Accretion geometry, pair production and jet in MAXI J1820+070

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- What is the geometry of the accretion flow in the hard state? Is the disc inner truncation radius, R_{in}, close to the innermost stable circular orbit (ISCO)? (Measurement methods: reflection spectroscopy, disc blackbody emission, reverberation time lags.)
- What is the $e^{\pm}$ pair abundance in the accretion flow?
- Can pairs be produced outside the flow and provide leptons for the synchrotron jet?

MAXI J1820+070

- A transient low-mass X-ray binary with a black-hole accretor, $P \approx 0.7$ d, $M_{\rm BH} \approx 6$–$8\ {\rm M}_{\odot}$ (Torres+20).
- A major outburst in 2018, the hard, intermediate, soft, intermediate and hard states and quiescence.
- The jet inclination 64±5° (Wood+21), the binary one 66–81° (Torres+20), the distance $D \approx 3 \pm 0.5$ kpc.
- A lot of observations by various instruments.

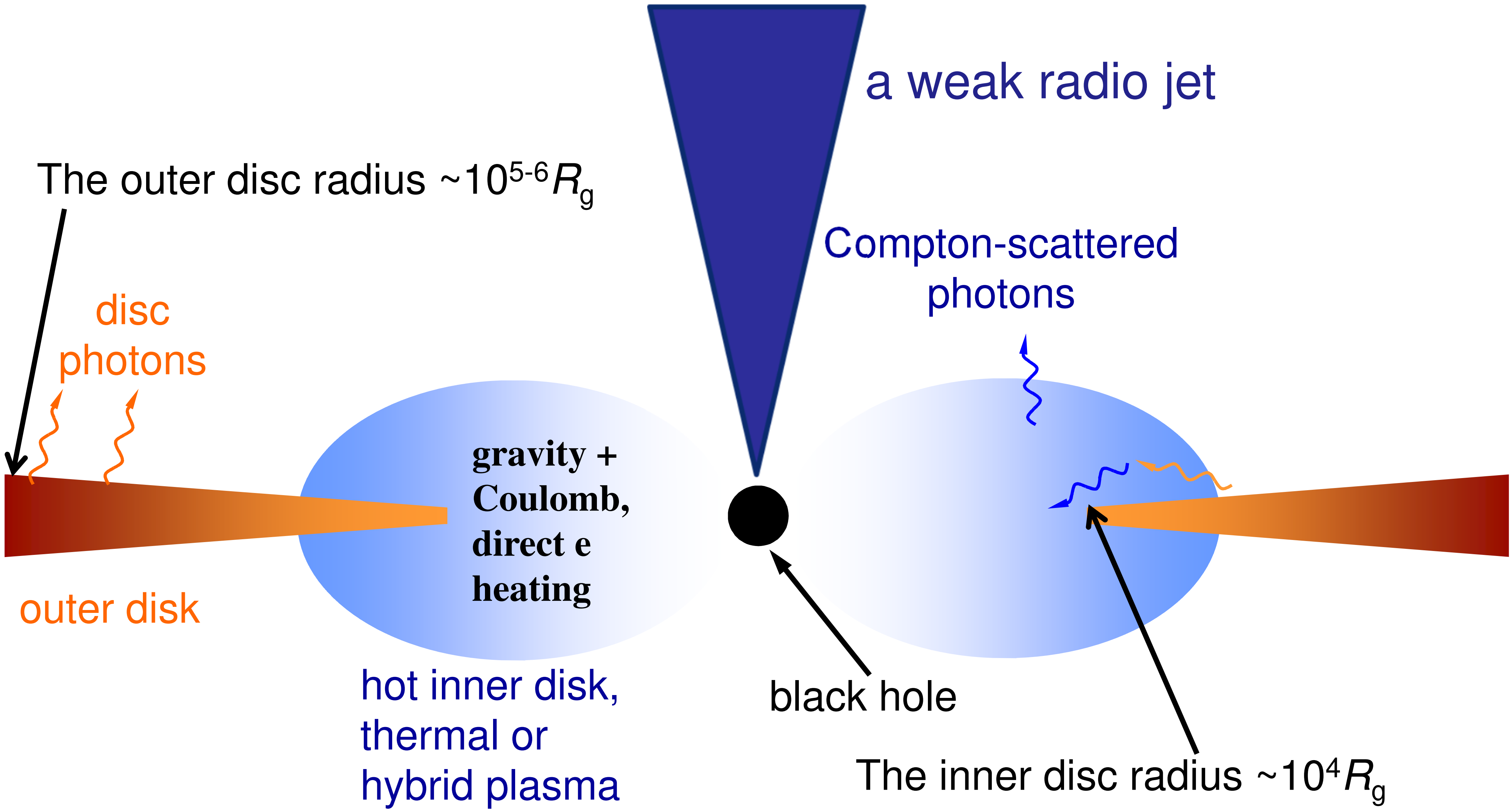
Our studies of MAXI J1820+070

1. AAZ+21a: spectral fitting of NuSTAR data, $R_{\rm in} \gg R_{\rm g}$, two Comptonization zones.
2. AAZ+21b: NuSTAR+INTEGRAL data, $R_{\rm in} \gg R_{\rm g}$, hybrid Comptonization, pair production.
3. Dziełak+21: spectro-timing studies of NICER data, Lorentzian-resolved spectroscopy. The continuum is complex, at least two zones.
4. De Marco+21: timing studies of NICER data, long reverberation lags, Fourier-resolved spectroscopy, $R_{\rm in} \gg R_{\rm g}$.
5. AAZ, Tetarenko & Sikora 22a: modelling the radio-to-optical jet in the hard state.
6. AAZ+22b: follow up on (2) including HXMT spectra.
7. Mikołajewska+22: a study of the donor, the distance.

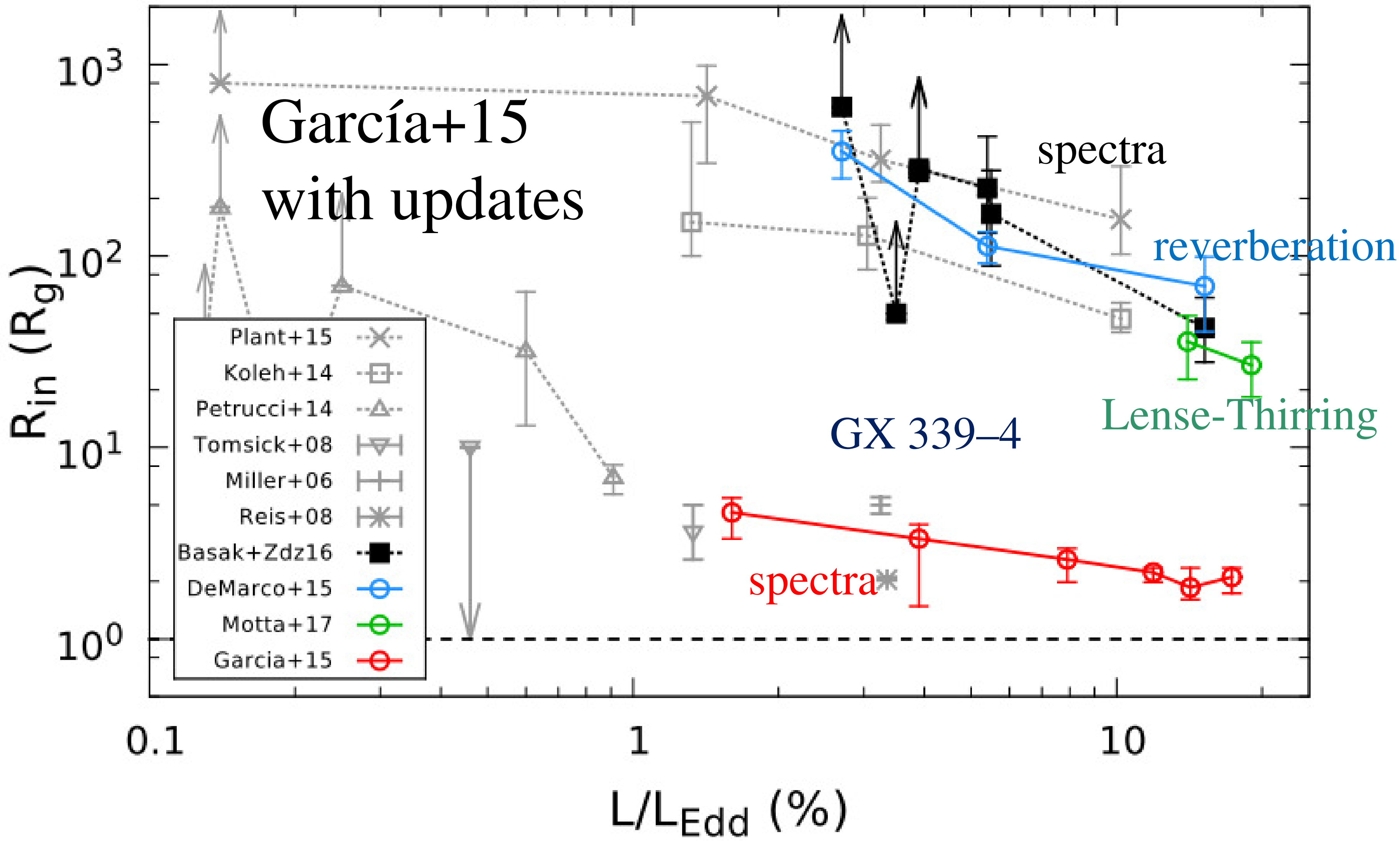
Evolution of discs and coronae in BH LMXBs

- Quiescence, years to tens of years, and outbursts (hard-soft-hard), months to years.
- Observed properties of outbursts in conflict with the disc instability model if the disc extends to the ISCO in quiescence. Also, a disc extending to ISCO cannot explain the observed quiescent X-ray luminosities (Dubus+01).
- $\longrightarrow$ the disc should be truncated at $R_{\rm in}\sim 10^{10}$ cm ($\sim 10^4\, R_{\rm g}$, $R_{\rm g}$=gravitational radius), with a hot accretion flow at $R<R_{\rm in}$.
- Confirming it, Bernardini+16 found (from the width of the Hα line) $R_{\rm in}\gtrsim 3\times 10^4 R_{\rm g}$ during the quiescence of V404 Cyg.
- The soft state: the disc at the ISCO.

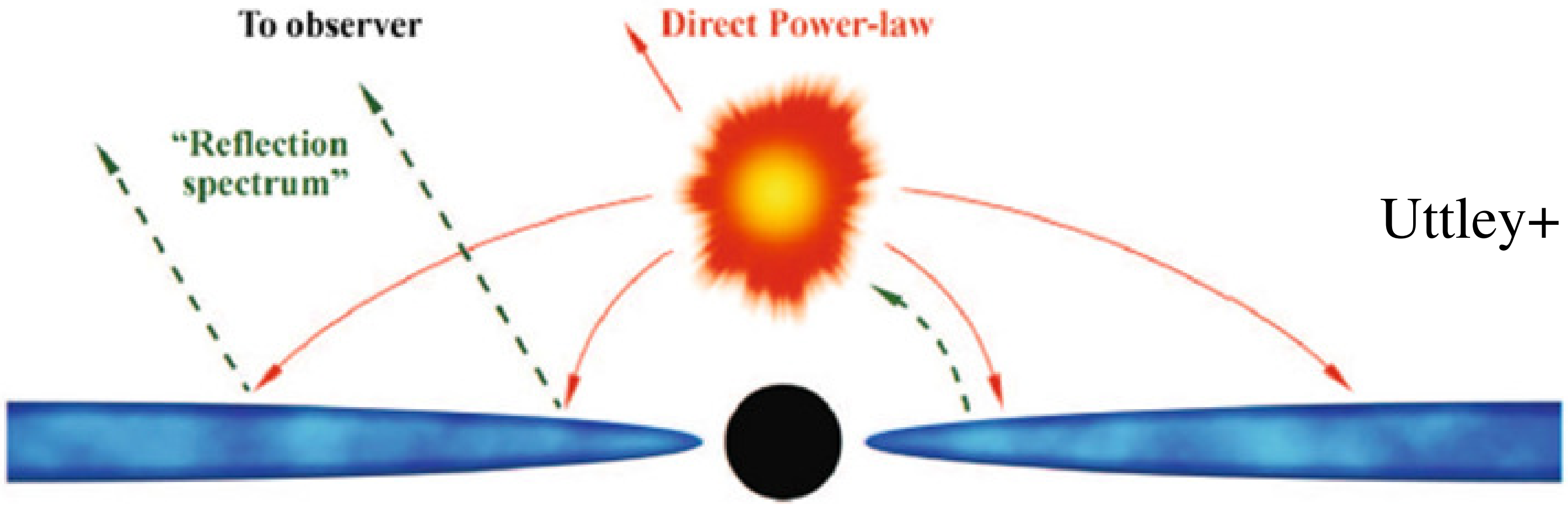
The geometry in the quiescent state



But a controversy regarding the truncation radii in the hard state: the case of GX 339–4



A popular model: a lamppost



Uttley+ 14

Originally adopted due to its mathematical simplicity but then widely used to describe the real source geometry.

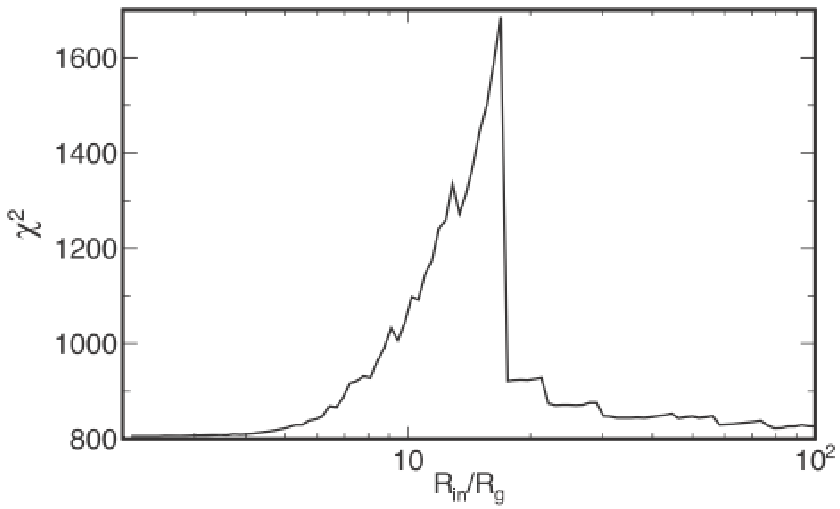
100% of the Comptonized emission in the lamppost; dissipation in the blackbody disc at a small fraction of the actual $\dot{M}$.

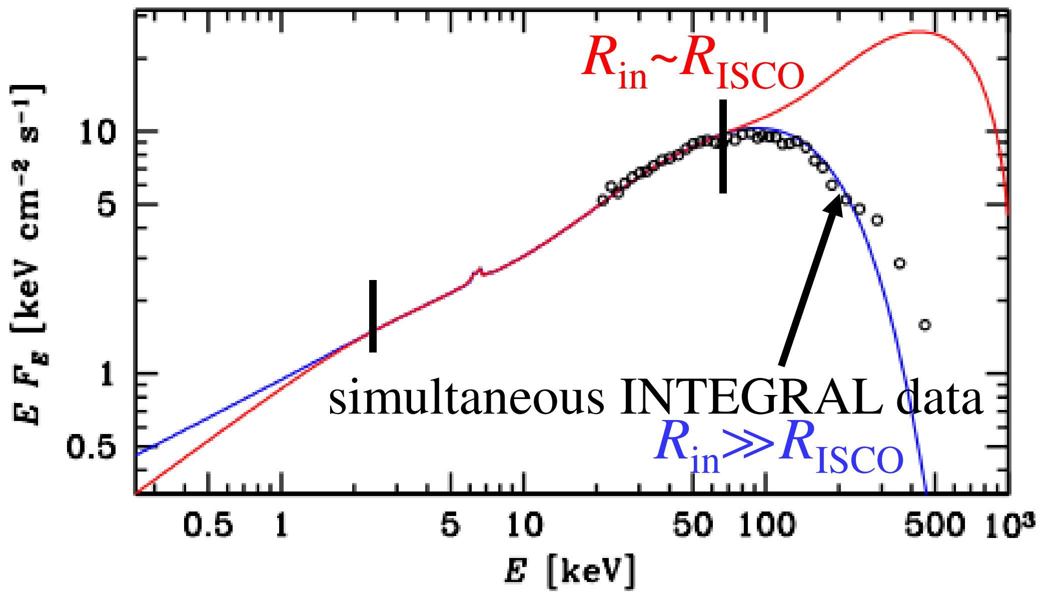
A small lamppost cannot intercept enough seed photons for Comptonization (Dovčiak & Done 2016).

Physically inconsistent if close to the horizon (which was claimed in many papers).

The lamppost model for MAXI J1820+070

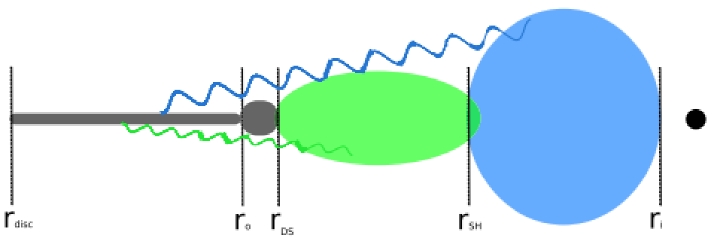
- Buisson+19 fitted the 3–78 keV NuSTAR data with two lampposts and $R_{\rm in}$~$R_{\rm ISCO}$, finding the disc inclination of i~30º and the Fe abundance of $Z_{\rm Fe}$≈4–7.
- However, both the binary and the jet have i ~60–80º (Atri+20, Torres+20), and the donor is likely to have a low metallicity.
- AAZ+21a found two solutions separated by a wall in χ^2, the 2nd one with $R_{\rm in} \gtrsim 20R_{\rm g}$, i~60–70º and $Z_{\rm Fe}$~1;
- the solution of Buisson+19 disagrees with the INTEGRAL data.





The continuum complexity:

- Given the observed complexity of the spectra, power spectra and time lags, it is highly unlikely that the hot emitting plasma in the accretion flow is homogeneous.
- Spectro-timing modelling of GX 339–4 by Mahmoud+2019 and of MAXI J1820+070 by Kawamura+2021 yield a flow with two cold and two hot zones:

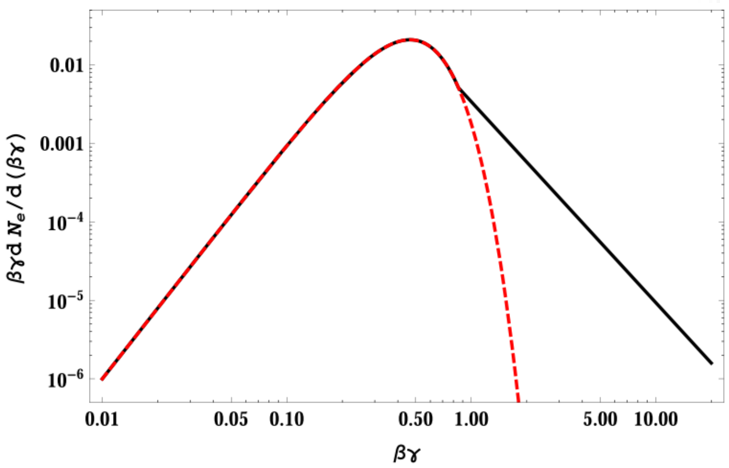


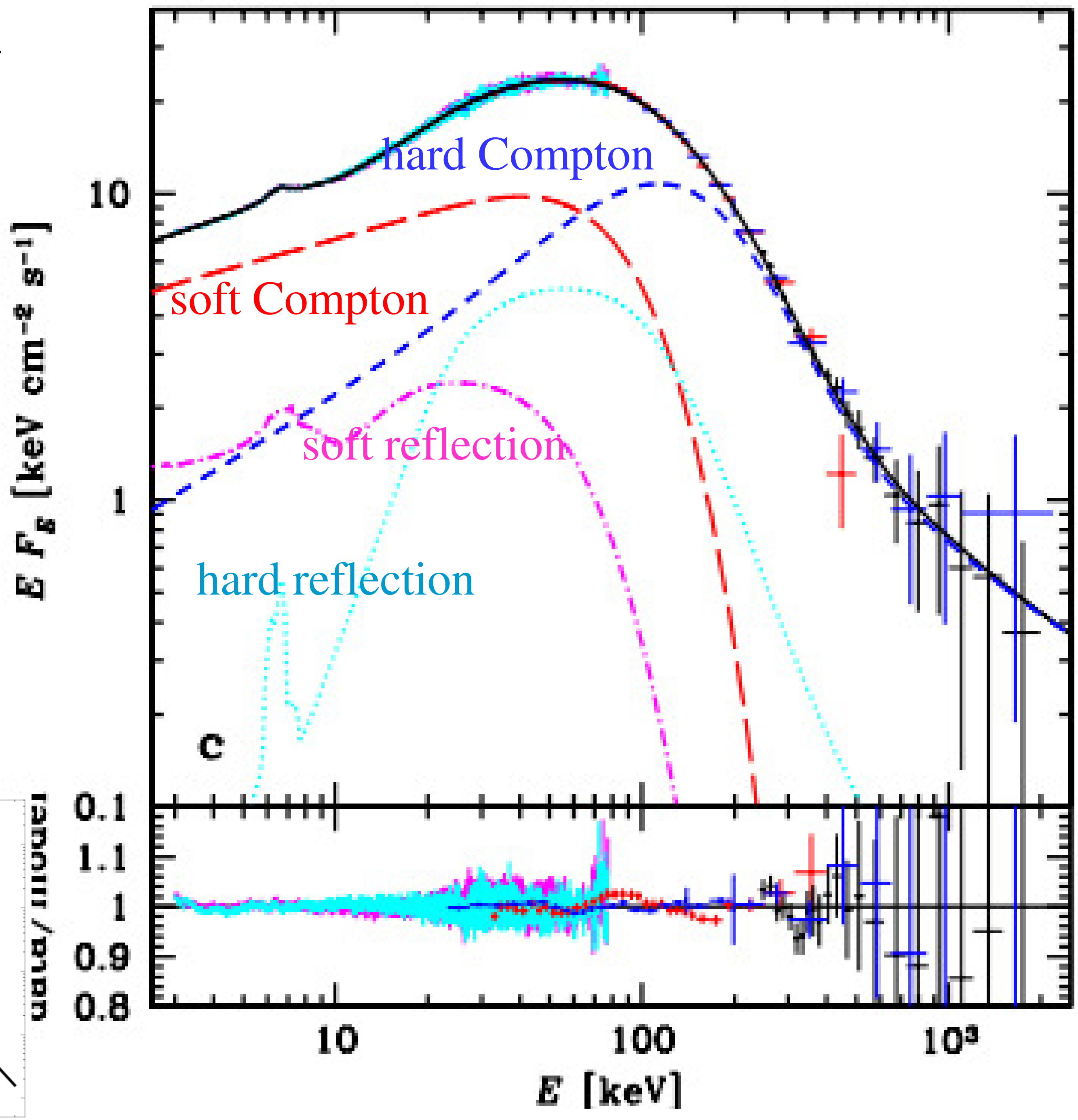
- They have been able to fit with their models the spectra, the power spectra and the lags between different energy bands in different frequency ranges.

Two-component Comptonization and reflection

$R_{\rm in} \gtrsim 20R_{\rm g}$,
i ~65°, $Z_{\rm Fe}$~1,
very good fits

Comptonization by hybrid electrons: Maxwellian + a high-energy tail:

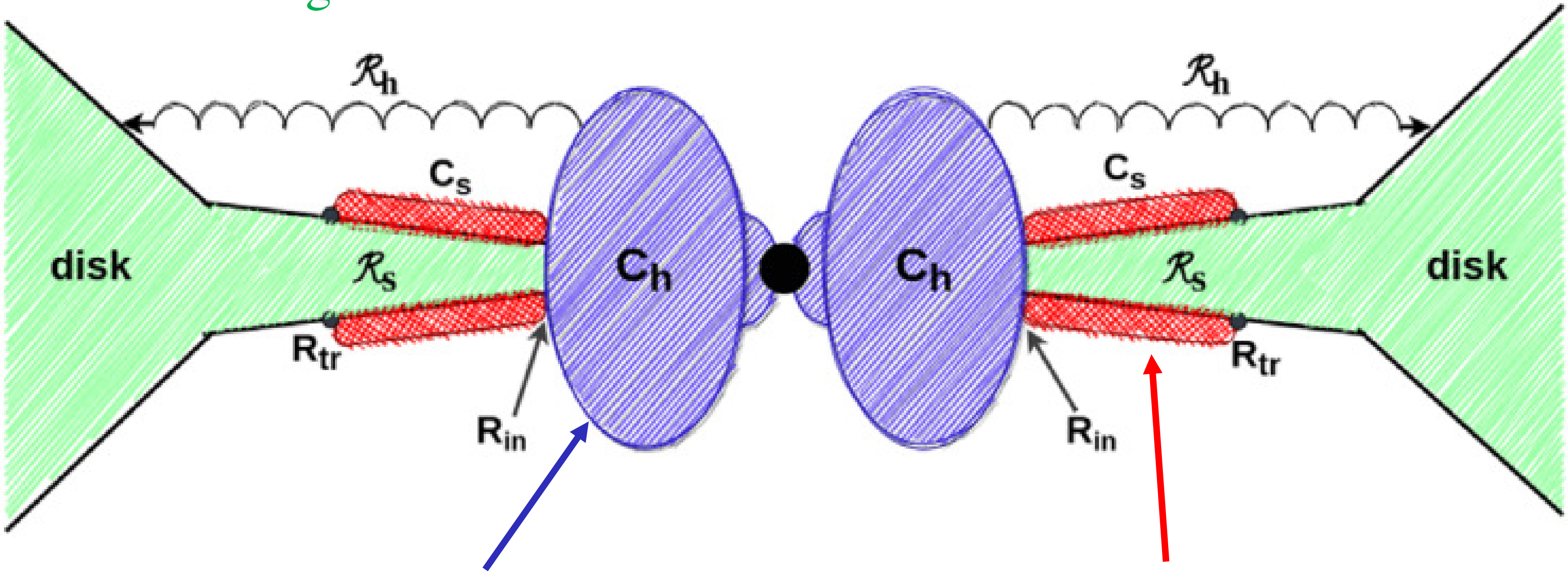




NuSTAR+INTEGRAL data; AAZ+21b

An accretion flow geometry implied by our fits

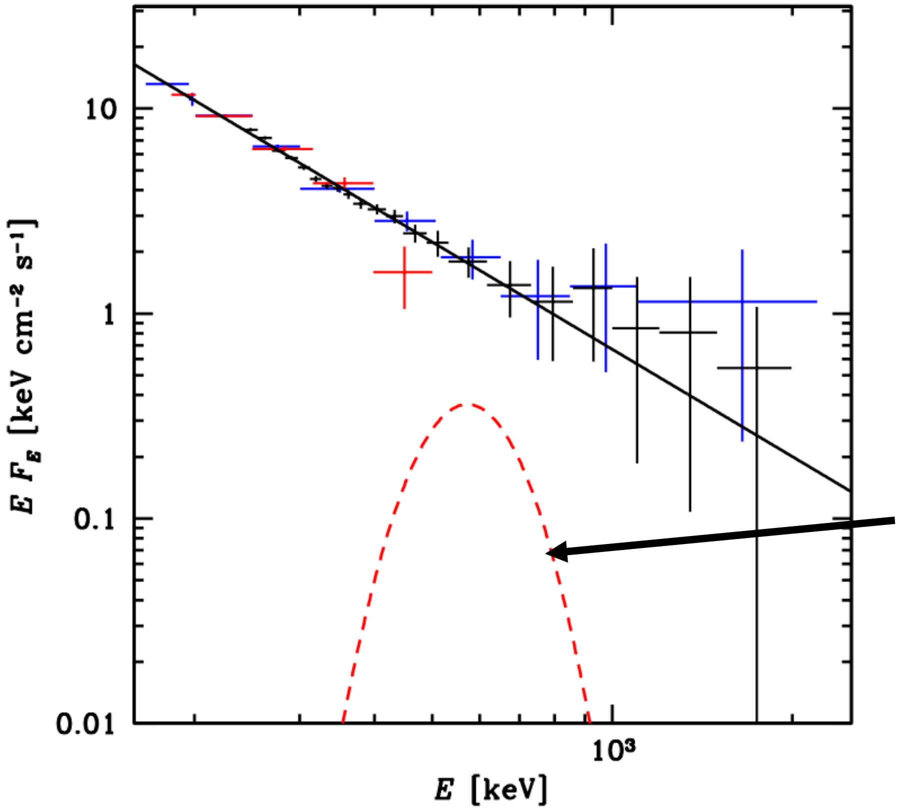
possible disc flaring



Hard hybrid Comptonization
in an inner flow reflecting
from remote parts of the disc

Soft Comptonization forming a
corona above the disc

A low e$^{\pm}$ pair density in the accretion flow

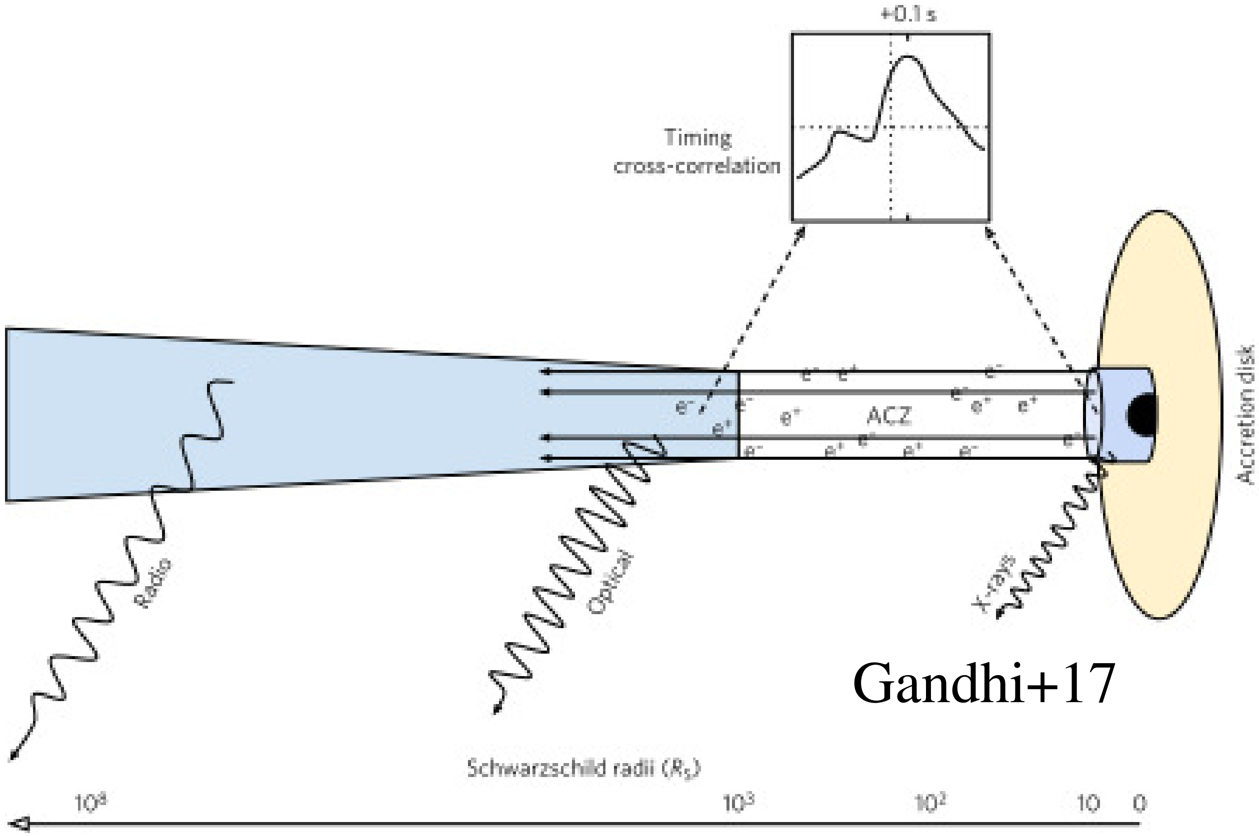


The 2σ upper limit on an annihilation line

AAZ+21b

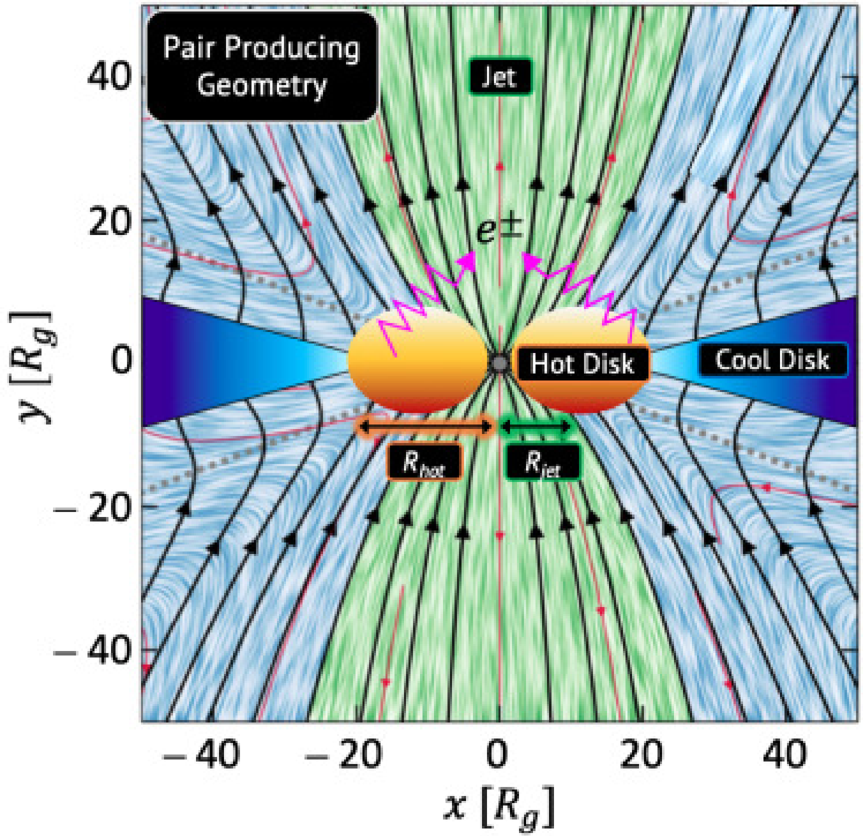
The continuum is detected up to ≈2 MeV; thus e$^{\pm}$ pairs are produced. However, the Thomson optical depth of the flow is large (several), pair annihilation is fast and the equilibrium fractional pair density found ≪1.

Pairs in jets: a disputed issue

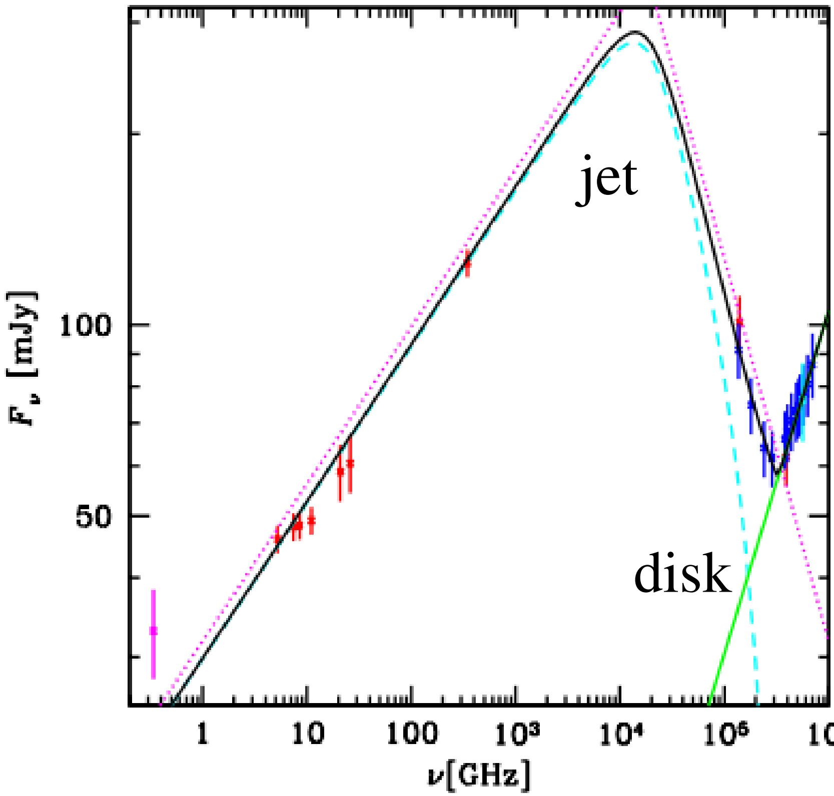


Gandhi+17

$e^{\pm}$ pair production in the jet base



The assumed geometry shown on the jet GRMHD simulation plot from Tchekhovskoy 2015.



The radio-to-optical spectrum with our fit

The pair production rate within the (empty) jet base: $10^{40-41} s^{-1} \approx$ the rate of the flow of $e^{\pm}$ calculated from the observed jet synchrotron emission. A remarkable coincidence, since both numbers are based on very different information.

AAZ+21c

→ Importance of pairs in the jet.

Conclusions

- The disc in accreting BH binaries is truncated during the quiescence and at ISCO in the soft state.
- $R_{\rm in} \gg R_{\rm g}$ in the hard state found in all our spectral and timing studies, in particular in MAXI J1820+070.
- The hot accretion flow consists of at least two Comptonization/reflection components.
- The electron distribution is hybrid, Maxwellian+a tail.
- Pairs are copiously produced, but the equilibrium pair density in the hot flow is low; no annihilation line seen.
- Pairs are also produced in the jet base, and can provide enough leptons for the radio–IR synchrotron emission.