Accreting stellar-mass black holes via X-ray polarimetry

Michal Dovčiak

Romana Mikušincová, Jiří Svoboda

Astronomical Institute
Academy of Sciences of the Czech Republic

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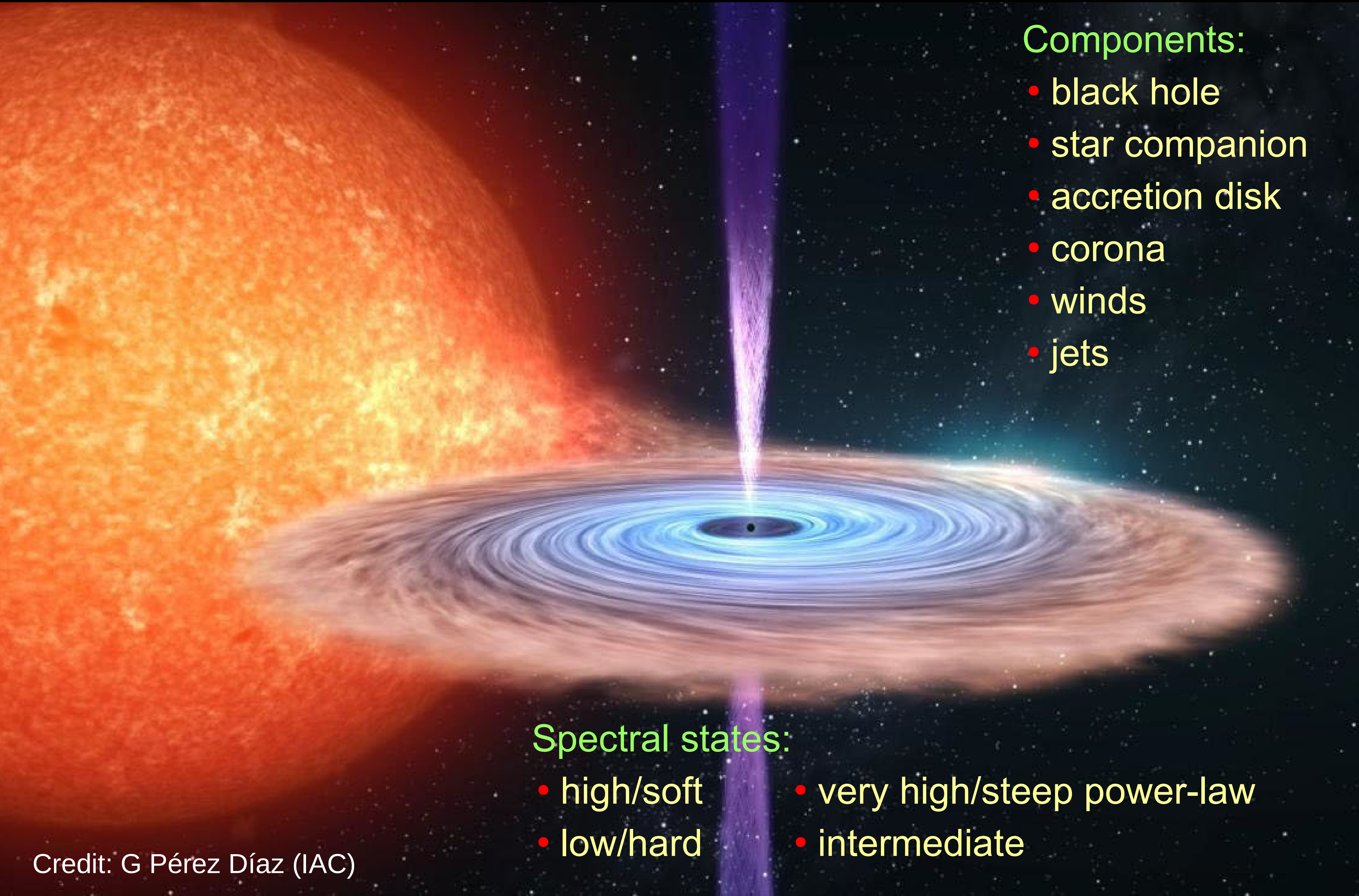
X-ray binaries with Black Hole



Components:

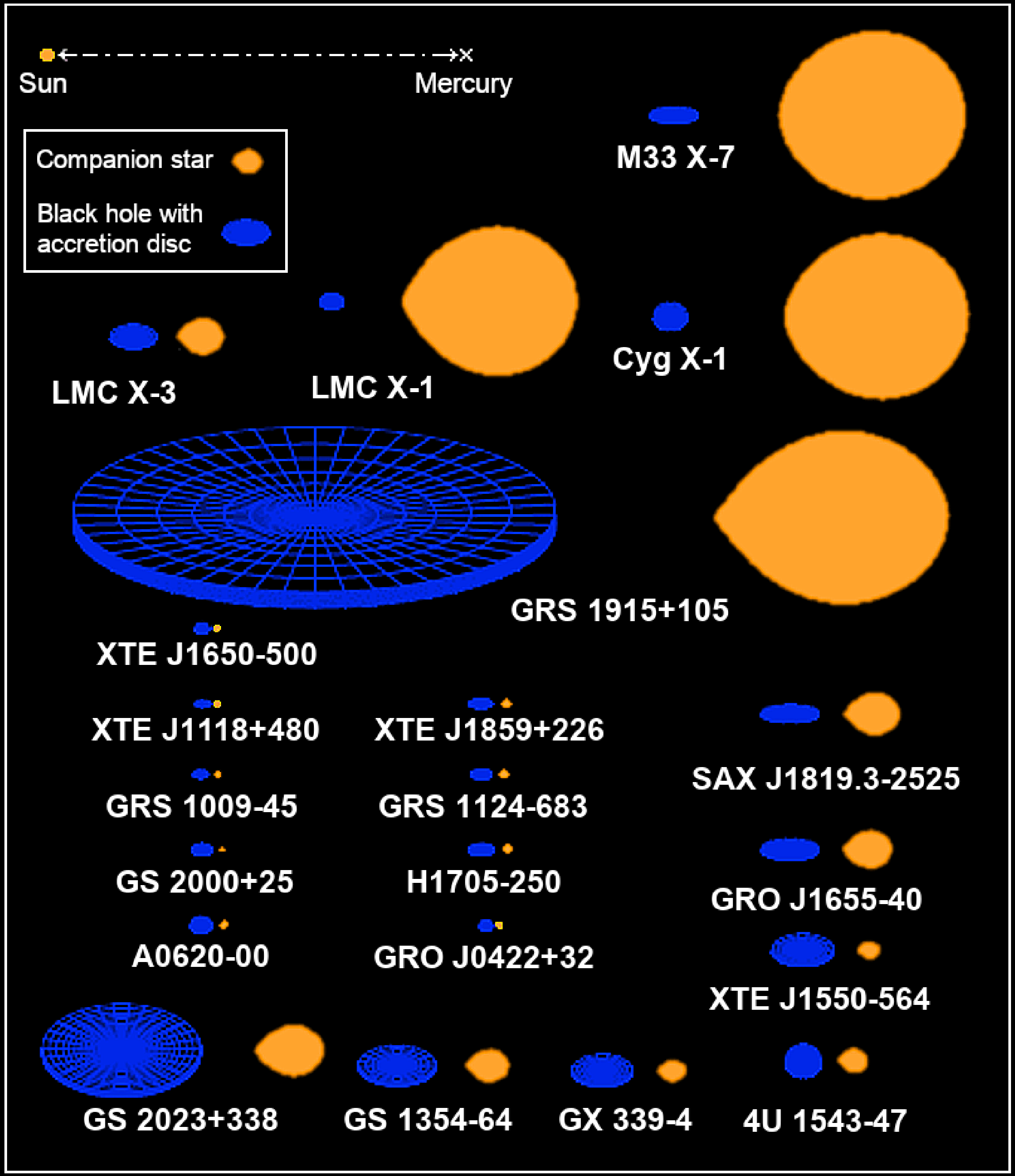
- black hole
- star companion
- accretion disk
- corona
- winds
- jets

Spectral states:

- high/soft
- low/hard
- very high/steep power-law
- intermediate

Credit: G Pérez Díaz (IAC)

Census of X-ray binaries with Black Hole



McClintock, Narayan & Steiner (2014)

Black hole spin measurement

Spin (rotation) of black hole

- information on black hole birth and growth
- connection with jets
- test "no-hair" theorem

Methods:

- Spectral
  - → Thermal radiation
  - → Reflection
- Timing
  - → QPO
  - → Reverberation
- Polarimetry
  - → Thermal radiation
  - → Reflection

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- Polarimetry
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often inconsistent results (Thermal radiation, Reflection, QPO)

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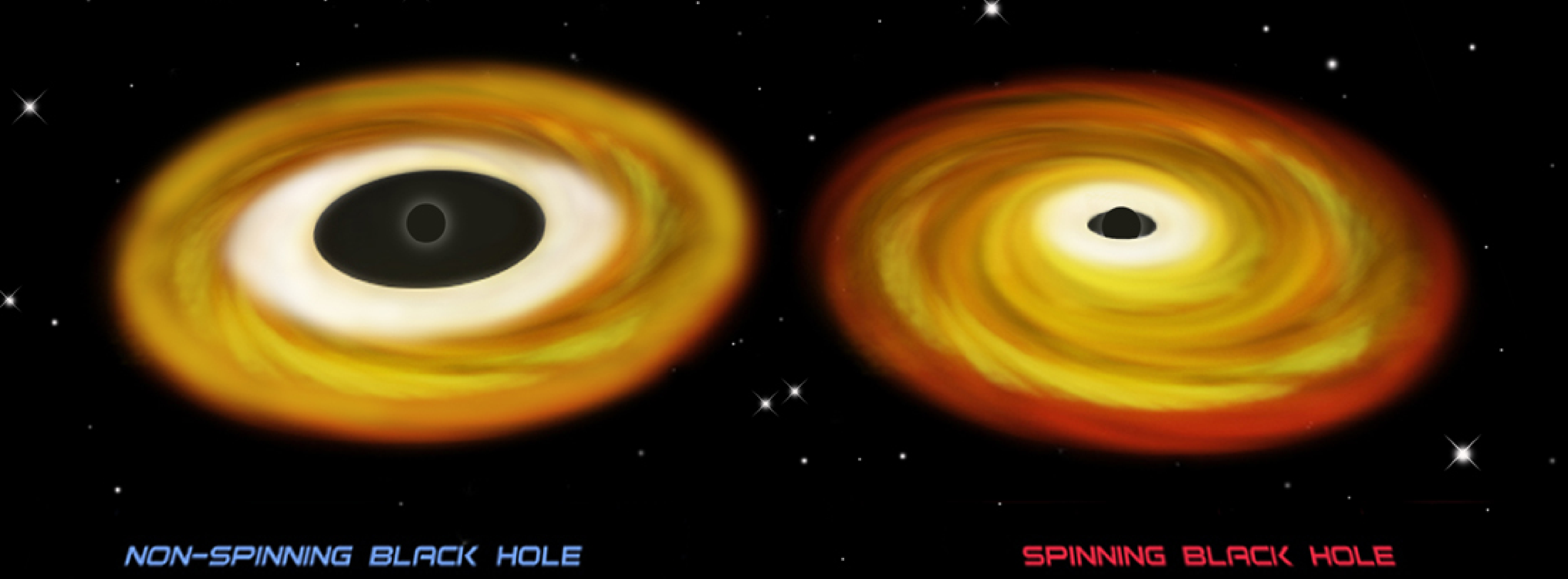
new methods for future (Reverberation; Polarimetry: Thermal radiation, Reflection)

Spin measurements in thermal state

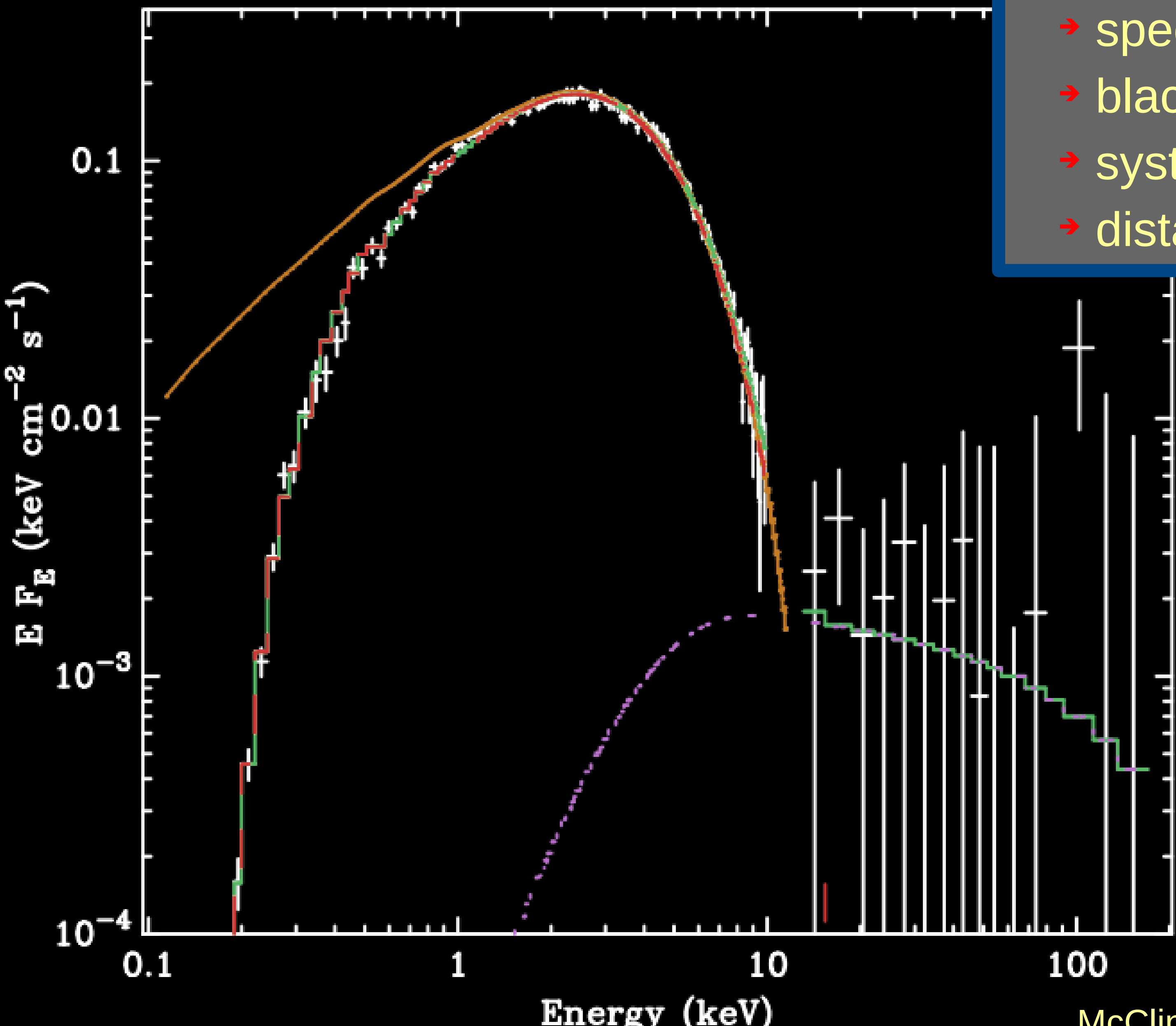
- inner edge of accretion disc at ISCO
  - ➔ larger emitting area and temperature for higher black hole spin
- luminosity
  - ➔ area, inclination, distance, temperature
- temperature
  - ➔ mass accretion rate, mass & inner disc edge (gravitational well), inclination (Doppler shift)



Credit: NASA/CXC/M.Weiss

Spin measurements in thermal state

- information needed
  - spectrum in thermal state
  - black hole mass
  - system inclination
  - distance to the system



McClintock, Narayan & Steiner (2014)

X-ray polarimetry

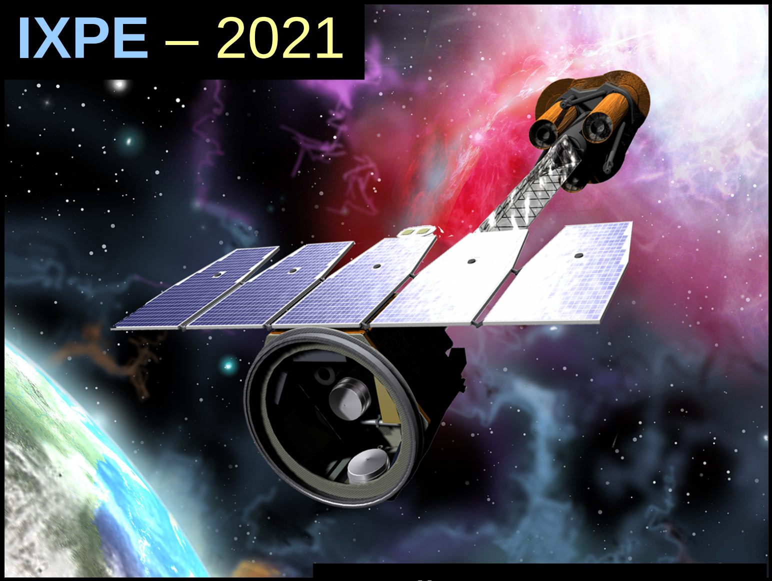
Polarization sensitive to asymmetry caused by

- geometry
  - ➔ system inclination
  - ➔ system orientation
- relativistic effects
  - ➔ black hole spin

Polarimetry could provide us with further constraints on **system geometry** and **black hole spin !!!**

planned X-ray polarimetry missions:

IXPE – 2021

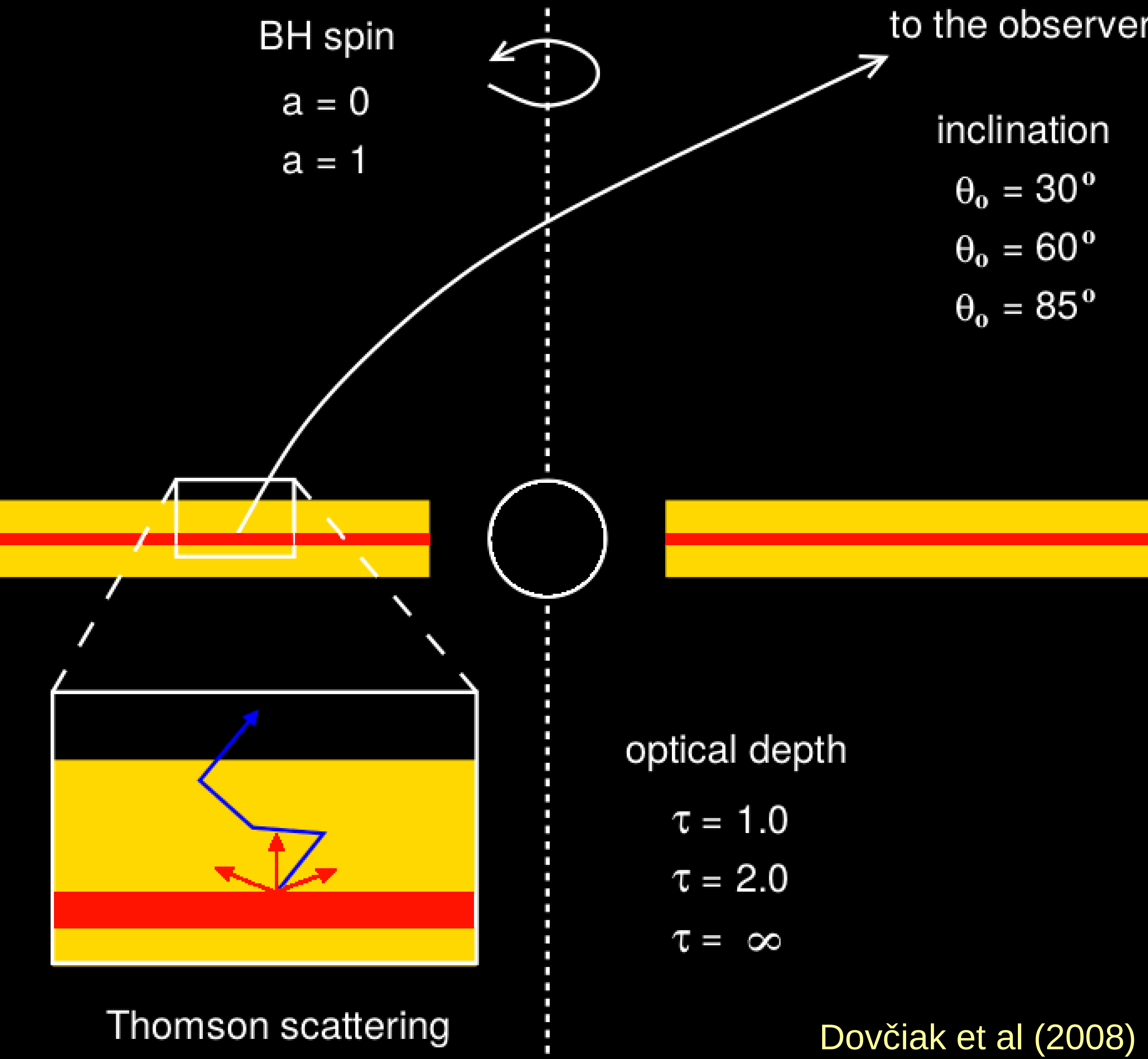


Credit: www.nasa.gov

eXTP – 2025

Credit: www.isdc.unige.ch/extp

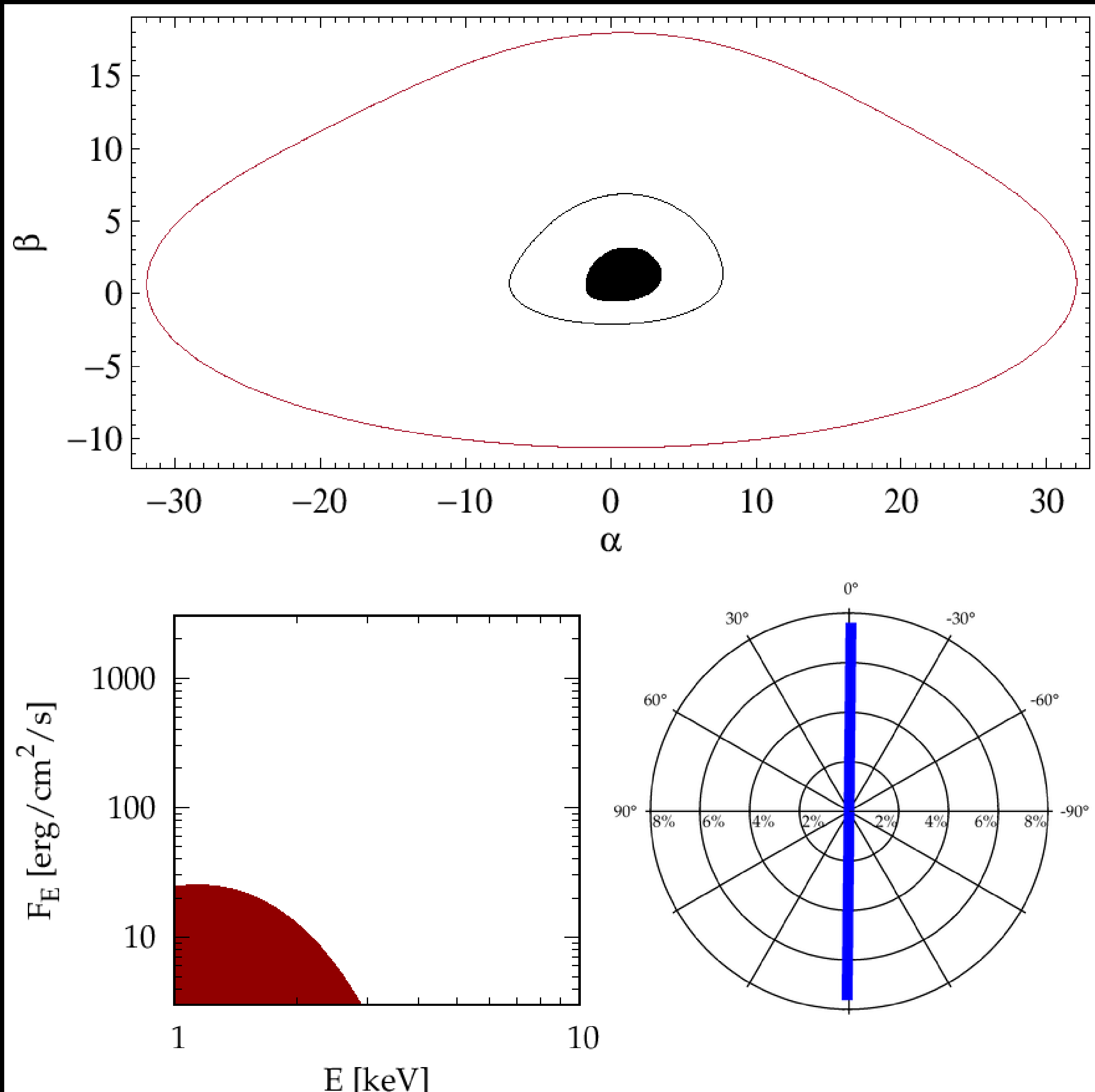
Polarization in thermal state – model



Dovčiak et al (2008)

- Disc thermal radiation (Novikov-Thorne disc)
- Comptonisation in the disc
  - energy shift simulated by colour correction factor
  - polarization computed by **STOKES code** (R. Goosmann & F. Marin) www.stokes-program.info
- Relativistic effects:
  - Doppler shift
  - gravitational energy shift
  - aberration & beaming
  - light bending
  - rotation of polarization angle

Polarization angle rotation with energy



- Up:
  BH (spin=1) on the sky of the observer
- Bottom left:
  flux dependence on energy
- Bottom right:
  energy dependent rotation of polarization angle due to relativistic effects

Photons from the inner regions of the disk are more energetic and of a different PA compared to the less energetic photons produced in the outer disk regions.

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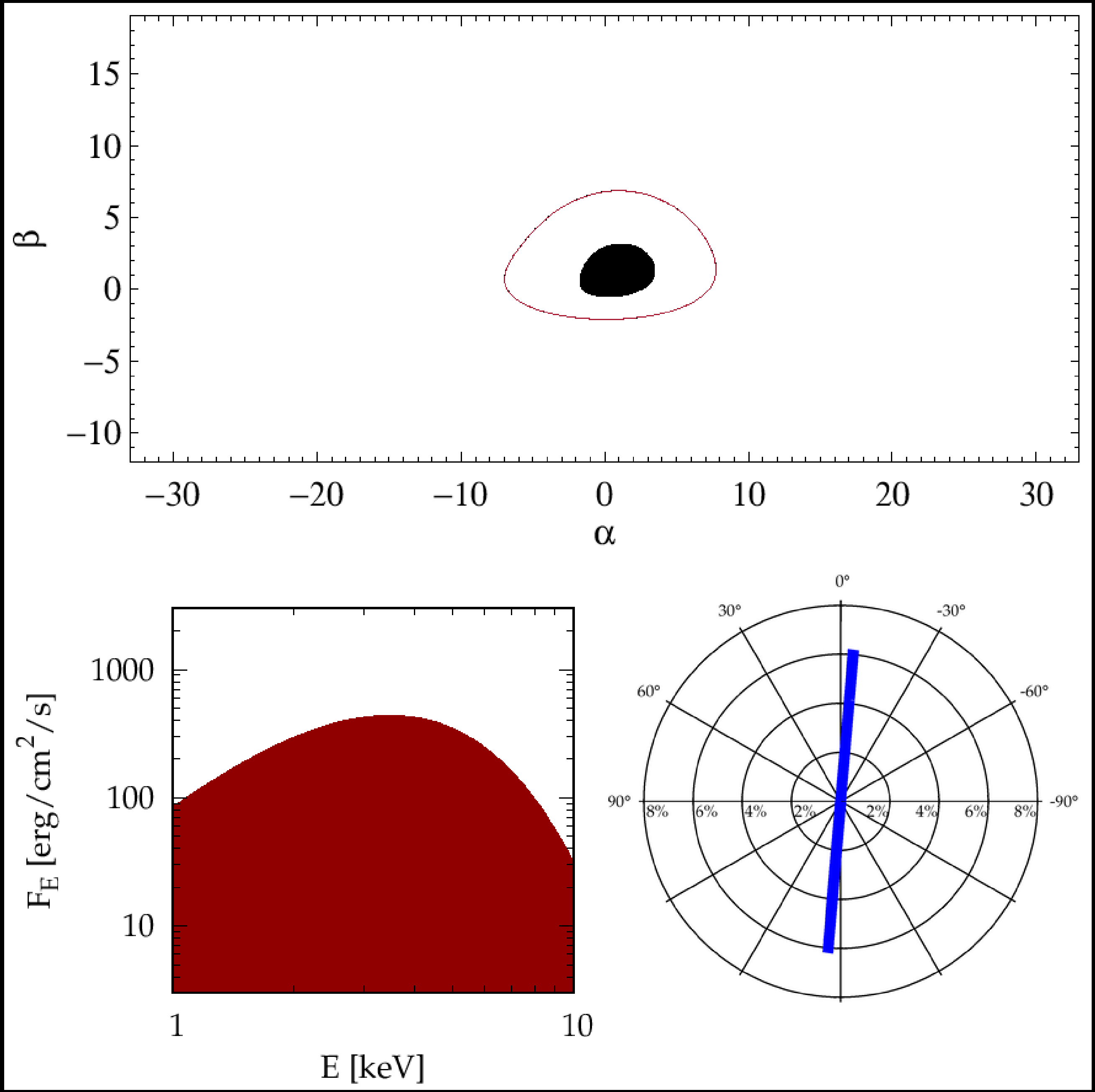

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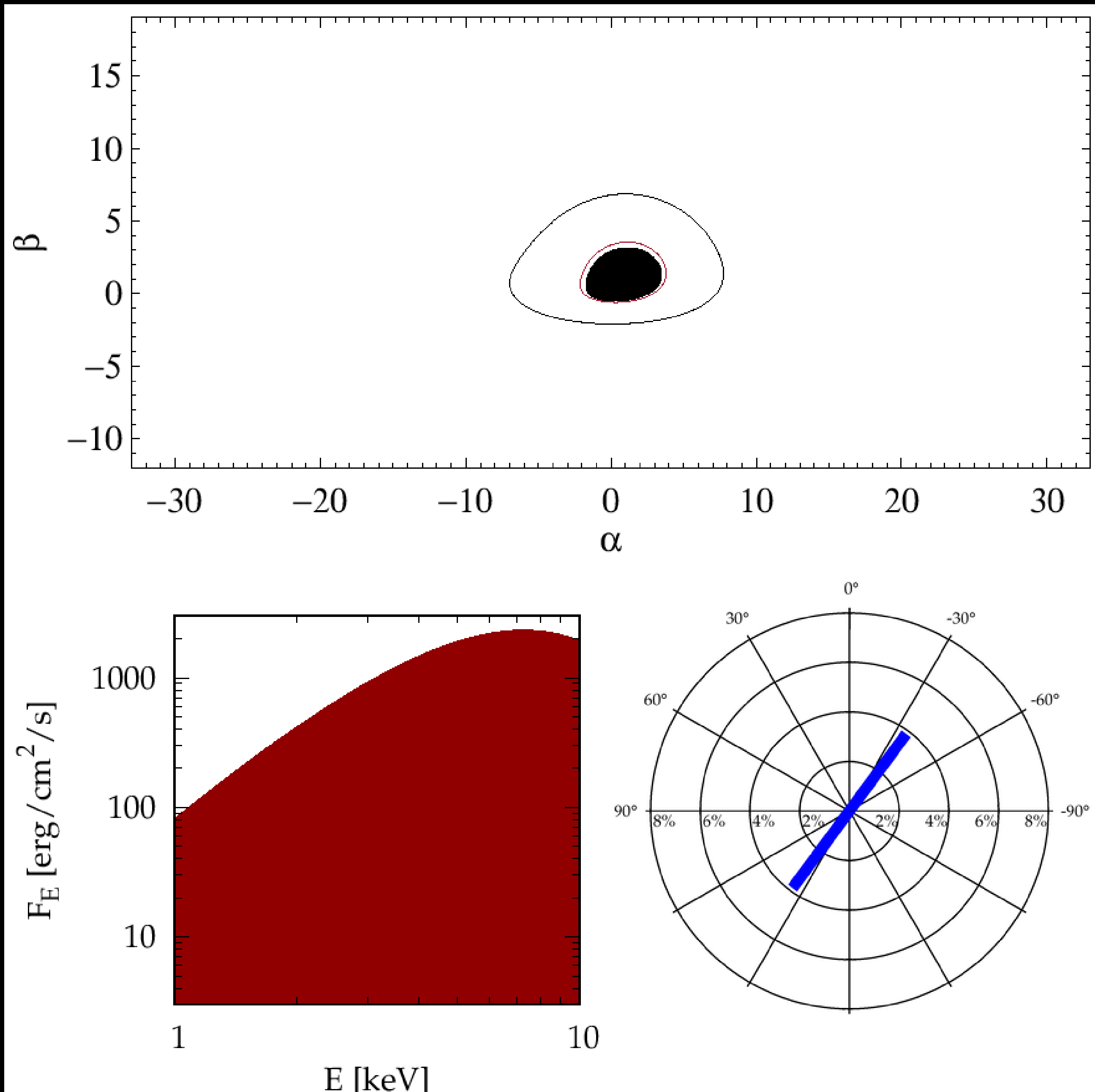

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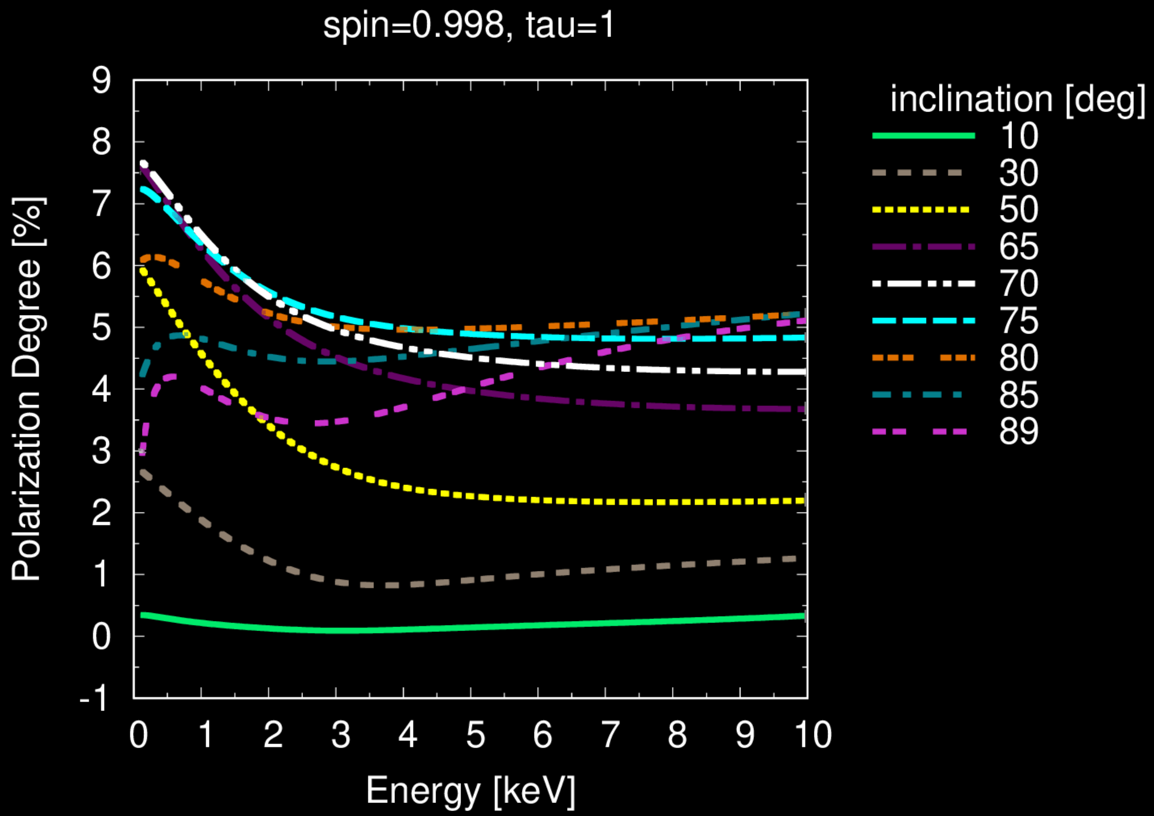
Optimal astronomical targets for BH spin measurements via X-ray polarimetry

- bright X-ray binaries
  - ➔ X-ray polarimetry needs lots of counts

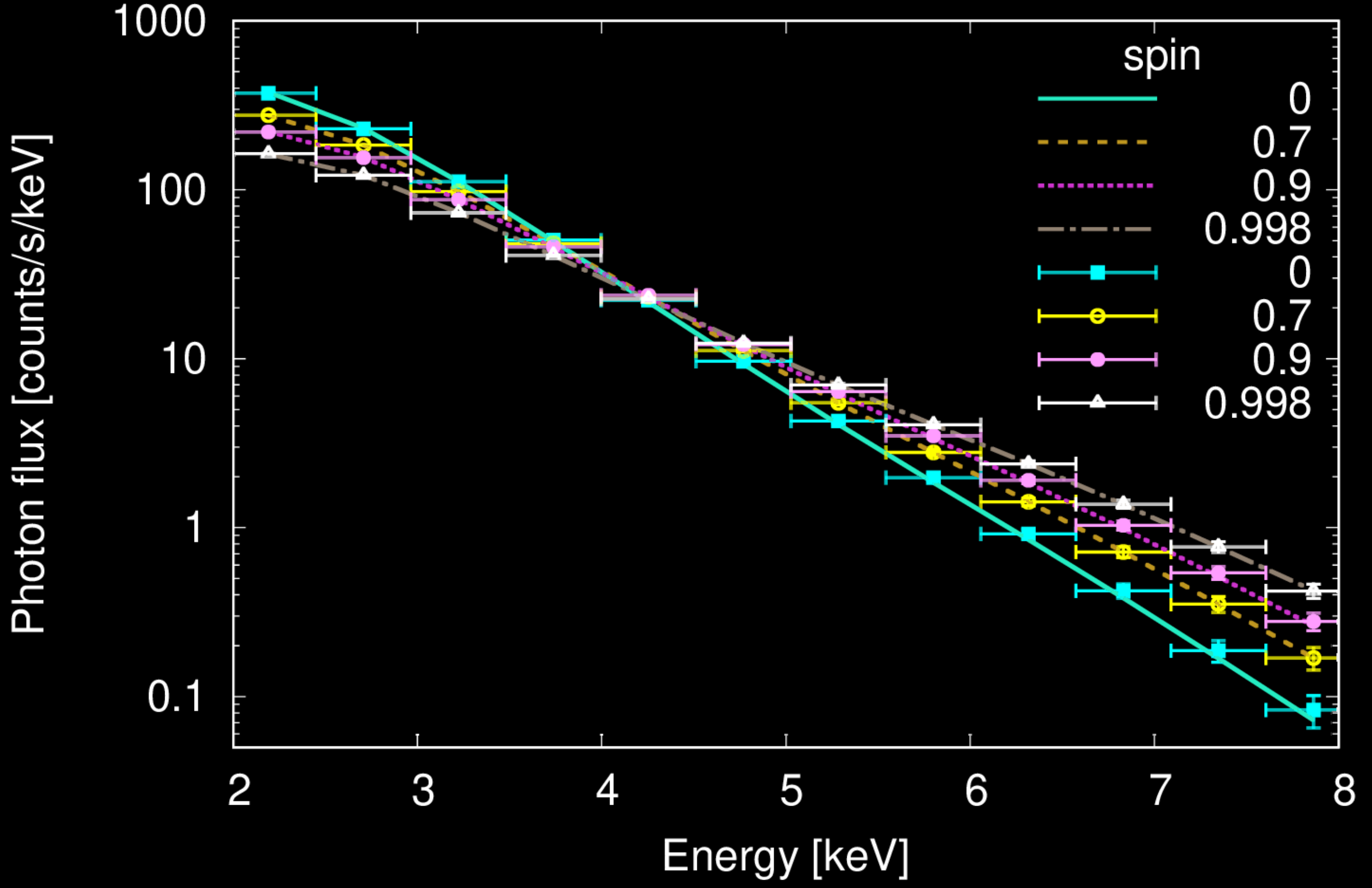
Optimal astronomical targets for BH spin measurements via X-ray polarimetry

- bright X-ray binaries
  - X-ray polarimetry needs lots of counts
- high-inclination systems
  - polarization degree of BH accretion-disc emission strongly depends on inclination



GRS1915-105 – observation simulation for IXPE mission

500 ks observation simulated with **XIMPOL**
(http://ximpol.readthedocs.io/en/latest/#)



Mikušincová (2018)

Simulated spectrum computed for TBABS(KYNBB) and
flux (2-8keV) fixed to 10^{-8} erg/cm^2/s

kynbb: https://projects.asu.cas.cz/stronggravity/kyn/tree/master#kynbb

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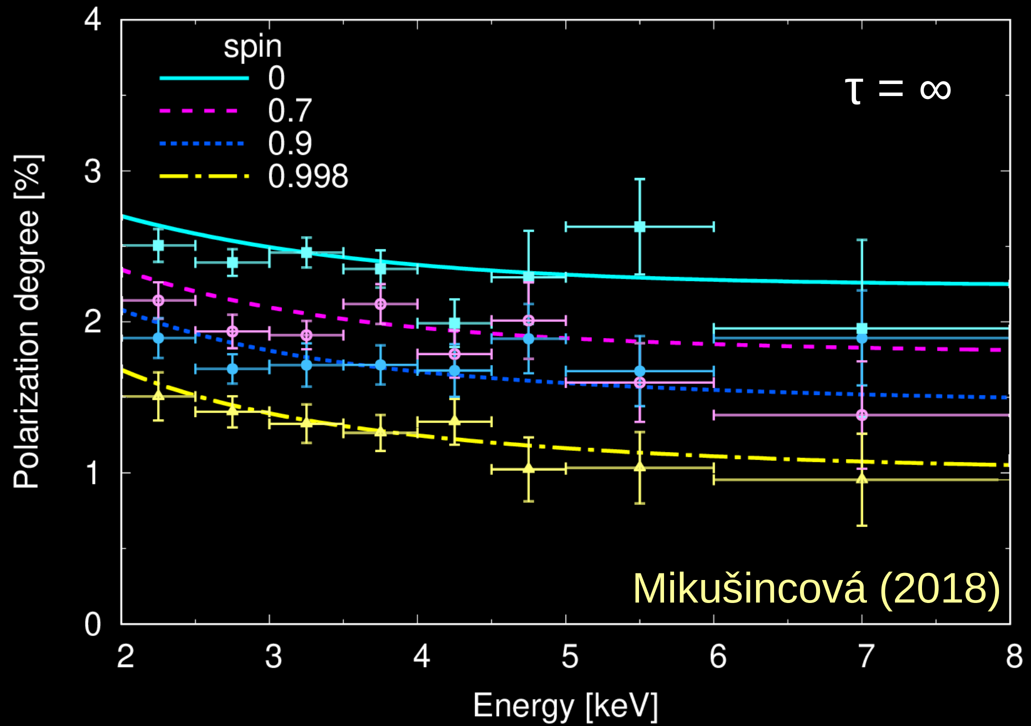

Polarization degree

- decreases with spin
- varies very little with energy
- larger errors for higher energies due to lower flux and lower sensitivity of the detector

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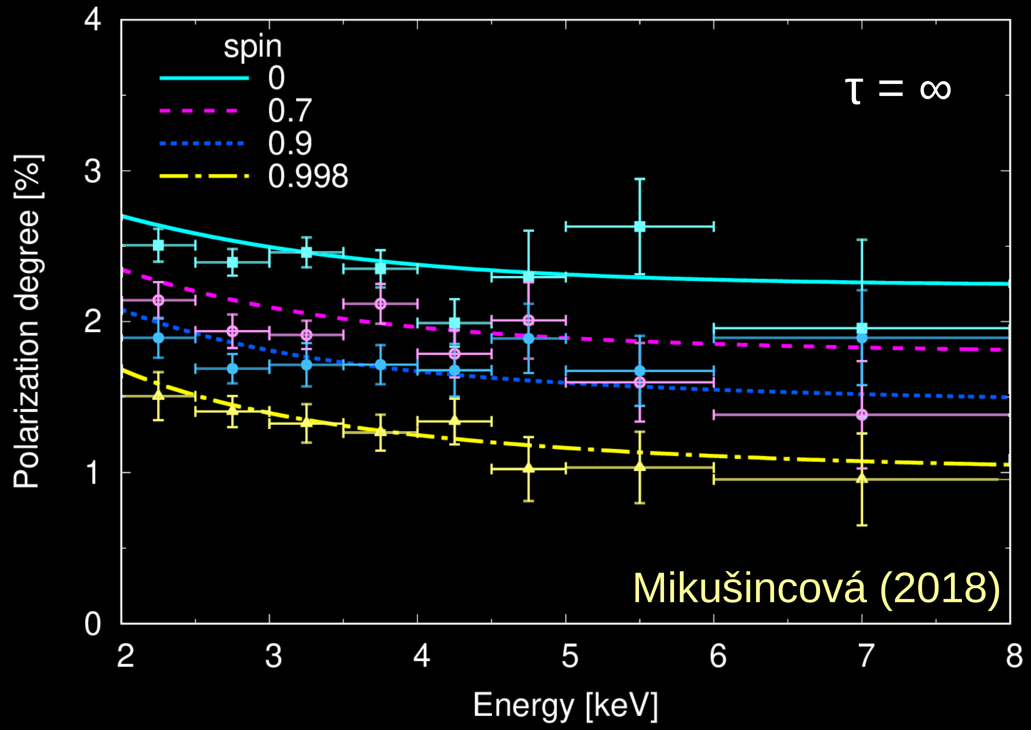

Polarization degree

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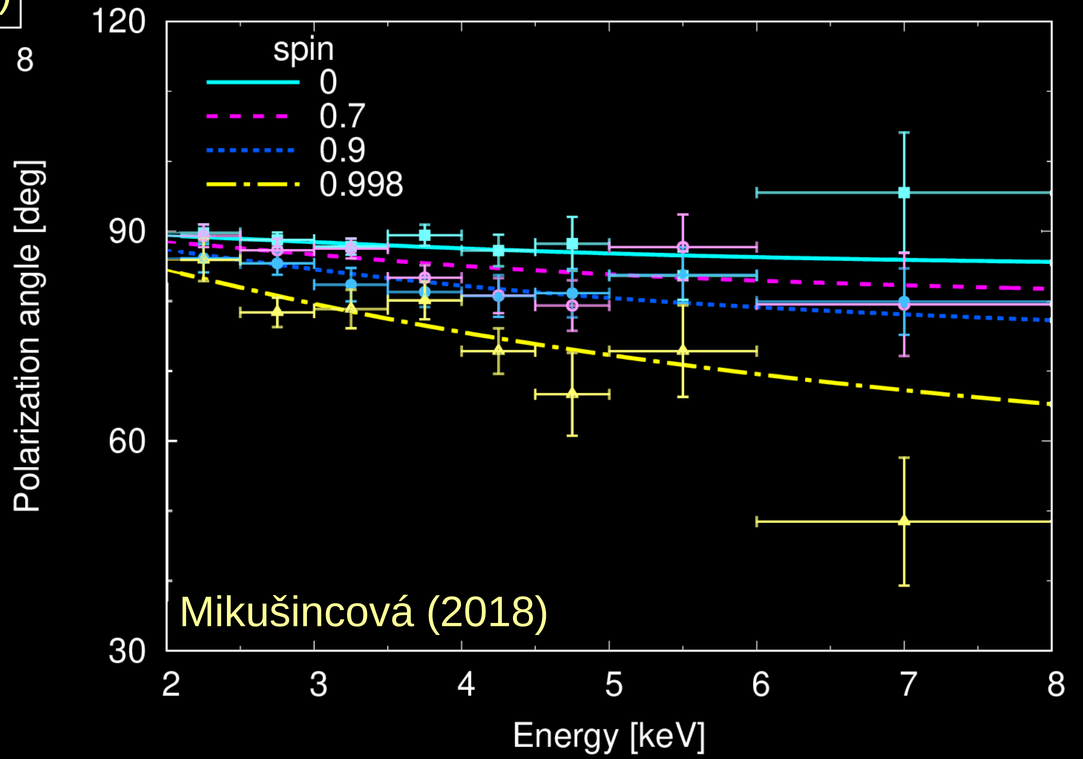
Polarization angle

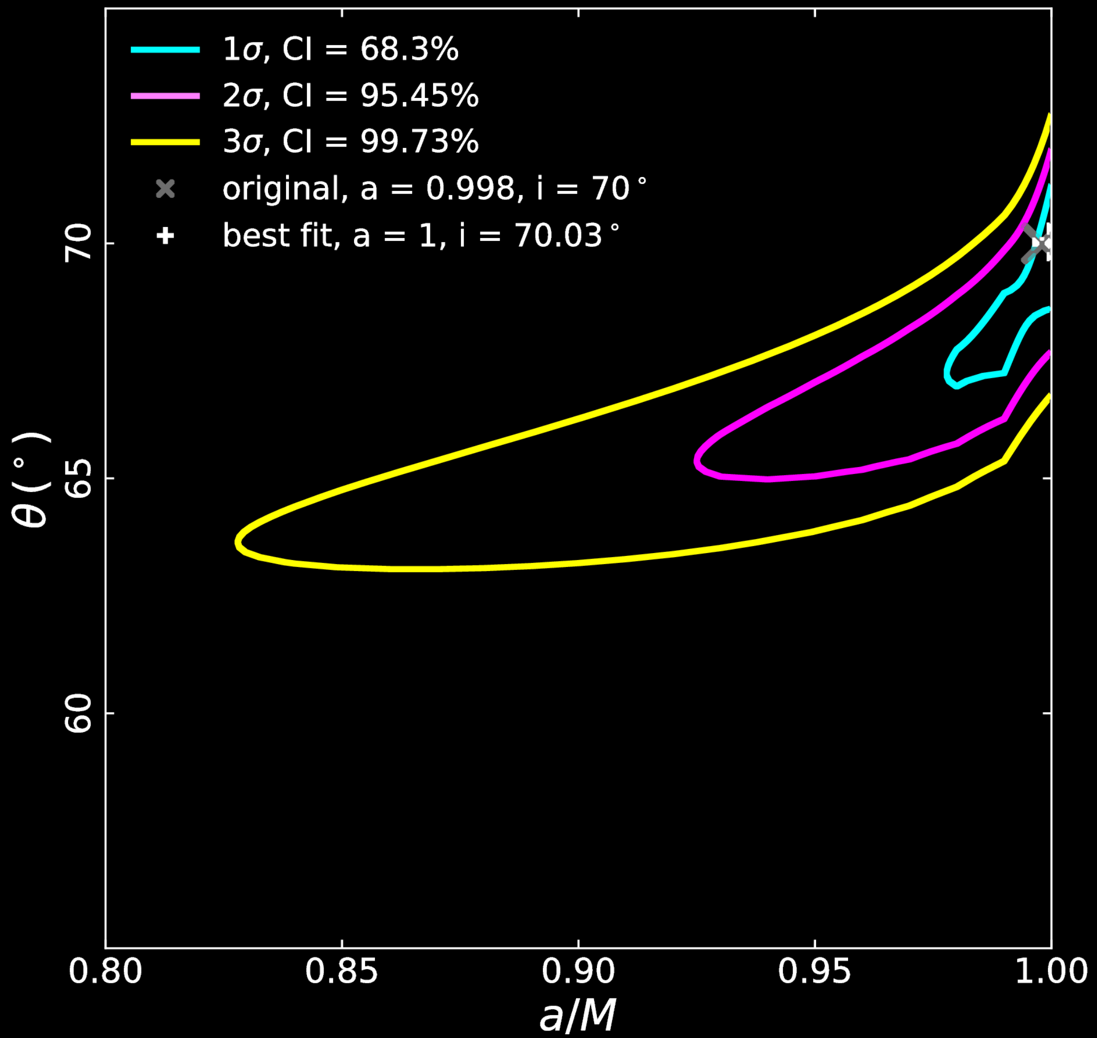
- rotation with energy larger for higher spins
- orientation of the system on the sky may be unknown



Spin vs. inclination – simulated error contours

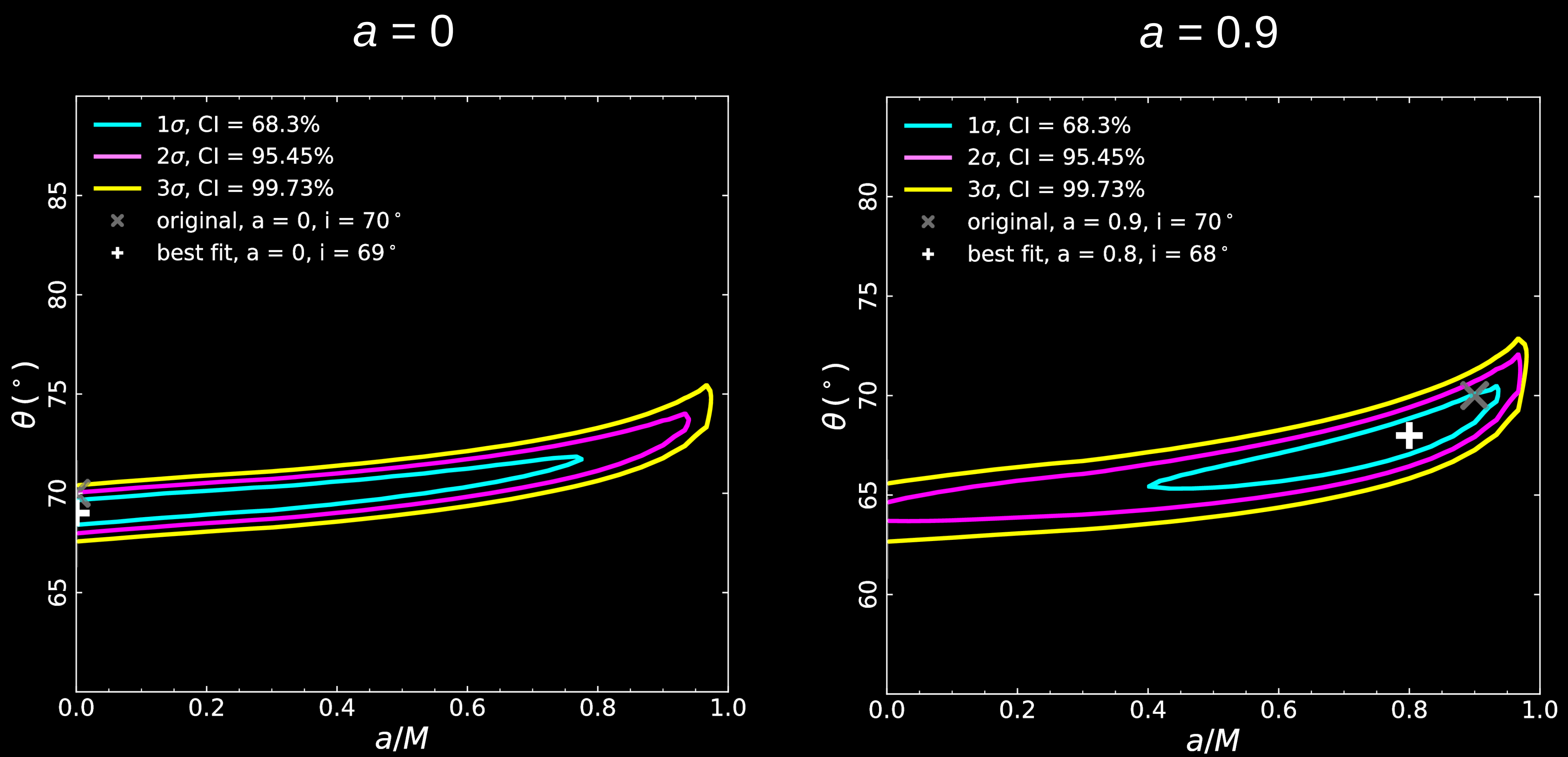
	model	best fit
spin	0.998	$1^{+0}_{-0.03}$
inclination [deg]	70	70^{+1}_{-3}
orientation [deg]	0	0^{+2}_{-0}
$\chi^2/d.o.f$		11.16/13

a = 0.998



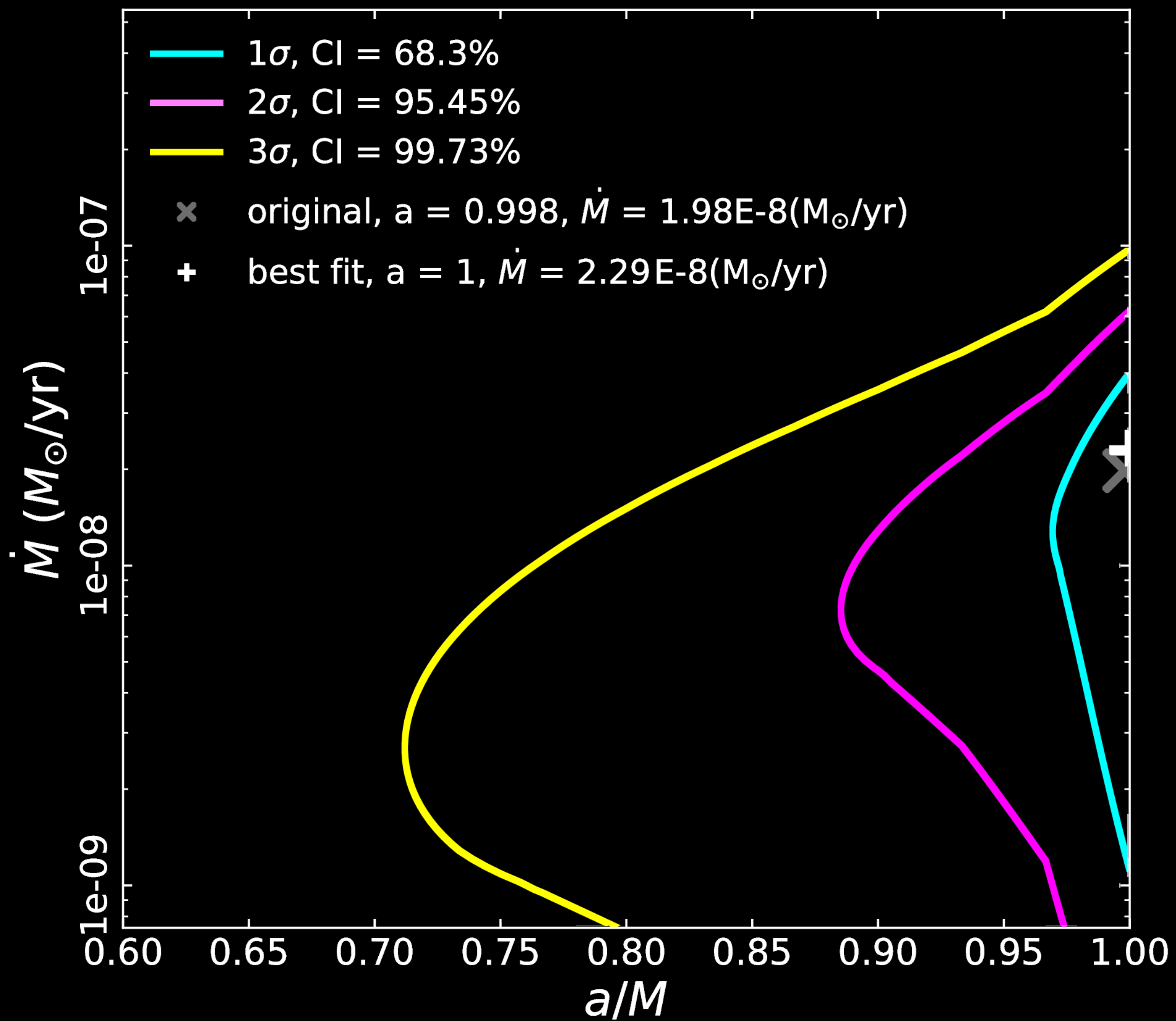
Mikušincová (2018)

Spin vs. inclination – simulated error contours



Mikušincová (2018)

Spin vs. accretion rate – simulated error contours



Mikušincová (2018)

Summary and conclusions

- Our group has developed and tested XSPEC model for energy-dependence of the polarization degree and the polarization angle in thermal state of X-ray binaries – **KYNBB**.
- We have created and fitted simulated data using KYNBB model and studied the constraints for the black hole spin, system inclination, mass accretion rate and orientation on the sky.

Caveat

- Our models do not account for polarization induced by disc self-irradiation (Schnittman & Krolik 2009)
- XSPEC model with realistic description of self-irradiation is under development

Summary and conclusions

Simulations for higher inclination (70 degree) system show:

- spin is rather well constrained only for its very large value (close to 1),
- inclination is quite well constrained,
- accretion rate is poorly constrained,
- orientation on the sky is very well constrained (except for 180 degree shift).

Polarimetric observations of X-ray binaries in thermal state could help to constrain their **geometry** (inclination, orientation on the sky) and give independent constraints on **black hole spin**.

Good astronomical targets for BH spin measurements via X-ray polarimetry are not only high-flux sources but also high-inclination systems.