Low Metallicity Dwarf Galaxies:

Bridging the Gap Between the Local Universe and Primordial Galaxies

The SPIRE Local Galaxies Working Group (SAG 2)

And

PACS: SHINNING

Presented by Suzanne Madden, CEA Saclay, France

The Dwarf Galaxy Survey - Science

1. Nearby low-metallicity laboratories in the local universe - Conditions similar to early universe galaxies

2. Dwarf galaxies (as low as 1/50 Zsolar) in local universe – can study of the evolution of the dust and gas properties as a function of metallicity

3. How does the lower dust abundance effect the star formation process?

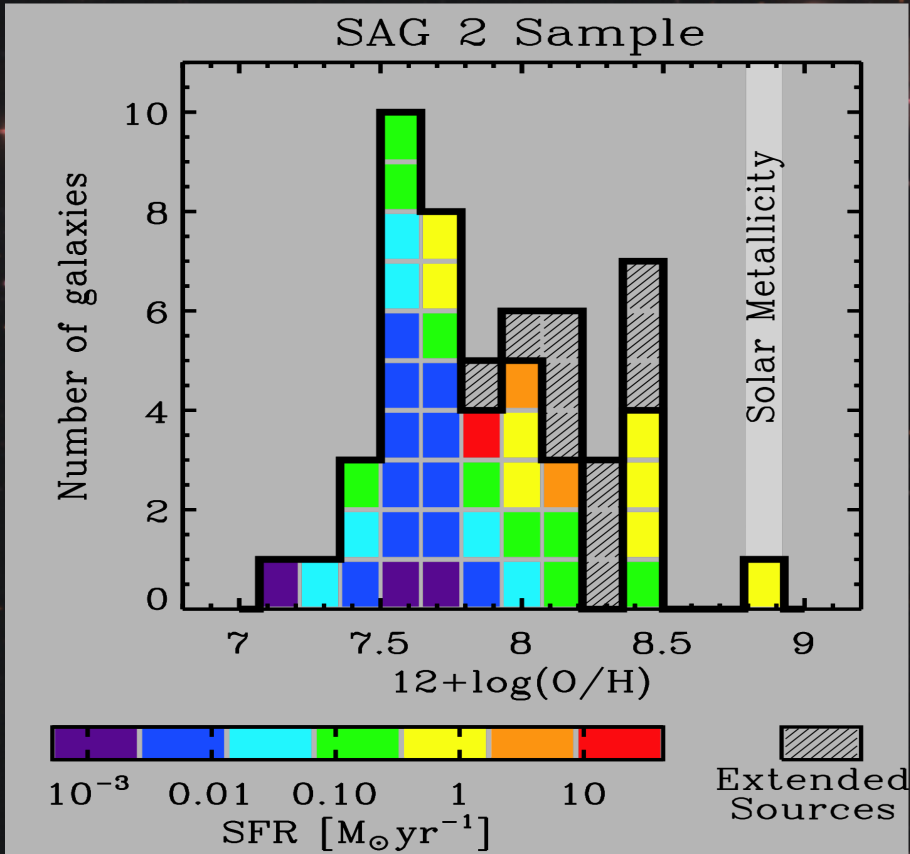
Dust enrichment in primeval environments <----> essential for enhancement of SF activity

4. Dwarf galaxies harbor prolific SSCs. How much star formation activity is actually hidden even in dust-poor environments?

5. What galactic properties and processes control the dust and gas evolution? How are ISM structure, star formation activity and metallicity related ?

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

The Dwarf Galaxy Survey - Targets



55 galaxies: statistical information in most metallicity bins

All sources observed with all 3 Spitzer instruments

Source Selection

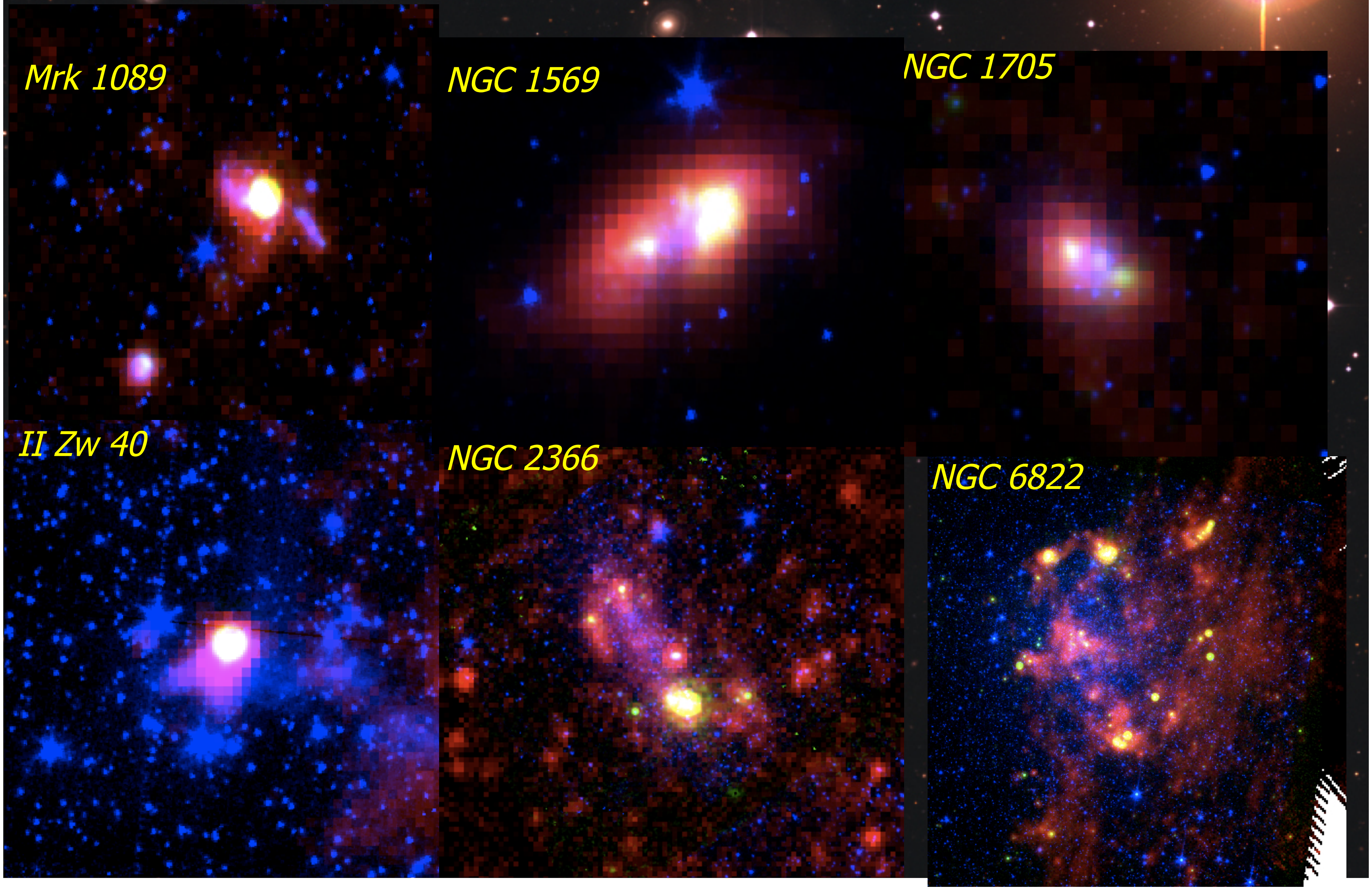
Fill metallicity bins:
~ 5 to 9 galaxies in 7 bins where possible

Extremely low metallicity galaxies: 1/50 to 1/20

The well-known extended galaxies of the local group

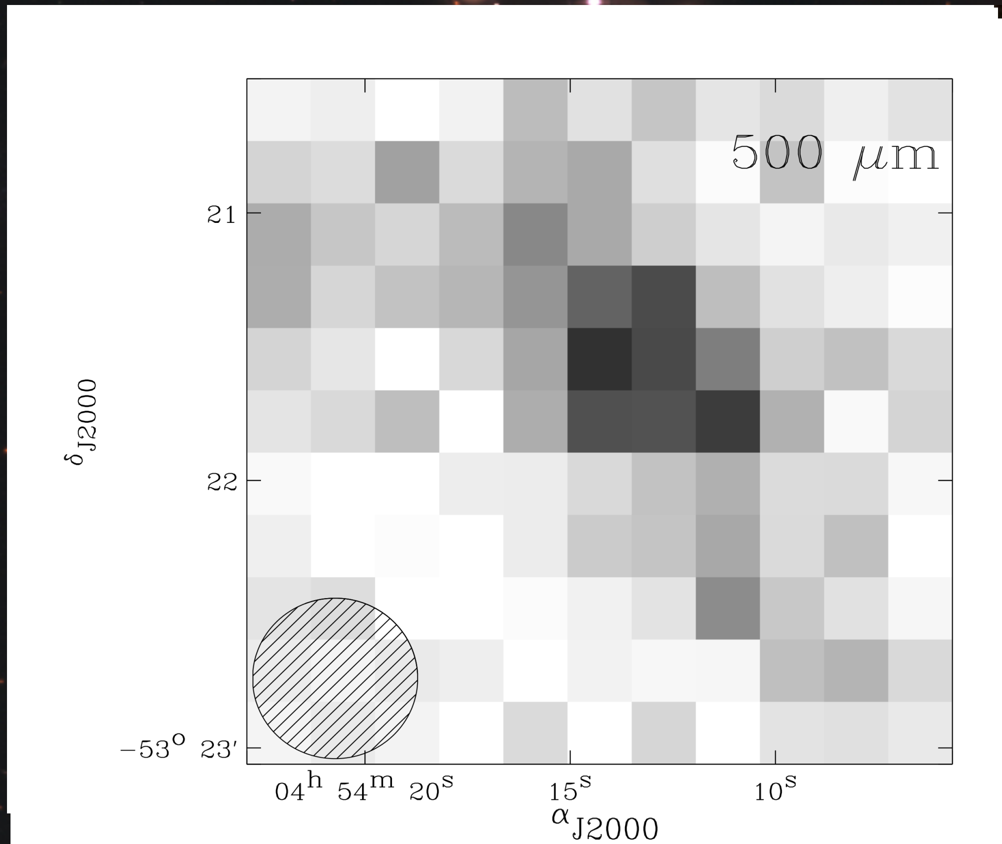
Dwarf Galaxies: Herschel-Spitzer 3-color images

Blue: 3.6 mu(stars)   green: 24 mu (hot dust)   red: 250 mu (cold dust)



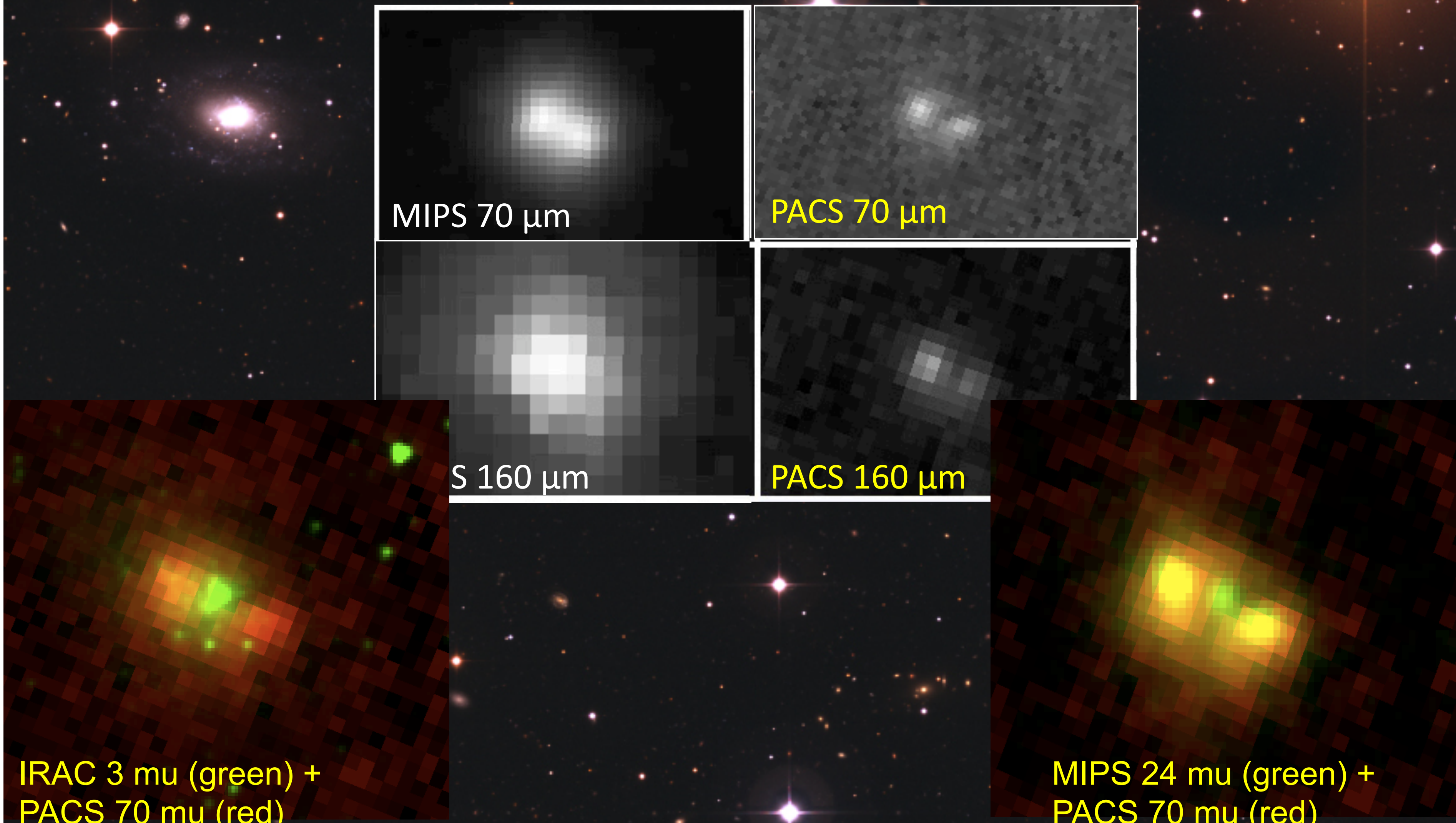
NGC 1705 *Herschel + Spitzer* D = 5 Mpc Z = 1/3 Zsolar

O'Halloran et al 2010 (see poster)



The Super Star Cluster dominates at short λ
but disappears > 24 μv
PACS isolates the 2 other clusters

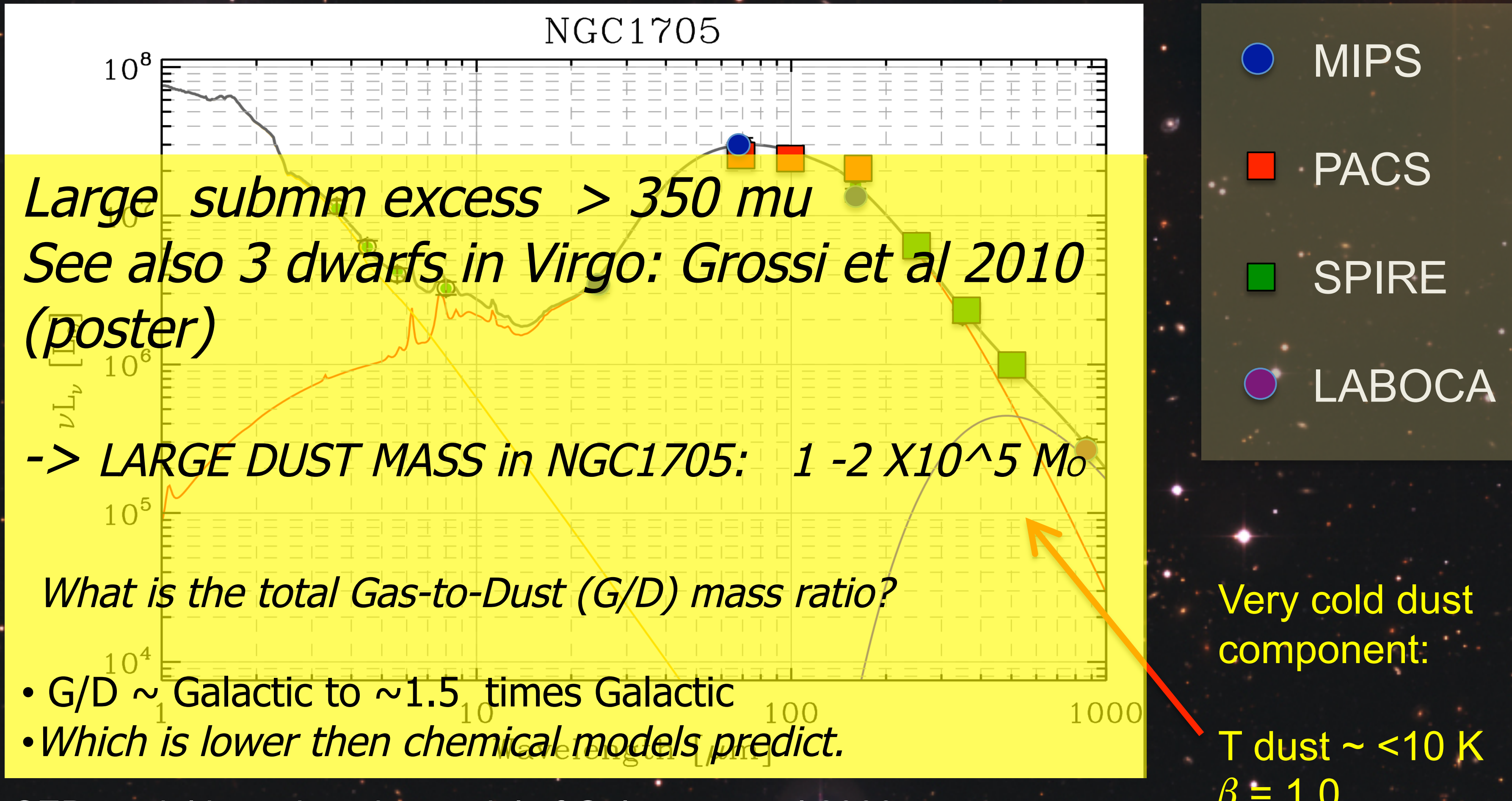
NGC1705: the Improved Spatial Resolution of Herschel



NGC 1705 submm excess:

O'Halloran et al 2010 (see poster)

IRAC + MIPS + PACS + SPIRE + Laboca 870 mu



Large submm excess > 350 mu

See also 3 dwarfs in Virgo: Grossi et al 2010 (poster)

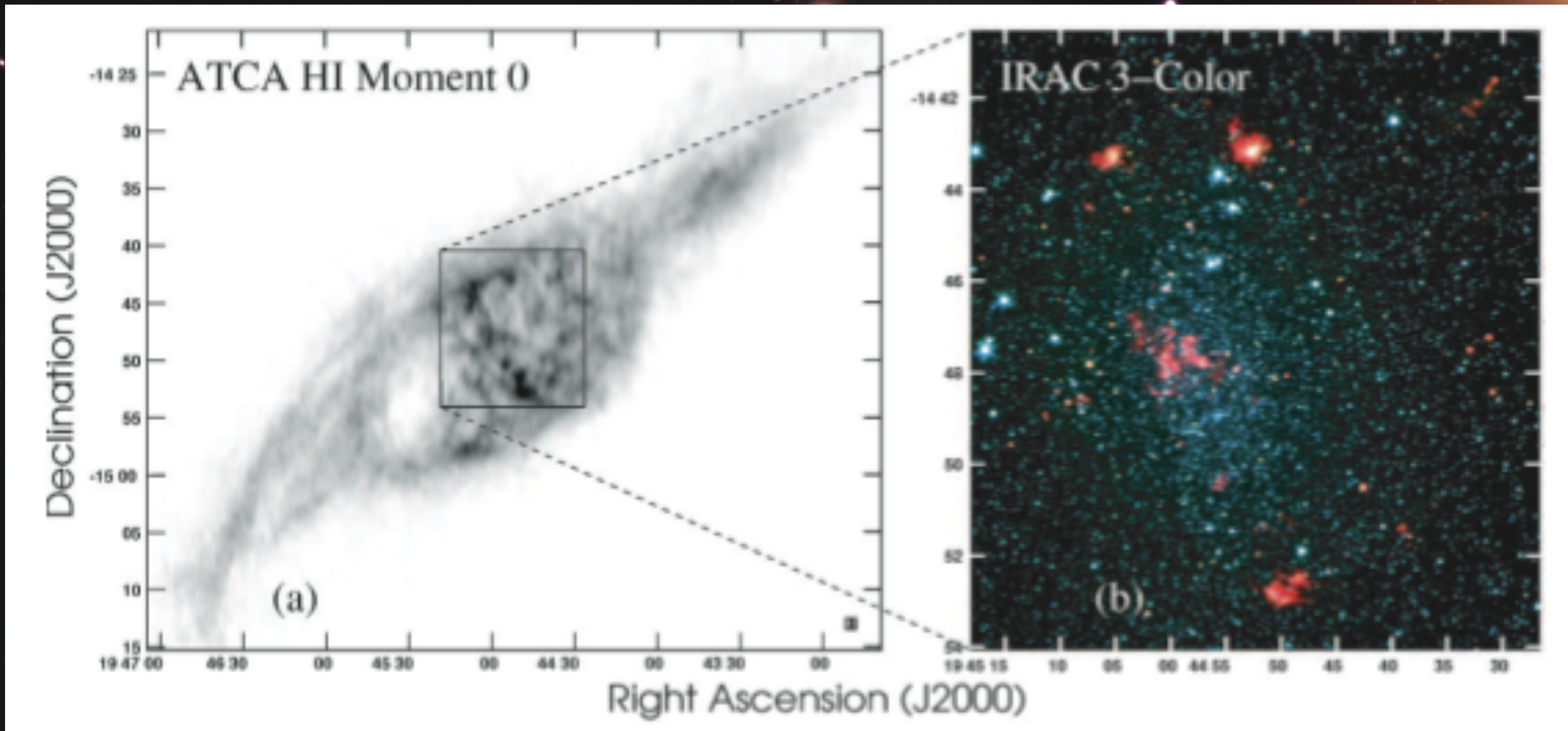
-> LARGE DUST MASS in NGC1705: 1 -2 X10^5 Mo

What is the total Gas-to-Dust (G/D) mass ratio?

- G/D ~ Galactic to ~1.5 times Galactic
- *Which is lower then chemical models predict.*

SED model based on the model of Galametz et al 2009

NGC 6822:
Galametz et al 2010 (see poster)



Cannon et al 2006

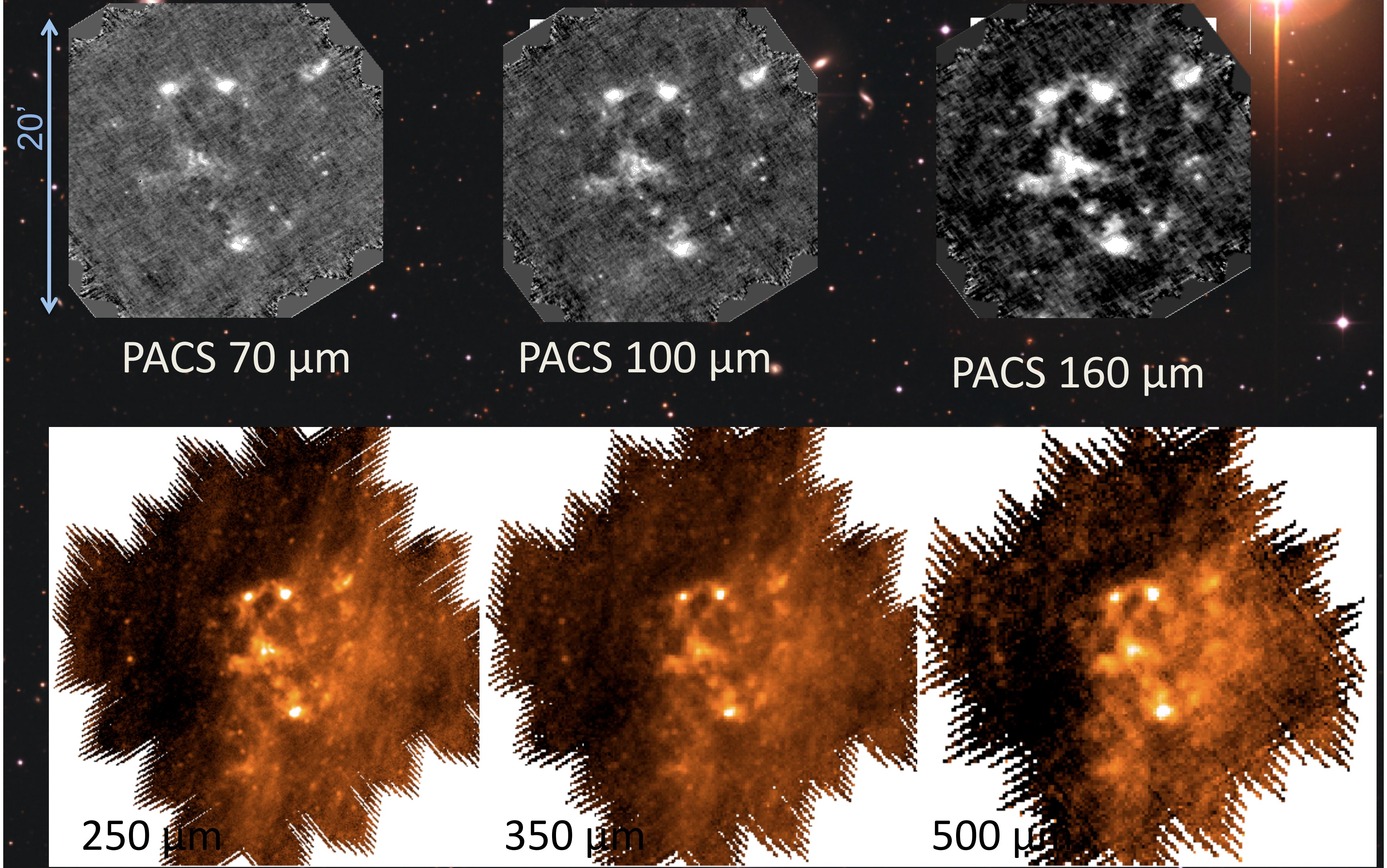
Atomic gas: 1.3 degrees

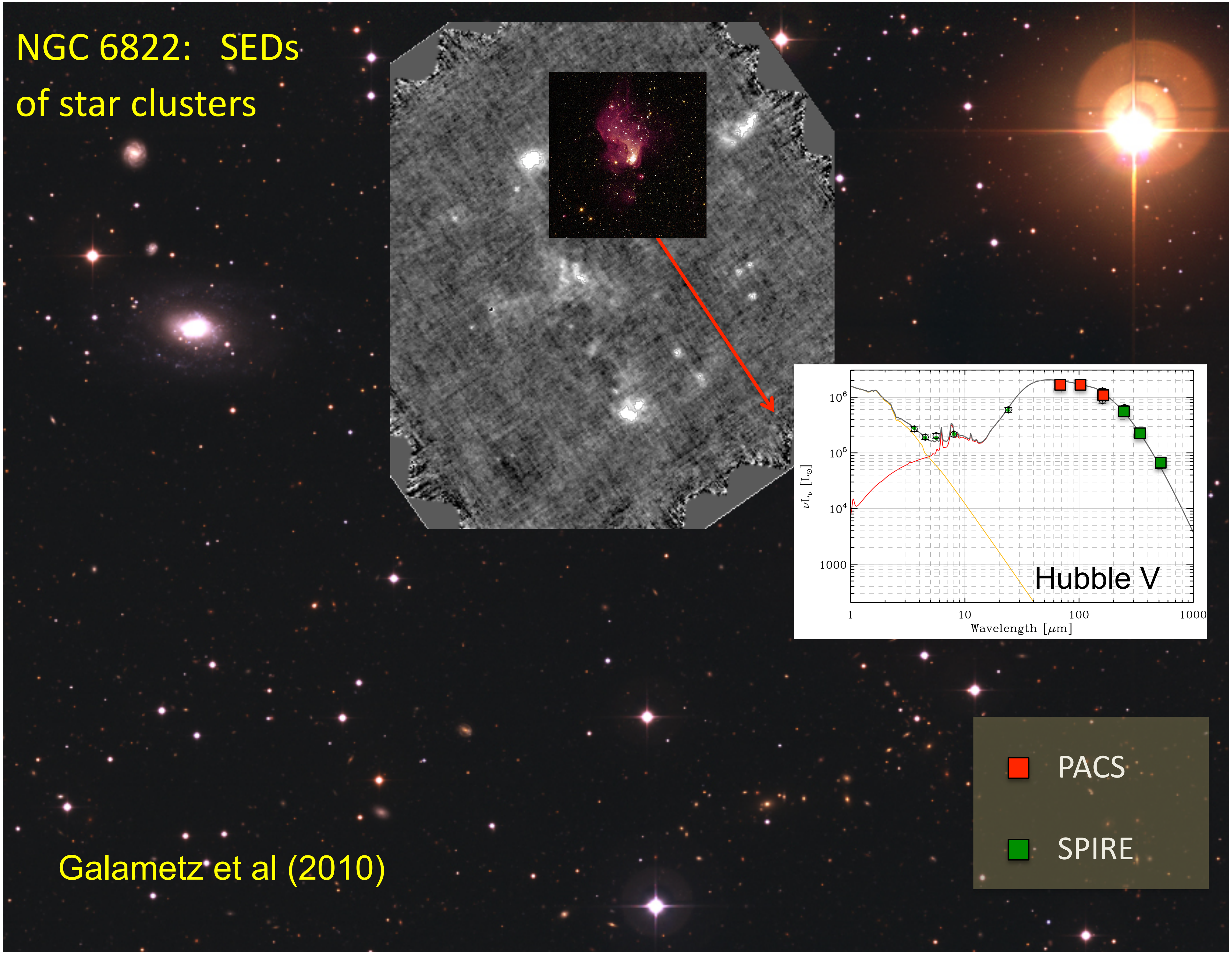
All the star formation activity
Confined to 20' region

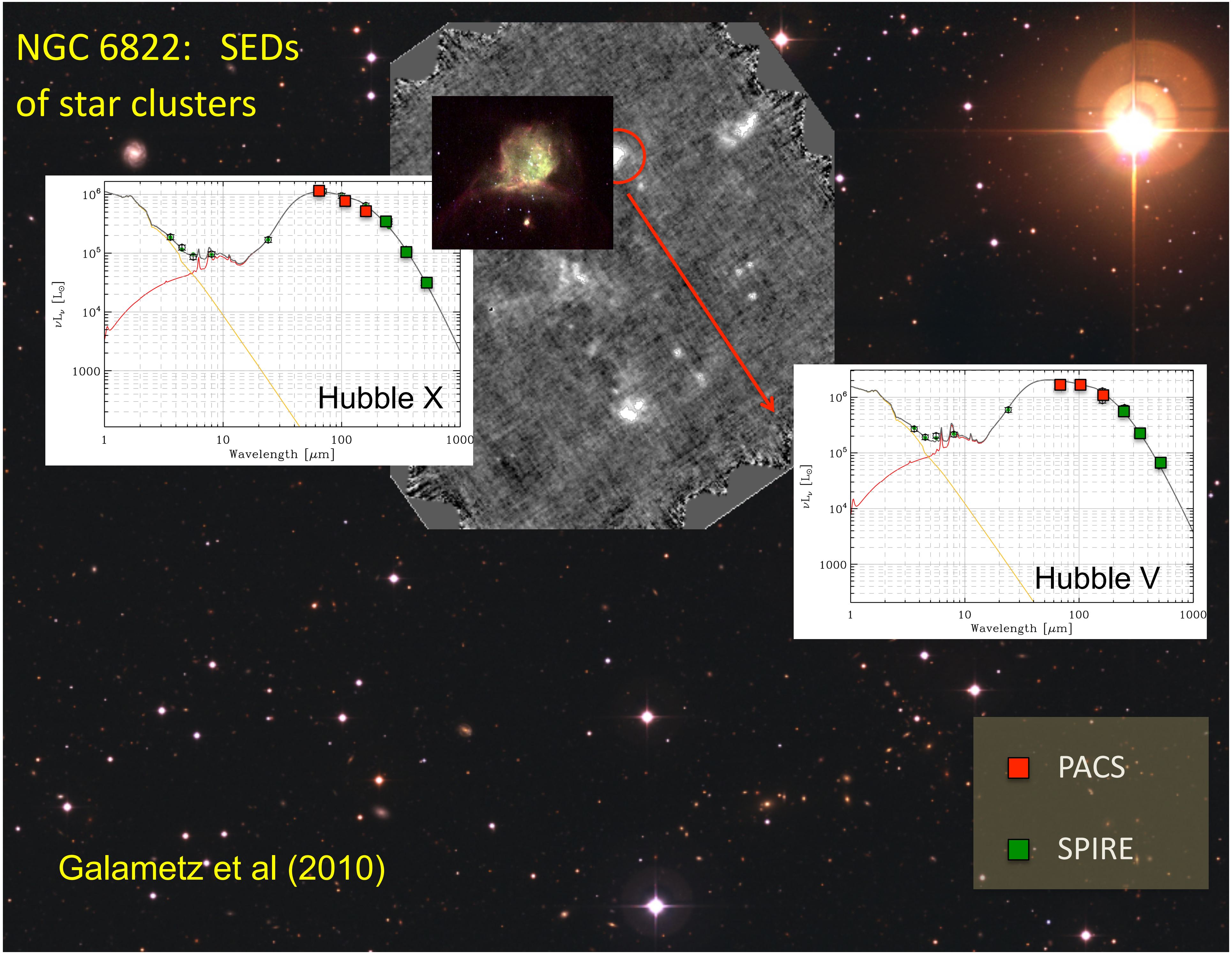
D = 0.5 Mpc
Z = 1/5 Z solar

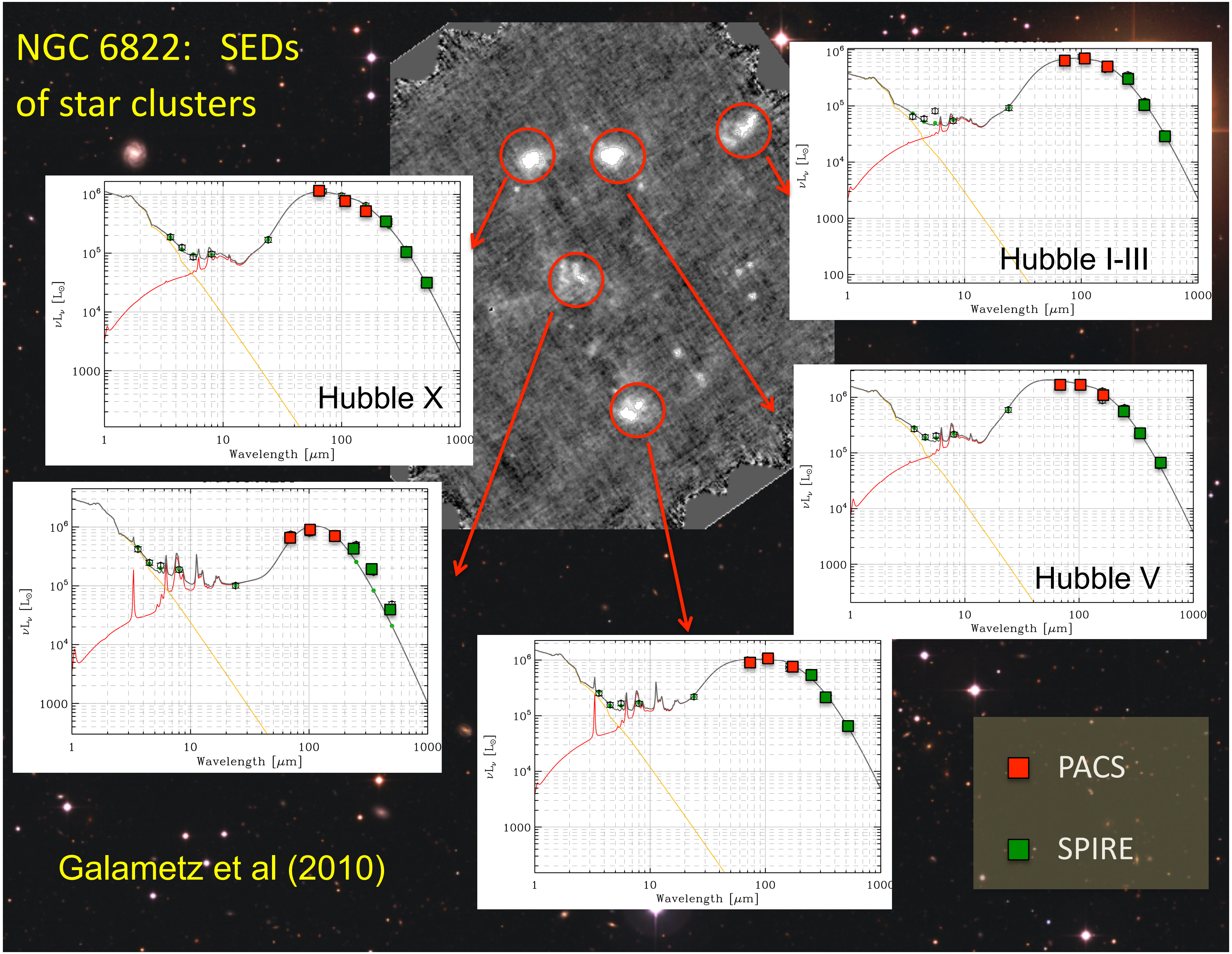
NGC 6822: PACS & SPIRE Mapping:

Galametz et al. 2010 (see poster)



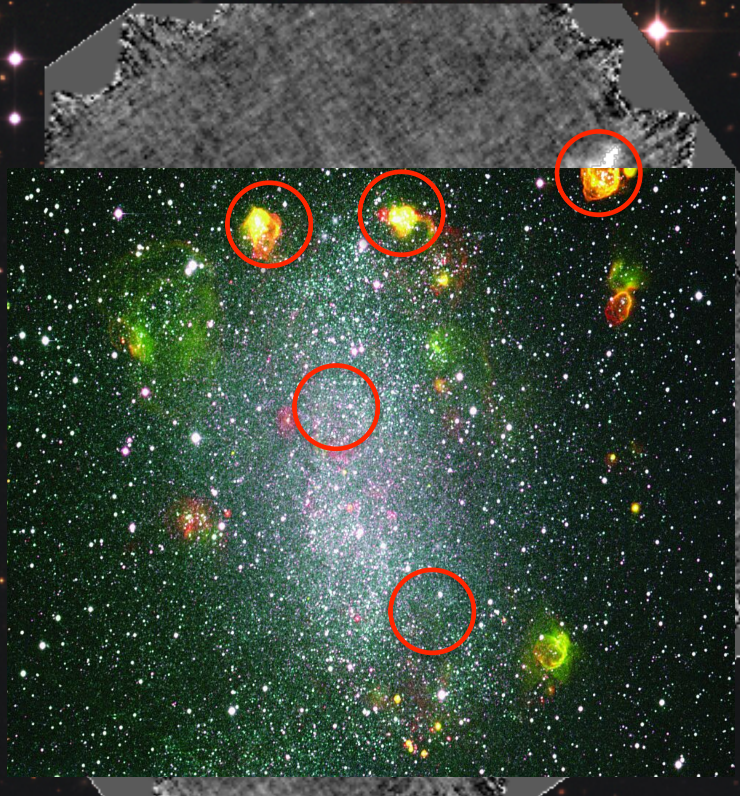

NGC 6822: SEDs
of star clusters
Hubble V
Wavelength [μm]
νLν [L⊙]
1
10
100
1000
1000
10^4
10^5
10^6
PACS
SPIRE
Galametz et al (2010)


NGC 6822: SEDs
of star clusters
10^6
10^5
10^4
1000
νL_ν [$L_\odot$]
Hubble X
1
10
100
1000
Wavelength [μm]
Hubble V
PACS
SPIRE
Galametz et al (2010)


NGC 6822: SEDs
of star clusters
Hubble X
Hubble I-III
Hubble V
Wavelength [μm]
νLν [L⊙]
PACS
SPIRE
Galametz et al (2010)

NGC 6822:

SEDs of star clusters



What is the total Gas-to-Dust (G/D) mass ratio?

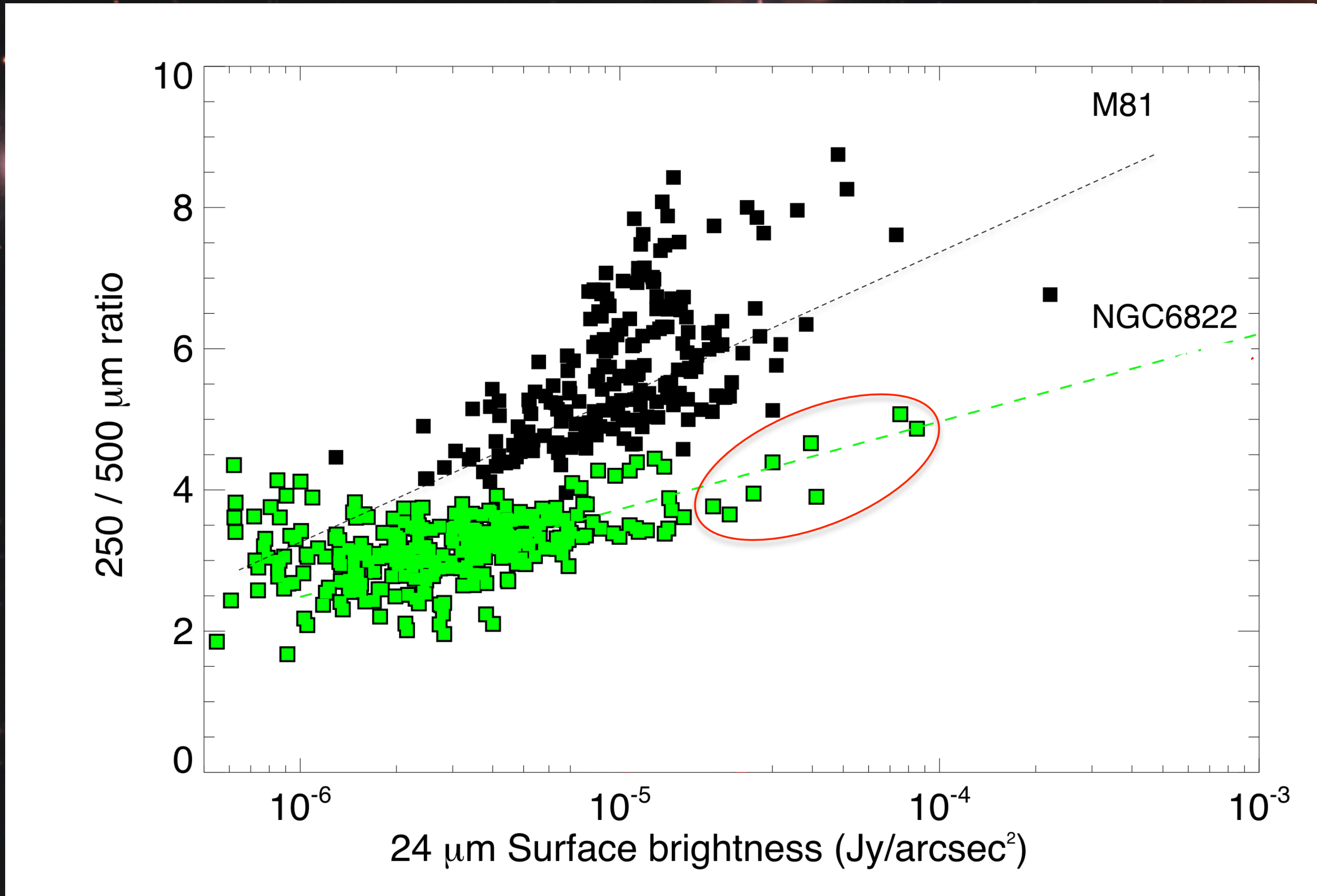
Hubble V

- G/D ~ 100 for graphite + silicate
- G/D ~ 200 for amorphous carbon + silicate of
  Rouleau & Martin 1991 (as in Meixner et al 2010 for LMC)
- Higher G/D using more emissive grains (flatter submm slope)

BUT G/D still lower than expected for its metallicity
(G/D should be ~500 – 1000)

What are the submm bands tracing ?

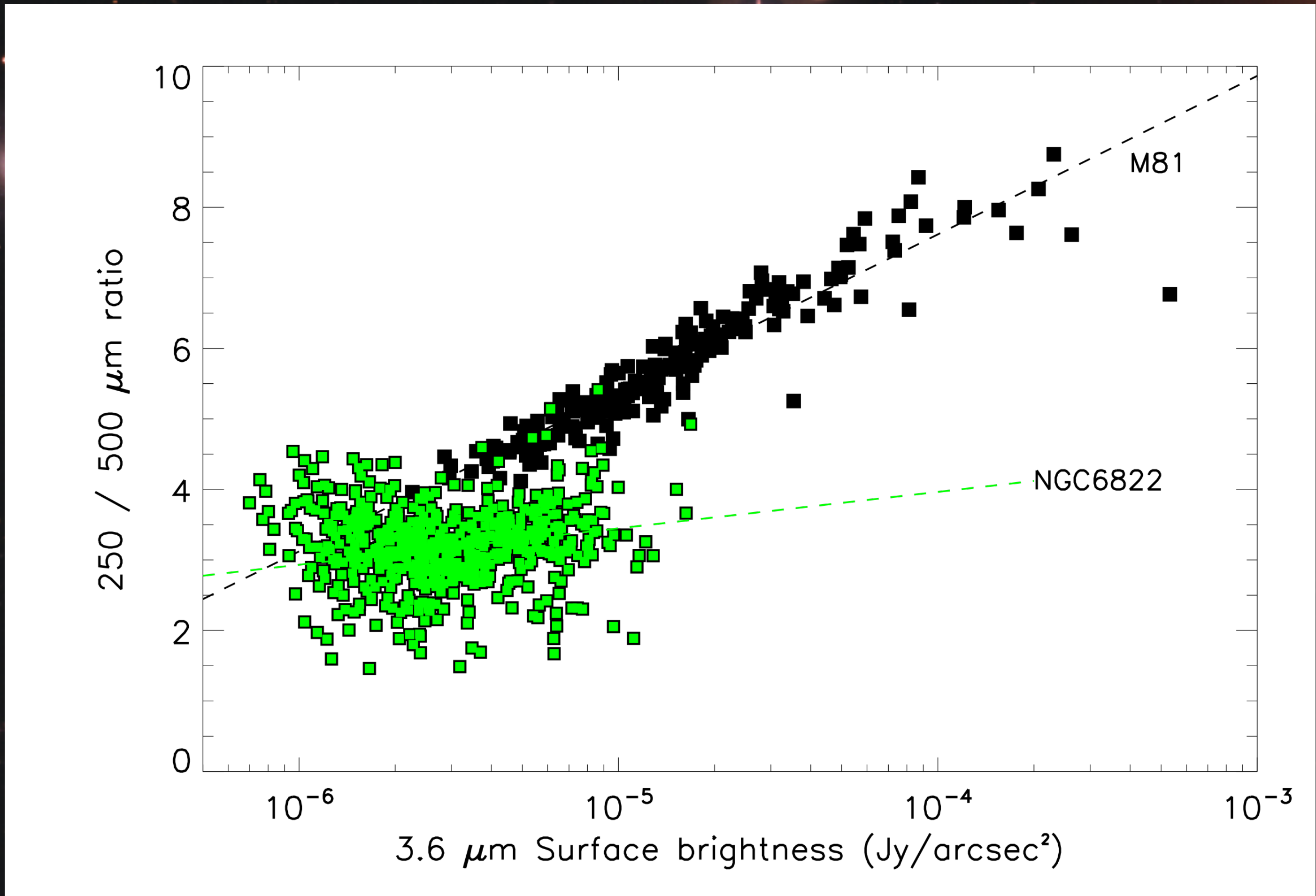
M81: Bendo et al 2010
NGC6822: Galametz et al 2010



Dust heated by star formation ?

What are the submm bands tracing ?

M81: Bendo et al 2010
NGC6822: Galametz et al 2010



Dust heated by evolved stars ?

The Dwarf Galaxy Survey – PACS Spectroscopy

Diagnostic tracers of HII regions, PDRs, Diffuse Ionised Medium =>

- *PACS spectroscopy + Spitzer IRS*

[CII] 158 µm Most important cooling lines of the atomic gas.
[OI] 63 µm Probes the conditions in PDRs - the largest fraction
[OI] 145 µm of the neutral medium in a galaxy.

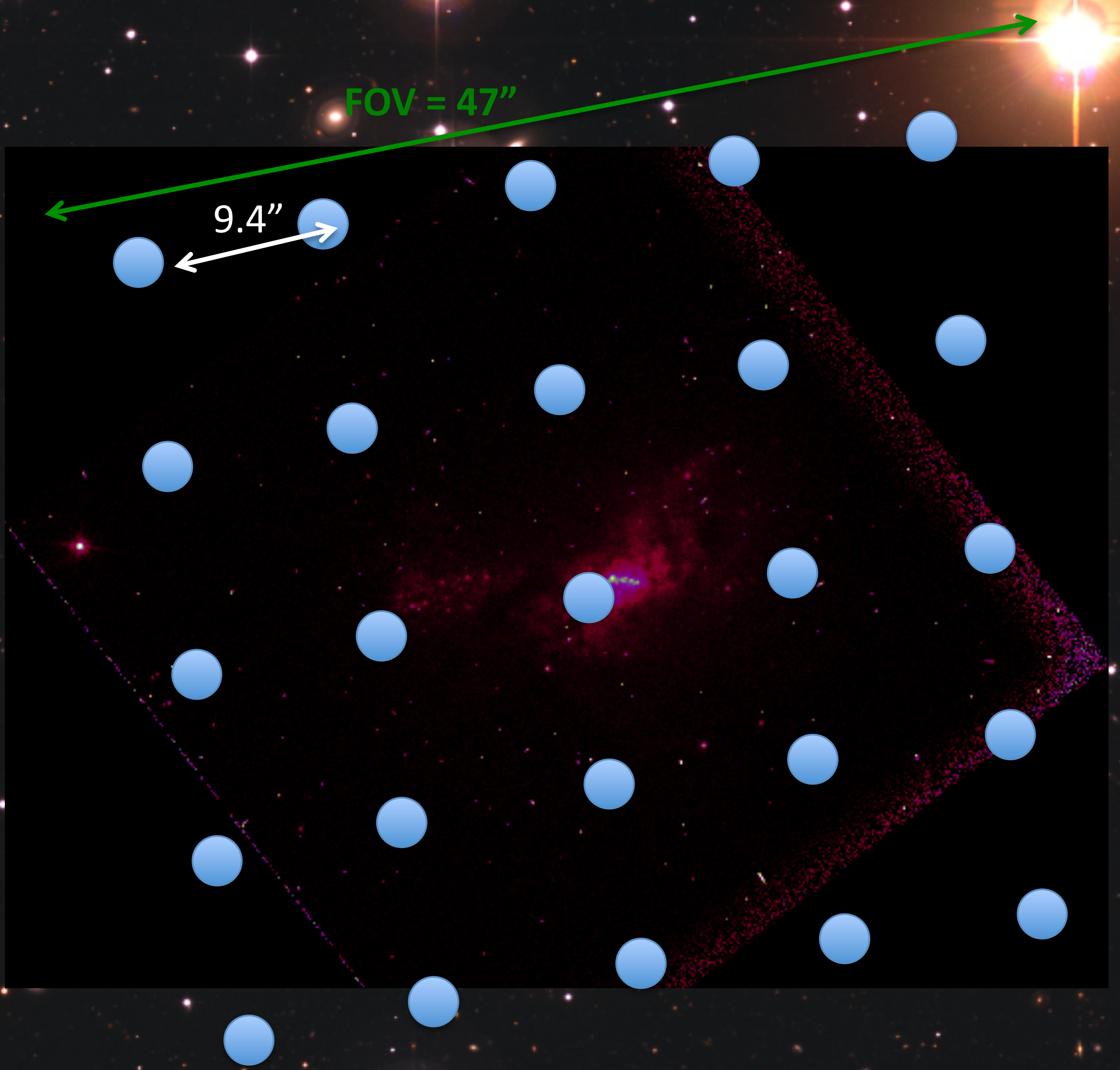
[NII] 122 µm Conditions in the ionized medium. Diagnostics
[NII] 205 µm of absolute level and excitation of star forming)
[NIII] 57 µm activity and of n_e @ low density (< 10^3 cm^{-3}) DIM

[OIII] 88 µm

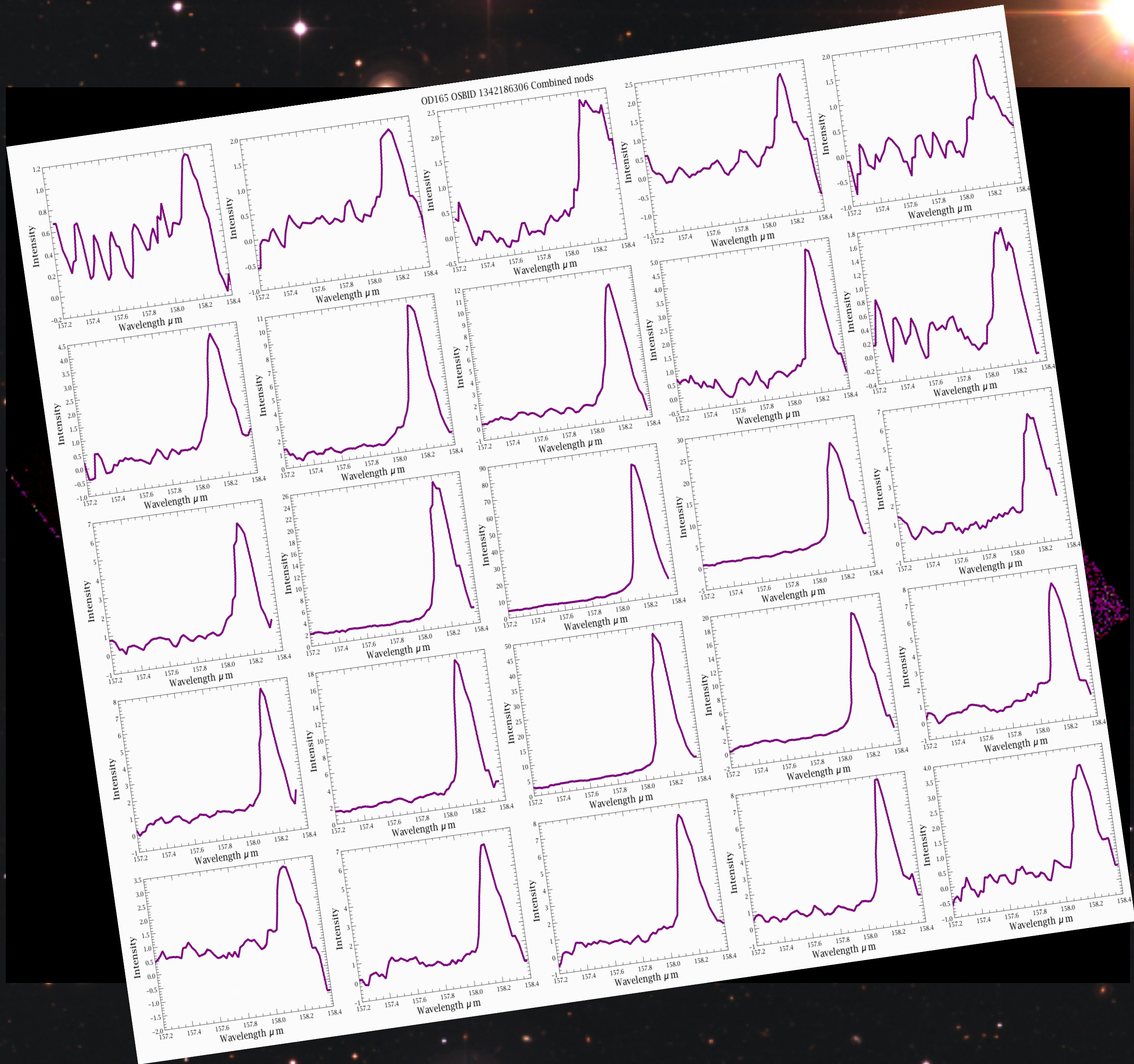
Abundances ***i.e. [NIII]/[OIII]***
Densities ***i.e. [NII], [OIII], [SIII] line pairs***
Gas pressure ***i.e. [OI] pairs***
UV hardness ***[NII]/[NIII]`. [SIII]/[OIII] pairs***
& intensity
ISM filling factor

He 2-10 : single pointing map

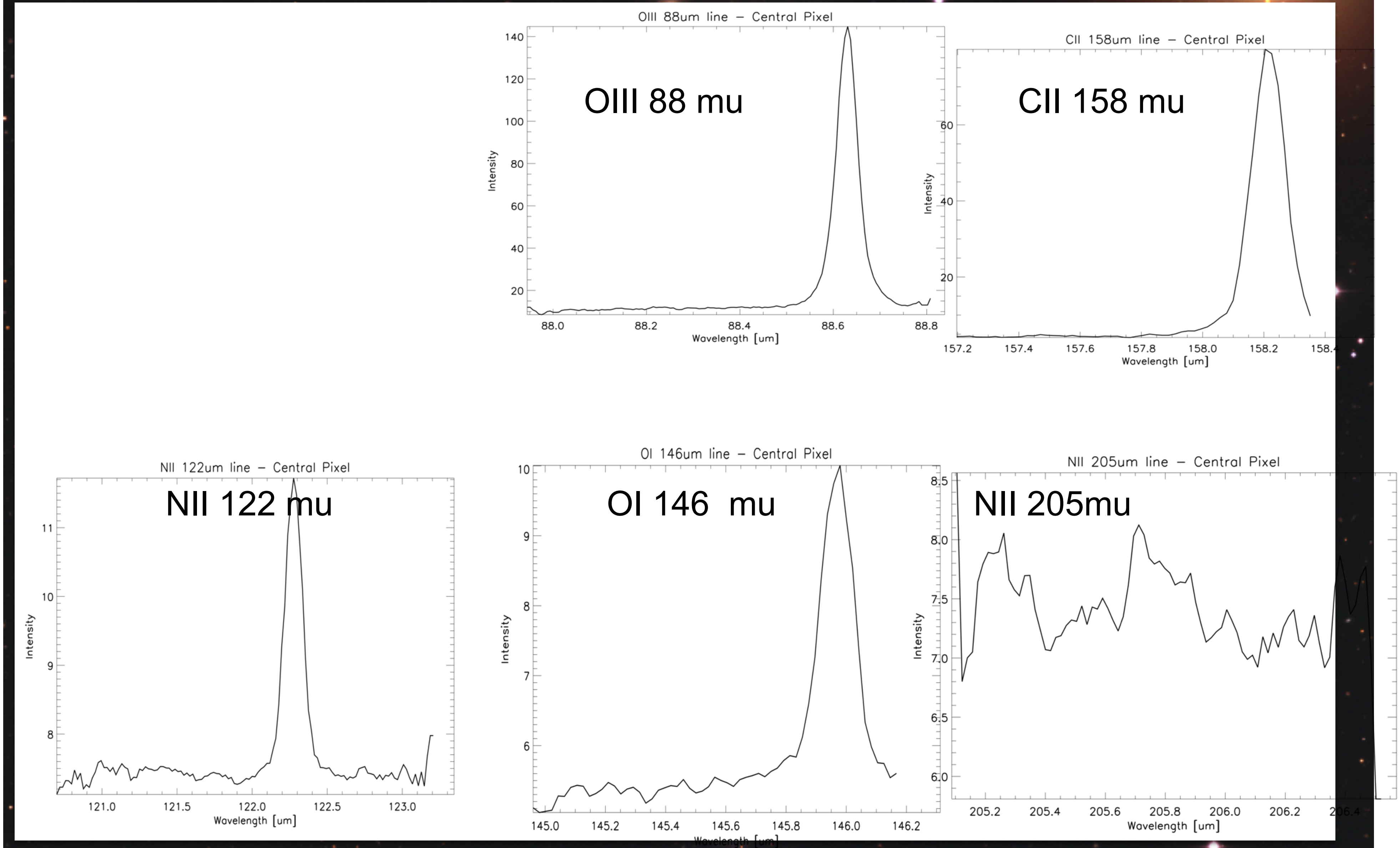
Located at 9Mpc
Metallicity ~ solar



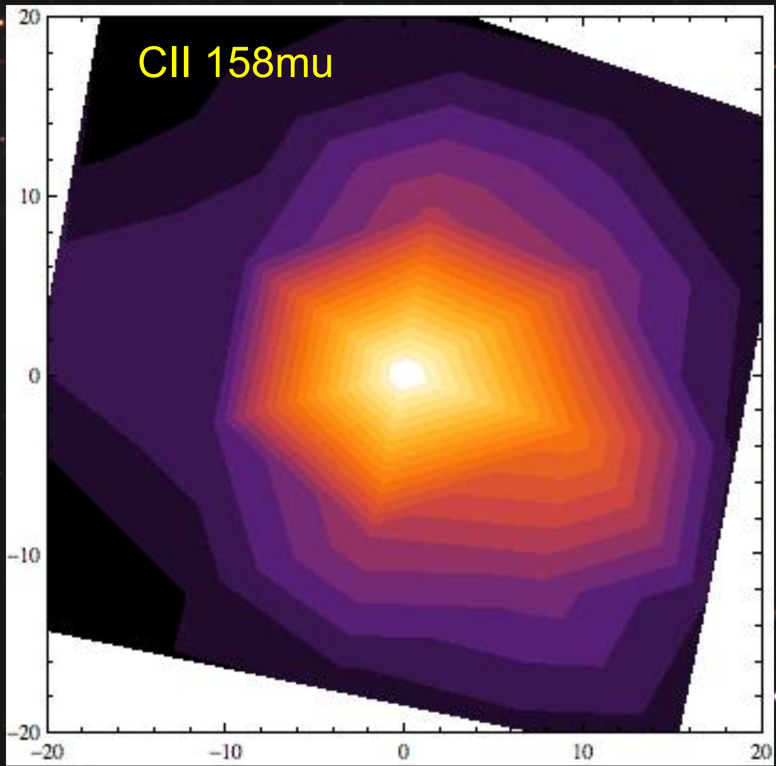
He 2-10 : single pointing map

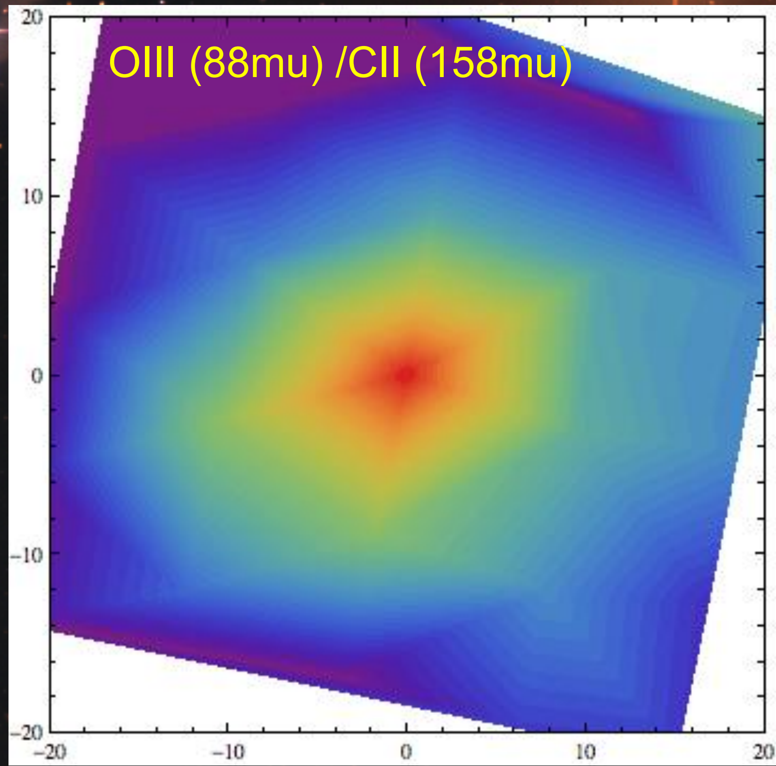


Spectroscopy Dwarf Galaxies (SHINING)
He 2-10 (D=9 Mpc)



Spectroscopy Dwarf Galaxies (SHINING): He 2-10 CII (158 mu) & OIII (88 mu)

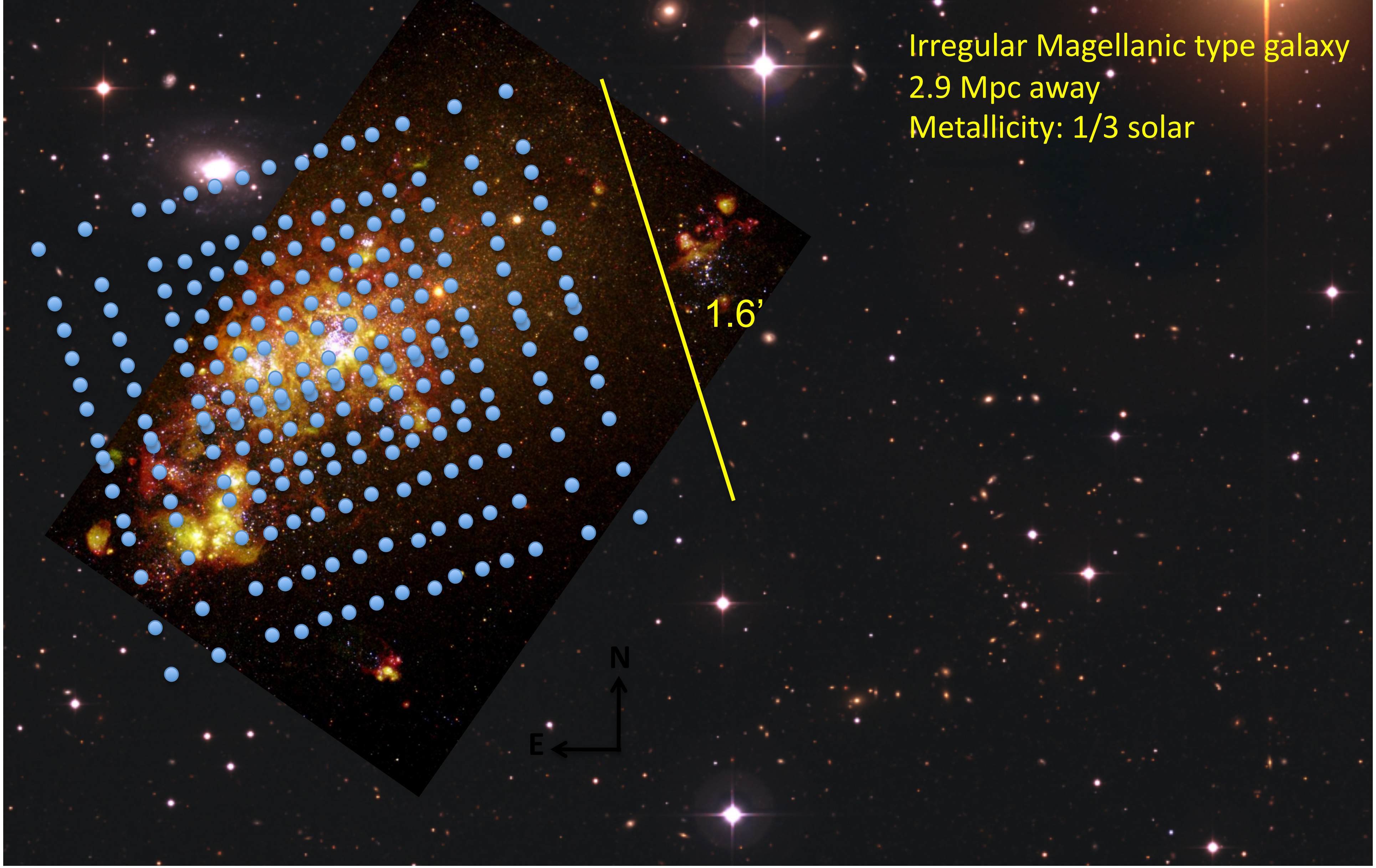




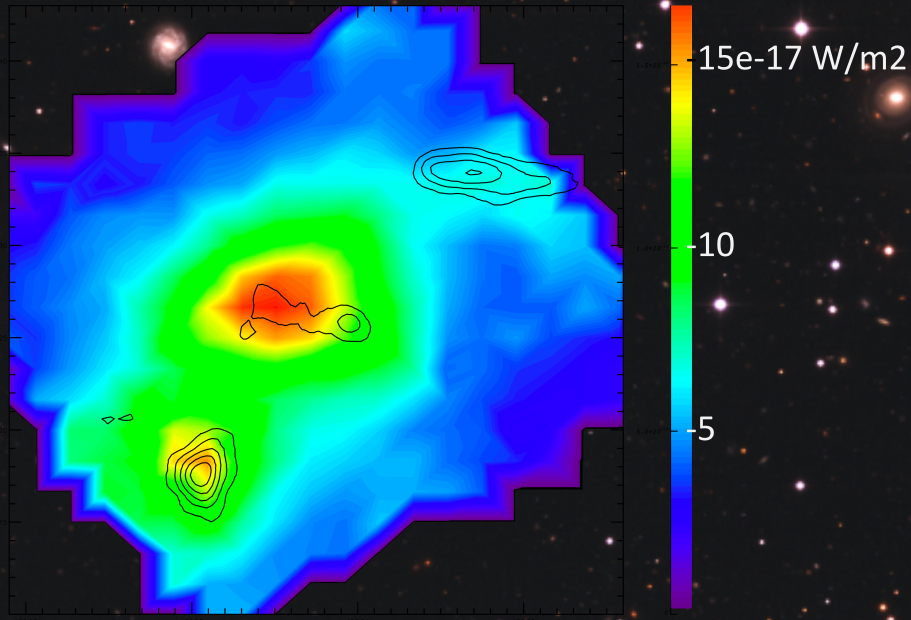
47 arc sec = 2 kpc

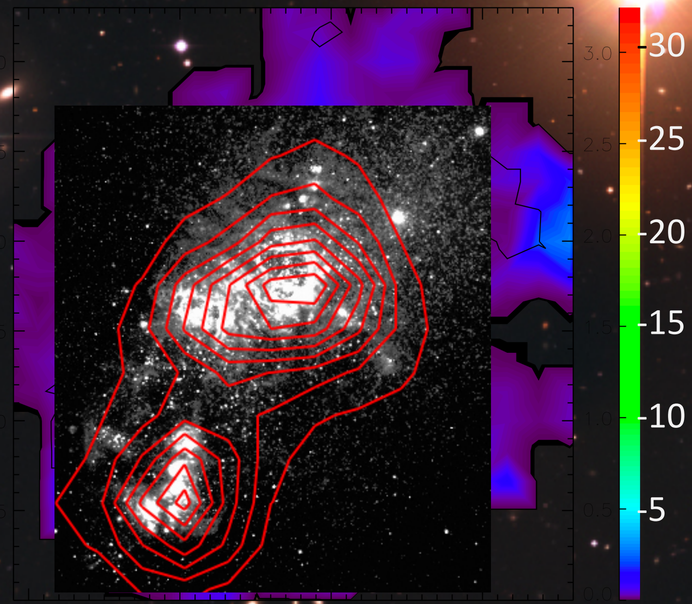
Hundreds of SSC: extent of hard radiation field and winds Seen in unusually high OIII/CII ratios > 2 toward the peak

NGC4214: Mapping
Cormier et al 2010 (see poster)



NGC 4214 : mapping mode

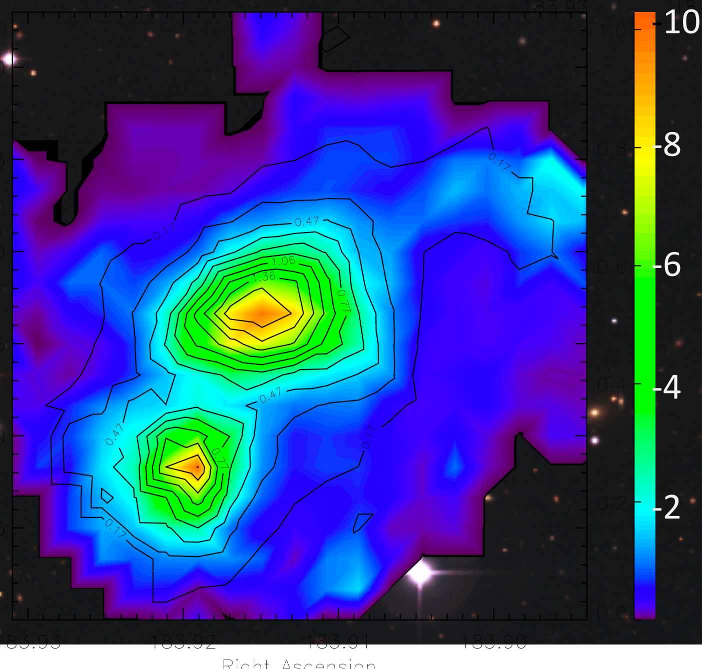




O III 88 µm

C II 158 µm

(CO contours: F. Walter)



Cormier et al 2010

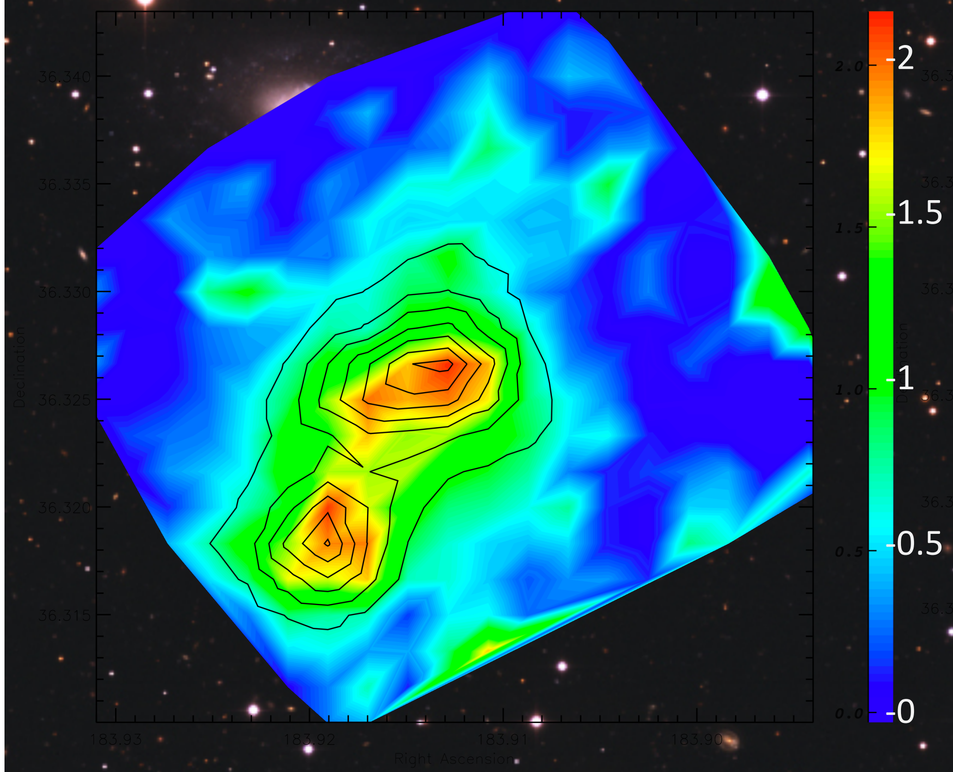
O I 63 µm

Other lines:

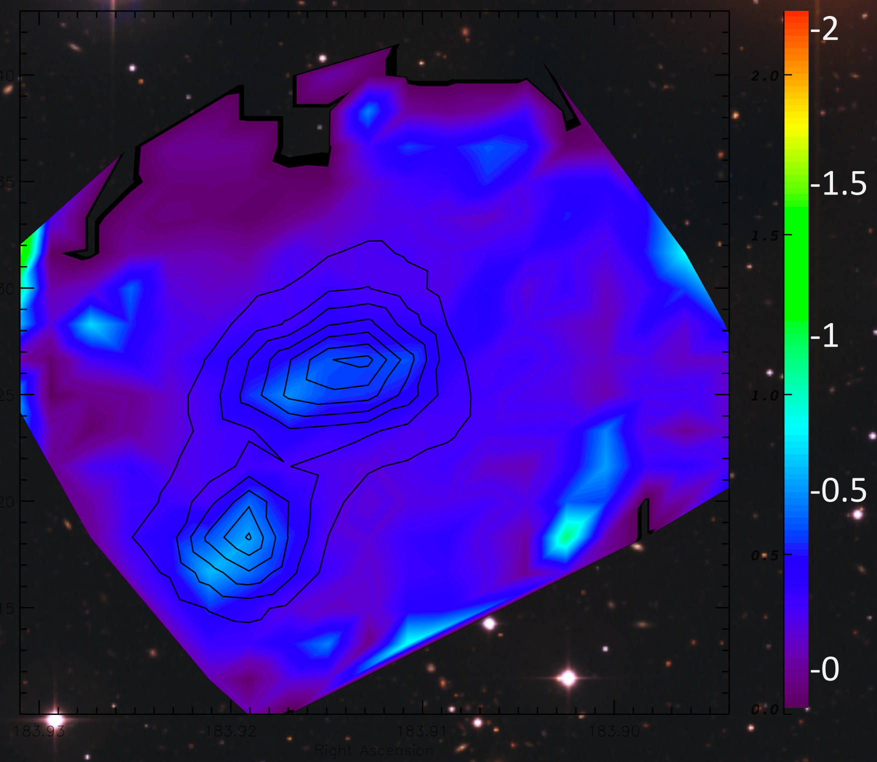
- **O I 145 µm**
- **N II 122 µm**
- **N II 205 µm**

NGC 4214 : mapping mode

O III 88 / CII 158 with C II 158 contours

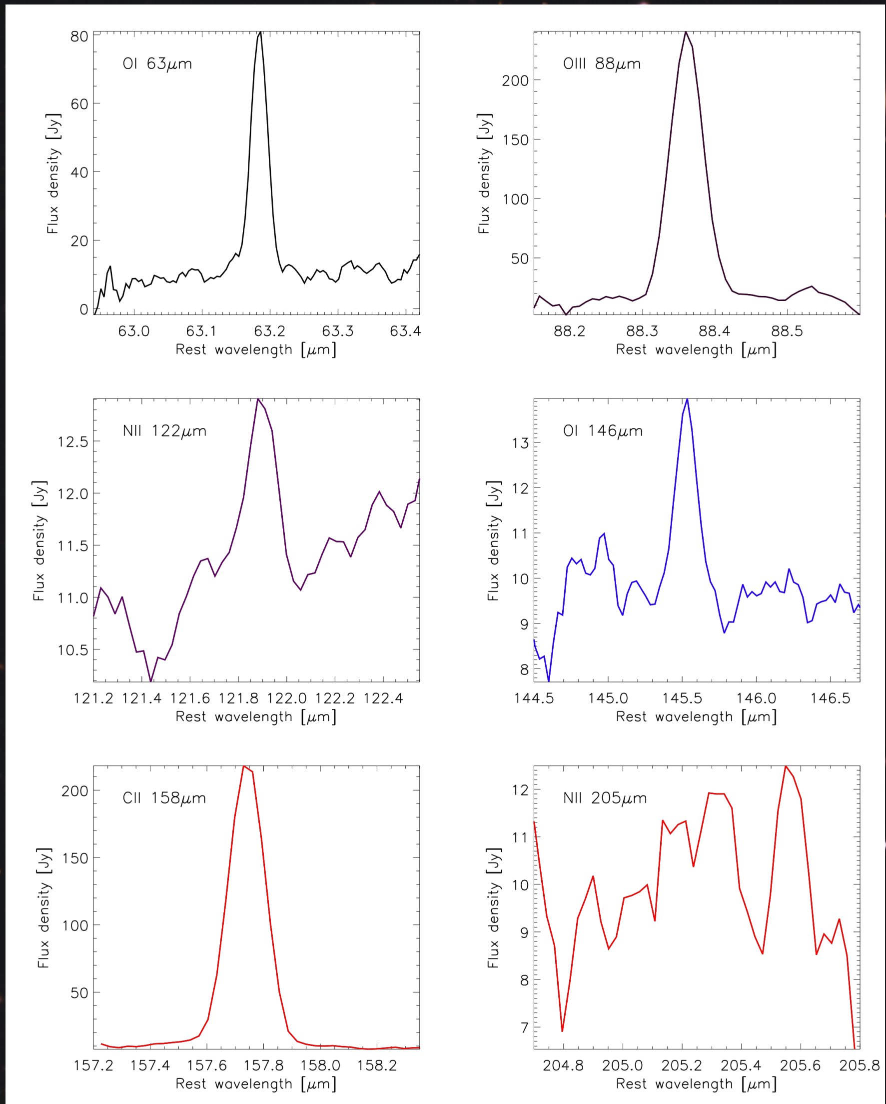


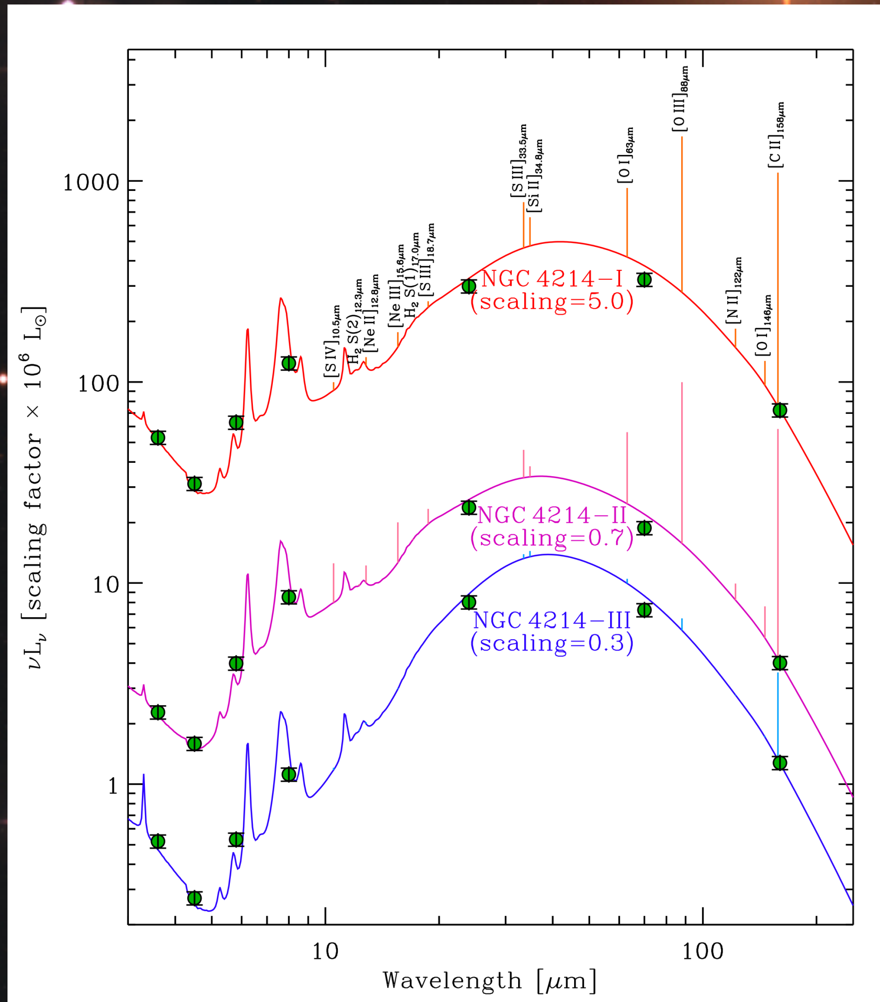
O I 63 / CII 158 with C II 158 contours



The O III 88 μm line
traces the sources of ionization

What do the FIR lines tell us?





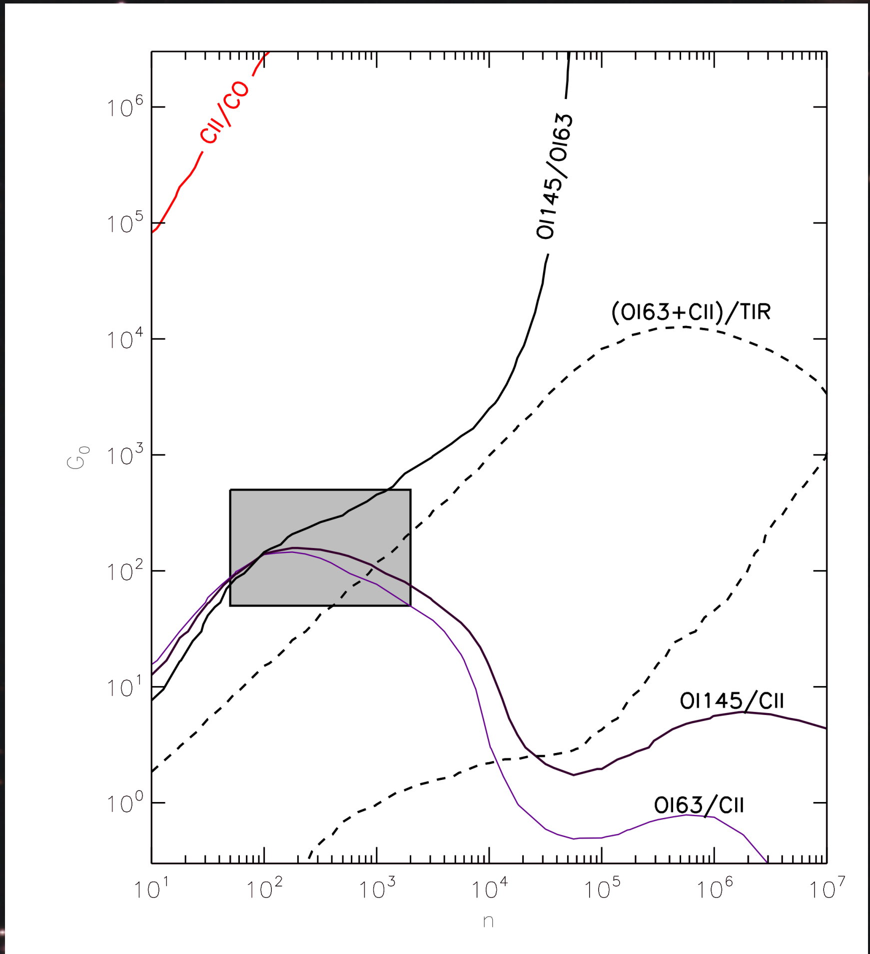
[CII is .5% to 1% of the L_{TIR}

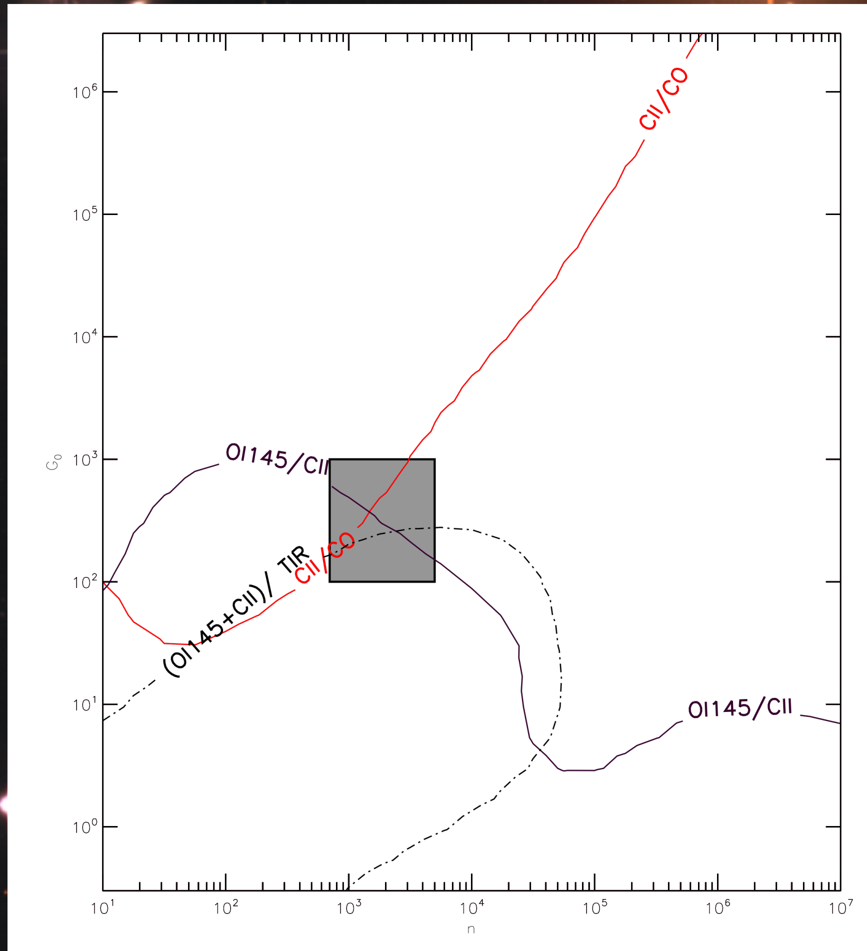
All FIR lines together are 2% of L_{TIR} (~4% L_{FIR})

PDR Model results

Kaufman et al PDR model

C C II / CO = 3.4e04 for NGC4214 and CII / CO = 5.4e03 for He2-10

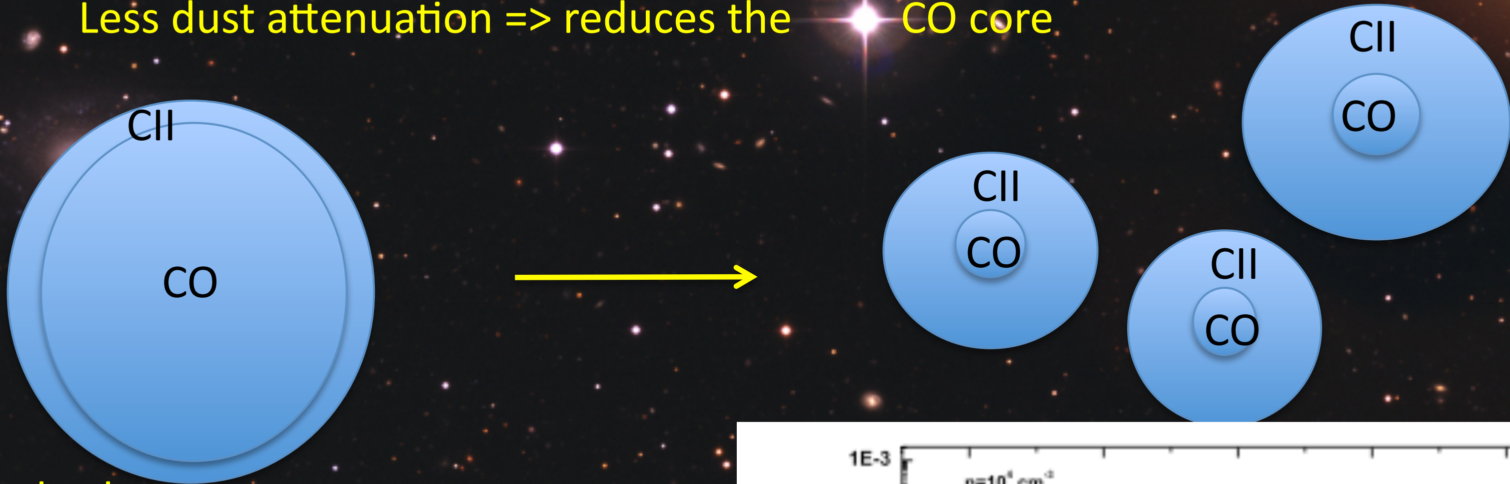


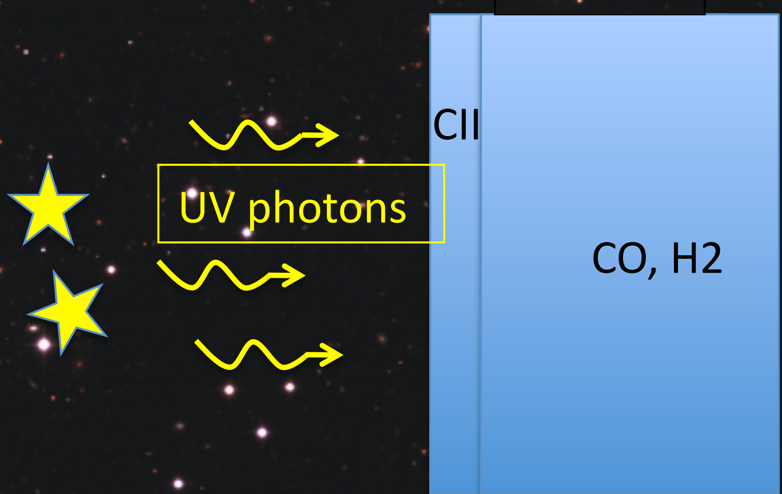


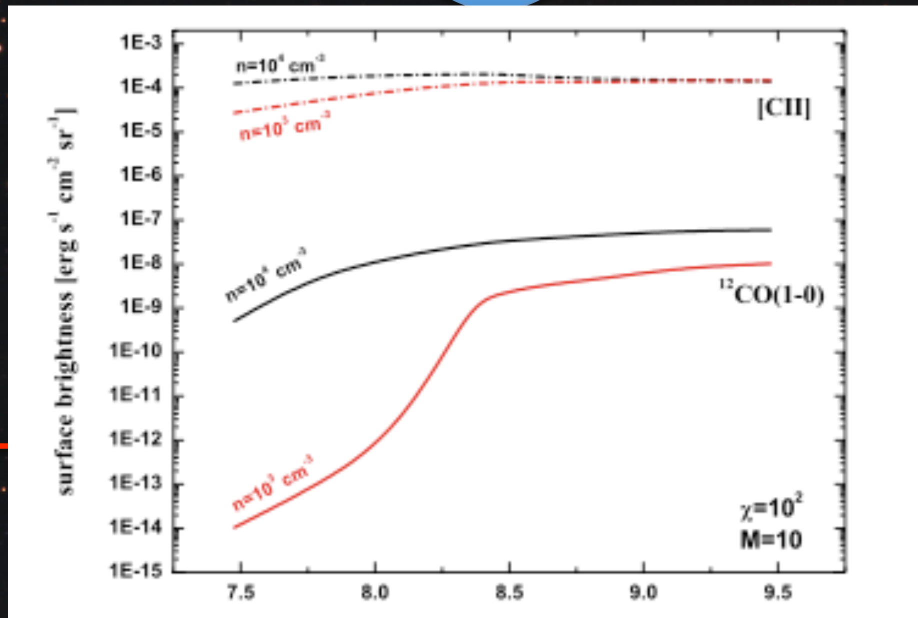
NGC4214-1 (center) Go ~ 800 nH ~ 2000 cm-3

PDR modeling

In low metallicity environments, higher 158µm [CII] / CO observed
Less dust attenuation => reduces the CO core







Roellig et al 2006 KOSMA PDR

Summary

- *The spatial resolution of Herschel photometry:*
  - new opportunity for detailed analyses of *individual* SF regions in low metallicity galaxies.
  - The 250/500 mu band ratio tracing SF in
  - We see submm excess somtimes and large dust masses, and sometimes *low gas-to-dust mass ratios*

    In dwarf galaxies - missing molecular gas mass?
- The sensitivity & mapping capability of PACS spectroscopy:
  - 6 strong FIR fine structure lines – will be powerful diagnostics.
  - CII line widely distributed throughout low metallicity galaxies
  - OIII surprisingly luminous throughout galaxies.
  - CII/CO high – is this tracing SF in dwarfs?
  - OIII/CII > 2 on galactic scale.   *OIII may be a workhorse diagnostic for dwarf galaxies*
- Herschel is bringing *new promises for understanding the nature of the star forming regions within dwarf galaxies.*

SPIRE Nearby Galaxies Science Working Group (SAG 2) members and SHINING

Auld Robbie, Baes Maarten, Barlow Mike, Bendo George, Bock Jamie, Boselli Alessandro, Bradford Matt, Buat Veronique, Castro Rodriguez Nieves, Chanial Pierre, Charlot Stephan, Clements Dave, Cormier Diane, Cortese Luca , Davies Jonathan, Dwek Eli, Eales Steve, Elbaz David, Galametz Maud, Galliano Frederic, Gear Walter, Glenn Jason, Gomez Haley, Griffin Matt, Hony Sacha, Isaak Kate, Levenson Louis, Lu Nanyao, Madden Suzanne, O'Halloran Brian, Okumura Koryo, Oliver Seb, Page Mat, Panuzzo Pasquale, Papageorgiou Andreas, Parkin Tara, Perez Fournon Ismael, Pohlen Michael, Rangwala Naseem, Rigby Emma, Roussel Helene, Rykala Adam, Sacchi Nicola, Sauvage Marc, Schulz Bernhard, Shirm Max, Smith Matthew, Spinoglio Luigi, Srinivasan Sundar, Stevens Jason, Symeonidis Myrto, Vaccari Mattia, Vigroux Laurent, Wilson Christine, Wozniak Herve, Wright Gillian, Zeilinger Werner

Alessandra Contursi, Albrecht Poglitsch, Eckhard Sturm, Vanessa Doublier, Helmut Feuchtgruber, Norbert Geis, J. deJong

Institutes: UCL, Imperial College, Caltech, Marseille, IAC, Univ Cardiff, NASA Goddard, CEA, Univ Colorado, Univ Sussex, MSSL, IPAC, Padova, IAP, IFSI, Univ. Hertsfordshire, McMaster Univ. Observatory Strasbourg, Univ. Ghent, Univ Vienna, MPE, Garching