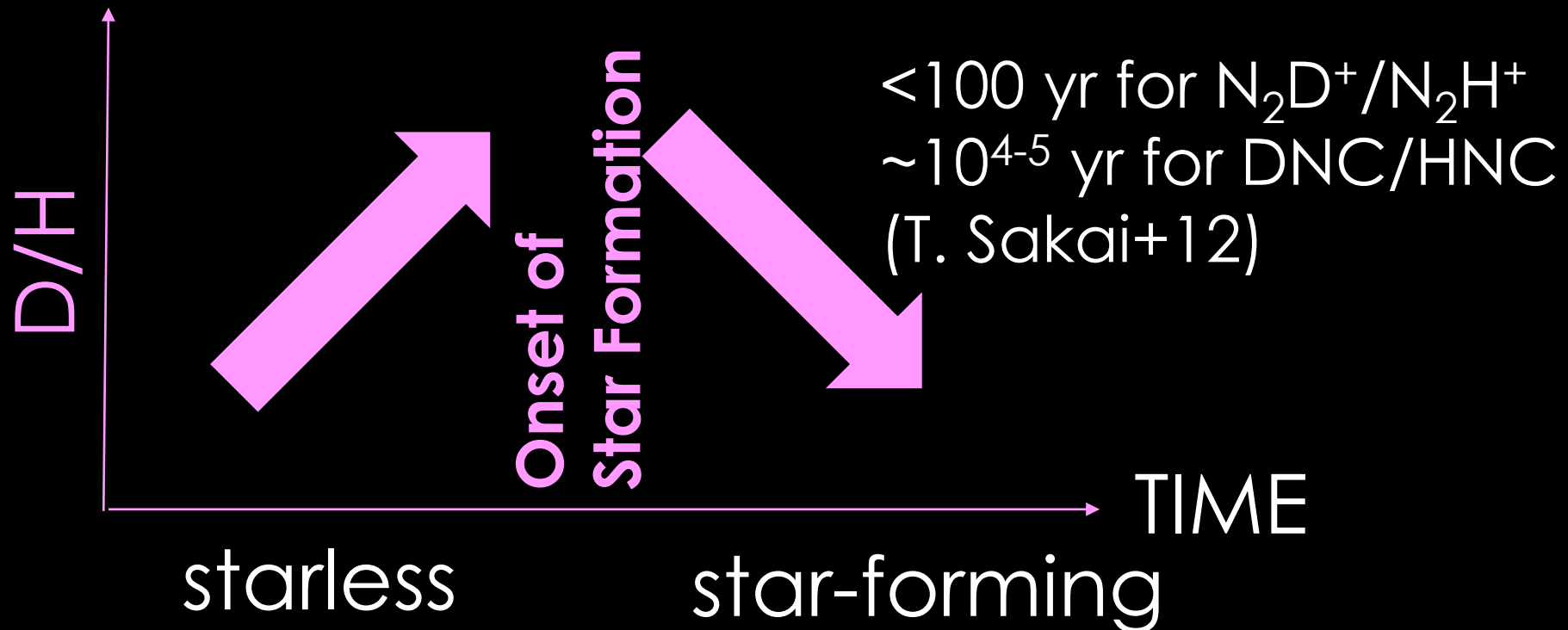


NOBEYAMA LARGE PROGRAM REPORT I:

DEUTERIUM FRACTIONS IN
SCUBA-2 CORES IN
PLANCK COLD CLUMPS

Ken TATEMATSU (NRO, NAOJ), et al.

DEUTERIUM FRACTION D/H (N_2D^+/N_2H^+ , DNC/HNC) IN COLD (10-20 K) MOLECULAR CLOUD CORES



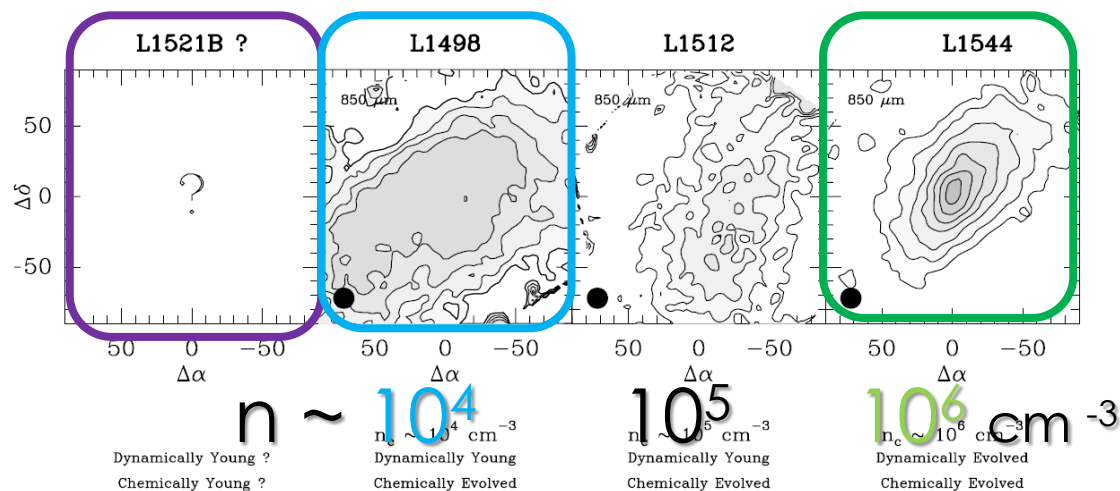
- Also, N_2D^+ will not be depleted, even in cold cloud cores.

D/H AS TRACER FOR STARLESS DARK CLOUD CORES

MOLECULAR ABUNDANCE RATIOS AS AN INDICATOR OF CHEMICAL EVOLUTION

Molecule	L1495B	L1521B	L1521E	TMC-1	L492	L1498	L1544
DNC/HN ¹³ C	<0.66 ^a	0.70 ^a	0.66 ^b	1.25 ^c	1.27	1.91 ^a	3.0 ^c
DCO ⁺ /H ¹³ CO ⁺	1.05 ^a	1.10 ^a	0.63 ^a	0.77 ^d	0.80	2.7 ^e	3.1–9.2 ^f
NH ₃ /CCS	3.8 ^{a,g}	3.5 ^{g,h}	2.6 ^{a,b}	2.9 ^h	6.5	25 ^h	15 ^{h,i}

↑ Hirota & Yamamoto 2006



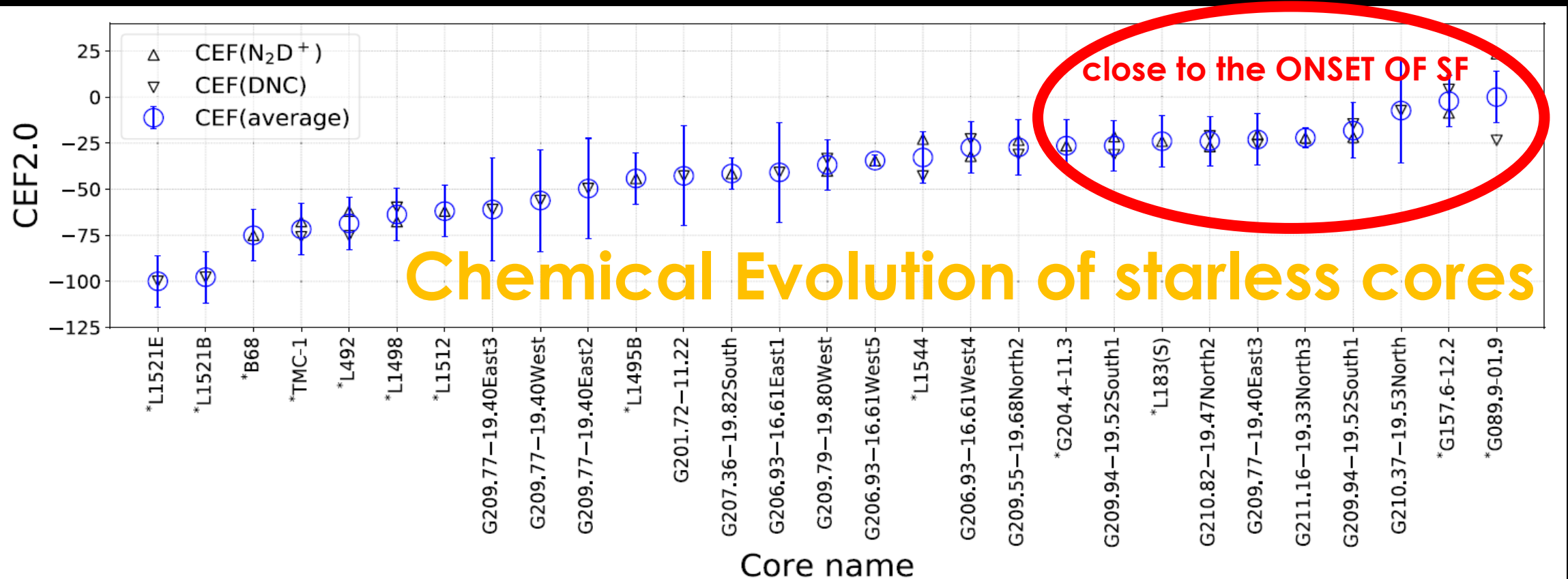
Shirley+05→

Evolutionary Sequence ?

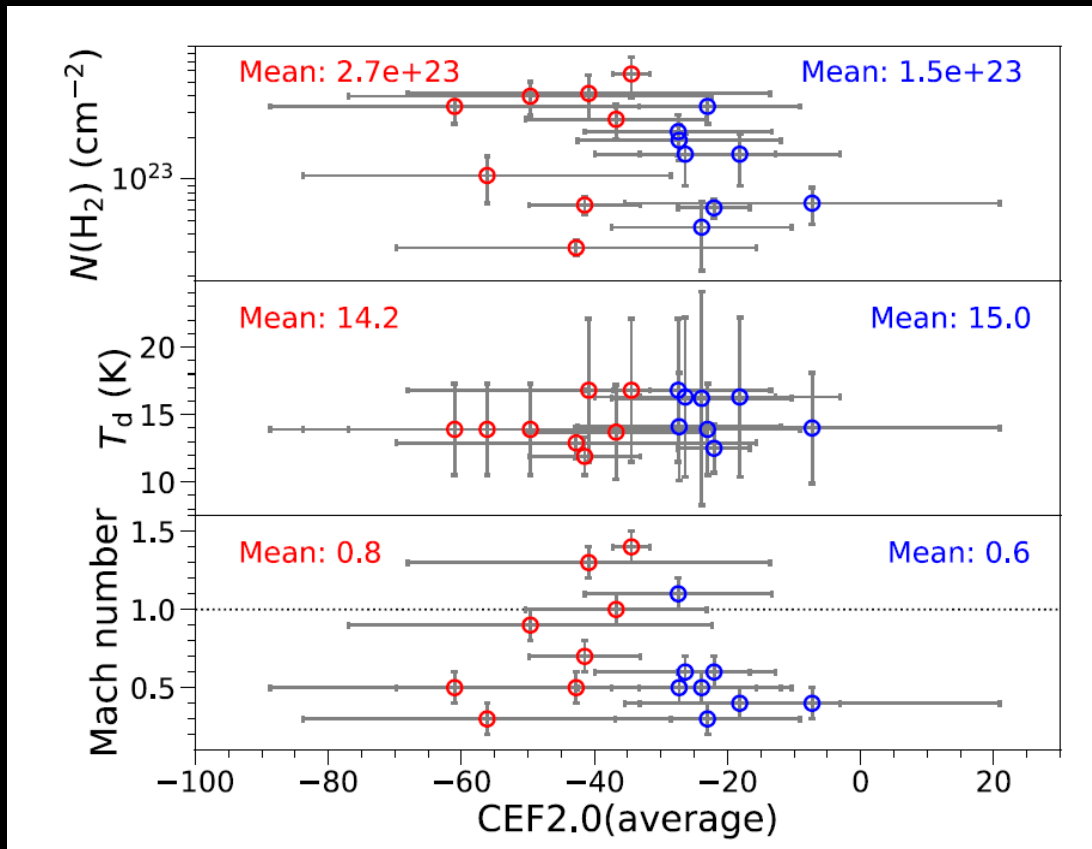
STRATEGY OF THE PROGRAM

- (1) **Planck Galactic Cold Clumps** all-sky survey, **10-20 K**
@ **4'** beam (13,000 clumps)
- (2) JCMT **SCUBA-2** 850 μ m imaging to identify **cores** @ **14"** beam
(SCOPE) (3,500 cores in 560 clumps) (Eden et al. 2019; Yi et al. 2018)
- (3) **Nobeyama 45m** large program to identify **N₂D⁺, DNC** bright
cores @ 18" (Nobeyama large program) **single-point** \rightarrow **OTF map**
~100 **Orion cores** (constant-distance sample)
~100 **other regions (Galactic plane, off-plane)** to compare various environments
- (4) **ALMA** follow-up

CHEMICAL EVOLUTION FACTOR (CEF): FUNCTION OF (N_2D^+/N_2H^+ , DNC/HNC)



CORE PROPERTIES VS CEF2.0



- Mach number = σ_{NT}/C_s does not seem to decrease with CEF2.0
→ No strong evidence for turbulence dissipation.

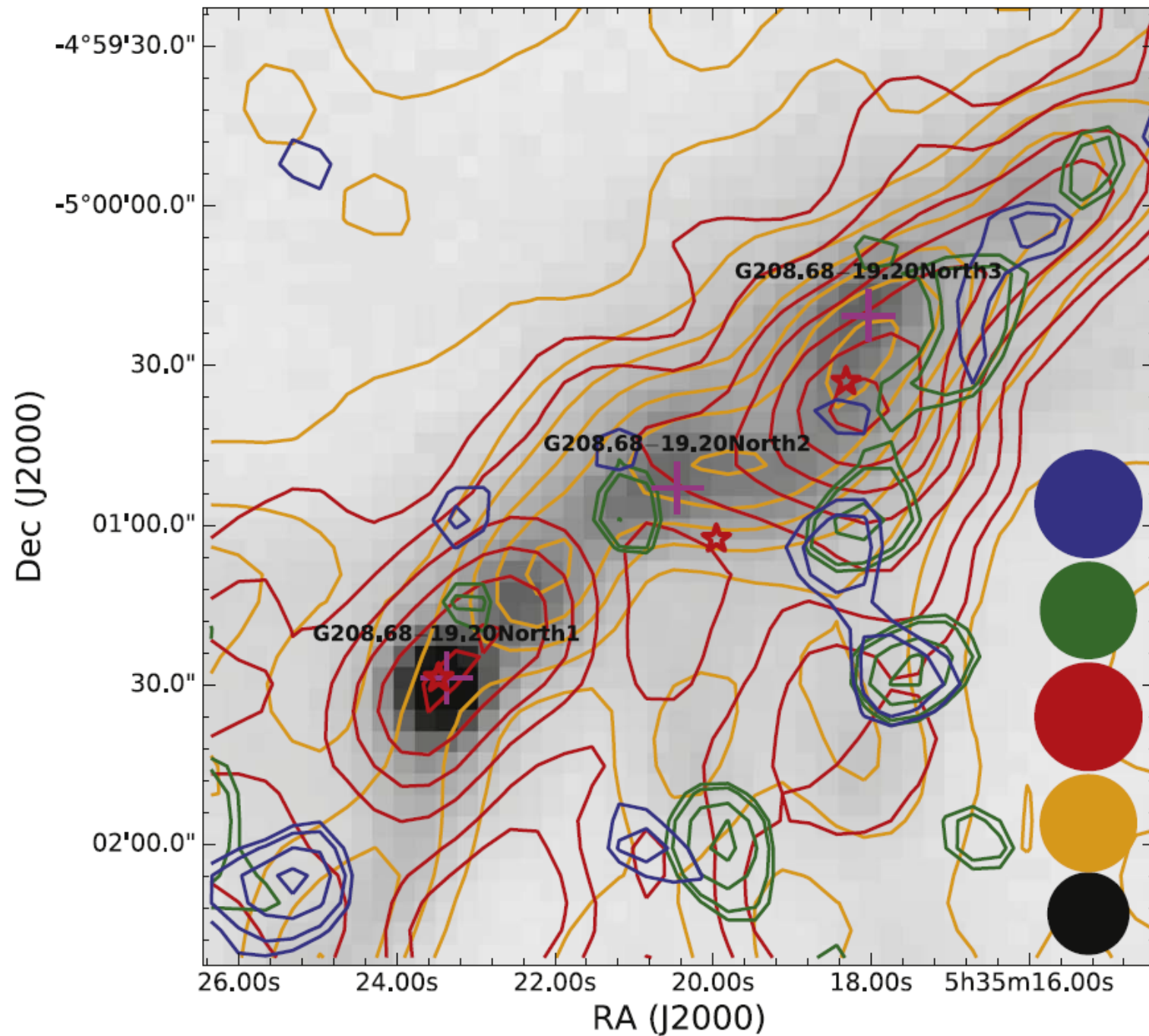
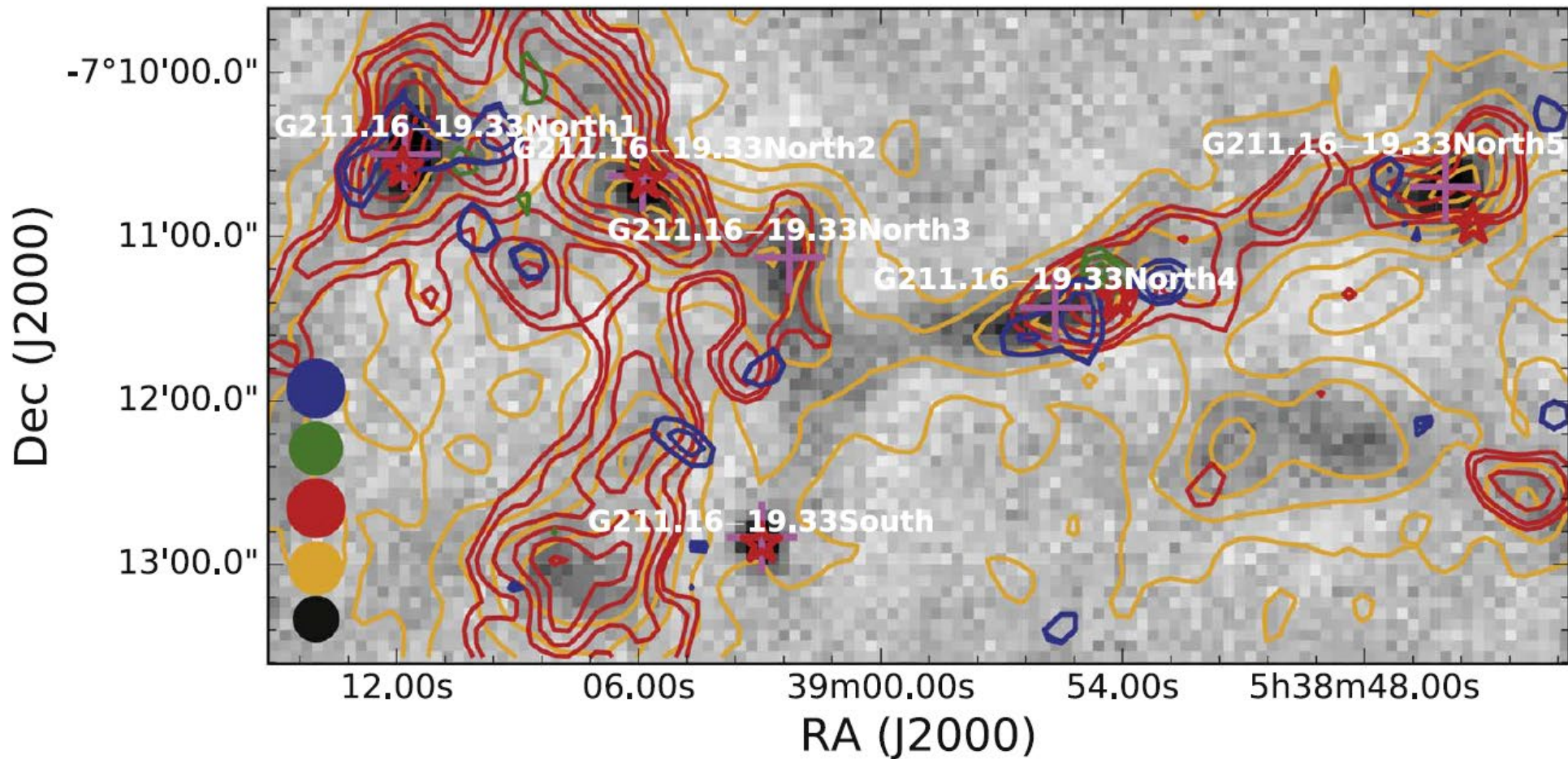
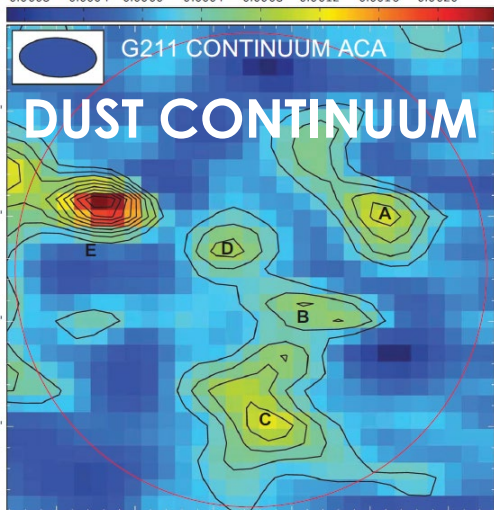


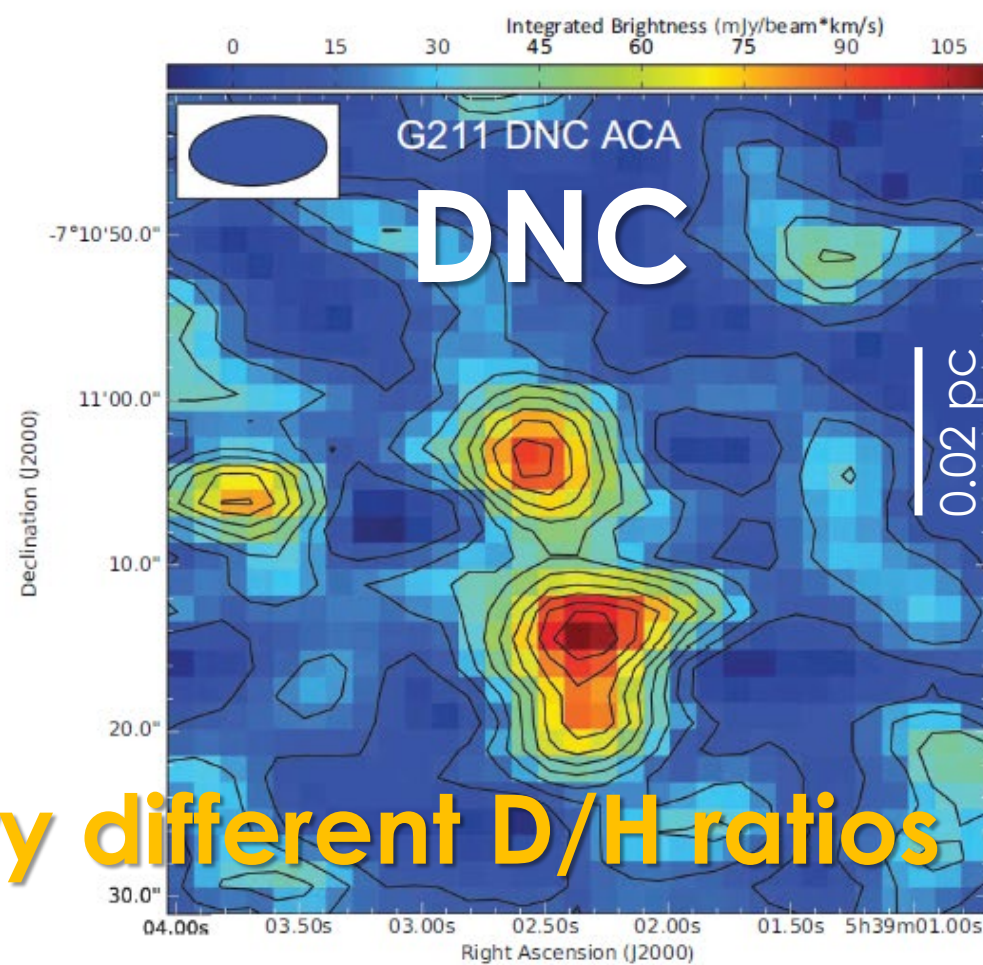
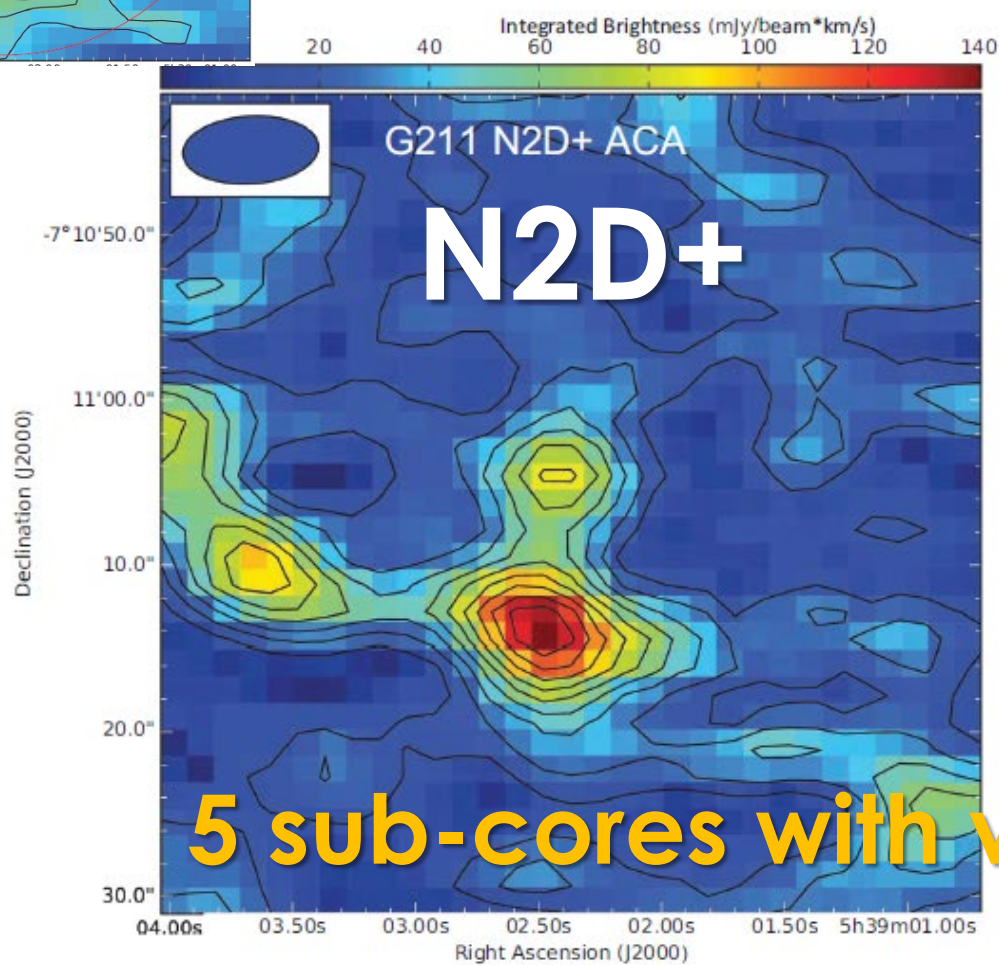
Figure 4. Same as Figure 1, but for field G208.68.

CCS 82GHz, CCS 94GHz, HC₃N, N₂H⁺,
SCUBA-2 850 MICRON

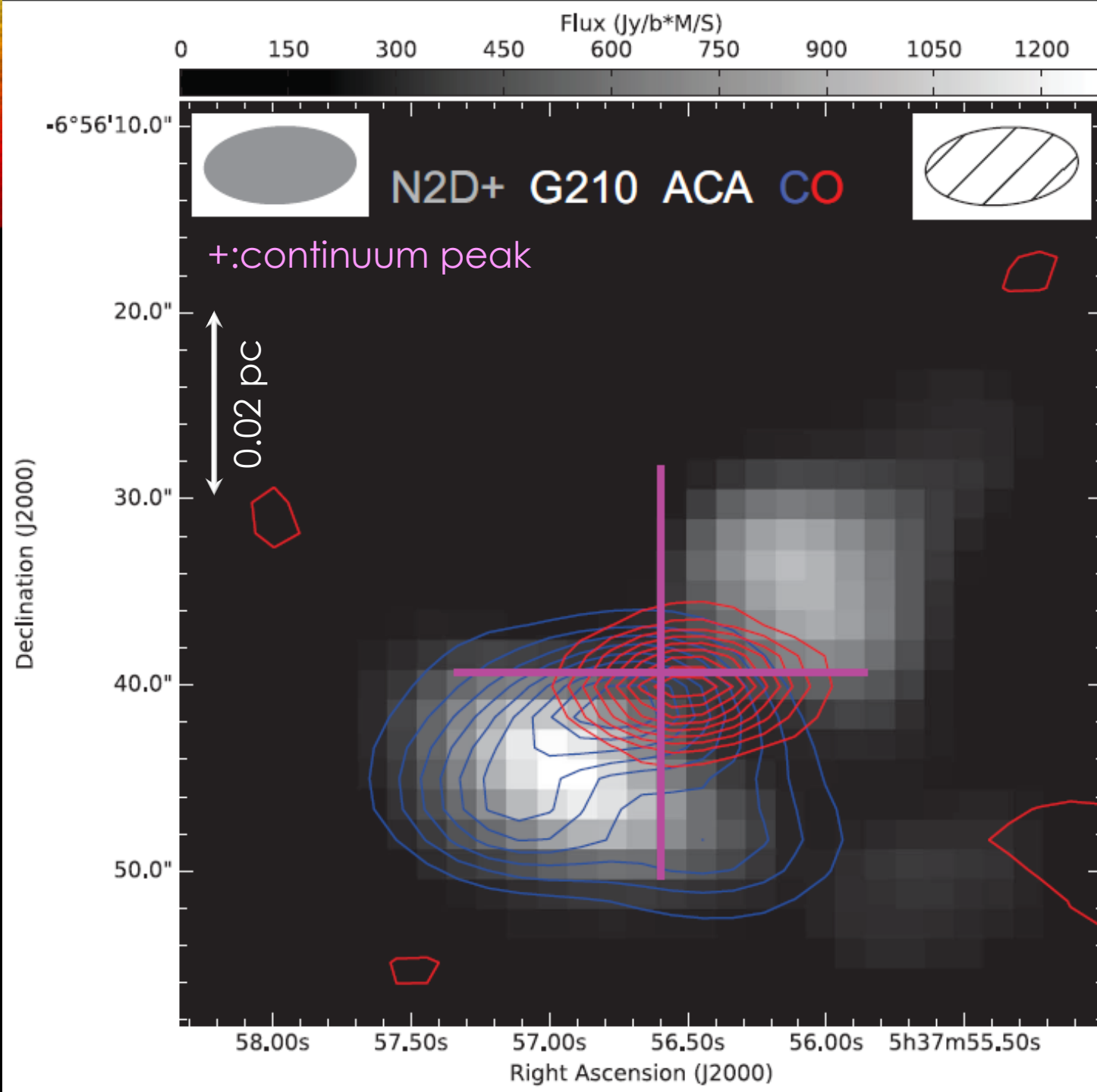




ALMA ACA FOLLOW-UP STARLESS CORE (TATEMATSU+20)



5 sub-cores with very different D/H ratios



ALMA ACA FOLLOW-UP STAR-FORMING CORE (TATEMATSU+20)

- Two N2D+ peaks centered on the dust peak
- **Compact outflow** (0.03 pc, 2E3 yr)

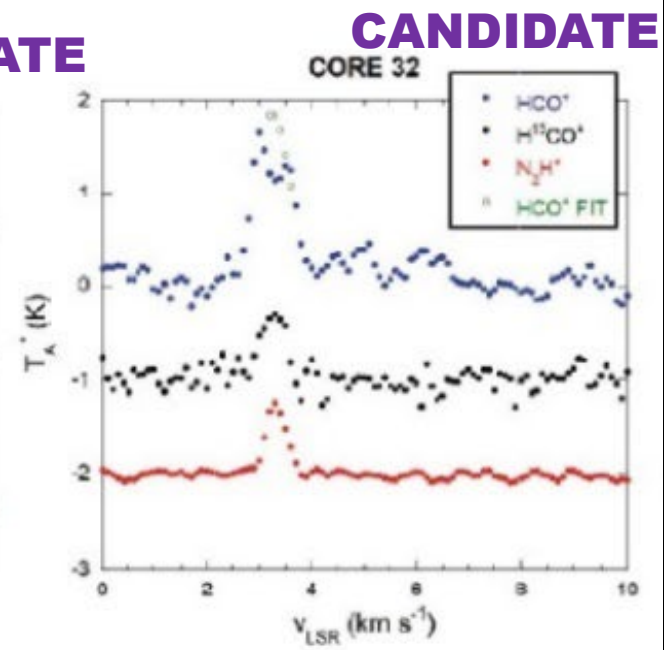
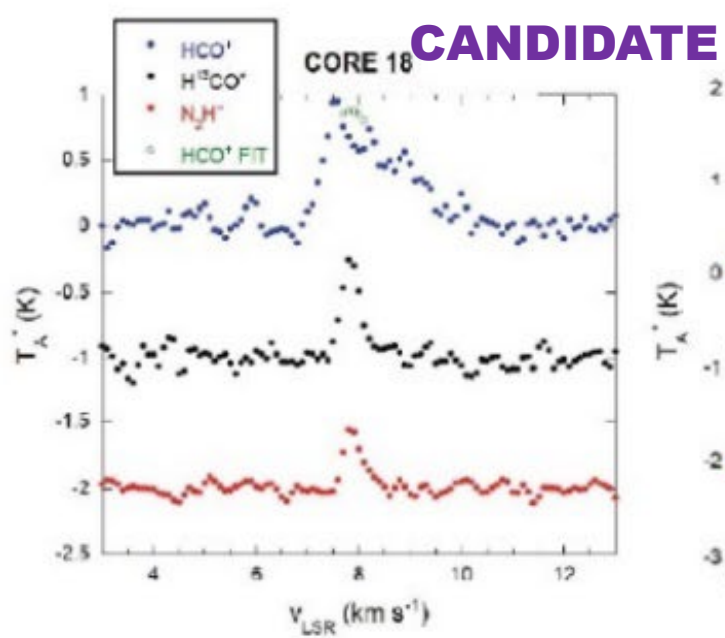
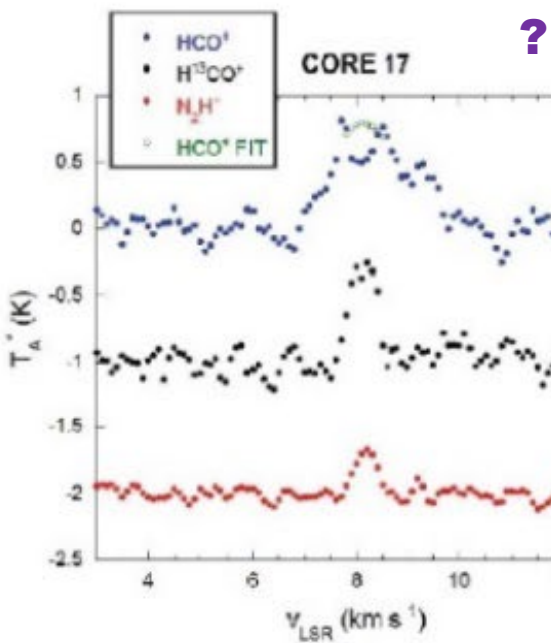
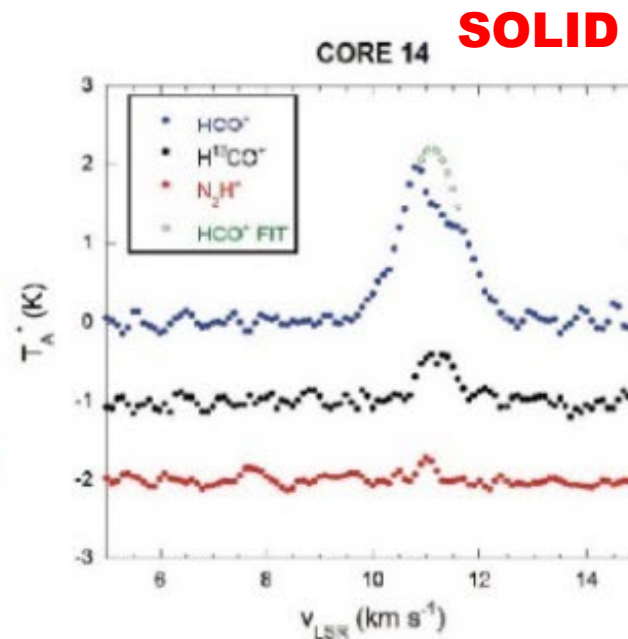
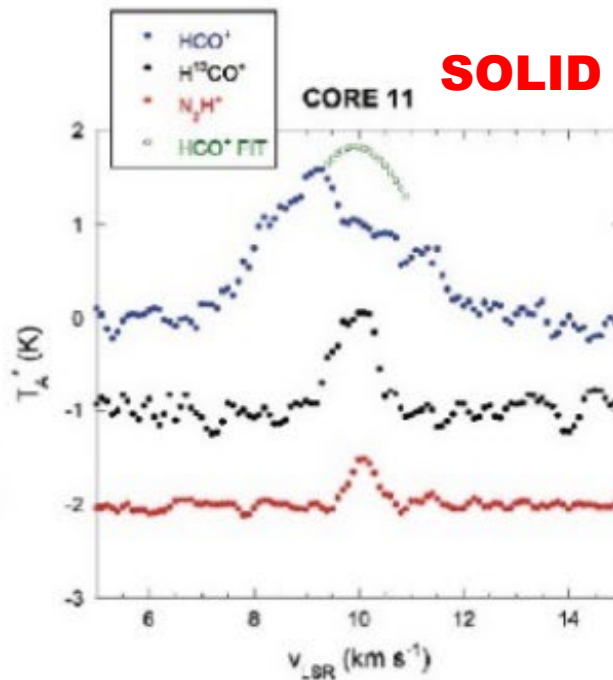
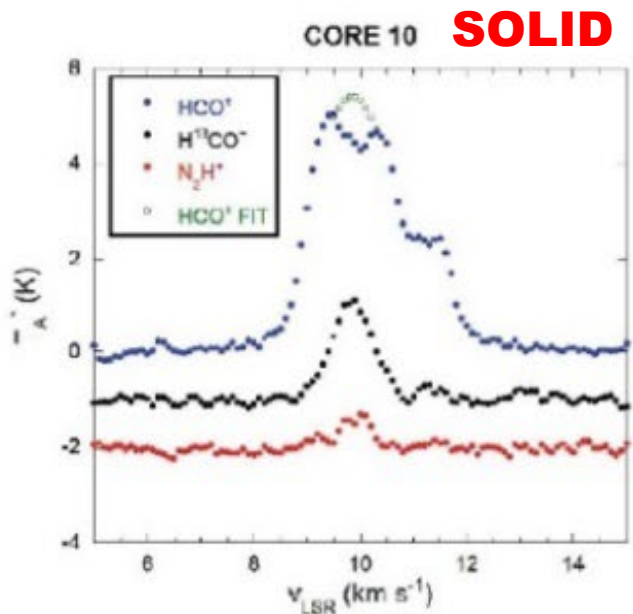
INWARD-MOTION SURVEY IN ORION

- $J=1-0$ of HCO^+ , H^{13}CO^+ , N_2H^+ to search for blueskewed profiles

Procedures:

- (1) check $v(\text{HCO}^+) - v(\text{H}^{13}\text{CO}^+)$ and $v(\text{HCO}^+) - v(\text{N}_2\text{H}^+)$ (**velocity difference between optically thick vs thin**)
- (2) compare **profiles** of them
- (3) check **spatial** distribution of HCO^+ profiles

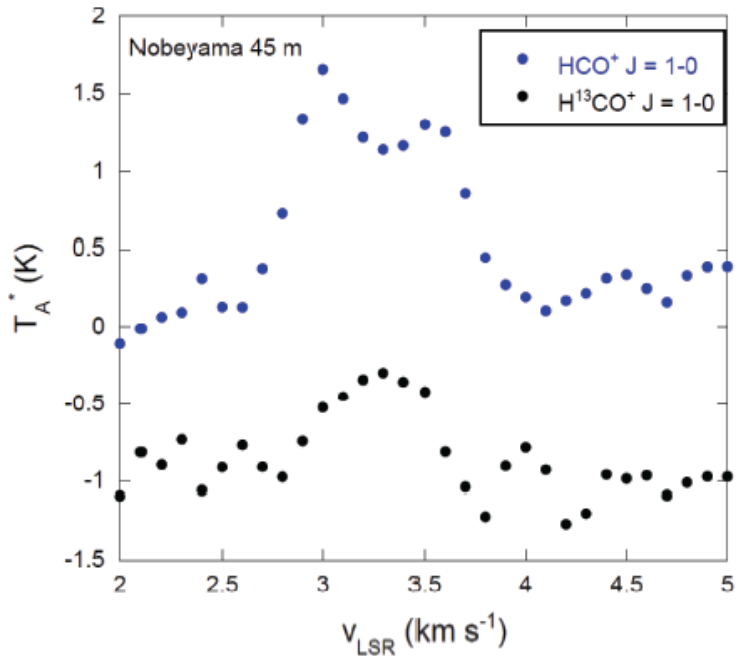
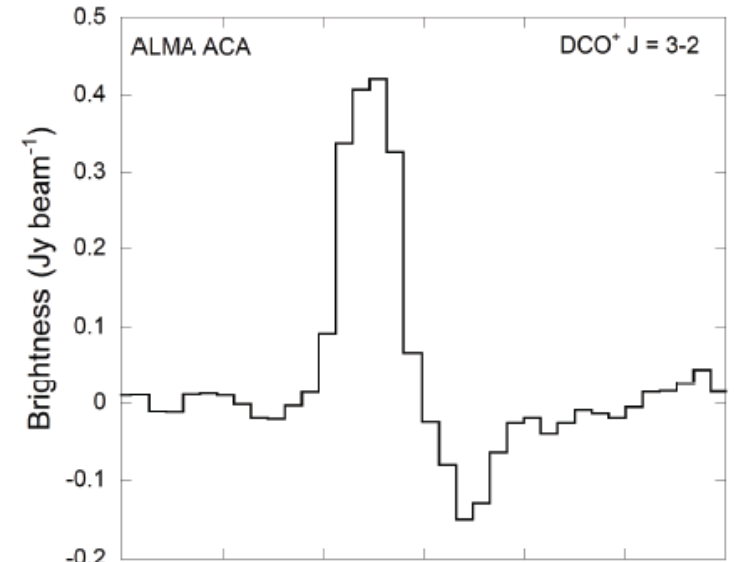
to drop two velocity components and any other possibilities



CORE 32:

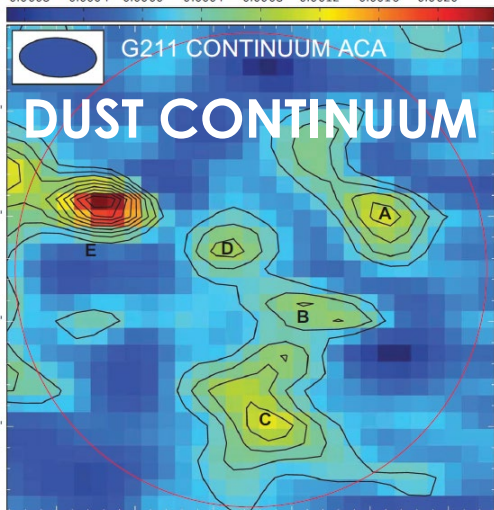
HINT OF GRAVITATIONAL ACCELERATION?

- $v(\text{dip}) - v(\text{peak})$ is larger in ACA than in 45m
- larger inward motion at smaller radii

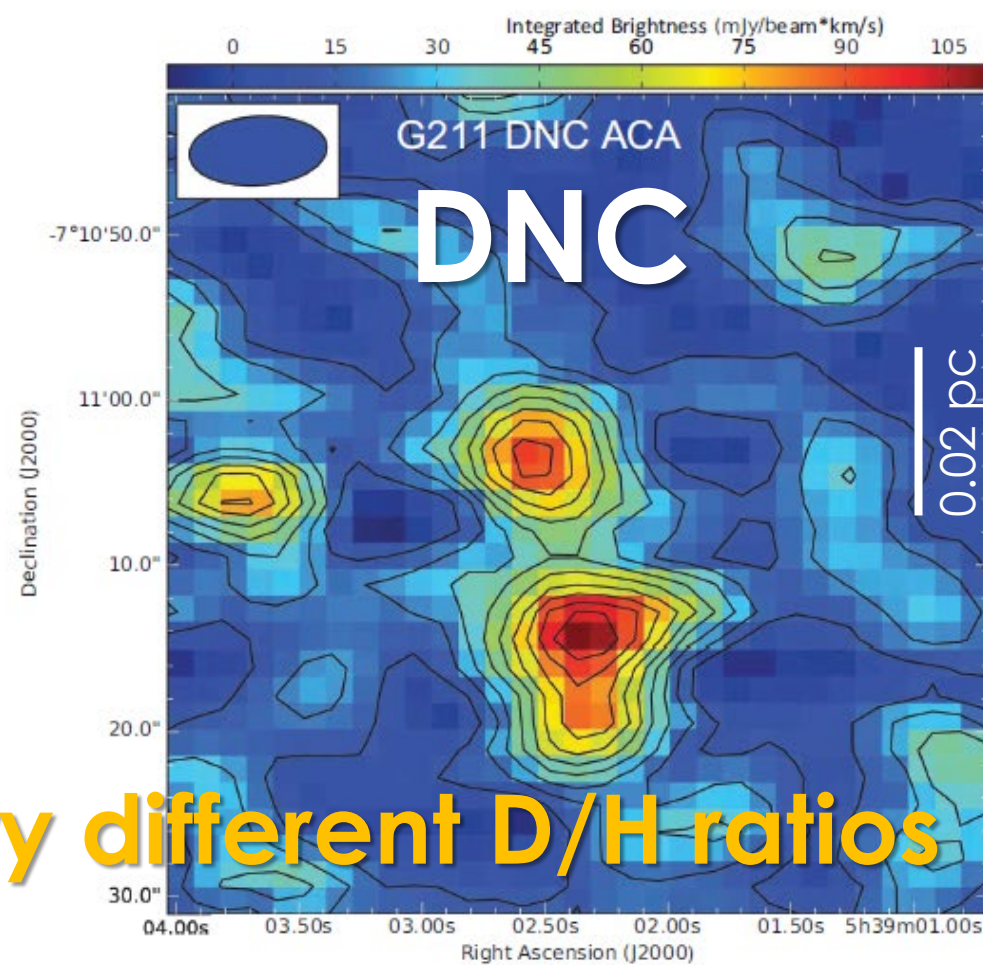
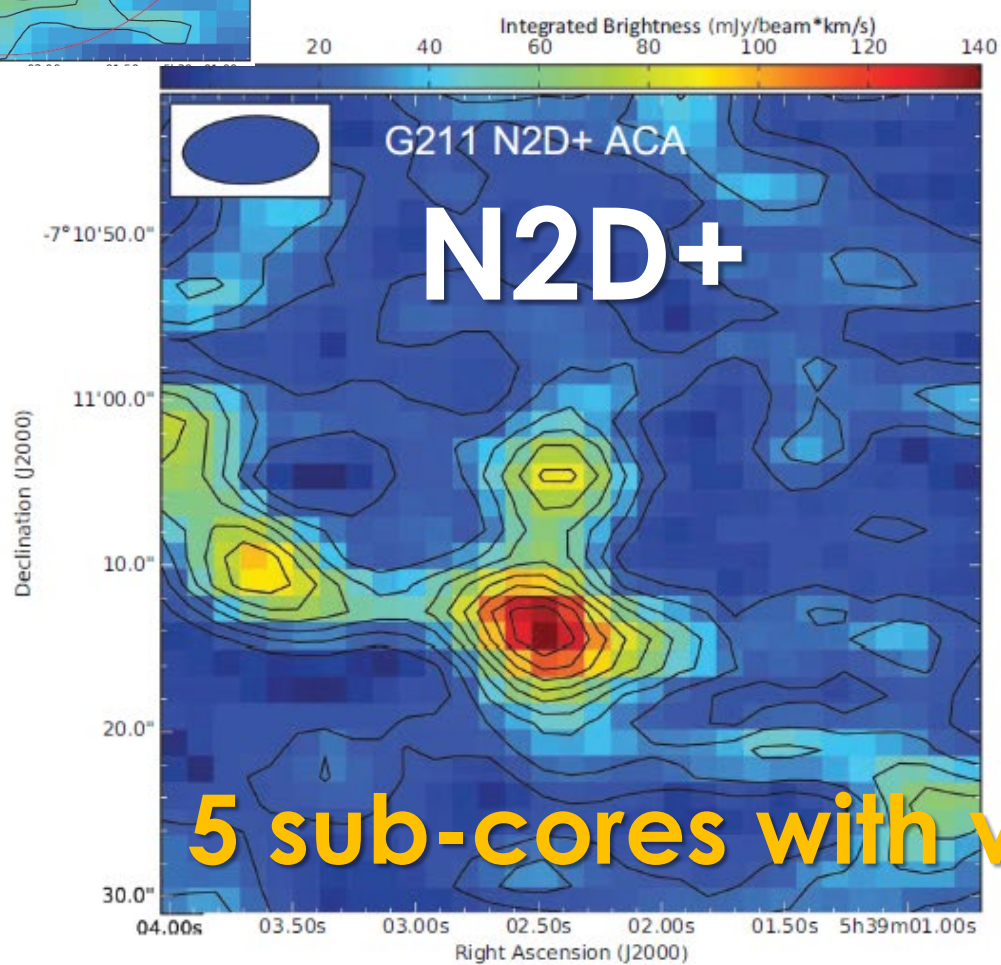


ACA $\theta \sim 5'' \sim 0.01$ pc

45m $\theta \sim 20'' \sim 0.04$ pc

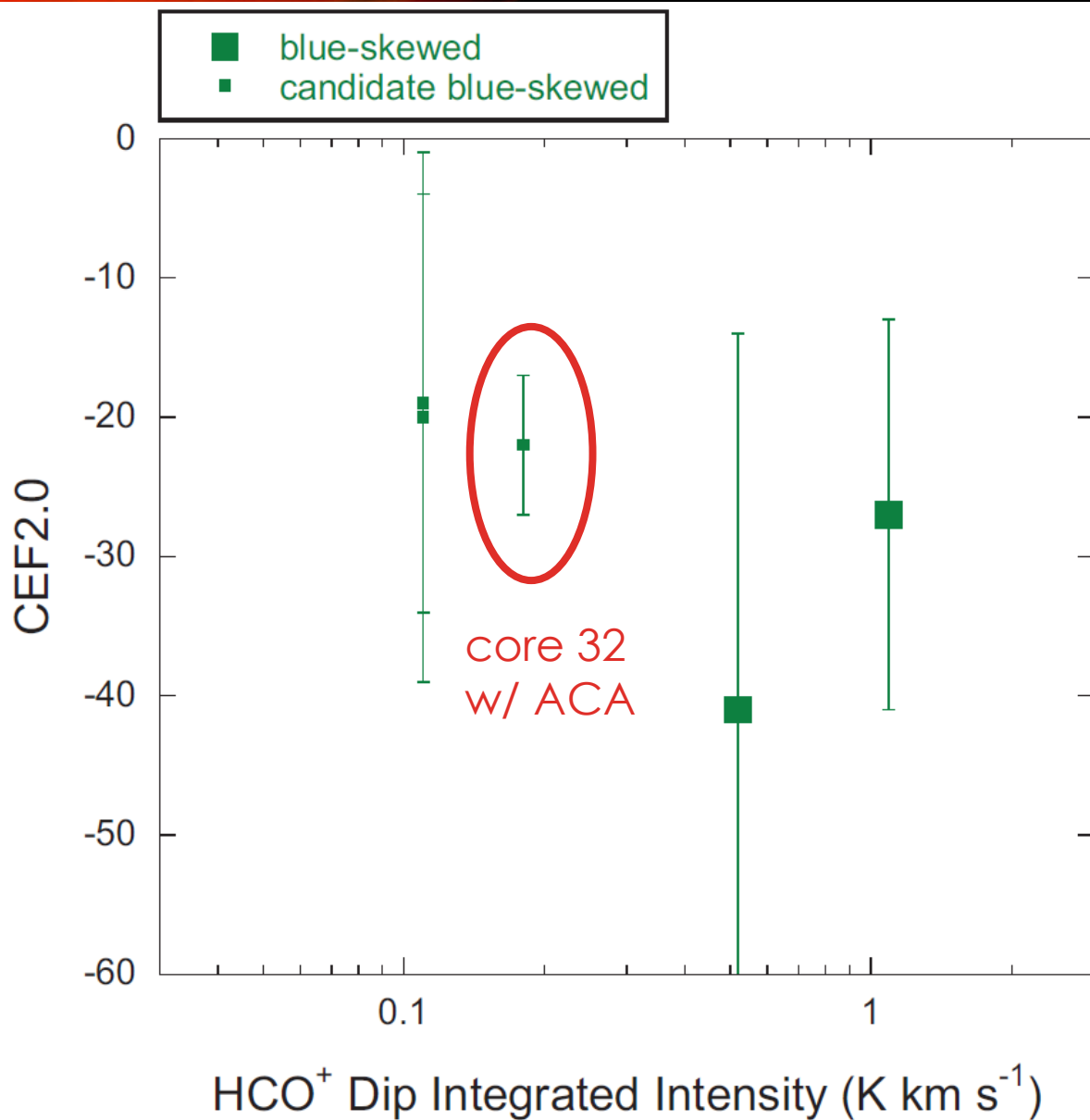


ALMA ACA FOLLOW-UP STARLESS CORE (TATEMATSU+20)



5 sub-cores with very different D/H ratios

CORE 32



- CEF2.0 = -22
- at a later stage of the starless core phase (closer to the onset of star formation)

REFEREED PUBLICATIONS

5 PUBLISHED + 1 SUBMITTED (INCLUDING PILOT OBSERVATIONS)

Ge, J. X., et al. "Three dimensional projection effects on chemistry in a Planck galactic cold clump," ApJ, 891, 36 (2020)

Kim, G., Tatematsu, K., Liu, T., et al. "Molecular Cloud Cores with High Deuterium Fraction: Nobeyama Single-Pointing Survey," ApJS, 249, 33 (2020)

Tatematsu, K., Liu, T., et al., "Astrochemical Properties of Planck Cold Clumps," ApJS, 228, 12 (2017)

Tatematsu, K., Liu, T., Kim, G., et al. "ALMA ACA and Nobeyama observations of two Orion cores in deuterated molecular lines," ApJ, 895, 119 (2020)

Tatematsu, K., Kim, G., Liu, T., et al. "Molecular Cloud Cores with High Deuterium Fractions: Nobeyama Mapping Survey," ApJS, 256, 25 (2021)

Tatematsu, K., et al., "Nobeyama Survey of Inward Motions toward Cores in Orion Identified by SCUBA-2," ApJ, submitted (2021)

SUMMARY

- We **established** CEF2.0 to measure the evolutionary stage of starless cores using **D/H**
- Nobeyama **D/H catalog** (Kim et al. 2020), N₂H⁺ **maps** (Tatematsu et al. 2021), ACA follow-up (Tatematsu et al. 2021)
- No strong evidence for turbulence dissipation
- Nobeyama inward-motion survey: obtained a hint of **gravitational acceleration** in core 32 (CEF = -22) by comparing the ACA and 45m spectra (Tatematsu et al, submitted)

A photograph of a radio telescope facility at dusk. Several large white parabolic satellite dishes are mounted on structures. In the foreground, there is a grassy area with a low fence. Bare trees are silhouetted against the twilight sky. The word "END" is overlaid in large, bold, yellow capital letters in the center of the image.

END