Survey of CH_2DOH Toward Starless and Prestellar Cores in the Taurus Molecular Cloud

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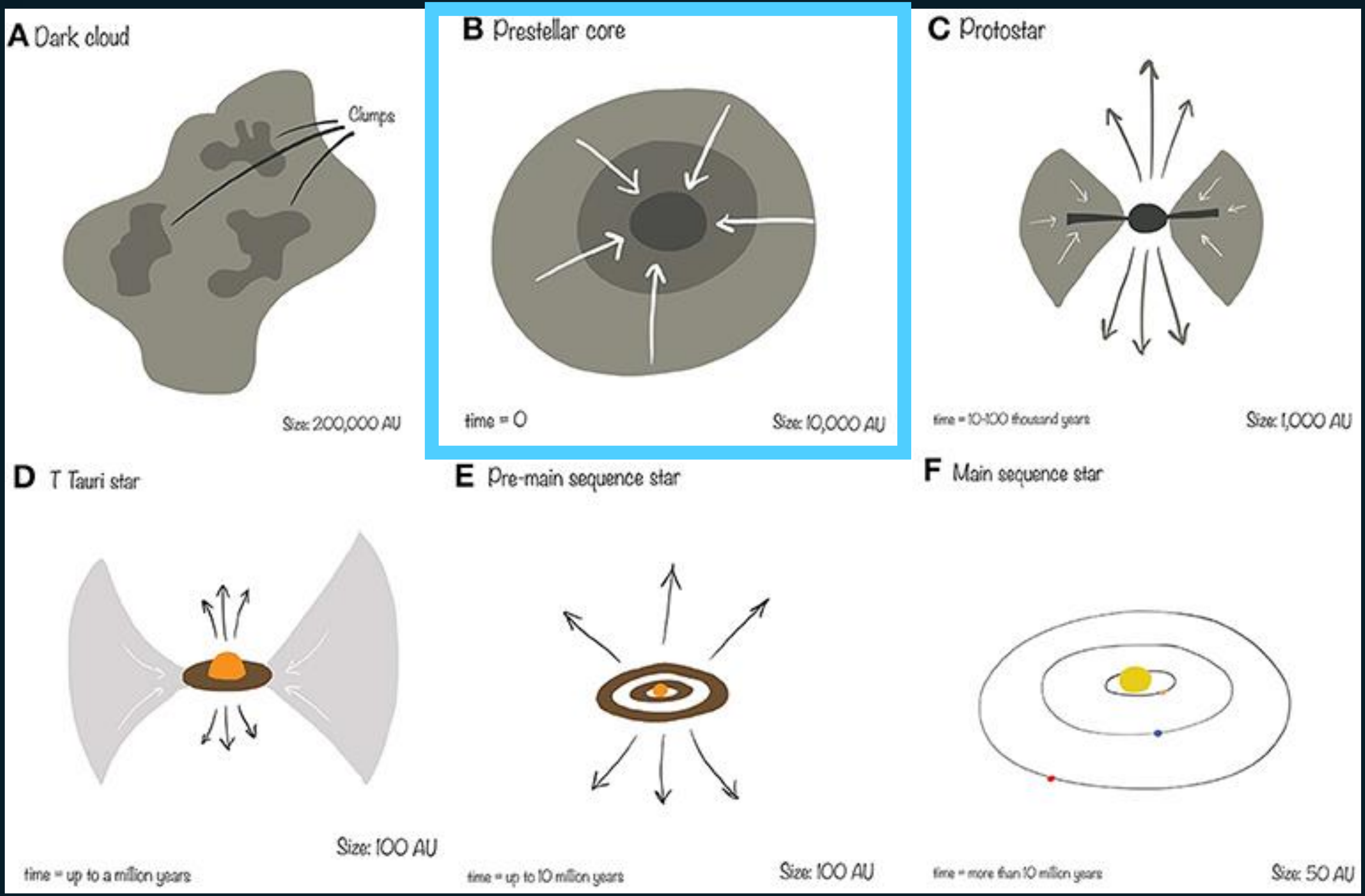
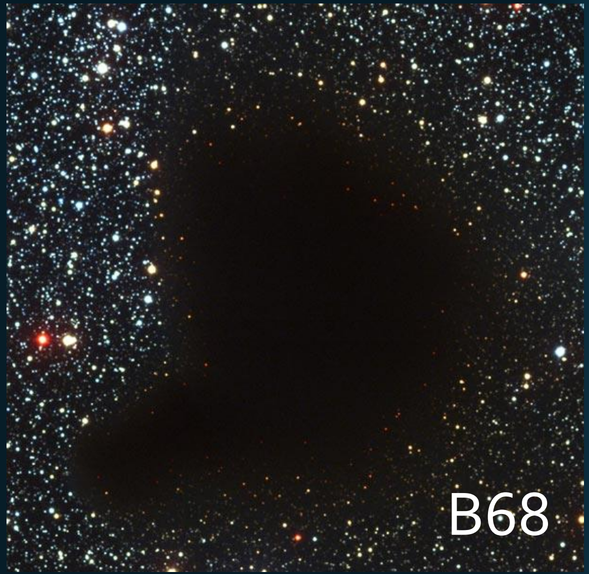
Starless and Prestellar Cores





Credit: FORS Team/8.2-meter VLT Antu/ESO

Starless and Prestellar Cores

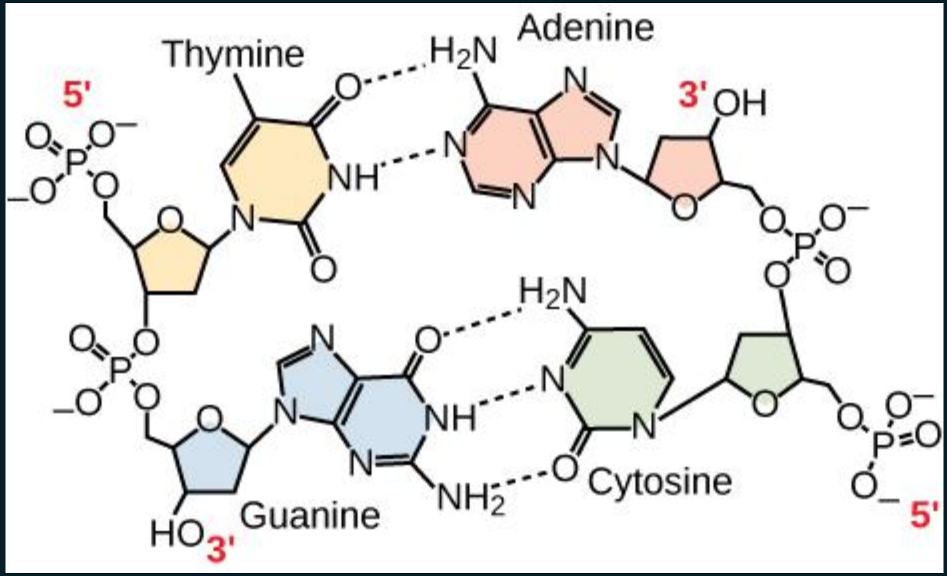
- Starless cores
  - Dense ($n_H > 10^4$ cm^{-3}), cold (T ~ 10 K), no embedded protostars
  - Calm, homogenous
- Prestellar cores
  - gravitationally bound ("virialized")
- Provide initial conditions for star and planet formation

Credit: FORS Team/8.2-meter VLT Antu/ESO

Complex Organic Molecules

- COMs
  - More than 5 atoms with C, N, or O
  - Building blocks of life

- Open questions in astrochemistry
  - Formation processes
  - Test formation models

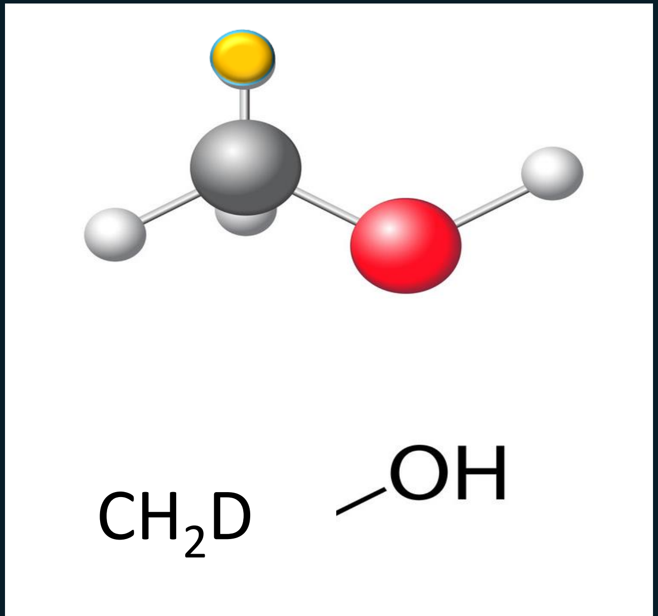


Complex Organic Molecules

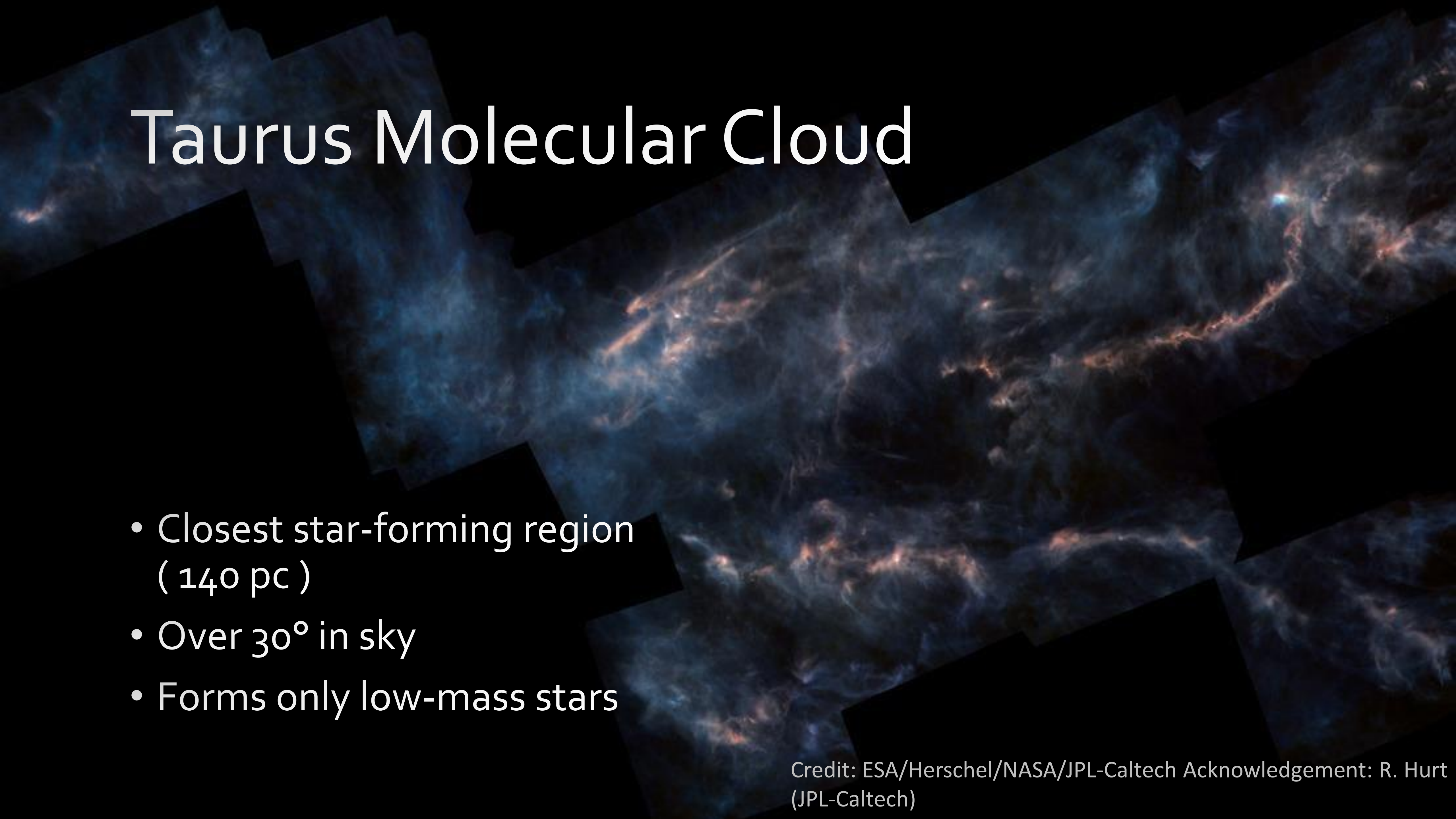
- Prevalent COMs in prestellar cores
  - CH_3OH in 100% of 31 cores
  - CH_3CHO in 68% of 31 cores (Scibelli & Shirley 2020, ApJ)
  - COMs form > 10^5 yr prior to protostar formation
- What about deuterated forms?
  - Not well-studied in prestellar phase

CH_2DOH

- What we know
  - Expect to find in cores with high CH_3OH
  - Only observed in 2 cores to date
  - Know CH_2DOH cannot form in gas phase
  - Thought to form in CO-rich ice on grains
- What we don't know
  - How it desorbs in T ~ 10 K
- Provides a probe of grain ice chemistry
- Undertook first systematic search for CH_2DOH in prestellar objects



Taurus Molecular Cloud



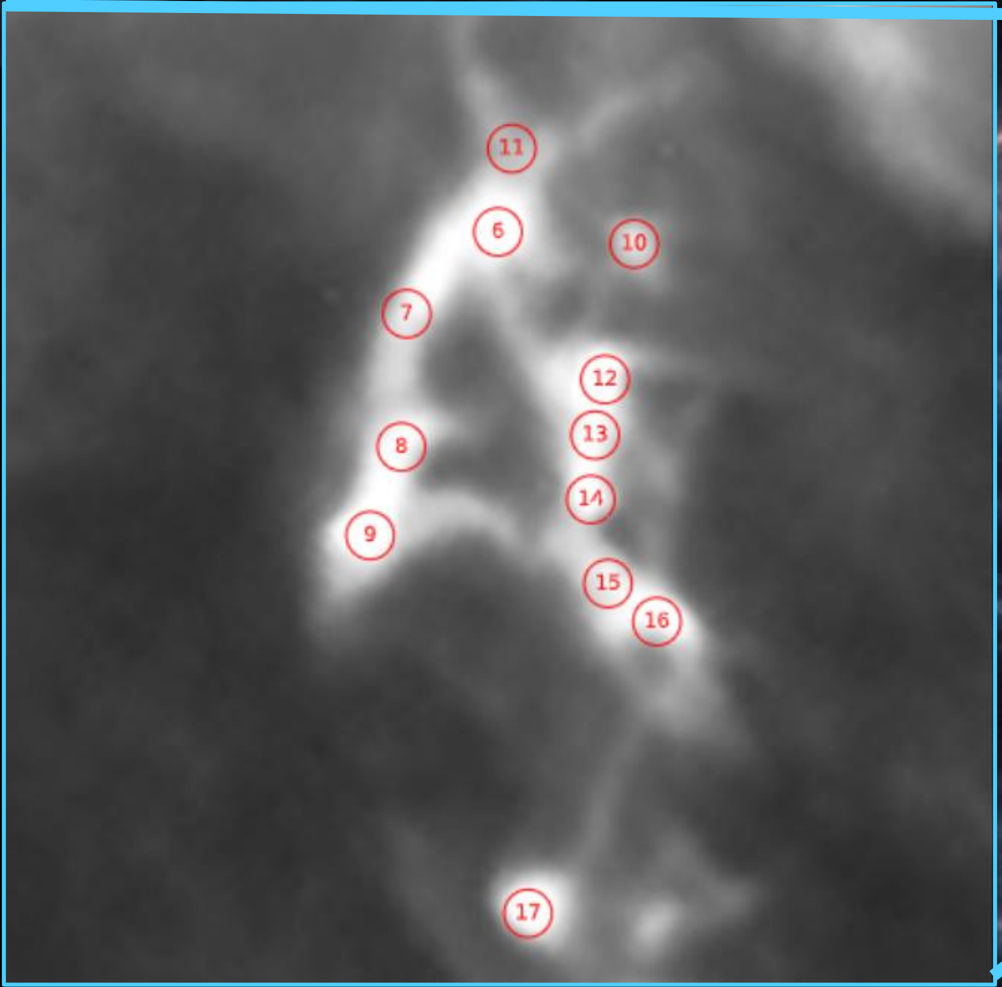
- Closest star-forming region (140 pc)
- Over 30° in sky
- Forms only low-mass stars

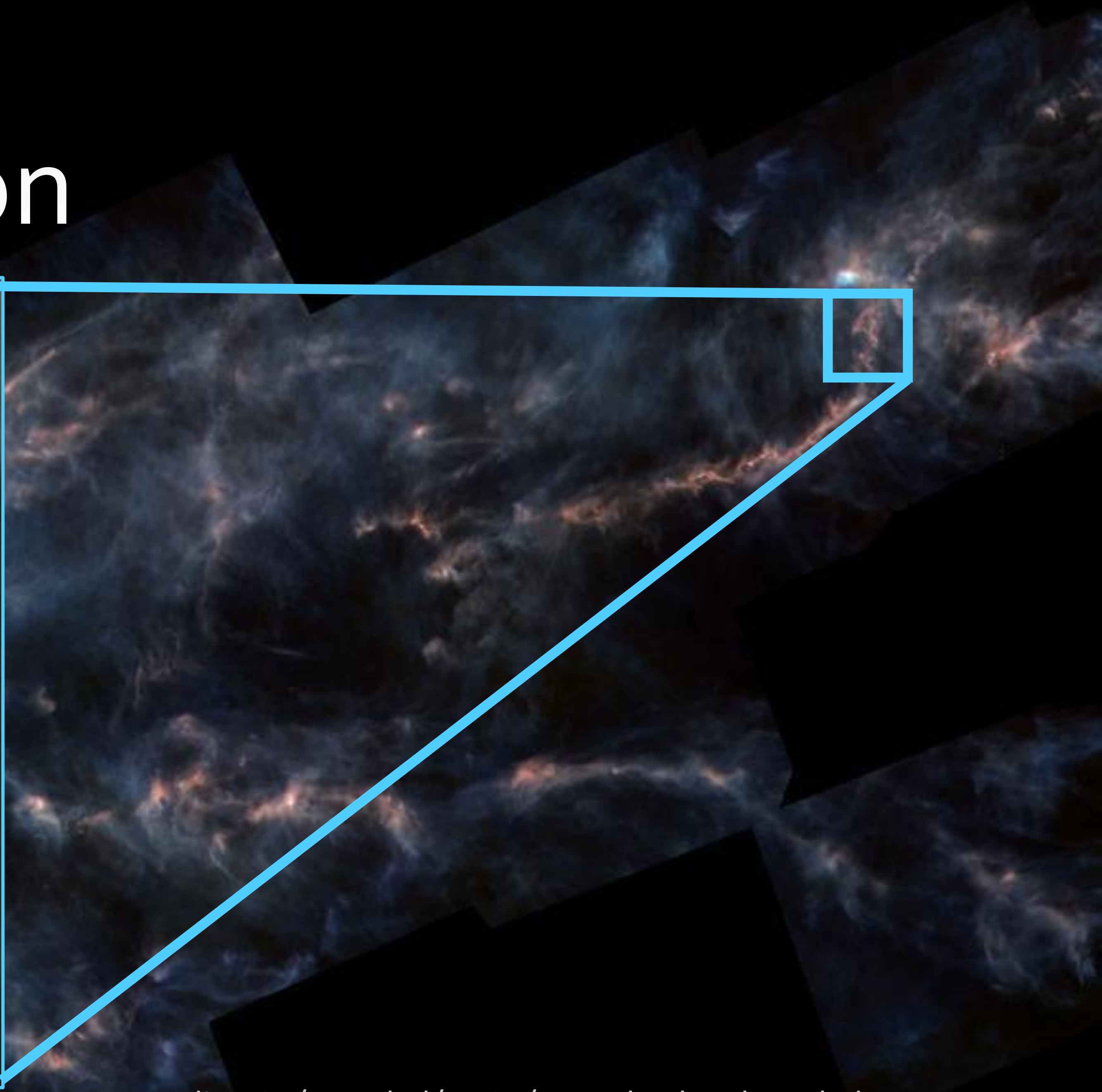
Credit: ESA/Herschel/NASA/JPL-Caltech Acknowledgement: R. Hurt (JPL-Caltech)

Barnard 10 Region

Credit: ESA/Herschel/NASA/JPL-Caltech Acknowledgement: R. Hurt (JPL-Caltech)

Barnard 10 Region

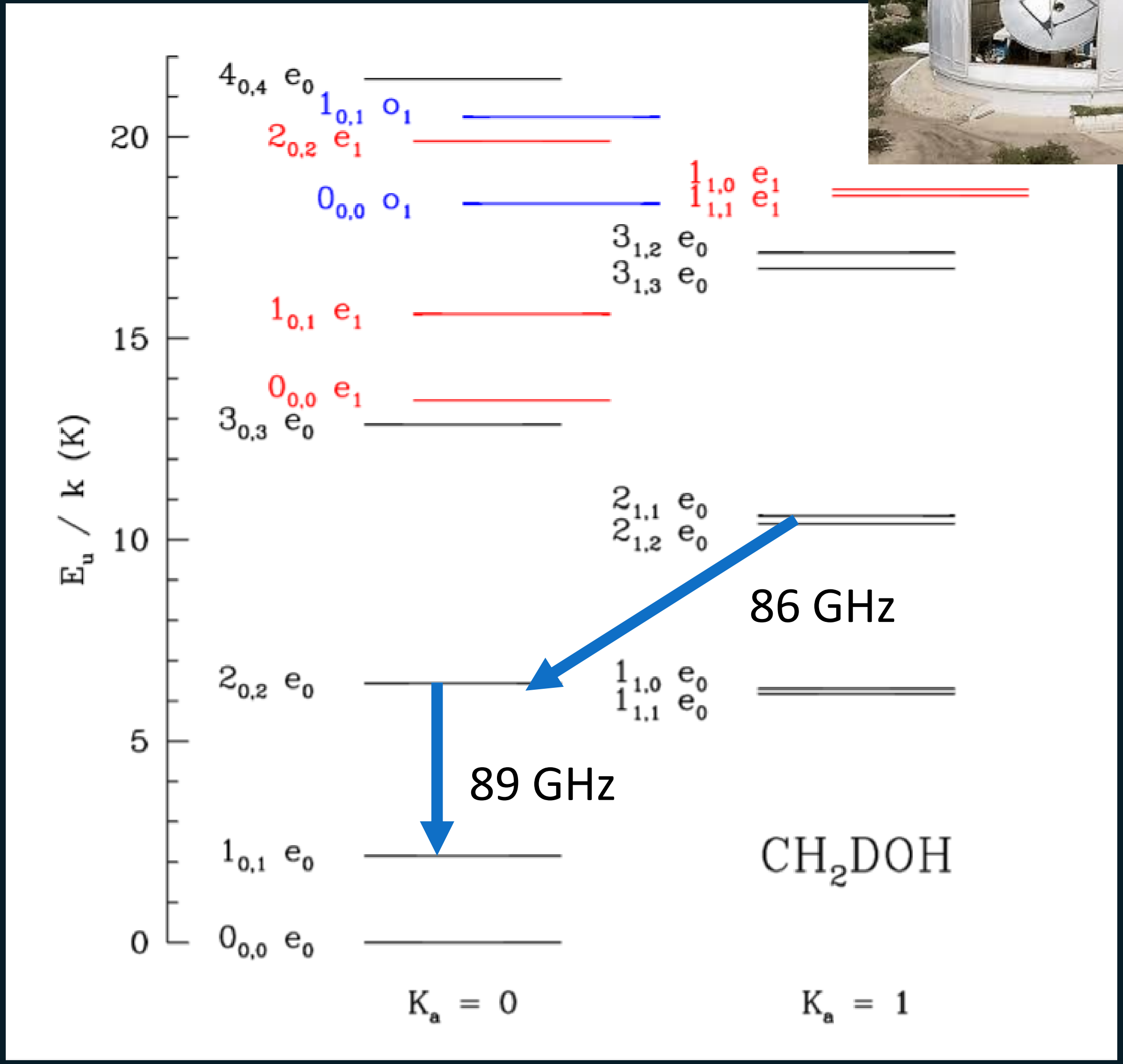




Credit: ESA/Herschel/NASA/JPL-Caltech Acknowledgement: R. Hurt (JPL-Caltech)

Observations

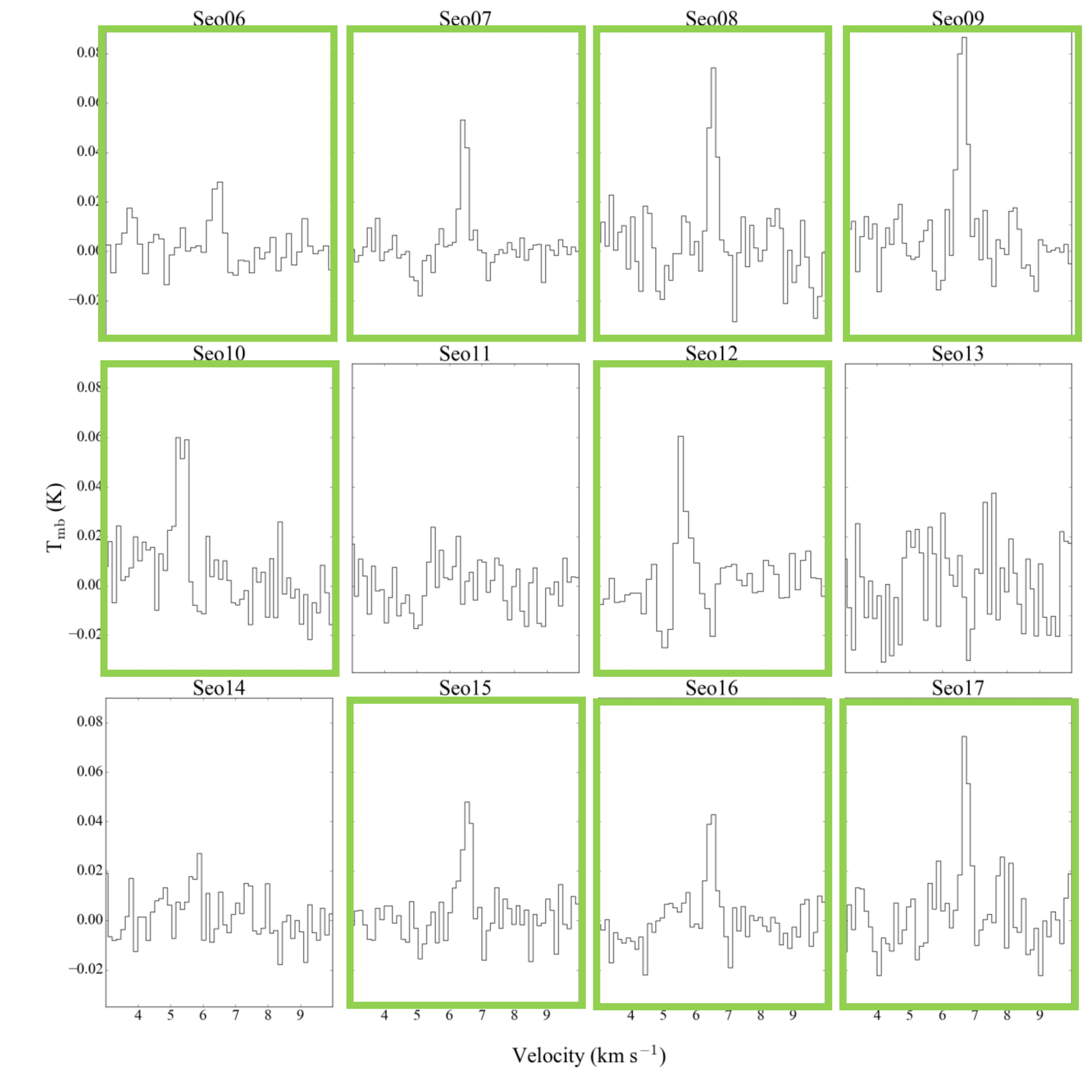
- ARO 12m Radio Telescope on Kitt Peak
  - June-Dec 2018
  - 8hr shift per source, 5-minute samples
- Sources
  - Seo06-17
    - $J_{Ka,Kc} = 2_{0,2}$ e0 – $1_{0,1}$ e0 (a-type) transition, 89 GHz
  - Seo09, 12, 17
    - $J_{Ka,Kc} = 2_{1,1}$ e0 – $2_{0,2}$ e0 (b-type) transition, 86 GHz.



Ambrose et al. 2020 (subm)

Detections

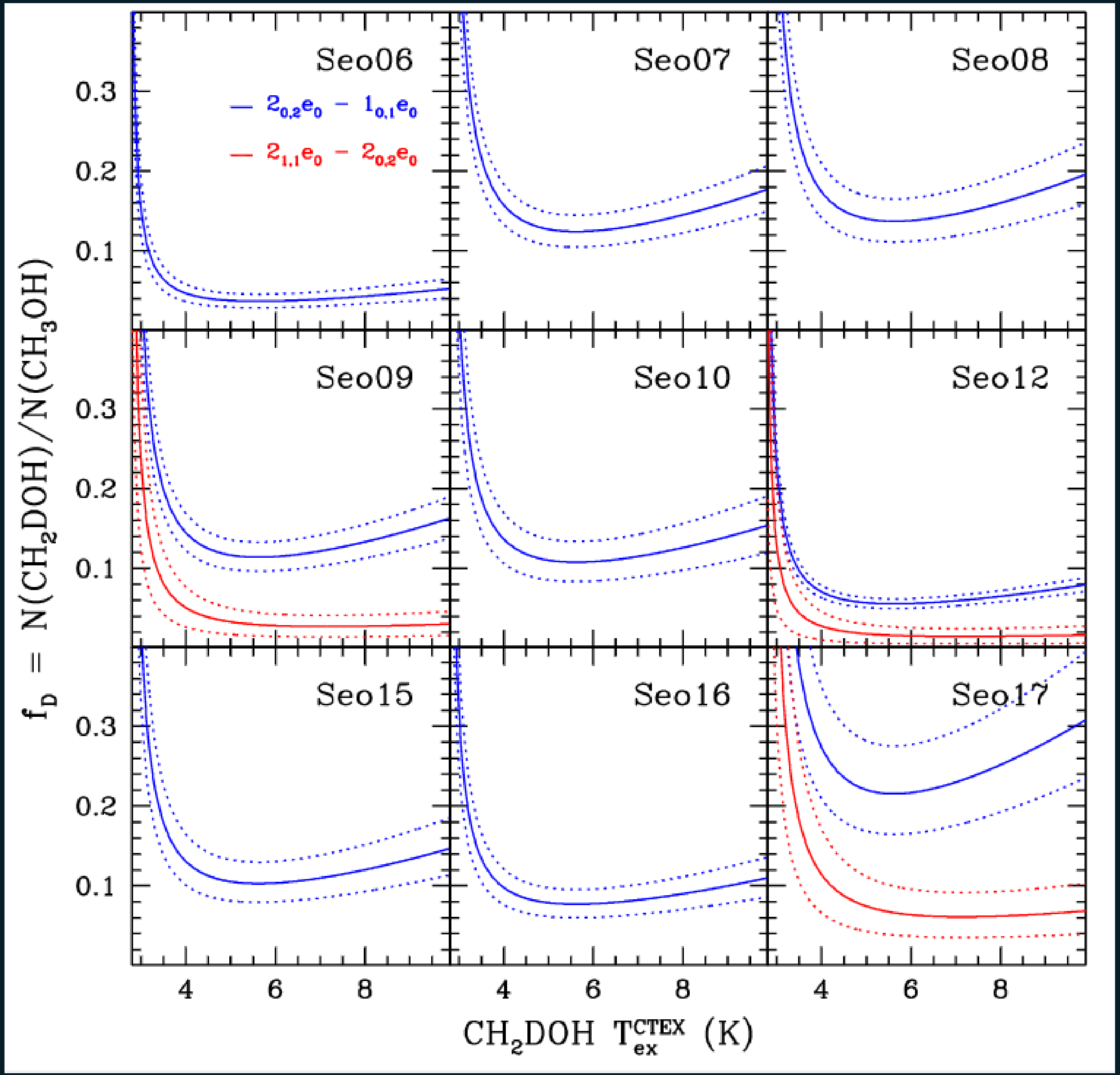
- CH_2DOH in 9 of 12 cores
  - $> 3\sigma_{Tmb}$ for detections
  - $< 3\sigma_{I}$ for non-detections
- Fit with gaussian line profiles
  - Integrated intensity
  - Velocity
  - FWHM linewidth



Ambrose et al. 2020 (subm)

Fractionation

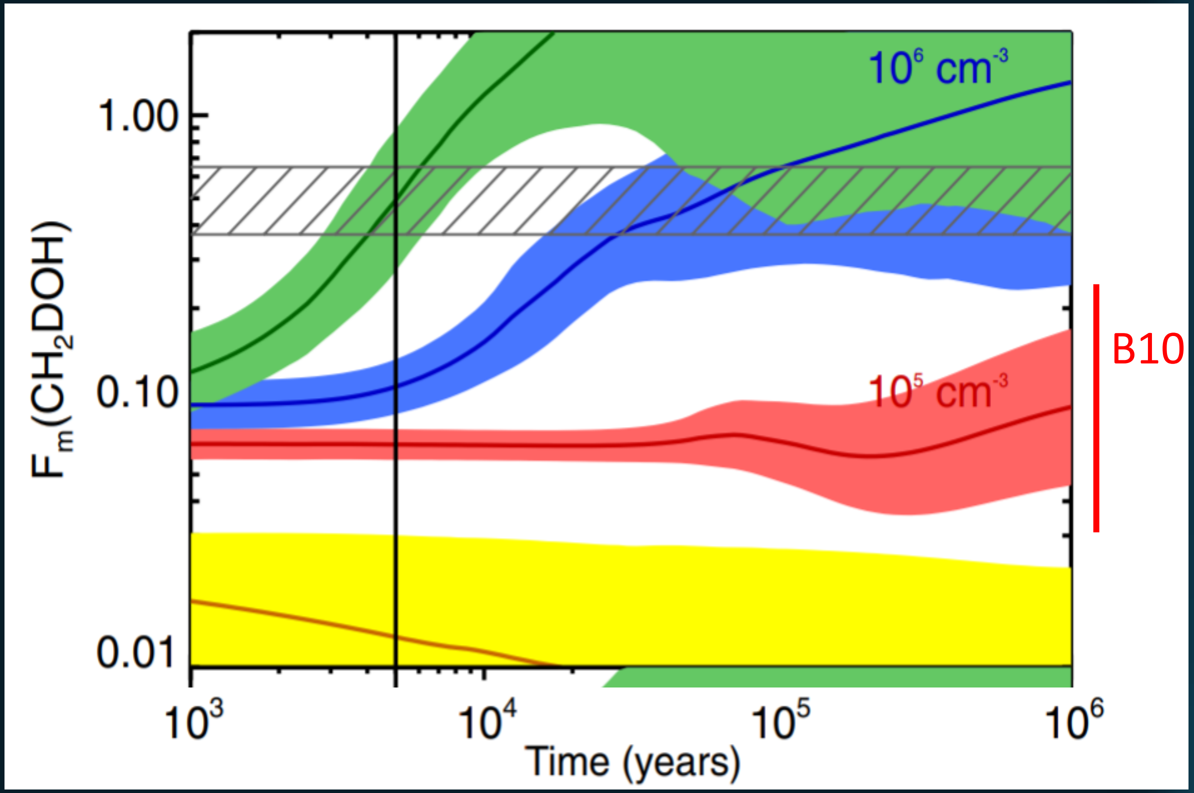
- Determining f_D
  - $f_D = [CH_2DOH]/[CH_3OH]$
  - Ratio of column densities
  - Assumes optically thin emission
  - Requires T_{ex}, unknown
    - Assume $T_{ex} = 4 - 8$ K
- Find $f_D <$ $0.04 - 0.23^{+0.12}_{-0.06}$



Ambrose et al. 2020 (subm)

Comparison with Models

- Taquet et al. 2012 model
  - Time-dependent gas-grain model
  - Grain treated as reactive layer over mantle bulk
  - Follows cores of different densities
- Model results
  - Found f_D = 0.05 – 0.16 by t = 10^6 yr
  - Agrees with observed f_D values
  - Suggests significant portion of CH_2DOH desorbs

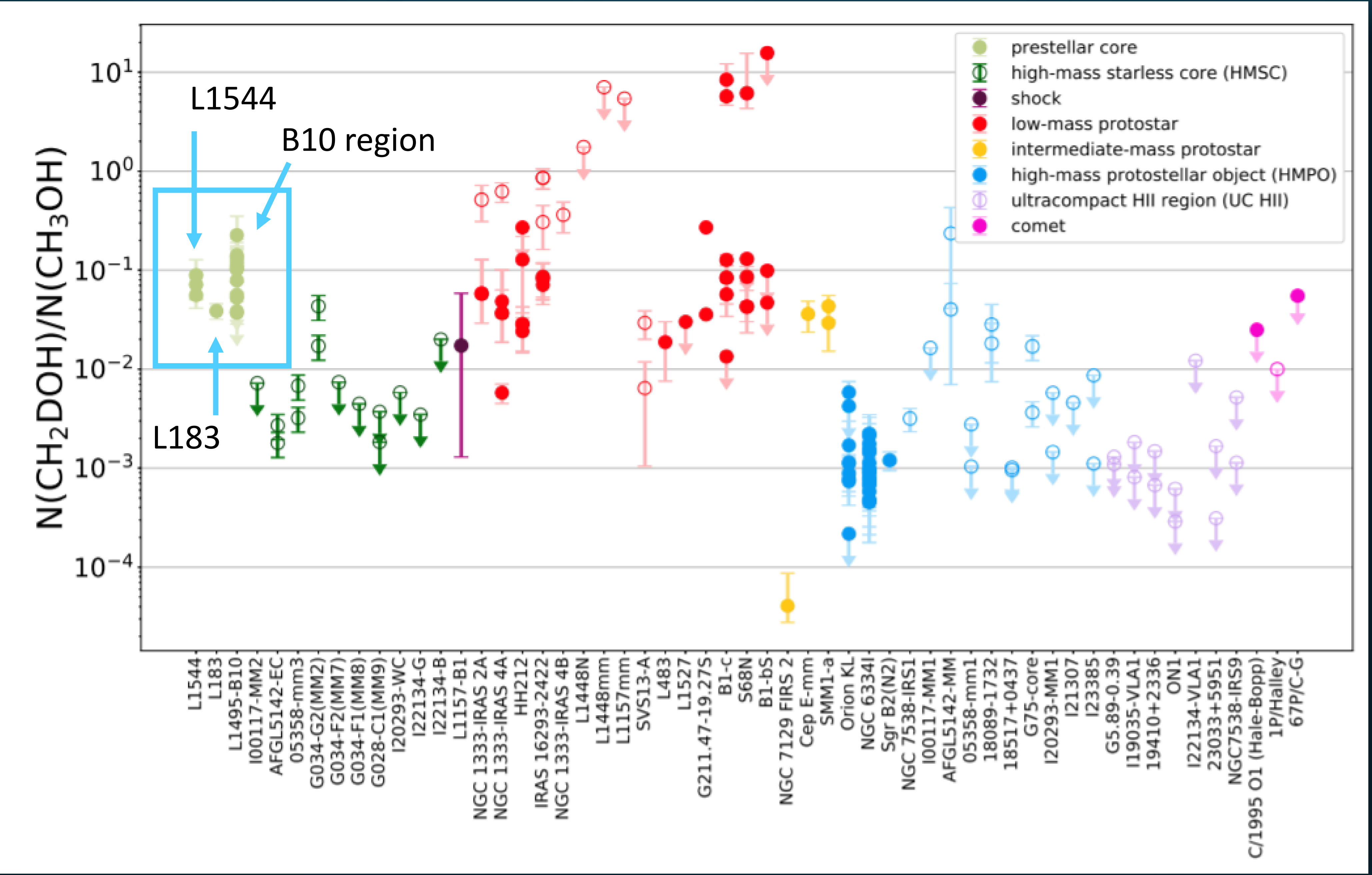


Taquet et al. 2012

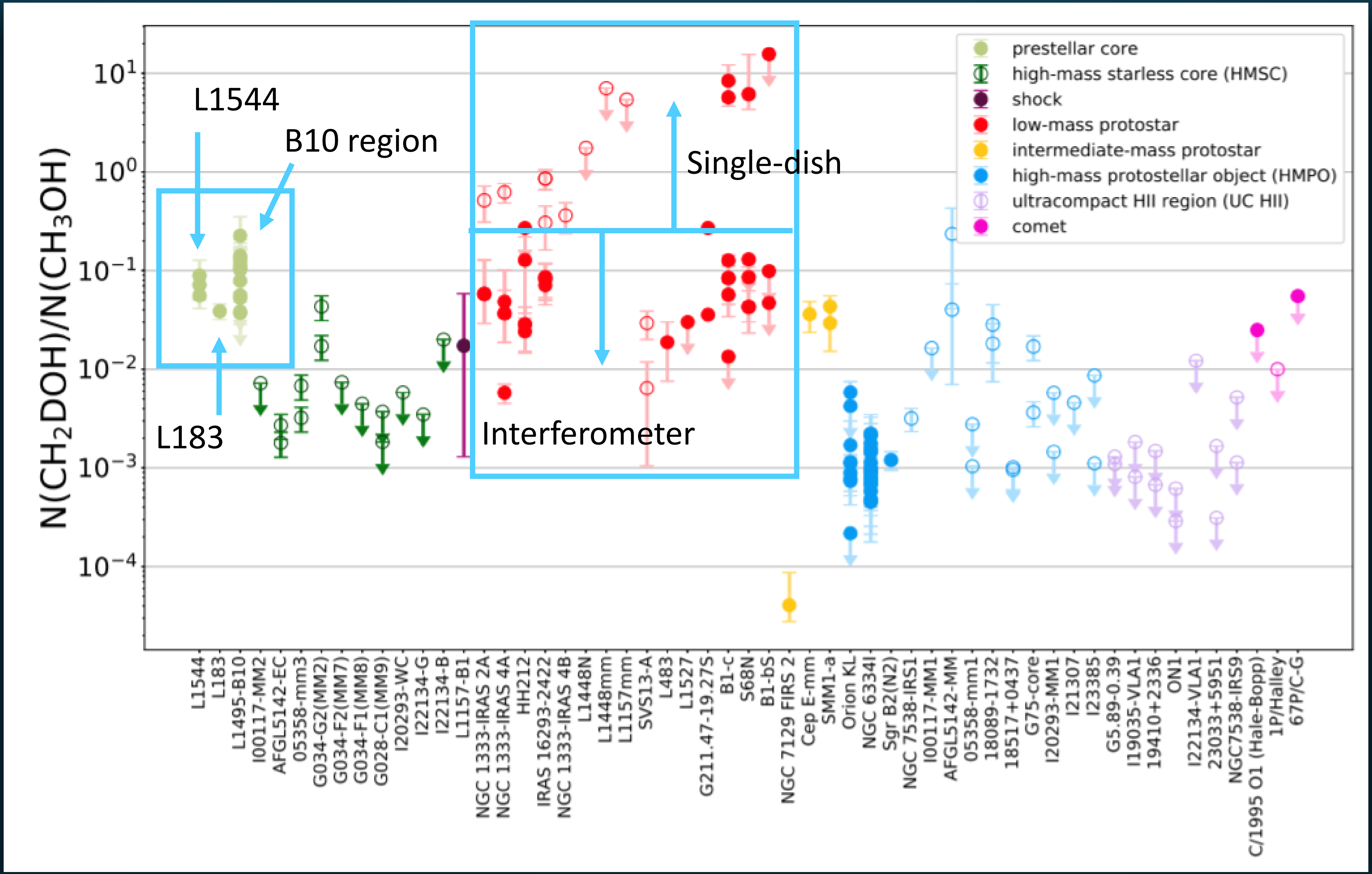
Comparison with Observations

- Prestellar Cores
  - L1544 : 0.08 ± 0.02 (Chacón-Tanarro et al. 2019)
  - L183 : ~ 0.04 (Lattanzi et al. 2020)

- Protostars
  - Fraction should initially increase in envelope as ice sublimates
    - Single-dish observations show higher fractions: ~0.30-0.60 (Parise et al. 2002, 2004, 2006)
  - Fraction should ultimately decrease toward center with evolution
    - Interferometric observations show lower fractions



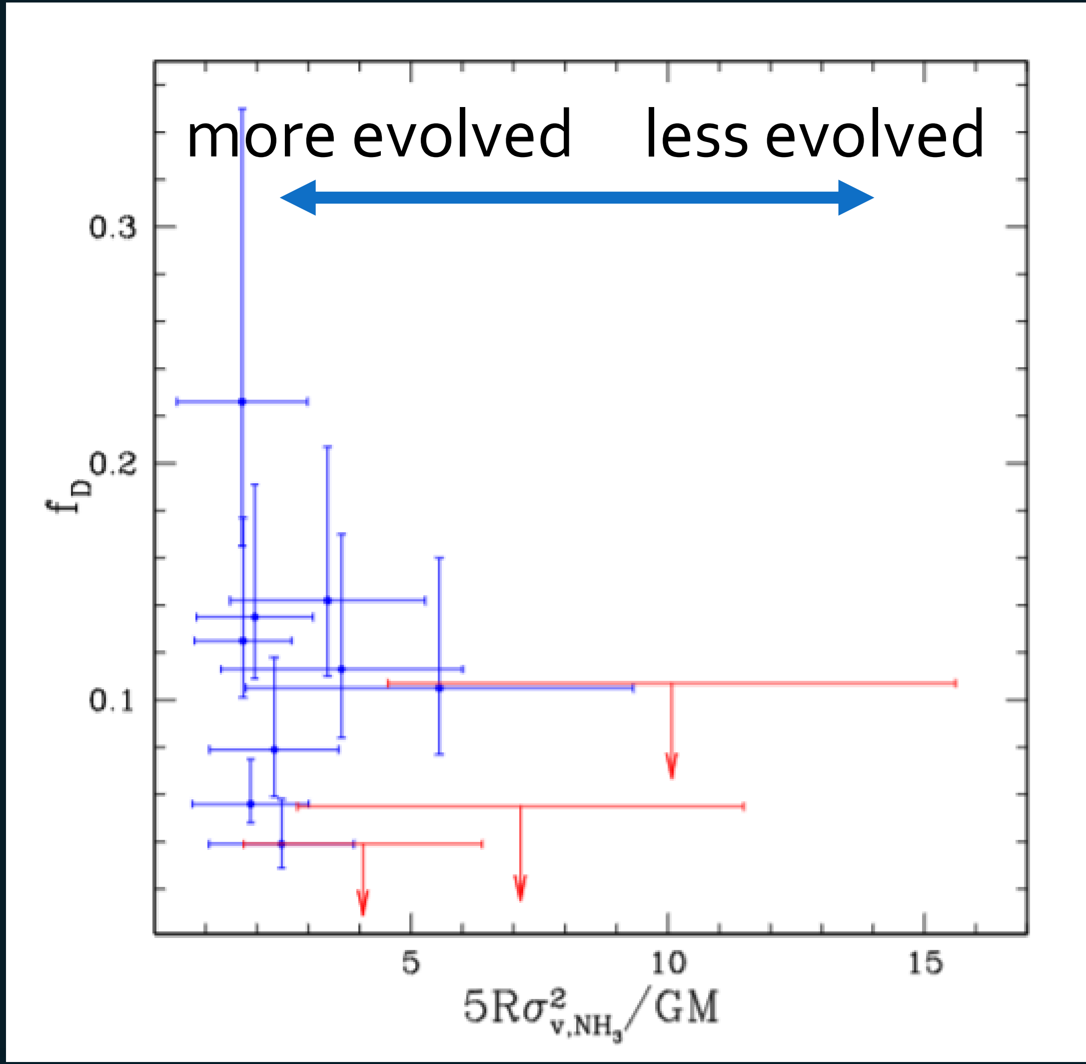
Drozdovskaya et al. 2020 (accepted)



Drozdovskaya et al. 2020 (accepted)

Evolutionary Comparisons

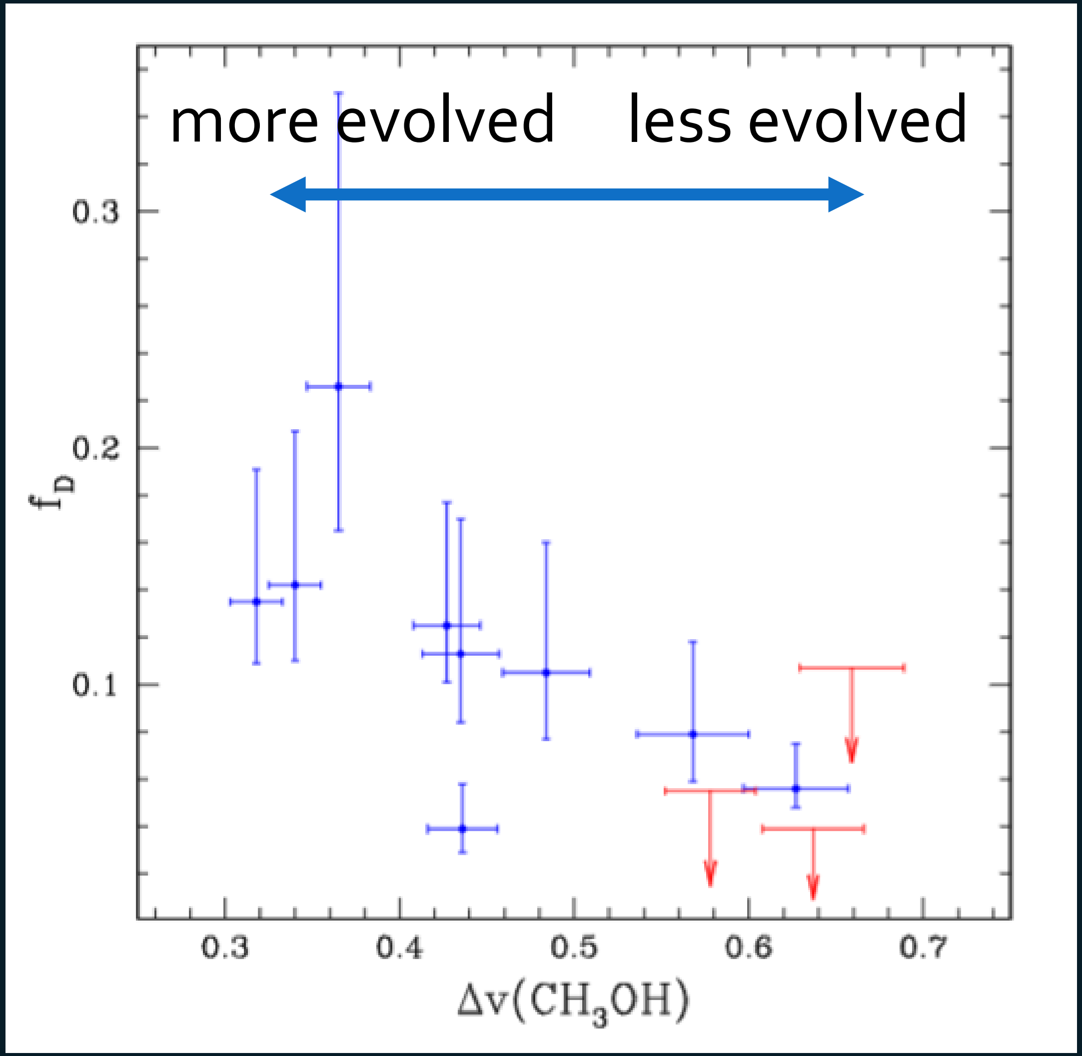
- Virial Parameter
  - Lower virial parameter = more evolved
  - Assumed virial coefficient for uniform-density sphere
  - Find non-detected cores to have larger virial ratios (α > 4), indicating less-evolved cores



Ambrose et al. 2020 (subm)

Evolutionary Comparisons

- FWHM Linewidth of CH_3OH
  - more turbulent source → larger doppler motions → larger linewidth
  - Motion dissipates with evolution
  - Consistent with higher fractionation in more evolved cores



Ambrose et al. 2020 (subm)

Conclusions

- Detected CH_2DOH in 75% of cores
  - Increases number of detections by 4x
  - $[CH_2DOH]/[CH_3OH]$ from < 0.04 - $0.23^{+0.12}_{-0.06}$
  - median value of 0.11
- Consistent with previous models and observations
- Non-detected sources tend to be less evolved
  - larger virial parameters, larger methanol linewidths
- Future implications
  - COM deuteration more easily detectable than previously thought
  - Probe of the deuteration on dust grains
  - New constraints for gas-grain astrochemical models

Acknowledgements

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Results

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  - $[CH_2DOH]/[CH_3OH]$ from $< 0.04 - 0.23^{+0.12}_{-0.06}$
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- Consistent with previous models and observations
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Evolutionary Comparisons

- “Late-time” species
  - Peak toward advanced stages of starless core evolution
  - Ex. NH3 or NH2+
- “Early-time” species
  - Peak early in starless core evolution
  - Ex. CH_3OH
    - Increases with CO freezeout
    - Decreases with CH_3OH freezeout in dense, cold interior
- CH_2DOH
  - Early-time? → deuterium fractionation increases with evolution
  - Late-time? → doesn’t peak with other late-time species (Chacón-Tanarro et al. 2019)

Data Reduction: T_{ex}

- CTEX Method
  - T_{ex} typically calculated using two transitions and assumed constant T_{ex}
  - Complexity of molecule prevents this:
    - The molecule contains "3 energetically-separated torsional symmetry substates (even or odd functions of the torsional angle)" for each of its 3 rotational levels
    - The secondary transition can change substate, making calculation of matrix elements too uncertain for reasonable use