The Fractal Dimension of Star-forming Regions in M33

Mary Crone Odekon, *Skidmore College*
Collaborators:
Néstor Sánchez and Emilio J. Alfaro, *Instituto de Astrofísica de Andalucía, Granada, Spain*
Neyda Añez, *Universidad del Zulia, Maracaibo, Venezuela*

ASNY Fall Meeting 2010, RPI

The clustering of young stars: Some theoretical expectations

OB associations → aggregates → complexes → supercomplexes

10 pc → 100 pc → 1 kpc

- If turbulence drives the distribution of gas, it will create an **approximately scale-free structure** as power cascades down to smaller scales. The **positions of young stars will reflect the gas distribution**, while **older stars will have gravitationally relaxed** into smoother distributions

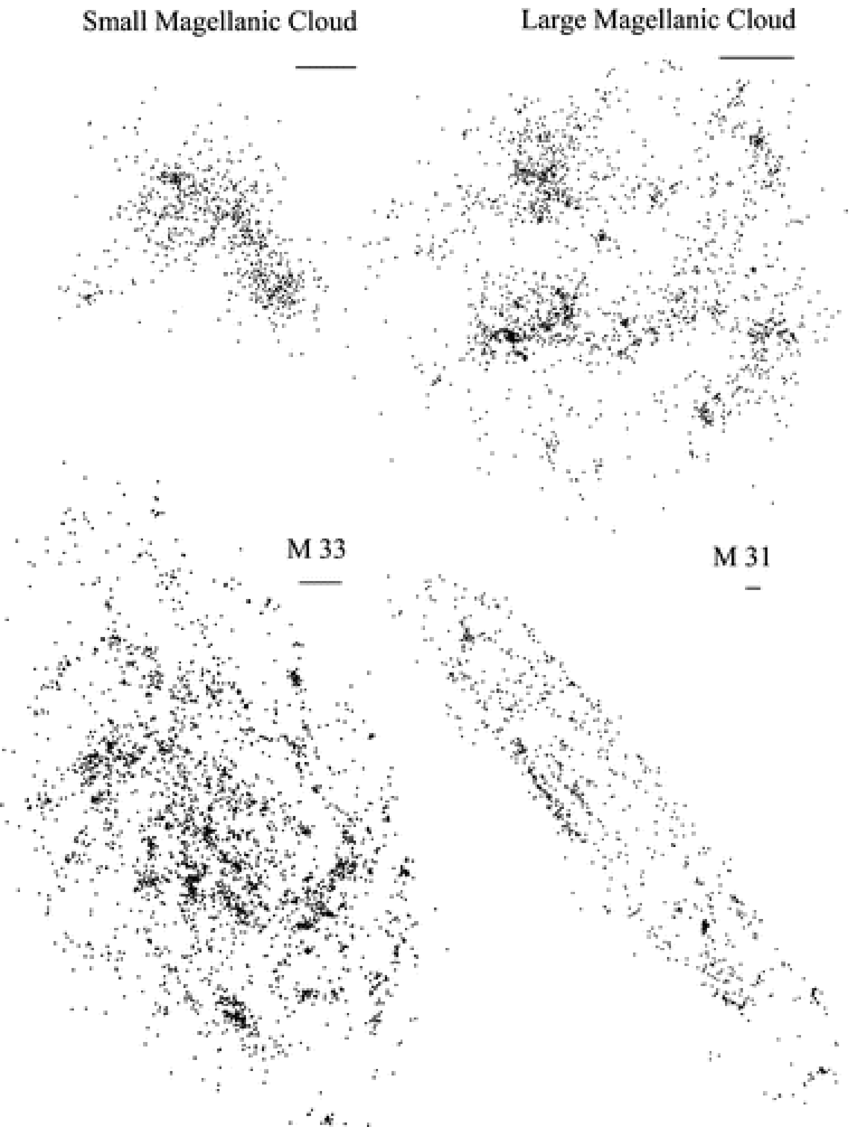
- Simple incompressible "Kolmogorov" turbulence will produce a fractal dimension of 2.67. The dimension for compressible turbulence depends on Mach number, with flatter spectra for high M_{rms}. (e.g. Kritsuk et al. 2007; Kim & Ryu 2005). Magnetic effects and self gravity are likely to flatten the power law dependence (e.g. Padoan et al. 2004).

- The structure will not be totally scale-free: we should see **features at scales where power is injected and where the properties of the gas are different.**

- The process of star formation is bound to **vary with time and location**, because of differences in chemical content of gas; mass, size, and shape of galaxy; ambient pressure/temperature; likelihood of mergers and accretions

A search for special scales using the correlation function

Odekon 2008



Two-point autocorrelation function

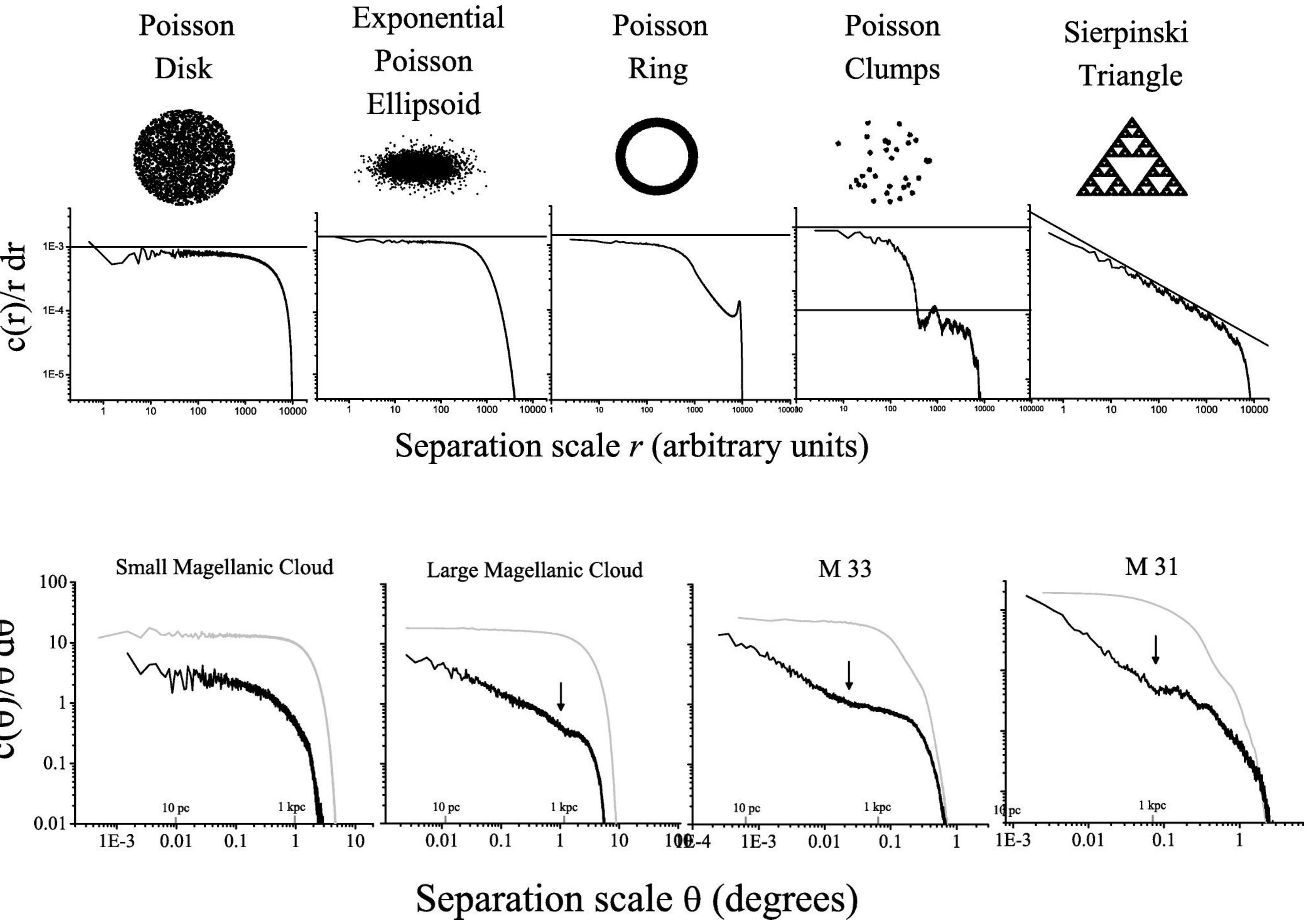
c(r)dr = the average number of stars between r and r+dr from any particular star

Correlation integral (integrated correlation function)

$$C(r) = \int c(r')dr'$$

Correlation dimension D

$$D(r) = \log C(r) / \log r$$



Poisson Disk
Exponential Poisson Ellipsoid
Poisson Ring
Poisson Clumps
Sierpinski Triangle
c(r)/r dr
1E-3
1E-4
1E-5
1
10
100
1000
10000
Separation scale r (arbitrary units)
Small Magellanic Cloud
Large Magellanic Cloud
M 33
M 31
c(θ)/θ dθ
100
10
1
0.1
0.01
10 pc
1 kpc
1E-4
1E-3
0.01
0.1
1
10
100
Separation scale θ (degrees)

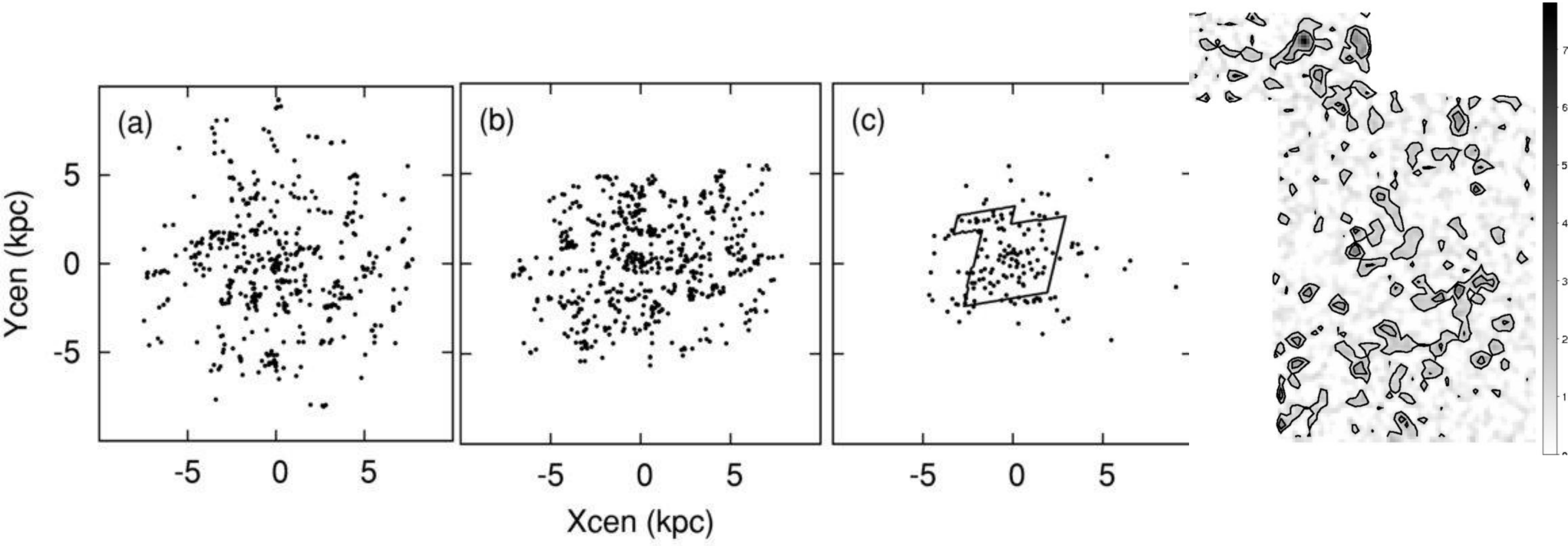
The current project

- Calculate numbers for clustering strength (fractal dimension) at small and large spatial scales including deprojection and appropriate boundaries for the “small” and “large” regions.
- Estimate 3D fractal dimension by comparing with simulated, projected fractals
- Compare fractal dimension within a single galaxy for stars, HII regions, molecular clouds
- Compare fractal dimension from galaxy to galaxy

Strategy: Focus on M33 (large, nearby, close to face-on, target of many surveys)

The data

Bright MS stars	HII regions	GMCs	CO map
Massey et al. 2006	Hodge et al. 1999	Rosolowsky et al. 2007	Rosolowsky et al. 2007
Brightest (0-20 Myr) Fainter (20-35 Myr)	Bright, resolved, no flags min 10^{16} $ergs^{-1}cm^{-2}$ $arcsec^{-2}$	BIMA+FCRAO	NRO+BIMA+FCRAO



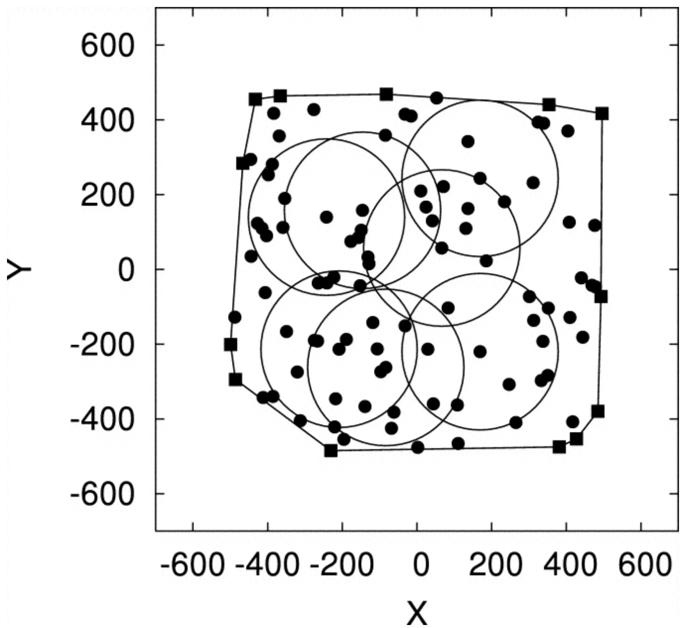
Deprojected using i=55°, p.a.=23°

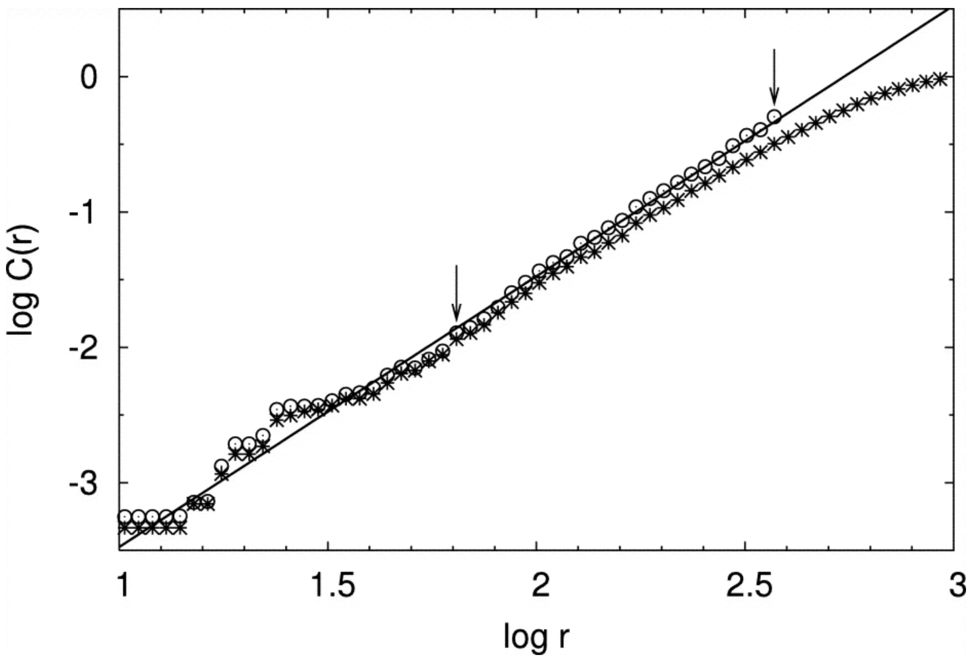
Boundaries of fitting region

In calculating C(r), use only points where r is within the minimum-area convex polygon enclosing all points.

Fit only over only ranges in r for which the standard deviation in C(r) from different random realizations less than C(r) itself

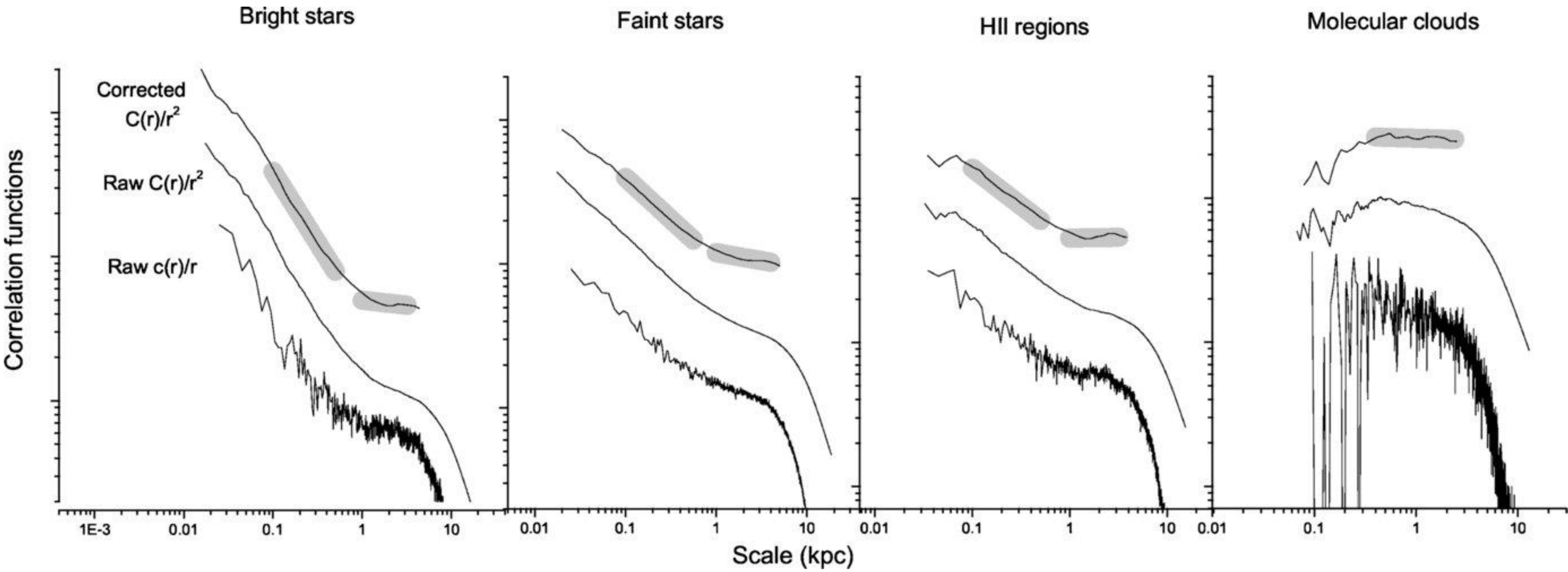
Vary the location of the transition region to get the smallest residuals when both sides are fit with power laws





Sánchez et al. 2007

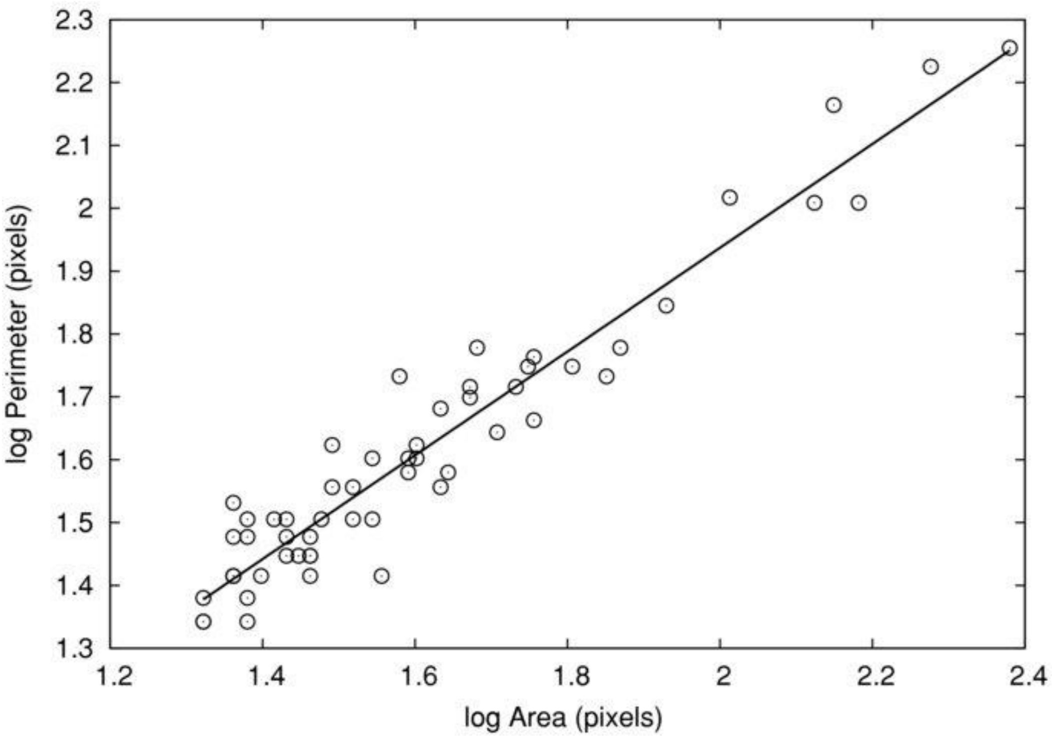
Results: Correlation functions for point distributions



Results: Perimeter dimension for CO map

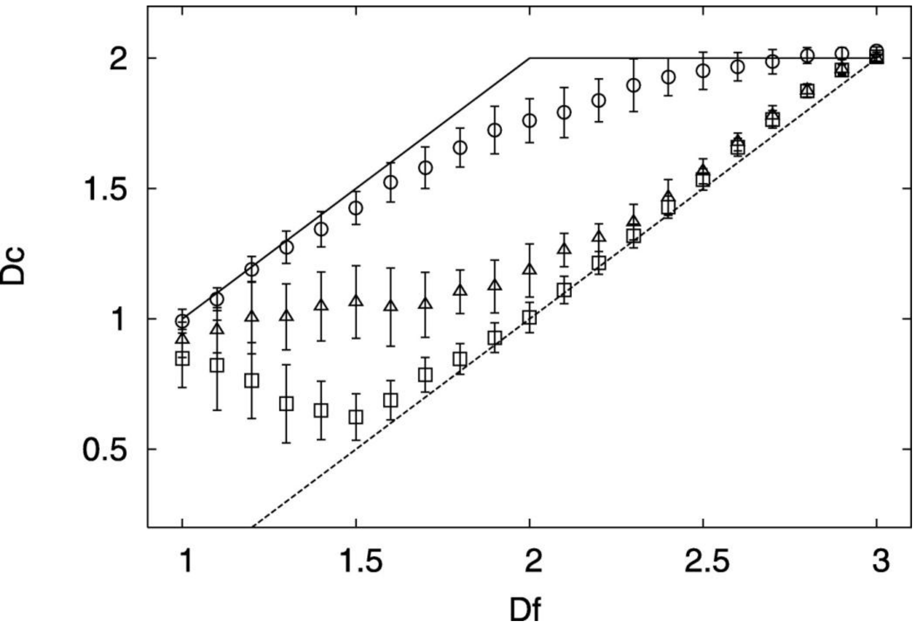
Perimeter-Area scaling
Sánchez et al. 2005.

Regions selected using brightness levels in steps of 0.5 K km/s



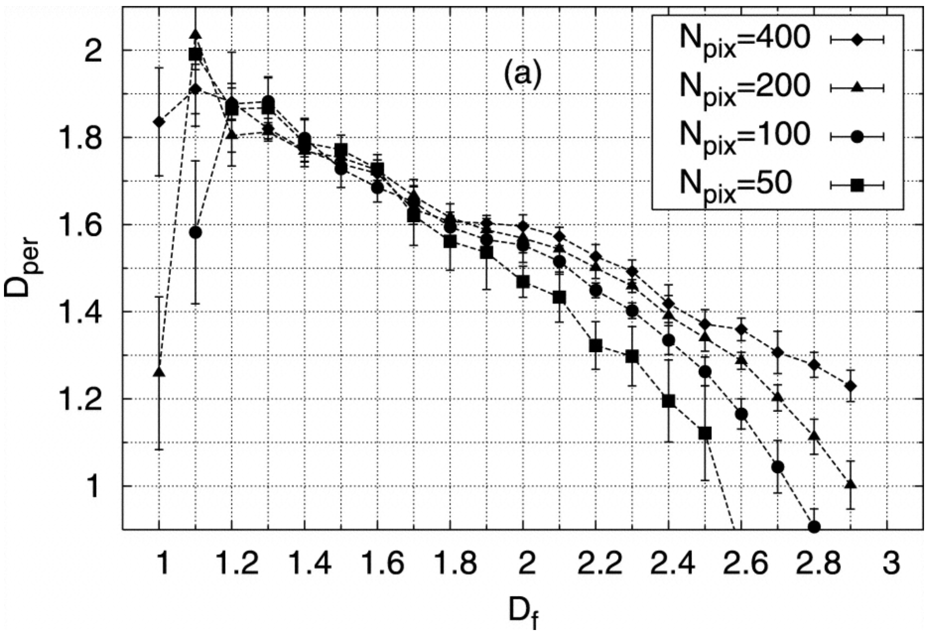
Inferring the 3D fractal dimension

Correlation dimension



Sánchez & Alfaro 2008.

Perimeter-Area scaling



Sánchez, Alfaro, & Pérez 2005

Table 1

Summary of Calculated Fractal Dimensions for M33

Sample	N_{dat}	Small Spatial Scales[a]		Large Spatial Scales	
		$D^{b}_{f,2D}$	$D_{f,3D}$	$D_{f,2D}$	$D_{f,3D}$
Bright stars	534	1.01 ± 0.05	1.0–1.9	1.93 ± 0.03	2.8–2.9
Faint stars	1644	1.42 ± 0.04	2.2–2.4	1.89 ± 0.02	2.8–2.9
H II regions	617	1.48 ± 0.08	2.3–2.5	2.01 ± 0.03	2.9–3.0
Molecular clouds	149	···	···	1.98 ± 0.04	2.8–3.0
CO emission map	···	1.65 ± 0.06	1.6–1.8	···	···

Notes.

[a] For bright and faint stars and H II regions, small spatial scale means $\lesssim$500 pc and large scale means $\gtrsim$1 kpc. For molecular gas large scale is $\gtrsim$500 pc (distribution of clouds) and small scale is $\lesssim$500 pc (CO map).

[b] $D_{f,2D}$ refers either to the two-dimesional correlation dimension D_c (for the distribution of stars, H II regions, and GMCs) or to the perimeter–area-based dimension D_{per} (for the CO map). $D_{f,3D}$ is the corresponding three-dimensional fractal dimension.

Conclusions

- The transition to a higher dimension (consistent with a random distribution) is seen for bright stars, faint stars, HII regions. It is seen indirectly in the CO distribution (CO map on small scale; GMC distribution on large scale)

  Interpretation: NOT a simple edge effect
  NOT a simple projection effect (thick disk → thin disk)
  * Different physics on scales larger than disk thickness *

- Brighter MS stars are more highly clustered (probably an evolutionary effect)
  HII regions are like fainter sample, CO map is like brighter sample

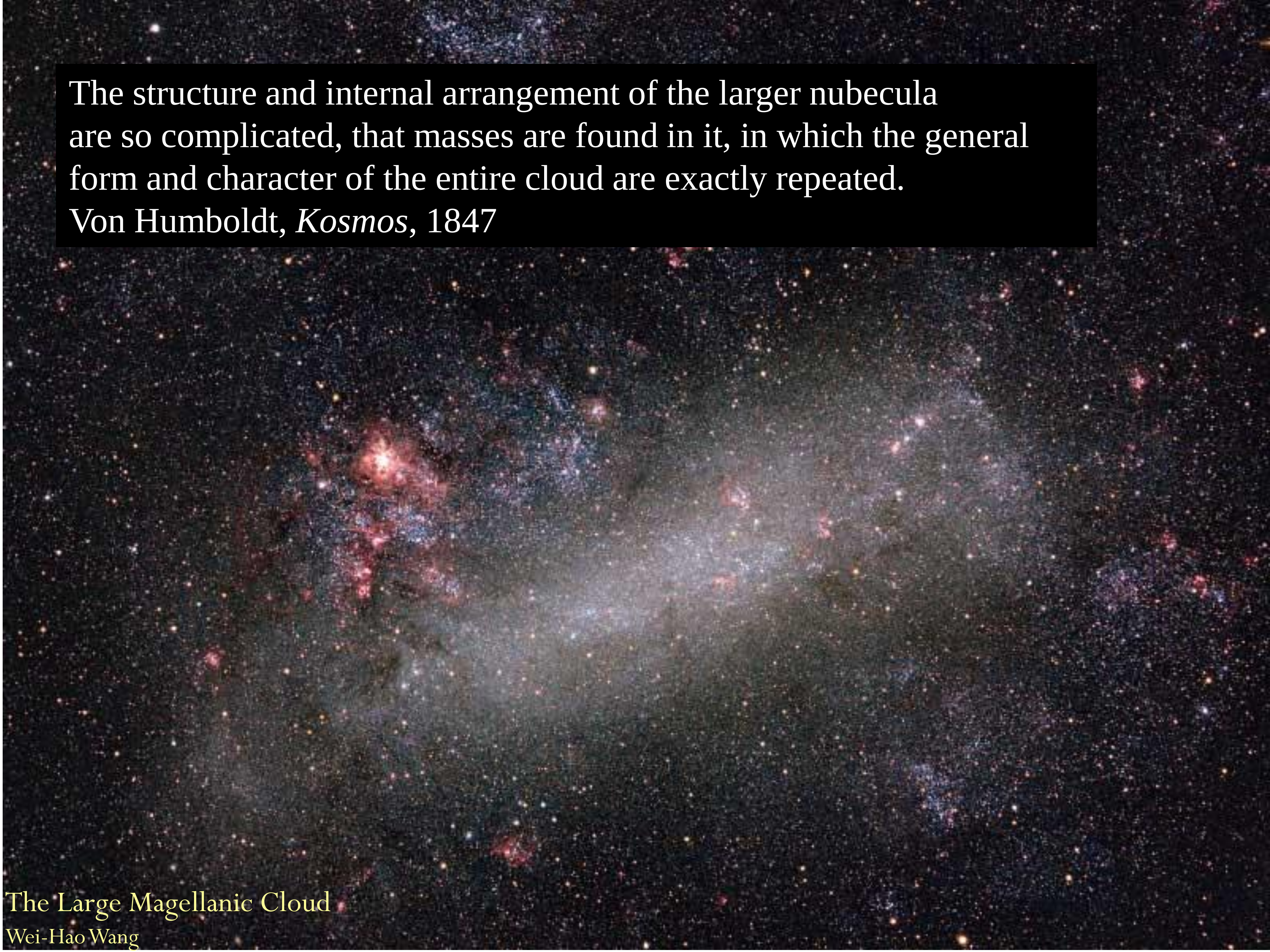
- Molecular gas is apparently more clustered in M33 than in our galaxy:

  CO in Milky Way: $D_{f,3D}$ =2.6-2.8
  CO in M33: $D_{f,3D}$ =1.6-1.8

  Young stars in MW: $D_{f,3D}$ =2.8-2.9 (local disk stars);
  $D_{f,3D}$ =2.6-2.7 (Gould Belt)
  Young stars in M33: $D_{f,3D}$ =1.0-1.9 (small scales)

  Location within galaxy? Size of galaxy?
  Issues with distances/blending/sample size in MW samples?

The structure and internal arrangement of the larger nubecula are so complicated, that masses are found in it, in which the general form and character of the entire cloud are exactly repeated.
Von Humboldt, *Kosmos*, 1847



The Large Magellanic Cloud
Wei-Hao Wang