Young Stellar Structures in the Magellanic Clouds as Revealed by the VMC Survey

SFDE17, Aug.11, 2017
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in collaboration with the VMC team

OUTLINE

- introduction
- the MCs and upper-MS stars
- identifying young stellar structures
- properties, formation, and evolution
- summary

The Stellar Hierarchy

star

cluster
10^0 pc

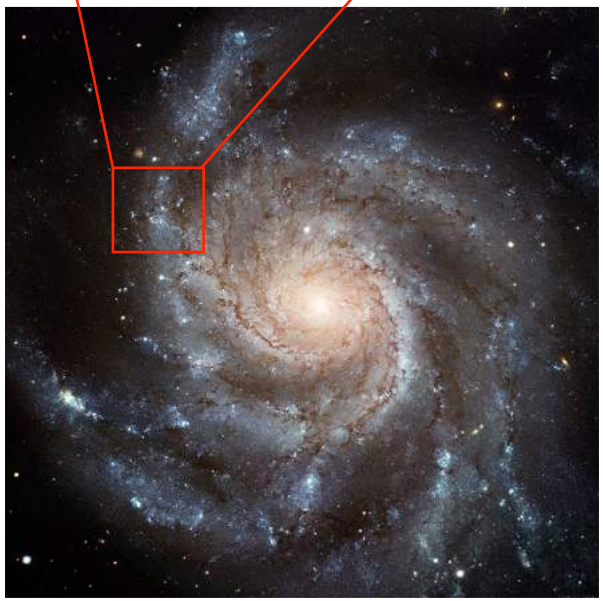
association
10^1–10^2 pc

complex
10^3 pc

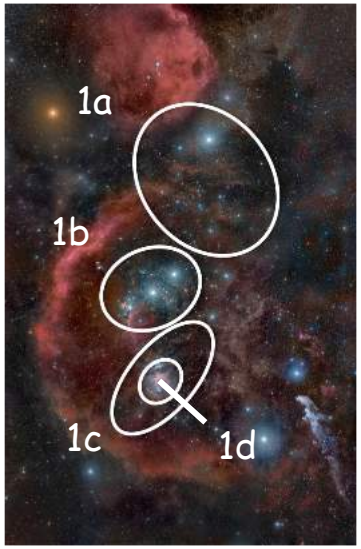
galaxy
10^4 pc

Stellar Complex

Pinwheel Galaxy



Orion OB1

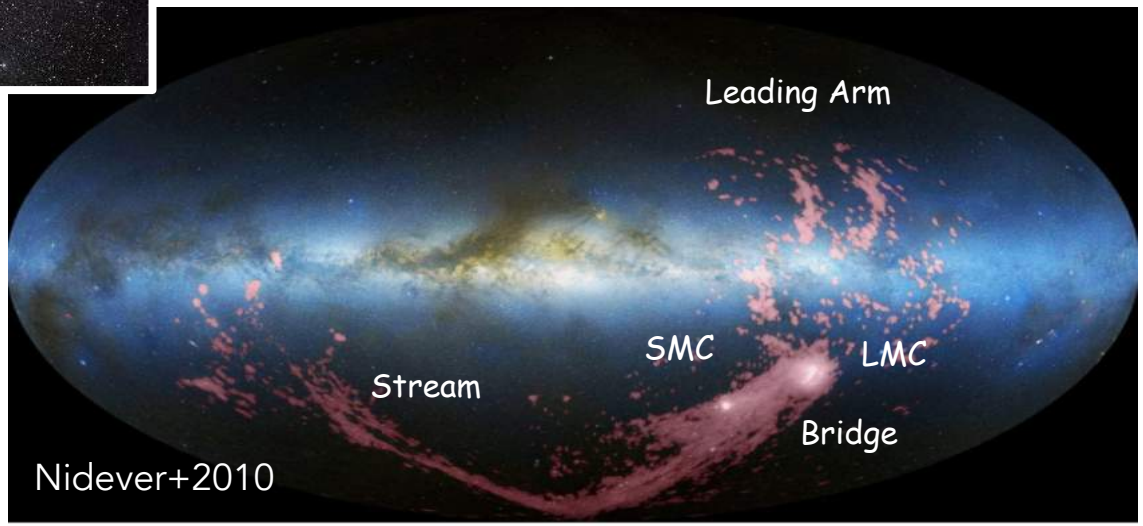


Double Cluster

IMAGE CREDITS:
Double Cluster: NASA/Picture of the Day

Orion: Rogelio Bernal Andreo
Pinwheel Galaxy: ESA & NASA

THE MAGELLANIC CLOUDS



Shapley (1931) "Constellations"

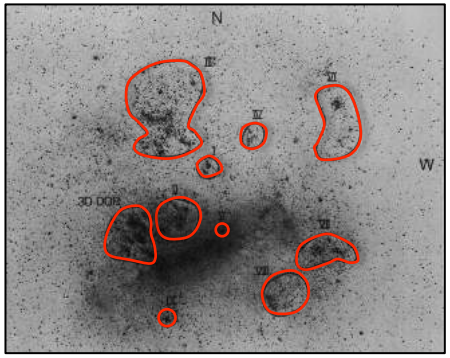
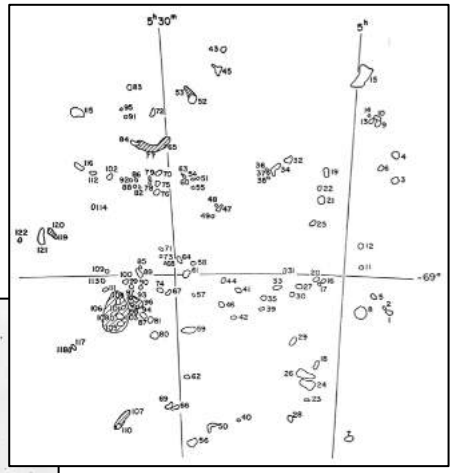
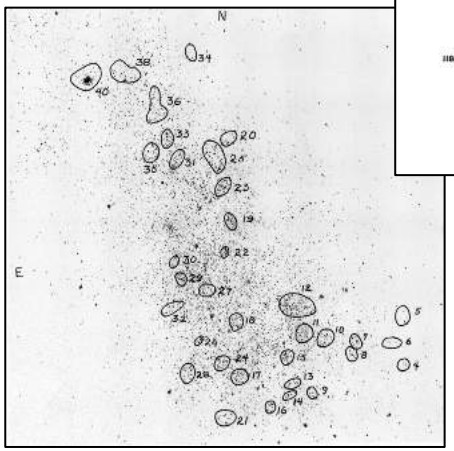


image: van den Bergh (1983)

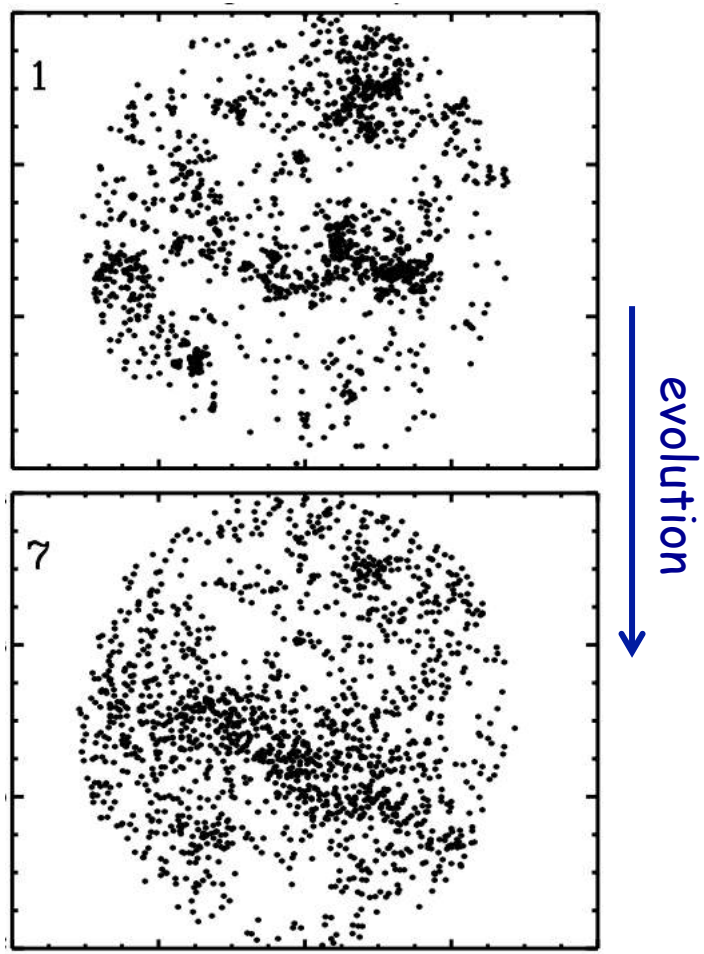
Lucke & Hodge (1970)



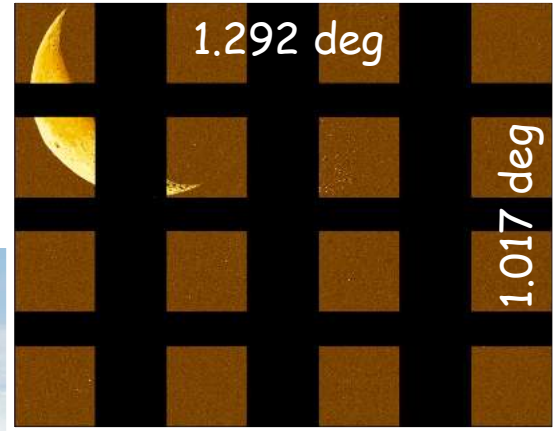
Hodge (1985)

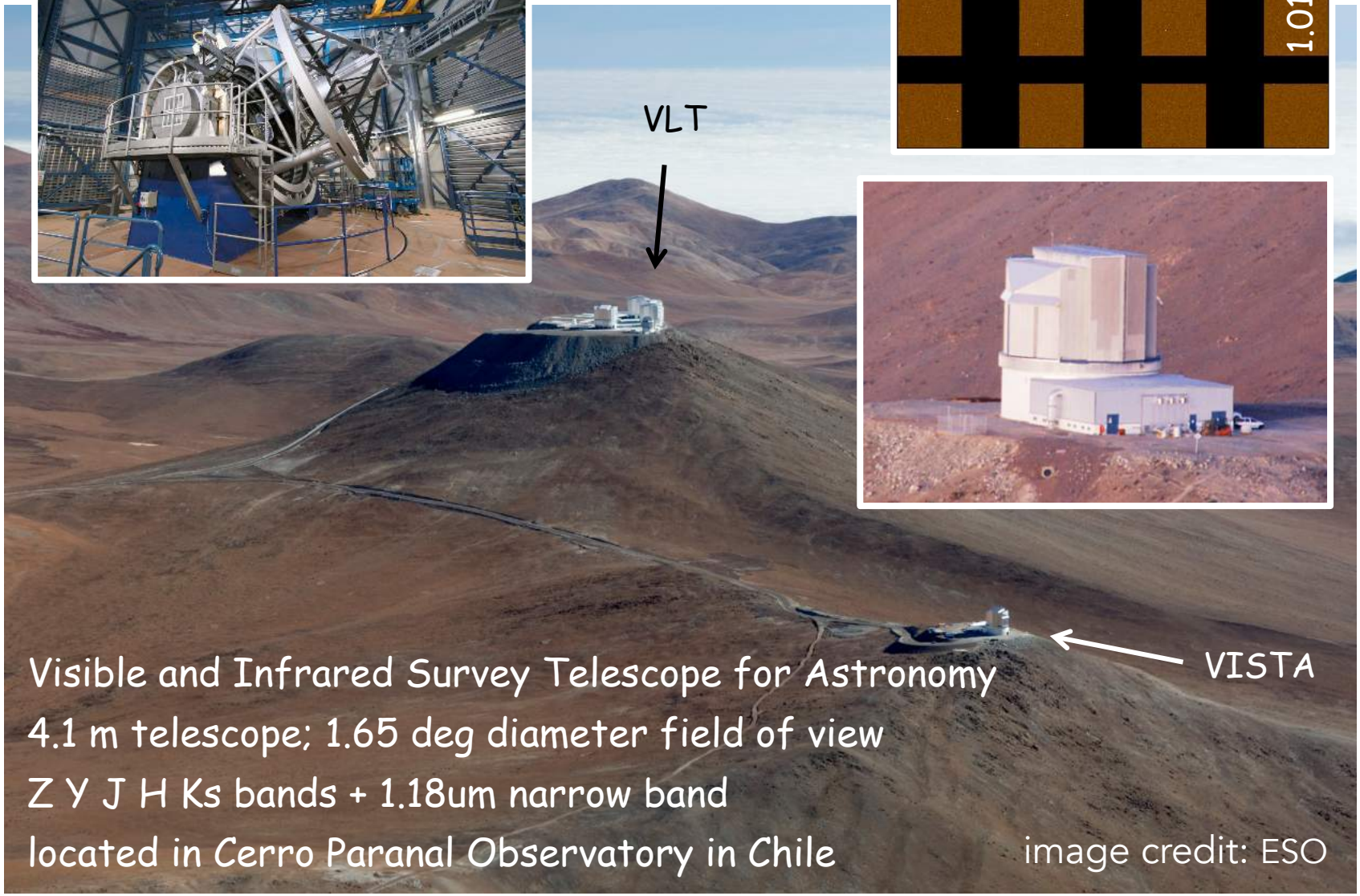


Bastian+09 (see also Gieles+08)



THE VMC SURVEY





Visible and Infrared Survey Telescope for Astronomy

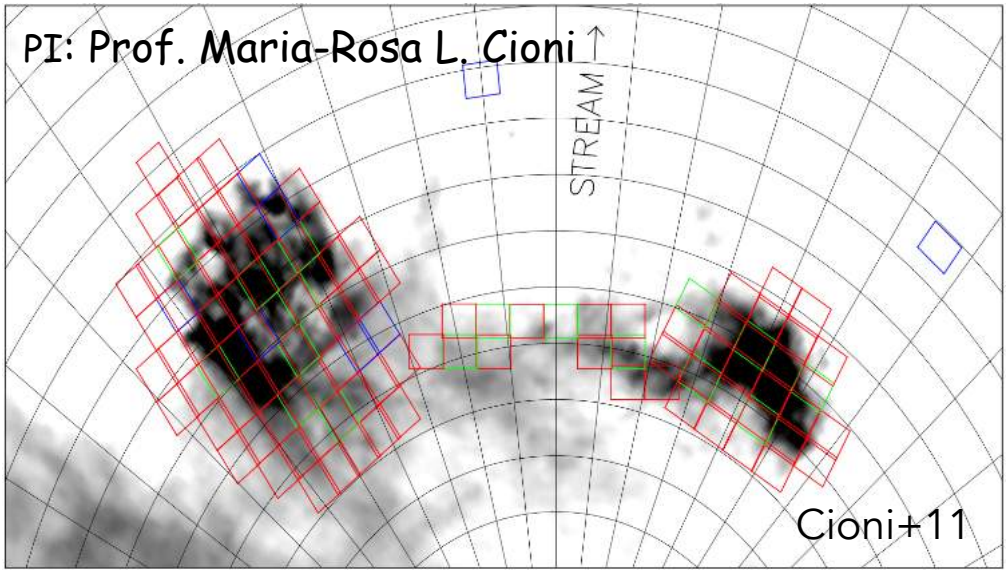
4.1 m telescope; 1.65 deg diameter field of view

Z Y J H Ks bands + 1.18um narrow band

located in Cerro Paranal Observatory in Chile

image credit: ESO

THE VMC SURVEY



- resolution ≤ 1″
- large survey area
- near-IR wavelengths
- deep photometry

wavelengths : Y (1.02 um), J (1.25 um), Ks (2.15 um)

exposure times : 800s x 3 (Y), 800s x 3 (J), 750s x 12 (Ks)

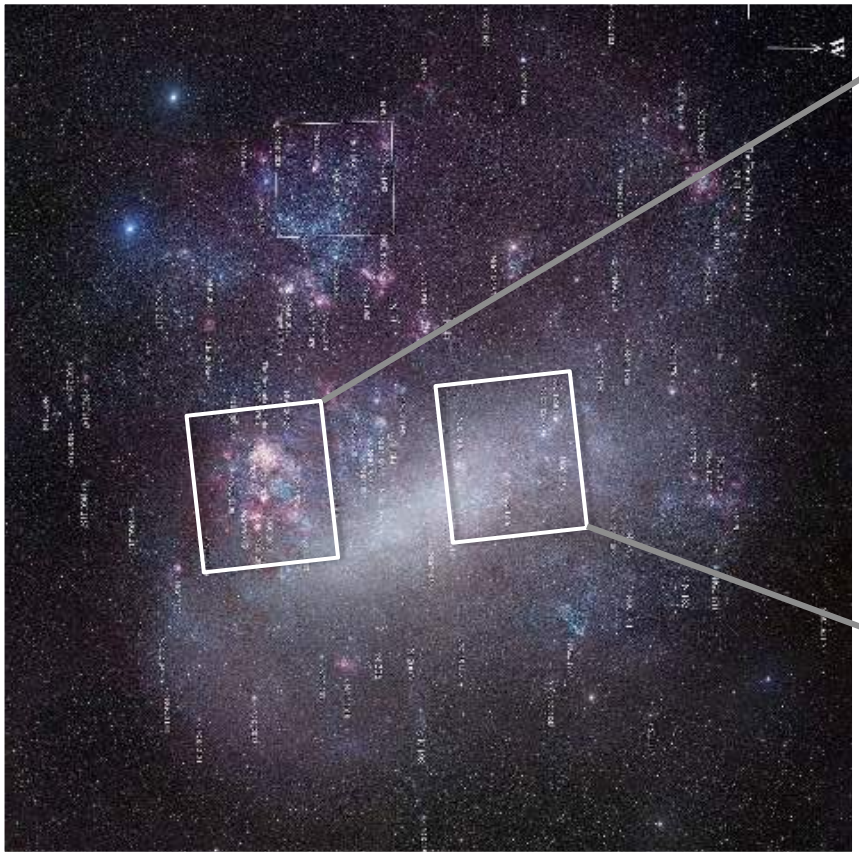
saturation limits : 12.9 mag (Y), 12.7 mag (J), 11.4 mag (Ks)

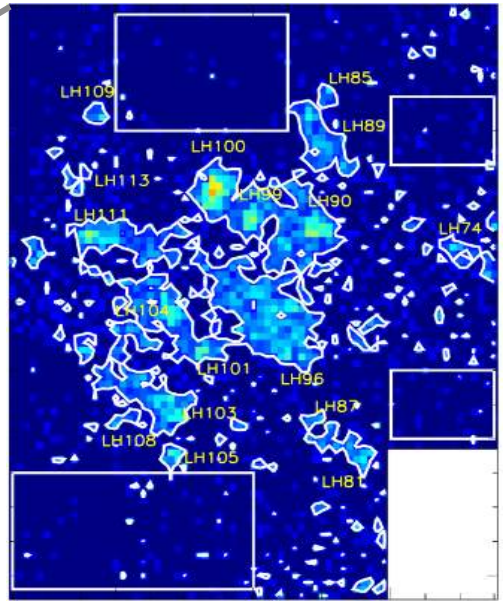
total sensitivities : 21.9 mag (Y), 21.4 mag (J), 20.3 mag (Ks)

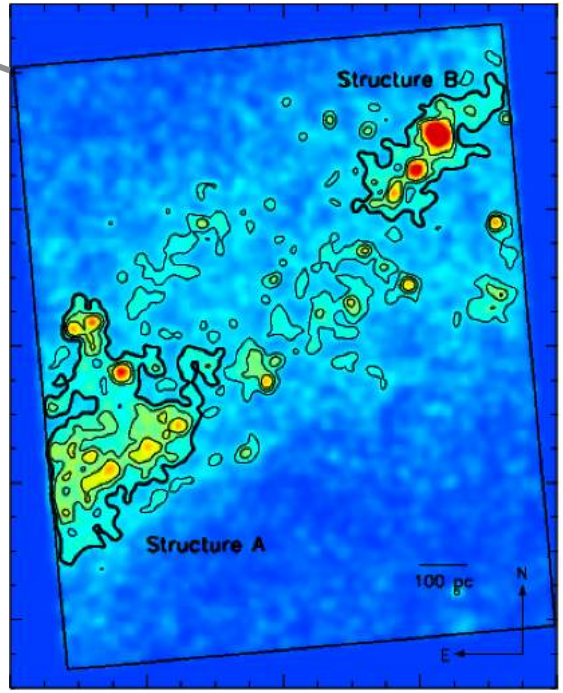
(at S/N = 10)

number of tiles : 68 (LMC) 27 (SMC) 13 (Bridge) 2 (Stream) 110 (total)

area (deg^2) : 116 (LMC) 45 (SMC) 20 (Bridge) 3 (Stream) 184 (total)







the 30 Dor complex:

Sun et al. 2017 ApJ 835, 171

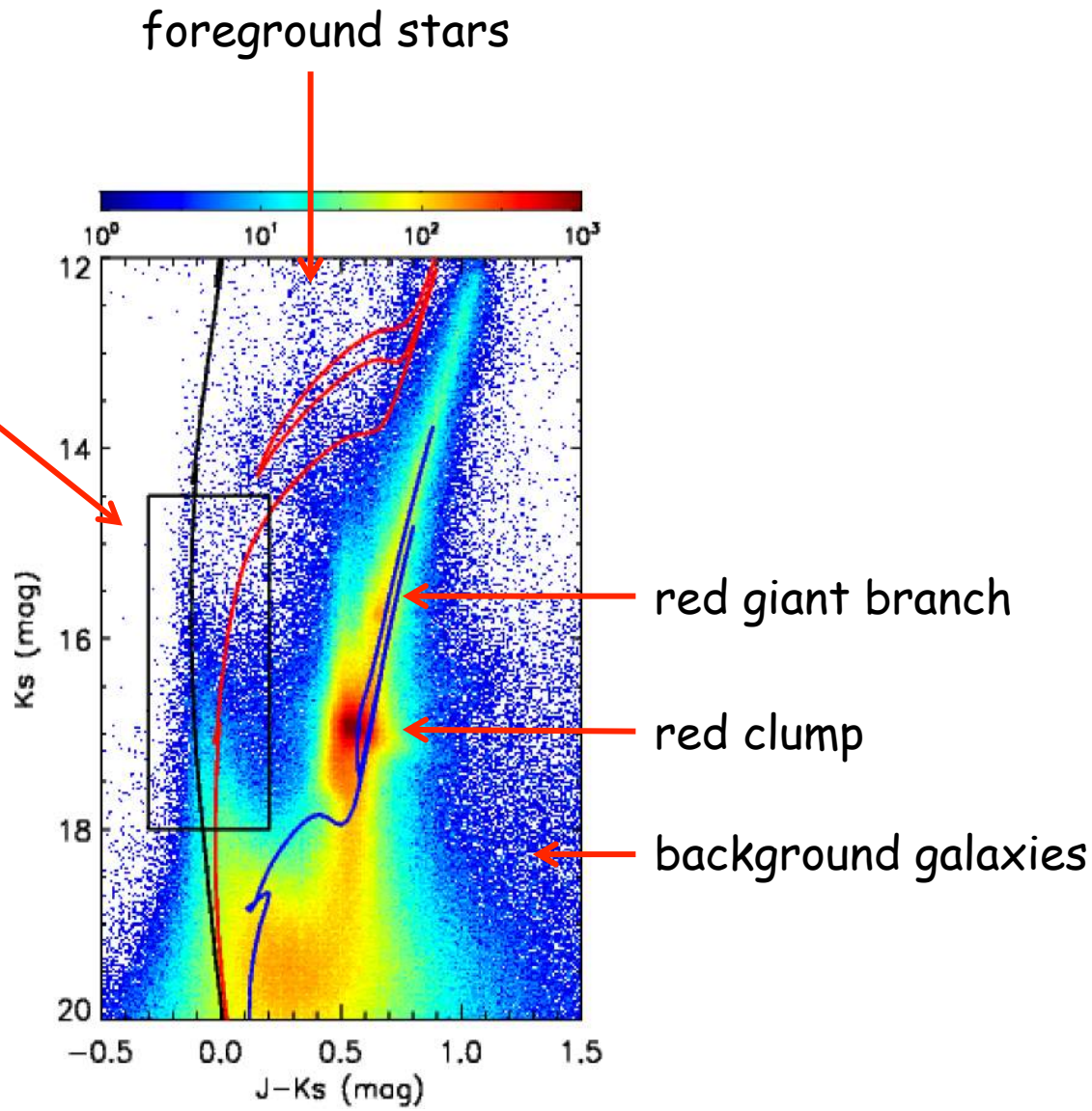
the Bar complex:

Sun et al. submitted to ApJ

TRACER

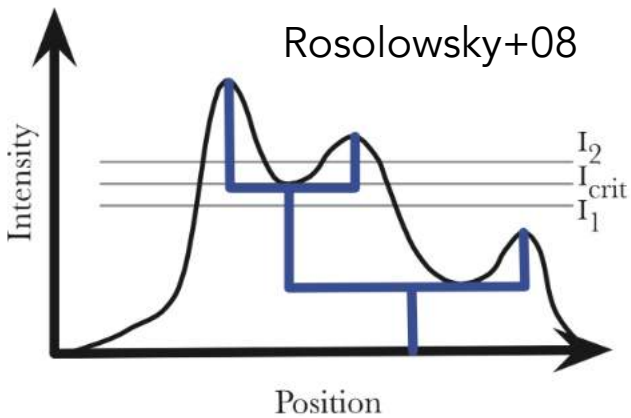
upper-MS stars

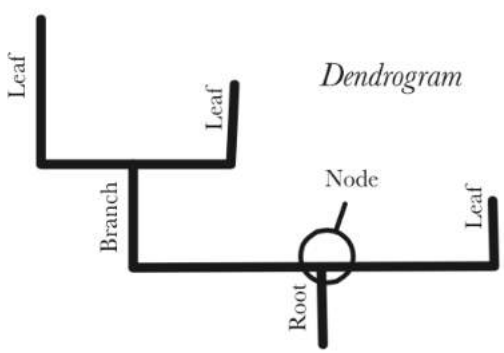
- numerous
- well studied
- bright
- blue colors

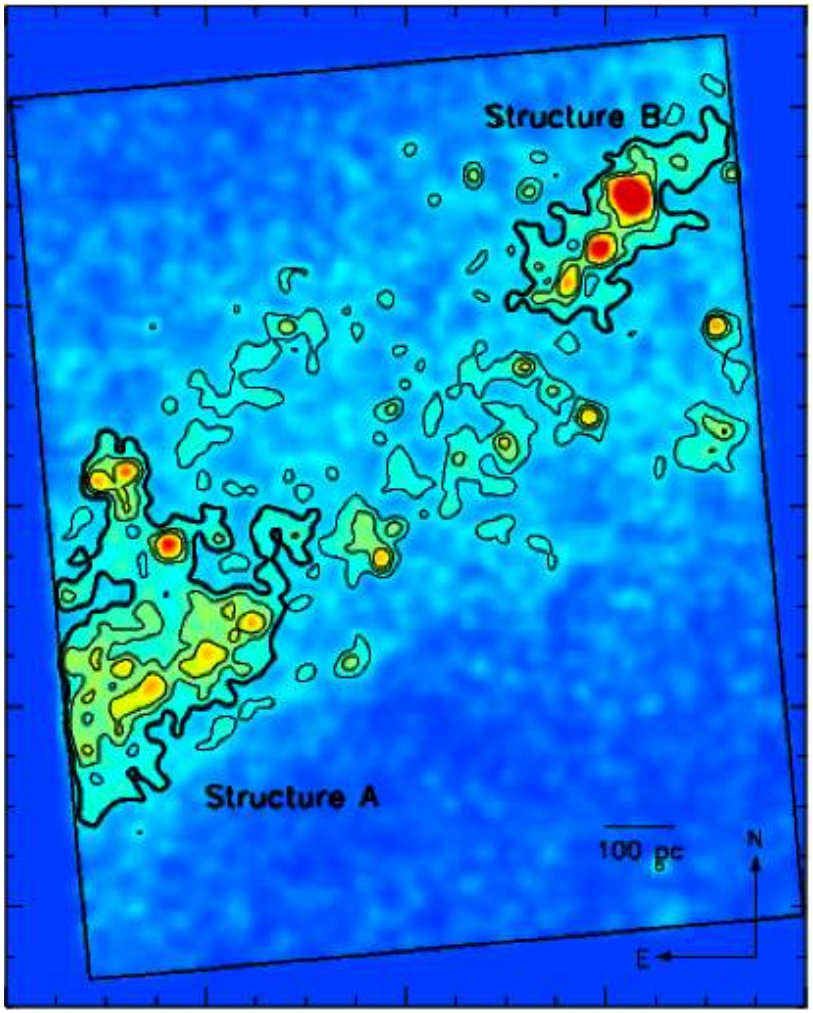


IDENTIFICATION

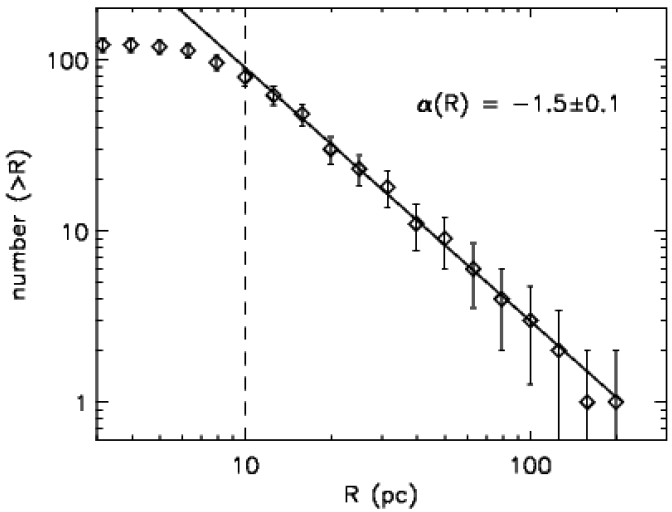
the dendrogram method



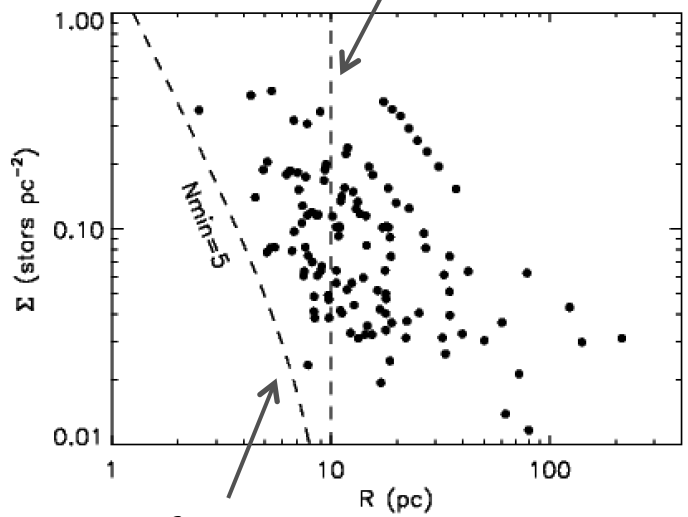




PARAMETERS

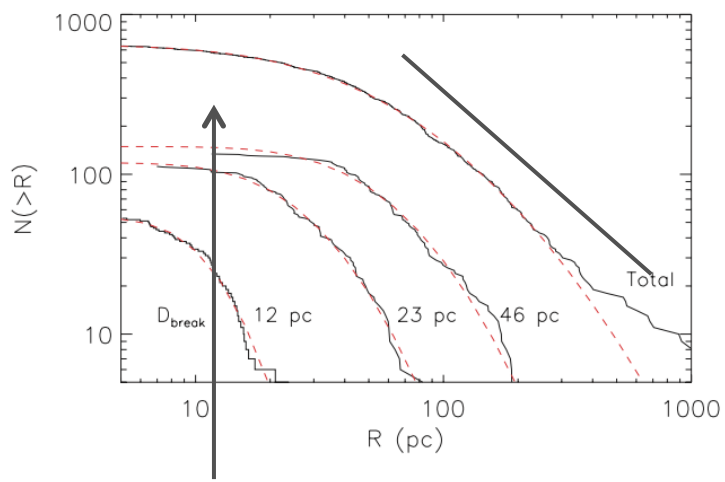


1. KDE map resolution



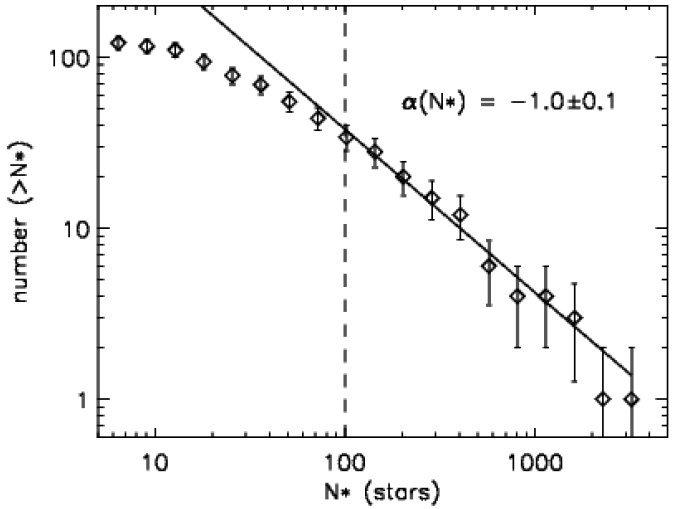
2. Nmin of stars

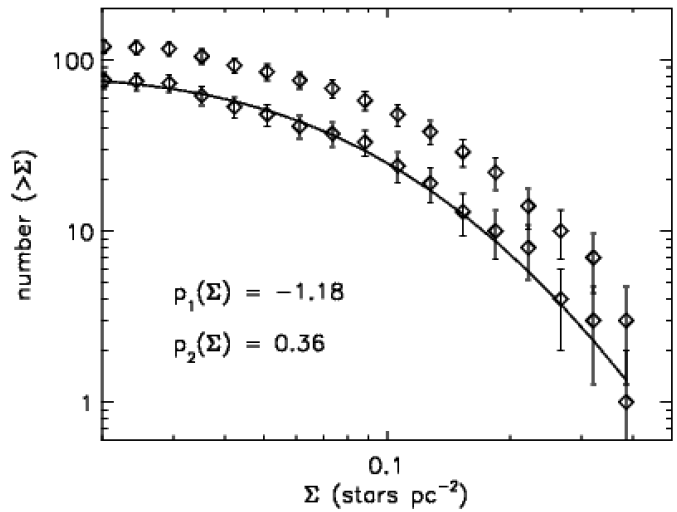
- **lognormal** v.s. **power-law**?
- no preferred scale
- fractal dimension D_2=1.5±0.1



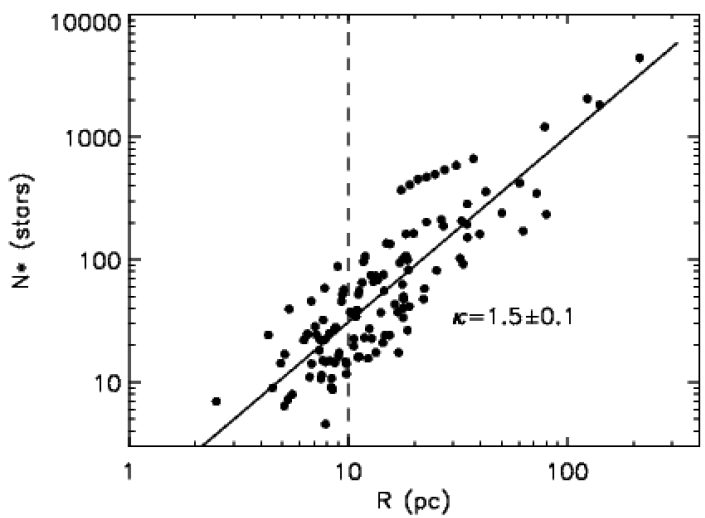
completeness analysis is necessary !

PARAMETERS





- **power-law** mass distribution $dn/dM \sim M^{-2.0\pm0.1}$
- **log-normal** surface density distribution
- **power-law** mass-size relation



properties	young stellar structures	ISM substructures
1. morphology	• irregular	• irregular
2. structure	• hierarchical	• hierarchical
3. size distribution	• power-law	• power-law
4. mass function	• power-law	• power-law
5. mass-size relation	• power-law	• power-law
6. density distribution	• lognormal	• lognormal
7. fractal dimension	• D_2=1.5±0.1	• D_3=2.4
… …	… …	… …

the hierarchical properties of young stellar structures may come from the natal ISM from which they form

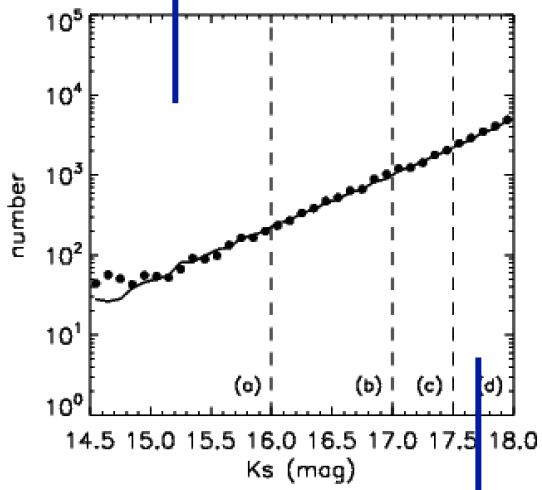
supersonic turbulence regulates the ISM

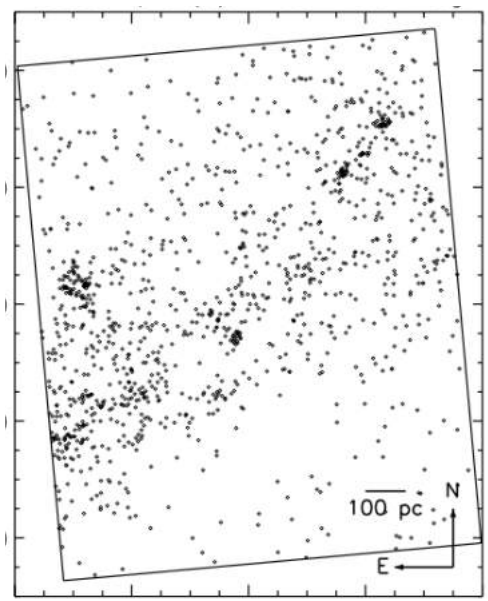
– clouds, clumps, cores, filaments

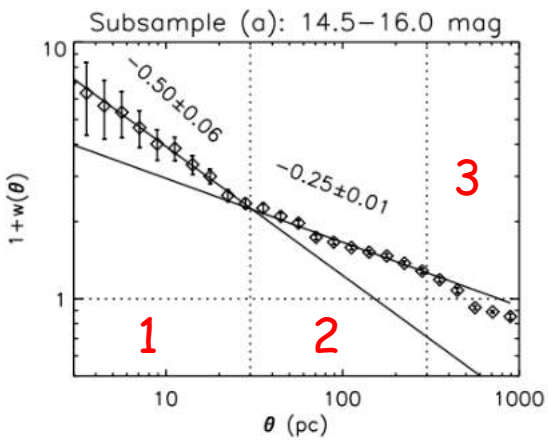
↓ formation

star formation follows these patterns

– young stellar structures

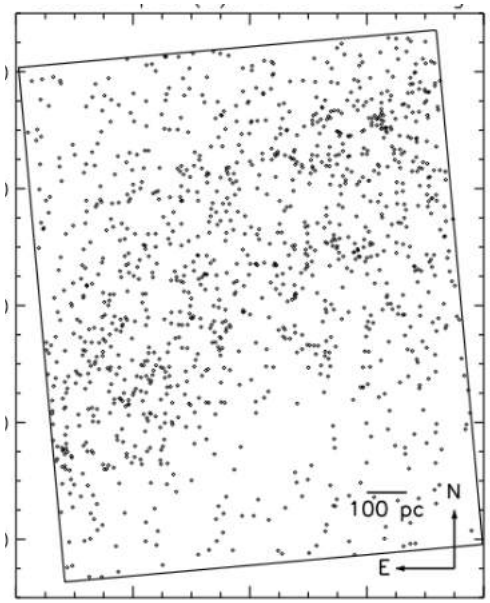


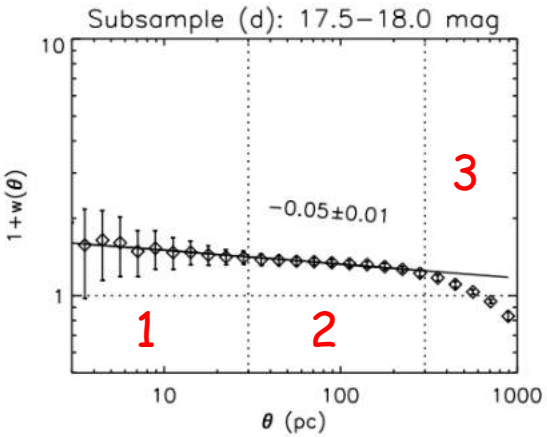




steeper slope

more substructures

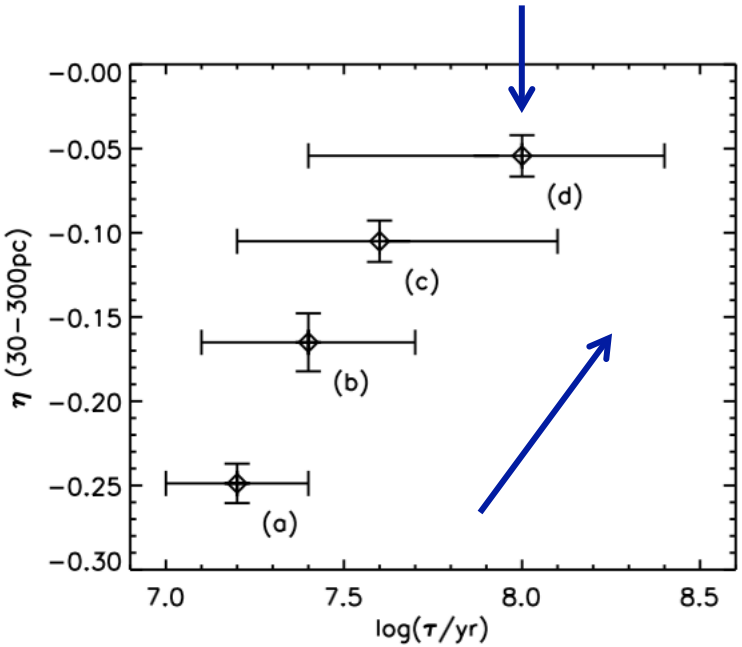




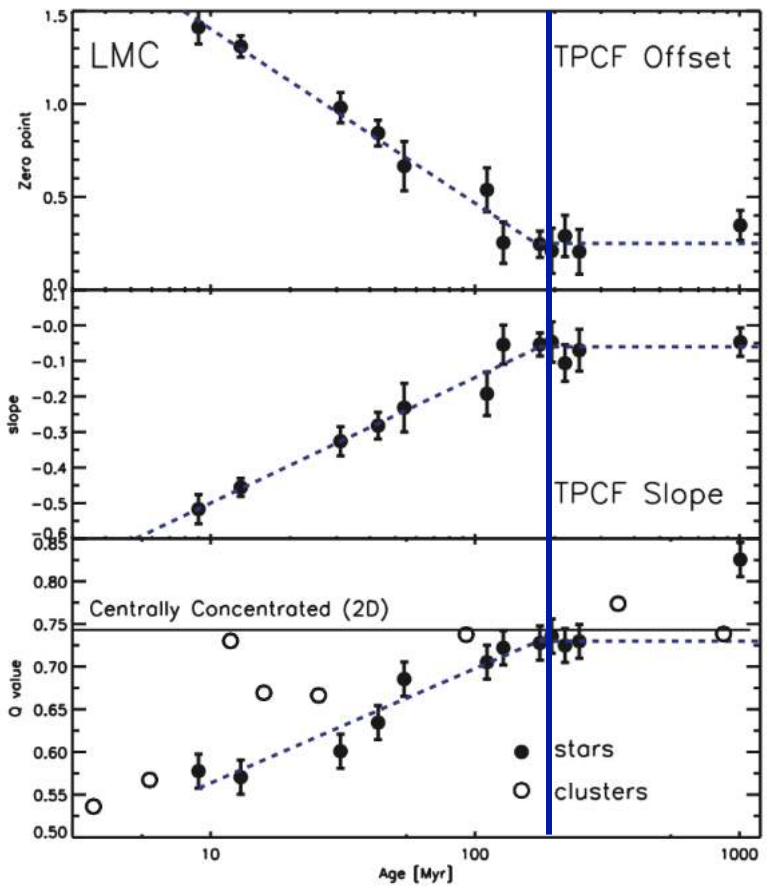
fainter magnitudes

older mean age

the young stellar structures disperse on a timescale of ~ 100 Myr



175 Myr



with increasing mean age, the stellar distribution becomes less clumpy and more uniform

Bastian+09

supersonic turbulence regulates the ISM
– clouds, clumps, cores, filaments

↓ formation

star formation follows these patterns
– young stellar structures

↓ evolution

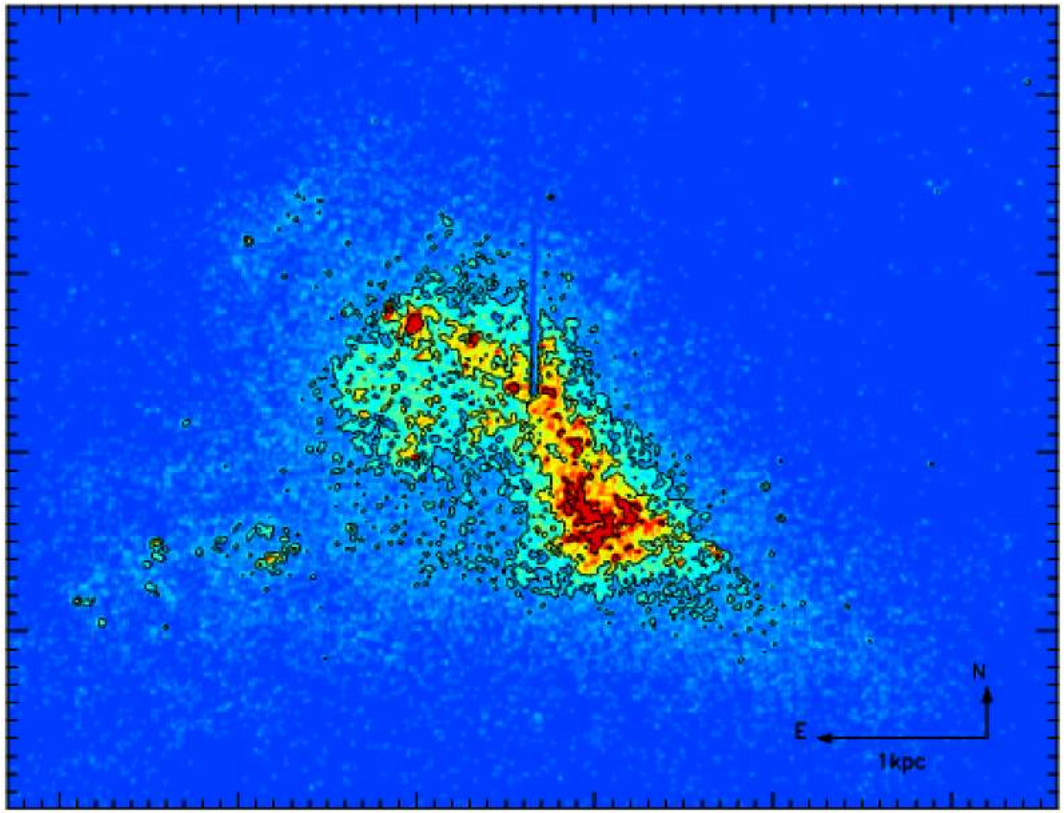
they are subject to disruptive processes
– dispersion in a crossing time

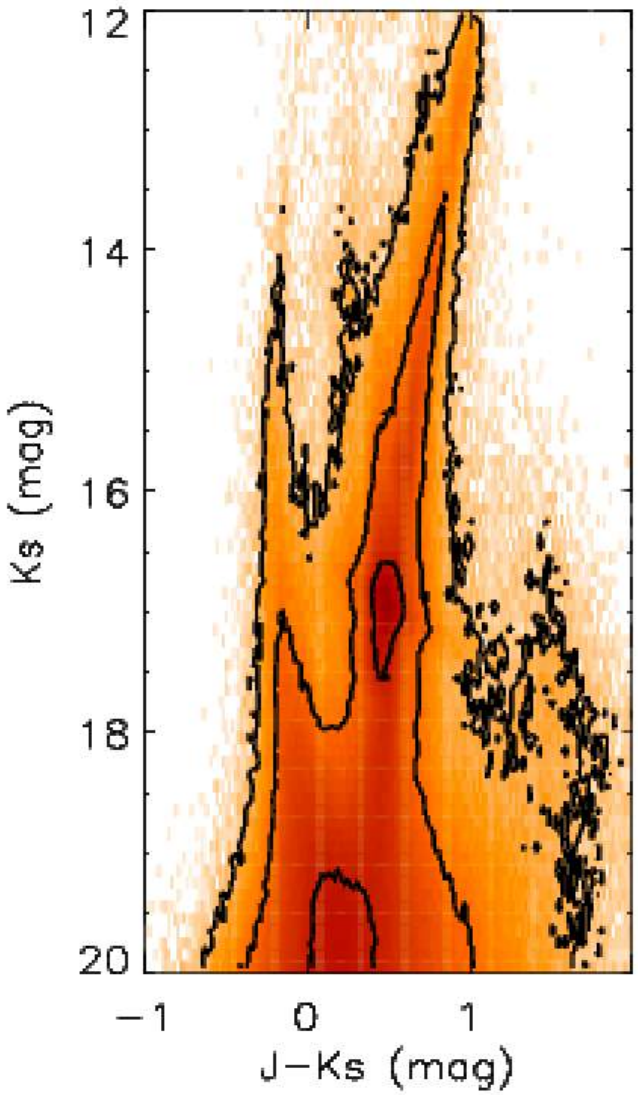
SUMMARY

- star formation generates young stellar structures over **a wide range of scales**, from sub-pc to kilo-pc
- the young stellar structures have **irregular** morphologies and are organized in a **hierarchical** manner
- they have **power-law** size and mass distributions, and **log-normal** surface density distributions
- **no preferred scale**, their formation may be related to supersonic **turbulence** in the parental ISM
- they are **transient** structures in the galaxy and are finally dispersed in a crossing time (~100 Myr for LMC)

FUTURE

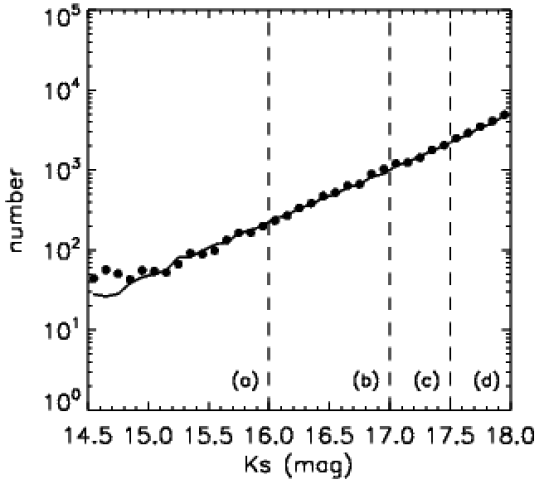
1. environmental dependence
2. relation to star clusters
3. anisotropy in stellar distributions
4. interesting regions

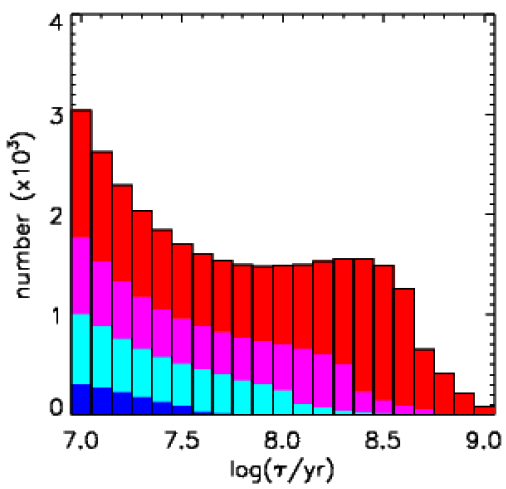


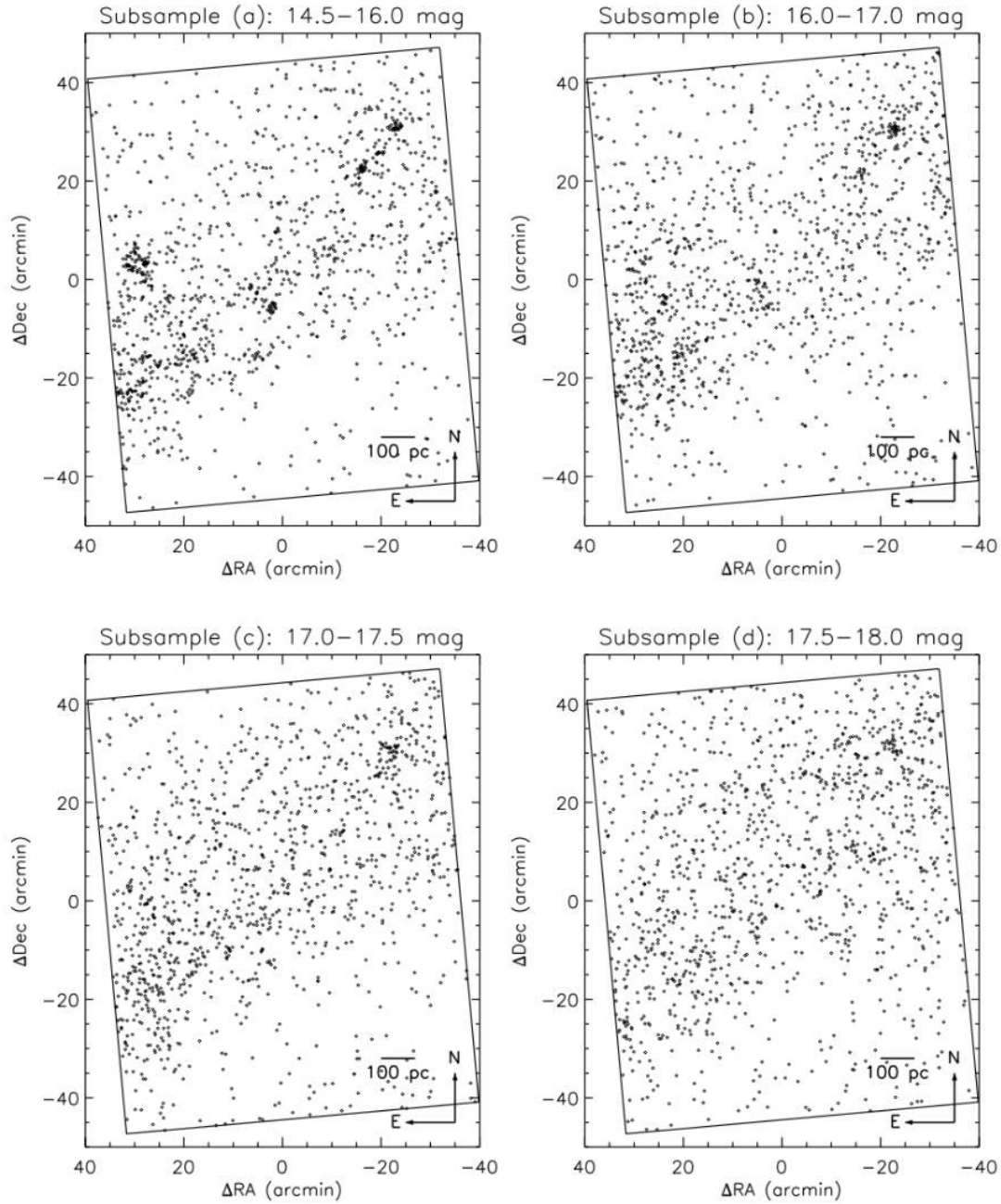

12
14
16
18
20
Ks (mag)
−1
0
1
J−Ks (mag)

fainter magnitudes

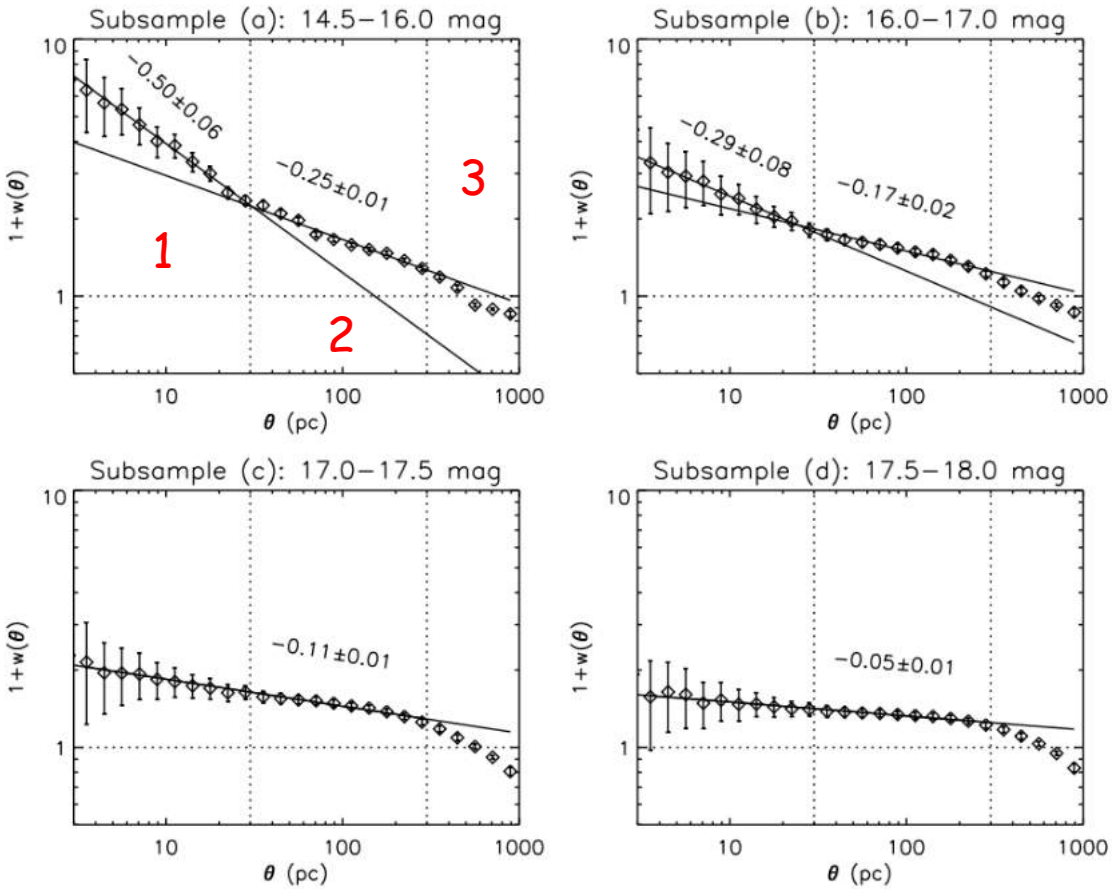
older mean age



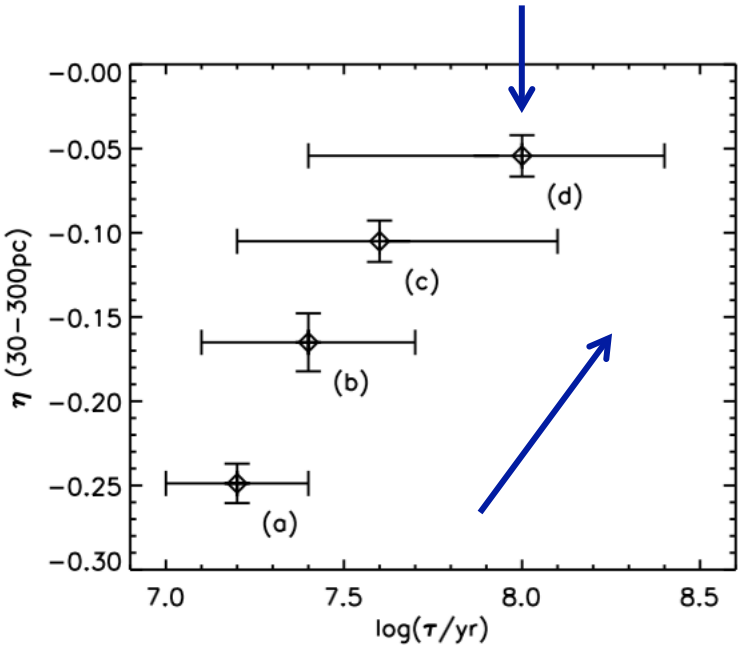




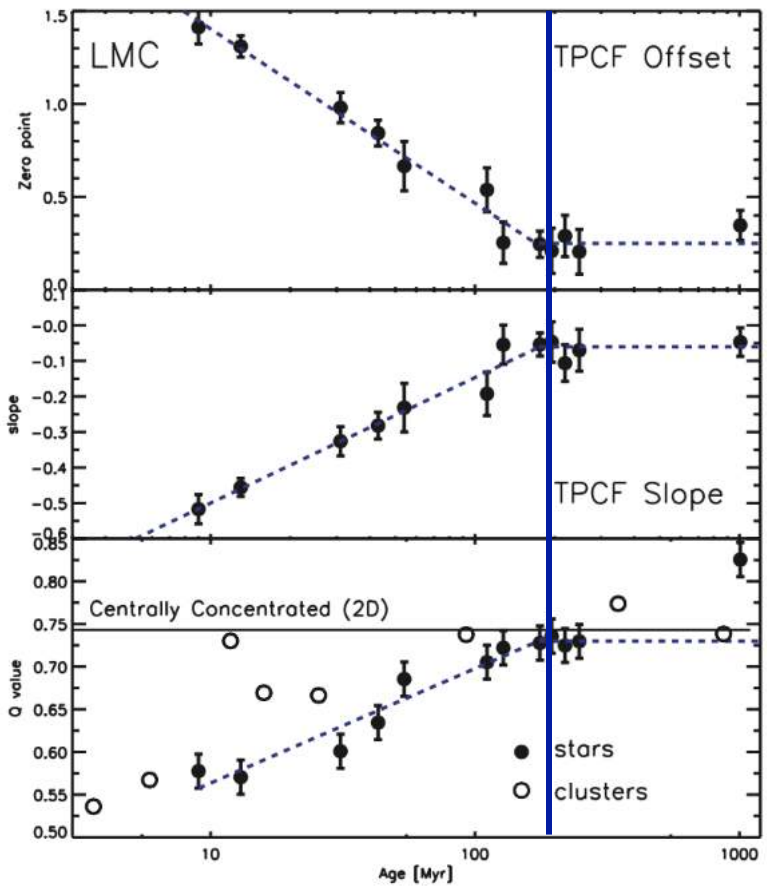
1. small-separation regime (<30 pc): presence of **star clusters**
2. intermediate-separation regime (30-300 pc): **hierarchical** component
3. large-separation regime (>300 pc): large-scale **density gradient**



the young stellar structures disperse on a timescale of ~ 100 Myr



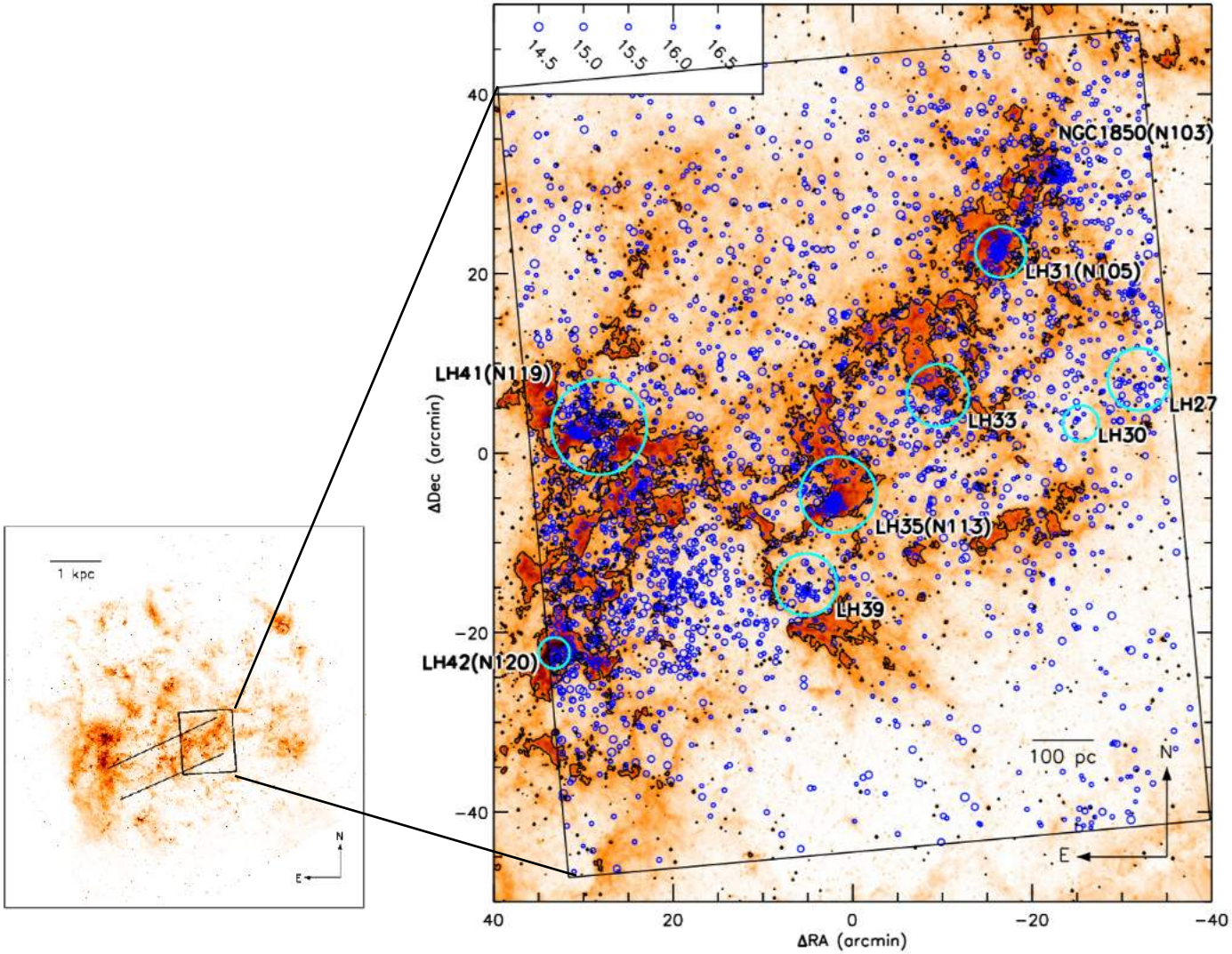
175 Myr



with increasing mean age, the stellar distribution becomes less clumpy and more uniform

Bastian+09

the 30 Dor complex (LMC 6_6): Sun et al. 2017 ApJ 835, 171
the Bar complex (LMC 6_4): Sun et al. submitted to ApJ
studies on more LMC tiles and the SMC are undergoing



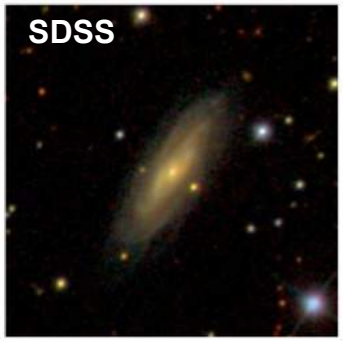
wide-field surveys: MCPS, VMC, etc.

galaxy-wide full views

Our Own Galaxy

Magellanic Clouds

Local Galaxies



Distant Galaxies

resolved stellar populations

high-resolution observations: LEGUS, etc.

IMAGE CREDITS
M11: NASA Picture of the Day
Car OB1: ESO/T. Preibisch
LMC: Robert Gendler/ESO
SMC: ESA/Hubble
NGC 1566/6503: LEGUS

DYNAMICS

- **local processes**
  - expansion and fragmentation
  - collision with coagulation or fragmentation
  - gas expulsion by stellar feedback
- **galactic processes**
  - shear by galactic rotation (e.g. flocculent spirals)
  - tidal heating by massive objects (e.g. GMCs)
  - spiral arms, bar, nearby galaxies
- **problems**
  - what is the initial kinematical condition ?
  - what is the role of self-gravity ?
  - what are the acting scales of these processes ?
  - what determines the structure dispersion timescale ?

two-point correlation function: $w(\theta) = N_p(\theta)/N_r(\theta)-1$

surface density of neighbors: $\Sigma(\theta) = N_*/A[1+w(\theta)]$

- given a random star in a location, the probability that another star will be found within a given distance (statistically)
- quantify the degree of lumpiness as a function of spatial scale, and is related to the Fourier space power spectrum

$$\xi(r) = \frac{1}{2\pi^2} \int dk\, k^2 P(k) \frac{\sin(kr)}{kr}$$

STAR COMPLEXES AND ASSOCIATIONS: FUNDAMENTAL AND ELEMENTARY CELLS OF STAR FORMATION[1]

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Hierarchical star formation from the time–space distribution of star clusters in the Large Magellanic Cloud

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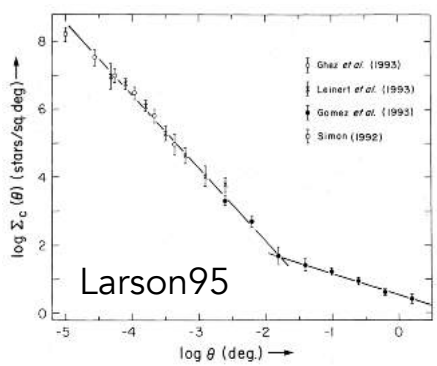
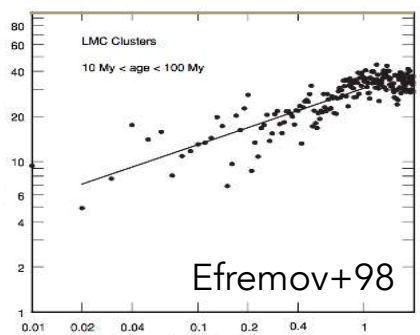
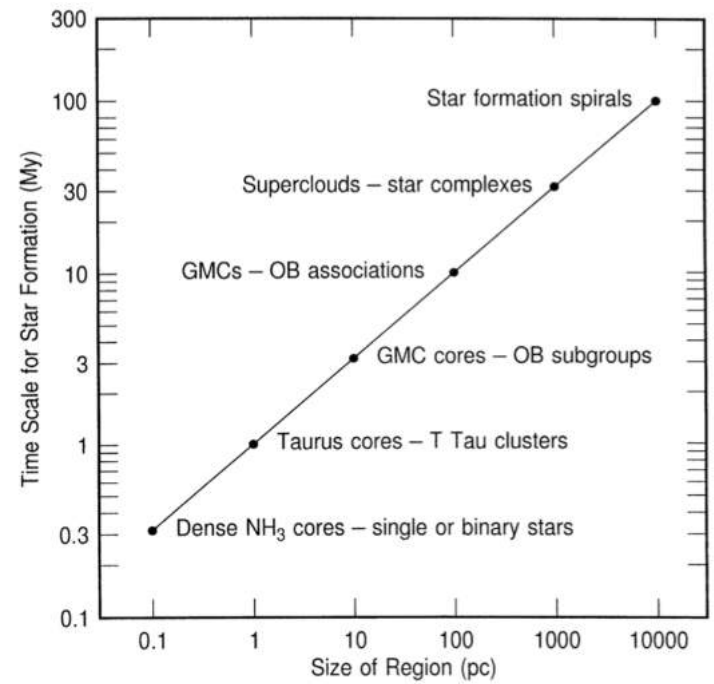
Accepted 1998 May 13. Received 1998 April 8; in original form 1997 December 31

correlated star positions



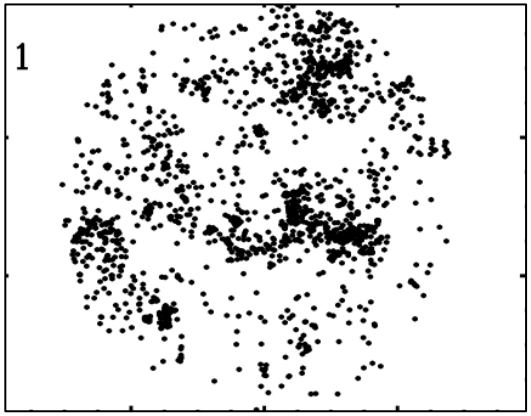
time-space correlations

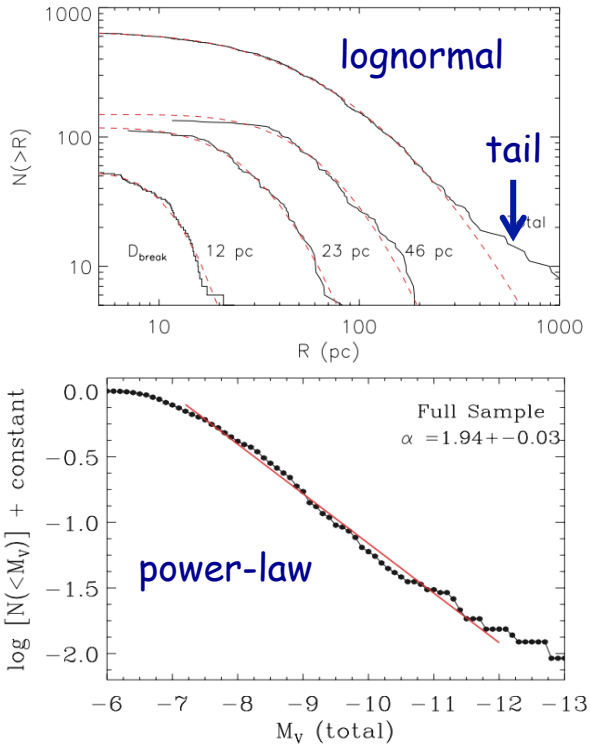


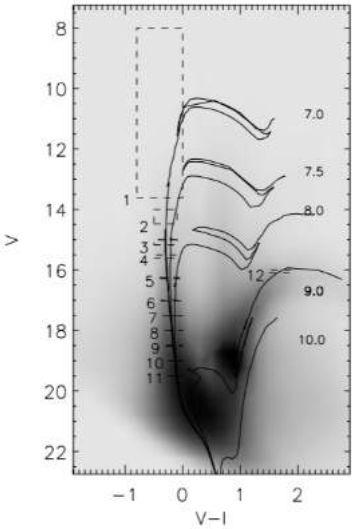


BASTIAN+09

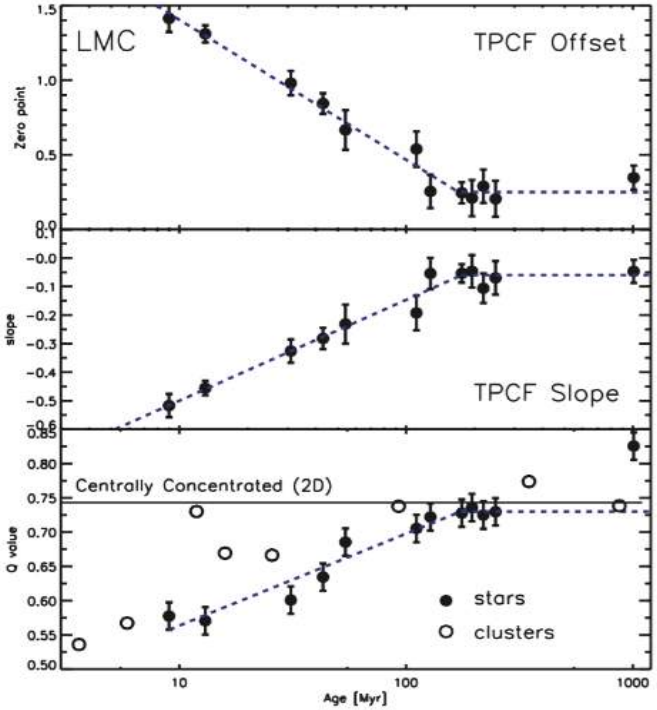
the stellar structures are completely removed on a timescale of 175 Myr, which is the crossing time of the LMC





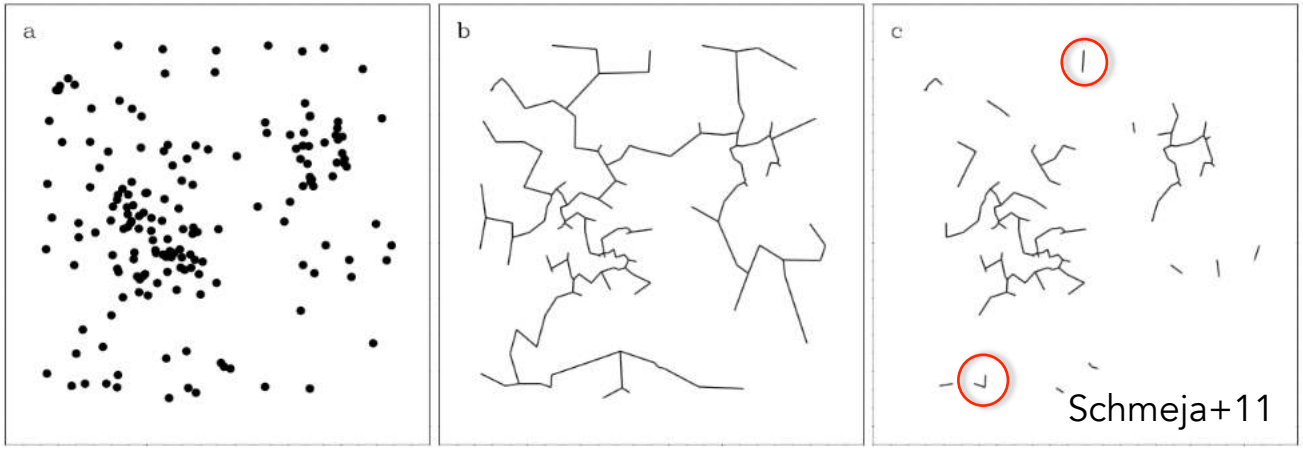


temporal evolution



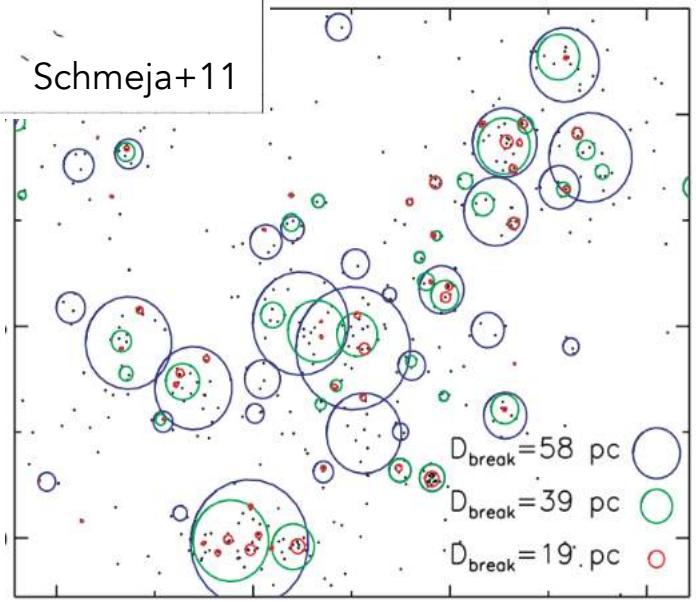
TOPOLOGY-BASED IDENTIFICATION

fractured Minimum-Spanning Tree

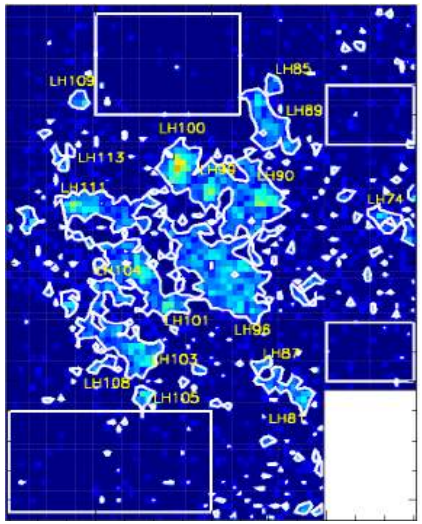


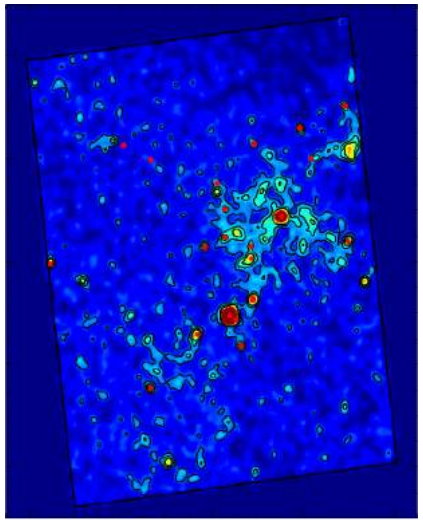
Schmeja+11

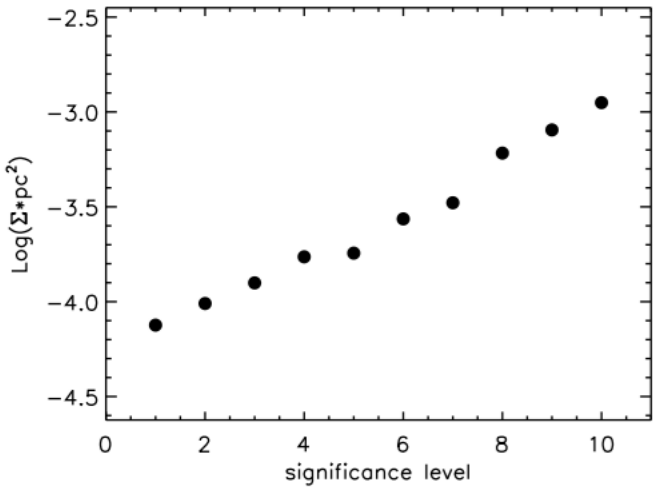
Bastian+07

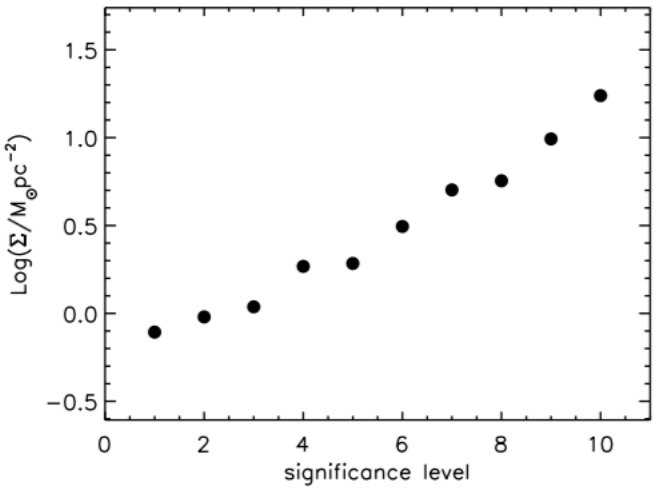


- ~~the critical length to fracture the MST~~
- **Nmin** of stars to define a structure?


LH105
LH85
LH89
LH100
LH113
LH90
LH74
LH104
LH101
LH98
LH103
LH87
LH108
LH105
LH81




Log(Σ*pc²)
−2.5
−3.0
−3.5
−4.0
−4.5
0
2
4
6
8
10
significance level


Log(Σ/M⊙pc⁻²)
1.5
1.0
0.5
0.0
−0.5
0
2
4
6
8
10
significance level