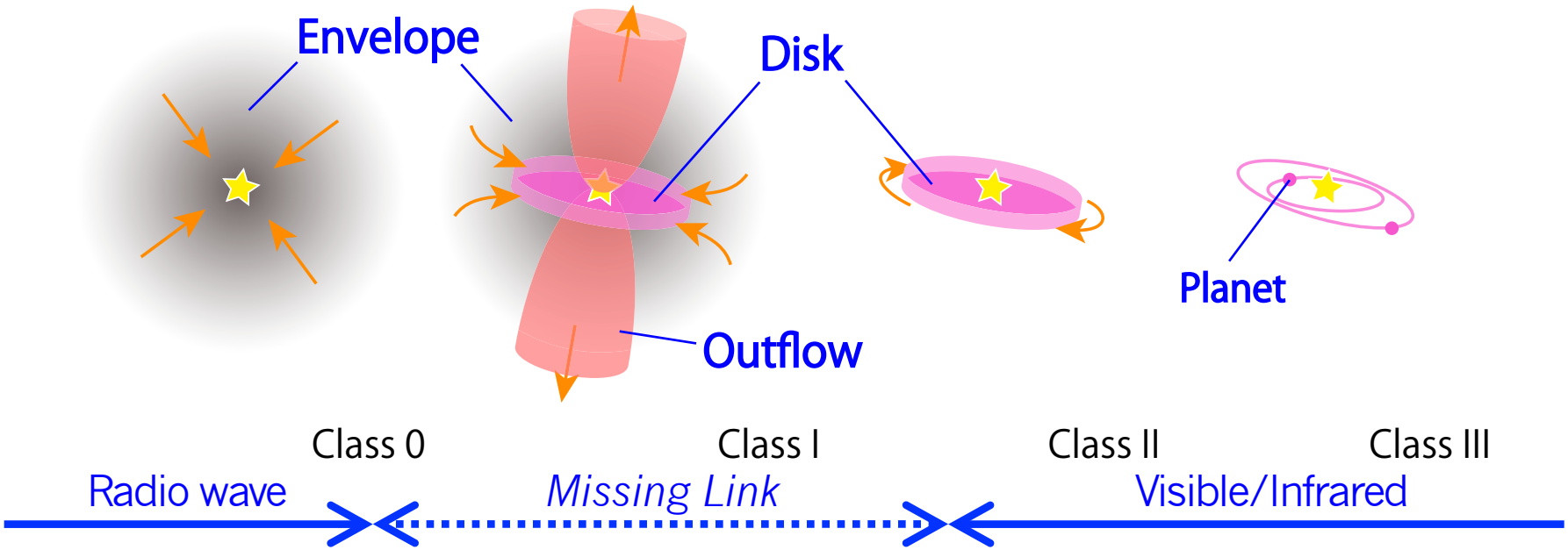
Low-Mass Protostellar Evolution



- When and how are disks formed from envelopes?
  - Physical evolution
    How does the envelope gas fall into disks?
  - Chemical evolution
    How does the chemical composition change during the disk formation?

Chemistry at a few 1000s au scale

Chemical Variation in Envelopes of Class 0-I Sources

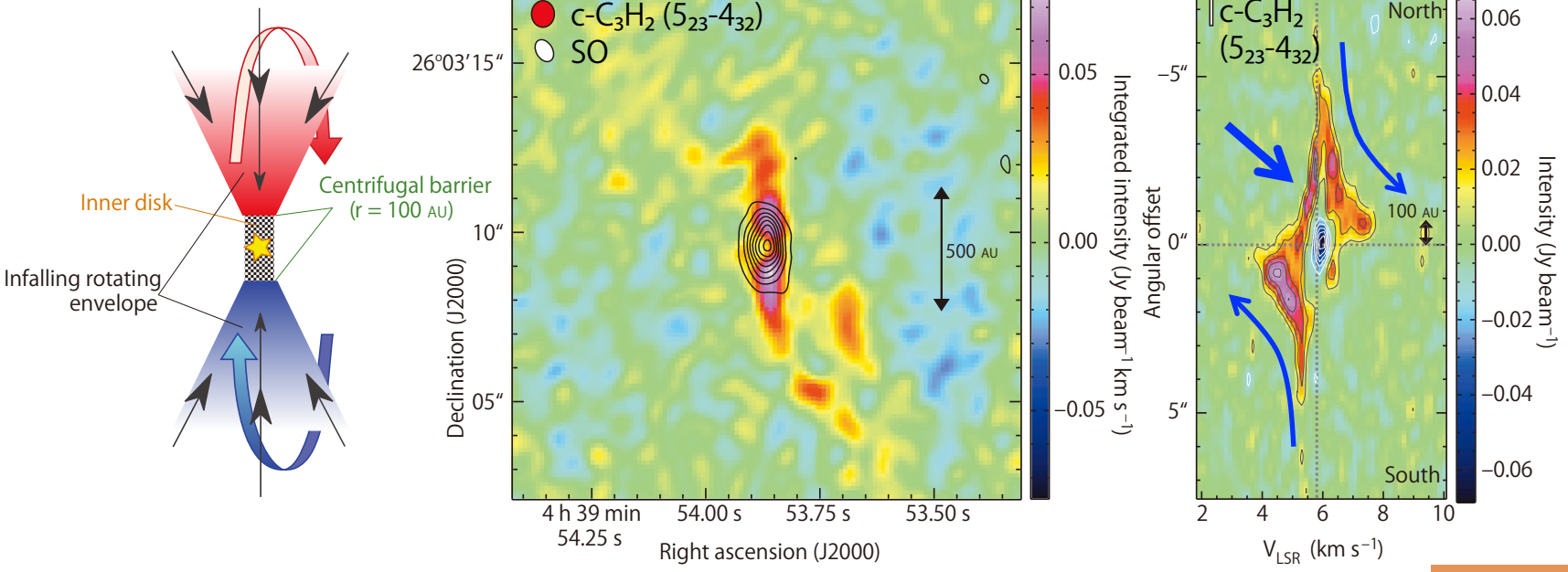
- Warm carbon-chain chemistry (WCCC)
  - Unsaturated carbon-chain molecules
    - e.g. CCH, C_4H, HC_7N
  - e.g. L1527, IRAS 15398−3359, L483
- Hot corino chemistry
  - Saturated complex organic molecules (COMs)
    - e.g. $HCOOCH_3$, $(CH_3)_2O$, C_2H_5CN, NH_2CHO
  - e.g. IRAS 16293−2422, NGC 1333 IRAS 2A, IRAS 4A
- Other types?

(e.g. Sakai & Yamamoto 2013)

→ *How about in disk forming regions?*

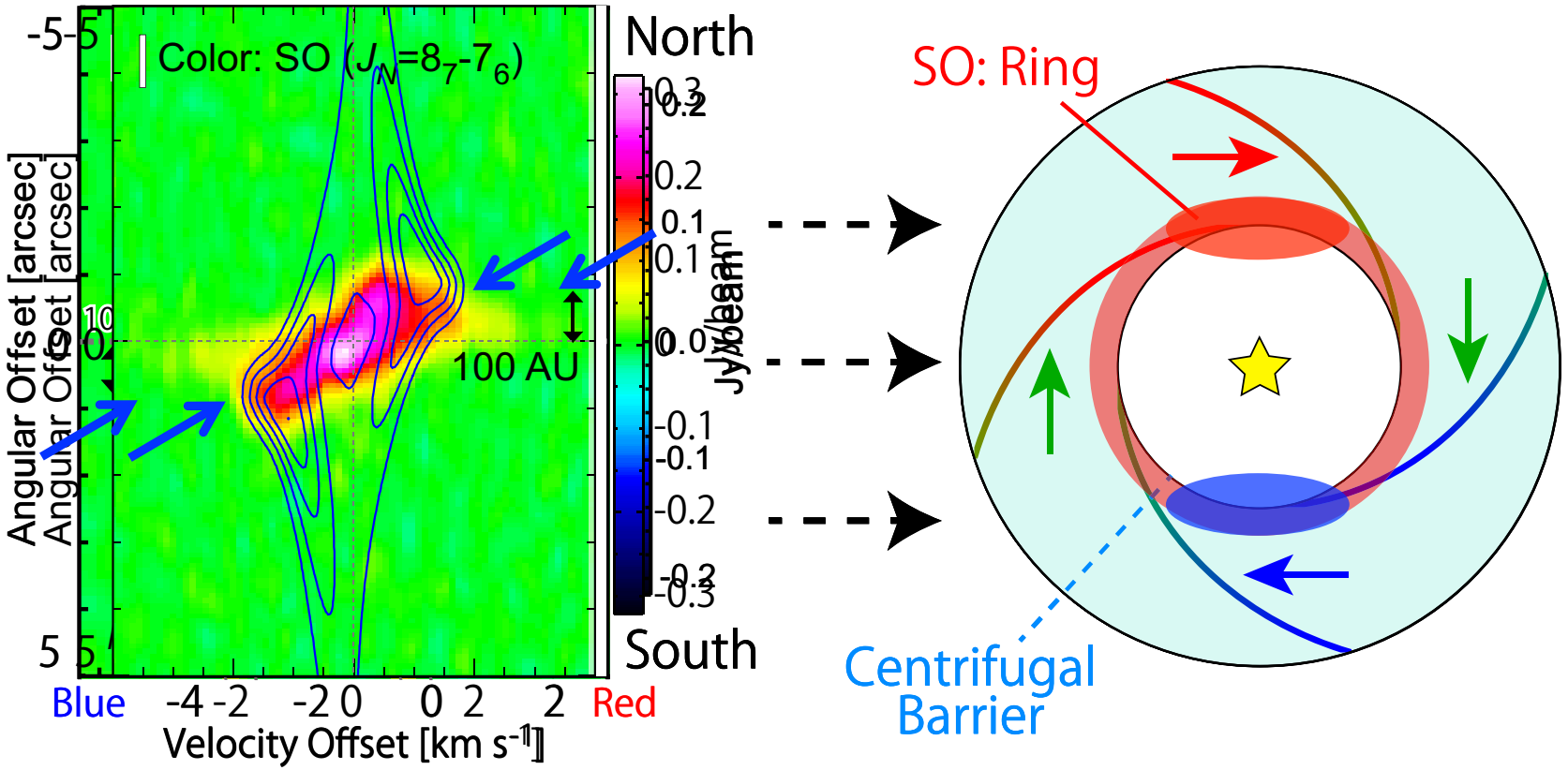
L1527: Class 0/I, WCCC

- IRAS 04368+2557
  - Class 0/I protostar in Taurus (d = 137 pc)
- Warm carbon-chain chemistry
- ↓ c-C_3H_2 observed with ALMA (Sakai et al. 2014a)
  - Resolution: ~0".9, ~0.15 km/s
  - Spin-up structure



L1527: Class 0/I, WCCC

- Infalling-rotating envelope model for L1527



→ r_{CB} = 100 ± 20 au, M = 0.18 ± 0.02 $M_\odot$ (i = 85°) (Sakai et al. 2014a,b)

Chemistry at a few 1000s au scale

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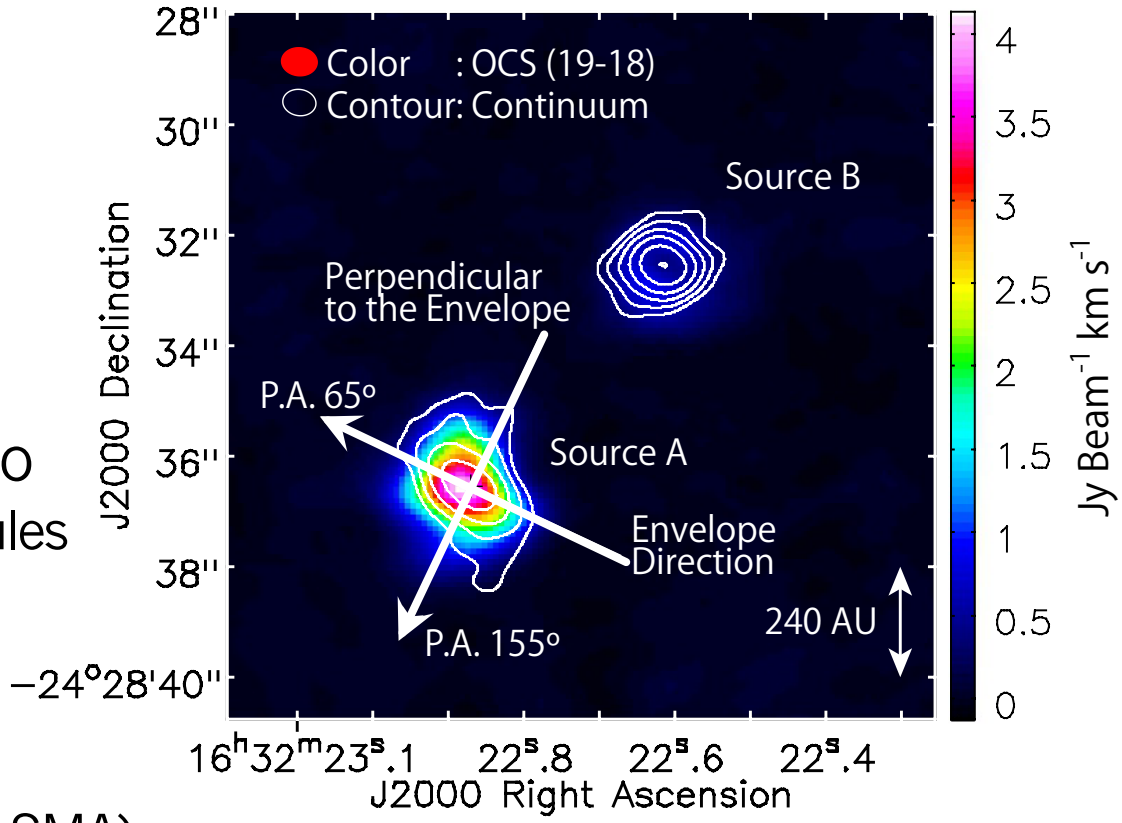
(e.g. Sakai & Yamamoto 2013)

→ *How about in disk forming regions?*

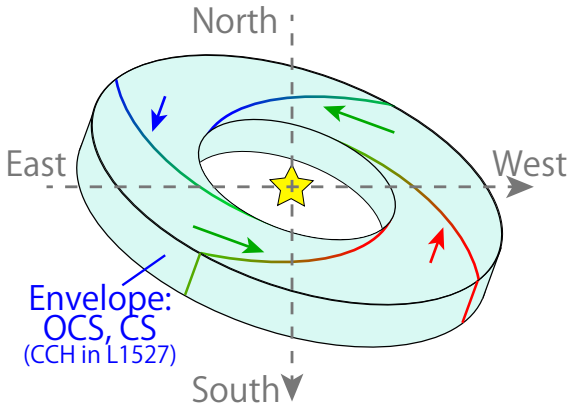
IRAS 16293−2422: Class 0, Hot Corino

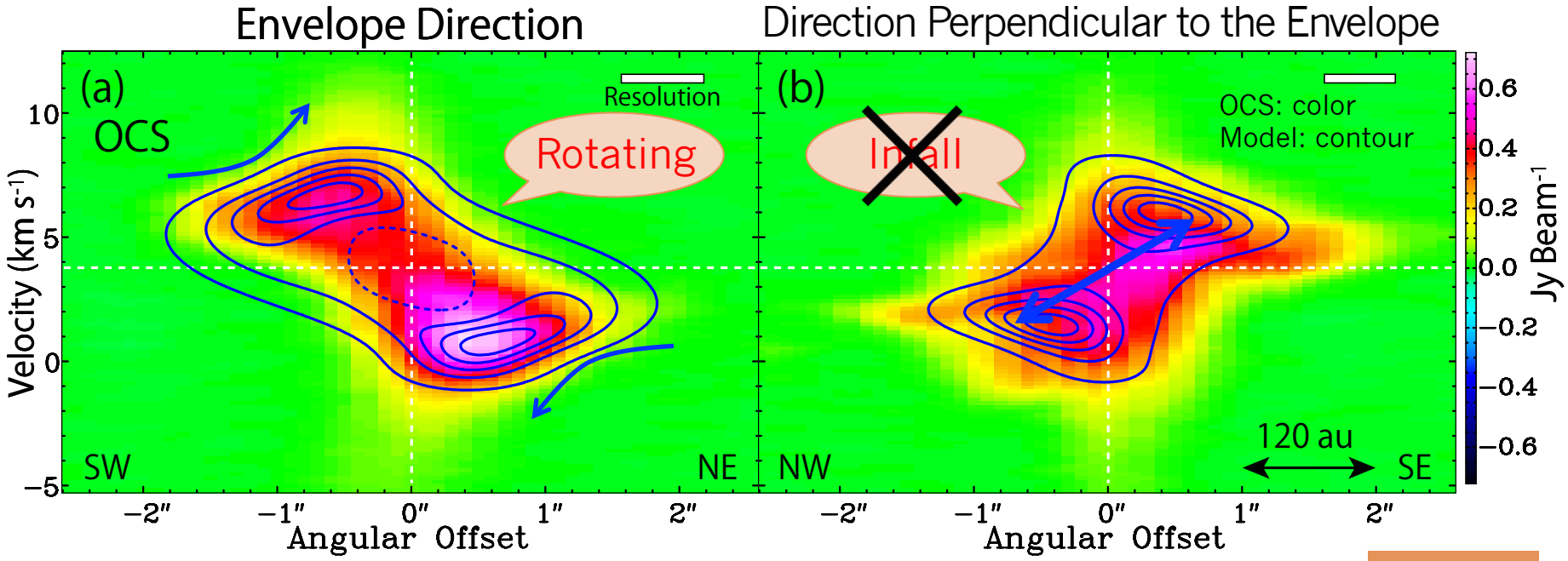
- Well-studied low-mass star forming region (Class 0)
- In Ophiuchus
  - Distance
    - d = 137~147 pc (Ortiz-León et al. 2017)
    - d = 120 pc (Chandler et al. 2005)
- Prototypical hot corino
  - Complex organic molecules (COMs)
- Rotation Motion
  - In Source A
  - e.g. $C^{17}O$, $C^{34}S$ (SMA + eSMA) (Jørgensen+ 2012; Pineda+ 2012; Favre+ 2014)



IRAS 16293−2422: Class 0, Hot Corino

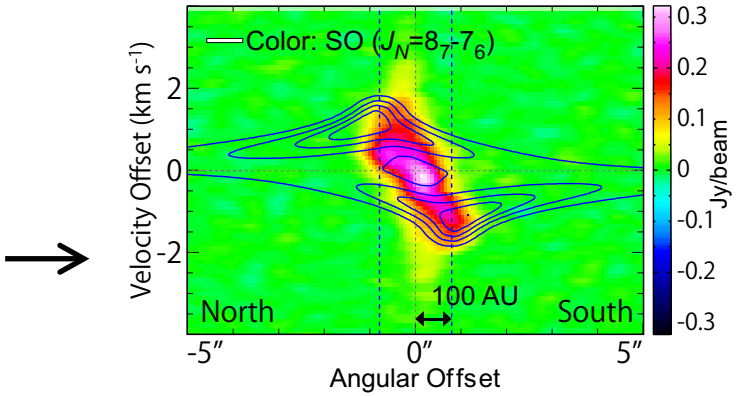
- Envelope traced by OCS
  - Not the Keplerian motion (1.5 $M_\odot$)
  - IRE model
    - $M = 0.75\ M_\odot$, $r_{CB} = 50$ au
    - $i = 60°$, $R_{out} = 180$ au

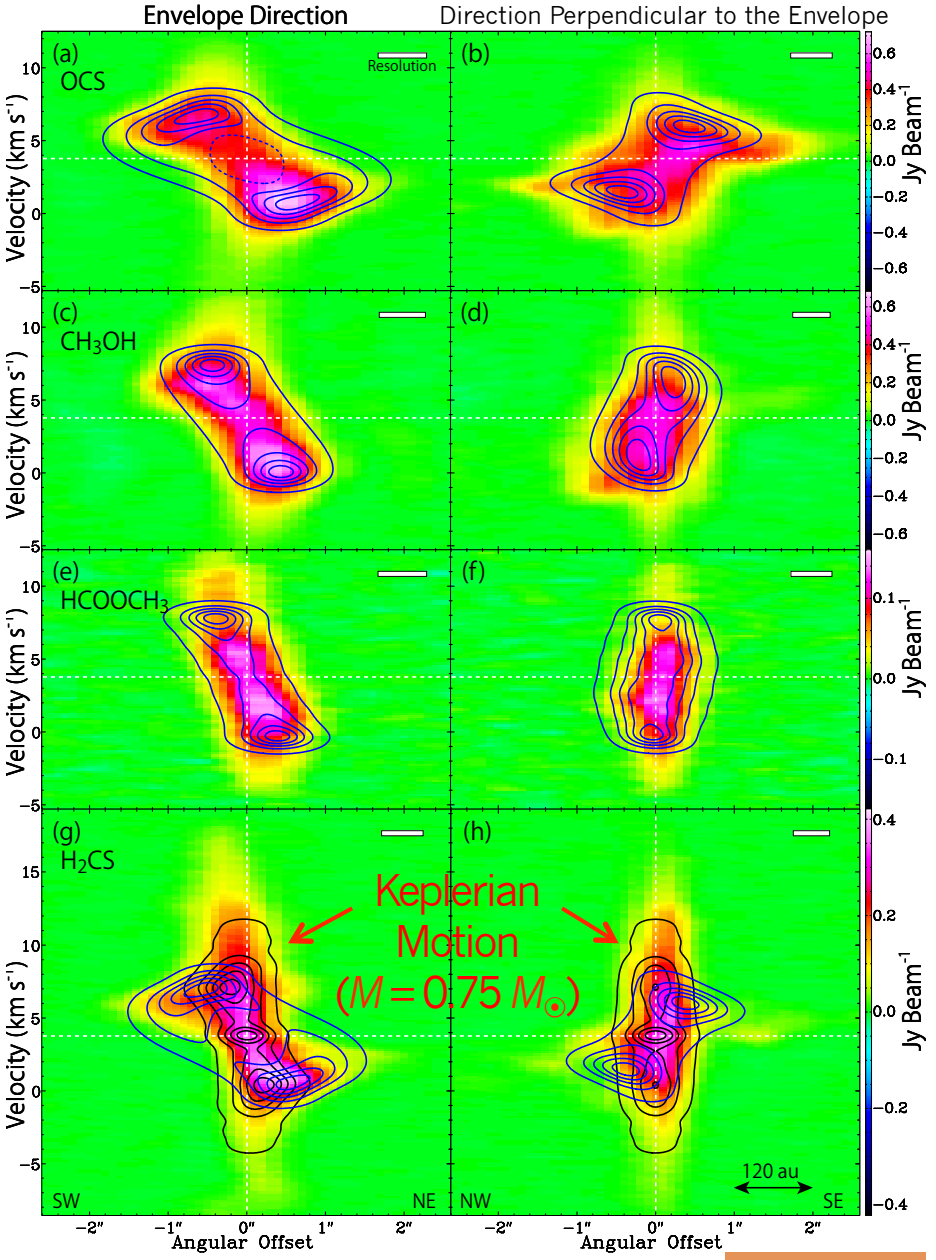




IRAS 16293−2422 A

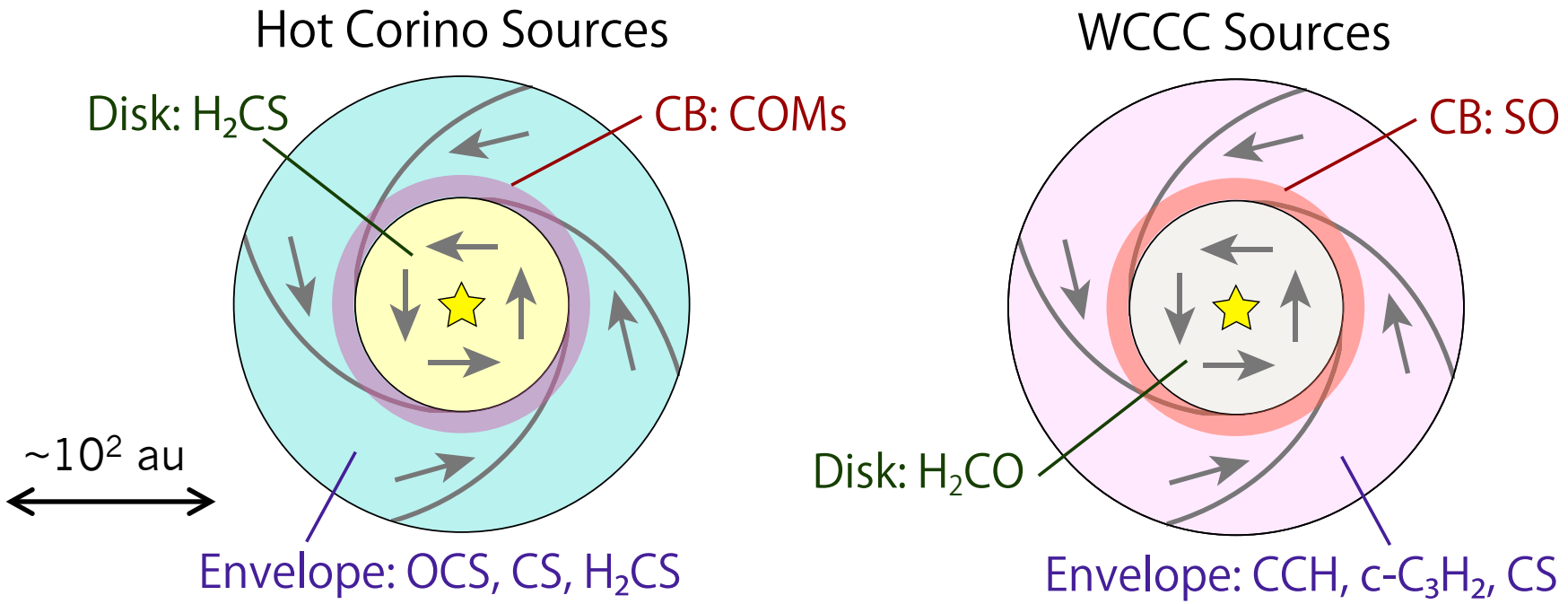
- OCS (19-18)
  - Infalling-rotating envelope (R = 180 au)
- CH_3OH ($11_{0,11}$-$10_{1,10}$; A^{++})
  - Rotating around CB (R = 80 au: compact)
- $HCOOCH_3$ ($19_{9,19}$-$19_{8,11}$; E)
  - Rotating around CB (R = 55 au: compact)
- SO in L1527





Chemical Change at 100 au Scale

- Chemical change at the centrifugal barrier

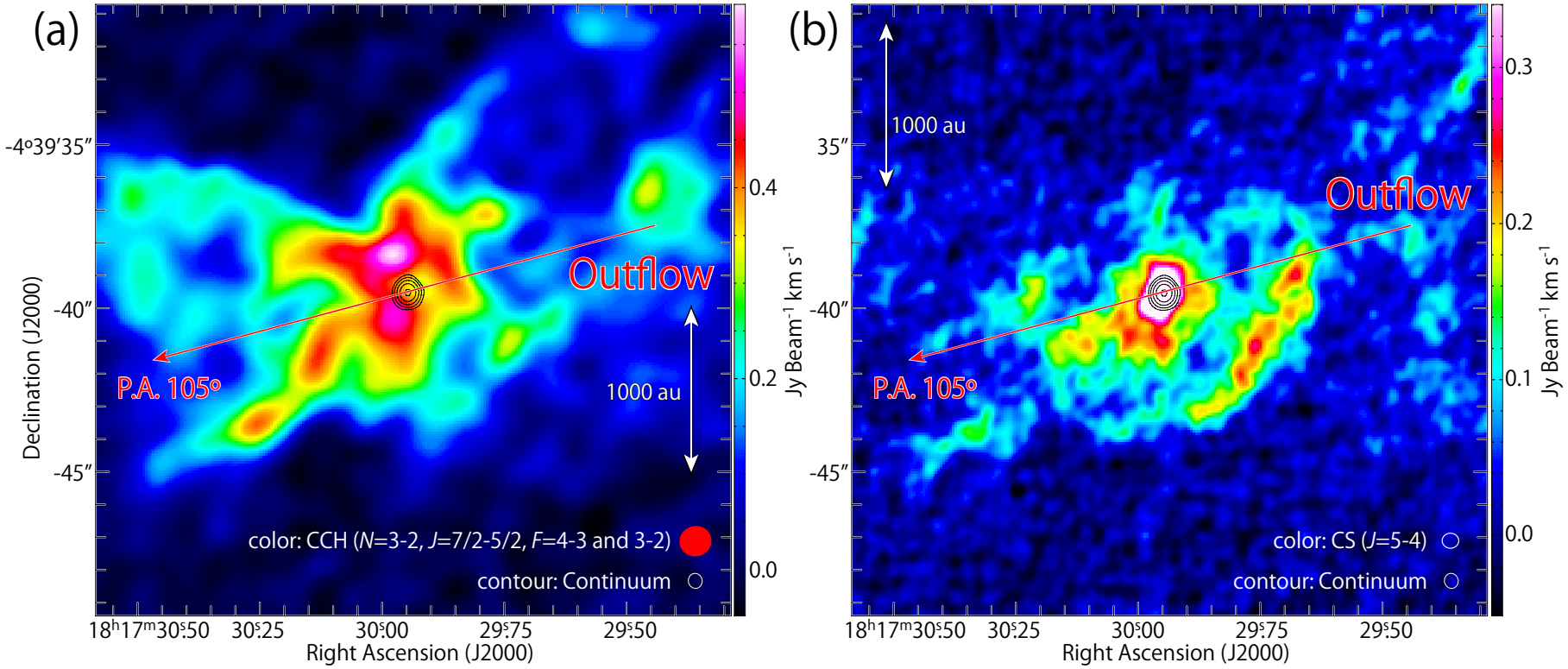


→ Different tracers for each component in HC/WCCC sources

→ *Chemical variation in the disk formation?*

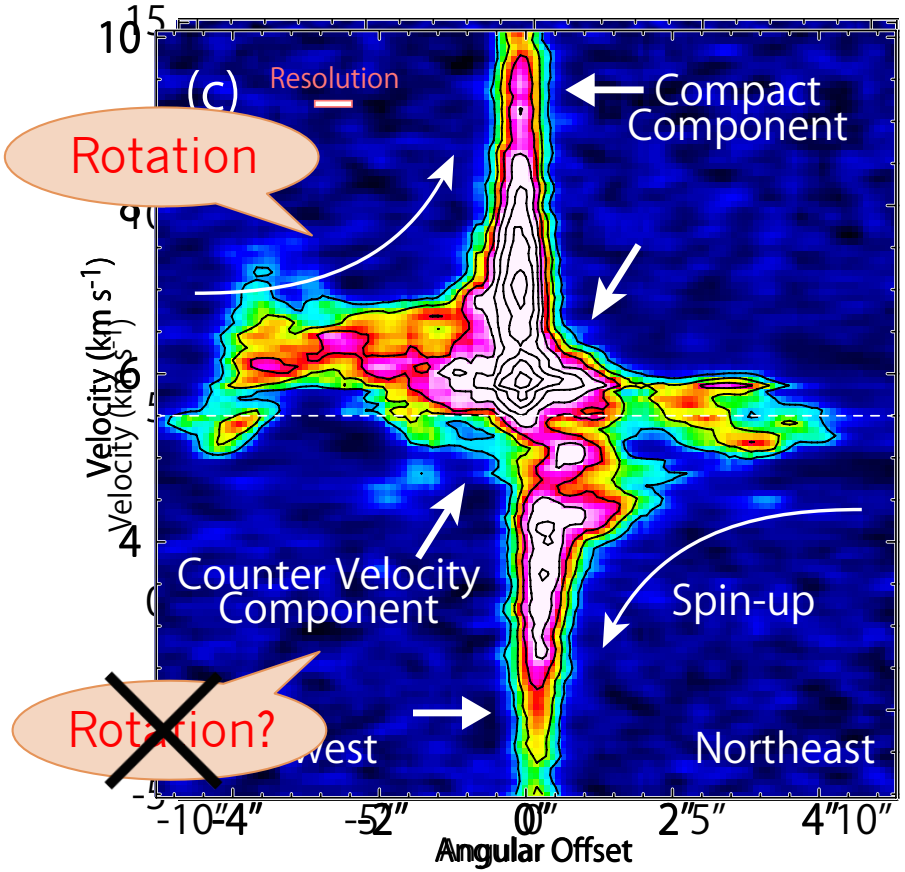
L483: Class 0/WCCC?

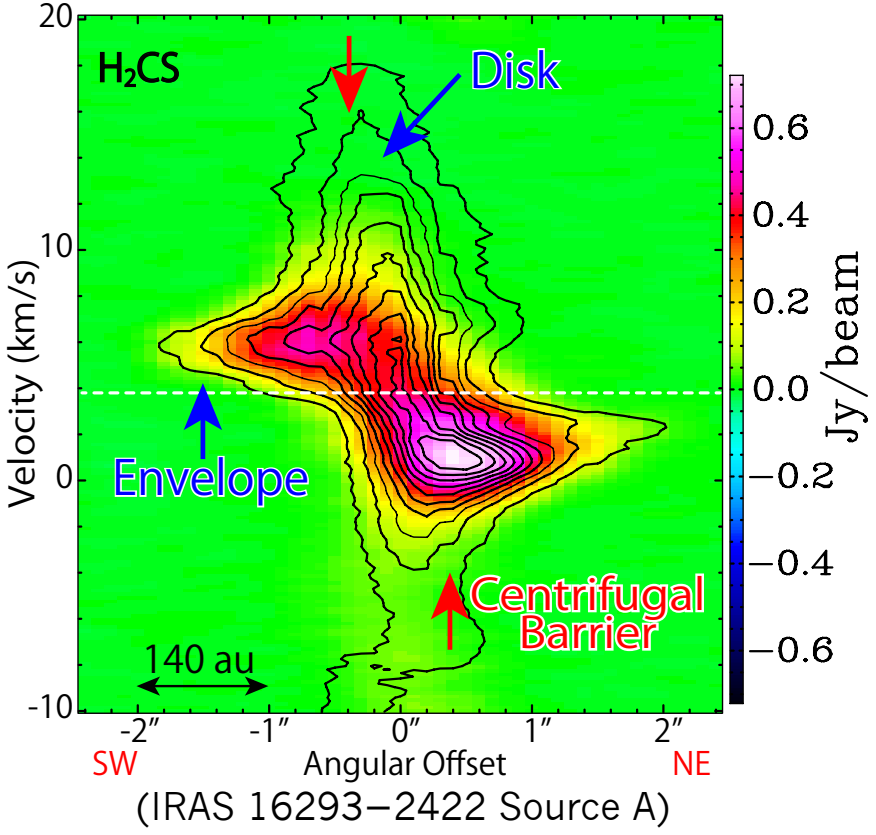
- ALMA Cycle 2 (Band 6; beam~100 au)
  - CCH: Bipolar outflow → WCCC
  - CS : Outflow + Compact component



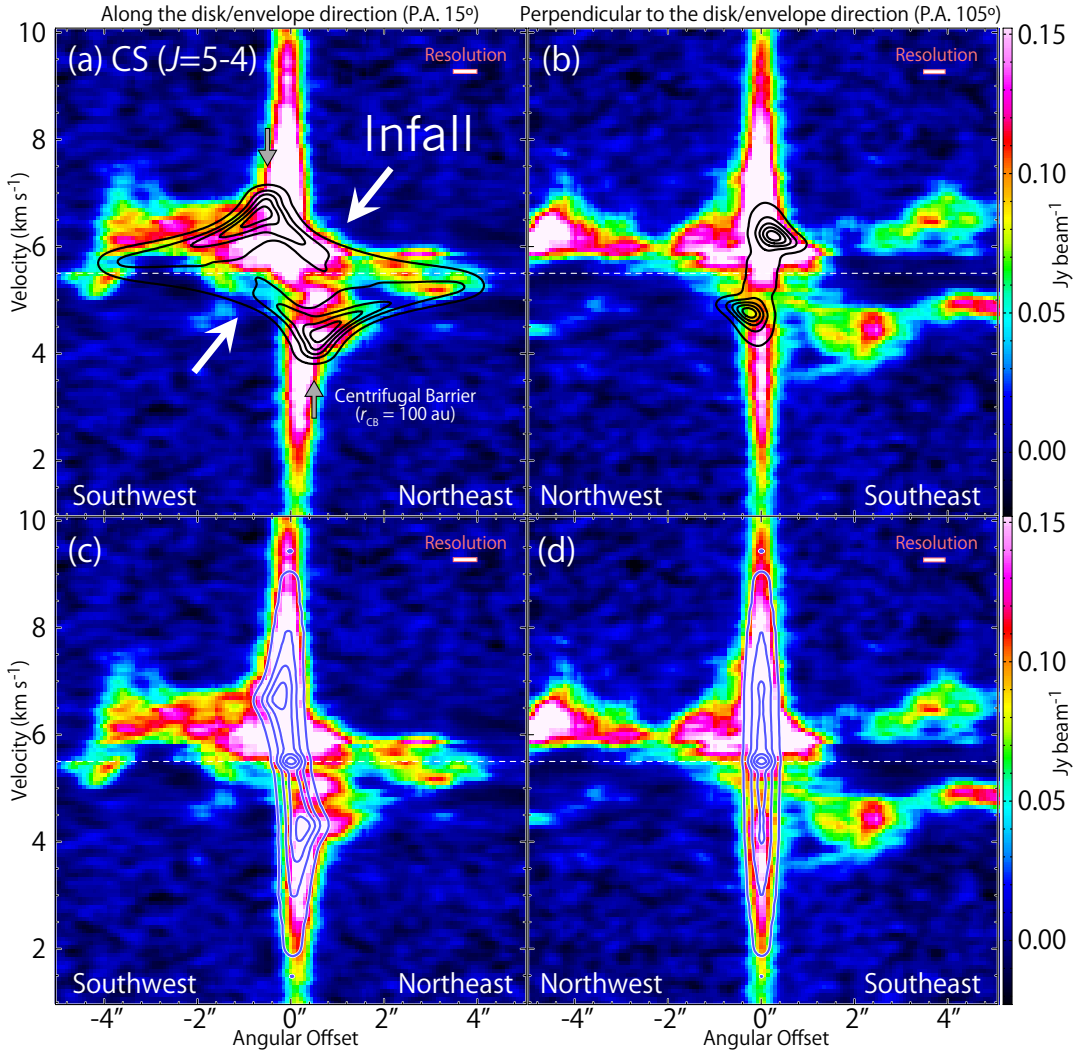
L483: Class 0/WCCC?

- High-velocity, compact (~100 au) ↔ SO
- Spin-up: Rotation (~1000 au) ↔ CCH

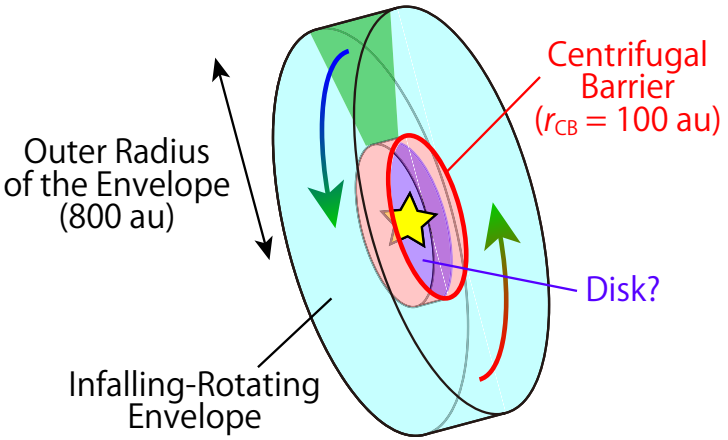




L483: Class 0/WCCC?

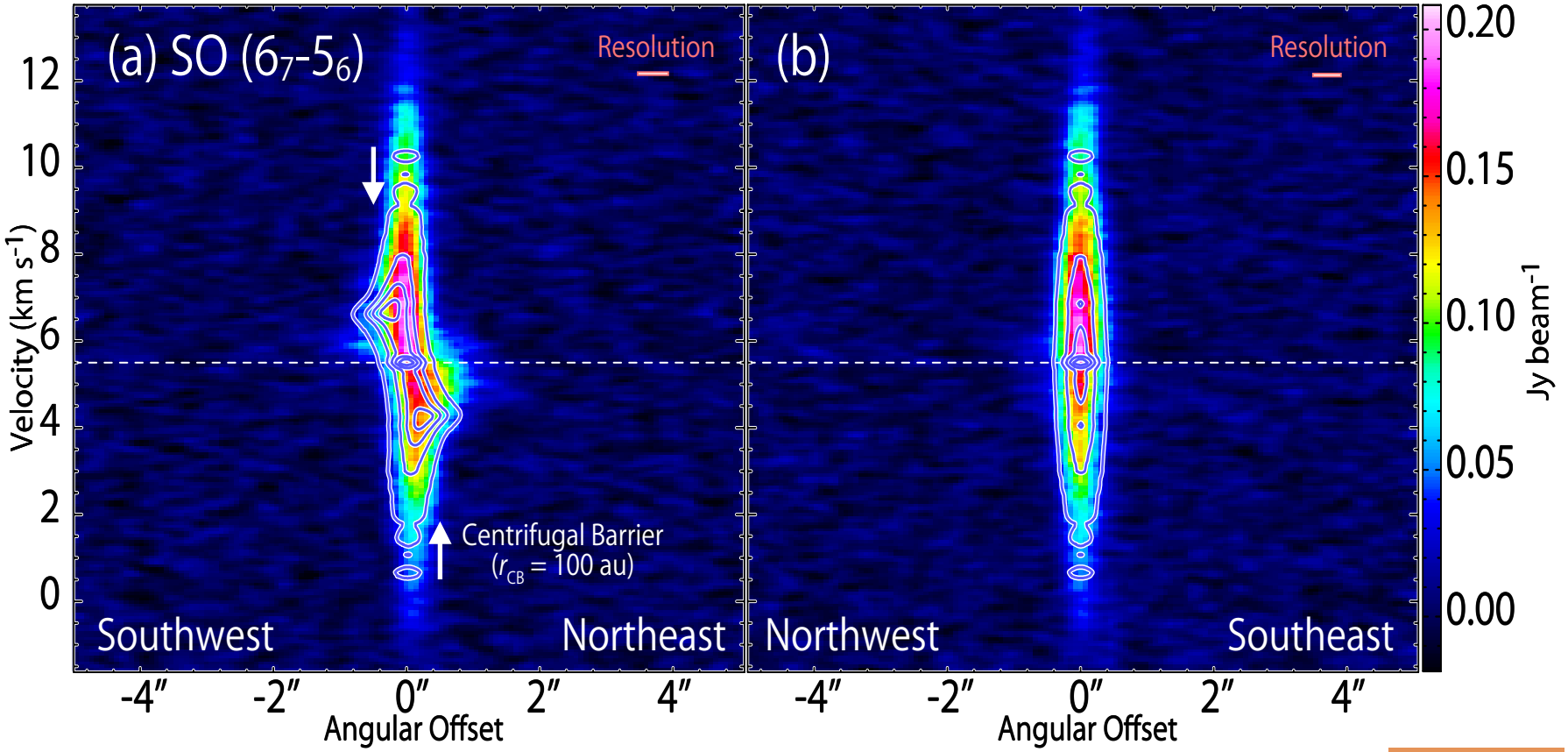


- Parameters:
  - IRE
    - $M = 0.15\ M_{\odot}$
    - $r_{CB} = 100$ au
    - ($i = 80^{o} \leftarrow$ outflows)
  - Keplerian motion
    - Same M and i
      - $V_{shift} = 6$ km/s $\rightarrow r \sim 4$ au



L483: Class 0/WCCC?

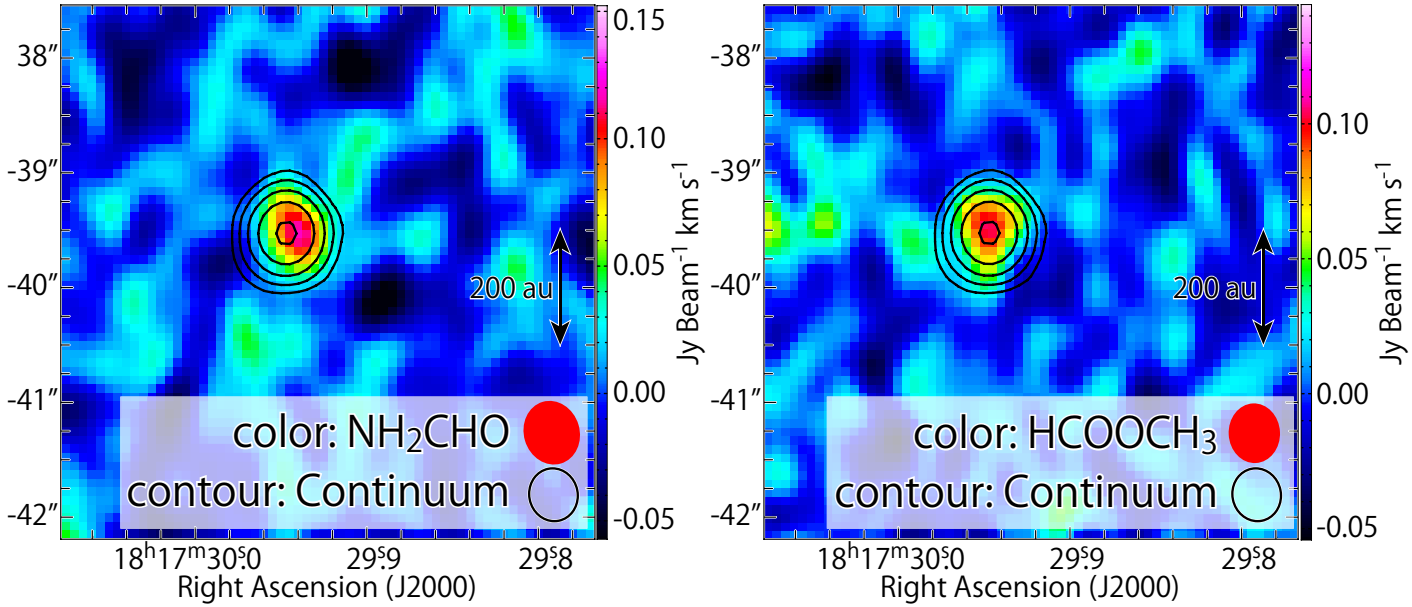
- SO: IRE model → X
  Keplerian model inside the CB?

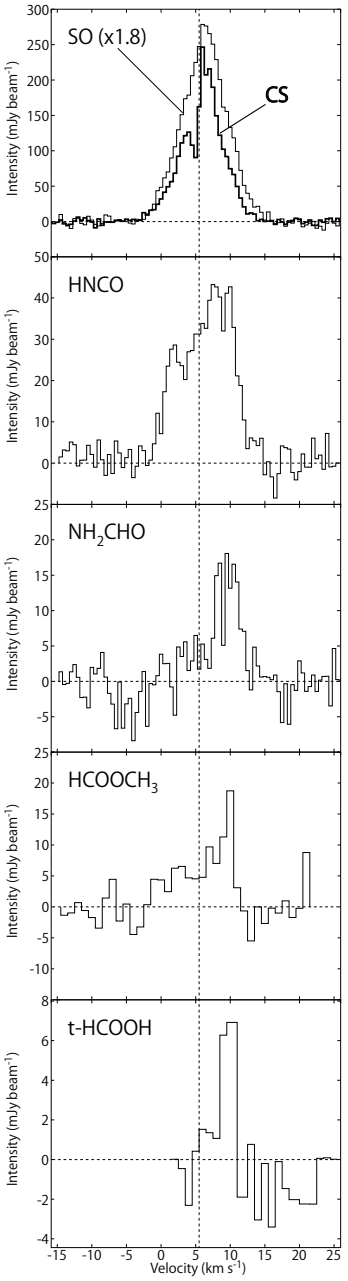


L483: Class 0/WCCC+HC

- Hot corino related species
  - NH_2CHO, $HCOOCH_3$: Marginally detected

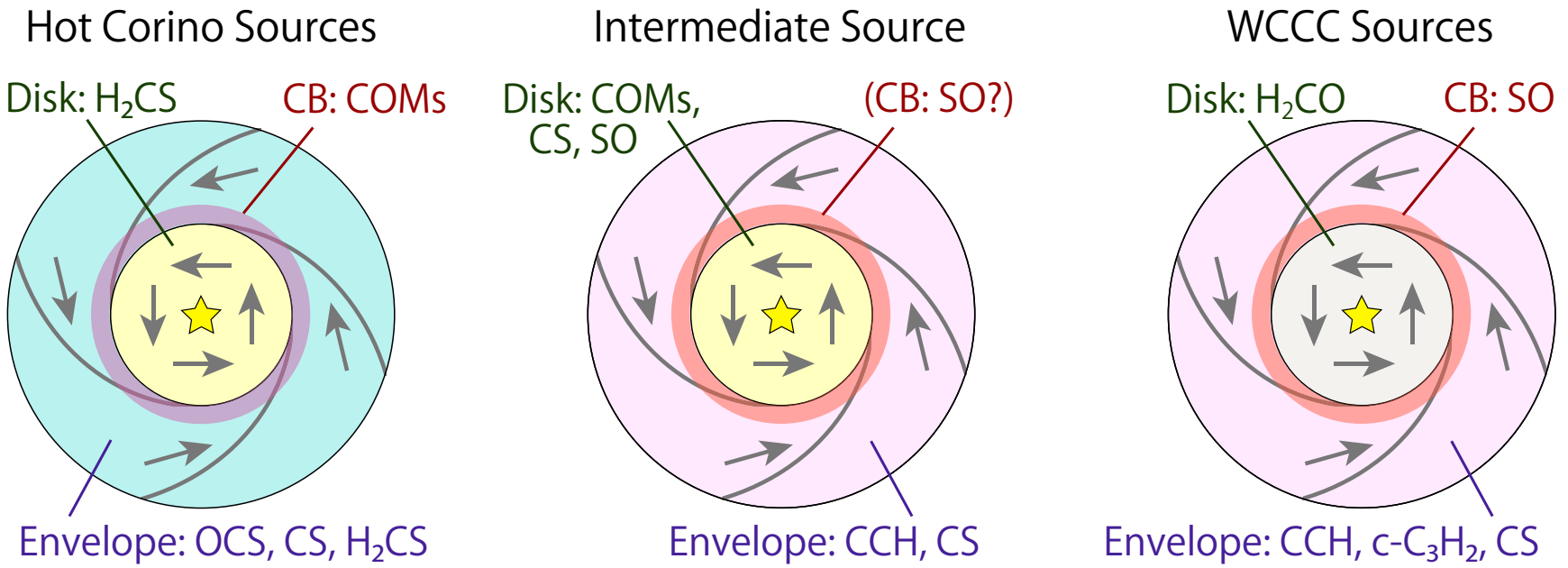
→ *This is the first detection of saturated COMs in the WCCC source.*





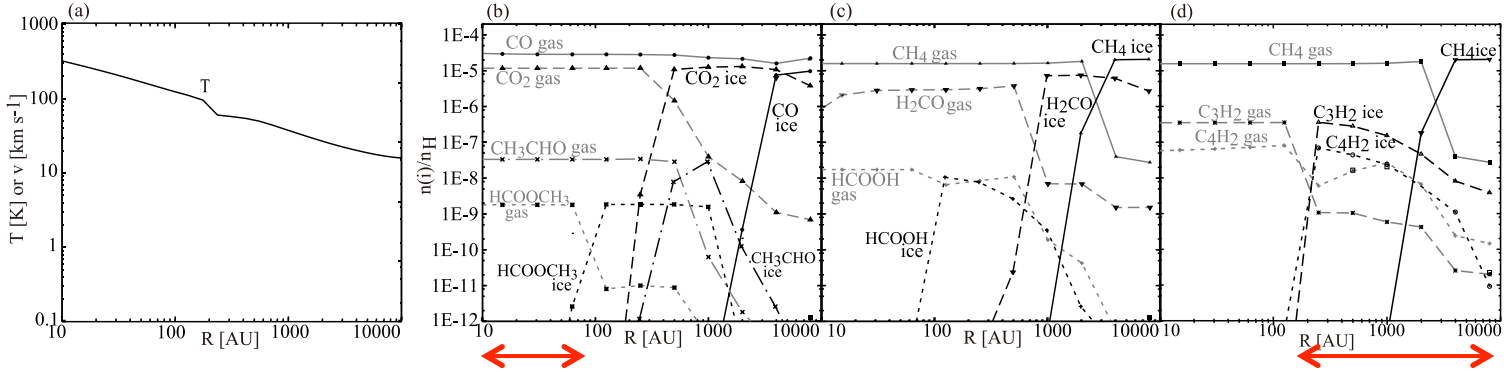
Summary

- Chemical change across the CB is seen in each source.
  - → Chemical heritage from the envelope to the disk.
- Chemical composition depends on sources.
  - Standard case?: Extended WCCC + Compact HC



Origin of the Chemical Change/Diversity

- Chemical model (Aikawa et al. 2008)



  - Hybrid case: L483, B335 (Imai et al. 2016)
- Duration time (e.g. Sakai & Yamamoto 2013)