Complex Organic Molecules in Protoplanetary Disks

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Why study protoplanetary disks?

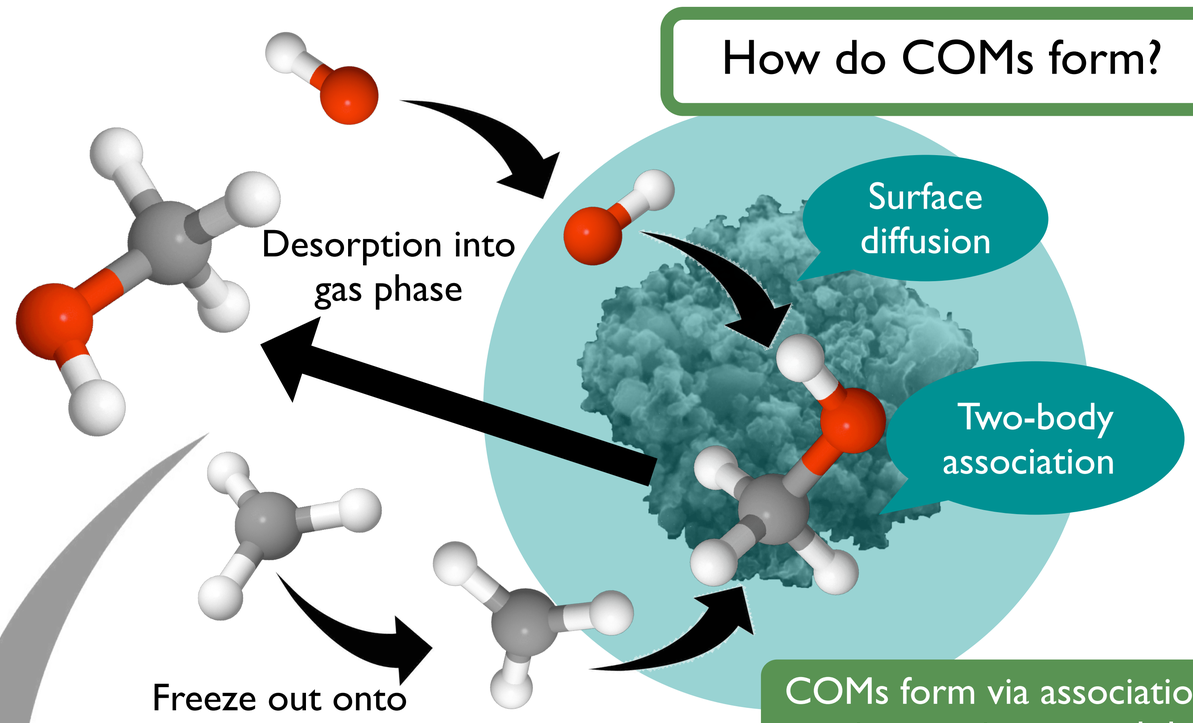
Birth sites of planetary systems

Complex interplay of radiation, dynamics, physics, and chemistry

Solar System likely formed within the Sun's natal disk

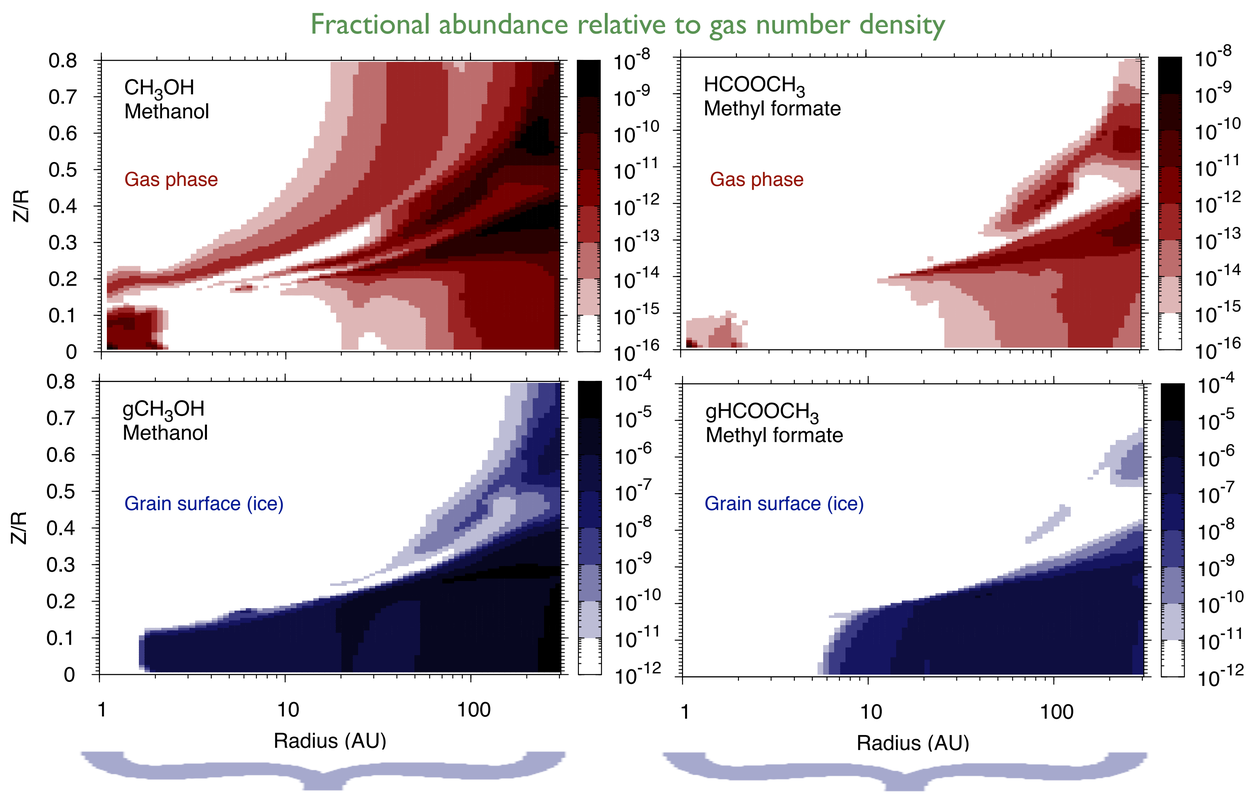
Is it possible for **complex organic molecules** (**COM**s) to form in protoplanetary disks and survive assimilation into planetary systems?

How do COMs form?



Can COMs form in protoplanetary disks?

We test this hypothesis using a protoplanetary disk model and comprehensive chemical network including the formation of COMs[1,2,3,4,5]



COMs are efficiently formed via thermal grain-surface chemistry in the cold, outer disk

Grain-surface COMs are abundant (x ~ 10^{-5}) in the disk midplane only

Grain-surface COMs reach much higher abundances than gas-phase analogs

COMs are released from the grain into the gas phase via non-thermal desorption

Molecular layer
Photodesorption

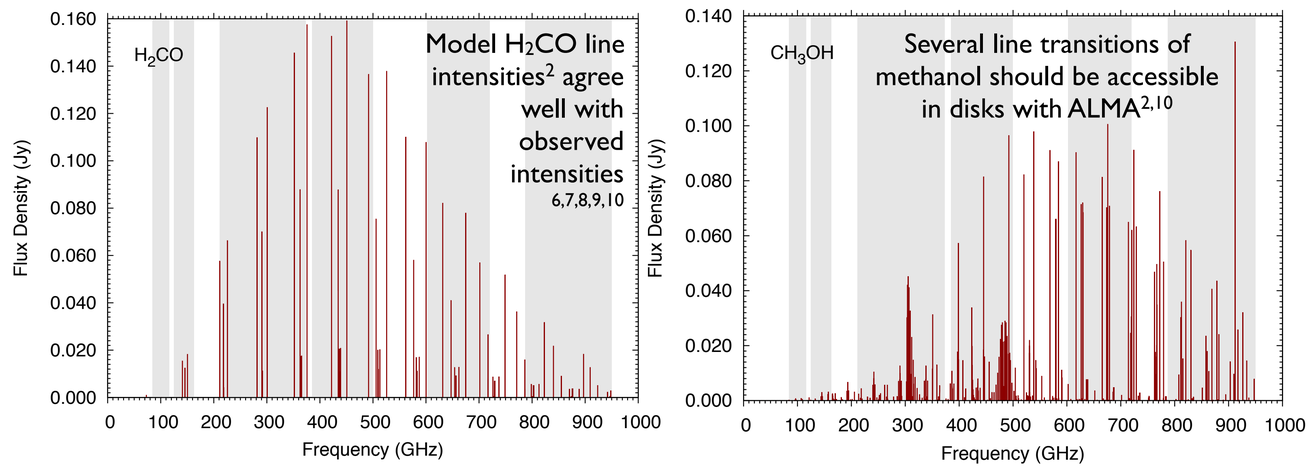
Midplane
Cosmic-ray desorption

'Complex' gas-phase COMs reach lower abundances (x 100 - 10000) than more 'simple' COMs

Can we observe gas-phase COMs in protoplanetary disks?

To determine this, we calculate the molecular line emission

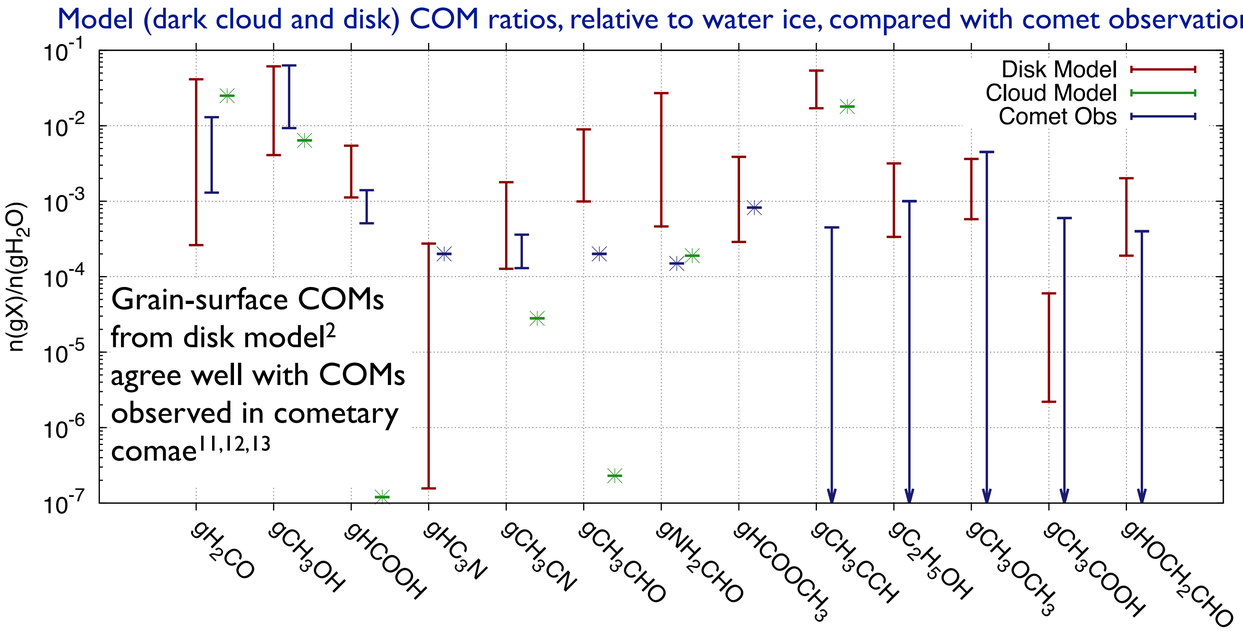
H_2CO and CH_3OH disk-integrated line flux densities (shaded regions are ALMA observing bands)



Origin of COMs in the Solar System?

We compare our initial ice abundances (dark cloud) and model disk abundances with comet observations

Model (dark cloud and disk) COM ratios, relative to water ice, compared with comet observations



- COMs form efficiently in disk midplane via thermal grain-surface chemistry
- Gas-phase COMs are released from the grain via non-thermal desorption
- Model results agree well with observations towards disks and comets
- Gas-phase methanol should be observable in disks with ALMA

References: (1) Walsh et al. 2010, ApJ, 722, 1607, (2) Walsh et al. 2013, A&A, in prep (3) Laas et al. 2011, ApJ, 728, 71, (4) Garrod et al. 2008, ApJ, 682, 283, (5) Harada et al. 2010, ApJ, 721, 1570, (6) Dutrey et al. 1997, A&A, 317, L55, (7) Aikawa et al. 2003, PASJ, 55, 11, (8) Thi et al. (2004), A&A, 425, 955, (9) Öberg et al. 2010, ApJ, 720, 480, (10) Qi et al. 2013, ApJ, 765, 34, (11) Bockelée-Morvan et al. 2004, in Comets II, 391, (12) Crovisier et al. 2004, A&A, 418, 1141, (13) Crovisier et al. 2006, in IAU Symposium 229, 133