Galactic center science with SOFIA

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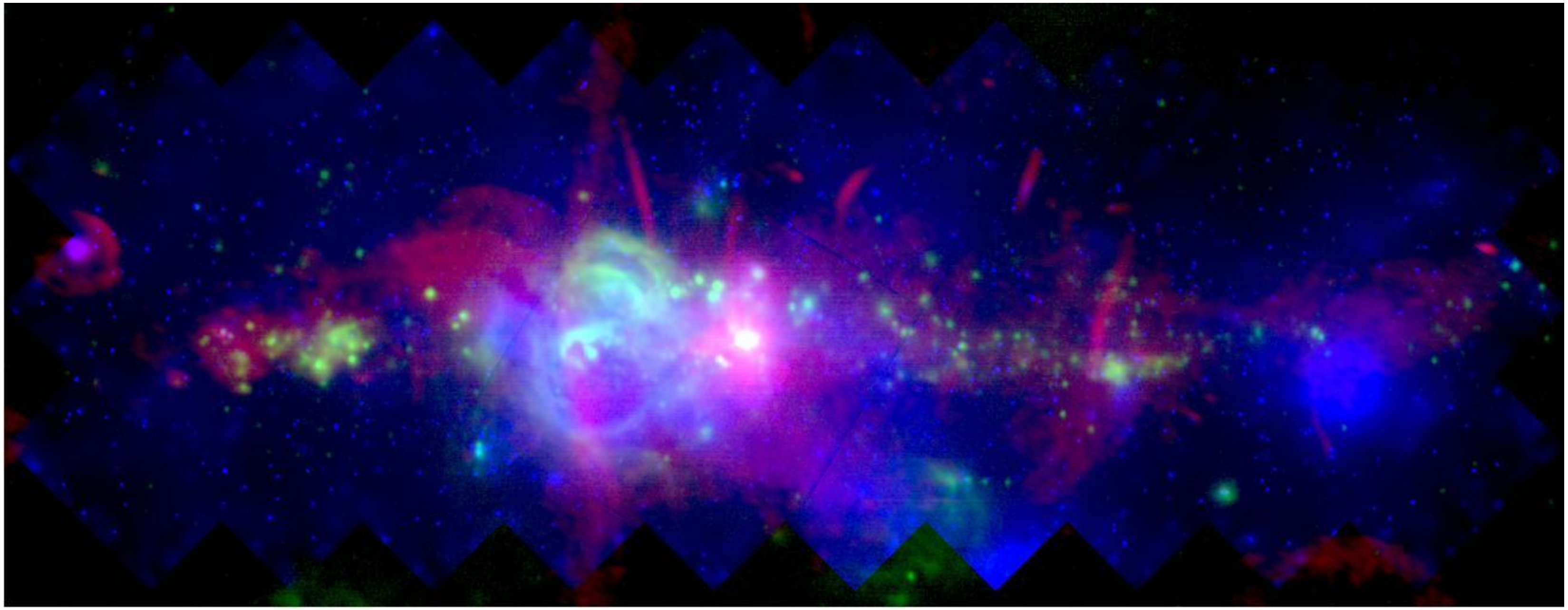


Outline

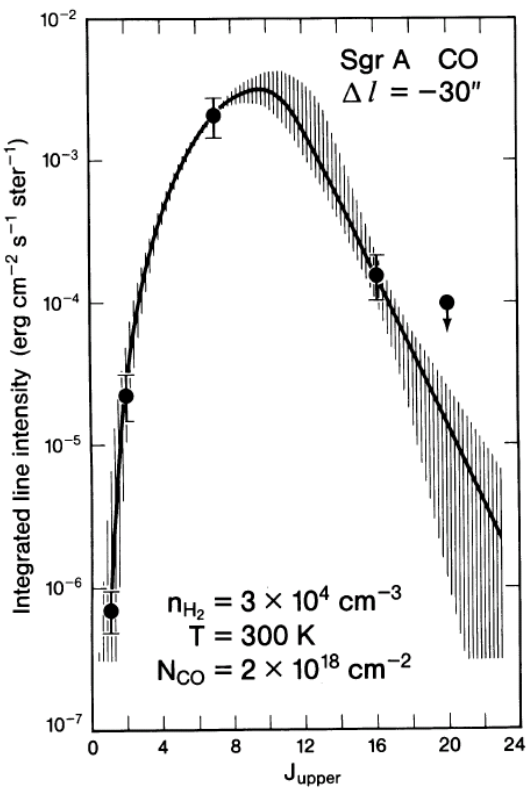
- Introduction
- The CO line SEDs in external galaxies
  - Model degeneracy (shocks, PDR, CRs and XDRs)
- The CO line SEDs in the GC (templates)
  - Herschel and SOFIA results
- Comparison between the GC and galaxies
- GC templates for XDRs
- Conclusions

Introduction

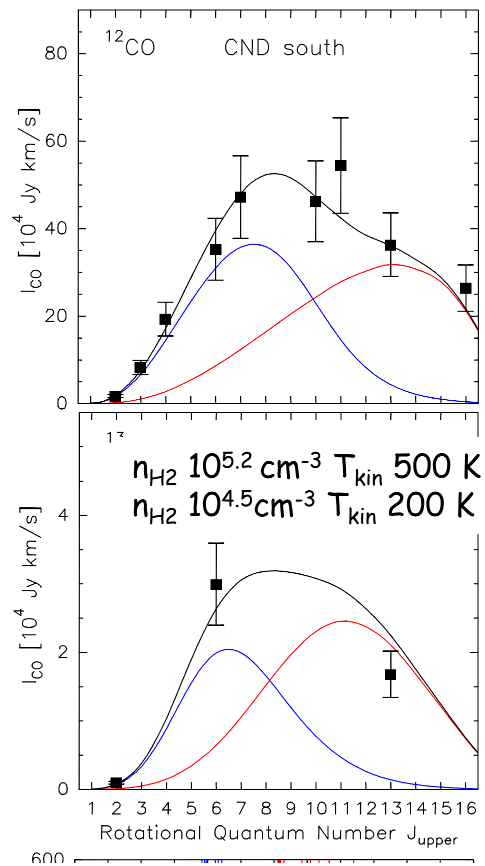
- SOFIA provides access to the main cooling lines
- Insight on the dominant heating mechanisms in the nuclei of galaxies
  - UV (PDR), shocks (feedback, accretion, turbulence), CRs and XDR (AGN torus), ..
- CO is one of the main coolants of the dense ISM, can be detected even at high z and have many transitions with very different excitation conditions

Evolution of CO line SED

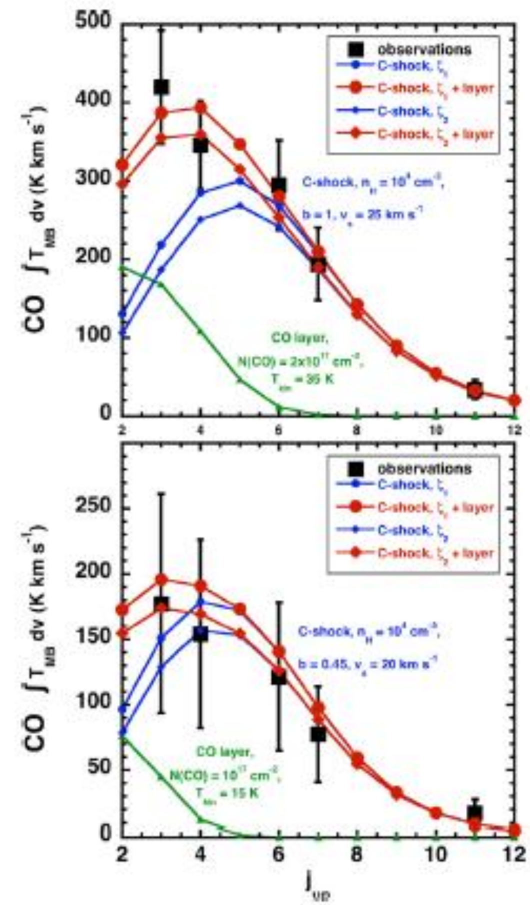
W28A



Harris et al. 1985
LVG



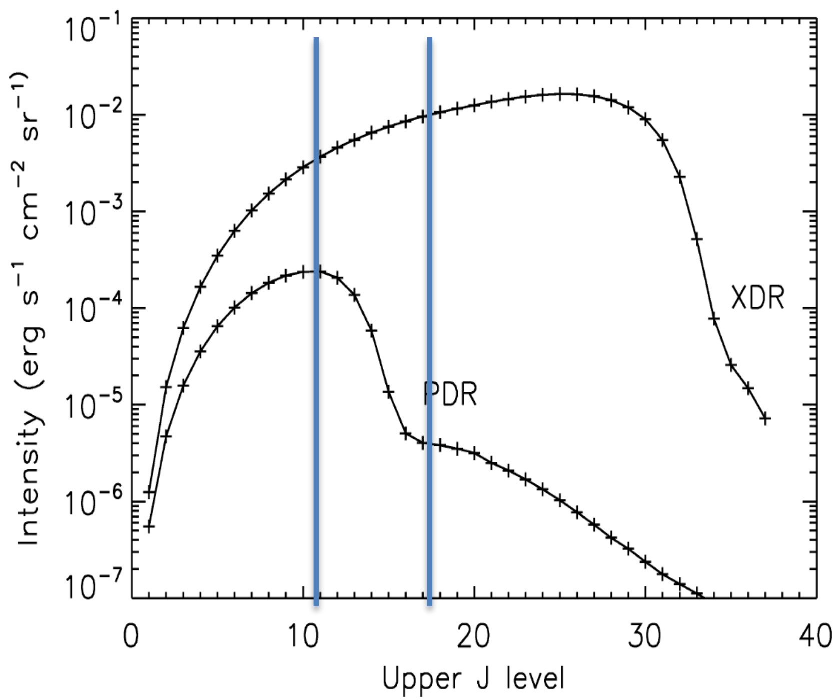
Requena-Torres (2012
LVG



Gusdorf et al. (2012
Shock model

CO line SEDs for PDR-XDR

Spaans & Meijerink, (2008)



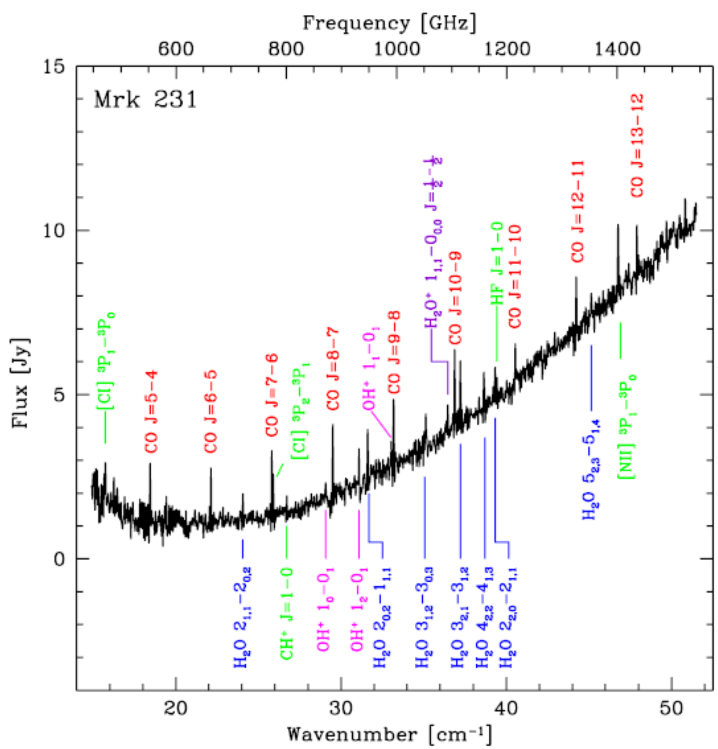
HerCULES

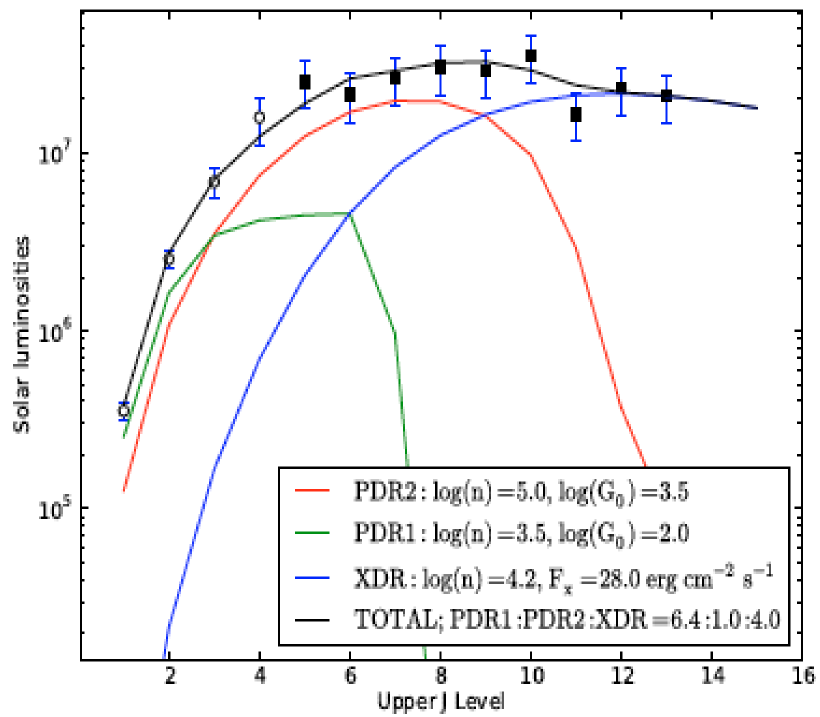
Mrk 231

- Optically visible AGN/XDR
  LX=6x1043 erg/s (2-10 keV)
  Star formation diks (PDR)

SPIRE

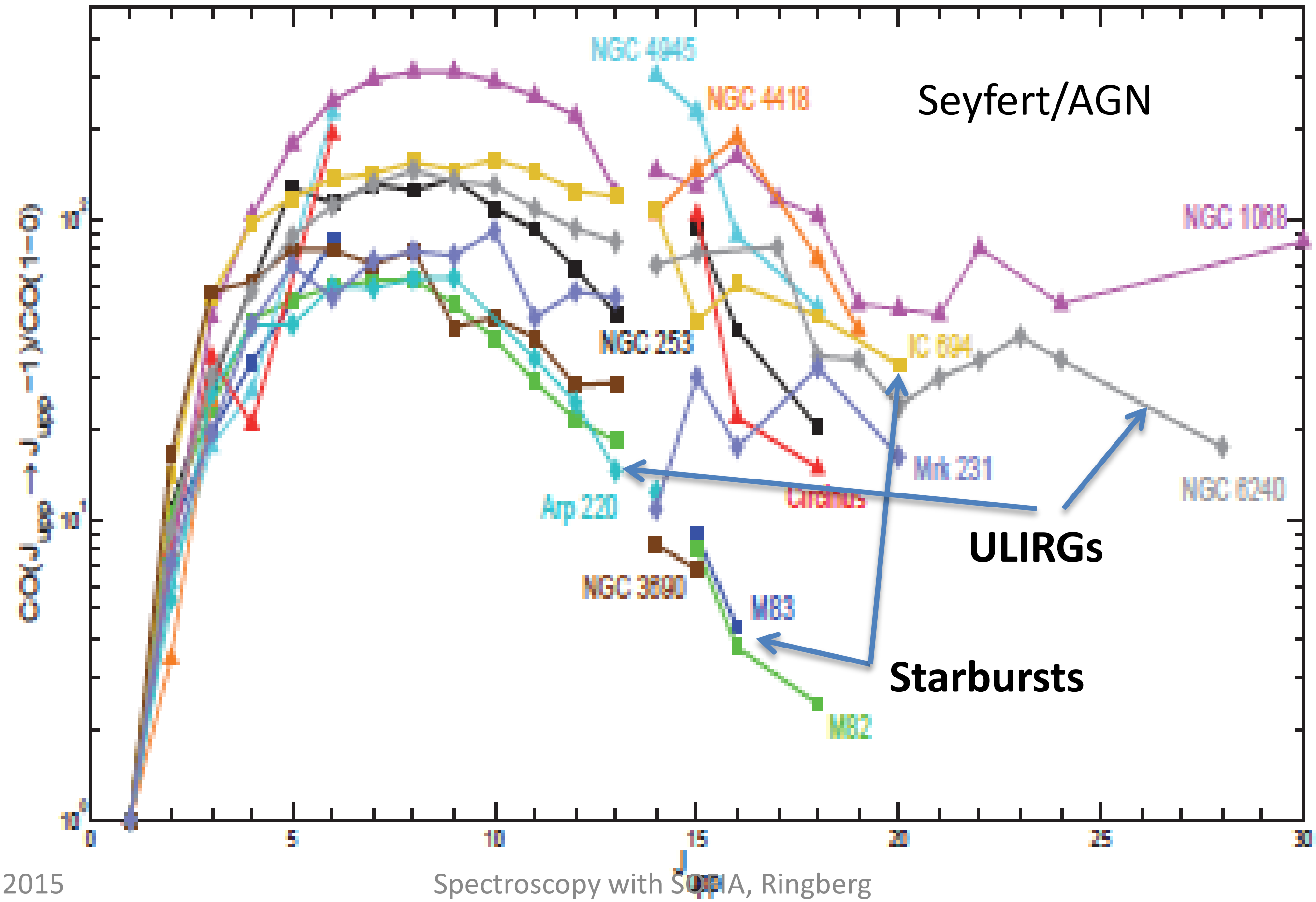
van der Werf et at (20 13)



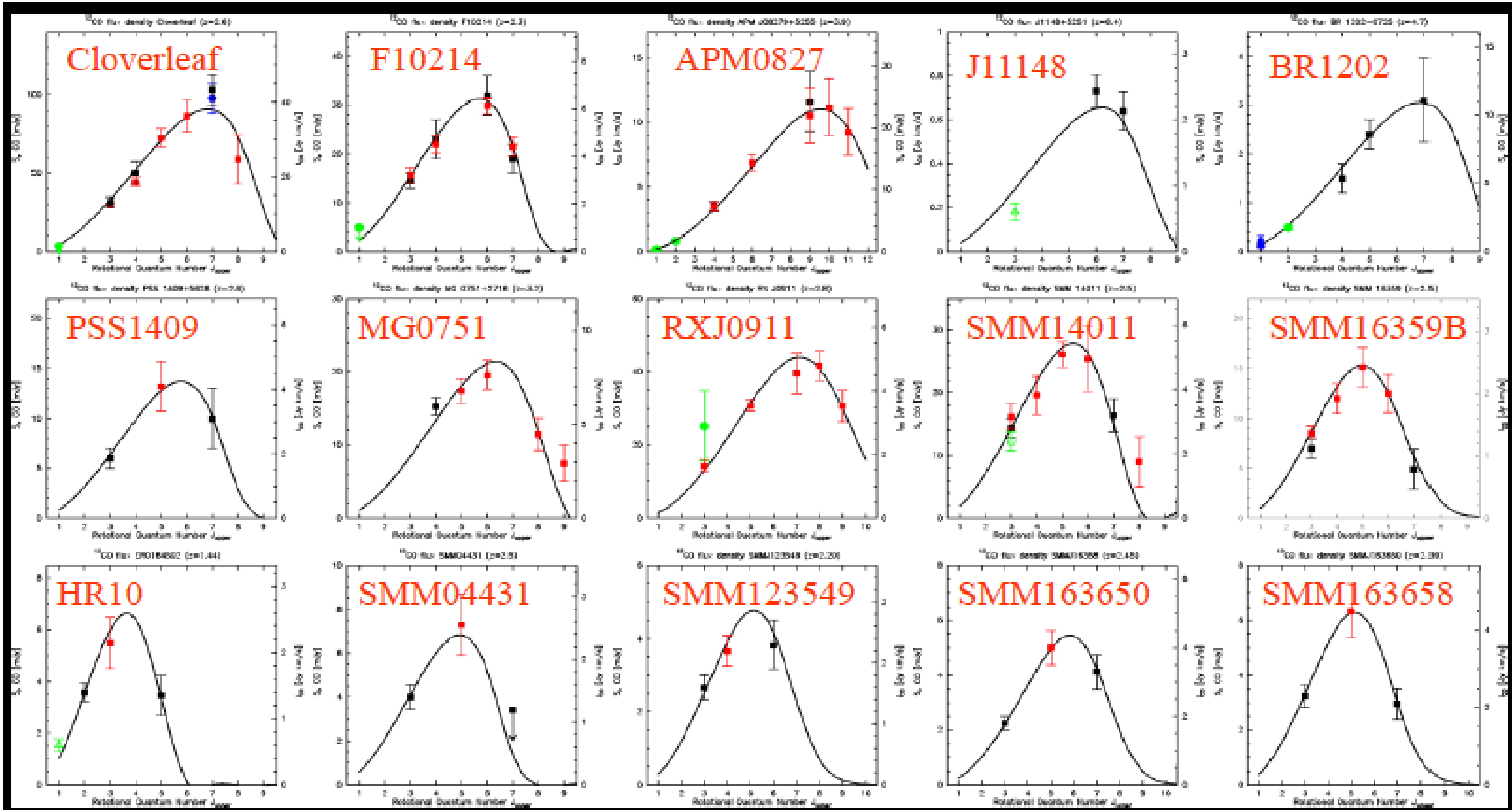


Nearby galaxies CO LSEDs

Ground based+SPIRE+PACS **N. Mashian, et al. (2015)**



CO Line SEDs at high z

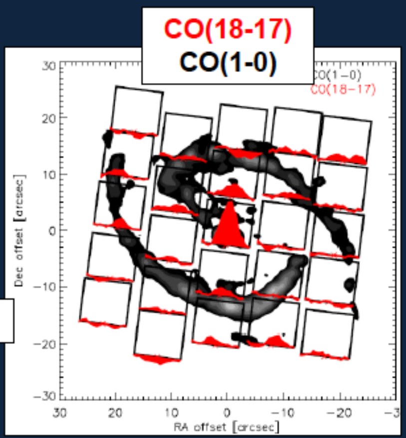


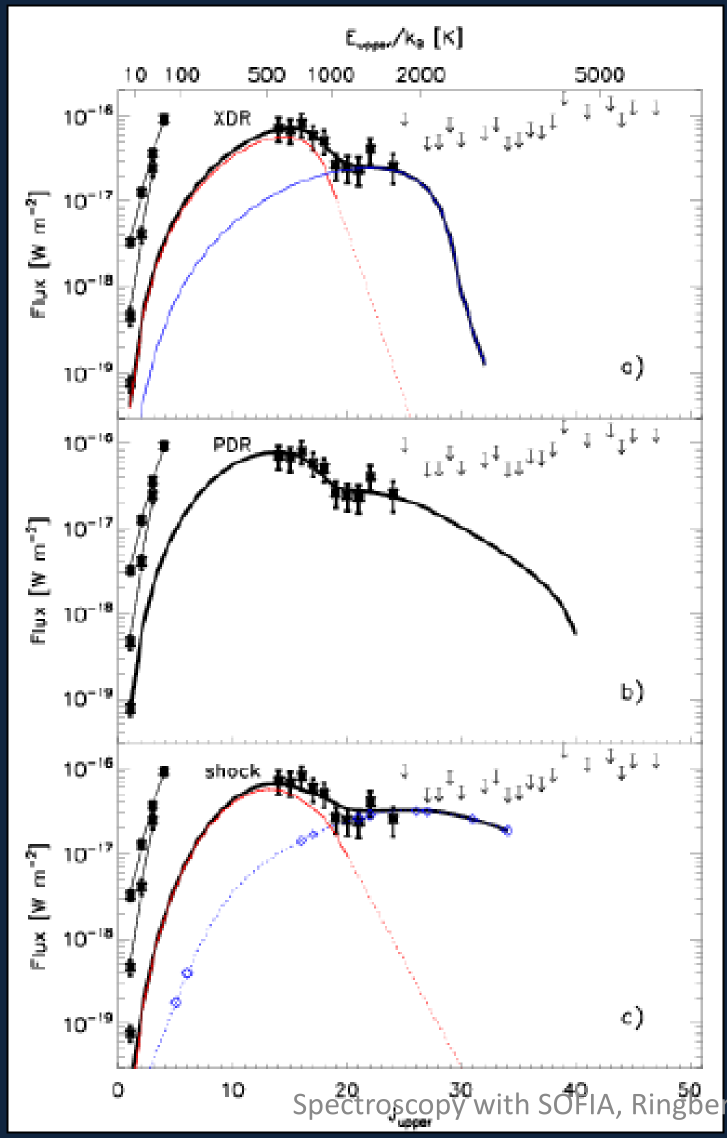
Alloin etal 1997, Ao etal. 2007, Barvainis etal 2002, Beelen etal 2004, Bertoldi etal 2003, Downes etal 2003, Greve etal 2003, Greve etal 2005, Hainline etal 2004, Riecherts etal 2006, Tacconi etal 2006/08, Papadopoulos etal 2002, Walter etal 2003, Weiss etal 2005, Weiss etal. 2007

AGN Model Degeneracy

The CO SED is fit with XDR/PDR/shock models

NGC1068





Hailey-Dunsheath et al. (2012)

Strong Fe 6.4 keV line

2 component XDR
Meijerink & Spaans 2005
Meijerink+07

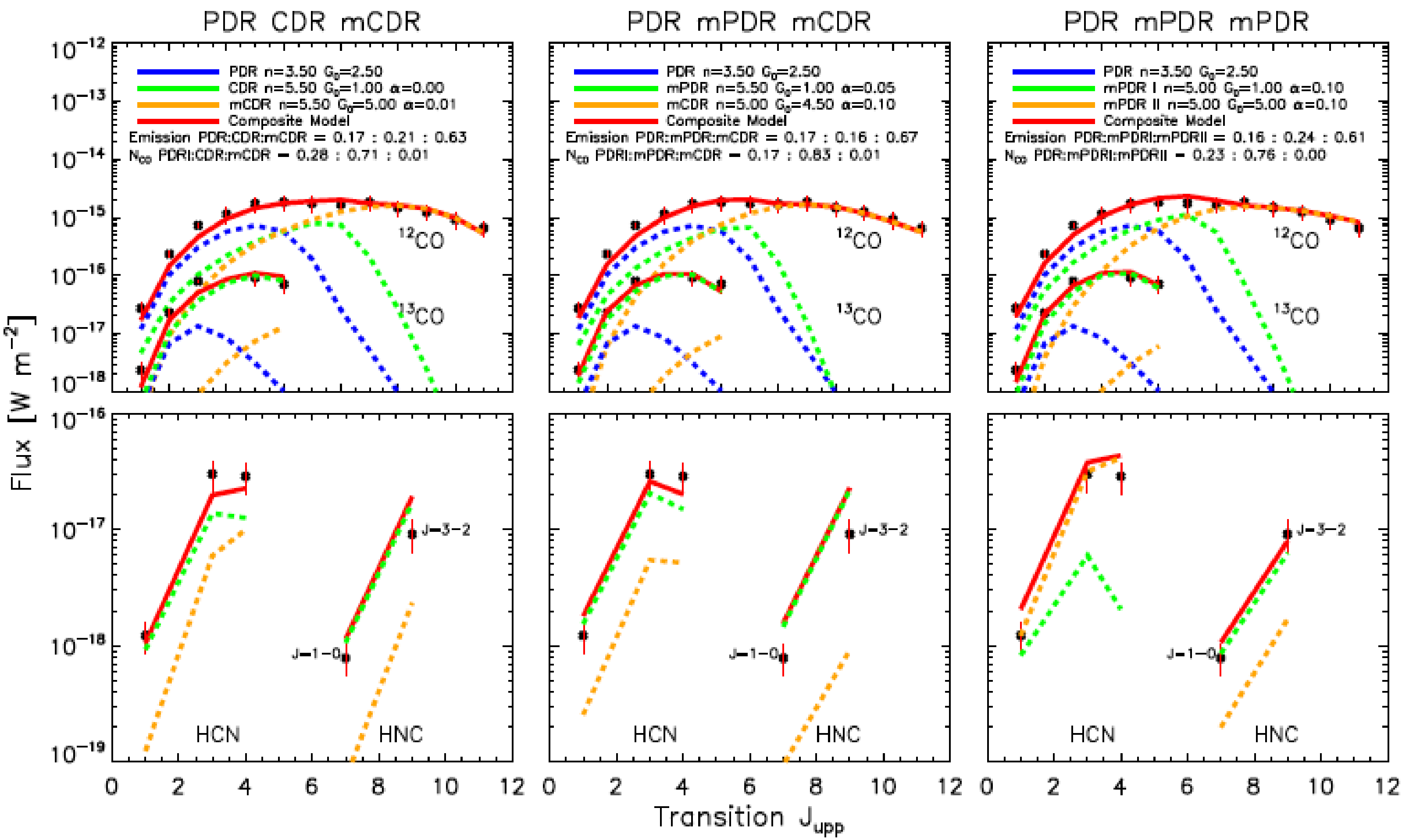
1 component PDR
Meijerink & Spaans 2005
Meijerink+07

Feedback:
Outflows in CO and OH

2 component C-shock
Flower & Pineau Des Forêts (2010)
Kaufman & Neufeld (1996)

Starburst model degeneracy

Rosenberg et al. (2014)

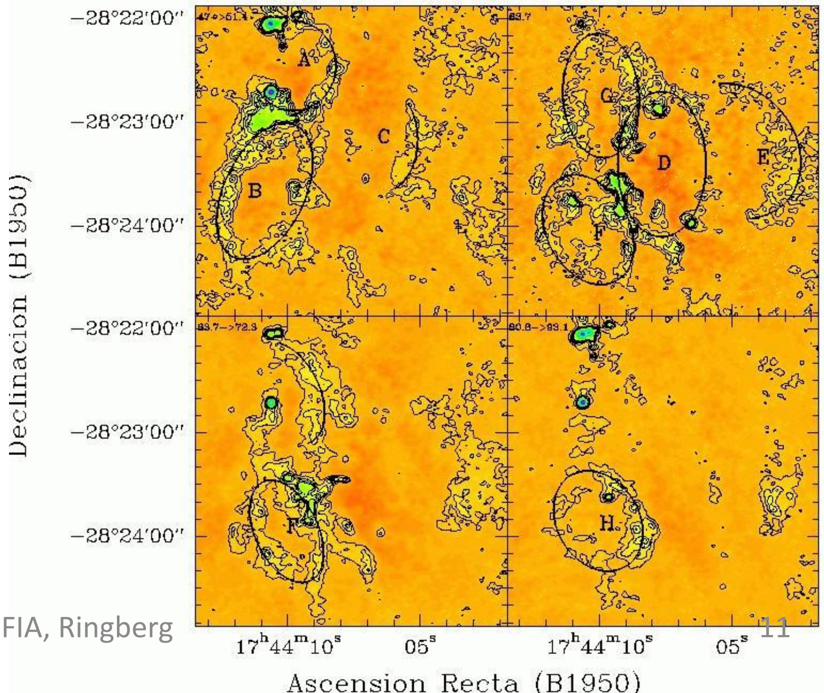


GC templates for CO LSEDs

The GC is a unique laboratory to understand the physics of the CO LSEDs (angular resolution)

- Star formation throughout the region
- PDRs illuminated by UV radiation from stars
- Shocks (local)
  - Bubbles in Sgr B2
    - Sizes of 1-2 pc
    - Powered by
      - Supernovae?
      - W-R stars?
  - 300 in CO Hasegawa et al. (1998)
  - FORECAST detected LBVs

Martin-Pintado (1993)



GC templates for CO LSEDs

GC ZMC unique laboratory to understand the physics of the CO LSEDs (angular resolution)

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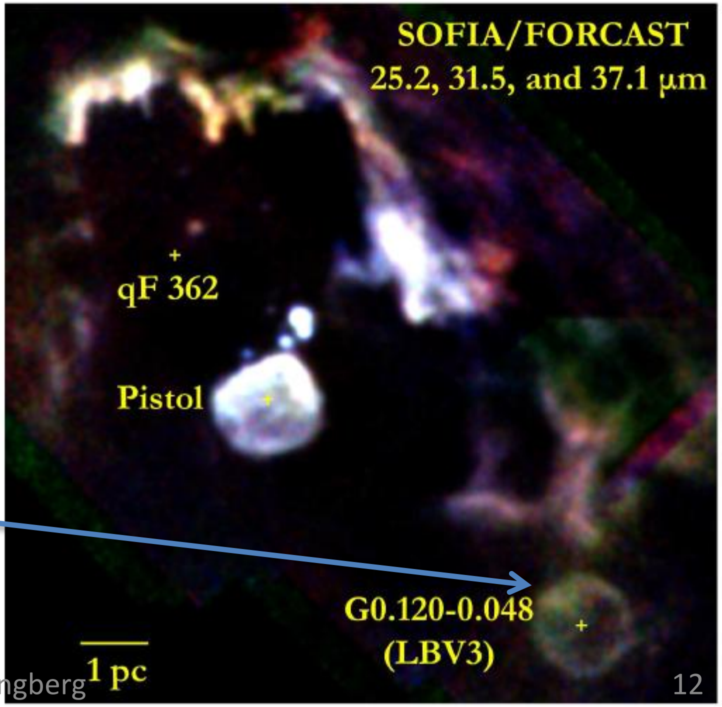
    - Sizes of 1-2 pc
    - Powered by
      - Supernovae
      - W-R stars
  - 300 in CO Hasegawa et al. (1998)
  - FORECAST detected LBVs
    - Sizes of 1 pc

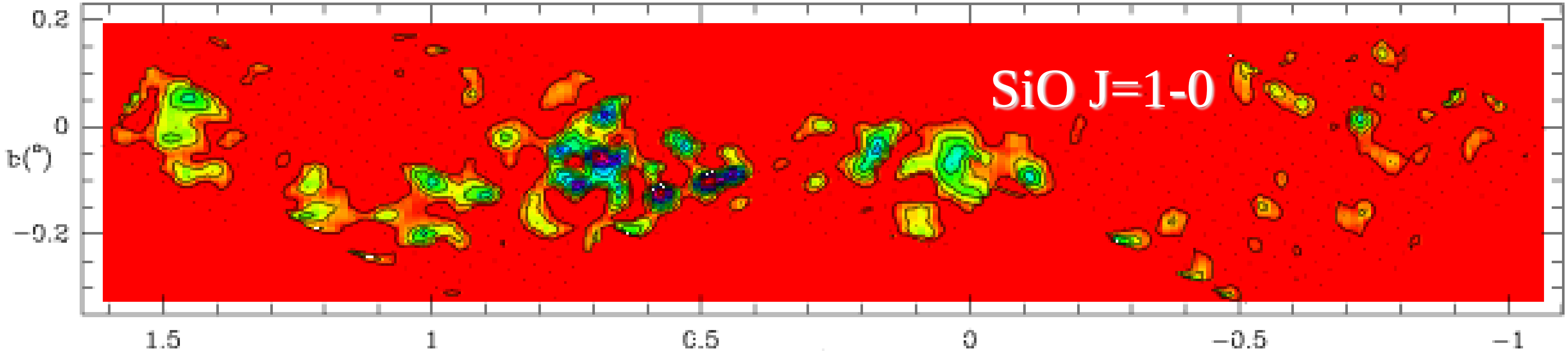


Lau et al. (2014)

GC templates for CO LSEDs

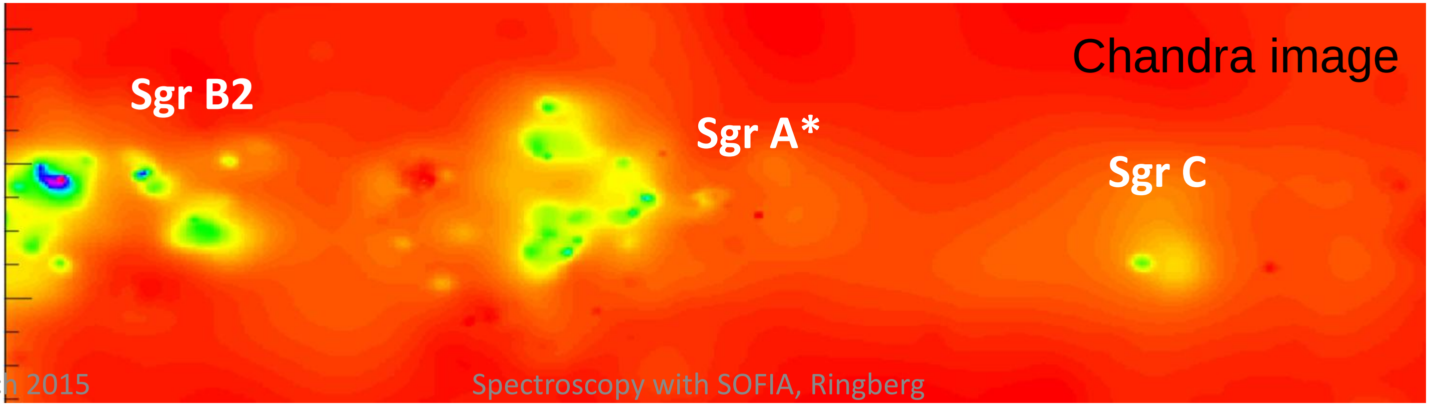
- Shocks (large scale)

Martin-Pintado et al. (1997)



- XDRs traced by the Fe 6.4 keV line

Illuminated by a burst of hard x-ray emission from Sgr A* (100 years ago)

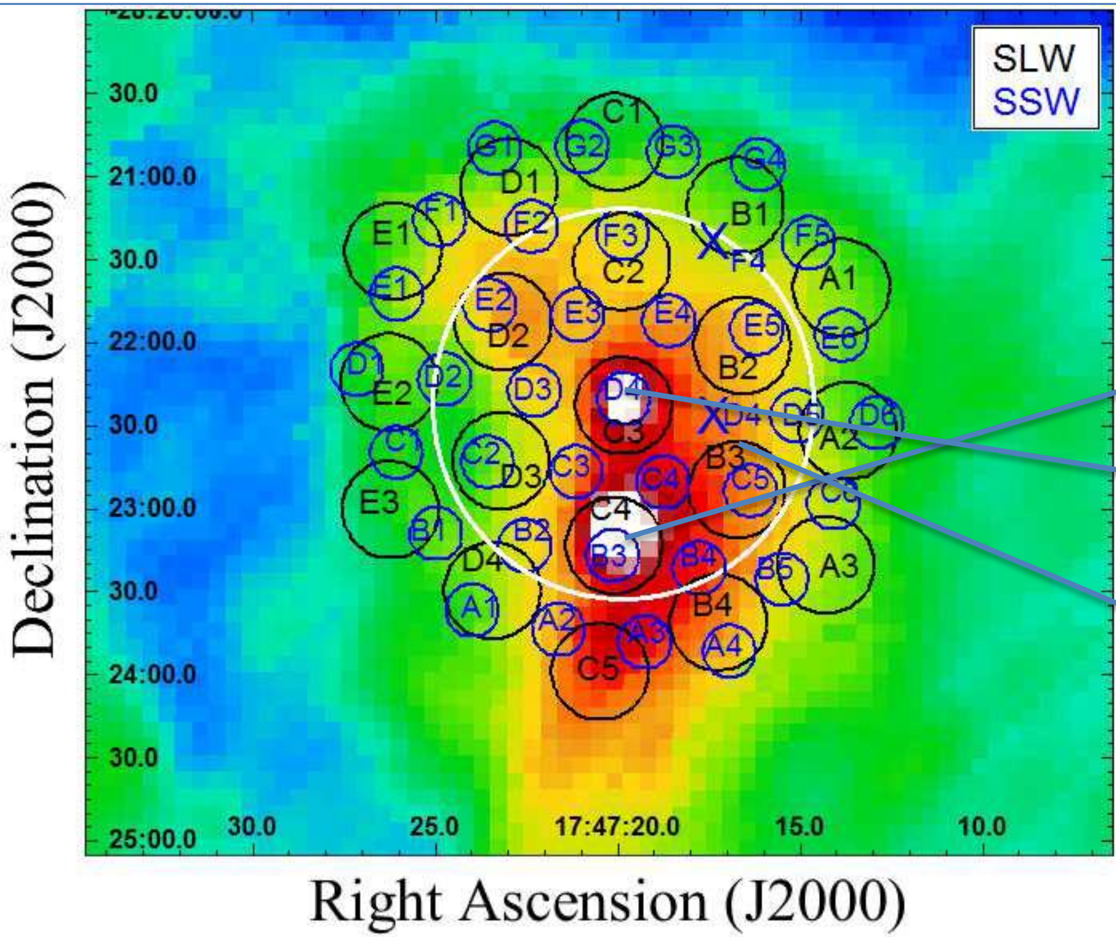


Herschel CO LSEDs in the GC

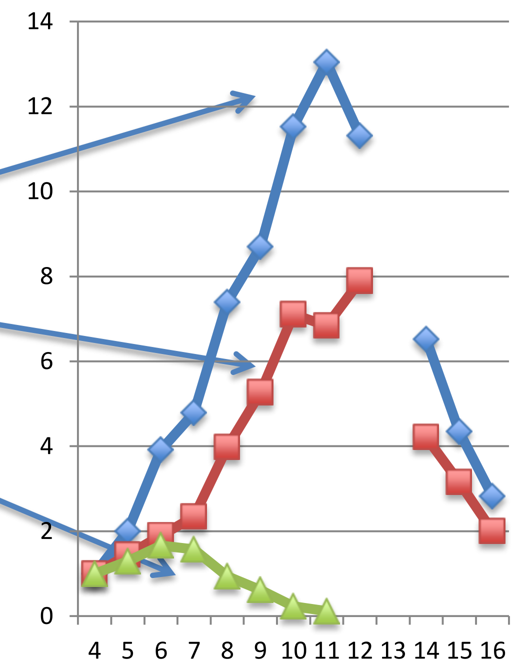
- Restricted to very small regions:
  - Sgr B2 star forming cores: HIFI and SPIRE 2’x 2’
  - Sgr A*: HIFI pointings, PACS (3’x3’) and SPIRE (2’x’2)
- Lack of observations of XDR and pure shock dominated regions

Herschel CO LSEDs in the GC

Sgr B2 star formation cores



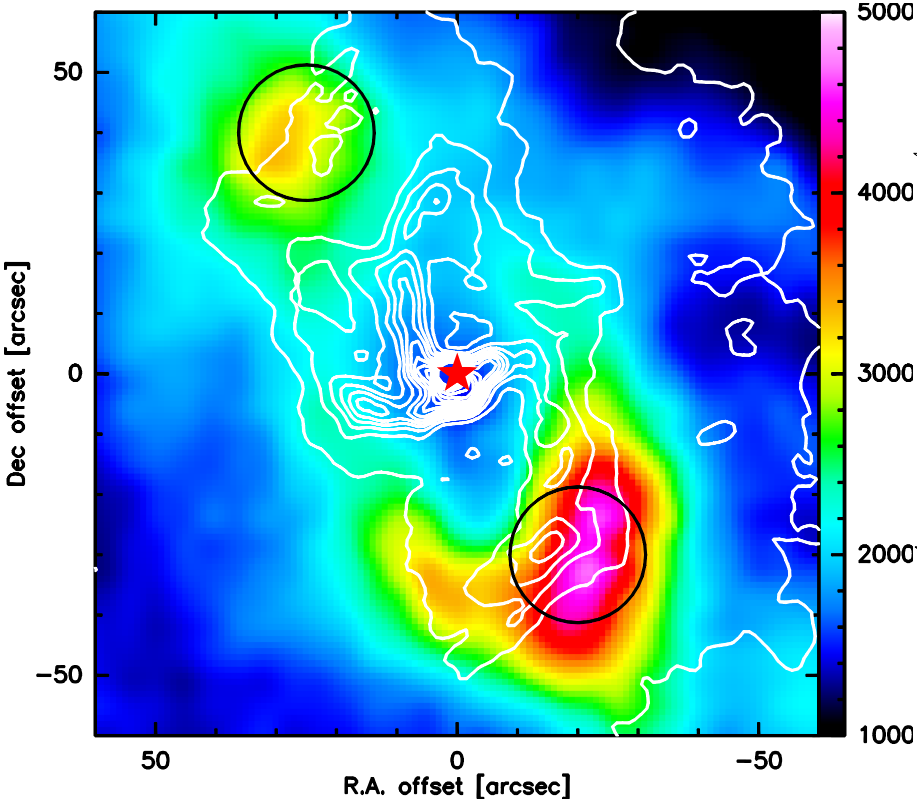
Hot cores and envelope



Etxaluze et al (2013)

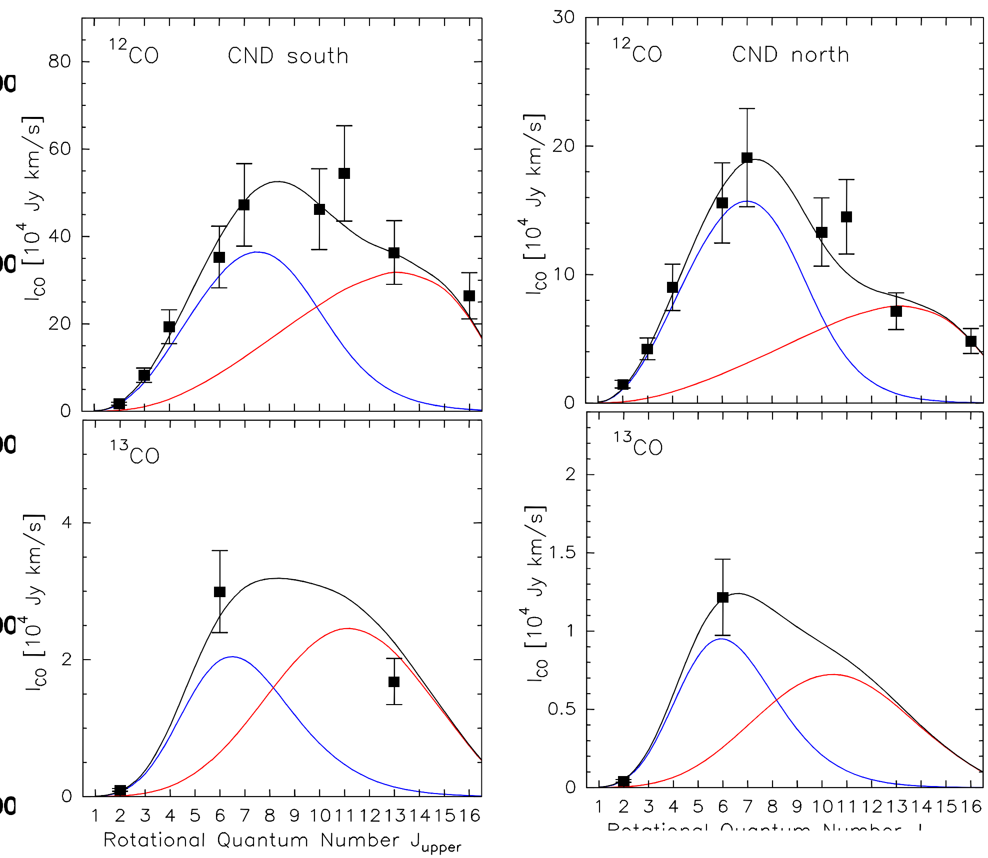
Herschel CO LSEDs in the GC

CND is a transient structure



Requena-Torres (2012)

HIFI+APEX+SOFIA

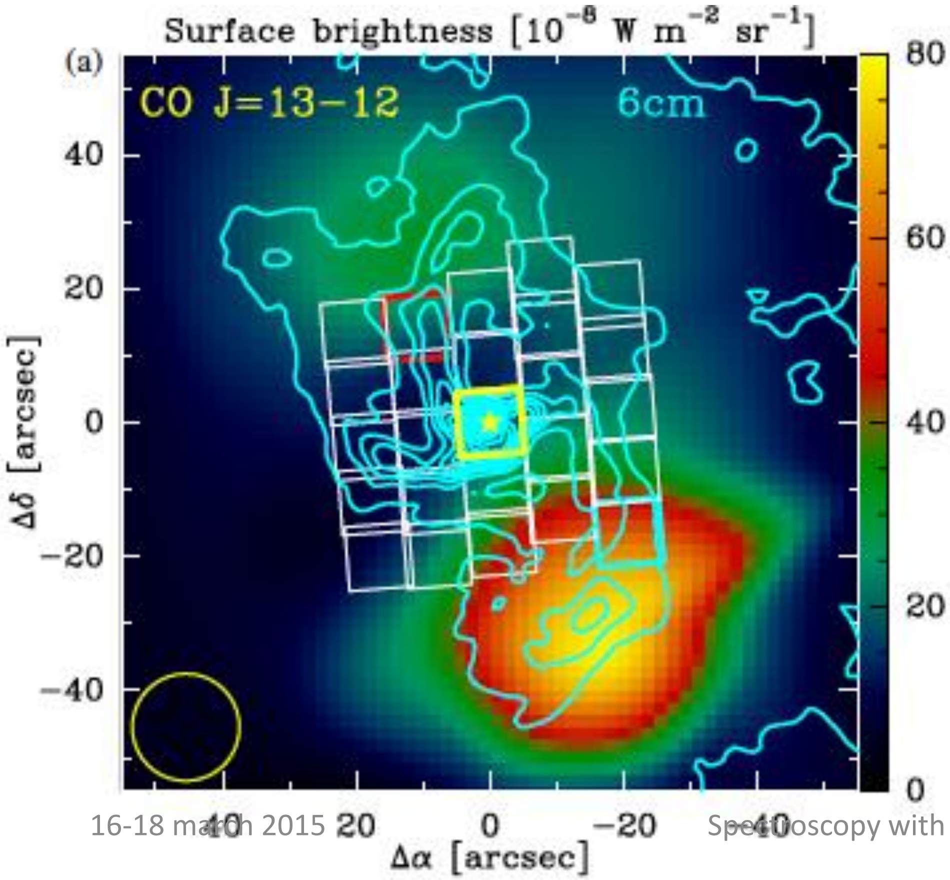


n_{H2} $10^{5.2}$ cm^{-3} T_{kin} 500 K
n_{H2} $10^{4.5}$$cm^{-3}$ T_{kin} 200 K

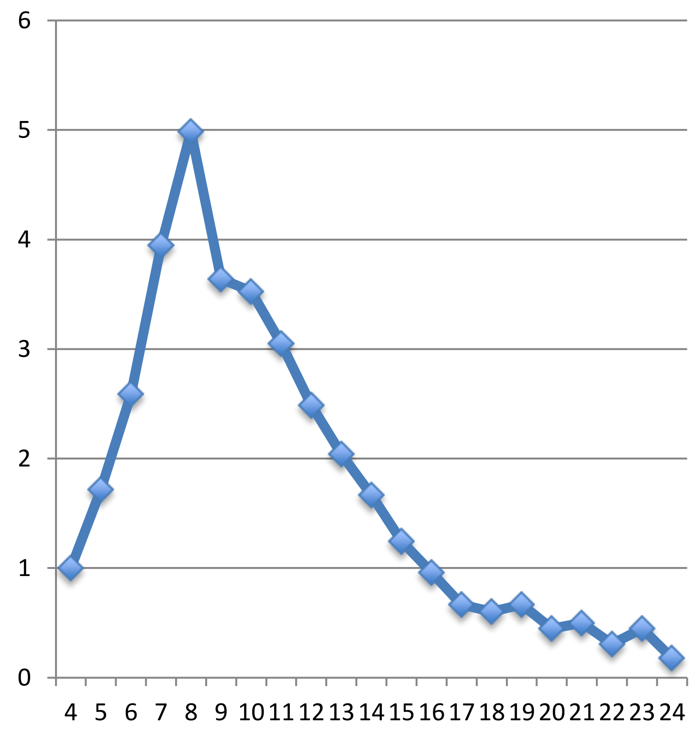
n_{H2} $10^{5.3}$ cm^{-3} T_{kin} 325 K
n_{H2} $10^{4.5}$$cm^{-3}$ T_{kin} 175 K

Herschel CO LSEDs in the GC

Shock+UV

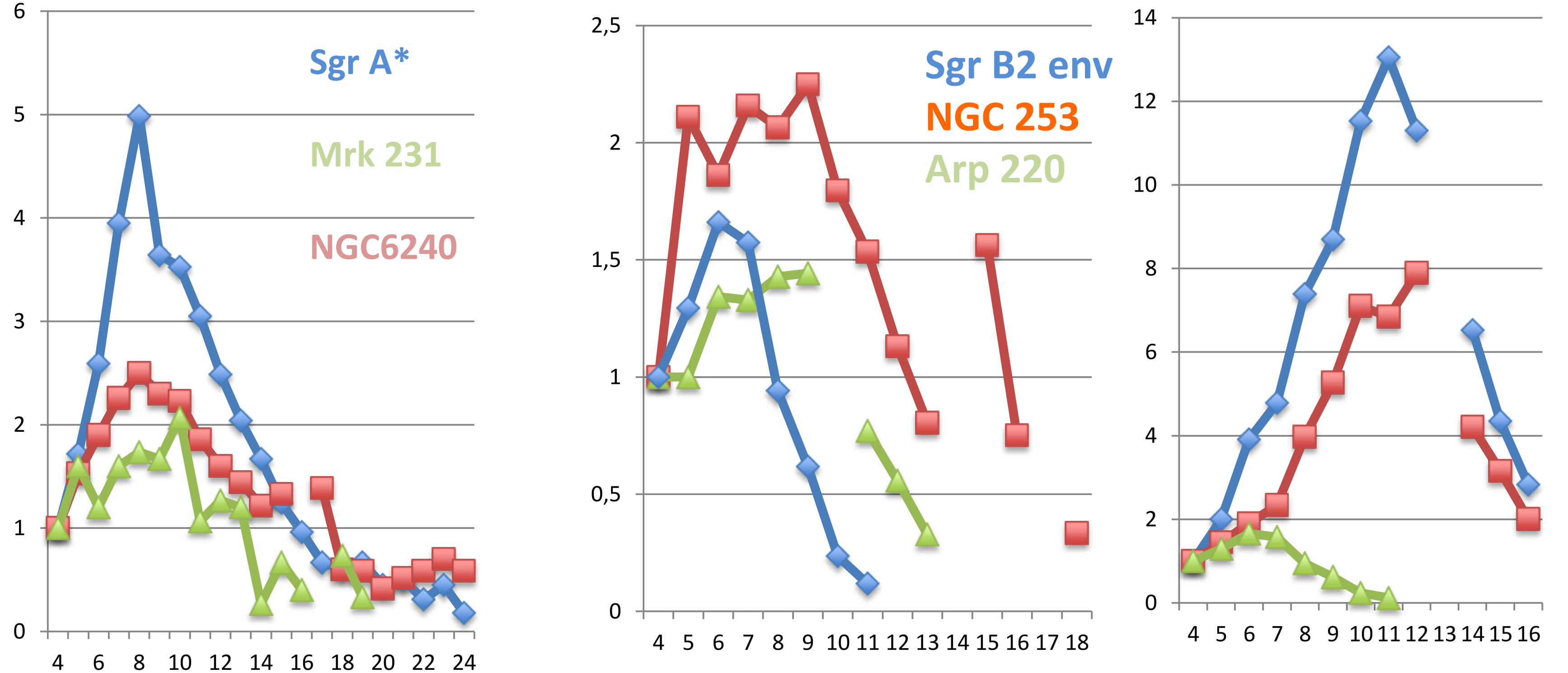


SPIRE+PACS



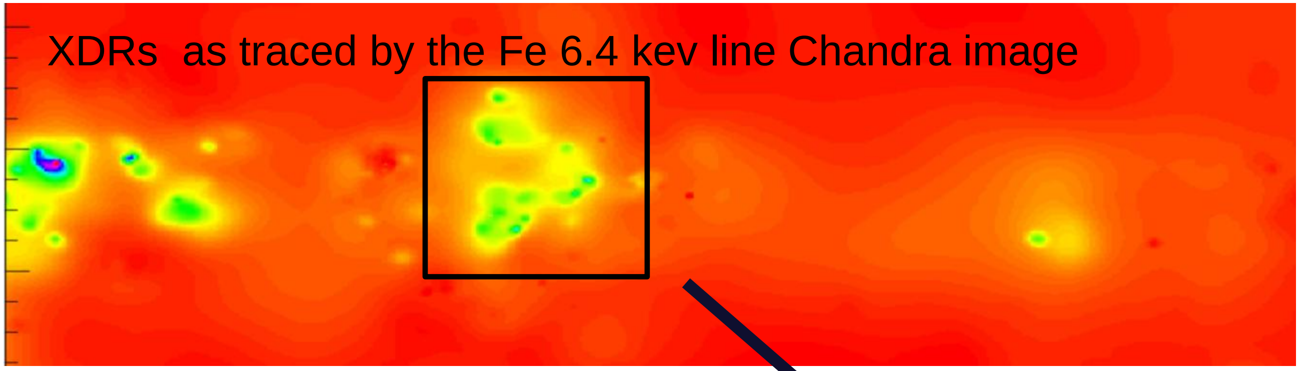
Goicoechea et al. (2013)

Nearby galaxies CO LSEDs



The four GC CO LSEDs do not fully reproduce those observed in external galaxies
One needs to get more "templates" to cover a wider range o heating mechanisms: PDRS (pistol, sickle), higher velocity shocks and XDRs

GC templates for XDRs

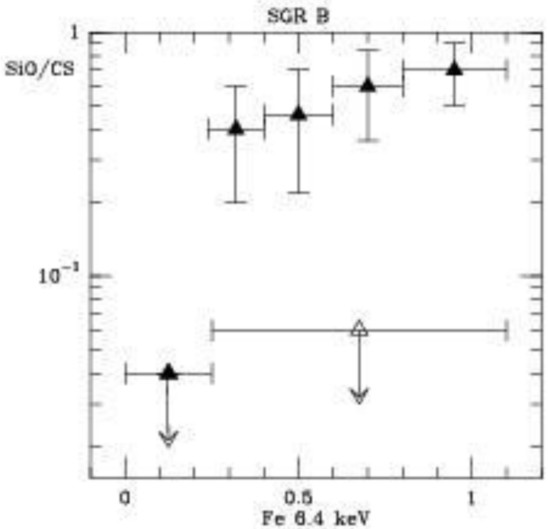


Herschel
HEXGAL

Sgr B2 clouds

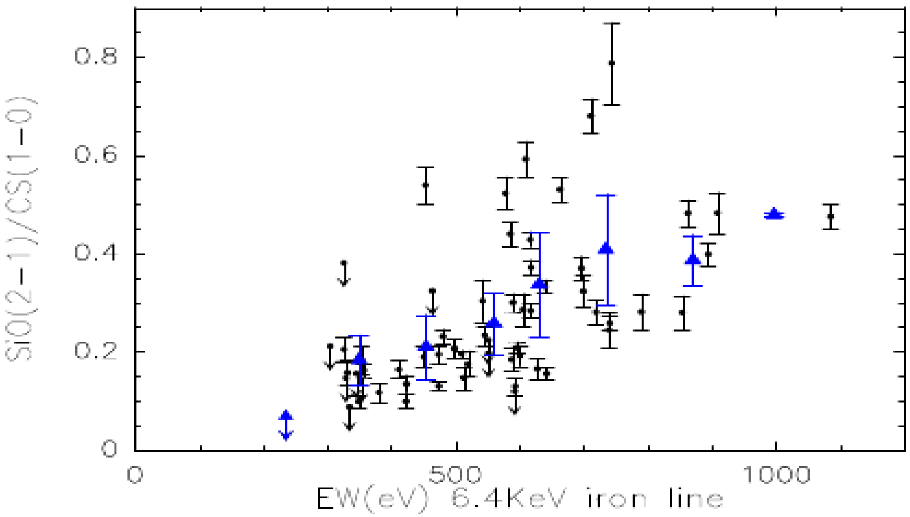
Sgr A Thermal filaments

SiO/CS correlated with the Fe 6.4 keV. VSG of 10 A



Martin-Pintado et al. (2000)

HCO abundace

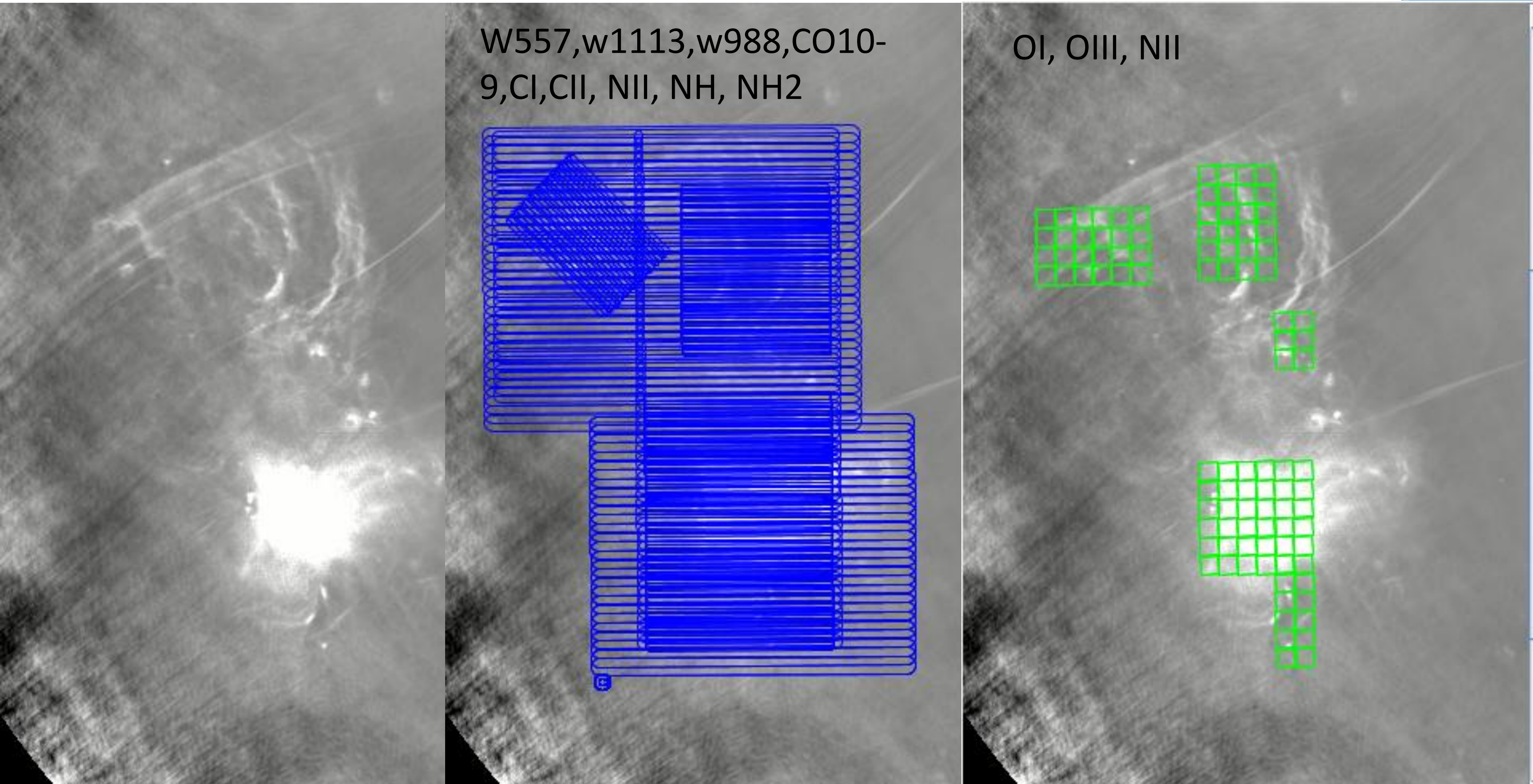


Amo-Balandron et al. (2009)

X-ray Dominated Regions

HERSCHEL HEXGAL KP

M. A. Requena Torres, A. Harris, Martin-Pintado, R. Guesten
M. Morris, J. Armijos, P. Garcia, R. Simon



Conclusions

- In combination with ground based facilities (IRAM, APEX, ALMA, ..), SOFIA will be the only facility to get full CO LSEDs in the GC.
- UpGREAT and FIFI-LS observations of the GC XDRs have the potential to measure the predicted hot molecular phase.
- Templates of the CO LSEDs representative of different heating mechanisms in the GC could help to understand the origin of the heating in nearby external galaxies, and high-z objects.