# NOEMA and NIKA2 synergies

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# Outline

**NOEMA performances vs NIKA2**

- Frequency coverage
- Sensitivities
- Beam sizes / Field of View

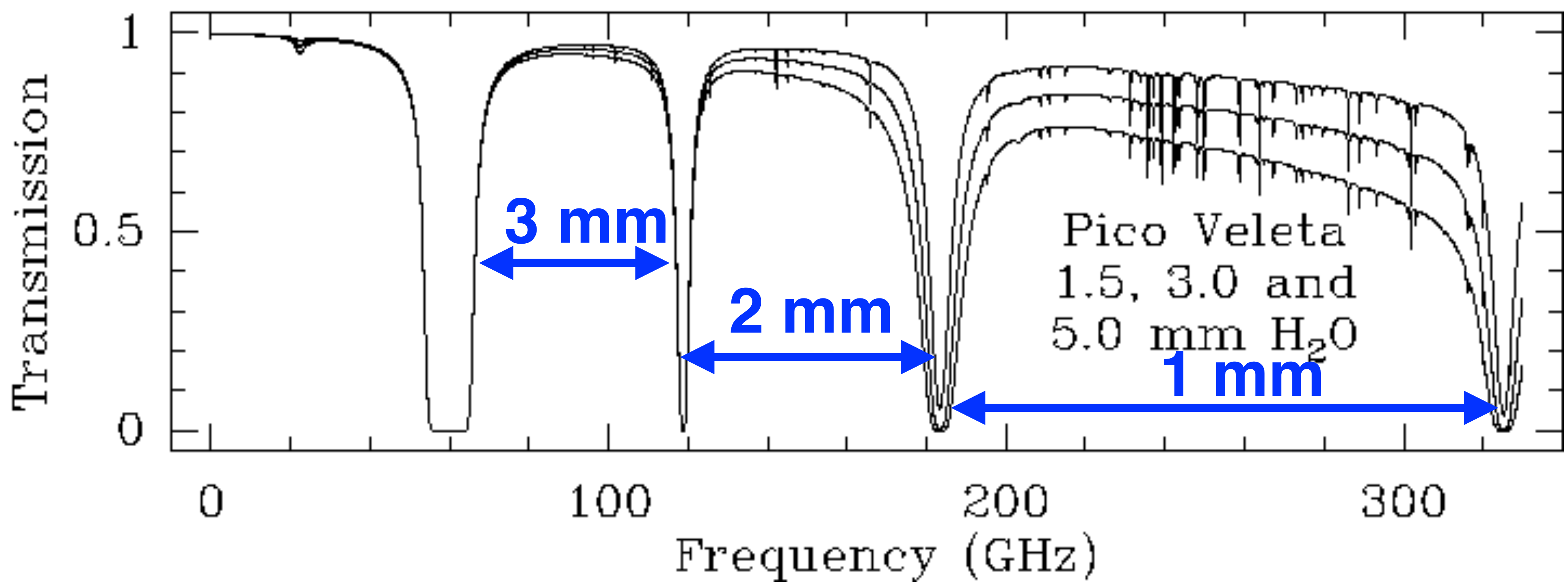
**NOEMA and NIKA2 Synergies:**

- Follow up from large scales to small scales (Massive SF regions)
- Line contamination (Galactic sources and High Redshift Galaxies)
- Point source contamination (Deep Field and SZ)
- NIKA2 as short spacing for NOEMA (Mapping the Interstellar Medium)
- SZ with interferometers (SZ)

# NOEMA frequency ranges

**NOEMA =**
**NOrthern Extended Millimeter Array**

**Observations are possible in atmospheric windows**




| | 3 mm | 2 mm | 1 mm |
|---|---|---|---|
| **NOEMA (GHz)** | 70.384–119.872 | 127.000–182.872 | 196.128–276.000 |

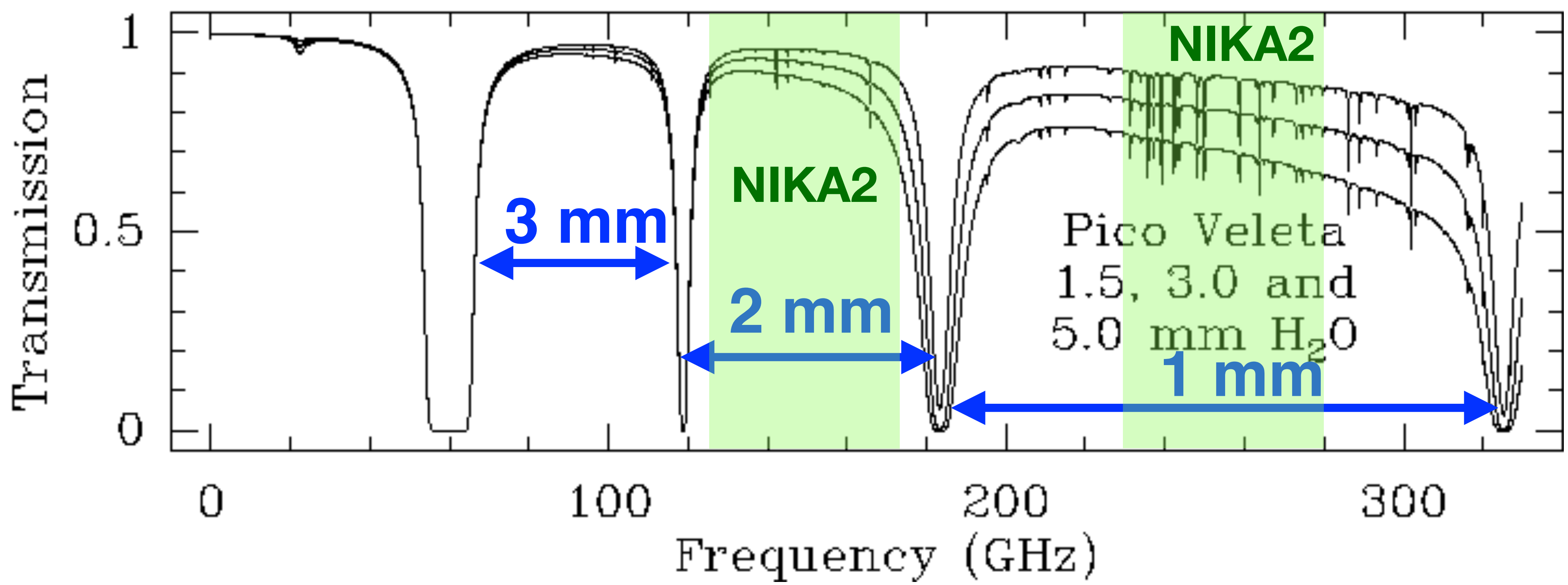
**Frequency range offered for Summer 2019 semester**

# NOEMA frequency ranges

**NOEMA:**
**All frequency range available**
**2 x 15.5 GHz** = 2 polarisations X 2 Side Bands of 7.744GHz each

**NIKA 2:**
**Fixed frequency range**
2mm atmospheric window + part of 1mm window

**Observations are possible in atmospheric windows**

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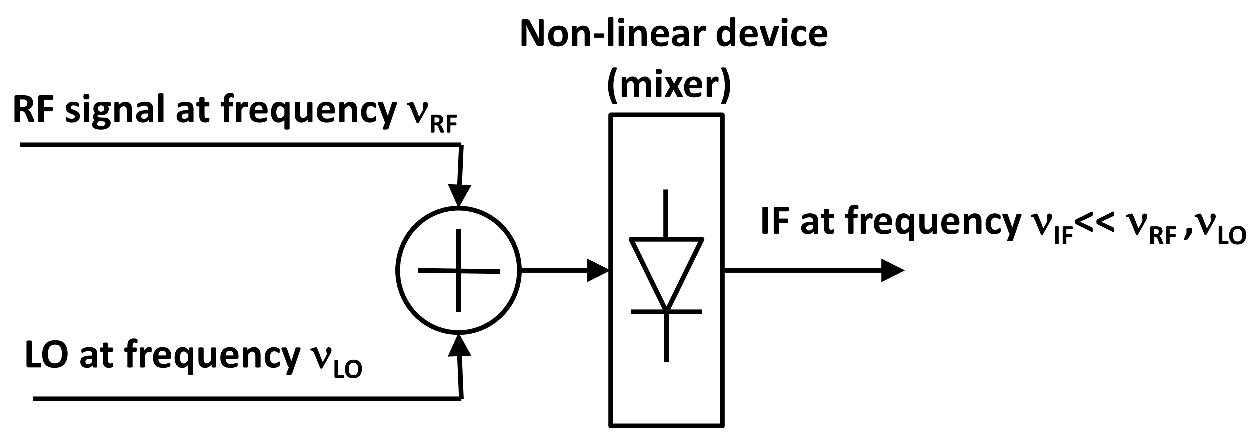
| **NOEMA (GHz)** | 70.384–119.872 | 127.000–182.872 | 196.128–276.000 |
| NIKA2 (GHz) | — | 125 - 175 | 230 - 280 GHz |

# NOEMA frequency ranges vs NIKA2

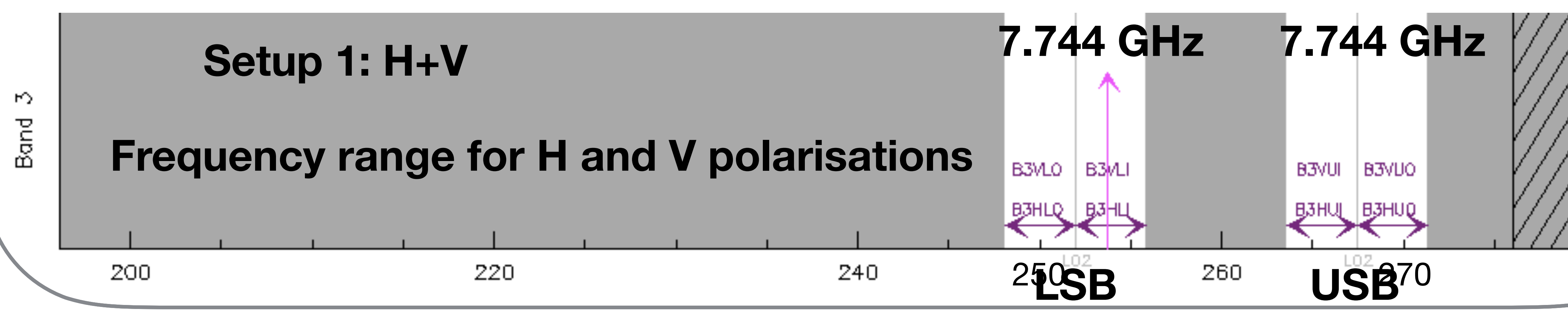




$\nu_{IF} = |\nu_{RF} - \nu_{LO}|$ DSB mixer: Two sidebands, LSB and USB

**Heterodyne Receivers (like EMIR)**

**Simultaneous continuum and line capabilities**



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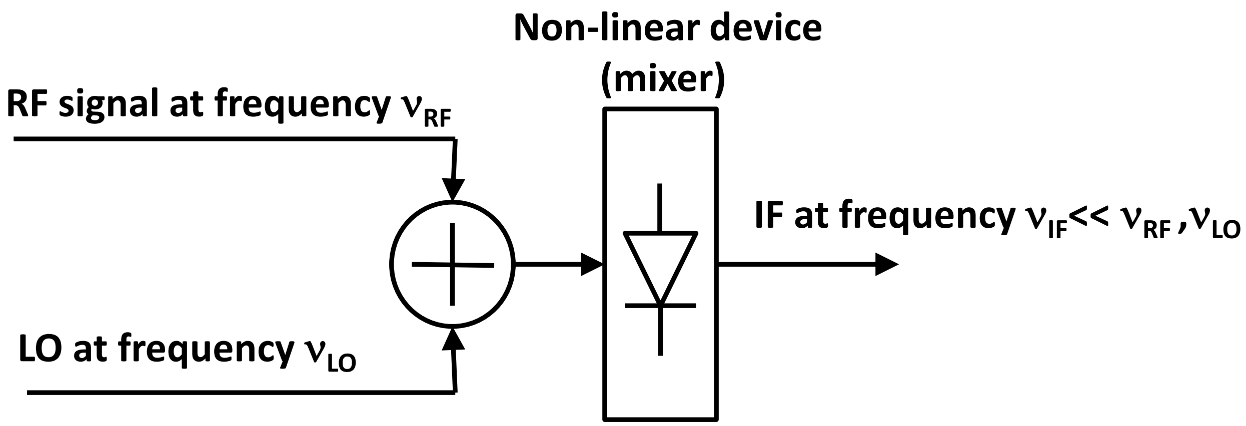
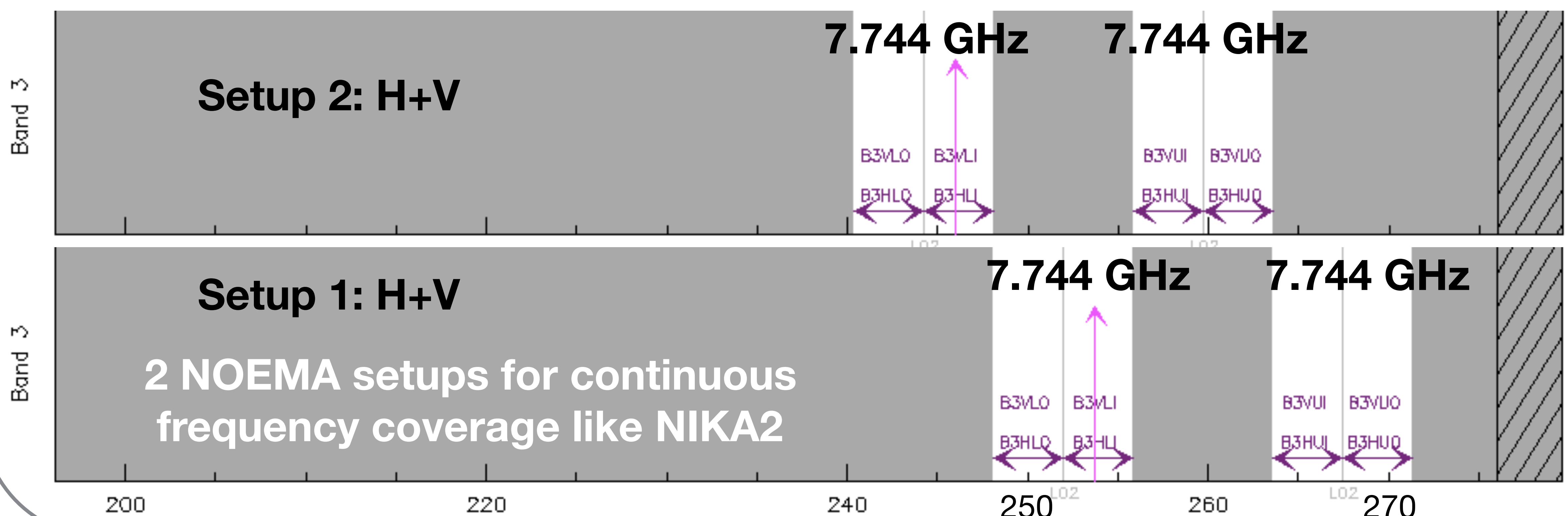



$\nu_{IF} = |\nu_{RF} - \nu_{LO}|$ **DSB mixer: Two sidebands, LSB and USB**

## Heterodyne Receivers (like EMIR)



# CAPABILITIES: Sensitivity

## NOEMA Point source continuum sensitivity with 10 antennas

- @ 150 GHz in a FoV of $33''$ in one hour of observing time with PolyFiX ( 31 GHz):

$$26\,\mathrm{Jy/K}\,.\,\frac{130}{0.85\,.\,\sqrt{90\times 31\,10^9\times 3600}}\simeq 0.04\,\mathrm{mJy/beam}$$

- @ 260 GHz in a FoV of $19''$ in one hour of observing time with PolyFiX ( 31 GHz):

$$33\,\mathrm{Jy/K}\,.\,\frac{220}{0.80\,.\,\sqrt{90\times 31\,10^9\times 3600}}\simeq 0.09\,\mathrm{mJy/beam}$$

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$$33\,\mathrm{Jy/K}\,.\,\frac{220}{0.80\,.\,\sqrt{90 \times 31\,10^9 \times 3600}} \simeq 0.09\,\mathrm{mJy/beam}$$

## NIKA2 Time Estimator (18/02/2019 version):

$$\boxed{t_{total} = \left(\frac{\mathrm{NEFD}_0 \cdot e^{\tau/\sin(el)}}{\sigma} \cdot h_{filter}\right)^2 \times \left(1 + \frac{\Delta_x \cdot \Delta_y}{f_{pix} A_{FoV}}\right) \times h_{overhead}}$$

Ladjelate et al. 2018

$h_{filter}$ = 1.0, $h_{overhead}$ = 1.0, pwv = 2mm, elevation = 25 degrees, Δx . Δy = $A_{FOV}$

$\mathrm{NEFD}_0$ (2 mm) = 8±1 mJy.$s^{1/2}$ **In one hour on source ~0.15 mJy/beam**

$\mathrm{NEFD}_0$ (1.15 mm) = 33±2 mJy.$s^{1/2}$ **In one hour on source ~1.15 mJy/beam**

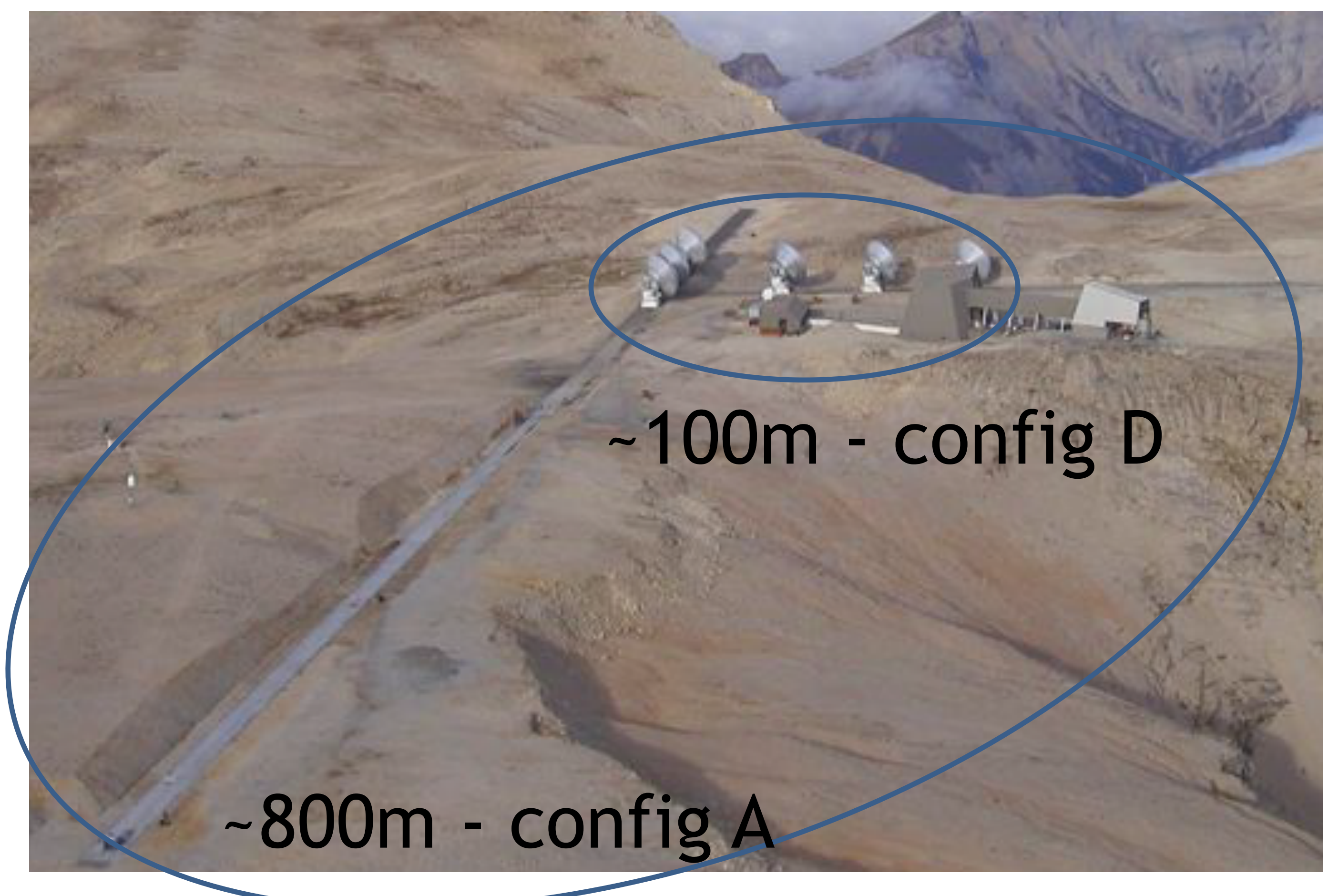
Adam et al. 2018

**NOEMA is much more sensitive but with smaller FoV !**

# But not the same FoV and Beam sizes

| | Bandwidth GHz | FoV | Beam size ($''$) A | C | D |
|---|---|---|---|---|---|
| NOEMA 2 mm | 127 – 183 | $33''$(150 GHz) | 0.6 | 1.3 | 2.6 |
| NIKA2 2 mm | 125 – 175 | $6.5'$ | 17.7 | | |

| | | | | | |
|---|---|---|---|---|---|
| NOEMA 1 mm | 196 – 276 | $19''$(260 GHz) | 0.35 | 0.75 | 1.5 |
| NIKA2 1 mm | 230 – 280 | $6.5'$ | 11.2 | | |



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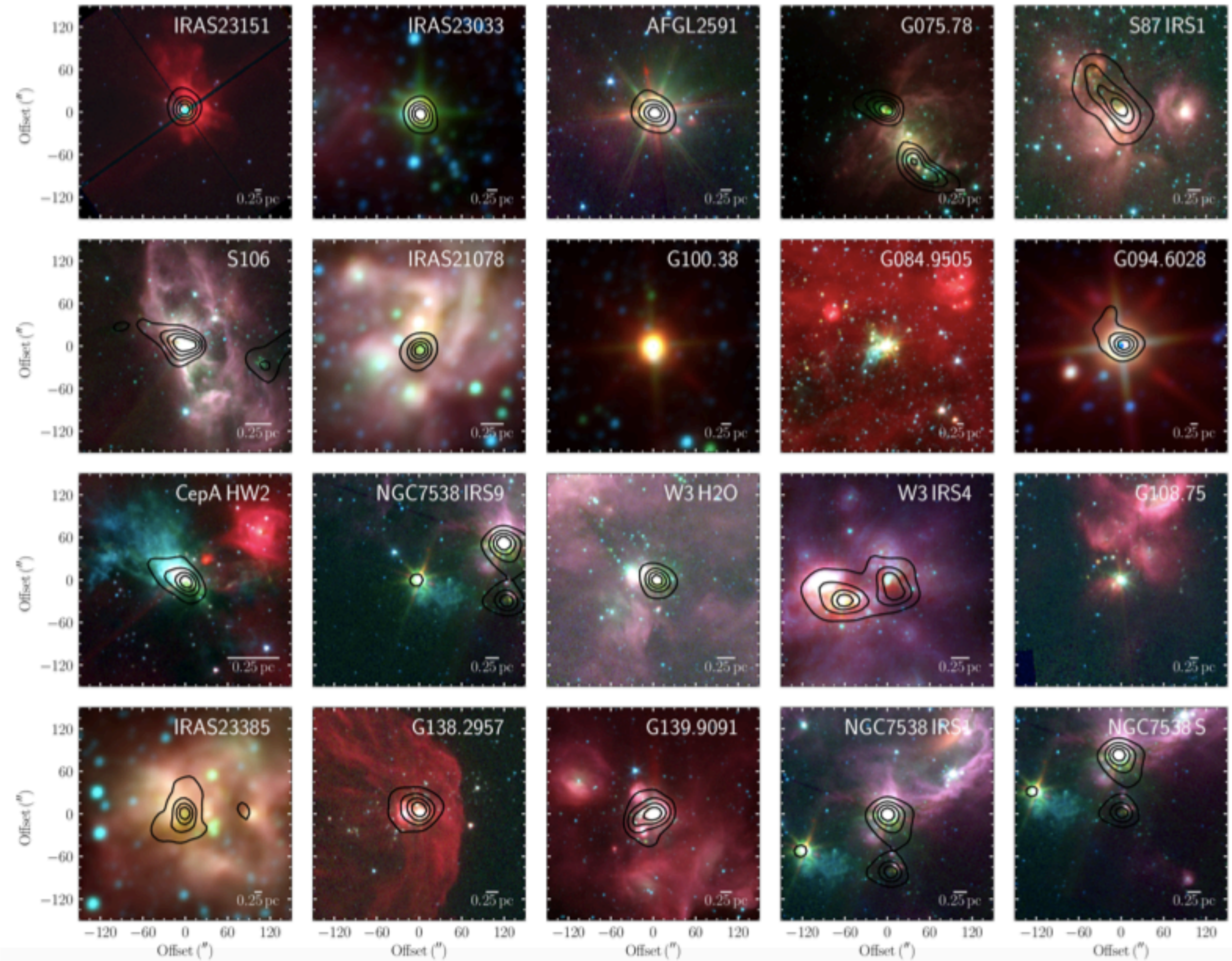
# Follow up: zooming in SF regions of galaxies

Colors
= **Spitzer**

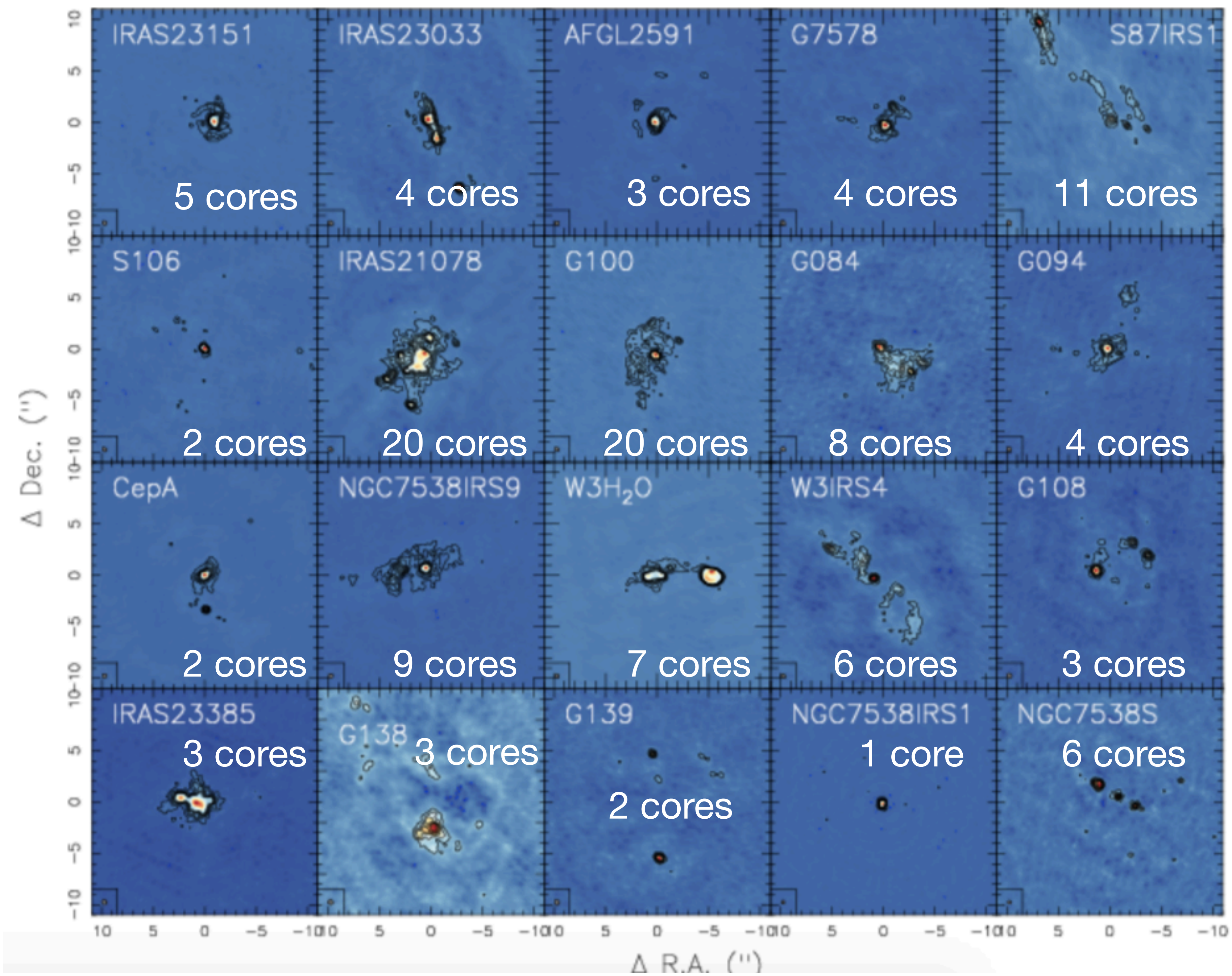
Black
Contours
= **850 µm**
**SCUBA**




Sample
of high mass
star forming
regions

How do form massive stars?
Massive star-forming regions (proto-clusters) embedded within their natal cores (mm)
Initial massive cores mass function vs IMF (stellar mass function of final stars)

# Follow up: zooming in SF regions of galaxies



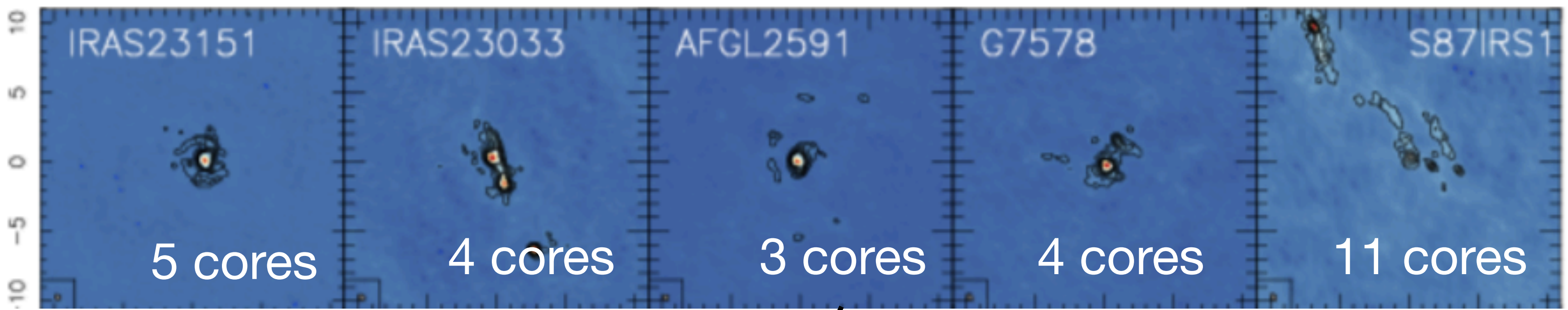

**Maps at 1.37 mm**

IRAM 30m > 20 hours
NOEMA (A, B, D configs) ~ 18 hours per source

**~ 0.4” beam size**
**~1000 AU**
**at 3kpc**

**CORE program :** Fragmentation of high-mass star forming cores
H. Beuther et al. (2018)

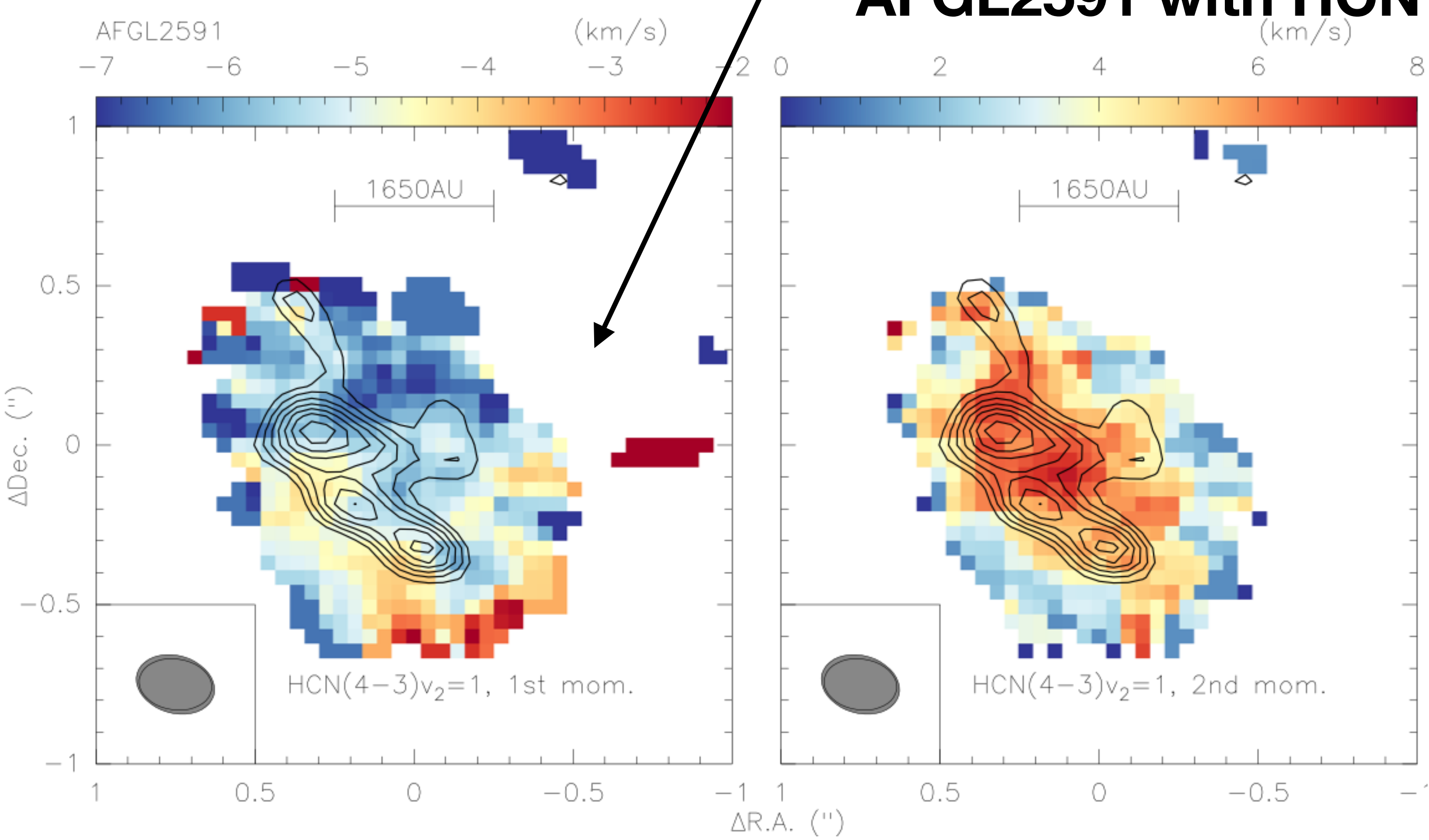
# Follow up: zooming in SF regions of galaxies




**Maps at 1.37 mm**

IRAM 30m > 20 hours
NOEMA (A, B, D configs) ~ 18 hours per source

**AFGL2591 with HCN**




**+ 0.8 mm (band 4)**
**+ kinematic with lines (HCN)**

**~ 0.2” beam size**
**~ 500 AU**
**at 3kpc**

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# Line contamination for Galactic sources

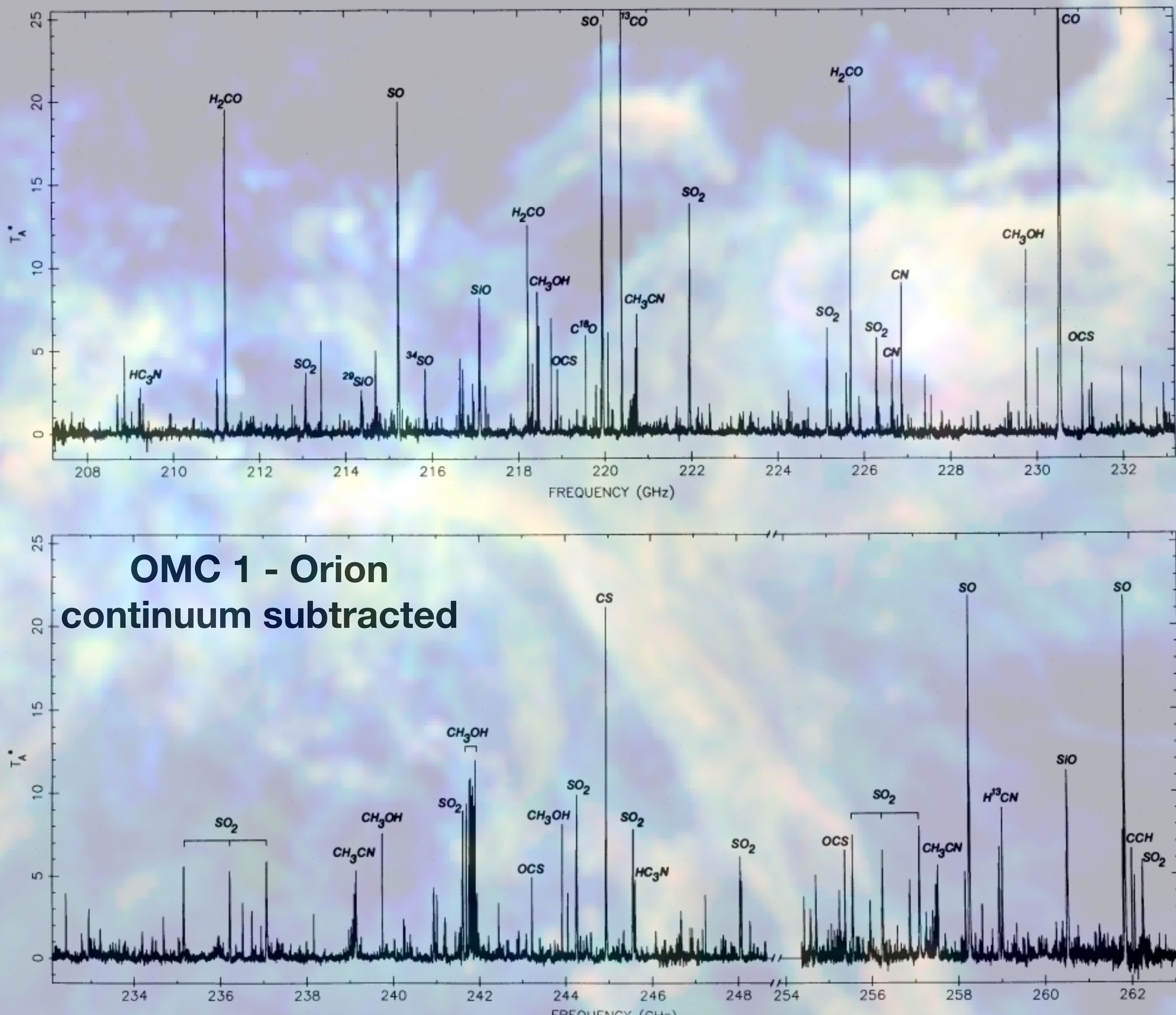



FIG. 1.—Compressed view of the OVRO spectral line survey of OMC-1

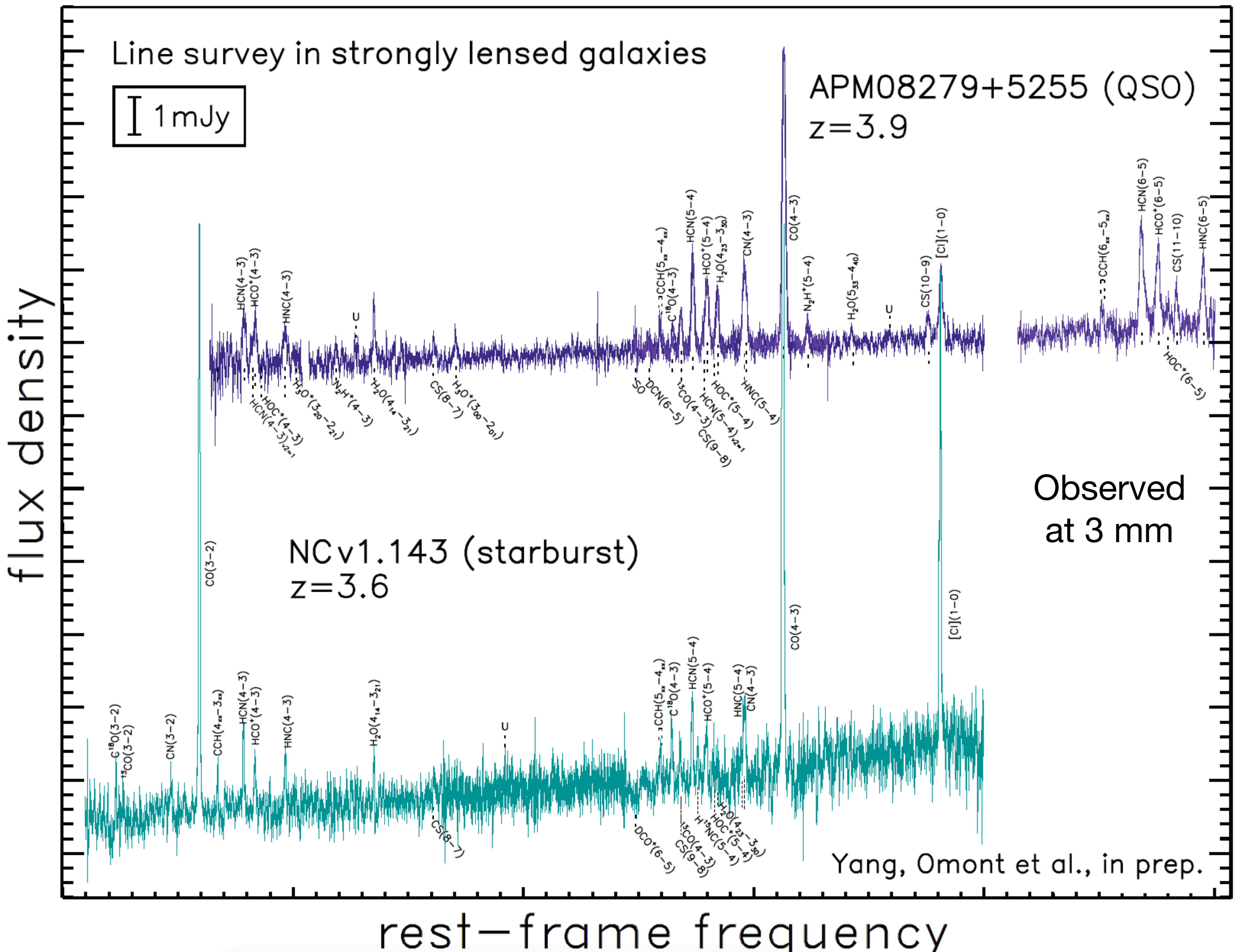
More sensitivity

= More molecules detected

NOEMA can help to estimate line contamination apart from CO

Will depend on excitation conditions (temperature, shocks, etc)

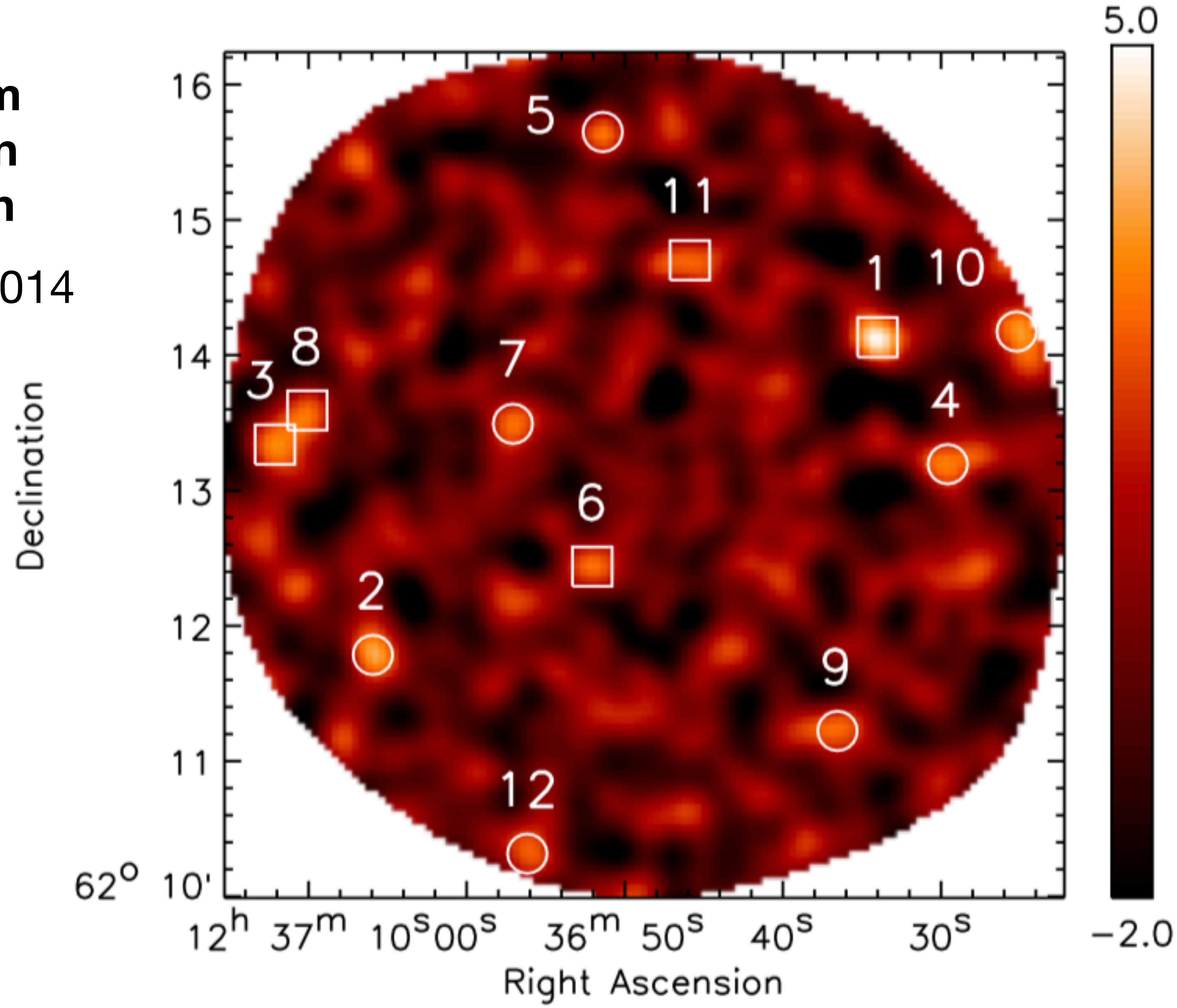
# Line contamination for High-z sources



# Point source contamination - Deep Field

**GISMO 2 mm Deep Field in Goods North**

Staguhn et al. 2014

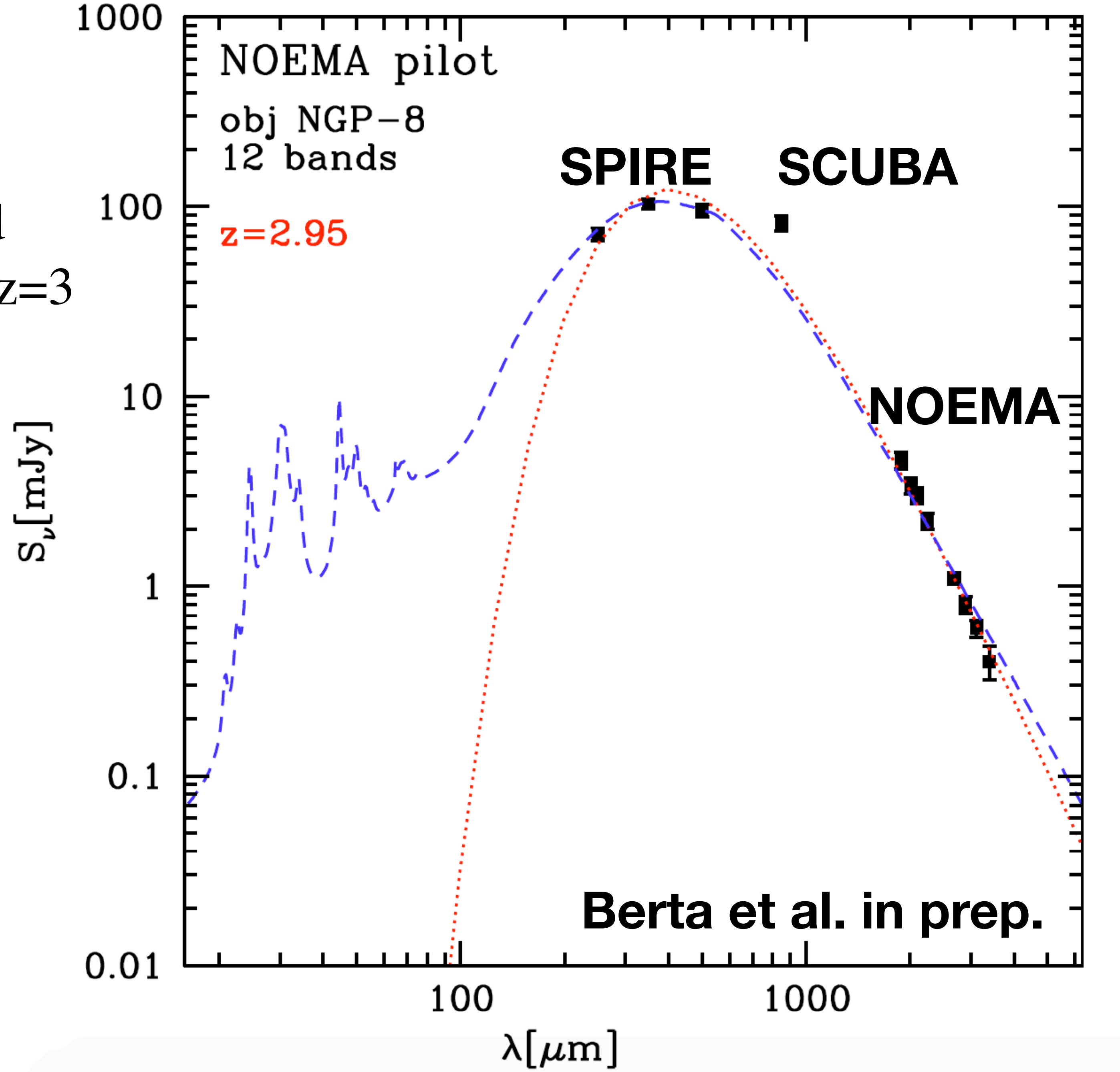



12 sources extracted + 3 more with correlations with known sources at 1.2 mm and 850 μm

**Maps were smoothed**
**from 17. 5" FWHM to an effective 24. 7" FWHM image resolution**
**for point-source extraction.**

# Point source SEDs with NOEMA

Herschel selected gravitational lens at z=3




**~ 1 hour on source: Flux accuracy of 10%**

**NOEMA complementarity :**

- Point source identification
- Flux measurement without extrapolation e.g. from Herschel (SZ)
- Estimate other contributions thanks to 3 mm band: Free-free, synchrotron

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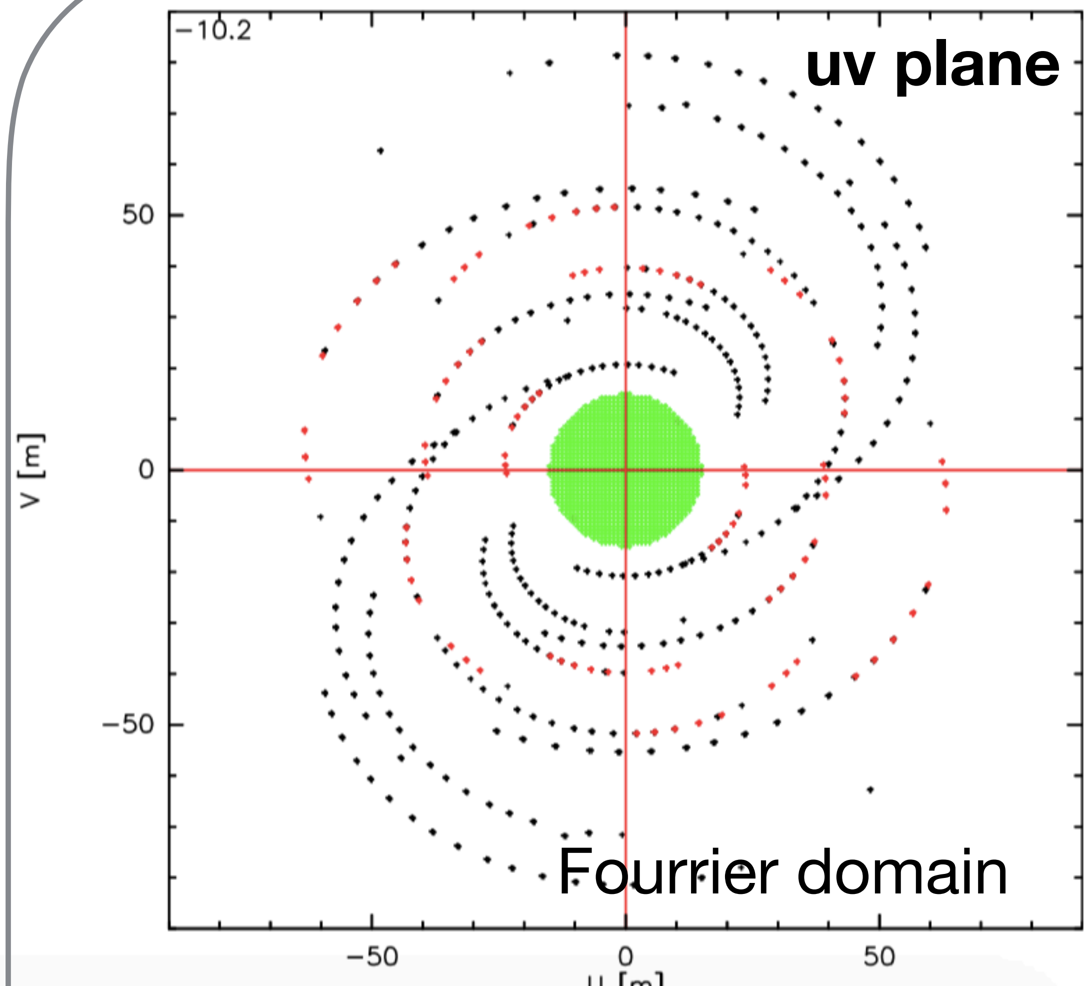
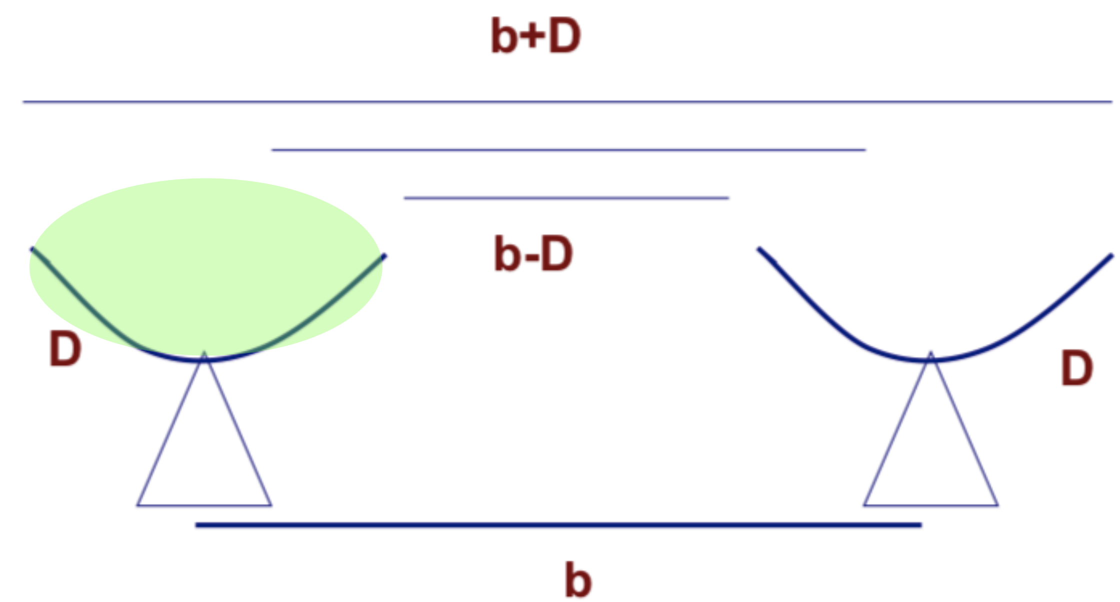
# Short spacing




**Single-Dish:** sensitive to spatial frequencies from 0 to D

**Interferometer:** sensitive to spatial frequencies from b-D to b+D



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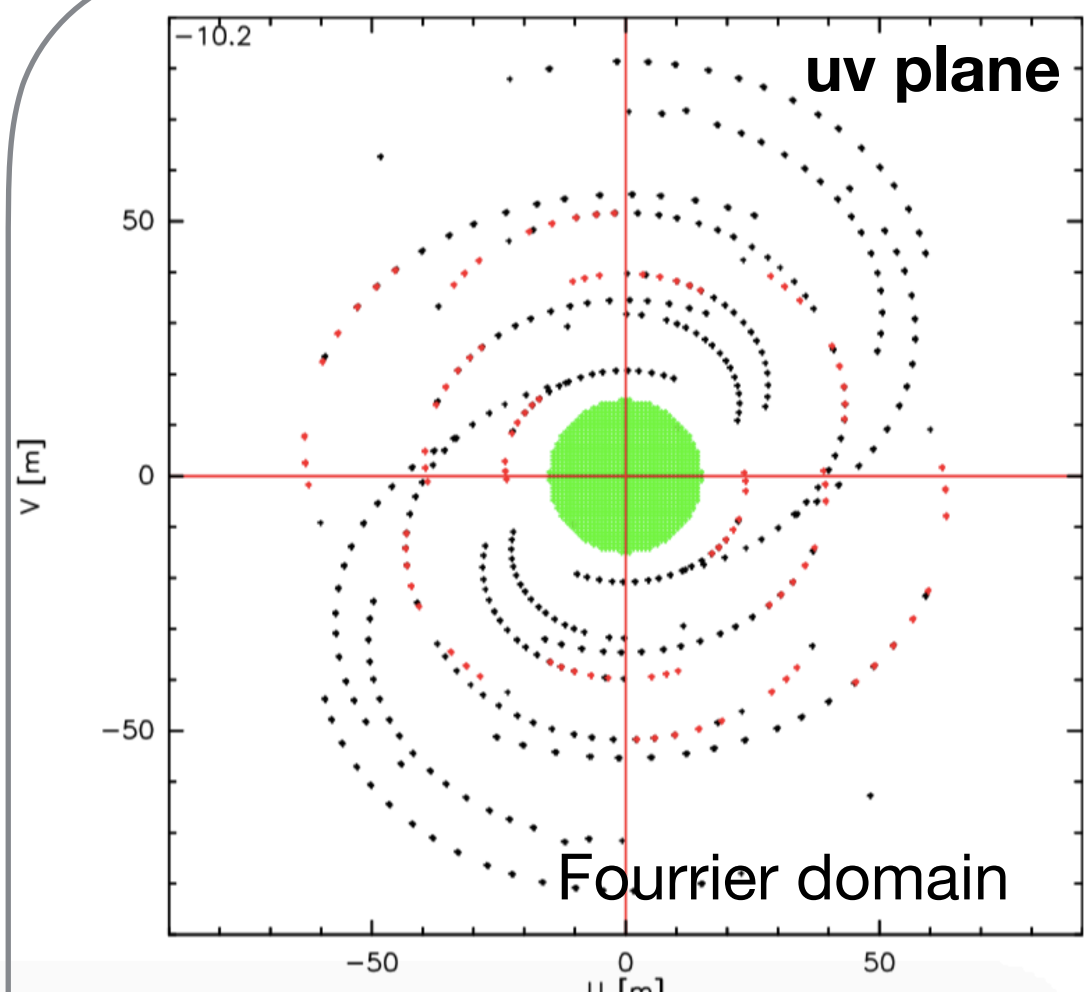


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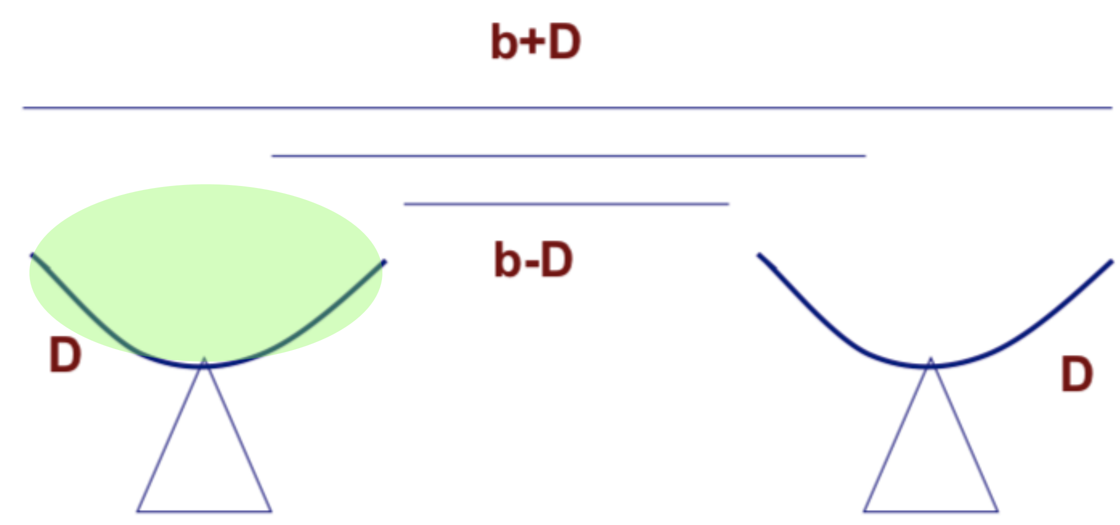
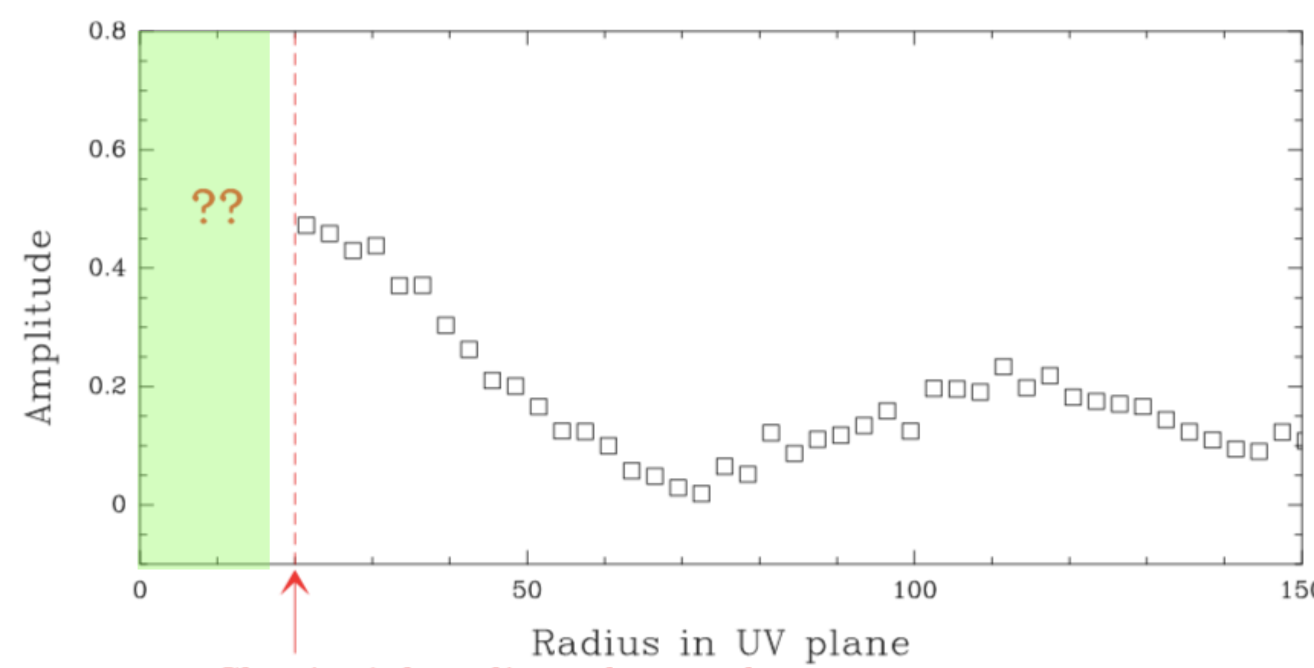
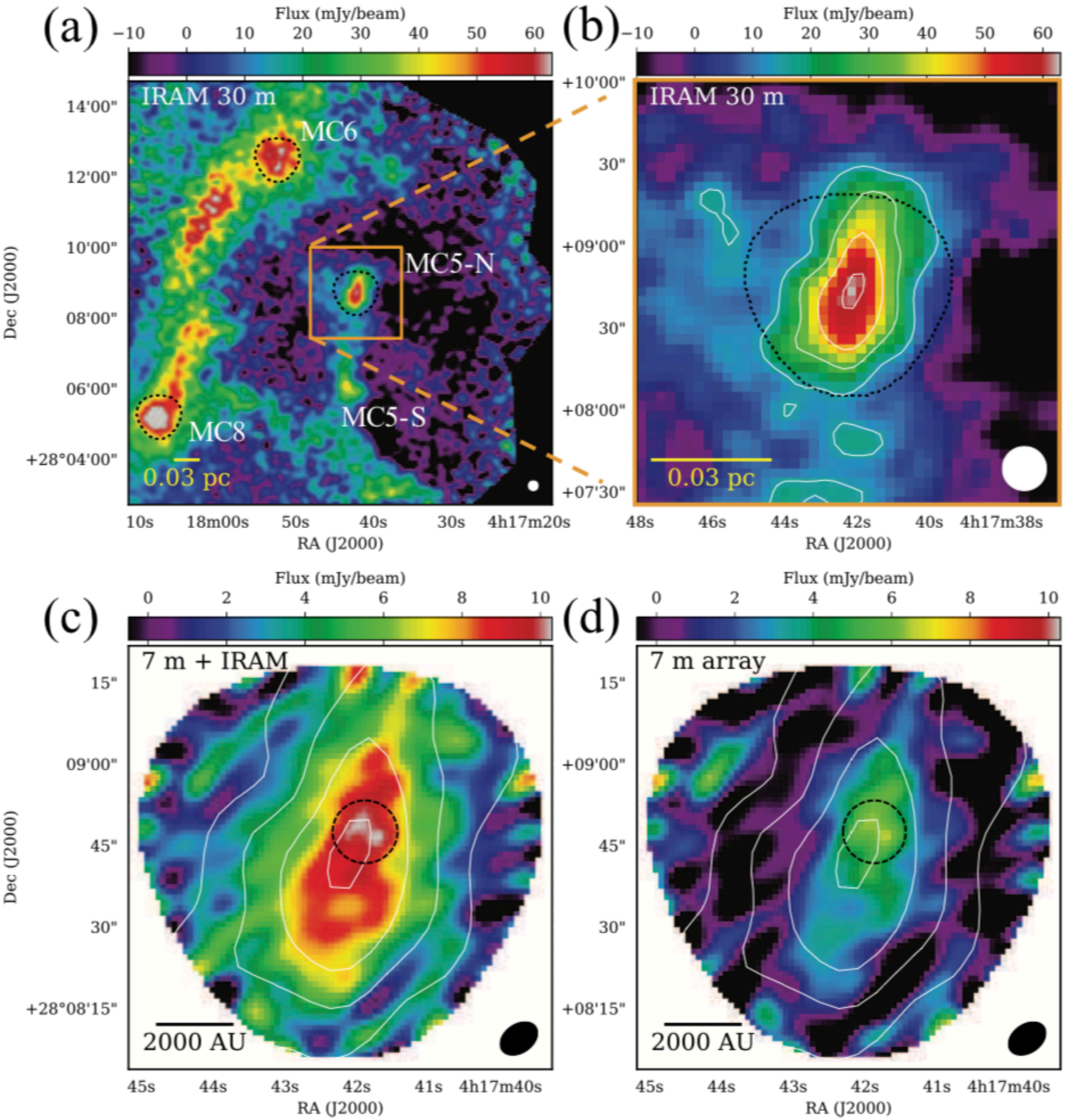



Smaller Radius in uv plane corresponds to extended structures in image plane



# Example of Short-spacing IRAM 30m MAMBO2 + ACA




IRAM 30m MAMBO2 (117 pixels)
P.I. : André

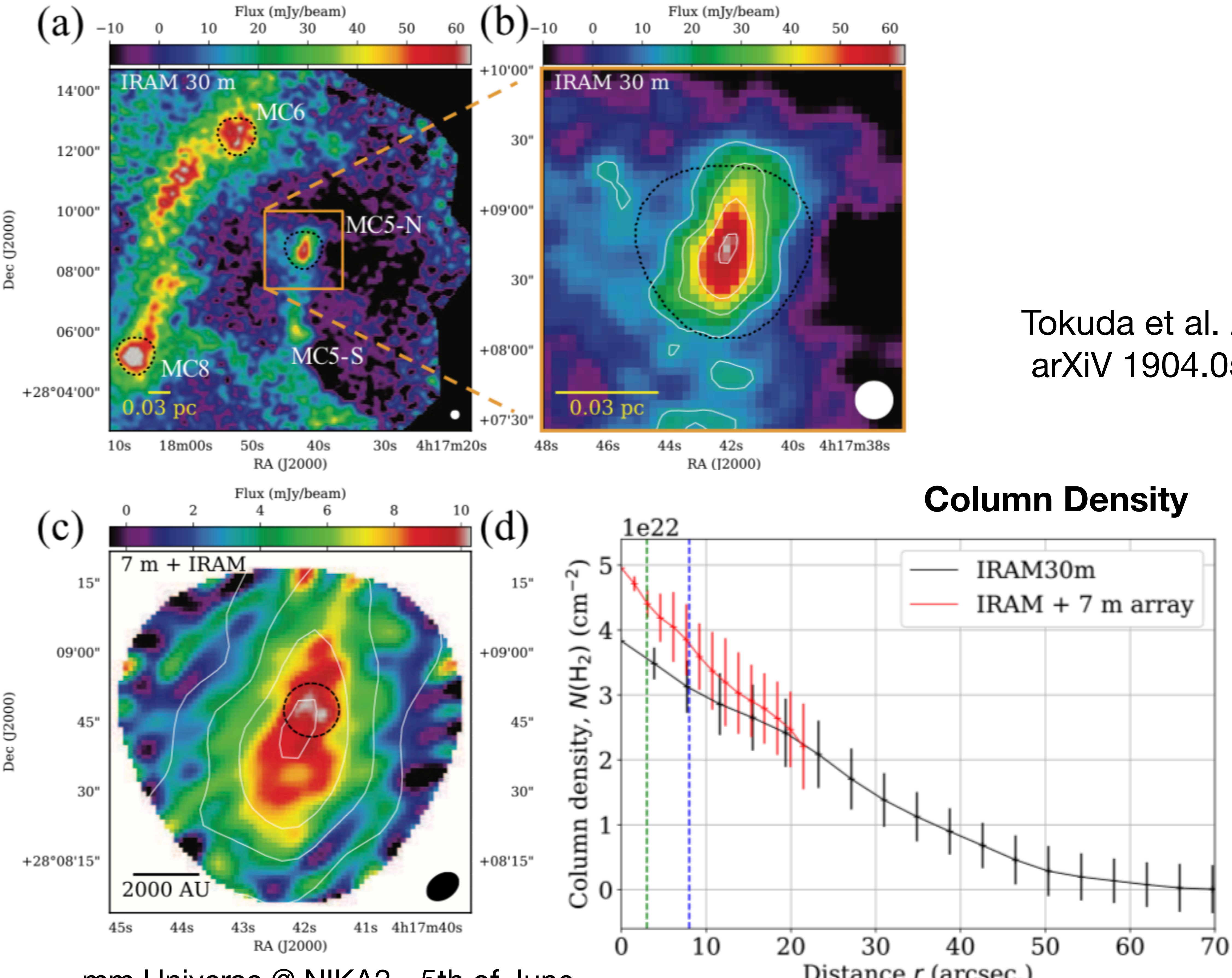
**A centrally concentrated sub-solar mass starless core in the Taurus L1495 filamentary complex**

Tokuda et al. 2019
arXiV 1904.05490

ALMA Compact Array 7m

# Example of Short-spacing IRAM 30m MAMBO2 + ACA

**Column Density**




Tokuda et al. 2019
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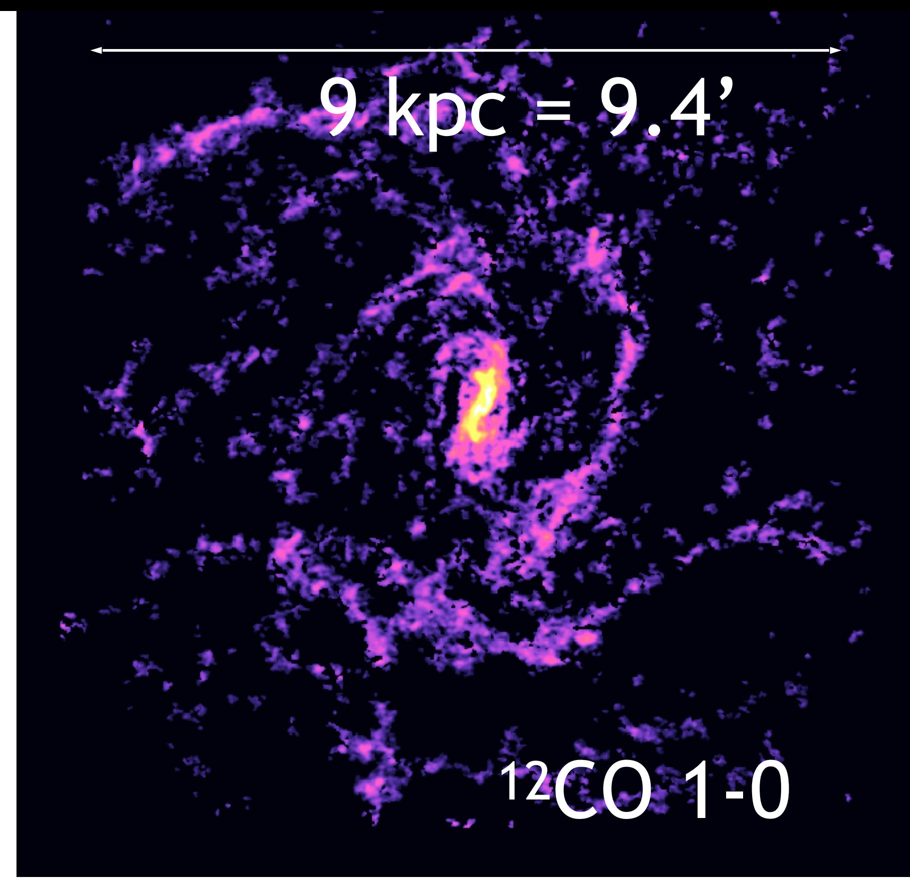
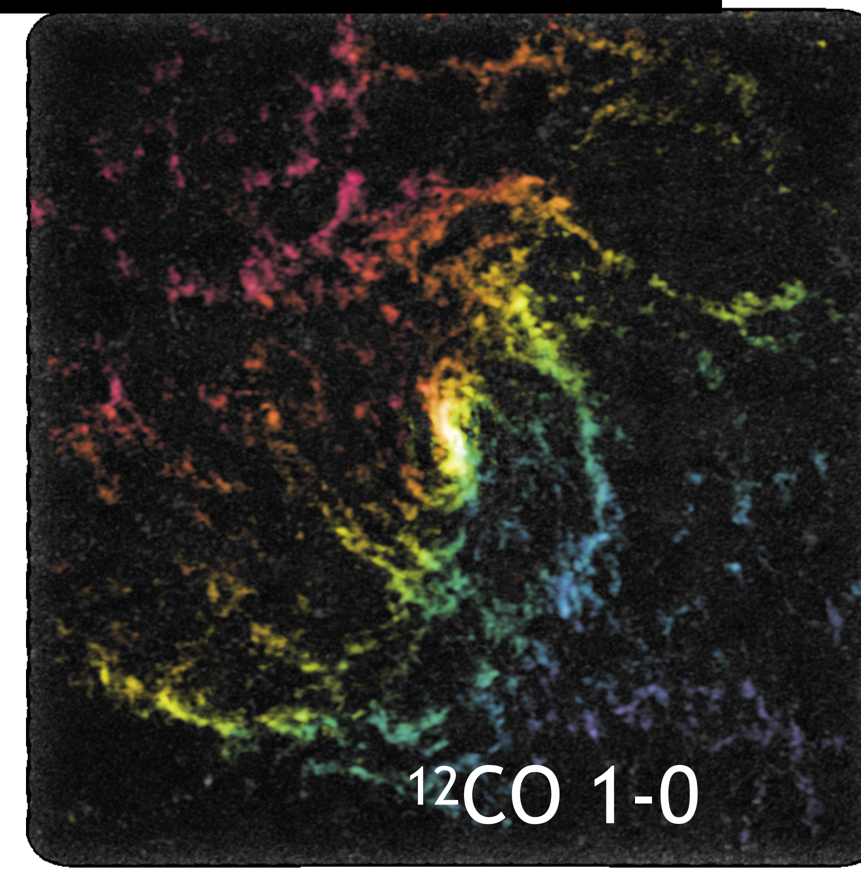
# NOEMA capabilities for Mosaics increased




Molecular clouds in IC342 - PI A.Schruba (MPE) at 3 mm

- ➢ D = 3.3 Mpc, M(gas) = $10^{10}$ $M_\odot$, SFR = 1.9 $M_\odot$/yr
- ➢ NOEMA + IRAM 30m cover 70% of the SF disk
- ➢ NOEMA = 1250-field mosaic, 60 pc resolution = 3.8”
- ➢ 1500 molecular clouds with S/N > 5

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- **SZ with interferometers (SZ)**

# SZ with interferometers

| Name | Location | $N_{dish}$ | Frequency (GHz) | Bandwidth (GHz) | Primary beam | $\ell$ | Reference |
|---|---|---|---|---|---|---|---|
| OVRO | U.S. | 6 | 30 | 2.0 | $4'$ | 6750 | [1] |
| VLA | U.S. | 27 | 8 | 0.2 | $5'$ | 6000 | [5, 15] |
| IRAM | France | 3 | 88 | 0.4 | $55''$ | 3000–70000 | [20] |
| Ryle | England | 8 | 15 | 0.4 | $6'$ | 4500 | [8] |
| BIMA | U.S. | 10 | 30 | 0.8 | $6'$ | 5000–9000 | [3] |
| ATCA | Australia | 6 | 9 | 0.1 | $8'$ | 3400 | [25] |
| T-W | U.S. | 2 | 43 | ... | $2^\circ$ | 20–100 | [27] |
| IAC-Int | Tenerife | 2 | 33 | 0.5 | $2^\circ$ | 110–220 | [7] |
| CAT | England | 3 | 13–17 | 0.5 | $2^\circ$ | 339–722 | [24] |
| VSA | Tenerife | 14 | 26–36 | 1.5 | $4.^\circ6/2.^\circ1$ | 150–1600 | [4] |
| DASI | South Pole | 13 | 26–36 | 10.0 | $3^\circ$ | 125–700 | [6, 9] |
| CBI | Chile | 13 | 26–36 | 10.0 | $45'/28'$ | 630–3500 | [14, 22, 26] |
| SZA | U.S. | 8 | 30 & 90 | 8 | $12'/4'$ | 4000 | [23, 12] |

**Dickinson (2012, arXiv 1212.1729)**

**+ ALMA (cf E. Pointecouteau talk)**

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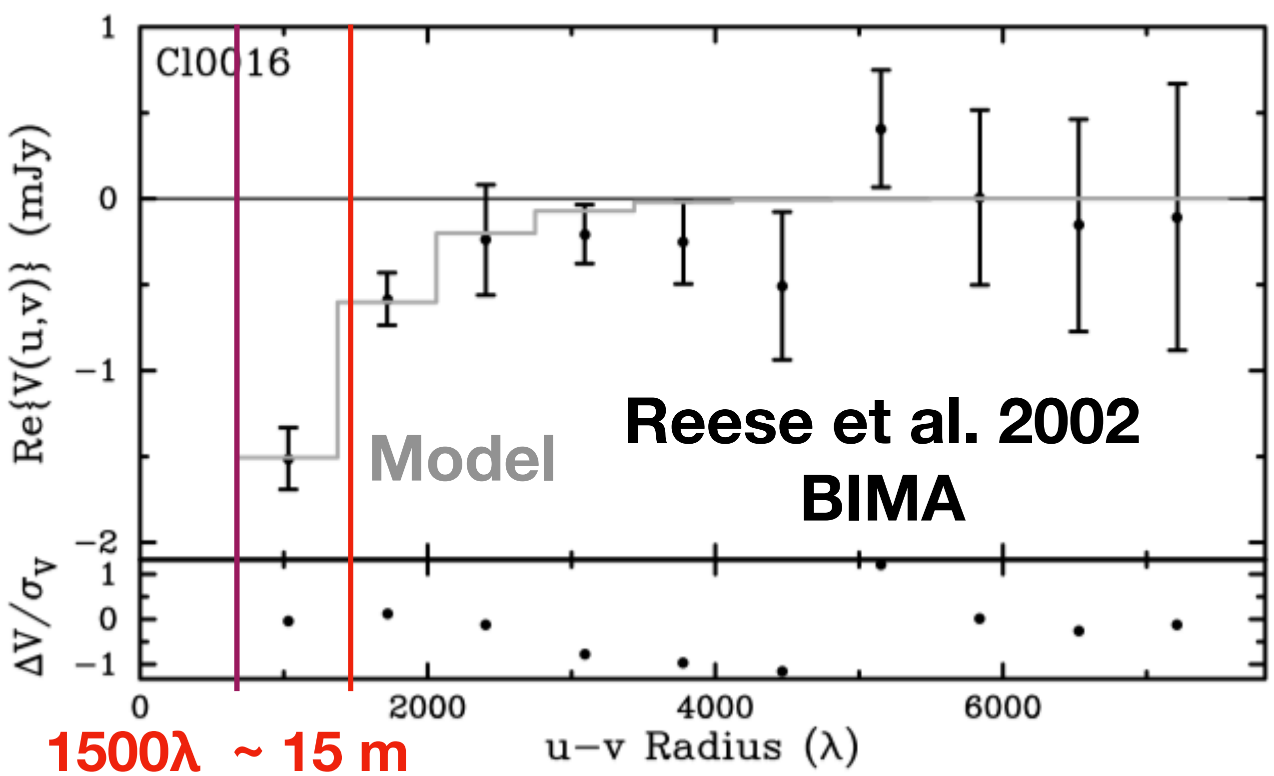
**SZ with interferometers:**

- low systematics = suitable for weak SZ signal
- separate the diffuse negative SZ emission from small-scale positive point-source emission through spatial filtering

**SZ is primarily present in short baselines but not point sources**

# SZ with interferometers

- needs models to be fitted in the uv plane rather than image deconvolution
- larger scales are filtered out = sensitive to small scales temperature gradients




**Shortest NOEMA baseline:**
**classic mapping mode = 15 m**
**mosaic mode ~ 7.5 m**

# SZ with interferometers

- needs models to be fitted in the uv plane rather than image deconvolution
- larger scales are filtered out = sensitive to small scales temperature gradients

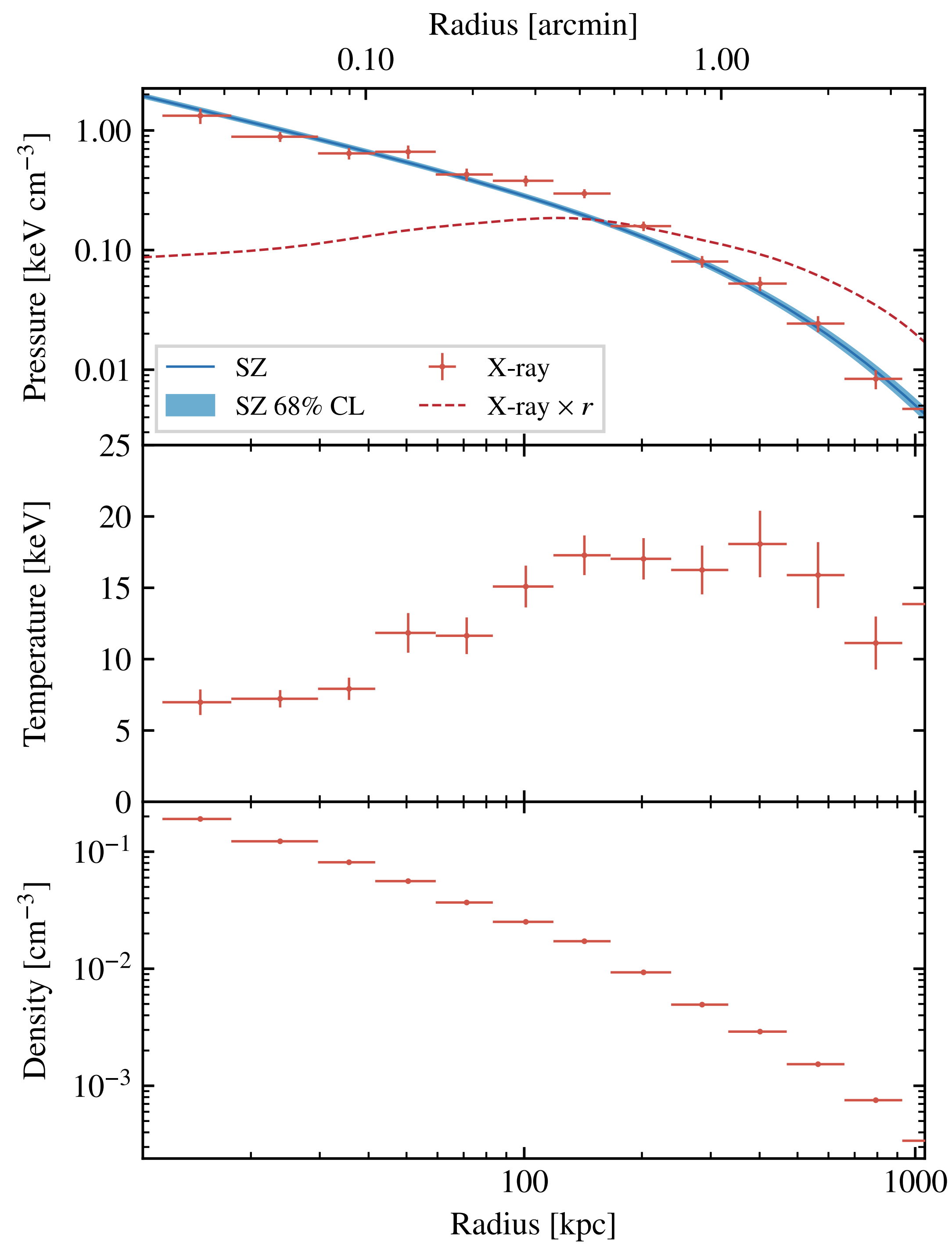
- joint studies are suitable

**Interferometers are sensitive to scales ~ λ/2D**

BIMA 2.8 arcmin

ALMA (ACA) 3mm ~ 50 arcsec @ 90GHz
NOEMA 3mm ~ 30 arcsec @ 70 GHz

NOEMA 2mm ~ 14 arcsec @ 150 GHz
can be combined with NIKA2 !




**ALMA-Bolocam-Planck SZ study of the pressure distribution in RX J1347.5–1145 (Di Mascolo et al., 2018)**

# SZ with interferometers

- **needs models to be fitted in the uv plane rather than image deconvolution**
- **larger scales are filtered out = sensitive to small scales temperature gradients**

**- joint studies are suitable**

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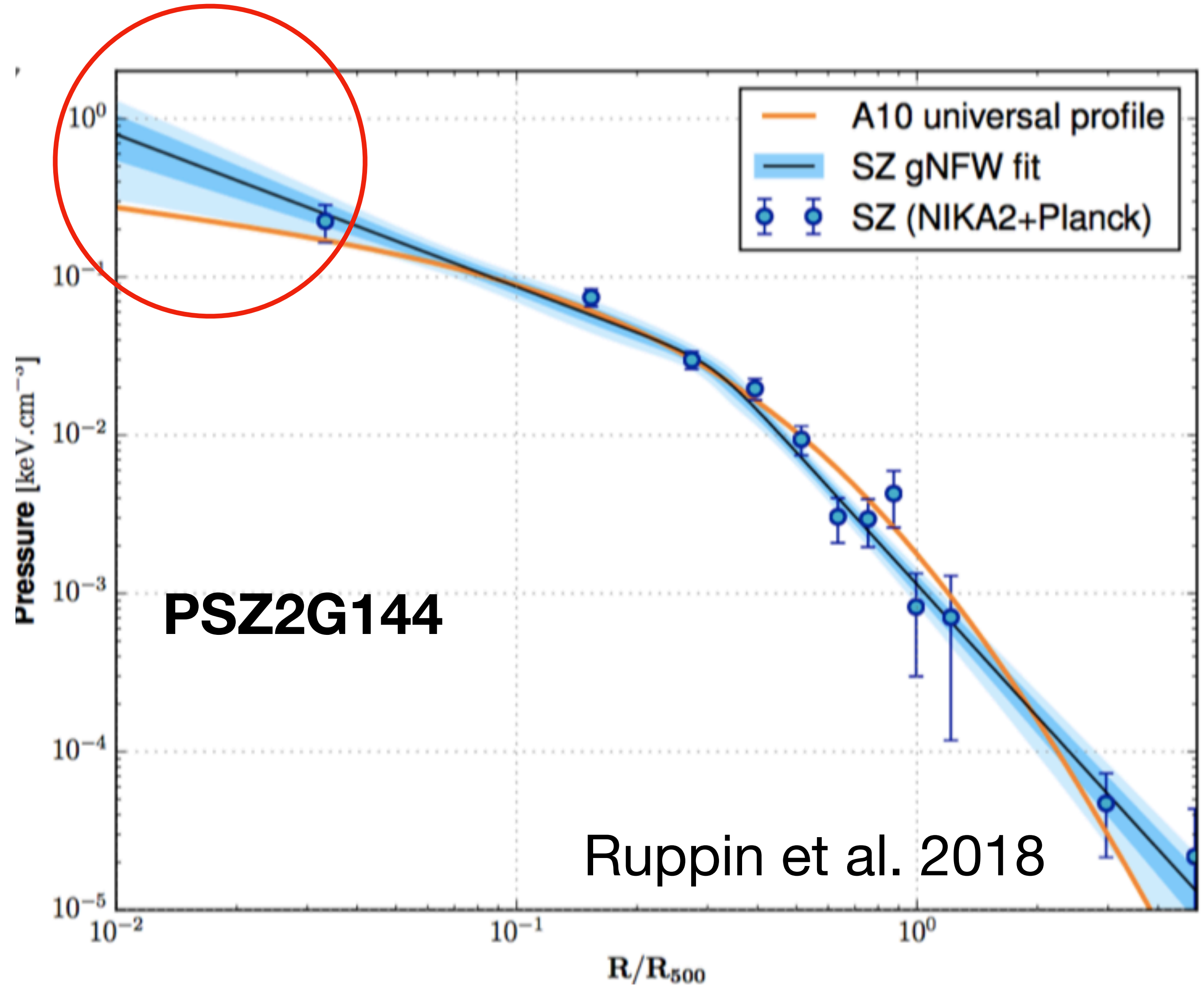


Small departure from Universal Profile
**cf F. Mayet talk**

# SZ with interferometers

- **surface brightness sensitivity and not point source source sensitivity matters:**

$$S = \frac{2kT_b\Omega}{f\lambda^2}$$

Relation between brightness temperature and surface brightness

**with**

$$f = N(D/d)^2$$

**Filling factor of the array**

Single Dish: f = 1
NOEMA 10 antennas: f ~ 0.22
**D = 15 m , d = 100 m**

- Accurate beam knowledge (u,v coverage known exactly)
- Rejection of systematics (baseline correlations, no 1/f noise, pointing)
- Direct access to power spectrum (square of visibilities)
- High dynamic range
- Easy access to wide range of angular scales (array configuration)
- Point source contamination

- Not as sensitive as total-power for extended sources (filling factor)
- Largest angular scales filtered out (short spacing)

# Final thoughts

## NOEMA future upgrades

**More sensitivity:**
- 2 more antennas for 2022
- Dual Band receiver (1+3 mm - Prototype end of September 2019)

**More angular resolution:**
- Baseline extension (starting summer 2019)
- Band 4 (0.8 mm)

**+ Polarisation: Full Stokes parameters**

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## NOEMA in practice

Proposals through our **Proposal Management System with time estimator included**

**In practice:** Friends of Project for NIKA2 vs Local contact for NOEMA

**Data reduction fully supported for NOEMA** (GILDAS)