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Modeling the dust emission in (U)LIRGs

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A step in the dark: The Dense Molecular Gas (DeMoGas) in Galaxies

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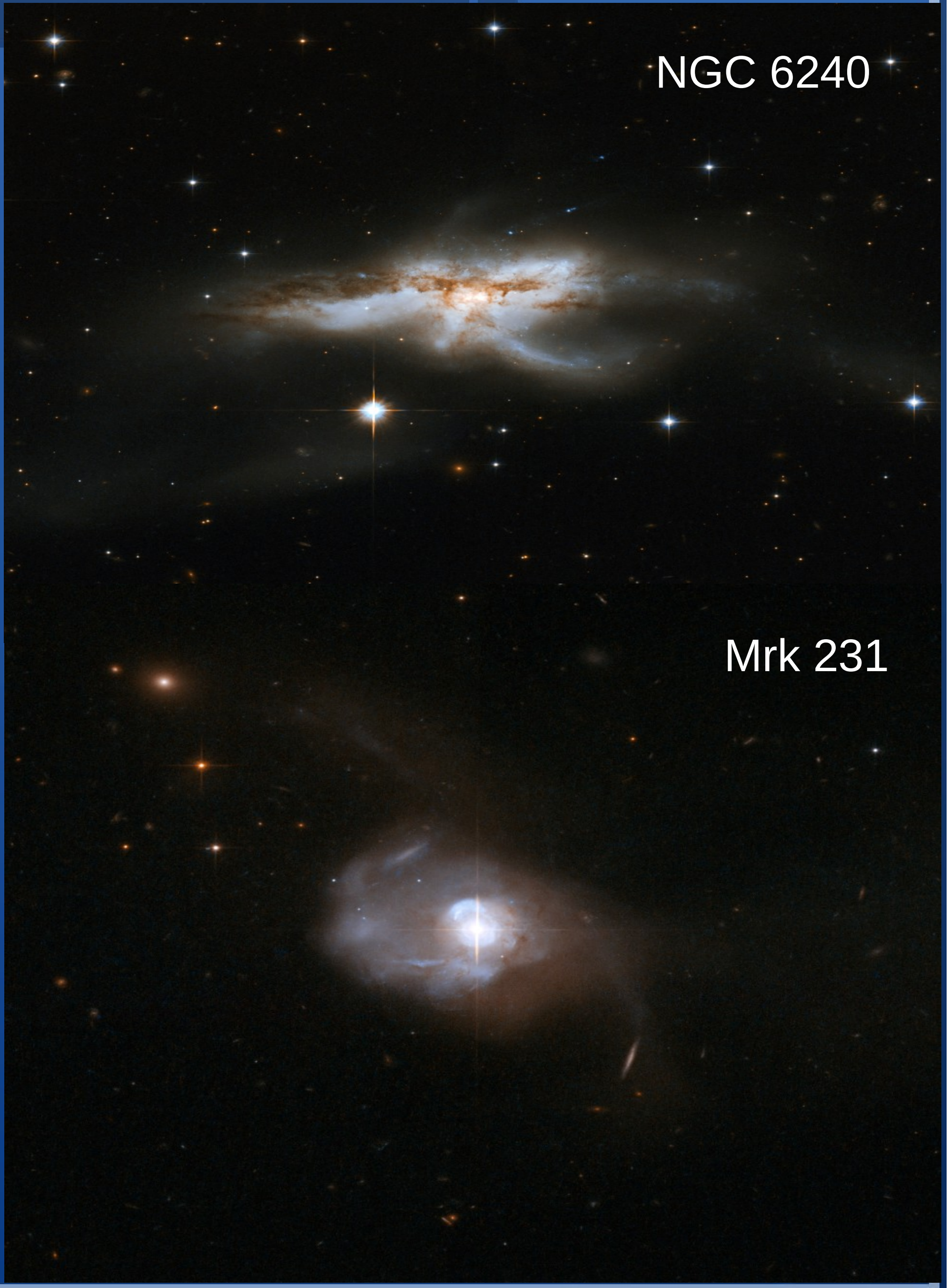
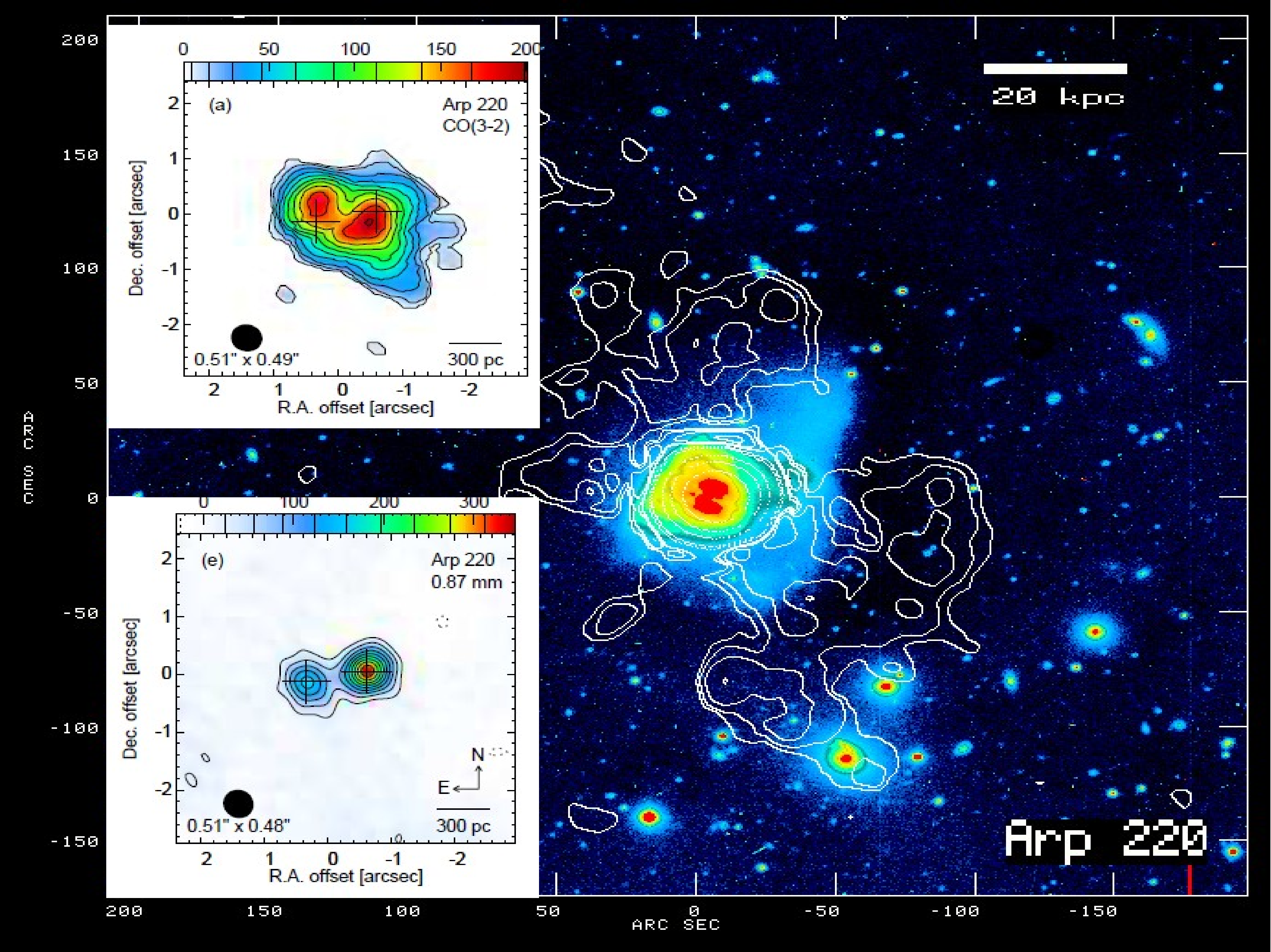
(Ultra) Luminous Infrared Galaxies (U)LIRGs

- Characteristic IR luminosity $\geq 10^{11}\ L_\odot$
- Most of their energy (90%-95%) is infrared
- Associated with interactions/mergers
- Mix of starbursts and AGNs
- Rich in molecular gas




20 kpc
Arp 220
ARC SEC
ARC SEC
(a)
Arp 220
CO(3-2)
Dec. offset [arcsec]
R.A. offset [arcsec]
0.51" x 0.49"
300 pc
(e)
Arp 220
0.87 mm
0.51" x 0.48"
300 pc
N
E

AIMS:

- Compute accurate L_{IR} luminosities by modeling the dust emission in (U)LIRGs

- Correlate with the molecular gas inventory in (U)LIRGs as traced by the CO molecule (high-J lines)

- Probe the densest regions in galaxies (where star-formation takes place) and derive the physical properties of the dust and the dense gas.

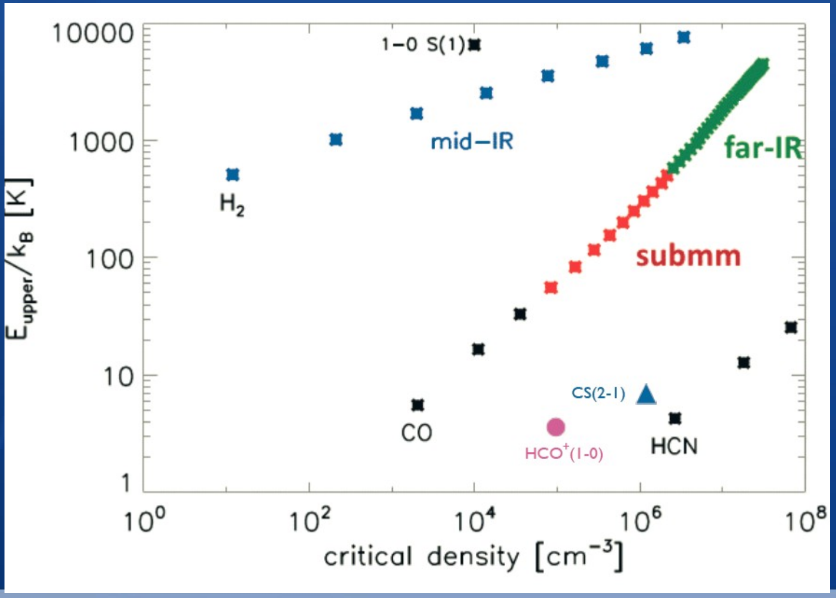
Challenges:

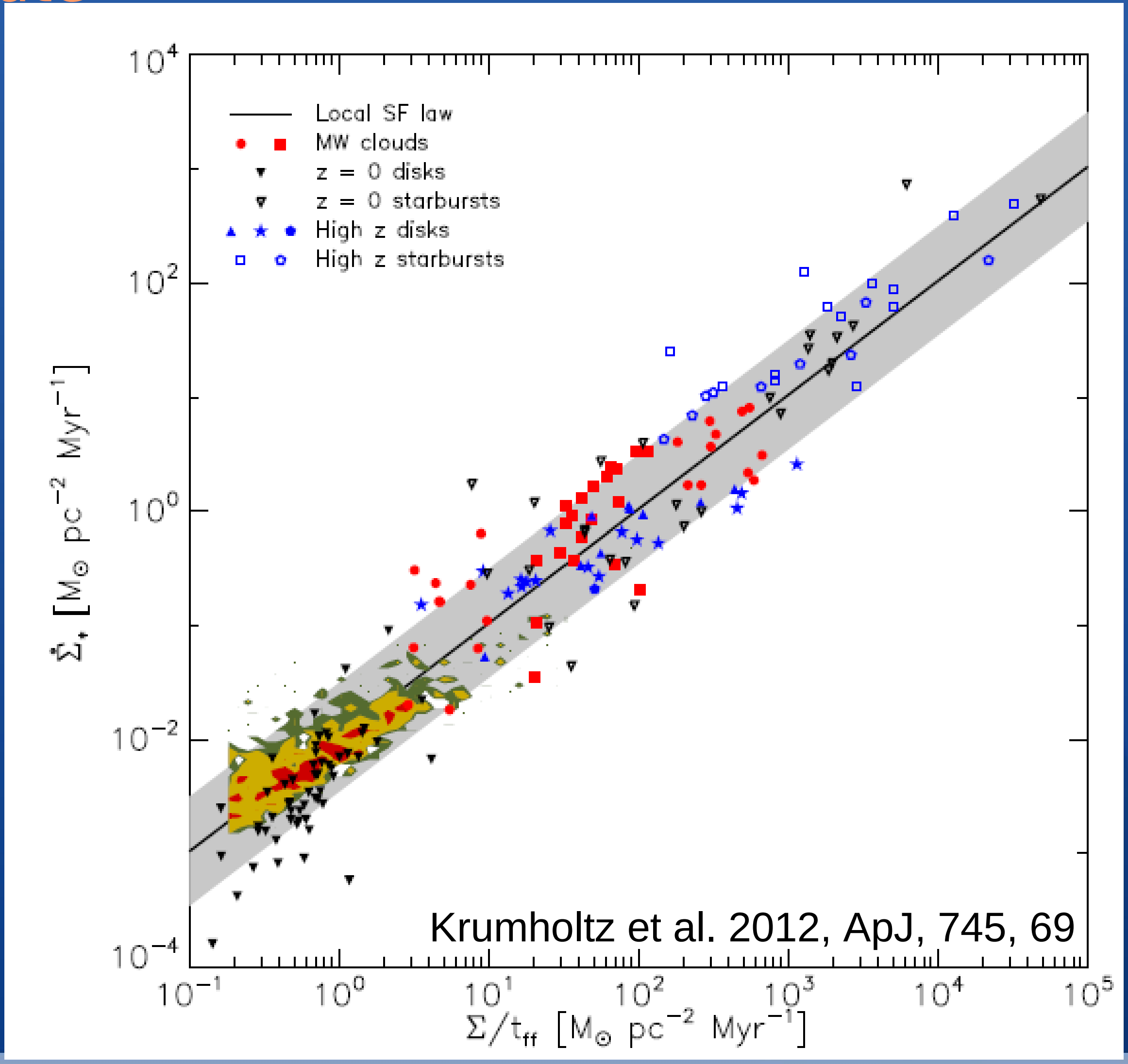
- Better defined samples

- Well-sampled SEDs and accurate L_{IR} calculation

- Use of higher-J CO lines in order to probe higher densities of the molecular gas.

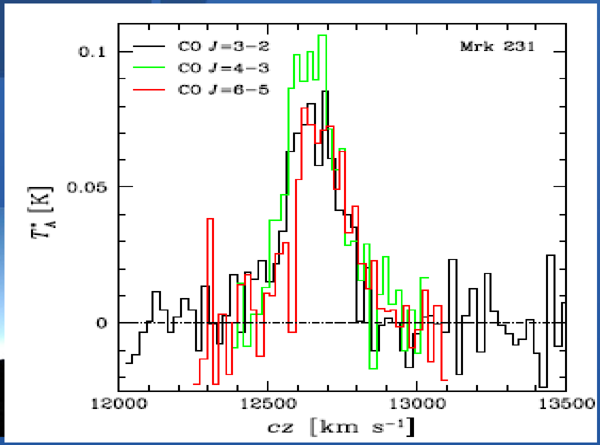
A universal star-formation law seems to hold from small Solar neighborhood clouds ~10^3 M⊙ to sub-mm galaxies ~10^{11} M⊙





Sample

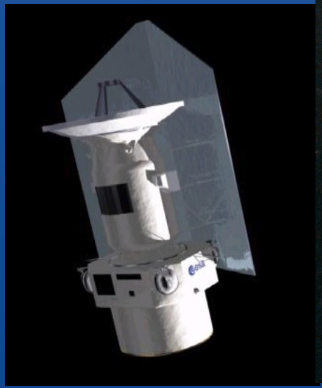
JCMT

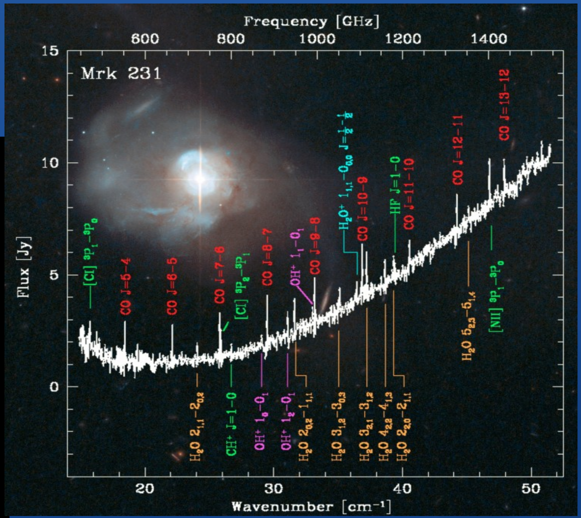


Local (U)LIRG sample

70 galaxies (presented in Papadopoulos et al. 2012) comprising objects with redshifts z<0.1.

HERSCHEL





HerCULES sample

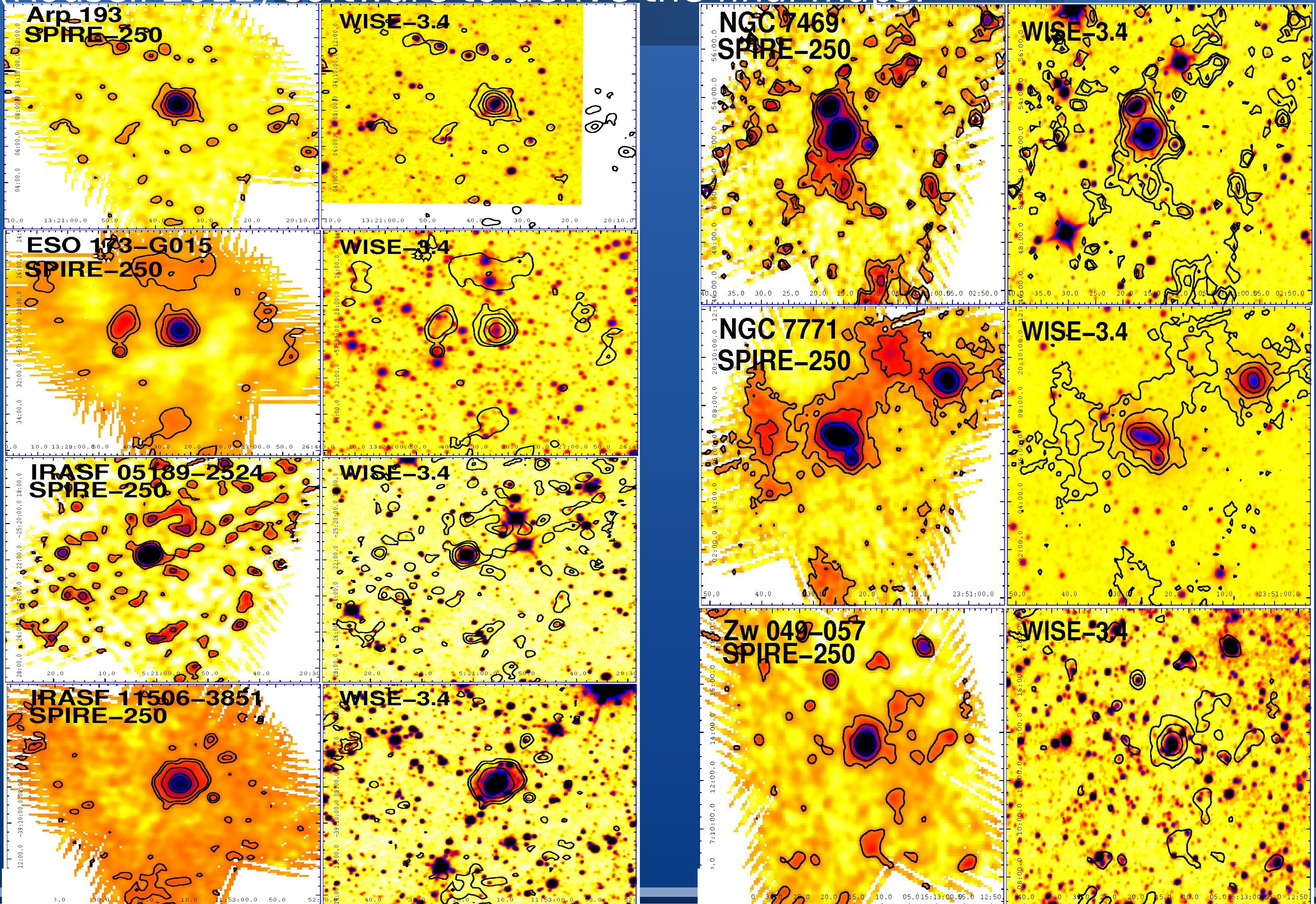
(Herschel Comprehensive (U)LIRG Emission Survey, van der Werf et al. 2010)

27 galaxies, chosen also due to the highest CO transition observations

High-z sample

44 dusty star forming galaxies (DFSGs) at high redshifts with multiple CO line and far-IR/(sub)mm continuum observations available (e.g. Riechers +2013, Aravena+2012, Harris+2012).

PACS and SPIRE data reduction was carried out using the dedicated Herschel pipeline tool *HIPE* (version 10) and the *Scanamorphos* (Rousell 2012) software to derive the final maps.



Dust modeling with *CIGALE*

- Careful compilation of panchromatic continuum data

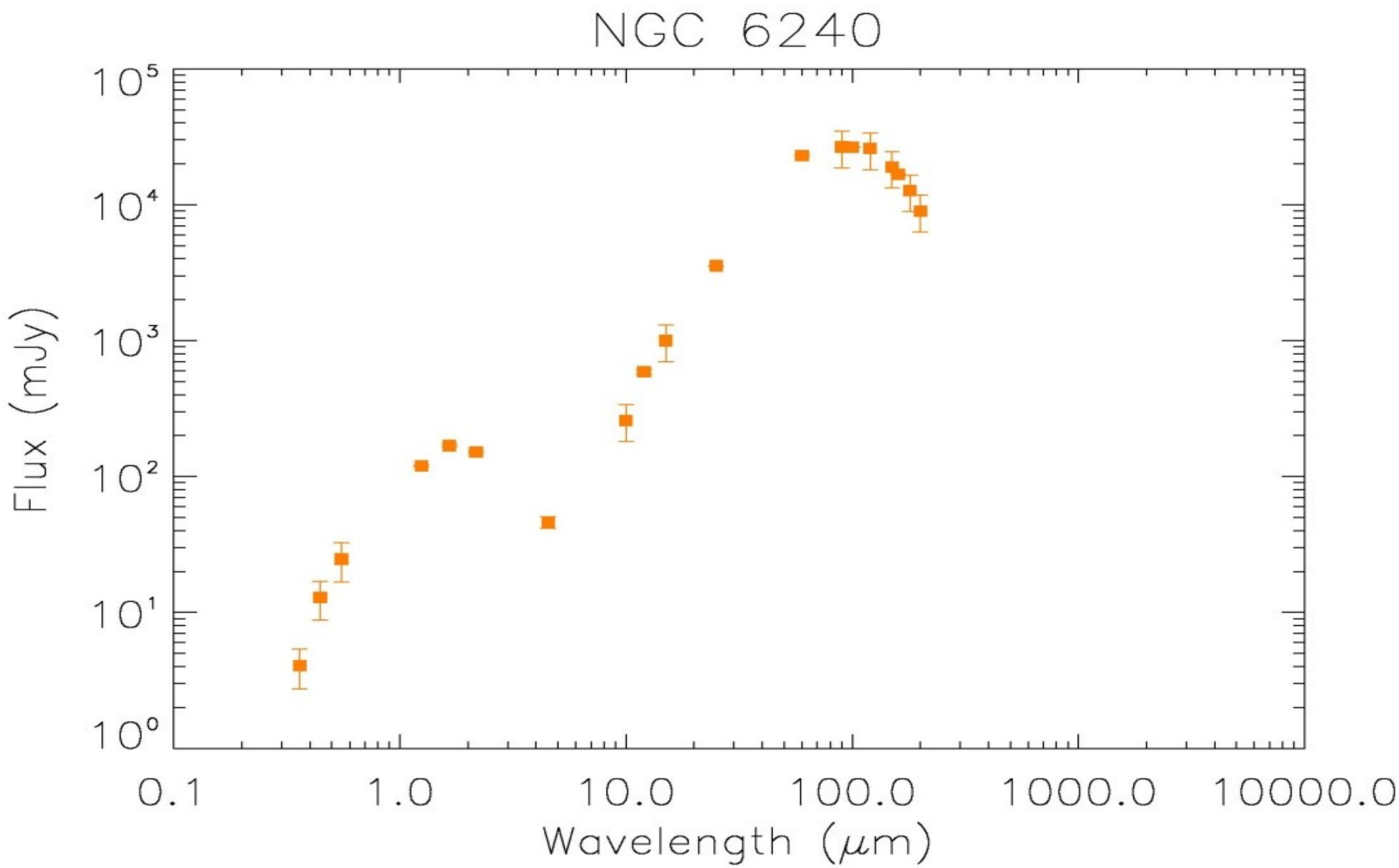
- We modeled their pan-chromatic spectral energy distributions (SEDs) using CIGALE
  (Code Investigating GALaxy Emission, Noll et al. 2012)

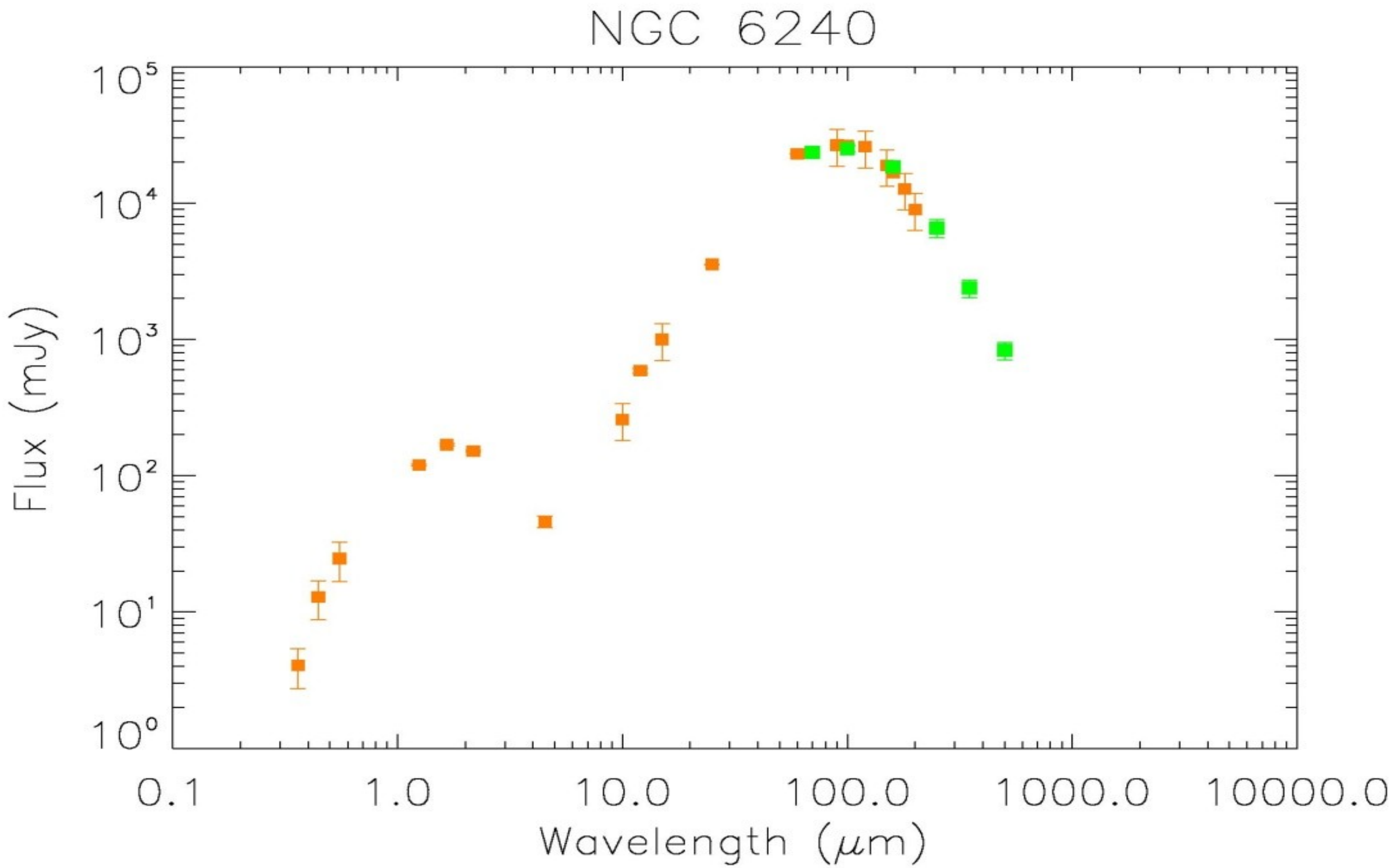
➔ Employs dust-attenuated stellar population models to fit the far-UV/optical SED

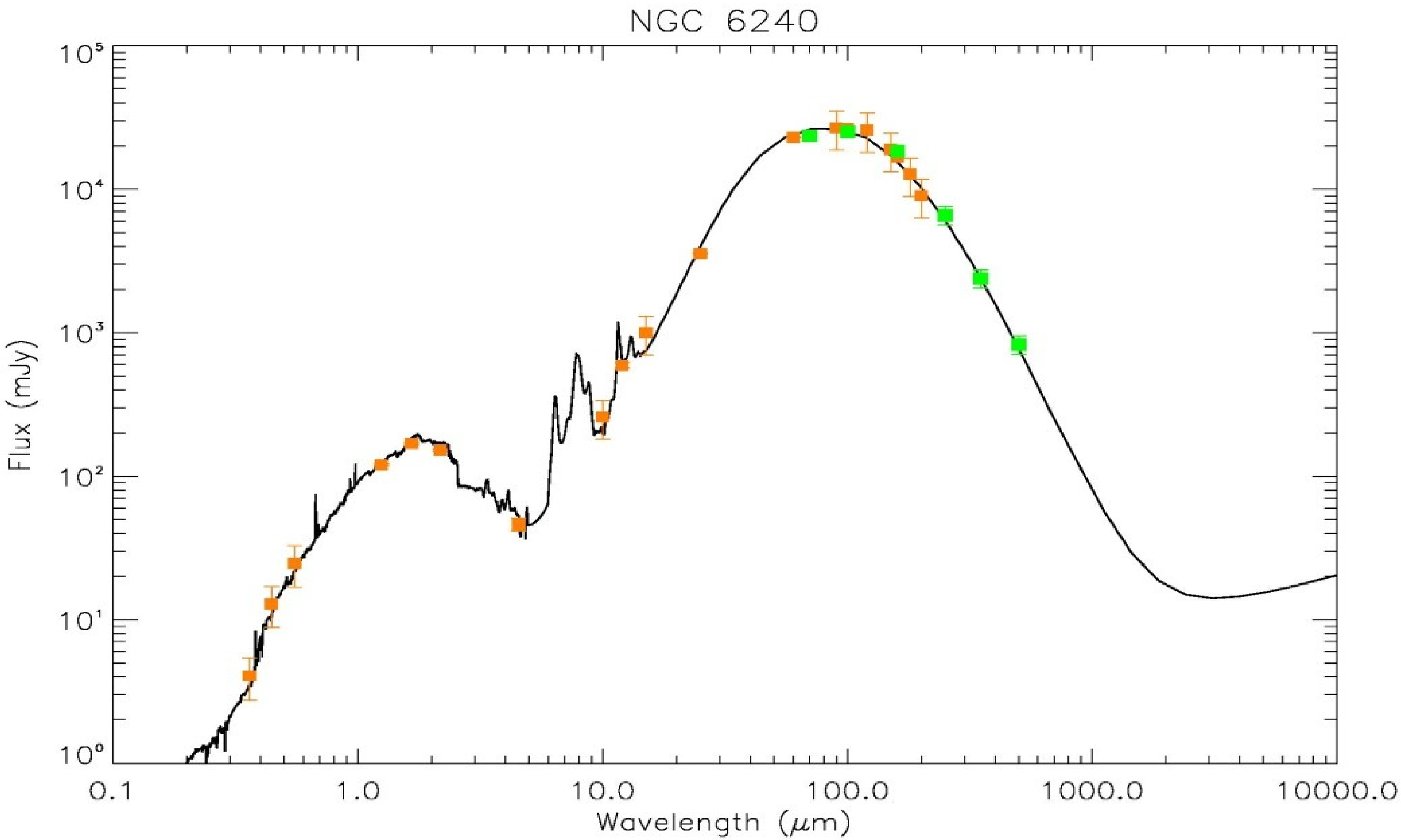
➔ Ensures that the dust-absorbed UV photons are re-emitted in the far-IR, thus ensures energy-balance between the far-UV and far-IR.

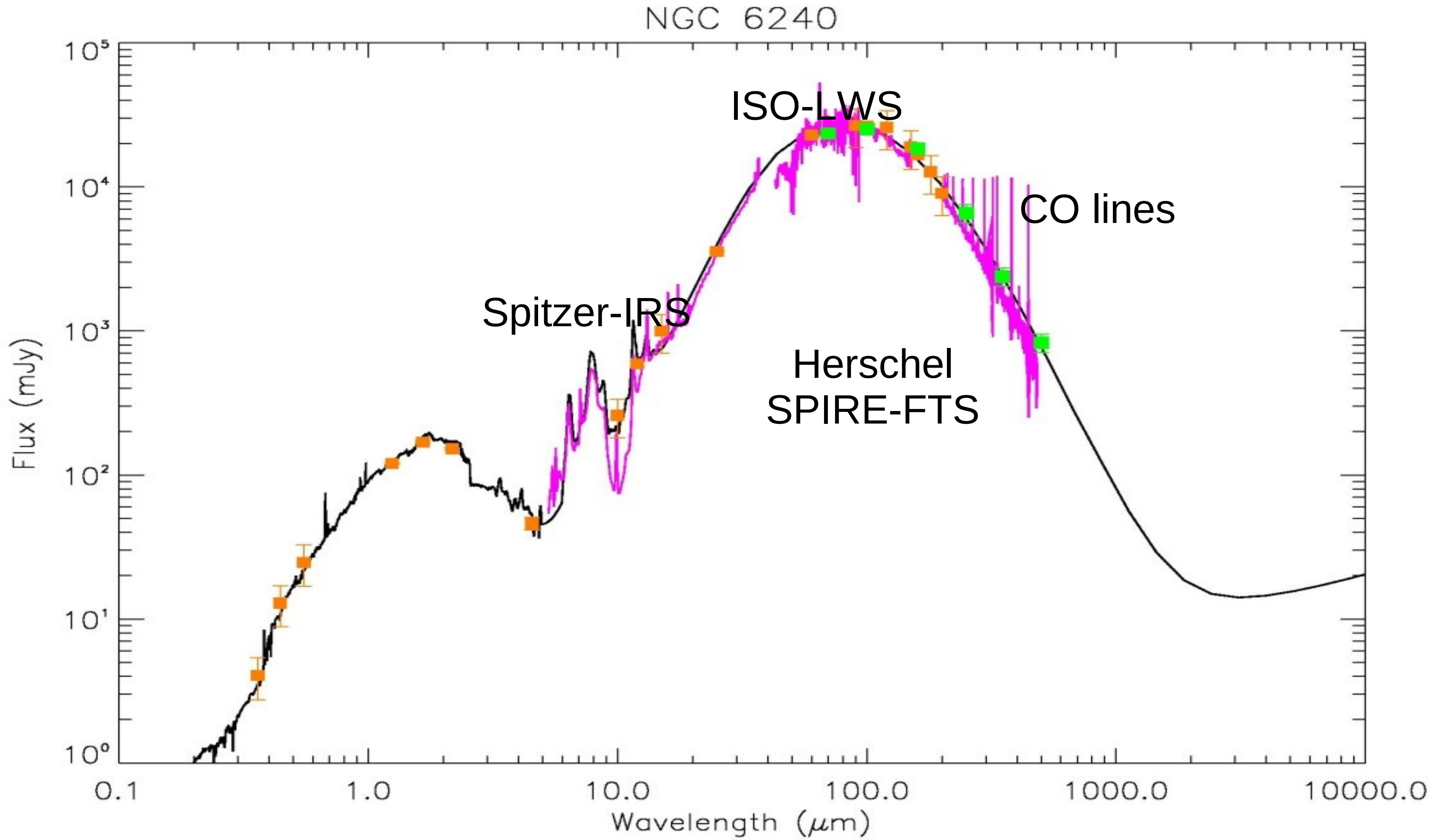
The far-IR continuum is modeled using the templates by Dale & Helou (2002) and Chary & Elbaz (2001).

Excellent fits were obtained for all of the local galaxies due to their well-sampled SEDs.

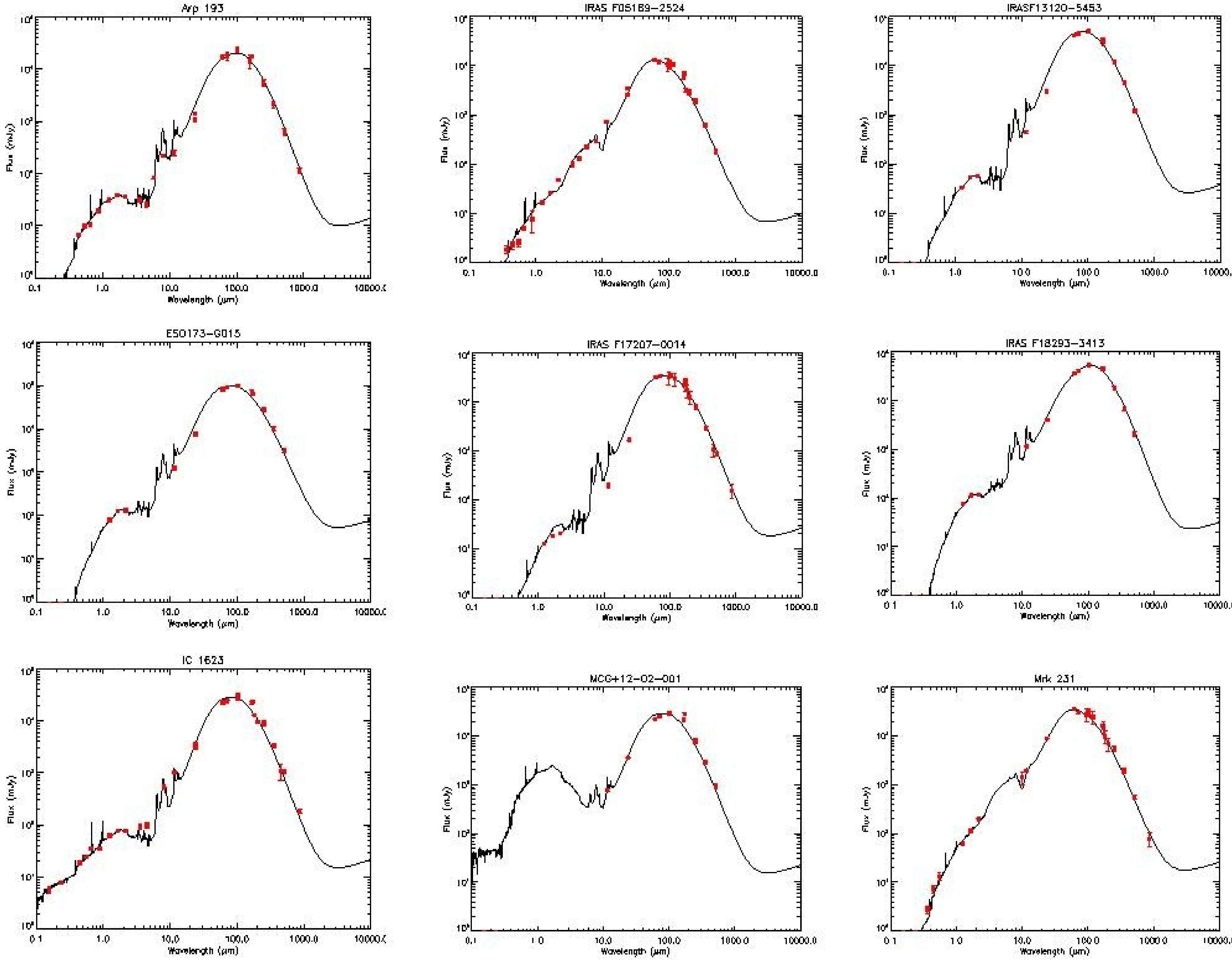

NGC 6240
Flux (mJy)
10^5
10^4
10^3
10^2
10^1
10^0
0.1
1.0
10.0
100.0
1000.0
10000.0
Wavelength (μm)


NGC 6240
Flux (mJy)
10^5
10^4
10^3
10^2
10^1
10^0
0.1
1.0
10.0
100.0
1000.0
10000.0
Wavelength (μm)


NGC 6240
Flux (mJy)
Wavelength (μm)
0.1
1.0
10.0
100.0
1000.0
10000.0
10^0
10^1
10^2
10^3
10^4
10^5



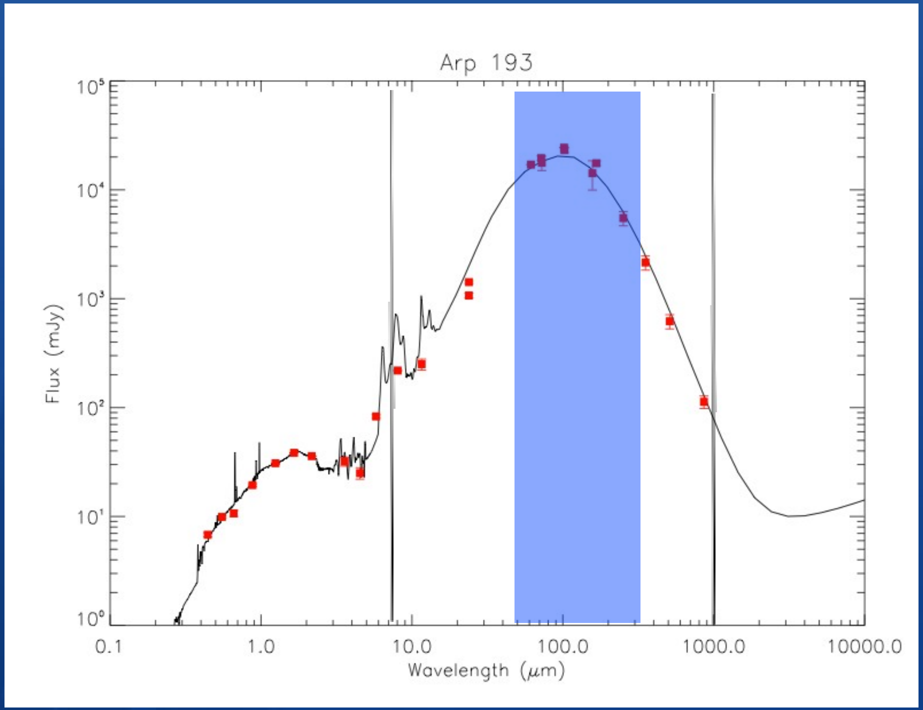
NGC 6240
ISO-LWS
CO lines
Spitzer-IRS
Herschel
SPIRE-FTS
Flux (mJy)
Wavelength (μm)
10⁰
10¹
10²
10³
10⁴
10⁵
0.1
1.0
10.0
100.0
1000.0
10000.0

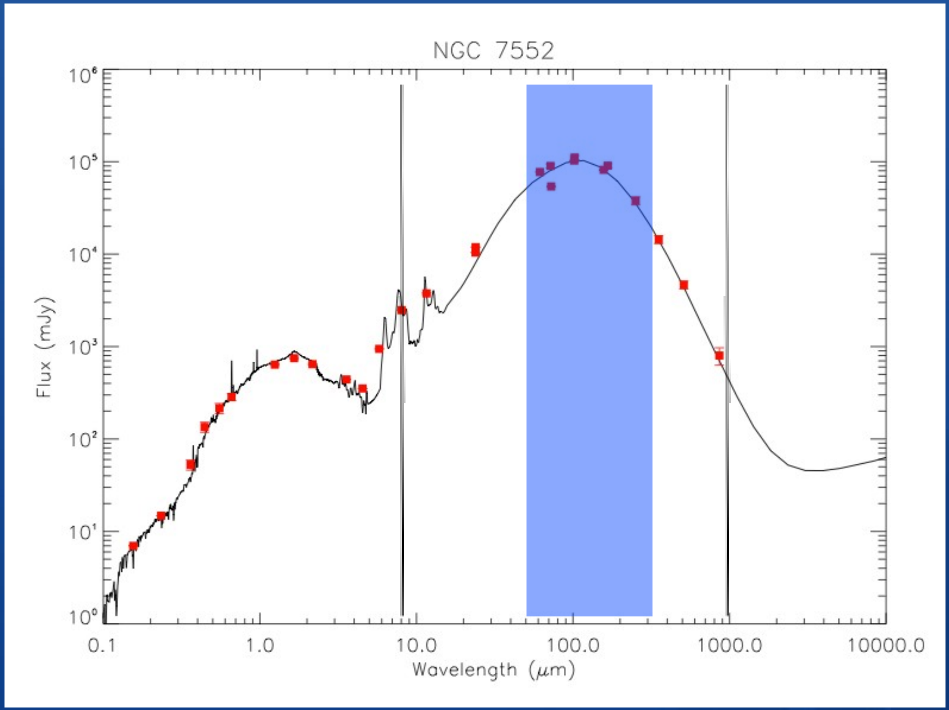


Arp 193
IRAS F05189−2524
IRASF13120−5453
ESO173−G015
IRAS F17207−0014
IRAS F18293−3413
IC 1623
MCG+12−02−001
Mrk 231
Flux (mJy)
Wavelength (μm)
0.1
1.0
10.0
100.0
1000.0
10000.0

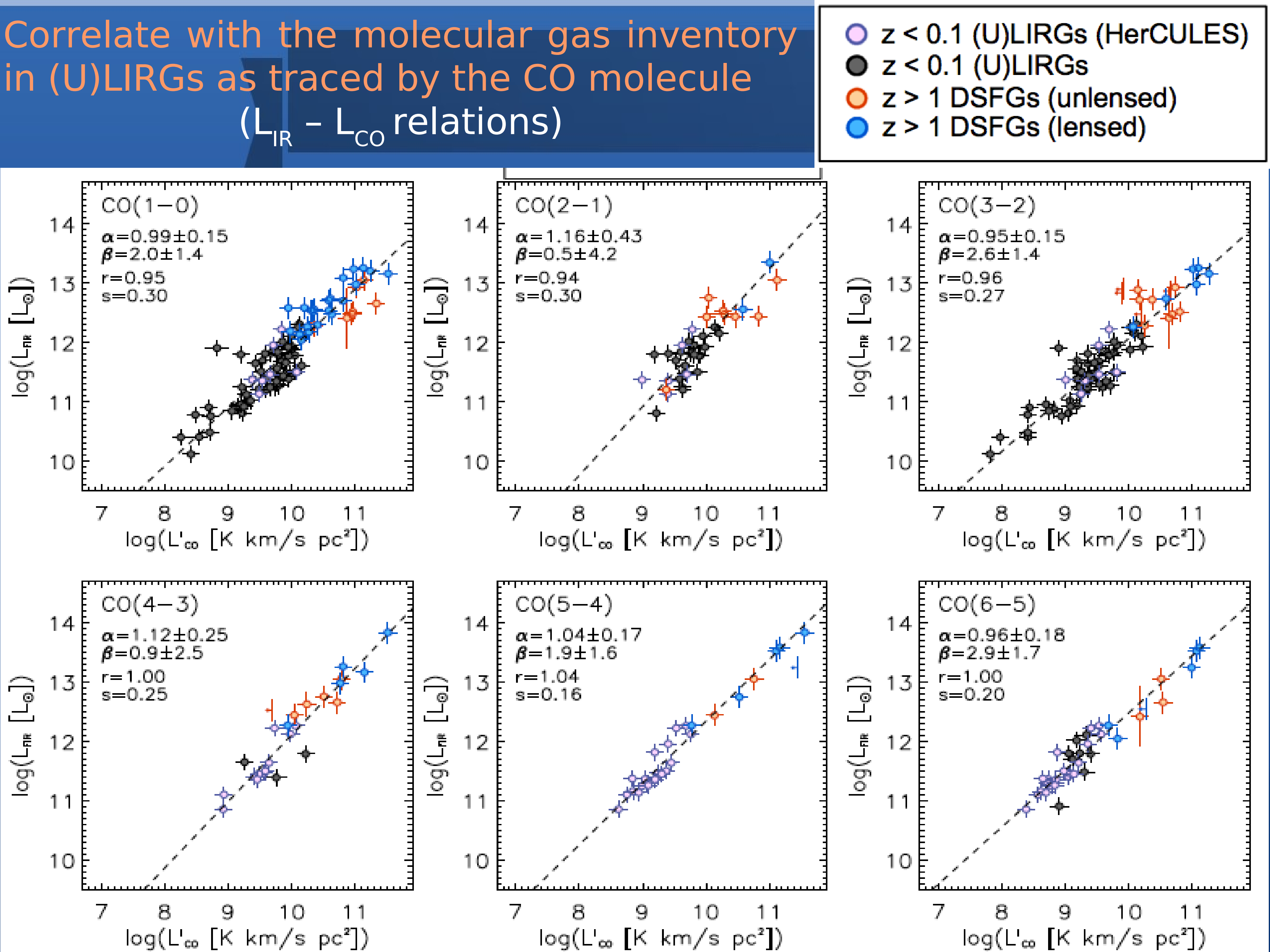
Compute accurate L_{IR} luminosities by modeling the dust emission in (U)LIRGs

We adopt FIR (50 – 300 μm) luminosities (clean compared to 8-1000μm)



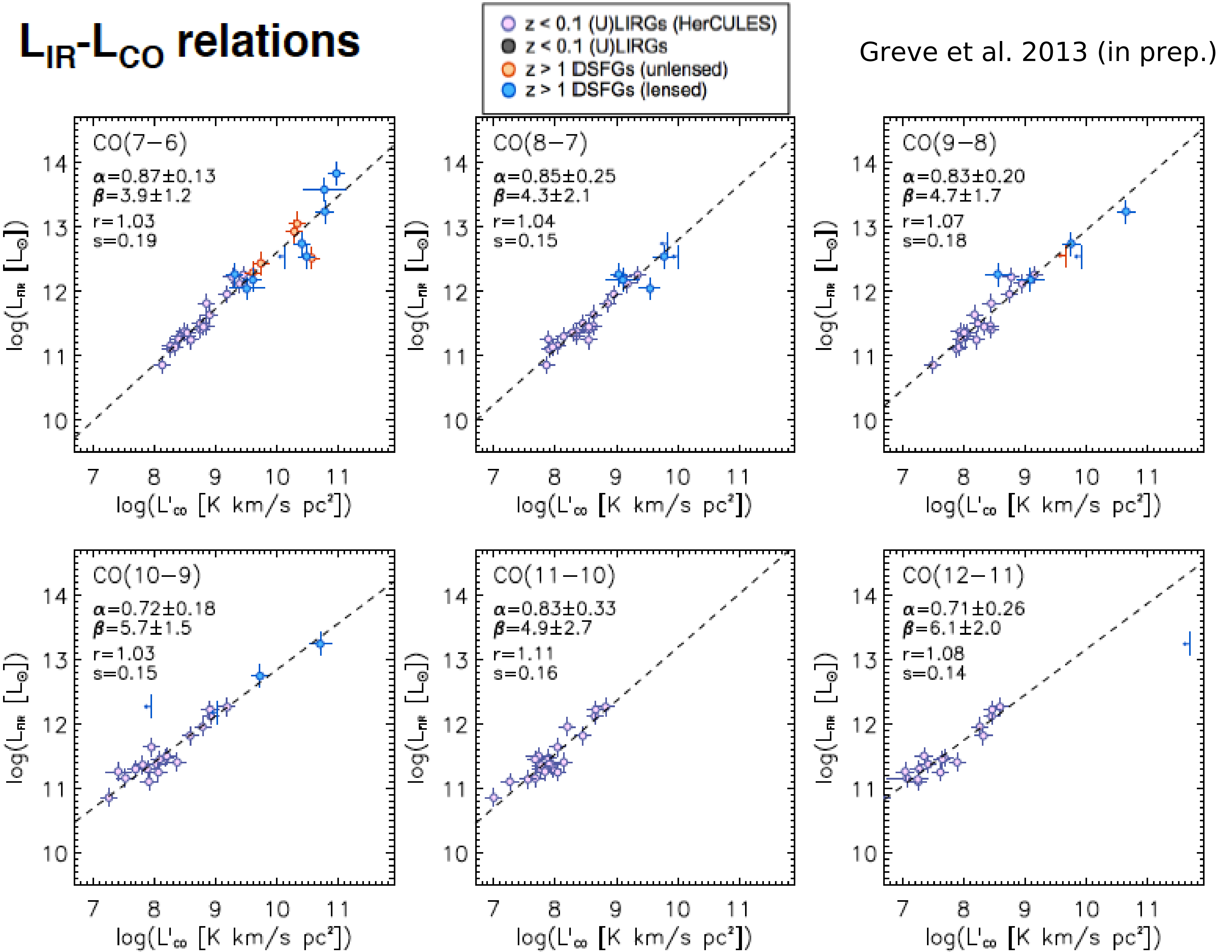


Correlate with the molecular gas inventory in (U)LIRGs as traced by the CO molecule
(L_{IR} – L_{CO} relations)

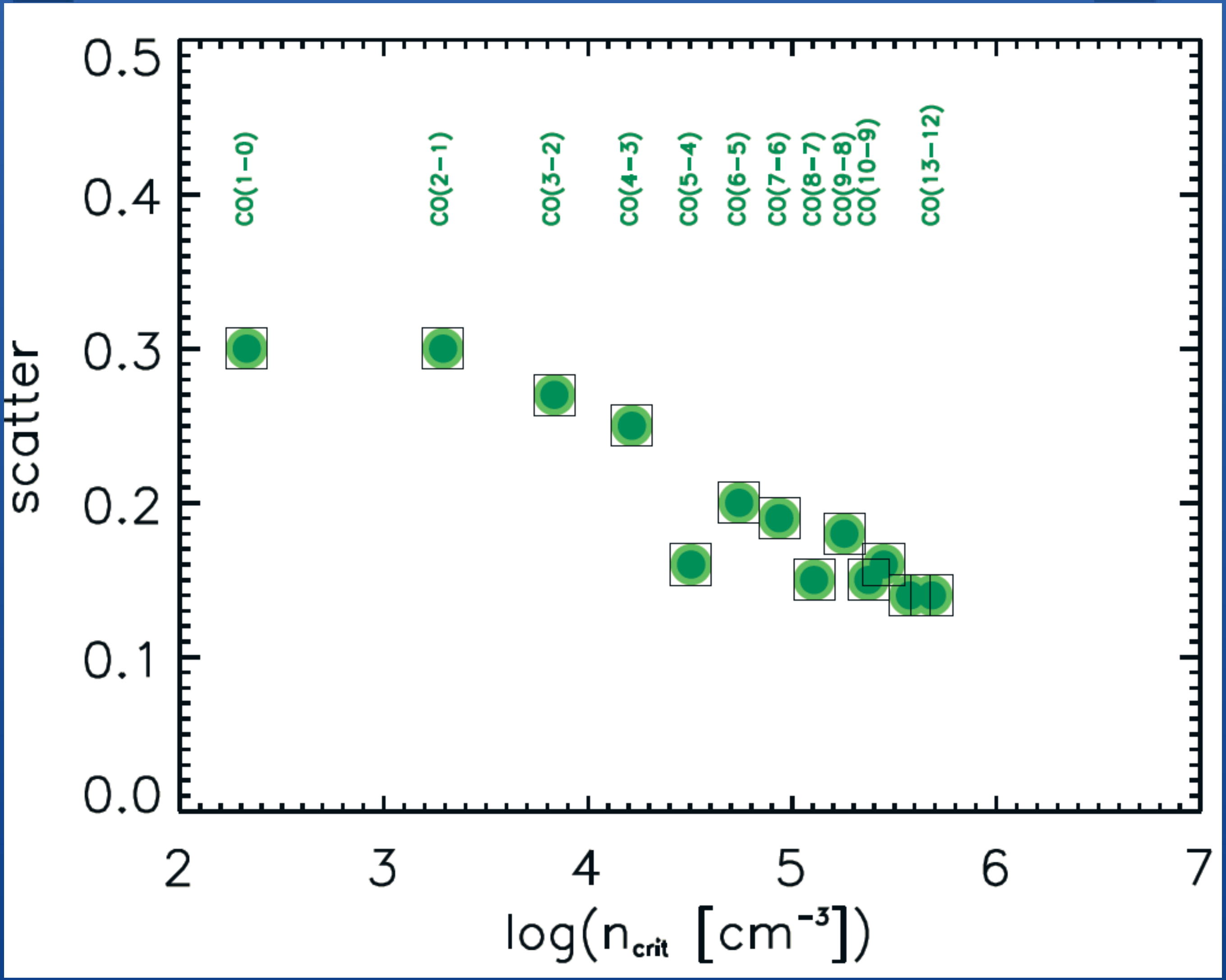


L_{IR}-L_{CO} relations

Greve et al. 2013 (in prep.)

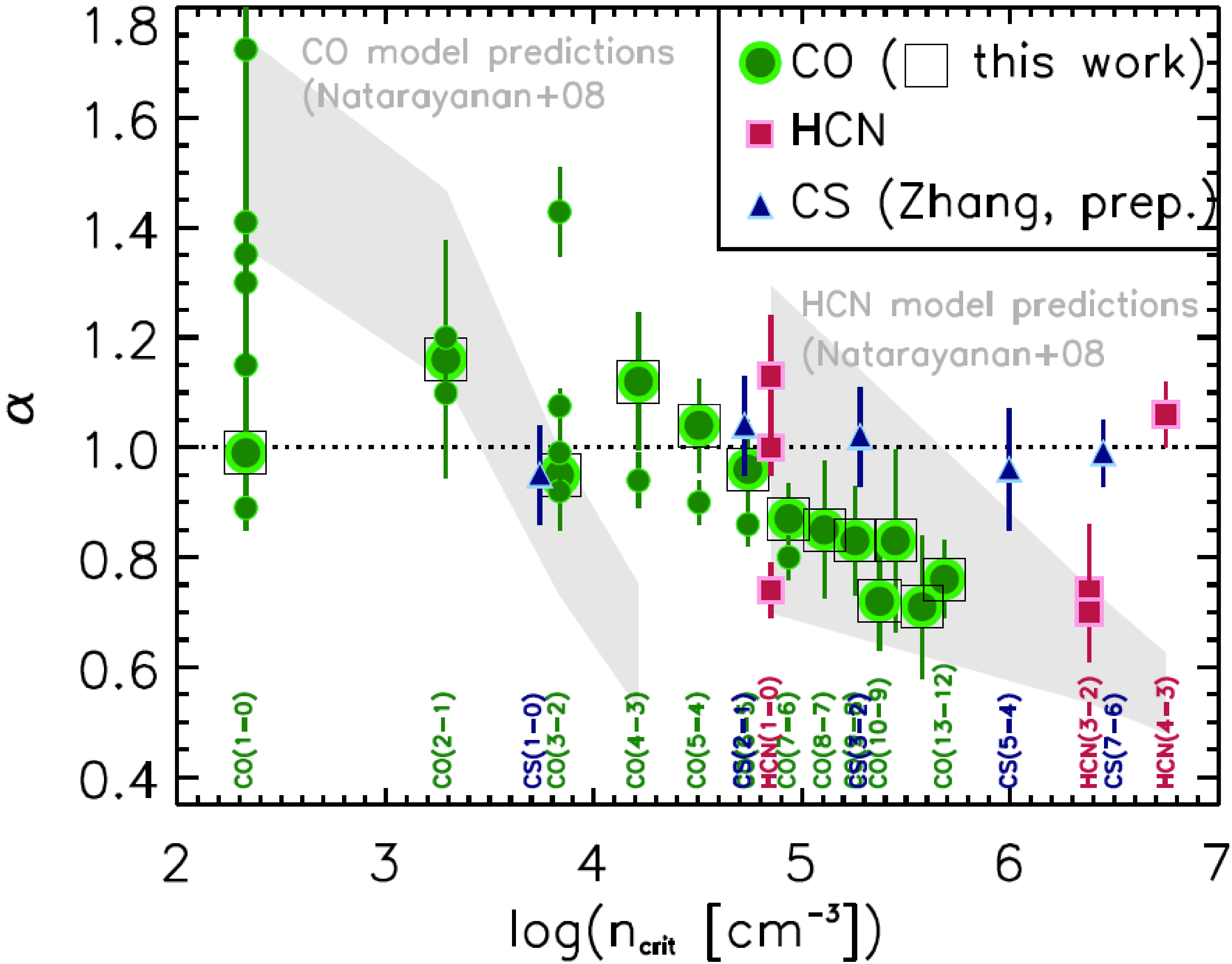


IR-mol scatter vs. critical density



Greve et al. 2013 (in prep.)

IR-mol slope vs. critical density



To sum up...

- PACS/SPIRE Herschel data were reduced for all galaxies of the HerCULES sample

- We modeled the dust emission of almost 100 (U)LIRGs with CIGALE (best fits of which can be found at http://demogas.astro.noa.gr)

- We compared the properties of dust and CO lines in order to probe the dense molecular gas (using for the first time CO lines up to J=13-12).

- We find linear slopes for lower-J CO lines and sub-linear for higher-J CO lines which is in agreement with existing models.

- Possible different excitation mechanisms between different molecules need to be investigated.