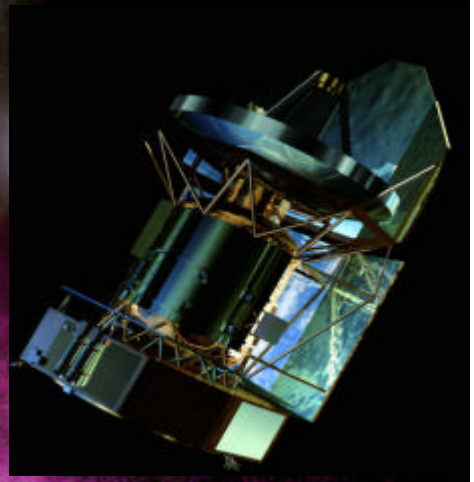
Herschel FIR and Submm Science Programs: The local universe



Suzanne Madden
CEA, SAp, Saclay

On behalf of the SPIRE and PACS teams extragalactic working groups

Guaranteed Time (GT) Extragalactic Science (local universe):

How do galaxies evolve? How do the phases of stars, dust and gas within galaxies evolve?

- Physics of the ISM of galaxies – interplay between energetic sources and the gas and dust
  - Programs together are designed to covers a vast range of galaxies (spirals, AGNs, starbursts, dwarf galaxies, ellipticals, interacting….)
- Galaxies harboring a broad range of physical diversity within
  - Spiral arms (inner and outer regions, metallicity…)
  - Bars
  - Nuclear and circumnuclear (AGN activity & starburst)
  - Inter-arm regions/spurs
  - Halo (metallicity; evolution of galaxies…)
  - Super star clusters
- What are the physical properties and history of these components?
- How to disentangle effects of metallicity, starformation, morphology, history, etc from the observations?

II. Gas Properties: FIR fine structure lines
PACS & SPIRE & HIFI

Some star formation/accretion tracers in the FIR/submm (atomic, ionic, molecular)

[CII]	158 µm	Most important cooling lines of the atomic gas.
[OI]	63 µm	Probe the conditions in PDRs, i.e. the warm neutral
[OI]	145 µm	gas cloud surfaces which constitute a large fraction
[CI]	370 µm	of the neutral medium in a galaxy.
[CI]	609 µm	

[NII]	122 µm	Conditions in the ionized medium. Important diagnostics
[NII]	205 µm	of absolute level and excitation of star forming (and AGN)
[NIII]	57 µm	activity and of n_e @ low density (< 10^3 cm^{-3})
[OIII]	52 µm	(z>0.1)
[OIII]	88 µm	

[OH], H_2O

CO(5-4)….(32-31) High-J CO as AGN diagnostics (Krolik & Lepp 1989)

Abundances ***i.e. [NIII]/[OIII]***
Densities ***i.e. [NII], [OIII], [SIII] line pairs***
Gas pressure ***i.e. [OI] pairs***
UV hardness & intensity ***[NII]/[NIII]. [SIII]/[OIII] pairs***

The "Nearby" Galaxies Guaranteed Time Key Programs

SPIRE GT Team:

1. Physics of the ISM in Nearby Galaxies
   Detailed photometry and spectroscopy of a wide range of galaxies (16 galaxies)
2. Physics of the ISM in low metallicity galaxies
   SEDs of 55 dwarfs, FIR spectroscopy

3. Herschel Galaxy reference survey of 320 galaxies – study the dust reservoirs in galaxies

PACS GT Team

4. Star formation and activity in infrared bright galaxies at z<1

HIFI GT Team

5. Physical and Chemical Complexity of the ISM in Galactic Nuclei:
   FIR/submm: line surveys toward exgal nuclei
   Excitation studies of SBs, AGNs & low Z environments

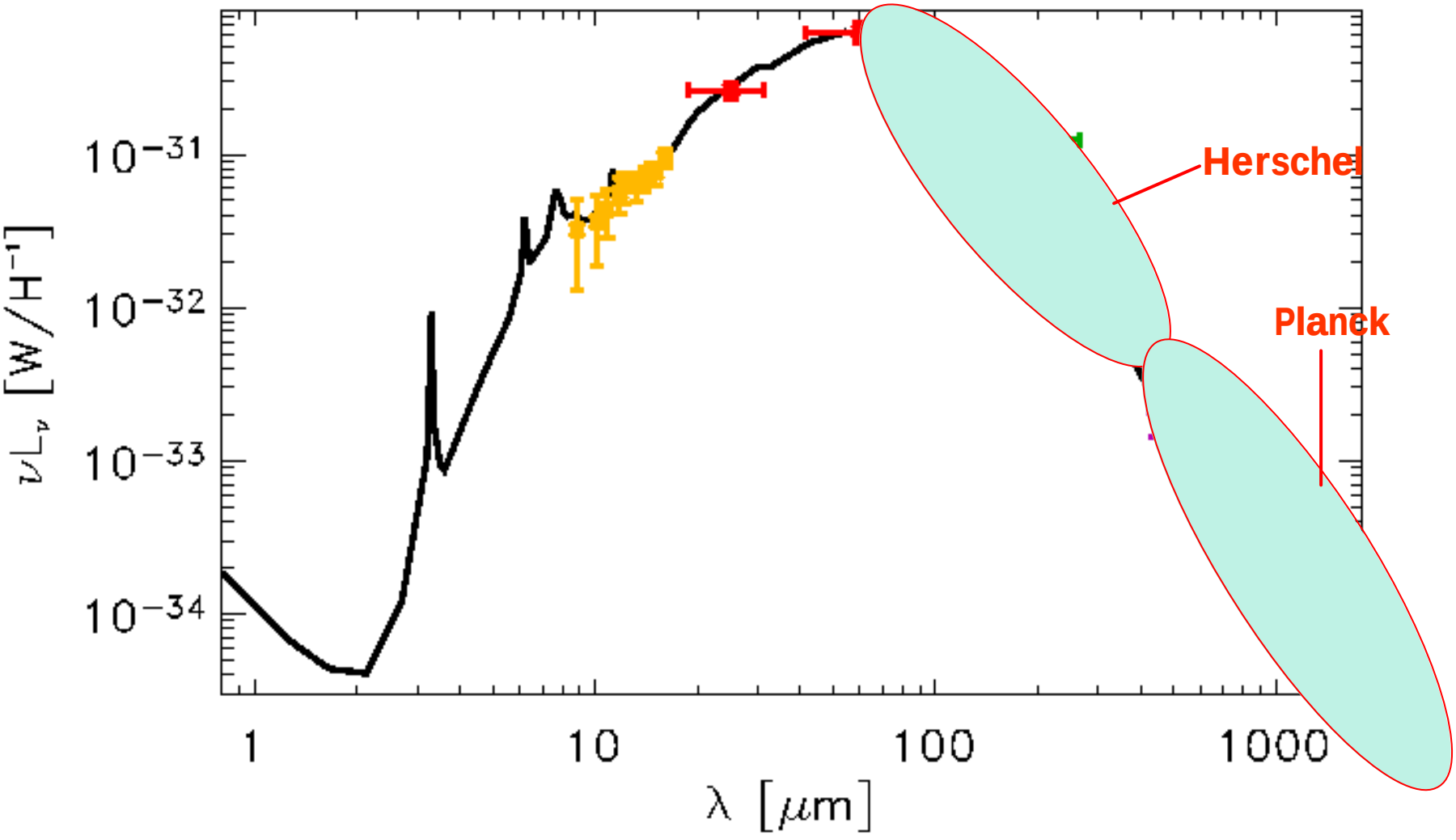
Together these programs will provide a physical basis for interpretation of dusty galaxies in the early universe

Key Program I: Detailed Study of Physical Processes in Nearby Resolved Galaxies

15 resolved nearby galaxies observed in detail in FIR & submm gas and dust properties

- Reference study for local unresolved galaxies and high-z galaxies - bridges the gap between local and high z
- Physics of different ISM components; 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
- Fundamental to understanding the origin of the FIR

I. Dust Properties: IR SEDs - more constraints for dust SED modeling



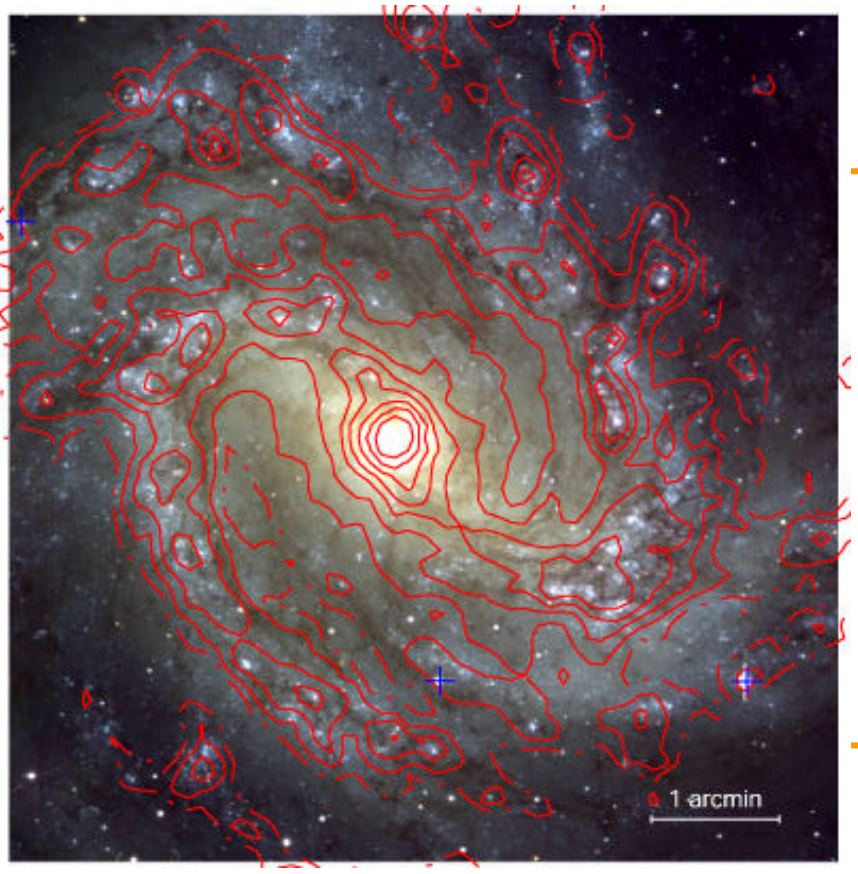
Key Program I: Detailed Study of Physical Processes in Nearby Resolved Galaxies - the Sources

Galaxy	type	FOV	D_{25}	Distance	SCUBA?	Spitzer?
M51	late-type spiral	11' x 17'	11.3'	8.0 Mpc	yes	yes
M81	early-type spiral	27' x 14'	26.9'	3.6	yes	yes
NGC2403	low mass spiral	22' x 12'	21.9'	3.2	yes	yes
NGC891	edge on spiral	13.5' x 6'	13.5'	10.5	yes	yes
M83	starburst spiral	13' x 12'	12.9'	4.5	yes	yes
M82	starburst	15' x 15'	11.2'	3.2	yes	yes
NGC6822	quiescent dwarf	16' x 14'	15.5'	0.50	no	yes
IC10	starburst dwarf	10' x 10'	6.3'	0.66	yes	yes
Arp220	late-phase merger	2' x 1'	1.5'	79	yes	yes
NGC4038/39	early-phase merger	6'x6'	$\sim$ 6'	14	yes	yes
NGC1068	Sy2	7' x 6'	7.1'	14.4	yes	yes
NGC4151	Sy1	6' x 5'	6.3'	14	no	yes
CenA	closest E; agn	26' x 20'	25.7'	3.8	yes	yes
NGC4125	normal E	6' x 3"	5.8'	17.5	yes	yes
NGC205	dwarf E	22' x 11'	21.9'	0.72	no	no

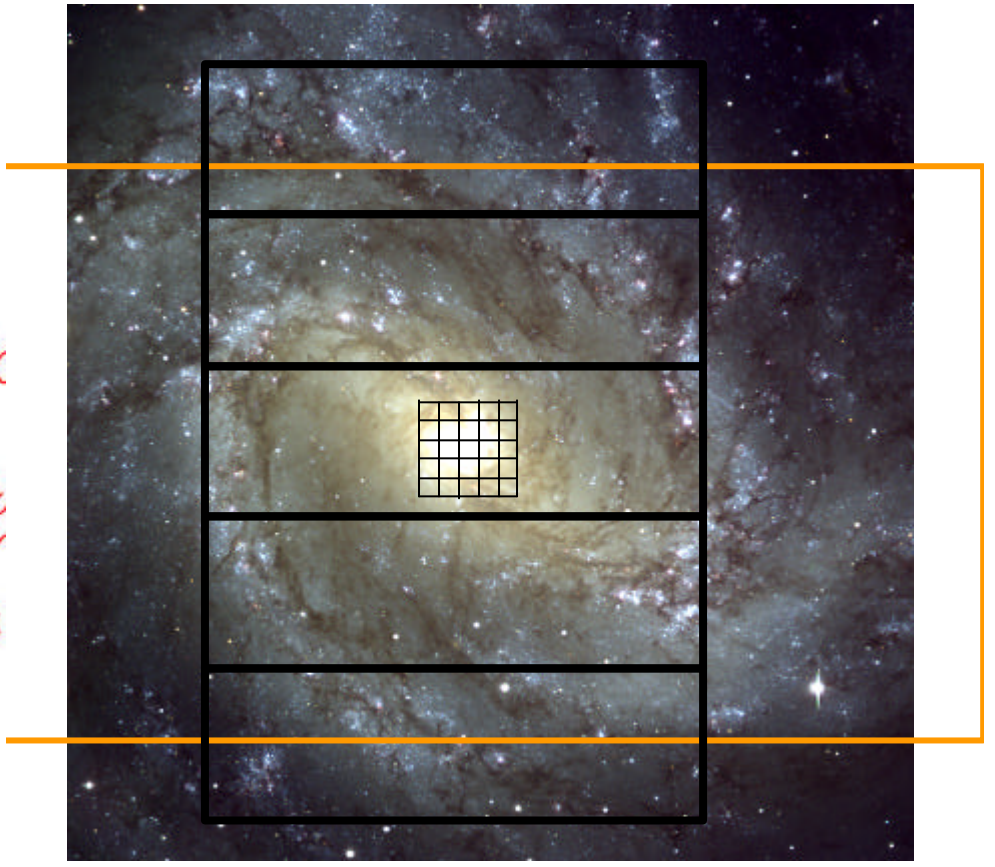
Key Program I: Detailed Study of Physical Processes in Nearby Resolved Galaxies - the Observations

Galaxy	FOV	PACS fields	SPIREphot	PACSphot	PACSspec	HIFI/FTS*	Total
M51	11'x7'	7	2.1	2.1	2.8	3	10.0 hr
M81	27x14'	18	5.4	5.4	5.2	3	19.0 hr
NGC2403	22x12'	14	4.4	4.4	4.4	3	16.2 hr
NGC891	13.5'x6'	9	2.2	2.2	3.3	3	10.7 hr
M83	13x12'	–	3.0	3.0	–	9*	15.0 hr*
M82	15x15'	–	3.7	3.7	–	9*	16.4 hr*
Arp220	2x1'	–	0.3(J)	0.3(J)	–	–	0.6 hr
NGC4038/39	6'x6'	–	1.5	1.5	–	–	3.0 hr
NGC1068	7x6'	–	1.6	1.6	–	–	3.2 hr*
NGC4151	6x5'	–	1.4	1.4	–	3	5.8 hr
CenA	26'x20'	16	6.9	6.9	4.1**	9*	26.9 hr*
NGC4125	6x3'	4	1.2	1.2	2.2	3	7.6 hr
NGC205	22'x11'	14	4.1	4.1	4.4	3	15.6 hr
Total			37.8 hr	37.8 hr	26.4 hr	21/27* hr	150.0 hr

Key Program I Example: Imaging M83 (D=3.5 Mpc) with PACS and SPIRE

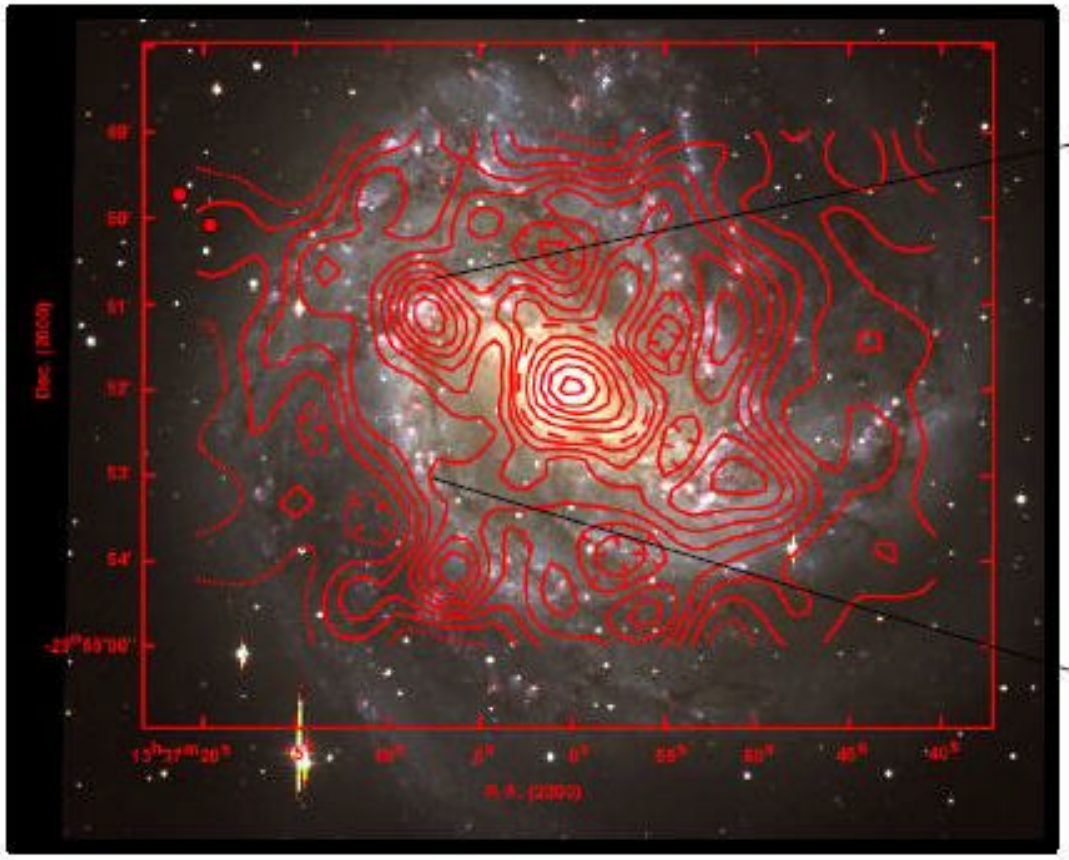


Vogler et al 2005

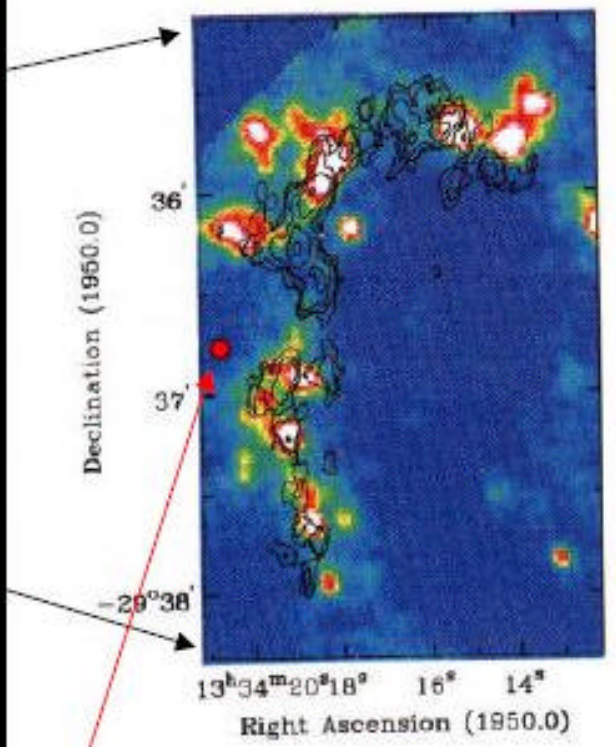


Contours: ISOCAM 7 mu
Image:VLT/FORS B R I
6“ beam with PACS
Matched to ISOCAM beam

Key Program I. FIR line mapping *within* galaxies



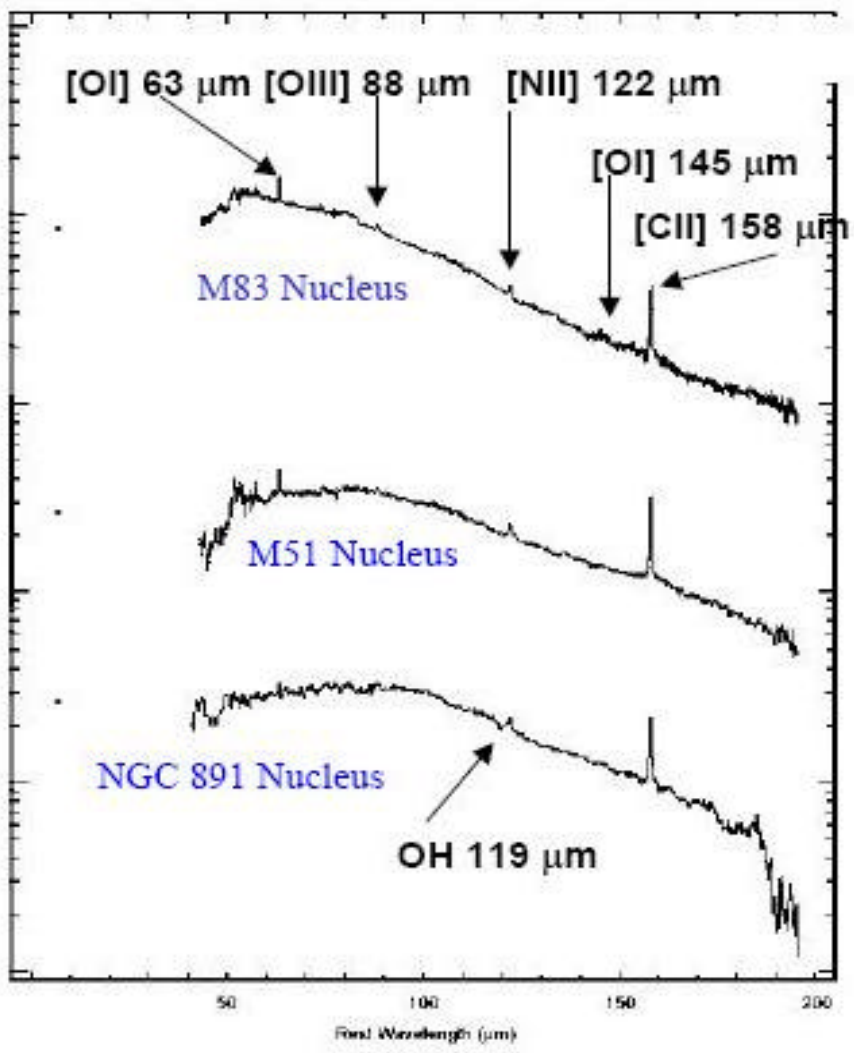
KAO Map in [CII] 55" Beam (Geis



6" Resolution CO (1-0) Map
Overlayed on false-color HI (Rand
Lord, & Higdon 1999

Herschel **Will Easily Resolve [OI] and [CII] Line Emission from Spiral Arms**
⇔ Starformation in Spiral Galaxies

Key Program I. example: variety of FIR lines in spiral galaxies



Key Program II: Evolution of the ISM of Galaxies as a function of metallicity: Dwarf Galaxy Survey

- Local universe low metallicity dwarf galaxies - analogs to high-z building blocks

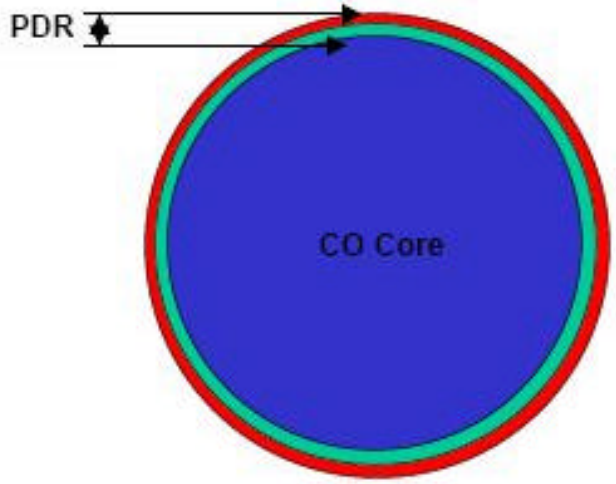
- How do metals evolve in the ISM of galaxies?

- Are dust properties different in dwarf galaxies? If so, why?
  - how does the metallicity figure in? influence of ISM structure, radiation field/star formation activity

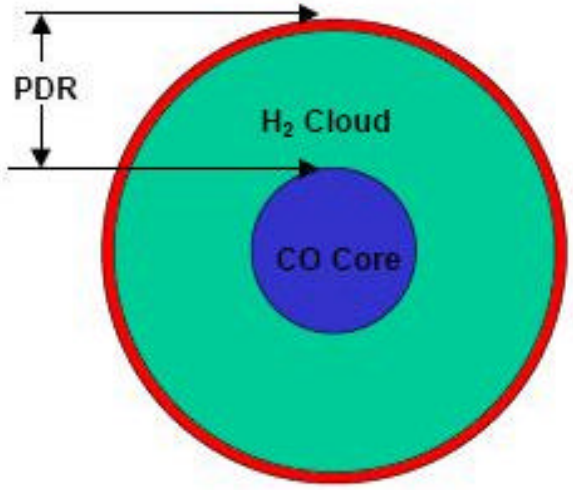
- Super Star Clusters prevalent in dwarf galaxies - profound impact on the surrounding gas and dust
  - how much SF is completely enshrouded and optically thick in NIR/MIR? (e.g. SBS0335, 1/40 solar metallicity – A_V ~ 20, Thuan et al 1999)

Requires a cohesive program of SPIRE & PACS & HIFI FIR/submm photometry and spectroscopy; other complementary data

Key Program II: Low metallicity - Effects on Molecular Clouds => structure of the ISM



Solar z cloud



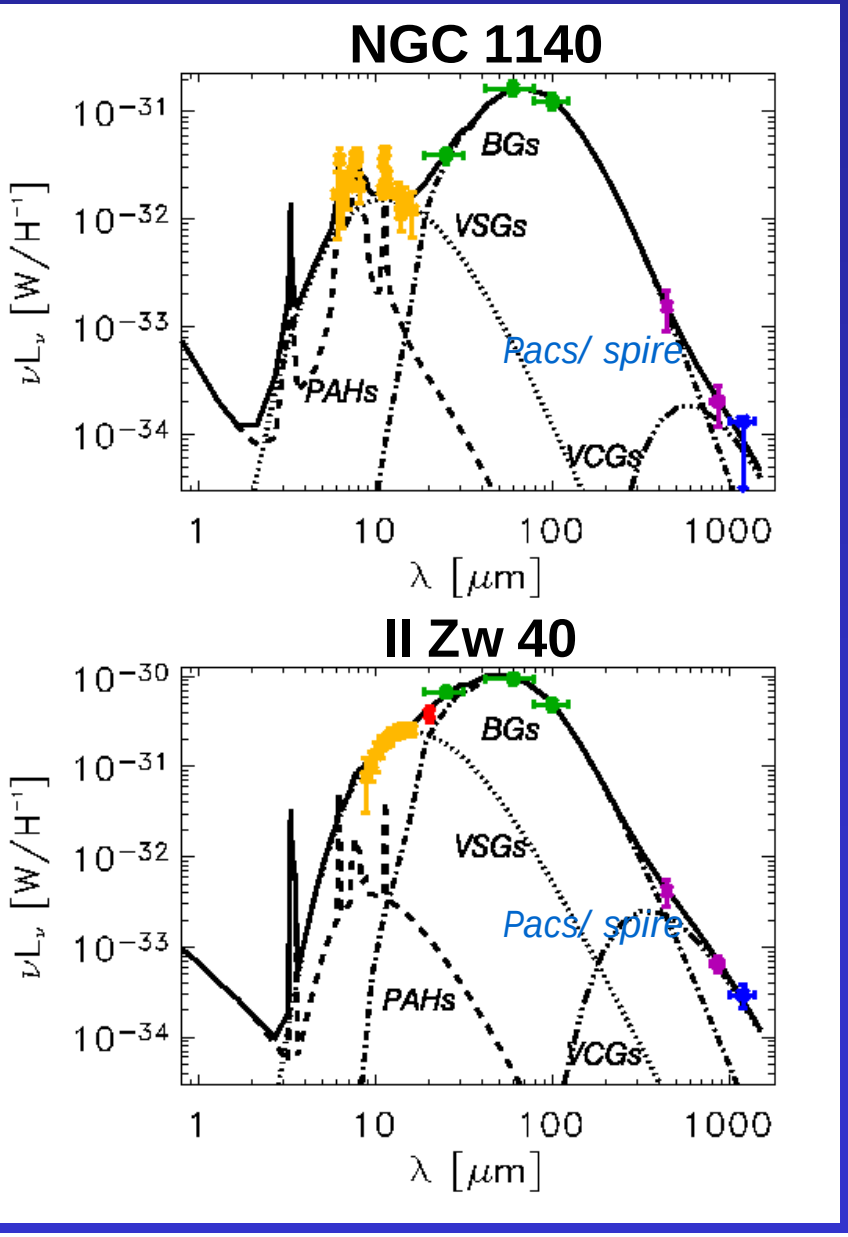
Low z cloud

- $N(C^+)$ not affected by z, since $N(C^+)$ governed by dust extinction.
- But, the linear penetration of carbon ionizing (and CO photodissociating) photons is much larger (assuming the dust to gas ratio scales with z).
- Therefore, the CO emitting core of the low metalicity cloud is relatively small
- However, the size of the molecular cloud itself is essentially unchanged since the H_2 molecule is self-shielding.

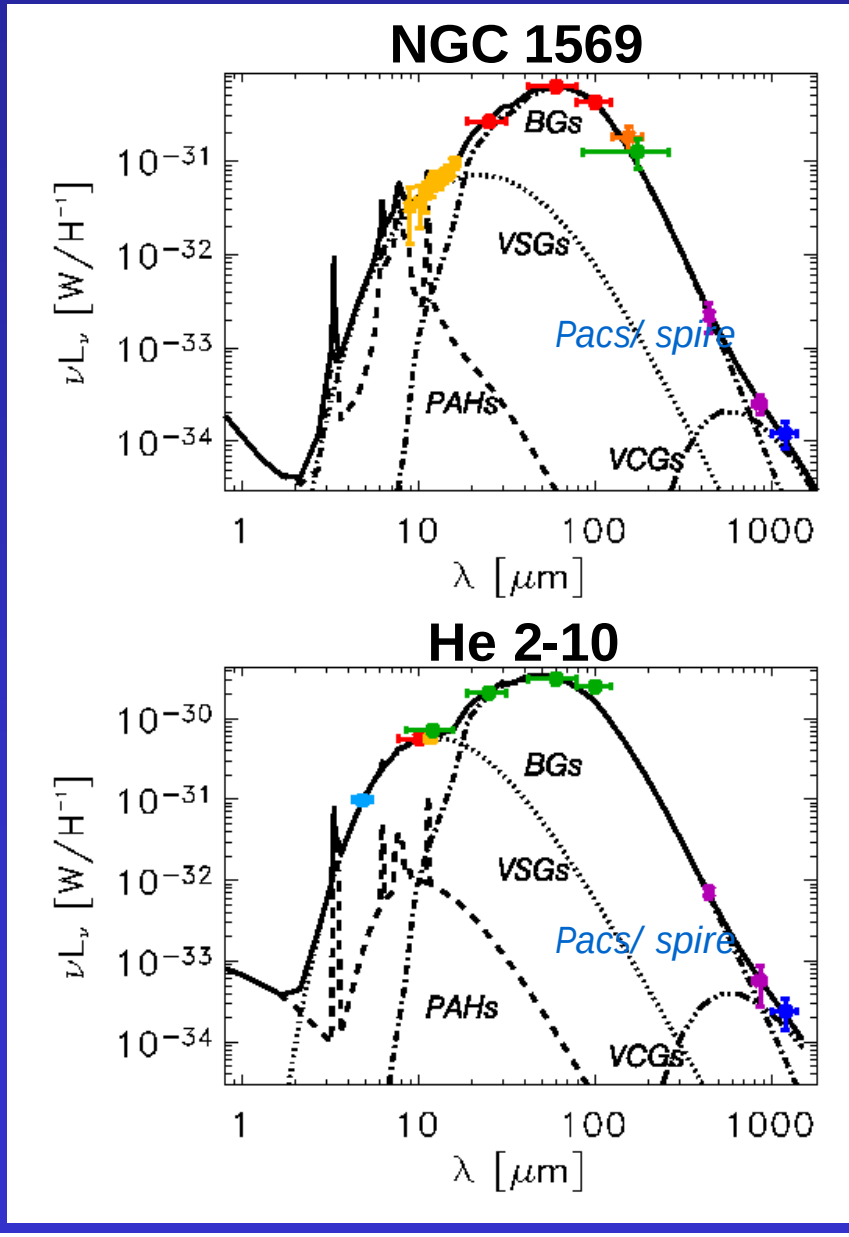
$\Rightarrow$ one can have CO free molecular clouds -- greatly affecting the CO luminosity to molecular mass conversion factor (cf. Cohen et al. 1988, and Johansson et al. 1990).

A substantial reservoir of molecular gas NOT traced by CO - Can be traced by FIR fine structure lines

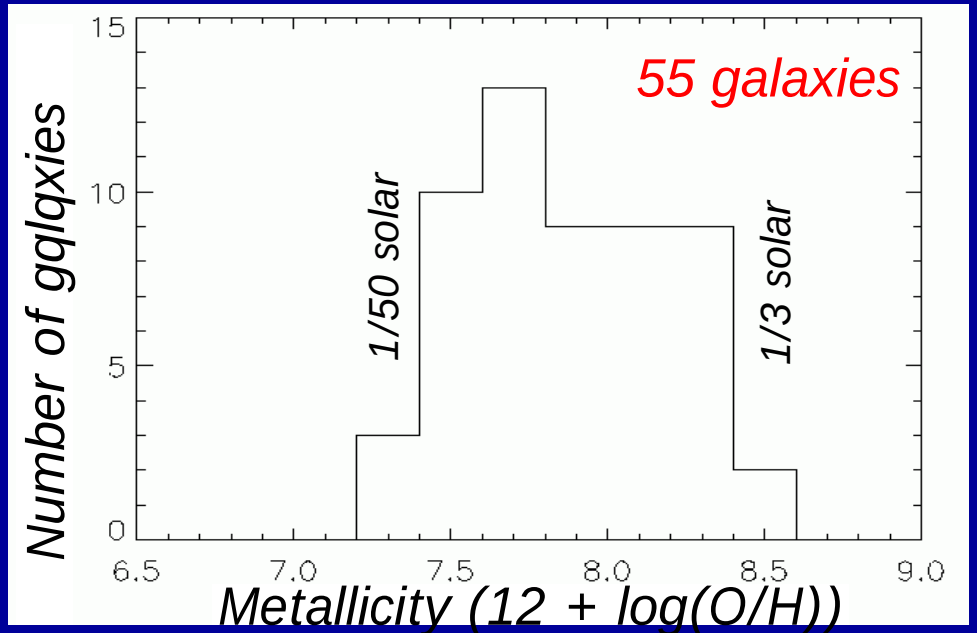
Key Program II : Dwarf Galaxies Survey: The Dust modeling



Galliano et al 2003; 2005



Key Program II: Dwarf Galaxy Survey



55 galaxies:
statistical information in each metallicity bin

Most sources observed with all 3 Spitzer instruments

Source Selection

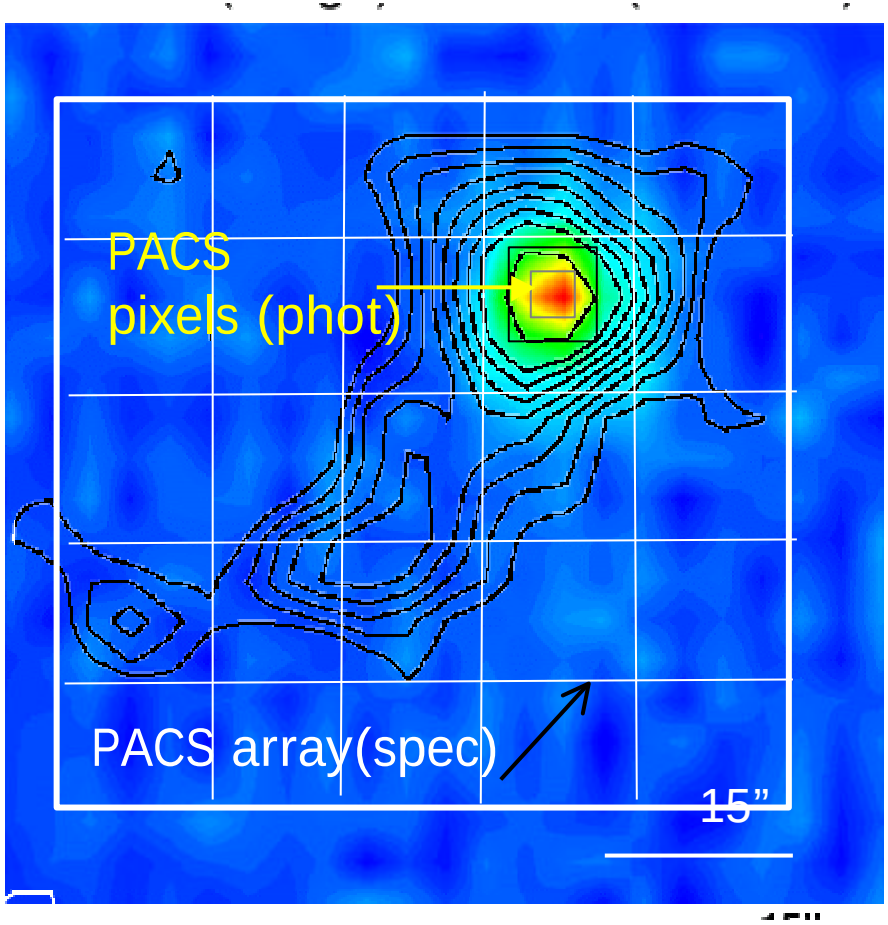
Fill metallicity bins:

at least 9 galaxies in 7 bins (accuracy 30%) where possible

Numerous extremely low metallicity: 1/50 to 1/20

Key Program II example Barely Resolved sources

IIZw40 D=10 Mpc 1/5 solar
ISOCAM : image (unresolved)
SCUBA (850 mu): contours - evidence for merging



SPIRE photometry s/n ~ 5
To the level of 8 mJy (to see merging remnants)
250, 350, 550 mu :1.8 hr jiggle (11mJy
1 hr scan (9mJy)

PACS photometry s/n ~ 10
75, 110, 170 mu 100 mJy .7 hr

PACS spectroscopy
CII, OI63, OI145,OIII88, NII122,
NII205 1hr (level CII ~5 Jy, 10 s/n)

total: SPIRE + PACS: 2.7 hr (lines +continuum)

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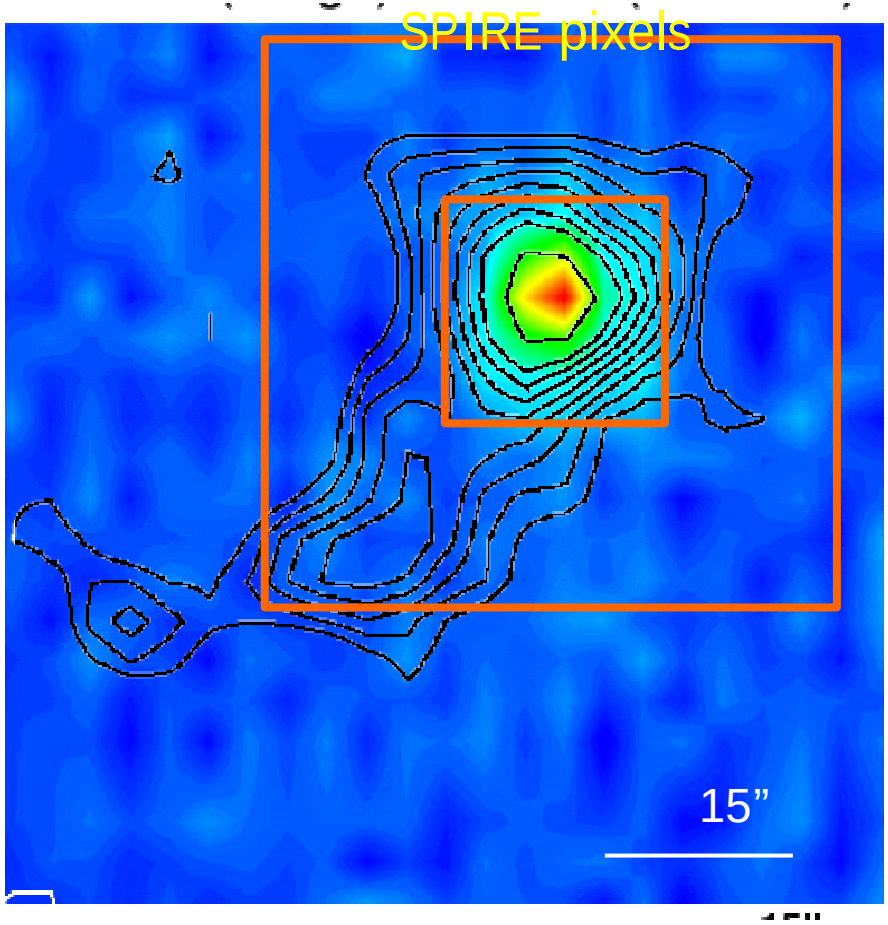

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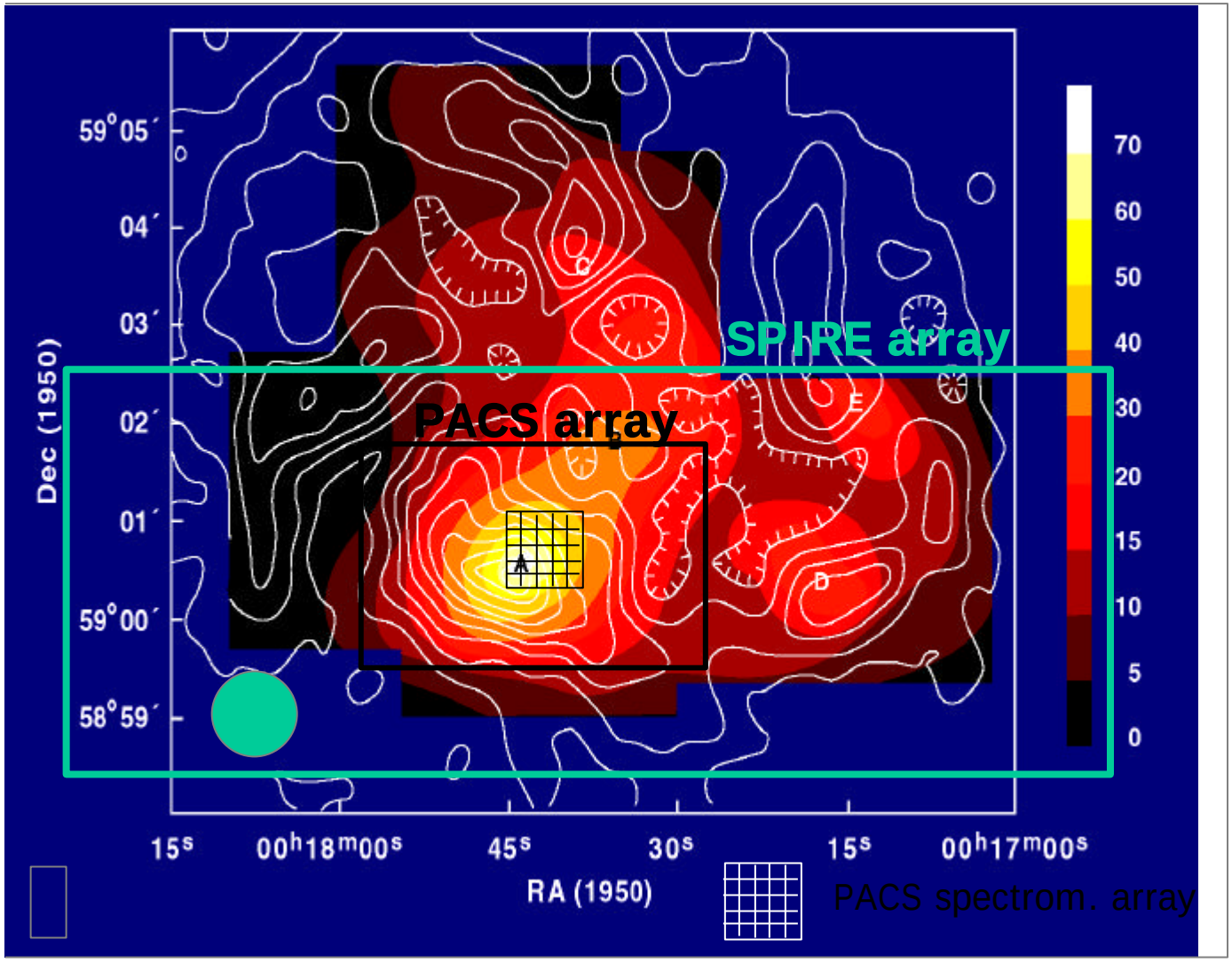
Dwarf Galaxies reolved by SPIRE & PACS IC10 (D ~ 1Mpc)



Contours: HI; Color 158 mu CII Madden et al 1997

FIR fine structure lines & molecules

KAO CII map 55" beam (image): 3 hours.

With PACS CII of 10 x10 pointings – Overhead limited

OI 63 mu –2.0 hrs.

line mapping to study the variations in star formation activity within nearby metal poor galaxies.

Key Program III : Star Formation and Activity in Infrared Bright Galaxies at z<1

measure the effects of star formation and accretion onto massive black holes in the nuclei and circumnuclear regions of Local Galaxies.

- find the interrelations between star formation & black hole accretion
- understand how these processes influence the far-IR/submm appearance of galaxies in the Local Universe
- triggering mechanism and temporal evolution of IR activity
- essential for the study of galaxy evolution

Key Program III: Star Formation and Activity in Infrared Bright Galaxies at z<1

- FIR spectroscopy: probe energetics, obscuration and physical conditions of dusty, infrared bright galaxies (starbursts, AGN, (U)LIRGs)
  - using tools like HII region/photoionization diagnostics (e.g. spatially resolved [N III]/[N II], [N III]/[O III]) and PDR modeling (e.g. spatially resolved [C II]/[O I])

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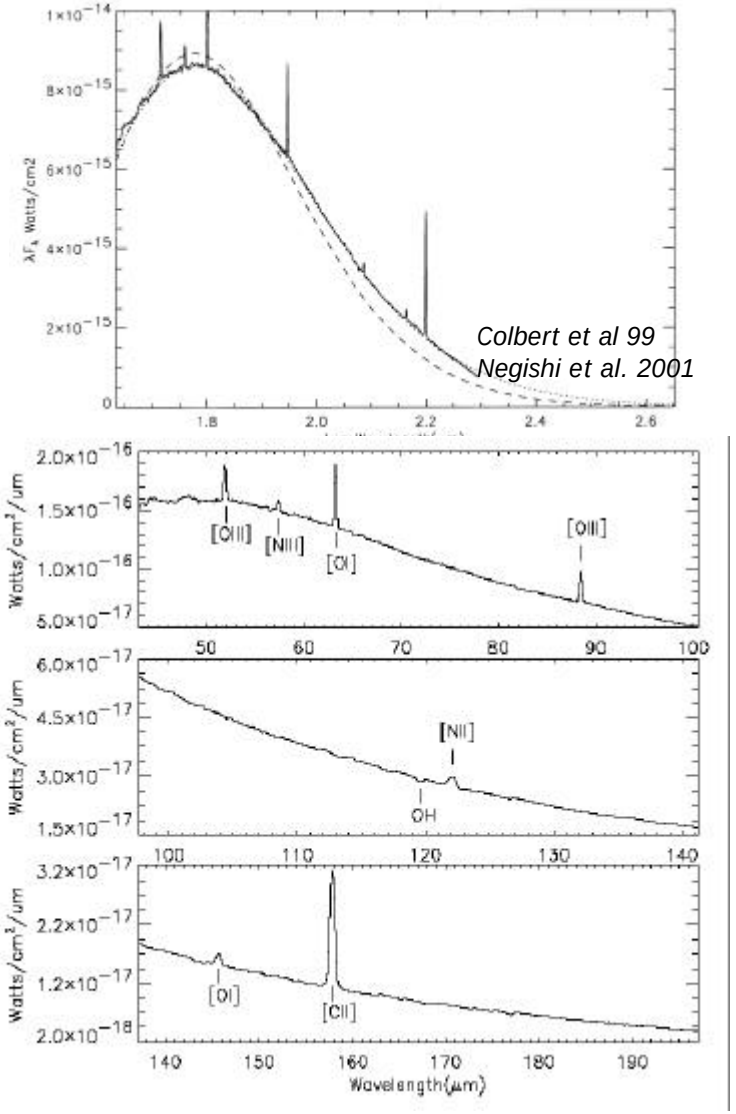
  - using tools like HII region/photoionization diagnostics (e.g. spatially resolved [N III]/[N II], [N III]/[O III]) and PDR modeling (e.g. spatially resolved [C II]/[O I])
  - Full PACS + SPIRE range spectroscopy in 5 galaxies

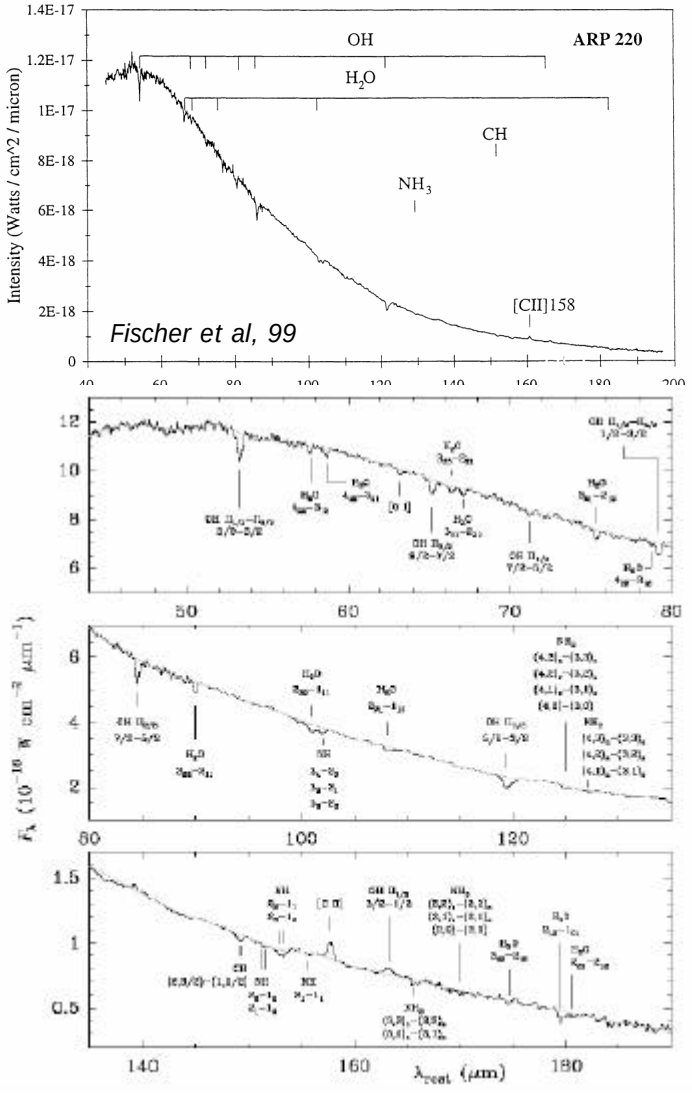
- Photometric mapping in six FIR/submm

- PACS + SPIRE bands (70 mu, 110, 170, 250, 350, 550), to study triggering mechanisms and evolution of a large sample of interacting
- galaxies, SBs, AGN, and ULIRGs

Starbursts & Environmental diversity:
M82 (3.4 Mpc) Arp220 (72 Mpc)

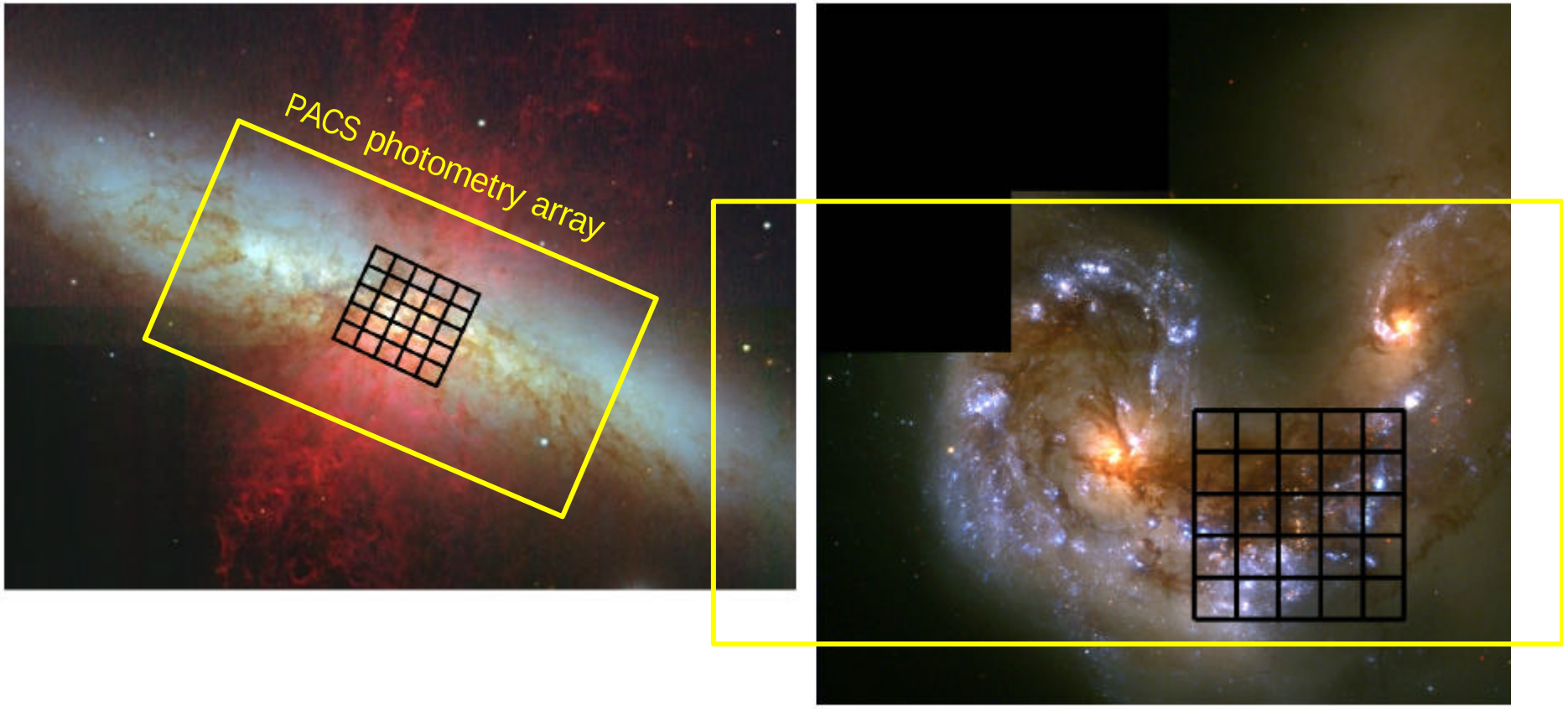


Colbert et al. 99



Gonzalez-Alfonso et al. 04

Key Program III Examples: M82 and The Antennae



PACS spectrometer array

Key Program IV. **The Herschel galaxy reference survey:** main objectives

For galaxies of different type and luminosity:

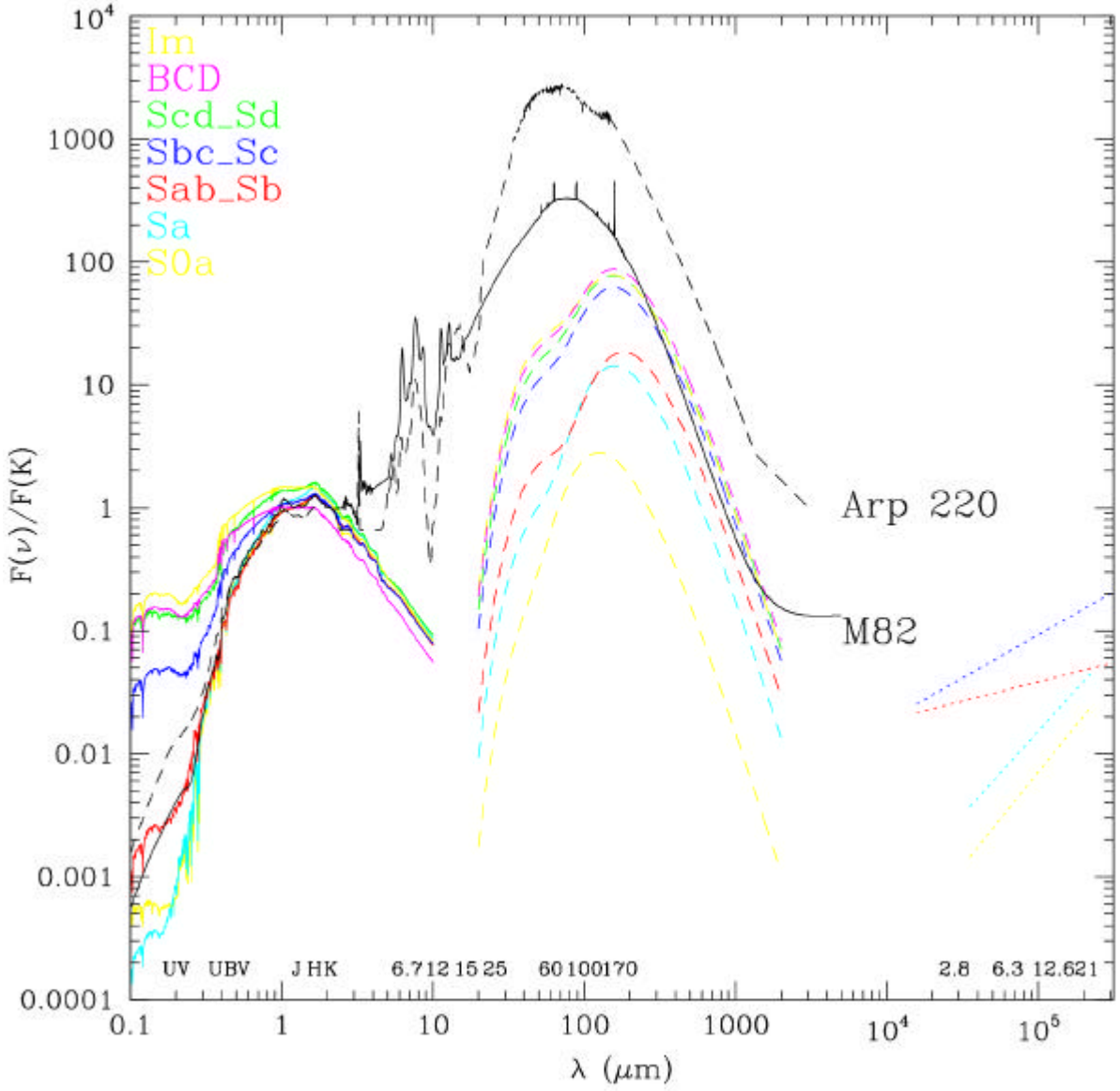
-**Dust properties** (mass, temperature, gas to dust ratio,..)
-**The role of dust in the physics of ISM** (relation with SFR)
-**Spectral Energy Distribution**
•**Effects of the environment on dust properties** of nearby galaxies (clusters vs. field)
• **Intergalactic dust** cycle
•**Dust properties in ellipticals** :merger history (dusty disks) and origin of dust in ellipticals
•**Local dust-mass function**

Key Program IV. **The Herschel galaxy reference survey: Why only SPIRE?:**

the peak of the dust emission in “normal” galaxies ~ 200 µm

SPIRE traces dust mass

IRAS, ISO, Spitzer, AKARI < 200 µm



Key Program IV. **The Herschel galaxy reference survey: The sample**

A representative sample of ~300 galaxies in the nearby universe

-distance range **15<dist<25 Mpc** (to have a volume limited sample)

- high galactic latitude (to avoid cirrus contamination) |b|>54 °

-pointed observations of few tens of minutes per galaxy at 250, 360 & 520 μm

Key Program IV. **The Herschel galaxy reference survey: the Sample**

-2MASS K selected sources (to have a luminosity/mass selection)

1) **K < 9 mag**: E + S0 + Spirals
2) **9 < K< 12 mag**: to add late type systems with a large range of luminosity and morphological type

E+S0: down to 11 mJy -> 10^4 M_{sun}(dust)
Spirals: down to 22 mJy -> to detect dust in the outer disk, from standard gas to dust ratios

313 selected galaxies, to be observed in 100 h

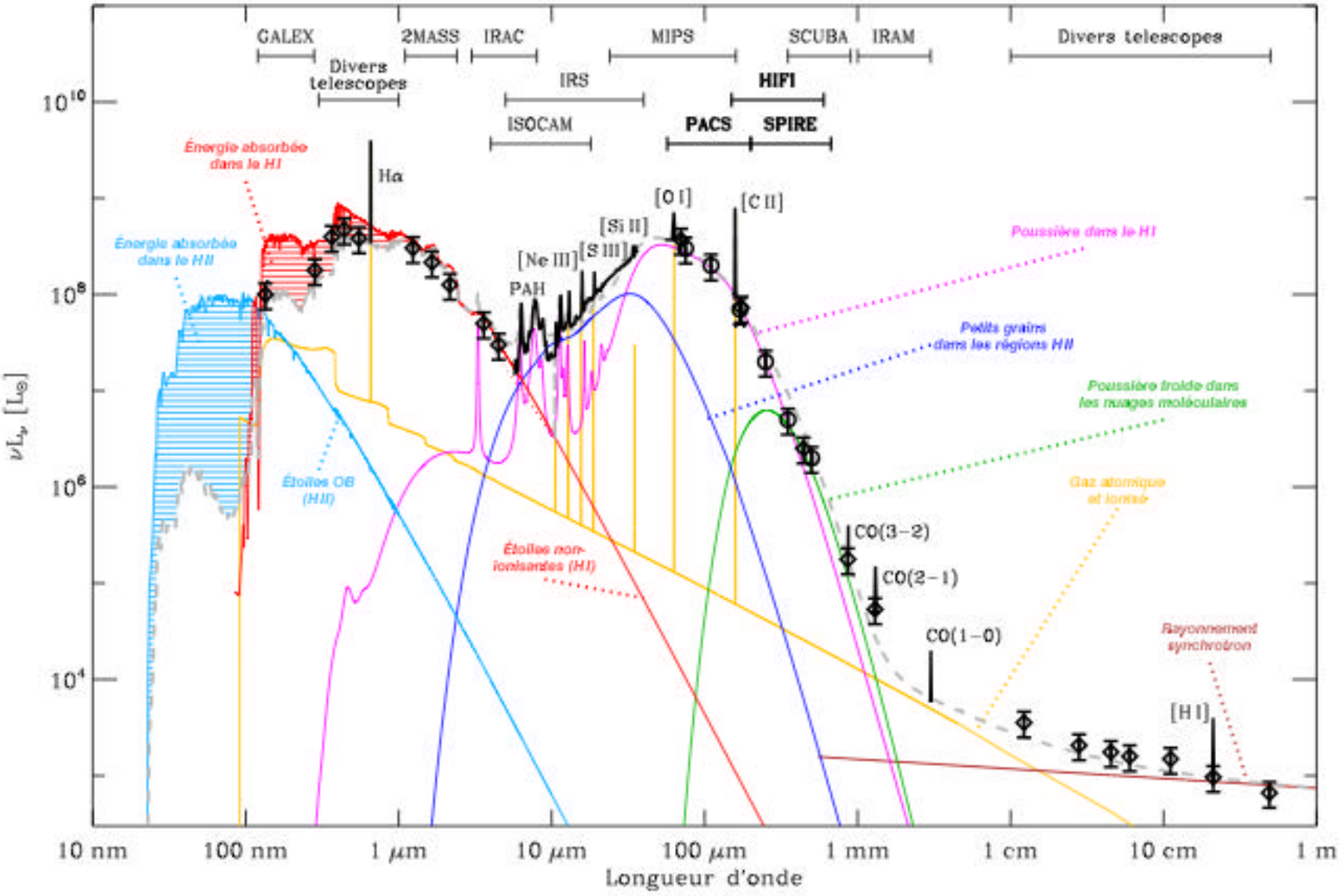
Virgo & Fornax:	K< 9 mag	36 galaxies
	9 < K< 12 mag	40 galaxies

Key Program IV. **The Herschel galaxy reference survey**: corollary data

- **Large surveys available or under way:**

-UV from GALEX (1500-2300 A)
-Visible from SDSS (u, g, r, I, z)
- NIR from 2MASS (J, H, K)
-radio continuum NVSS/FIRST (20 cm)
-R~1000 integrated spectroscopy (Balmer decrement, metallicity…) with CARELEC at the OHP
- Halpha imaging (SFR) with 2.1m telescope in San Pedro Martir (Mexico
- Mid- and Far-IR (<200 mic) from AKARI + Spitzer (to be submitted)
- HI from HIPASS & ALFALFA
-Westerbok/VLA HI : for ellipticals
-CO survey of all galaxies without CO measurements(JCMT & FCRAO)
-850 microns with SCUBA2
-Xrays from Chandra/XMM

Objective: What does an SED of a galaxy tell us? Multiphase modeling !!!



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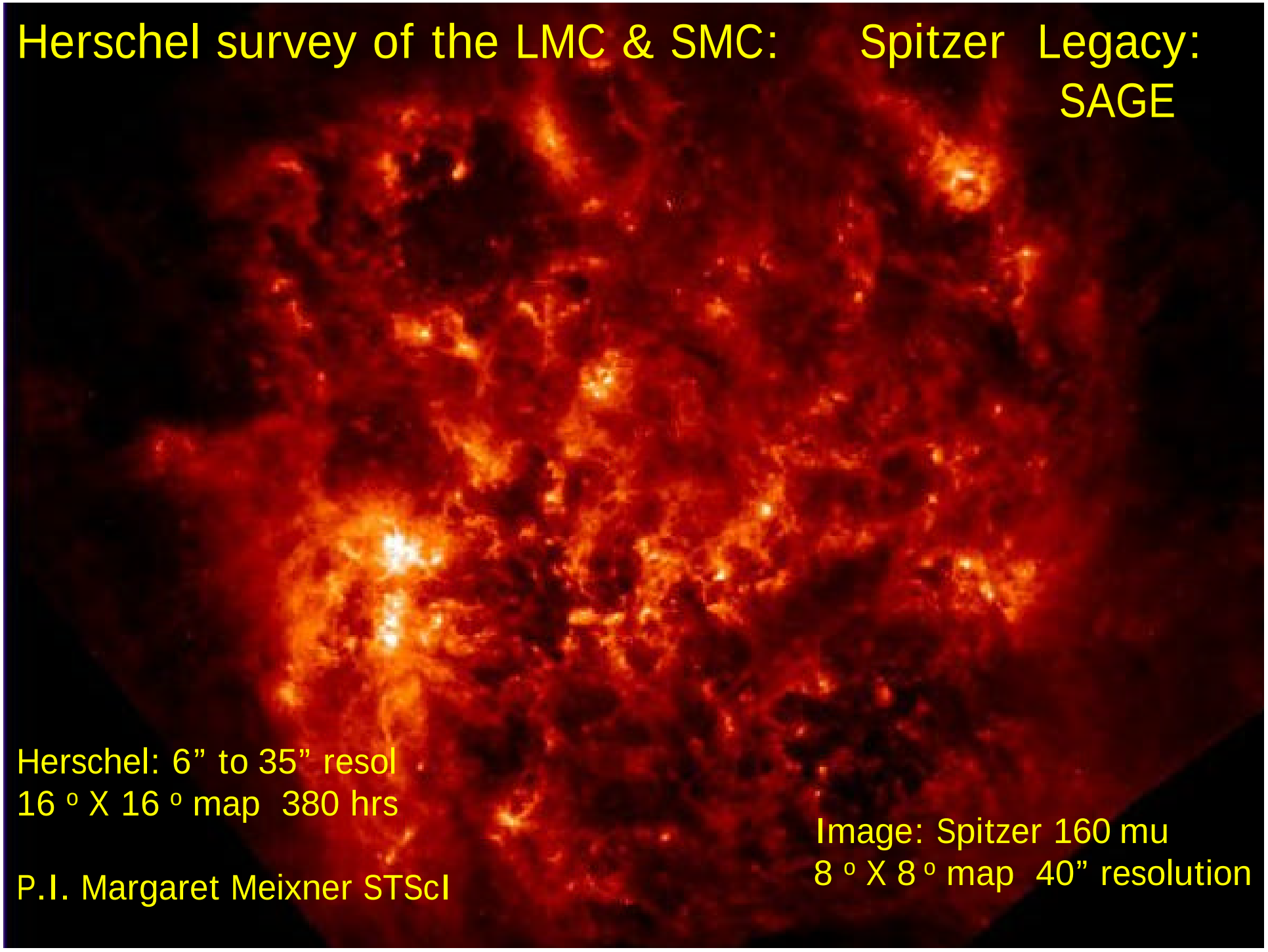

Herschel survey of the LMC & SMC:
Spitzer Legacy:
SAGE
Herschel: 6” to 35” resol
16 o X 16 o map 380 hrs
P.I. Margaret Meixner STScI
Image: Spitzer 160 mu
8 o X 8 o map 40” resolution

Some Open Time Key Programmes being proposed by the community

1. **Deep PACS survey of the COSMOS field/Chandra Deep Field South/ELAIS S1**
   - **Extend in area the confusion-limited PACS surveys**
   - **Comprehensive investigation of galaxy evolution at z < 1.5**
   - **Coordinator: Eric Bell, MPIA**

2. **SPIRE (+ PACS ?) survey of SCUBA-2/Laboca legacy areas**
   - **Complement the GT confusion-limited SPIRE survey**
   - **Comprehensive investigation of star-formation/AGN activity as a function of environment and redshift**
   - **Coordinator: Eric Bell, MPIA**

3. **Large-area shallow survey**
   - **Few x 100 sq. deg. to ~ 20 mJy rms**
   - **Strongly lensed sources, rare objects**
   - **High-z clustering**
   - **Planck foregrounds**
   - **Coordinator: Gianfranco de Zotti, Padua**

Open Time Programmes

4. **High-redshift AGN**
   - **Sample of AGN over a wide range of luminosity in a narrow redshift slice at z = 1**
   - **Coordinator: Matt Jarvis, Oxford**

5. **High-mass cluster survey**
   - **Survey 30 high-mass clusters, ten each at z = 0.4, 0.8 and 1.2**
   - **Evolution of infall/star formation in rich environments.**
   - **Coordinator: Eelco Van Kampen, Innsbruck**

6. **Herschel survey of local-universe activity: AGN vs. starbursts (HERLOGA):**
   - **AGNs as tracers for high-z FIR galaxy formation and evolution**
   - **ULIRG power source**

   Coordinator: Luigi Spignolio, IFSI

7. **Herschel follow-up to PLANCK HFI sources**
   - **Coordinator: Gianfranco de Zotti, Padua**

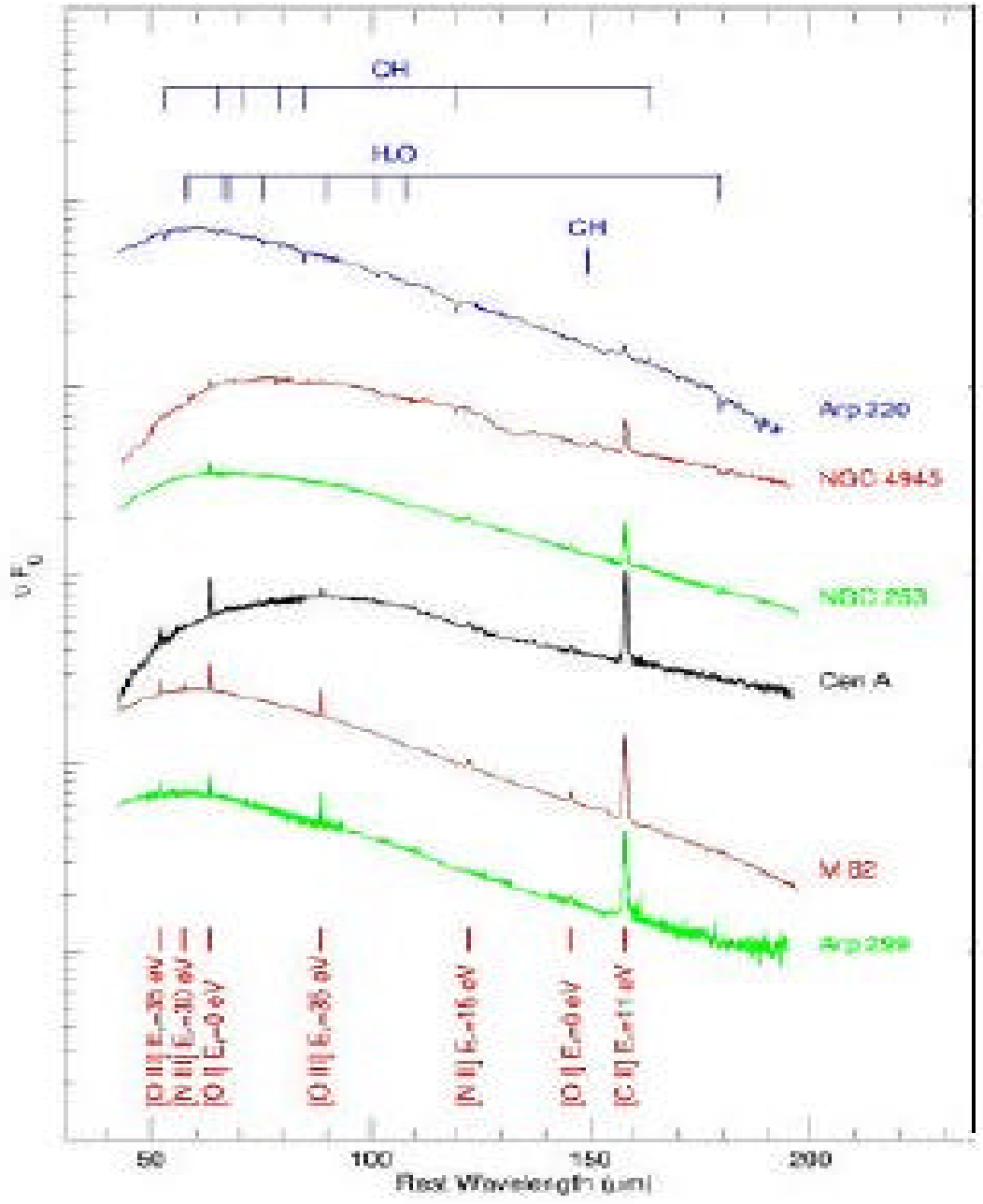
Open Time Programmes

8. **FTS surveys of the high-z universe**
   - **Coordinator: Dimitra Rigopoulou, Oxford**
9. **Extended dust around nearby galaxies and intracluster dust**
   - **Coordinator: Jon Davies, Cardiff**
10. **Dust in Ellipticals - Coordinator: Manfred Stickel, MPIA**
11. **Herschel follow-up of Astro-F/SCUBA-2 sources**
   - **Coordinator: Steve Serjeant, Kent**
12. **HIFI open-time key-programme on nearby galaxies**
   - **Coordinator: Carsten Kramer, Cologne**
13. **Herschel Survey of the Magellanic Clouds: Follow-up to Spitzer SAGE**
   - **Coordinator: Margaret Meixner (StSci)**
14. **Herschel SINGS: Follow up to Spirtzer SINGS**
   - **Coordinator: Laurent Vigroux (IAP)**

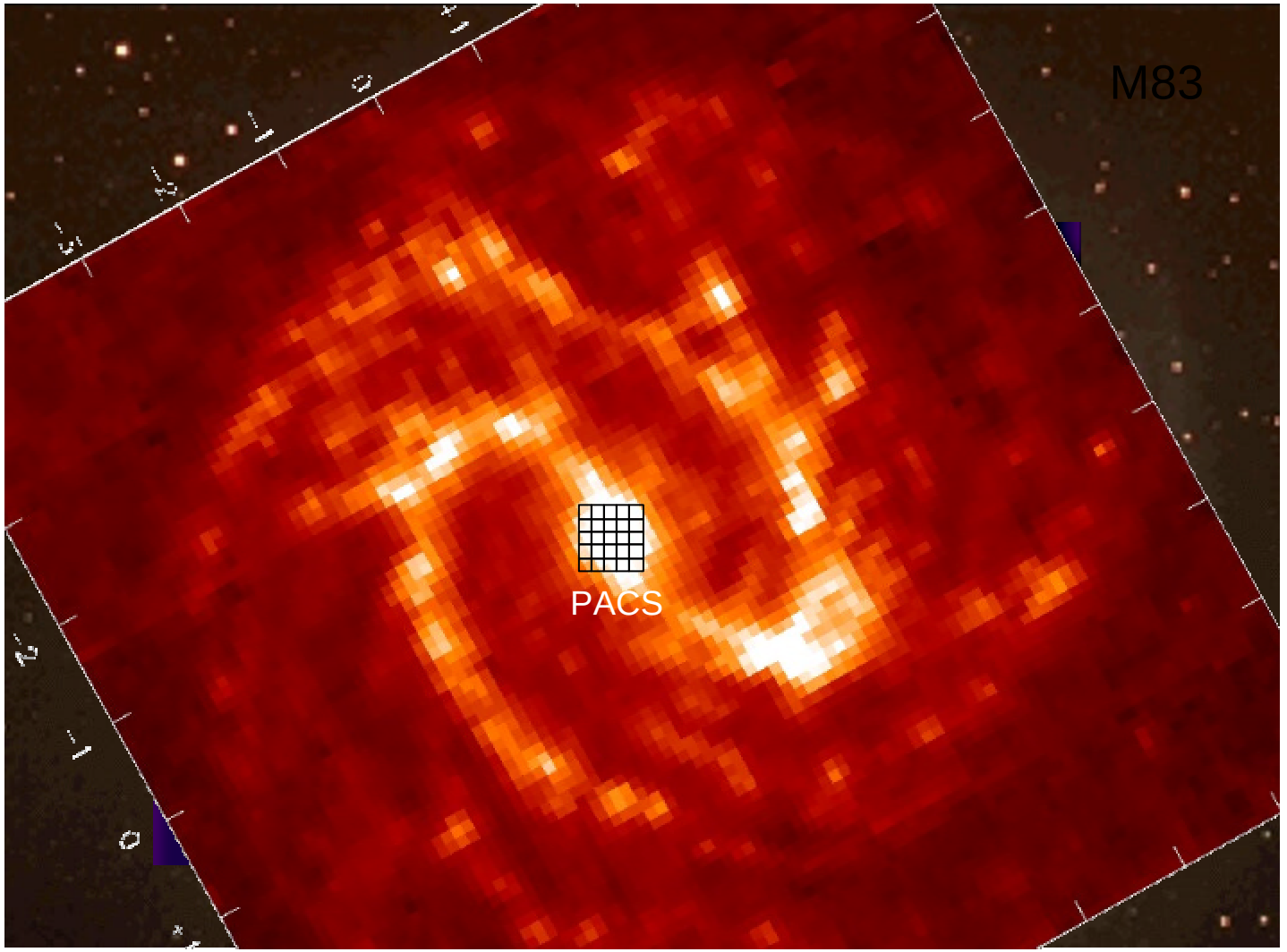
Key Program III: Star Formation and Activity

FIR lines in variety of galaxies – studies useful for interpreting cosmological galaxies

ULIRGS (ISO LWS: Fischer et al)



Star Formation and interplay with the ISM
galaxy-wide



AAT [C II] FIFI/KAO 7μm ISOCAM

PACS: [CII] 10'x10' Map $2x10^{-18}$ W/m^2 => 4 - 8 h.....+ other lines