eXtreme gravity with X-rays

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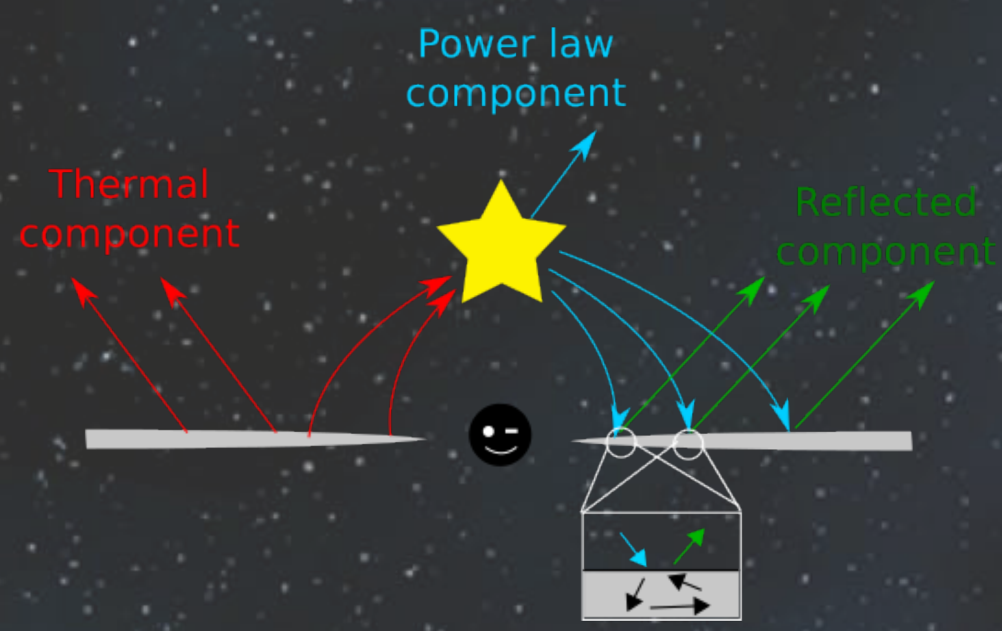
Overview

Accreting black holes are commonplace in our universe. A typical system can be understood in terms of the following components: a central black hole (BH), matter falling on the BH, and a corona which illuminates the falling matter. In the simplest case, pictured on the right, the matter forms a thin disk, the coronal illumination falls off as disk radius increases and the BH is described by the Kerr metric. **General relativity** (GR) describes how things travel under gravity. The schematic on the right shows how the redshift (and blueshift!) due to the

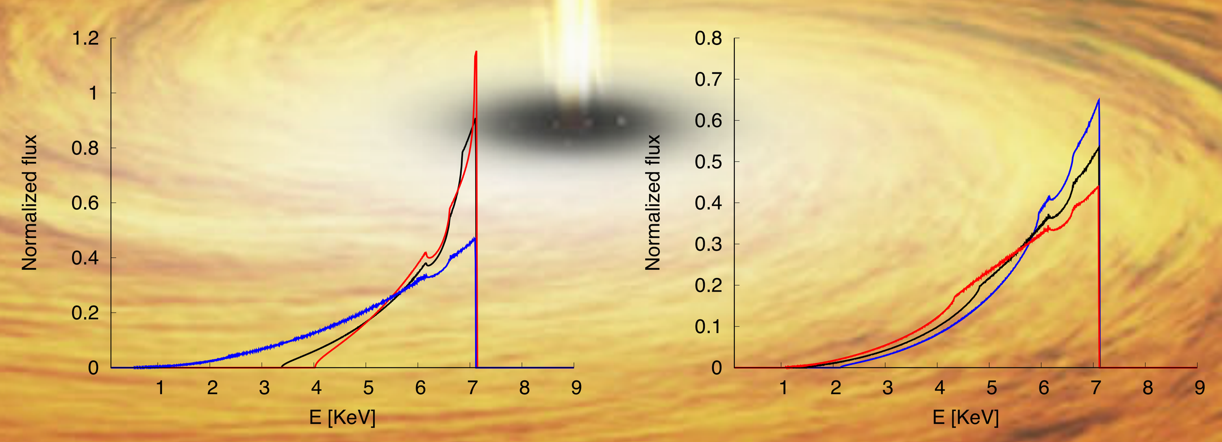


motion of disk and the gravity of the BH cause a spectral line (typically the Fe Kα line) to broaden into a characteristic shape. This relativistic broadening forms the core of our framework. **No hair theorem** states that any BH can be completely described by a few parameters.

Astrophysical BHs within GR admit only two parameters: mass and spin, and are described by the Kerr metric. The shape of a spectral line depends on the BH metric and thus, using spectral data from accreting BHs, we can learn about the nature of these fantastic beasts!

Present

Modified theory	Model-independent
New theory → new BHs	Kerr metric → new BHs
New theory of gravity!	Maps to other theories
Complicated solutions	Spacetime pathologies
EdGB Kerr-Sen Chern-Simons	Johannsen/Yunes et al. CPR KRZ



X-ray satellites → data

RELXILL_NK → model

data, model → Xspec fitting

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Model Model Component  Parameter  Unit     Value
 par  comp
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   2    1   relxill_nk Index2              3.00000      frozen
   3    1   relxill_nk Rbr                 15.0000      frozen
   4    1   relxill_nk a                   0.998000     +/-  0.0
   5    1   relxill_nk Incl       deg      30.0000      frozen
   6    1   relxill_nk Rin                 -1.00000     frozen
   7    1   relxill_nk Rout                400.000      frozen
   8    1   relxill_nk z                   0.0          frozen
   9    1   relxill_nk gamma               2.00000      +/-  0.0
  10    1   relxill_nk logxi               3.10000      +/-  0.0
  11    1   relxill_nk Afe                 1.00000      +/-  0.0
  12    1   relxill_nk Ecut       keV      300.000      frozen
  13    1   relxill_nk refl_frac           3.00000      +/-  0.0
  14    1   relxill_nk defpar_type         1.00000      frozen
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  16    1   relxill_nk norm                1.00000      +/-  0.0
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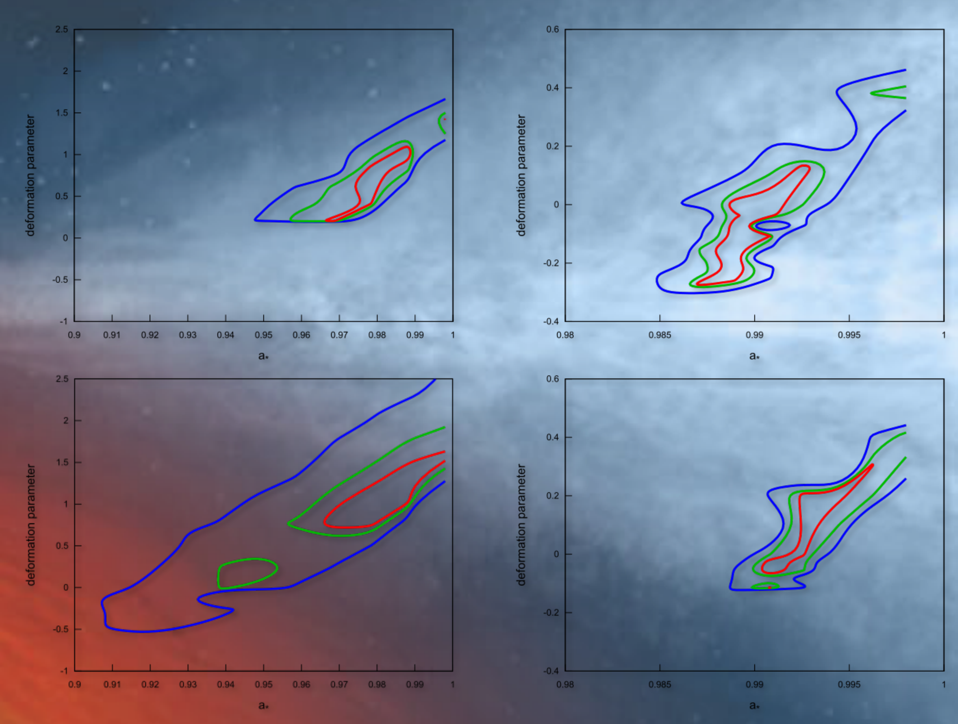
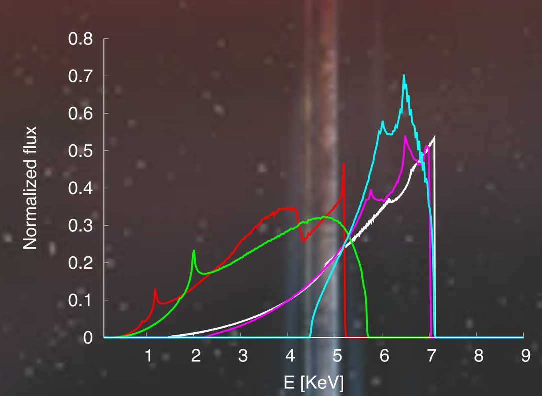


A natural degeneracy exists between the BH spin and the deformation parameters. The fitting is highly sensitive to correct astrophysical modeling of the BH system, in particular the emissivity profile.

Future

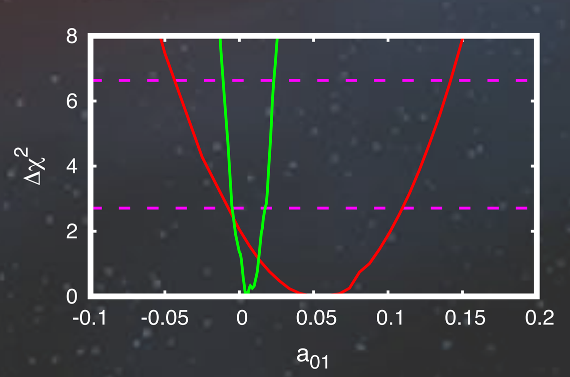
Better modeling

- More coronal geometries(RELXILLLP_NK)
- More disk compositions (RELXILLD_NK)
- More disk shapes (e.g., polish doughnut)



Better data (analysis)

- Correct model combinations
- Control over systematic errors
- New telescopes (e.g., ATHENA)



Better metrics

- More modified theory BH metrics (e.g., rotating EdGB)
- Nicer model-independent metrics (e.g., numerically matching exact metrics)

$$ds^2 = -\frac{N^2(r,\theta) - W^2(r,\theta)\sin^2\theta}{K^2(r,\theta)}dt^2 - 2W(r,\theta)r\sin^2\theta dtd\phi$$
$$+K^2(r,\theta)r^2\sin^2\theta d\phi^2 + \Sigma(r,\theta)\left(\frac{B^2(r,\theta)}{N^2(r,\theta)}dr^2 + r^2d\theta^2\right).$$

References:

"Public Release of RELXILL_NK: A Relativistic Reflection Model for Testing Einstein's Gravity ", ApJ 878 (2); "Testing General Relativity with X-ray reflection spectroscopy: The Konoplya-Rezzolla-Zhidenko parametrization", arXiv:1903.12119; "Tests of the Kerr hypothesis with GRS 1915+105 using different RELXILL flavors", arXiv:1907.03084;

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