Accretion onto black holes
- evaporation and condensation

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X-ray binaries

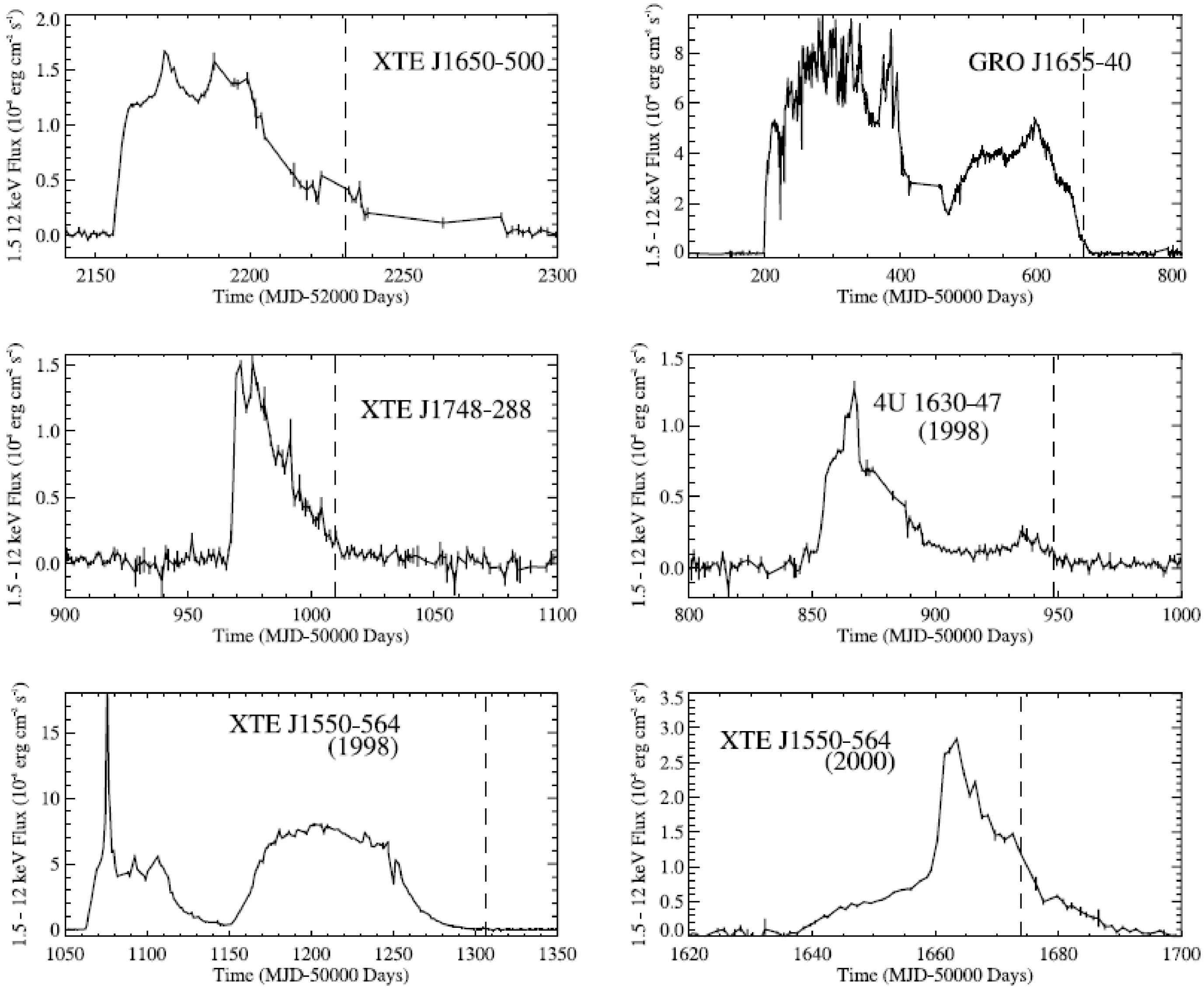
neutron star binaries
black hole binaries (HMXB or LMXB, different companion star)

- outburst lightcurves
- spectral state - accretion mode
- HID hardness-intensity diagram for outburst cycle:

  hard state - intermediate - soft - (very high state) - soft - intermediate - hard state
  jets & radio emission,
  disk inner radius
  time variability of the flux, quasi-periodic oscillations QPO

examples of outburst light curves (RXTE ASM data, 1.5-12 keV)

Kalemci et al. 2004



cause for the outburst cycles:

dwarf-nova instability of the accretion disk
= ionisation instability

the accretion disk structure depends on
the mass flow rate through the disk
and the viscosity (due to the radial shear of the Keplerian motion)
--
vertical structure at each distance from the compact object provides surface density (mass in a column per cm^2)

the surface density is higher for lower viscosity (less transport of angular momentum in the disk)
--

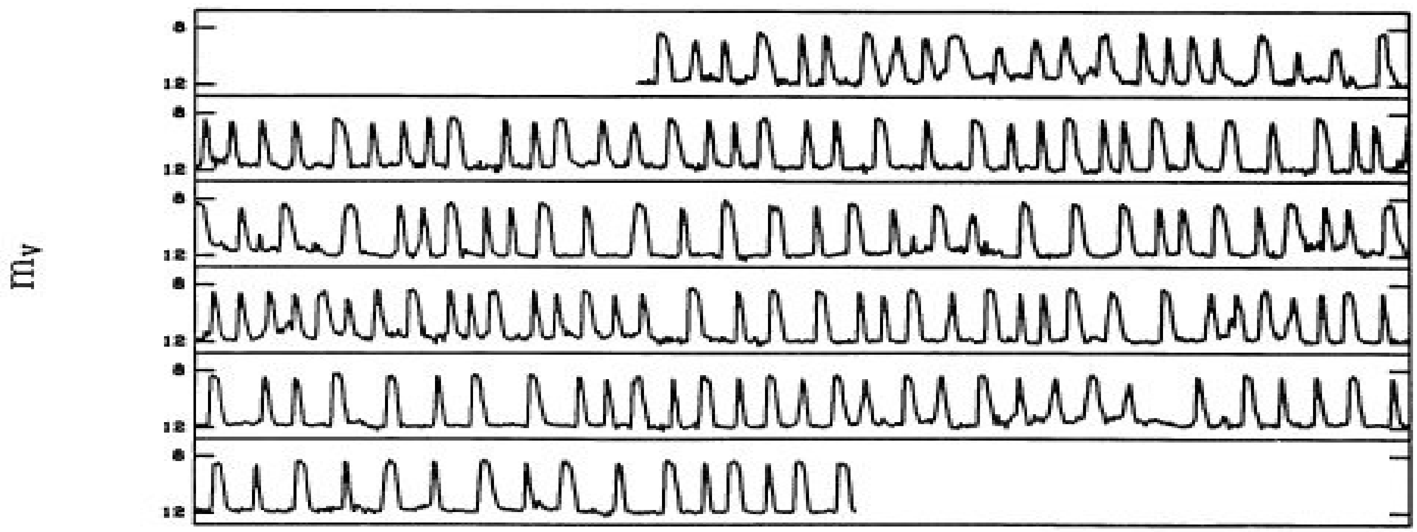
>>>>> the same surface density at a certain distance can be present for
>>>>> either a low mass flow rate (cool , unionized disk)
>>>>> or a high mass flow rate (hot, ionized disk)

disk instability

understood first for dwarf novae (close binaries with mass accreting from a low mass companion star onto a white dwarf) (Meyer & Meyer-Hofmeister 1984)

present in all disks around stars whereever the temperature allows an ionized and an unionized structure;

around white dwarfs, neutron stars, black holes and supermassive black holes



AAVSO LIGHT CURVE OF SS CYGNI (1963–1985)

------------- many investigations by different authors in different binaries:

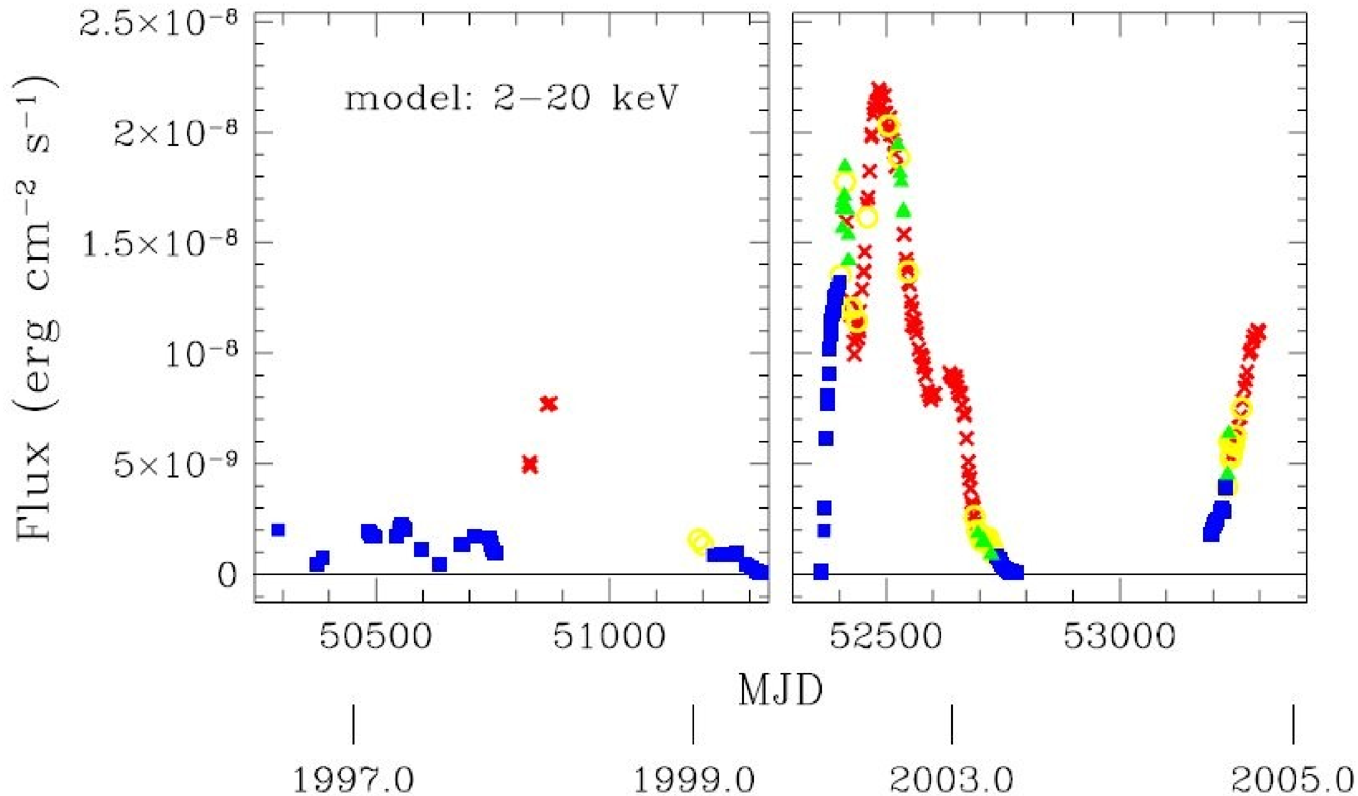
different disk size
different myass accretion rate
effect of irradiation in neutron stars
effect of magnetic fields (no disk close to the compact object as in magnetic white dwarfs)
--- surface temperature

$$T_{eff} = \left(M \dot{M} r^{-3} \right)^{1/4}$$

in disks around supermassive black holes

soft - intermediate - hard spectra of LMXBs

GX 339-4 (Remillard 2005)



2 modes of accretion possible in the inner region:

via an accretion disk (geometrically thin, optically thick)

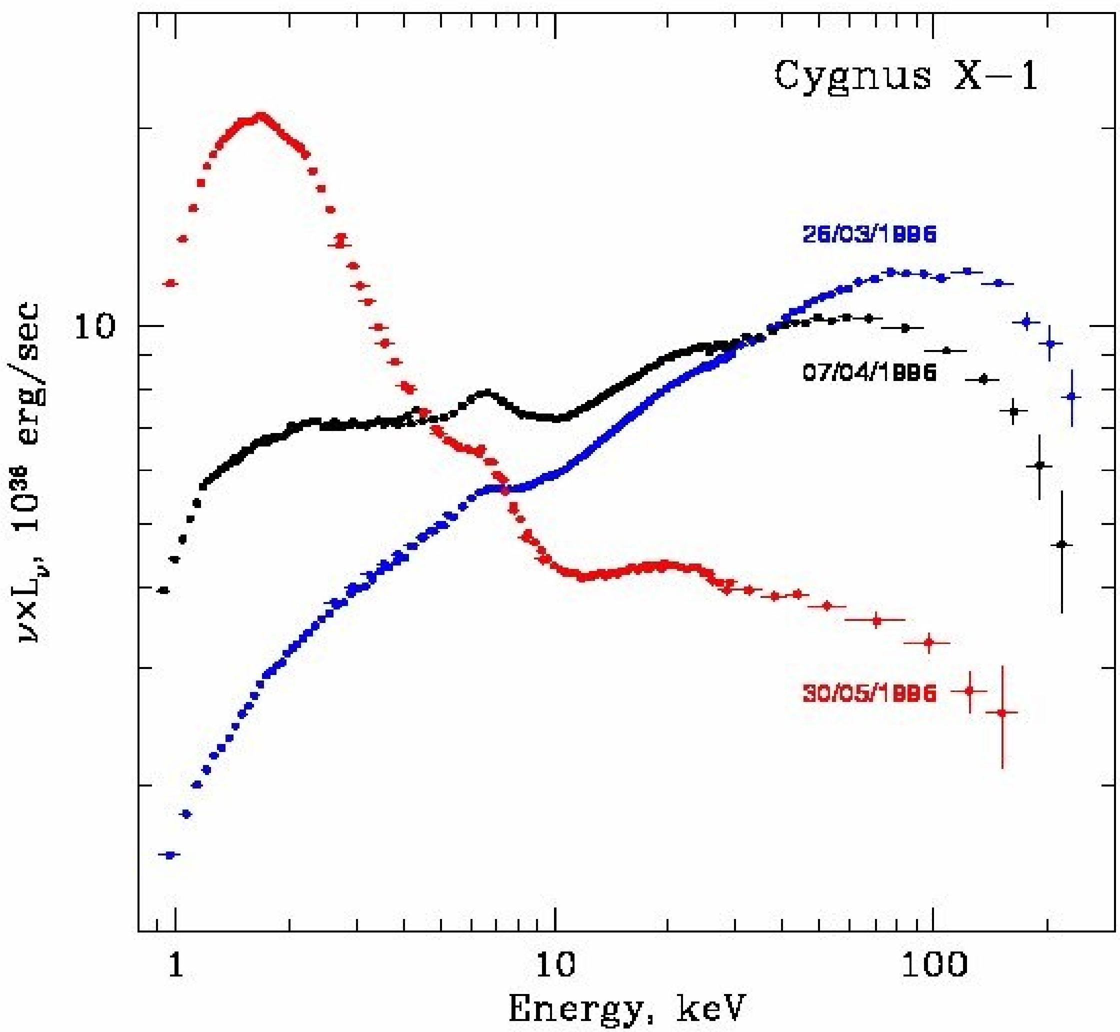
via a hot flow (more spherically extended, optically thin)

= ADAF = advection-dominated accretion flow

due to the nature of the very hot gas the flow cannot radiate away the energy released when the gas settles in the gravitational potential

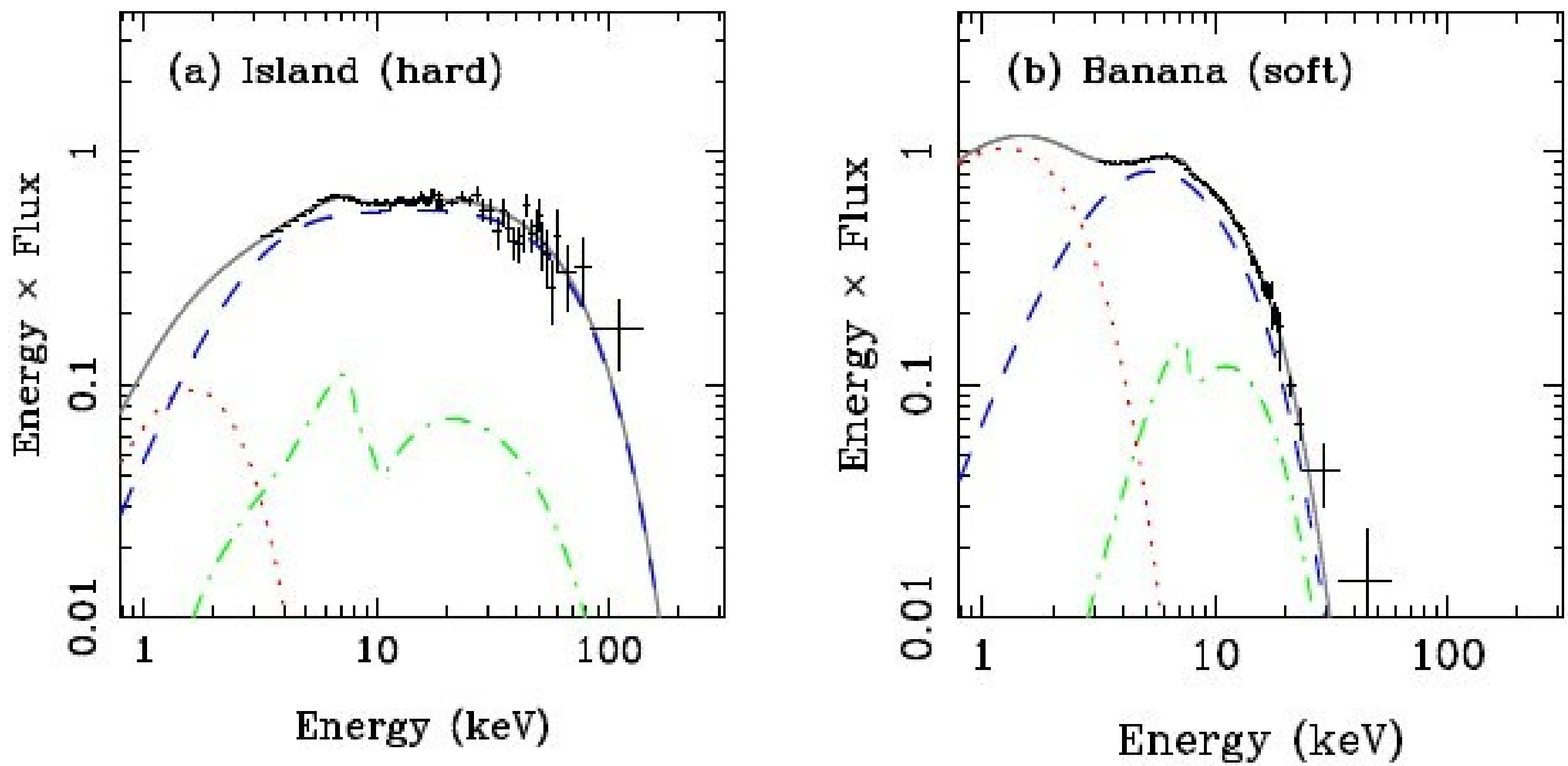
Narayan et al. 1995

(variants of the ADAF worked out later)



Cygnus X−1
26/03/1996
07/04/1996
30/05/1996
10
1
10
100
Energy, keV
$\nu \times L_\nu$, 10^{36} erg/sec

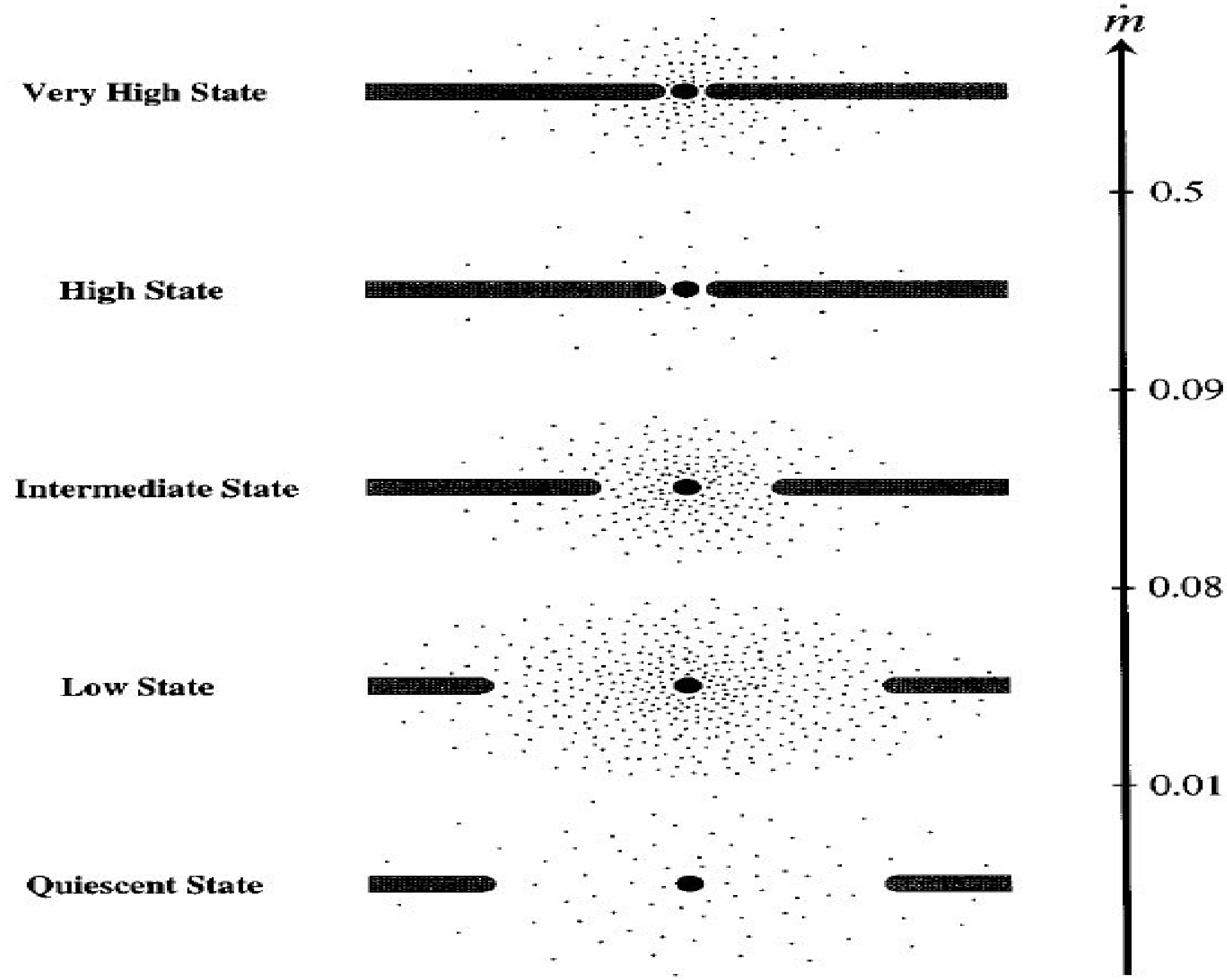
neutron star 4U 1705-44, hard and soft state



unabsorbed X-ray spectra, RXTE
best-fitting models: red : disk blackbody, blue : thermal Comptonisation, green : reflection

in outer disk regions always accretion via the thin disk
in inner regions both modes are possible, either disk accretion or an ADAF

>>>> where is the thin disk truncated ?
>>>> where is the change to the ADAF ?



Esin et al. 1997

the key question: where does **disk accretion change to an ADAF**

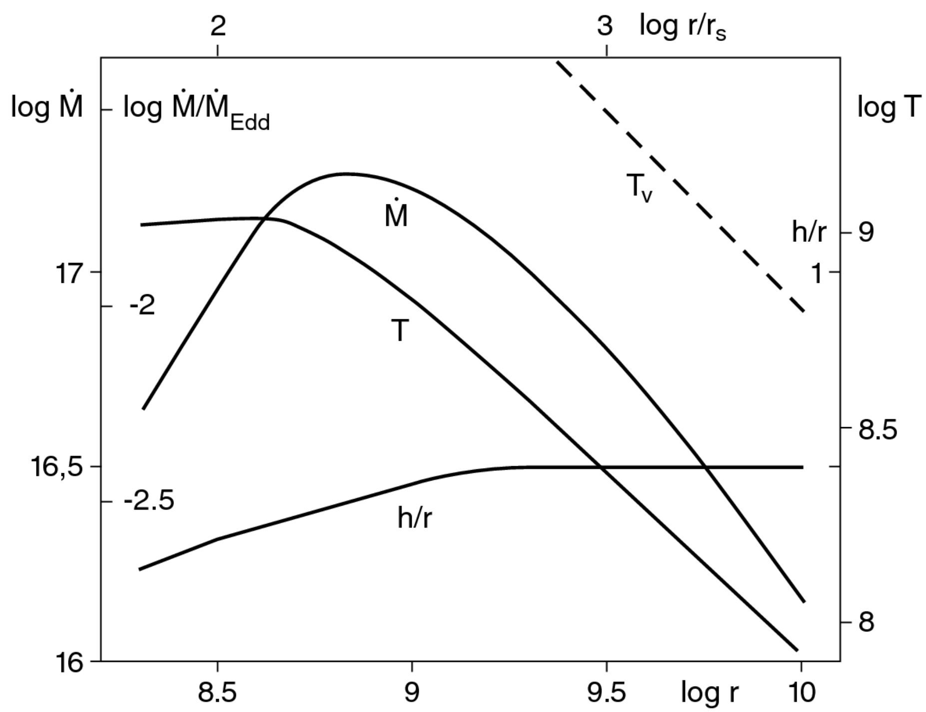
answer from
modelling the interaction of the disk matter with the gas in the corona above

physics:

An equilibrium establishes between the disk and the hot coronal flow above,
the corona is fed by matter which evaporates from the cool disk underneath.

In the inner region evaporation becomes so efficient that at low accretion rates all matter flows via the corona and procedes towards the black hole as an ADAF.

evaporation efficiency

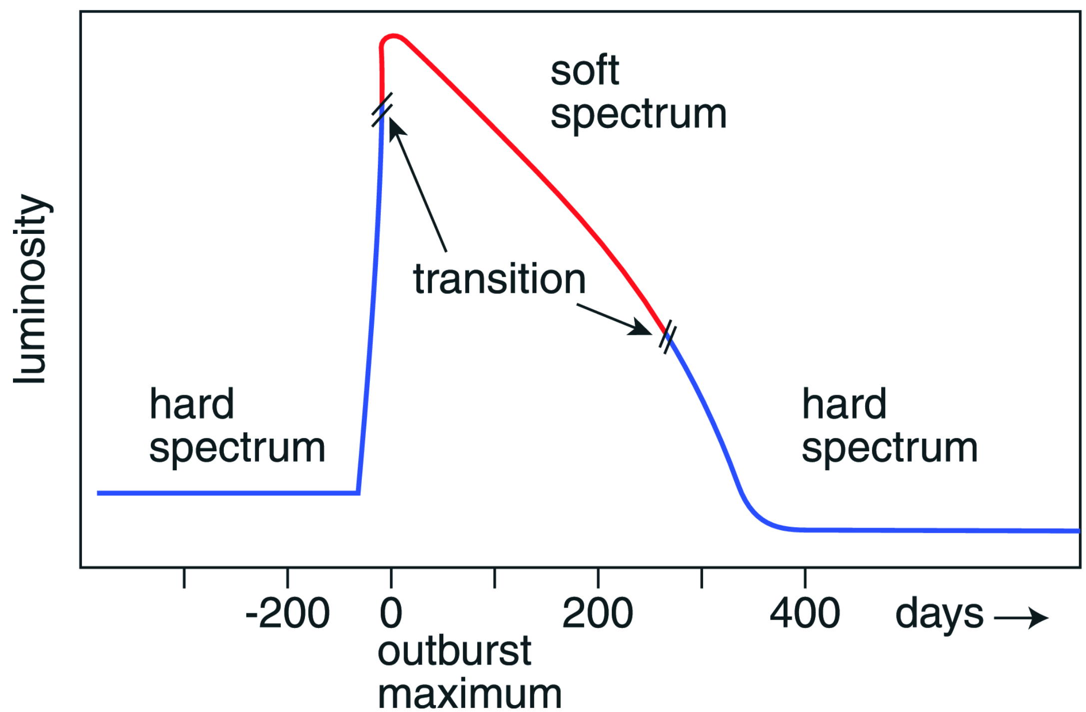


rate of inward mass flow in the corona [g/s]

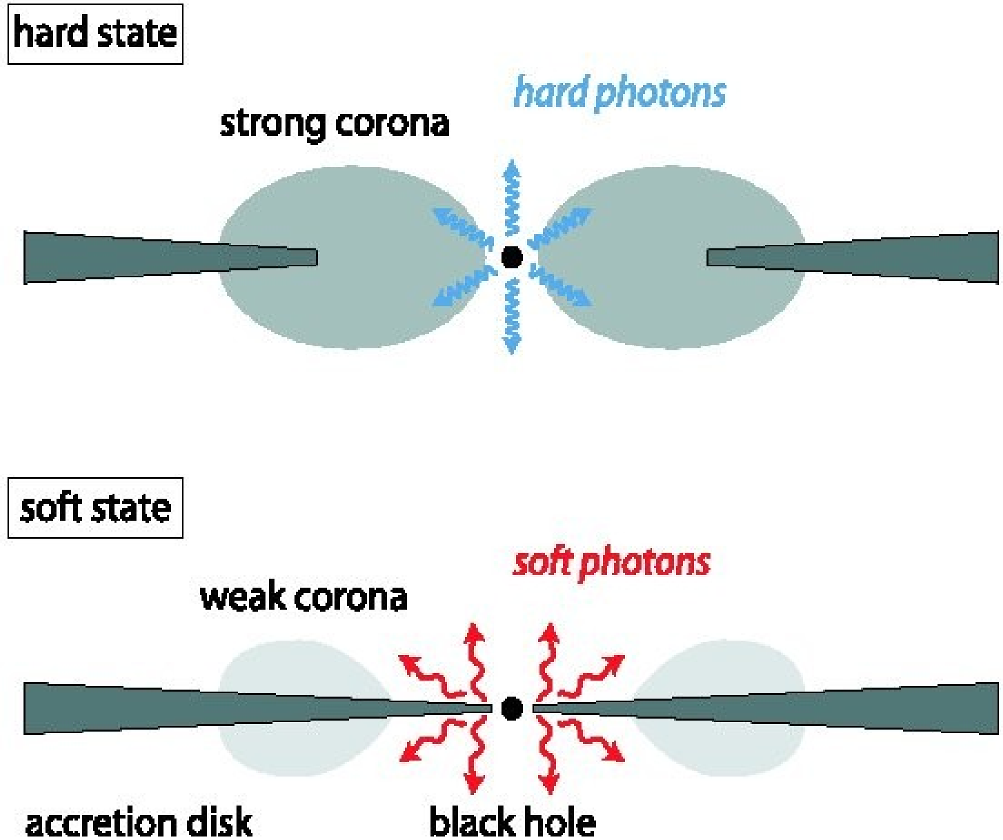
Meyer, Liu, Meyer-Hofmeister 2000

(Rozanska & Czerny 2000)

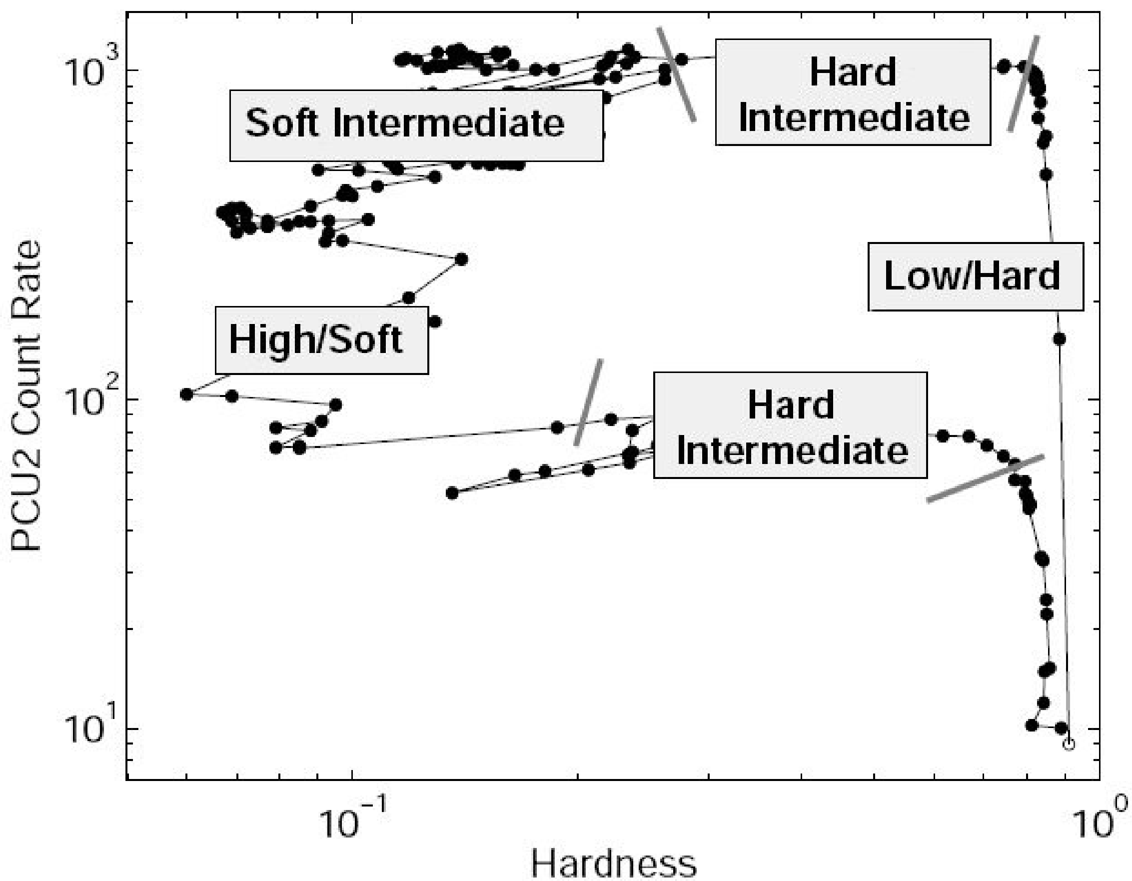
outburst cycle: low mass flow in quiescence -- hard spectrum
high mass flow during outburst -- soft spectrum



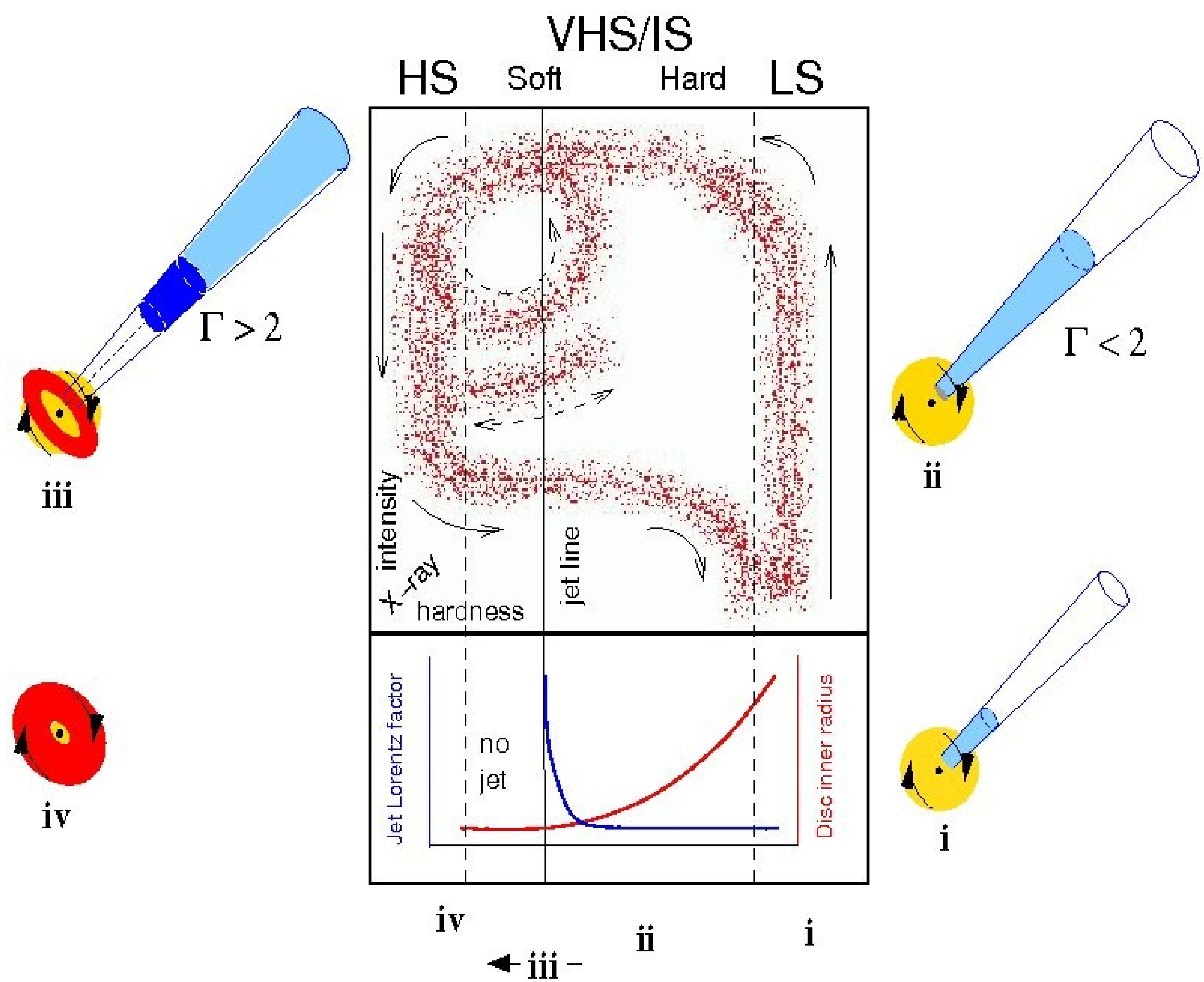
- hysteresis in spectral state transition luminosity
  can be understood as resulting from irradiation of the corona


hard state
hard photons
strong corona
soft state
soft photons
weak corona
accretion disk
black hole

hardness-intensity diagram (HID)



GX 339-4 outburst 2002/2003



hardness · intensity diagram (path of GRS 1915+105)
jet production episode, Lorentz factor, optically thin radio outbursts
sketches: relative contributions of jet (blue), corona (yellow), disk(red)
Fender, Belloni, Gallo 2004

AGN

mass accretion from the environment
modulation of the mass flow rate caused by the ionization instability in the disk

>>> 2 modes of accretion close to the supermassive black hole - same physics

hard state : low-luminosity AGN, M 81 (ADAF + thin disk model Xu & Cao 2008
evidence for mass scaling accretion Markoff et al. 2008)
large-scale radio jets of galaxies
soft state : bright quasars (selected by their strong blue/UV continuum flux)
strong accretion disk component

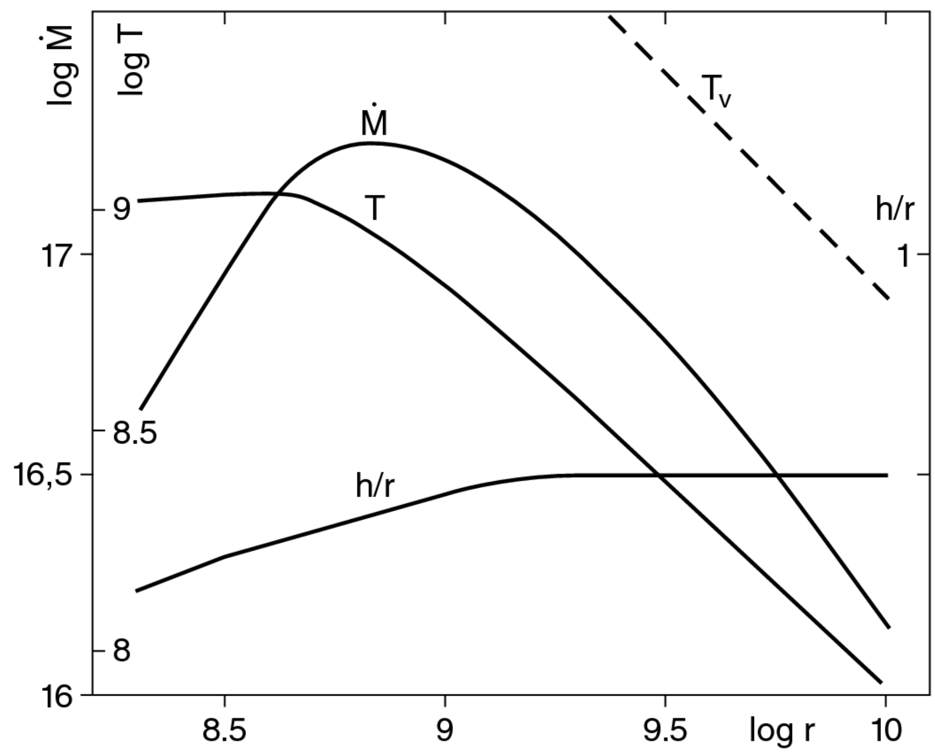
difference between galactic black hole and AGN spectra
due to strong absorption by a disk wind in AGN (Done & Gierlinski)

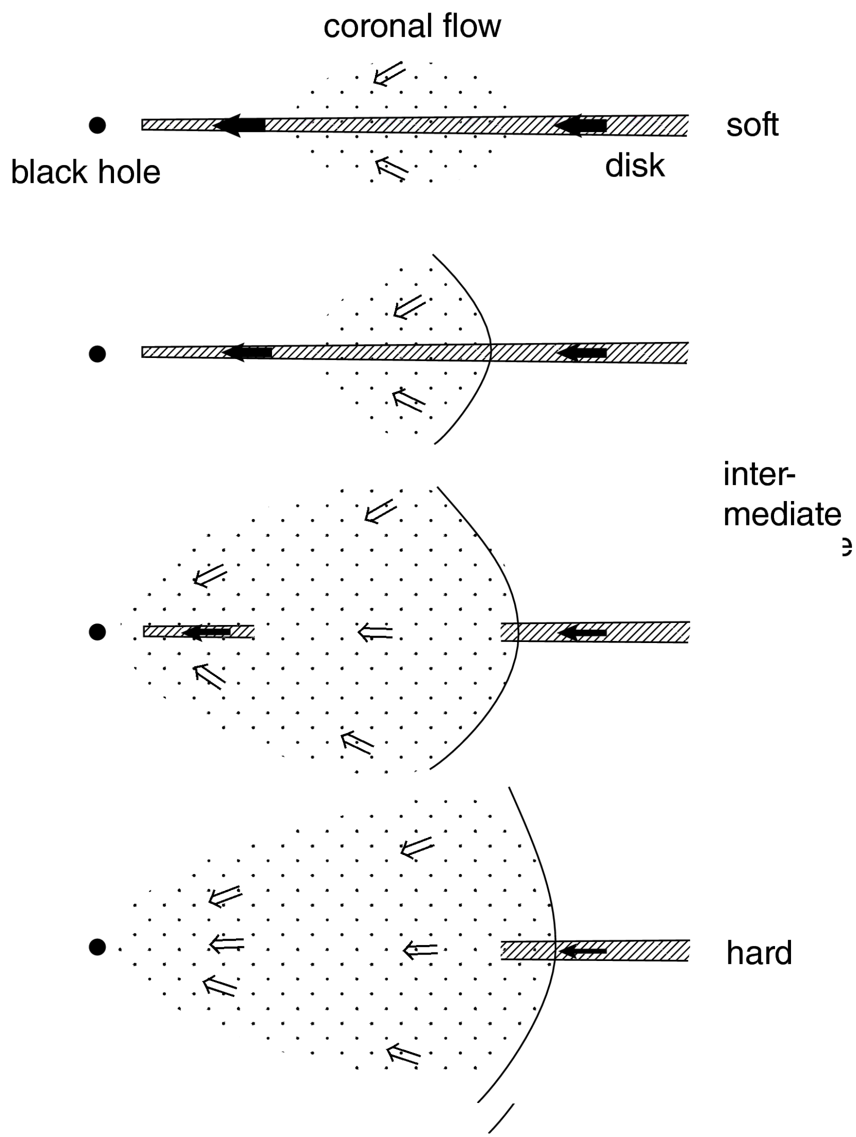
long timescales of AGN >>>>>
no changes observable, only the present distribution of types of AGN

evaporation model : truncation of the thin disk for low mass transfer rate = corona -- hard spectral state

hysteresis caused by the dependence of the evaporation efficiency on irradiation of the corona by the inner disk at soft/hard transition

----------- what happens at distances where the evaporation efficiency
----------- decreases ? ? ?




coronal flow
soft
black hole
disk
inter-
mediate
e
hard

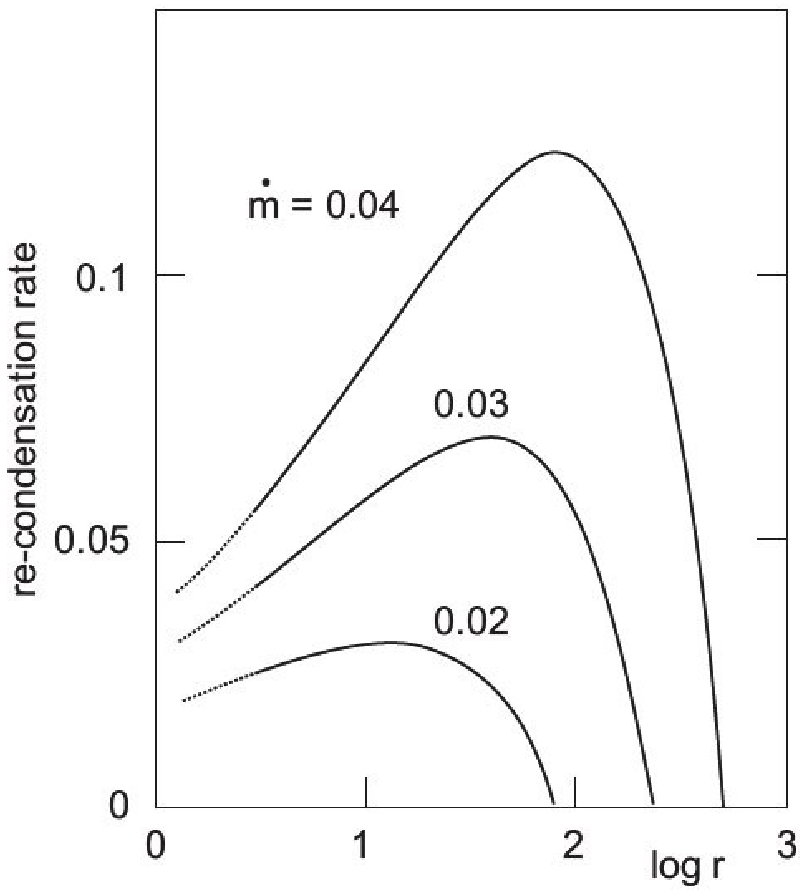
condensation of gas from the ADAF into a disk below ?

condensation allows a disk to remain below an ADAF ?

similar physics as for the equilibrium of disk and corona
important is the heat conduction downward

high pressure in the ADAF >>
high density at the interface between ADAF/disk
large radiative cooling >> condensation

condensation rate depends on the mass flow rate in the ADAF
decreases with decreasing distance r



re-condensation rate relative to the mass flow rate in the ADAF
(in units of the Eddington rate)

Liu, Meyer, Meyer-Hofmeister 2006

Meyer, Liu, Meyer-Hofmeister 2007

observations:

- occurrence of reflection and a Fe Kα line indicate cool matter in the inner disk   Zycki et al. 1998

If the radius at which the hot flow evaporates from cool disc progressively decreases as the source approaches the transition to the soft state then this can account for the observed evolution in spectral and timing properties. However, if there really are detections of substantial amounts of iron line emission from cool disc-like material down at the last stable orbit *in the low/hard state*, then the truncated disc idea is simply

wrong !!!

Done & Gierlinski 2005

- XMM and RXTE observations of GX 339-4 showed thermal emission from an inner accretion disk and a relatistic Fe Kα emission line
Miller, Homan, Steegs et al. 2006

- XMM and RXTE observations of Swift J1753.5 reveal an inner accretion disk
Miller, Homan, Miniutti 2006

- XRT observations for XTE J1817-330 show an accretion disk present at or near the innermost stable orbit
Rykoff et al. 2007

….. and further analysis of these sources important for the re-condensation process are

- conductive cooling (heat conduction)
- cooling by Compton (Compton scattering of photons from the disk underneath)

detailed investigations allow to derive information on the inner disk

given the mass accretion rate, mass of central object, viscosity
one gets

>>>>> luminosity, temperature, size of inner disk

comparison with observations

Liu, Taam, Meyer-Hofmeister, Meyer 2007
Taam, Liu, Meyer, Meyer-Hofmeister 2008

GX339-4

- Input parameters

From Observation (Miller et al. 2006):

$m=10$, $L/L_{Edd}=0.03$, disk temperature $kT=0.3$keV,

Optional: $\alpha=0.3$

- Model predictions
  - Compton dominant cooling
  - Inner disk size: $r_d=66$
  - $L_{disk}/L_{ADAF}=12.7\%$
  - accretion rate=0.037, producing $L/L_{Edd}=0.03$
  - $kT_{eff}=0.16$keV

J1753.5-0127

- Input parameters

  From Observation (Miller et al. 2006):

  $m=10$, $L/L_{Edd}=0.01$(extrapolation), Soft component $kT=0.2keV$

  Optional: α =0.3

- Model predictions
  - Compton dominant cooling
  - Inner disk size: $r_d=22$
  - $L_{disk}/L_{ADAF}=10\%$
  - accretion rate=0.034
  - $kT_{eff}=0.115keV$

accretion geometry near black holes :

critical rate = maximal evaporation rate, 0.02 of the Eddington accretion rate
different regimes of radiation

high mass flow rate ===> thin accretion disk inward to the ISCO
soft spectral state

low mass flow rate ===> thin disk truncated, ADAF in the inner region
truncation radius depends on mass flow rate
hard spectral state

near the critical rate ===> intermediate spectral state
following the mass flow rate decrease gap opens
inner disk can be maintained

what can be learn for the accretion flow in AGN ???

Vassily Kandinsky: Small worlds II, 1922, Munich Lehnbachhaus

binary black hole for Liu Fukun