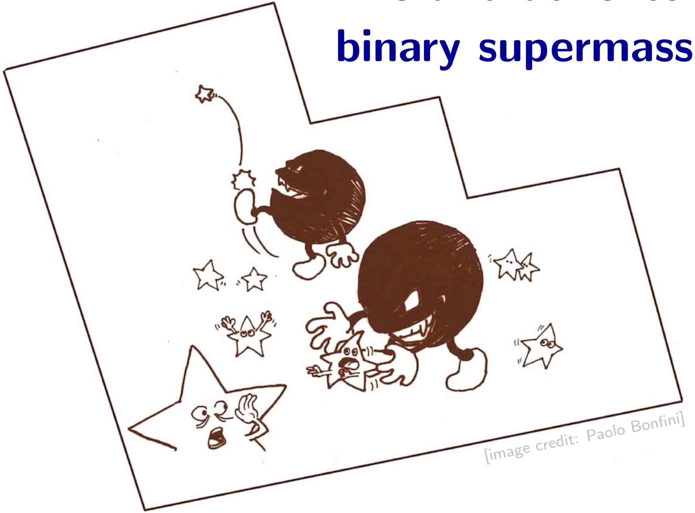
Life and adventures of binary supermassive black holes



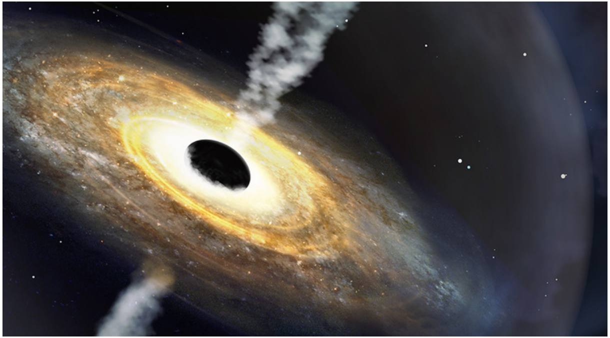
Eugene Vasiliev

Institute of Astronomy

Cambridge, March 2021

HST captures a binary SMBH kicking stars out of a galaxy

What is a supermassive black hole (SMBH)?



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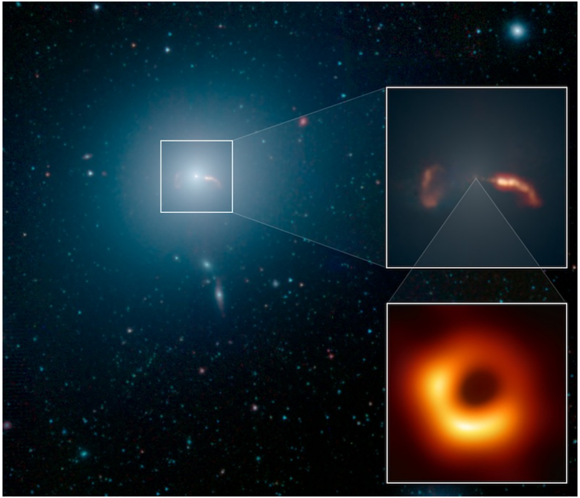

M 87

SMBH mass: $6 \times 10^9\, M_\odot$, radius: $3\times$ Pluto's orbit

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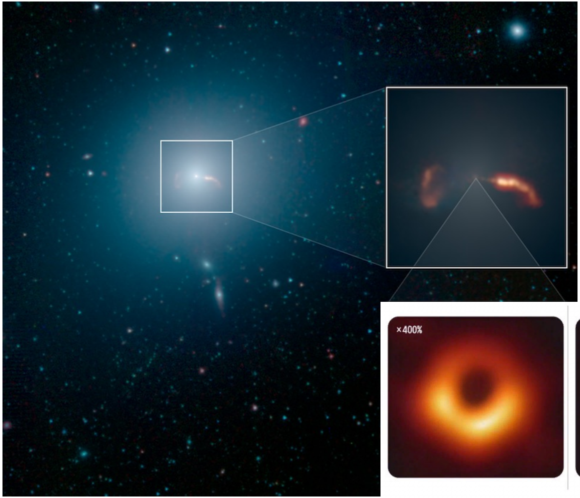

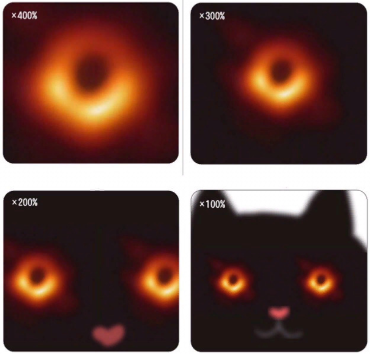

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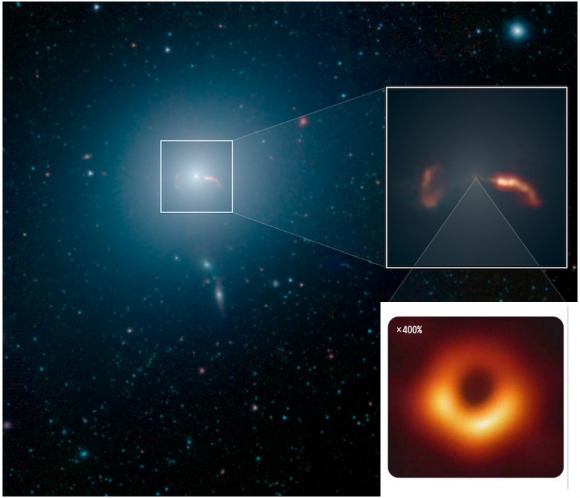

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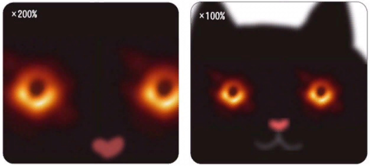
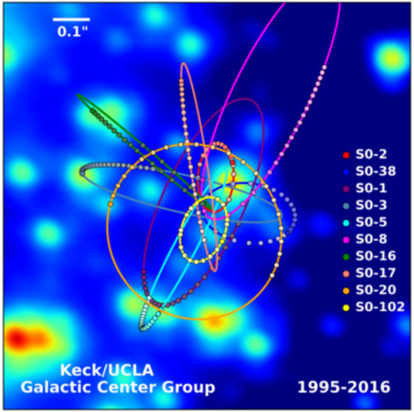




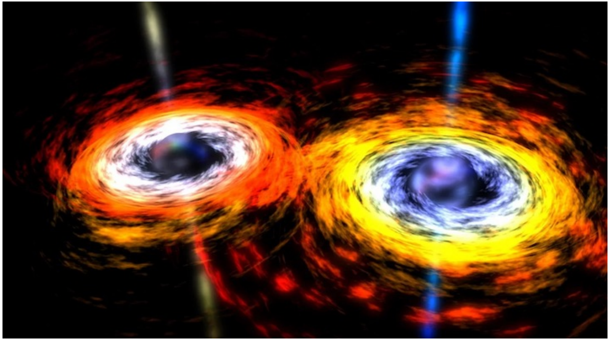
Milky Way (Sgr A*)

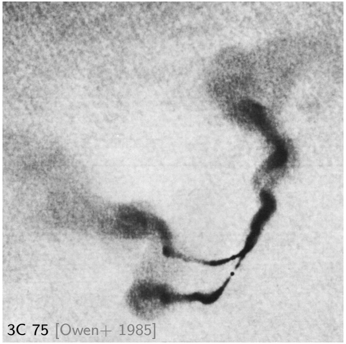
mass: $4 \times 10^6\, M_\odot$

What is a binary SMBH?

– two SMBHs orbiting each other!

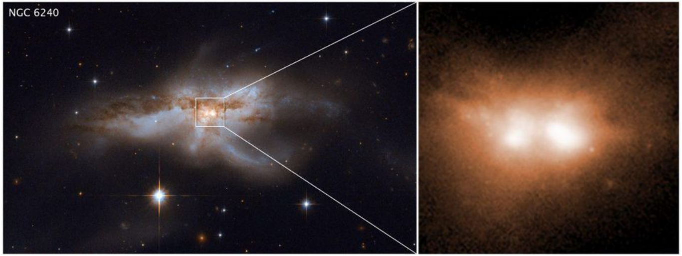
(and not just roaming somewhere in the same galaxy)

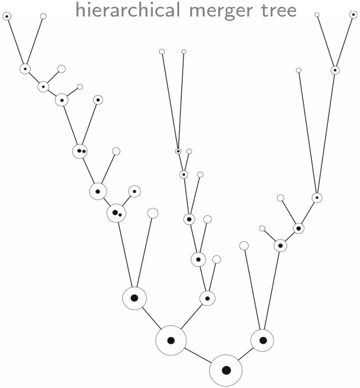




3C 75 [Owen+ 1985]

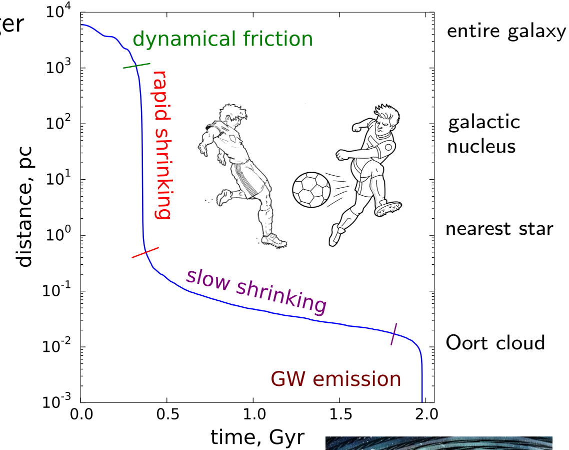
How do they come about?





Life path of a typical binary SMBH

galaxy merger



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Massive black hole binaries in active galactic nuclei

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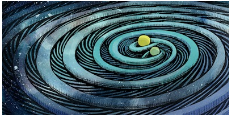
SMBH coalescence



Dynamical friction

DYNAMICAL FRICTION

S. CHANDRASEKHAR
Yerkes Observatory
Received January 7, 1943

ABSTRACT

In this paper it is shown that a star must experience *dynamical friction*, i.e., it must suffer from a systematic tendency to be decelerated in the direction of its motion. This dynamical friction which stars experience is one of the direct consequences of the fluctuating force acting on a star due to the varying complexion of the near neighbors. From considerations of a very general nature it is concluded that the *coefficient of dynamical friction*, η, must be of the order of the reciprocal of the time of relaxation of the system. Further, an independent discussion based on the two-body approximation for stellar encounters leads to the following explicit formula for the coefficient of dynamical friction:

$$\eta = 4\pi m_1 \left(m_1 + m_2\right) \frac{G^2}{v^3} \log_e \left[\frac{D_0 \overline{|u|^2}}{G(m_1 + m_2)}\right] \int_0^v N(v_1) dv_1 \,,$$

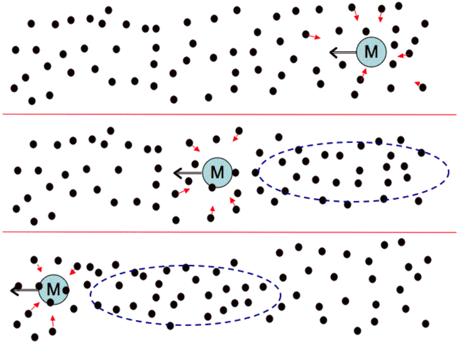
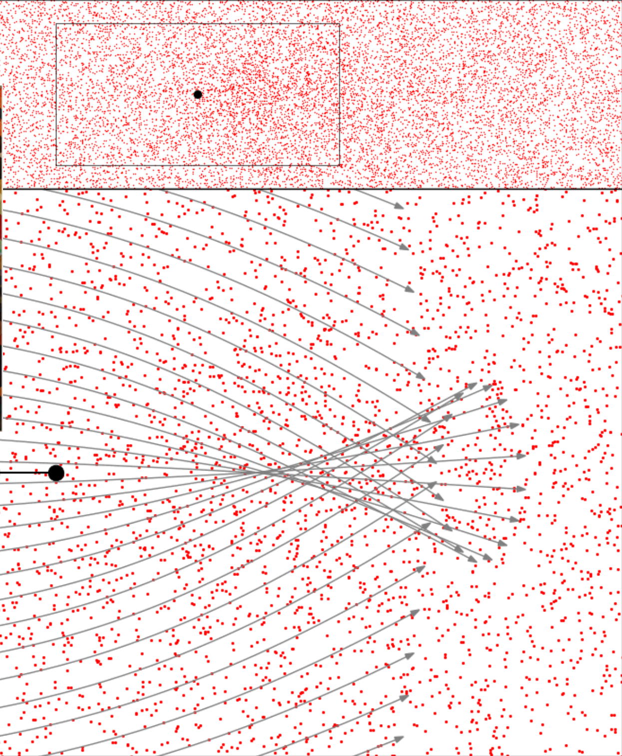
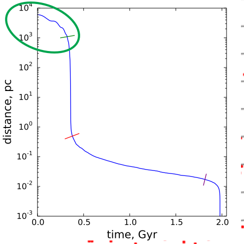


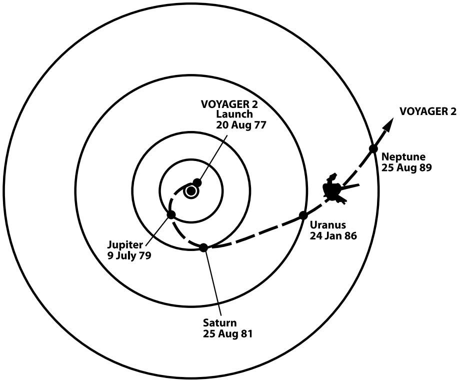
illustration by M.Whittle

Dynamical friction

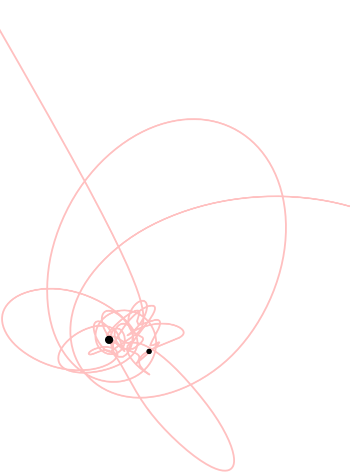




Gravitational slingshot

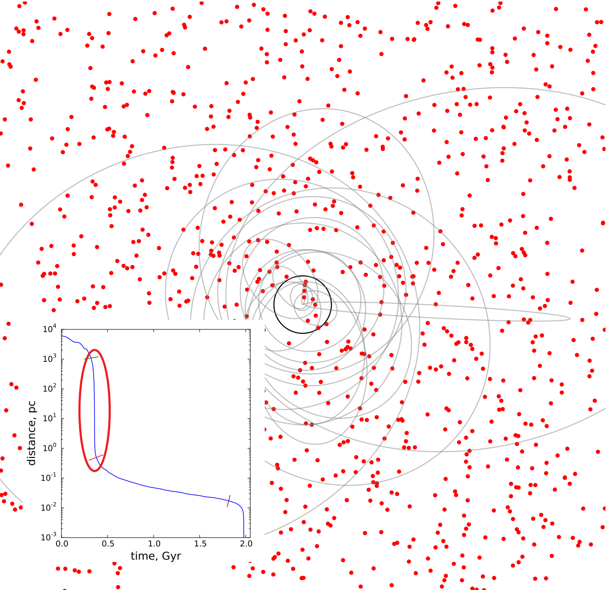


interplanetary transport



3-body scattering

Shrinking of the binary



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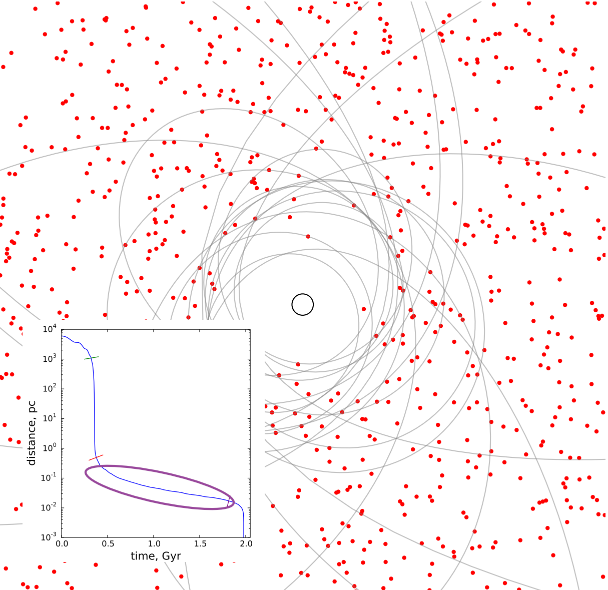
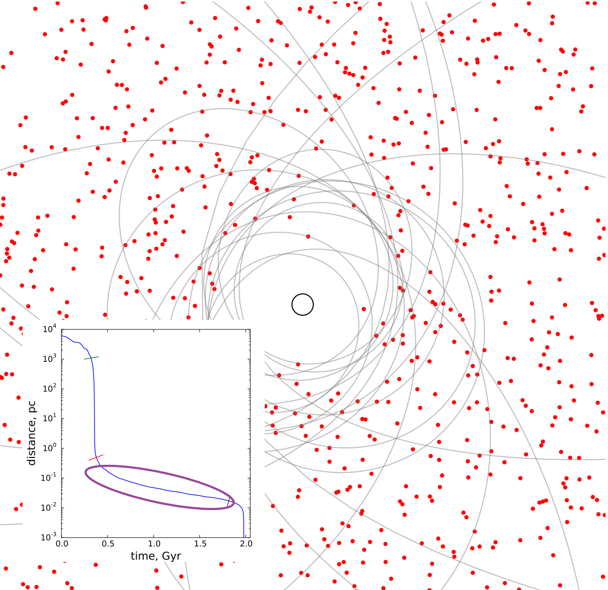


Shrinking of the binary

The final-parsec problem!

(stalling of the binary shrinking at ~ 1 pc)

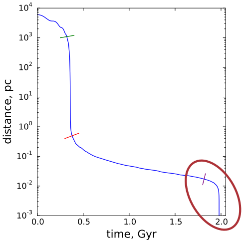


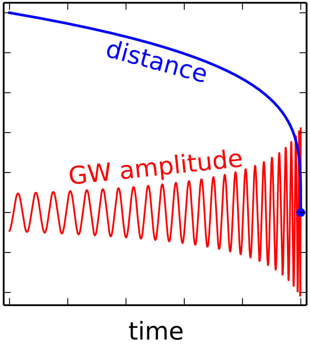
Energy loss to gravitational waves

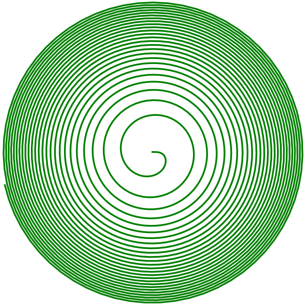
rate of orbital shrinking: $\dfrac{dr}{dt} \propto -\dfrac{1}{r^3}$

$\Longrightarrow$ orbital radius: $r \propto (t_{\text{end}} - t)^{1/4}$

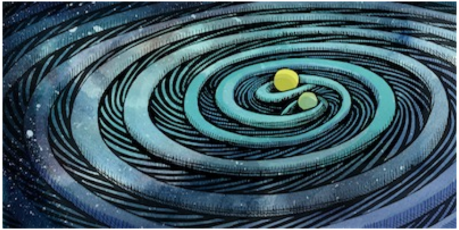
when $r \lesssim 0.01$ pc, the binary merges in $\lesssim 10^9$ yr

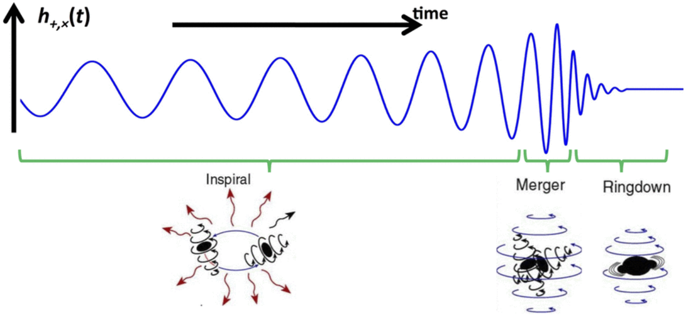






Final coalescence





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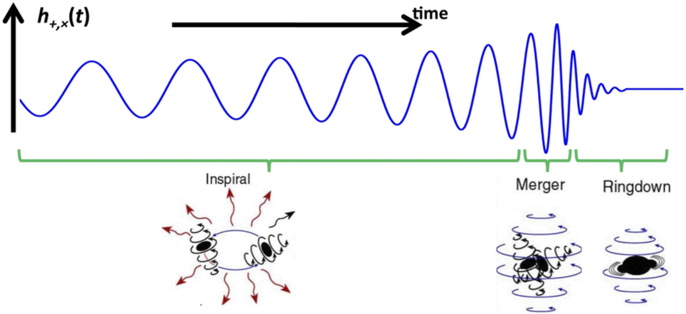

Gravitational-wave observatories

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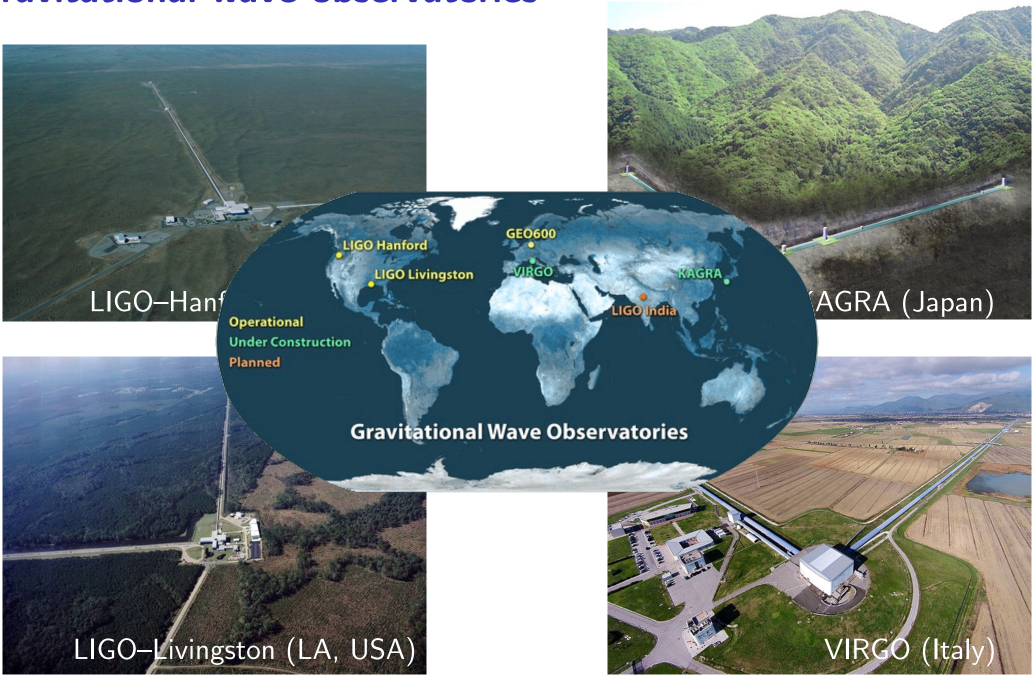
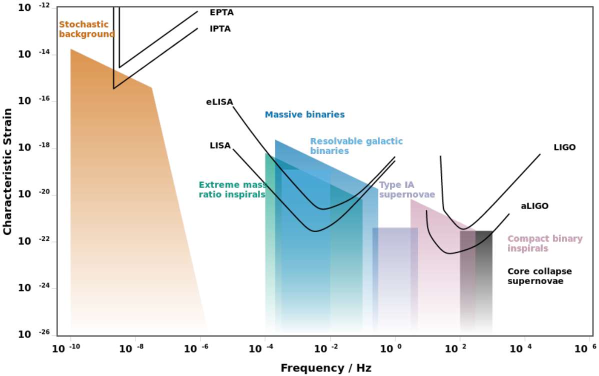
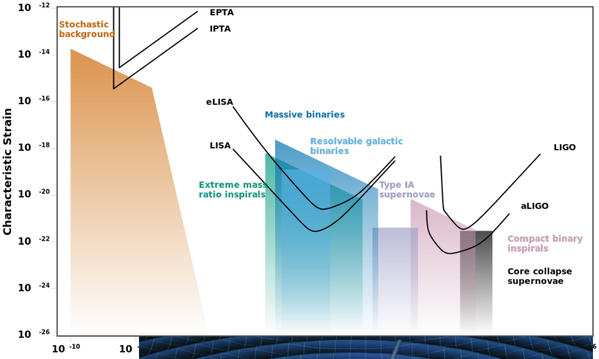


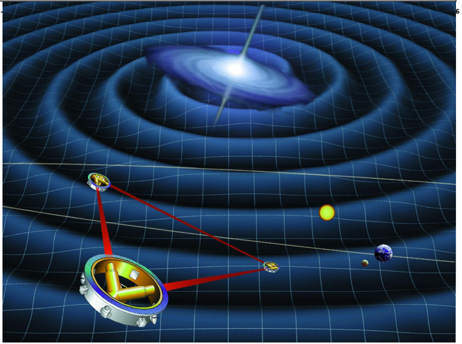
Gravitational-wave observatories in space

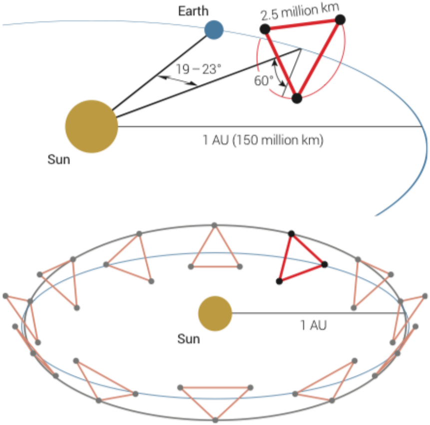


SMBH $10^6\ M_\odot$ stellar BH $10\ M_\odot$

Gravitational-wave observatories in space





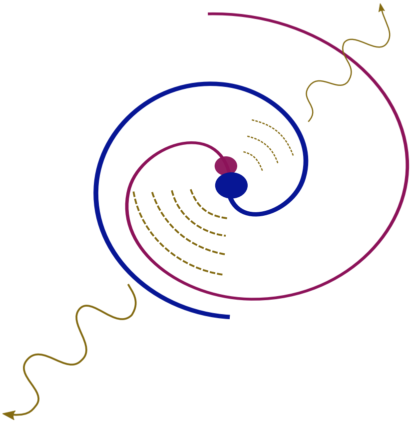


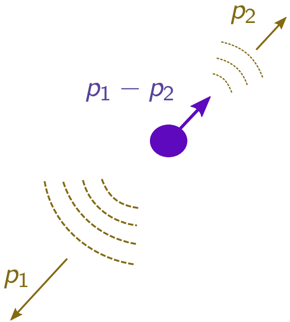
LISA space mission (ESA, 2030s)

Final handwave

Anisotropic emission of gravitational waves

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





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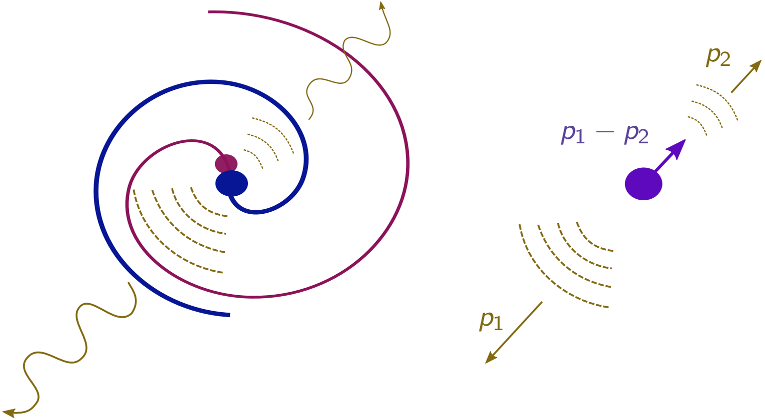

Summary: life cycle of binary SMBHs