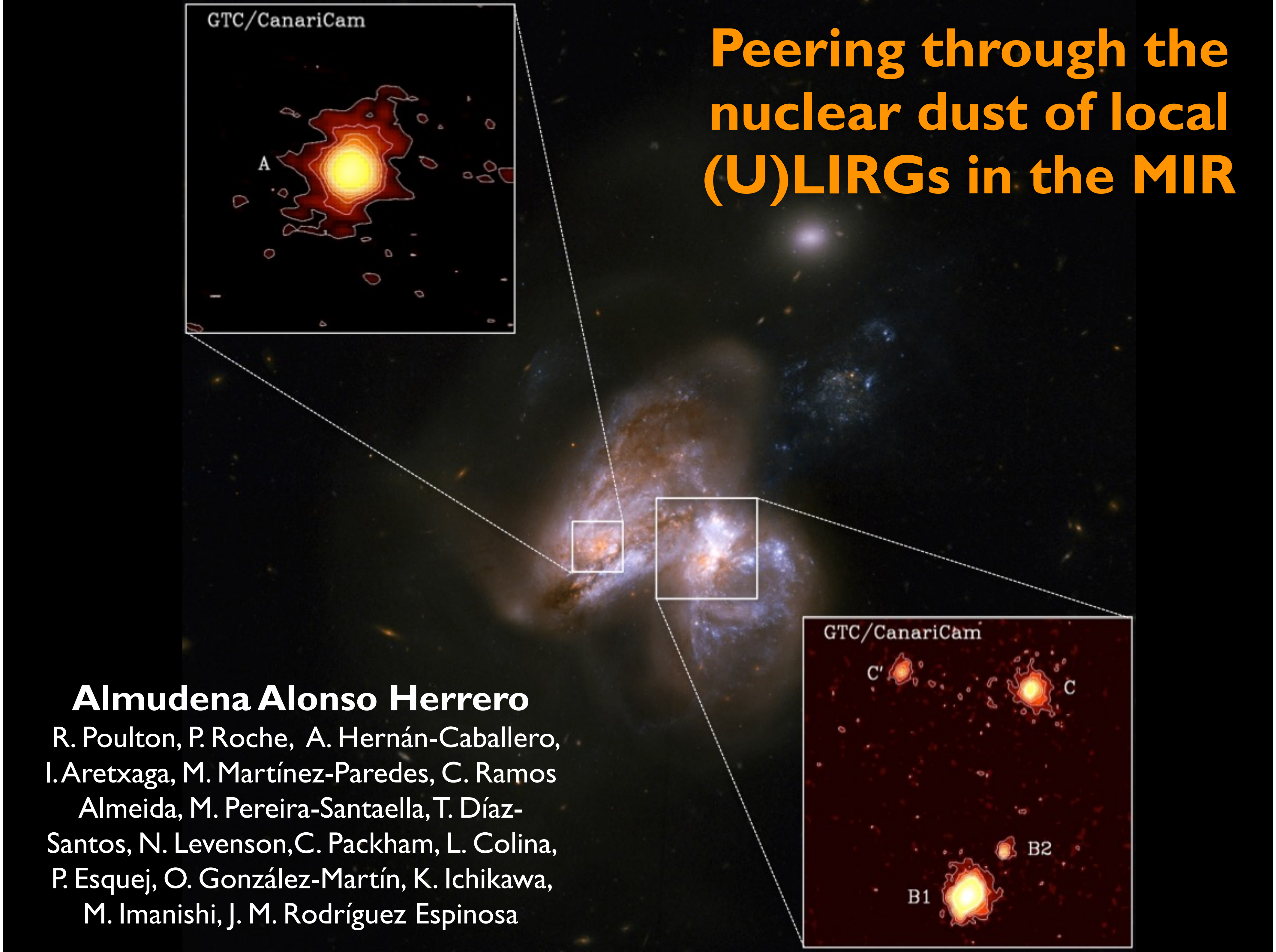
# Peering through the nuclear dust of local (U)LIRGs in the MIR

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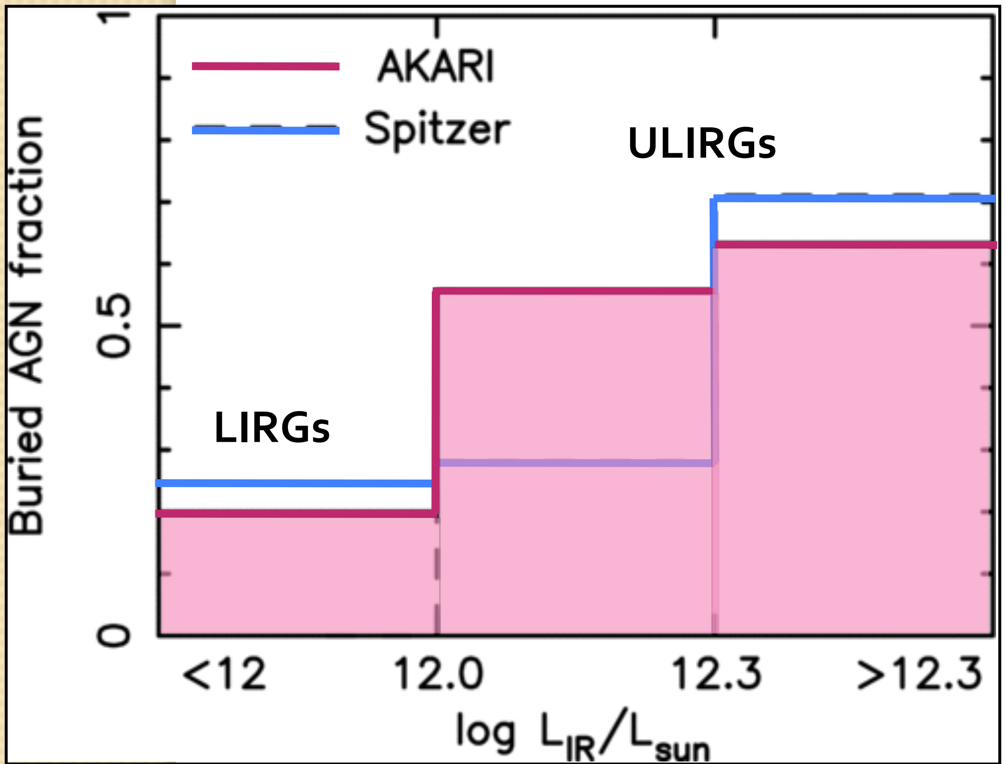
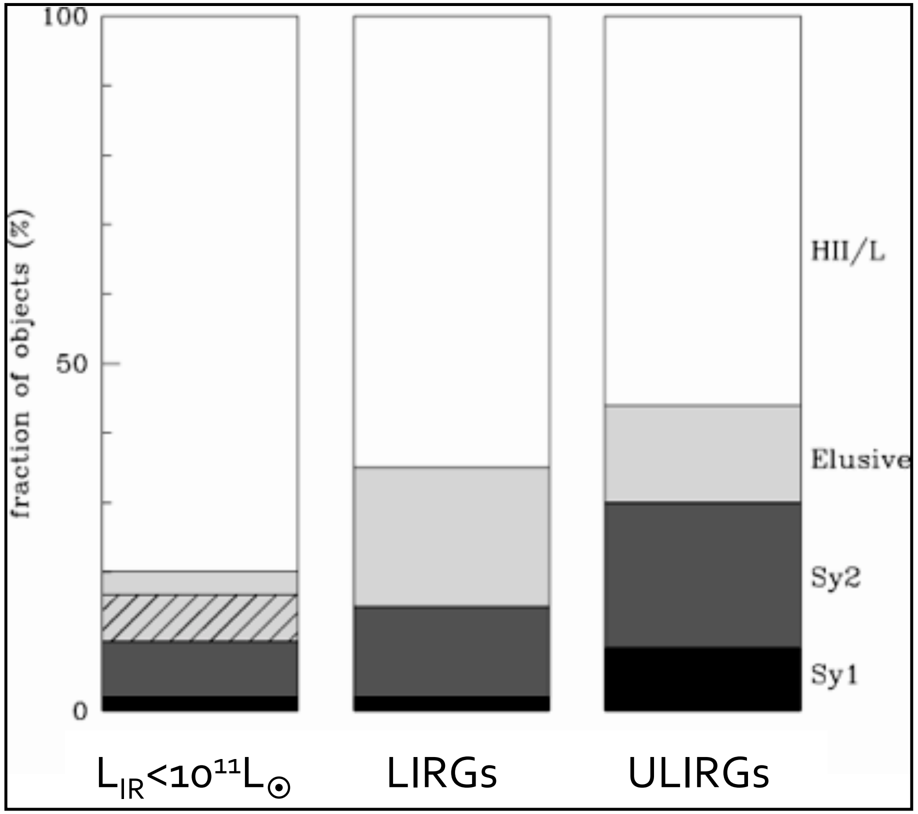
# Buried AGN in local (U)LIRGs

IR indicators provide the fraction of buried (non-Seyfert) AGN in local (U)LIRGs that are not identified by X-rays and/or optical spectroscopy

Local **LIRGs:** Fraction of buried (=non-Seyfert) AGN is 20-25%
Local **ULIRGs:** Fraction of buried (=non-Seyfert) AGN is 50-70%



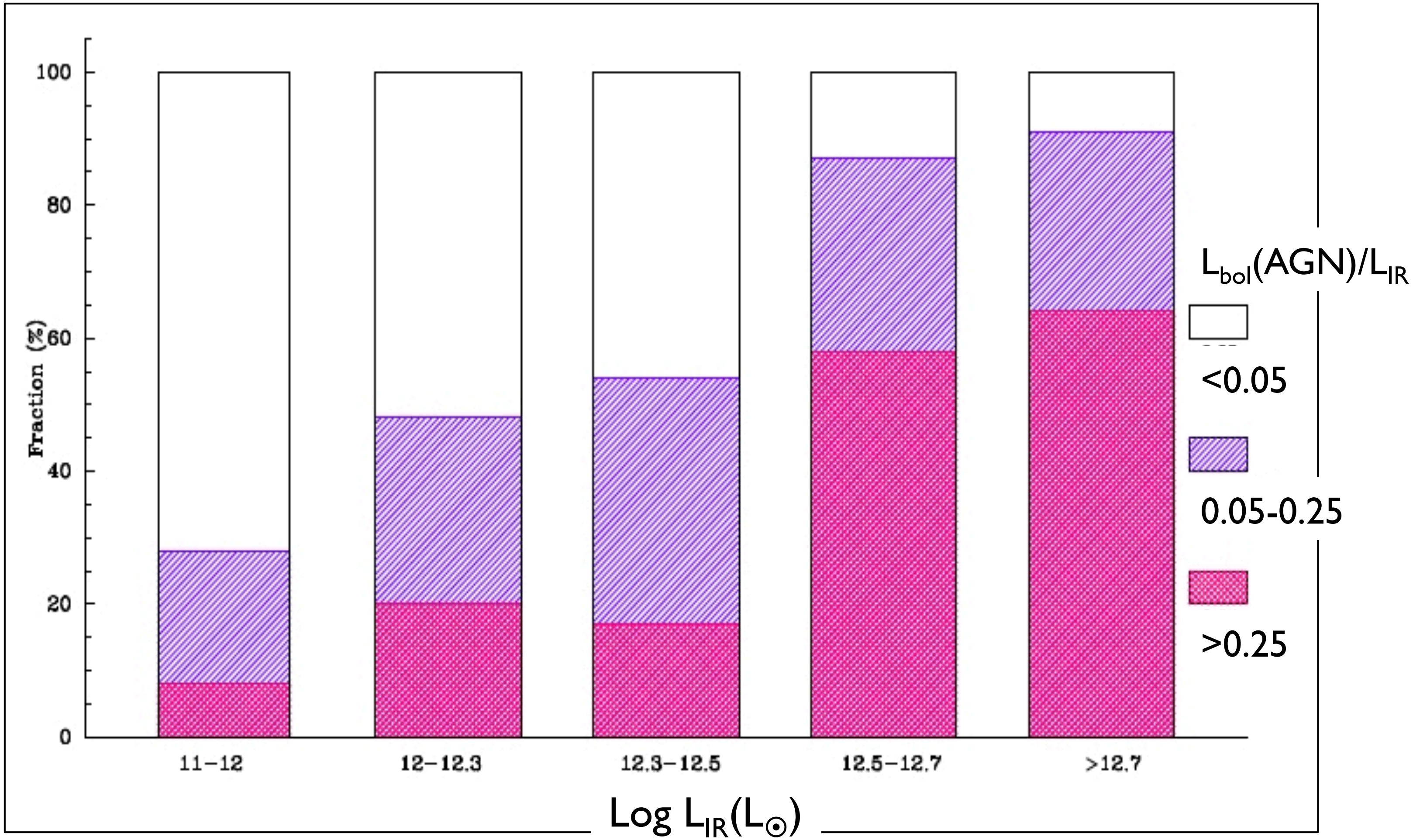




IR indicators: Imanishi+2010,2011, Alonso-Herrero+2012

X-rays: Maiolino+2003

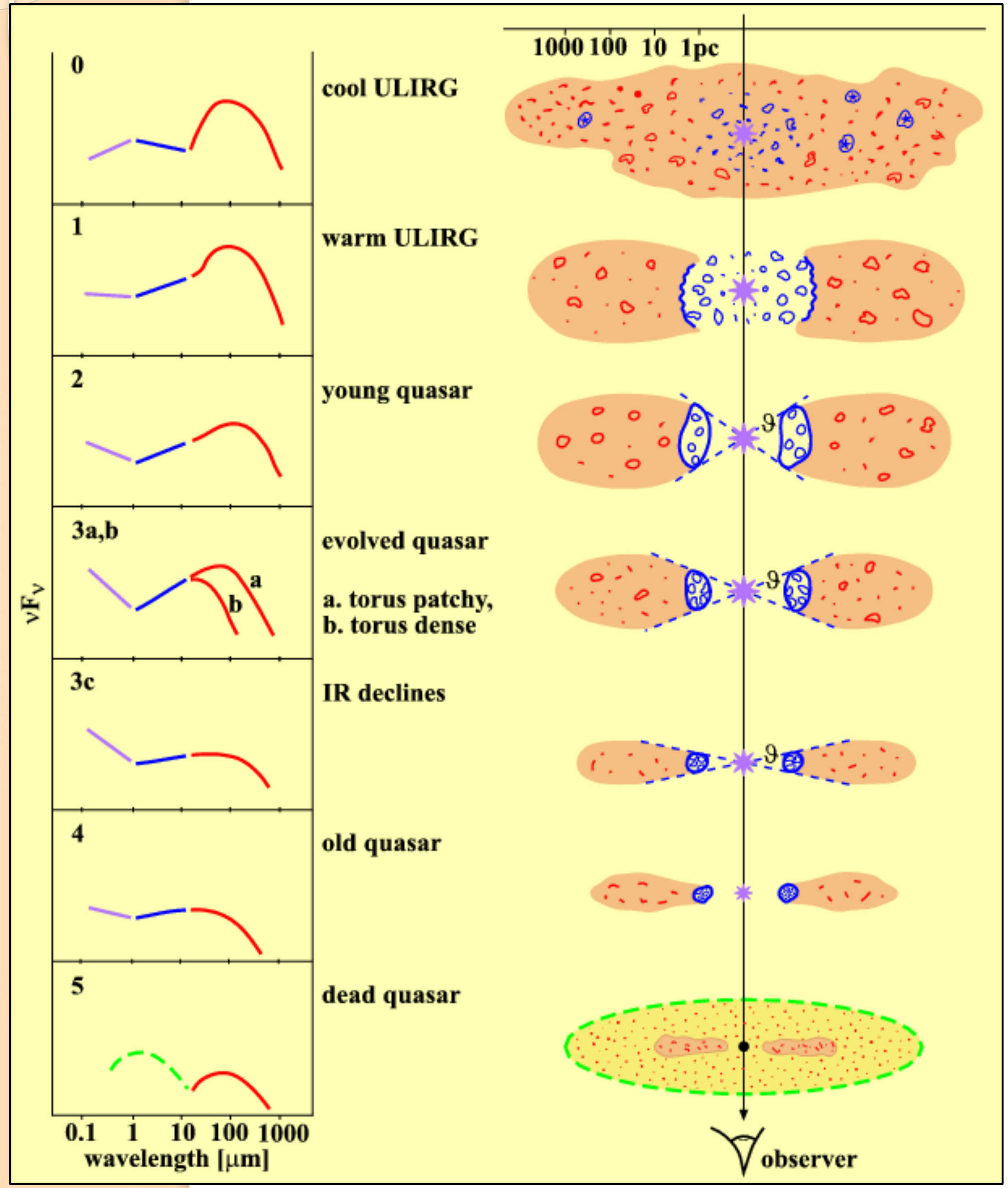
# AGN bolometric contribution in local (U)LIRGs

Alonso-Herrero+2012 and Nardini+2010




A large fraction of local (U)LIRGs are predominantly powered by **STAR FORMATION** based on low angular resolution Spitzer and ISO spectroscopy (see also Rigopoulou+1999, Veilleux+2009)

# IR emission of QSO and (U)LIRGs




Scenario: diversity of QSO and (U)LIRG IR SEDs reflects evolution of SF and AGN fractional contributions.

"*During the evolution the surrounding dust redistributes, settling more and more into a torus/disk configuration. The corresponding SEDs show an initial FIR bump, then an increased MIR emission and a steeper NIR-to-MIR slope, both of which finally also decrease.*"

Prediction: evolution of the nuclear dust distribution from (U)LIRGs to IR-bright QSO to IR-weak (optical) QSOs as well as increased AGN fractional contributions.

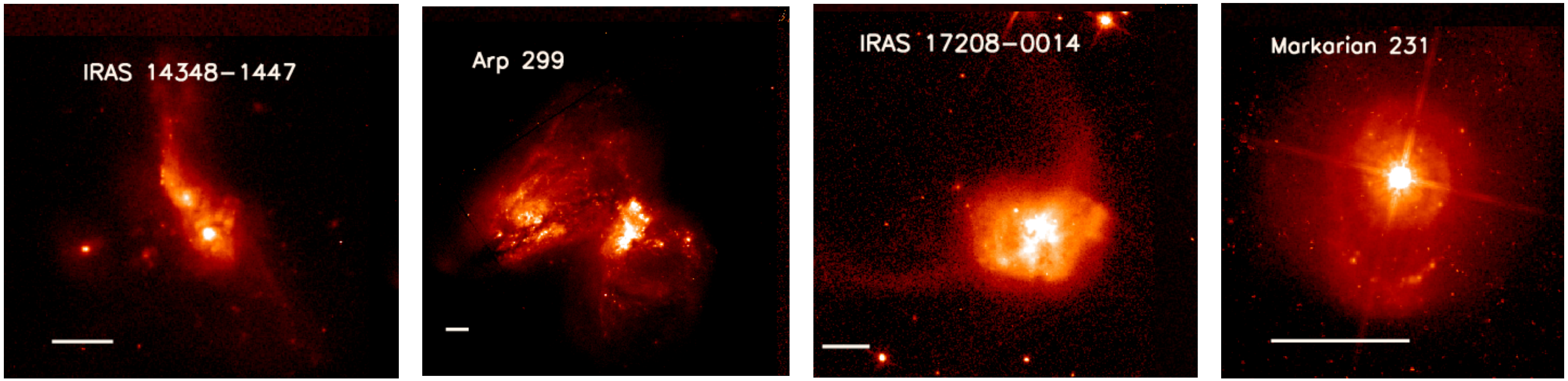
Haas+2003, after Sanders+1988, 1989. See also Hopkins+2008, Lyu+2017

# The samples

**Sample of 16 IR bright galaxies log ($L_{IR}/L_{\odot}$)>11.40 with an AGN identification,** including 5 IR-bright quasars from the GTC/CanariCam mid-IR spectroscopic catalog of Alonso-Herrero+2016.

Range of morphologies (III, IV, V using Veilleux+2002 scheme) and median distance of 200Mpc. Physical resolutions ~500pc.

**IIIb** **IIIb** **IIIb** **IVb**

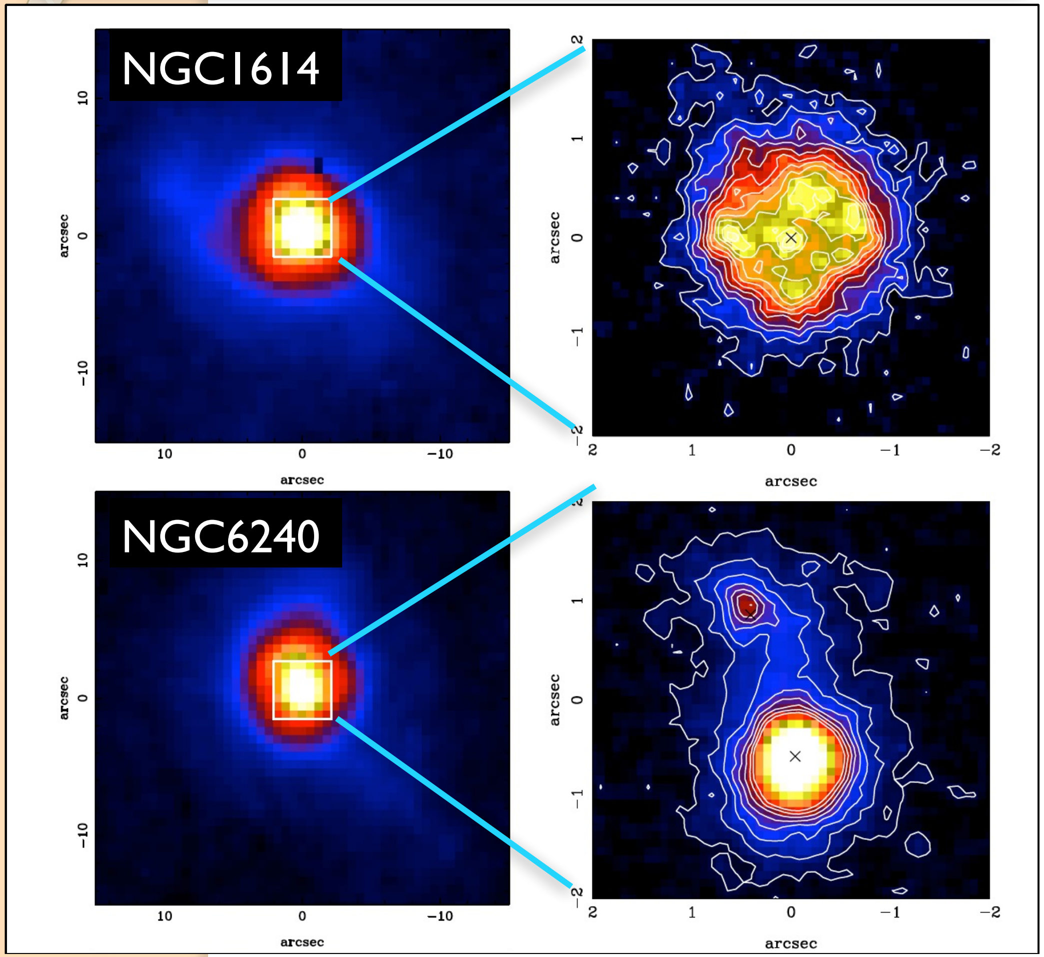



García-Marín+2009

**Comparison sample: 10 non-IR bright quasars.**

# MIR observations: Ground-based vs. Spitzer

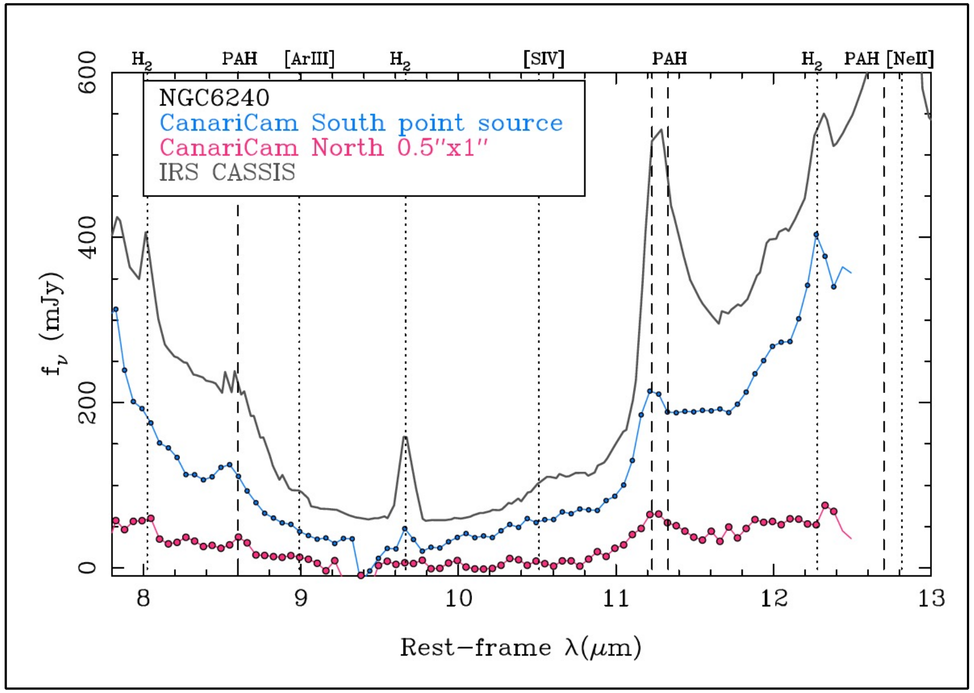
Spitzer/IRAC 8μm GTC/CanariCam 8.7μm




2” resolution 0.3” resolution

Alonso-Herrero+2016b

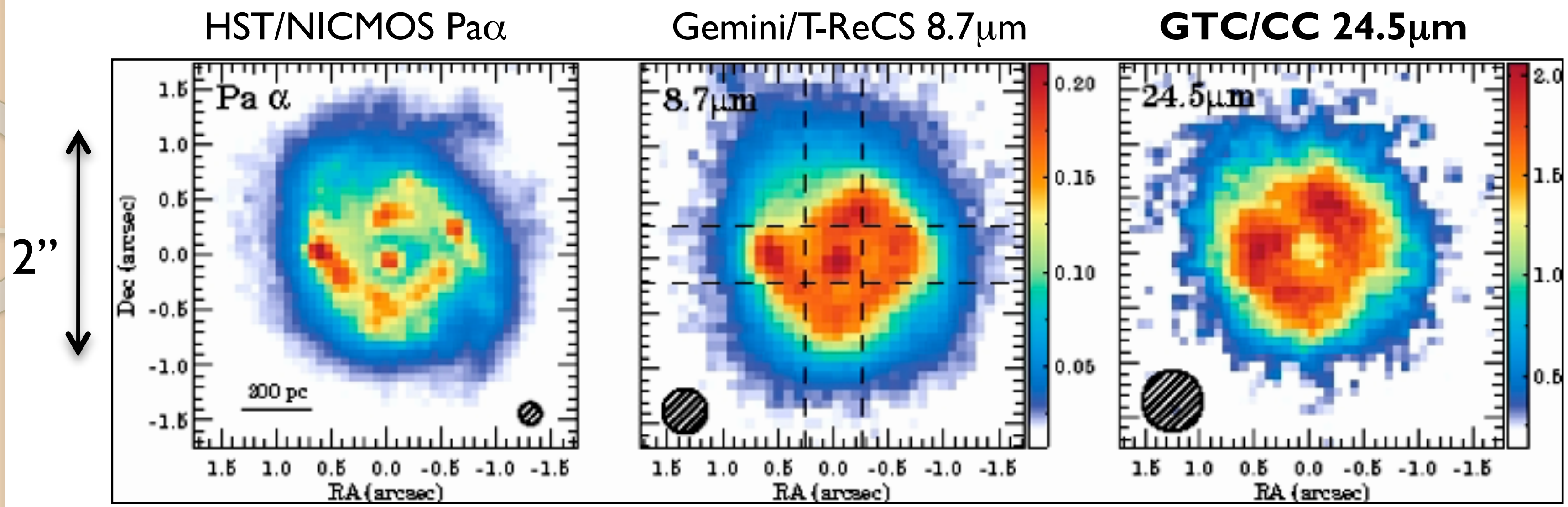
Spitzer/IRS vs. GTC/CanariCam

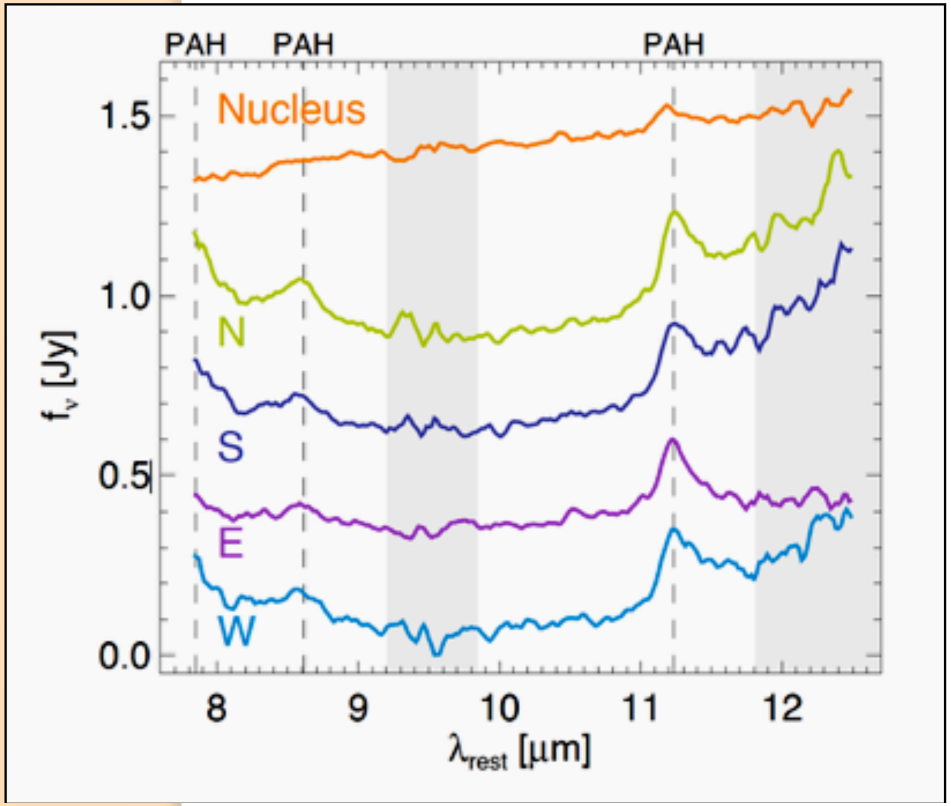



Alonso-Herrero+2014

MIR observations on 8-10m class telescopes provide **~10x higher angular resolution than Spitzer** which is critical to disentangle AGN and SF properties

# The minor merger LIRG NGC1614




Pereira-Santaella+2015

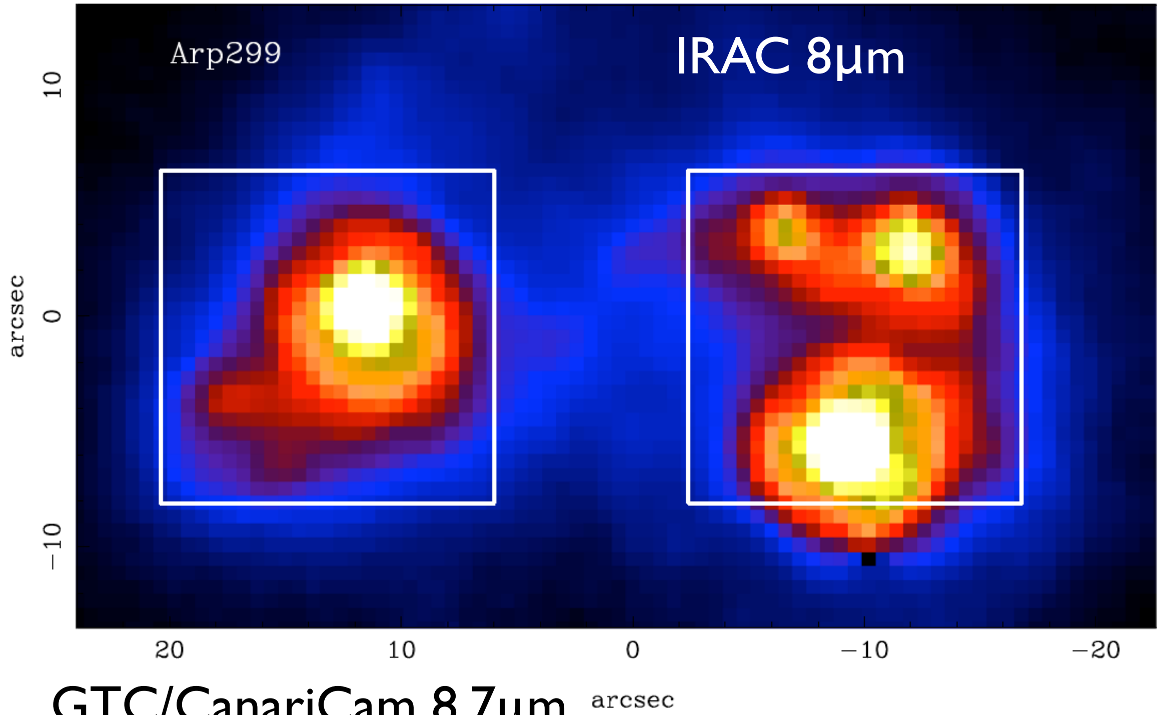
**CanariCam spectroscopy** with a ~100pc resolution resolves nucleus and star forming regions in the ring.

EW of 11.3μm PAH feature in the nucleus is much lower than regions in ring: N, S, E, W.

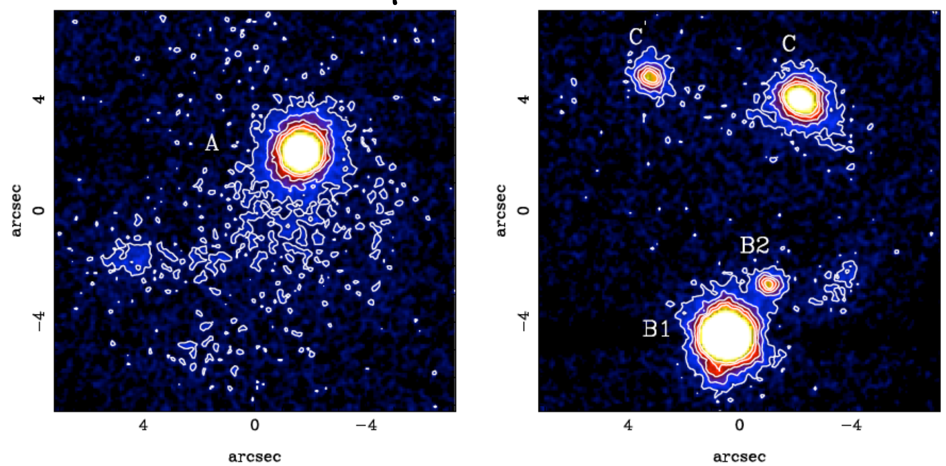
Presence of an extra mid-IR continuum at nucleus **Hidden AGN?**

In contradiction with VLBI observations Herrero-Illana+2017?

# The interacting LIRG Arp299



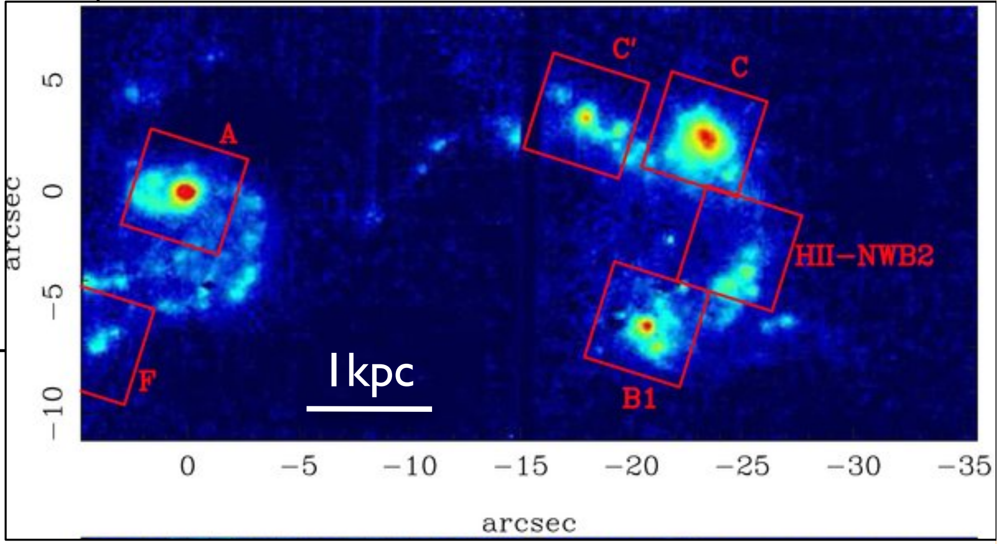

GTC/CanariCam 8.7μm




Interacting system with an IR luminosity $L_{IR}=6.7\times10^{11}\ L_{\odot}$ at a distance of 44 Mpc. The nuclei are at a projected distance of 4.5kpc.

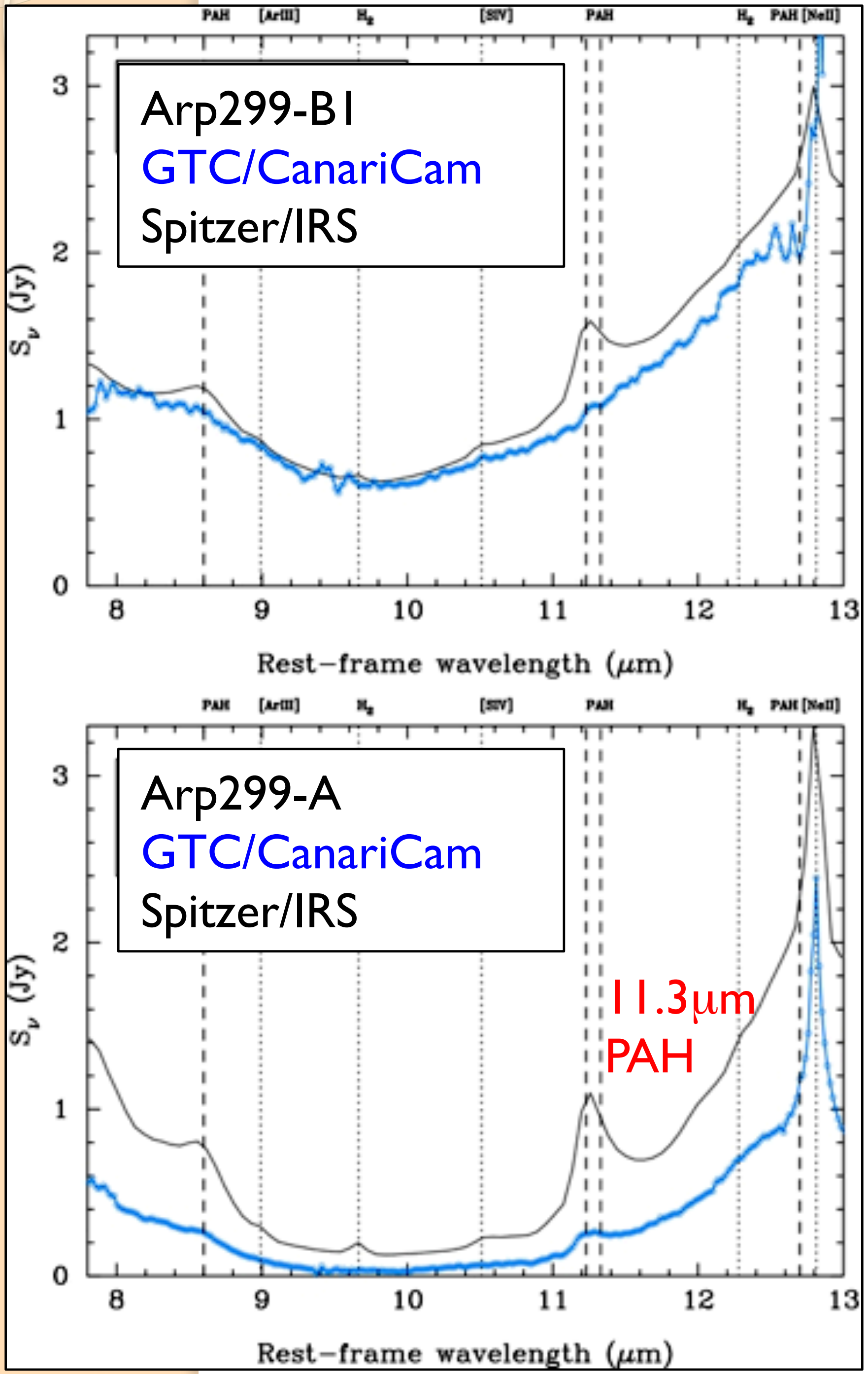
X-ray and radio evidence for one or two obscured AGN in the IR-bright nuclei.

HST/NICMOS Paα




CanariCam angular resolution 0.3-0.6'' or 60-120pc.

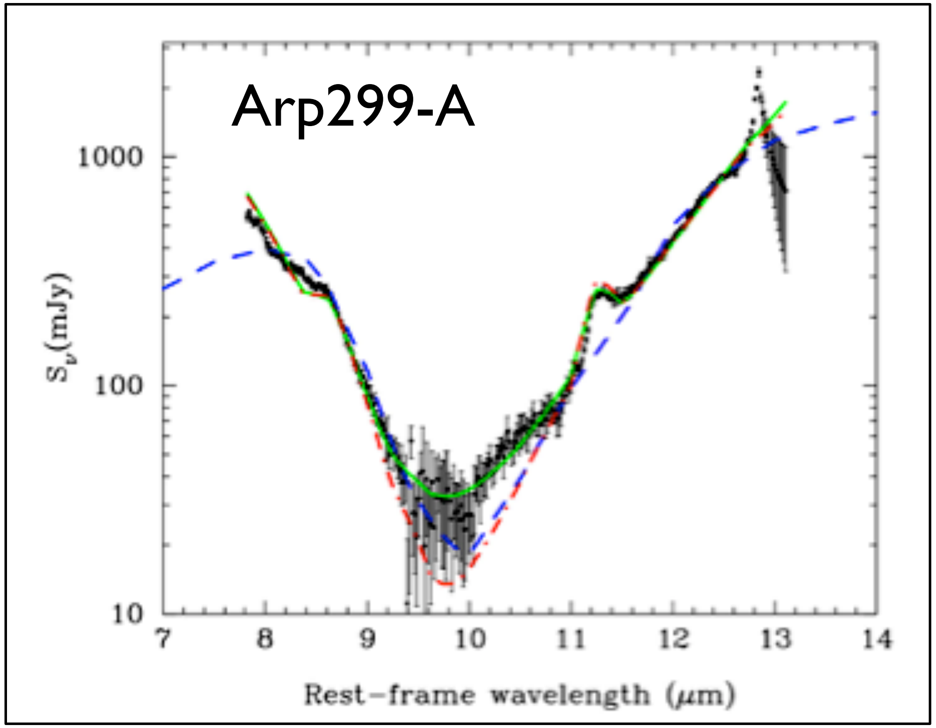
# The interacting LIRG Arp299



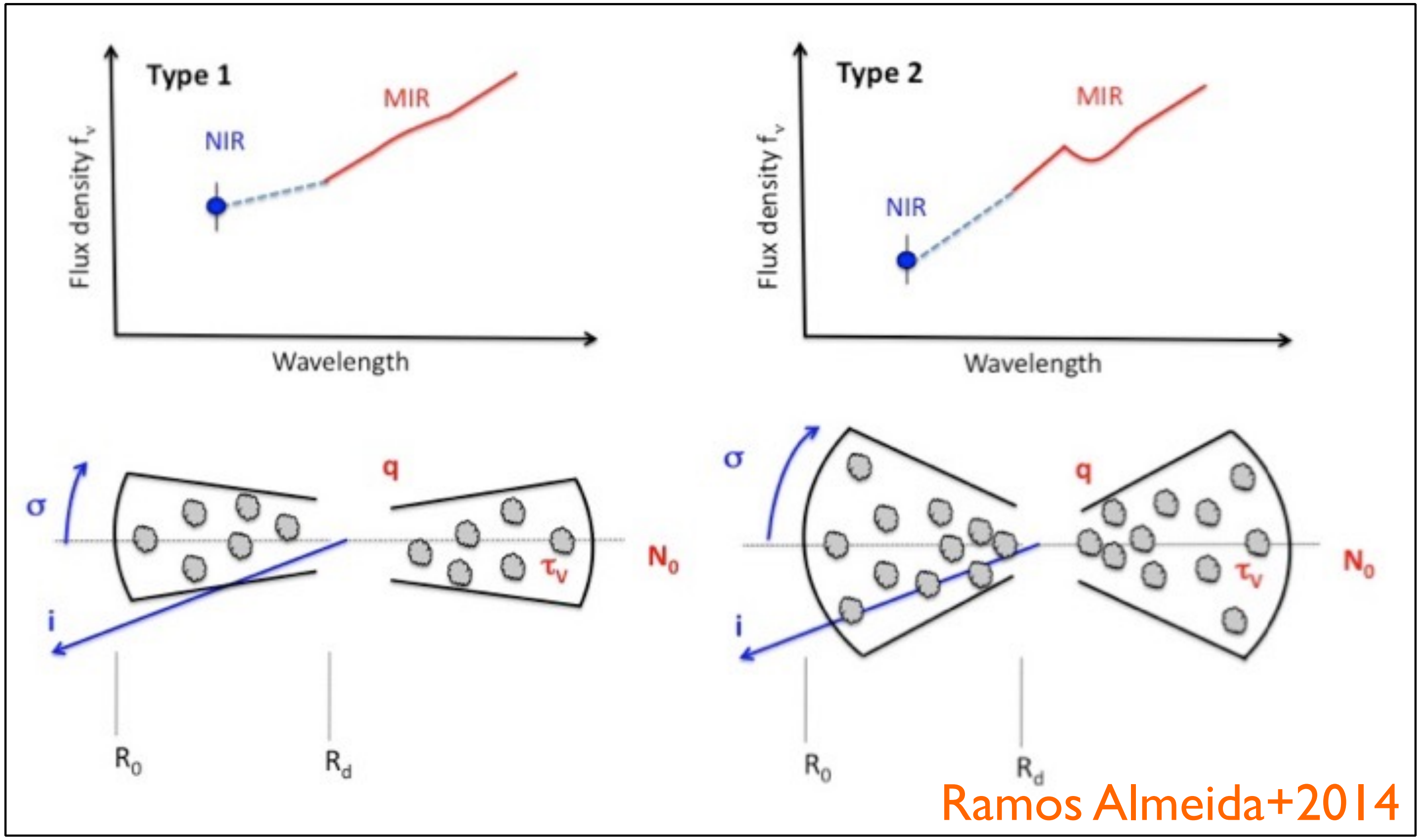

The CanariCam spectra -> evidence **of deeply embedded AGN activity in both nuclei.**

**Arp299-B1** nuclear MIR emission dominated by the AGN.
**Arp299-A** nuclear emission dominated by SF in the MIR with AGN only contributing 30% and luminosity ~ 10% of that of Arp299B1.

Alonso-Herrero+2013



# Modelling of AGN IR unresolved emission




$$N_{LOS}(i) = N_0 e^{-(90-i)^2/\sigma^2_{torus}}$$

$$P_{esc} \simeq e^{(-N_{LOS})}$$

ß=90-i

$$f_2 = 1 - \int_0^{\pi/2} P_{esc}(\beta) cos(\beta) d\beta.$$

NIR: Torus angular width and viewing angle
MIR: Number of clouds, radial distribution

**Geometrical covering factor (CF) $f_2$** is only a function of torus angular width and number of clouds along equatorial direction

Elitzur 2012

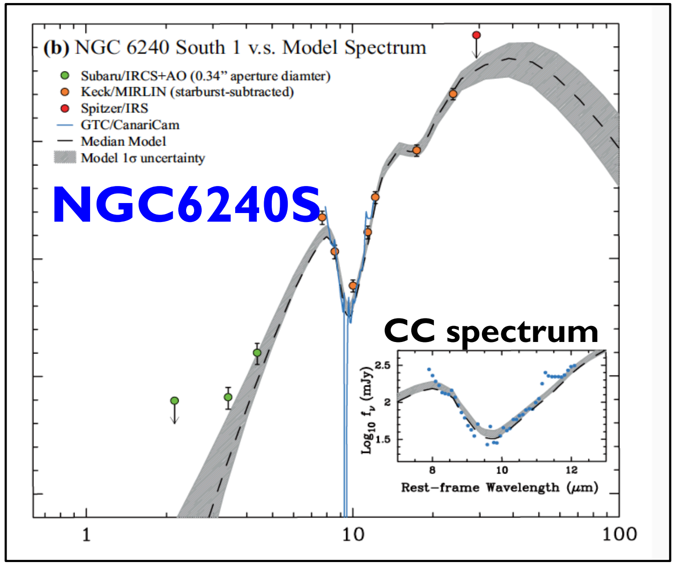
# Properties of the AGN obscuring material in local LIRGs

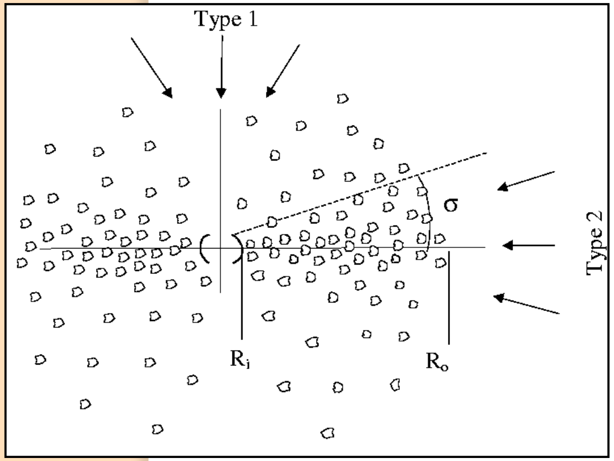
All require foreground extinction

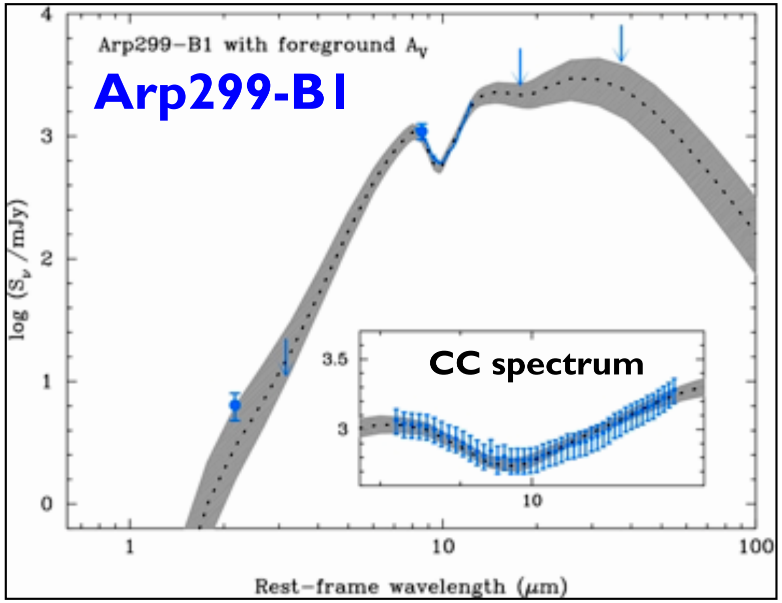
Large angular sizes σ and large number of clouds $N_0$

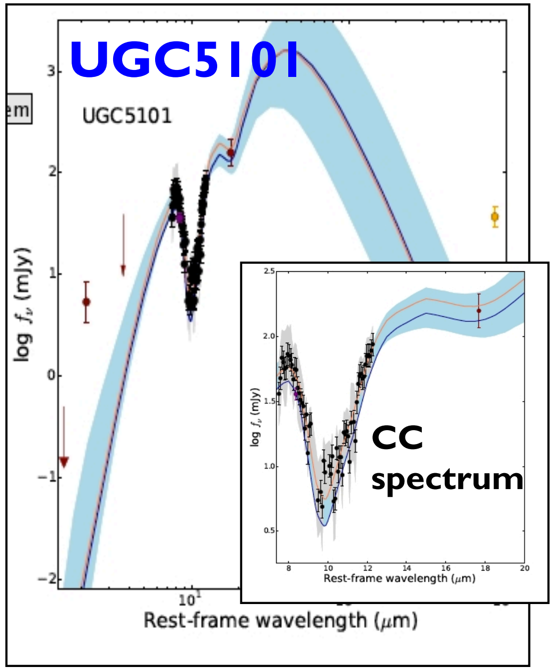
→ **large covering factors $f_2$>0.9**

Good way to predict AGN bolometric luminosities for highly absorbed objects



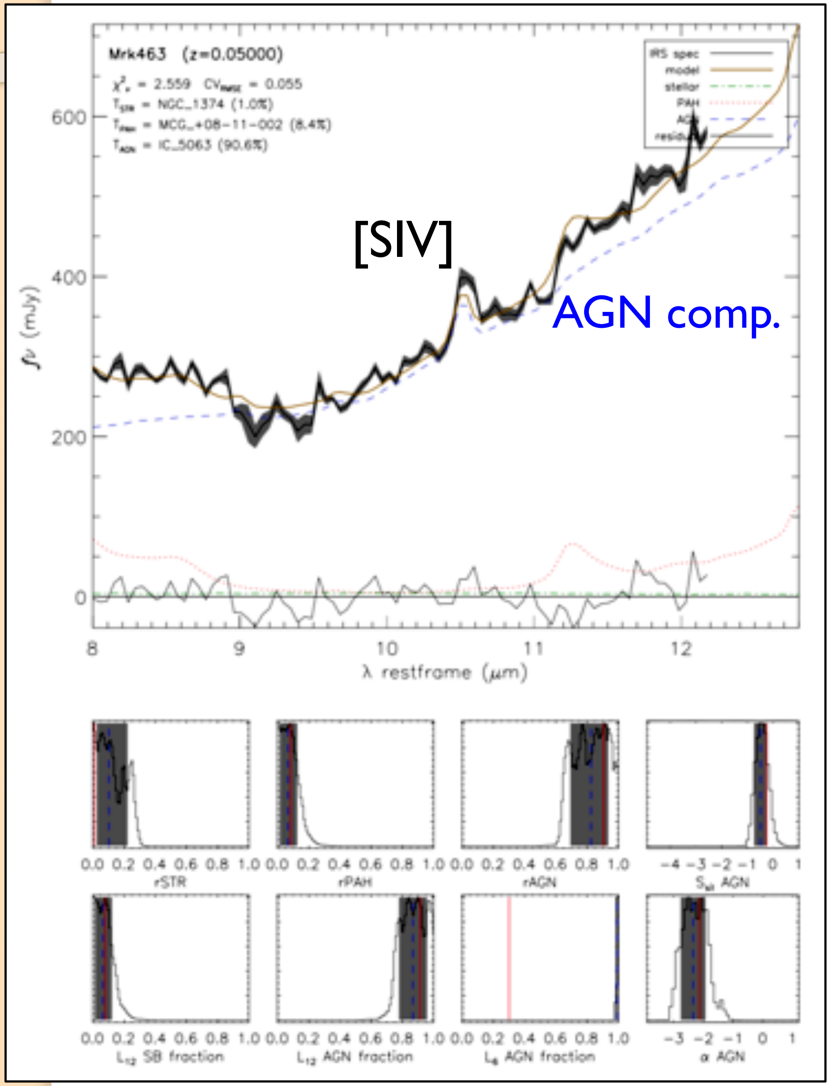



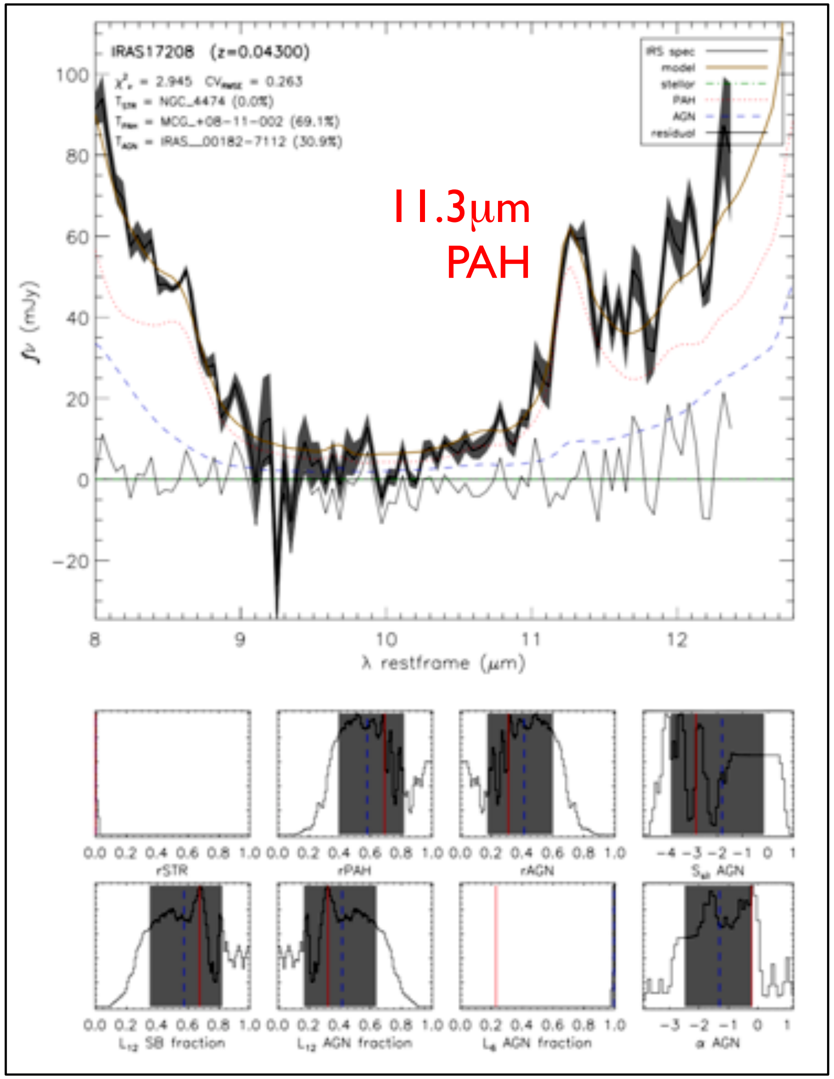

Alonso-Herrero+2013, Mori+2014, Martínez-Paredes+2015 and also Levenson+2007

# Spectral decomposition to disentangle the AGN and SF emissions

## Mrk463E: AGN dominated in the MIR




## IRAS17208-0014: SF dominated in the MIR



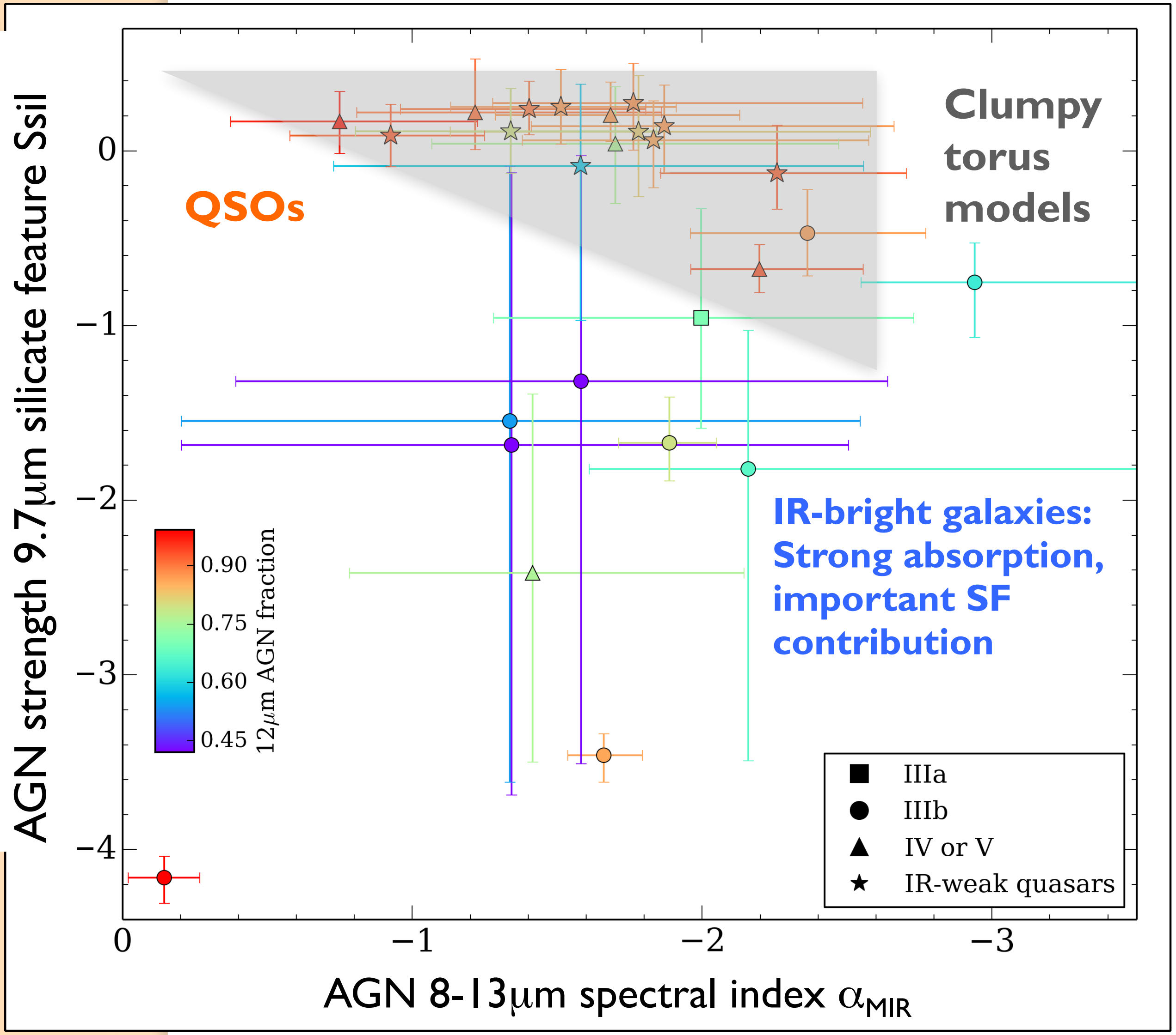

AGN strength 10μm feature $S_{sil}$

AGN 8-13μm spectral index

Alonso-Herrero+2016b

# AGN MIR properties of Quasars and IR-bright galaxies

Alonso-Herrero+2016b




IR-bright and IR-weak QSO have AGN 8-13μm spectral indices (~ radial cloud distribution) and silicate feature strengths (~ number of clouds, few clouds) reproduced with clumpy torus models.

Most QSO are well reproduced with clumpy torus models.

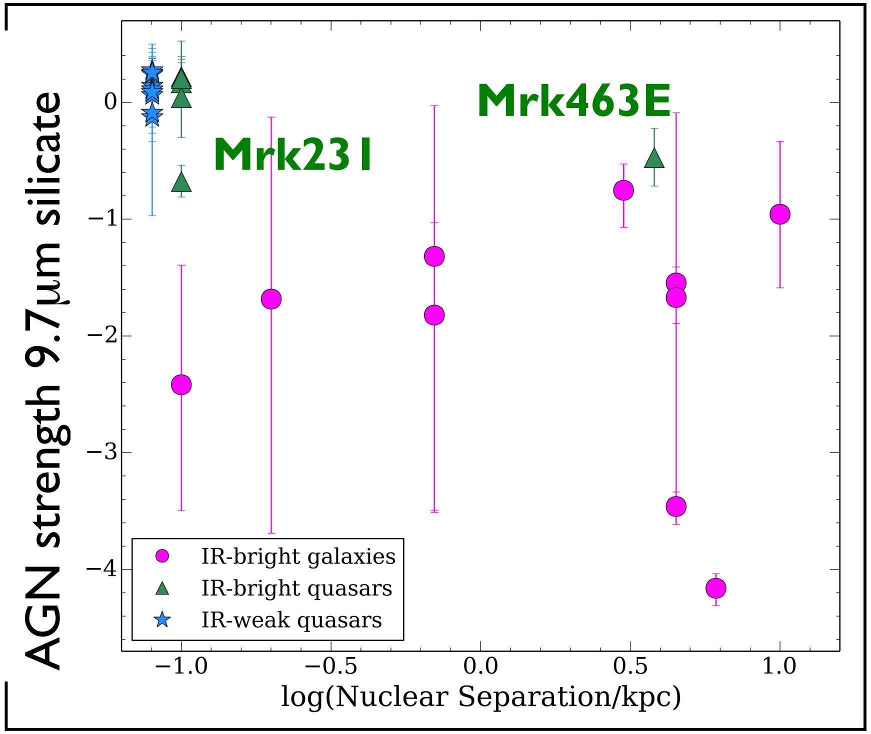
AGN properties of most IR-bright galaxies cannot be reproduced with clumpy torus models alone, irrespective of SF dominance or stage of interaction -> **heavily embedded**

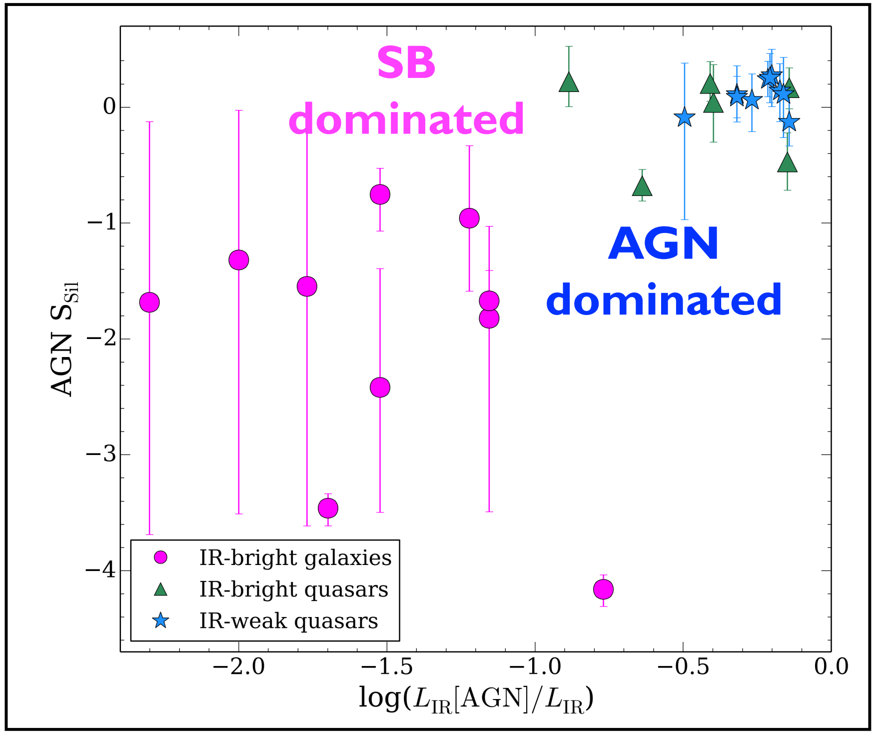
# Nuclear obscuration in IR-bright galaxies and IR-bright quasars

There is a tendency for the AGN component of IR-bright galaxy nuclei with low (<10%) AGN fractional contributions to $L_{IR}$ to show deeper silicate features.

Nuclear obscuration high in close pairs, whereas it's low in most QSO except transitional ones.

Alonso-Herrero+2016b

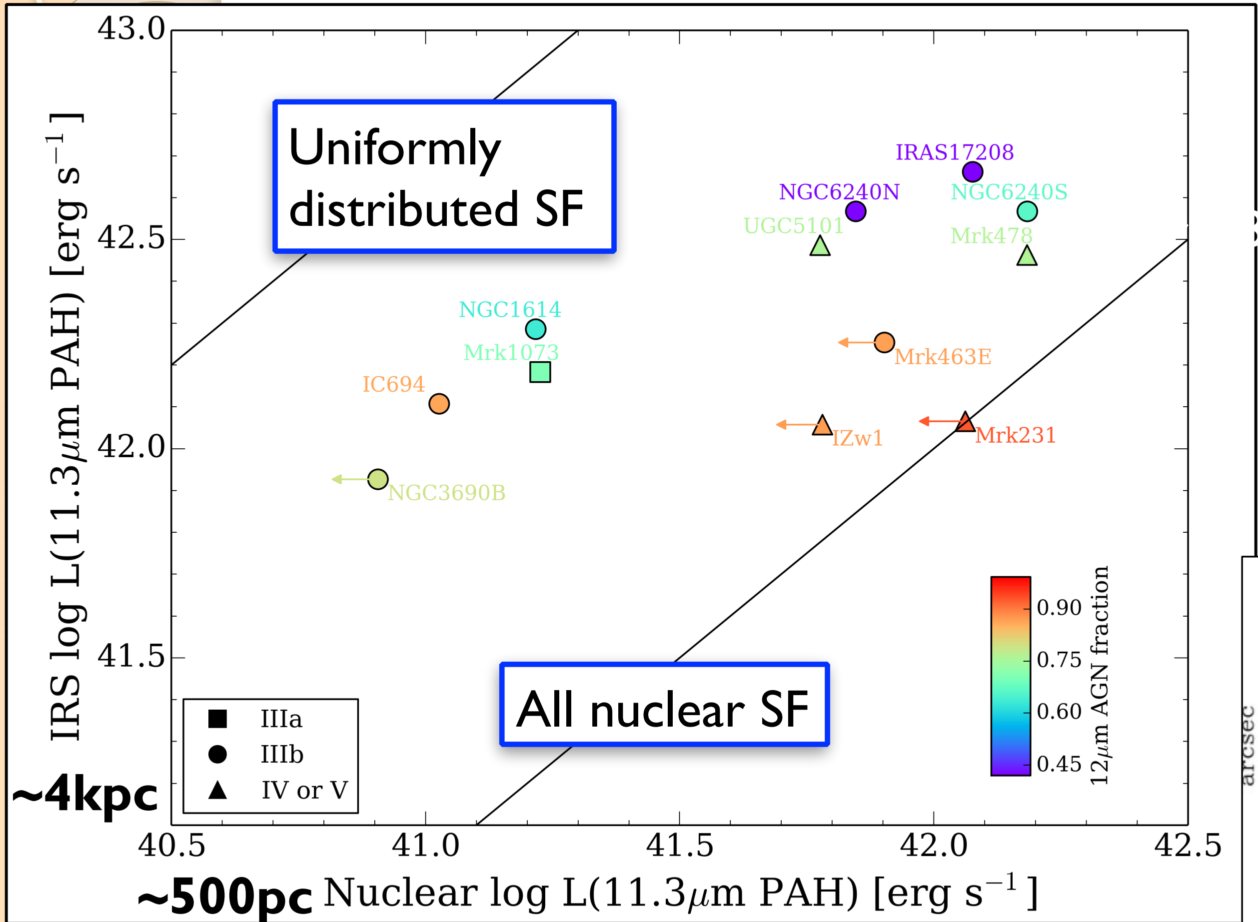


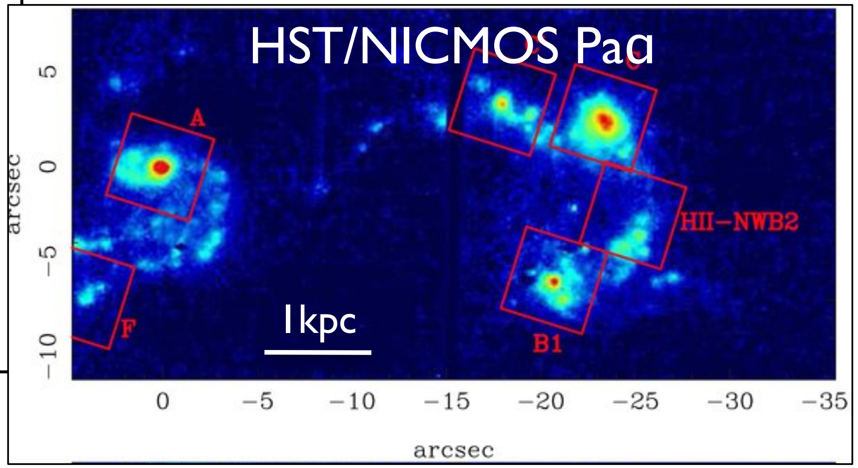

**However, while ground-based MIR observations have great angular resolution they suffer from low sensitivity and limited spectral range**

# Nuclear vs extended Star Formation Activity

Alonso-Herrero+2016b



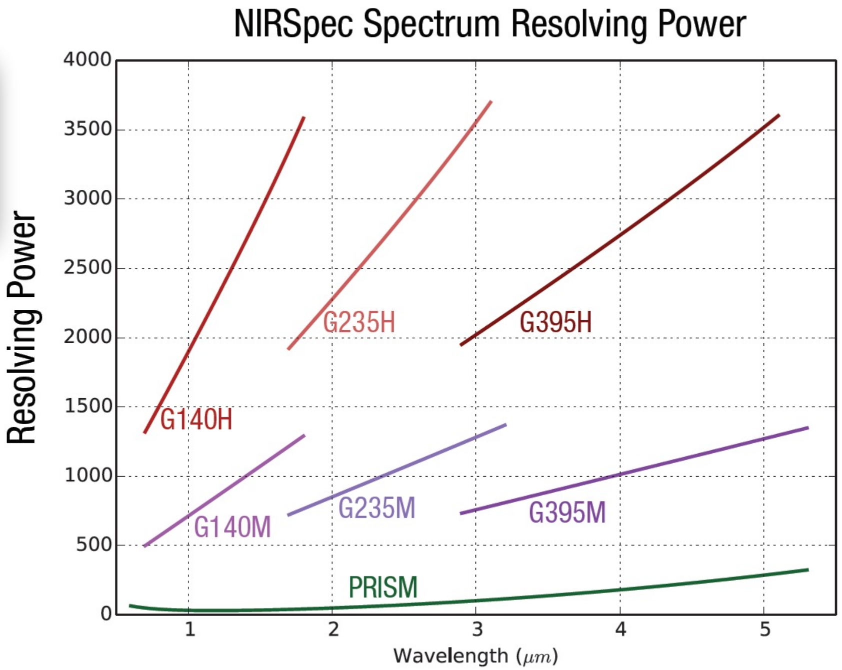

Nuclear SFR densities between: 18M⊙yr$^{-1}$ kpc$^{-2}$ IRAS 17208 160M⊙yr$^{-1}$ kpc$^{-2}$ NGC 6240S.

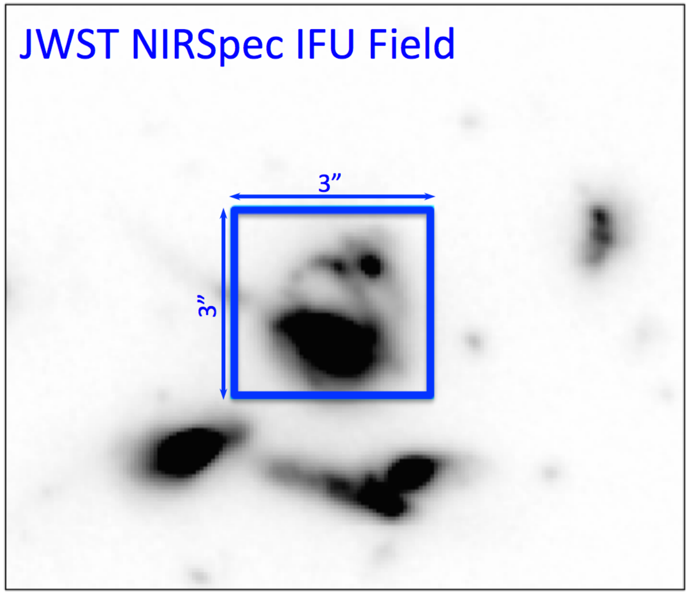



SF in many local IR-bright galaxies extended over several kpc, not uniformly distributed and taking place in individual bright regions. See also Alonso-Herrero+2006.

# JWST Integral Field Units

**NIRSpec: ~1-5μm**

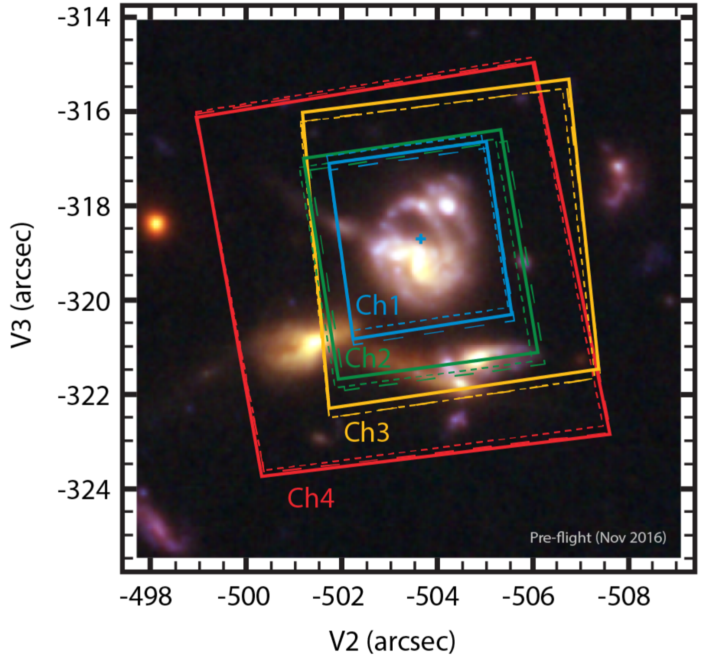



**MIRI: 5-28μm**

| Channel | Band | Nr. slices | Wavelength Range [μm] | Spectral Resolution | FoV [arcsec] |
|---|---|---|---|---|---|
| 1 | 1A | 21 | 4.88 - 5.77 | ~3500 | 3.46 x 3.72 |
| | 1B | | 5.64 - 6.67 | | 3.46 x 3.72 |
| | 1C | | 6.50 - 7.70 | | 3.41 x 3.72 |
| 2 | 2A | 17 | 7.47 - 8.83 | ~3000 | 4.16 x 4.76 |
| | 2B | | 8.63 - 10.19 | | 4.16 x 4.76 |
| | 2C | | 9.96 - 11.77 | | 4.12 x 4.76 |
| 3 | 3A | 16 | 11.49 - 13.55 | ~2600 | 6.00 x 6.24 |
| | 3B | | 13.28 - 15.66 | | 5.96 x 6.24 |
| | 3C | | 15.34 - 18.09 | | 5.91 x 6.24 |
| 4 | 4A | 12 | 17.60 - 21.00 | ~1600 | 7.14 x 7.87 |
| | 4B | | 20.51 - 24.48 | | 7.06 x 7.87 |
| | 4C | | 23.92 - 28.55 | | 6.99 x 7.87 |

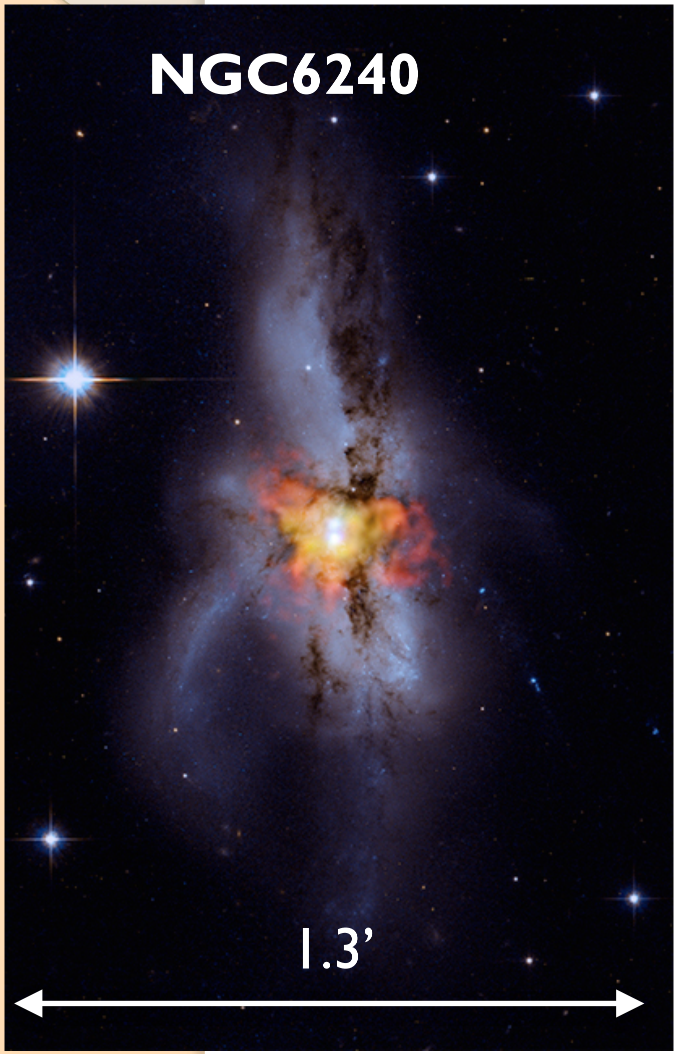
MIRI/MRS FoV



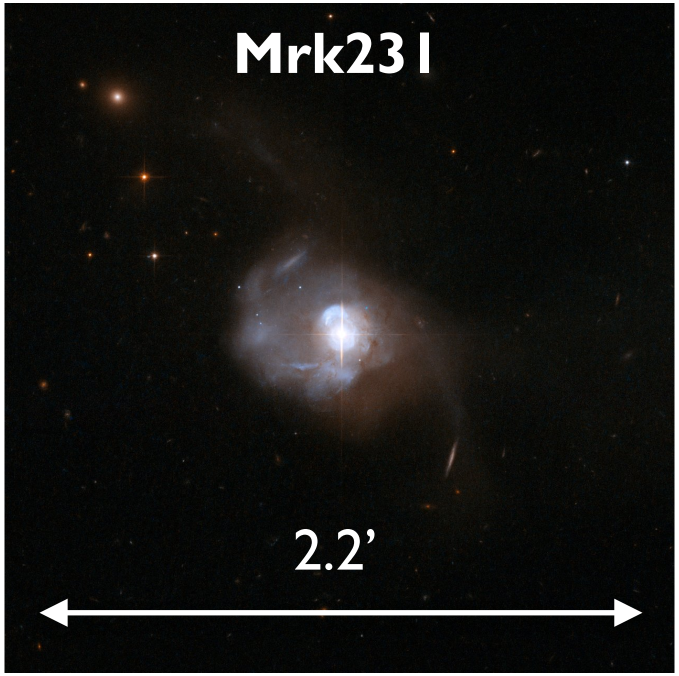

Credit: JWST webpage at STScI

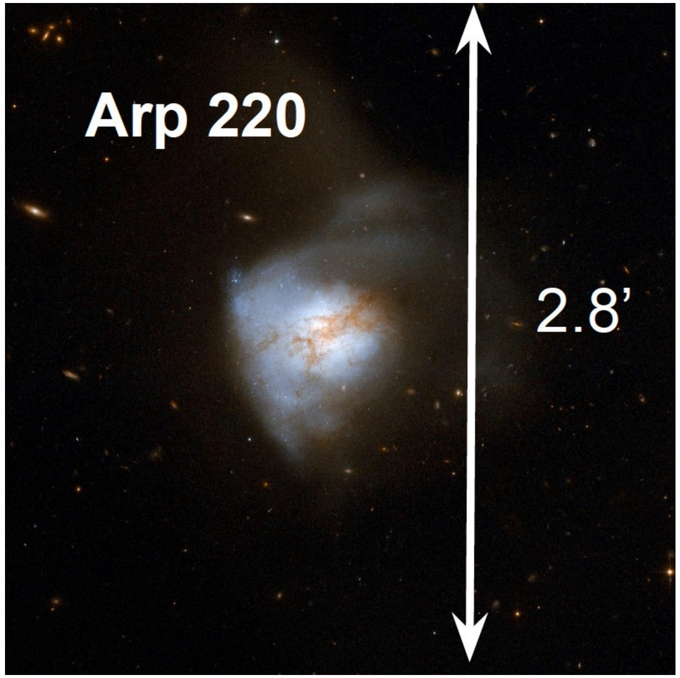
# GTO: NIRSpec+MIRI IFU of (U)LIRGs

Program of nearby galaxies of NIRSpec and MIRI teams includes 3 (U)LIRGs to observe the obscured central regions (a few arcsec) using the IFU observing mode.




Credit: HST




Credit: HST + Chandra

# Prospects with JWST

NIRSpec+MIRI IFU data of central regions of local (U)LIRGs + AGN will provide an exquisite view into the relation between BH growth, nuclear/circumnuclear SF and outflows (both AGN and SF powered) and inflows