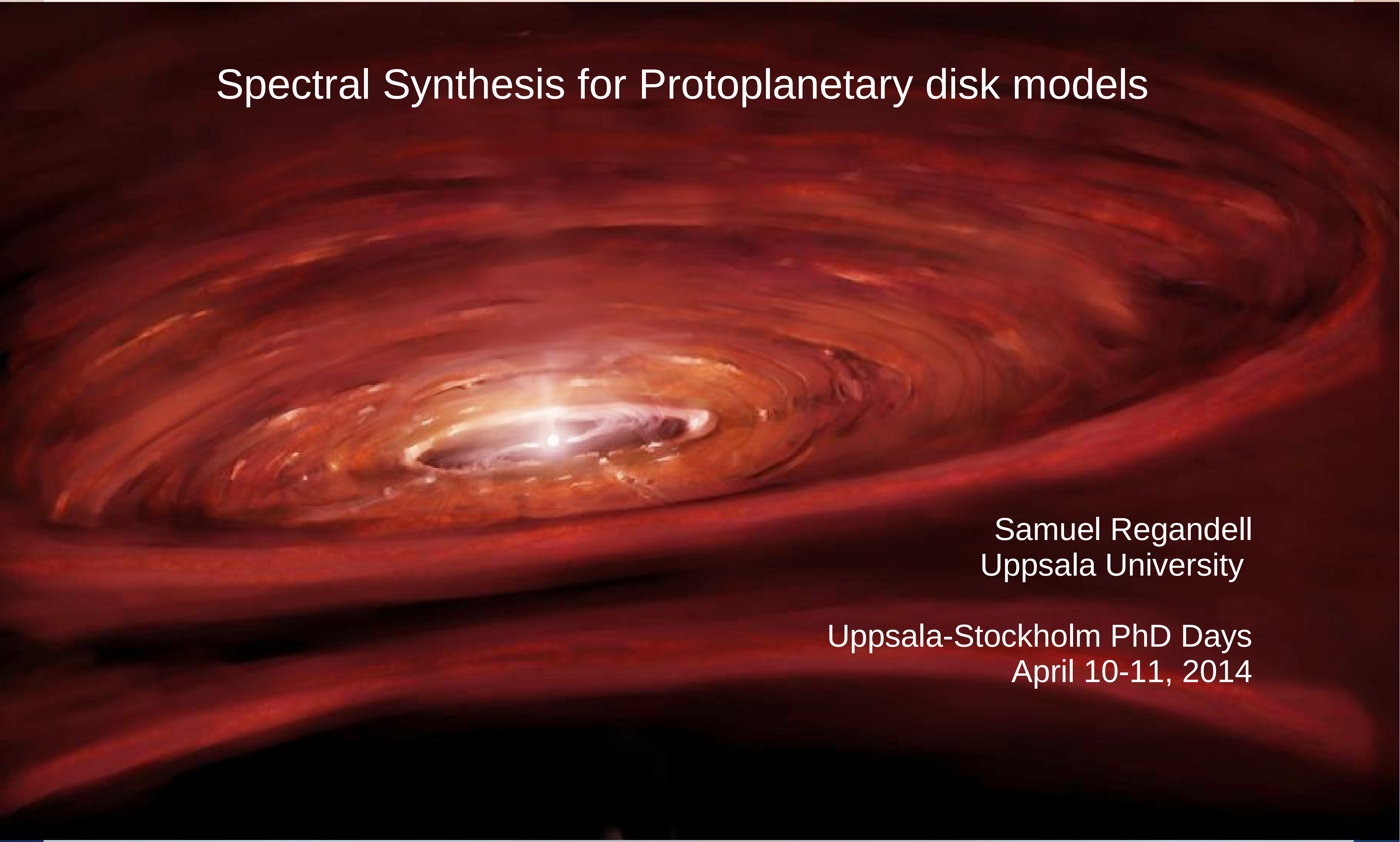
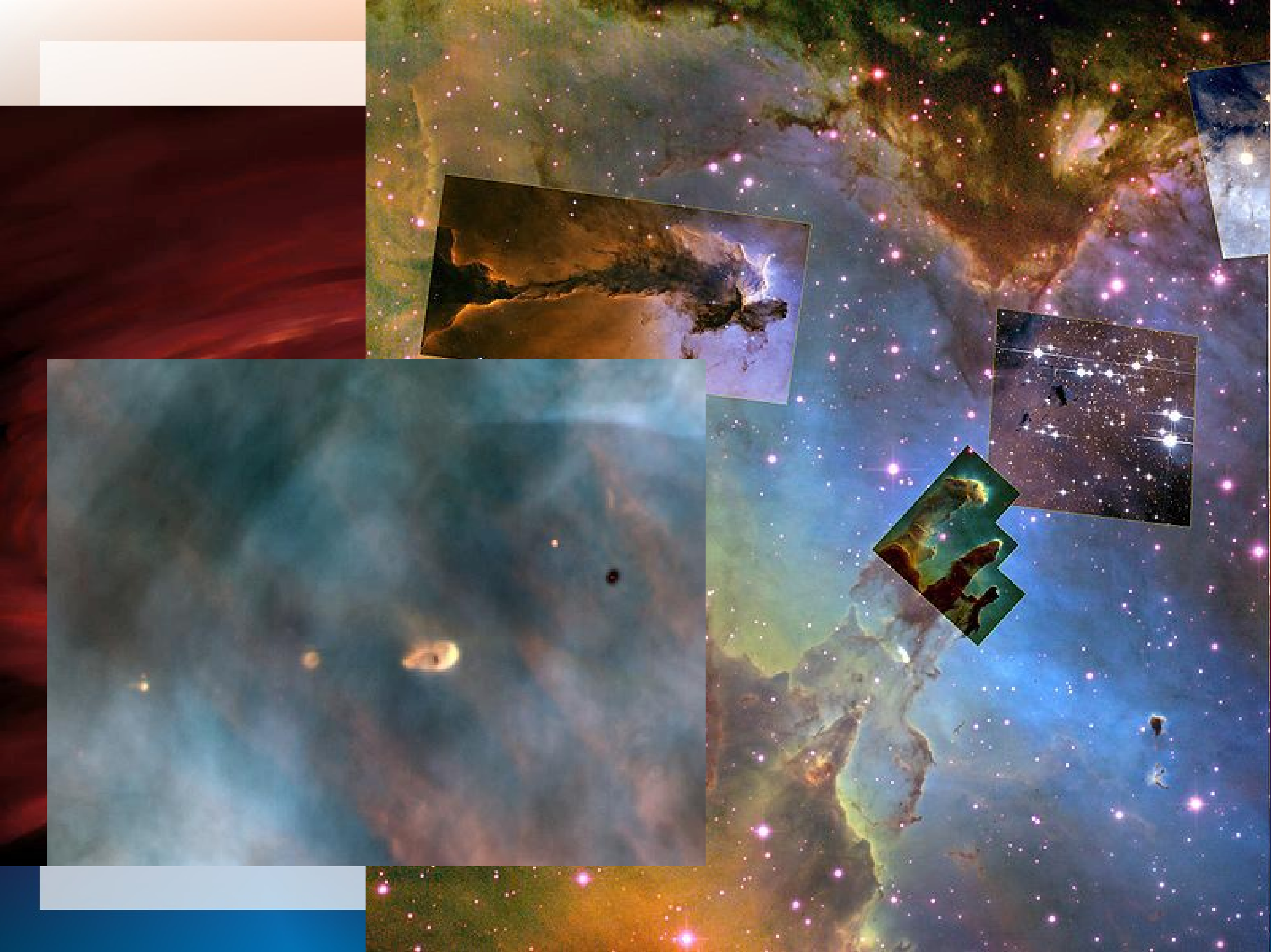
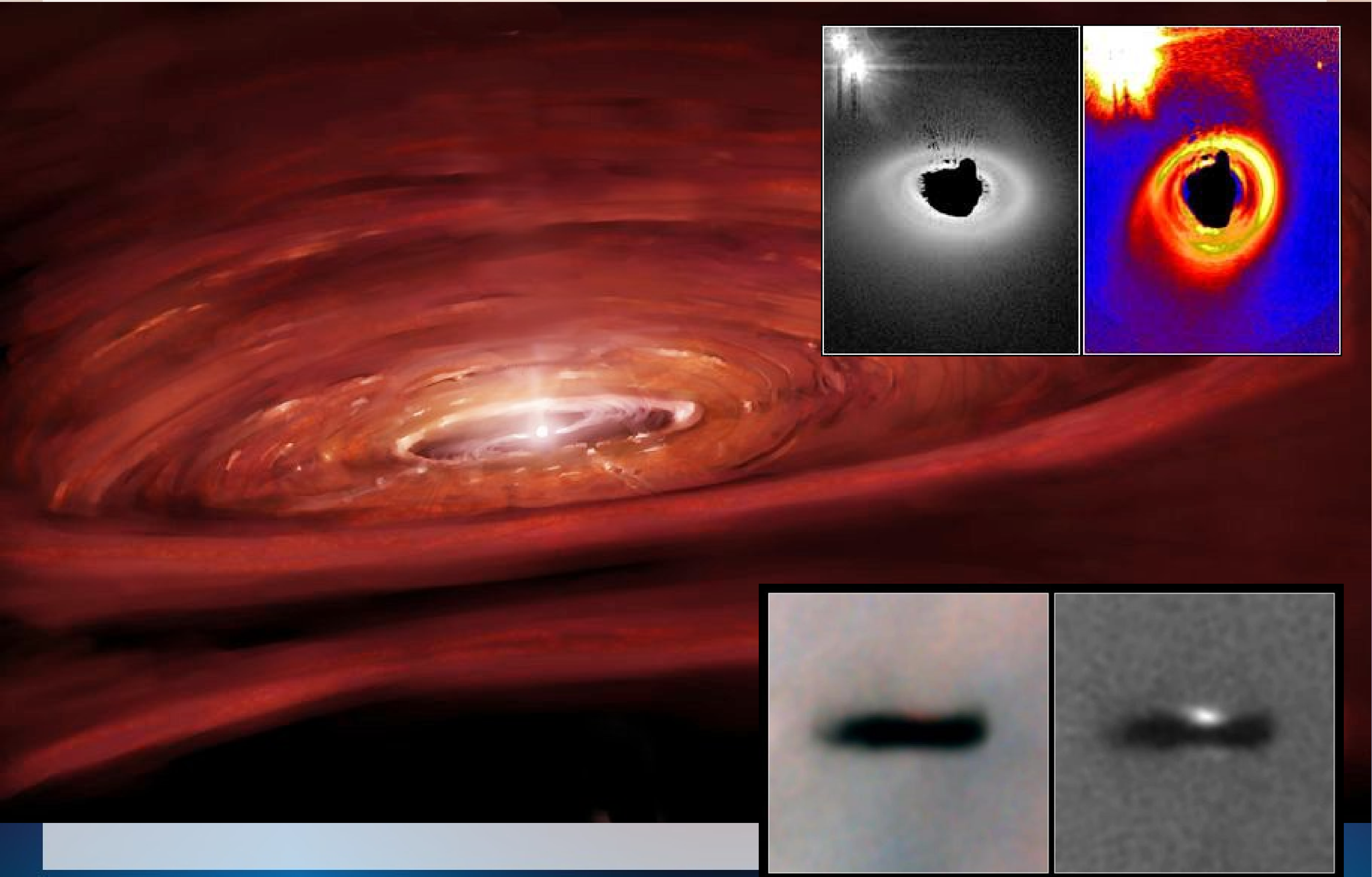
Spectral Synthesis for Protoplanetary disk models

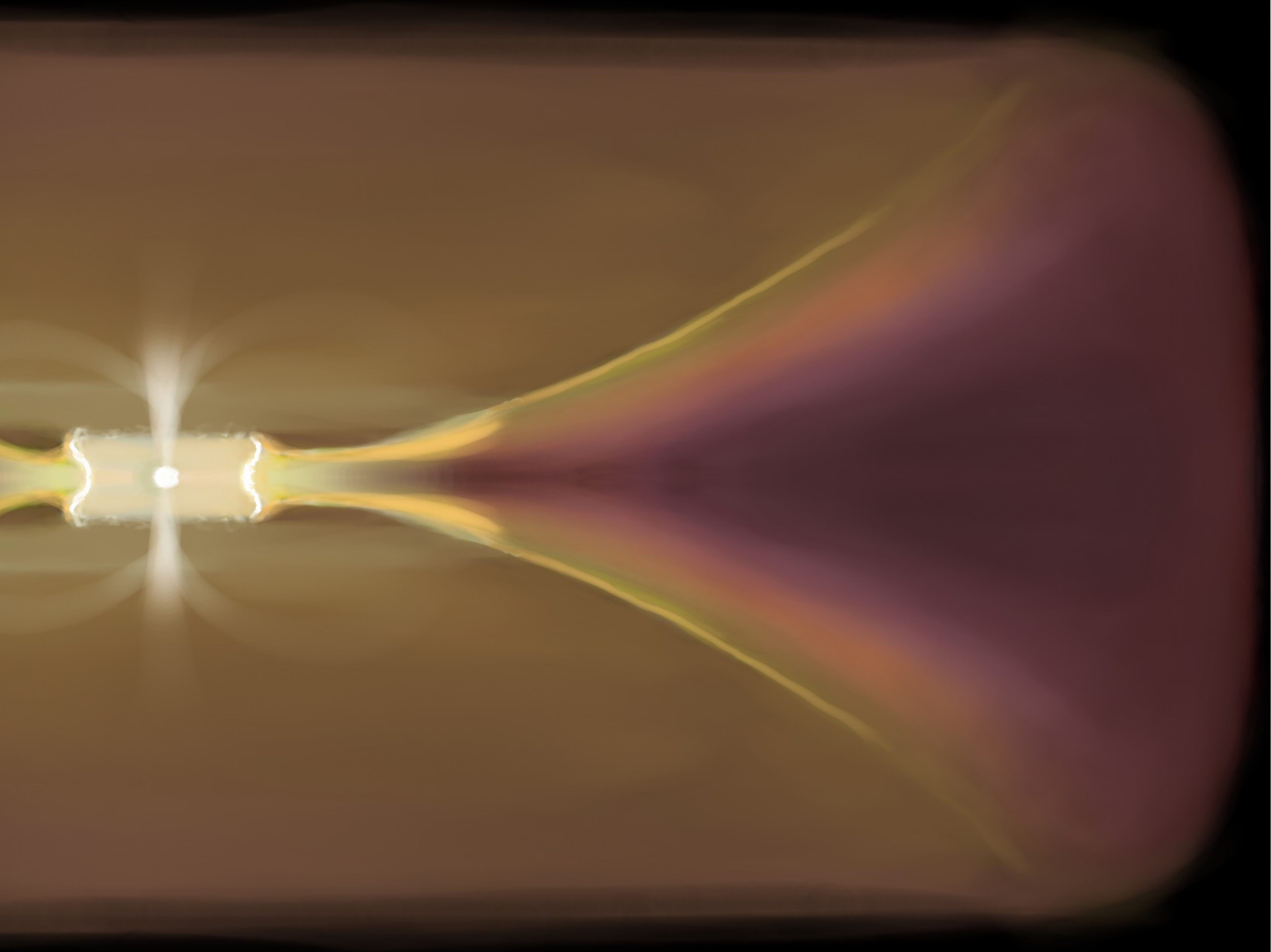


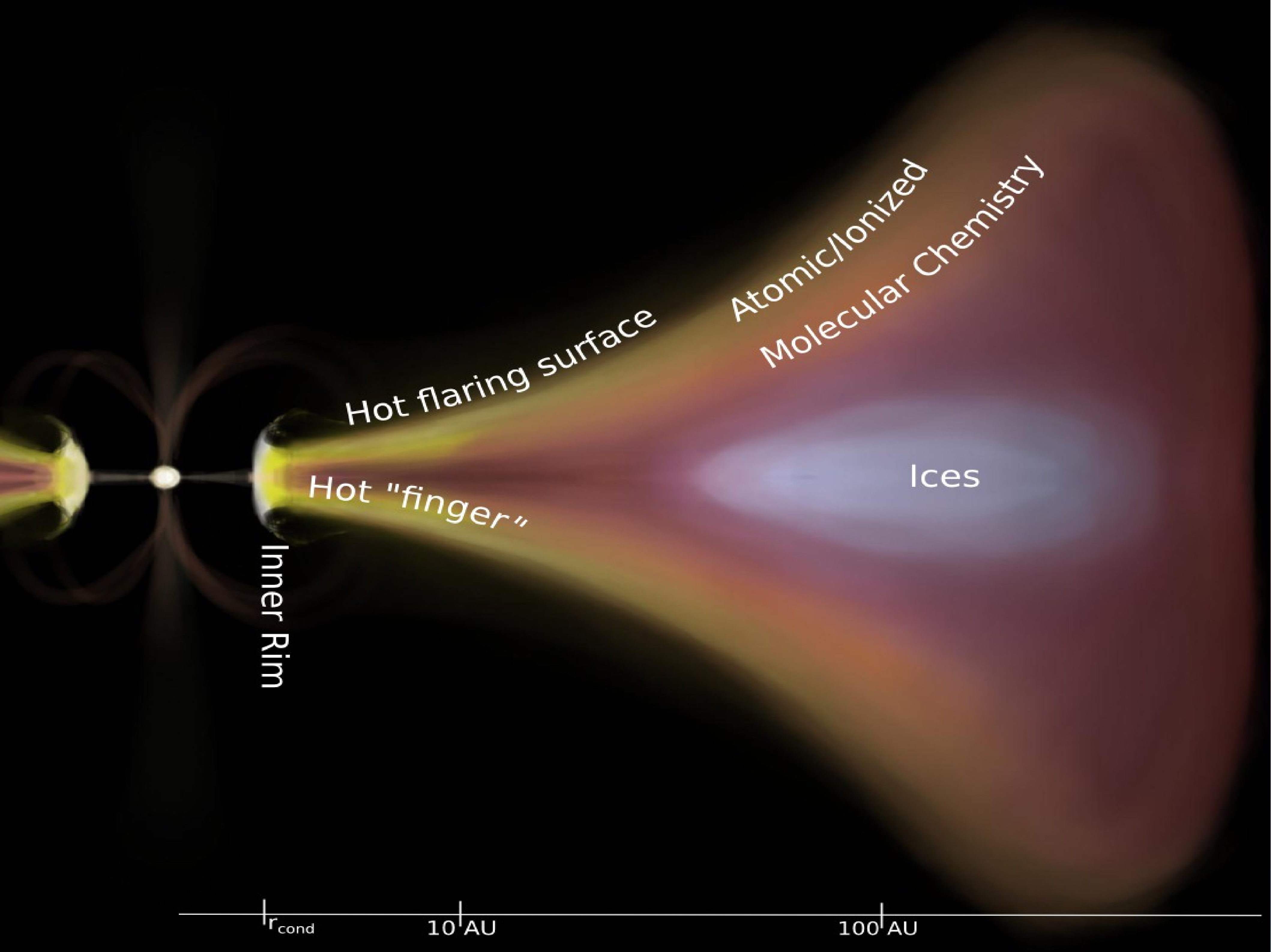
Samuel Regandell
Uppsala University

Uppsala-Stockholm PhD Days
April 10-11, 2014

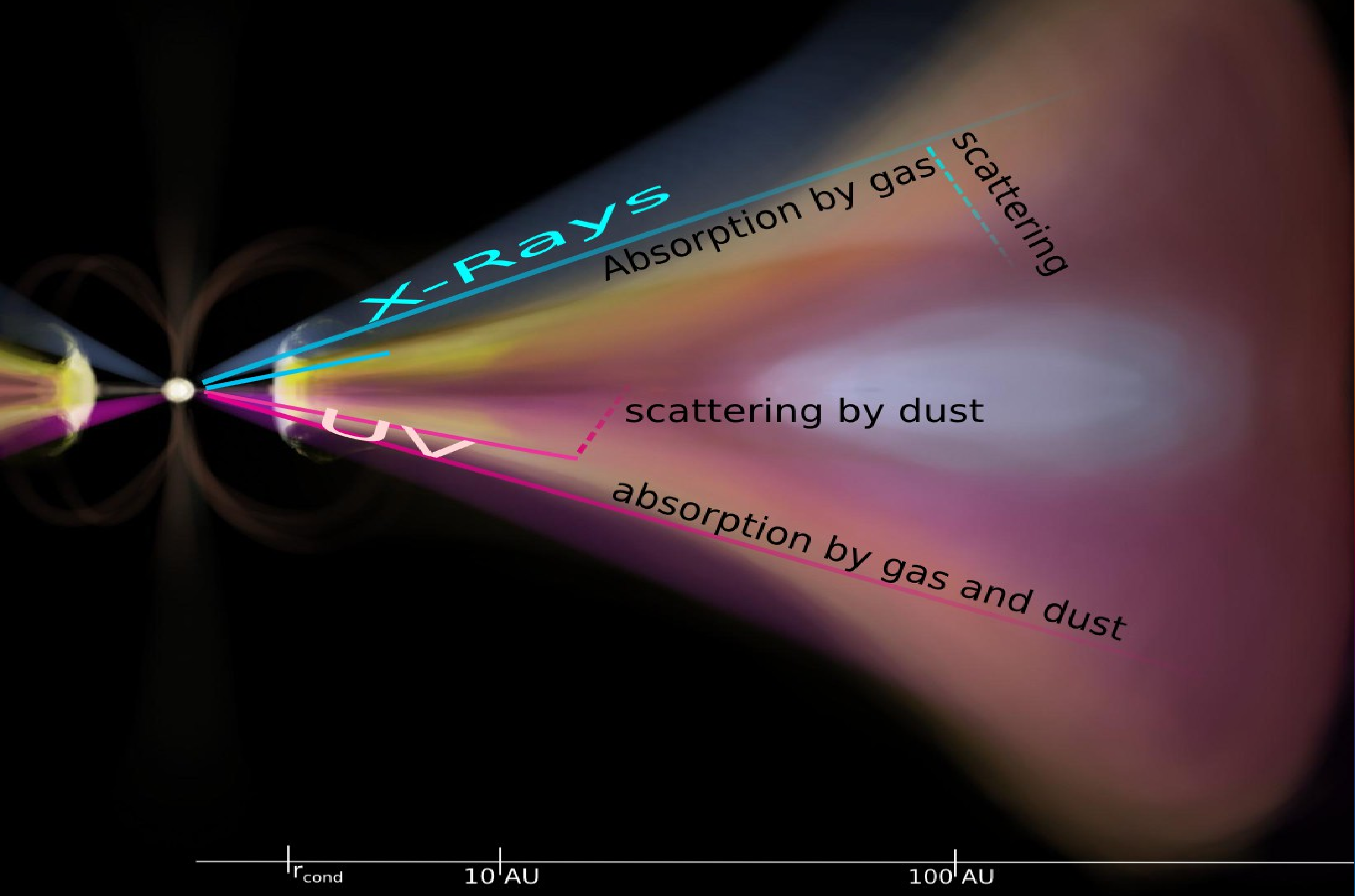




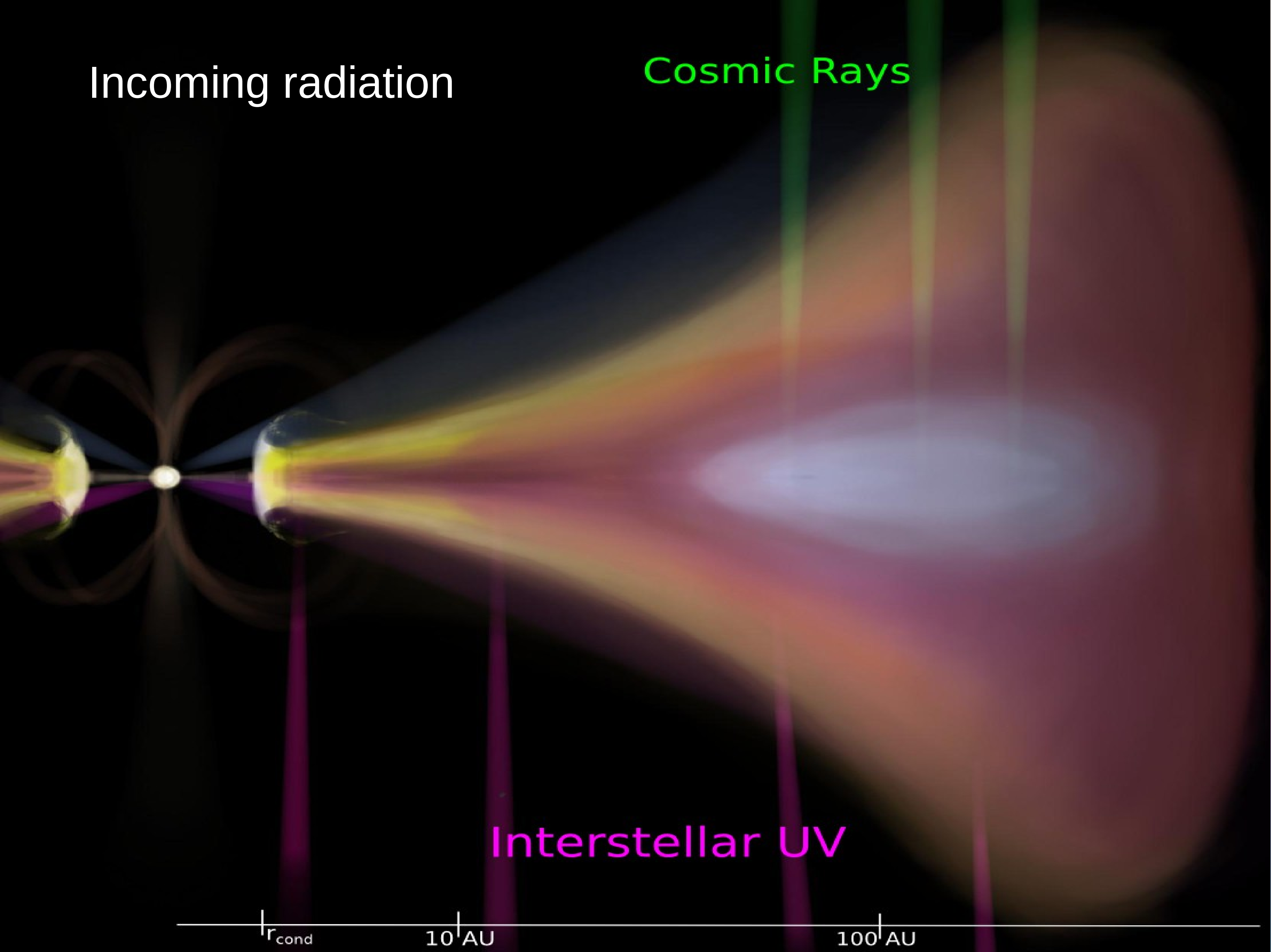



Hot flaring surface
Atomic/Ionized
Molecular Chemistry
Hot "finger"
Ices
Inner Rim
r_{cond}
10 AU
100 AU

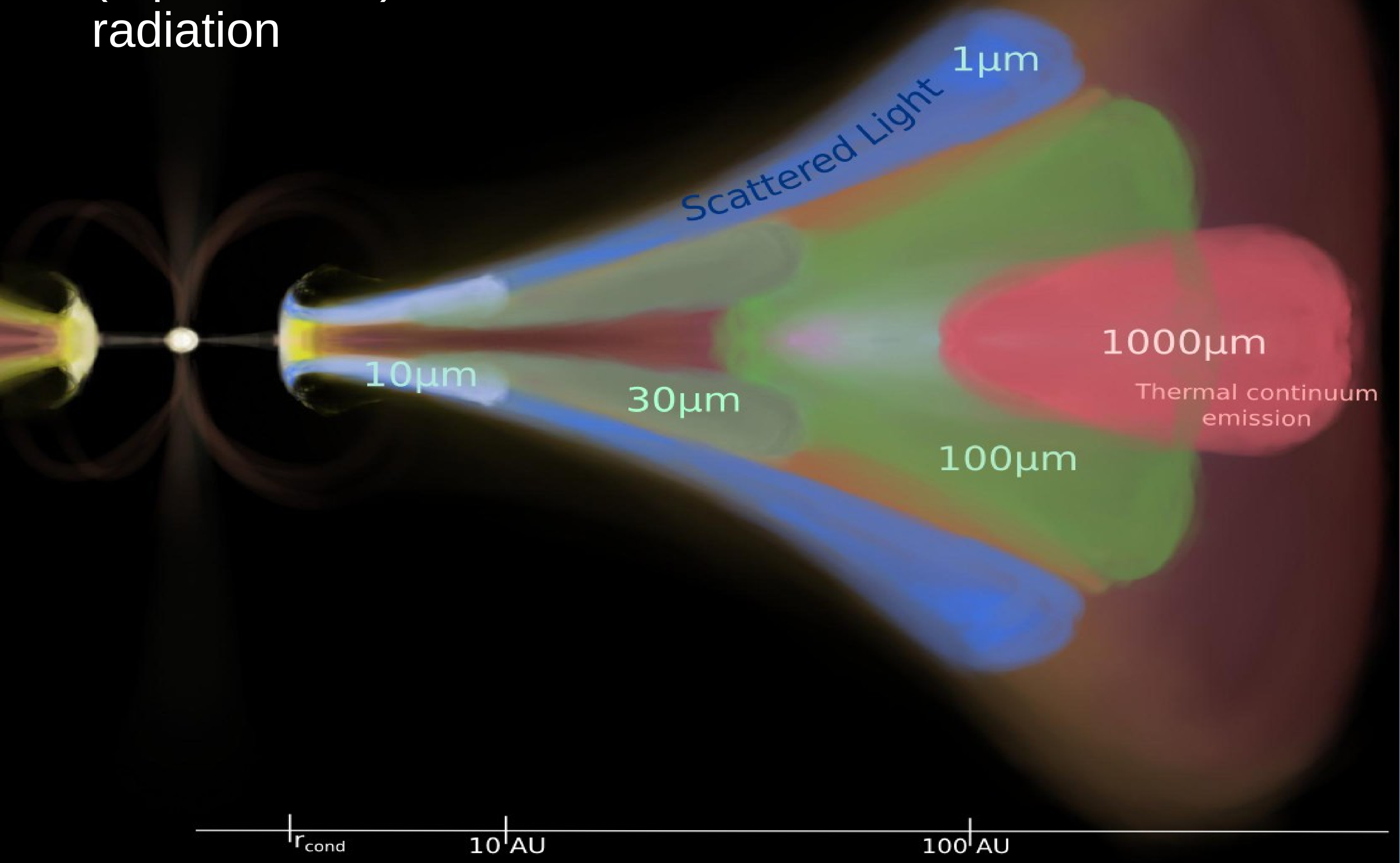
Incoming radiation

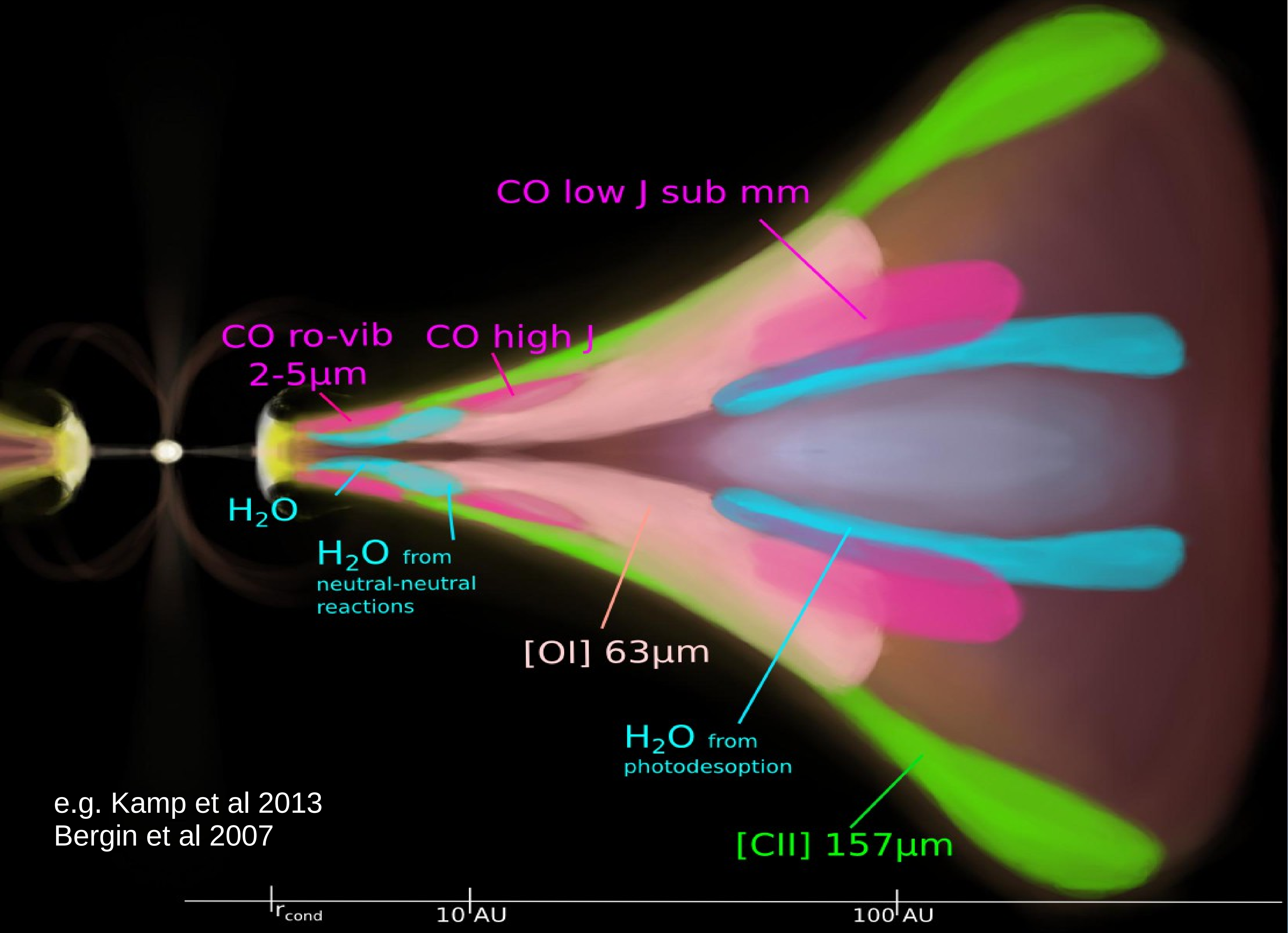


Incoming radiation

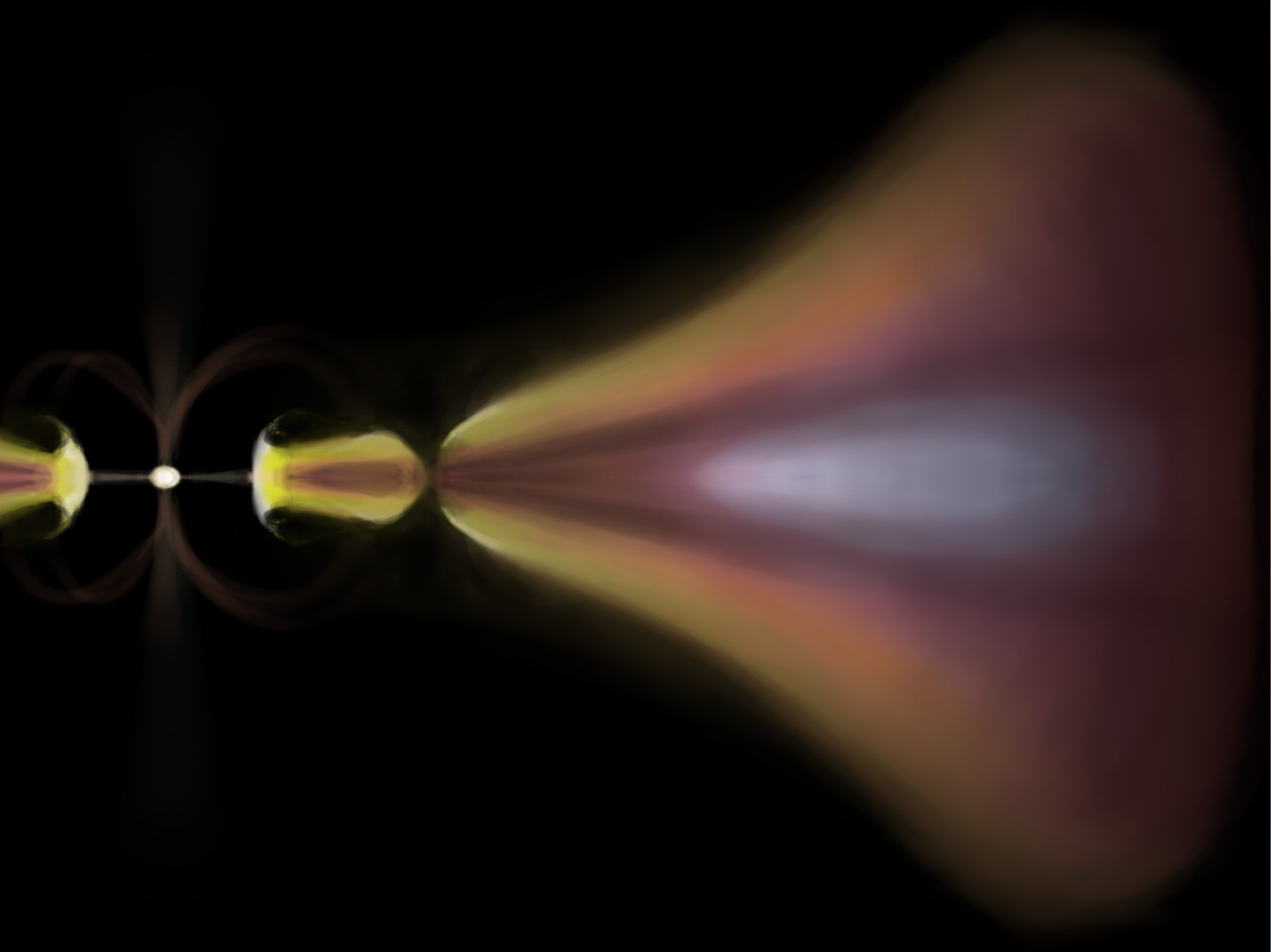


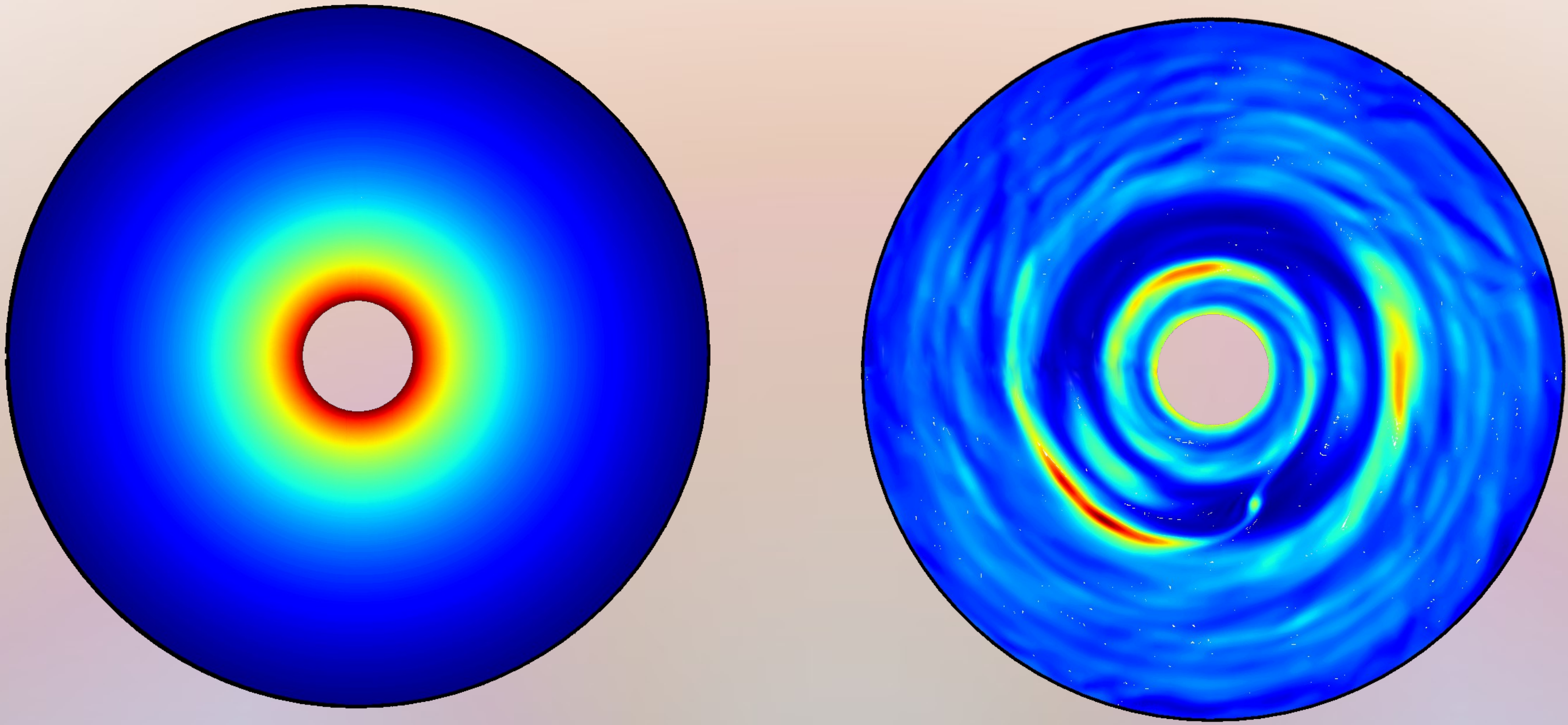
Outgoing
(reprocessed)
radiation





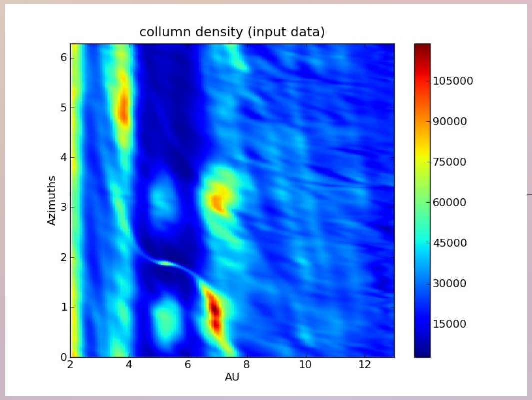
e.g. Kamp et al 2013
Bergin et al 2007



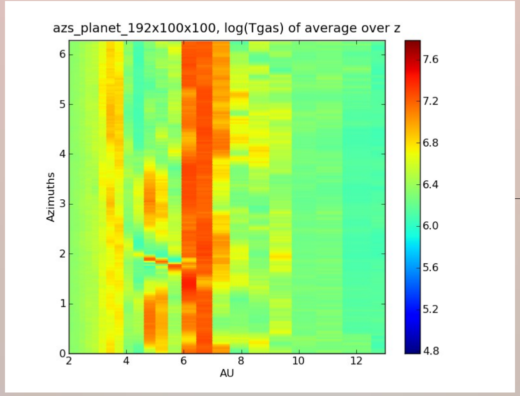


Summary

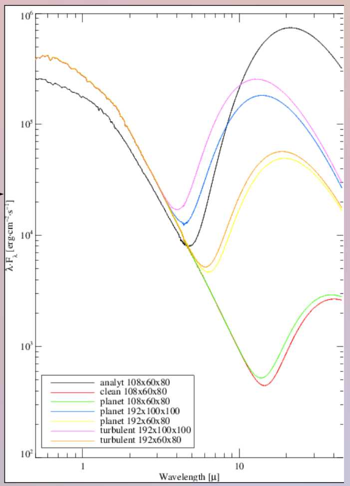
3D hydrodynamical Models



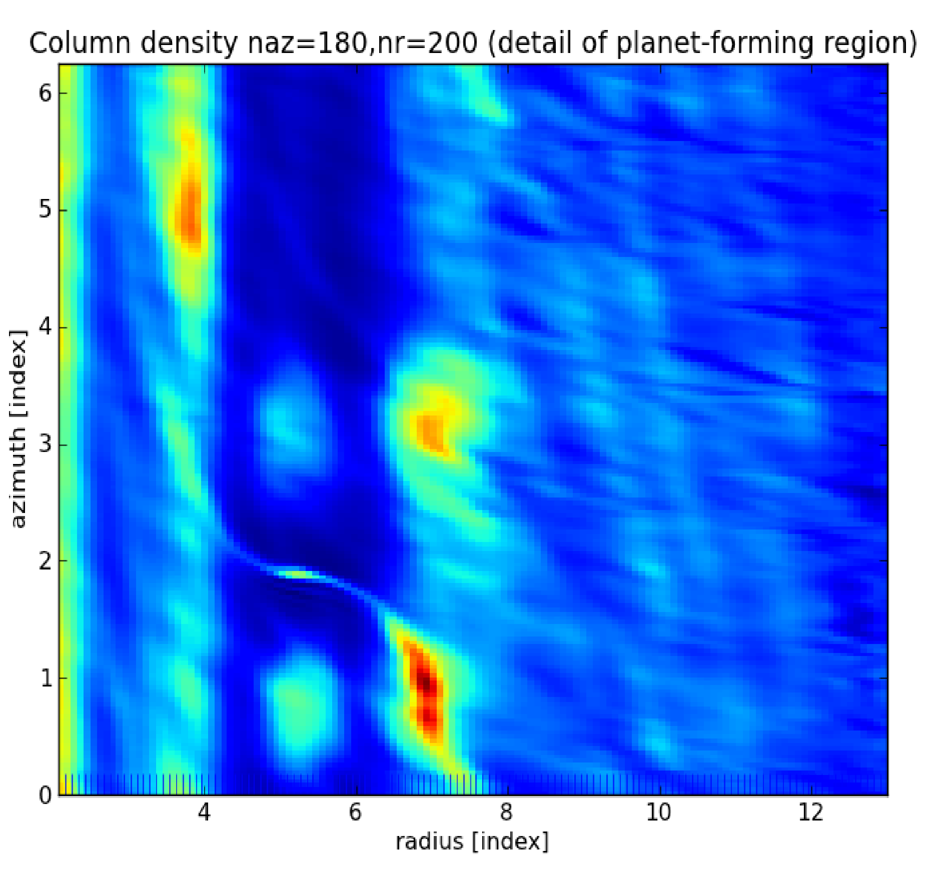
Hydrostatic modeling (Radiative transfer, chemistry)



Spectral synthesis - SEDs, detailed spectra

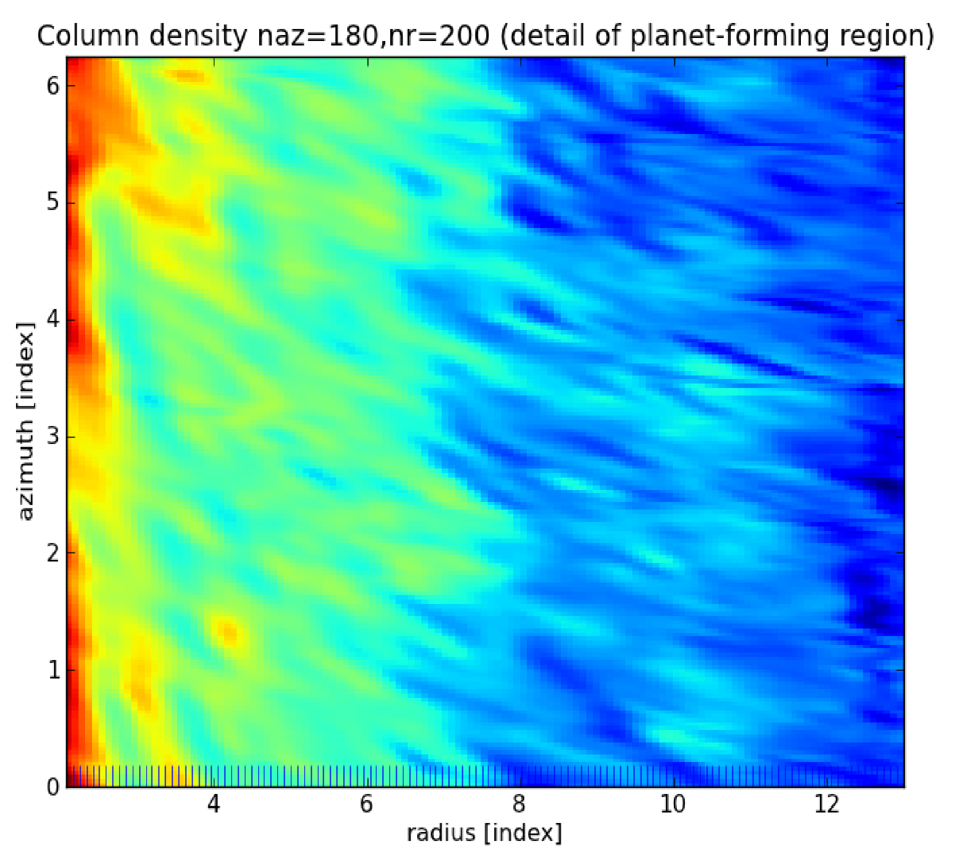


3D hydrodynamical models

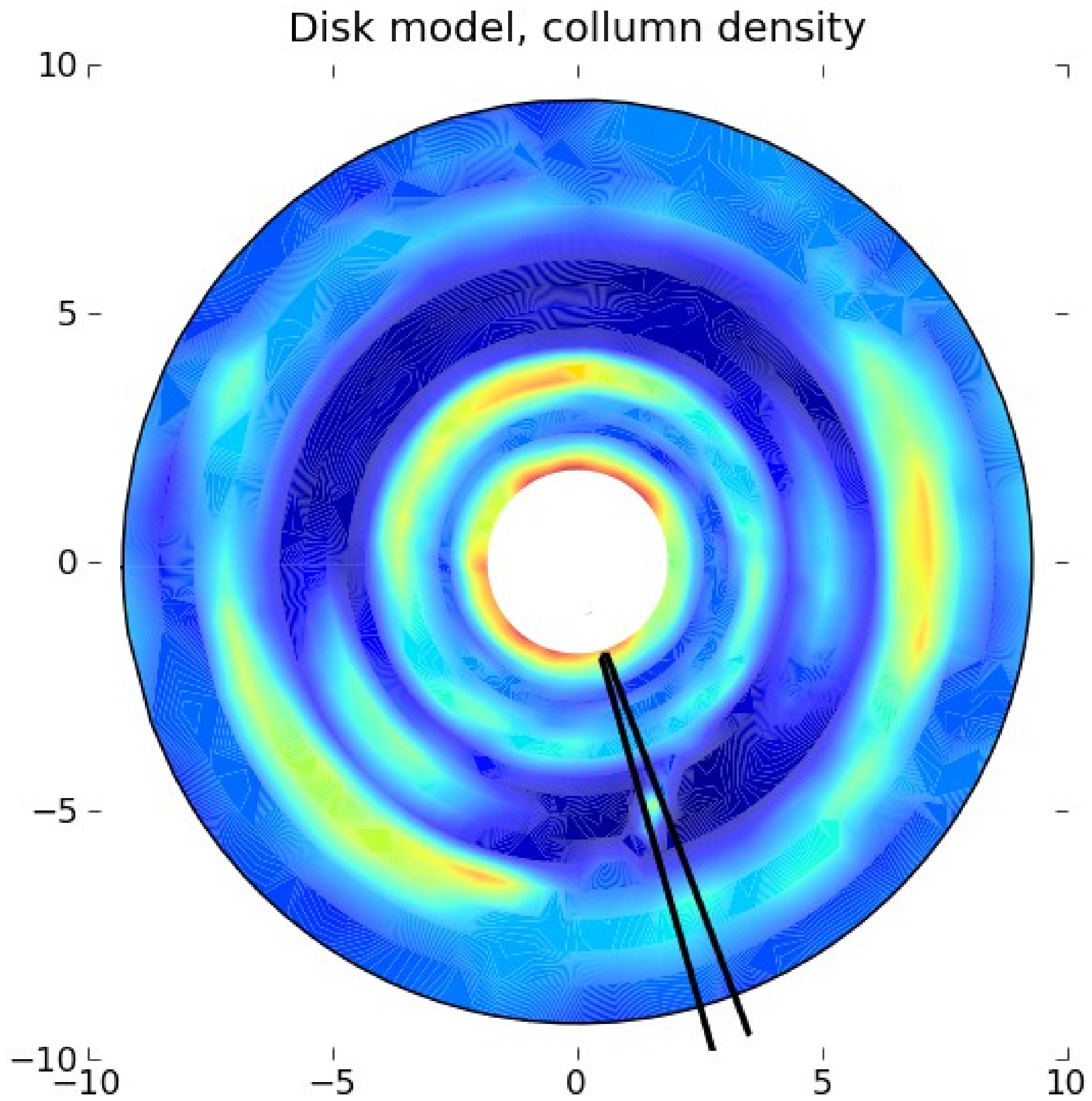


Giant planet at 5 AU

Turbulent disk
without planet

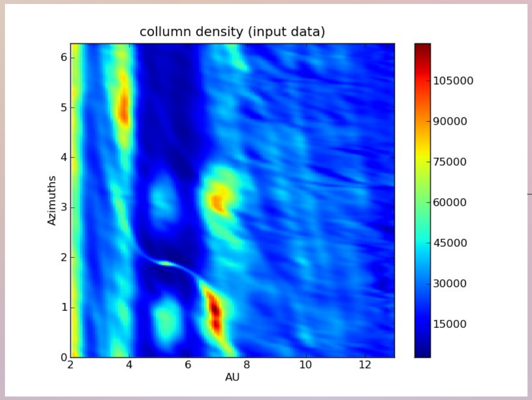


W Lyra 2009

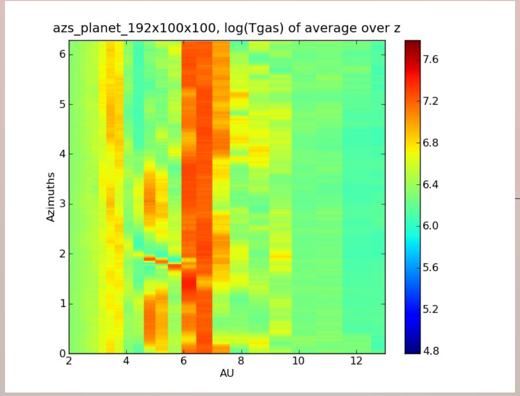


Disk model, collumn density
10
5
0
−5
−10
−10
−5
0
5
10

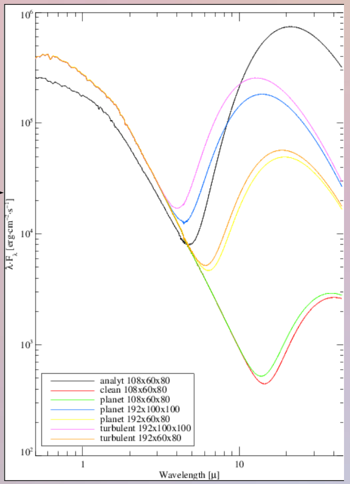
3D hydrodynamical Models



Hydrostatic modeling (Radiative transfer, chemistry)



Spectral synthesis - SEDs, detailed spectra



3D model

$$c_T^2 \frac{dP}{dz} = -\frac{zGM_*}{(r^2+z^2)^{3/2}}$$

$$\sum(r) = 2\int_0^{zmax(r)} \rho(r,z)dz$$

Hydrostatic disk structure

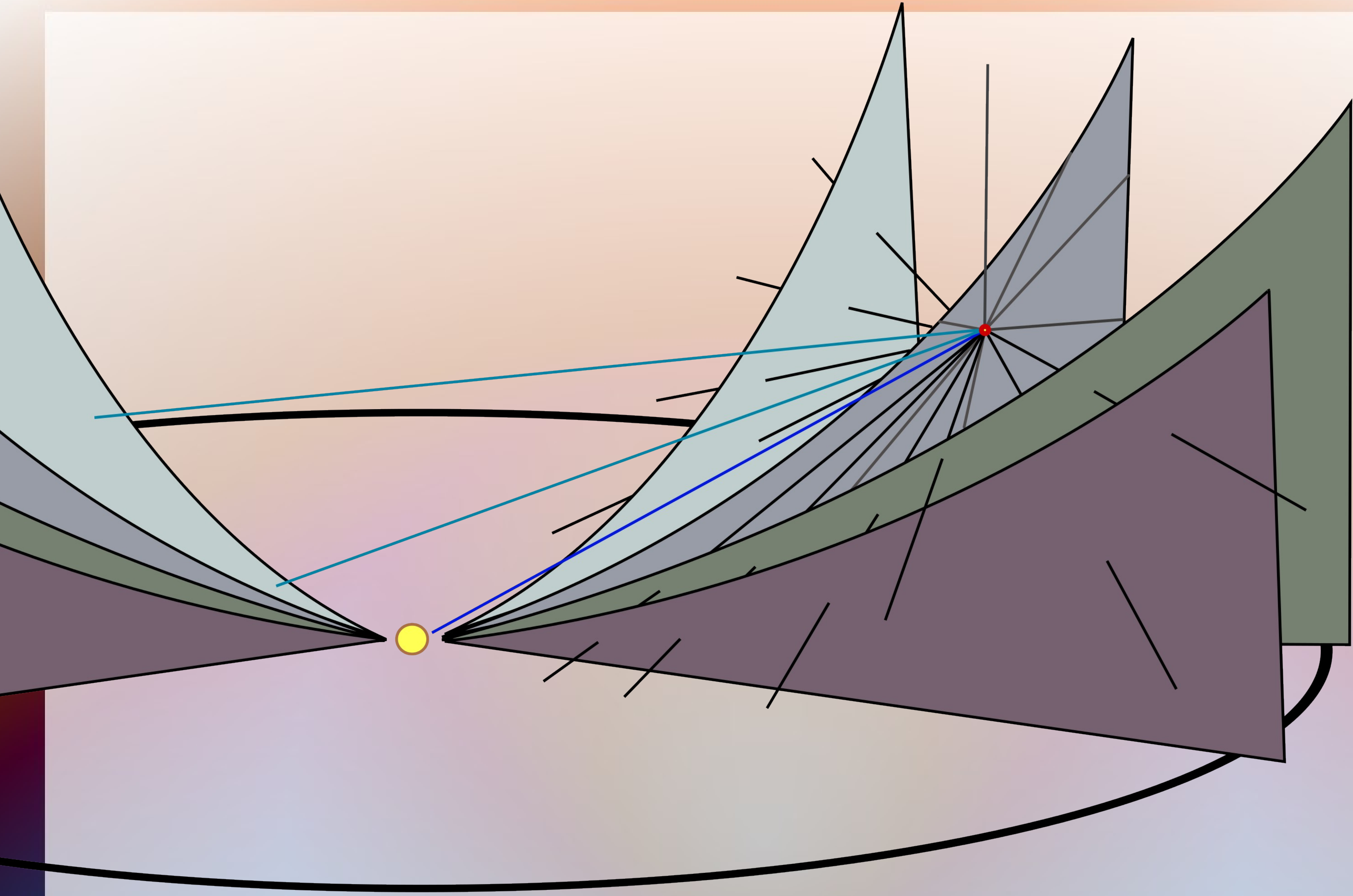
$$\frac{dI}{d\tau_\nu} = S_\nu - I_\nu$$

$$\int \kappa_\nu^{abs} B_\nu(T_d)d\nu - \int \kappa_\nu^{abs} J_\nu d\nu - \Gamma_{dust} = 0$$

$$J_\nu(r_0) = \frac{1}{4\pi}\left(I(r_0,0,0)\Omega_* + \sum_{i=1}^{N_\theta \cdot N_\phi} I_\nu(r_0,\theta_i,\phi_i)\Omega_i \right)$$

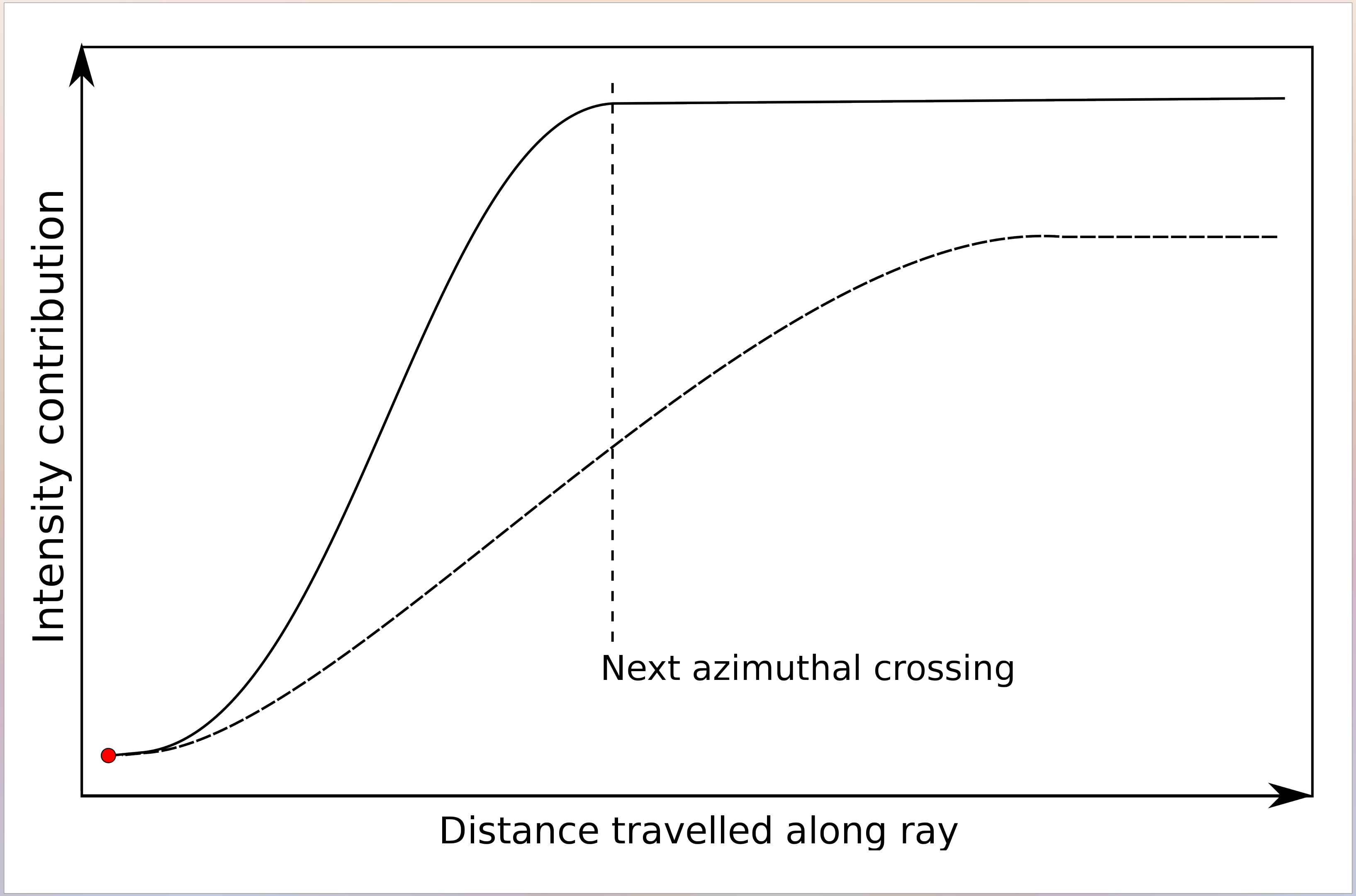
3D Radiative transfer (dust continuum)

Dust temperatures
Intensities



Radiative transfer - ray directions

Short Characteristic solver



10-20% of rays are suitable for short-chara

3D model

$$\frac{dn_i}{dt} = \sum_{jkl} R_{jk\to il}(T_g) n_j n_k + \sum_{jl} \left(R^{ph}_{j\to il} + R^{cr}_{k\to il} \right) n_j - n_i \left(\sum_{jkl} R_{il\to jk} n_l + \sum \left(R^{ph}_{i\to jk} + R^{cr}_{i\to jk} \right) \right)$$

$$p - \sum_i n_i (1 + z_i) k T_g = 0$$

Chemistry

Gas thermal balance

$$\frac{de}{dt} = \sum_k \Gamma_k (T_g, n_{sp}) - \sum_k \Lambda_k (Tg, n_{sp}))$$

Gas temperature

$$\rho = n_e m_e + \sum_i n_i m_i$$

$$p = \left(n_e + \sum_i n_i \right) k T_g$$

$$c_T^2 = p/\rho$$

Obtain structure for next iteration

3D model

$$\frac{dn_i}{dt} = \sum_{jkl} R_{jk\to il}(T_g) n_j n_k + \sum_{jl} \left(R^{ph}_{j\to il} + R^{cr}_{k\to il} \right) n_j - n_i \left(\sum_{jkl} R_{il\to jk} n_l + \sum \left(R^{ph}_{i\to jk} + R^{cr}_{i\to jk} \right) \right)$$

$$p - \sum_i n_i (1 + z_i) k T_g = 0$$

Chemistry

Gas thermal balance

$$\frac{de}{dt} = \sum_k \Gamma_k (T_g, n_{sp}) - \sum_k \Lambda_k (Tg, n_{sp}))$$

Gas temperature

$$\rho = n_e m_e + \sum_i n_i m_i$$

$$p = \left(n_e + \sum_i n_i \right) k T_g$$

$$c_T^2 = p/\rho$$

Obtain structure for next iteration

2D+3D model

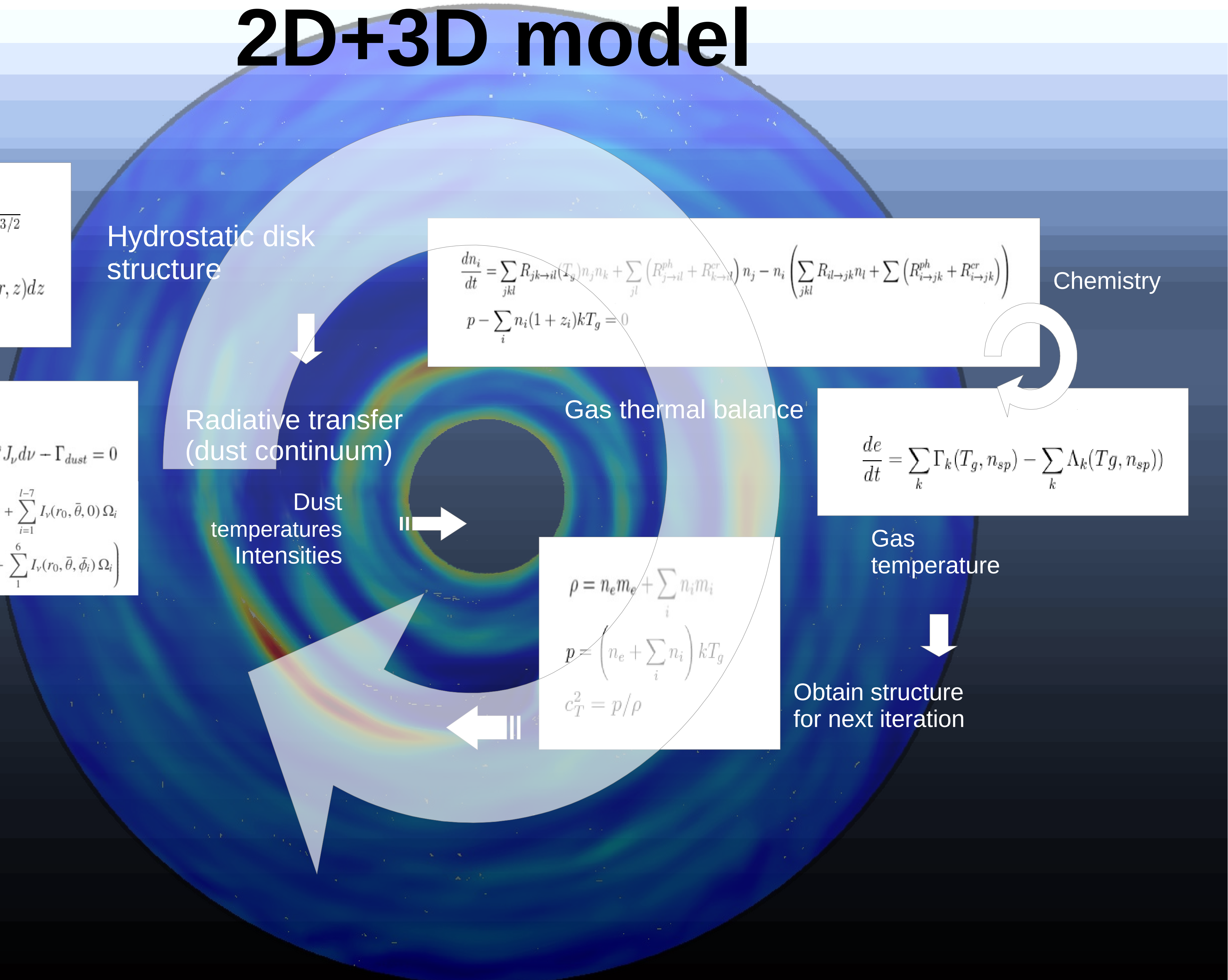
$$c_T^2 \frac{dP}{dz} = -\frac{zGM_*}{(r^2+z^2)^{3/2}}$$

$$\Sigma(r) = 2\int_0^{zmax(r)} \rho(r,z)dz$$

$$\frac{dI}{d\tau_\nu} = S_\nu - I_\nu$$

$$\int \kappa_\nu^{abs} B_\nu(T_d)d\nu - \int \kappa_\nu^{abs} J_\nu d\nu - \Gamma_{dust} = 0$$

$$J_\nu(r_0) = \frac{1}{4\pi}\left(I_\nu(r_0,0,0)\,\Omega_\star + \sum_{i=1}^{l-7} I_\nu(r_0,\bar{\theta},0)\,\Omega_i + \sum_{1}^{6} I_\nu(r_0,\bar{\theta},\bar{\phi}_i)\,\Omega_i \right)$$



$$\frac{dn_i}{dt} = \sum_{jkl} R_{jk\rightarrow il}(T_g)n_j n_k + \sum_{jl}\left(R^{ph}_{j\rightarrow il} + R^{cr}_{k\rightarrow il}\right)n_j - n_i\left(\sum_{jkl} R_{il\rightarrow jk} n_l + \sum\left(R^{ph}_{i\rightarrow jk} + R^{cr}_{i\rightarrow jk}\right)\right)$$

$$p - \sum_i n_i(1+z_i)kT_g = 0$$

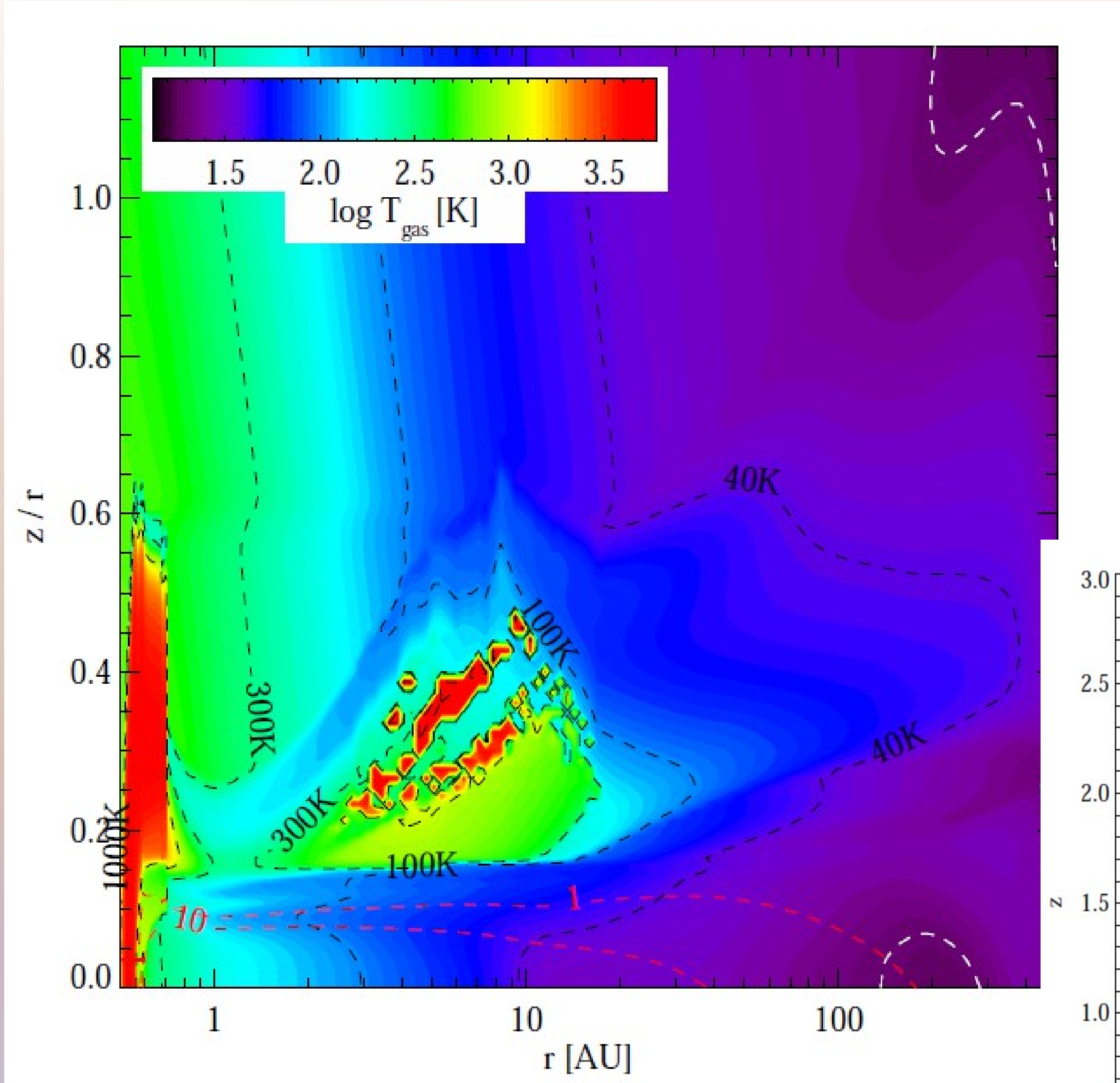
$$\frac{de}{dt} = \sum_k \Gamma_k(T_g, n_{sp}) - \sum_k \Lambda_k(Tg, n_{sp}))$$

$$\rho = n_e m_e + \sum_i n_i m_i$$

$$p = \left(n_e + \sum_i n_i\right) kT_g$$

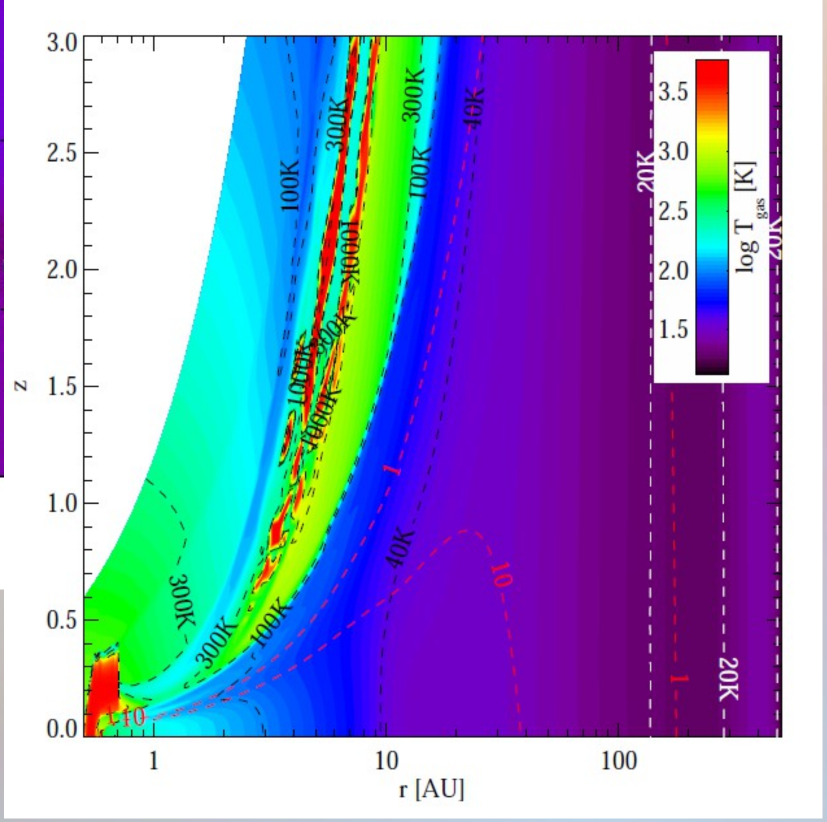
$$c_T^2 = p/\rho$$

Resulting
Tgas for one azimuth

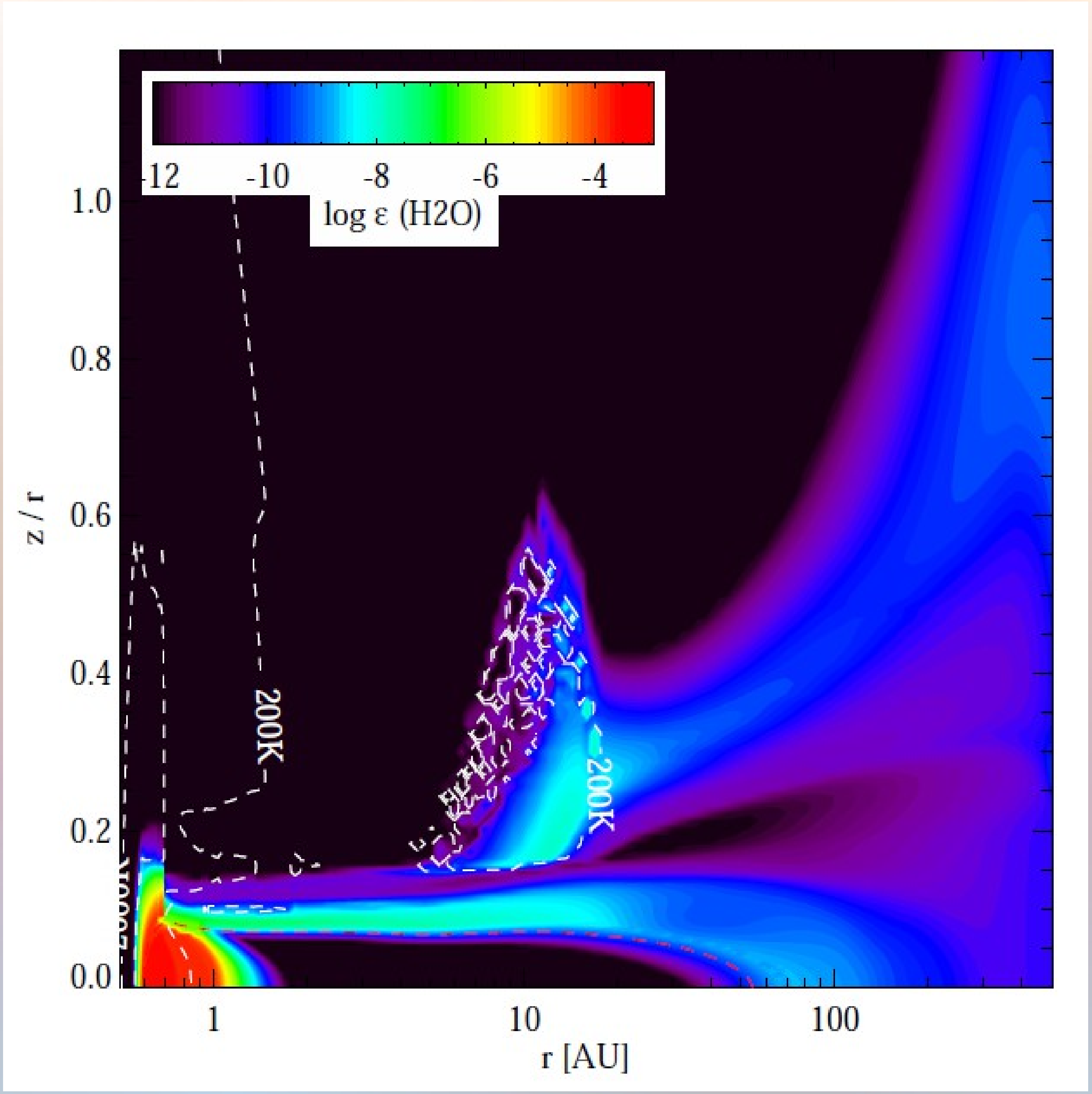


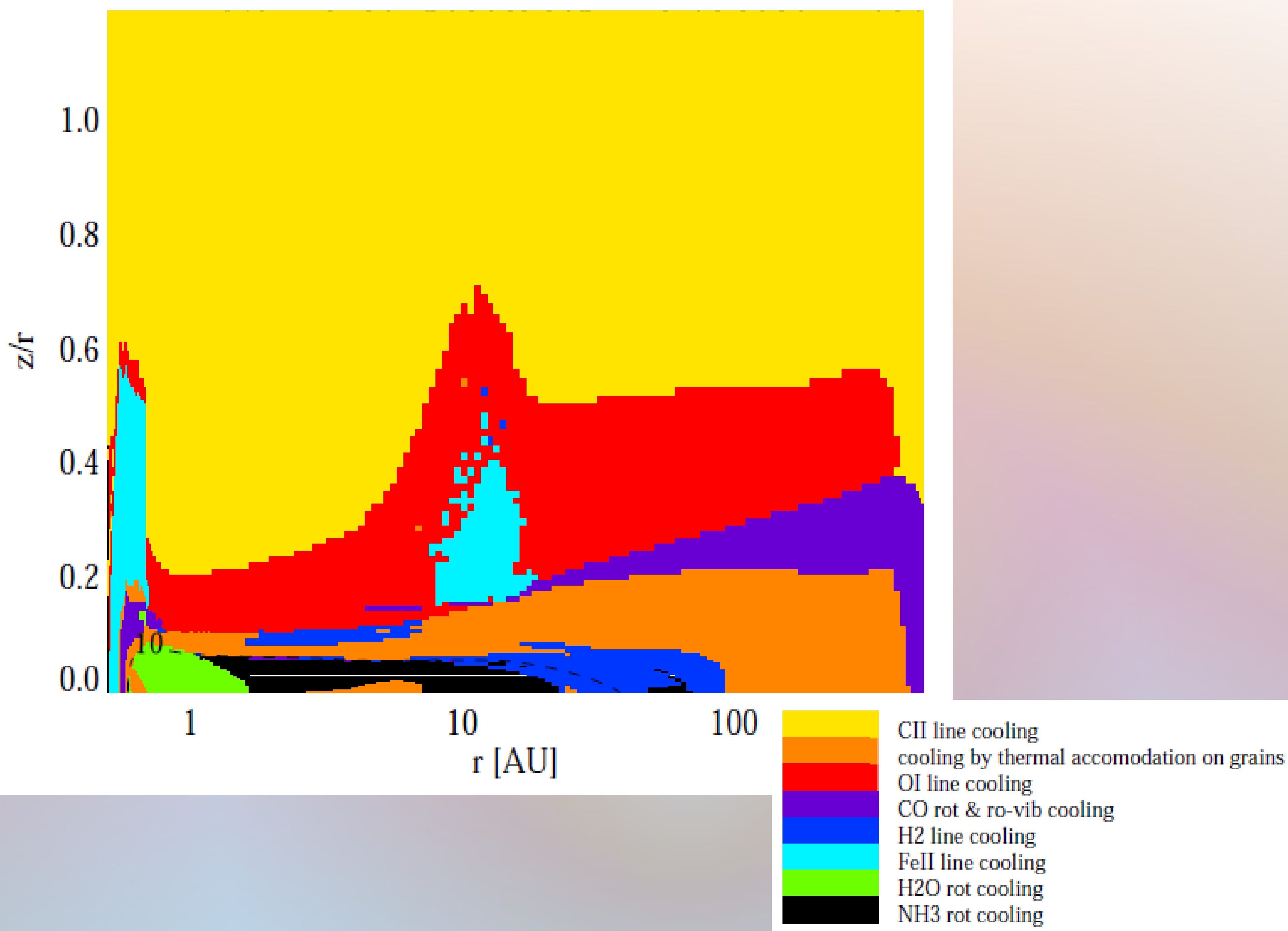
Obs-z/r on y-axis

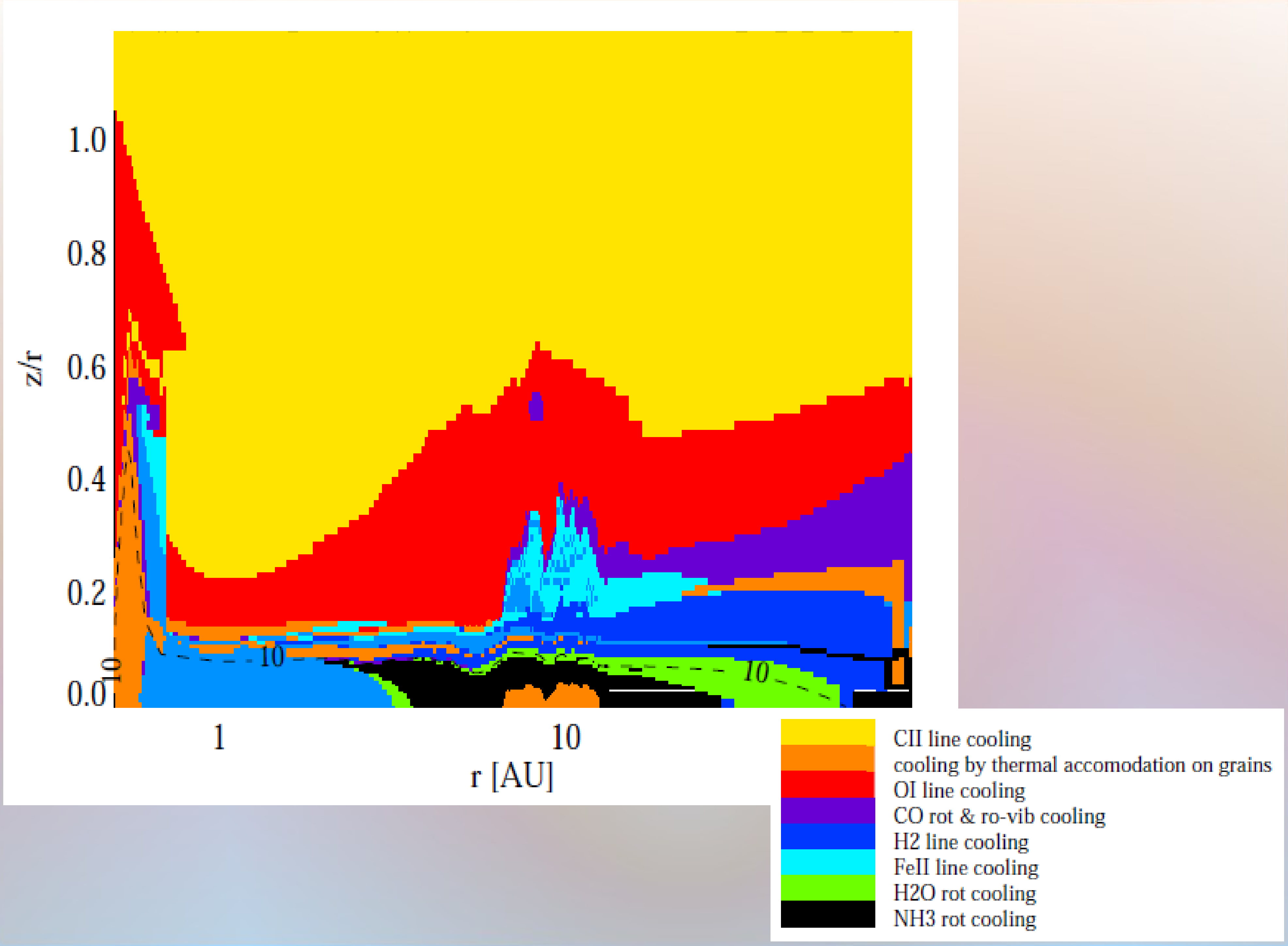
Linear z

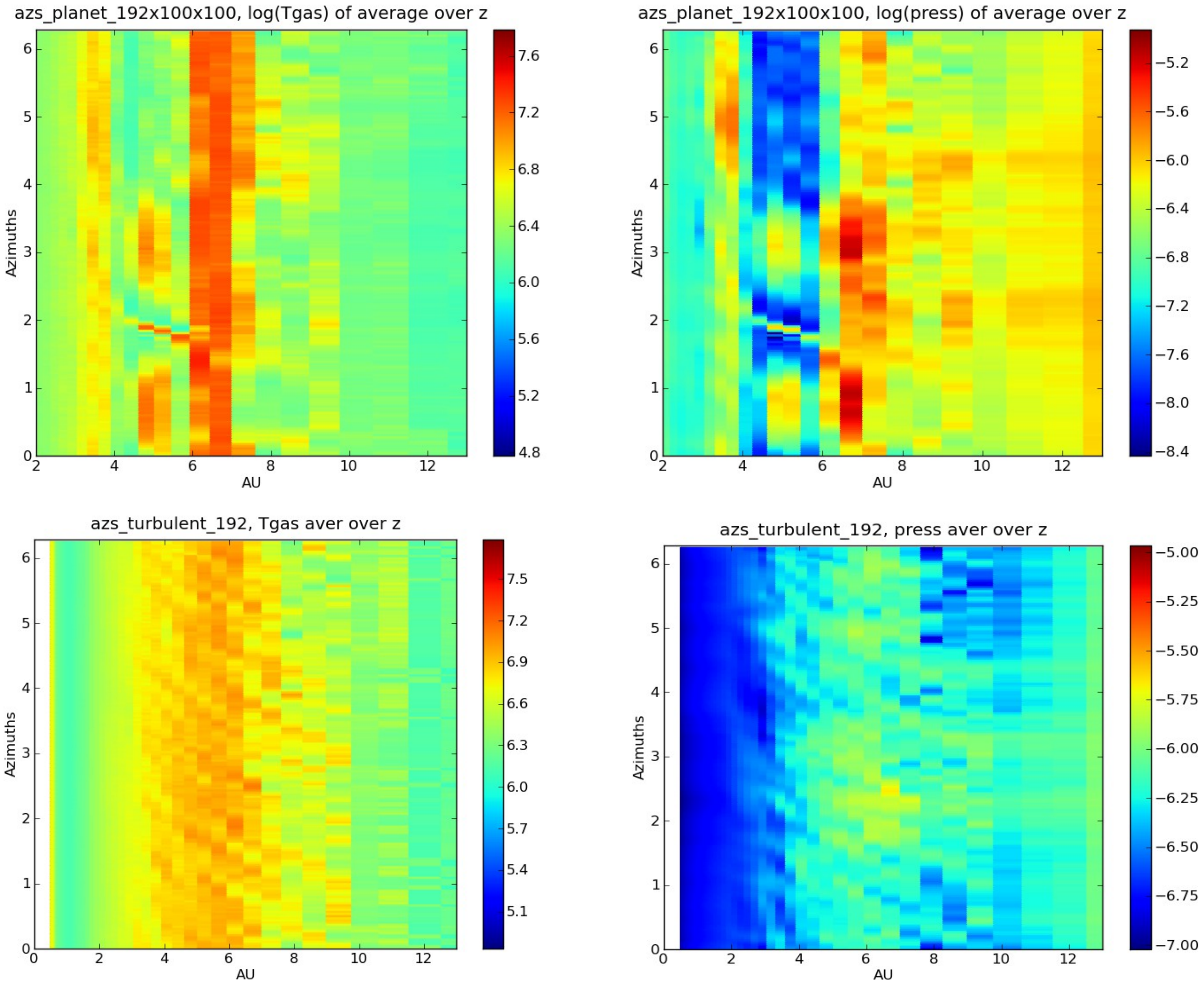


Water structure



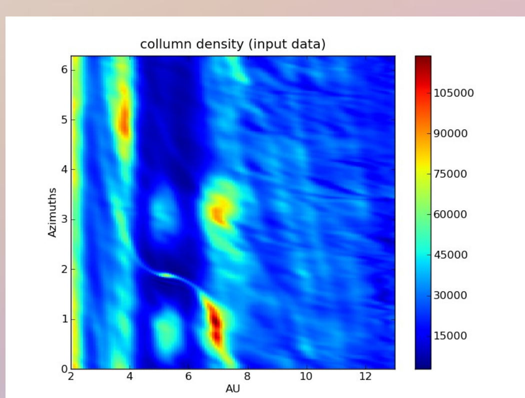

z/r
1.0
0.8
0.6
0.4
0.2
0.0
10
1
10
100
r [AU]
CII line cooling
cooling by thermal accomodation on grains
OI line cooling
CO rot & ro-vib cooling
H2 line cooling
FeII line cooling
H2O rot cooling
NH3 rot cooling


z/r
1.0
0.8
0.6
0.4
0.2
0.0
10
10
10
1
10
r [AU]
CII line cooling
cooling by thermal accomodation on grains
OI line cooling
CO rot & ro-vib cooling
H2 line cooling
FeII line cooling
H2O rot cooling
NH3 rot cooling

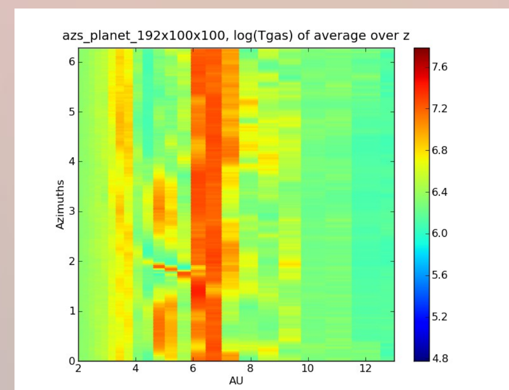


azs_planet_192x100x100, log(Tgas) of average over z
azs_planet_192x100x100, log(press) of average over z
azs_turbulent_192, Tgas aver over z
azs_turbulent_192, press aver over z
Azimuths
AU

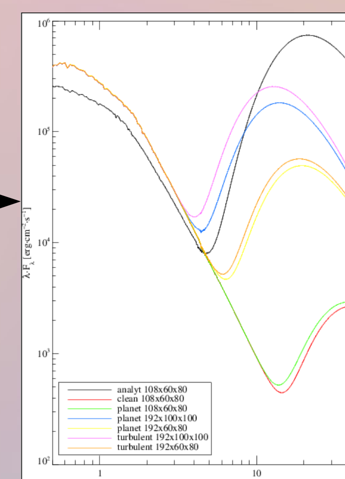
3D hydrodynamical Models

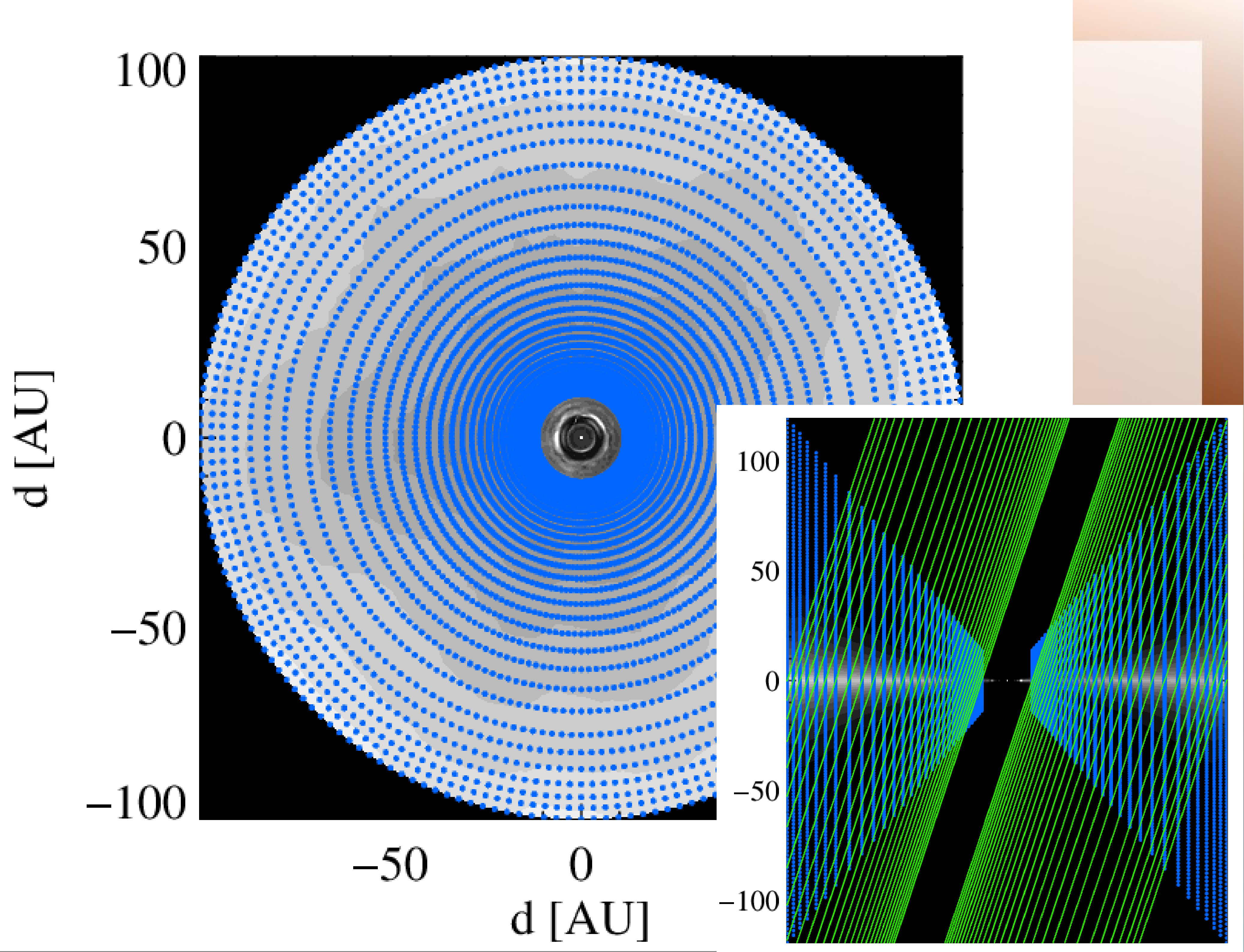


Hydrostatic modeling (Radiative transfer, chemistry)



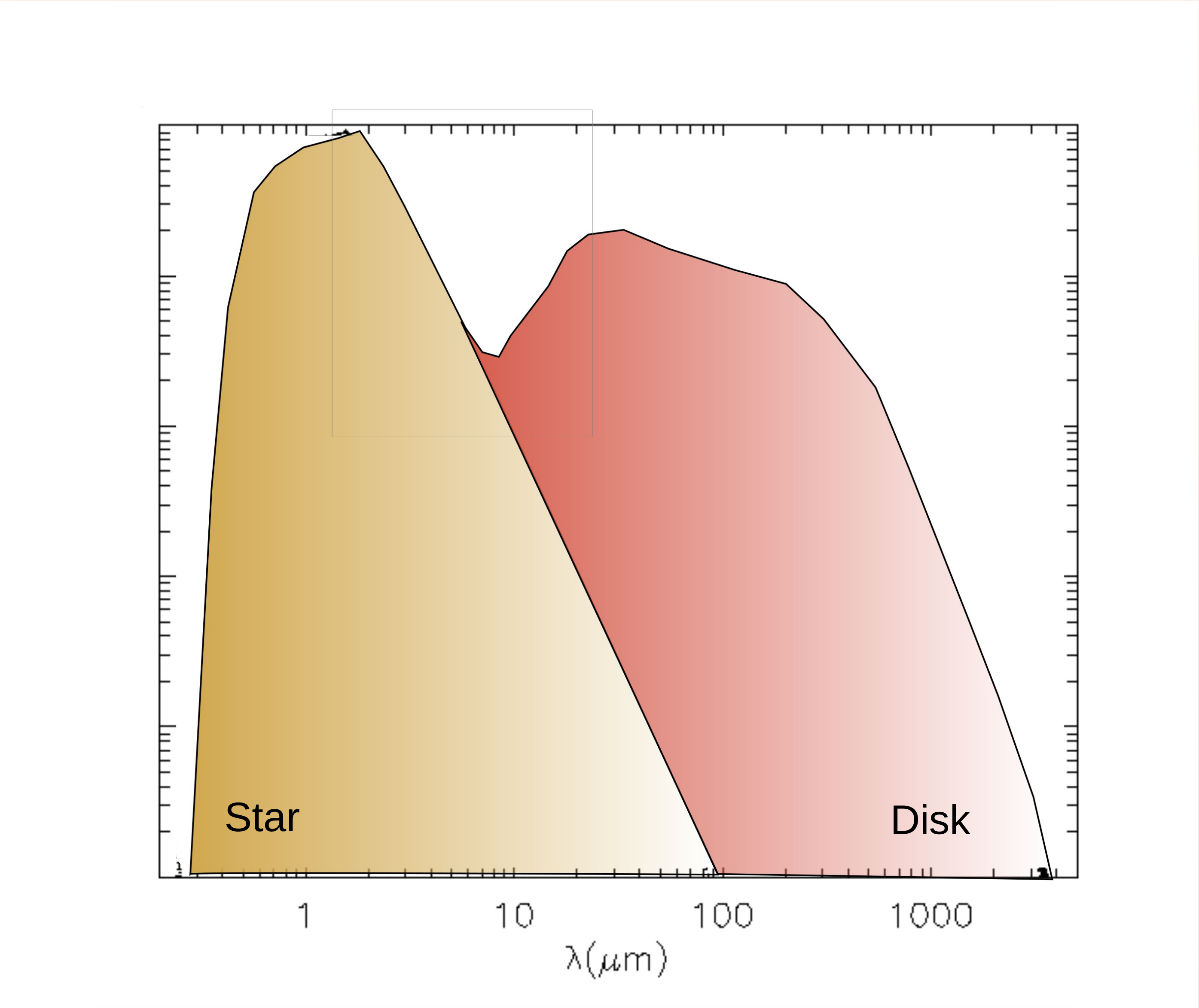
Spectral synthesis - SEDs, detailed spectra





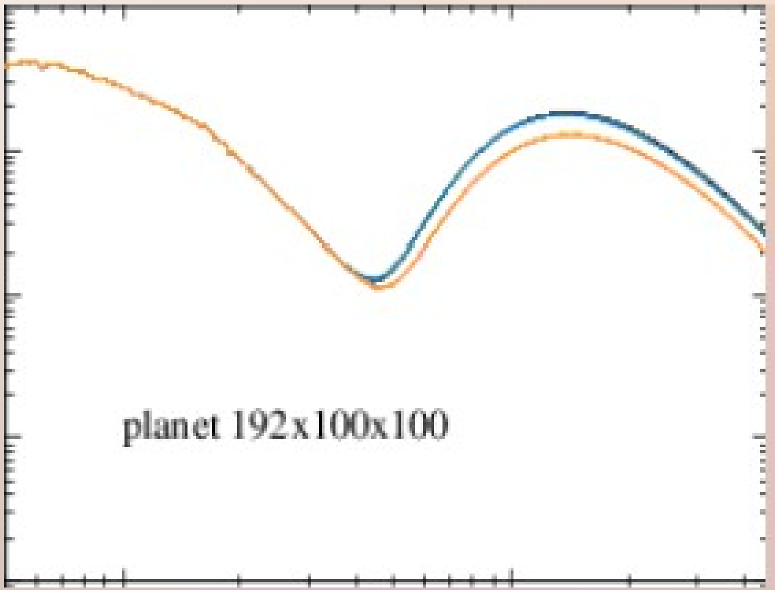
100
50
0
−50
−100
d [AU]
−50
0
d [AU]
100
50
0
−50
−100

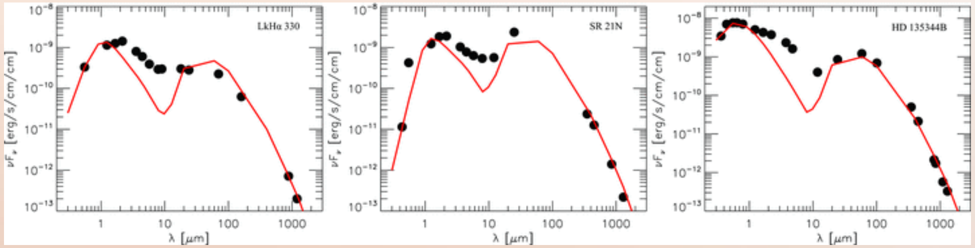
Spectral Energy Distribution



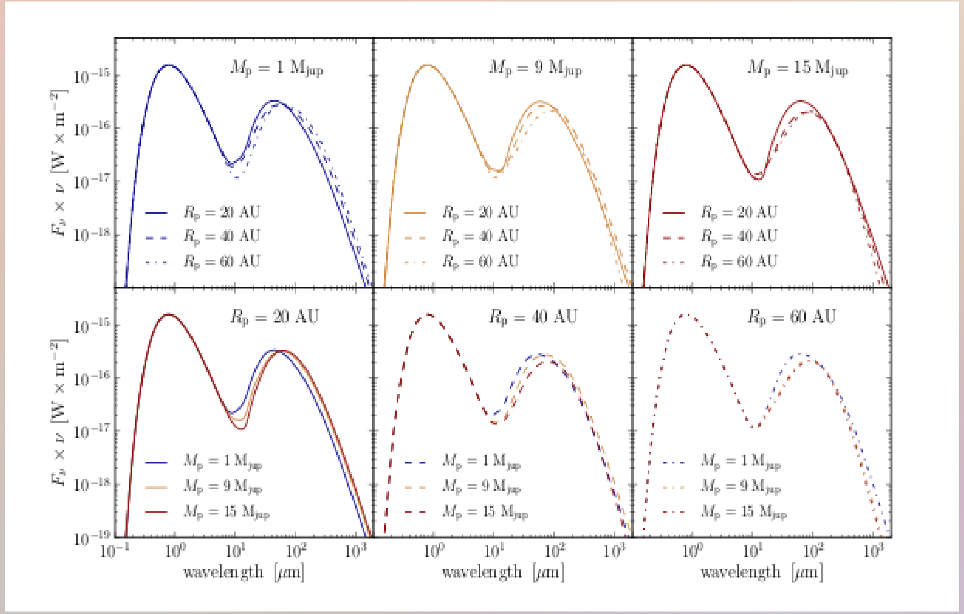
(T-tauri star)

Spectral Energy distributions

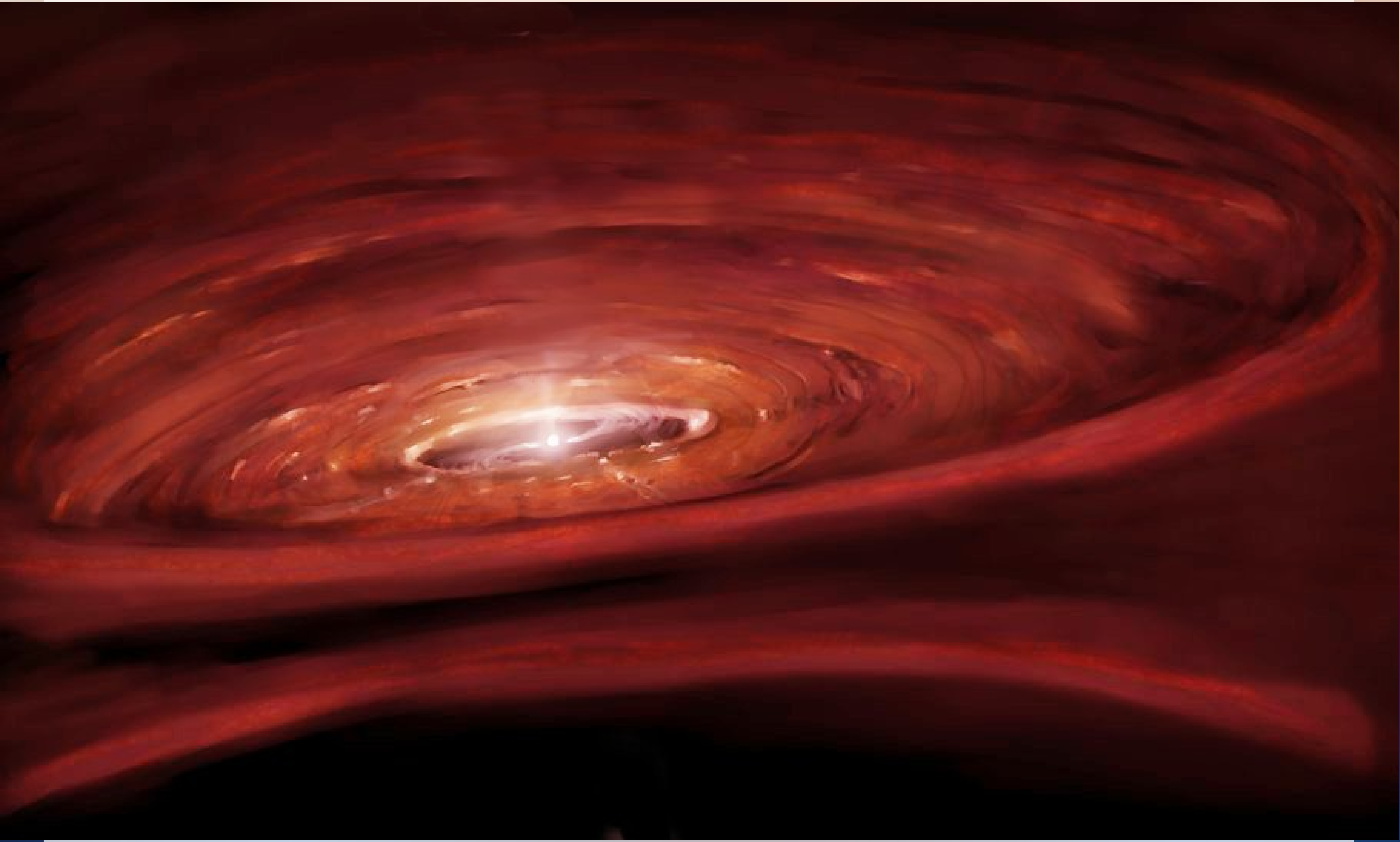




Regaly et al, 2012



Ovelar et al, 2013



Questions?