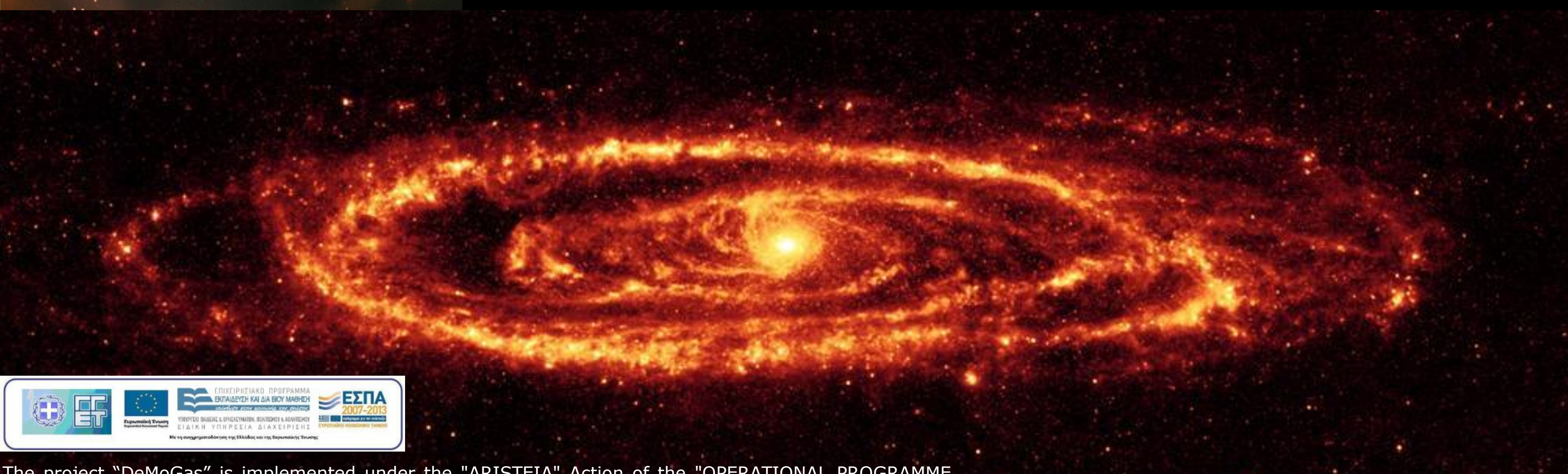
# Nearby galaxies as seen by the Herschel Space Observatory

Manolis Xilouris
National Observatory of Athens

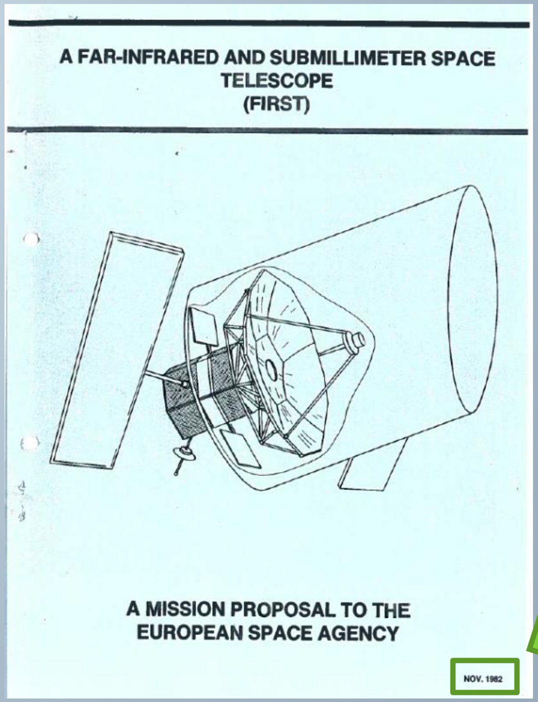


The project "DeMoGas" is implemented under the "ARISTEIA" Action of the "OPERATIONAL PROGRAMME EDUCATION AND LIFELONG LEARNING" and is co-funded by the European Social Fund (ESF) and National Resources.

Hel.A.S. – September 12th 2013

# Herschel Space Observatory

**Mass** - about 3400 kg at launch
**Dimensions** - 7.5m high, 4m × 4m overall cross section
**Launcher** - Ariane 5 ECA from Guiana Space Centre
**Mission Lifetime** - 3 years nominal from end of commissioning phase
**Wavelength** - Infrared and sub-millimetre: 55 to 672 μm
**Telescope** - Cassegrain, 3.5m primary and 0.3m secondary mirror
**Orbit –** L2


A FAR-INFRARED AND SUBMILLIMETER SPACE TELESCOPE (FIRST)

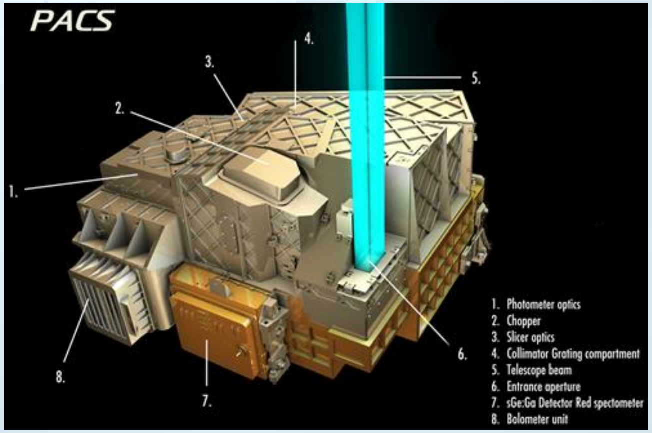
A MISSION PROPOSAL TO THE EUROPEAN SPACE AGENCY

NOV. 1982

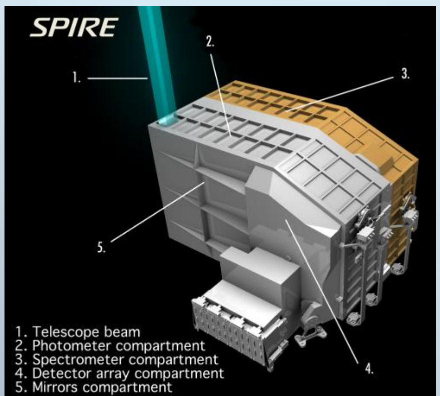
**Nov 1982**

**Herschel launch: 14 May 2009**
**Herschel run dry: 29 April 2013**
**www.herschel.esac.esa.int**

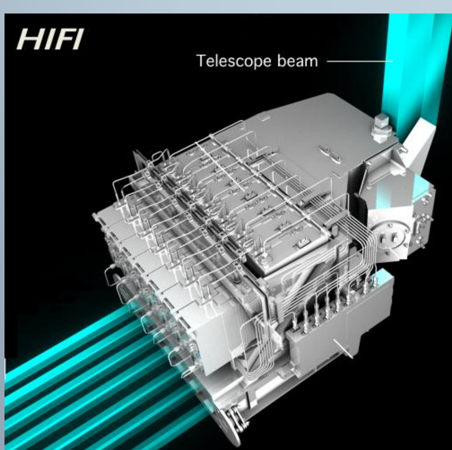
# HERSCHEL'S INSTRUMENTS




**PACS:** Photoconductor Array Camera and Spectrometer
**Wavelength range:** 55-210 microns in 3 bands (2 imaged at any time)
**Field of view:** 1.75 x 3.5 arcminutes (camera), 50 x 50 arcseconds (spectrometer).
**Number of pixels:** 2560 (camera), 400 (spectrometer)
**Resolution:** 5 arcseconds (camera), 10 arcseconds (spectrometer)
**Spectrometer resolution:** 150-200 km/s



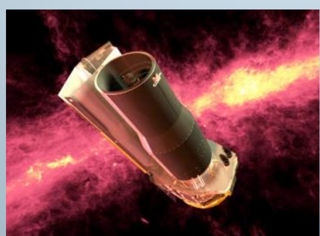

**SPIRE:** Spectral and Photometric Imaging Receiver
**Wavelength range:** 200-672 microns in 3 bands
**Field of view:** 4 x 8 arcminutes (camera), 2.6 x 2.6 arcminutes (spectrometer).
**Number of pixels:** 270 (camera), 56 (spectrometer)
**Resolution:** 20-30 arcseconds (camera), 20-50 arcseconds (spectrometer)
**Spectrometer resolution:** 300 km/s




# Herschel photometry with PACS & SPIRE
# Colder dust seen with better resolution

1980s: IRAS, NASA
Diameter = 57 cm, $\lambda_{max}$ =100µm
Devereux & Young (1990): G/D=1000

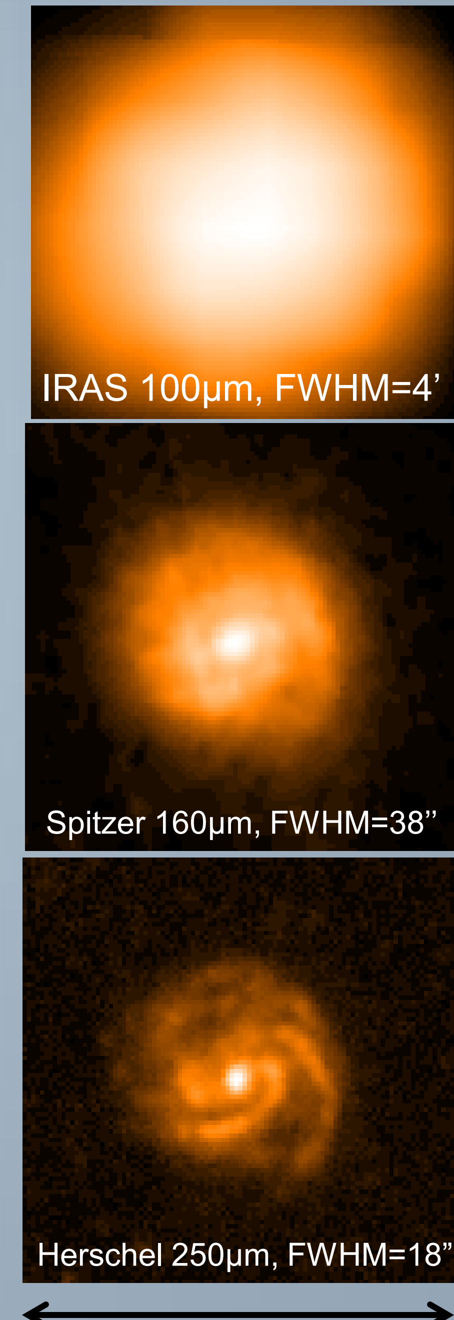
1990s: ISO, ESA
Diameter = 60 cm, $\lambda_{max}$ =200µm
Alton et al. (1998): G/D=220



2000s: Spitzer, NASA
Diameter = 85 cm, $\lambda_{max}$ =160µm
Draine et al. (2007): G/D=190

2010s: Herschel, ESA
Diameter = 3.5 m, $\lambda_{max}$ =500µm
Corbelli et al. (2011): G/D=100

M100



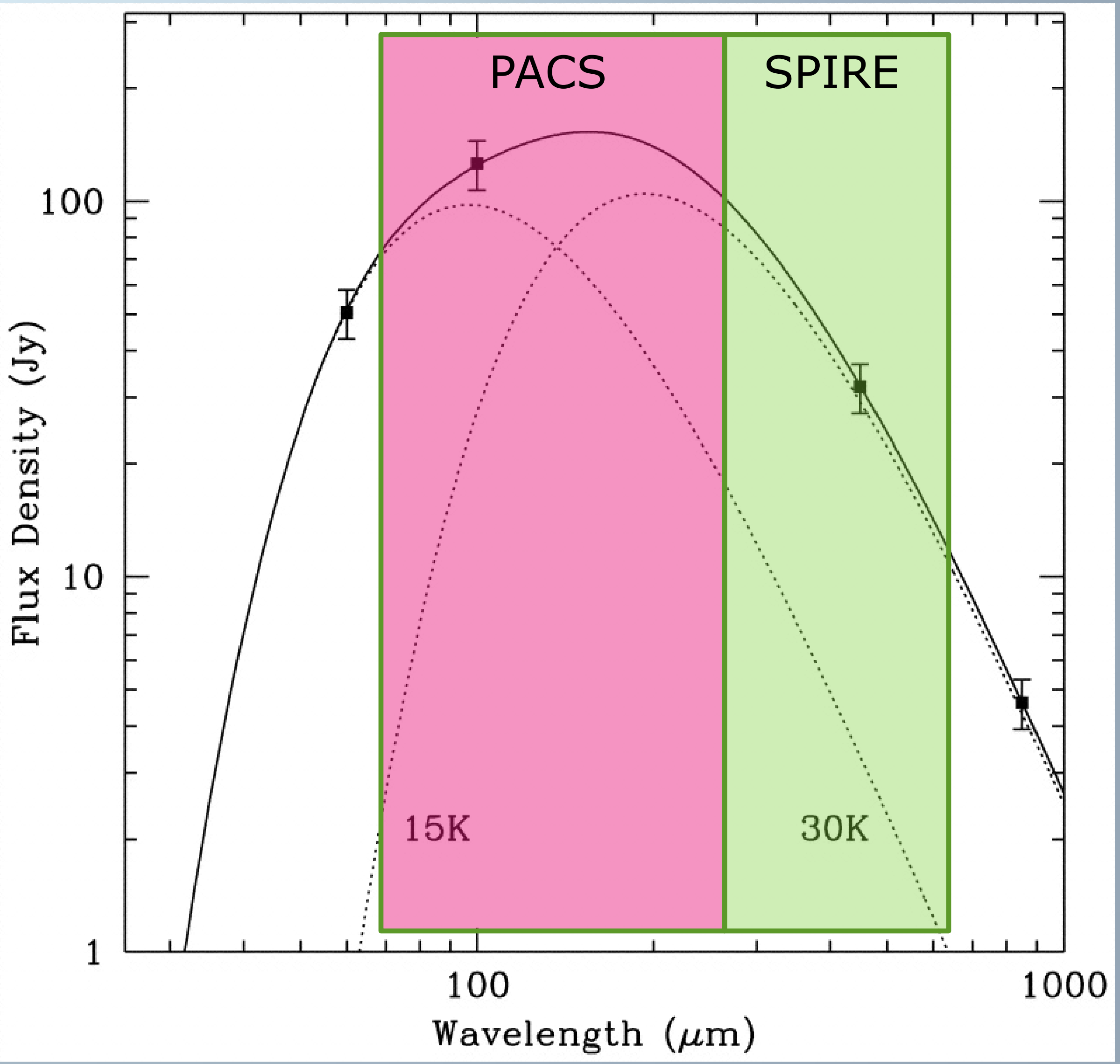

7′

# Why Herschel observations are important for galaxies ?

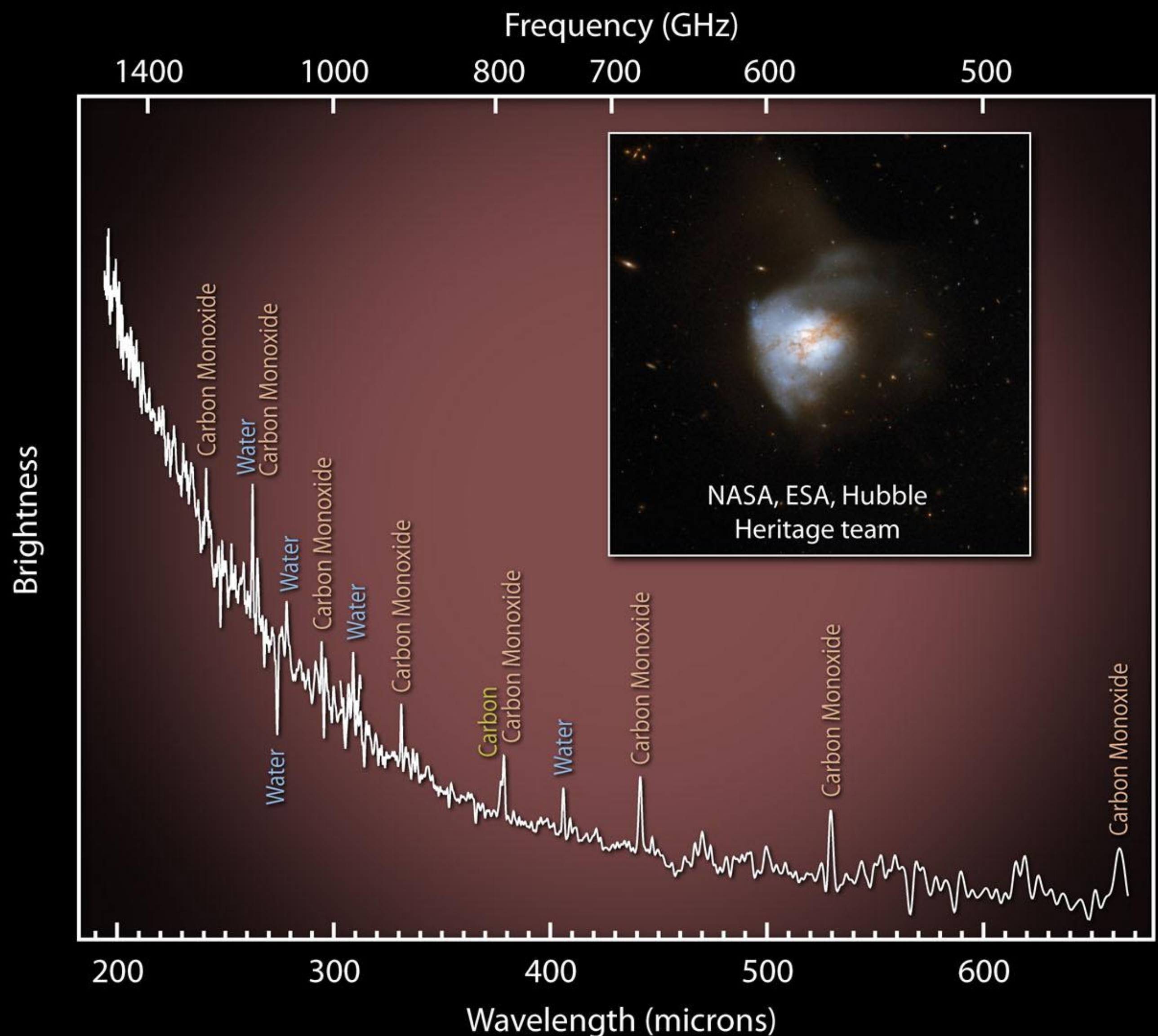
Peak of thermal emission at 170μm.

SED beyond 170μm largely unexplored.

$$L \sim M_d \ T^{4+\beta}$$



# Why Herschel observations are important for galaxies ?




Arp 220

# HERSCHEL PROGRAMS

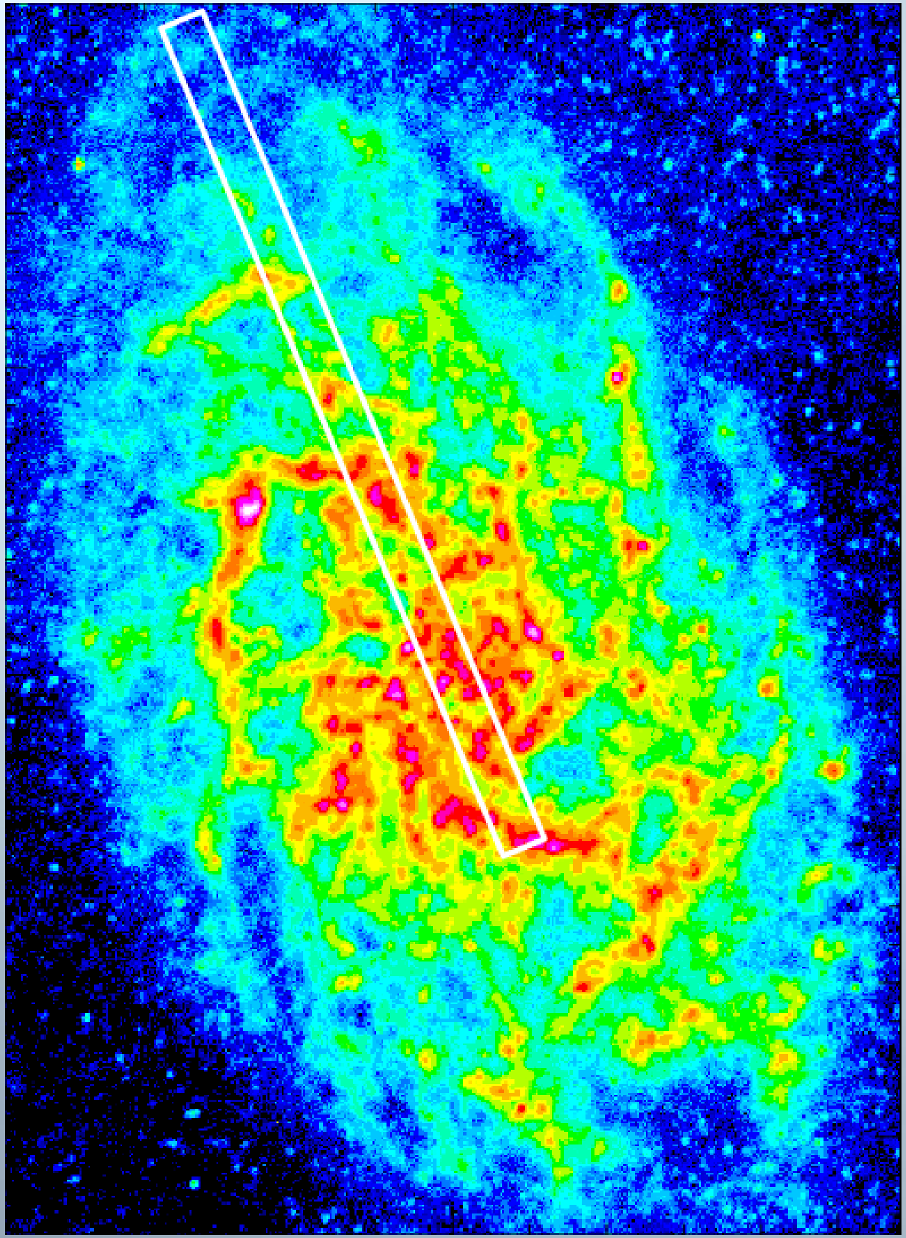
## Open Time Key programs (2010)

- HerM33es : Herschel M33 extended survey (191.9 hours; PI: C. Kramer)

- HeViCS: Herschel Virgo Cluster Survey (286 hours;  PI: J. Davies)

- HerCULES: Herschel Comprehensive (U)LIRG Emission Survey (100 hours; PI: P. van der Werf)

# HerM33es



## Why M33?

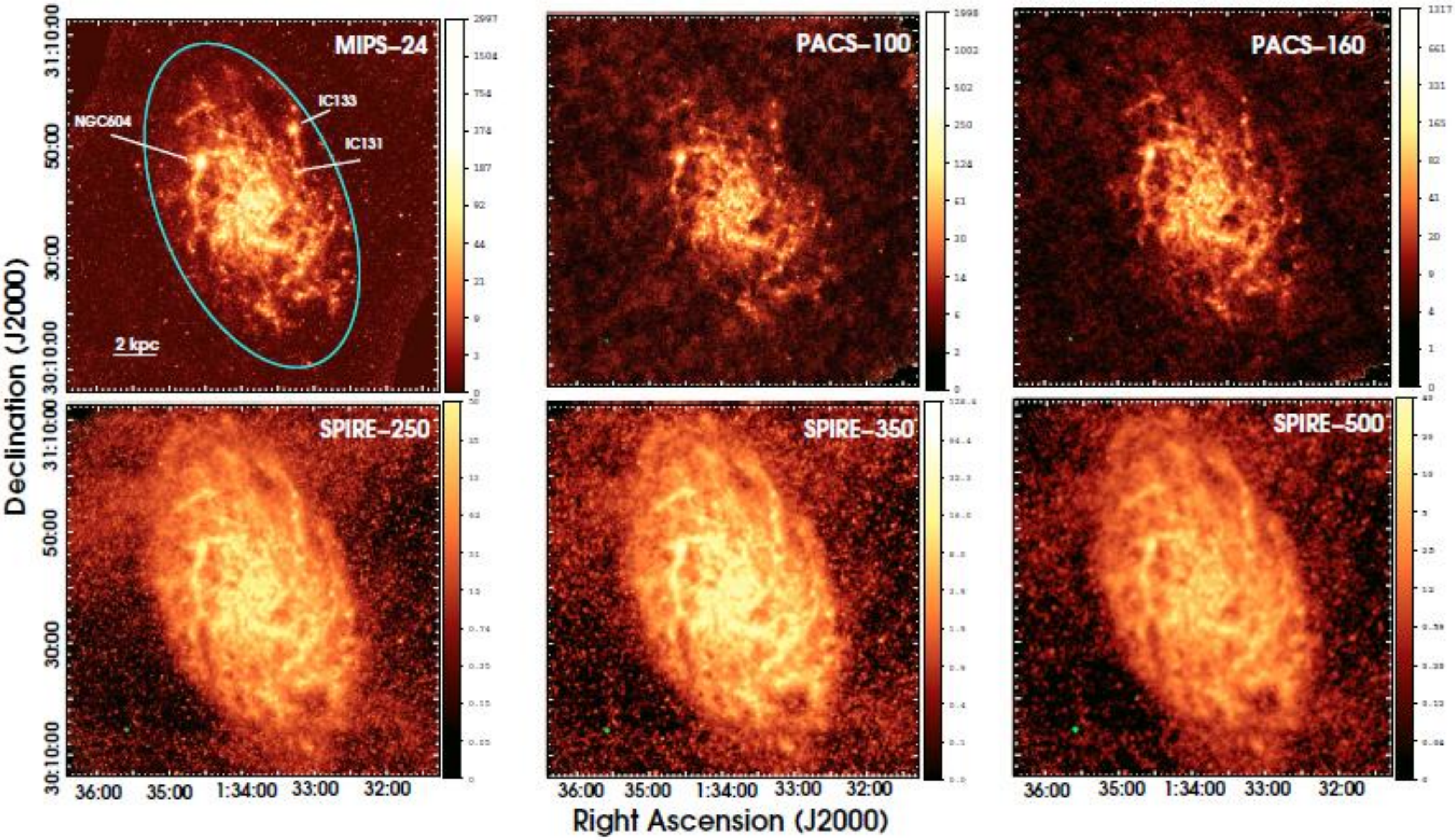
+ nearest late-type spiral galaxy
840kpc, 12” = 49pc
+ Low inclination of 56$^o$
+ Mass = 10% of the Milky Way
+ gas rich
+ several giant HII regions
+ mostly unperturbed galaxy
note giant HI bridge connecting M31 and M33
+ About half solar metallicity, similar to LMC:

## Observations:

-100, 160, 250, 350, 500 μm maps
-The strip is observed with PACS & HIFI out to 8 kpc

***Kramer, Buchbender, Xilouris, et al., 2010, A&A, 518, 67.***

# HerM33es




Observation date: January 7, 2010

***Xilouris, Tabatabaei, Boquien, Kramer, et al., 2012, A&A, 543, 74***

# HerM33es

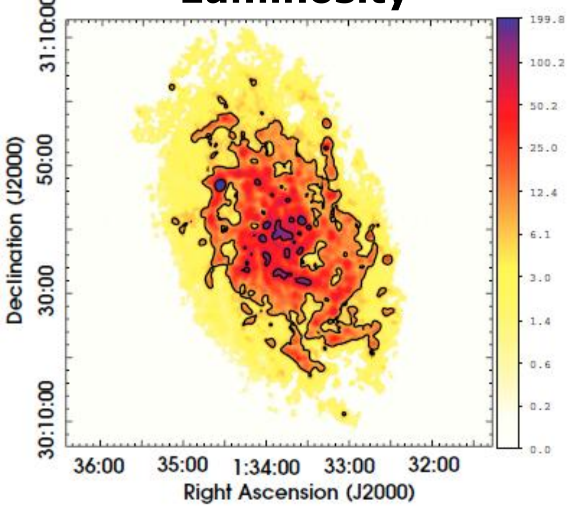
## Spectral Energy Distributions - Entire galaxy & Azimuthal Averages

$$S_\nu = M_c B(\nu, T_c)\kappa_\nu + M_w B(\nu, T_w)\kappa_\nu$$

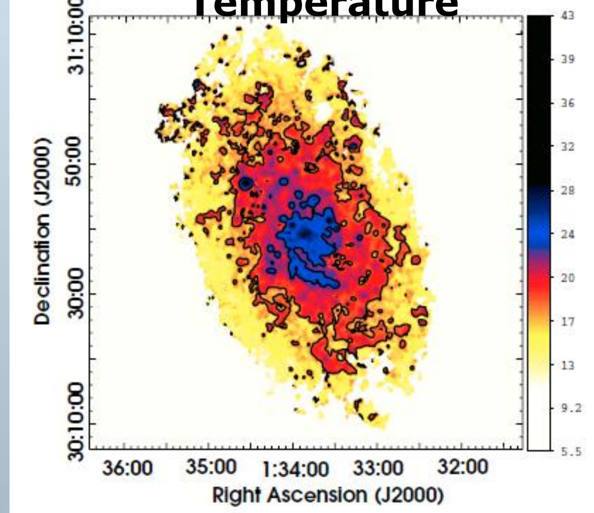
$$\kappa_\nu = 0.04(\nu/250\mathrm{GHz})^\beta$$ (Kruegel &Siebenmorgen 1994)

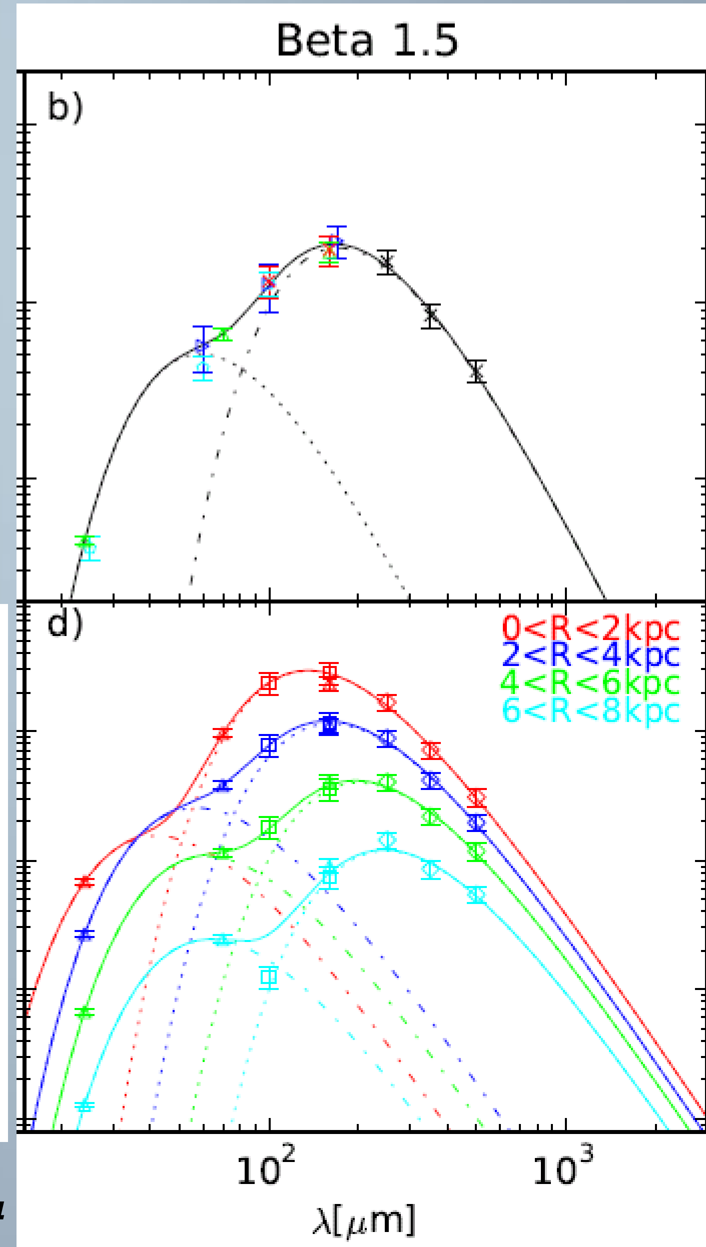
| | Total | (1) | (2) | (3) | (4) |
|---|---|---|---|---|---|
| Two-component fits with $\beta = 1.5$ | | | | | |
| $T_c/[\mathrm{K}]$ | 19 | 24 | 20 | 16 | 13 |
| $T_w/[\mathrm{K}]$ | 55 | 77 | 57 | 52 | 51 |
| $M_c/[10^6\ \mathrm{M}_\odot]$ | 10 | 1.2 | 3.0 | 4.6 | 4.9 |
| $M_c/M_w$ | 500 | 3800 | 480 | 730 | 2200 |
| $\chi^2_{\mathrm{red}}$ | 0.14 | 0.10 | 0.12 | 0.20 | 1.8 |
| $M_{\mathrm{gas}}/M_c$ | 200 | 190 | 150 | 120 | 160 |

**Luminosity**



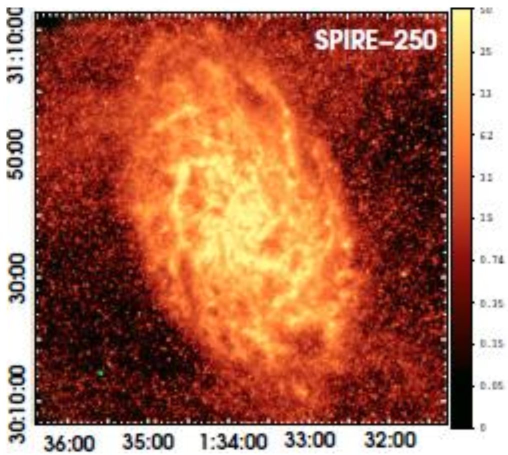

**Temperature**

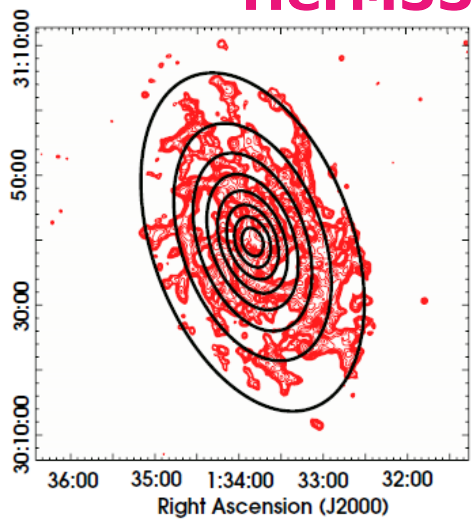


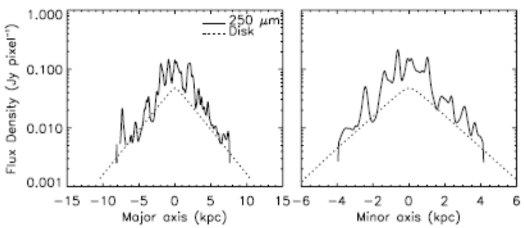



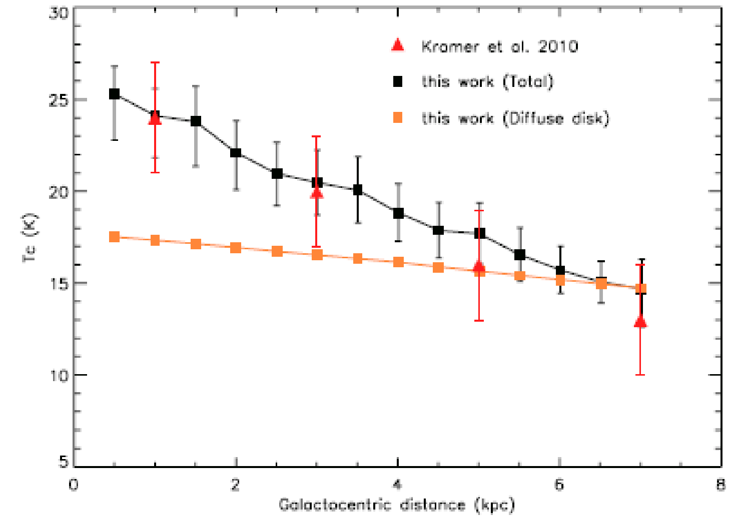

*Xilouris, Tabatabaei, Boquien, Kramer, et al., 2012, A&A, 543, 74*
*Kramer, Buchbender, Xilouris et al. 2010, A&A, 518,0 67*

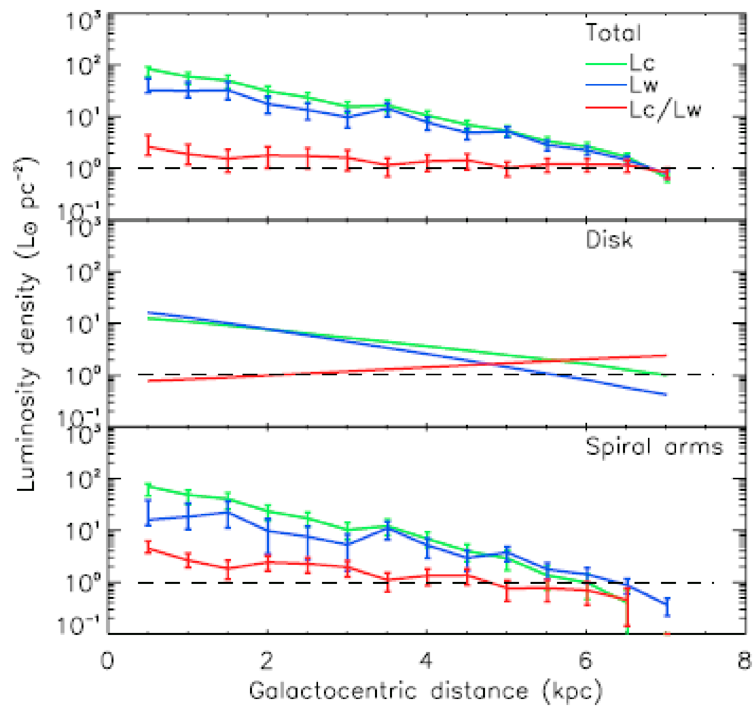
# HerM33es



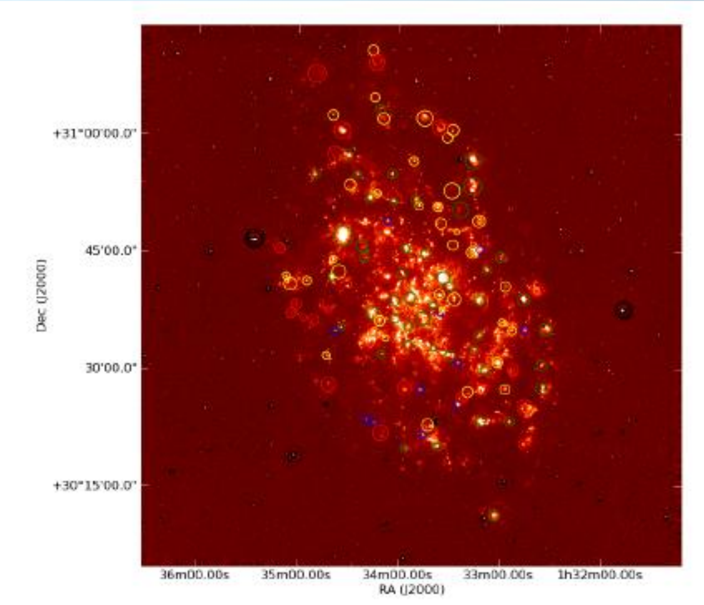

* The cold dust temperature in the disk is between ~15-18 K.
* The disk emission is ~21% in the MIR and it rises up to ~57% in the submm.
* The dust in the disk produces ~30% the total luminosity.
* 23% of the warm dust luminosity comes from the disk.
* 42% of the cold dust luminosity comes from the disk.
* Lc/Lw is about 1 throughout the galaxy.
* Lc/Lw is greater than 1 beyond ~3 kpc in the disk.
* Lc/Lw is greater than 1 within ~3 kpc in the spiral arms.

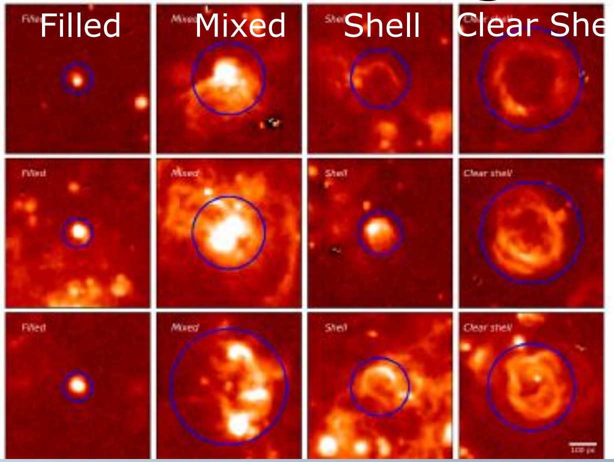
***Xilouris, Tabatabaei, Boquien, Kramer, et al., 2012, A&A, 543, 74***

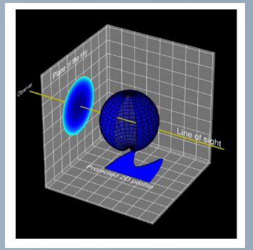
# HerM33es

# HII Regions in M33

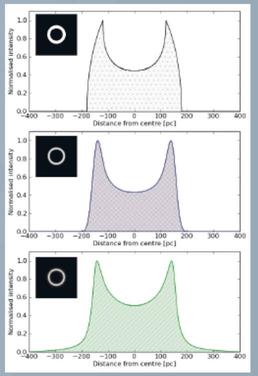
Location of 119 HII regions on the Hα map. Classification according to their morphology: filled (**blue**), mixed (**green**), shell (**yellow**), clear shell (**red**).



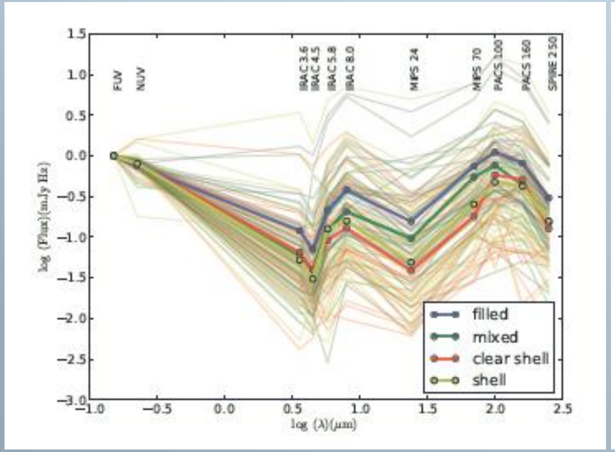



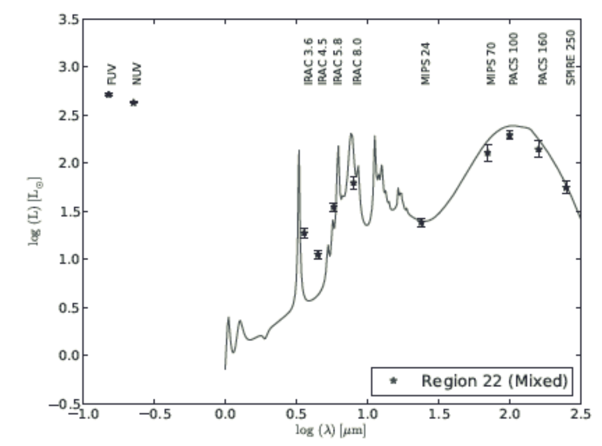

For clear shells we constructed a simple model of a 3D spherical shell that appears circular on the sky. We find that the density within the shell follows more closely a Cauchy-Lorentz distribution rather than a Gaussian.

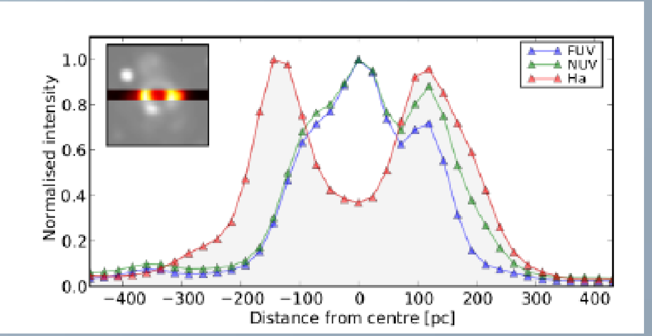



SEDs for our set of HII regions. Filled are warmer compared to shell. Filled have the highest FIR fluxes compared to shell which means that they are closer to the central stars.

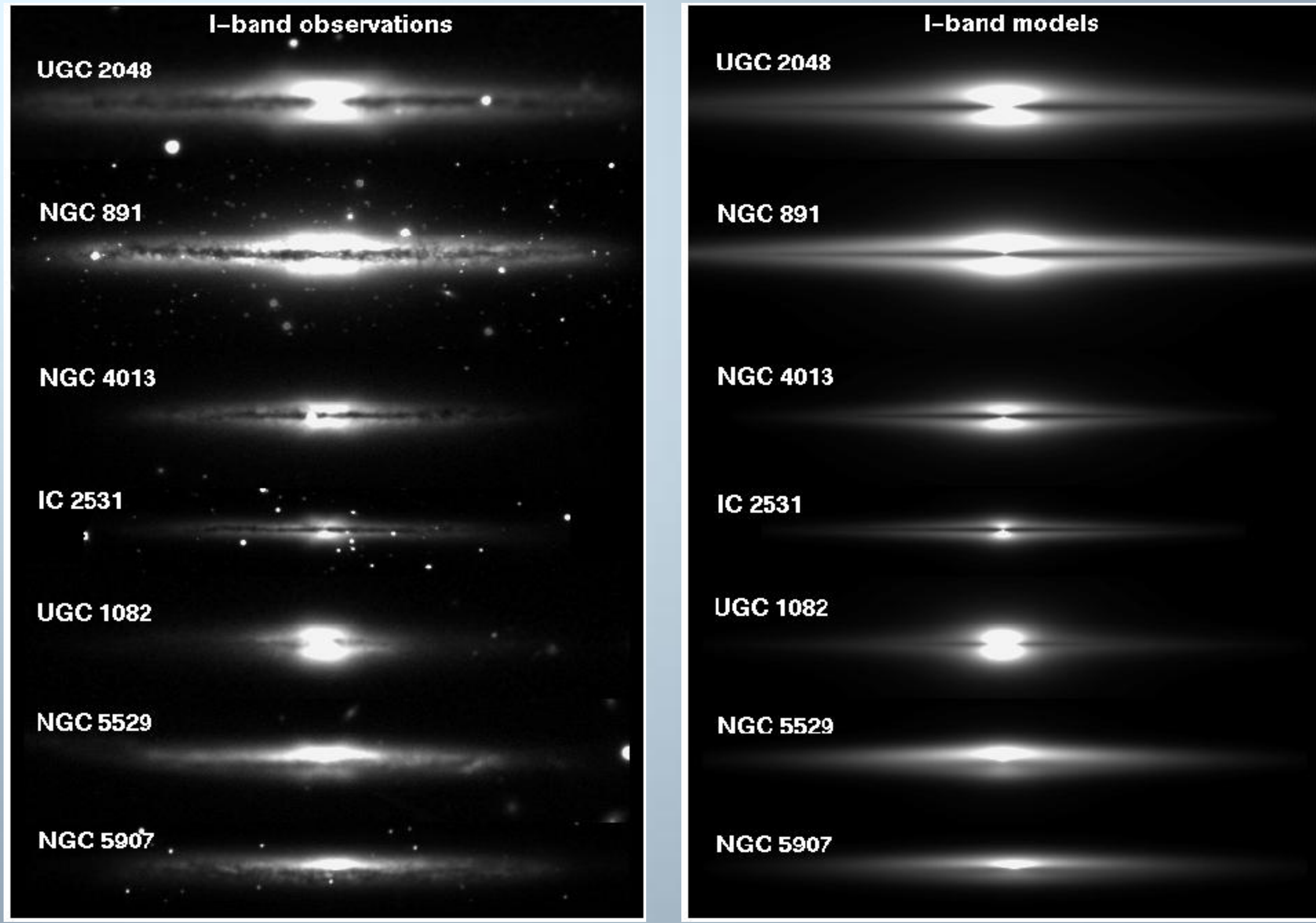



Fitting the SEDs with DL07 models we find dust masses within the range of $10^2$ – $10^4$ Msun and cold temperatures ~12 – 27 K.



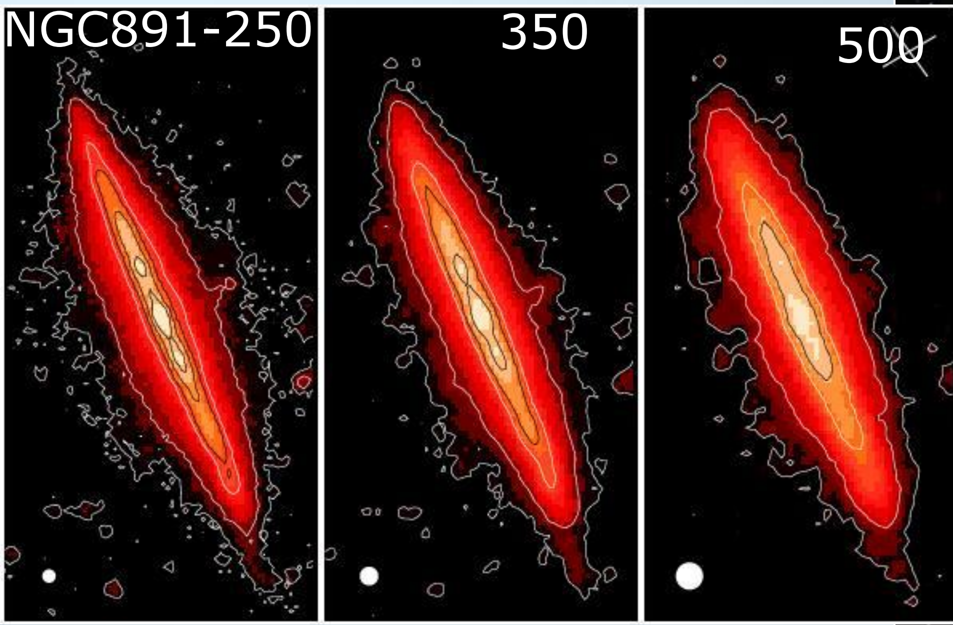

*Relano M., Verley S., Perez I., Kramer C., Calzetti D., Xilouris E.M. et al., 2013, A&A, 552, 140*

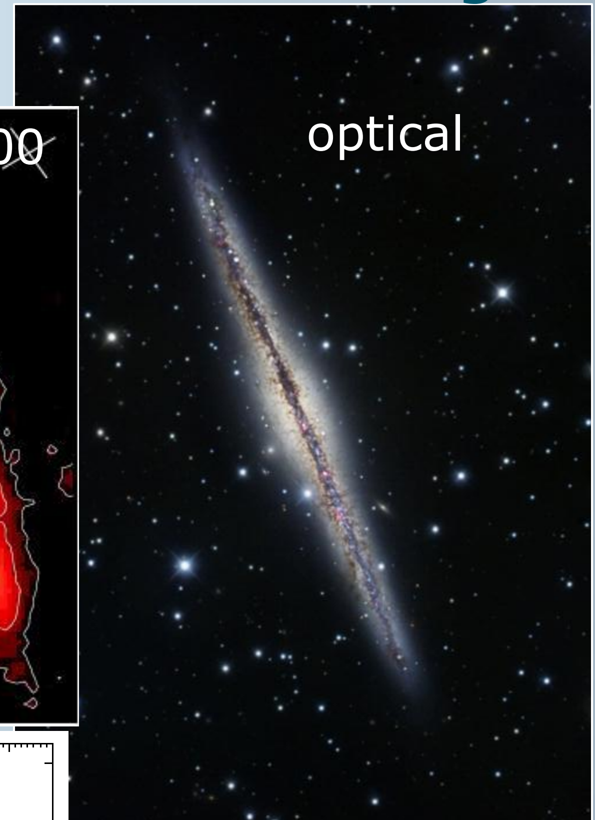



*Xilouris, M. Y.I. Byun, N.D. Kylafis, E.V. Paleologou and J. Papamastorakis 1999, A&A, 344, 868*

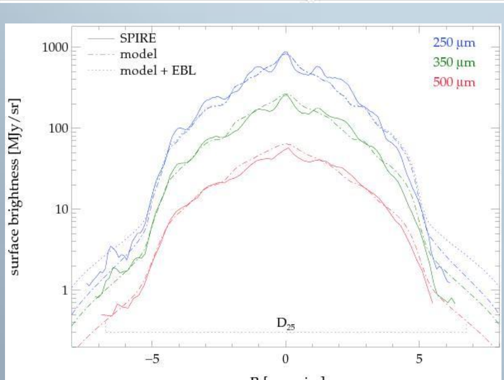
# HEROES – HERschel Observations of Edge-on Spirals

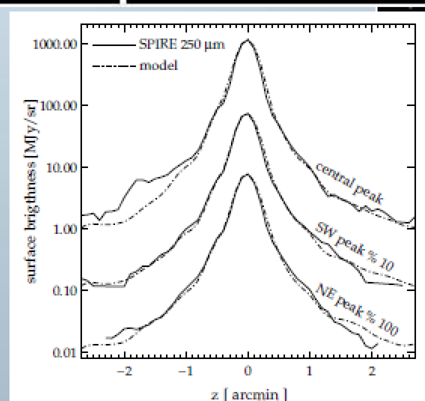
# NHEMESES – New HErschel Multiwavelength Extragalactic Survey of Edge-on Spirals

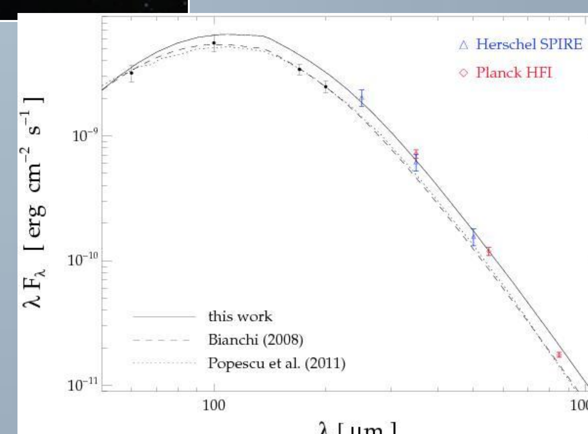



Herschel data confirm the predictions of the radiative transfer modelling done in the optical bands.

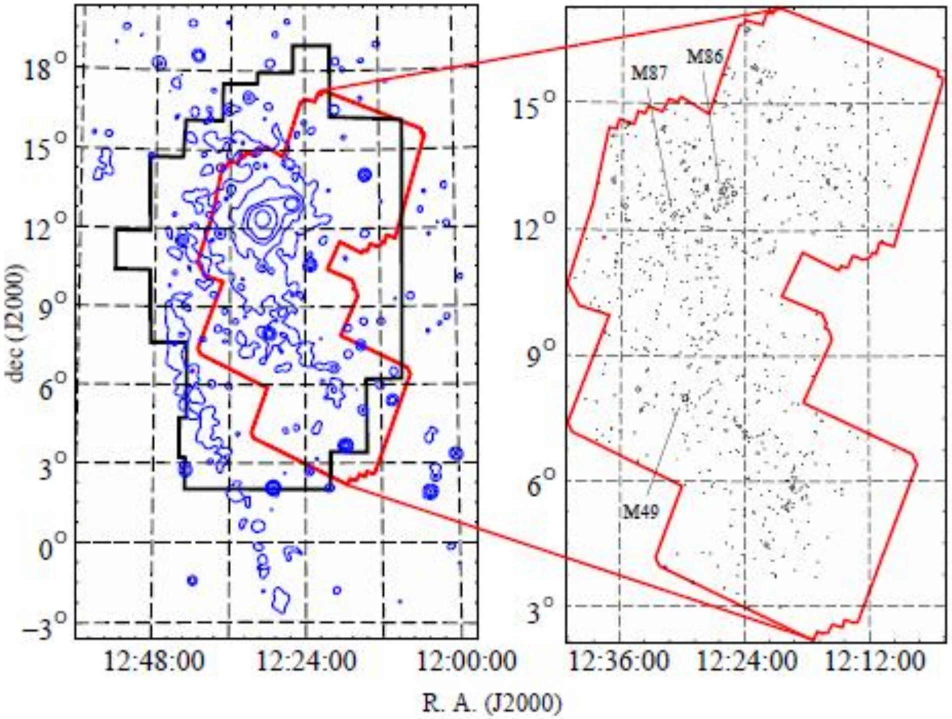


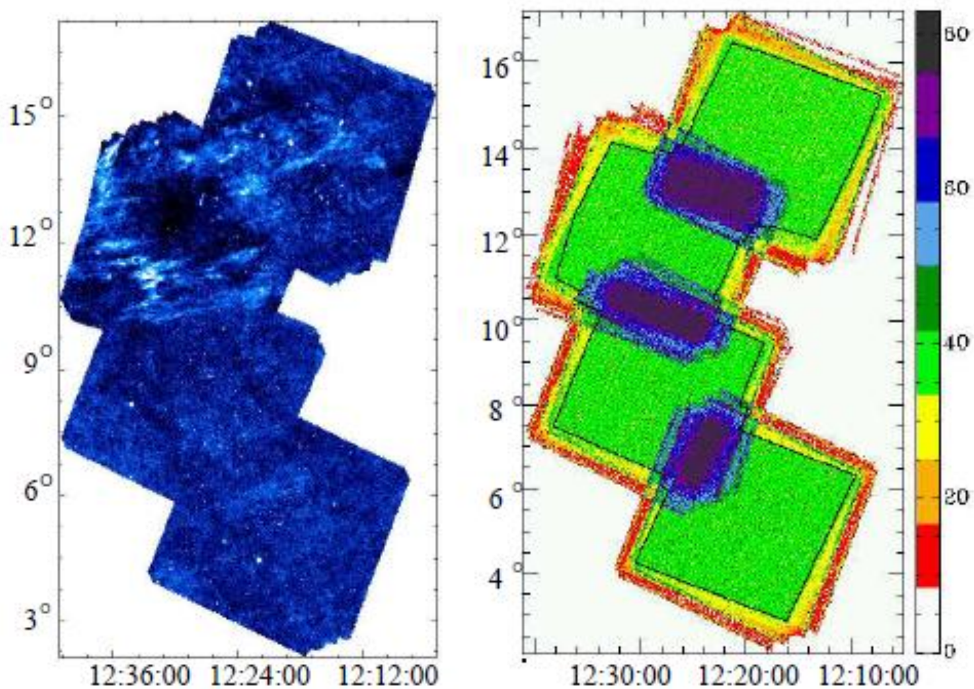




***Bianchi & Xilouris, 2011, A&A, 531, 11***

***Verstappen et al., 2013, A&A, 556, 54***




VCC (Binggeli et al. 1985)
ROSAT (Bohringer et al.1994)
HeViCS (Davies et al. 2010)

# HeViCS Herschel Virgo Cluster Survey

## Survey Area ≈ 60 deg$^2$

## PACS/SPIRE parallel mode

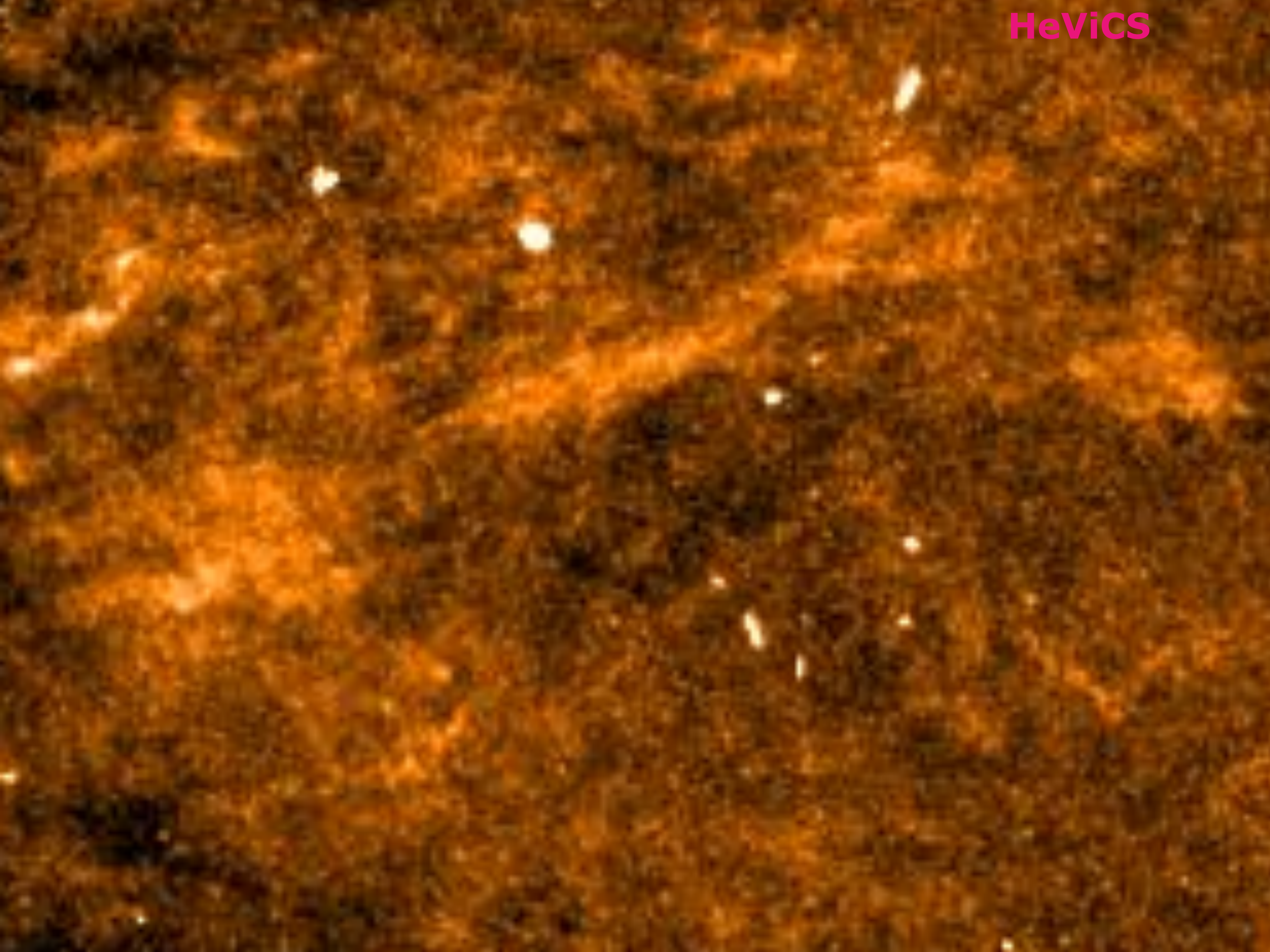
fast scanning

## 8 scans per field

PACS B (100-μm)
PACS R (160-μm)
SPIRE (250, 350, 500-μm)

## 286 hours

| | λ [μm] | FWHM [arcsec] | 1-σ [MJy/sr] |
|---|---|---|---|
| PACS | 100 | 7 x 13 | 8.6 |
| | 160 | 12 x 16 | 4.9 |
| SPIRE | 250 | 18 | 1.3 |
| | 350 | 24 | 0.6 |
| | 500 | 36 | 0.3 |


HeViCS

# HeViCS

esa
IC 769
IC 3061
IC 3115
IC 3225
IC 3258
IC 3259
IC 3268
IC 3322
IC 3476
IC 3521
NGC 4165
NGC 4189
NGC 4192
NGC 4193
NGC 4197
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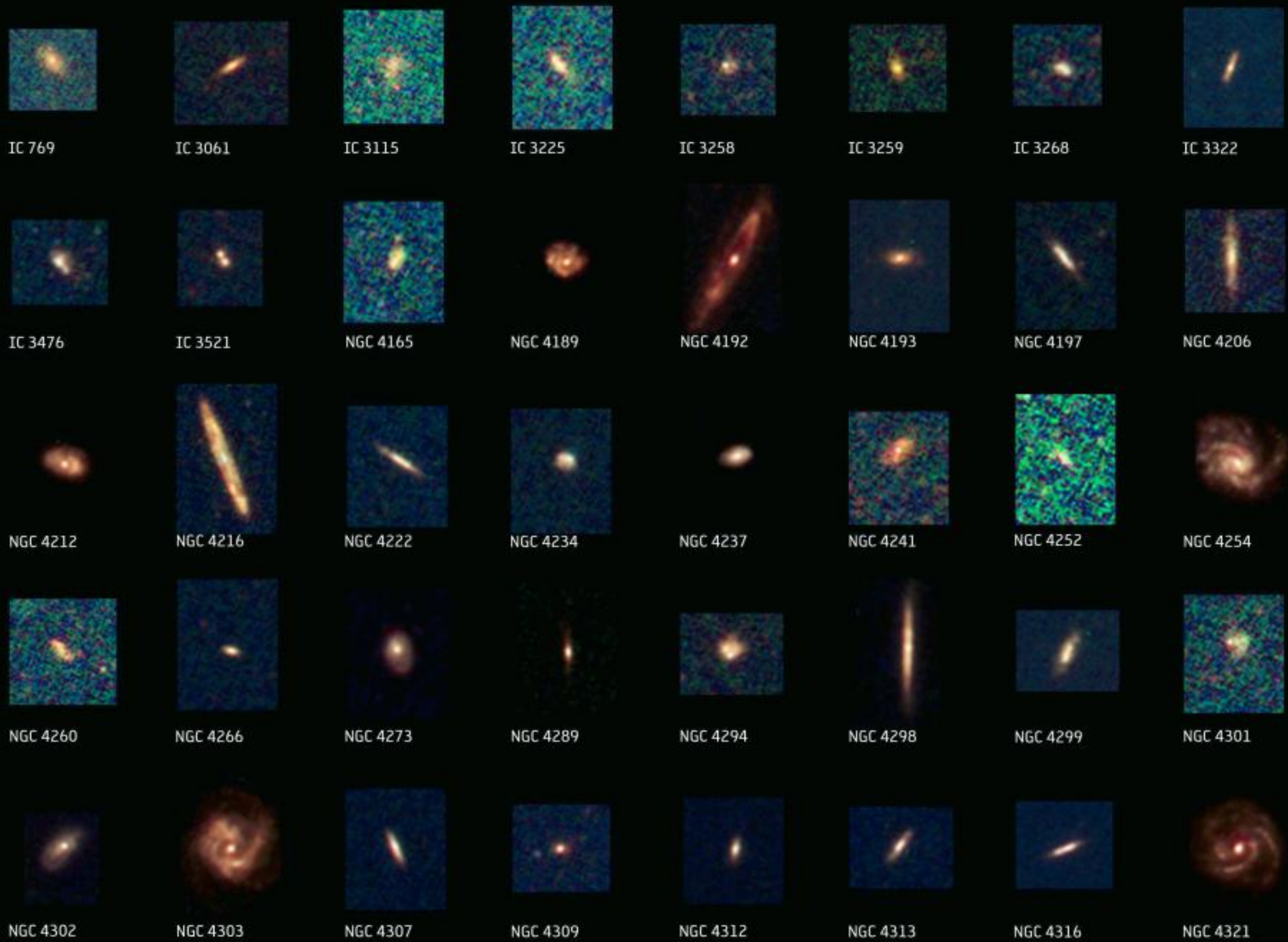
NGC 4309
NGC 4312
NGC 4313
NGC 4316
NGC 4321
NGC 4324
NGC 4330
NGC 4343
NGC 4351
NGC 4374
NGC 4376
NGC 4378
NGC 4380
→ HERSCHEL
VIRGO CLUSTER SURVEY
The seventy-eight brightest galaxies detected
in the Herschel Virgo Cluster Survey (HeViCS).
NGC 4388
NGC 4390
NGC 4402
NGC 4412
NGC 4413
NGC 4416
NGC 4423
NGC 4424
NGC 4435
NGC 4438
NGC 4445
NGC 4451
NGC 4459
NGC 4466
NGC 4469
NGC 4470
NGC 4486
NGC 4492
NGC 4519
NGC 4522
NGC 4526
NGC 4531
NGC 4535
NGC 4567
NGC 4568
UGC 7387
UGC 7513
UGC 7537
UGC 7546
UGC 7557
www.esa.int
100 micrometer
160 micrometer
250 micrometer
herschel
European Space Agency

# HeViCS


IC 769
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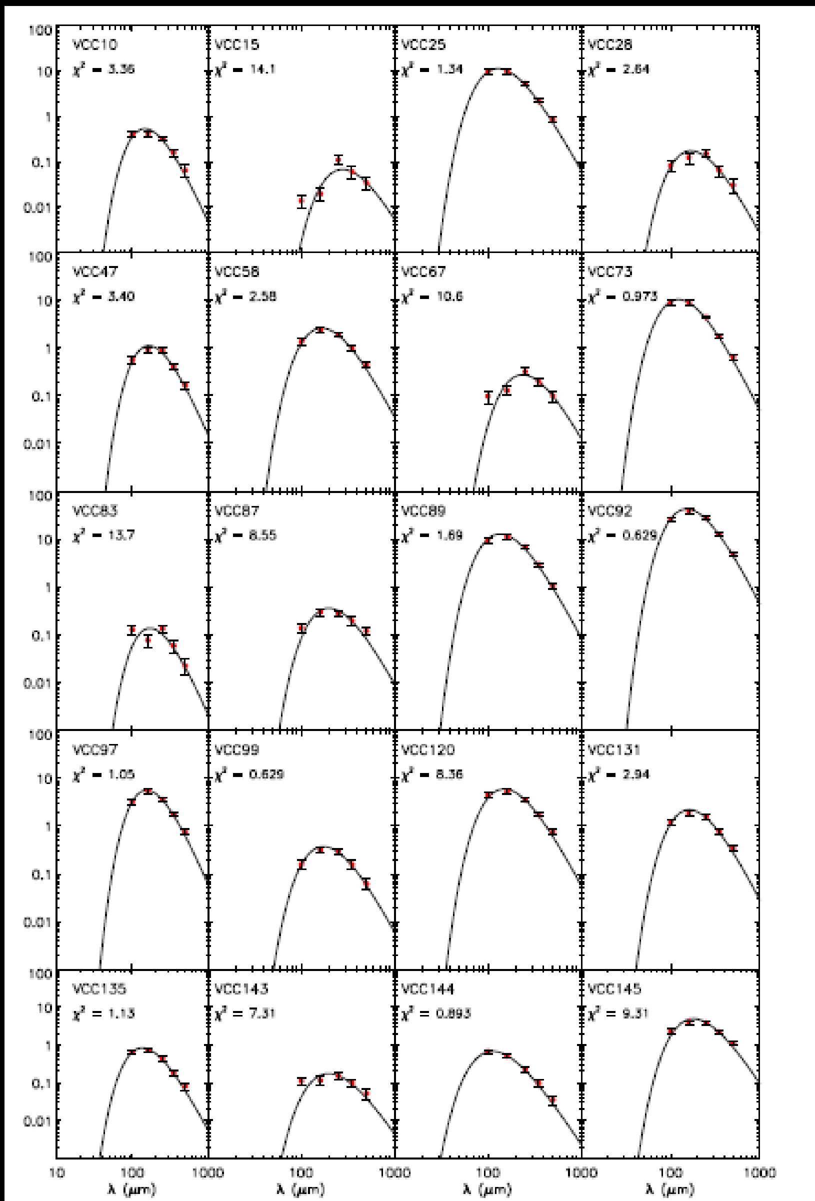
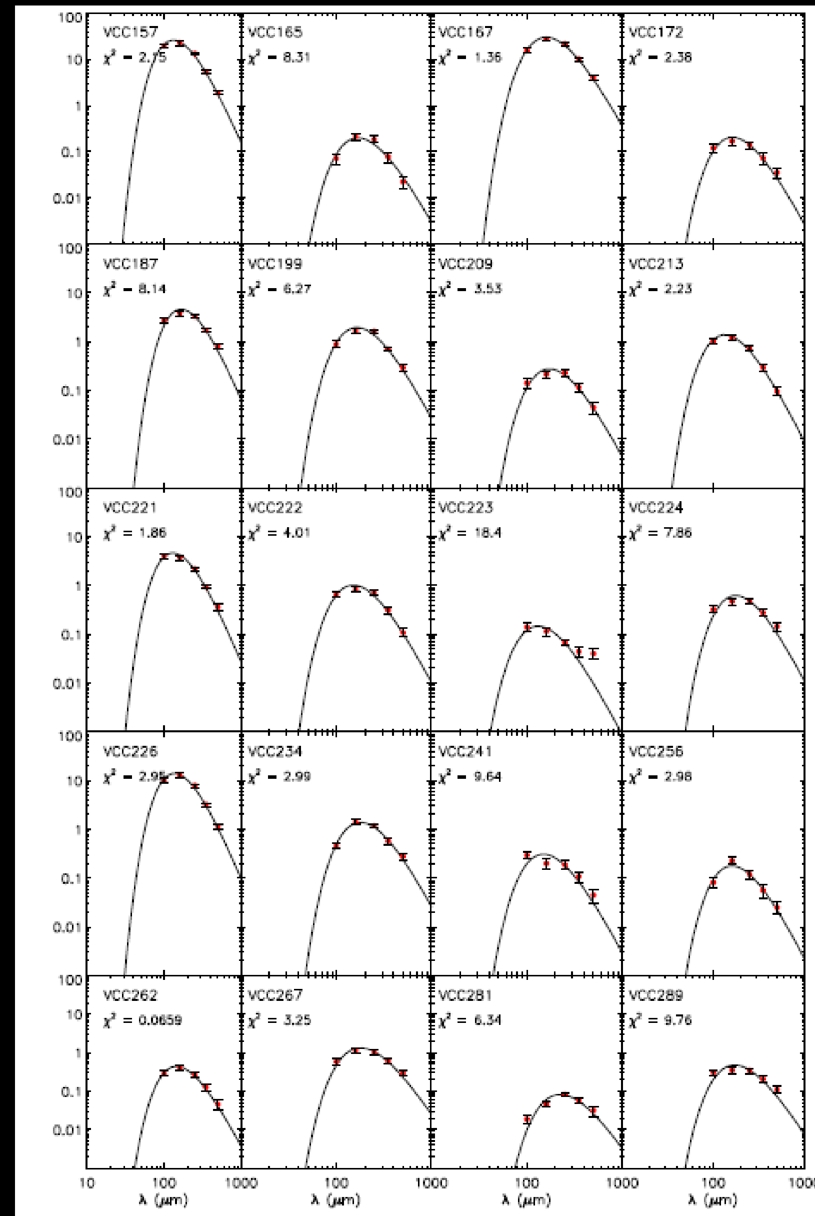
NGC 4321

# HeViCS

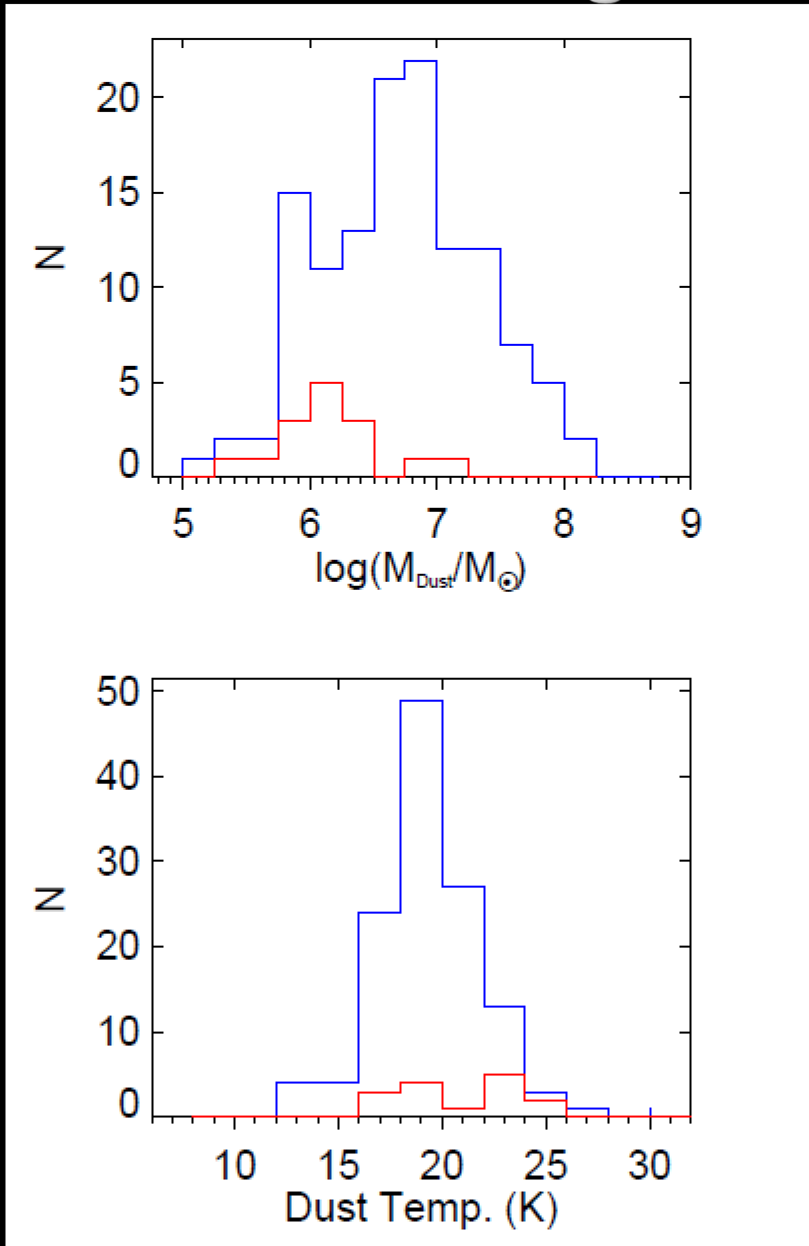
## Auld et al. 2013, MNRAS, 428, 1880

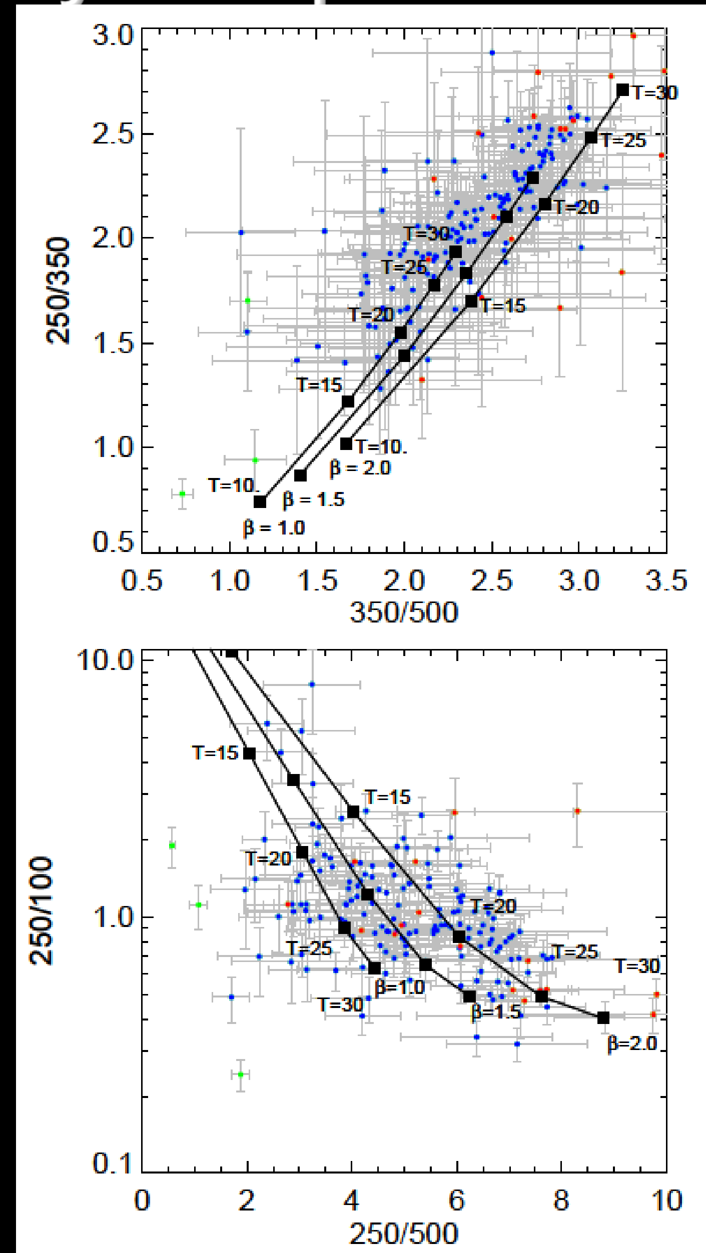


HeViCS

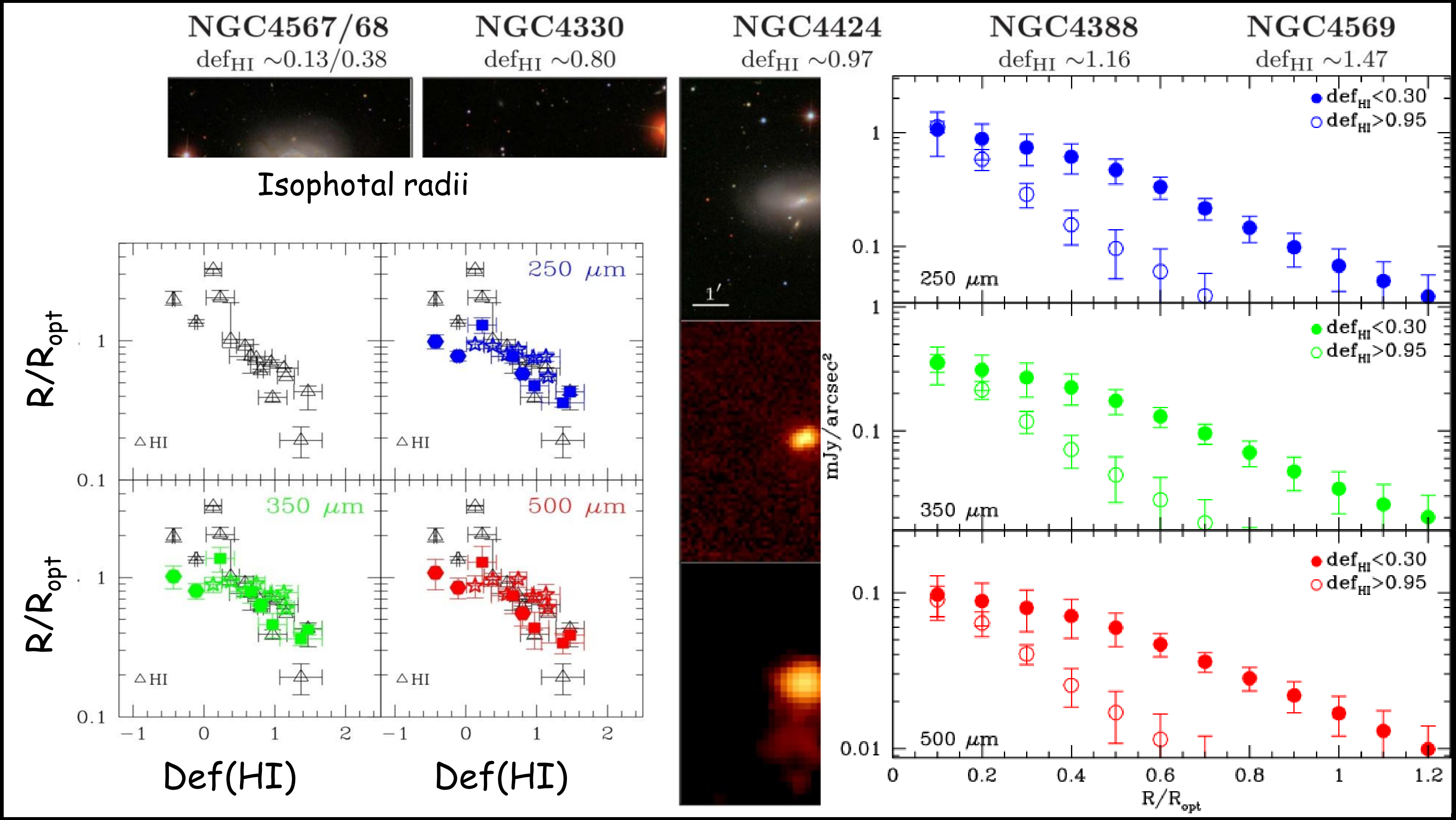
# The Bright Galaxy Sample



# Truncated dust disks in HI-deficient spirals

L. Cortese et al. (2010)



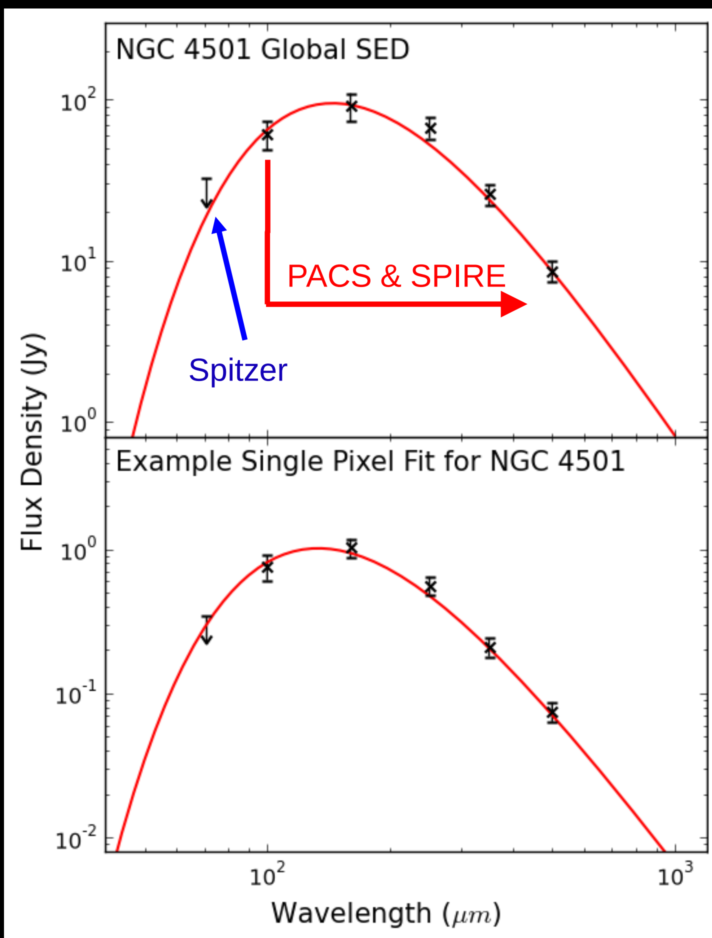

Def(HI) = $\log M_{HI}$(expected) – $\log M_{HI}$(observed)

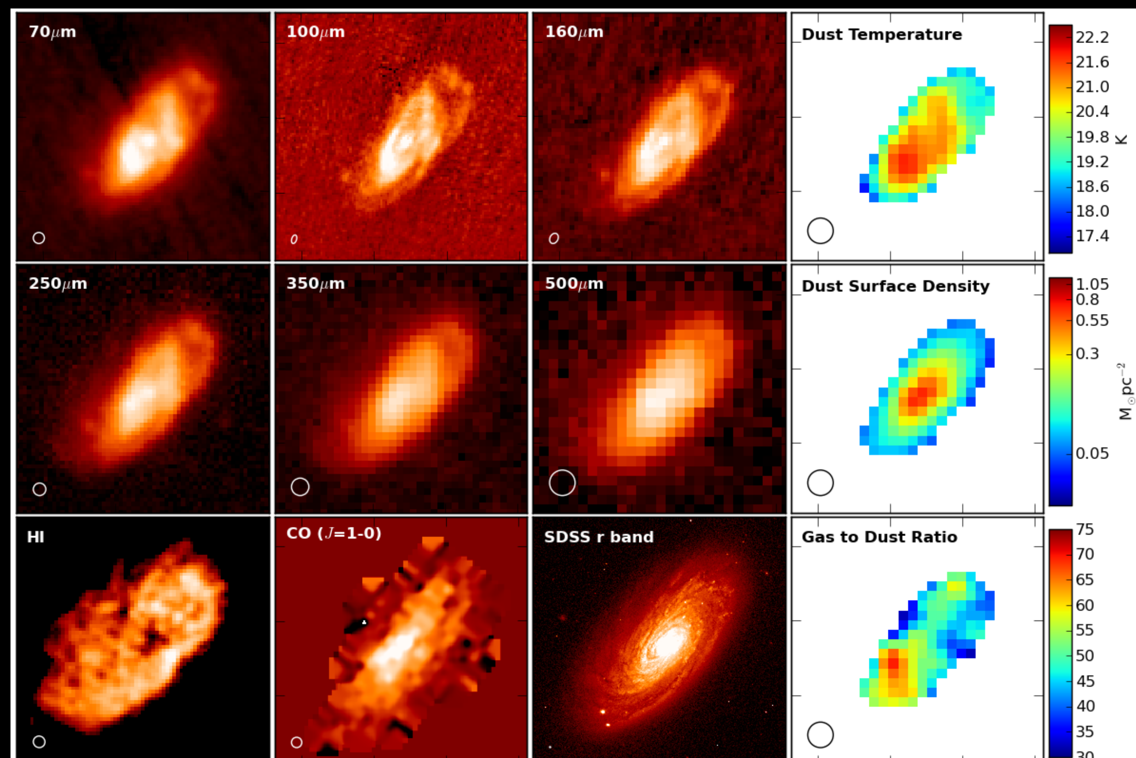
HeViCS

# Resolved Dust Analysis of Spiral Galaxies

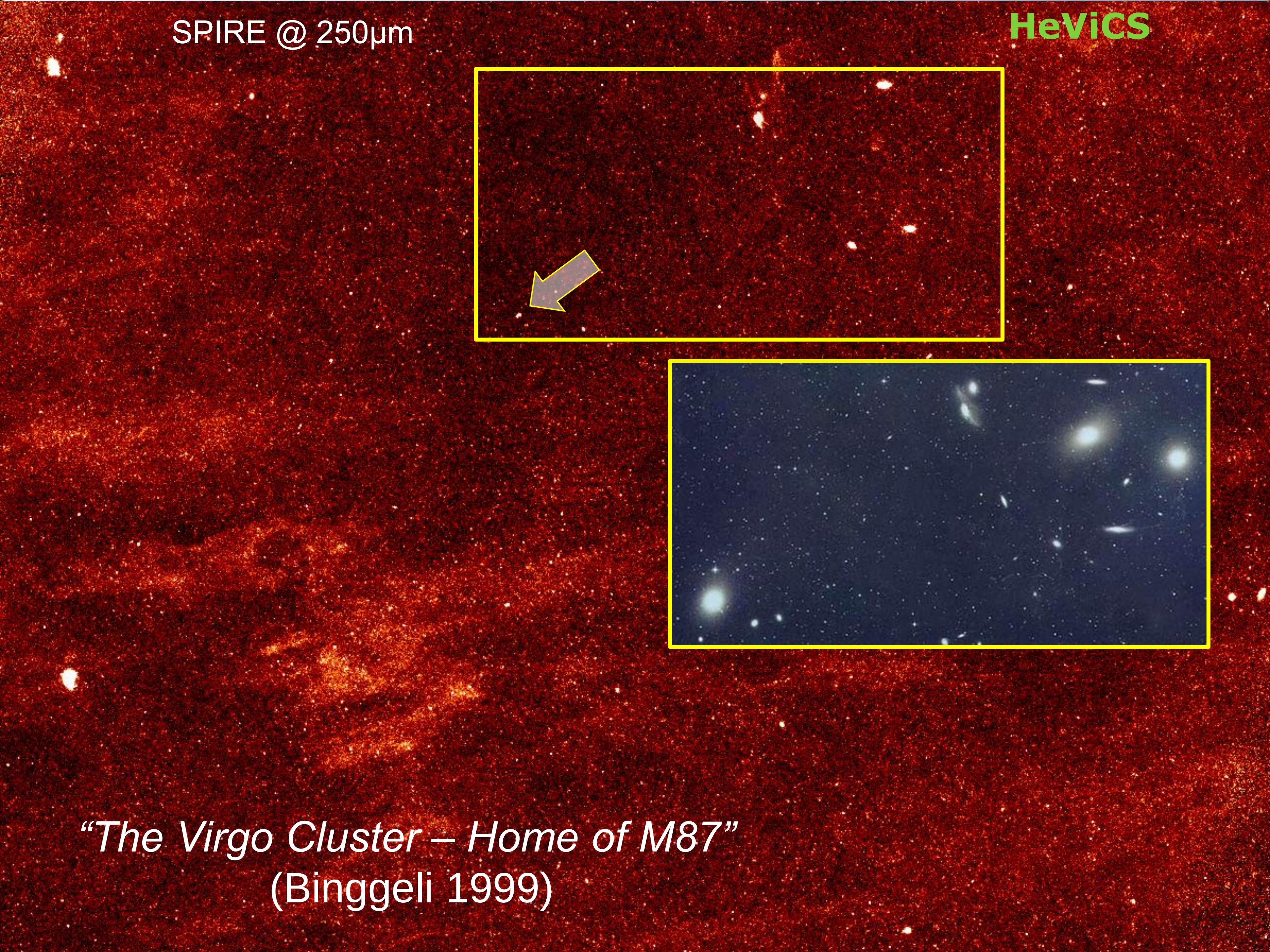
## M. W. L. Smith et al. (2010)

Two galaxies: NGC4501 (M88) and NGC4567/8




Temperature ~22-19 K
Gas-to-dust mass ratio = 42 ±13


SPIRE @ 250μm
HeViCS
“The Virgo Cluster – Home of M87”
(Binggeli 1999)

# The far-infrared view of M87

## M. Baes, M. Clemens, M. Xilouris et al. (2010)

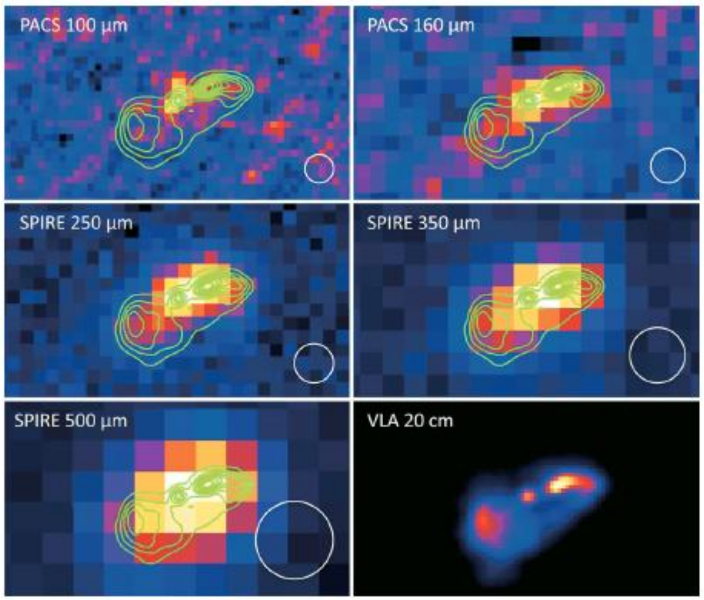
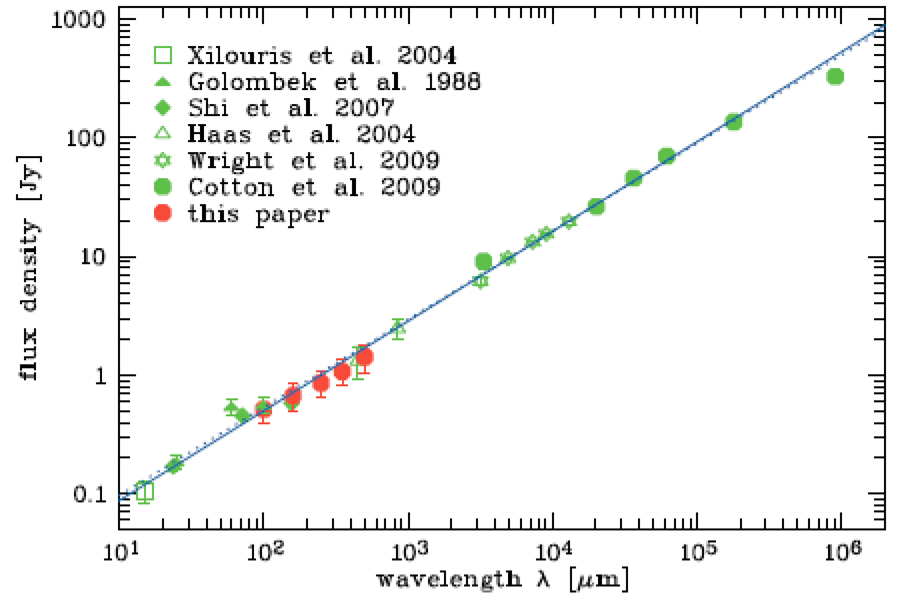


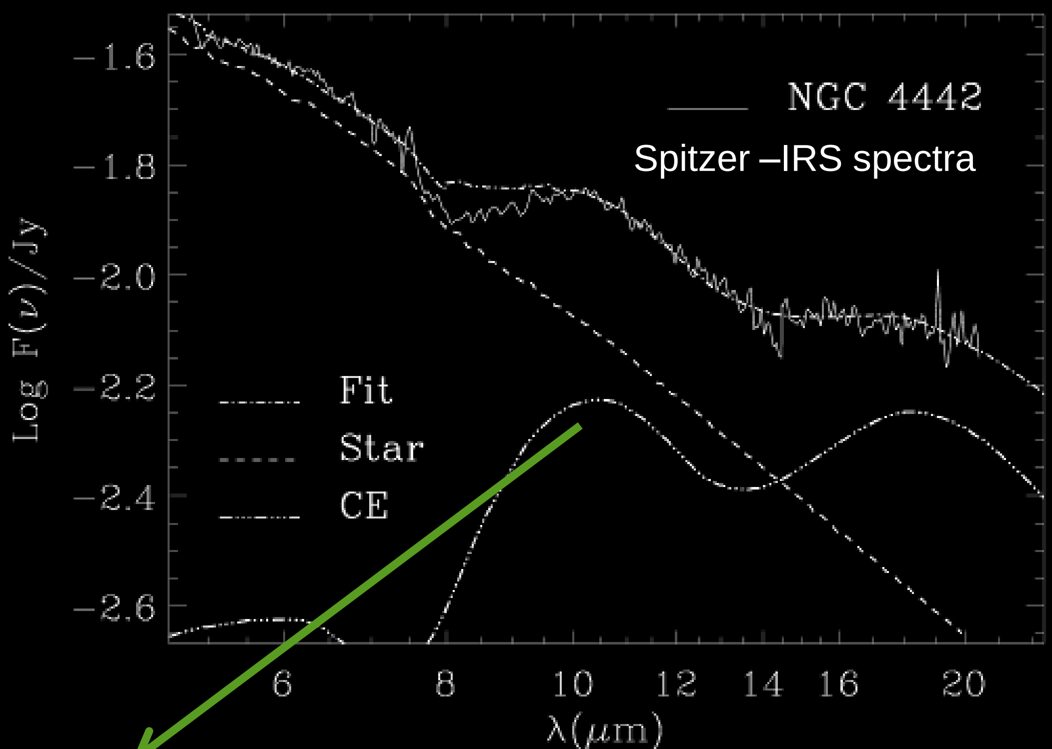

**Fig. 1.** The *Herschel* view of the central regions of M 87. *The bottom right* image is a VLA 20 cm image from the FIRST survey. The 20 cm radio contours have been overlaid on the *Herschel* images. The field of view of all images is 160″ × 90″, beam sizes are indicated in the bottom right corner.



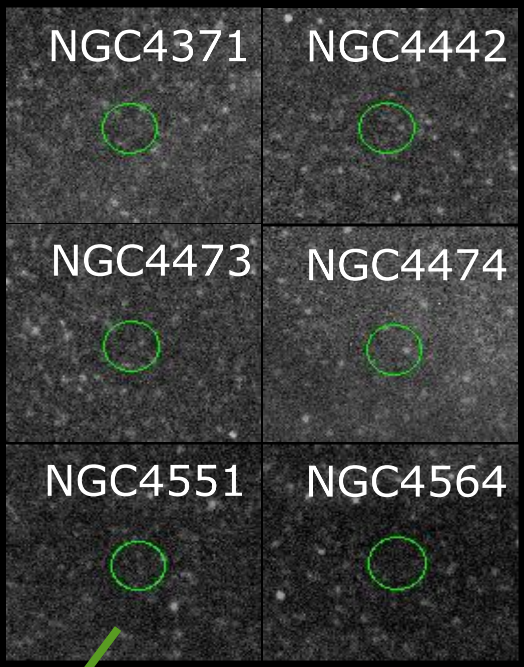

Herschel data are fully consistent with synchrotron emission.

# A constraint on dust grain lifetime in early-type galaxies

## M. S. Clemens et al. (2010)




Truly passively evolving ETG are not detected




$dM_{dust}/dt = A\, \tau_1\, v_\infty\, (L_4)^{1/2}$

$A \sim 6.5\times10^{-10}$ Msun yr$^{-1}$/(km s$^{-1}$)

$V_\infty \sim 10$ km s$^{-1}$

$L_4 \sim 0.3 \times 10^4$ Lsun

Upper limits for $M_{dust}$

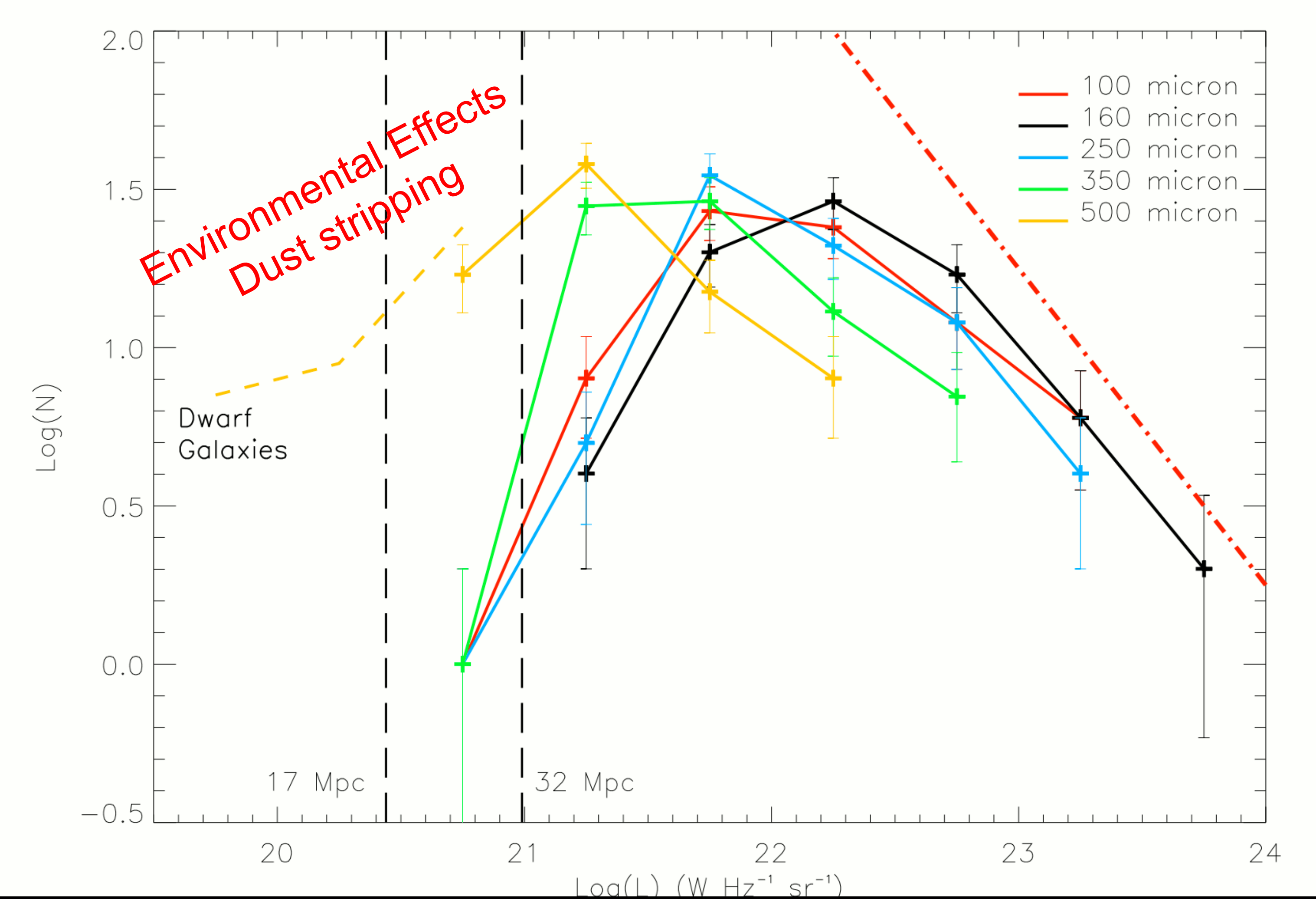
Grain Lifetime $= M_{dust} / (dM_{dust}/dt) < 46 \pm 25$ Myrs

# The Bright Galaxy Sample

**HeViCS**

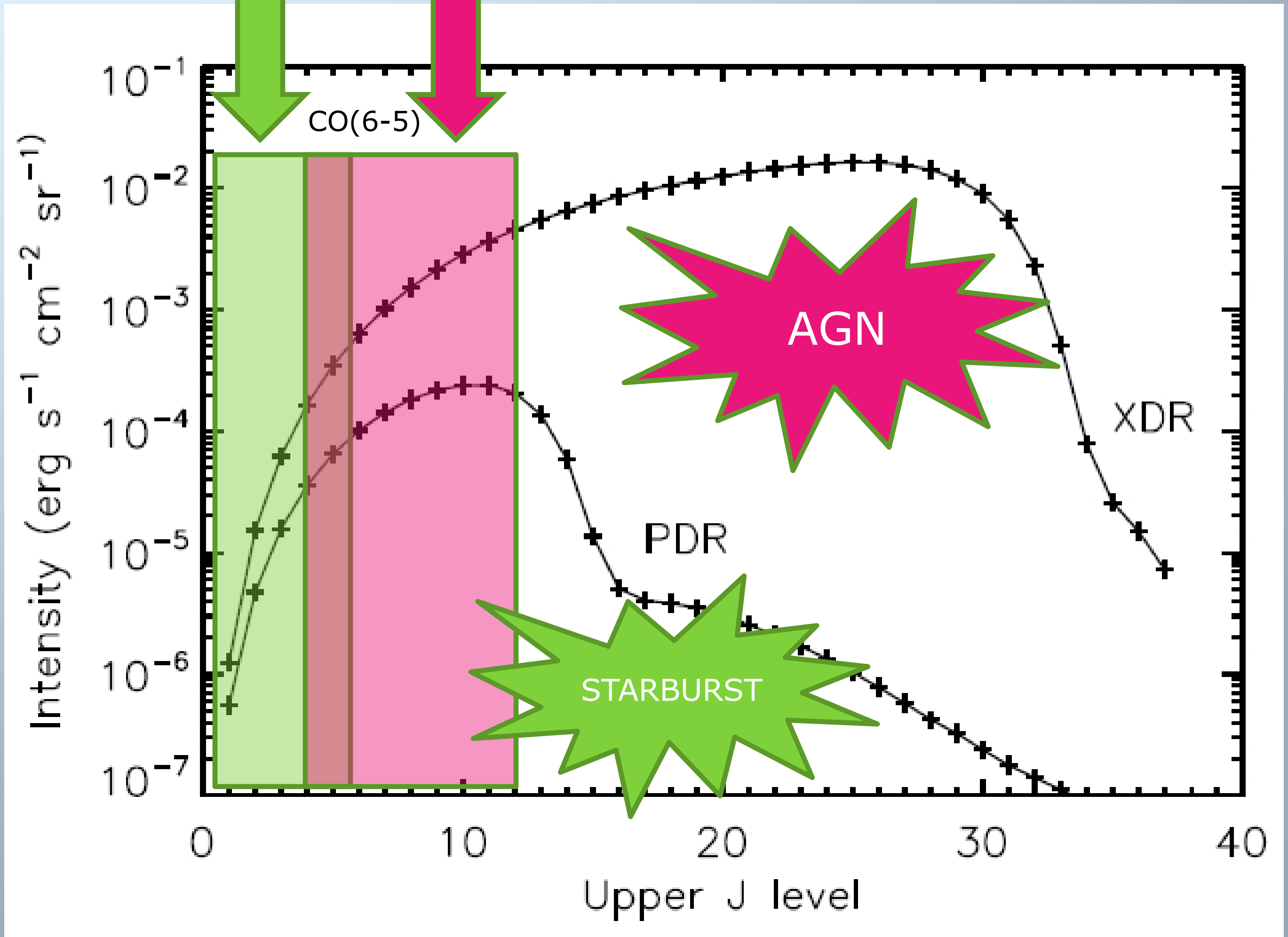
**HeViCS I, J. I. Davies et al. (2010)**
**HeViCS VIII, J. I. Davies et al. 2012, MNRAS, 419, 3505**

78 galaxies selected at 500µm with ⃠>1.4’ and $S_{500}$ > 0.2 Jy
10% of the VCC (Binggeli et al. 1985) galaxies in the field



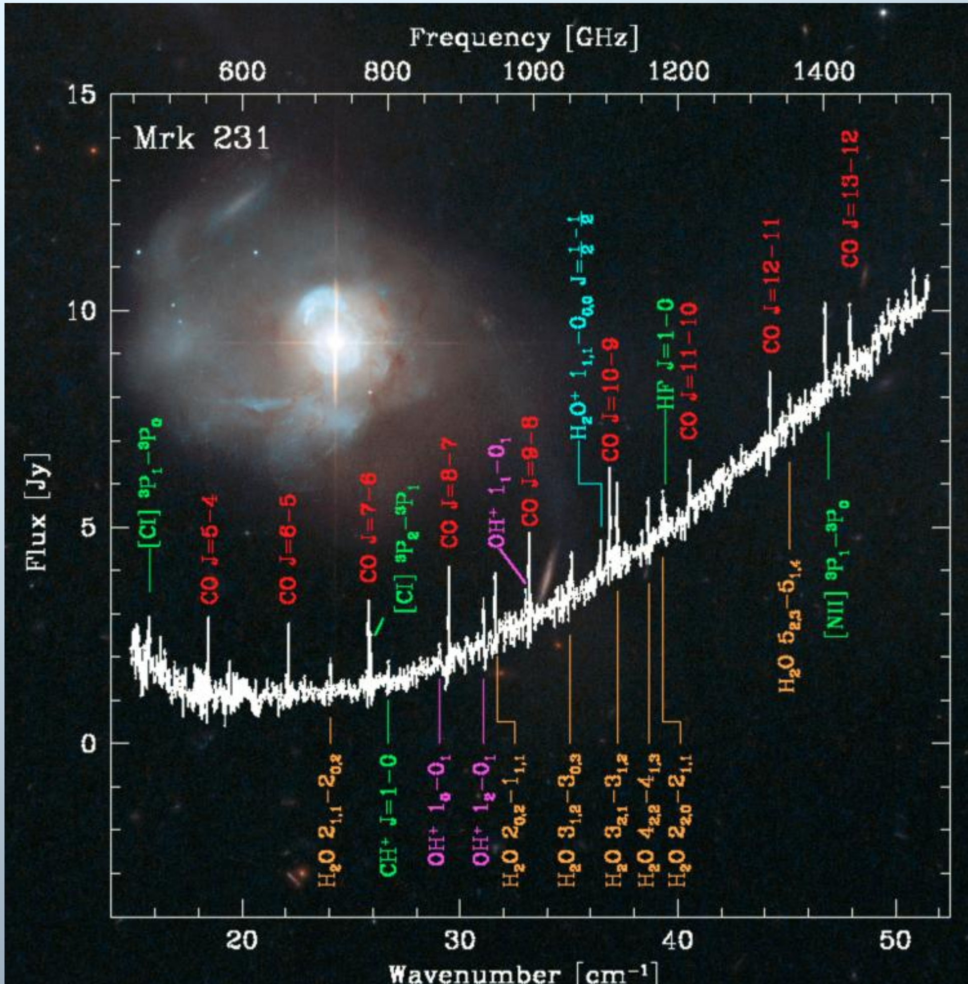
JCMT/IRAM
***Papadopoulos P., van der Werf P., Xilouris E.M., Isaak K., Gao Y., Muehle S., 2012, MNRAS, 426, 2601***

HerCULES
***van der Werf P. et al. 2010, A&A, 518, 42***



**HerCULES**

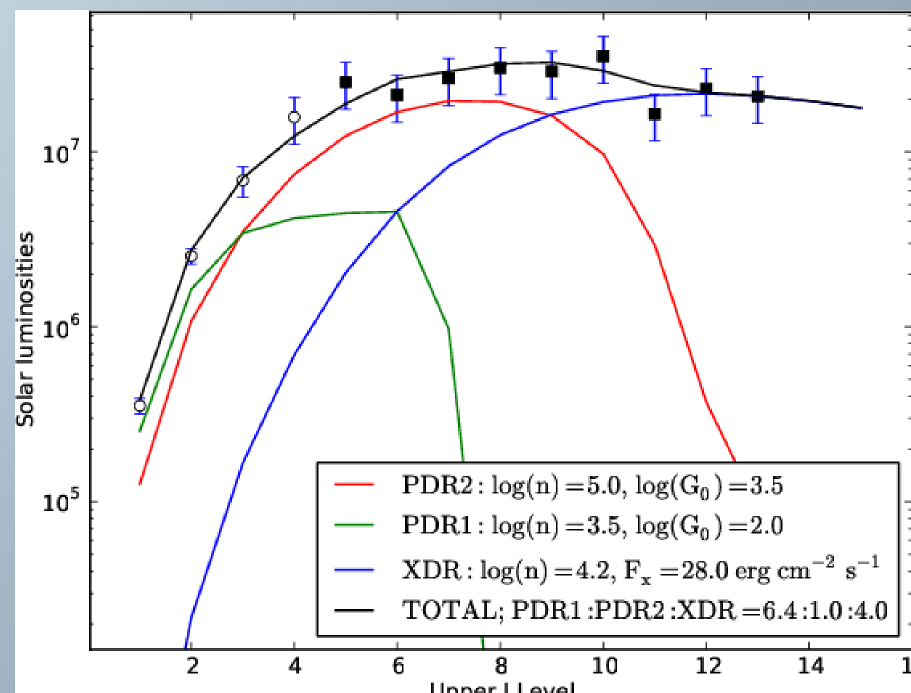
SPIRE-FTS




SPIRE-FTS observations of Mrk231 reveals 25 lines including CO J=5-4 through J=13-12.

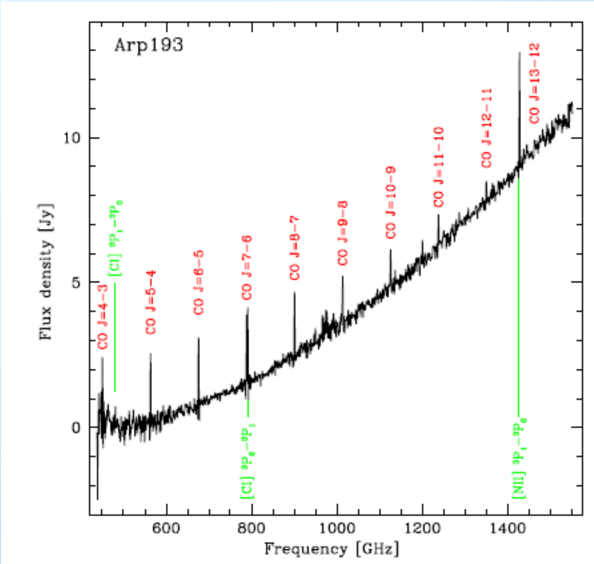
Levels up to J=8: Star-forming (560 pc) disk with clumps.

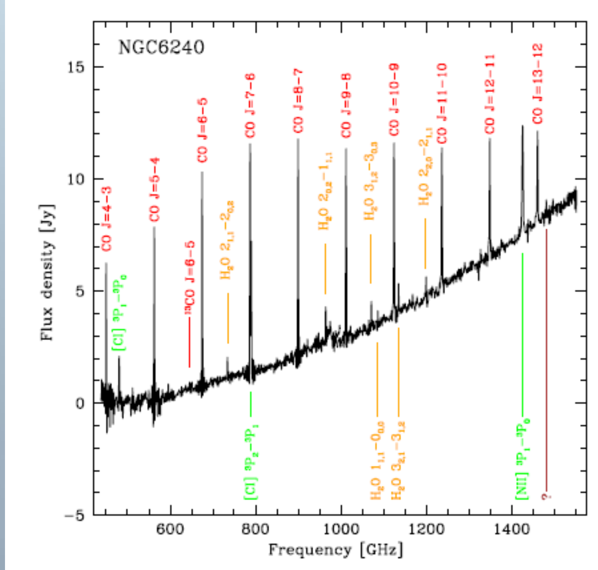
Levels above J=8: X-ray heating from the inner disk (160 pc)



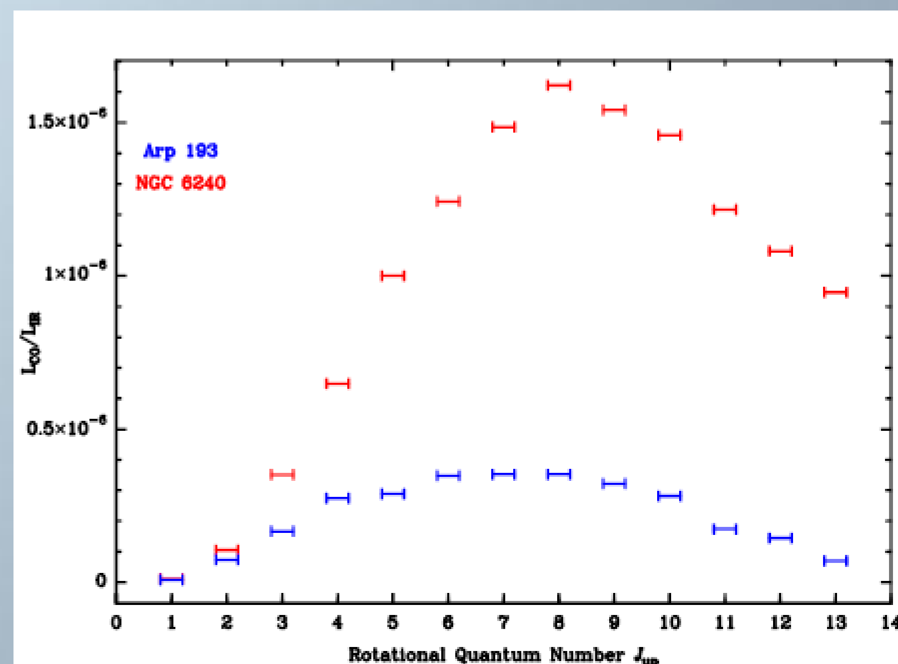

*van der Werf, et al., 2010, A&A, 518, 42*
*Gonzalez-Alfonso, et al., 2010, A&A, 518, 43*

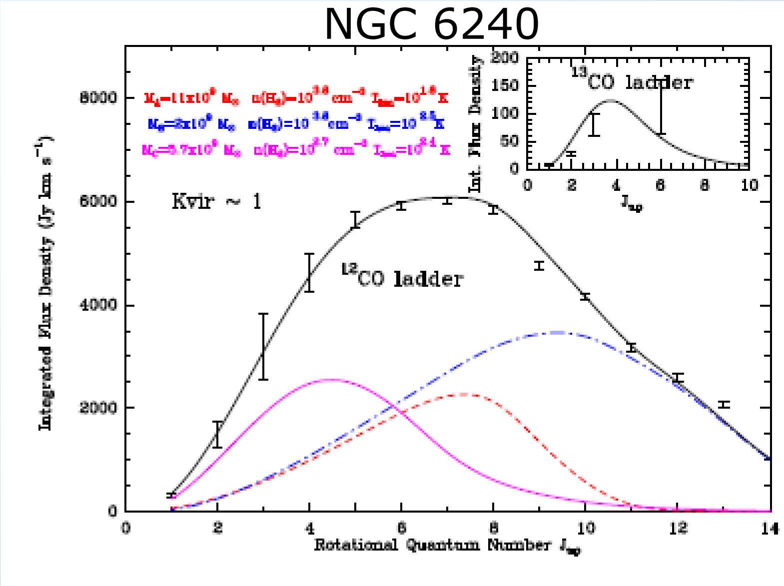
# Spectral Line Energy Distributions (SLEDs) of Arp193 and NGC6240

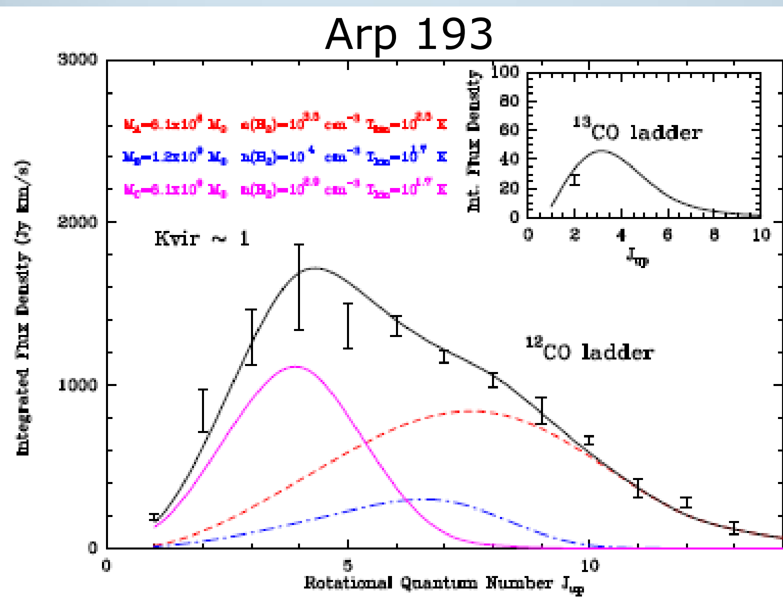



The two SLEDs are strongly diverging from J=4-3 onwards with NGC6240 having a much higher CO line excitation than Arp193.






Arp193 seems to have only ~(5-15)% of molecular gas at densities n>$10^4$ $cm^{-3}$ (i.e. the primary star formation "fuel"), while in NGC6240 this fraction rises to ~(70-90)%, as expected for a prominent merger/starburst. Intense SF feedback, within Arp193, may be the reason behind this disparity.

Papadopoulos et al. 2013, to be submitted

Our aim is to model all HerCULES galaxies.

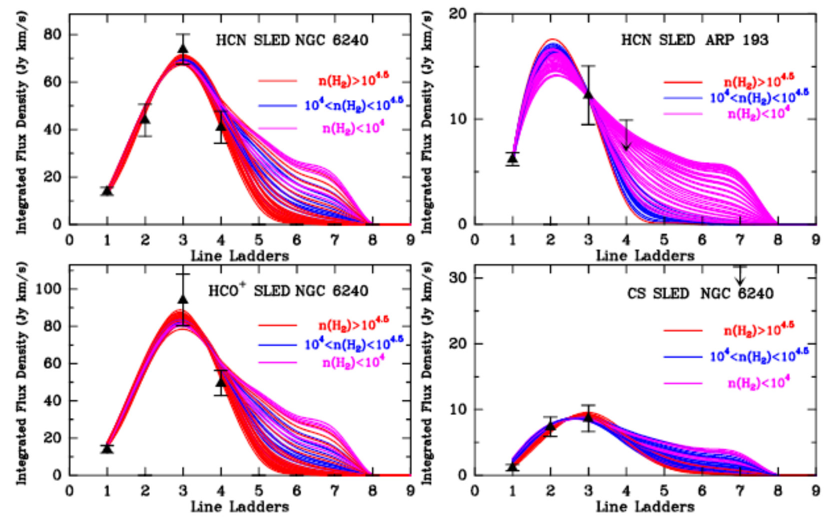
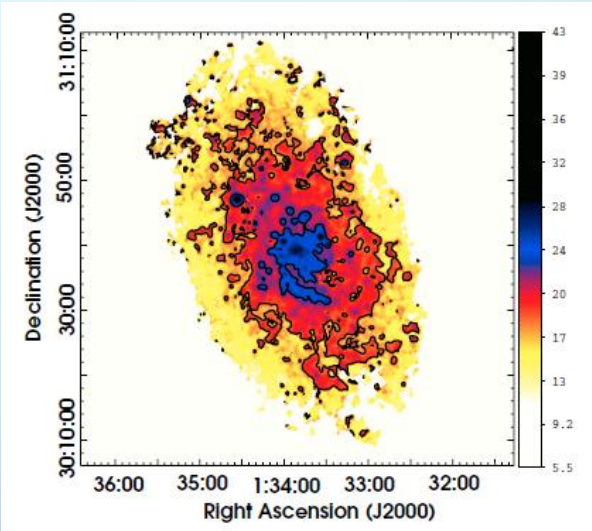
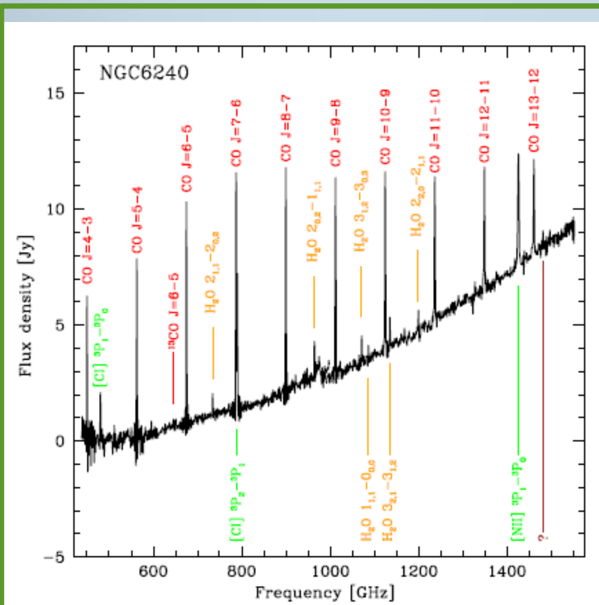



Fig. 7.— The molecular SLEDs that correspond to the [n, $T_{kin}$, dV/dR] solution range shown in Figure 5, parametrized by their density ranges. There is good agreement with all available high-dipole molecular line data, while measurements of HCN and/or the HCO$^+$ J=5–4 line could much reduce the remaining denegeracies on the conditions of the dense gas.

# CONCLUSIONS




For the first time we can "look" at ~10 pc scales in nearby galaxies at submm wavelengths and determine the dust characteristics.




For the first time we can have not only the full SED (Spectral Energy Distribution) of a galaxy but also the SLED (Spectral Line Energy Distribution) and determine the physical properties not only of the dust but also that of the dense star-forming gas.

For the first time we can have deep surveys at submm wavelengths and carry out statistical studies of the dust inventory in field and cluster environments.