Nearby Galaxies

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Far Infrared Astronomy from Space, Pasadena (CA), May 28-30, 2008

Definition of -Nearby-

Any galaxy closer than ~15-30 Mpc

This defines a Volume of Universe (~30-60 Mpc in diameter) comparable to that probed by some of the famous deep fields:

- GOODS at z~3 has comoving size ~28 Mpc

- COSMOS at z~0.7 has comoving size ~80 Mpc

Outline

- Introductory rambling….
- Upcoming facilities and what will they address; what not?
- What do we need to address the open questions?
- Conclusions

The Burning Questions

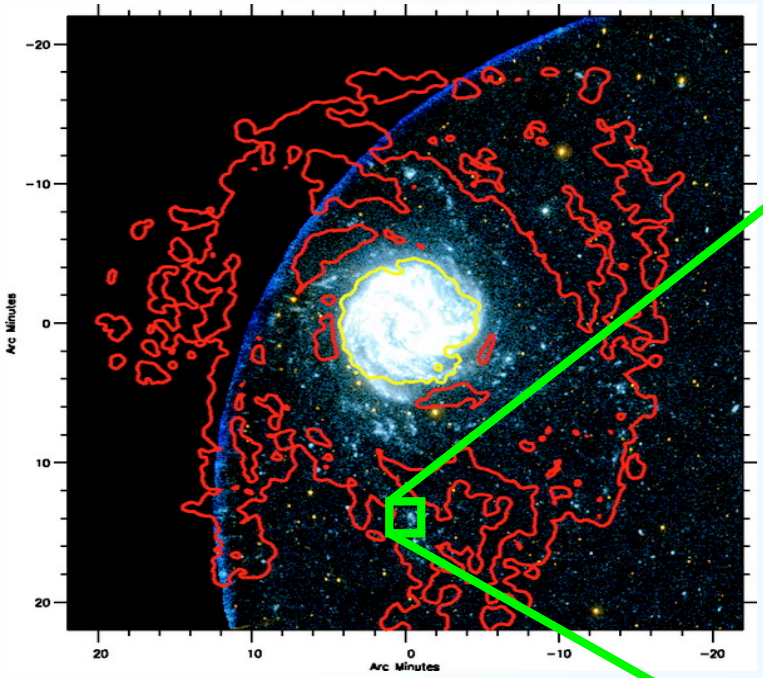
How do stars, gas, dust cycle in galaxies?

- star formation; measurement, phases, relation to gas/dust
- gas phases, evolution, enrichment
- heating of dust; physics of dust
- galaxy transformations; morphology, bars, interactions, etc.
- AGN role(s) [BH-bulge mass relation]

How does the cycling occur at the interface of galaxies and IGM?

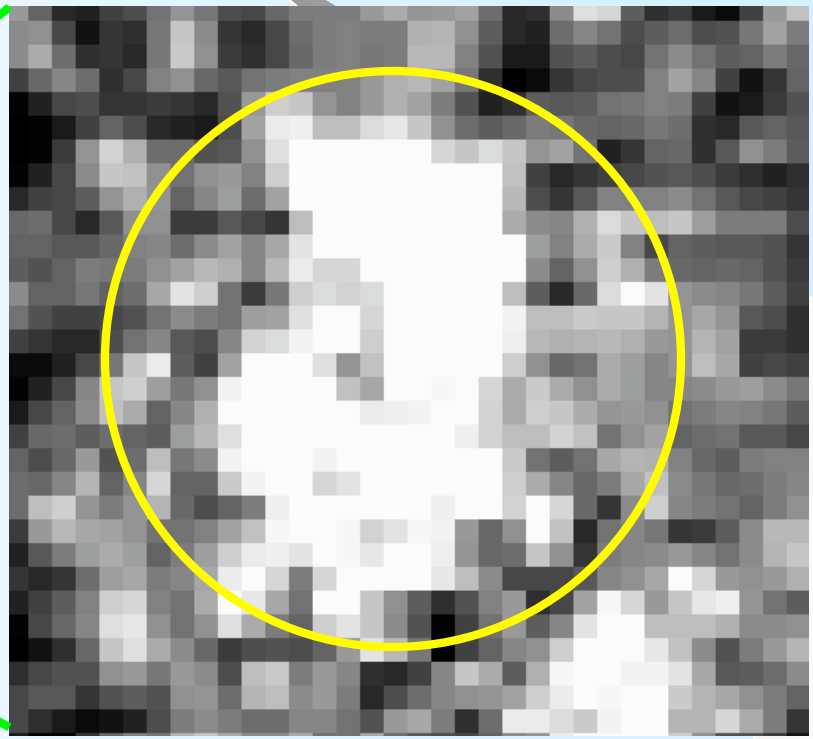
- mechanical, luminous, chemical feedback (stellar and AGN)
- gas accretion

Angular Resolution - 1



Thilker et al, 2005

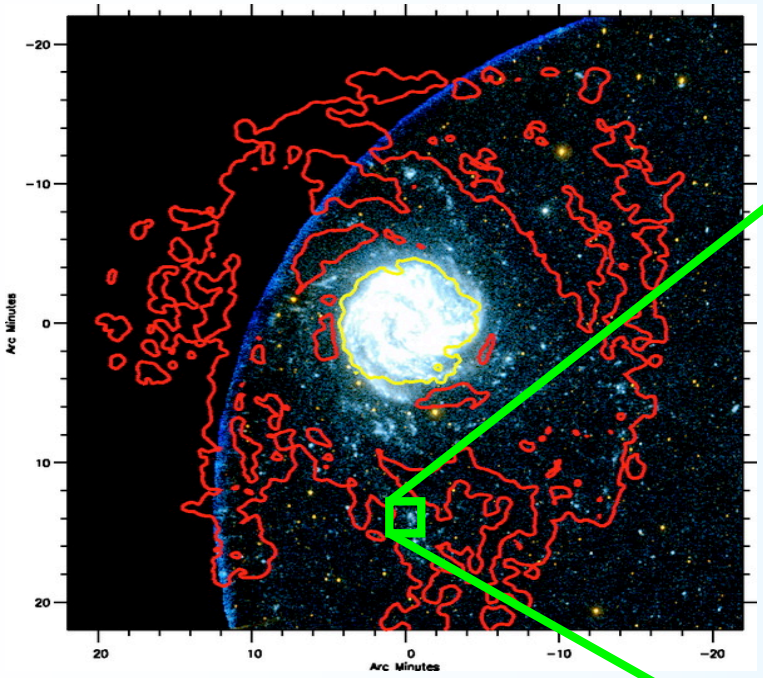
M83 - GALEX



Resolution ~ 5”, similar to Spitzer/24 and Herschel/75

How do I infer that these are stellar clusters, how many, their stellar population content? (degeneracies: dust, metallicity, age, etc.)

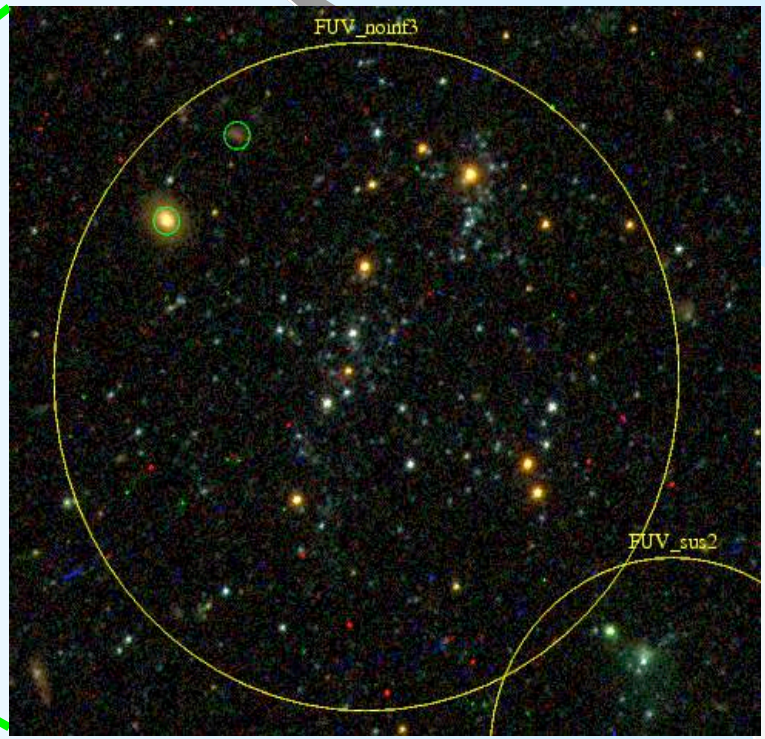
Angular Resolution - 2



Thilker et al, 2005

M83 - HST/ACS

Thilker et al.

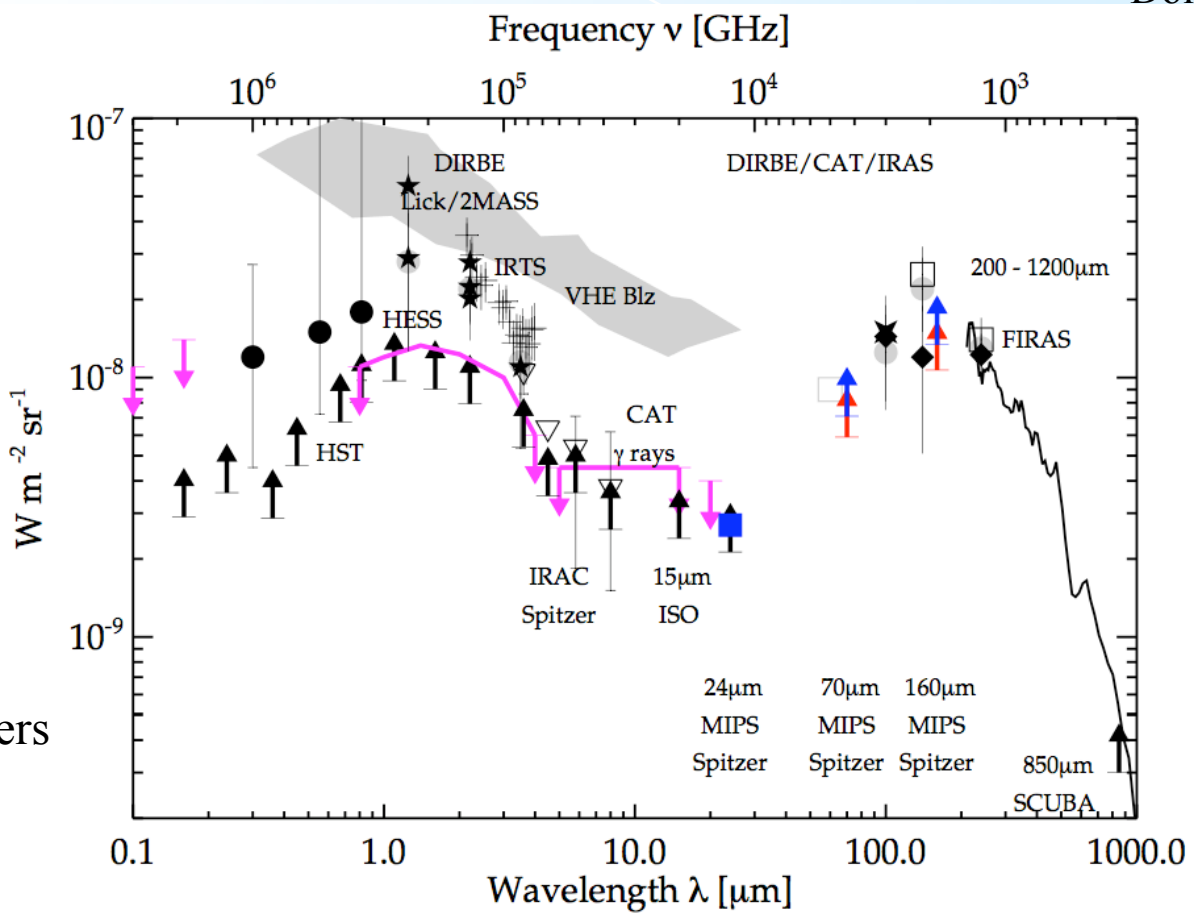


Resolution ~ 0.1”

I rest my case.

Interest in the FIR

Dole et al. 2006



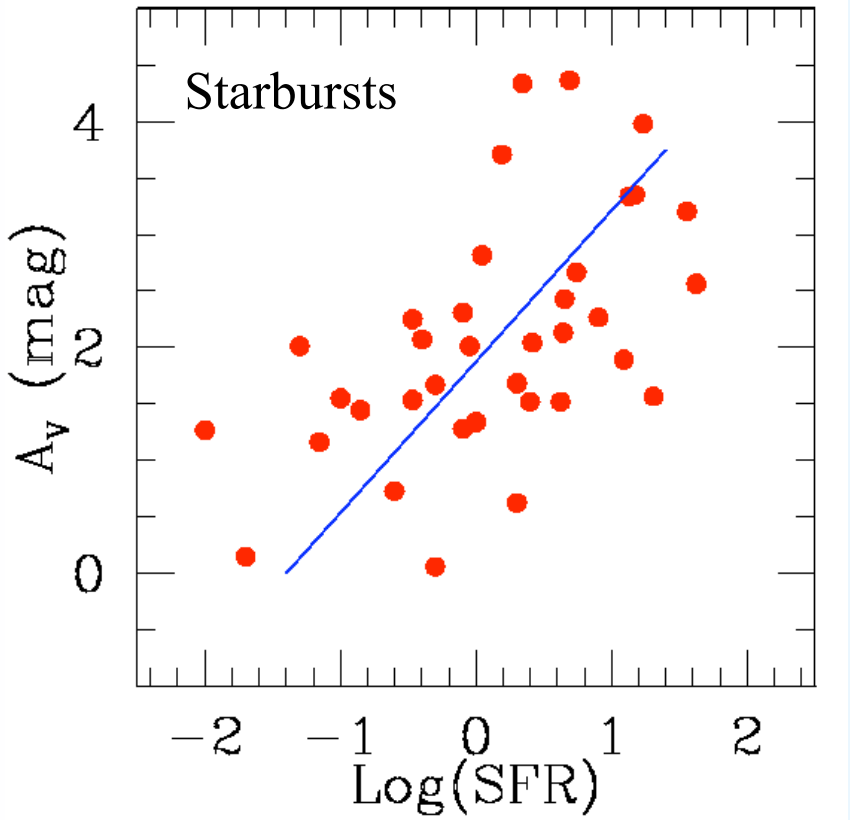
Point made by Soifer and others in earlier talks

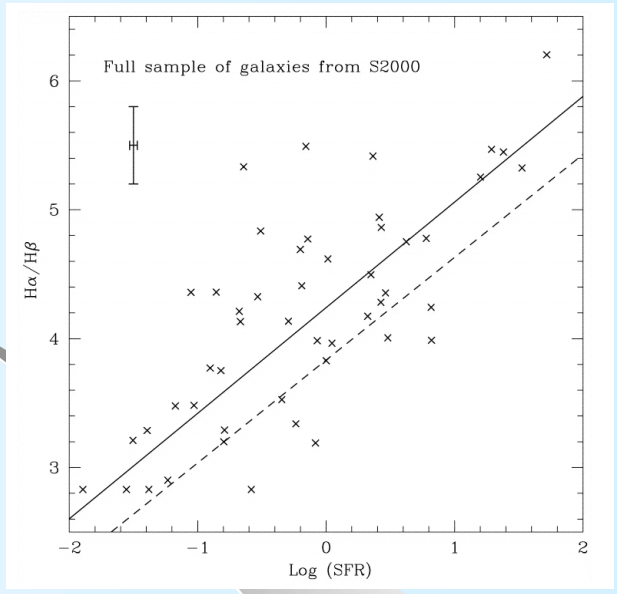
About 80% of UV light (tracer of SF) is absorbed by dust; AGNs are also heavily dust-absorbed.

SFR-Extinction

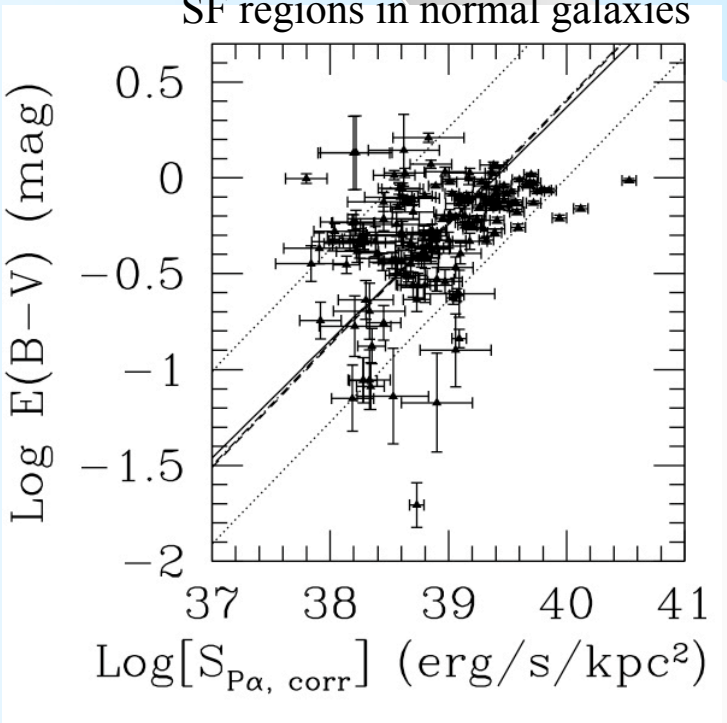
(Wang & Heckman, 1996; Heckman et al. 1998; Calzetti 2001
Hopkins et al. 2001, Sullivan et al. 2001, C. et al. 2007)

Strongest SF systems tend to be the most dust obscured; need for IR.



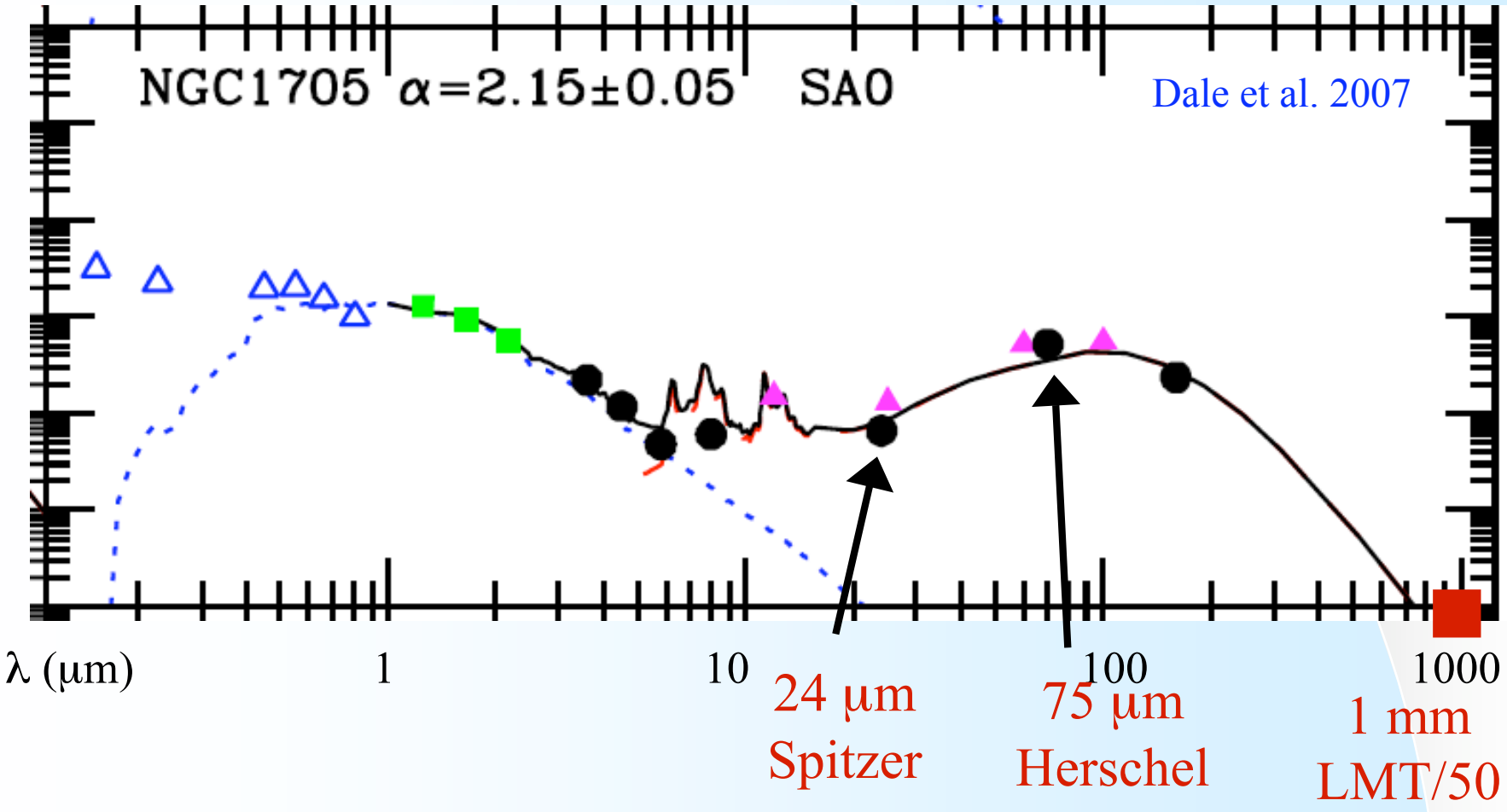


SF regions in normal galaxies



Upcoming Facilities, and what will they address. And what not.

Synergy: Spitzer/Herschel/LMT

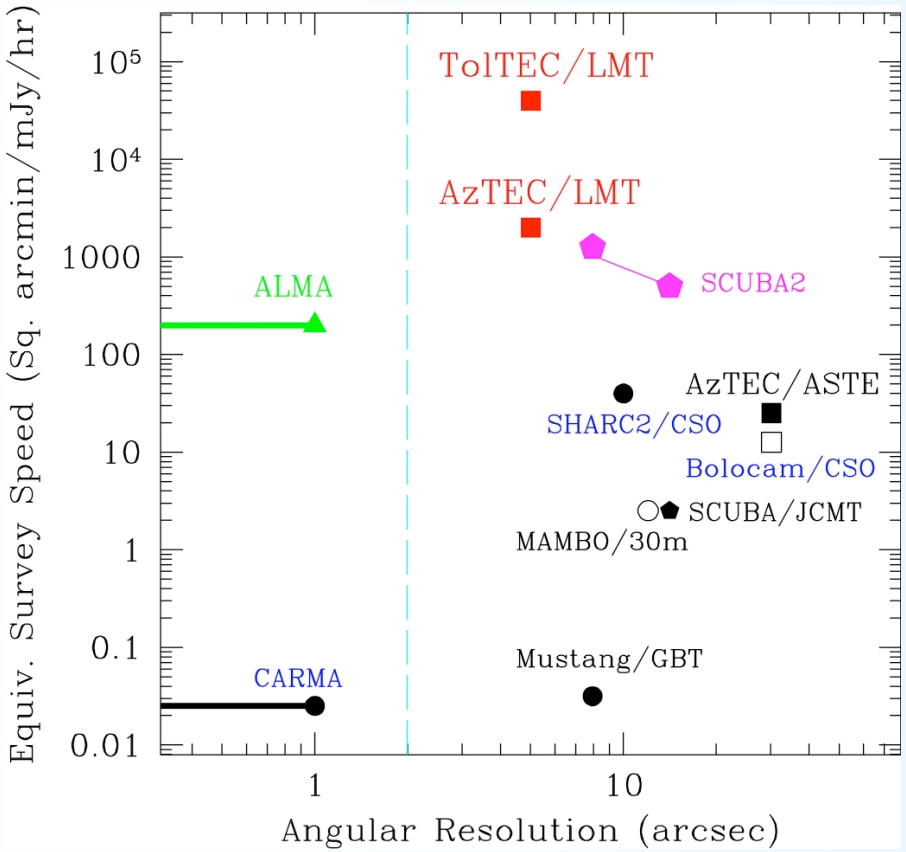


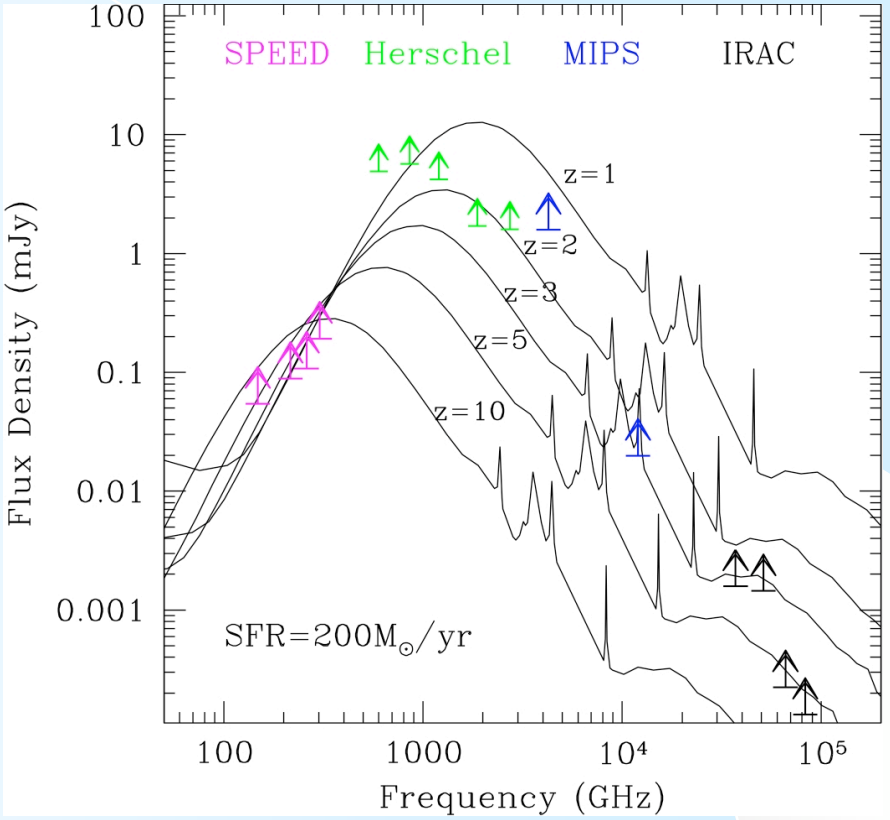
Angular resolution ~ 5-6 arcsec

The Large Millimeter Telescope

- UMass-Mexico (INAOE) collaboration
- Single-dish 30/50 m antenna; 2.5 m secondary
- 4'-8' non-aberrated FOV; 5" resolution at 1 mm
- ~1-4 mm science: cold dust emission, CO, HCN, etc.
- Expected first *science* light ~ October 2008
- Accessible to broad US community

LMT `Discovery Space'





Yun et al. 2008 (priv. comm.)

KINGFISH:

Key Insights on Nearby Galaxies: a Far Infrared Survey with **Herschel**

R. Kennicutt (PI), D. Calzetti (Deputy-PI, US-PI), Phil Appleton, Lee Armus, Alberto Bolatto, Bernard Brandl, Daniel Dale, Bruce Draine, Charles Engelbracht, Karl Gordon, Brent Groves, Joannah Hinz, Leslie Hunt, Jin Koda, Oliver Krause, Adam Leroy, Eric Murphy, John Richer, Hans-Walter Rix, Helene Roussel, Marc Sauvage, Eva Schinnerer, JDT Smith, Laurent Vigroux, Fabian Walter, Brad Warren, Christine Wilson, Mark Wolfire

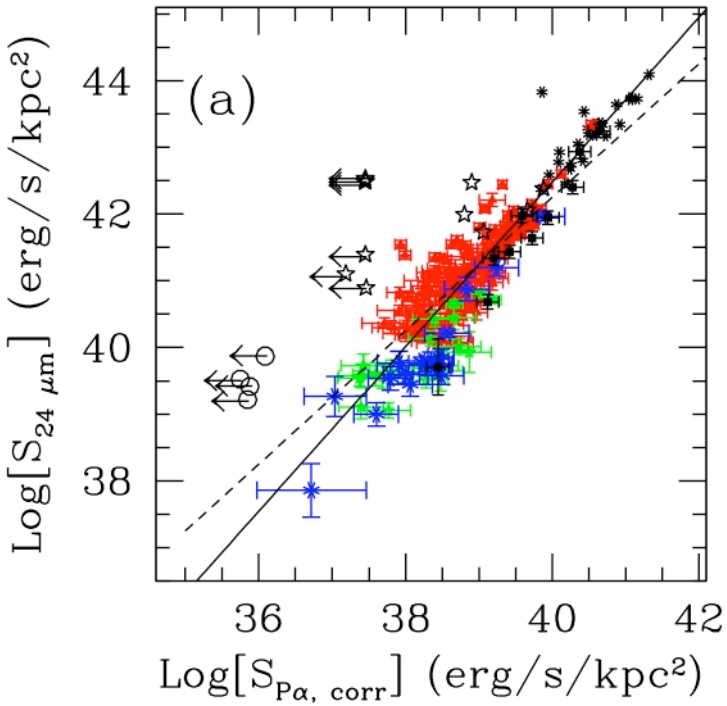
Approach:

- Over 500 hours of approved Herschel time, to image 61 nearby galaxies at 75, 110, 170, 250, 350, and 500 μm, and obtain low-res spectroscopy in [OI]63μm, [OIII]88μm, [NII]122,205μm, and [CII]158μm.
- The sample, representative of morphologies, luminosities, and IR/optical ratios of local Universe galaxies, is mainly drawn from SINGS

Core Science Objectives:

- Derive robust SFR tracers in the long wavelength regime (~near the IR peak)
- Model dust heating and emission in galaxies
- Probe the nature/origin of extended cold dust envelopes; link warm-cold dust emission
- Understand the physical underpinning of the IR-radio correlation
- Probe the ISM physical properties, and understand the metal abundance scale.

SFR Measures



Red: High Metallicity SF regions
Green: Medium Metallicity SF regions
Blue: Low Metallicity SF regions
Black filled symbols: Low Met SBs and LIRGs

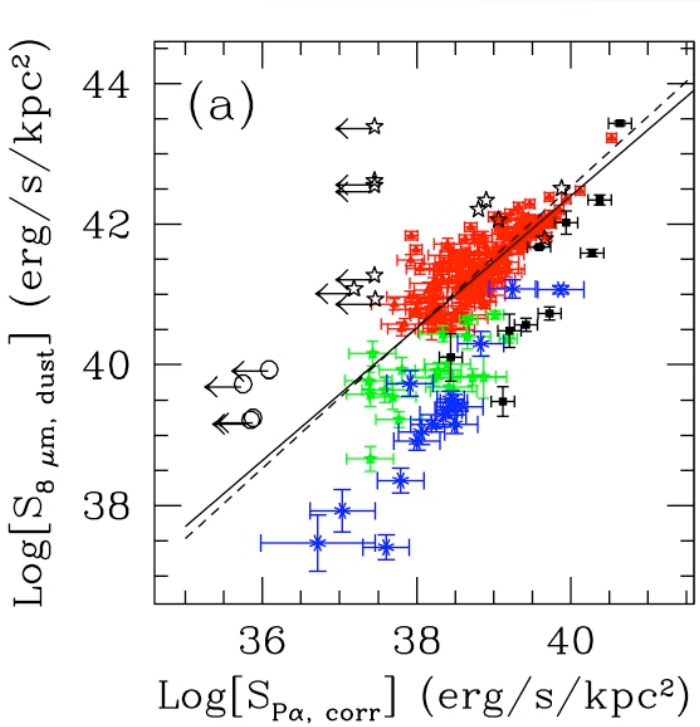
Spitzer/24 provides `sufficient' angular resolution (typical spatial scale ~ 0.5 kpc) to derive mid-IR SFR calibrations:

$$SFR(M_o\ yr^{-1}) = 1.27 \times 10^{-38}\ [L_{24}(erg\ s^{-1})]^{0.885}$$

Herschel (via KINGFISH, HerMES, and other programs) will provide comparable data to test longer wavelength monochromatic emission, ~near the IR peak, as SFR indicators.

C. et al.2007, Alonso-Herrero et al. 2006, etc.

Aromatic Features in Emission



Red: High Metallicity SF regions
Green: Medium Metallicity SF regions
Blue: Low Metallicity SF regions
Black symbols: Low Met Starbursts

C. et al.2007

Proposed as SFR tracer (Roussel et al. 2001, Forster-Schreiber et al. 2004; high-z studies), but found to:

- depend on metallicity (Boselli et al. 2004, Engelbracht et al. 2005)
- depend on strength of local radiation field (Helou et al. 2004, Madden et al. 2006)
- suspected to be sensitive to heating by older stellar populations (Haas et al. 2002, C. et al. 2007, Bendo et al. 2008)

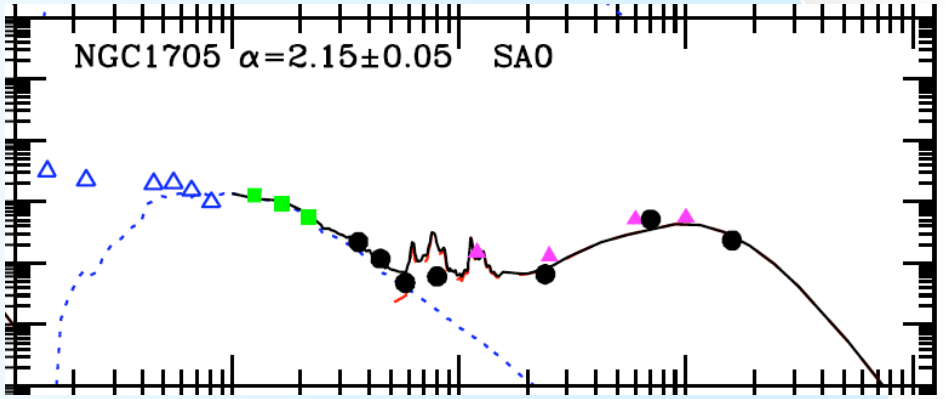
Herschel will provide better angular resolution to test the latter point.

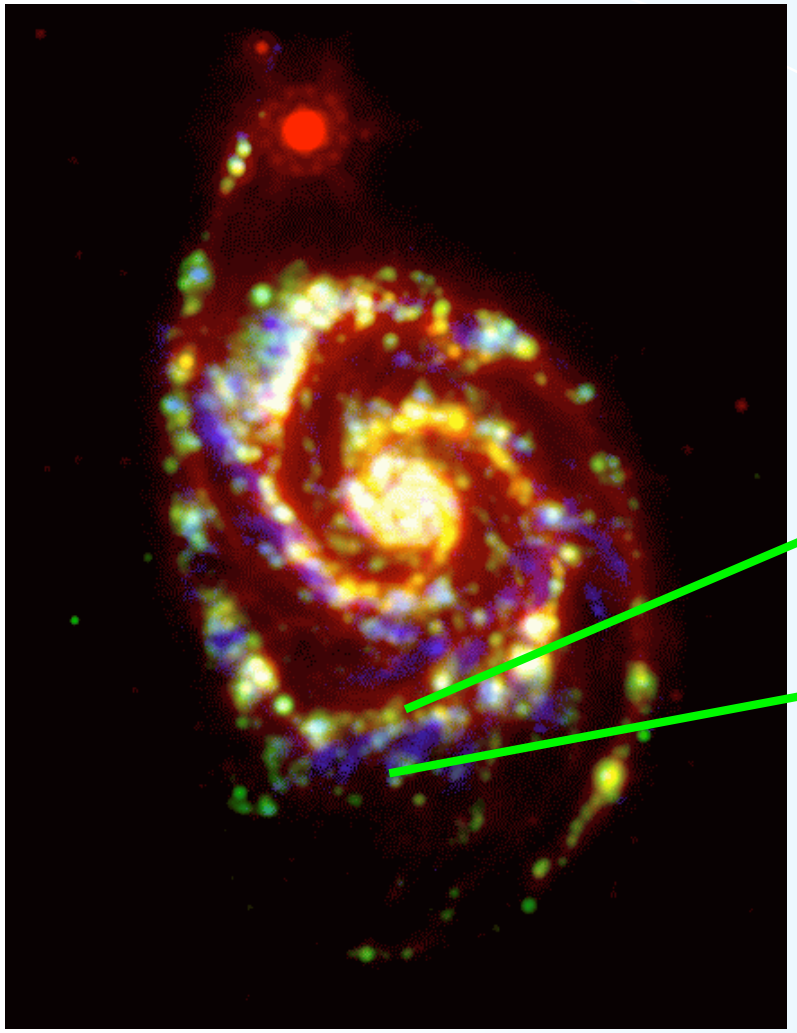
However, Spitzer and Herschel will not provide insights into the detailed relation between the PAH heating and the heating sources.

Open Questions

- The ~kpc resolution of Spitzer/Herschel integrates over stellar populations and dust components, thus association between heaters and emitters is challenging.
  - How is the dust emission (e.g., temperature) dependent on the heating population? And on the local conditions (ISM)?
  - How do we constrain dust composition and grain size distribution?
  - What are the masses and emissivity(ies) of the dust? [in and outside galaxies]
  - What is the duration of the dust-enshrouded SF phase? What its census? How does it depend on the local environment (disk/nuclei, local ISM, etc.)?
    - Duty cycle(s) of SF?

Want predictive power for stellar pop+ISM mix, to inform high-z studies.

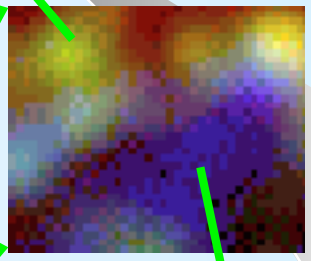




M51, UV(GALEX)+Hα+24(Spitzer)

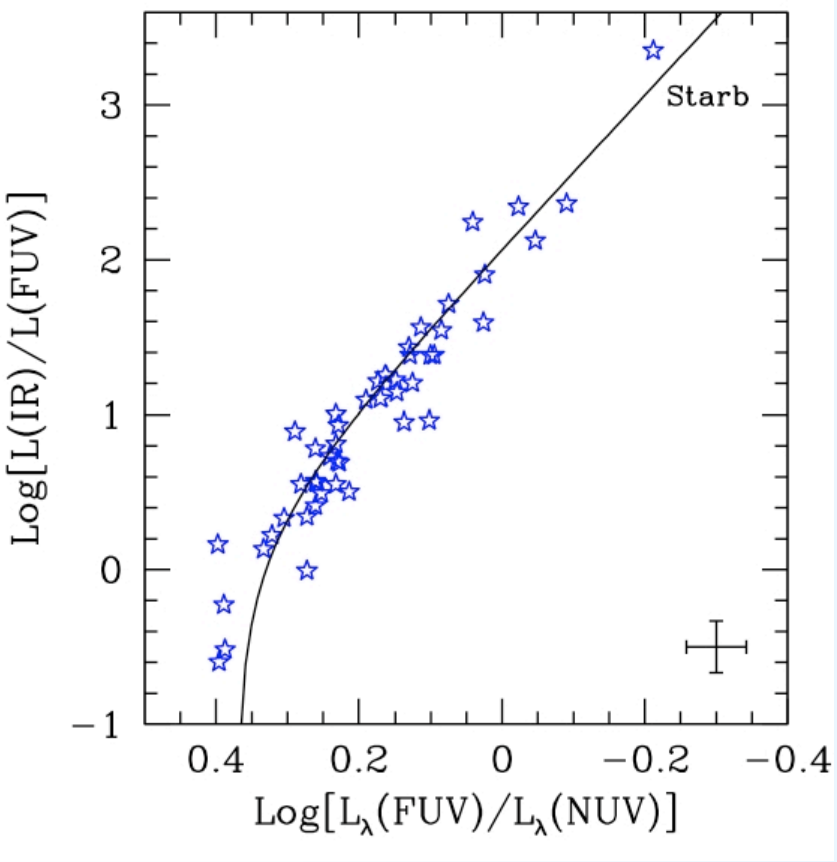
?

In the IR we still miss the `Hubble effect' that has produced the paradigm shift of galaxies from `blob collections' to fossil records of galaxy evolution!



HST/ACS

Impact

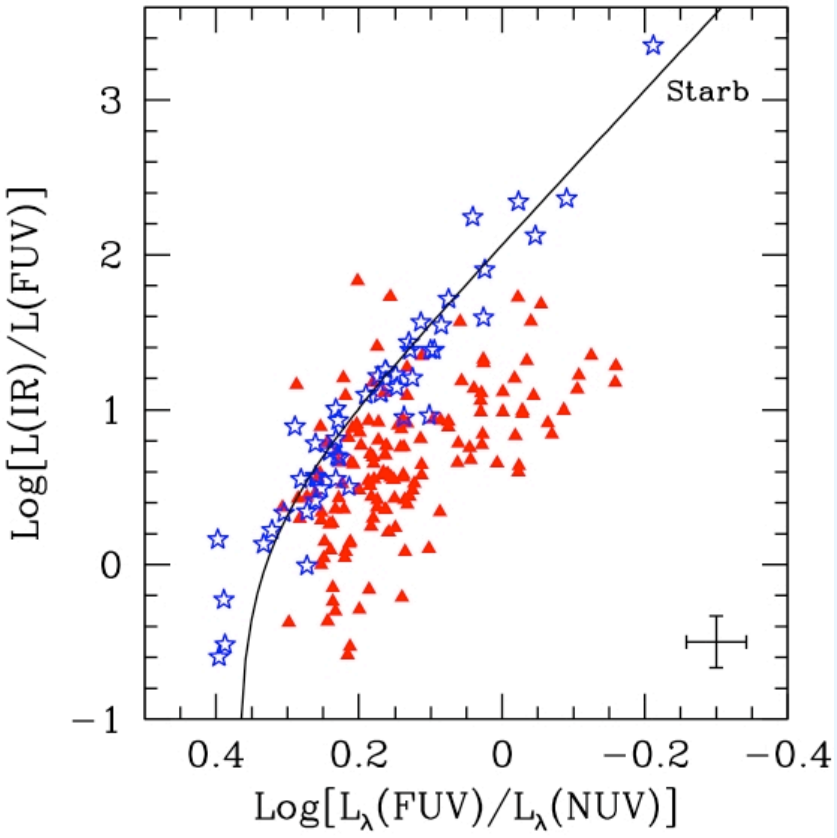


(Meurer et al. 1999, C. et al. 2000, C. 2001)

Offers useful leverage for recovering the full UV emission (SFR) at high z.

However….

Impact



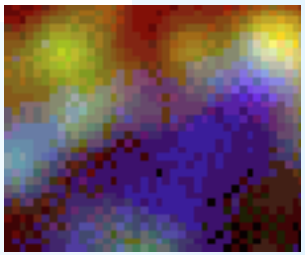
(Meurer et al. 1999, C. et al. 2000, C. 2001)

Offers useful leverage for recovering the full UV emission (SFR) at high z.

However….

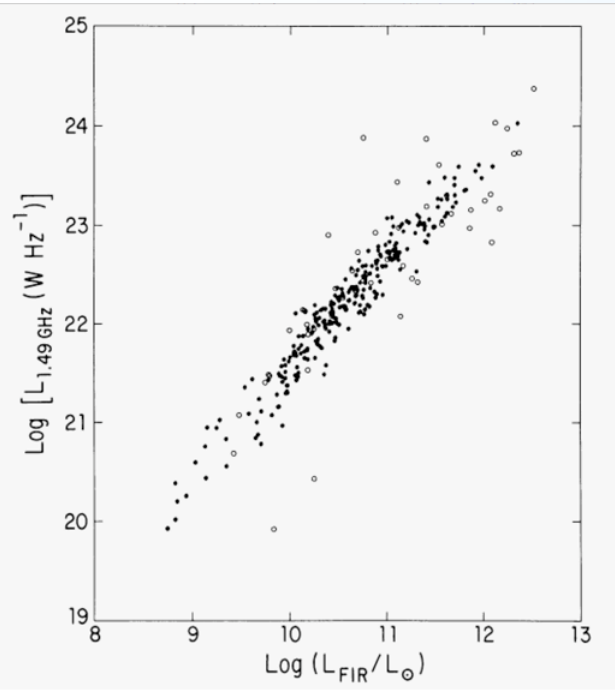
Normal SF galaxies and regions follow same trend with ~1 dex spread (Buat et al. 2002, 2005, Bell 2002, Gordon et al. 2004, Xu et al. 2004, C. et al. 2005, Seibert et al. 2005):

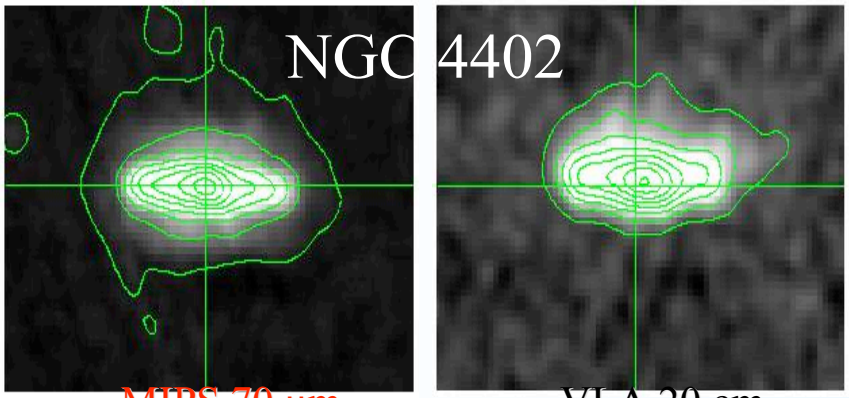
Intrinsic UV `recovered' with 1 dex uncertainty…



Age?
Geometry?
Need to `resolve' HII regions in IR

The FIR-Radio Correlation





MIPS 70 μm

VLA 20 cm

What is the underlying physics of the FIR-radio correlation?

From Spitzer data (Murphy et al. 2006), radio images are smoother versions of FIR images. Kernel lengths prop to SFR/area.

`Age effect': CR electrons in more recent SF events have not diffused significantly.

Clearly, SF involved. However, how are different processes, heating of dust and propagation of CRs, related over 4-5 orders of magnitude?

Herschel will provide better leverage (~3-4X higher angular resolution -> sub-kpc scales).

The answer will come from HII-region-size resolved observations:

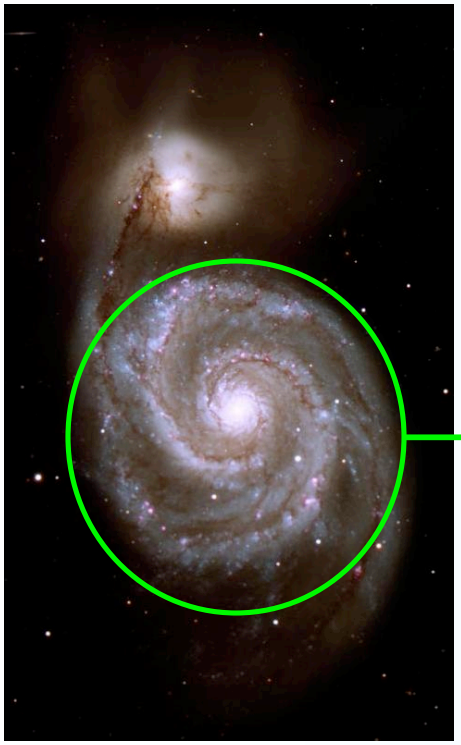
Radio: EVLA

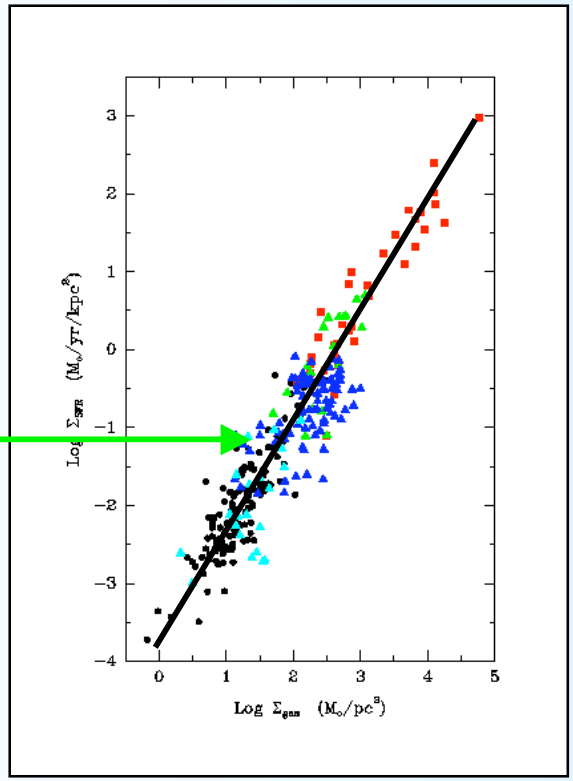
FIR: ?????

The Scaling Law of SF

In galaxies considered as a whole, the SFR scales with the gas surface density **(Kennicutt 1989, Kennicutt 1998, Kennicutt 2006)**:

$$\Sigma_{SFR} \sim \Sigma_{gas}^{1.4}$$





Questions:

Down to which scales?

Physical model?

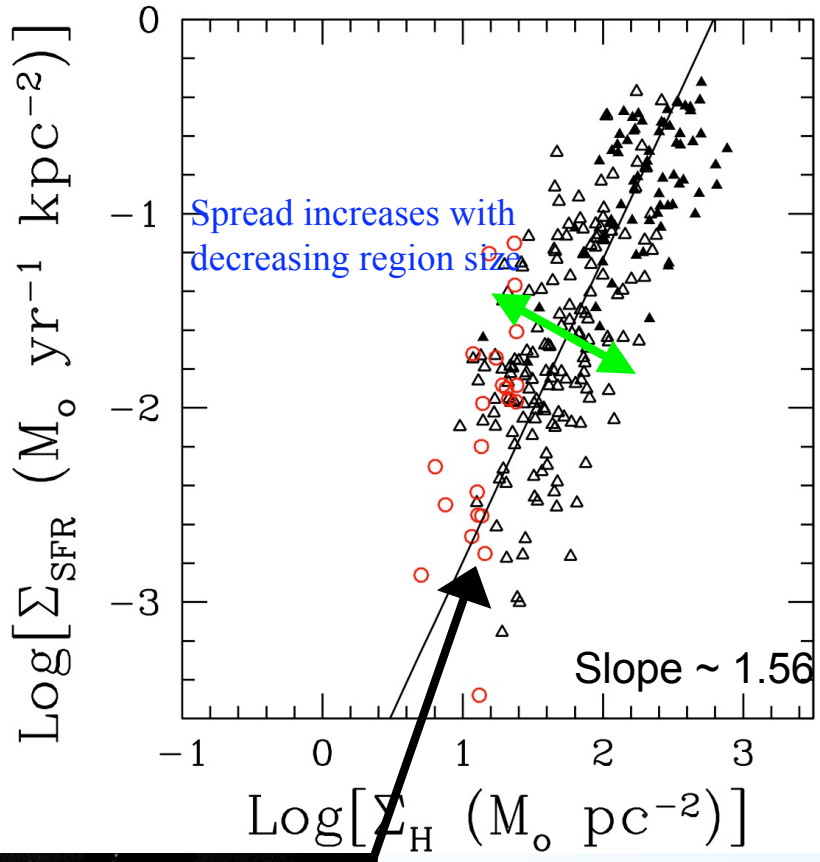
- local: $\rho_{SFR} \sim \rho_{gas}^{1.5}$
- global: $\rho_{SFR} \sim \rho_{gas} \Omega_r f(Q)$

Primary correlation?

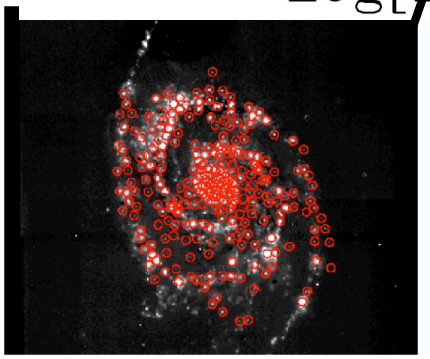
Gas, H_2, HCN, …

Thresholds?

Local (~0.5 kpc) Scaling Law



Kennicutt et al. 2007



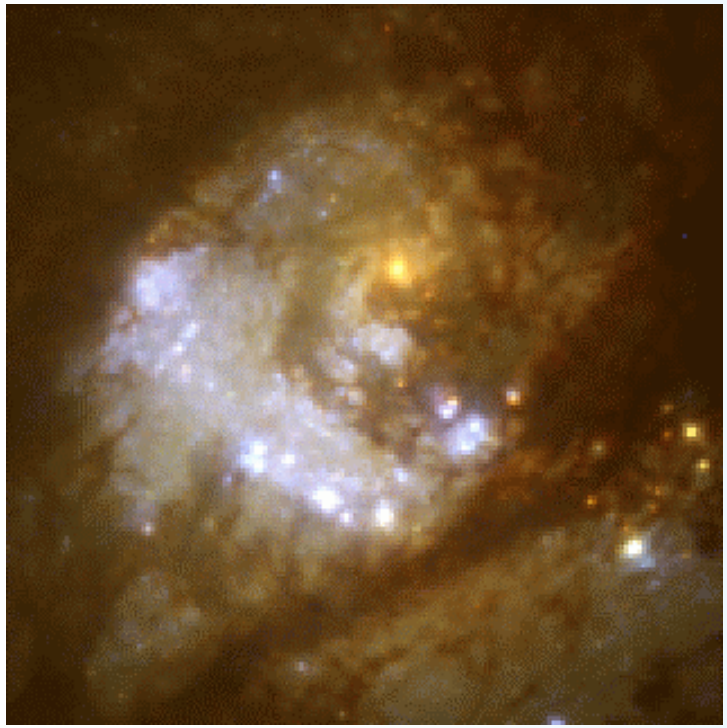
Spitzer, ground

For many of the outstanding questions, lack of adequate H_2 images is the main limitation

- Dominant dependence?
  - LMT, CARMA
- Environmental dependence? (interarm regions, etc.)
  - LMT
- Thresholds? (low SB galaxies; dwarf galaxies)
  - LMT
- H_2/CO conversion?
  - ALMA
- Break-down scale(s)? Dependence? Physical model?
  - ALMA; what about SFR?

Scales of Interest

In the crowded inner regions of galaxies, angular resolution becomes key to resolve individual gas and dust components, to compare them to the `resolved' stellar populations.



Center of M83, HST/WFPC2, 0.2"

Star forming regions are the fundamental `blocks' to investigate.

- An HII/SF region (~10 pc) at 10 Mpc distance subtends ~0.2"
- Freely taking a 30-m segmented telescope (from P. Stahl's talk), we get an angular resolution of 0.6" at 75 μm.

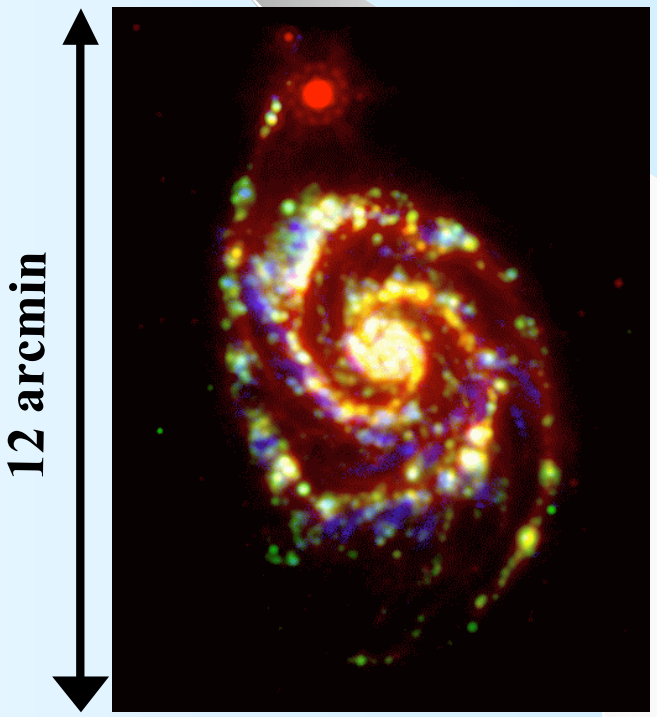
FOV/Mapping Speed - 1

When investigating nearby galaxies, angular resolution is not all.

Field-of-View/Mapping Speed is equally important!!

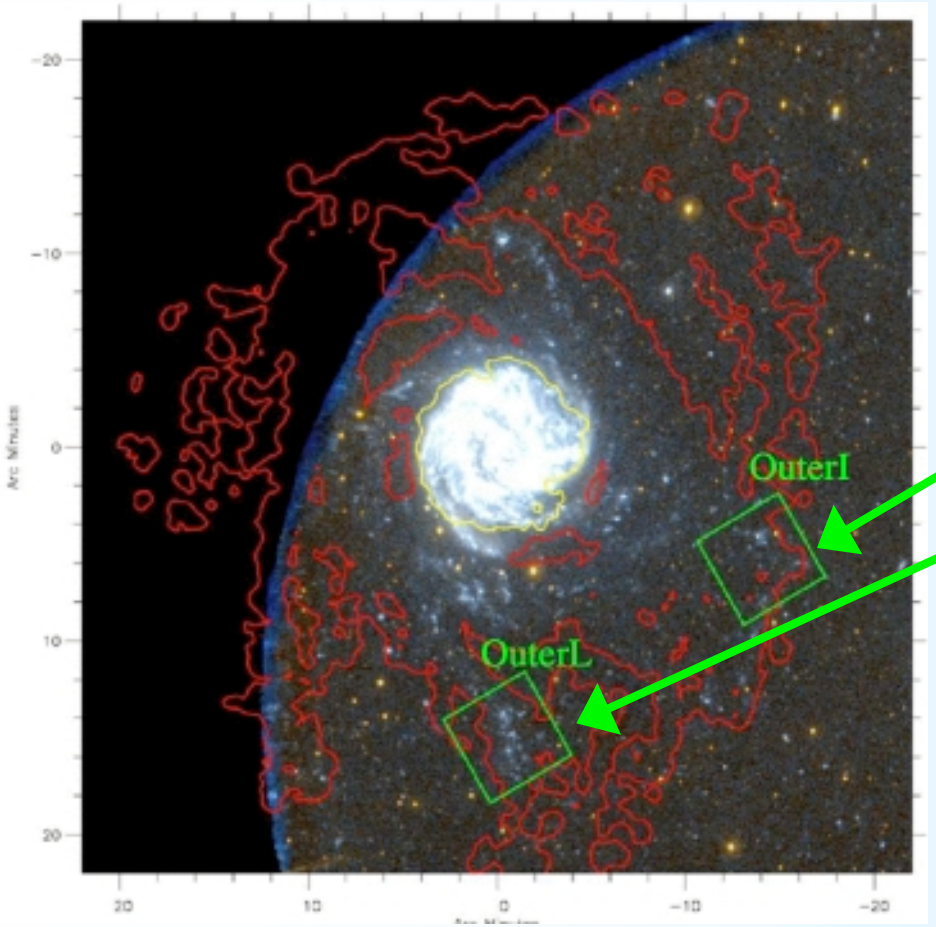
Nearby galaxies are many arcmin across. Many of the studies of interest (star formation, duty cycles, relation between gas/dust and stellar pops) are/need to be statistical in nature.

FOVs need to be ~a few arcmin in size.



M51, D=9 Mpc

FOV/Mapping Speed - 2



IRAC FOV (5 arcmin)
Imprints ~ LMT imprint

M83, D=4.5 Mpc

Conclusions

- The next major step in the field of nearby galaxies requires an order-of-magnitude improvement in the 2-parameters space of angular resolution and field-of-view (sensitivity not an issue)

- Science cases for sub-arcsec resolution:
  - Enshrouded SF (properties, phase duration, census, duty cycle, gas-SFR relation)
  - Relation between stellar populations and dust components (predictive power for high-z galaxy populations)
  - Radio-FIR correlation (physics)