
Supermassive
Black
Holes
and
Low-Frequency Gravitational Waves
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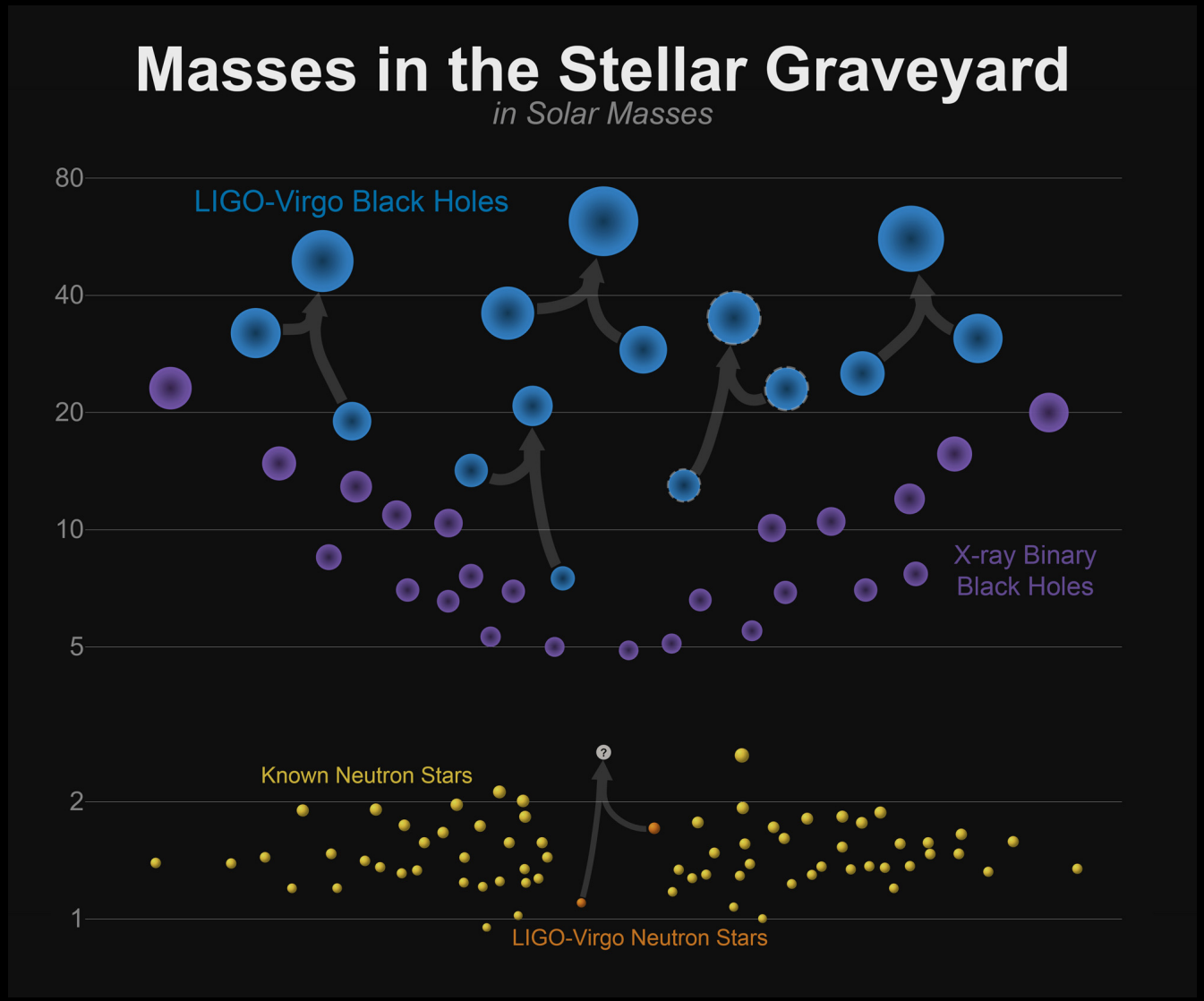
UC Berkeley

Where are black holes found?

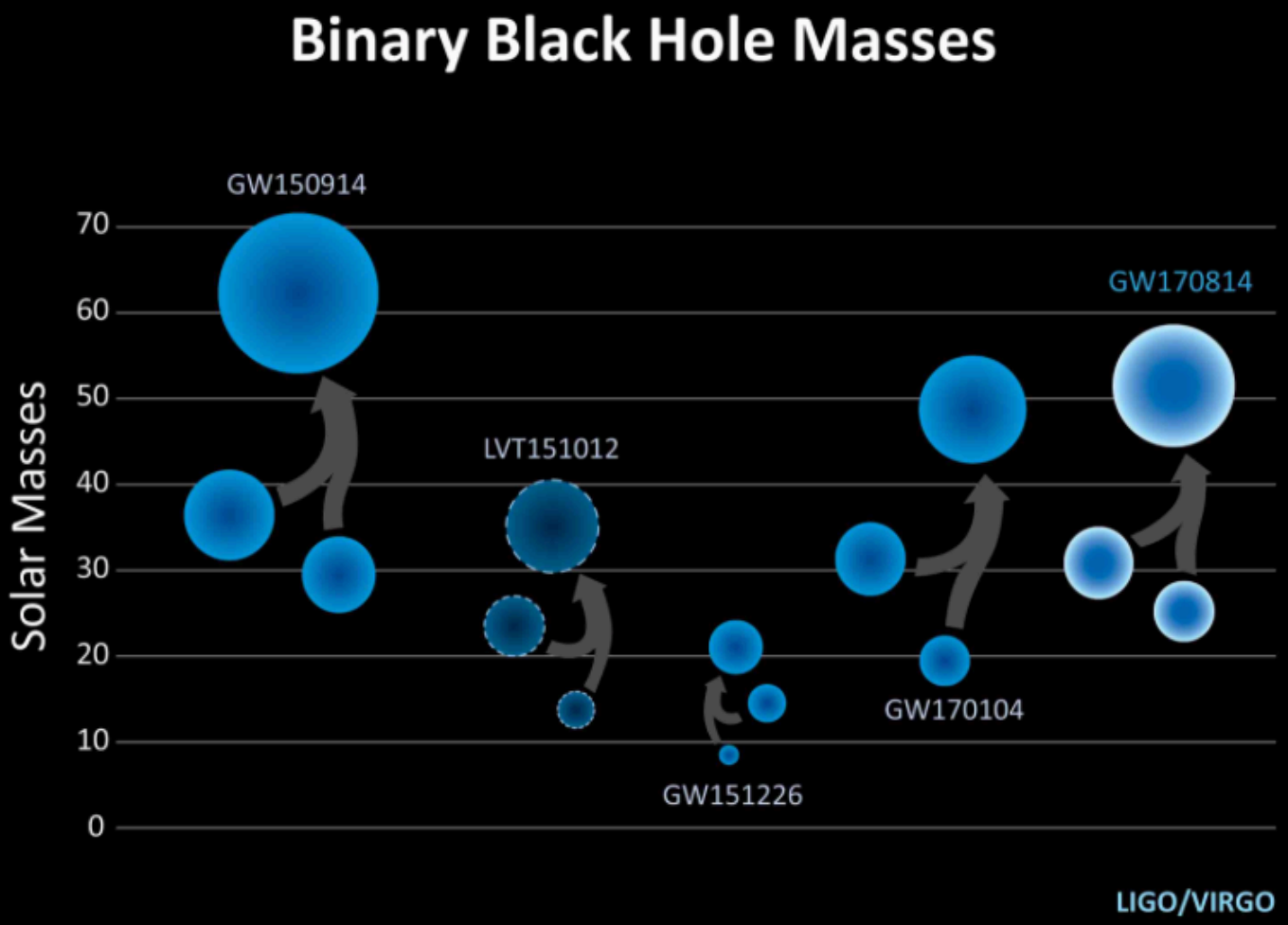
Stellar Black Holes

22 X-ray Binaries with dynamical BH masses



Stellar Black Holes

But no confirmed binary black holes until LIGO



Supermassive Black Holes

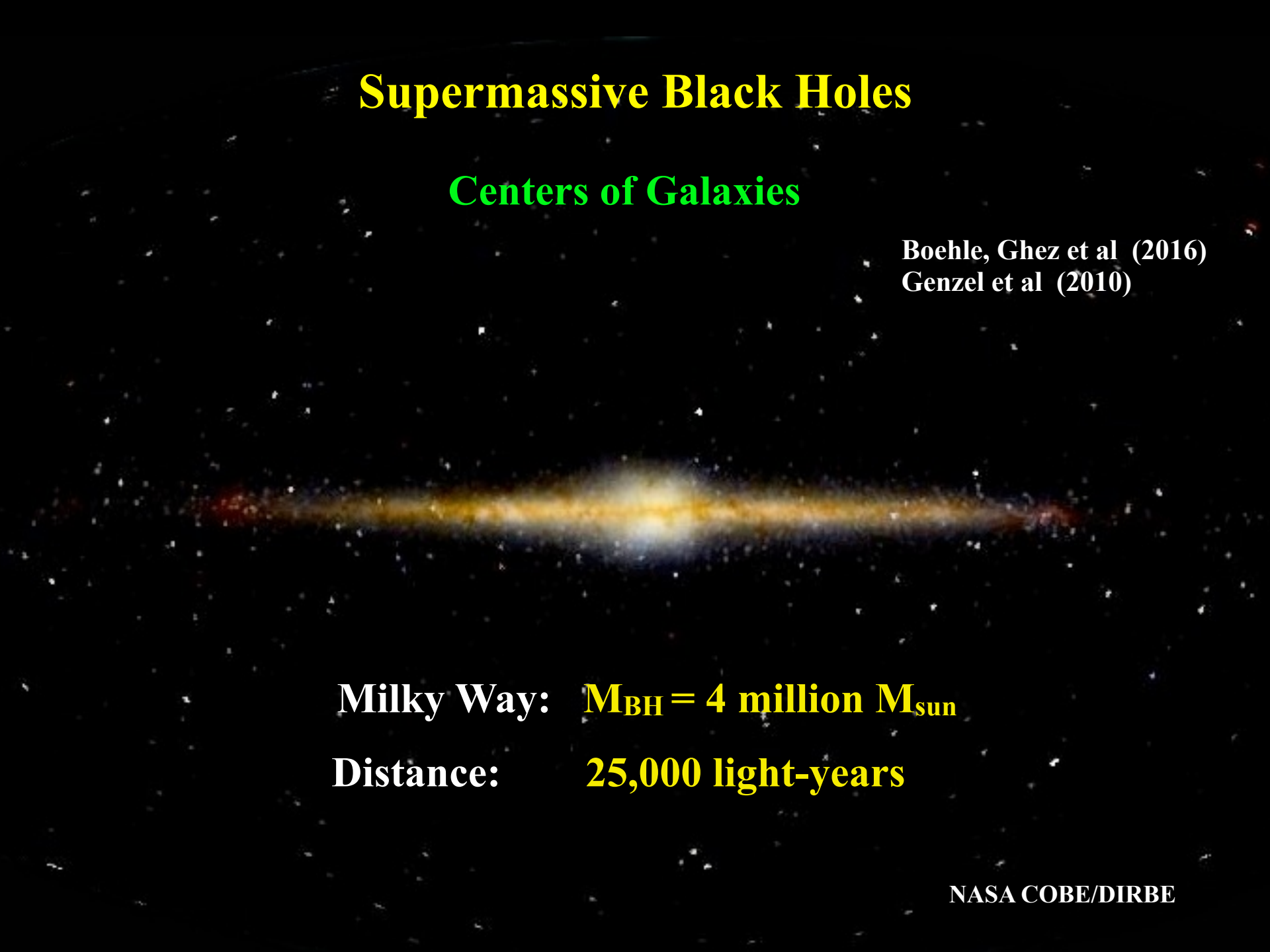
Centers of Galaxies

~100 nearby galaxies with (direct) dynamical BH masses

Supermassive Black Holes

Centers of Galaxies

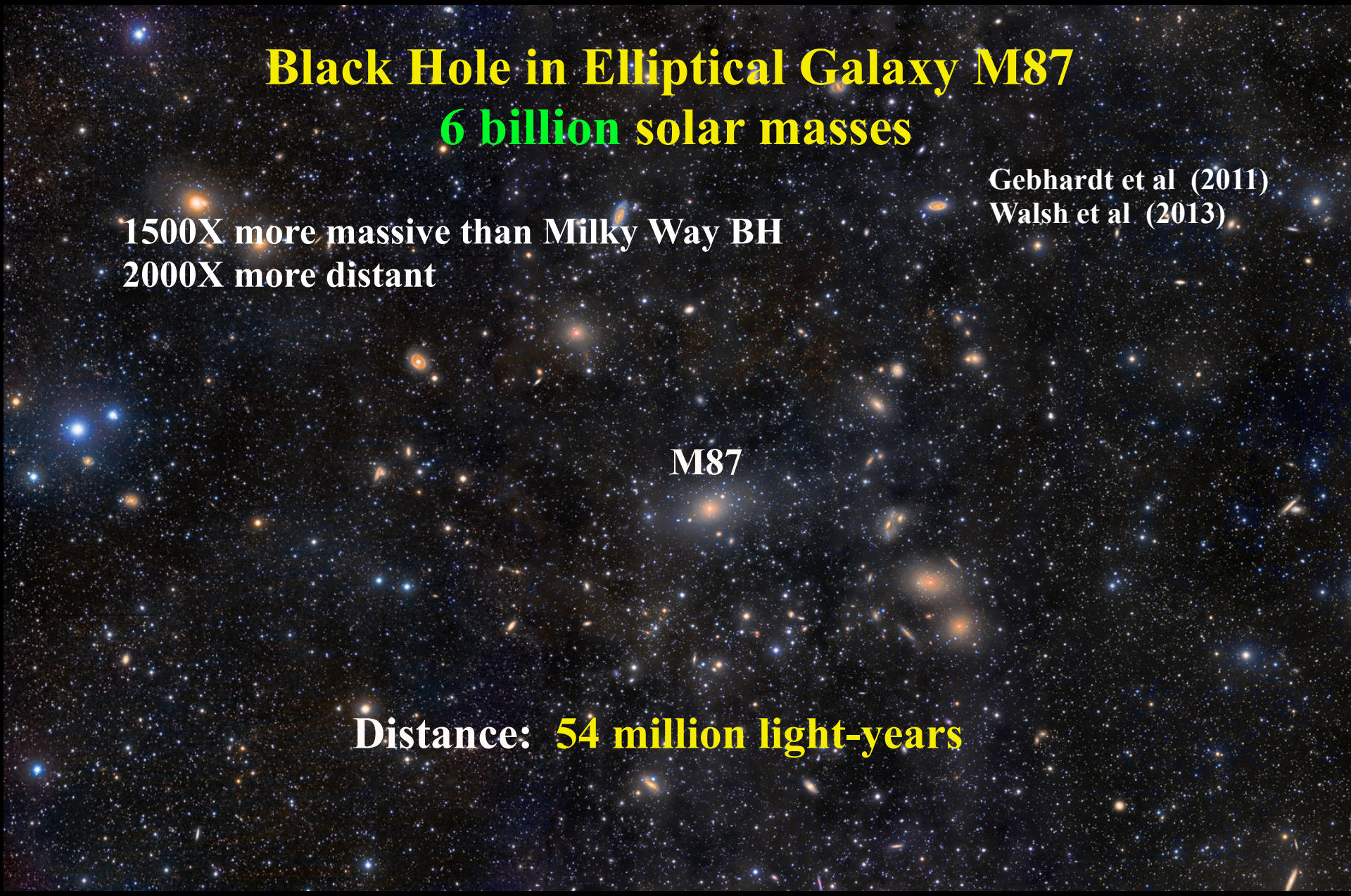
Boehle, Ghez et al (2016)
Genzel et al (2010)



Milky Way: M_{BH} = 4 million M_{sun}

Distance: 25,000 light-years

NASA COBE/DIRBE


Black Hole in Elliptical Galaxy M87
6 billion solar masses
Gebhardt et al (2011)
Walsh et al (2013)
1500X more massive than Milky Way BH
2000X more distant
M87
Distance: 54 million light-years

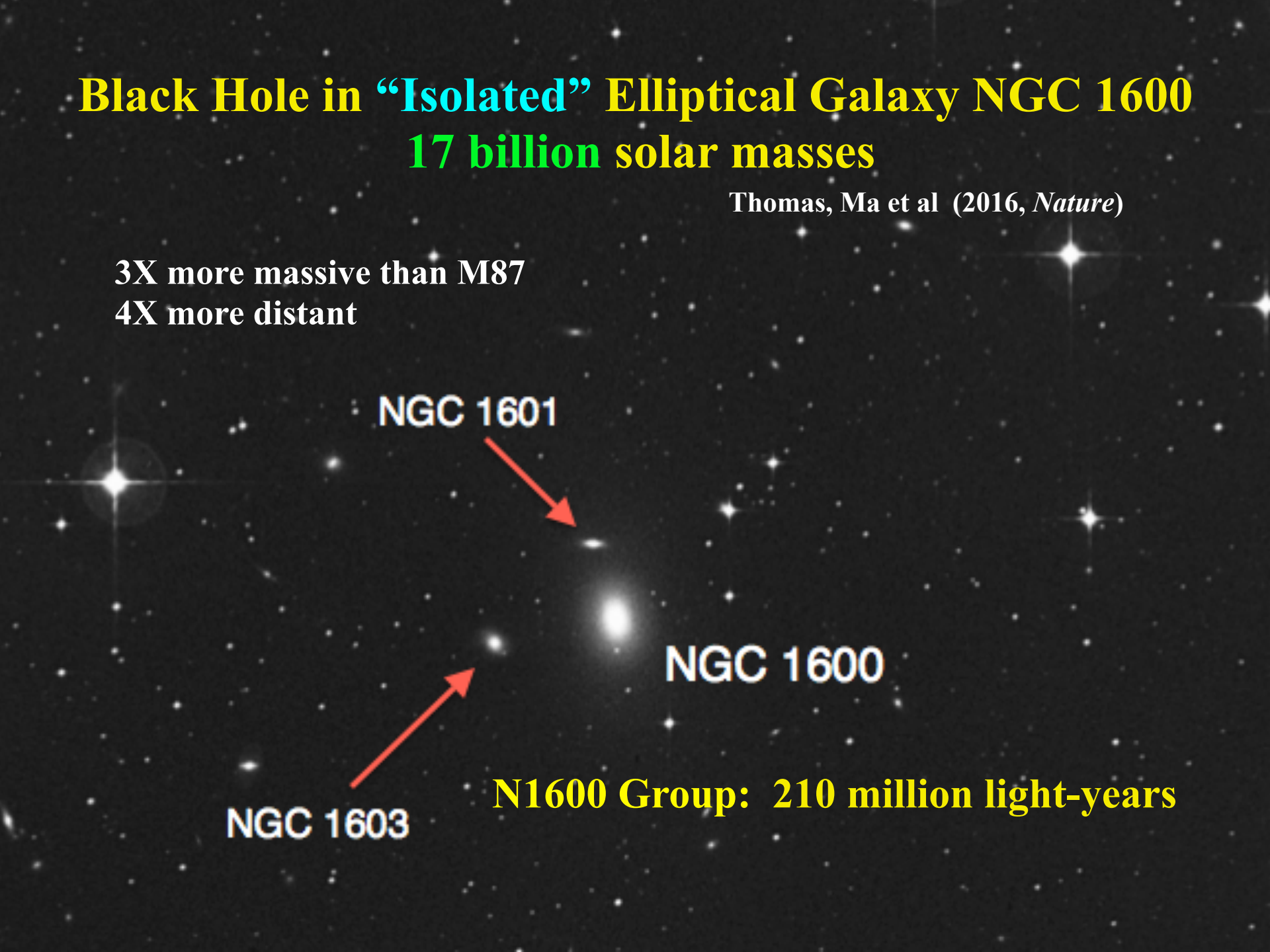
How massive do black holes get?


Black Hole in Elliptical Galaxy NGC 4889
15-20 billion solar masses
McConnell, Ma et al (2011, *Nature*)
~3X more massive than M87
6X more distant
NGC 4889
Coma Cluster: 330 million light-years

Black Hole in "Isolated" Elliptical Galaxy NGC 1600
17 billion solar masses

Thomas, Ma et al (2016, *Nature*)

3X more massive than M87
4X more distant



N1600 Group: 210 million light-years

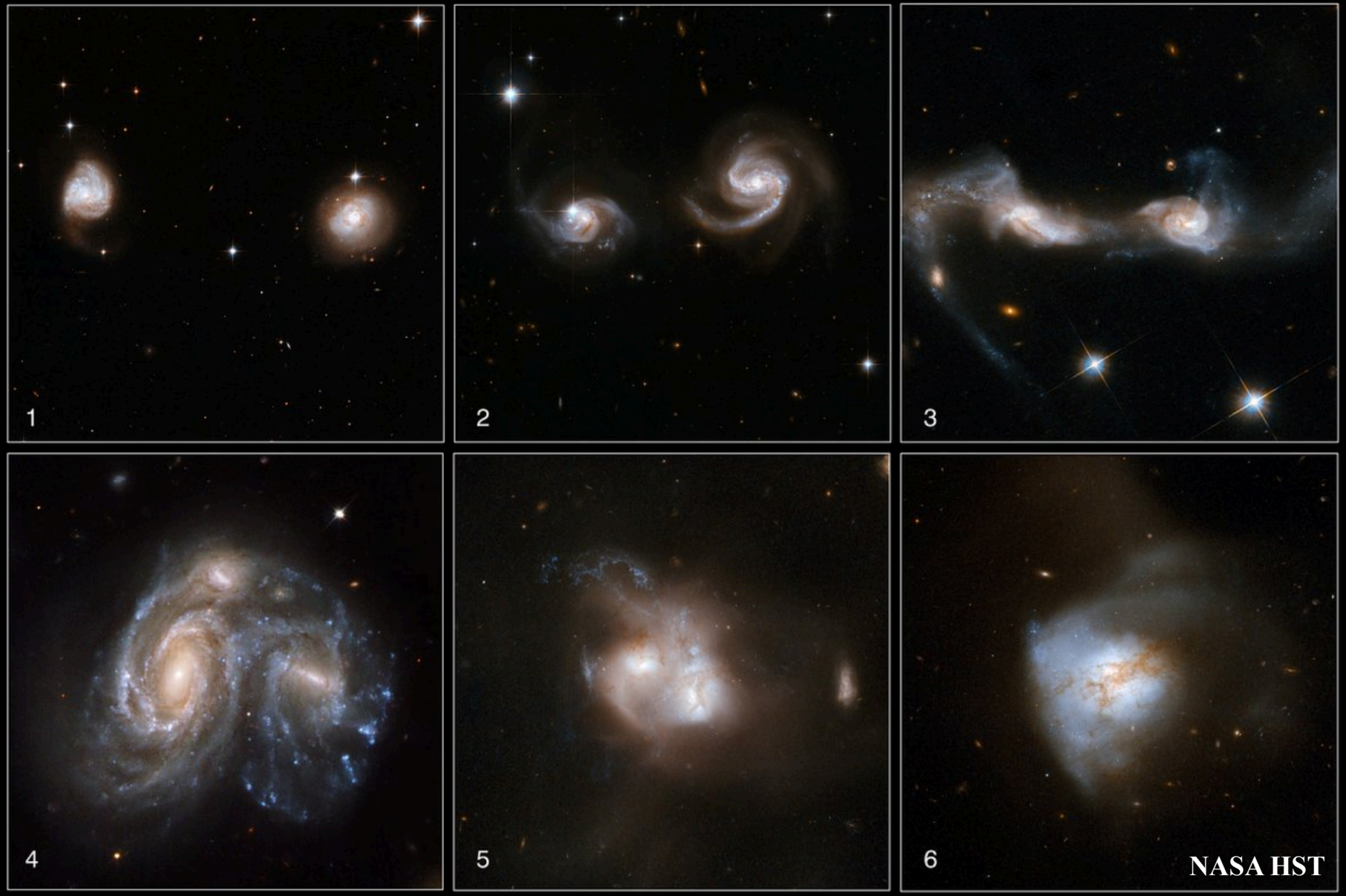
A Hefty Black Hole in a *Really* Isolated Elliptical Galaxy

No companion known within **0.5 Mpc**

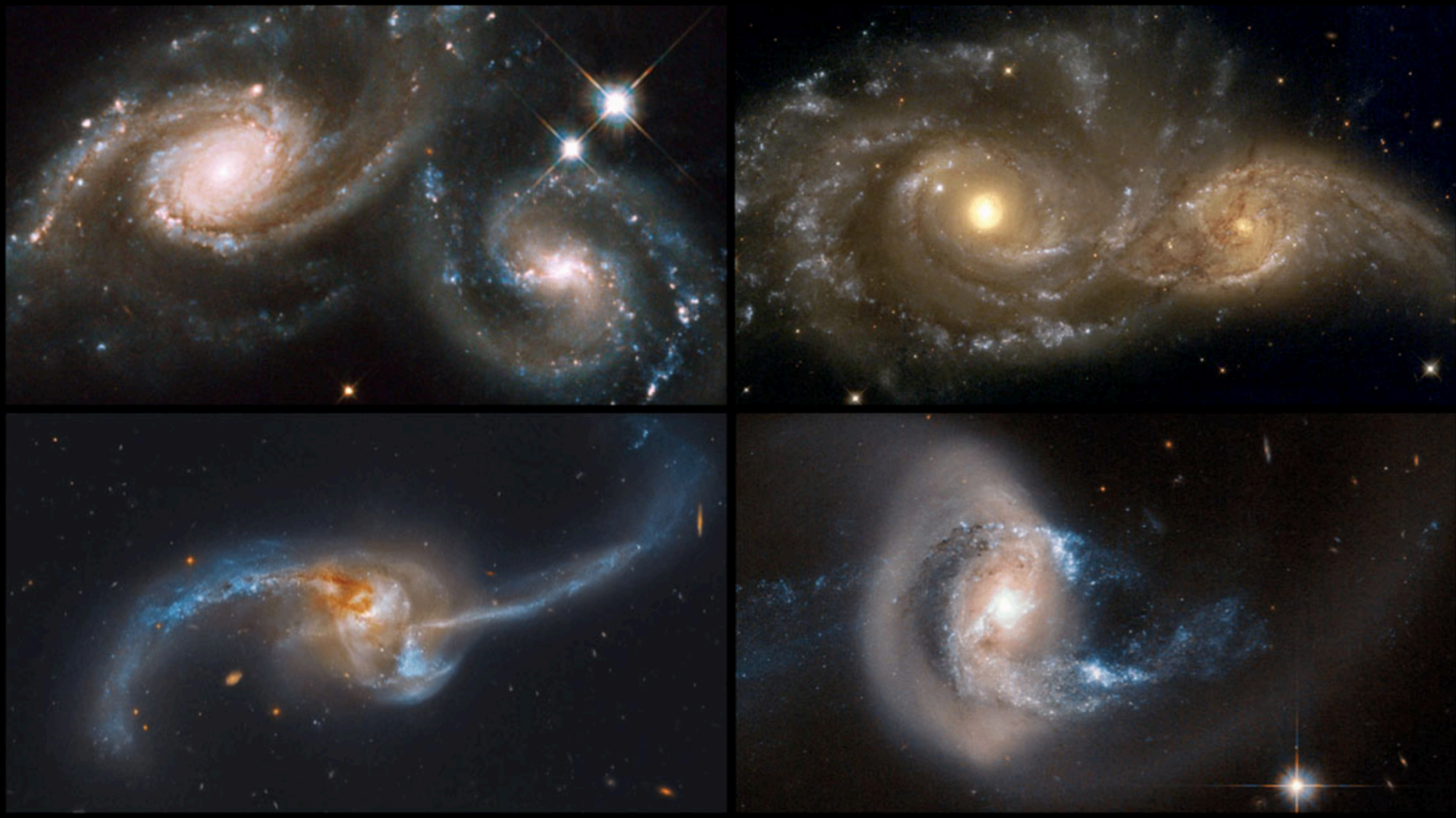
3 other galaxies within **1 Mpc**

Supermassive Black Hole Binaries?

Galaxies Grow by Mergers



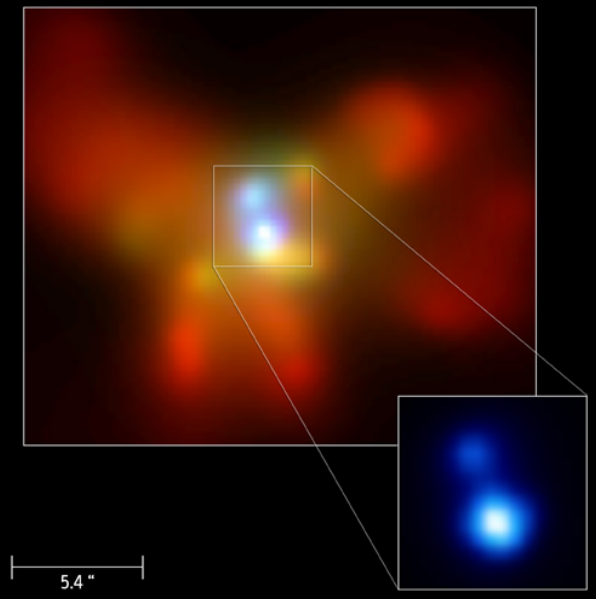
Galaxies Grow by Mergers



NASA HST

Supermassive Black Hole Binaries?

NGC 6240



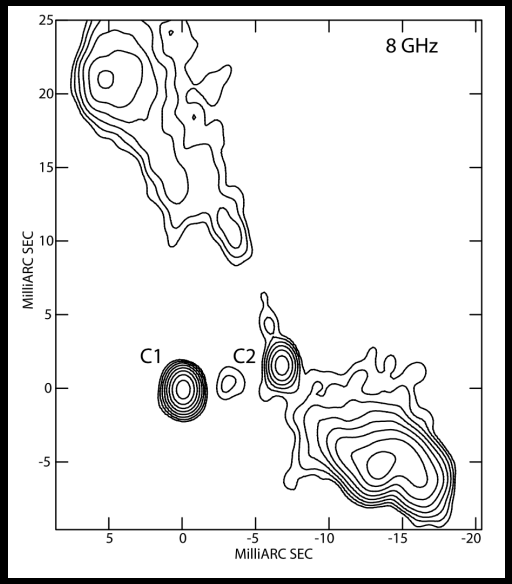
z=0.024 LIRG

Luminous hard X-ray from two cores

Separation 1.4 kpc

Komossa+ (2003)

0402+379



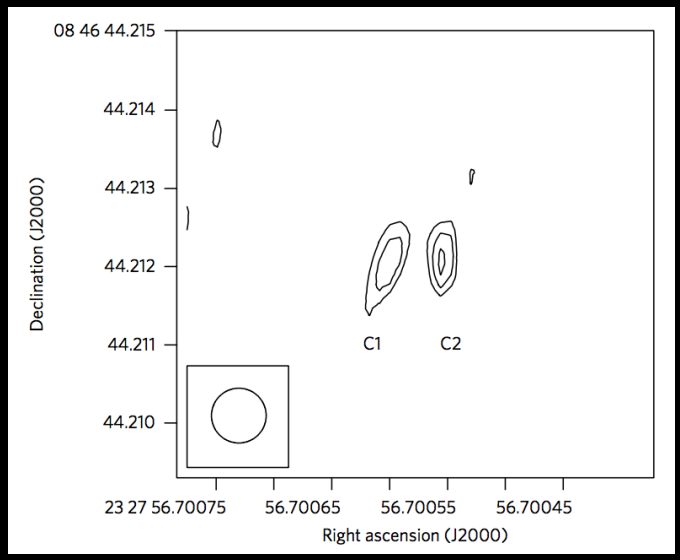
z=0.06 radio galaxy

Two compact radio cores, flat spectrum

Separation 7.3 pc

Rodriguez+ (2006)

NGC 7674



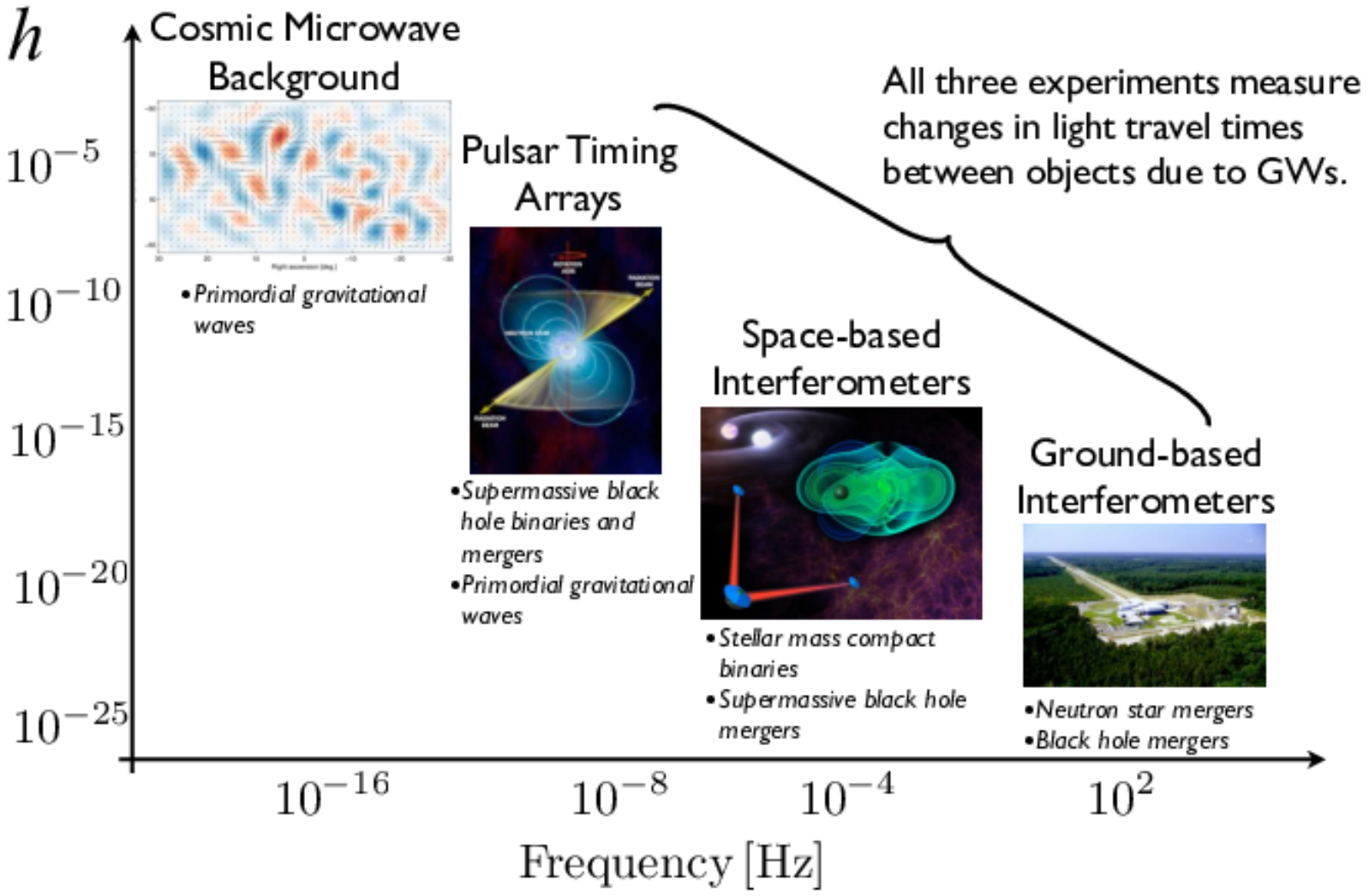
z=0.029 LIRG AGN

Two compact radio cores

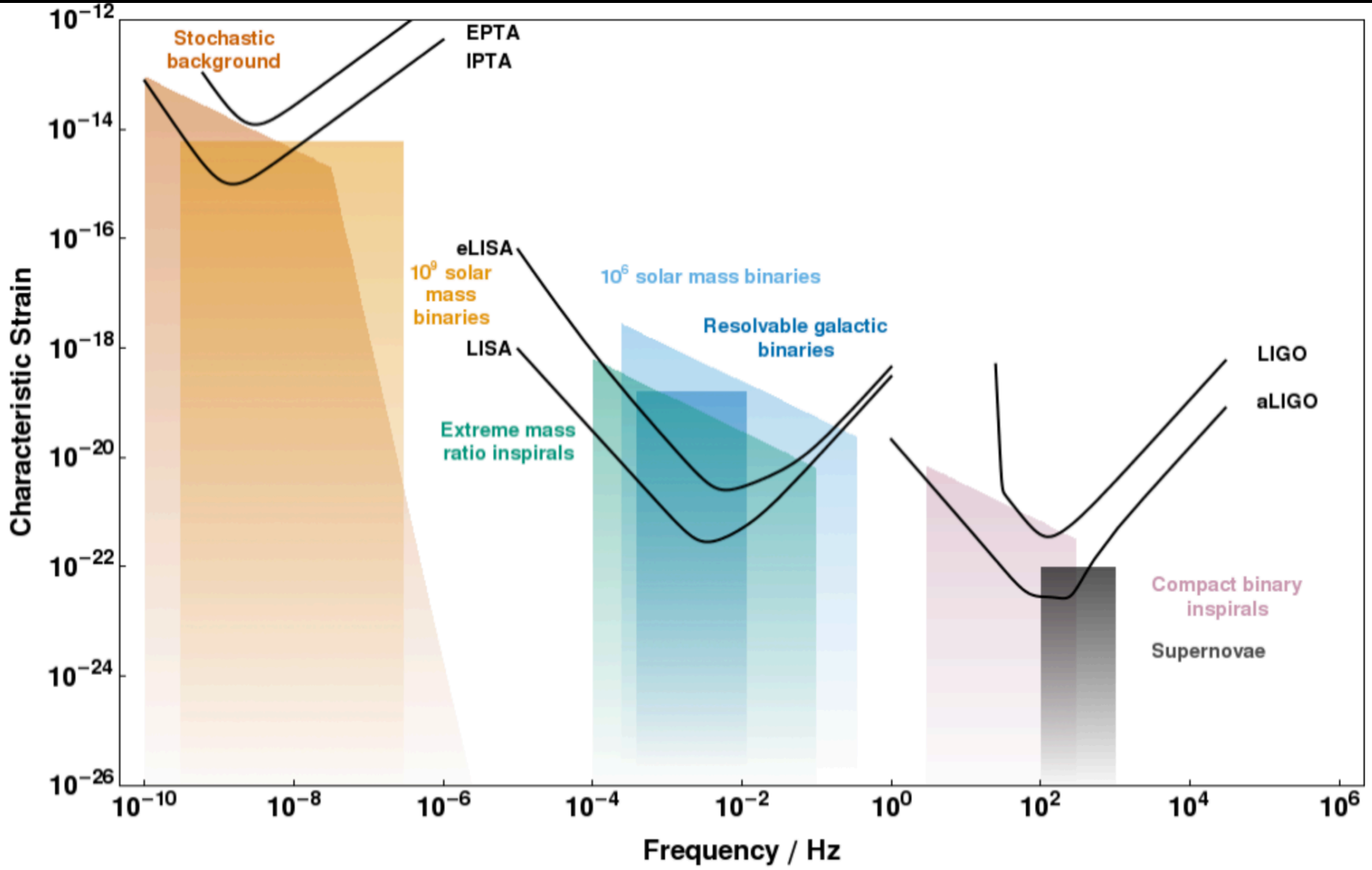
Separation 0.35 pc

Kharb+ (2017)

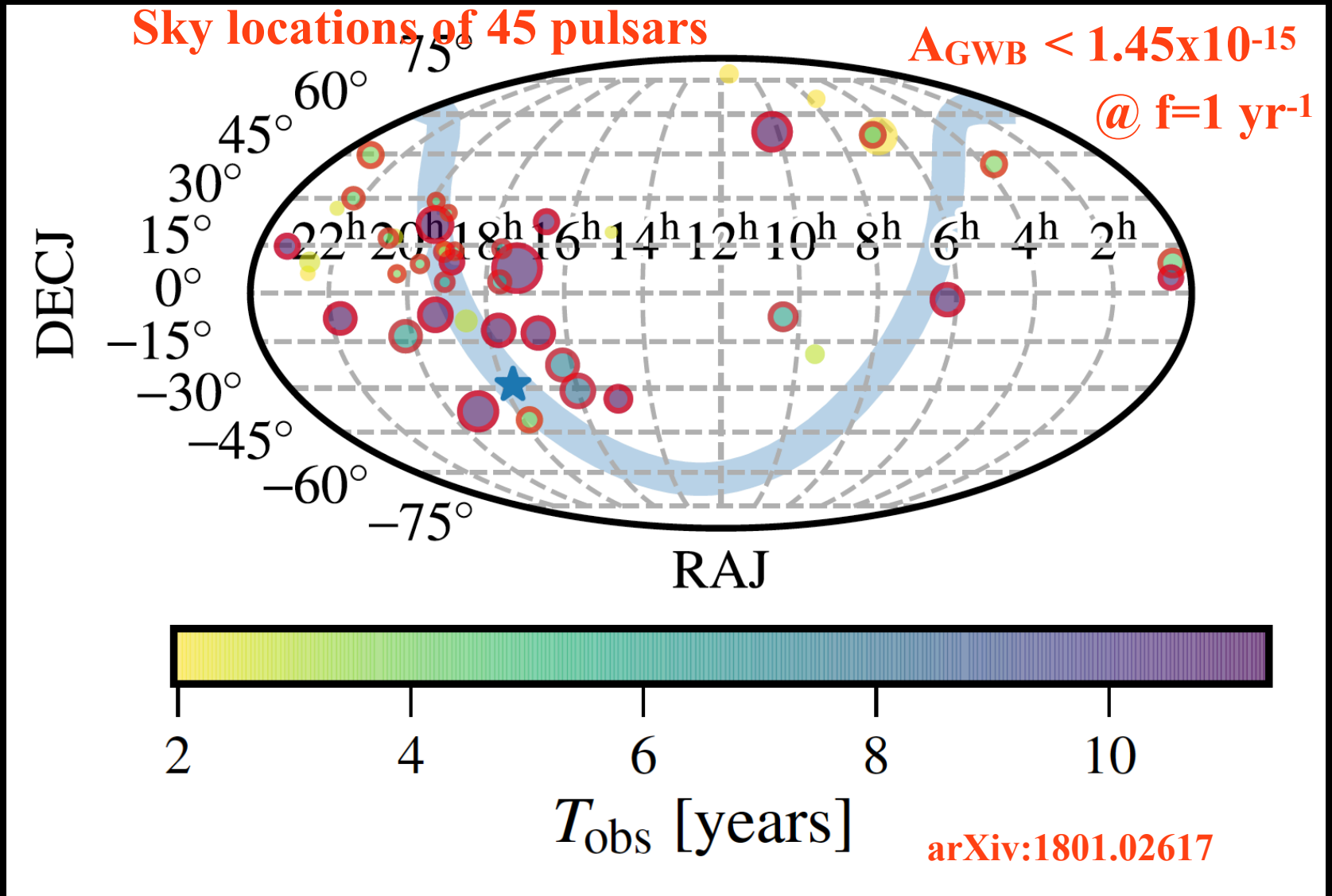
The spectrum of gravitational wave astronomy



Spectrum of Gravitational Waves



NanoGRAV (11-yr data) upper limit on stochastic gravitational-wave background



Big Questions

How massive can black holes get?

What and how are they fed?

Where do they live?

What is the mass function of supermassive black holes?

How symbiotic is their relation with host galaxies?

How do binary SMBHs evolve?

What is the gravitational-wave signal from binary mergers?

From city-sized pulsars spinning fast in galaxies to large, massive galaxies themselves and their merging central black holes, all in 50 years.

That is a large step for humankind, and not one that we could have foreseen.

What will the next 50 years bring?

Pulsars and gravitational waves will continue to be big news, I'm sure.

Jocelyn Bell

50th Anniversary of
the Discovery of Pulsars