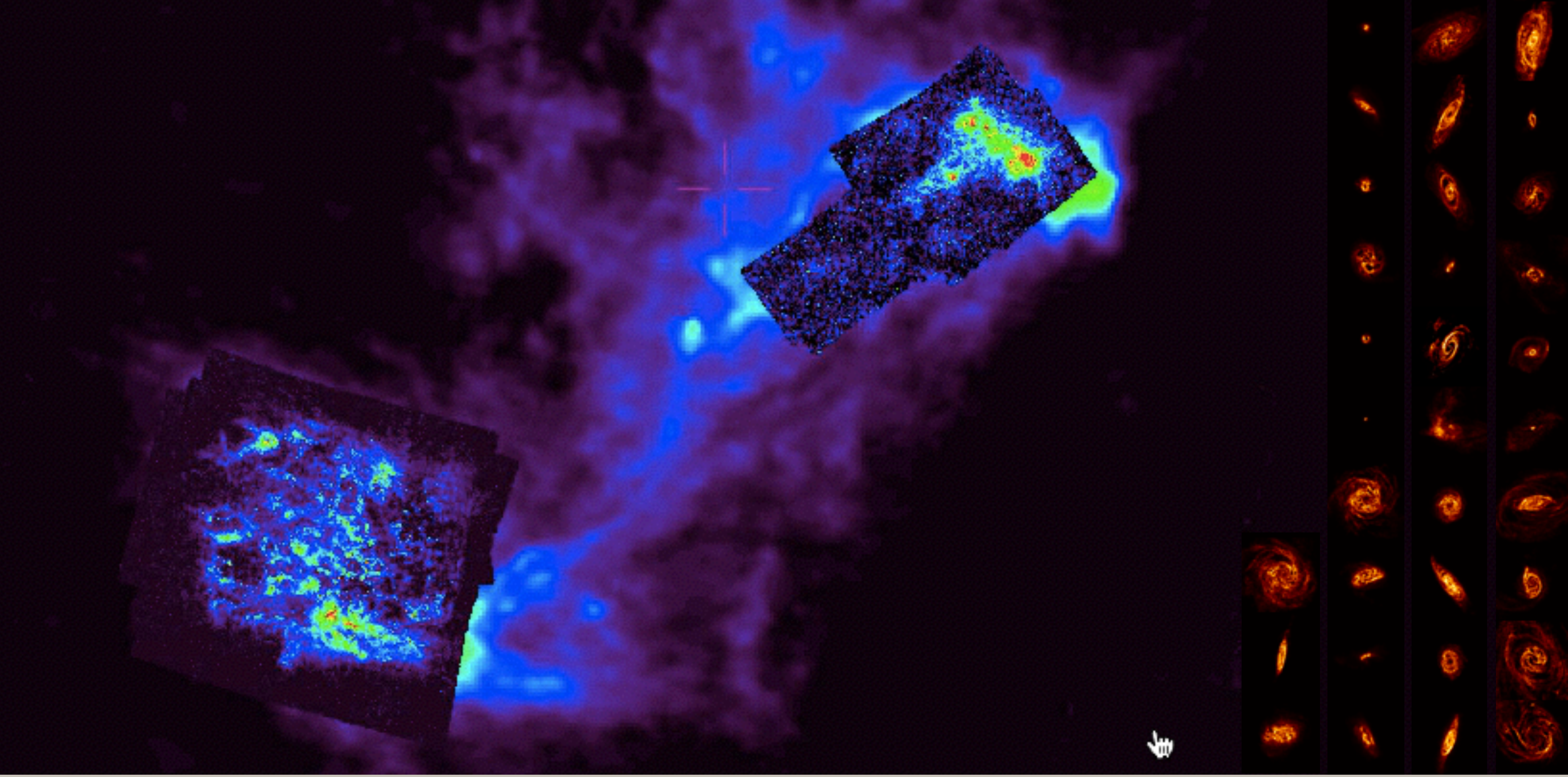
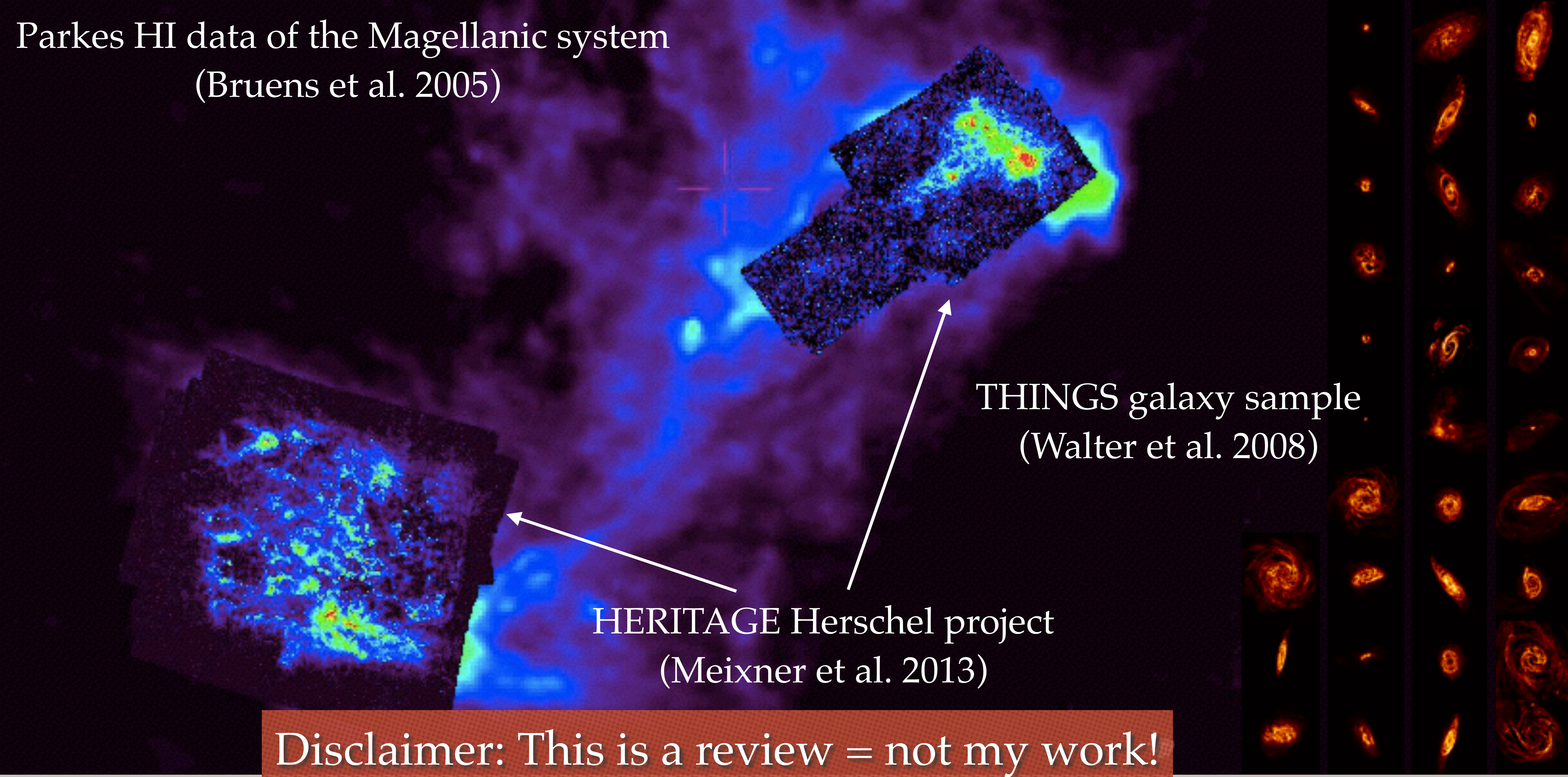


What does the study of nearby galaxies teaches us about the ISM processes?

Caroline Bot
Observatoire Astronomique de Strasbourg

with help from: *Annie Hughes*
Margaret Meixner
Laurent Cambrésy
Karin Sandström



Disclaimer: This is a review = not my work!
But opinions are my own…

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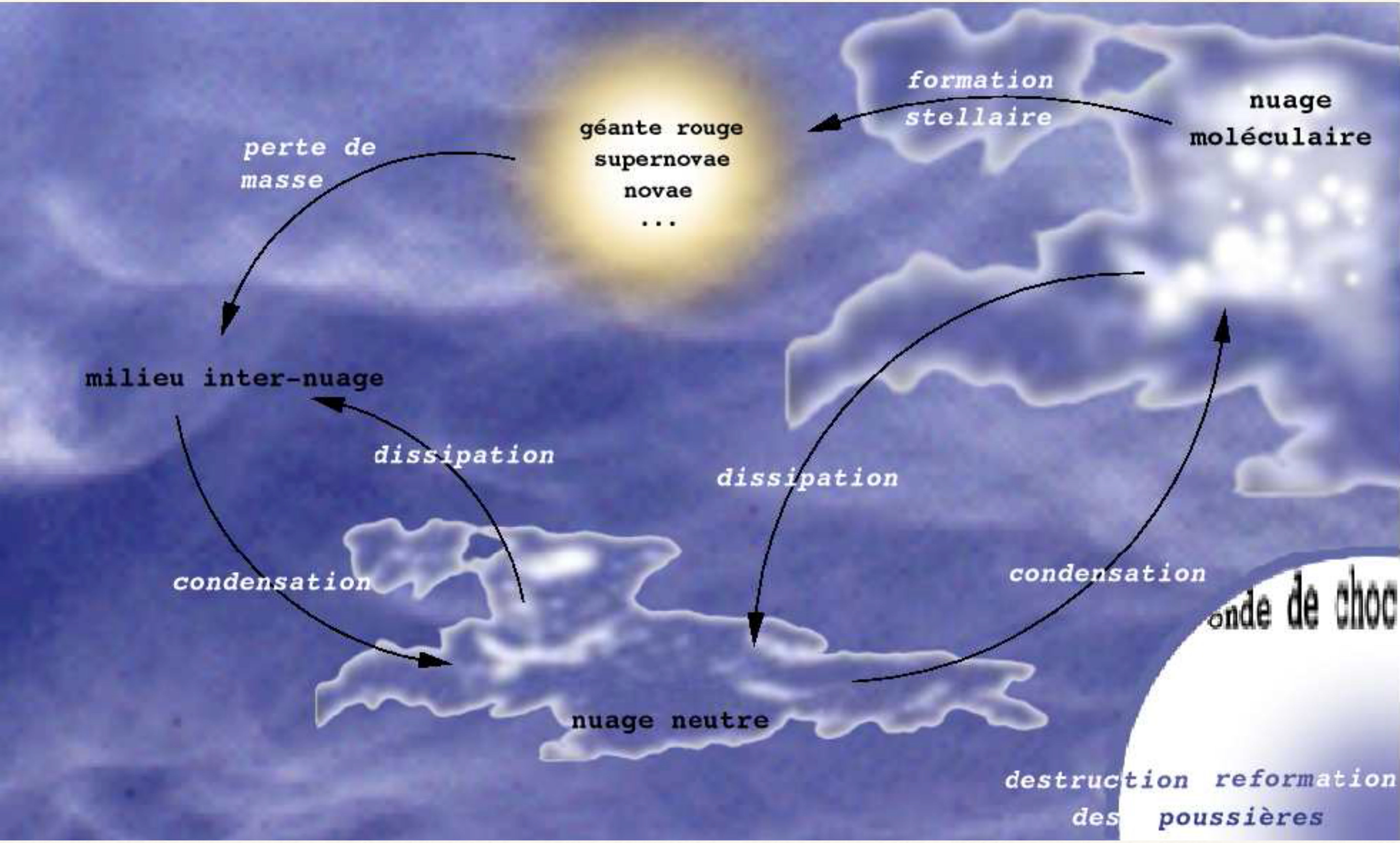
Processes at stake in the ISM?

Timescales? Environmental dependences?

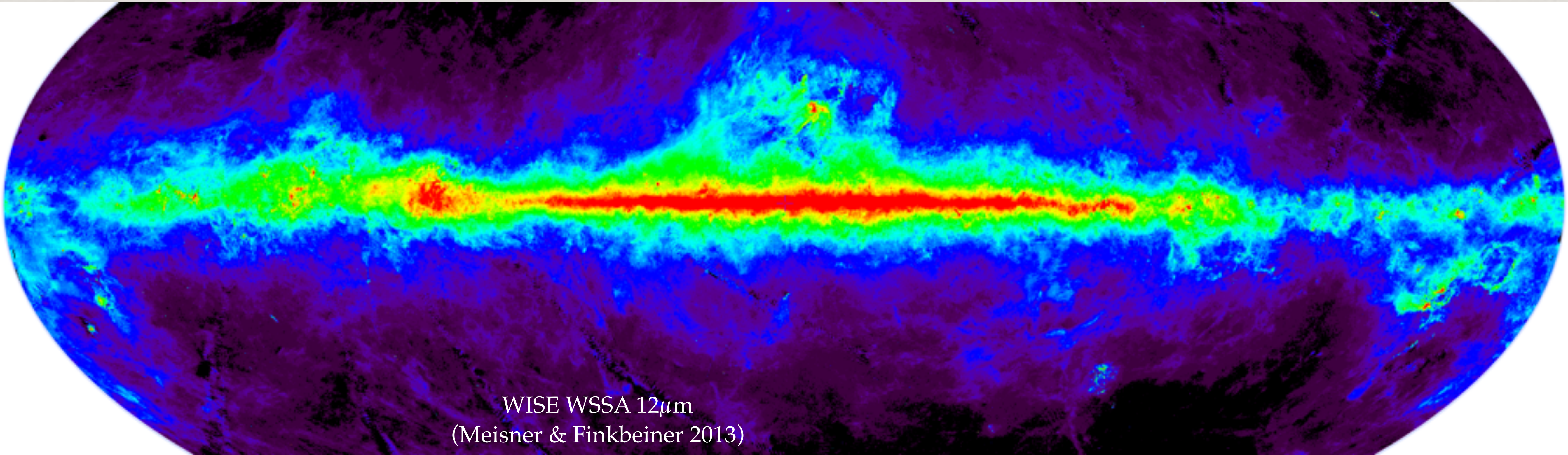


Why study nearby galaxies?

- External view, Global view
  - inventory of the different phases, contributors…
- Look at a variety of environments
  - evolution with metallicity
  - impact of galaxies interactions, …

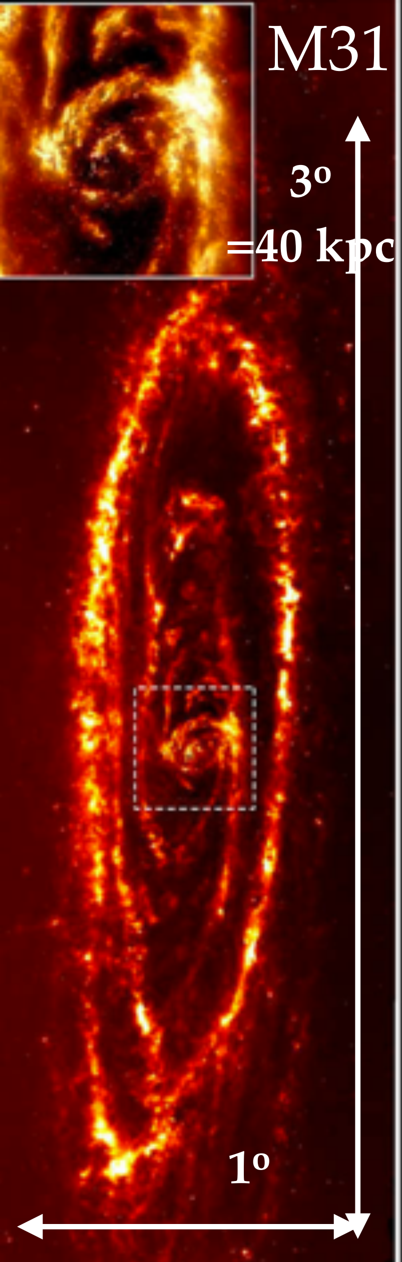
Milky Way is good but…

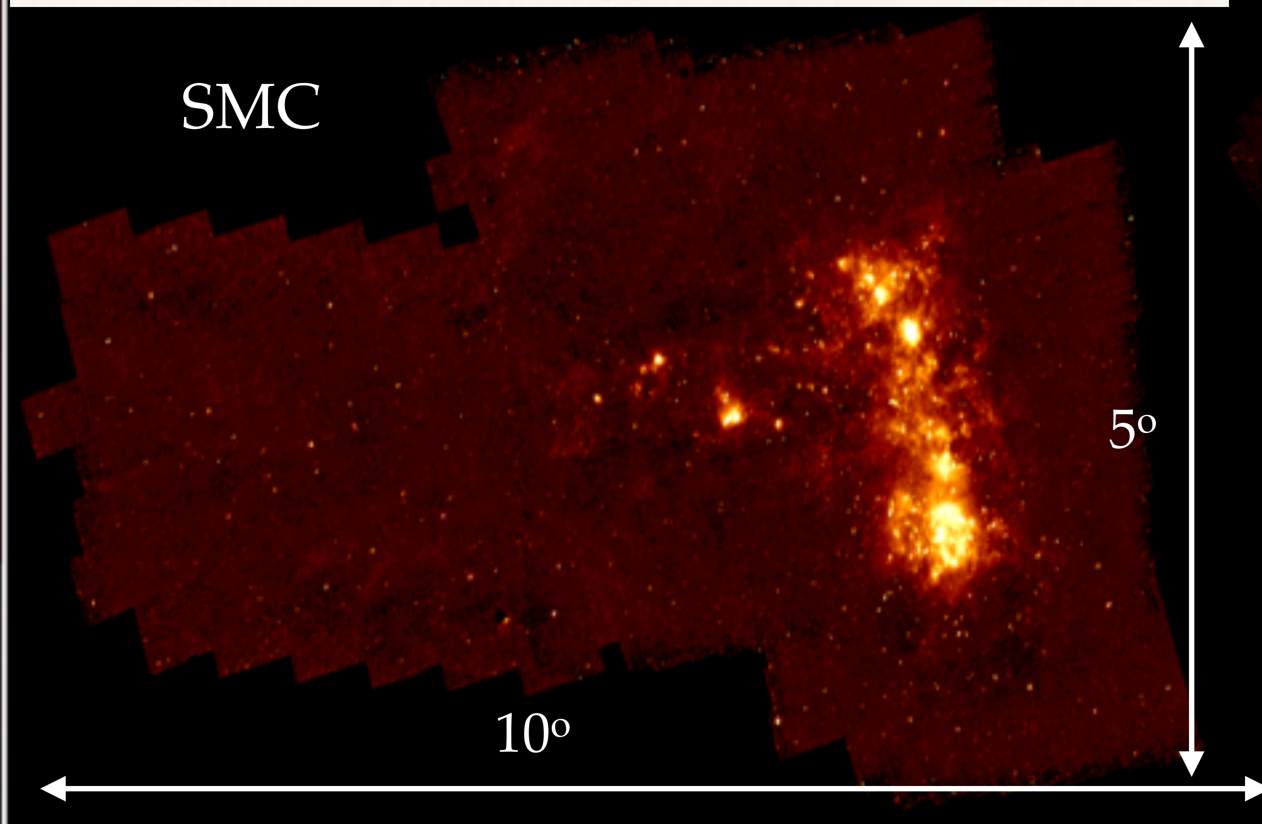
- confusion along the line of sight
- you need to know the distance to know the intrinsic luminosity
- we don't have a global view
- allsky view versus resolution

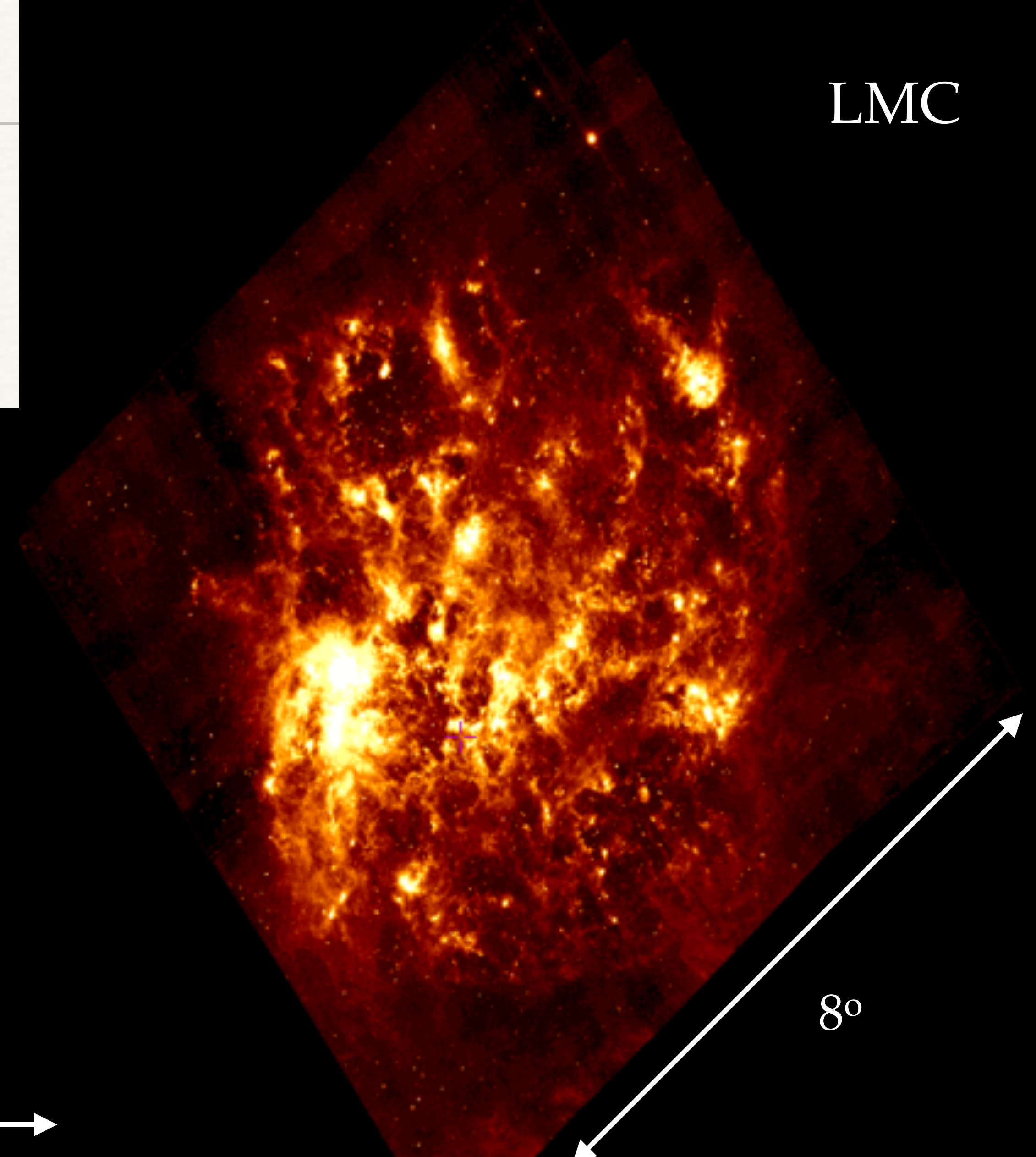

WISE WSSA 12μm
(Meisner & Finkbeiner 2013)

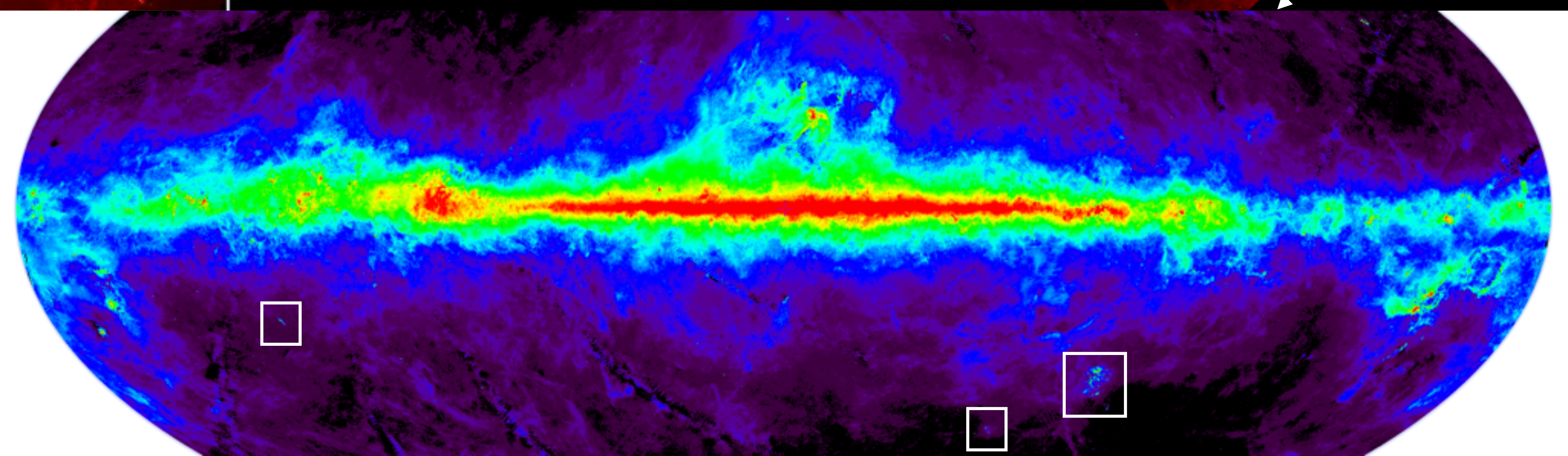
Spitzer MIPS 24μm images: Gordon et al. (2011), Meixner et al. (2006), Barmby et al. (2006)

our neighbors









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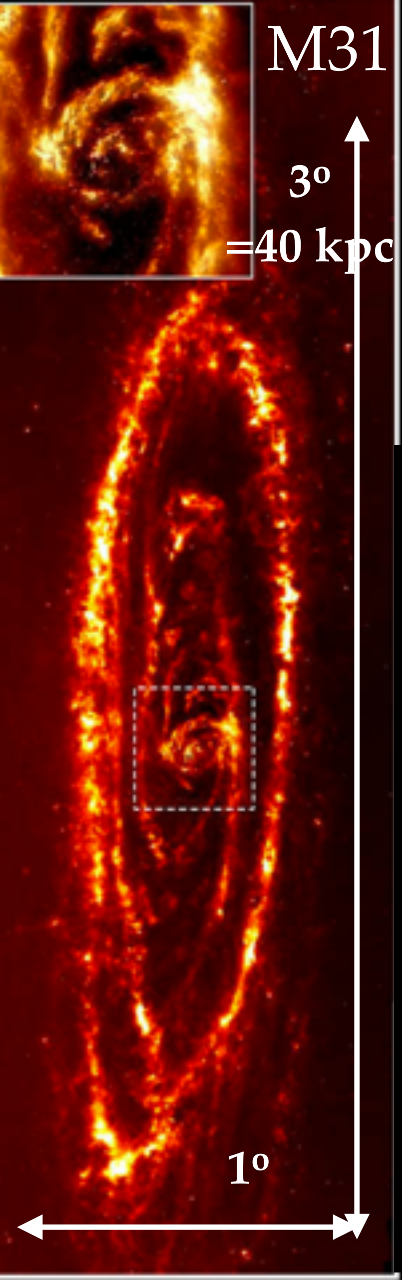
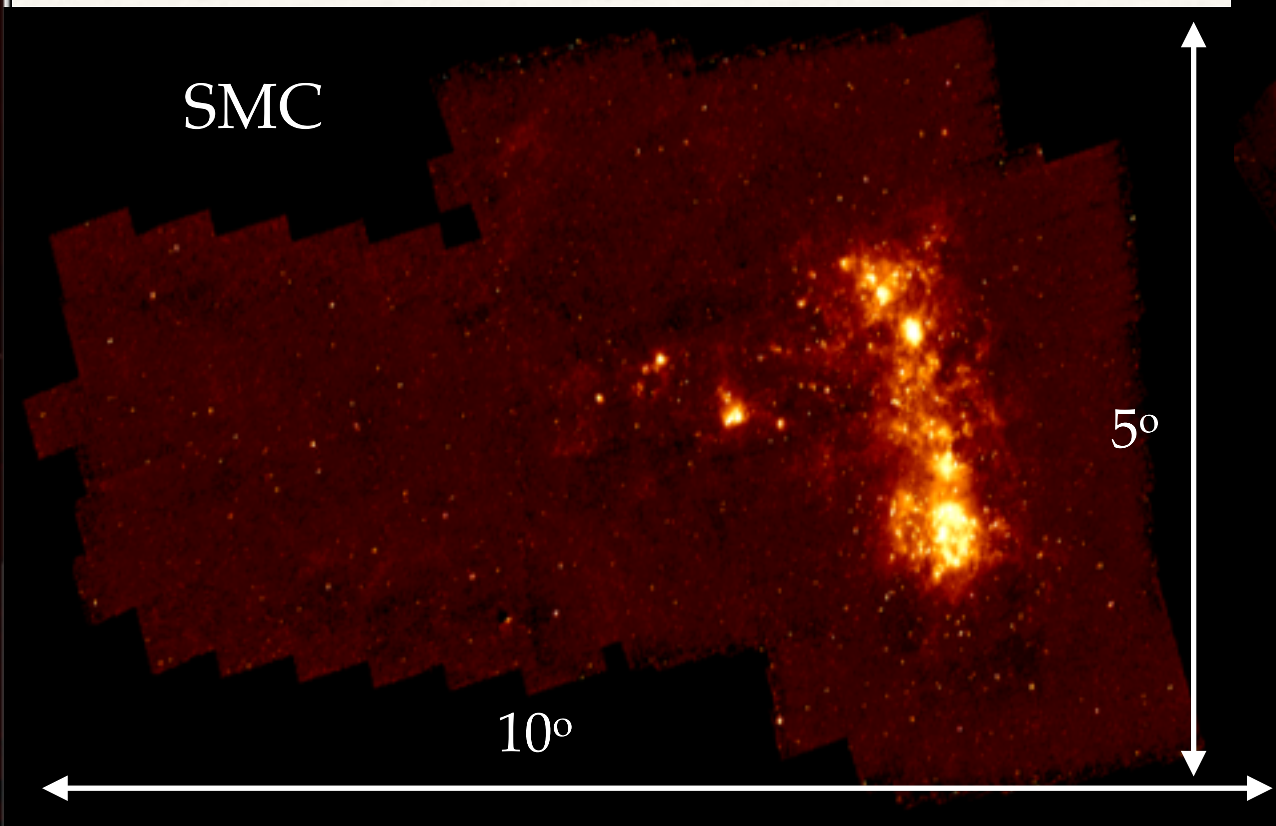
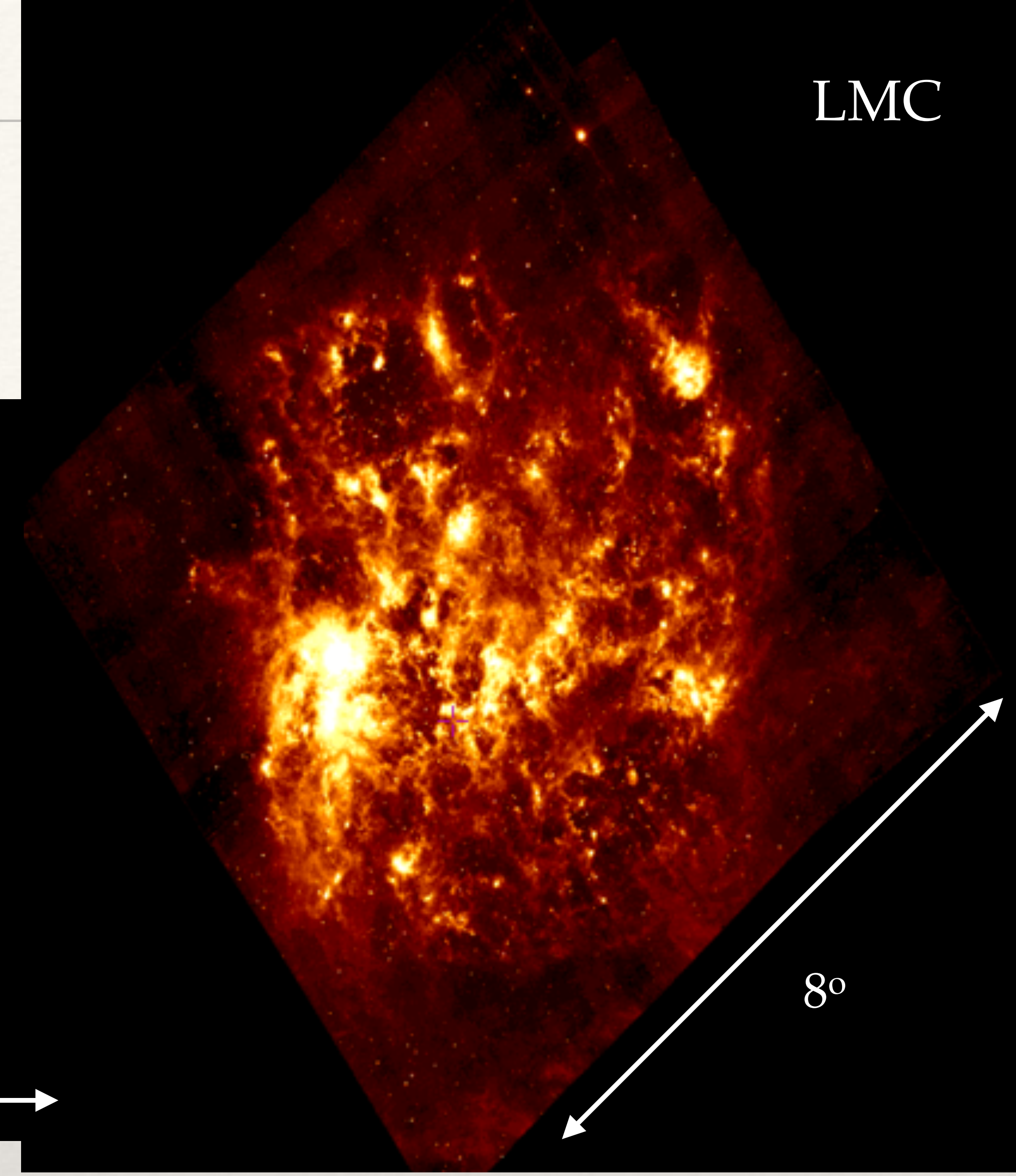


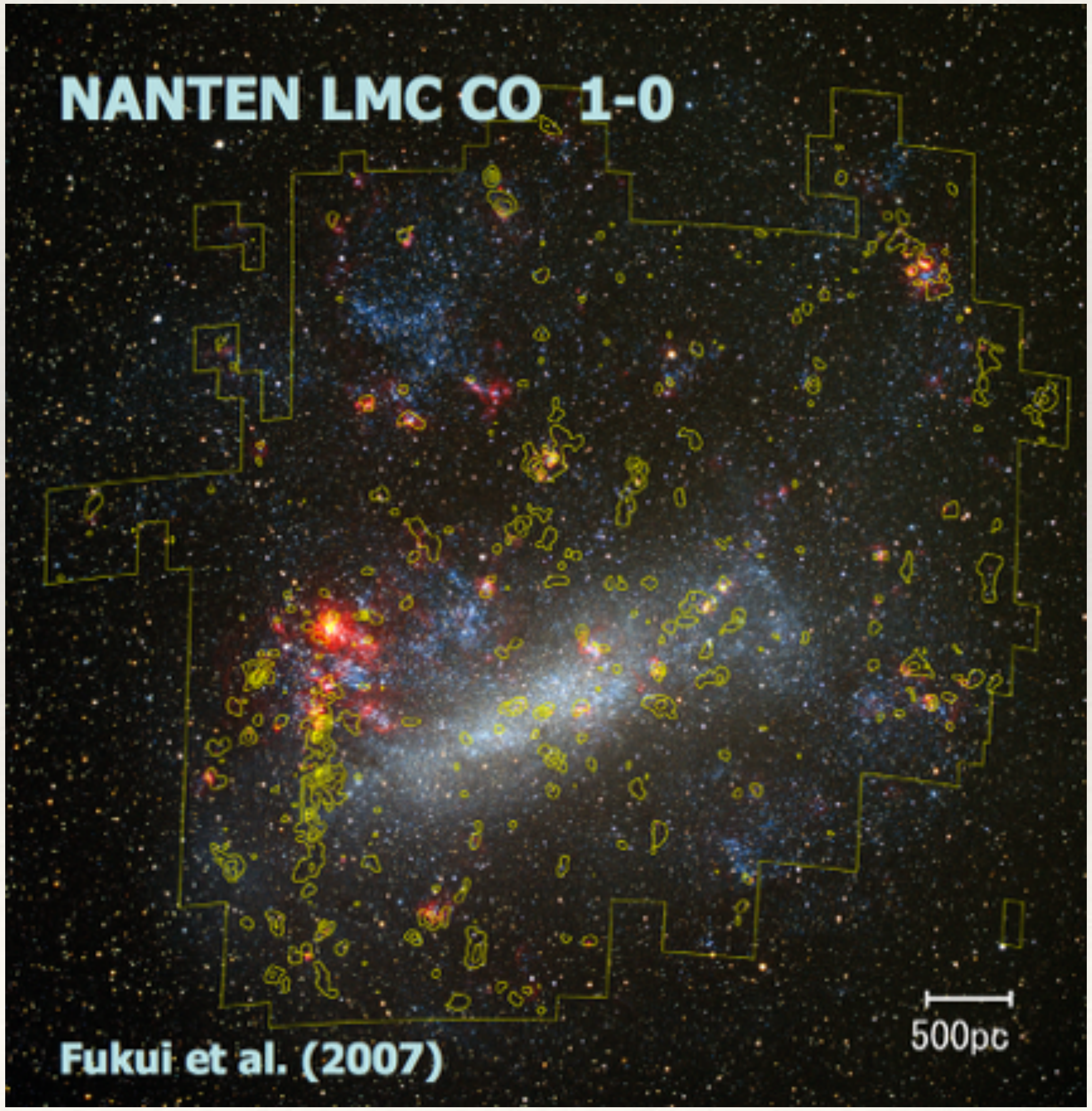


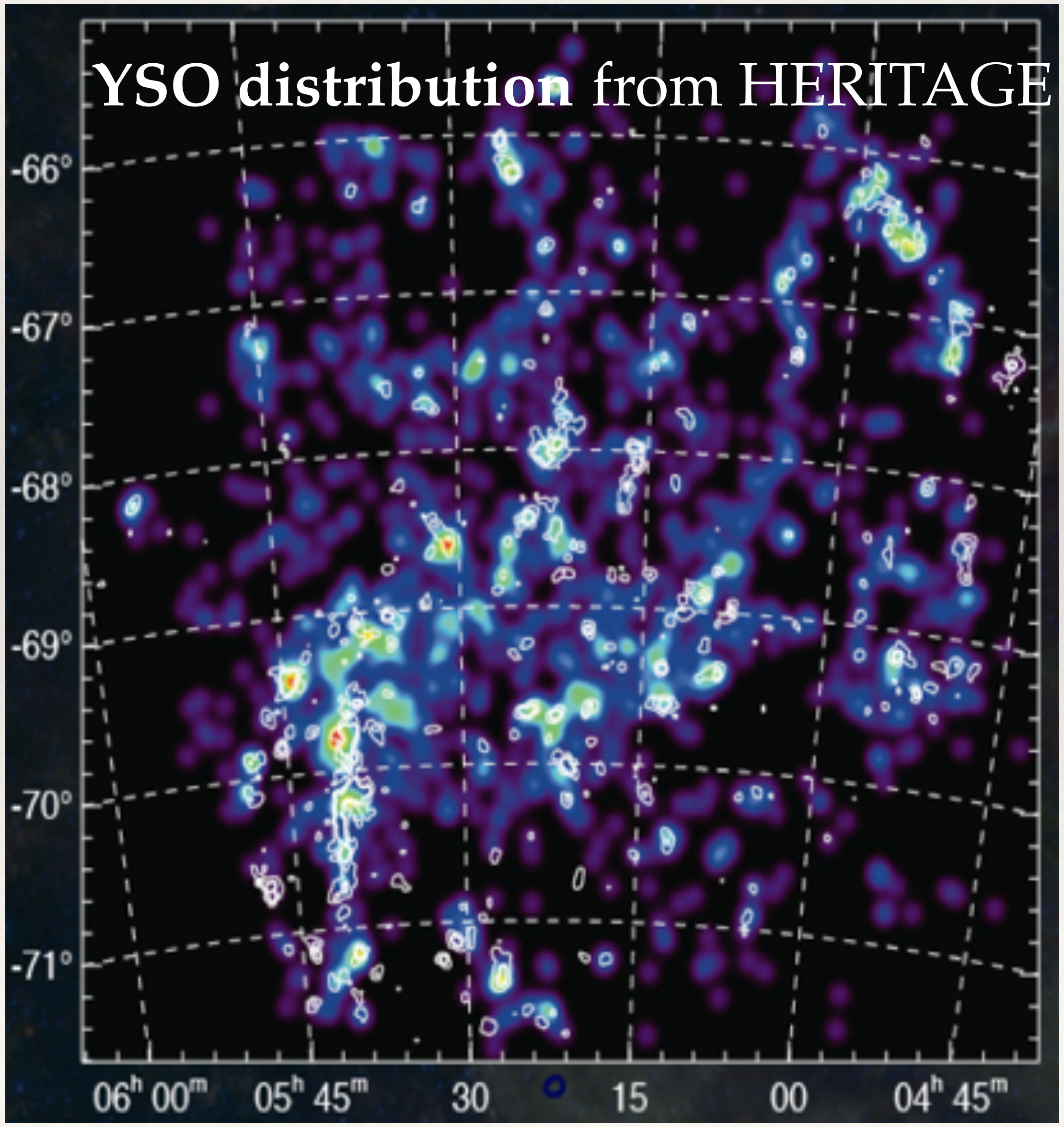


	LMC	SMC	M31	M51
	@50kpc	@60kpc	@800kpc	@8Mpc
1″	0.25pc	0.3pc	4pc	40pc
10″	2.5pc	3pc	40pc	400pc
1′	15pc	17pc	200pc	2kpc

distribution of GMCs versus stars

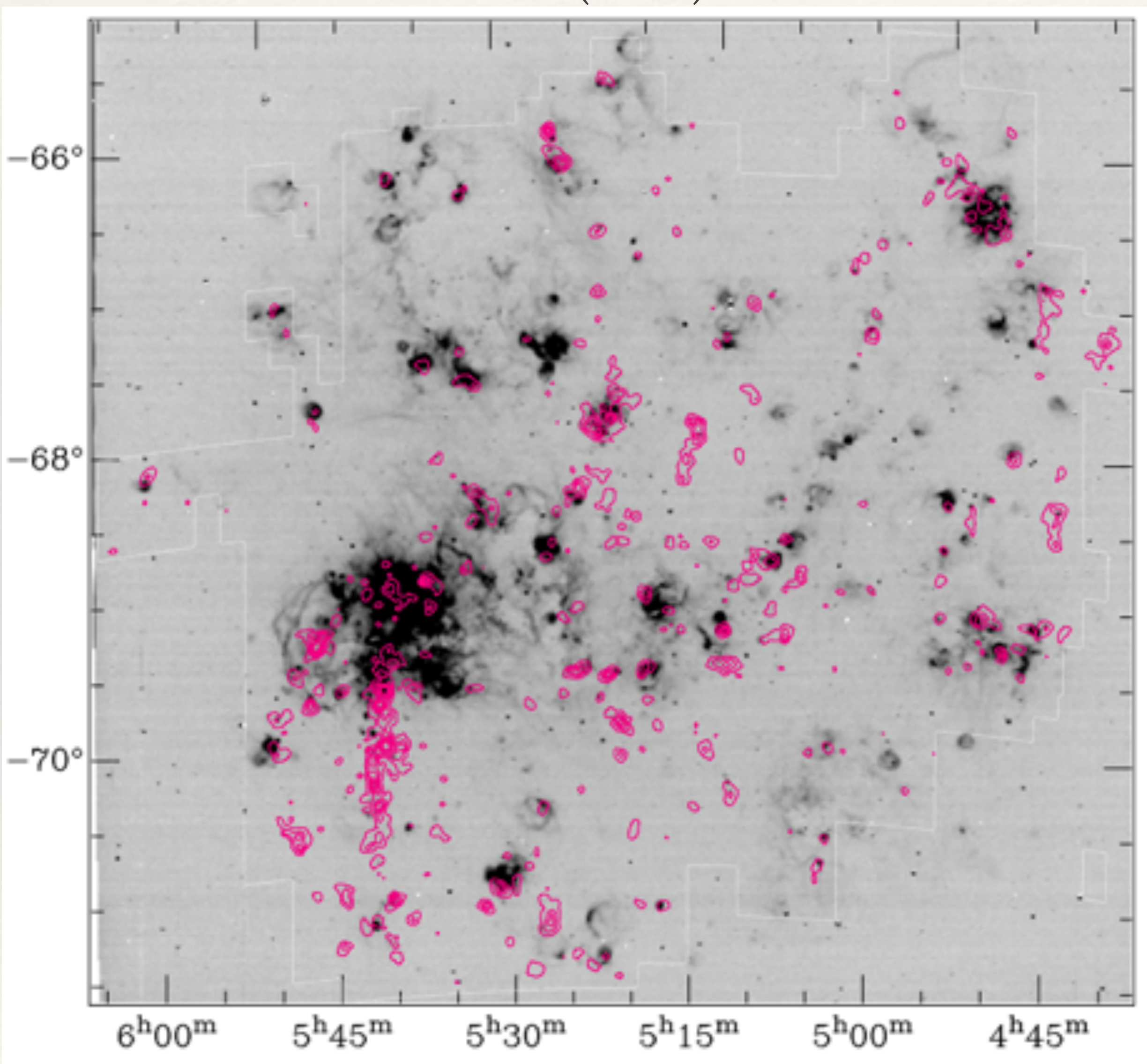
- Giant Molecular Clouds have a different spatial distribution than old stars
- Follow HII regions and recent star formation (expected)

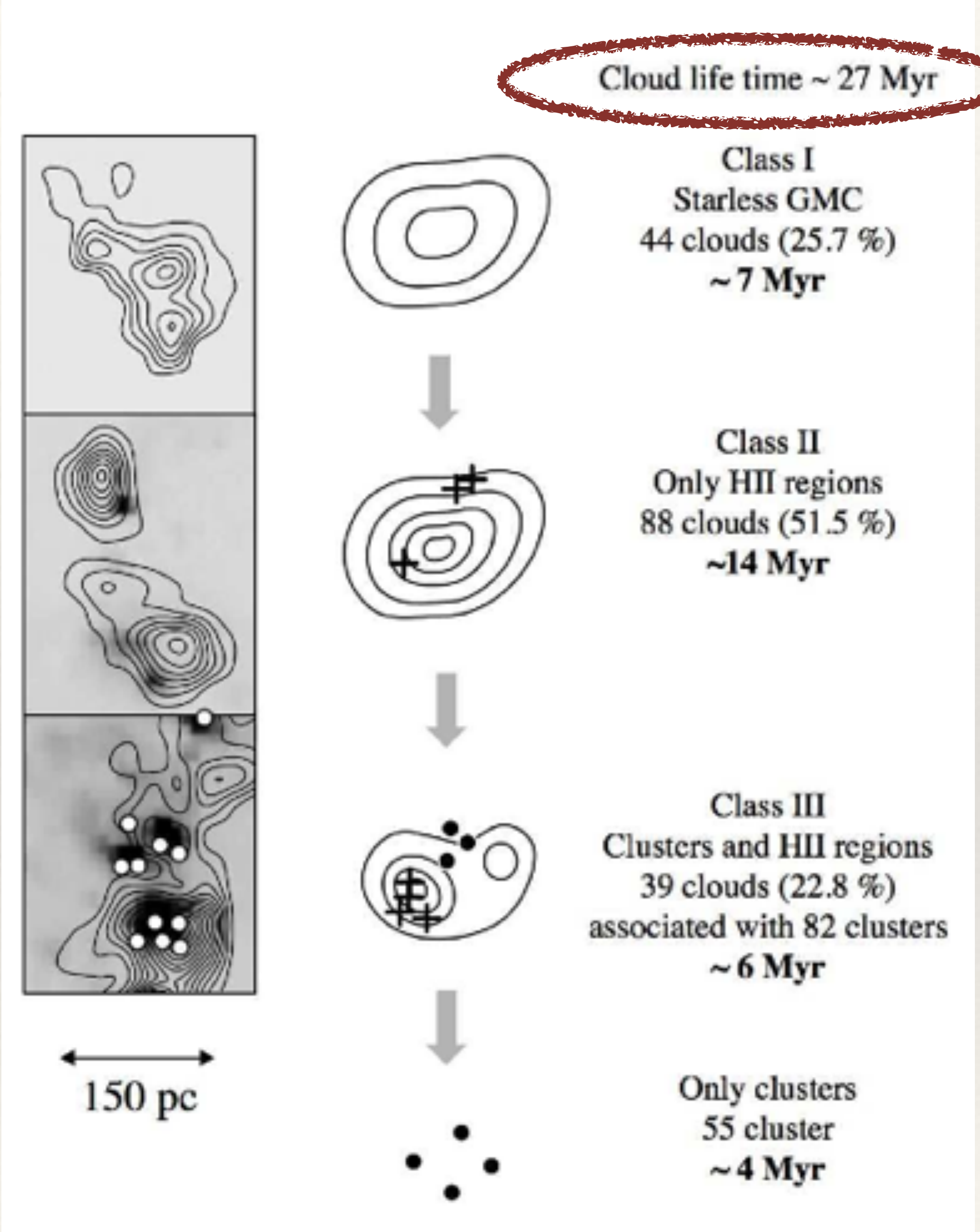




Evolution of Giant Molecular Clouds in the LMC

NANTEN CO observations: Fukui et al. (2008)
Kawamura et al. (2009)
Hα observations: Kim et al. (2003)

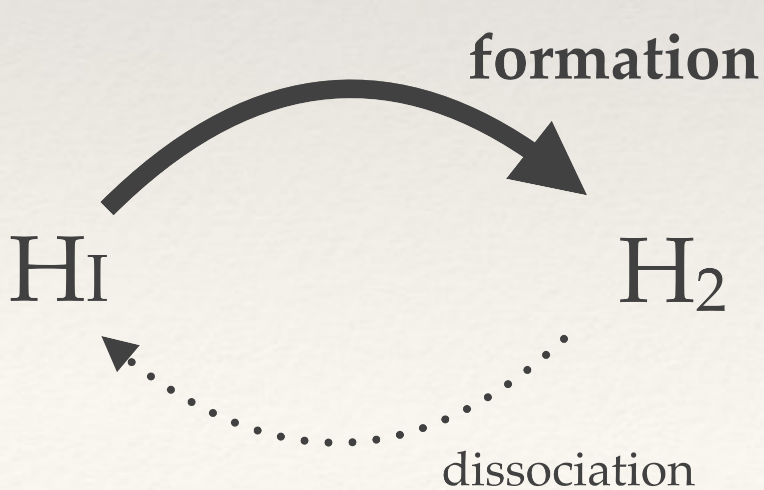


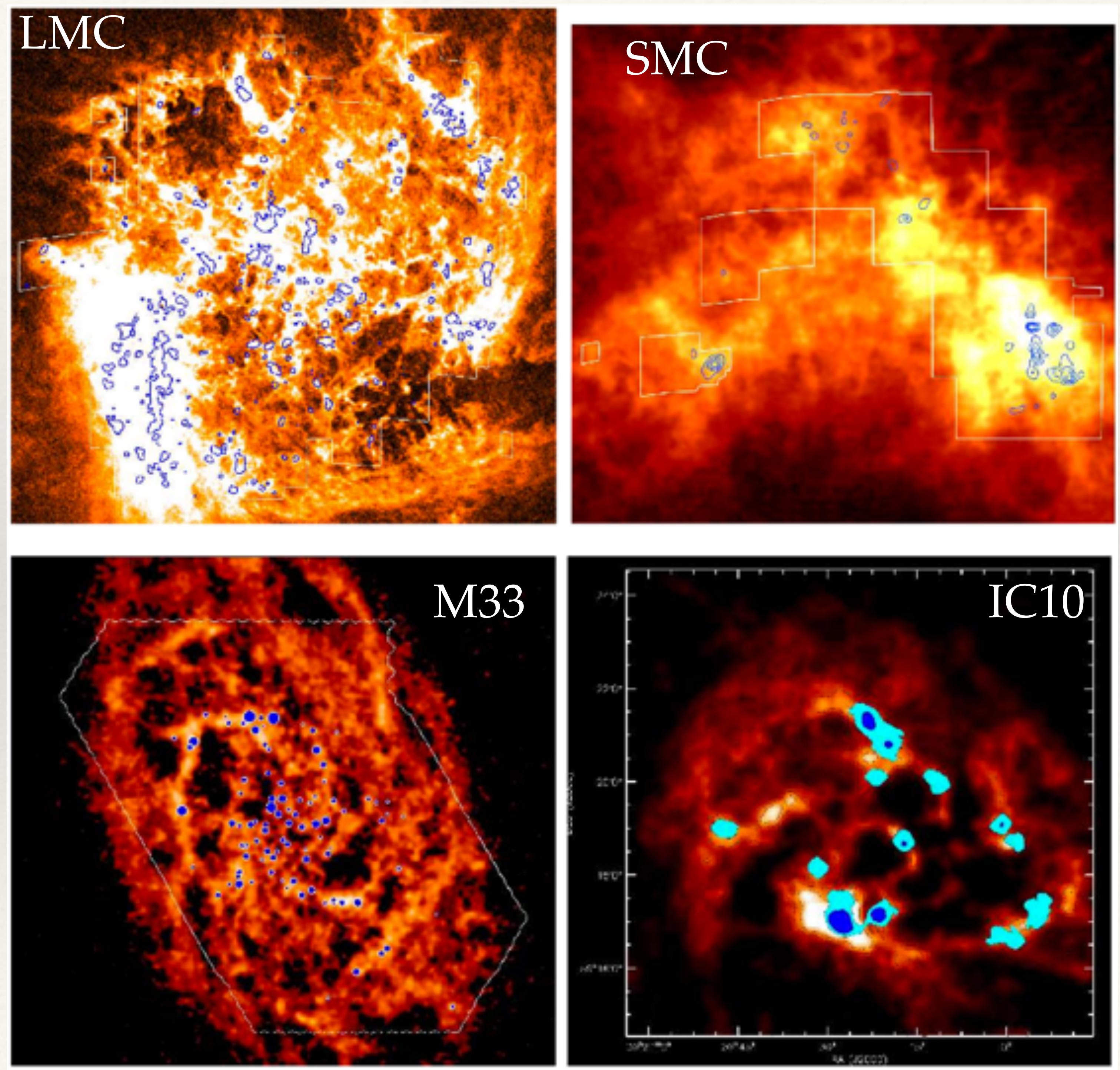


The absolute timescale is given by the age of the star clusters
The timescale of each phase is given by the proportion of clouds at this stage

HI-H_2 transition

- Every GMC is found on a bright HI filament / clump
- But many bright HI filaments without CO
- HI necessary condition for H_2 formation, but not sufficient

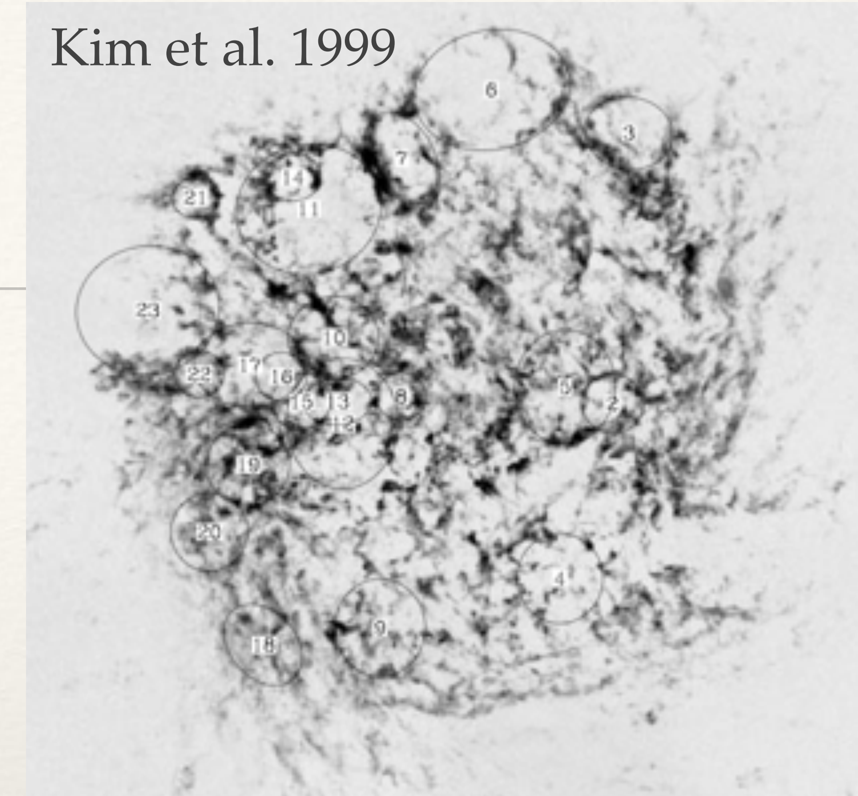




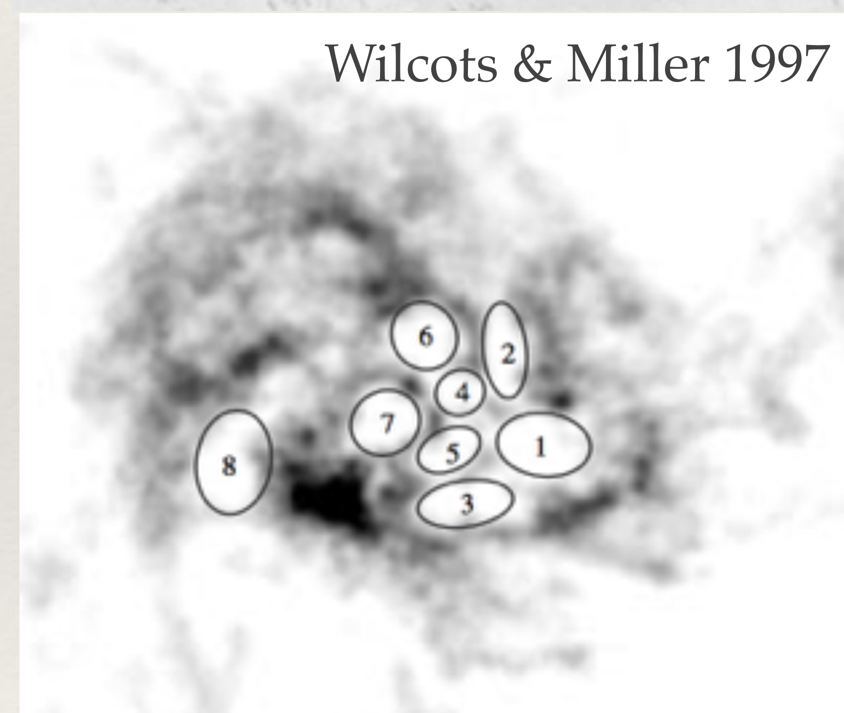
Review on GMCs in Local Group Galaxies (Blitz et al. 2011)

supergiant shells

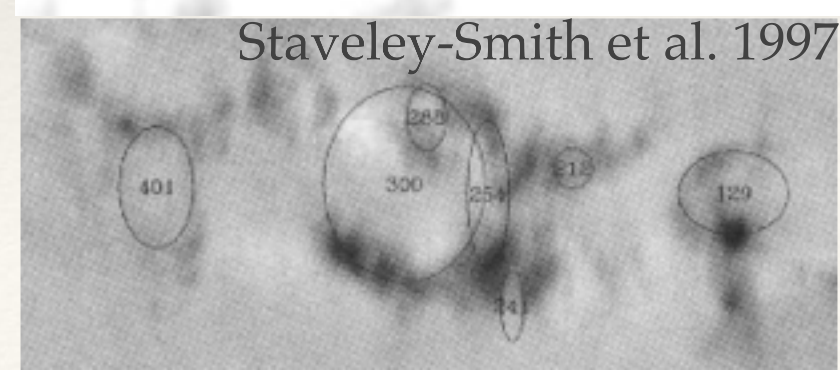
- ubiquitous shells: Hα, HI, CO
- **stellar feedback or density waves?**
- **Impact on GMCs/star formation?**
- Dawson et al. 2013: 12-25% is direct results of stellar feedback in LMC
- M33: large holes require 10^{53}ergs, no obvious stellar clusters, likely from density waves
- IC 10: some from action of SN or stellar winds



Kim et al. 1999



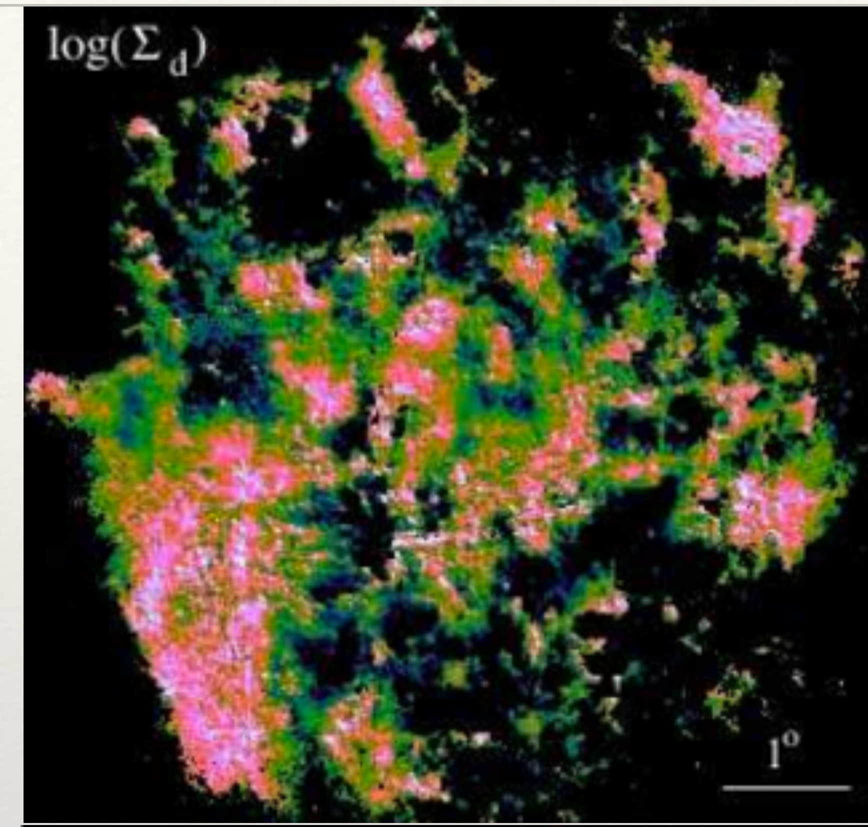
Wilcots & Miller 1997

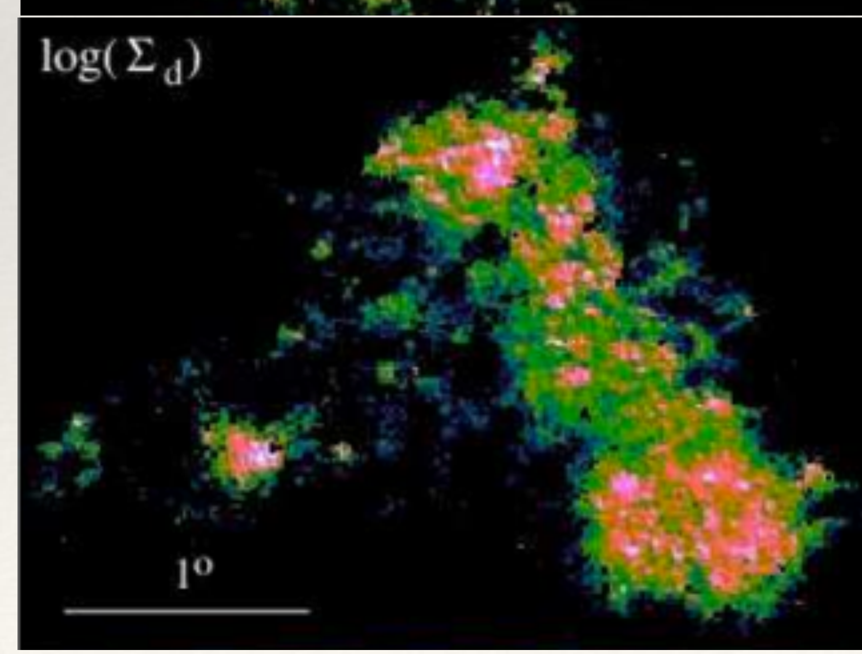


Staveley-Smith et al. 1997

Inventory of dust (1)

- SAGE (P.I. M. Meixner), SAGE-SMC (P.I. K. Gordon), HERITAGE (P.I.)projects
- all Spitzer + Herschel bands for the Large and Small Magellanic Clouds
- modelling in each point of the SED of dust emission (Gordon et al. 2014)
  - dust maps = **current dust content of the galaxies**





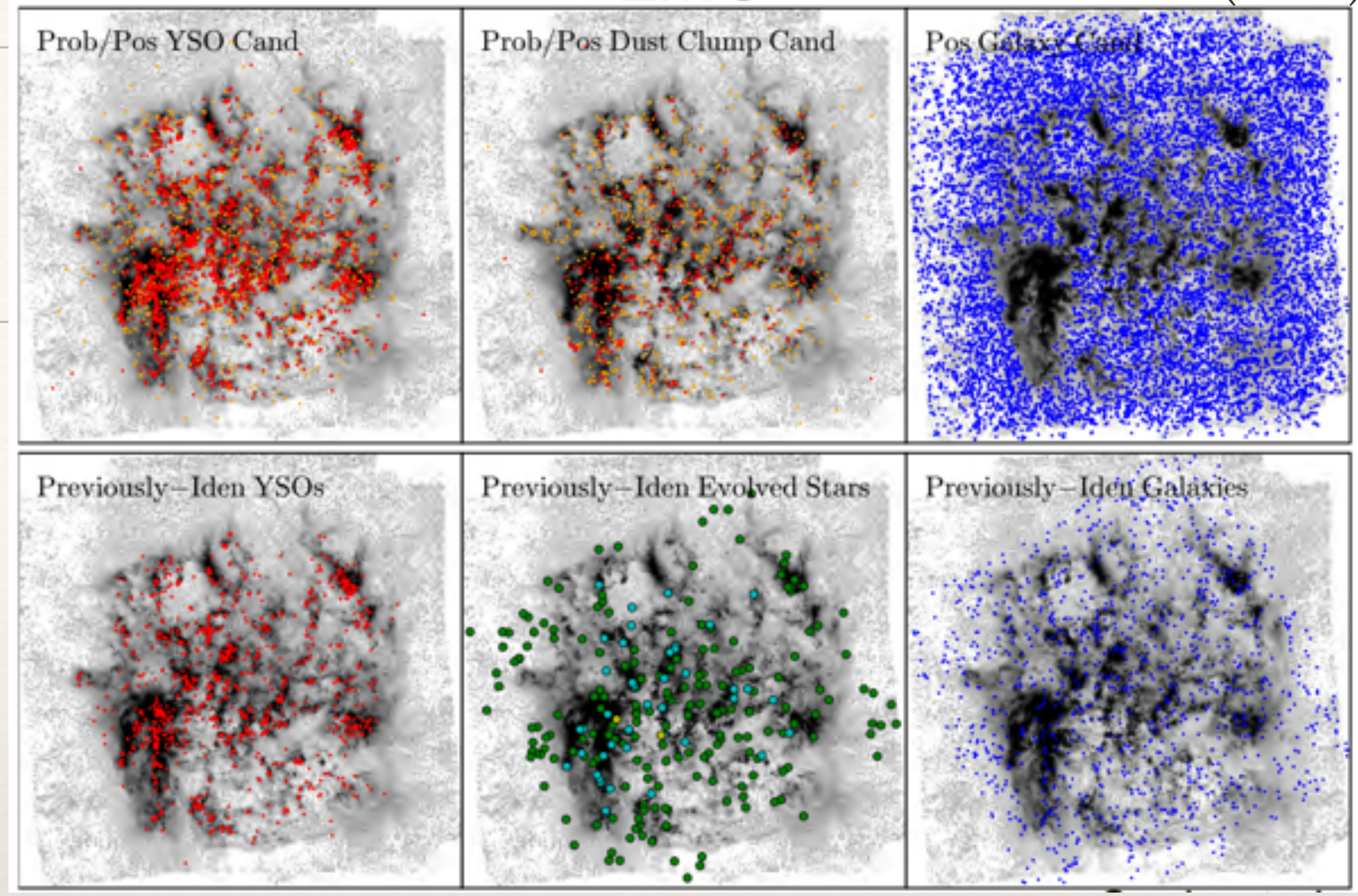
$(7.3 \pm 1.7) \times 10^5$ and $(8.3 \pm 2.1) \times 10^4\ M_\odot$ for the LMC and SMC.

LMC

Seale et al. (2014)

Inventory of the dust (2)

- catalogs of point sources
- classification
- compute dust inputs from different type of sources



- Matsuura et al. (2009):

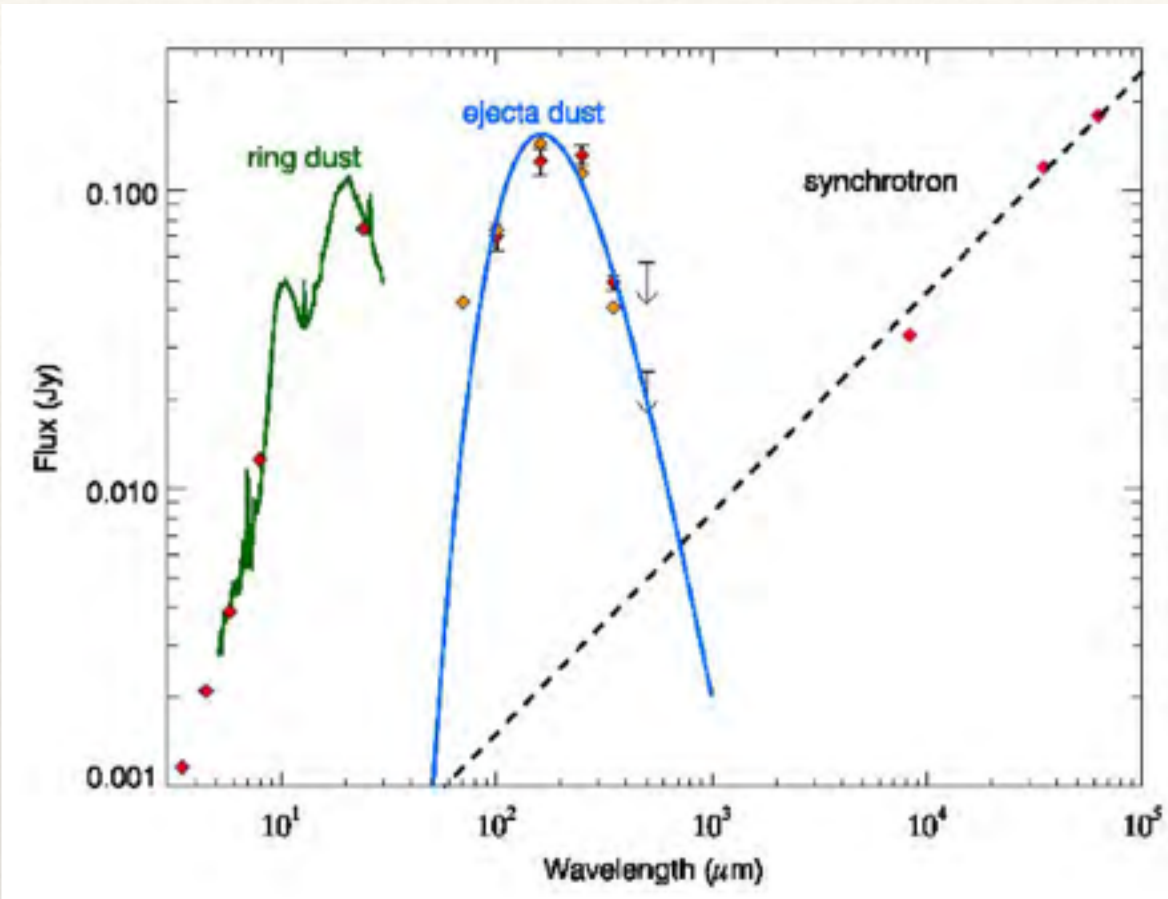
Dust budget	
AGB dust production rate	(5.5–11.5) × 10^{-5} $M_\odot$ yr^{-1}
SNe dust production rate	(0.01–13) × 10^{-5} $M_\odot$ yr^{-1}
SNe dust destruction rate	?
Life time of dust	2–4 × 10^{8} yr
Accumulated dust mass over the life time of dust (with constant rate)	5 × 10^{4} $M_\odot$
Existing dust in the ISM	~~1.6 × 10^{6} $M_\odot$~~ $(7.3 \pm 1.7) \times 10^{5}$
Age of the LMC	10–15 Gyr

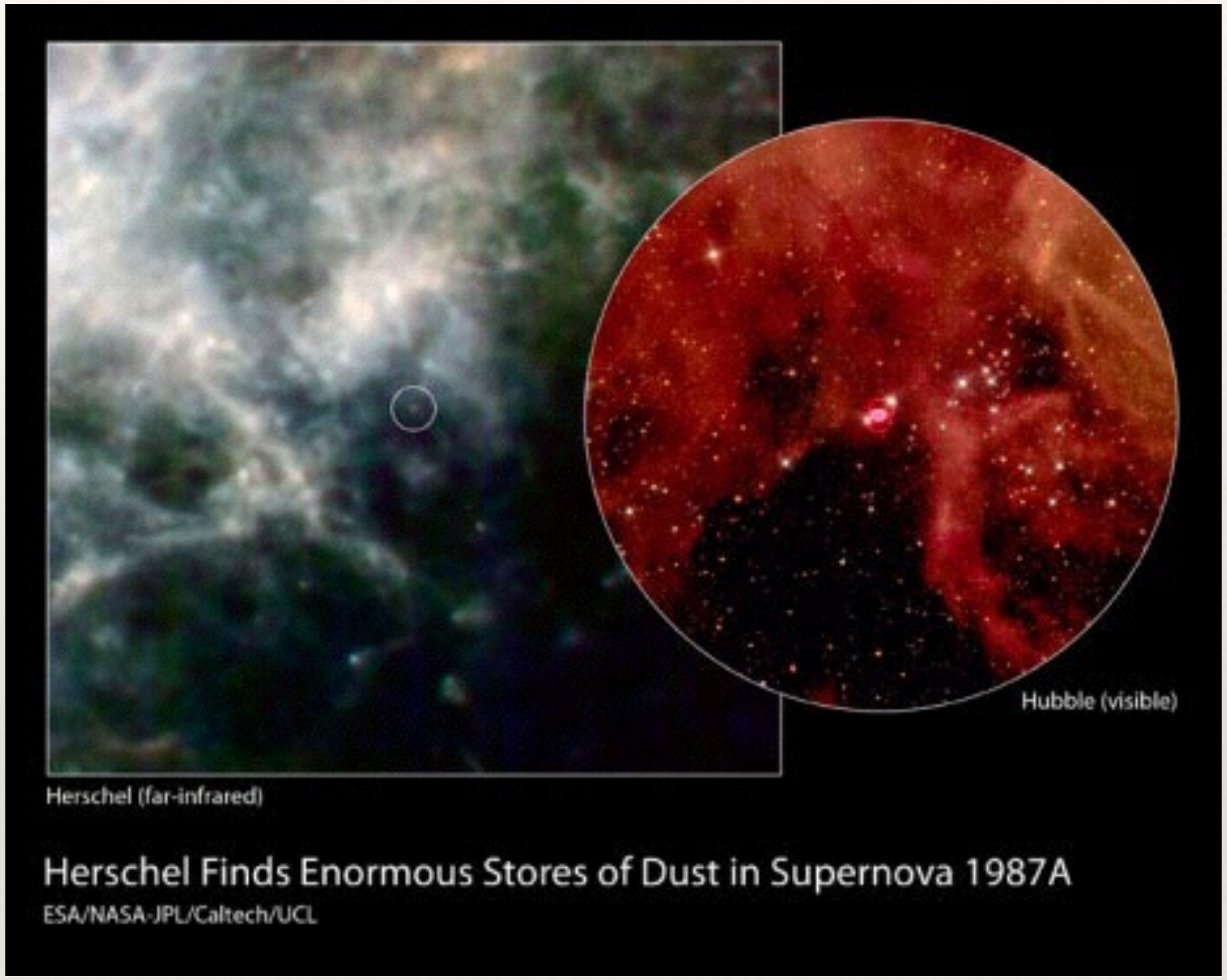
AGB input

~ SNe input

AGB+SNe dust production account for only ~10% of the dust content

SN 1987 A





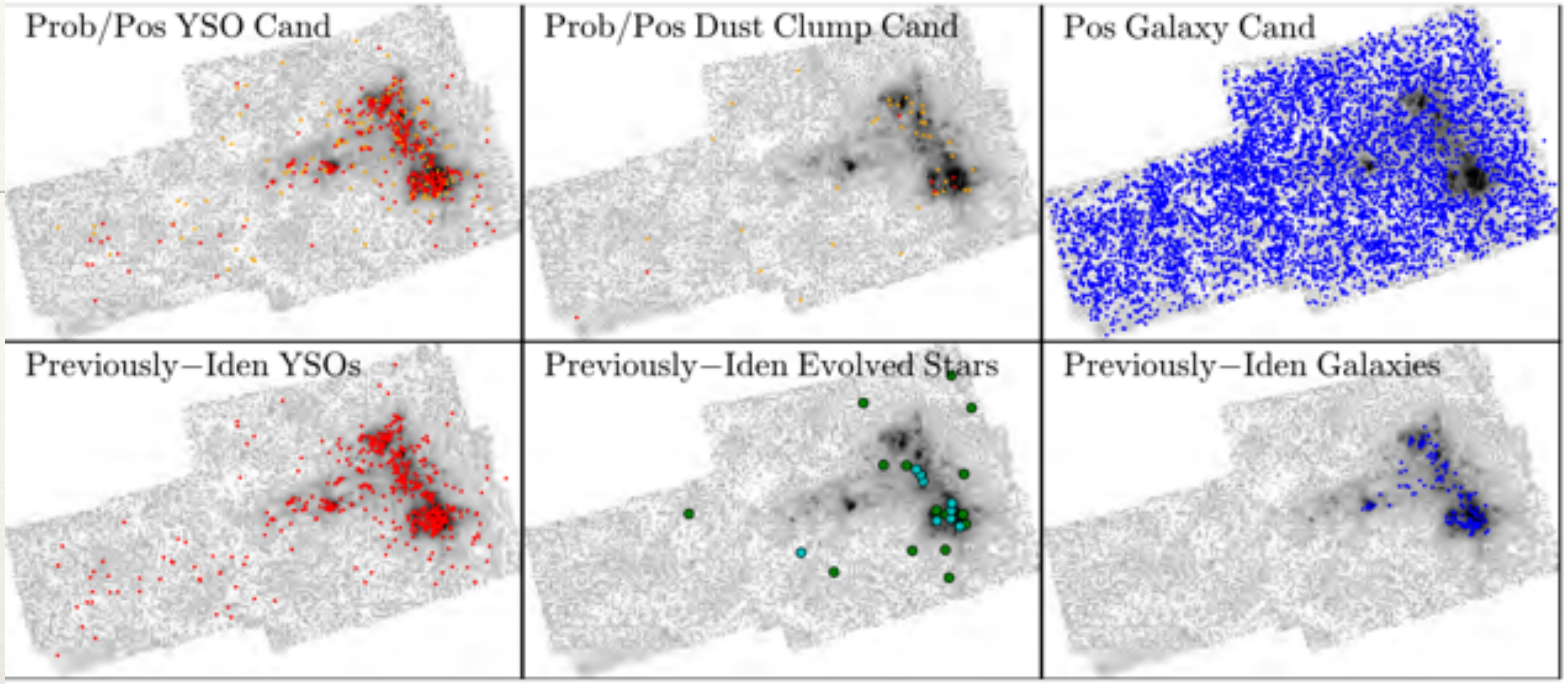
Matsuura et al. (2011): 1Mo of dust (equivalent of input of 10^7 - 10^{10} dusty AGB stars)

Inventory of the dust (2)

- catalogs of point sources
- classification
- compute dust inputs and compare to current dust mass!

SMC

Seale et al. (2014)



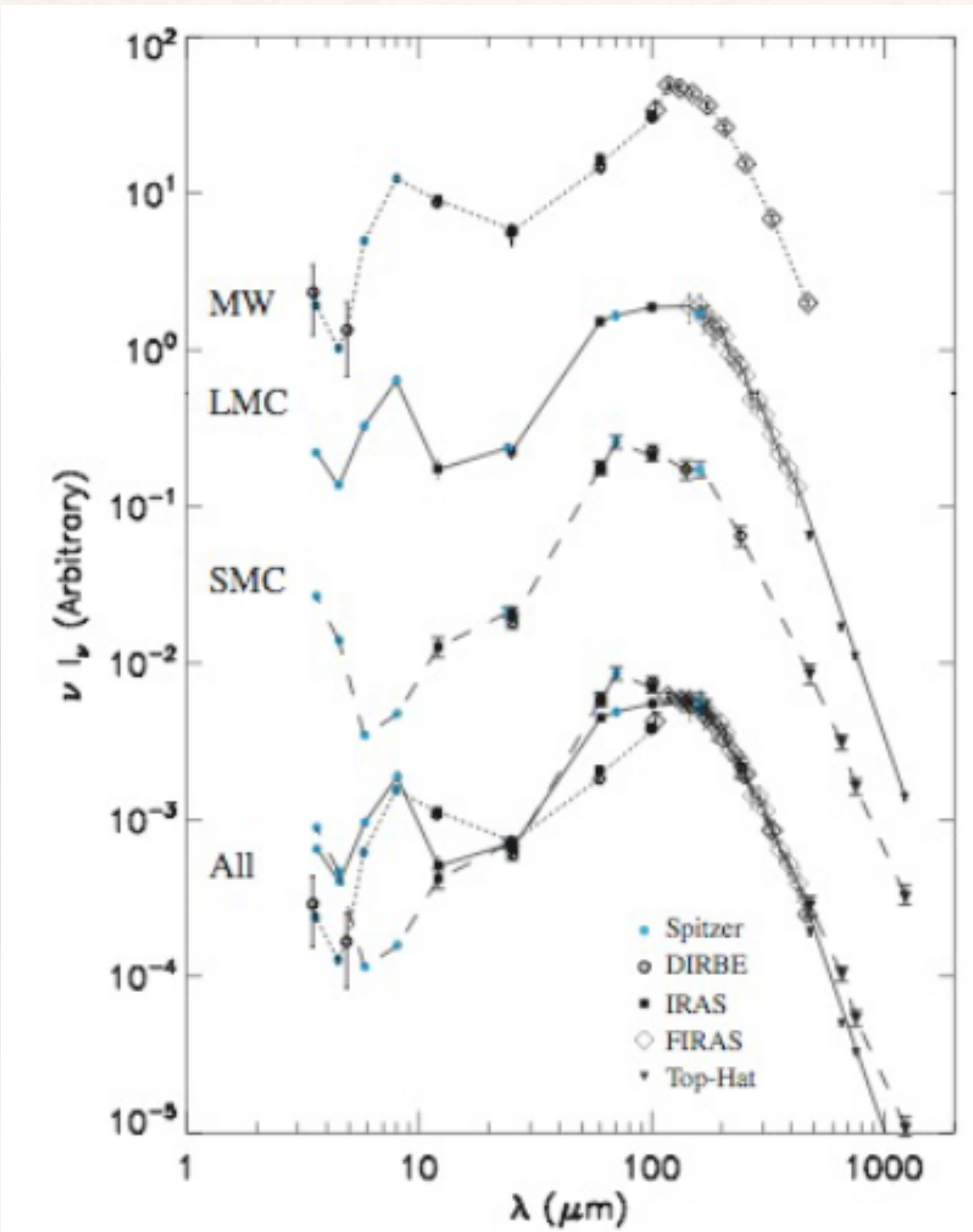
- Boyer et al. (2012):
  - cool stars (AGB + RSG): $(8.6\text{–}9.5) \times 10^{-7}\, M_{\odot}\, \mathrm{yr}^{-1}$
  - SNe: $10^{-3}\, M_{\odot}$ of dust each
  - AGB input ~ SNe input

only 25% of the dust content!!

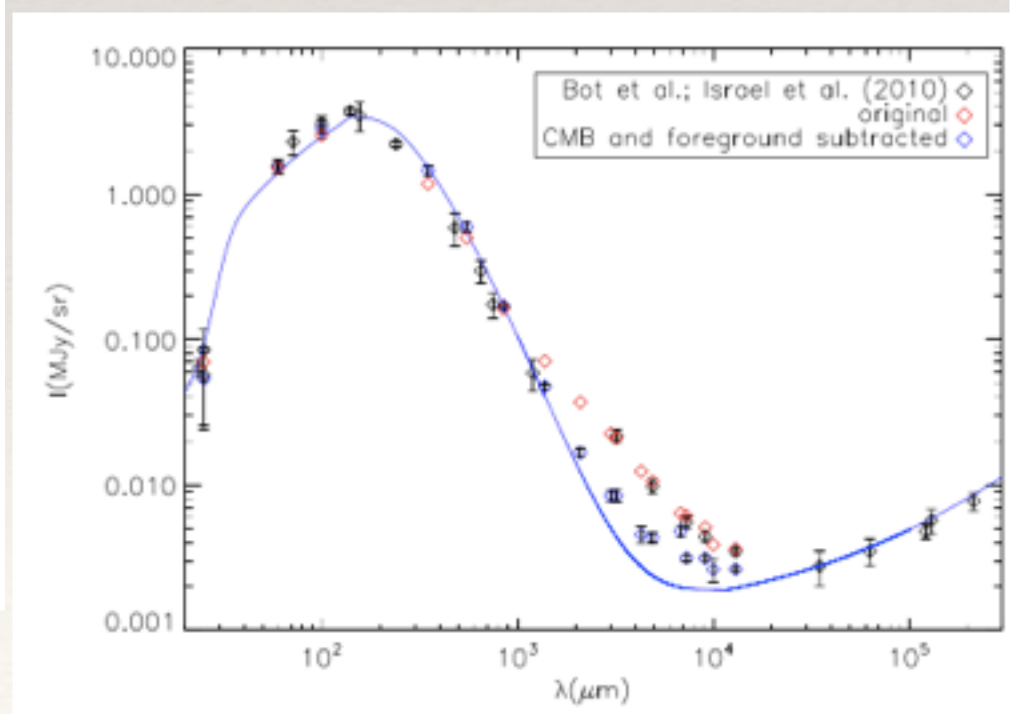
need for an additional source of dust: unknown mechanism or **growth in the ISM**

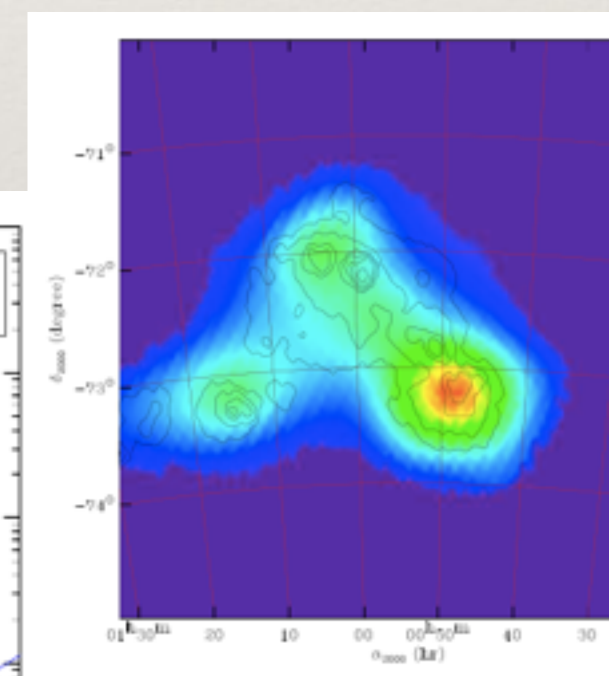
dust emission in the Magellanic Clouds

Bernard et al. 2008



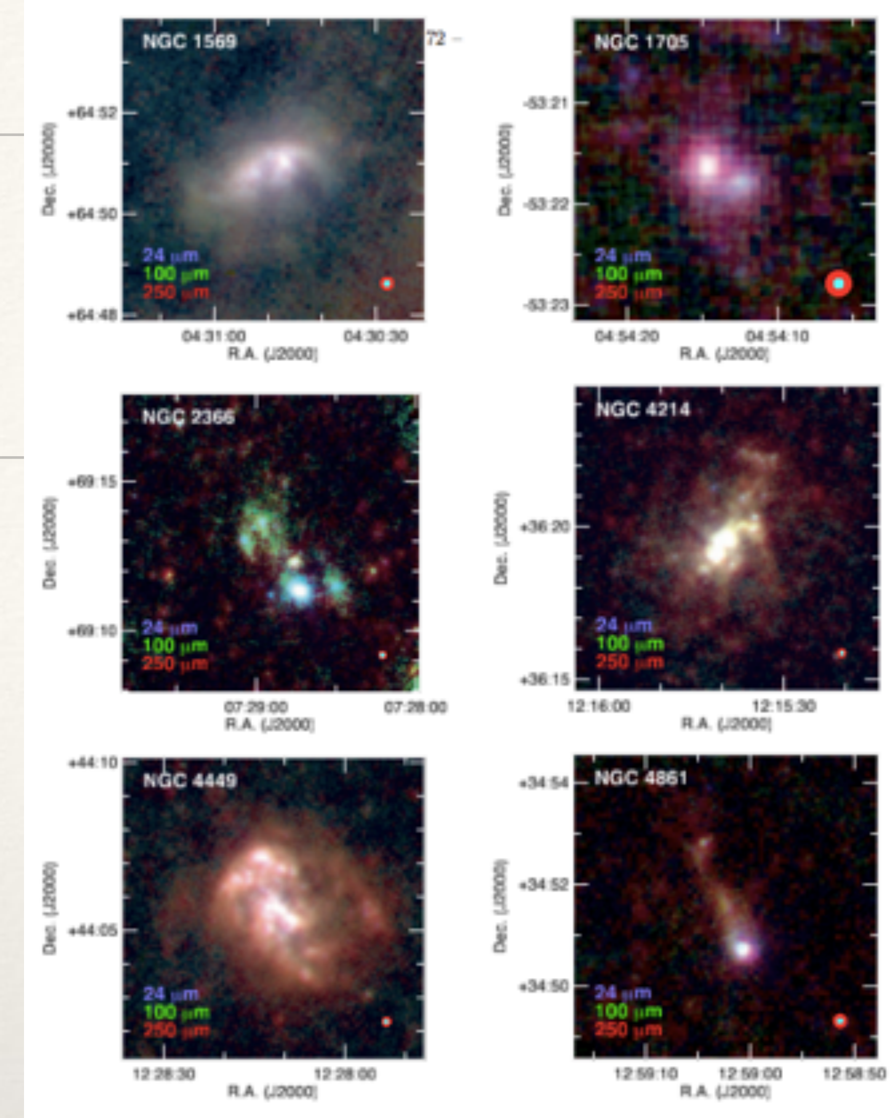
- difficult to model the SEDs of dust in the IR-mm in the Magellanic Clouds
- LMC: 1/2 Z⊙, SMC: 1/5 Z⊙
- sub-mm, mm excess (Israel et al. 2010, Bot et al. 2010, Planck collaboration 2011)

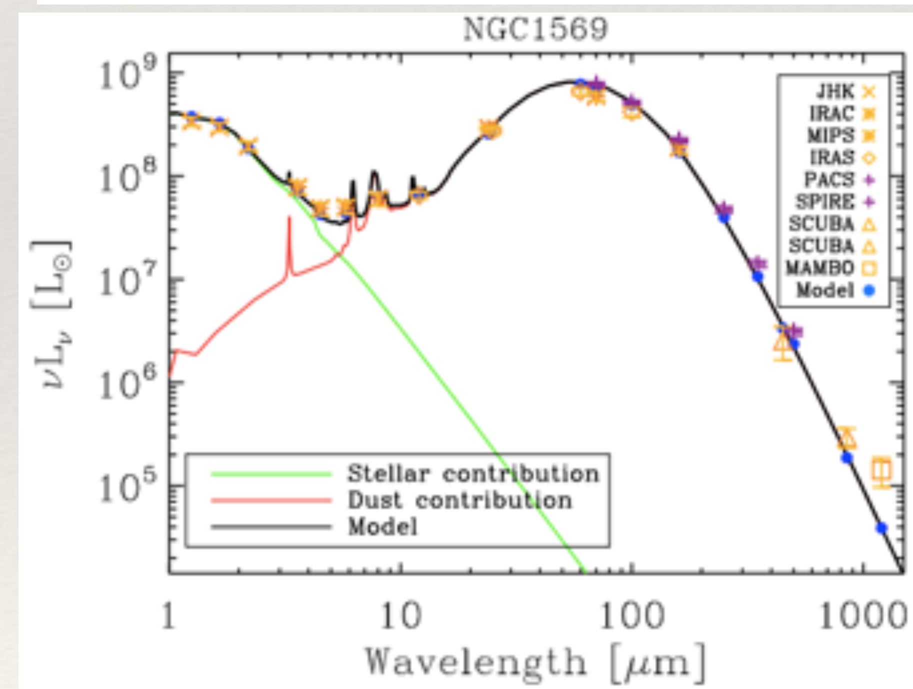




sub-mm excess and metallicity

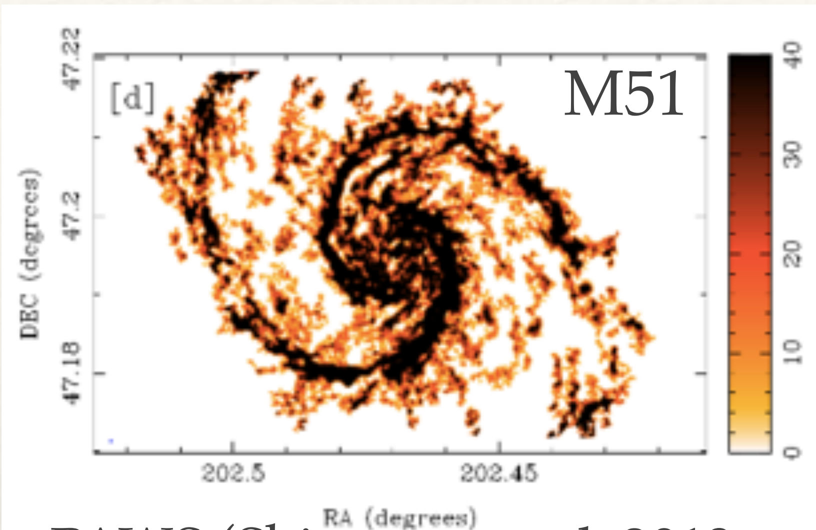
- Using galaxies as samples of the environment
- sub-mm excess seen in other galaxies (Galametz et al. 2014, Gordon et al. 2014, Galliano et al. 2011…)
- ~~cold dust?~~ flattening of the dust emissivity (DCD-TLS effects, carbon/silicates ratios)? Spinning dust grains? Magnetic dipole emission?
- Dwarf galaxy survey (P.I. S. Madden)
  - 50 gal. from $Z_\odot$ to $1/50\ Z_\odot$, ≠SFR
- KINGFISH (P.I. Kennicutt)
- 40% of DGS gal. show an excess, mostly at low metallicities (12+log O/H <8.3) (Remy-Ruyer et al. 2013)



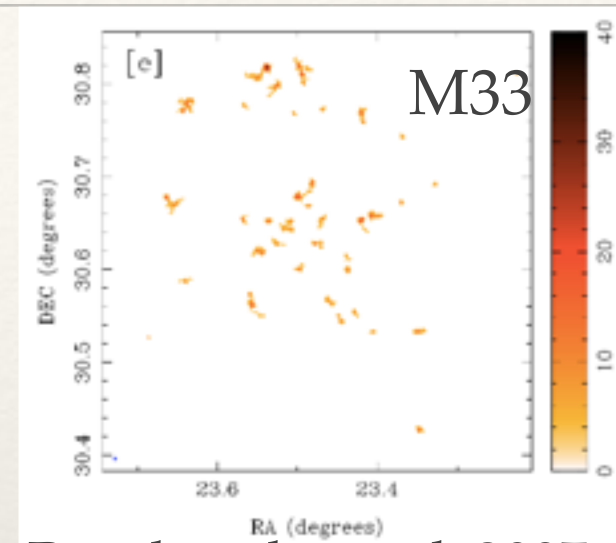


see talk by A. Remy-Ruyer

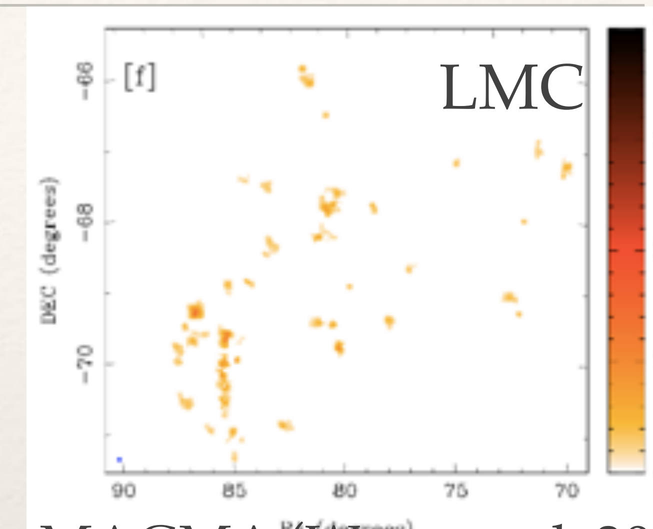
GMCs with environment



PAWS (Shinnerer et al. 2013, Pety et al. 2013), PdBI



Rosolowsky et al. 2007, BIMA+FCRAO



MAGMA (Wong et al. 2011) Mopra

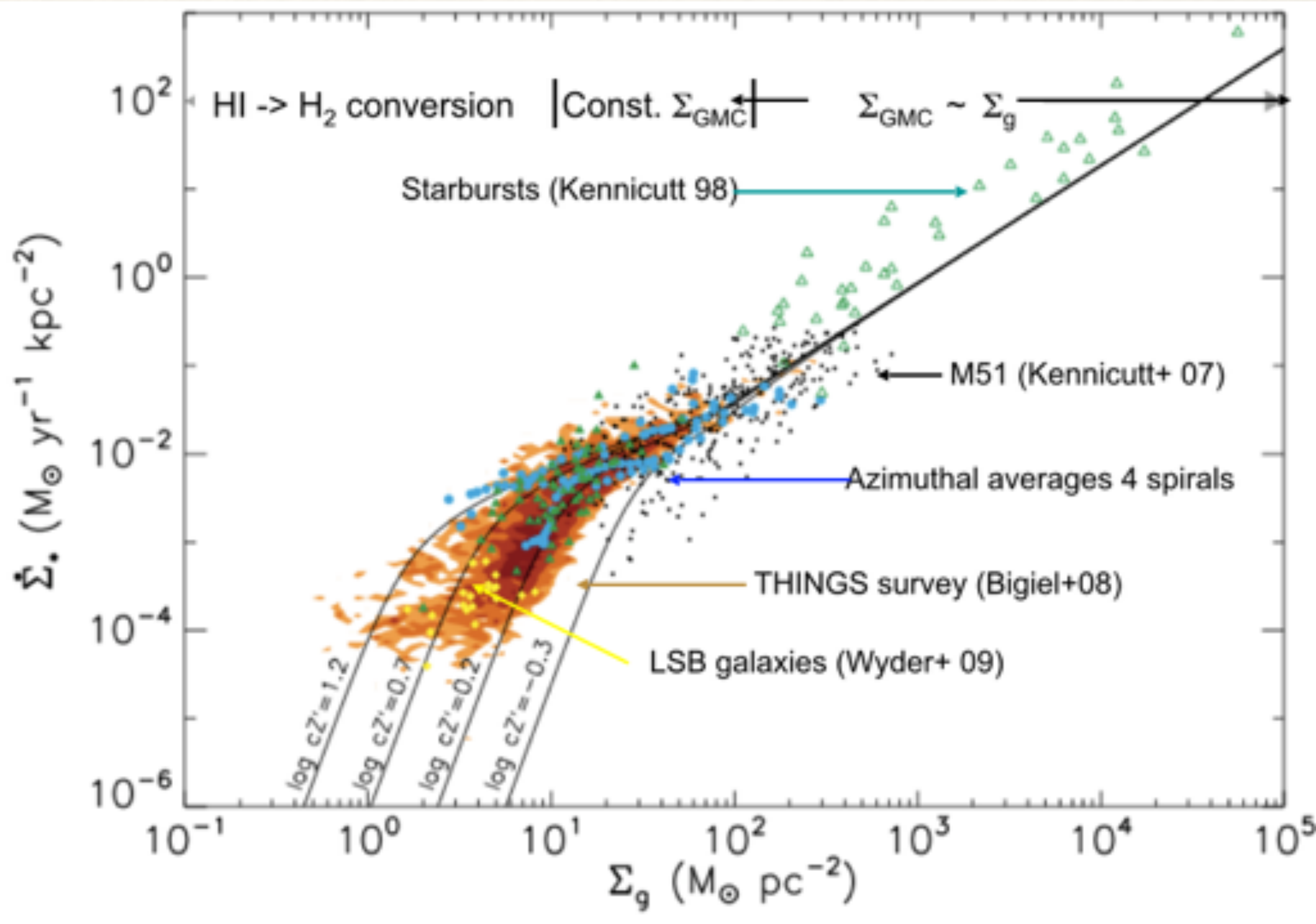
- CO Observations in nearby galaxies at <50pc resolution
- Hughes et al. 2013: matching spatial and spectral resolution of CO observations
- GMCs in M51 are larger, brighter and have higher velocity dispersions
- pressure in the ISM surrounding the GMCs play a role in regulating their density and velocity dispersion

star formation theories:
I-turbulence regulated star formation

- turbulence regulated star formation
- Krumholz et al. (2008, 2009), McKee & Krumholz 2010:

$$\Sigma_{\rm SFR} = d\Sigma_*/dt = (\varepsilon_{\rm ff}/t_{\rm ff})\, f_{\rm GMC}\, \Sigma_{\rm g}$$

- f(H2): competition between H2 formation on grains and photodissociation by UV radiation.
    - for a given cloud, f(H2) depends on the dust optical depth of the cloud and the strength of the external radiation field
    - dependence on metallicity arises from dependence on the dust

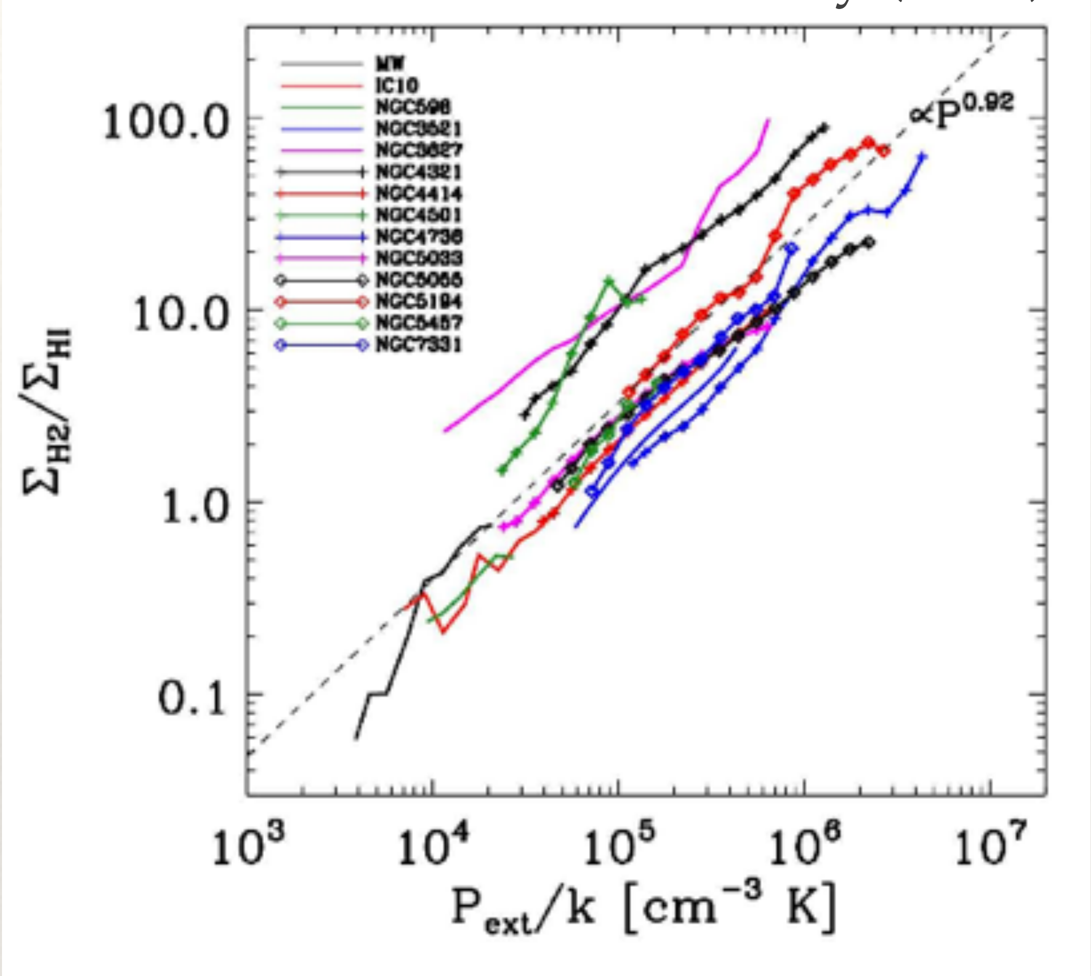


Credit: C. McKee

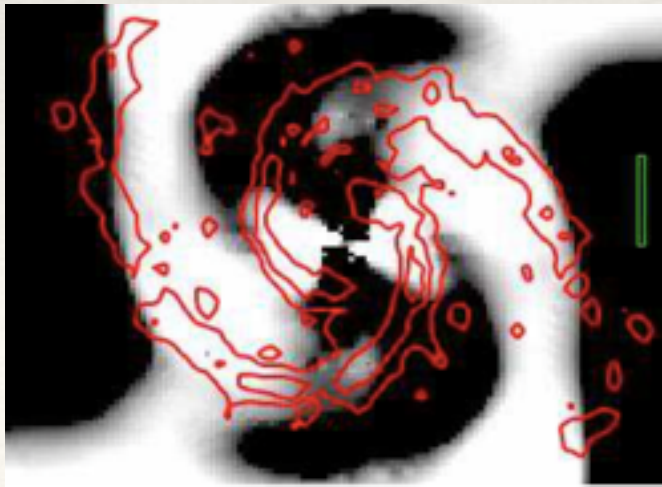
star formation theories:
II-regulation in the two-phase ISM of galactic disks

- Ostriker et al. 2010, Bolatto et al. 2011
- ISM=diffuse gas and gravitationally bound clouds (GBCs)
- includes <u>effect of stellar gravity</u>
- relies on:
  - hydrostatic equilibrium of the ISM in the disk. Mid plane pressure =weight of gas above
  - thermal equilibrium (P_{th} α G_0)
  - star formation equilibrium (G_0 α SFR α Σ_{GBCs})

Blitz & Rosolowsky (2006)

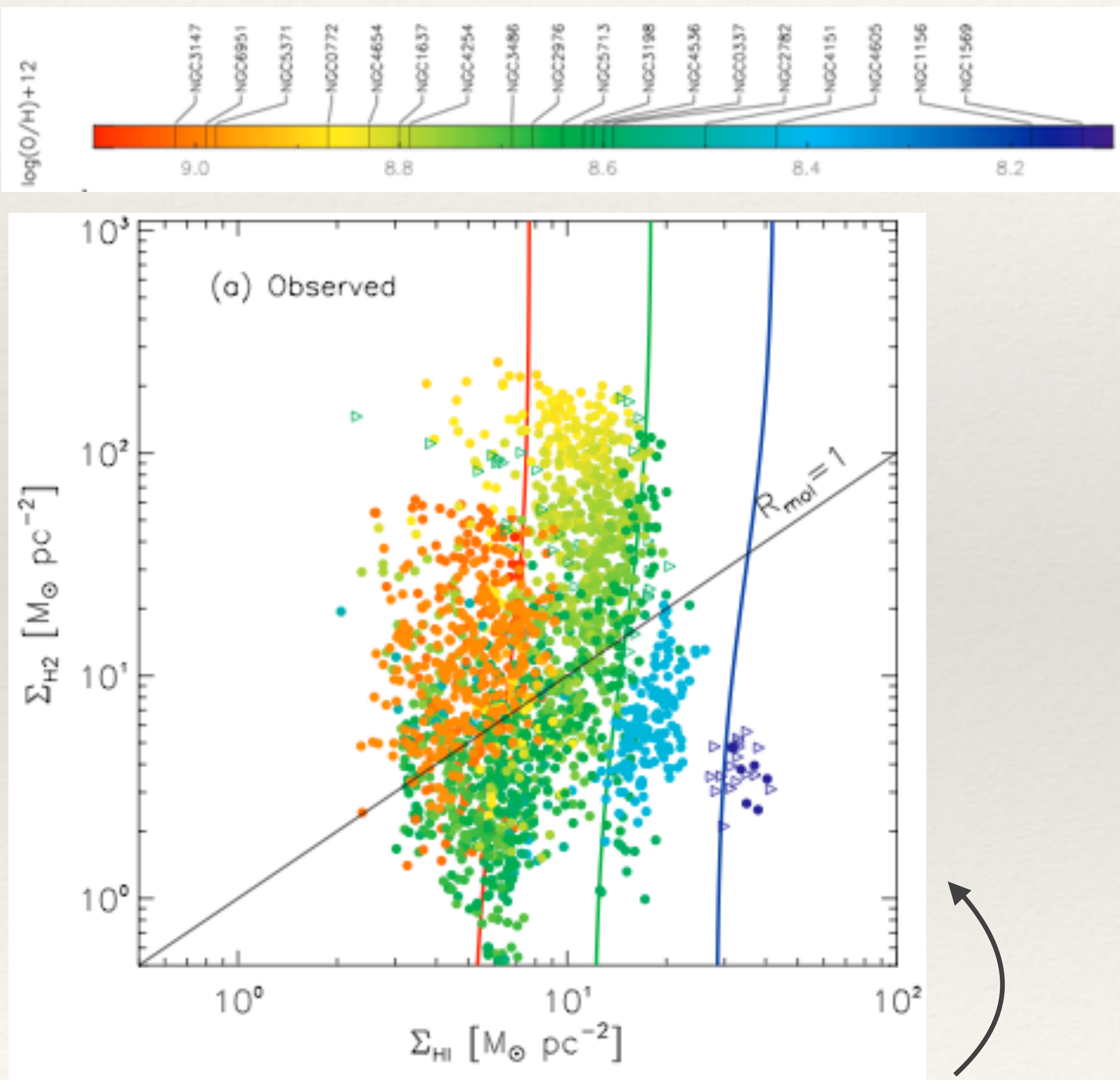


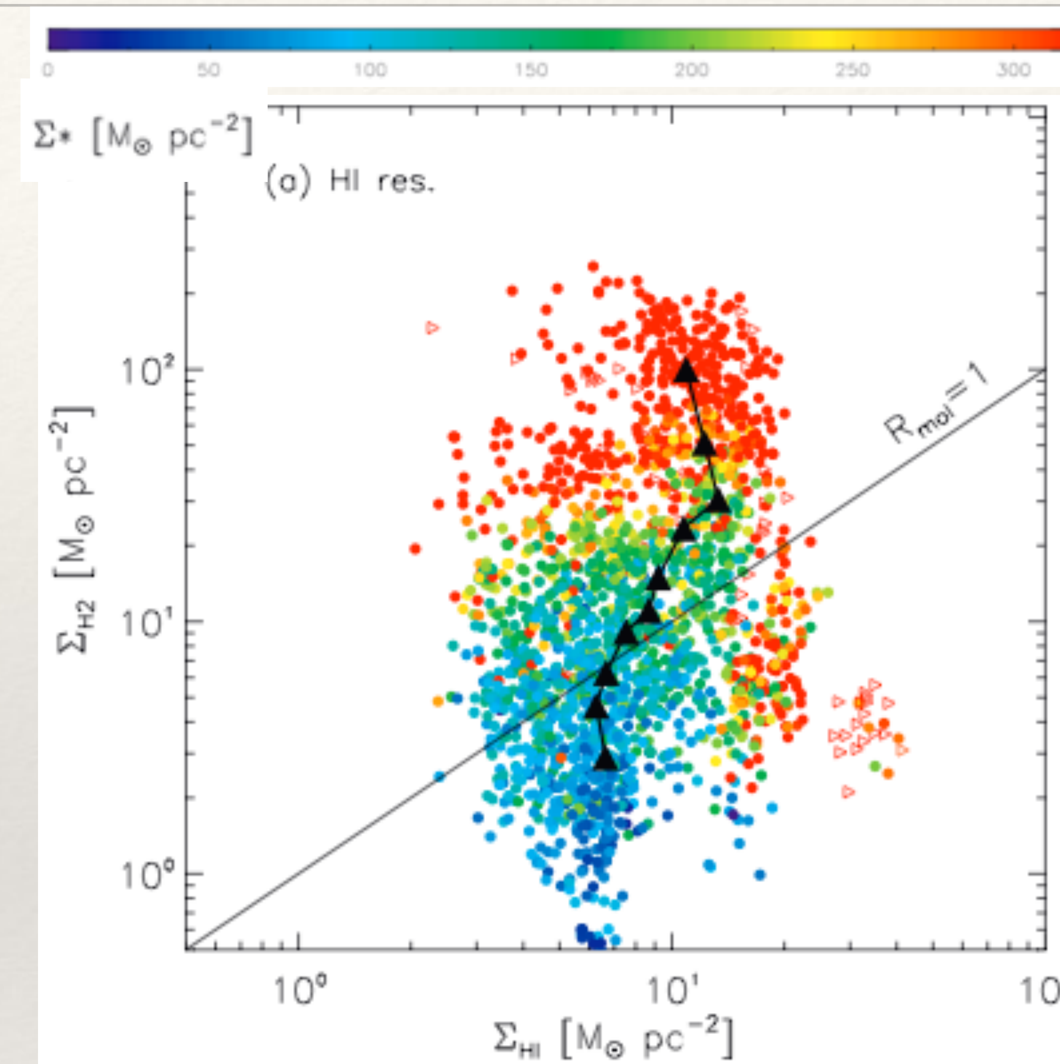
Meidt et al. 2013
M51: torques from stellar potential
white: motions are driven outward
black: motions are driven inward



metallicity on HI-H2

- Wong et al. 2013: 13 galaxies



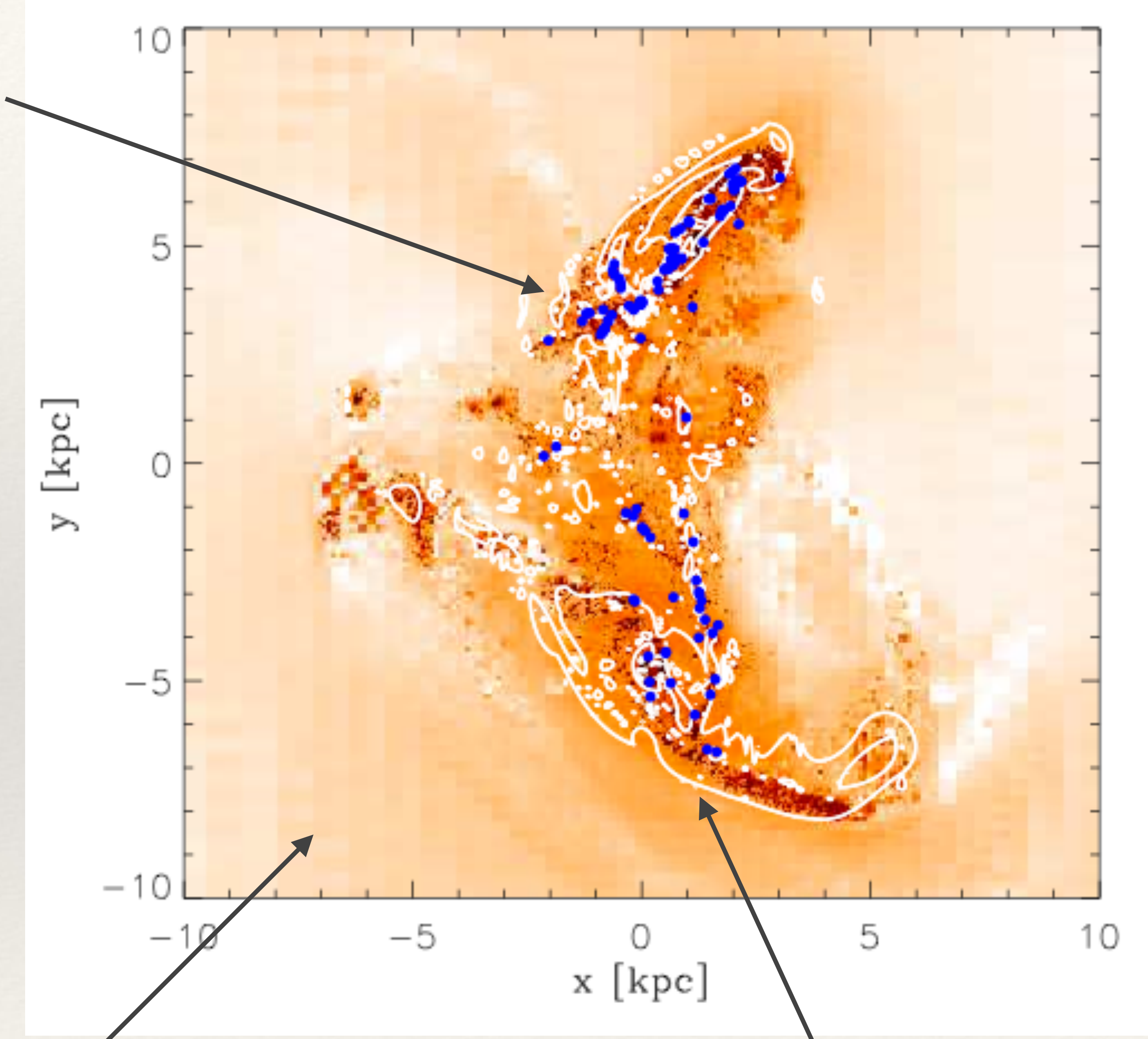


GMC covering factor correlates with stellar density
Why?
Higher stellar density,
higher pressure in diffuse gas,
increase cooling rate,

Clear dependence of N(HI) @GMCs on metallicity
Models from Krumholz et al. 2009, 2010

Simulation of compressive tides

position of young
star clusters (<10Myr)



- Renaud et al. 2014
- simulation of the Antennae galaxy

strength of the tidal field

Contours: converging
compressive turbulent flows

Conclusion and perspectives

- Do you care about ISM processes? Have a look at (nearby) galaxies too!
  - changes of environment (Z, SFR, Heating, …)
  - global view
- Future?
  - ALMA is changing the view of galaxies now!
  - Optical studies like PHAT (P.I. Dalcanton): high resolution, dust in absorption
  - NOEMA, CCAT, JWST, …