Rapid radio variability of X-ray binary jets and neutron star jet polarization

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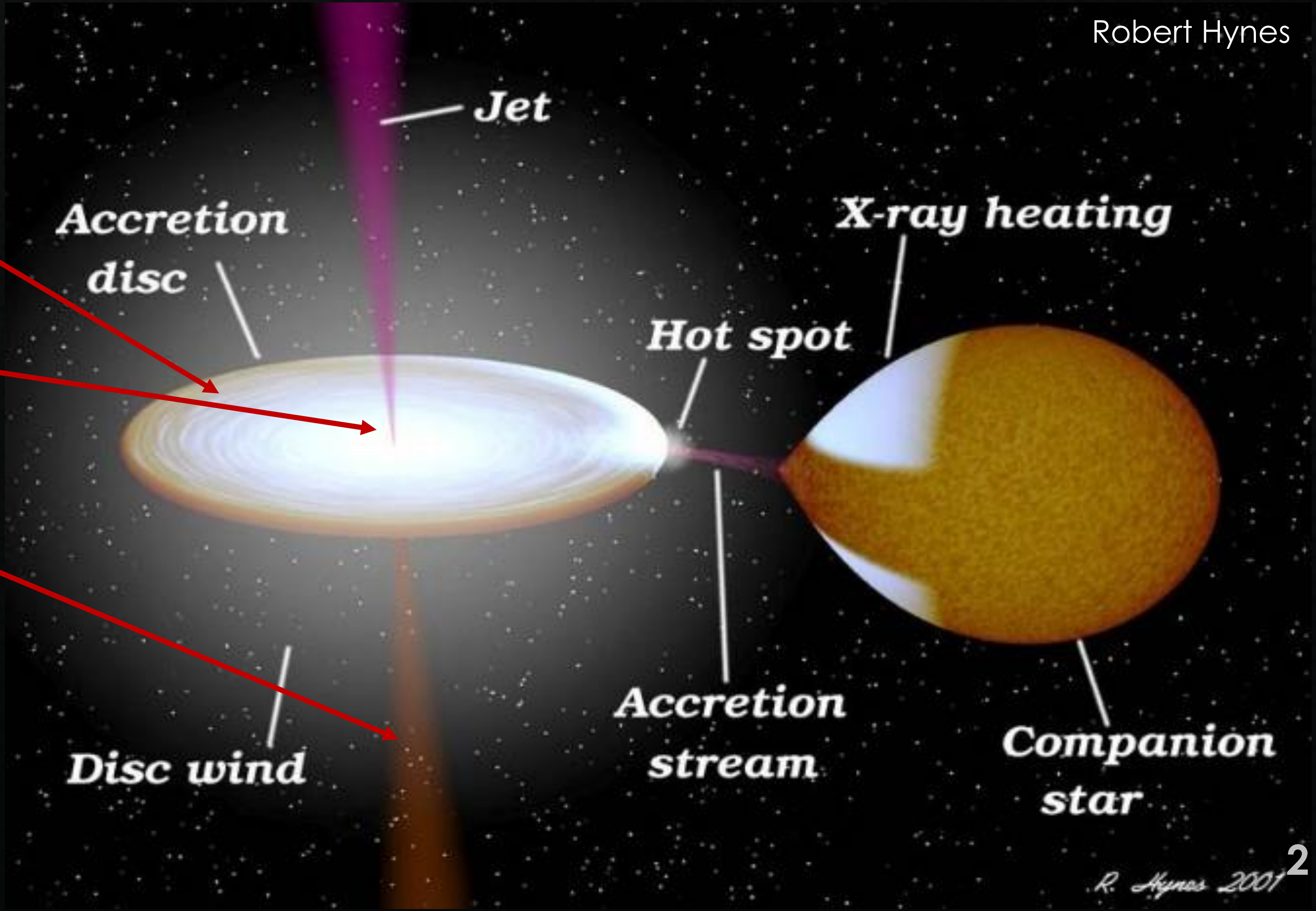
X-ray Binaries (XRBs)

- Black hole (BH) or neutron star (NS) accreting matter from a companion

- Accretion disk: optical/infrared
- Inner accretion disk: X-rays
- Jets: Sub-mm to radio
  - mildly or highly relativistic



X-ray Binary Jets

- Many open questions regarding their formation and launching by magnetic fields, and how they are fed material
- Neutron star jets are less understood than black hole jets

Fender+99

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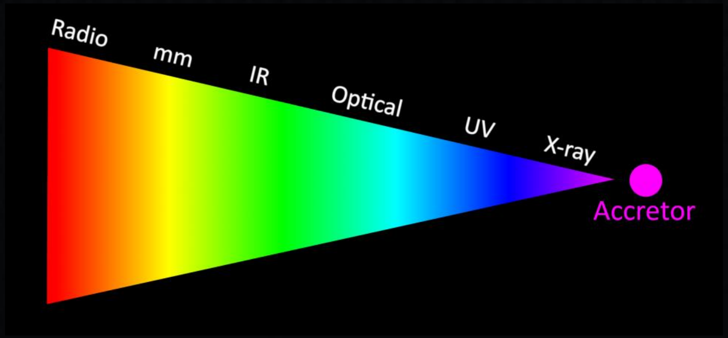
- Compact, steady jets
  - Blandford-Königl (1979)
  - Internal shocks (Malzac 2014)
  - Low $\dot{m}$ ($\lesssim 0.1\ L_{Edd}$)



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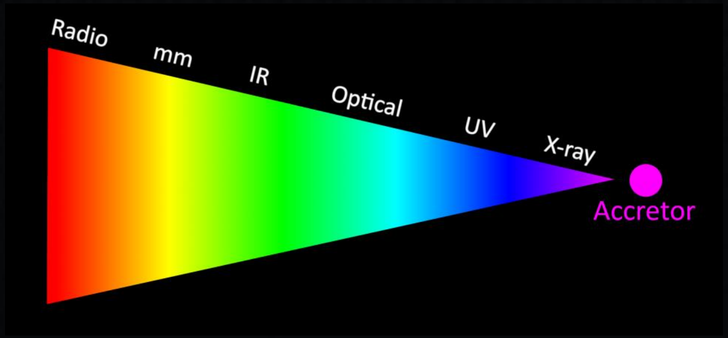
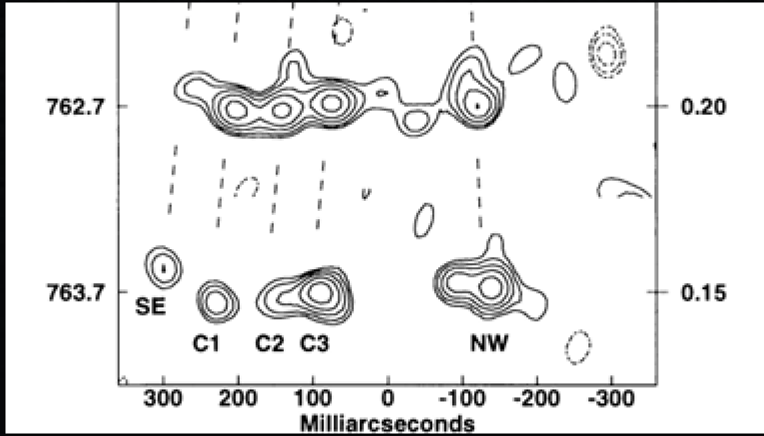


- Discrete ejecta jets
  - Adiabatically expanding plasmoids
  - Occur at transition to higher $\dot{m}$



BHXB
GRS 1915
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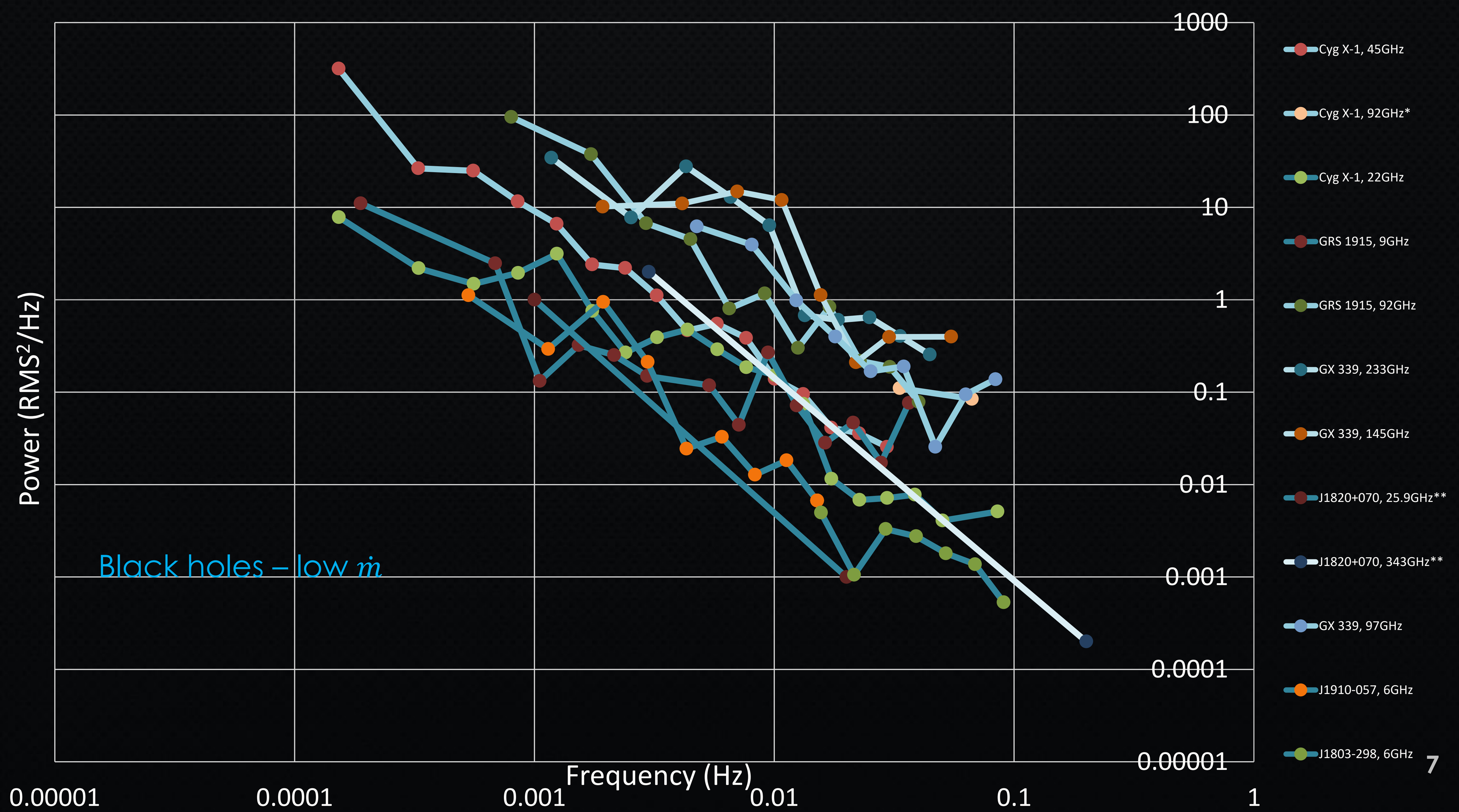
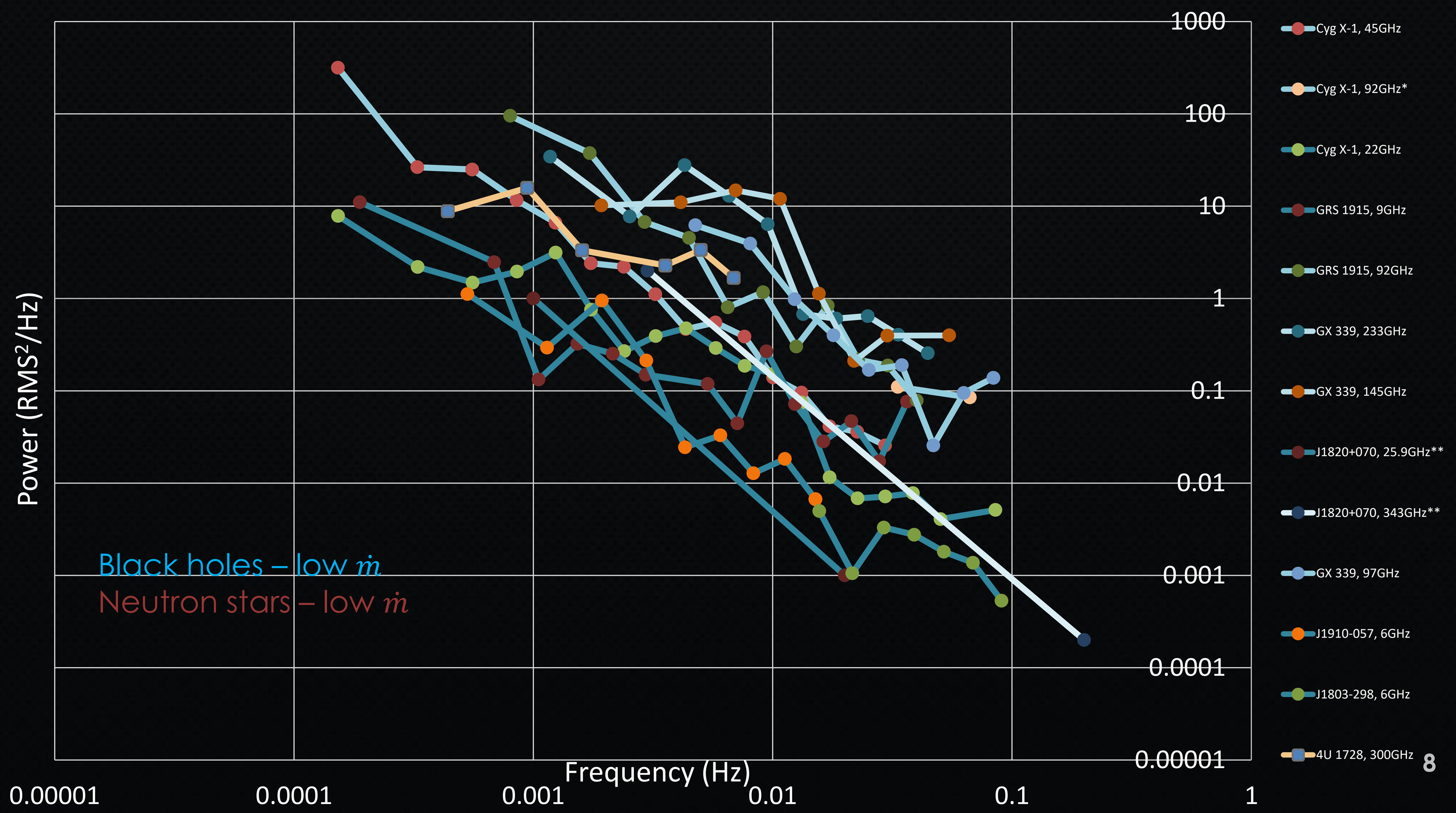
Radio power spectra

- Power spectra quantify variability present
- Compare variability of jet structures
- Compare variability of BH to NS accretor jets

- Mostly archival data from VLA & ALMA



Power (RMS^2/Hz)
1000
100
10
1
0.1
0.01
0.001
0.0001
0.00001
Frequency (Hz)
0.00001
0.0001
0.001
0.01
0.1
1
Black holes – low $\dot{m}$
Cyg X-1, 45GHz
Cyg X-1, 92GHz*
Cyg X-1, 22GHz
GRS 1915, 9GHz
GRS 1915, 92GHz
GX 339, 233GHz
GX 339, 145GHz
J1820+070, 25.9GHz**
J1820+070, 343GHz**
GX 339, 97GHz
J1910-057, 6GHz
J1803-298, 6GHz


Black holes – low $\dot{m}$
Neutron stars – low $\dot{m}$
Power (RMS^2/Hz)
Frequency (Hz)
1000
100
10
1
0.1
0.01
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0.0001
0.00001
0.00001
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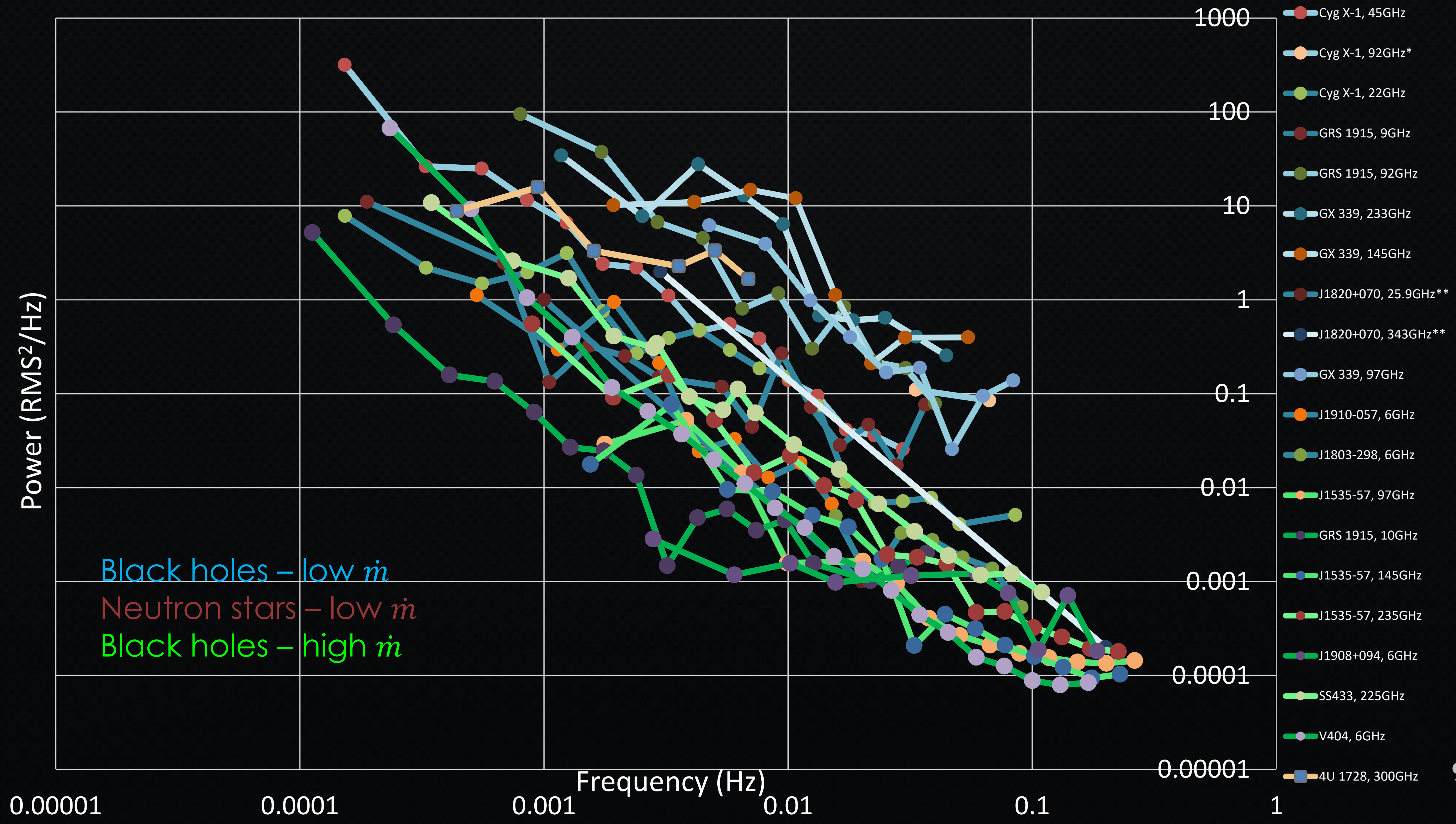

Power (RMS^2/Hz)
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1000
100
10
1
0.1
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Black holes – low $\dot{m}$
Neutron stars – low $\dot{m}$
Black holes – high $\dot{m}$
Cyg X-1, 45GHz
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GX 339, 97GHz
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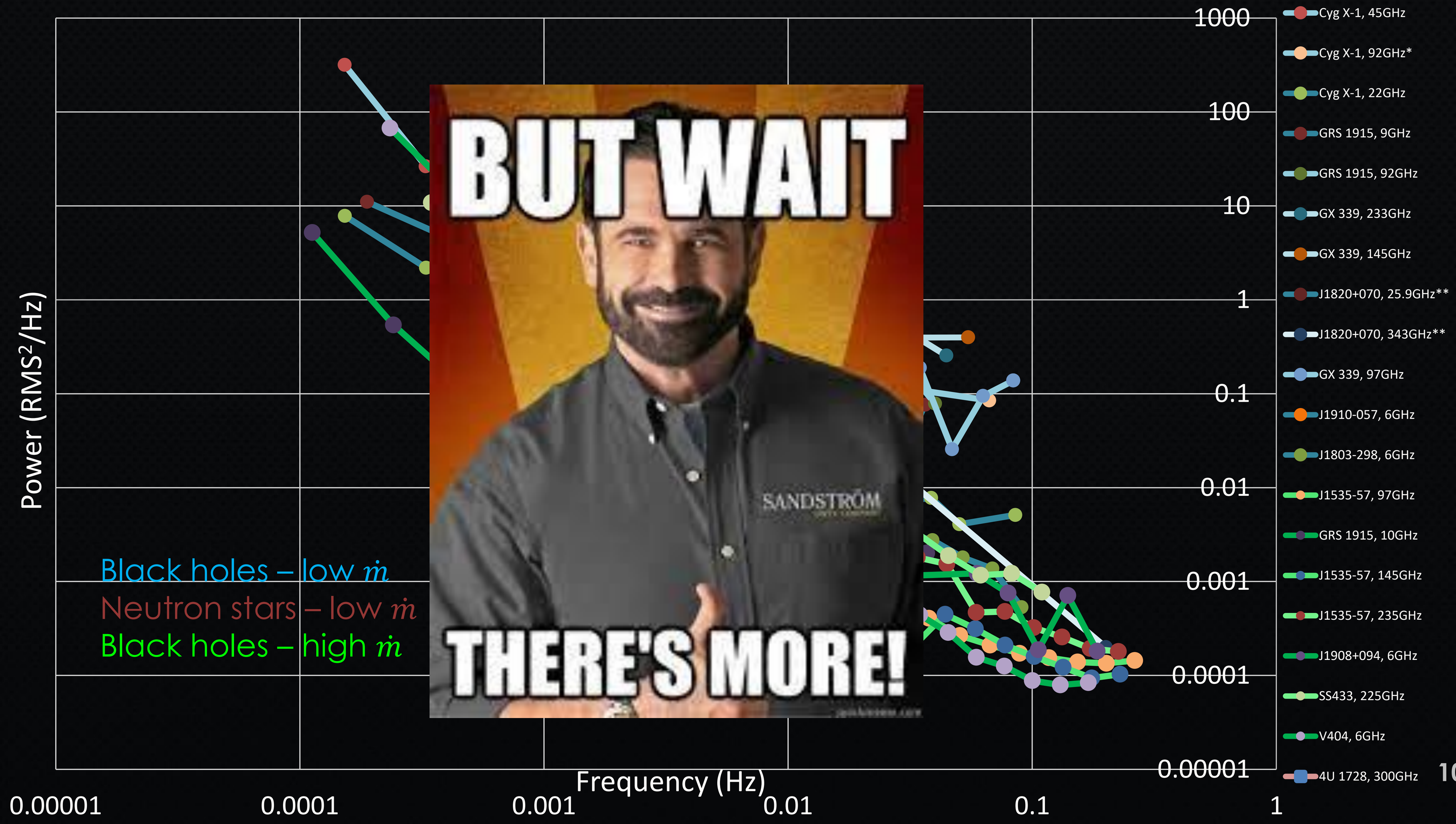
J1535-57, 97GHz
GRS 1915, 10GHz
J1535-57, 145GHz
J1535-57, 235GHz
J1908+094, 6GHz
SS433, 225GHz
V404, 6GHz
4U 1728, 300GHz



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Black holes – low ṁ
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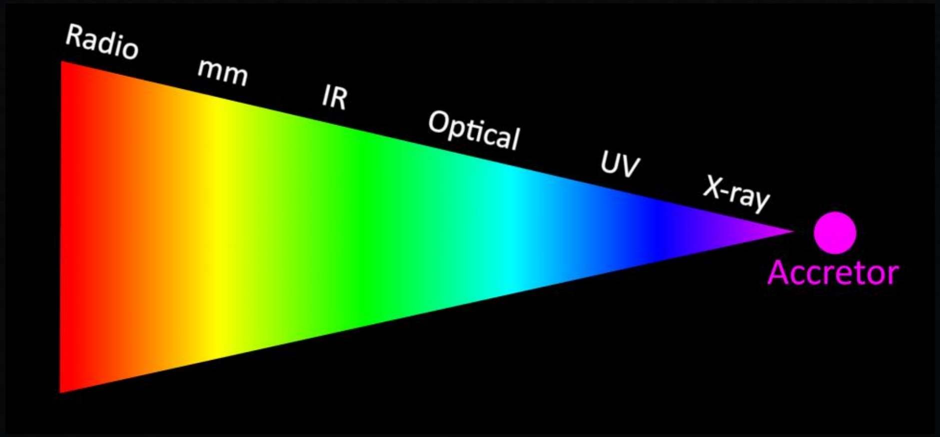
V404, 6GHz
4U 1728, 300GHz
BUT WAIT
THERE'S MORE!
SANDSTRÖM

Very high accretion rate jets

- At or above Eddington accretion rates
- Unclear jet structure
  - Persistent compact jets + discrete ejecta?
  - Unusually steep radio spectral indices for persistent radio emission



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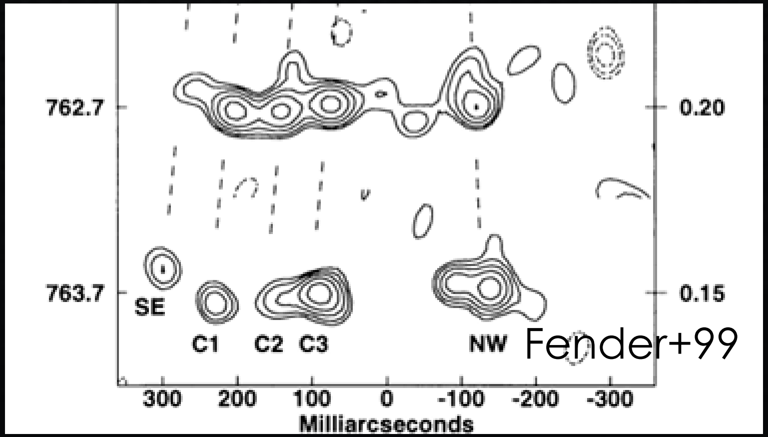

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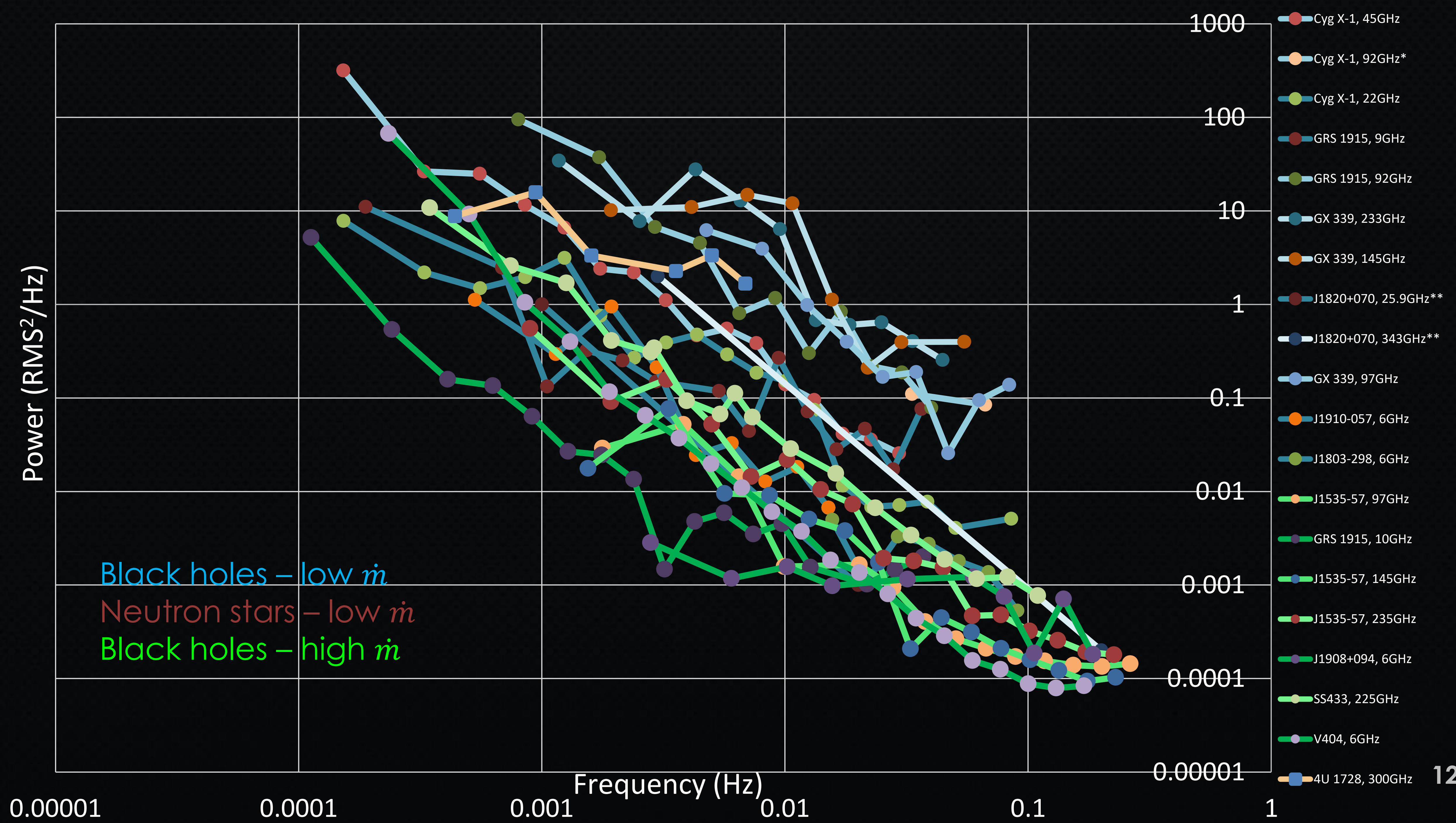
?



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Black holes – high ṁ
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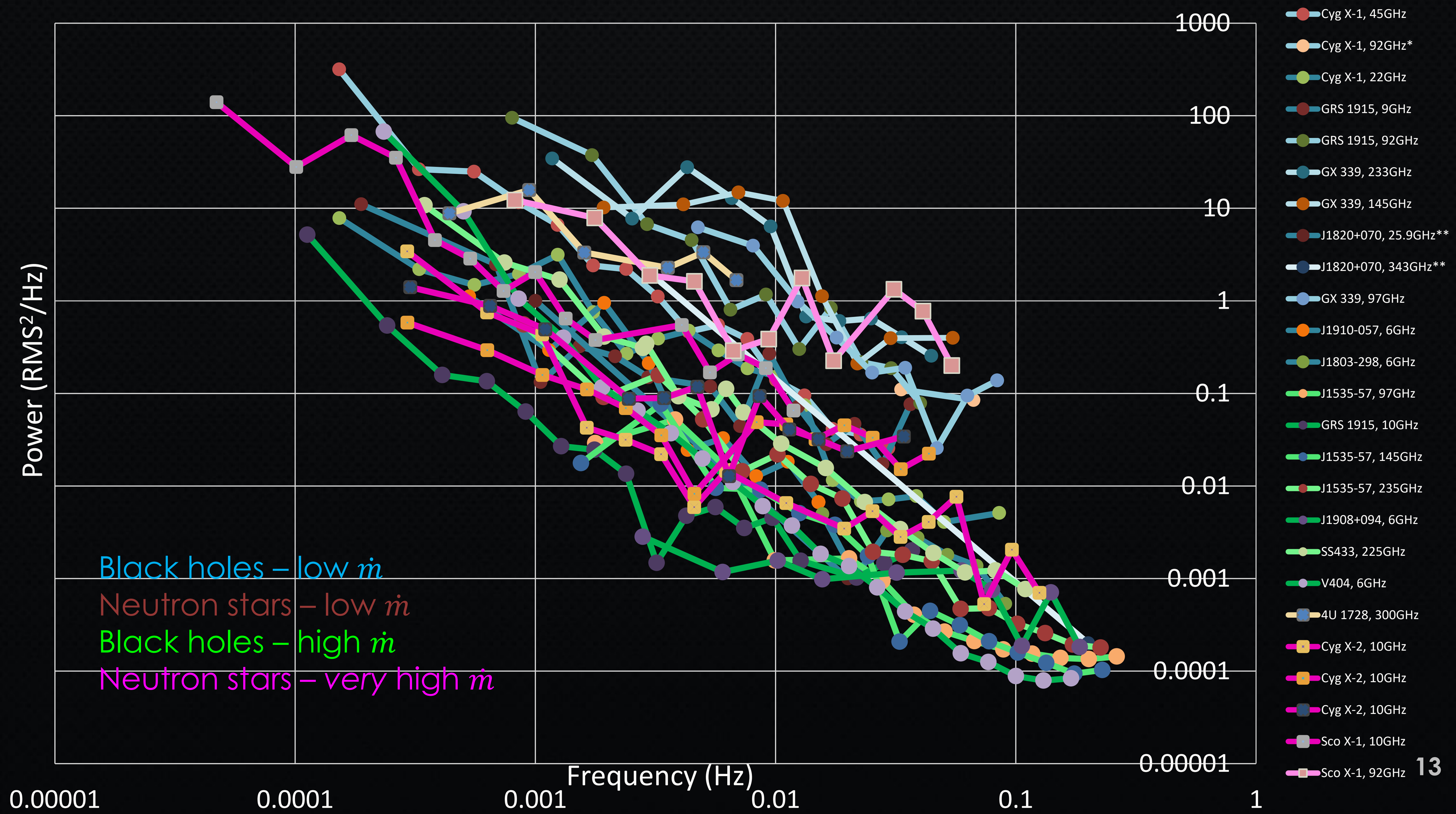
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Frequency (Hz)
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0.001
0.01
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1
Black holes – low ṁ
Neutron stars – low ṁ
Black holes – high ṁ
Neutron stars – very high ṁ
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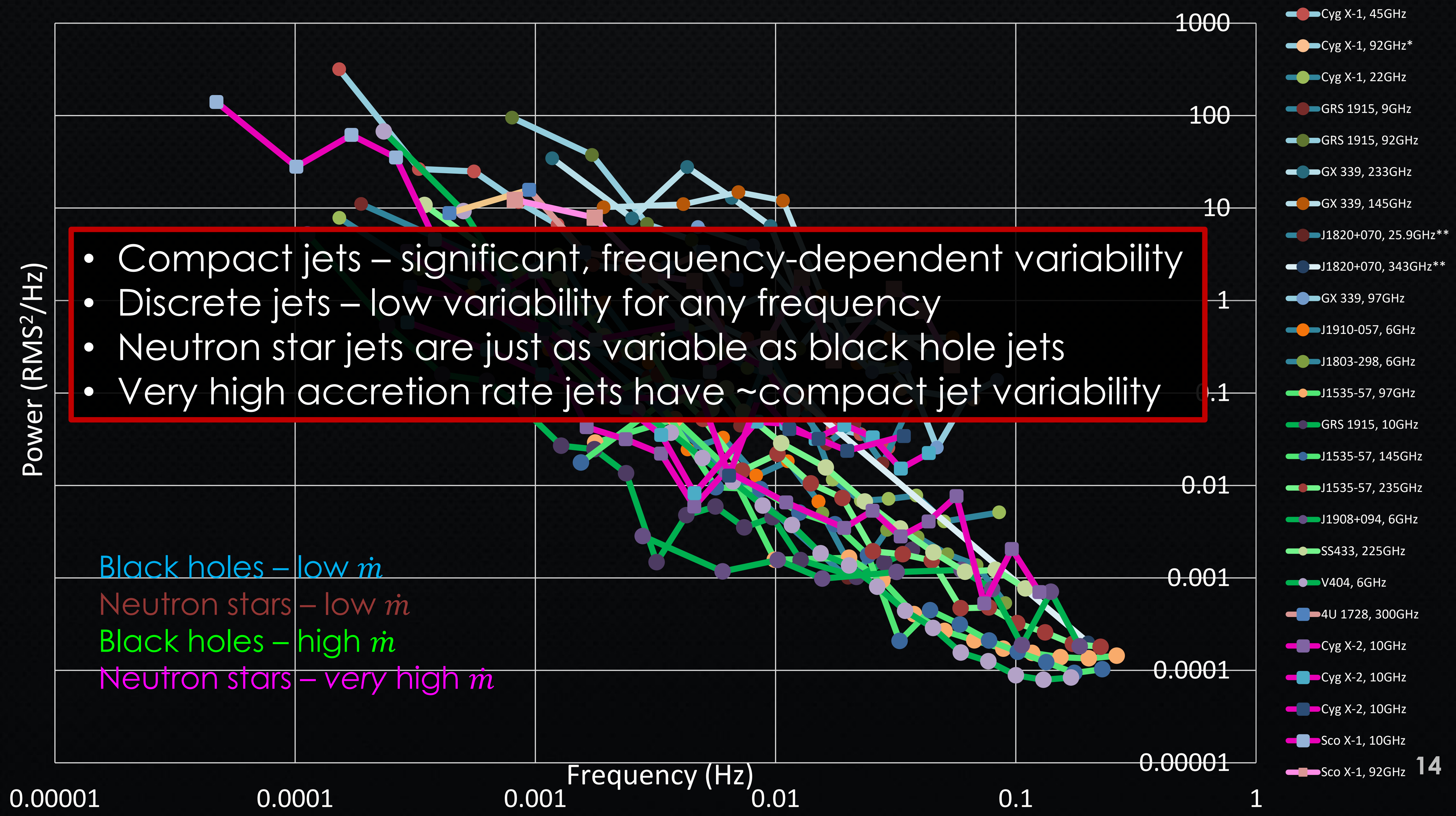
SS433, 225GHz
V404, 6GHz
4U 1728, 300GHz
Cyg X-2, 10GHz
Cyg X-2, 10GHz
Cyg X-2, 10GHz
Sco X-1, 10GHz
Sco X-1, 92GHz

- Compact jets – significant, frequency-dependent variability
- Discrete jets – low variability for any frequency
- Neutron star jets are just as variable as black hole jets
- Very high accretion rate jets have ~compact jet variability



First NSXB jet polarization detections

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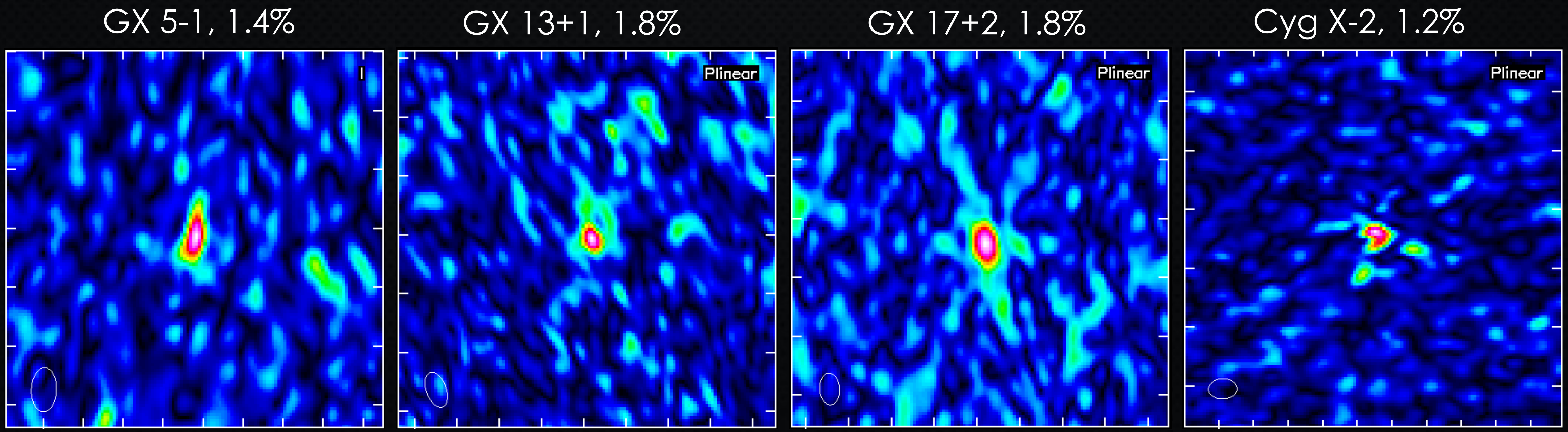
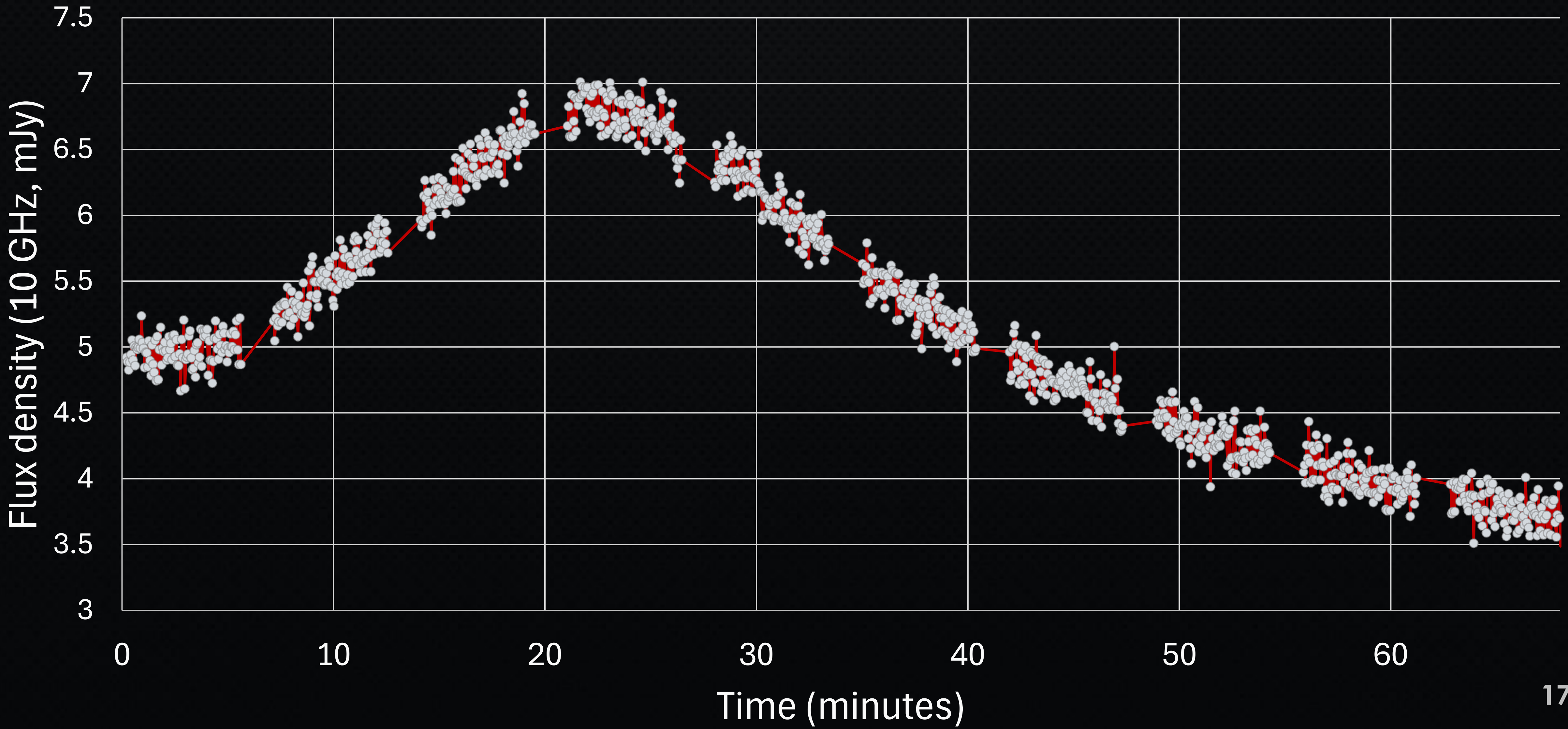


GX 17+2: discrete ejecta event



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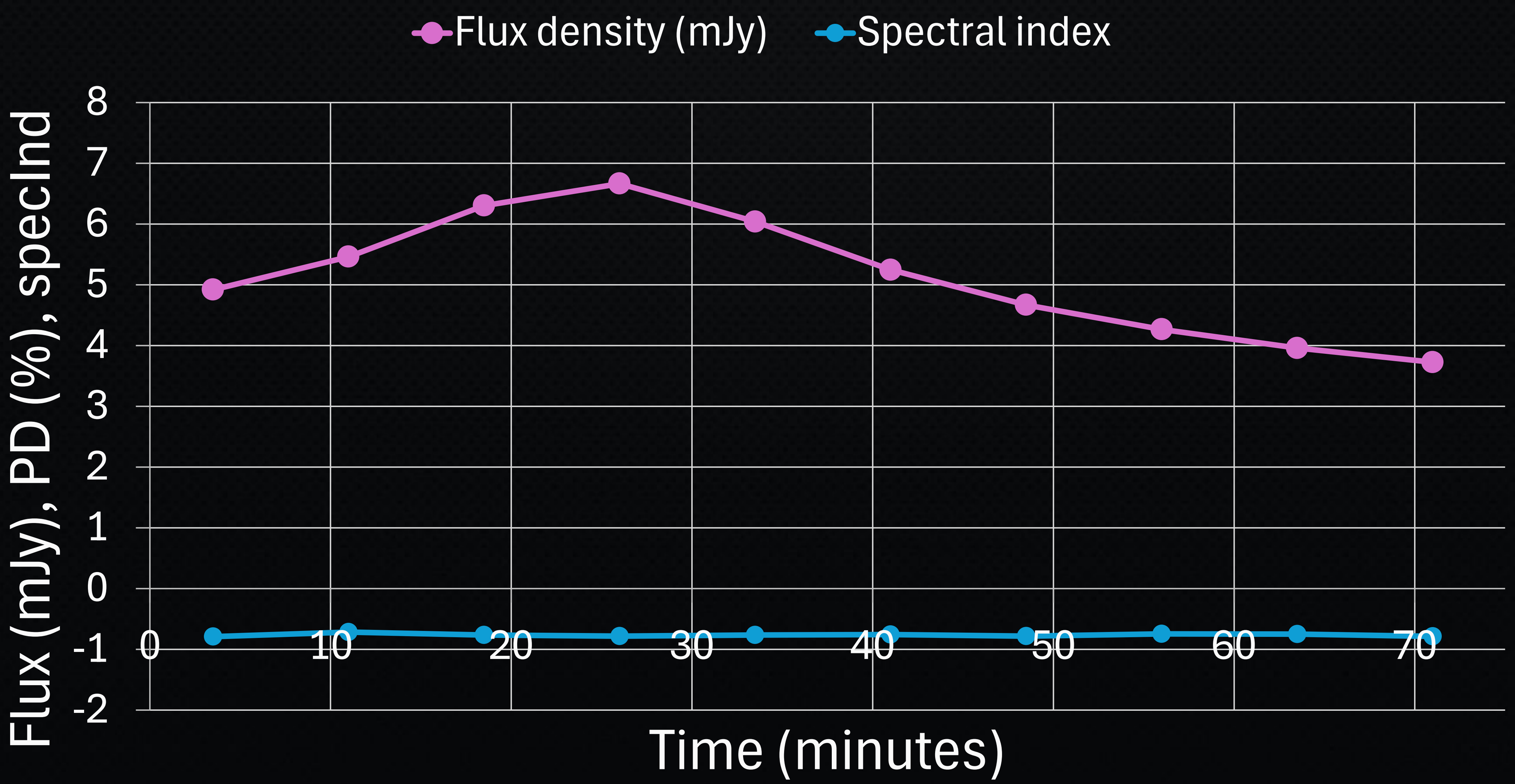

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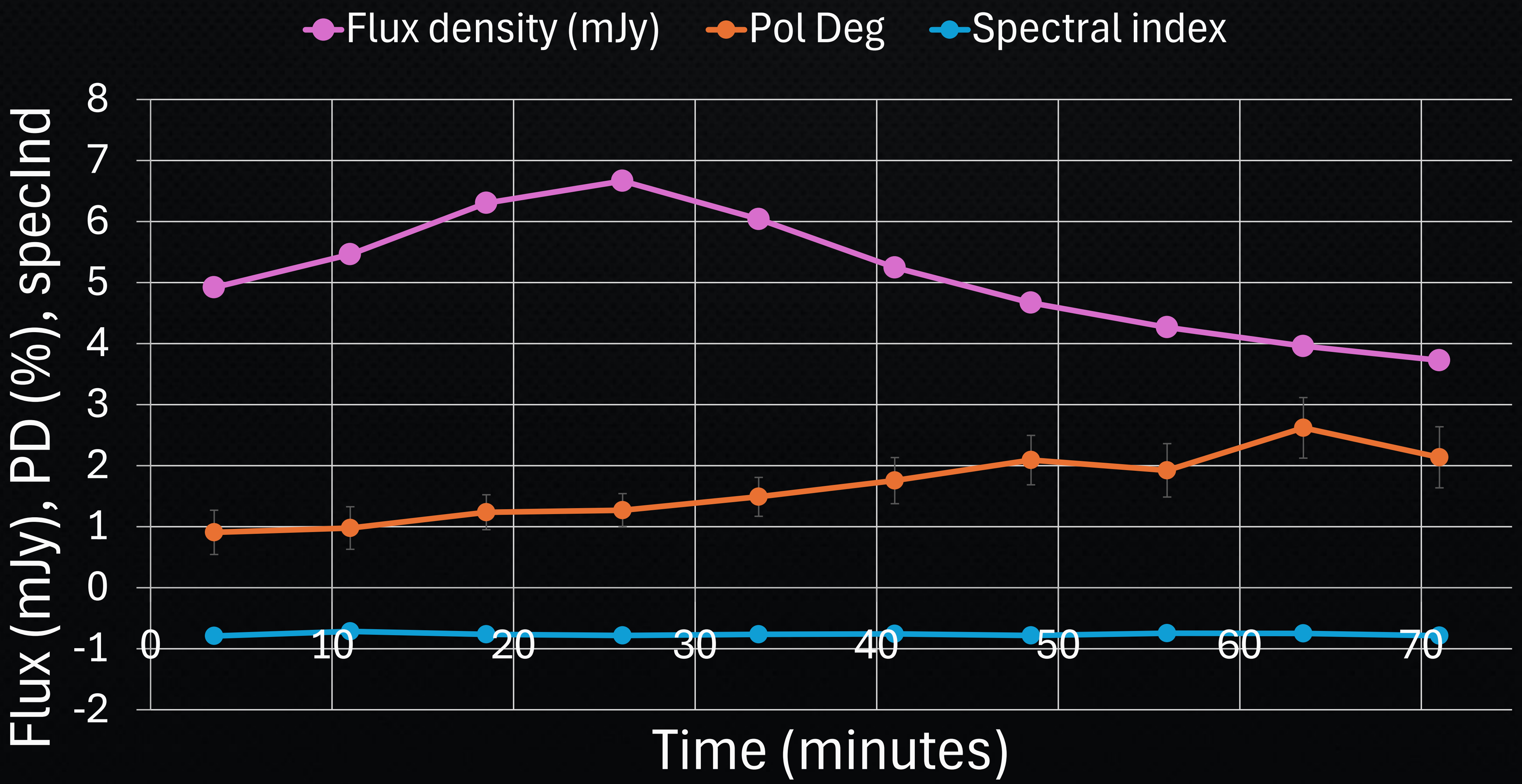

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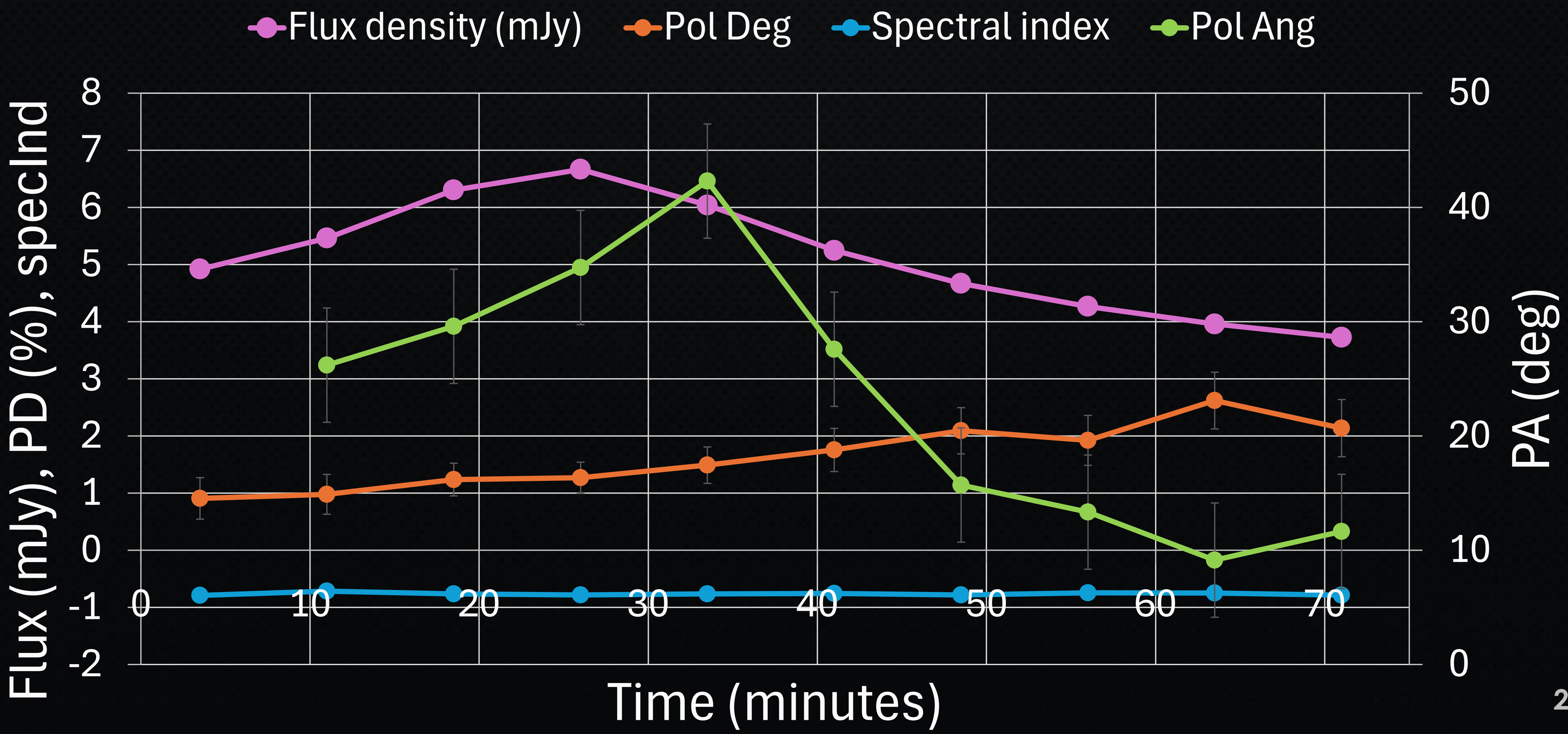
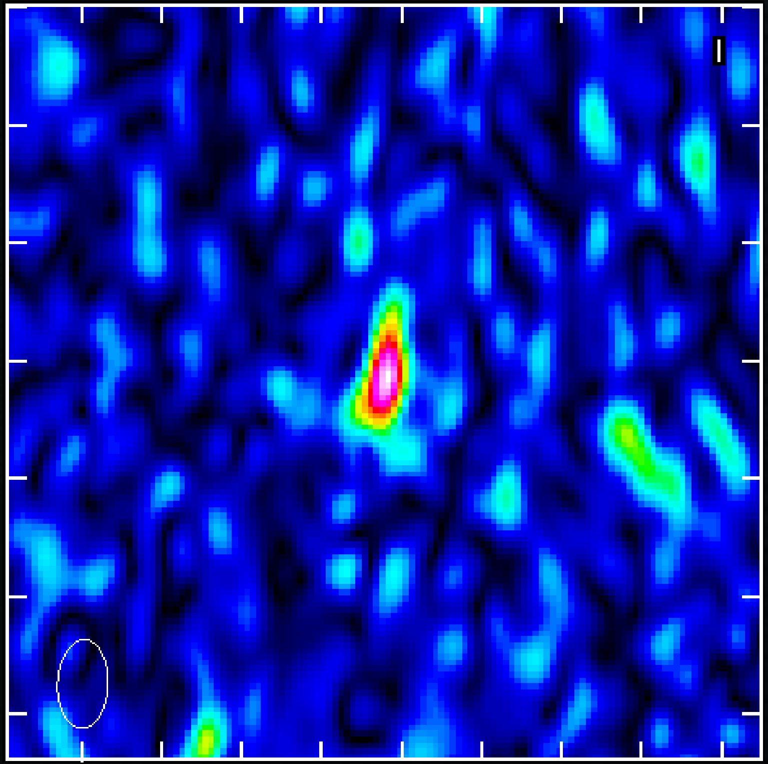


GX 5-1: variable radio polarization

PD = 1.4%



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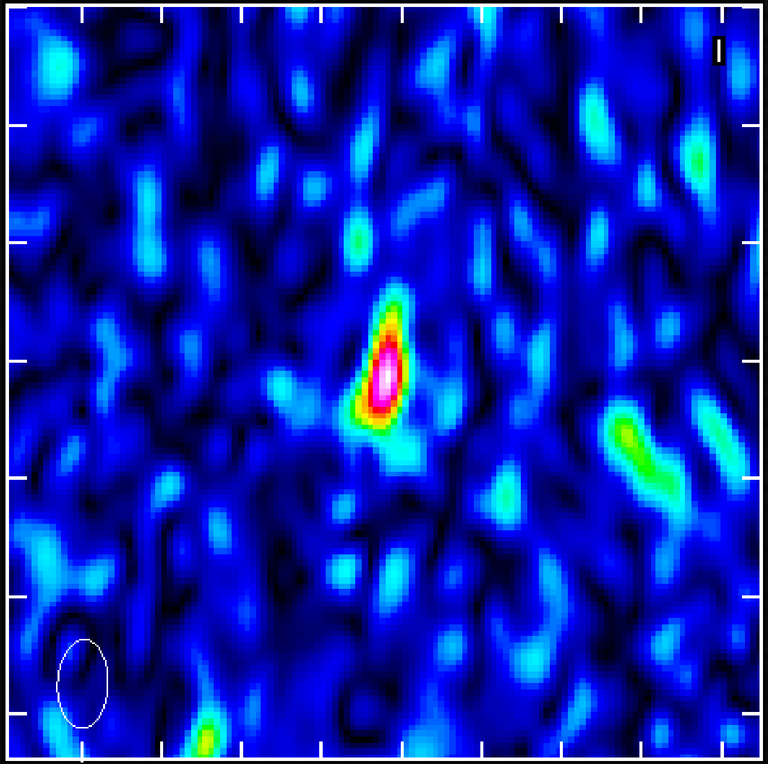
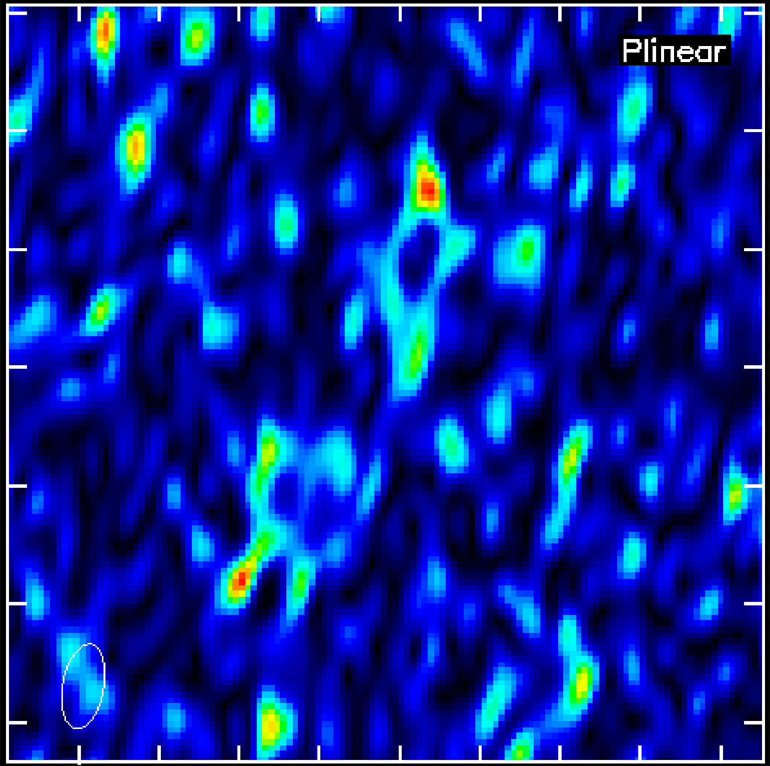


Radio PA aligned with X-ray PA

PD 3σ < 0.5%



8 days later

Summary

- Jet variability
  - Rapid variability in radio/mm of X-ray binary jets can indicate jet structure
  - Neutron star jets are just as variable as black hole jets
  - Very high accretion rate jets appear to have low $\dot{m}$ compact jet variability
- Polarization
  - First detections of NSXB jet polarization in radio
  - Polarization → jet position angle
  - Evidence of jet polarization variability
- Plenty of avenues for future research

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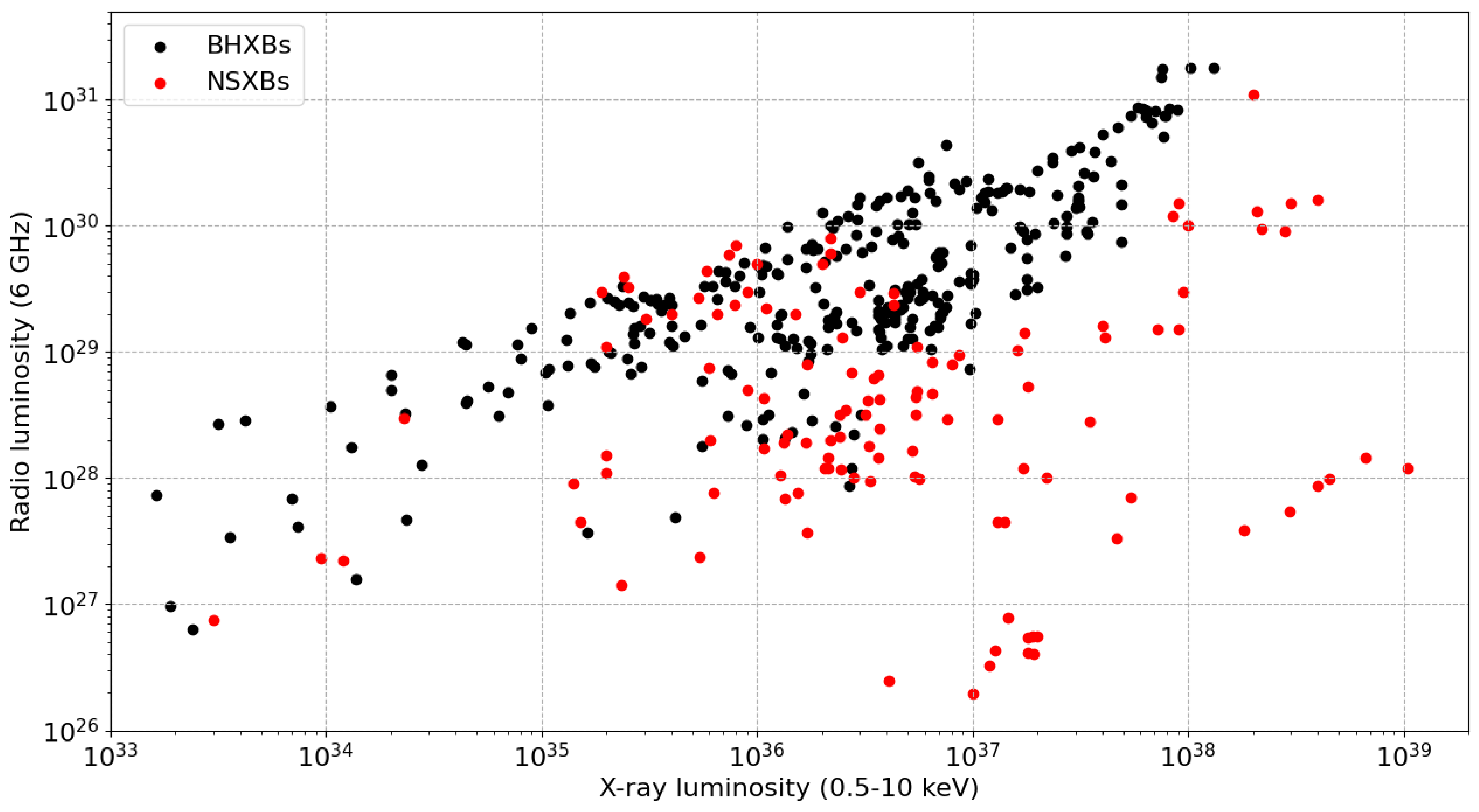
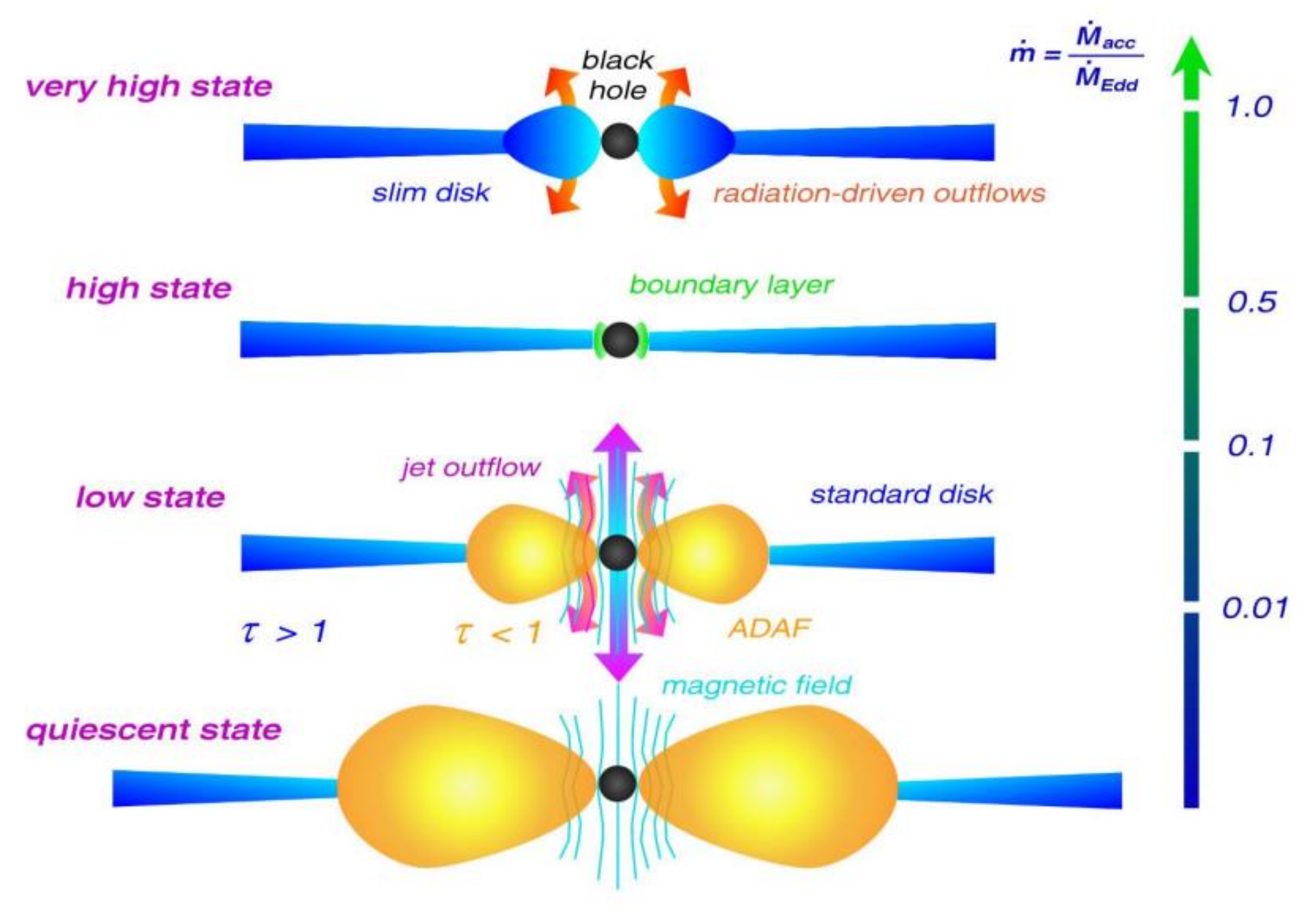
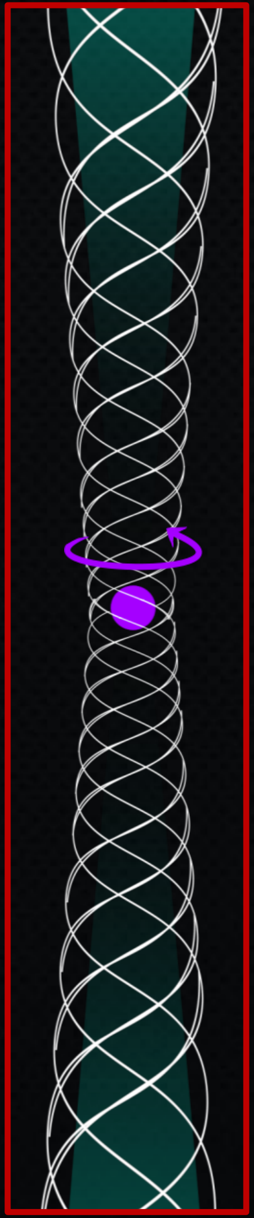
The Fundamental Plane: (L_R/L_X)





very high state
black hole
$\dot{m} = \frac{\dot{M}_{acc}}{\dot{M}_{Edd}}$
1.0
slim disk
radiation-driven outflows
high state
boundary layer
0.5
0.1
jet outflow
low state
standard disk
0.01
$\tau > 1$
$\tau < 1$
ADAF
magnetic field
quiescent state

Müller 2004

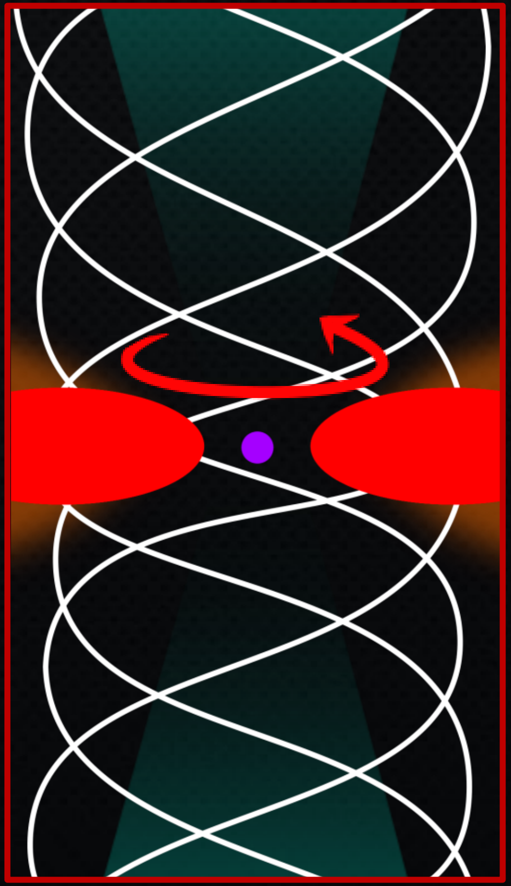


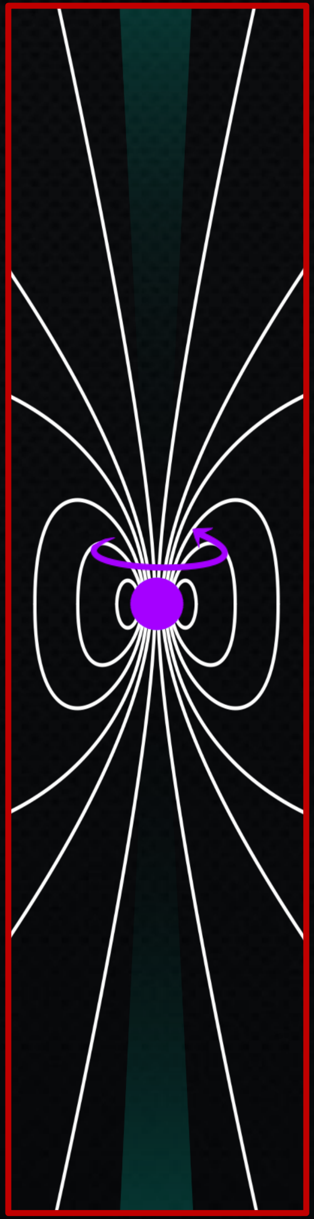
Blandford
-Znajek

Jet production mechanisms

- Black holes: Blandford-Znajek: Magnetic fields are dragged and twisted by BH spin
  - Depends on magnetic field ($\propto B^2$) and spin ($\propto \alpha^2$)
- Neutron stars: produce own magnetic fields and rotate
  - Depends on magnetic field ($10^{8\text{-}13}$ G) and spin (~10ms to 100s sec.) of NS
- Blandford-Payne: Accretion disk rotation and magnetic field
  - Depends on B_z and B_φ of disk, rotation Ω, and jet launch radius R_j

Blandford-Payne





Neutron Star