# Mysterious fine structure lines in S140

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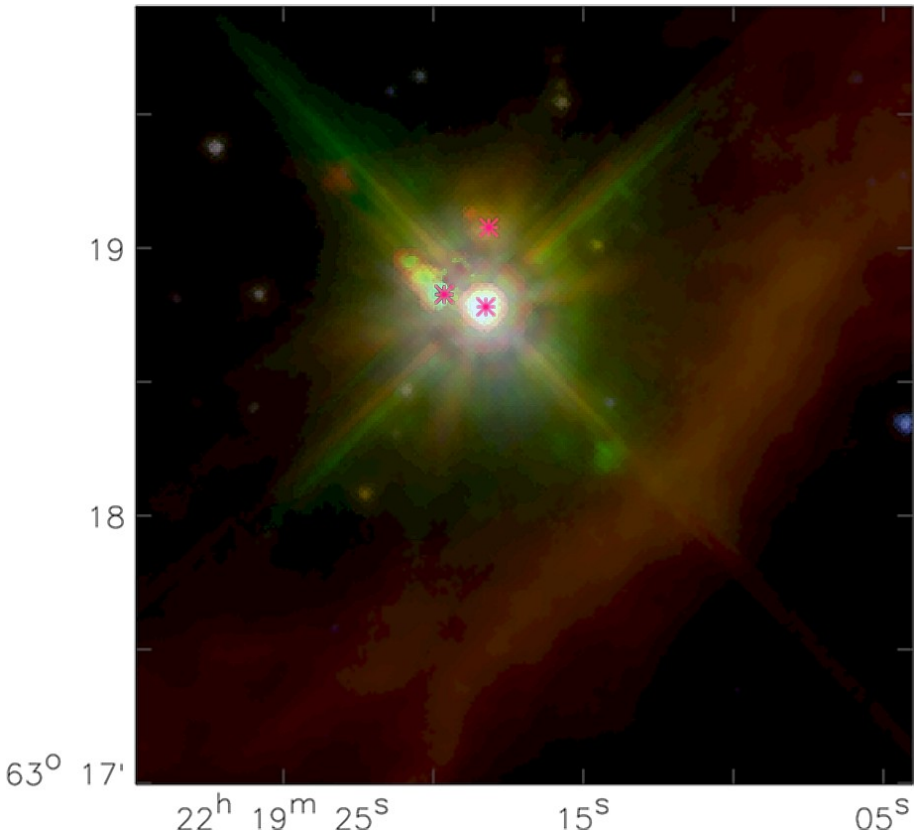
# Overview

- S140 properties
- [OI] and [CII] GREAT observations
- Complementary data
- Line profiles
- Properties of the main emission source
- The line-to-continuum cooling balance
- Comparison to PDR model

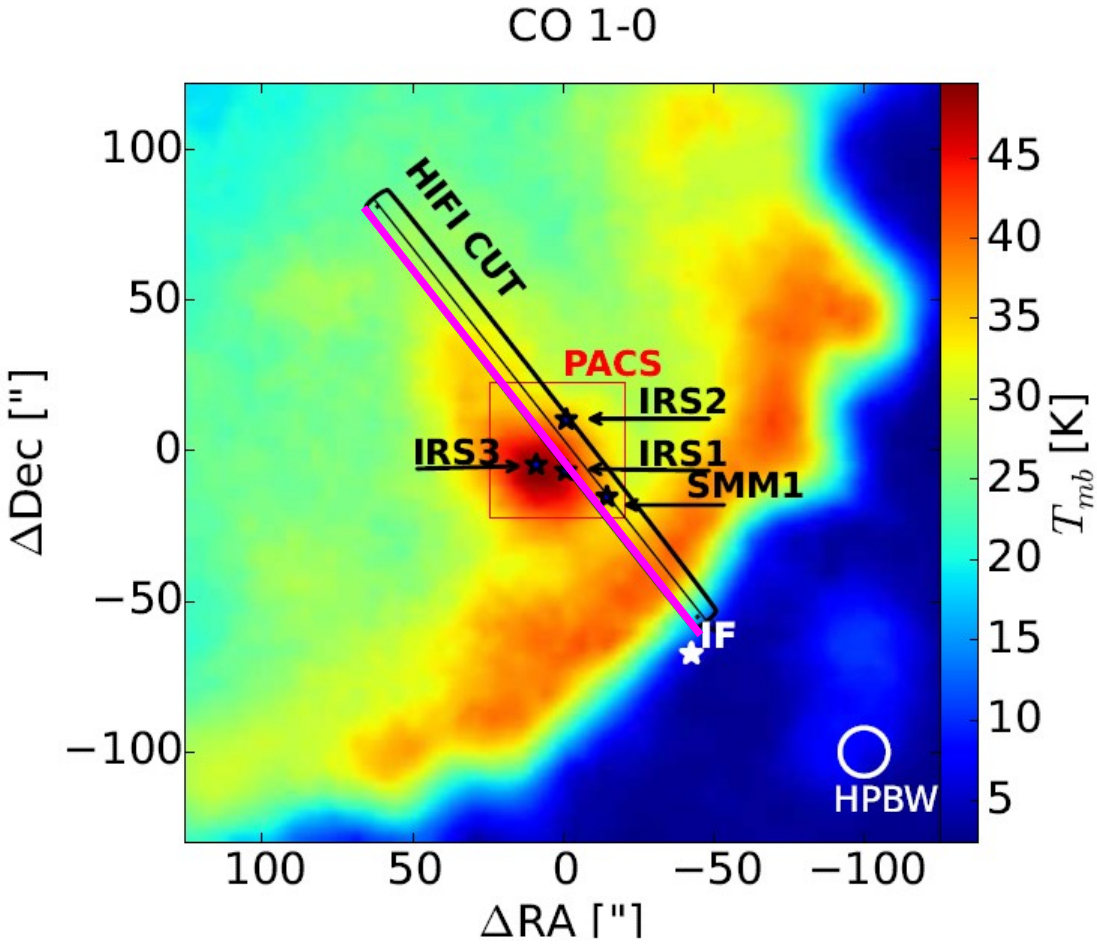
## Well-studied molecular cloud:

- **External PDR** ($G_0$=250) and deeply **embedded star-formation** (IRS1-3):

IRAC map (3.6, 5.6, 8μm)



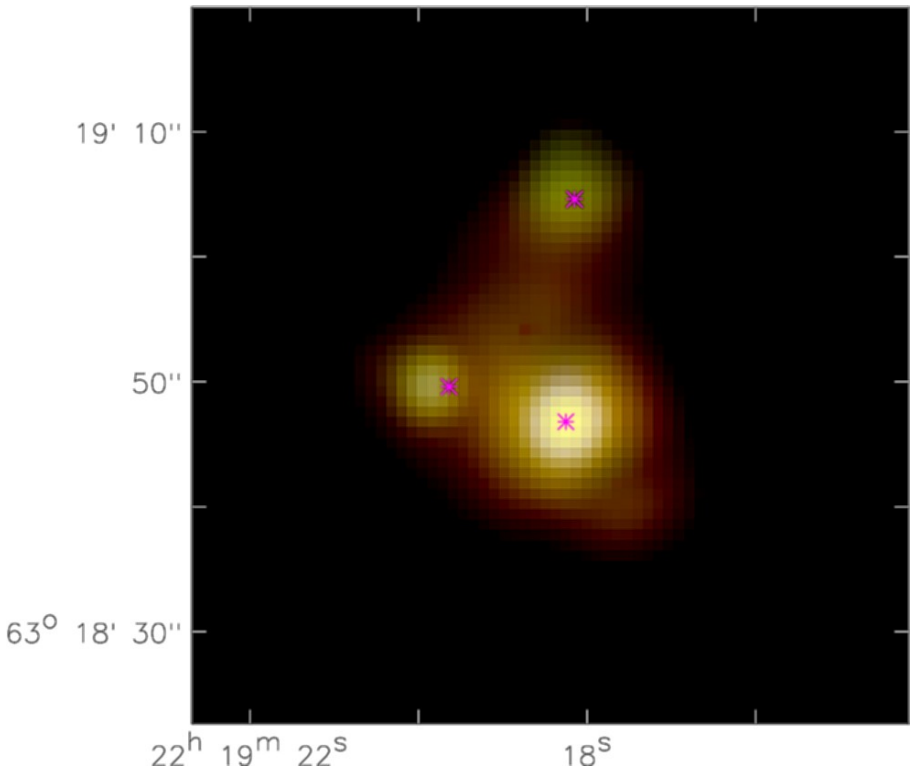

CO 1-0 peak intensity (IRAM)

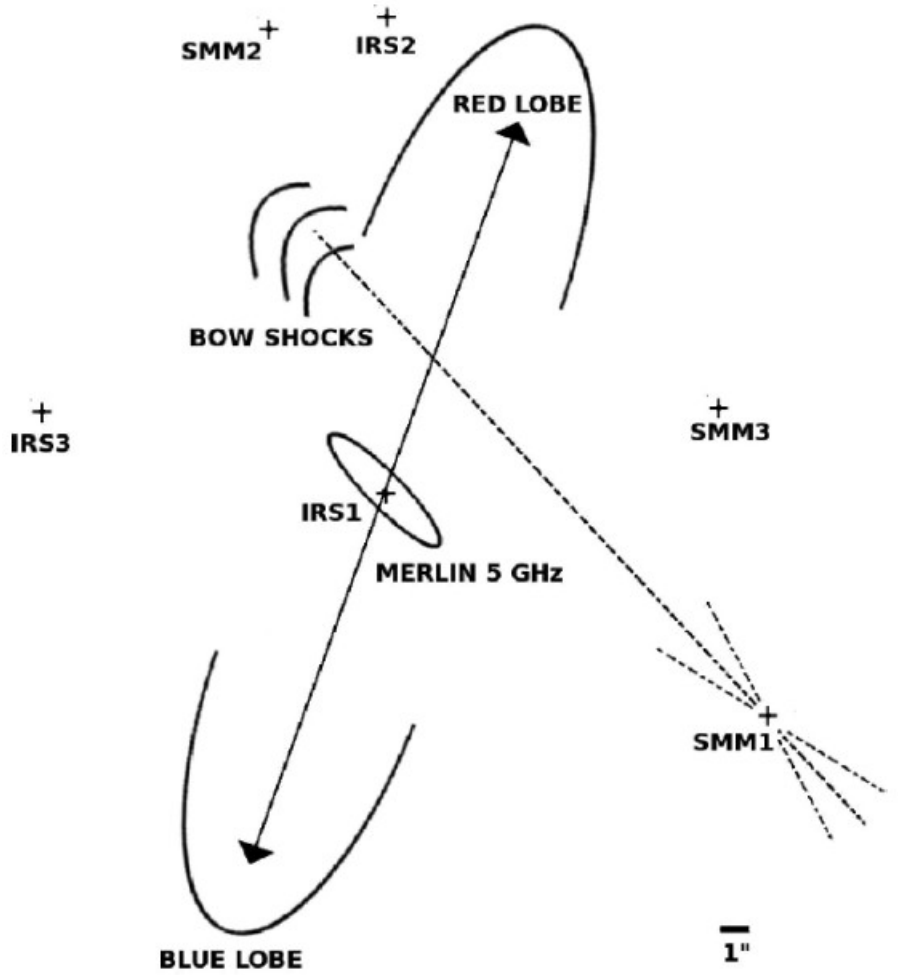


## Herschel/PACS and SOFIA/FORECAST observations:

- IRS1 as the central source with 10000L
- Drives molecular outflow (Maud et al. 2013)

FORECAST map (11, 31, 37μm)

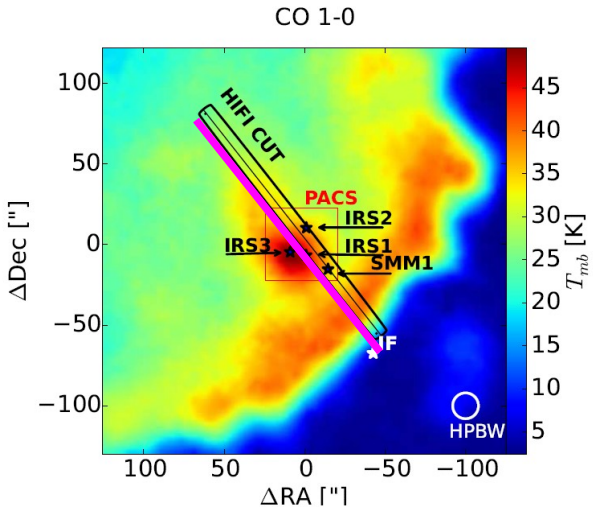


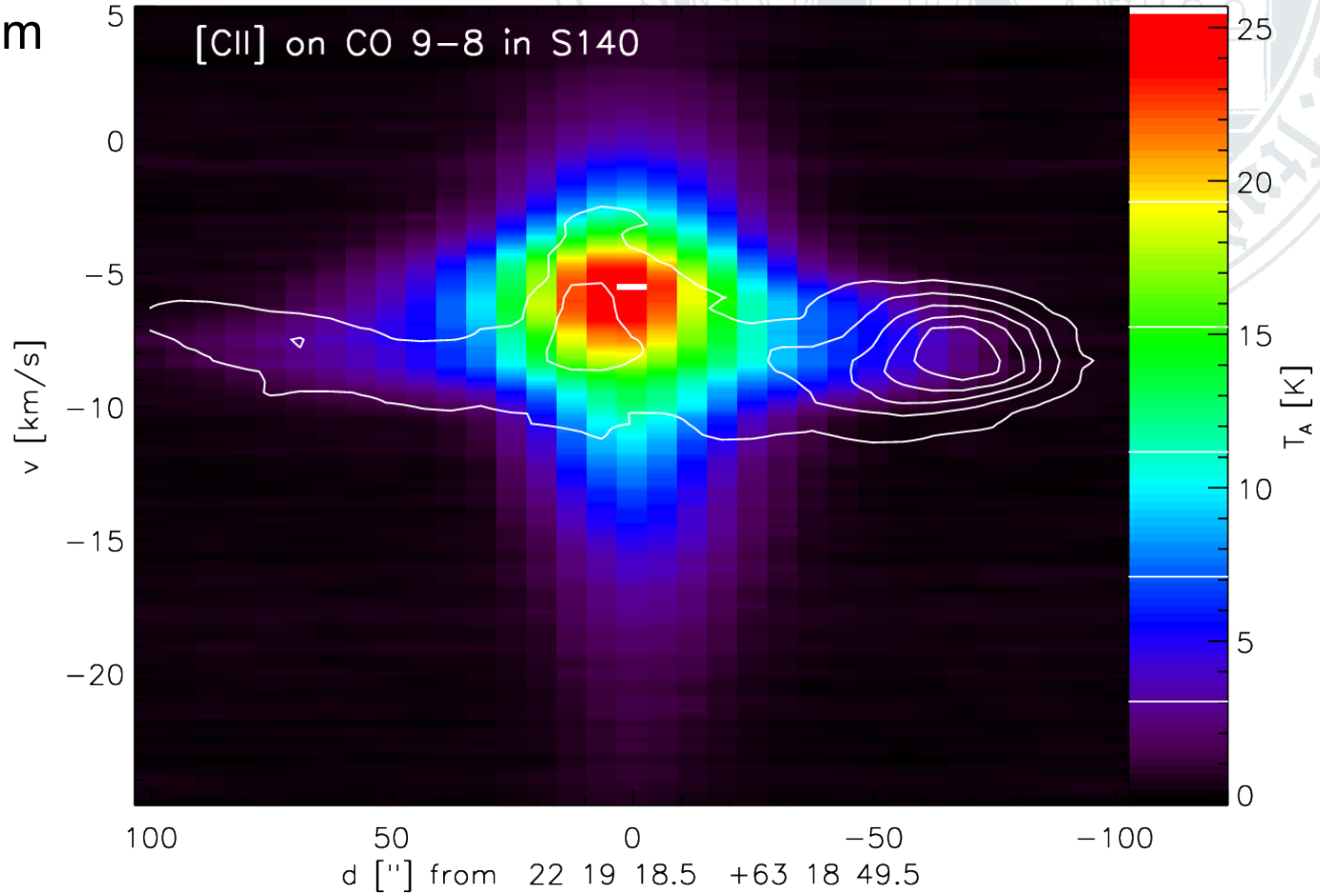



## Herschel/HIFI observations of [CII] and many other lines:

- Confirm outflow from IRS1
- [CII] strong at interface, weaker, but pronounced at IRS1

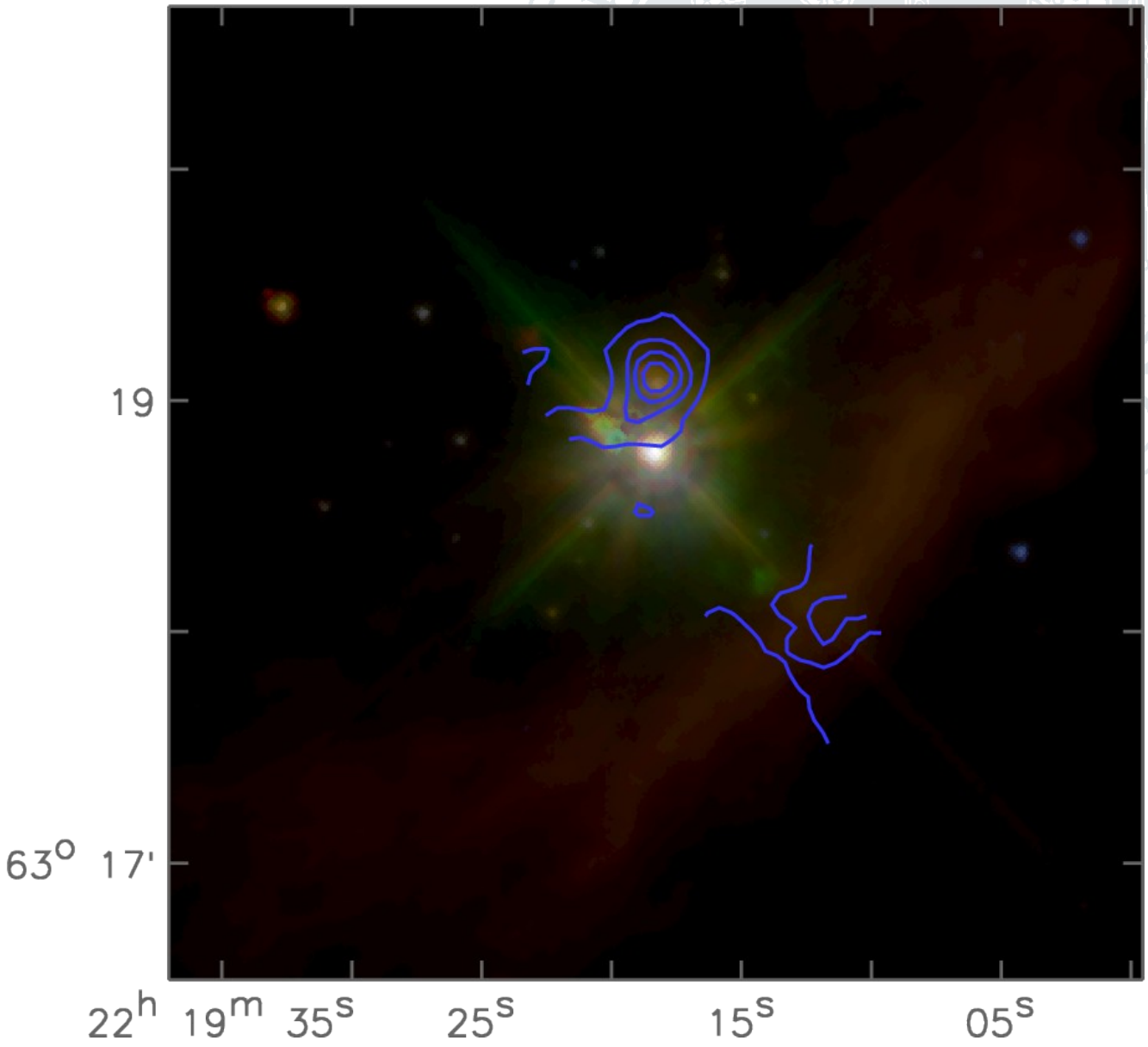
Position-velocity diagram along HIFI cut:



## First [OI] 63μm observations in 2014:

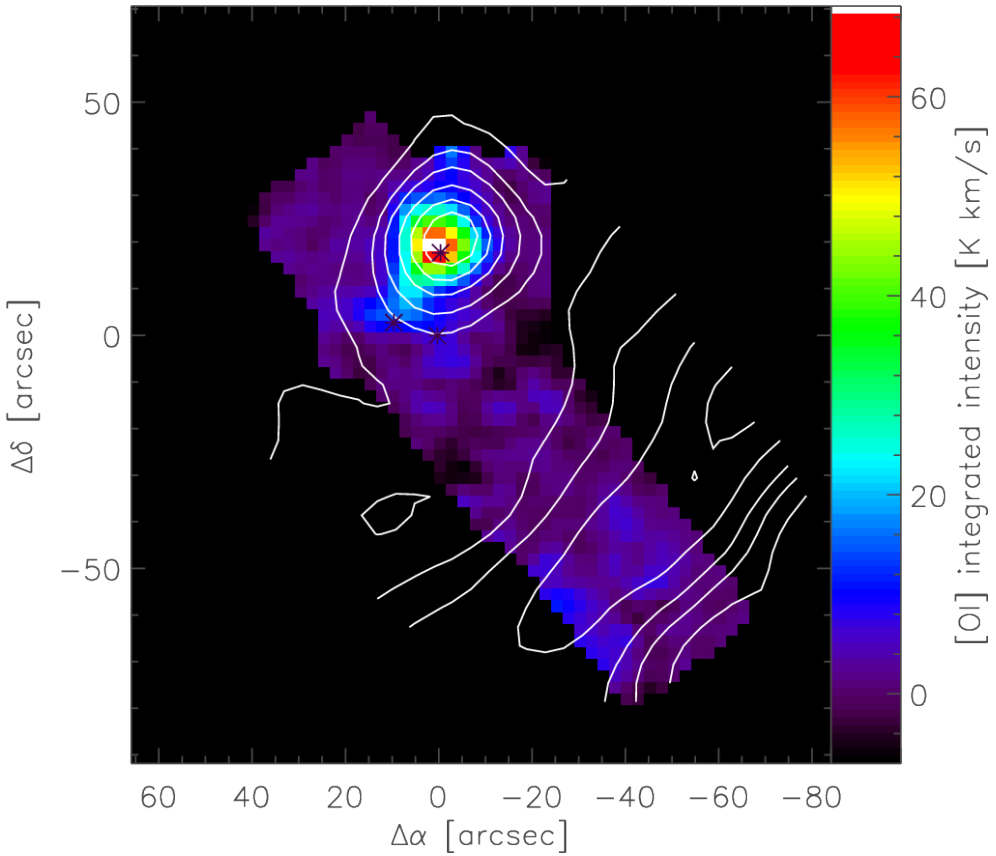
- [OI] strongly peaked, but peak offset by 20" from IRS1

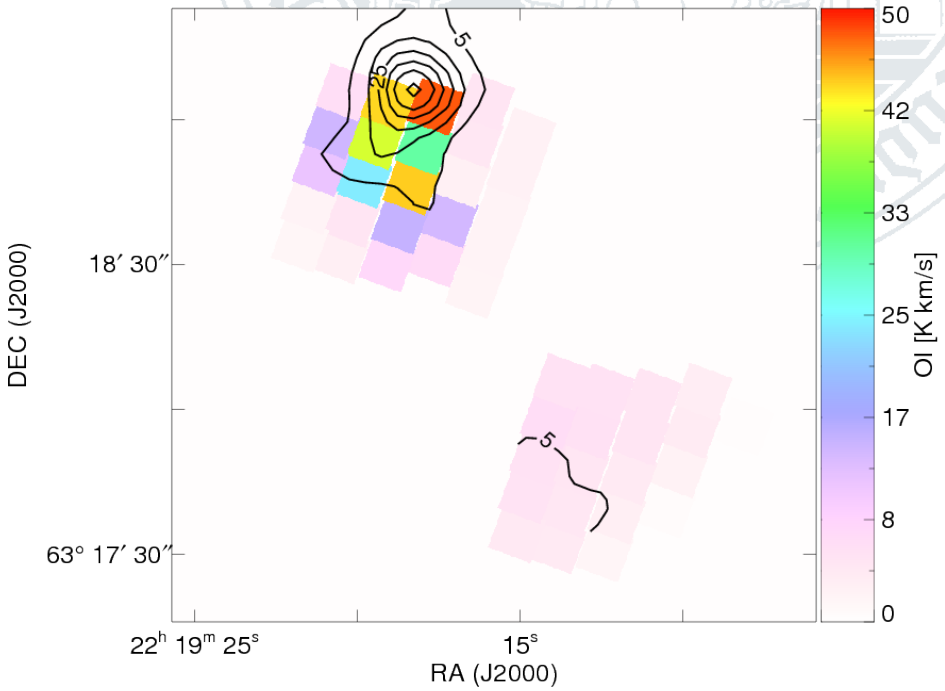



[OI] peak intensity

## [OI] peak confirmed by [CII] map and comparison to PACS:

- Both fine structure lines do **NOT** peak at the main source (IRS1) but 20" north, close to IRS2

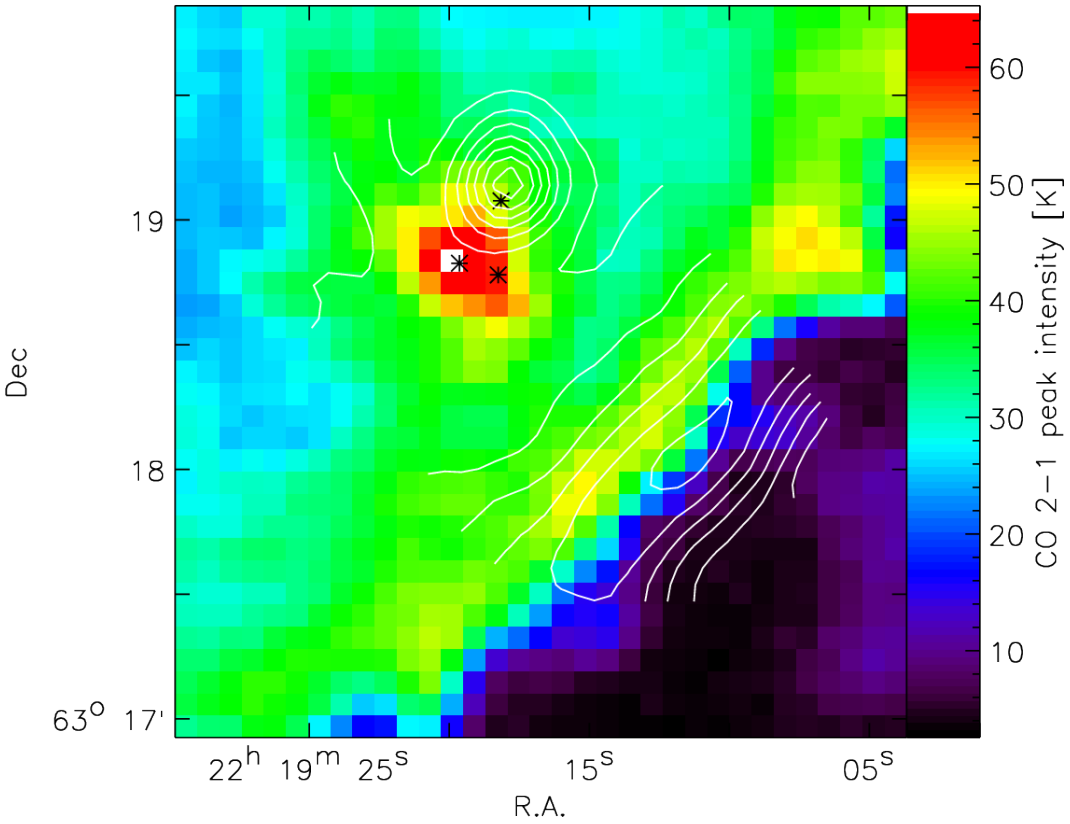


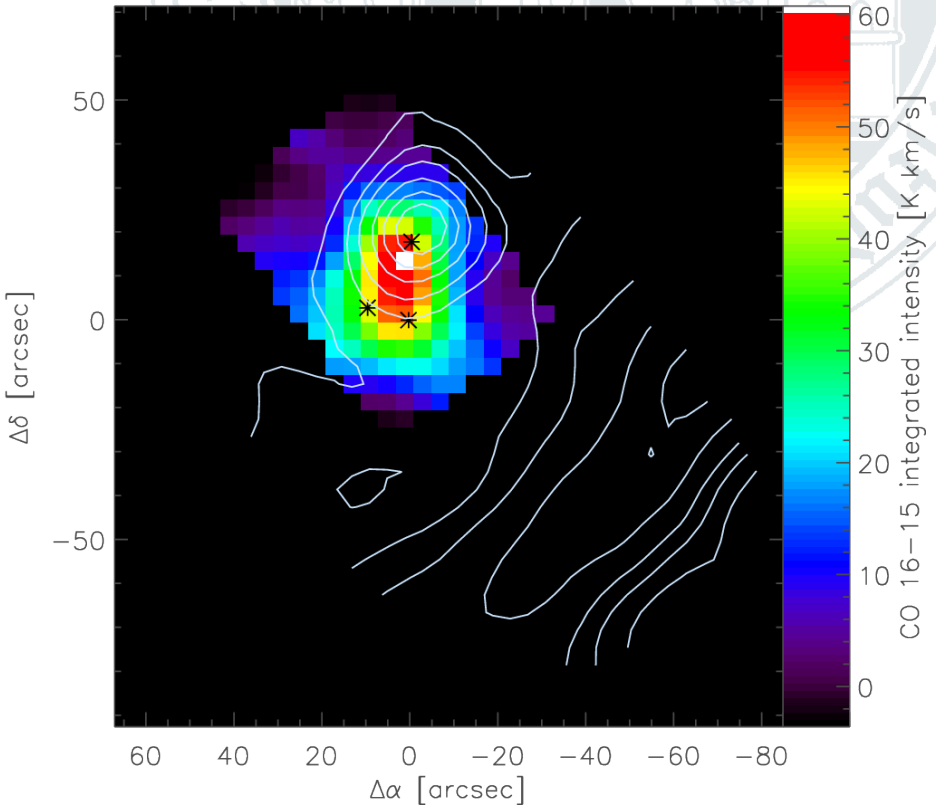

Integrated [OI] (colours) and [CII] contours

## IRAM maps of low-*J* CO, GREAT observations of CO 16-15

- Low-*J* lines peak around at IRS1
- CO 16-15 extended between IRS1 and IRS2




CO 2-1 with contours of [CII] (peak intensity)

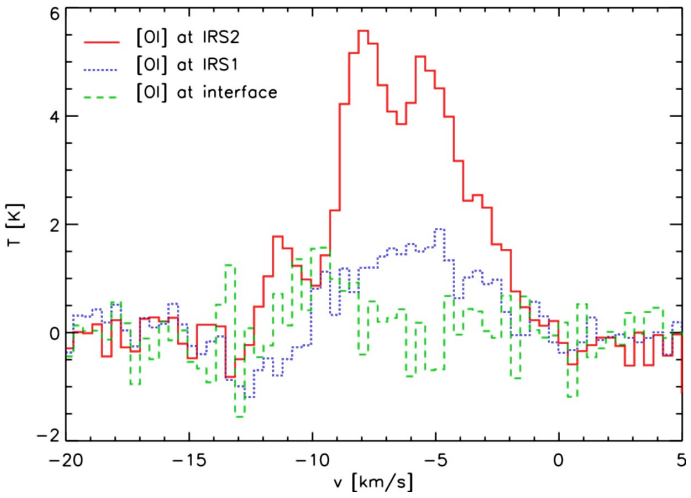


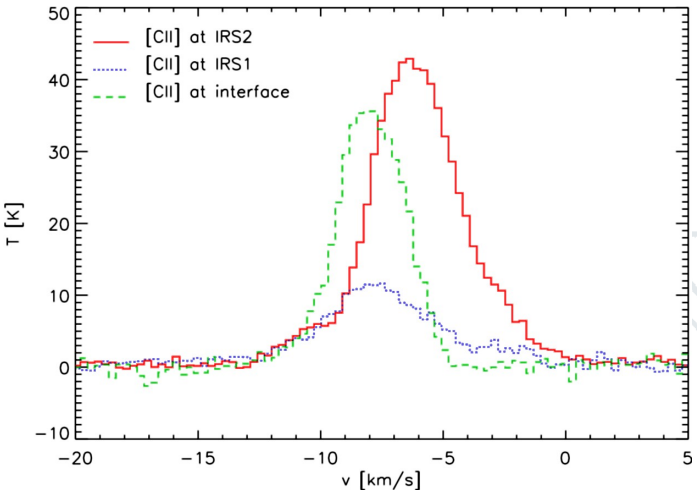

CO 16-15 with contours of [CII] (integrated intensity)

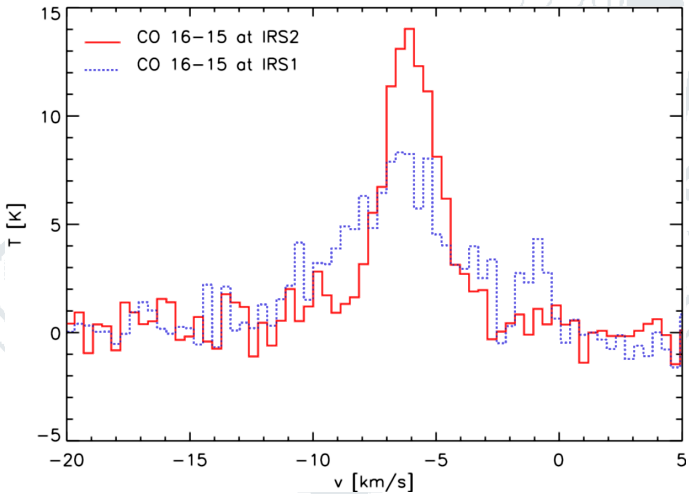
# Line profiles

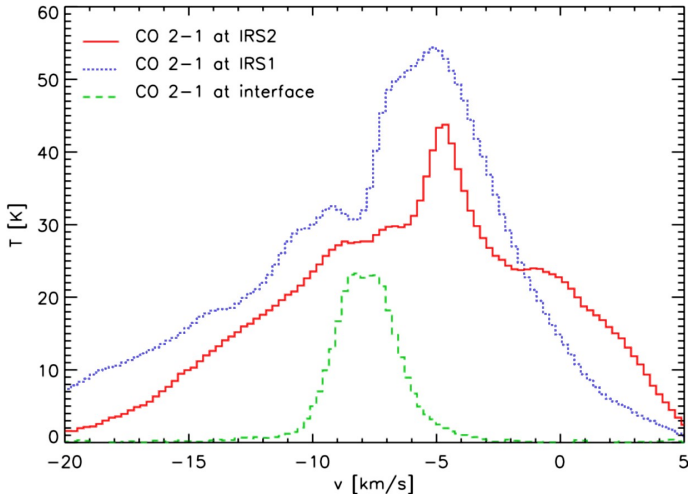
## [OI] with clear self-absorption, [CII] also partially optically thick

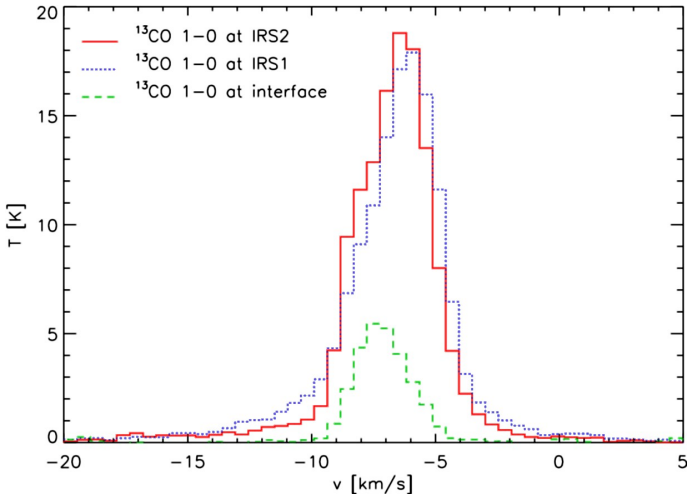
- Different velocity components towards IRS2 and interface+IRS1

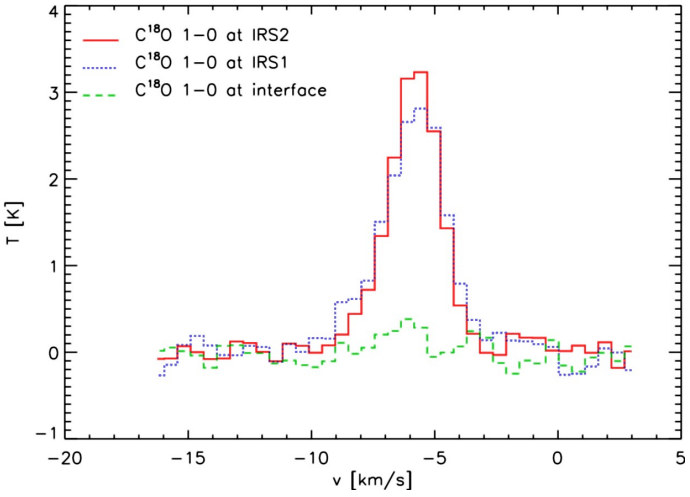


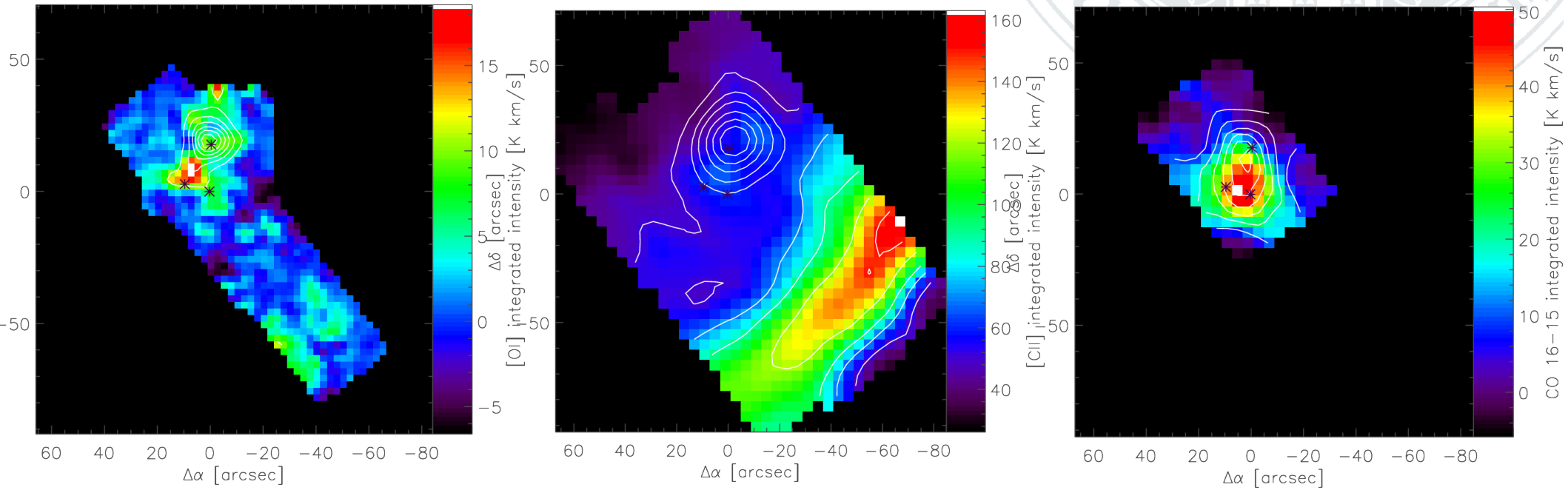



## Fit of peak by Gaussian intensity profile

- Resolved in [OI]: FWHM = 8.3" = 0.03pc, M = 2.3 $M_\odot$
  - [OI]: 76 K km/s, 0.28 $L_\odot$
  - [CII]: 212 K km/s, 0.05 $L_\odot$
  - CO 16-15: 46 K km/s, 0.01 $L_\odot$ - compare embedded heating: 2000 $L_\odot$

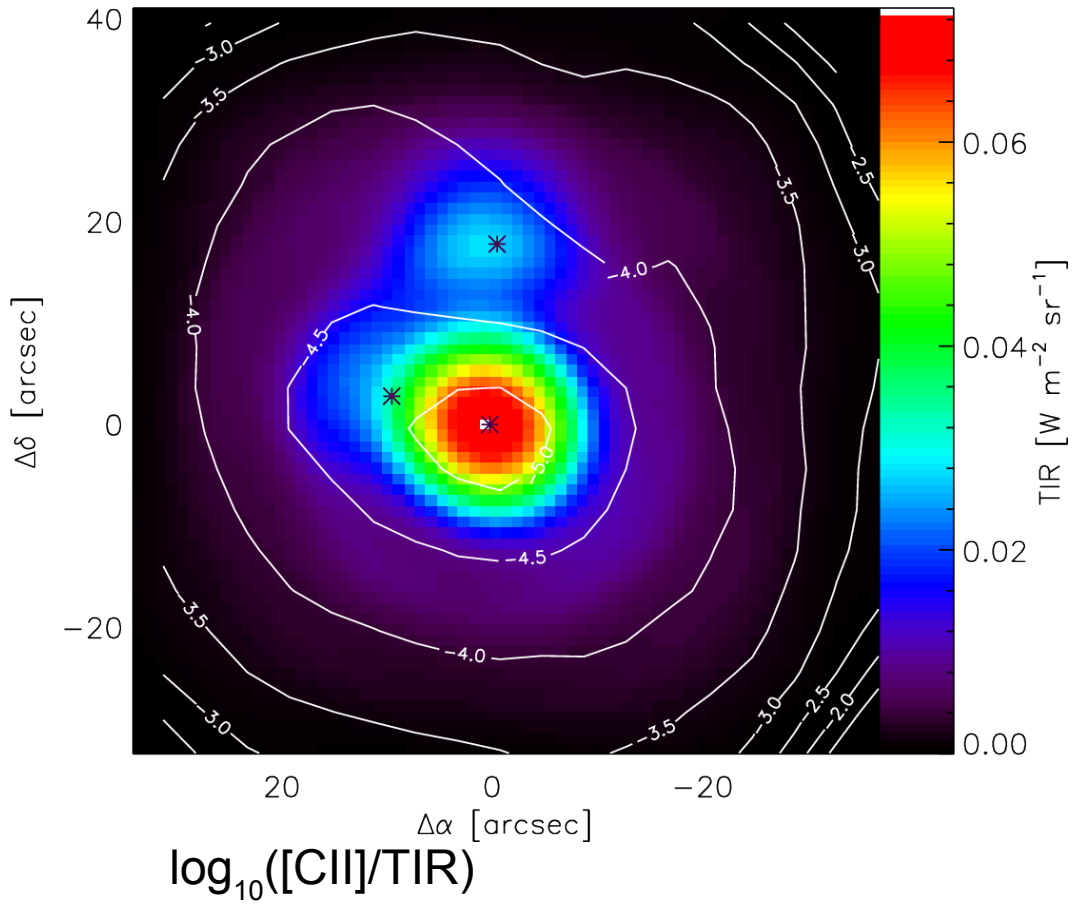



Original maps of [OI], [CII], CO 16-15 (contours) and after source subtraction (colors)

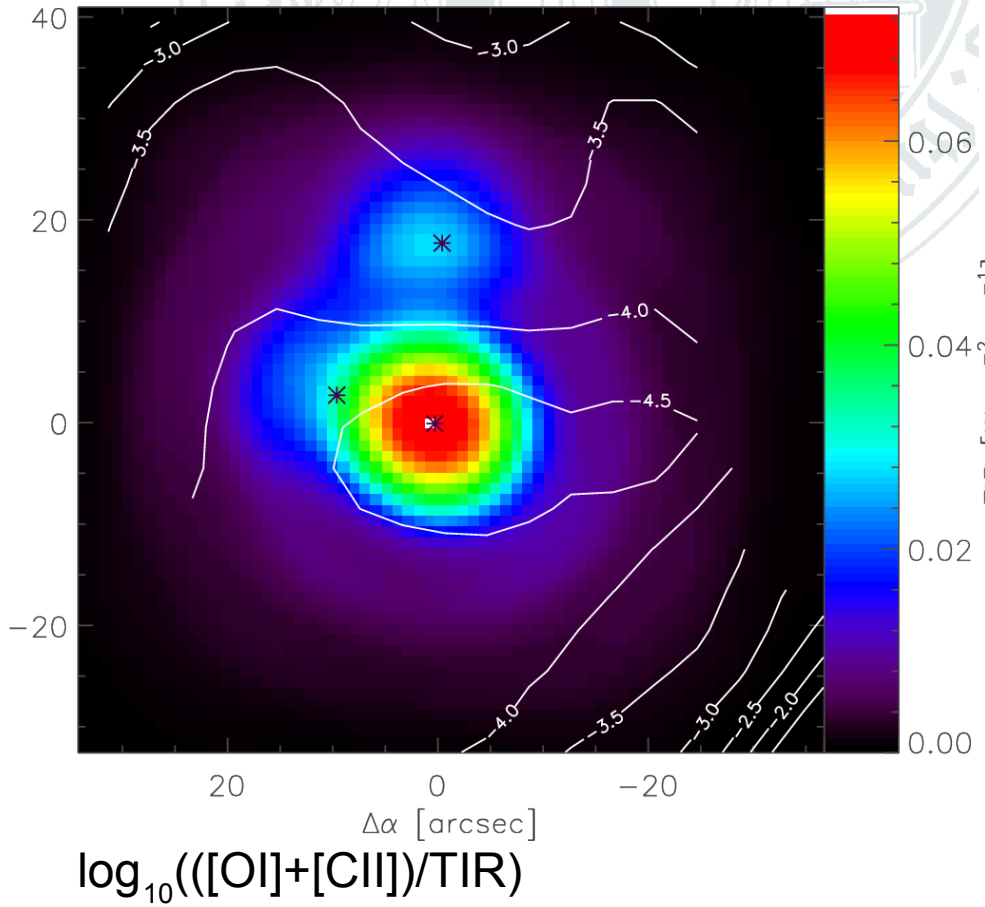
# Cooling balance

## Ratio between line and continuum cooling

- Should measure gas heating efficiency
- IRS1/2/3: **factor 100 lower** than in most PDRs (0.001-0.01- [CII]/TIR)
- Reminiscent of line deficiency in ULIRGS



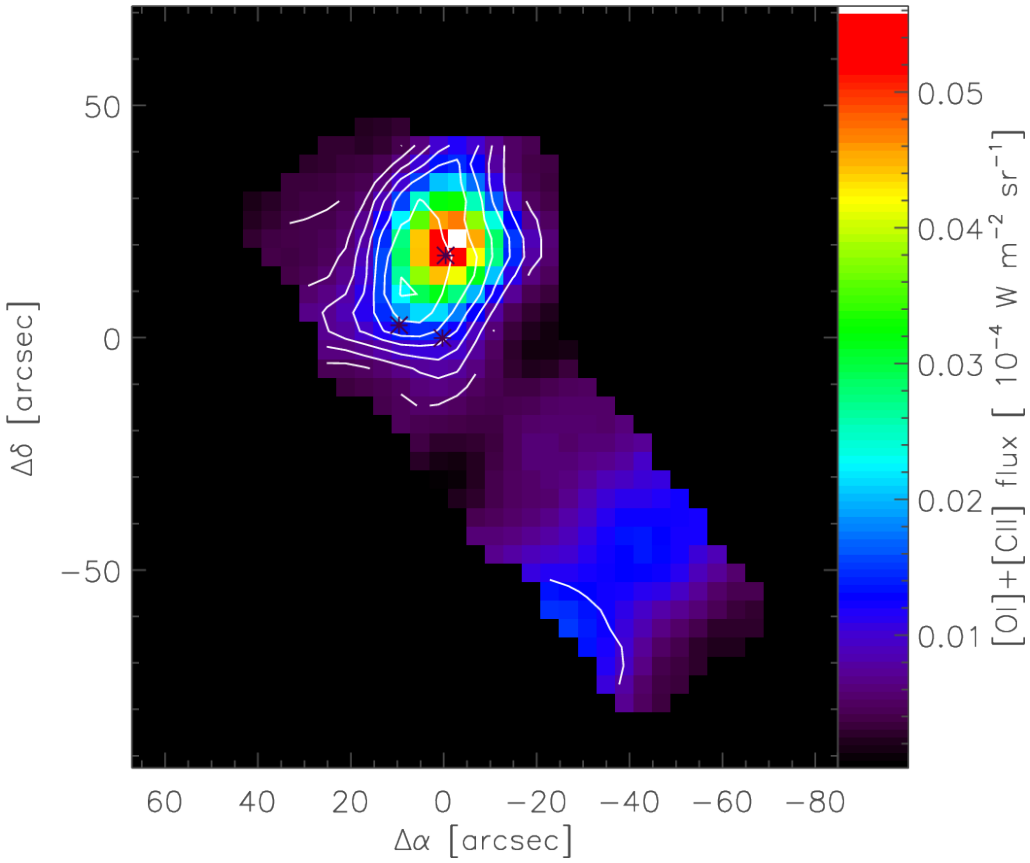

$\log_{10}$([CII]/TIR)

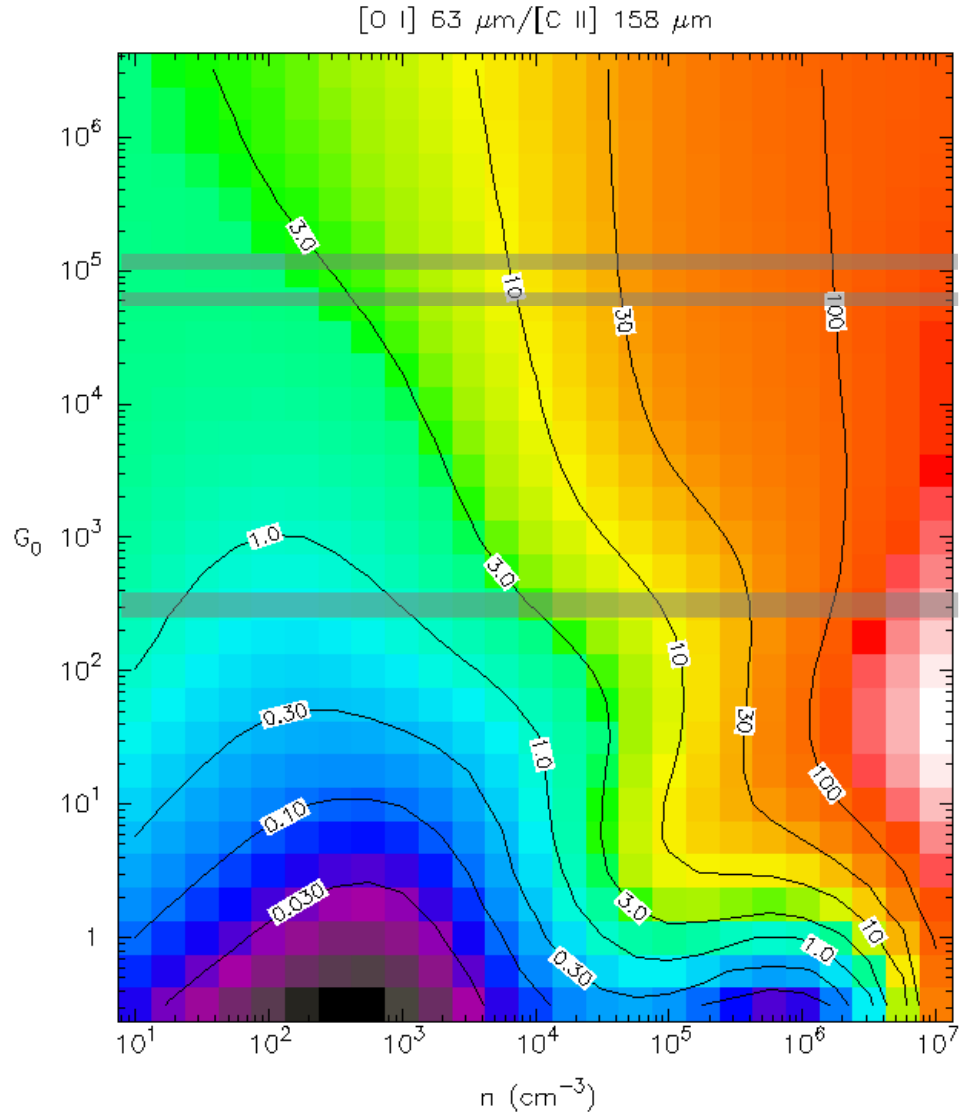



$\log_{10}$(([OI]+[CII])/TIR)

## Comparison with plane-parallel PDR model (Kaufman 1999)

- [OI]/[CII] ratio:
  - 3.0 at IRS1, 2.7 at IRS2
  - 0.3 at interface

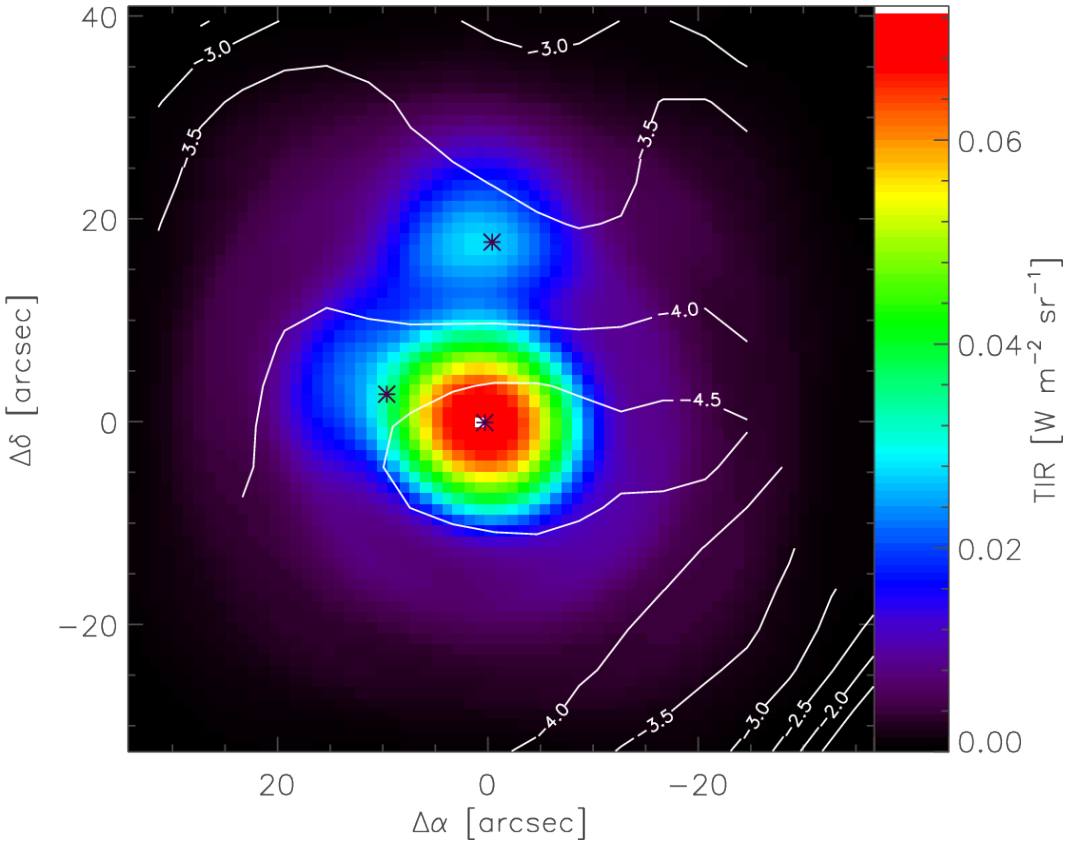


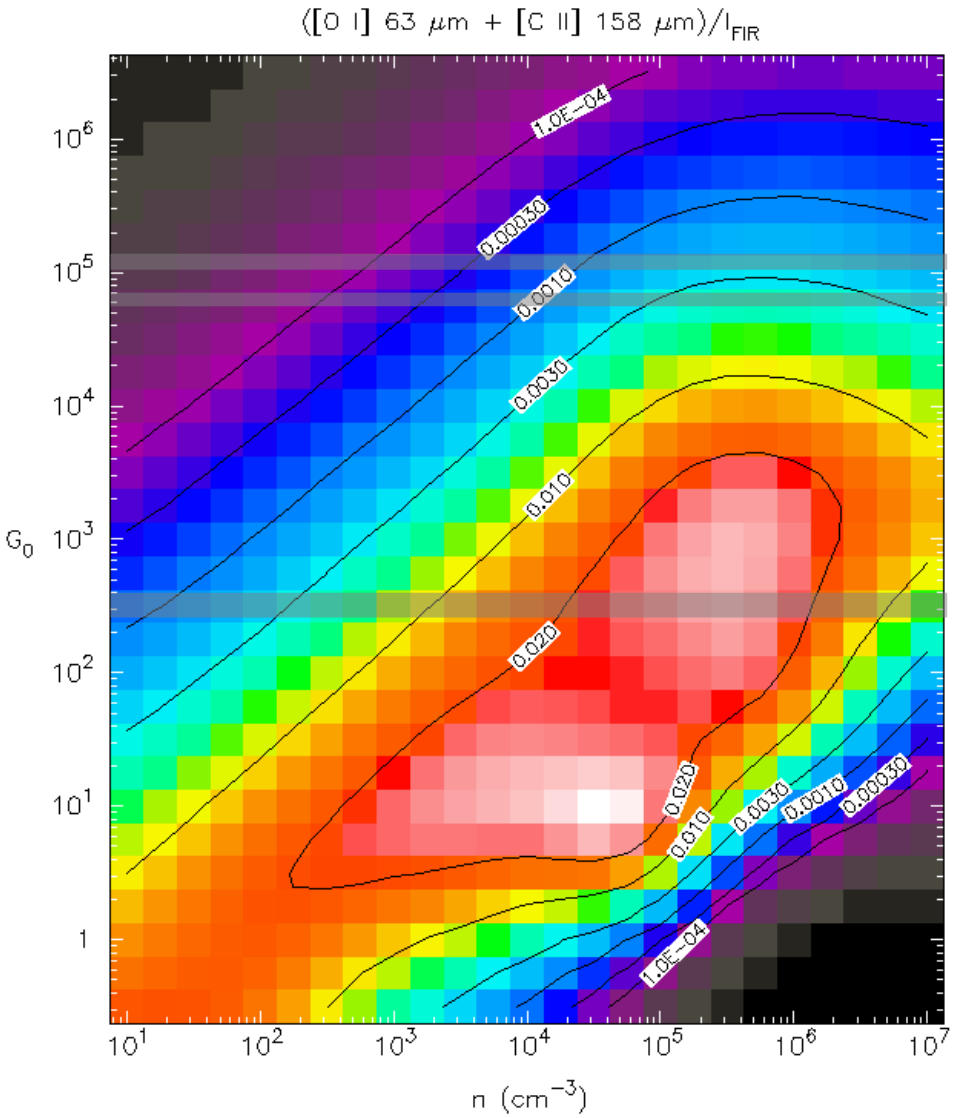




Cooling line strength (colors) [OI]/[CII] ratio (contours from 0.4...2.8)

## Comparison with plane-parallel PDR model (Kaufman 1999)

- ([CII]+[OI])/FIR
  - 2 $10^{-5}$ at IRS1, 2 $10^{-4}$ at IRS2
  - > 0.02 at interface

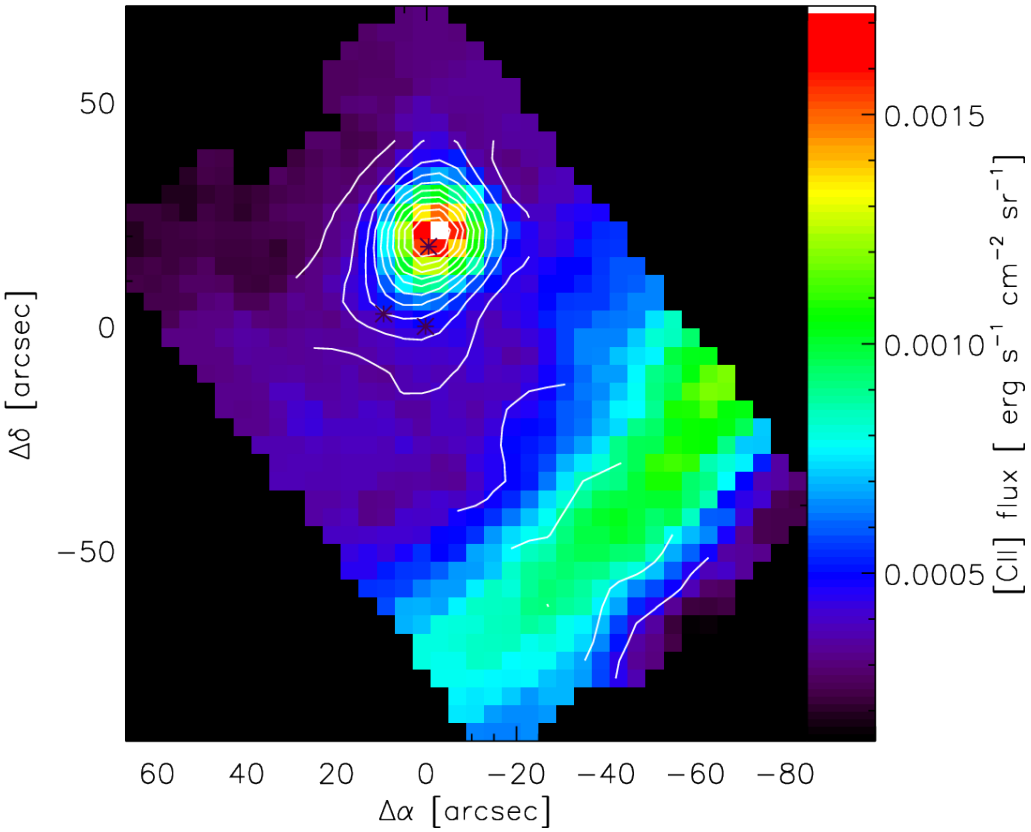


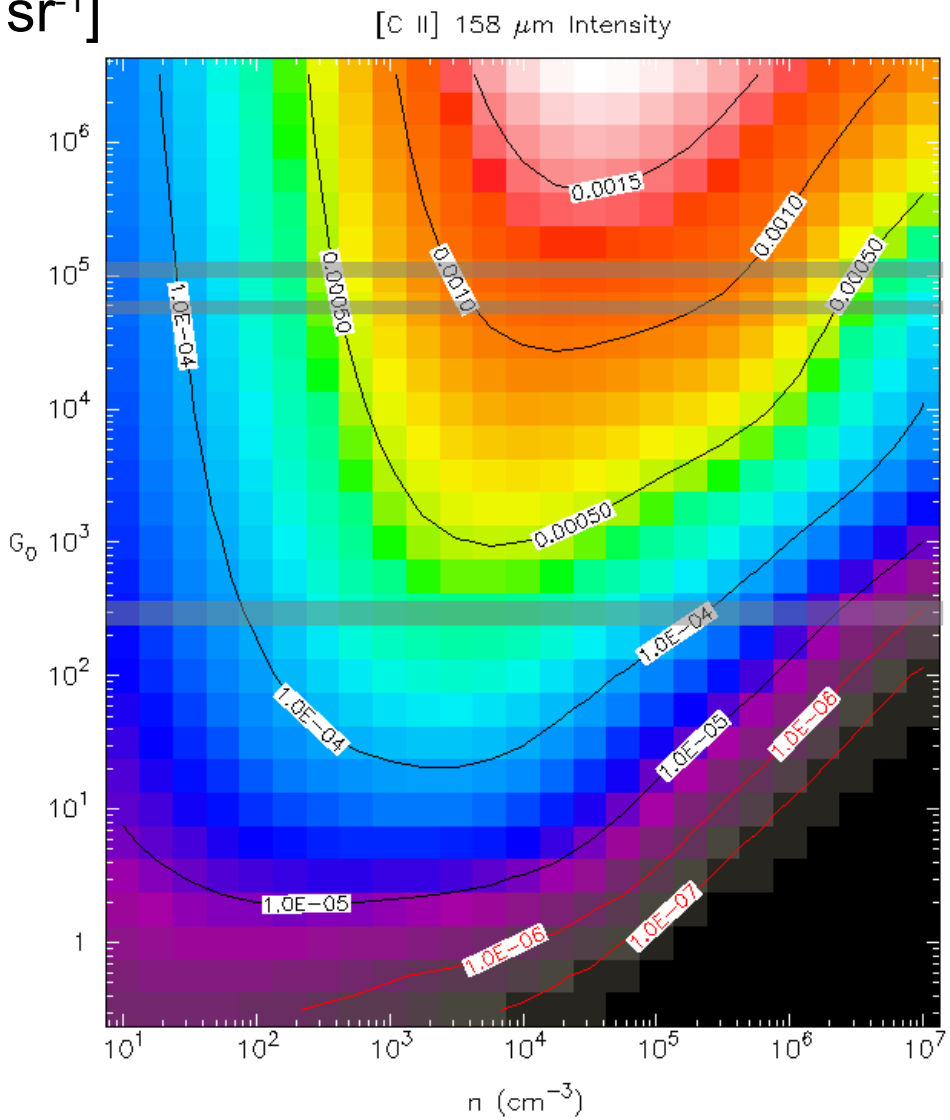




FIR (colors) and $\log_{10}$(([OI]+[CII])/TIR) (contours)

## Comparison with plane-parallel PDR model (Kaufman 1999)

- [CII] integrated intensity [erg $s^{-1}$ $cm^{-2}$ $sr^{-1}$]
  - 0.0005 at IRS1, 0.0017 at IRS2
  - 0.0011 at interface




[CII] intensity (colors) and [OI]+[CII] intensity (contours from 0.0005...0.005)

# Summary

- IRS1:
  - Main energy source of the region produces almost no [CII] and [OI]
  - FS lines suggest density of 300 $cm^{-3}$, but dust emission requires $10^6$ $cm^{-3}$
- IRS2:
  - Prominent [CII] and [OI] peak, spatially resolved
  - Velocity offset from main cloud (-6.5km/s instead of -8 km/s)
  - [CII] intensity requires $10^5$ $cm^{-3}$, dust $10^6$ $cm^{-3}$, [OI] 300 $cm^{-3}$
  - **Please tell me what this source is!**
- Whole cluster:
  - Extremely low line to continuum ratio: **line deficiency**
- Interface:
  - Inclination by 83° needed to explain strong [CII] emission
  - Low [OI] possibly due to density gradient
  - Consistent with external PDR