = \frac{S_\lambda \times D^2}{\kappa_\lambda \times B_\lambda(T_d)}$$

S_λ : flux density, D : 50kpc, B_λ(Td) : Planck function, T_d : dust temperature
κ_λ : mass absorption coefficient (1.15 ㎠/g at 500㎛)

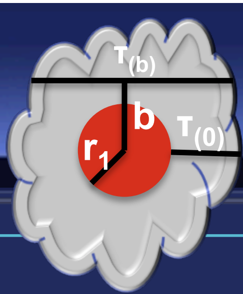


DUSTY model spectra



GRASIL model spectra

DUSTY radiative transfer code: Ivezić et al. (1999)



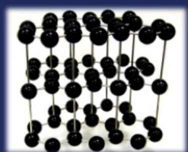
[Physical parameters for DUSTY run]

TYPE[1]	T_{BB} (K)	L_{BB} ($L_\odot$)	X_{ISRF} (G0)	DENSITY DISTRIBUTION r_i/r_c[2]	r_i (cm)	y_1[3]	p_1[4]	y_2	p_2	τ_{160}	g/s	T_d(K)
											0.25	17.5
ISM	6×10^3	1	1	1.55×10^2	1×10^{13}	30	0.7	1.5×10^4	0.2	0.0015	0.50	18.1
											0.80	18.2
											0.25	21.9
AGB	3×10^3	2×10^4	3.5	1.1×10^1	4×10^{14}	50	0.7	3×10^4	0.4	0.002	0.50	22.6
											0.80	23.0
											0.25	22.4
YSOs	1×10^4	1×10^2	7	8.6×10^2	2×10^{14}	200	1.3	1×10^4	0.5	0.003	0.50	23.2
											0.80	23.6

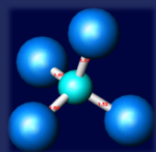
1. dominant component part in each regions
2. Ratio of the inner to the stellar radius
3. the ratio of shell's outer boundary to inner boundary
4. density index $n(r) \propto r^{-p}$

Grain size distribution – KMH distribution (q=3.5, a_{min}=0.005㎛, a_{max}=0.25㎛)

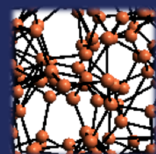
Grain chemical composition



Graphite



Silicate



Amorphous carbon

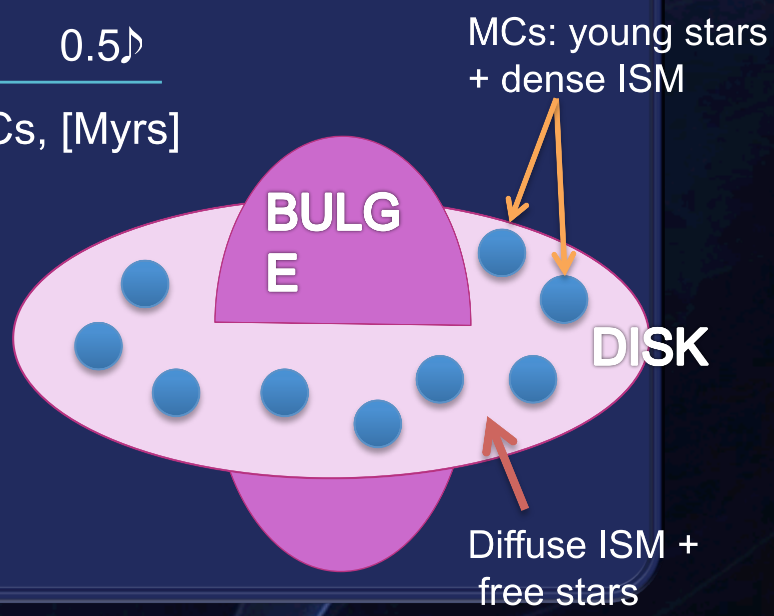
GRASIL spectro-photometric model : Silva et al. (1998)

[Physical parameters for GRASIL run]

Schurer et al.(2008) : Irregular galaxy parameters

t_{esc}[1]	f_{mc}[2]	M_{mc}[3]	R_{mc}[4]	r^*_d[5]	z^*_d[6]	r^d_d[7]	z^d_d[8]
1-20	0.1	10^6	40	1	0.5	1	0.5

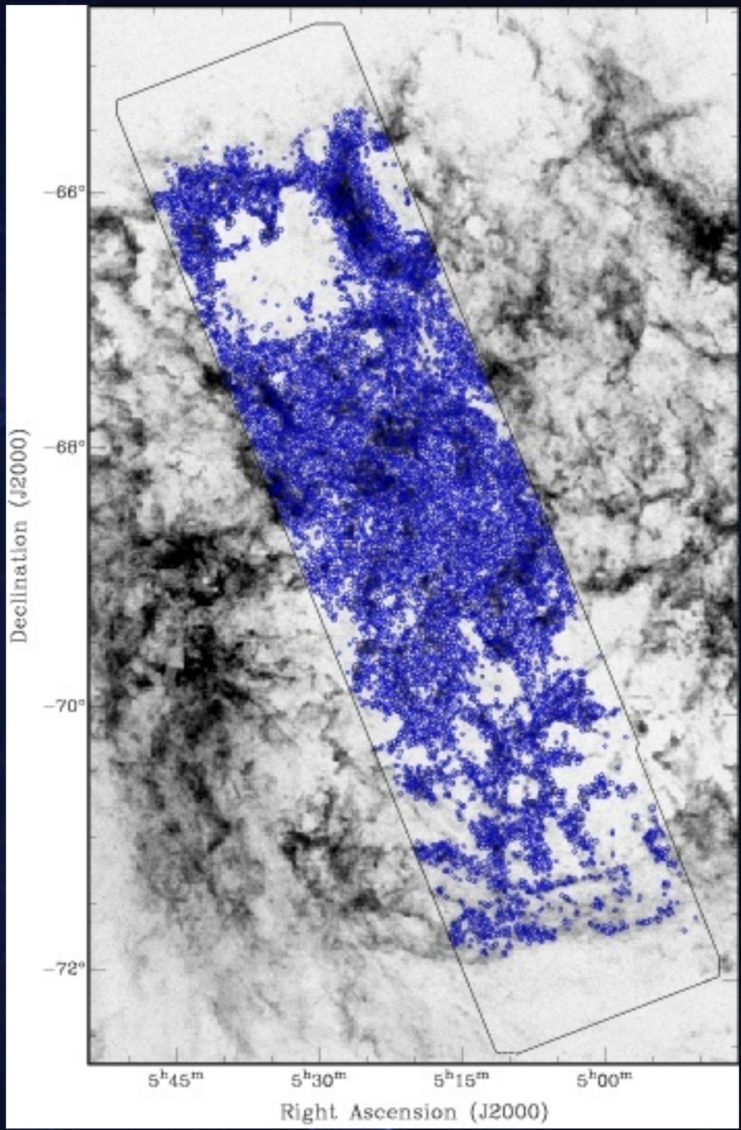
[1] Escape time of the young stars from their parent MCs, [Myrs]
[2] Molecular to total gas mass ratio
[3] Gas mass of MC, [$M_\odot$]
[4] Radius of MC, [pc]
[5] Radial scalelength for stars in disk, [Kpc]
[6] Vertical scalelength for stars in disk, [Kpc]
[7] Radial scalelength for dust in disk, [Kpc]
[8] Vertical scalelength for dust in disk [Kpc]



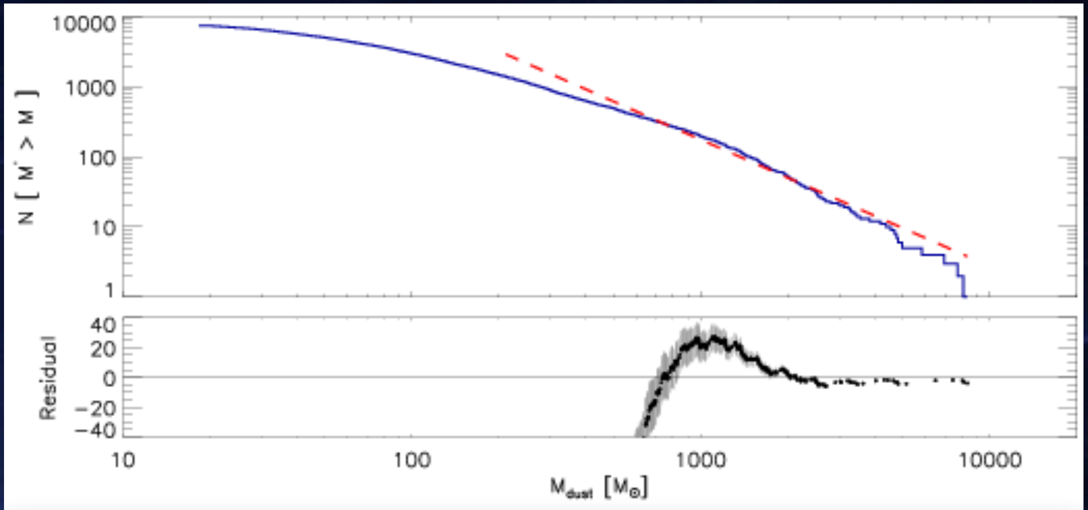
Cold Dust Clumps in Dynamically Hot Gas in the LMC

Dust clumps

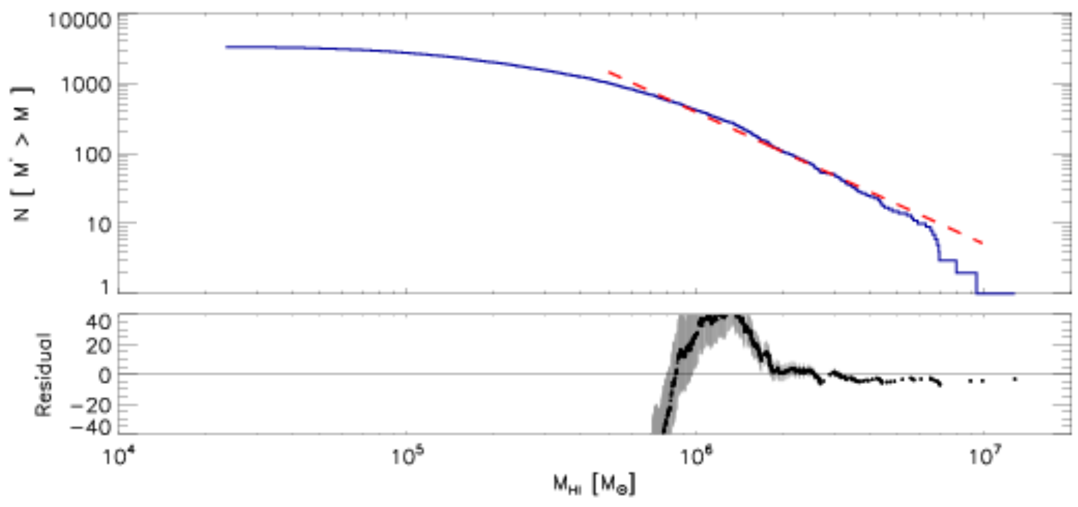
SPIRE 500μm	
1σ (RMS)	~0.3 MJy/sr
N_{clumps}	7449
Size range	9.8 – 47±1 pc (median 15±1 pc)
Mass range	$1.8 \times 10^{1}\ M_{\odot}$ to $7.9 \times 10^{3}\ M_{\odot}$



Cold Dust Clumps in Dynamically Hot Gas in the LMC



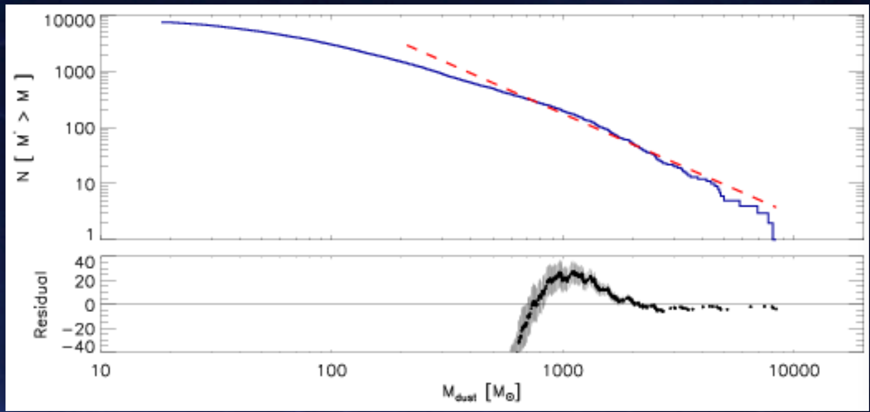
Dust clump mass spectrum

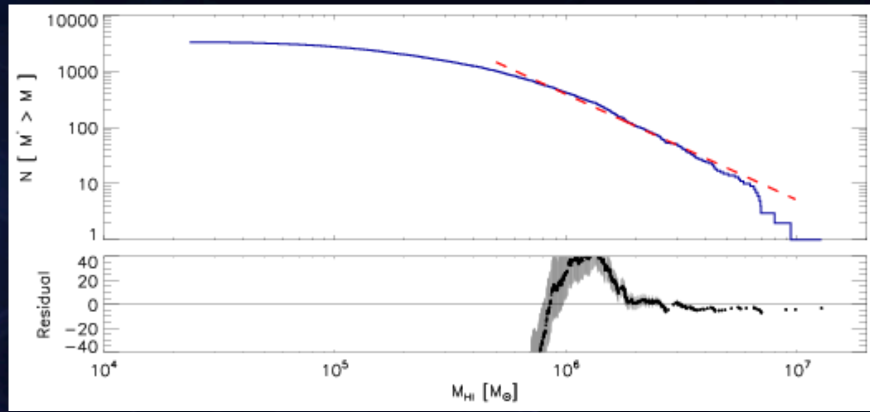


HI mass spectrum

Cold Dust Clumps in Dynamically Hot Gas in the LMC

Gas and dust mass spectrum





Cumulative mass distribution

$$N(M' > M) = N_0\left(\frac{M}{10M_\odot}\right)^{\gamma+1}$$

	Dust clump	HI clump	Vigorous star formation
ϒ	-1.8	-1.88	-2.1

Summary

- ❖ Dust Clumps have been identified and cataloged in the Herschel SPIRE survey of the LMC using an automated cloud-finding algorithm.

- ❖ The distribution of cold dust clumps is remarkably similar to the HI clump mass distribution, sharing an index of mass distribution, γ=-1.8. → Since the dust emission in the far-IR continuum provides an estimate of the star formation rate (SFR) and grains remain strongly coupled to the neutral gas, the mass spectra of the dust clouds to behave in a similar way to the mass spectra resulting in the diffuse gas.

- ❖ However, the dust clump mass spectrum in the lower mass regime follows a flatter power law than the Salpeter stellar IMF, γ=-0.8. → Most of the clump mass resides in massive clumps, while the most of the stellar mass is in low-mass stars.

- ❖ The resulting graphite and silicate abundances from fitting the observed SEDs differ by 50% among the clumps in different environments in the LMC.