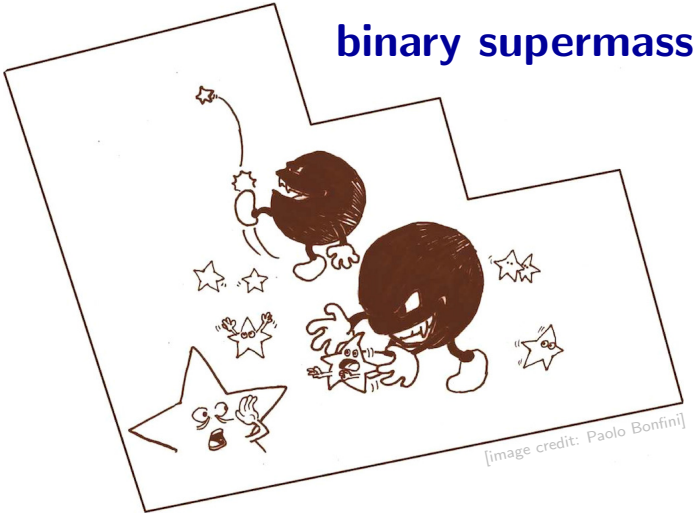
Life and adventures of binary supermassive black holes

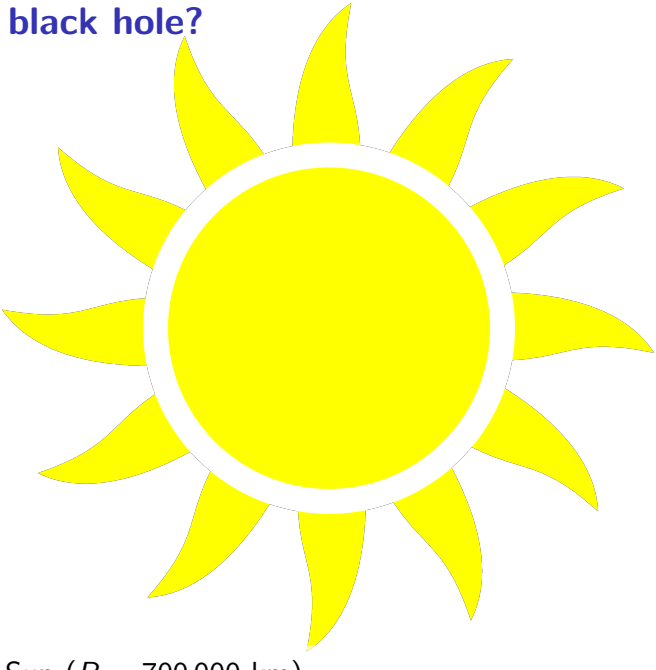


HST captures a binary SMBH kicking stars out of a galaxy

Eugene Vasiliev

Edinburgh, December 2023

What is... a black hole?



Sun ($R = 700\,000$ km)

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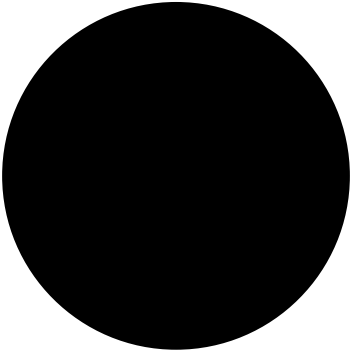
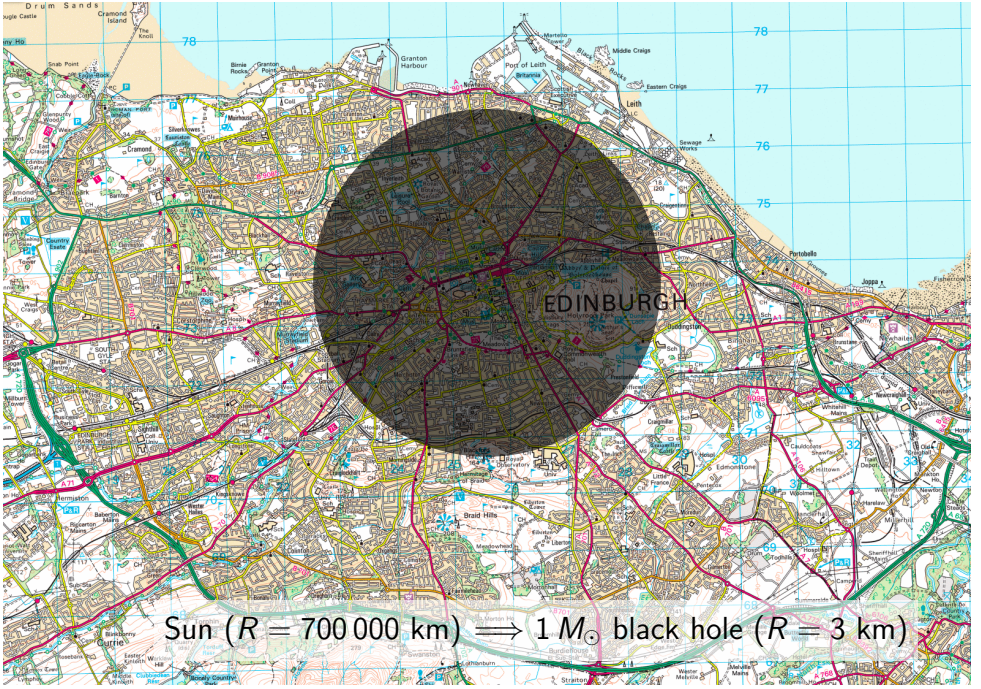


Sun ($R = 700\,000$ km) $\Longrightarrow$ 1 $M_\odot$ black hole ($R = 3$ km)

What is... a black hole?



What is... a supermassive black hole (SMBH)?

$1\,M_\odot \;\Rightarrow\; R = 3$ km

for black holes, $R \propto M$

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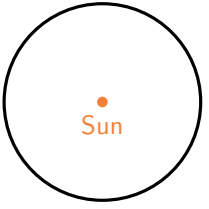

Sagittarius A*
(Milky Way centre)

$M = 4.3$ million $M_\odot$
$R = 13$ million km

for black holes, $R \propto M$

Mercury's orbit

What is... a supermassive black hole (SMBH)?

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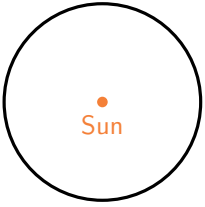

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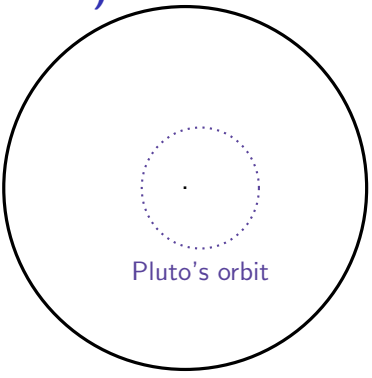


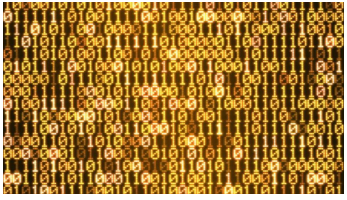
black hole in M 87
(central galaxy of the Virgo cluster)

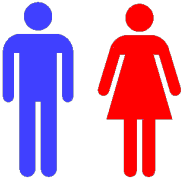
$M = 6$ billion $M_\odot$
$R = 18$ billion km

for black holes, $R \propto M$

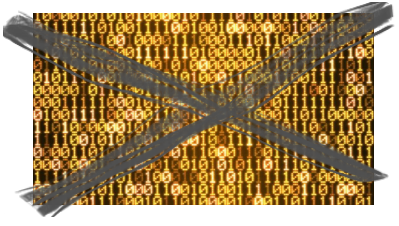
Mercury's orbit

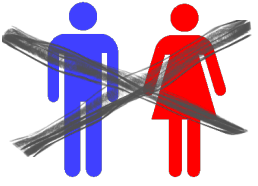
What is... a binary SMBH?

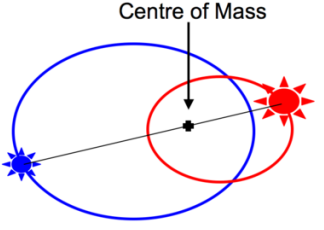




What is... a binary SMBH?





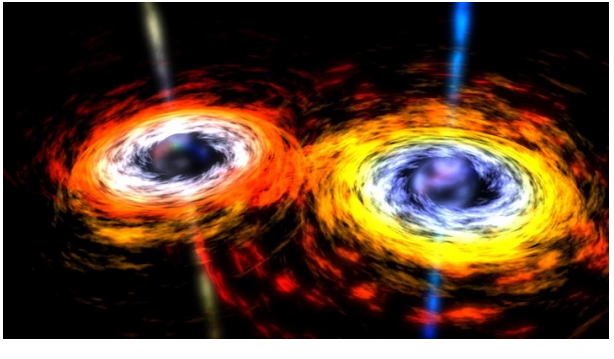


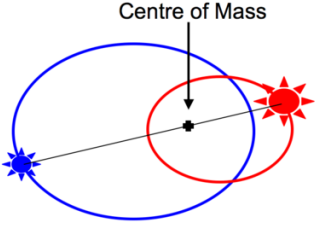
binary stellar system

What is... a binary SMBH?

– two SMBHs orbiting each other!

(and not just roaming somewhere in the same galaxy)





binary stellar system

What black holes are and are not?

cosmic villains

vacuum cleaners

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cosmic villains

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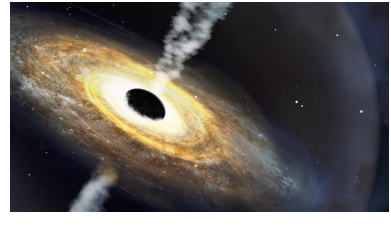
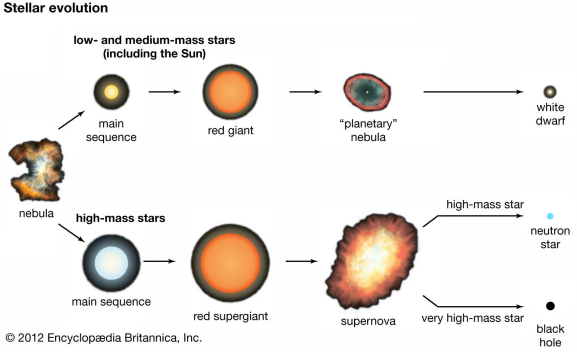


gravitating masses

(possibly accreting surrounding gas, which is heated by friction)

How do black holes form?



Stellar black holes
($M \simeq 5 - 100\, M_\odot$)

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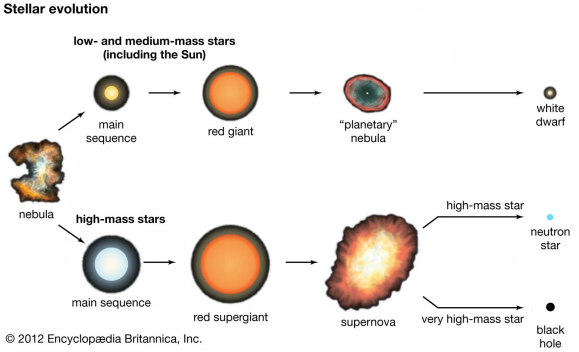

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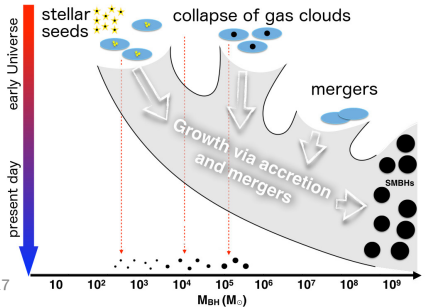
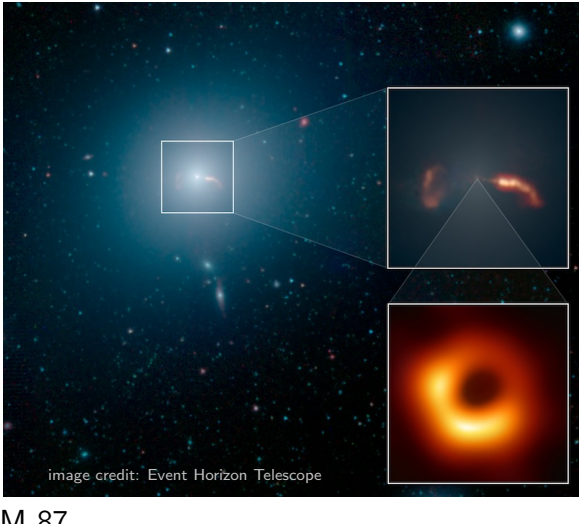


Supermassive black holes
($M \simeq 10^5 - 10^{10}\, M_\odot$)

adapted from Mezcua 2017

Where do supermassive black holes (SMBH) live?



M 87
SMBH mass: $6 \times 10^9\, M_\odot$

SMBHs are found at the centres of most galaxies!

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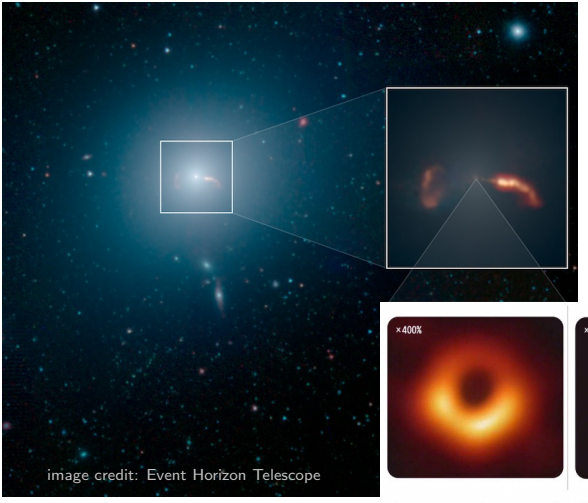

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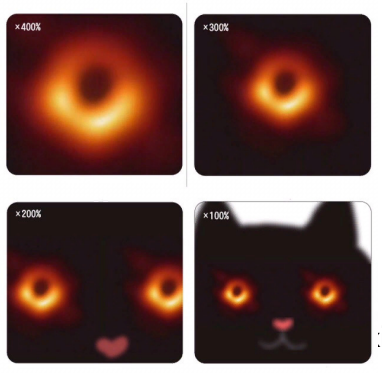

SMBHs are found ies!

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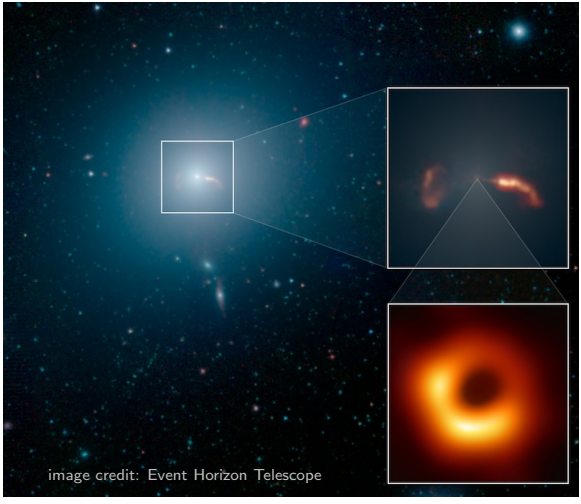

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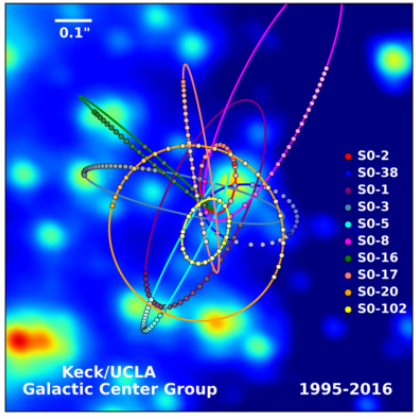
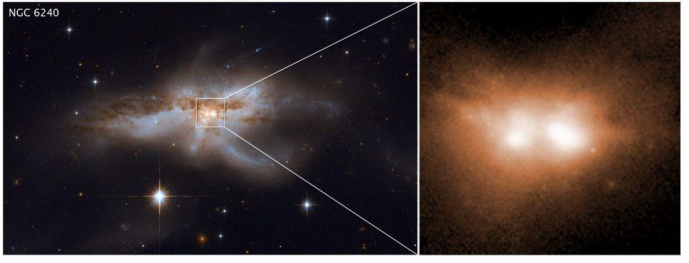
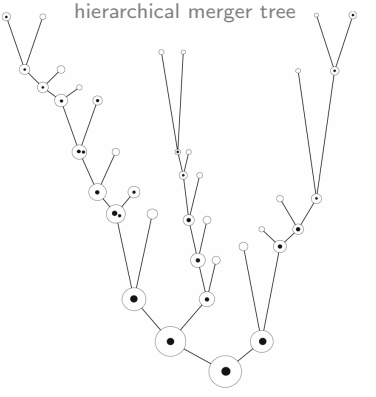


Milky Way (Sgr A*)
mass: $4 \times 10^6\, M_\odot$

SMBHs are found at the centres of most galaxies!

How do binary SMBHs come about?

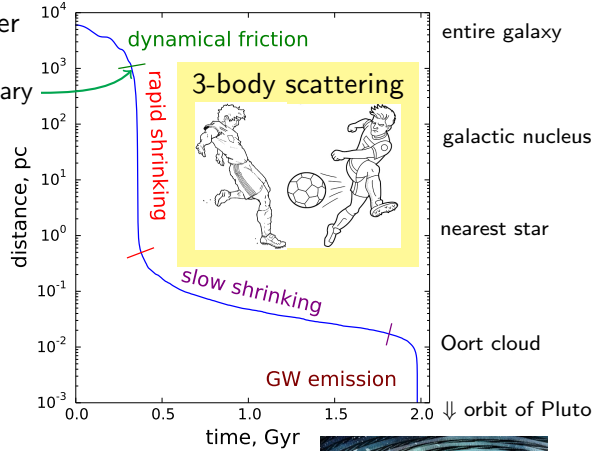




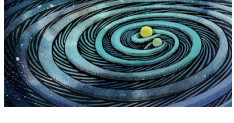
Life path of a typical binary SMBH

galaxy merger

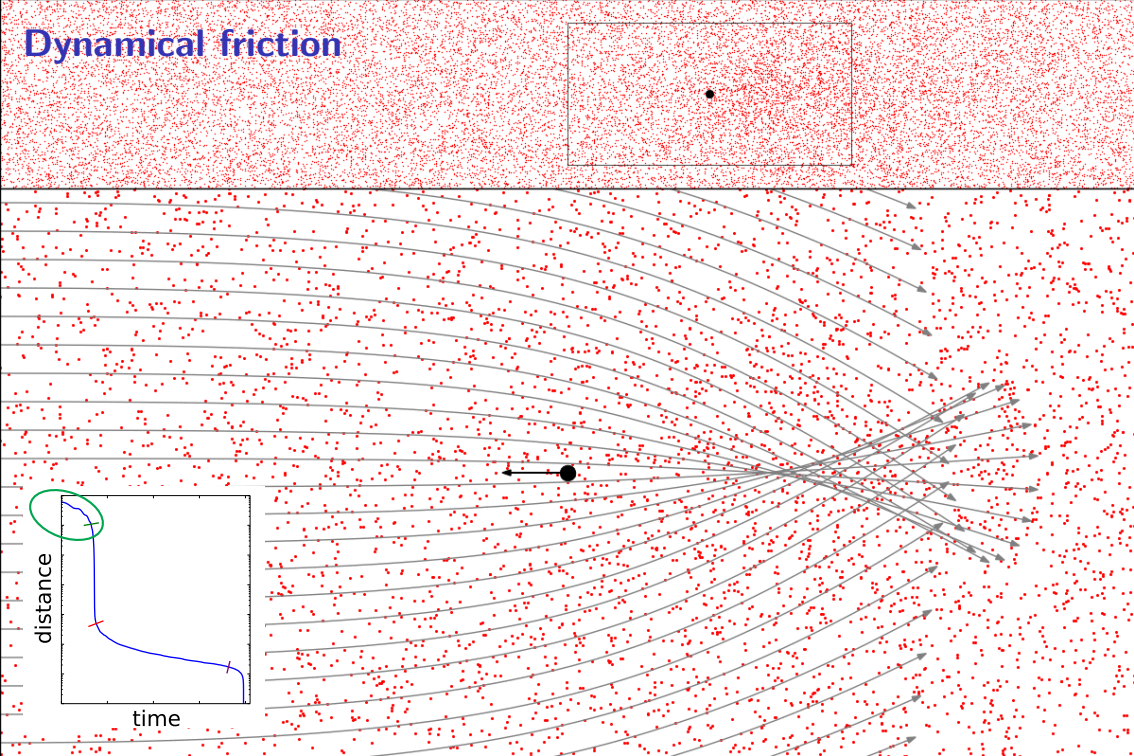
formation of the binary



SMBH coalescence



Dynamical friction



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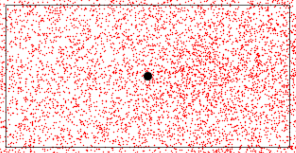
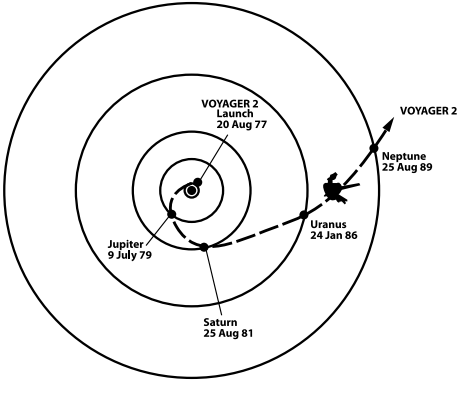


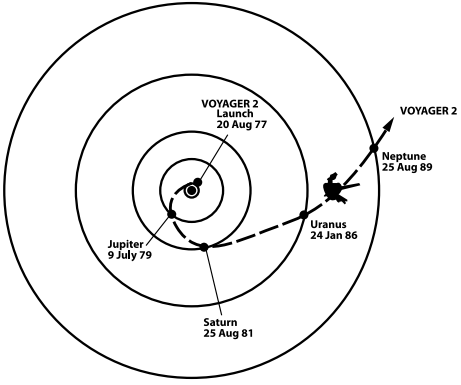
Gravitational slingshot



interplanetary transport

Gravitational slingshot

ejected stars extract energy
from the binary SMBH ⇒
its orbit shrinks



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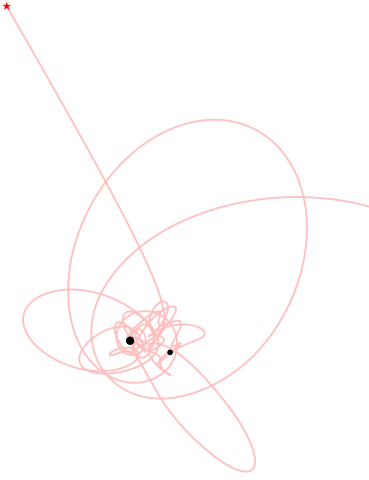
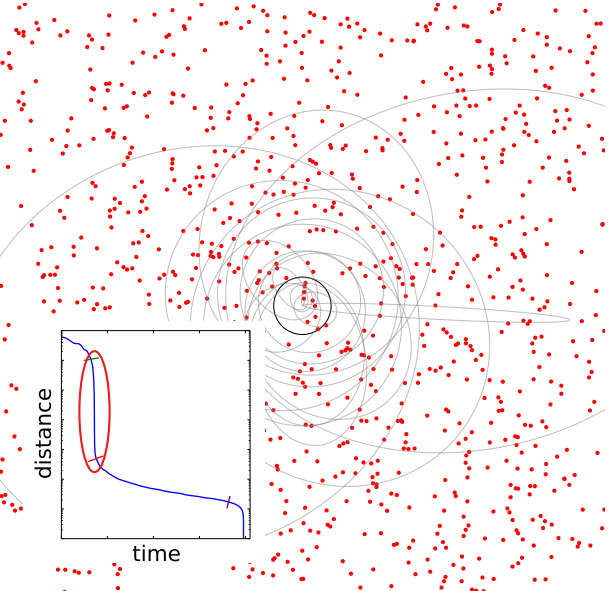


3-body scattering

Shrinking of the binary



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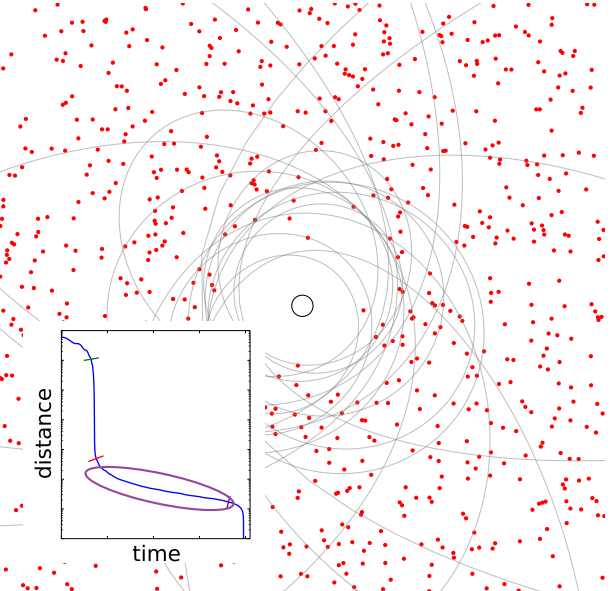
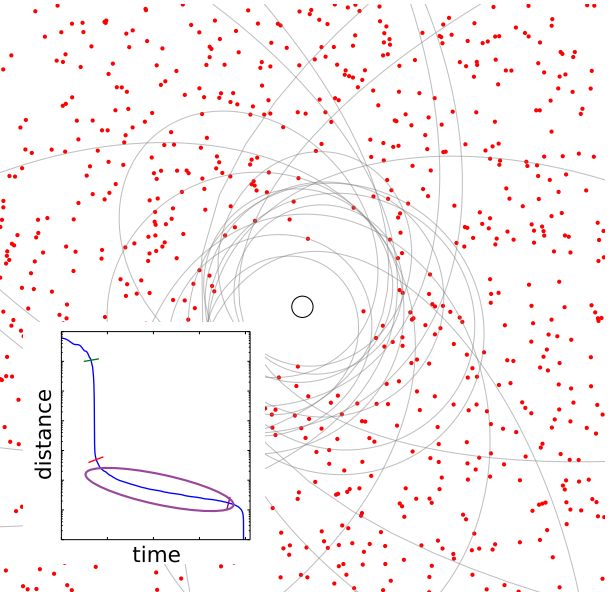


Shrinking of the binary

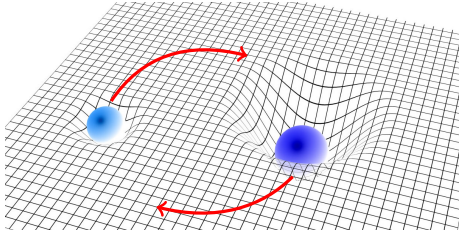
The final-parsec problem!
(stalling of the binary shrinking at ~ 1 pc)



Energy loss to gravitational waves

An object moving on a curved trajectory emits gravitational waves, which carry away energy.

Rate of orbital shrinking rapidly accelerates as the binary orbit becomes smaller and its orbital velocity approaches speed of light.



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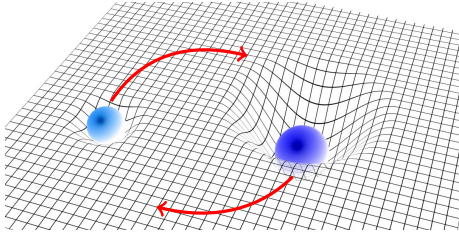

It is analogous to synchrotron radiation emitted by charged particles circulating in the Large Hadron Collider.

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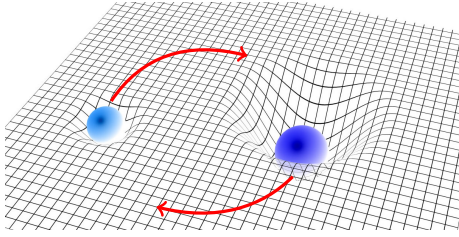
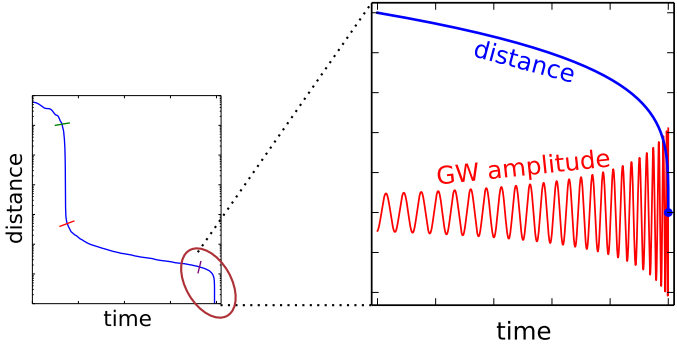
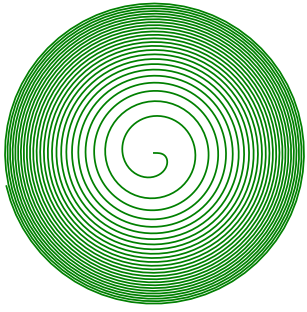
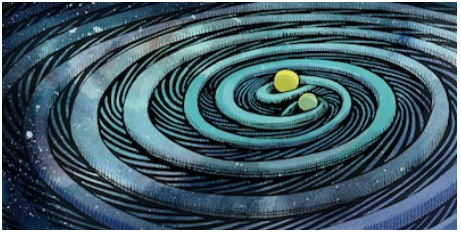
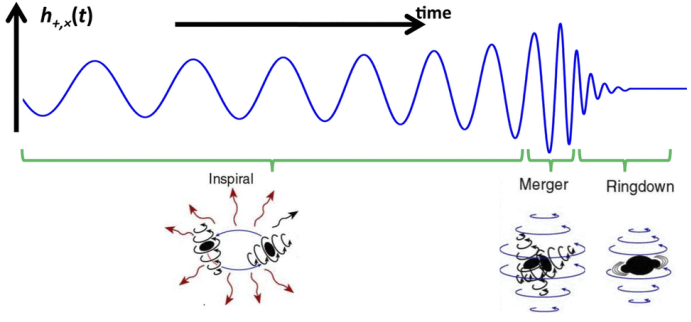






Final coalescence





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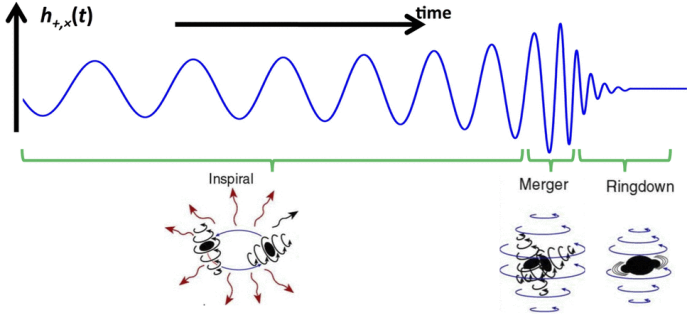
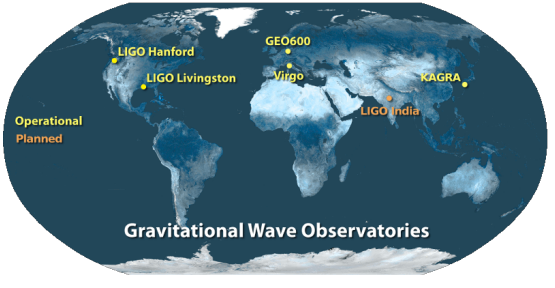


Gravitational-wave observatories

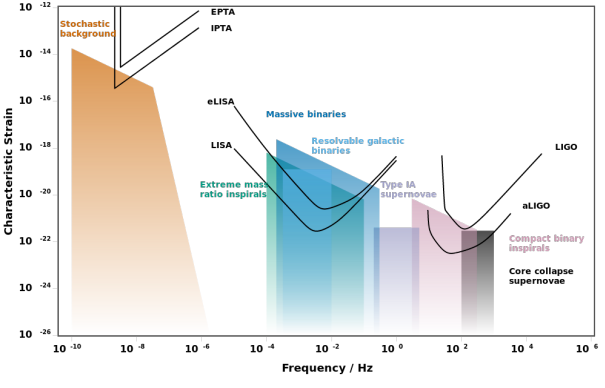



KAGRA (Japan)


LIGO–Livingston (LA, USA)

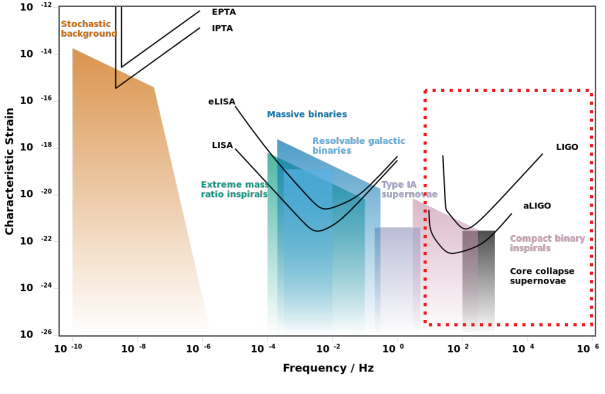

VIRGO (Italy)

Gravitational-wave observatories



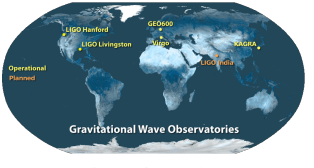
SMBH $10^6\,M_\odot$ stellar BH $10\,M_\odot$

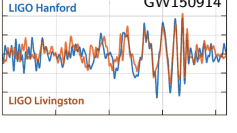
Gravitational-wave observatories



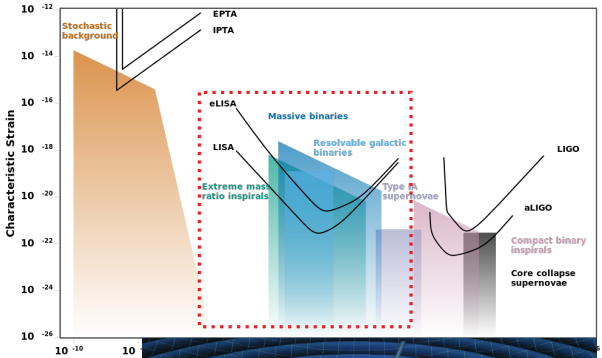
SMBH $10^6\,M_\odot$ stellar BH $10\,M_\odot$

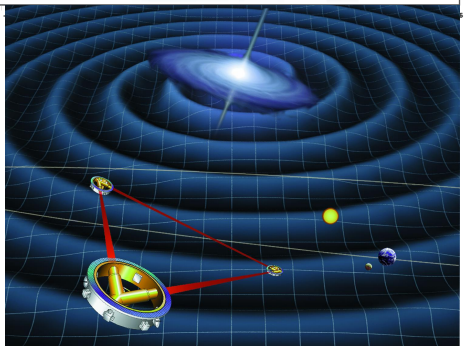
ground-based observatories

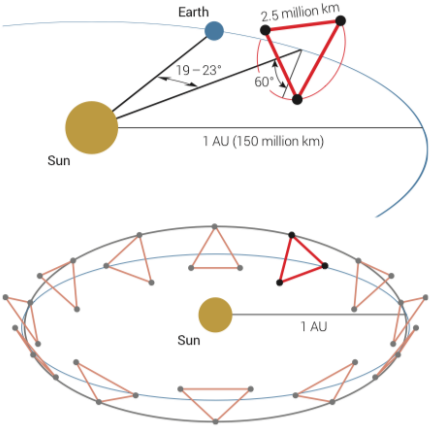




Gravitational-wave observatories in space





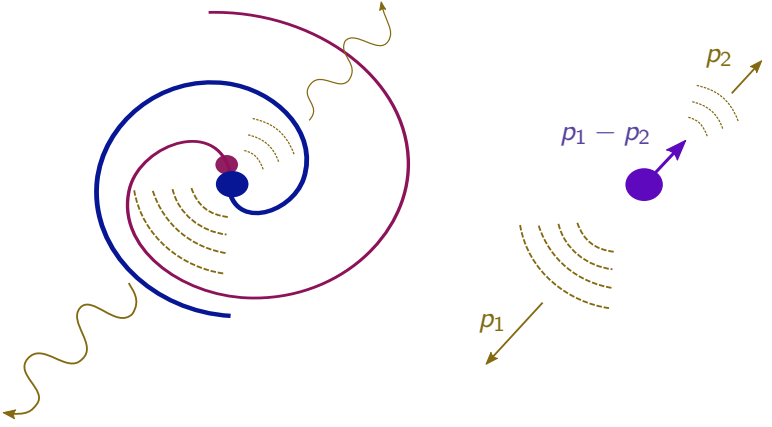


LISA space mission (ESA, 2030s)

Final handwave

Anisotropic emission of gravitational waves

$\Longrightarrow$ recoil velocity $\sim 100 - 1000$ km/s



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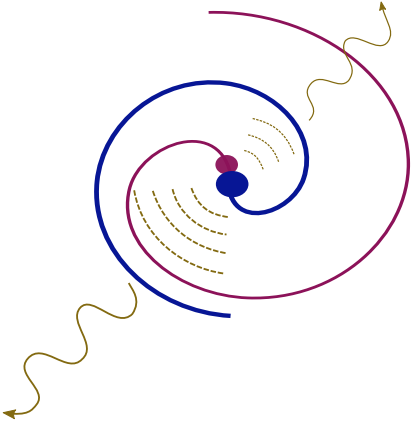
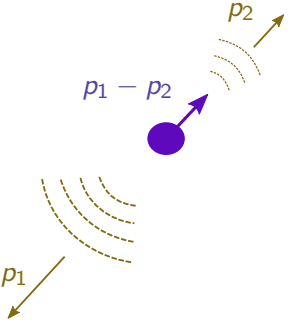
$\Longrightarrow$ recoil velocity $\sim 100 - 1000$ km/s





Summary: life cycle of binary SMBHs