BLACK HOLE PHYSICS

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Brief course of lectures at 18th APCTP Winter School on Fundamental Physics

Pohang,   January 20 -- January 28, 2014

3. Black Holes in Astrophysics

Black holes have very high efficiency of rest-mass-to-energy transformation

Black holes are now used as a natural engine model whenever it is required to explain large energy production in a small compact space region

How many black holes are in our Galaxy?

Total number of stars in our Galaxy is about 10^{11}. Estimated number of black holes in it is about $10^{8} - 10^{9}$. The number of neutron stars is up to 10 times larger .

Black hole concept in '60s

Final state of matter evolution

Exotic objects of stellar mass

Too small and dark to be observed


R.I.P.
Black Holes as Graves of Matter

Stellar mass Black Holes now

More than 20 stellar mass BH candidates are observed

All of them are X-ray sources in binaries

All except 4 are in our Galaxy

Name	P_{orb}(hr)	$f(M)/M_\odot$	M_{BH}
(GRO J)	5.1	1.19±0.02	3.7–5.0
LMC X–3	40.9	2.3±0.3	5.9–9.2
LMC X–1	93.82008	0.13±0.05	10.91± 1.41
(A)	7.8	2.72±0.06	8.7–12.9
(GRS)	6.8	3.17±0.12	3.6–4.7
(XTE J)	4.1	6.1±0.3	6.5–7.2
Nova Mus 91	10.4	3.01±0.15	6.5–8.2
(GS)	61.1^g	5.75±0.30	–
(4U)	26.8	0.25±0.01	8.4–10.4
(XTE J)	37.0	6.86±0.71	8.4–10.8
(XTE J)	7.7	2.73±0.56	–
(GRO J)	62.9	2.73±0.09	6.0–6.6
GX 339–4	42.1	5.8±0.5	–
Nova Oph 77	12.5	4.86±0.13	5.6–8.3
V4641 Sgr	67.6	3.13±0.13	6.8–7.4
(XTE J)	9.2	7.4±1.1	7.6–12.d
(GRS)	804.0	9.5±3.0	10.0–18.0
Cyg X–1	134.4	0.244±0.005	6.8–13.3
(GS)	8.3	5.01±0.12	7.1–7.8
V404 Cyg	155.3	6.08±0.06	10.1–13.4
M33 X-7	82.80	0.46±0.08	15.65±1.45
IC 10 X-1	34.40	7.64±1.26	23–33

This Table contains 22 confirmed black hole binary candidates. The column 1 gives name of the object. The orbital period of the binary, its mass function and the mass of the black hole candidate is given in columns 2, 3, and 4, respectively.

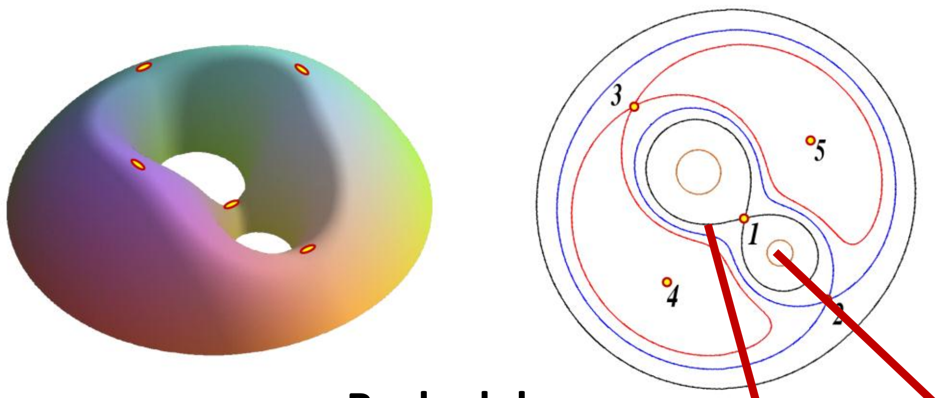
How to detect Black Holes?

Gravitational collapse will always occur on any star core over 3-5 solar masses, inevitably producing a black hole.

To identify an astrophysical object as a black hole candidate one needs first of all to ‘measure’ its mass. Such a measurement is possible, for example, when a black hole enters a binary system. Approximately 1/3 of the star systems in the Milky Way are binary or multiple. The rest 2/3 are single stars. A heavier companion in the stellar binary has faster evolution than the lighter one. If the mass of the heavy star is large enough a system may become a *black hole binary*.

Most of the known candidates for stellar mass black holes were discovered in such systems. The motion of a star companion in the binary can be detected. This gives information about the mass of the black hole candidate.

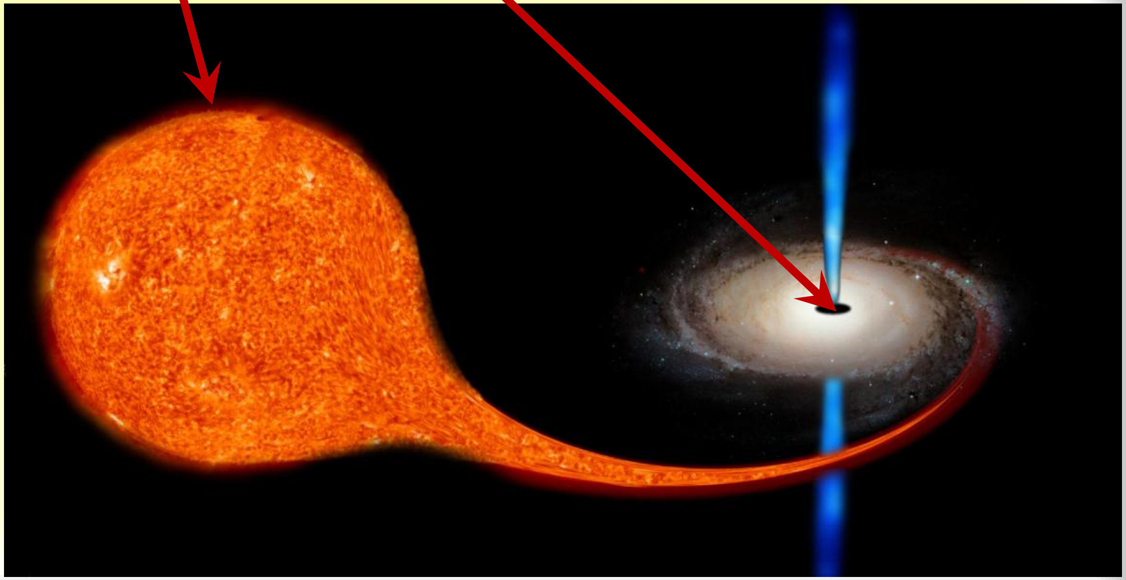
A black hole in a close binary system. A star companion emits matter which is falling into a black hole. This flux is large when the size of the star is comparable with the size of the Roche lobe.

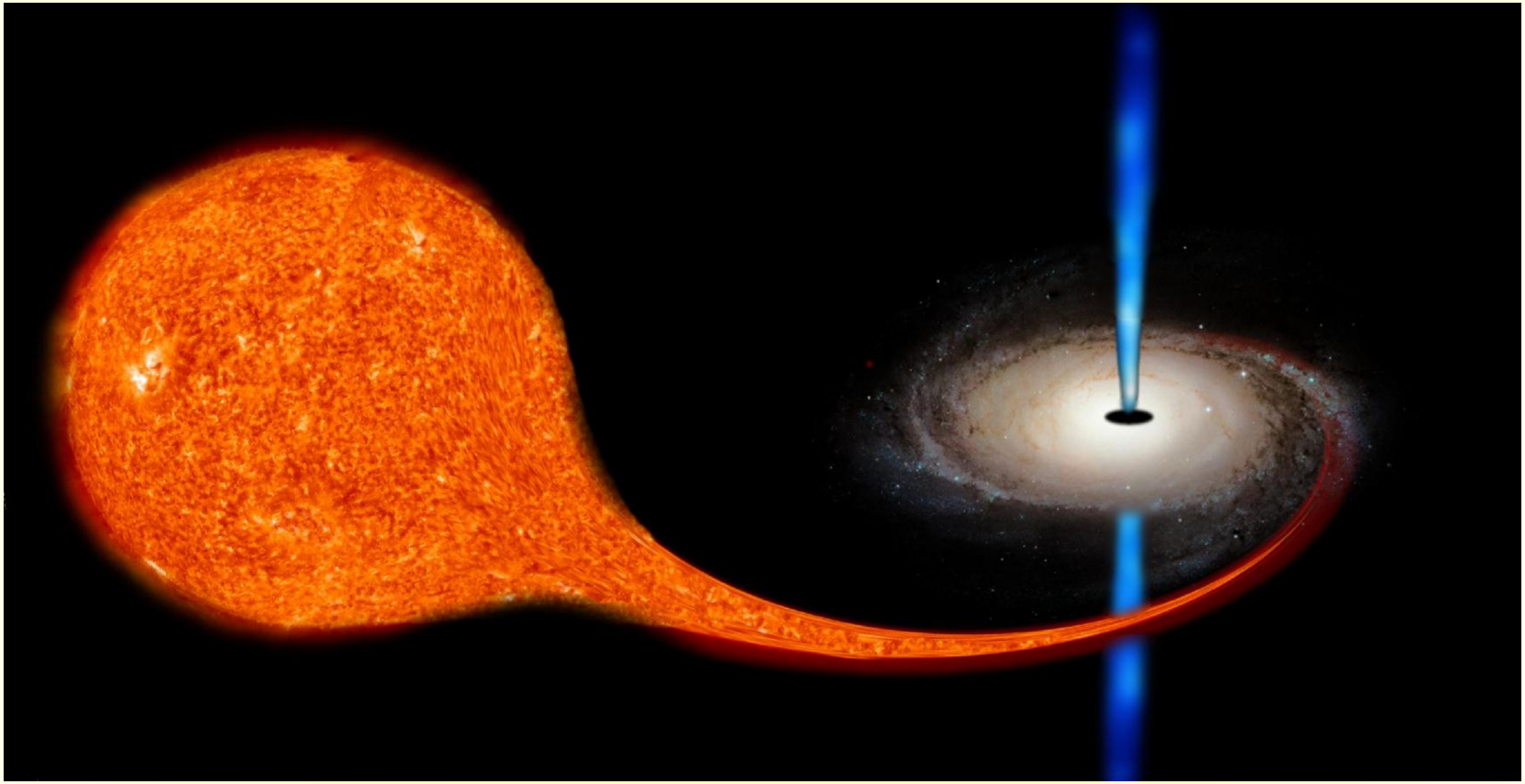


Roche lobe

The accreting matter has the angular momentum and forms an accretion disk around the black hole. Transition from the outer to inner orbits occurs as a result of friction.

The released energy is partly transformed into the thermal energy which makes the disk hot and emitting X-rays. Such a system can be observed as the X-ray binary. The jet, which is a collimated beam of the relativistic plasma, is emitted by some of black holes.





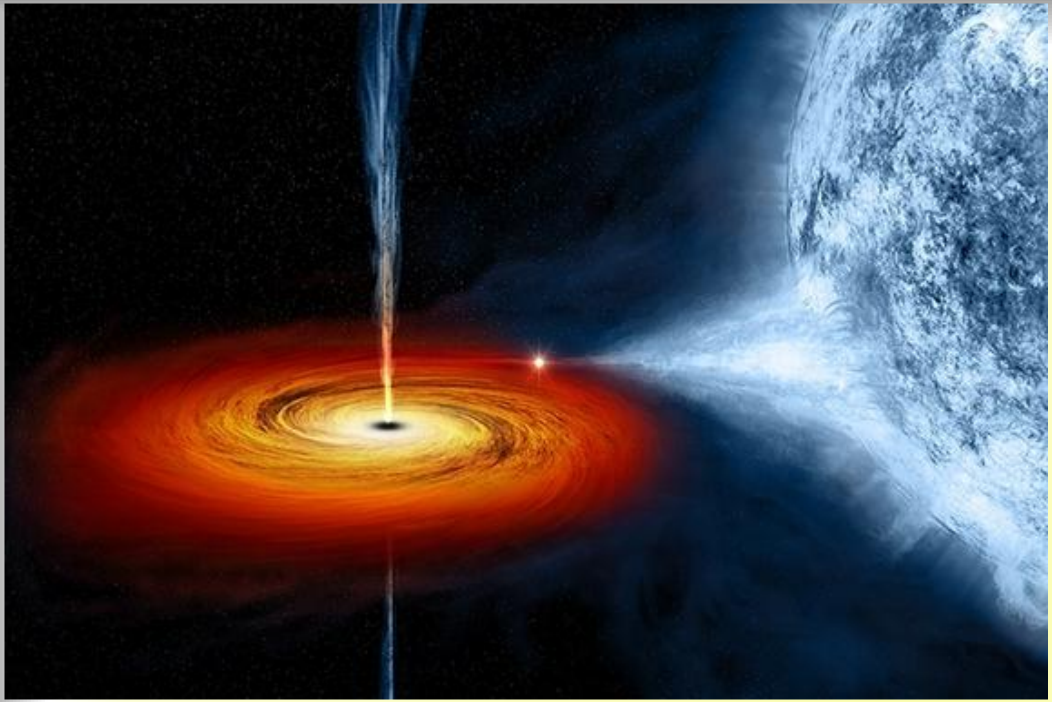
Persistent BHs ($Syg\ X-1,\ LMC\ X-1, LMC\ X-3$)

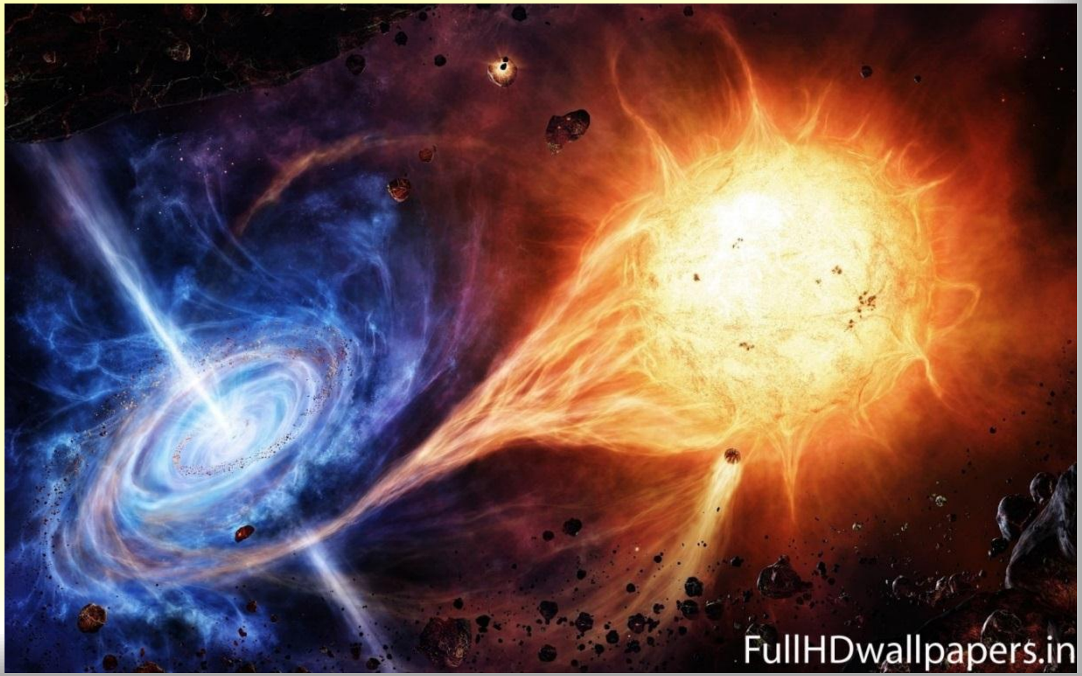
Transient BHs

Black Hole binaries

The first discovered black hole binary candidate was Cygnus X-1. This is a galactic X-ray source in the constellation Cygnus. It was discovered in 1964. It is one of the strongest X-ray sources seen from Earth. It is persistently bright in X-rays but shows variability on timescales of seconds. Its companion was identified as a blue super-giant variable star designated HDE 226868. A size of this binary is about 0.2 AU.

Following Cyg X-1, the second discovered black hole binary candidate was LMCX-3. This is one of the brightest X-ray sources in the Large Magellanic Cloud, with luminosity $>10^{38}$ erg/s.

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