Testing theories of gravity with X-ray reflection spectroscopy

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Tests of general relativity

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- What about gravitational waves?

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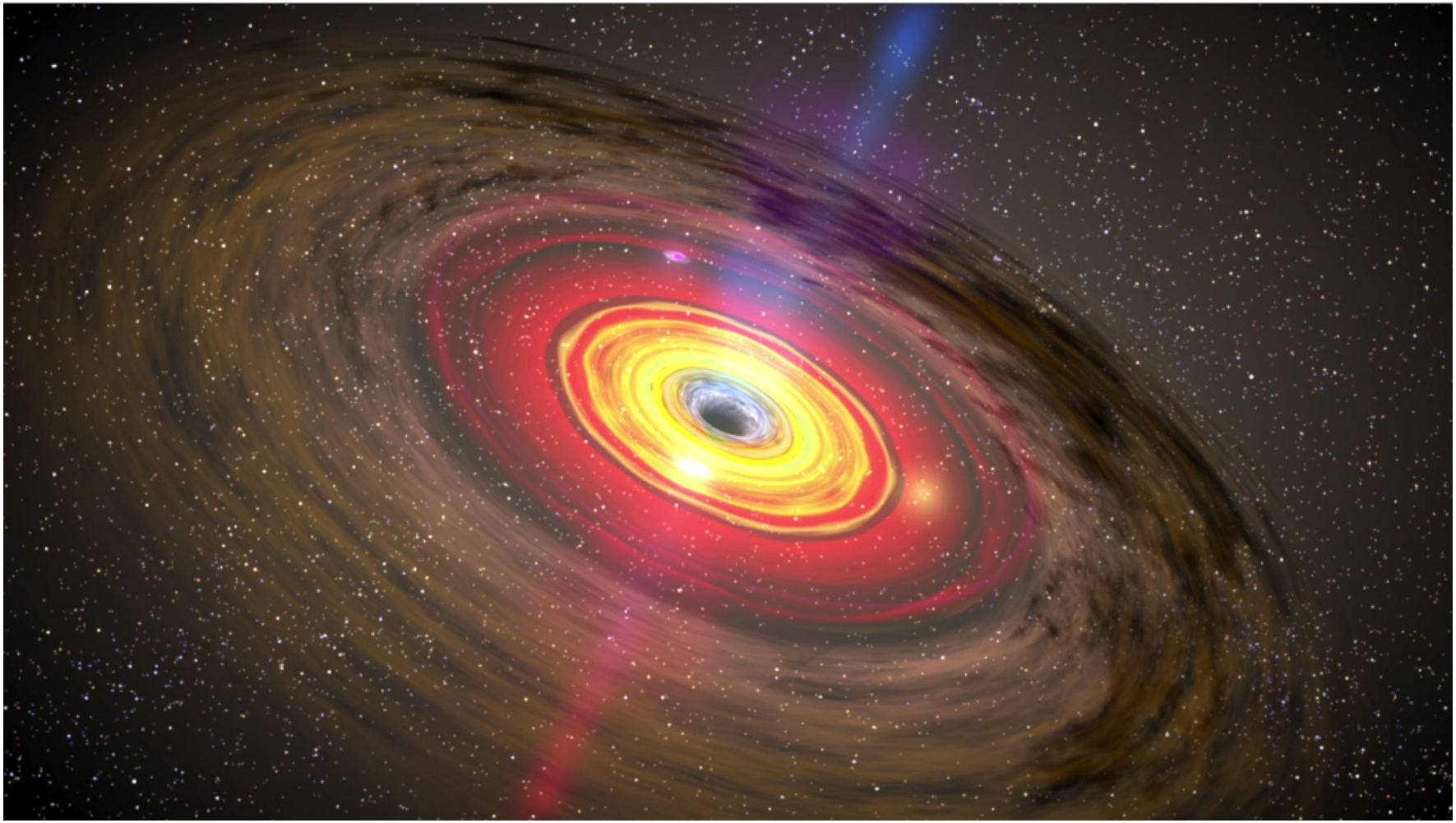
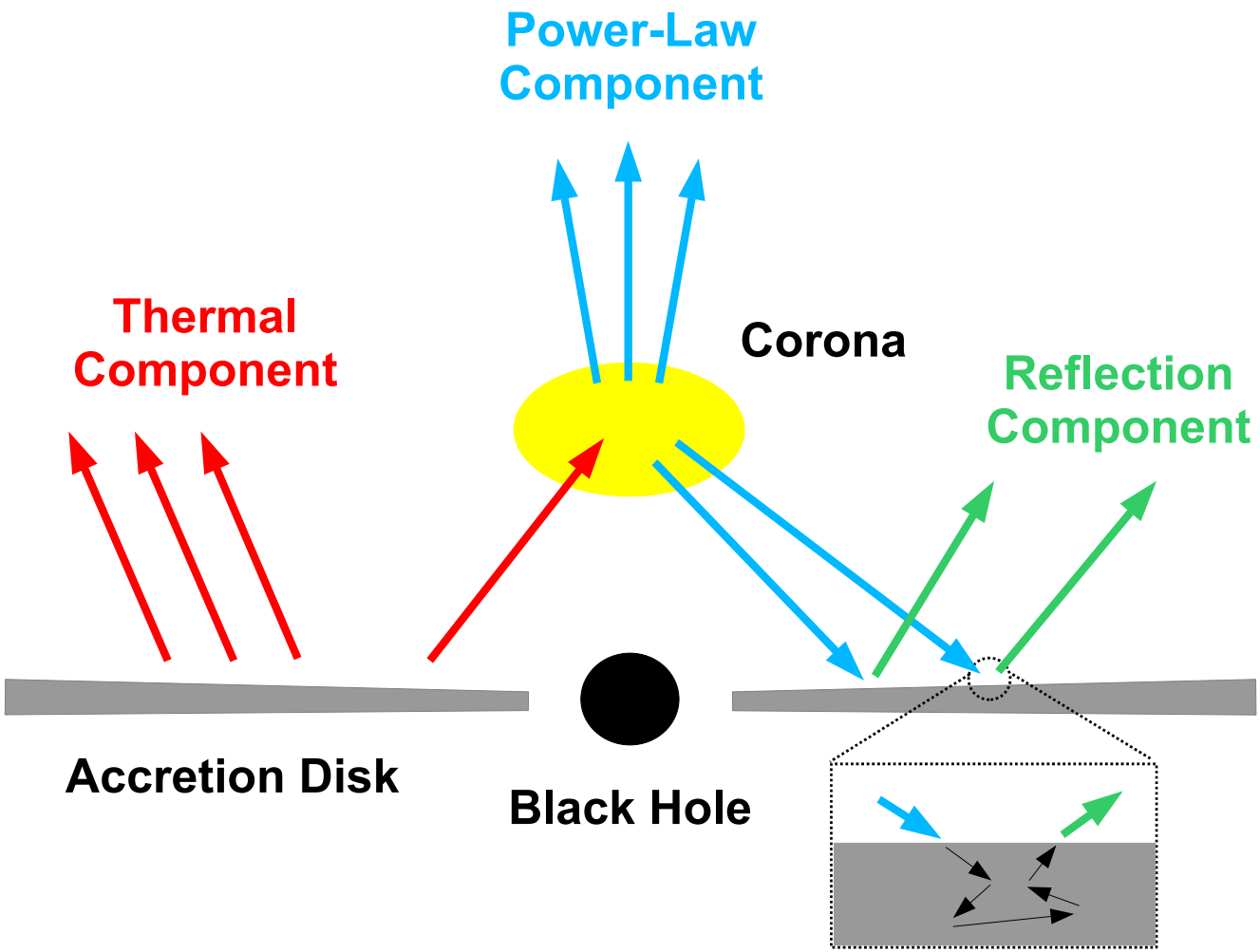
- Top-down and bottom-up approaches.

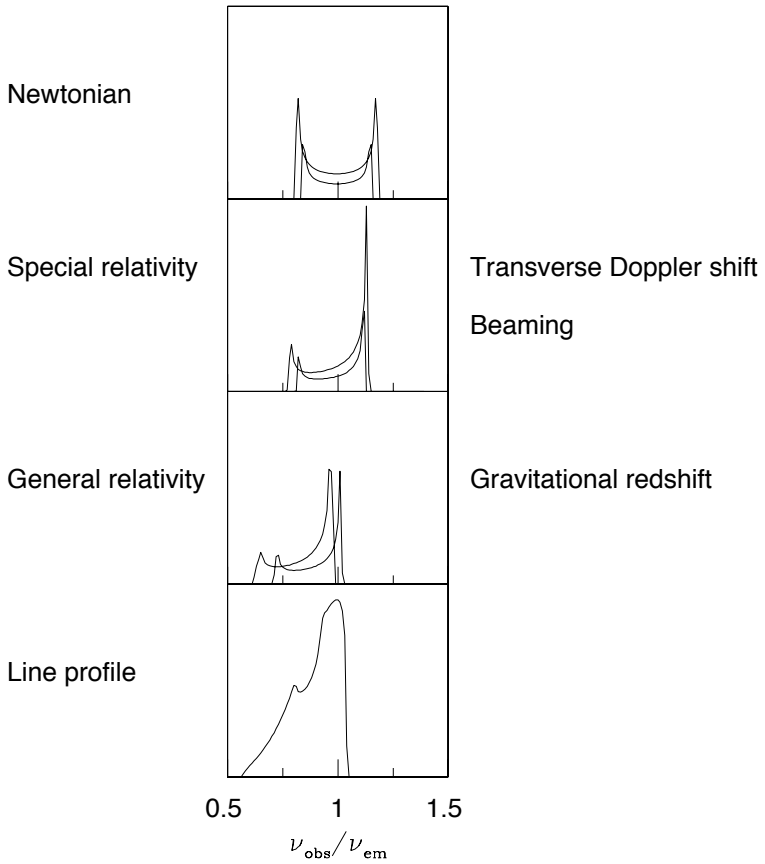
Accreting black holes



Radiation profile



Broadening of a line



via Fabian et al., PASP, 112, 775 (2000)

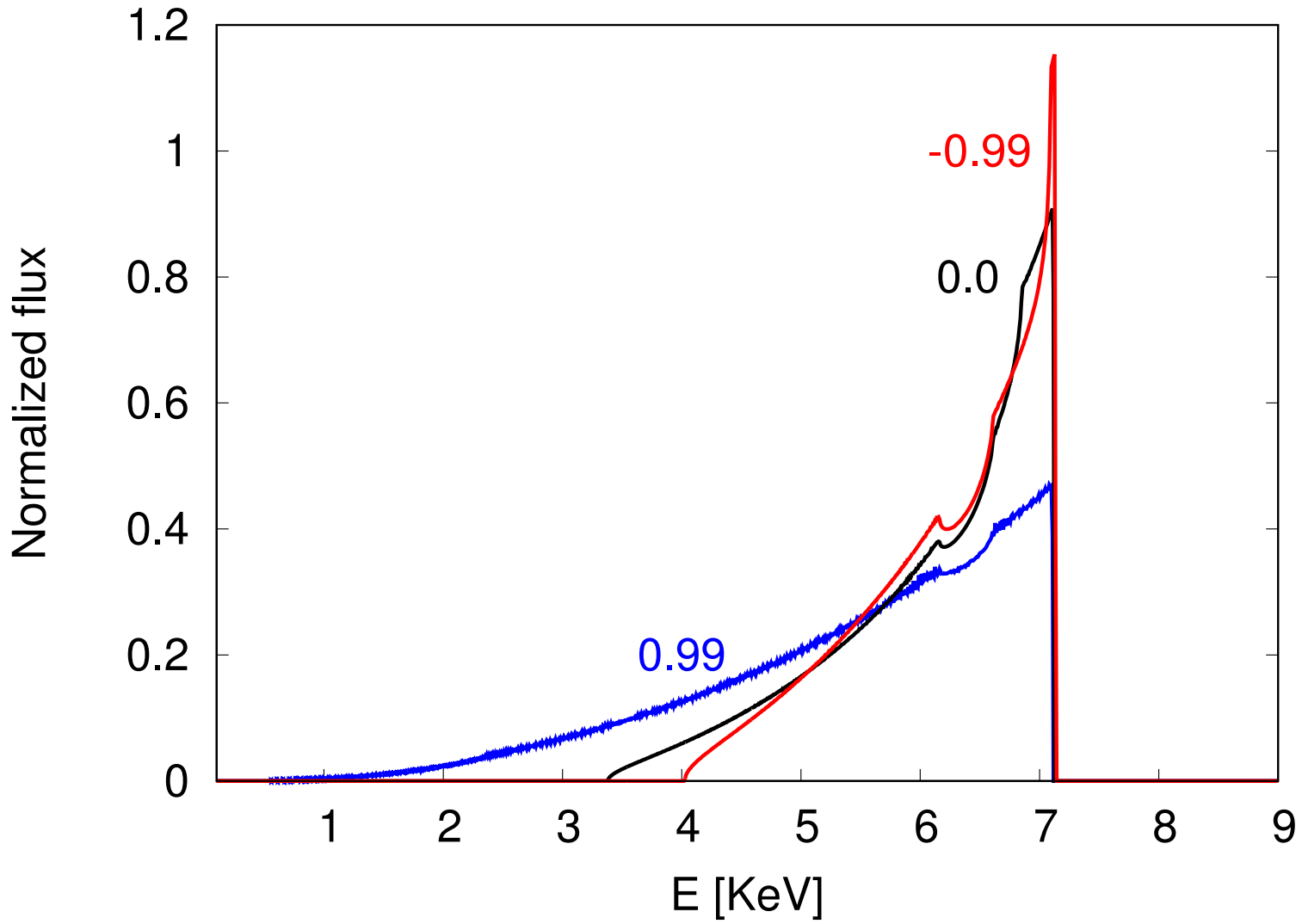
Black holes within GR

- Kerr metric:

$$ds^2 = -\left(1 - \frac{2Mr}{\Sigma}\right) dt^2 + \frac{\Sigma}{\Delta} dr^2 - \frac{2Mar\sin^2\theta}{\Sigma} dt\, d\phi + \Sigma d\theta^2 + \left(r^2 + a^2 + \frac{2Ma^2 r \sin^2\theta}{\Sigma}\sin^2\theta\right) d\phi^2 \quad (1)$$

$$\Delta \equiv r^2 - 2Mr + a^2, \quad \Sigma \equiv r^2 + a^2\cos^2\theta \quad (2)$$

Iron lines within GR



Black holes beyond GR: top-down

$$\mathcal{L} = \frac{1}{2}R - \frac{1}{4}\partial_\mu \partial^\mu \phi + \frac{\alpha'}{8g^2} e^{\phi} \left(R_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma} - 4 R_{\mu\nu} R^{\mu\nu} + R^2 \right)$$

Black holes beyond GR: bottom-up

- Johannsen metric[1]:

$$
\begin{aligned}
ds^2 = &-\frac{\tilde{\Sigma}[\Delta - a^2 A_2^2 \sin^2\theta]}{\Xi} dt^2 + \frac{\tilde{\Sigma}}{\Delta A_5} dr^2 \\
&- \frac{a[(r^2+a^2)A_1 A_2 - \Delta]}{\Xi} dt\, d\phi + \tilde{\Sigma} d\theta^2 \\
&+ \frac{\tilde{\Sigma}\sin^2\theta[(r^2+a^2)^2 A_1^2 - a^2\Delta\sin^2\theta]}{\Xi} d\phi^2 \qquad (3)
\end{aligned}
$$

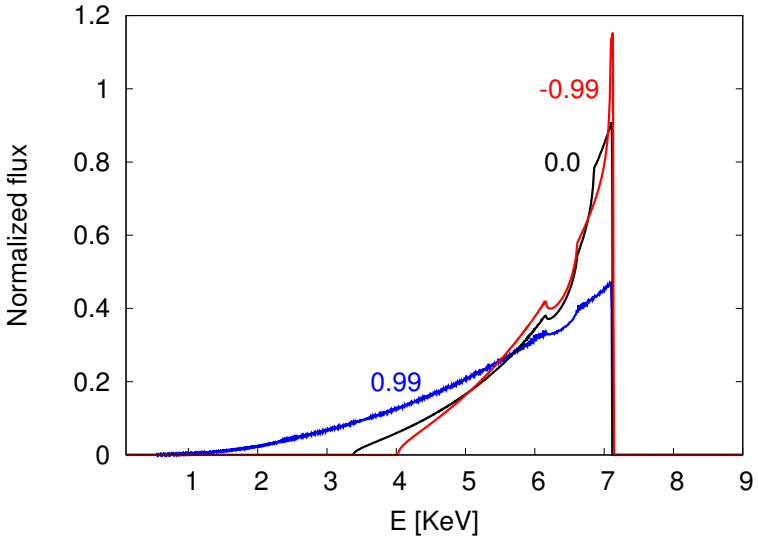
$$
\Xi = ((r^2+a^2)A_1 - a^2 A_2 \sin^2\theta)^2,
$$

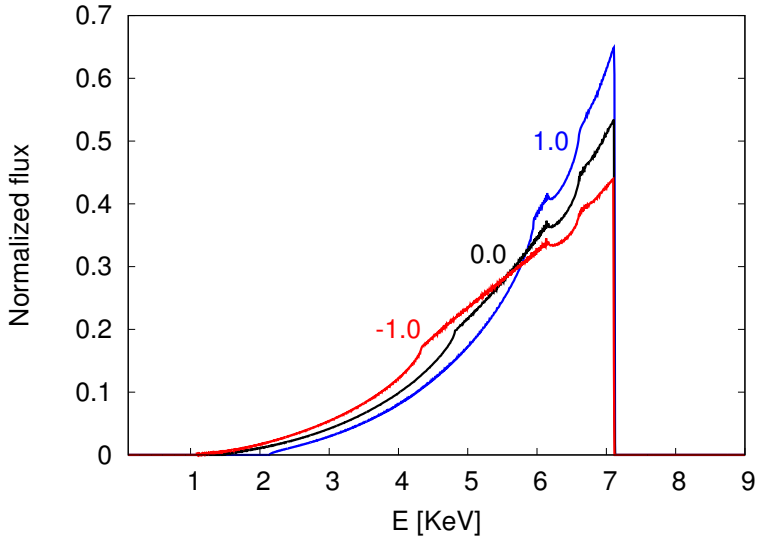
$$
A_1 = 1 + \alpha_{13}(M/r)^3 + \ldots, \quad A_2 = 1 + \alpha_{22}(M/r)^2 + \ldots
$$

$$
A_5 = 1 + \alpha_{52}(M/r)^2 + \ldots, \quad \tilde{\Sigma} = \Sigma + \epsilon_3(M^3/r) + \ldots
$$

[1] Johannsen, PRD, 88, 044002 (2013)

Iron lines beyond GR





RELXILL_NK

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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      +/-  0.0
   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                5.00000      +/-  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
  15    1   relxill_nk defpar_value        0.0          +/-  0.0
  16    1   relxill_nk norm               1.00000      +/-  0.0
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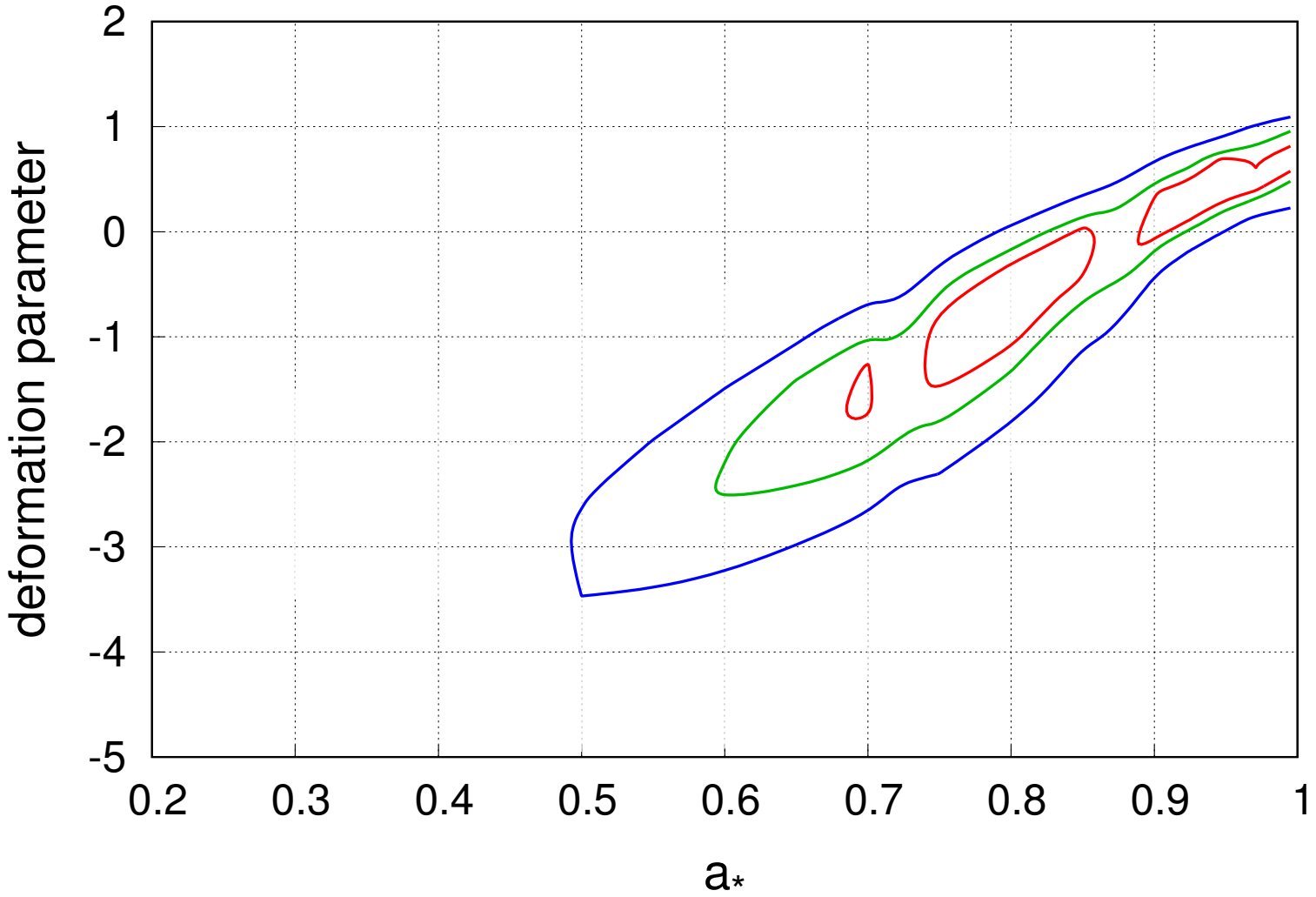
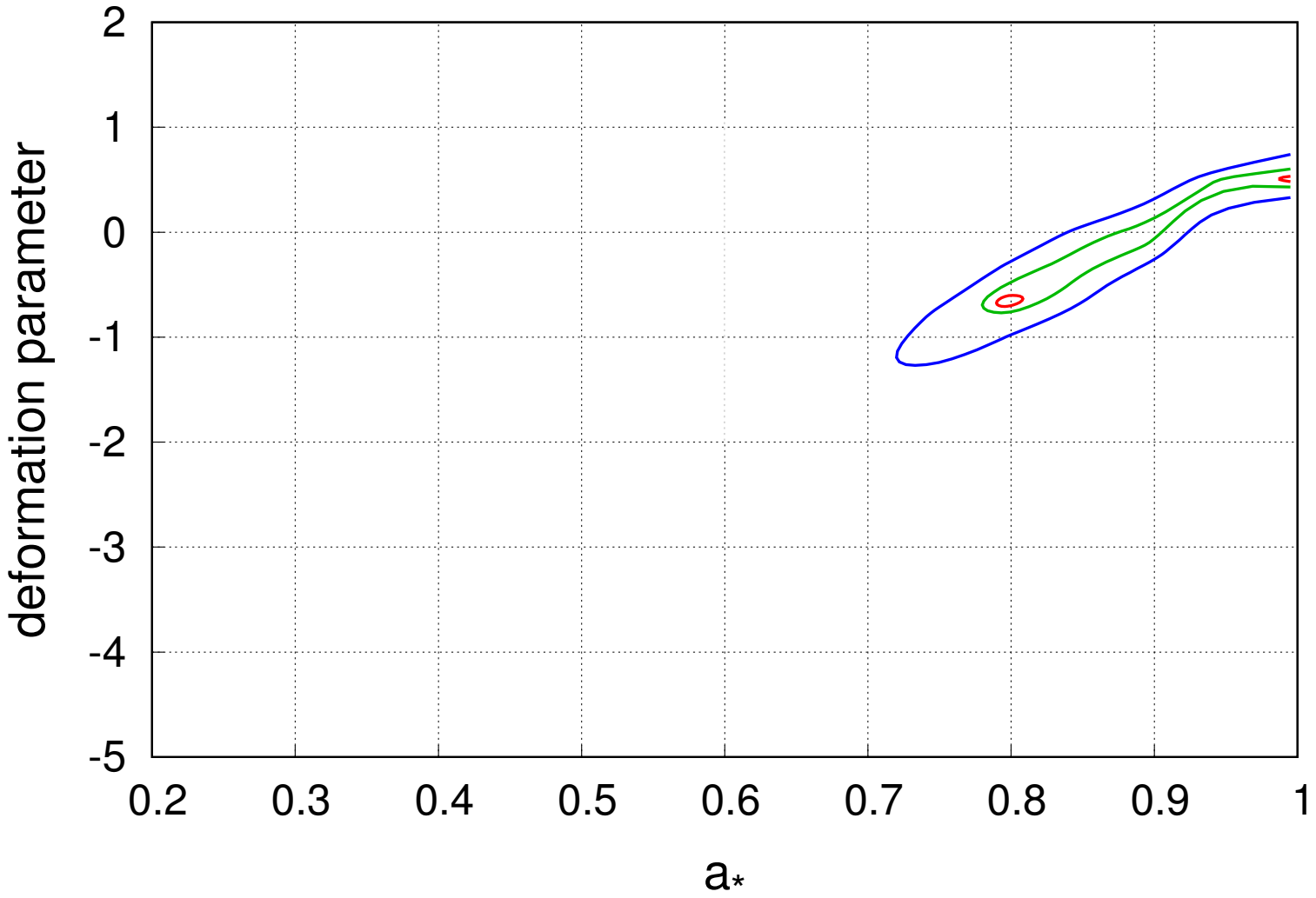
Constraints with current instruments

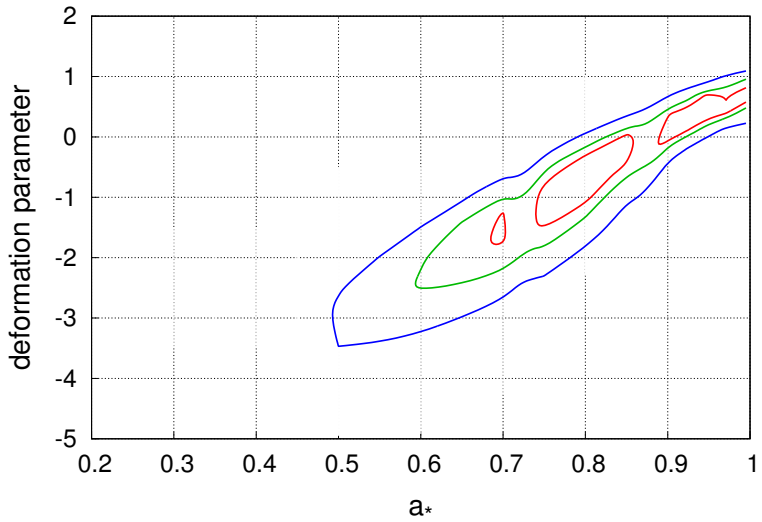


arXiv:1804.10380, under review

Scope with future instruments



A glimpse into the future



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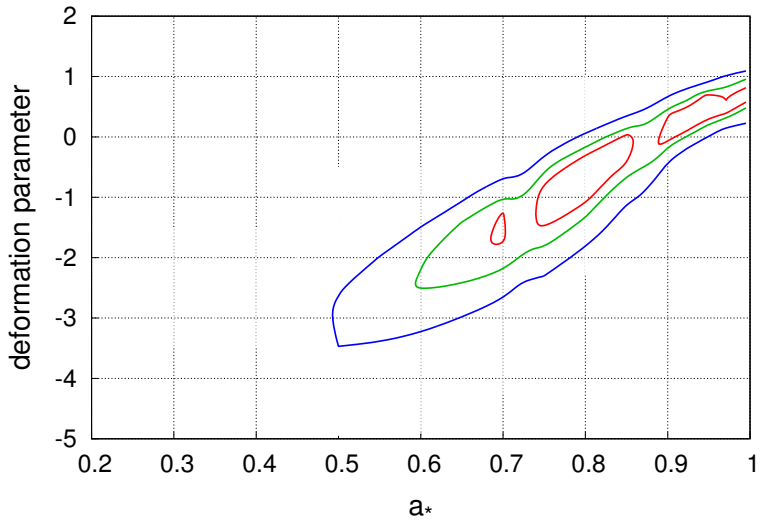

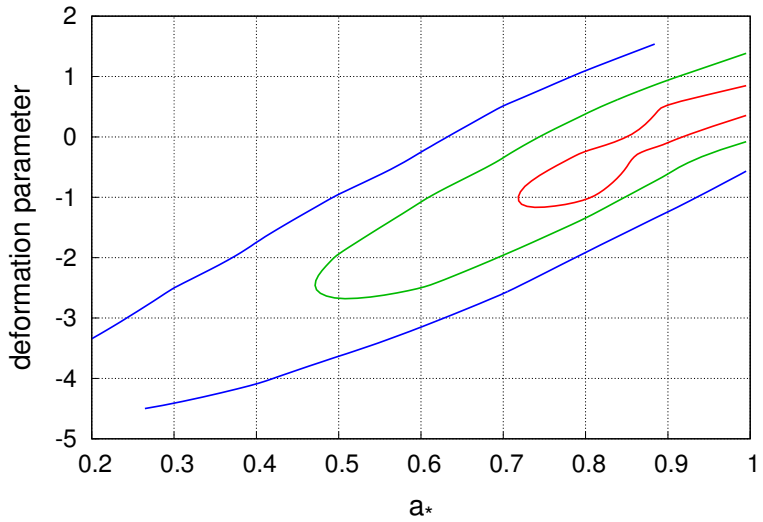

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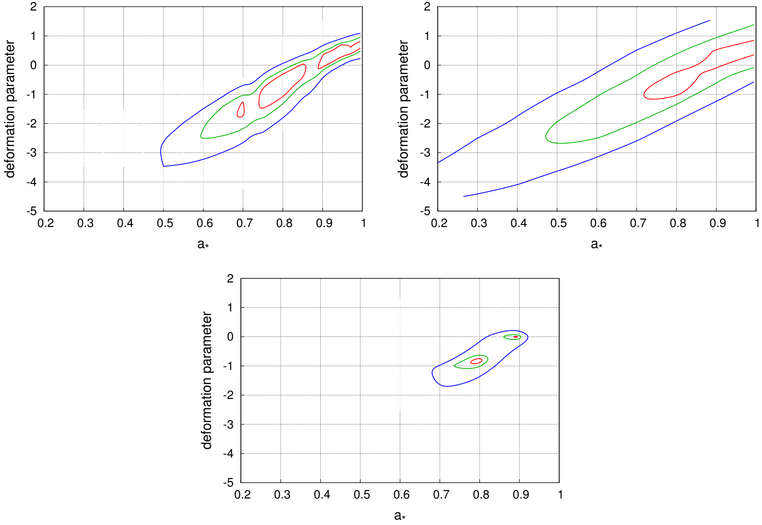

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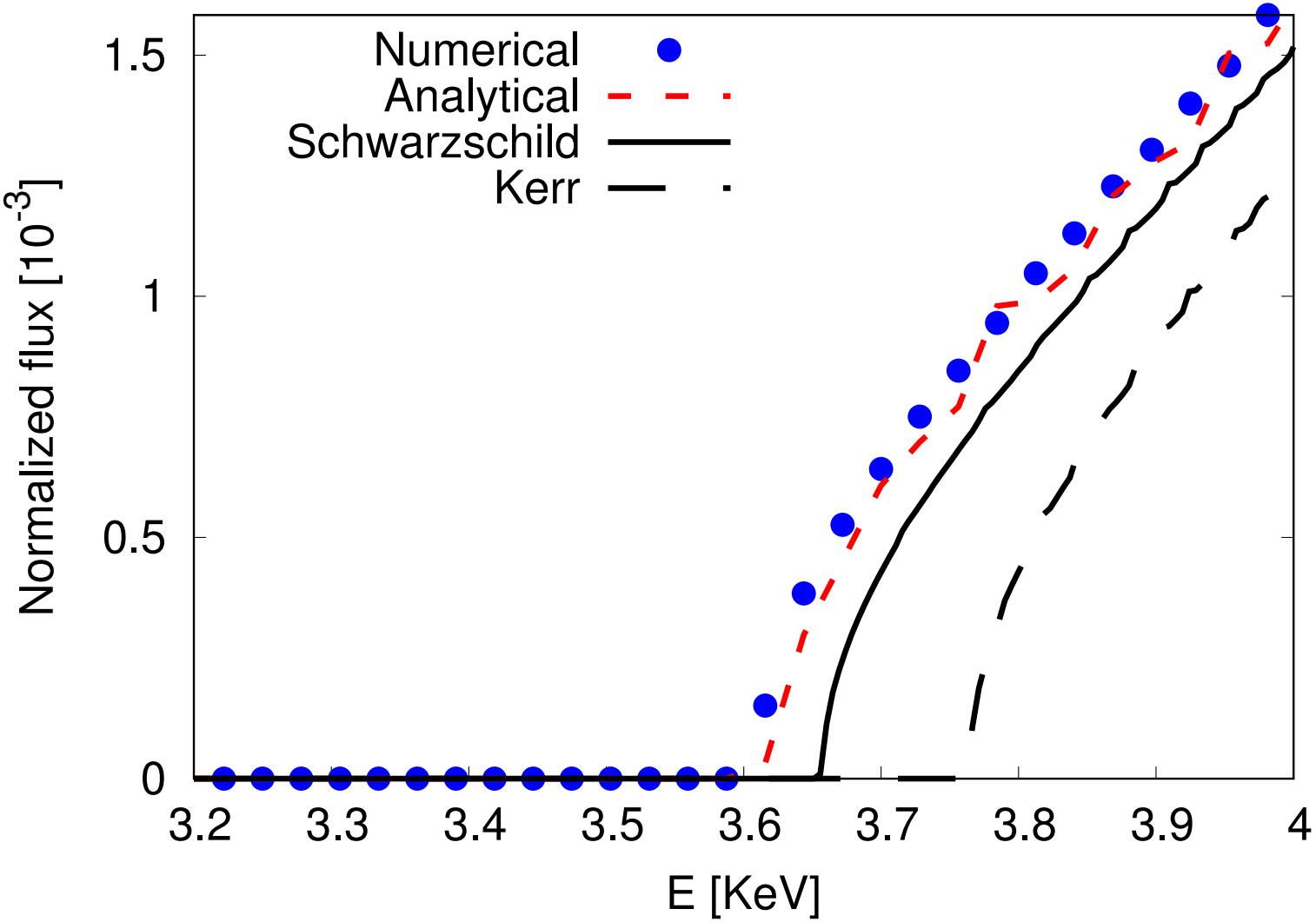
The curious case of Einstein dilaton Gauss Bonnet



arXiv:1803.10819, to appear in PLB

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Thank you!

ISCO contours