“Large scale (pc) mechanical heating in the nearby AGN-SB composite galaxy NGC 4945”

Enrica Bellocchi

Collaborators: Jesús Martín-Pintado &

R. Güsten, M. A. Requena–Torres, A. Harris, P. P. van der Werf,

F. P. Israel, A. Weiss, C. Kramer, S. García-Burillo, J. Stutzki

CENTRO DE ASTROBIOLOGÍA
ASOCIADO AL NASA ASTROBIOLOGY INSTITUTE
CSIC INTA
EXCELENCIA MARÍA DE MAEZTU

13 May 2019, ESAC

Molecular gas emission in galaxies

Diagnostic tool to study :

- ✓ Properties of the ISM: density, temperature, kinematics..
- ✓ Conditions and processes leading to the starbursts
- ✓ Evolutionary state of starbursts
- ✓ Feeding of the nucleus
- ✓ Discriminate the powering source (PDR, XDR, shocks)
- ✓ Obscured regions (molecular emission can penetrate deeply into obscured nuclear power sources: AGN or starburst)

Main goal

@ high J:

- Spectral Line Energy Distribution (SLED) of ^{12}CO

  → to distinguish the powering source (XDR, PDR, shocks)
  [Meijerinsk+13, Galleriani+14, Rosenberg+15 …]

- Nuclear excitation distribution using SPIRE and PACS (^{12}CO)

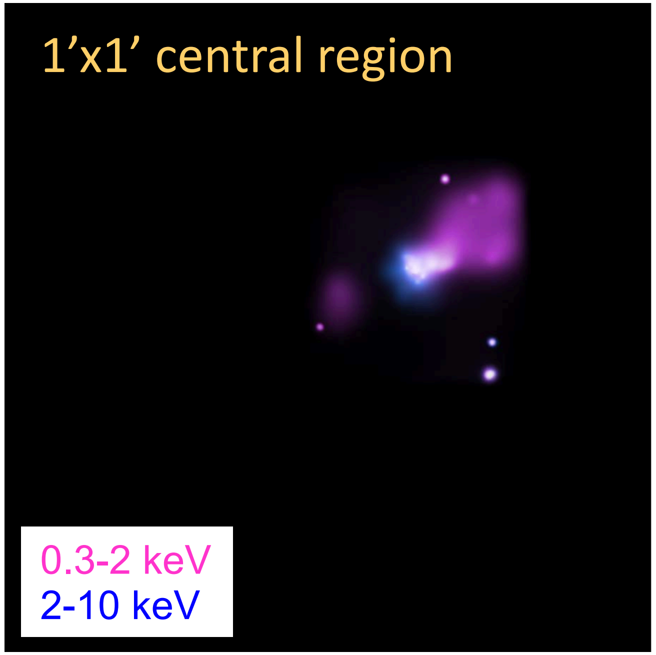
  → How the heating mechanism is distributed

NGC 4945

- Edge-on spiral Sy2 galaxy
- Distance = 3.8 Mpc
- Size ~ Milky Way
- Outflow (X-ray and Opt)

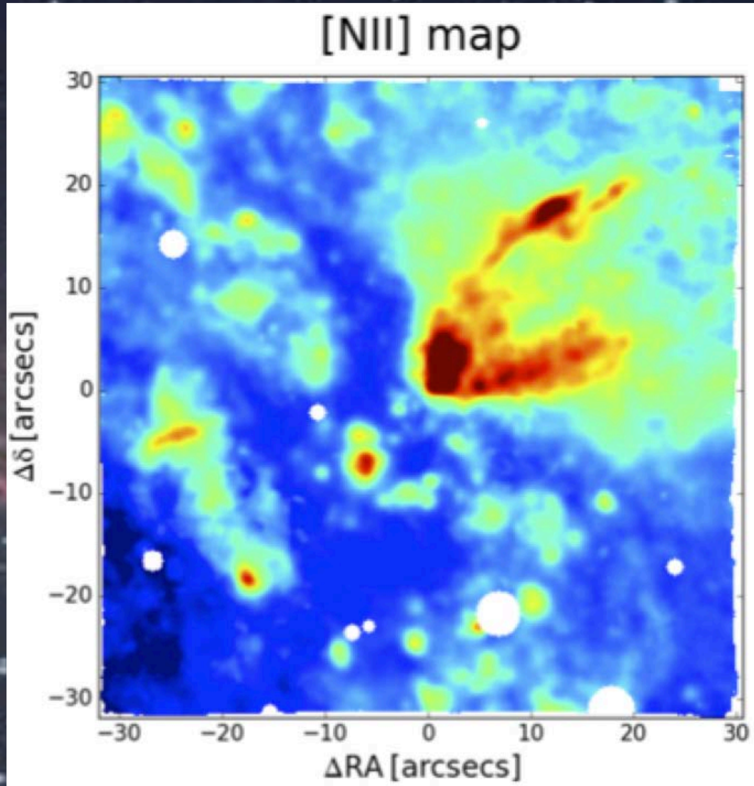
- Prototypical AGN+SB composite
- Hidden AGN in X-rays (Iwasawa+93; Guinazzi+00)
- One of the Brightest extra-galactic source at 100 keV
- HST-NICMOS of Paα line → starburst disk (radius ~5", Marconi+00) embedded in a molecular disk (radius~ 8"; Chou+07)

Optical: ESO/VLT & NASA/STScI



X-ray

(Marinucci+12)



Optical: MUSE

(Venturi+17)

The observations

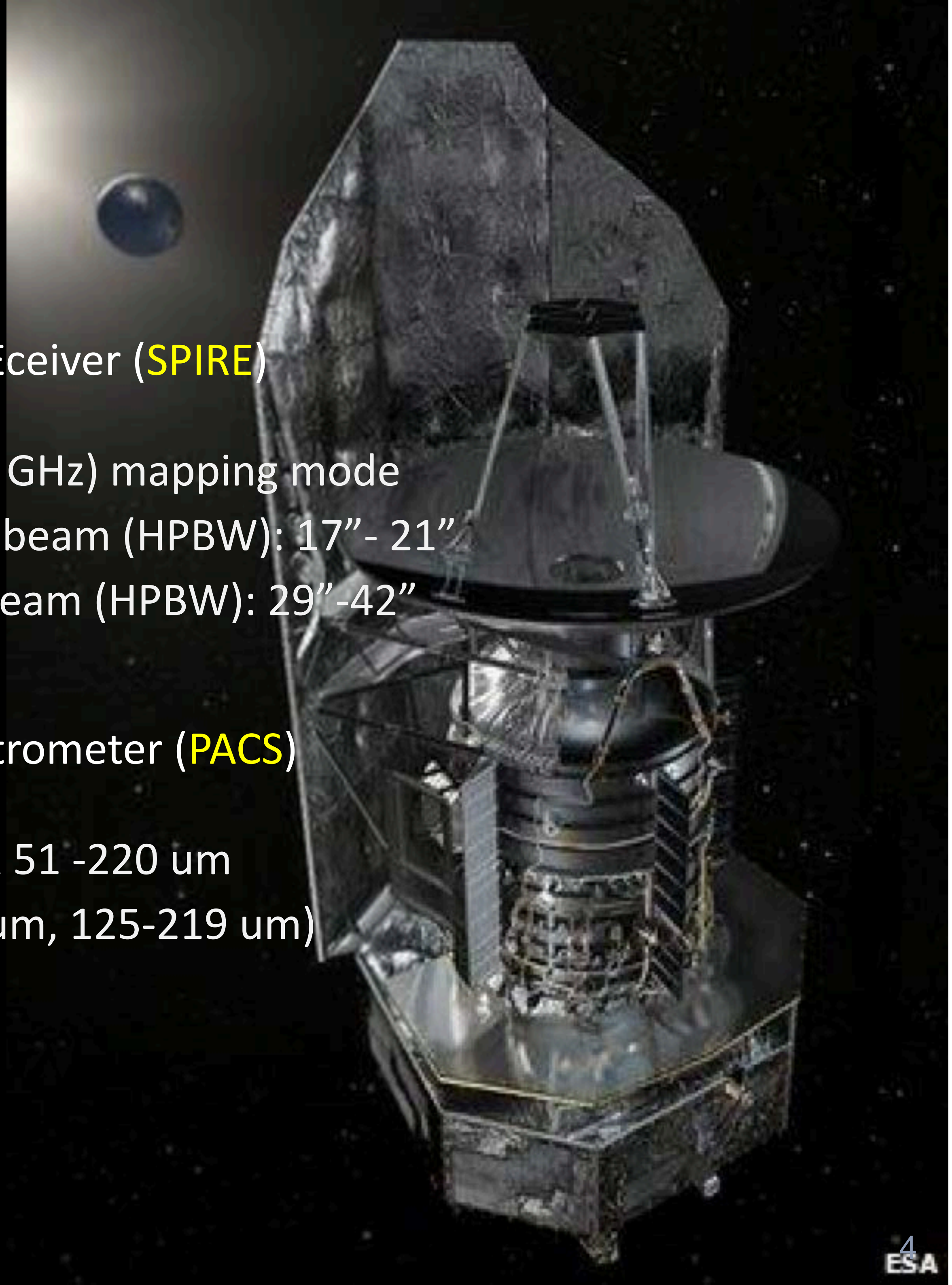
Herschel

Spectral and Photometric Imaging REceiver (SPIRE)

- ✓ SPIRE Spectrometer (450 - 1550 GHz) mapping mode
- ✓ SSW: Far-IR 950 to 1550 GHz → beam (HPBW): 17”- 21”
- ✓ SLW: Far-IR 450 to 950 GHz → beam (HPBW): 29”-42”

Photodetector Array Camera & Spectrometer (PACS)

- ✓ Frequency spectral range: Far-IR 51 -220 um
  (photometry 60-85 um, 85-125 um, 125-219 um)
- ✓ FoV = 47”x 47”
- ✓ beam (HPBW): 5”- 13”



Mechanisms that heats the Molecular gas (CO)

1) Radiation:
- photoelectrical effect by UV photons (PDR)
  (They also heat the dust grains)
- X-ray photons

2) Energetic particles (Cosmic Rays) → (emission from Super Novae)

3) Mechanical processes (i.e., shocks, stellar winds, outflows…)

→ X-ray photons /Shocks efficiently heat the gas but not the dust.

→ PDRs mostly heat the dust.

CO Spectral Line Energy Distribution (SLED) provides constraints on the dominant heating mechanisms

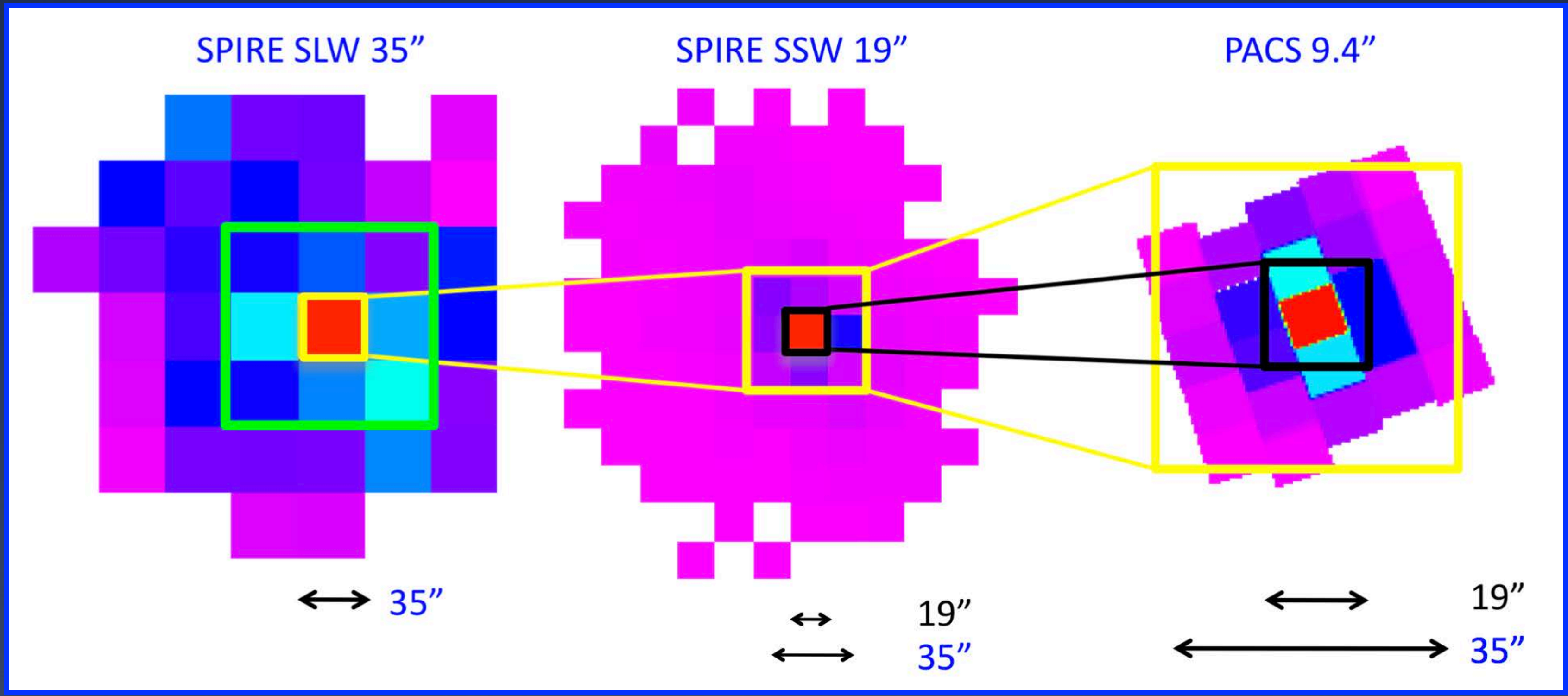
- CO SLED increases up to CO(5-4) transition & then decreases for typical regions around newly formed stars (PDRs)

  @ high-J CO → Low CO SLED/IR ratios

- Higher CO SLED contribution at high J (>10) heated by X-ray photons (XDRs) or by shocks)

  @ high-J CO → High CO SLED/IR ratios

2D analysis of ^{12}CO using SPIRE and PACS

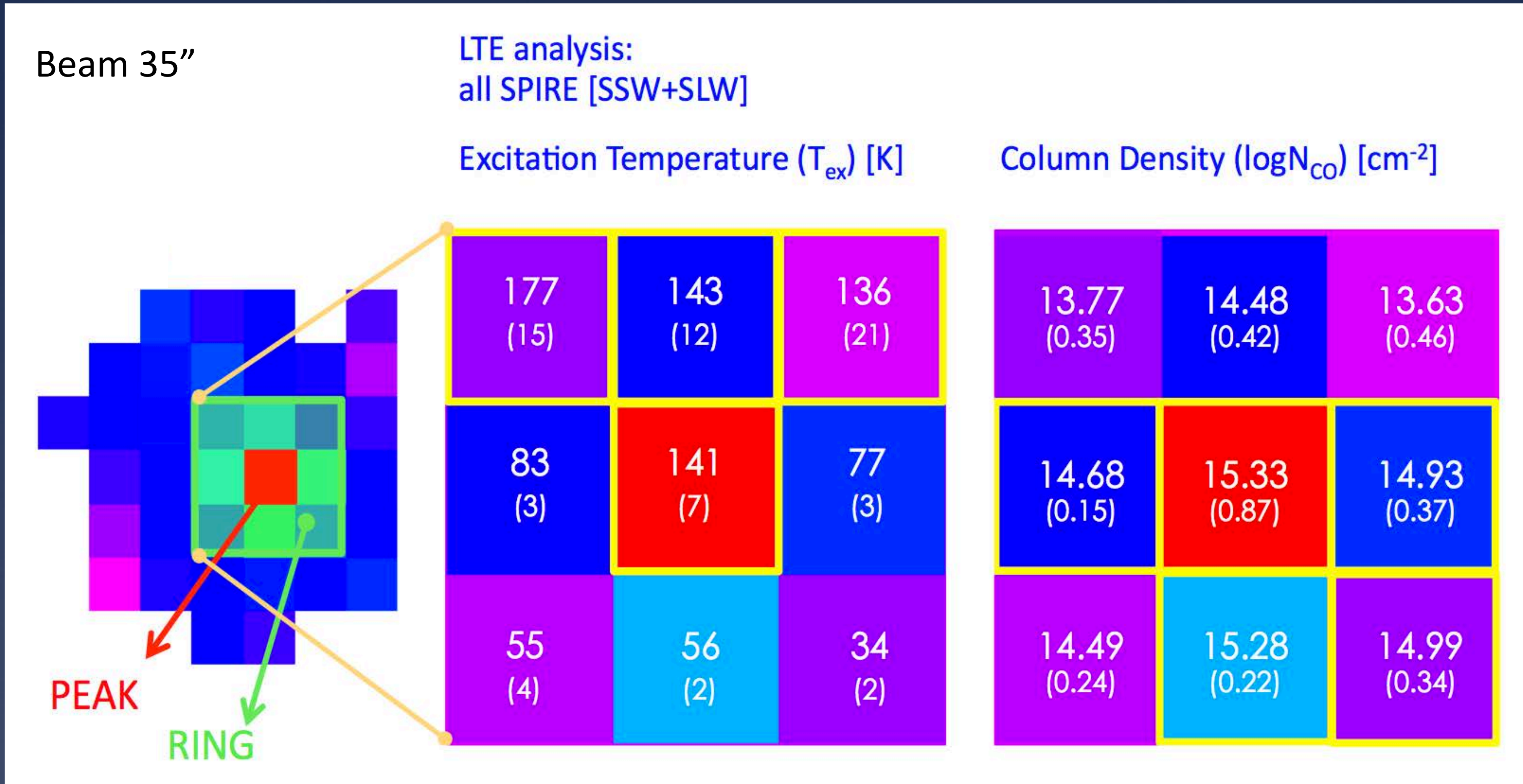


Large scales	Intermediate scales	Small scales
(700 pc – 2 kpc)	(350 pc – 1 kpc)	(200 pc – 2 kpc)

→ We study the CO emission at different scales through the CO Spectral Line Energy Distribution (SLED)/IR ratios

1) CO at Large spatial scale : 700 pc - 2 kpc (35” - 3x35”)

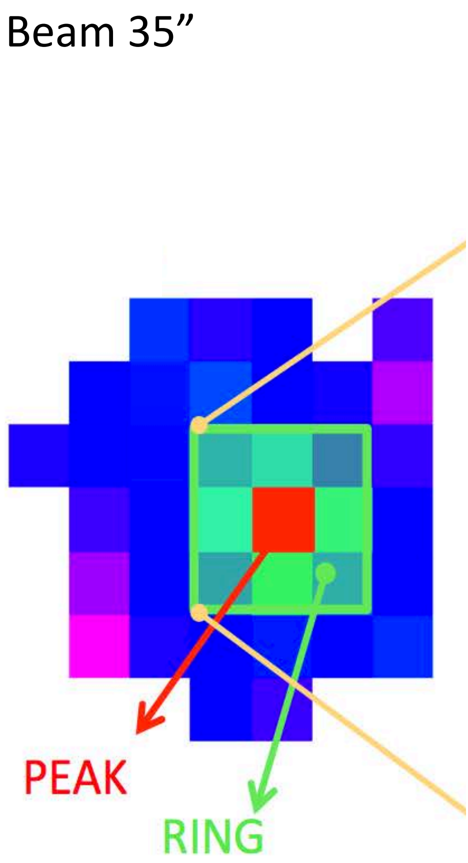
Combination of SLW and SSW SPIRE data using LTE analysis (@ 35”)

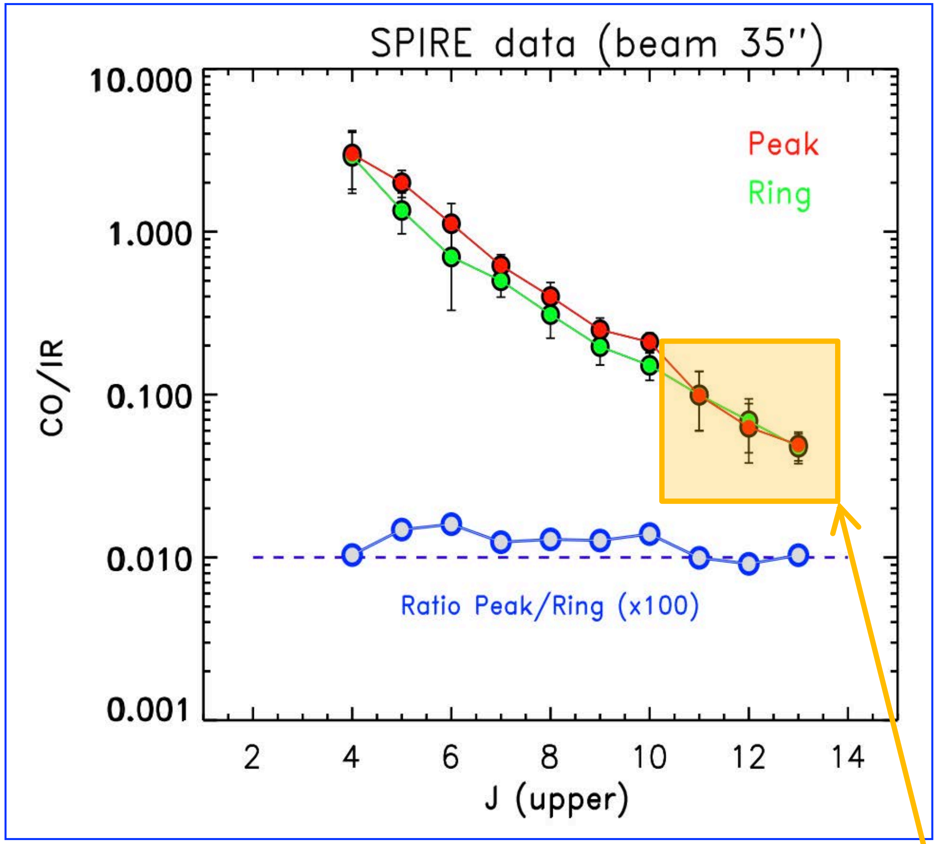


- Higher T_{ex} in the north direction (outflow)

1) CO at Large spatial scale : 700 pc - 2 kpc (35” - 3x35”)

Combination of SLW and SSW SPIRE data using LTE analysis (@ 35”)





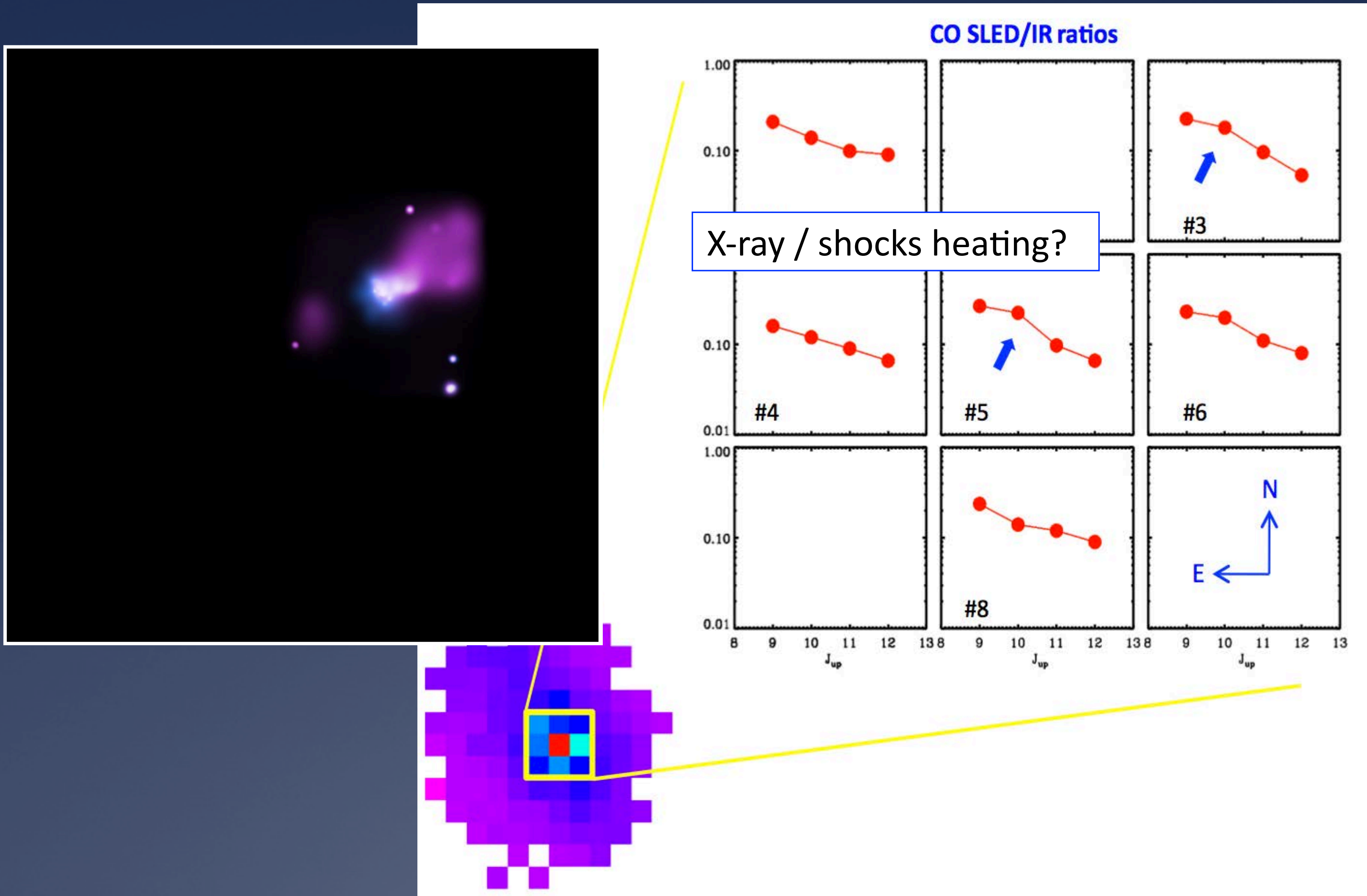
- Higher T_{ex} in the north direction (outflow)
- Higher CO/IR ratios in the RING wrt PEAK at higher J transitions

✓ Which is the heating mechanism ?

We focus on high J CO transitions to distinguish the powering source …

2) Intermediate scales: 350 pc - 1 kpc (19” - 3x 19”)

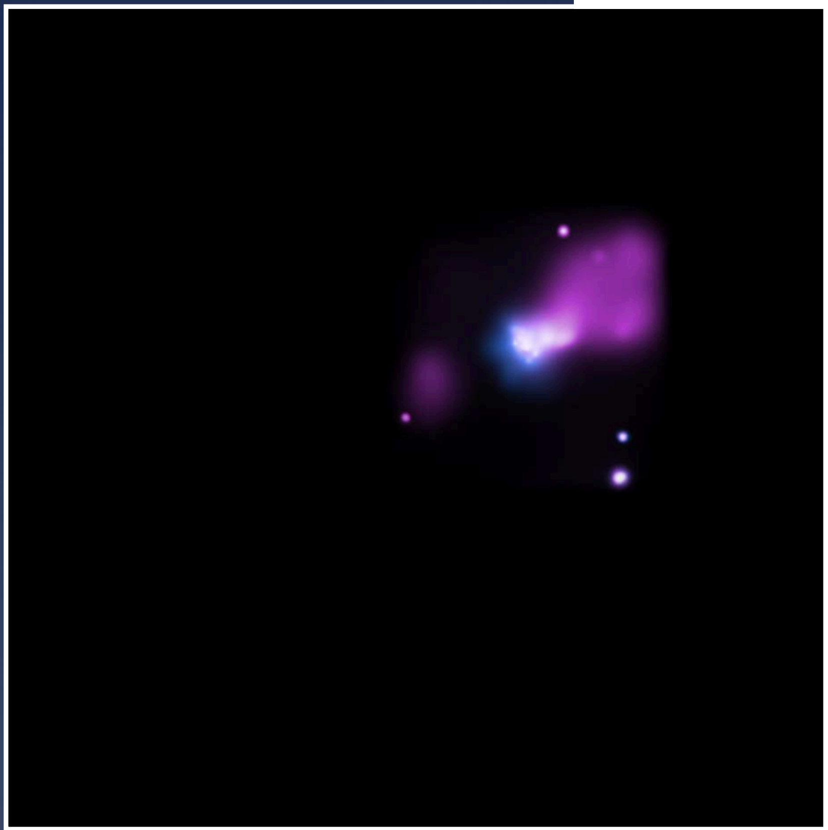
SSW SPIRE (beam 19”)

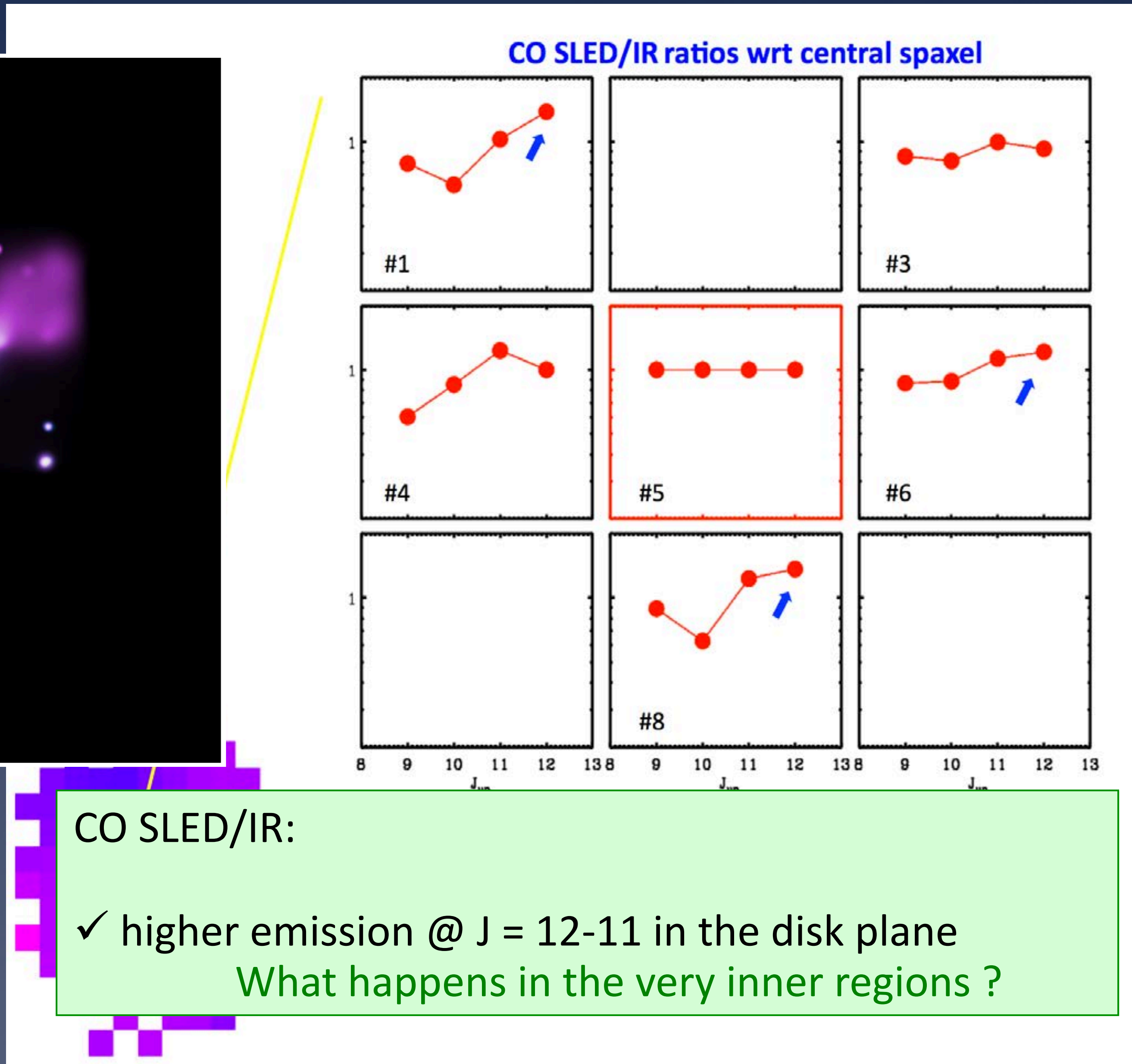


@J=9-8 and @J=10-9 probably dominated by X-ray

2) Intermediate scales: 350 pc - 1 kpc (19” - 3x 19”)

SSW SPIRE (beam 19”)





CO SLED/IR:

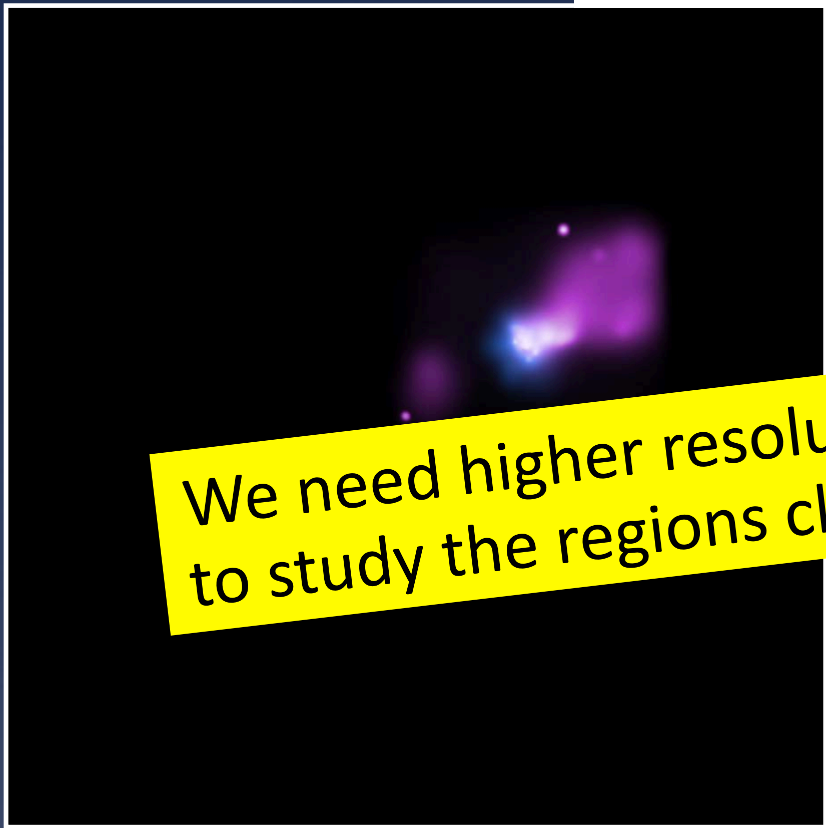
✓ higher emission @ J = 12-11 in the disk plane

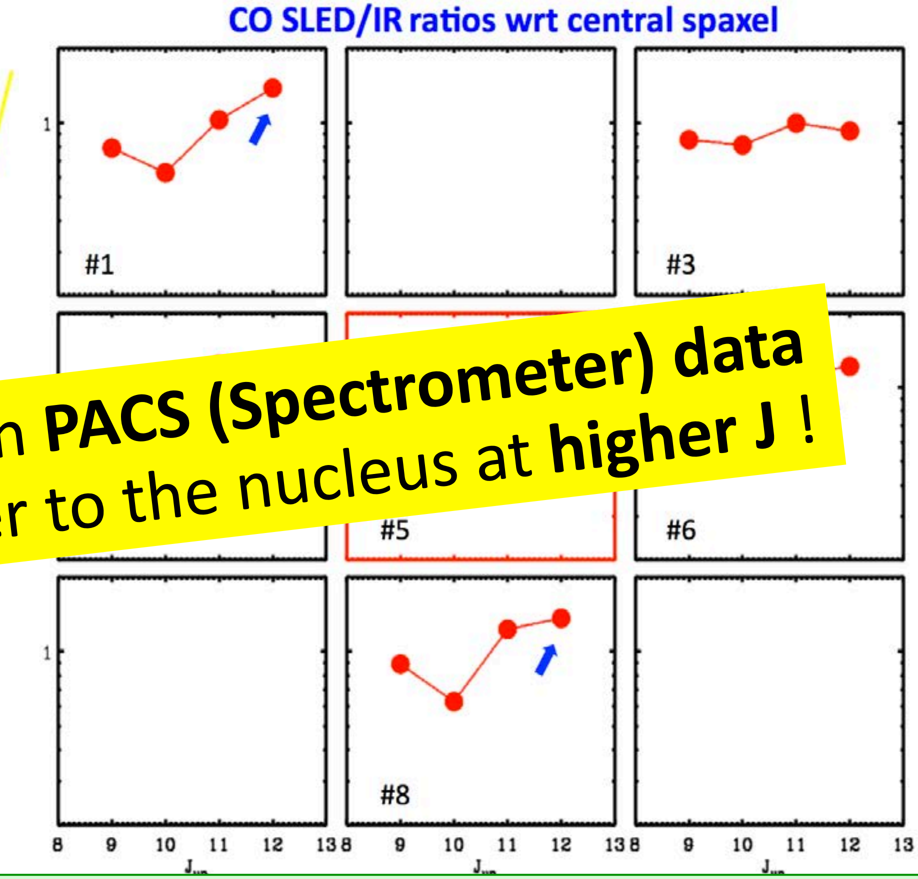
What happens in the very inner regions ?

@J=12-11 emission dominated by shocks?

2) Intermediate scales: 350 pc - 1 kpc (19” - 3x 19”)

SSW SPIRE (beam 19”)





We need higher resolution **PACS (Spectrometer) data** to study the regions closer to the nucleus at **higher J** !

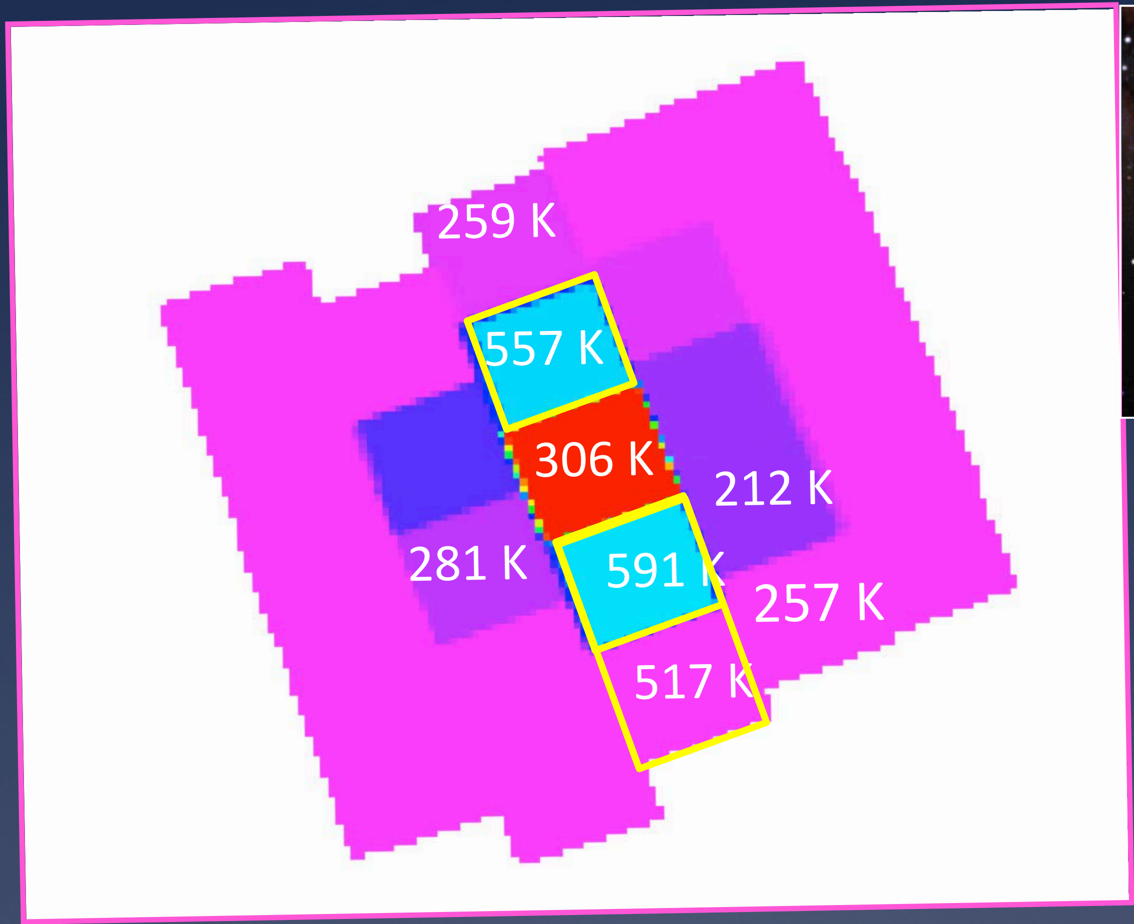
CO SLED/IR:

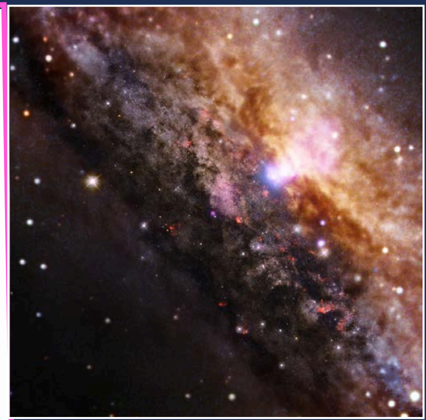
✓ higher emission @ J = 12-11 in the disk plane

What happens in the very inner regions ?

@J=12-11 emission dominated by shocks?

3) Small scales: 200 pc – 350 pc (9.4" - 18")



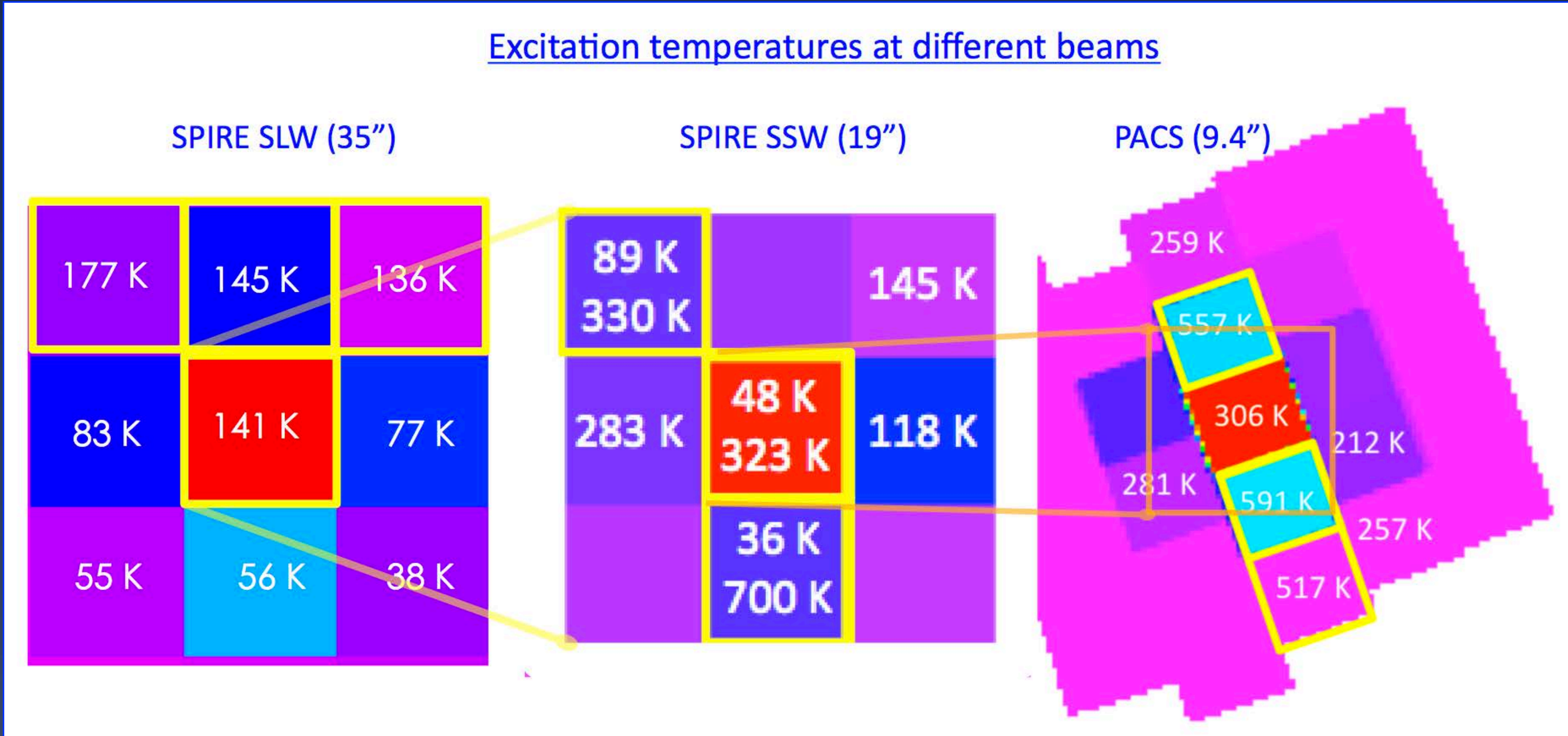


✓ Higher temperatures around the nucleus, mainly found in the disk plane

✓ if XDRs are present we would expect the maximum contribution in the nuclear region but it is not..

→ Shocks might be the most probable heating mechanism at work

Summary – Distribution of T_{ex}

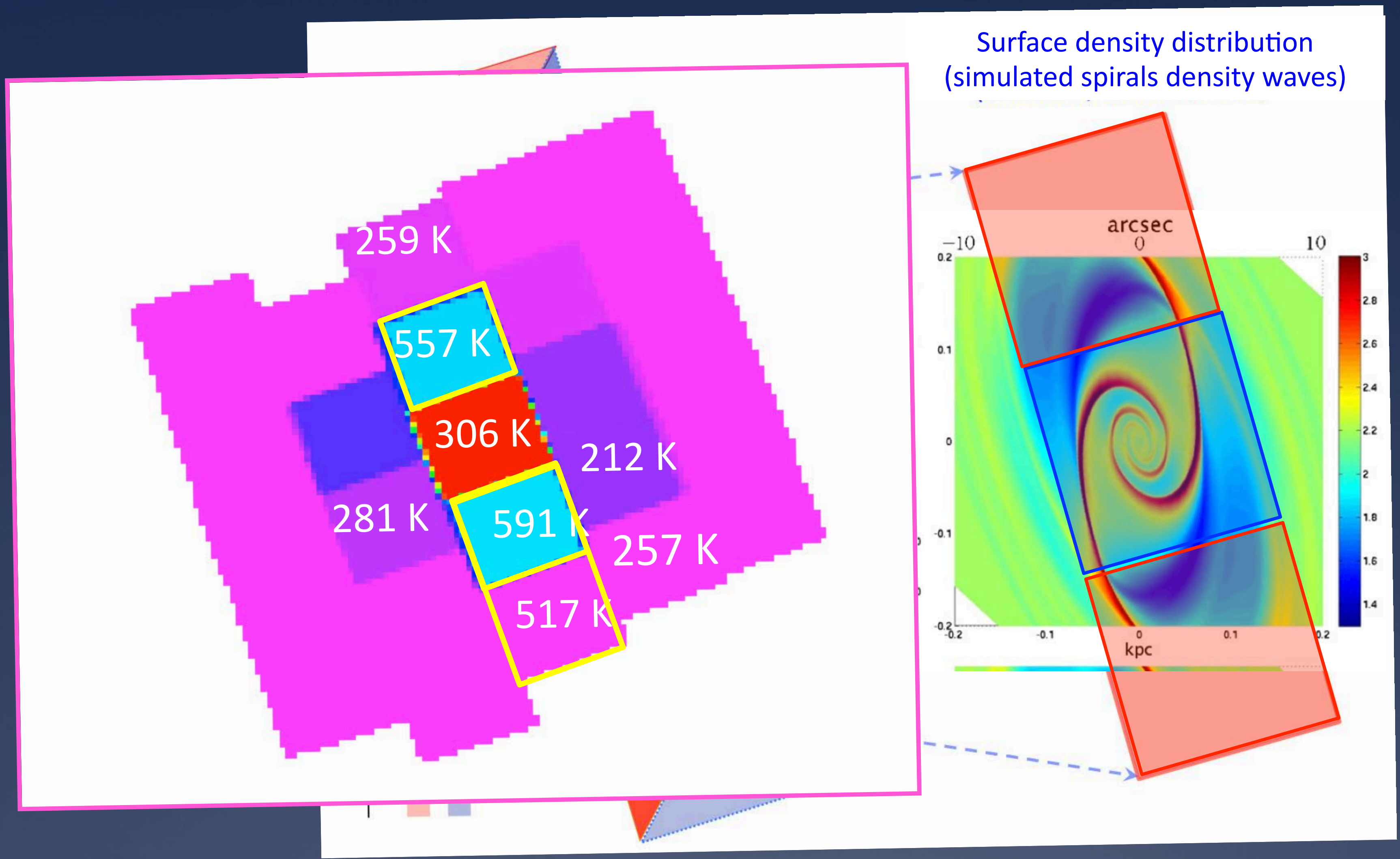


@ SPIRE SLW: Higher T_{ex} in the northern part of the galaxy (outflow?)

@ SPIRE SSW: 2 component temperatures along the disk plane and in the south

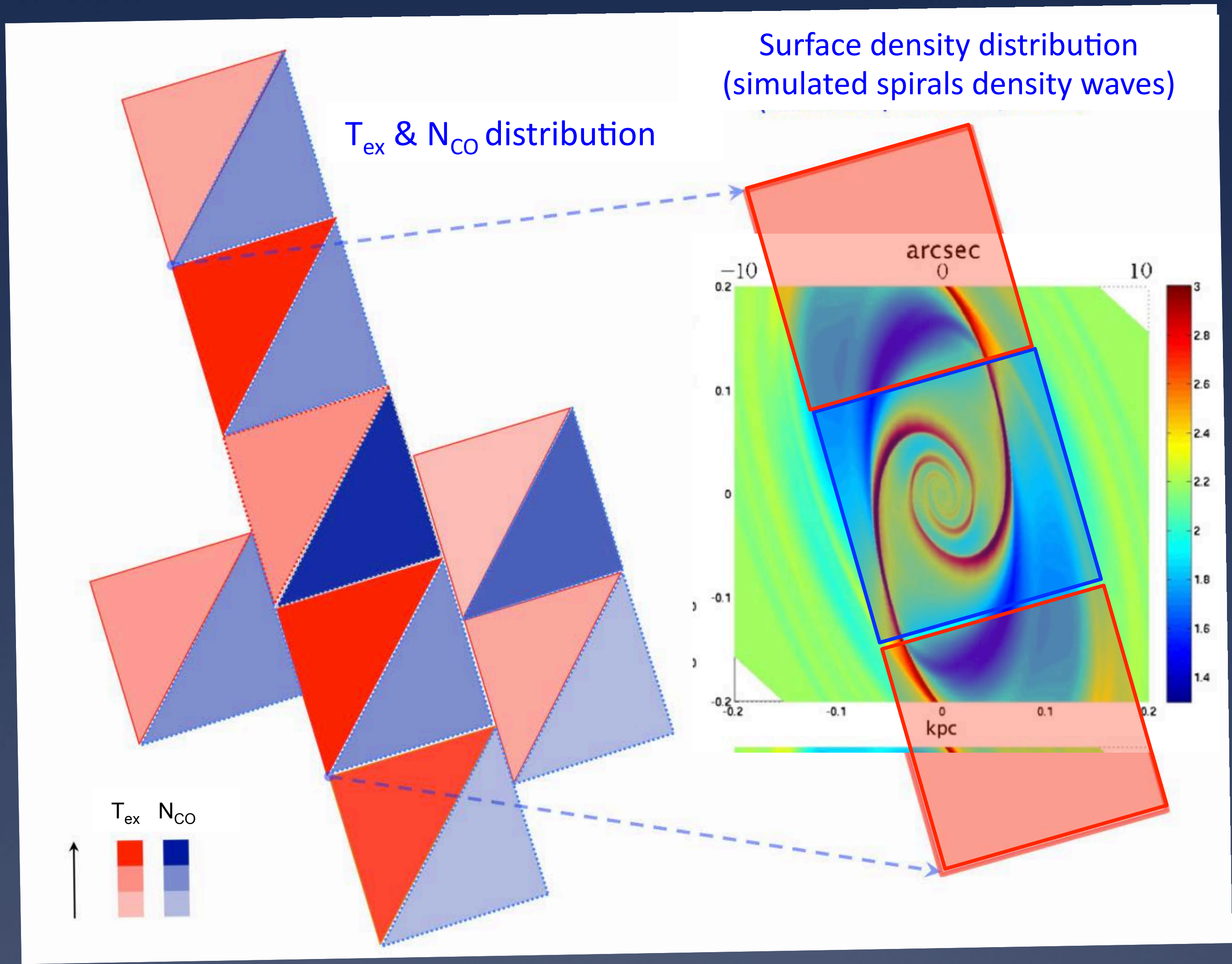
@ PACS: High T_{ex} around the center → X-ray mechanisms ruled out in the nucleus

Comparison with Lin et al 2011



→ In agreement with the presence of tightly wound spirals to explain the distribution of the surface density in a 20”x20” region (Lin+2011)

Comparison with Lin et al 2011



→ In agreement with the presence of tightly wound spirals to explain the distribution of the surface density in a 20”x20” region (Lin+2011)

- Peak in the column density in the central spaxel &
- Surrounded by lower column density but larger excitation temperatures

Shocks are likely produced by the barred potential and the outflow observed in X-rays

Conclusions

@ SPIRE SLW: Higher T_{ex} in the northern part of the galaxy (outflow?)

@ SPIRE SSW: 2 component temperatures along the disk plane and in the south

@ PACS: High T_{ex} around the center → X-ray mechanisms ruled out in the

→ Shocks dominate the heating of the ISM in the nucleus of NGC 4945

→ agreement with Lin+2011: tightly wound spirals able to explain the temperature and density distributions

Ongoing work

✓ To model the CO SLED (e.g., Kazandjian+15, Meijerink+13) to check our prediction (Heating dominated by shocks)

✓ and to quantify the contribution of the different mechanisms

Stay Tuned...

... and Thank you !