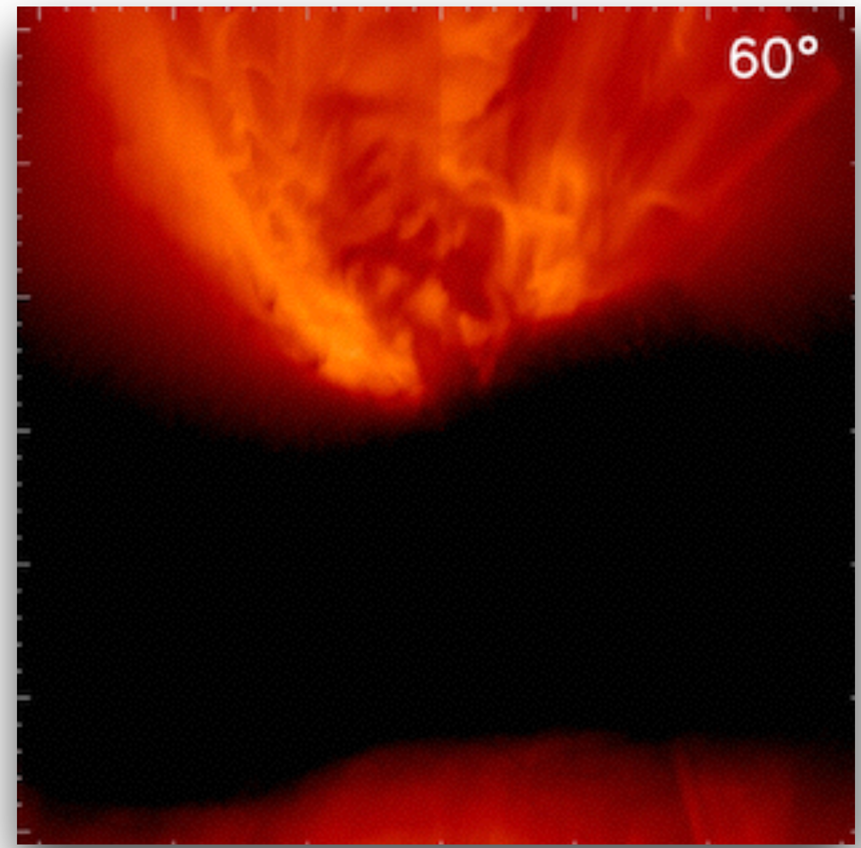
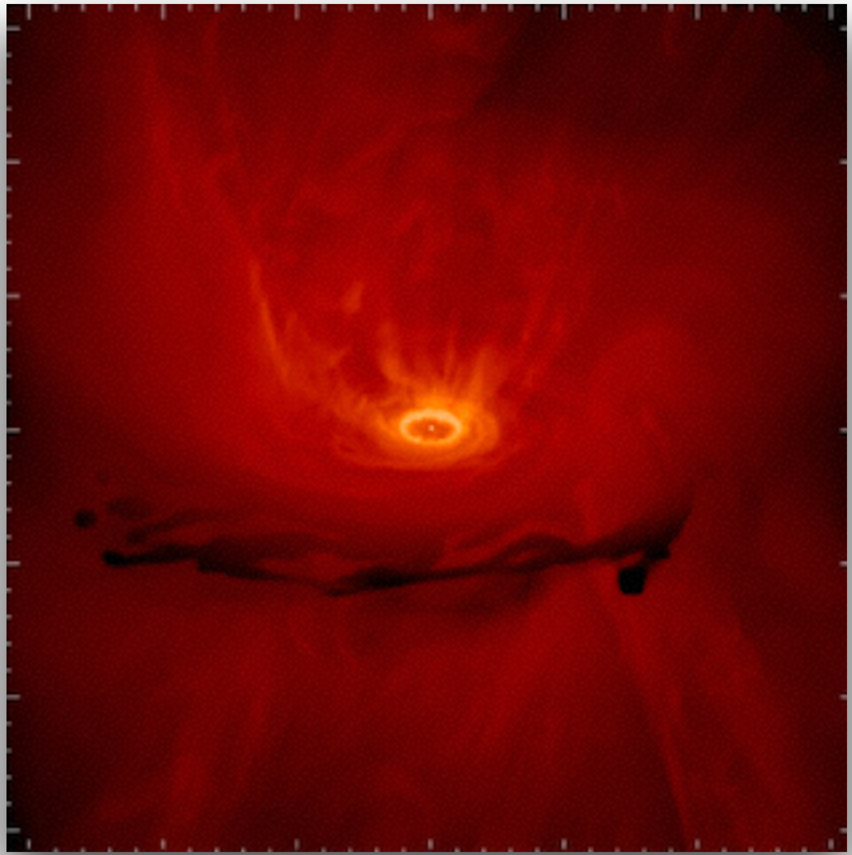
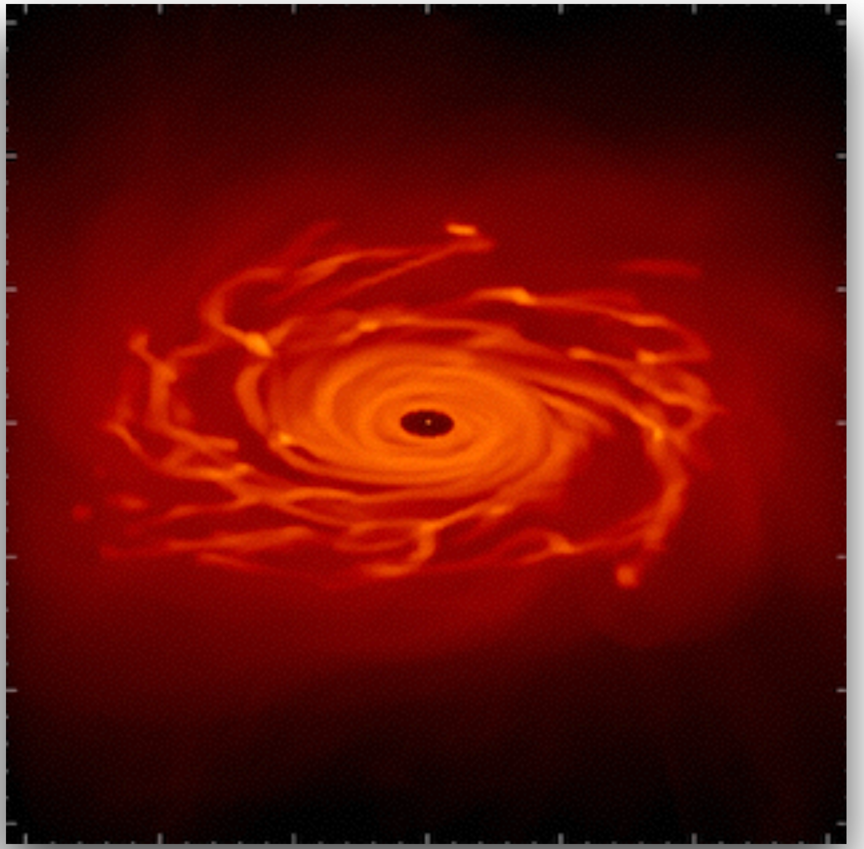
Time-resolved infrared emission from a radiation-driven dusty AGN torus

work in progress, comments welcome…







Marc Schartmann, Keiichi Wada,
Almudena Prieto, Andreas Burkert

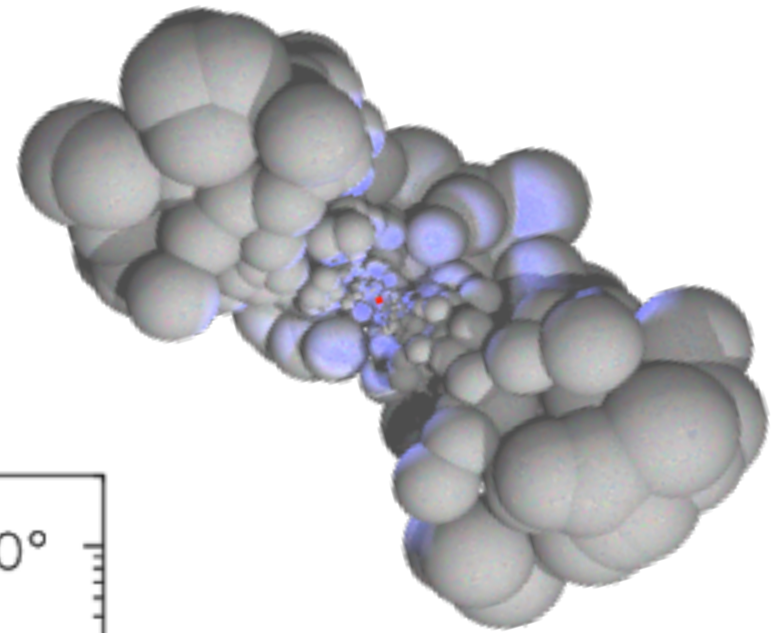
DFG Priority Program 1573 ISM-SPP Interstellar Medium

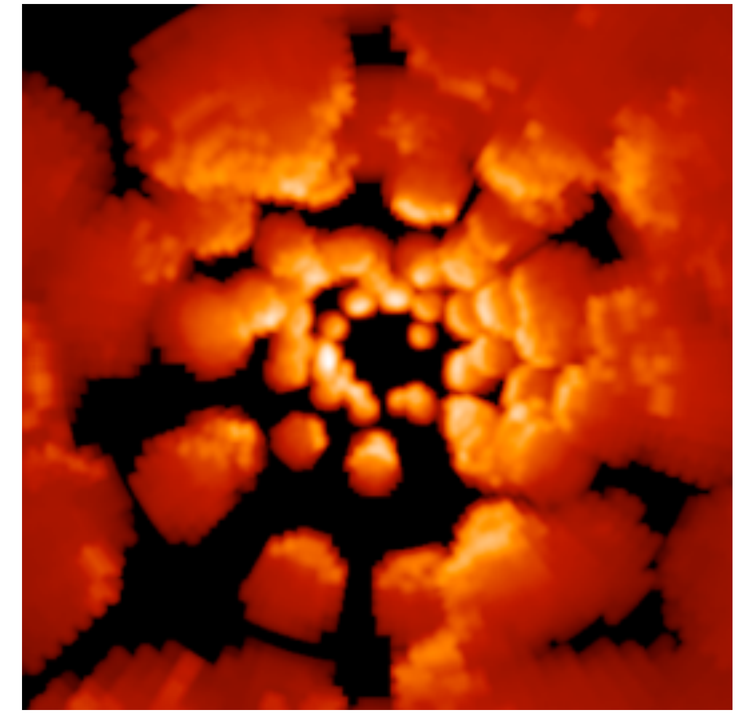
Munich University Observatory CAST Computational Astrophysics Group

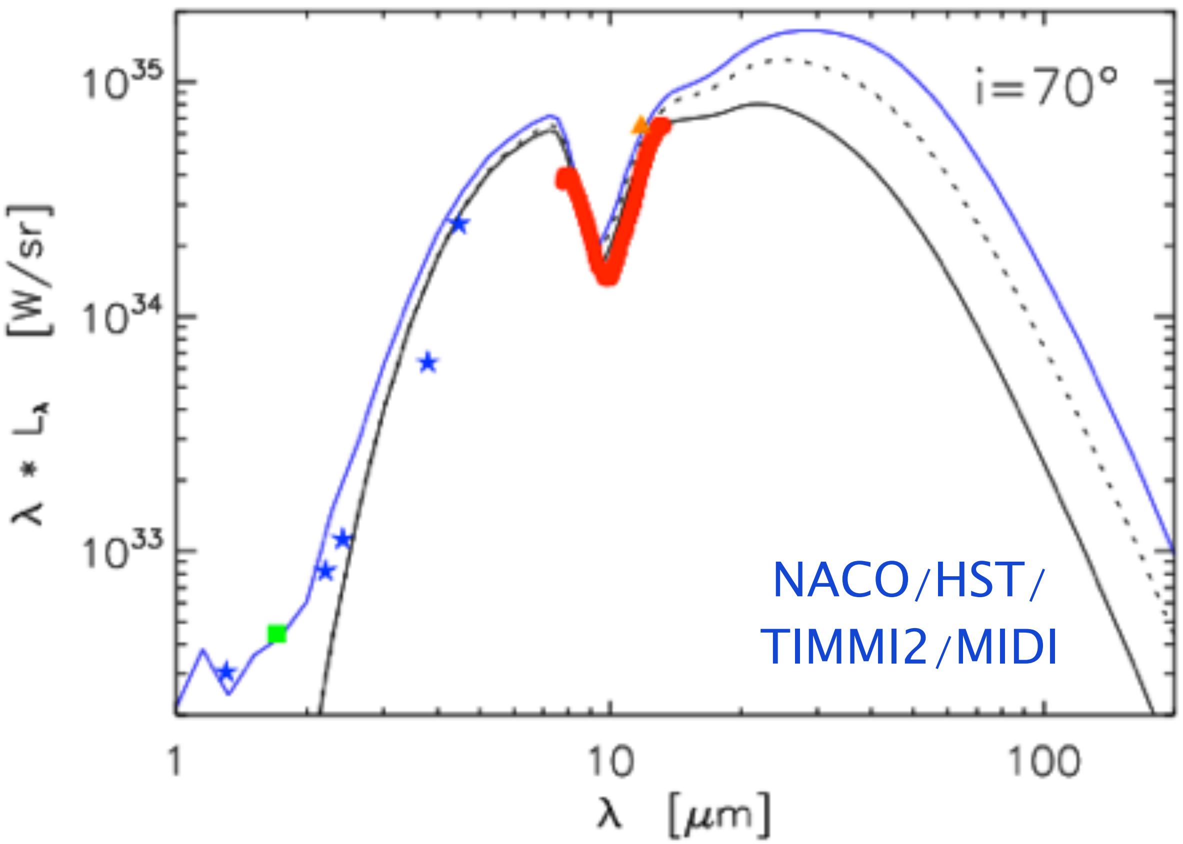
3D Radiative Transfer models for Clumpy tori

- distribute clumps in a 3D geometry
- simultaneously account for high spatial resolution data as well as interferometric data
- good idea of torus structure

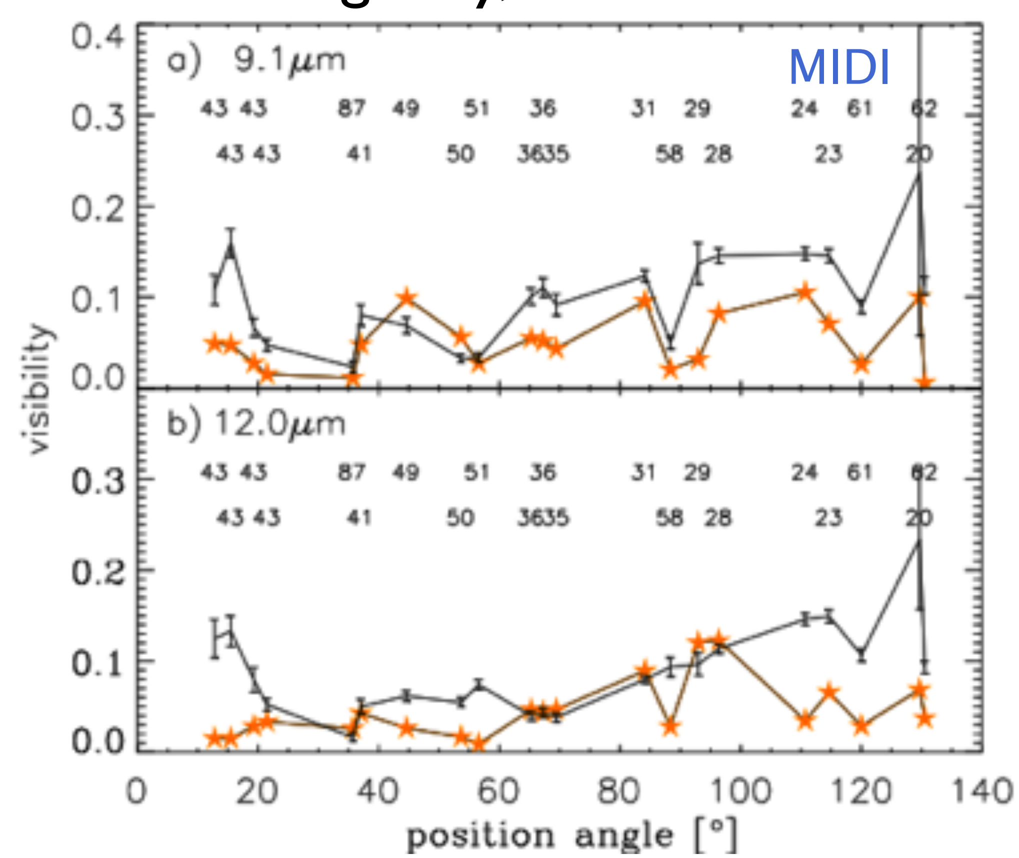
Schartmann+ 2008







Circinus galaxy, Tristram+ 2007



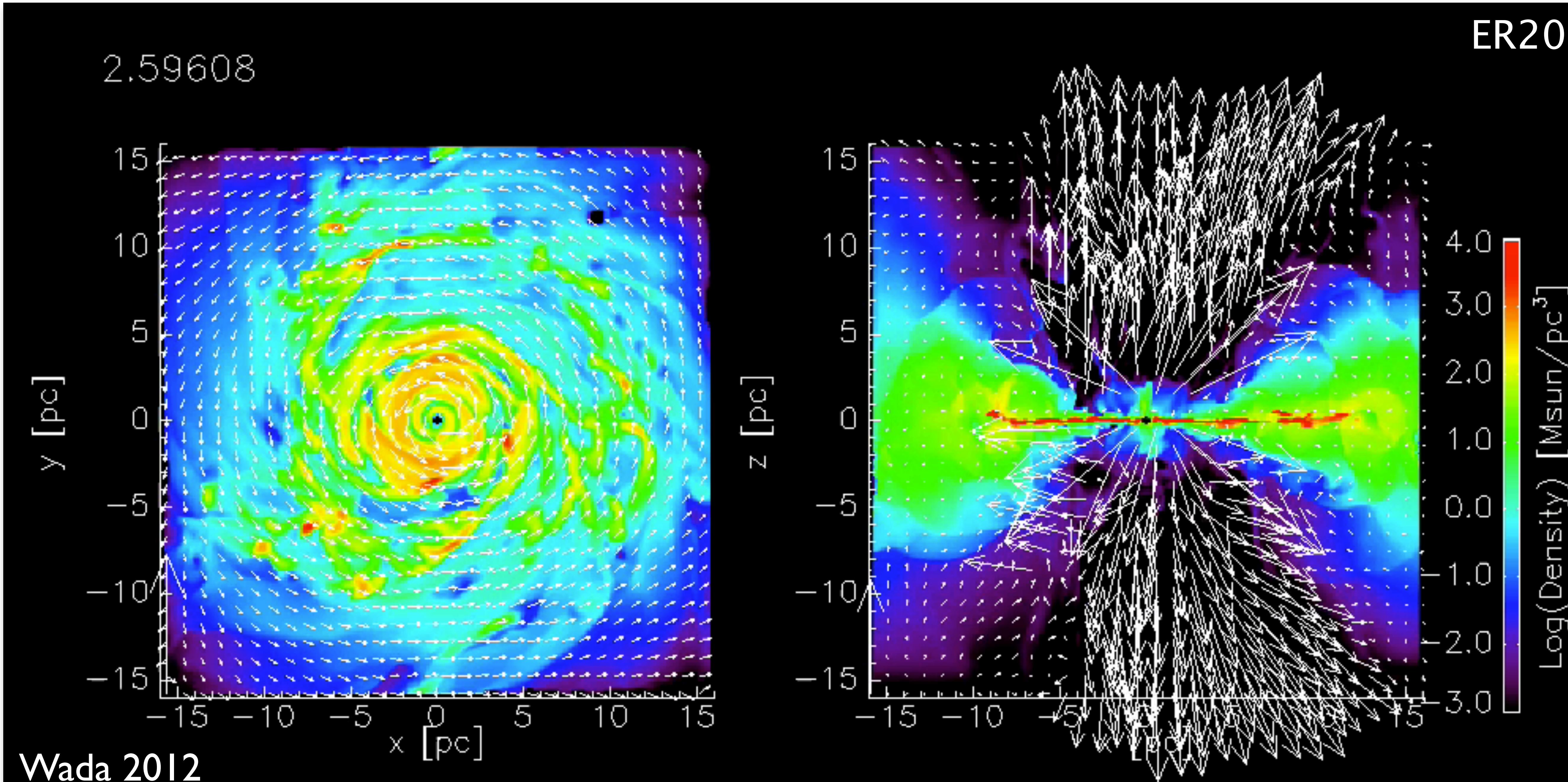
- ambiguities
- toy models
- dynamical stability

→ need for physical models

Radiation-driven AGN tori

- self-gravitating gas disc (10^6 M☉)
- central SMBH (10^7 M☉)
- fixed DM and stellar potential

- X-ray heating, dust radiation pressure
- ray-tracing method
- 3 Eddington ratios: 0.01, 0.1, 0.2
- 0.125pc resolution
- 32^3 pc box



Radiation-driven AGN tori

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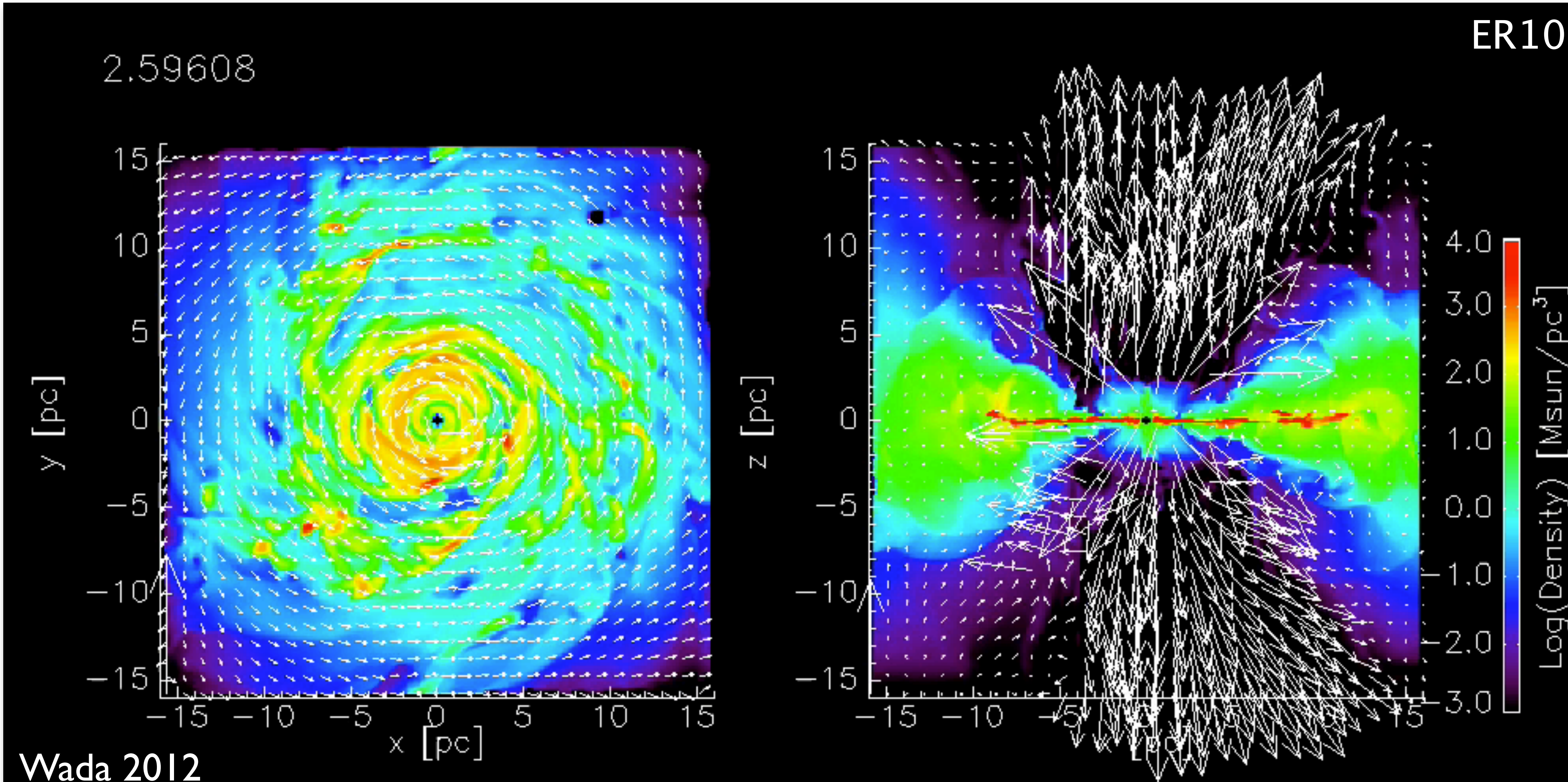
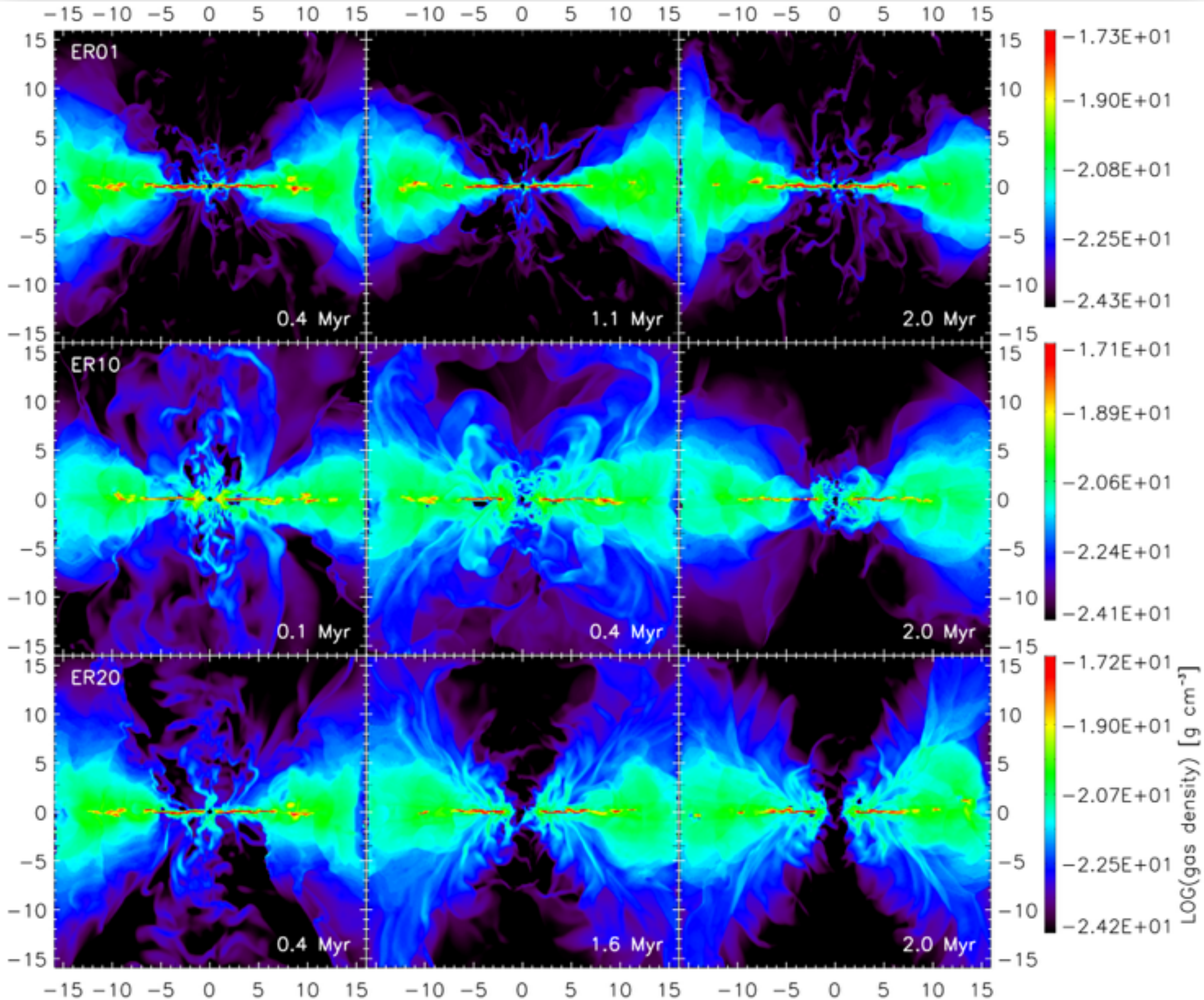


Radiation-driven AGN tori



gas density distribution

X-ray heating and radiation pressure

$0.01\ L_{Edd}$

- thin disk
- tenuous outflow

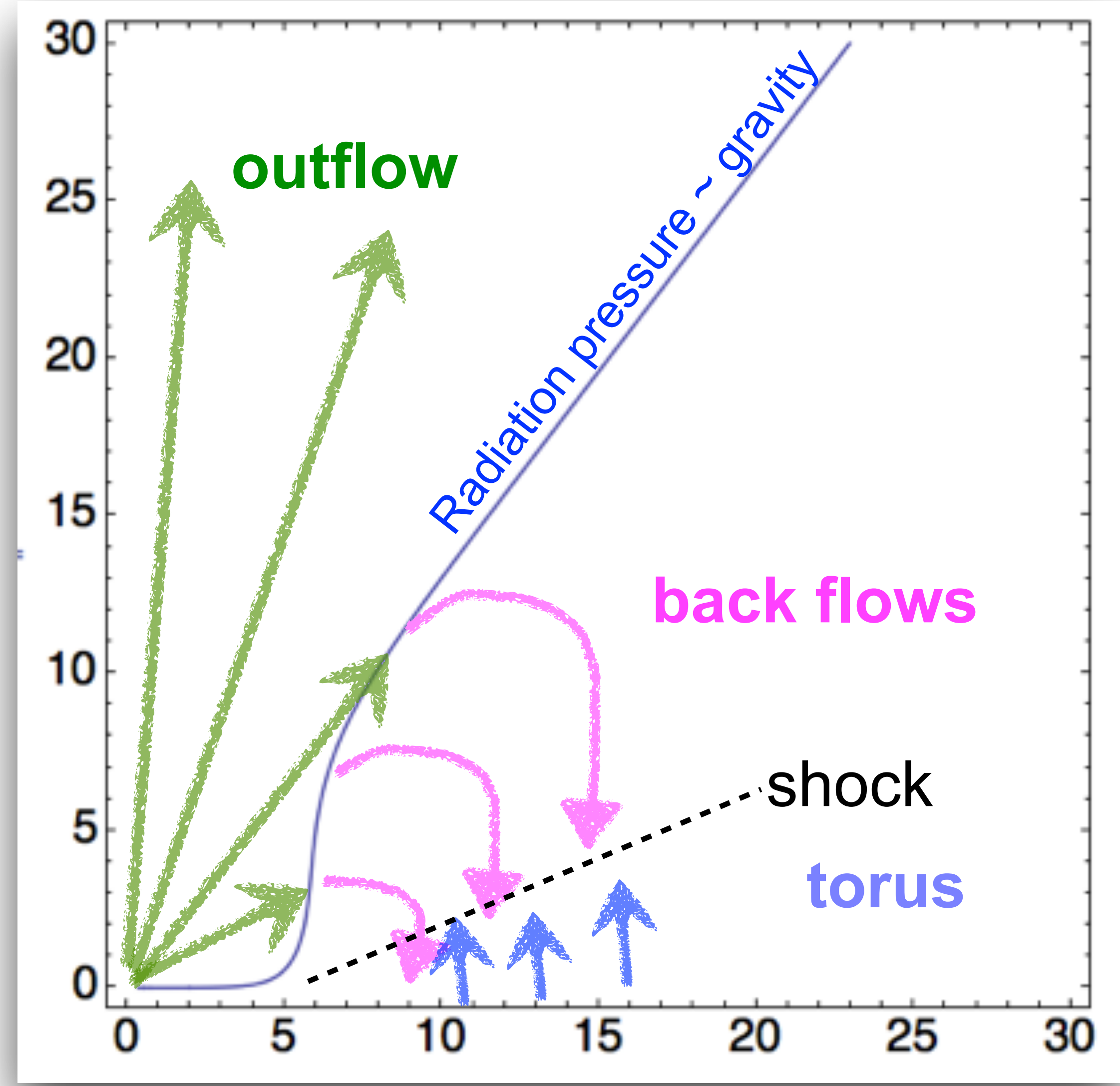
$0.10\ L_{Edd}$

- dense, puffed-up structure
- outflow ceases

$0.20\ L_{Edd}$

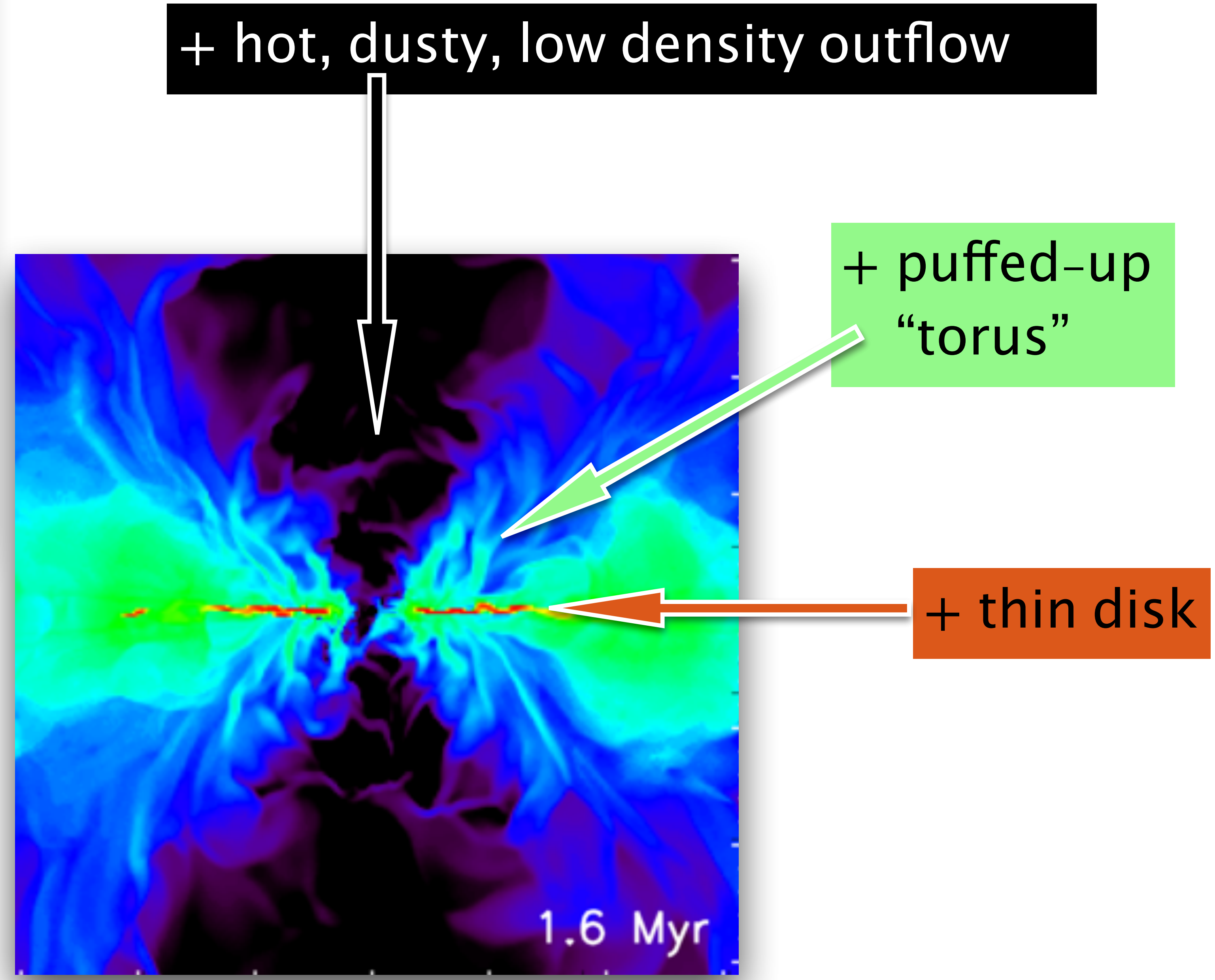
- dense, puffed-up structure
- tenuous outflow

"Radiation pressure driven fountain"



Wada 2012

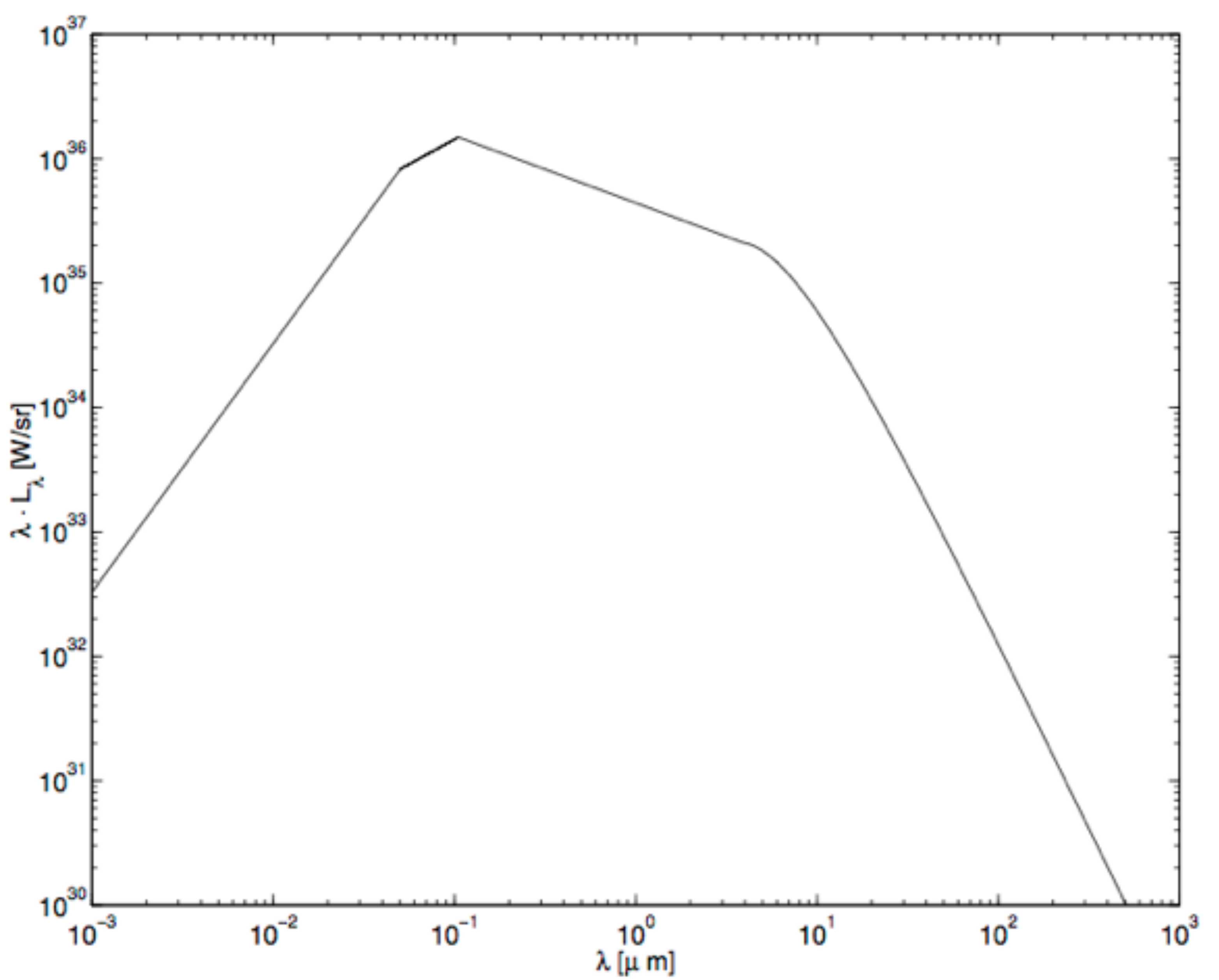
3-component obscuring structure replaces the classical "torus":



Dust Continuum Radiative Transfer & RADMC-3D

$$\frac{1}{c}\frac{\partial I_\nu(\vec{x},\vec{n})}{\partial t} + \vec{n}\cdot\vec{\nabla} I_\nu(\vec{x},\vec{n}) = \frac{1}{4\pi}\rho_d(\vec{x})\, j_\nu(\vec{x},T) - \rho_d(\vec{x})\,\{\kappa_{\nu,\mathrm{abs}}(T) + \kappa_{\nu,\mathrm{sca}}(T)\}\, I_\nu(\vec{x},\vec{n}) + \rho_d(\vec{x}) \int_{4\pi} d\Omega'\, \Phi(\vec{n},\vec{n}')\, \kappa_{\nu,\mathrm{sca}}(T)\, I_\nu(\vec{x},\vec{n}')$$

- solve radiative transfer equation with 3D Monte-Carlo code RADMC-3D (Dullemond et al.)
- primary source SED, point-like with cos(theta) radiation characteristic



Dust Continuum Radiative Transfer & RADMC-3D

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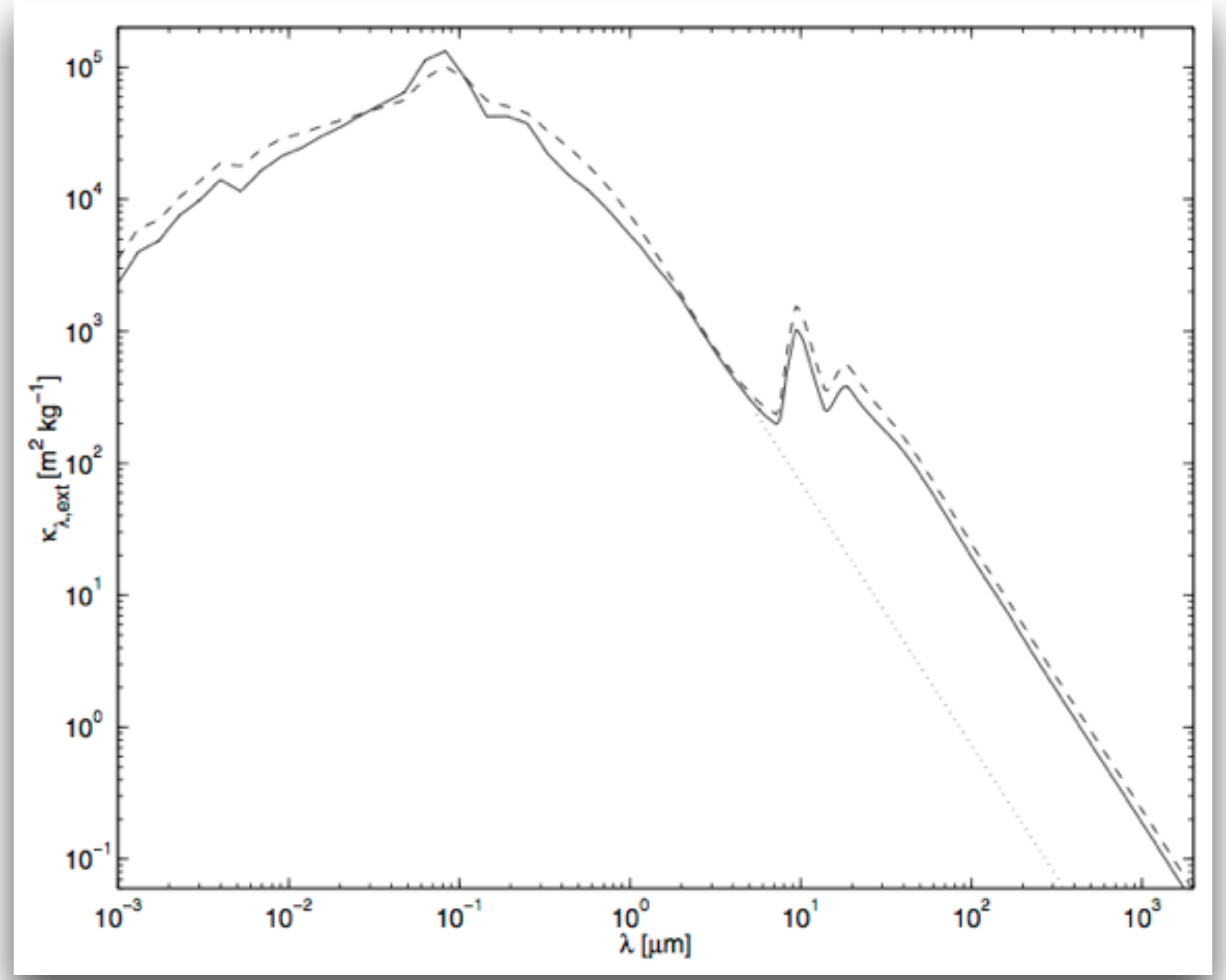
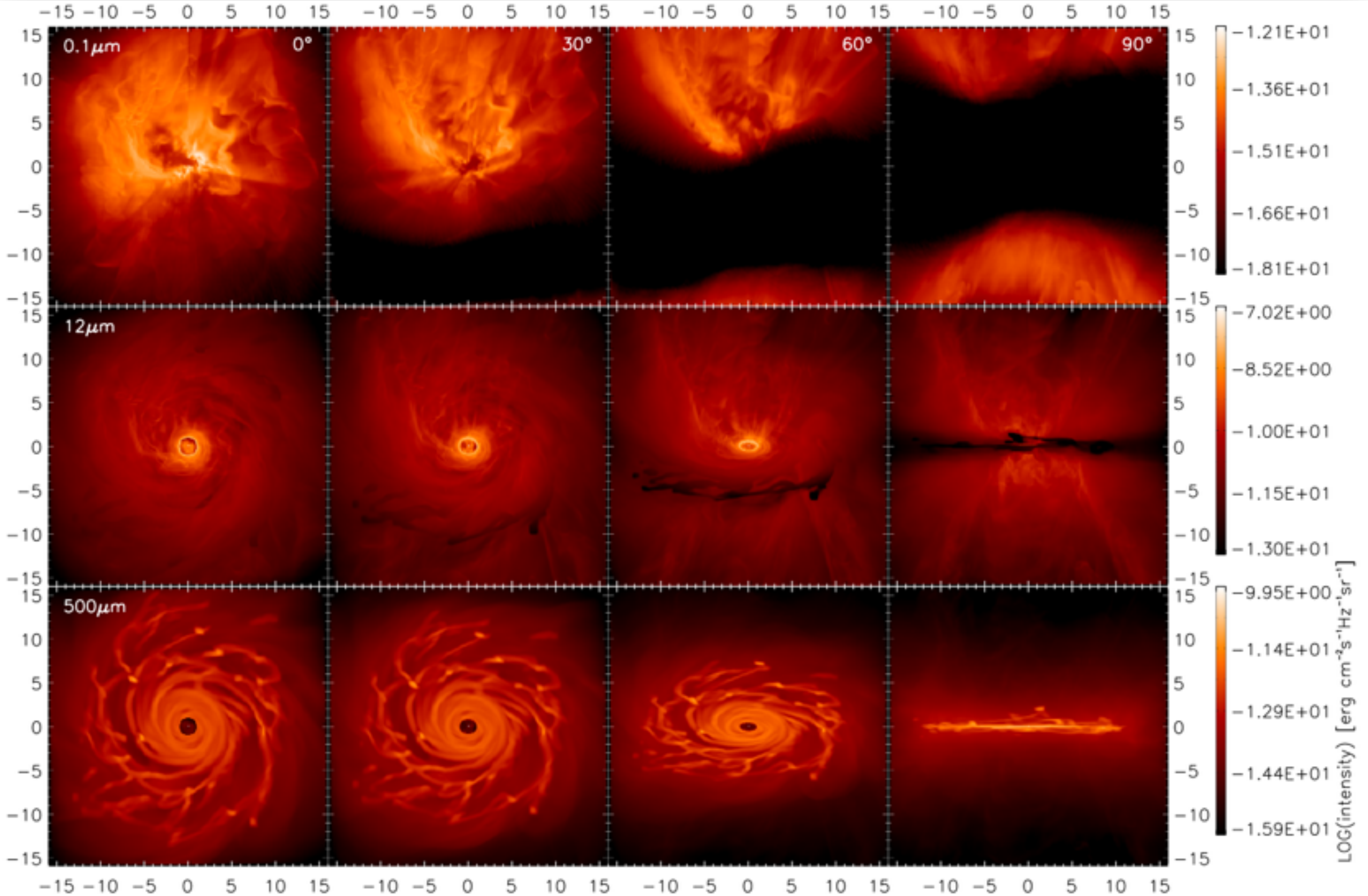
- solve radiative transfer equation with 3D Monte-Carlo code RADMC-3D (Dullemond et al.)
- primary source SED, point-like with cos(theta) radiation characteristic
- local ISM dust model: 62.5% silicate, 37.5% graphite
- spectral features
- cut at r_{in}=1pc



Wavelength-dependent appearance

20% L_{Edd}

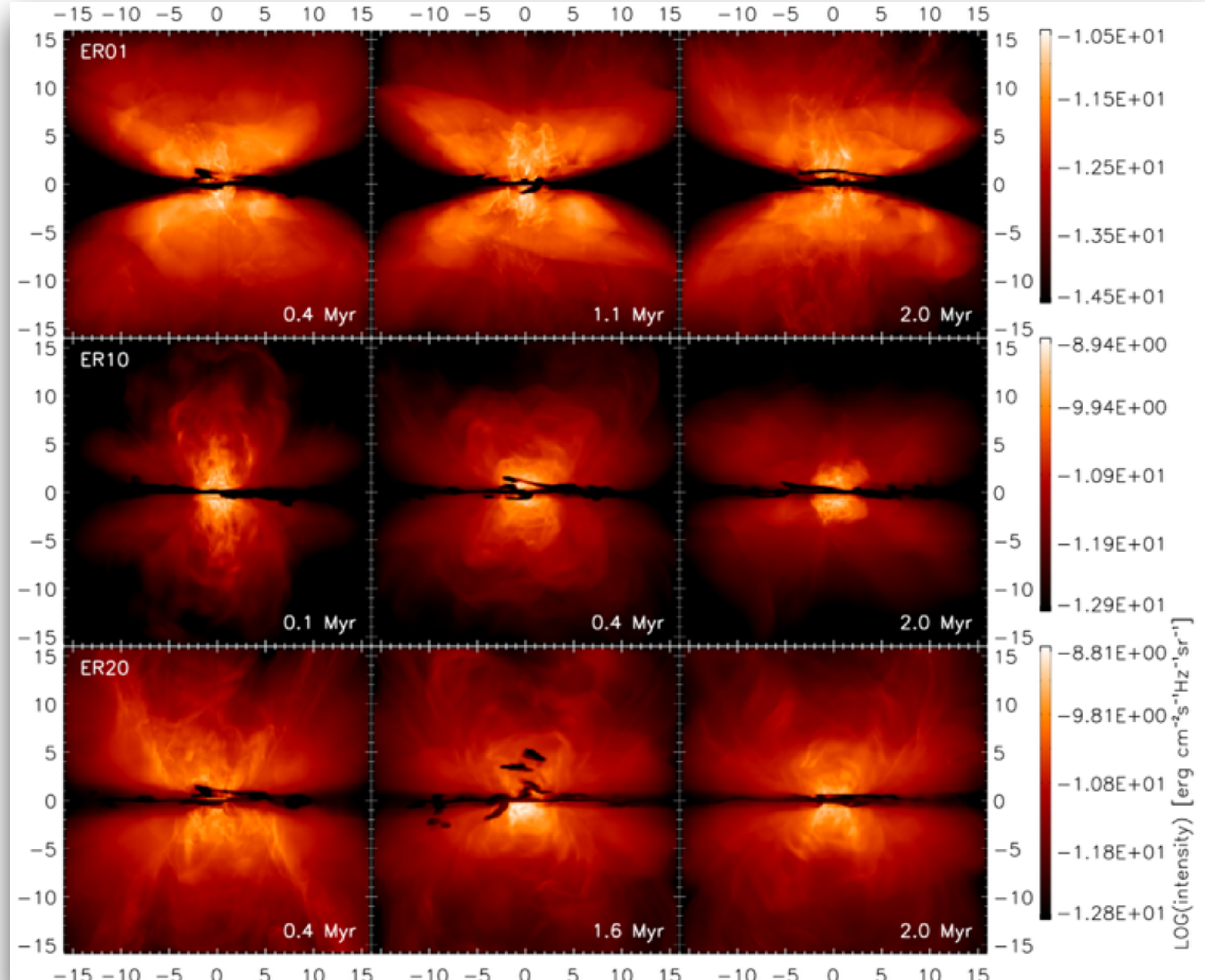


- scattered light within the cone
- cone edge
- inner disk rim
- clumpy disk in absorpt.
- cold filaments and clumpy disk

- orders of magnitude different intensity levels

Time evolution of MIR images

12 micron



- filamentary outflow
- wide opening angle

- ceasing outflow
- vert. elongation changes to spherical shape

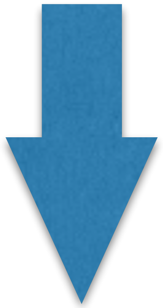
- vertical elongation
- low density cone

Spectral Energy Distributions

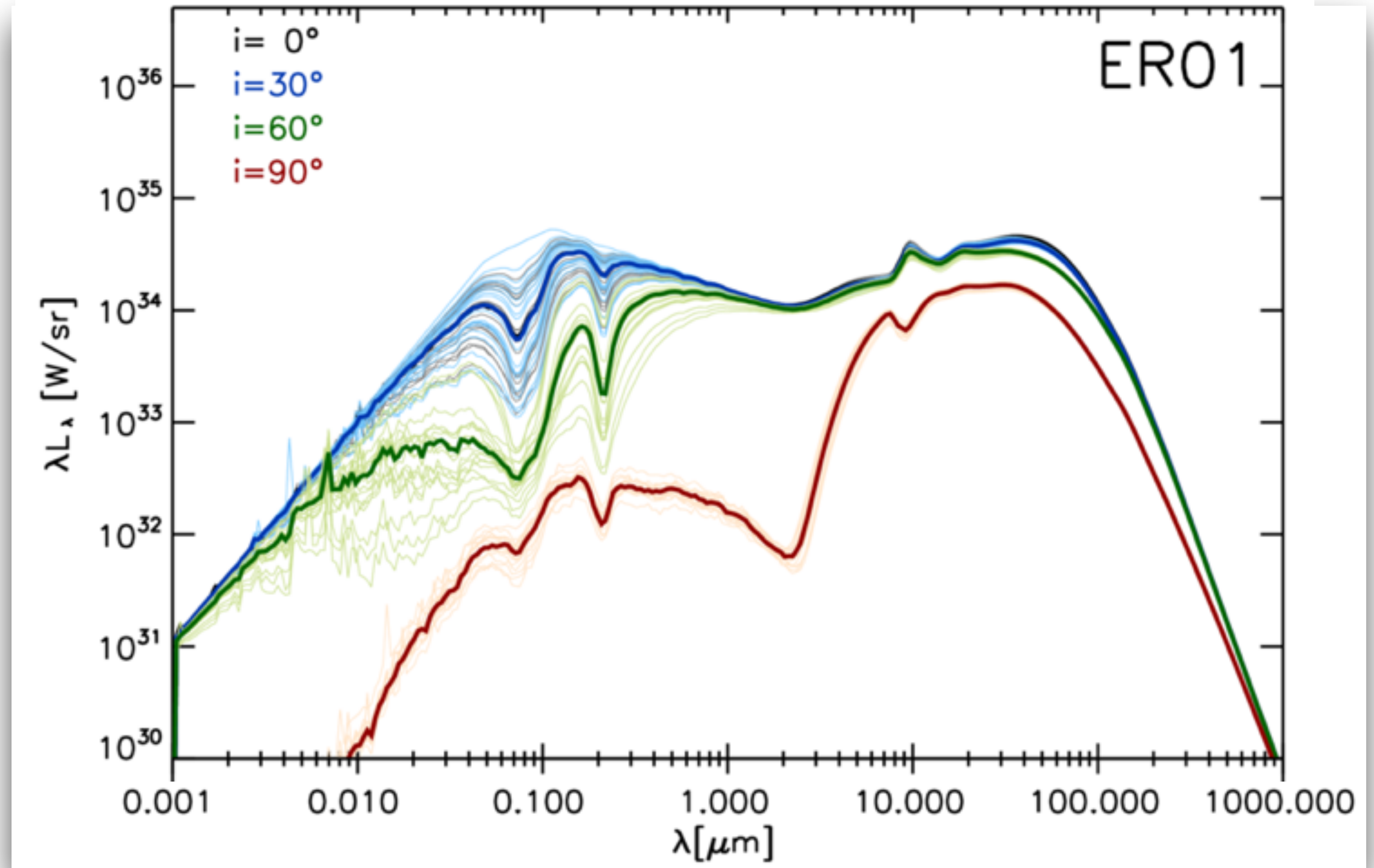
1% Eddington

- "Big Blue Bump", IR re-emission bump
- spectral features
- evolution for ~ 2 Myr

- 0,30 and 60 very similar
- large differences to edge-on view



typical for a thin disk

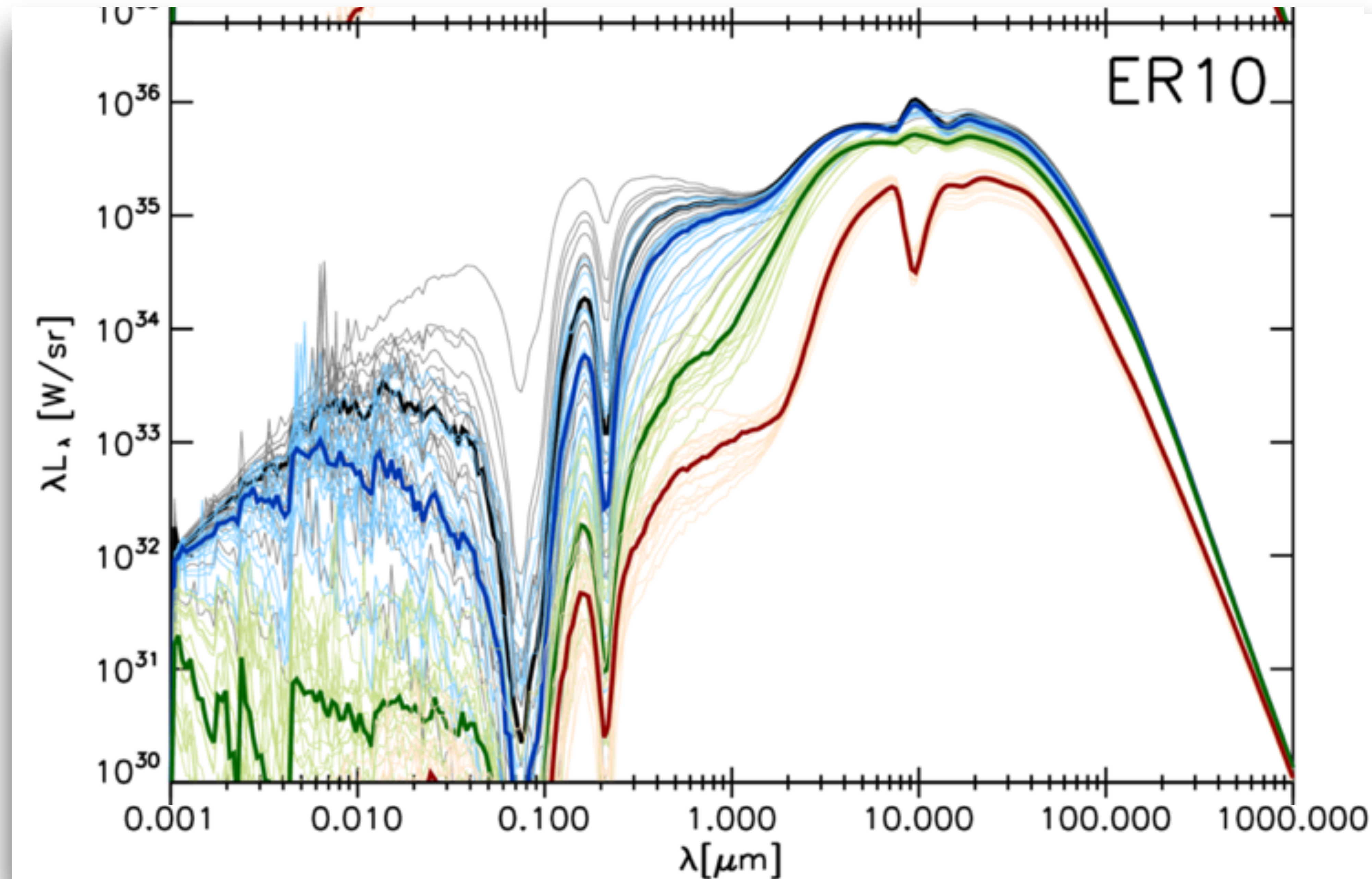


Spectral Energy Distributions

10% Eddington

- much larger differences between inclination angles
- strong absorption in the visible
- deep silicate absorption features

- ceased wind
- (completely) dust enshrouded AGN

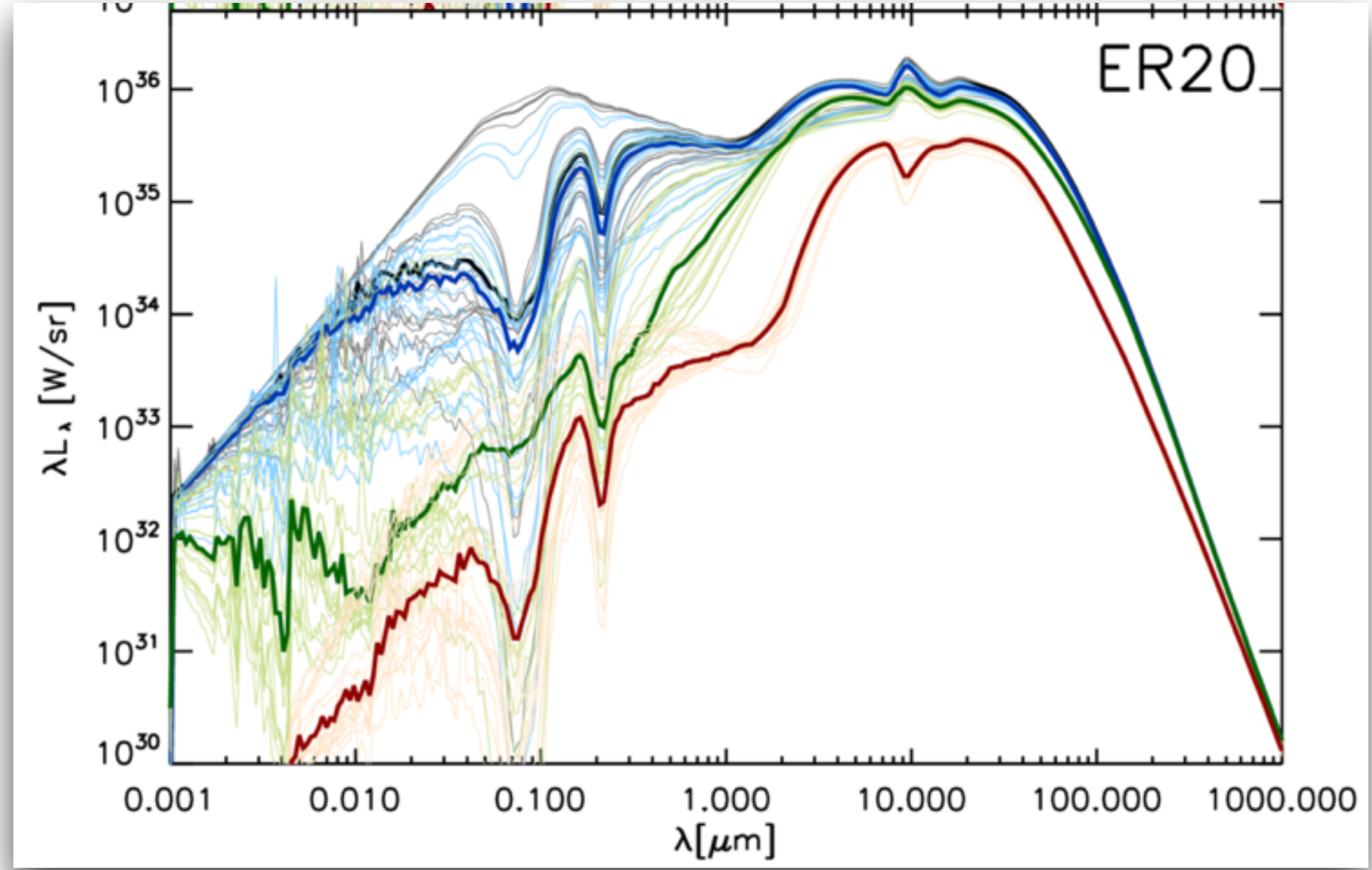


Spectral Energy Distributions

20% Eddington

- large differences between inclination angles
- large variety of absorption in the visible
- moderately deep abs. features in IR

three-component system: disk plus low density outflow plus puffed-up structure

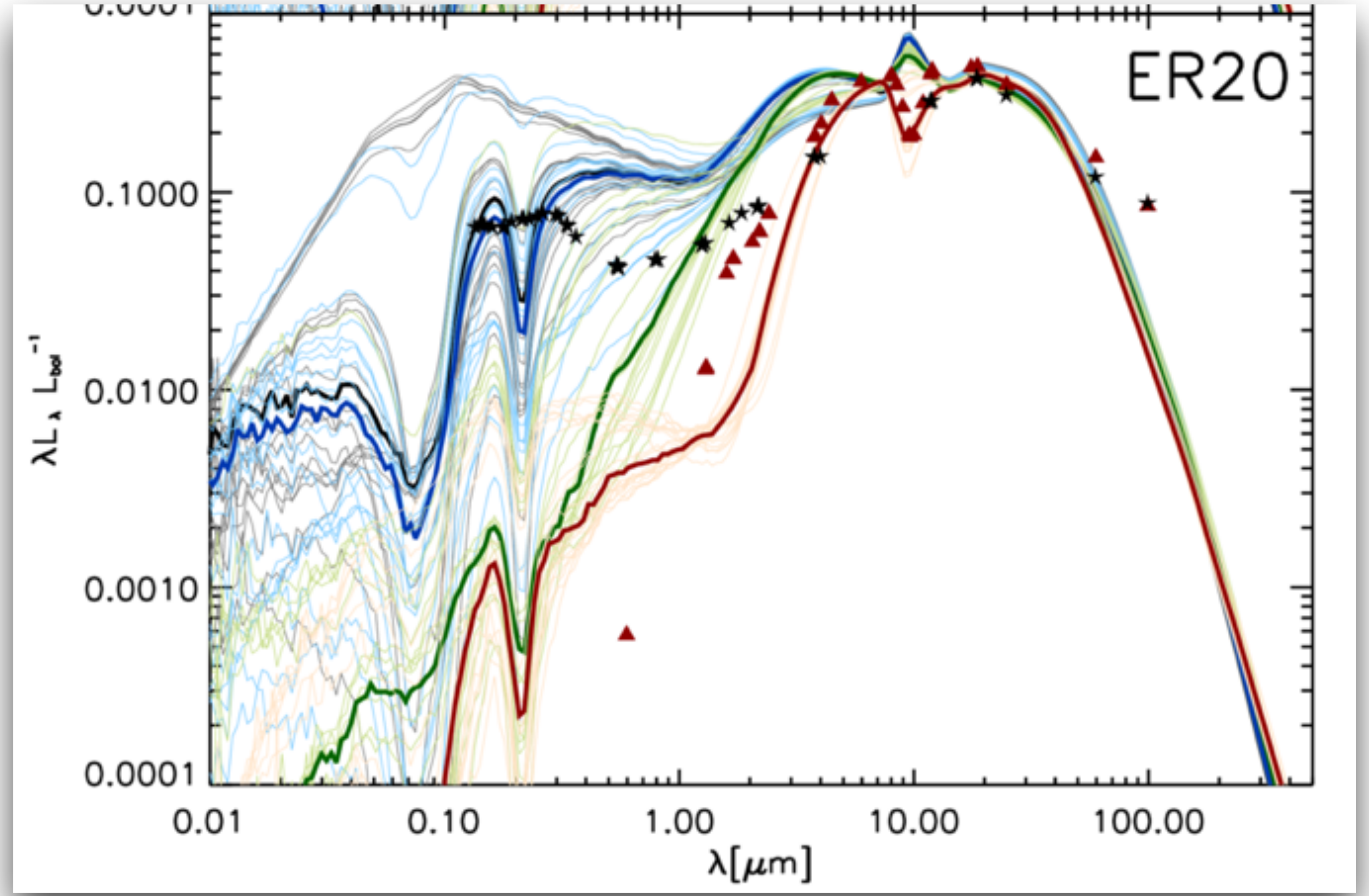


Comparison to observed SEDs

20% Eddington

- Seyfert galaxy templates (Prieto et al. 2010)
- type I - black stars
- type 2 - red triangles
- normalised to total bolometric luminosity

- edge-on case: overall good agreement
- face-on case: reasonable agreement at short and long wavelengths
- too much flux at NIR wavelengths (outflow, resolution?)

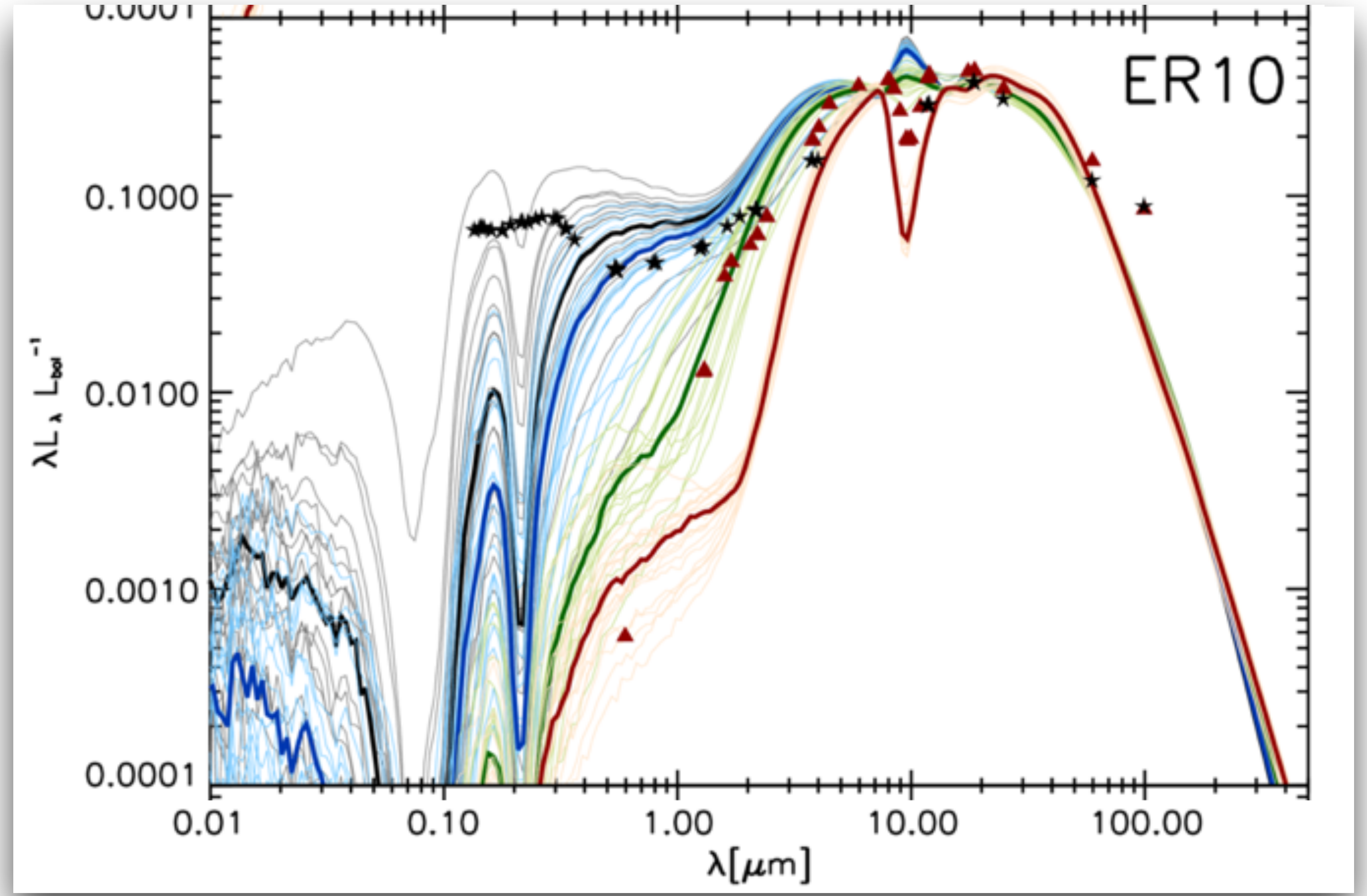


Comparison to observed SEDs

10% Eddington

- Seyfert galaxy templates (Prieto et al. 2010)
- type I - black stars
- type 2 - red triangles
- normalised to total bolometric luminosity

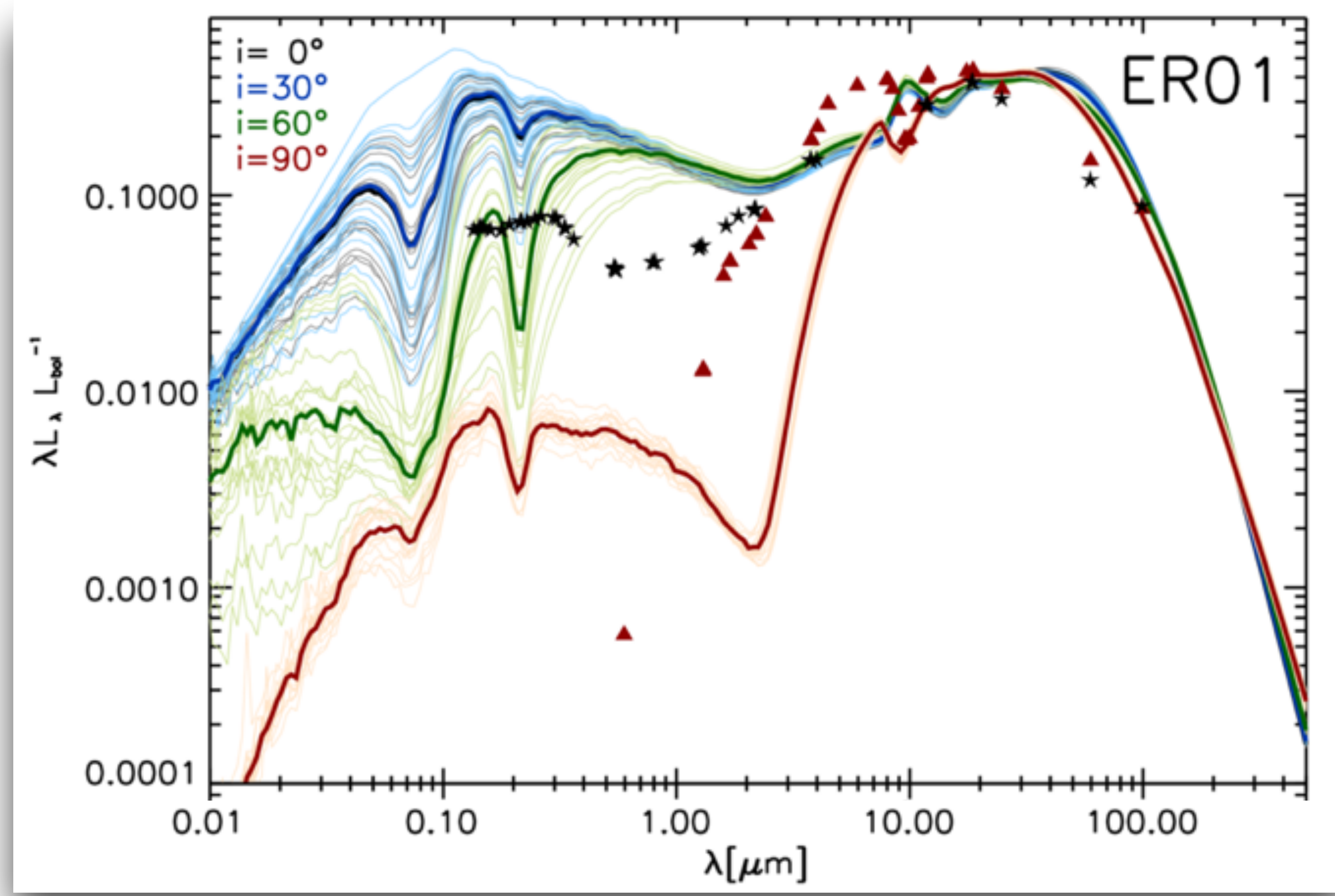
- edge-on case: similarly good agreement, but too strong silicate absorption
- face-on case: too much extinction at short wavelengths



Comparison to observed SEDs

1% Eddington

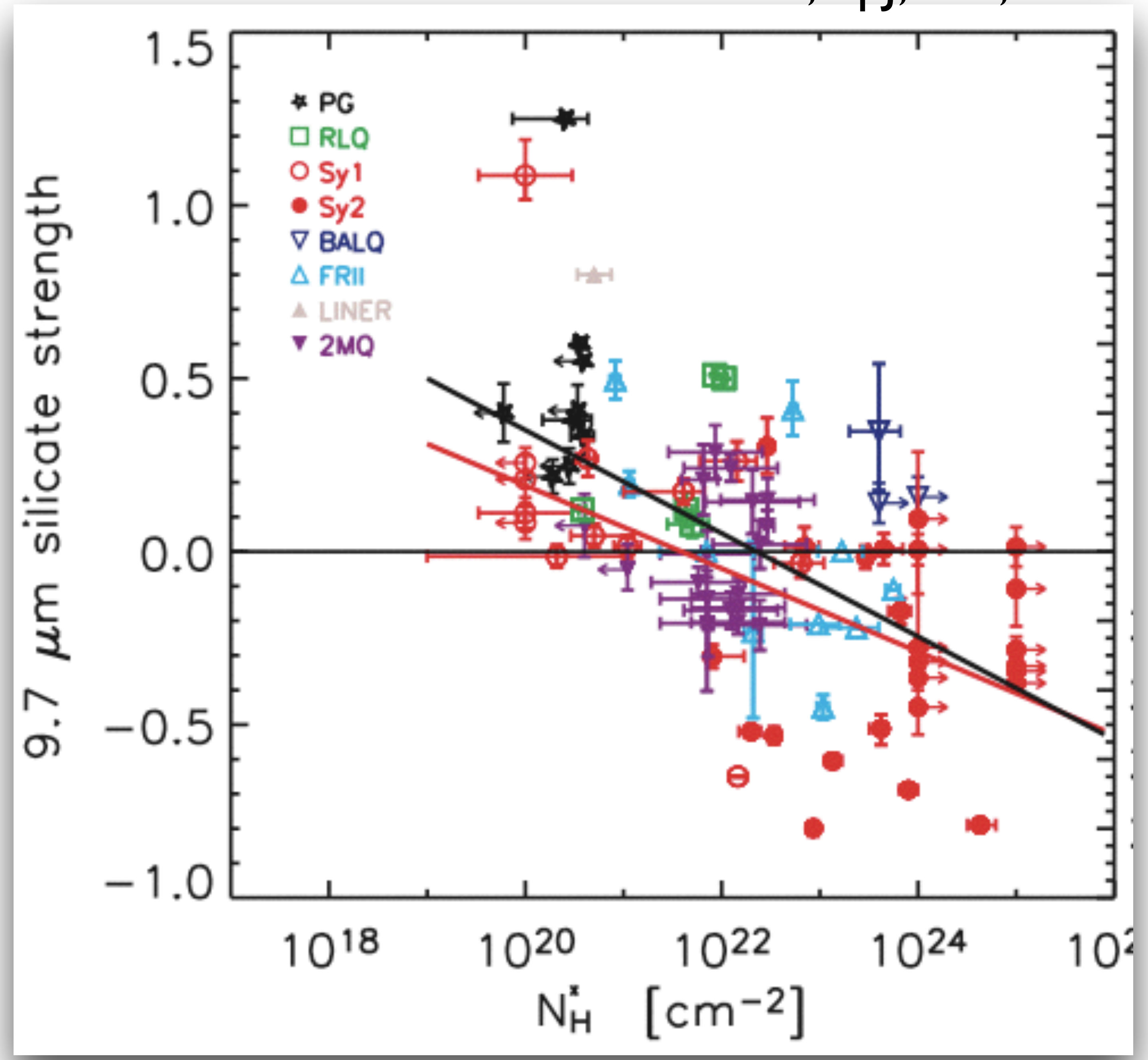
- Seyfert galaxy templates (Prieto et al. 2010)
- type I - black stars
- type 2 - red triangles
- normalised to total bolometric luminosity



- neither explains face-on nor edge-on case very well

Comparison with observations: silicate feature vs gas column density

Shi et al. 2006, ApJ, 653, 127



- red line = Seyfert sub-sample
- black line = all objects
- NH probes single line of sight
- silicate feature = mixture of emission and absorption components within the beam
- linear relation found with large amount of scatter
- interpreted as being the result of clumpiness

Comparison with observations: silicate feature vs gas column density

ER20 - stars

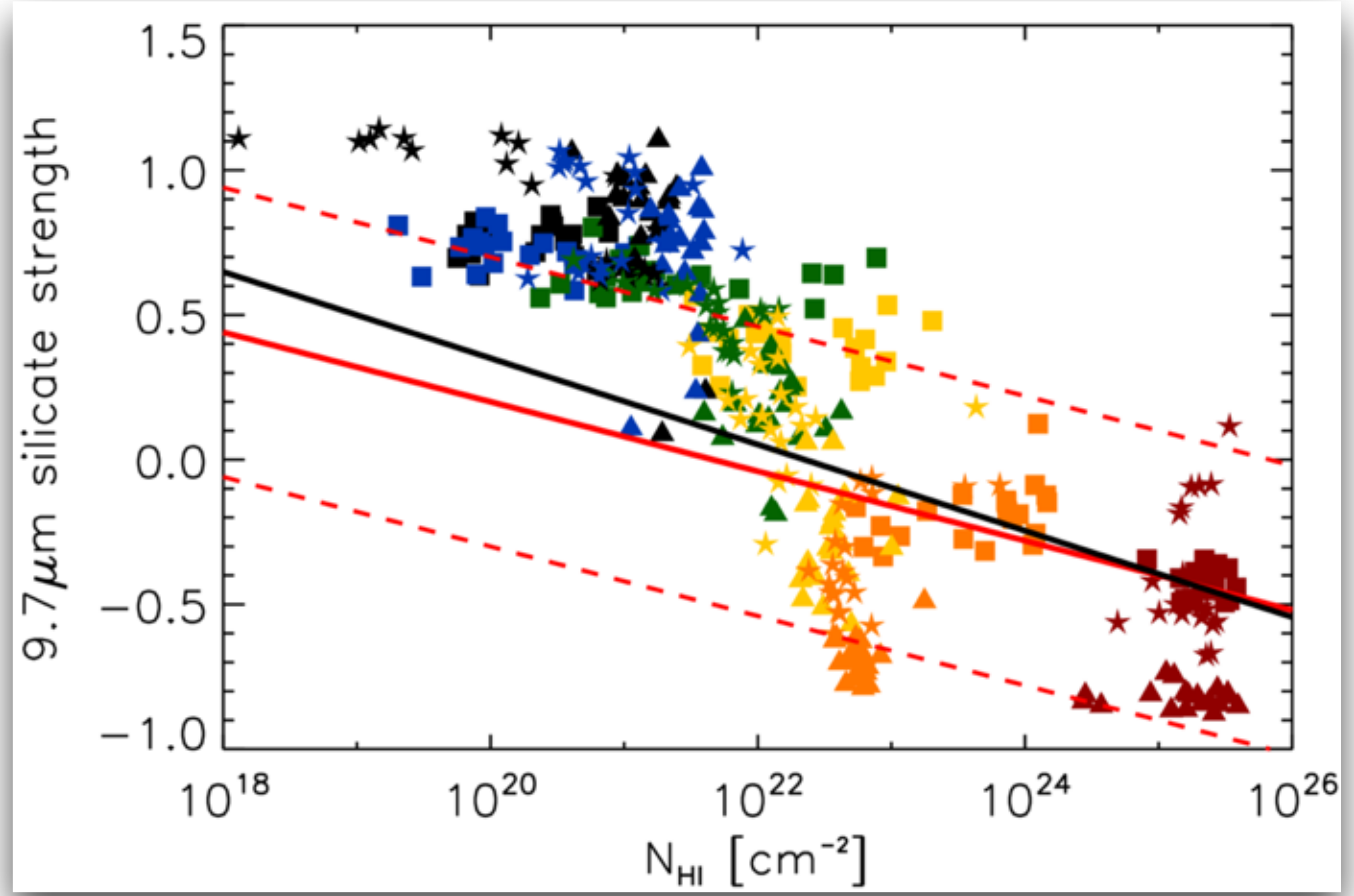
- overall best match

ER01 - squares

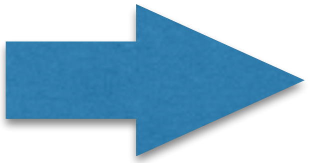
- too little scatter

ER10 - triangles

- 90: compactness problem



too strong silicate feature emission



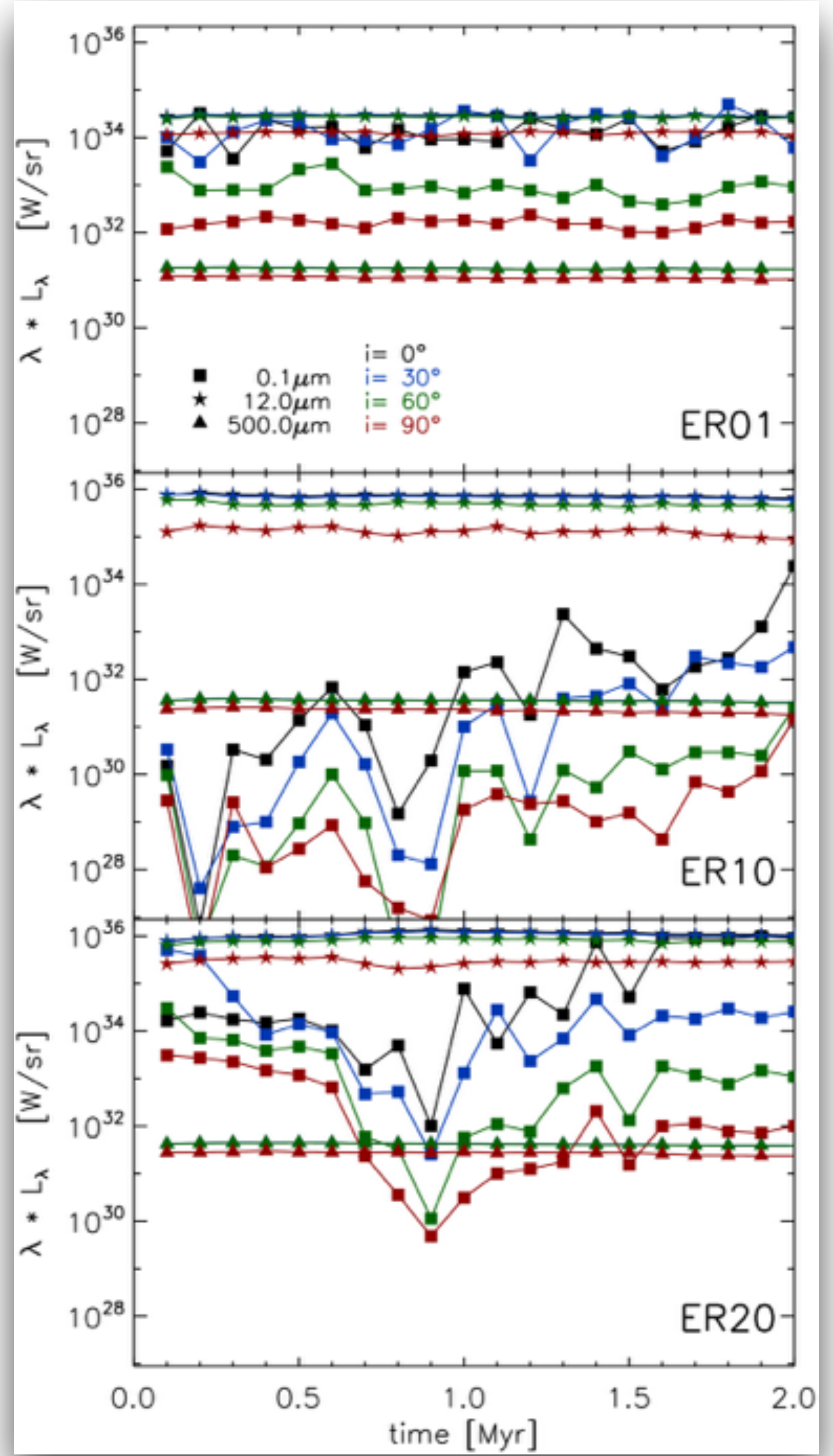
missing clumpiness in central region?

Seyfert Light Curves

- 500 micron (triangles): cold, dense disk, optically thin, in quasi-steady state

  → no time evolution

- at shorter wavelengths, the curves for the inclination angles split up
- the strongest evolution visible for 0.1 micron (max of opacity): scattering plus primary
  - ER01: constant (low density lifted dust)
  - ER10: rising trend, decreasing optical depth in cone (no steady state)
  - ER20: episode of strong and dense outflows



Summary

- X-ray heating plus radiation pressure on dust able to maintain geometrical thickness by invoking a "fountain" process (Wada 2012)
- dust continuum radiative transfer calculations to connect to available and future observations
- best agreement with observations is found for models which show a three-component obscuring structure: a dense disk and a puffed-up structure in combination with a tenuous outflow component
- strong morphological differences between MIR and FIR images
- might be testable with ALMA observations (work in progress)