The Zoo of AGN:
Experimental Tests of the General Relativity Theory and its pseudo-complex extension

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Outline

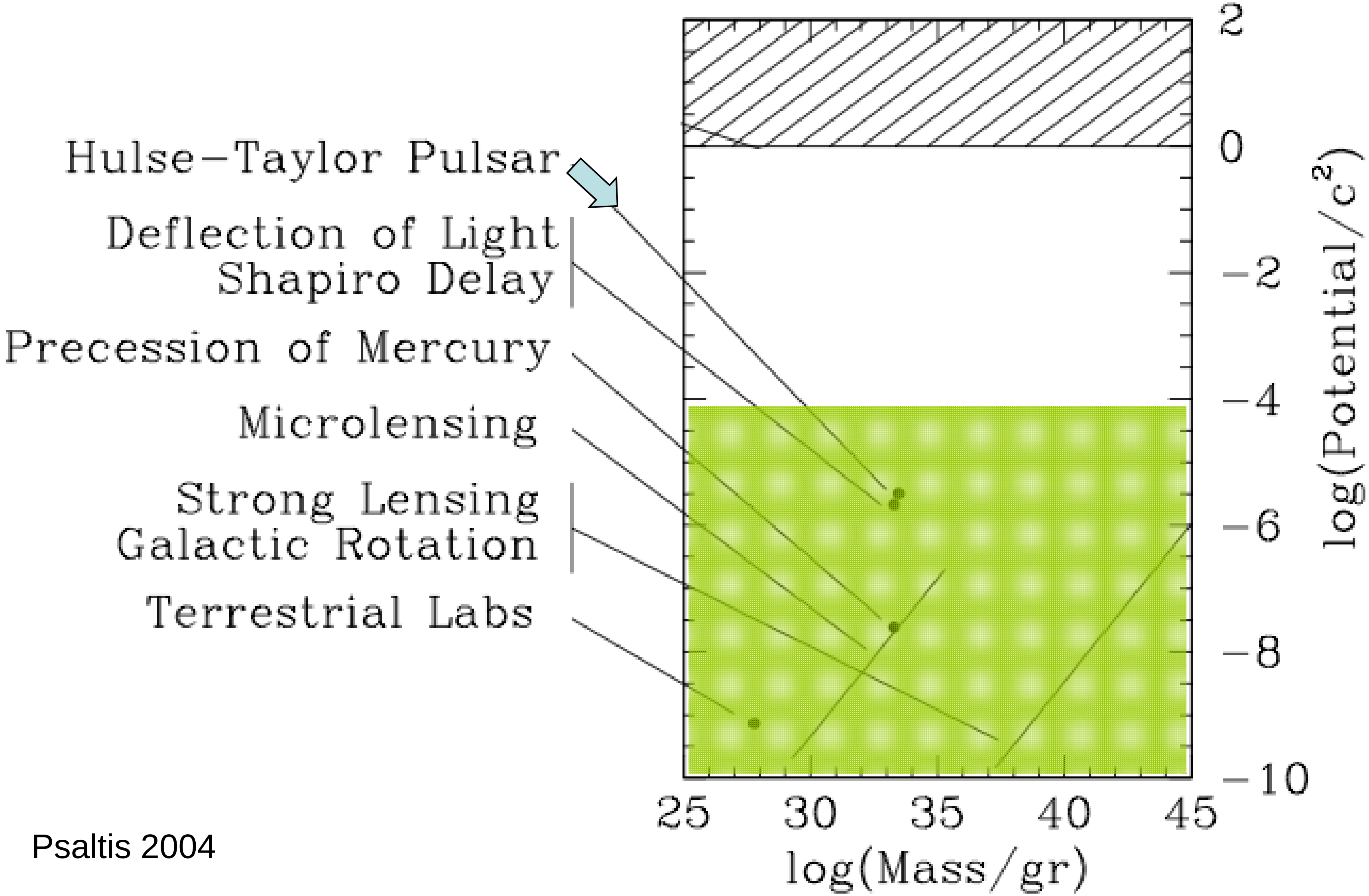
1. Present tests of the theory of General Relativity

2. The Pseudo-Complex Theory

3. Future tests of GR theories

1. Present tests of the theory of General Relativity

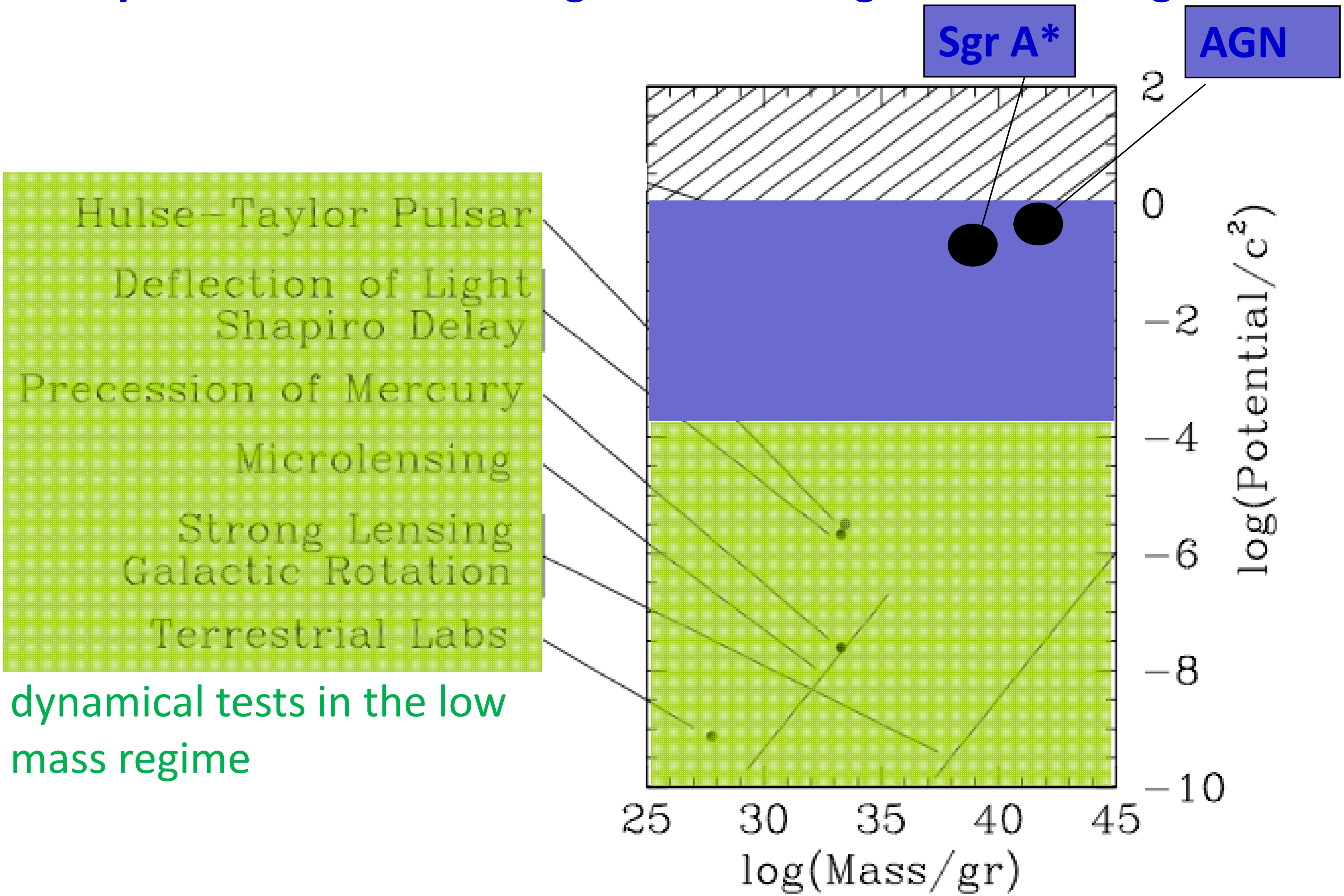
dynamical tests in the low mass regime



Psaltis 2004

Future tests of the theory of General Relativity

dynamical tests in the high mass and high curvature regime



dynamical tests in the low mass regime

2. The Pseudo-Complex Theory (Hess, Greiner 2007-2012)

$$X = X_R + I\ X_I \ \text{ with } \ I^2 = +1$$

X: pseudo-complex number

$$R^{\mu\nu} - \frac{1}{2} g^{\mu\nu} R = -\frac{8\pi\kappa}{c^2} T^{\mu\nu} \sigma_-$$

new Einstein equation
energy represents repulsion

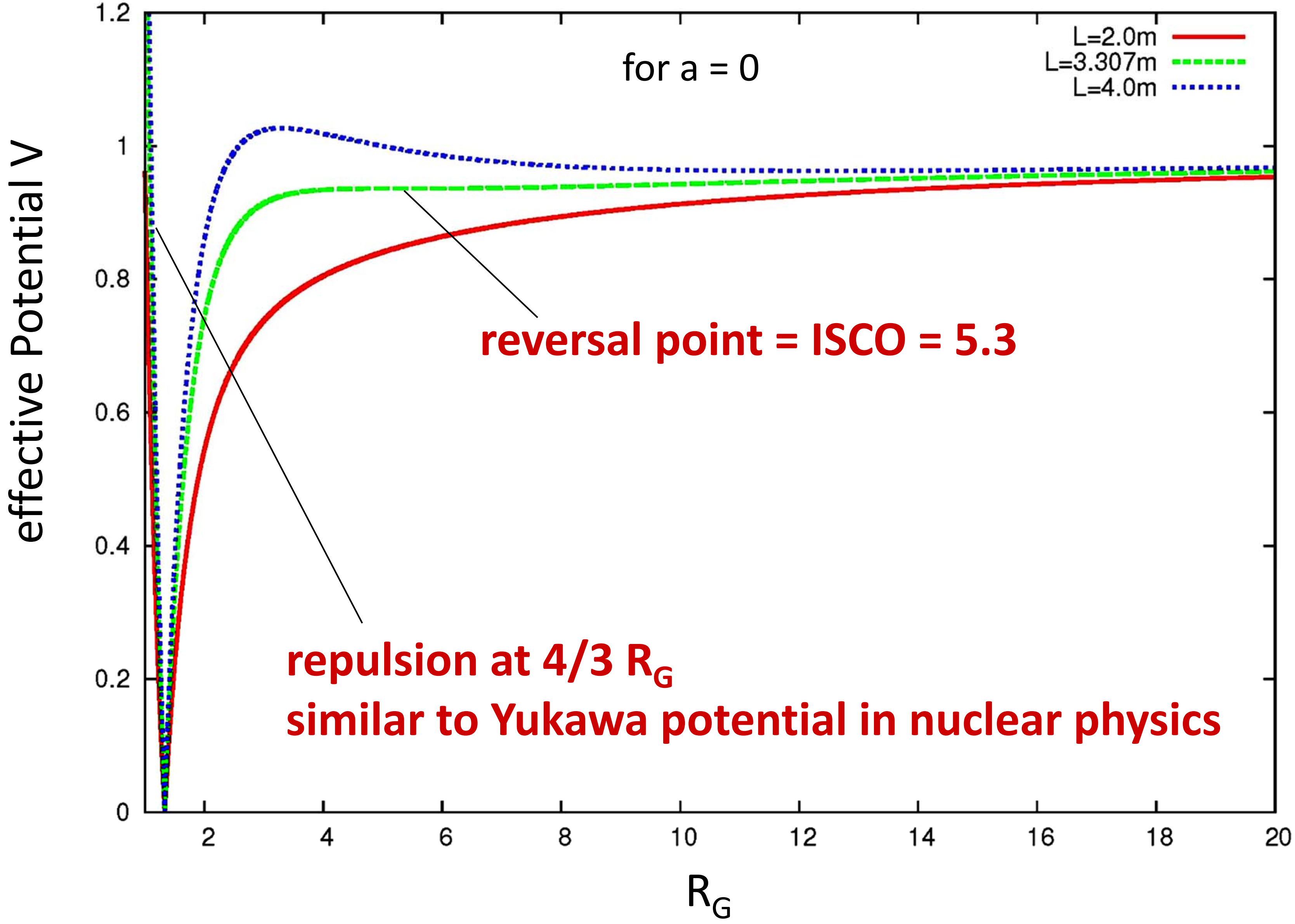
$$\sigma_- = \frac{1}{2}(1 - I) \qquad \sigma_- \sigma_+ = 0 \qquad \sigma_-^2 = \sigma_-$$

$$g_{00} = \frac{r^2 - 2mr + a^2 \cos^2\theta + \dfrac{B}{2r}}{r^2 + a^2 \cos^2\theta}$$

g_{00}: metric tensor
B: new pseudo-complex variable
a: spin parameter

no coordinate singularity
at r = 2m for a = 0

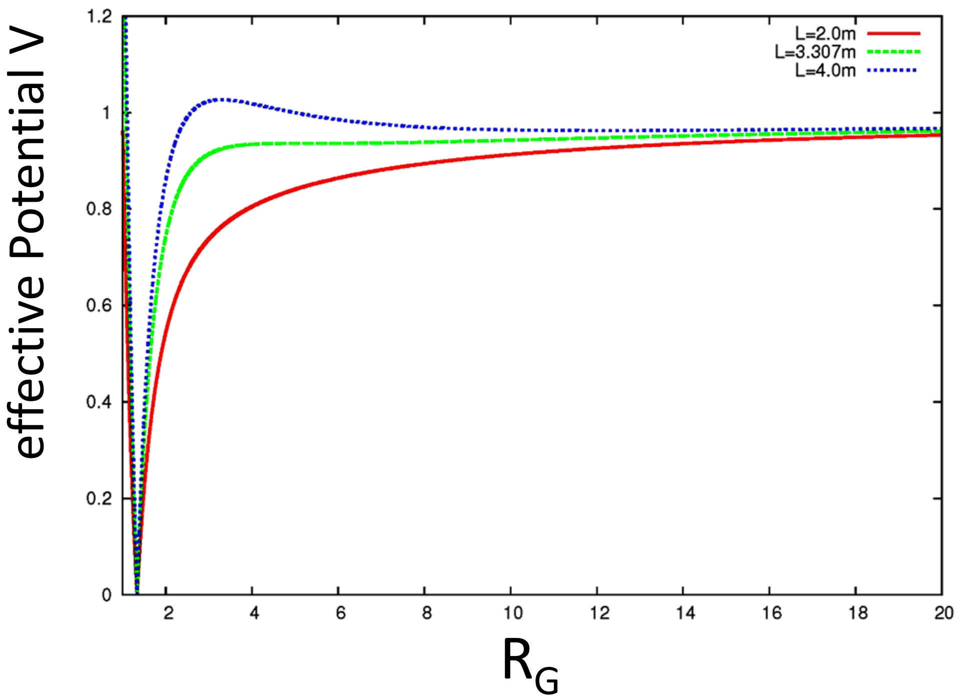
Effective potential in Pseudo-Complex theory



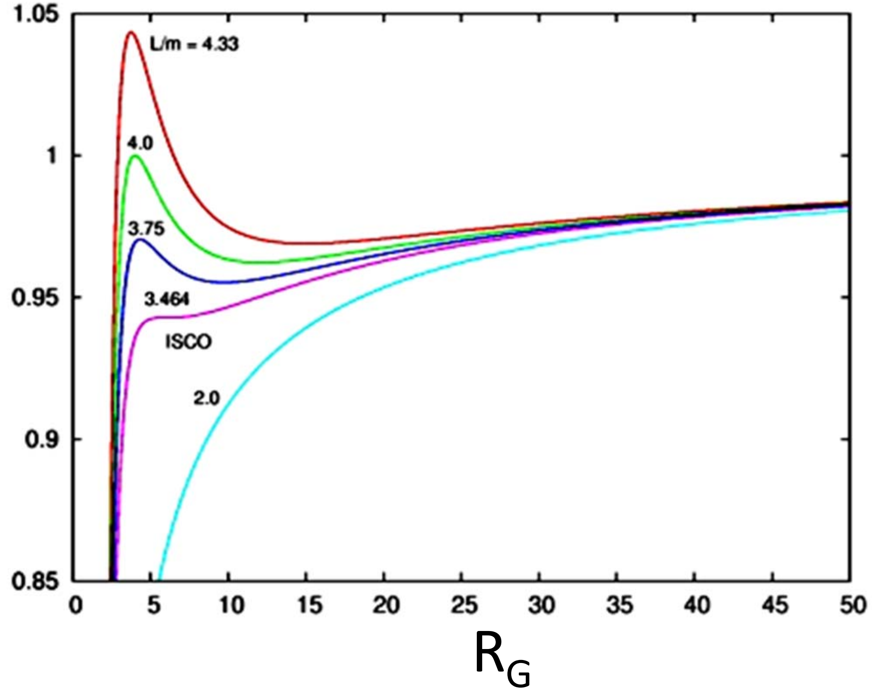
The Pseudo-Complex Theory vs. General Relativity

BH spins becomes different

Pseudo-Complex[Hess, Greiner et al. 07-12]



Standard GR[plot by A. Müller]



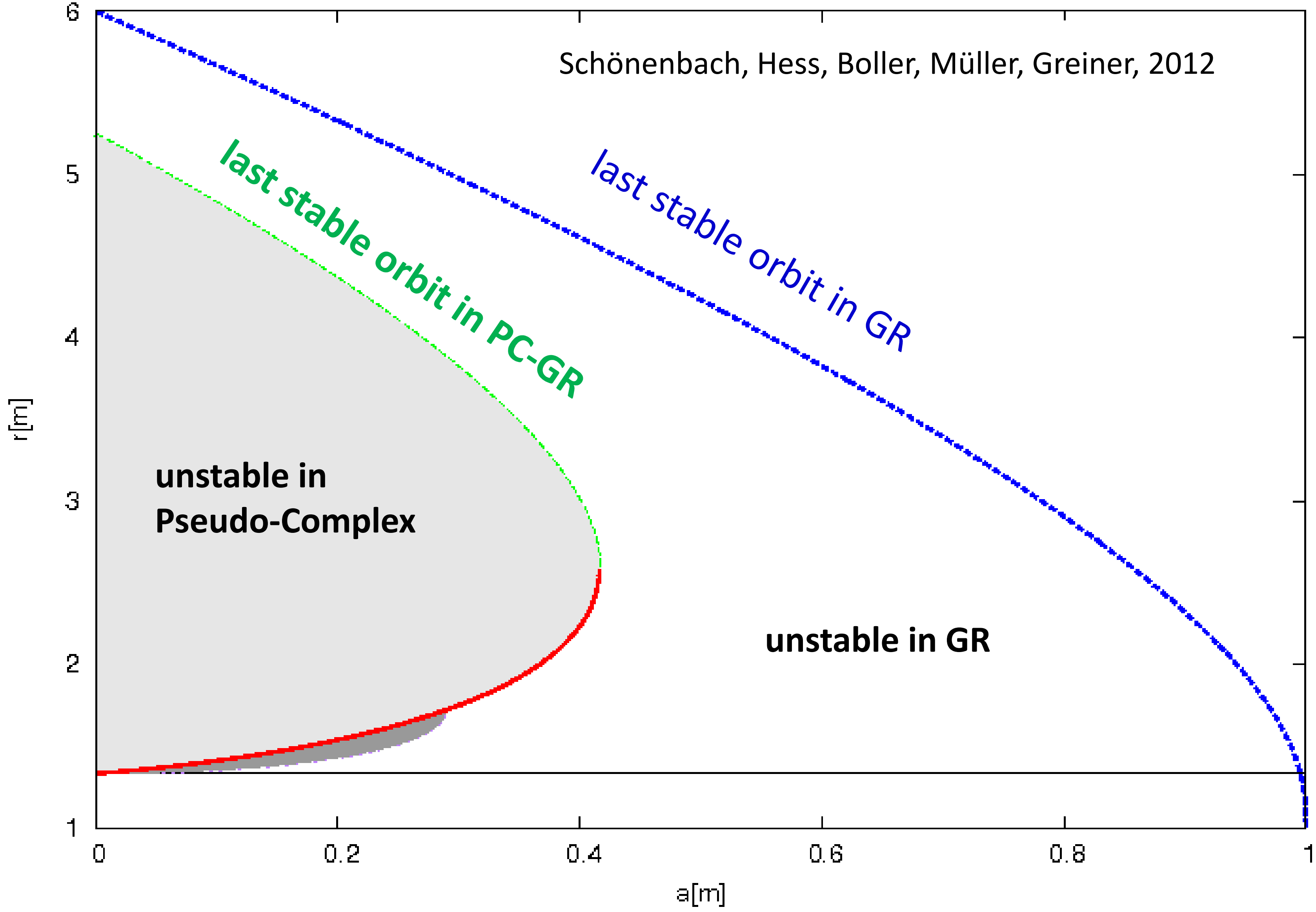
Reversal point = ISCO = 5.3

Reversal point = ISCO = 6

Repulsion at 4/3 R_G

minima: stable Kepler orbits
maxima: infall into BH

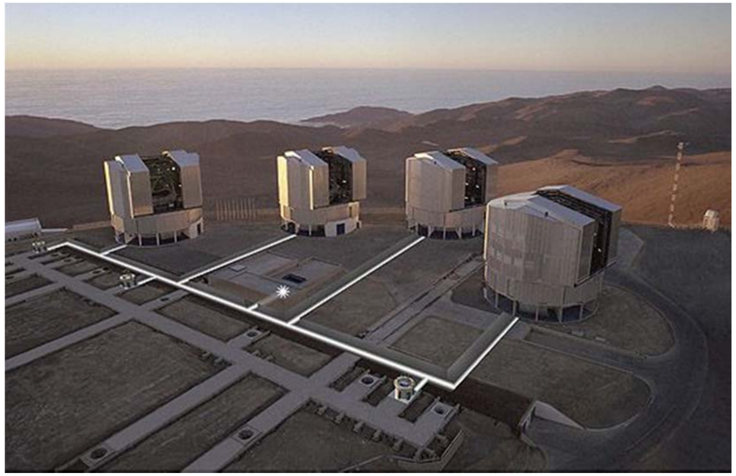
ISCO predictions:
last stable orbits different



3. Future tests of the GR theories

VLTI interferometry

Eisenhauer et al. 2007-2012



GRAVITY on VLT:
R = 3 mas, Δx = 10 µas

X-ray spectroscopy in the strong limit

Boller2012, World Scientific Publishing

the inner accretion flows around black holes emit significant amounts of X-rays

the radiation originates so close to the black hole that it allows for probing general relativity models

3. Future tests of GR theories

3.1 VLTI in the GC

Eisenhauer et al. 2007-2012

3.2 X-ray spectroscopy

Boller, Müller:
“Astronomical tests of General Relativity and its pseudo-complex extension”
Springer 2012, special issue of the Symposium on “Astrophysics, Quark-Gluon-Plasmas, Biology”, Makutsi, South Africa, in press

Schönenbach, Caspar, Hess, Boller, Müller, Greiner:
“Possible experimental tests of the pseudo-complex General Relativity”
"Journal of Astronomy and Astrophysics (IJAA)“, 2012, submitted

3.3 X-ray and NIR timing analysis

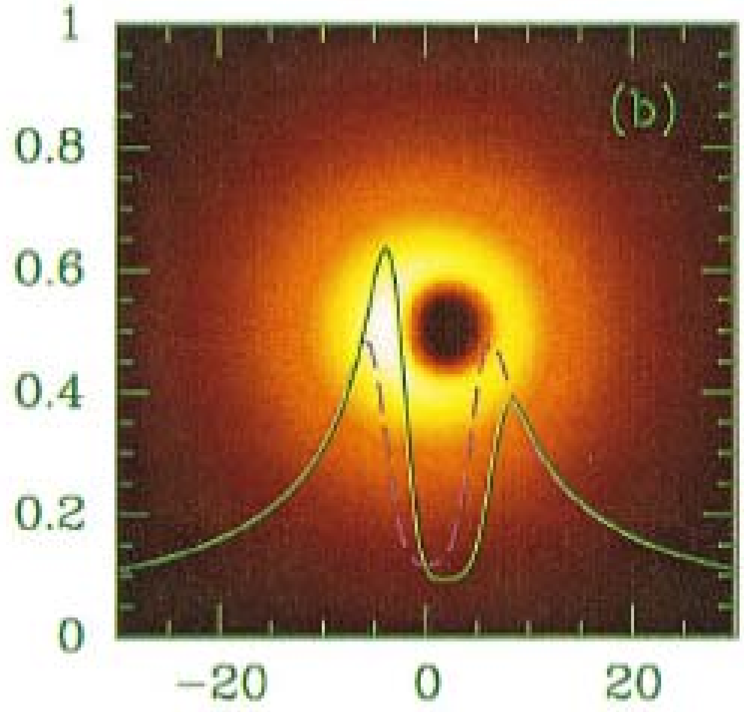
papers as above

3.4 Tracing infall of matter

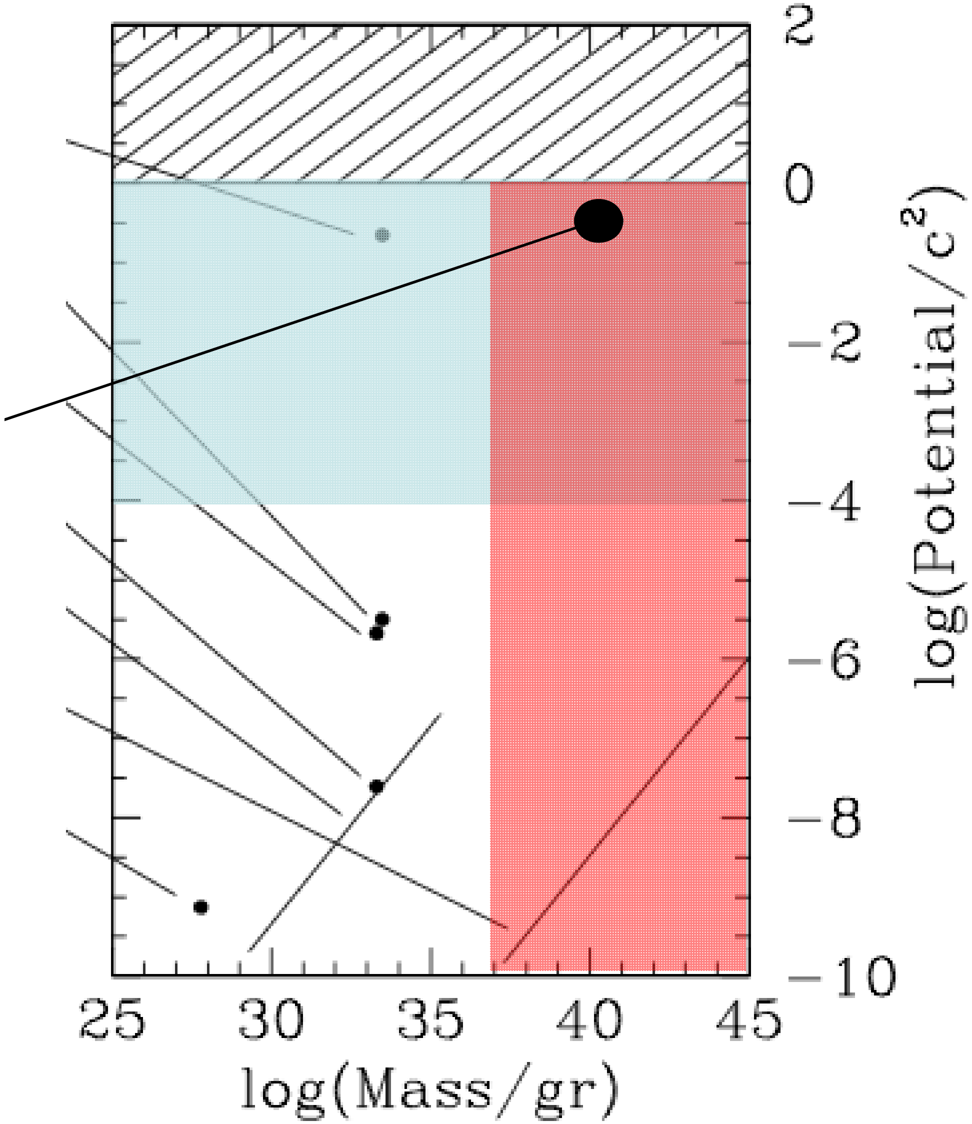
Boller, Müller, Räth, Dovciak, Svoboda
GRAVITAS Yellow Book, 2011

3.1 VLTI in GC: GRAVITY

Sub-mm shadowing



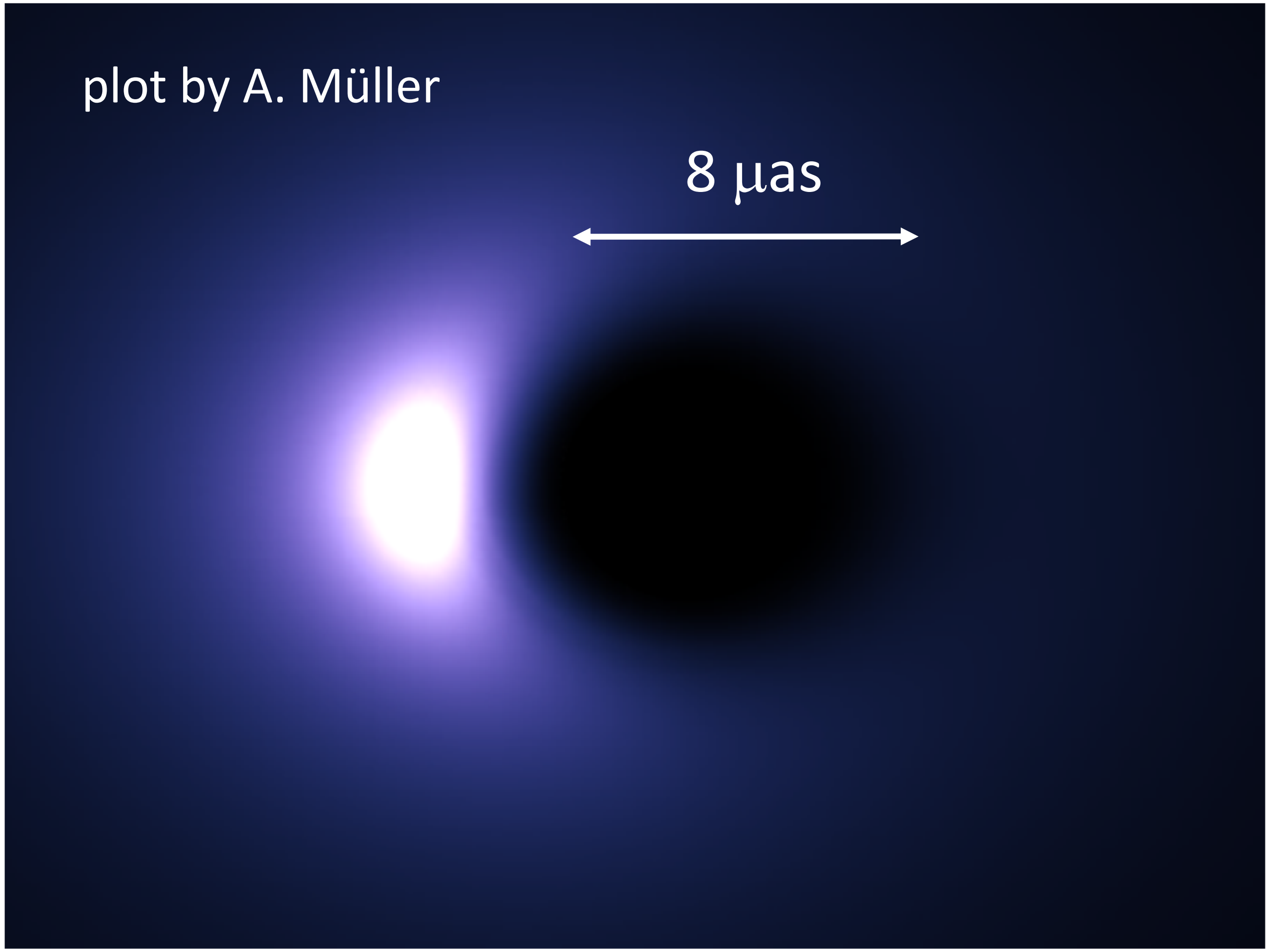
Falcke et al. 2000



Plot by S. Gillessen

3.1 VLTI in AGN: GRAVITY

sub-mm shadowing in M87



$M = 6.6 \times 10^9 M_{sun}$

$R_S = 1.8 \times 10^{15}$ cm

$\Delta x = 8\ \mu as = 1 R_S$

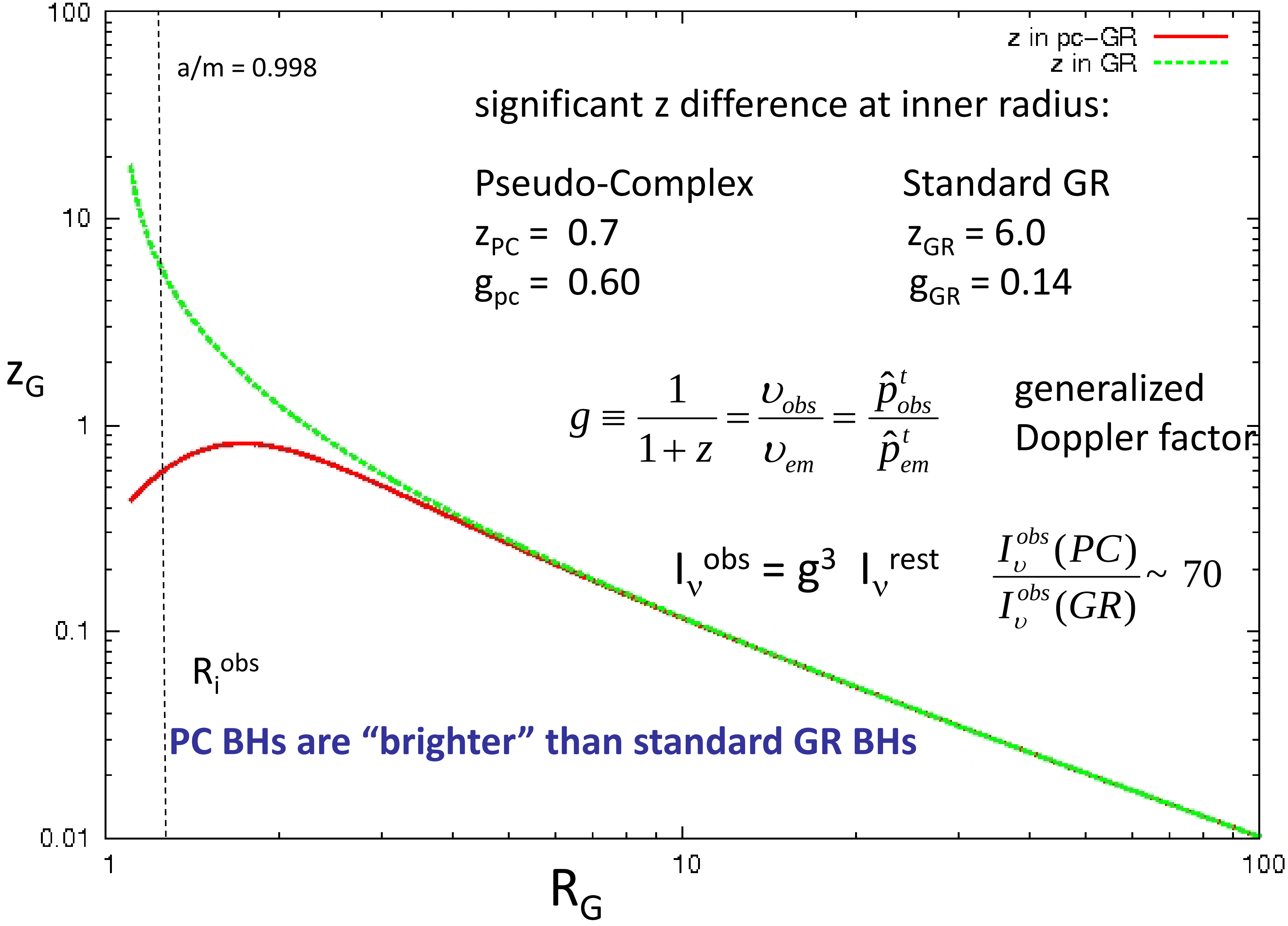
observing:

- sub mm shadowing
- disk tomography

image different for PC and standard GR due to different z_G

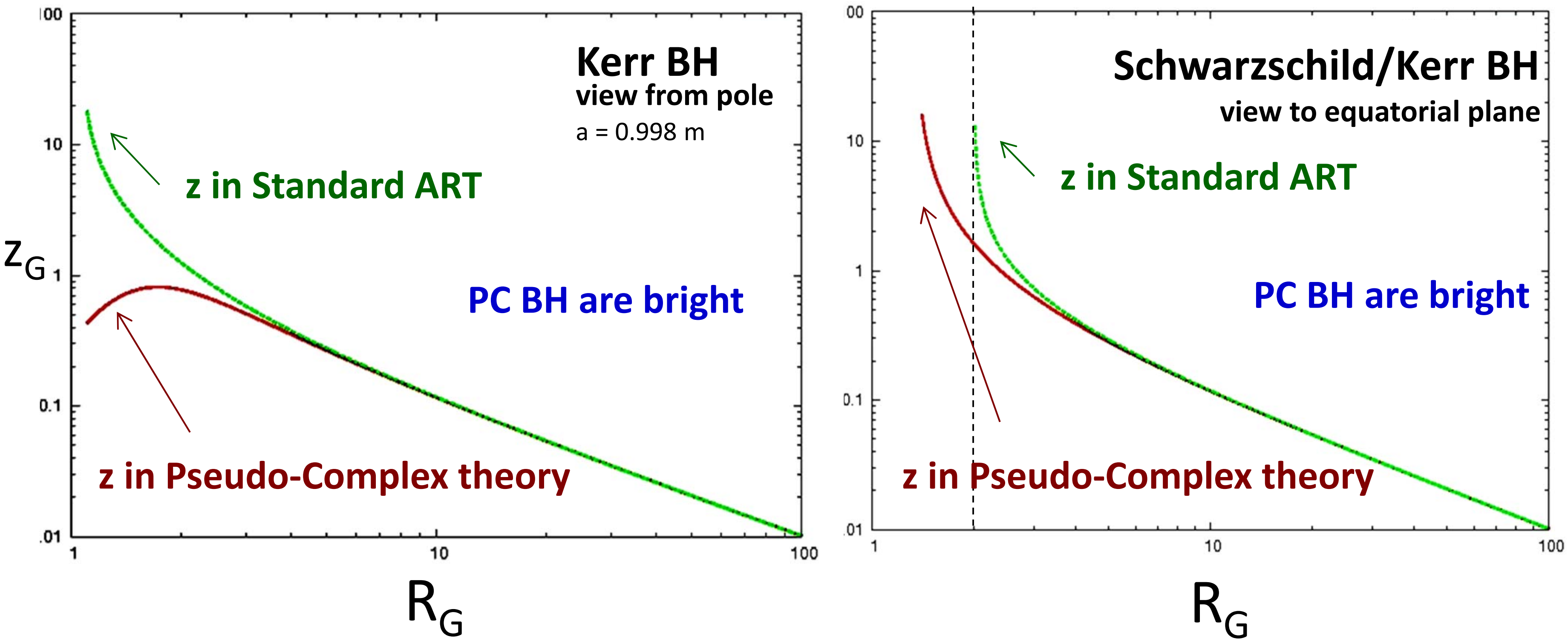
3.2 X-ray spectroscopy

gravitational redshift as a function of distance



3.2 X-ray spectroscopy

gravitational redshift as a function of distance

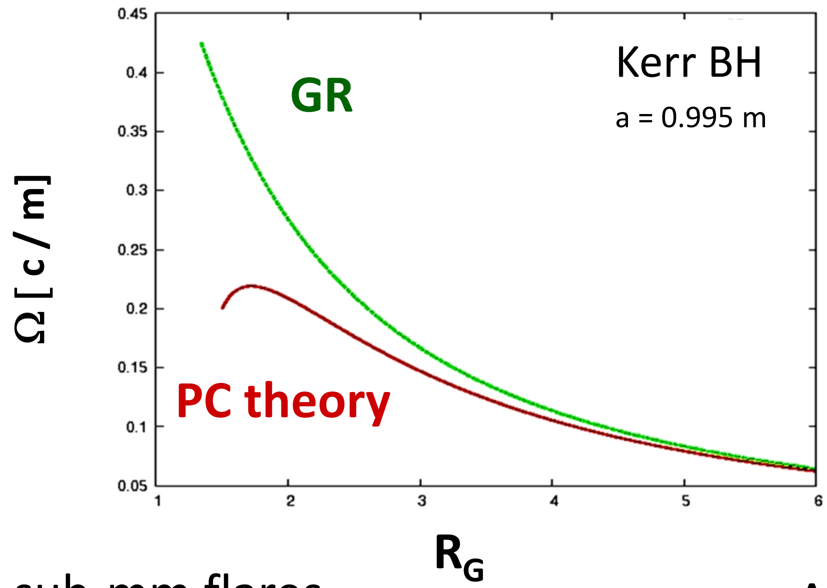


significant differences in z_G between standard and PC theory

3.3 X-ray and NIR timing analysis

Keplerian frequencies

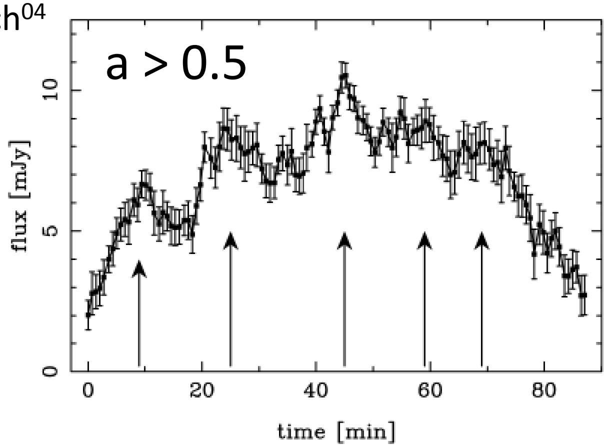
maximum at
11 minutes for
a = 0.995 m for
the mass of the GC



Test:
compare QPO
frequencies from
theories with
observations

GC: X-ray and sub-mm flares

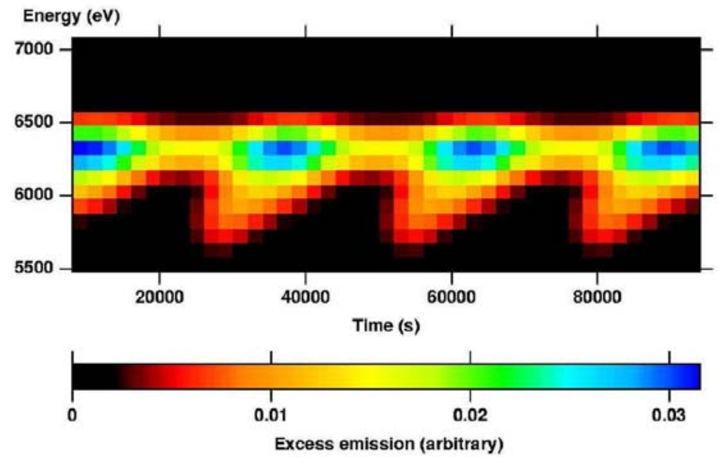
Aschenbach[04]
Genzel[03]



QPO time scale ~ 17 min = 265 mas =34 R_S

AGN hot spots

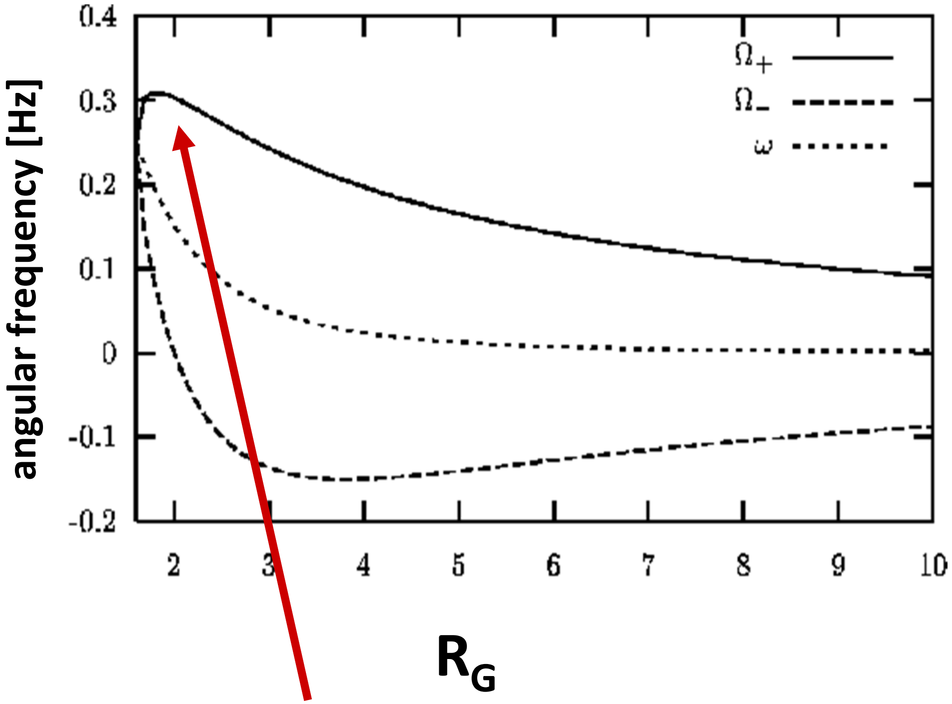
Iwasawa[04]



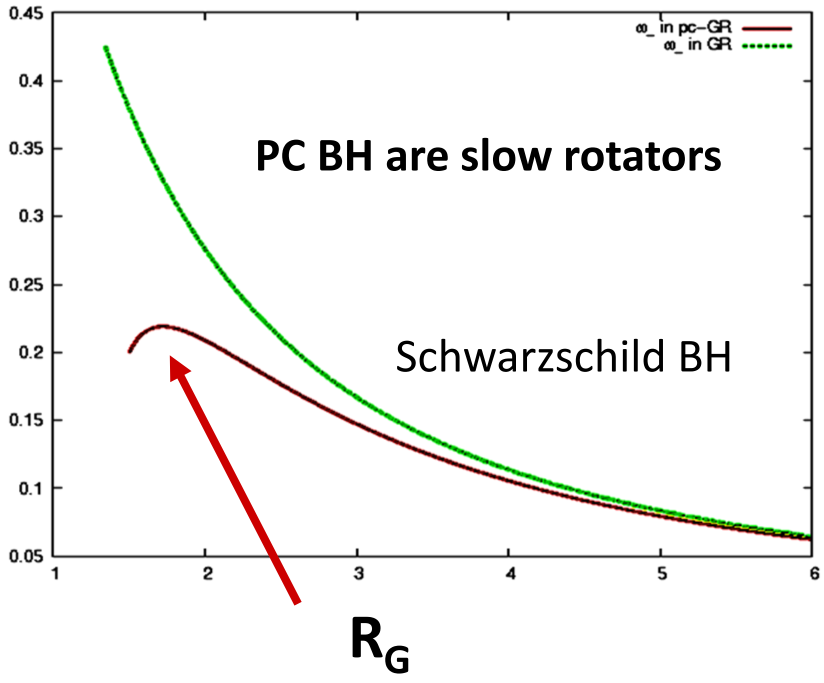
GR and PC similarities

Keplerian frequencies

GR Müller[04]



Pseudo-Complex GR Hess,Greiner[07]

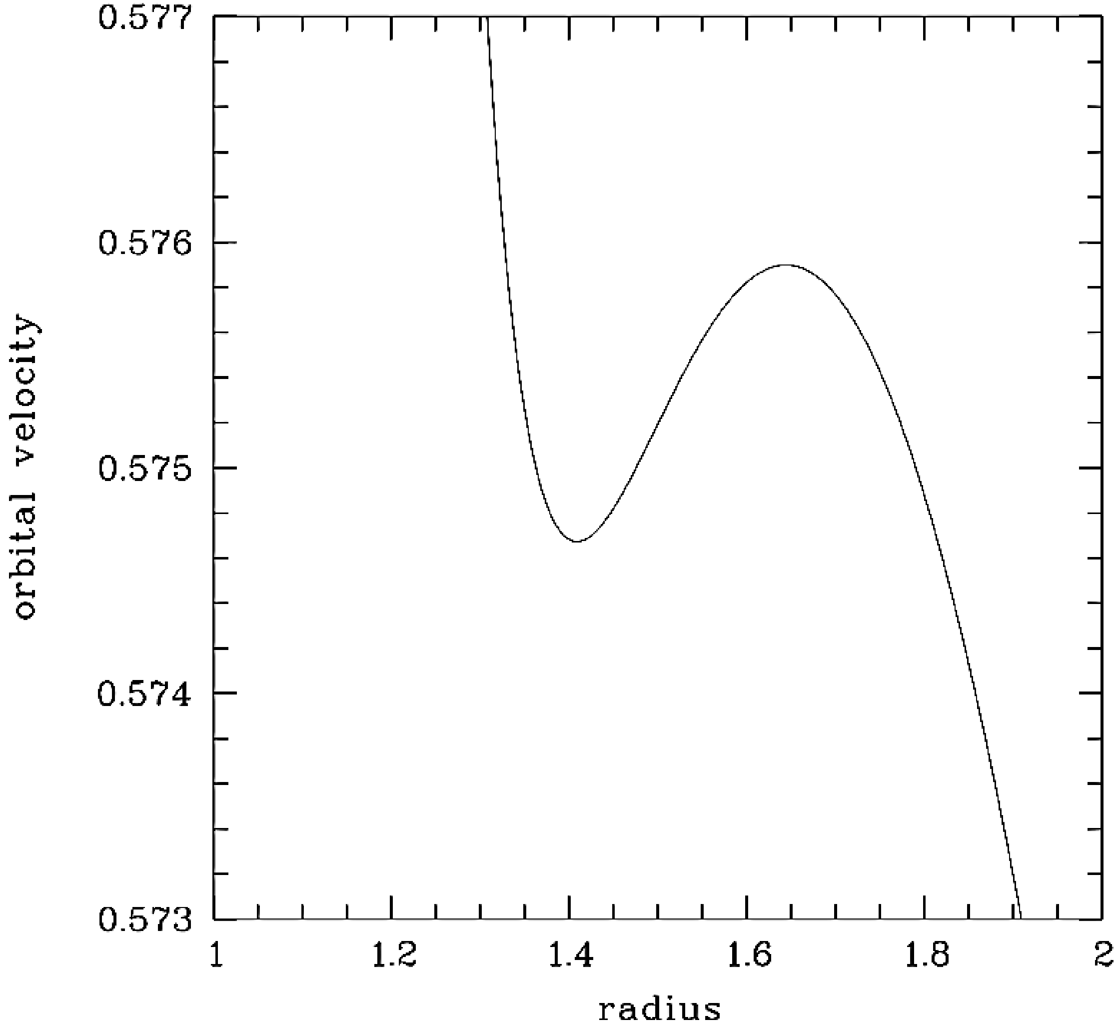


local maximum in Keplerian frequencies below last stable orbit in ART

local maximum in Keplerian frequencies before last stable orbit in PC theory

GR and PC similarities

Orbital velocities (Aschenbach 2004)

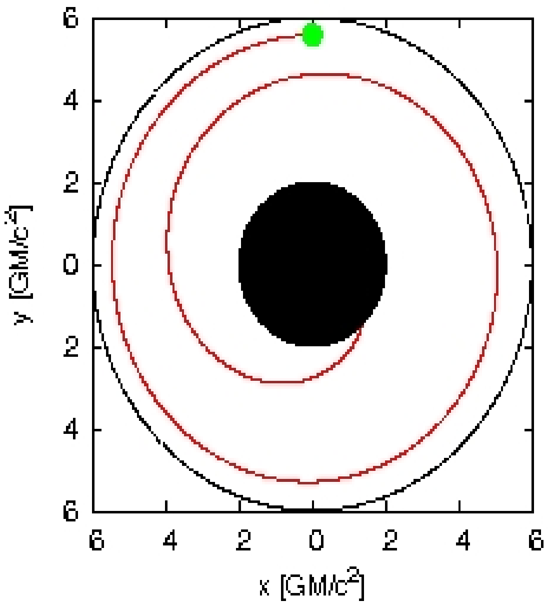


The orbital velocity $v^{(\Phi)}$ described in the *Zero Angular Momentum Observer´s frame* reaches a minimum and from thereon increases again (Müller&Camenzind2004)

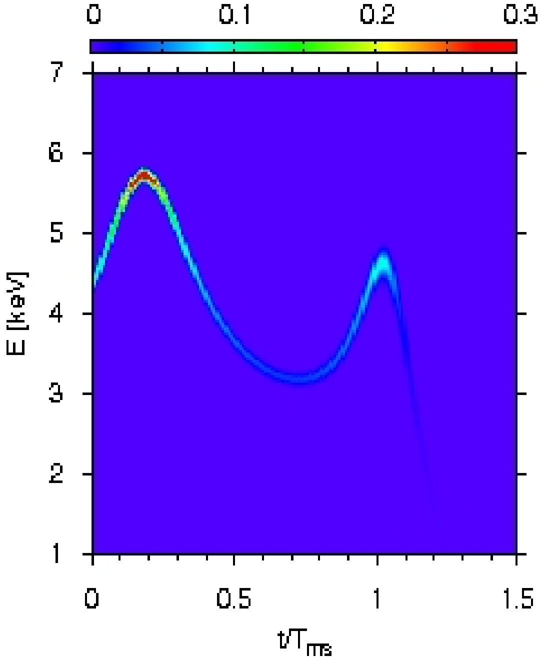
3.4 Tracing the infall of matter

The model in standard GR

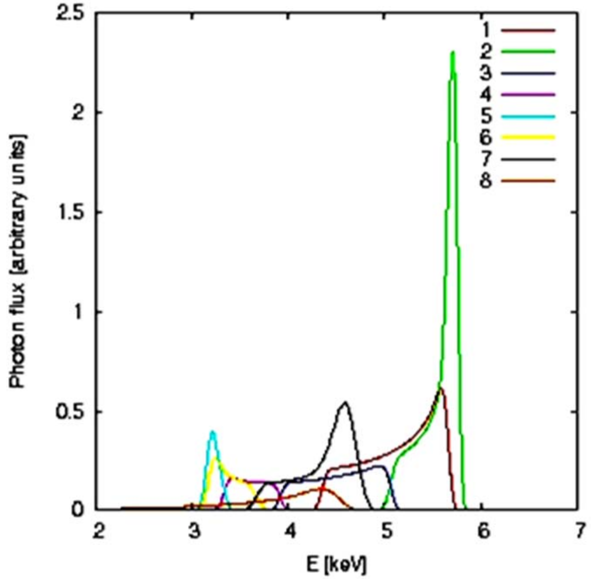
The trajectory of the infall



The dynamical spectrum in the energy-time plane.



The spectrum for time bins



matter is falling on a Schwarzschild BH, disappearing at event horizon at 2 R_G

T. Boller, A. Müller, C. Räth, M. Dovciak, J. Svoboda
GRAVITAS, YELLOW BOOK, 2010

3.4 Tracing the infall of matter

Feasibility study for a $1m^2$ class X-ray telescope

first infall segment:

the relativistic line is clearly visible

third infall segment:

the infalling matter is receding from the observer and strongly Doppler-deboosted

fourth infall segment:

the relativistic line profile becomes visible again at around 4.5 keV due to strong Doppler-boosting

Significant differences between GR and Pseudo-Complex theory are expected for

- **the Fe Kα line profiles**
- **the infall frequencies**

Summary

Gravitation is well described by Einstein´s General Relativity, however several predictions like the existence of an event horizon are under debate

we have contrasted predictions of the GR with the pseudo-complex field theory

among them we have studied

- gravitational redshift effects
- orbital motions
- perihelion shifts
- timing measurements and gravitationally distorted spectral lines

we consider supermassive black holes as ideal laboratories to test theoretical predictions in the regime of strong gravity