Inga Kamp

Disk-Star interaction:

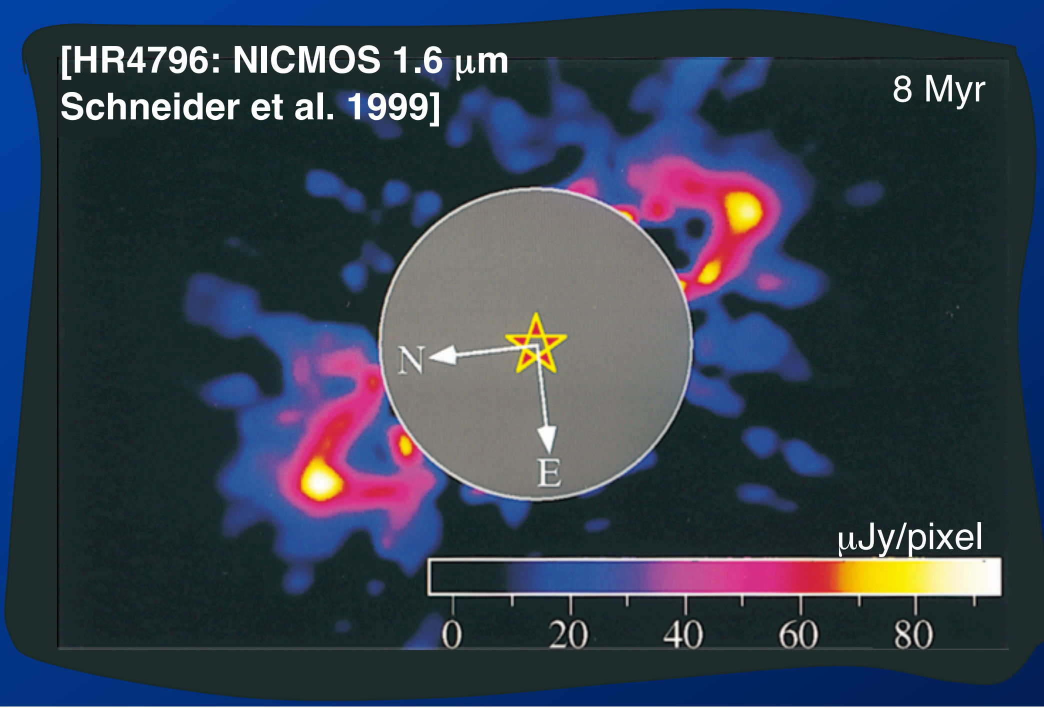
effects of the stellar irradiation on the disk structure and appearance

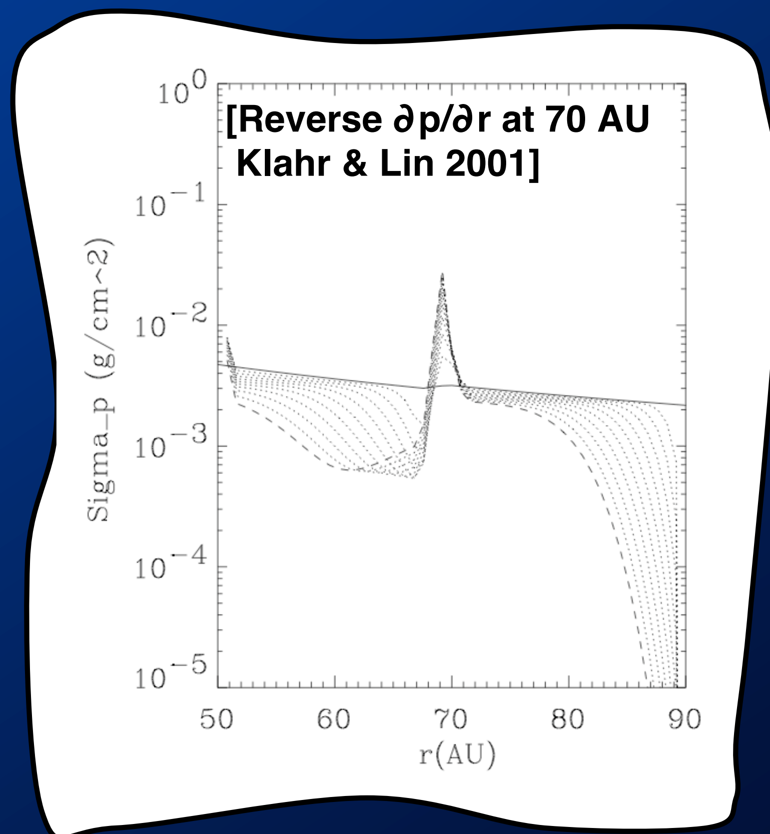
Peter Woitke, Wing-Fai Thi from Edinburgh

Protoplanetary Disks and Planet Formation

Dust dynamics are controlled by gas, even at late times !

- dust substructure
- dust coagulation
- dust settling





[Barge & Sommeria 1995,
Johansen et al. 2006, 2007]

Protoplanetary Disk Models

Key astrophysical questions:

- What is the environment in which planets form ?
  disk structure - boundary conditions for planet formation

- Can planets form around stars different from our Sun ?
  star-disk interaction - impact on disk structure and dispersal

Outline

- Various planet forming environments (BD - T Tauri - Herbig)
- Second generation disk structure modeling
- How do observations inform us about the star-disk interaction ?

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Disk properties

Dust evolution timescale in BD and T Tauri disks similar

[2 BDs @ 2 and 10 Myr: Sterzik et al. 2004]

Inner disk clearing occurs much faster in T Tauri disks

[8μm excess @ 5 Myr: Carpenter et al. 2006]

Dust models fit BD, T Tauri and Herbig SEDs in the same way indicating the first steps of planetesimal formation in all cases

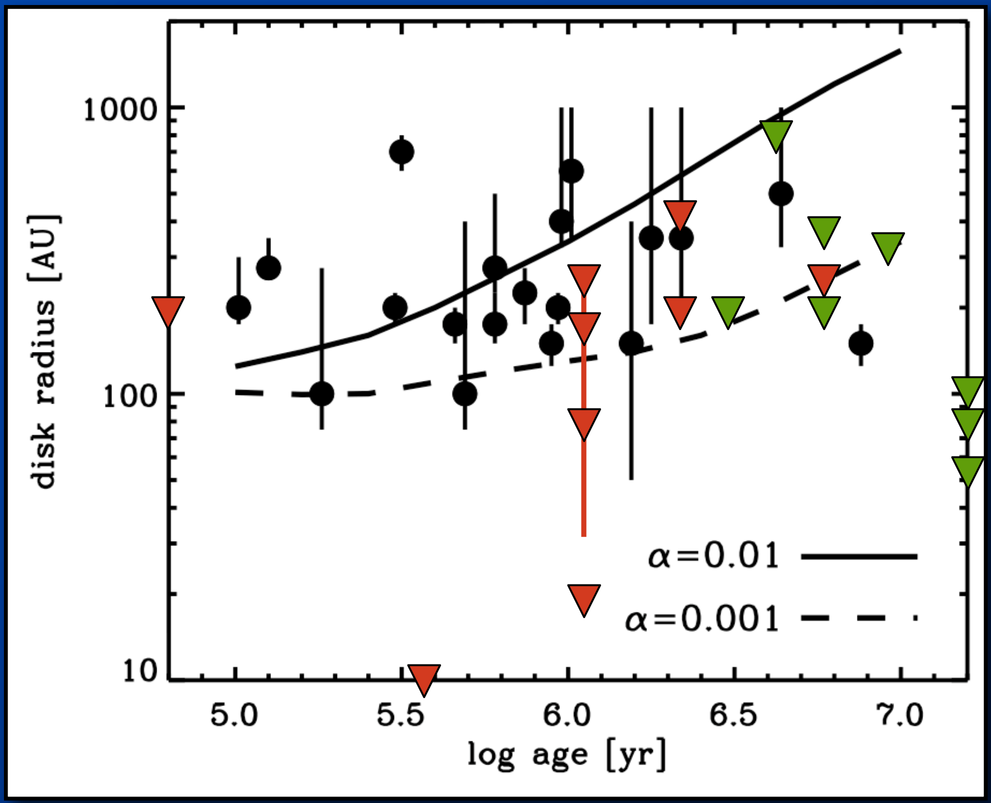
[Pascucci et al. 2003, Allers et al. 2006, Bouy et al. 2008]

some BD SEDs require flaring disks, others flat… low # statistics

Disk properties

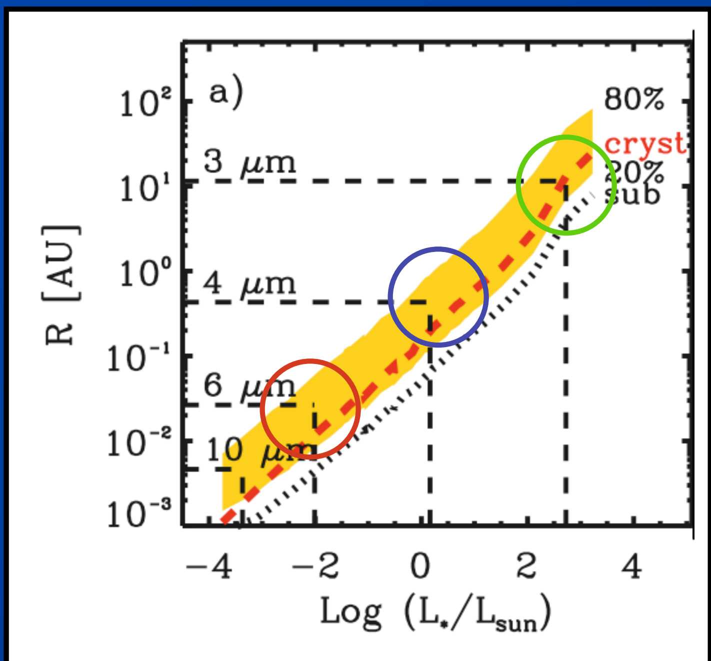
Disks around T Tauri stars on average larger than those around Herbig stars

[e.g. Andrews & Williams 2008, Alonso-Albi et al. 2009
Panic & Hogerheijde 2009, Panic et al. 2008,
Isella et al. 2007, Pietu et al. 2005]

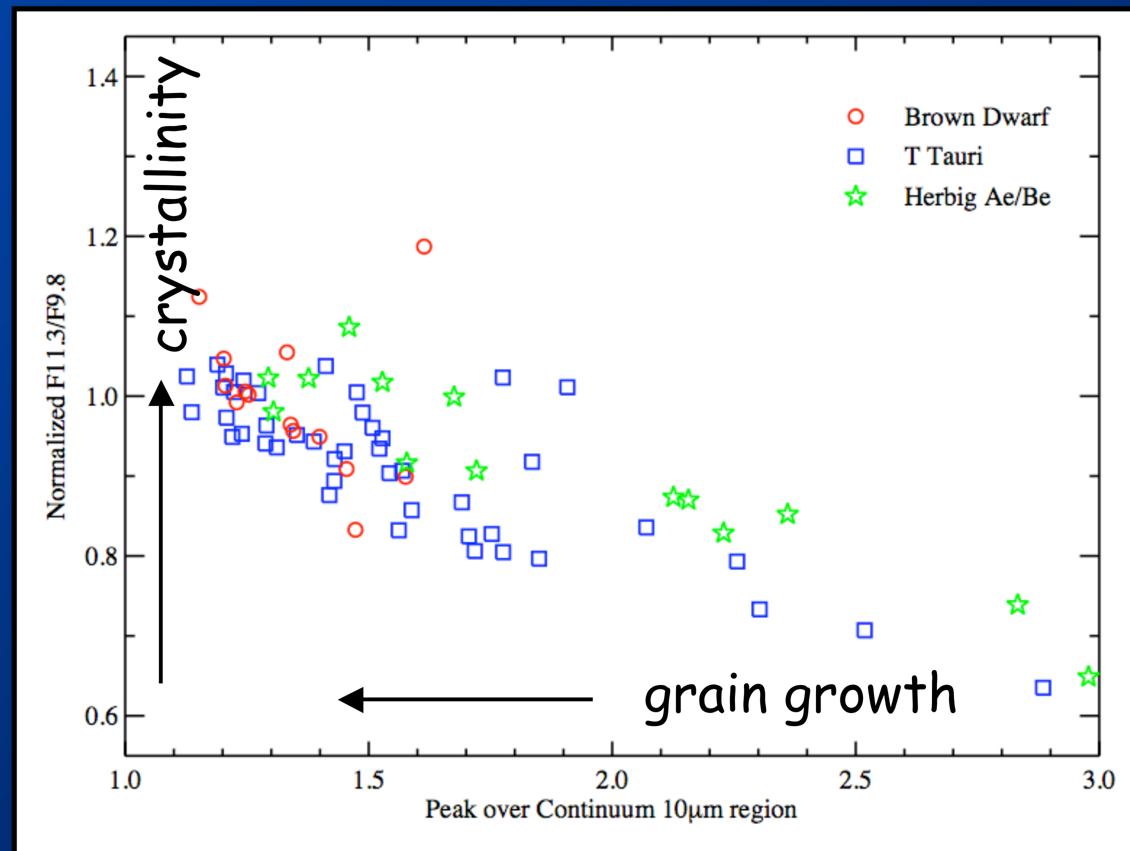


Herbig star submm imaging hampered by remnant envelope material ...

Disk properties



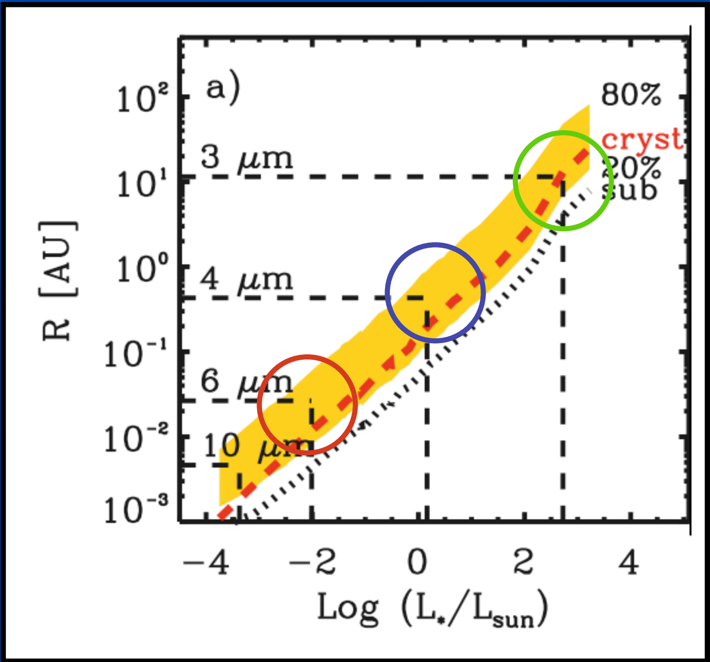
[Kessler-Silacci et al. 2007]



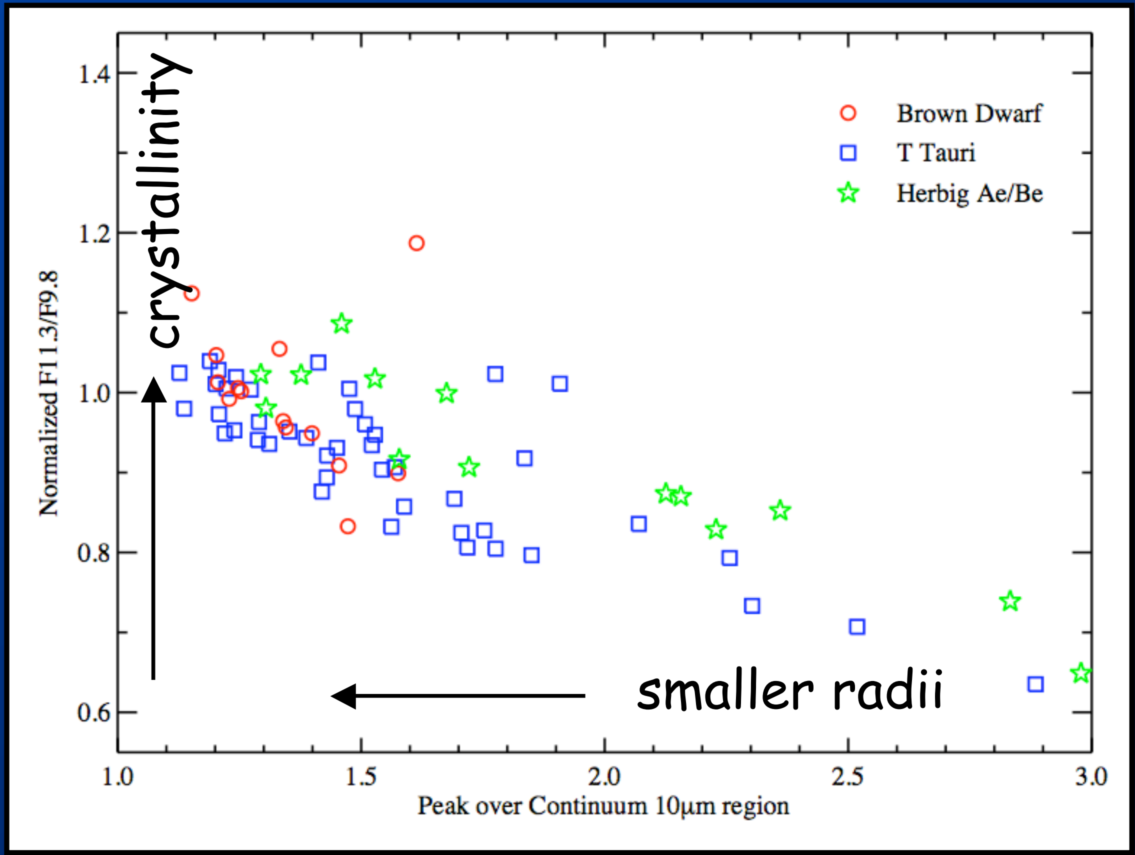
[Pascucci et al. 2009]

lower HCN/H_2C_2 ratios in the disks around brown dwarfs
more processed silicate features from larger grains

Disk properties



[Kessler-Silacci et al. 2007]



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Protoplanetary Disk Models

surface density	$\Sigma = \Sigma_0 \, (r/r_0)^{-p}$
dust temperature	$T = T_0 \, (r/r_0)^{-q}$
disk scale height	$H = H_0 \, (r/r_0)^{-e}$

[e.g. Menard et al., Pinte et al. 2006]

Protoplanetary Disk Models

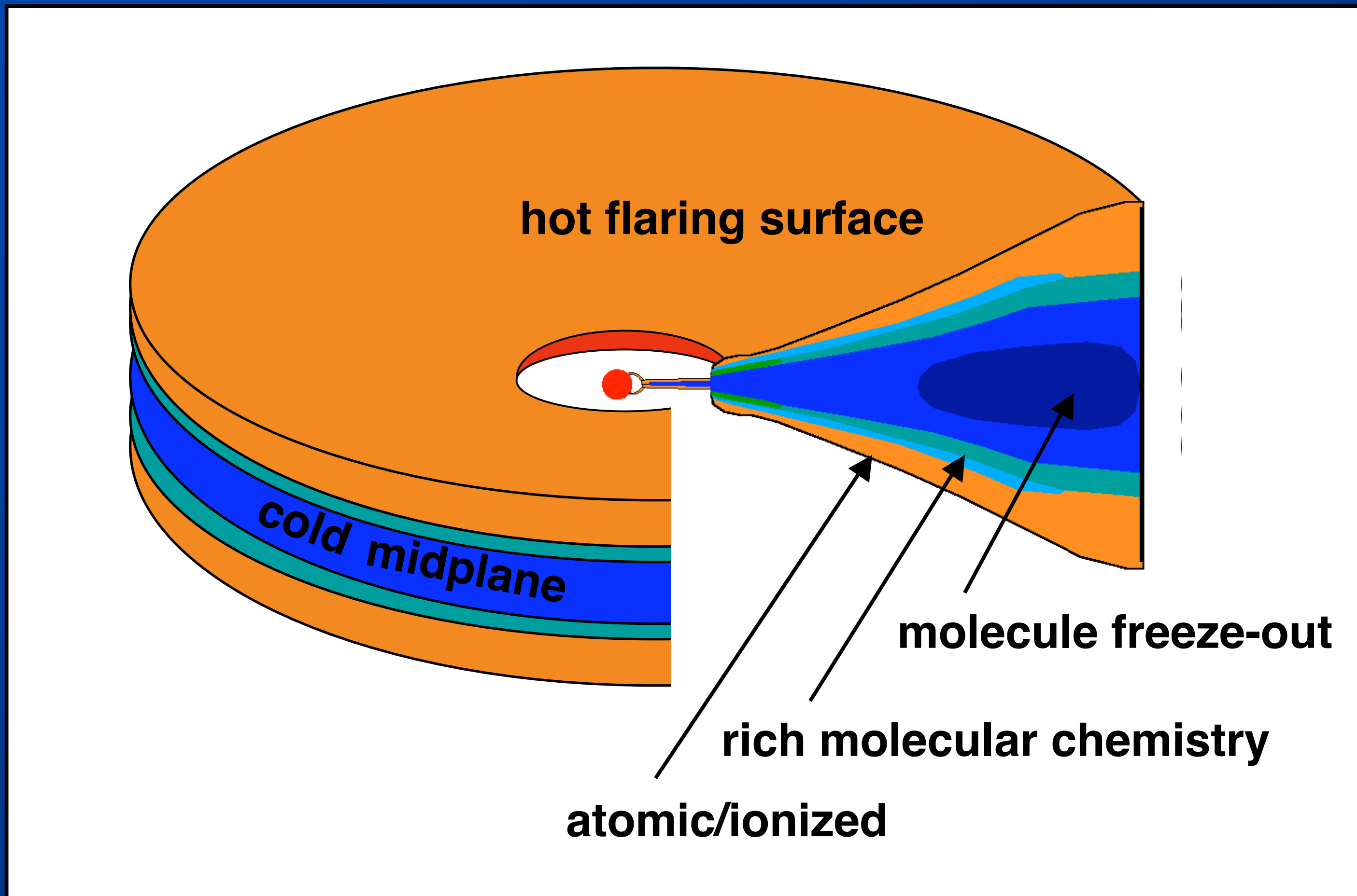
surface density	$\Sigma = \Sigma_0 \, (r/r_0)^{-p}$
dust temperature	2D continuum RT
disk scale height	$H = (c_s^2 \, r^3/GM_*)^{0.5}$

[e.g. D'Alessio et al. 1998, Dullemond et al. 2002]

Gas chemical modeling on top of fixed density structure

[e.g. Aikawa et al. 2002, Semenov et al. 2008]

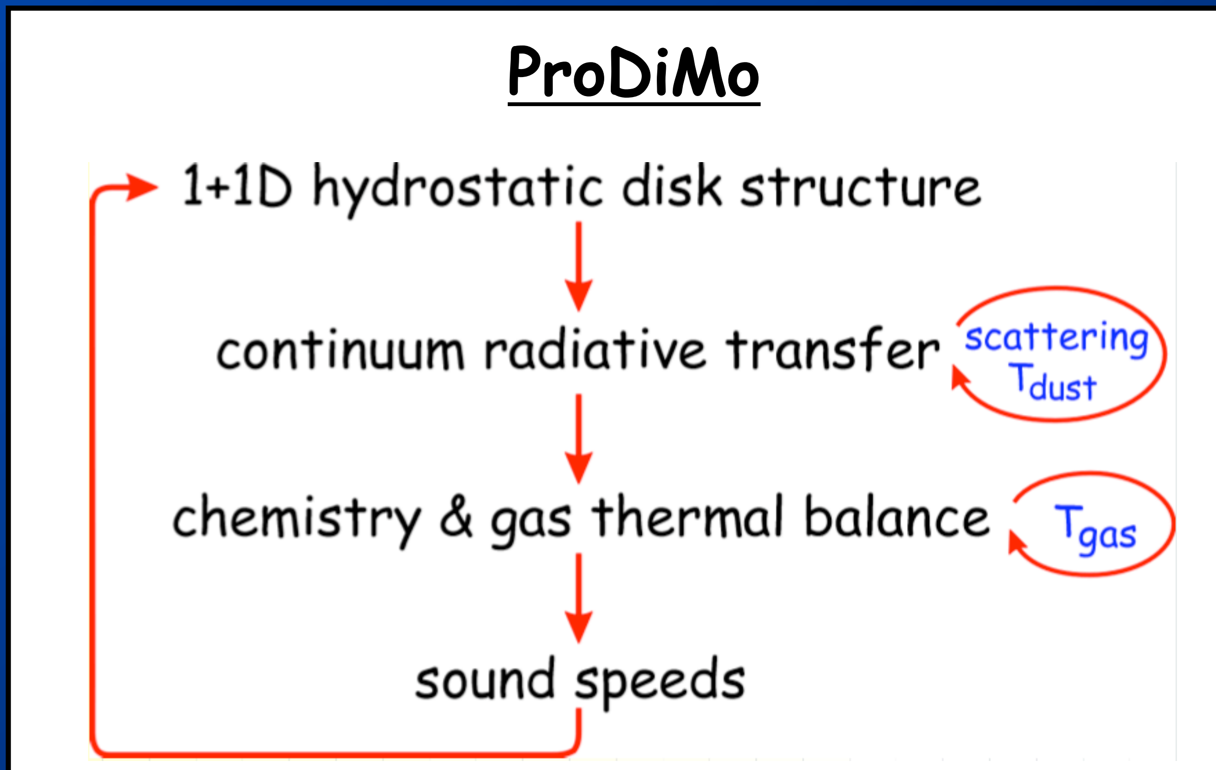
Protoplanetary Disk Models



[e.g. Aikawa et al. 2002, Kamp & Dullemond 2004]

[PPV chapters: Dullemond et al. 2007, Bergin et al. 2007]

Protoplanetary Disk Models

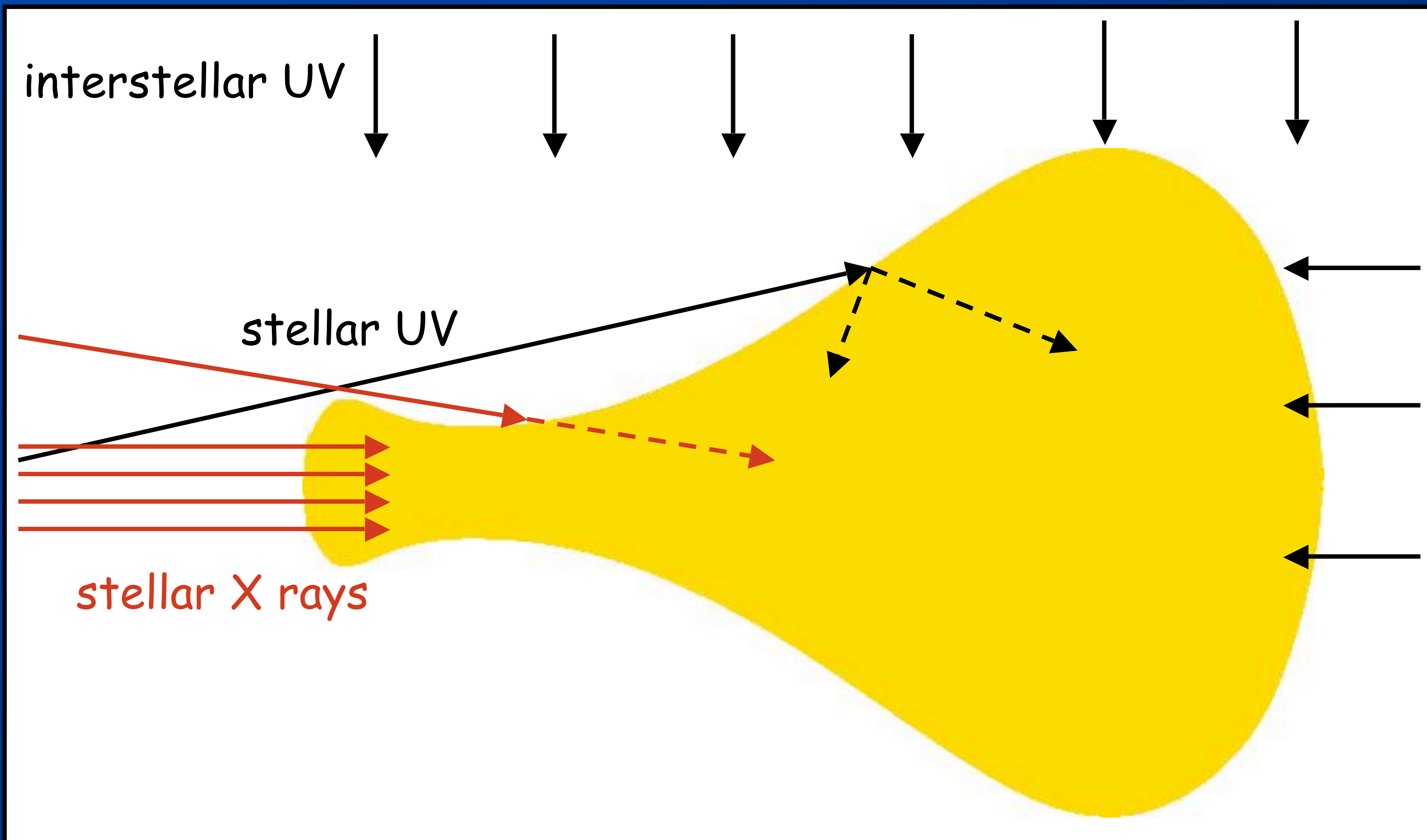


[Woitke, Kamp, Thi 2009]

Similar approaches have been followed earlier by other groups

[Nomura & Millar 2005, Gorti & Hollenbach 2004, 2008]

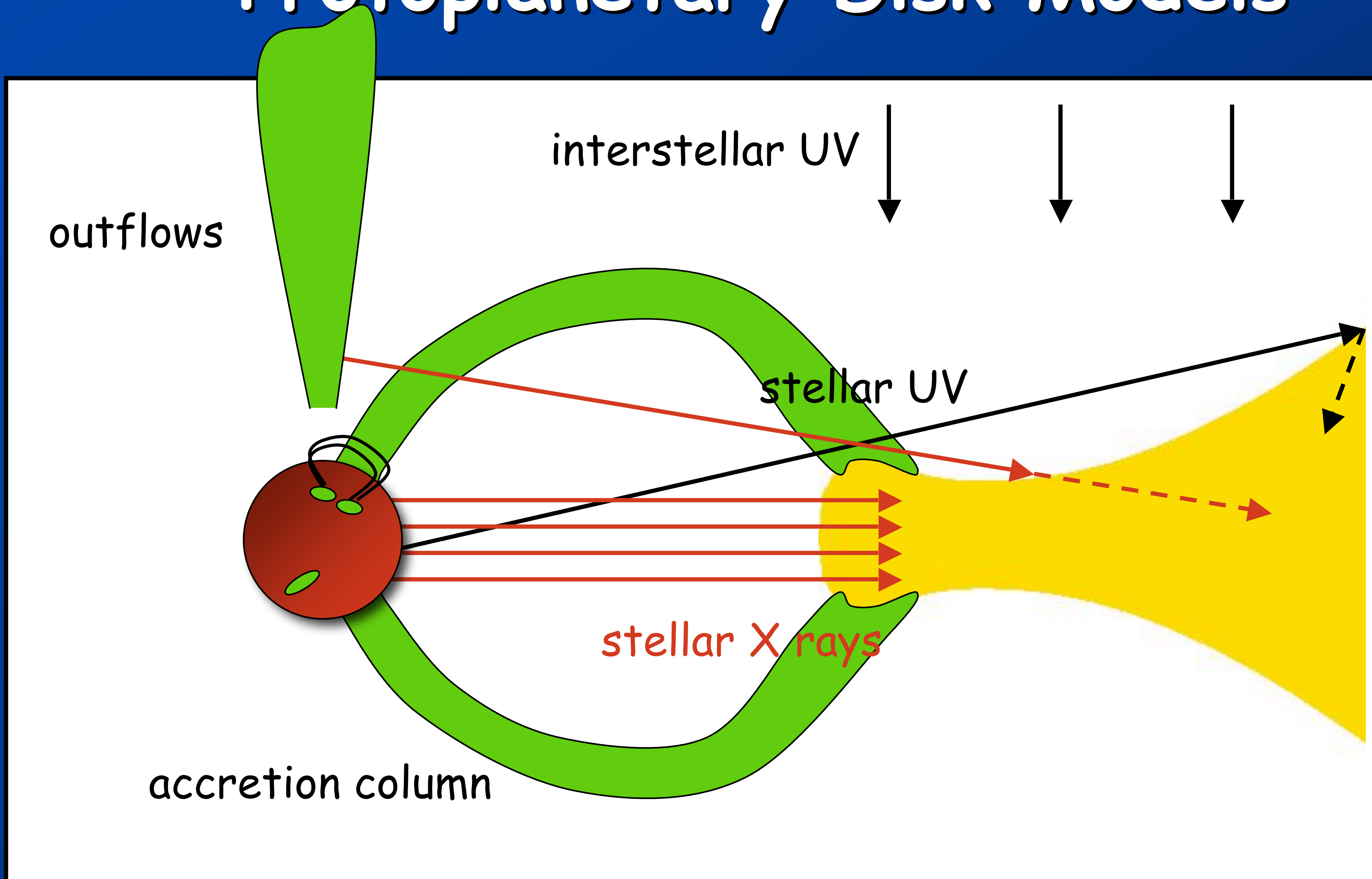
Protoplanetary Disk Models

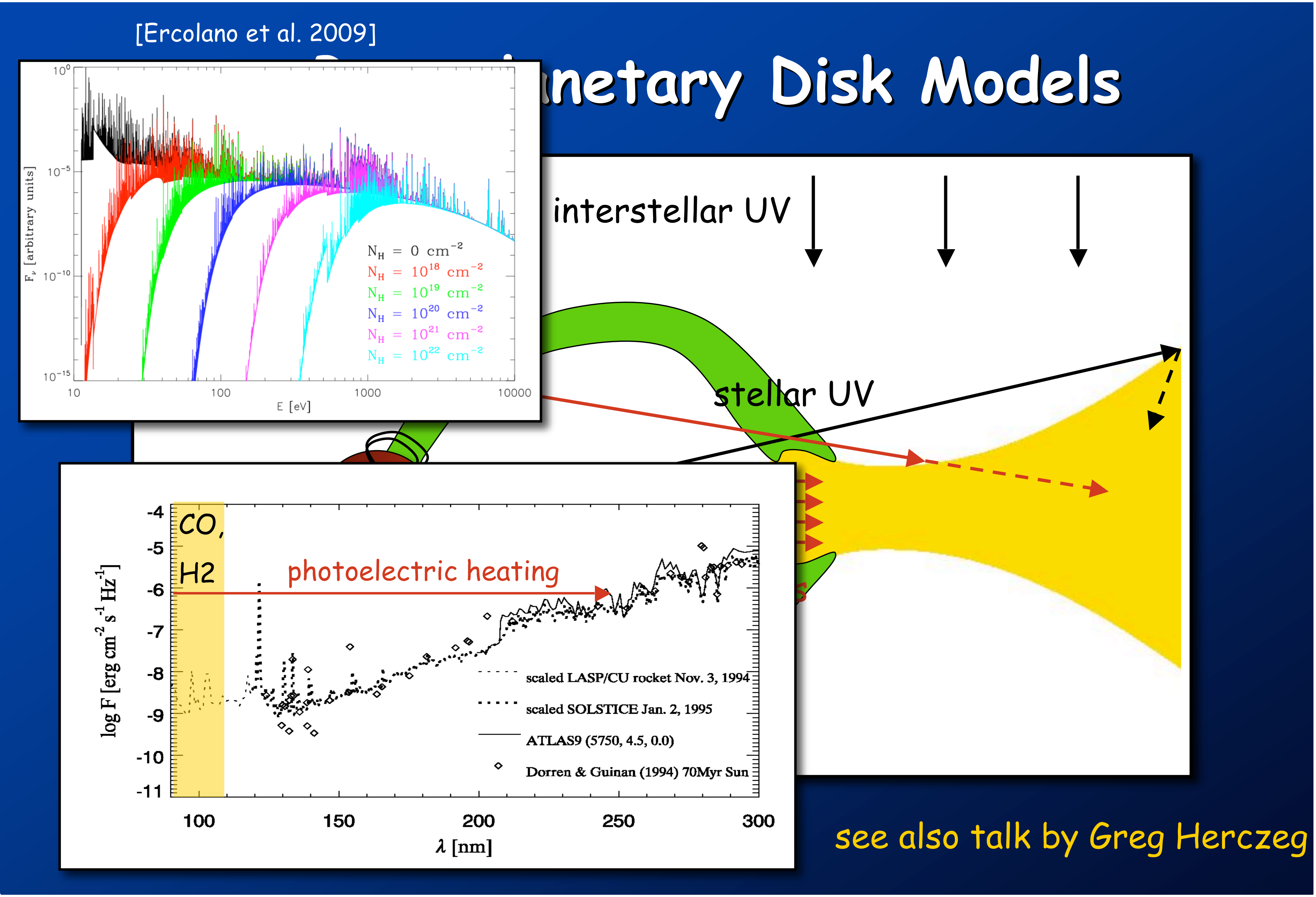


soft inner and outer edges

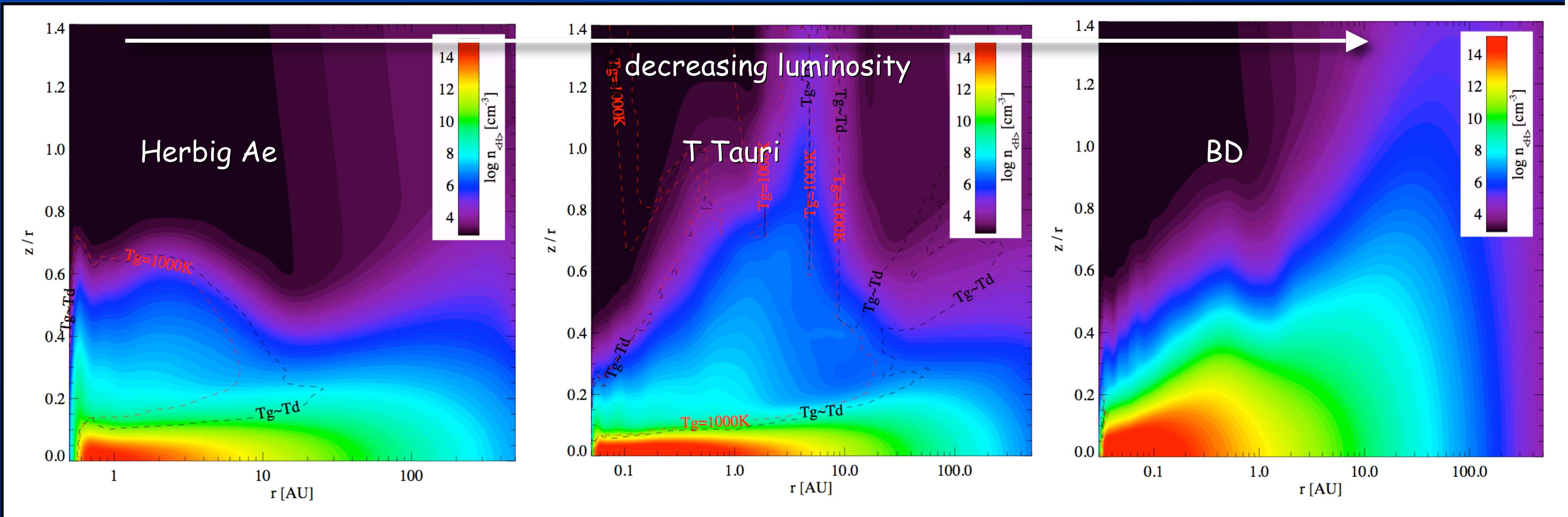
[Hartmann et al. 1989, Hughes et al. 2008, Woitke, Kamp & Thi 2009]

Protoplanetary Disk Models




[Ercolano et al. 2009]
...anetary Disk Models
interstellar UV
stellar UV
F_ν [arbitrary units]
E [eV]
N_H = 0 cm^-2
N_H = 10^18 cm^-2
N_H = 10^19 cm^-2
N_H = 10^20 cm^-2
N_H = 10^21 cm^-2
N_H = 10^22 cm^-2
CO,
H2
photoelectric heating
log F [erg cm^-2 s^-1 Hz^-1]
λ [nm]
scaled LASP/CU rocket Nov. 3, 1994
scaled SOLSTICE Jan. 2, 1995
ATLAS9 (5750, 4.5, 0.0)
Dorren & Guinan (1994) 70Myr Sun
see also talk by Greg Herczeg

Protoplanetary Disk Models

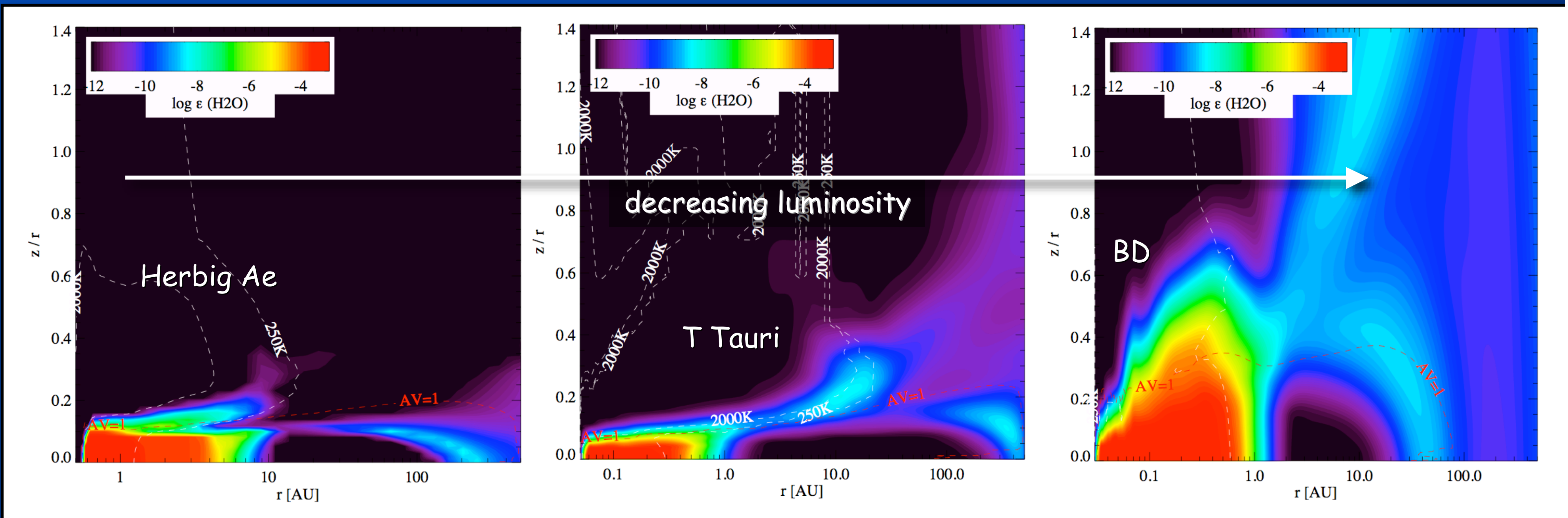


Flaring disk structure Herbig/TTauri/BD (UV only)

$M_* = 2.2, 1, 0.06\ M_\odot$
$L_* = 32, 1, 0.054\ L_\odot$
$T_{eff} = 8500, 5770, 3000$ K
$M_{disk} = 10^{-2}\ M_{star}$
8 R_{star} - 500 AU

dust:
Astronomical silicates
(Draine & Lee 1984)
0.1-10 μm (3.5)
no PAHs

Protoplanetary Disk Models



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[Woitke et al. 2009b]

Protoplanetary Disk Models

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Herbig Ae star

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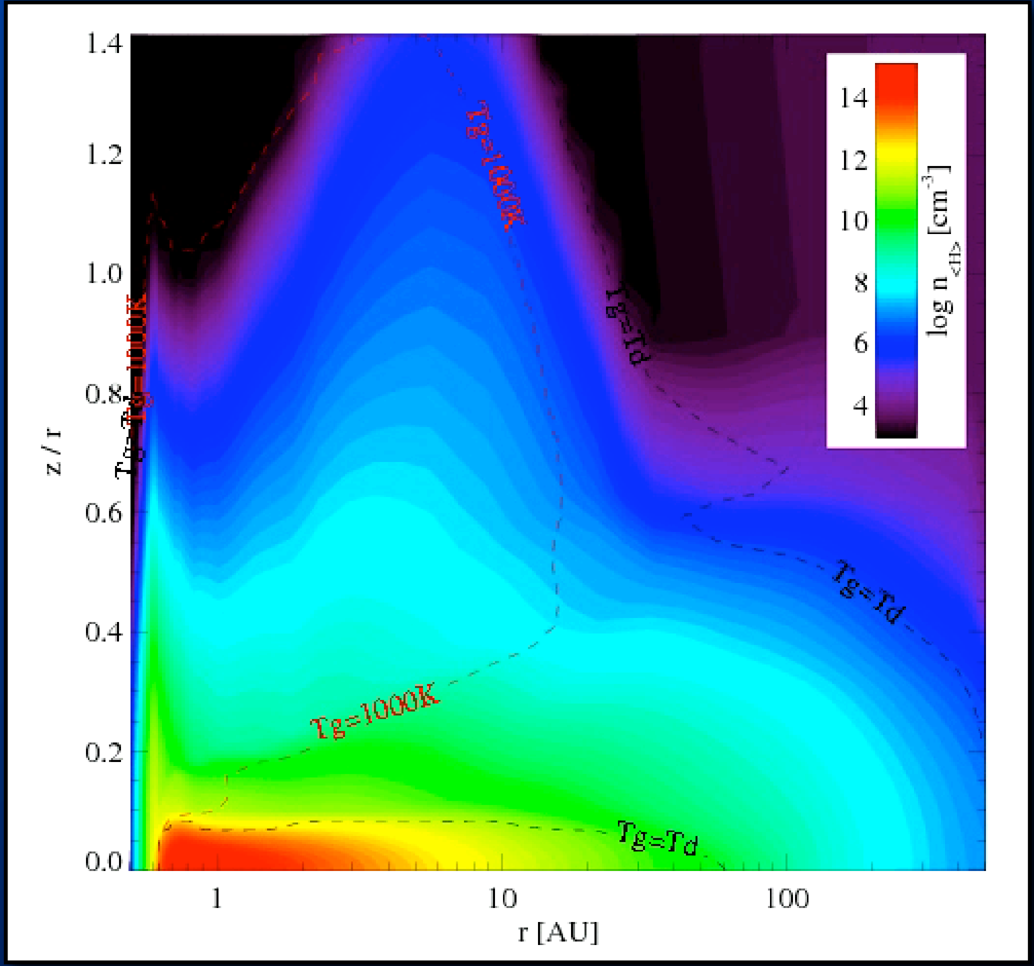
total hydrogen number density $n_{\langle H \rangle}$



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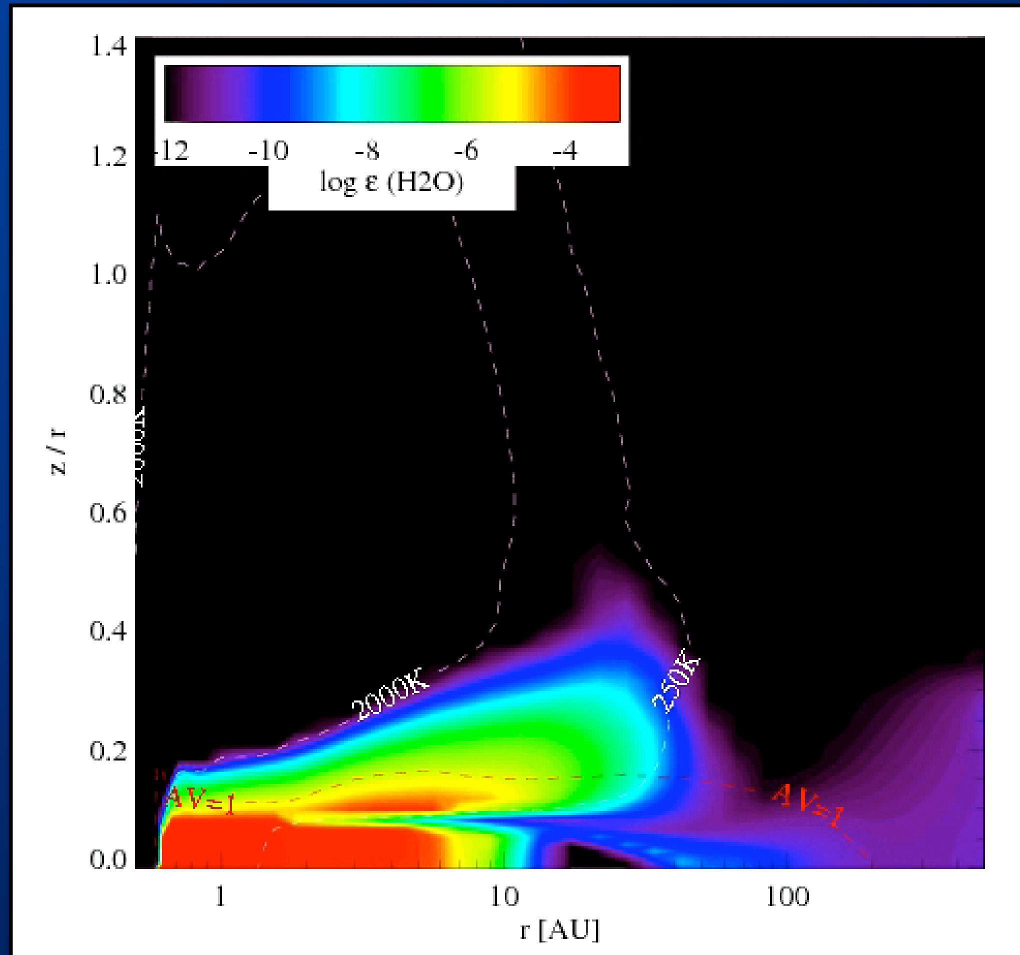
gas phase H_2O abundance



Chemical pathways and the role of CRUV --> see poster A15 by G. Chaparro

[Woitke et al. 2009b]

Protoplanetary Disk Models

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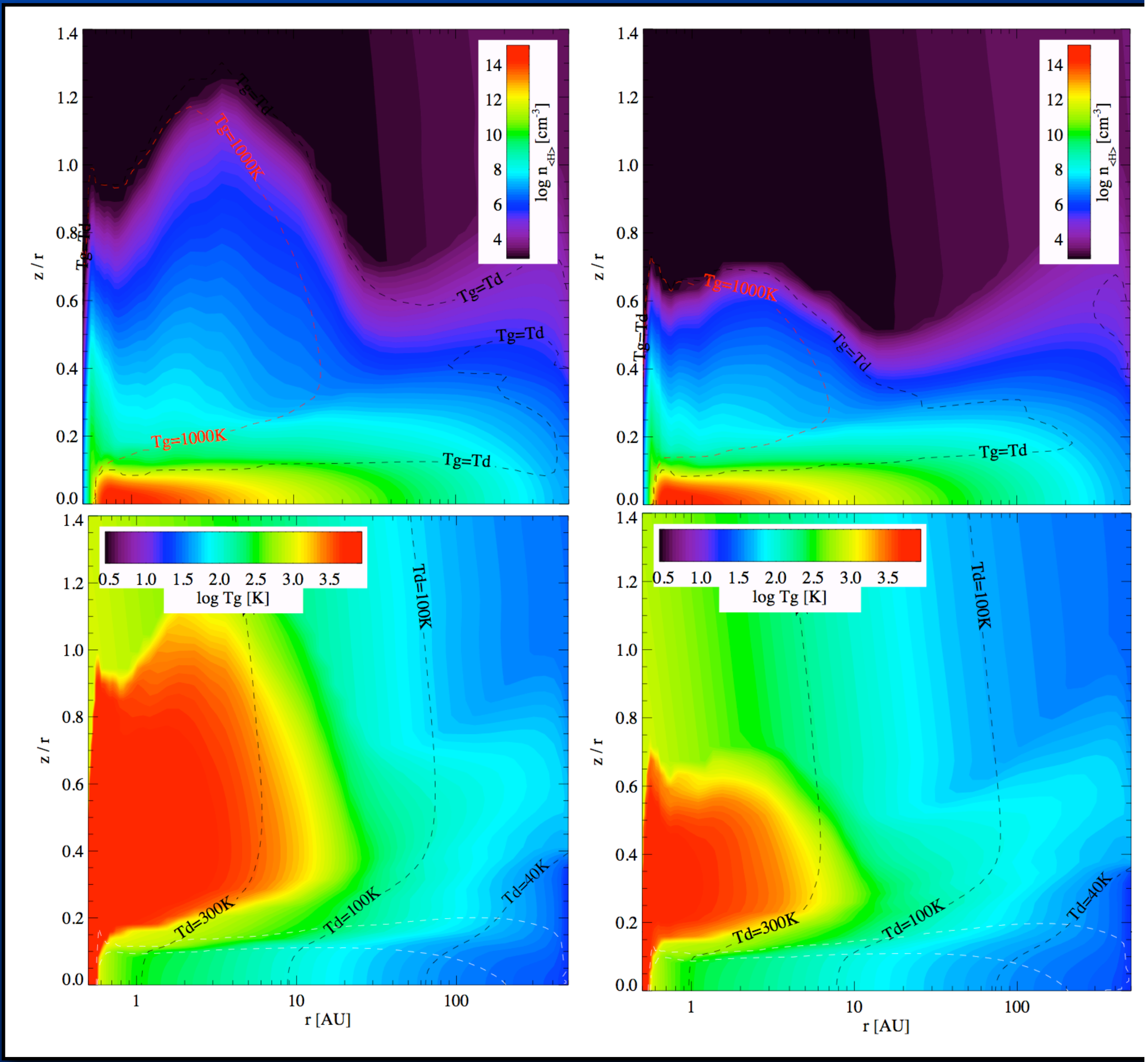

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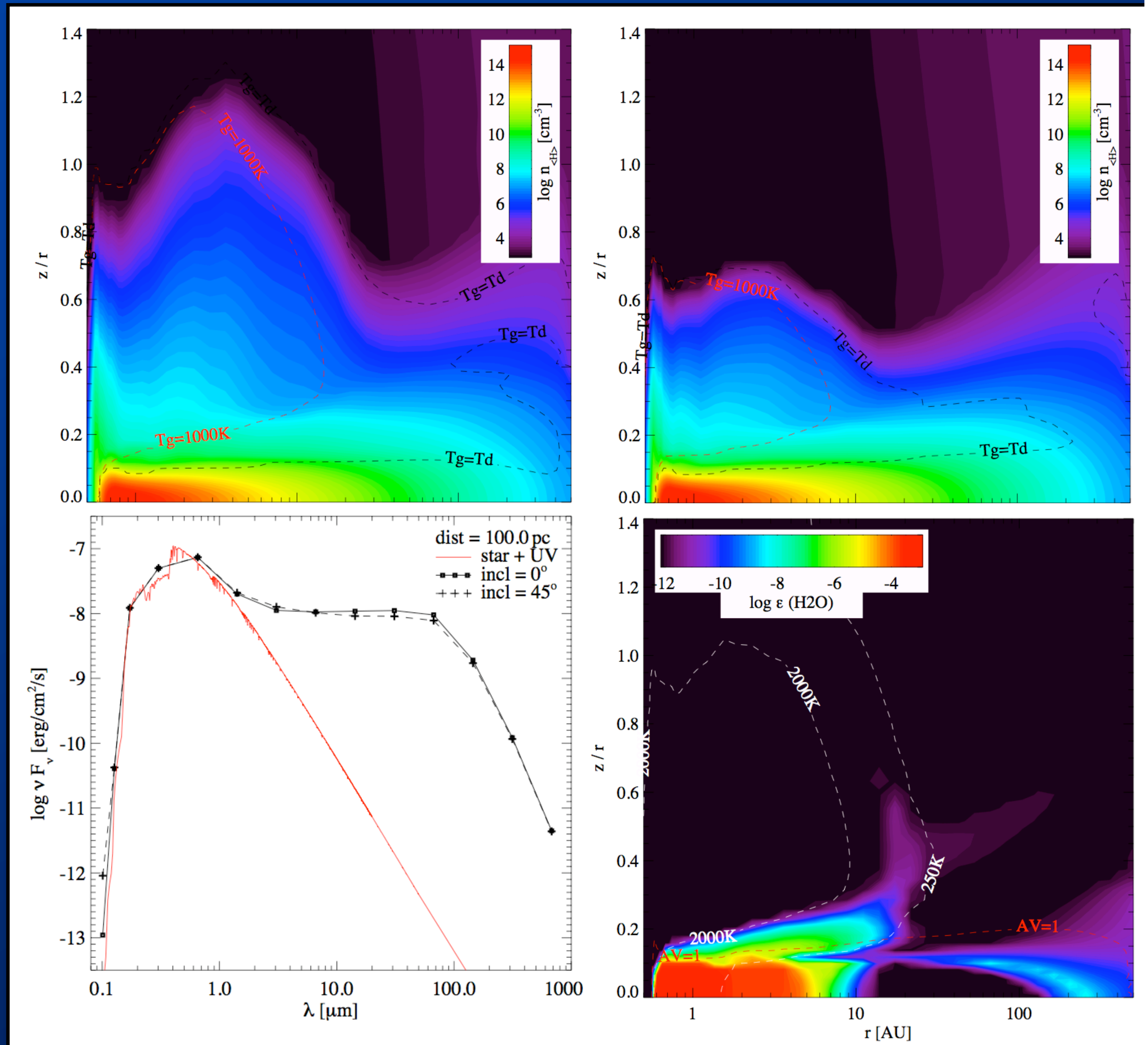

Protoplanetary Disk Models

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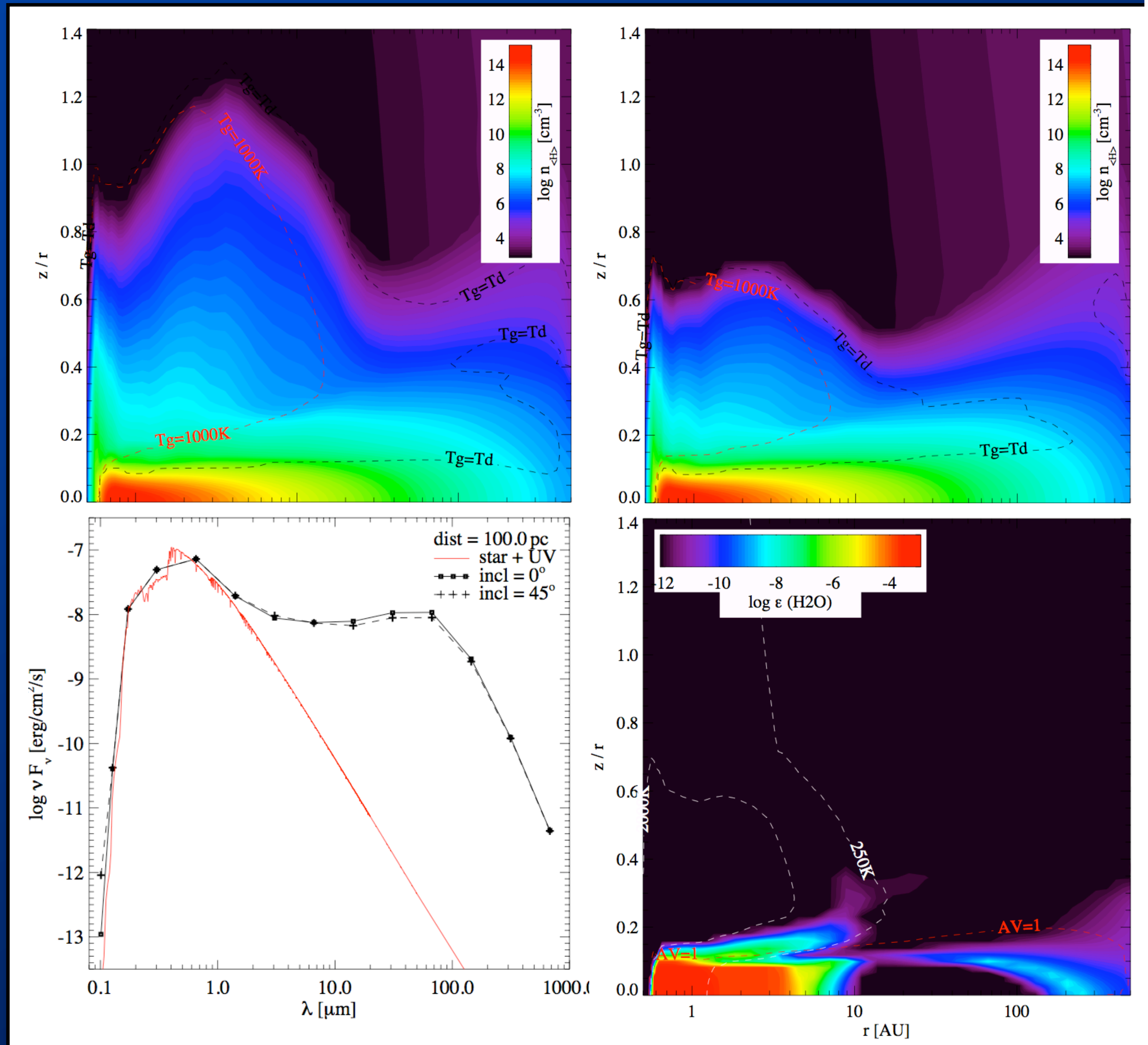


Protoplanetary Disk Models

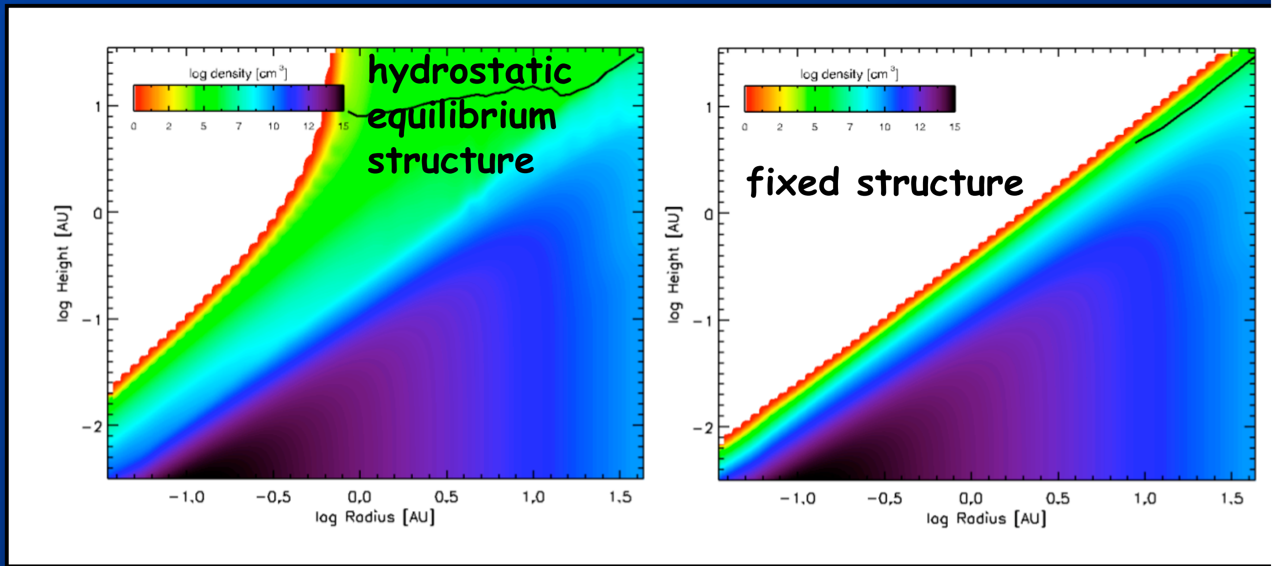
Flaring disk structure
T Tauri star
(UV + X-rays)

$M_* = 0.7\ M_\odot$
$L_* = 1.44\ L_\odot$
$T_{eff} = 4000$ K
$M_{disk} = 2.7\ 10^{-2}\ M_\odot$
$R_{out} = 500$ AU

dust:

Astronomical silicates
(Draine & Lee 1984)
0.005-0.25 μm (3.5)

[Ercolano et al. 2009]



Letting the disk structure adjust puffs up the surface

X-rays & disk structure: see poster by G. Aresu [A3]

Outline

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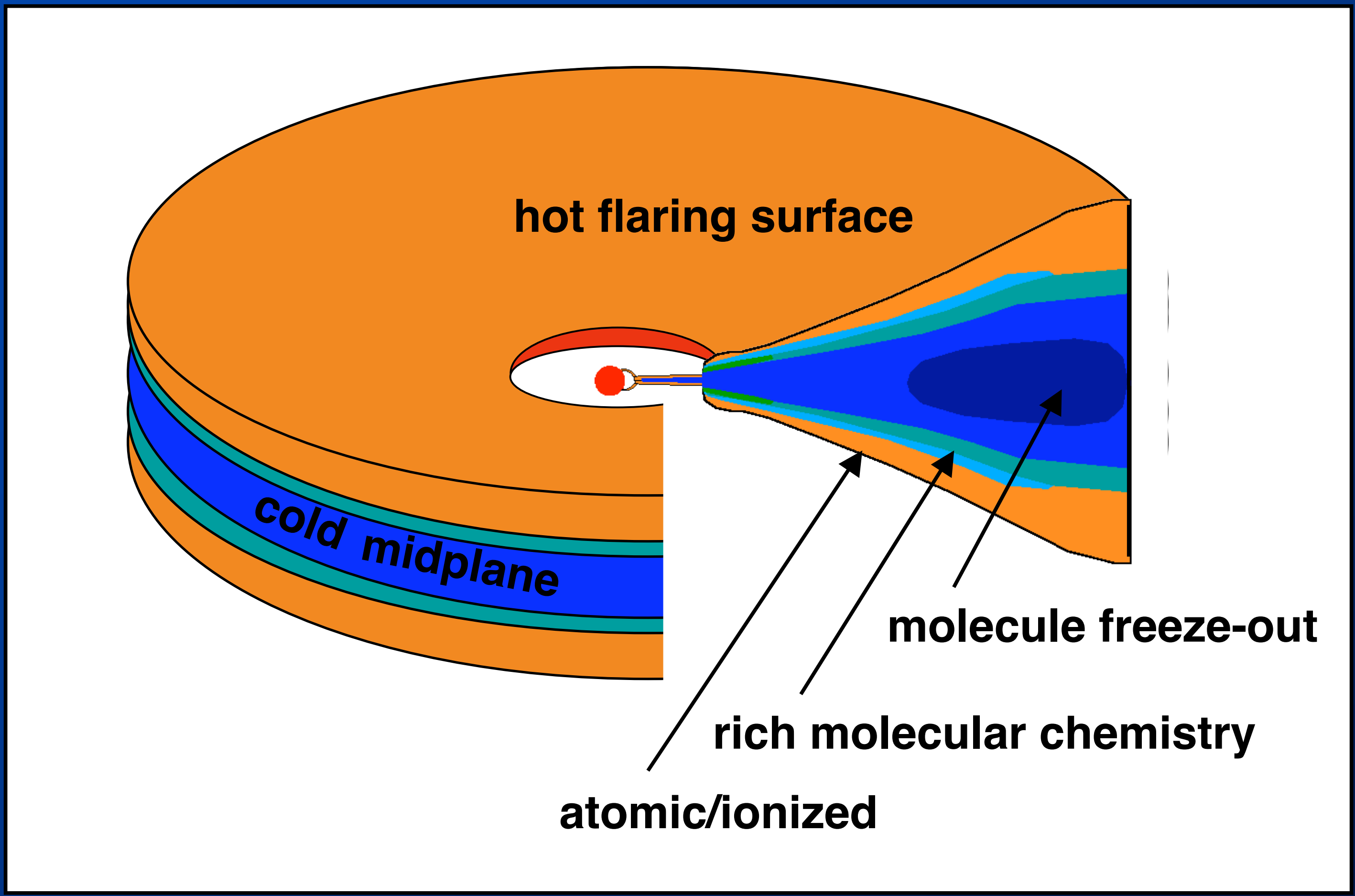
Probes of Irradiation



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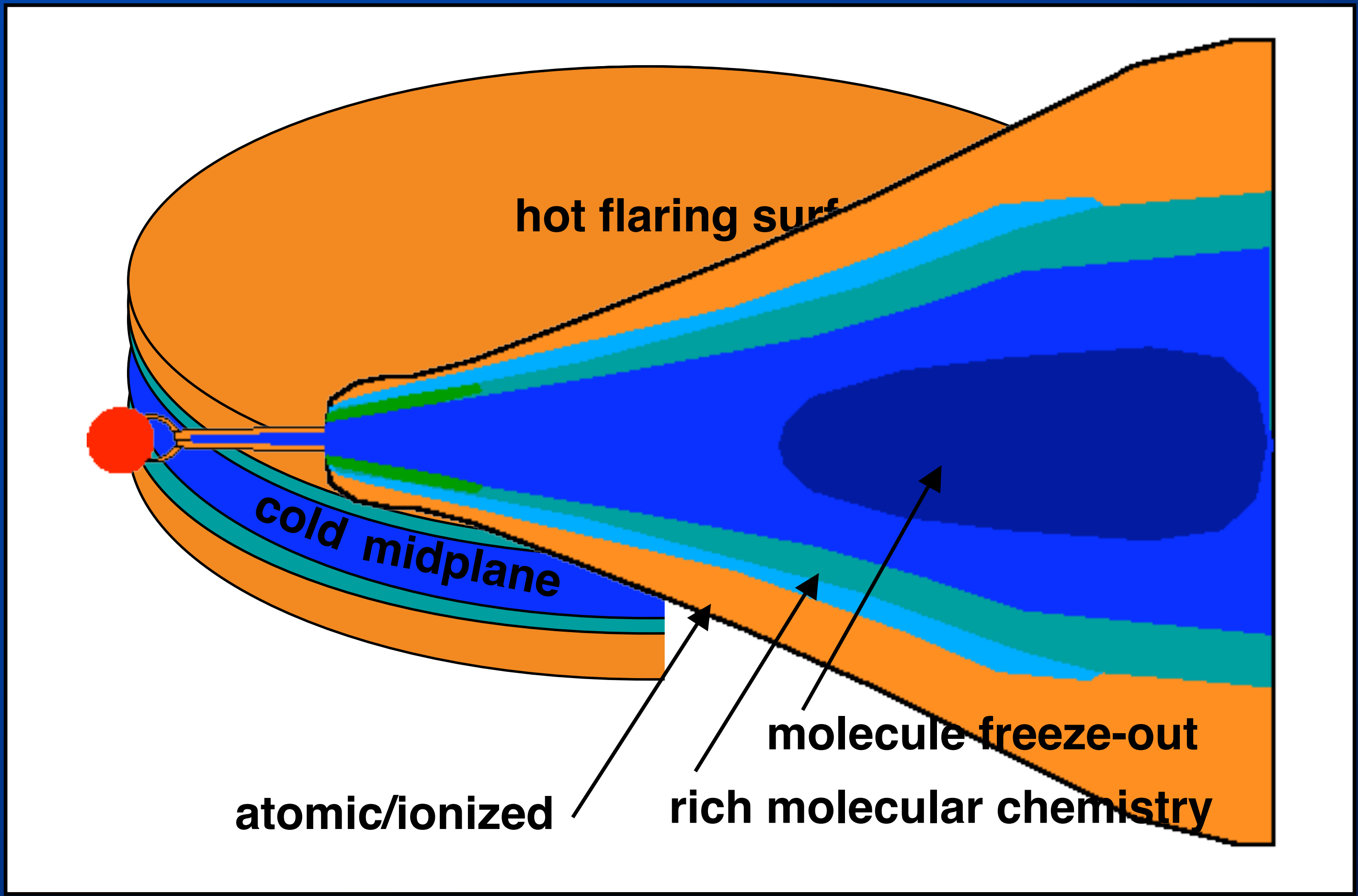

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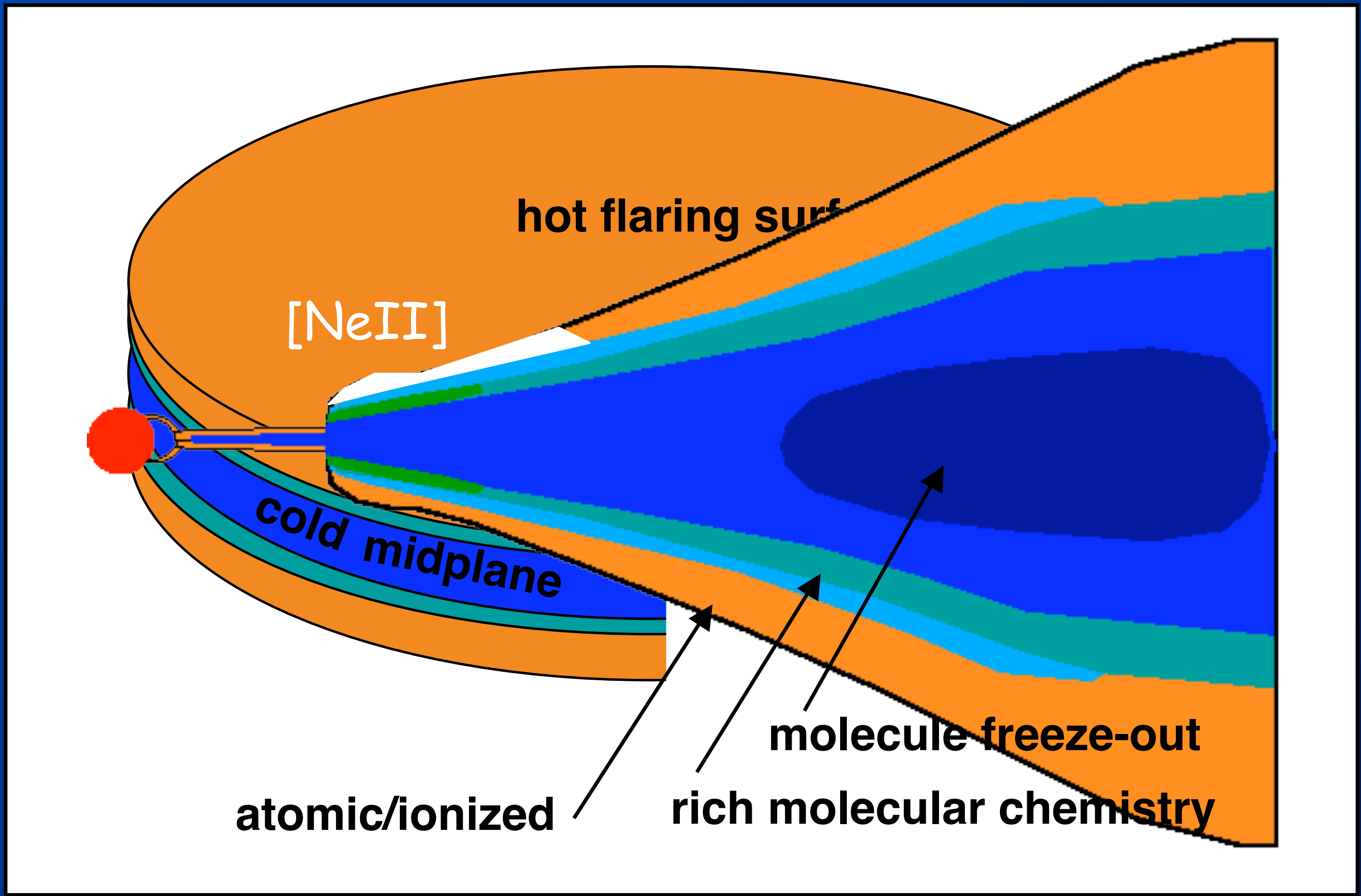

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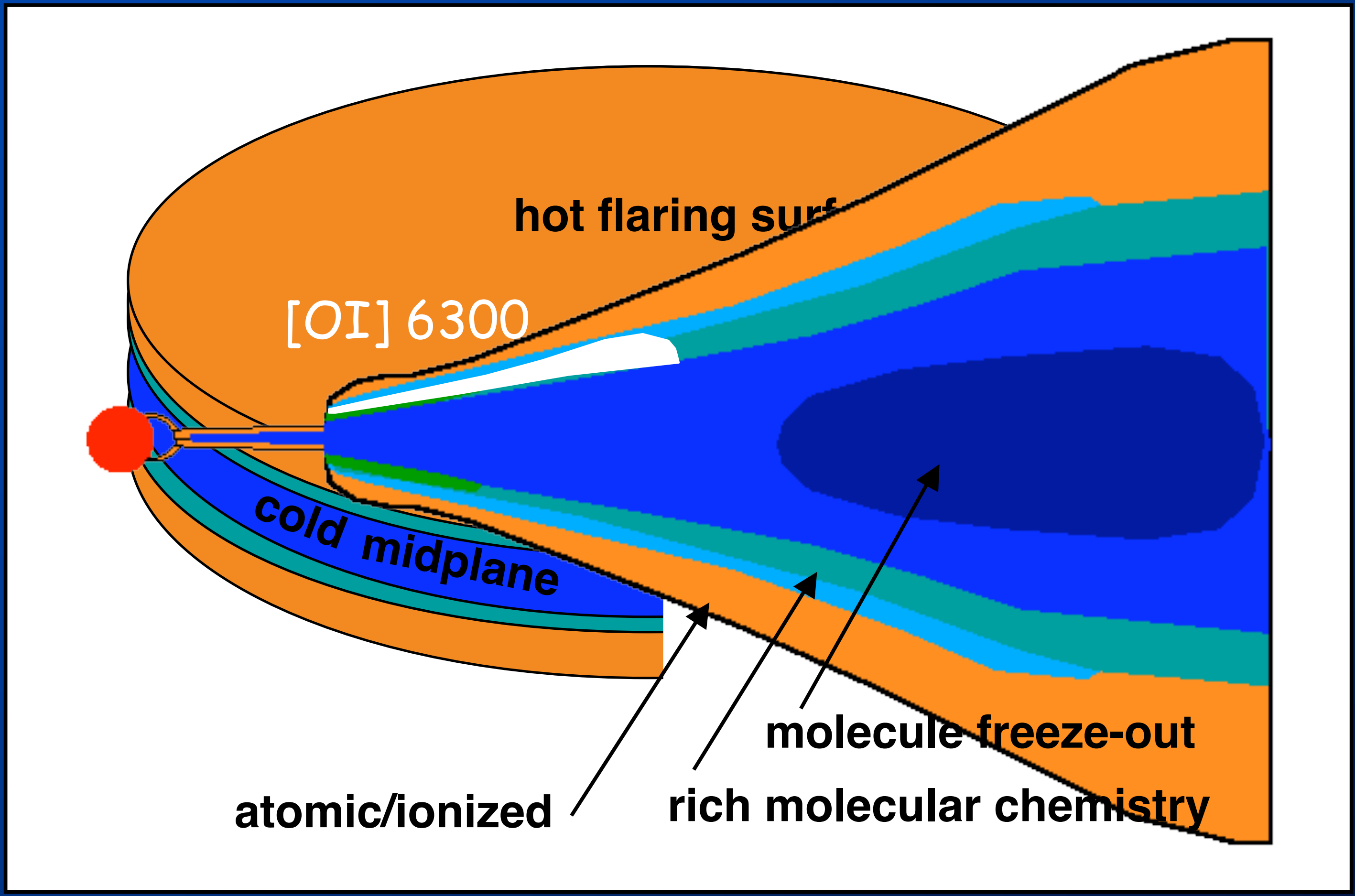

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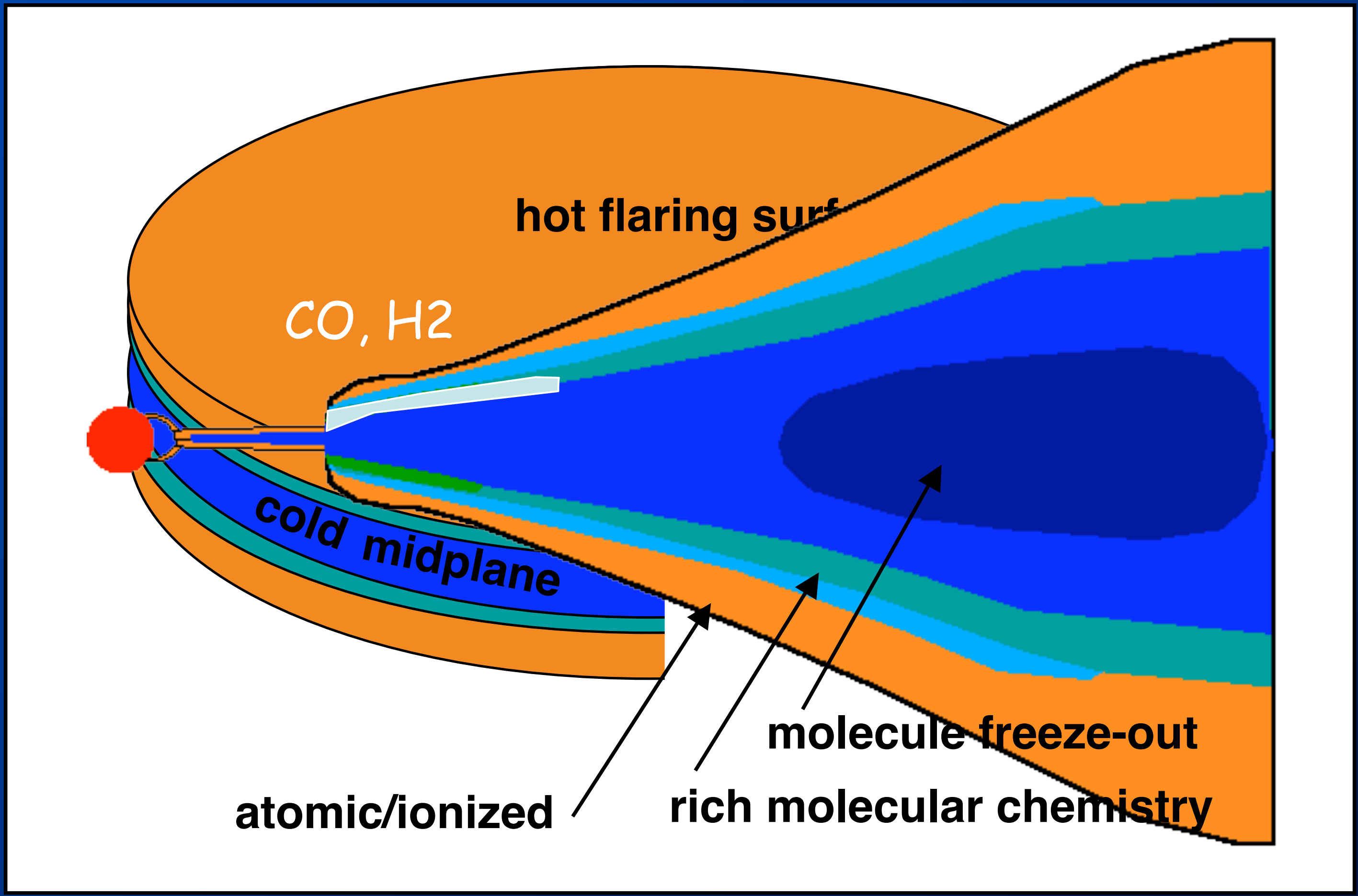
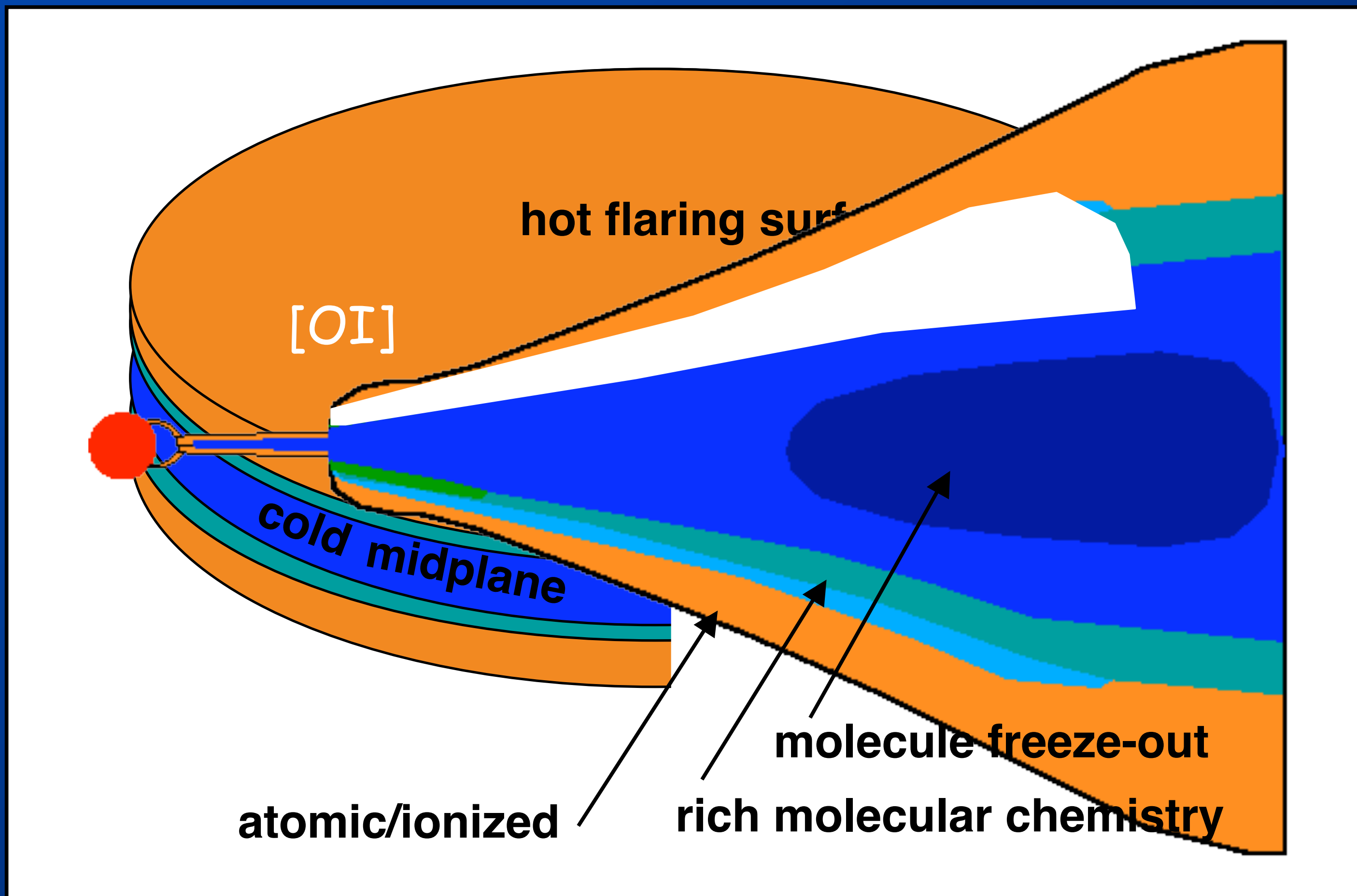
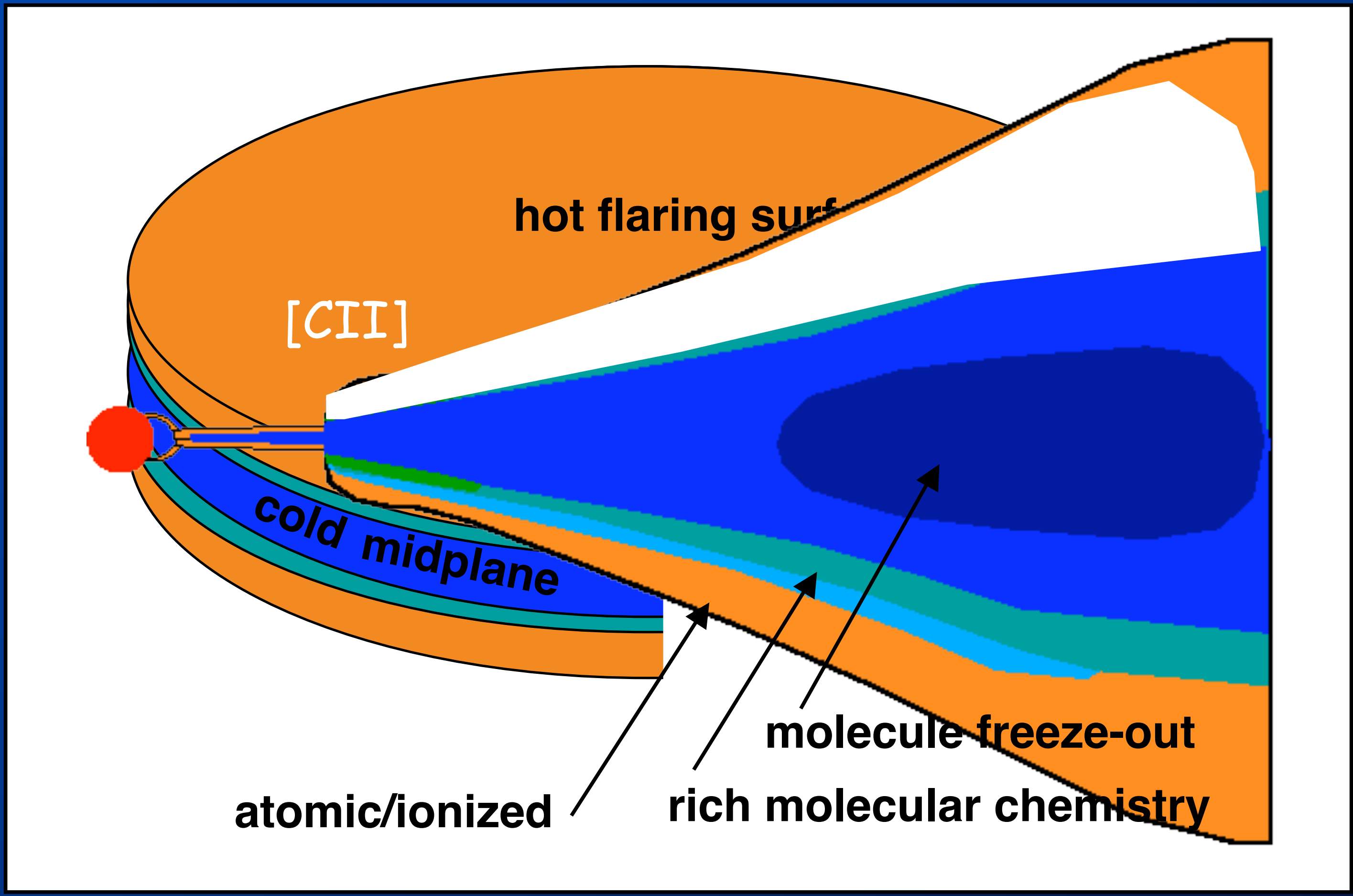


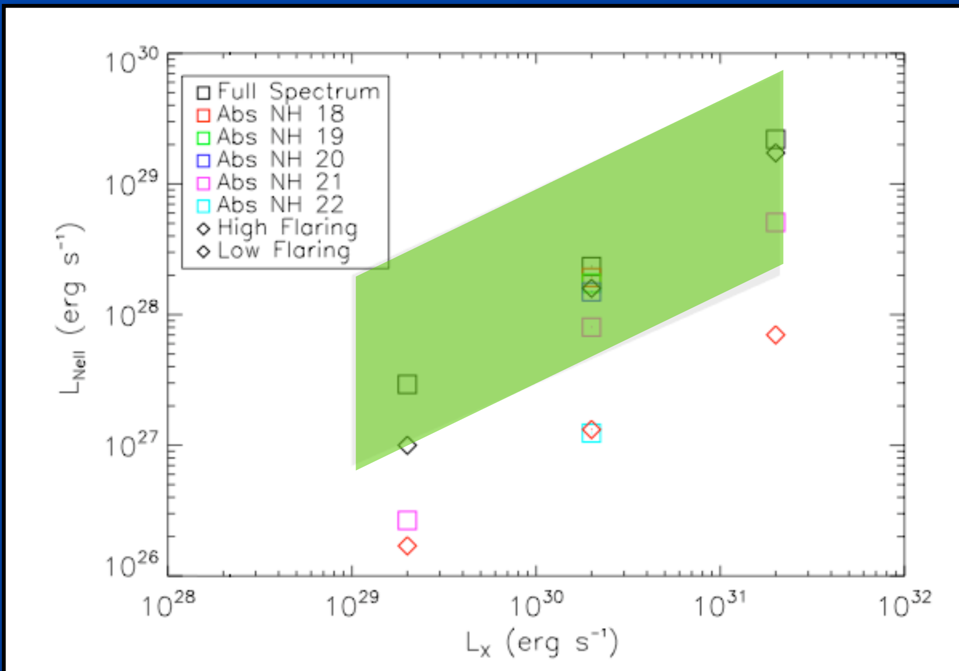
Probes of Irradiation

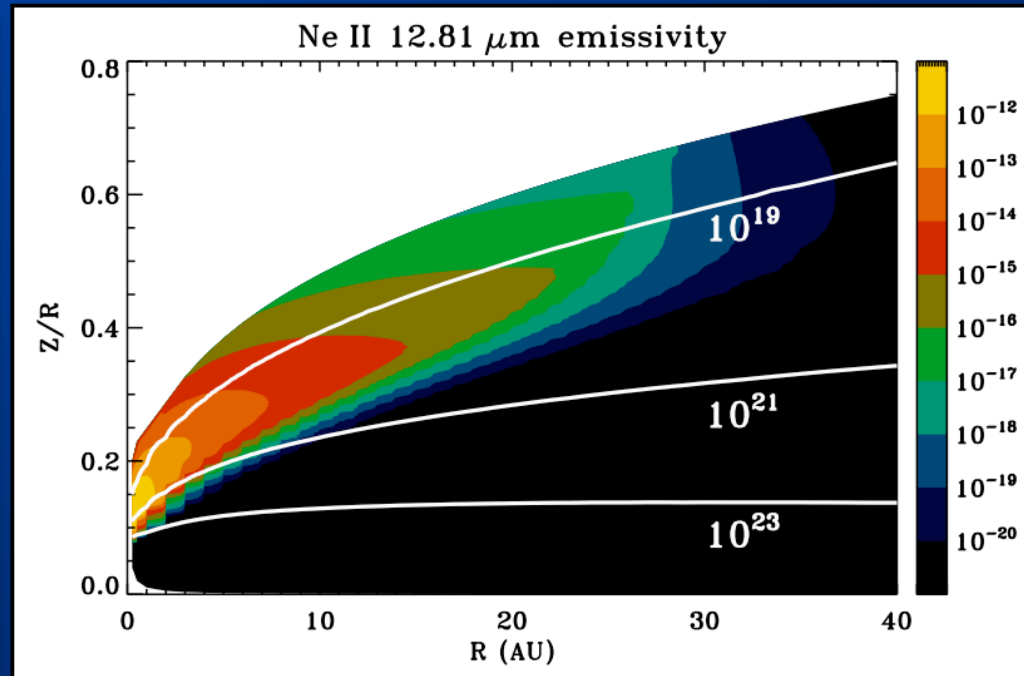


Probes of Irradiation



Probes of X-ray Irradiation: NeII





[Ne II] probes the most tenuous innermost disk surface, r<10 AU

Problems: confusion with jets and tenuous remnant material

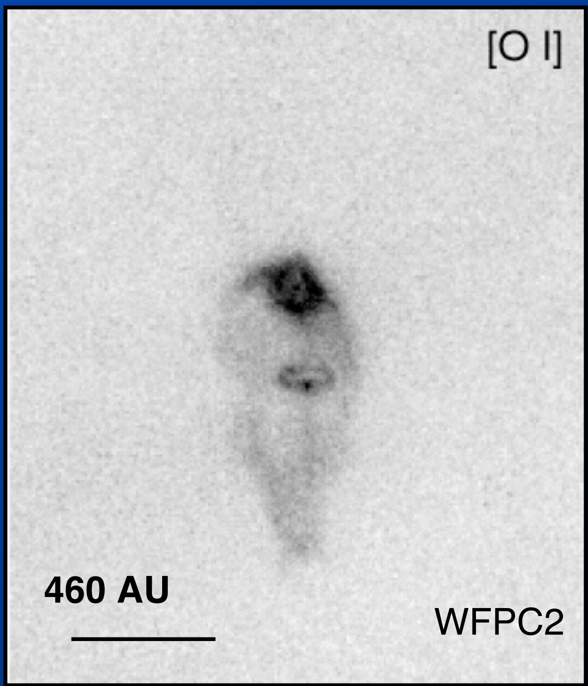
[e.g. Glassgold et a. 2007, Pascucci et al. 2007, Lahuis et al. 2007, Meijerink et al. 2008, Schisano et al. 2009]

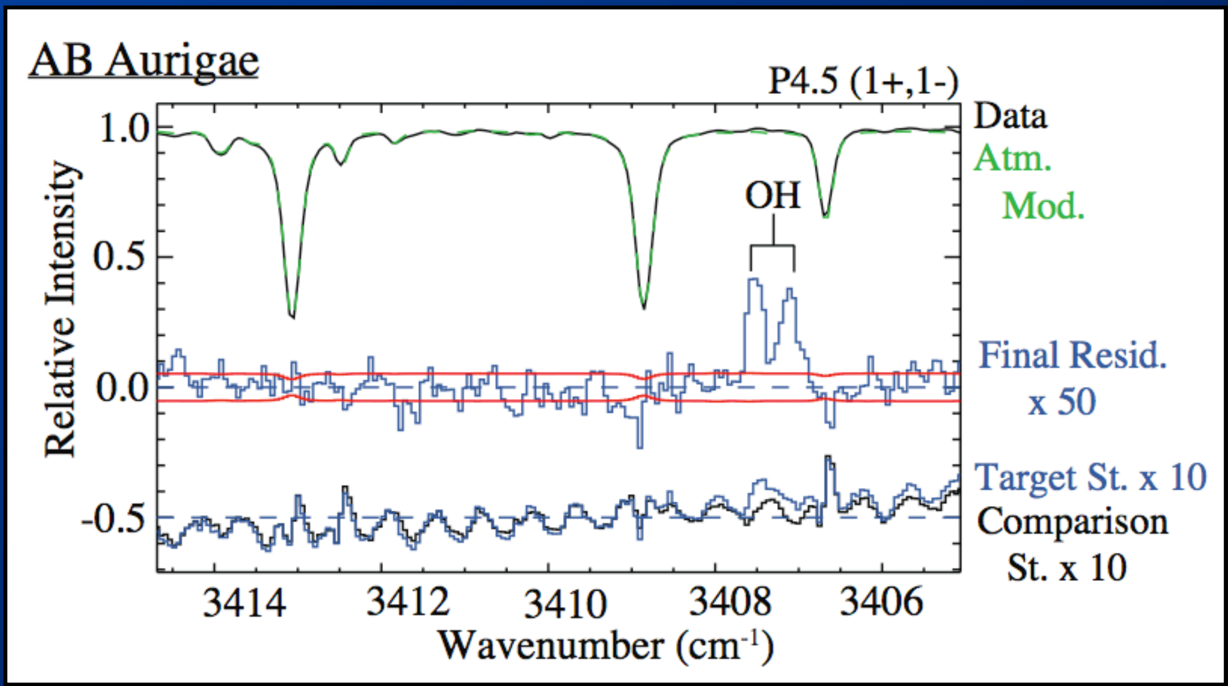
see talk by M. Guedel

Probes of UV Irradiation: [OI], OH

OH photodissociation layer: OH + ν → O* + H

O* denotes the $^1D_2$ excited level (decay emits a 6300 Å photon)





[Bally et al. 2000, Störzer & Hollenbach 1998, Acke et al. 2005]

[Mandell et al. 2008, Salyk et al. 2008]

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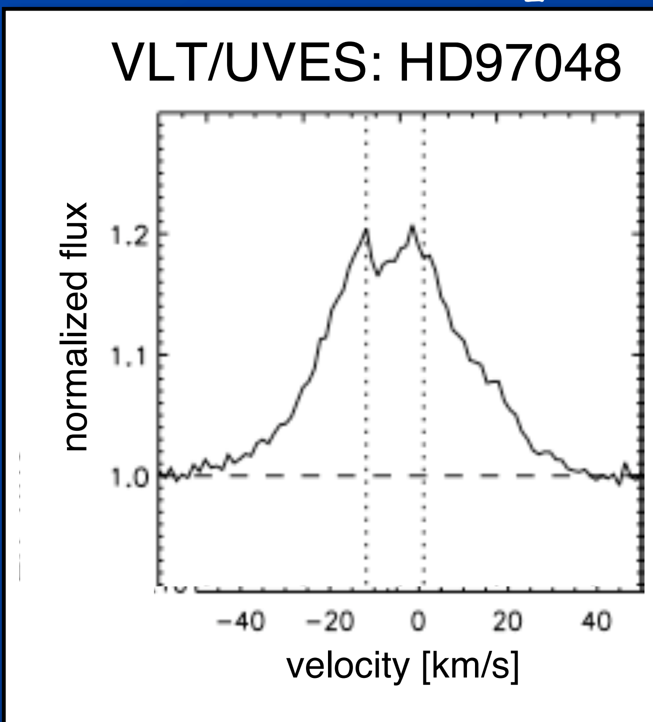
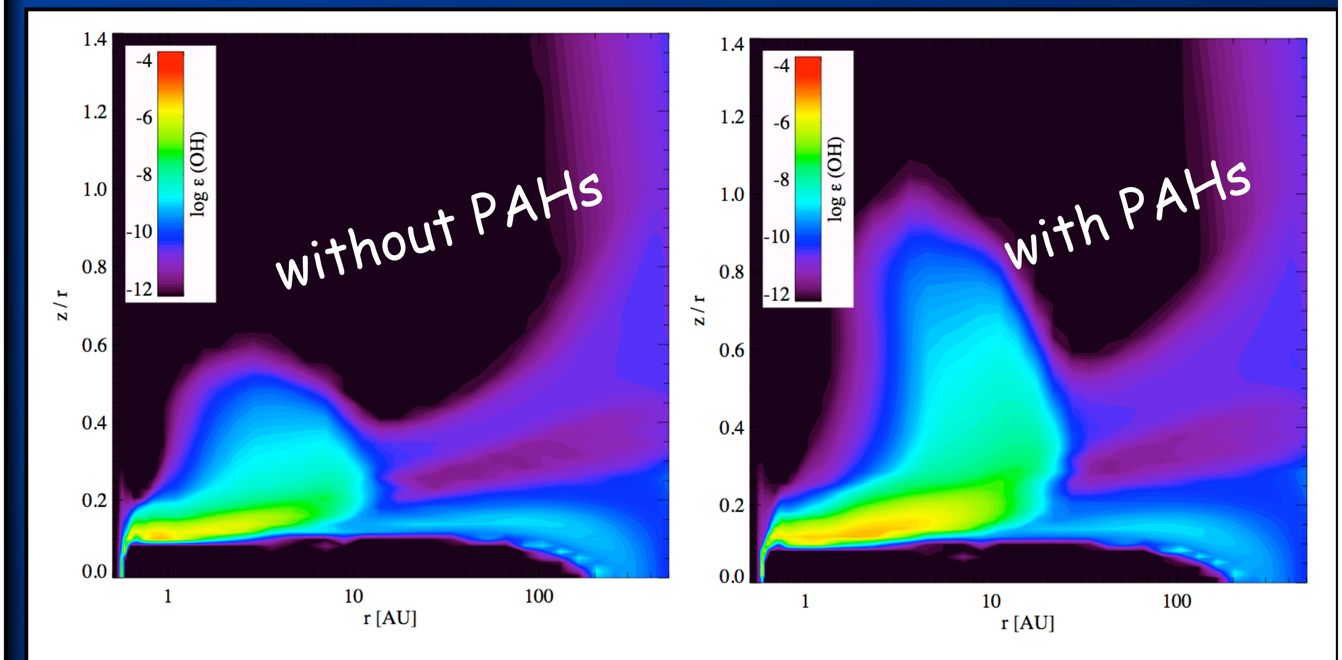


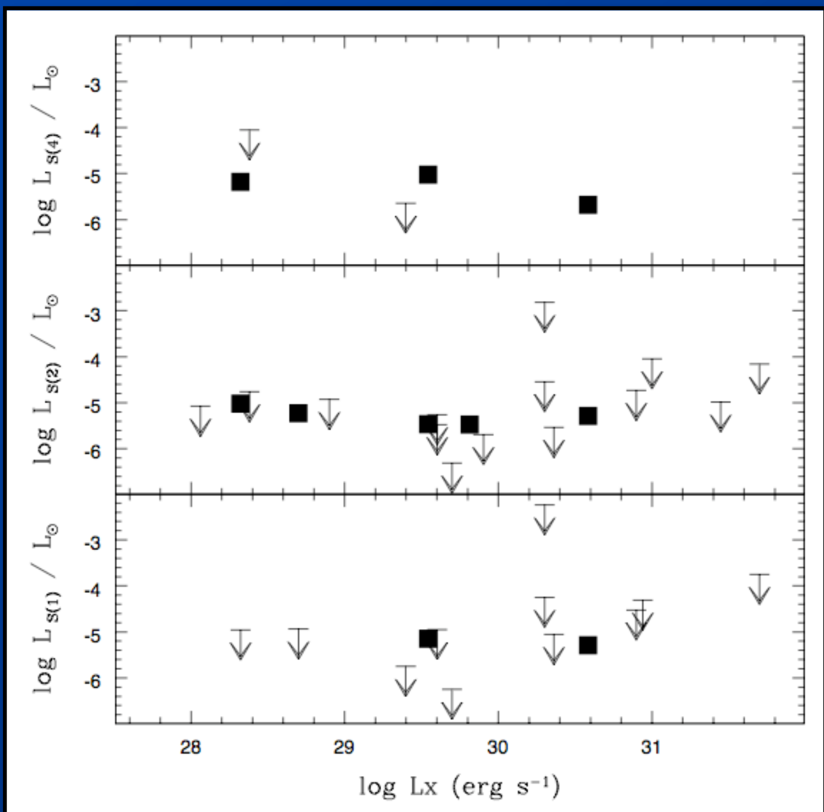


[Bally et al. 2000, Störzer & Hollenbach 1998, Acke et al. 2005]

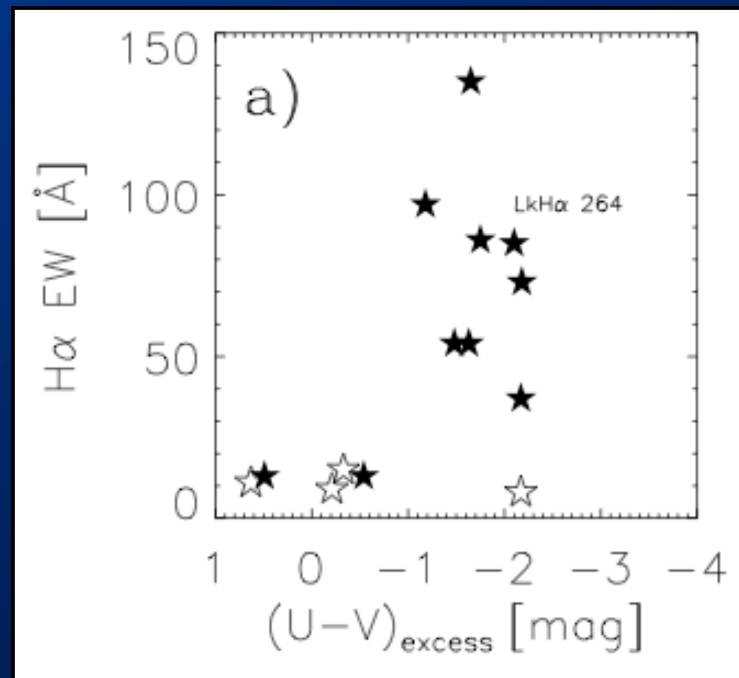
inner ~10 AU surface

Probes of UV, X-ray Irradiation: H_2

H_2 UV (Lyman & Werner bands) or X-rays (collisions with fast e^-)



[S(1), S(2), S(4) pure rot. MIR lines: Bitner et al. 2008]

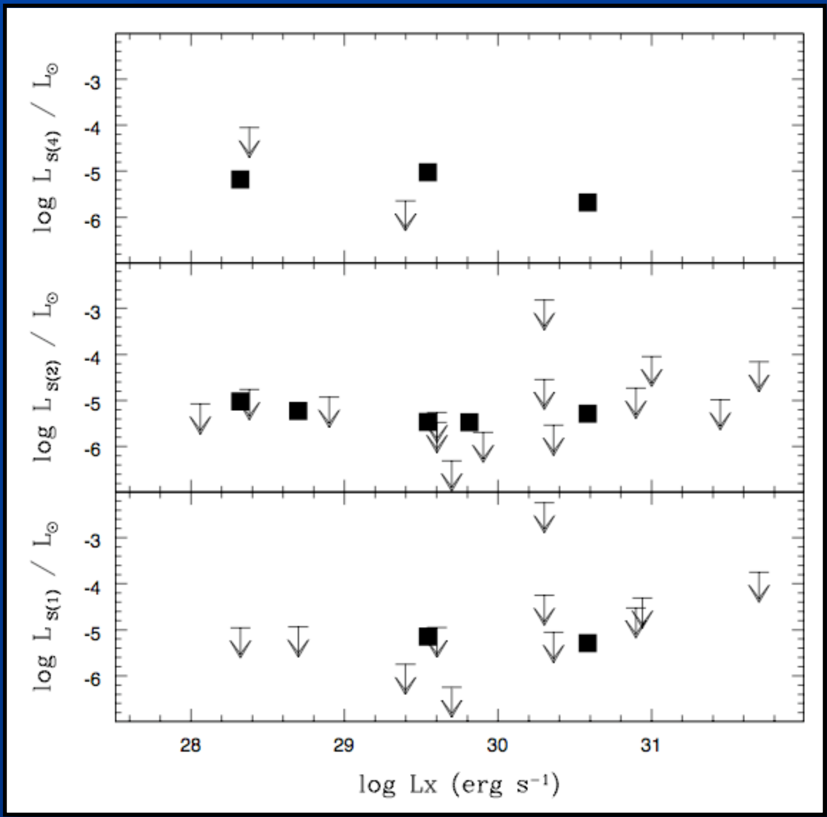


[v=1-0 S(1), S(0), v=2-1 S(1) NIR: Carmona et al. 2008

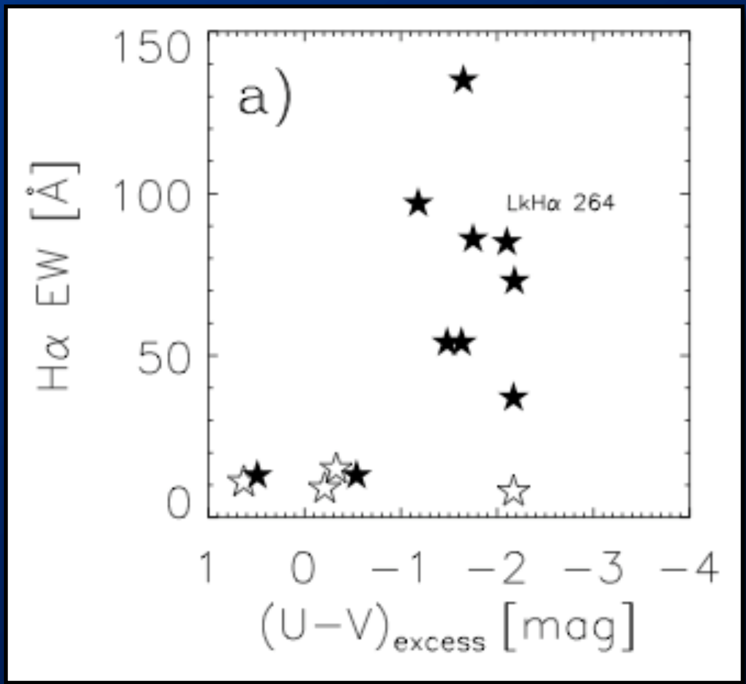
Probes of UV, X-ray Irradiation: H_2

H_2 originates from surfaces where $T_{gas} \neq T_{dust}$ (inside few 10 AU)

no correlation with L_X, tentative correlation with L_{UV}

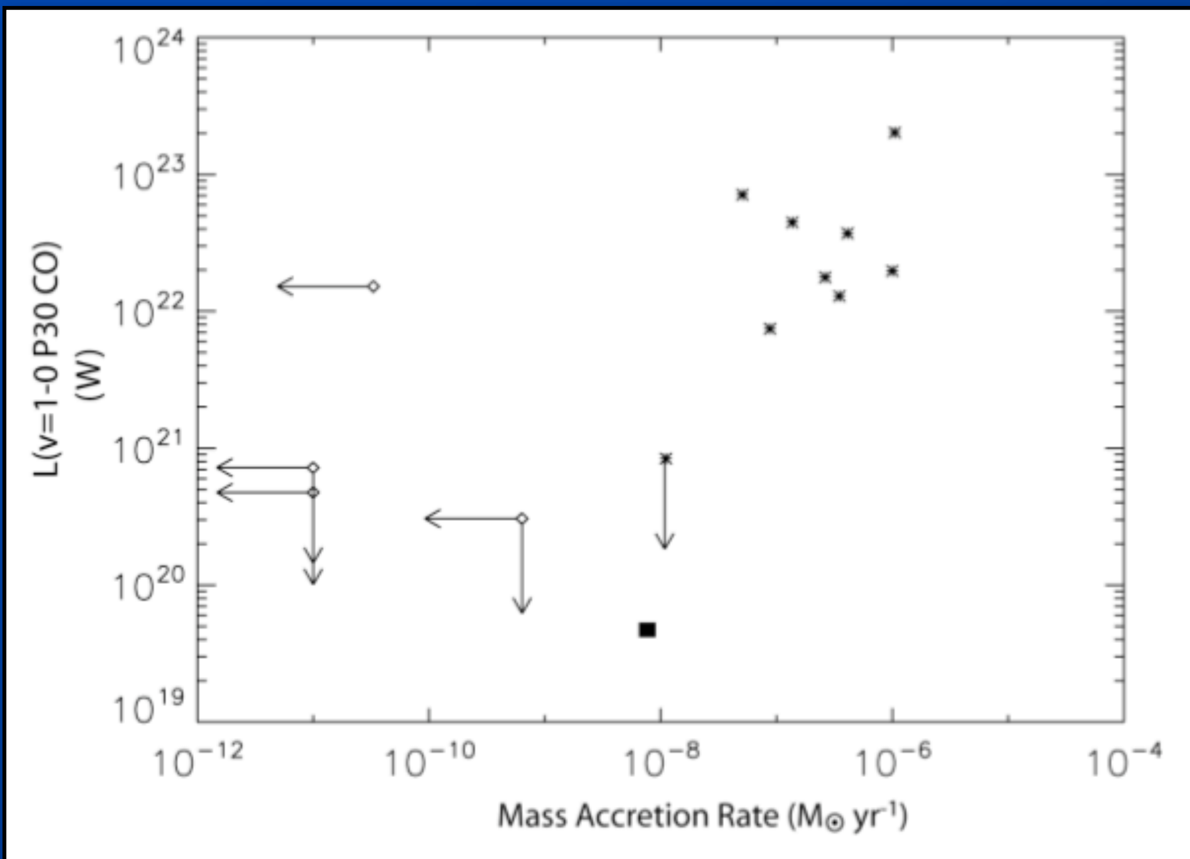


[S(1), S(2), S(4) pure rot. MIR lines: Bitner et al. 2008]



[v=1-0 S(1), S(0), v=2-1 S(1) NIR: Carmona et al. 2008]

Probes of UV Irradiation: CO



[Brittain et al. 2007, van der Plas et al. 2009]

CO excitation:

thermal excitation
UV fluorescence

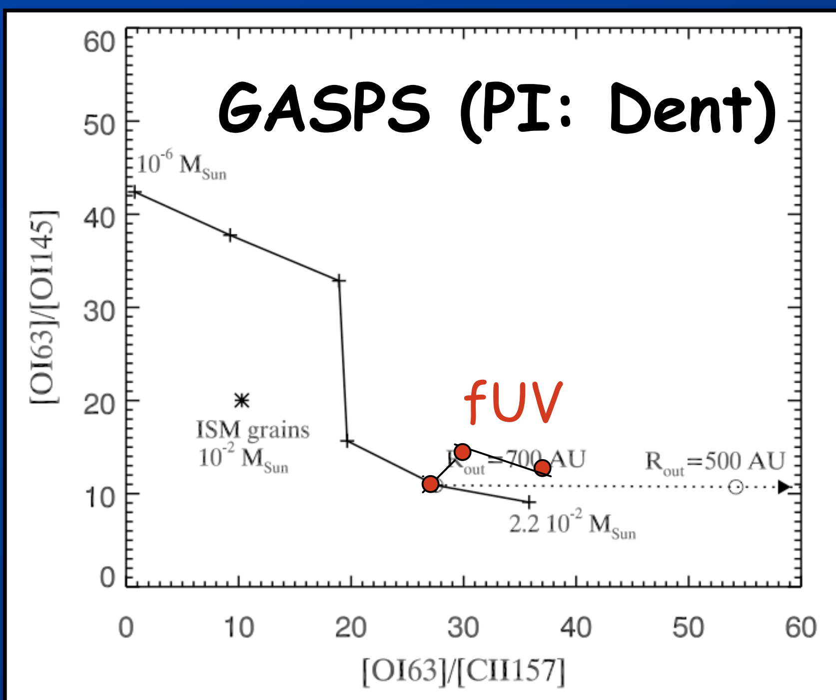
CO inner radius larger than [OI] 6300 inner radius - depletion ?

see poster B41 by Gerrit van der Plas

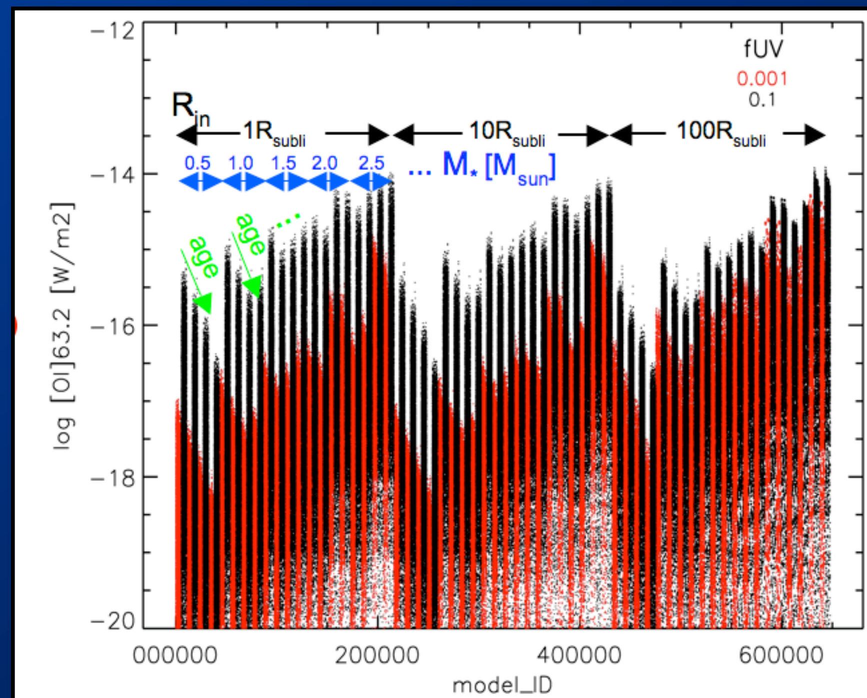
Probes of UV Irradiation: [OI], [CII]

[CII] originates in the tenuous surface out to R_{out}

[OI] lines originate slightly deeper (down to 10^8 cm^{-3}) and are not dominated by R_{out}



[Liseau et al. 2006, Kamp et al. 2009, DENT: Woitke et al.]



MCFOST + ProDiMo

[Pinte et al., Woitke et al.]

--> see poster by Woitke et al. B47

Key points to take home

- Models predict that stellar UV and X-ray radiation shape the disk structure and chemistry *and* we actually observe that !
- Gas/dust coupling is very complex and suggests some interesting new possibilities in disk evolution
- Gas lines DO probe the physical and chemical conditions in the region where they arise (interplay between radiative transfer and chemical structure) -> line ratios can measure disk masses
- Disk modeling can help to understand the differences in disk structure and chemistry observed as a function of SpType

Thank You !