The Cosmic Cycle of Dust and Gas in the Galaxy:
From Old to Young Stars,
July 9-13, 2018 @ Quy Nhon, Vietnam

Gas and Dust in Protoplanetary Disk:

their connection to materials in our Solar System

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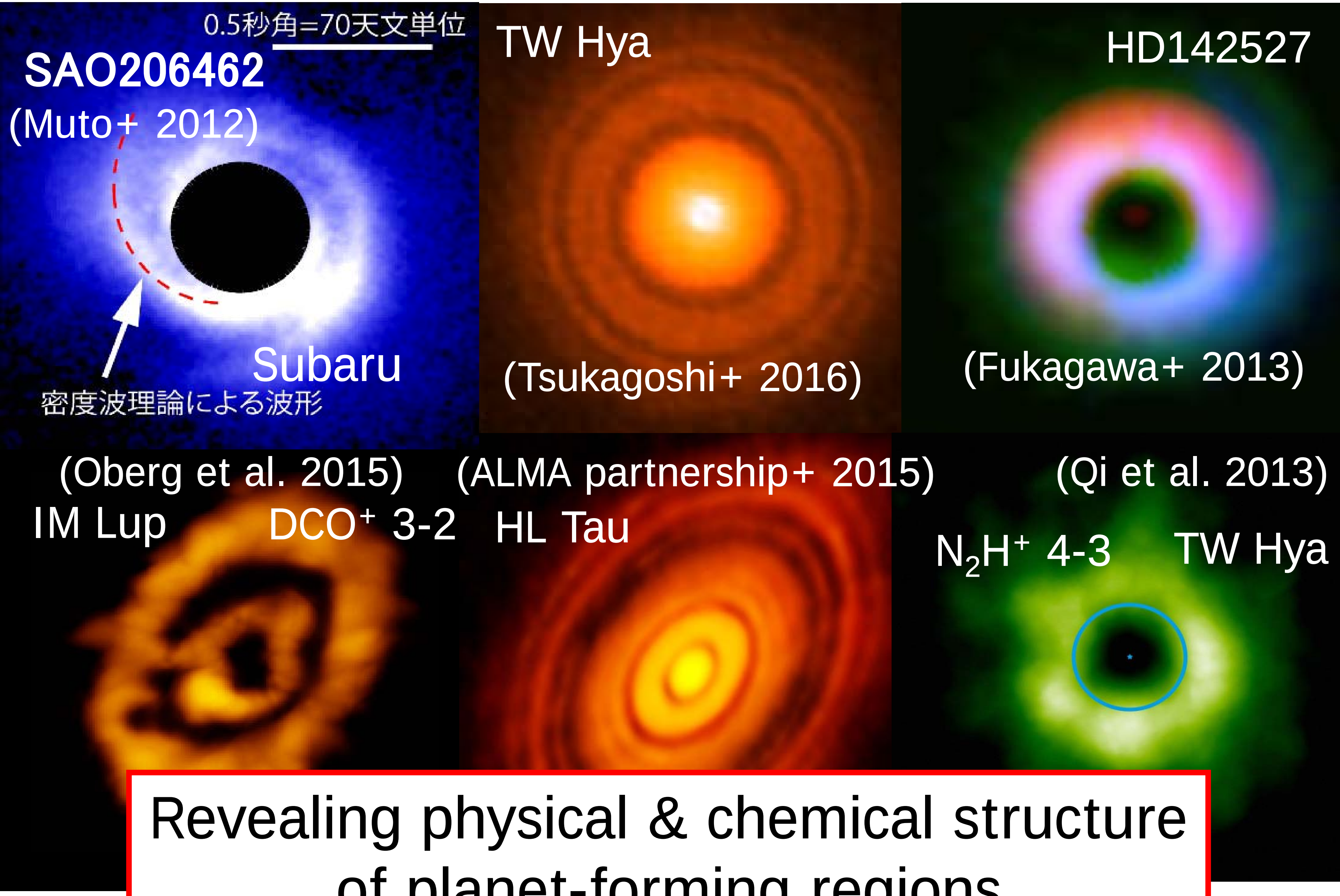
Contents

- Introduction
- Complex Organic Molecules in Disks
- Effect of C/O Ration in Gas in Disks

Wei, HN, Lee, Ip, Walsh & Millar in prep.

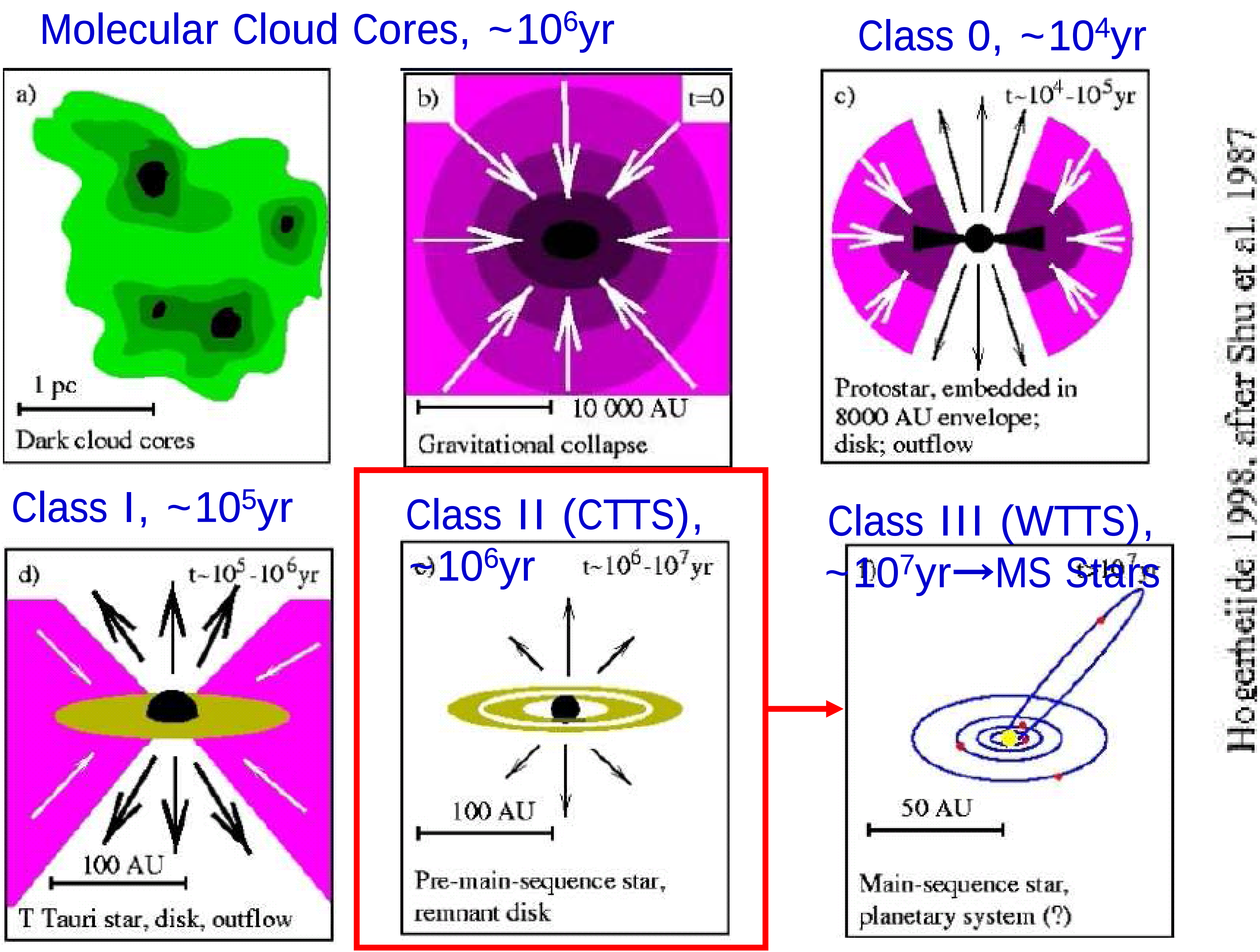
Introduction

Gas & Dust Observations in PPDs



Revealing physical & chemical structure of planet-forming regions

From Molecular Clouds to Planetary Systems

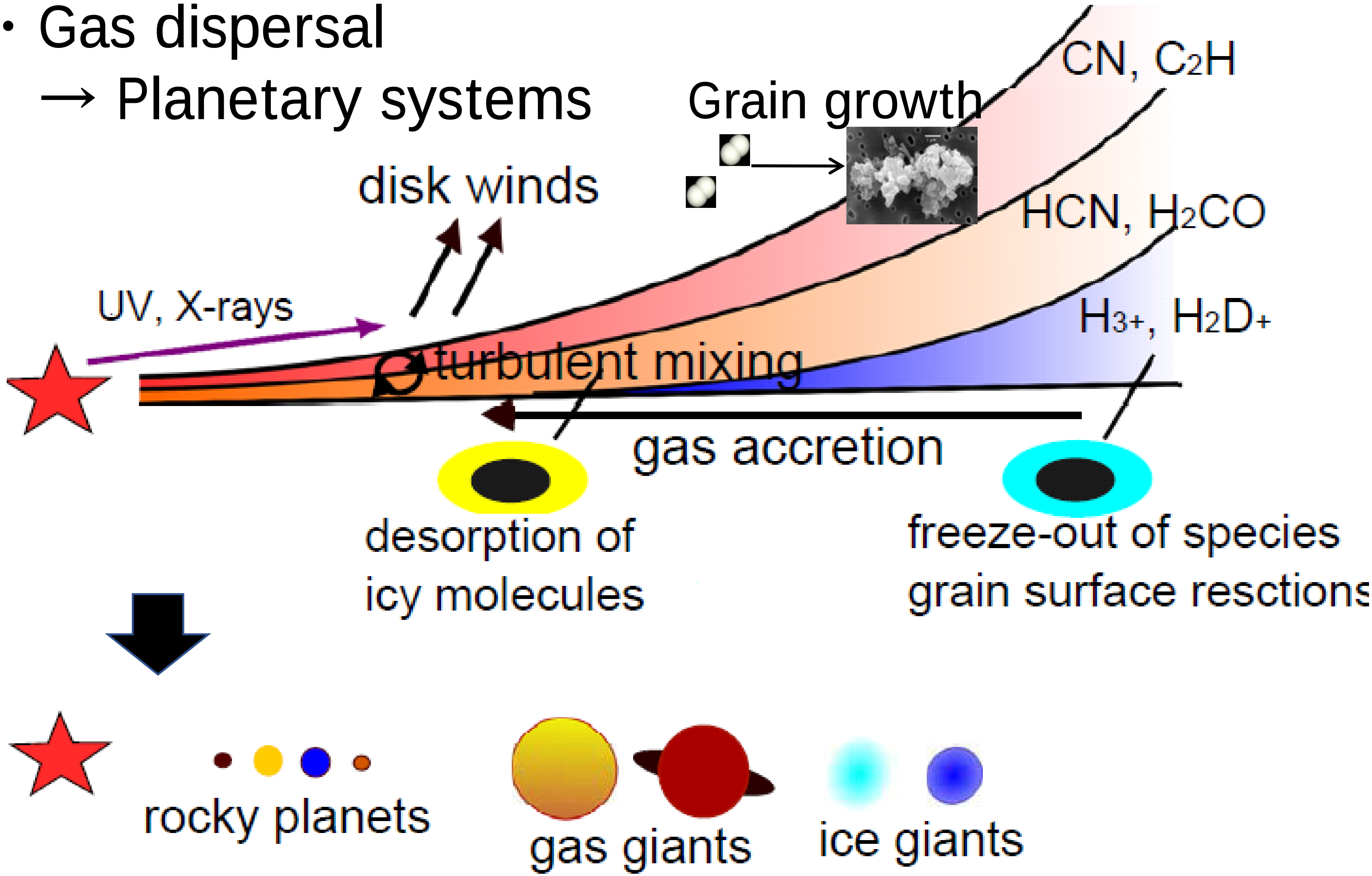


Hogerheijde 1998, after Shu et al. 1987

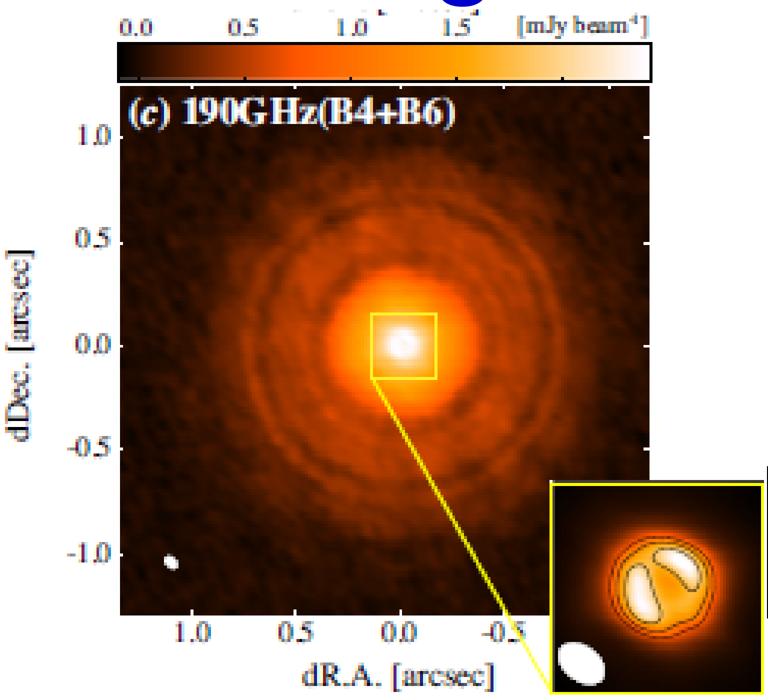
From Protoplanetary Disks to Planetary Systems

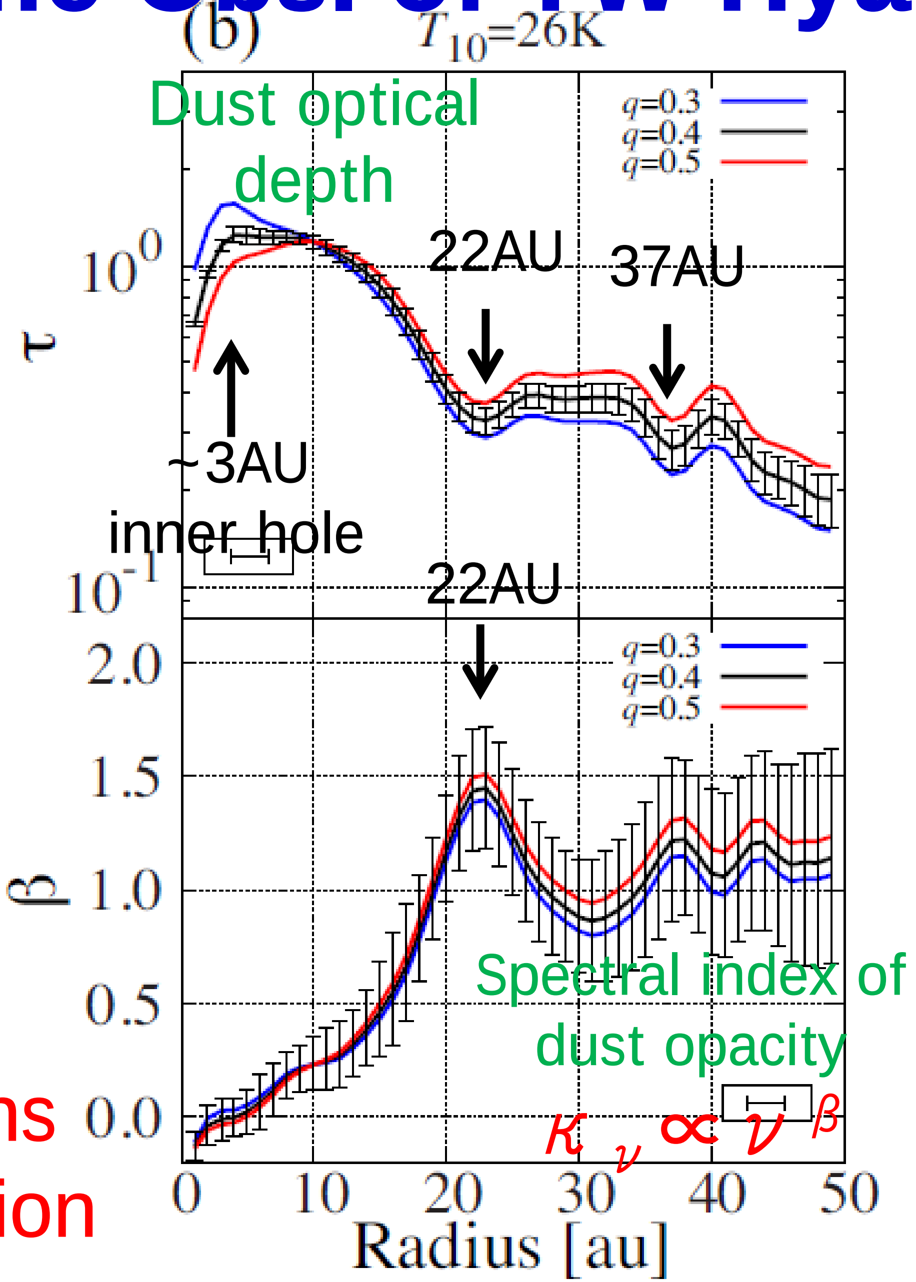
- Grain growth, settling, radial drift
- Gas dispersal

→ Planetary systems



ALMA Long Baseline Obs. of TW Hya





ALMA cycle 3 DDT B4 & B6

Spectral index enhances at the gap

→ Depletion of large grains

→ indicating planet formation

(Tsukagoshi et al. 2016)

Dust in Gap Opened by a Planet

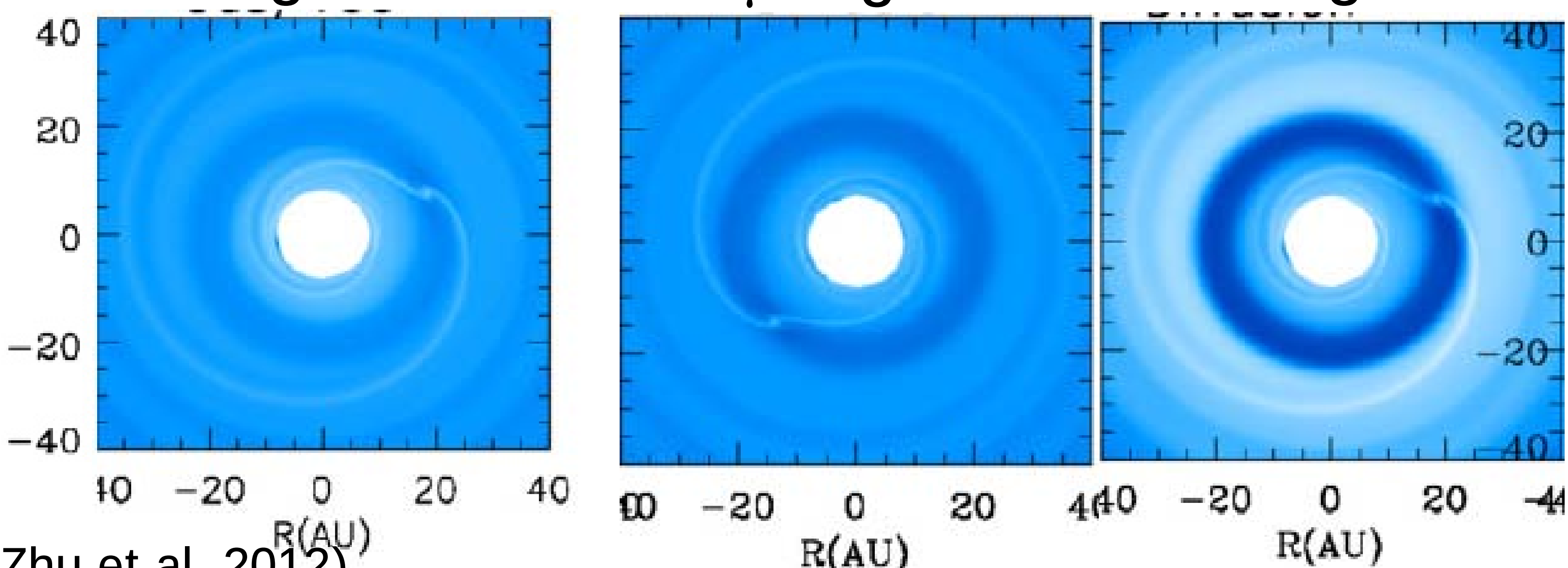
Planet opens a gap in gas

→ Distribution of small grains are similar to gas

Large grains are depleted in the gap due to dust filteration

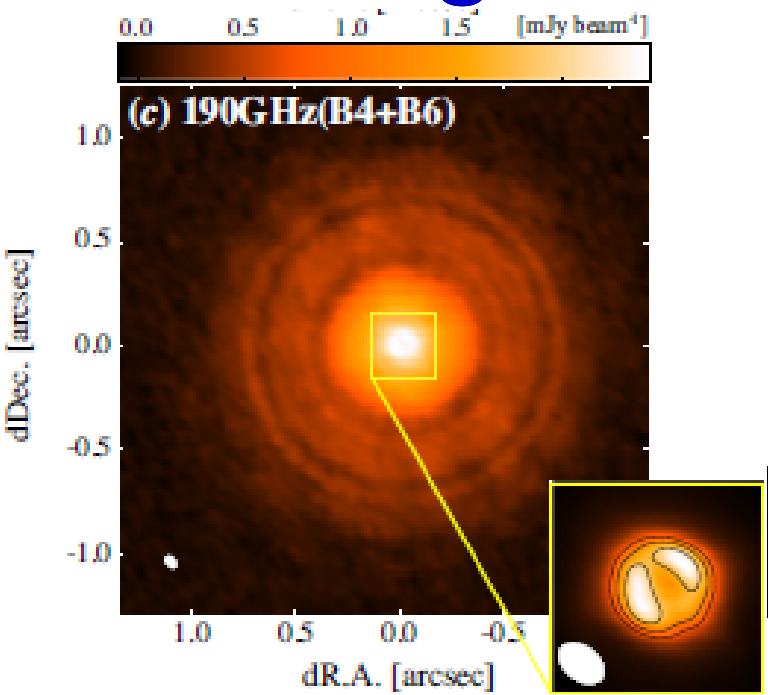
→ only small grains are left in the gap

gas | 30μm grains | 1mm grains



(Zhu et al. 2012)

ALMA Long Baseline Obs. of TW Hya



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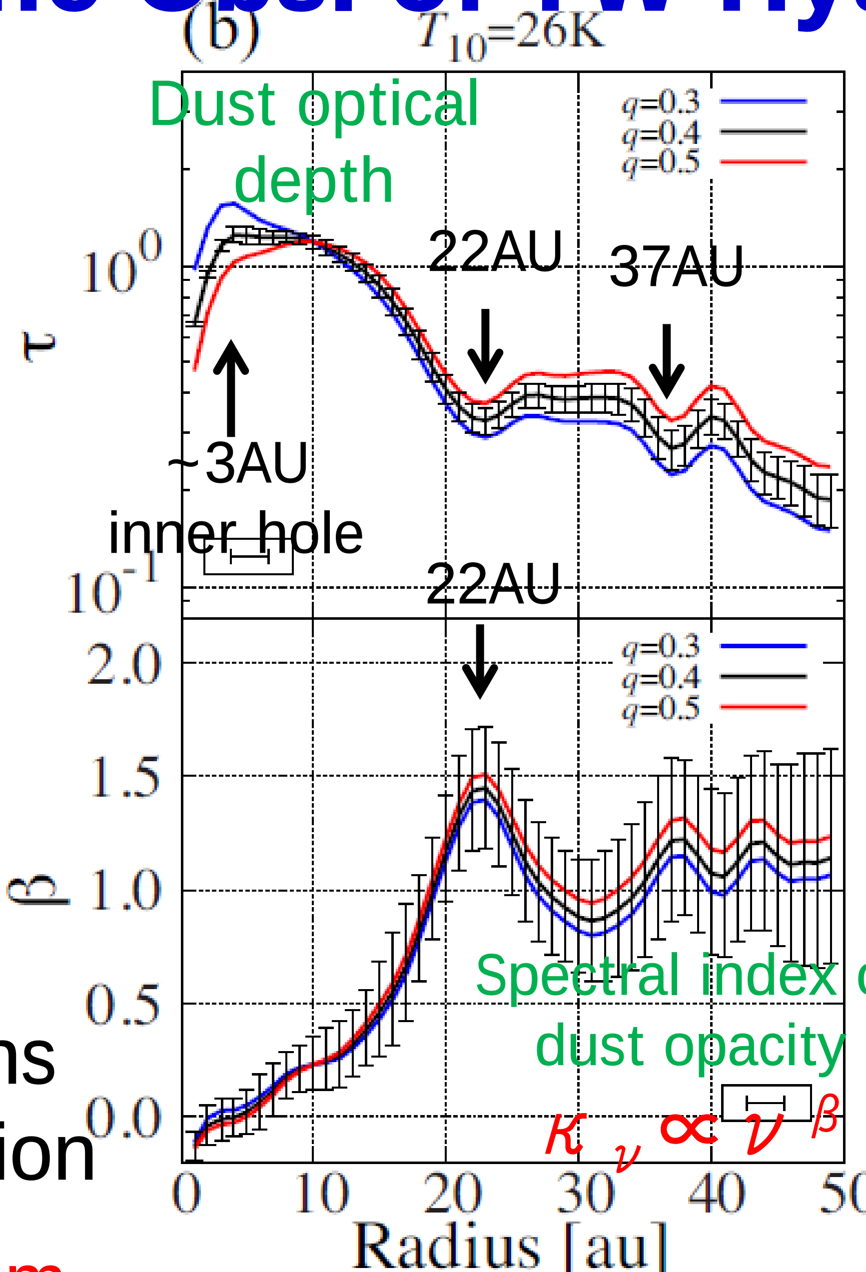
⇒ Poster by Seongjoong Kim

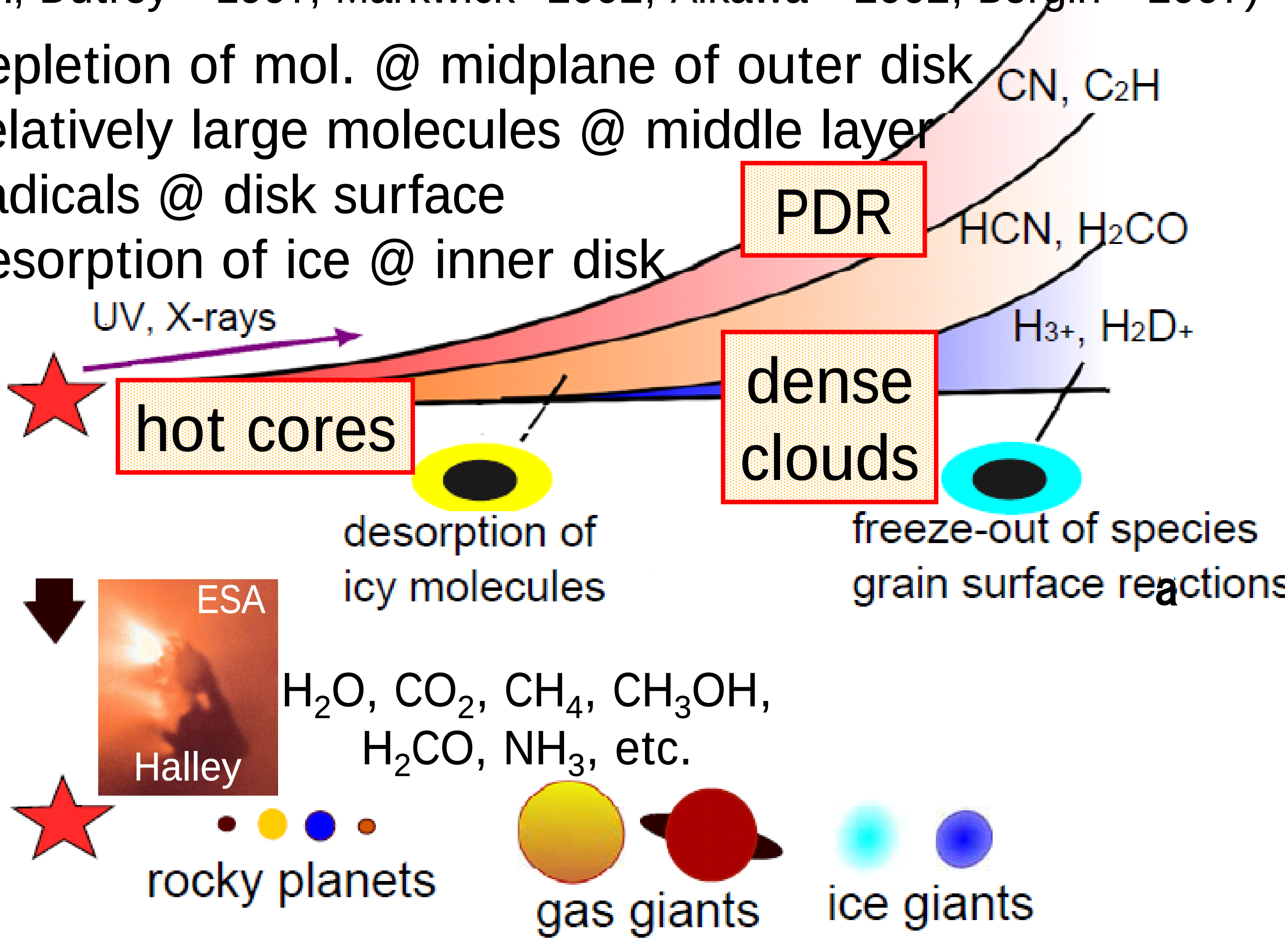


(Tsukagoshi et al. 2016)

Chemical Structure of PPDs

(e.g., Dutrey+ 1997, Markwick+2002, Aikawa+ 2002, Bergin+ 2007)

- Depletion of mol. @ midplane of outer disk
- Relatively large molecules @ middle layer
- Radicals @ disk surface
- Desorption of ice @ inner disk



Complex Organic Molecules in Disks

Observed Interstellar Molecules

CH+	HCN	H2CO	HC3N	CH3OH	HC5N	HCOOCH3	HC7N
CS	HNC	H2CS	HCOOH	CH3CN	CH3CCH	CH3C3N	HC9N
CO	HCO	H2CN	CH2NH	CH3NC	CH3NH2	CH3COOH	HC11N
CN	OCS	HNCO	CH2CO	CH3SH	CH3CHO	CH2CHCHO	C2H5CN
C2	CH2	HNCS	NH2CN	NH2CHO	CH2CHCN	CH2OHCHO	CH3C4H
						H2C6	CH3C5N
					H4O		CH3OCH3
					CHOH		C2H5OH
					-		CH3CONH2
							CH3COCH3
							OHCH2CH2OH
							C2H5OCHO
		HCNH+	C4H-				H2COOH?

C3N-

Amino acids in comet
@ STARDUST (Elsila et al. 2009)
ROSETTA (Altwegg et al. 2016)
Amino acids in meteorites
⇔ relation with
interstellar molecules ?

amino acids ?

1970 → **1980** → **1995** → **2018**

~10 species | **~50** | **~100** | **~210 species**

Obs. of Gas in Protoplanetary Disks

UV H_2 Lyman-Werner band transitions

Optical [OI] 6300A

NIR

H_2 v=1-0 S(1), S(0), CO Δv=2, Δv=1, H_2O, OH, HCN, C_2H_2, CH_4

MIR

H_2 v=0-0 S(1), S(2), S(4)

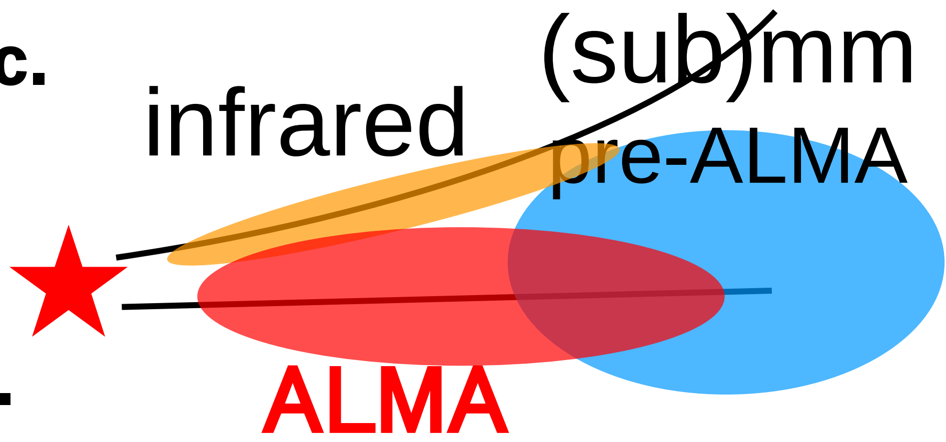
H_2O, OH, HCN, C_2H_2, CO_2, etc. (Spitzer Space Telescope)

FIR

[OI] 63um, 145um, CO, H_2O, CH^+, HD, NH_3, etc. (Herschel Space Observatory)

(sub)mm

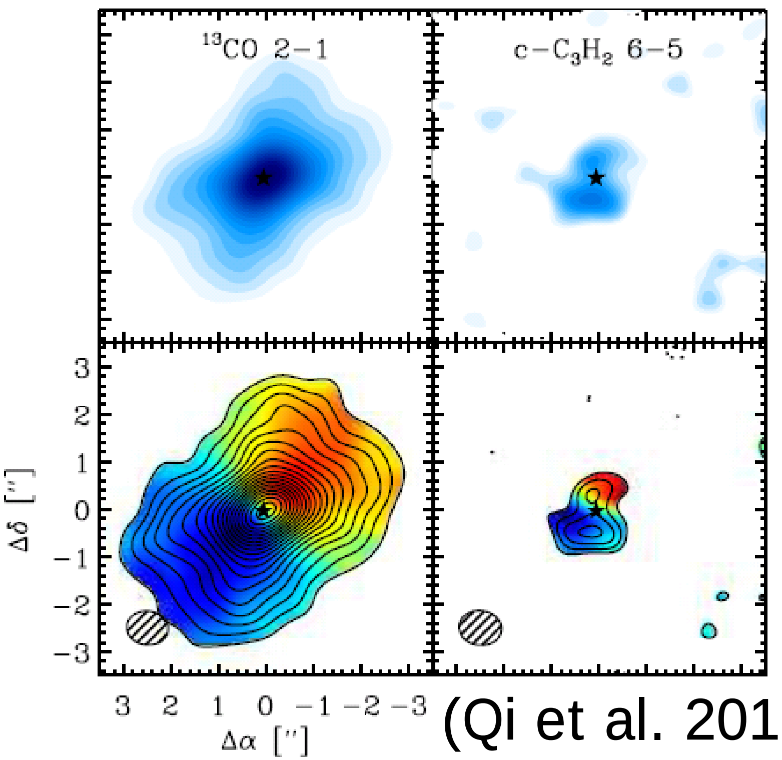
CO, ^{13}CO, $C^{18}O$, $C^{17}O$, $^{13}C^{18}O$, HCO^+, $H^{13}CO^+$, DCO^+, [CI], C_2H, c-C_3H_2, H_2CO, CH_3OH, HCN, $H^{13}CN$, DCN, $HC^{15}N$, HNC, CN, N_2H^+, N_2D^+, HC_3N, CH_3CN, CS, $C^{34}S$, SO etc.



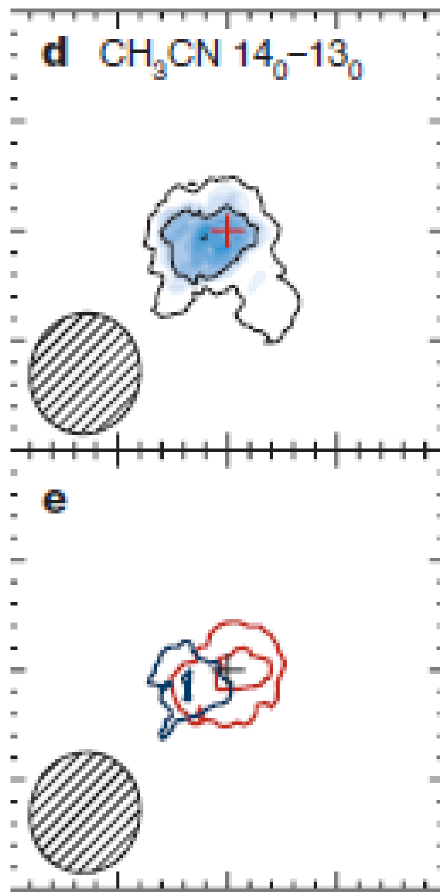
Complex Organic Molecules in Disks

HC_3N J=16-15, 12-11, 10-9 @ 146, 109, 91GHz
MWC480, LkCa15, GO Tau, IRAM 30m, PdBI
(Chapillon et al. 2012)

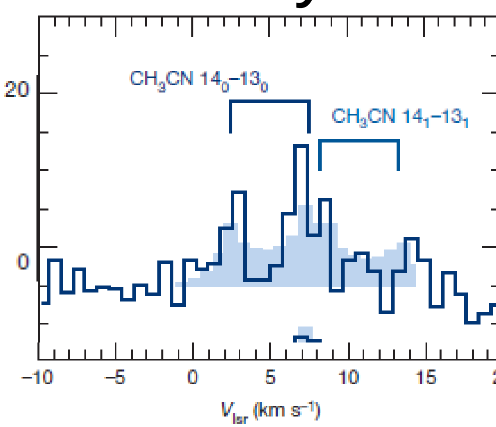
$c\text{-}C_3H_2$ J=6-5 @ 218GHz
HD163296, ALMA SV



(Qi et al. 2013b)



CH_3CN
14_0-13_0, 14_1-13_1,
@ 257GHz,
MWC480,
ALMA cycle 2

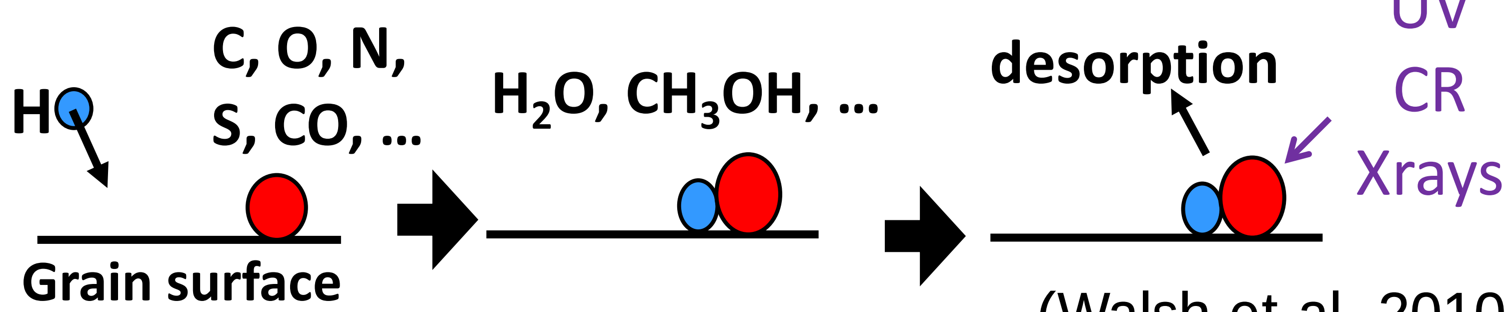


(Oberg et al. 2015)

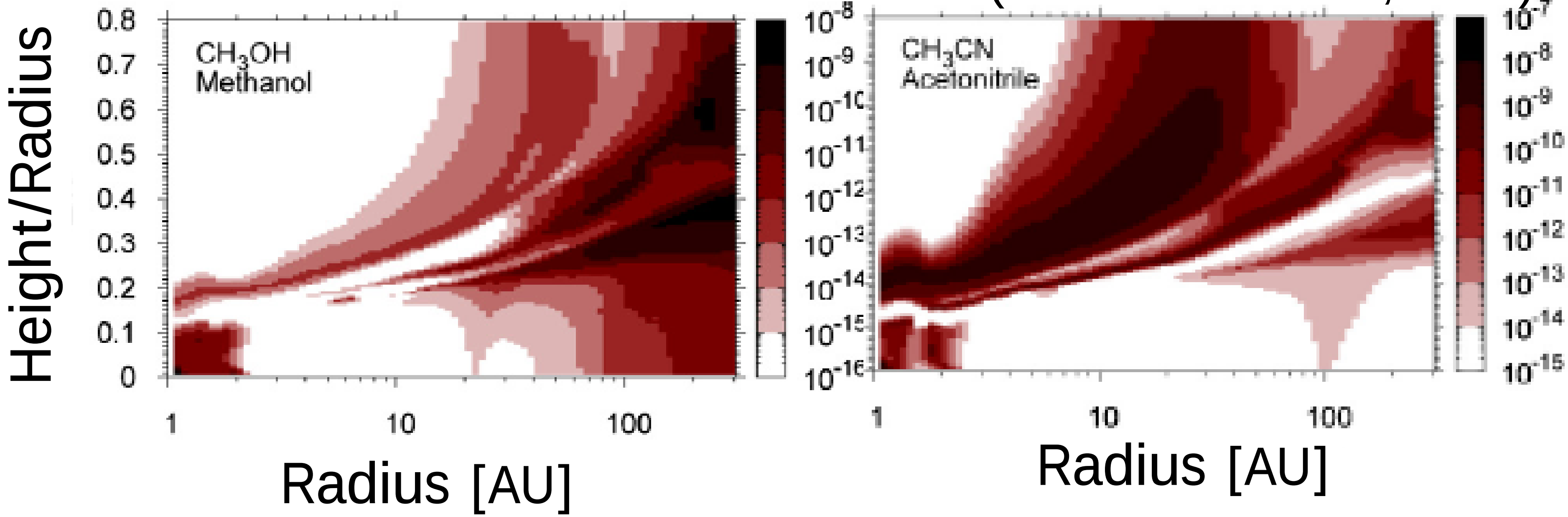
→more complex mol. will be found by ALMA

Modeling Complex Molecules in PPD

Grain surface reactions   Photodesorption

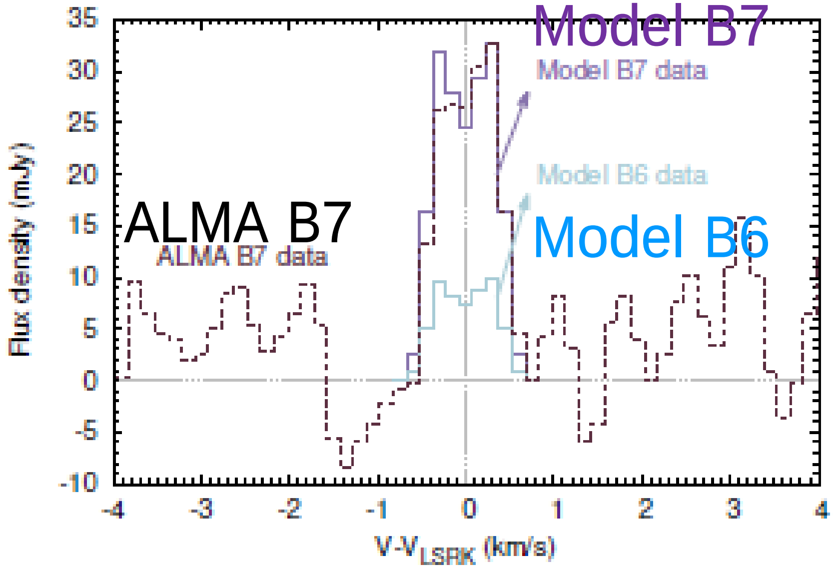


(Walsh et al. 2010, 2014)



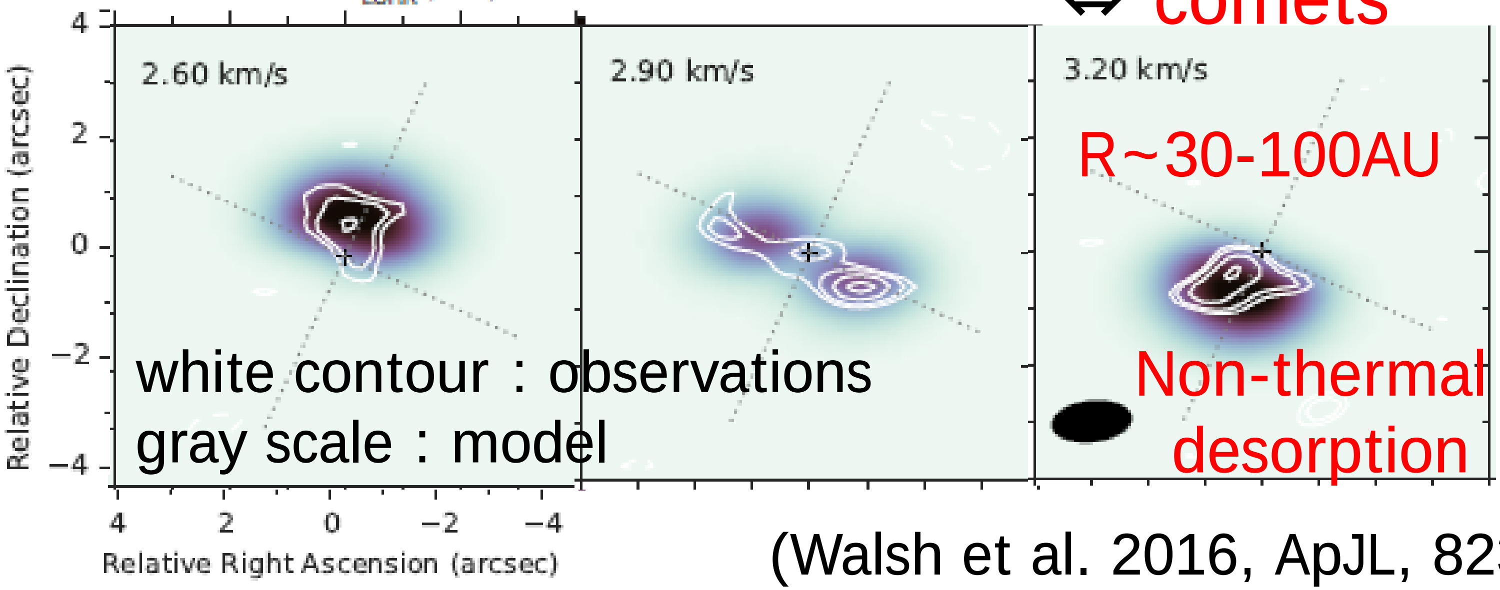
Complex organic mol. are formed efficiently
by grain surface reactions near the disk midplane

CH_3OH detection from TW Hya



CH_3OH
@ 304, 305, 307GHz
TW Hya, ALMA cycle 2
Stacking three lines of CH_3OH

CH_3OH/H_2O ~ 0.7-5%
⇔ comets

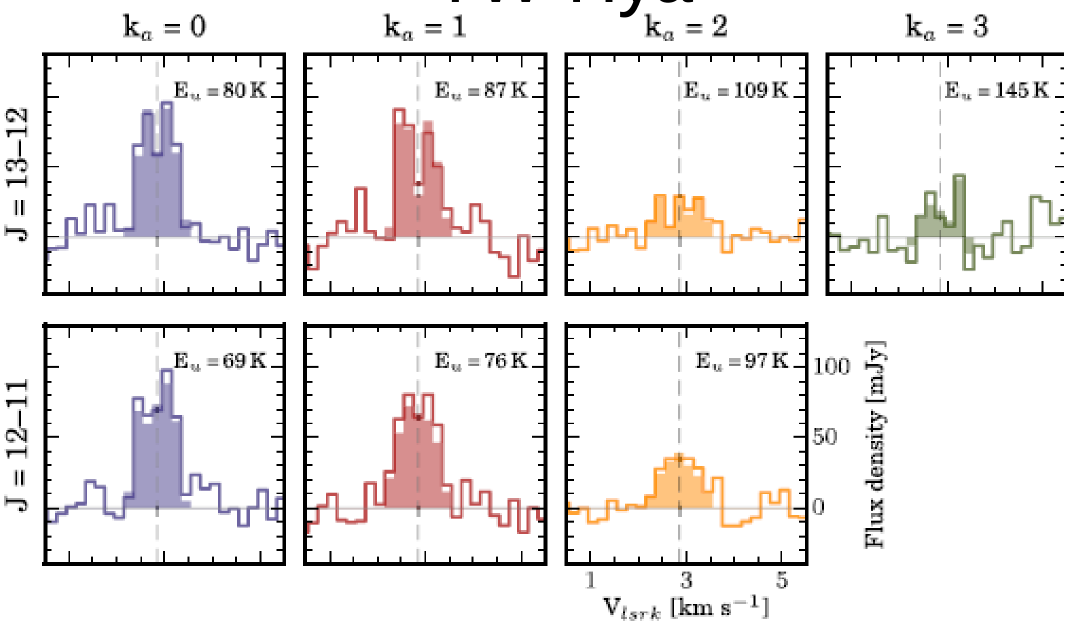


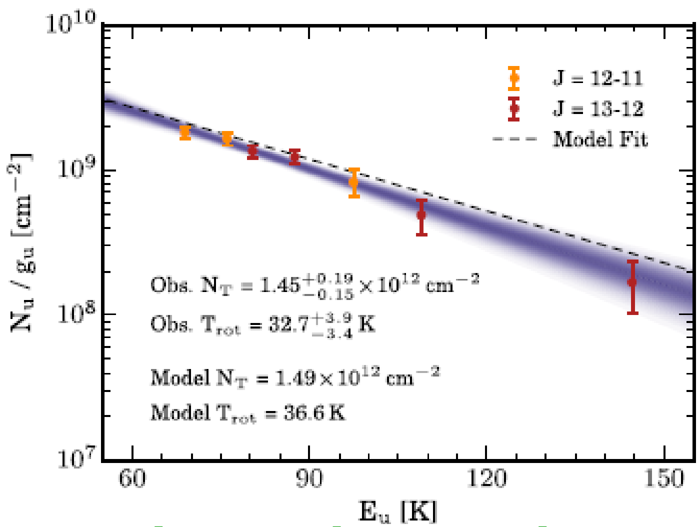
(Walsh et al. 2016, ApJL, 823, L10)

First detection of CH_3OH from protoplanetary disk!

CH_3CN & HC_3N detection in Disks

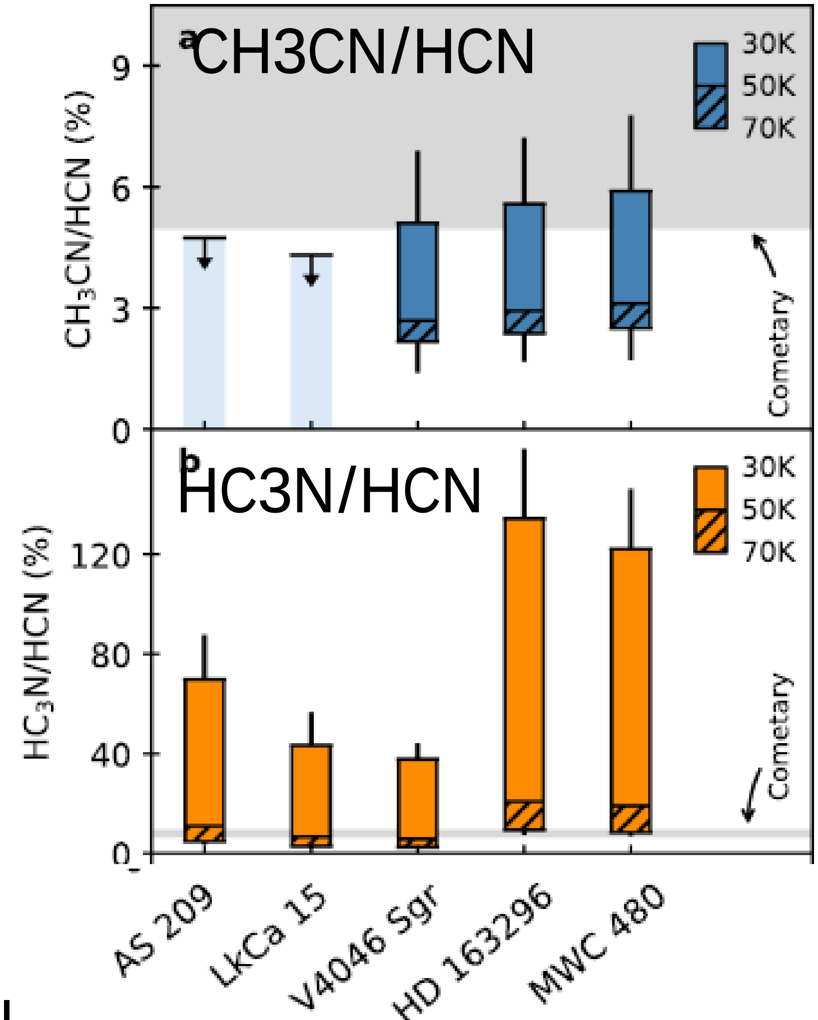
TW Hya





CH3CN
7 lines
@ Band 6

(Loomis et al. 2018)

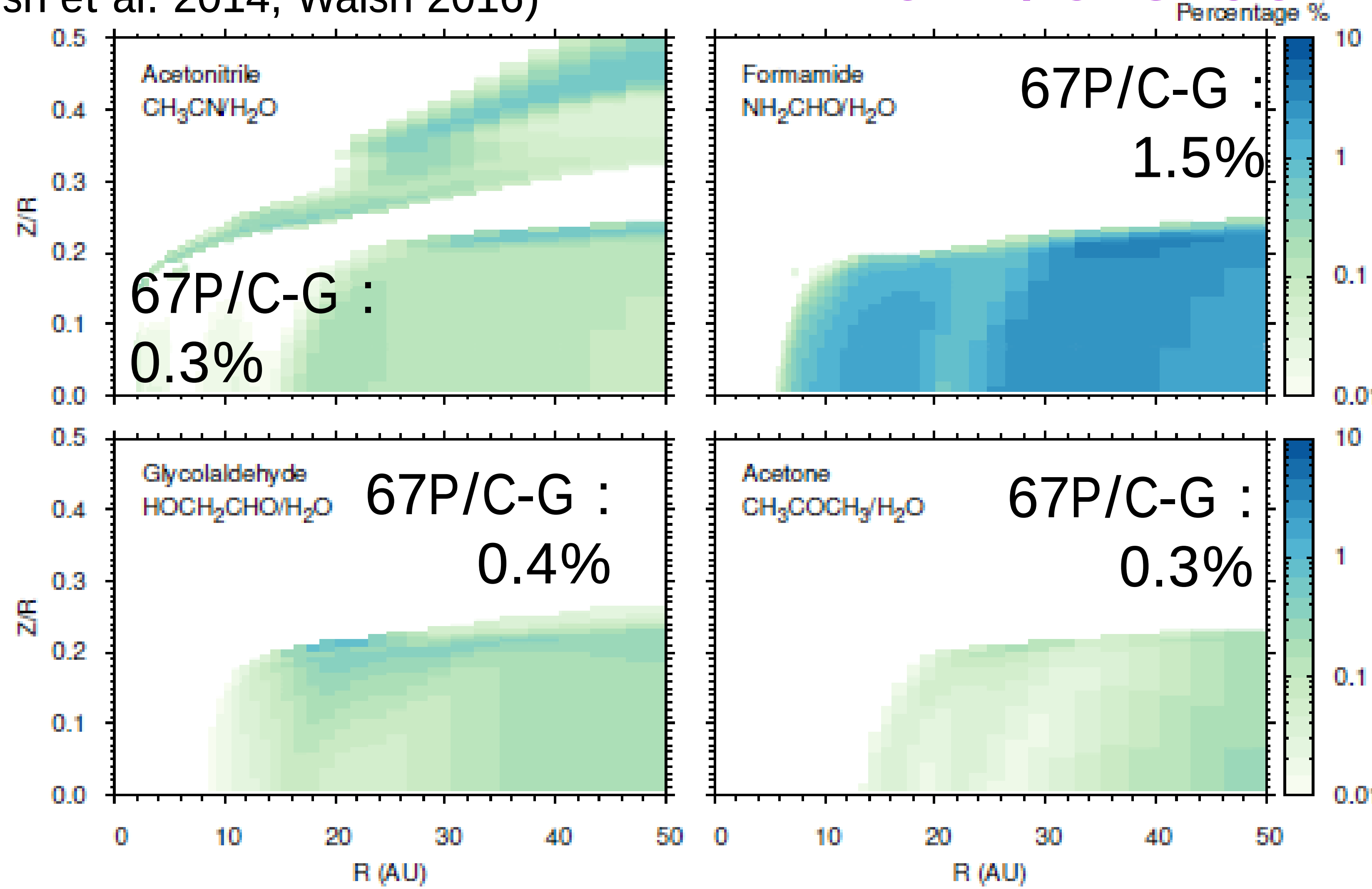


(Bergner et al. 2018)

Further detection & further investigation is needed

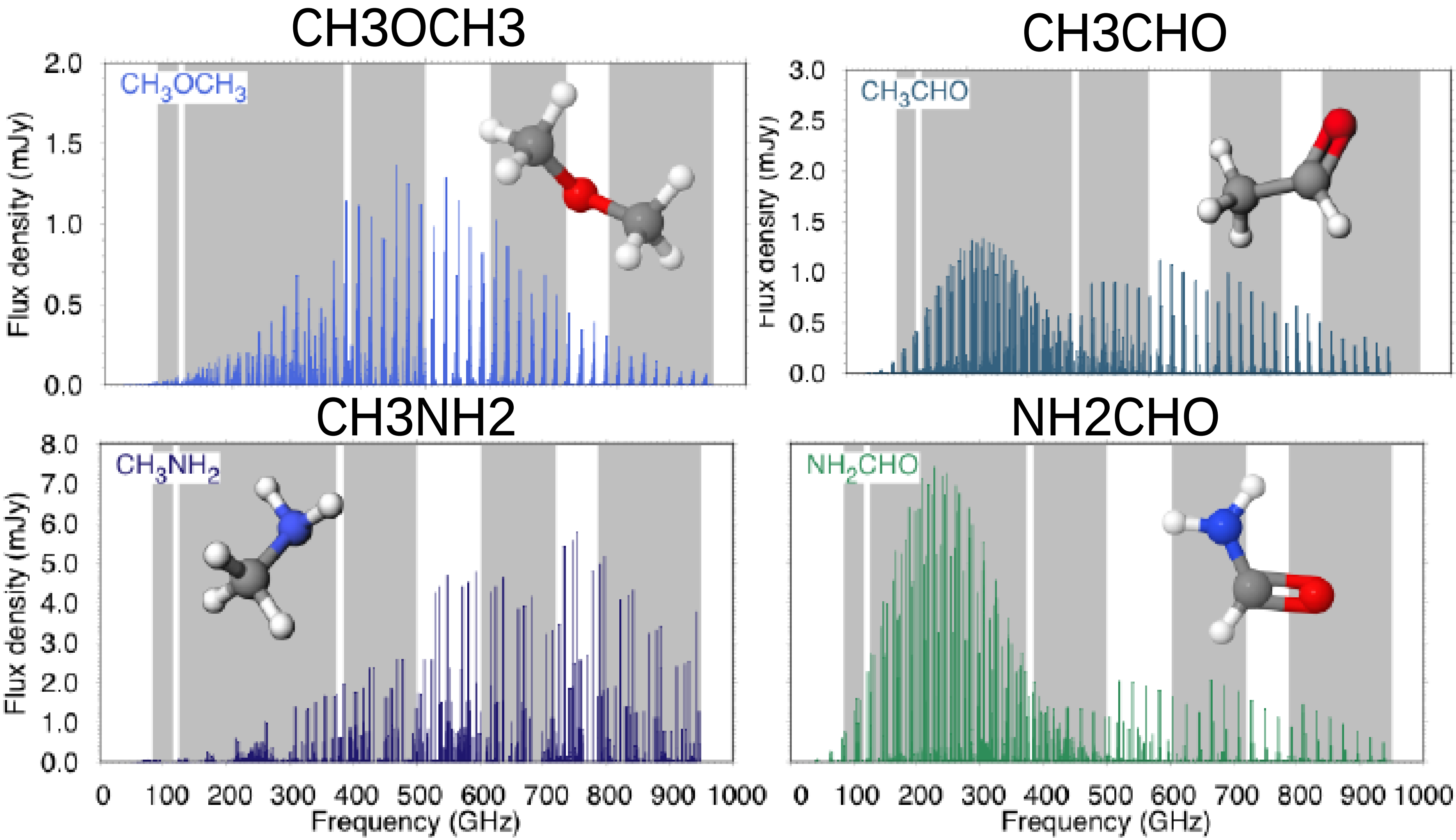
Distribution of Molecules in Disks found in 67P/C-G Comet

(Walsh et al. 2014, Walsh 2016)



Abundances of relatively small molecules are consistent, but we need more complete model especially for larger molecules

Model Spectra of More COMs in Disks

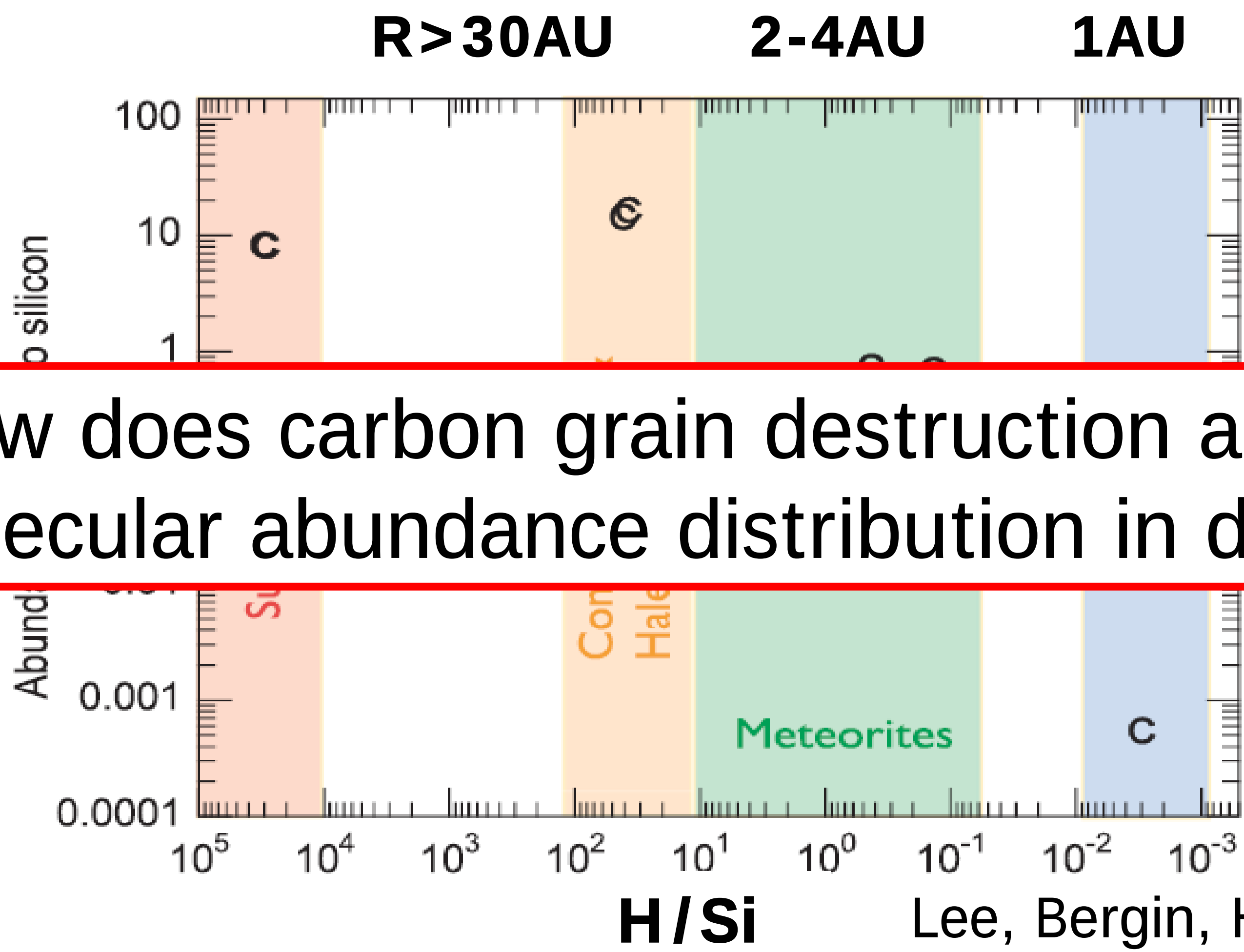


Searching more COMs in disks by ALMA!

(Walsh et al. 2017)

Effect of C/O Ratio in Gas in Disks

Carbon Depletion in Inner Solar System



Lee, Bergin, HN (2010)

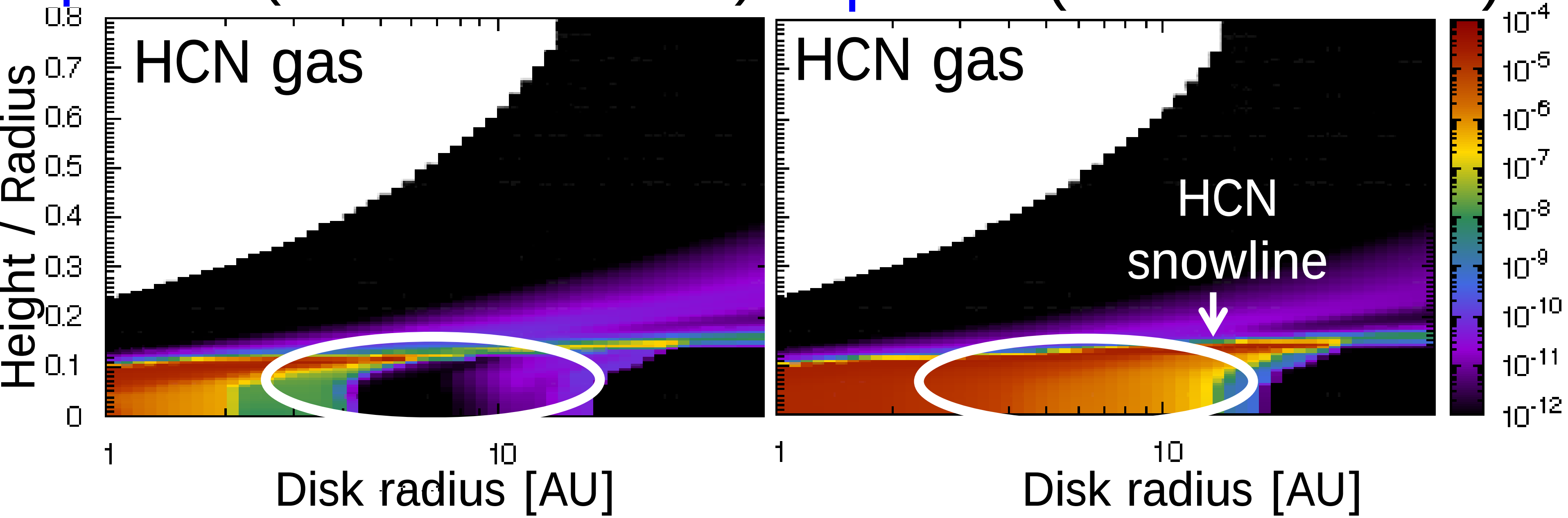
How does carbon grain destruction affect molecular abundance distribution in disks?

Carbon grains must be destroyed and carbon bearing species in gas escape from the Solar Nebular

Effect of carbon grain destruction

w/o C-grain destruction
C/O < 1 in gas
→ CO + O
→ rich in O-bearing species (molecular clouds)

with C-grain destruction
C/O > 1 in gas
→ CO + C
→ rich in C-bearing species (cf. carbon stars)



HCN gas abundance is significantly affected at 2AU<R<20AU

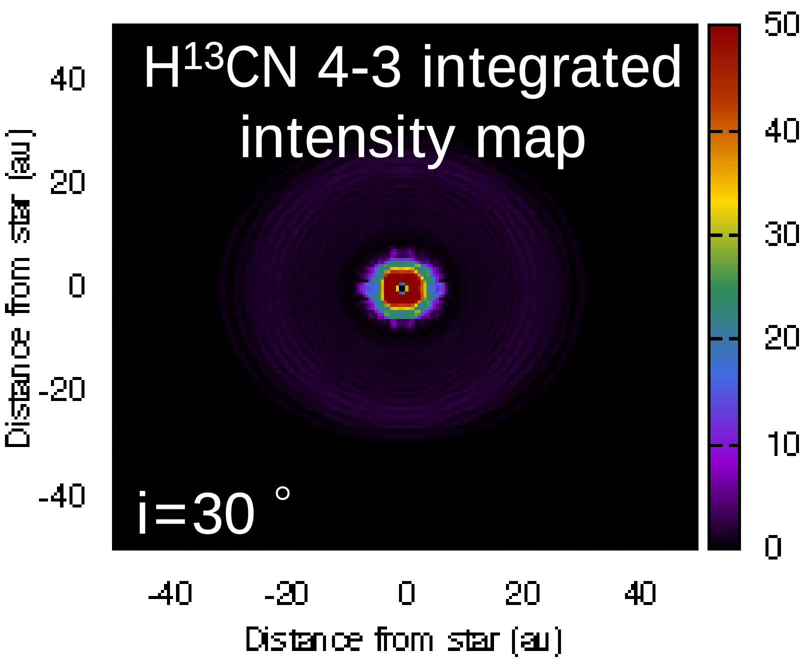
Herbig Ae disk

(Wei, HN, et al. in prep.)

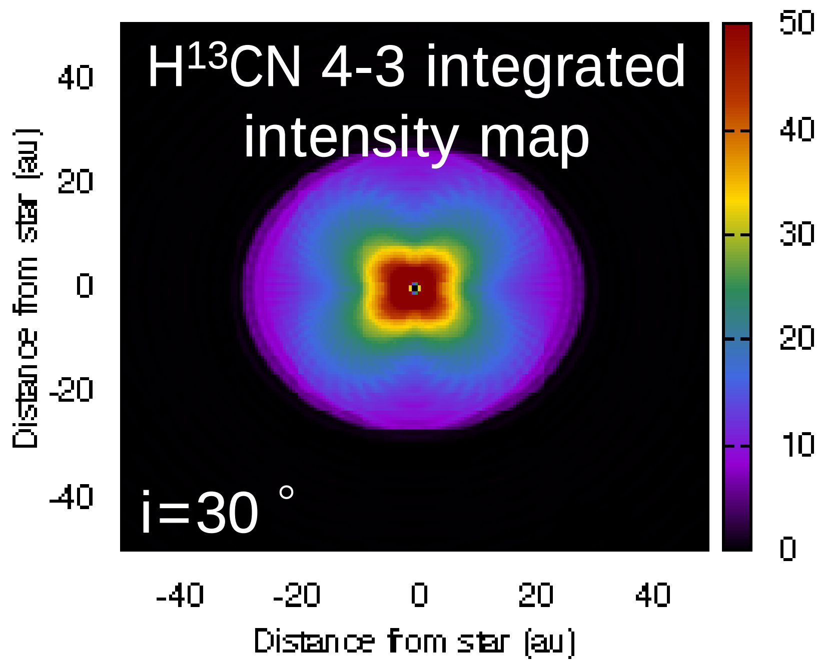
Effect of carbon grain destruction

physical model + chemical reactions
+ line radiative transfer

C/O < 1 in gas



C/O > 1 in gas



$H^{13}CN$ intensity map is affected at R<20AU
→ testable by ALMA observations?

Herbig Ae disk

(Wei, HN et al. in prep.)

Effect of carbon grain destruction

w/o C-grain destruction

C/O < 1 in gas

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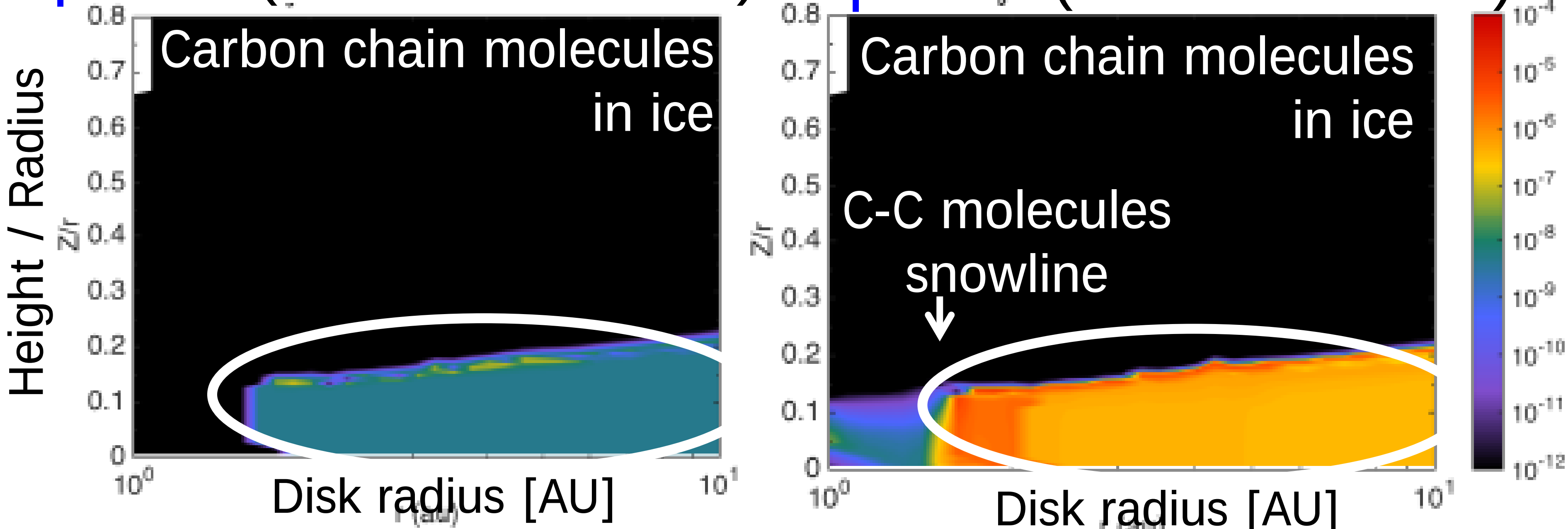


Effect on composition of C-bearing species in ice

T Tauri disk → Solar system objects (Wei, HN et al. in prep.)

Summary

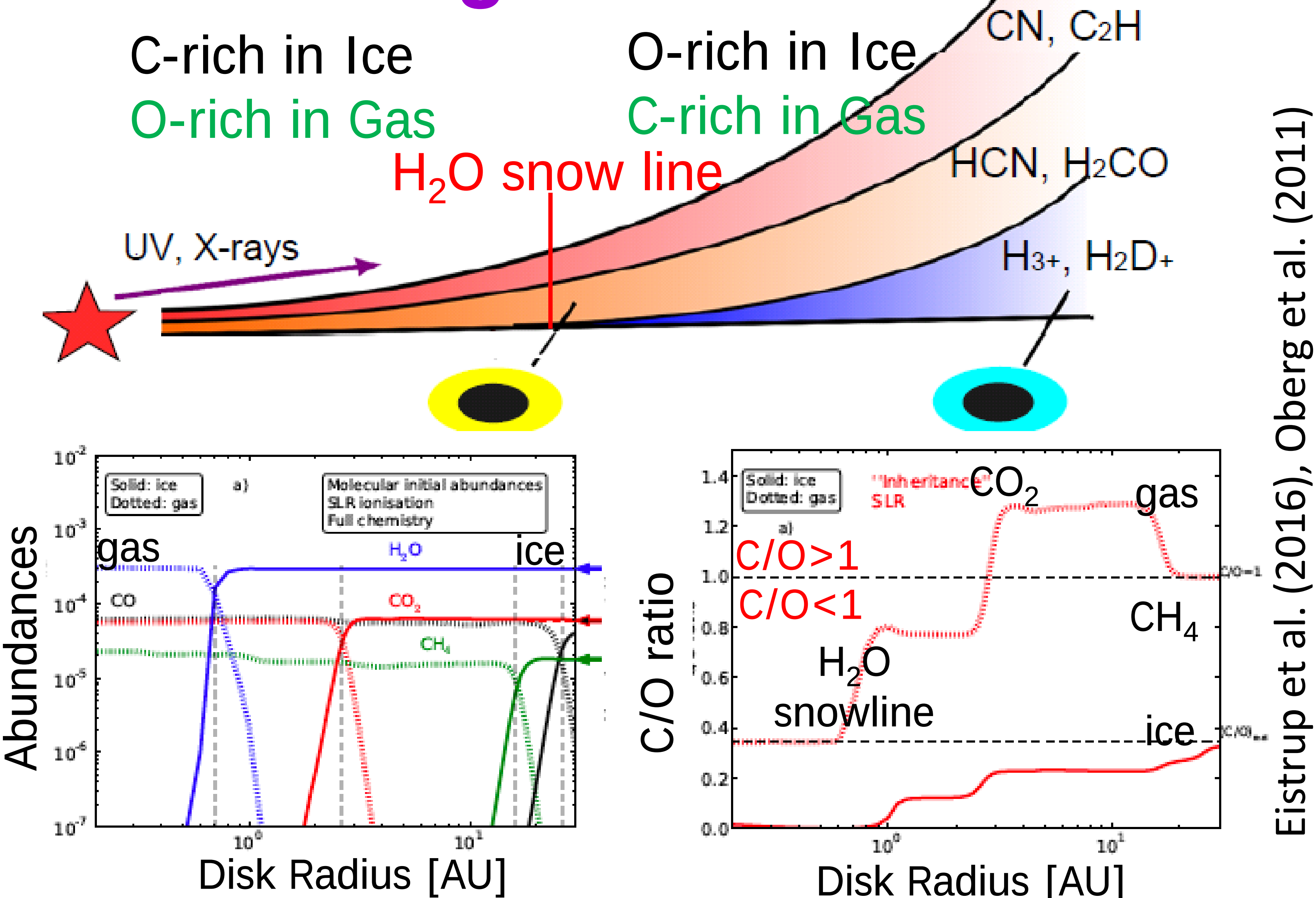
Observation & modelling of organic molecules in protoplanetary disks by ALMA

- Detection of HC_3N, CH_3CN, CH_3OH from disks
- Observed CH_3OH could be formed via grain surface reactions and non-thermally desorbed into gas
- CH_3OH/ H_2O ratio consistent with that in comets
- Further investigation is needed for connection to Solar System objects

Effect of C/O ratio in gas on disk chemistry

- Carbon grain destruction leads to enhancement of carbon-bearing species, such as HCN and carbon-chain molecules → testable by ALMA observations, effect on Solar System objects?

C/O ratio in gas around snowlines



C/O ratio in gas changes across the snowlines