



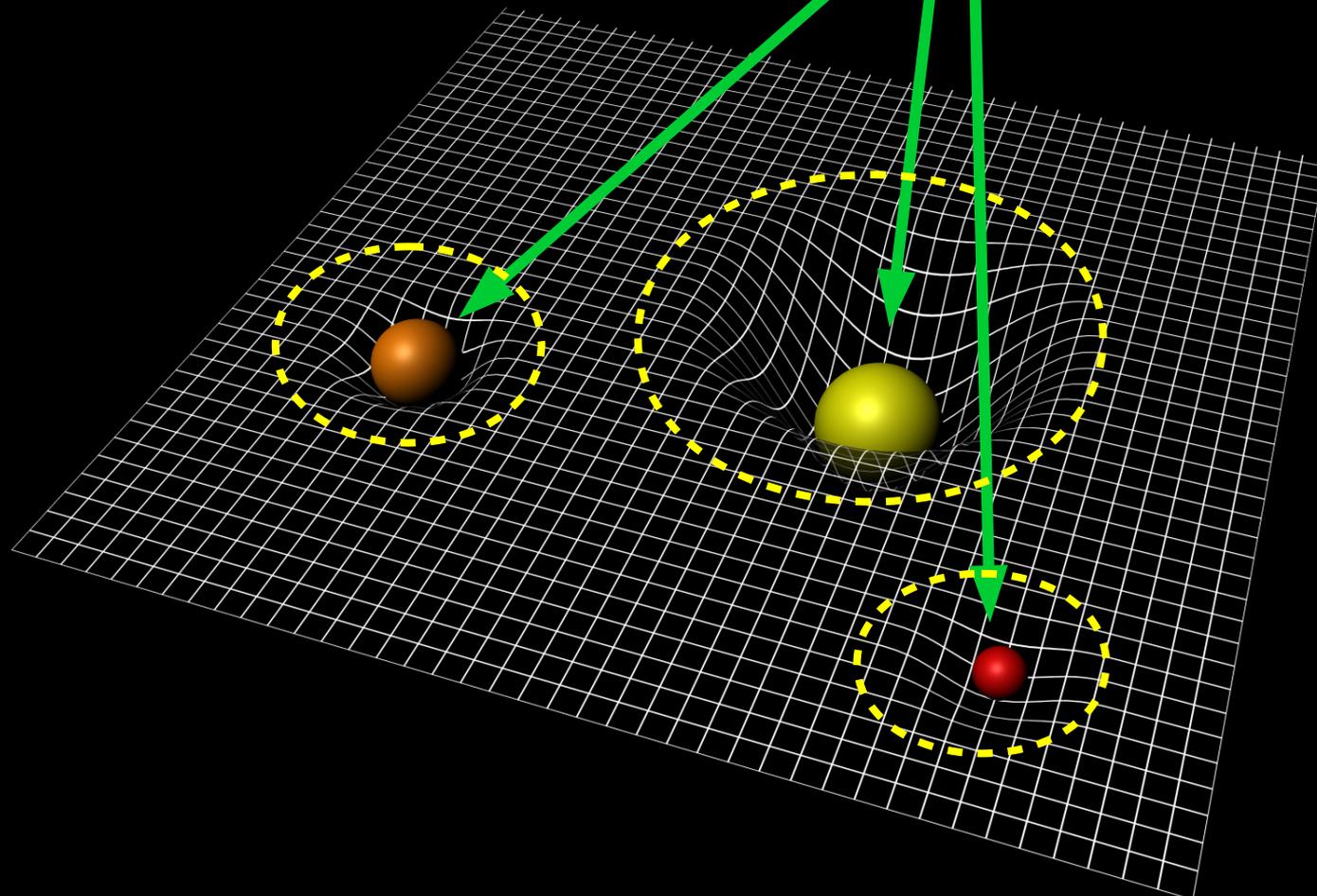
Challenging your imagination:

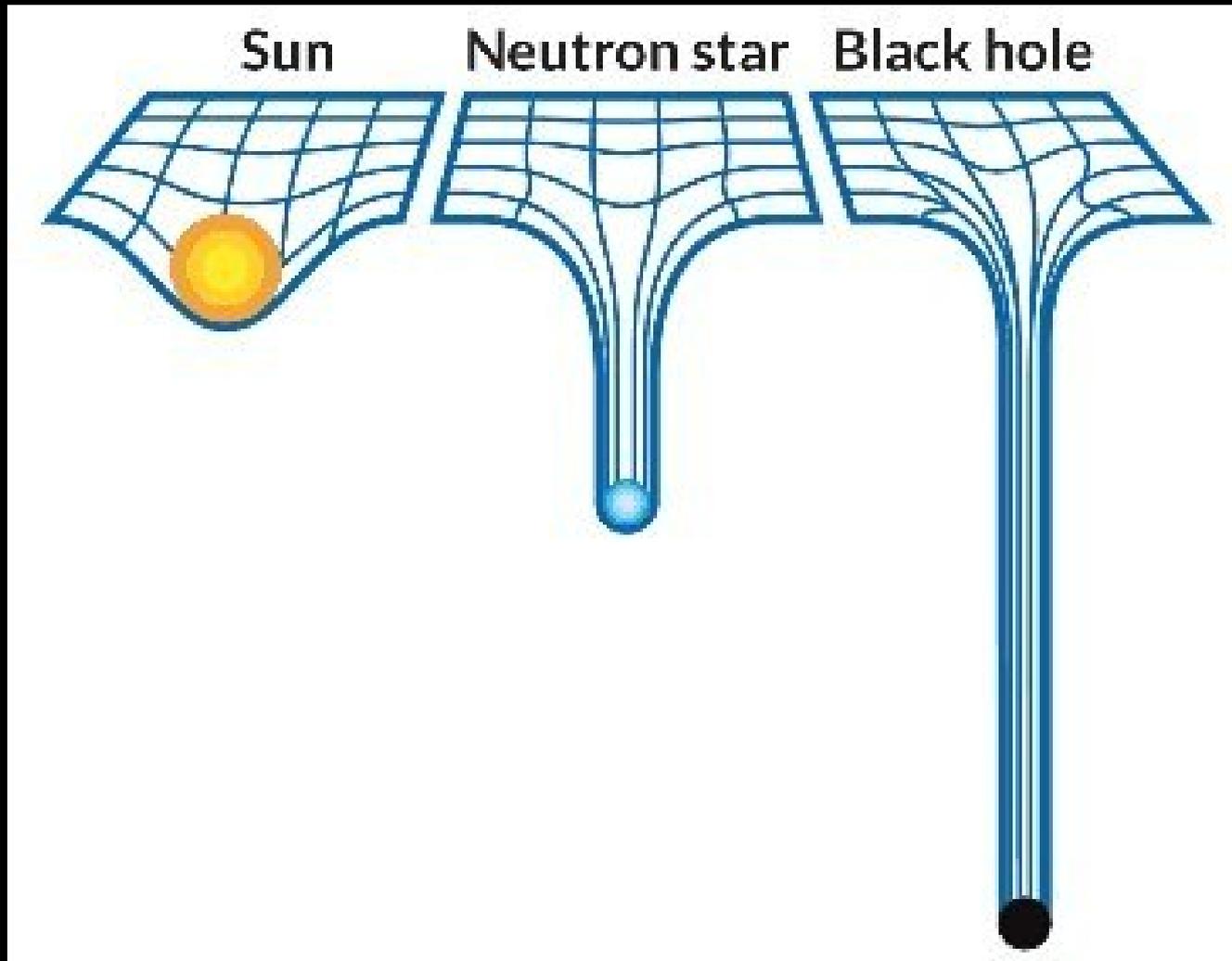
# **SUPERMASSIVE BLACK HOLES**

Alberto Sesana

# General relativity: masses curve spacetime

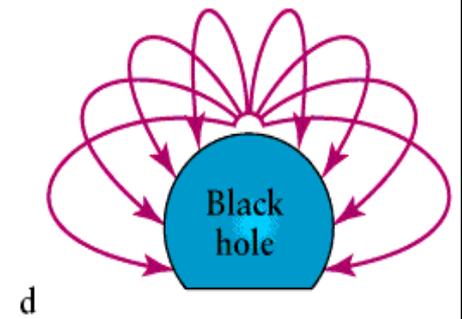
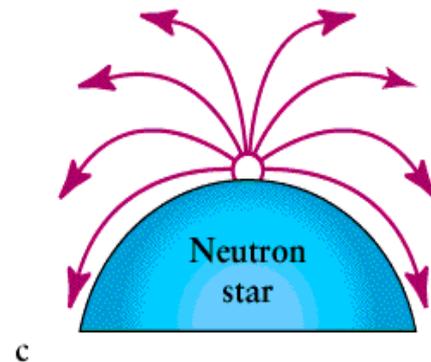
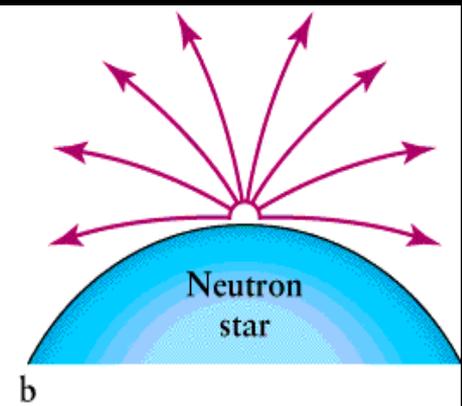
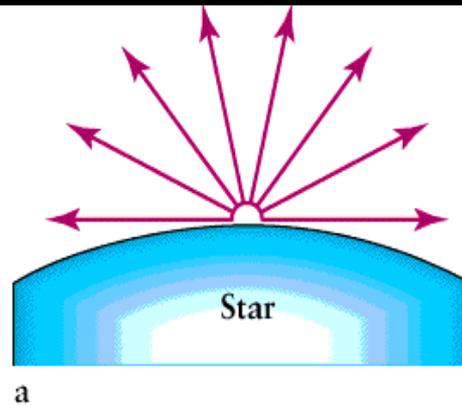
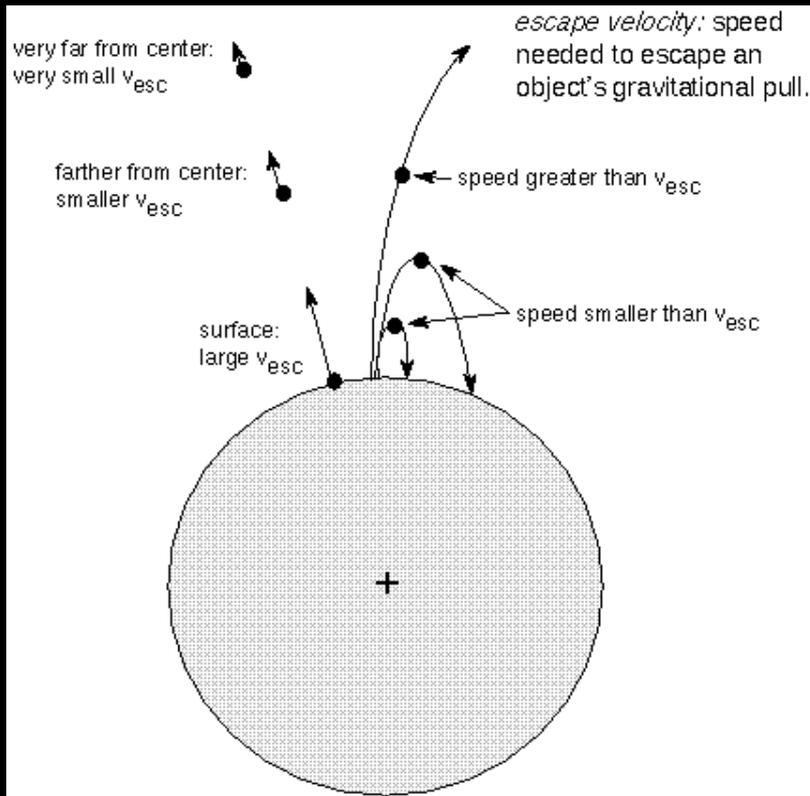
$$\textcircled{G}_{\mu\nu} = \frac{8\pi G}{c^4} \textcircled{T}_{\mu\nu}$$





**The more massive and compact an object, the larger is the distortion of the space geometry**

# Another way to look at it: escape velocity



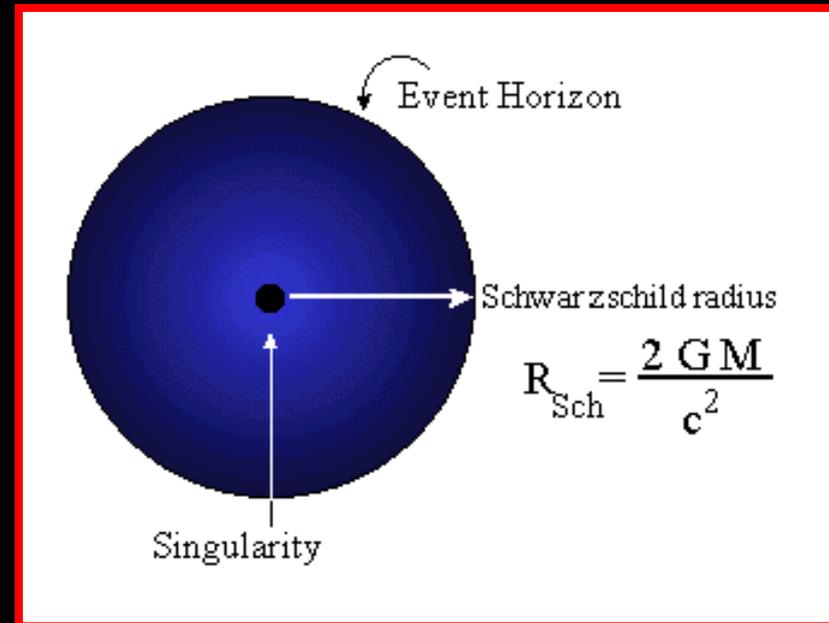
astronomical object	mass (kg)	radius (km)	escape velocity (km/sec)
Earth	$6 \times 10^{24}$	6,400	11
Sun	$2 \times 10^{30}$	700,000	610
neutron star	$4 \times 10^{30}$	10	230,000
black hole	$8 \times 10^{30}$	1	$1,000,000 > c = 300,000$

Objects with escape velocity larger than the speed of light might exist!

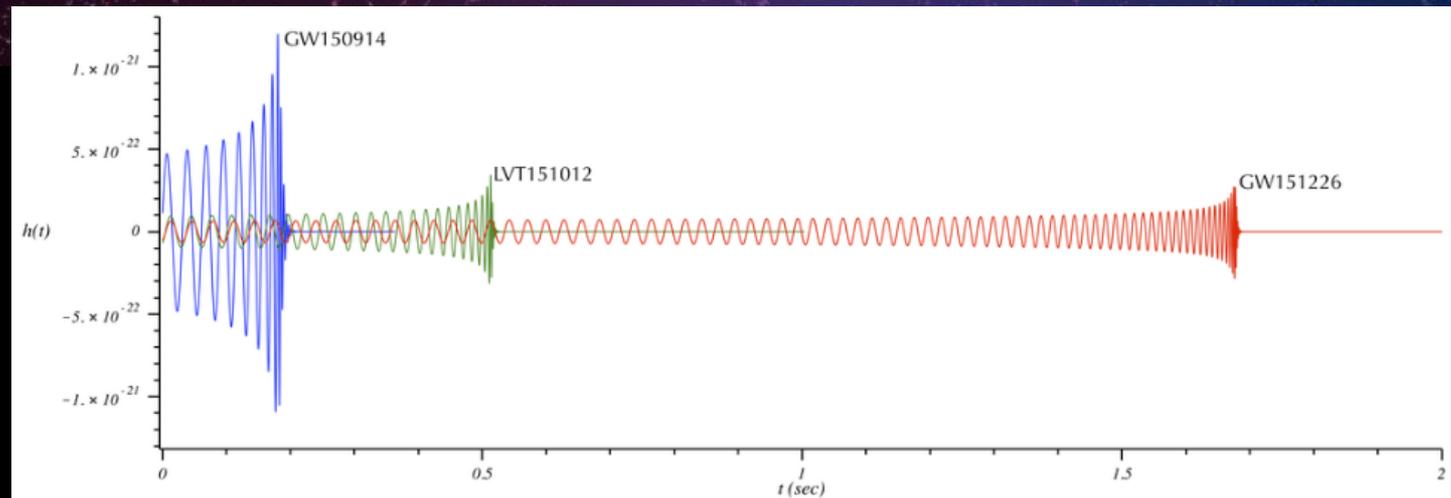
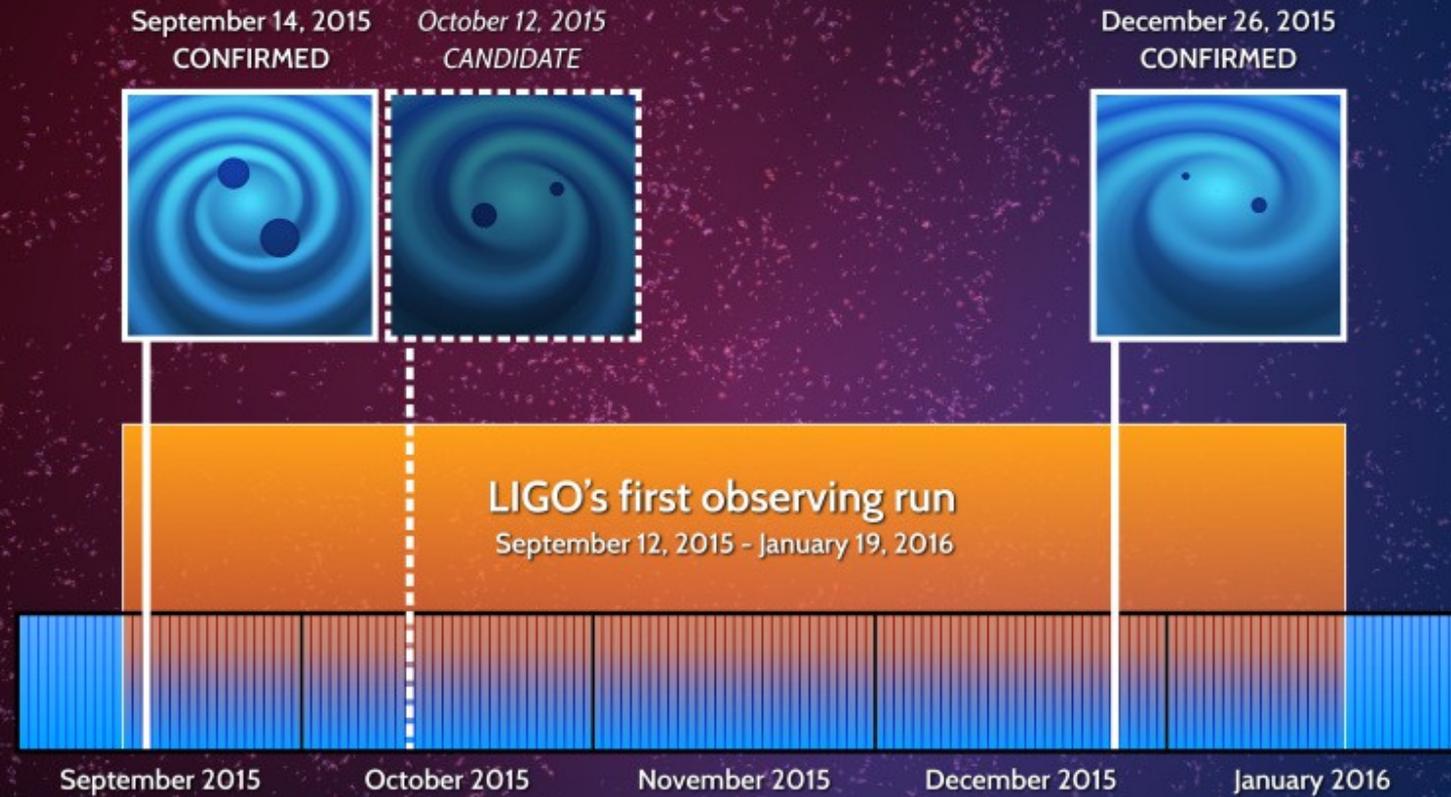


# BLACK HOLES

Differently from their classical counterparts (Michell, Laplace 1783), General Relativity Predicts the existence of a **Event horizon**: a surface from which nothing can emerge.



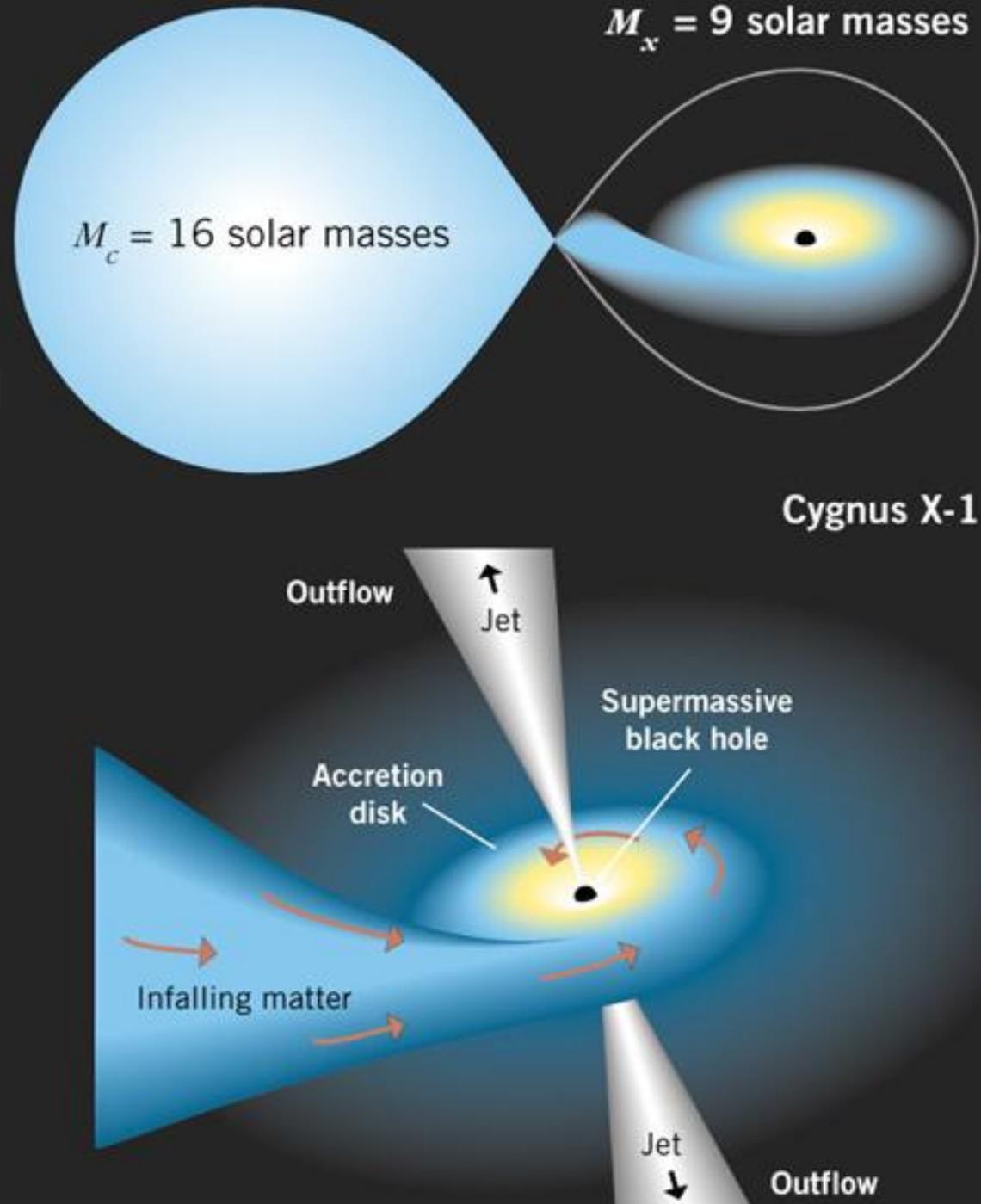
# We now directly observe them: gravitational waves!



...but we already knew they are out there.

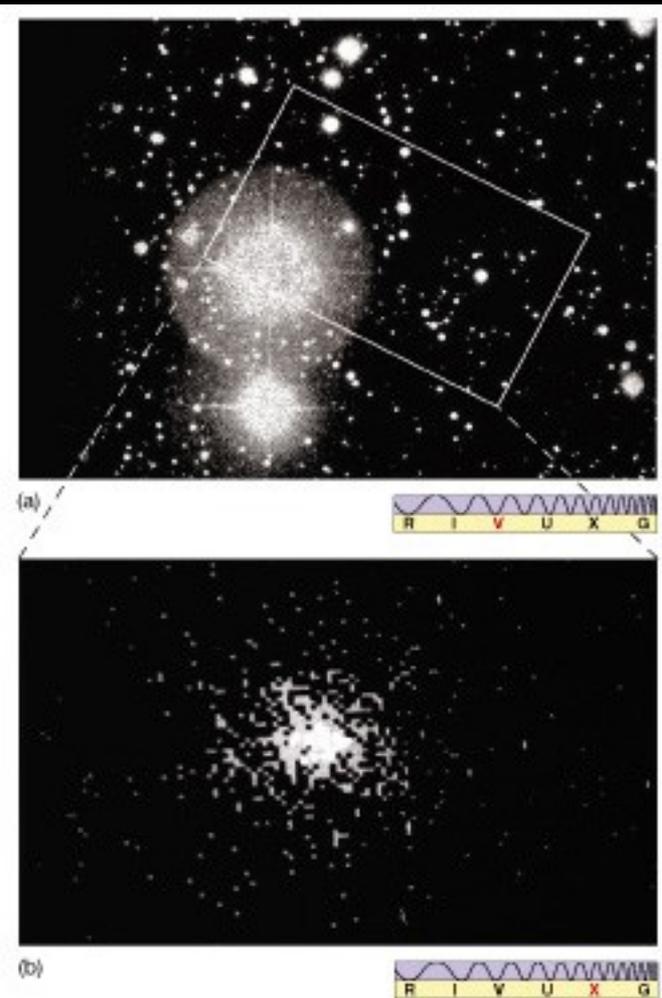
Black holes strip material out of companion stars and accrete it emitting enormous amount of radiation.

Jets are ejected in a direction perpendicular to the accretion flow.



# Observations of stellar mass black holes

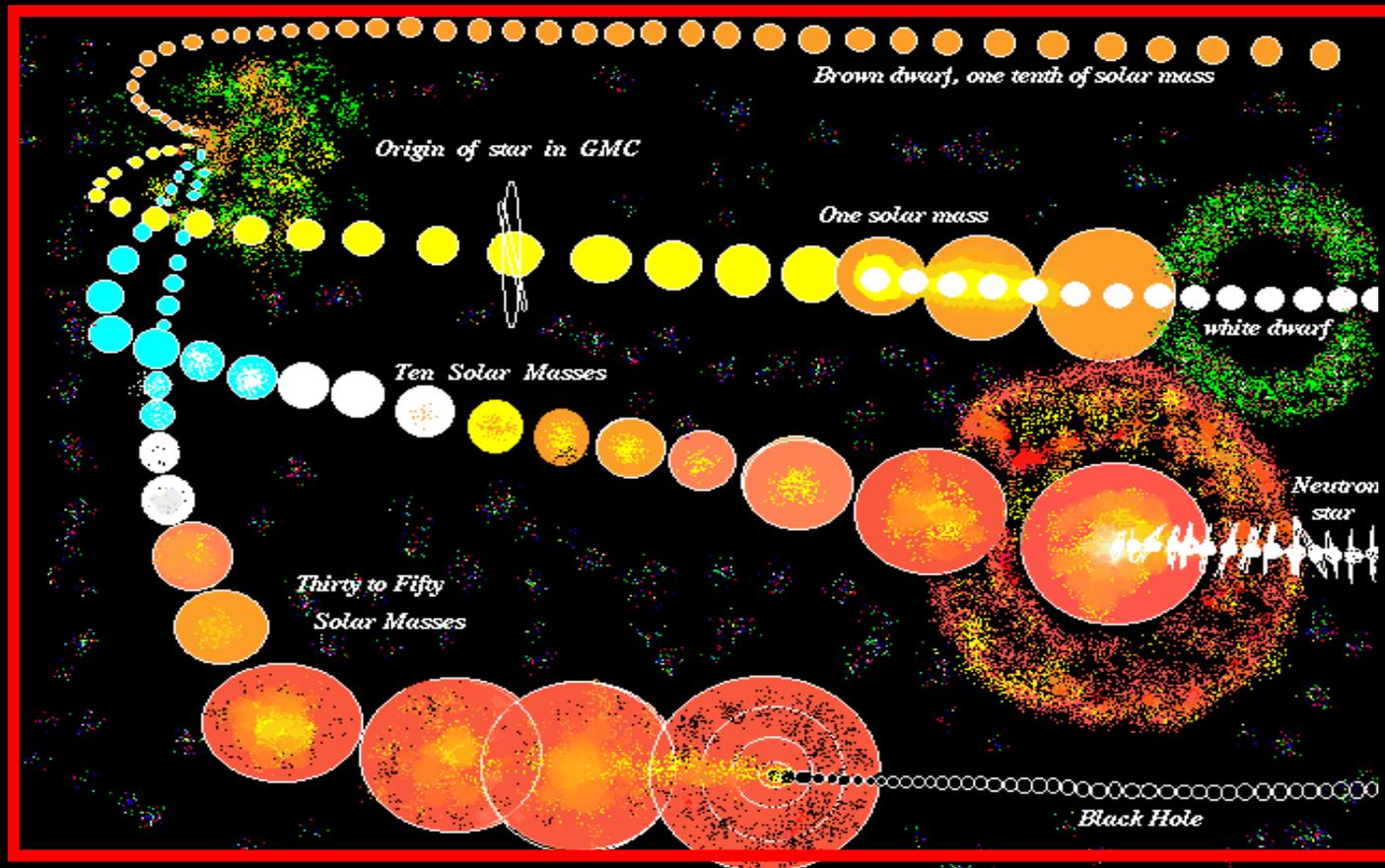
They are difficult to observe, they do not emit a lot of visible light.  
The hot material accreted by the black hole emits a lot of X-ray radiation instead



The first to be detected was **Cygnus X-1**, its optical emission is too dim to be observed.

X-ray astronomy revealed this incredible source, emitting a lot of X-rays. Its mass is larger than four solar masses and the emission comes from a region which is **smaller than 15 km in size**: the only plausible explanation is a stellar mass black hole.

# How do stellar mass black hole form?



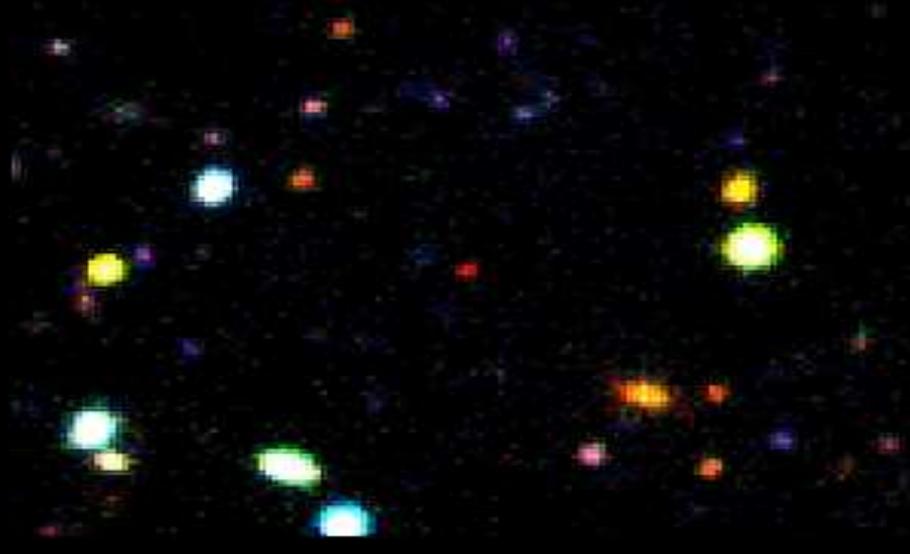
They are the natural final evolutionary stage of stars more massive than ~20 solar masses.

# Observations of supermassive black holes

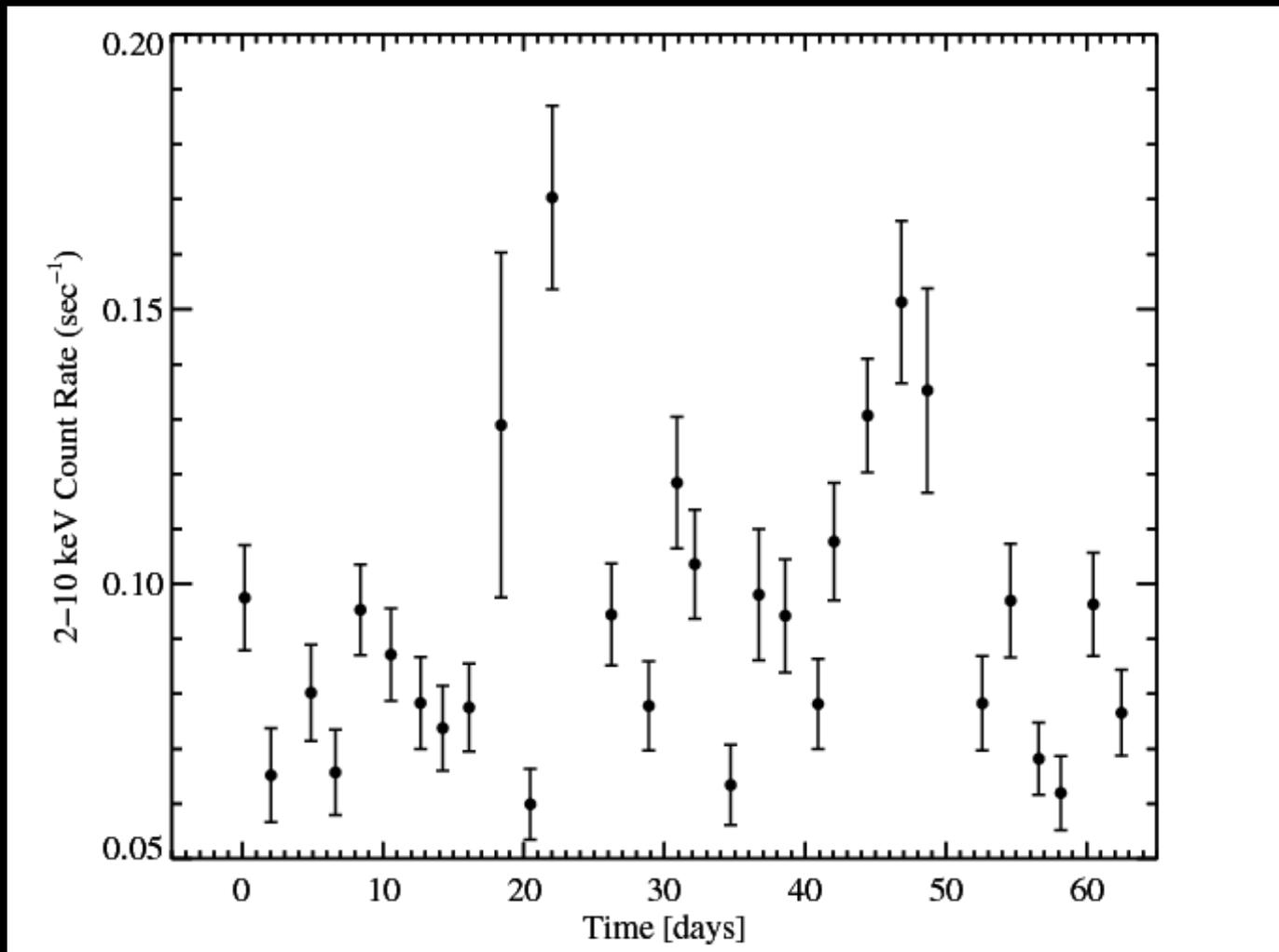
A stellar mass black hole cannot be associated to a **quasar**:

In fact, when their distance has been calculated (the furthest known is at 13 billion light years from us), people realized their intrinsic luminosity must be enormous, and so their mass.

We now know that quasars host **billion solar mass black holes**.

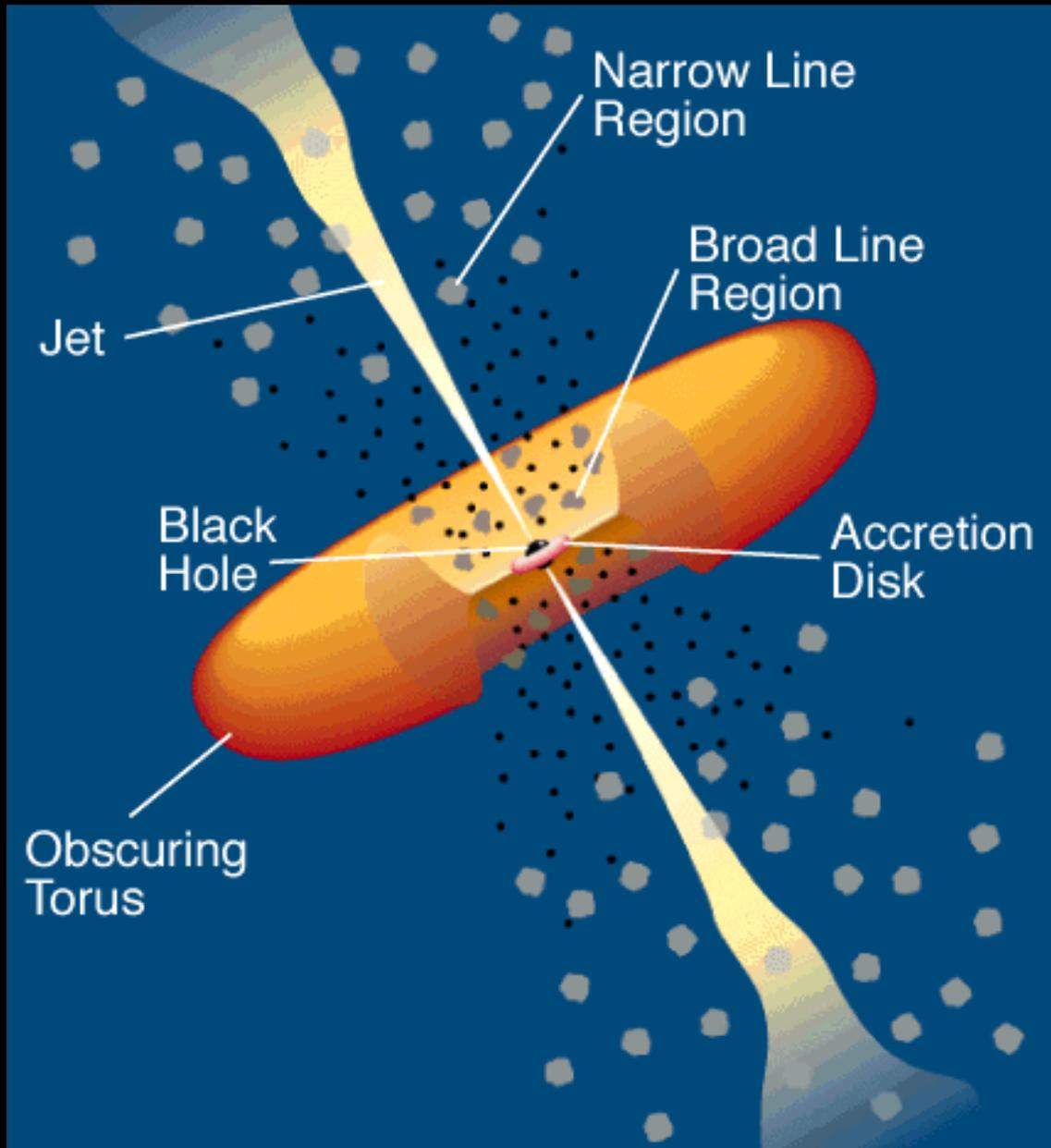


We are observing **accreting supermassive black holes** sitting at the center of remote galaxies!!!



Short timescale time variability tells us that the radiation is emitted by a compact region.

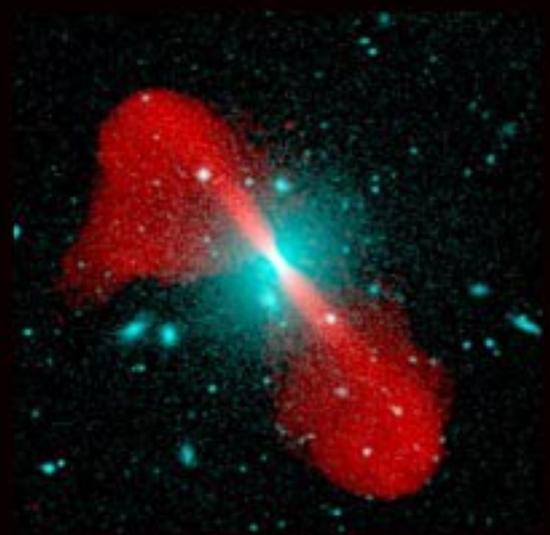
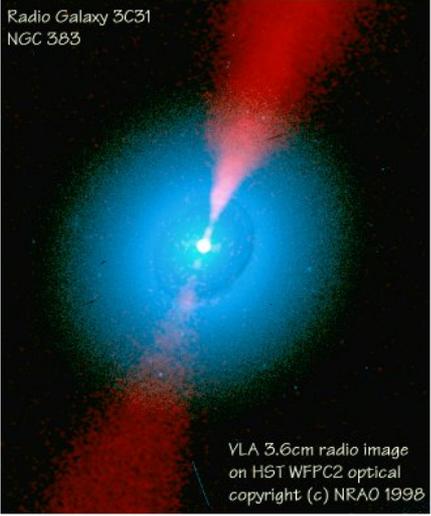
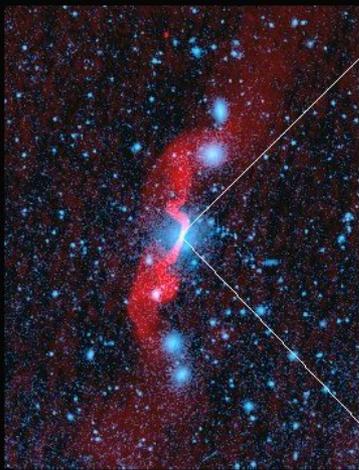
**The luminosity of a galaxy from a region of the size of the solar system!**



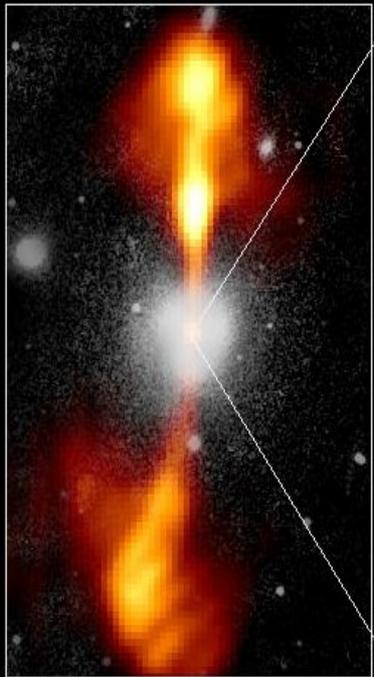
In galactic nuclei, rich of stars and gas, the black hole is surrounded by an enormous amount of gas

The radiation from this gas, spiralling toward the black hole, can be millions of billions of time more luminous than our Sun

Likewise enormous jets are produced, reaching scales much larger than our galaxy



Ground-Based Optical/Radio Image

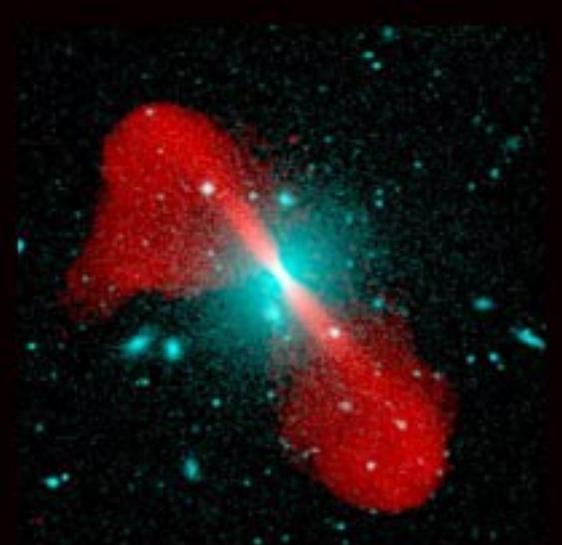
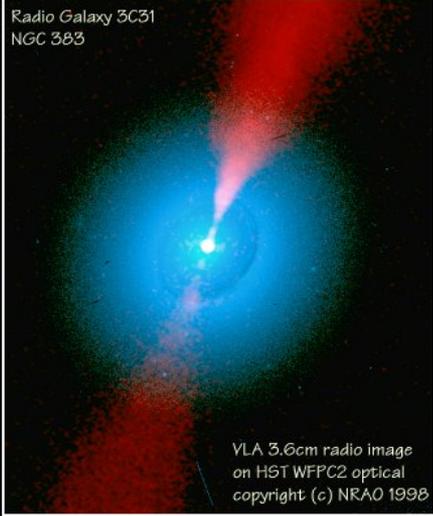
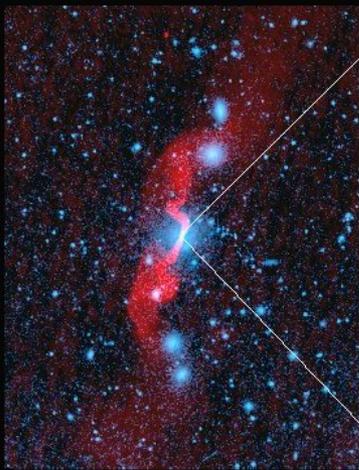


380 Arc Seconds  
88,000 LIGHT-YEARS

HST Image of a Gas and Dust Disk



17 Arc Seconds  
400 LIGHTYEARS

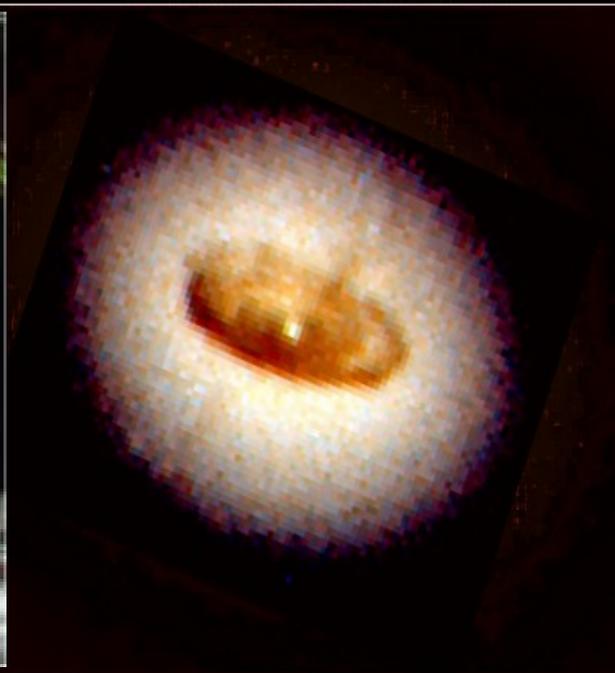


Ground-Based Optical/Radio Image

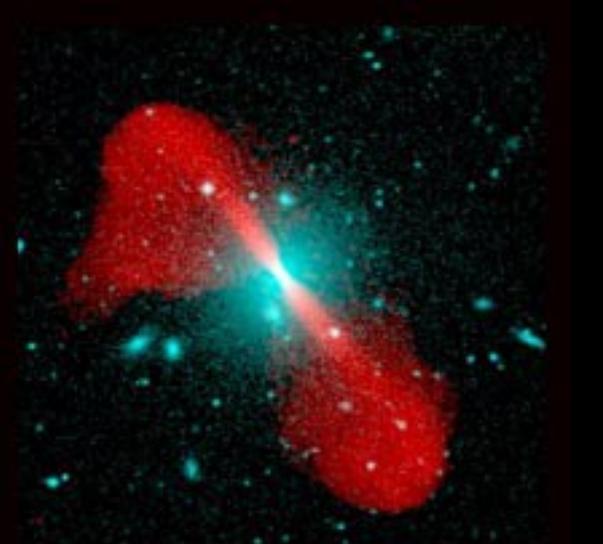
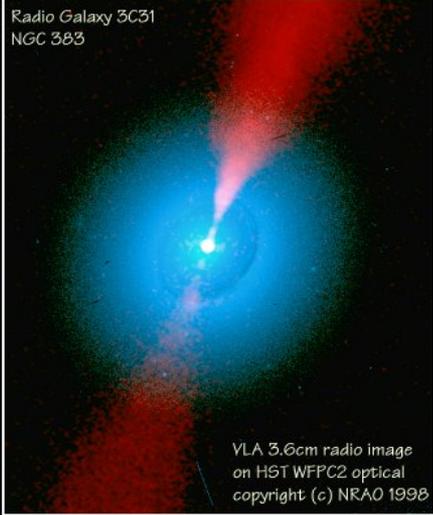
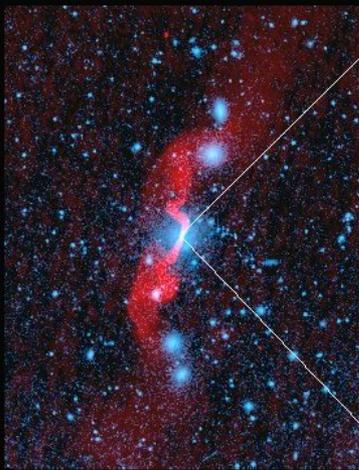
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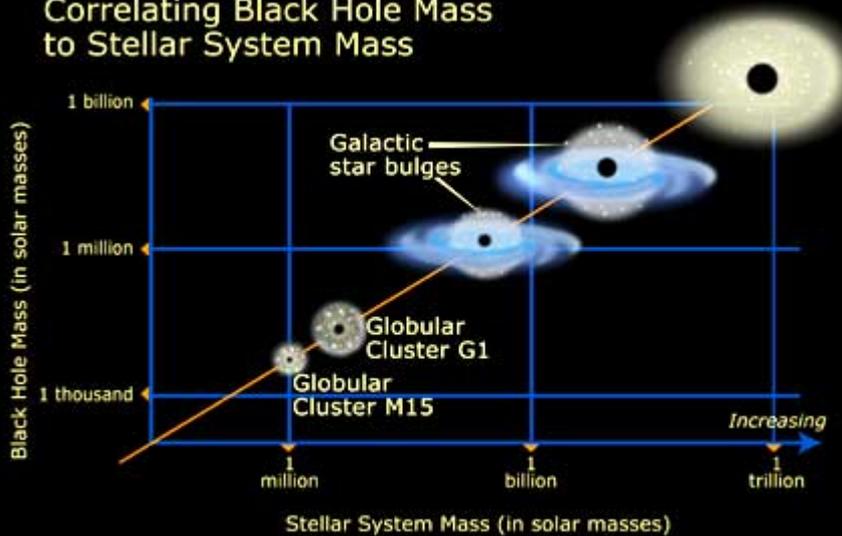
Another spectacular effect caused by supermassive black holes is the **tidal disruption** of stars.

If a star transits too close to a supermassive black hole the tidal force....

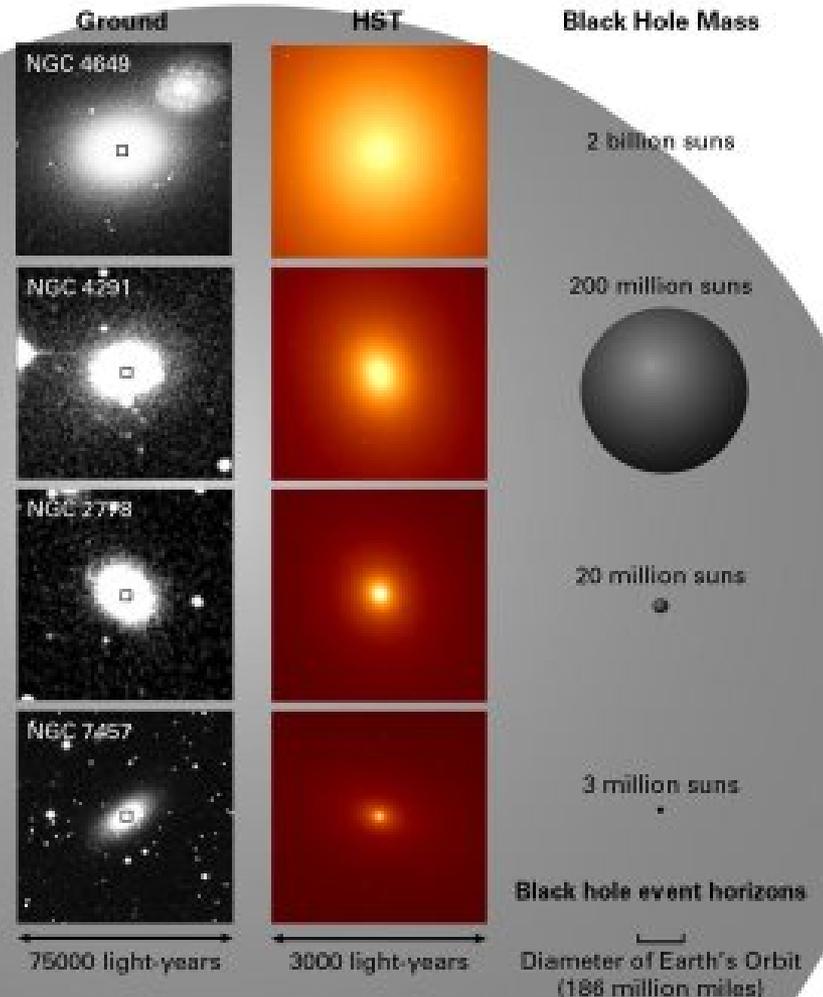


# Every galaxy hosts a supermassive black hole!

Correlating Black Hole Mass to Stellar System Mass



Black Hole Mass Scales with Galaxy Size



**NGC 1277  
Black Hole**  
*(4 light-days)*

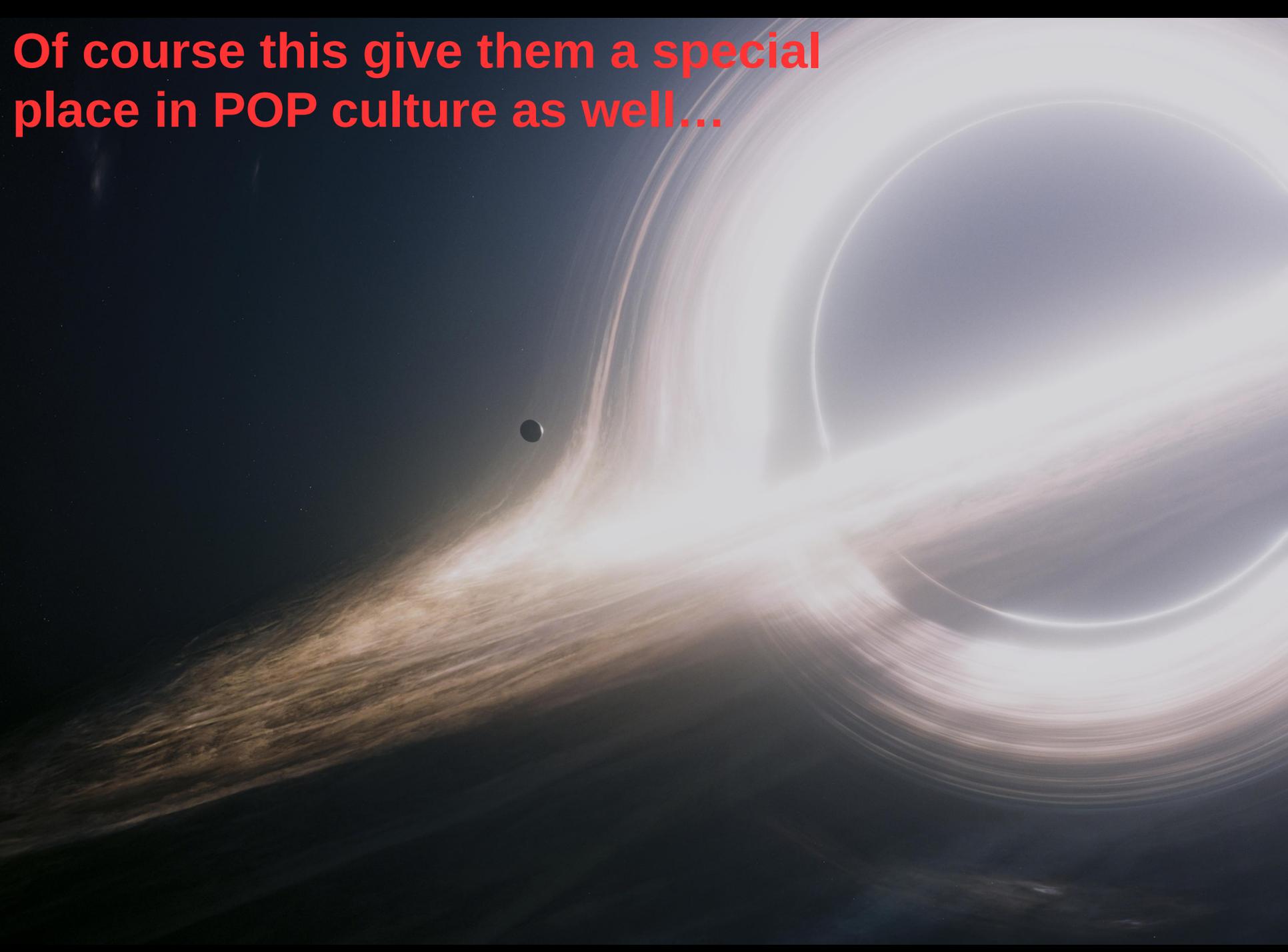
**Neptune's Orbit**  
*(8.3 light-hours)*

**Earth's Orbit**  
*(17 light-minutes)*

**Galaxy NGC 1277**

**...AND THEY CAN BE HUGE!!!**

**Of course this give them a special  
place in POP culture as well...**



GLACIERS MELTING  
IN THE DEAD OF  
**NIGHT**  
AND THE  
SUPERSTARS  
SUCKED INTO THE  
SUPERMASSIVE  
SUPERMASSIVE  
**BLACK HOLE**



**MUSE**

BLACK HOLES & REVELATIONS



GLACI  
IN THE  
NE  
MAN  
SU  
SUKE  
SUPE  
SUPE  
BLA



**But how do supermassive black holes form  
in galaxy centres?**



**YOU NEED TO FEED THEM!**

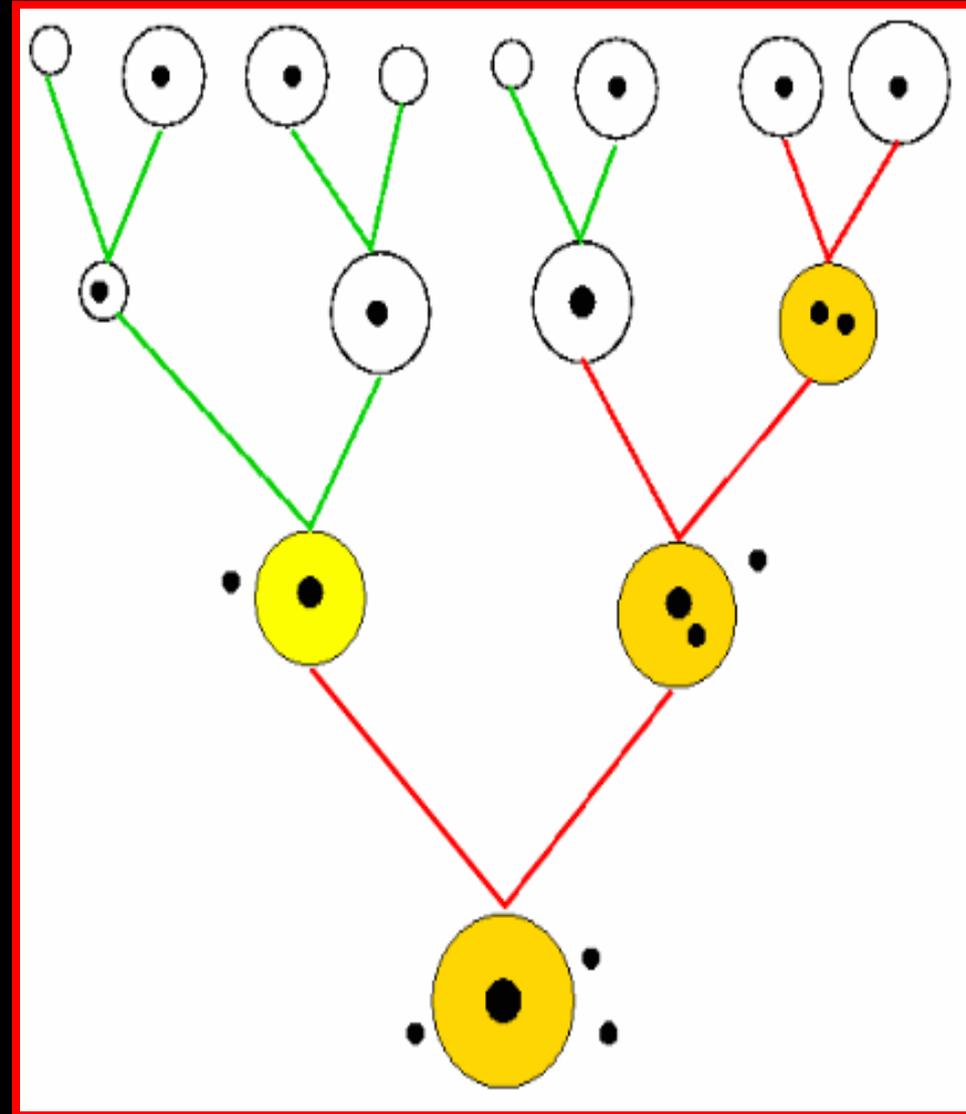




Current theories trace back the formation of those beasts to much lighter **seeds** ( $100-10^5$  solar masses)

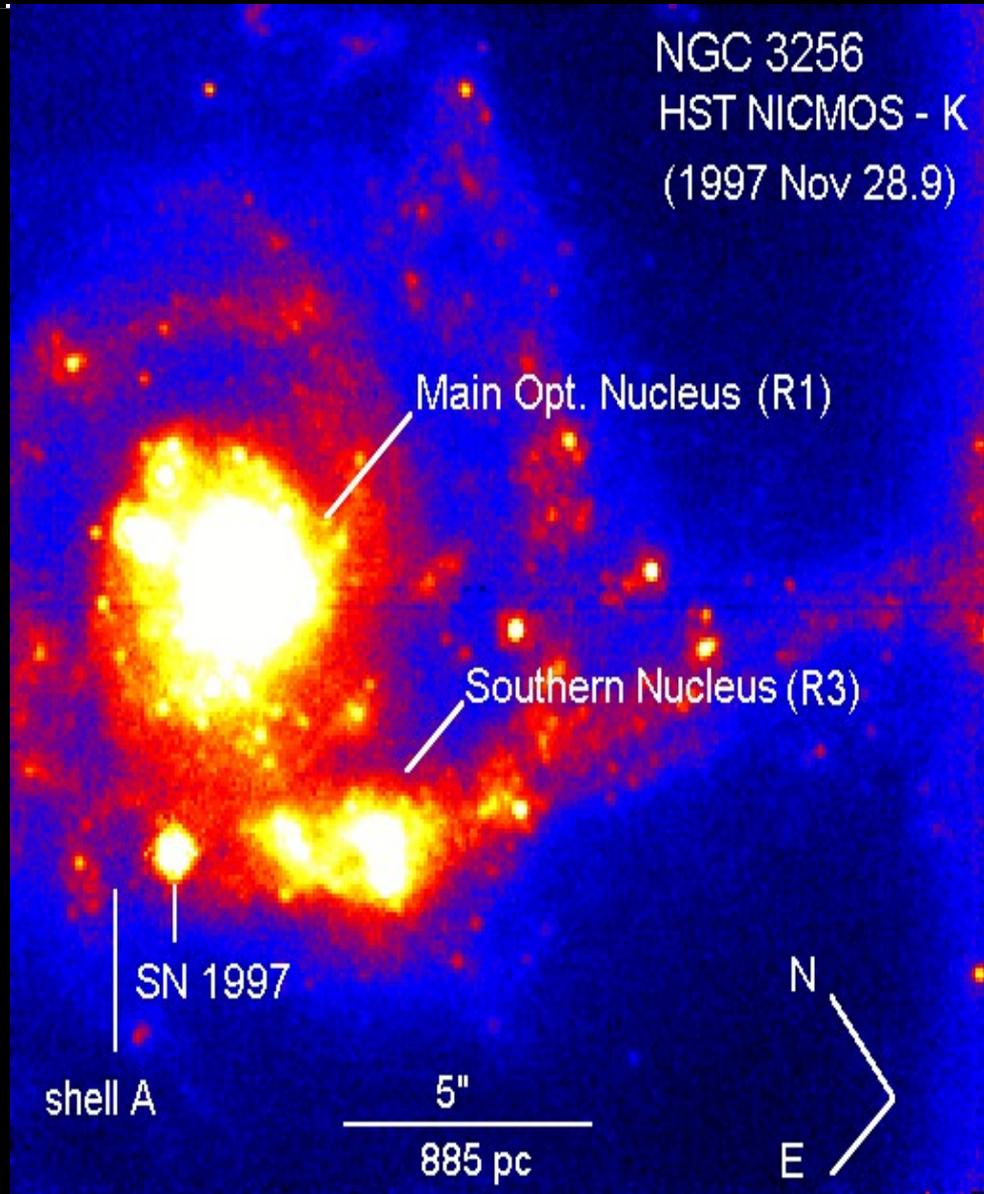
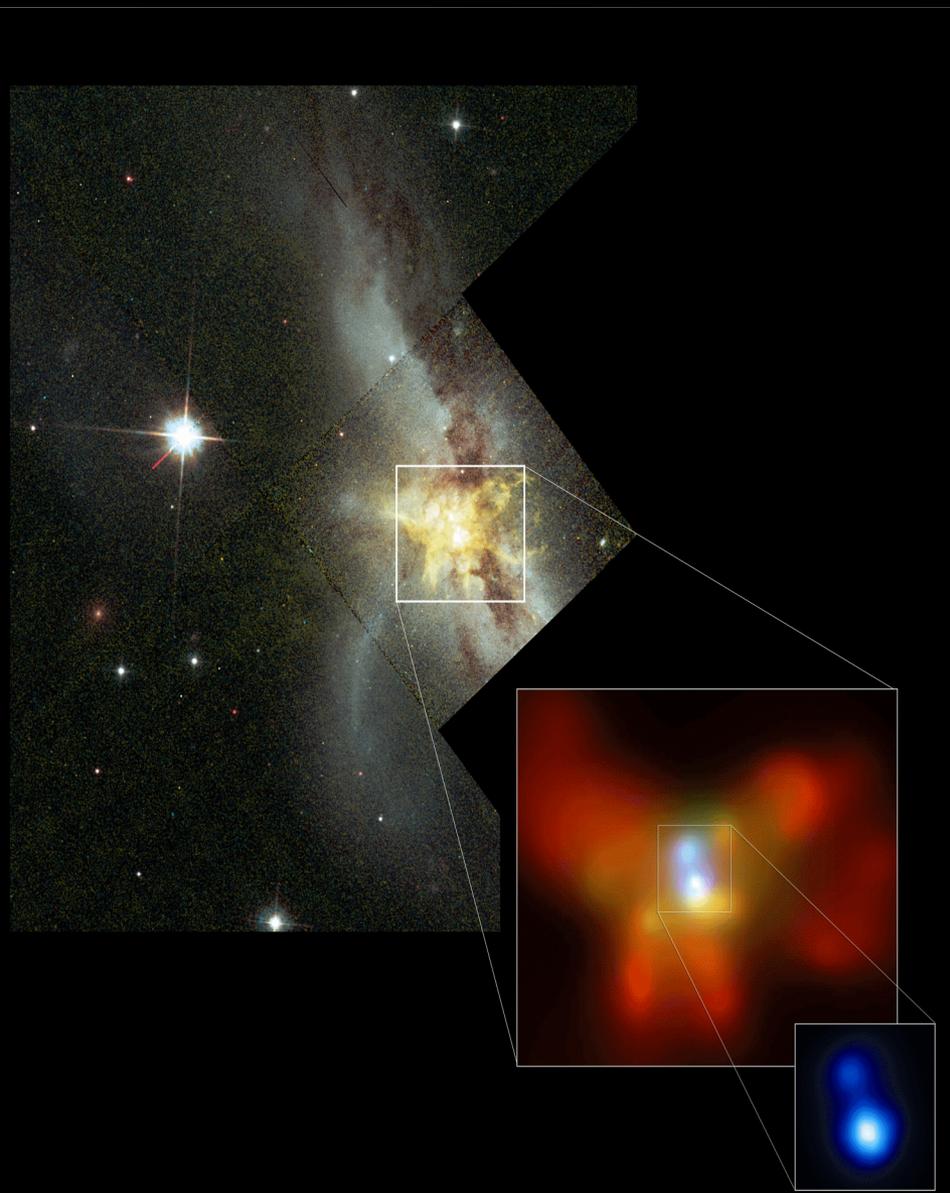
Along cosmic times, **galaxies merge** with each other forming bigger and bigger galaxies

During those mergers, Instabilities channel this **gas** to the centre. Part of it will be **accreted** by the **black hole**, growing its mass





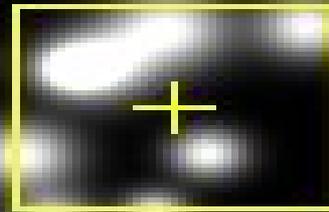
# ...we indeed observe galaxy merging and supermassive black hole pairs

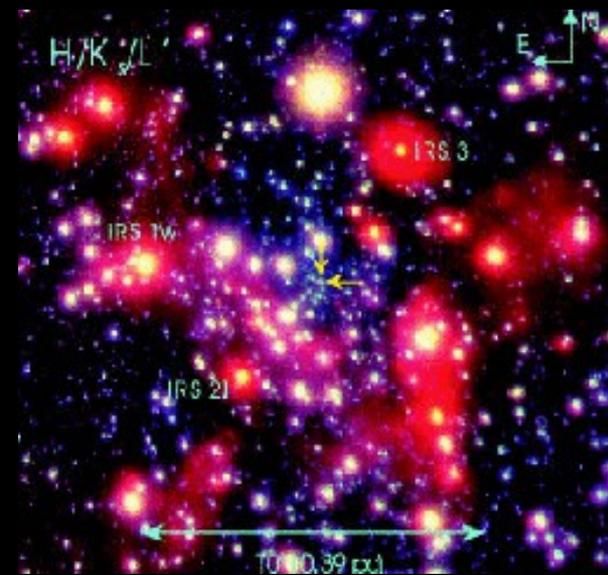


In the centre of our Milky Way there is a supermassive black hole!

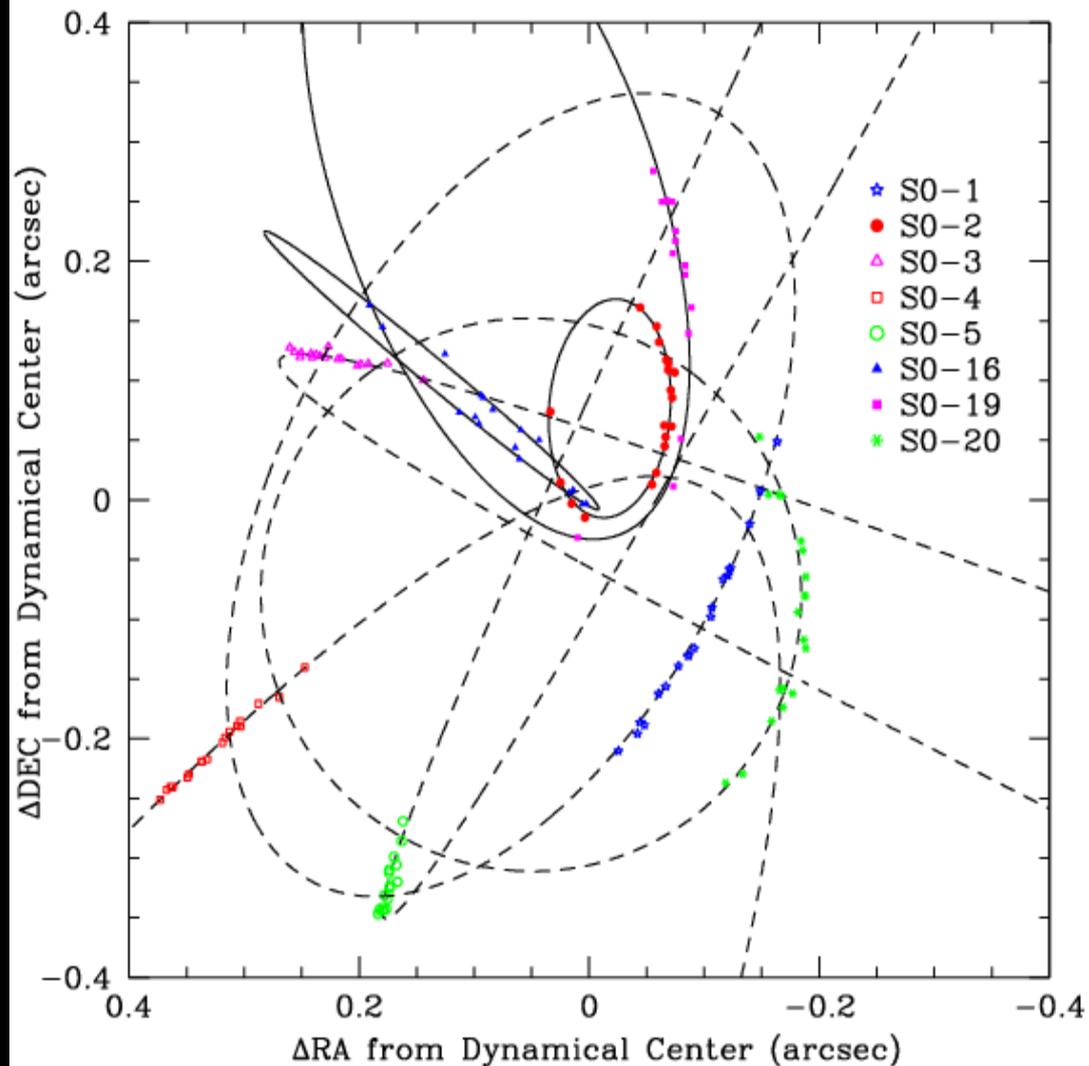
1992

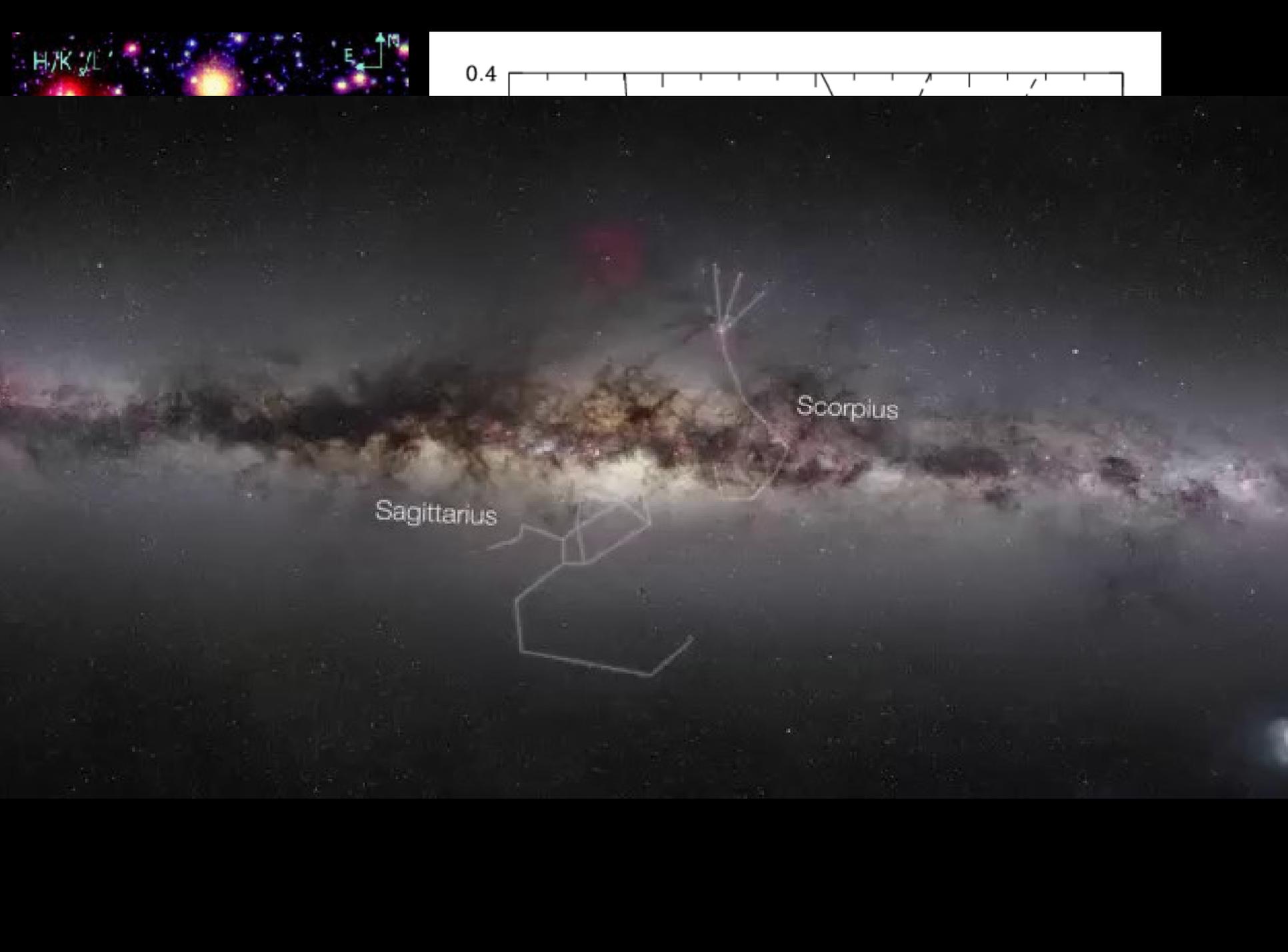
10 light days





The measured mass is about **four million solar masses!**





H, K, L

$l$   
 $b$   
E

0.4

Scorpius

Sagittarius