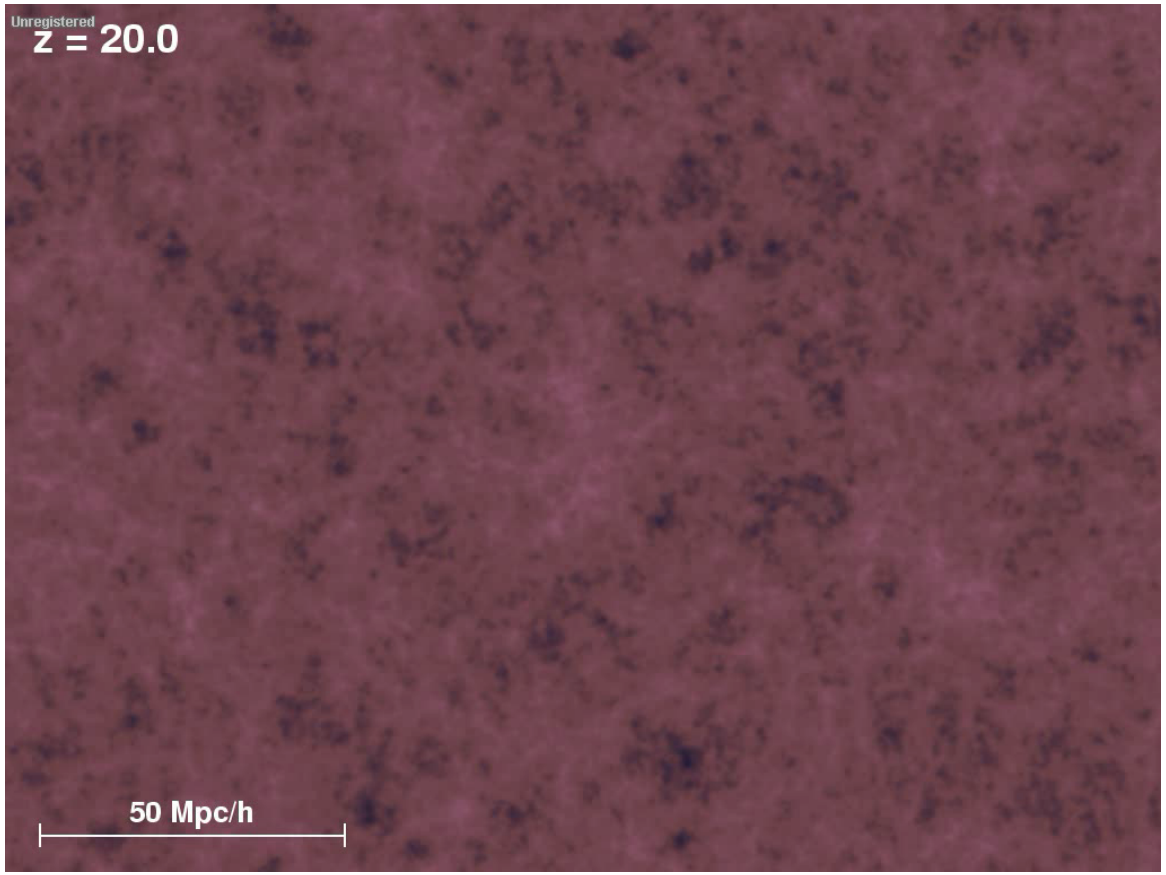
Gas, ISM properties, and Star Formation in Galaxies: connecting the Nearby and the Distant Universe

…or, what the heck is that I do?

Prof. Alberto Bolatto

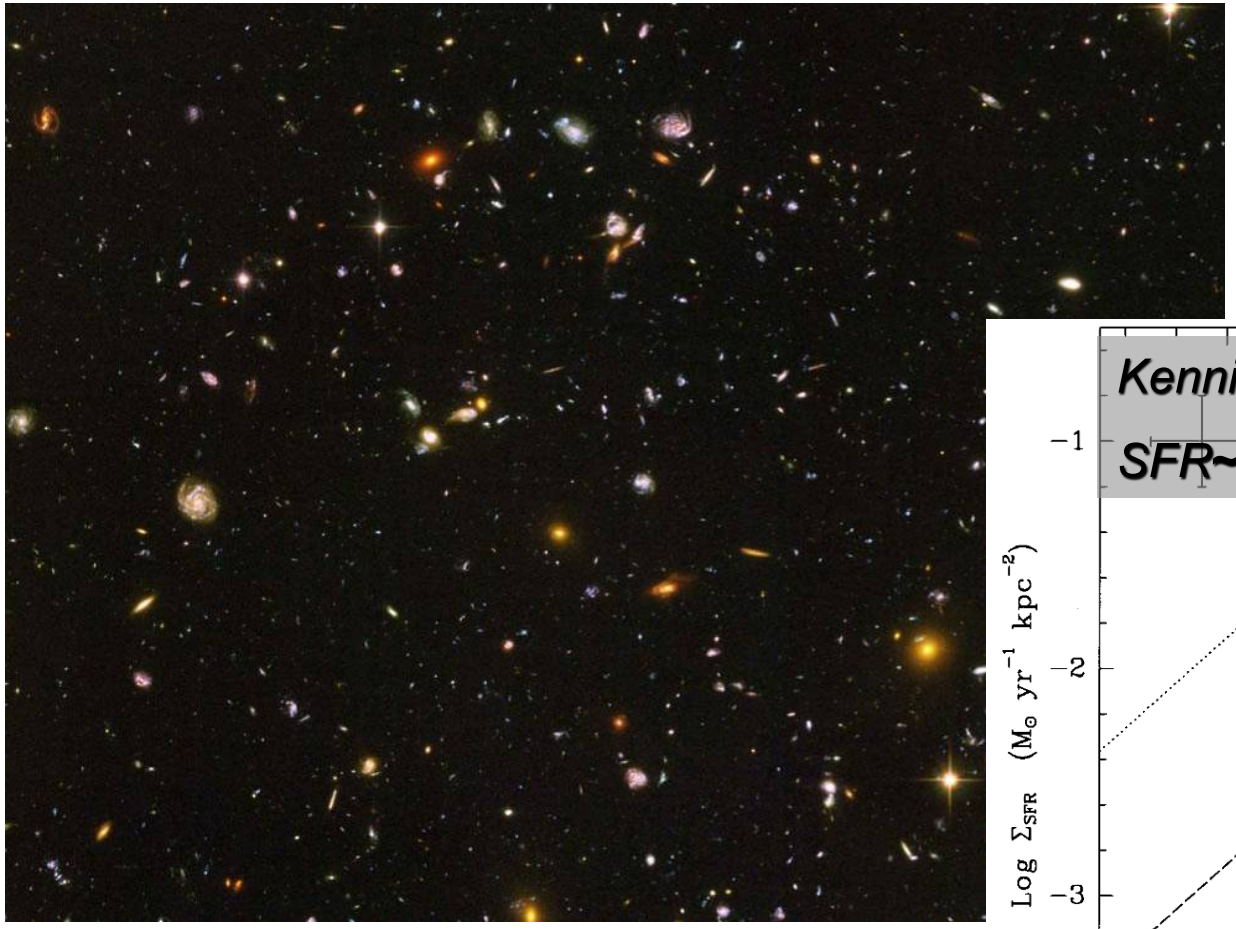
Motivation: understanding structure formation



V. Springel et al.,
Millenium Simulation

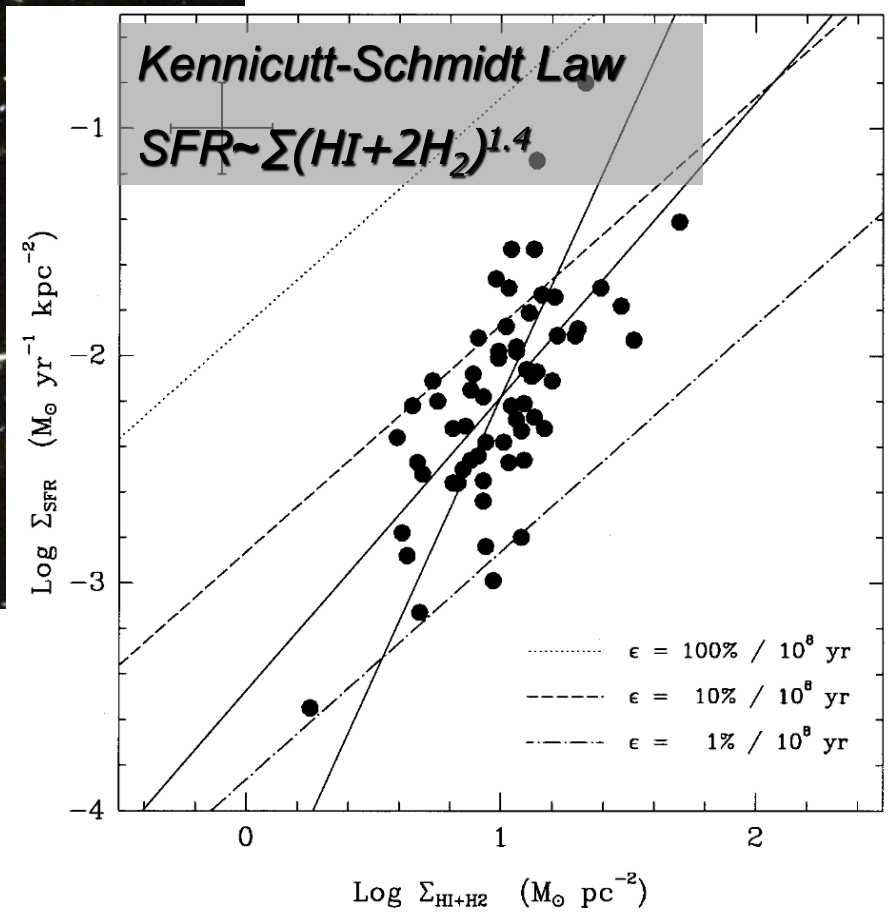
Dark matter (gravity)

Structure formation in the Universe: Light



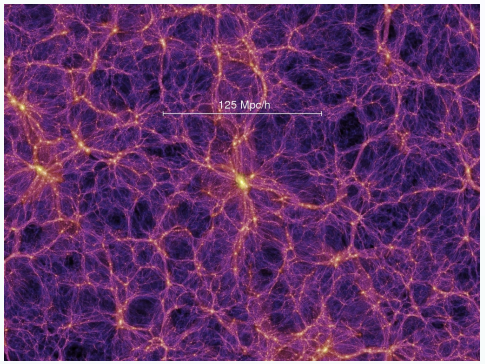
Hubble UDF

Kennicutt (1989,1998)



Dark matter (gravity) → HI → H_2 → stars → observable structure (astrophysics)

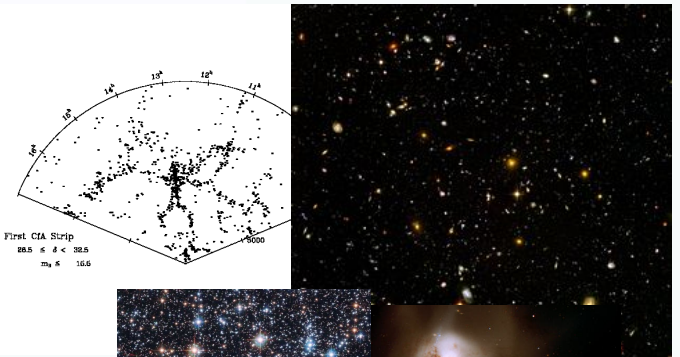
The evolution of structure in the universe

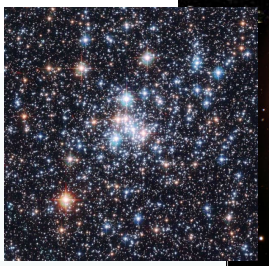


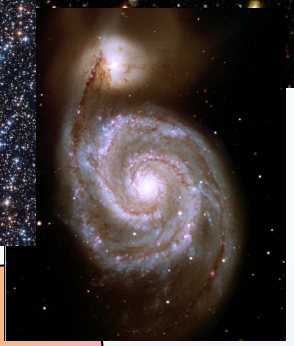
Stars form in Giant Molecular Clouds (GMCs)

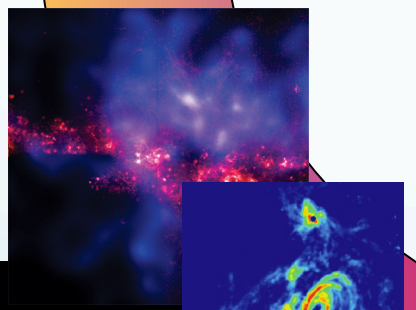
Molecular transitions are necessary to radiate the heat of contraction

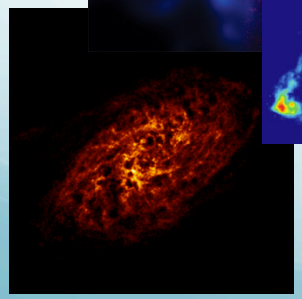
HI is the dominant gas reservoir in galaxies, but star formation occurs only in H_2

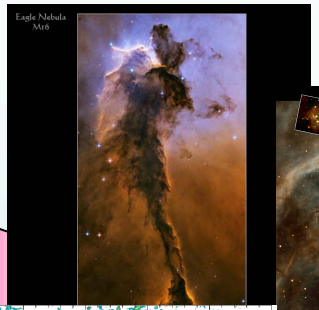


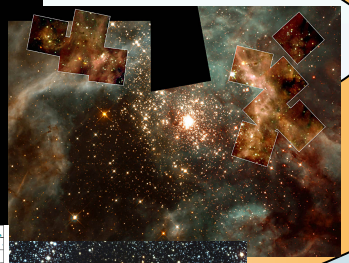


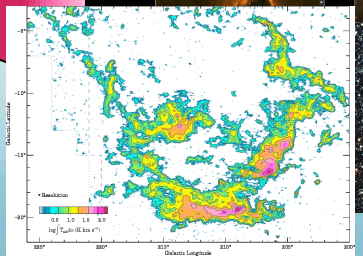




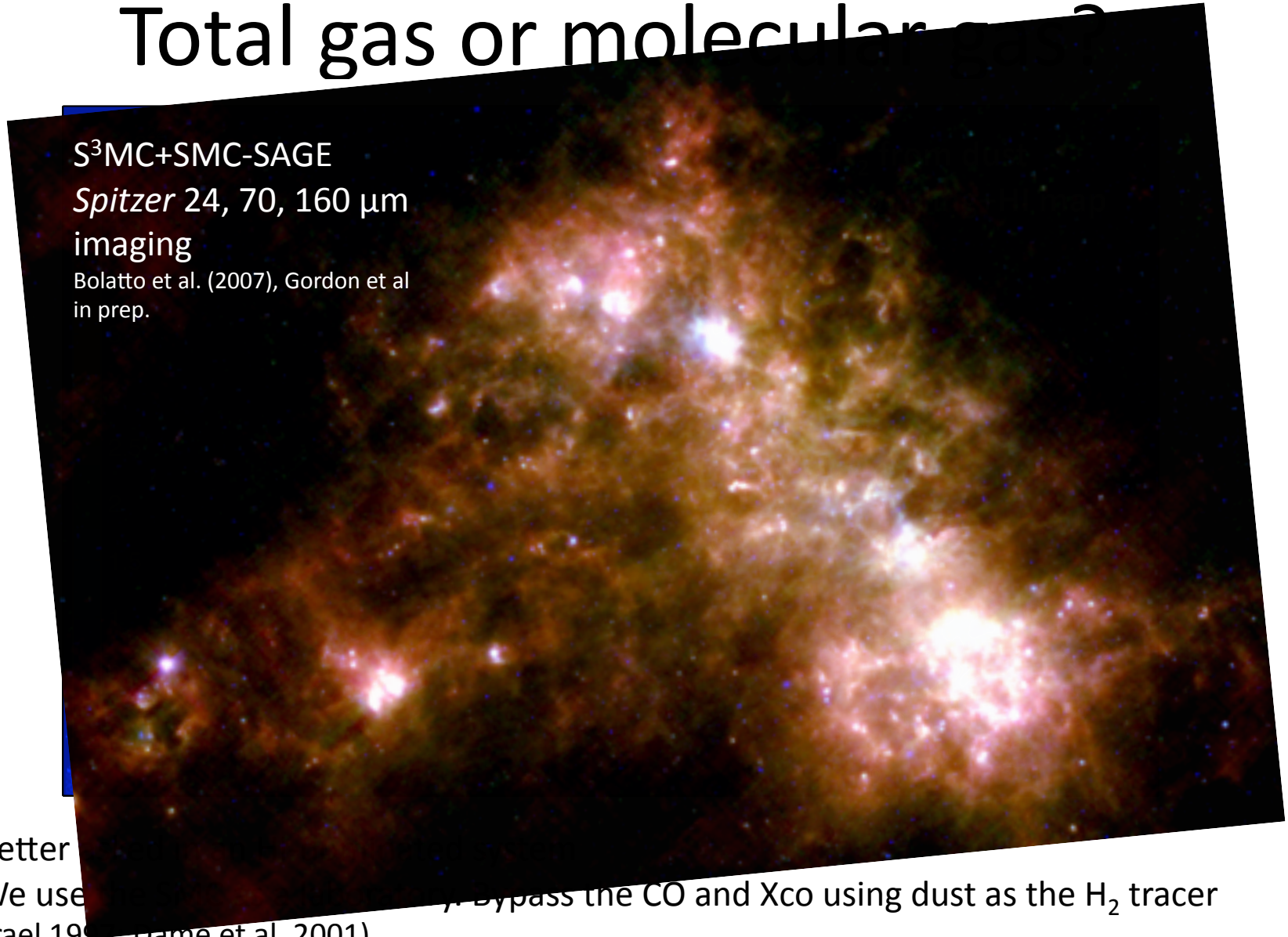








Total gas or molecular [illegible]



- Better [illegible]
- We use [illegible]. Bypass the CO and Xco using dust as the H_2 tracer

(Israel 1997, Dame et al. 2001)

Leroy, Bolatto, et al. (2007, 2009,2010); Bolatto, Leroy, et al. in prep.

Mapping H_2 without CO

Self consistently estimated using HI-dominated lines of sight

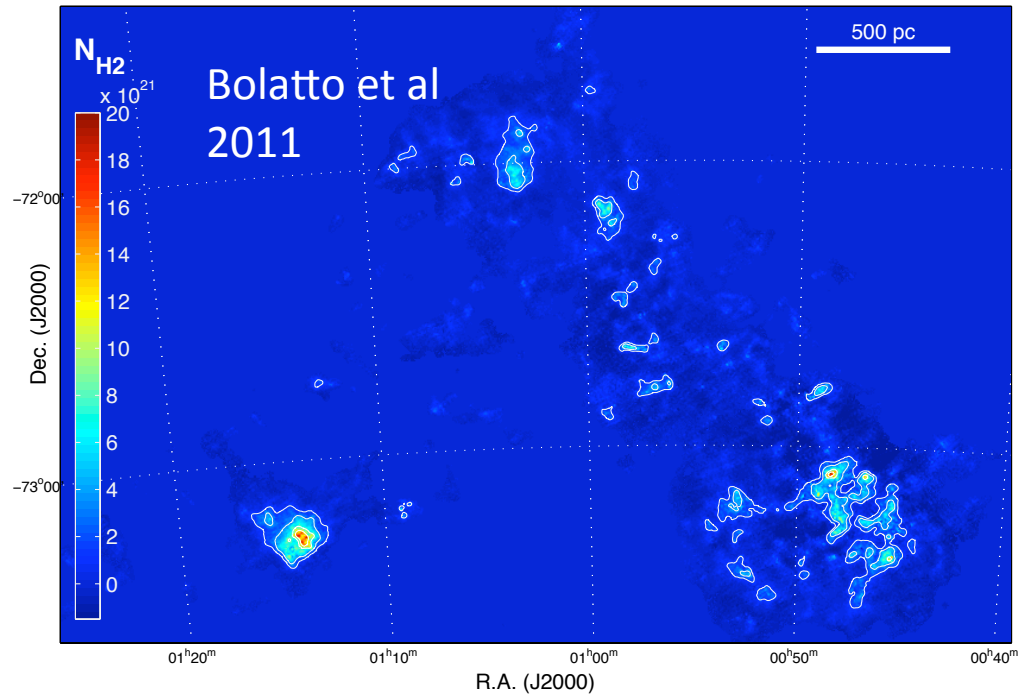
$$\Sigma_{H2} = (\Sigma_{dust} \times GDR) - \Sigma_{HI}$$

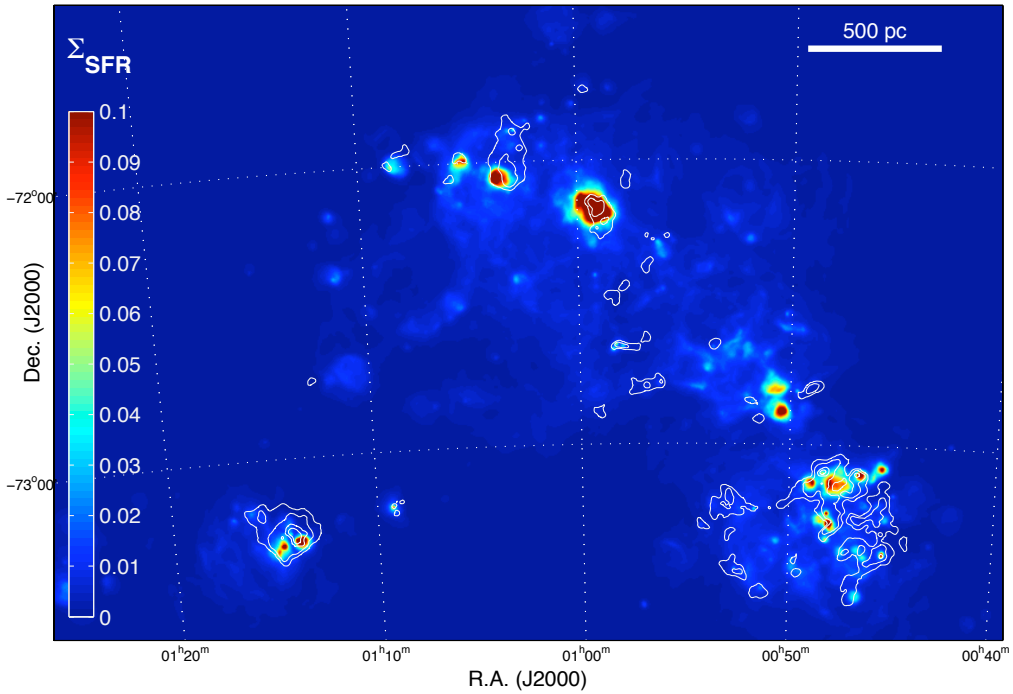
From FIR SED modeling

From 21 cm mapping

The SMC is dominated by "dark" molecular gas

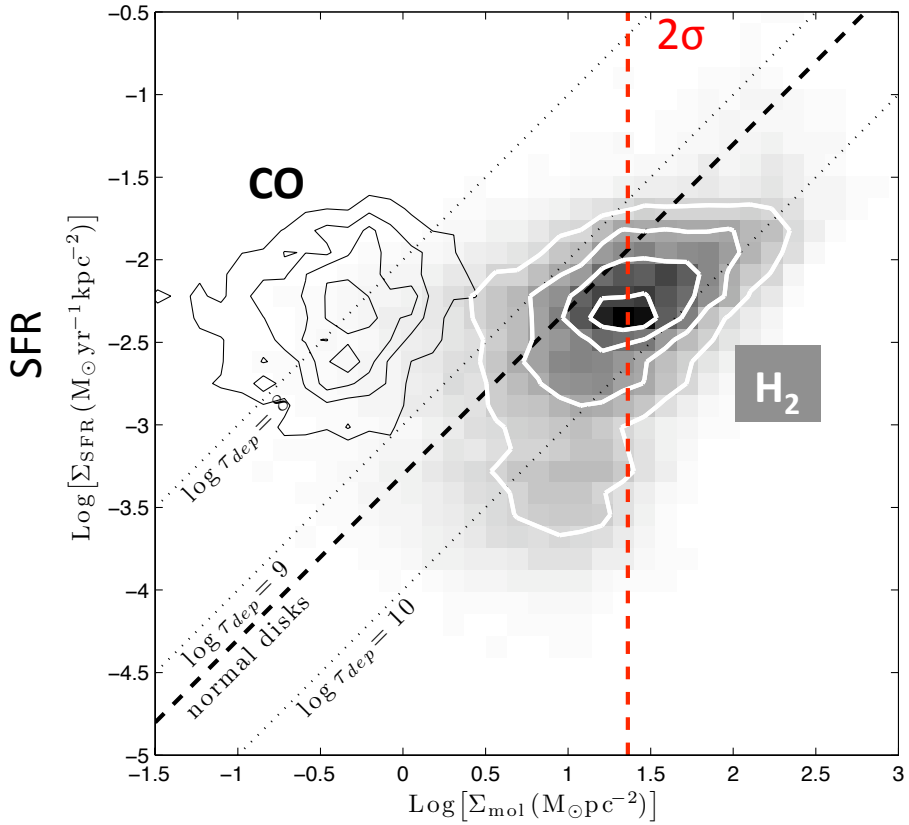
Israel 1997; Dame et al. 2001; Leroy et al. 2007,2009,2011



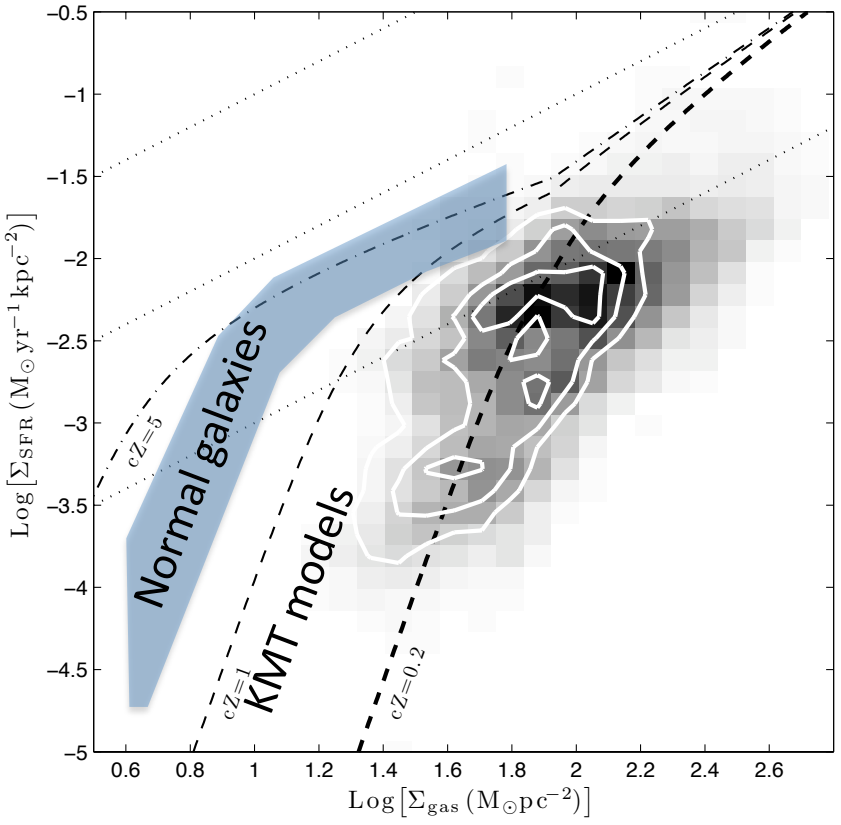


Relations for H_2 and total gas

Molecular Gas



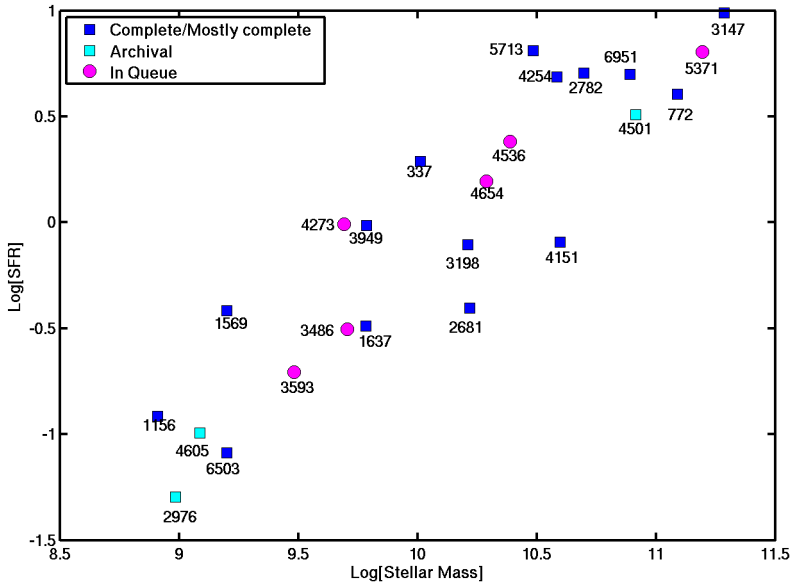
Atomic+Molecular Gas

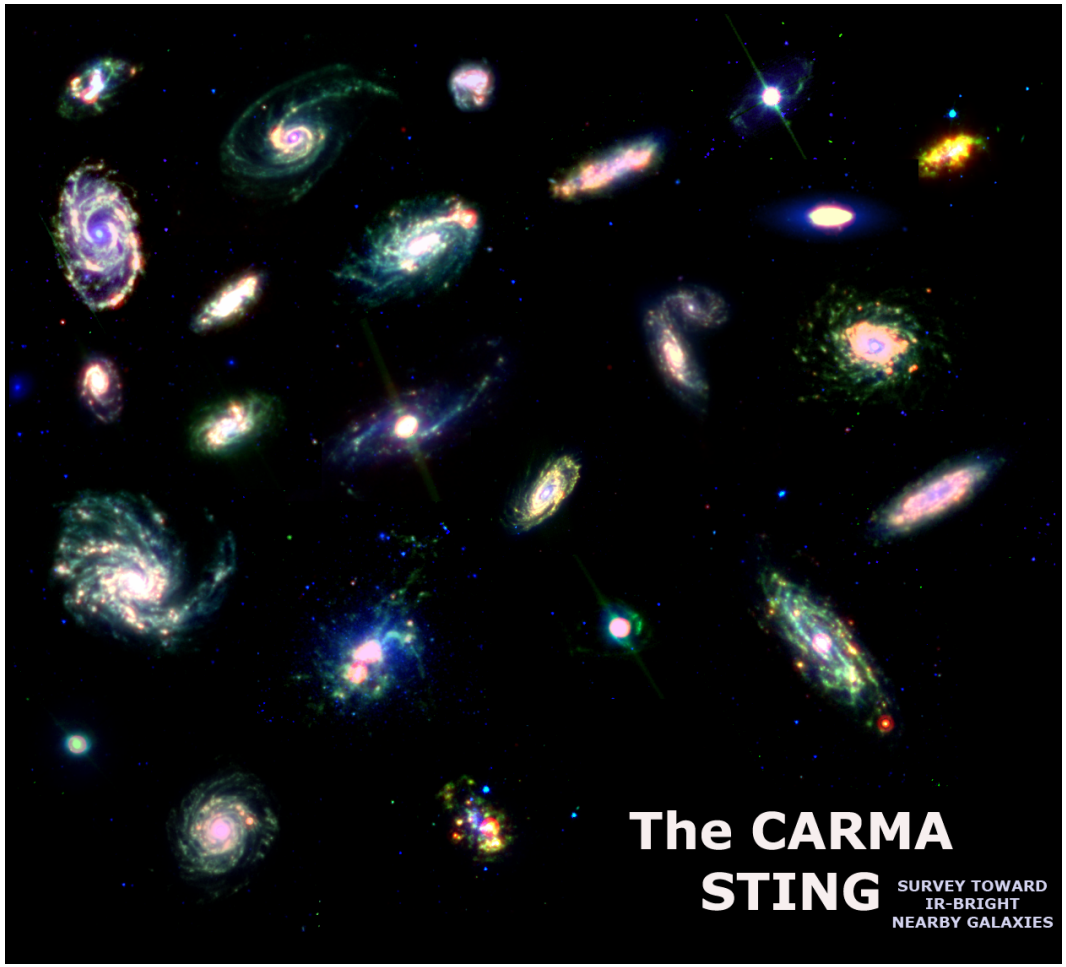


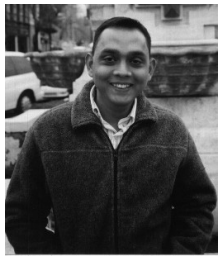
- The SMC is "normal" in H_2 vs. SFR
- The SMC is vastly underperforming in total gas vs. SFR (explains Wolfe & Chen 2006)
- KMT09 models where HI➔H_2➔SFR fit the data reasonably well

Krumholz, McKee, & Tumlinson (2009)

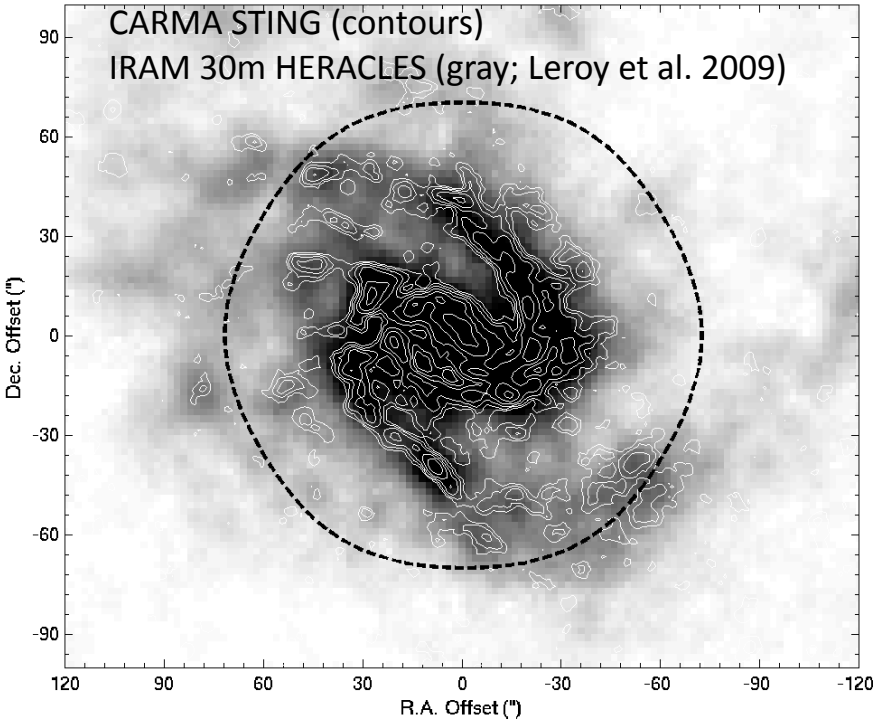
Molecular Gas in the Blue Sequence

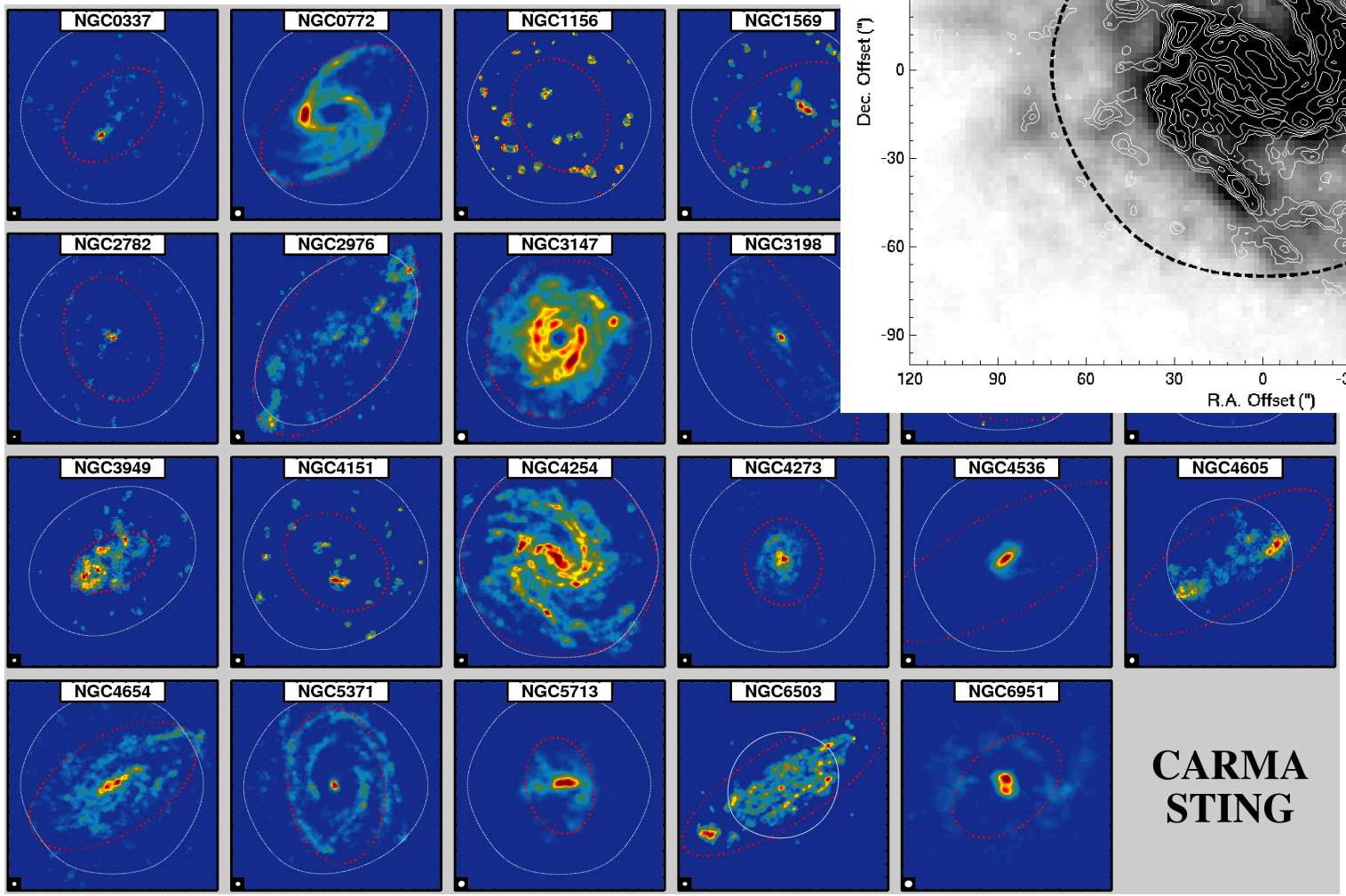






STING





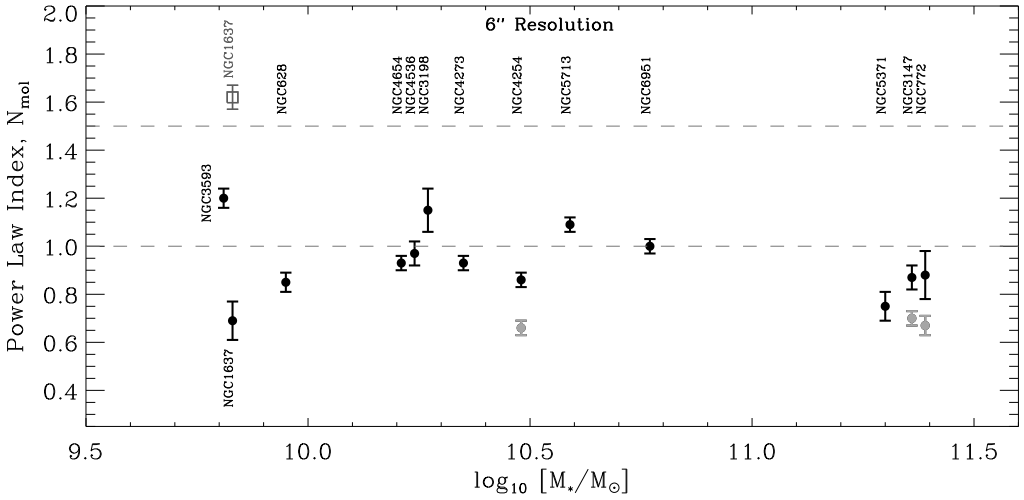
What is the relation between gas and SFR?

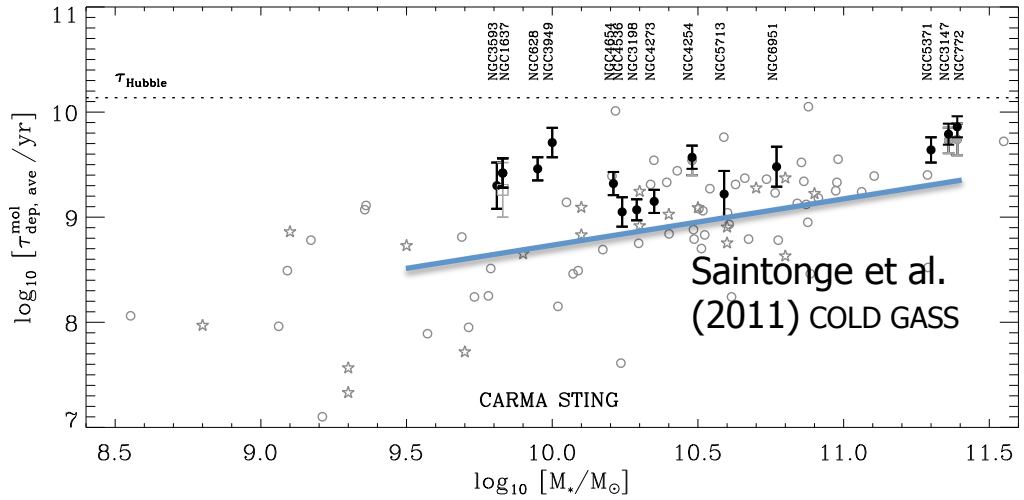
(Rahman, Bolatto, Wong, Leroy, Rosolowsky, Blitz, et al. 2010)

The SLF throughout the blue sequence

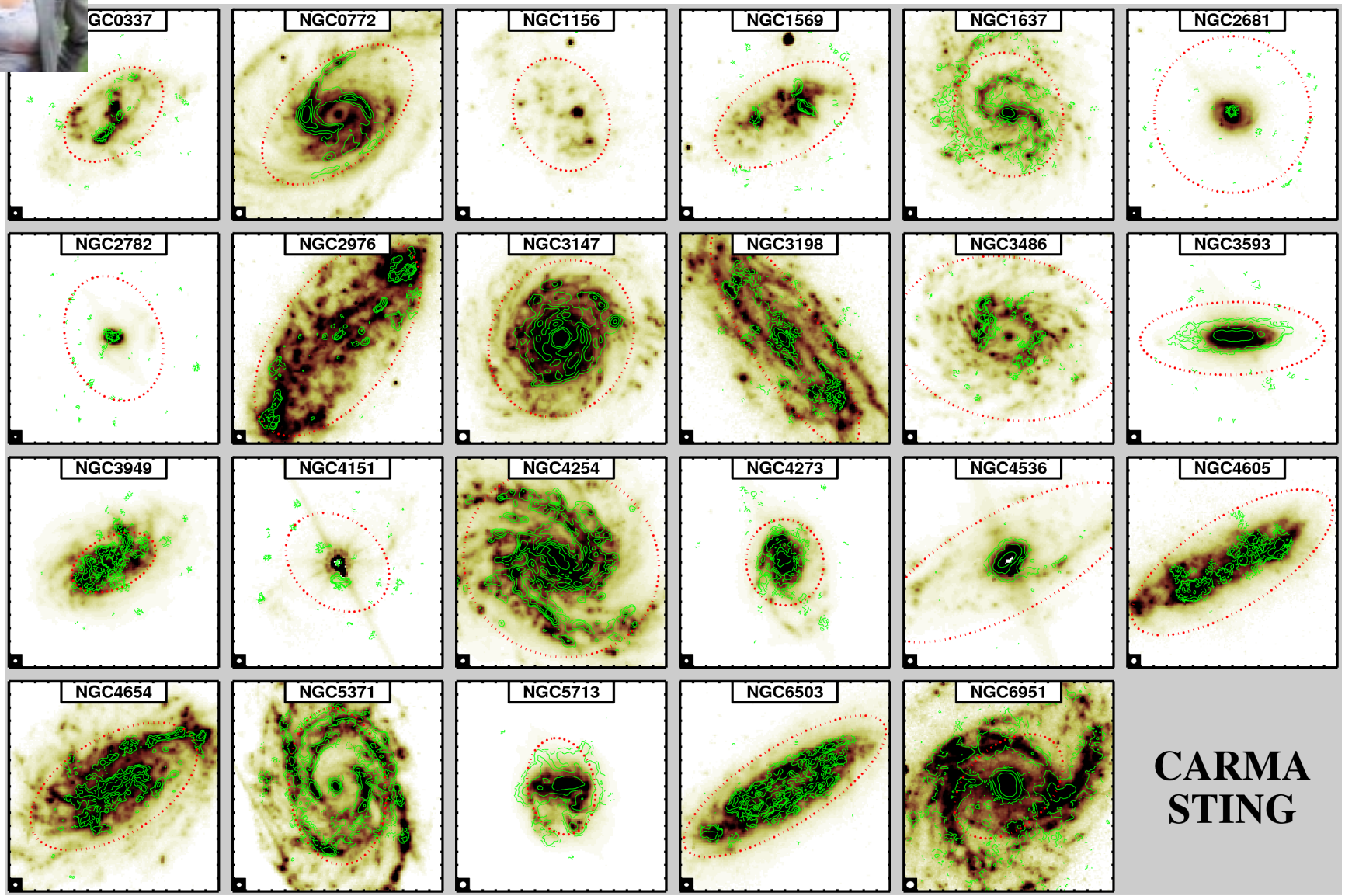
- The resolved relation between SFR and H_2 is approximately linear and independent of galaxy mass
- A molecular depletion time τ_{dep}~2 Gyr is good for the entire galaxy mass range surveyed
- Uptick at high M_*?
- Note difference with unresolved measurements

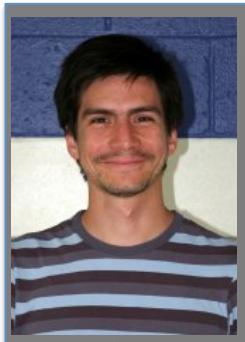
Rahman et al. (2011)





Relation between CO and mid-IR, particularly PAHs

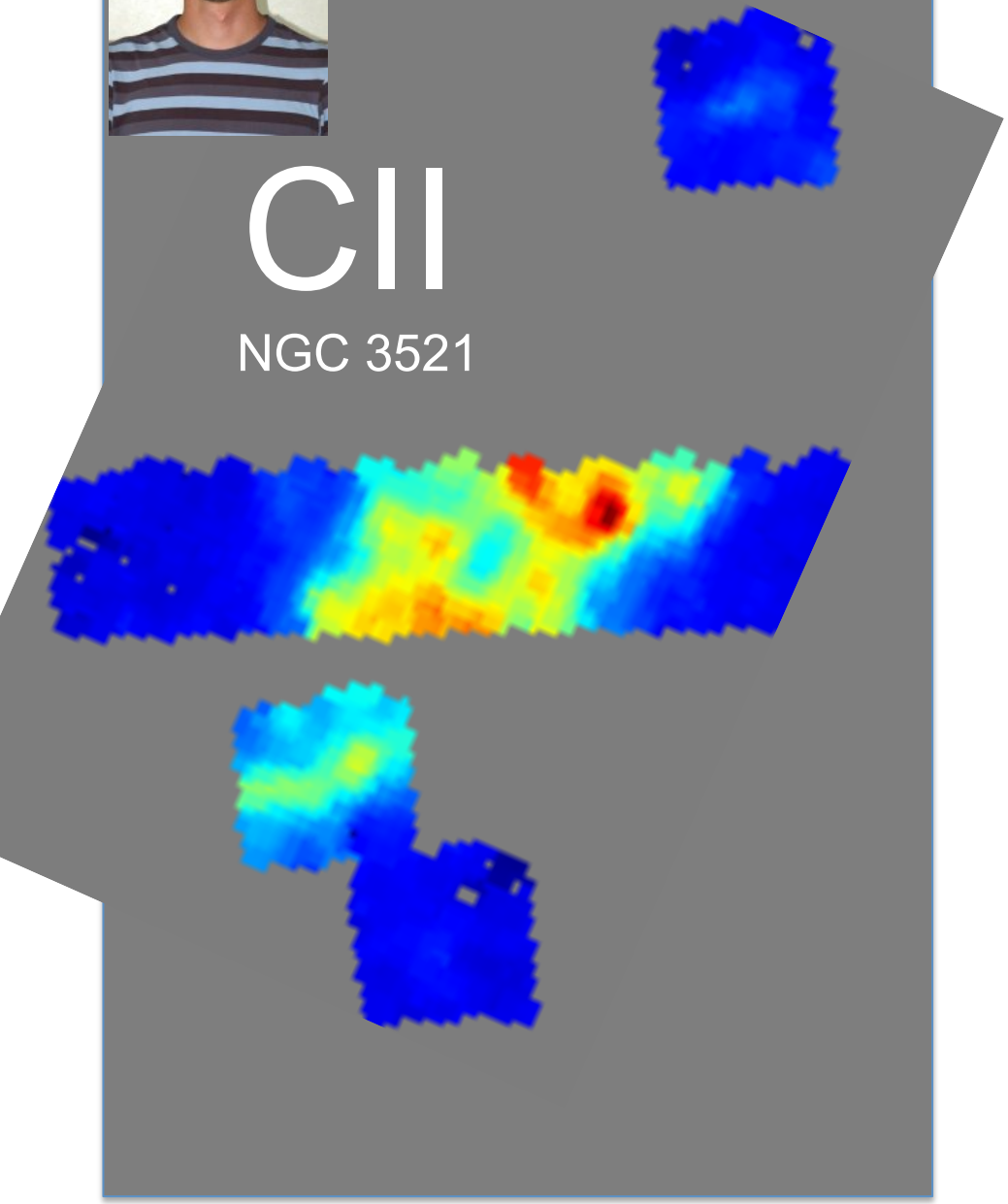


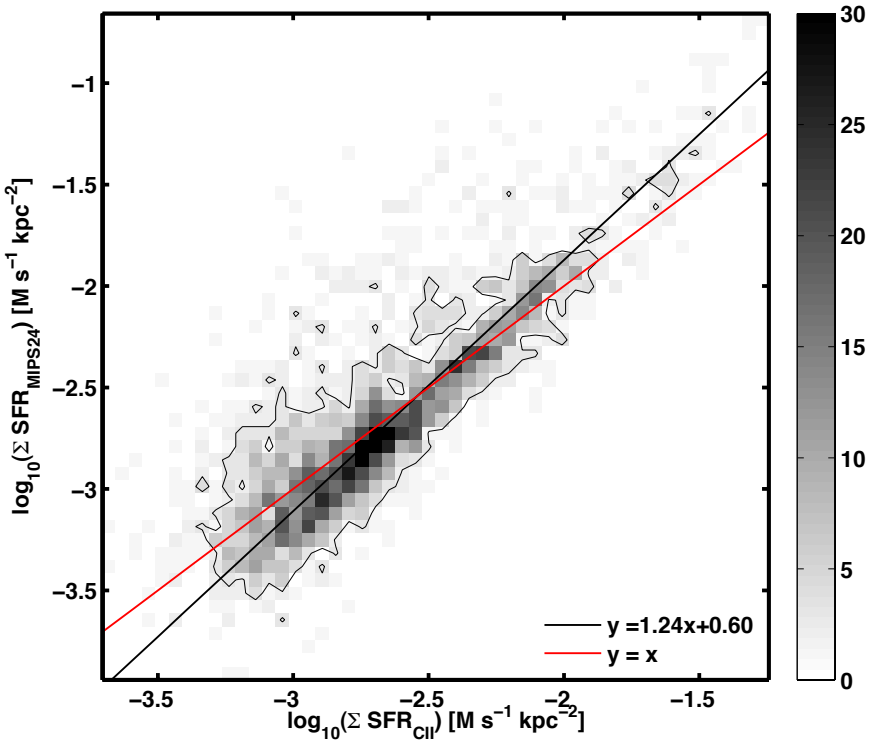


SFRs at high-z

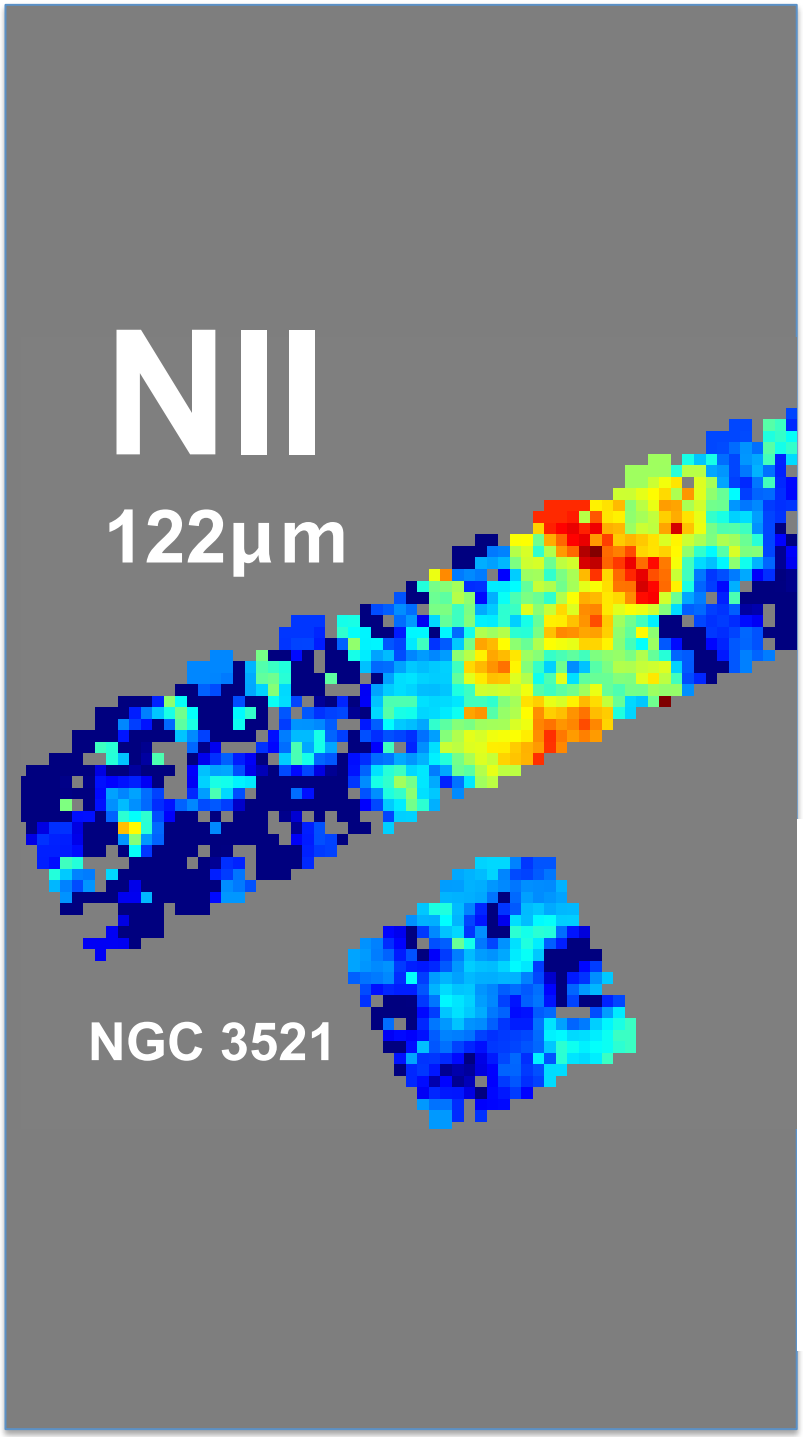
CII

NGC 3521





- Composite from 20 KINGFISH galaxies
- [CII] and 24 μm have almost precisely the predicted relation assuming
  - -continuous SFR
  - -20 Myr or older population
  - -3% photoelectric heating efficiency
- Failures? PAH charge? Link to dust properties



Ionizing Luminosity

McKee & Williams 1997

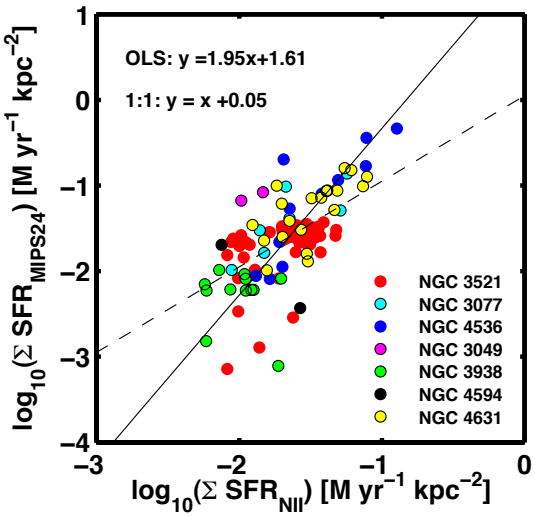
$$S'_T = \alpha_{\mathrm{H}}^{(2)} \left(\frac{L_{122\,\mu\mathrm{m}}}{h\nu_{122\,\mu\mathrm{m}}\, q_{122\,\mu\mathrm{m}} [\mathrm{N}^+]/[\mathrm{H}^+]} \right)$$

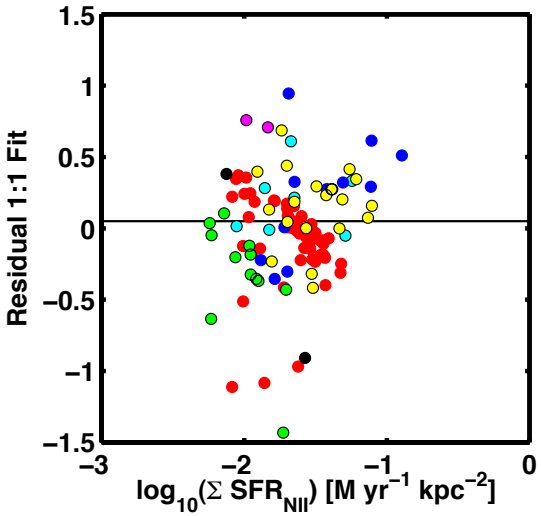
$q_{122\mu m}$: excitation rate for the 122µm line

$q_{122\mu m}$ = 3.89e-8 for T = 7000K

$[N^+]/[H^+] = [N]/[H] = 6.9e\text{-}5$

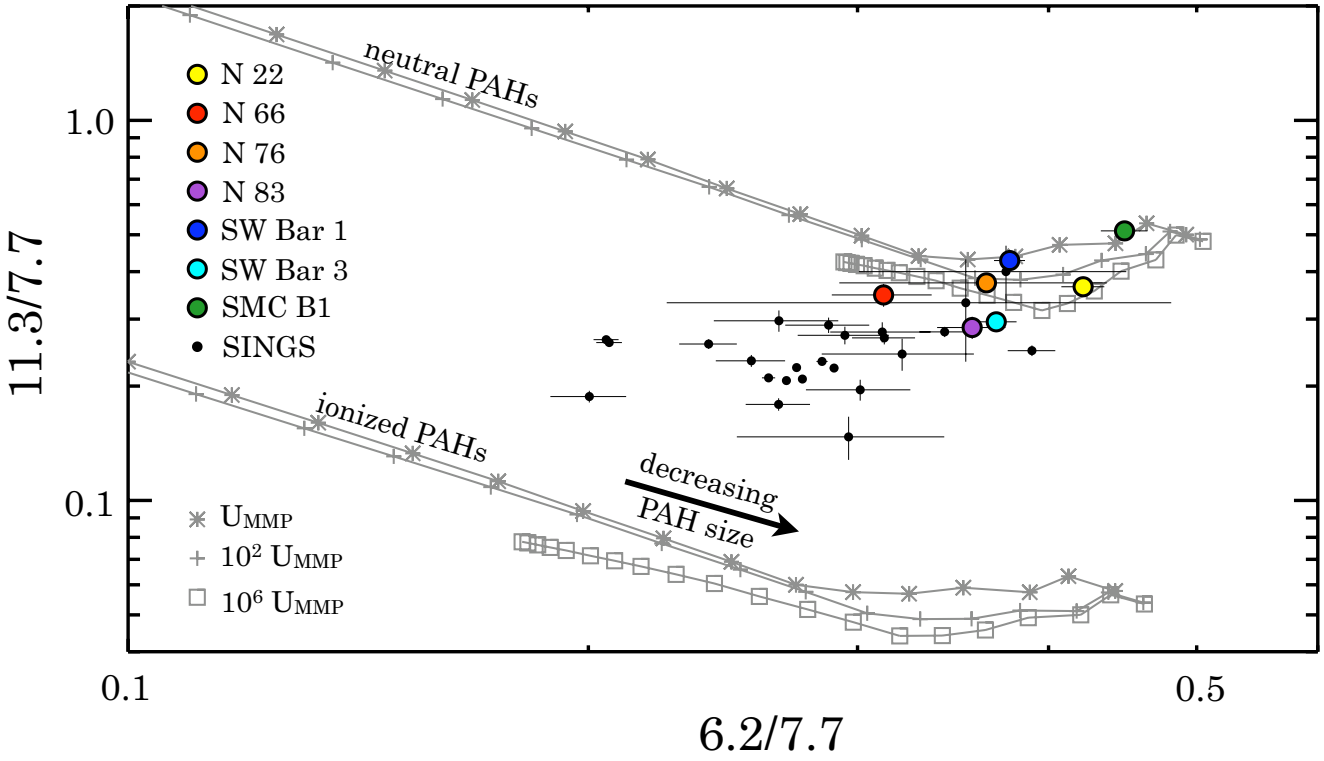
$\alpha^{(2)}_H$ = 3.57e-13





Heating efficiencies at low metallicity

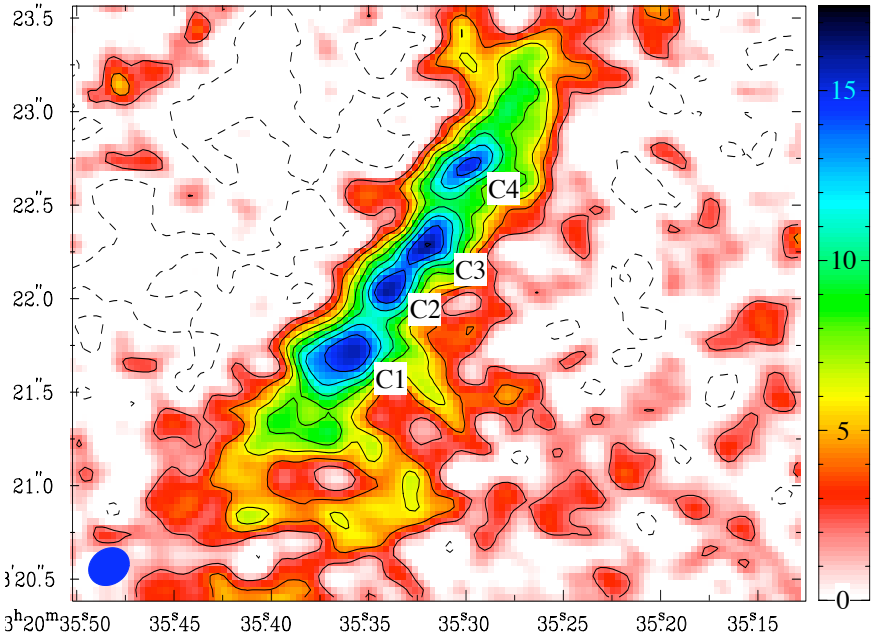
- PAHs are smaller and more neutral at low metallicity!
- Enhanced photoelectric heating? (Israel et al. 2011)

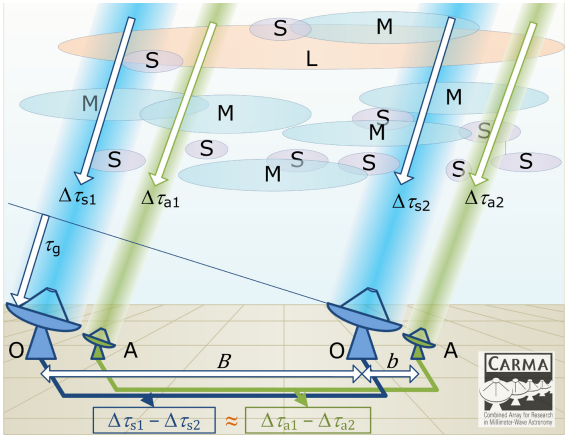


Sandstrom, Bolatto, et al. (2011)

Resolving GMCs in ULIRGs?

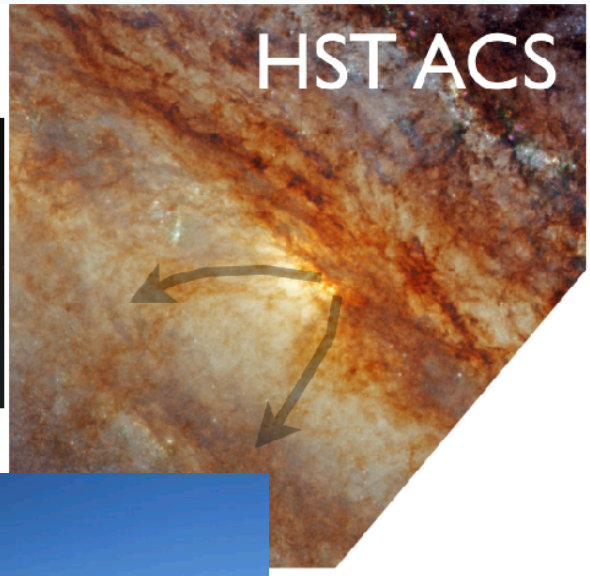
Arp 193: CO 2-1 at 0.15” (Zauderer, Bolatto, et al., in prep.)

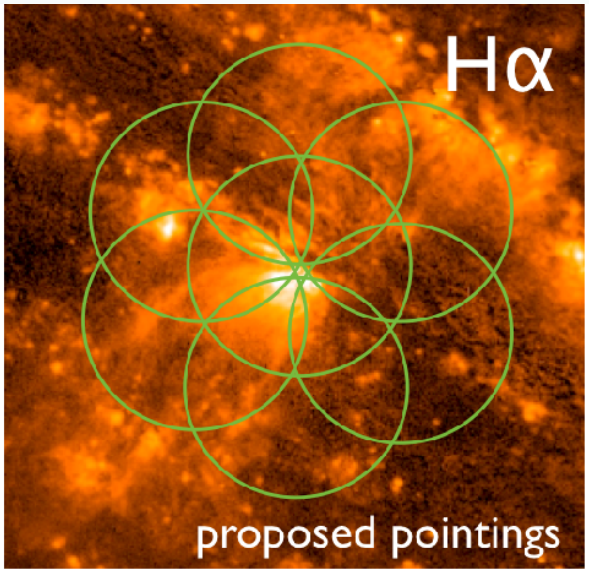


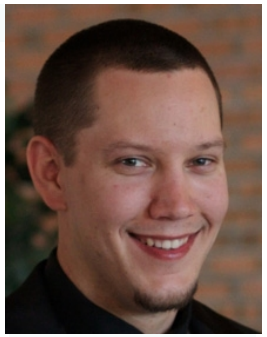


- Using atmospheric phase correction CARMA can reach 0.15” resolution at 1.3 mm (2km baselines)
- That is 70 pc at 100 Mpc!!!
- GMCs are 20-50 pc in size for the MW. We are not that far from resolving them.
- Σ_{H2} ~ 5,000 Mo/pc^2
- ALMA will be able to pin down GMC properties across a range of galaxy types
- ALMA cycle0 time for GMC properties in NGC253!

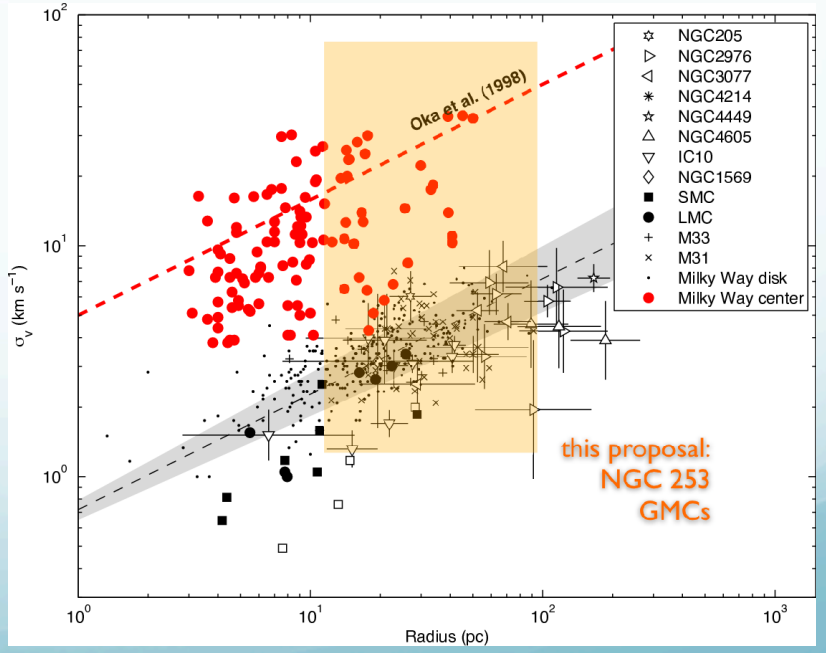
NGC 253: optical





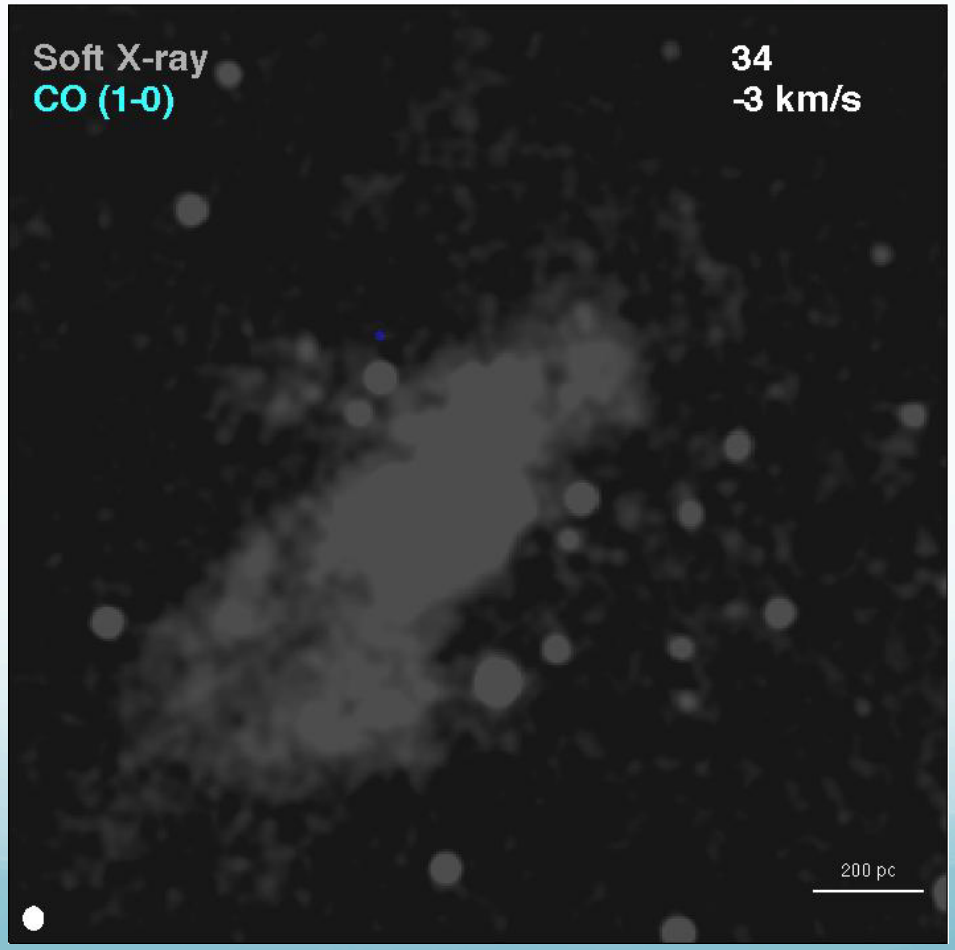


- Study of the central starburst in NGC253
  - GMC properties: are GMCs different?
  - Origin of the wind



Bolatto, Walter, Leroy, Scoville, Ott, Weiss, Zwaan, Veilleux, Ostriker

NGC 253, the nearest circumnuclear starburst



Bolatto, Walter, Leroy, Scoville, Ott, Weiss, Zwaan, Veilleux, Ostriker

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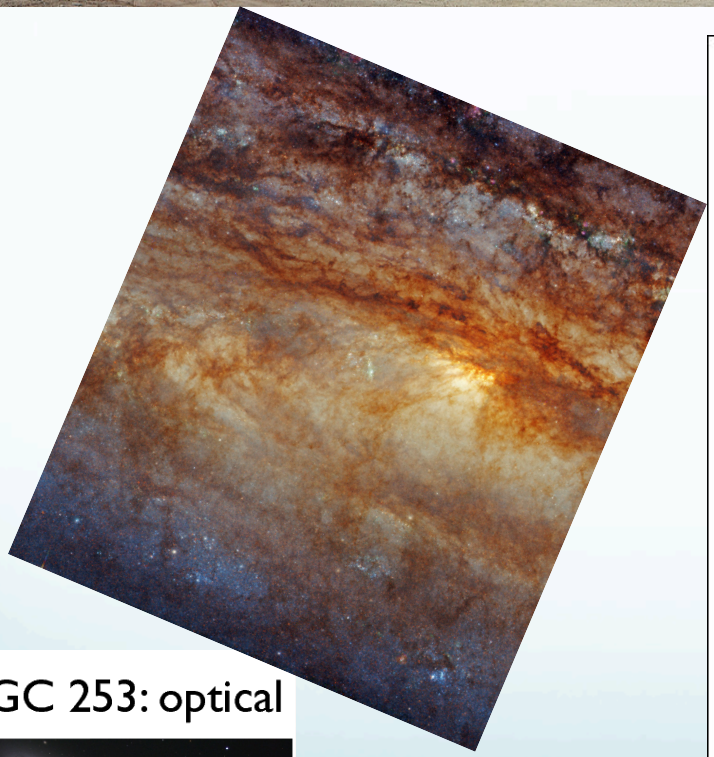
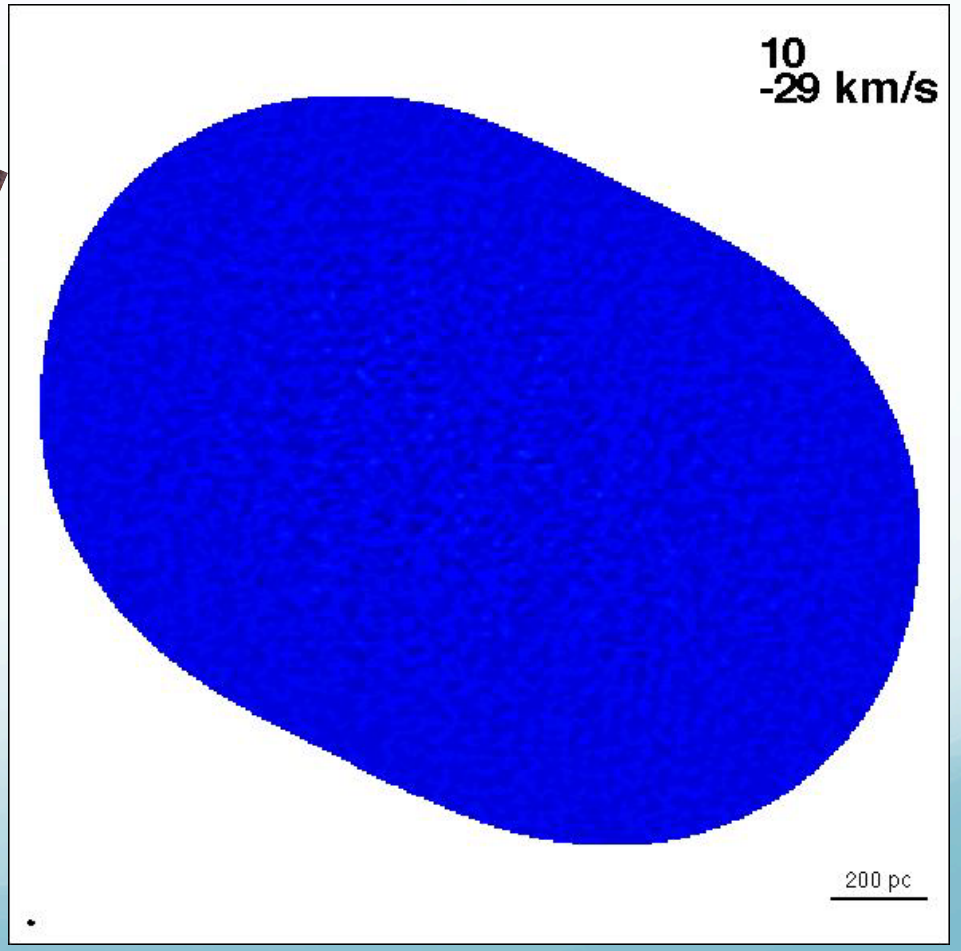


NGC 253: optical



Opportunities for students

- CARMA STING (Nearby Galaxies)
  - Star formation law (PI)
- KINGFISH (Nearby Galaxies)
  - FIR spectroscopy and imaging
  - Submm spectroscopy
- HERITAGE (Magellanic Cloud science)
  - FIR spectroscopy for SMC submitted (PI)
- IRAM LP (z~1-2 Medium Redshift)
  - EVLA program (PI)
- ALMA!
  - PI in cycle 0/1 project: the center of NGC 253
  - ISM physics at z=6.4? Follow up of GRB hosts?
  - Partnership with PUC