

THE UNIVERS OF BLACK HOLES

A detailed illustration of a black hole. At the center is a bright, glowing accretion disk with a yellow and orange core. Two powerful, teal-colored jets of plasma extend from the poles of the black hole, crossing at the center. The background is a dark, starry space with faint, wispy clouds of gas and dust.

Félix Mirabel

THE IDEA OF “BLACK HOLE”

Michell: in 1783 proposed the existence of
“bodies from which light could not arrive at us”
that could be detected in stellar binary systems



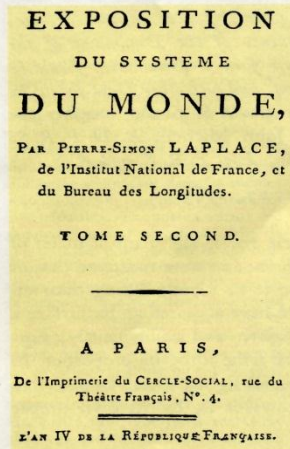
Laplace:

Corps obscurs en aussi grand nombre que les étoiles

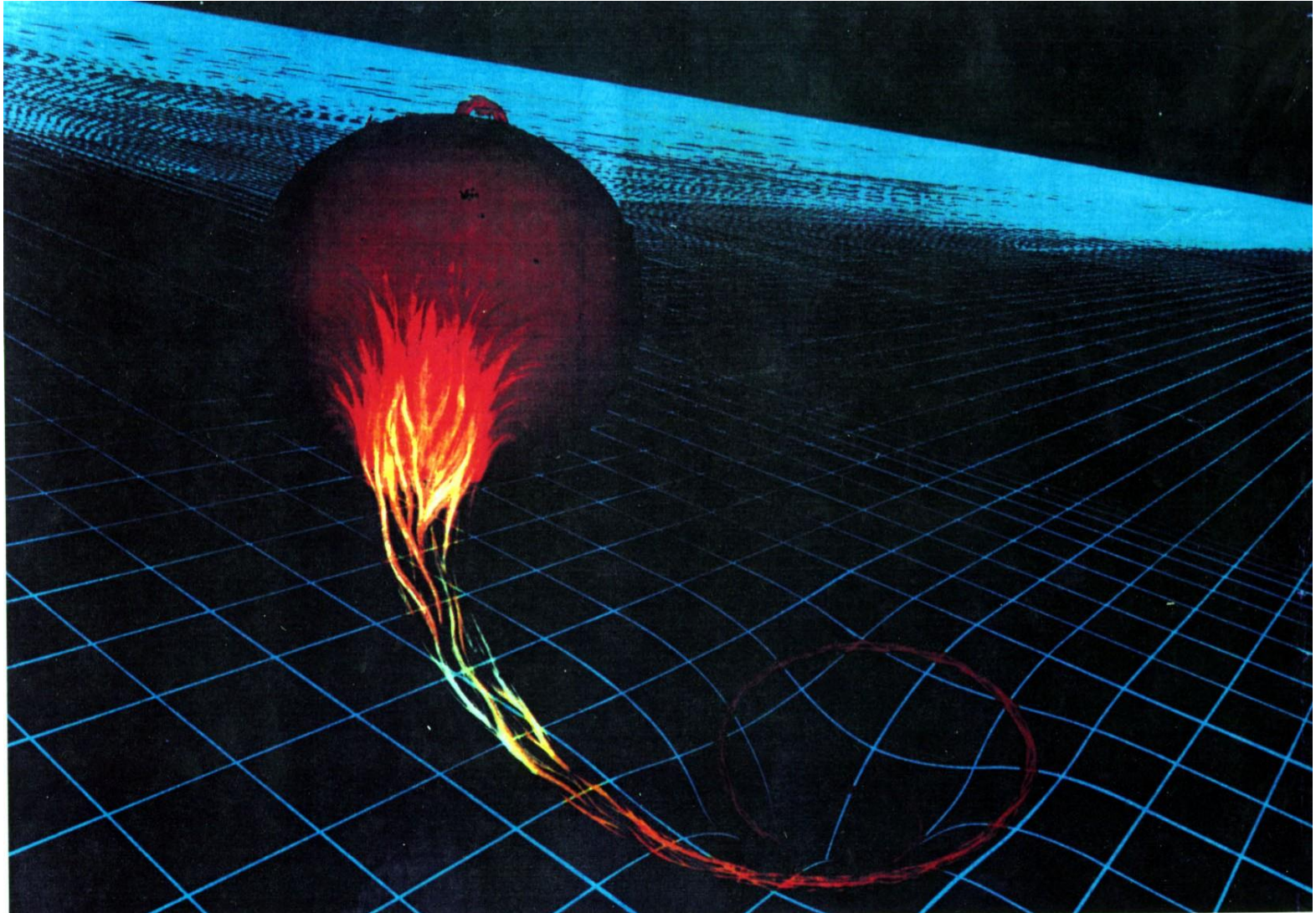
“Il est possible que les plus grands corps de l’univers, soient par cela même, invisibles.”

⇒ **Supermassive Black Holes**

The idea of “black hole” was forgotten for ~ 140 yr



RELATIVISTIC CONCEPT OF GRAVITY



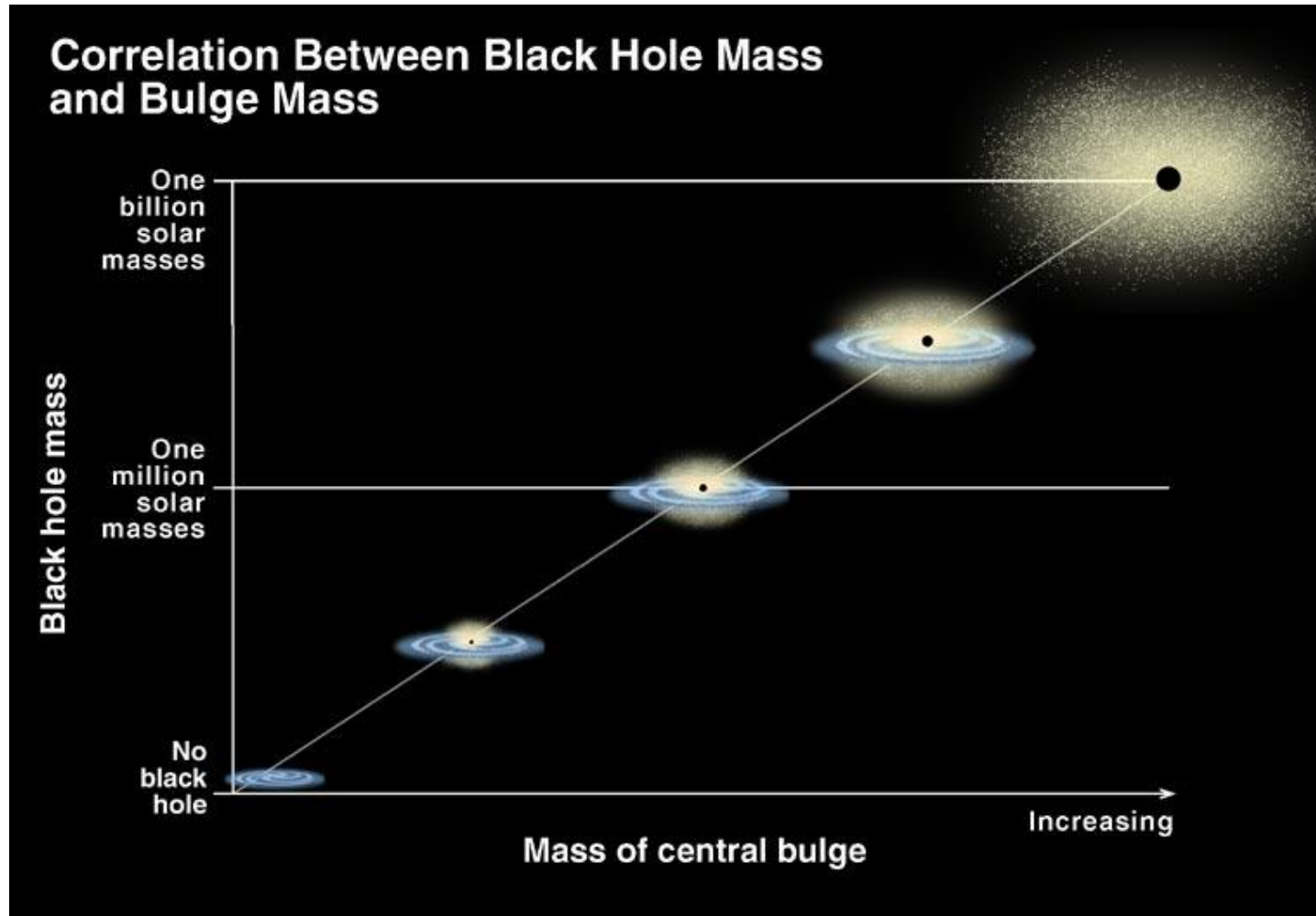


ARTIST'S VIEW OF BLACK HOLE

by the French scientist and artist

J.P. Luminet

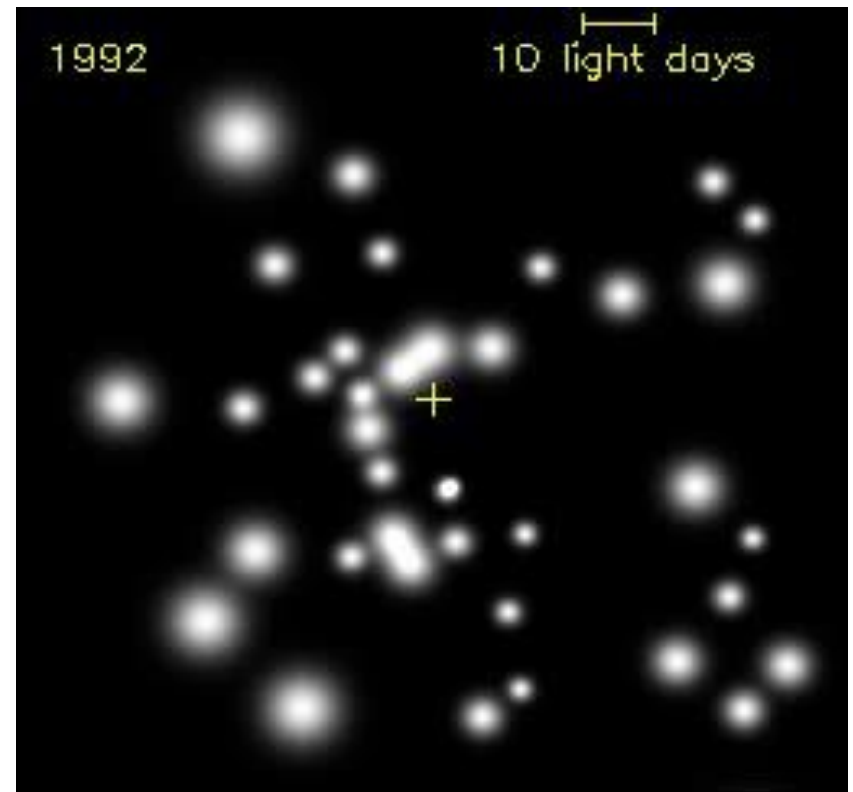
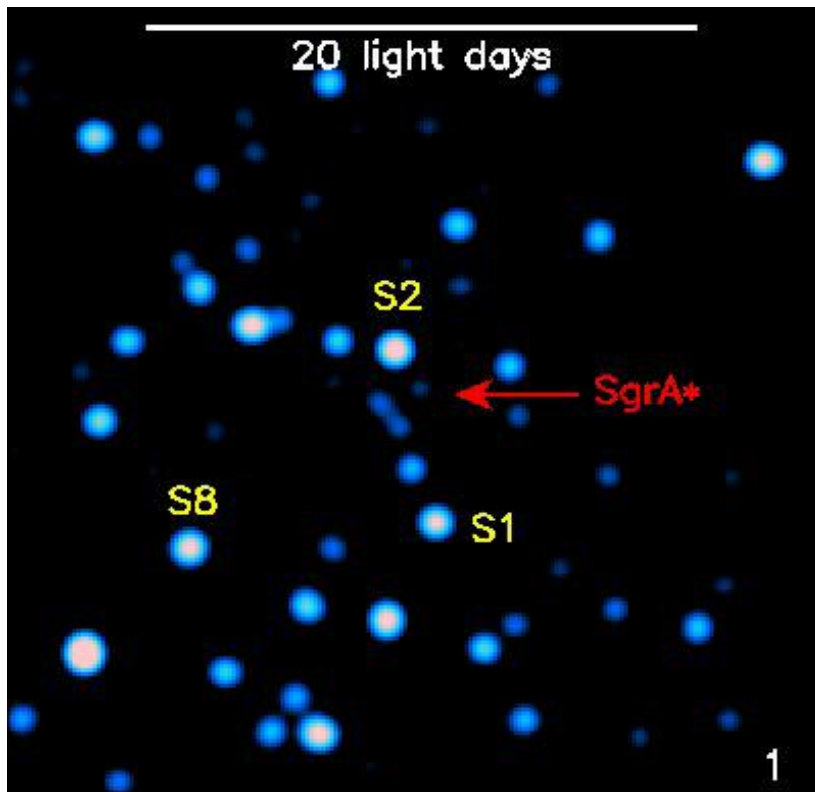
MASSIVE GALAXIES HOST SUPERMASSIVE BLACK HOLES



•HOW ARE SUPERMASSIVE BLACK HOLES FORMED ?

SUPERMASSIVE BLACK HOLE AT THE GALACTIC CENTRE

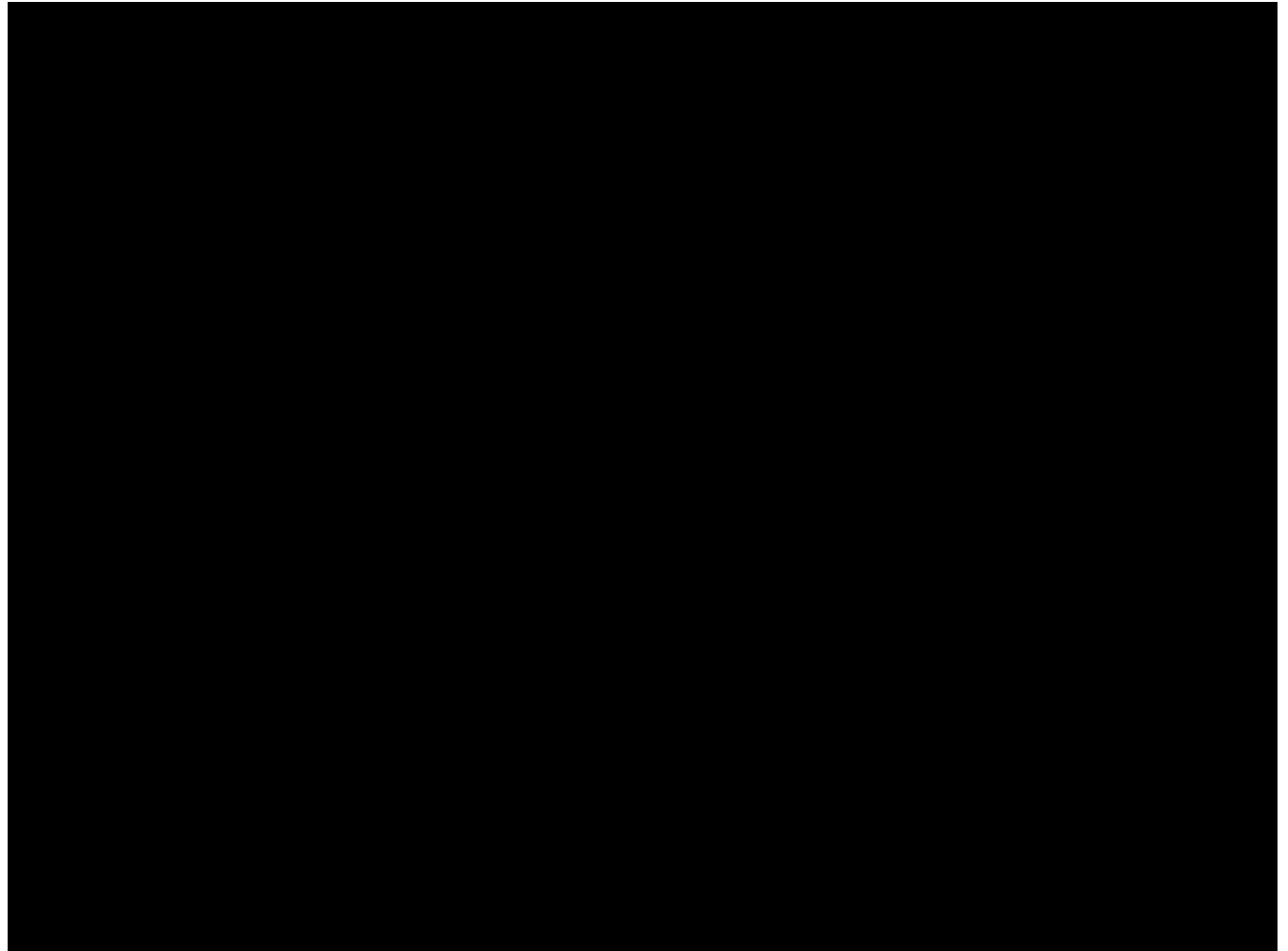
- The black hole of ~ 4 million solar masses at the Galactic Center
- Infrared monitoring with adaptive optics (Genzel et al., 2008)



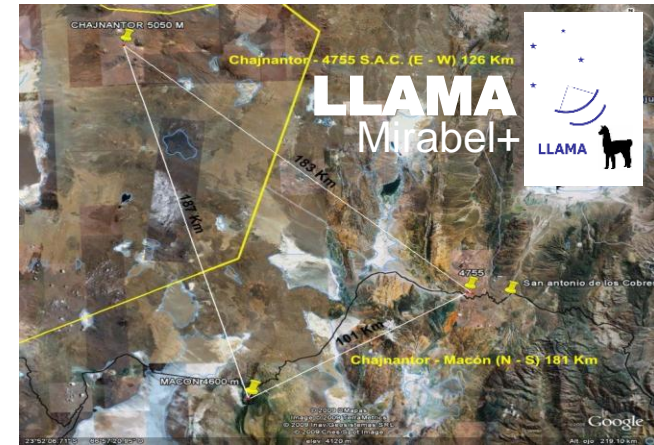
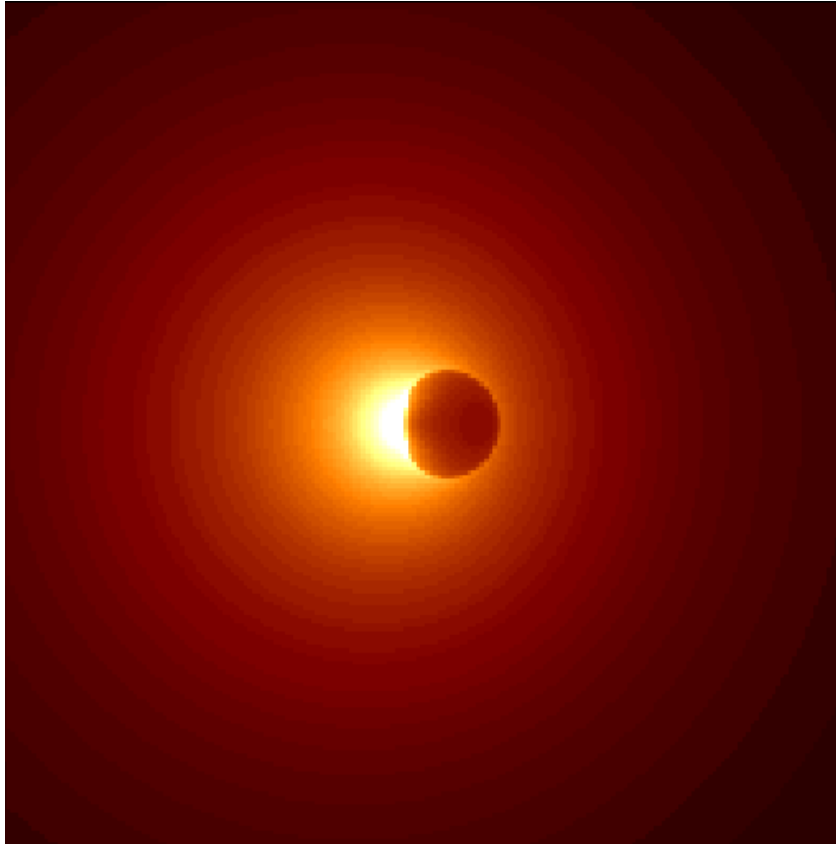
- How could a cluster of massive stars $< 10^7$ yr old exist in such environment ?
- Still without direct evidence of the event horizon

A GAS CLOUD ACCRETED BY THE BLACK HOLE AT THE GALACTIC CENTRE

Gillessen et al. 2012



THE BLACK HOLE IN THE GALACTIC CENTRE



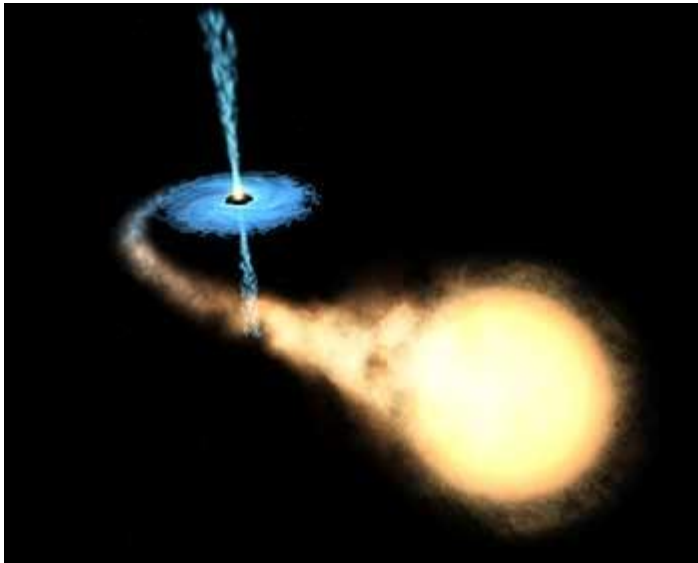
- $4 \times 10^6 M_{\odot}$ confined in a region smaller than the solar system
- $D = 30 \mu\text{arcsec}$ with VLBI at sub-millimeter wavelengths

LLAMA: « Long Latin American Millimeter Array (Salta & Jujuy) »
(A bi-national project of Argentina & Brasil)

STELLAR-MASS BLACK HOLES

DISCOVERED AS X-RAY SOURCES

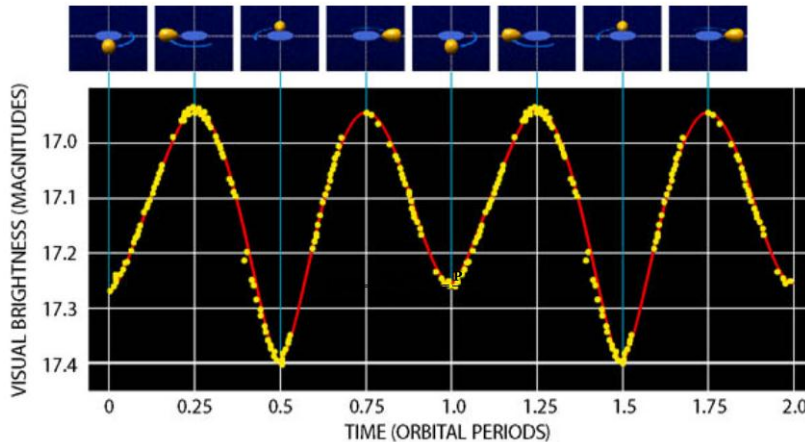
(Giacconi, 1962...Nobel Prize in 2002)



IN BINARY STELLAR SYSTEMS:
as predicted by Michell (1783)

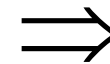
$M > 3 M_{\odot} \Rightarrow \text{BLACK HOLE}$

- 30 BHs known in binaries and other 20 additional candidates
- Estimated population in the Galaxy $\sim 3 \times 10^8$



Fonction de masse:
$$f_x(M) = \frac{M_n^3 \sin^3 i}{(M_n + M_x)^2} = \frac{P_{\text{orb}} K}{2\pi G}$$

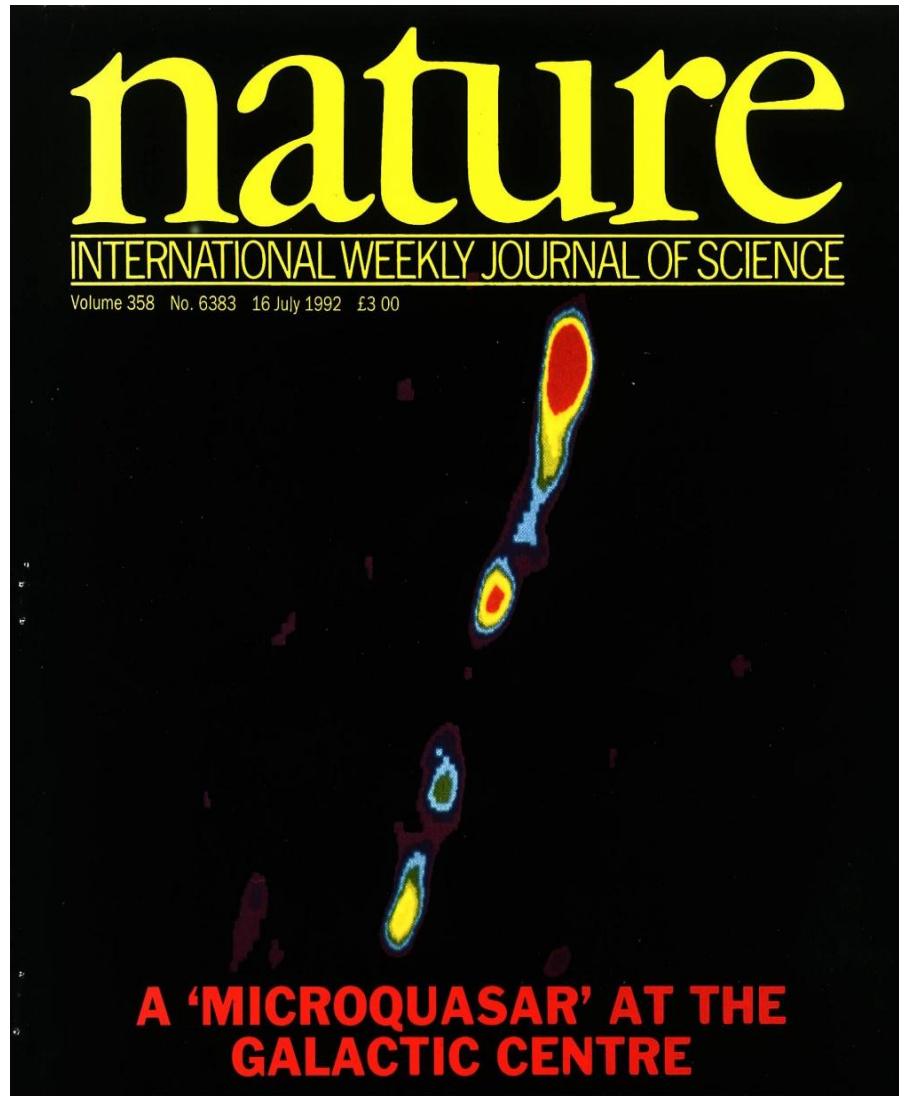
Minimum de masse de l'objet compact



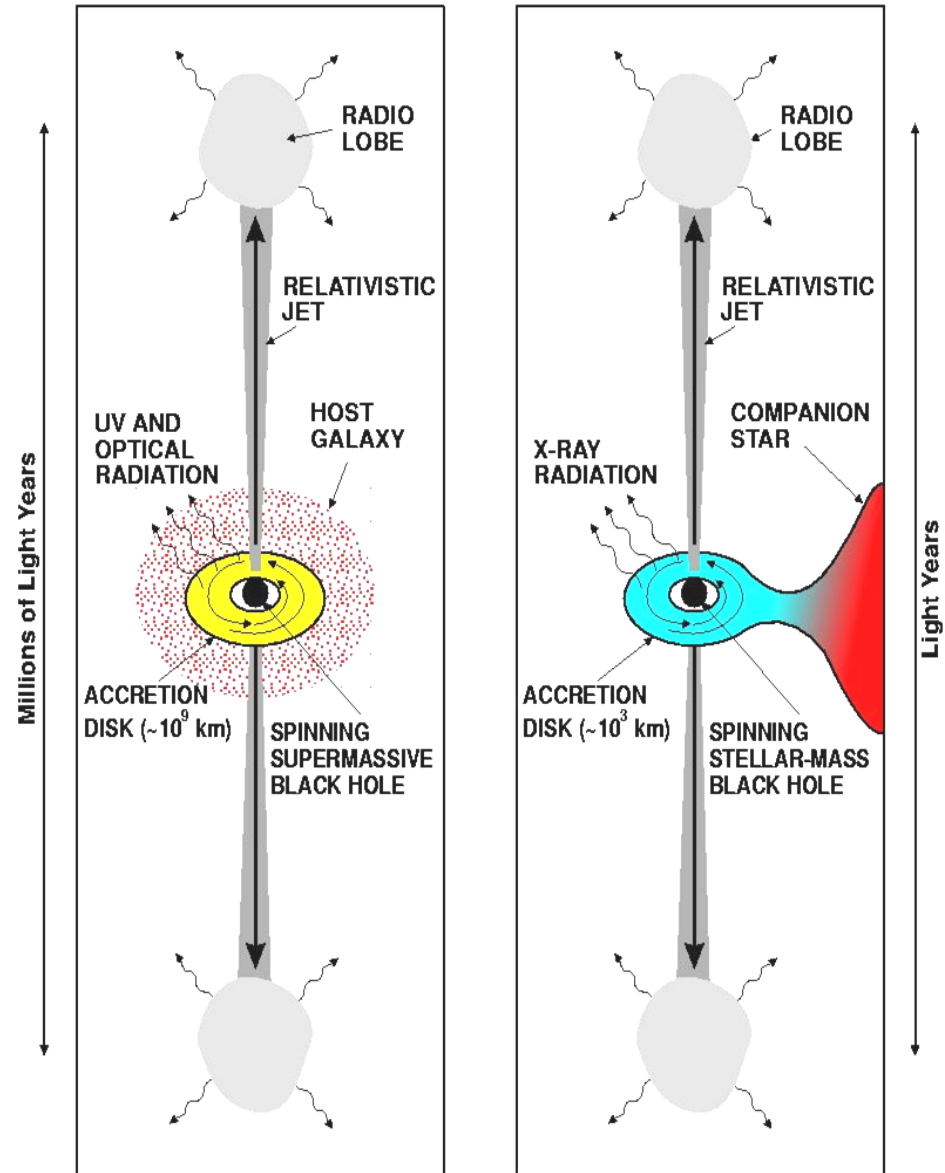
- Assuming $\sim 10 M_{\odot}$ this form of dark mass is $\sim 4\%$ of total baryonic mass of the Galaxy
- Outweighs the supermassive black hole at Galactic Centre by a factor of 10^3

A "MICROQUASAR" IN THE GALACTIC CENTRE REGION

Mirabel, Rodriguez, et al. (1992)



Mirabel & Rodriguez (Nature, 1998)



A SUPERLUMINAL SOURCE IN THE GALAXY

Mirabel & Rodriguez, 1994

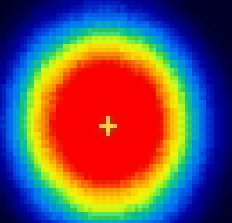


1 arcsec

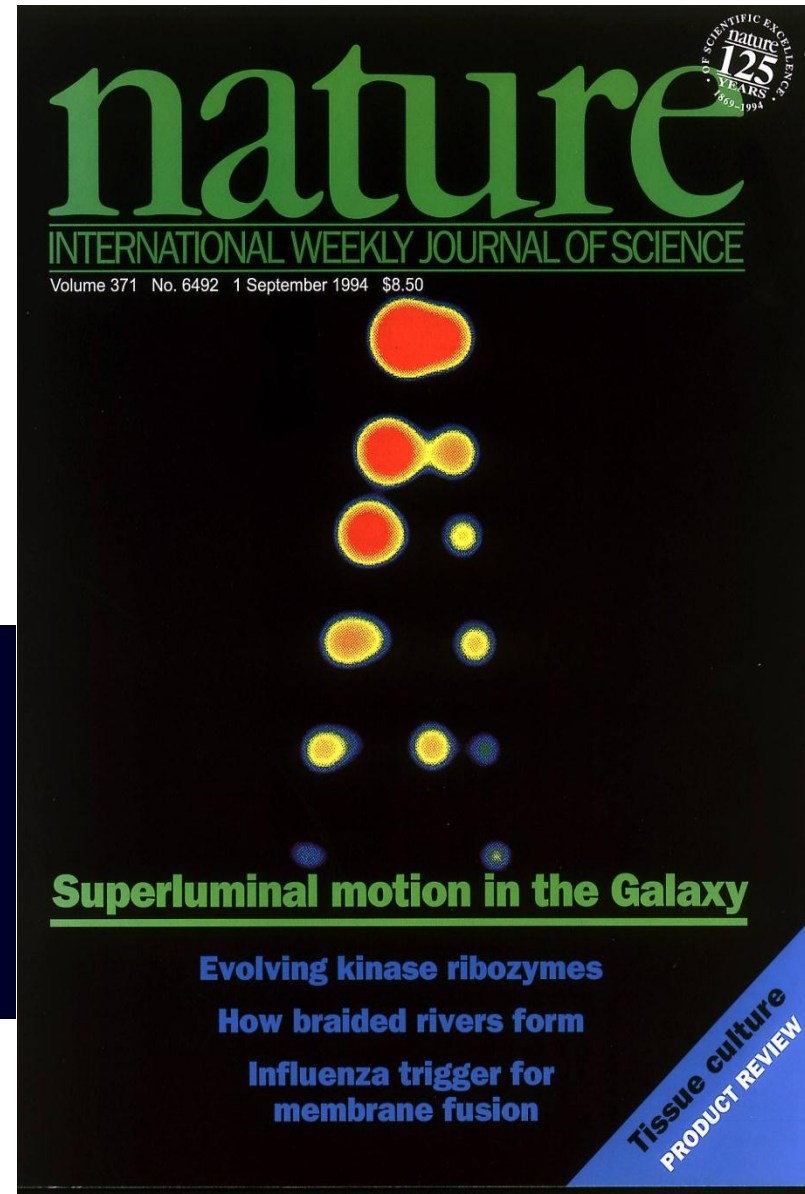
$\lambda 3.6\text{cm}$

GRS 1915+105

18-III-1994

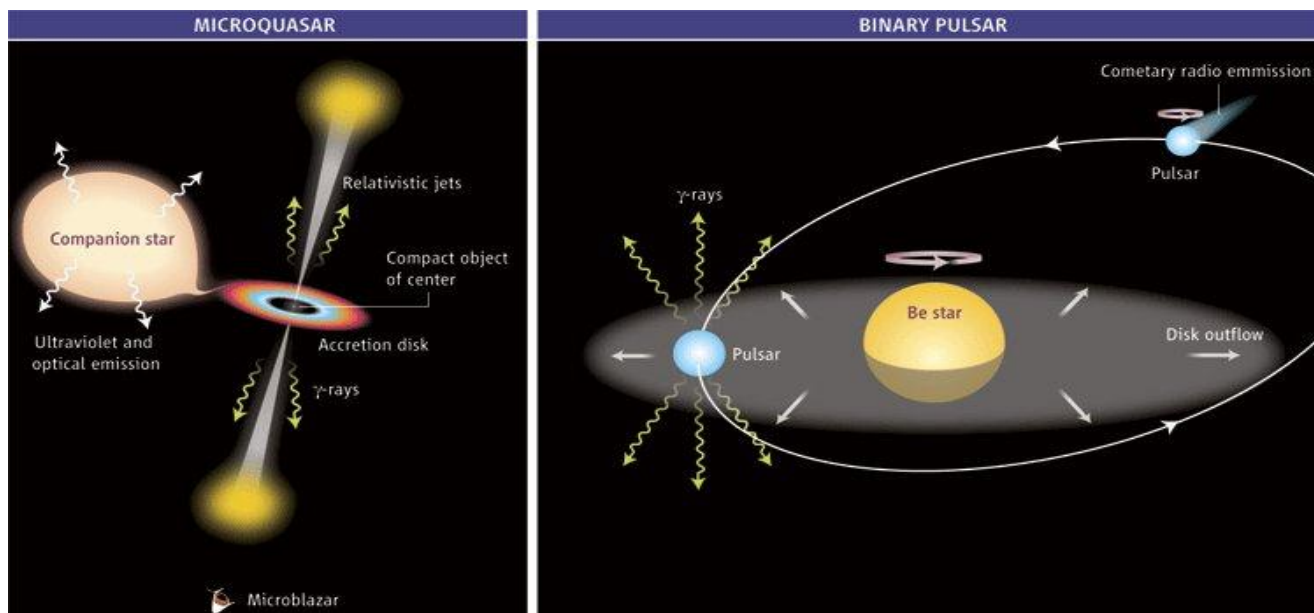


$V_{\text{ap}} > C$ at a distance > 8 Kpc

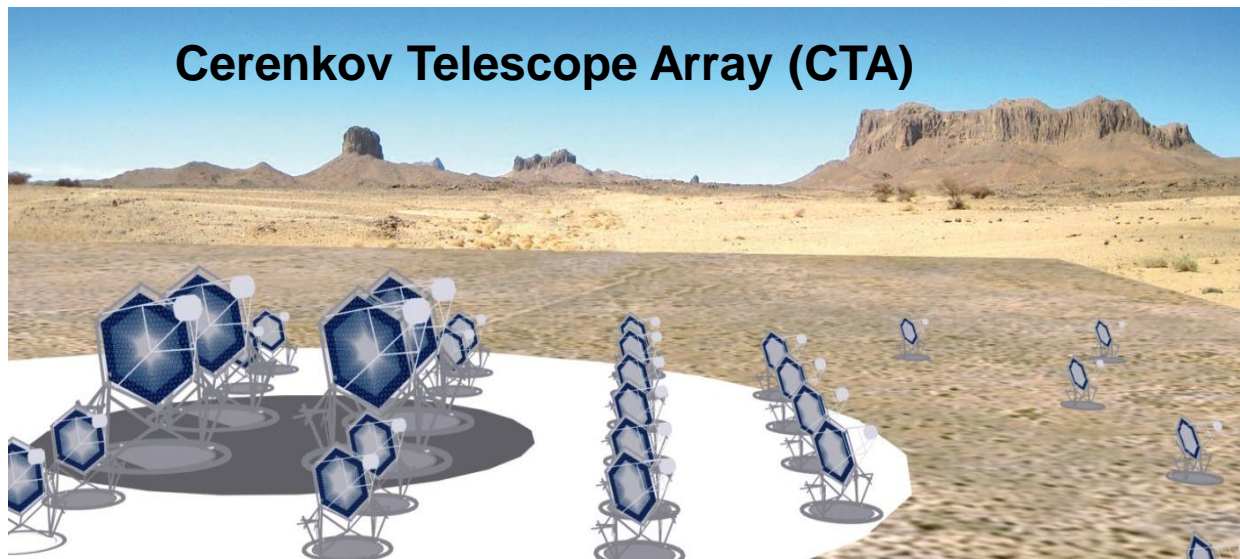


HIGH ENERGY EMISSION FROM BLACK HOLES & NEUTRON STARS

Mirabel (Perspective article in Science, 2006)



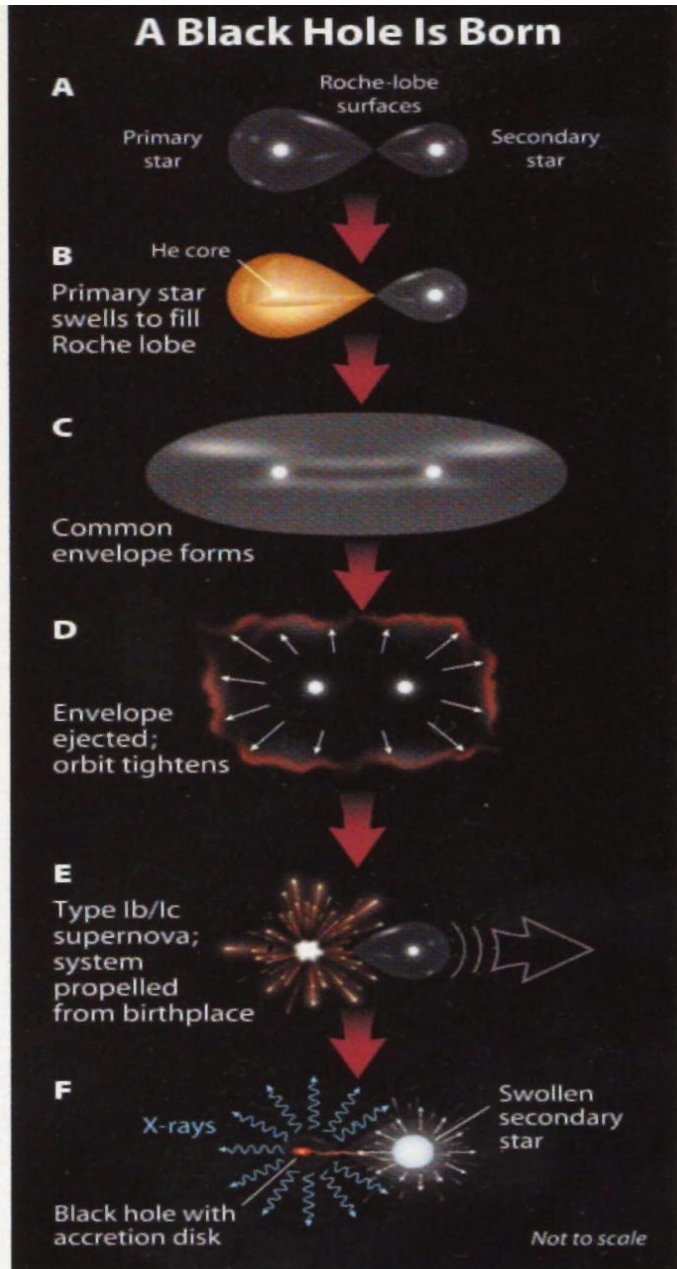
Cerenkov Telescope Array (CTA)



Argentina and Namibia as possible countries to host this international observatory

CEA-Saclay evaluates the infrastructure for CTA

HOW ARE STELLAR BLACK HOLES FORM ?



BY CORE COLLAPSE OF MASSIVE STARS:

DELEYED VERSUS DIRECT COLLAPSE AS A
FUNCTION OF THE MASS OF THE CORE:

BUT THERE WERE NO OBSERVATIONS

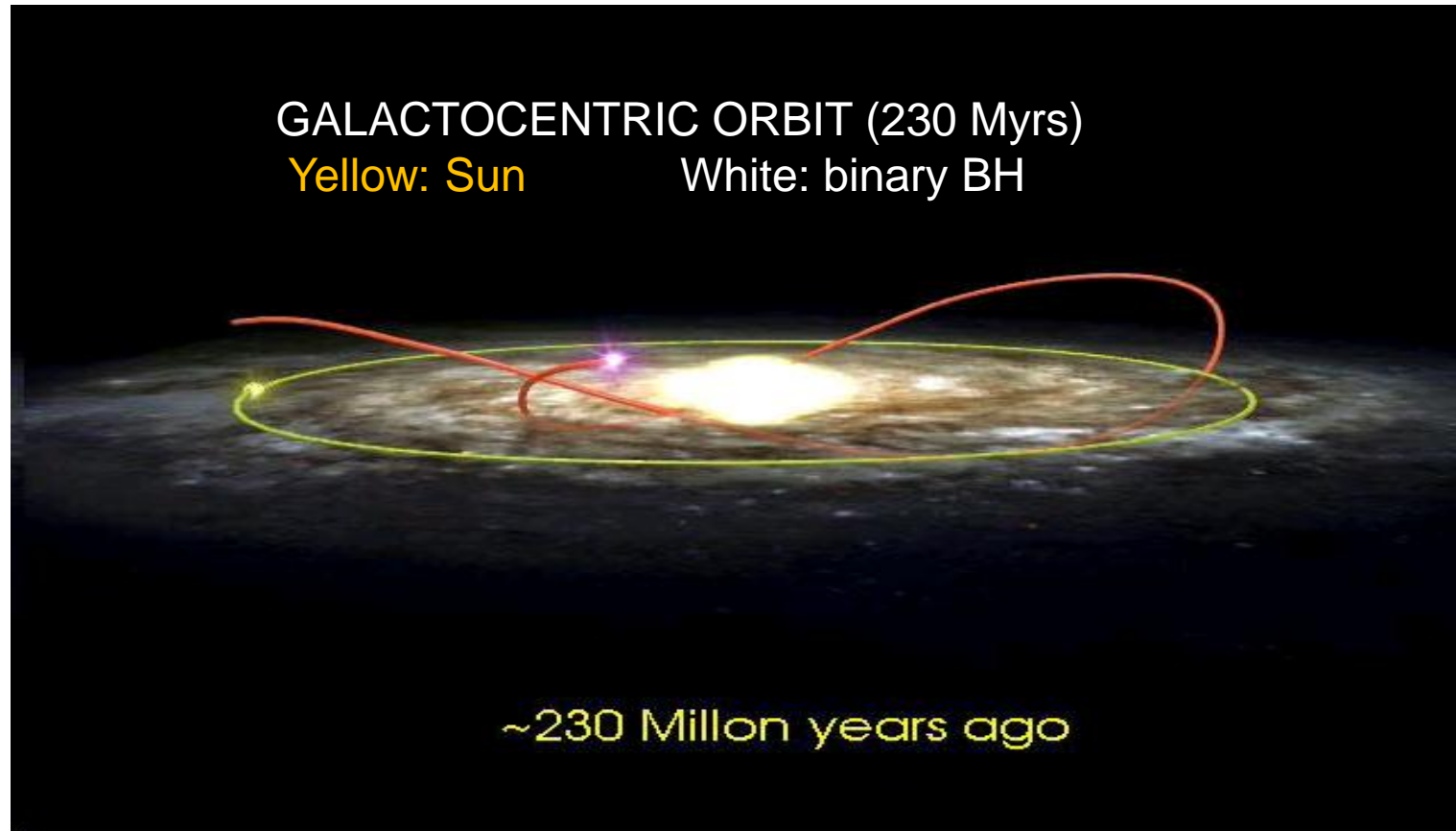
Mirabel & Irapuan Rodrigues (2001-2009)

USED THE KINEMATICS OF μ QSOs AS TESTS

RUNAWAY BLACK HOLES

XTE J1118+480 $M_{\text{BH}} \sim 7 M_{\odot}$ $M_* \sim 0.4 M_{\odot}$ $V_p = 145\text{-}210 \text{ km/s}$

Mirabel, Dhawan, Rodrigues et al. (Nature, 2001)



THE TWO BHs WITH $5\text{-}7 M_{\odot}$ DID NOT
REMAIN IN THEIR BIRTH PLACE



31 DECEMBER 1995

THE CANNIBAL STAR

Pictures from the Hubble telescope of a black hole swallowing an entire galaxy have revealed how the Earth, too, may one day be swallowed up

1 The black hole is surrounded by an 'accretion disc' of dust, gas and stars spiralling into the hole at near light speeds

2 The disc around the black hole is so big that it is 600 light years across. By contrast, light takes just 12 hours to cross our solar system

Black hole centre has moved 20 light years

3 Giant plumes of gas, generated as matter is swallowed, are driving the black hole from the centre of the disc. Astronomers estimate it has moved 20 light years since the galaxies collided

The Hubble space telescope can see objects which our atmosphere renders invisible to earth-bound telescopes

Images produced by Hubble show a huge disc of gas, seen at an oblique angle, whirling around a black hole

The view from Earth

The stars surrounding the black hole lie in the direction of the Virgo constellation and are visible in the northern sky. Their light has taken 100m years to reach us

Graphics by Chris Goggin and Ian Moore

Killer black hole cruises universe devouring stars

THE PUBLICATION IN NATURE
OF RUNAWAY BLACK HOLES

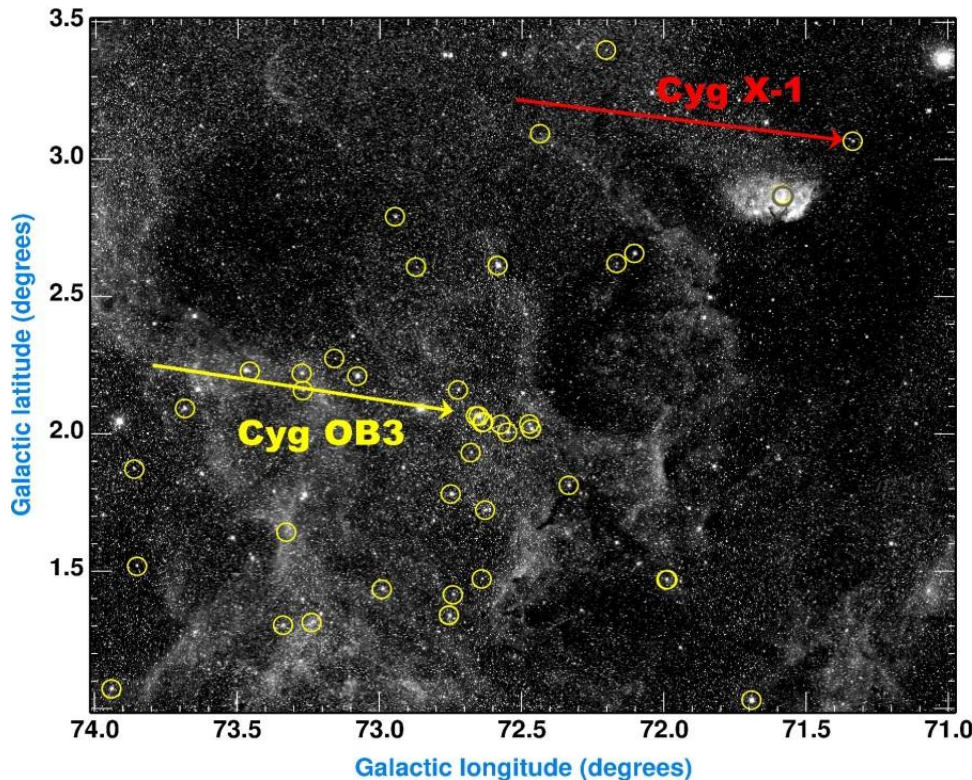
REINFORCED THE
HOLLIWOOD VIEW OF

BLACK HOLES AS

“CANNIBAL STARS”

BLACK HOLES WITH $>10 M_{\odot}$ FORMED IN THE DARK

Mirabel & Rodrigues (Science, 2003)



$V_p < 9 \pm 2 \text{ km/s} \Rightarrow$
 $< 1 M_{\odot}$ ejected in a SN

Otherwise it would have been shot out
from the parent stellar association

**THE $\sim 14 M_{\odot}$ BH IN Cyg X-1 WAS
FORM BY DIRECT COLLAPSE**

GRS 1915+105: $V_p=50-80 \text{ km/s}$ & $W=7\pm 3 \text{ km/s}$ (Dhawan, Mirabel, Rodríguez 2001)

V404 Cyg: $V_p= 45-100 \text{ km/s}$ & $W = 0.2\pm 3 \text{ km/s}$ (Miller-Jones et al. 2009)

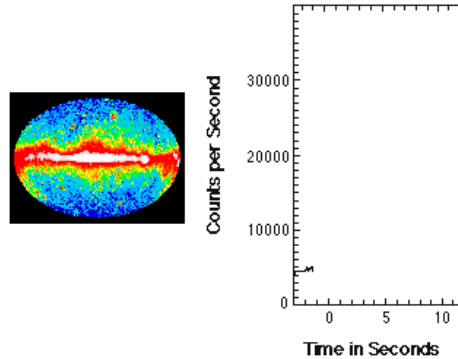
BLACK HOLES with $>10 M_{\odot}$ FORM BY DIRECT COLLAPSE

GAMMA-RAY BURST = FORMATION OF STELLAR BLACK HOLES

THE MOST ENERGETIC EXPLOSIONS AFTER THE “BIG BANG”

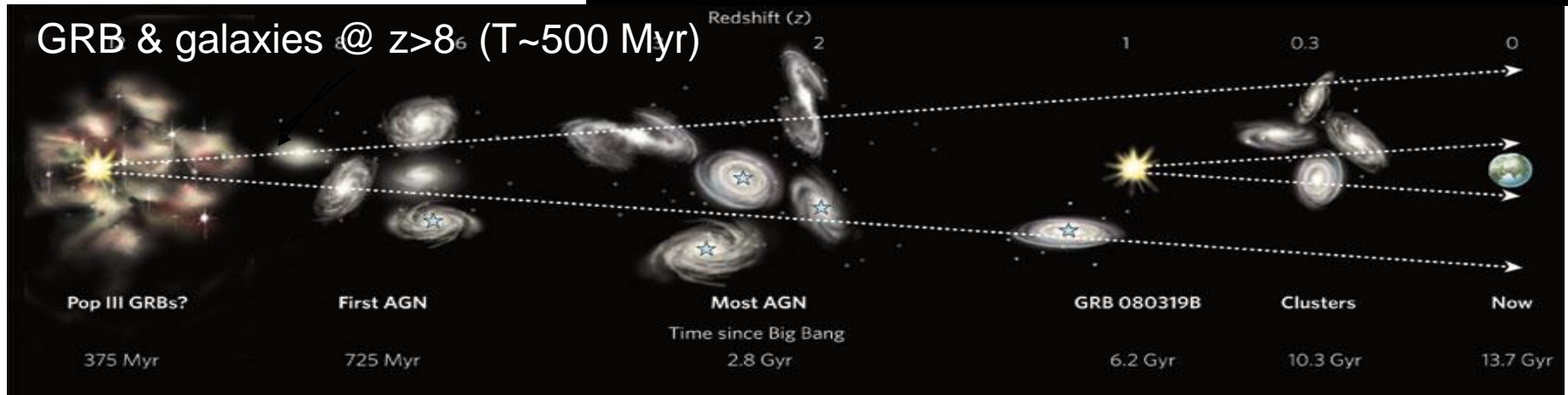
Stellar collapse & super-relativistic jets

Associated to Hiper-novae (SNe Ic)



or by implosion (Mirabel & Rodrigues, Science)

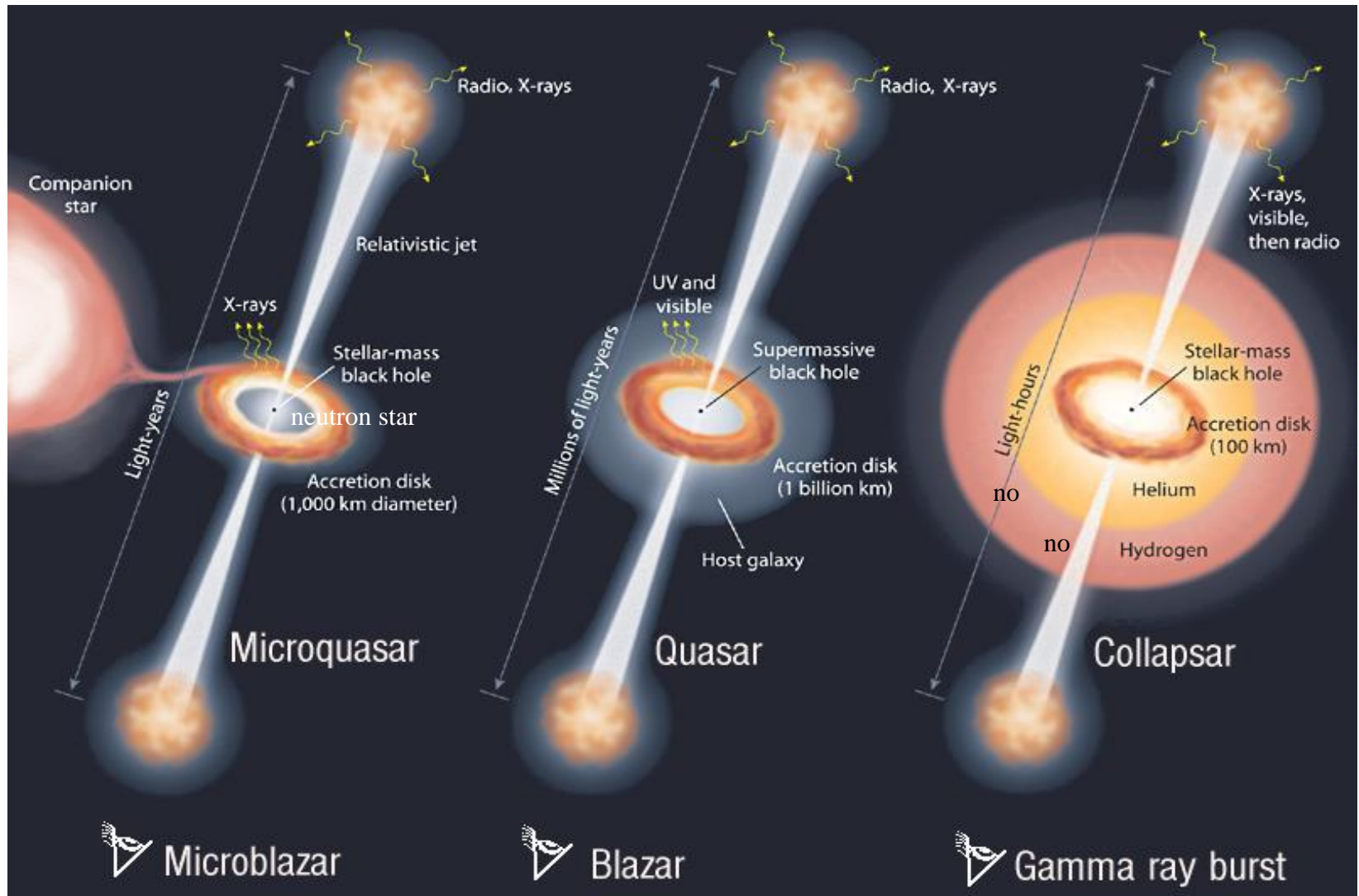
GRB & galaxies @ $z > 8$ ($T \sim 500$ Myr)



Universal time line since the formation of the first stars

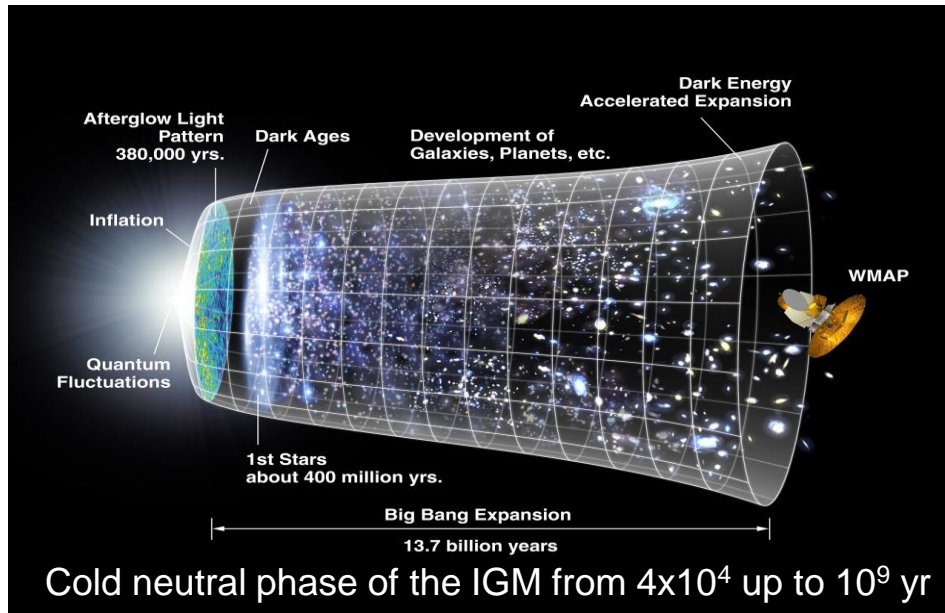
QSO - μ QSO - GRB ANALOGY

HAVE THE SAME 3 BASIC INGREDIENTS (Mirabel & Rodríguez, S&T 2002)

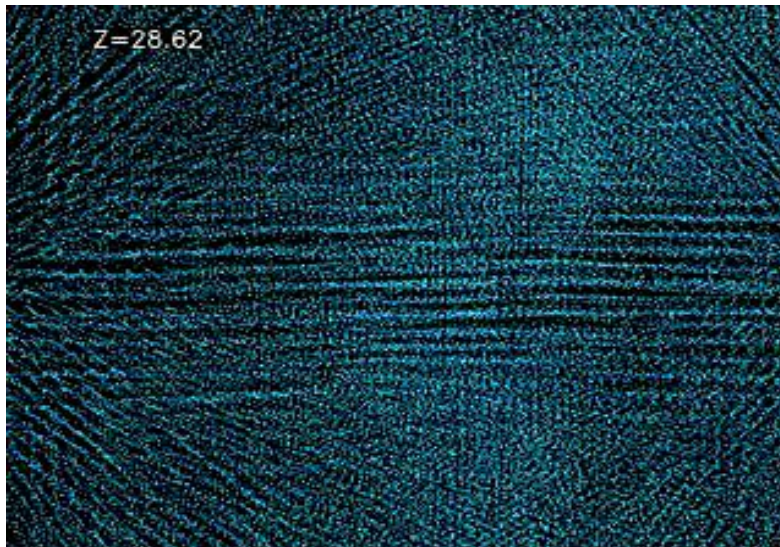


AN UNIVERSAL MAGNETO-HYDRODYNAMIC MECHANISM FOR JETS ?

STELLAR BLACK HOLES AT THE DAWN OF THE UNIVERSE



Cold dark matter model



THE « SWISS CHEESE » MODEL

Localized in individual Stromgren spheres

- Presently, the cosmology community assumes that the IGM was fully ionized by the UV from the first stars (Pop III & II)
- I proposed that at $z > 8$ there has been a large population of Black Holes, which played an important role that has so far been overlooked.

Merci de votre attention!