A kinetic model of jet-corona coupling in accreting black holes

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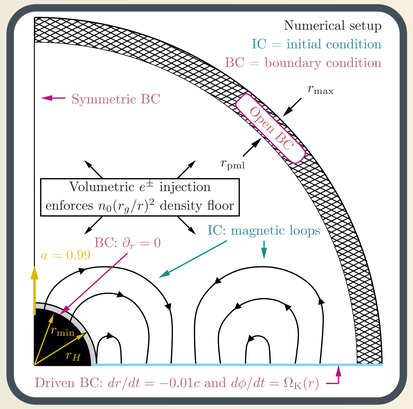
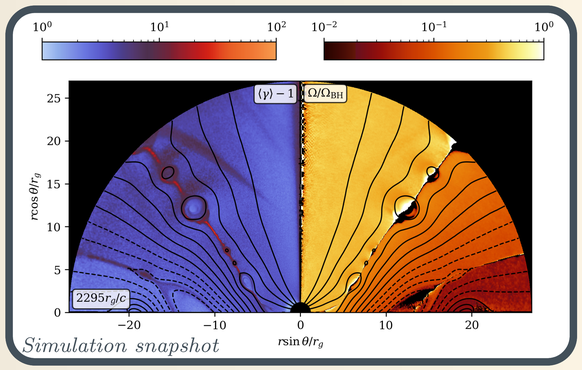
Context

- Black hole (BH) accretion disk coronae may emit high-energy radiation and influence BH jet production, as suggested, e.g., by concomitant radio ejections and X-ray flaring in BH X-ray binaries [1]
- Reconnection is a likely essential mechanism for both powering the coronal emission [2] and regulating jet formation [3]
- Only kinetic plasma physics captures both particle acceleration and the true reconnection rate, allowing a reliable link between reconnection-powered high-energy radiation and reconnection-regulated jet production.
- We aim to elucidate this link via a global kinetic model of a BH feeding on its accretion disk corona.

Model



- General relativistic particle-in-cell simulations
- Code GRZELTRON [4]
- Initial poloidal magnetic loops, size $\gg r_g = GM/c^2$
- Driven equatorial BC as a proxy for accretion disk
- Loop footpoint driving: Keplerian rotation + radial inward dragging



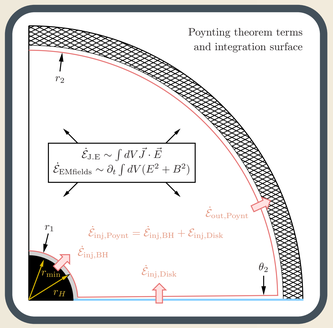
Simulation snapshot

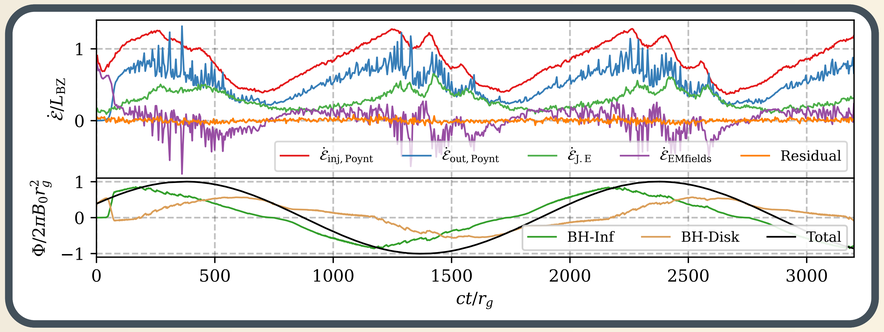
- Rotational shear inflates loops and opens field lines
- Reconnection closes field lines back up, setting balance between open/closed flux bundles
- Open field lines attached to BH form powerful jet
- BH unties loops, ejecting them towards infinity
- Loop accretion and ejection cycles dominate energy budget and radiative signatures

Link to film

Energy budget

- Integrate Poynting's theorem across simulation domain (left-hand figure)
- Extract time series of Poynting power injected by disk plus BH ($\dot{\mathcal{E}}_{\rm inj,Poynt}$), outflowing Poynting power ($\dot{\mathcal{E}}_{\rm out,Poynt}$), dissipation by reconnection ($\dot{\mathcal{E}}_{\rm J.E}$), and rate-of-change of field energy ($\dot{\mathcal{E}}_{\rm EMfields}$; middle figure)
- Compare to time series of total, open (BH-Inf), and disk-connected (BH-Disk) magnetic flux threading BH (middle figure)
- All quantities vary on loop accretion and ejection period ($1000r_g/c$)
- Dissipation peaks as reconnection whittles down jet-funnel magnetic flux
- **Reconnection efficiently dissipates Poynting power**: consumes $\simeq 1/3$ of time-averaged energy budget (right-hand table)

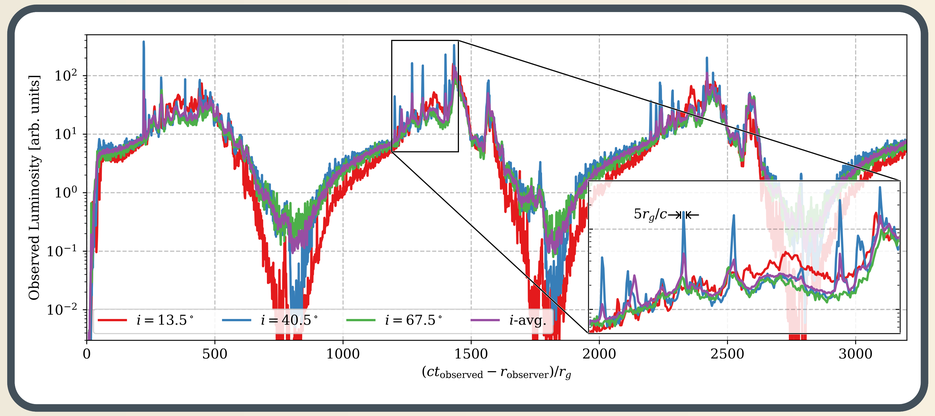




Time-averaged terms in Poynting's theorem

	$\langle\dot{\mathcal{E}}\rangle/\langle\dot{\mathcal{E}}_{\rm inj,Poynt}\rangle$
$\langle\dot{\mathcal{E}}_{\rm inj,Poynt}\rangle$	1.00
$\langle\dot{\mathcal{E}}_{\rm out,Poynt}\rangle$	0.64
$\langle\dot{\mathcal{E}}_{\rm E.J}\rangle$	0.36
$\langle\dot{\mathcal{E}}_{\rm EMfields}\rangle$	0.00
Residual	0.00

Radiative signatures



- Ray-trace [5] synchrotron photons to far-away observers
- Vary observer inclination angle, i, from BH spin axis
- All observers see alternating bright/dark periods on loop accretion/ejection period
- Bright periods powered by vigorous jet-wall reconnection
- Current-sheet-aligned observers ($i = 40.5°$) witness Doppler-enhanced variability down to timescales $\sim r_g/c$

⇒ **Ejection of magnetic flux heralded by bright observable counterpart**

Conclusions

1. **Magnetic reconnection links jet launch to high-energy emission in BH accretion disk coronae**
   (a) Reconnection preys on the jet funnel and can eject the flux initially tied to the BH
   (b) This may explain correlated radio ejections and X-ray flares frequently seen during X-ray binary state transitions [1]
2. **Reconnection efficiently converts jet Poynting power into particle kinetic energy**
   (a) Already $\simeq 1/3$ of energy budget dissipated within simulation. Expect to continue to larger radii
3. **Loop accretion and ejection cycles lead to dramatic radiative signatures**
   (a) All observers see one bright and one dark period per processed loop
   (b) Privileged current-sheet-aligned observers witness enhanced, exceptionally rapid ($\sim r_g/c$) variability

References

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This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement no. 863412).