Spatial variations in the mid-IR/radio correlation in Luminous Infrared Galaxies

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outline

- aims
- sample description
- methods:
  - monochromatic mid-IR/radio ratios q_8, q_{24}
  - dust-temperature T_d maps (70μm & 100μm)
- results: q_8, q_{24}, T_d, radio-spectral-index α
- conclusions

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aims

- study AGN/SB connection in LIRGs
- study spatial variations of $q_{8,24}$ in local LIRGs
- relate to spatially resolved galaxy properties, e.g.

dust-temperature (PACS 70μm, 100μm) and radio-spectral-index (α-maps using 1.49 & 8.44 GHz; Vardoulaki+15)

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greater sample

- **GOALS:** Great Observatories All-sky LIRG Survey

  (*Armus+09, Petric+11, Stiewalt+13, Diaz-Santos+10,11*;

  http://goals.ipac.caltech.edu)

- **202** systems:180 LIRGs ($L_{IR} > 10^{11}\ L_{\odot}$) & 22 ULIRGs ($L_{IR} > 10^{12}\ L_{\odot}$)
- **complete sample** from the IRAS Revised Bright Galaxy Sample

  ($S_{60\mu m} > 5.24$ Jy & $z < 0.088$)

- **full range of nuclear spectral types** (type-1 and type-2 AGN, LINERs, and starbursts) **and interaction stages** (major mergers, minor mergers, and isolated galaxies)
- data: GALEX, Hubble, Spitzer, Herschel, Chandra, VLA, JVLA, ALMA

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our sample

- **26** LIRG systems from GOALS:
  - resolved at VLA B-array 1.49 GHz (~6 arcsec resolution)
  - 24 μm MIPS Spitzer maps ➔ q_{24} maps (~6 arcsec resolution)
  - 70 & 100 μm PACS Herschel maps ➔ $T_{\rm d}$
- **28** LIRG systems from GOALS:
  - resolved at VLA A-array 1.49 GHz (~1.5 arcsec resolution)
  - 8 μm IRAC Spitzer maps ➔ q_8 maps (~2 arcsec resolution)
  - radio-spectral-index α-maps for 16 LIRGs (Vardoulaki+15)
- 5 LIRG systems with resolved q_8, q_{24}, $T_{\rm d}$ and α-maps

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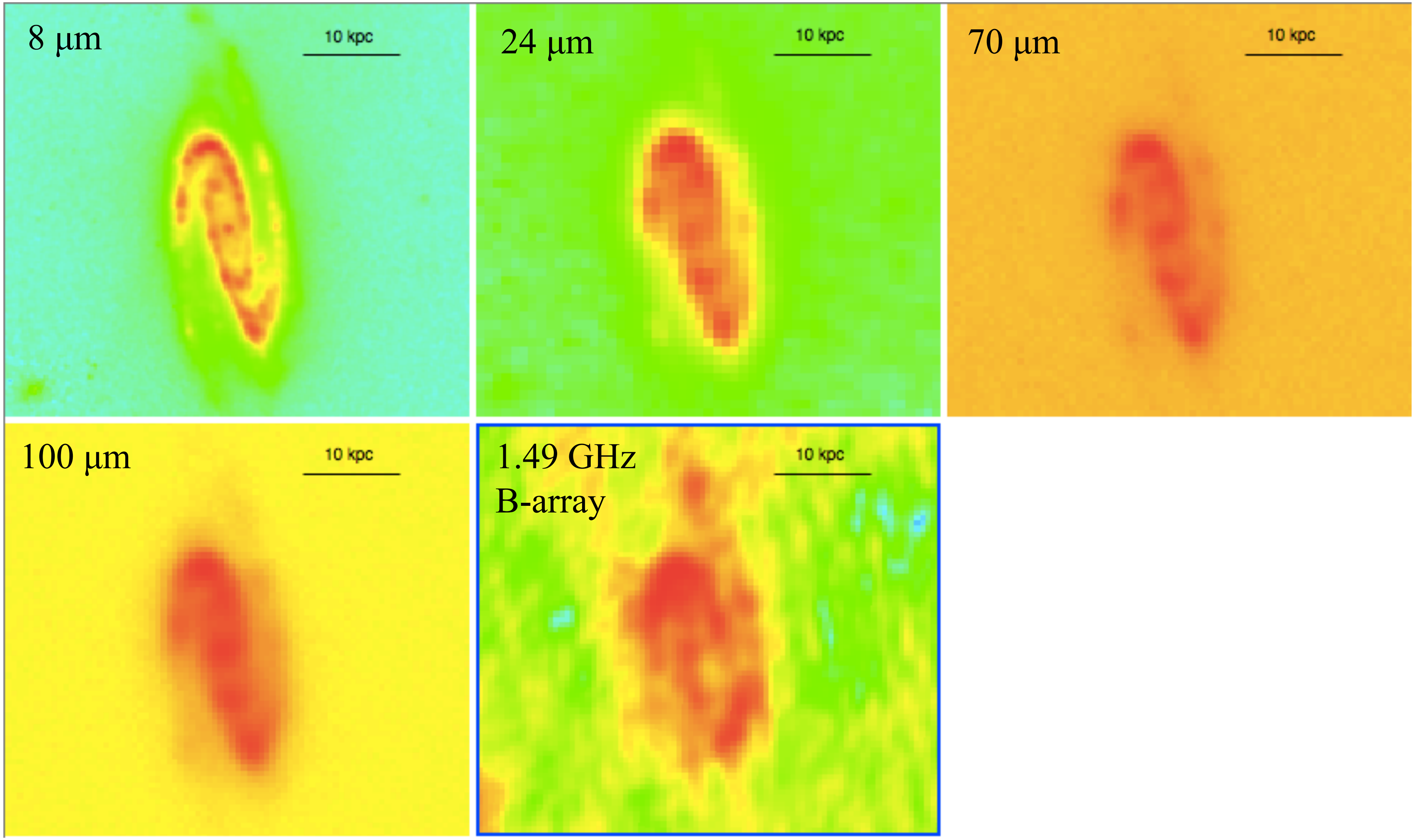
NGC0958



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methods

- q_8, q_{24} maps (resolution ~ 2, 6 arcsec):
  - $q_{8,24} = \log_{10}(f_{\nu 8,24\mu m}\,(Jy) / f_{\nu 20cm}\,(Jy))$
- T_d (K):
  - $f_\nu = N / \lambda^{\beta+3} (e^{hc/\lambda kT} - 1)$; modified Planck function
  - $f_{70\mu m}$ & $f_{100\mu m}$ Herschel PACS (resolution ~ 7 arcsec)
  - χ^2 minimalization, $\beta = 2$, $10 < T_d\,(K) < 80$, single component fit
- α-maps (resolution ~ 1.5 arcsec):
  - $S_\nu \sim \nu^{-\alpha}$, 1.49 & 8.44 GHz (Vardoulaki+15)

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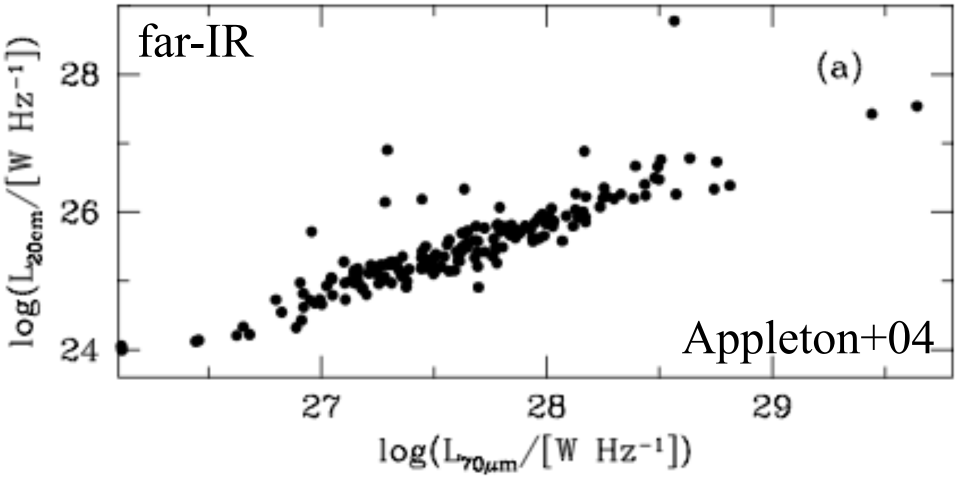
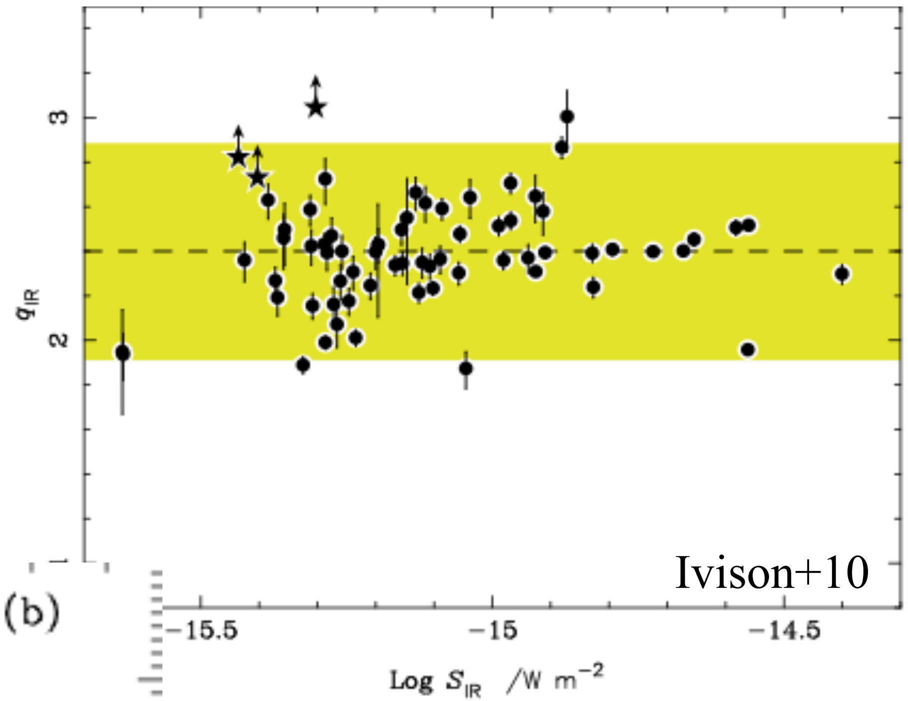
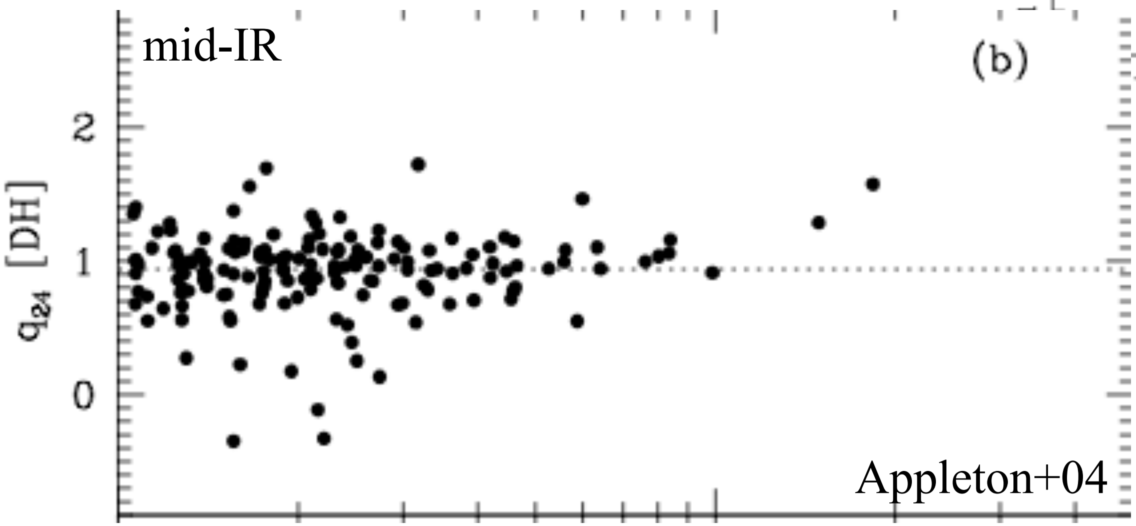
IR/radio ratio







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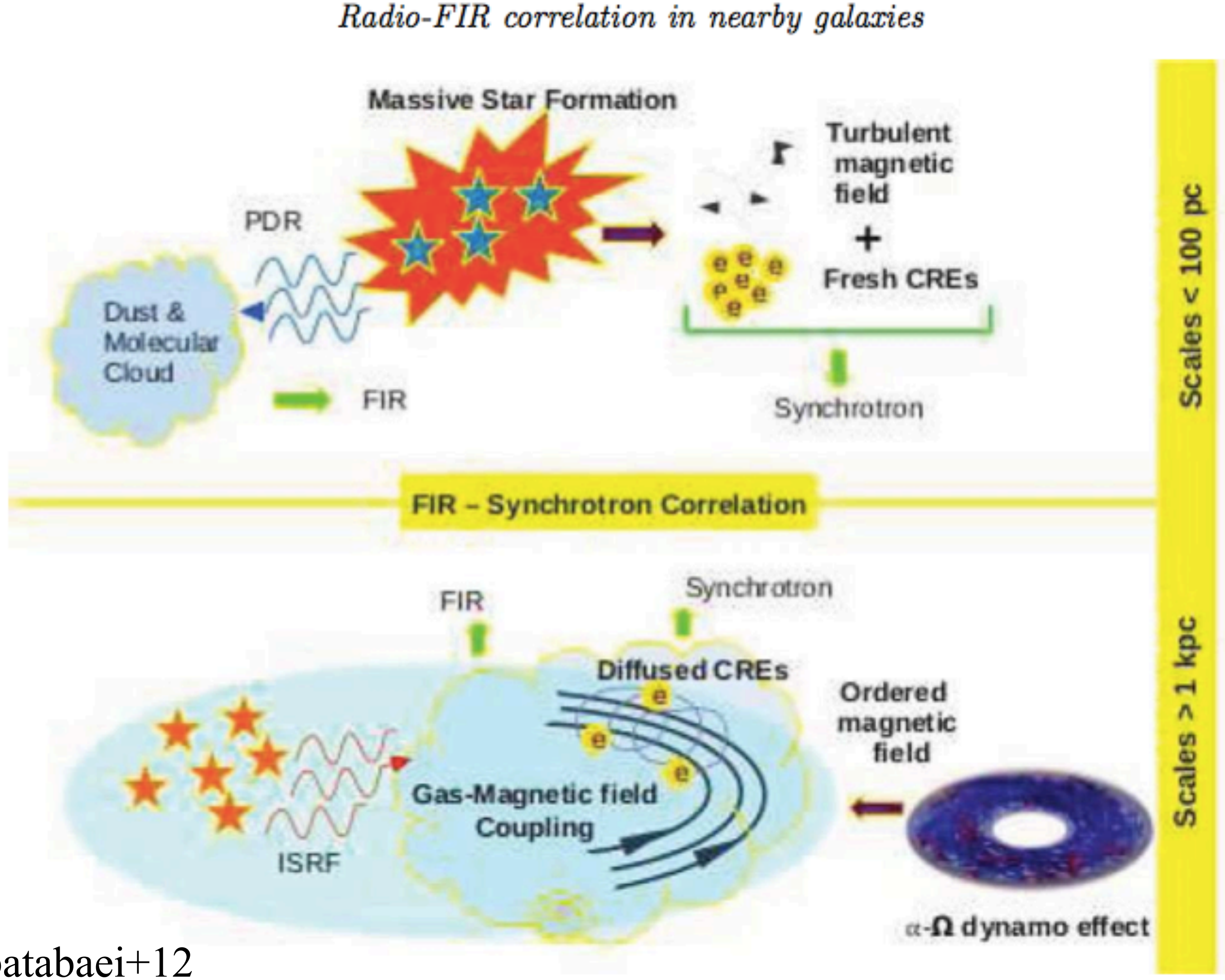
IR/radio ratio v scale



Tabatabaei+12

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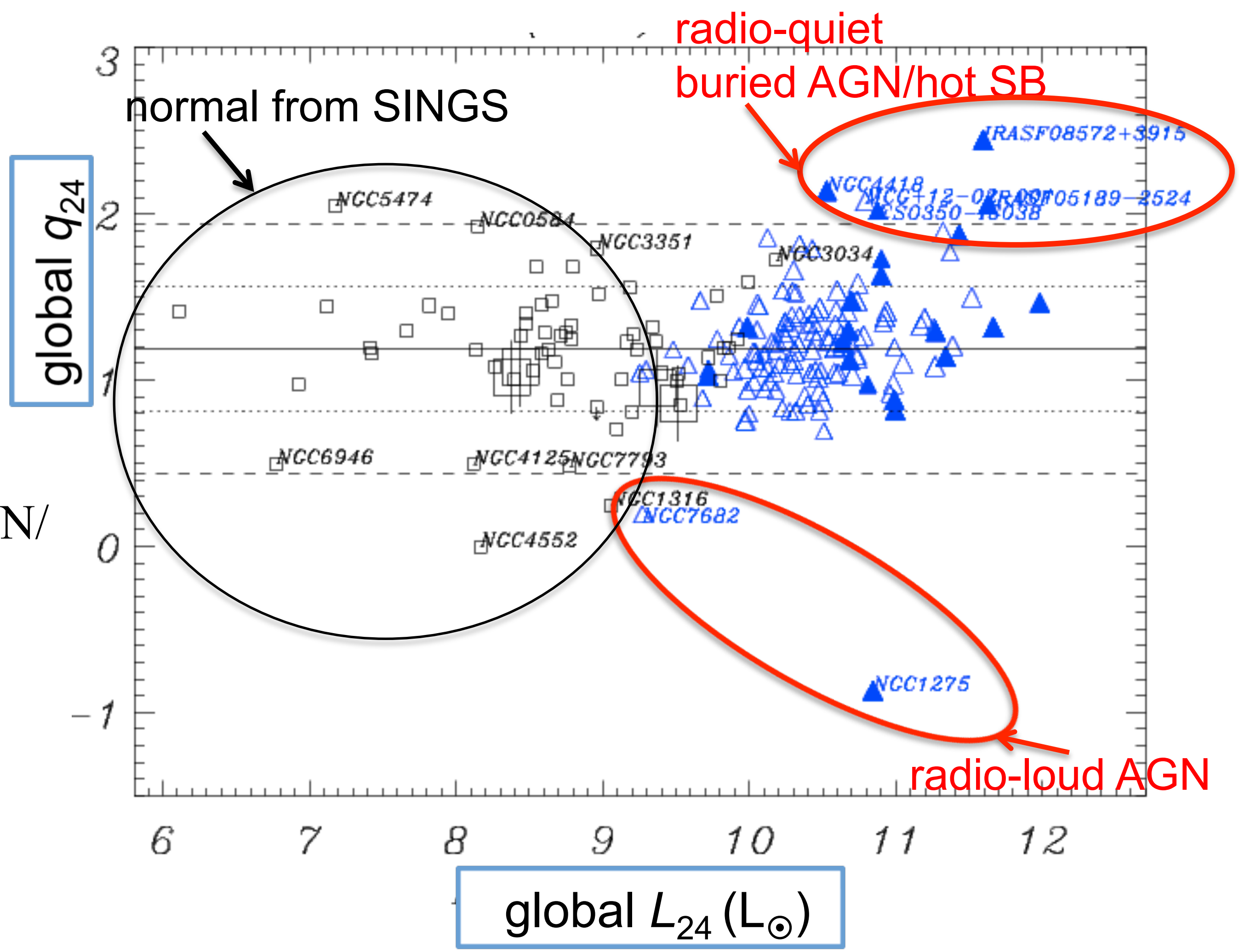
global q_{24}

symbols:

- △ 137 LIRGs GOALS
- ▲ 22 mid-IR AGN
- □ 75 normal SINGS



- LIRGs ~ normal gals
- high q_{24}: RQ buried AGN/ hot SB
- low q_{24}: RL AGN

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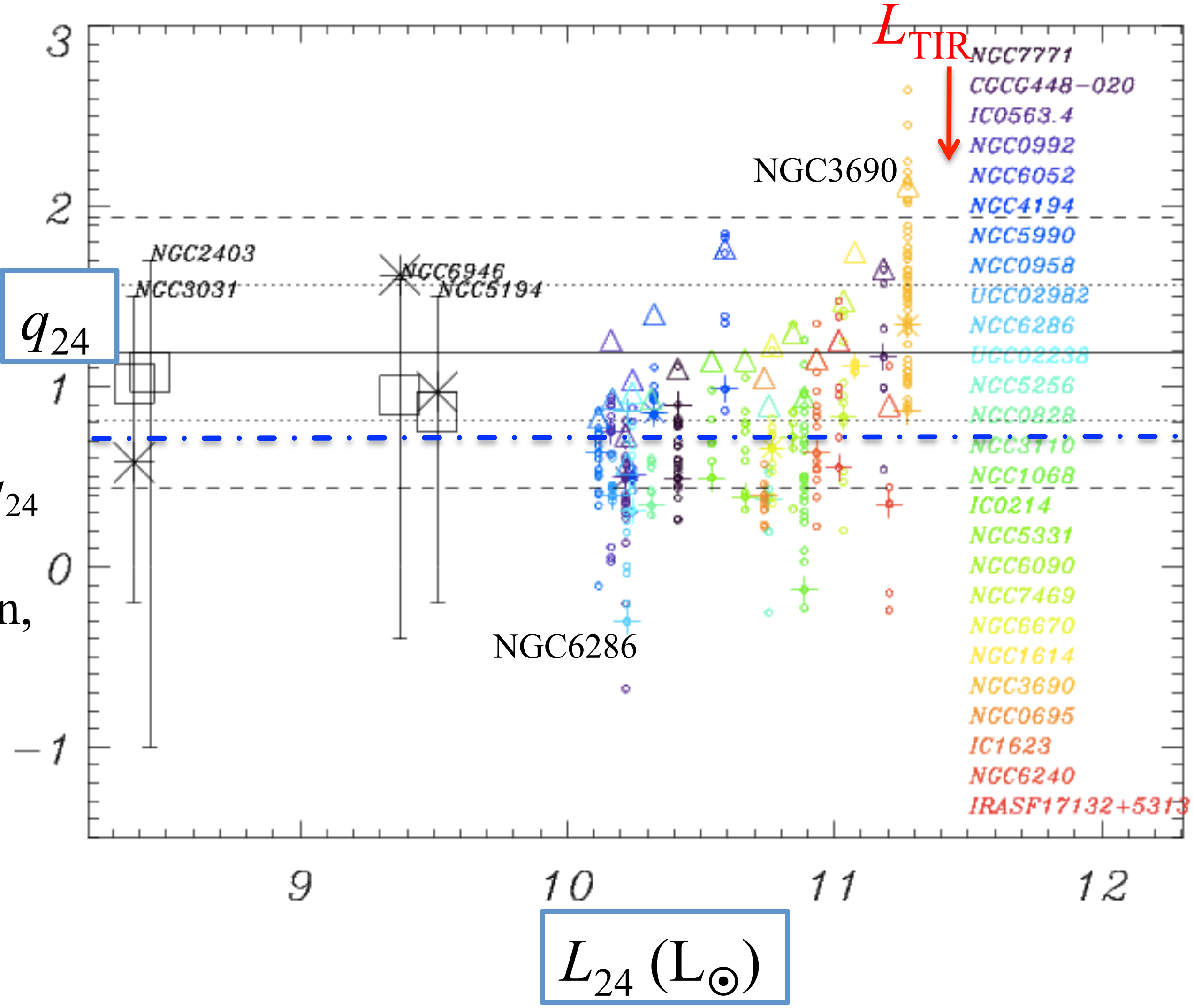
spatially resolved q_{24} (kpc scale)

- 26 LIRGs GOALS
- 4 normal SINGS (Murphy +06)

▪ LIRGs ~ normal gals

▪ BUT in some LIRGs low q_{24} values associated with nucleus/circumnuclear region, while in normal associated with disk/spiral arm



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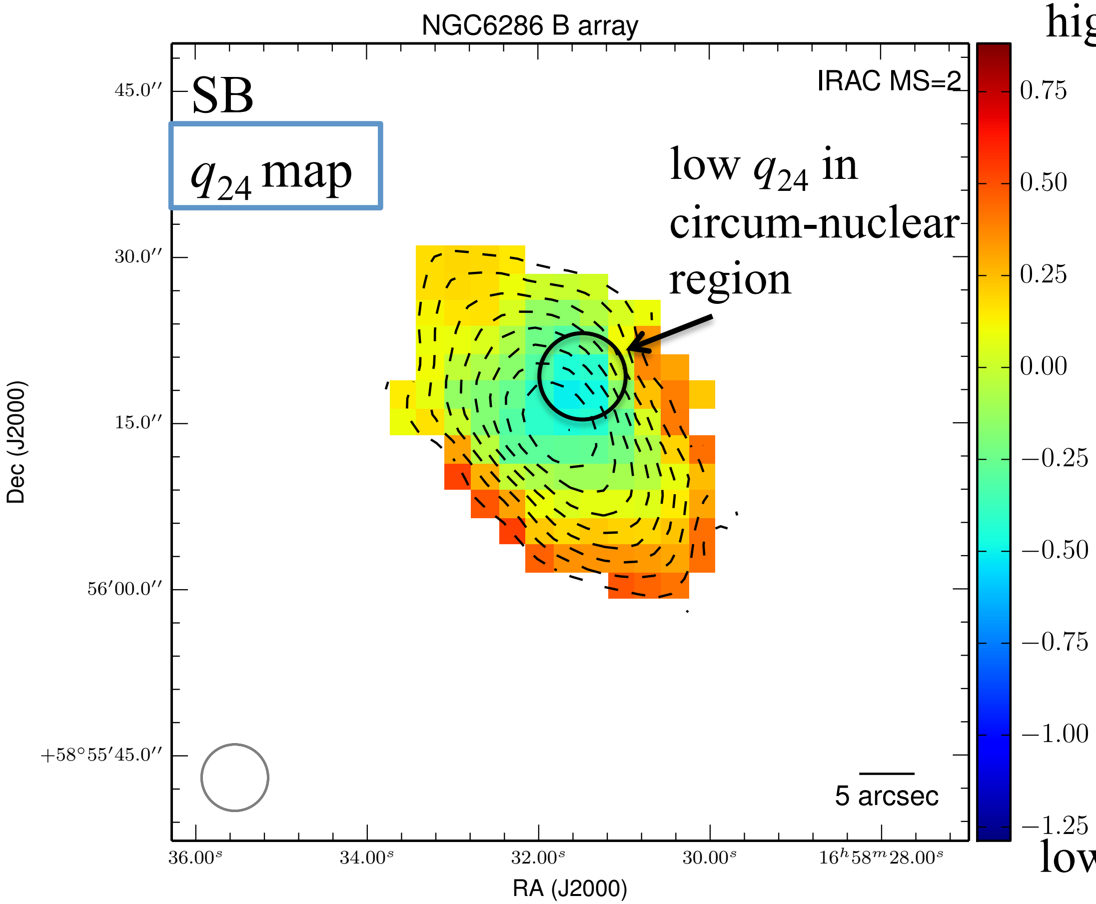
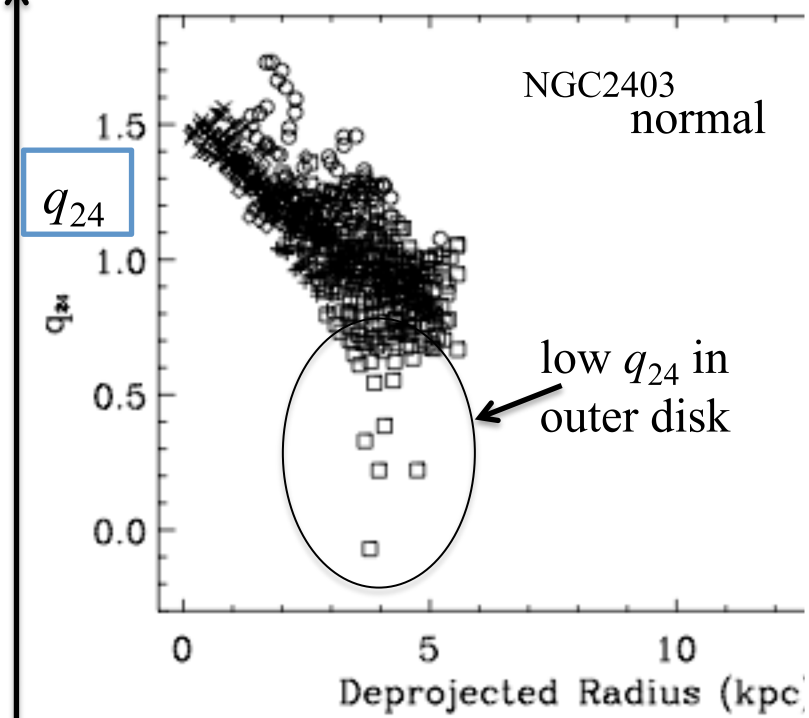
spatially resolved q_{24}

- q_{24} values increase from the nucleus outwards ➔ different scale length of 24 μm and radio
- known superwind in NGC6286 ➔ shocked emission ➔ dust heating without additional radio
- deficit of recent CR electron injection into the ISM in regions with high q_{24} ? (as in Murphy+06)



high q_{24} (high 24 μm, low radio)



Murphy+06

low q_{24} (low 24 μm, high radio)

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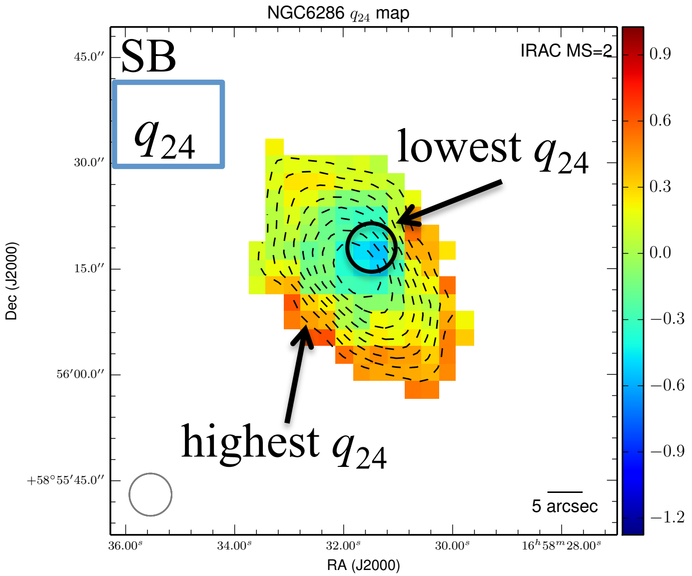
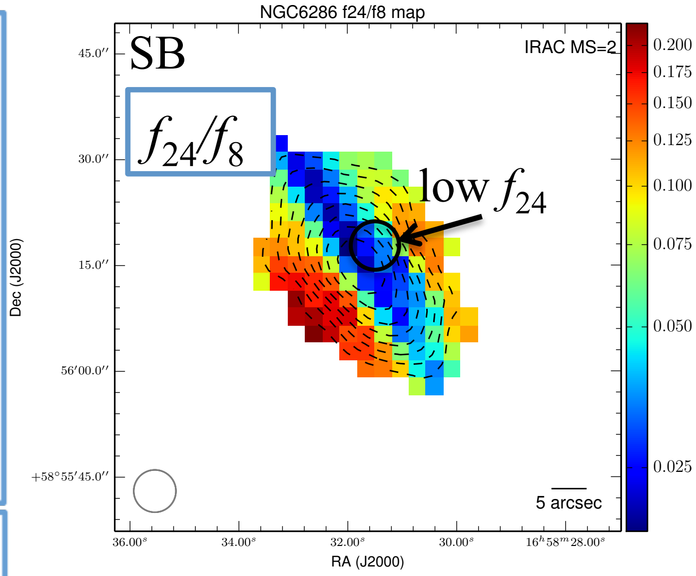
NGC6286

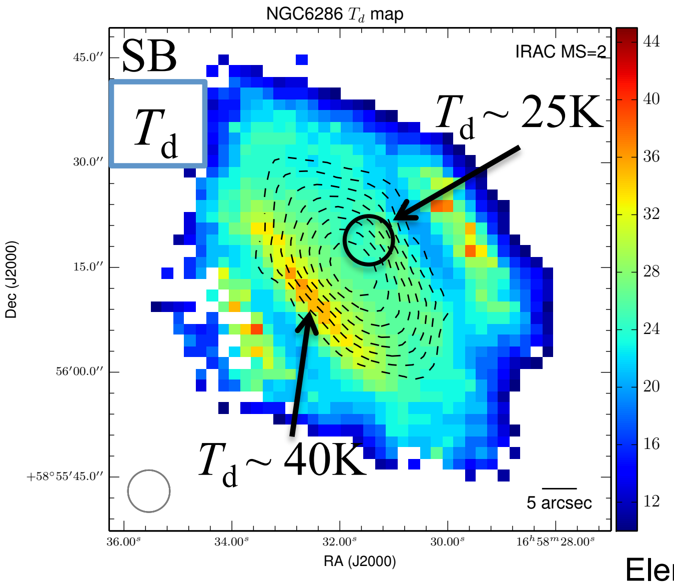
$-0.6 < q_{24} < 0.9$



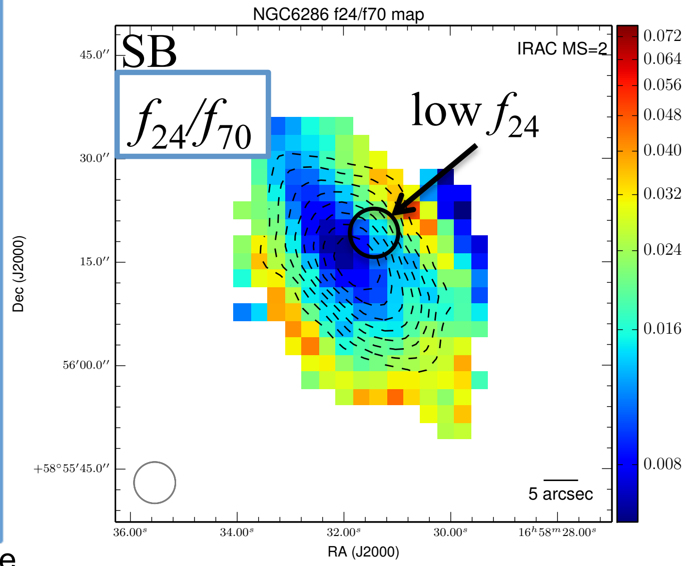
$0.02 < f_{24}/f_8 < 0.2$



$12 < T_d (K) < 44$



$0.008 < f_{24}/f_{70} < 0.072$



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T_d from 70 & 100 μm

- based on 70/100 colour and estimated T_d from χ^2 minimalization and single component fit for 26 LIRGs:
  - warmer objects $<T_d> \sim$ 56K
  - colder objects $<T_d> \sim$ 15K
  - nuclear regions $<T_d> \sim$ 30K
  - mean for 26 LIRGs $<T_d> \sim$ 30K
- a double component fit could improve T_d estimate in some cases, but we are limited by the resolution of our data in the radio

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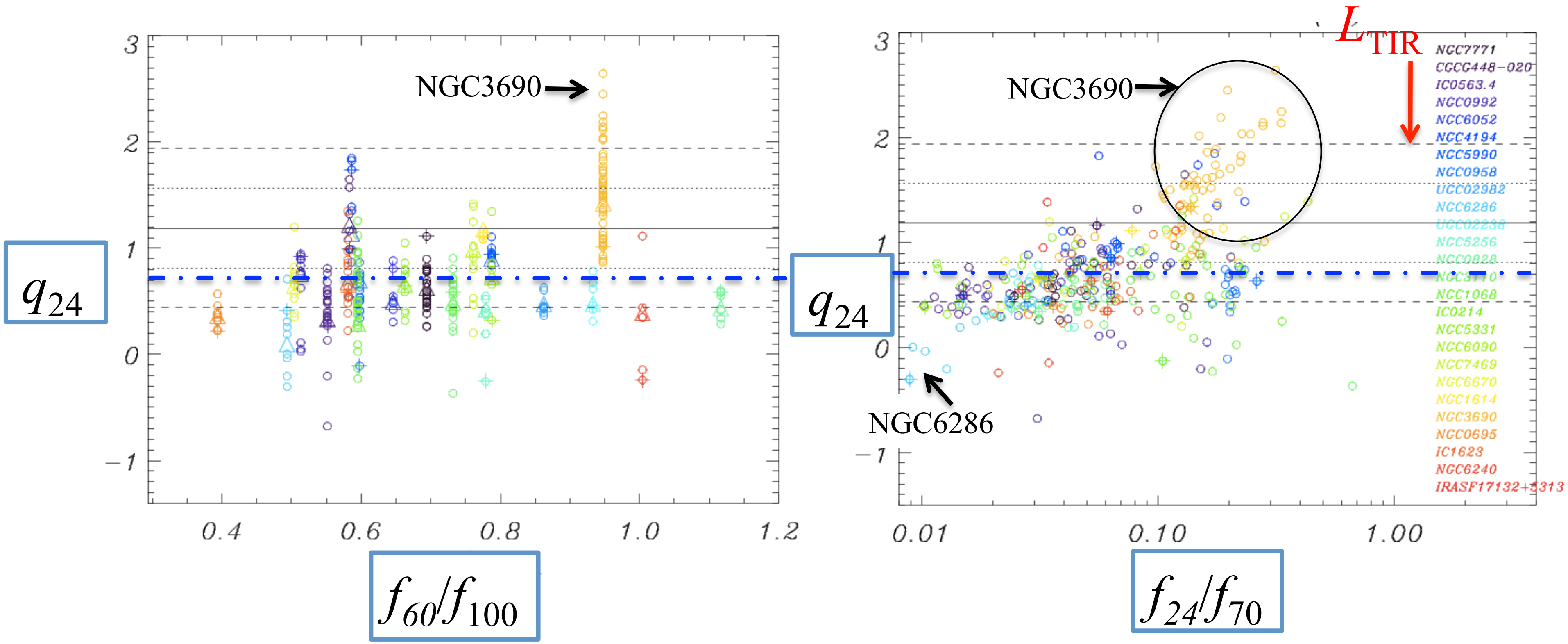
warm & cold dust

- the dispersion in q_{24} from LIRG to LIRG does not depend on 60/100 colour
- within LIRGs q_{24} increases with increasing 24/70 colour as expected
- no dependence to L_{TIR}



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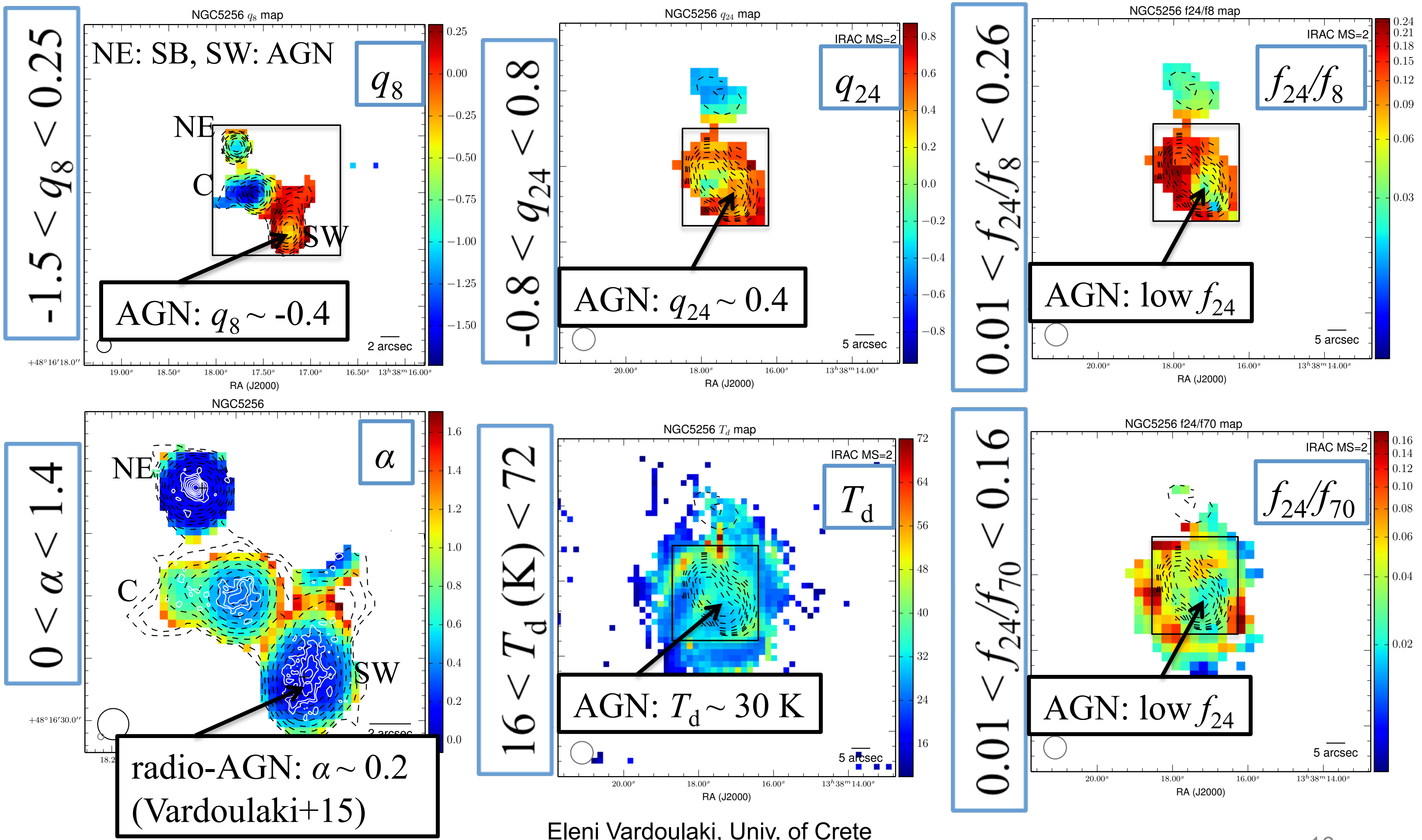
NGC5256



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conclusions

- similar q_{24} values and spread for mid-IR AGN and SB in LIRGs
- on global scale LIRGs similar values and dispersion in q_{24} as normal galaxies
- on a resolved scale within LIRGs, large dispersion as in normals but lower on average q_{24}
- some SBs show increase of q_{24} from the nucleus outwards – warm dust in disk
- T_d from single component fit gives similar values for AGN and circumnuclear SB with mean values of ~30K
- further investigation on spatially resolved properties of ISM needed to understand in dept the variations in the mid-IR/radio ratios

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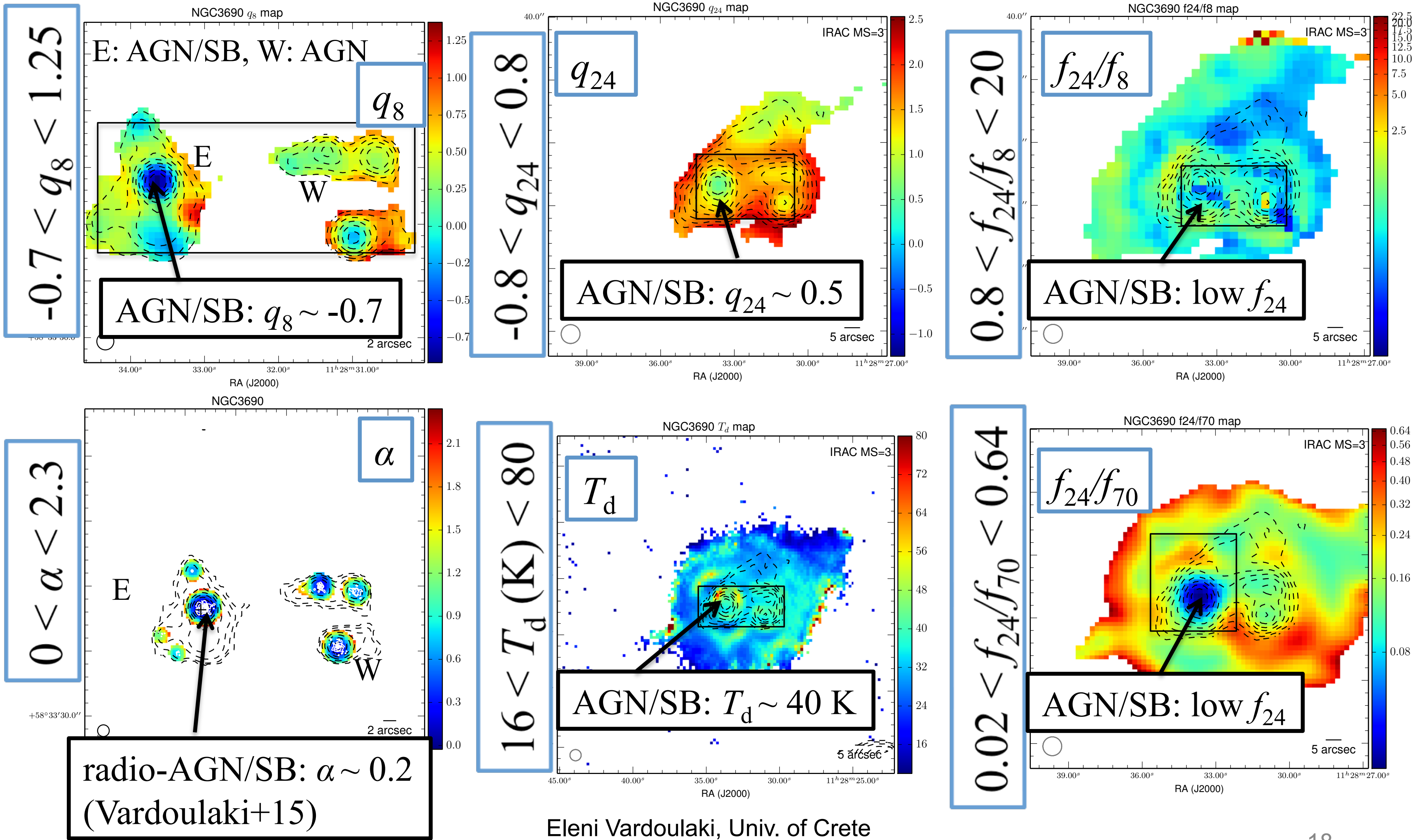
NGC3690



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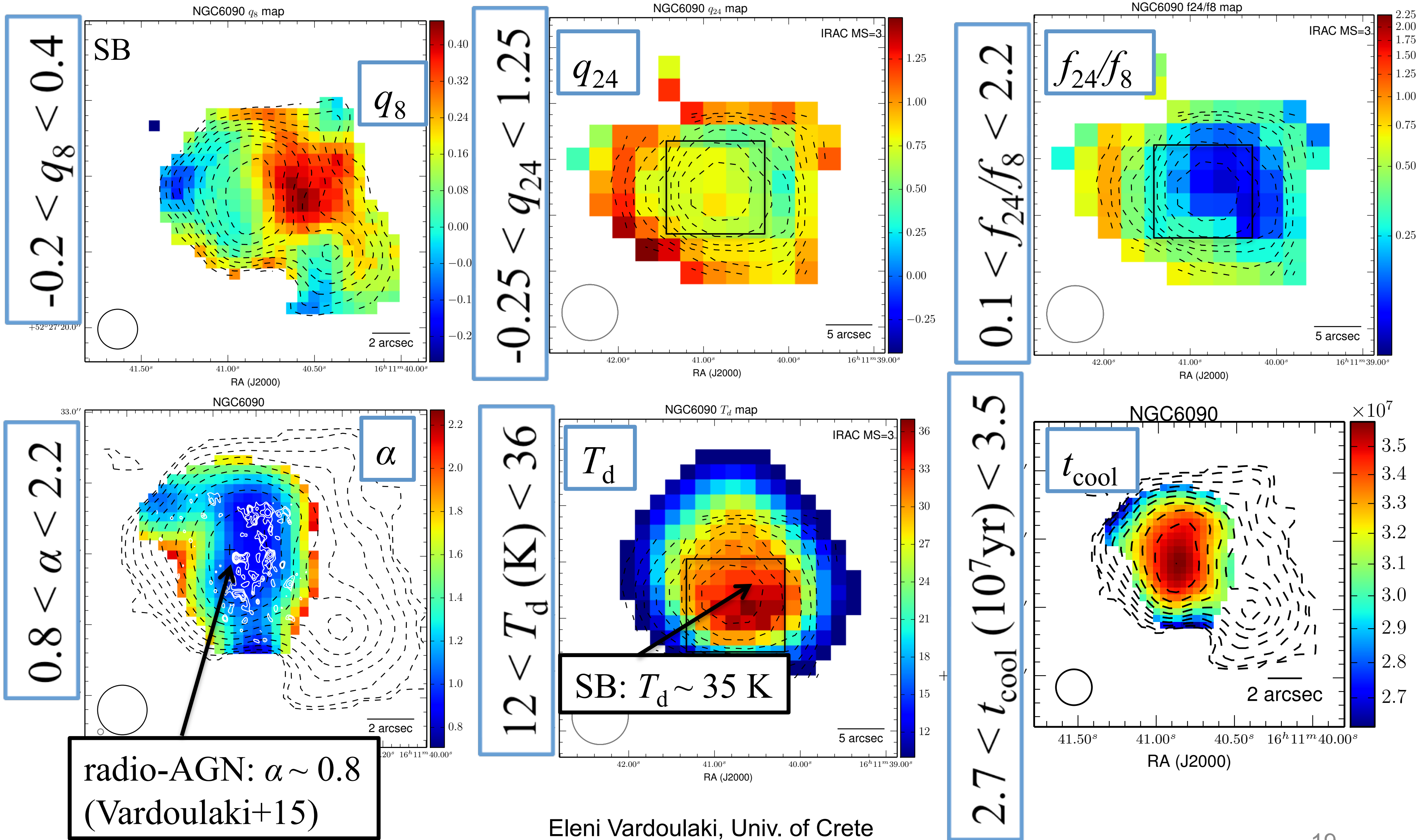
NGC6090



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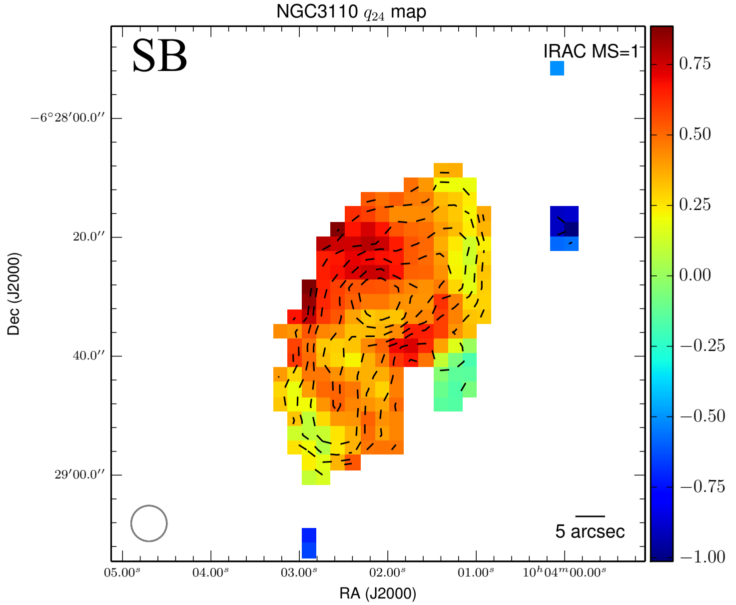
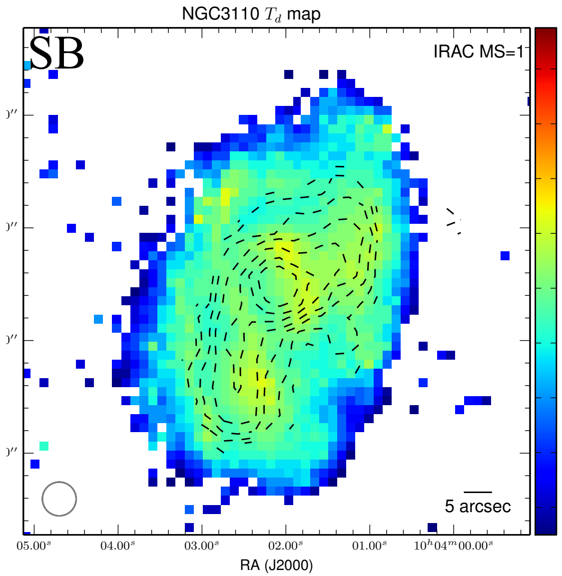
q_{24}-maps v T_d-maps

NGC3110

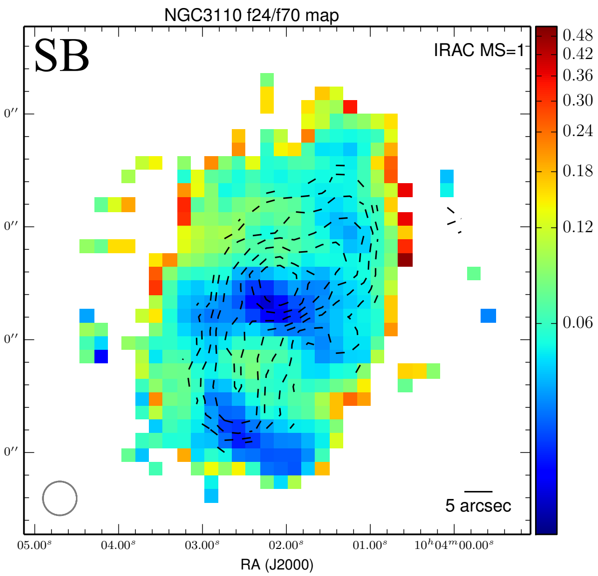
$-1.0 < q_{24} < 0.75$



$12 < T_d\ (K) < 44$



$0.01 < f_{24}/f_{70} < 0.48$



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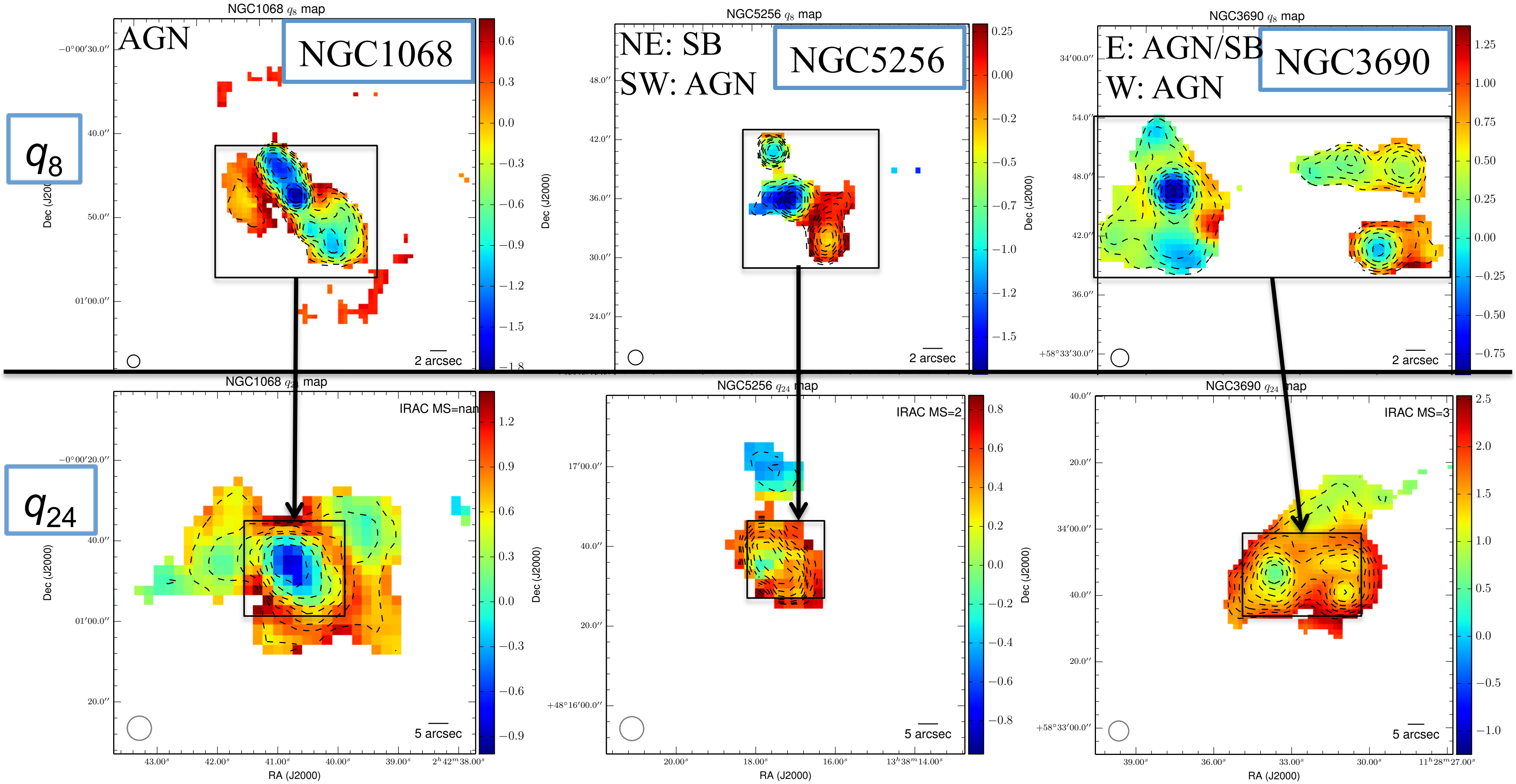
spatial variations in $q_{8,24}$

- $q_{8,24} = \log_{10}(f_{\nu 8,24\mu m}\,(Jy)/\ f_{\nu 20cm}\,(Jy))$



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