Focussing on X-ray binaries and microquasars

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Thank you Peter and Dolorès and the organizing committee

I will start with the conclusions

- Accreting X-ray binaries are powerful gamma-ray emitters
- Gamma-rays carry unique information about accretion onto compacts stars: they are hard to produce in models, yet they are powerful probes of the strong field region (jet formation, quasi-periodic variability, ...)
- The sensitivity of gamma-ray observations must be brought to the level currently achieved with X-ray observations (RXTE). This requires at least 1 m^2 at 100 keV
- Great discovery space ahead for two reasons: poorly explored domain and gamma-rays are always associated with the most violent phenomena observed in the Universe
- Observing binaries requires flexibility, broad band coverage (from at least 1 keV), high-time resolution and an all-sky monitor

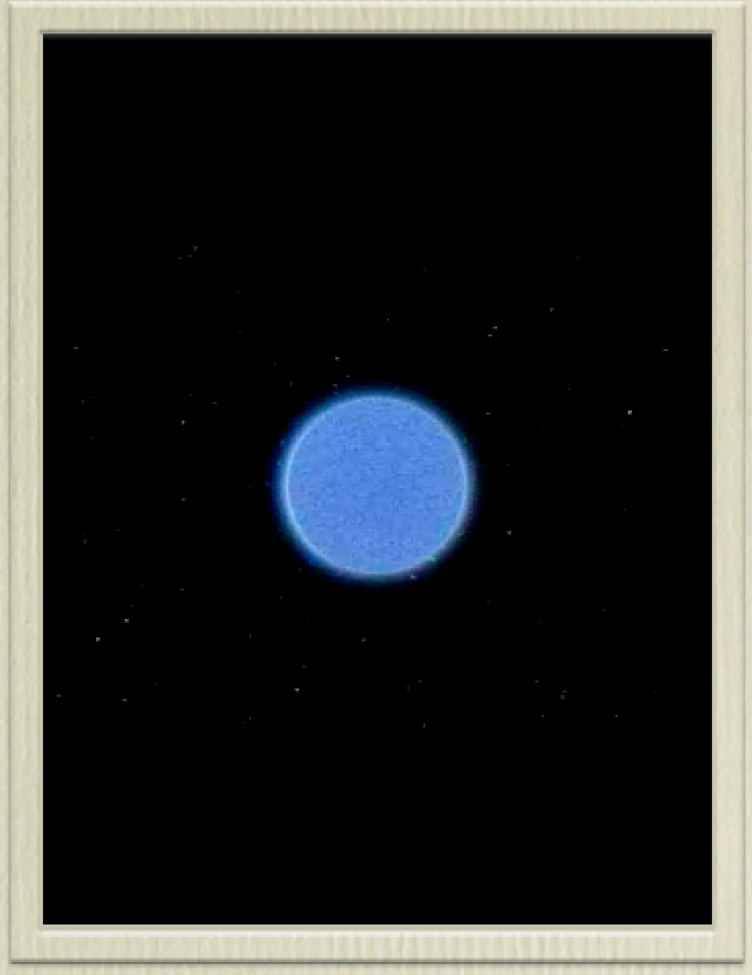
Why looking at X-ray binaries above 50 keV?

- The power of gamma-ray observations
- Common spectral states of X-ray binaries
- Hard X-ray fast time variability in X-ray binaries
- X-ray binaries as particle accelerators
- X-ray binaries as exotic sources of gamma-rays
- Conclusions

My personal and certainly incomplete and biased view on what I think should be included for selling a gamma-ray mission (>50 keV) to ESA

X-ray binaries

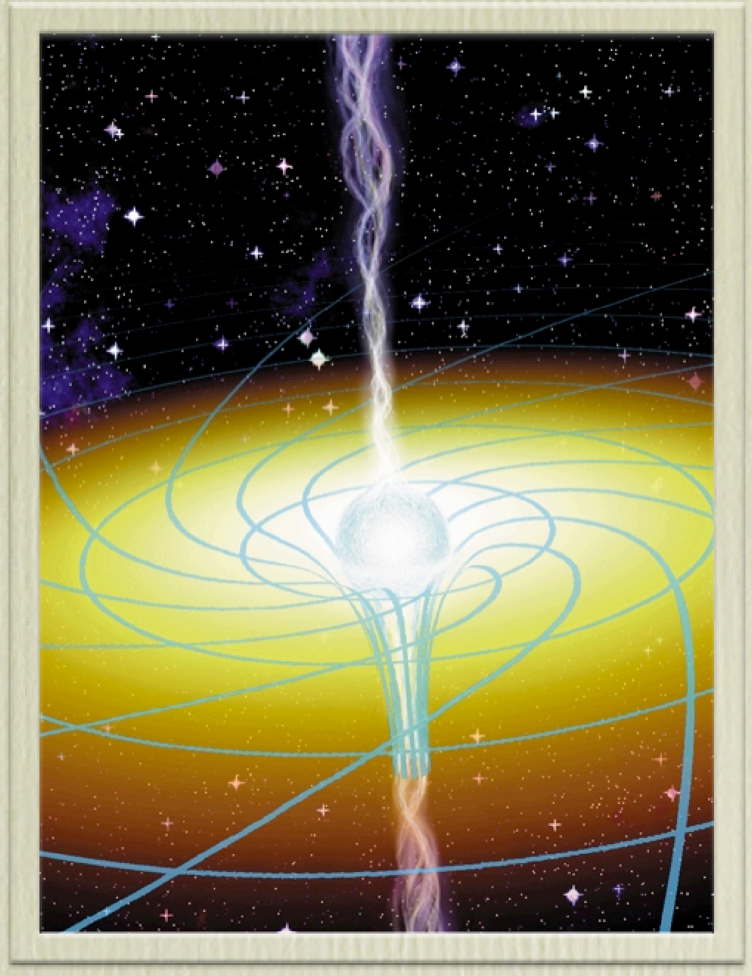
- Two flavors: with black holes and neutron stars
- X-rays/gamma-rays are powered by <u>accretion</u> onto the compact star
  - Accretion is a rather universal phenomenon: from protostellar objects, gamma-ray bursts, to supermassive black holes in AGN
  - High energy emission probes the motion of matter under strong gravity, hence can be used to test fundamental GR predictions



Gamma-ray emission is associated with the most violent phenomena of the Universe

Observable signatures of strong gravity

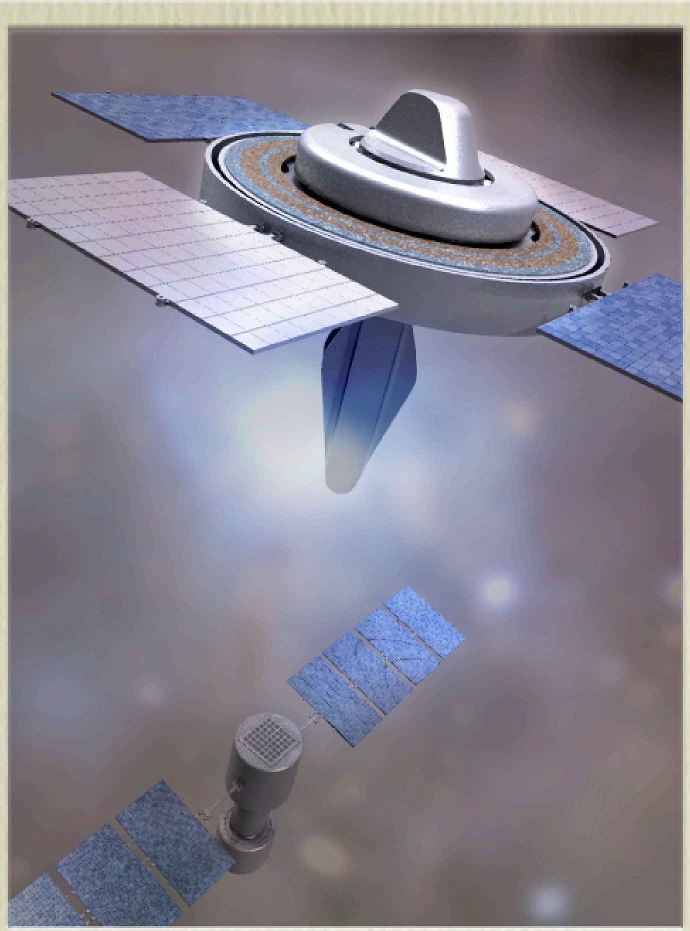
- Gravitational redshifts: gravity stealing energy from photons
- Fundamental GR predictions:
  - Innermost stable circular orbit
  - Dragging of inertial frames: spinning compact stars twisting spacetime like a tornado
  - Event horizon



Gamma-ray observations can help for probing GR in the strong field limit

Ways to address these issues

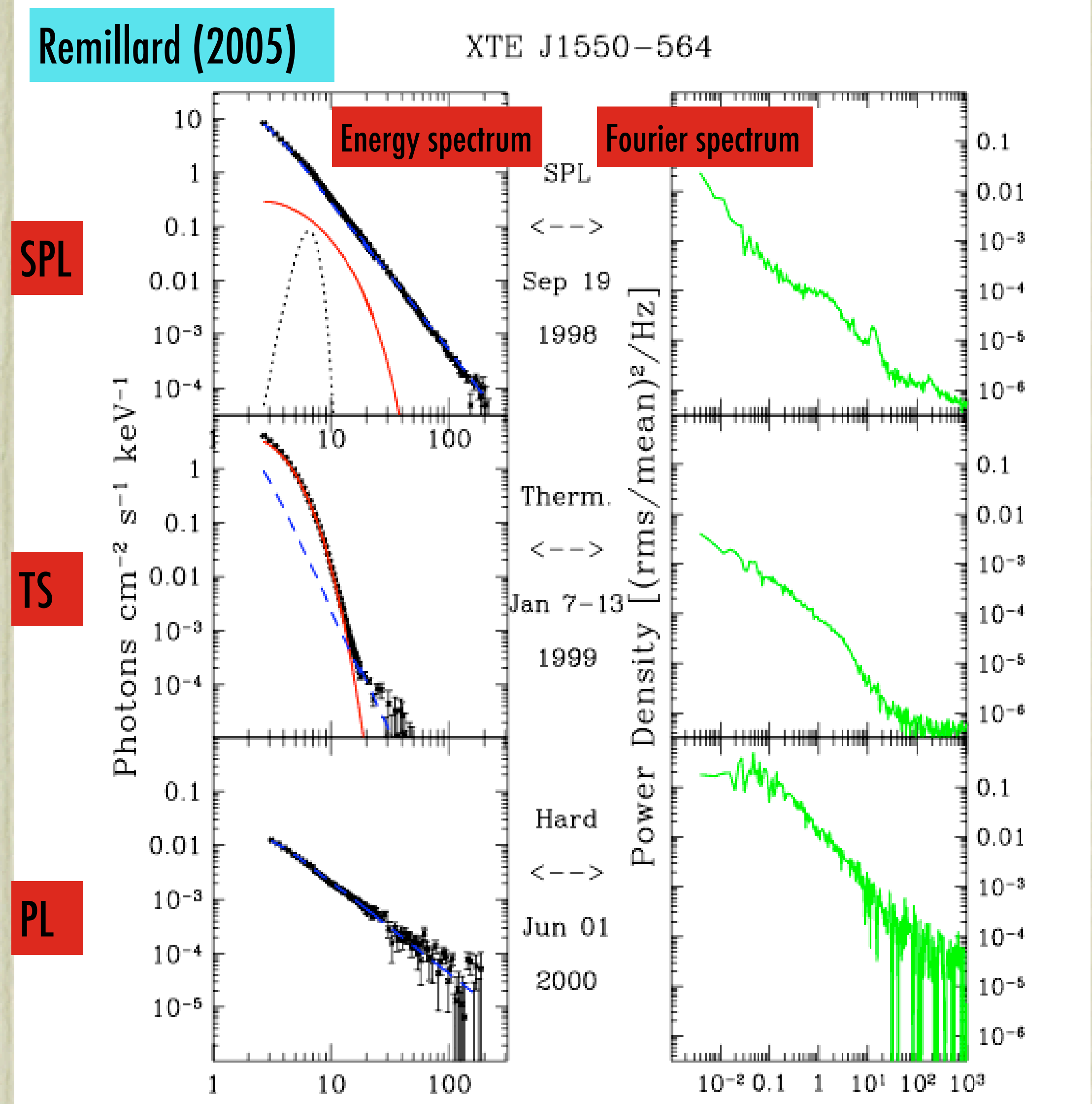
- Better understand accretion in general: origin of viscosity, accretion geometry, coupling between accretion and ejection, emission processes
  - Perform more sensitive broad band spectral and timing (ultimately imaging) observations of what is going on very close to the compact star
  - Combine broad band spectroscopy, timing, polarimetric measurements



A gamma-ray observatory must be sold as a tool for fundamental astrophysics

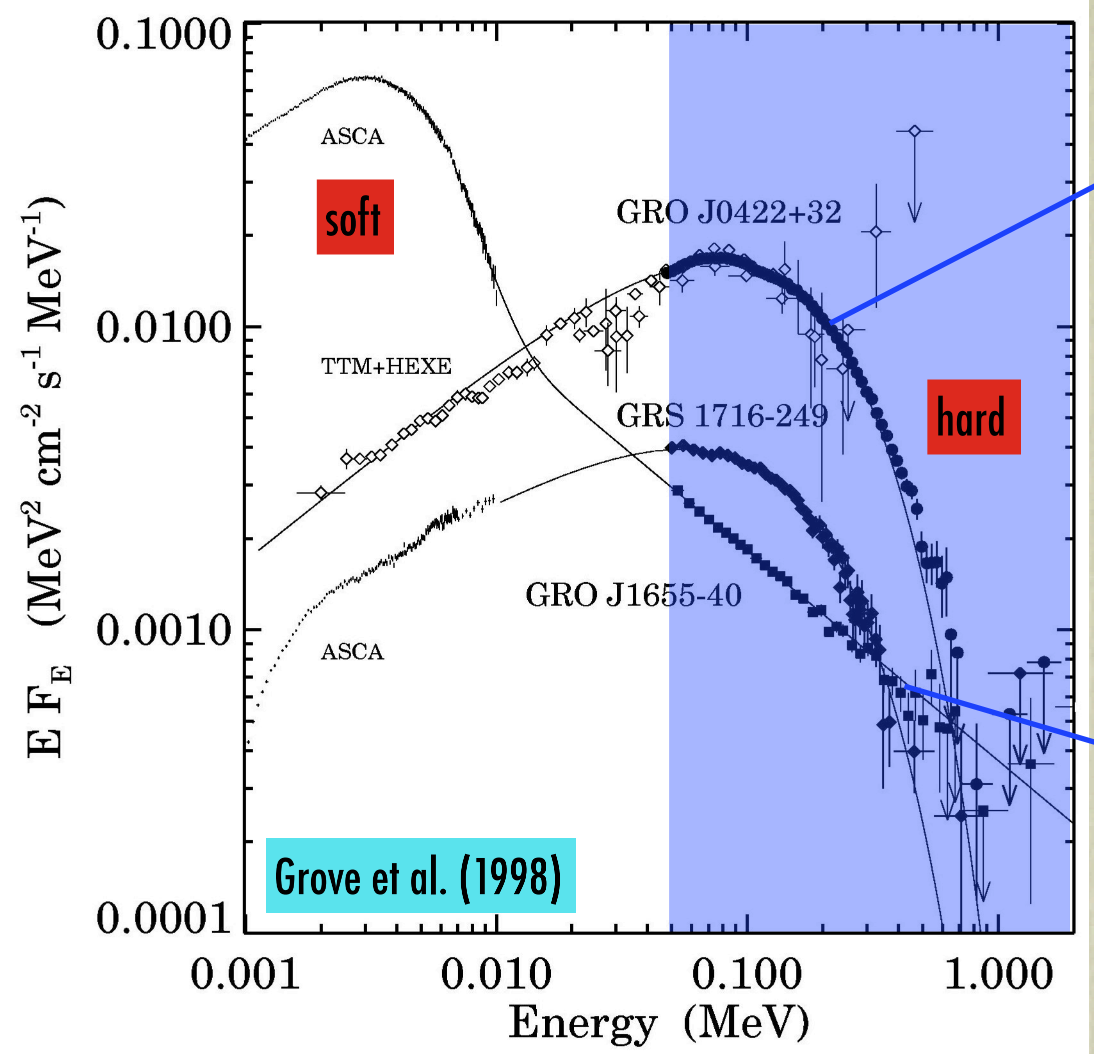
Canonical spectral states

- Steep power law state (soft)
  - No evidence for high-energy cutoffs
  - Quasi-periodic variability above 100 Hz
- Thermal state (soft)
  - Weak hard X-ray tail extending above 100 keV
- Power law state (hard)
  - High energy cutoff around a few 100s keV



Time variability strongly coupled to energy spectrum hence timing must be combined with spectroscopy

Canonical black hole states



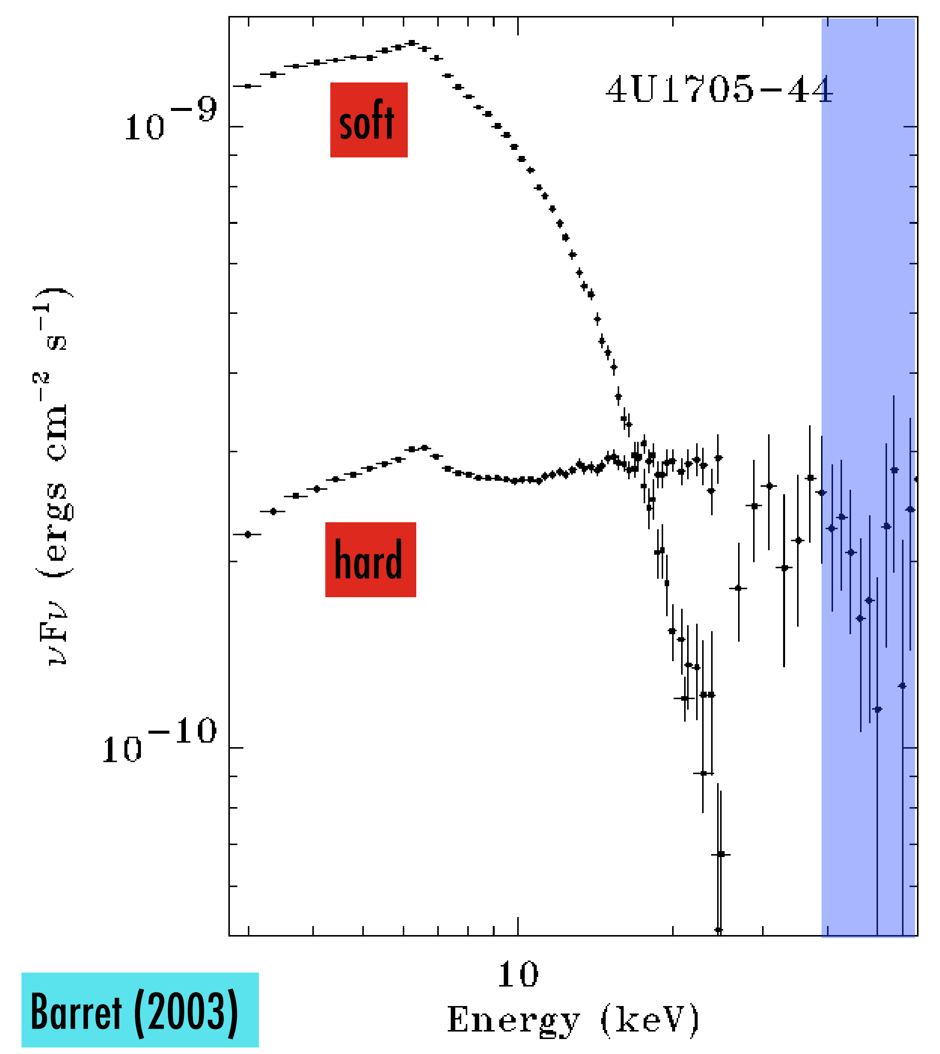
Grove et al. (1998)

Hard state displaying a high energy cutoff above 50 Hz

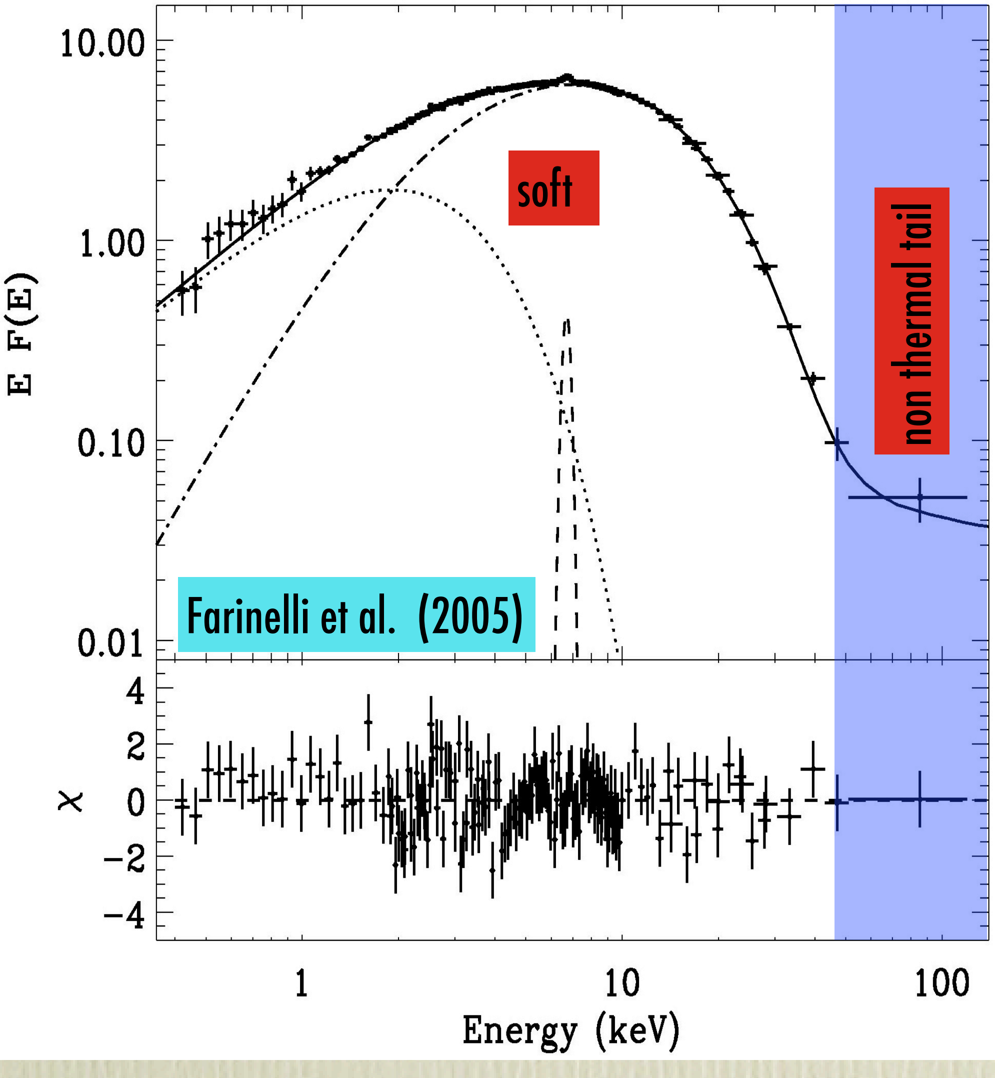
Soft steep power law state with no evidence for a high energy cutoff up to 300 keV

Poor statistics above 200 keV - A lot is also happening in X-rays (<10 keV)

Canonical neutron star states



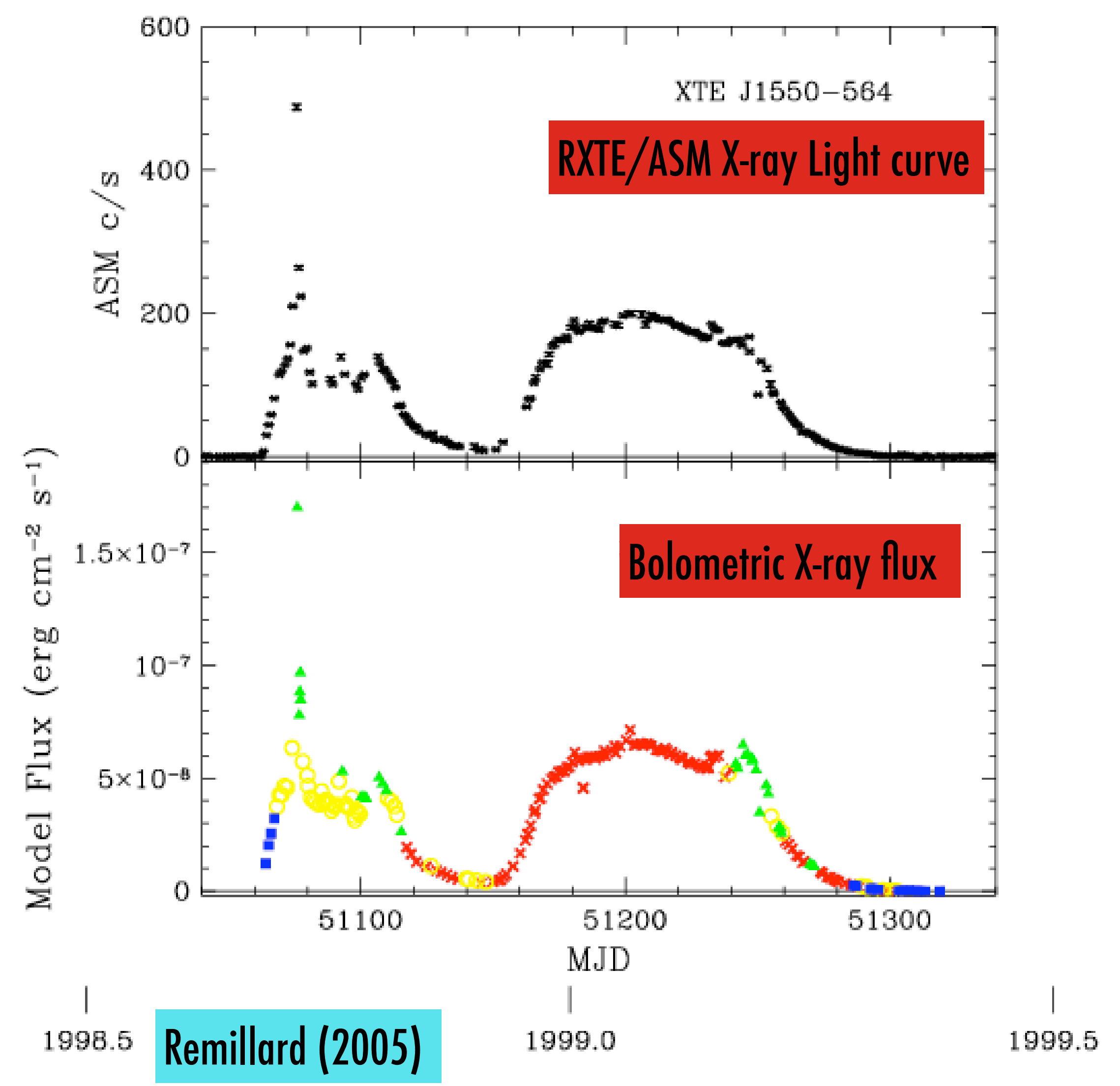
Barret (2003)



Farinelli et al. (2005)

Show great similarities with black hole systems (despite the presence of a solid surface and a magnetosphere) - Same emission mechanisms at work? Poor statistics above 100 keV

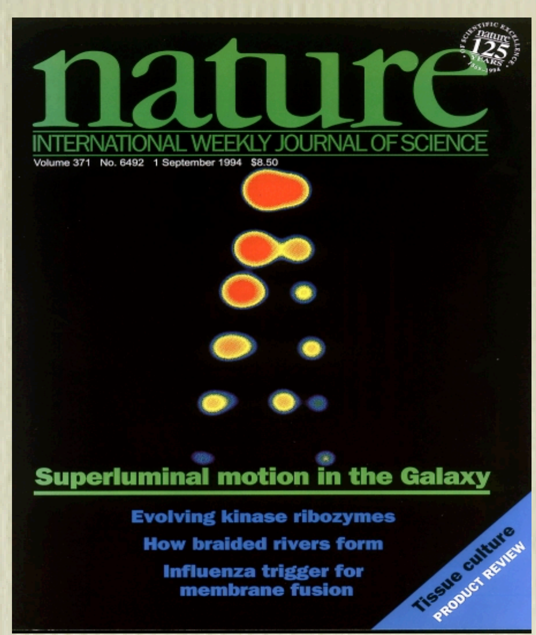
Black hole state transitions



RXTE/ASM X-ray Light curve

Bolometric X-ray flux

Remillard (2005)



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Superluminal motion in the Galaxy

Evolving kinase ribozymes

How braided rivers form

Influenza trigger for membrane fusion

Tissue culture PRODUCT REVIEW

Mirabel & Rodriguez

Hard (jet) state

Intermediate state

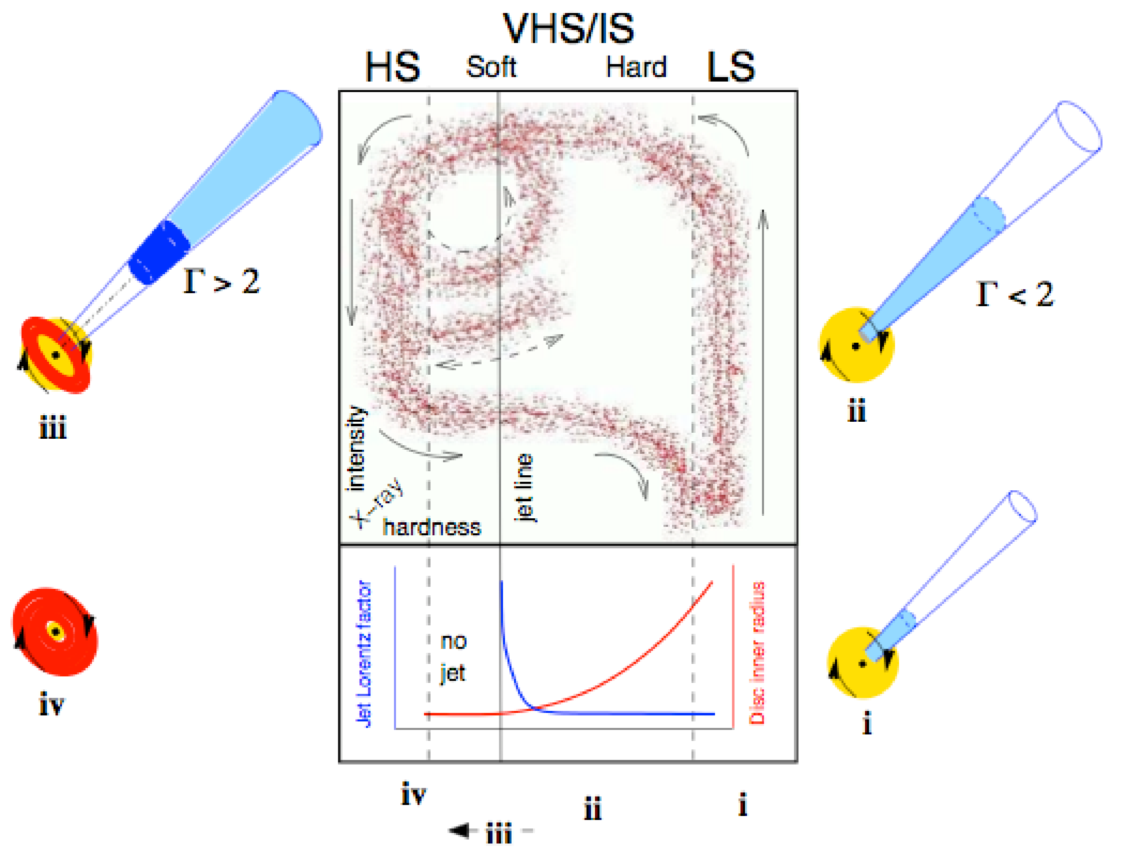
Steep power law state (HF QPOs)

Thermal state

Transient sources span wide range of accretion rates - need simultaneous all sky monitor

Link between gamma-rays and jets

Fender, Belloni & Gallo (2005)



Jets are strongly coupled to state transitions: hard states have steady jets, transition from hard to soft states have super-luminal ejections

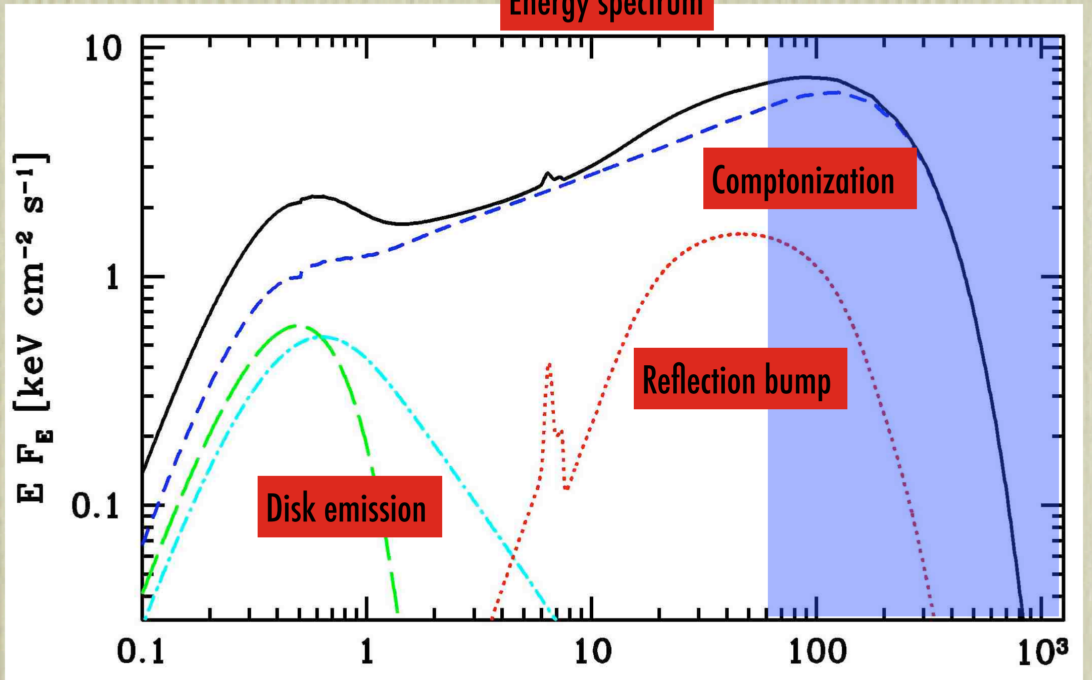
Jets are important to study: outflows are part of accretion, jets dissipate a large fraction of the total accretion energy, provide input energy to the ISM

Gamma-ray observation can help to better understand jets (from GRBs to quasars): what are they made of? are they powered by extraction of rotational energy from the hole?...

Thermal comptonization

Zdiarski & Gierlinski (2005)

Energy spectrum



Comptonization

Reflection bump

Disk emission

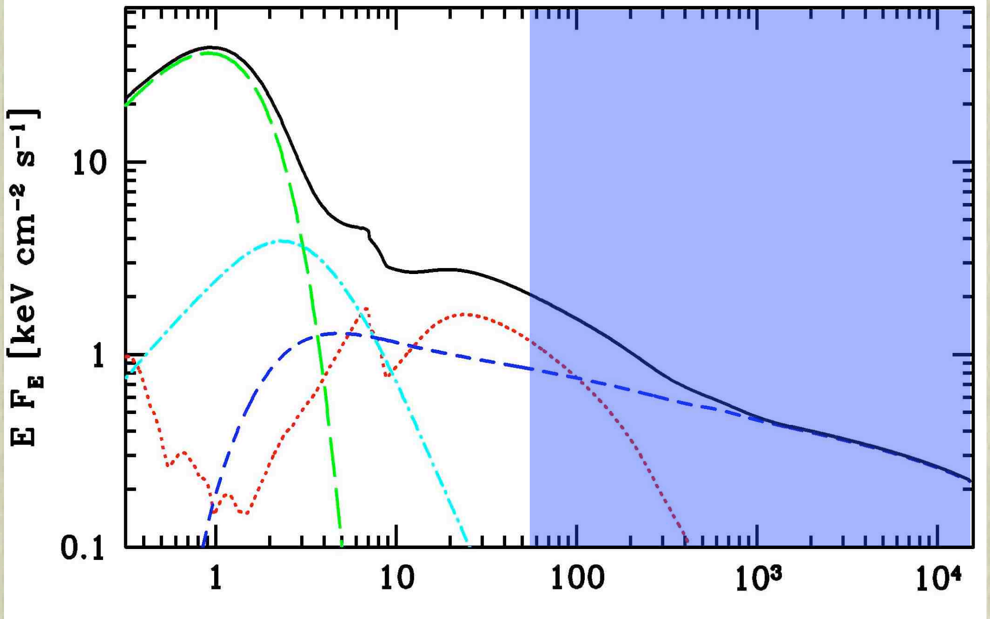
Main emission mechanism is Comptonization: Inverse Compton scattering of soft cool photons on hot electrons having a thermal Maxwelian distribution

Accretion disk is seen through primary emission and reflection features: Iron line, and continuum bump

Open questions: source of seed photons (disk, electron cloud itself)? accretion geometry? electron heating? Structure of the comptonizing region? Presence of a non-thermal component?

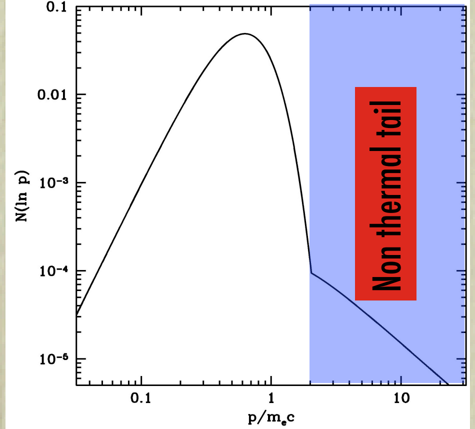
Non-thermal comptonization

Zdiarski & Gierlinski (2005)



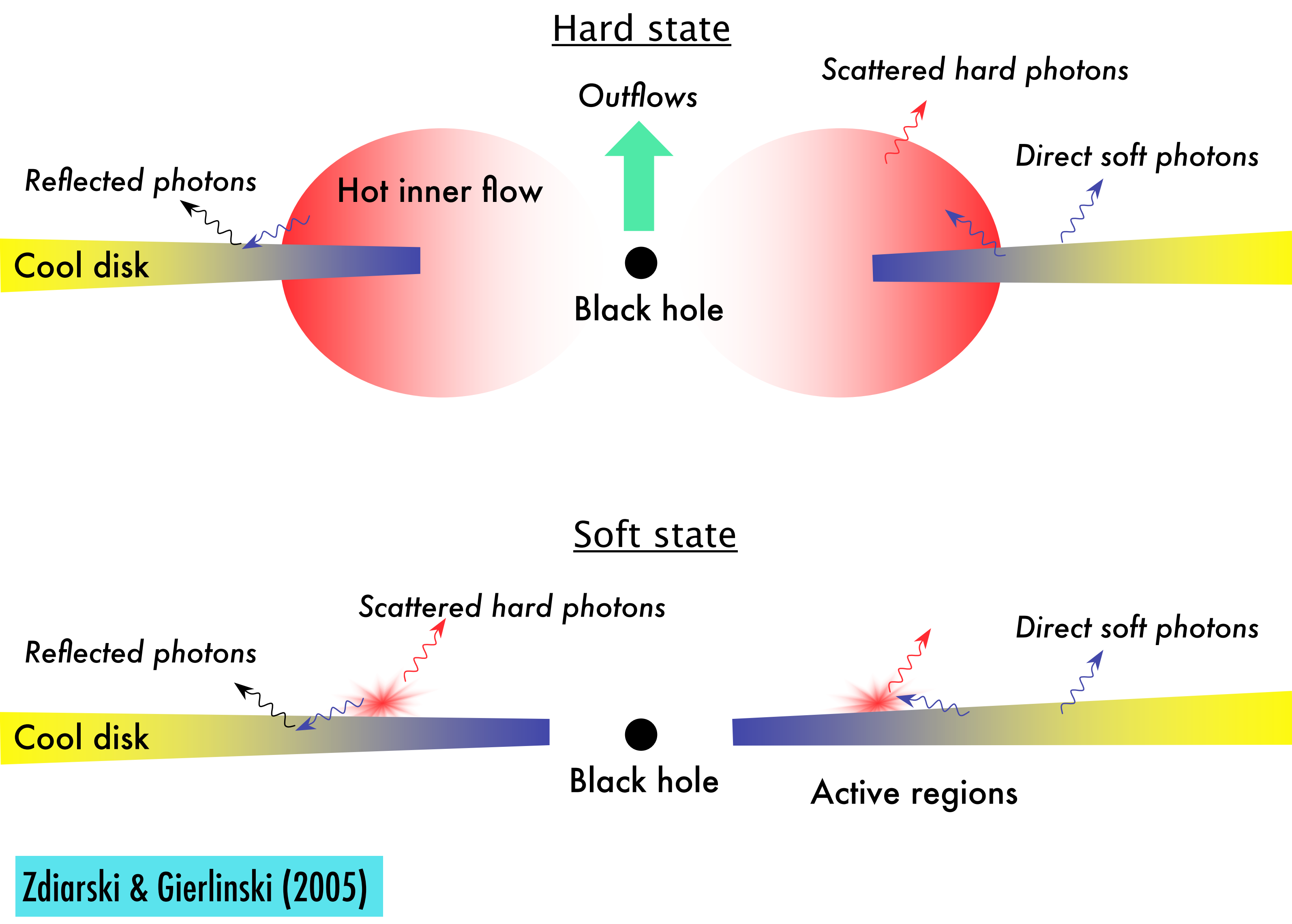
Main emission mechanism is Comptonization of seed photons onto an hybrid electron distribution

Emission potentially extends up to 10 MeV



Open questions: source of seed photons? accretion geometry? electron heating (magnetic reconnection) ?

The emerging picture for black holes

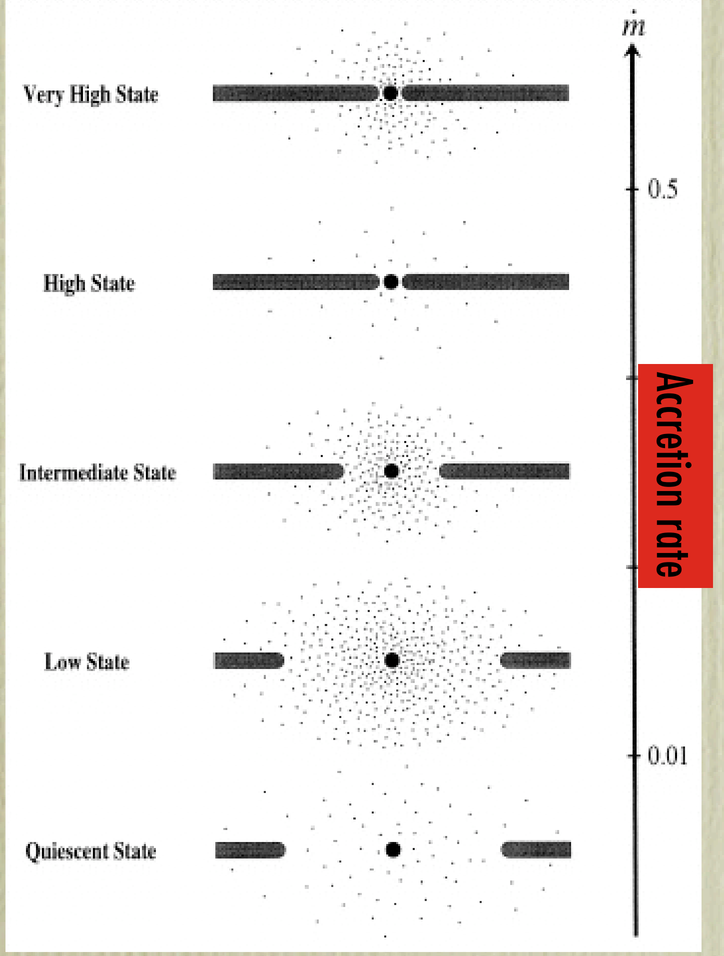


Zdiarski & Gierlinski (2005)

How universal this picture is? How does that depend on the nature of the compact star?

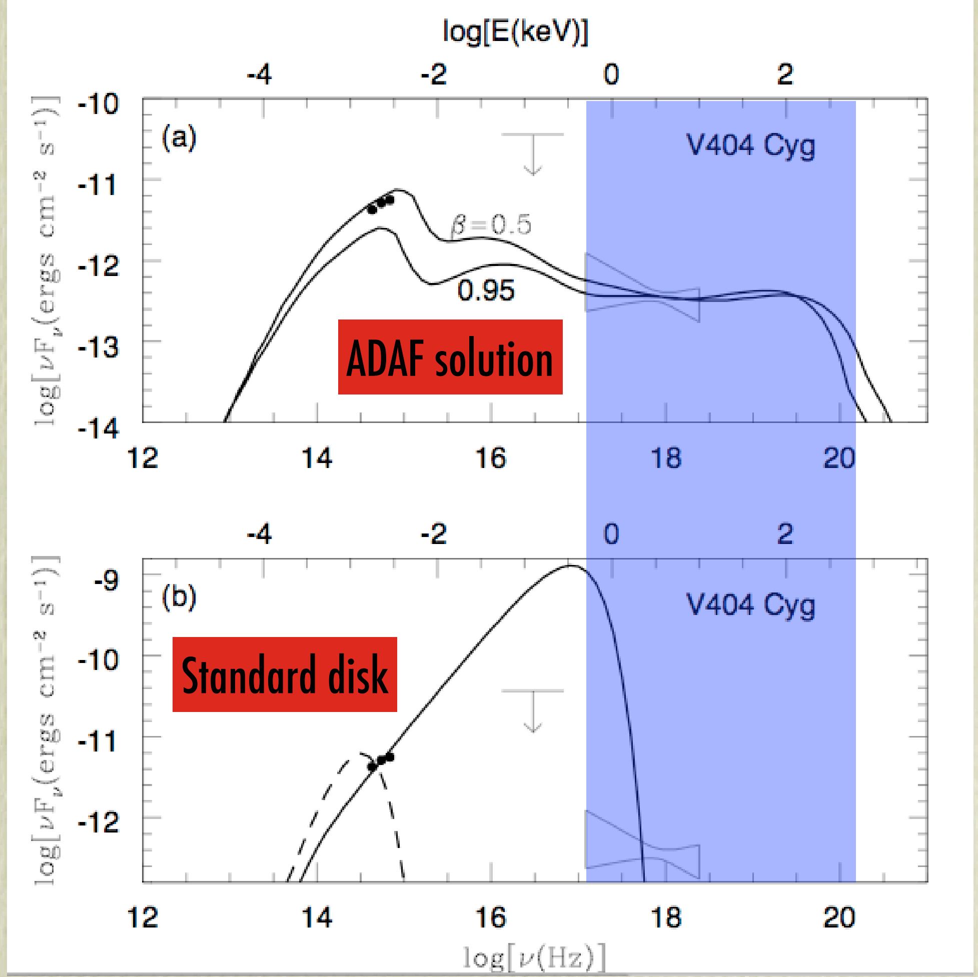
Black holes in quiescence: advective flows

Esin et al. (2001)



Accretion rate

Narayan, Barret & McClintock (1997)



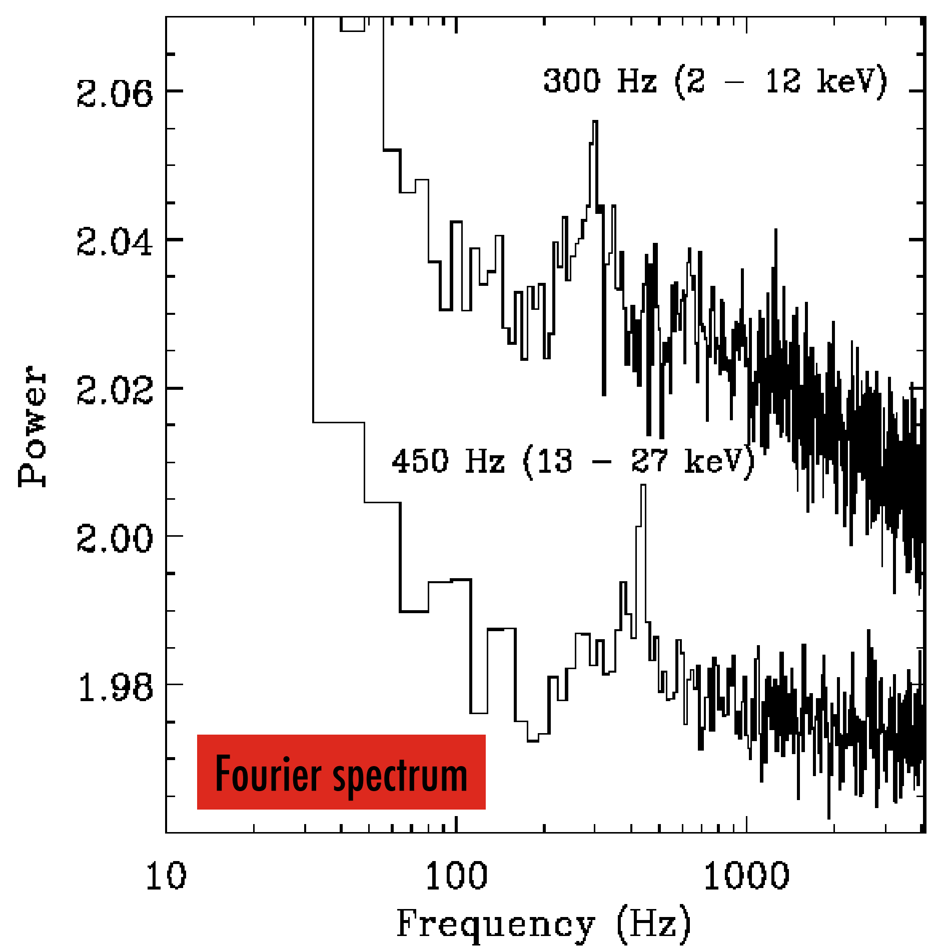
ADAF solution

Standard disk

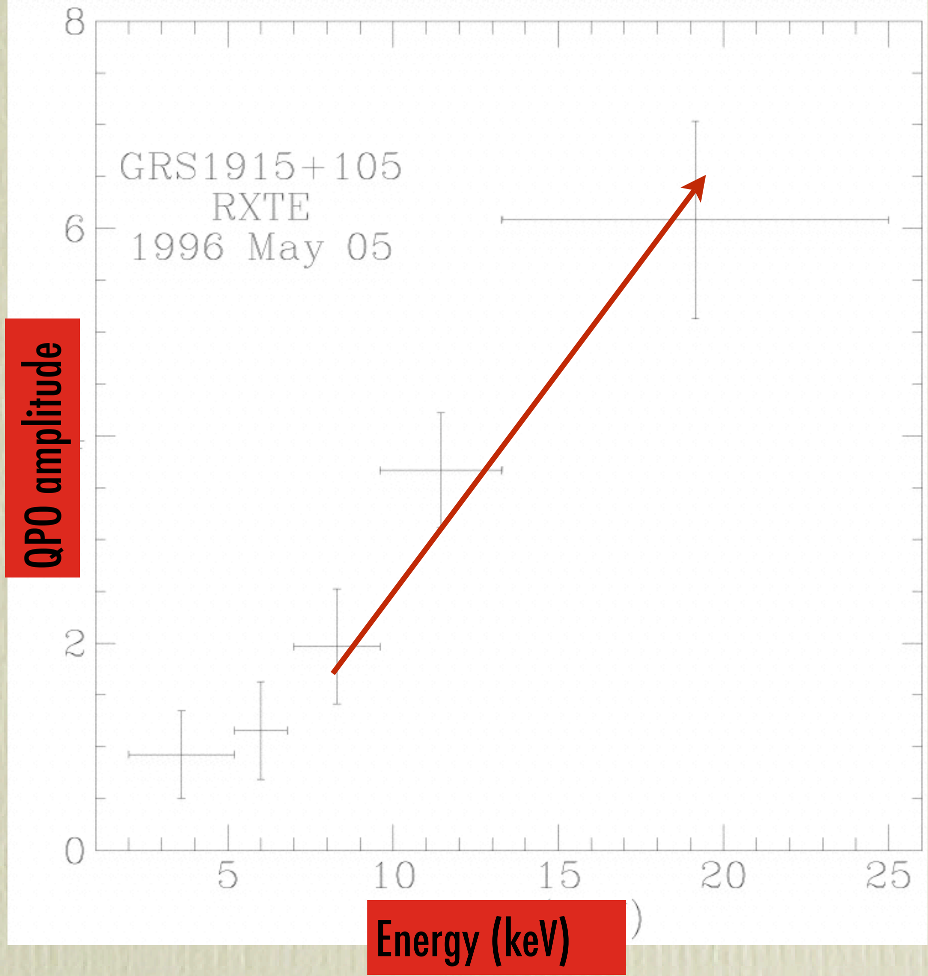
Beyond reach of current instrumentation - Gamma-ray observations are likely to provide very stringent test of ADAF based models - ADAFs and the event horizon

Quasi-periodic oscillations

Strohmayer (2002)



Morgan et al. (1997)

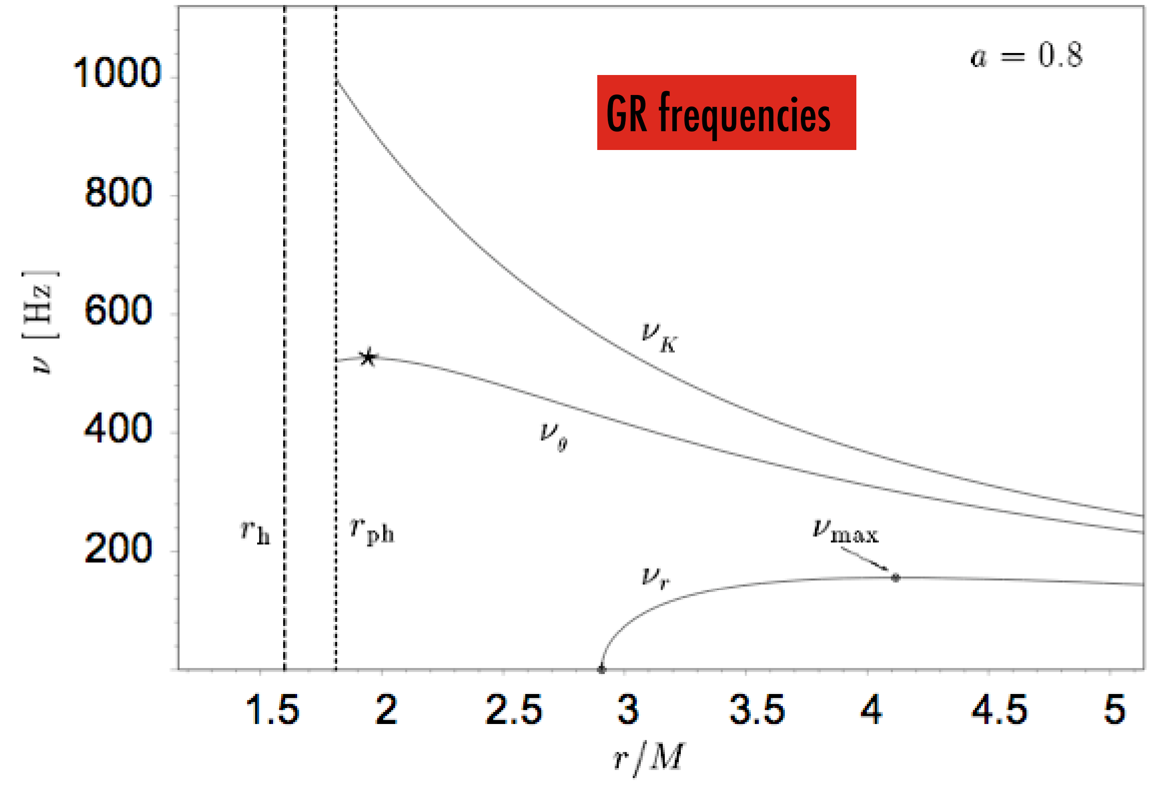


?

High frequency QPOs are weak and hard (not seen below 10 keV)- associated with the less known steep power law state extending to gamma-rays - interpreted as general relativistic frequencies - 3:2 ratios in a handful of sources

General relativistic frequencies

Abramowicz & Kluzniak (2004)



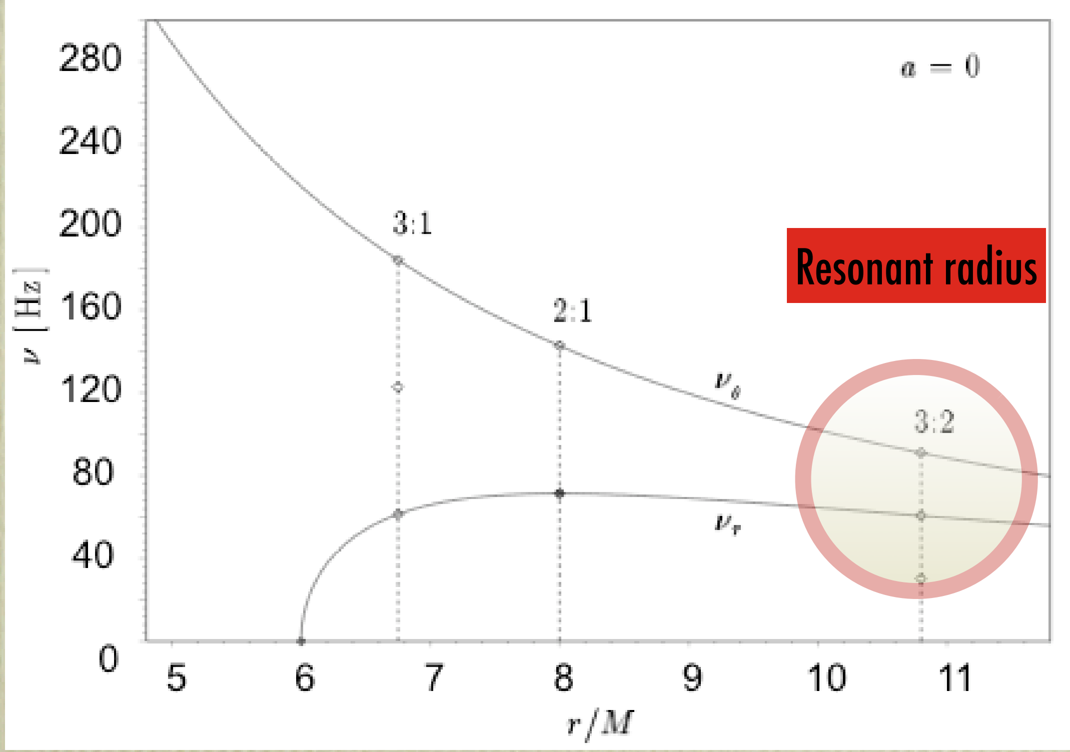
In GR, test particle orbits are characterized by 3 frequencies: Azimuthal, Radial epicyclic, Vertical epicyclic

All three frequencies depend on the mass, spin and orbital radius

$$\nu = \frac{1}{M} F(a, r)$$

Non linear resonance

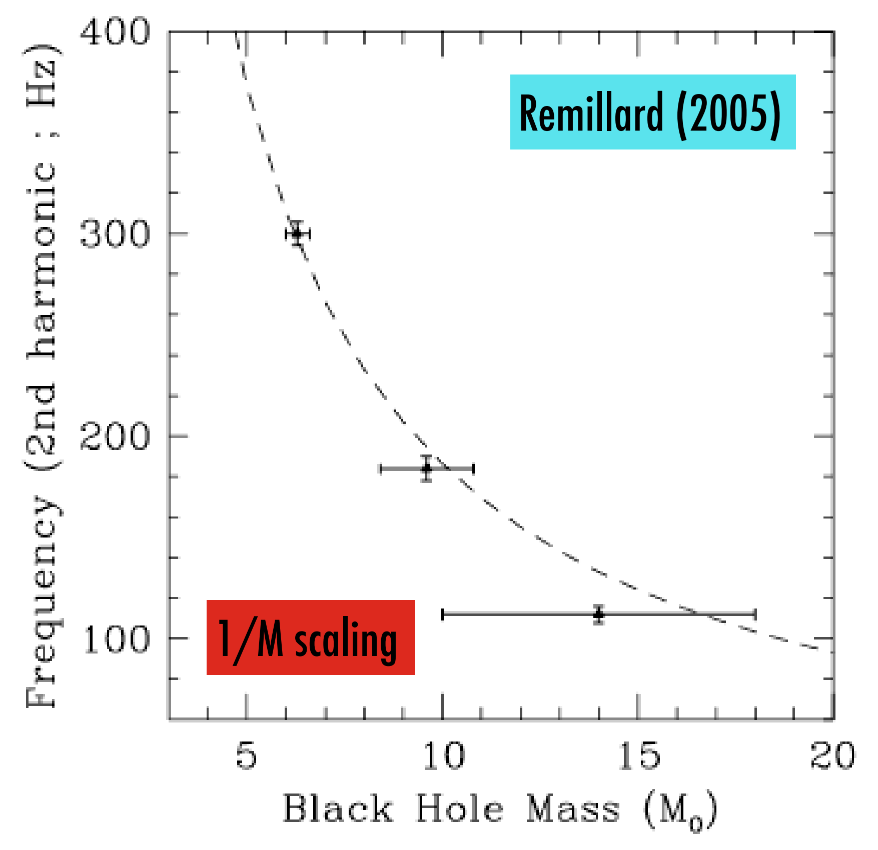
Abramowicz & Kluzniak (2004)



Resonance can occur at a radius where the ratio between 2 GR frequencies equal small integer ratios

If so, the radius is fixed and one expects a 1/M scaling of the frequencies

QPOs and black hole spin



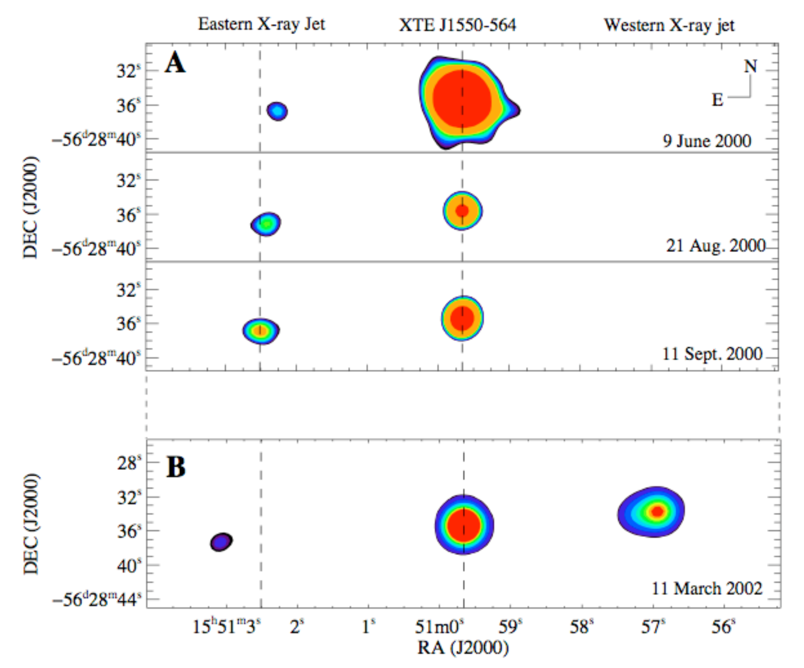
1/M scaling for three black hole systems of known masses from dynamical estimates

Spin parameter inferred (>0.4 and up to close to 1 depending on the interpretation)

1 m^2 at 50 keV would enable to detect QPOs 1% at 5 sigma in 10 ksec for a 5 Crab source in a steep (2.3) power law state (so far HF QPOs have been detected from a handful of systems)

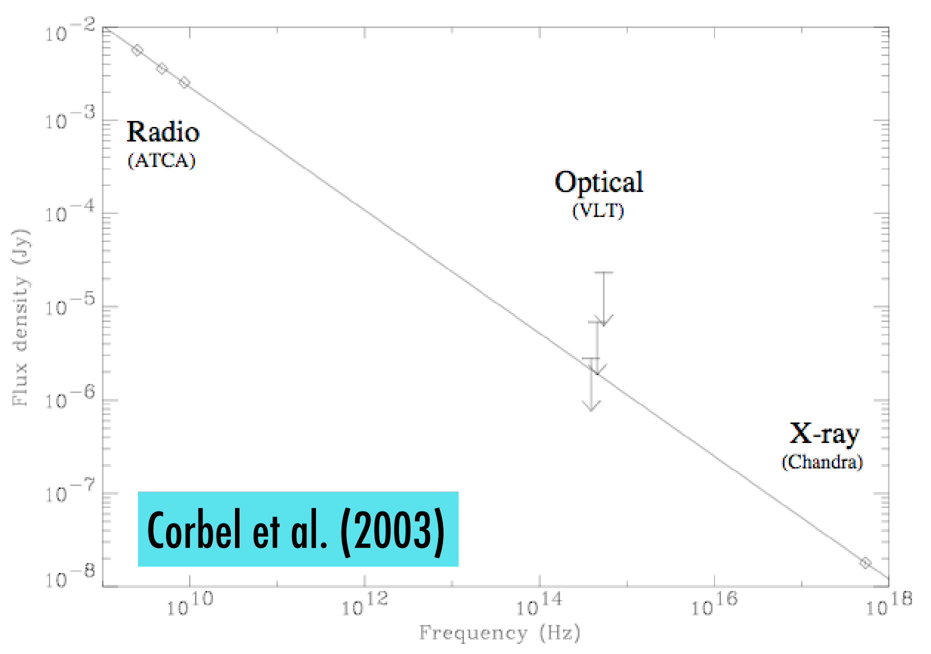
Black hole X-ray jets

Corbel et al. (2003)



Broad band spectral energy distribution distribution consistent with a power law: synchrotron emission from high energy particles (10 TeV)

Particles accelerated in shock waves (internal instabilities, varying flow speed within the jet as in GRBs, jet material interacting with the ISM)

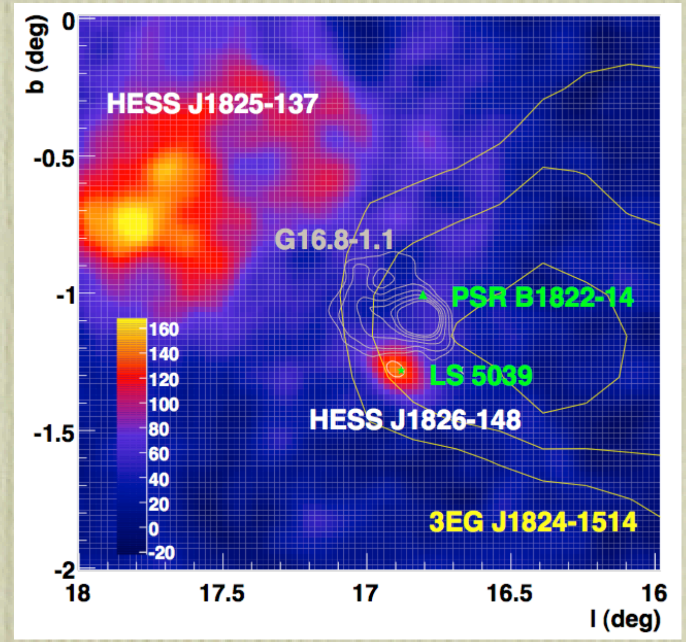


Corbel et al. (2003)

Resolved with Chandra (proper motion of 20 mas/day)

Sub-arcsecond resolution needed to resolve the jet

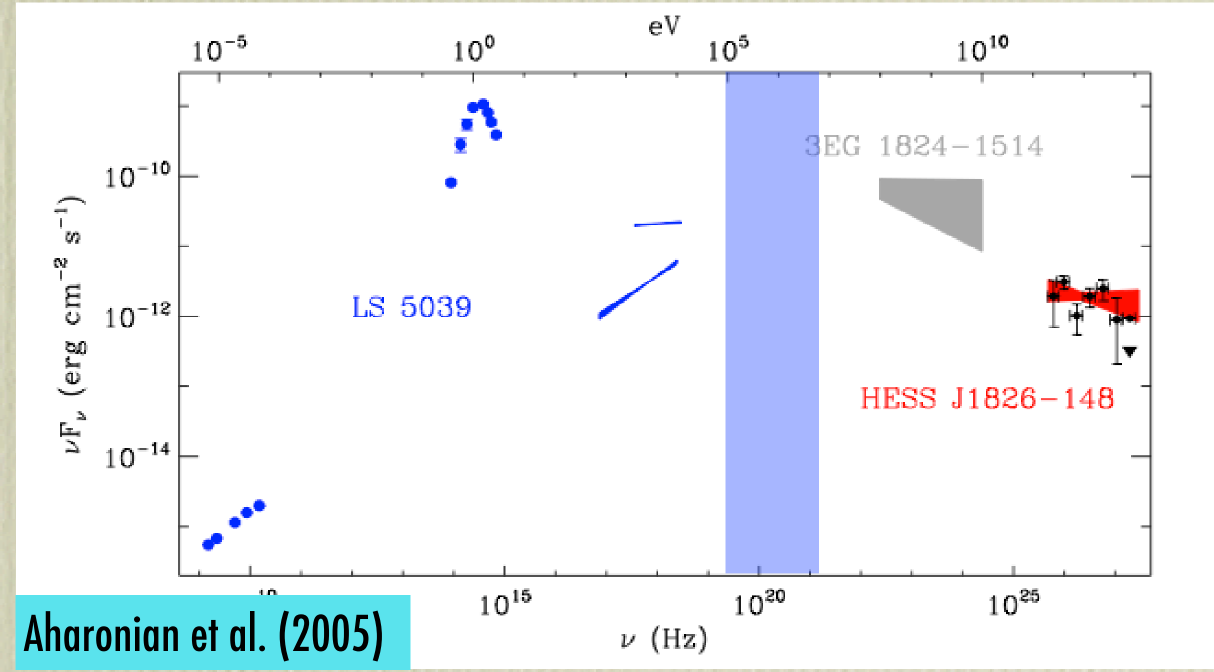
X-ray binaries as TeV sources



Gamma-rays produced via inverse Compton scattering of stellar photons on VHE electrons or via proton-proton interactions with the stellar wind

Absorption of HE photons can be mitigated if the electrons are accelerated far from the companion (in a jet for instance)

HESS detection of the microquasar LS 5039 above 100 keV, likely associated with an unidentified EGRET source



Aharonian et al. (2005)

Highly sensitive gamma-ray observations are needed to fill the gap between INTEGRAL and GLAST

X-ray binaries as exotic sources of gamma-rays

- Microquasars as potential sources of 511 keV positron annihilation radiation when the jet hits the companion star: Guessoum, Jean, Prantzos (2005)
- 2.2 MeV line emission resulting from the capture of accretion disk neutrons in the atmosphere of the secondary: Guessoum and Jean (2004)
- CNO spalliation induced 2.2 MeV emission to account for the Lithium excess in X-ray binaries: Yi & Narayan (1997) - Guessoum & Kazanas (1999)

Within reach of an instrument 10 to 100 times more sensitive than INTEGRAL

Conclusions

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