Horizon and exotics

Main reviews and articles

- gr-qc/0506078 **Black Holes in Astrophysics**
- astro-ph/0207270 **No observational proof of the black-hole event-horizon**
- gr-qc/0507101 **Black holes and fundamental physics**
- astro-ph/0401549 **Constraining Alternate Models of Black Holes: Type I X-ray Bursts on Accreting Fermion-Fermion and Boson-Fermion Stars**
- arXiv: 0903.1105 **The Event Horizon of Sagittarius A***
- arXiv: 1312.6698 **Observational evidence (review)**

The horizon problem

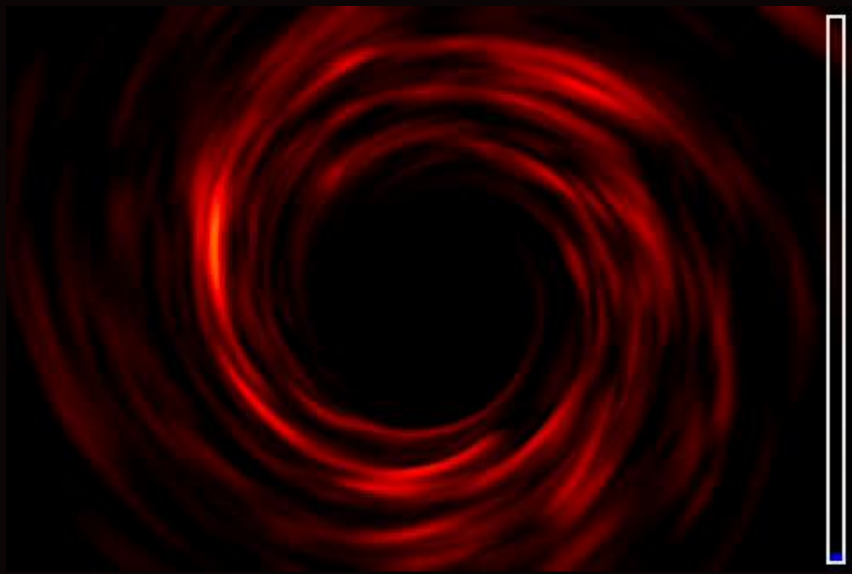
What can be a 100% proof that we observe a BH?
Of course, only a direct evidence for the horizon existence!
But it is very difficult to prove it!
One can try to follow three routes:

1. To look for direct evidence for the horizon.
2. To try to prove the absence of a surface.
3. To falsify the alternative models.

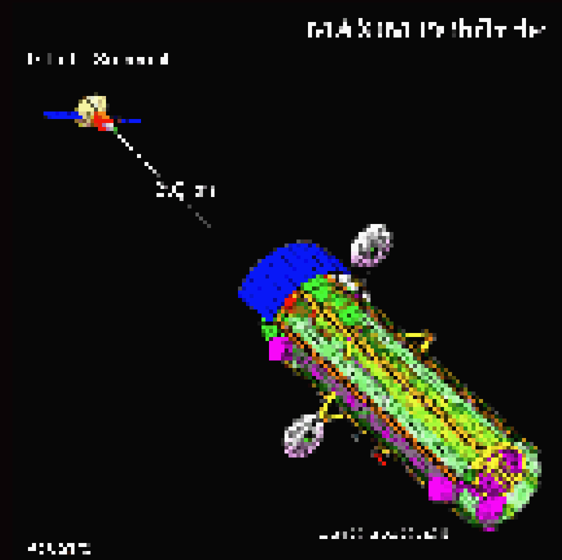
The first approach is not very realistic (astro-ph/0207270 Abramowicz et al.)

We can hope to have direct images from the horizon vicinity
(for example, for Sgr A* the corresponding size is 0.02 milliarcseconds),
or to have data from BH coalescence via GW detection.
(see Narayan gr-qc/0506078)

Dreams about direct images



(Narayan 2005)



Prototype: 100 microarcsecs
MAXIM: 100 nanoarcsecs
33 satellites with X-ray optics
and a detector in 500 km away.

The MAXIM Project (Cash 2002)
http://beyondeinstein.nasa.gov/press/images/maxim/

Absence of surface

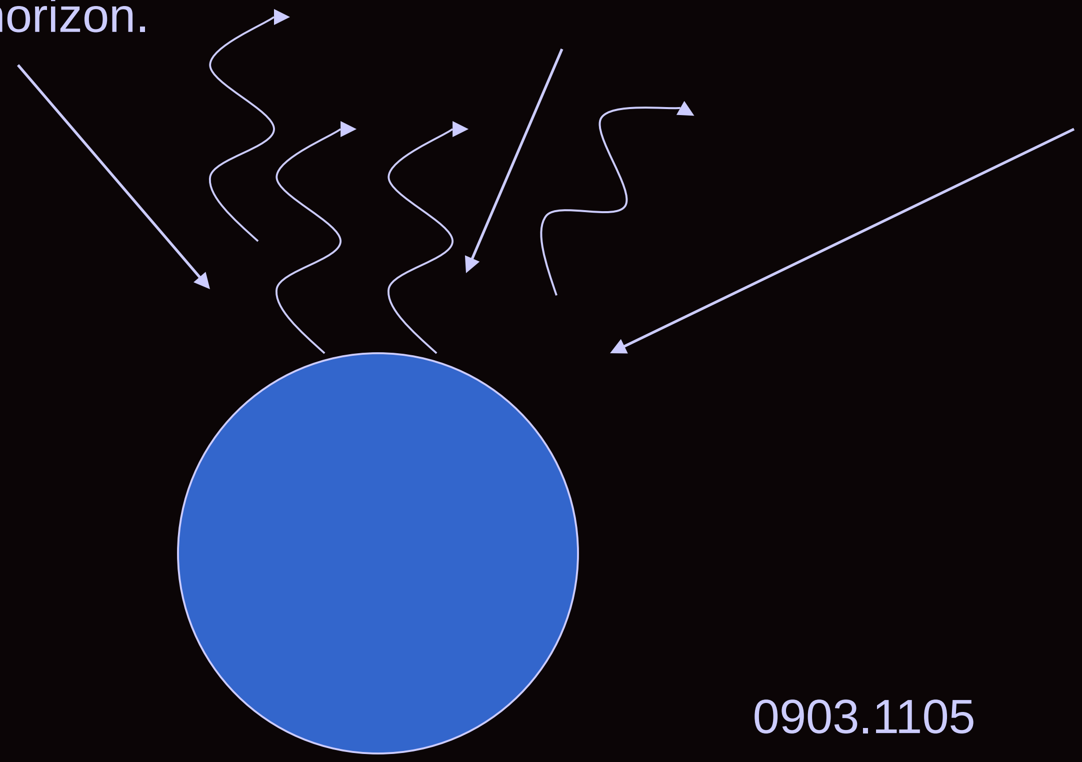
Here we mostly discuss close binaries with accretion

- Lack of pulsations
- No burster-like bursts
  Nowhere to collect matter.
  (however, see below about some alternatives)
- Low accretion efficiency (also for Sgr A*)
  ADAF. Energy is taken under horizon.
- No boundary layer (Sunyaev, Revnivtsev 2000)
  Analysis of power spectra.
  Cut-off in BH candidates above 50 Hz.

The case of Sgr A*

Recent millimeter and infrared observations of Sagittarius A* (Sgr A*), the supermassive black hole at the center of the Milky Way, all require the existence of a horizon.

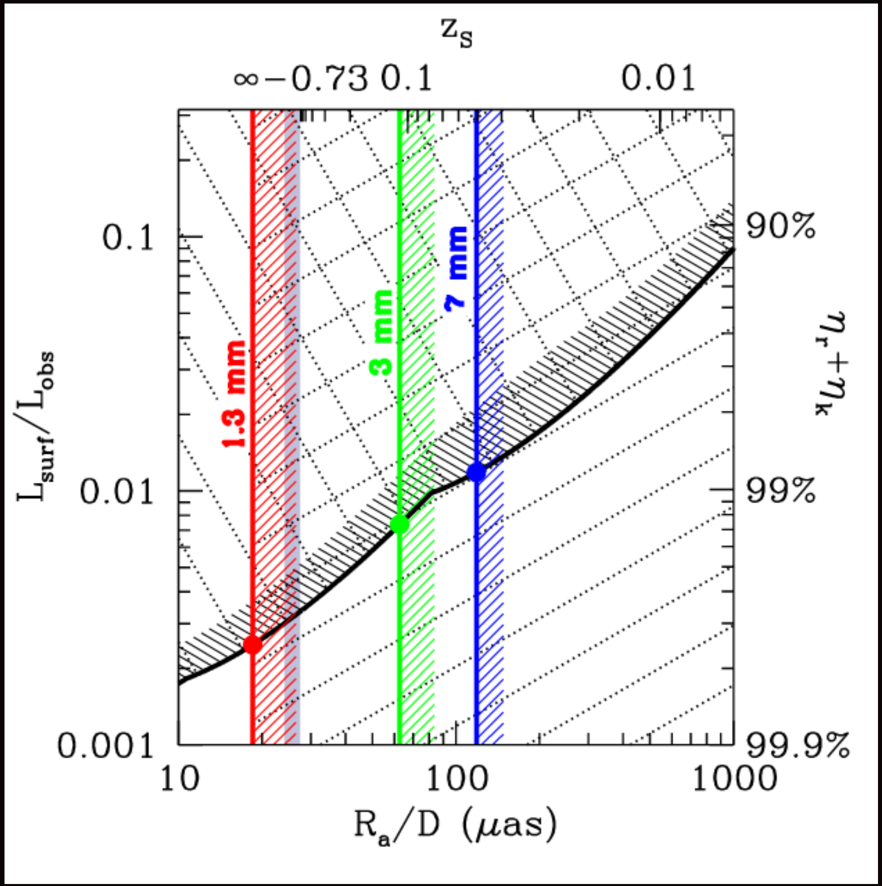
Magnetic field observed around Sgr A* due to faraday rotation of the radio pulsar emission can explain the energy release in the flow:
1308.3147.
Now fields are observed directly:
1512.01220.

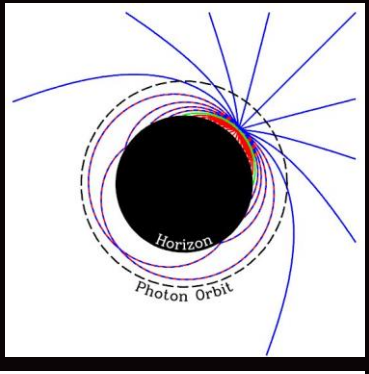


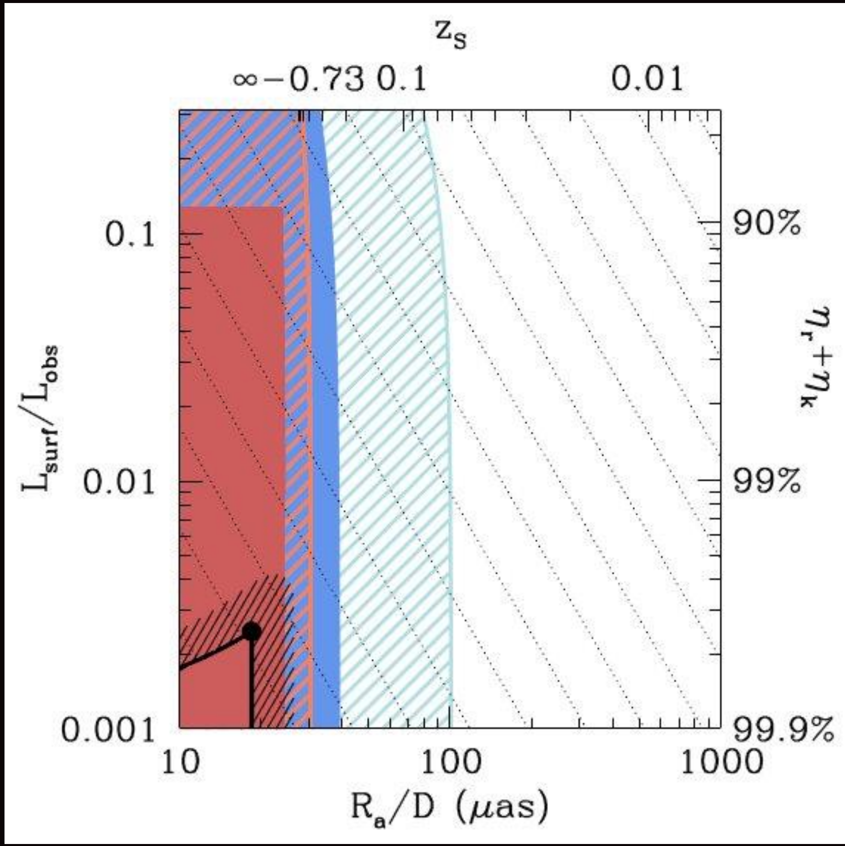
0903.1105

See also 1503.03873 about M87

Sgr A*







arXiv:0903.1105

Parameters of different models

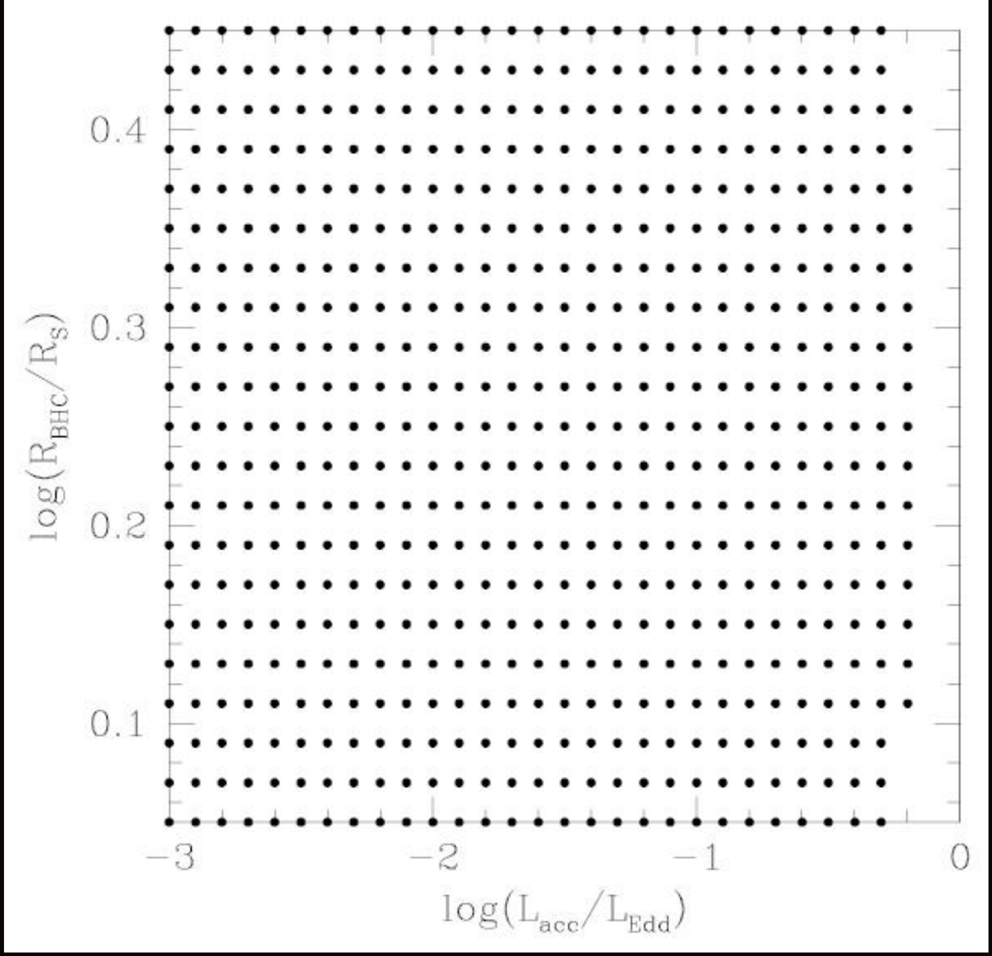
Fermion stars:
M_f=223 MeV (non-interacting)
M_{max}=12.61 M_0
R(M=10M_0)= 252 km= 8.6 R_{sh}
Collapse after adding 0.782 M_0 of gas.

Bozon stars:
M_b=2.4 10^{-17}MeV, λ=100
M_{max}=12.57 M_0
R(M=10M_0)= 153 km (99.9% of mass)
Collapse after adding 0.863 M_0 of gas.

Model parameters are constrained by limits on the maximum size of an object derived from QPOs at 450 Hz

astro-ph/0401549

Stability respect to flares on a surface

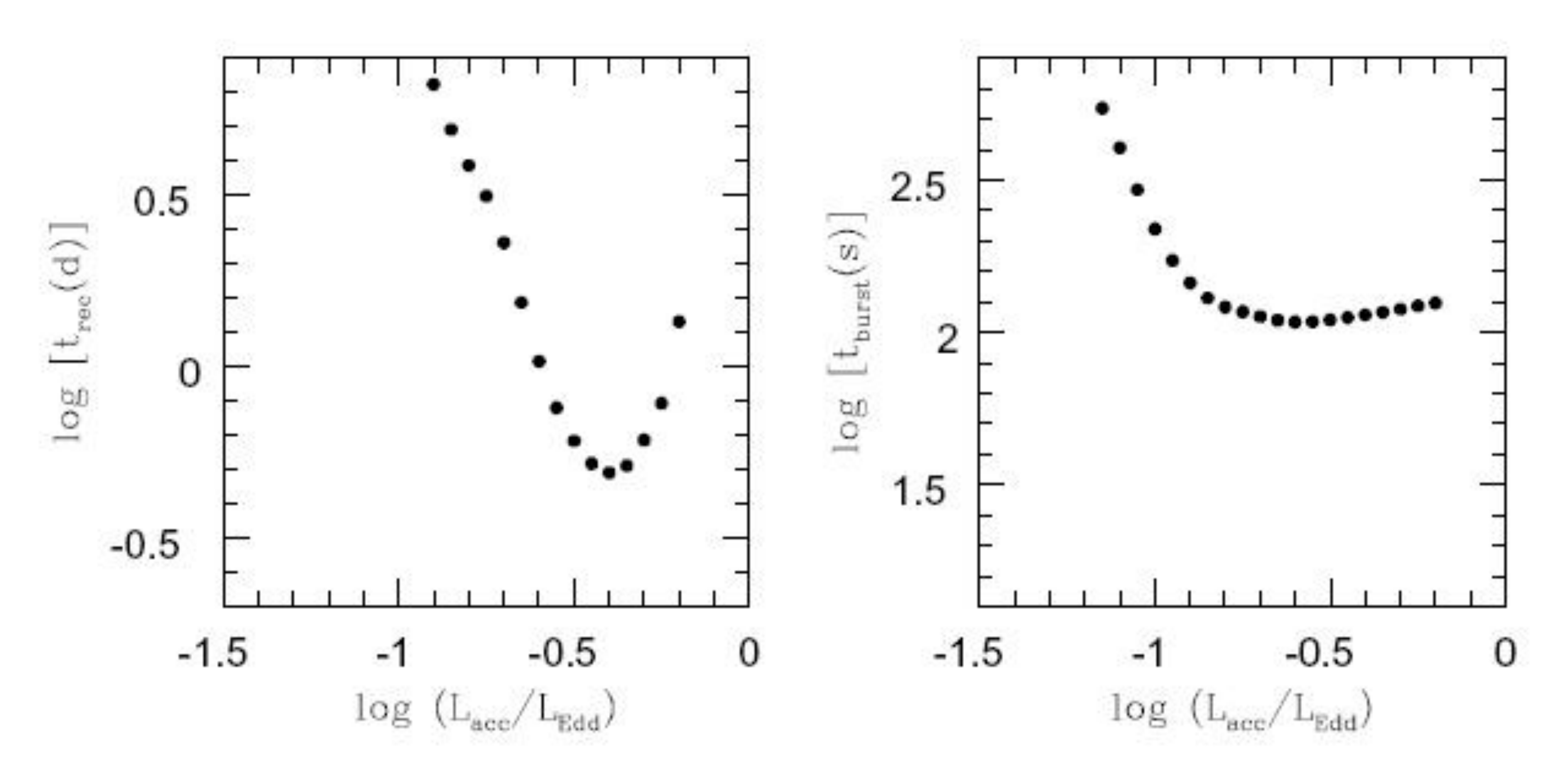


R_{min}=9/8 R_{sh}
Potentially, smaller radii are possible,
but such objects should be
unstable in GR.
Still, if they are possible,
then one can "hide" bursts due to
high redshift.

Solid dots – bursts.
Blanc field – stable burning.

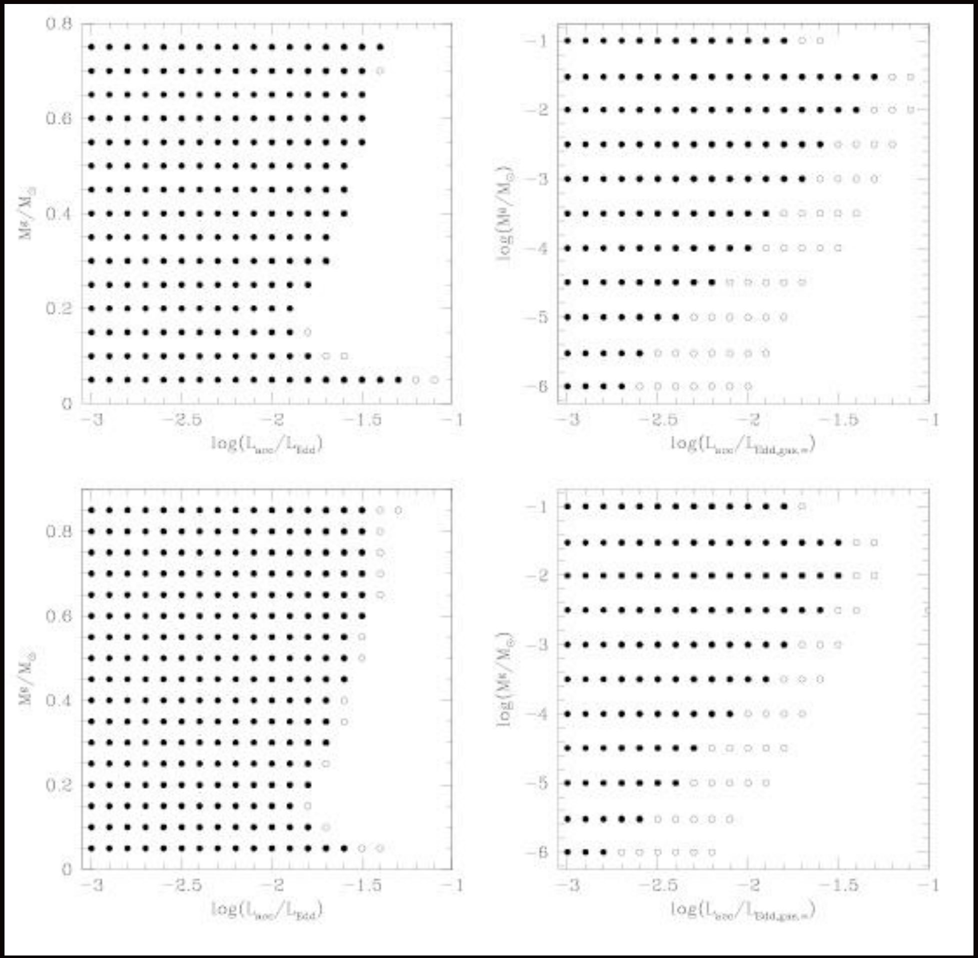
astro-ph/0401549

Timing characteristics of surface bursts



astro-ph/0401549

Stability respect to flares inside an object

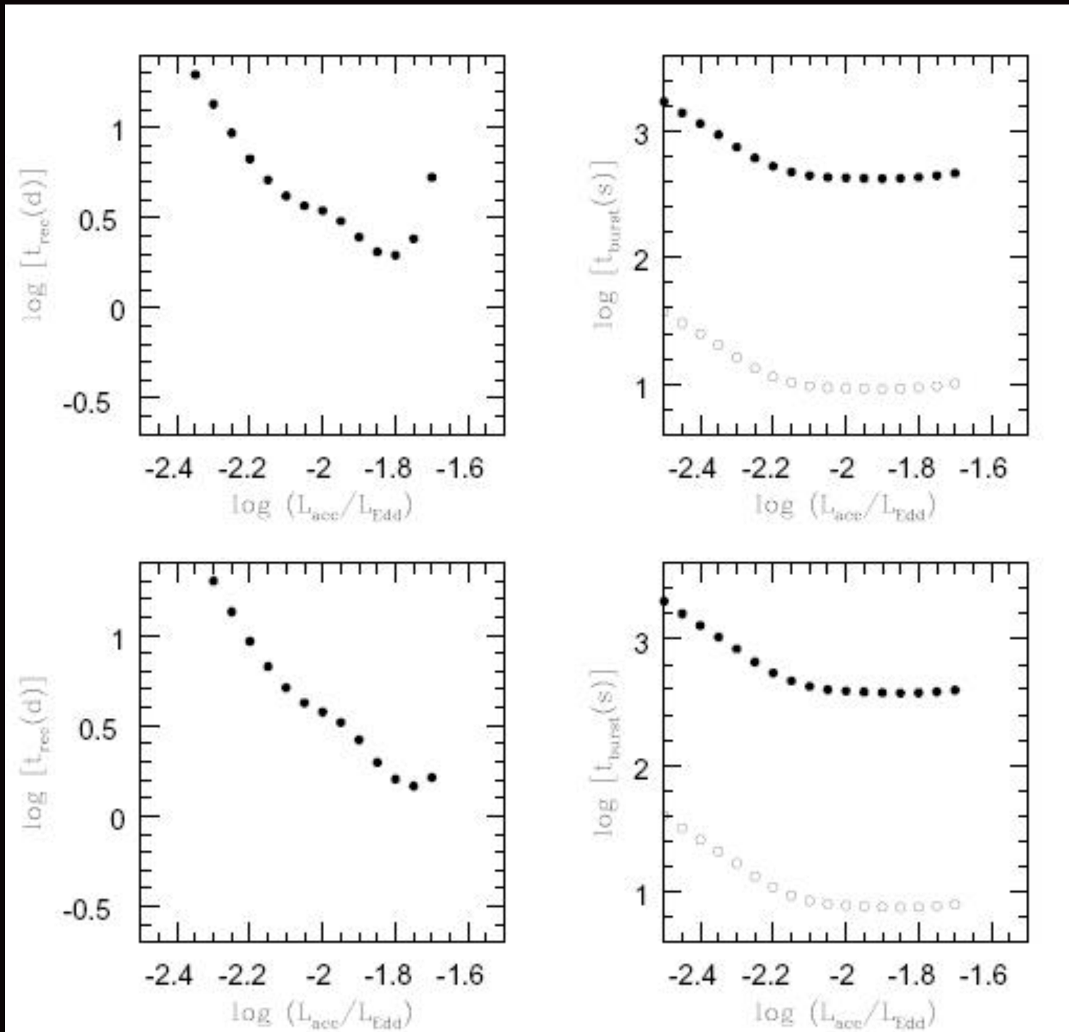


Fermion stars

Bozon stars

astro-ph/0401549

Timing characteristics of internal bursts



Fermion stars

Bozon stars

astro-ph/0401549

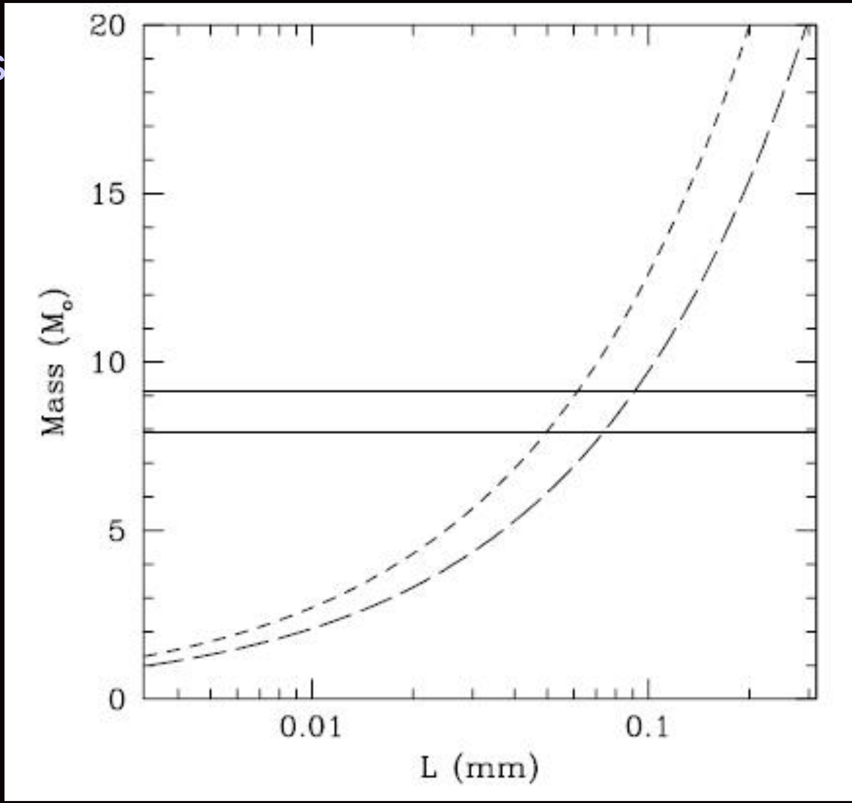
BHs and fundamental theories

1. Thermodynamics of BHs and Hawking radiation.
2. Testing alternative theories of gravity.
3. Black holes and extra dimensions
4. Accelerator experiments

Under some reasonable assumptions astrophysical data can provide strong and important constraints on parameters of fundamental theories.

Brane worlds and black holes

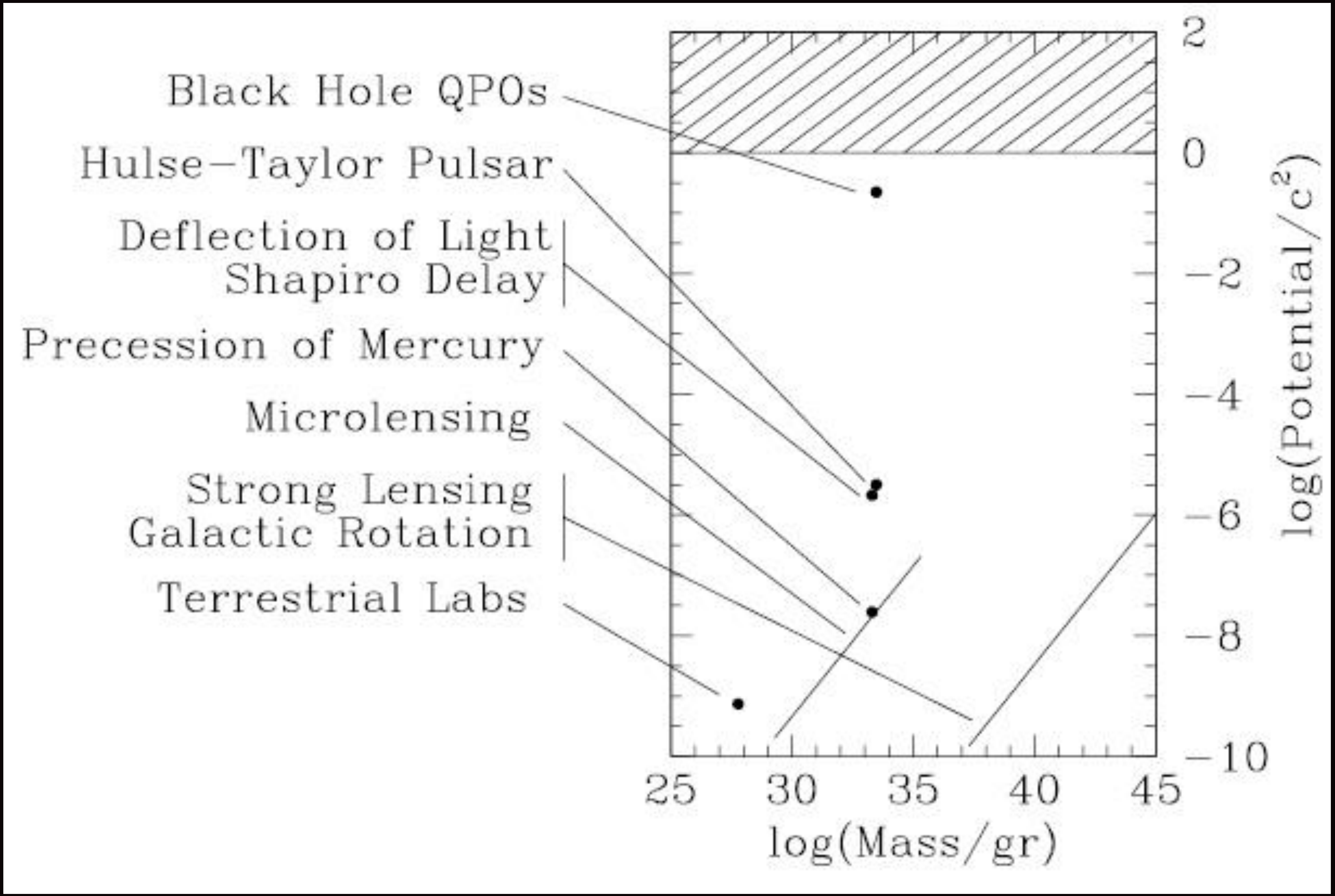
In astro-ph/0612611 the authors discuss constraints on parameters of world on brane basing on observations of XTE J1118+408. The idea is the following. In many scenarios of brane world BHs lifetimes are short. An estimated of a lower limit on the age of a BH can provide a stronger limit than laboratory experiments.



$$\tau \simeq 1.2 \times 10^2 \left(\frac{M}{M_\odot}\right)^3 \left(\frac{L}{1\ \mathrm{mm}}\right)^{-2} \mathrm{yr}$$

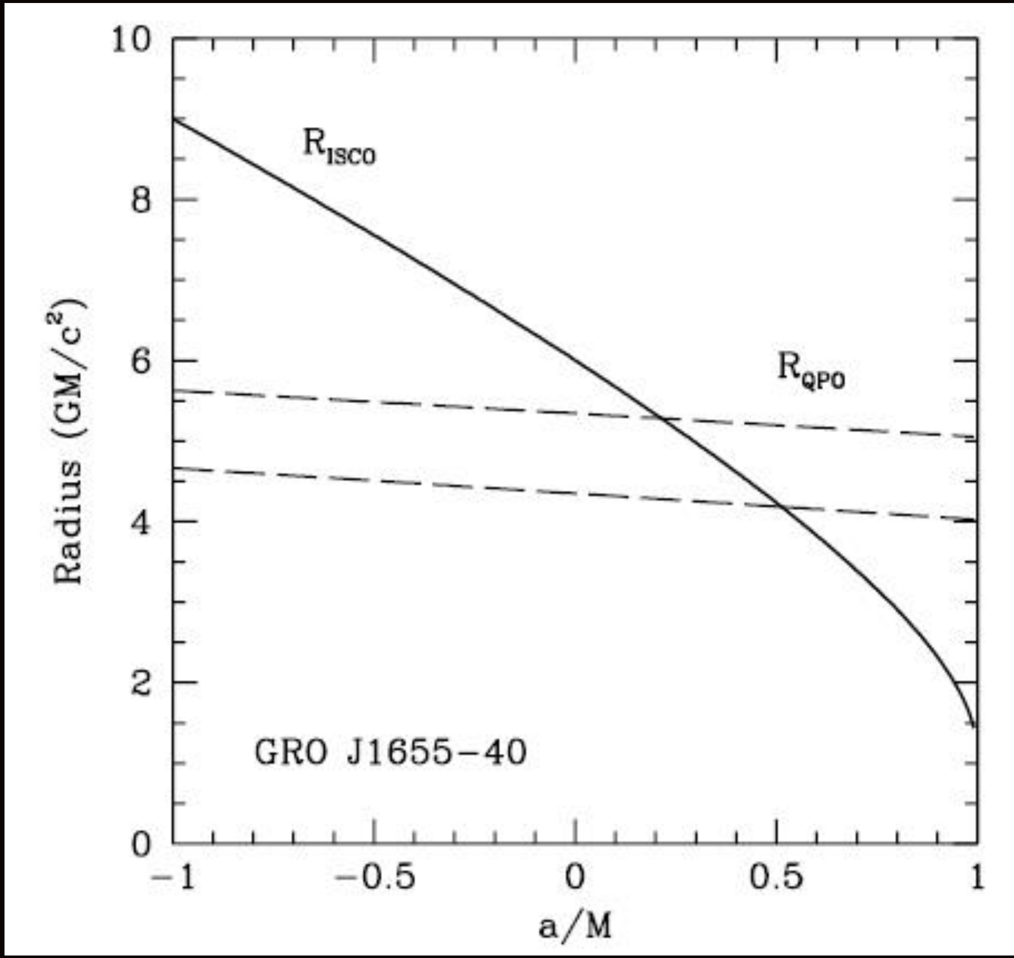
(see also astro-ph/0401466)

BH spin and testing the GR



astro-ph/0402213

QPO in GRO 1655-40



If the interpretation of QPOs in this source is correct, than we can "look inside" 3Rg.

The observed frequency is 450 Hz. Uncertainties (dashed lines) are due to uncertainty in the mass: 5.8-7.9 solar masses.

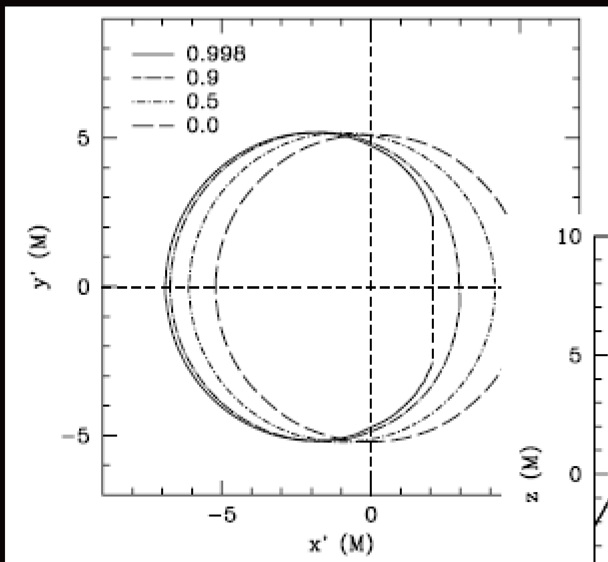
However, this conclusion crucially depends on our understanding of the QPO phenomenon.

Here it is assumed that $f_{QPO}<f_{AZIM}=(GM)^{1/2}/2\pi R^{3/2}$

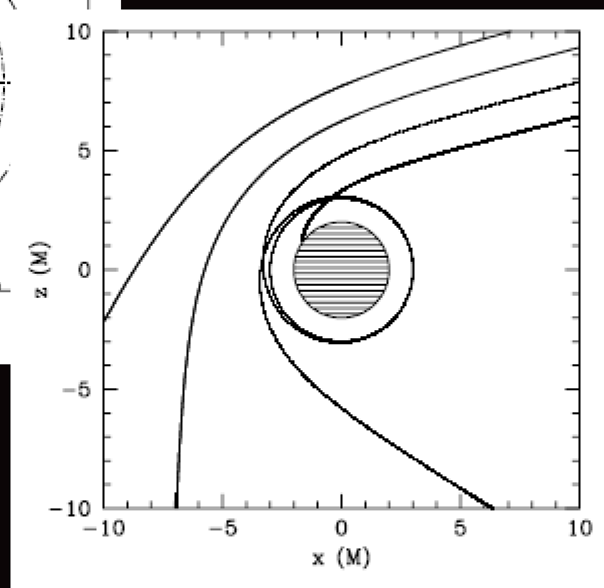
astro-ph/0402213

Testing no-hair theorem

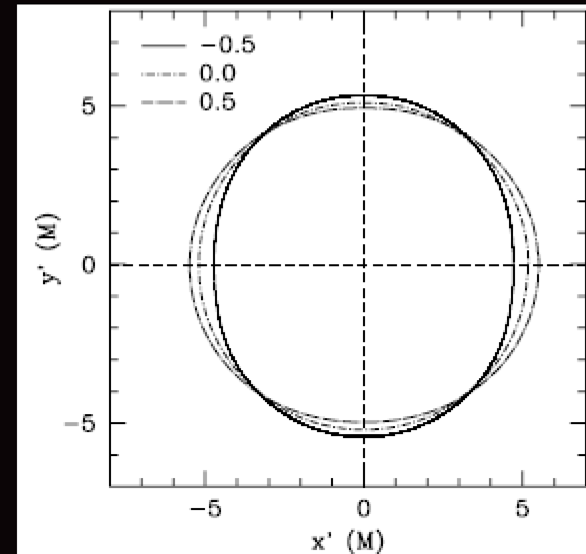
It is possible to study and put limits for the existence of quadrupole moments.



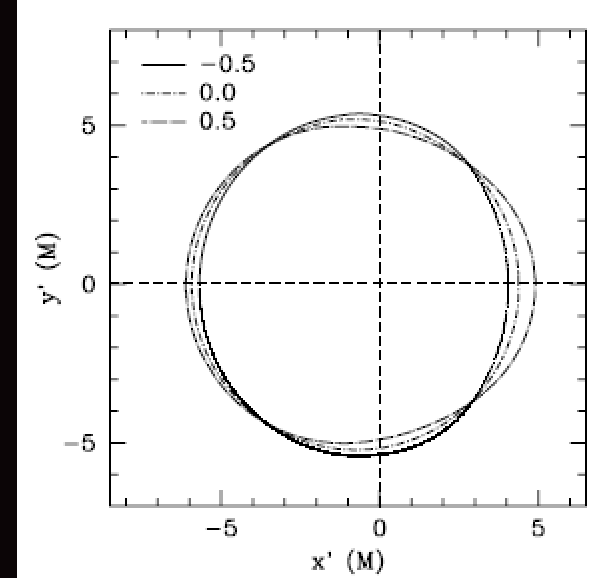
Spinning BHs



Photon ring formation



quadrupoles



1005.1931

Alternatives

1. Gravastar - GRAvitational VAcuum STAR (Mazur, Mottola gr-qc/0109035)
2. Dark energy stars (Chaplin astro-ph/0503200)
3. Boson stars (see, for example, Colpi et al. 1986 Phys. Rev. Lett.)
4. Fermion balls (see discussion in Yuan et al. astro-ph/0401549)
5. Evaporation before horizon formation (Vachaspati et al. gr-qc/0609024)

Except general theoretical criticizm, some models are closed by absence of burster-like flares (Yuan et al. astro-ph/0401549).

This is not the case for models like those proposed by Vachaspati et al. However, they are activley critisized by theorists.

Taking all together, black hole – is the most conservative hypothesis!

GRAvitational VAcuum STAR

$$
\begin{array}{llll}
\text{I.} & \text{Interior:} & 0 \le r < r_1\,, & \rho = -p\,, \\
\text{II.} & \text{Shell:} & r_1 < r < r_2\,, & \rho = +p\,, \\
\text{III.} & \text{Exterior:} & r_2 < r\,, & \rho = p = 0\,.
\end{array}
$$

Vacuum outside,
Vacuum inside

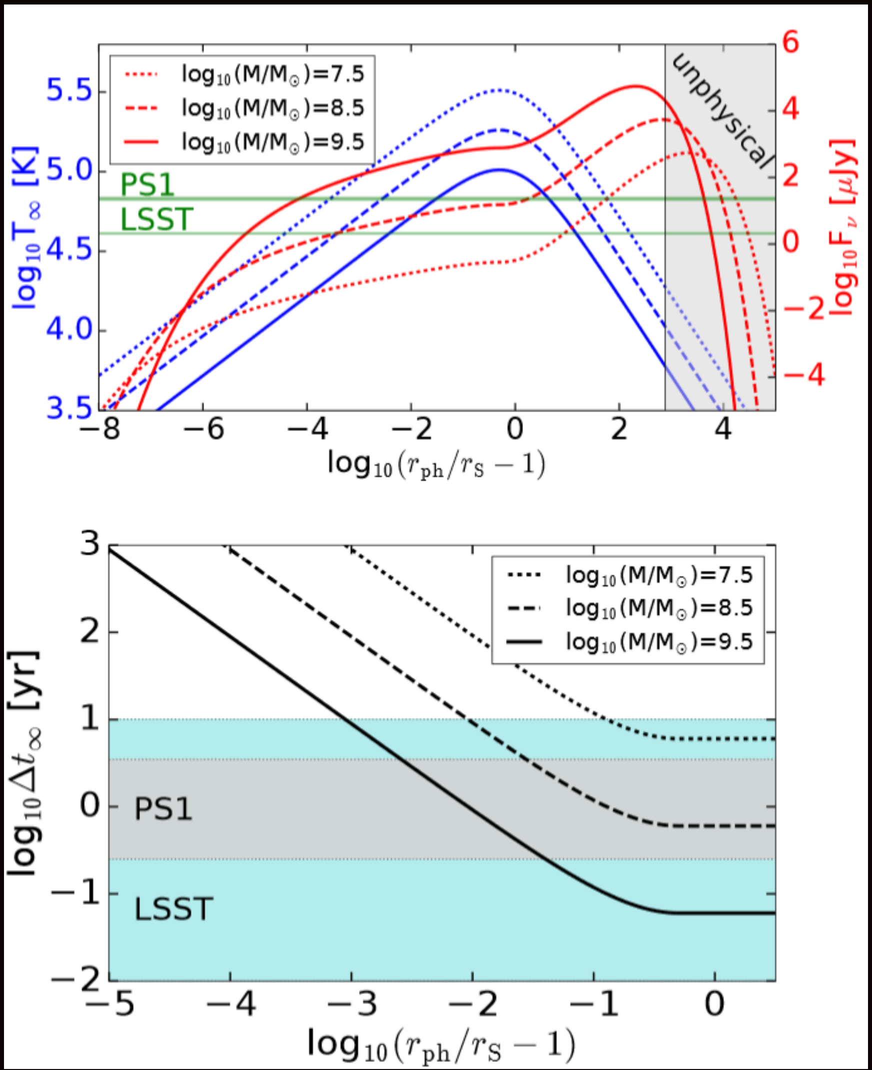
Do not produce
Hawking radiation.

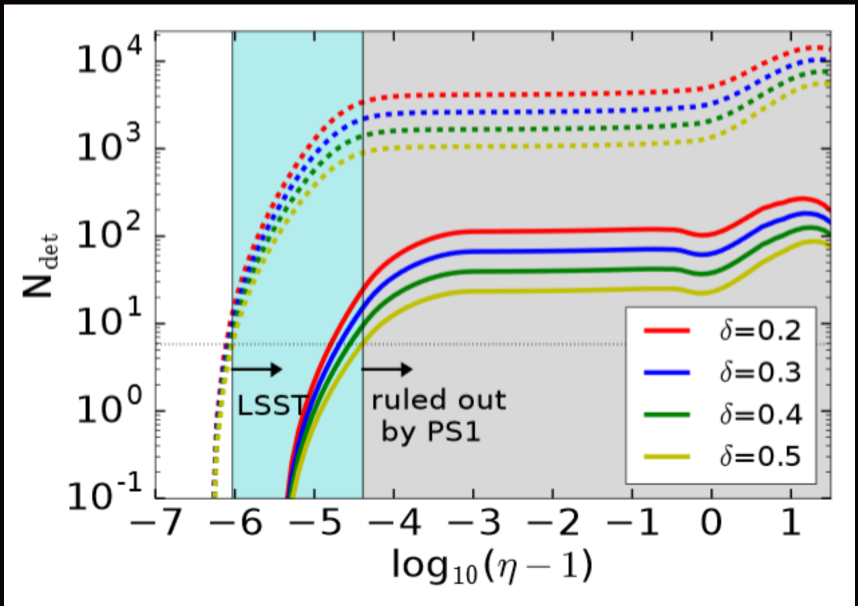
Can be distinguished
in coalescence.

See recent developments
in 1512.07659

Mazur, Mottola gr-qc/0109035

Tidal disruption and horizons





No surface emission after tidal events.
Limit $1+10^{-4.4}$ of the Schwarzschild radius.

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