Nobeyama 45 m Follow-up to TOP-SCOPE project

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Initial Conditions for Star Formation

- **Not just** before/after star formation
- **But IMMEDIATELY** before/after star formation

- Starless cores may evolve before star formation!

What starts star formation?

- It is likely that (most of) starless cores are stable. (If not, star formation rate will be very high)
- Stable cores cannot become unstable, without a reason. Which mechanism?

Possible mechanisms

- Dissipation of turbulence (e.g., Nakano 1998; Aso+00)
- Mass accretion onto cores (Gomez+07)
- Energy loss due to oscillation (Stahler & Yen 09)
- Etc

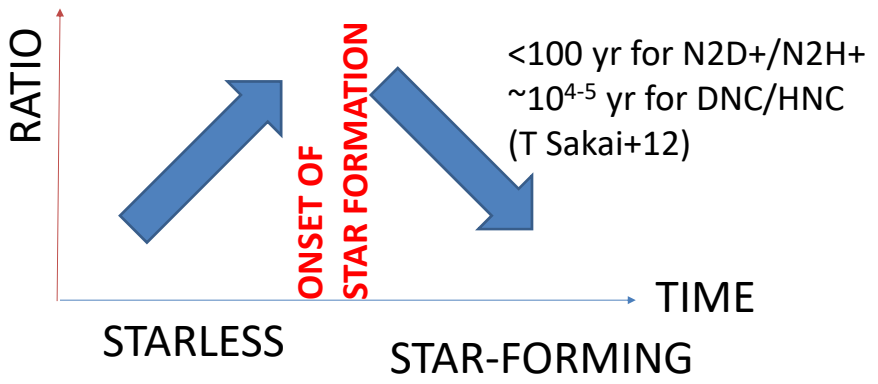
- We are not discussing “triggered” star formation by OB association, but more general cases.

How to find cores IMMEDIATELY before/after star formation?

- **SCUBA-2 cores in PGCCs (TOP-SCOPE) having high deuterium fraction (D/H)!**

Chemical Evolution (I)

N2D+/N2H+ or DNC/HNC in cold cores

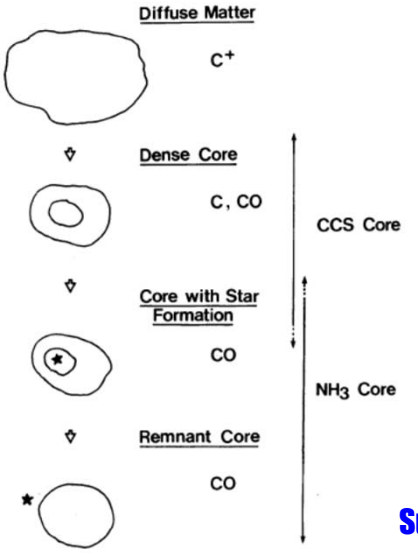


<100 yr for N2D+/N2H+
~10^{4-5} yr for DNC/HNC
(T Sakai+12)

Byproduct in ALMA era (deuterated molecules)

- Molecules are seriously depleted in starless cold cores with ALMA resolution.
- N2D+, and then N2H+ are known to be less affected by depletion, even for cold cores.
- D/H is enhanced in cold cores, so deuterated molecules are easier to observe.

Chemical Evolution (II)
Dark Clouds : (CCS, HC_3N)→(NH_3, N_2H^+)



Suzuki et al. (1992)

Observations

(1) Initial observation of 13 Planck cold clumps with Nobeyama 45 m

(2) Nobeyama 45 m Large program for 200 cores (100 in Orion and 100 in other regions) 350 hrs over two years

(3) ALMA ACA 7m observations of two Orion cores

N2D+ intense cores

- Nobeyama 45m follow-up

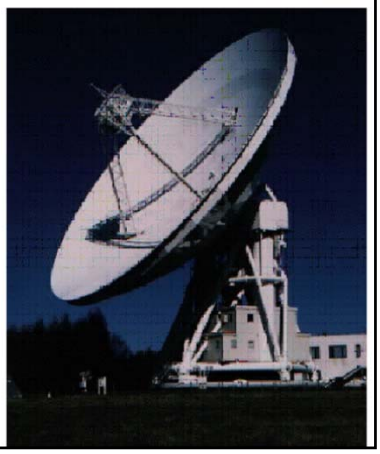
  (1) Initial 13 clumps (Tatematsu+17)

  (2) 115 cores in Orion region (Ori A and B GMCs, λ Ori)

  - N_2D^+ was detected toward ~40 cores out of 115 Orion cores(37%)
  - There are several N_2D^+ intense cores in 115 cores.
  - We select two N2D+ intense Orion cores for ALMA 7m observations (Cycle 4 Suppl. call)

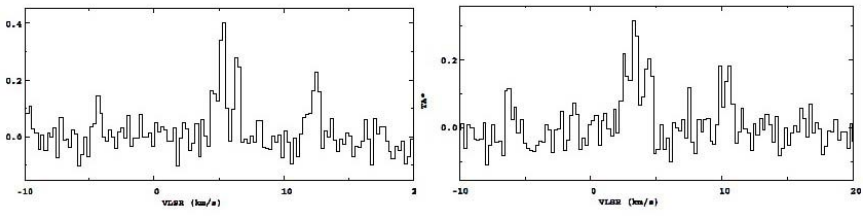
OBSERVATIONS with 45m

- **NOBEYAMA 45-m RADIO TELESCOPE**
- **RECEIVERS**
  - **TZ1, T70 (single beam)**
  - **FOREST (4-beam)**
- **N_2H^+, CCS, HC_3N**
  - **single pointing→OTF mapping for interesting sources**
- **N_2D^+, DNC, $HN^{13}C$, c-C_3H_2**
  - **single-pointing**
- **20" BEAM@80-100GHz**
- **2015 Dec-2019 May**



N_2D^+ obtained with Nobeyama 45m toward G210 and G211

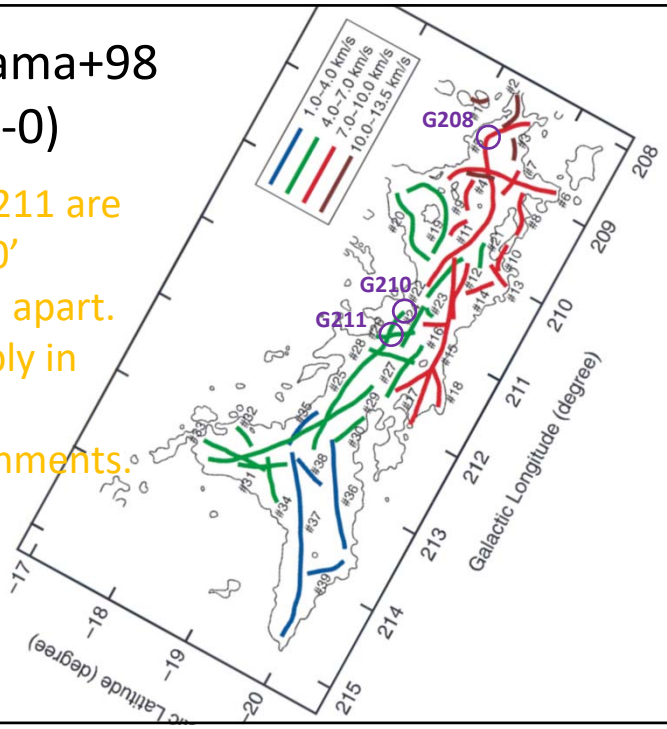
Star forming vs starless



Δv (N_2D^+) is as narrow as 0.41 and 0.45 km/s for G210 and G211, respectively, although they are located in Orion A GMC.

Nagahama+98
^{13}CO (1-0)

- G210/211 are only 20’ (2.6pc) apart. Probably in similar environments.



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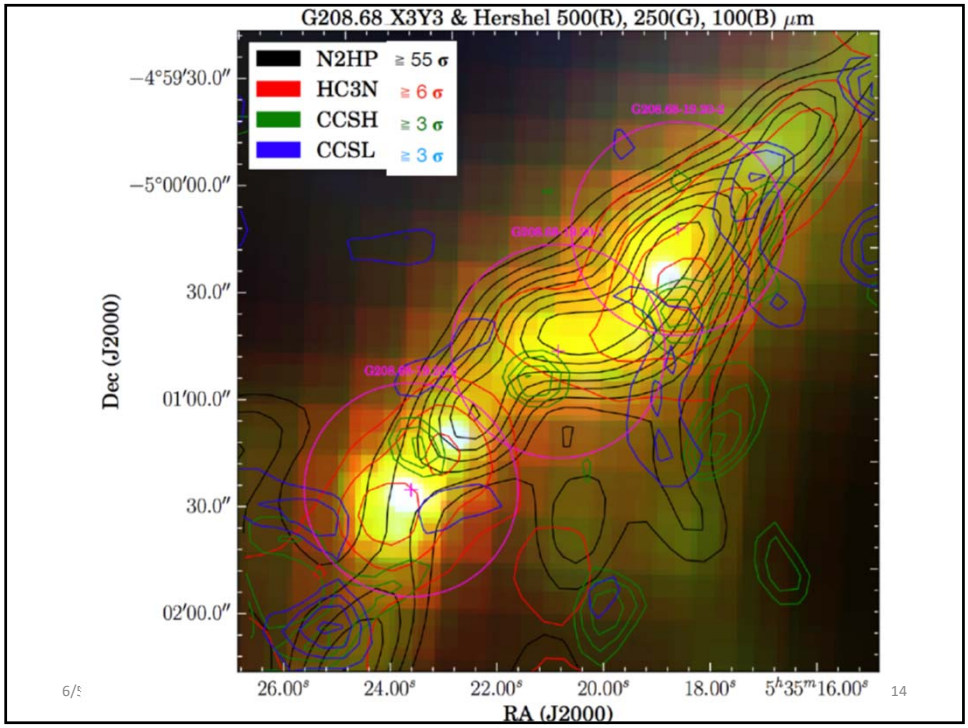

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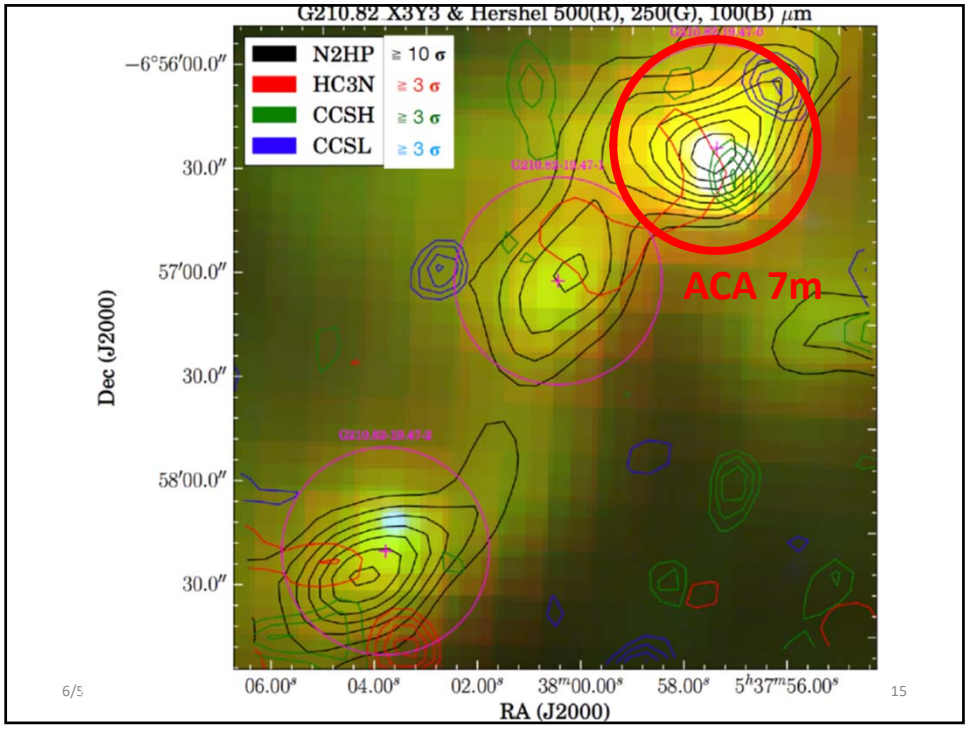
G210.82 X3Y3 & Hershel 500(R), 250(G), 100(B) μm
N2HP ≥ 10 σ
HC3N ≥ 3 σ
CCSH ≥ 3 σ
CCSL ≥ 3 σ
ACA 7m
−6°56′00.0″
30.0″
57′00.0″
30.0″
58′00.0″
30.0″
Dec (J2000)
06.00ˢ
04.00ˢ
02.00ˢ
38ᵐ00.00ˢ
58.00ˢ
5ʰ37ᵐ56.00ˢ
RA (J2000)
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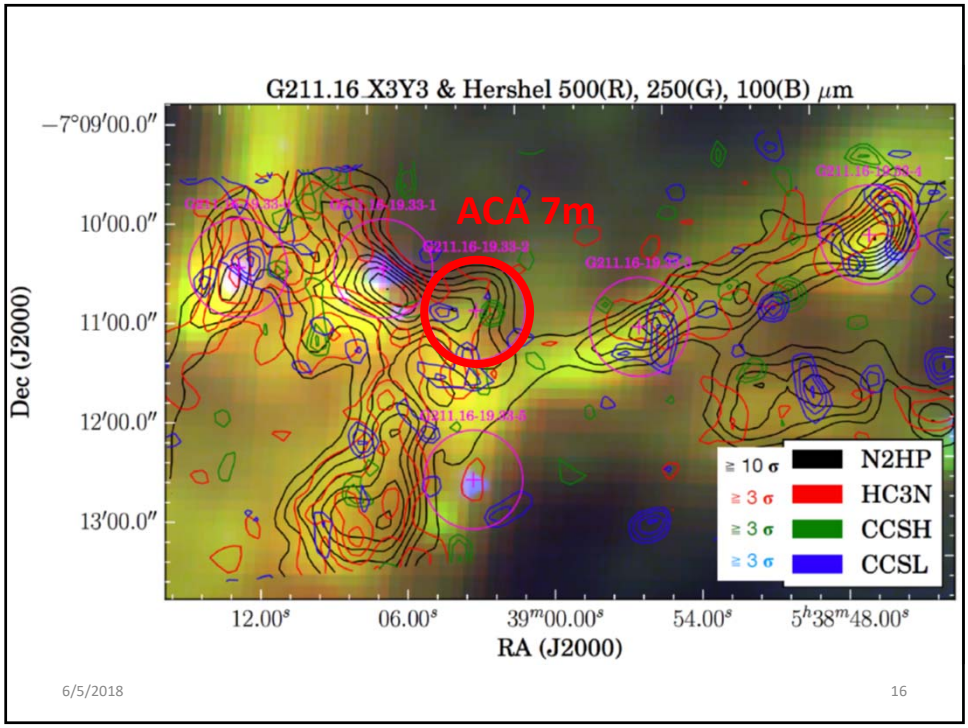
G211.16 X3Y3 & Hershel 500(R), 250(G), 100(B) μm
ACA 7m
−7°09′00.0″
10′00.0″
11′00.0″
12′00.0″
13′00.0″
Dec (J2000)
12.00ˢ
06.00ˢ
39ᵐ00.00ˢ
54.00ˢ
5ʰ38ᵐ48.00ˢ
RA (J2000)
≥ 10 σ N2HP
≥ 3 σ HC3N
≥ 3 σ CCSH
≥ 3 σ CCSL
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Initial result from Nobeyama maps: CCS vs N2H+

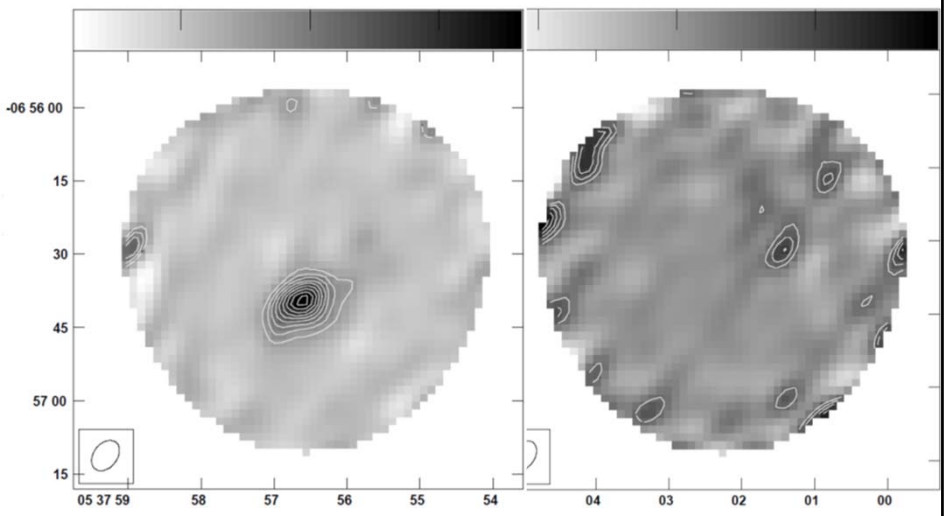
- CCS (young gas) is very clumpy
- It seems that clumpy clouds evolve into less-clumpy N2H+ cores.
  - It is known that N2H+ traces the dust continuum very well.

(3) Observations with ALMA 7m

- We select two N2D+ intense Orion cores for ALMA 7m observations (Cycle 4 Suppl. call)
- ~5" resolution, Band 6

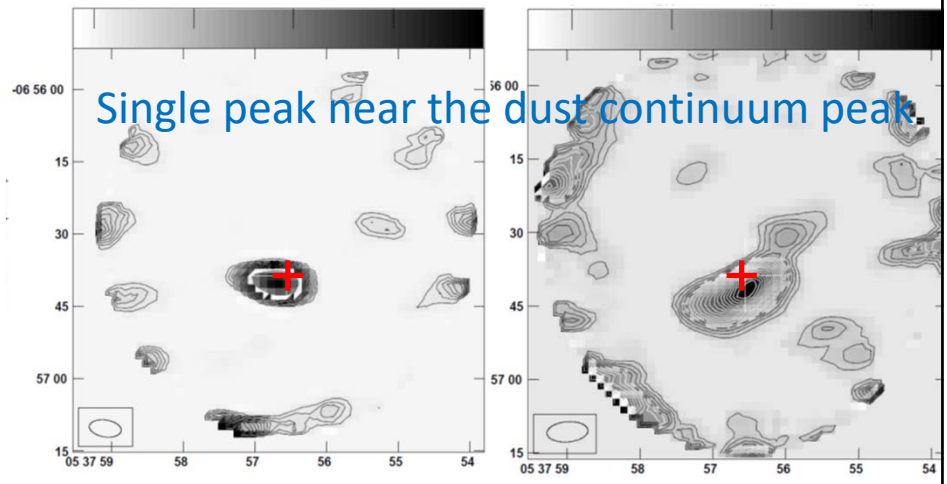
B6 continuum

G210(star forming) G211 (starless)



G210 (star forming) in

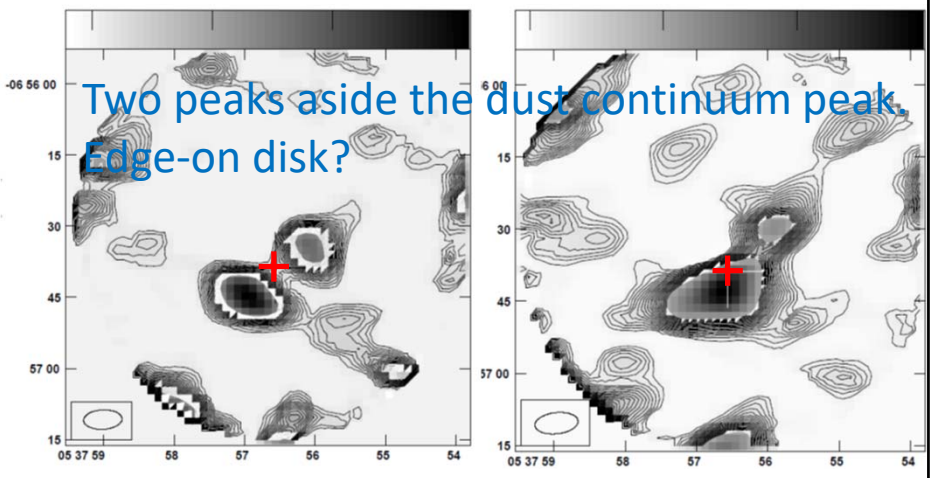
CS DNC



+:ALMA 7m B6 continuum peak

G210 (star forming) in

N2D+ DCO+

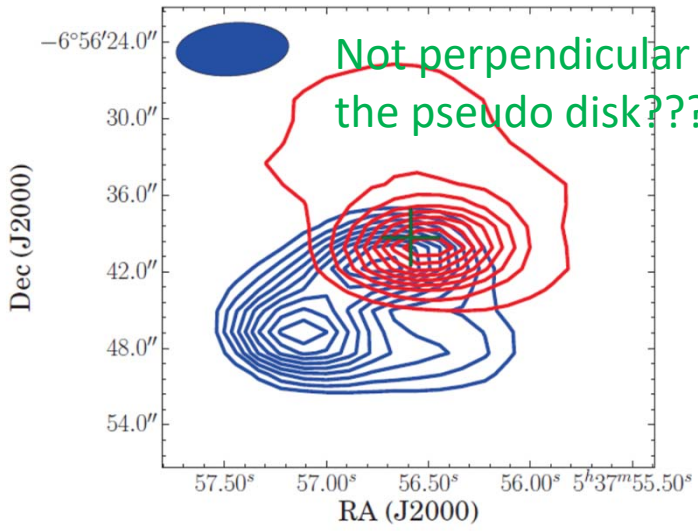


Two peaks aside the dust continuum peak. Edge-on disk?

+:ALMA 7m B6 continuum peak

However…

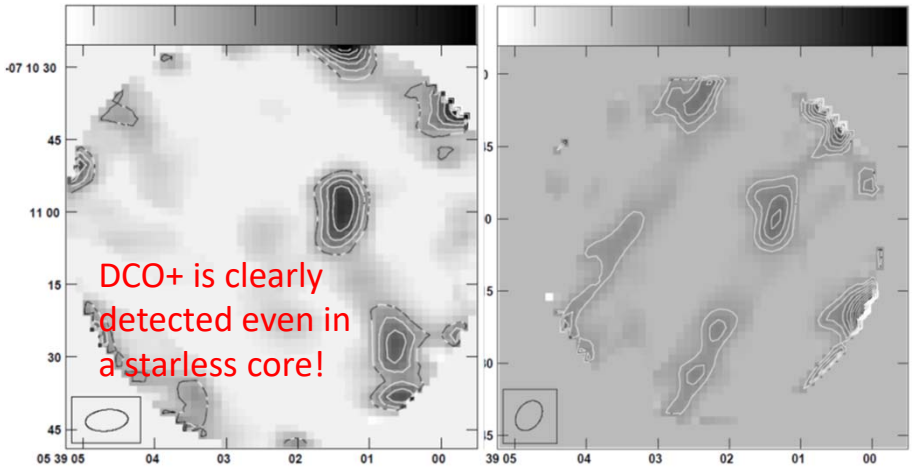
G210 CO outflow



Not perpendicular to the pseudo disk???

G211 (starless) in

DCO+ HCO+



DCO+ is clearly detected even in a starless core!

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SUMMARY

- We are surveying cores IMMEDIATELY before/after star formation, by using deuterium fraction (high D/H)
- We completed single-pointing survey toward 200 cores (100 Orion and another 100 including high-column density cores), and are continuing OTF mapping (15 already mapped).
- Two out of them have already been imaged with ACA.

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THANK YOU!