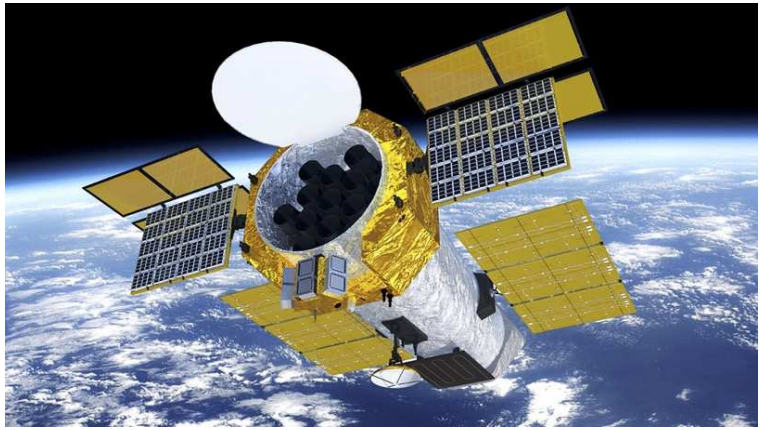
Electromagnetic signatures of strong-field gravity from the synergy of upcoming X-ray polarimetry and ground-based techniques

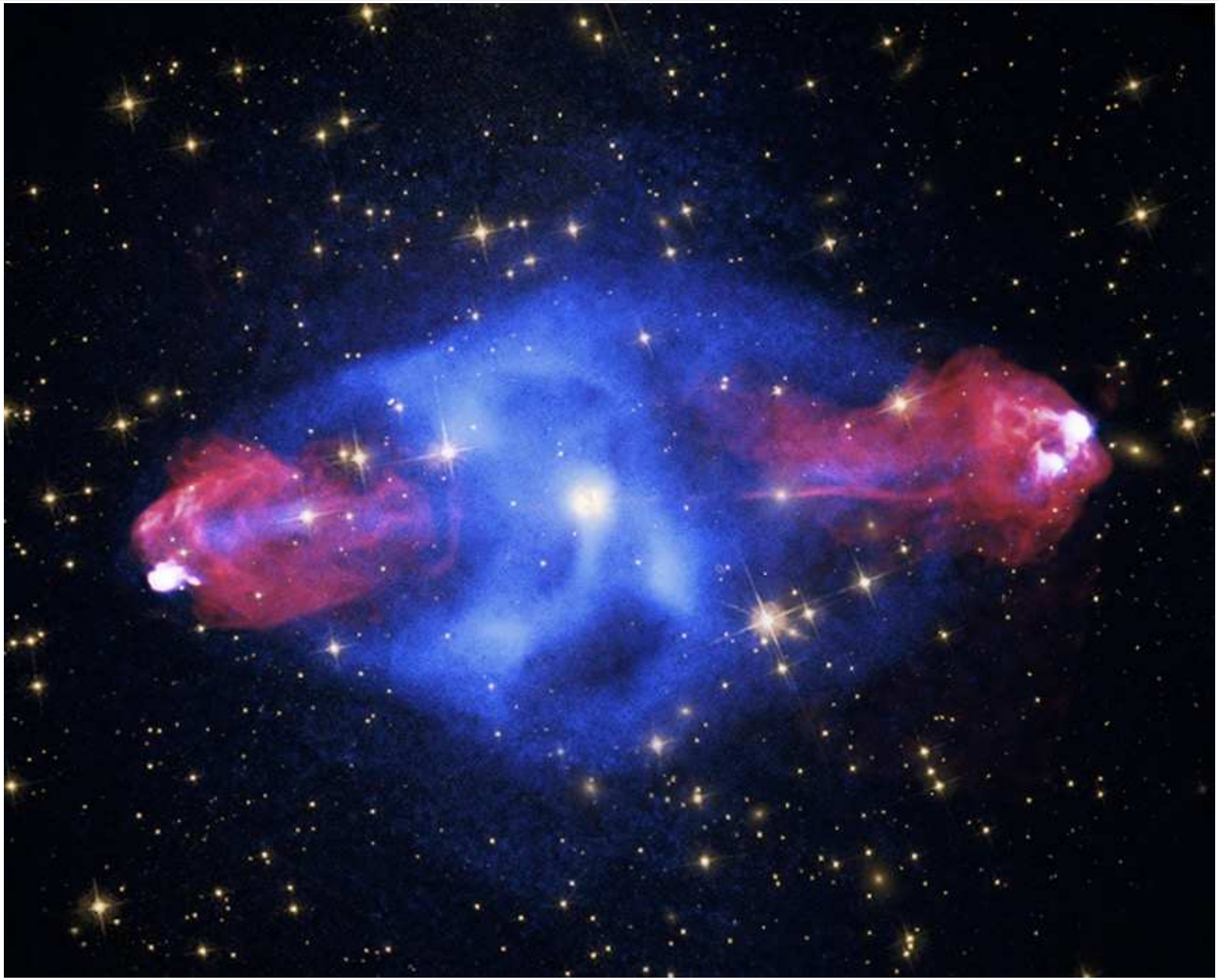
Elektromagnetické projevy silné gravitace v synergii nadcházející rentgenové polarimetrie s pozemními metodami

Selected topics as science drivers for mission proposals

Vladimír Karas & Michal Dovčiak (ASU CAS, Prague), Michal Zajaček (UTFA MU, Brno)



Cygnus A



VLA/Chandra

Objects and models

- Active galactic nuclei
- Stellar-mass black holes
- Intermediate-mass black holes (?)

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- GR effects taken into account
- Link to a spectrum-fitting procedure $\rightarrow$ <u>parameters</u>

Mathematics

Exact solution – magnetized Kerr-Newman BH:

$$
\begin{aligned}
g &= |\Lambda|^2 \Sigma \left(\Delta^{-1}\,\mathrm{d}r^2 + \mathrm{d}\theta^2 - \Delta A^{-1}\,\mathrm{d}t^2\right) \\
&\quad + |\Lambda|^{-2}\Sigma^{-1} A \sin^2\theta \left(\mathrm{d}\phi - \omega\,\mathrm{d}t\right)^2,
\end{aligned}
$$

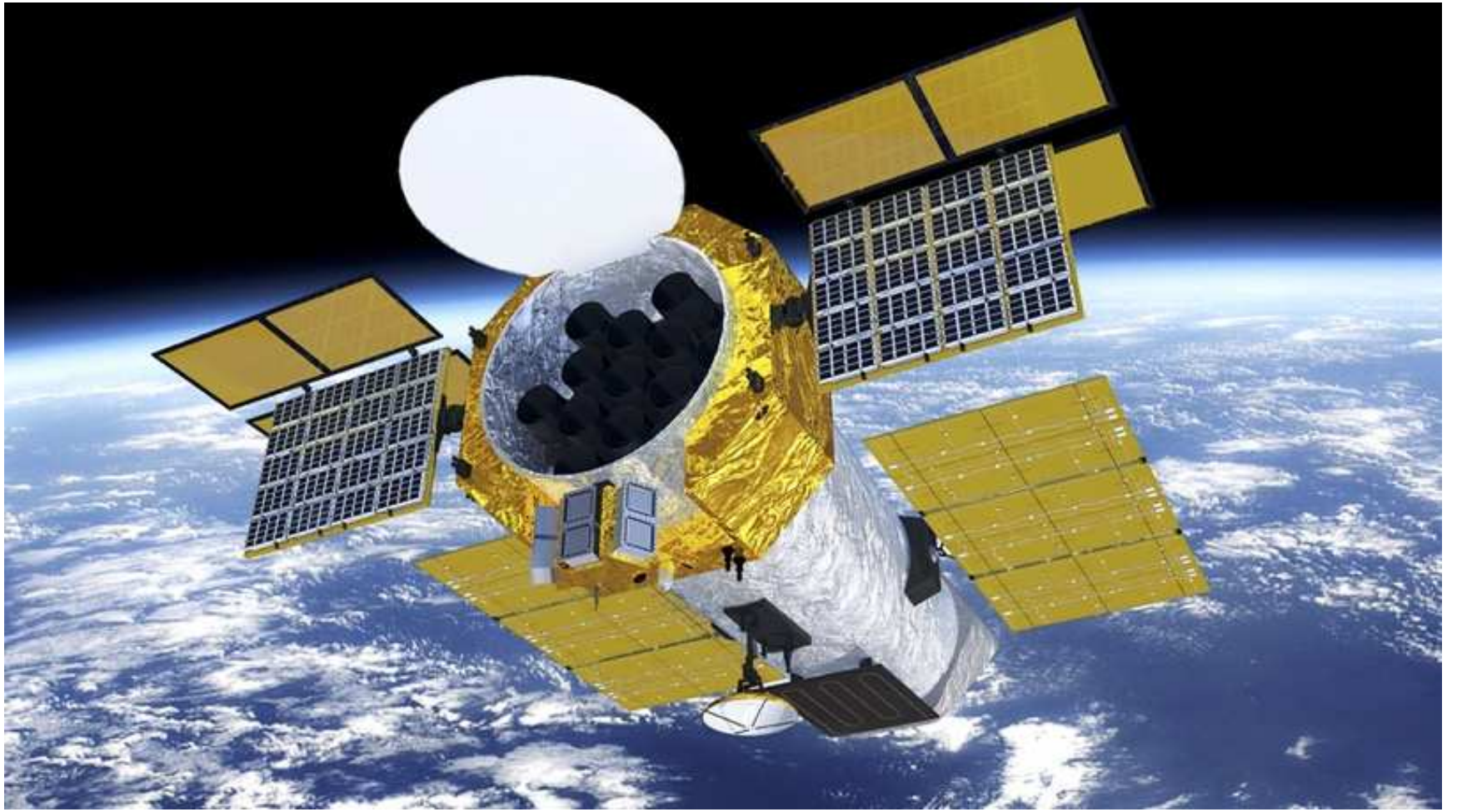
$\Sigma = r^2 + a^2\cos^2\theta$, $\Delta = r^2 - 2Mr + a^2 + e^2$,
$A = (r^2 + a^2)^2 - \Delta a^2 \sin^2\theta$ are functions from the Kerr-Newman metric.
$\Lambda = 1 + \beta\Phi - \frac{1}{4}\beta^2\mathcal{E}$ is given in terms of the Ernst complex potentials $\Phi(r,\theta)$ and $\mathcal{E}(r,\theta)$:

$$
\begin{aligned}
\Sigma\Phi &= ear\sin^2\theta - \Im e\left(r^2 + a^2\right)\cos\theta, \\
\Sigma\mathcal{E} &= -A\sin^2\theta - e^2\left(a^2 + r^2\cos^2\theta\right) \\
&\quad + 2\Im a\left[\Sigma\left(3 - \cos^2\theta\right) + a^2\sin^4\theta - re^2\sin^2\theta\right]\cos\theta.
\end{aligned}
$$

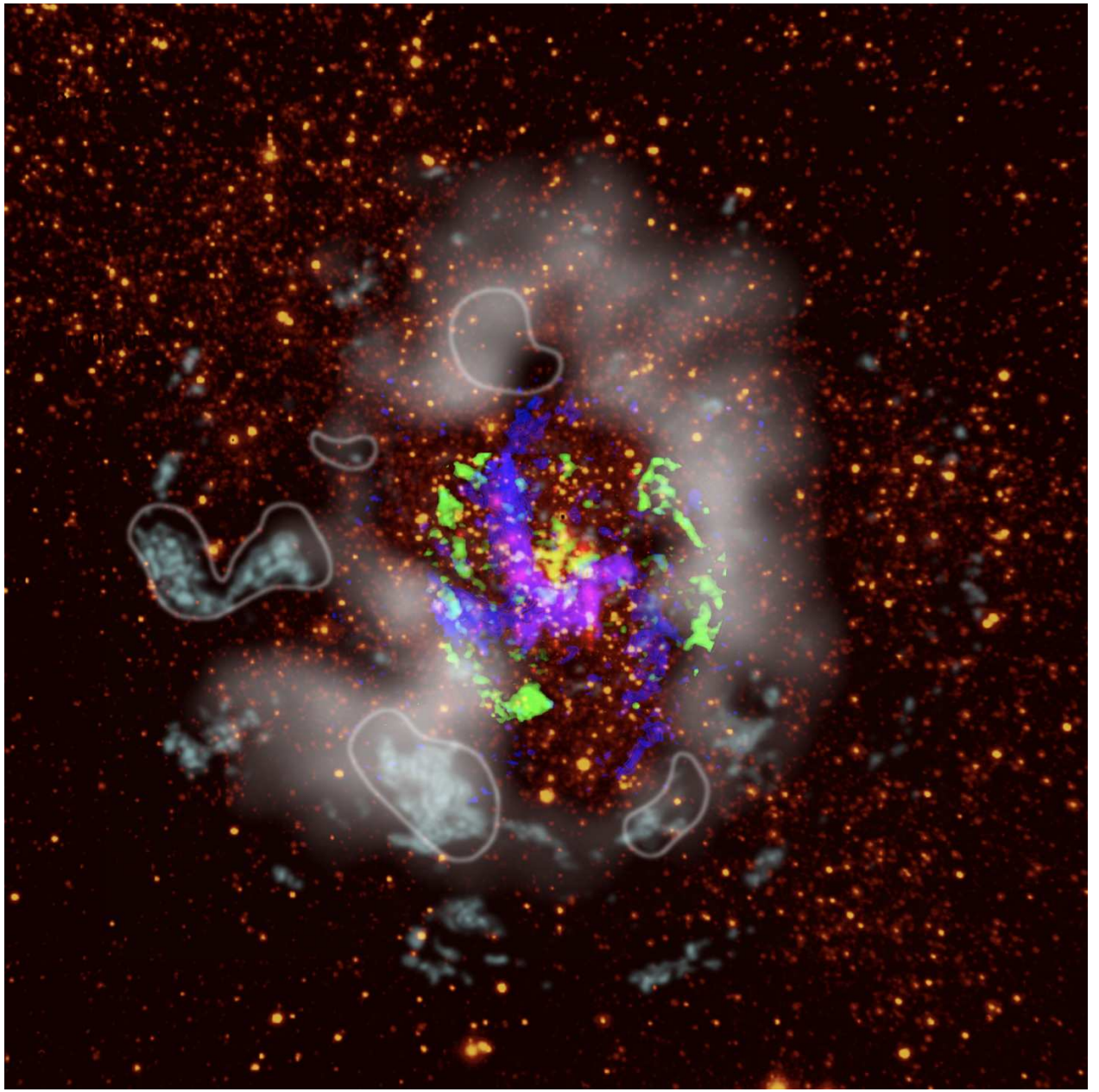
Technology

IXPE (NASA) and eXTP (China/Europe) satellite missions

VLT/GRAVITY (ESO) and ALMA/EHT observatories



Sagittarius A*



Eckart et al (2019)

Thank you / Děkuji!

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Advances in Space Research xxx (xxxx) xxx

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Electromagnetic signatures of strong-field gravity from accreting black-holes ☆

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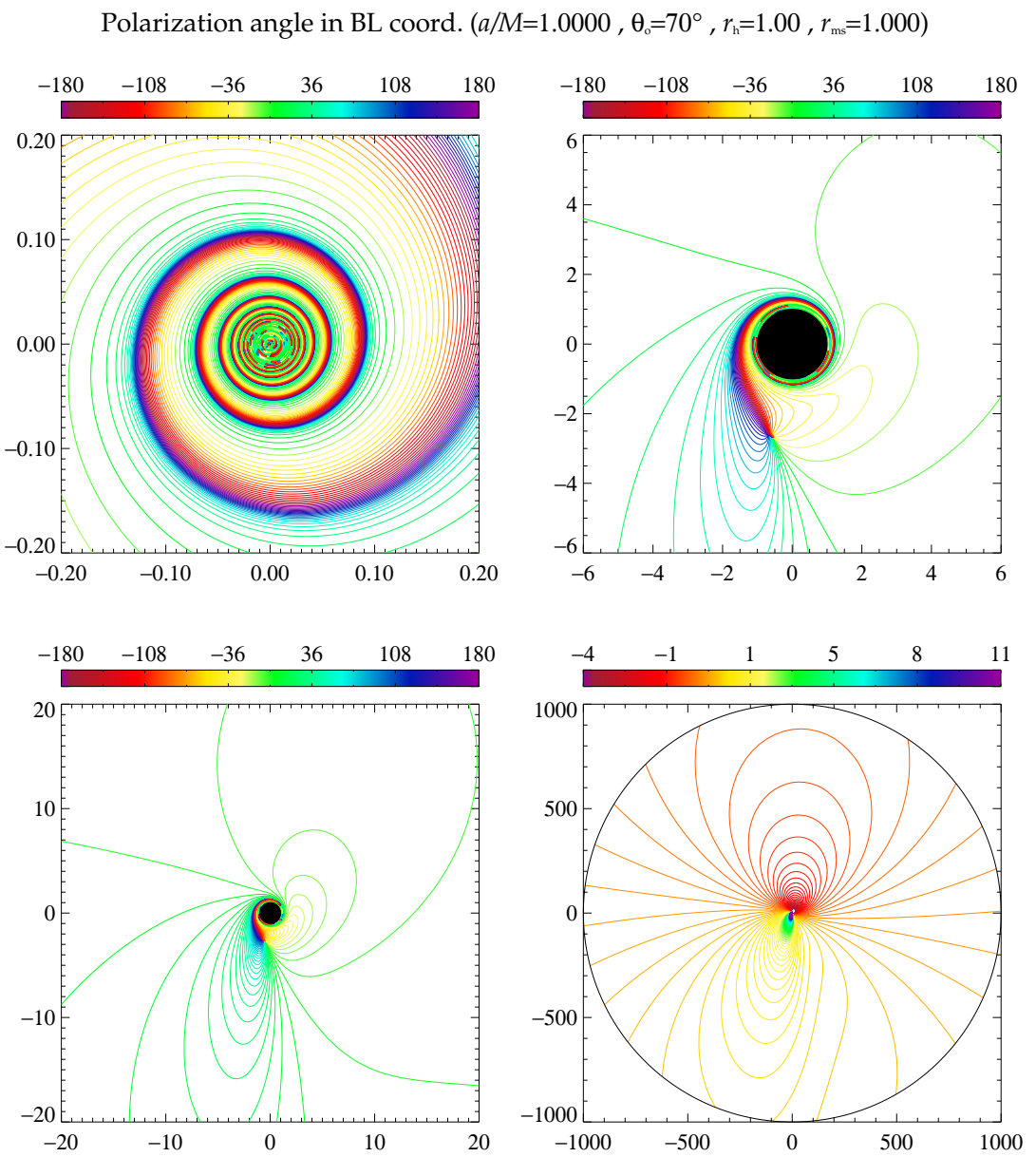
Received 23 March 2021; received in revised form 5 September 2021; accepted 12 September 2021

arXiv:2110.11136

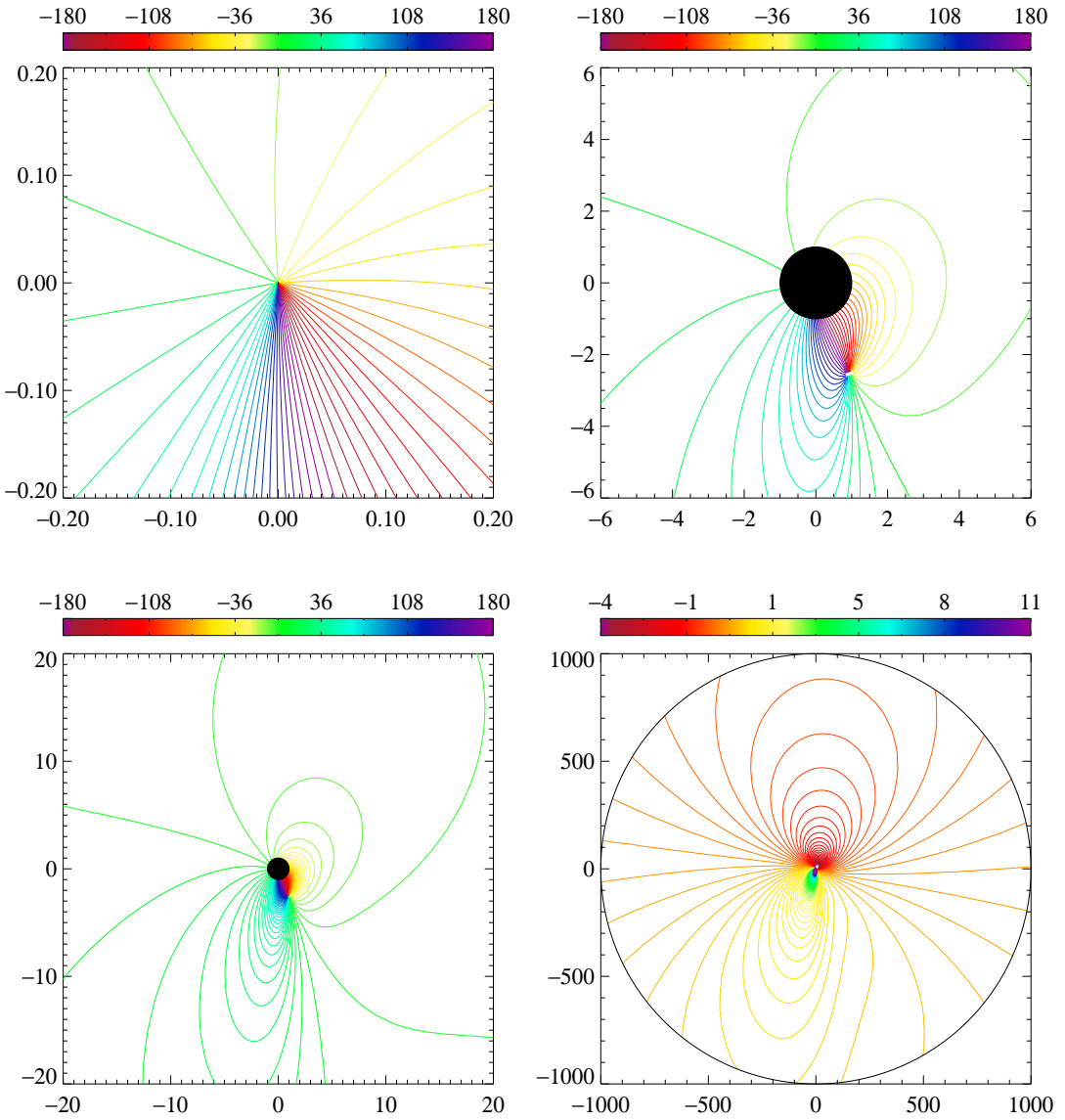
Discussion slides 1



Dovciak et al (2012)

Discussion slides 2

Polarization angle in Kerr coord. (a/M=1.0000 , θ_o=70° , r_h=1.00 , r_{ms}=1.000)



Dovciak et al (2012)

Discussion slides 3

Stokes parameters

$$
\begin{aligned}
S_0 &\equiv J_{\alpha\beta}\left(e^{\alpha}_{(1)}e^{\beta}_{(1)} + e^{\alpha}_{(2)}e^{\beta}_{(2)}\right) = \langle |E_{(1)}|^2 + |E_{(2)}|^2 \rangle \\
S_1 &\equiv J_{\alpha\beta}\left(e^{\alpha}_{(1)}e^{\beta}_{(1)} - e^{\alpha}_{(2)}e^{\beta}_{(2)}\right) = \langle |E_{(1)}|^2 - |E_{(2)}|^2 \rangle \\
S_2 &\equiv J_{\alpha\beta}\left(e^{\alpha}_{(1)}e^{\beta}_{(2)} + e^{\alpha}_{(2)}e^{\beta}_{(1)}\right) = \langle E_{(1)}\bar{E}_{(2)} + E_{(2)}\bar{E}_{(1)} \rangle \\
S_3 &\equiv \Im J_{\alpha\beta}\left(e^{\alpha}_{(1)}e^{\beta}_{(2)} - e^{\alpha}_{(2)}e^{\beta}_{(1)}\right) = \Im\langle E_{(1)}\bar{E}_{(2)} - E_{(2)}\bar{E}_{(1)} \rangle
\end{aligned}
$$

S_1, S_2, and S_3 determine the polarization state.

References: [5] Anile (1989), *Relativistic fluids and magneto-fluids* (Cambridge)
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