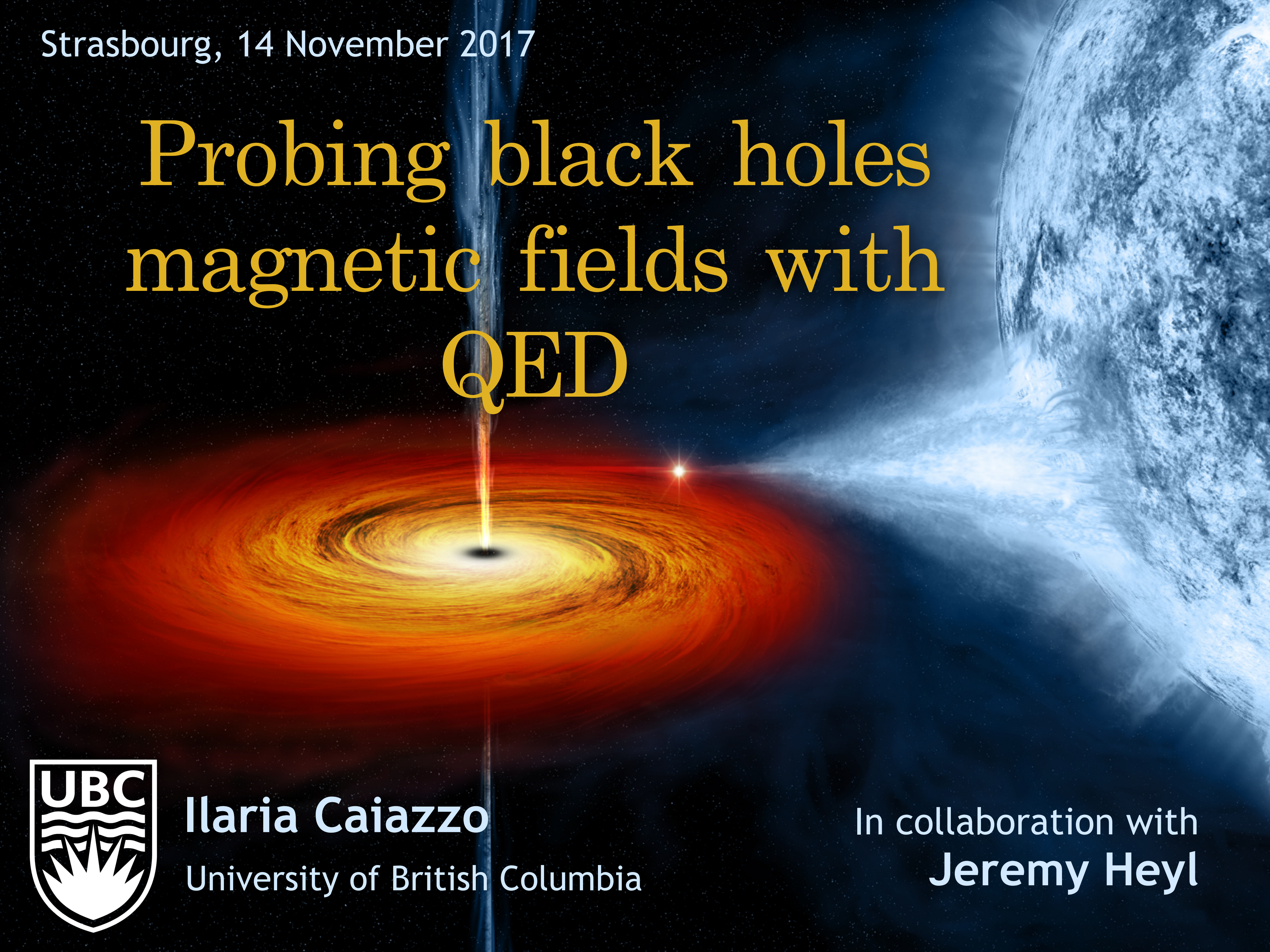
Strasbourg, 14 November 2017

Probing black holes magnetic fields with QED



Ilaria Caiazzo

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In collaboration with

Jeremy Heyl

The role of magnetic fields: Theory

ACCRETION
The magnetic field in the disk is expected to be the major source of viscosity

JETS
The magnetic field close to the black hole could lead to the formation of jets through the Penrose-Blandford-Znajek mechanism

The role of magnetic fields: Observations

LETTER

doi:10.1038/nature12499

A strong magnetic field around the supermassive black hole at the centre of the Galaxy

R. P. Eatough[1], H. Falcke[1,2,3], R. Karuppusamy[1], K. J.
L. G. Spitler[1], M. Kramer[1,4], B. Klein[1,5], C. Bassa[4], G.
P. C. C. Freire[1], A. Kraus[1], A. G. Lyne[4], A. Noutsos[1], E

BLACK HOLES

Resolved magnetic-field structure and variability near the event horizon of Sagittarius A*

Michael D. Johnson,[1*] Vincent L. Fish,[2] Sheperd S. Doeleman,[1,2] Daniel P. Marrone,[3]
ichi Asada,[8]
ower,[9]
rew A. Chael,[1]
Friberg,[14]
Makoto Inoue,[8]
m Loeb,[1]
Moran,[1]
gers,[2]
Titus,[2]
Young,[1]

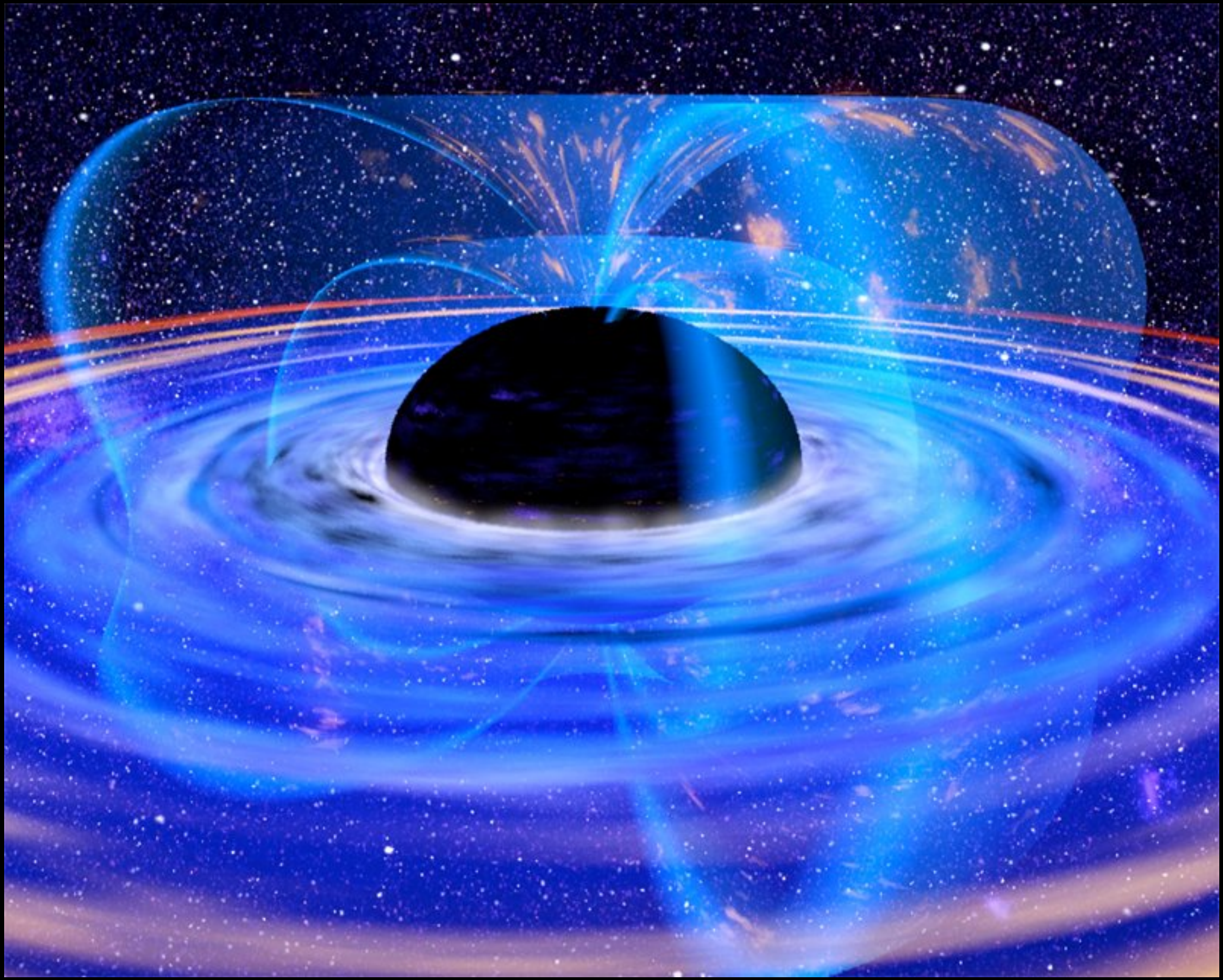
LETTER

doi:10.1038/nature13399

Dynamically important magnetic fields near accreting supermassive black holes

M. Zamaninasab[1], E. Clausen-Brown[1], T. Savolainen[1] & A. Tchekhovskoy[2,3]

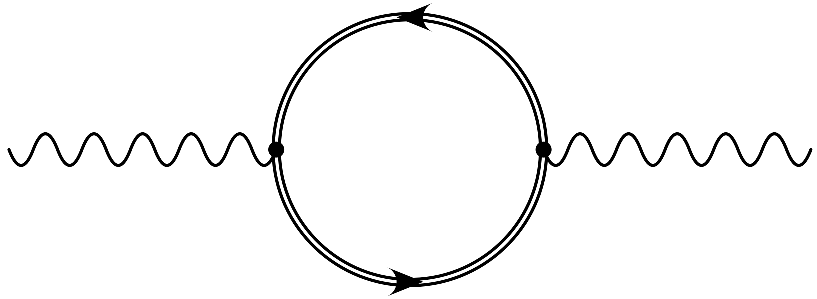
Can X-ray polarimetry help?



Can X-ray polarimetry help?

Well, the QED effect of vacuum birefringence is sensitive to both magnetic field's structure and strength…

Is vacuum birefringence important for BHs?



After an x-ray photon is emitted from the accretion disk, its polarization changes as the photon travels through the accretion disk's magnetosphere, as a result of the vacuum becoming birefringent in presence of a magnetic field.

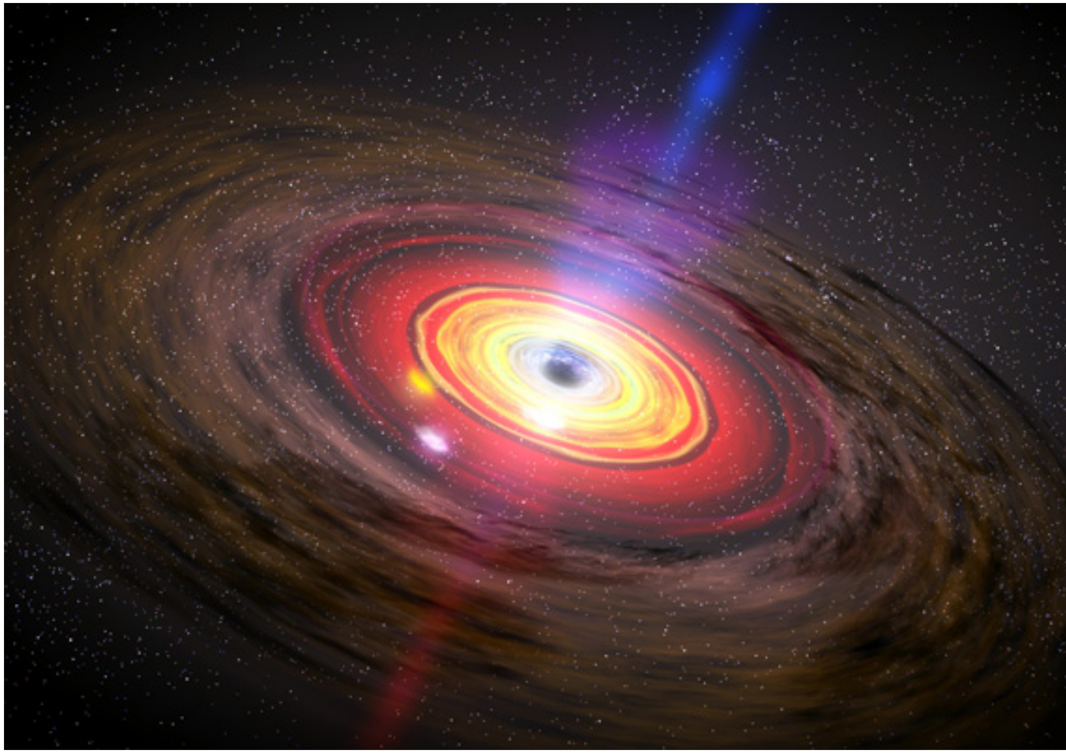
How much the final polarization changes depends both on the strength of the magnetic field and on for how long the photon travels through the strong magnetic field.

Accretion disk model

Novikov & Thorne (1973) accretion disk: spinning black hole in a Kerr metric

spinning parameter:

$$a = \frac{cJ}{GM^2}$$



viscosity:

$$t_{\hat{\phi}\hat{r}} = \rho c_s v_t + \frac{B^2}{4\pi} = \alpha P$$

turbulence

magnetic field

Minimum magnetic field needed for accretion:

$$B^2 \sim 4\pi\alpha P \sim \frac{8\pi c}{3\kappa_R}\sqrt{\frac{GM}{r^3}}\frac{\mathcal{B}^2\mathcal{E}}{\mathcal{A}^2}$$

Shakura & Sunyaev parameter

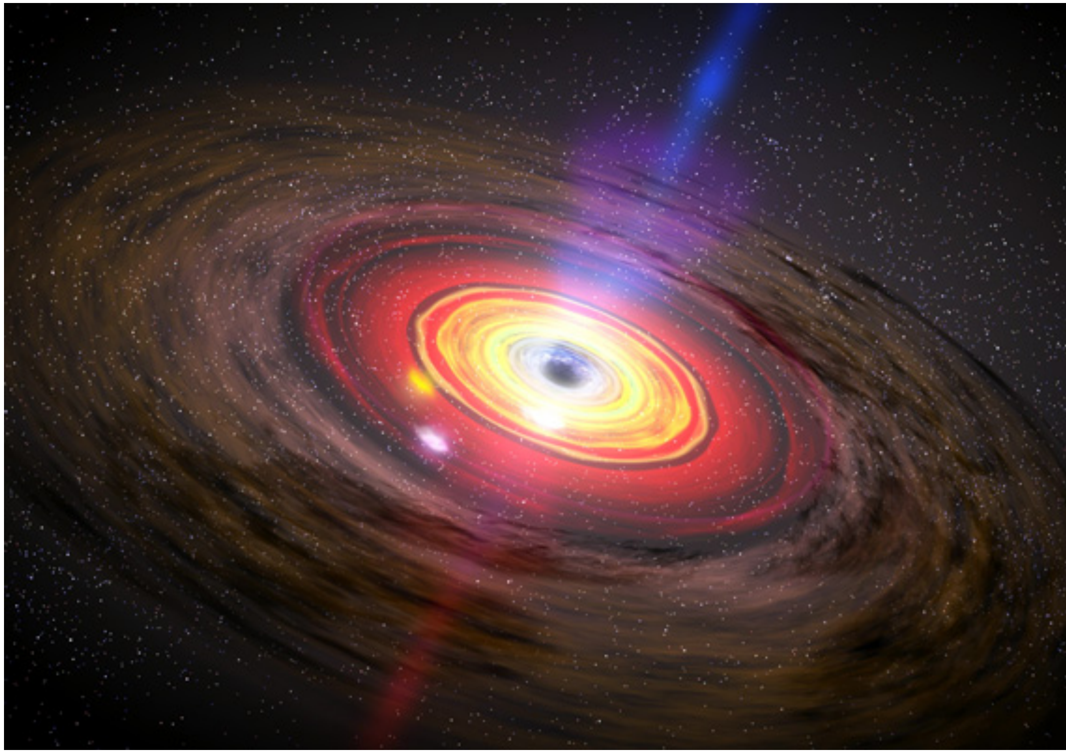
GR functions of a and r

Accretion disk model

Novikov & Thorne (1973) accretion disk: spinning black hole in a Kerr metric

spinning parameter:

$$a = \frac{cJ}{GM^2}$$



viscosity:

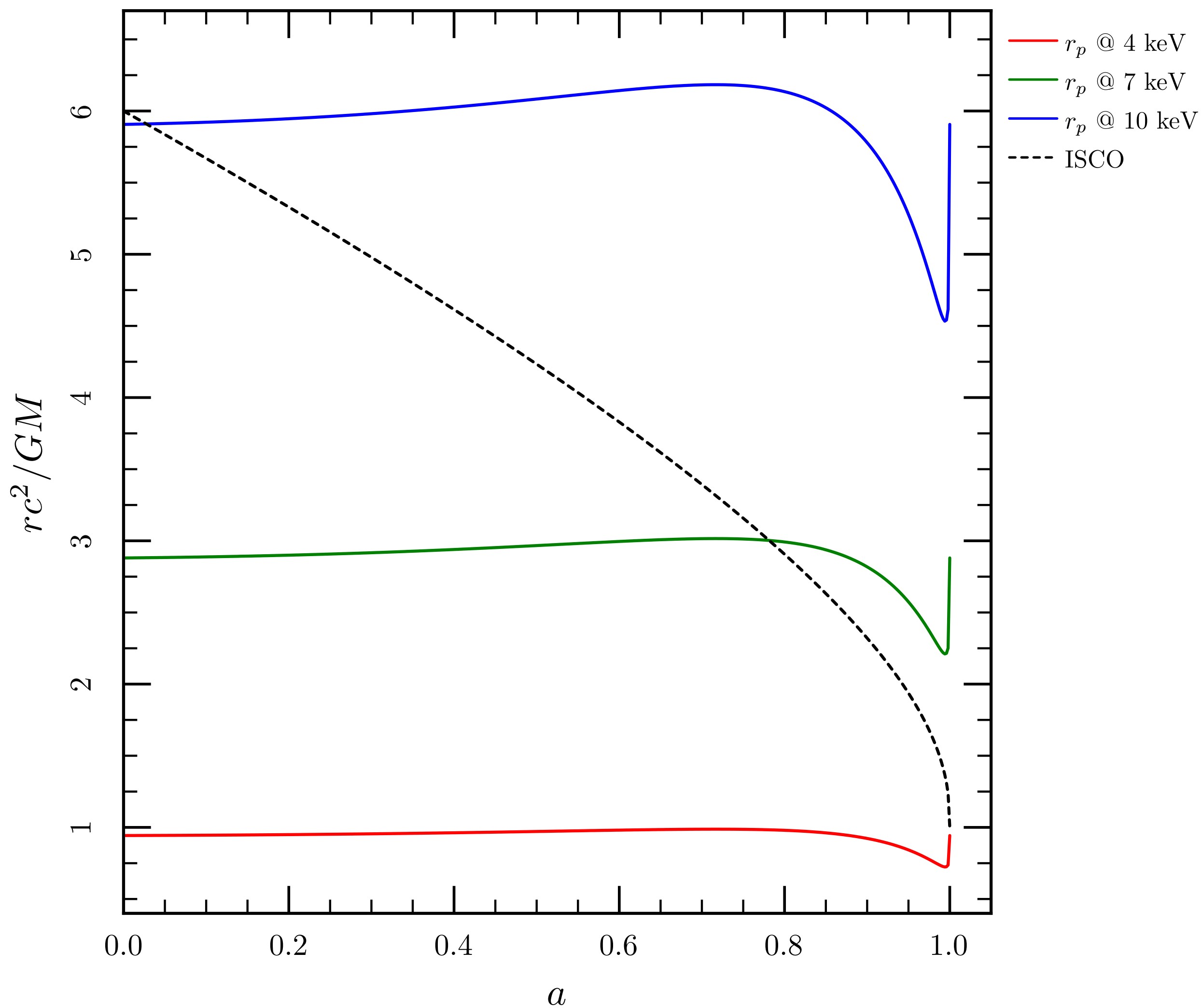
$$t_{\hat{\phi}\hat{r}} = \underbrace{\rho c_s v_t}_{\text{turbulence}} + \underbrace{\frac{B^2}{4\pi}}_{\text{magnetic field}} = \alpha P$$

Minimum magnetic field needed for accretion:
(at ISCO)

$$B^2 = (\underbrace{0.29}_{a\,=\,0} - \underbrace{1.13}_{a\,=\,1} \times 10^8\ \mathrm{G})^2 \left(\frac{10M_\odot}{M}\right)\left(\frac{2}{1+X}\right)$$

Is QED important?

$$\frac{r_p c^2}{GM} = \frac{15\pi}{\alpha_{\rm QED}} \frac{c\hbar}{E_p} \left(\frac{B_{\rm QED}}{B(r_p)} \right)^2 = \left(\frac{2k_0 \hbar m_p}{15\pi m_e^2 c (1+X)} \frac{\mathcal{B}^2 \mathcal{E}}{\mathcal{A}} \right)^2$$



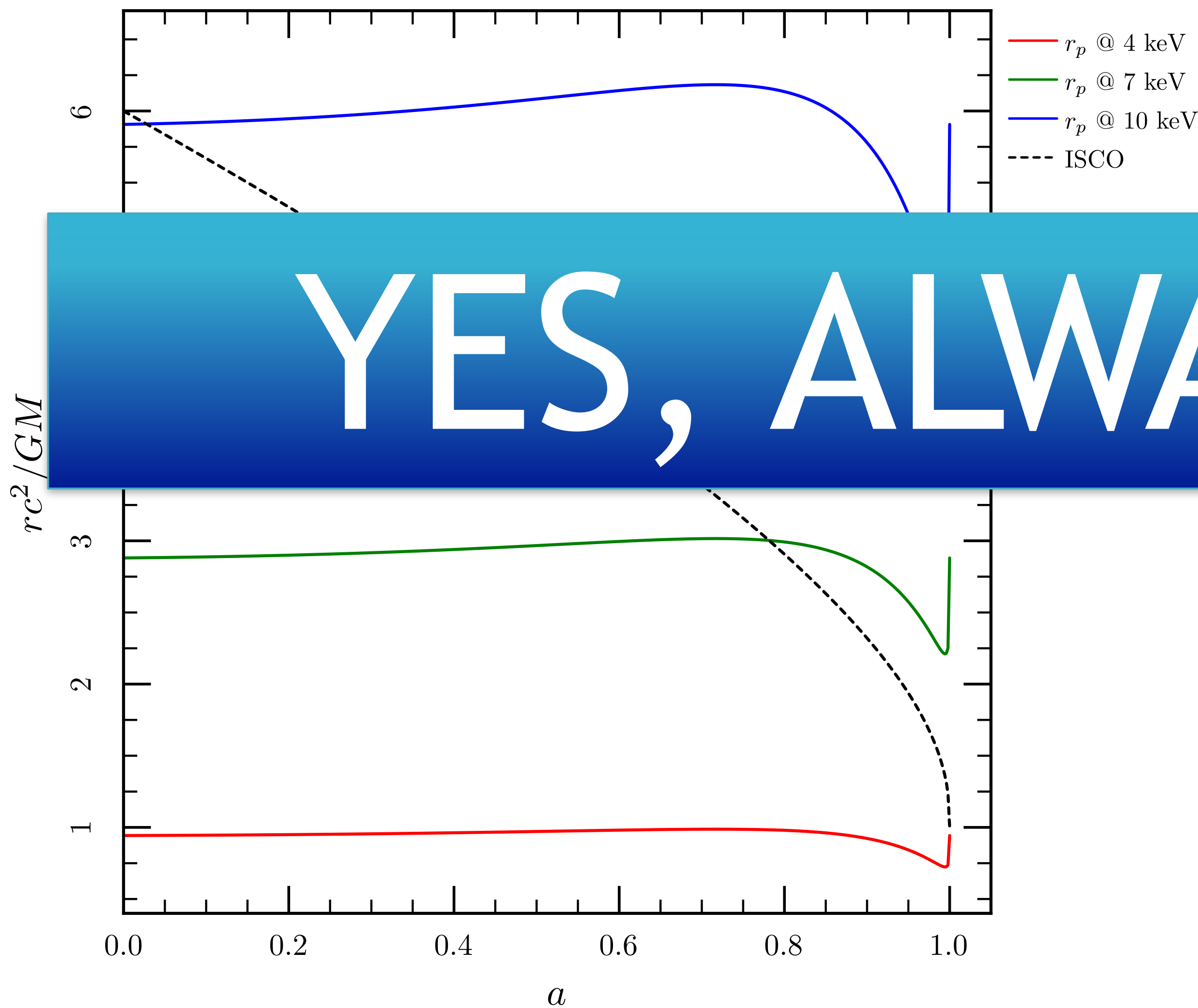
Red 4 keV
Green 7 keV
Blue 10 keV

Dashes: ISCO,
Innermost Stable
Circular Orbit

Caiazzo & Heyl, in preparation

Is QED important?

$$\frac{r_p c^2}{GM} = \frac{15\pi}{\alpha_{\rm QED}} \frac{c\hbar}{E_p} \left(\frac{B_{\rm QED}}{B(r_p)} \right)^2 = \left(\frac{2 k_0 \hbar m_p}{15\pi m_e^2 c (1+X)} \frac{\mathcal{B}^2 \mathcal{E}}{\mathcal{A}} \right)^2$$



Red 4 keV
Green 7 keV
Blue 10 keV

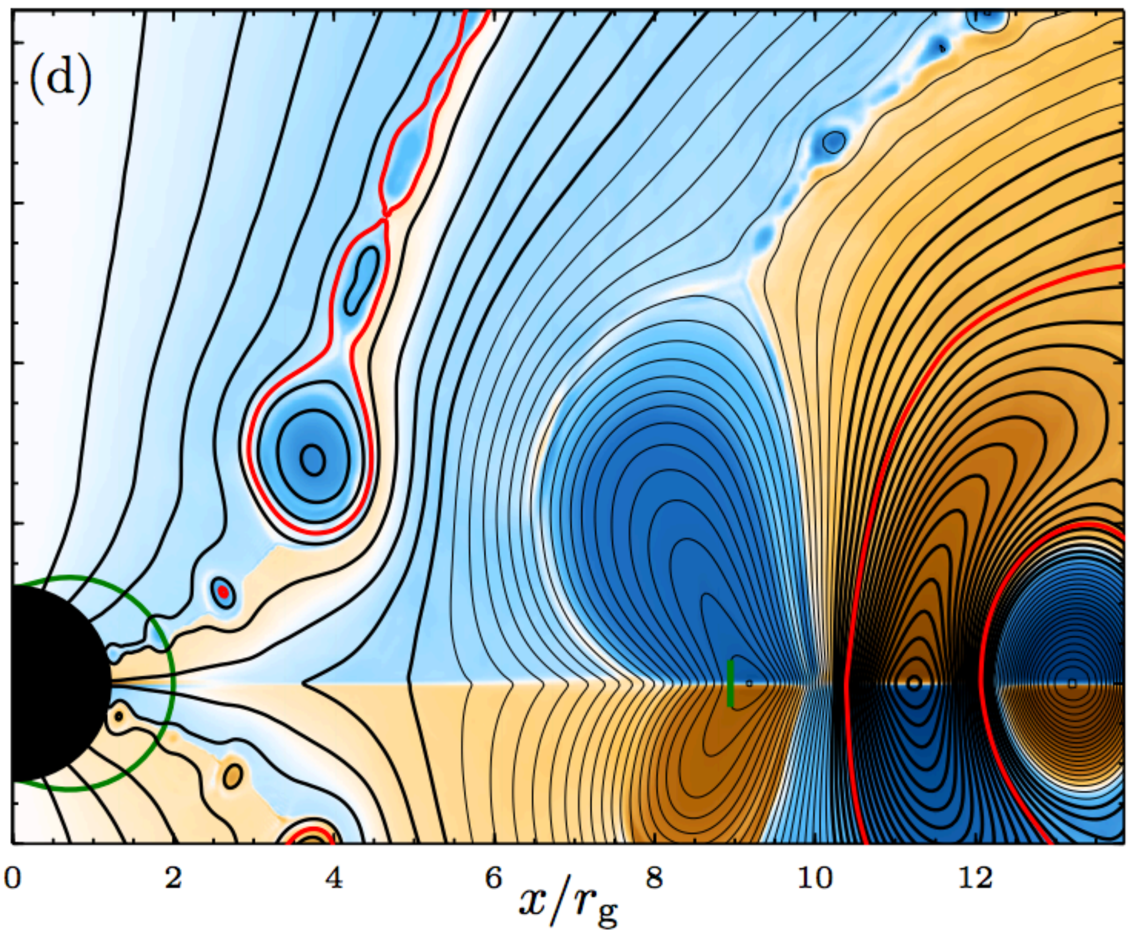
YES, ALWAYS

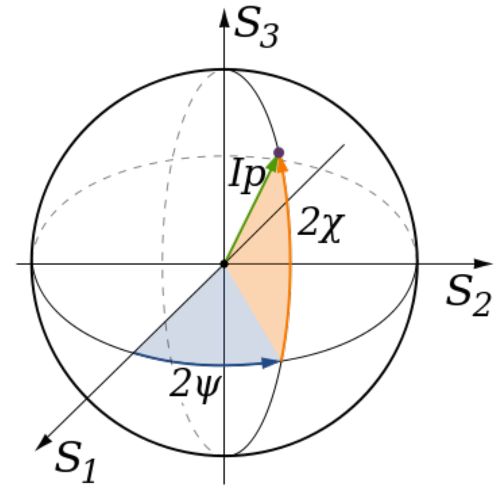
Dashes: ISCO, Innermost Stable Circular Orbit

Caiazzo & Heyl, in preparation

QED effect for a semi-organized field

As a first step, we considered a partially organized magnetic field in the plane of the disk. We evolved the polarization of a photon coming along a geodesic from the ISCO to the observer, near the accretion disk plane.



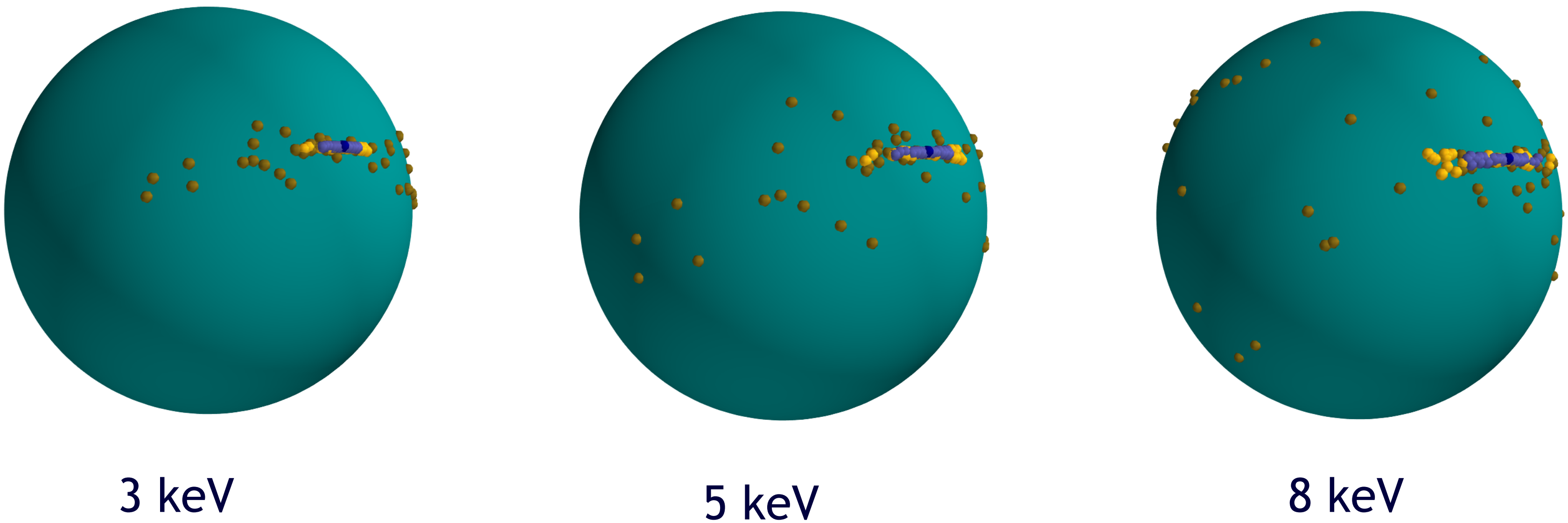


$$\frac{\partial \mathbf{s}}{\partial x_3} = \hat{\boldsymbol{\Omega}} \times \mathbf{s}$$

Parfrey, Giannious, Beloborodov 2015

QED effect for a semi-organized field

Monte-Carlo simulation of the depolarization of radiation from a black hole with a = 0.84 (as NGC 1365) for three photon energies:

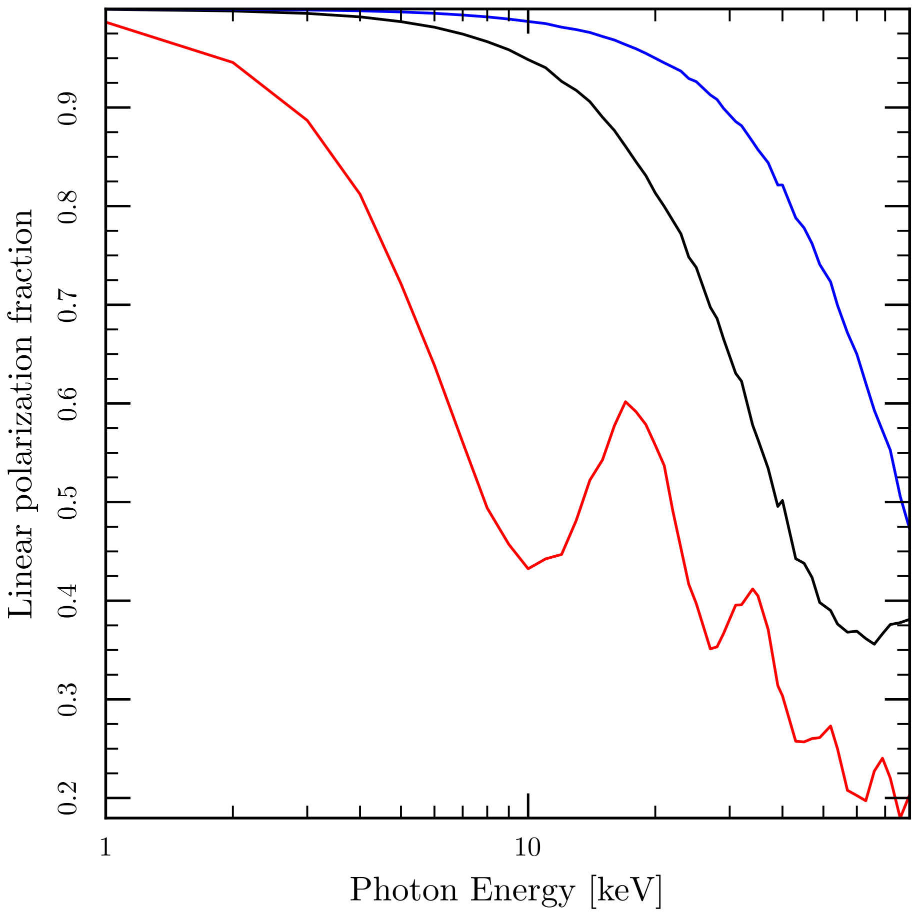


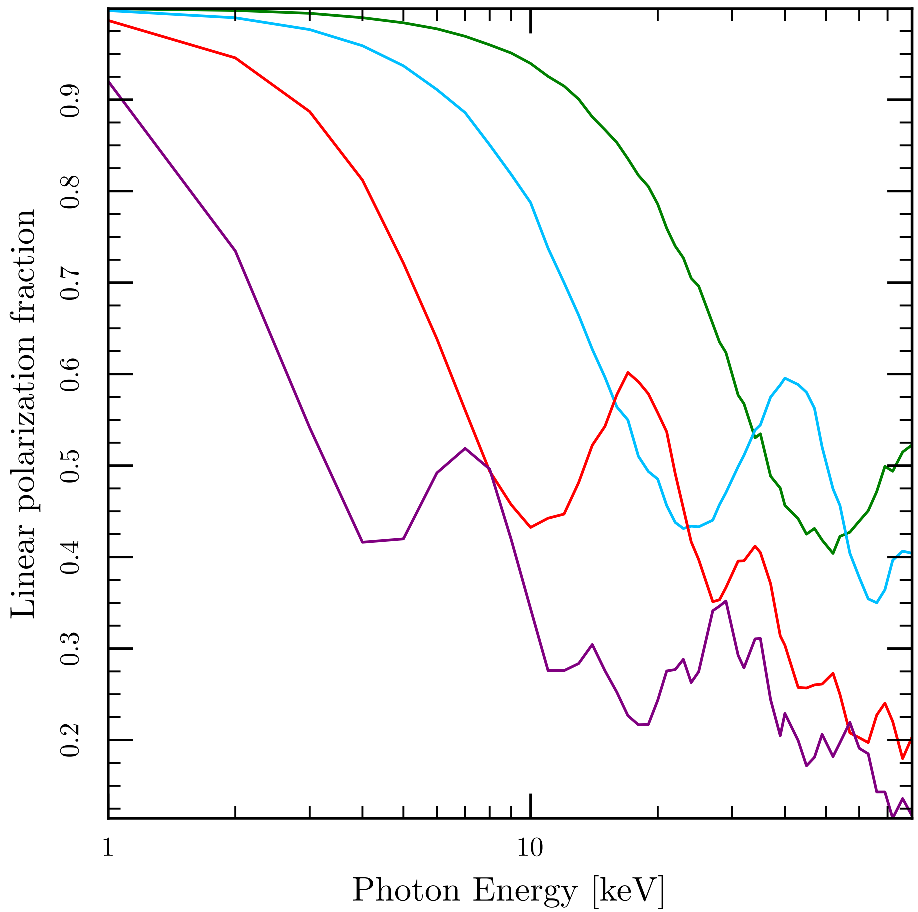
Polarization is represented on the Poincaré sphere: the dots represent the end-point of the polarization vector.

- dark blue dot: initial polarization
- violet dots: final polarization of photons that receive a large blue shift
- gold dots: final polarization of photons with zero-angular-momentum
- copper dots: final polarization of photons that receive a large red shift on their way from the ISCO to us.

Caiazzo & Heyl, in preparation

QED effect for a semi-organized field



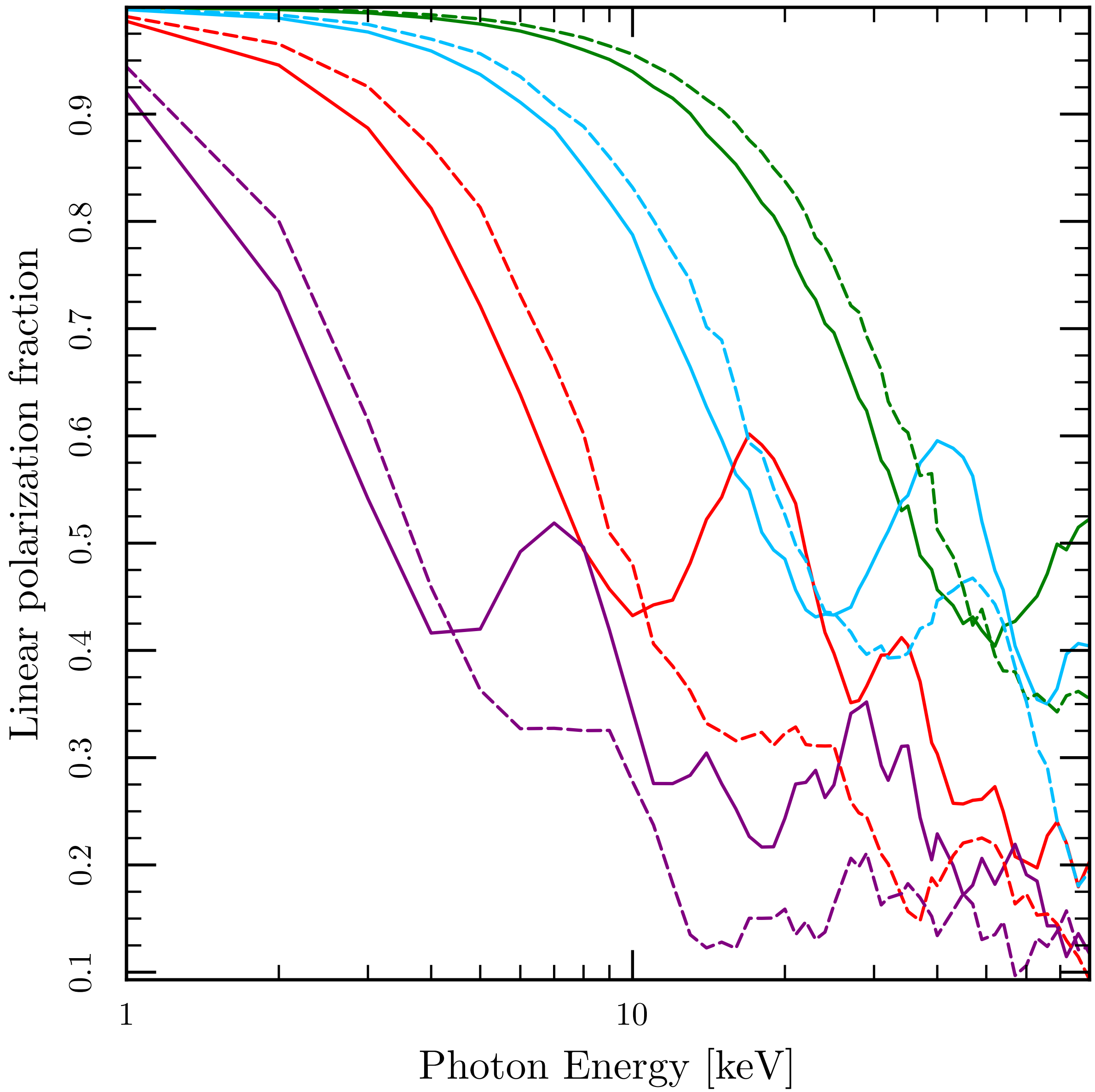


a = 0.9
Blue: blue shifted photons
Black: zero angular momentum photons
Red: redshifted photons

Redshifted photons
Green: a = 0.5
Light Blue: a = 0.7
Red: a = 0.9
Purple: a = 0.99

Caiazzo & Heyl, in preparation

QED effect for a semi-organized field



Redshifted photons
Green: a = 0.5
Light Blue: a = 0.7
Red: a = 0.9
Purple: a = 0.99

Solid lines:
every region with constant magnetic field direction is twice bigger than the previous one

Dashed lines:
every region with constant magnetic field direction is 1.5 times bigger than the previous one

Caiazzo & Heyl, in preparation


Thank you!