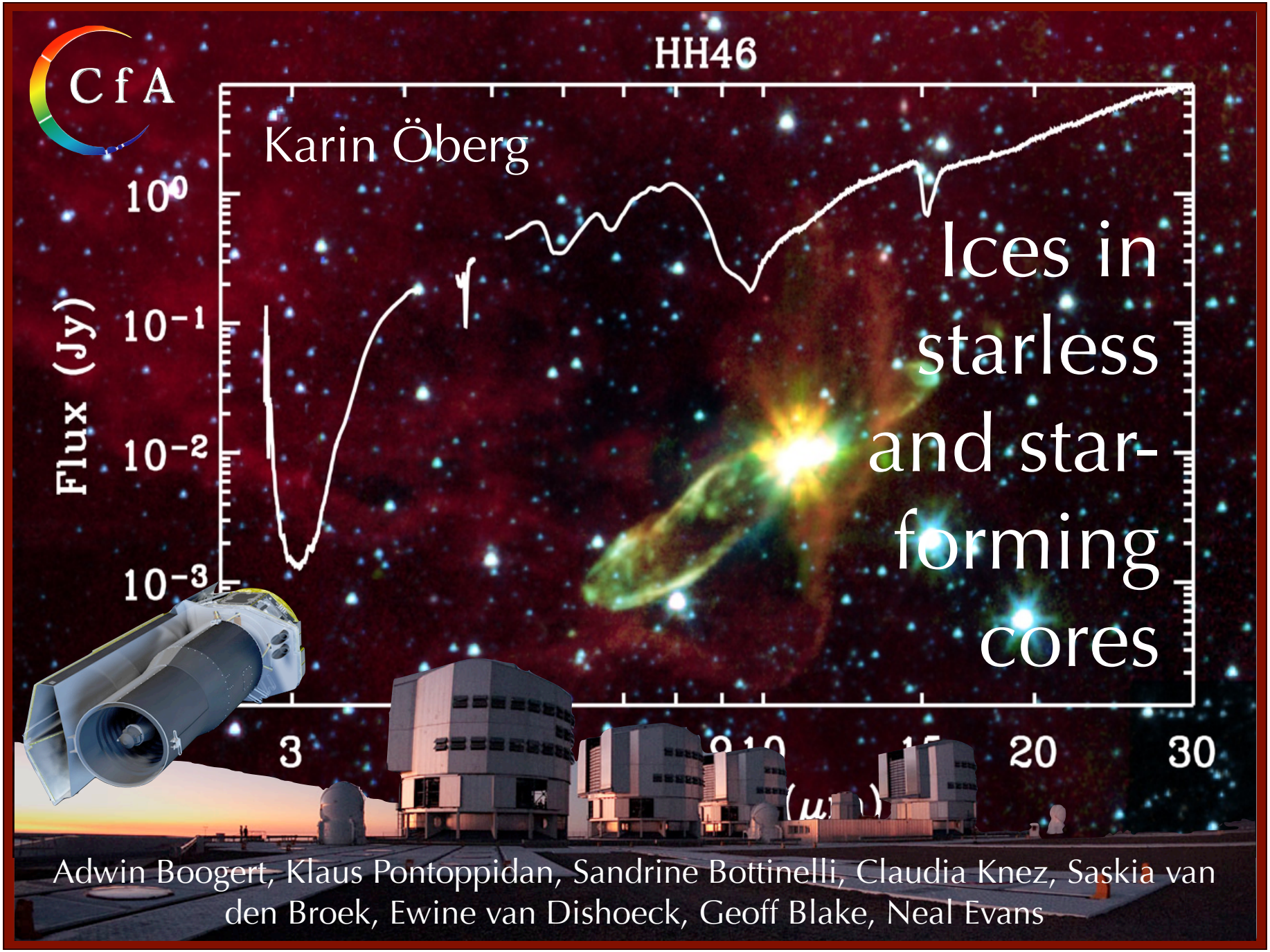
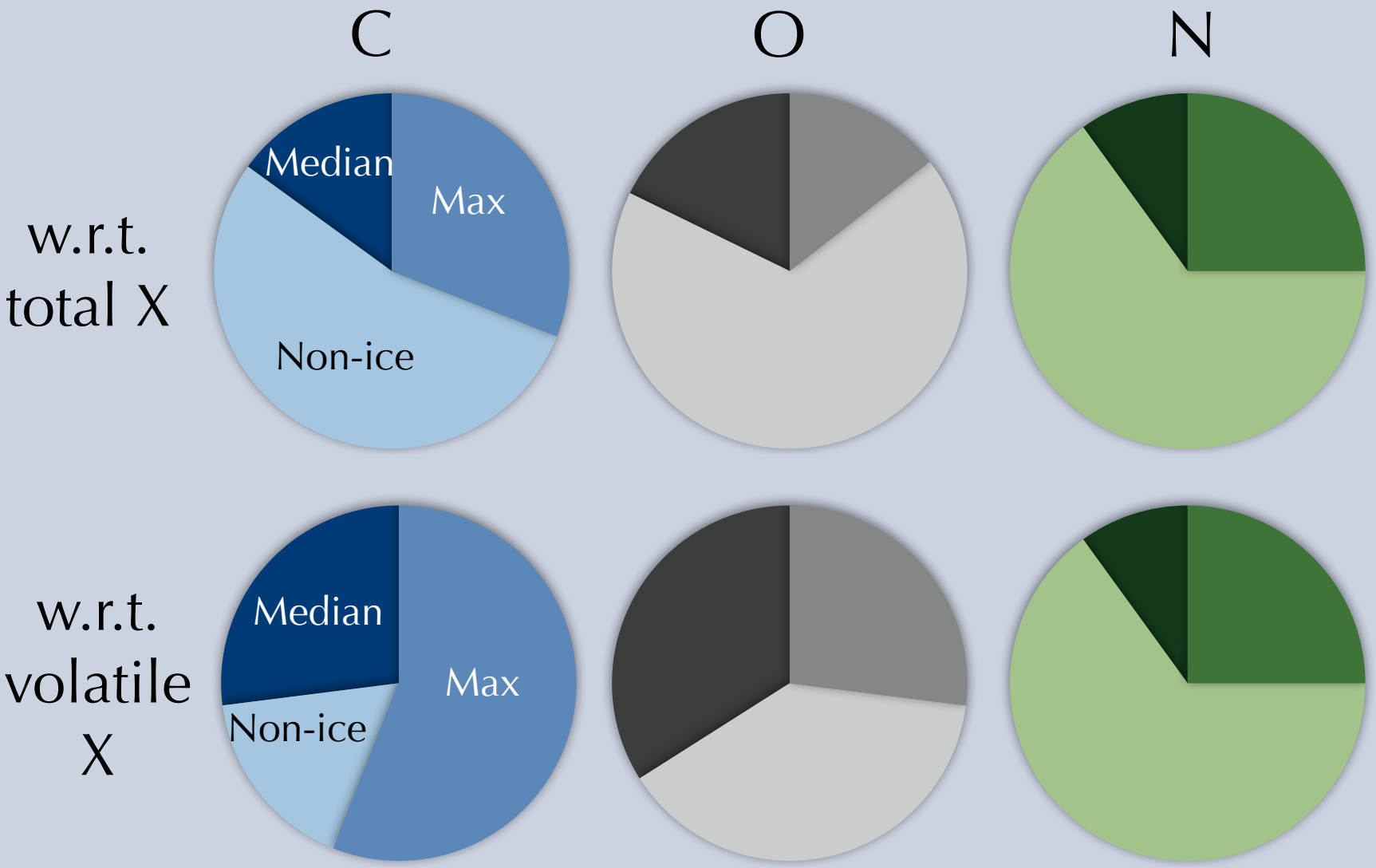

CfA
HH46
Karin Öberg
Flux (Jy)
10^{0}
10^{-1}
10^{-2}
10^{-3}
3
20
30
Ices in starless and star-forming cores
Adwin Boogert, Klaus Pontoppidan, Sandrine Bottinelli, Claudia Knez, Saskia van den Broek, Ewine van Dishoeck, Geoff Blake, Neal Evans

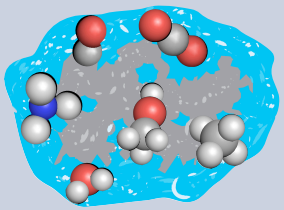
The C, O and N budget in ices



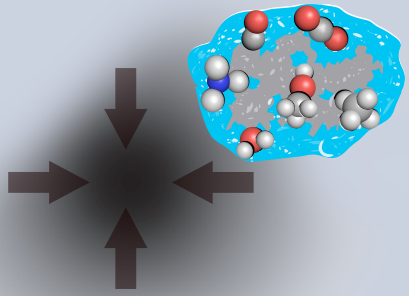
[Przybilla et al. 2008, Weingartner & Draine, 2001, Whittet et al. 2010]

Icy pathways to chemical complexity

(i) Simple ices at 10 K

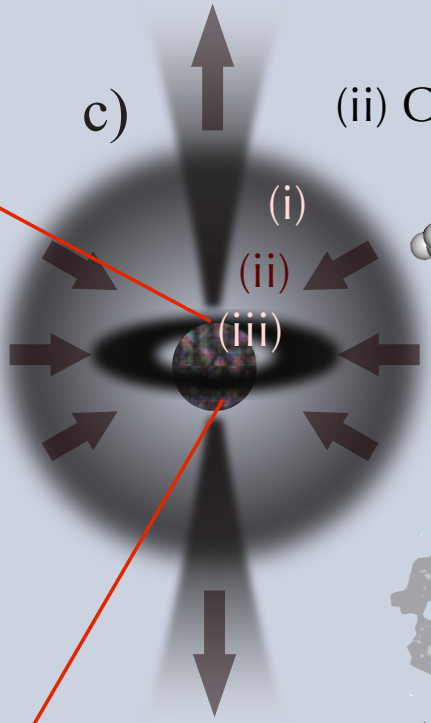


b)

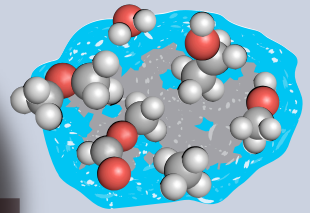


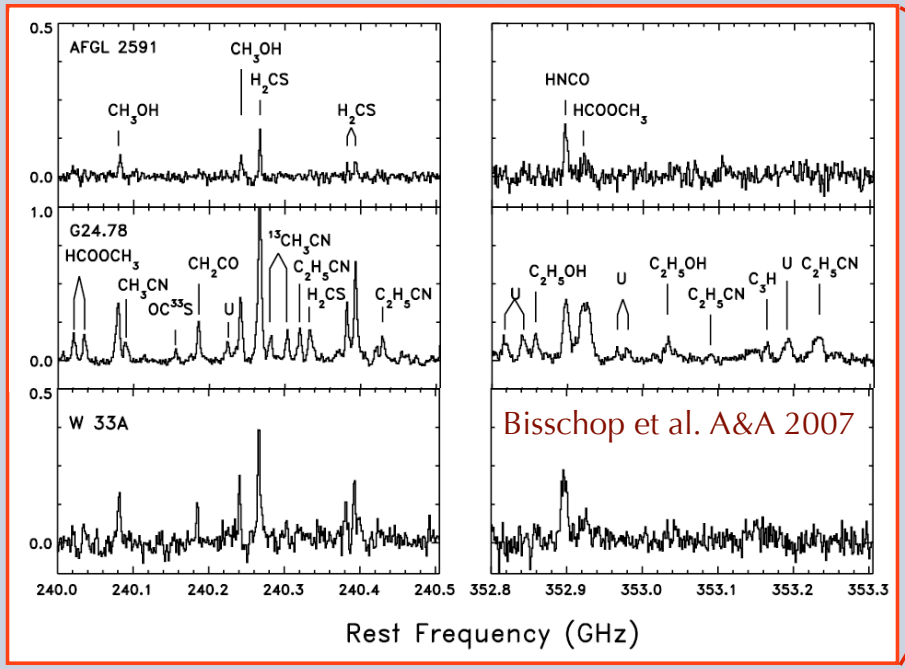
Complex species
1-10% w.r.t. CH_3OH
toward low- and high-mass protostars, outflows and comets

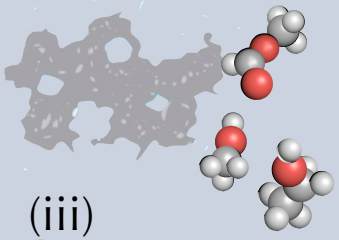
c)



(ii) Complex ices?



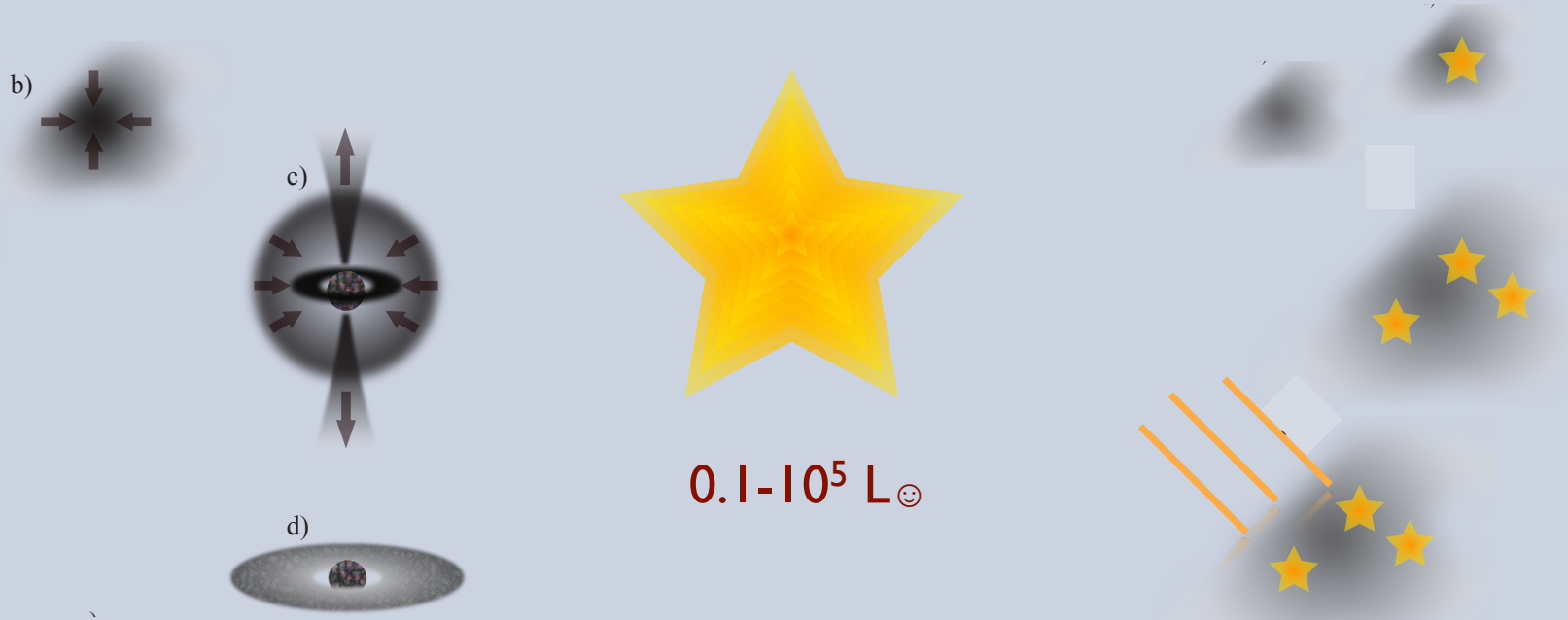




(iii)
Evaporated ices >100 K

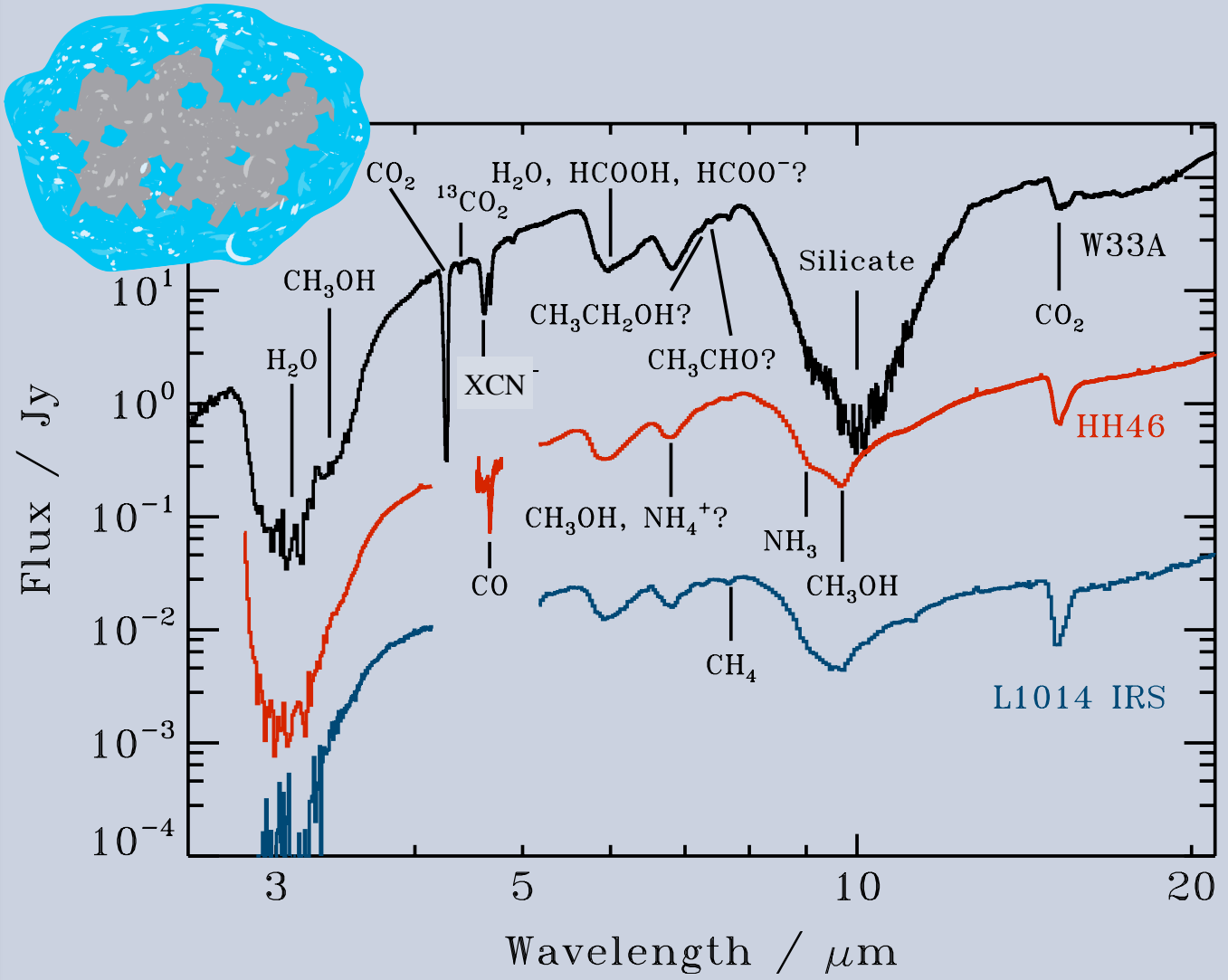
A combined Spitzer, ISO, VLT and Keck Legacy

Low mass YSOs (c2d)	54	Pontoppidan 2003ab, van Broekhuizen et al. 2005, Boogert et al. 2008, Pontoppidan et al. 2008, Öberg et al. 2008, Reach et al. 2009, Bottinelli et al. 2010
High mass YSOs	9	Gibb et al. 2004
Background stars	31	Knez et al. 2005, Boogert et al. 2011



[Gillet & Forest 1973, Chiar et al. 1995, Bergin et al. 2005, Whittet et al. 2009, Zasowski et al. 2009]

Similar ices in different environments



H_2O, CO, CO_2, CH_4, NH_3, CH_3OH, XCN

pure CO, CO:CO_2, CO:H_2O

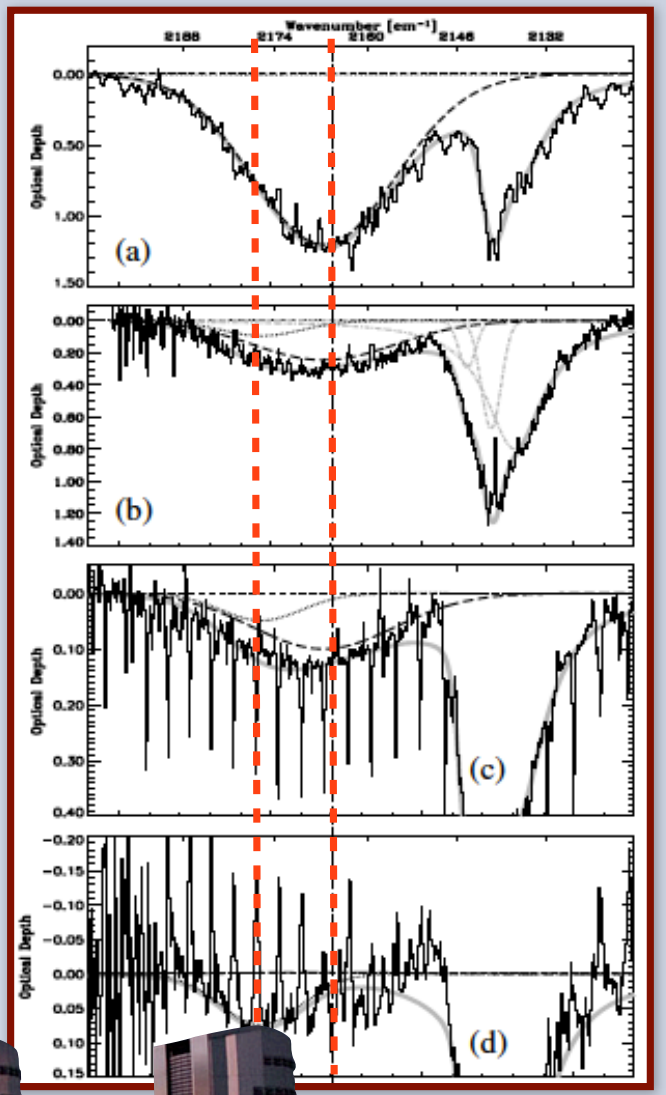
CO_2:H_2O, CO_2:CO, CO_2 shoulder, pure CO_2

C1-C5

XCN: OCN^-, 2175 cm^{-1}

XCN vs. OCN^-

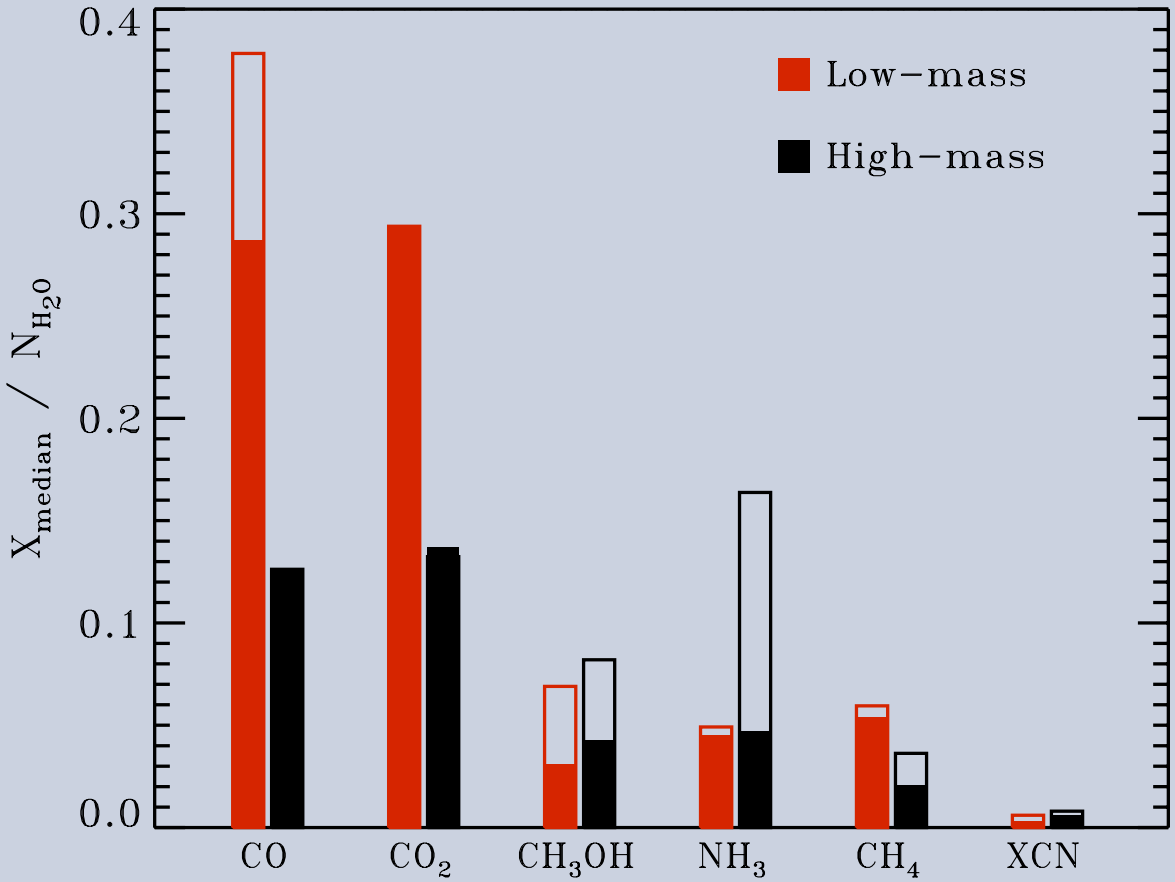
- ★ XCN refers to entire feature
- ★ empirically it consists of two bands
- ★ One band is identified with OCN^- from laboratory spectroscopy
- ★ Carrier of second band (2175 cm^{-1}) unknown: OCN^- in other ice environment, other XCN ice, CO bound to silicate?



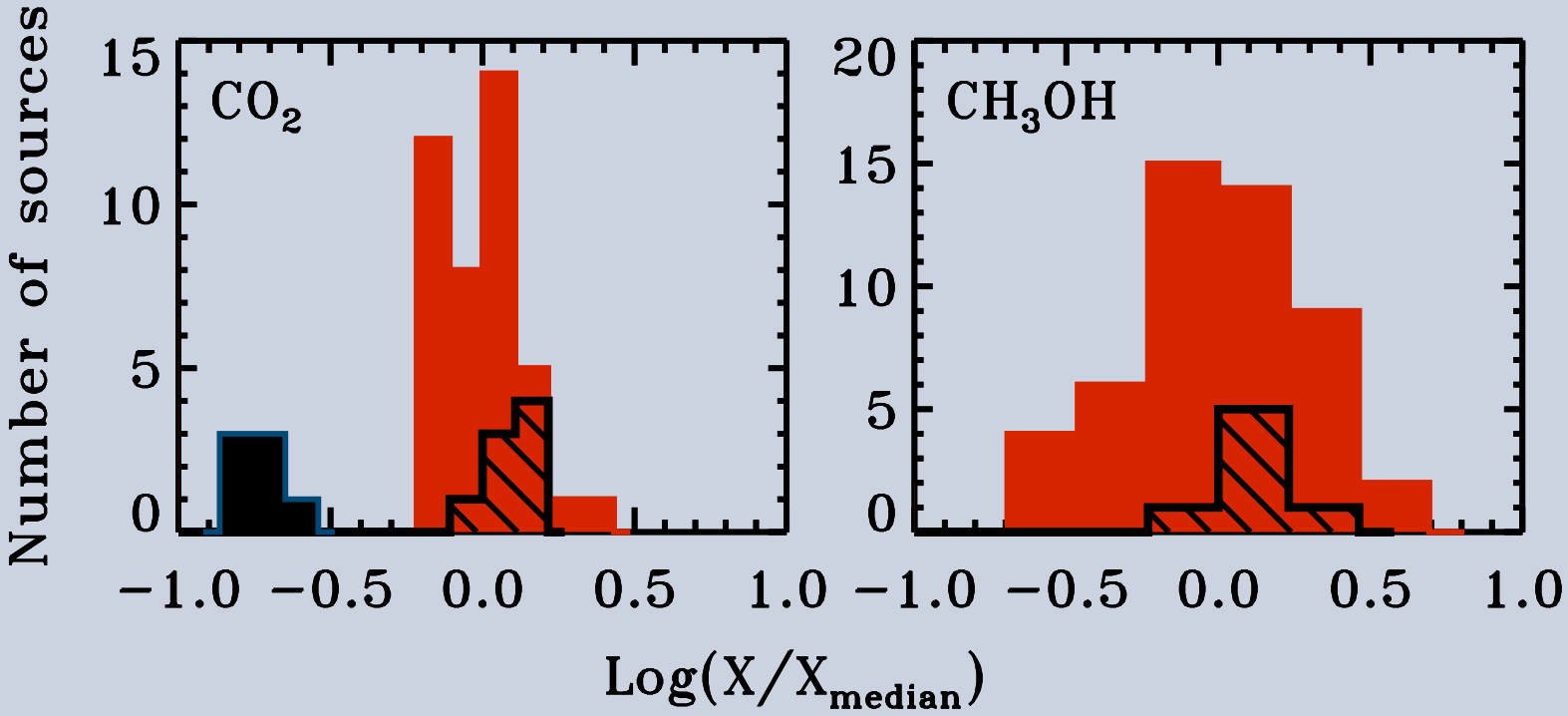
[van Broekhuizen et al. 2005]

Median ice abundances around protostars

- ★ CO, CO_2, and CH_4 ices are significantly more abundant toward low-mass protostars
- ★ XCN is more abundant toward high-mass protostars
- ★ Upper limits important!



Ices before the onset of star formation

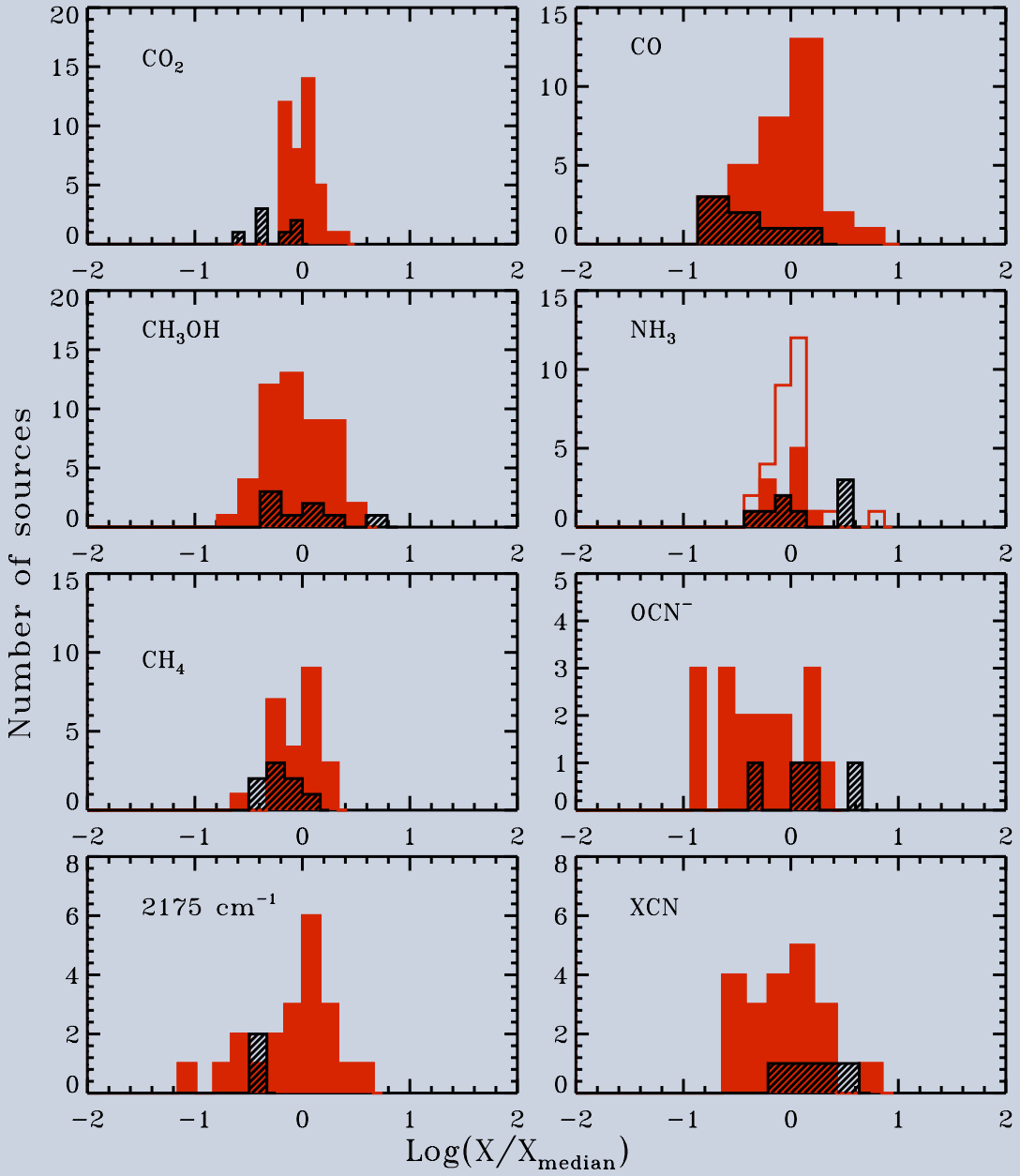


Warning: The Taurus ices are NOT representative of the larger sample!

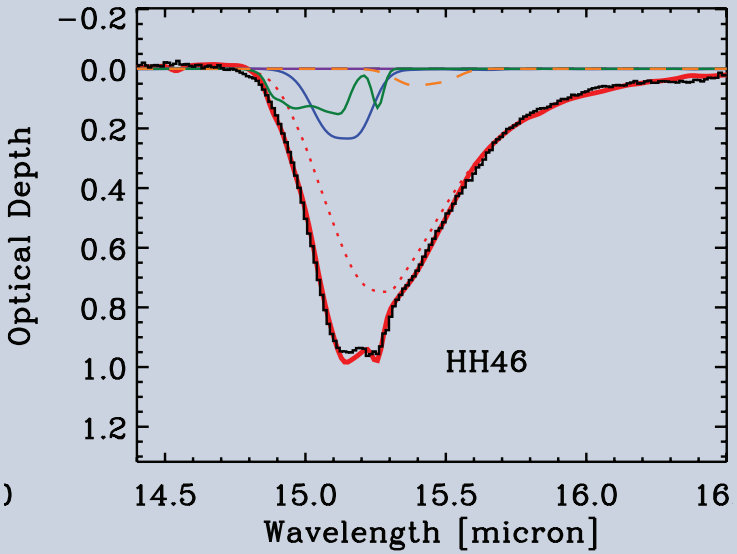
Simple ice evolution = prestellar ice evolution

Protostellar ice distributions trace prestellar variability

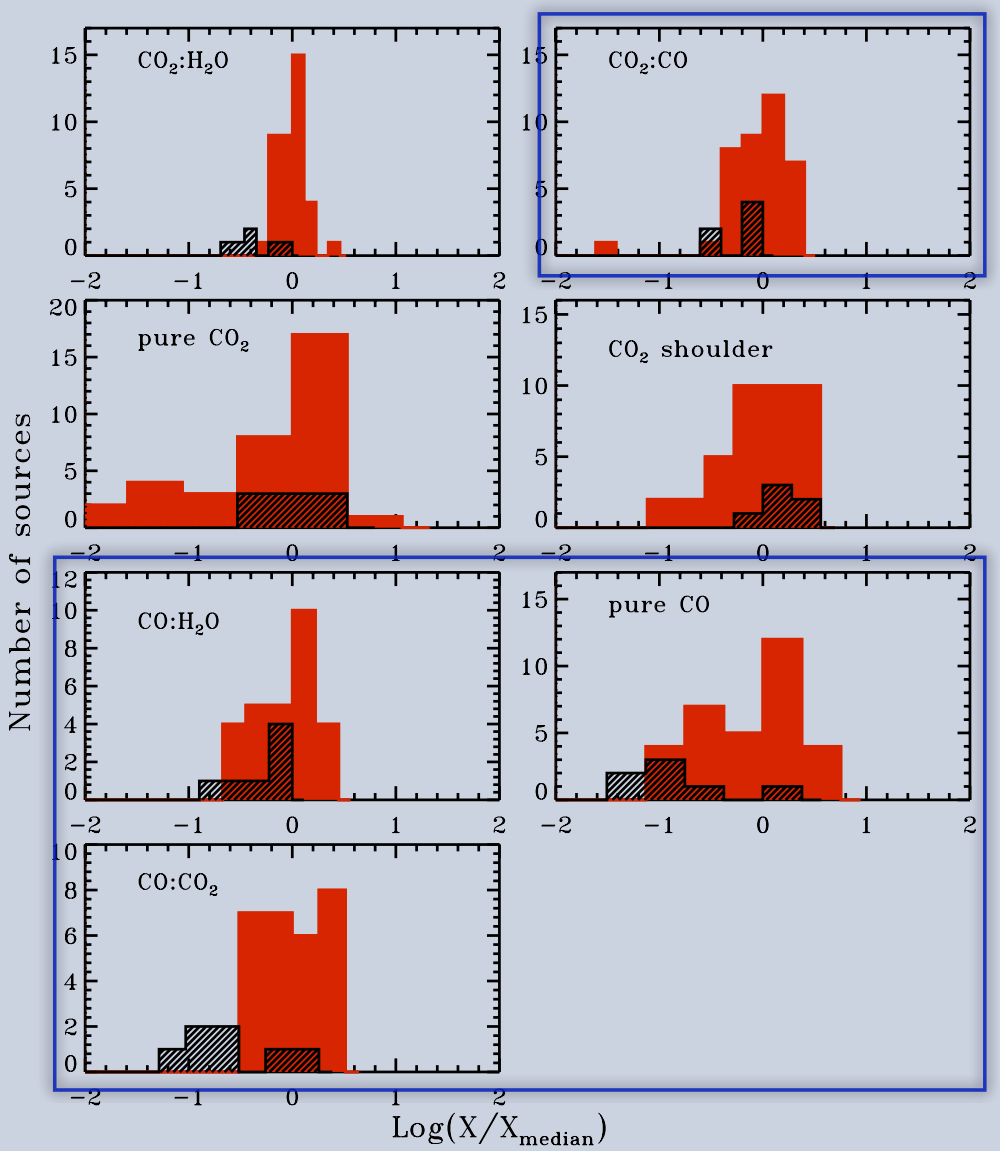
- ★ CO_2, CH_4 and NH_3 vary little with respect to H_2O
- ★ CO, CH_3OH and XCN vary by 1-2 orders of magnitude
- ★ Co-formation with H_2O versus later formation?



Not all CO and CO_2 form equal

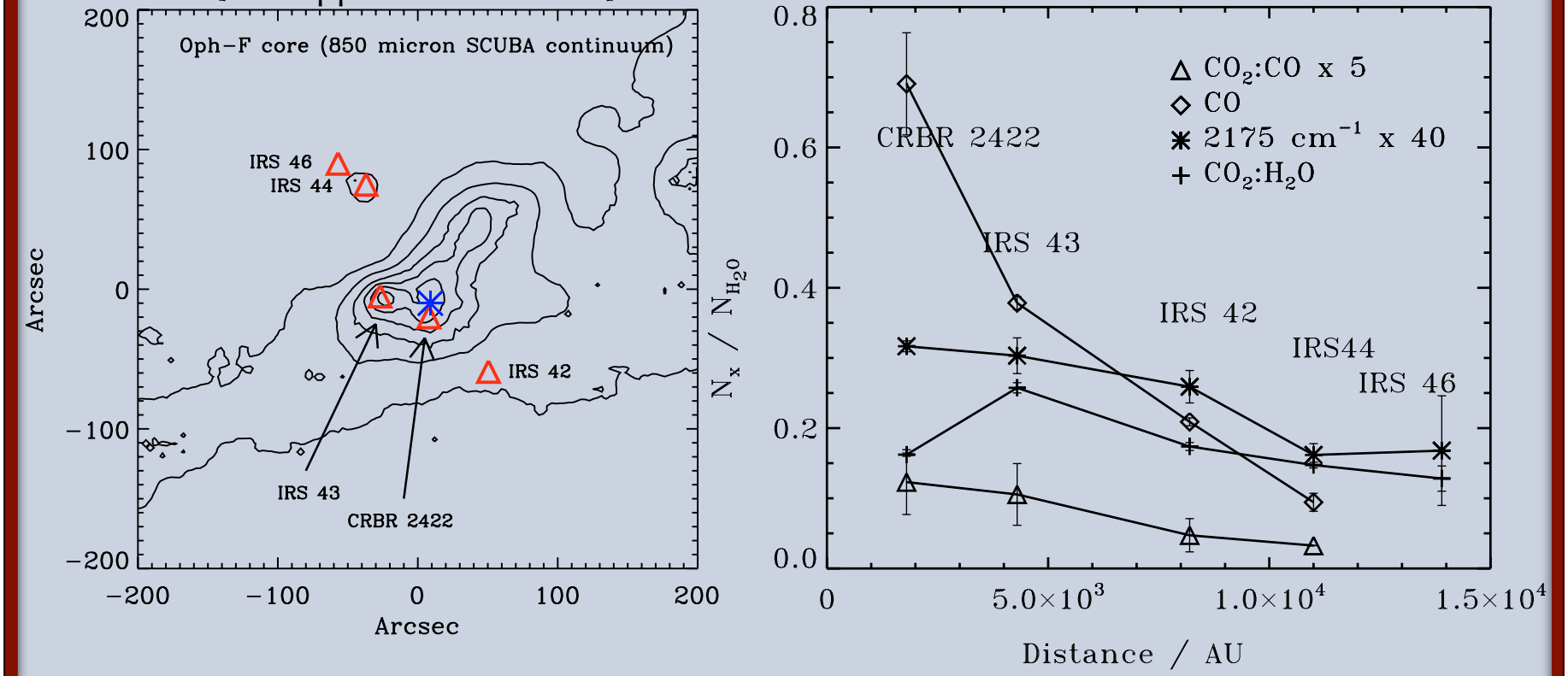


- ★ CO and CO_2 present in 3-4 unique environments from component analysis
- ★ CO_2:H_2O alone associated with H_2O ice formation
- ★ Most other components well correlated with CO



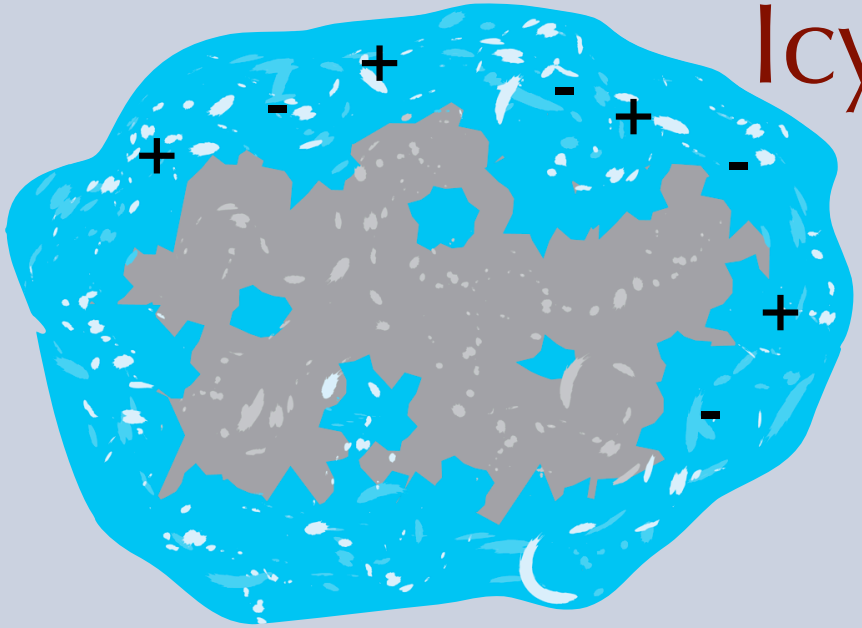
CO freeze-out as a source of ice chemistry variability

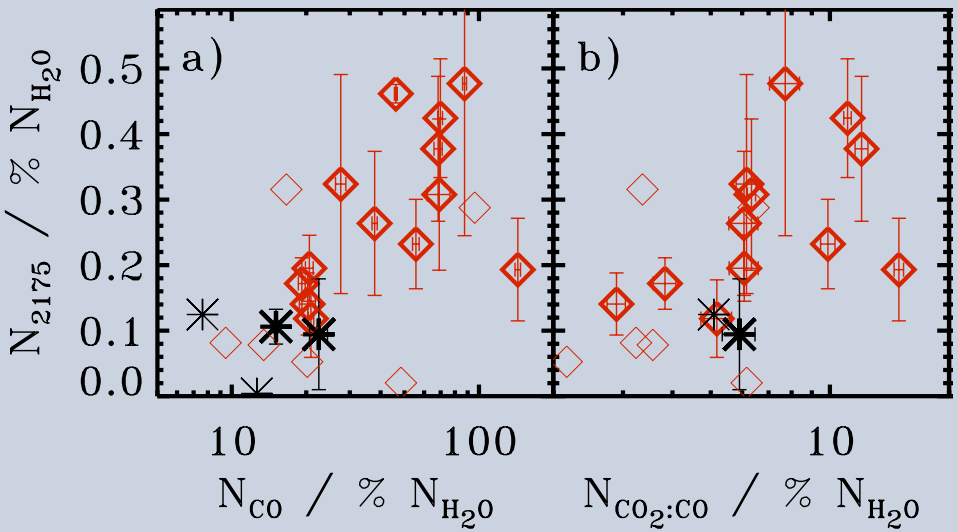
[Pontoppidan et al. 2006]



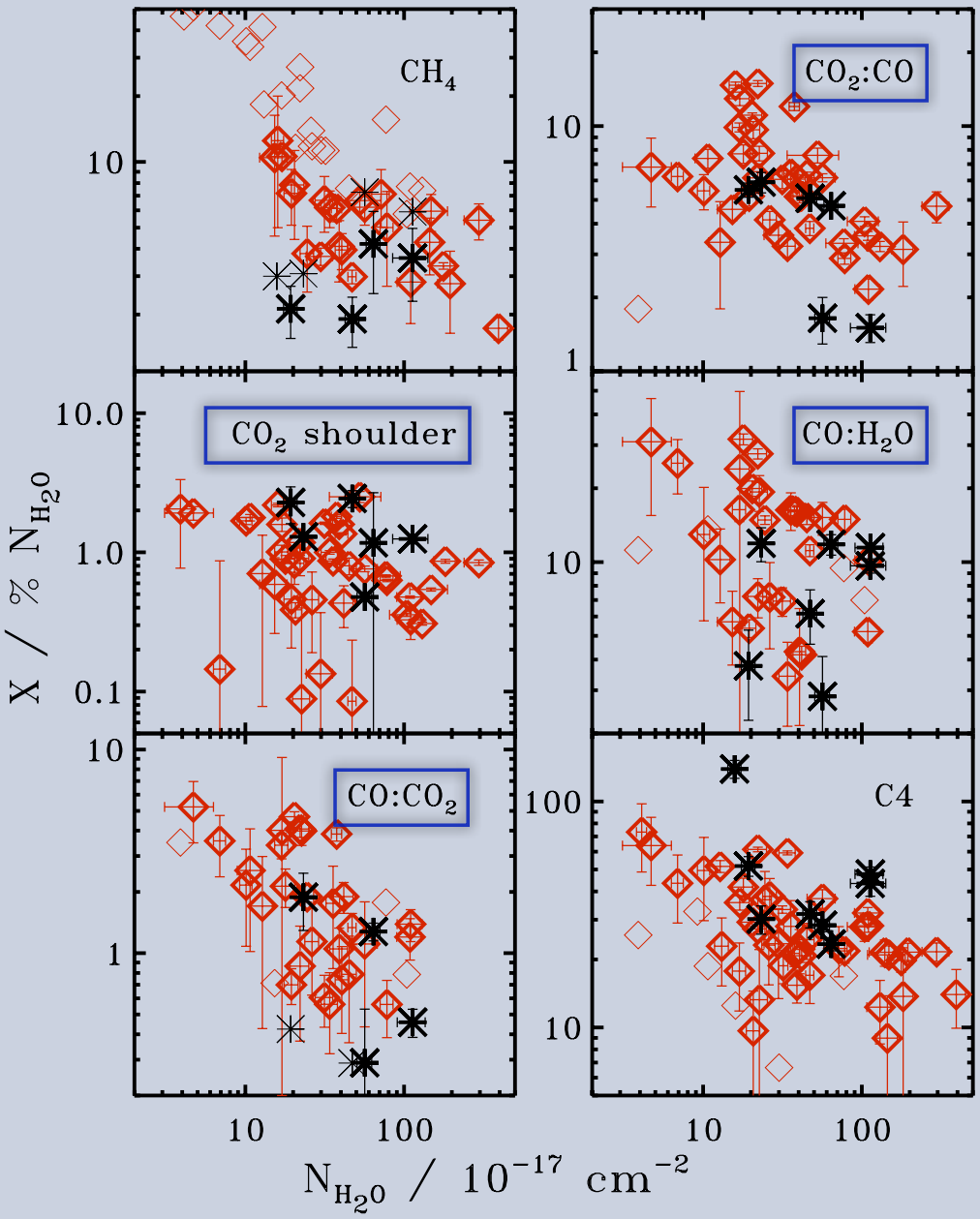
Dramatic CO ice increase toward core center accompanied by CO chemistry. Ice composition depends on source position in cloud!

Icy ions - ionic ices





- ★ OCN^- : verified spectroscopically and assignment consistent with CO correlations. Prestellar formation!
- ★ NH_4^+ : most likely carrier of bands in the 6-8 μm region, abundances up to 15%.
- ★ $HCOO^-$: suggested carrier of 7.4 μm band.



Competition between H_2O and CO ice formation?

$O \rightarrow OH \rightarrow H_2O$

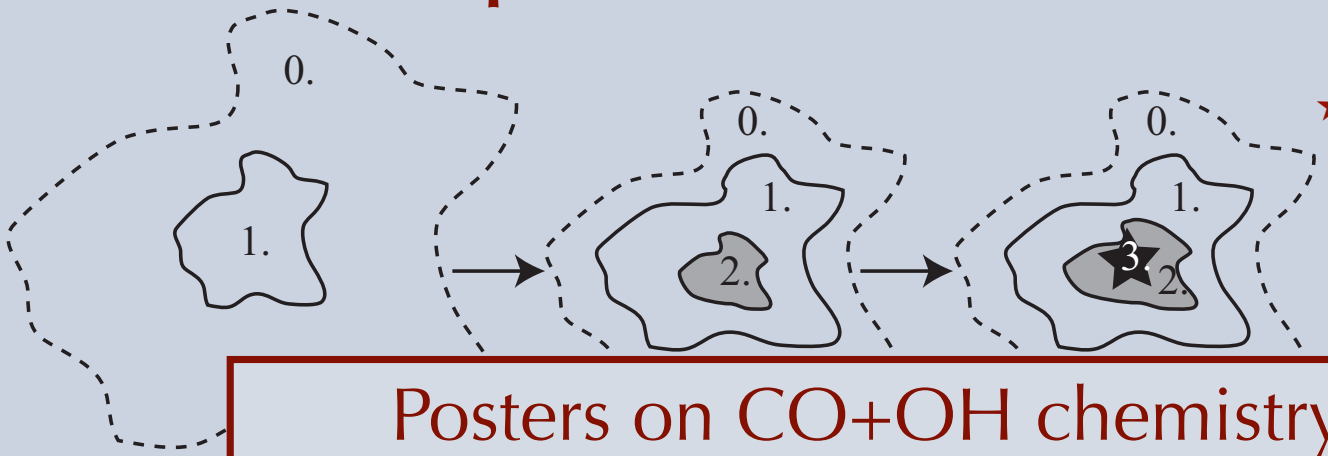
$CO + OH \rightarrow CO_2:H_2O$

vs.

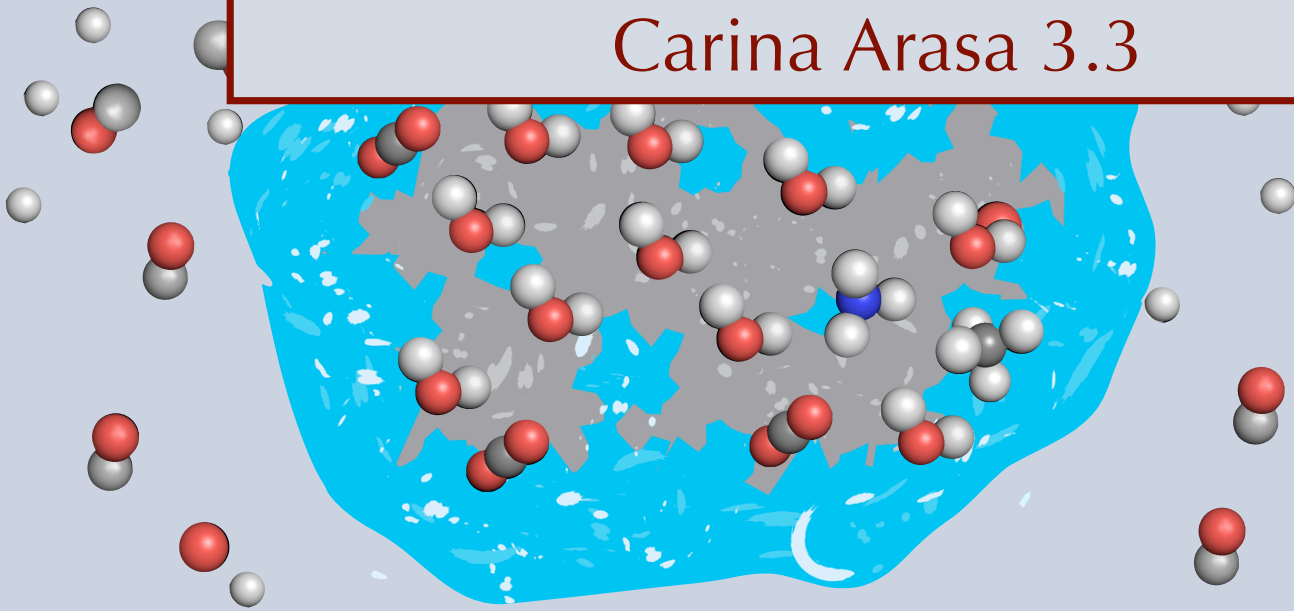
$CO + OH \rightarrow CO_2:CO$

Rob Garrod's poster 3.34: CO_2 formation in quiescent clouds

A sequential ice formation



Posters on CO+OH chemistry:
Sergio Ioppolo 3.43, Yasuhiro Oba 3.74
Carina Arasa 3.3

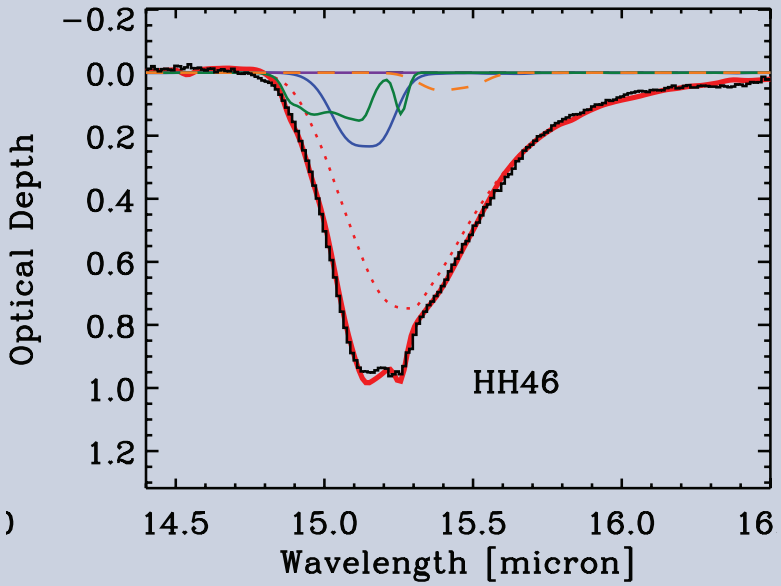


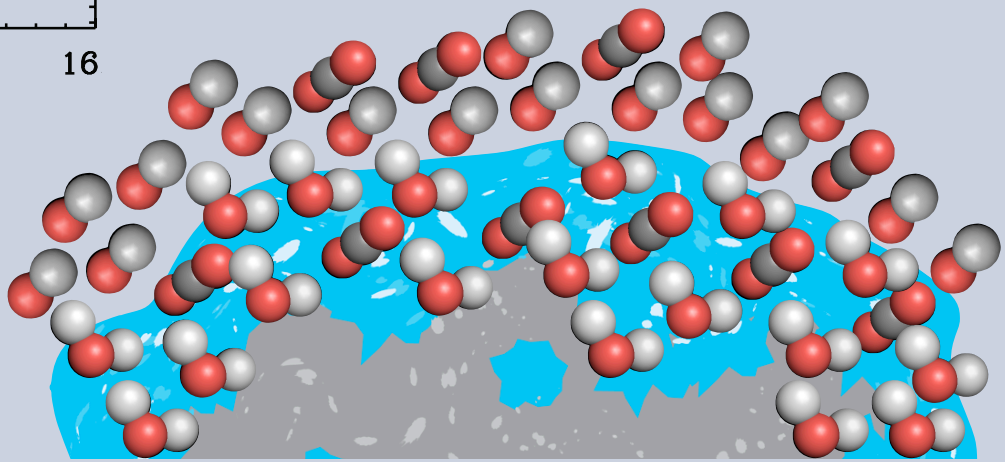
★ Hydrogenation of atoms. All CO converted into CO_2.

on
n O/CO
on sets
O ice
transition.

★ CO chemistry later and products environment dependent.

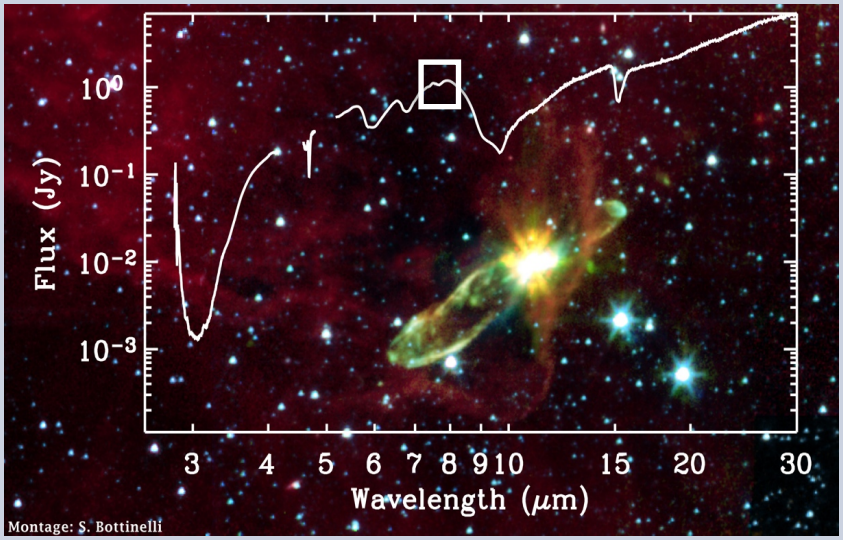
Protostellar heating I:
Segregation and evaporation





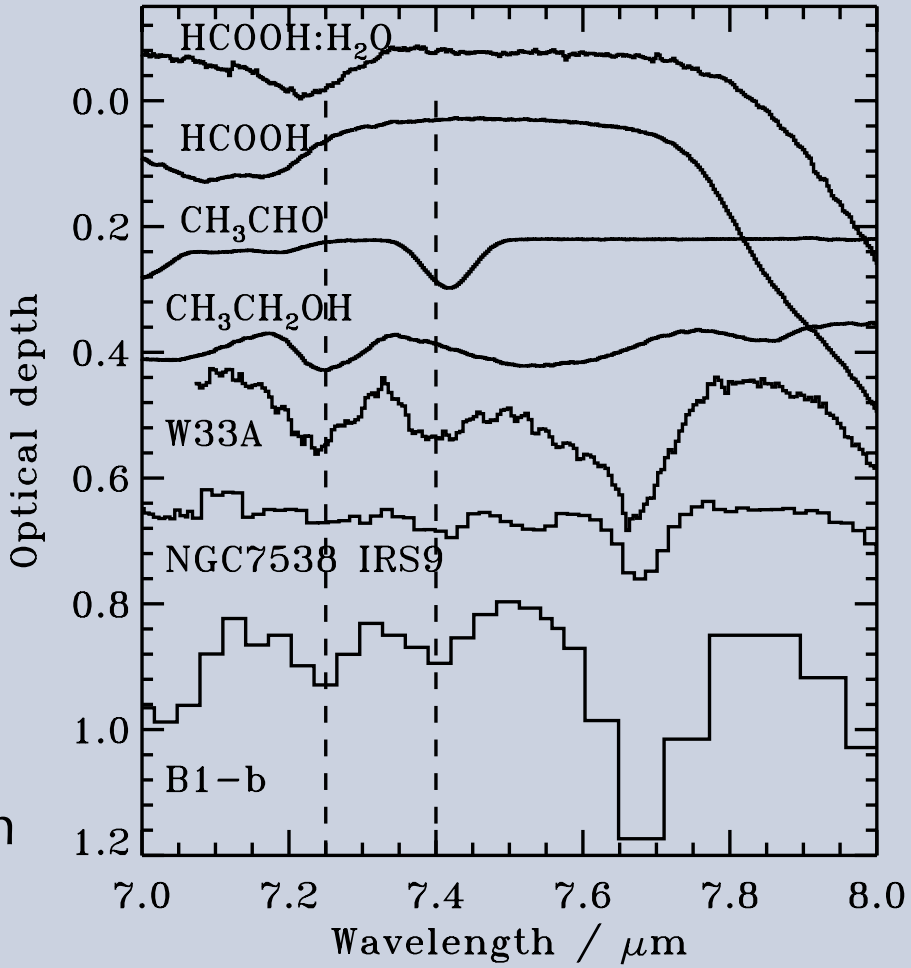
Ice processes as a probe of transient heating events: 1.43

Protostellar heating II:
Complex ice chemistry



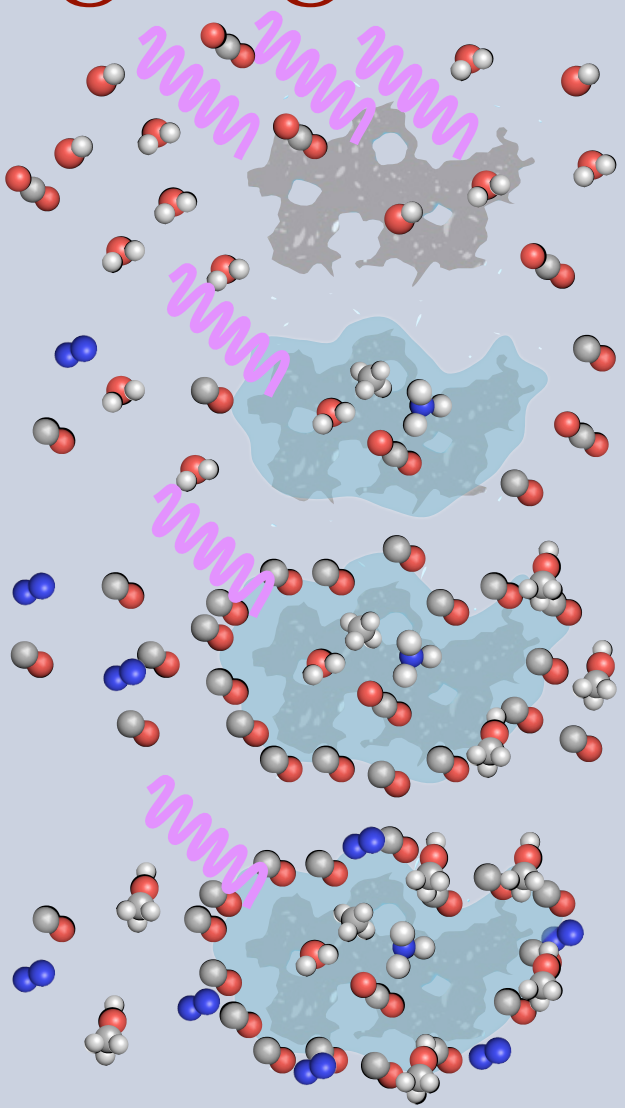
Small ice features present that trace complex organics

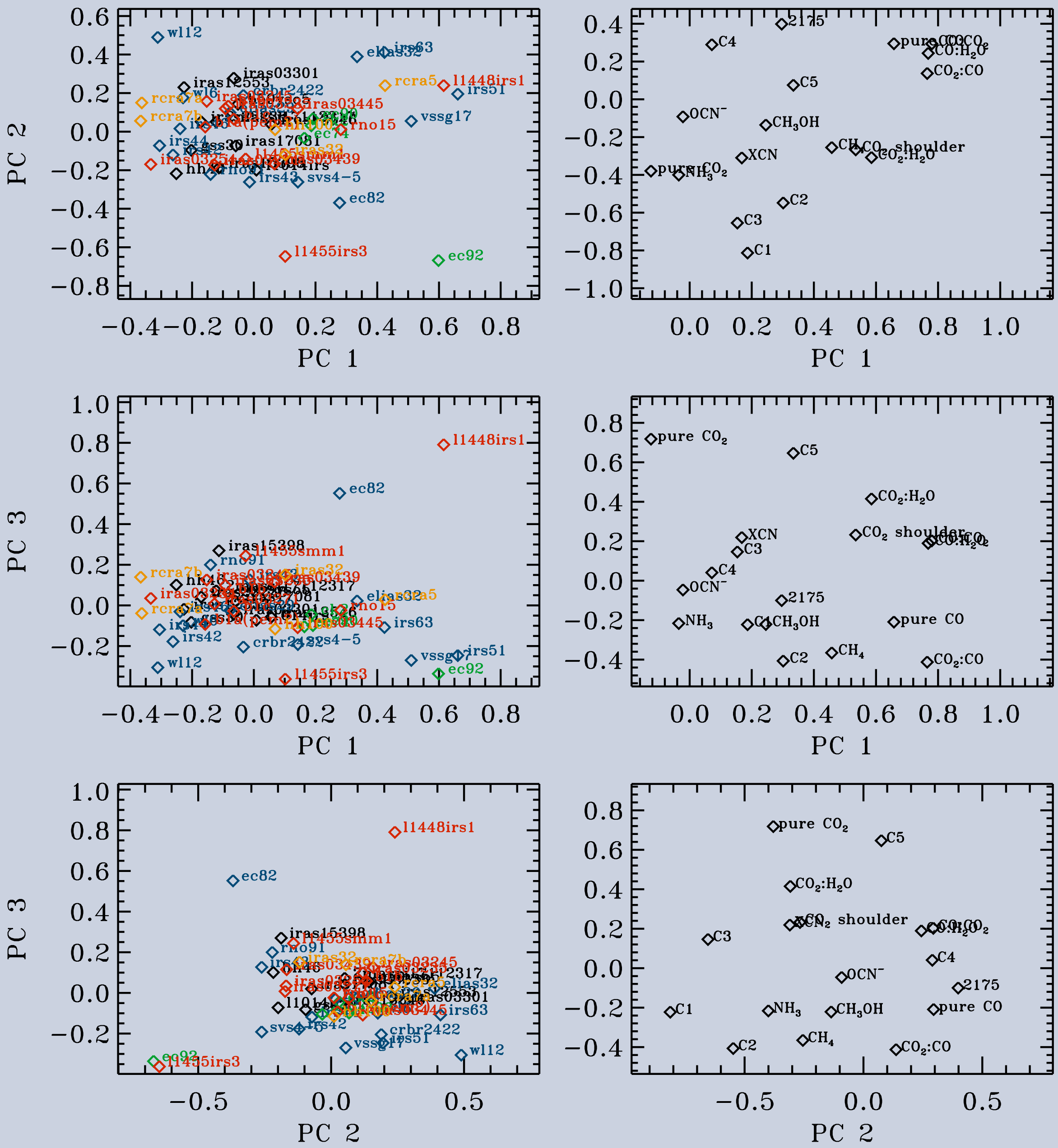
Need Spitzer-type sample with higher spectral resolution to assign carrier



Ices in star forming regions

- ★ Thanks to Spitzer and ISO statistics, typical ice abundances in a range of pre- and proto-stellar sources are known
- ★ Most ice formation does not care about the star: ice variation due to competition between early H_2O-dominated ice formation and late CO-driven ice formation
- ★ Protostellar processing segregates, evaporates and allows for radical diffusion required for most complex molecule formation schemes





PC 2
PC 1
PC 3
PC 2
wl12
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rcra5
l1448irs1
irs51
vssg17
rno15
ec74
ec82
l1455irs3
ec92
iras15398
l1455mm1
rno91
svs4-5
crbr2422
irs42
iras03445
C4
2175
pure CO
CO:H$_2$O
CO$_2$:CO
C5
OCN$^-$
CH$_3$OH
CH$_4$
CO$_2$ shoulder
CO$_2$:H$_2$O
XCN
pure CO$_2$
NH$_3$
C2
C3
C1