Nearby Galaxy Surveys at Submillimeter Wavelengths

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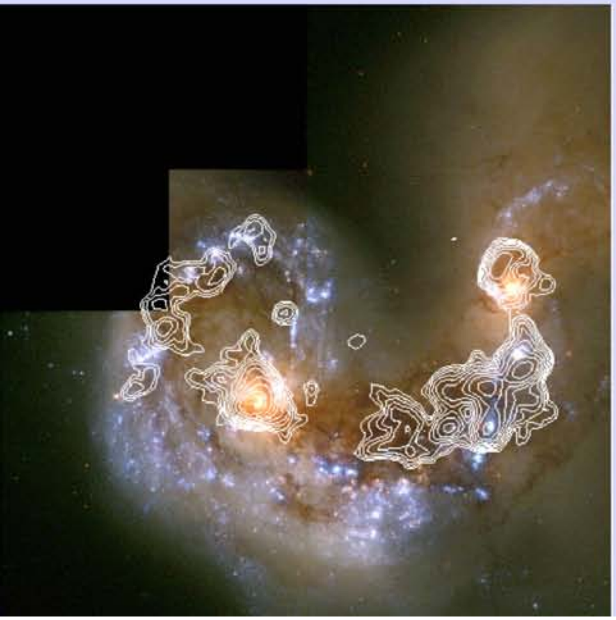
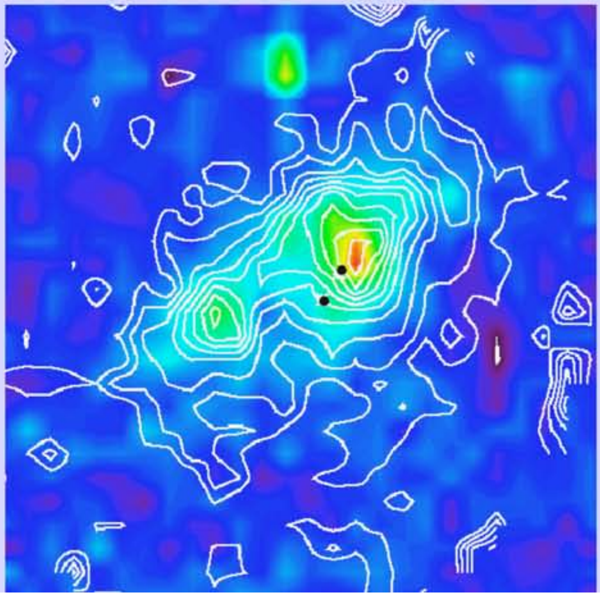


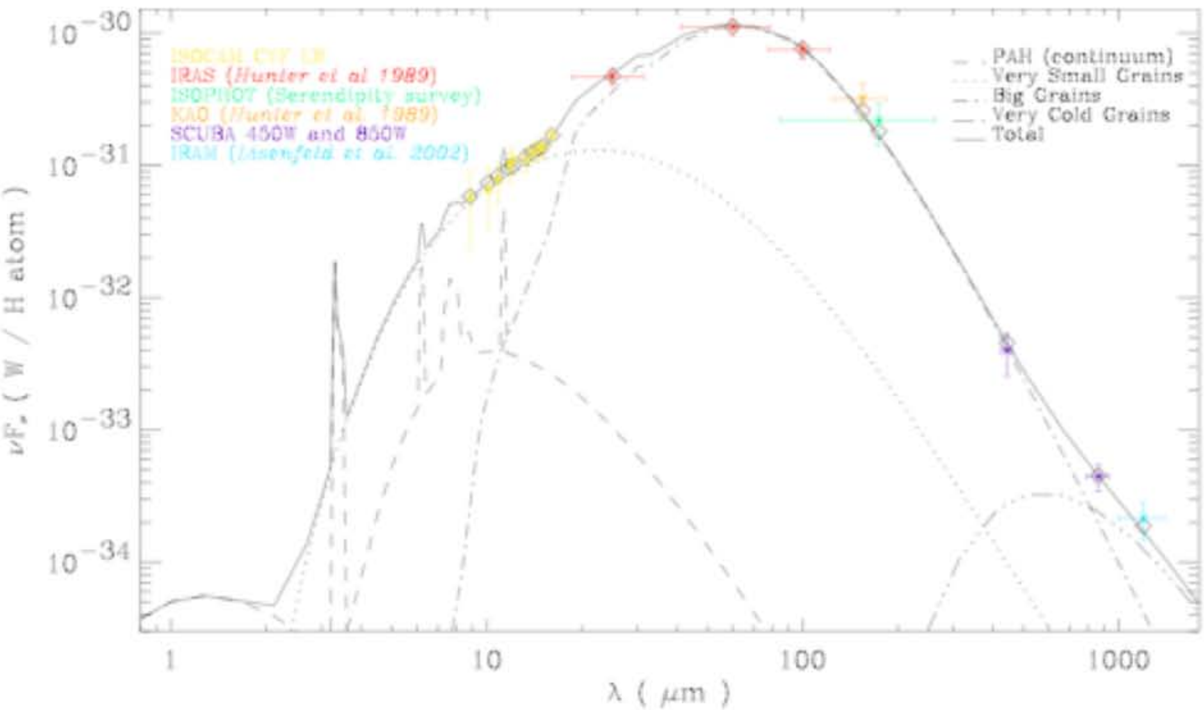


The JCMT Nearby Galaxy Legacy Survey

- Awarded 205 hr of JCMT time
  - 70 hr 850/450 micron SCUBA-2
  - 135 hr 12CO J=3-2 with HARP-B
- Survey to be carried out over two years
- 70 field galaxies, 30 Virgo galaxies, SINGS galaxies
- All galaxy types from E to Irr

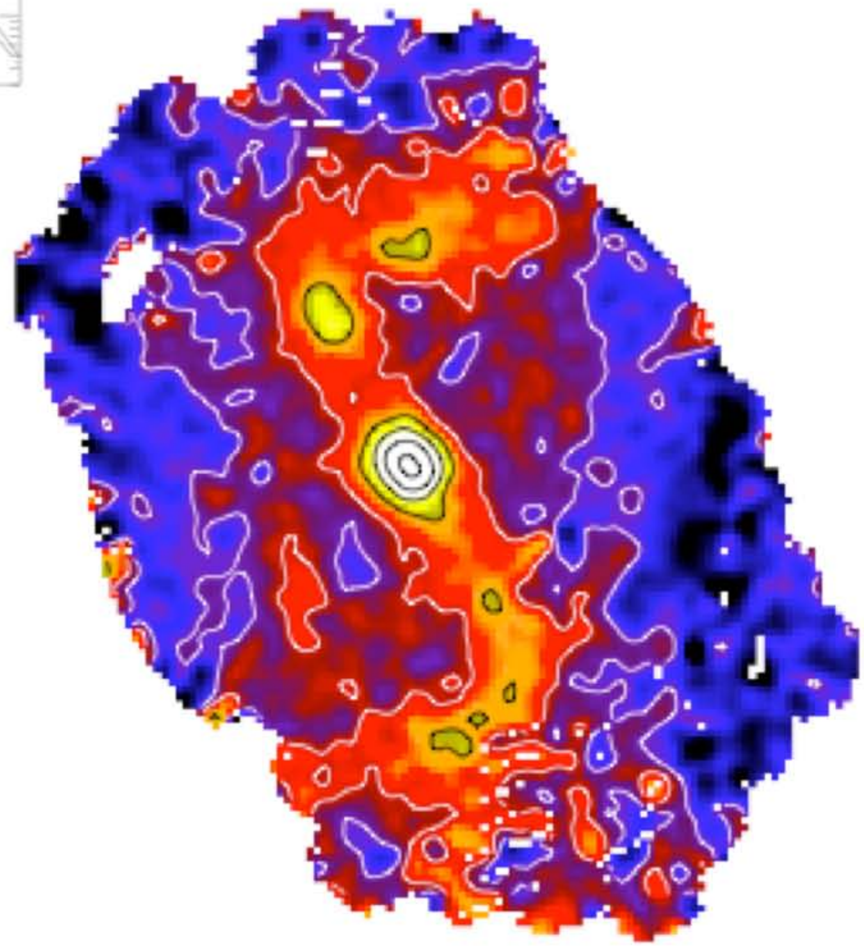
NGLS Scientific Goals

- Search for evidence of cold dust and measure its mass fraction
- Measure amount of warm dense molecular gas (associated with star formation)
- Look for differences due to cluster membership
- Measure local submillimeter luminosity function and mass function 100 times fainter than previous studies
- Search for variations in physical conditions in ISM as a function of galaxy type, metallicity, environment, star formation rate, and mass

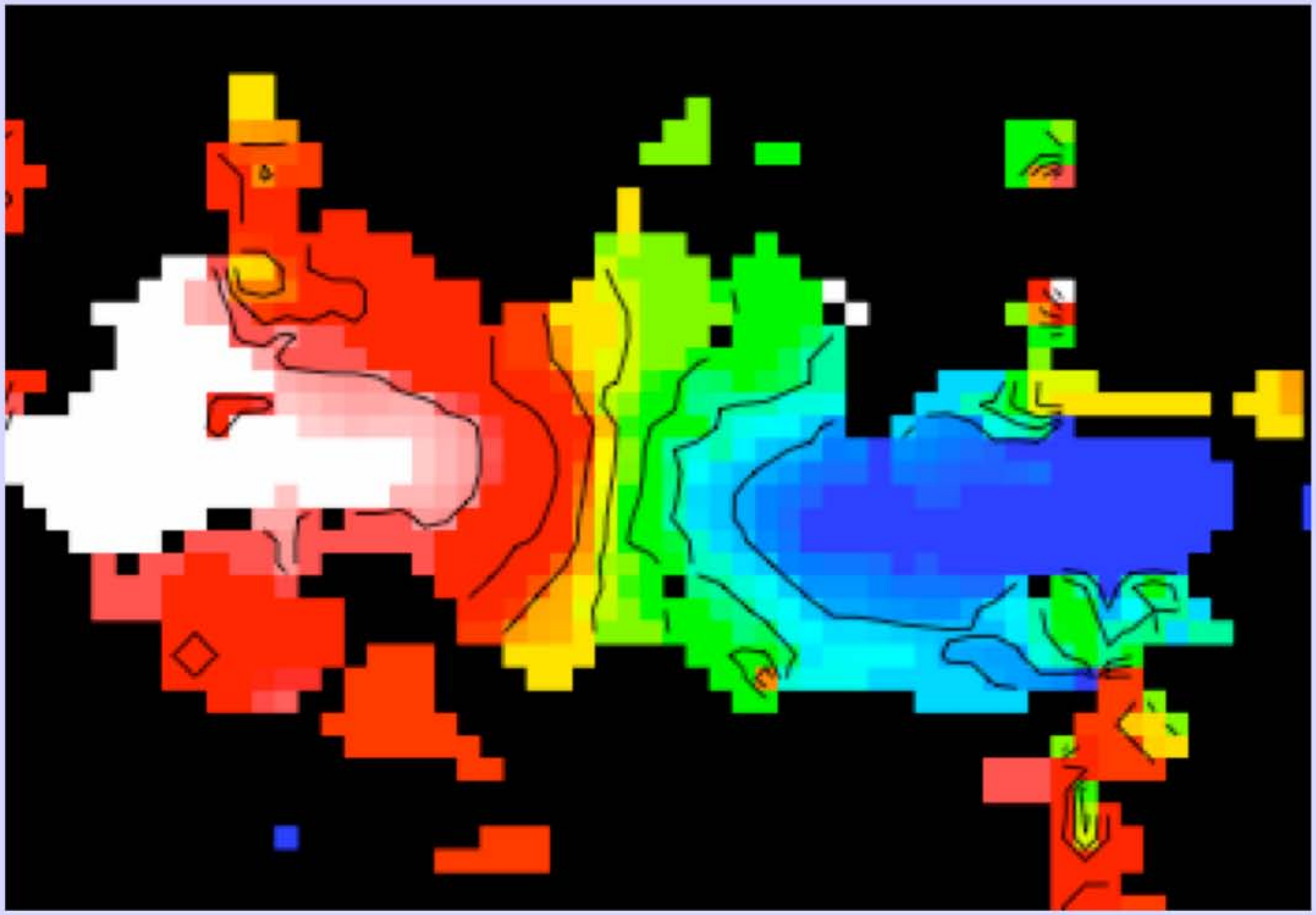


SED for dwarf galaxy NGC1569 (Galliano et al. 2003)

SCUBA 850 micron image of spiral galaxy NGC2903 (Stevens et al. 2005)



Velocity field of spiral galaxy NGC5055 (obtained during Legacy Science Verification May 2007)



NGLS Sample Selection

- HI selected sample
- Galaxies within 2-25 Mpc, Galactic latitudes > +/- 25 degrees, declinations > -25 degrees
- Total of 1150 galaxies (148 in Virgo)
- Randomly selected 1/3 of the sample to arrive at 331 galaxies
- Further reduced sample by a factor of two (to brighter half of sample) when awarded half the requested time

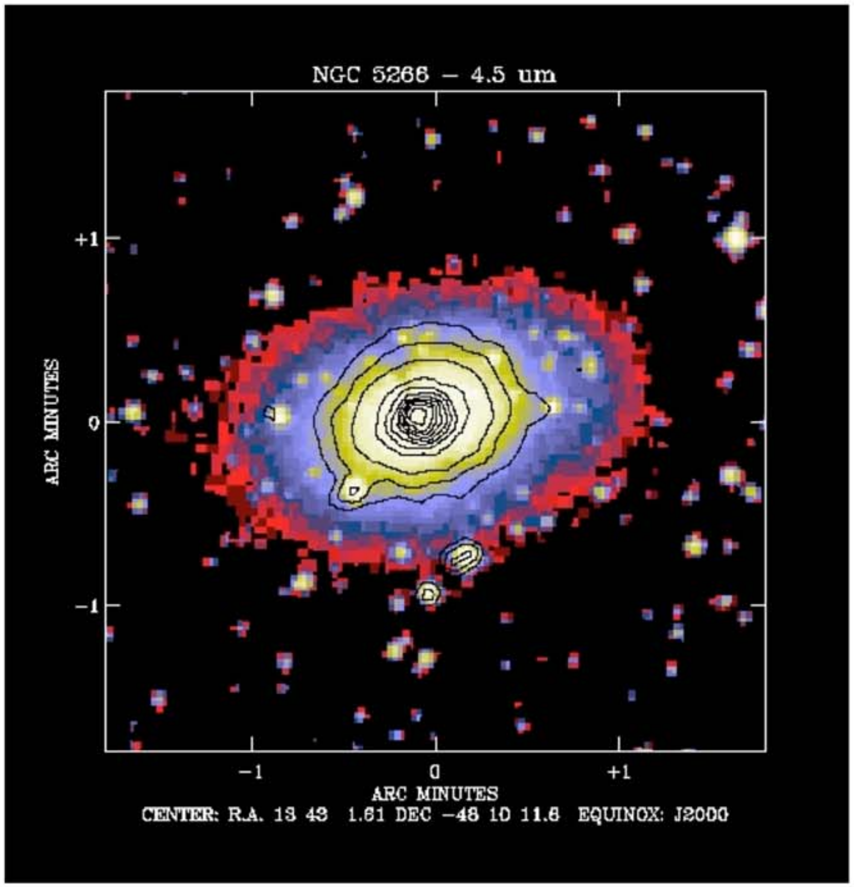
Local Galaxies: Herschel SPIRE Guaranteed Time Key Programs

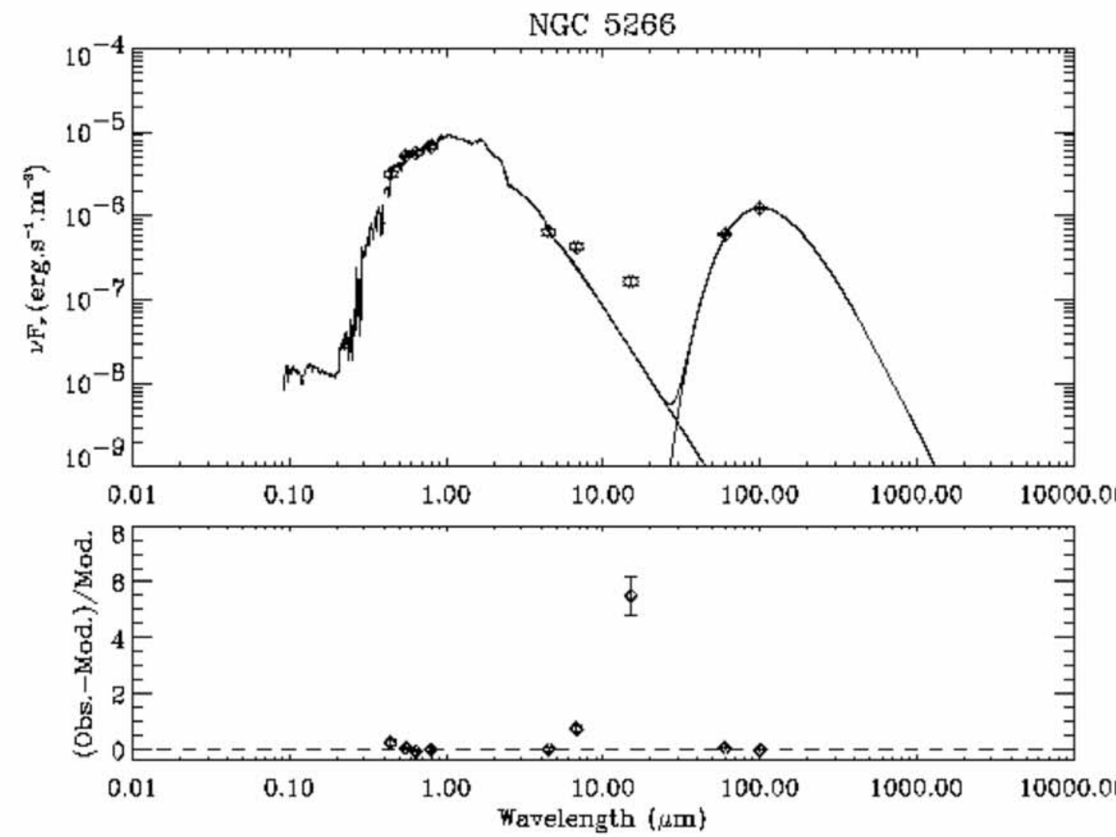
- ***Herschel Reference Survey (A Volume-Limited Galaxy Survey: 110 hours)***
  - SPIRE (3 bands)
- ***Survey of the ISM of Low Metallicity Galaxies (150 hours)***
  - SPIRE & PACS photometry, PACS spectroscopy
- ***Physical Processes in Nearby Resolved Galaxies (144 hours)***
  - SPIRE & PACS photometry, PACS spectroscopy & SPIRE FTS spectroscopy

Herschel Reference Survey: Scientific Motivation

- Provides a statistical submm survey of the nearby universe
  - How dust content (mass, distribution) depend on galaxy types and environment
  - Relate the dust properties to other tracers of the ISM (molecular gas, atomic gas, X-ray emitting gas)
- Particular interest in dust in ellipticals
  - Merging events, cooling flows, mass loss from late-type stars
  - ISOPHOT FIR observations of 54 early-types: 10^6 – 10^7 Msolar (Temi et al 2004) , but data sparse and no spatial resolution
  - ISOCAM MIR observations of 42 early-types: (Ferrari et al 2002; Athey et al 2002; Xilouris et al 2003) PAHs (~7 mu) and warm dust (15 mu) common

Herschel Reference Survey
Elliptical Galaxies are important!
ISOCAM observations of NGC 5266 (60 Mpc)





NGC 5266
Xilouris et al 2004

Hubble ST: 75% of ellipticals contain dust (van Dokkum & Franx 1995)

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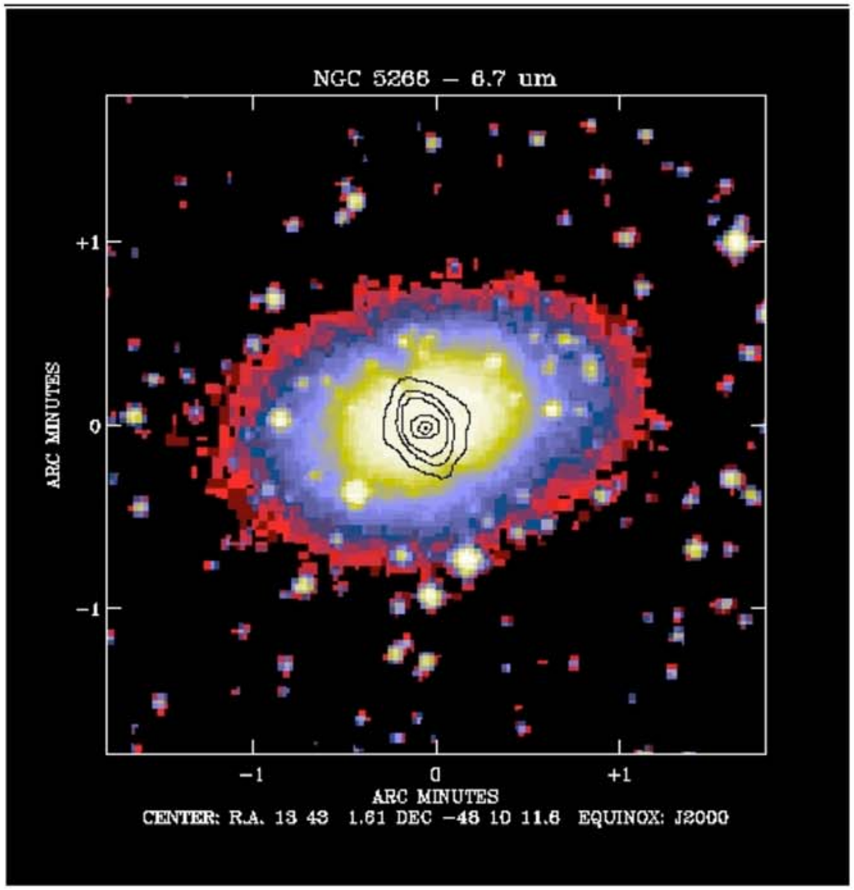

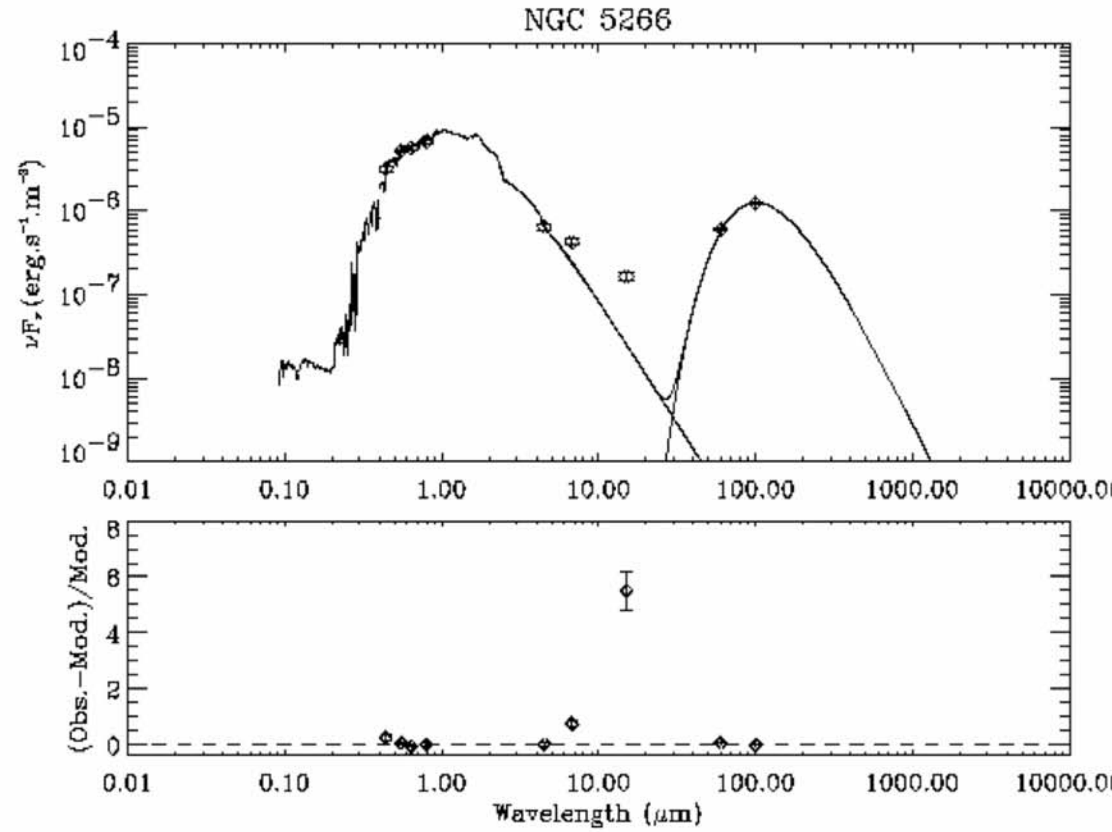

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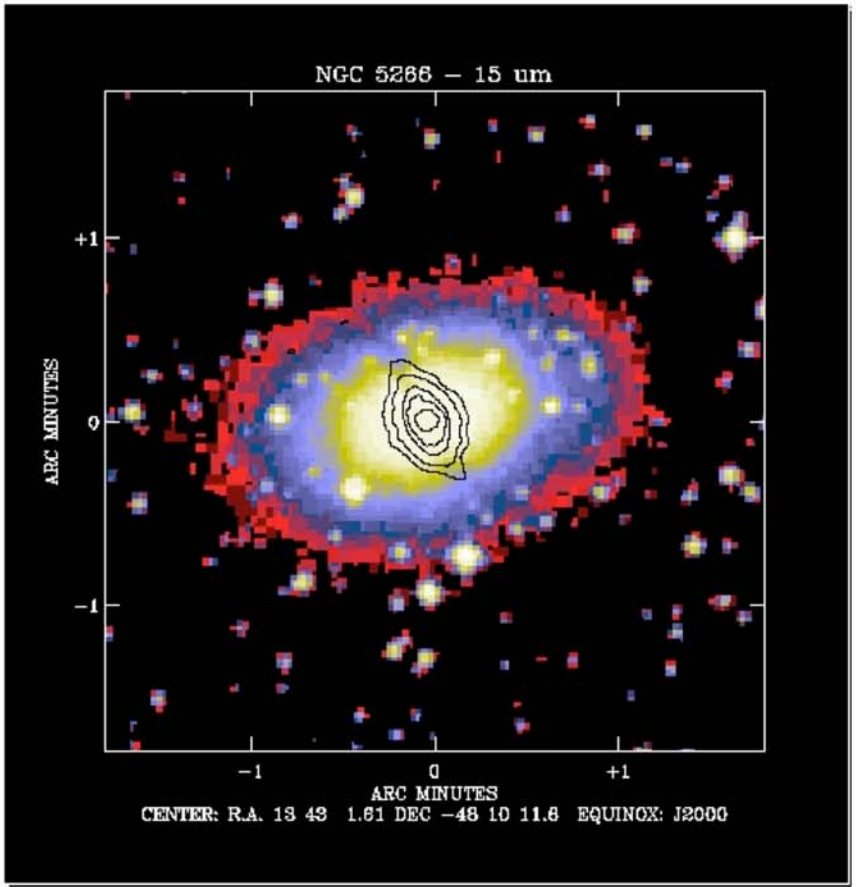

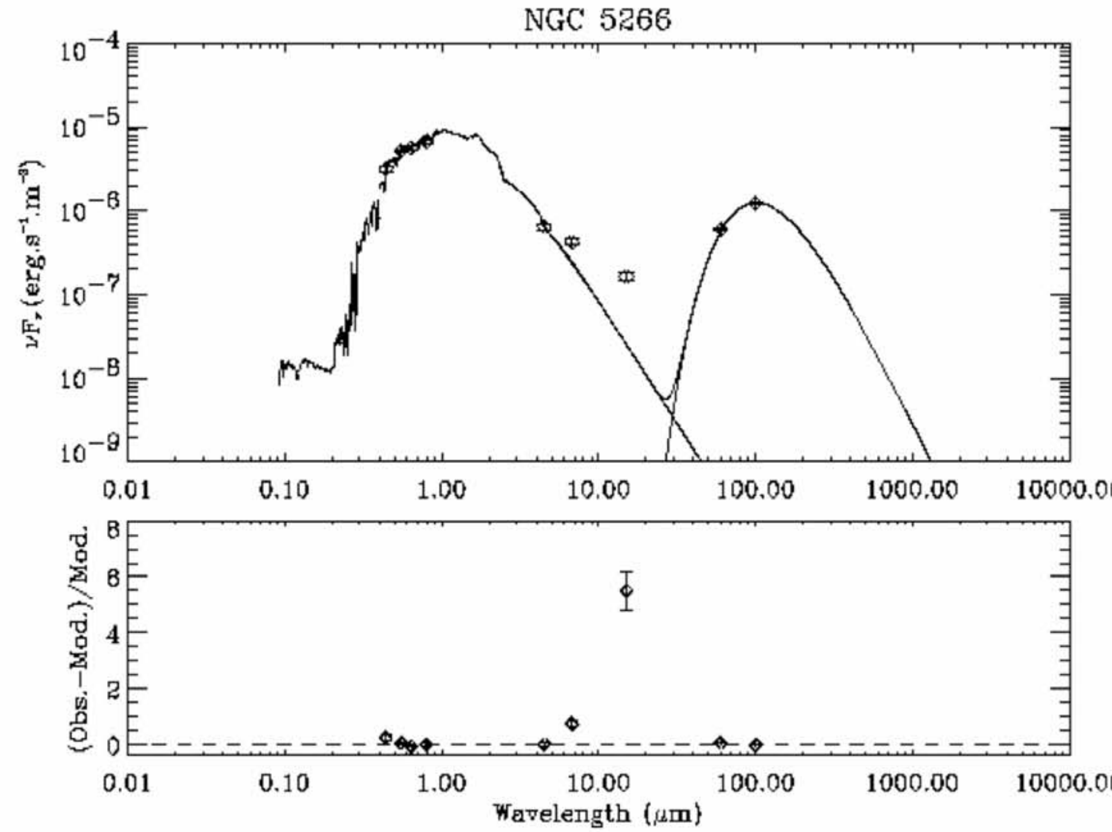

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Herschel Reference Survey: Sample Selection

Tully's Nearby Galaxies Catalogue

- 10 Mpc < d < 25 Mpc : far enough for single SPIRE pointing & to include ellipticals; close enough for spatial resolution
- Spans all Hubble types: 106 E + S0 and 652 late types

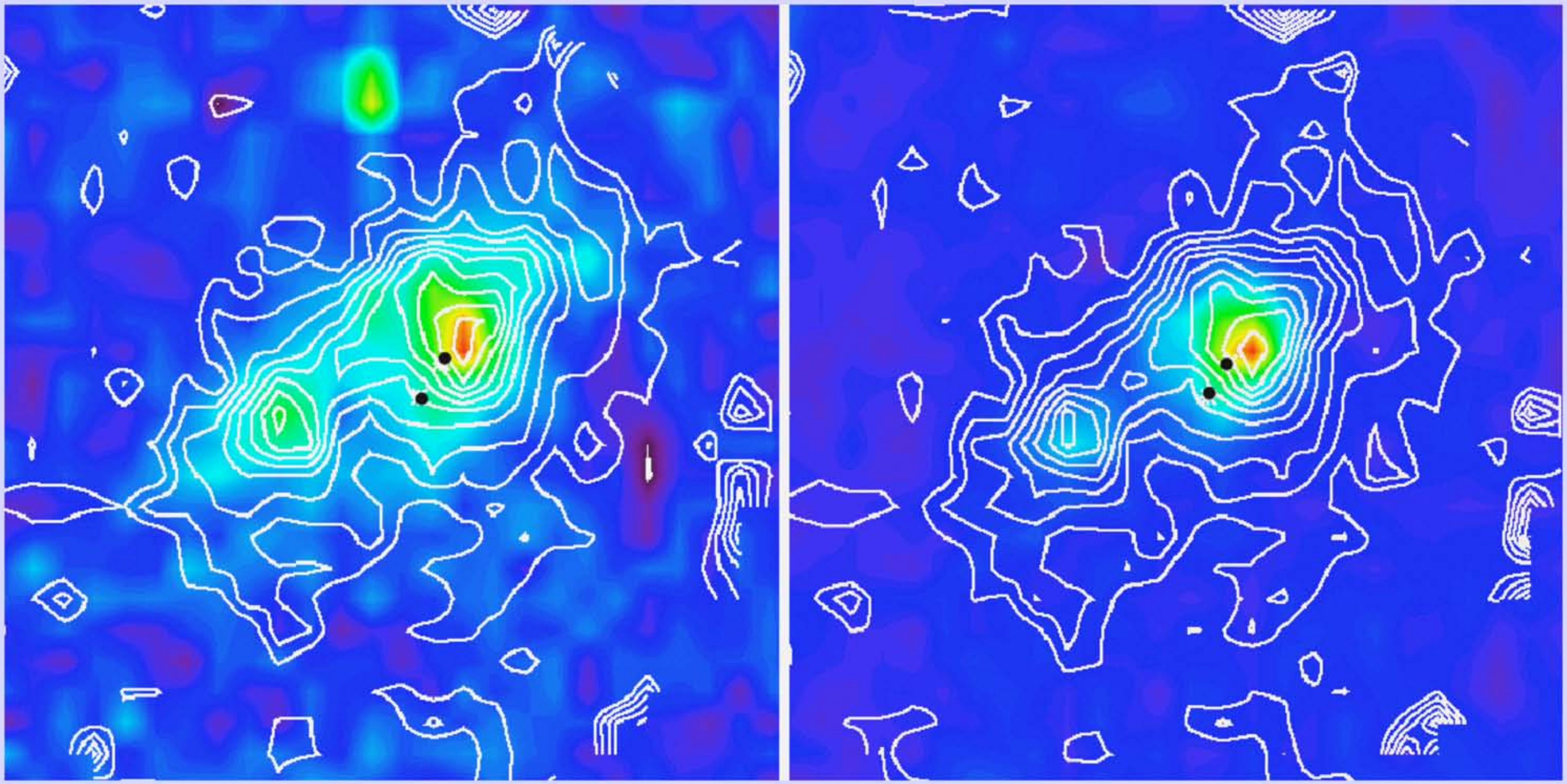
- Randomly choose 1/3 of the late types -> 217 galaxies
- Keep all 106 early-type galaxies
  - Herschel provides first opportunity to study the nature of the dust in elliptical galaxies unambiguously

Low-Metallicity Galaxies: Science Motivation

1. Nature of dust in low metallicity environments
   - Dust size distribution? Dust spatial distribution?
2. Consequences on the heating and cooling
3. Impact of Super Star Clusters on the surrounding gas and dust
   - How much SF enshrouded and optically thick in NIR/MIR?
4. What galactic properties and processes control the dust properties
   - How to disentangle effects of ISM structure, radiation field/star formation activity and metallicity in the SED?
5. Impact of dust abundance and composition on the evolution of the ISM
6. Relationship between metals in the gas phase and those in the dust as a function of metallicity
   - Reconcile with dust evolution models
7. The ISM and SF in truly primordial galaxies

NGC 1569: evidence for cold dust

7.7 μm image 850 μm (contours) 15 μm image

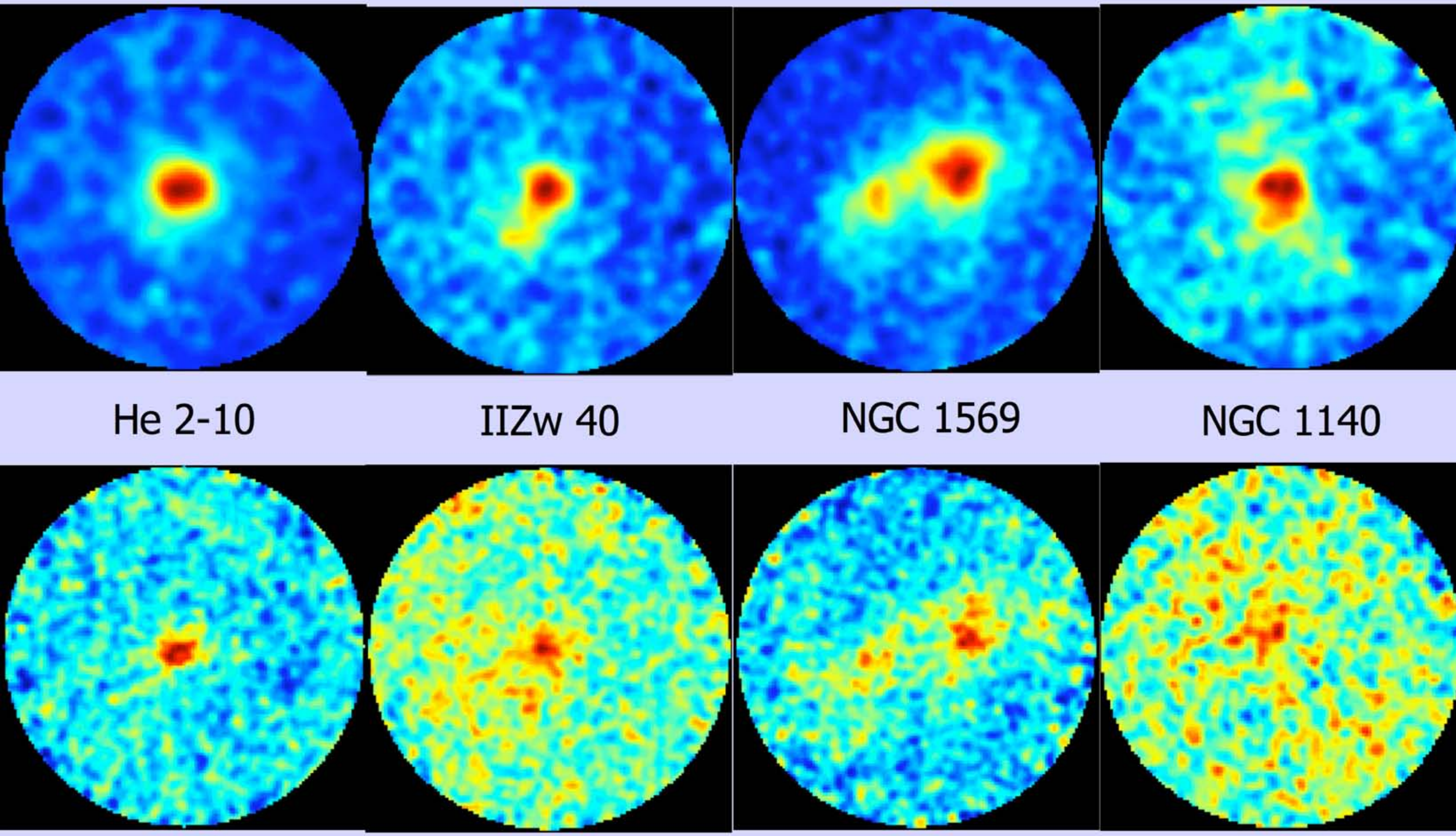


Galliano et al. 2003

Spatial distribution of different dust components: 7.7 um PAH, 15 um small grains, colder grains in submillimeter

SCUBA Observations of Dwarf Galaxies

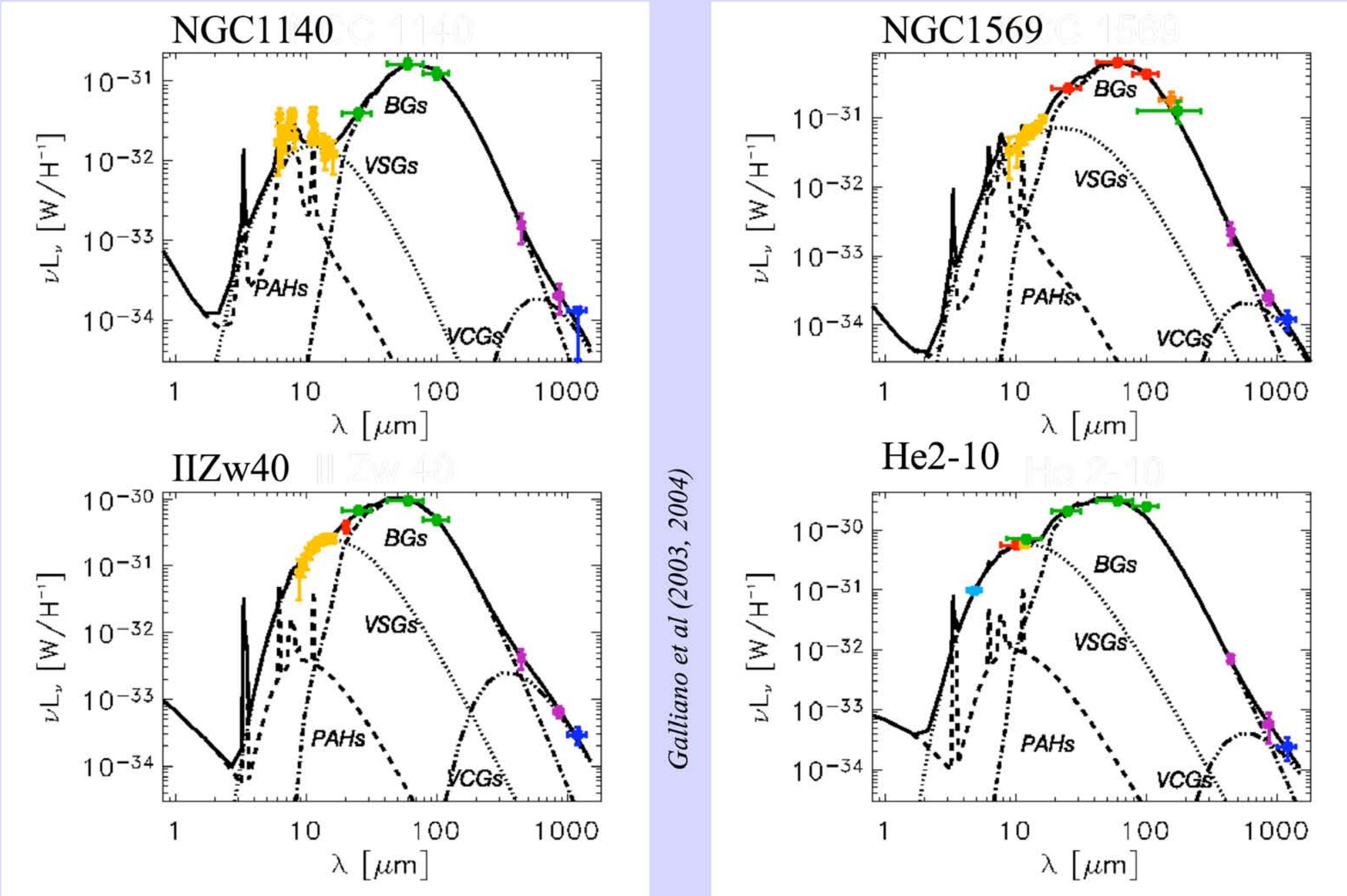
850 μm



450 μm

Galliano et al (2003, 2004)

SEDs of Four Dwarf Galaxies



Low Metallicity Galaxies Survey

60 galaxies, ½ to < 1/50 solar metallicity

SPIRE + PACS Photometry:

(6 bands) 1hr to 3hr/galaxy

PACS Spectroscopy:

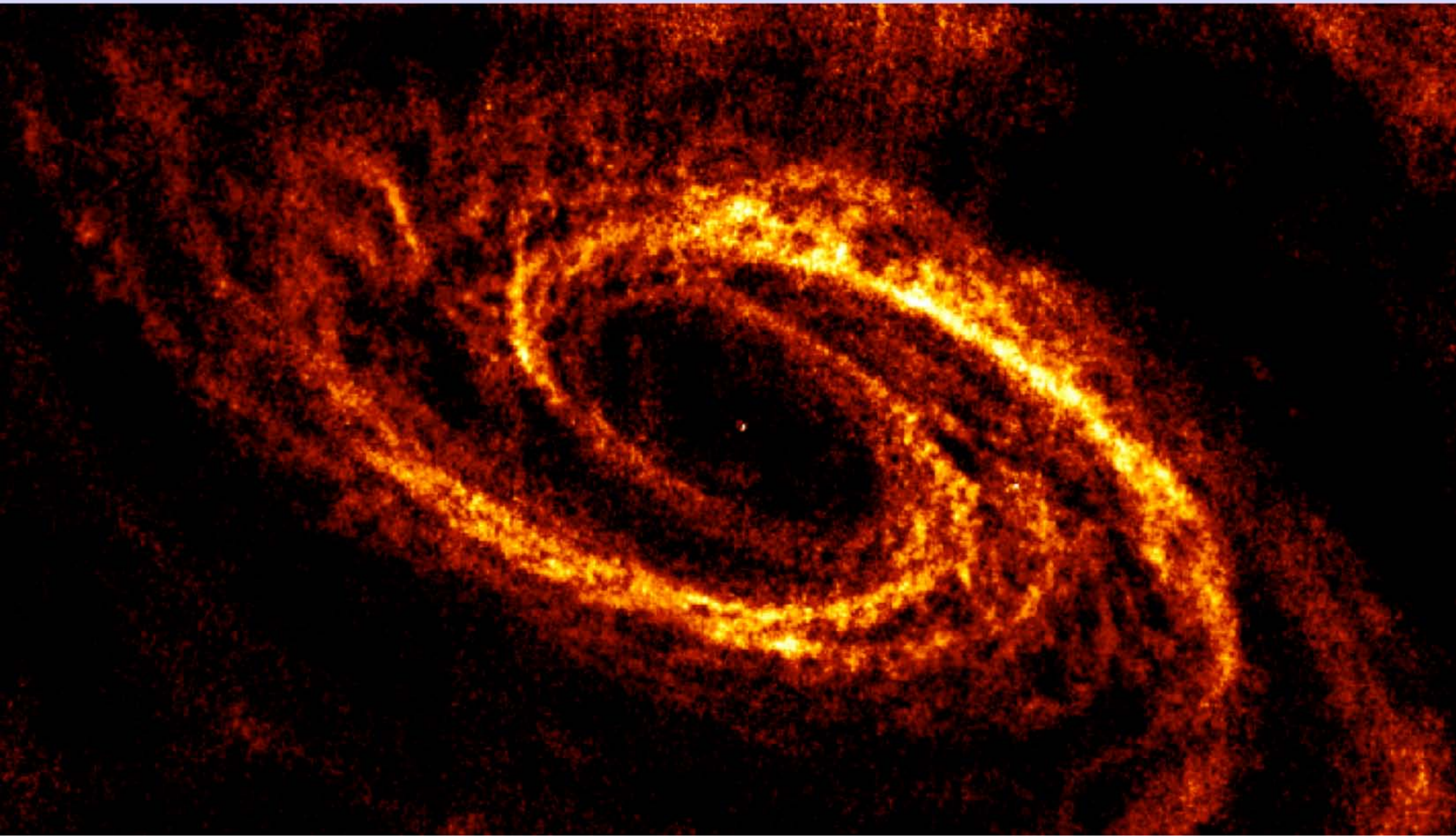
- *Some or all of CII, OI63, OI145, OIII88, NII122, NII205* (depending on expected brightness)
- Extended galaxies(e.g. NGC1569, IC10, NGC5253, NGC6822, NGC2366..) 5'x5' CII, OI 63, 145

Physical Processes in the Interstellar Medium of Very Nearby Galaxies: Science Motivation

A small selection (~15) of resolved nearby galaxies observed in detail in FIR & submm gas and dust properties

- ISM physics,i.e. heating, cooling
- star formation interplay with ISM with conditions spanning a wide range of SF activity, morphology, luminosity & metallicity
- variations inside a galaxy as well as global properties

M81 in HI: 34x20′, 6″ resolution (from THINGS survey)



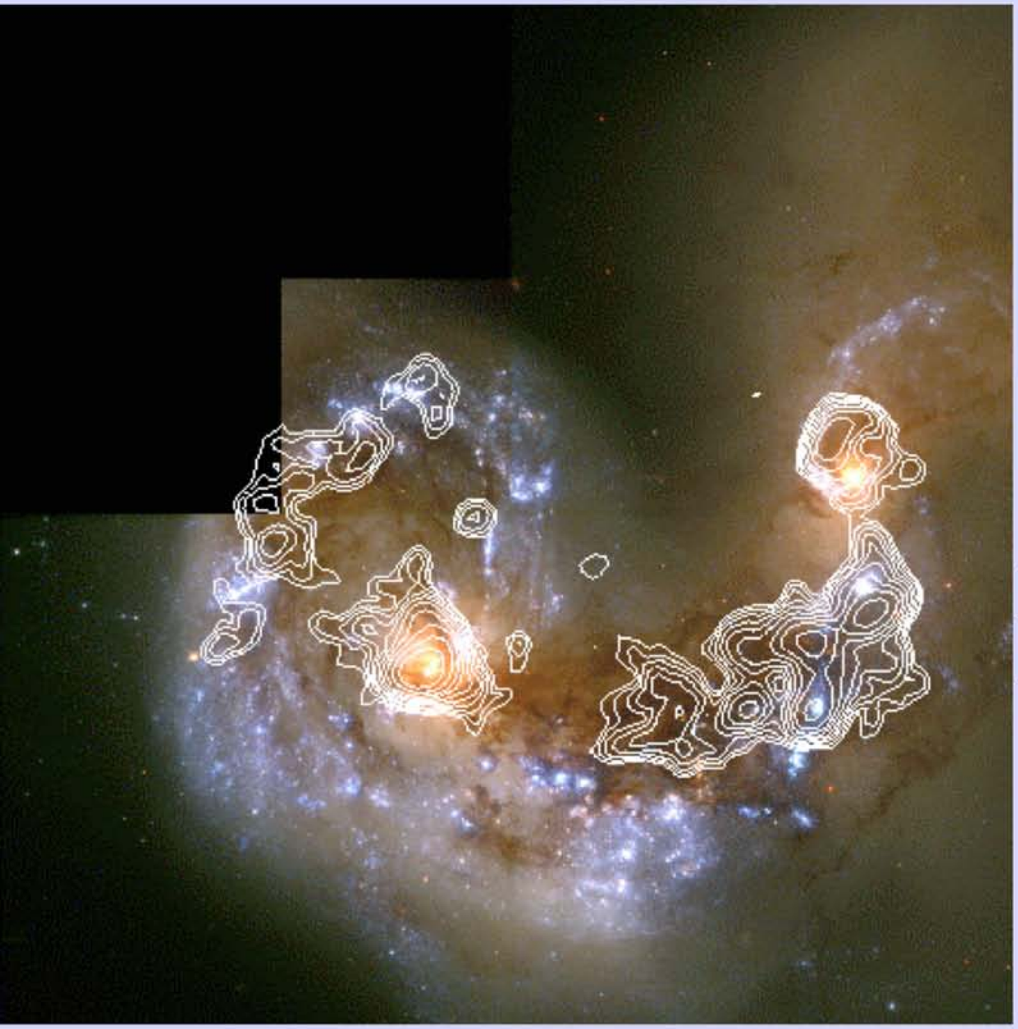
Source Selection

Galaxy	Type	FOV (' x')	spire phot	pacs phot	pacs spec	FTS	Total (hr)
M51	Late-type spiral	11'x7'	1.7h	1.7	3.2	y	6.5
M81	Early-type spiral	27'x14'	4.4	4.4	5.9	y	14.7
NGC2403	Low mass spiral	22'x12'	3.4	3.4	5.2	y	12.0
M83	Starburst spiral	13'x12'	2.4	2.4	y	y	17.4
NGC891	Edge-on spiral	14'x3'	1.7	1.7	3.6	y	7.0
NGC1068	Sy2	7'x6'	1.2	1.2	n	y	13.1
NGC4151	Sy1	6'x5'	1.0	1.0	n	y	3.7
NGC6822	Quiescent dwarf	16'x14'	3.0	3.0	3.5	n	9.5
IC10	Starburst dwarf	10'x10'	1.8	1.8	2.5	n	6.1
M82	starburst	11'x4'	1.7	1.7	n	y	14.9
Arp220	Late phase merger	2'x1'	0.2	0.2	n	y	10.3
Antennae	Early phase merger	4'x4'	0.2	n	n	y	10.9
CenA	Closest Ellip; AGN	2'x8'	0.5	0.5	y	y	11.9
NGC4125	Normal E	<4'	0.2	0.2	1.2	y	1.6
Total (hr)			23.5	23.5	38.8	54	140

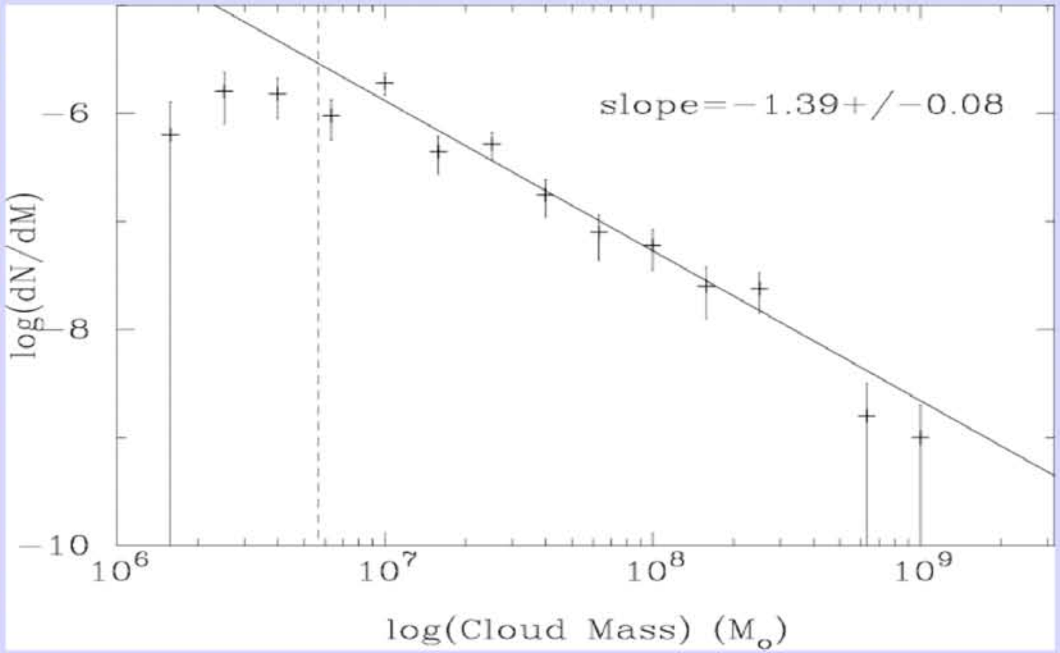
What can CCAT contribute?

- Higher angular resolution (than Herschel) and sensitivity (than JCMT) particularly important for continuum at 250-450 microns
  - Probes close to peak of dust SED
  - Important for temperature
  - Millimeter wavelengths also interesting to trace mass
- High excitation molecular lines also interesting
  - But may not be very common or spatially extended
  - consider large array receivers at 230 or 345 GHz?
  - Or perhaps telescopes like JCMT, APEX, LMT will be pathfinders for CCAT by mapping lines at longer wavelengths?

Giant Clouds and Star Clusters in the Antennae



- Hundreds of young massive star clusters discovered with HST
- population of very massive clouds is unique among galaxies to date

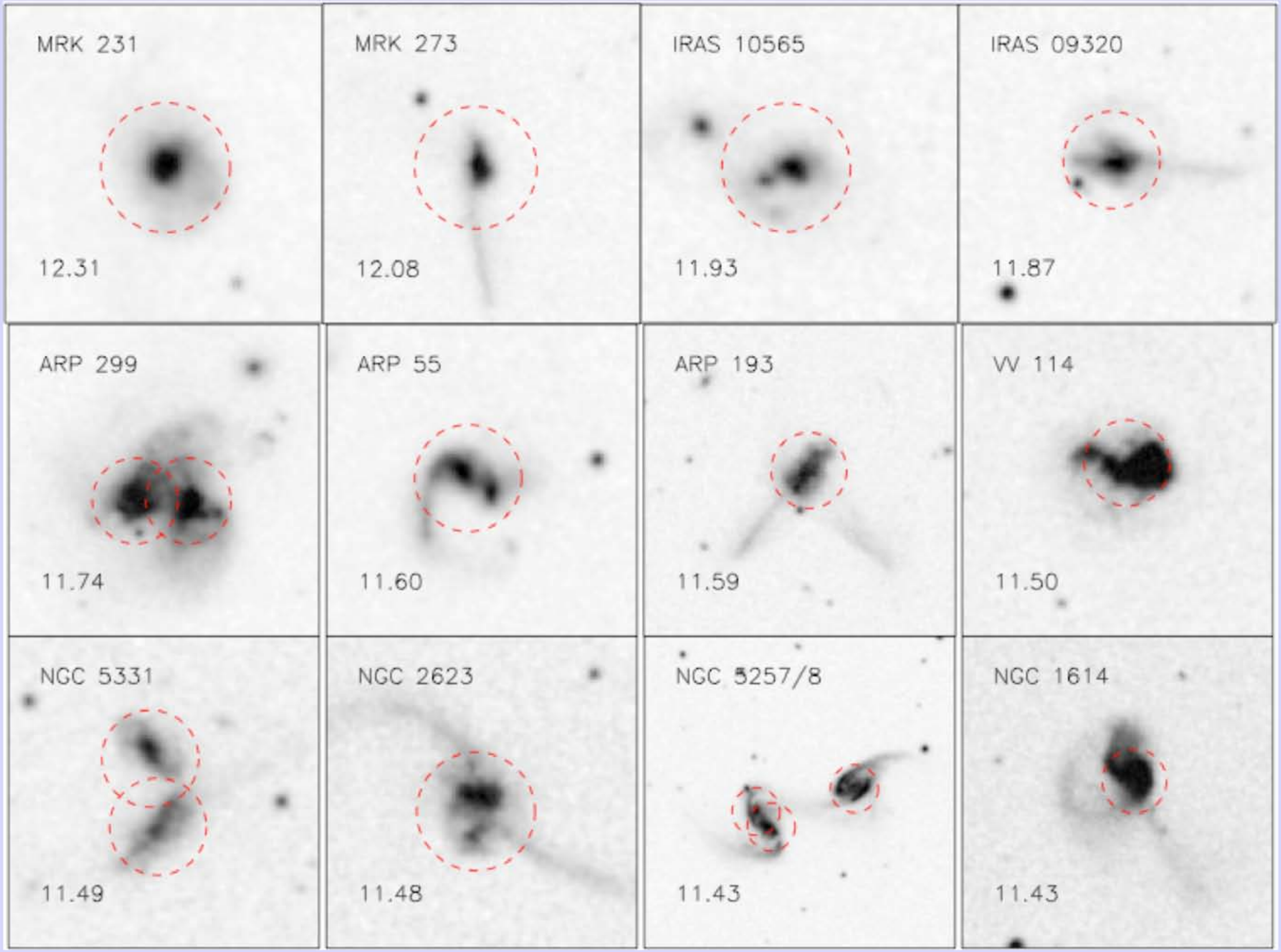


Wilson et al. 2000, Whitmore et al. 1999

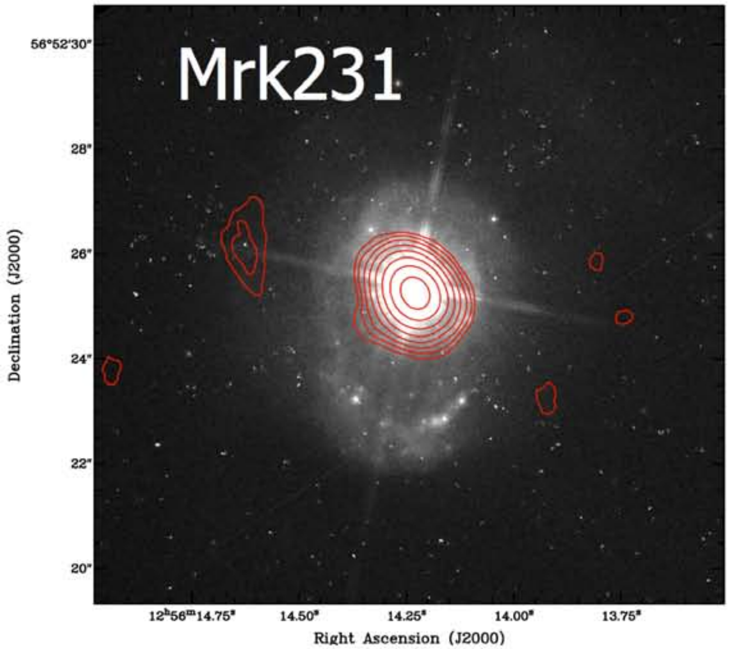
Wilson et al. 2003

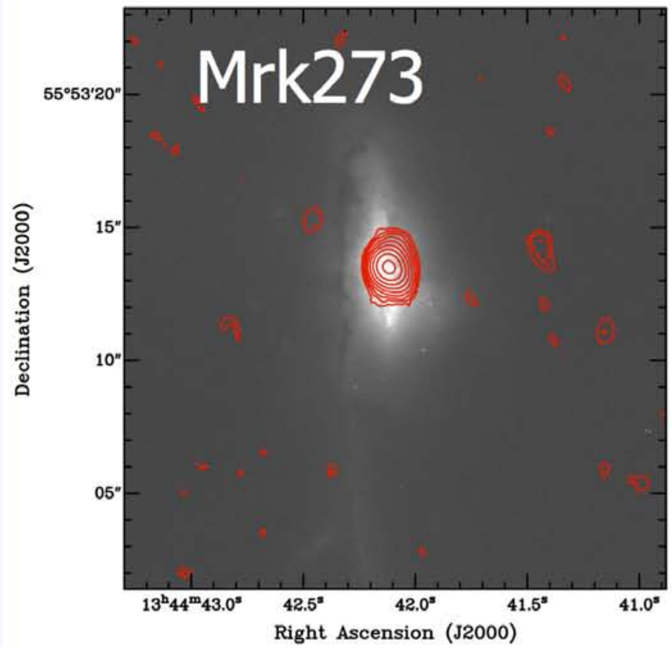
Similar angular resolution of 5" achievable with CCAT at 450 microns

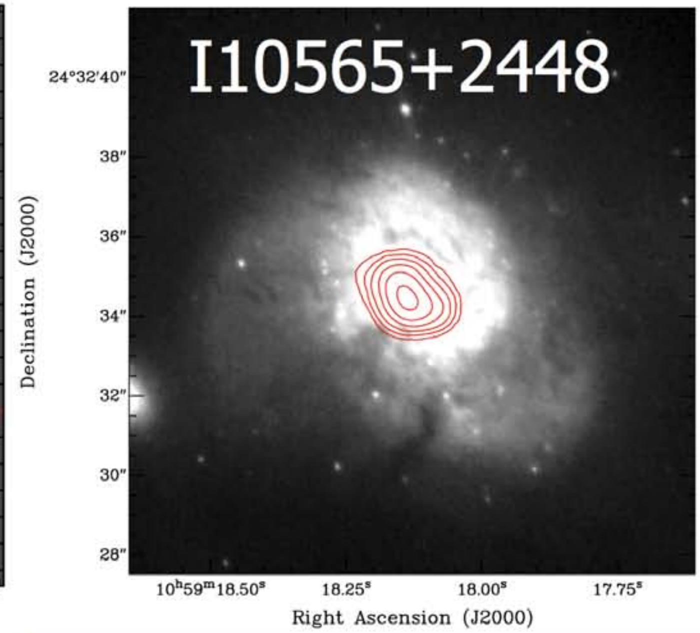
The Nearby Luminous Infrared Galaxy Sample (SMA Legacy Project 2005-2007)

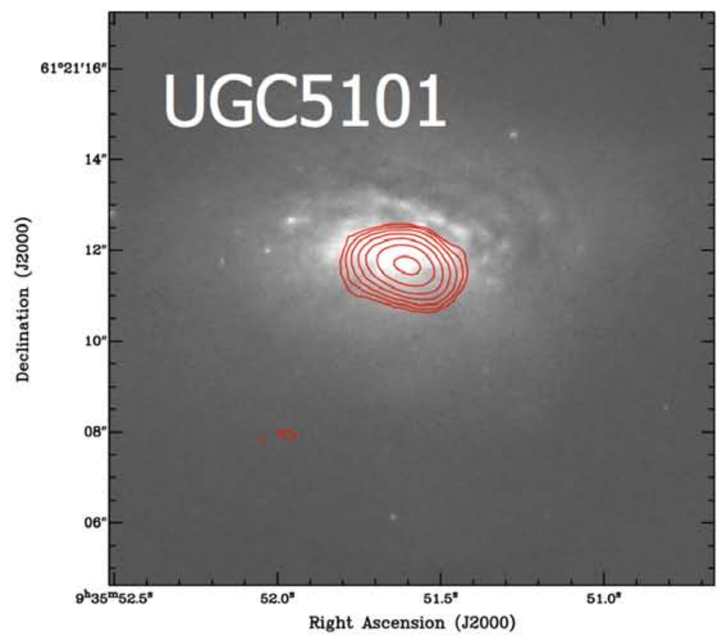


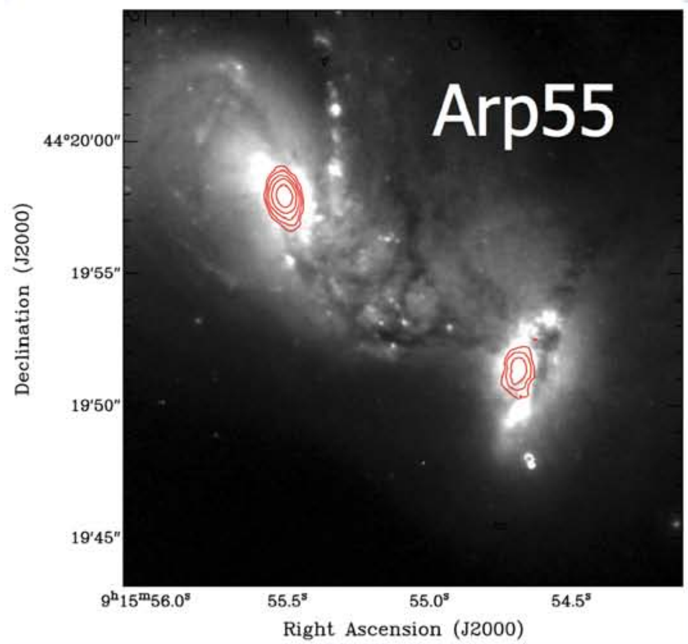
Centrally compact CO 3-2 emission





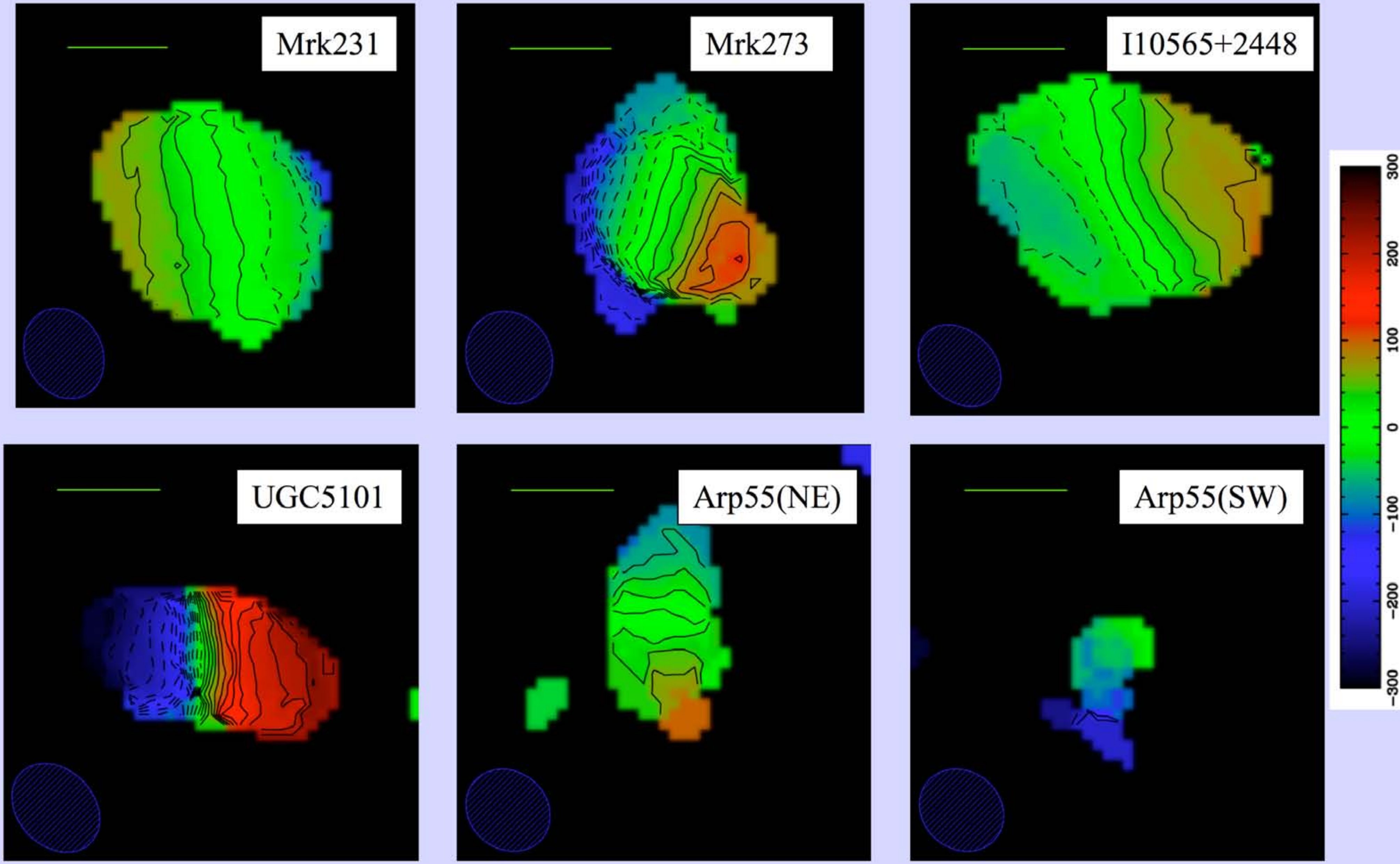




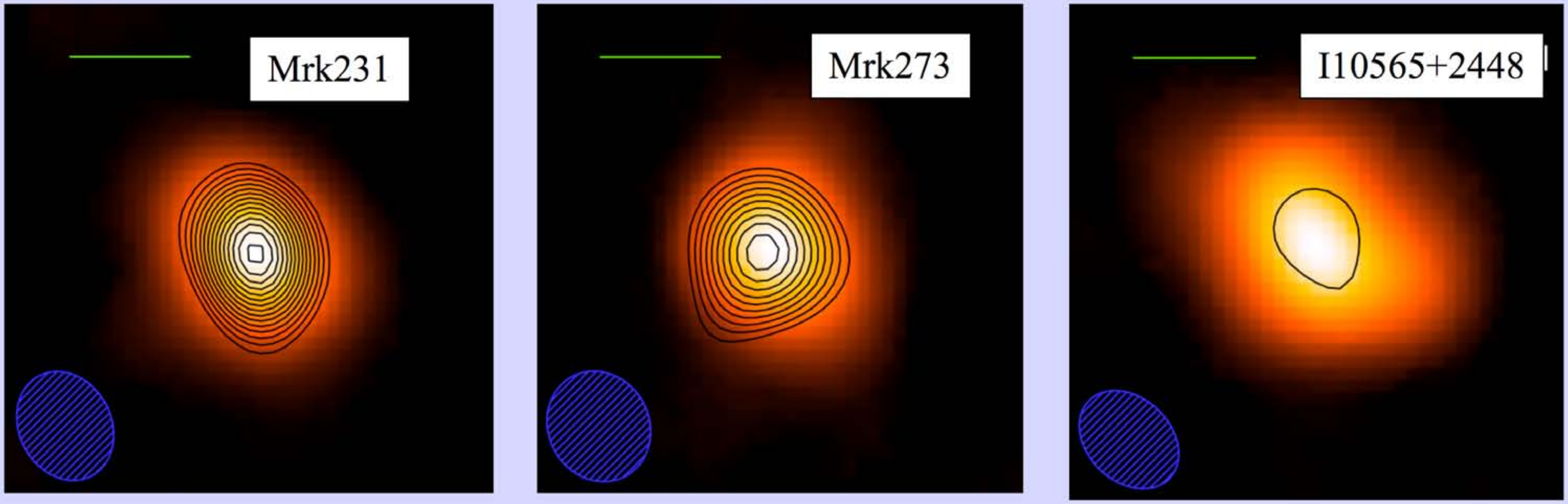


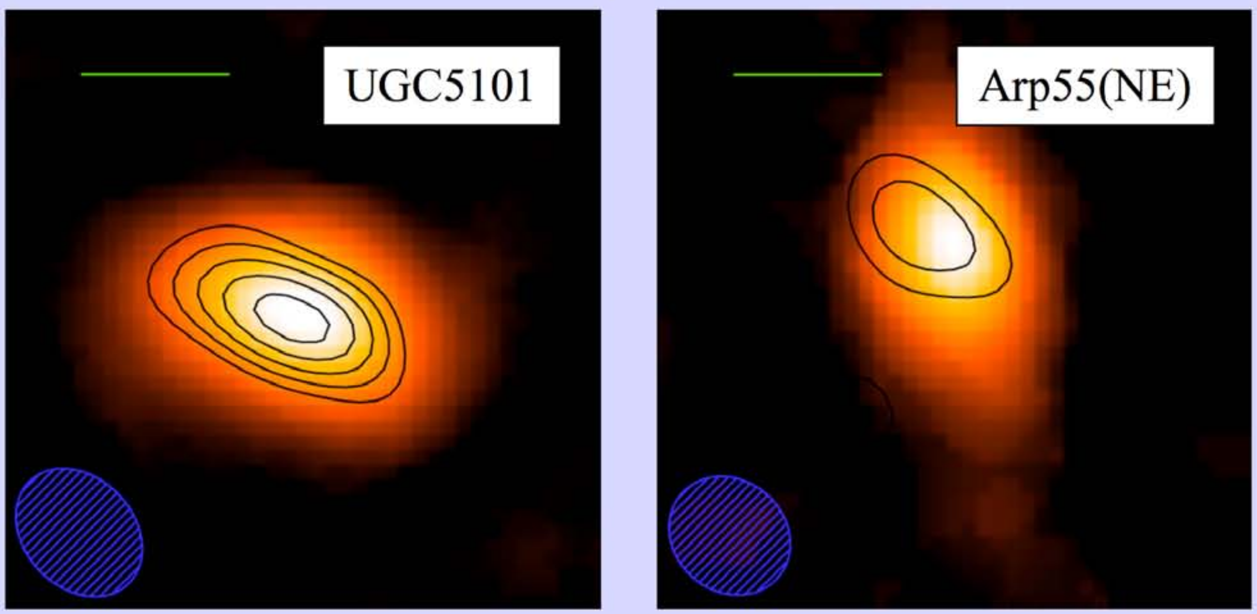
(HST images of Arp55 and I10565+2448 from Evans, Vavilkin, et al., 2006, in prep.)

Velocity Fields within R<1 kpc



850 μm continuum overlaid on CO3-2





Contours are 2,3,4 …
X 5 mJy/beam

Field of view 4”x4”.
All sources detected
at 4 sigma or better.

The Gas to Dust Mass Ratio

Galaxy	M_{dust} (10^7 $M_\odot$)	M_{H_2} (10^9 $M_\odot$)	Gas/Dust Ratio
Mrk231	4.43	4.13	93
Mrk273	3.26	5.10	156
10565+2448	1.27	3.10	244
UGC5101	3.45	2.66	77
Arp55(NE)	1.79	1.18	66
Arp55(SW)	<0.75	0.65	>87

Average gas/dust ratio = 120 +/- 30

(good agreement with typical Galactic value)

- M_{dust} assumes $\kappa = 1$ cm^2/g and T_{dust} from blackbody fit to IRAS 60 and 100 μm (Solomon et al. 1997)

Complete surveys with CCAT?

- With rapid mapping and high sensitivity, it would be possible to do complete surveys of all galaxies within the local volume
  - It would be nice not to have to take random subsamples that may miss a particularly interesting individual galaxy …
  - For example, the original random NGLS sample on the JCMT missed most of the SINGS galaxies

CCAT, ALMA and Herschel

- Sensitive, whole-galaxy surveys
- access more distant galaxies so wider range of environments possible
- higher spatial resolution for peak of dust SED and for cooling lines e.g. [CII]

- Amount, location, nature of cold dust
- link between cloud mass function and intense star formation
- effects of metallicity on ISM structure and star formation process

Will provide a physical basis for understanding dusty galaxies in the early universe!