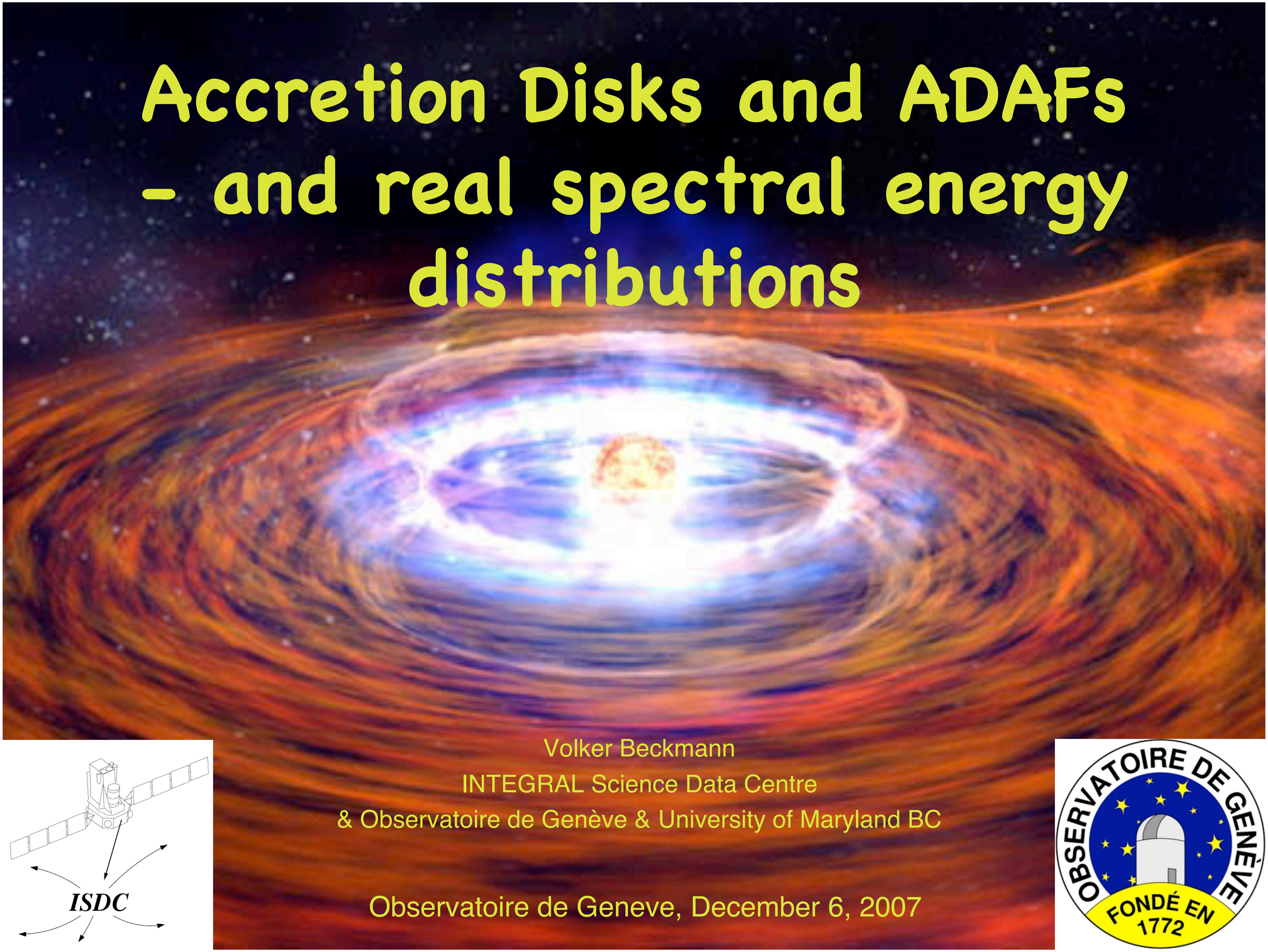
Accretion Disks and ADAFs – and real spectral energy distributions



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INTEGRAL Science Data Centre
& Observatoire de Genève & University of Maryland BC

Observatoire de Geneve, December 6, 2007

ISDC

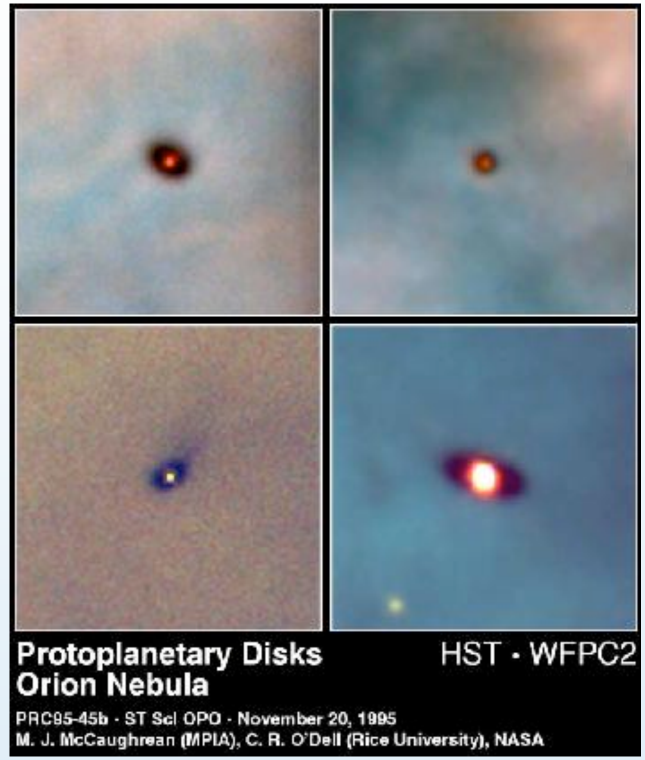
OBSERVATOIRE DE GENÈVE FONDÉ EN 1772

Overview

- Spherically symmetric accretion
- Accretion disks
- Advection Dominated Accretion Flow
- Sgr A* - the super-massive black hole in the center of our Galaxy
- Real spectral energy distributions and spectra

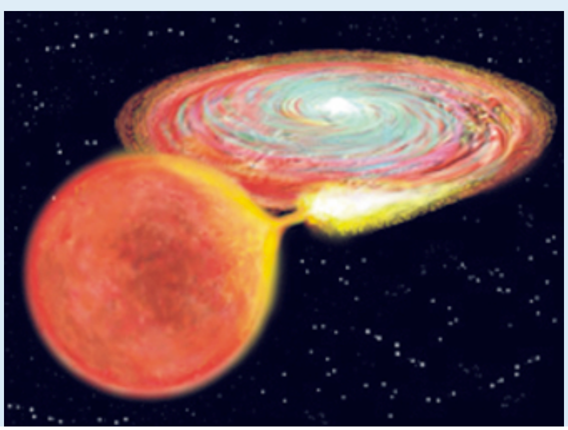
… please ask questions!
… please don't expect all answers!

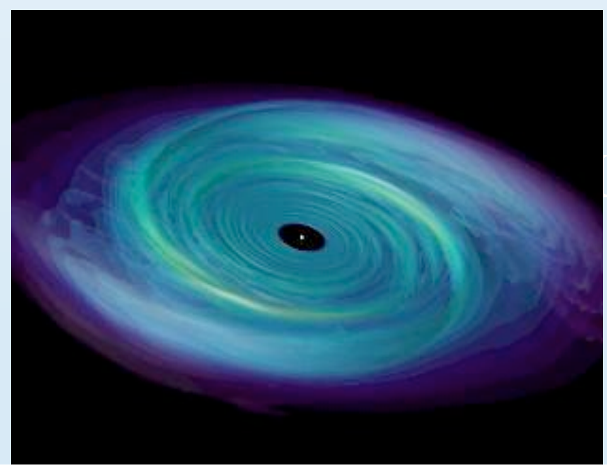
Spherically symmetric accretion



- Where do we observe accretion?

- Star formation
- Close binary systems
- AGN
- Mostly not spherically symmetric!





Spherically symmetric accretion

JWST (2013)

- Our starting point:

CONX

$$\frac{1}{2}\left(1-\frac{c_s^2}{v^2}\right)\frac{d(v^2)}{dr} = -\frac{GM}{r^2}\left(1-\frac{2c_s^2 r}{GM}\right)$$

- Sound speed:

$$c_s = \sqrt{\frac{dP}{d\rho}}$$

M

LISA

Spherically symmetric accretion

$$\frac{1}{2}\left(1-\frac{c_{\mathrm{s}}^{2}}{v^{2}}\right)\frac{d(v^{2})}{dr}=-\frac{GM}{r^{2}}\left(1-\frac{2c_{s}^{2}r}{GM}\right)$$

JWST (2013)

CONX

- Mass accretion rate:

$$\frac{dM}{dt}=4\pi r_{s}^{2}\rho(r_{s})c_{s}(r_{s})$$
$$\simeq 1.4\times 10^{11}\left(\frac{M}{M_{\odot}}\right)\frac{\rho(\infty)}{10^{-24}}\left(\frac{c_{s}(\infty)}{10\,\mathrm{km\,s^{-1}}}\right)^{-3}\,\mathrm{g\,s^{-1}}$$

ADAFs

- Assume that all gravitational energy is fully radiated:

$$L_{Edd} = \eta \dot{M}_{Edd} c^2$$

- With efficiency ~0.1 this gives:

$$L_{Edd} \simeq 1.3 \times 10^{38} \left(\frac{M}{M_\odot}\right) \left[\frac{erg}{sec}\right]$$

- So the maximum mass accretion rate would be:

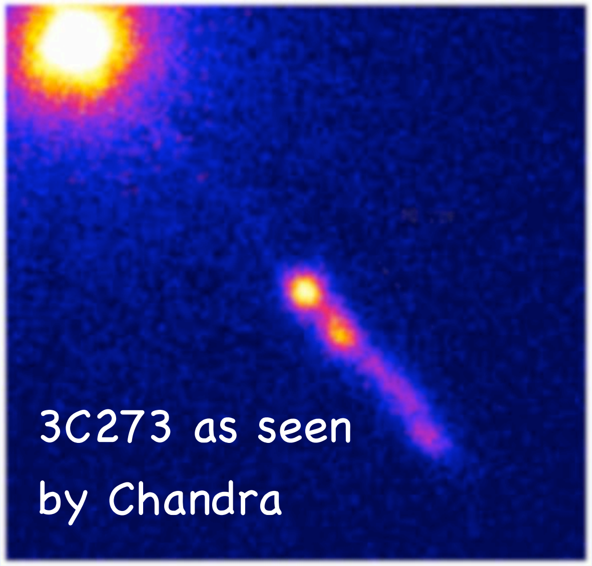
$$\frac{dM}{dt} \simeq 1.3 \times 10^{-8} \left(\frac{M}{M_\odot}\right) \left[\frac{M_\odot}{yr}\right]$$

JWST (2013)

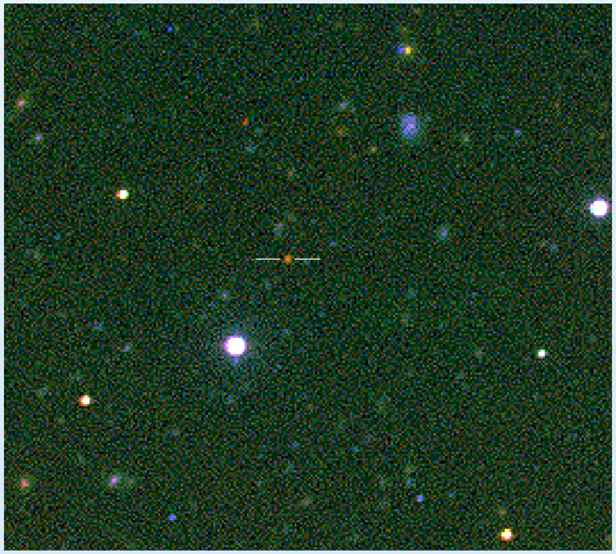
CONX

ADAFs

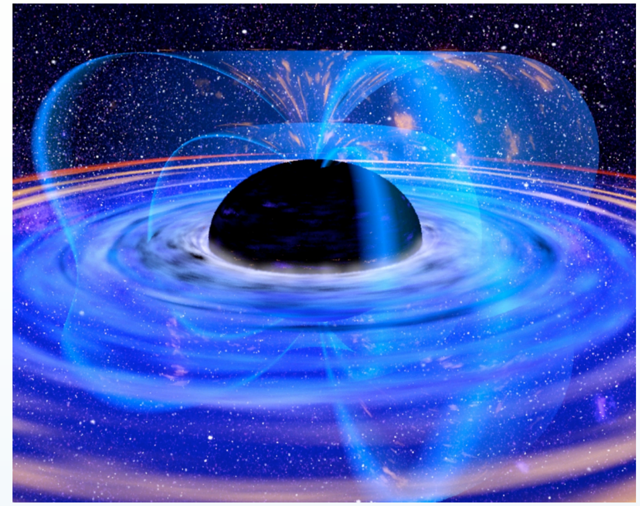
- For a super massive black hole (like 3C 273) with 10^9 $M_\odot$ this makes 10 $M_\odot$/yr
- Any problem with that?



Highest redshift quasars are at z~6.5
That's about 0.9 Gyr after the Big Bang



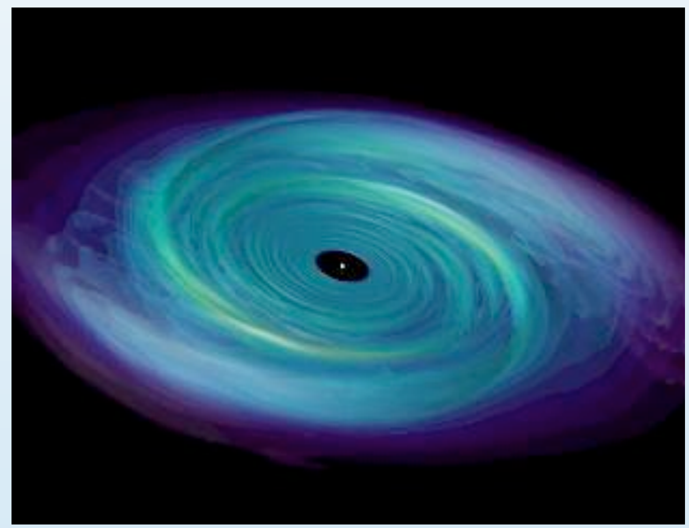
Optically thin ADAFs



Graphic: ESA/J. Wilms

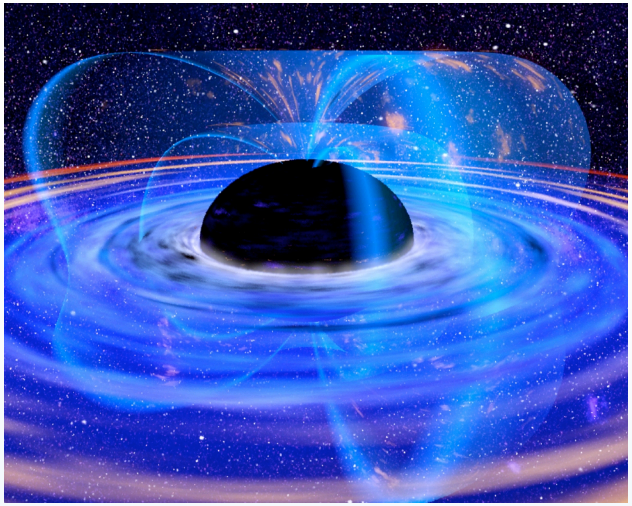
- Basic idea: do not radiate away the energy
- Kept with the ions
- Advected toward the central object -- and might fall (disappear!) in the black hole
- Why lost? What is the effect for the appearance of an ADAF disk?

A black hole has only mass, charge, and angular momentum.
Luminosity of ADAF is very low.
So, if you have a sub-luminous object, an ADAF might explain this.



Graphic: Owen/Blondin (NCSU)

Optically thin ADAFs



Graphic: ESA/J. Wilms

Consider a plasma:

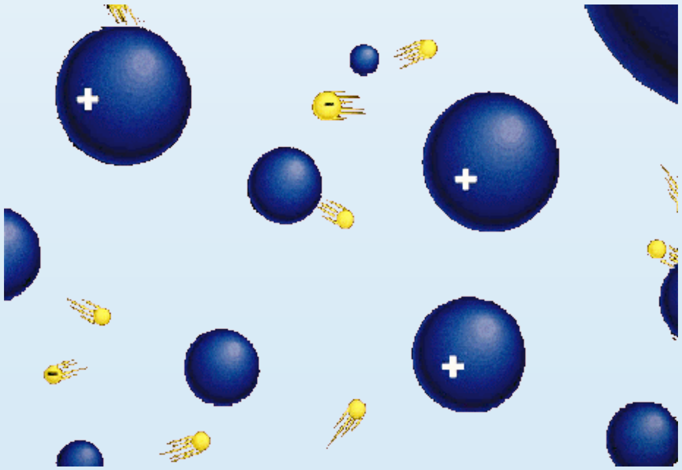
Density $\rho(R)$, temperature $T(R)$,

radial velocity $v(R)$

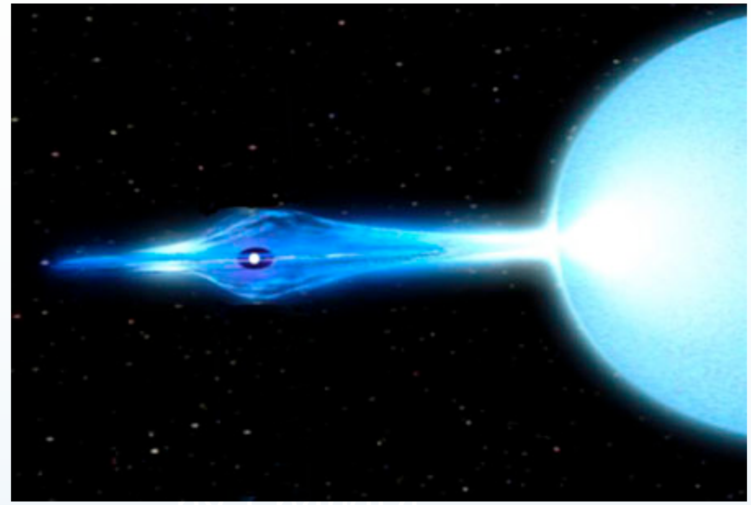
Surface element $d\sigma$

What is the energy transfer through the surface element?

Standard model: all energy gained through viscosity is radiated.
ADAF disk: temperature of the plasma increases, I.e. $Q^+ >> Q^-$

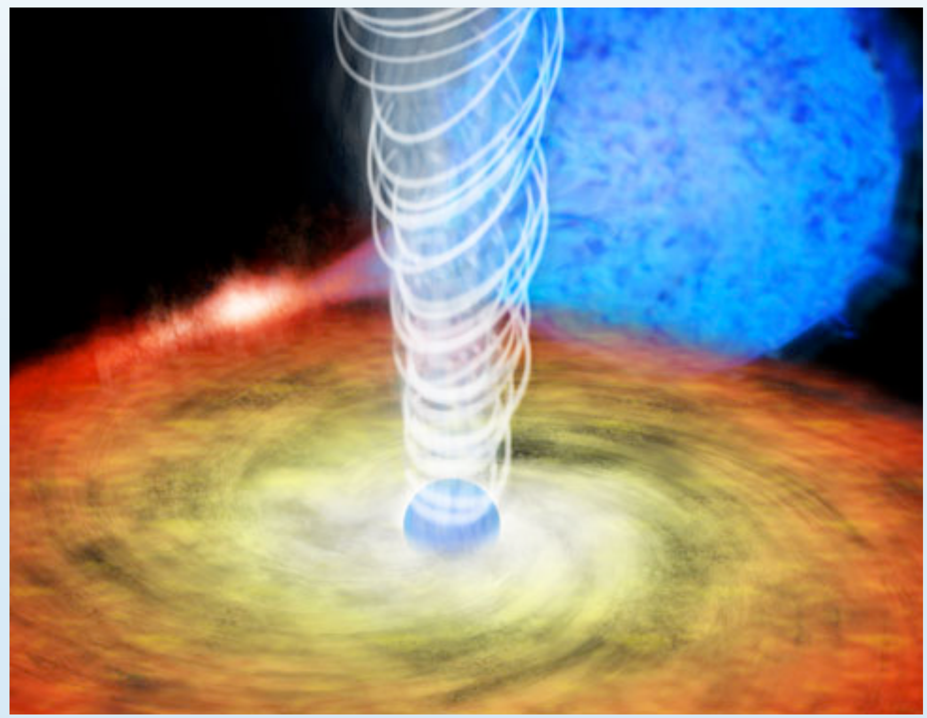


Properties of ADAFs



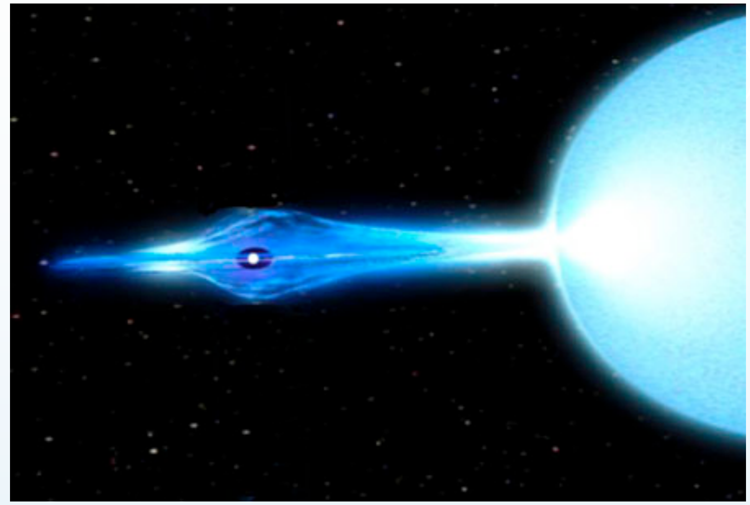
by Chandra

- ADAFs exist below a critical mass accretion rate
- An ADAF is not a disk
- $\rho \sim R^{-3/2}$
- What happens if too much heat is stocked in the ions of the plasma?



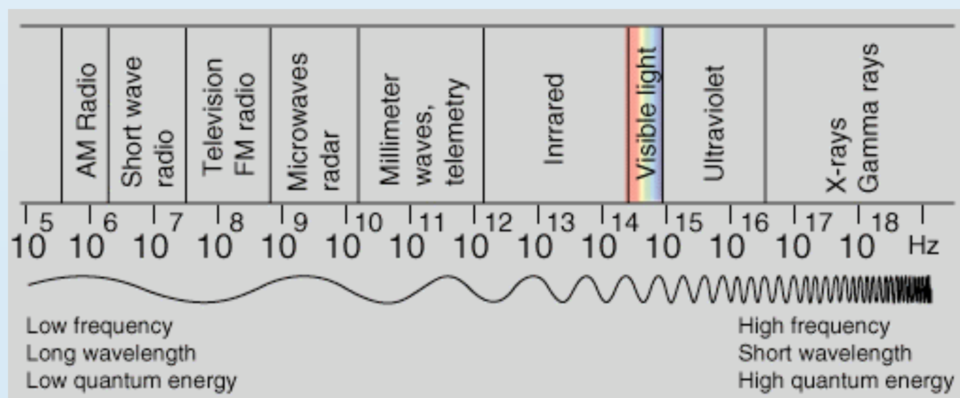
Strong outflow, producing huge jets

Spectrum of ADAFs

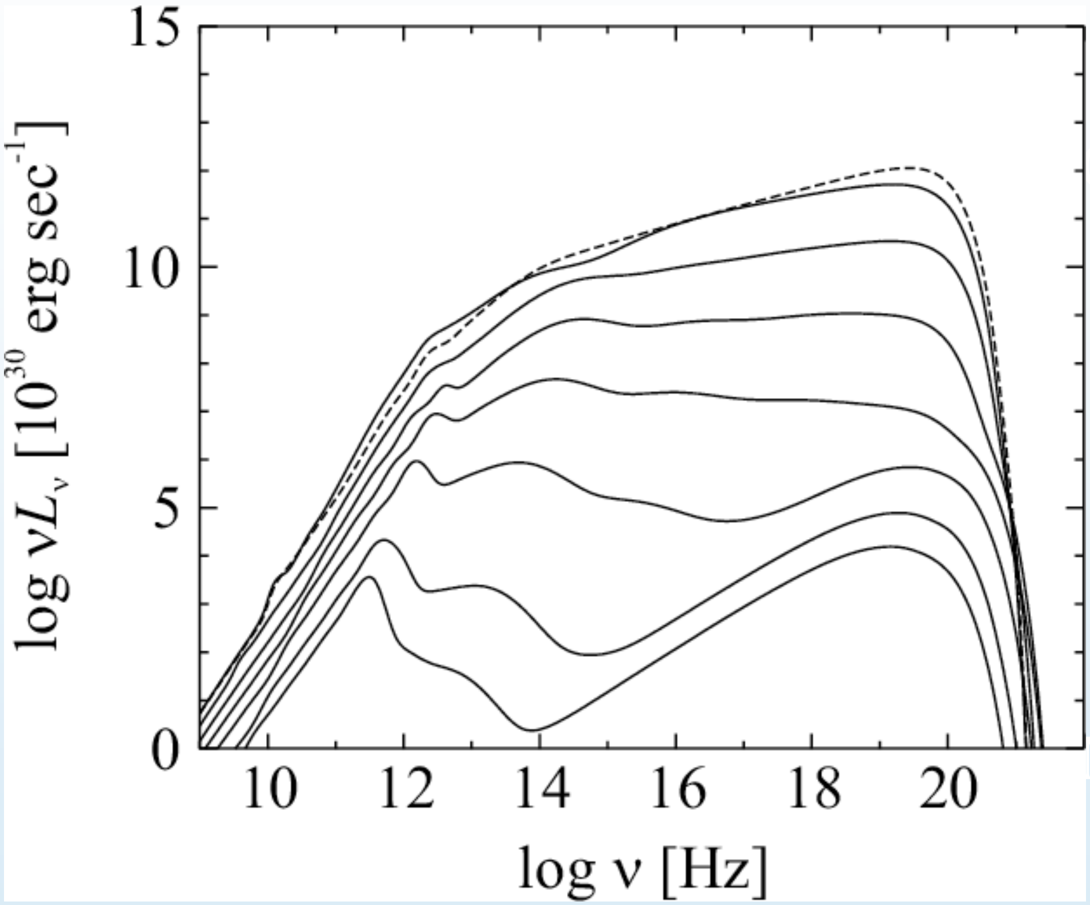


- No direct observation so far
- Radio-IR: synchrotron from different parts of the plasma
- Optical-UV: inverse Compton (synchrotron photons off hot electrons)
- X-rays: bremsstrahlung
- proton-proton collision produces π^0, decays should produce gamma-ray photons
- Thermal emission from electrons and ions

The spectrum of the ADAF is not well-defined



Spectral energy distribution of an ADAF for a small SMBH

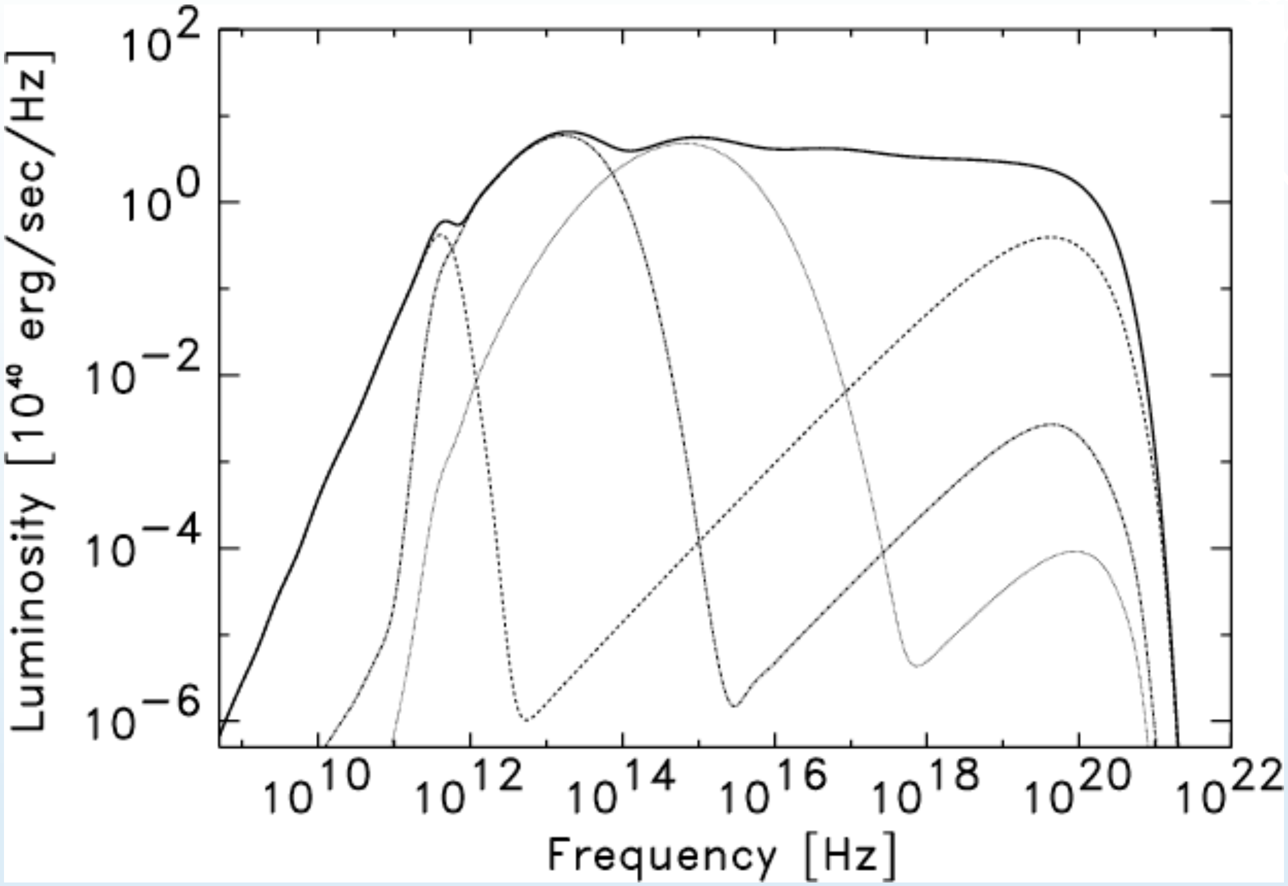


2.6 x 10^6 M_o black hole

dm/dt = 10^{-6}, 2 10^{-6}, 5 10^{-6}, 10^{-5} … 1.27 10^{-4} $M_\odot$/year

Beckert & Duschl 2002, A&A, 387, 422

Spectral energy distribution of an ADAF



10^9 M_o super massive black hole

dm/dt = 3.6 10^{-4}, photon flux, 1st, 2nd Compton

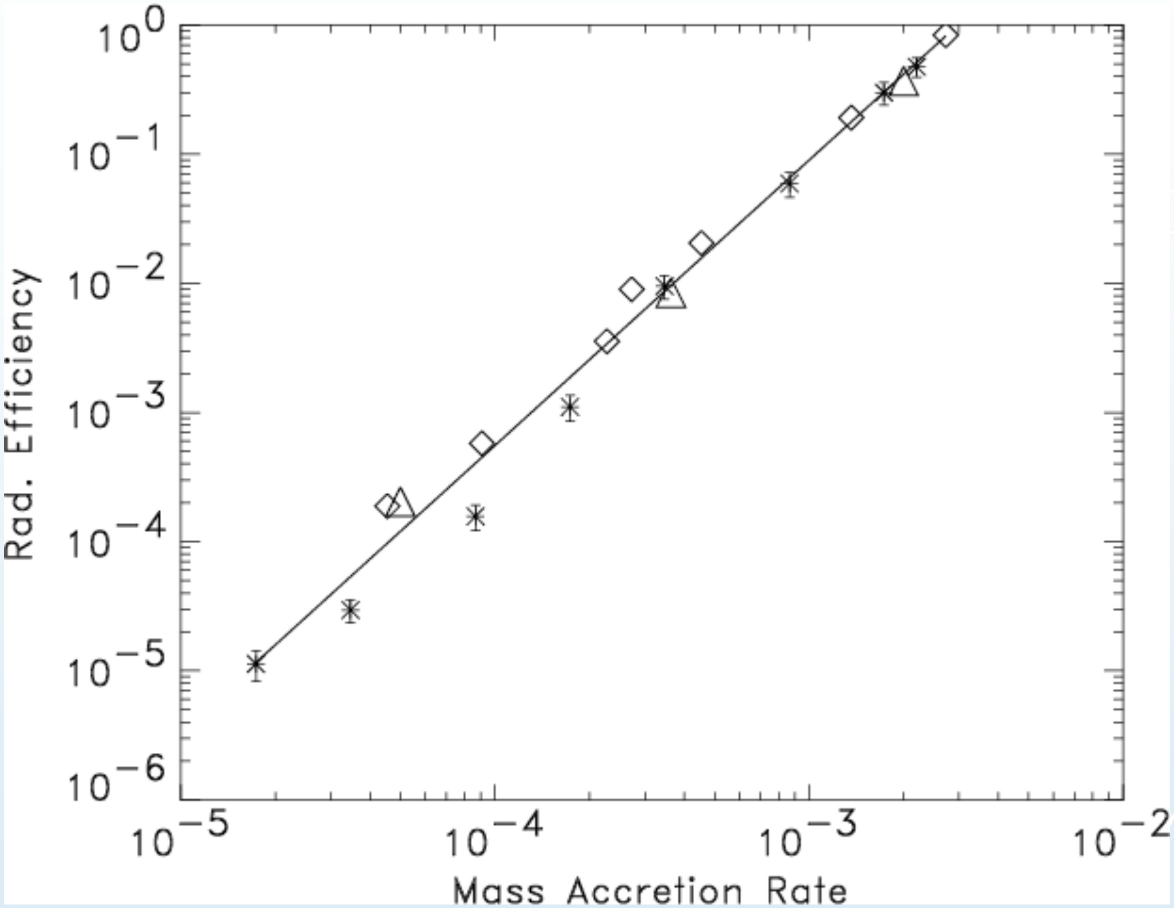
Beckert & Duschl 2002, A&A, 387, 422

Comparison of ADAFs

- Position of synchrotron peak anticorrelated with M_{BH}
- Synchrotron seed photons produced closer to the BH than Compton scattering -> anisotropic
- Most synchrotron photons scattered back into high density region -> 2nd peak stronger than first one.
- Bremsstrahlung only visible below

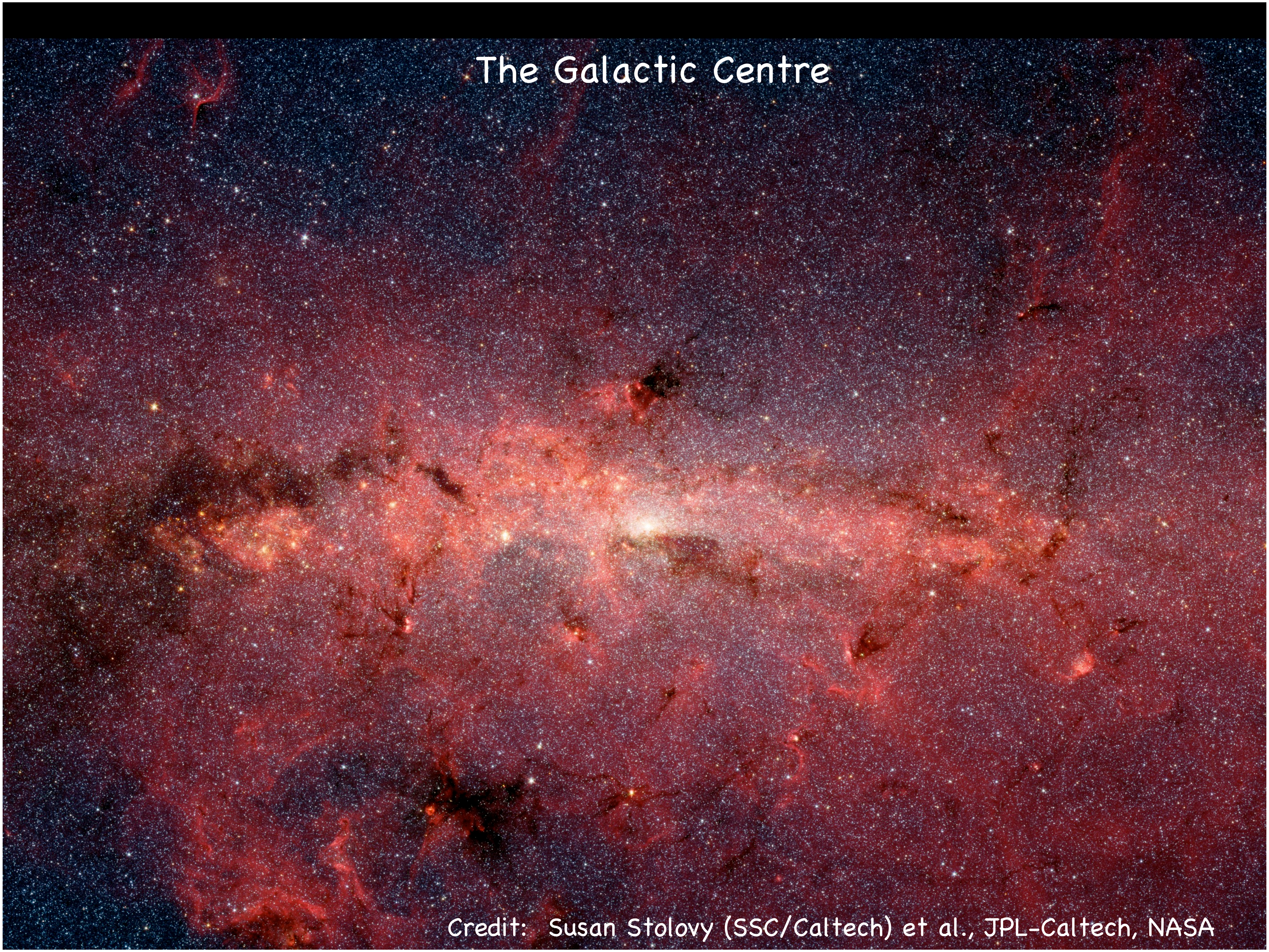
  $dm/dt < 1.5 \times 10^{-4} M_{\odot}$

Spectral energy distribution of an ADAF disk

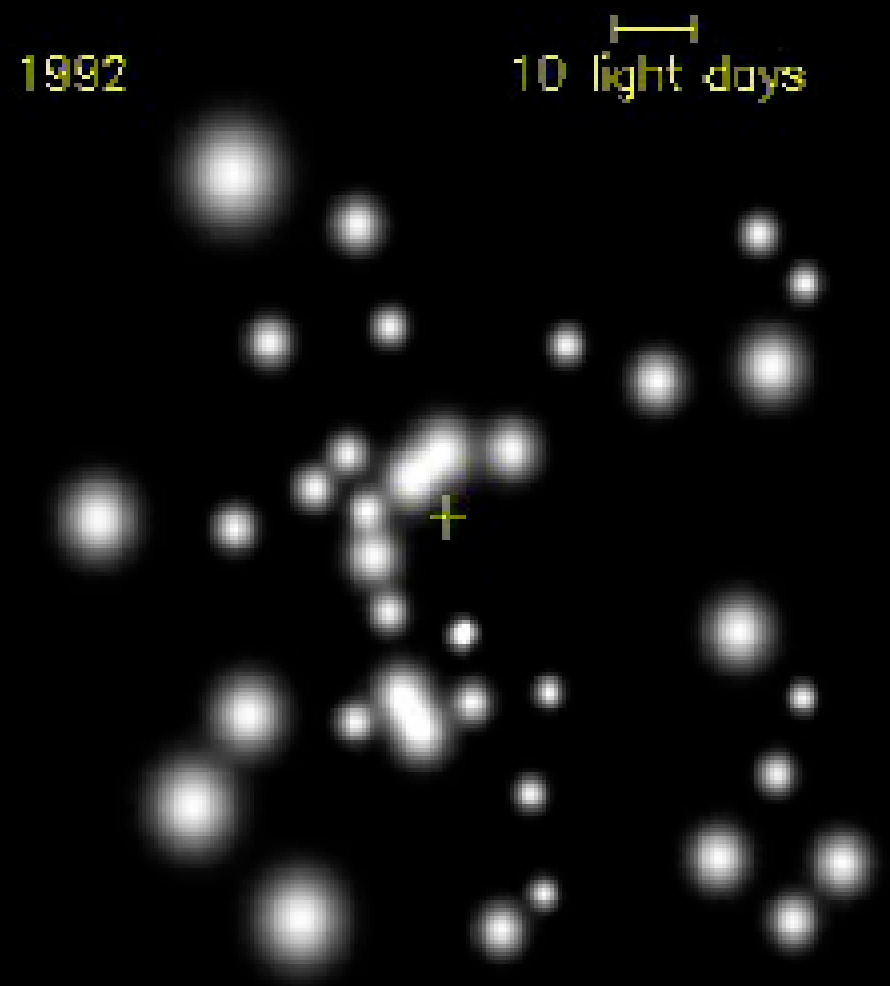


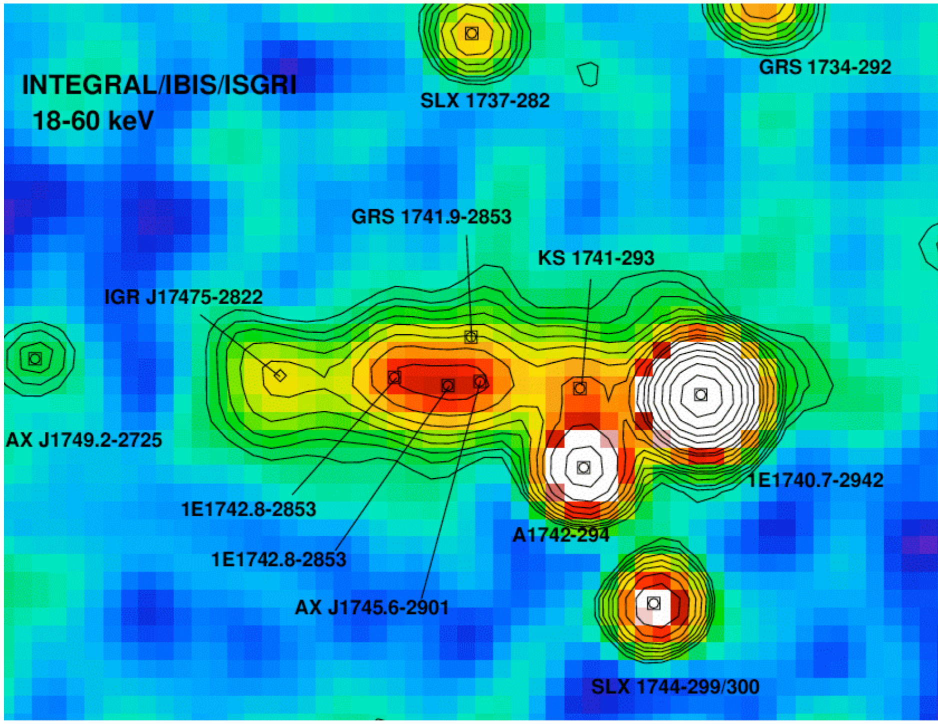
Radiation efficiency ε depends on accretion rate (and not on the mass of the black hole).

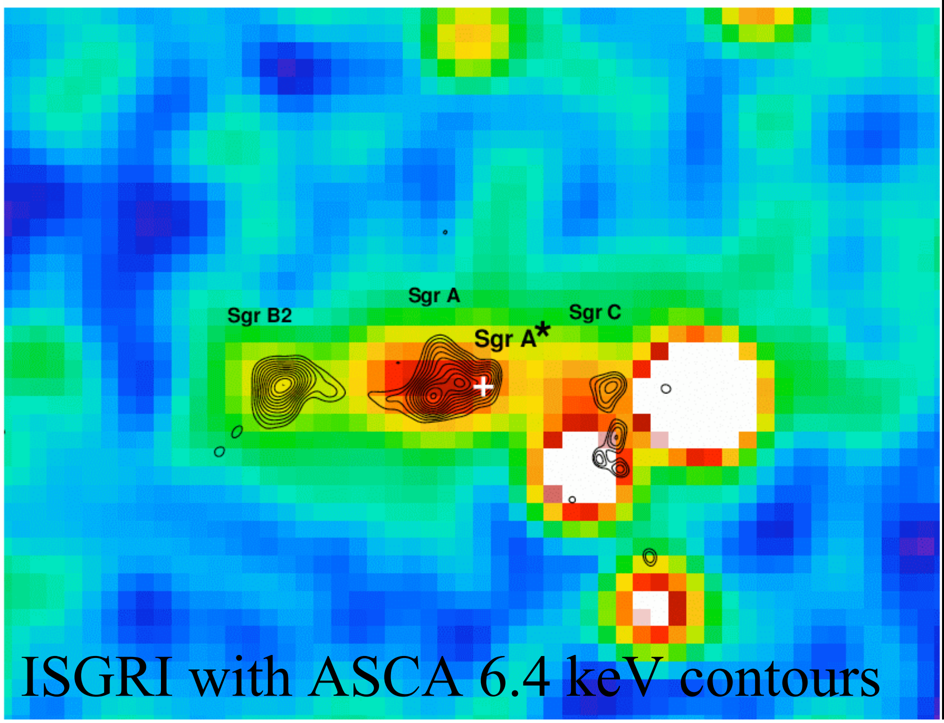
Beckert & Duschl 2002, A&A, 387, 422


The Galactic Centre
Credit: Susan Stolovy (SSC/Caltech) et al., JPL-Caltech, NASA

The massive object in the Galactic Centre



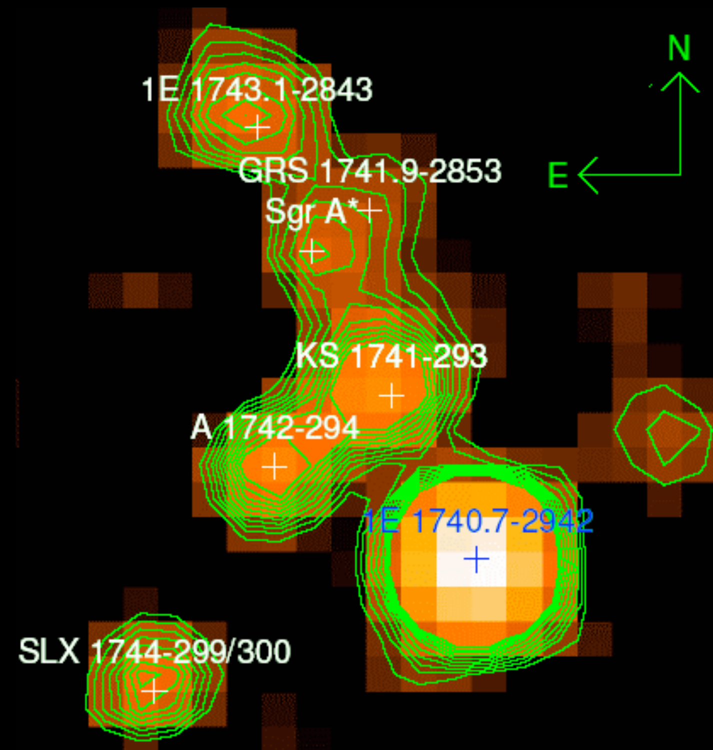




A giant molecular cloud functioning as a “Compton mirror” of Sgr A*

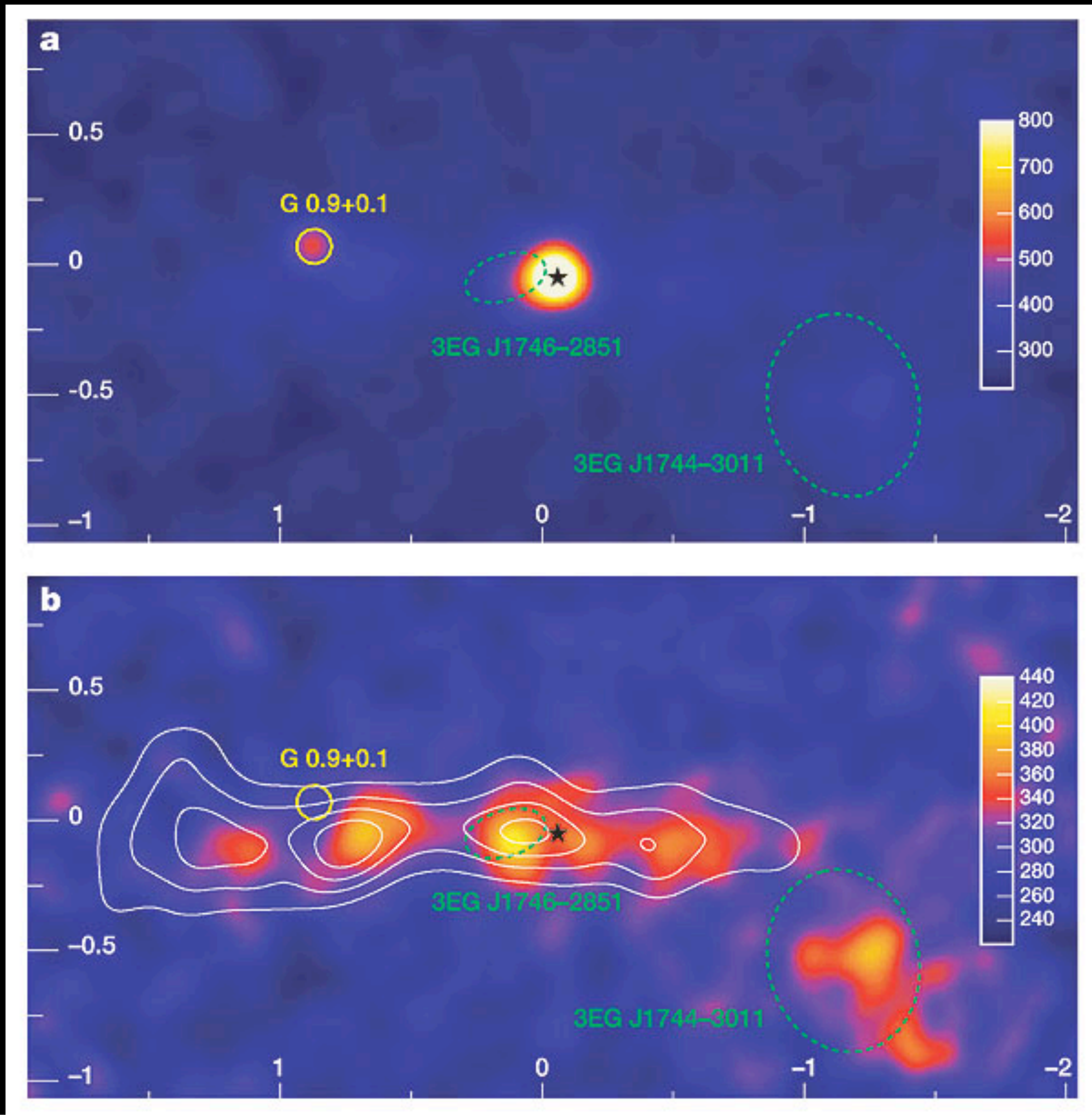
The SMBH is faint but persistent at >20 keV

Revnivtsev et al. 2004



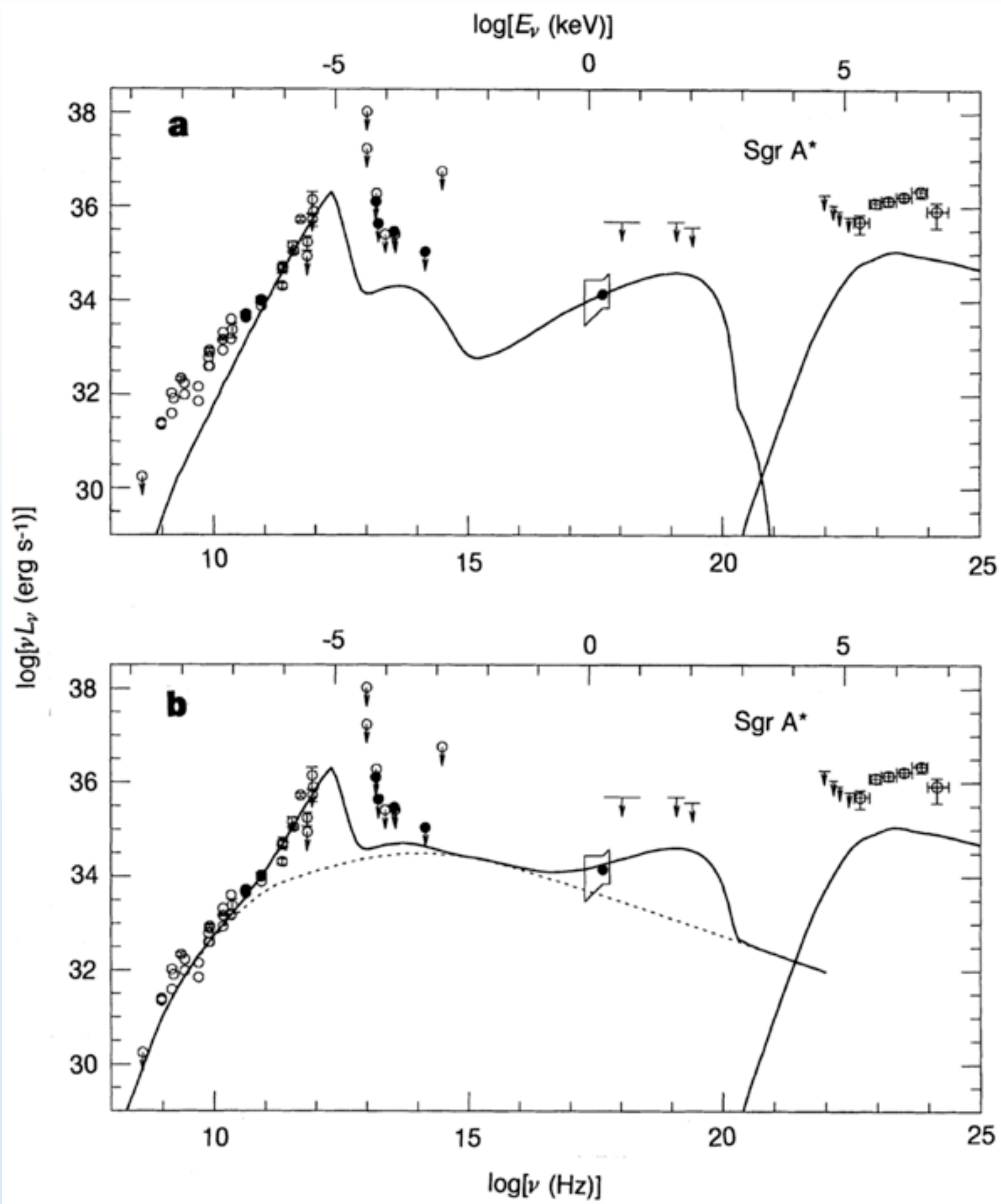
Belanger et al. 2004, 2006

Sgr A* is also a TeV emitter - is this the predicted π^0 decay?



Aharonian et al. 2006

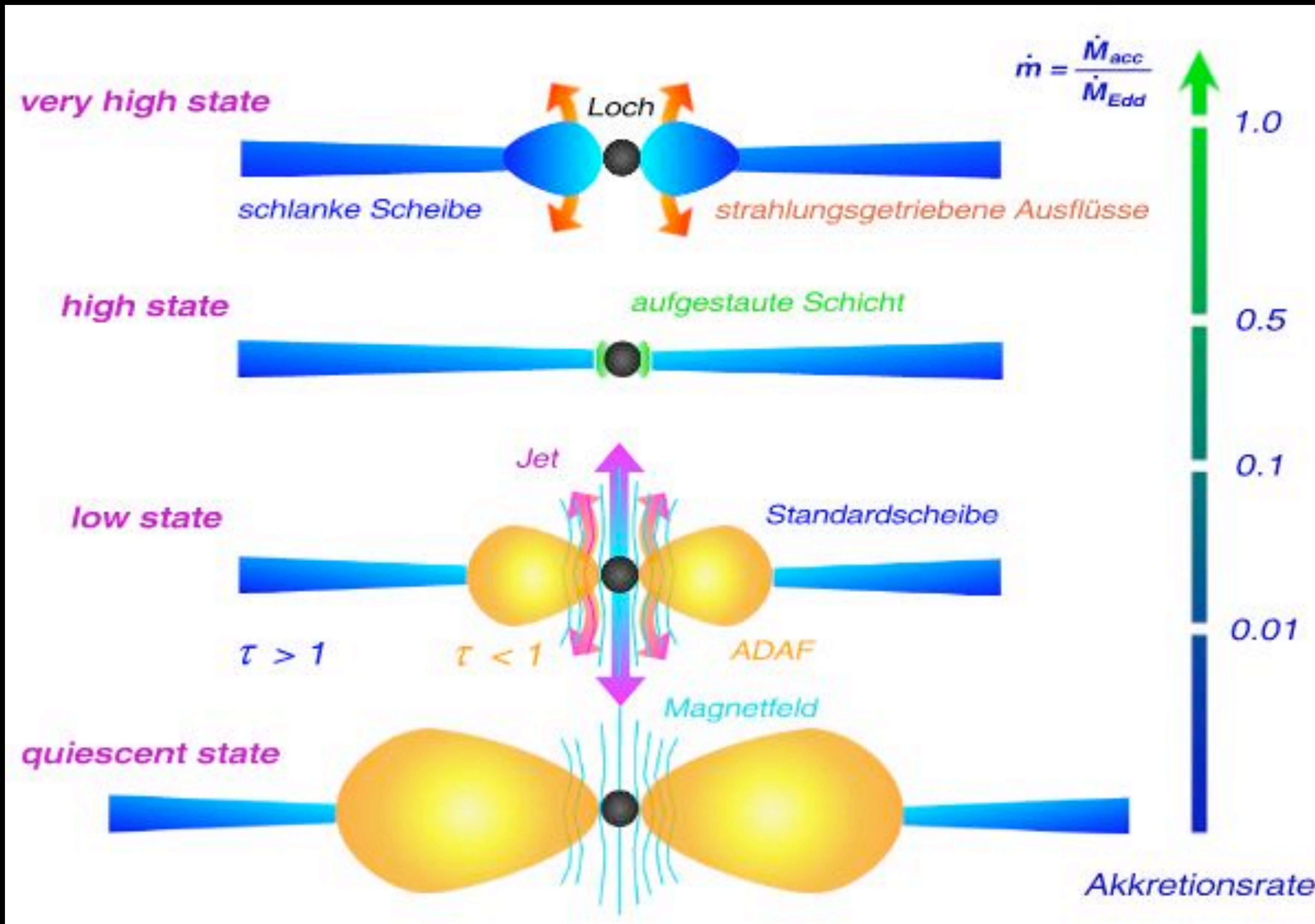
ADAF model for the Galactic Centre



ADAF model (dotted line is synchrotron emission of electrons and positrons).

Mahadevan 1998, Nature 394, 651

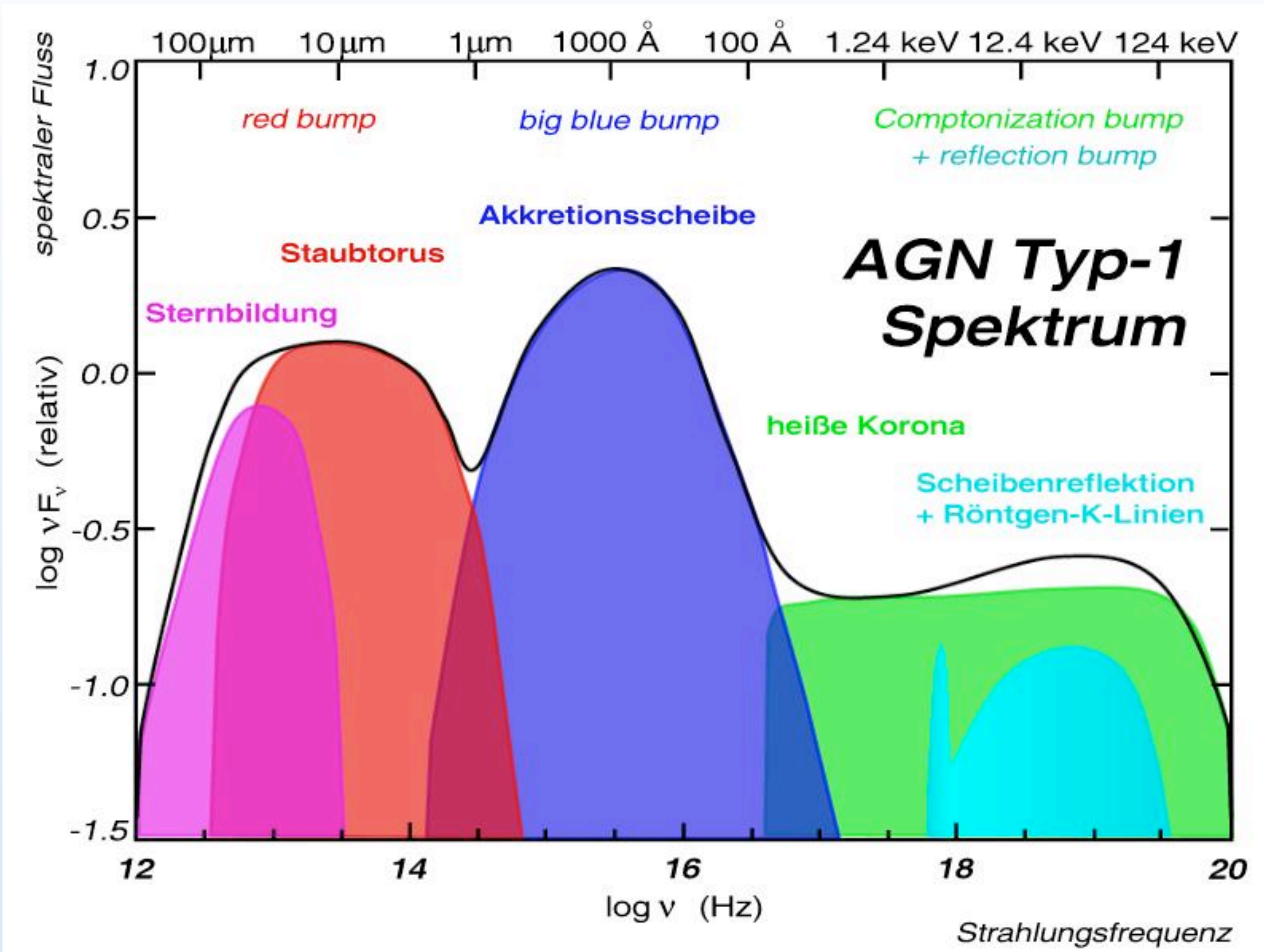
Unification of accretion processes



- ADAF is not the perfect model
- might describe some aspects of accretion (I.e. the advection part of it)
- low accretion rate, near quiescent state
- note: the observed spectrum is always a mix

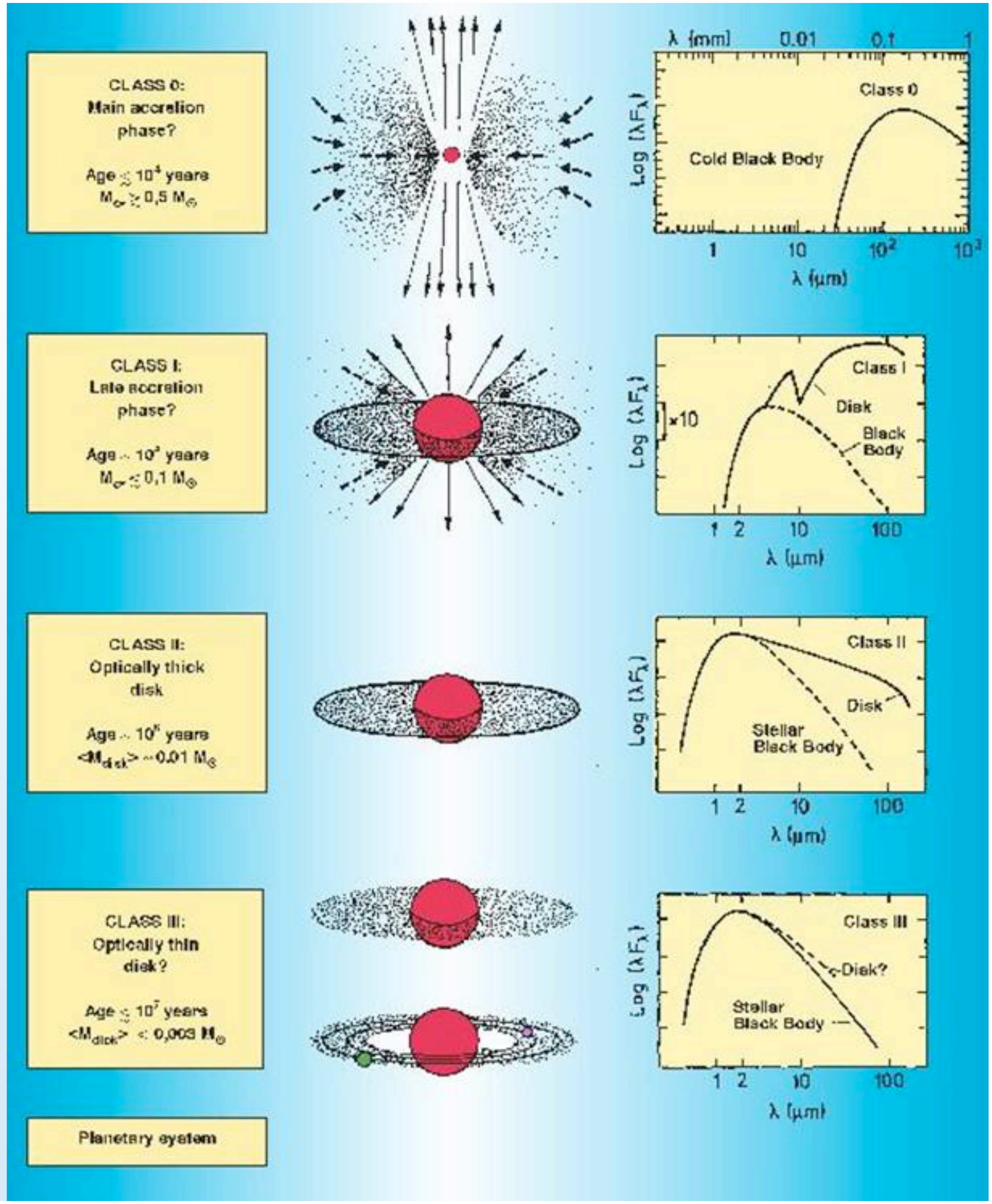
The real spectrum

• note: the observed spectrum is always a mix of several components

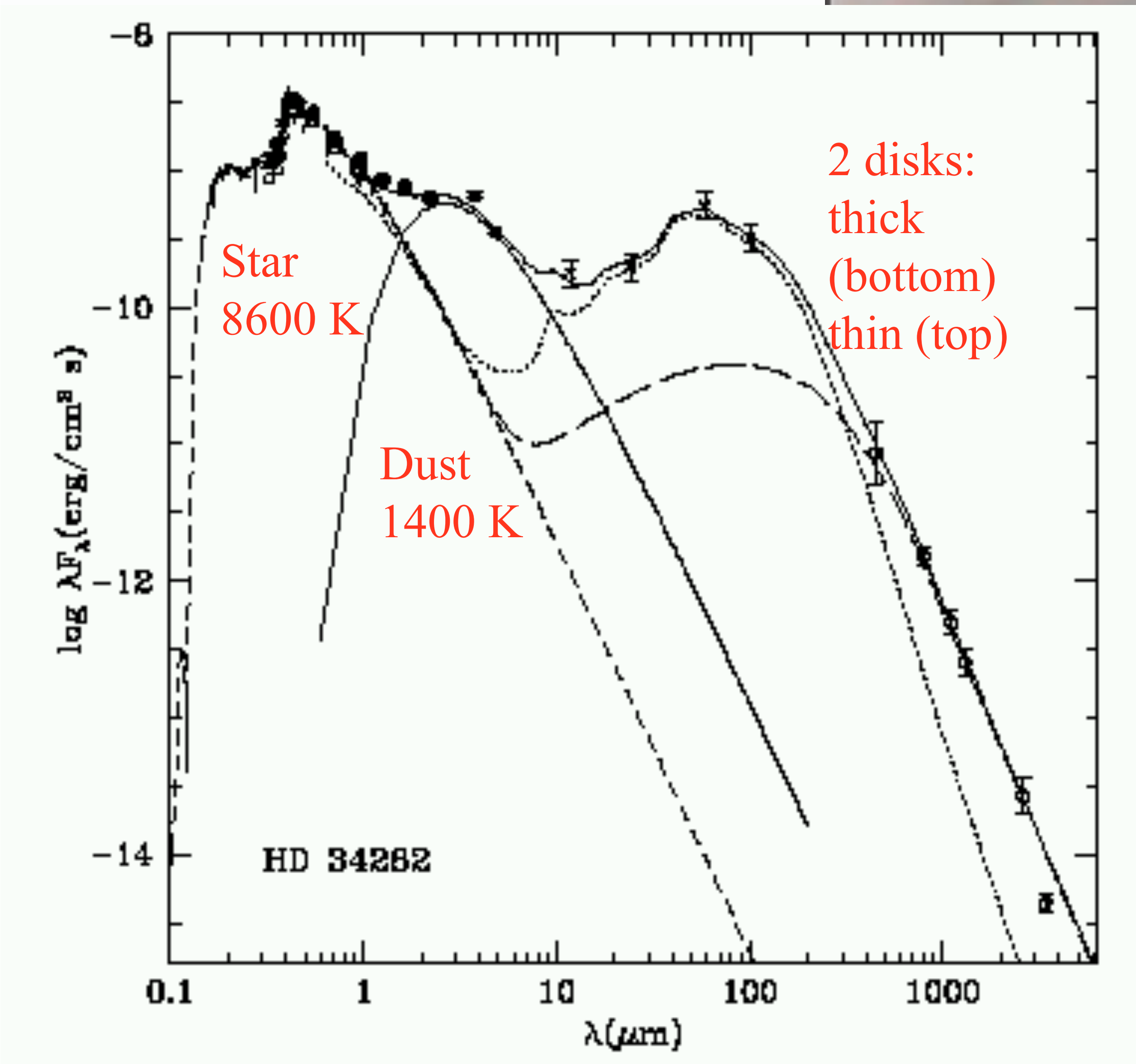


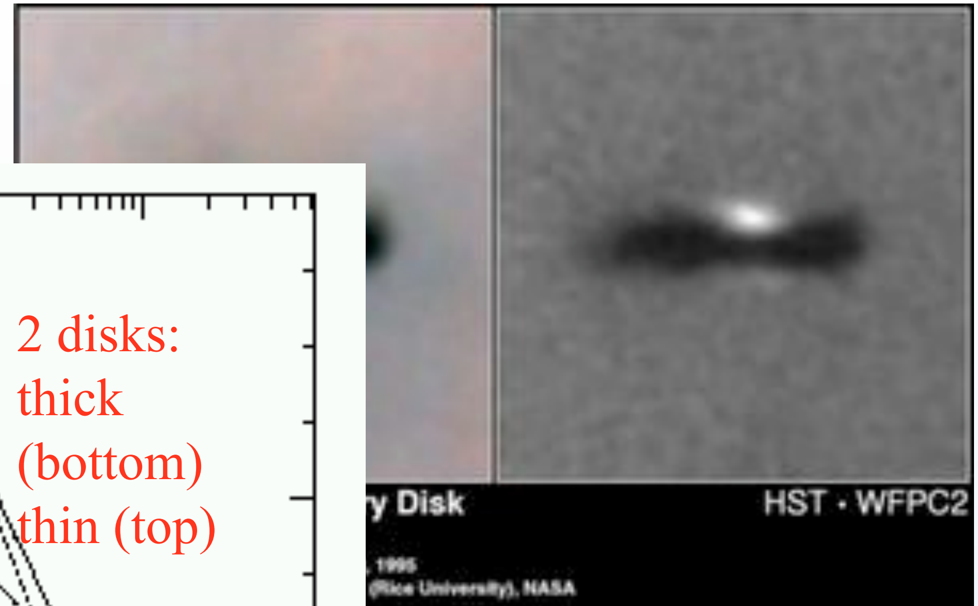
The real spectrum

Model SEDs of protoplanetary disks. From dust- to disk- to star-dominated emission.



The real spectrum





SED of protoplanetary disk (Merin et al. 2004, A&A, 419, 301)