Signature of stable stellar-mass black holes in X-ray spectra

Based on the paper:

Srimanta Banerjee, Marat Gilfanov, Sudip Bhattacharyya, Rashid Sunyaev, MNRAS, 498, 5353 (2020)

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Plan

1. Why is a signature of stable stellar-mass black holes important?

2. What would be a signature of stable stellar-mass black holes?

3. Finding a strong signature of stable stellar-mass black holes

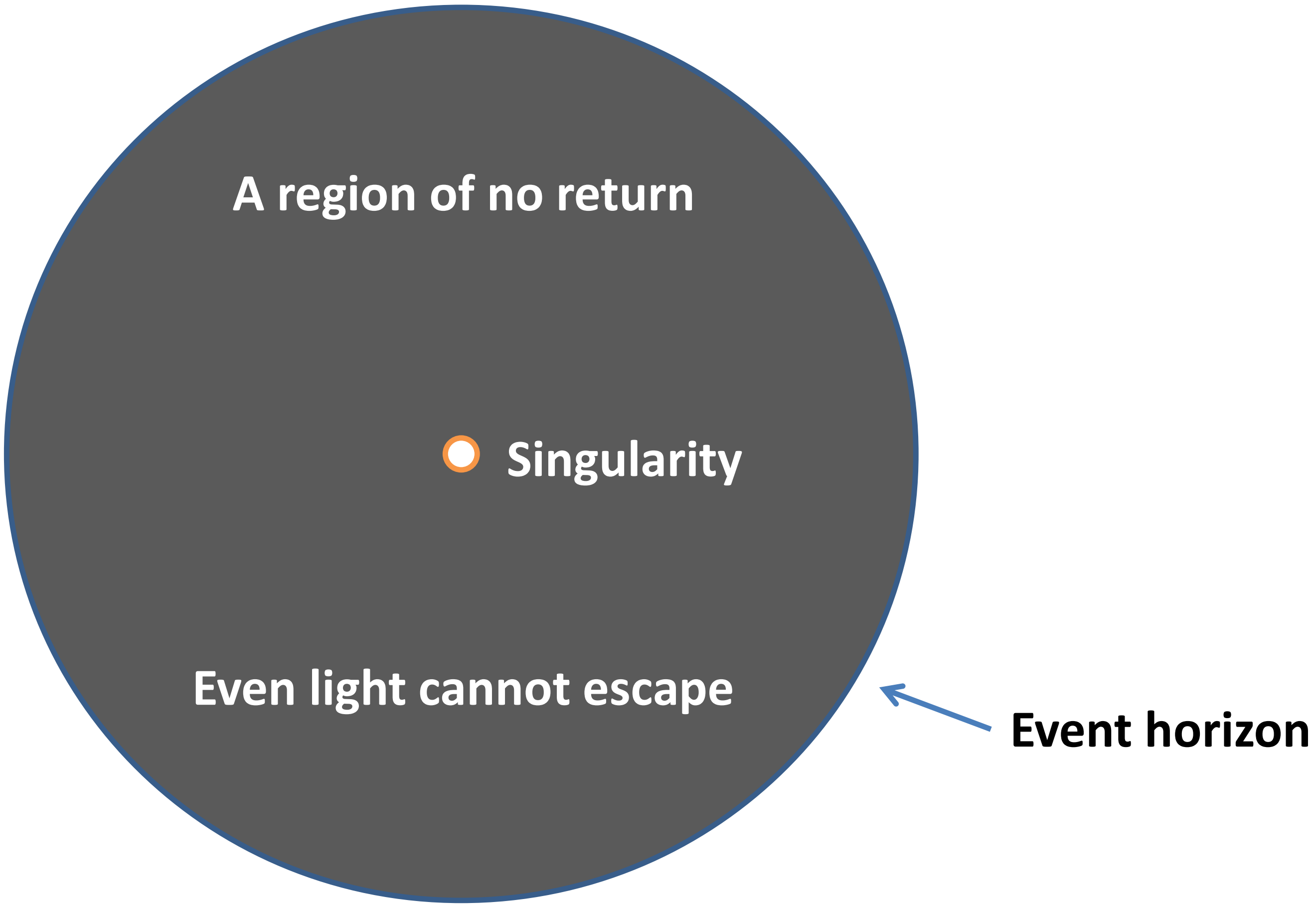
4. Conclusion

1. Why is a signature of stable stellar-mass black holes important?

Why

Two types of black holes and their signature

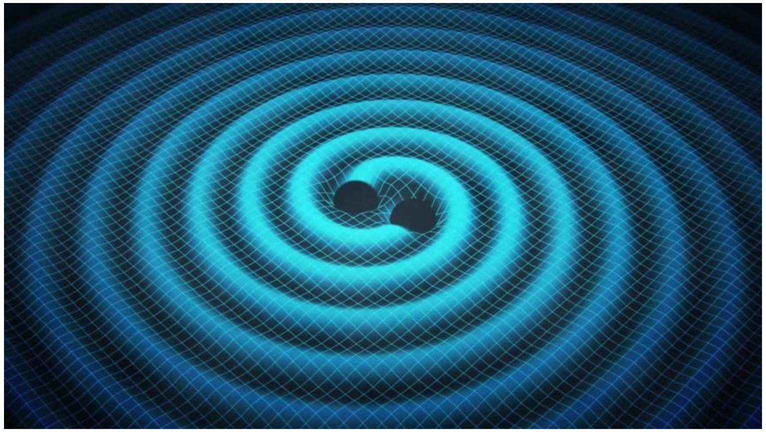
Stellar-mass and Supermassive



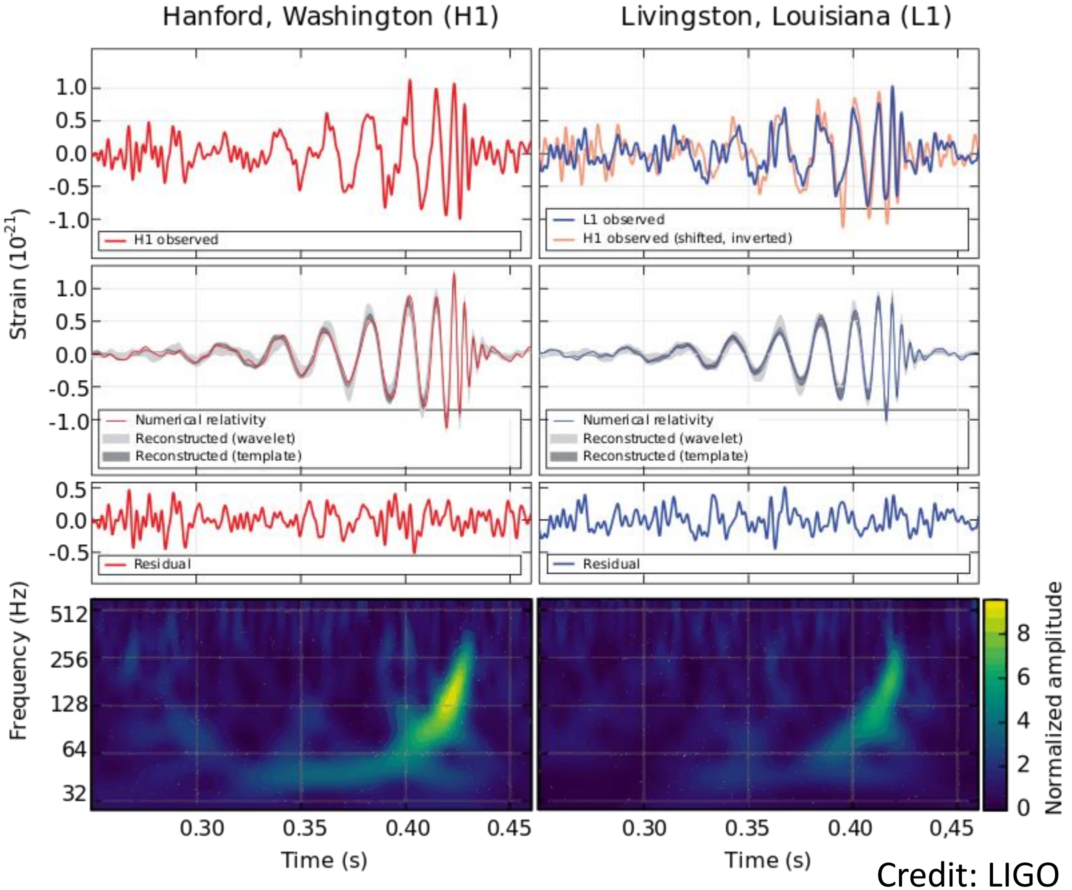
Signature of a black hole is the signature of the intangible event horizon!

Why

Merger of stellar-mass black holes



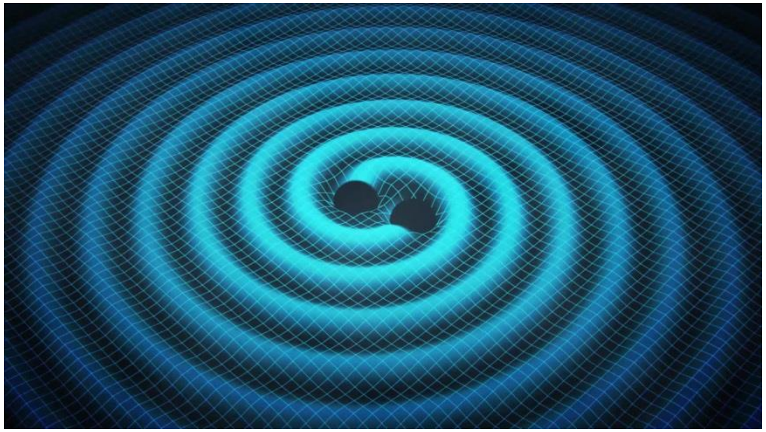
We can 'hear' black holes through gravitational waves, and we can study their properties.

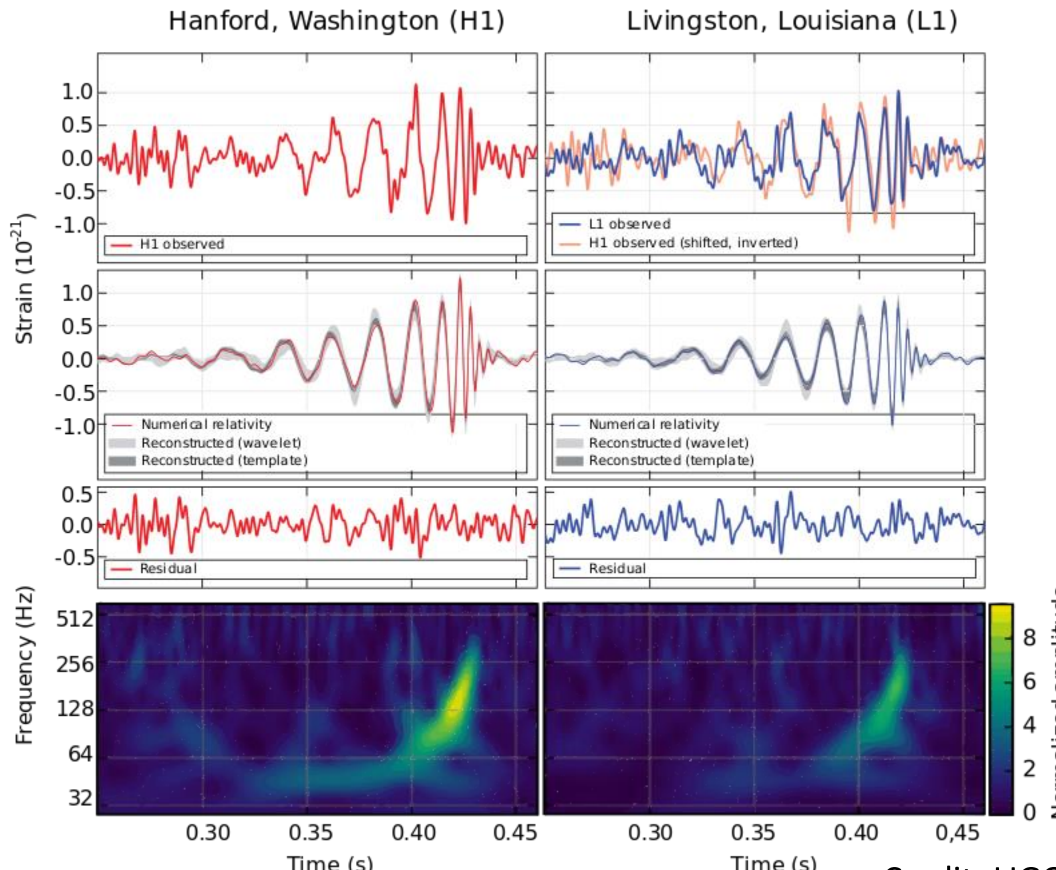


Credit: LIGO

Why

Merger of stellar-mass black holes





Credit: LIGO

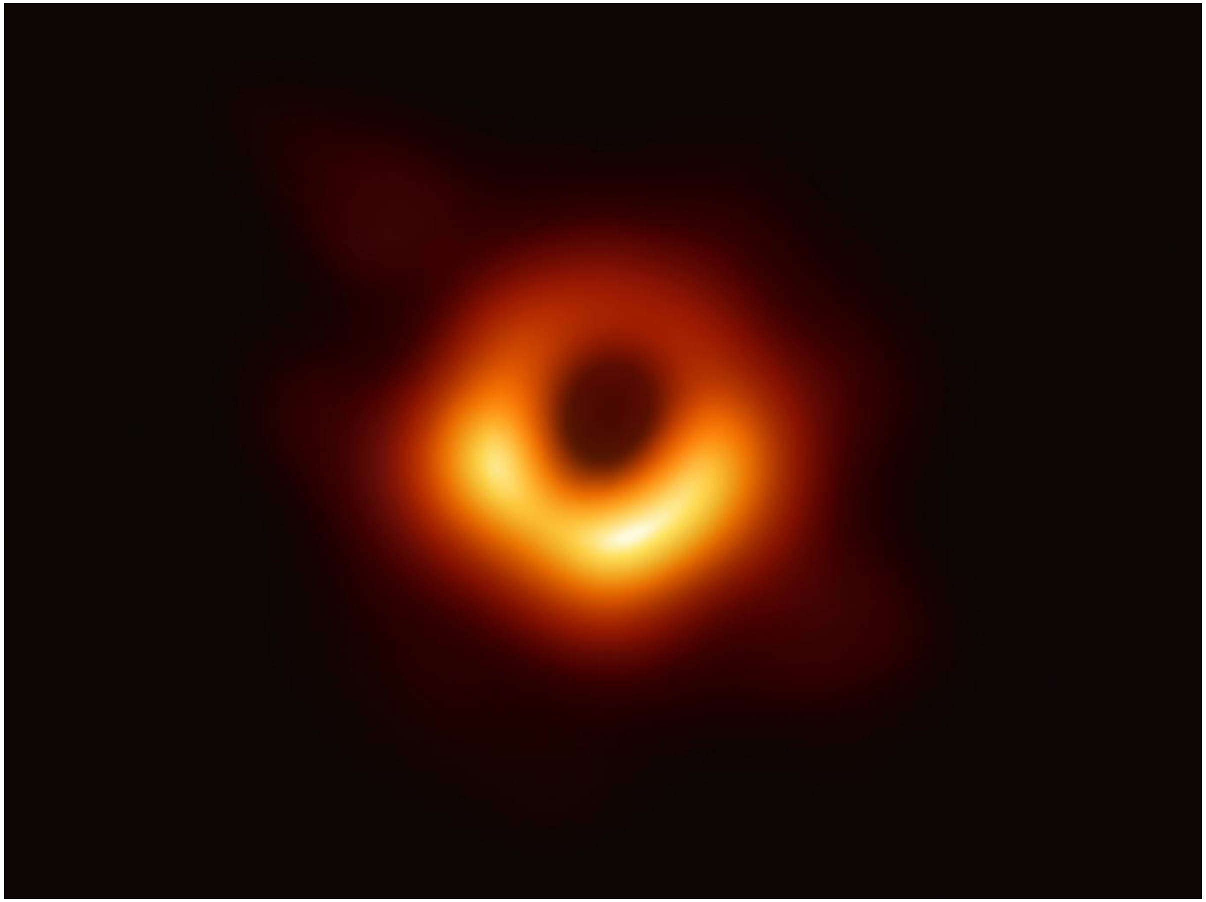
We can 'hear' black holes through gravitational waves, and we can study their properties.

But we cannot 'see' them.

And these are dynamic systems. We can hear them for only a fraction of a second, and the observation cannot be repeated for a given system. These dynamic systems are useful to study some aspects black holes and space-time.

Why

Imaging the shadow of a black hole



EHT image of M87*. The image is in radio wavelength of 1.3 mm (The Event Horizon Telescope Collaboration, ApJ, 875, L1, 2019).

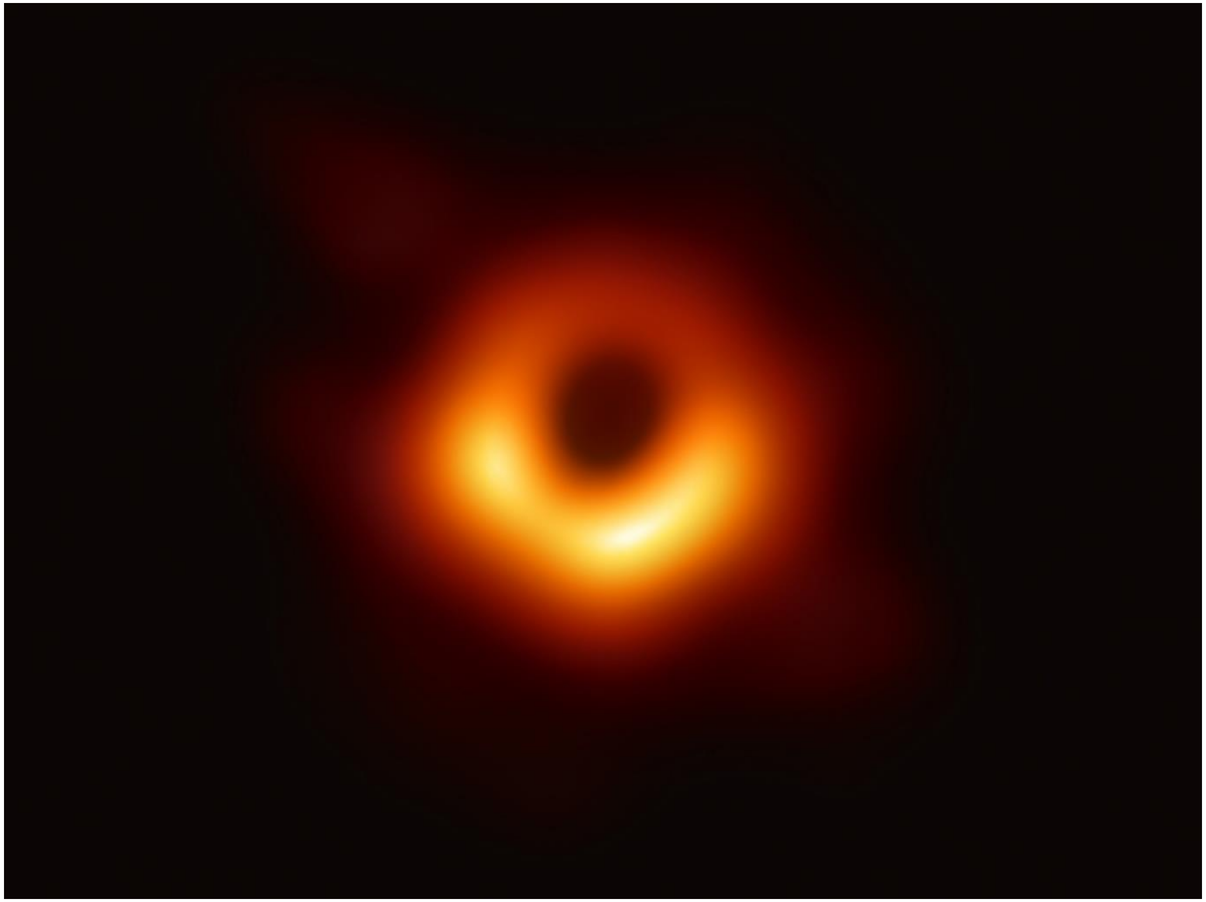
Measured parameters:

Ring diameter:
~42 micro-arcsec

Black hole mass:
~6.5×10^9 solar mass

Why

Imaging the shadow of a black hole



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So this is a supermassive black hole.

The angular size of a typical Galactic stellar-mass black hole would be ~ 10^{-5} – 10^{-4} micro-arcsec, and hence cannot be imaged in near future.

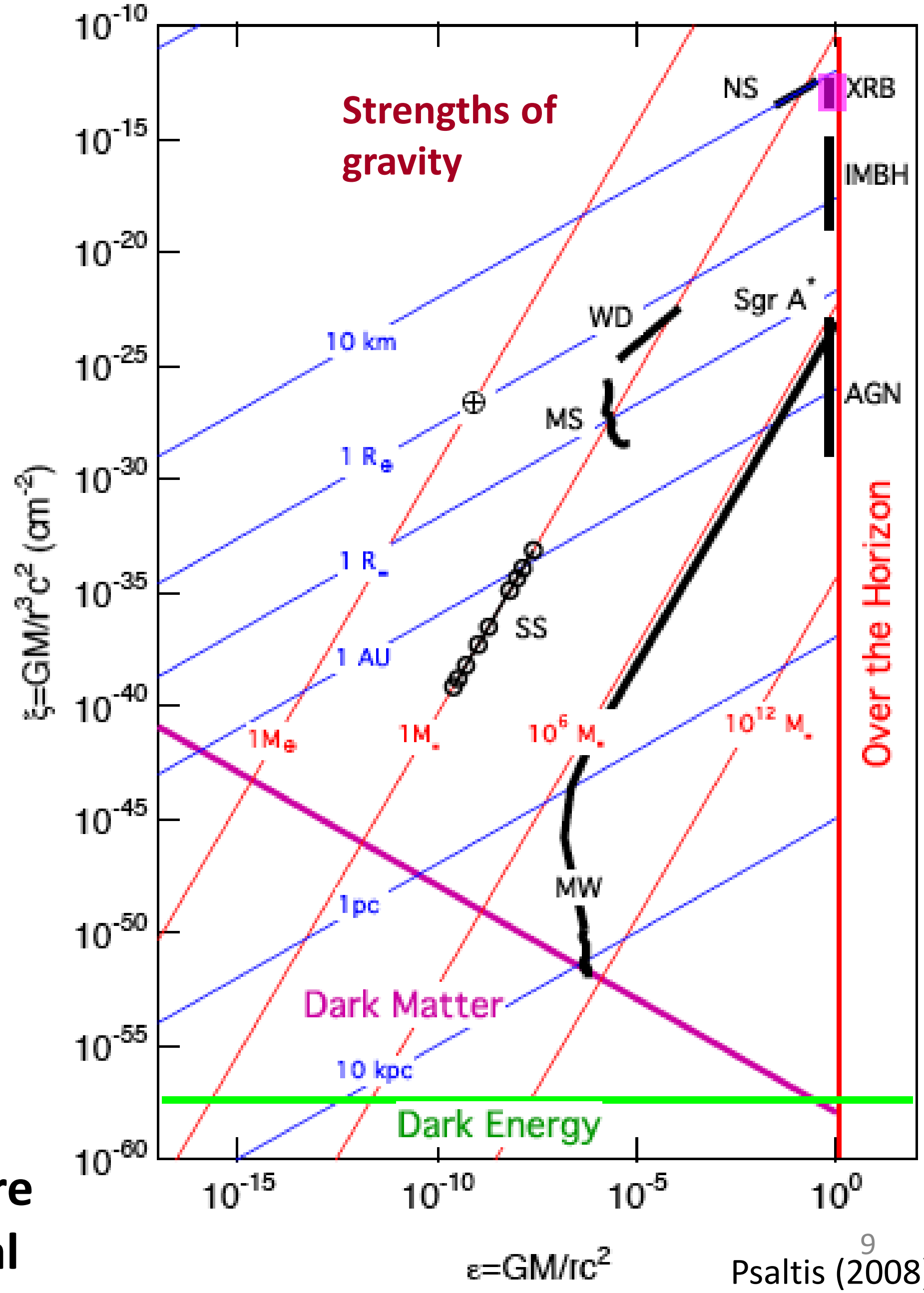
Why stable stellar-mass black holes?

1. Orders of magnitude higher space-time curvature than that for a supermassive black hole. Studies of a different regime.

2. Studies of a stable, that is a long-lived system.

3. Studies can usually be repeated any number of times in the future with better instruments and techniques.

4. Accreting: otherwise cannot be observed in electromagnetic wavelengths.



$\xi \Rightarrow$ **A measure of curvature**

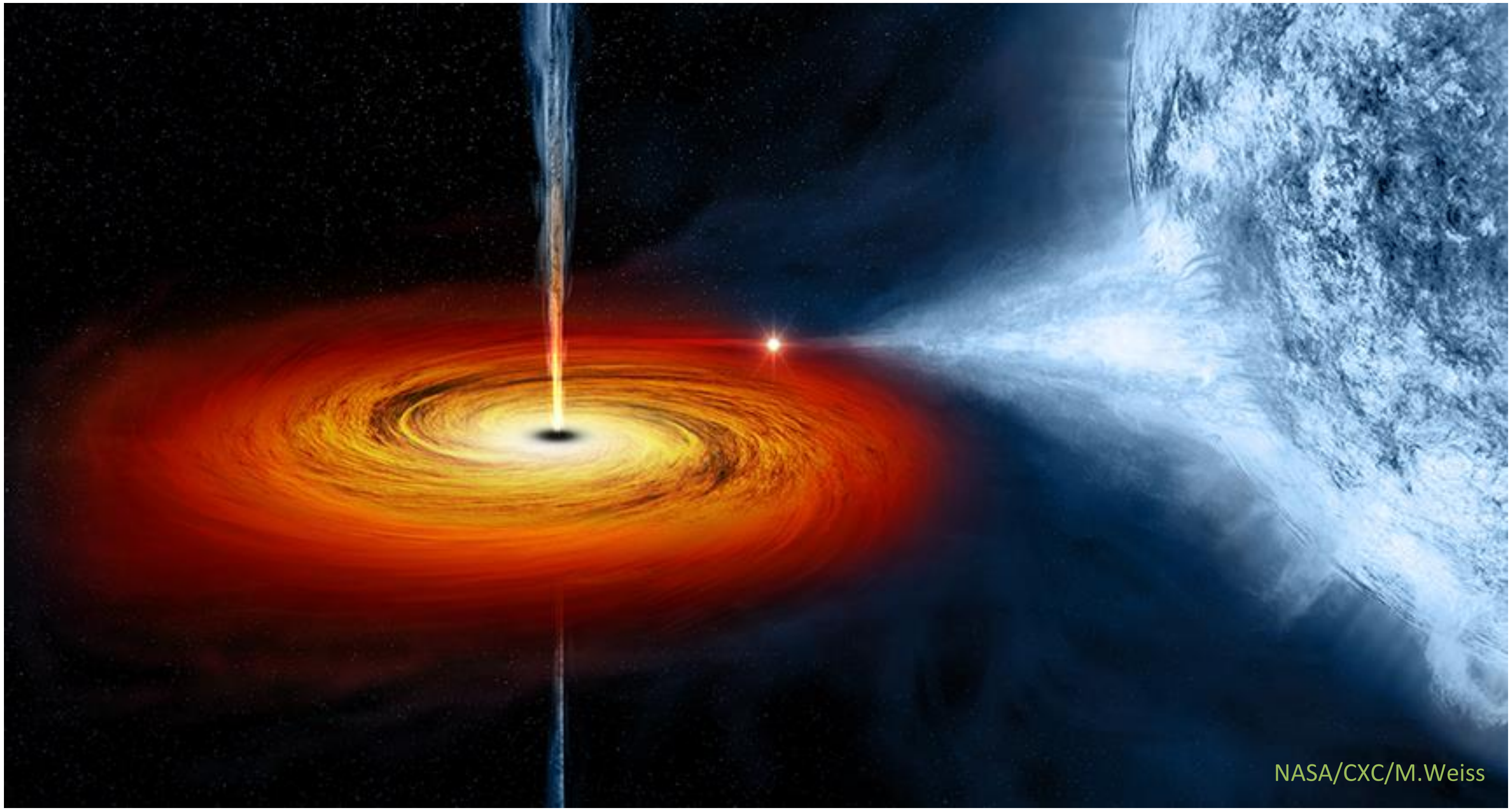
$\varepsilon \Rightarrow$ **A measure of potential**

Psaltis (2008)

Why

Black hole X-ray binary (BHXB)

(Accreting stellar-mass black hole)



(Artist's impression)

Primarily emits X-rays, so we need to look for a signature of event horizon in observed X-rays.

2. What would be a signature of stable stellar-mass black holes?

Signature of black hole event horizon in X-ray spectrum

Our aim is to find a signature of the lack of a hard surface, that is something does not exist!

Such a signature could be found only using the contrast with observations of other similar objects with hard surface. Such similar objects are low magnetic field neutron stars.

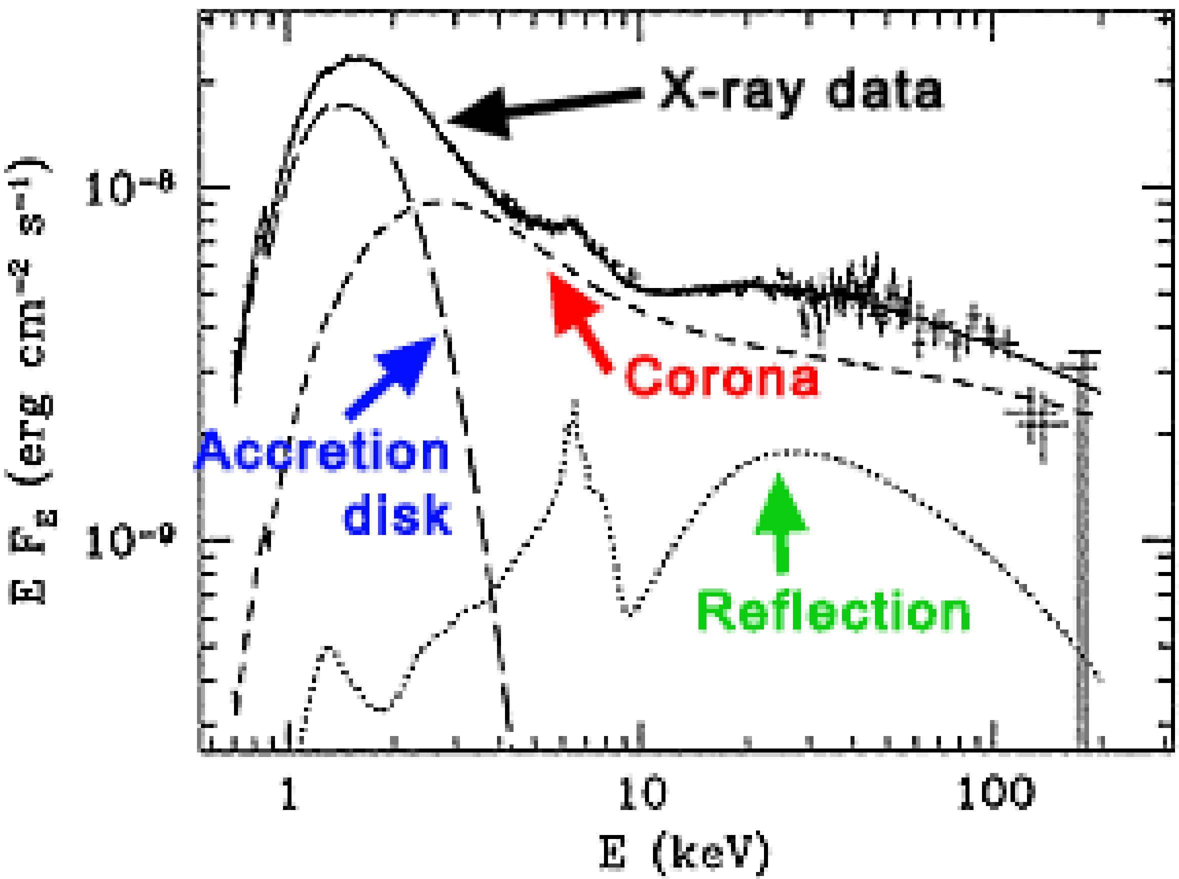
Therefore, we can find a signature of event horizon, if we can compare the spectra of accreting black hole candidates with those of known accreting low magnetic field neutron stars, separate these two populations almost entirely based on some measured parameter values, and can argue that this separation is due to a hard surface of a neutron star and a lack of hard surface for a black hole candidate.

What

Signature of black hole event horizon in X-ray spectrum

Two canonical states: Hard and Soft.

Typical spectrum



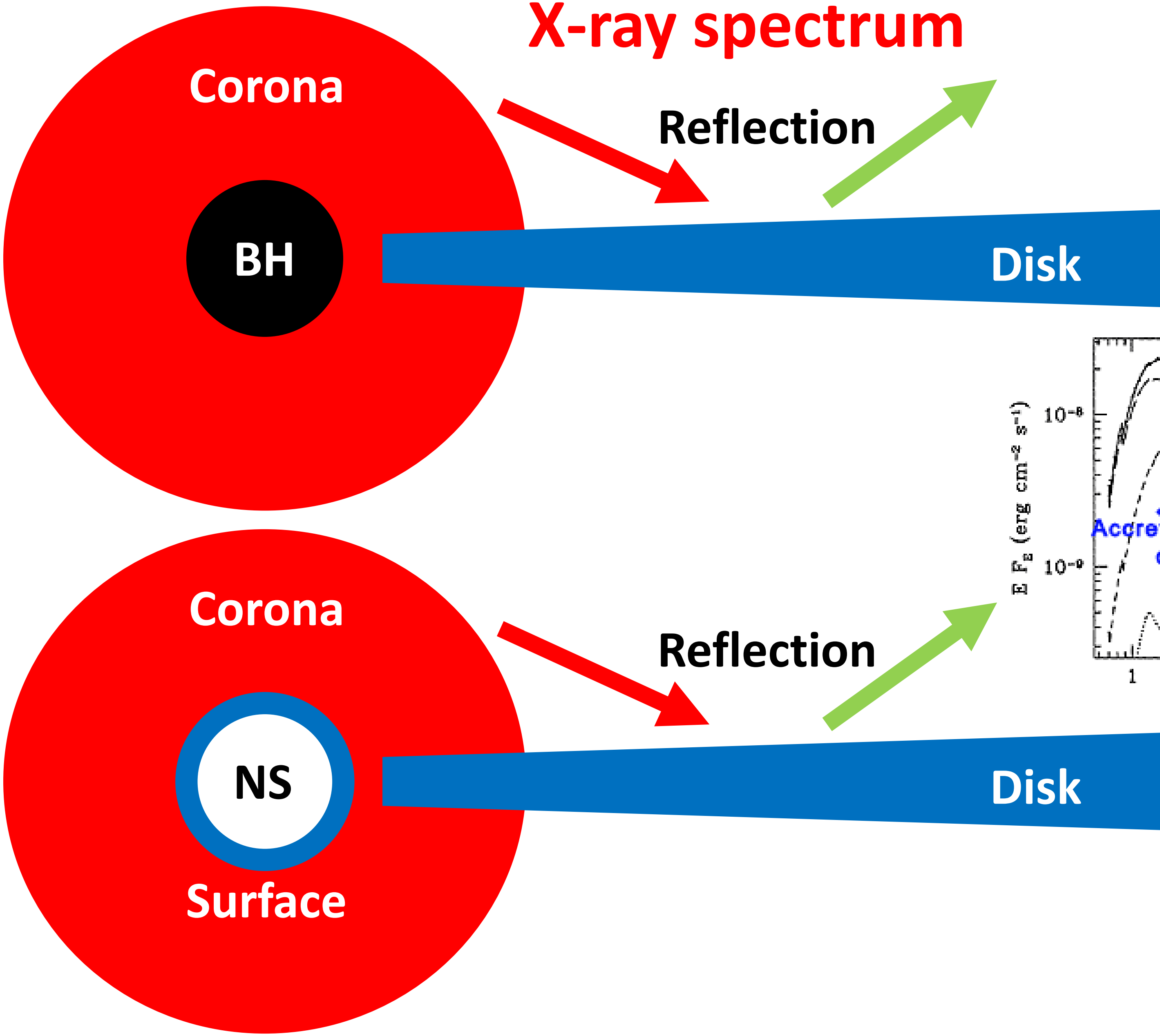
Three emission components:

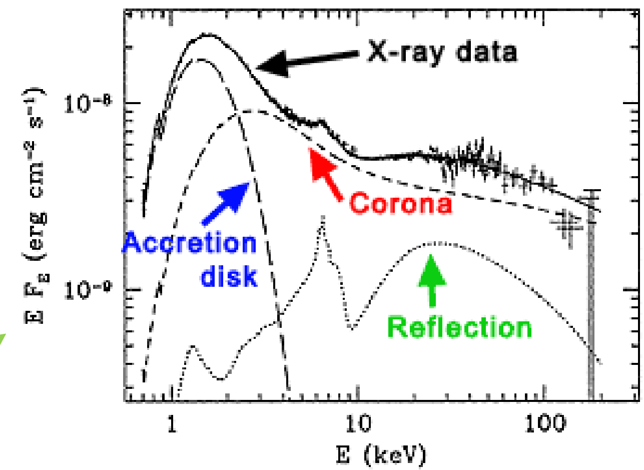
Each of accretion disk and NS surface can emit blackbody; each of them can be partially or fully covered with a Comptonizing corona; hard X-ray photons from corona can be reflected from disk.

http://www.gothosenterprises.com/black_holes/images/

What

Signature of black hole event horizon in X-ray spectrum





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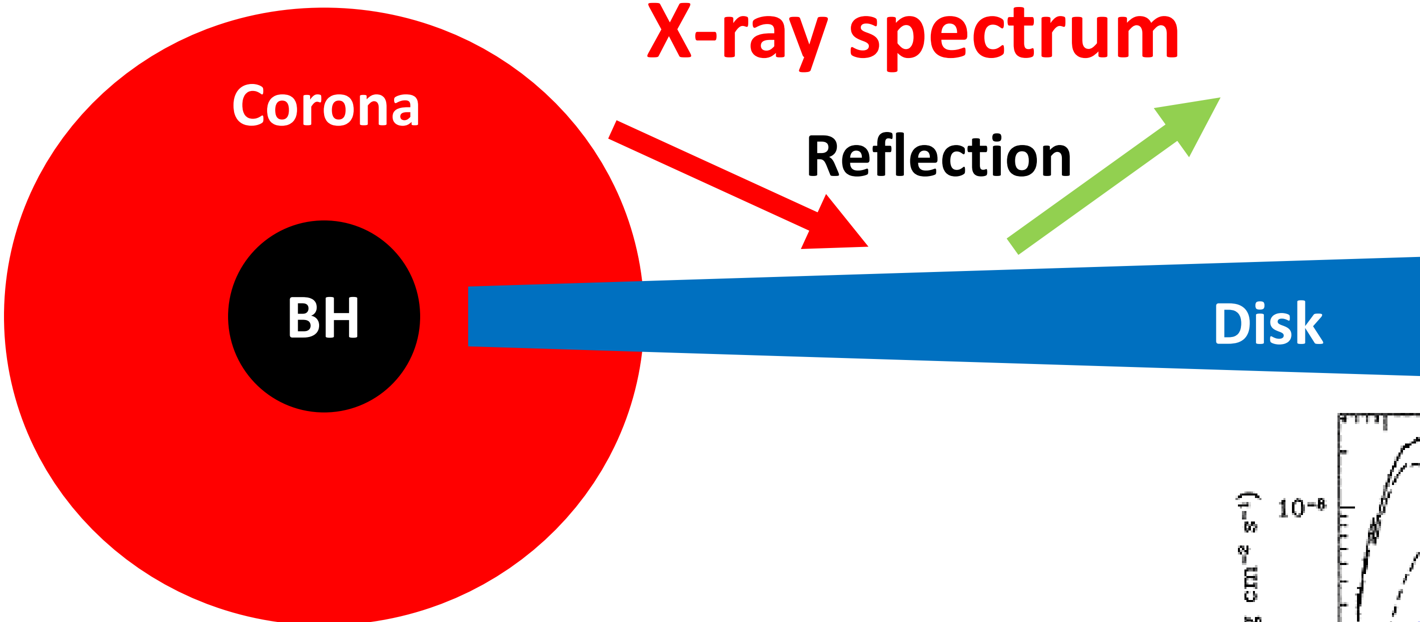
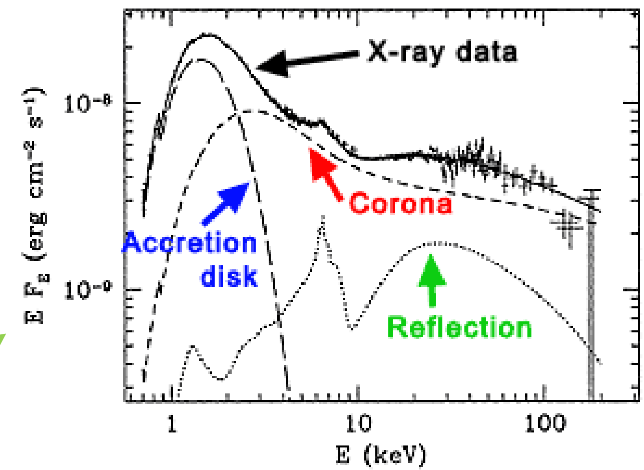
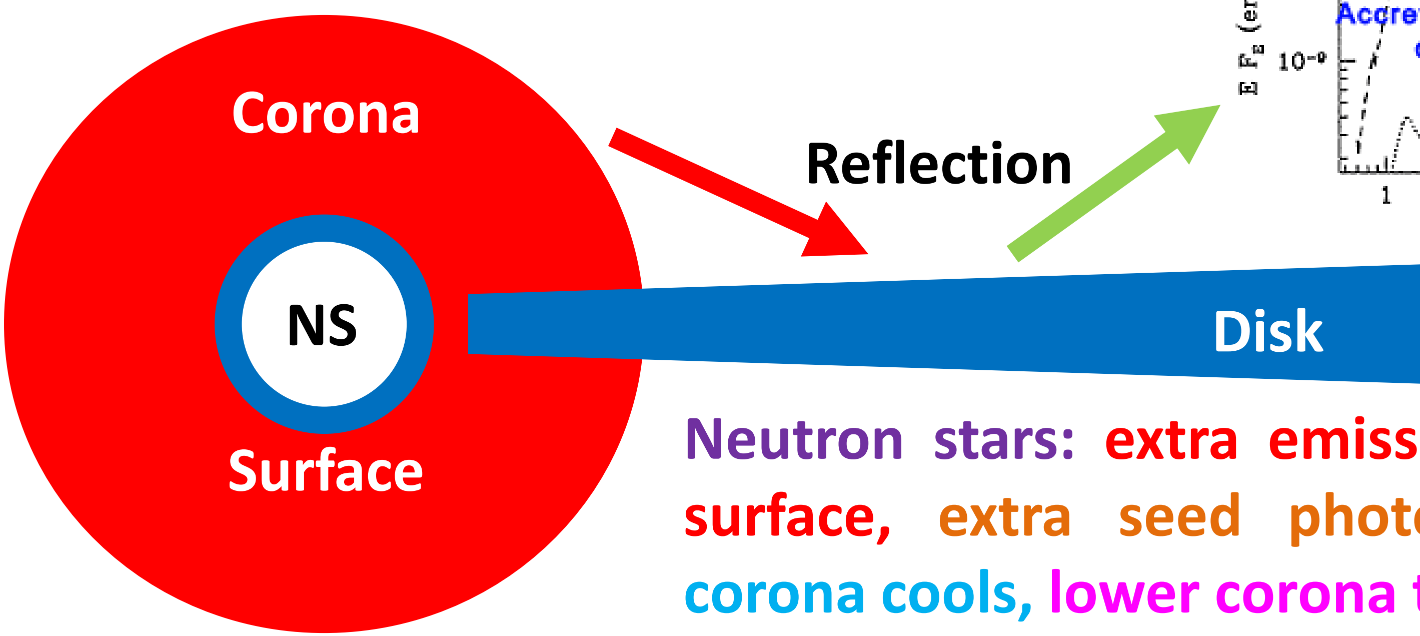
Signature of black hole event horizon in X-ray spectrum







Neutron stars: extra emission from stellar surface, extra seed photons to corona, corona cools, lower corona temperature.

3. Finding a strong signature of stable stellar-mass black holes

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Finding

Distinguishing X-ray spectra from accreting neutron stars and black holes

(by far the most extensive, uniform and systematic study to date)

1. About 5000 *RXTE* PCA (3-20 keV) and HEXTE (20-200 keV) observations from 11 accreting stellar-mass black holes and 13 accreting low magnetic field neutron stars.
2. We use hard state data of all sources, for which significant corona component in the spectrum is present.
3. We select about 900 spectra from 24 sources based of uniform criteria on hard colour (to find the hard state), count rates, good time intervals, etc.
4. We fit these spectra with an absorbed compPS + gauss model of XSPEC. The compPS model is for the Comptonization by corona, which also includes a reflection continuum component and seed photons from a blackbody component. The gauss is a Gaussian component representing the Fe Kα line emission.

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5. We use 3 parameters (best-fit or calculated from best-fit) to distinguish between black holes and neutron stars. These are corona electron temperature kT_e, Compton y-parameter (average fractional energy change due to Comptonization) and the Compton amplification factor A, which is the ratio of the luminosity of the Comptonized component to the luminosity of the soft seed photons.

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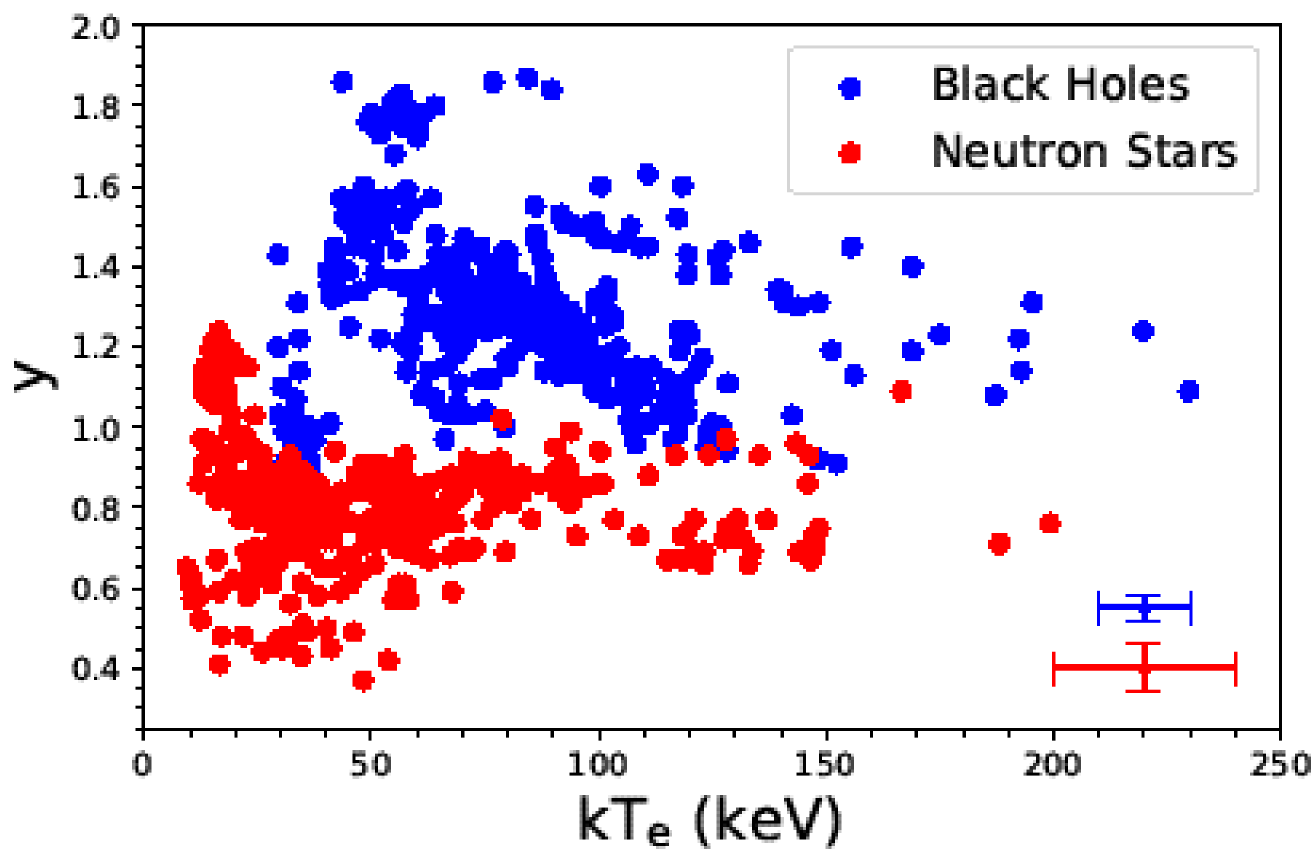

Data from two dozens of black hole candidates and neutron stars. It is clearly seen that the black hole candidates (blue symbols) and the neutron stars (red symbols) occupy well separated distinct regions on the *y* - kT_e plane.

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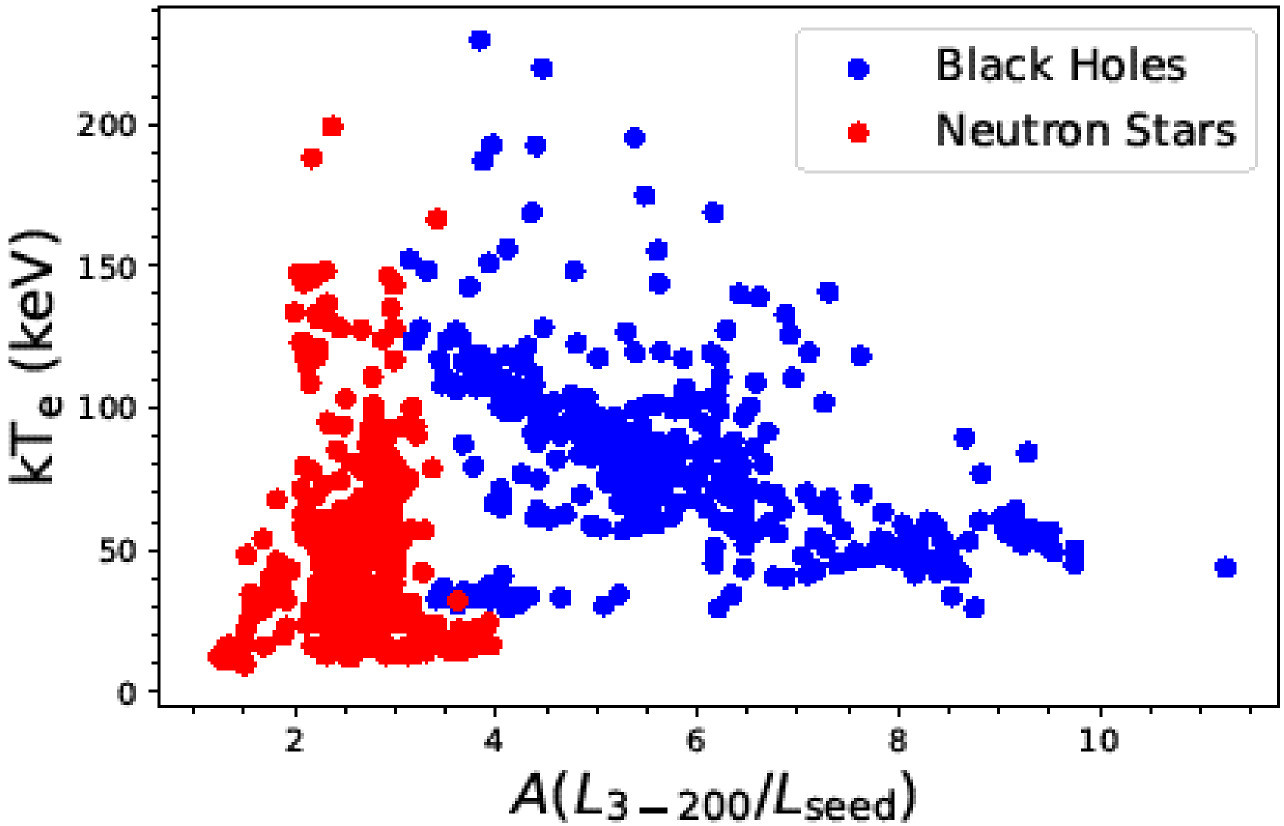

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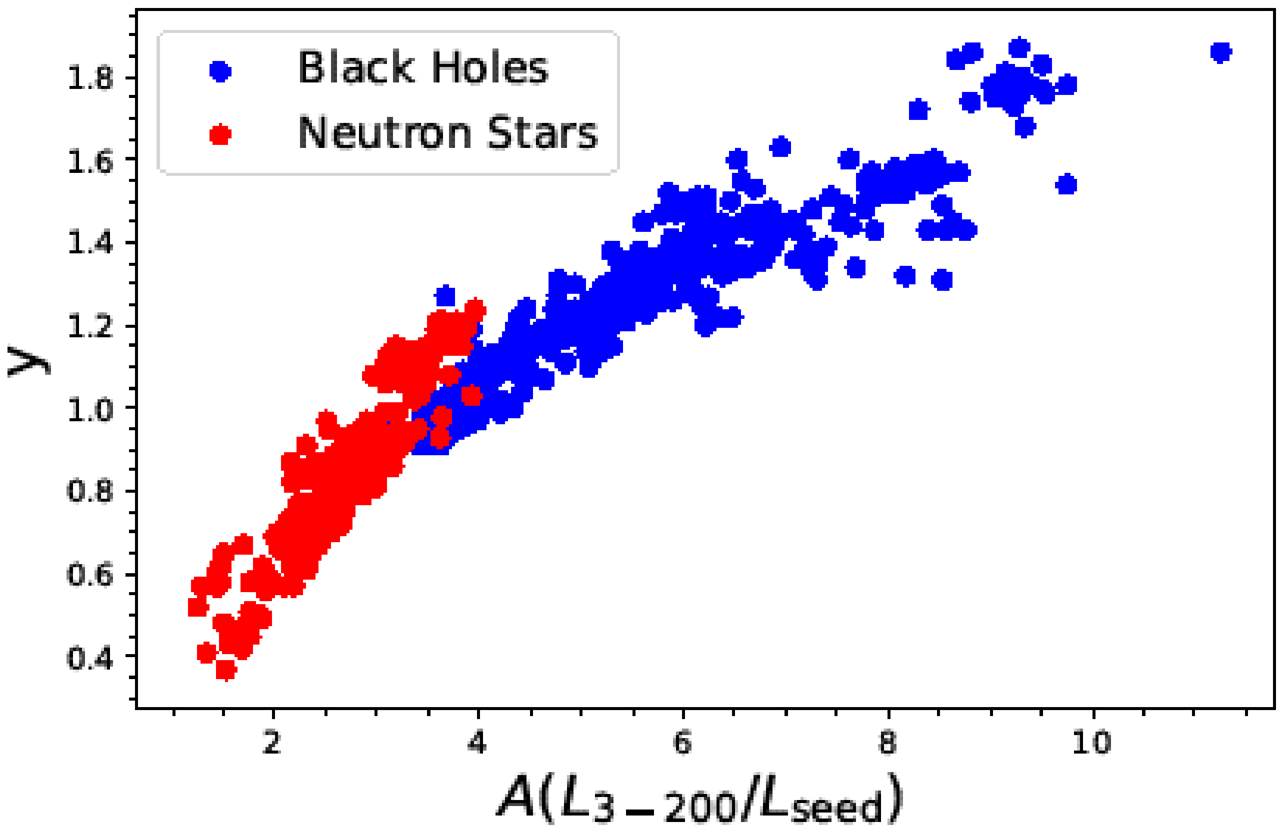

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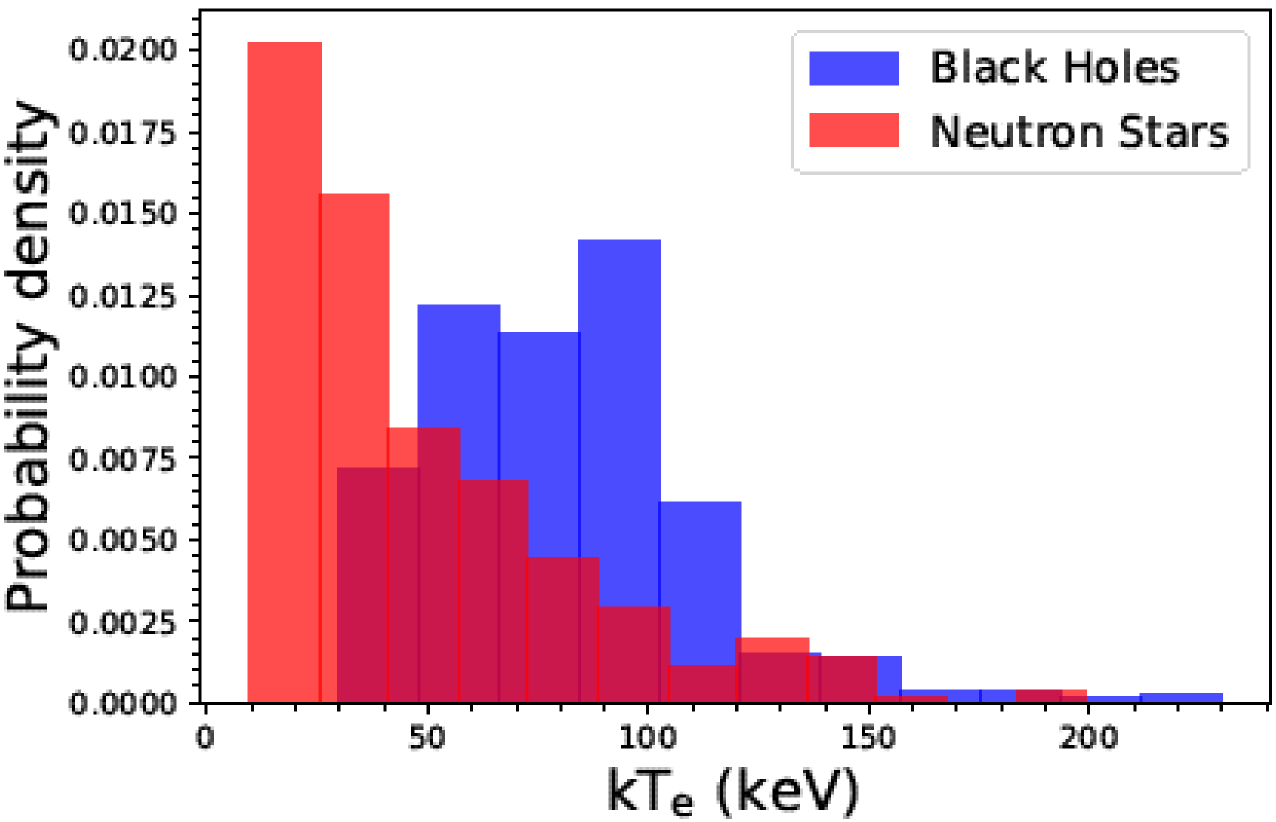

The mean of kT_e for our NS sample is ≈ 47 keV, and its 80 per cent quantile is 16−93 keV, while BHs are characterized by the mean of ≈ 80 keV and 80 per cent quantile of 45−117 keV.

A clear dichotomy: the probability for distributions to be the same is $\approx 8.1 \times 10^{-47}$ (from Kolmogorov–Smirnov test).

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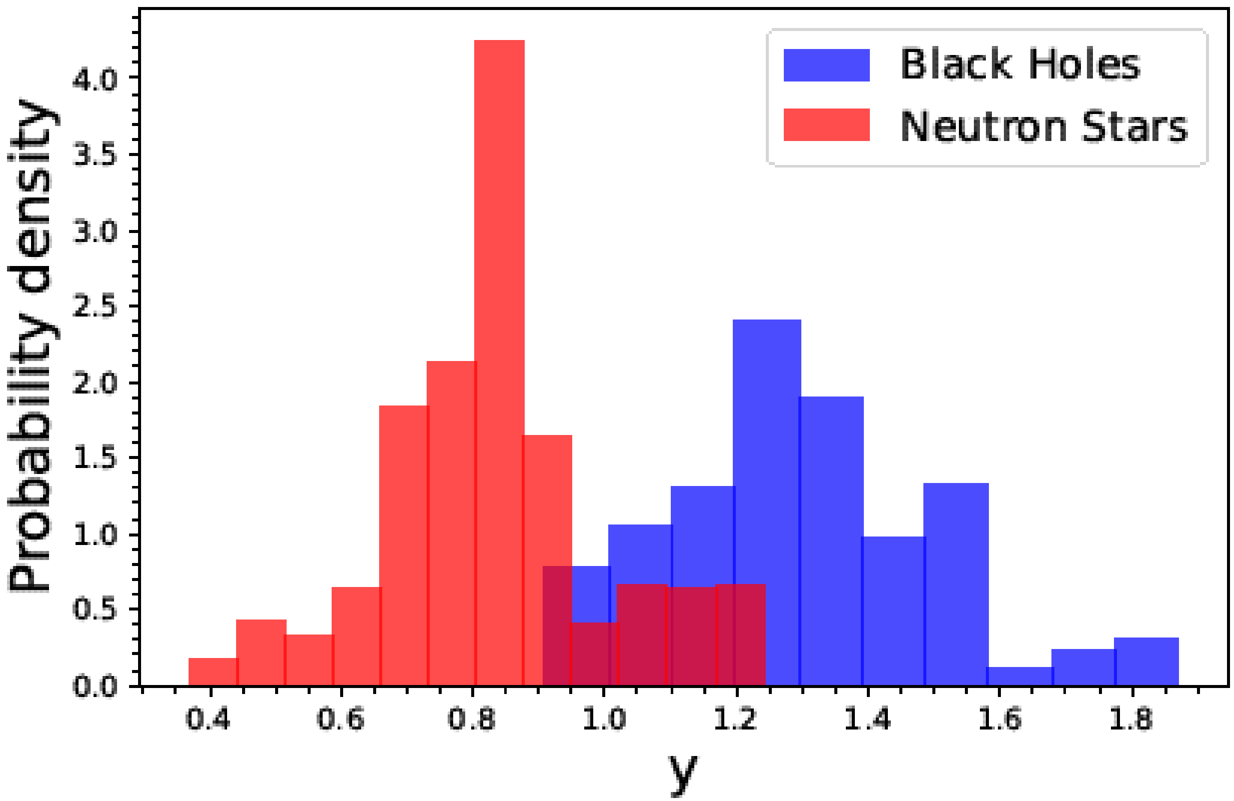

The mean of y for our NS sample is ≈ 0.83, and its 80 per cent quantile is $0.64-1.09$, while BHs are characterized by the mean of ≈ 1.3 and 80 per cent quantile of $1.03-1.55$.

A clear dichotomy: the probability for distributions to be the same is $\approx 1.1\times10^{-121}$ (from Kolmogorov–Smirnov test).

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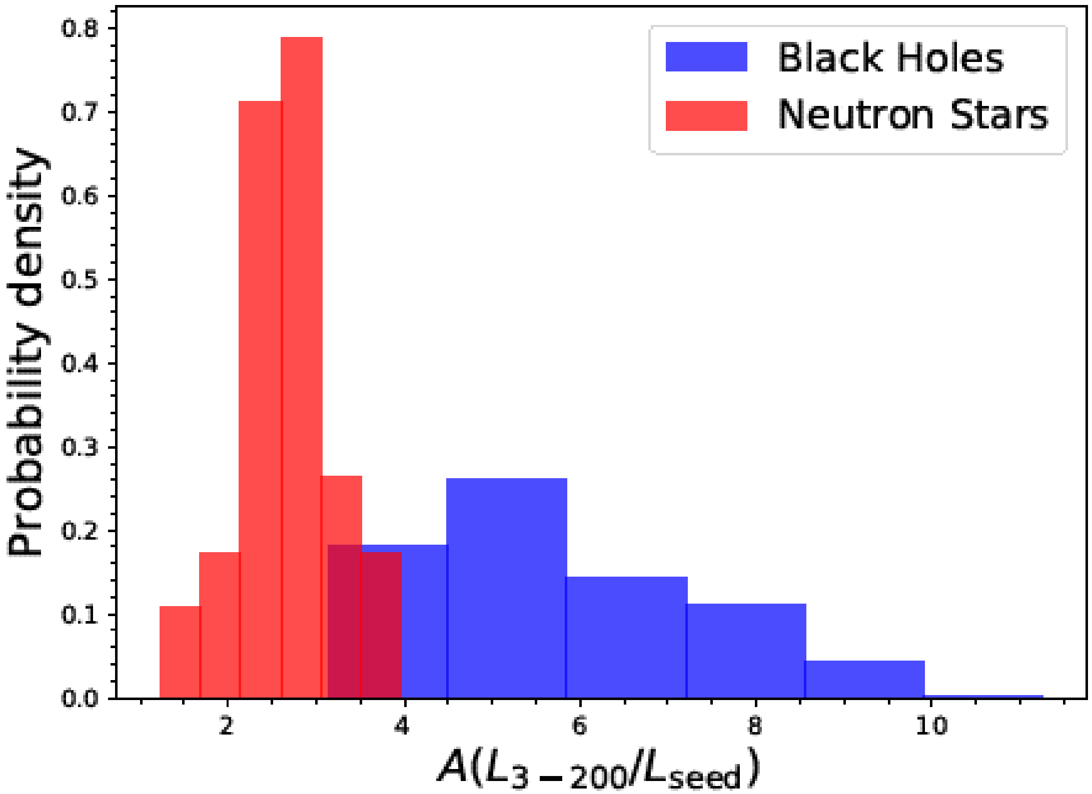

The mean of *A* for our NS sample is ≈ 2.7, and its 80 per cent quantile is $2.08 - 3.32$, while BHs are characterized by the mean of ≈ 5.8 and 80 per cent quantile of $3.94 - 8.17$.

A clear dichotomy: the probability for distributions to be the same is $\approx 2.2 \times 10^{-160}$ (from Kolmogorov–Smirnov test).

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4. Conclusion

Conclusion

We have found a clear dichotomy in the distributions of spectral parameters for black hole candidates and neutron stars, with the probability for distributions to be the same being $\sim \mathbf{10^{-160}}$ for one parameter.

Thus, we have distinguished the black hole candidates from neutron stars with an extremely high significance.

This is by far the most significant detection of the imprint of the event horizon on the X-ray spectra for stable stellar-mass black holes.

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Thank you!