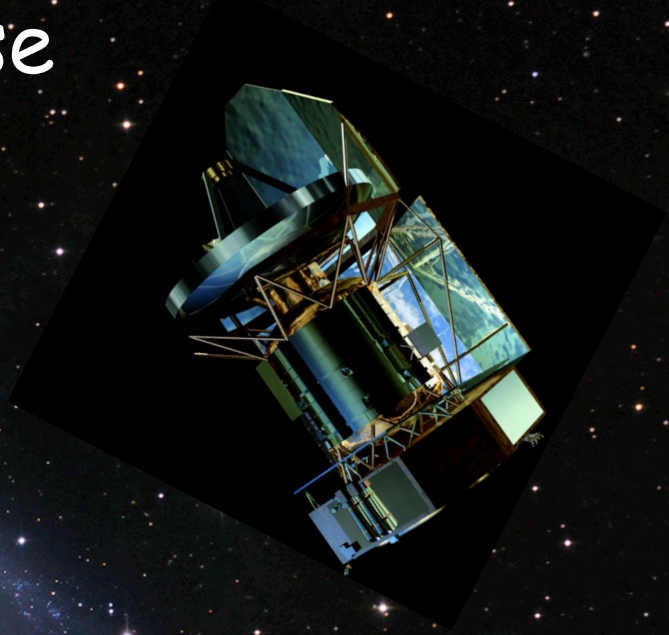
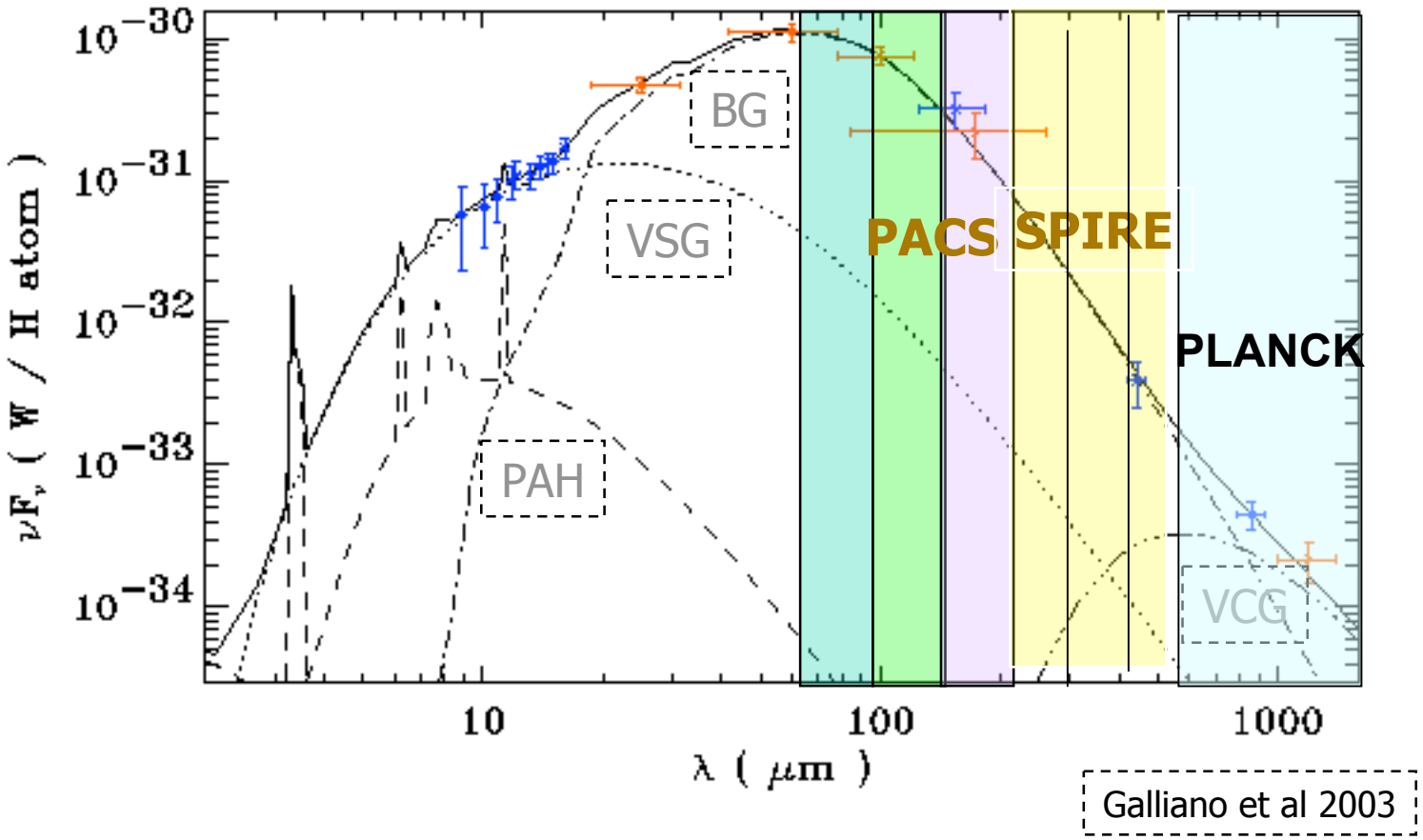
Herschel FIR and Submm Science Programs: The local universe



As seen from the SPIRE & PACS instrument consortia
(viewgraphs by S. Madden)

SED of a well-observed Galaxy - more constraints with herschel + Planck



PAHs, very small grains (VSGs), big grains (BGs), very cold grains (VCGs)

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	

→ *Determine T, n, filling factor*

[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 + lots more molecules in submm with HIFI

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 PI: C. Wilson
   Detailed photometry and spectroscopy of a wide range of galaxies (16 galaxies)
2. Physics of the ISM in low metallicity galaxies PI: S. Madden
   SEDs of 55 dwarfs, FIR spectroscopy

3. Herschel Galaxy reference survey of 320 galaxies – study the dust reservoirs in galaxies PI: S. Eales

PACS GT Team PI: E. Sturm

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

HIFI GT Team PI: R. Guesten

5. HEXGAL: 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

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

- 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?

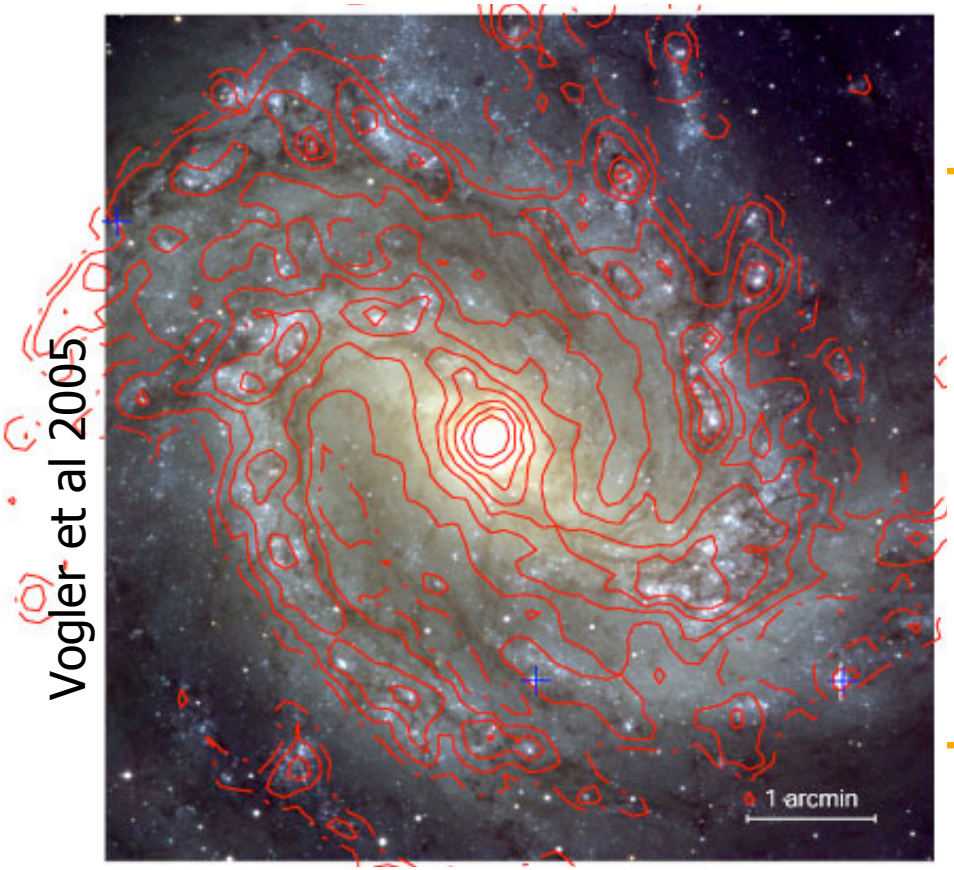
•How to disentangle effects of metallicity, star formation, morphology, history, etc from the observations?

Key Program I: Detailed Study of Physical Processes in Nearby Resolved Galaxies (PI: Wilson)

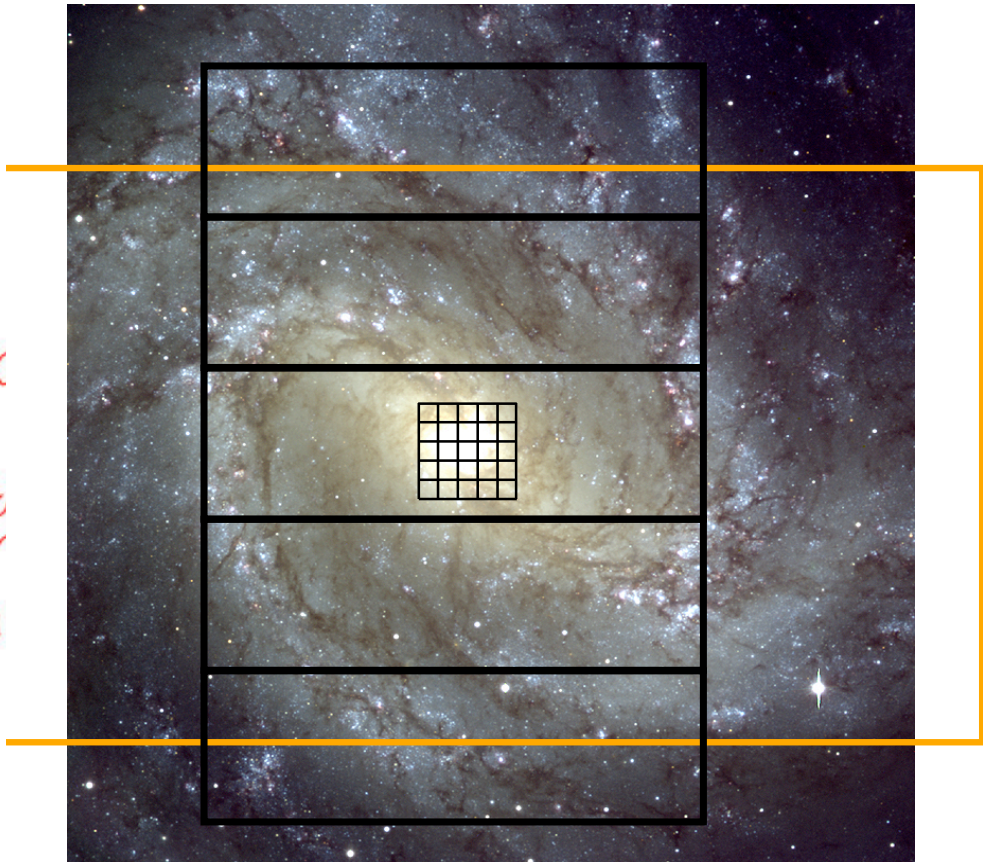
15 resolved nearby galaxies observed in detail in FIR & submm gas and dust properties

- 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

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



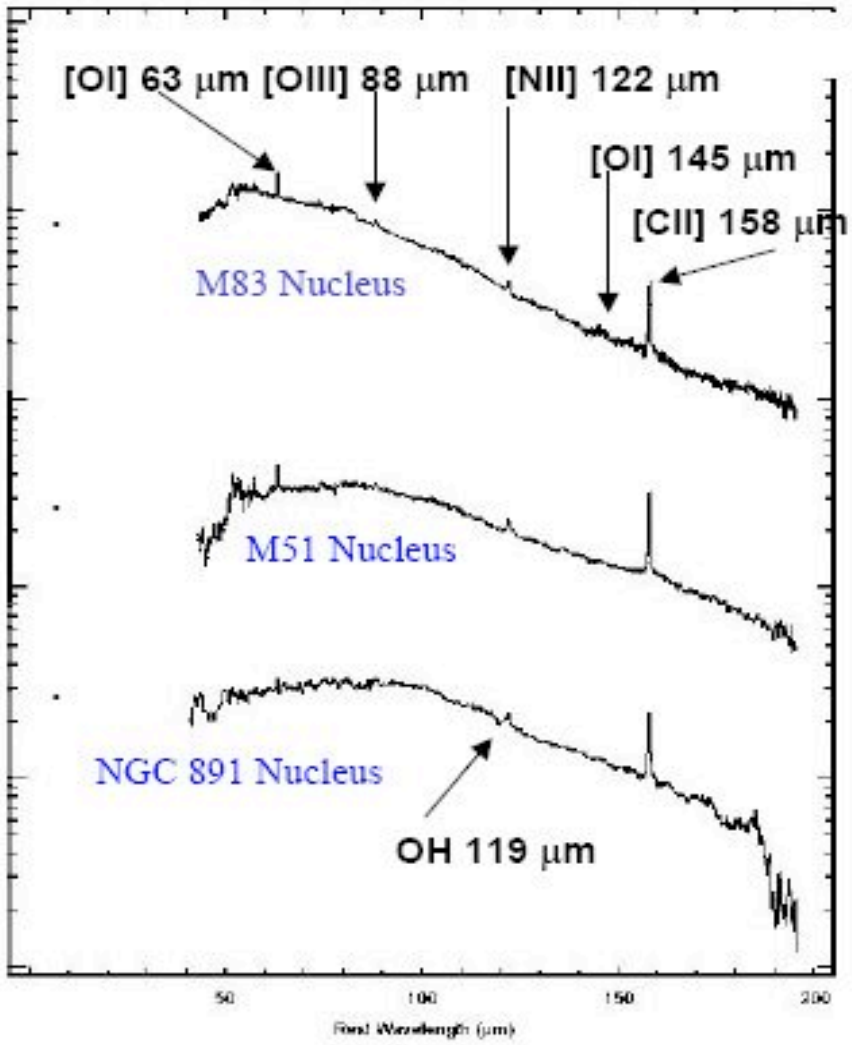
Vogler et al 2005



Contours: ISOCAM 7 mu
Image:VLT/FORS B R I

6" beam with PACS
Matched to ISOCAM beam 7 mu (PAH) & Spitzer 24 mu

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 (PI: Madden)

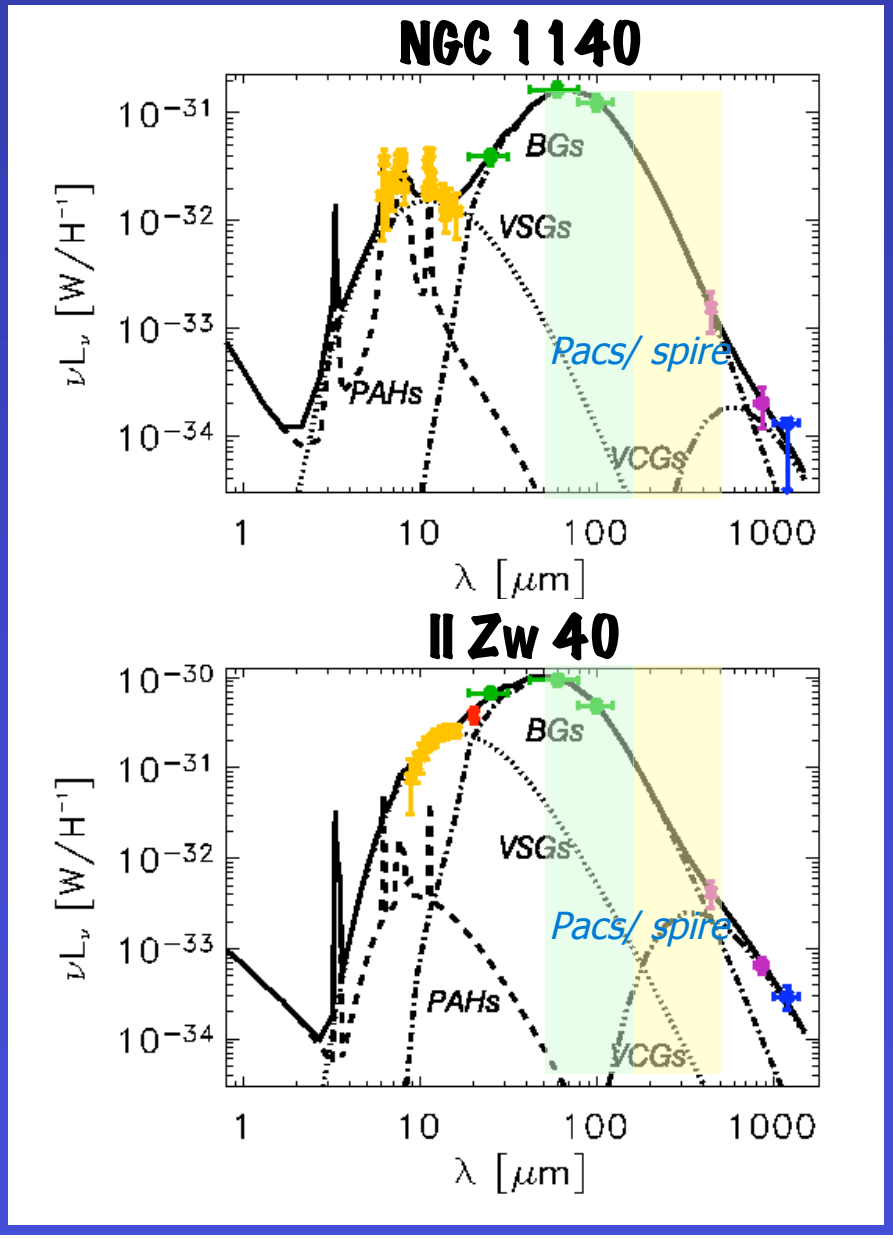
- Local universe low metallicity dwarf galaxies - analogs to high-z building blocks

- Chemical evolution: evolution of metals in the ISM of galaxies?

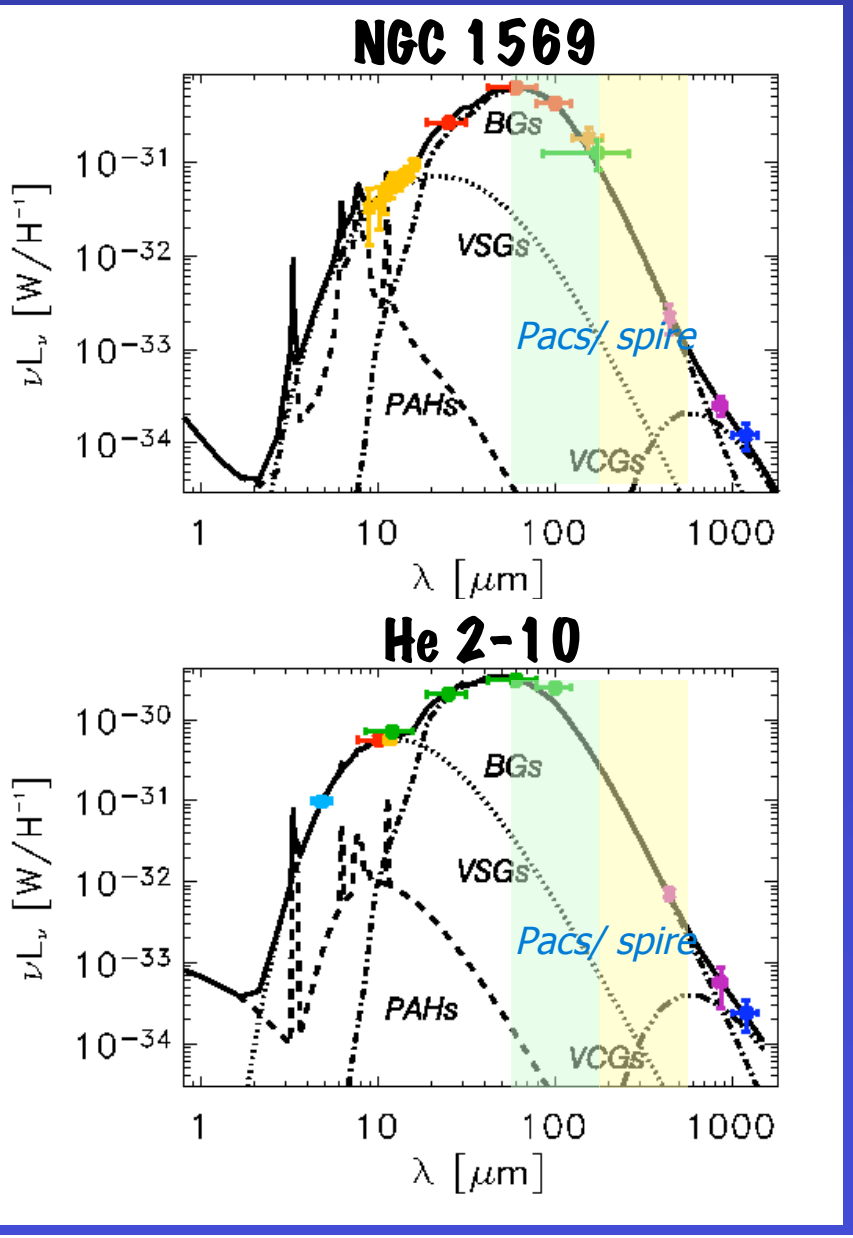
- Are dust properties different in dwarf galaxies? If so, why?
  - PAHs low abundance. How does the metallicity, ISM structure, radiation field/star formation activity figure in?

- 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; Houck 2004)

Key Program II : Dwarf Galaxies Survey: The Dust modeling: dust < 10 K

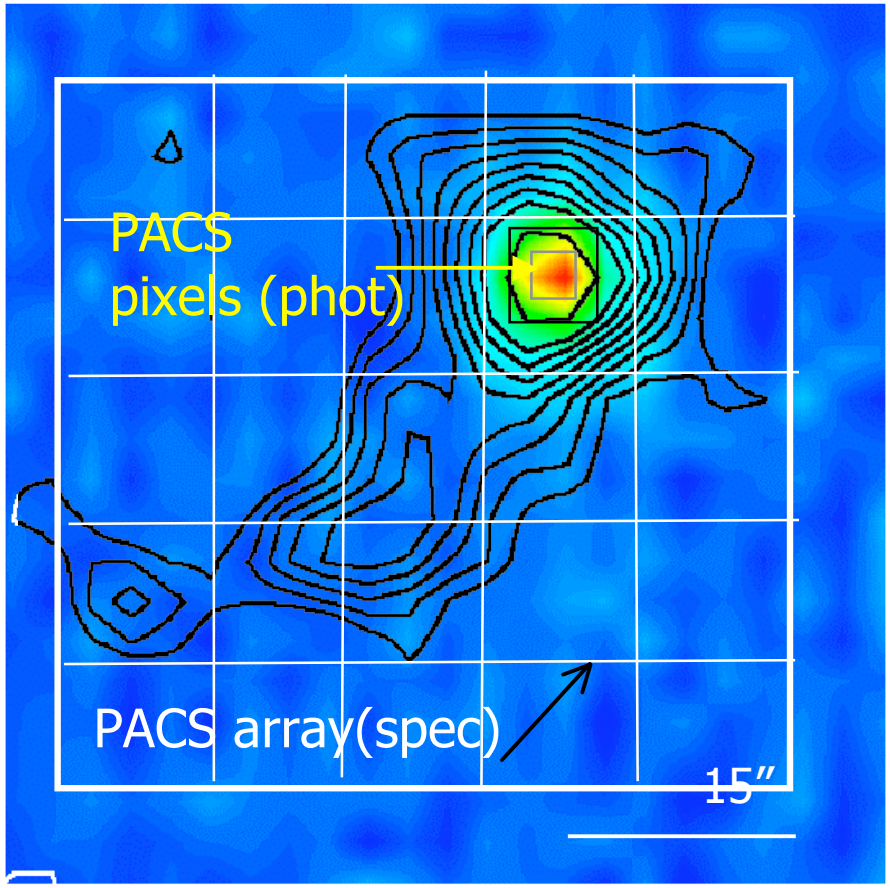


Galliano et al 2003; 2005



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)

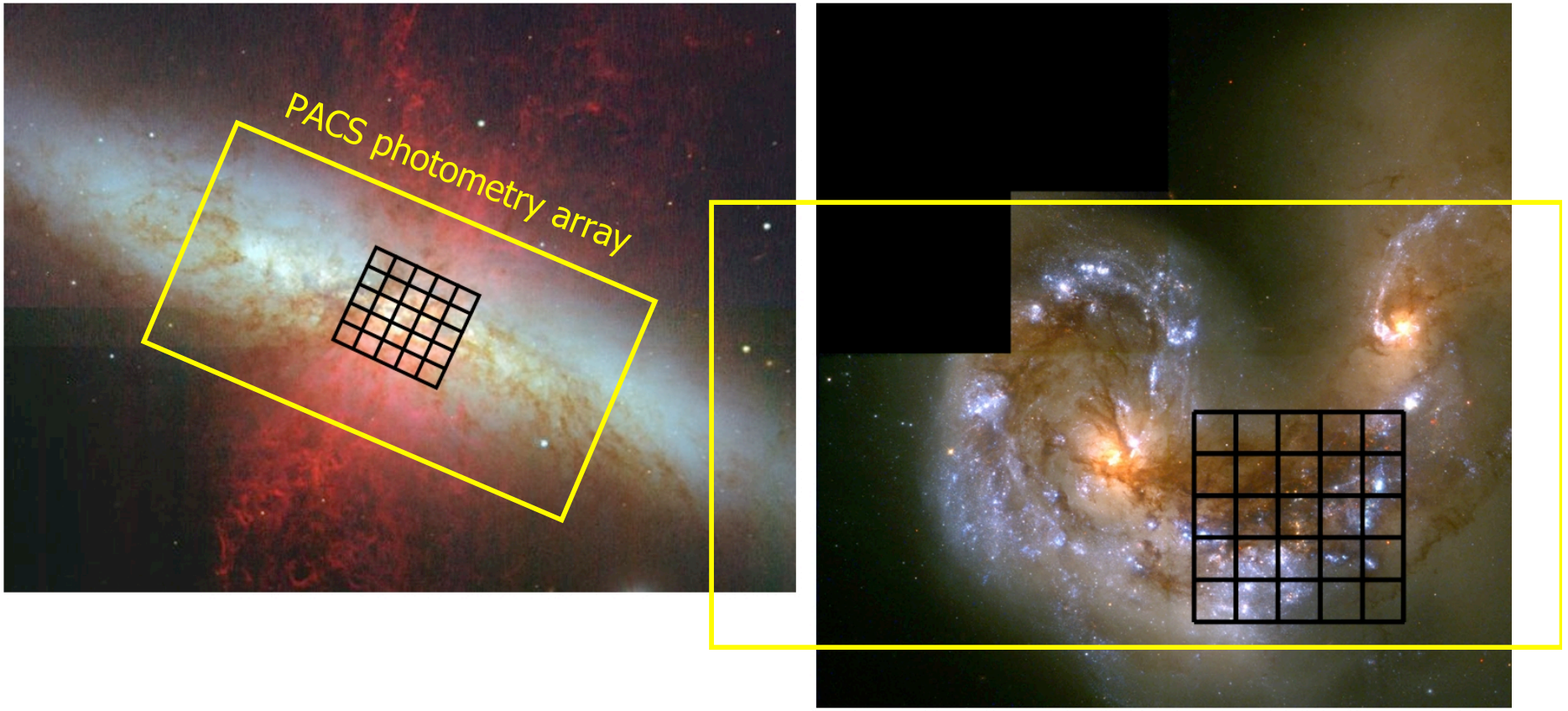
total: SPIRE + PACS: 2.7 hr (lines +continuum)

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

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 Examples: M82 and The Antennae



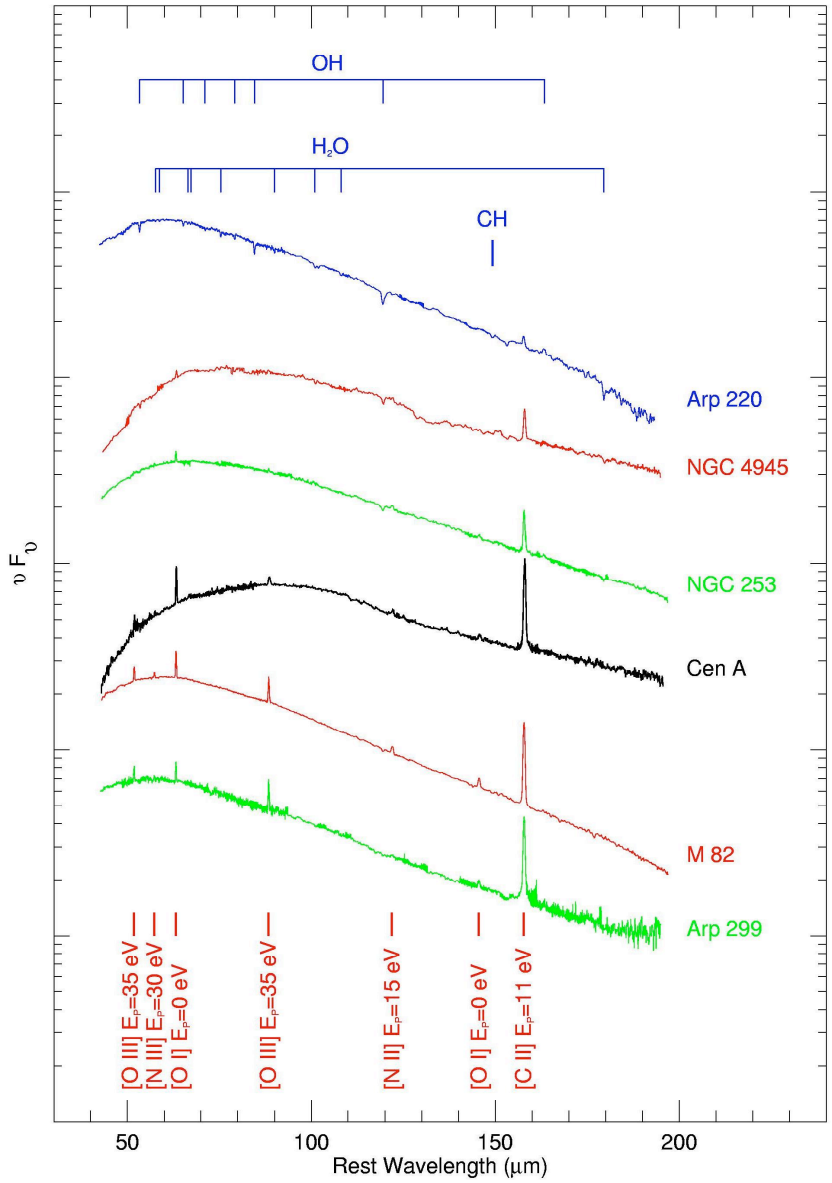
PACS spectrometer array

Key Program III: Star Formation and Activity

FIR lines in variety of galaxies –

Disentangling the roles of starbursts and AGN in the formation and evolution of galaxies

ULIRGS (ISO LWS: Fischer et al 1999)



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

FIR spectroscopy:

1. **Complete FIR(PACS)/submm(SPIRE FTS) Nuclear Spectra of Starbursts and AGN (~5 objects)**

2. **Fine-Structure Line Survey**

   ~10 SBs +~25 AGNs+ ~30 ULIRGs in [N III] 57μm, [O I] 63μm, [O III] 88μm, [N II] 122μm, [O I] 145μm, [C II] 157μm, [N II] 205μm, OH lines, high-J CO lines

   PDR and XDR modelling ; HII regions/photoionisation modelling

3. **Diagnostic lines of (few) z~1 IBGs**
   ([O I] 63μm/[O III] 52μm/[O III] 88μm)

4. **Highly excited molecular emission in (few) AGN: OH** lines, high-J CO lines, H2O….

Photometric mapping:

• 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

GT Key Program IV. **The Herschel galaxy reference survey: the Sample (HRS) (PI: S. Eales)**

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)

-

•**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**

GT Key Program IV. **The Herschel galaxy reference survey (HRS)**

The Sample

-Volume-limited: distance range **15<dist<25 Mpc**

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

-**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

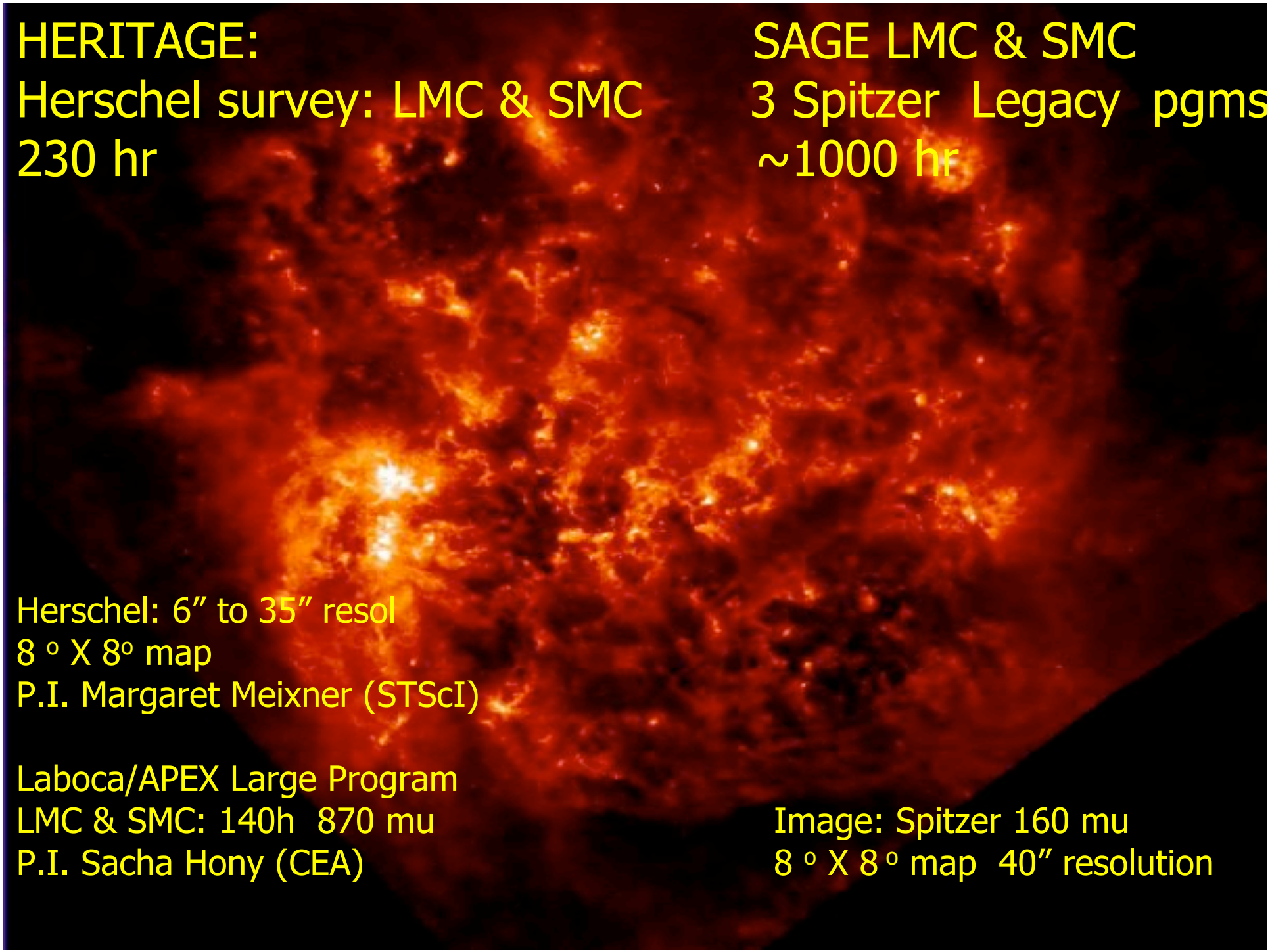
-**E+S0**: down to 11 mJy -> 10^4 M_{sun}(dust) (65 gals)

•**Spirals**: down to 22 mJy -> to detect dust in the outer disk, from standard gas to dust ratios (258 gals)

313 selected galaxies 114 hr

The "Nearby" Galaxies Open Time Time Key Programs

1. HERMES M33 Survey: PI: C. Kramer
2. HERITAGE LMC SMC survey: PI: M. Meixner
3. KINGFISH SINGS survey PI: R. Kennicutt
4. HERCULES molecular lines in ULIRGS PI: P. van der Werf
5. HeViCS Virgo Cluster survey PI: Jon Davies


HERITAGE:
Herschel survey: LMC & SMC
230 hr
SAGE LMC & SMC
3 Spitzer Legacy pgms
~1000 hr
Herschel: 6” to 35” resol
8 ° X 8° map
P.I. Margaret Meixner (STScI)
Laboca/APEX Large Program
LMC & SMC: 140h 870 mu
P.I. Sacha Hony (CEA)
Image: Spitzer 160 mu
8 ° X 8 ° map 40” resolution

Herschel M33 Extended Survey (HERMES)

a Herschel open time key project (http://www.astro.uni-koeln.de/hermes/)

C.Kramer, S.Aalto, R. Beck, F.Bertoldi, J.Braine, D.Calzetti, F.Combes, M. Dumke, S.Garcia-Burillo, R.Guesten, C.Henkel, F.Israel, B.Koribalski, S.Lord, A.Lundgren, B.Mookerjea, K.Schuster, M.Roellig, K.Sheth, G.Stacey, J.Stutzki, F.van der Tak, F.Tabatabaei, R.Tilanus, P.van der Werf, M.Wiedner, T.Wiklind, M.Xilouris

Key Topics:

A. Phases of the Interstellar Medium (ISM):
   The origin of [CII] emission

B. Energy Balance of the ISM

C. Star formation traced by [CII] and [NII]

D. Formation of molecular clouds from the diffuse atomic medium

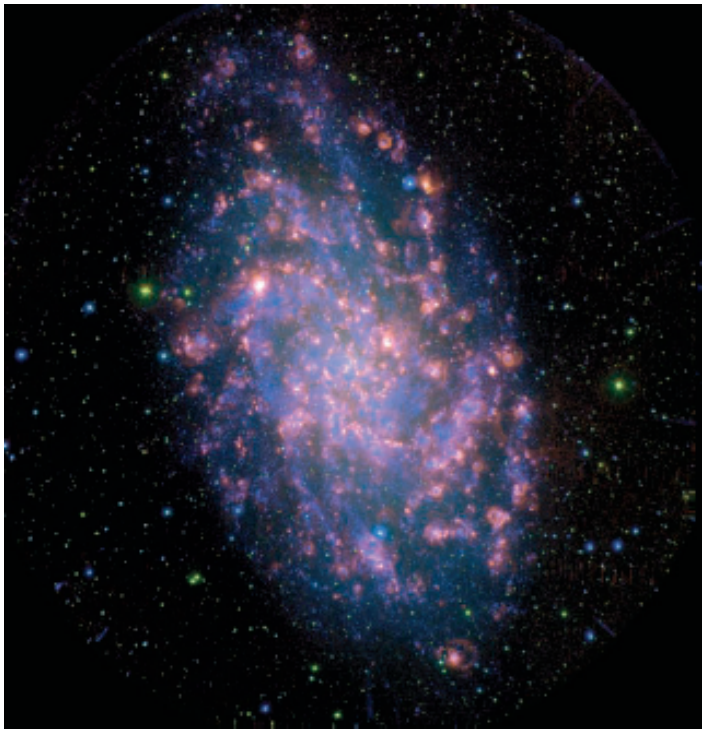
Herschel observations of the major FIR cooling lines and of the dust:

Extended Cut along the major axis:

- [CII] and H_2O with HIFI
- [CII], [NII], [OI], [NIII] with PACS

Entire galaxy:

- dust continuum between 85μm and 500μm with PACS & SPIRE



Star formation in M33: Hα+continuum (red), GALEX NUV (blue) by Thilker et al. 2005, ApJ, 619, 67

Herschel Cooling in ULIRGs Emission Survey (HerCULES)

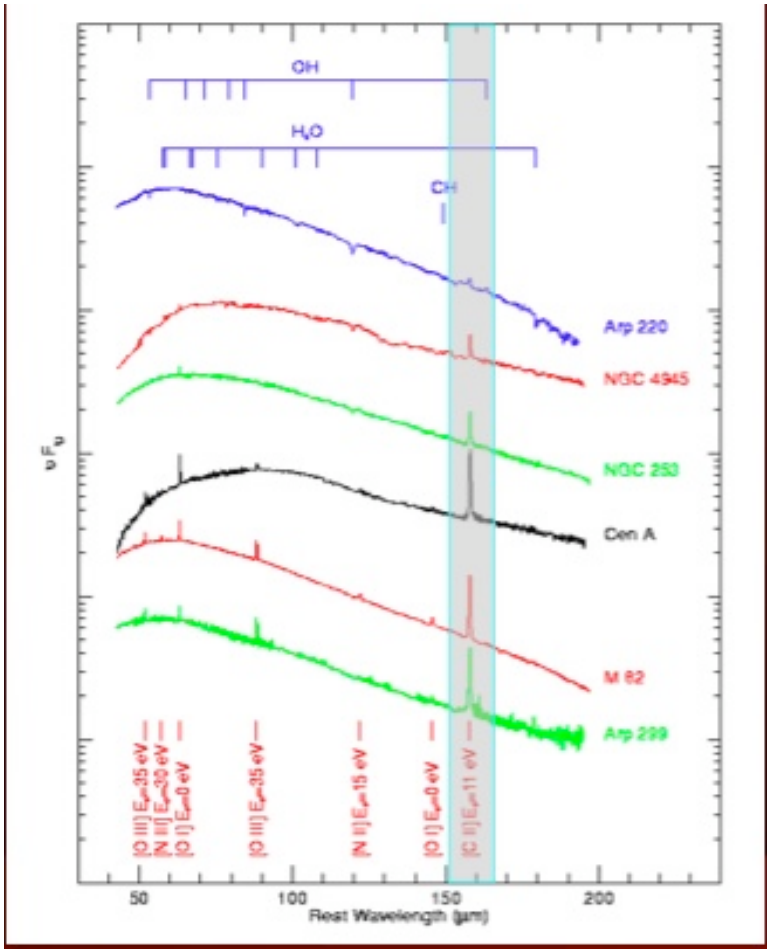
P.I. Paul van der Werf (Leiden) Herschel:100 h.

Objectives:
1. Uniformly & statistically measure the neutral Gas cooling lines in a flux-limited sample of ULIRGS
2. Derive the distribution of molecular gas mass over T, n, and relate to
3. Properties of mass, type, IR colour, IL(IR) size compactness, gas mass, power source….
4. Low Z benchmark for future ALMA

Complimentary to the GT KP of PACS team

SPIRE/FTS scans 200 to 670 mu, R~600:
CO 5-4 to CO 13-12 and [CI]
PACS line scans of [CII] and [OI] lines

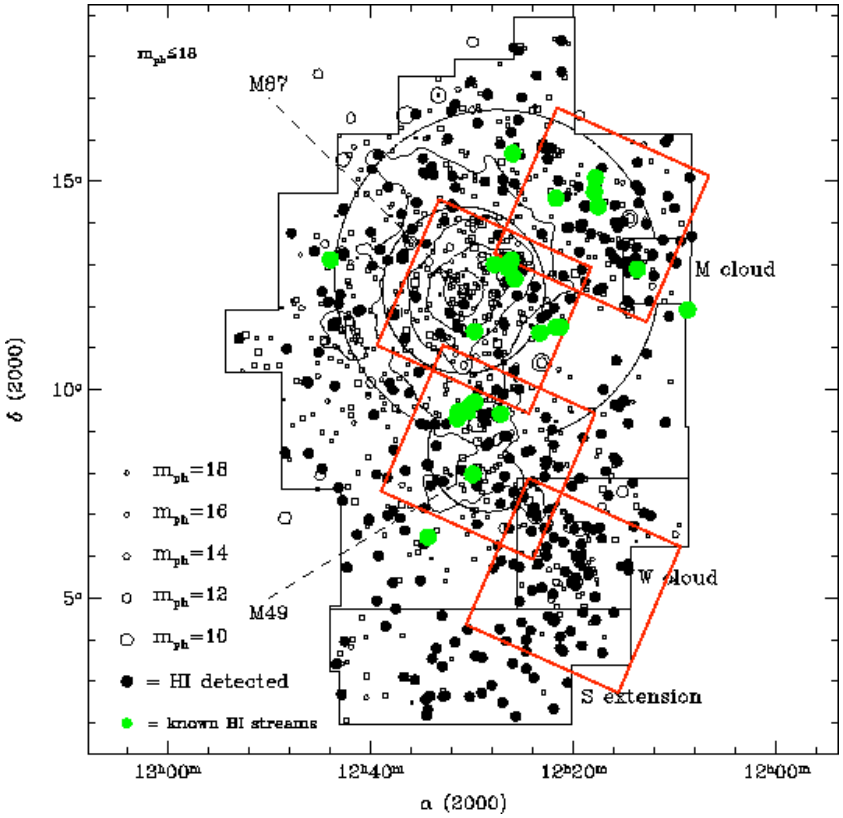
Following CO(3-2), HCN, HCO
(P.Papadopoulos, et al
ground-based obs.)



Arp220: L[CII]/L[FIR] =1.3x10-4
Normal galaxies: 10-2, 10-3

Herschel Virgo Cluster Survey (HeVICS)
P.I. Jon Davies (Cardiff) 286 hr.

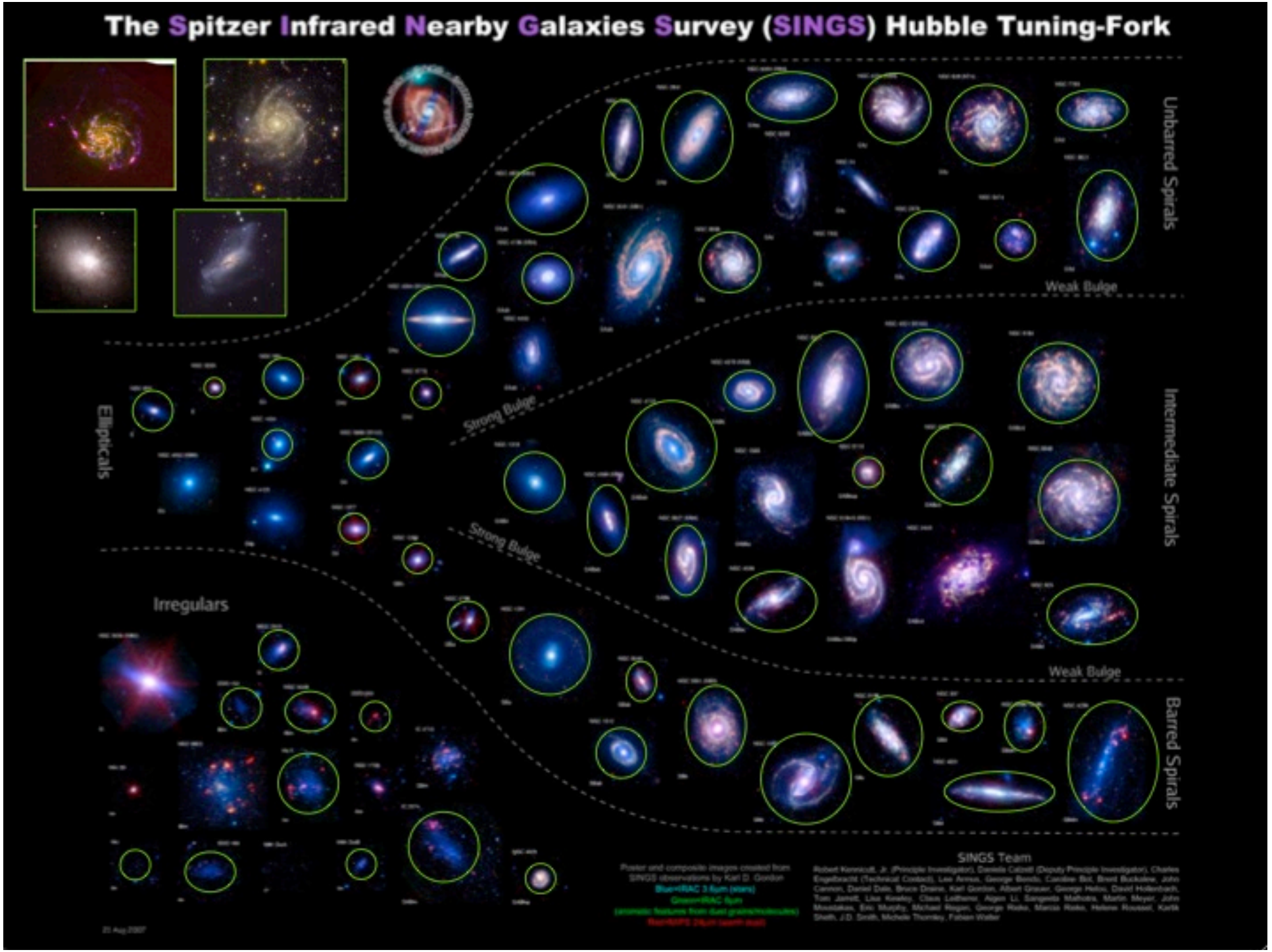
1. Galaxy evolution in the cluster environment.
2. Nearest and best studied cluster.
3. Wide range of other observations available.
4. Comparison with other more distant clusters.
5. Galaxies and intra-cluster environment.



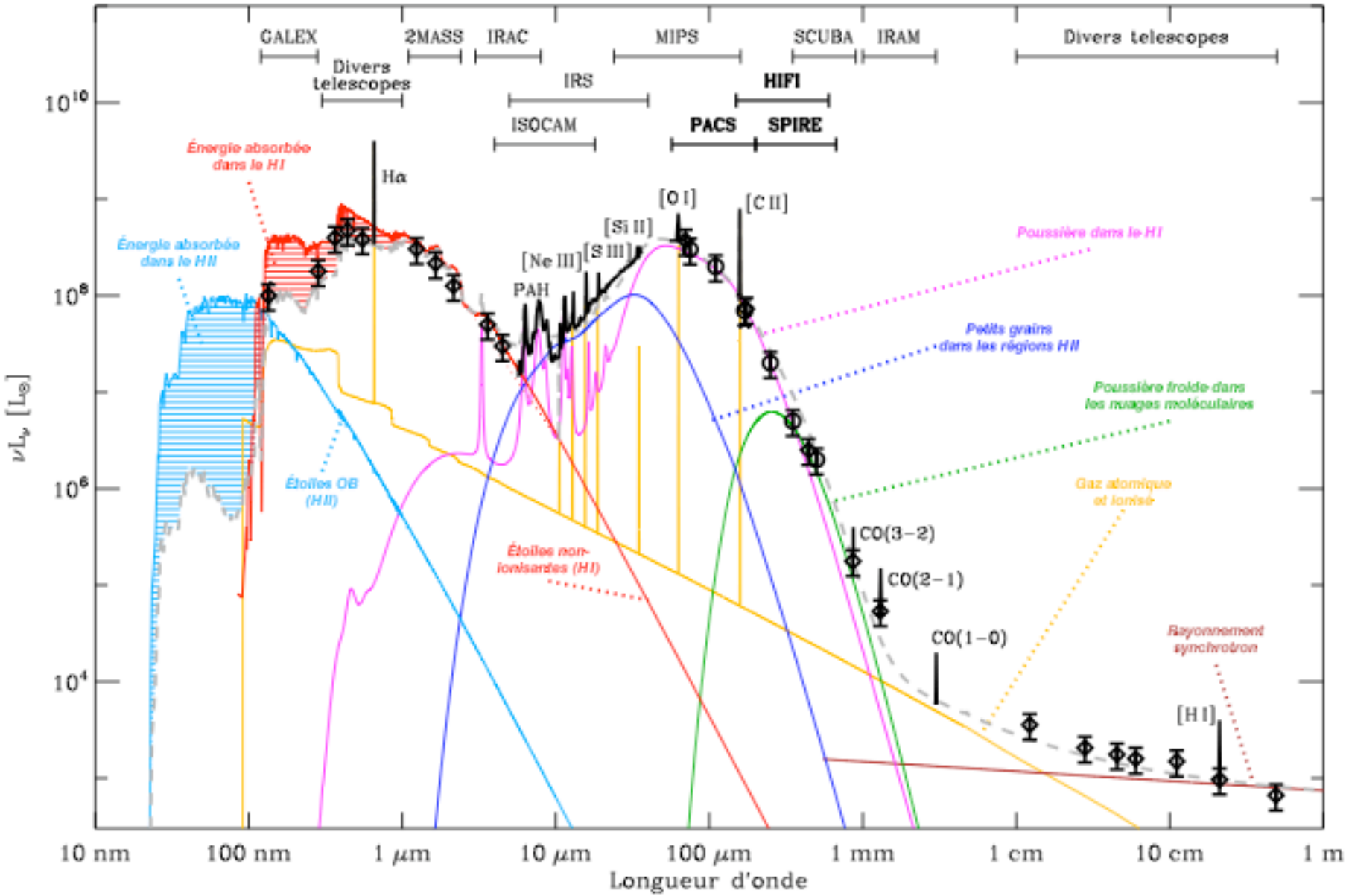
60 sq deg
SPIRE and PACS
Parallel Mode:
100, 170, 250, 350, 500μ.

Key Insights on Nearby Galaxies: A FIR Survey With Herschel (KINGFISH)
PI: R. Kennicutt (Cambridge, UK) ~500 hr

- Multiwavelength observations of 61 galaxies (57: SINGS + M101, IC342, NGC3077, NGC2146)
- Complete, deep PACS/SPIRE imaging all 6 bands
- PACS emission line imaging
  - 54 galactic nuclei, 43 HII regions
  - 33 radial strips (148 positions)
  - [CII]158, [OI]63, [OIII]88, [NII]122. [NII]205
- SINGS/Spitzer ancillary data
  - Ancillary imaging X-ray/UV/BVRIJHK/Halpha/Palpha
  - Radio/HI/CO


The Spitzer Infrared Nearby Galaxies Survey (SINGS) Hubble Tuning-Fork
Unbarred Spirals
Weak Bulge
Intermediate Spirals
Strong Bulge
Ellipticals
Strong Bulge
Irregulars
Weak Bulge
Barred Spirals
SINGS Team

Conclusion: What does the gas and dust SED of a galaxy tell us? Multiphase Multiscale modeling !



F. Galliano 2008