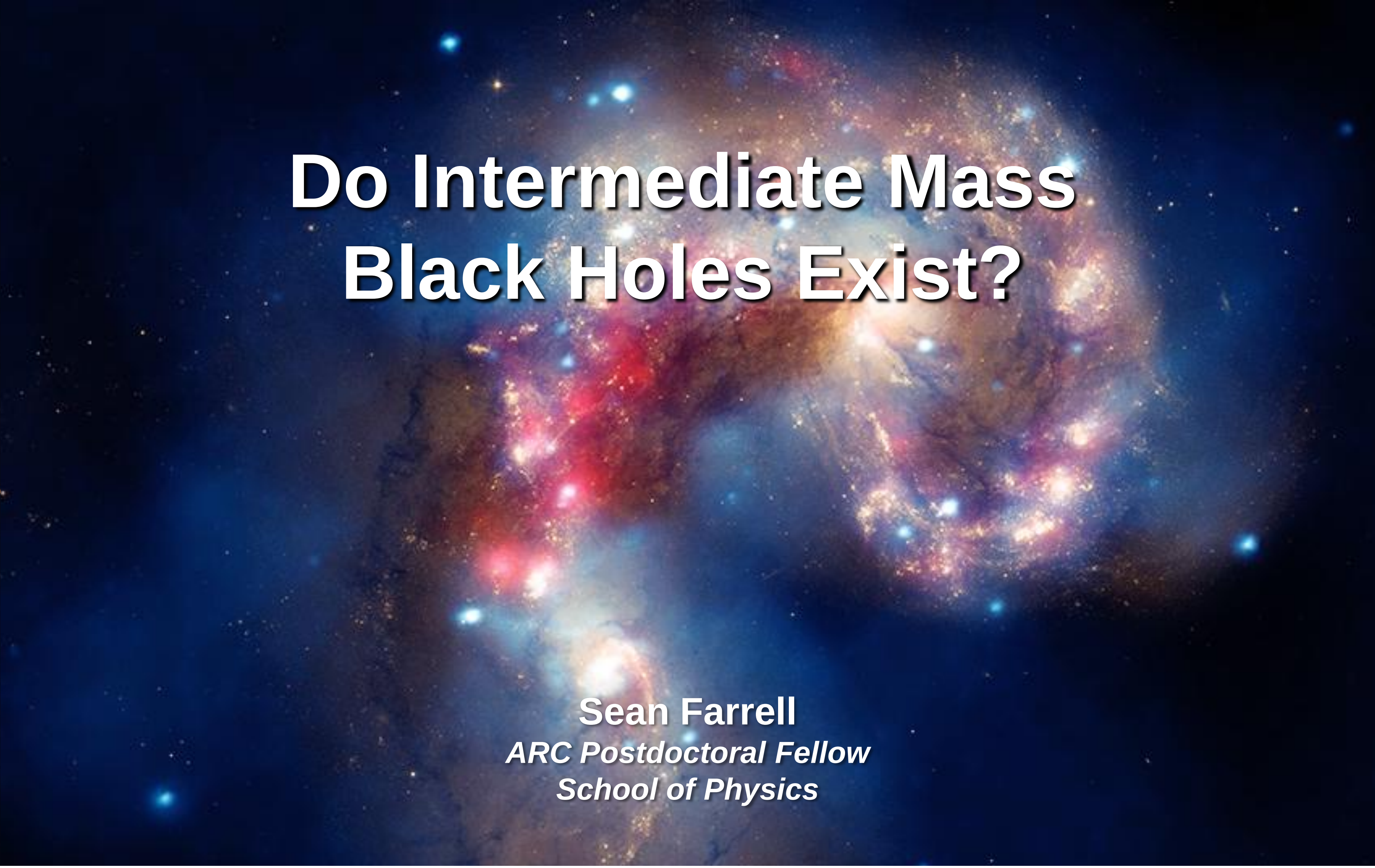
Do Intermediate Mass Black Holes Exist?



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About Me

1996 – 2002: Undergraduate degrees in Mech. Eng. & Physics at U. Newcastle

2002 – 2003: Worked for 2 years as Maintenance Engineer at Aluminium smelter

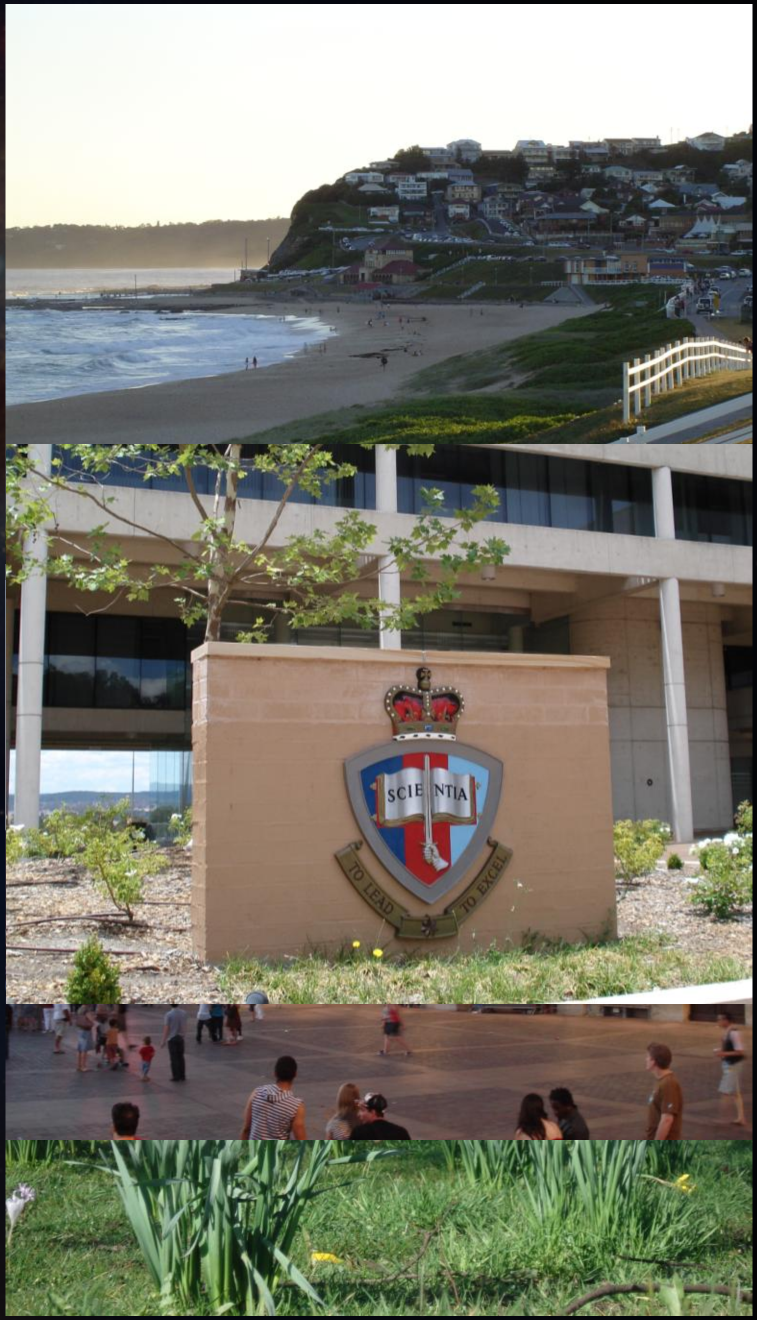
2003 – 2004: Travelled around Norway & Europe

2004 – 2006: PhD in High Energy Astrophysics at UNSW@ADFA in Canberra

2007 – 2008: Postdoc at the CESR in Toulouse, France, working on XMM-Newton catalogue

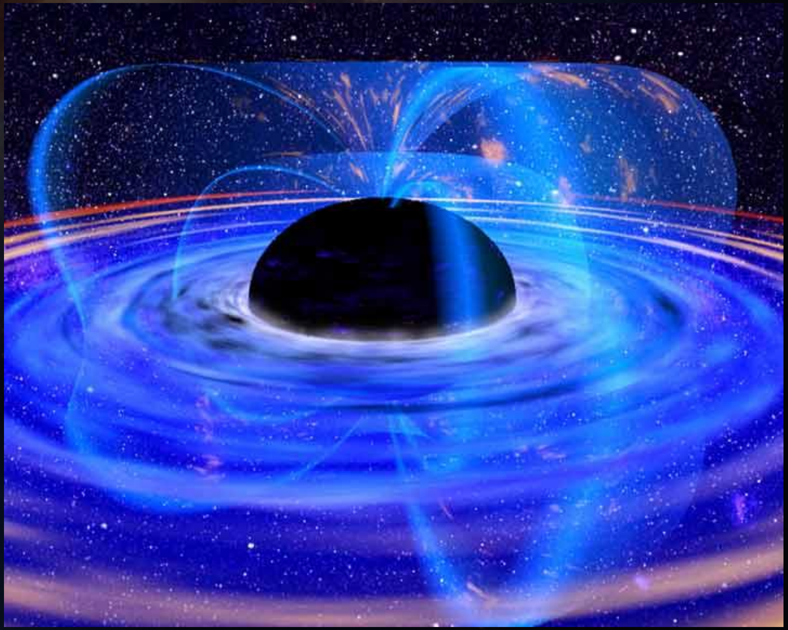
2009 – 2010: Postdoc at U. of Leicester in the UK, working as catalogue scientist for XMM Survey Science Centre

2011 – Present: ARC postdoctoral fellow at USyd



WHAT ARE BLACK HOLES?

- Black holes are objects with definite mass but no volume, therefore infinite density
- Only 3 physical parameters: mass, spin, and charge (latter can't be measured)
- Black holes ~1-100 million times the mass of the Sun found in the centres of most (maybe all) galaxies
- Lighter mass black holes ~3-30 times the mass of the Sun found in binary star systems
- What about black holes with masses between these classes ("intermediate mass")?



Artist's impression of a black hole

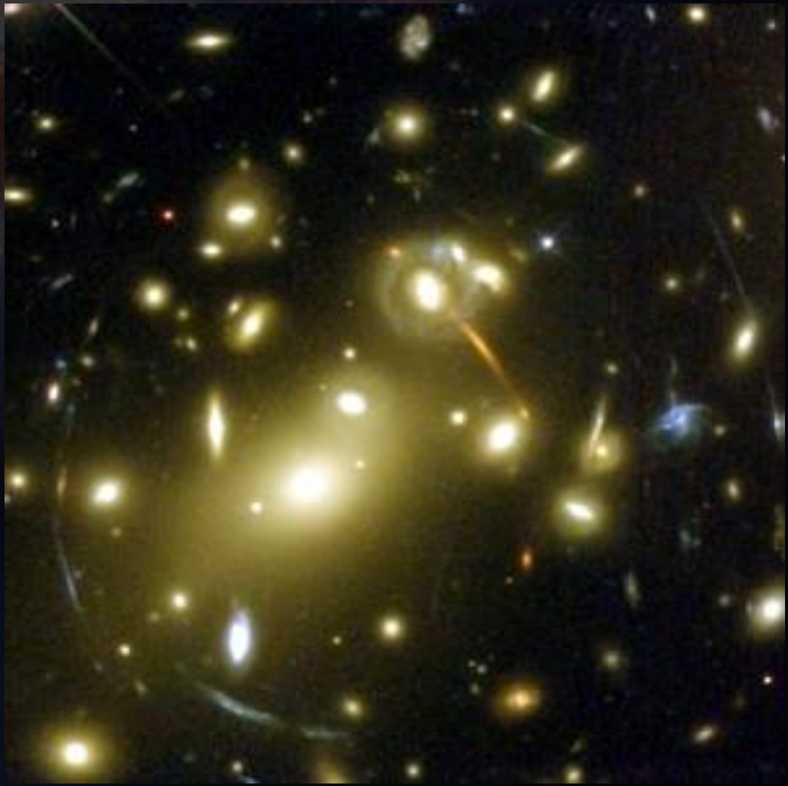
HOW CAN WE "SEE" BLACK HOLES?

- Black holes are so dense even light cannot escape from their field, so need indirect methods to detect them:

1. Gravitational lensing (distortion of background light by gravitational field)

2. Motion of stars around "invisible" object (can use Kepler's laws to determine mass)

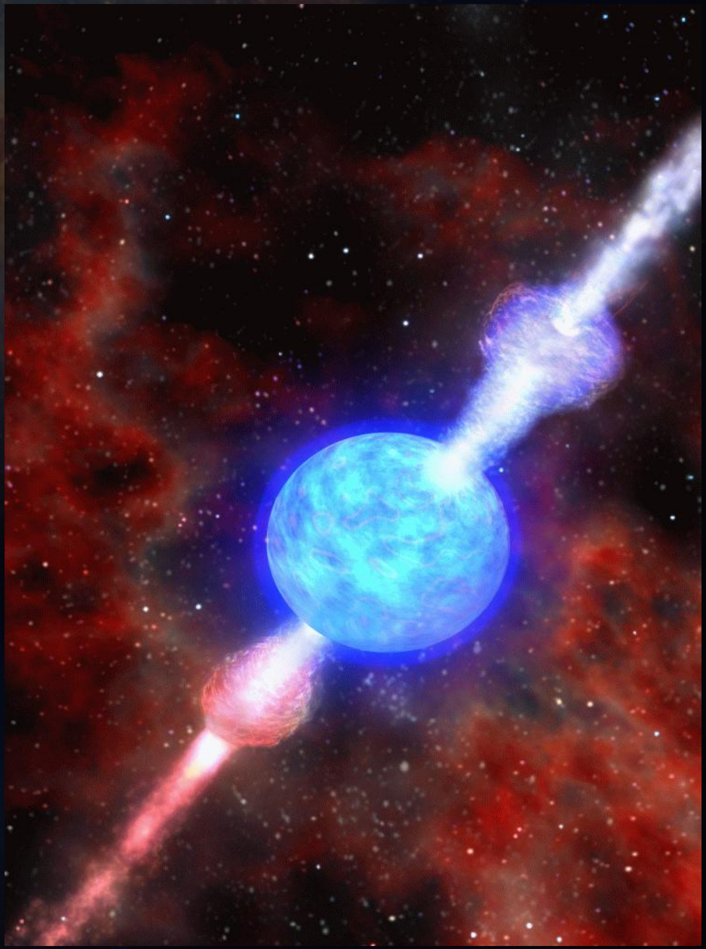
3. Accretion of matter produces copious amounts of radiation (most efficient energy production process known)



Gravitational lensing by foreground black hole

HOW DO BLACK HOLES FORM?

- When massive star runs out of fuel, it will collapse then explode as a supernova
- If mass of core >~ 3 Solar masses, star will collapse into black hole with mass ~3-30 Msun
- Its not known how super-massive black holes form. Possible they formed shortly after Big Bang, with galaxies forming around them
- Alternative: they could form through merger of lighter black holes (through an *intermediate mass* stage)


Artist's impression of a supernova

BLACK HOLE ACCRETION

- Matter falling into a black hole forms a disc to conserve angular momentum

- Viscous effects transfer angular momentum from inner to outer regions of disc

- Material in the inner regions spirals inwards

- Friction heats gas, with temperature increasing as orbital radius decreases

- Radiation produced in a broad spectrum, from optical to X-ray wavelengths

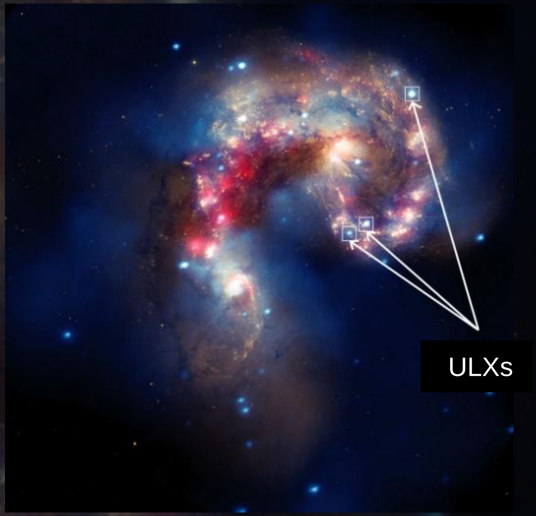
- Luminosity depends on mass of black hole

M 104 – the Sombrero galaxy

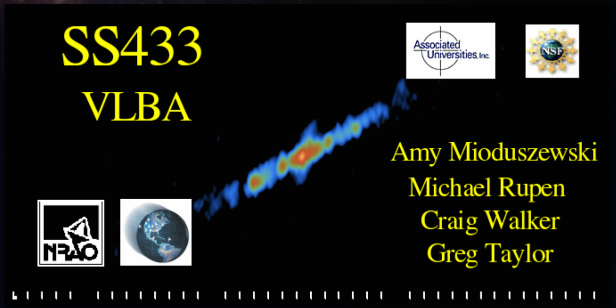
M 31 – the Andromeda galaxy

ULTRALUMINOUS X-RAY SOURCES

- X-ray sources located in distant galaxies but outside galaxy nucleus (so not central engine)
- X-ray luminosities much higher than could be produced by stellar mass black hole, but lower than super-massive black hole
- Alternative explanations for most ULXs: extreme accretion onto stellar mass black hole or "beamed" emission (i.e. jets)
- Most extreme ULXs cannot be explained without a black hole with mass ~100 -100,000 Msun (i.e. *intermediate mass black holes*)



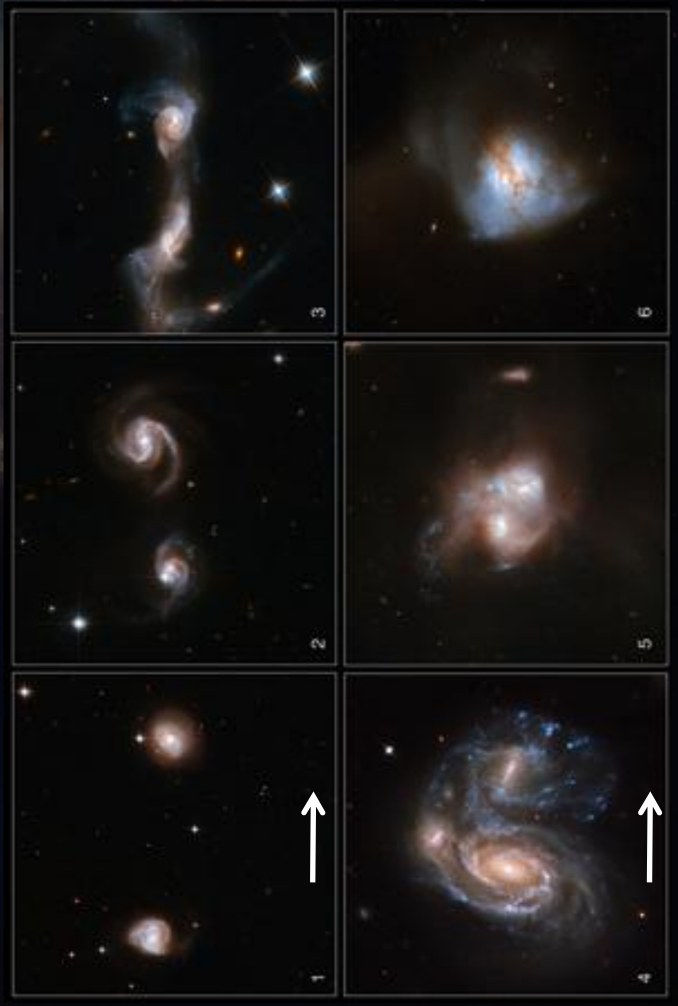
Antennae galaxies



Radio jets from a microquasar

HOW DO YOU FORM AN IMBH?

- Collapse of very massive Hydrogen star could produce black hole mass of ~100-200 Msun
- Otherwise need dense environment in order to feed a black hole enough fuel to reach ~1,000-100,000 Msun
- Problem is not so much feeding it, but how do you *stop* it from growing to be super-massive?
- Simple solution: put it in an environment that is very dense but has limited fuel (i.e. mass)
- Possible environments: massive star clusters, globular clusters, or *dwarf galaxies*
- Merger of dwarf galaxy with larger galaxy could produce an extreme ULX

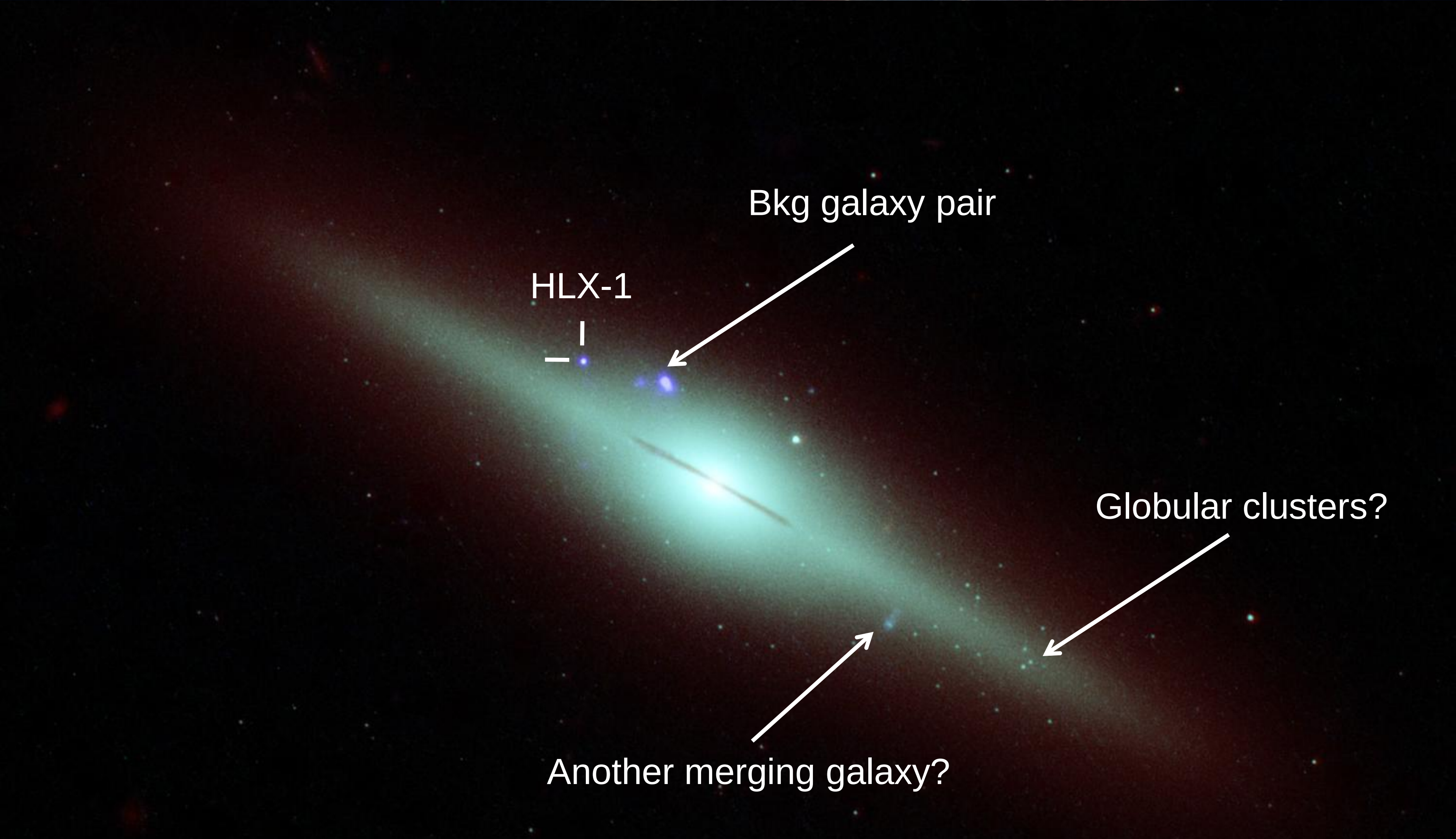


Evolution of a galaxy merger

HLX-1: THE MOST EXTREME ULX

- HLX-1 discovered in spiral galaxy ESO 243-49 at distance of ~330 million light years (Farrell et al. 2009)
- X-ray luminosity is *~10,000 times brighter than stellar mass black hole and ~100 times brighter than most ULXs*
- Detection of Hydrogen emission line from optical counterpart confirms distance and luminosity
- X-ray spectrum and detection of radio jets points to mass ~10,000 Msun
- Hubble space telescope imaging points to HLX-1 lying in a young cluster of stars only ~40 million years old
- Location of HLX-1 in ESO 243-49 and age of stellar population points towards a dwarf galaxy merger
- *HLX-1 is the best candidate intermediate mass black hole currently known*

HLX-1: THE MOST EXTREME ULX



Composite 6-band *HST* image

WHY ARE IMBHS IMPORTANT?

- Intermediate mass black holes may be building blocks of super-massive black holes, therefore crucial to formation of galaxies

- Simulations predict that there may be many undetected IMBHs floating around in halos of galaxies. Possible nature of (some) dark matter?

- Halo IMBHs could produce minispikes of radiation through compression of surrounding dark matter, therefore excellent targets in search for dark matter through annihilation signals

- Mini-quasars containing IMBHs predicted to be significant contributors to the reionisation of the Universe ~400 million – 1 billion years after Big Bang (ionising capability predicted to be ~25% - 50%)

- IMBHs spiraling in to merge with super-massive black holes should be strong emitters of gravitational wave radiation (tests of Einstein's theory of General Relativity)