THE CHEMICAL AND PHYSICAL STRUCTURE OF THE HOT MOLECULAR CORE G31.41+0.31

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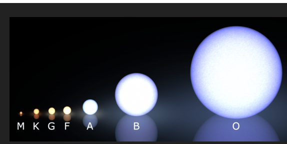
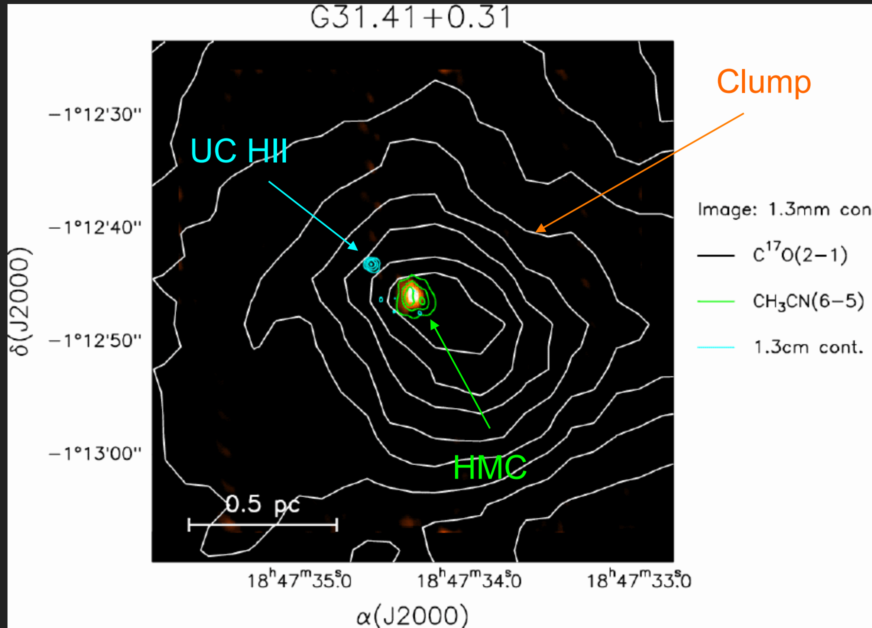
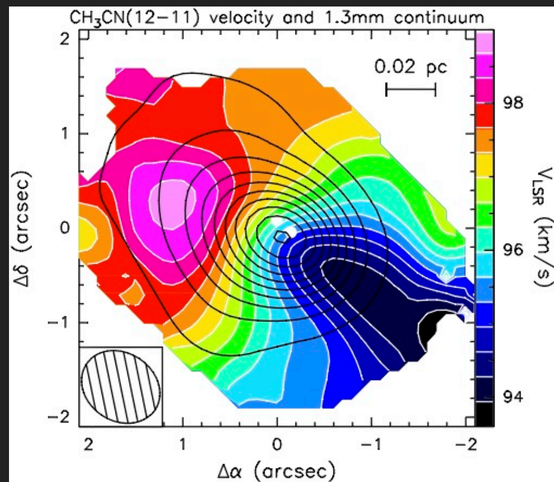
INAF-Osservatorio Astrofisico di Arcetri

A LITTLE BIT OF HISTORY



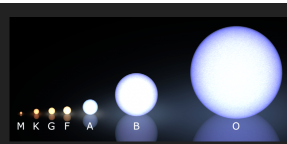
- G31.41+0.41 is a hot molecular core located at 7.9 kpc and has a luminosity of 3 ×10^5 $L_{\odot}$
- No embedded HII region. Two centimeter continuum sources associated (likely radio jets) (Cesaroni+2010)
- A compact core and a velocity gradient detected in COMs (Beltrán+ 2004, 2005; Cesaroni+ 2011)
- Dust core: mass ~500-1700 $M_{\odot}$ (Beltrán+ 2004; Girart+ 2009; Cesaroni+ 2011)
- Dust linearly polarized emission detected with SMA, mainly along major axis of the core. B lines perpendicular to the major axis of the hot core (Girart, Beltrán+ 2009).
- The magnetic field has a clear ''pinched'' morphology along major axis. The dust polarization pattern suggests an hourglass shape morphology





Cesaroni+ (2011)

A LITTLE BIT OF HISTORY



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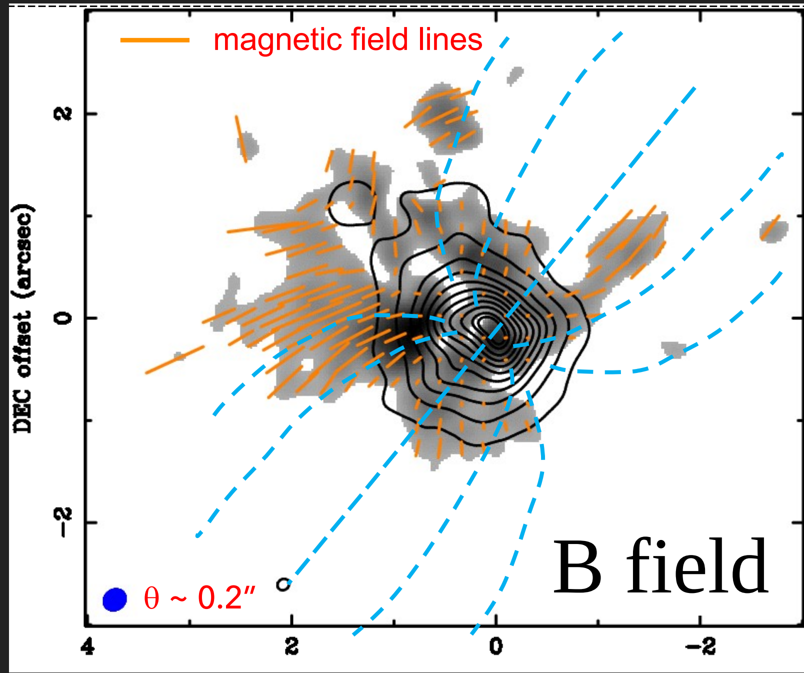
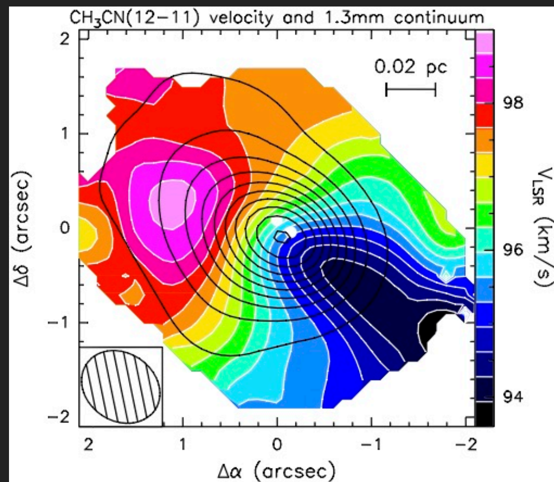
ALMA new data





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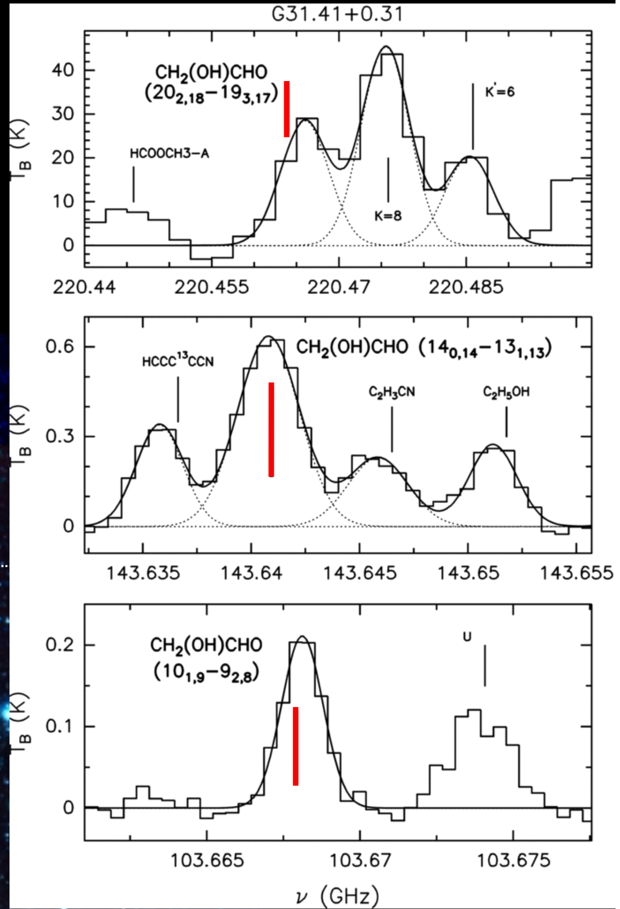
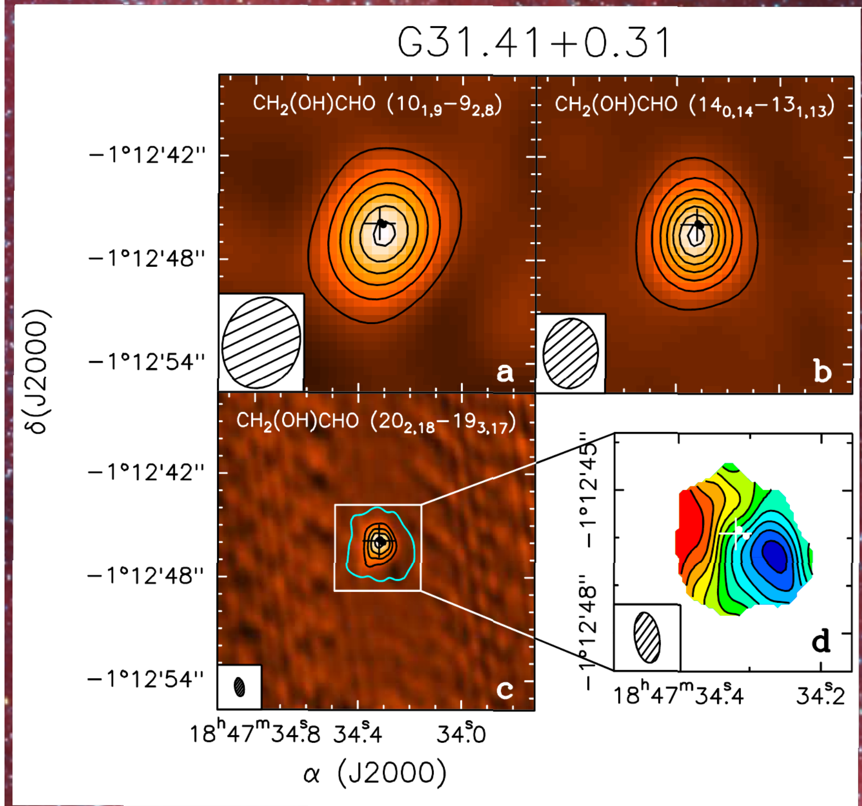
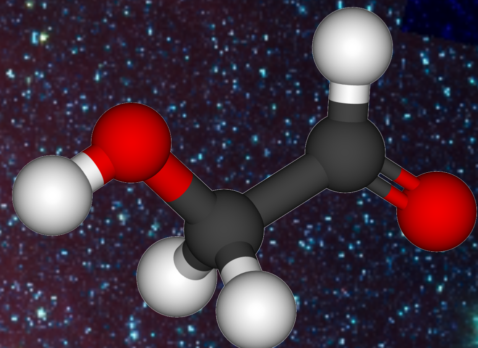
G31.41+0.31

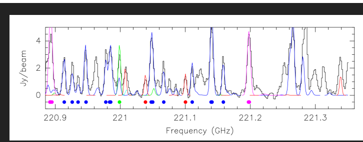




- First detection of **glycolaldehyde** outside the Galactic Center (Beltrán et al. 2009)



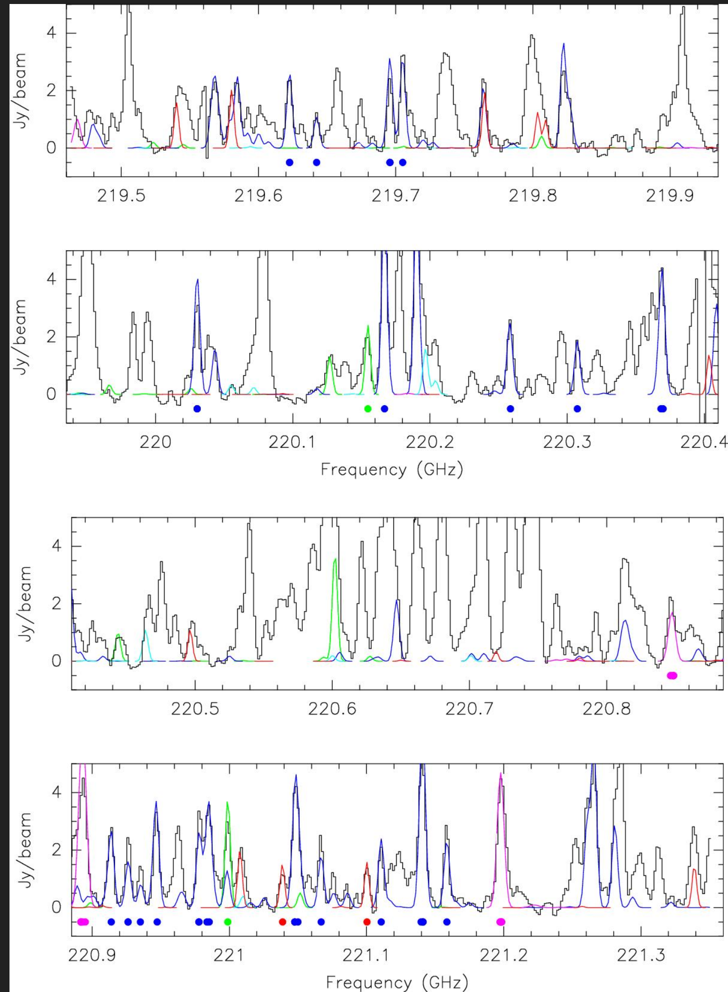
COMPLEX ORGANIC MOLECULES



- Glycolaldehyde (CH_2OHCHO) has been extensively confirmed, and its reduced alcohol, ethylene glycol $(CH_2OH)_2$ has also been detected (Rivilla+ 2017).

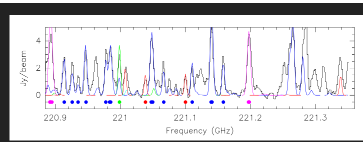
- The emission of these COMs is very compact, peaking towards the peak of the 1.3 mm continuum. Low abundance complex organic molecules, like $(CH_2OH)_2$ or CH_2OHCHO, are good probes of the gas located closer to the forming stars.

G31.41+0.31



Rivilla+ (2017)

methanol, methyl cyanide, methyl formate, ethanol, dimethyl ether, glycolaldehyde, ethylene glycol …



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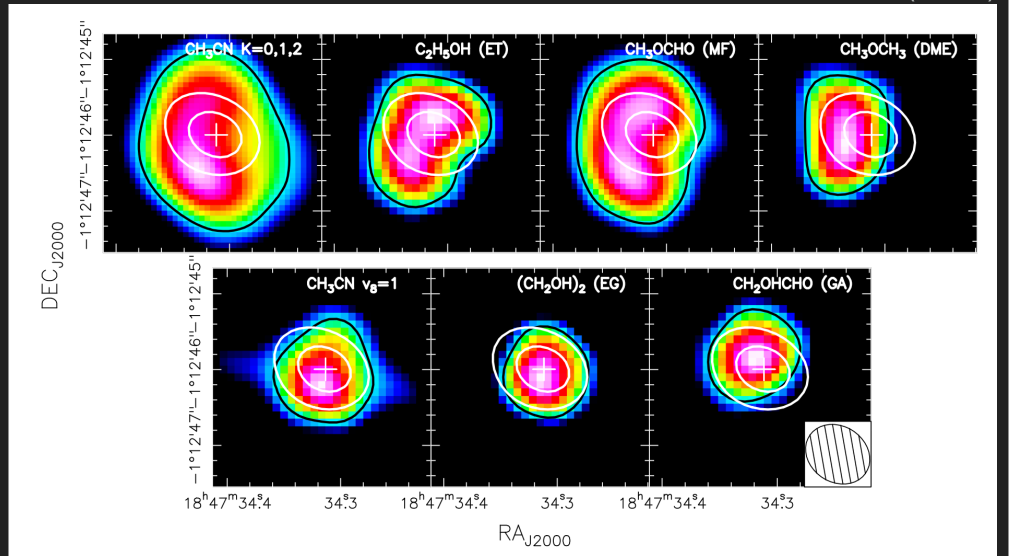
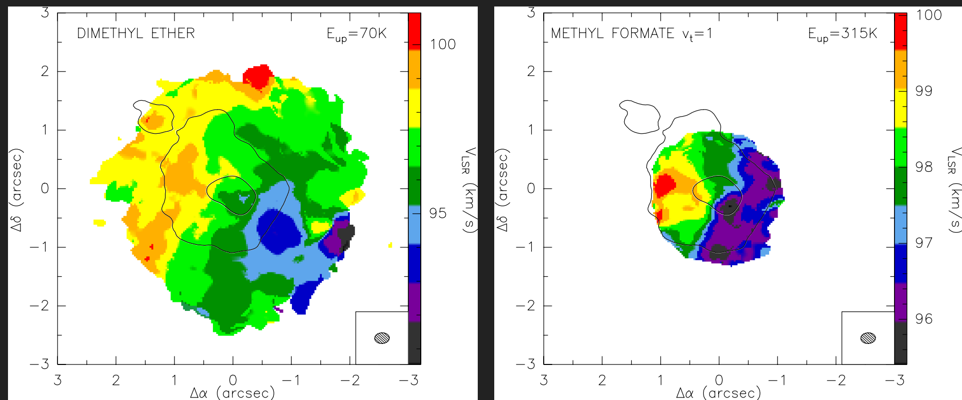
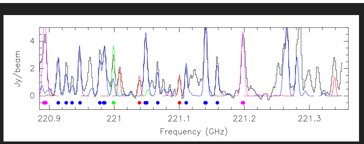
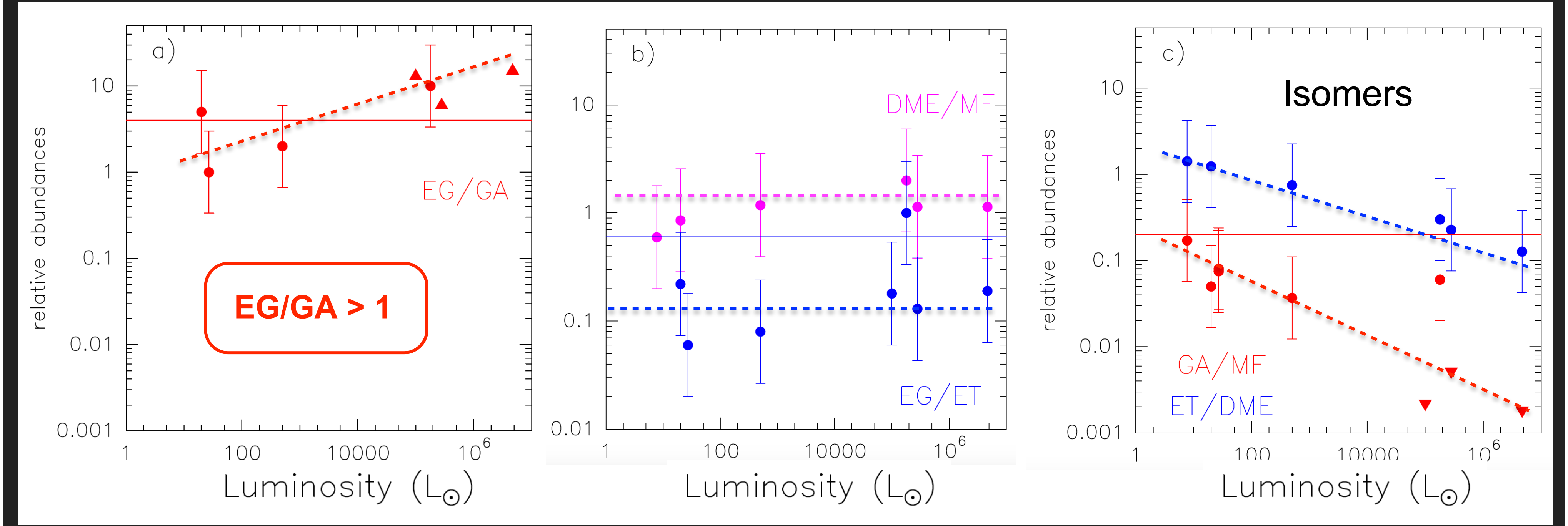




Beltrán+ (2018)

OBSERVED MOLECULAR RATIOS





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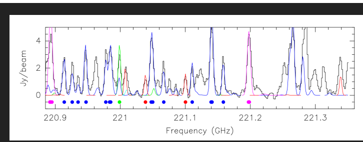
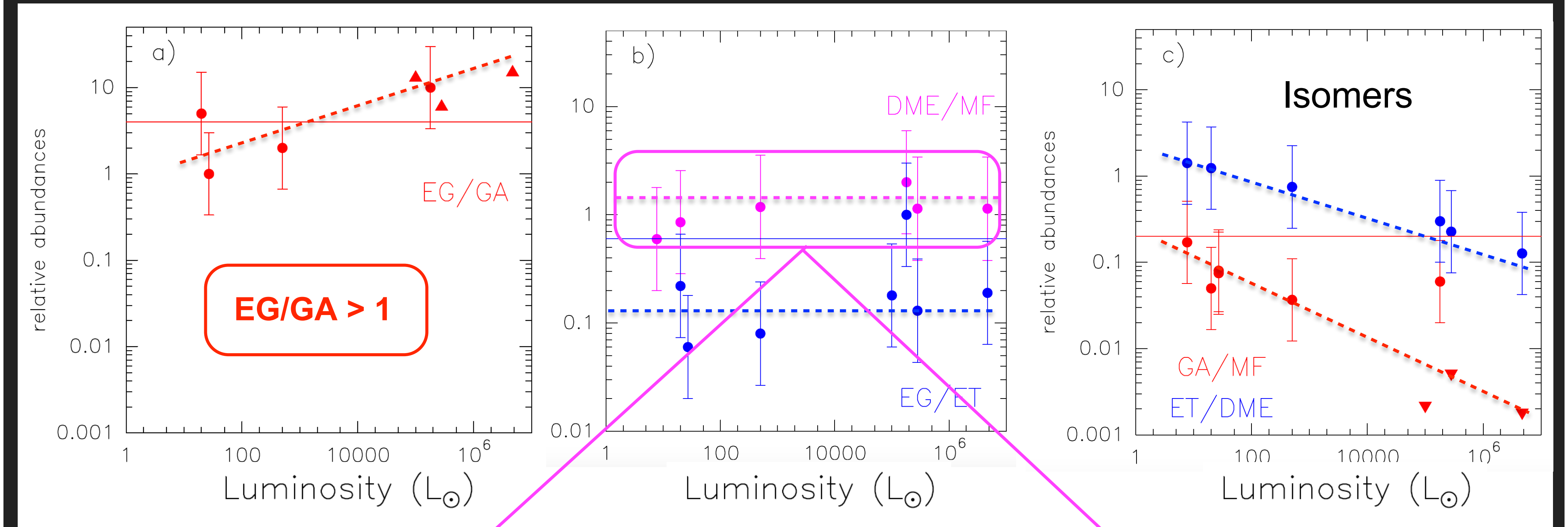




Rivilla+ (2017)

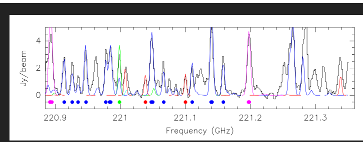
MF and DME are formed from the common precursor CH_3O on **dust grains** (Garrod et al. 2008)

$CH_3O + HCO \longrightarrow CH_3OCHO$ (MF)

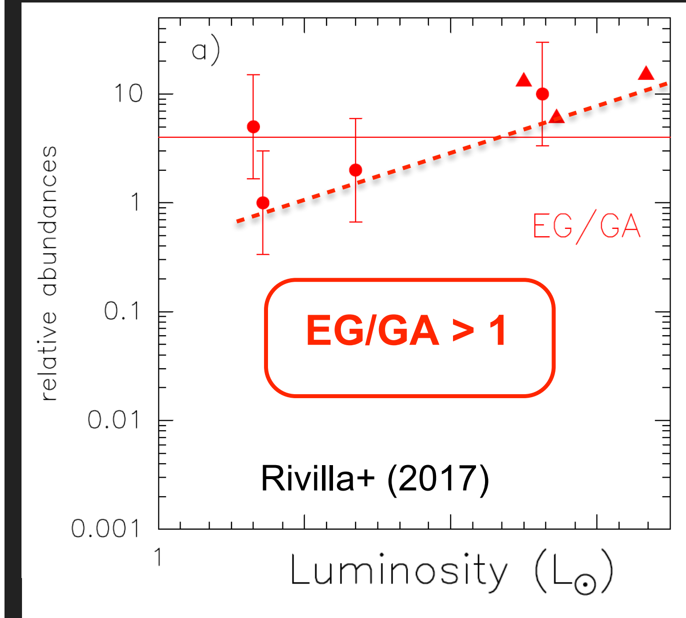
$CH_3O + CH_3 \longrightarrow CH_3OCH_3$ (DME)

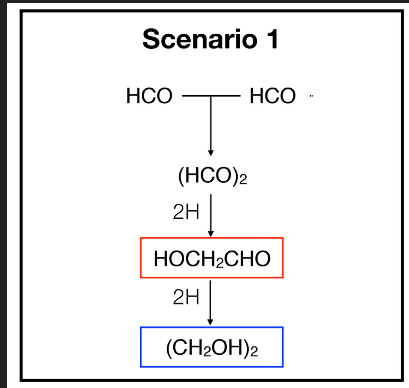
MF is formed directly from DME in **gas-phase** (Balucani+2015)

CH_3OCH_3 (DME) + O $\longrightarrow CH_3OCHO$ (MF) + H

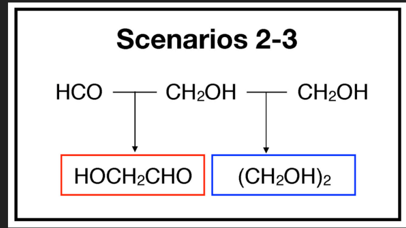


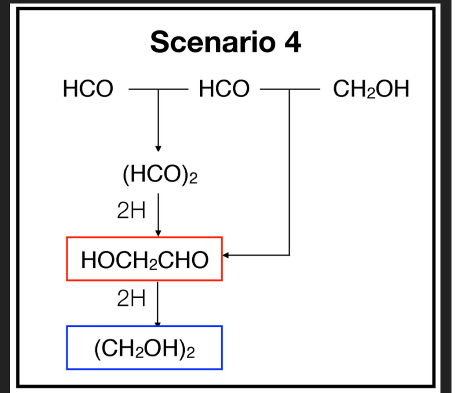
FORMATION OF GA AND EG



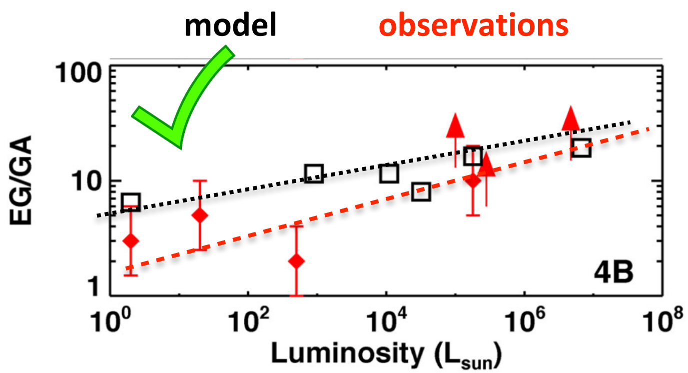


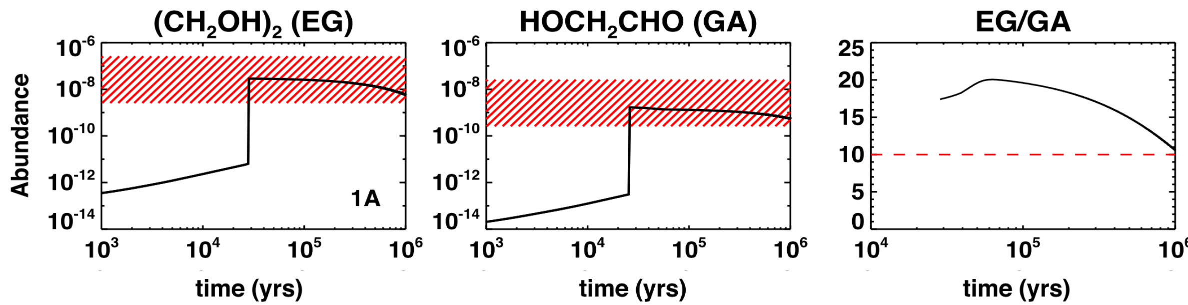
Coutens+ (2018)



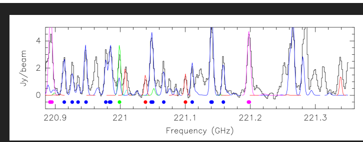


- Coutens+ (2018) have explored with the UCLCHEM chemical code different **surface-chemistry** formation mechanisms for EG and GA and compared the predictions for a range of sources of different luminosities with the observations.



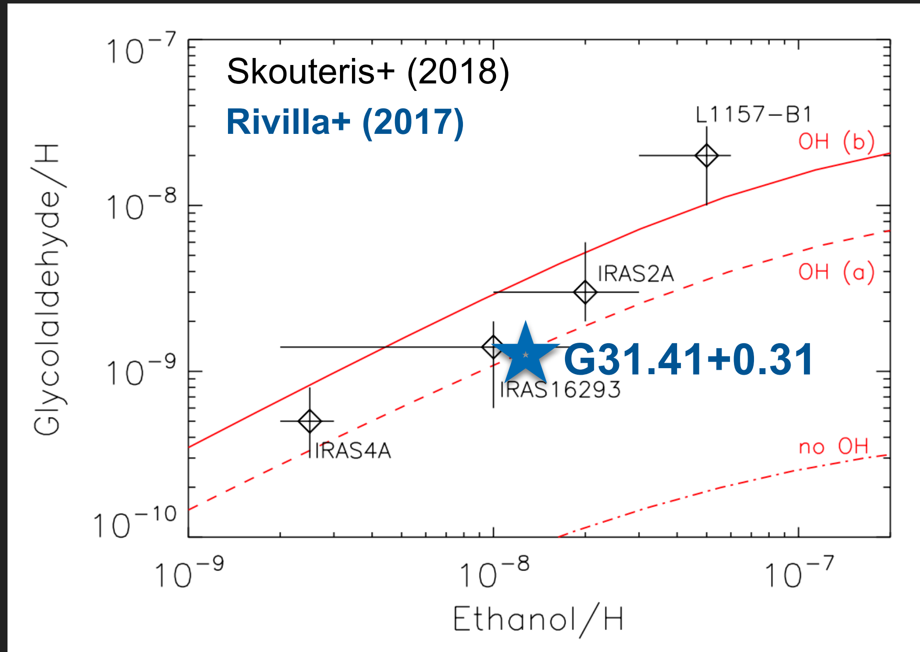


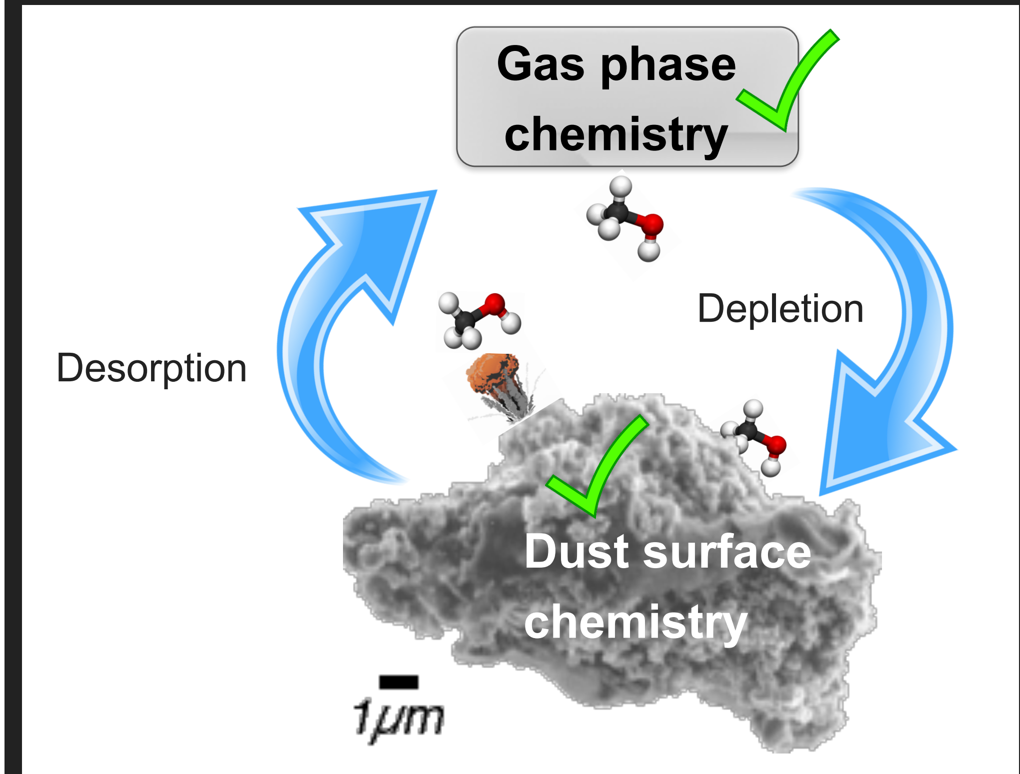
- A better agreement is found for a formation through recombination of two HCO radicals (scenario 1), but the reaction between HCO and CH2OH could also contribute to form GA (scenario 2).



FORMATION OF GA AND EG

- However, the observed molecular ratios among COMs are also compatible with a new proposed **gas-phase route** in which GA is formed from ethanol (Skouteris+ 2018).





O-bearing

- 2 atoms: CO, $C^{17}O$, $C^{18}O$, $C^{13}O$
- 3 atoms: HCO, $HC^{18}O+$, $HC^{17}O+$, $H^{13}CO^{+}$
- 4 atoms: H_2CO, $H_2{}^{13}CO$
- 5 atoms: CH_2CO, HCOOH
- 6 atoms: CH_3OH, $^{13}CH_3OH$
- 7 atoms: CH_3CHO, c-H_2COCH_2
- 8 atoms: CH_3OCHO, CH_2OHCHO
- 9 atoms: CH_3OCH_3, C_2H_5OH,
- 10 atoms: CH_3COCH_3, $(CH_2OH)_2$

N-bearing

- 2 atoms: NH, CN, NS
- 3 atoms: HCN, $H^{13}CN$, $HC^{15}N$, $HN^{13}C$, $H^{15}NC$, $N^{15}NH+$
- 4 atoms: HNCO, $HNC^{18}O$
- 5 atoms: HC_3N
- 6 atoms: NH_2CHO, CH_3CN, $CH_3{}^{13}CN$
- 7 atoms: HC_5N, CH_3NCO, C_2H_3CN
- 9 atoms: C_2H_5CN

Only C and H

- 3 atoms: CCH
- 5 atoms: c-C_3H_2
- 7 atoms: CH_3CCH

S-bearing

- 2 atoms: SO, ^{34}SO, ^{13}CS, $^{13}C^{34}S$, $C^{34}S$
- 3 atoms: SO_2, $^{34}SO_2$, H_2S, OCS, $O^{13}CS$, ^{18}OCS, $OC^{34}S$, HCS^{+}
- 4 atoms: H_2CS

Deuterated

- 3 atoms: DCN, DCO+
- 4 atoms: NH_2D
- 6 atoms: CH_2DCN, CH_2DOH, CH_3OD

Si-bearing

- 2 atoms: SiO, SiS

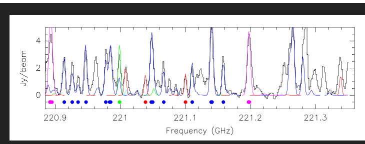
P-bearing

- 2 atoms: PN

H recombination lines

- H-alpha
- H-beta
- H-gamma,
- He-alpha

45 molecular species, **16 COMs**, 23 isotopologues, 6 deuterated species, 2 cyclic molecules, 4 positive ions and hydrogen recombination lines

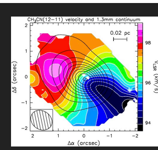


GUAPOS: G31.41+0.31 Unbiased ALMA sPectral Observational Survey

- PI: Beltrán
- A-granted Cycle 5 ALMA proposal to carry out an unbiased spectral survey in Band 3 @ 1” resolution
- 4 out of 9 spectral setups already observed
- Different aspects: line identification, COMs, deuteration and fractionation, phosphorus and sulfur, chemical modeling, and kinematics

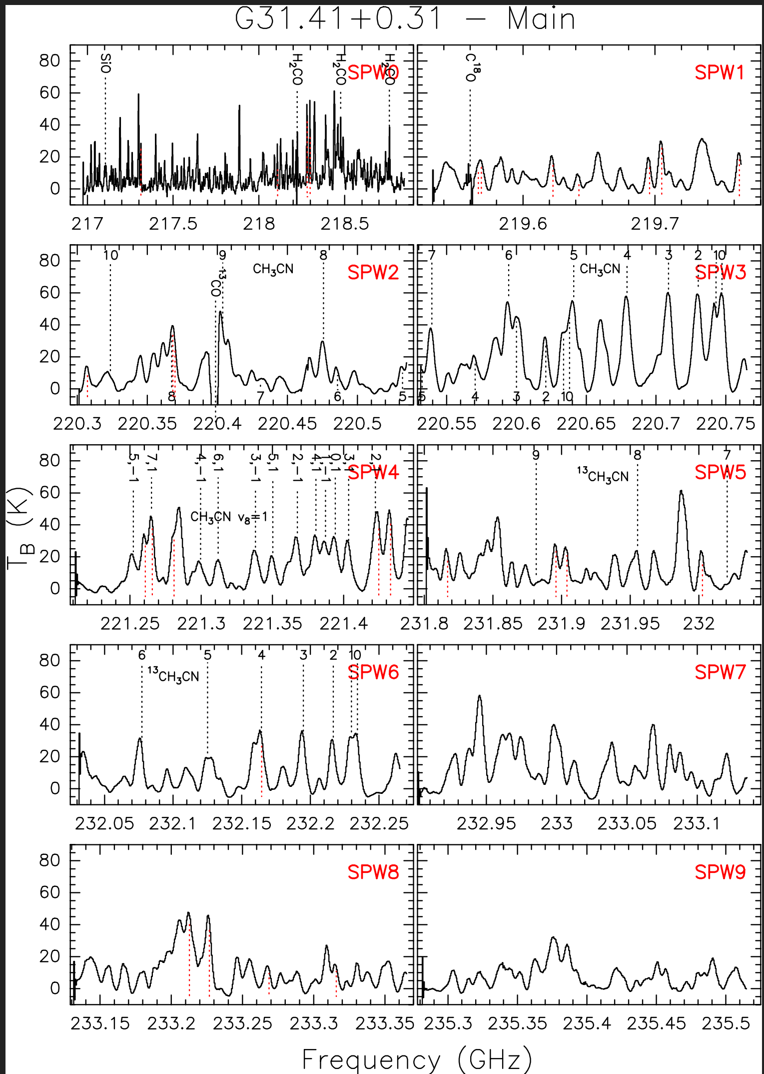
THE GUAPOS TEAM

- Arcetri: Maite Beltrán, Riccardo Cesaroni, Laura Colzi, Francesco Fontani, Chiara Mininni, Víctor Rivilla
- Cologne: Álvaro-Sánchez-Monge, Peter Schilke
- UCL: Serena Viti
- Queens Mary: Izaskun Jiménez-Serra, David Quénard
- ESO: Leonardo Testi

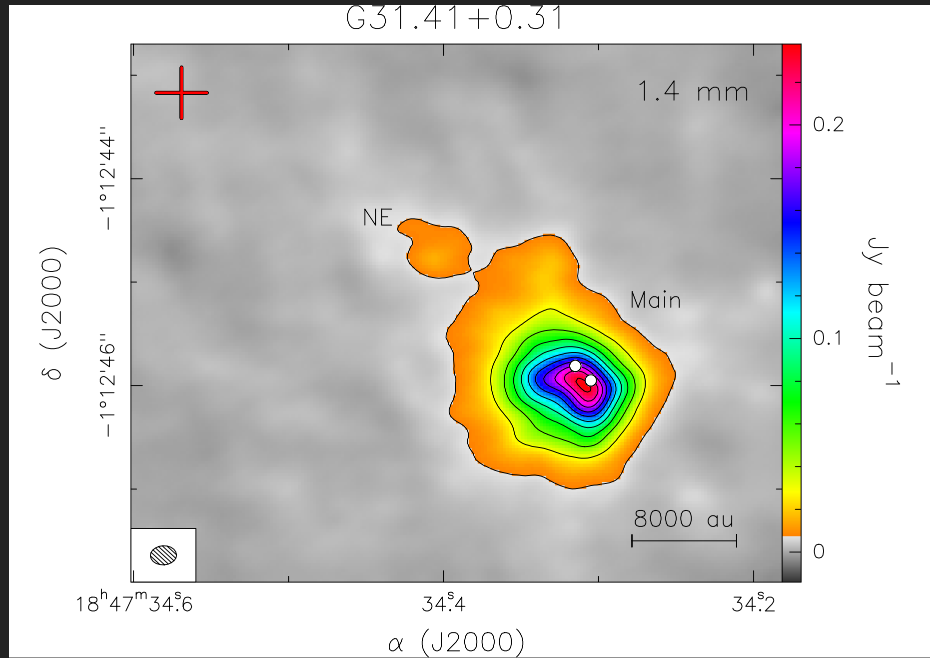


KINEMATICS AND STRUCTURE OF THE CORE

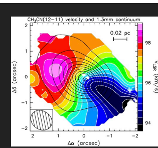
ALMA 1.4mm @ 0.2”



Beltrán+ (2018)

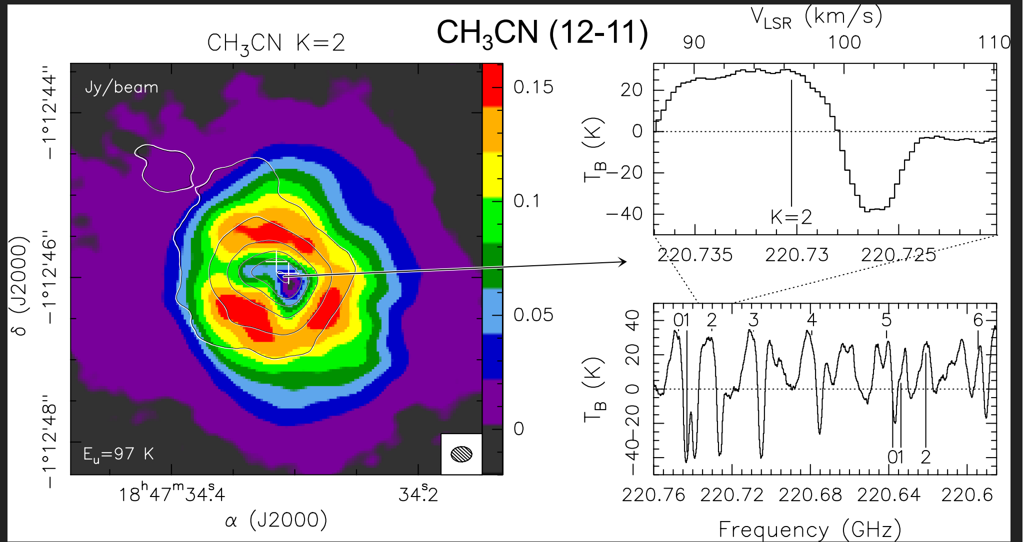


- Albeit well resolved, the continuum emission unveils a very smooth structure of the HMC without any hint of fragmentation ➪ the continuum emission at 1.4 mm is optically thick, as suggested by the high value of the peak brightness temperature (~132 K)
- The high opacity/brightness explains the existence of deep absorption



- Inverse P-Cygni profiles in practically all species (or red-shifted absorption) towards bright embedded sources have been detected ⇨ the core is undergoing free-fall collapse

G31.41+0.31



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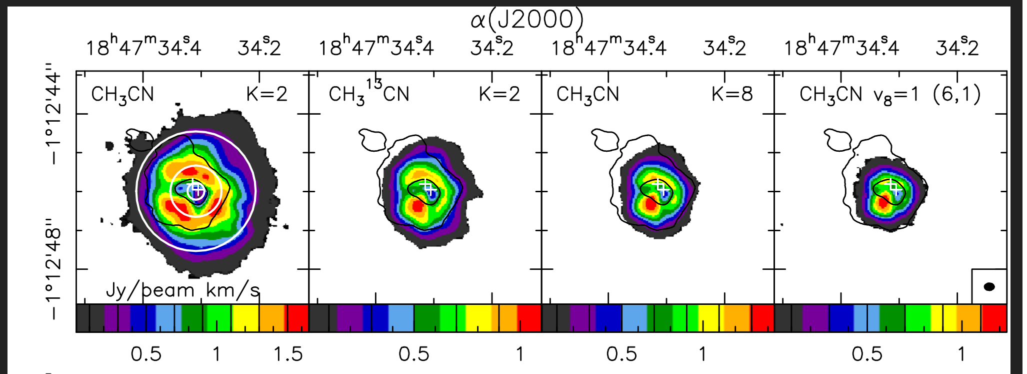
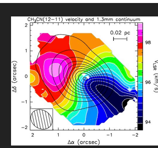


E_{up}= 97 K E_{up}= 97 K E_{up}= 526 K E_{up}= 778 K

KINEMATICS: ACCELERATING INFALL



G31.41+0.31

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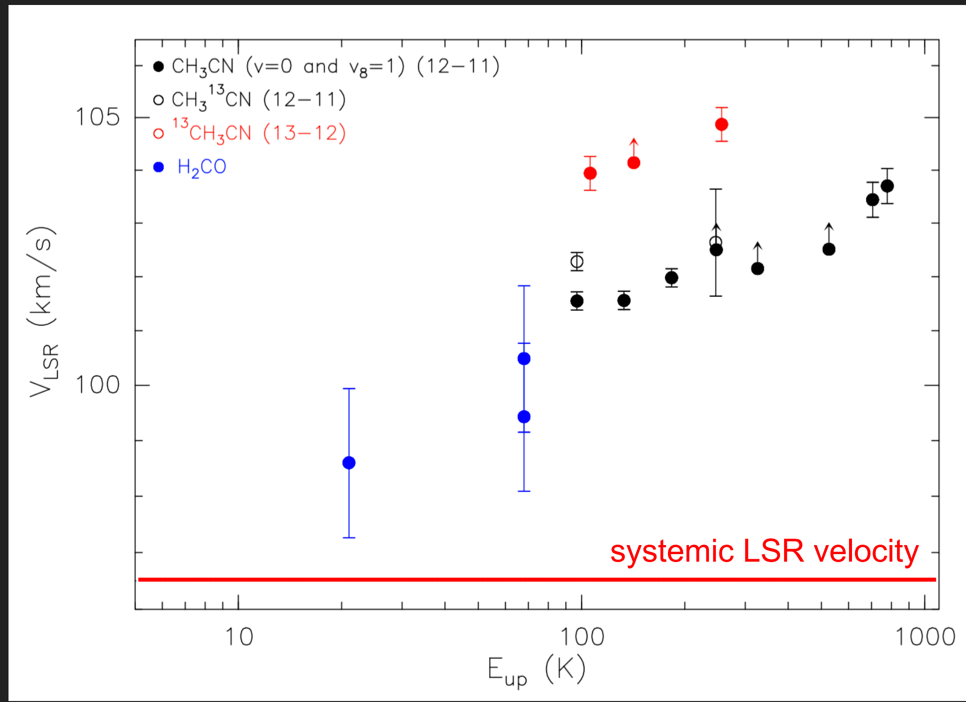
- The red-shifted absorption velocity changes with the energy of the line. $|V_{sys}-V_{red}|$ ranges from ~2 to 8 km/s ➩ the infall is accelerating towards the center of the core



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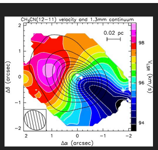
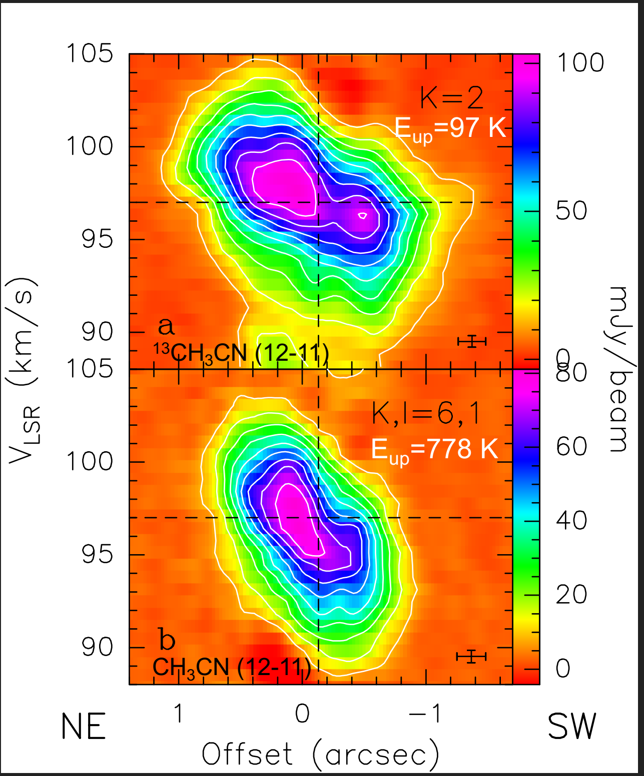


KINEMATICS: ROTATION SPIN-UP

- The emission of high-density tracers shows a clear velocity gradient along the NE–SW direction regardless of the upper level energy of the transition ➪ consistent with rotation
- PA of the velocity gradient is ~68° ➪ consistent with PA~63° of the HMC dust continuum emission
- The slope of PV plots is steeper for higher energy transitions
- Rotation velocity increases with increasing energy of the transition ➪ rotation speeds up towards the center of the core
- This is expected for conservation of angular momentum in a rotating and infalling structure



Cesaroni+ (2017); Beltrán+ (2018)

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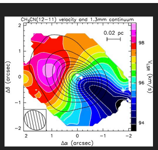

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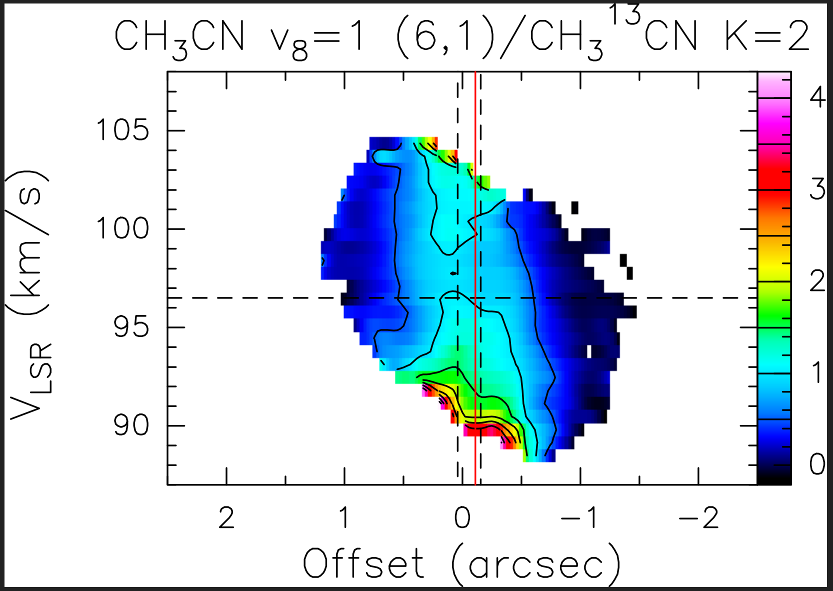

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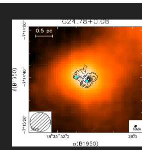


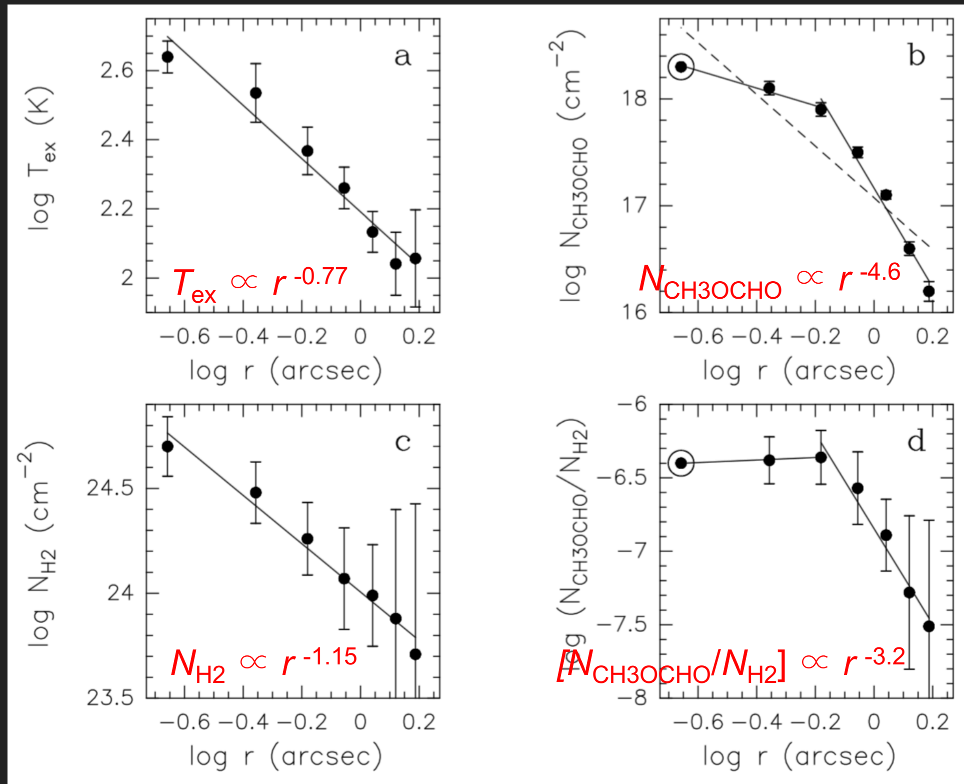
STRUCTURE OF THE CORE

- Physical parameters across the determined by fitting the ground state rotational transitions of methyl formate (v = 0) and those in the first torsionally excited state (v_t = 1).
- $\rho_c \propto r^{-n}$
- $T \propto r^{-q}$
- By integrating the density distribution over the volume

$$M_c = \frac{4\pi}{3-n}\rho_c r_c^3$$

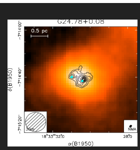
- For r_c = 8500 au, T_c = 146 K, n=2, q=-0.77 ⇨ volume density@r_c = 5x10^6 cm^{-3} and M_c = 120 $M_\odot$

CH_3OCHO

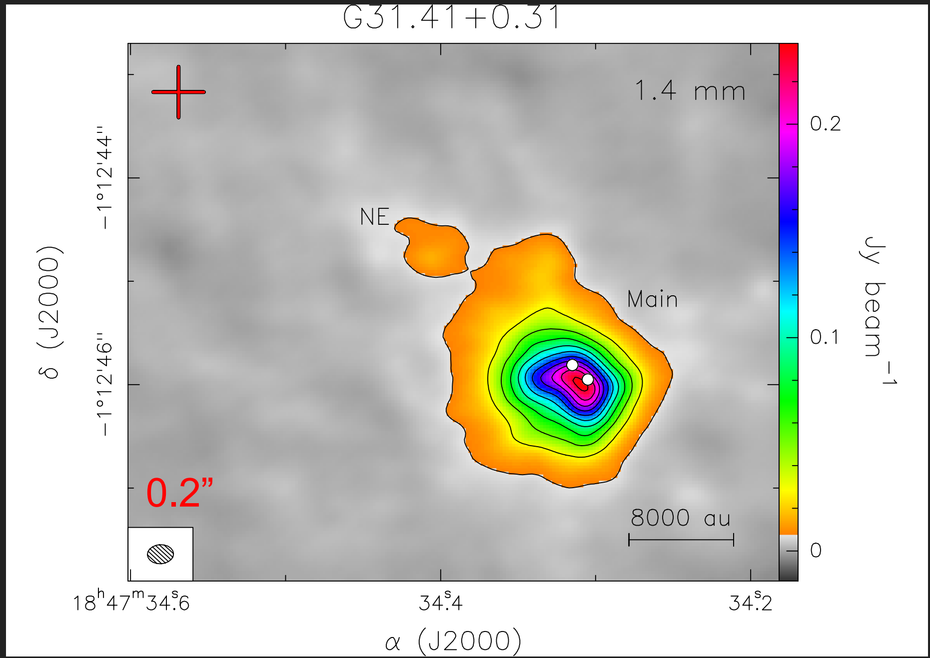


Beltrán+ (2018)

MONOLITHIC CORE?



- Dust continuum emission shows does NOT show any hint of fragmentation
- The presence of redshifted absorption in the core would suggest that what we are observing in G31 is a “real” massive core undergoing monolithic collapse, as suggested by McKee & Tan (2002)
- BUT …
- Two free-free sources already present in the core ⇨ fragmentation
- Rotational spin-up towards core center
- Monolithic appearance due to opacity of the core



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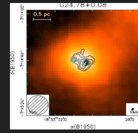
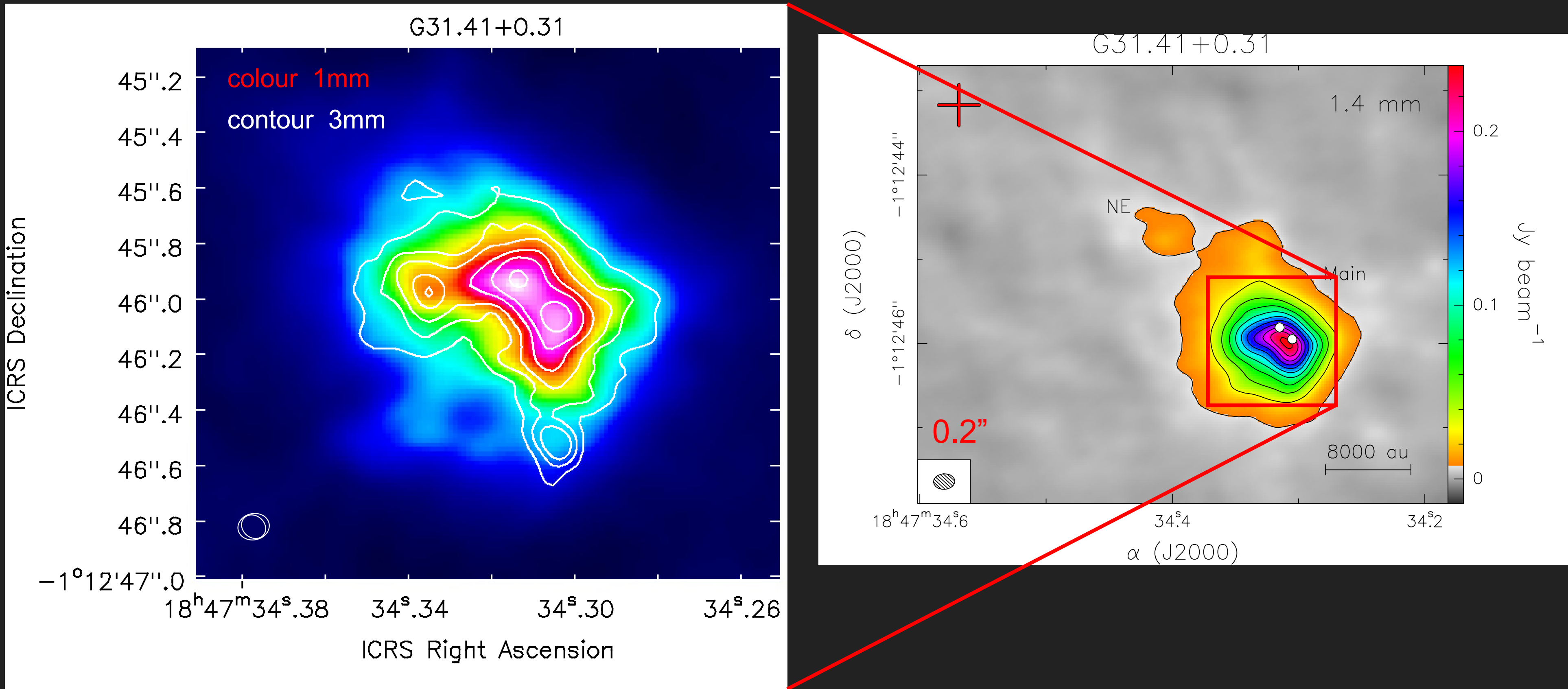
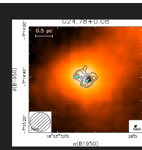
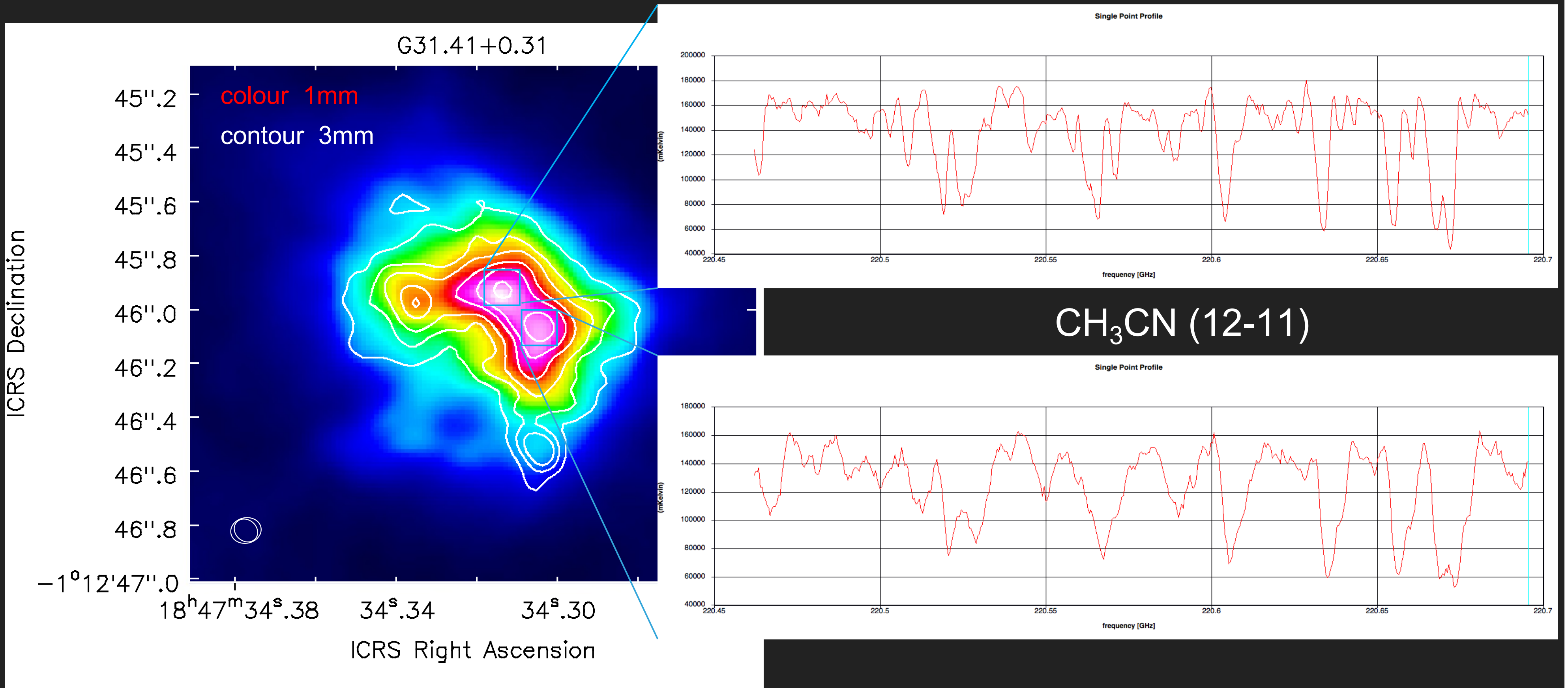




ALMA 3.3mm + 1.4mm @ 0.08"

MONOLITHIC CORE?





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STAY TUNED!