Juggling dust with light

Self-consistent radiative hydrodynamics simulations of dusty AGN tori

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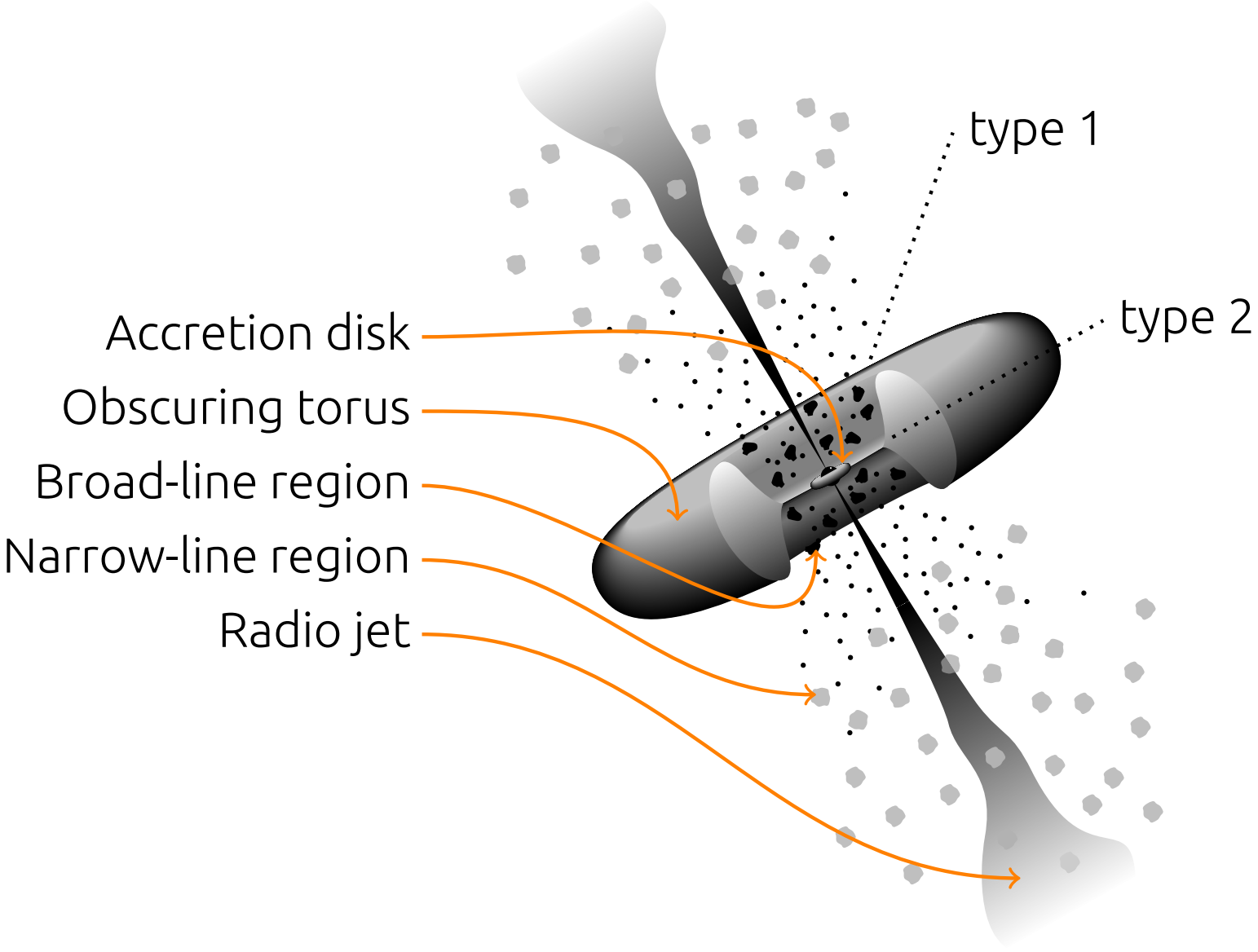
Unification of active galactic nuclei (AGNs)



(Urry & Padovani 1995)

Dynamical models of the obscuring torus

- Warped disk (e.g., Phinney 1989)
  blocks large solid angle only with severe warps and twists
- Clumpiness (Krolik & Begelman 1988)
  needs unusual magnetic fields to counter inelastic collisions
- Magnetocentrifugal wind (e.g., Königl & Kartje 1994)
  needs large-scale magnetic fields
- Direct magnetic support (Lovelace et al. 1998)
  needs large-scale magnetic fields
- Supernovae (e.g., Wada & Norman 2002; Schartmann et al. 2009)
  needs more energy than observed; ties torus lifetime to starburst
- Radiative support (e.g., Pier & Krolik 1992)
  has not been tested with full radiative hydrodynamics (RHD)

Most recent work on IR support

Simulation

(Dorodnitsyn et al. 2011, 2012)

Method:

- Radiative hydrodynamics

Result:

- Self-consistent, geometrically thick structure

Drawbacks:

- Only IR support
- Flux-limited diffusion (FLD) approximation

Radiative transfer

(Roth et al. 2012)

Method:

- Detailed radiative transfer (RT)

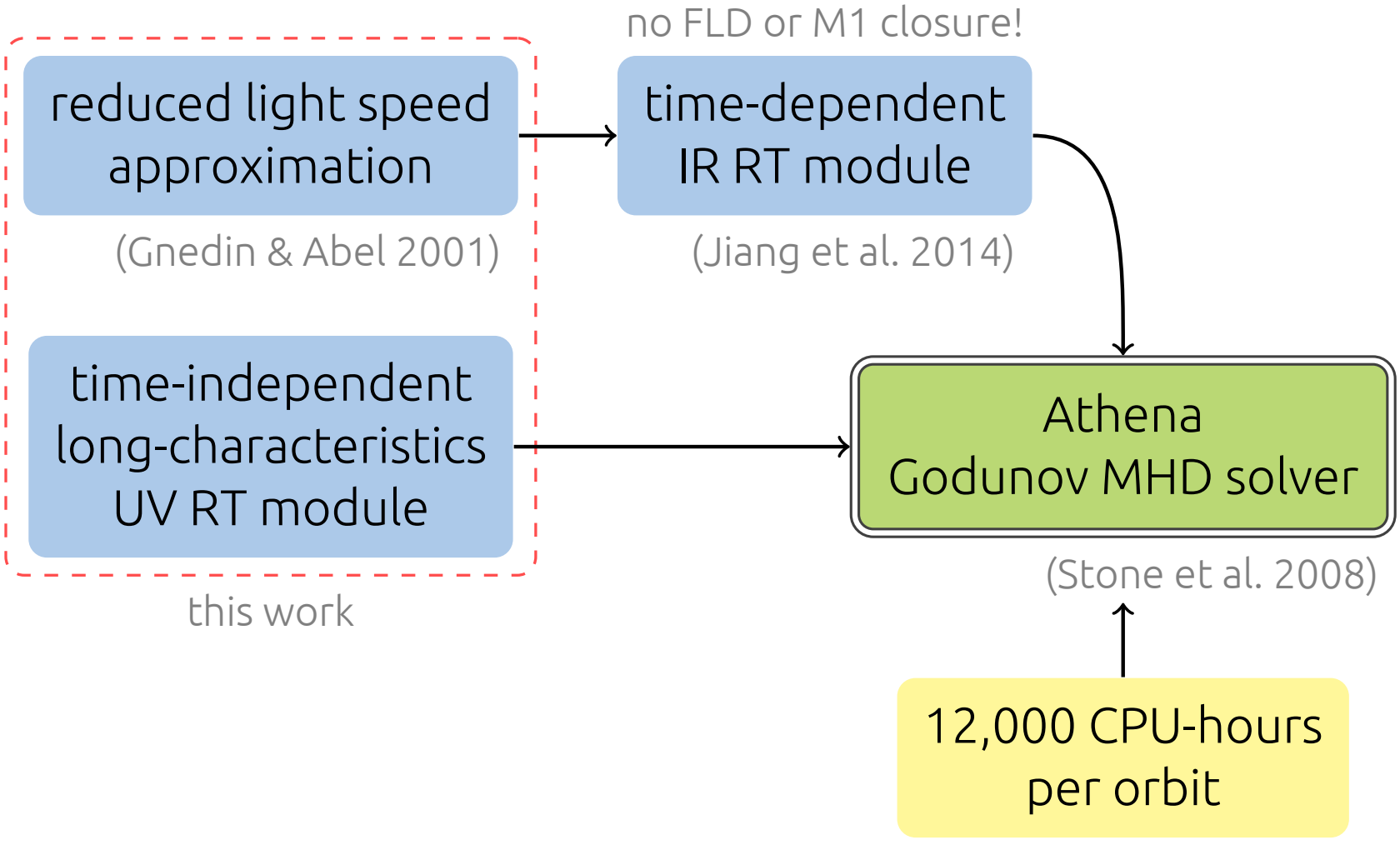
Result:

- Accelerations comparable to gravity

Drawbacks:

- Static, *ad hoc* gas distribution

Numerical code



Simulation parameters

IR opacity

20 times Thomson
if below sublimation

UV opacity

80 times Thomson
if below sublimation

Luminosity

0.10 to 0.15
times Eddington

Central mass

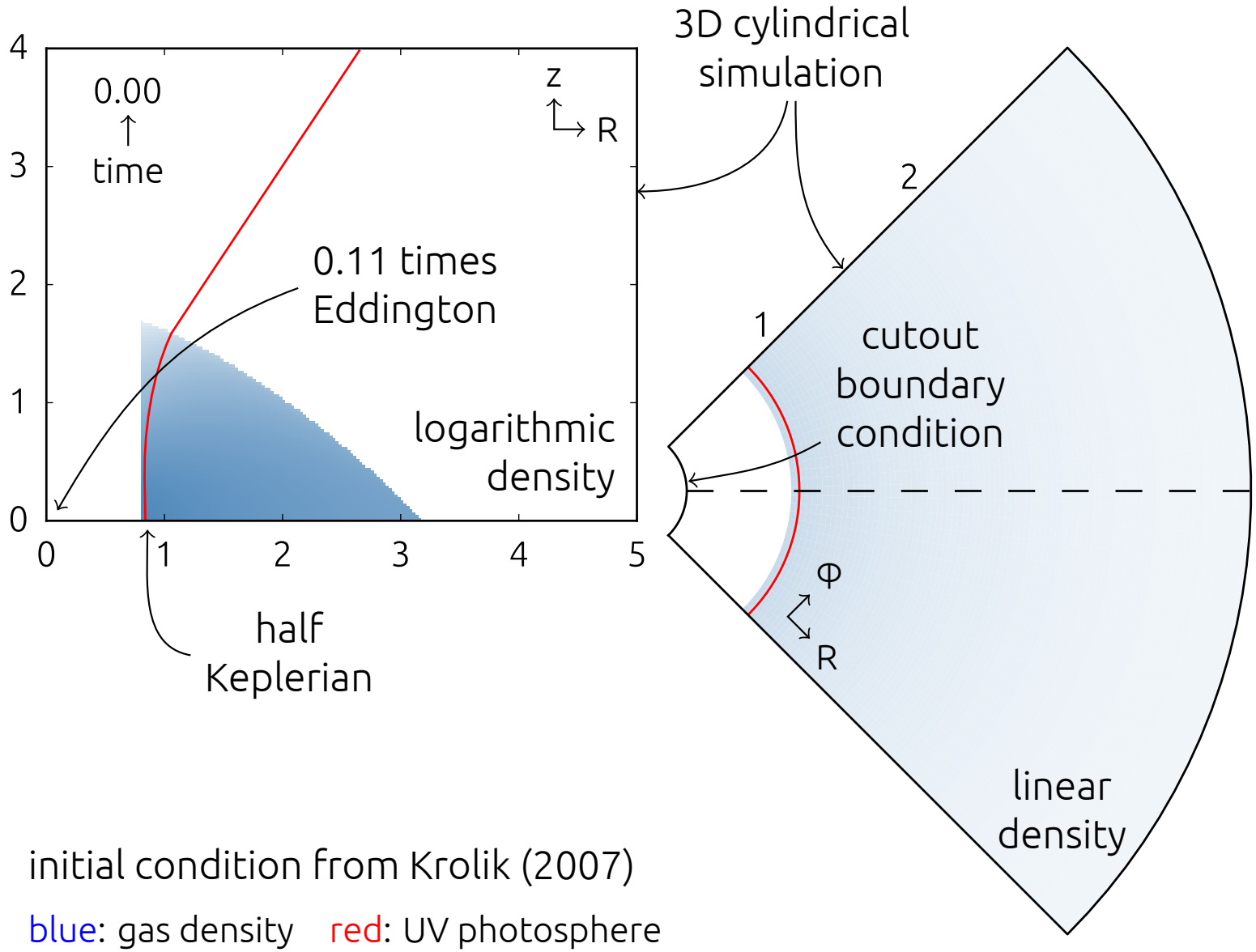
0.8 solar mass

requires extrapolation
to realistic AGNs

Optical depths

Thomson: 1
Infrared: 20

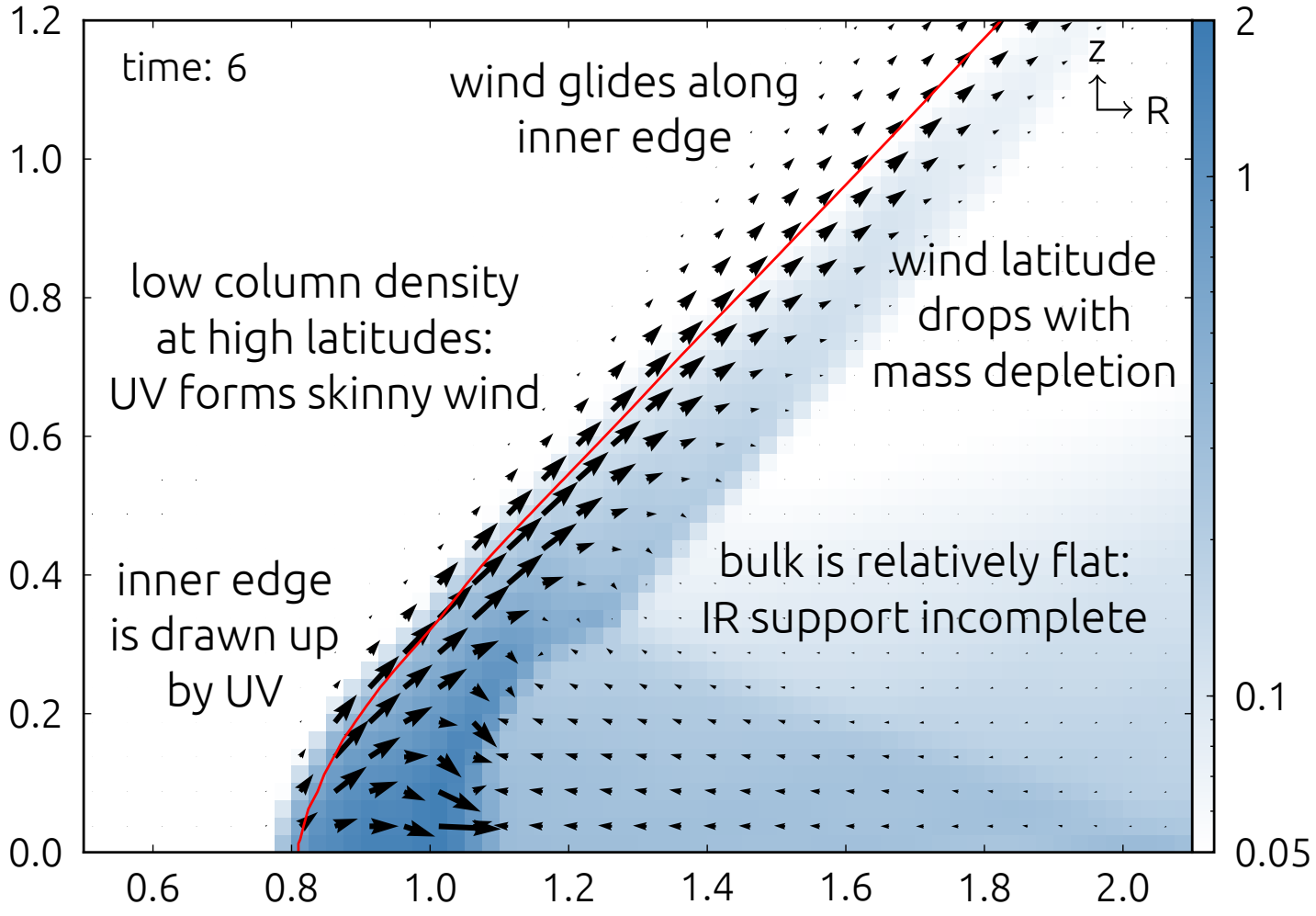
Poloidal and mid-plane slices of simulation



initial condition from Krolik (2007)

blue: gas density red: UV photosphere

Radiation-driven wind



blue: gas density red: UV photosphere arrows: gas momentum

Radiation-driven wind

- Mass, momentum and kinetic energy carried in wind are consistent with UV-driven wind

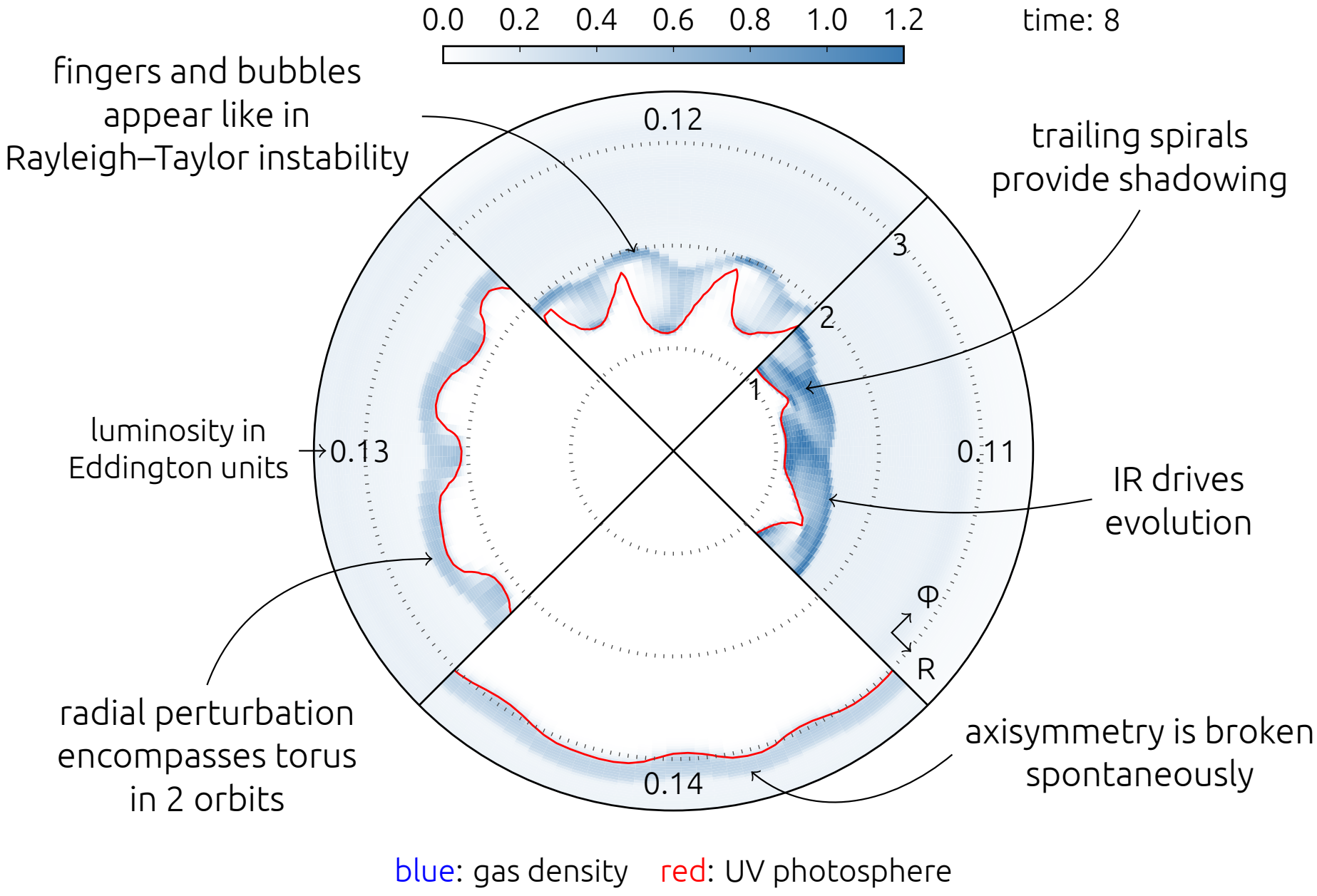
$$\dot{M}_{\rm wind} \sim \frac{L_{\rm UV}}{c v_\infty} \qquad \frac{L_{\rm kin}}{L_{\rm UV}} \sim \frac{v_\infty}{c} \qquad v_\infty^2 \equiv \frac{GM}{R_{\rm in}} \frac{L_{\rm UV}}{L_{\rm E}} \frac{\kappa_{\rm UV}}{\kappa_{\rm T}}$$

- UV pressure on dust is potent torus mass loss mechanism

$$\dot{M}_{\rm wind} \sim 0.12\, M_\odot\, {\rm yr}^{-1} \times \left(\frac{M}{10^7\, M_\odot} \right)^{3/4} \left(\frac{L_{\rm UV}/L_{\rm E}}{0.1} \right)^{3/4}$$

  - Mass loss could be balanced by external accretion
  - MHD stresses may be important for accretion and resupply

Fragmentation of the inner edge



Summary

- Realistic RHD torus simulations are possible with and require genuine RT in IR and UV
- UV acceleration props up inner edge and maintains covering fraction
- Radiation-driven wind has mass loss rates comparable to observations
- Fragmentation of inner edge is possible mechanism for clump formation
- Future work will include MHD stresses to drive accretion

References

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