Electron-positron pairs in jets in black-hole X-ray binaries

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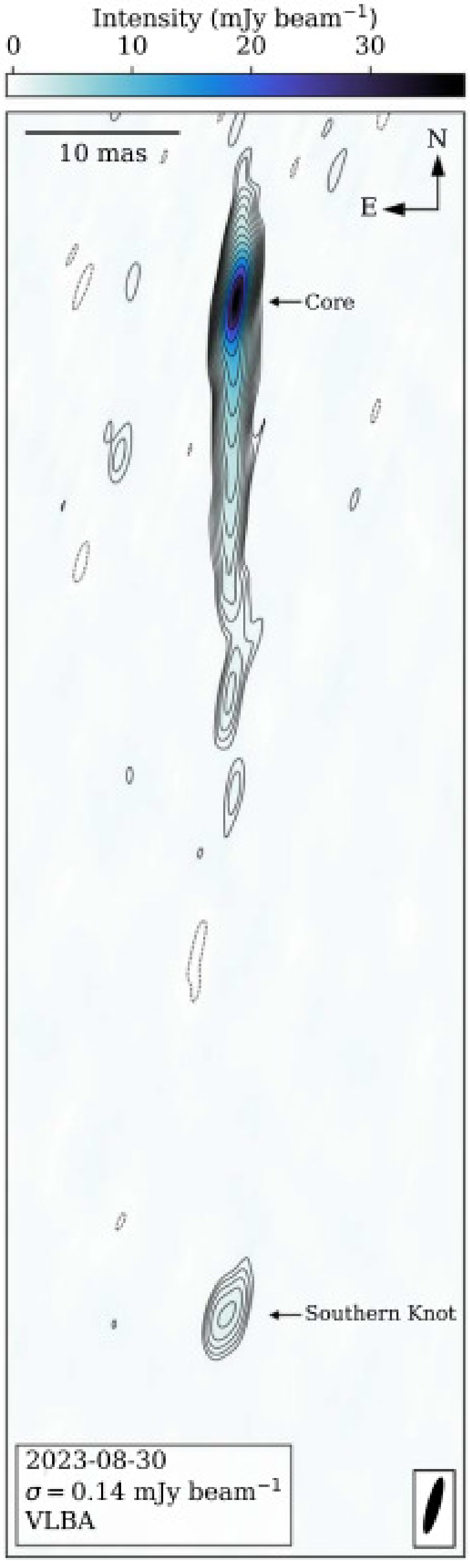
Two kinds of jets in BH binaries

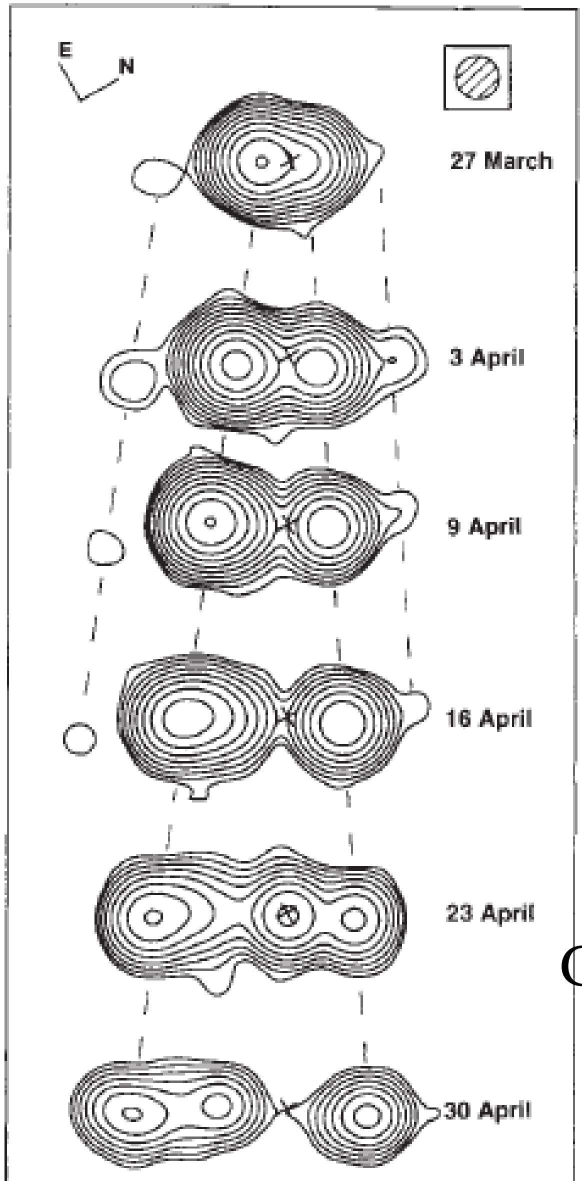


steady and compact,
low to high L,
hard state

~$10^{14\text{-}15}$cm

Swift J1727.8−1613

Wood+24



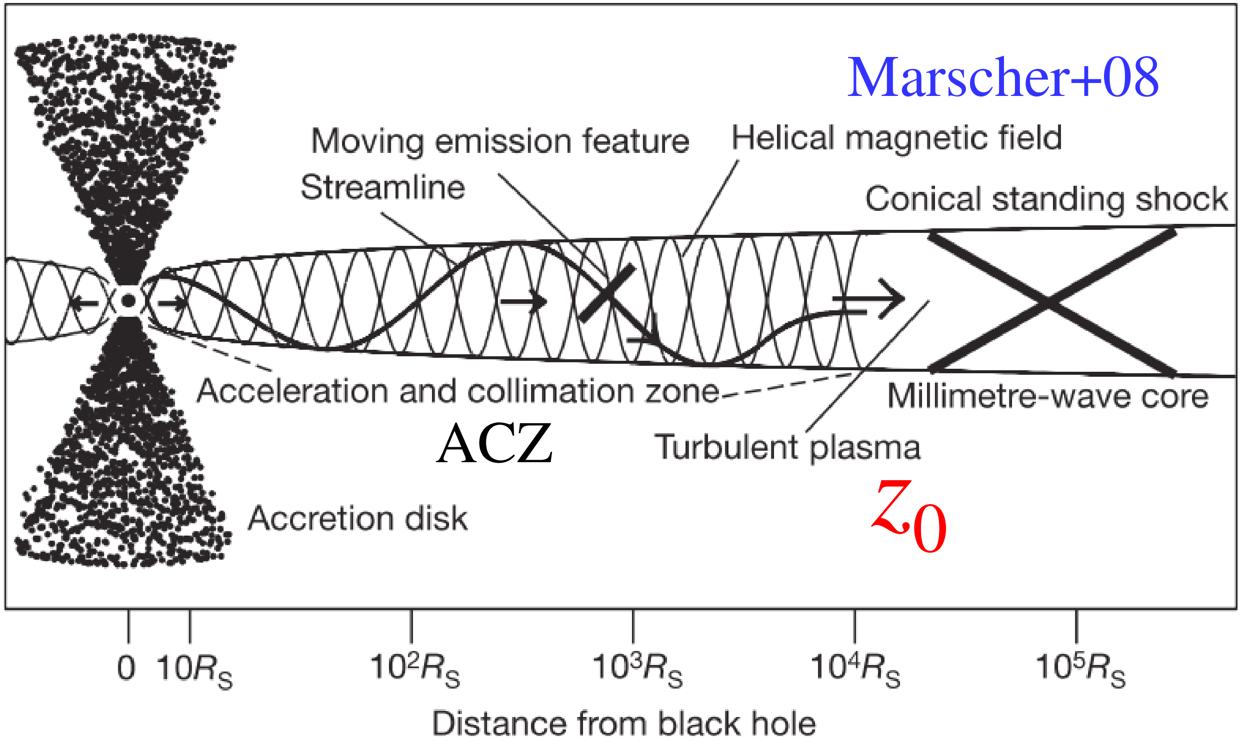
~$10^{17\text{-}18}$cm

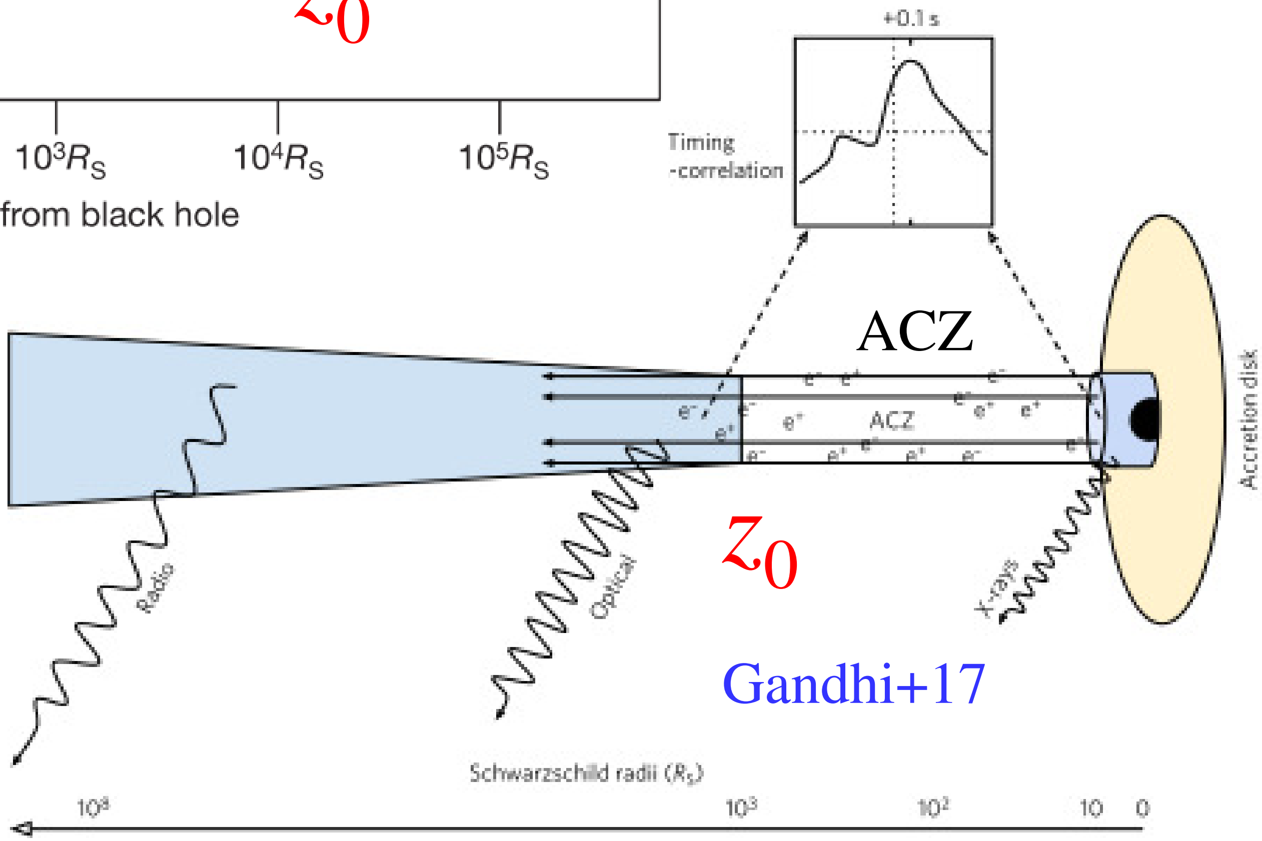
at
hard-to-soft
transitions

Mirabel+94

GRS 1915+105

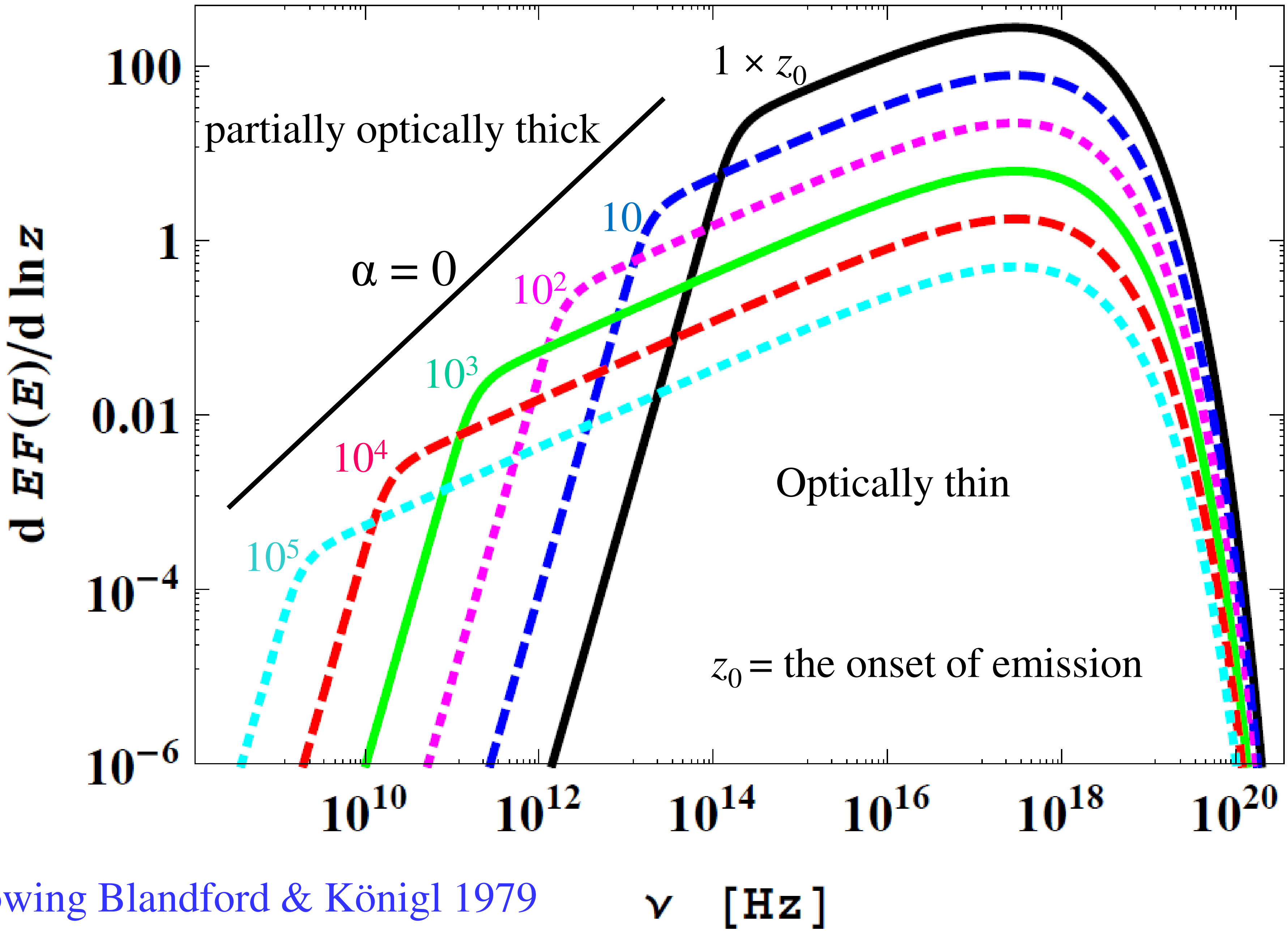
The compact jet structure





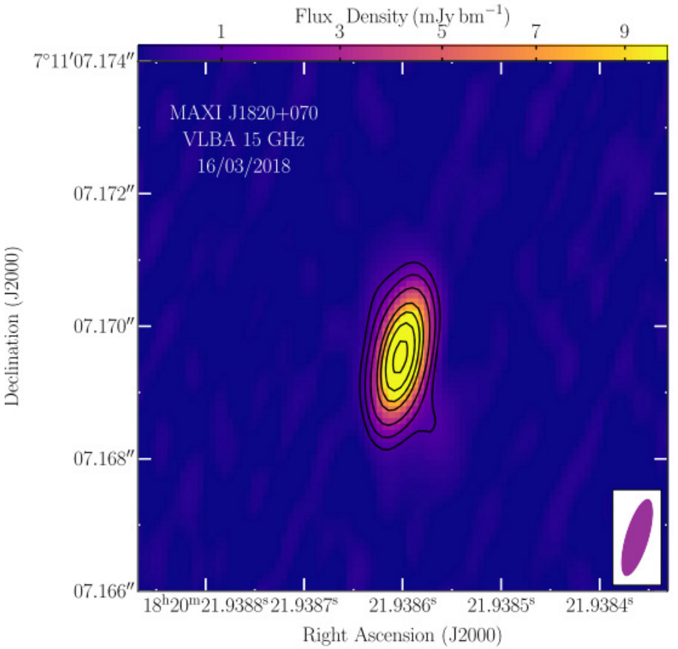
$z_0 \sim 10^{3\text{-}4}\ R_g$ from a ~0.1 s time lag of the IR vs. X-rays (Gandhi=17)

Spectra from different parts of the jet



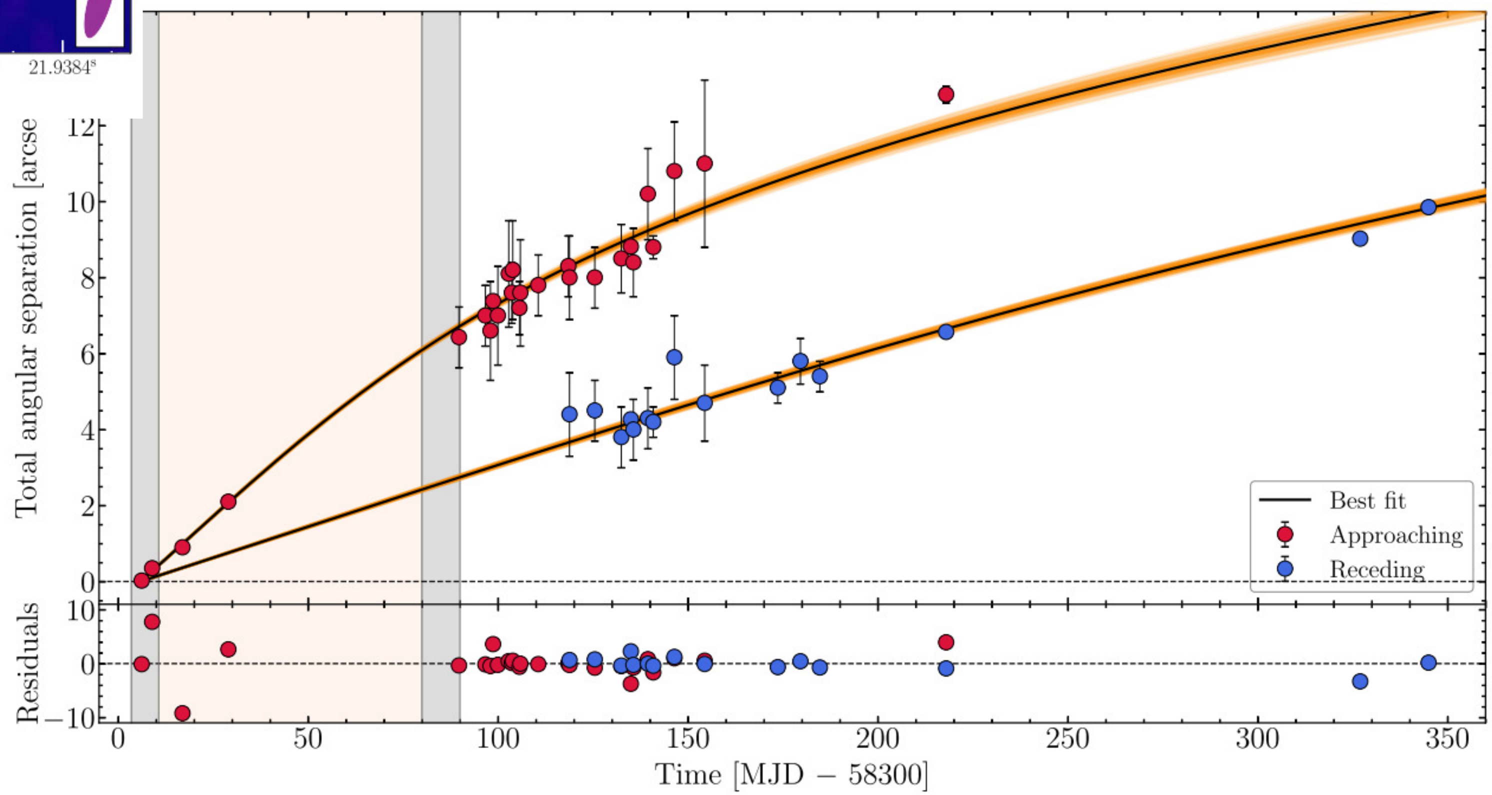
Following Blandford & Königl 1979

Jet propagation in MAXI J1820+070



Compact jet: barely resolved, milliarcsec scale (Tetarenko+21). Also, timing studies on a day with a high X-ray flux indicate the size $\lesssim 10^{14}$ cm.

Transient twin ejecta: seen up to 12 arcsec ≈ 6×10^{17} cm (Carotenuto+24).



How to explain the difference in the propagation?

- Transient jets propagating to pc scale have to be powerful; the highest possible jet power ~$\dot{M}_{\rm accr}c^2$.
- Compact jets, launched at similar $\dot{M}_{\rm accr}$ as transient jets, propagate to much shorter distances → a low power.
- Their power can be estimated from the synchrotron emission, which gives the e^{-}+e^{+} component only.
- The highest contribution to the jet power would be from the bulk motion of ions. For an e^{-}–ion jet in MAXI J1820+070, the compact jet power would equal that of the transient jets.
- **This implies that compact jets are dominated by $e^{\pm}$ pairs.**
- Can enough pairs be produced to account for the observed emission?

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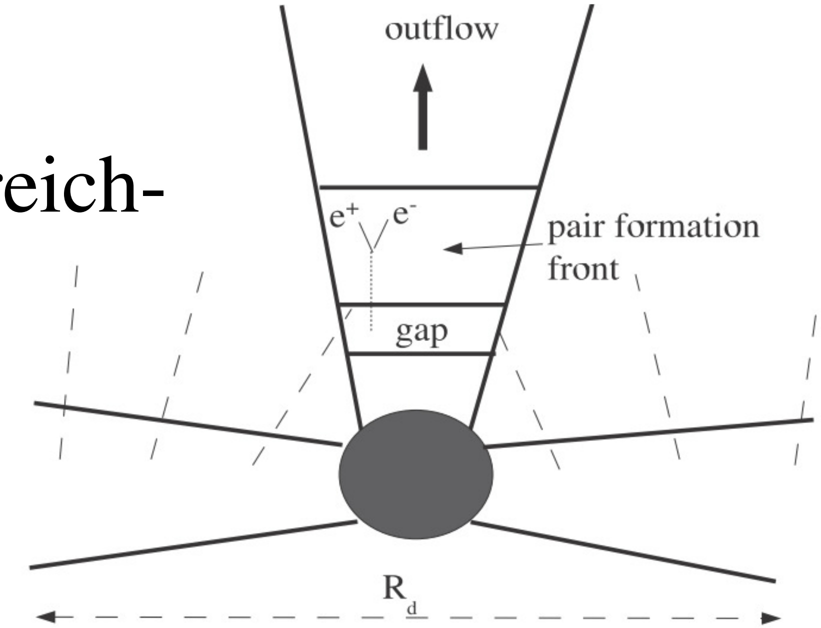
How to make e± pairs in jets?

- Arguments for $n_e \gg n_p$ in blazars and radio galaxies (e.g. Sikora+20).
- Pair production in spark gaps possible in the Blandford-Znajek mechanism.
- But this is limited by the Goldreich-

Julian density: $n_{GJ} = \frac{\Omega B}{2\pi e c} \propto P_j^{1/2}$

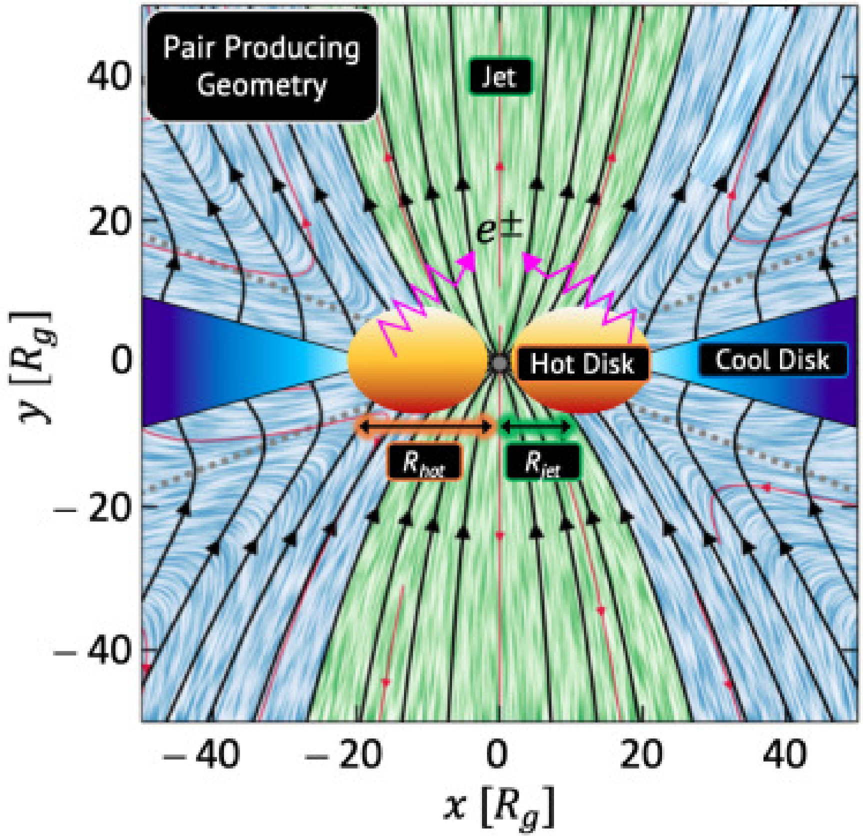
- Levinson & Rieger 07 give

a limit of $n \lesssim 10^3 n_{GJ}$.

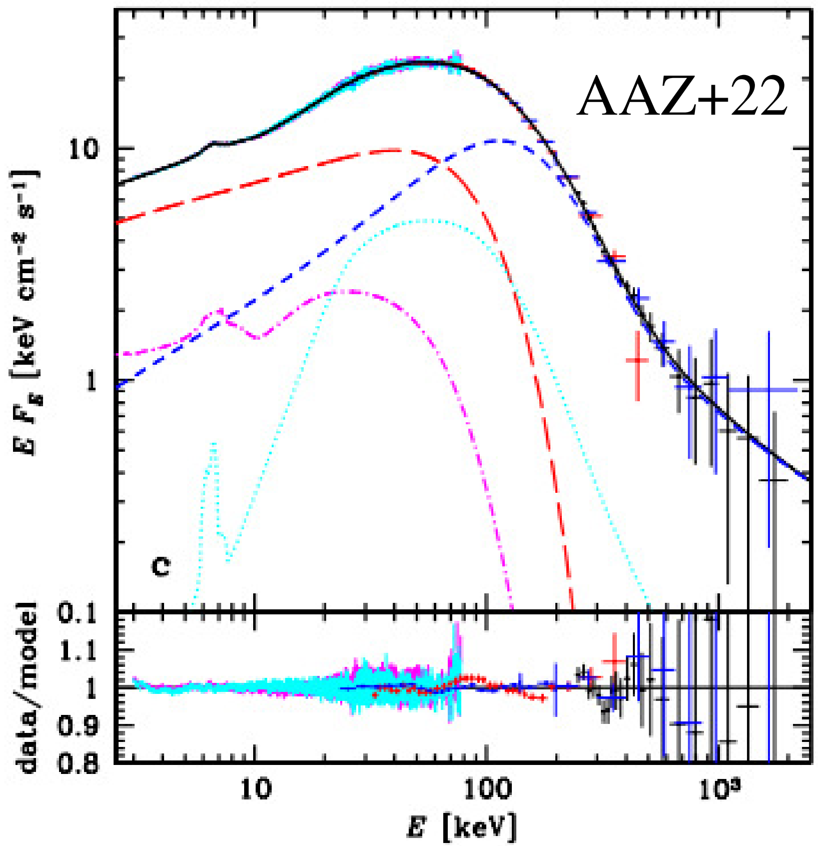


- Nokhrina+15 find ~$10^{12\text{-}15} n_{GJ}$ in blazars, and we find $>10^7 n_{GJ}$ in MAXI J1820+070.
- This rules out this process as producing most of pairs.

An alternative: $\gamma\gamma$ $e^{\pm}$ pair production



The proposed geometry overplotted on the jet simulation from Tchekhovskoy 15.

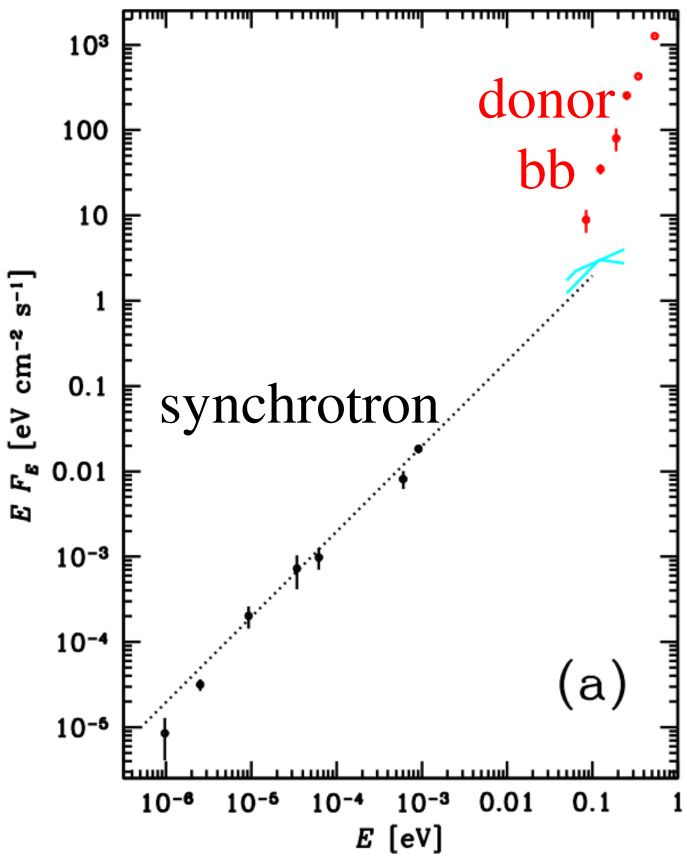


The spectrum of MAXI J1820+070 from NuSTAR and INTEGRAL

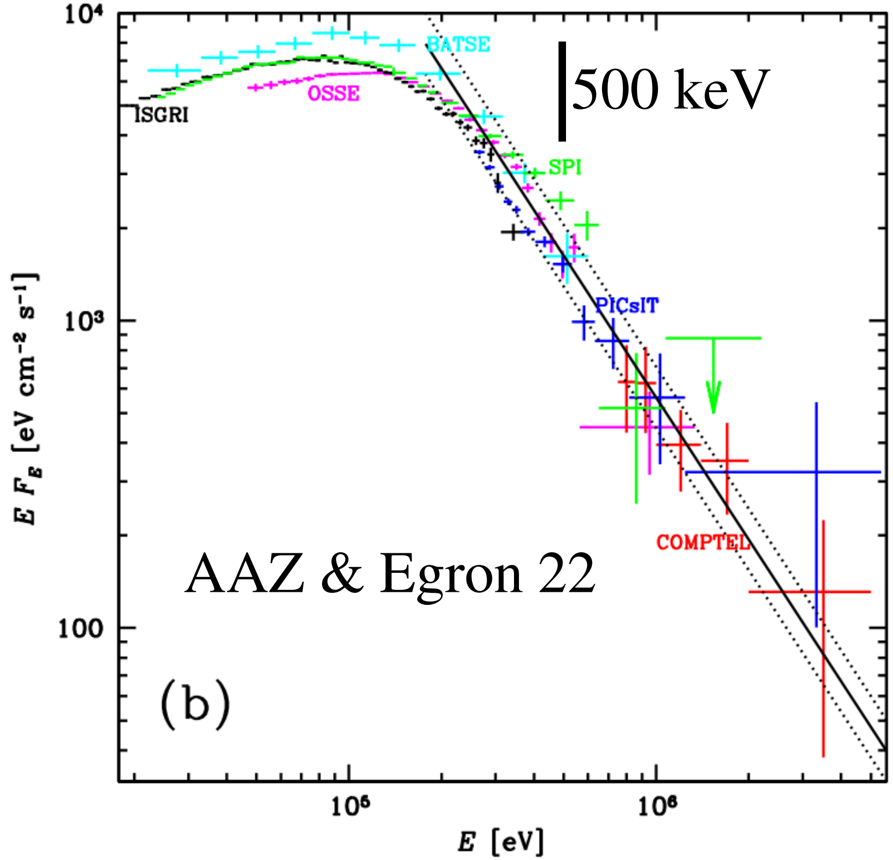
The pair production rate within the (empty) jet base: $10^{40-41}\mathrm{s}^{-1} \approx$ the rate of the flow of $e^{\pm}$ calculated from the observed synchrotron emission. A remarkable coincidence, since both numbers are based on very different information.

→ Pairs dominate the jet by number. The same results for Cyg X-1 and 3C 120.

$\gamma\gamma$ $e^{\pm}$ pair production in Cyg X-1



The radio-to-IR spectrum
→ the electron flow rate

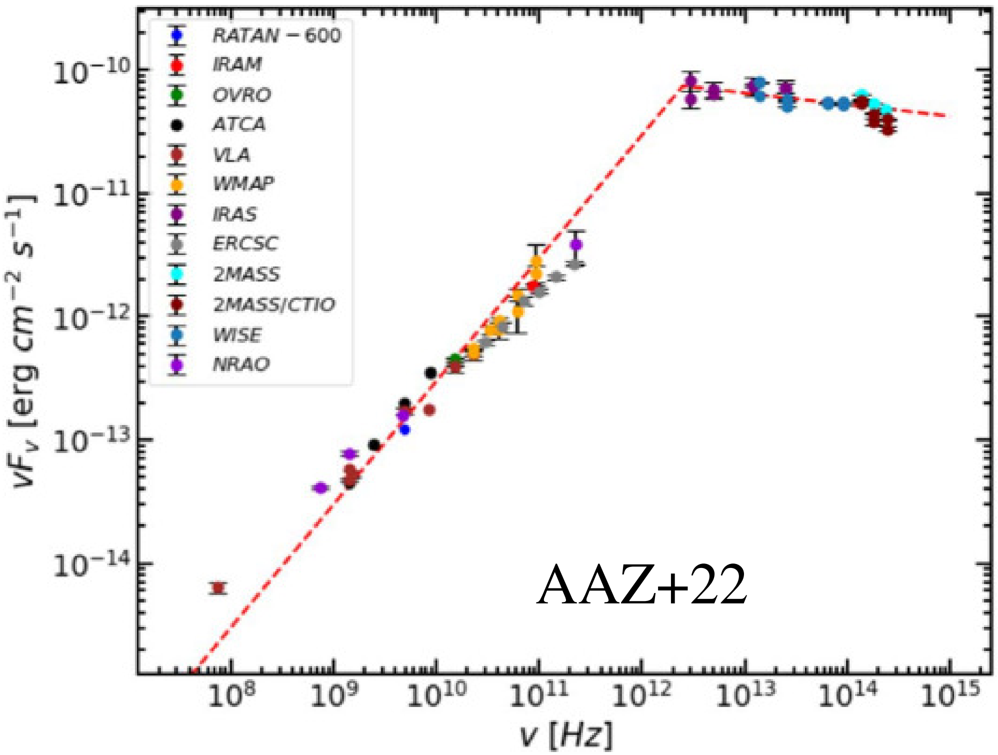


The Xγ spectrum of Cyg X-1
from CGRO and INTEGRAL →
the pair production rate

The pair production rate within the jet base: ~10^{40} s^{-1} ≈ the rate of the flow of $e^{\pm}$
calculated at ~$10^6 R_g$ from the observed synchrotron emission

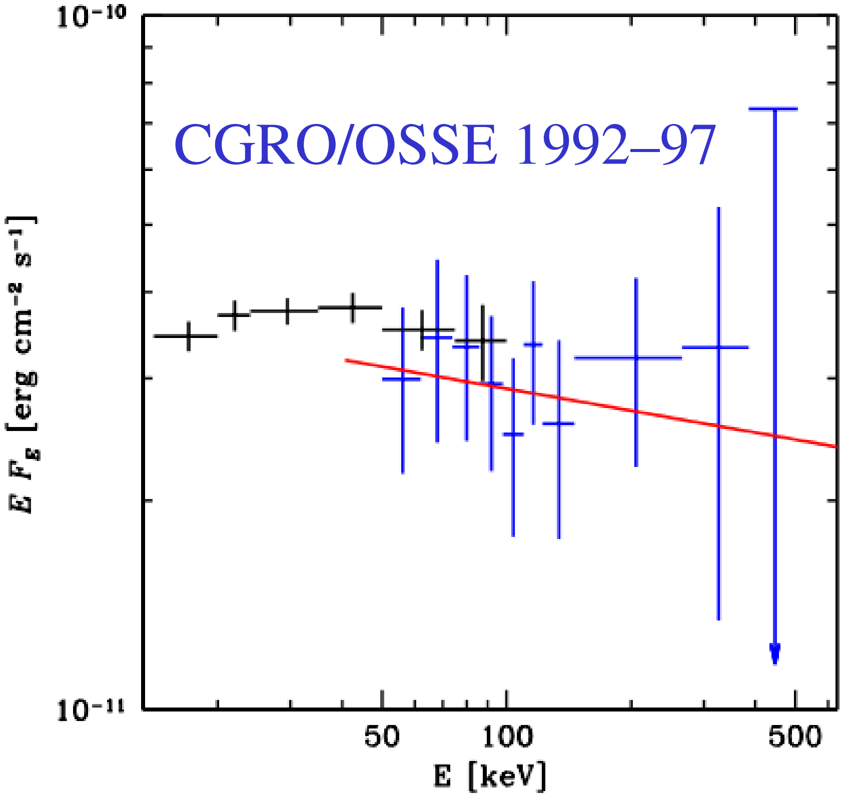
→ Pairs may dominate the jet by number.

γγ e± pair production in 3C 120



The radio-to-IR spectrum → the electron flow rate

$$\dot{N}_{\rm e} \approx 2.7^{+12}_{-2.3} \times 10^{49}\ {\rm s}^{-1}$$



The Xγ spectrum → the pair production rate

$$2\dot{N}_{+} \approx 3.9^{+6.3}_{-2.8} \times 10^{49} \left(\frac{R_{\rm hot}}{10R_{\rm g}}\right)^{-1} \left(\frac{R_{\rm jet}}{R_{\rm hot}}\right)^{2} {\rm s}^{-1}$$

The same agreement as in Cyg X-1 and MAXI J1820+070.
Compact/core jets are likely to be dominated by e± pairs.

Conclusions

- Two types of jets in accreting BH binaries: compact steady jets and transient ejections.
- Their propagation is completely different, to milliarsec scale in compact jets, and to arcsec scale in transient jets, in spite of the similar $\dot{M}_{\rm accr}$ estimated from the accretion emission.
- Both types of jets probably launched magnetically, but $P_{\rm jet} \approx \dot{M}_{\rm accr}c^2$ in transient jets and $P_{\rm jet} \ll \dot{M}_{\rm accr}c^2$ in compact jets.
- $P_{\rm jet}$ estimated from synchrotron emission in compact jets implies those jets are made mostly of $e^{\pm}$ pairs.
- Pair production within the compact jet base by accretion-flow photons can provide enough $e^{\pm}$ pairs.
- Transient jets too heavy to be dominated by pairs; mostly ions.