Molecular gas in the immediate vicinity of Sgr A* seen with ALMA

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Next month: ALMA Regional Center (ARC) node · University of Bonn

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Álvaro Sánchez-Monge, Andreas Eckart, Miguel Requena-Torres, Macarena García-Marin, Devaky Kunneriath, Anton Zensus, Silke Britzen, Elisabeth Mills, Nadeen Sabha, Banafsheh Shahzamanian, Abhijeet Borkar, and Sebastian Fischer

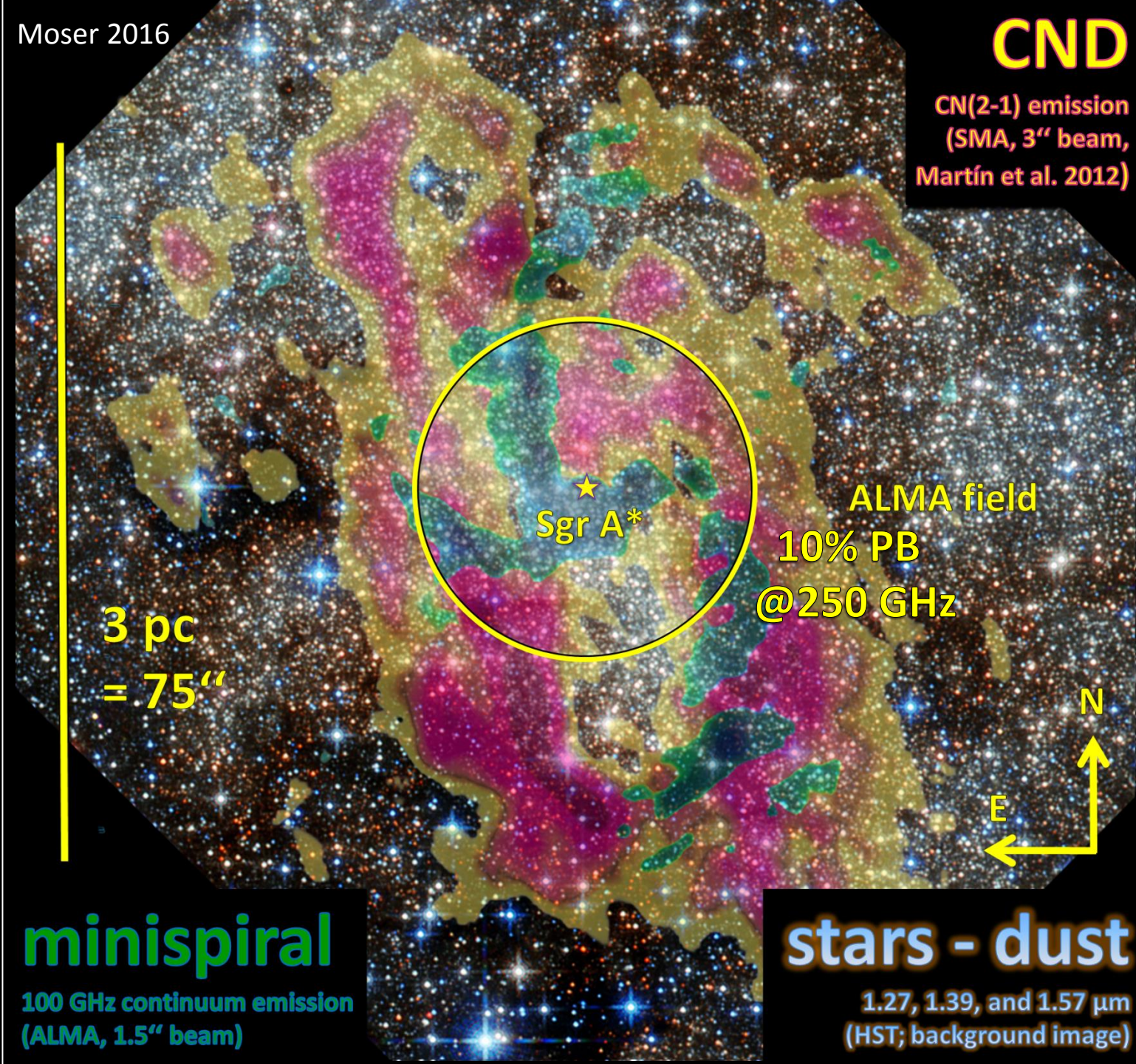
Outline

<u>Continuum emission</u>

- Spectral index

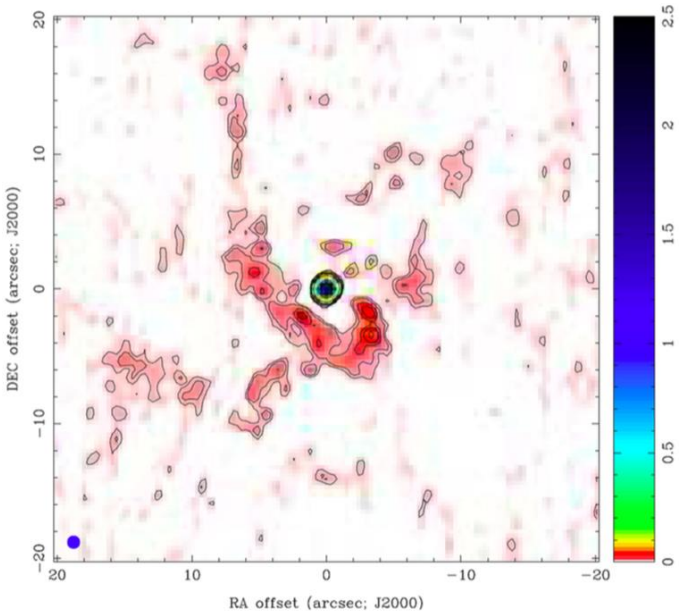
<u>Molecular gas</u>

- **CA**
- SEW
- Triop
- V-cloud / SEE



The Galactic Center (GC)
continuum information

Older data …



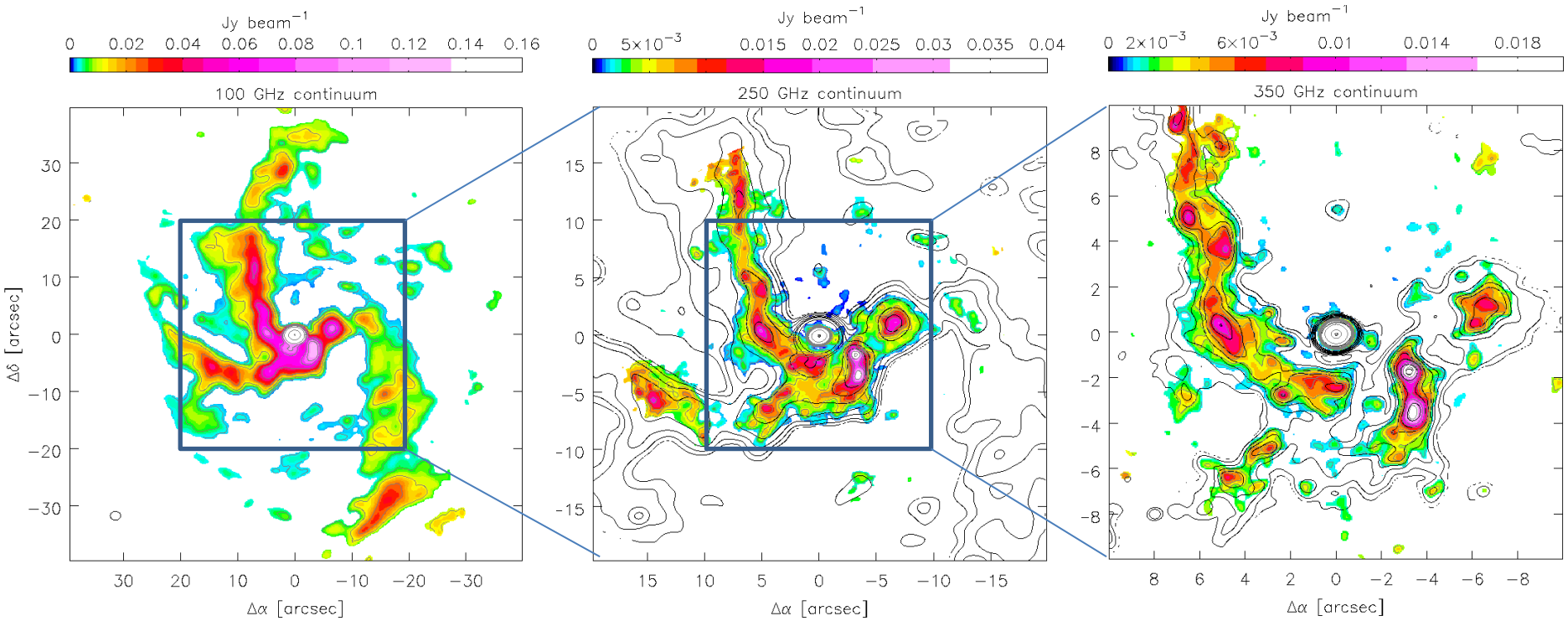
CARMA 230GHz, beam: 0.9’’,
Kunneriath et al. 2011

GC – continuum seen by ALMA

100 GHz – 1.5''
80''x 80''

250 GHz – 0.75''
40''x 40''

340 GHz – 0.5''
20''x 20''



ALMA C0 data set (PI: H. Falcke):
- Monitor Sgr A*
- Cycle through all 3 bands
- One configuration

Highest resolution at this frequency so far

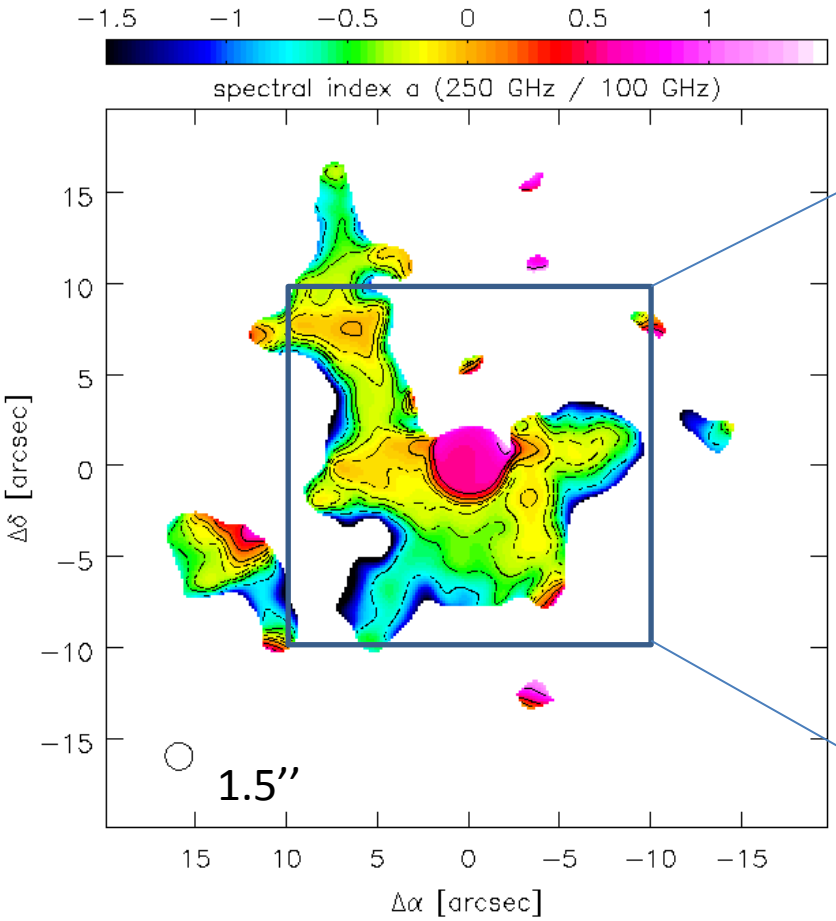
First resolved 340 GHz map ever

Highest resolution in sub-mm

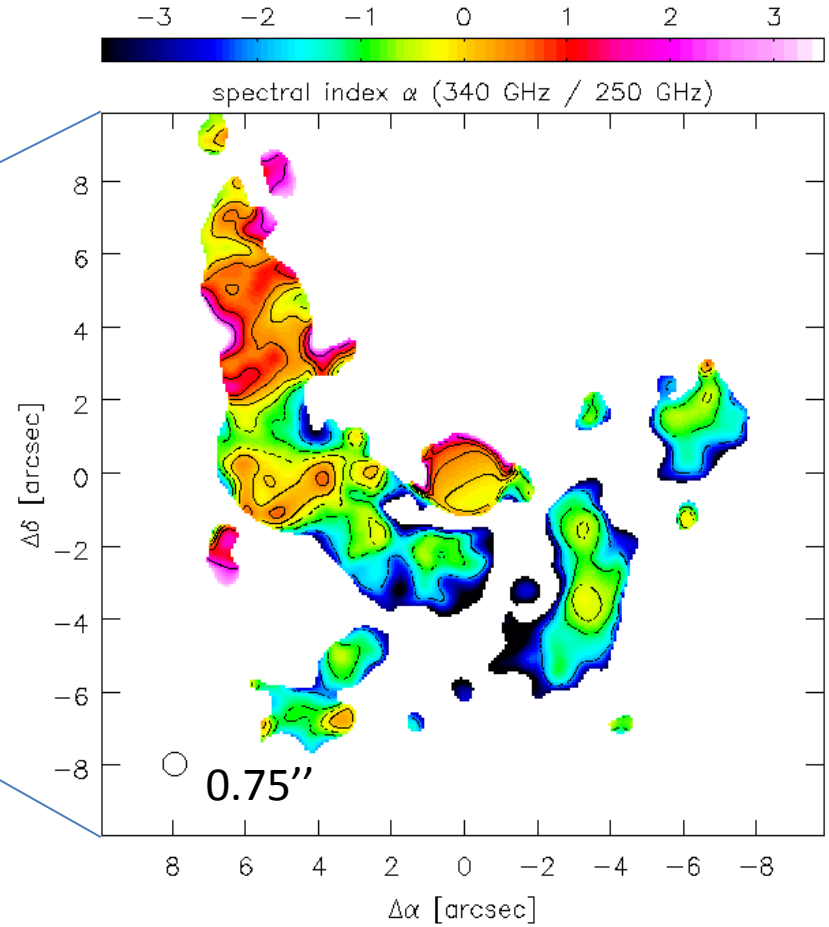
GC – continuum spectral index

α ~ - 0.1	Bremsstrahlung
α ~ - 0.7	Synchrotron
α ~ 2 – 4	dust

100 – 250 GHz
40''x 40''



250 – 340 GHz
20''x 20''



Sgr A*: $\alpha_{100-250} = 0.58 \pm 0.21$
$\alpha_{250-340} = 0.17 \pm 0.45$

Kunneriath et al. (2012a,b) , Falcke et al. (1998b) , Marrone et al. (2006b) , Eckart et al. (2012), Bower et al. (2015)

GC – spectral information of ALMA data

100 GHz (1.5'' - 50 km/s):

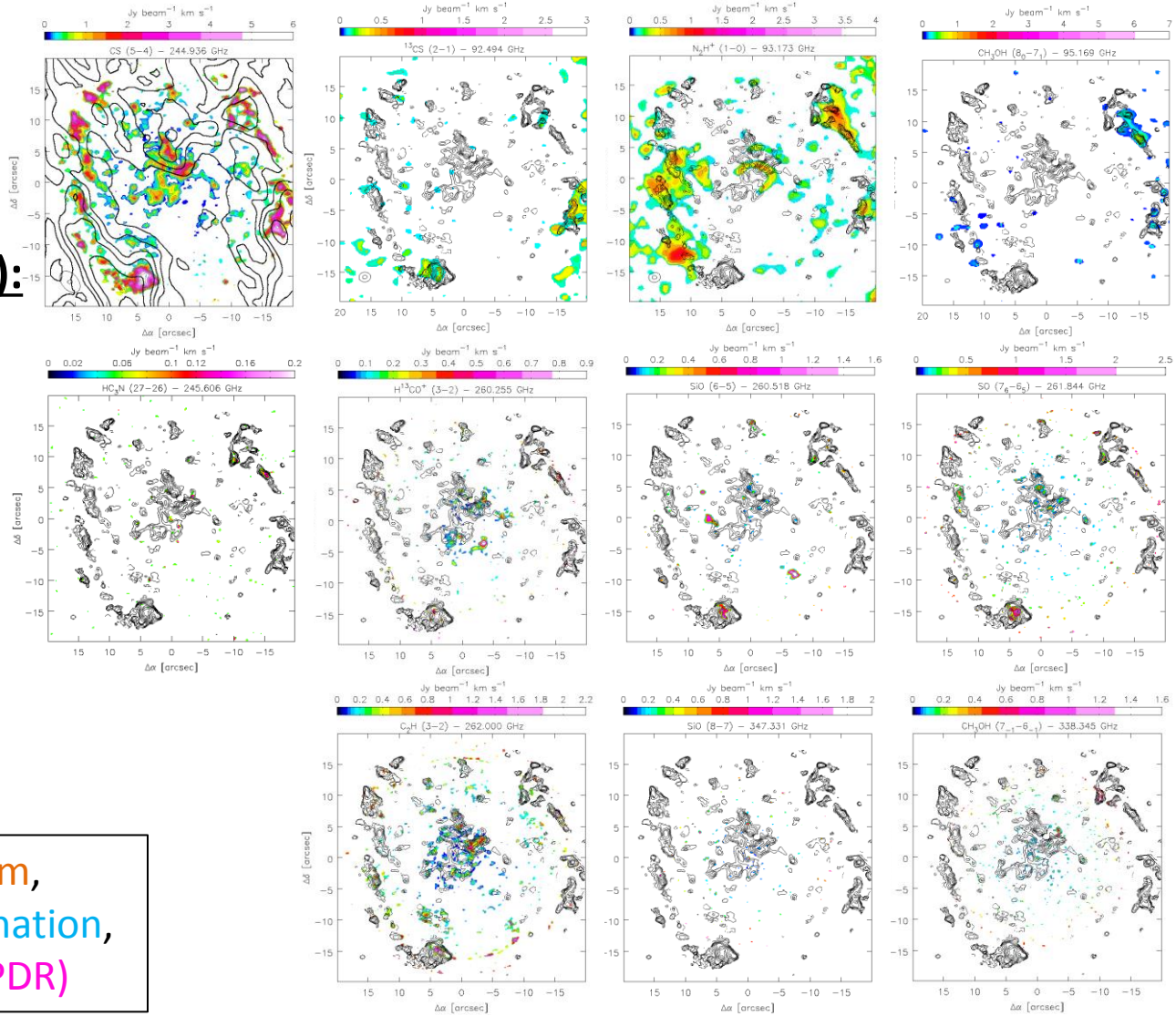
- ^{13}CS, N_2H^+, CH_3OH
- H39α, H51β, H49β

250 GHz (0.75'' - 20 km/s):

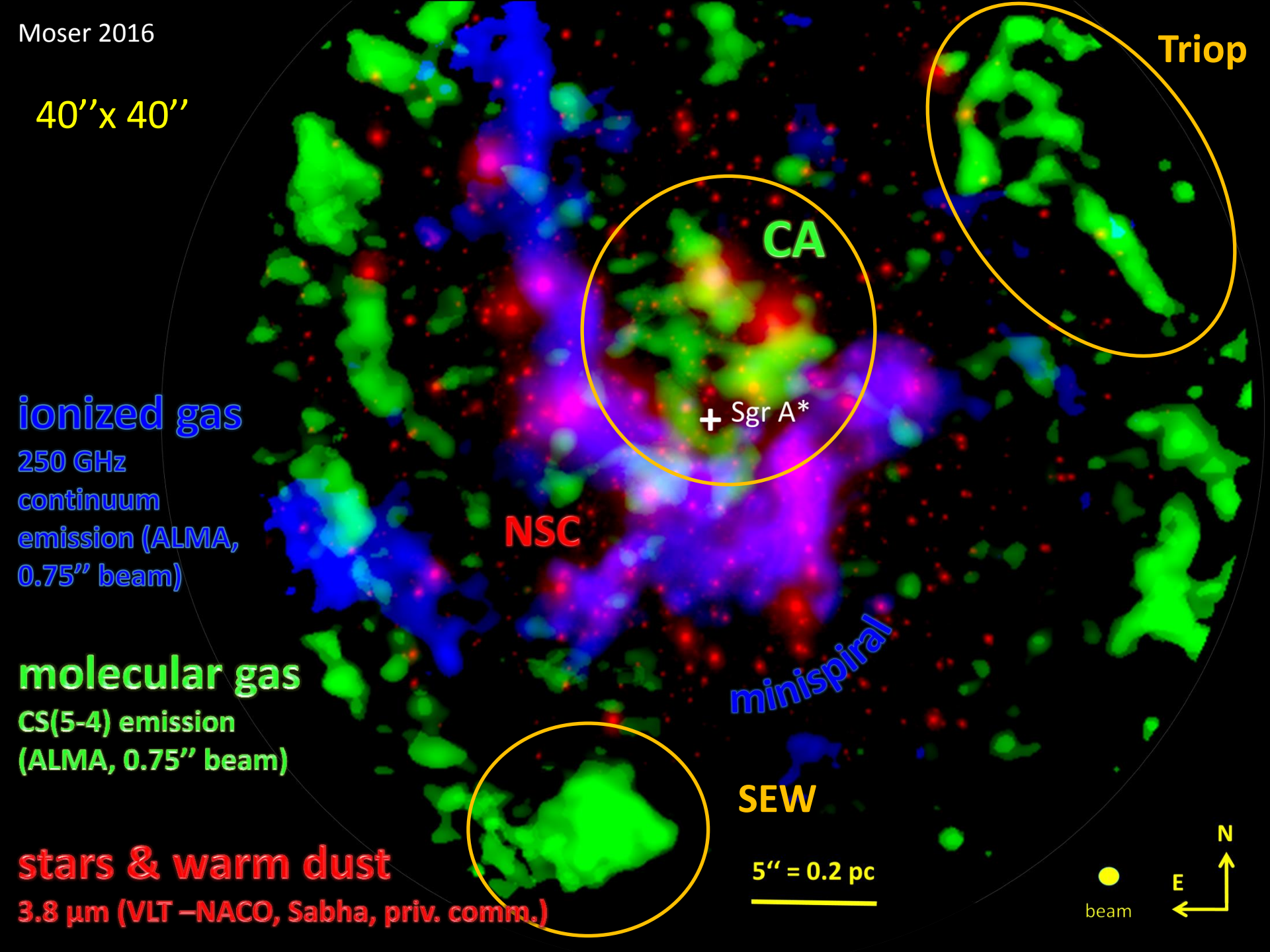
- CS, HC_3N, $H^{13}CO^+$, SiO, SO, C_2H
- H36β

340 GHz (0.5'' - 15 km/s):

- CH_3OH, SiO
- H33β

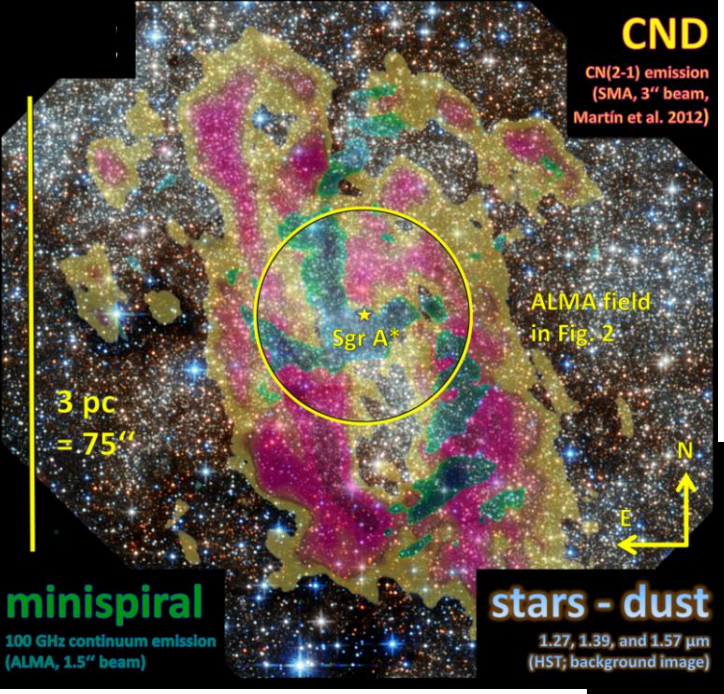


high density (hd), hd – warm,
hd – cold, shocks, recombination,
photodissociation region (PDR)

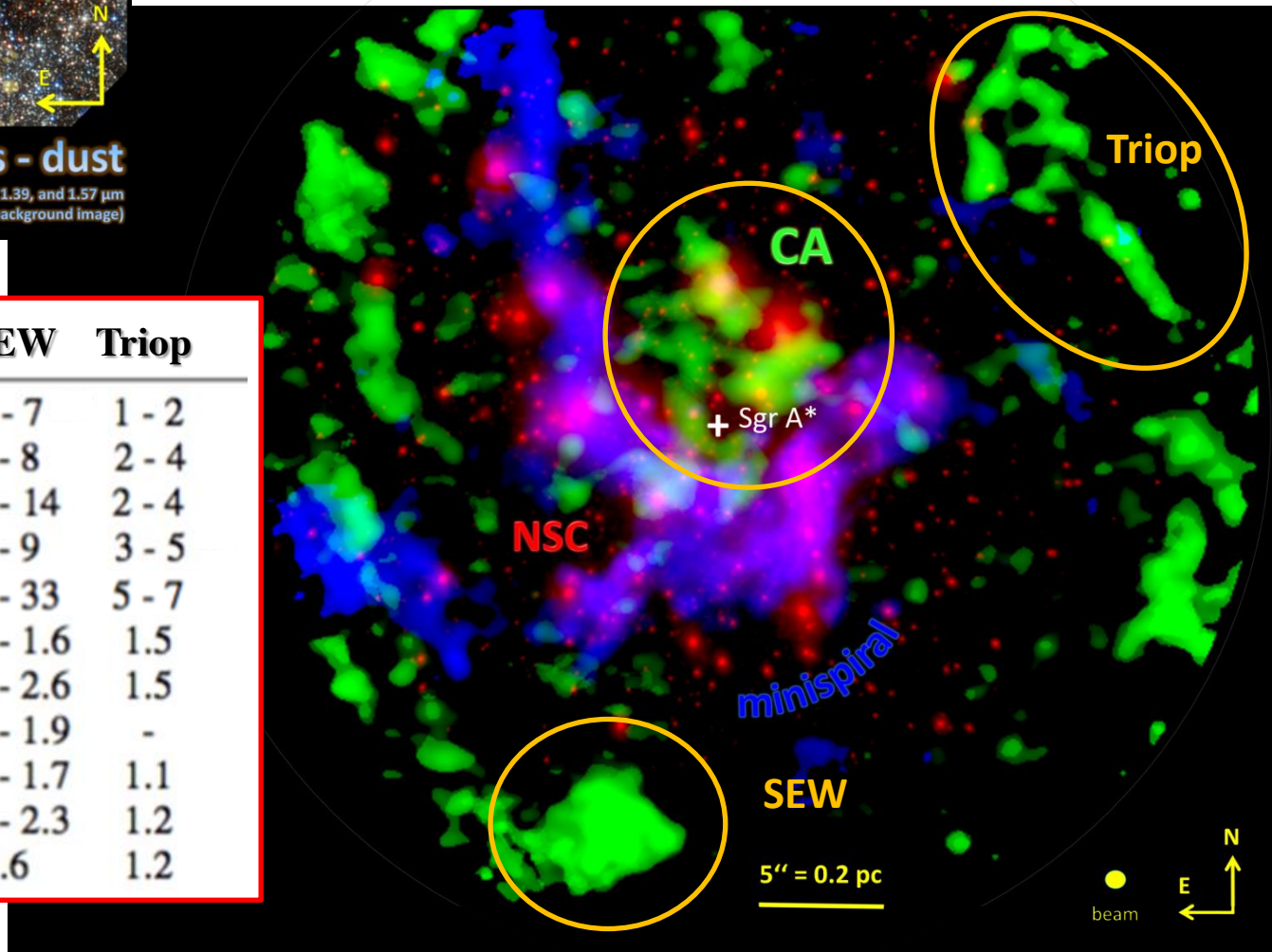

Moser 2016
40''x 40''
Triop
CA
Sgr A*
ionized gas
250 GHz continuum emission (ALMA, 0.75'' beam)
NSC
minispiral
molecular gas
CS(5-4) emission (ALMA, 0.75'' beam)
SEW
stars & warm dust
3.8 µm (VLT –NACO, Sabha, priv. comm.)
5'' = 0.2 pc
beam
N
E

GC - central association (CA)

compare Goto 2014, Martin 2012, Montero-Castaño 2009, Geballe 1989



Ratio	CA	SEW	Triop
CS / C_2H	5 - 7	5 - 7	1 - 2
CS / SO	5 - 15	5 - 8	2 - 4
CS / $H^{13}CO^+$	5 - 16	8 - 14	2 - 4
CS / SiO	5 - 17	7 - 9	3 - 5
CS / ^{13}CS	-	28 - 33	5 - 7
C_2H / SO	1.3 - 2.1	1.0 - 1.6	1.5
C_2H / $H^{13}CO^+$	1.8 - 3.0	2.1 - 2.6	1.5
C_2H / SiO	2.2 - 2.6	1.1 - 1.9	-
SO / SiO	1.0 - 2.4	1.2 - 1.7	1.1
SO / $H^{13}CO^+$	0.7 - 1.9	1.7 - 2.3	1.2
SiO / $H^{13}CO^+$	0.6 - 1.7	1.6	1.2



GC - central association (CA)

3x higher CS/X line ratios than CND

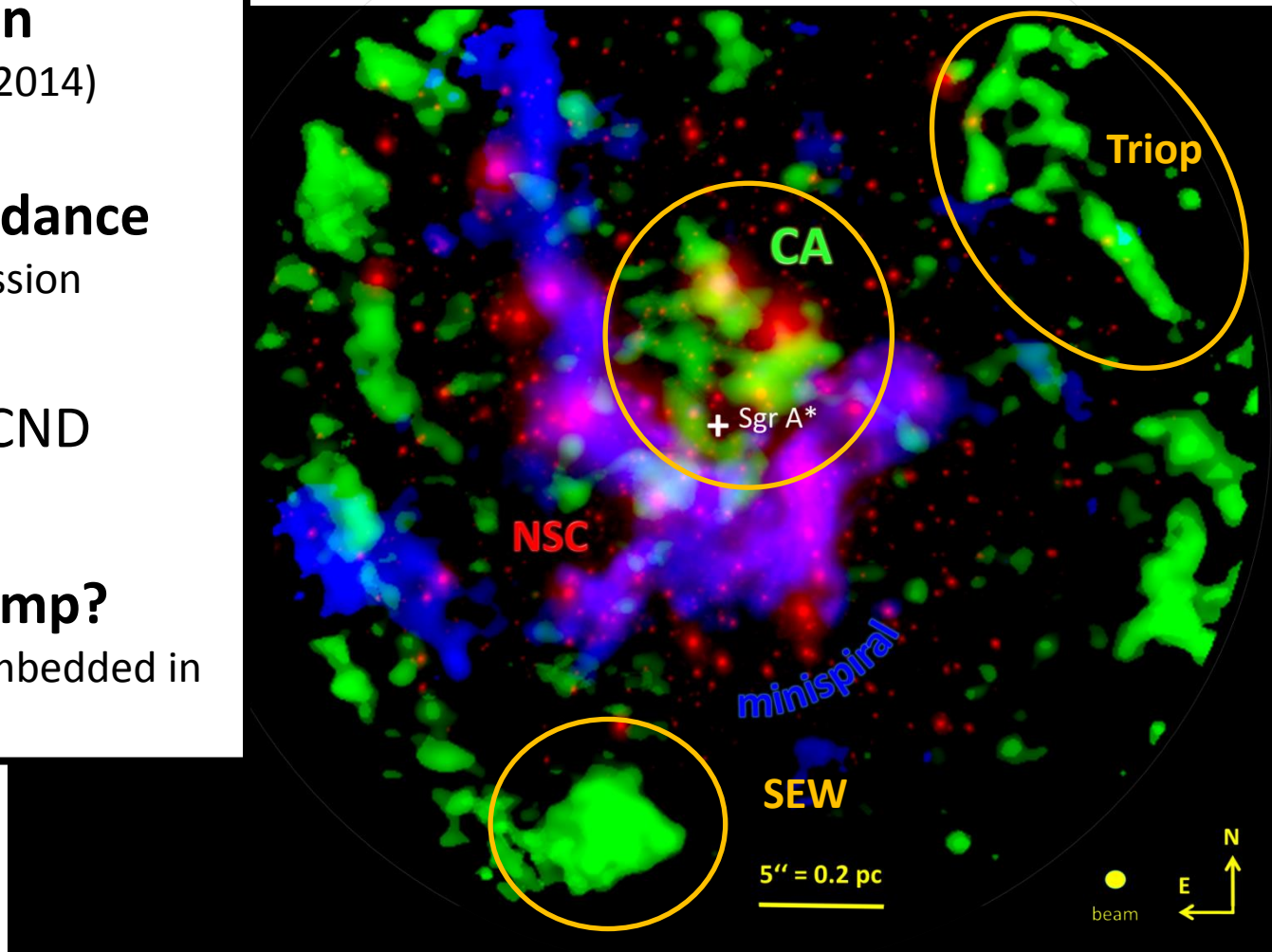
(X: other ALMA molecules)

- **higher excitation**
  (temperature – Goto 2014)
  IR-pumping

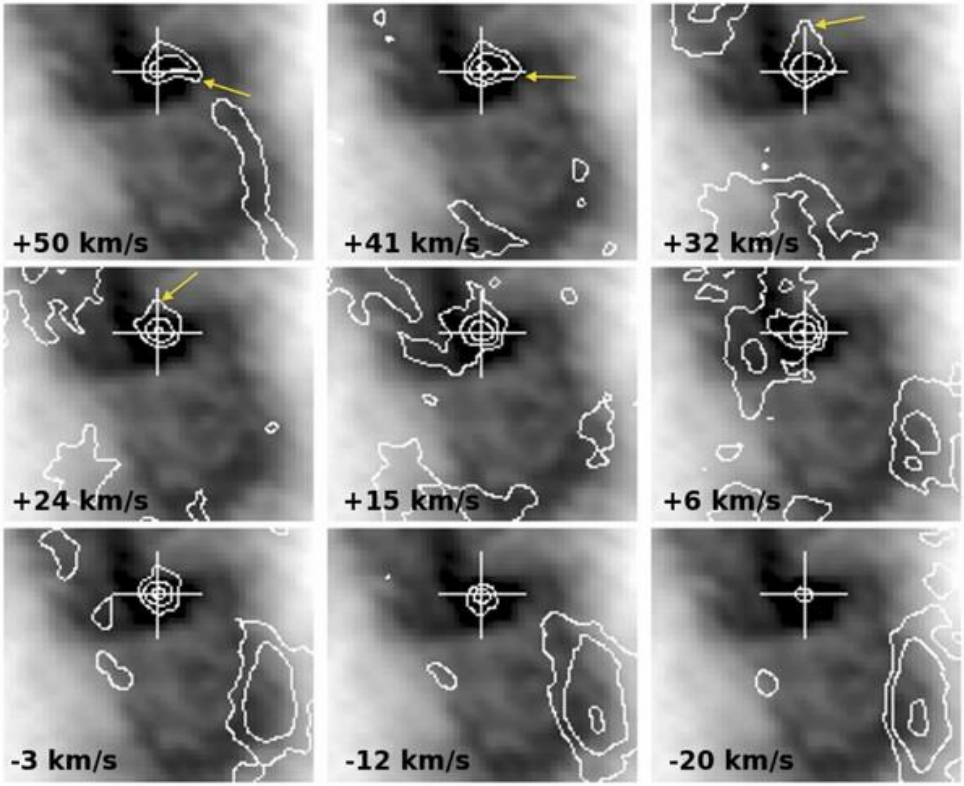
\+ **enhanced abundance**
  UV- and/or X-ray emission

- CA **closer** than CND

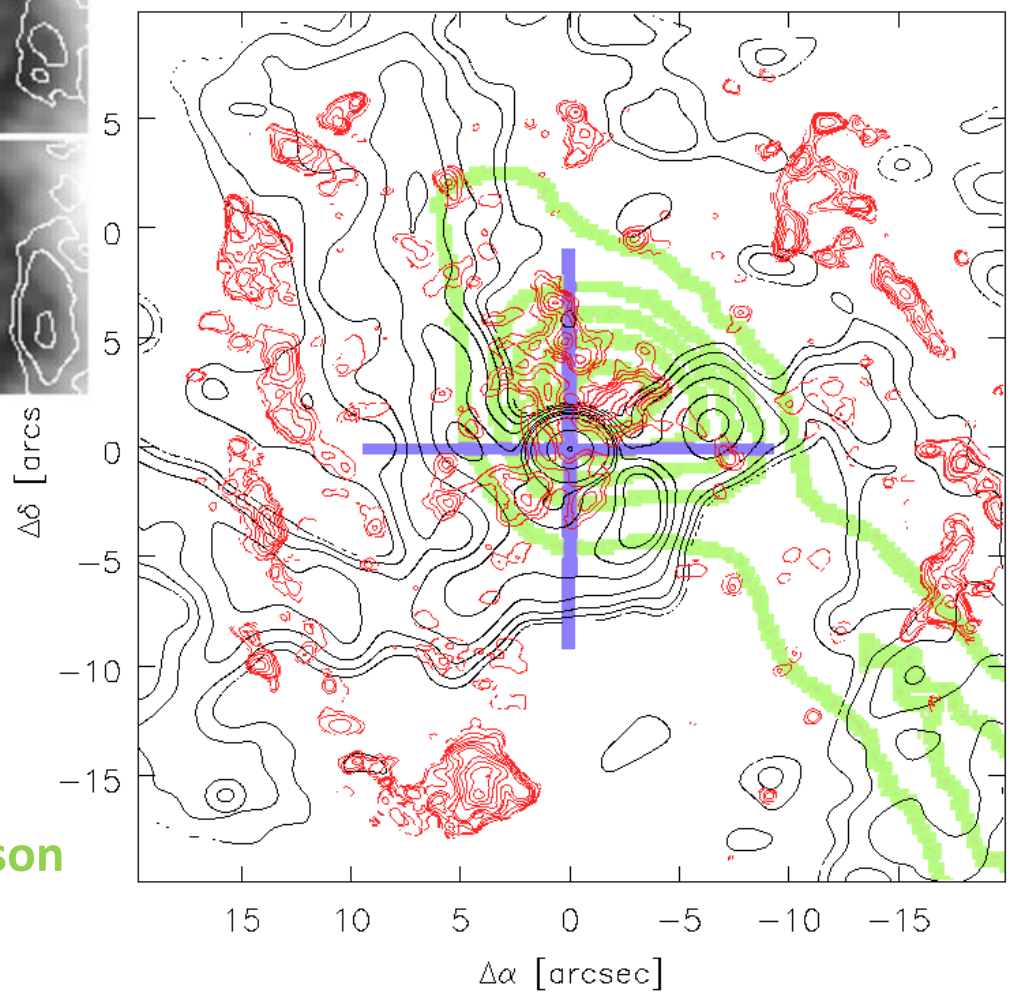
- **CA: infalling clump?**
  denser cloud cores embedded in diffuse gas



GC – origin of CA

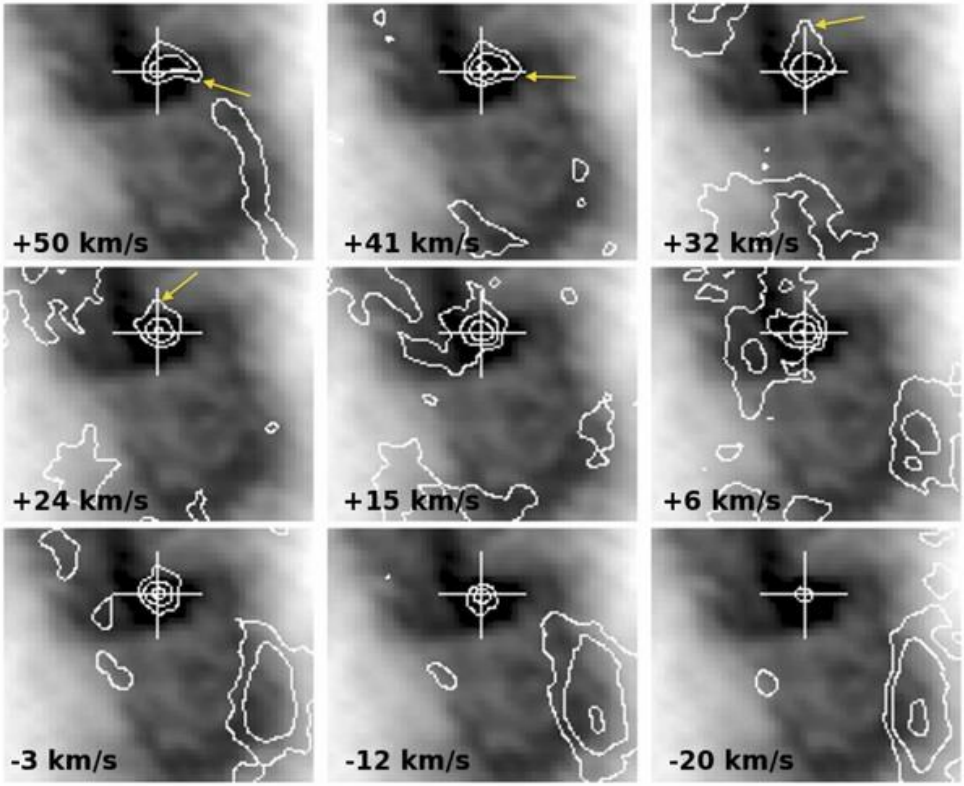


OH-streamer head at 1667 MHz on 18 cm continuum Karlsson 2015
(greyscale: Sgr A West/ minispiral, +: Sgr A*)



OH-streamer (15 - 45 km/s, Karlsson et al. (2015), 100 GHz continuum, CS(5-4) , Sgr A*, 40'' x 40''

GC – origin of CA



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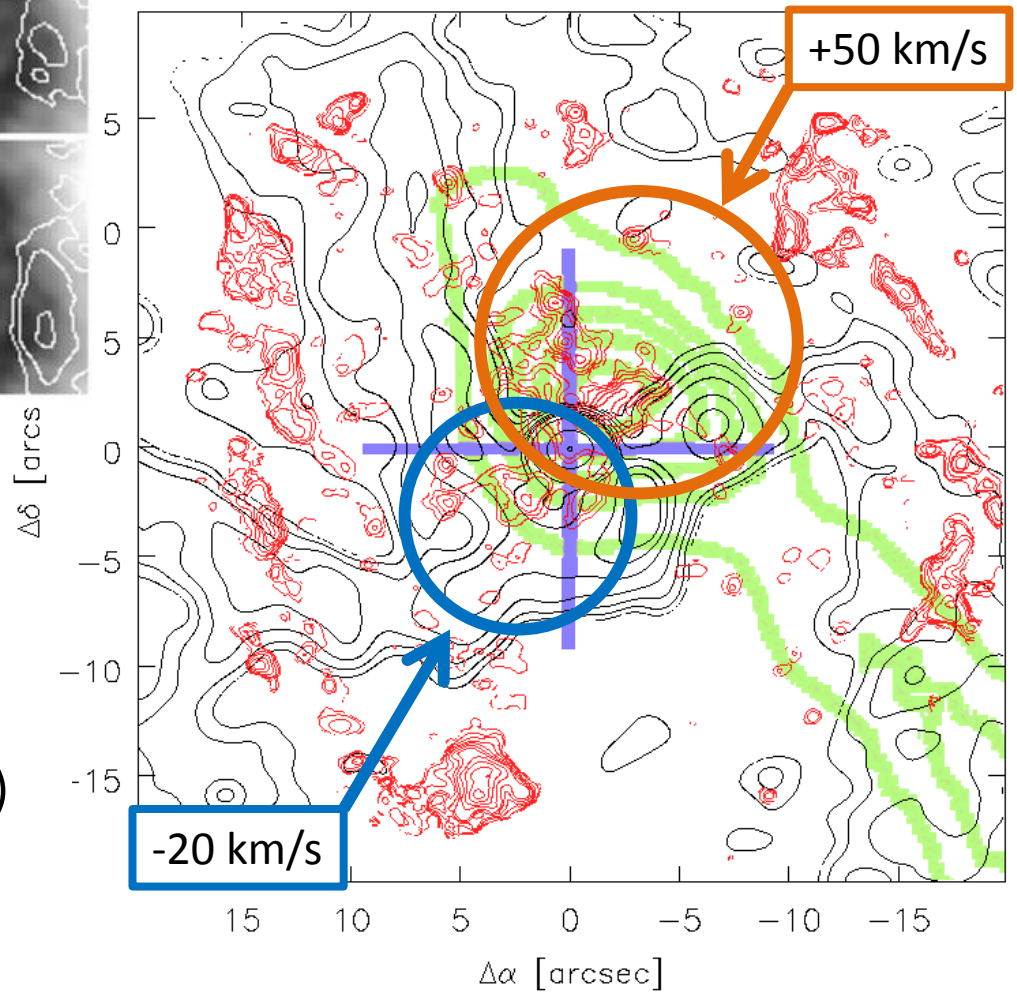
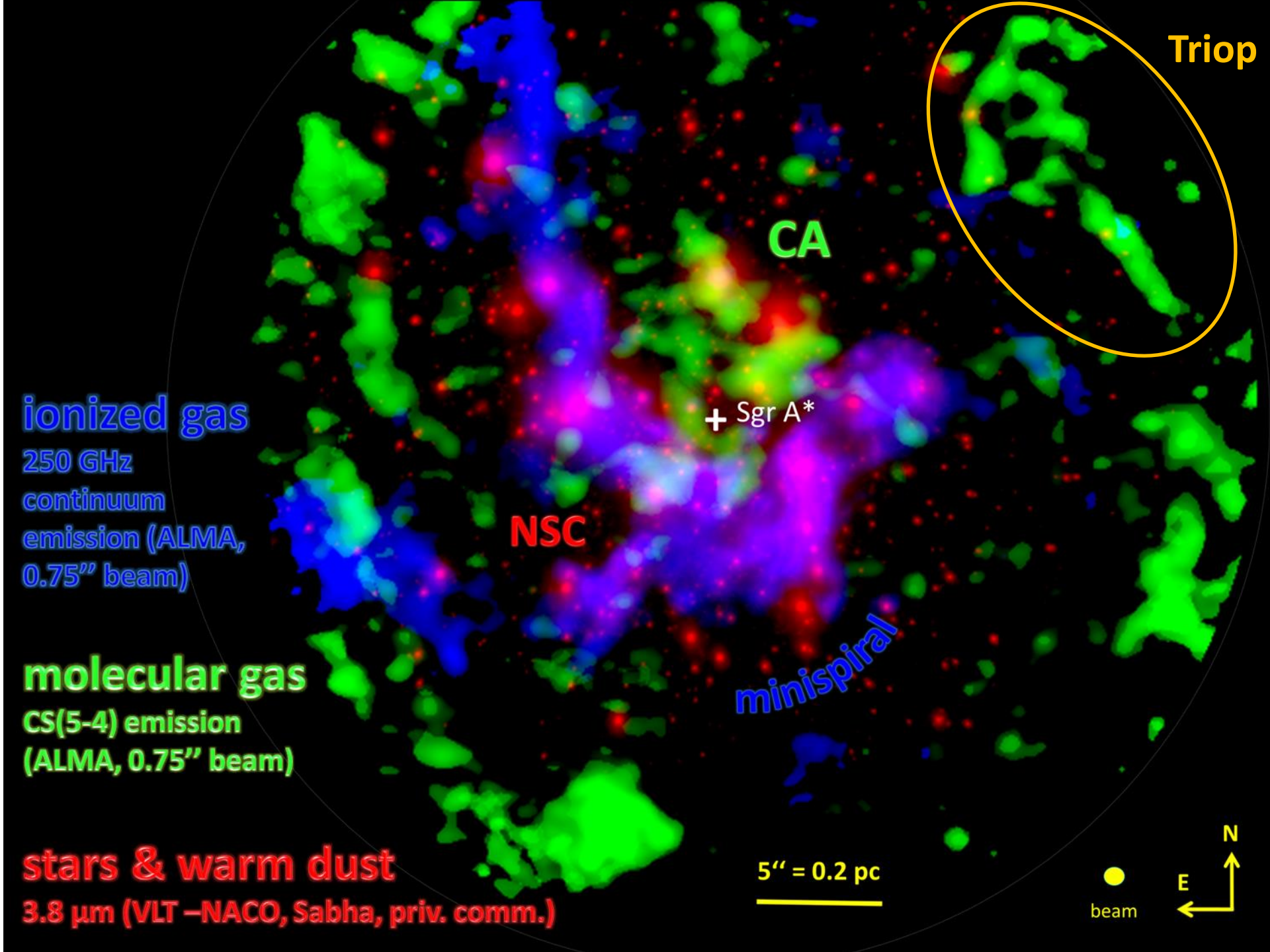


- **Head: 65 $M_\odot$** (Karlsson 2015)
- **CA: 7 $M_\odot$** ($n \sim 10^5 cm^{-3}$)


Triop
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Sgr A*
NSC
minispiral
ionized gas
250 GHz continuum emission (ALMA, 0.75'' beam)
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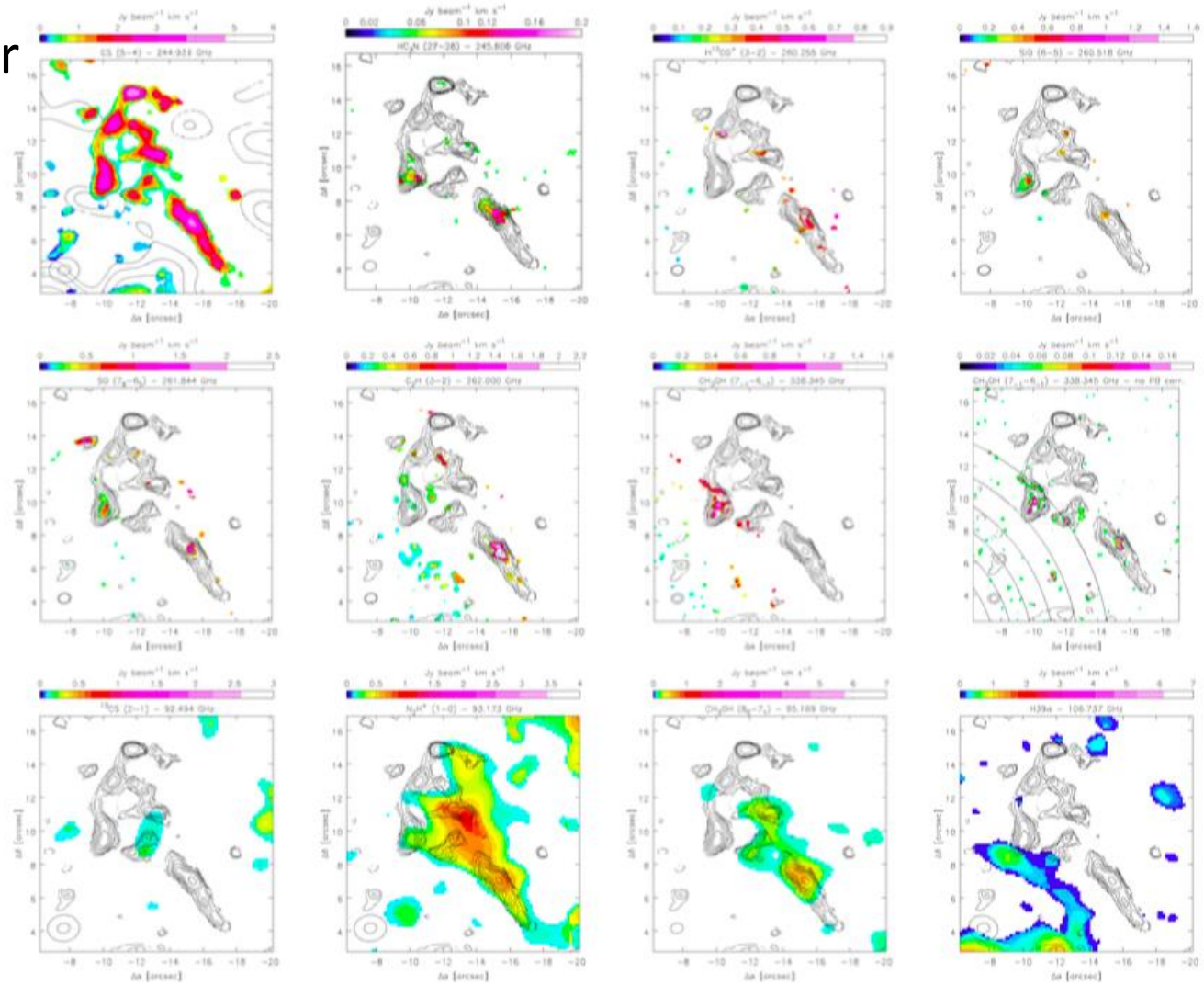
E

GC - Triop

- prominent molecular line emission
(CARMA, SMA, ALMA, literature)
- complex molecules
- shielded from UV
- HC_3N with E_u ~ 150K
- CH_3OH class I maser
(15'' beam, Yusef-Zadeh 2007)

→ hot core/early star formation (SF) ?



GC

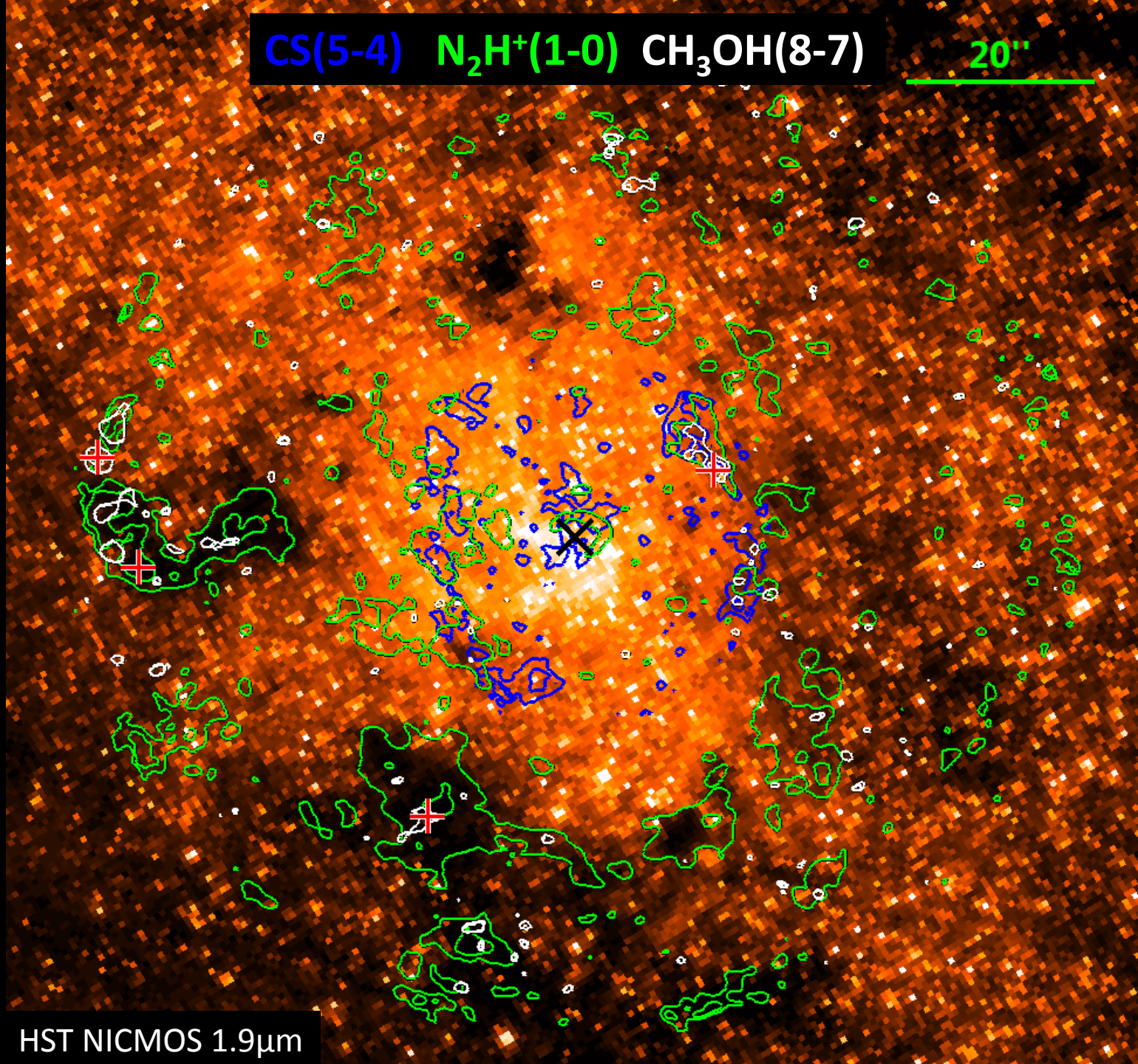
IR dark clouds (IRDC)

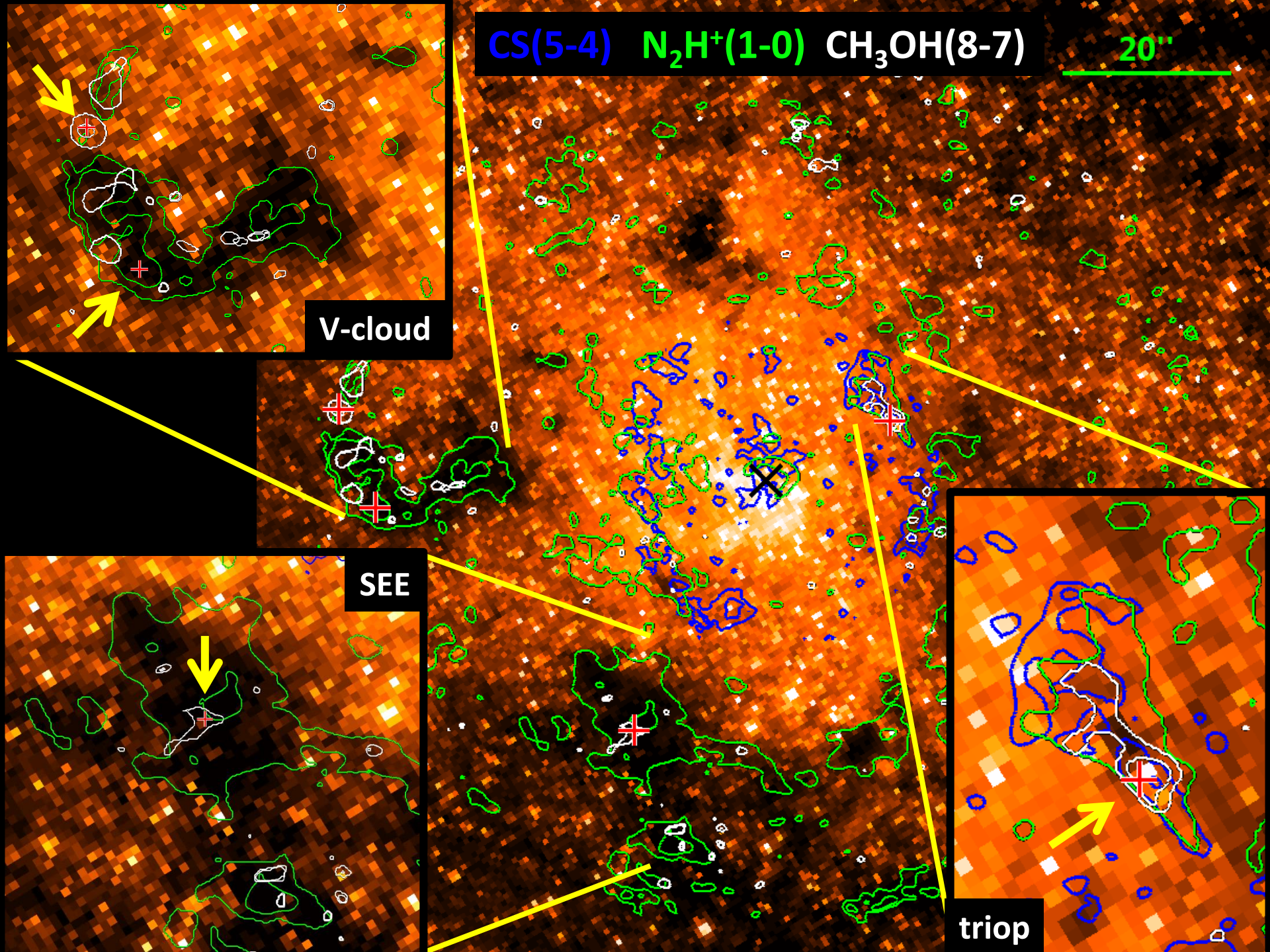
&

class I methanol masers

(36 & 44 GHz)

(Yusef-Zadeh et al. 2001; Sjouwerman et al. 2010; Pihlström et al. 2011)




CS(5-4)
N_2H^+(1-0)
CH_3OH(8-7)
20''
V-cloud
SEE
triop

GC – summary & outlook

- Highest spatial resolution at 250 and 340 GHz
- **Clumps-catalogues: position, size, flux, ratio, velocity, line width**

- **<u>Continuum emission</u>** - Spectral index — Dust vs. ionized gas

- **<u>Molecular gas</u>** - Line ratios - trends
  - **CA – high excitation!**
    infalling clump ? — Kin/Dyn
  - SEW – excitation similar to CA

  External radiation
  - Triop – complex molecules — hot core chemistry
  - V-cloud / SEE – IR dark clouds — cold core chemistry

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Approaching hell's kitchen: molecular daredevil clouds in the vicinity of Sgr A*

Lydia Moser[1,2], Álvaro Sánchez-Monge[1], Andreas Eckart[1,2], Miguel Requena-Torres[3], Macarena García-Marin[4], Devaky Kunneriath[5], Anton Zensus[1,2], Silke Britzen[2], Nadeen Sabha[1], Banafsheh Shahzamanian[1,2], Abhijeet Borkar[1,2], and Sebastian Fischer[6]

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[6] German Aerospace Center (DLR), Köln

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Millimeter/submillimeter Array (ALMA) in band 3, 6,
an up to now highest resolution (<0.5″) view of the Galactic Center
the 100 GHz continuum and the H39α emission we obtain a uniform electron
minispiral. The spectral index of Sgr A* is ~ 0.5 at 100 - 250 GHz and ~ 0.0 at 230 - 340 GHz.
center show spectral indices ($S \propto \nu^{\alpha}$) around -0.1 implying Bremsstrahlung emission, while dust emission
in the minispiral exterior. Apart from CS, which is most widespread in the center, also $H^{13}CO^{+}$, HC_3N, SiO, SO, C_2H,
CH_3OH, ^{13}CS and N_2H^{+} are detected. The bulk of the clumpy emission regions is at positive velocities and in a region confined by the minispiral Northern Arm, Bar and the sources IRS 3 and 7. Though partly spatially overlapping with the radio recombination line (RRL) emission at same negative velocities, the relation to the minispiral remains unclear. A likely explanation is an infalling clump consisting of denser cloud cores embedded in diffuse gas. The central association of clouds shows three times higher CS/X (X: any other observed molecule) ratios than the circumnuclear disk (CND) suggesting a combination of higher excitation - by a temperature gradient and/or IR-pumping - and abundance enhancement due to UV- and/or X-ray emission. Hence, we conclude that this central