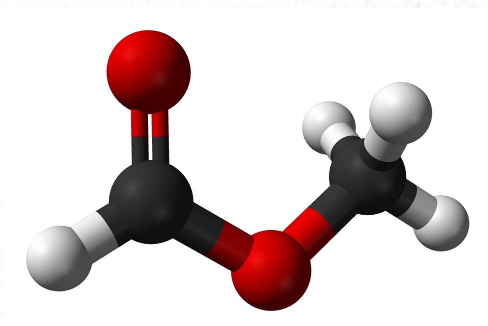
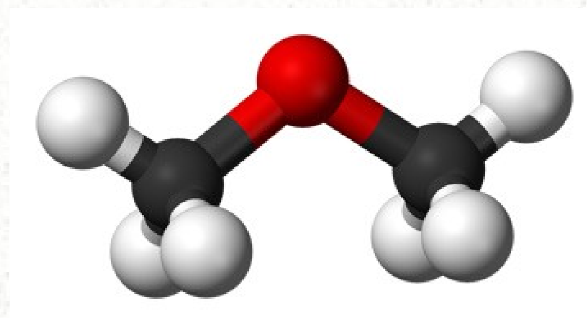
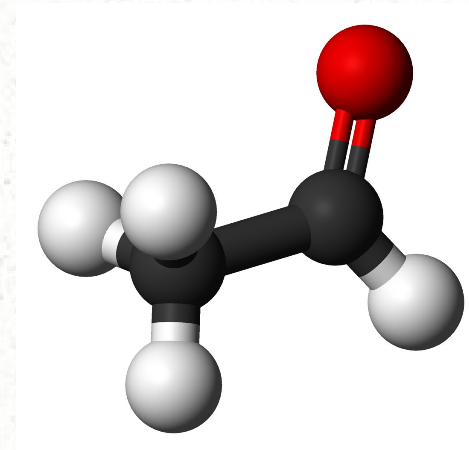
Cold complex organic molecules toward low-mass protostars and outflows







Öberg et al. 2011

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August 11th, 2011

ESAC

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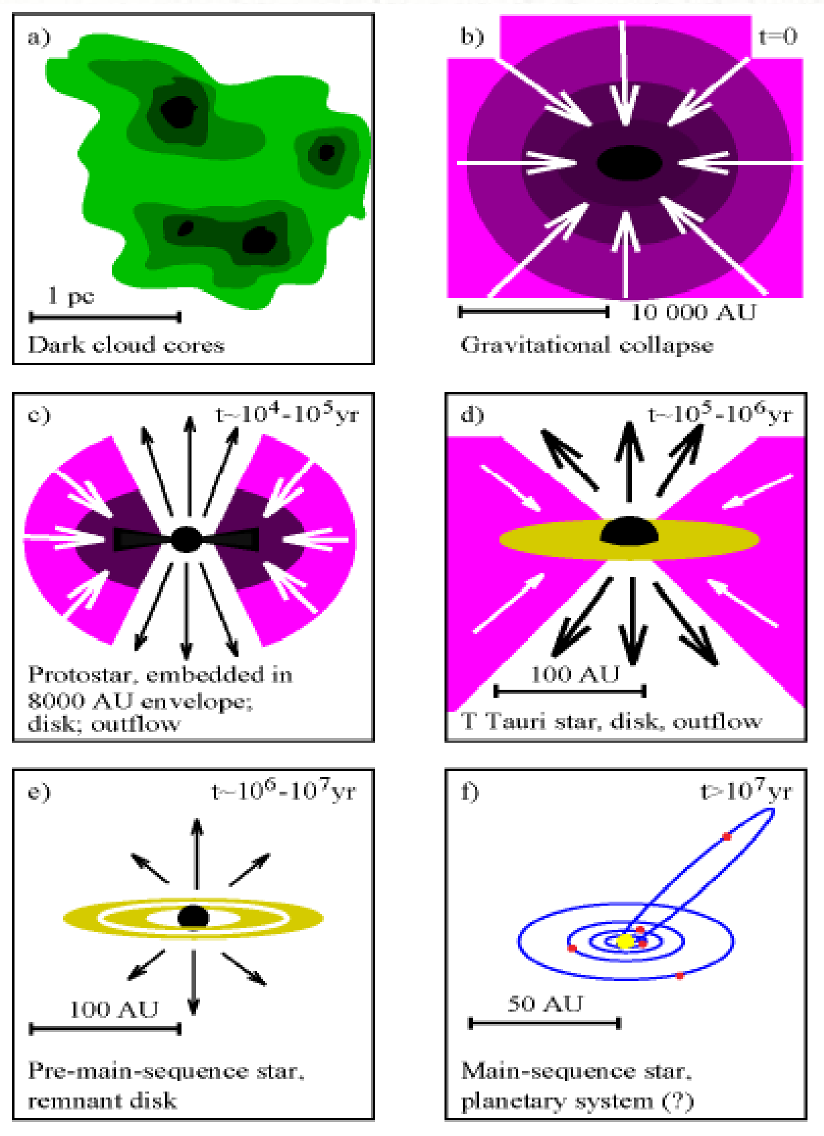
Star formation



- Many changes in temperature, density and chemistry during star formation process

Hogerheijde, 1997

Star formation

- Low mass
  - < 8 Mo
  - Slow evolution
  - Low luminosity
  - Less complicated mechanisms
  - Complex molecules?

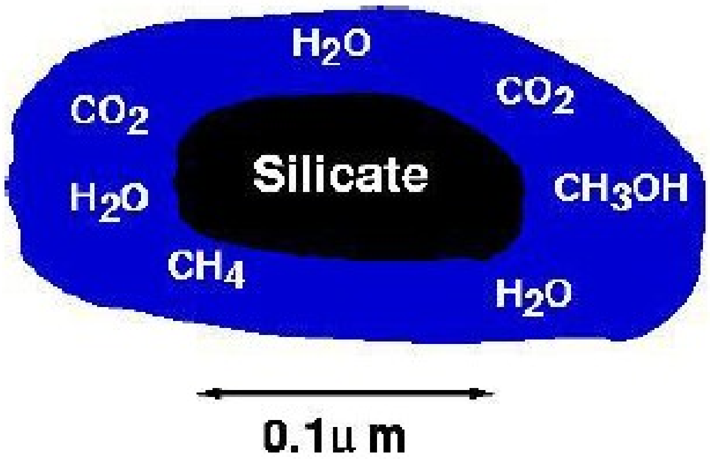
- High mass
  - > 8 Mo
  - Fast evolution
  - High luminosity
  - More complicated mechanisms
  - Many complex molecules (hot)

Astrochemistry

- > 150 different molecules detected
- Conditions in space: low T, n => formation ánd destruction reactions slow!
- Tracers of physical conditions
- Gas and solid phase (ice)
- Approach: observations, modeling and lab experiments

Astrochemistry

- Dust grains very important
- Gas-grain/ice chemistry => formation (larger) molecules
- Most abundant ice: H_2O



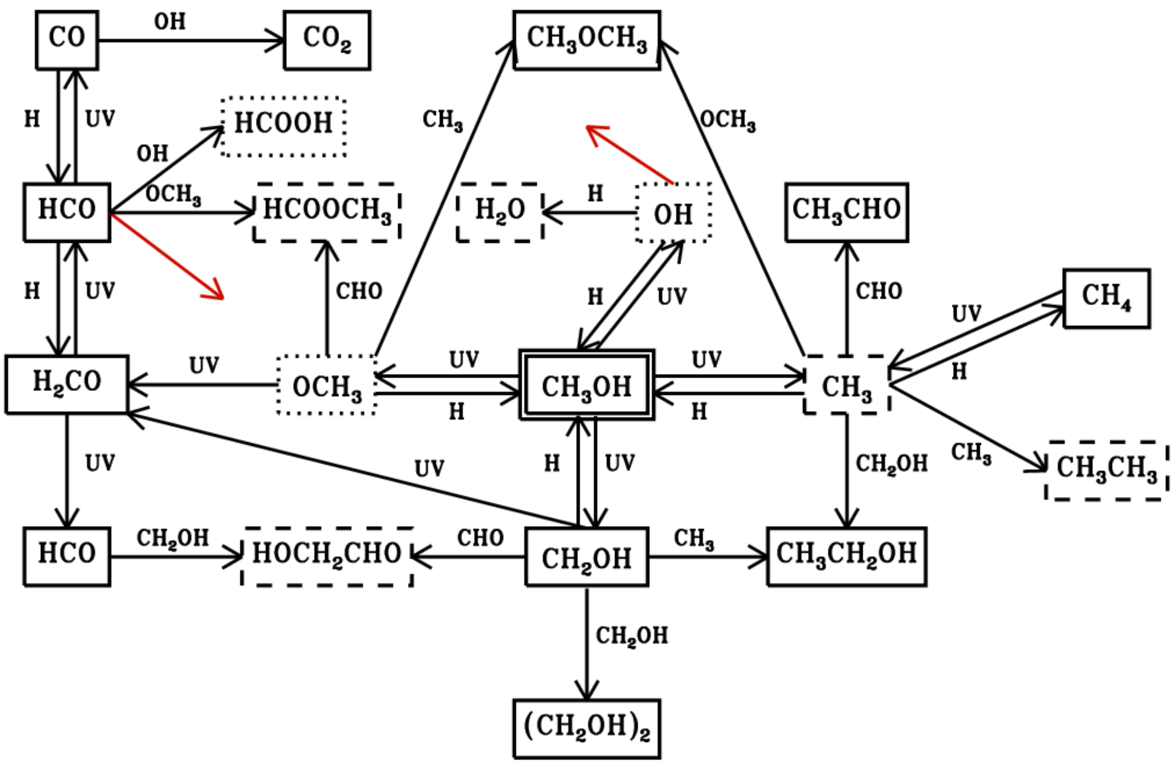
Astrochemistry

- Ice processes
  - Freeze out
  - Formation
  - Desorption (sublimation)
- Triggering factors
  - Temperature
  - UV radiation
  - Atom bombardments
  - Shocks

- **Main observables are desorbed gas phase molecules!**

Complex organic molecules

- Molecules with >6 atoms
- Formation in gas-phase & in ice (thermal)



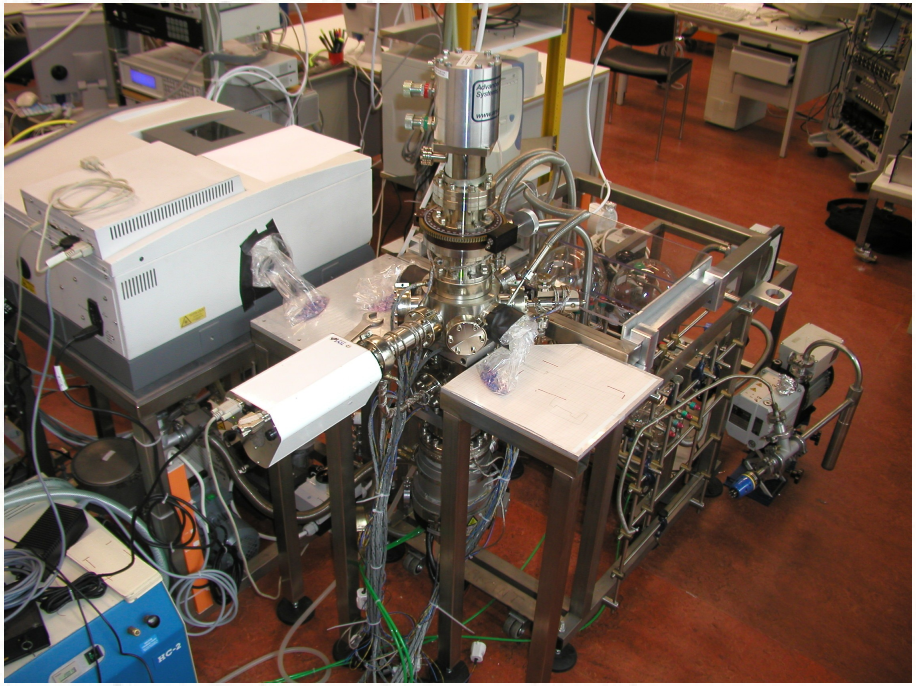
Öberg et al 2009

Complex organic molecules

- Long time thought: only complex organics in hot cores (high mass) => warm chemistry
- Detections in low mass protostars rare (4) => some kind of cold chemistry has to exist!

Lab results

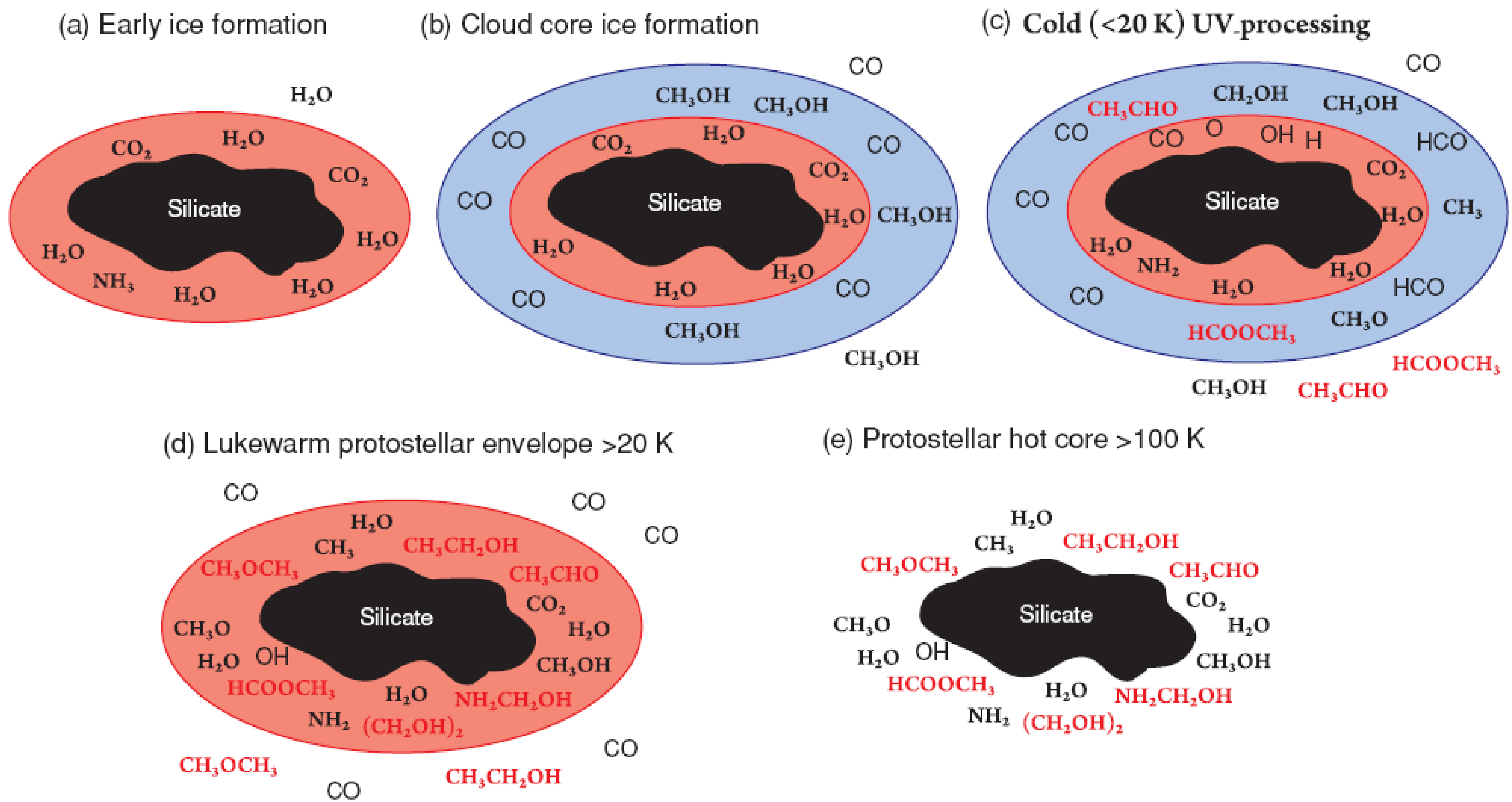
- Lab experiments ice (Öberg et al 2009)
- Freeze out CH_3OH and CO/CH_3OH ice in UHV setup (Sackler lab Leiden)



Lab results

- UV irradiation
  => production complex organic molecules at low (<30 K) temperatures!
- FTIR and QM spectrometer (TPD) to measure ice composition and desorbed gas molecules
- Also UV photodesorption

Lab results



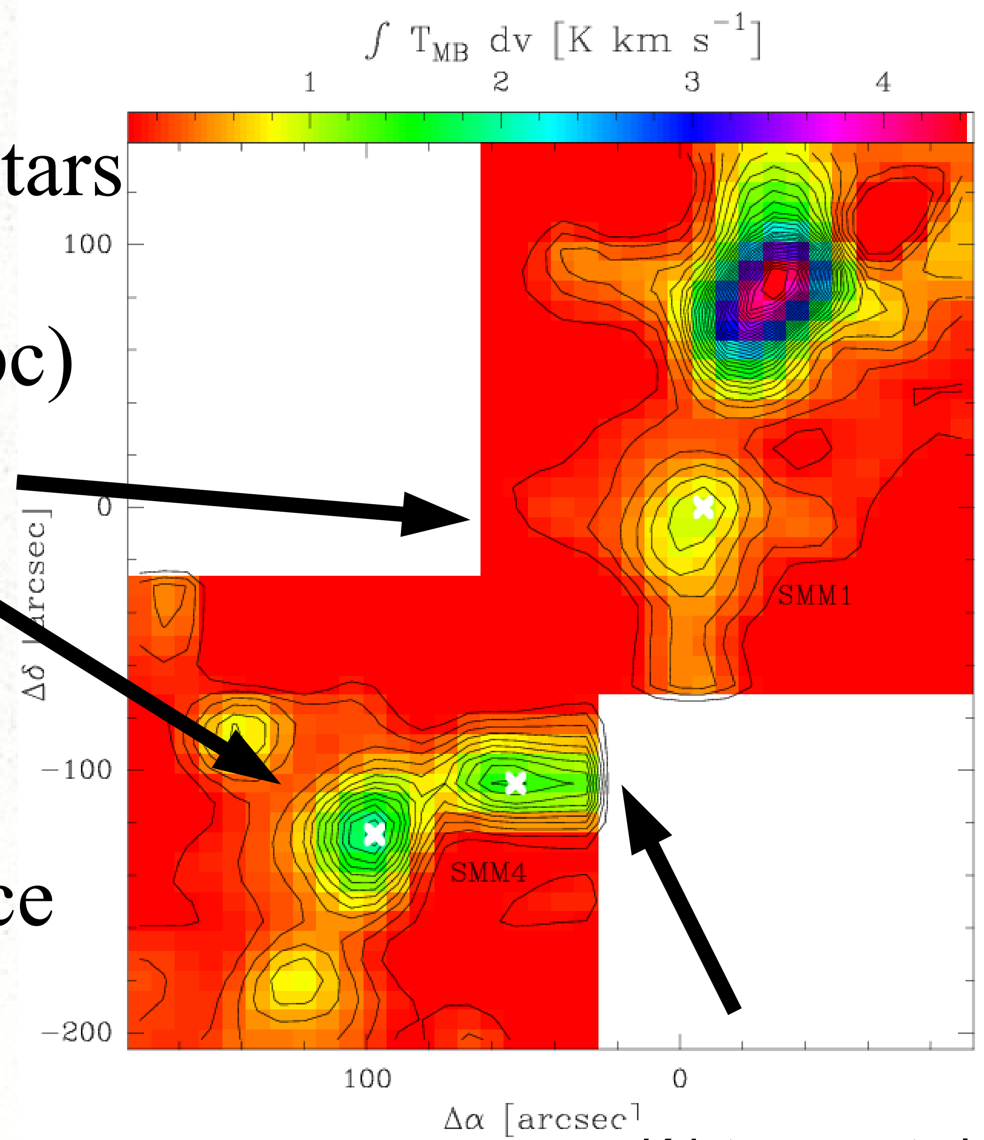
Öberg et al 2009

Motivation

- Understanding formation in low mass
  => Need for larger sample!
- Observation demands:
  - Low mass protostellar environments
  - Very abundant CH_3OH
  - Submm telescope
  - Spectral settings with several complex organic target molecule transitions
  - **<u>Long</u>** integration times: lines weak!

Observations

- Targets: two protostars + one outflow in Serpens (d=250 pc)
  - SMM1 (30 Lo)
  - SMM4 (5 Lo)
  - SMM4-W
- Rich in CH_3OH ~ 30% wrt H_2O ice
- Single pointing



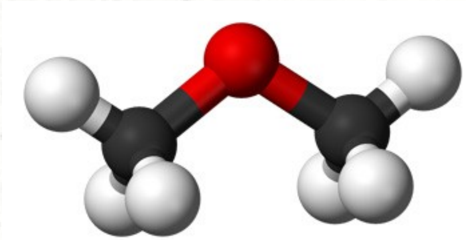
Kristensen et al 2010
Pontoppidan et al 2004

Observations

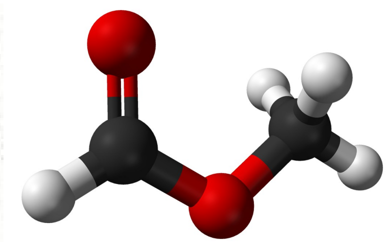
- IRAM 30m telescope
- EMIR receivers tuned to 89, 107, 115, 130 and 146 GHz
- Beam size 17-28”
- ~2-3 hr int. time per setting
- During WC finals...

Observations

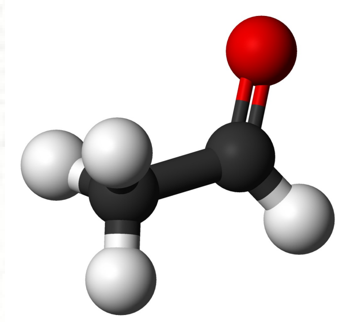
- Main target molecules (network)
  - CH_3OCH_3 – dimethylether



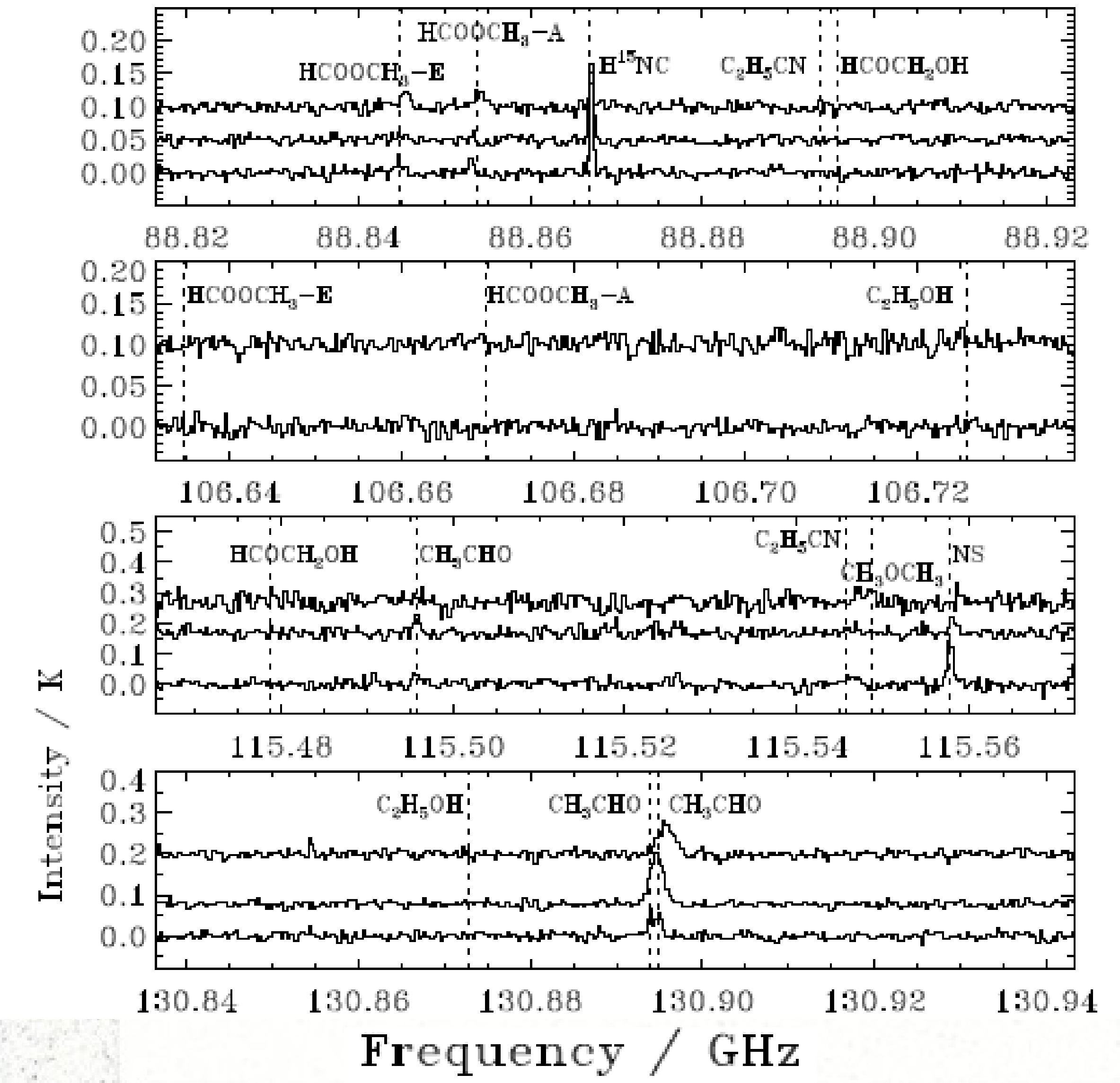
  - $HCOOCH_3$ – methylformate



  - CH_3CHO – acetaldehyde

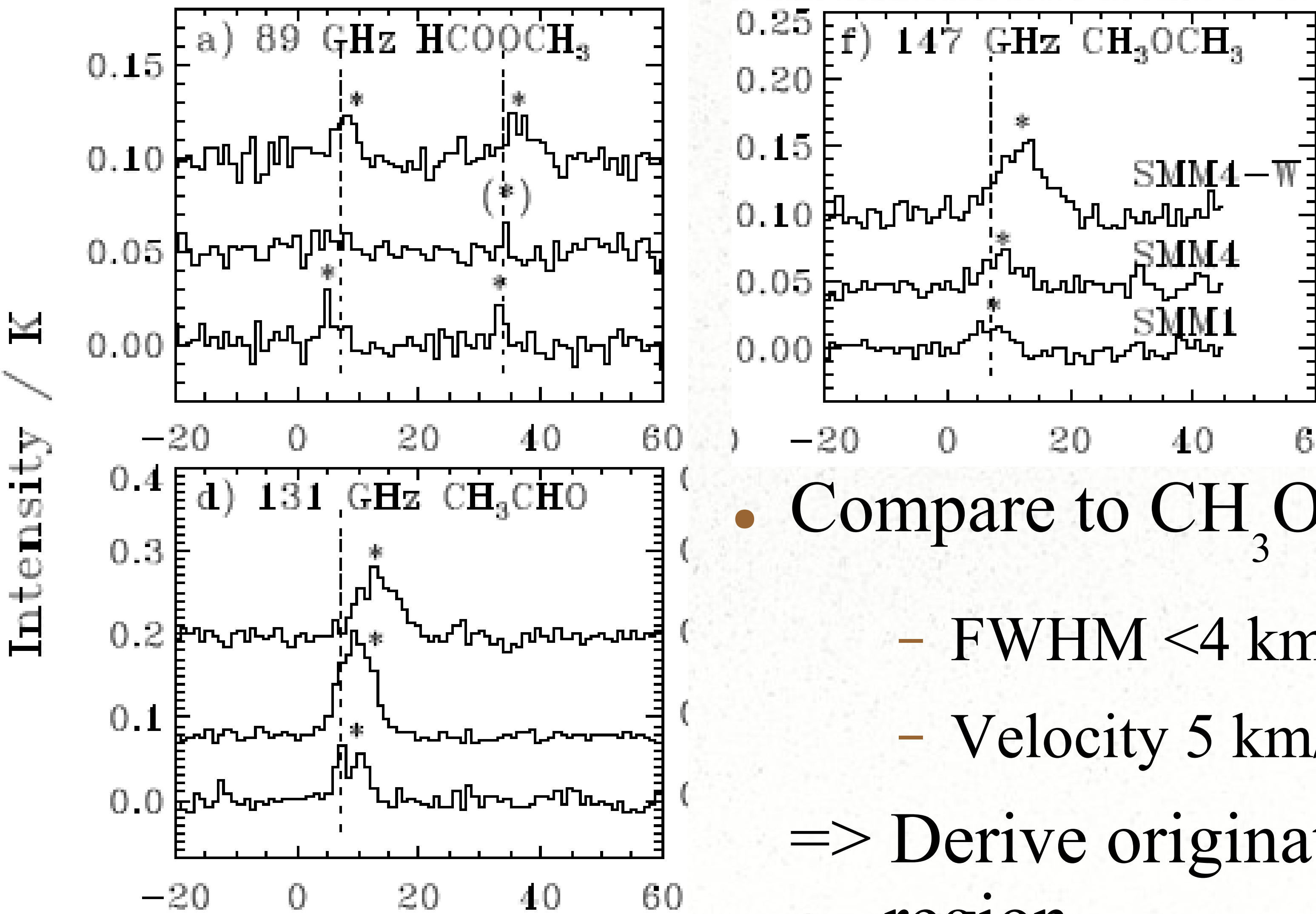


Data analysis



- Many potential detections in spectral range
- Smoothing 0.1 to 0.4 km/s rms ~10 mK
- Detections & upper limits

Results



- Compare to CH_3OH:
  - FWHM <4 km/s
  - Velocity 5 km/s

=> Derive originating region

Results

- CH_3OH convolved to 17"/28" beam => eq. abundant => origin in envelope, not core
- CH_3OH 8 transitions => derive T_{rot}
- Calculate column densities

$$N = \frac{1.67 \times 10^{14}}{\nu \mu^2 S} Q(T_{\rm rot}) e^{-{\rm E_u}/{\rm T_{rot}}} \int T_{\rm b} dv,$$

  using T_{rot} from CH_3OH lines (10-15 K)
- Derive ratio complex/CH_3OH (CC)

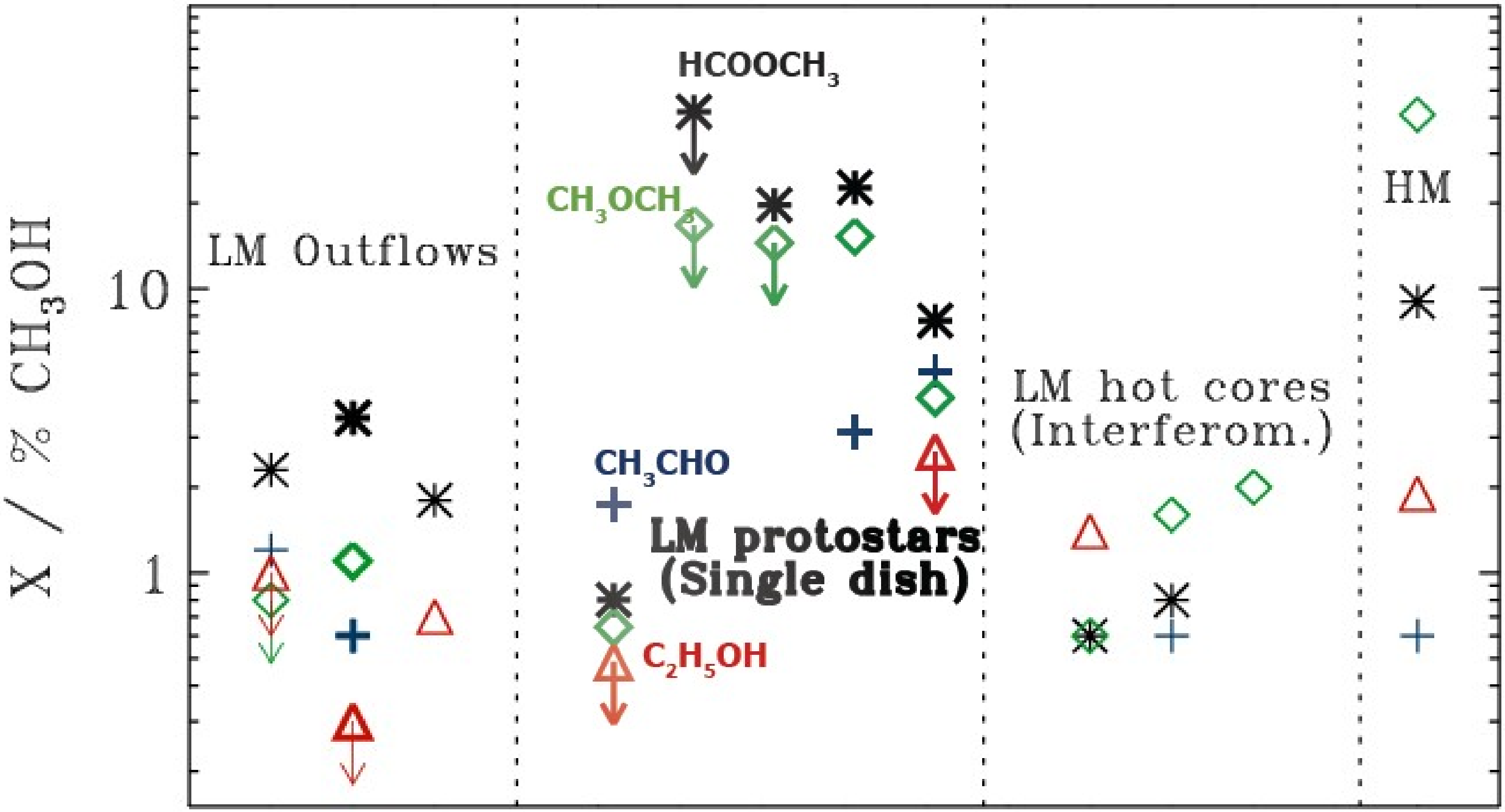
Results

- CC = 5 - 22%
- Results consistent with cold UV photochemistry:
  - CC ratio largest for SMM1 (most luminous)
  - $(HCOOCH_3+CH_3CHO)/CH_3OCH_3$ ~ 3 (cold chemistry => CH_3OCH_3 forms after CO desorption)

Results

- Desorption mechanisms
  - Thermal
  - UV: only surface layer! (lab)
  - Outflow shocks: entire ice mantle!
- Abundance ratios depend on desorption mechanism and formation structure
- More modeling required to constrain formation, layer structure, desorption processes

Comparison with other studies

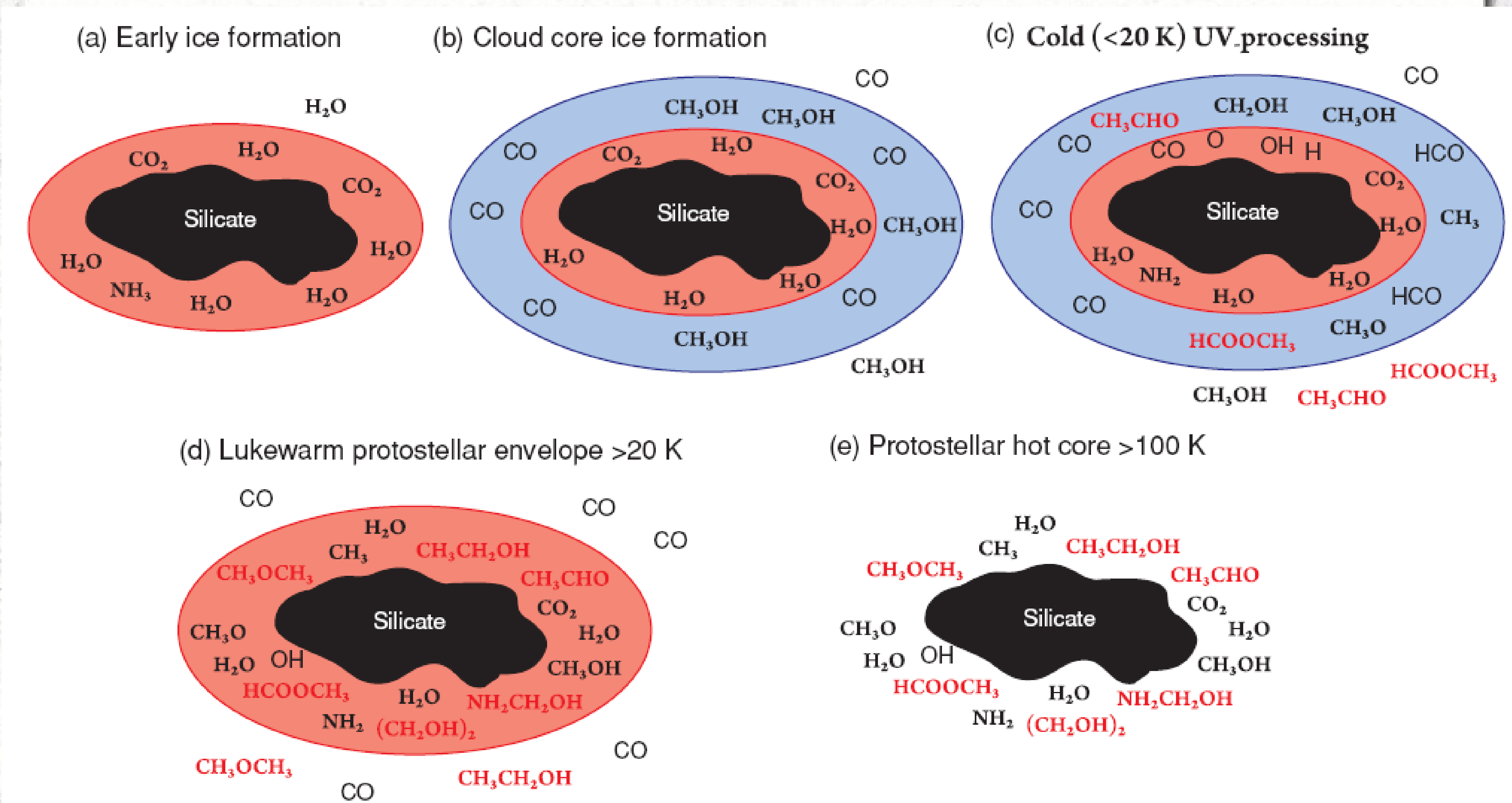


Relative abundances similar for low and high mass!

Comparison with other studies

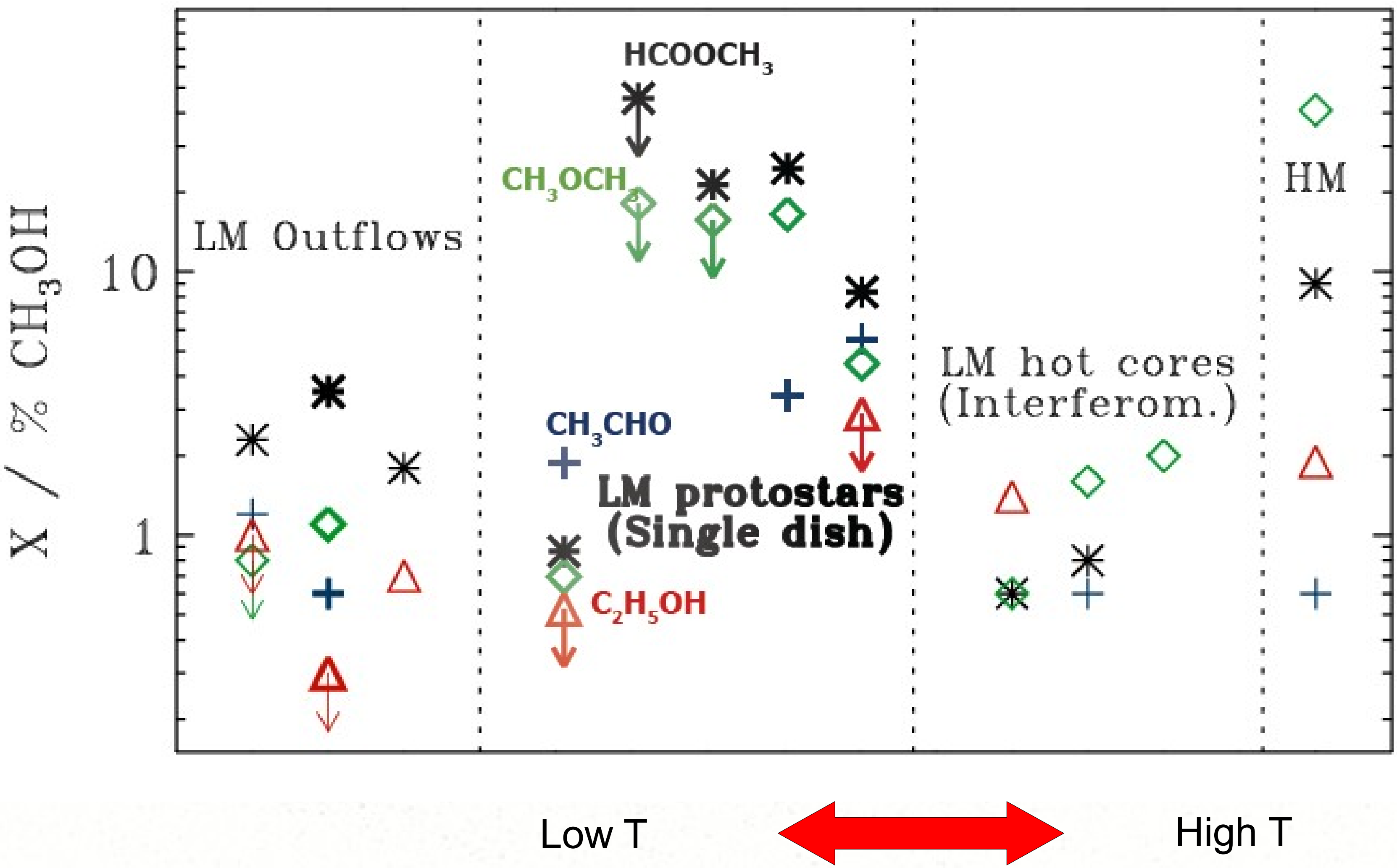
- $HCOOCH_3 > CH_3OCH_3$ for cold chemistry
- $HCOOCH_3 < CH_3OCH_3$ for hot core/high mass with high T
  => support for sequential formation with $HCOOCH_3$ formed in colder CO-rich ice and CH_3OCH_3 in warmer CO-poor ice

Comparison with other studies



Öberg et al 2009

Comparison with other studies



Conclusions

- Complex organics can be detected in cold gas.
- Abundances of complex organics are similar for high-mass hot cores and low-mass protostars and outflows, although the chemical mechanisms are different.
- $HCOOCH_3/CH_3OCH_3$ is larger in low-mass sources. This supports a sequential formation of complex molecules for CO-rich and CO-poor ice