The effect of far-UV irradiation on the thermal structure of disks

Jon P. Ramsey

C. P. Dullemond

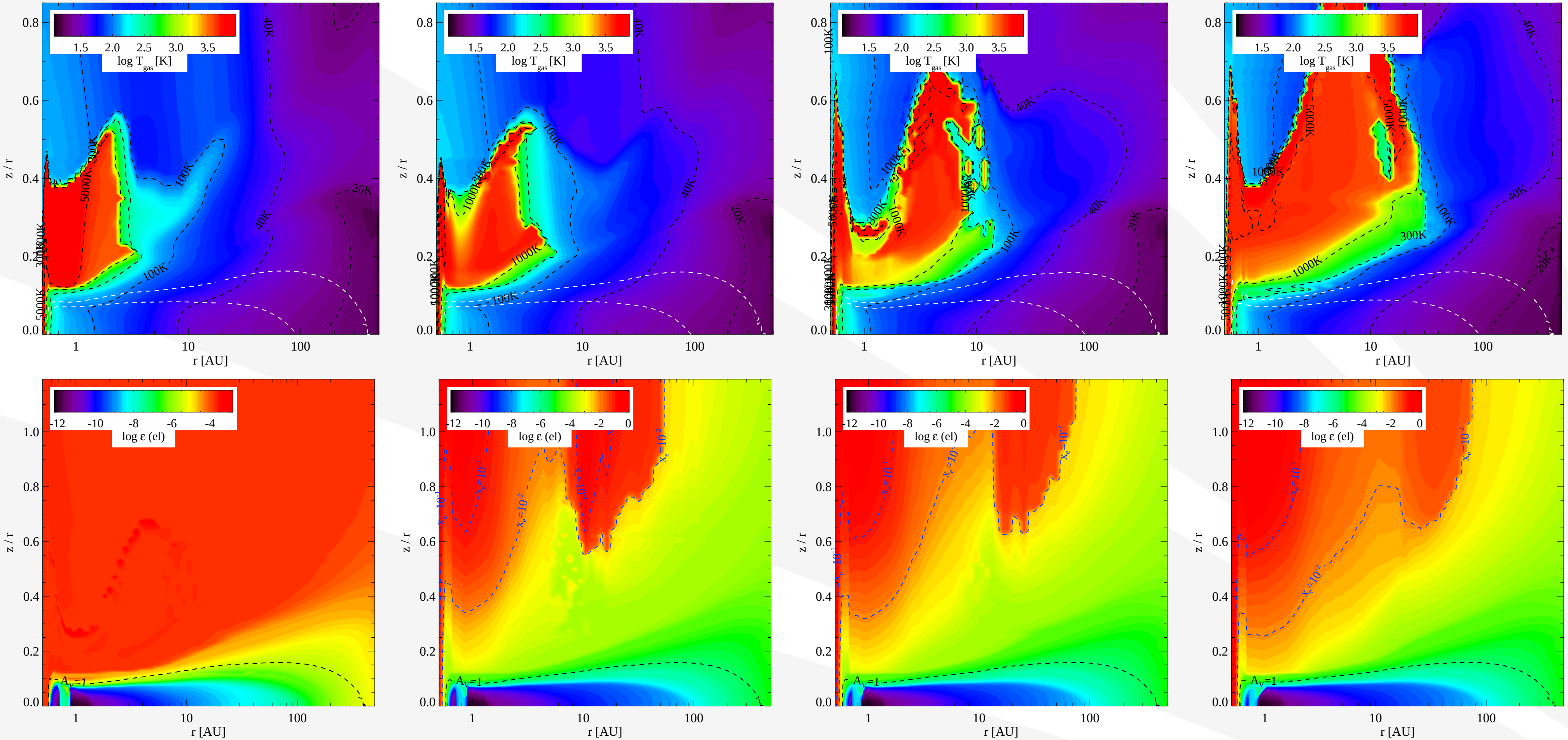
Universität Heidelberg, Zentrum für Astronomie, Institut für Theoretische Astrophysik

S. Bruderer

Max Planck Institut für extraterrestrische Physik, Garching

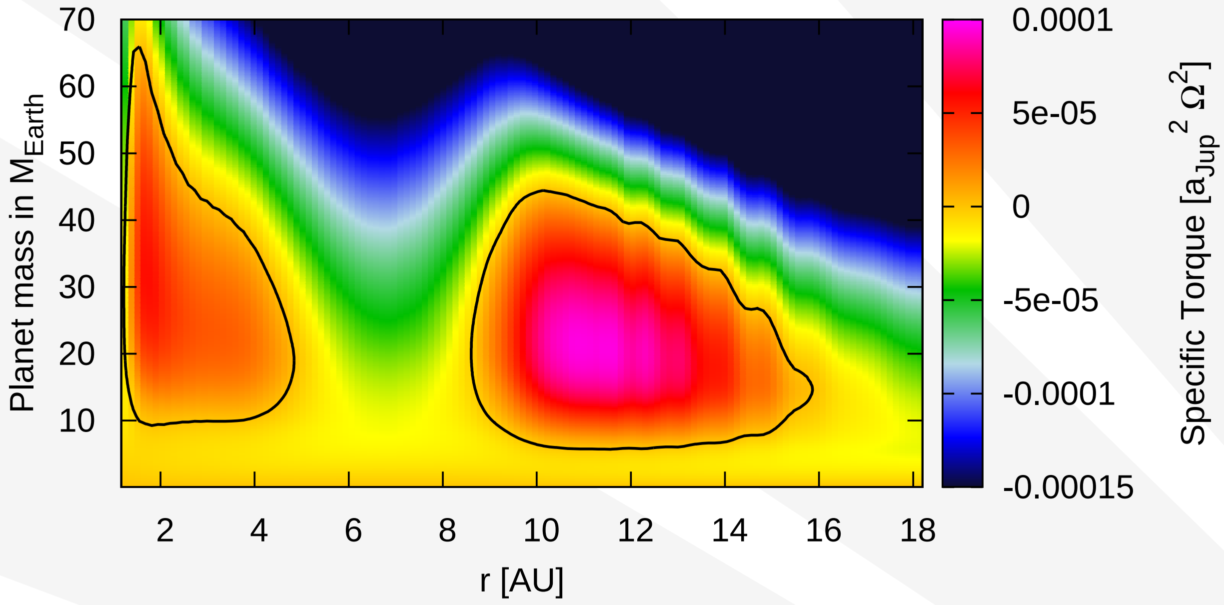
August 7, 2014

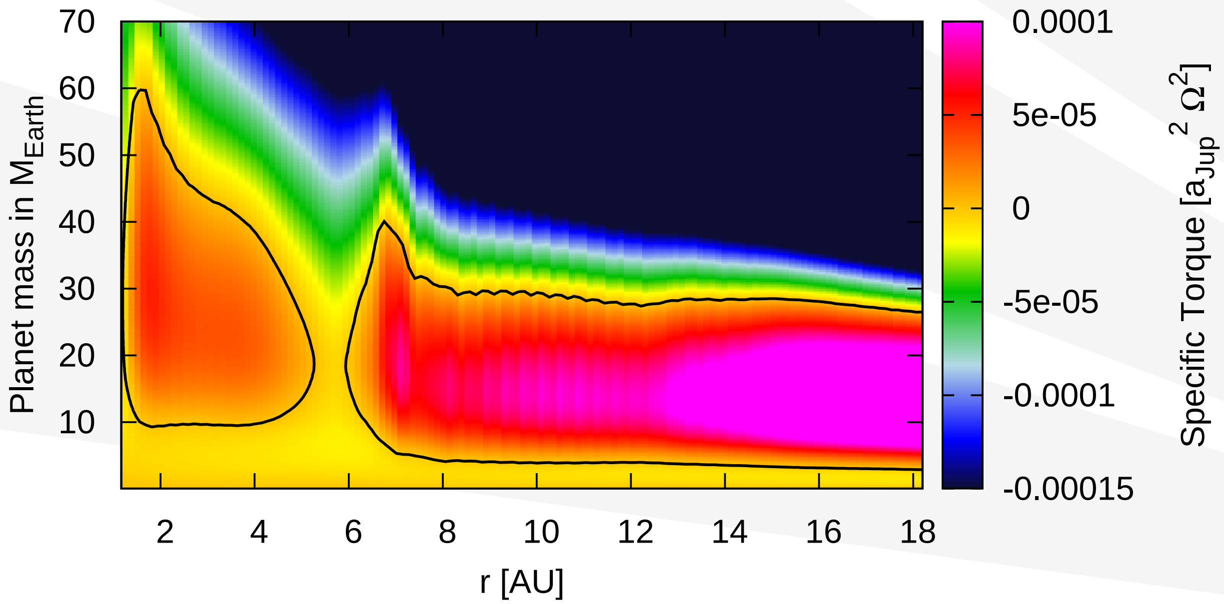
Motivation



Meijerink et al. (2012)

Motivation



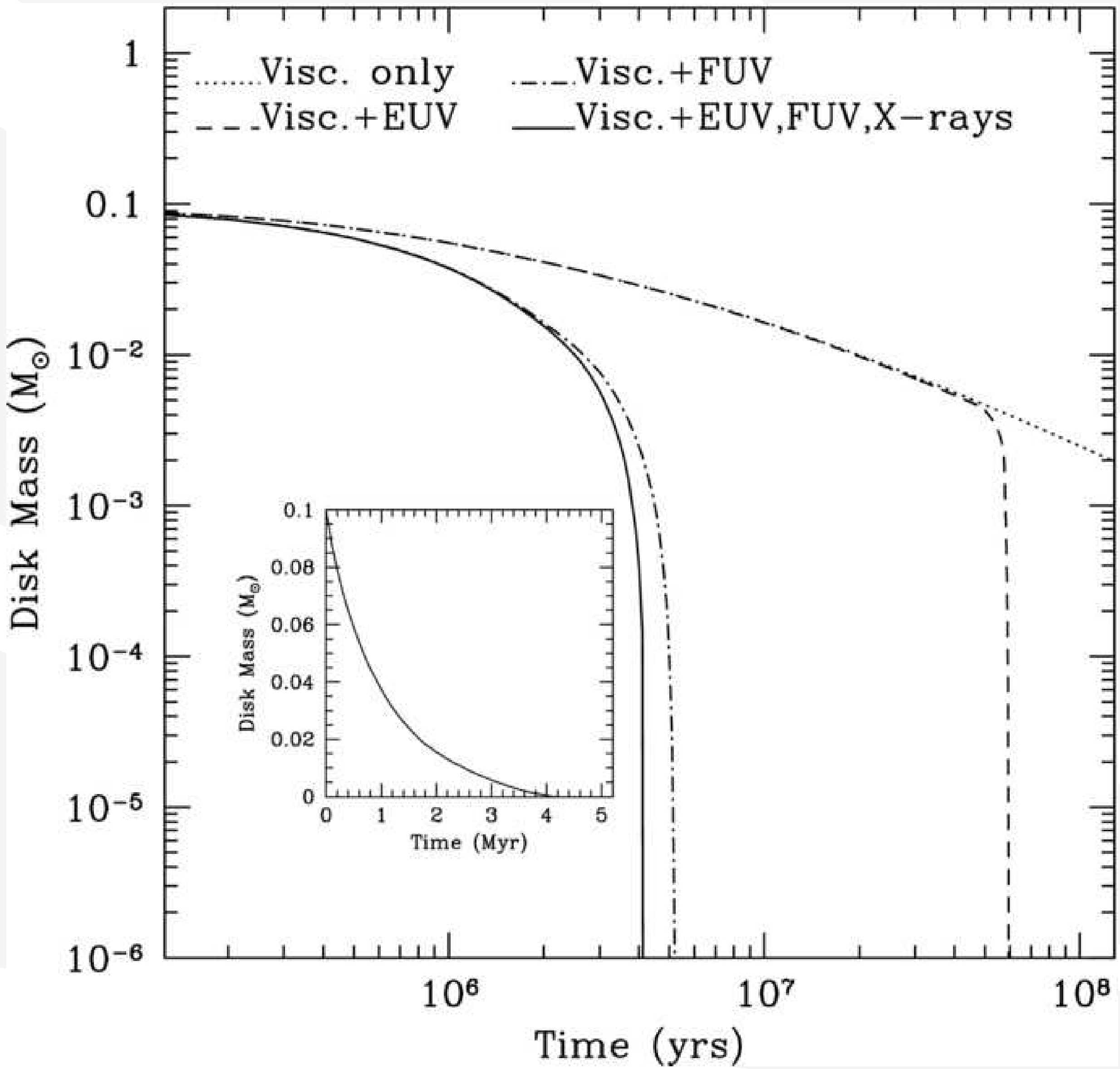


Bitsch et al. (2013)

Context: FUV photoevaporation

- Extreme-UV: 13.6 eV $< h\nu <$ 100 eV.
  - ⇒ analogous to an HII region; produces a nearly-isothermal atmosphere at $\sim 10^4$ K.
  - ⇒ e.g., Font et al. (2004), Alexander et al. (2006a,b).
- X-rays: $h\nu >$ 100 eV.
  - ⇒ thermal and chemical structure of the disk important.
  - ⇒ e.g., Owen et al. (2010, 2011, 2012).
- Far-UV: 6 eV $< h\nu <$ 13.6 eV.
  - ⇒ e.g., Gorti, Dullemond, & Hollenbach (2009).
  - ⇒ Can dissociate molecules and ionise metals.
- Why do we care? ⇒ Disk clearing timescales!

Context: FUV photoevaporation



Gorti, Dullemond, & Hollenbach (2009)

Methods

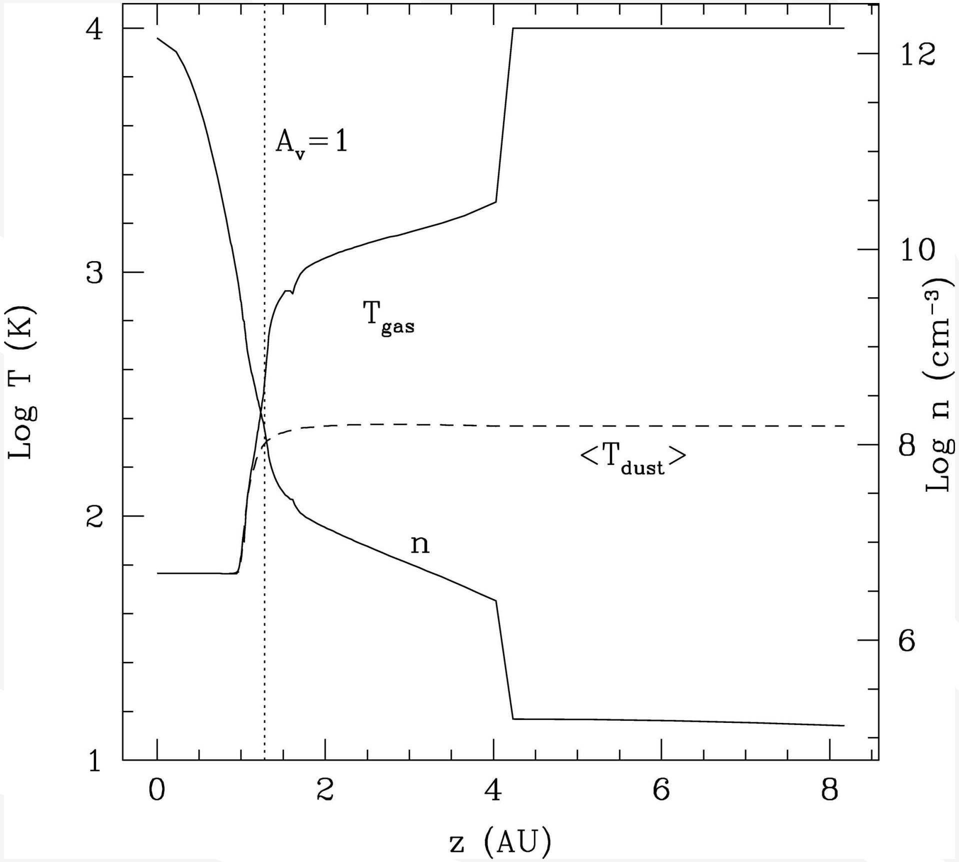
- Hydrodynamics: AZEuS
  - ⇒ Fully-staggered AMR-MHD code (magnetic field and momenta are both face-centred).
  - ⇒ 1-, 2-, 3-D; Cartesian, cylindrical, spherical coordinates.
- Radiation transport:
  - I. Non-equilibrium (two-temperature) flux-limited diffusion (FLD) (e.g., Hayes et al. 2006; Commerçon et al. 2011; Zhang et al. 2011).
  - II. Direct (stellar) irradiation (e.g., Kuiper et al. 2010; Bitsch et al. 2013; Kolb et al. 2013; Flock et al. 2013).
    - → Fast, but radiation is restricted to propagating along coordinates axes.
- Simplified chemistry: with Simon Bruderer (MPE, Garching).

Methods: Dust-gas coupling

(or lack thereof)

$$\Gamma_{\mathrm{g-d}} \propto \pi \langle a \rangle^2 n_{\mathrm{d}} n_{\mathrm{g}} \sqrt{T_{\mathrm{g}}} (T_{\mathrm{d}} - T_{\mathrm{g}})$$

- Adopt a two-fluid approximation (i.e., two temperatures).
- Dust-to-gas ratio of 0.01 assumed; dust and gas have the same velocity.
- Dust treated as pressureless fluid.
- Only the dust interacts directly with the radiation.



Gorti & Hollenbach (2008)

Methods: Chemistry

- In the FUV, the disk surface layers behave like a PDR.
- A simplified version of the thermochemical models of Bruderer et al. (2012); Bruderer (2013) have been implemented.
- Approximate, equilibrium chemistry treatment for H, H_2, C^+, C, CO, O, e^-.

  ⇒ Gas line heating and cooling rates given by a look-up table.
- Several specific heating and cooling processes included.

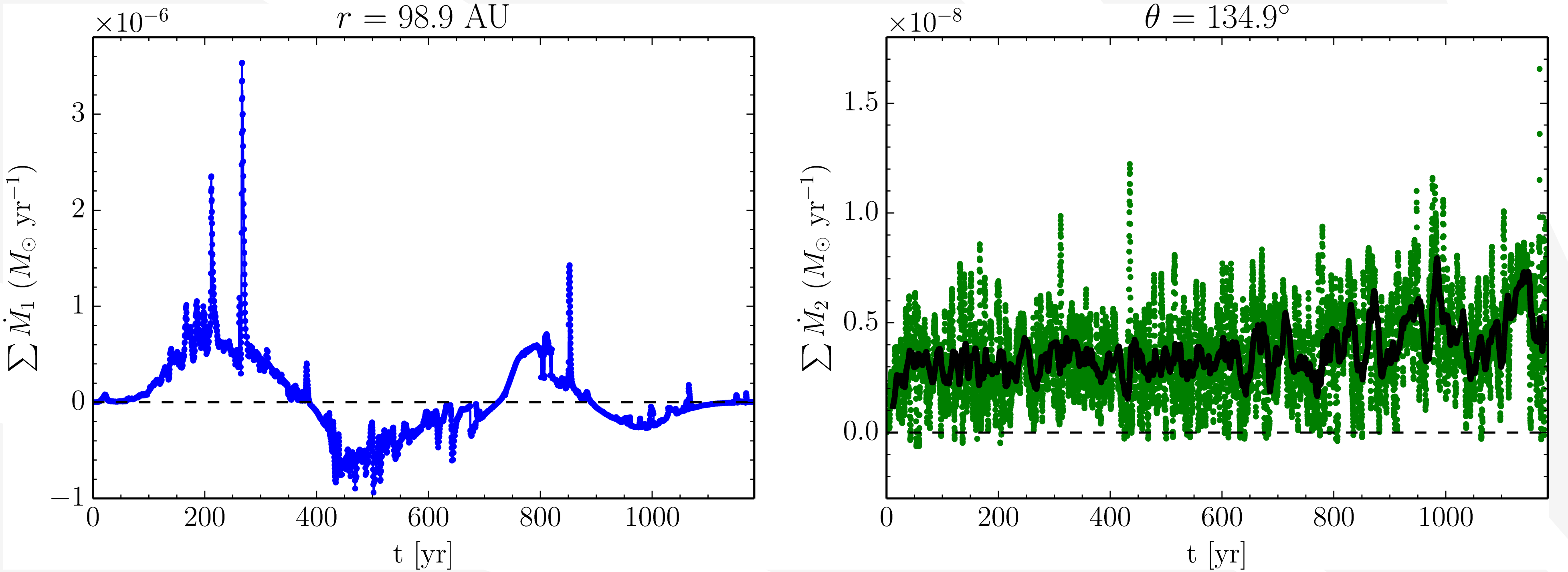
  ⇒ e.g., photoelectric heating by dust, Lyman-α line cooling, CR heating, OI 630 nm line cooling, C ionisation heating, H_2 heating & cooling.
- Applied as a one-zone model; ⇒ 500 grid cells take ~ 0.01 s while a full PDR code takes at least minutes.

Results

Initial conditions

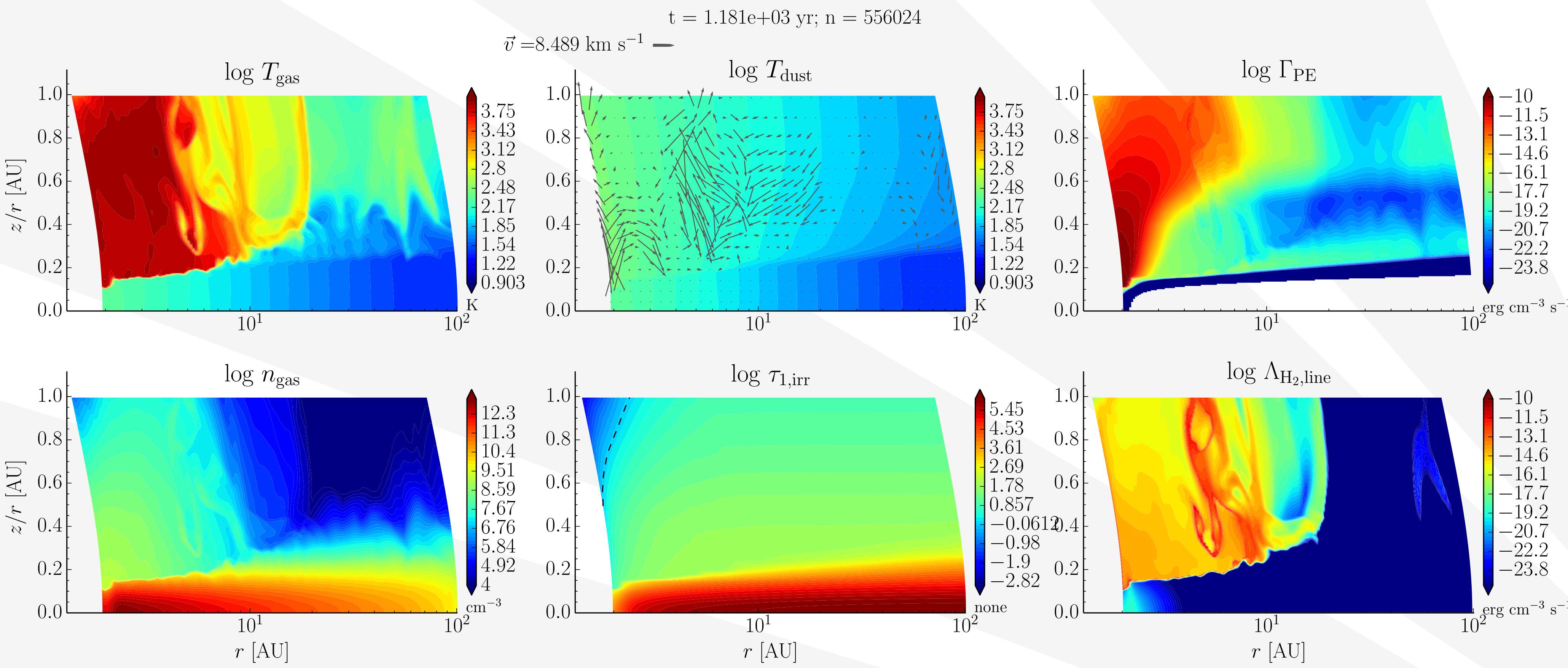
- Axisymmetric, spherical polar coordinates;
  $2 \leq r \leq 100$ AU; $90 \leq \theta \leq 135°$.
- Ideal EOS.
- $T_* = 4000$ K; $L_{\rm FUV} = 0.01 L_\odot$; $M_{\rm disk} = 0.1 M_\odot$.
- A virtual inner disc is used to prevent direct irradiation of the inner "edge".

Results

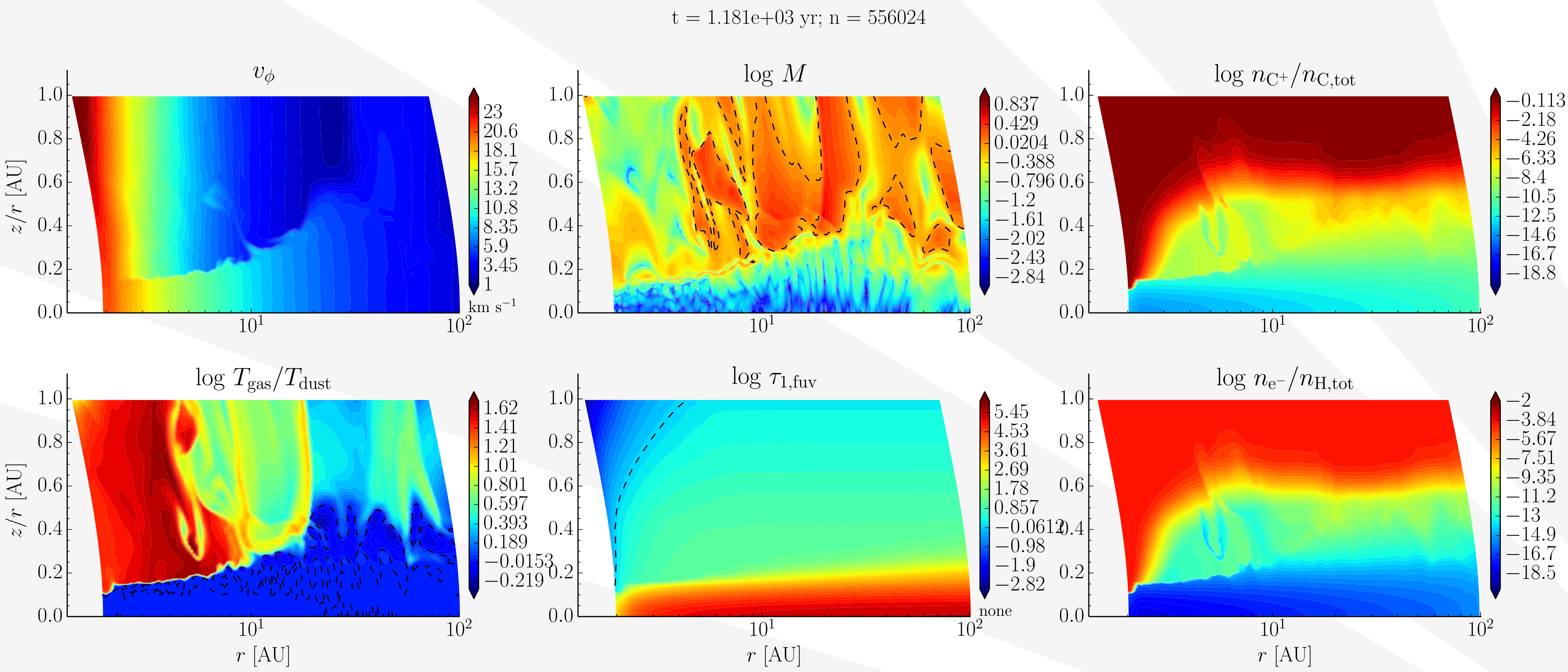


- EUV: $\dot{M}_{\rm EUV} \sim 1.6 \times 10^{-10}$ M$_\odot$ yr^{-1} (Font et al. 2004).
- X-rays: $\dot{M}_{\rm X-ray} \sim 6.3 \times 10^{-9}$ M$_\odot$ yr^{-1} (Owen et al. 2011, 2012).
- Far UV: $\dot{M}_{\rm FUV} \sim 3 \times 10^{-8}$ M$_\odot$ yr^{-1} (Gorti & Hollenbach 2009).

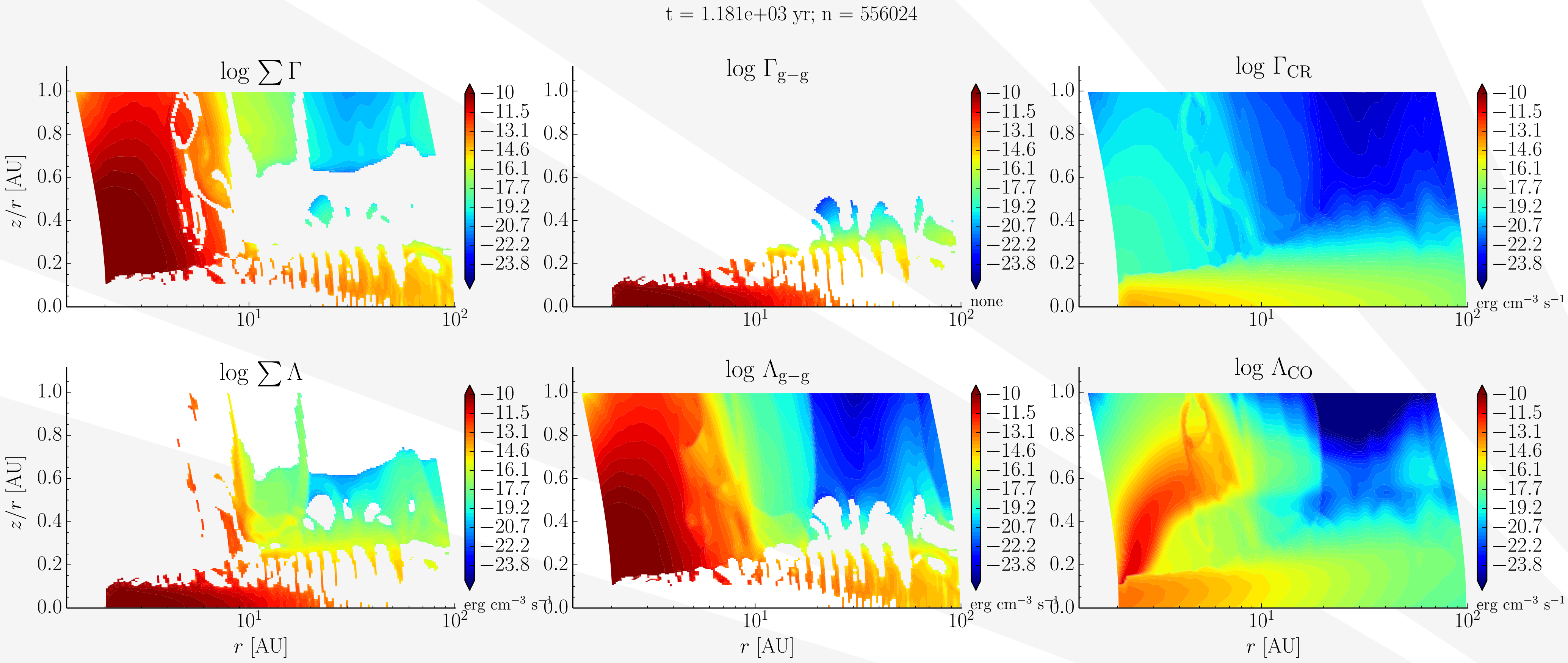
Results, cont'd



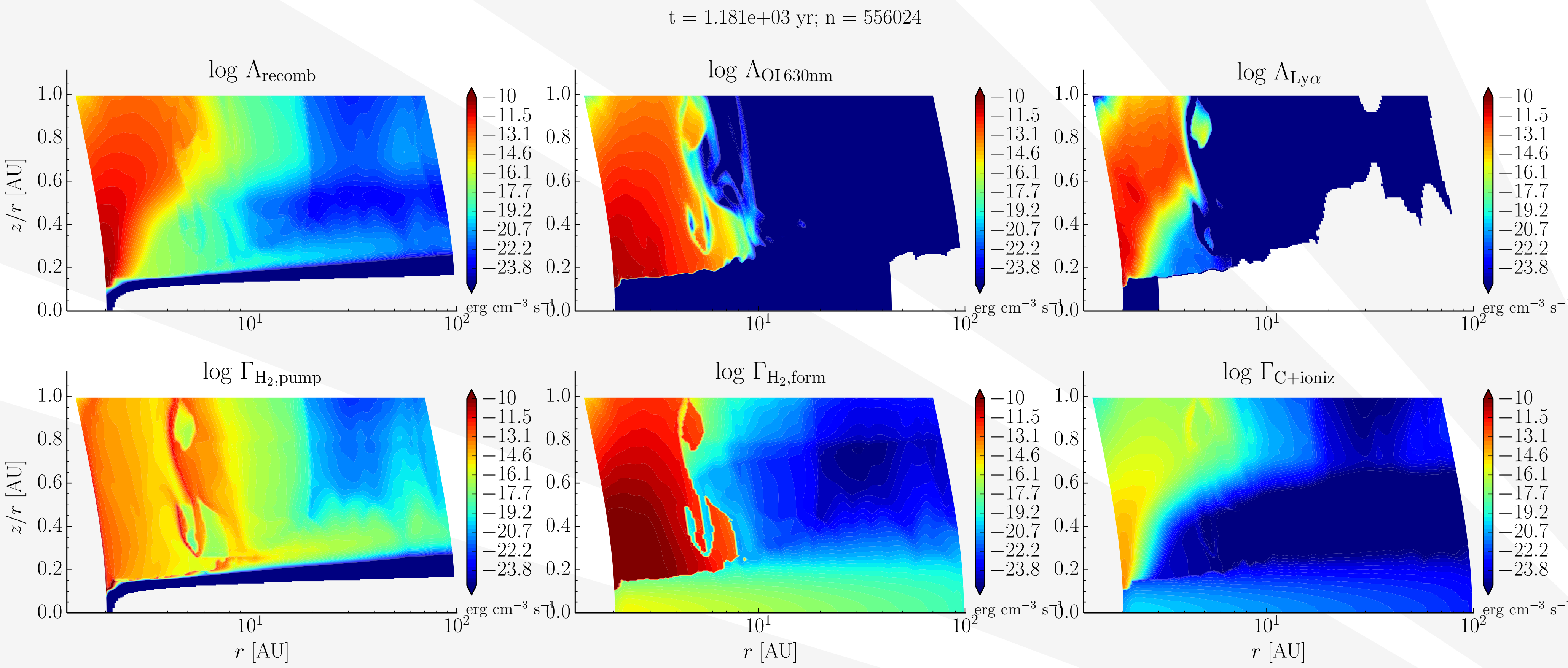
Results, cont'd



Results, cont'd



Results, cont'd



Summary

- Presented the first radiation hydrodynamics models of FUV photoevaporation.
  - ⇒ Includes hydrodynamics, radiation, two-fluids, and simplified chemistry.
- Mass loss rates are comparable to previous FUV models, but with large temporal variations.
- The interesting dynamics happen in the atmosphere above the disk.

To Do

- Scattering is not yet included.
- Only "primordial" disks have been examined so far, but disks with gaps are also interesting.
- For disk clearing, few $\times 10^3$ yr is not long enough.