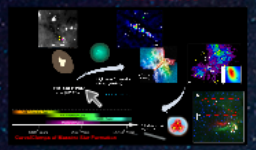
Astrochemistry tool: from the star formation to the cradle of life

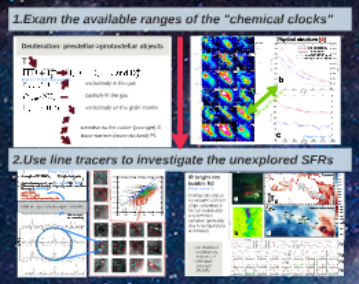
Siyi Feng (EACOA fellow)

1 Molecular line

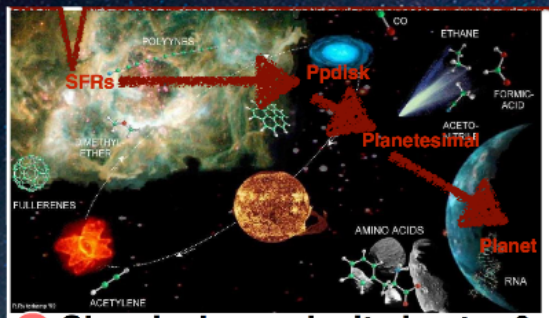
powerful diagnosing tool ?

efficient





HOW

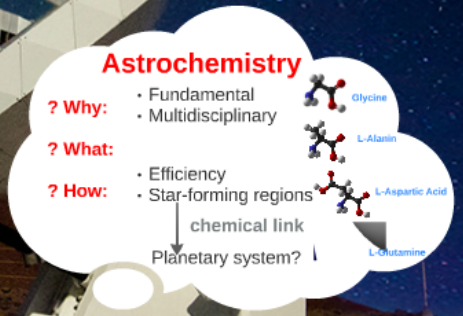


From COMs to the seed of life

- **Protoplanetary disk (Ppdisk)**: formation and condensation of COMs into new ice mantles
- **Planetesimal**: storage of dirty ices, with COMs, and reprocessing
- **Earth-like planet**: comets/ astreroids rain deliver the water and COMs

propose for FAST-500m L-band COMs survey (collaborate with NAOC), SKA in the near future

2 Chemical complexity in star & planet forming regions



Thank You

siyi.feng@naoj.ac.jp http://alma-intweb.mtk.nao.ac.jp/~syfeng/

Astrochemistry

? Why:

- Fundamental
- Multidisciplinary

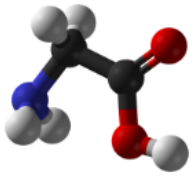
? What:

? How:

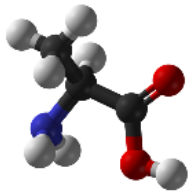
- Efficiency
- Star-forming regions

chemical link

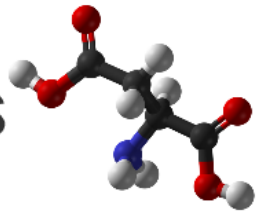
Planetary system?



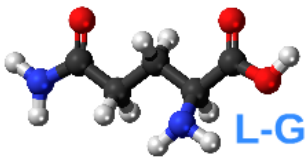
Glycine



L-Alanin

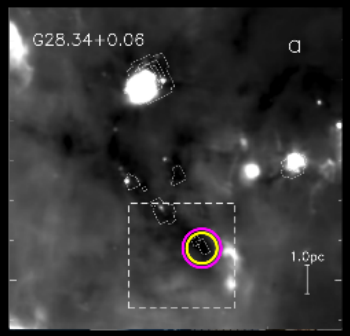


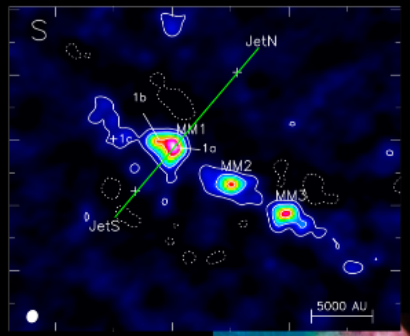
L-Aspartic Acid

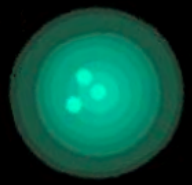


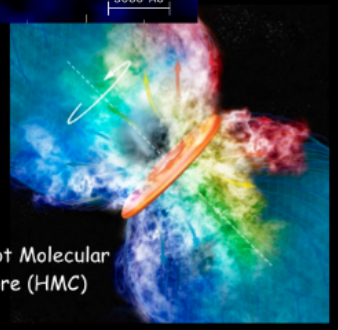
L-Glutamine

efficient







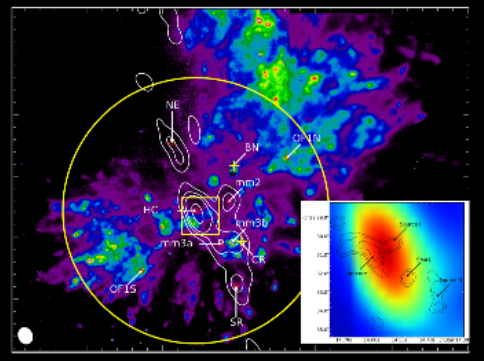


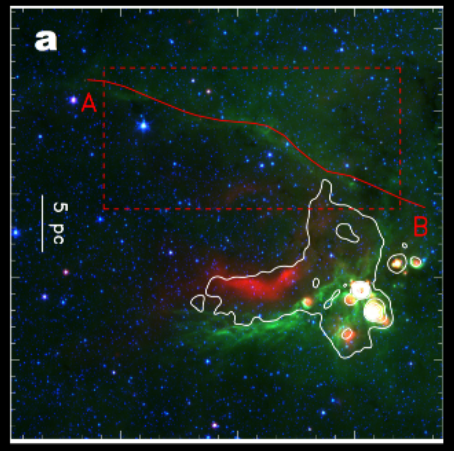
Hot Molecular Core (HMC)

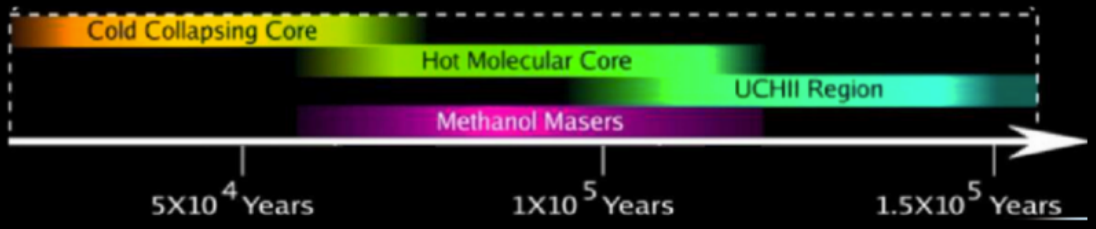
High-mass Protostellar Object (HMPOs)

High-mass starless cores (HMSCs)

Beuther et al. 2007





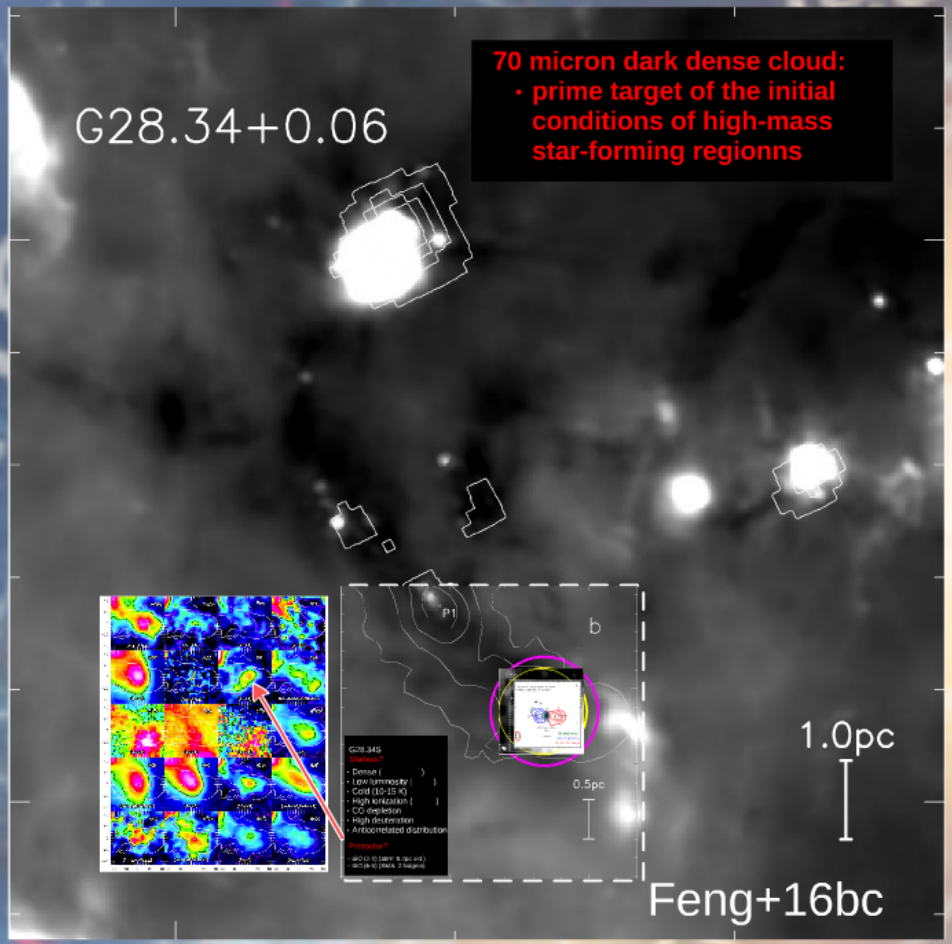


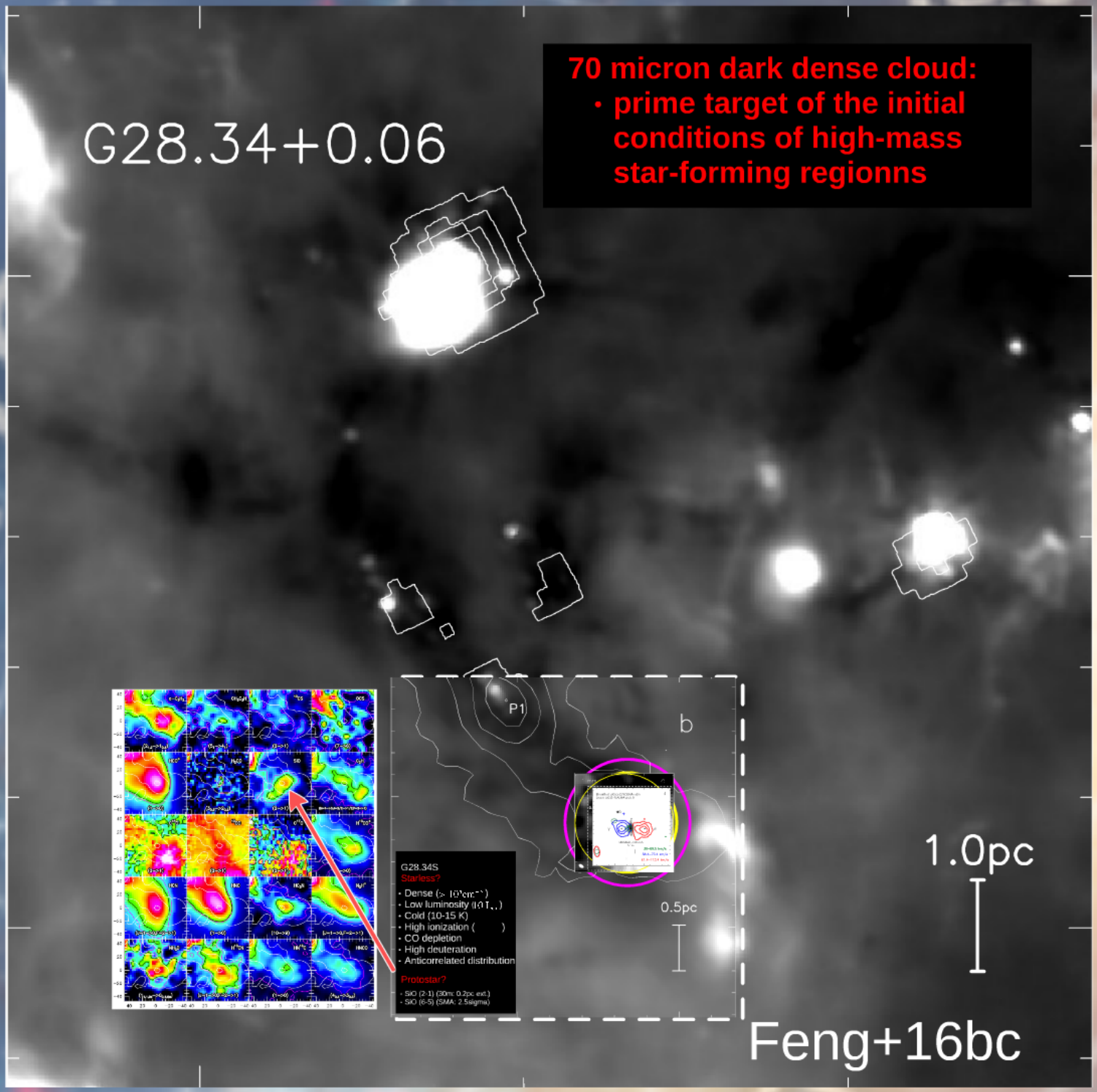
Ultra Compact HII region (UCHII)

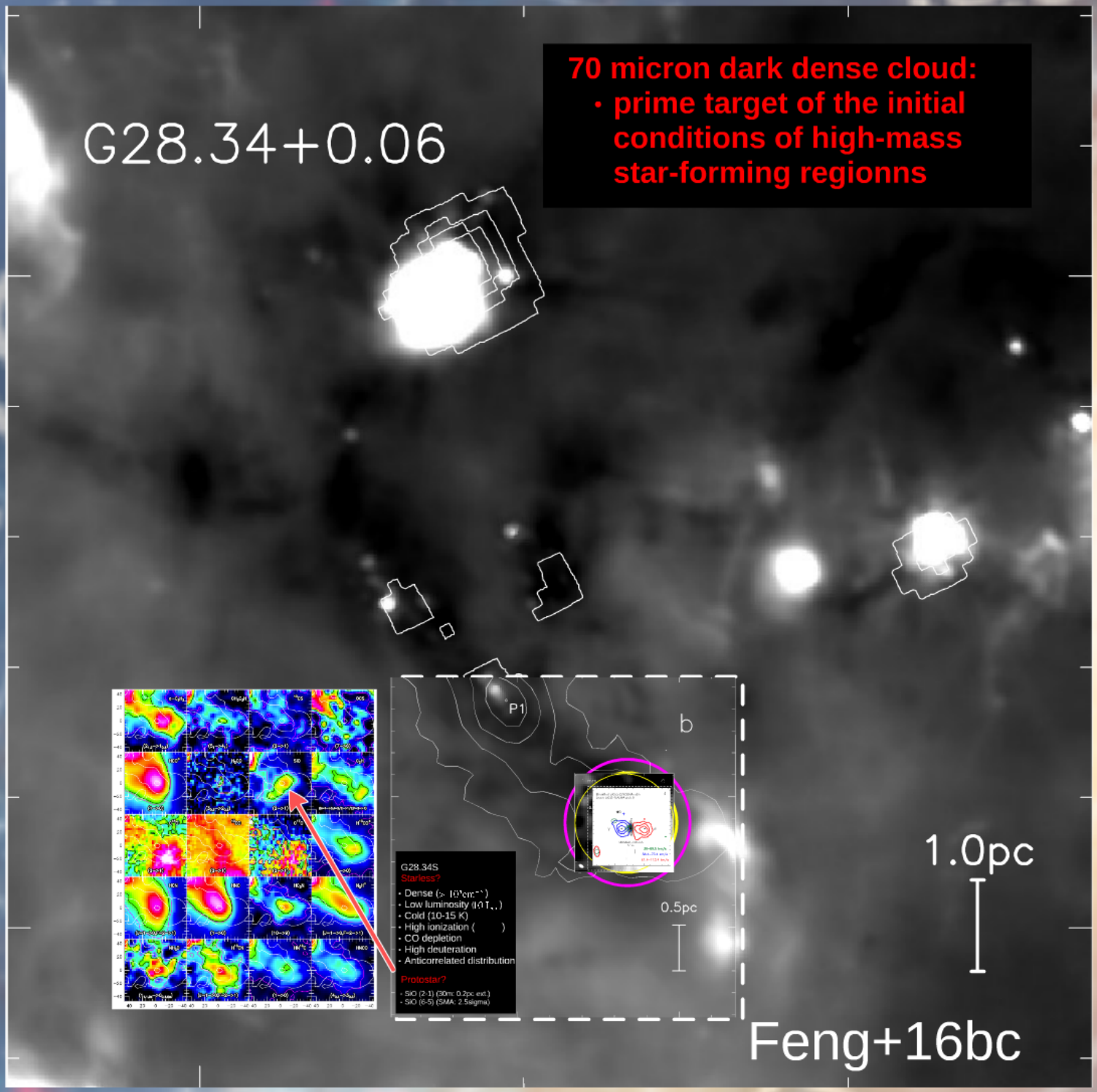
Cores/Clumps of Massive Star Formation


NOEMA

G28.34S


G28.34+0.06
70 micron dark dense cloud:
・prime target of the initial conditions of high-mass star-forming regionns
P1
b
1.0pc
0.5pc
Feng+16bc


G28.34+0.06
70 micron dark dense cloud:
• prime target of the initial conditions of high-mass star-forming regionns
P1
b
G28.34S
Starless?
• Dense (> 10⁶cm⁻³)
• Low luminosity (10 T⊙)
• Cold (10-15 K)
• High ionization ( )
• CO depletion
• High deuteration
• Anticorrelated distribution
Protostar?
• SiO (2-1) (30m: 0.2pc ext.)
• SiO (6-5) (SMA: 2.5sigma)
0.5pc
1.0pc
Feng+16bc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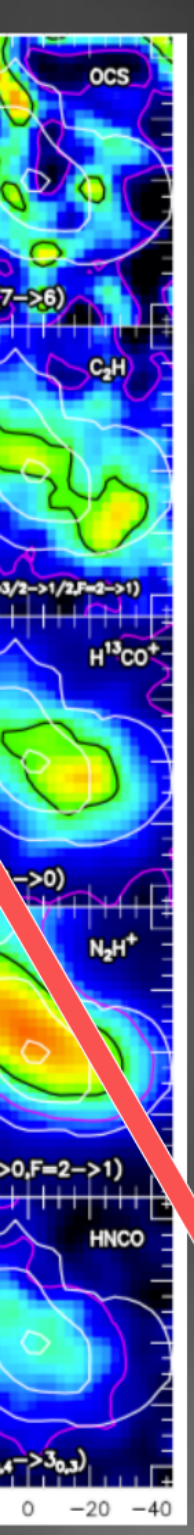
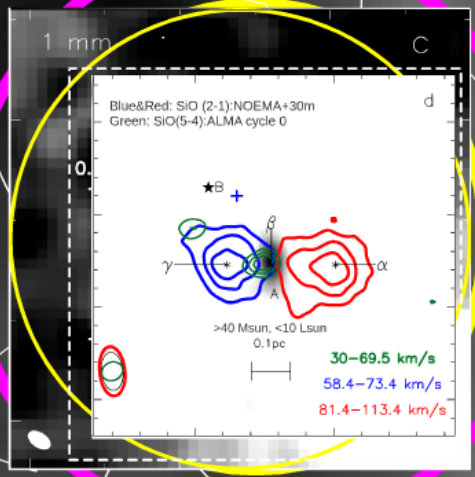


P1

b



0.5pc

G28.34S

Starless?

- Dense ($> 10^5 \mathrm{cm}^{-3}$)
- Low luminosity ($10\ \mathrm{L}_\odot$)
- Cold (10-15 K)
- High ionization ($> 10^{-7}$)
- CO depletion
- High deuteration
- Anticorrelated distribution

Protostar?

- SiO (2-1) (30m: 0.2pc ext.)
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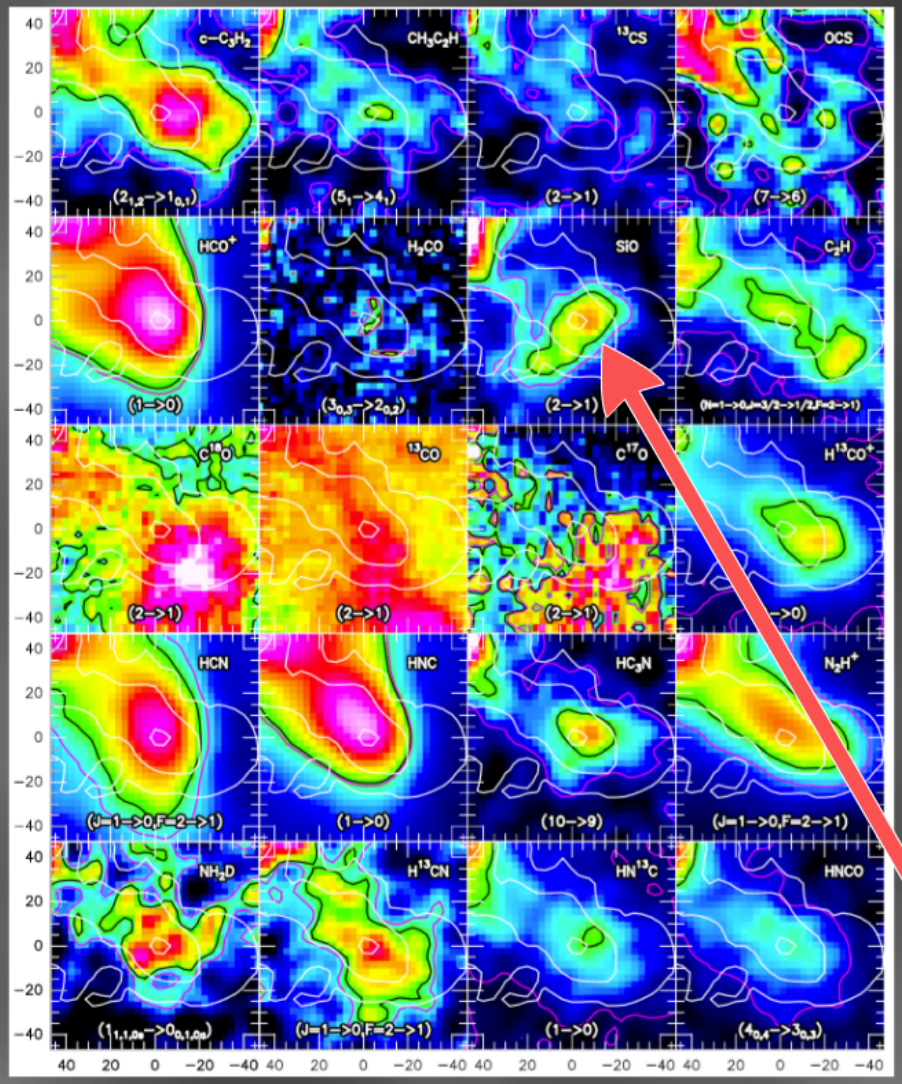

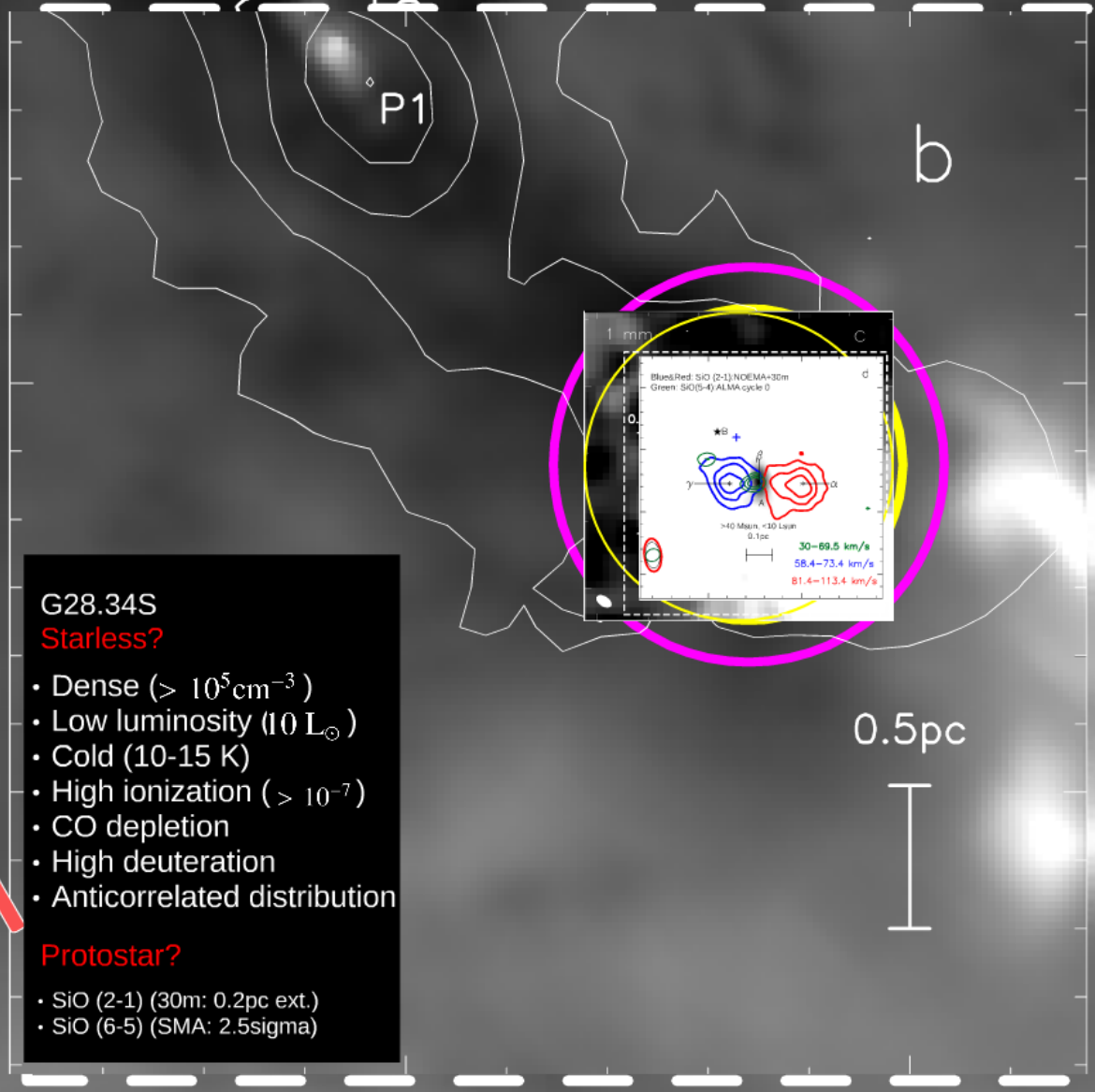

G28.34S

Starless?

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Protostar?

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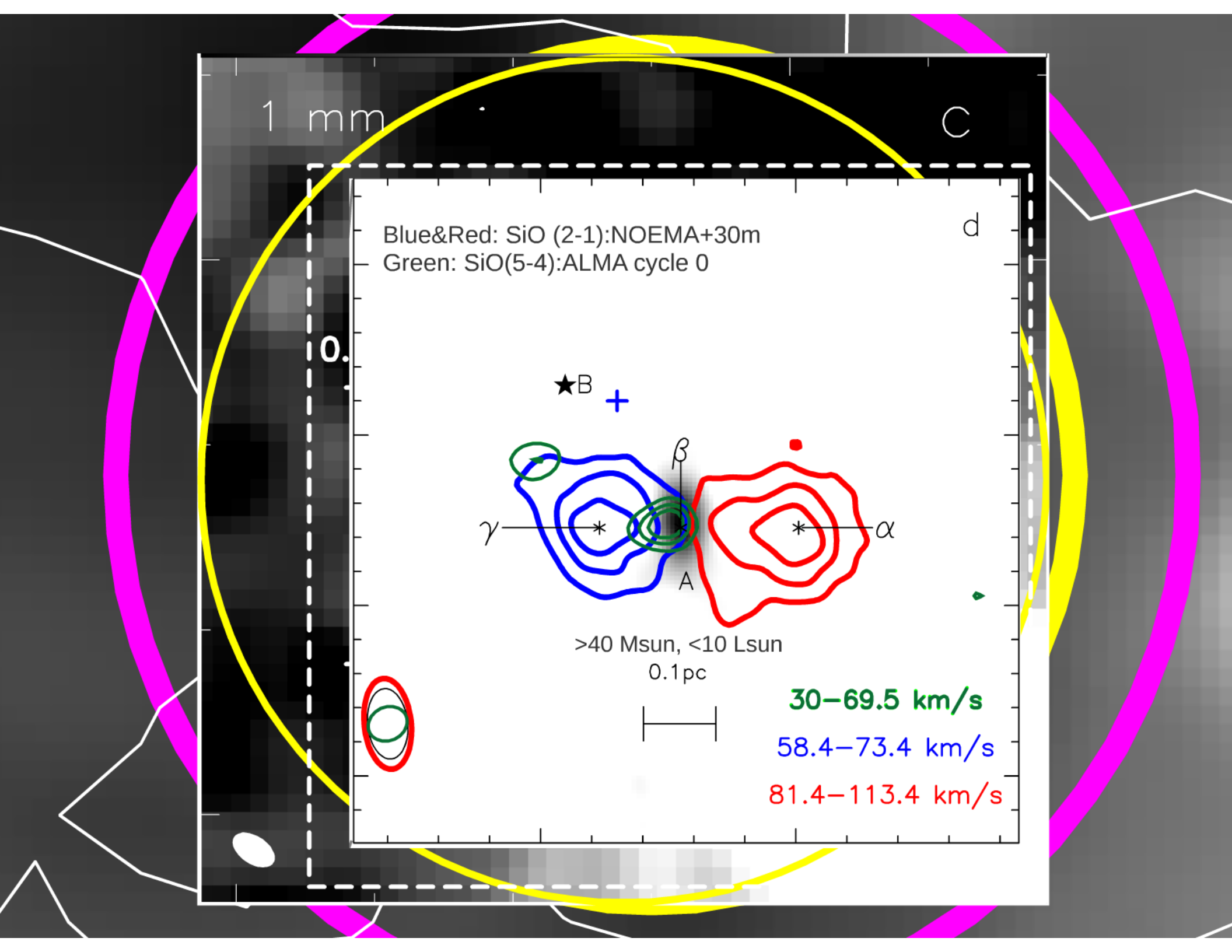
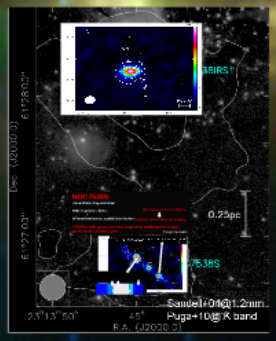
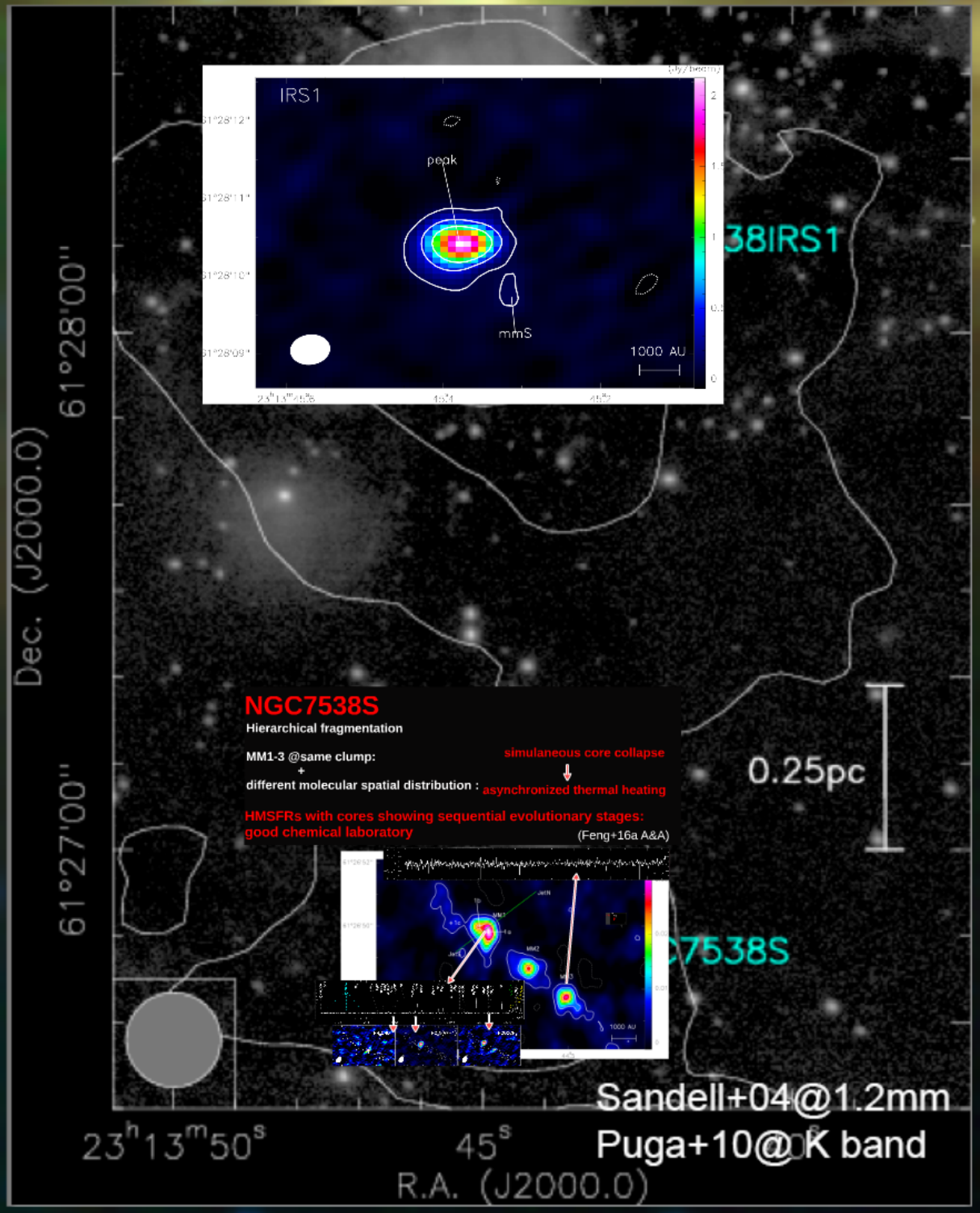

1 mm
C
d
Blue&Red: SiO (2-1):NOEMA+30m
Green: SiO(5-4):ALMA cycle 0
0.
★B
β
γ
α
A
>40 Msun, <10 Lsun
0.1pc
30−69.5 km/s
58.4−73.4 km/s
81.4−113.4 km/s

NGC7538



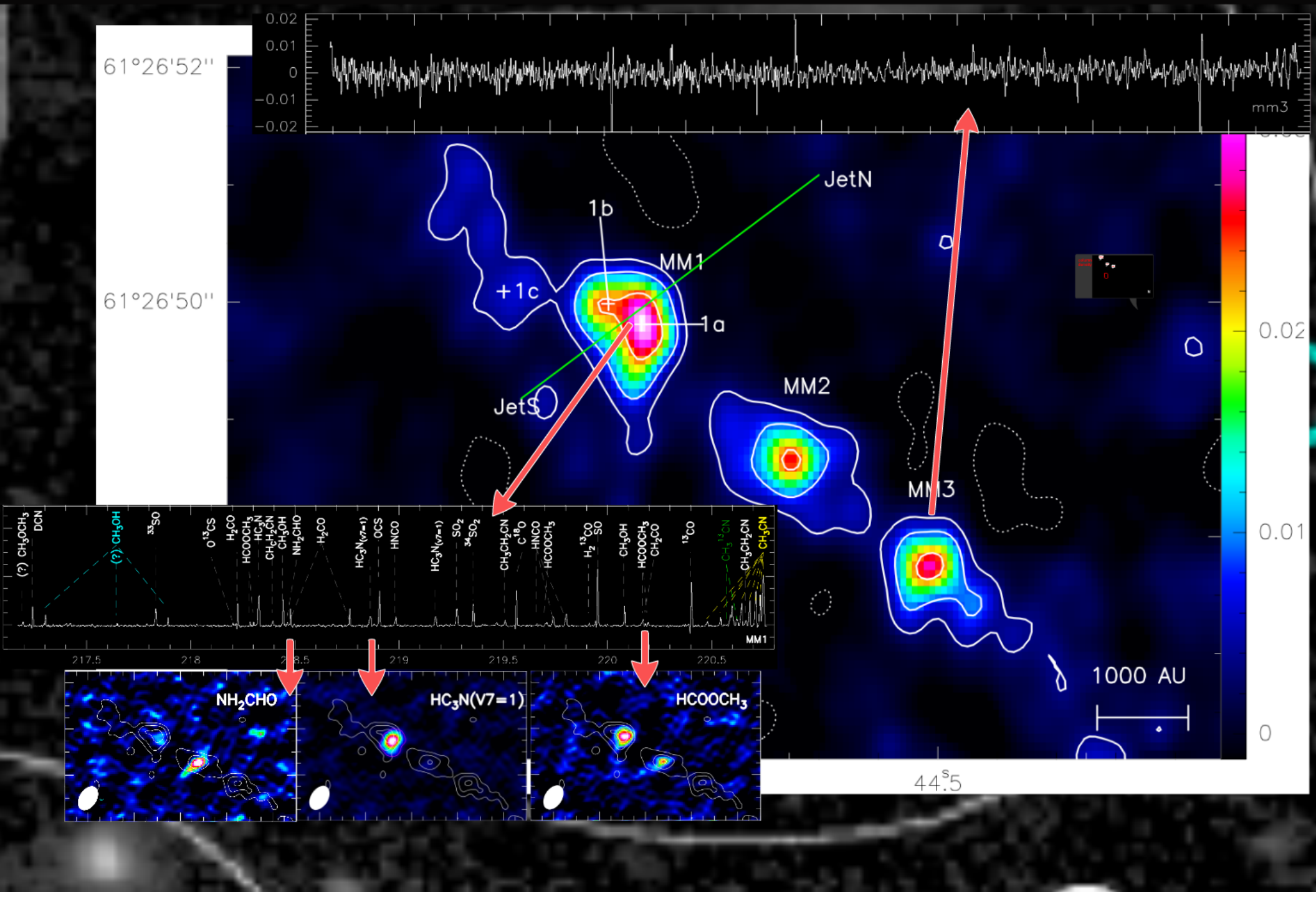
IRS9

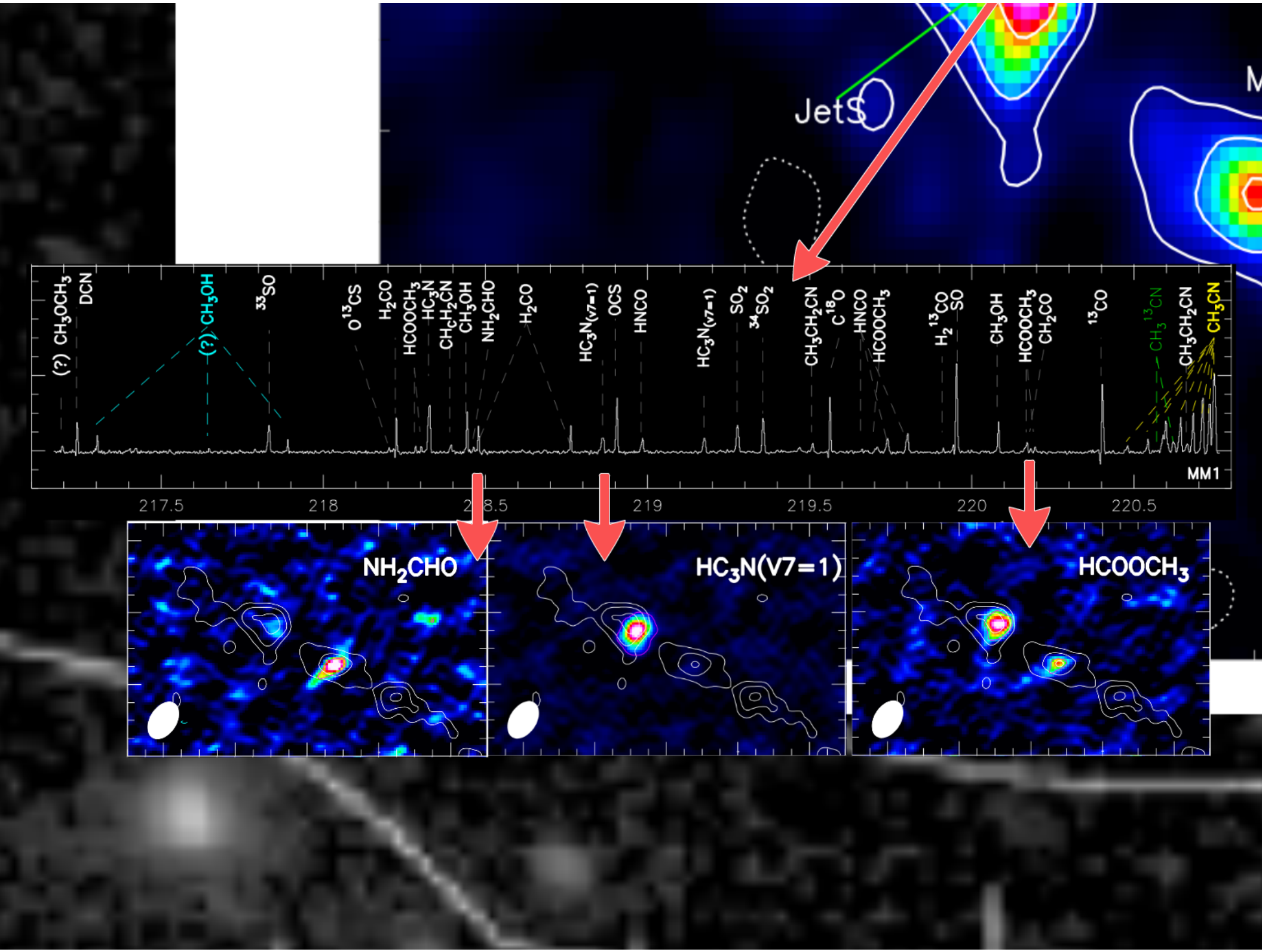
Wright+12@4.5 & 8 mum


IRS1
peak
mmS
1000 AU
38IRS1
NGC7538S
Hierarchical fragmentation
MM1-3 @same clump:
+
different molecular spatial distribution :
simulaneous core collapse
asynchronized thermal heating
HMSFRs with cores showing sequential evolutionary stages:
good chemical laboratory
(Feng+16a A&A)
0.25pc
7538S
Sandell+04@1.2mm
Puga+10@K band
61°28'00"
61°27'00"
Dec. (J2000.0)
23h13m50s
45s
R.A. (J2000.0)

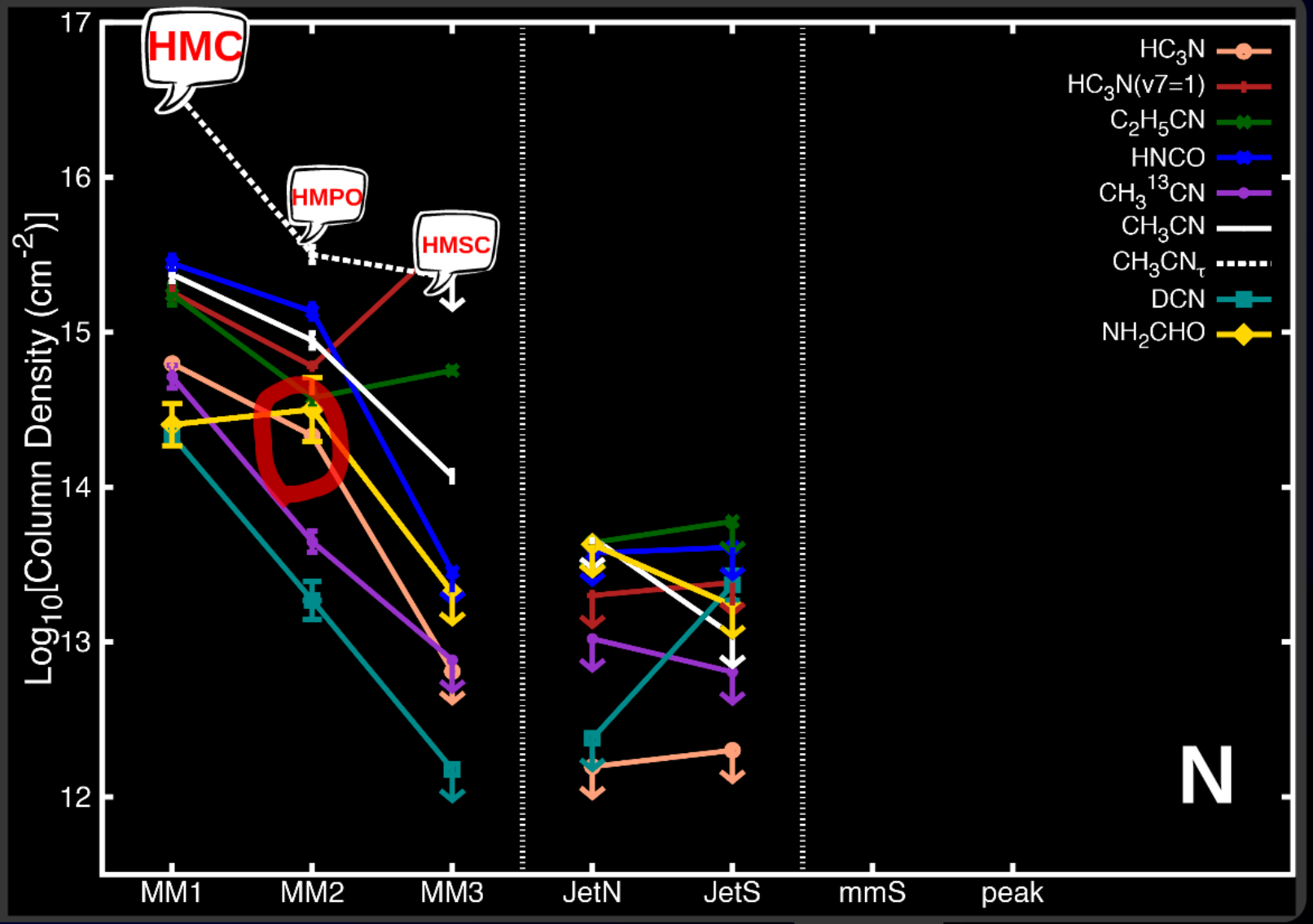
nical laboratory

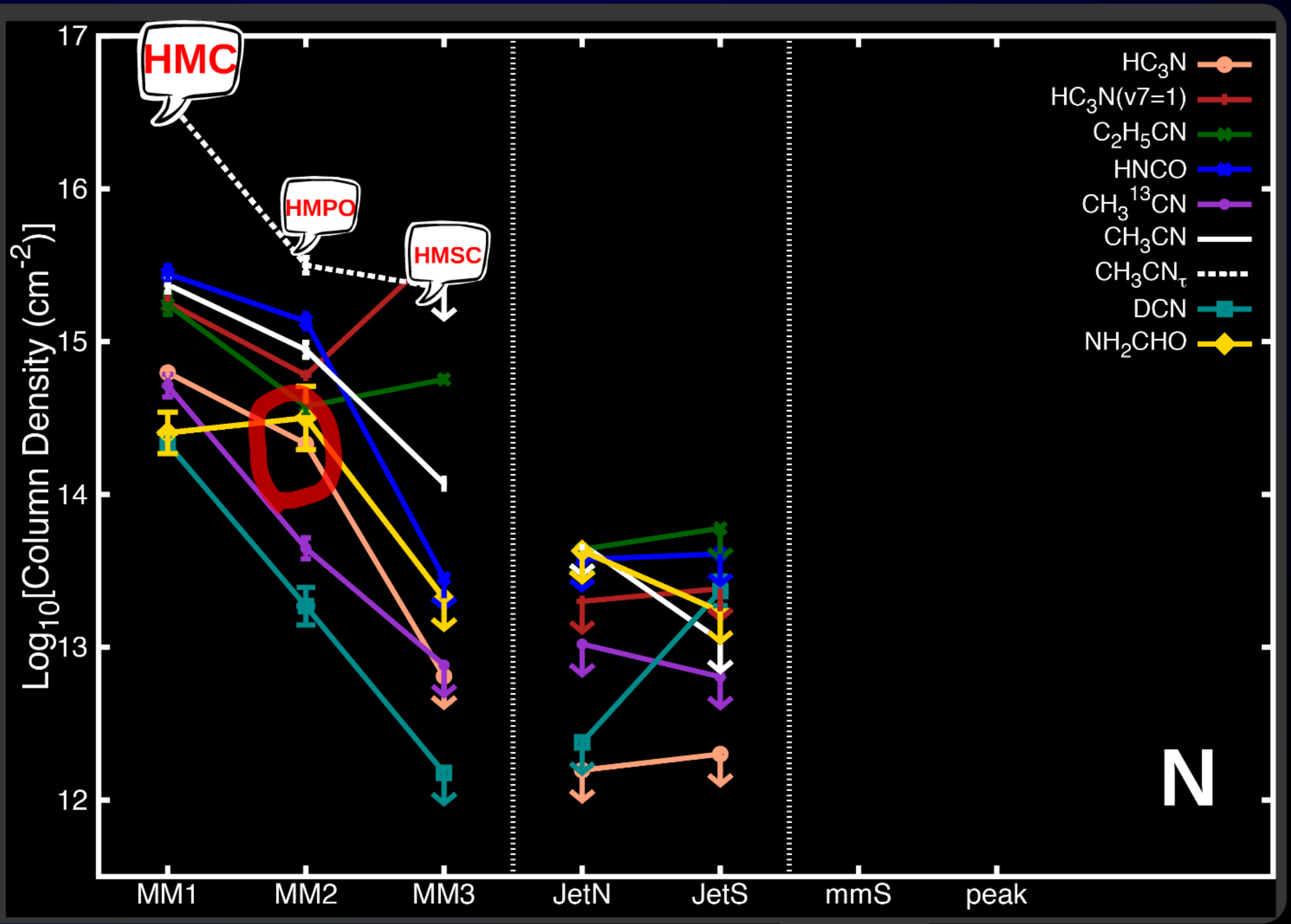
(Feng+16a A&A)




Jet S
M
(?) CH3OCH3
DCN
(?) CH3OH
33SO
O13CS
H2CO
HCOOCH3
HC3N
CH2CHCN
CH3OH
NH2CHO
H2CO
HC3N(v7=1)
OCS
HNCO
HC3N(v7=1)
SO2
34SO2
CH3CH2CN
C18O
HNCO
HCOOCH3
H2 13CO
SO
CH3OH
HCOOCH3
CH2CO
13CO
CH3 13CN
CH3CH2CN
CH3CN
MM1
217.5
218
218.5
219
219.5
220
220.5
NH2CHO
HC3N(V7=1)
HCOOCH3

column density




HMC
HMPO
HMSC
O
N
HC3N
HC3N(v7=1)
C2H5CN
HNCO
CH3 13CN
CH3CN
CH3CNτ
DCN
NH2CHO
Log10[Column Density (cm-2)]
17
16
15
14
13
12
MM1
MM2
MM3
JetN
JetS
mmS
peak

NGC7538S

Hierarchical fragmentation

MM1-3 @same clump:

+

different molecular spatial distribution :

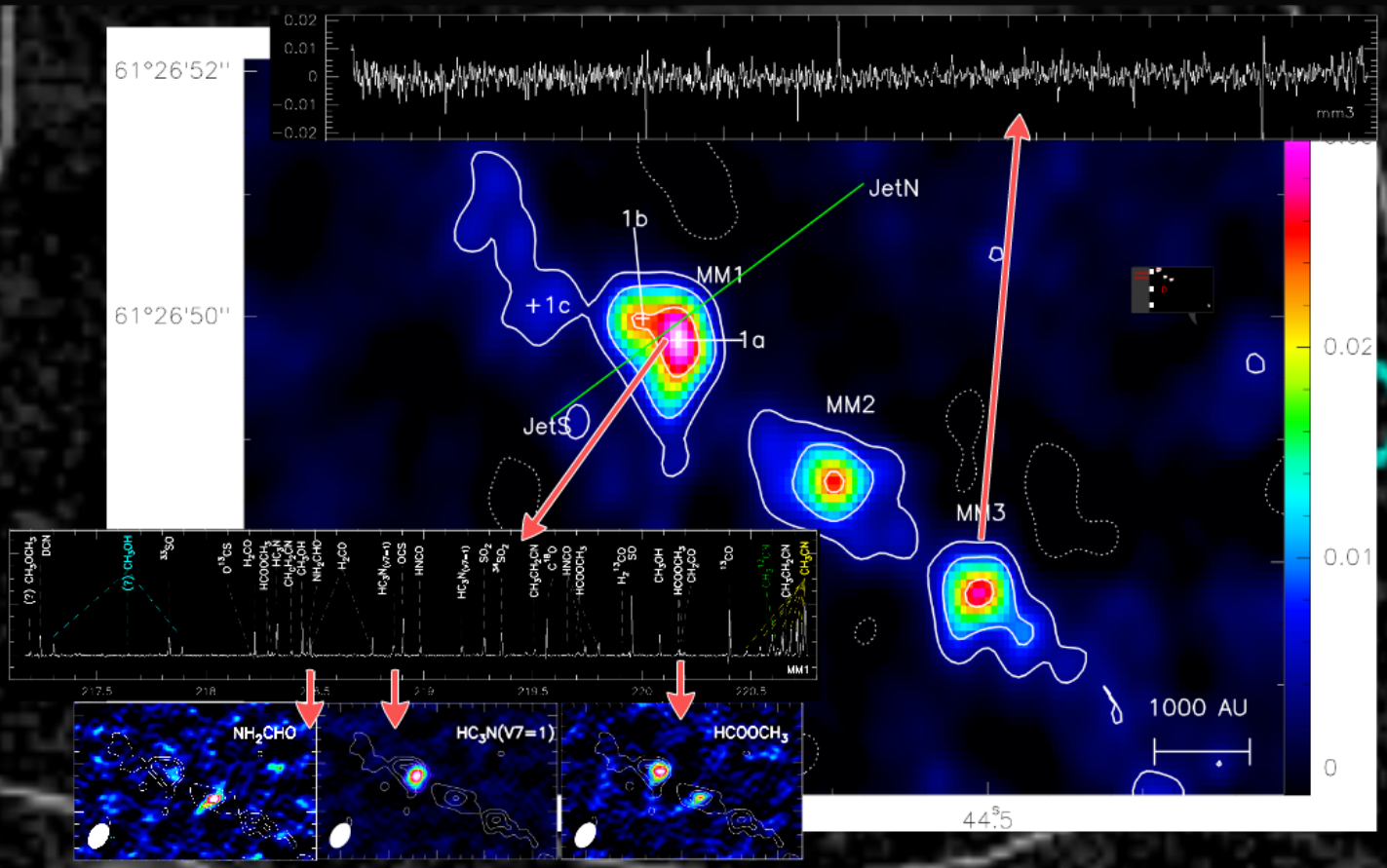
simulaneous core collapse

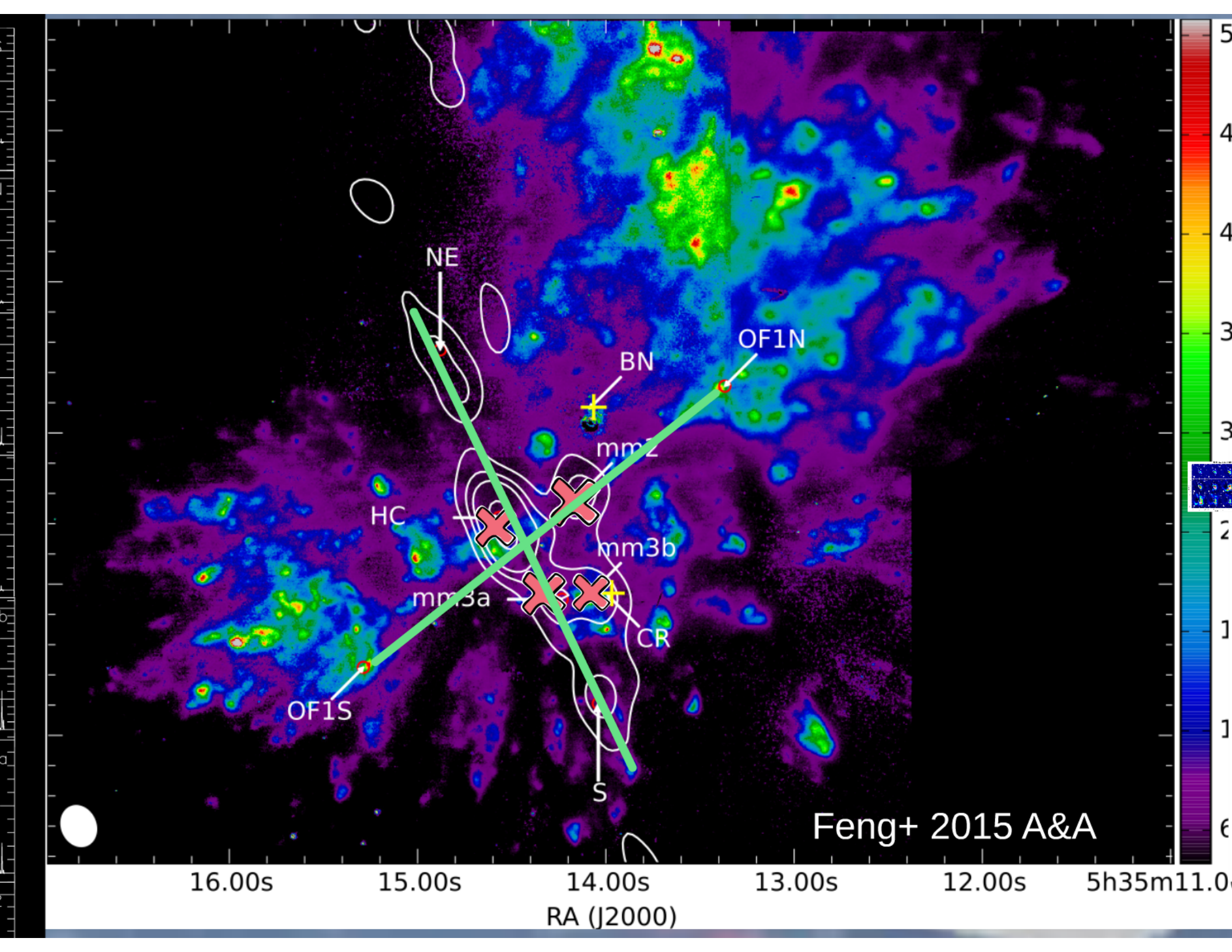
↓

asynchronized thermal heating

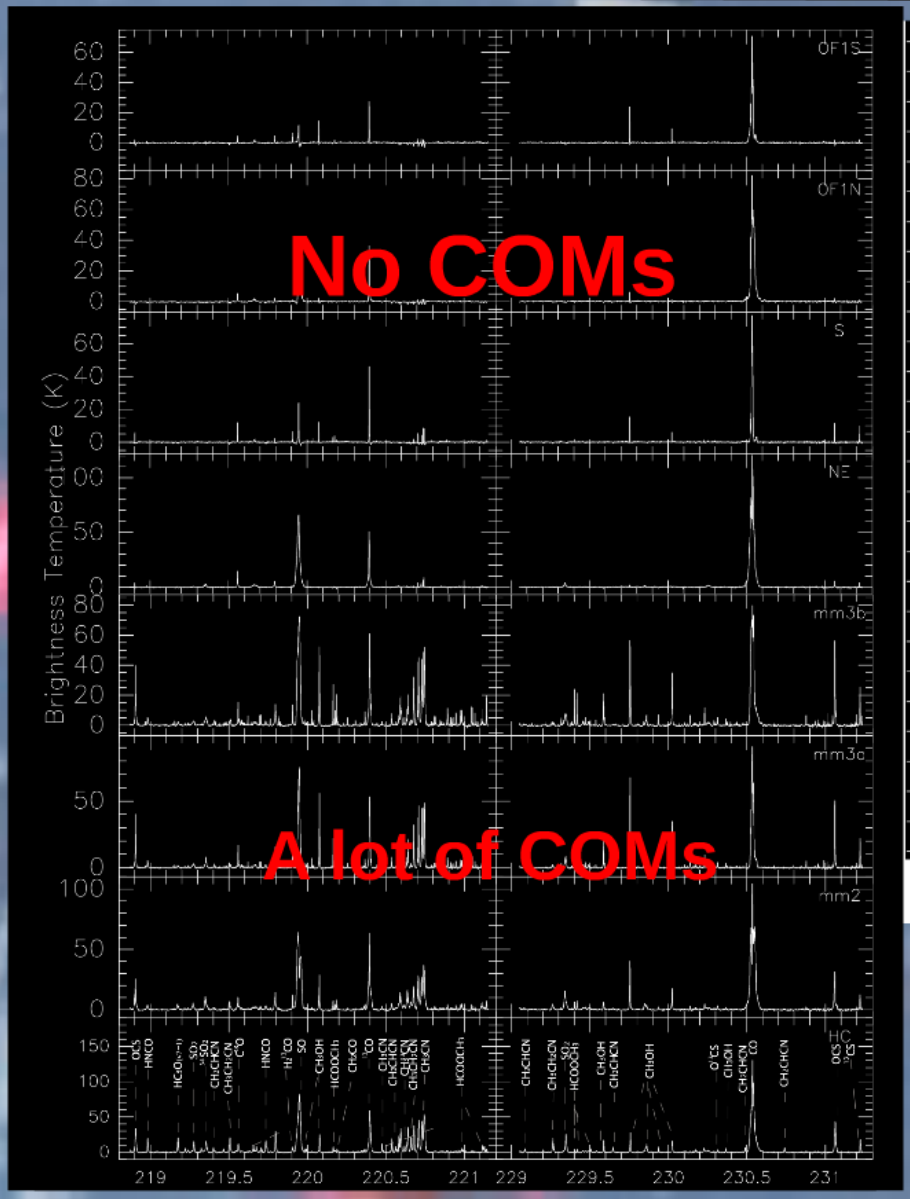
HMSFRs with cores showing sequential evolutionary stages: good chemical laboratory

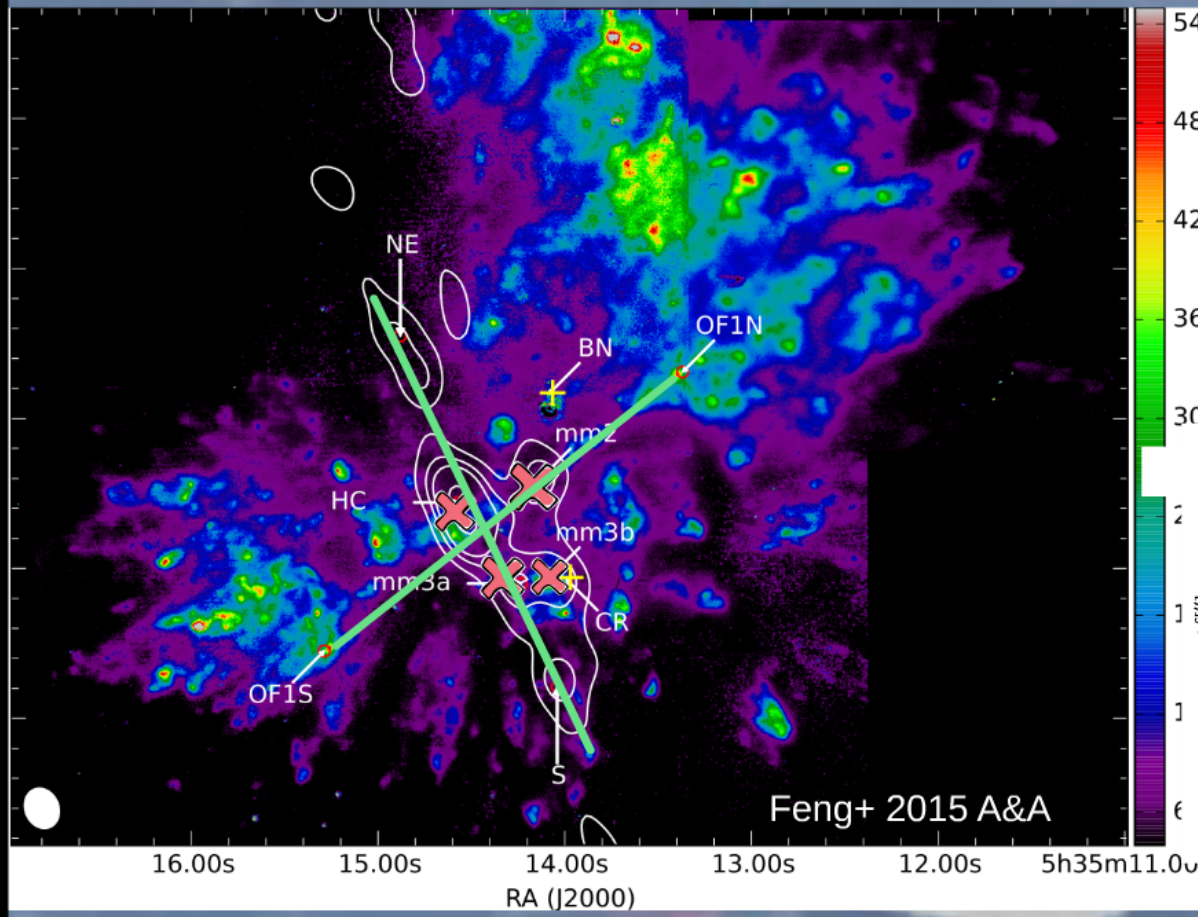
(Feng+16a A&A)



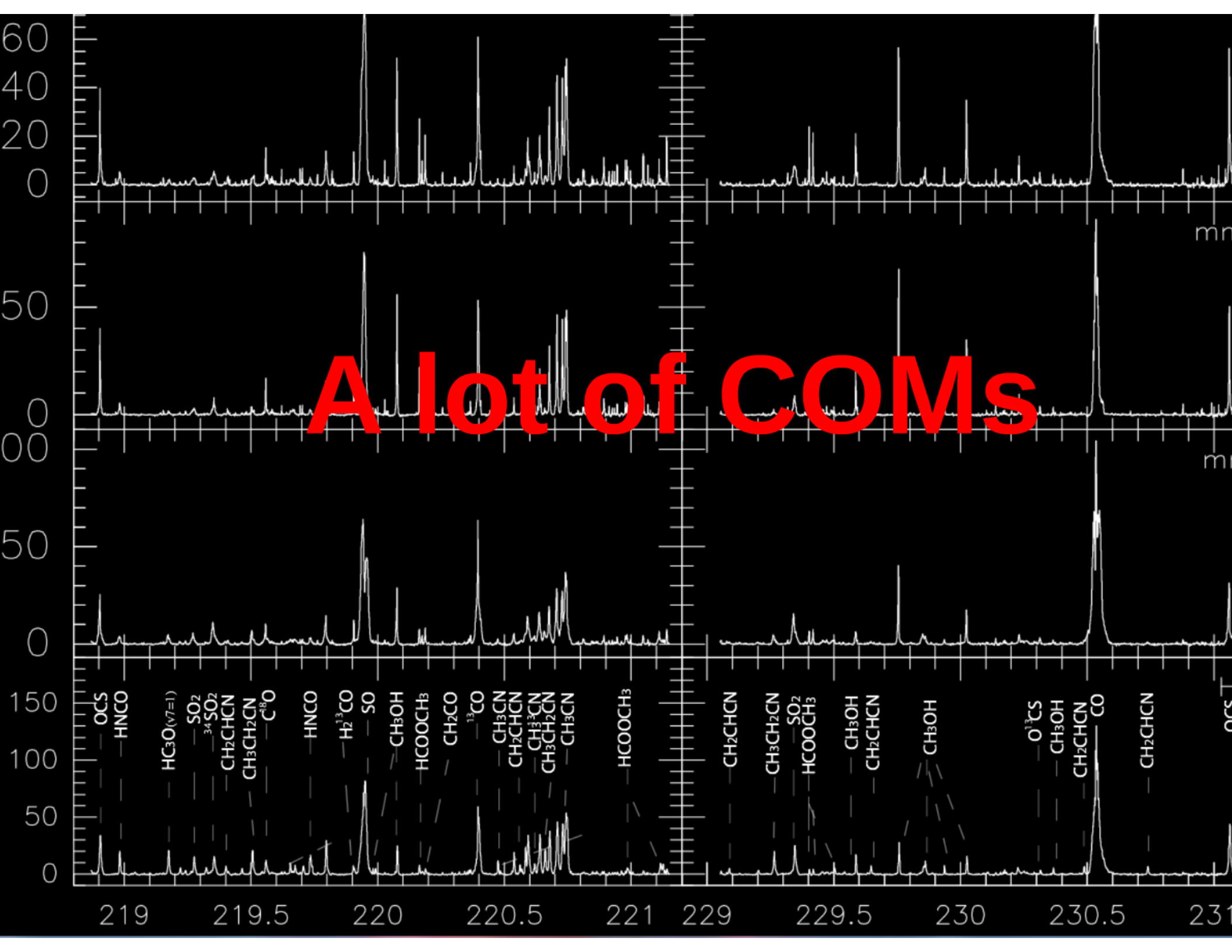

NE
OF1N
BN
mm2
HC
mm3b
mm3a
CR
OF1S
S
Feng+ 2015 A&A
16.00s
15.00s
14.00s
13.00s
12.00s
5h35m11.0
RA (J2000)

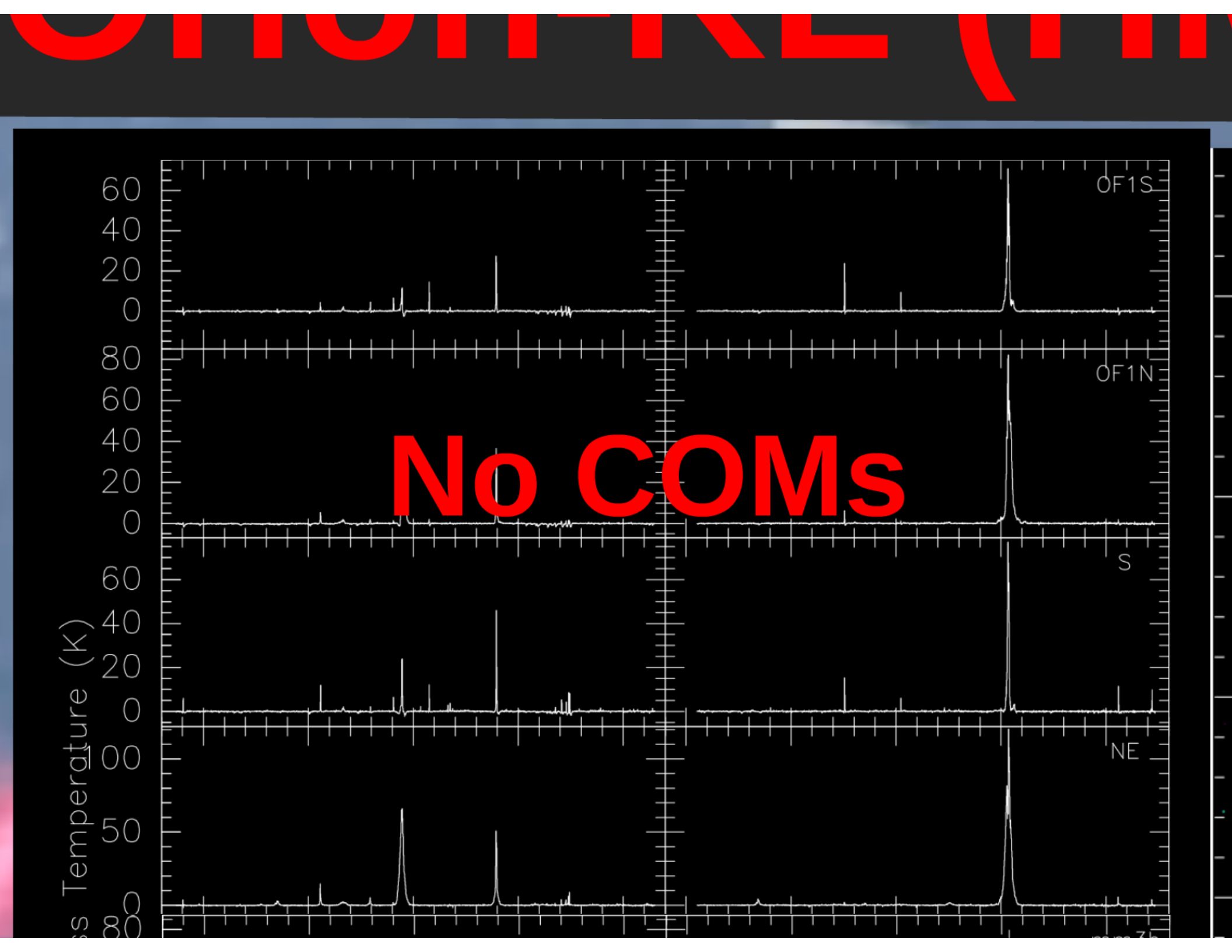
Orion-KL (HMC)

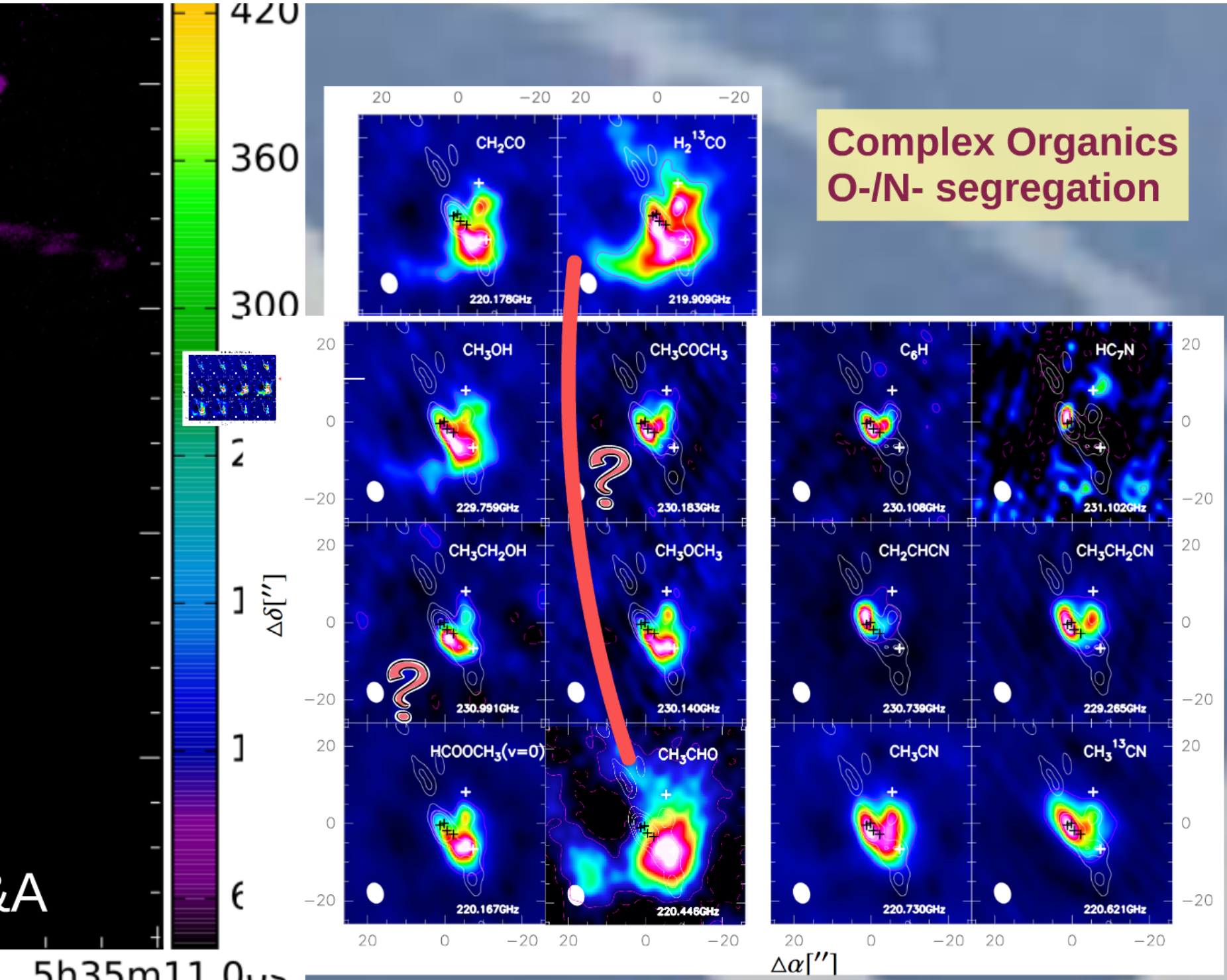


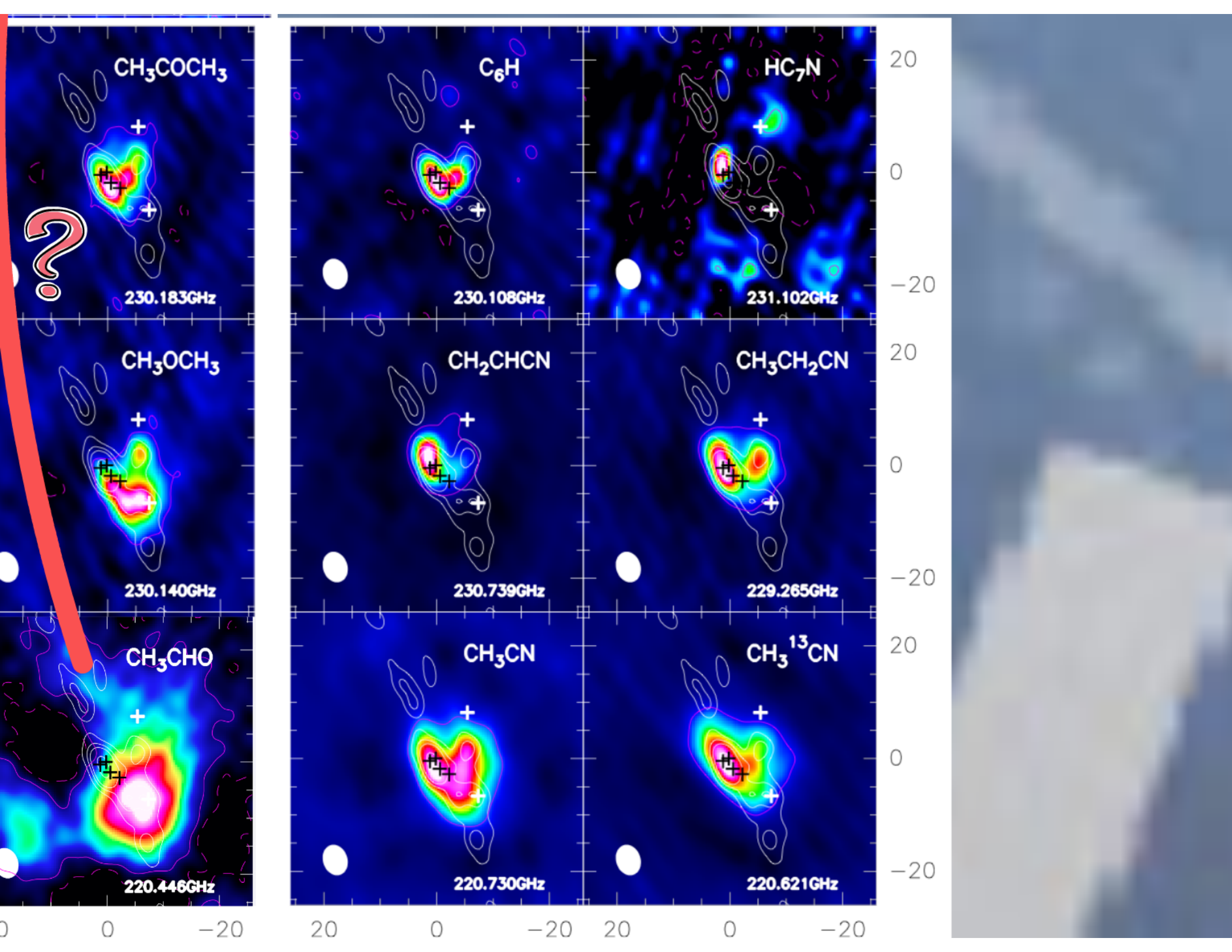


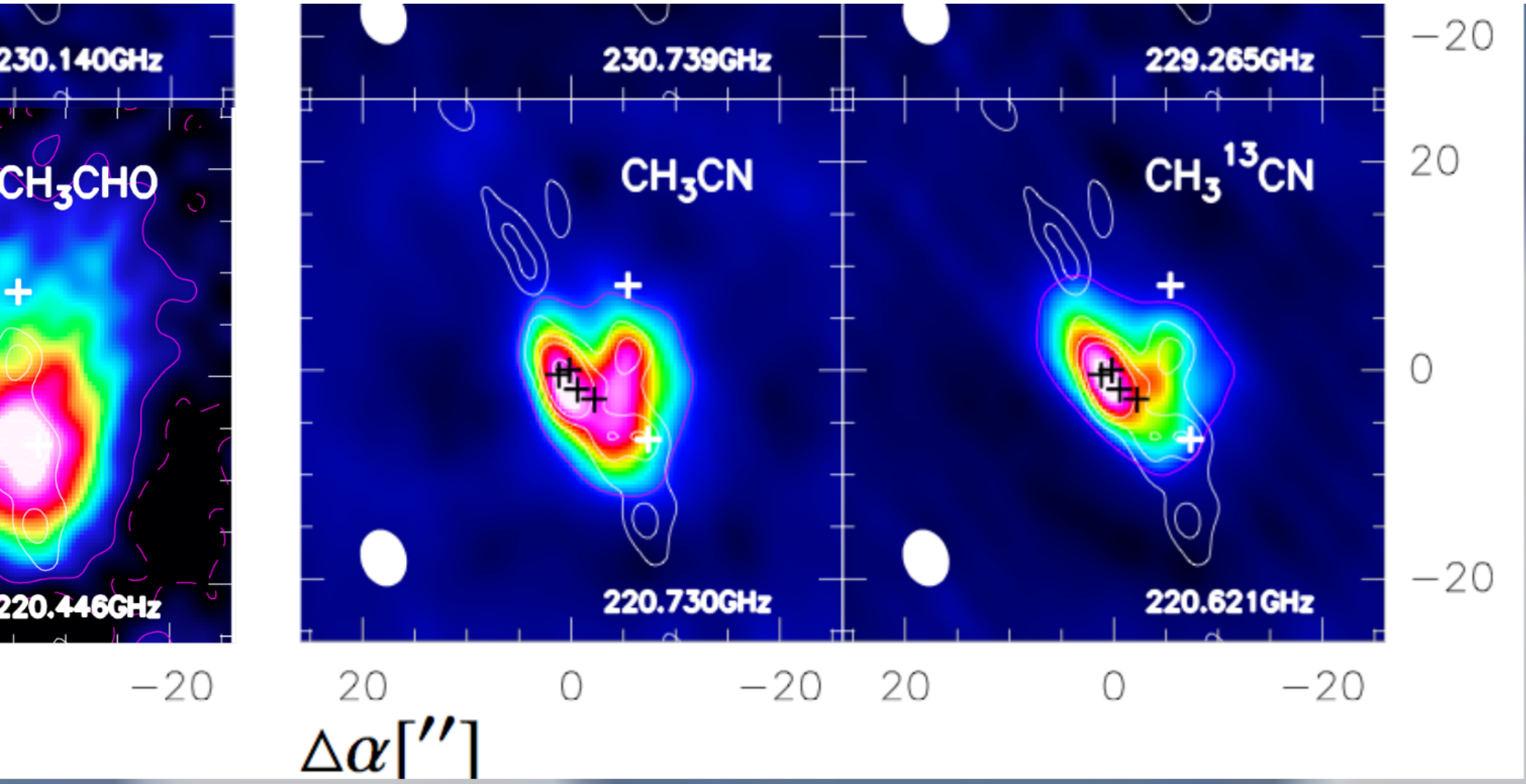
Chemical segregation (esp. COMs)
forming paths of species differ-->loc

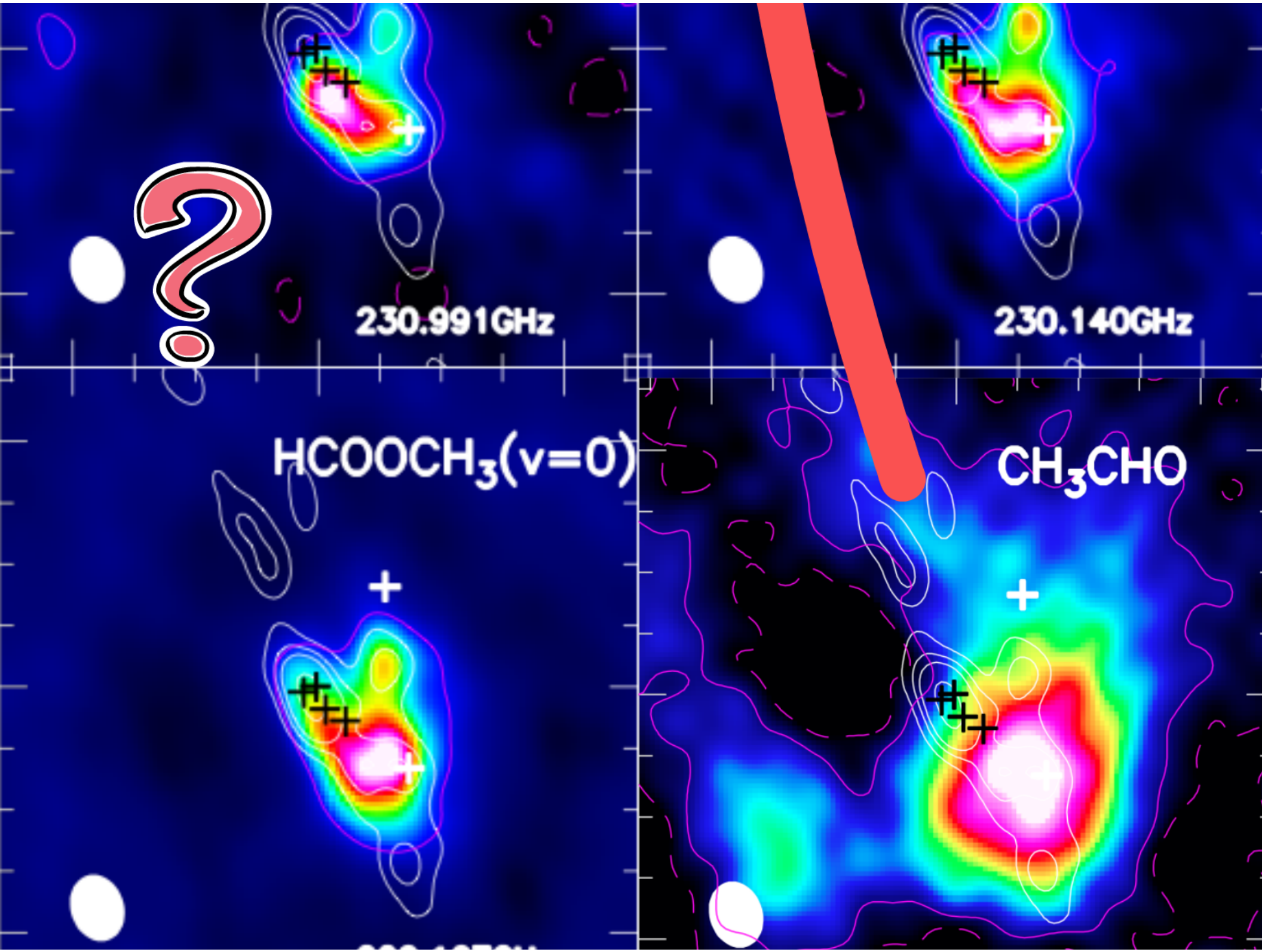

A lot of COMs
OCS
HNCO
HC3O(v7=1)
SO2
34SO2
CH2CHCN
CH3CH2CN
C18O
HNCO
H2 13CO
SO
CH3OH
HCOOCH3
CH2CO
13CO
CH3CN
CH2CHCN
CH3 13CN
CH3CH2CN
CH3CN
HCOOCH3
CH2CHCN
CH3CH2CN
SO2
HCOOCH3
CH3OH
CH2CHCN
CH3OH
O13CS
CH3OH
CH2CHCN
CO
CH2CHCN
219
219.5
220
220.5
221
229
229.5
230
230.5

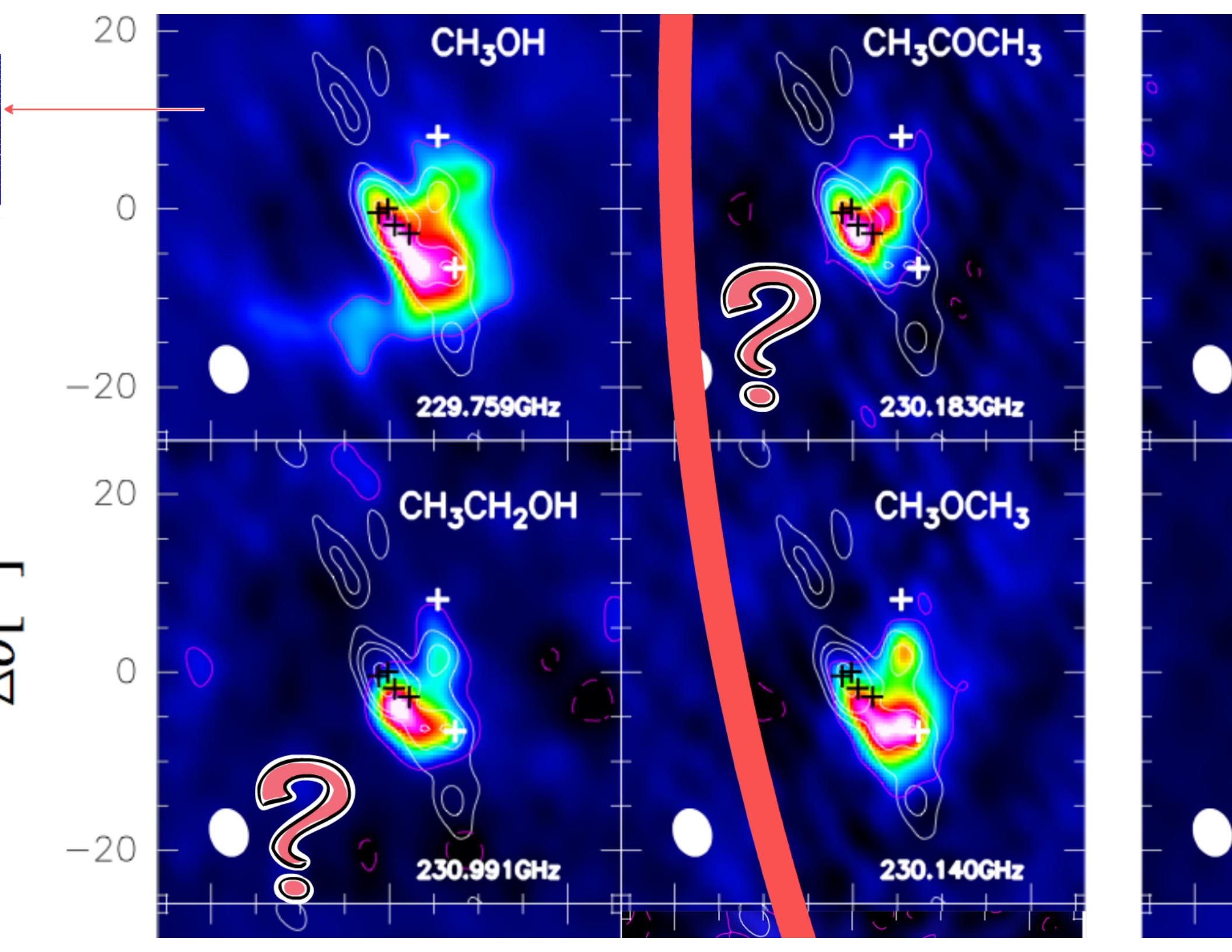

OF1S
OF1N
S
NE
No COMs
Temperature (K)

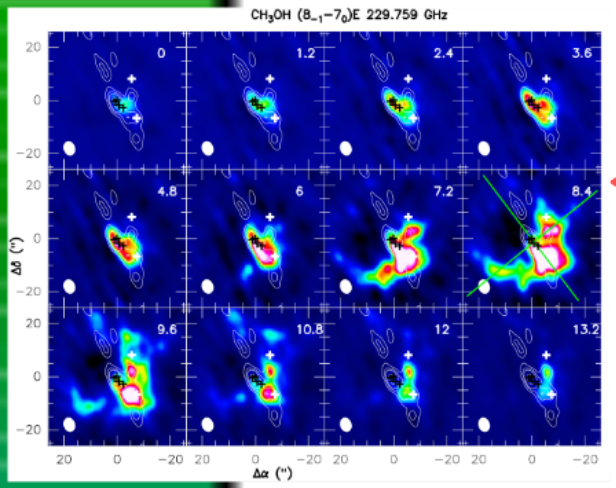

Complex Organics
O-/N- segregation
CH2CO
H2 13CO
CH3OH
CH3COCH3
C6H
HC7N
CH3CH2OH
CH3OCH3
CH2CHCN
CH3CH2CN
HCOOCH3(v=0)
CH3CHO
CH3CN
CH3 13CN
220.178GHz
219.909GHz
229.759GHz
230.183GHz
230.108GHz
231.102GHz
230.991GHz
230.140GHz
230.739GHz
229.265GHz
220.167GHz
220.446GHz
220.730GHz
220.621GHz
Δδ[″]
Δα[″]
5h35m11.0s

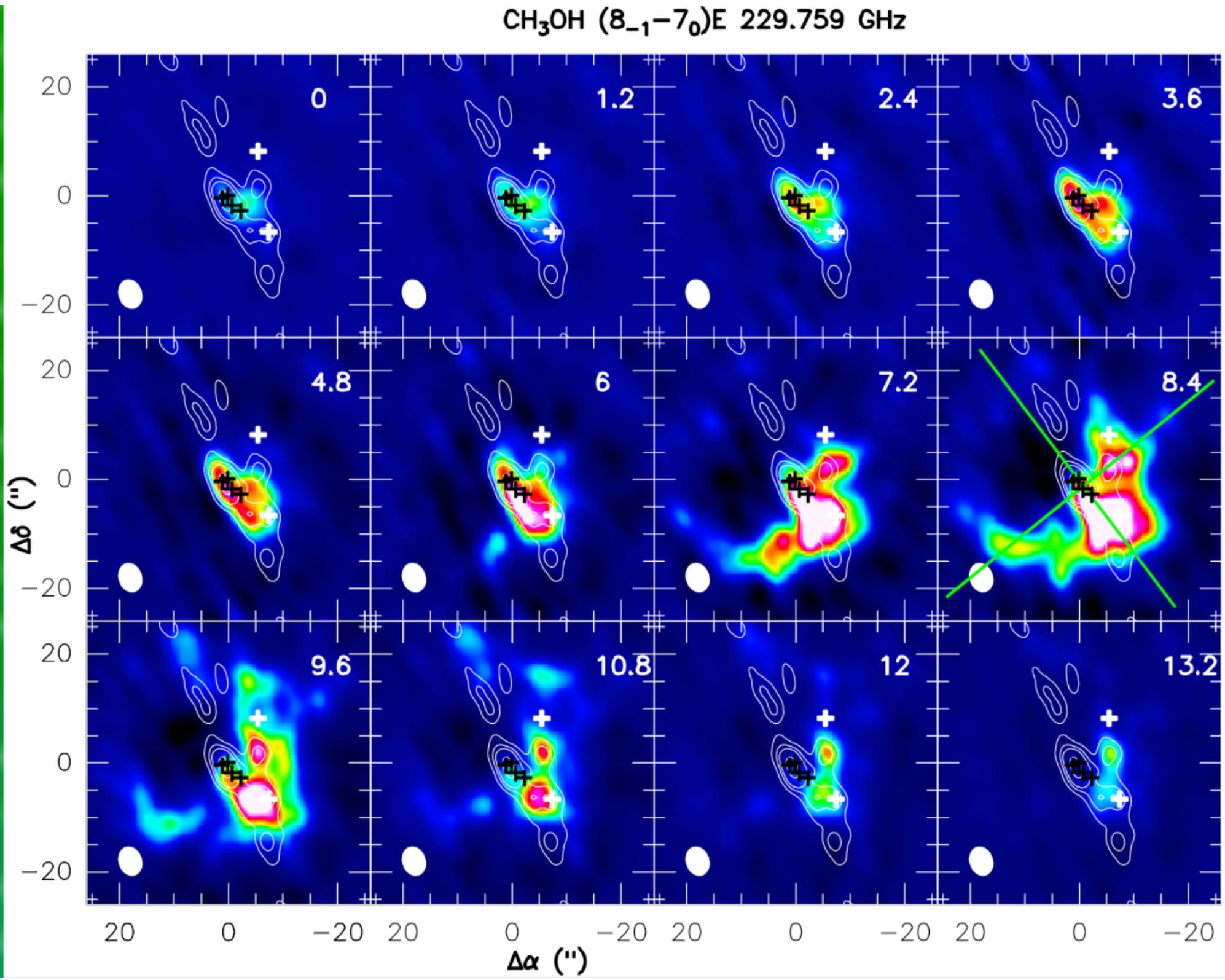

CH3COCH3
230.183GHz
C6H
230.108GHz
HC7N
231.102GHz
CH3OCH3
230.140GHz
CH2CHCN
230.739GHz
CH3CH2CN
229.265GHz
CH3CHO
220.446GHz
CH3CN
220.730GHz
CH3 13CN
220.621GHz
?
20
0
−20

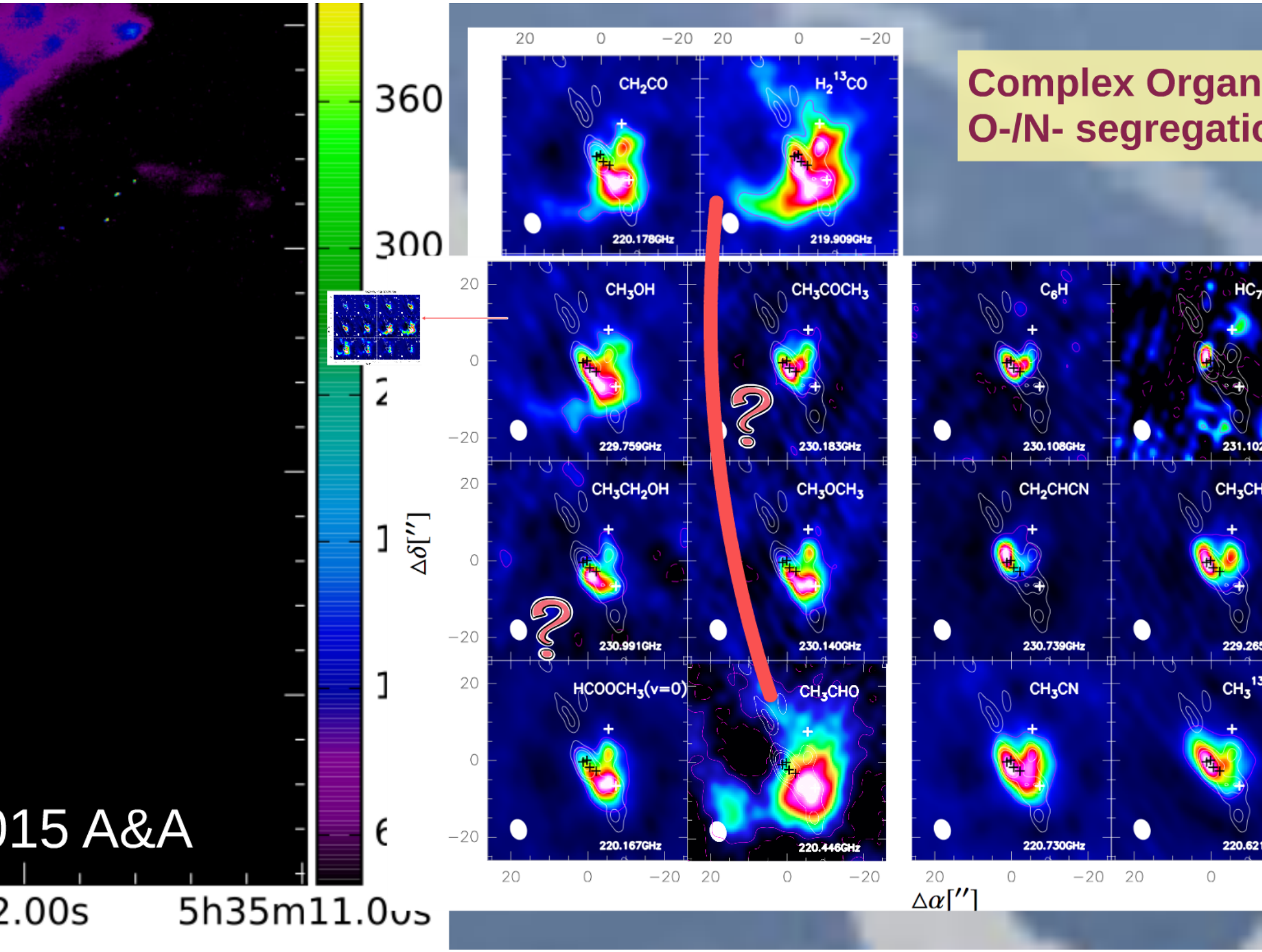

230.140GHz
CH3CHO
220.446GHz
230.739GHz
CH3CN
220.730GHz
229.265GHz
CH3 13CN
220.621GHz
−20
20
0
−20
20
0
−20
20
0
−20
Δα[″]


?
230.991GHz
230.140GHz
HCOOCH3(v=0)
CH3CHO

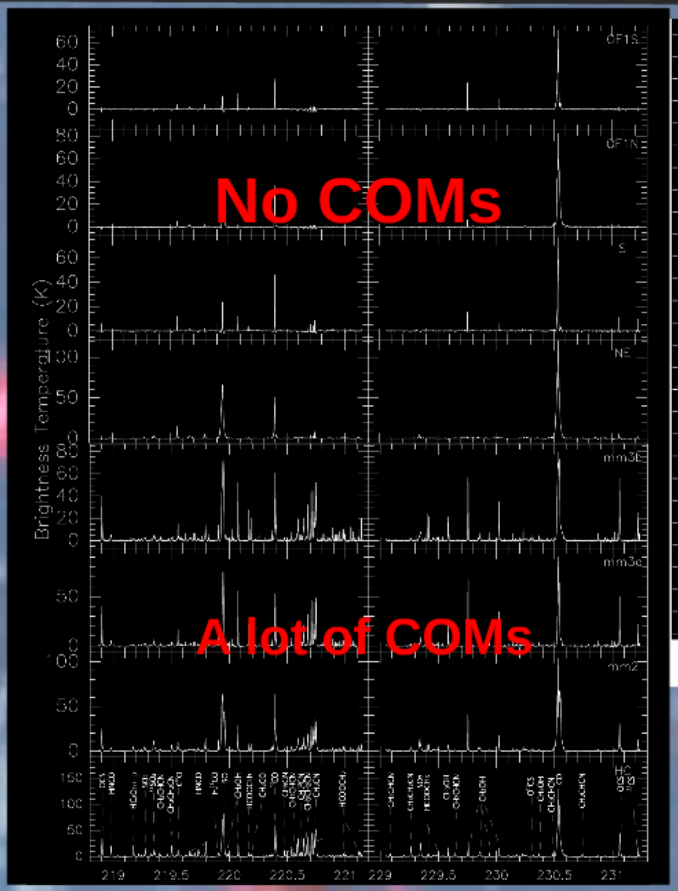

CH3OH
229.759GHz
CH3COCH3
230.183GHz
CH3CH2OH
230.991GHz
CH3OCH3
230.140GHz
20
0
−20
20
0
−20
?
?

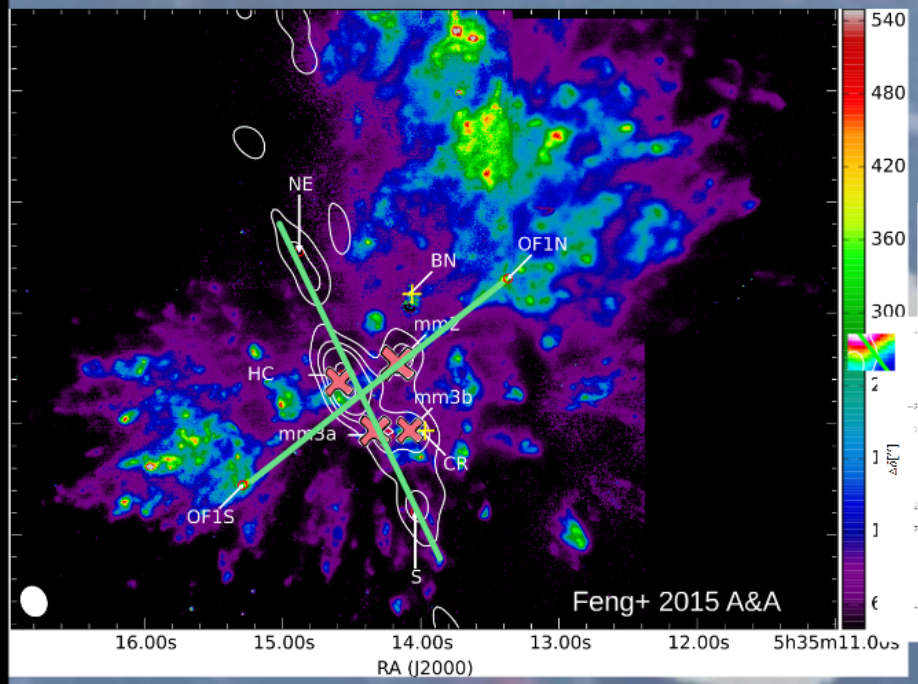

CH3OH (8−1−70)E 229.759 GHz
0
1.2
2.4
3.6
4.8
6
7.2
8.4
9.6
10.8
12
13.2
Δδ (")
Δα (")

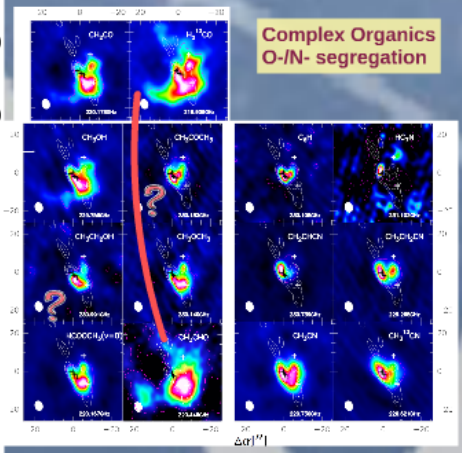

CH3OH (8−1−70)E 229.759 GHz
0
1.2
2.4
3.6
4.8
6
7.2
8.4
9.6
10.8
12
13.2
20
0
−20
Δδ (")
Δα (")


Complex Organ
O-/N- segregatio
CH2CO
H2 13CO
220.178GHz
219.909GHz
CH3OH
CH3COCH3
229.759GHz
230.183GHz
CH3CH2OH
CH3OCH3
230.991GHz
230.140GHz
HCOOCH3(v=0)
CH3CHO
220.167GHz
220.446GHz
C6H
230.108GHz
CH2CHCN
230.739GHz
CH3CN
220.730GHz
Δδ[″]
Δα[″]
20
0
−20
015 A&A
2.00s
5h35m11.0s
360
300

Orion-KL (HMC)







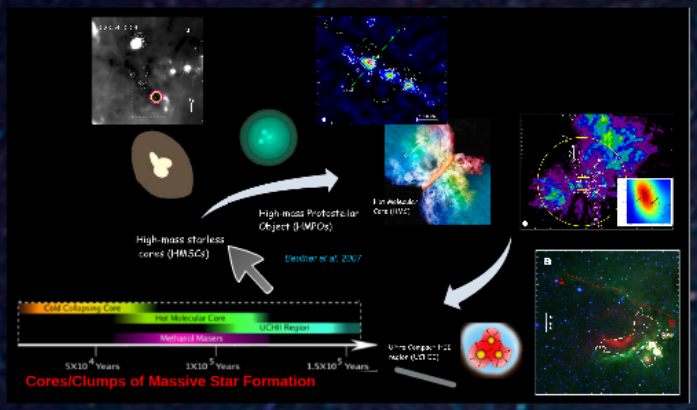
Chemical segregation (esp. COMs) <1000AU scale
forming paths of species differ-->local kinematics

1

Molecular line

powerful diagnosing tool ?

efficient



1.Exam the available ranges of the "chemical clocks"

Deuteration: prestellar->protostellar objects

T ↘

$HD + H_3^+ \rightarrow H_2D^+$, D_2H^+, and D_3^+ (Fontani+15 point observations)

$D_{frac}(N_2H^+)$ ↗ exclusively in the gas

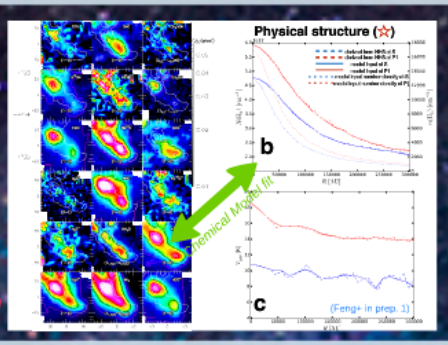
$D_{frac}(NH_3)$ — partially in the gas

$D_{frac}(CH_3OH)$ ↘ exclusively on the grain mantle

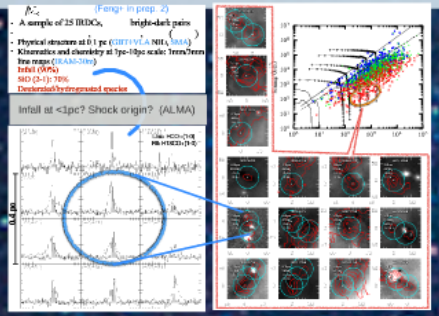
$D_{frac}(HCO^+)$ ↗

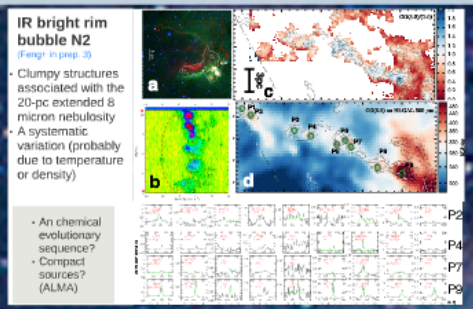
$D_{frac}(HNC)$ sensitive to the colder (younger) S

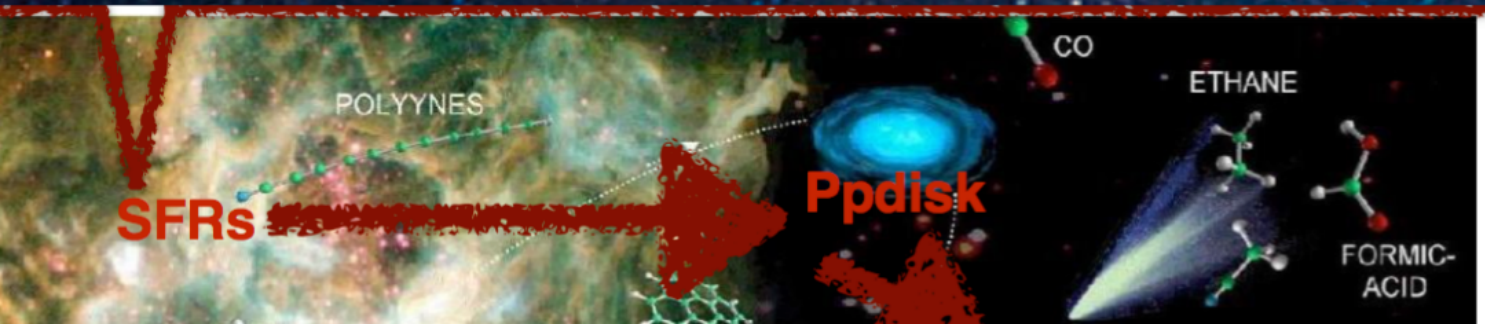
$D_{frac}(HCN)$ trace warmer (more evolved) P1



2.Use line tracers to investigate the unexplored SFRs







From COMs to the see

- **Protoplanetary disk** formation and conde COMs into new ice m

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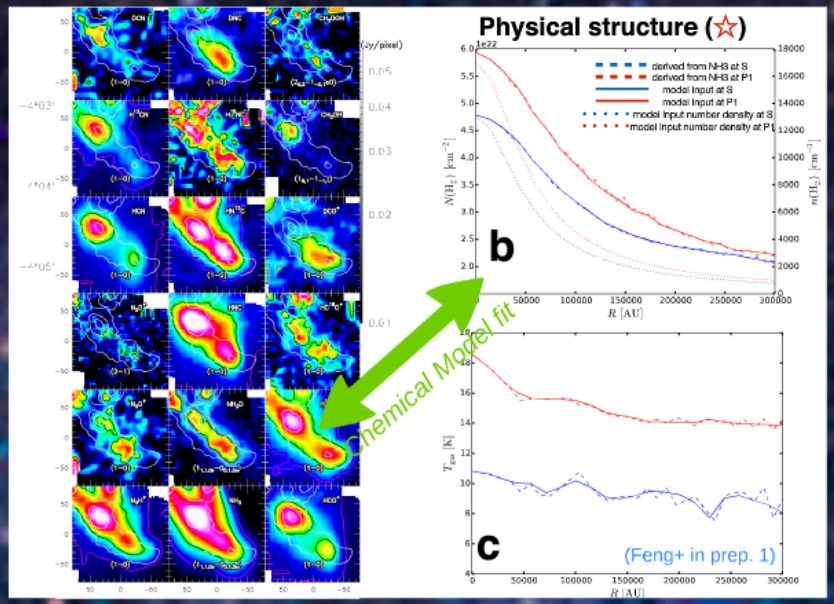

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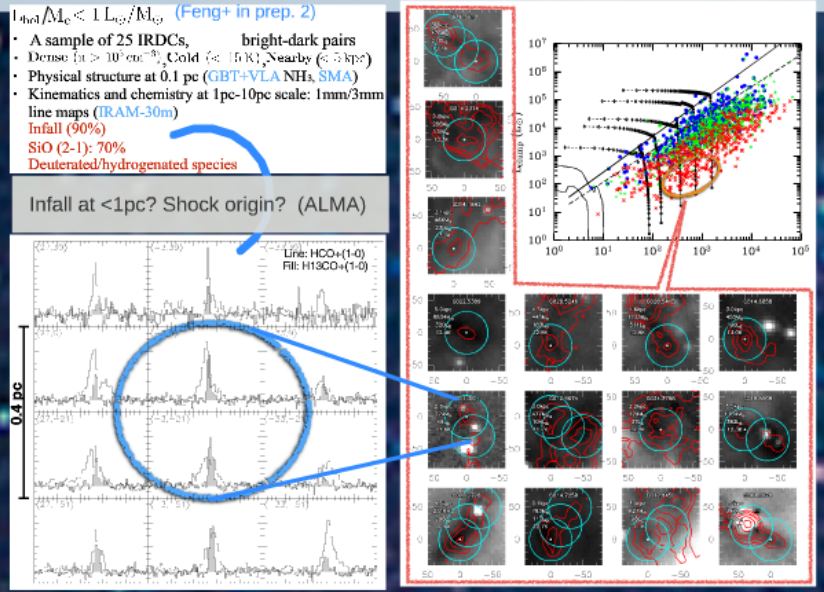
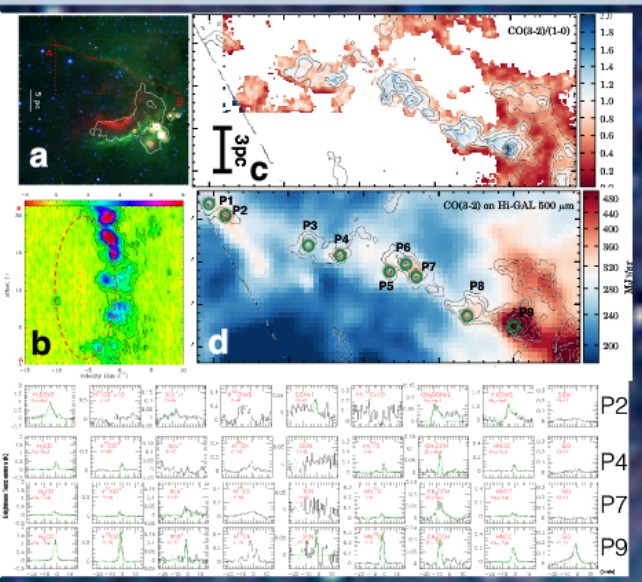


IR bright rim bubble N2

(Feng+ in prep. 3)

- Clumpy structures associated with the 20-pc extended 8 micron nebulosity
- A systematic variation (probably due to temperature or density)

- An chemical evolutionary sequence?
- Compact sources? (ALMA)



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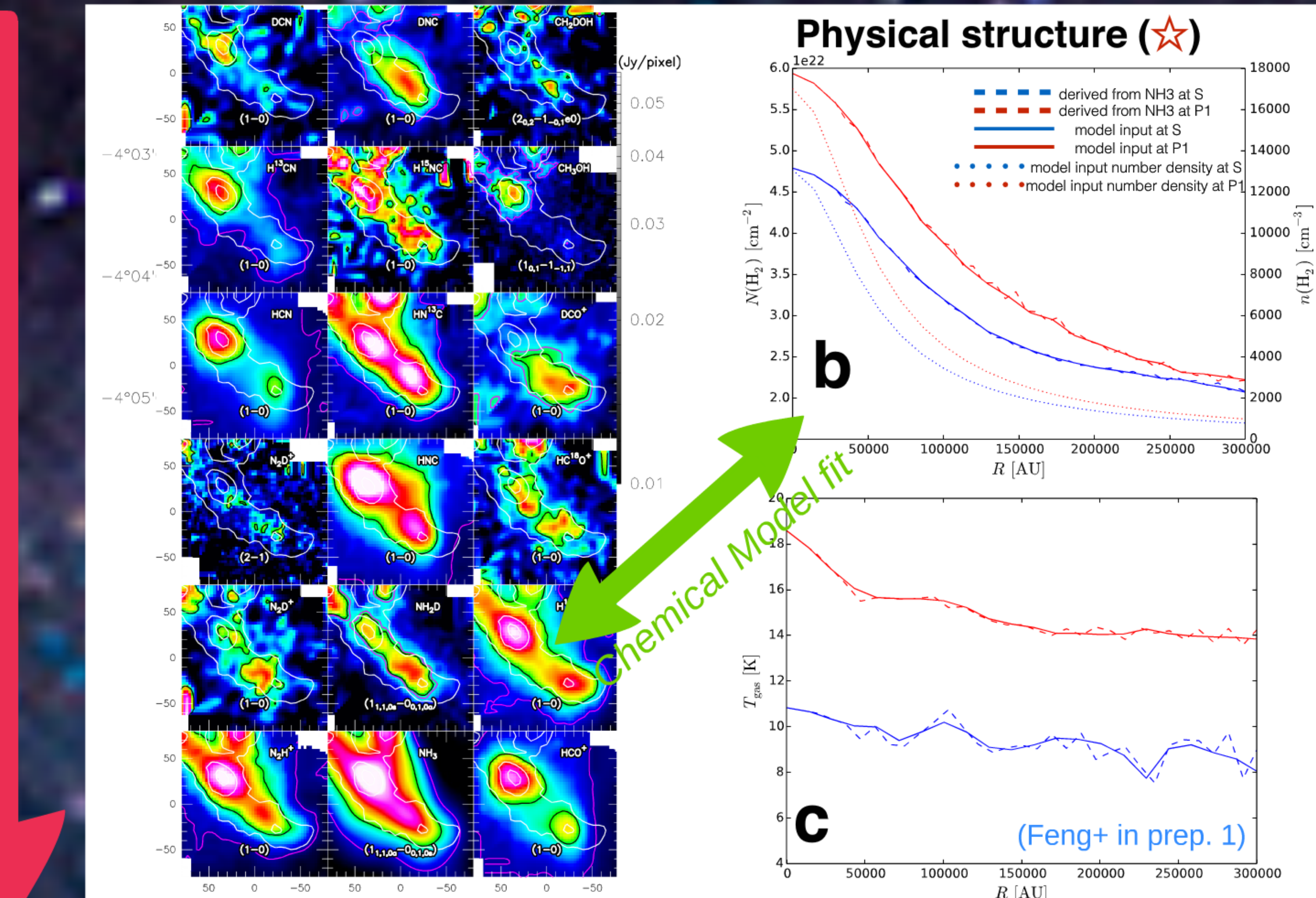

Physical structure (☆)
derived from NH3 at S
derived from NH3 at P1
model input at S
model input at P1
model input number density at S
model input number density at P1
b
c
R [AU]
Chemical Model fit
(Jy/pixel)
DCN
DNC
HCN
HNC
NH2D
NH3
HCO+
DCO+
N2H+
N2D+
CH3OH
(Feng+ in prep. 1)

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2.Use line tracers to investi

$L_{bol}/M_c < 1\,L_\odot/M_\odot$ (Feng+ in prep. 2)

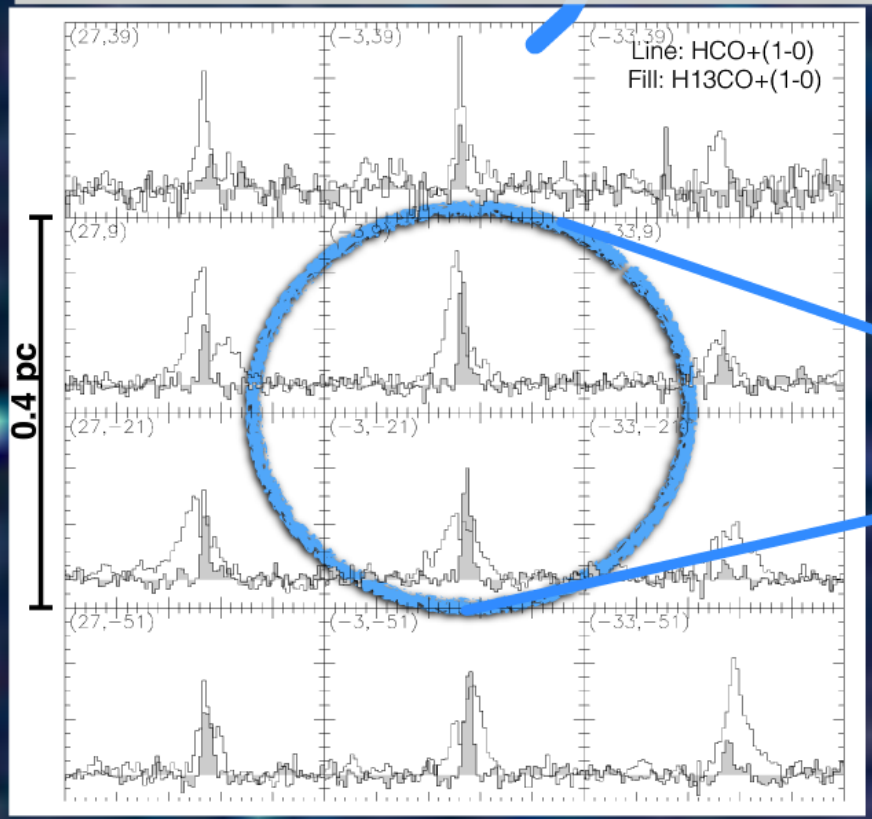
- A sample of 25 IRDCs, 70 μm bright-dark pairs
- **Dense** ($n > 10^5\,cm^{-3}$), **Cold** ($< 15\,K$), **Nearby** ($< 5\,kpc$)
- Physical structure at 0.1 pc (GBT+VLA NH_3, SMA)
- Kinematics and chemistry at 1pc-10pc scale: 1mm/3mm line maps (IRAM-30m)

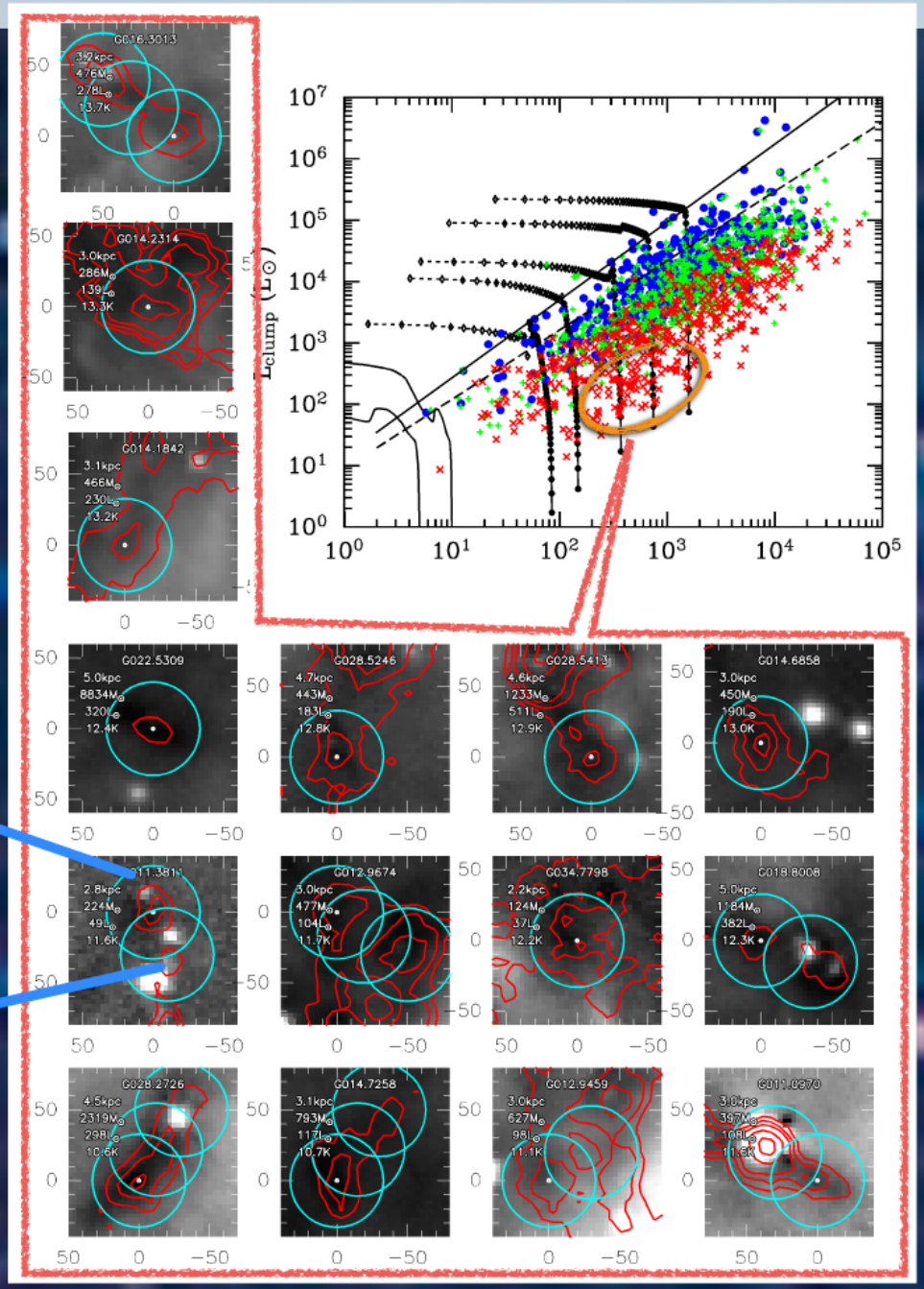
Infall (90%)

SiO (2-1): 70%

Deuterated/hydrogenated species

Infall at <1pc? Shock origin? (ALMA)





gate the unexplored SFRs

IR bright rim bubble N2

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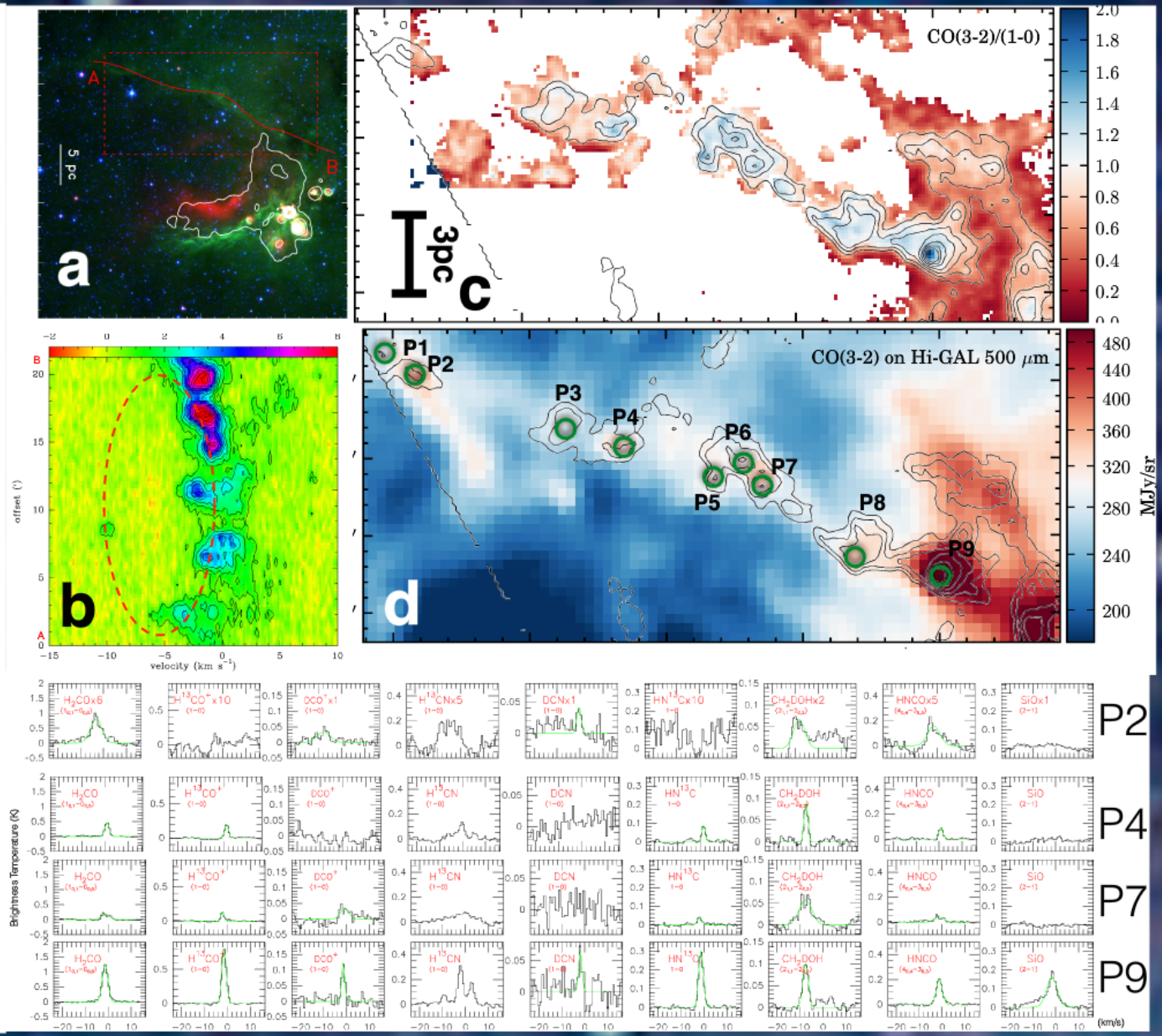

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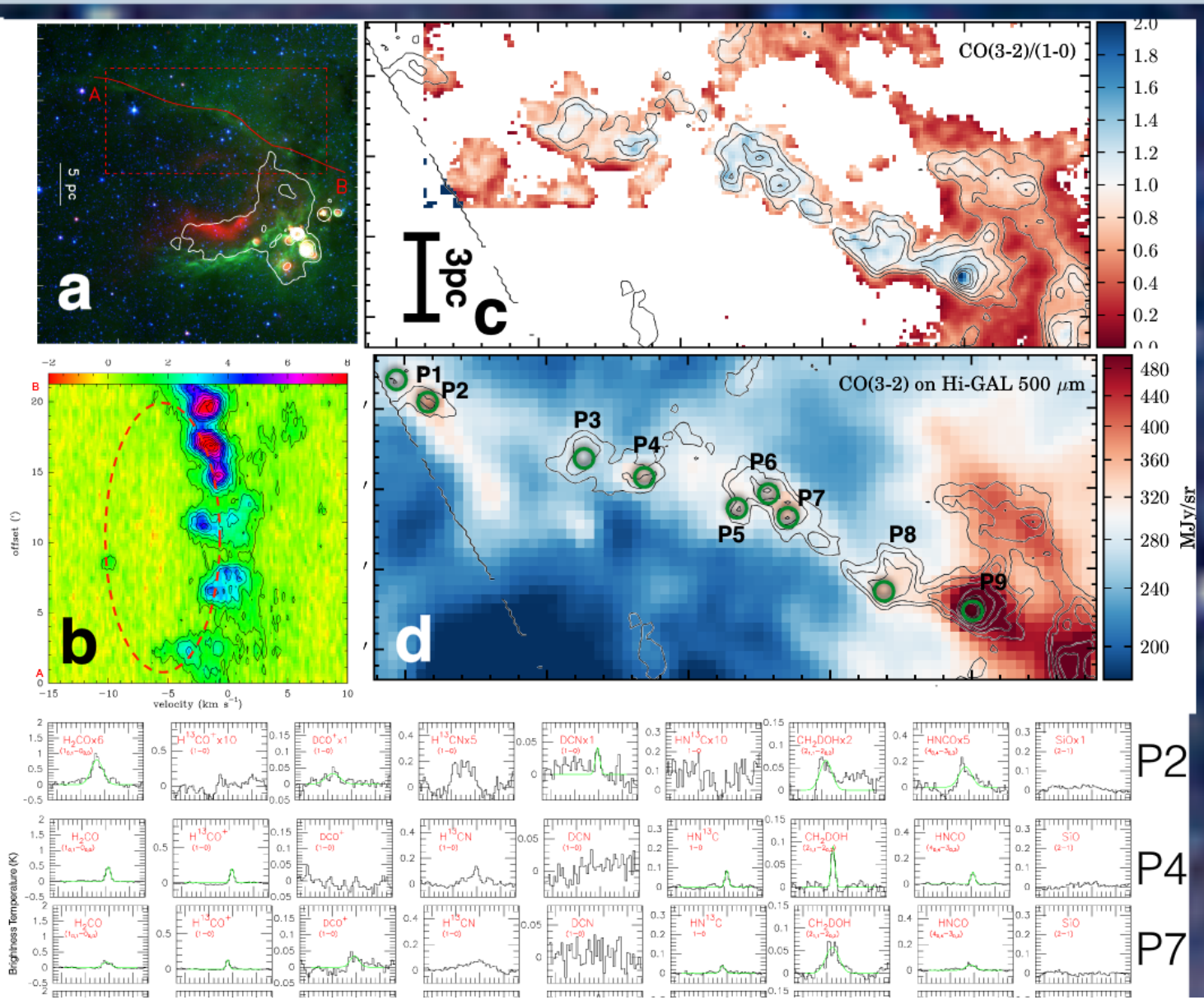

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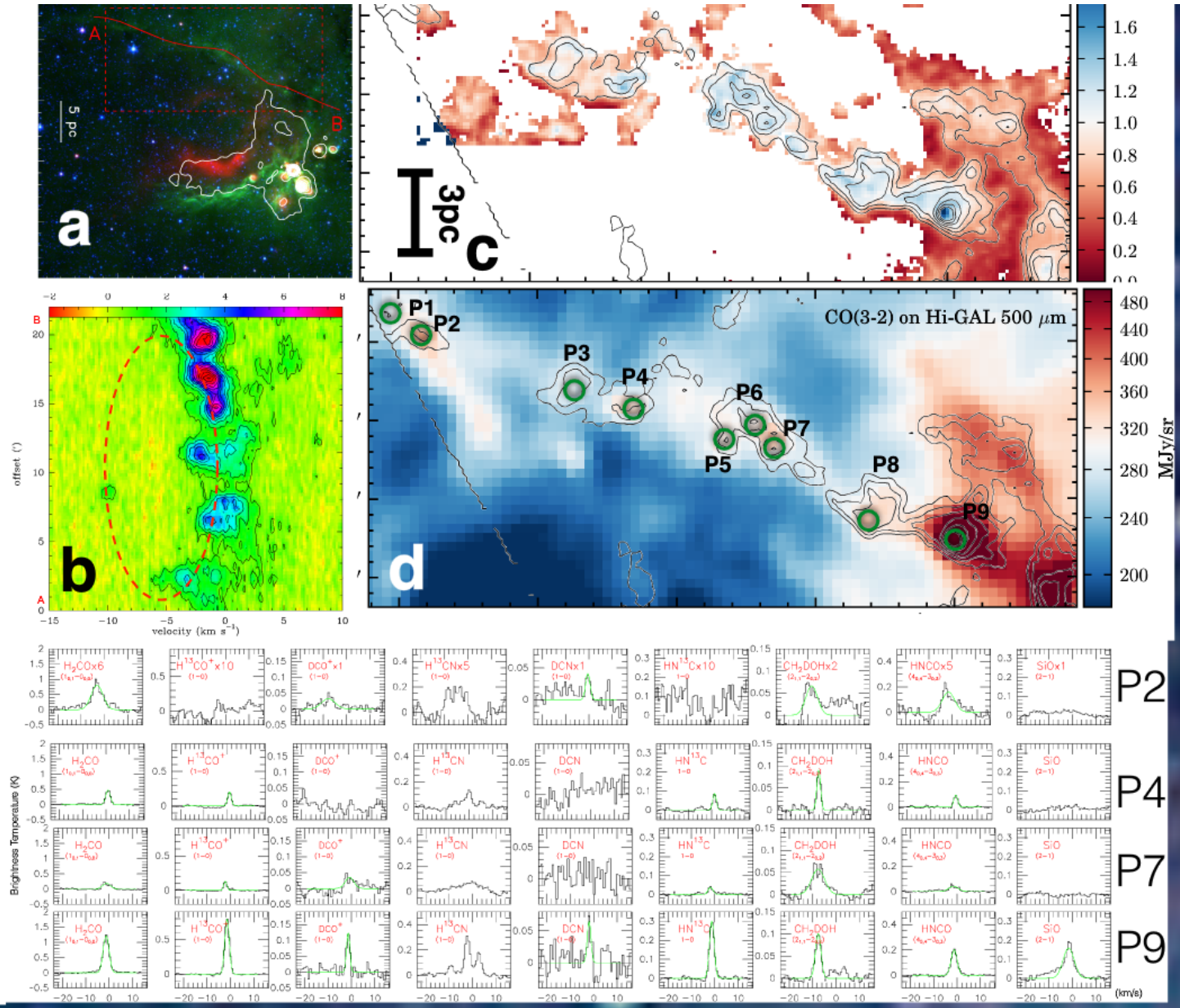
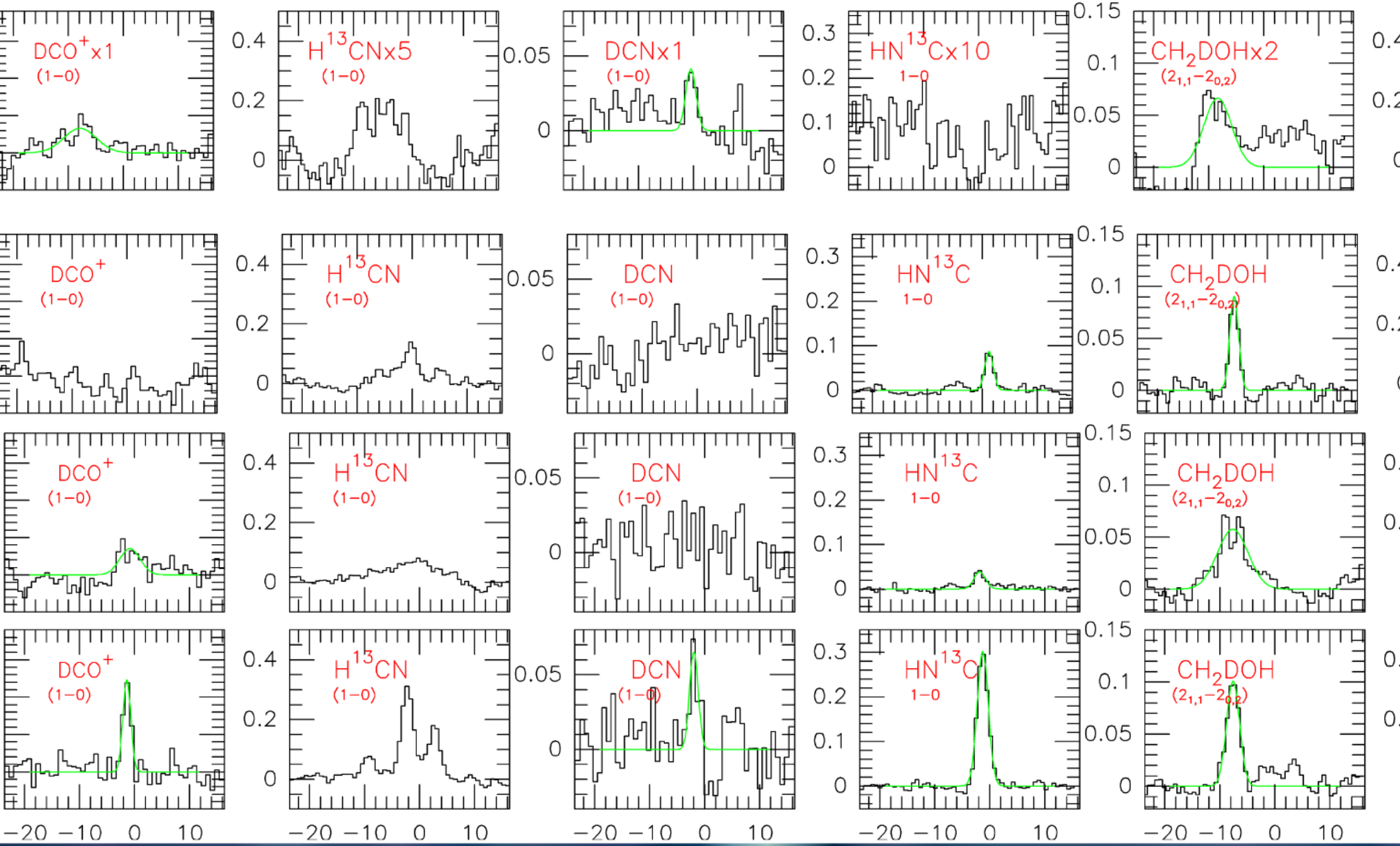
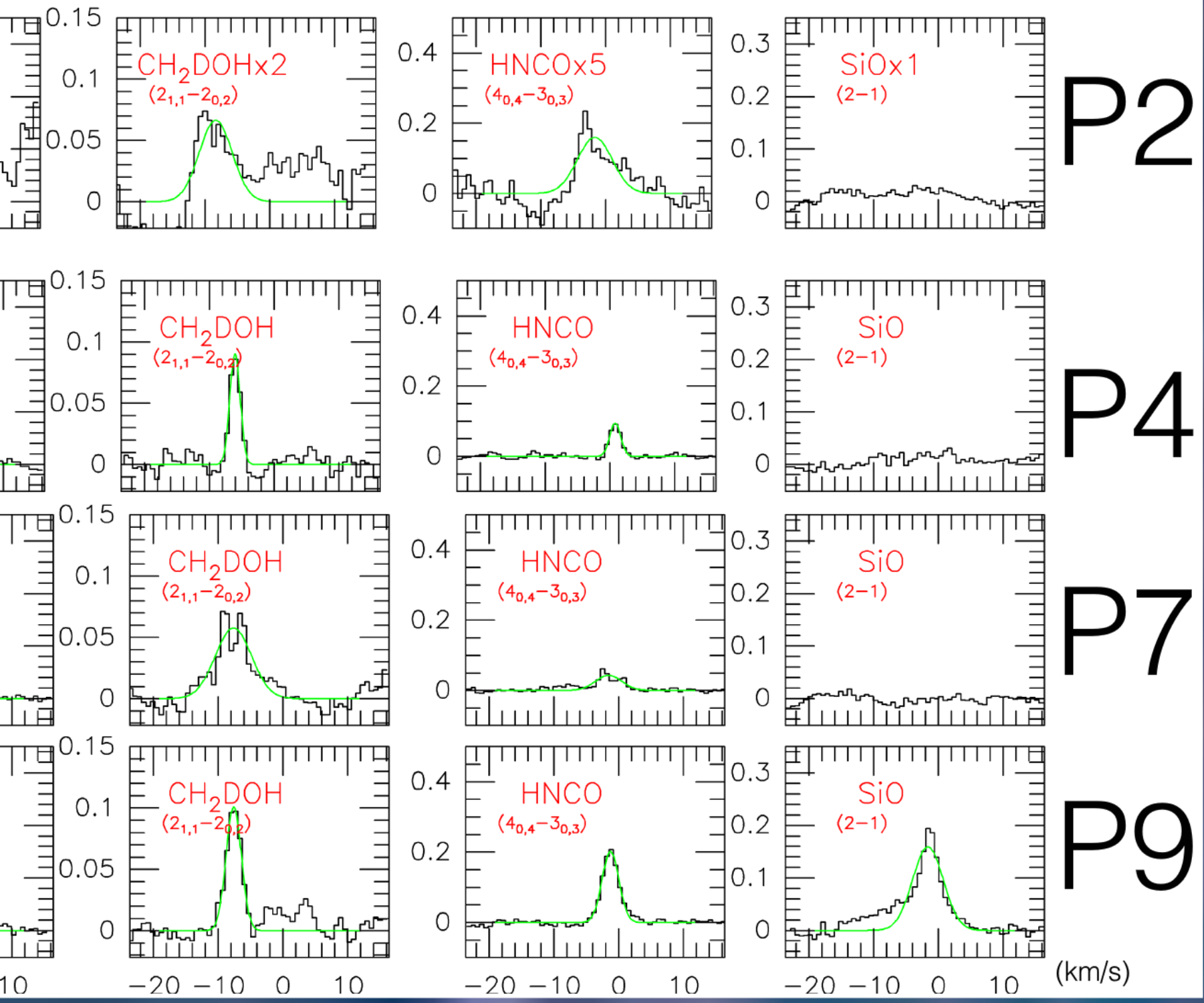
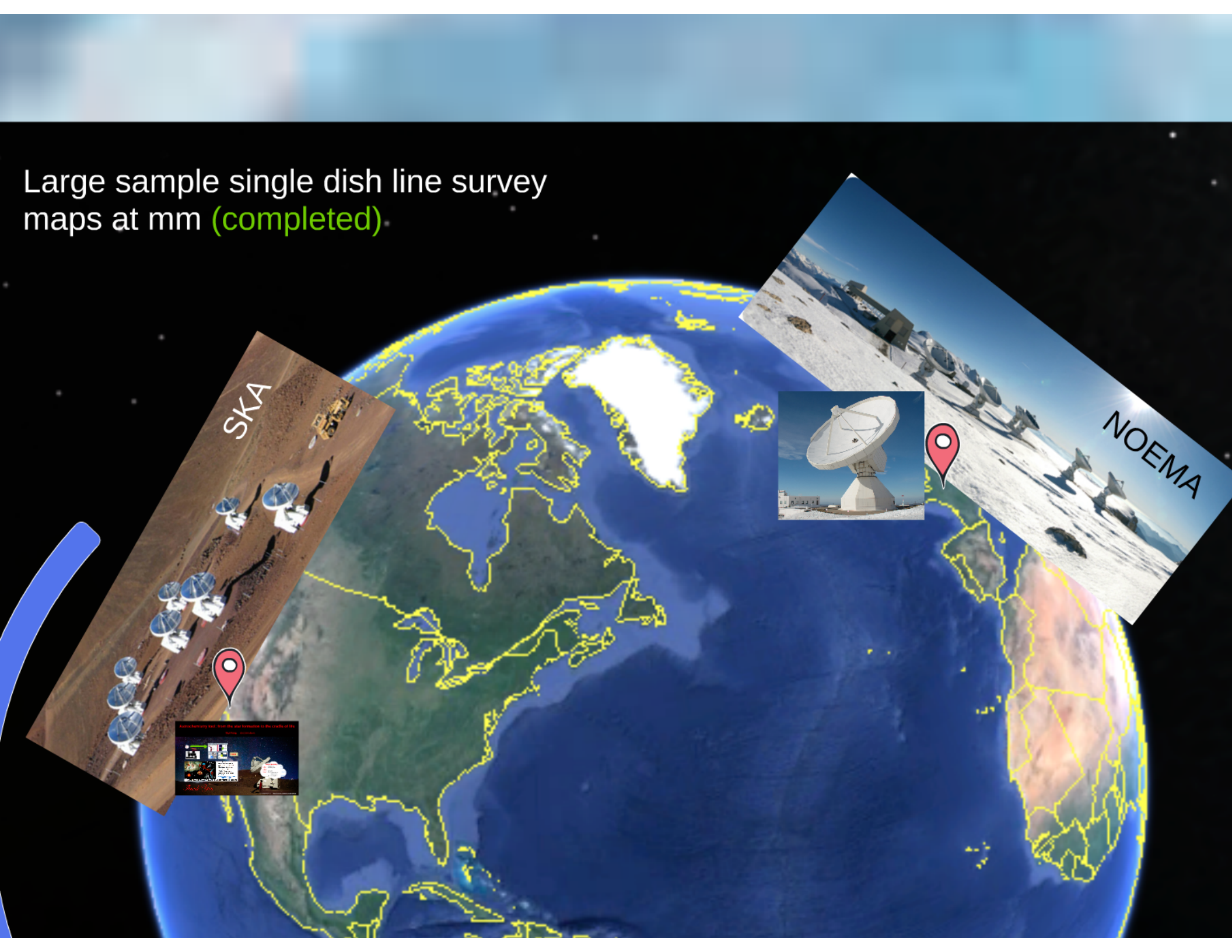



DCO+x1
(1–0)
H13CNx5
(1–0)
DCNx1
(1–0)
HN13Cx10
1–0
CH2DOHx2
(2₁,₁–2₀,₂)
DCO+
(1–0)
H13CN
(1–0)
DCN
(1–0)
HN13C
1–0
CH2DOH
(2₁,₁–2₀,₂)
DCO+
(1–0)
H13CN
(1–0)
DCN
(1–0)
HN13C
1–0
CH2DOH
(2₁,₁–2₀,₂)
DCO+
(1–0)
H13CN
(1–0)
DCN
(1–0)
HN13C
1–0
CH2DOH
(2₁,₁–2₀,₂)
0.4
0.2
0
0.05
0
0.3
0.2
0.1
0
0.15
0.1
0.05
0
−20 −10 0 10

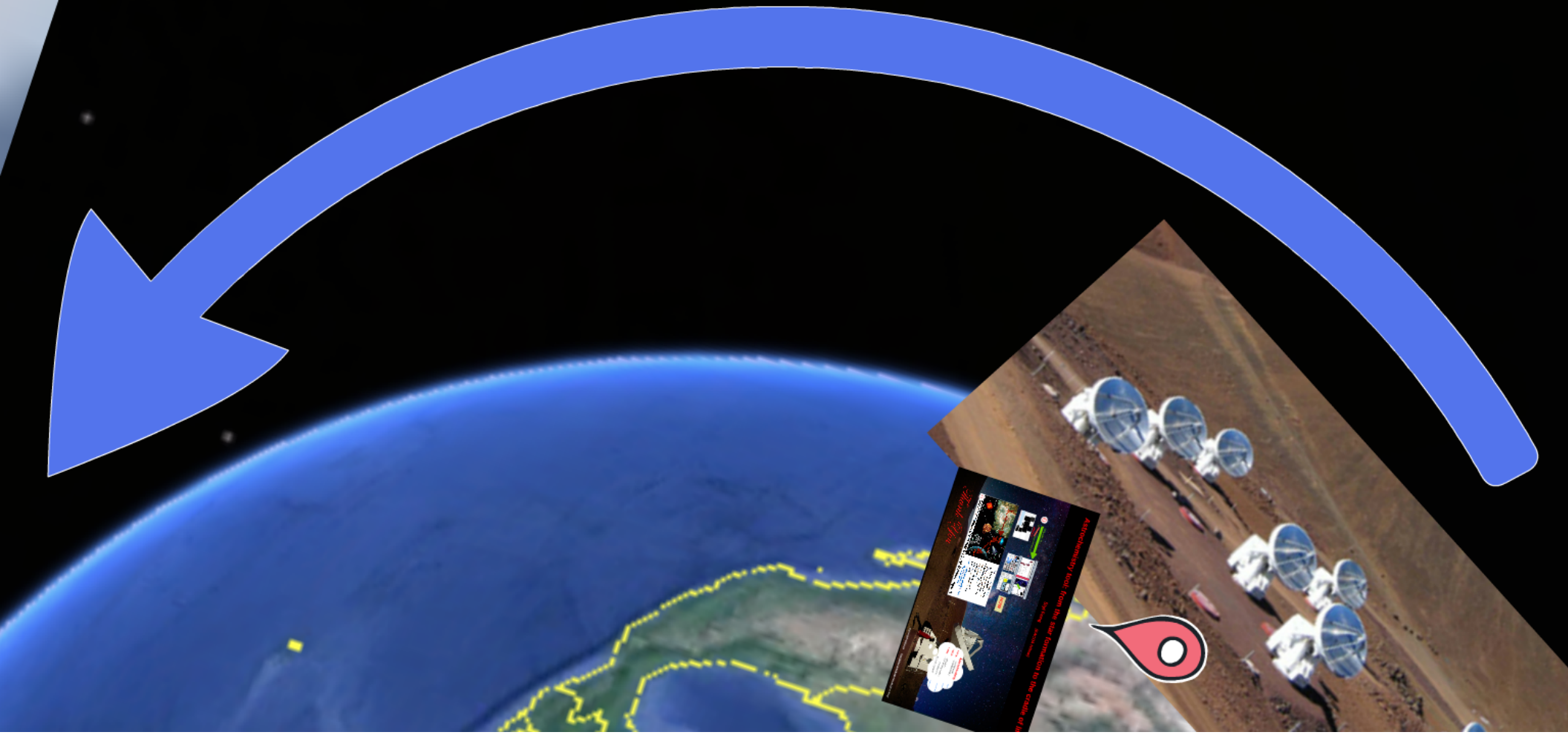

CH2DOHx2
(2₁,₁−2₀,₂)
HNCOx5
(4₀,₄−3₀,₃)
SiOx1
(2−1)
P2
CH2DOH
(2₁,₁−2₀,₂)
HNCO
(4₀,₄−3₀,₃)
SiO
(2−1)
P4
CH2DOH
(2₁,₁−2₀,₂)
HNCO
(4₀,₄−3₀,₃)
SiO
(2−1)
P7
CH2DOH
(2₁,₁−2₀,₂)
HNCO
(4₀,₄−3₀,₃)
SiO
(2−1)
P9
0.15
0.1
0.05
0
0.4
0.2
0
0.3
0.2
0.1
0
−20 −10 0 10
(km/s)

Large sample single dish line survey maps at mm (completed)



Follow up projects

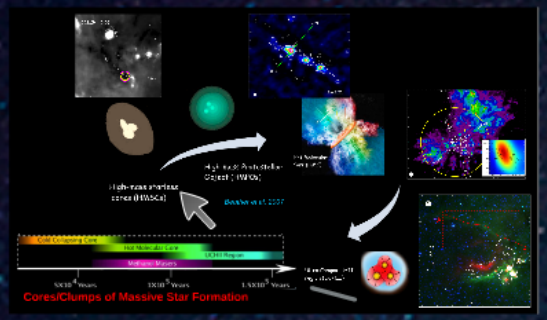
Pin down molecules: high (spatial/spectral) resolution, high sensitivity

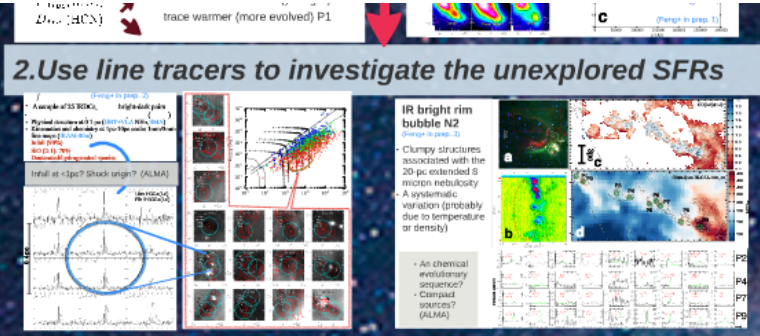



ALMA

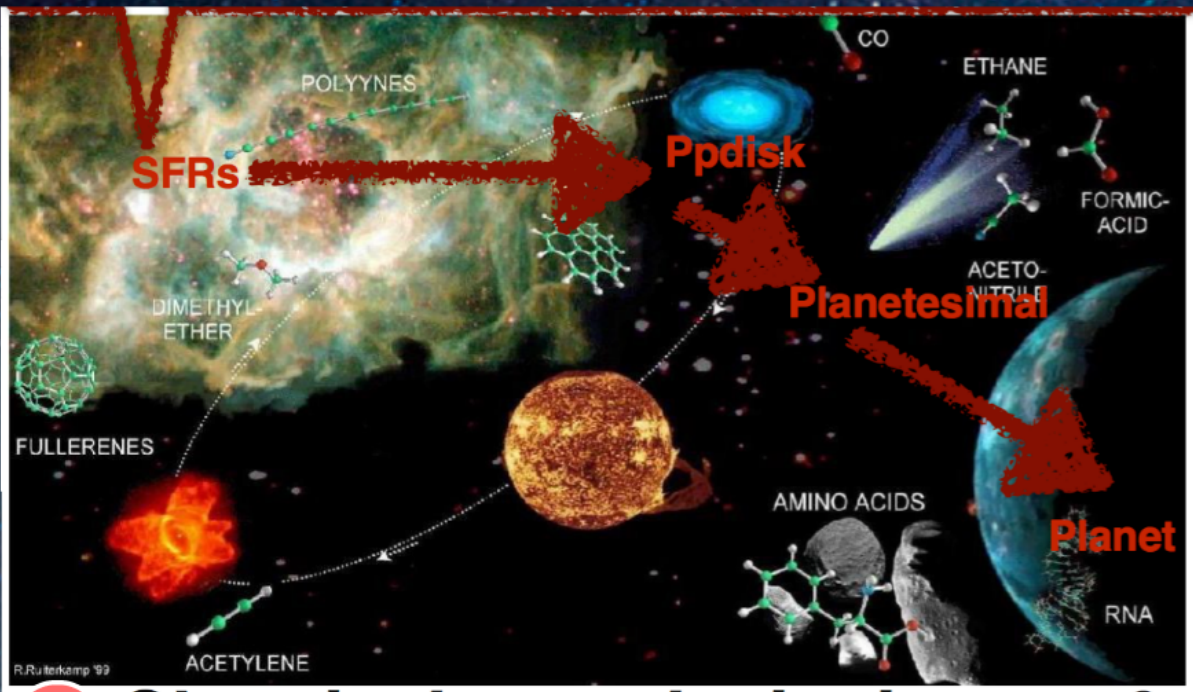
Upcoming projects
prestellar objects;
low T, less line confusion (cm-band)
grain surface origin of COMs: ice desorption

Previous studies
protostars (e.g., GBT-PRIMOS)
high T, line confusion (mm/submm-band)
gas phase COMs





HOW



From COMs to the seed of life

- **Protoplanetary disk (Ppdisk)**: formation and condensation of COMs into new ice mantles
- **Planetesimal**: storage of dirty ices, with COMs, and reprocessing
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propose for FAST-500m L-band COMs survey (collaborate with NAOC), SKA in the near future

2 Chemical complexity in star & planet forming regions

Thank You

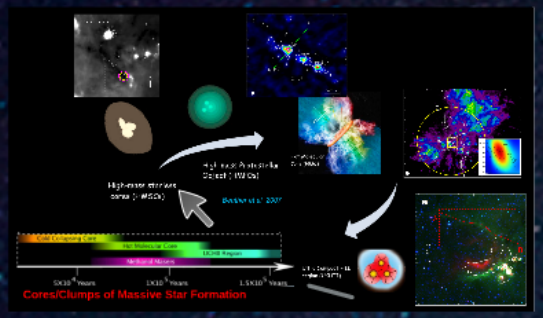
1

Molecular line

powerful diagnosing tool

efficient

?



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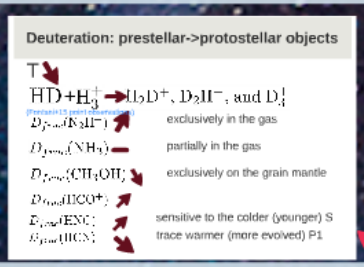

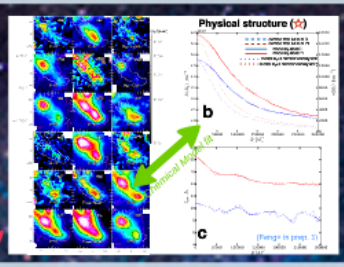

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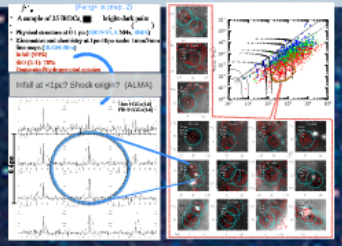

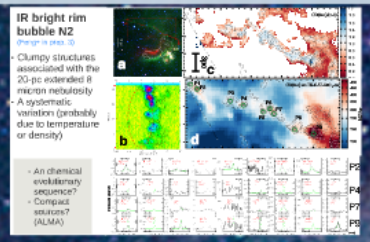

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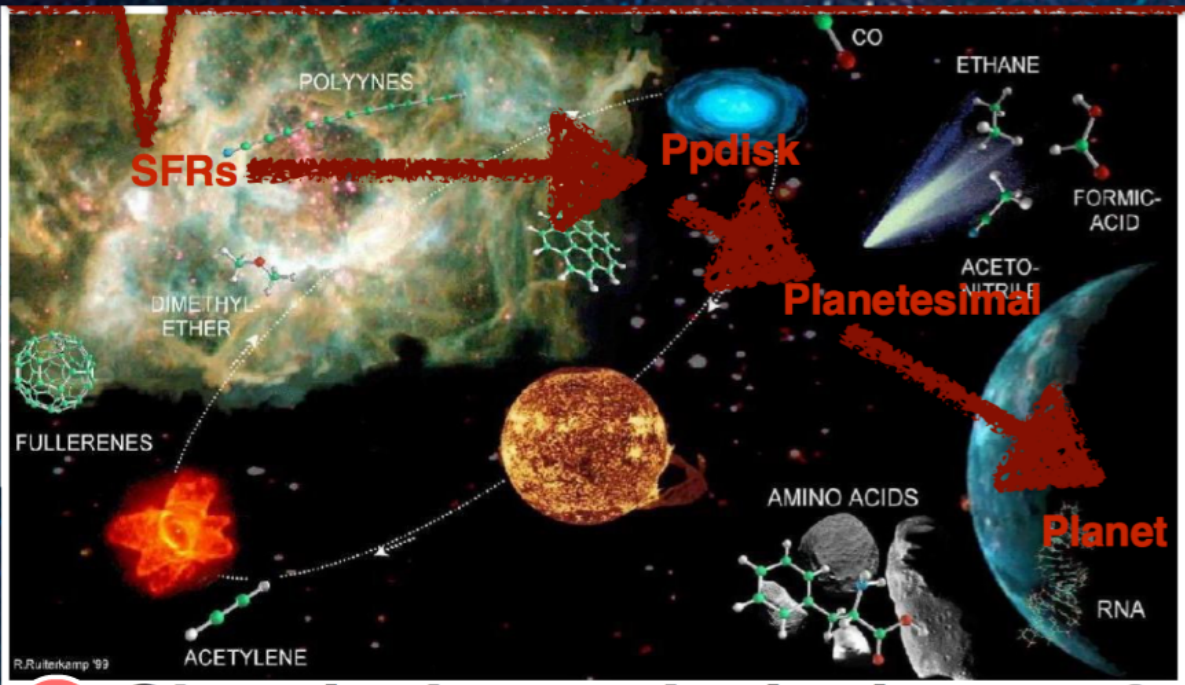

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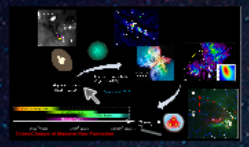
2 **Chemical complexity in star & planet forming regions**

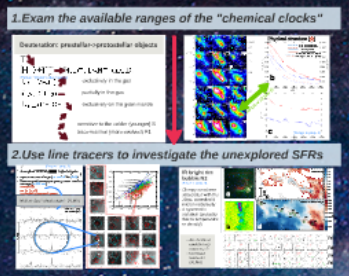
Astrochemistry tool: from the star formation to the cradle of life

Siyi Feng (EACOA fellow)

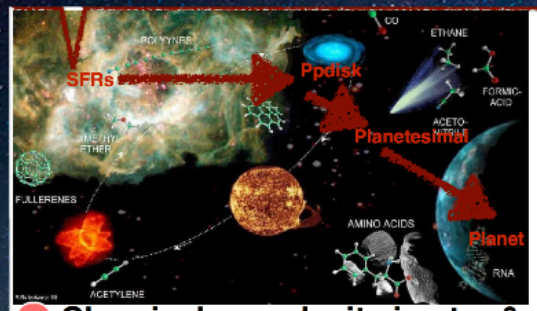
1 Molecular line

powerful diagnosing tool ~~efficient~~ ?





HOW



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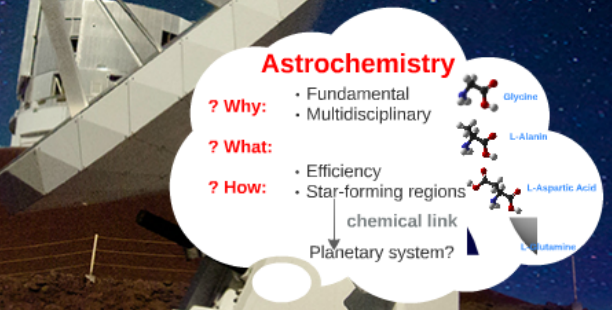

Thank You

siyi.feng@naoj.ac.jp http://alma-intweb.mtk.nao.ac.jp/~syfeng/