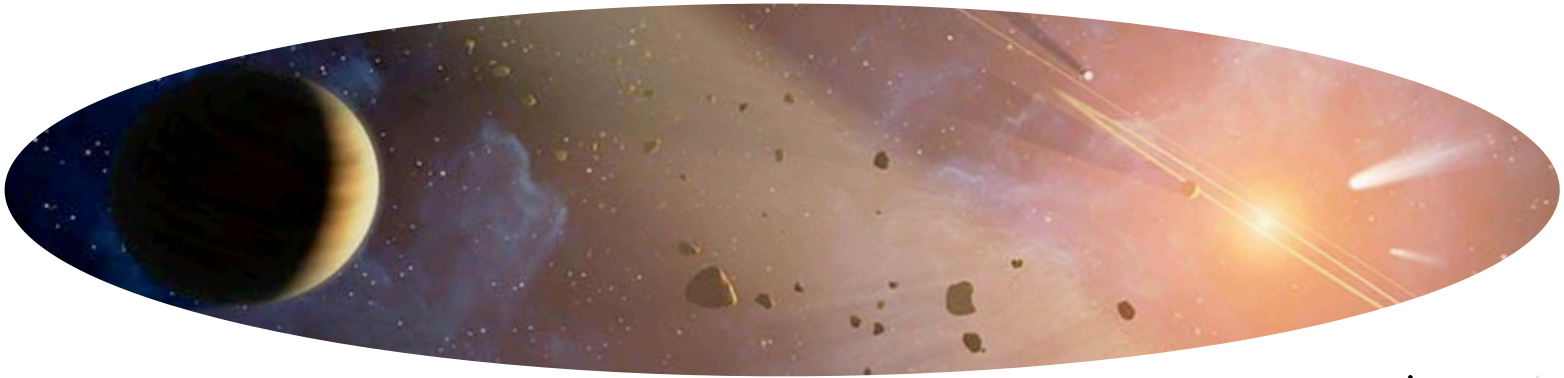
Photodissociation of N_2 and its impact on nitrogen chemistry in protoplanetary disks



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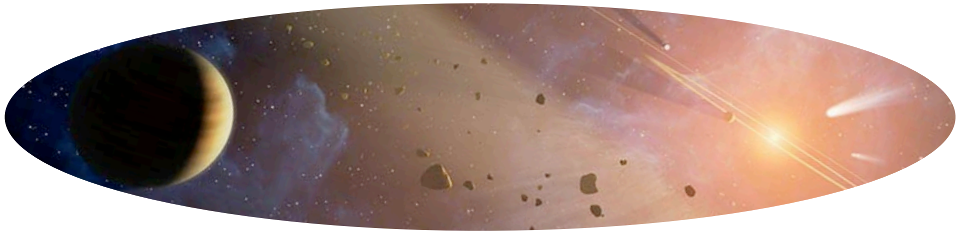
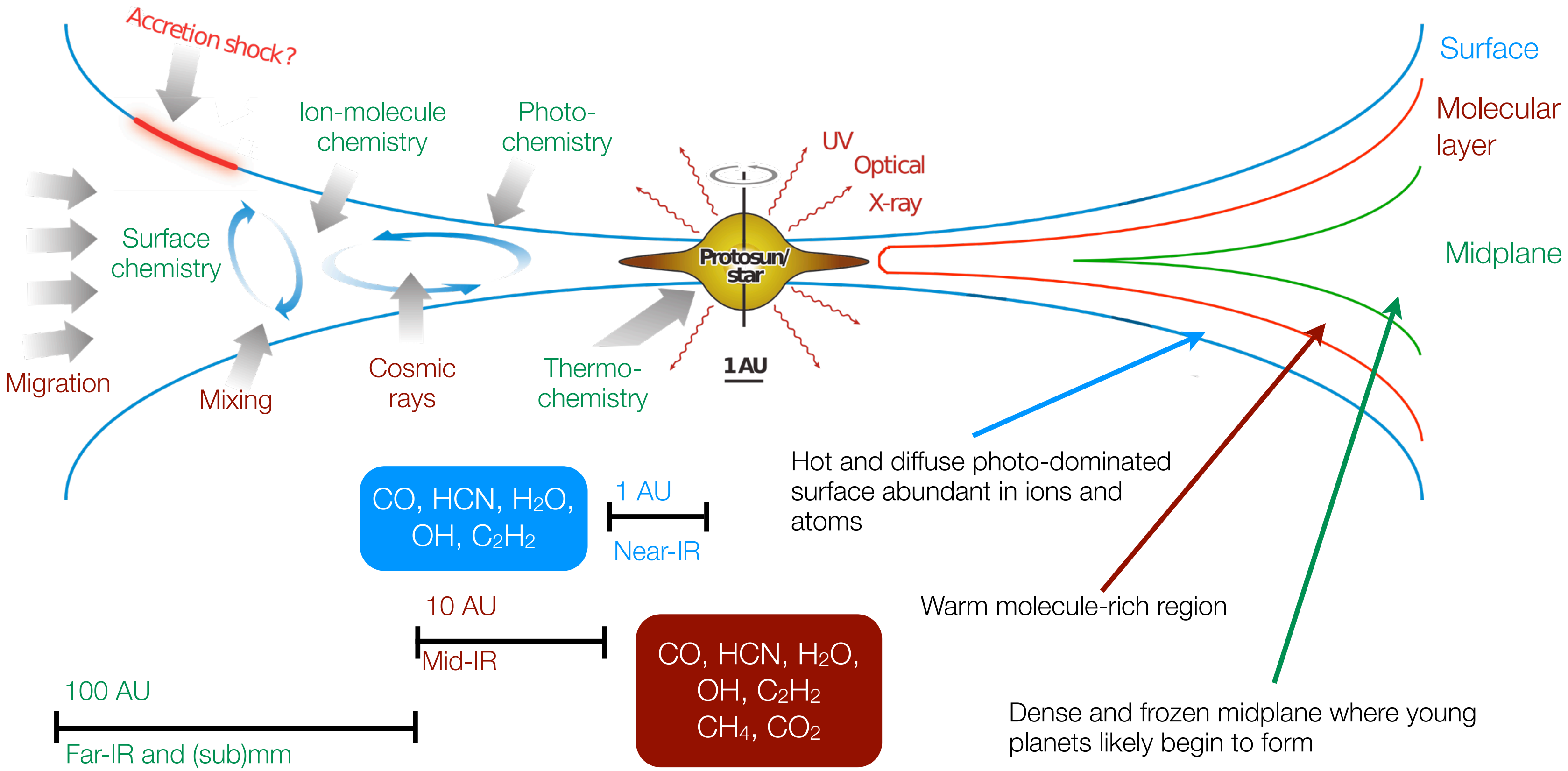
Protoplanetary Disks

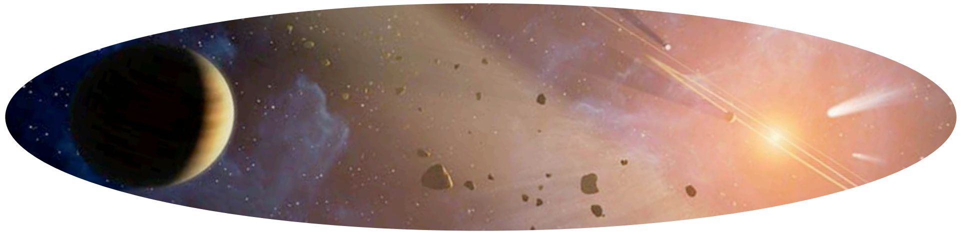


Protoplanetary disks are chemically layered

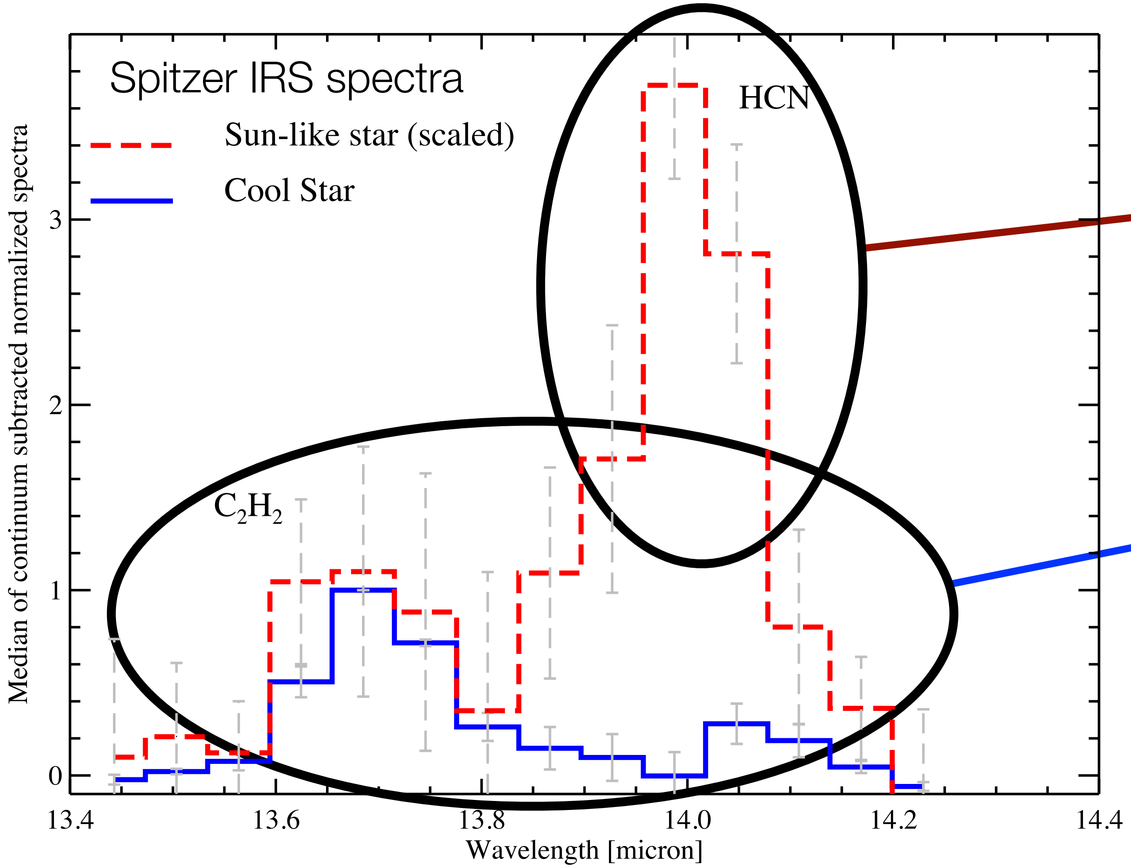


Adapted from Mumma & Charnley, 2011, ARA&A, 49, 471

Protoplanetary Disks



Zooming into the planet forming region (< 10 AU) ...

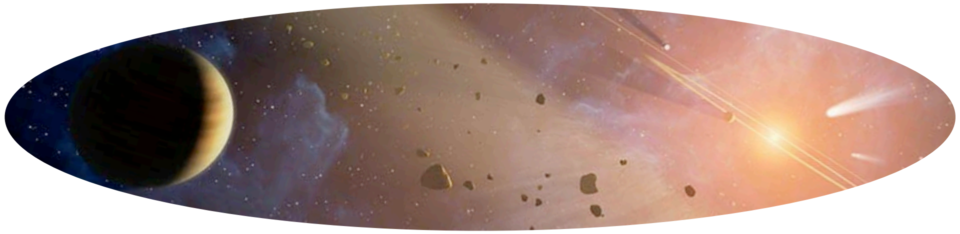


Sun-like stars
show
C_2H_2 emission at 13.7 µm
AND
HCN emission at 14.0 µm

Cool stars
show
C_2H_2 emission at 13.7 um
AND NO
HCN emission at 14.0 um

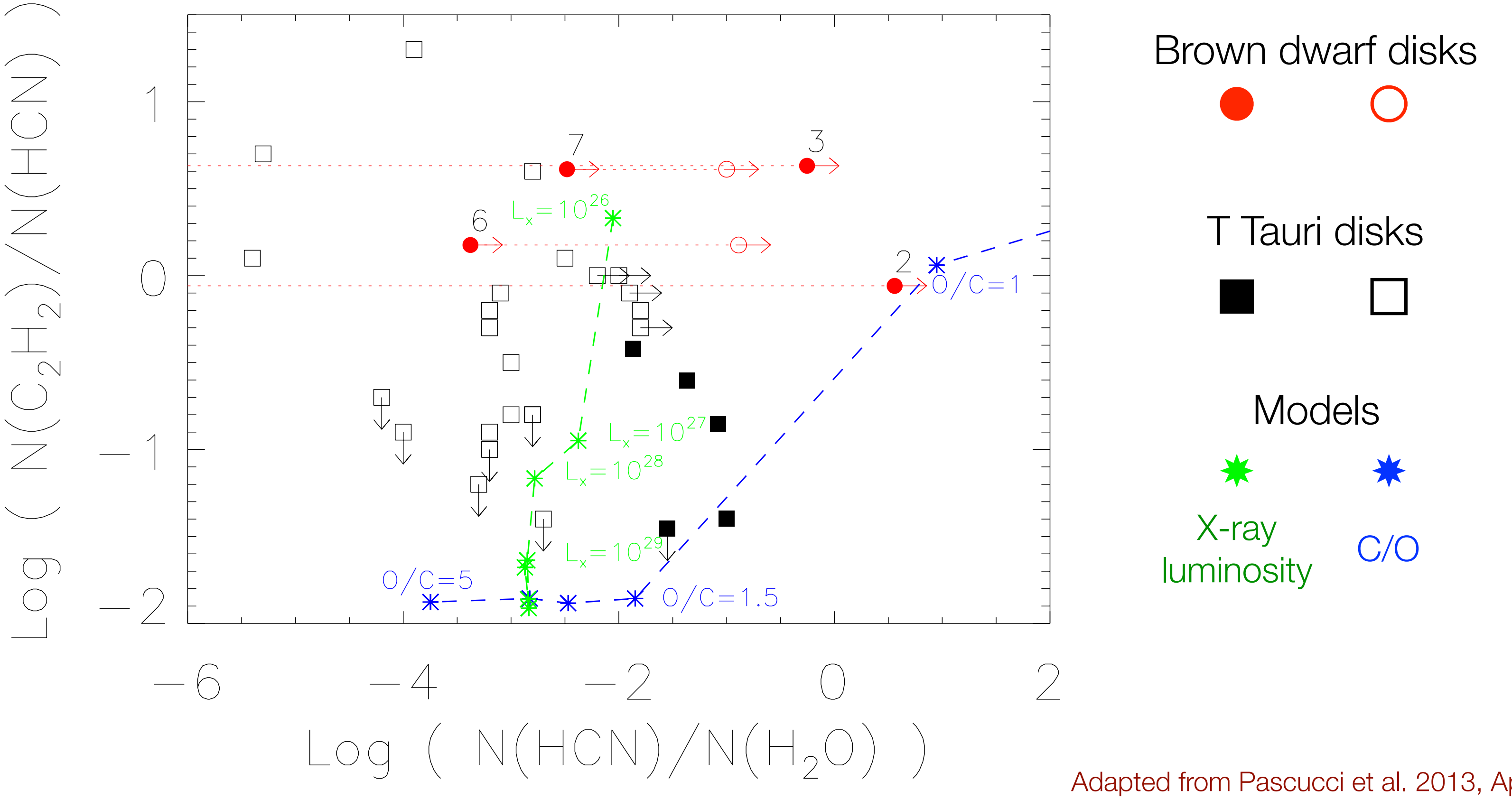
Adapted from Pasucci et al. 2009, ApJ, 696, 143

Protoplanetary Disks



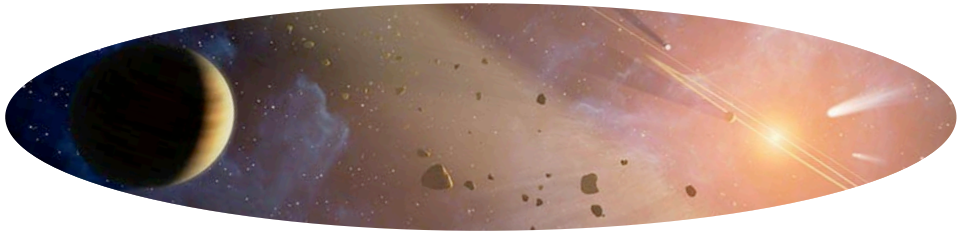
Zooming into the planet forming region (< 10 AU) ...

Higher spectral resolution Spitzer IRS spectra



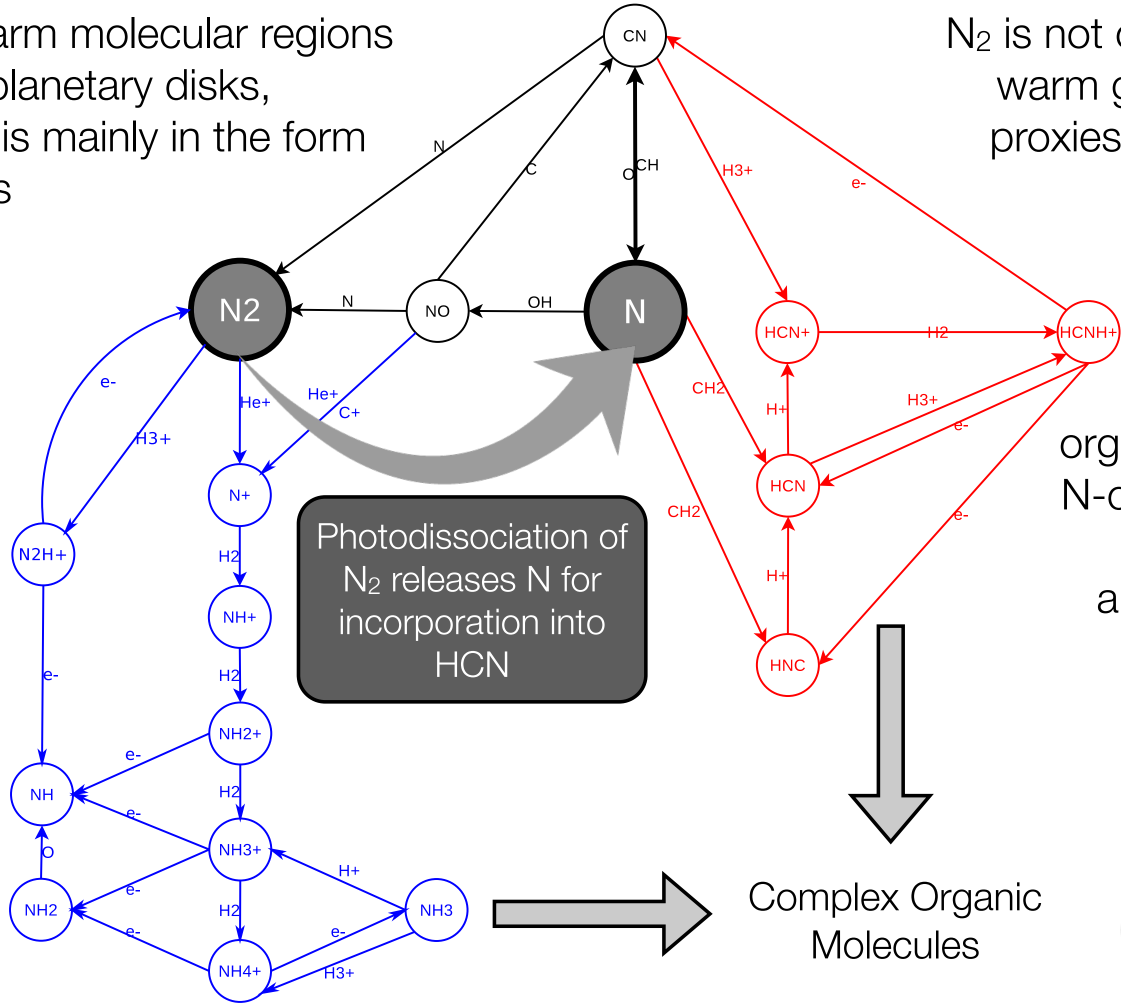
Adapted from Pascucci et al. 2013, ApJ, 779, 178

Nitrogen Chemistry

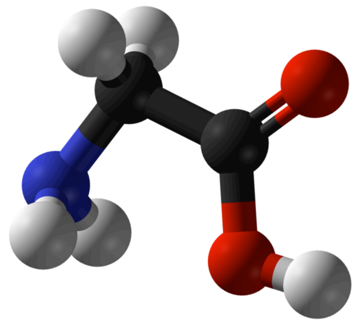


In the warm molecular regions of protoplanetary disks, nitrogen is mainly in the form of N_2 gas

N_2 is not observable in cold/warm gas so need to use proxies such as N_2H^+ and CN/HCN

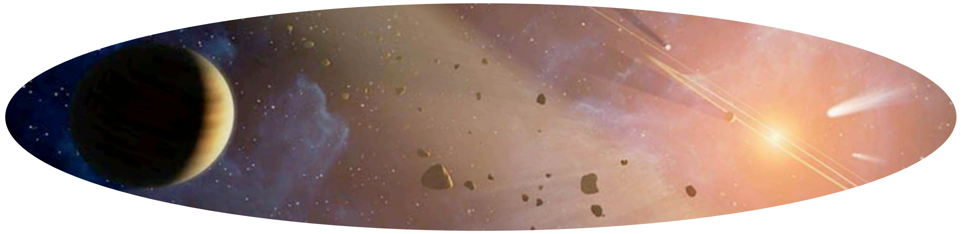


Many complex organic molecules are N-containing species, e.g., the simplest amino acid, glycine, NH_2CH_2COOH



Adapted from Hily-Blant et al. 2013, Icarus, 223, 585

Protoplanetary Disks



Does the radiation field present in the disk influence the nitrogen chemistry through the photodissociation and shielding of N_2?

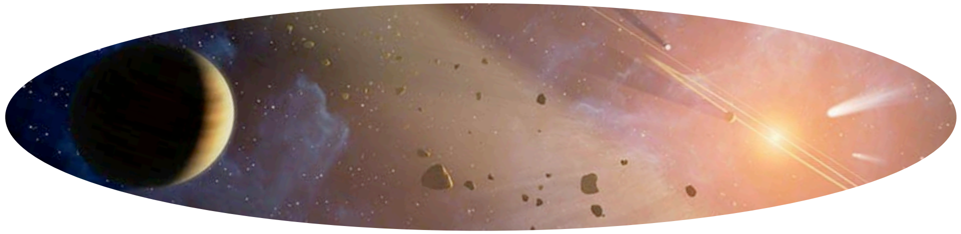
If so, can this explain the trend seen in the strength of HCN line emission at 14 μm?

M K G F A

Cool
3000 K
Weak FUV

Hot
10,000 K
Strong FUV

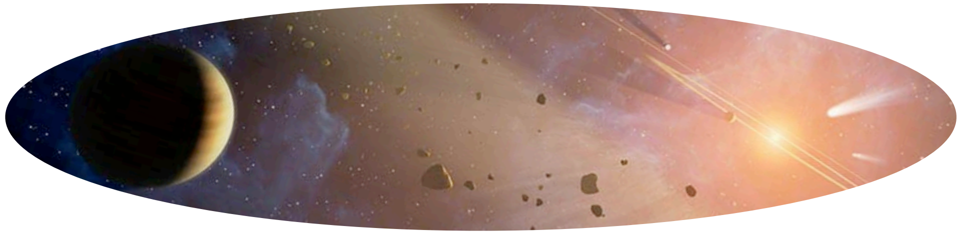
Protoplanetary Disks



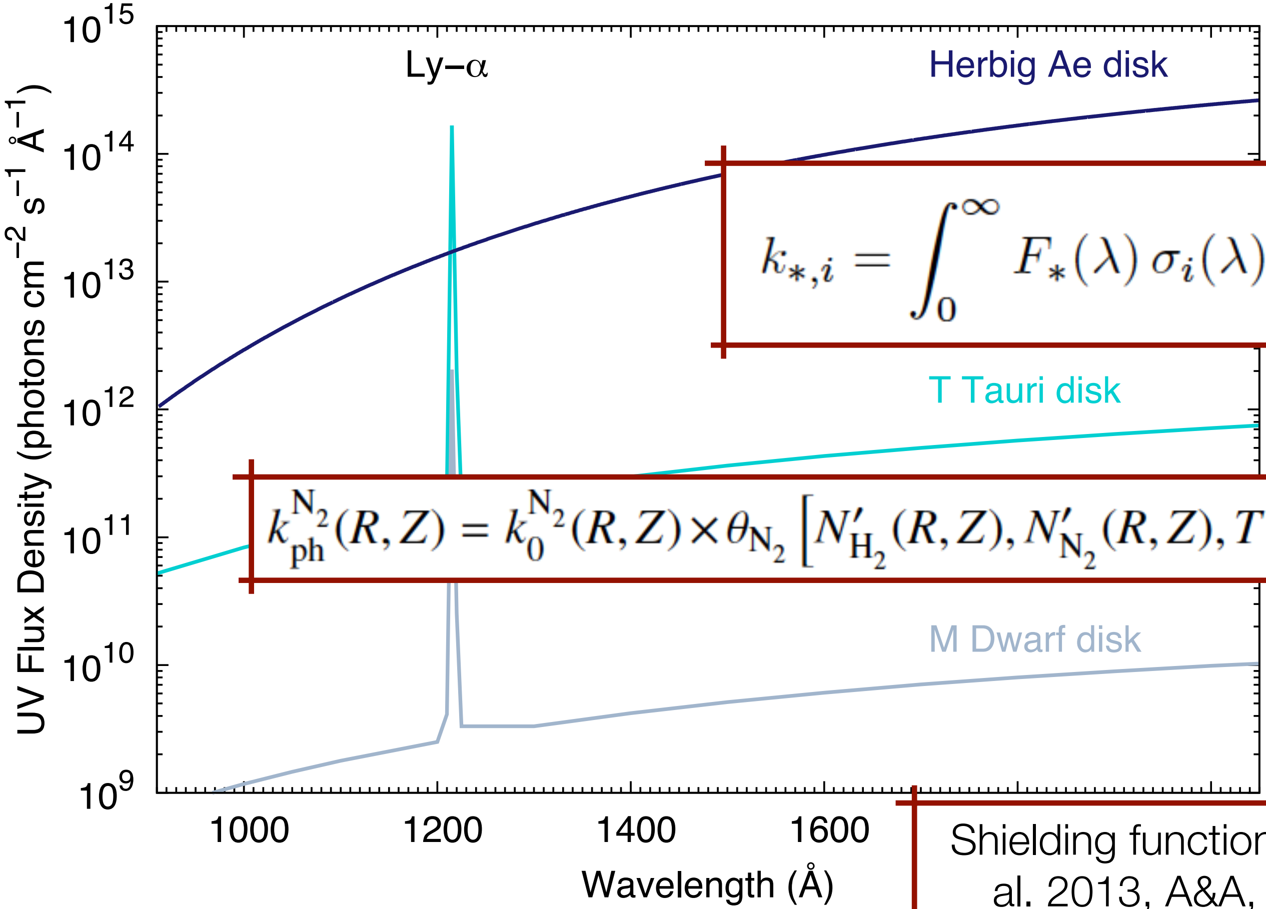
Spectral type	M Dwarf	T Tauri	Herbig Ae
Effective temperature	3000 K	4000 K	10,000 K
Stellar mass	$0.1\ M_{\odot}$	$0.5\ M_{\odot}$	$2.0\ M_{\odot}$
Stellar radius	$0.7\ R_{\odot}$	$2.0\ R_{\odot}$	$2.0\ R_{\odot}$
UV excess[1]	Yes	Yes	No
X-ray model[2]	TW Hya	TW Hya	$L_X \sim 10^{29}$ erg s^{-1}

[1] Young low-mass stars have a strong UV excess thought to be triggered by accretion
[2] Low-mass stars are more X-ray bright than higher-mass stars (TW Hya, $L_X \sim 10^{30}$ erg s^{-1})

Radiation Fields



Radiation fields at R = 1 AU



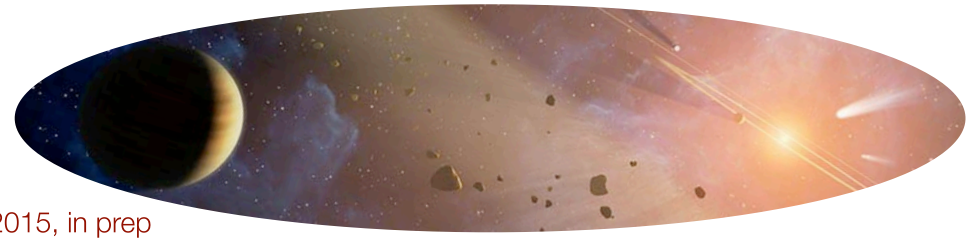
$$k_{*,i} = \int_0^\infty F_*(\lambda)\, \sigma_i(\lambda)\, d\lambda \qquad \mathrm{s}^{-1}$$

$$k_{\mathrm{ph}}^{\mathrm{N_2}}(R,Z) = k_0^{\mathrm{N_2}}(R,Z) \times \theta_{\mathrm{N_2}}\left[N'_{\mathrm{H_2}}(R,Z), N'_{\mathrm{N_2}}(R,Z), T(R,Z)\right] \qquad \mathrm{s}^{-1}$$

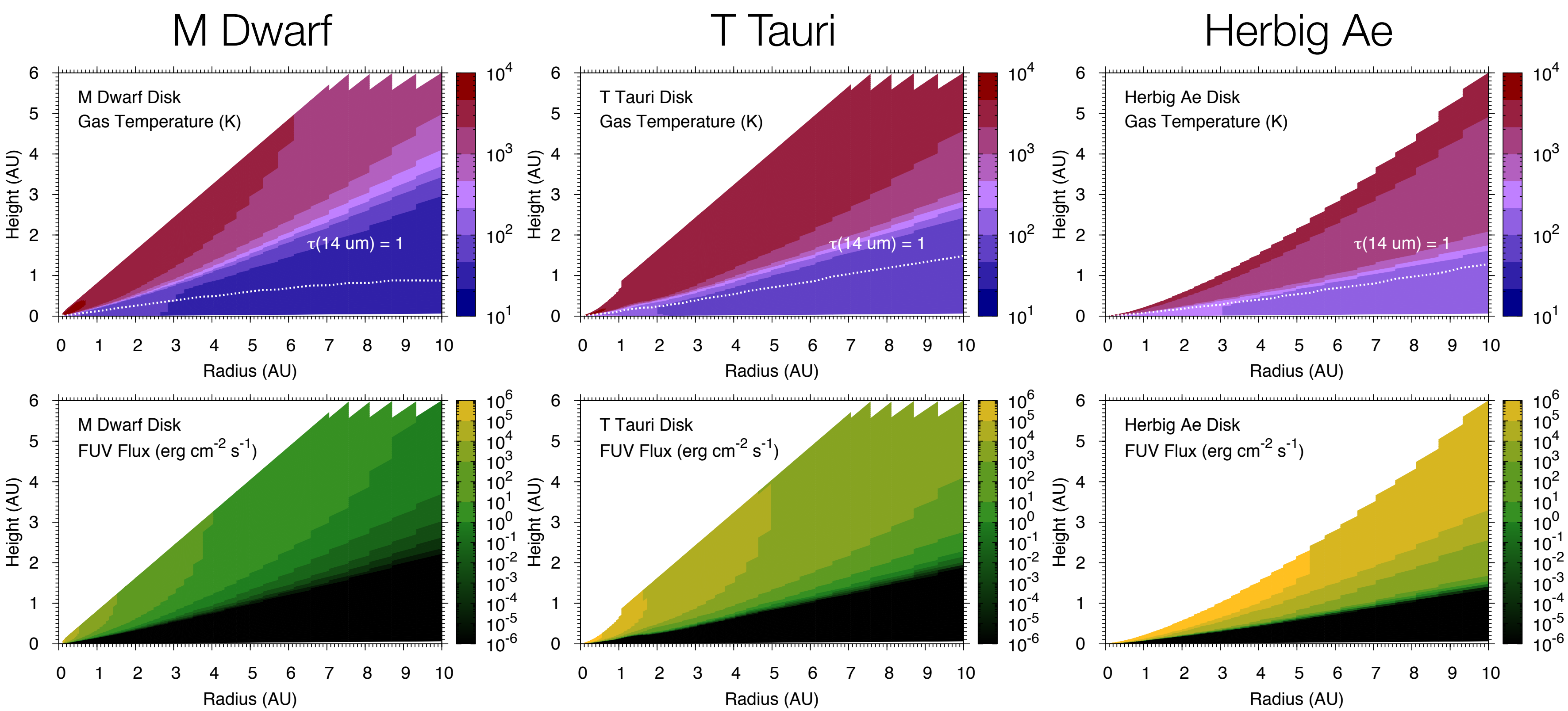
Shielding functions from Li et al. 2013, A&A, 555, A14

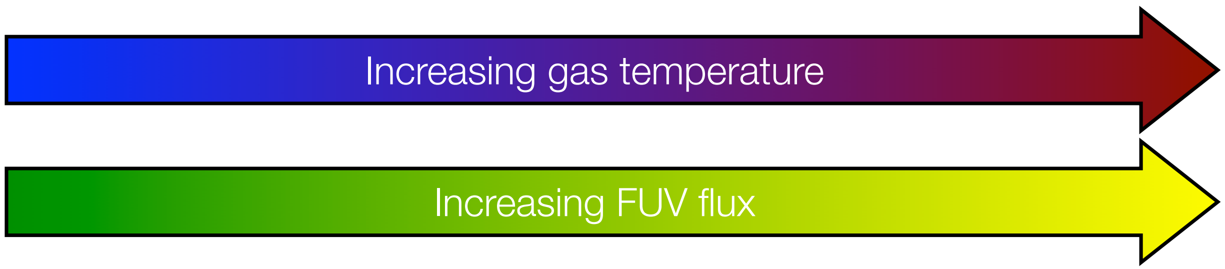
Adapted from Walsh et al. 2015, in prep

Disk Physical Structure



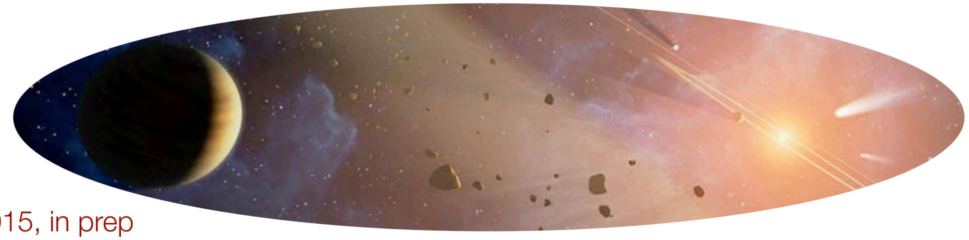
Adapted from Walsh et al. 2015, in prep

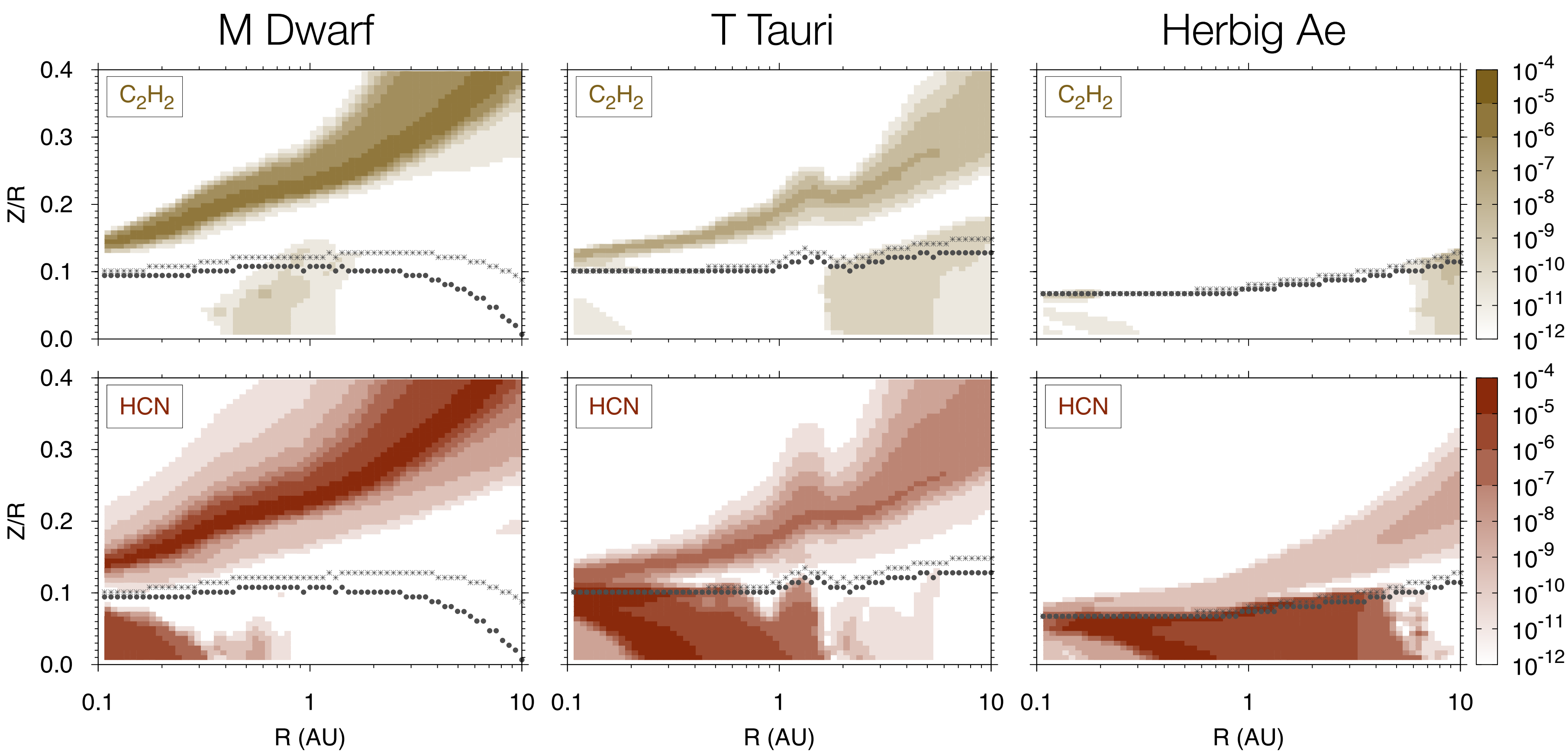




Disk Molecular Structure

Figures from Walsh et al. 2015, in prep

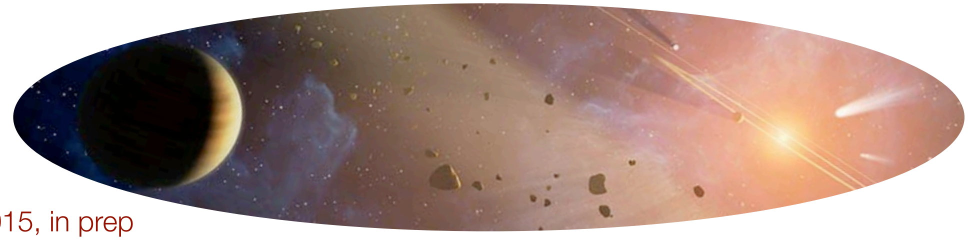




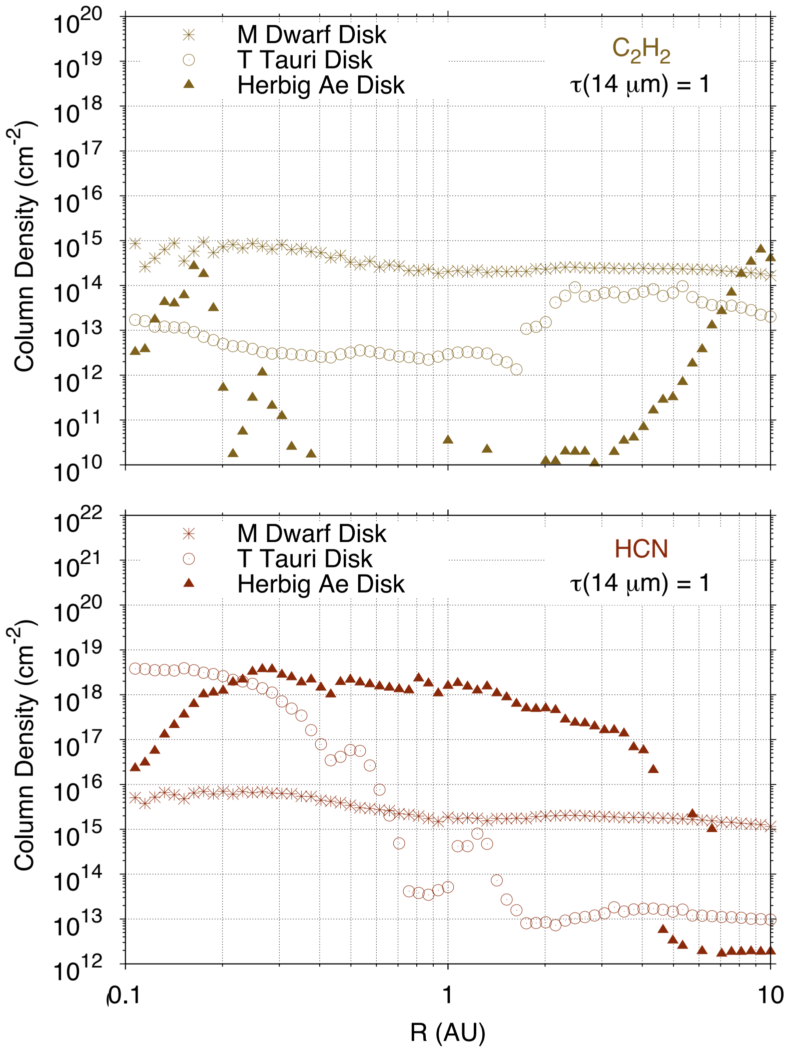
Decrease in molecules in disk atmosphere with increasing spectral type

C_2H_2 and HCN relatively abundant in atmosphere of M Dwarf disk

Disk Molecular Structure

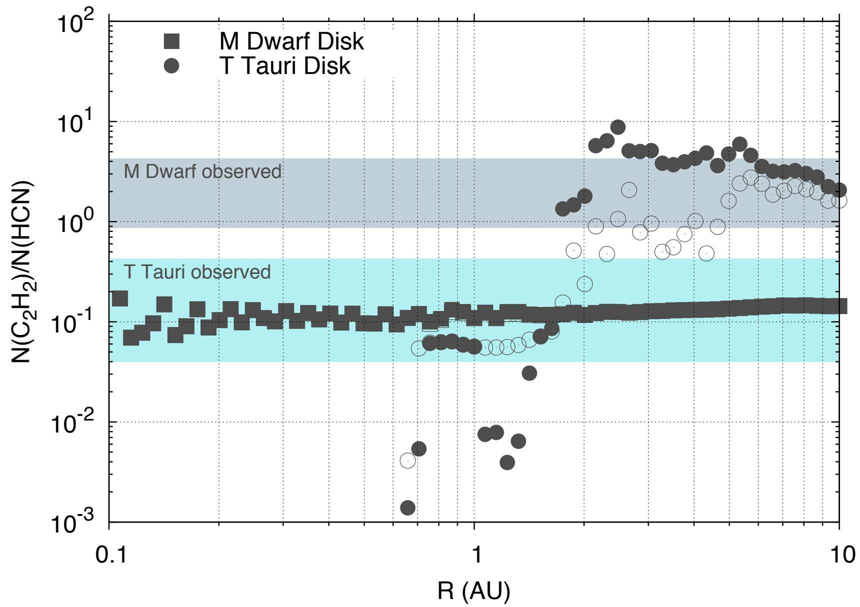


Figures from Walsh et al. 2015, in prep



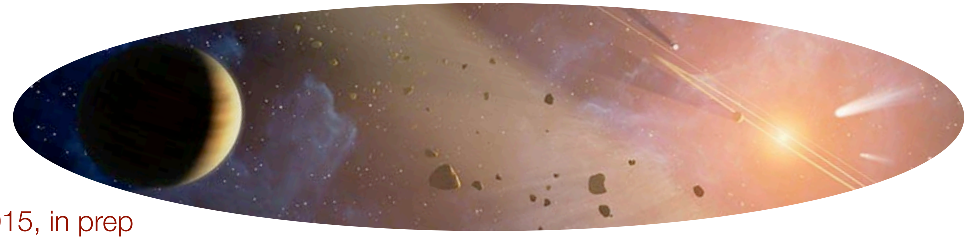
T Tauri C_2H_2/HCN ratio agrees well with observations
M Dwarf C_2H_2/HCN ratio too low by one order of magnitude

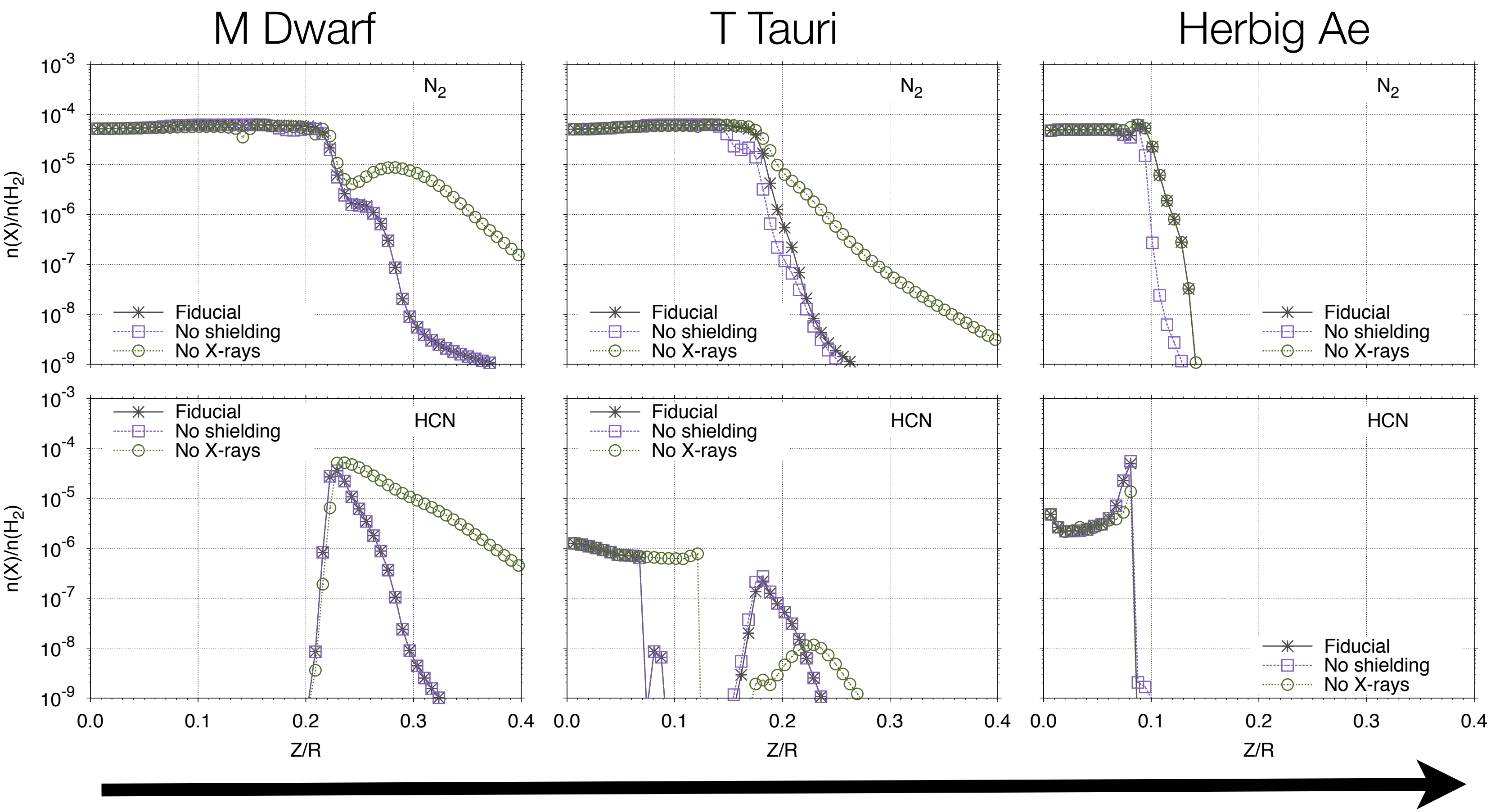
Are X-rays or shielding playing a role?



Shielding and X-rays

Figures from Walsh et al. 2015, in prep



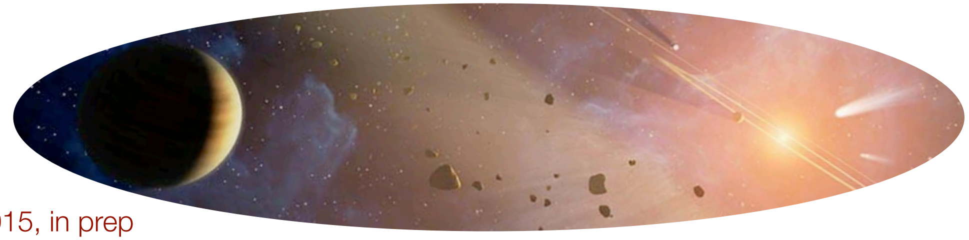


Shielding becomes increasingly important / N_2 shielding occurs in the outer disk where gradients in

X-ray chemistry becomes increasingly less important / density and UV are smaller (e.g., Li et al. 2013)

R = 1AU

Nitrogen Reservoirs



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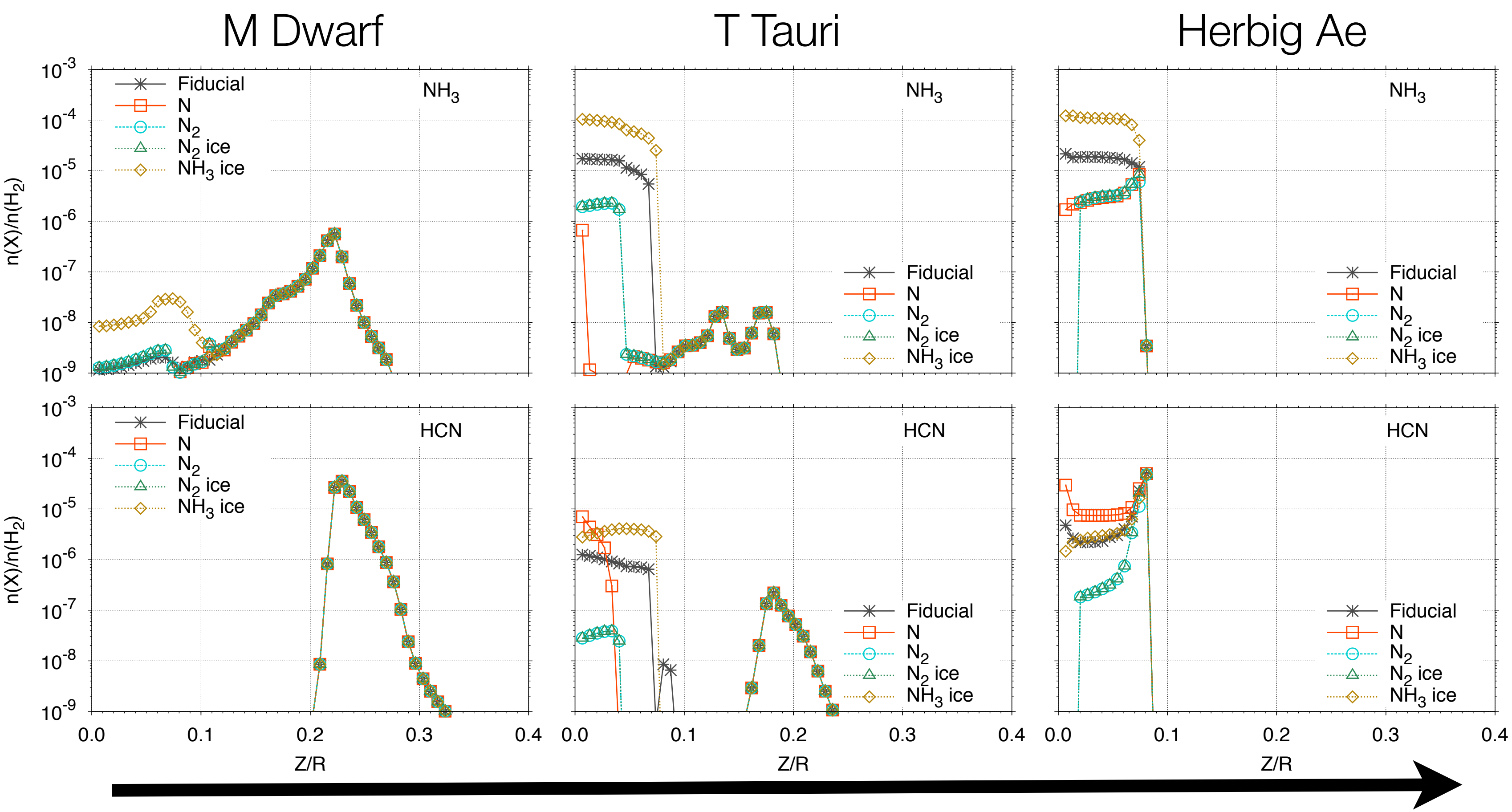
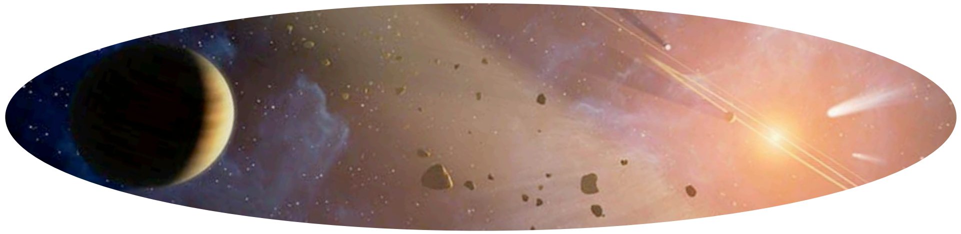


Initial nitrogen reservoir not important in disk atmosphere

Is important in the disk midplane: building blocks of planets

R = 1AU

Summary



- Stellar spectral type influences the molecular composition of the disk
- Disks around cooler stars have a higher fractional abundance of molecules in the upper disk atmosphere: weak FUV is amenable to molecule synthesis
- C_2H_2/HCN trend reproduced for T Tauri stars: ratio for M Dwarfs low compared with observations
- N_2 shielding hinders the formation of N-bearing species in a narrow region of the disk molecular layer only: effect is enhanced in disks around hotter stars
- Exclusion of X-rays helps to build more complexity in disk atmosphere around cooler stars
- Initial nitrogen reservoir important in disk midplane only: building blocks for planets
- Observations suggest higher C/O ratio in disks around cooler stars: indicative of mixing in atmosphere?