An Observational Signature of Sub-equipartition Magnetic Fields in the Spectra of Black Hole Binaries

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Basic model structure

Image credit: Nemmen et al. (2014)
Equipartition

Magnetic field properties in inner region uncertain

Magnetic field influences disk structure & spectral properties

Equipartition assumption proposed by Shvartsman (1971)

Requires dissipation mechanism, not well understood

\[
\varepsilon_B = \frac{B^2}{8\pi} \quad \varepsilon_{gr} = \frac{1}{2} \rho u^2
\]

\[
\varepsilon_B \sim r^{-4} \quad \varepsilon_{gr} \sim r^{-5/2}
\]

\[
\varepsilon_{eq} = \frac{\varepsilon_B}{\varepsilon_{gr}}
\]
The thin disk contributes mainly in the optical/infrared range

\[ T(r) = \left\{ \frac{3GM\dot{M}}{8\pi r^3\sigma} \left[ 1 - \left( \frac{r}{r_s} \right) \right]^{1/2} \right\}^{1/4} \]
The thick disk contributes from the radio to the optical

\[ B(r) = \sqrt{4\pi \varepsilon_0 \mu m_n} n_0 \left( \frac{r}{r_s} \right)^{-5/4} \]
The thin disk constrains the accretion rate

$$\dot{M} = 1.2 \times 10^{-11} \, \text{M}_\odot \, \text{yr}^{-1}$$

Data: Gallo et al. (2019)
The thin disk constrains the accretion rate

\[ \dot{M} = 9 \times 10^{-12} M_\odot \text{ yr}^{-1} \]

Data: Gallo et al. (2019)
The thin disk constrains the accretion rate

\[ \dot{M} = 6 \times 10^{-12} M_\odot \text{ yr}^{-1} \]

Data: Gallo et al. (2019)
The thin disk constrains the accretion rate

\[ \dot{M} = 4 \times 10^{-12} M_\odot \text{ yr}^{-1} \]

Data: Gallo et al. (2019)
The thin disk constrains the accretion rate

\[ \dot{M} = 2.75 \times 10^{-12} M_\odot \text{ yr}^{-1} \]

Data: Gallo et al. (2019)
Result – magnetic field in inner disk must be sub-equipartition

\[ \varepsilon_{eq} = 1 \]

Data: Gallo et al. (2019)
Result – magnetic field in inner disk must be sub-equipartition

$\dot{M} = 2.75 \times 10^{-12} M_\odot \text{ yr}^{-1}$

$\varepsilon_{eq} = 0.5$

Data: Gallo et al. (2019)
Result – magnetic field in inner disk must be sub-equipartition

\[ \dot{M} = 2.75 \times 10^{-12} M_\odot \text{ yr}^{-1} \]

\[ \varepsilon_{\text{eq}} = 0.2 \]

Data: Gallo et al. (2019)
Result – magnetic field in inner disk must be sub-equipartition

\[ \dot{M} = 2.75 \times 10^{-12} M_\odot \text{ yr}^{-1} \]

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\[ \varepsilon_{\text{eq}} = 10^{-1} \]

Data: Gallo et al. (2019)
Result – magnetic field in inner disk must be sub-equipartition

\[ \dot{M} = 2.75 \times 10^{-12} M_\odot \text{ yr}^{-1} \]

\[ \varepsilon_{eq} = 10^{-2} \]

Data: Gallo et al. (2019)
Result – magnetic field in inner disk must be sub-equipartition

\[
\dot{M} = 2.75 \times 10^{-12} M_\odot \text{ yr}^{-1}
\]

\[\varepsilon_{eq} = 10^{-3}\]

Data: Gallo et al. (2019)
Other quiescent sources also have $\varepsilon_{\text{eq}} << 1$

\[ \dot{M} = 3 \times 10^{-12} M_\odot \text{ yr}^{-1} \]

\[ \varepsilon_{\text{eq}} = 8 \times 10^{-4} \]

\[ \dot{M} = 1.5 \times 10^{-9} M_\odot \text{ yr}^{-1} \]

\[ \varepsilon_{\text{eq}} = 2 \times 10^{-9} \]

Data: Gallo et al. (2007)

Low magnetization across multiple quiescent sources
Implications of a low magnetic field strength

Magnetic field strength in the quiescent state is found to be strongly sub-equipartition across several sources

Jet launching powered by magnetic field – does B-Z mechanism work here?

Strong dissipation could result in strong heating

Is disk structure affected by dissipation?

Image credit: Damien Bégué
Remaining questions

Model does not explain lowest energy observations

Jet or outflow still required for those data points

Can a weak magnetic field power a jet?

What mechanisms can dissipate magnetic field strongly enough?
Summary

Magnetic field properties in BHBs still uncertain

Often assumed to be at equipartition

Modeled three sources in quiescent state

Synchrotron in inner disk provides the magnetic field constraint

Qualitatively matched spectrum with low magnetic field strength

Agreement at $\epsilon_{eq} \sim 10^{-3}$, even as low as $10^{-9}$

Consequences for jet-launching and disk structure

How does strong dissipation affect the disk? Is a jet still launched? What about other states?