A multi-wavelength study on the impact of SMBHs on their host galaxies

Michael Cowley
Macquarie University / Australian Astronomical Observatory

The Astronomical Society of New South Wales
6th March 2015

MACQUARIE University
SYDNEY · AUSTRALIA

Timeline of Black Holes

1915: Einstein's Theory of Gravity predicted the possibility of black holes, but no one believed they actually existed!

1919: During a total solar eclipse, Sir Arthur Eddington performs the first experimental test of Albert Einstein's general theory of relativity.

1967: Princeton physicist, John Wheeler coined the term "Black Hole" for an object in space so massive and dense that light could not escape

1970's: Stephen Hawking proposes laws of black hole mechanics and the first convincing evidence for black holes is presented

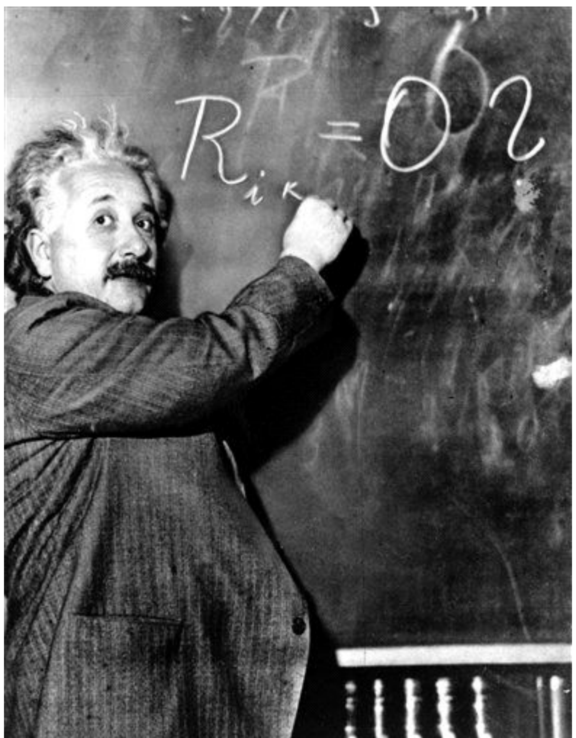
2002: Astronomers present evidence that Sagittarius A*, a supermassive black hole, exists at the center of the Milky Way galaxy

Today: Modern day telescopes now provide us with the best evidence to date of black holes

MACQUARIE University SYDNEY·AUSTRALIA
AAO

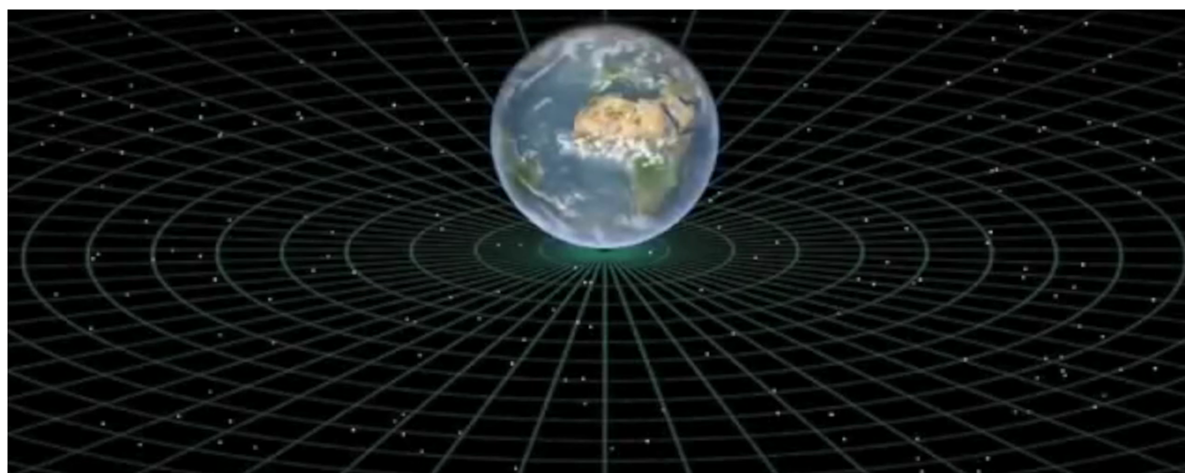
Black Holes

1915: Einstein's Theory of Gravity predicted the possibility of black holes, but no one believed they actually existed!



Credit: NASA

The Einstein field equations are a set of equations in Albert Einstein's general theory of relativity that describes the interaction of gravity as a result of spacetime being curved by matter.

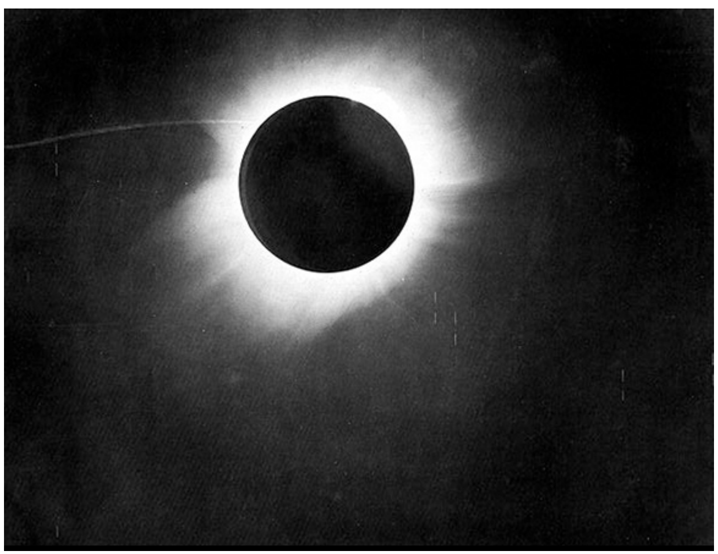


Credit: http://youtu.be/f0VOn9r4dq8

Testing General Relativity

1915: Einstein's Theory of Gravity predicted the possibility of black holes, but no one believed they actually existed!

1919: During a total solar eclipse, Sir Arthur Eddington performs the first experimental test of Albert Einstein's general theory of relativity.



- The light from the stars passes through the sun's gravitational field on its way to Earth, yet would be visible due to the darkness of the eclipse.
- This allows accurate measure of the stars' gravity-shifted positions in the sky.

1919 photo from Sir Arthur
← Eddington's expedition report.

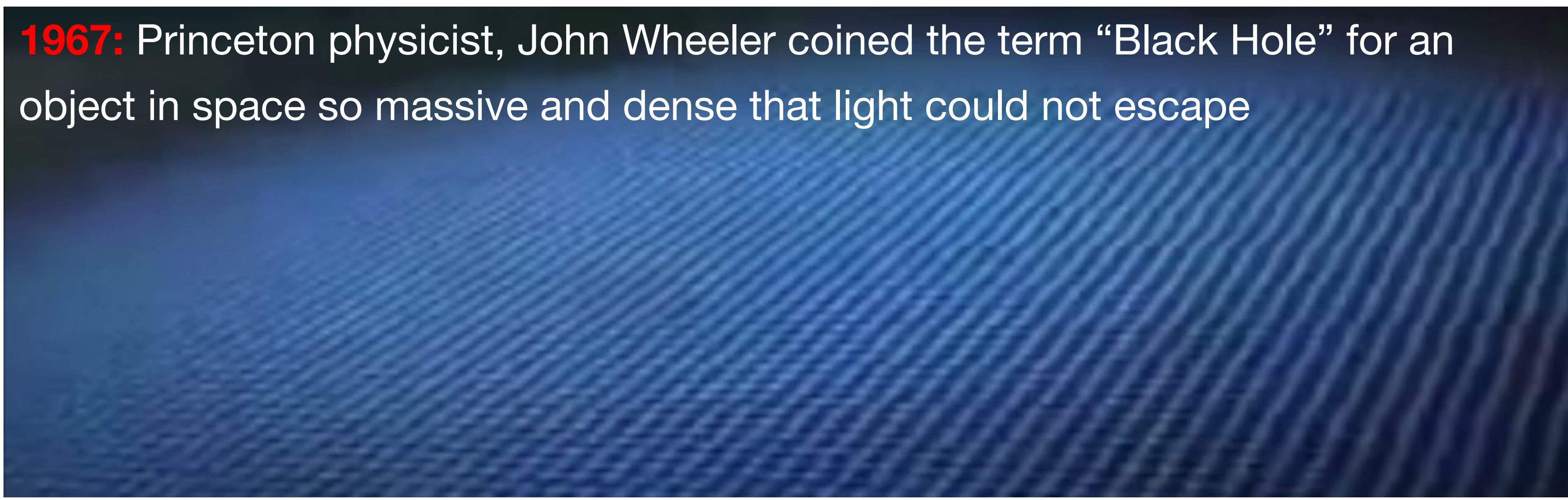
MACQUARIE University SYDNEY·AUSTRALIA

AAO

Coining "Black Hole"

1915: Einstein's Theory of Gravity predicted the possibility of black holes, but no one believed they actually existed!

1919: During a total solar eclipse, Sir Arthur Eddington performs the first experimental test of Albert Einstein's general theory of relativity.



1967: Princeton physicist, John Wheeler coined the term "Black Hole" for an object in space so massive and dense that light could not escape

Credit: http://youtu.be/f0VOn9r4dq8

MACQUARIE University SYDNEY·AUSTRALIA

Black Hole Laws & Evidence

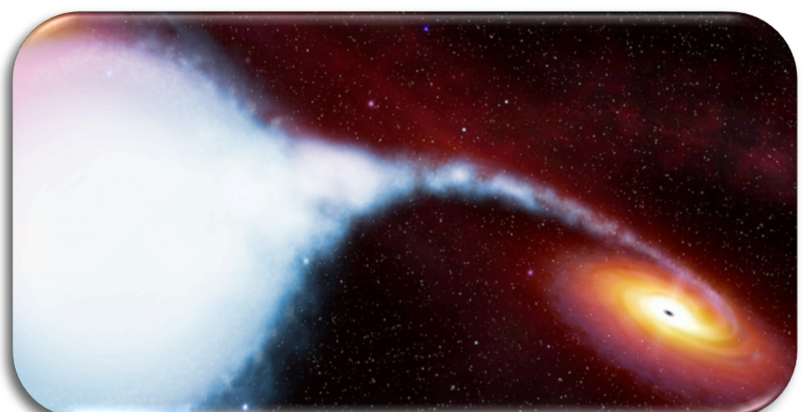
1915: Einstein's Theory of Gravity predicted the possibility of black holes, but no one believed they actually existed!

1919: During a total solar eclipse, Sir Arthur Eddington performs the first experimental test of Albert Einstein's general theory of relativity.

1967: Princeton physicist, John Wheeler coined the term "Black Hole" for an object in space so massive and dense that light could not escape

1970's: Stephen Hawking proposes laws of black hole mechanics and the first convincing evidence for black holes is presented

Cygnus X-1 →



Credit: ESA/Hubble

Black Holes

1915: Einstein's Theory of Gravity predicted the possibility of black holes, but no one believed they actually existed!

1919: During a total solar eclipse, Sir Arthur Eddington performs the first experimental test of Albert Einstein's general theory of relativity.

1967: Princeton physicist, John Wheeler coined the term "Black Hole" for an object in space so massive and dense that light could not escape

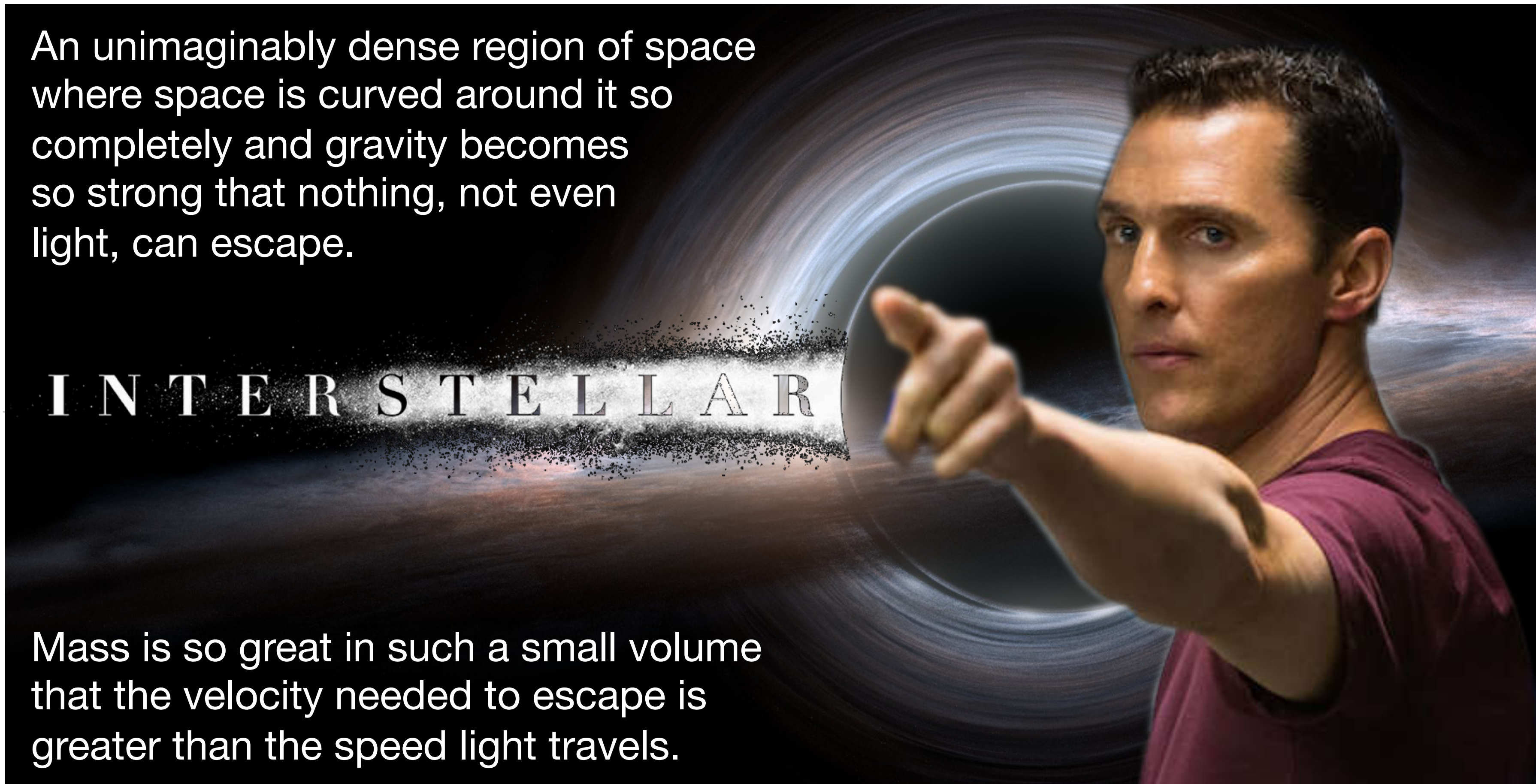
1970's: Stephen Hawking proposes laws of black hole mechanics and the first convincing evidence for black holes is presented

2002: Astronomers present evidence that Sagittarius A*, a supermassive black hole, exists at the center of the Milky Way galaxy

Today: Modern day telescopes now provide us with the best evidence to date of black holes

Black Holes

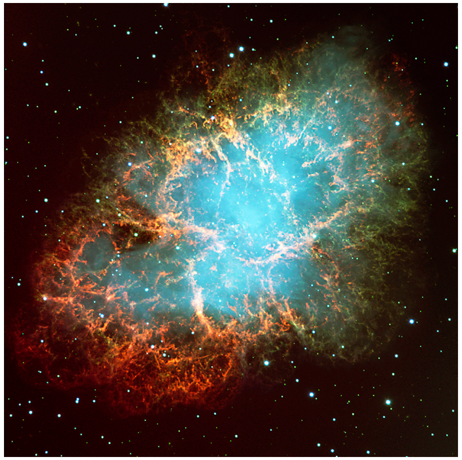
An unimaginably dense region of space where space is curved around it so completely and gravity becomes so strong that nothing, not even light, can escape.

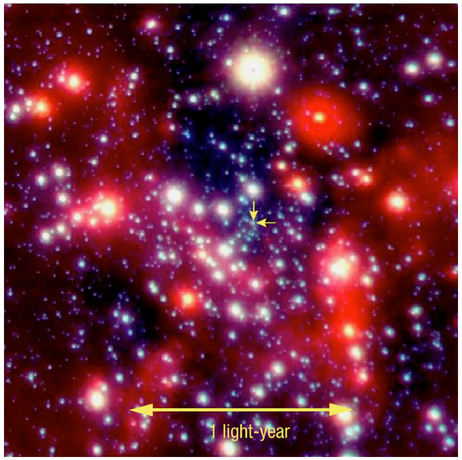


Mass is so great in such a small volume that the velocity needed to escape is greater than the speed light travels.

Credit: Warner Bros.

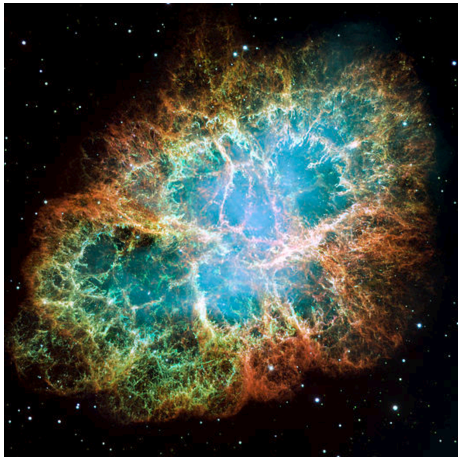
Black Hole Types





1. **Stellar-mass:** 3 to 20 times the mass of our own Sun
2. **Supermassive:** Black holes with millions to billions of times the mass of our own Sun
3. **Mid-mass:** In between stellar-mass and supermassive

How are Black Holes Made?



Credit: European Southern Observatory

Stellar-mass:

Black holes are made when a giant star, many times the mass of our Sun, dies.

Most of the star's atmosphere is blown into space as a supernova explosion.

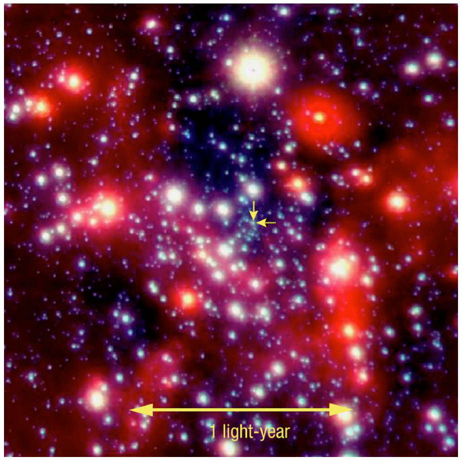
The star's spent core collapses under its own weight.

If the remaining mass is more than the mass of 3 times the Sun, it will collapse into a black hole.

How are Black Holes Made?

Supermassive:

Supermassive black holes are believed to form by one of two possible scenarios. The first is the collapse of a supermassive star in the early universe. The second is by the merger of one or more stellar-mass black holes.



Credit: European Southern Observatory

How are Black Holes Made?

Mid-mass:

Possibly an early stage of a supermassive black hole, mid-mass black holes are being found in the centers of large, dense star clusters, like the globular cluster M15.

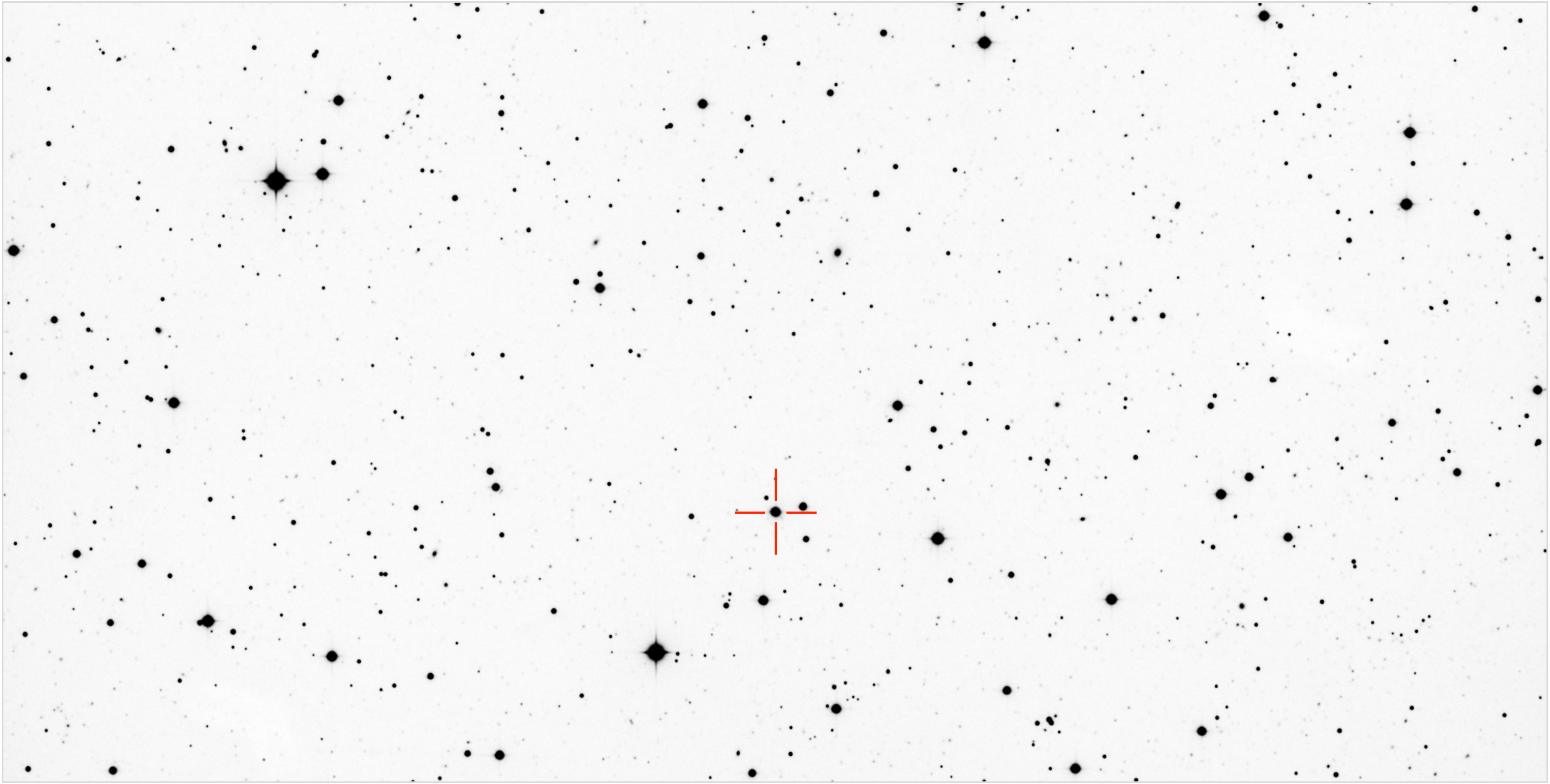
Credit: : NASA and The Hubble Heritage Team (STScI/AURA)

A globular cluster is a spherical collection of stars that orbits a galactic core as a satellite.

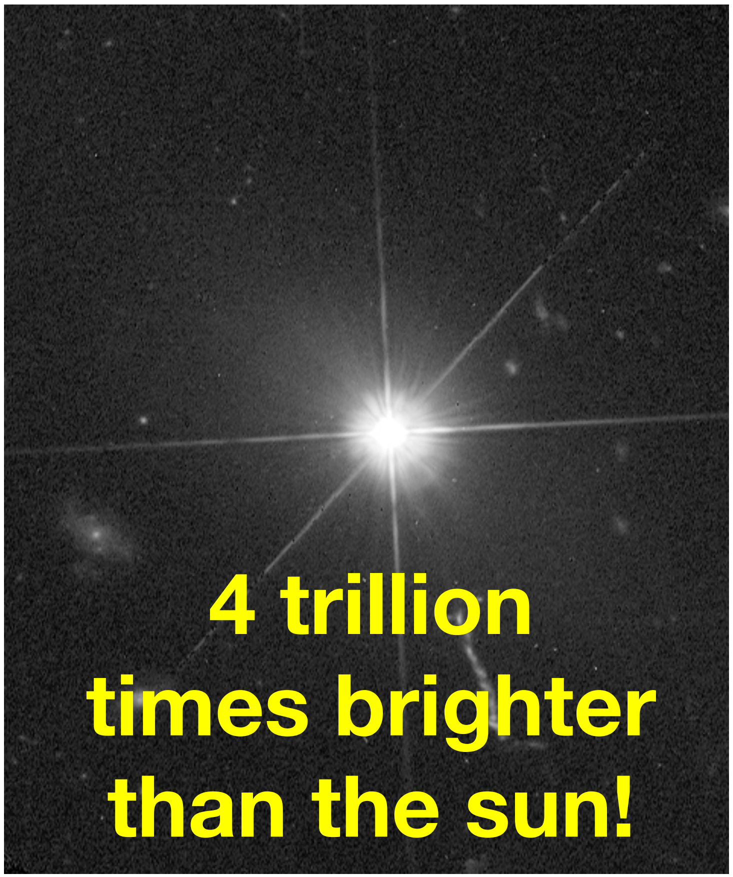
How Do We Find Them?

Credit: ESO

How Do We Find Them?



Quasar 3C 273

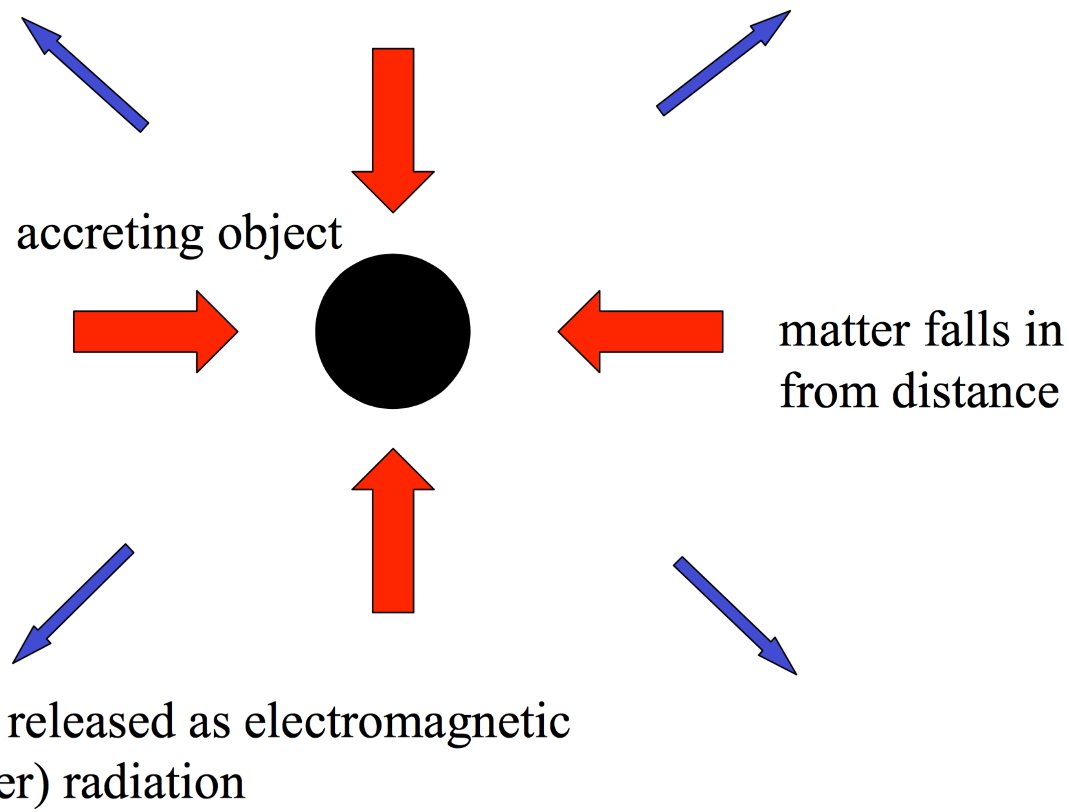


- Discovered in 1959
- 273rd object of the 3rd Cambridge Radio Survey (3C 273)
- Approx. two billion light years away
- How bright?

MACQUARIE University SYDNEY·AUSTRALIA

How Much Energy?

accretion = release of gravitational energy from infalling matter



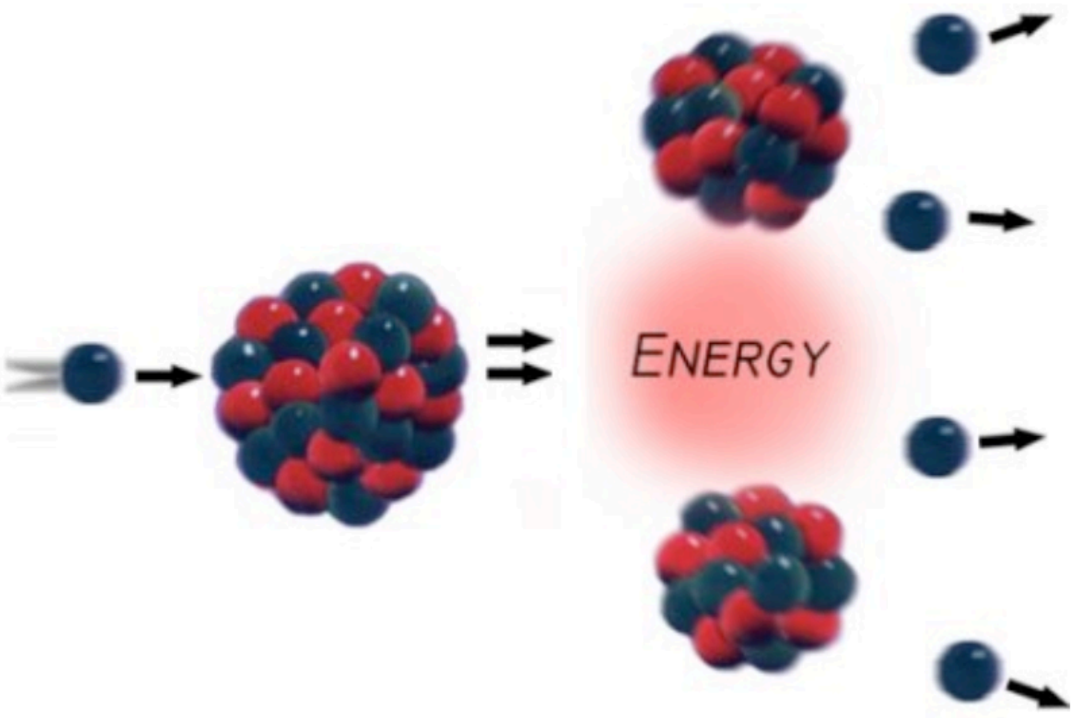
How Much Energy?

constant mass

energy — $$\Delta E_{acc} = \frac{GM}{R}$$

radius

Nuclear Reactions

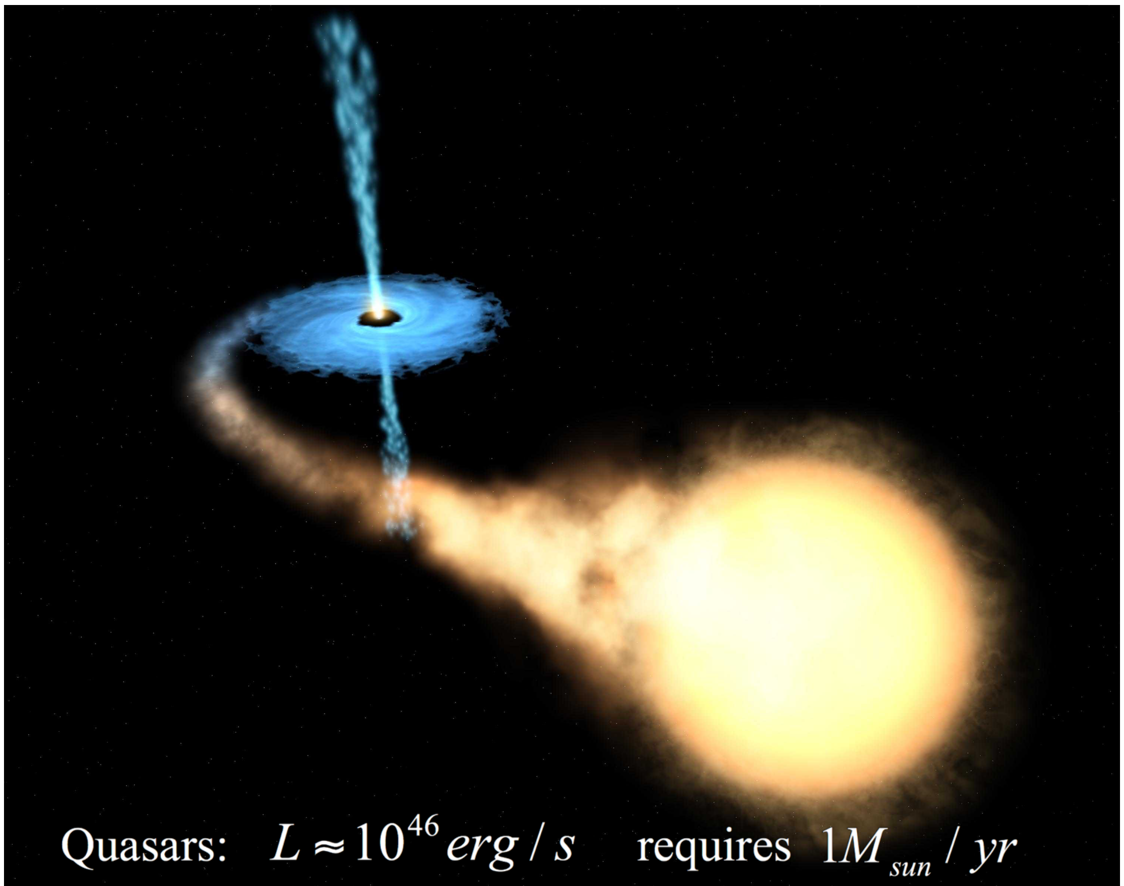


$\varepsilon = 0.07\%$

MACQUARIE University SYDNEY·AUSTRALIA

AAO

Accretion Energy

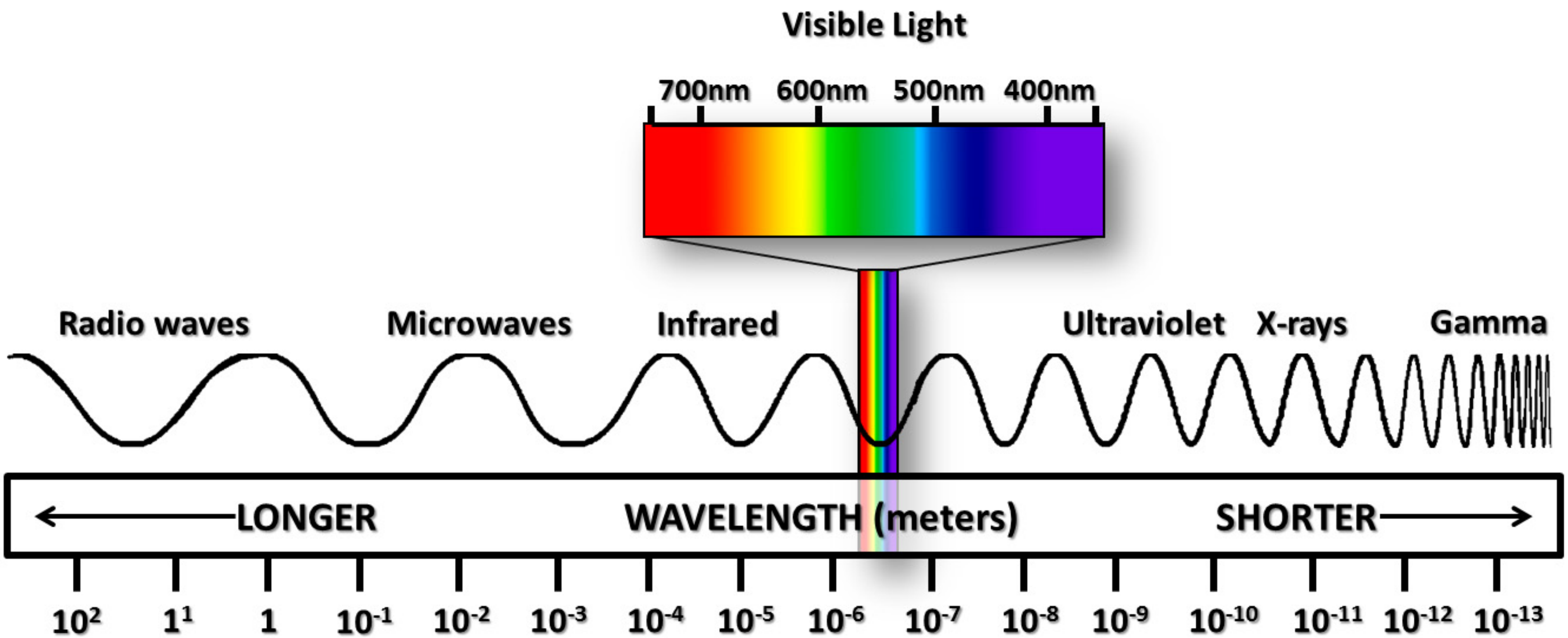


ε = 50%!

This is the most efficient known way of using mass to get energy

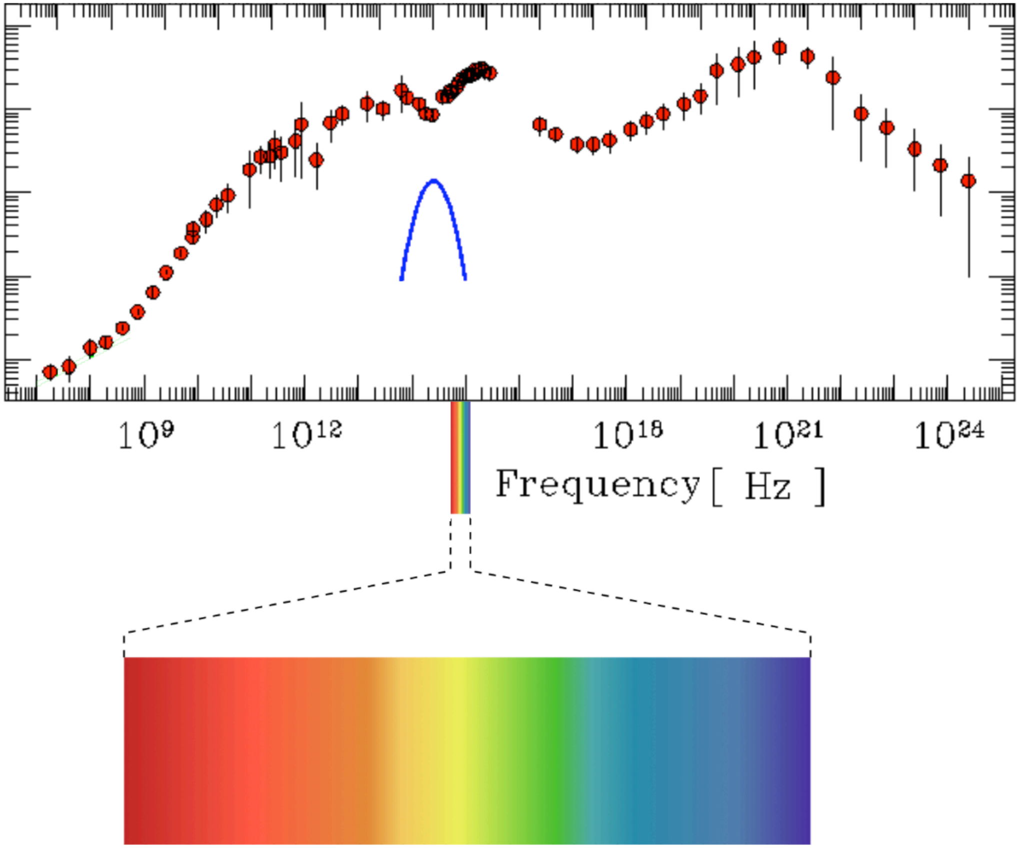
MACQUARIE University SYDNEY·AUSTRALIA

Electromagnetic Spectrum

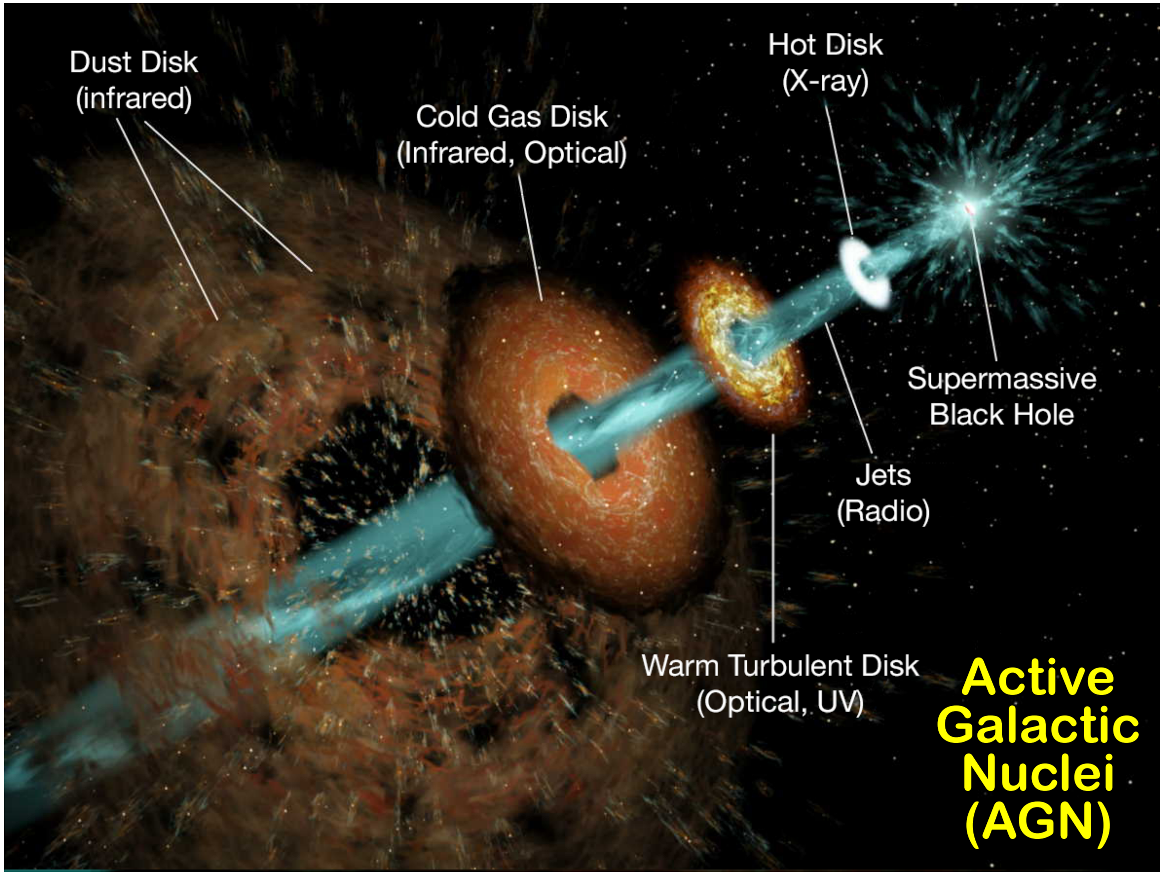


Credit: Climate Science Investigations

Quasar 3C 273 Spectrum



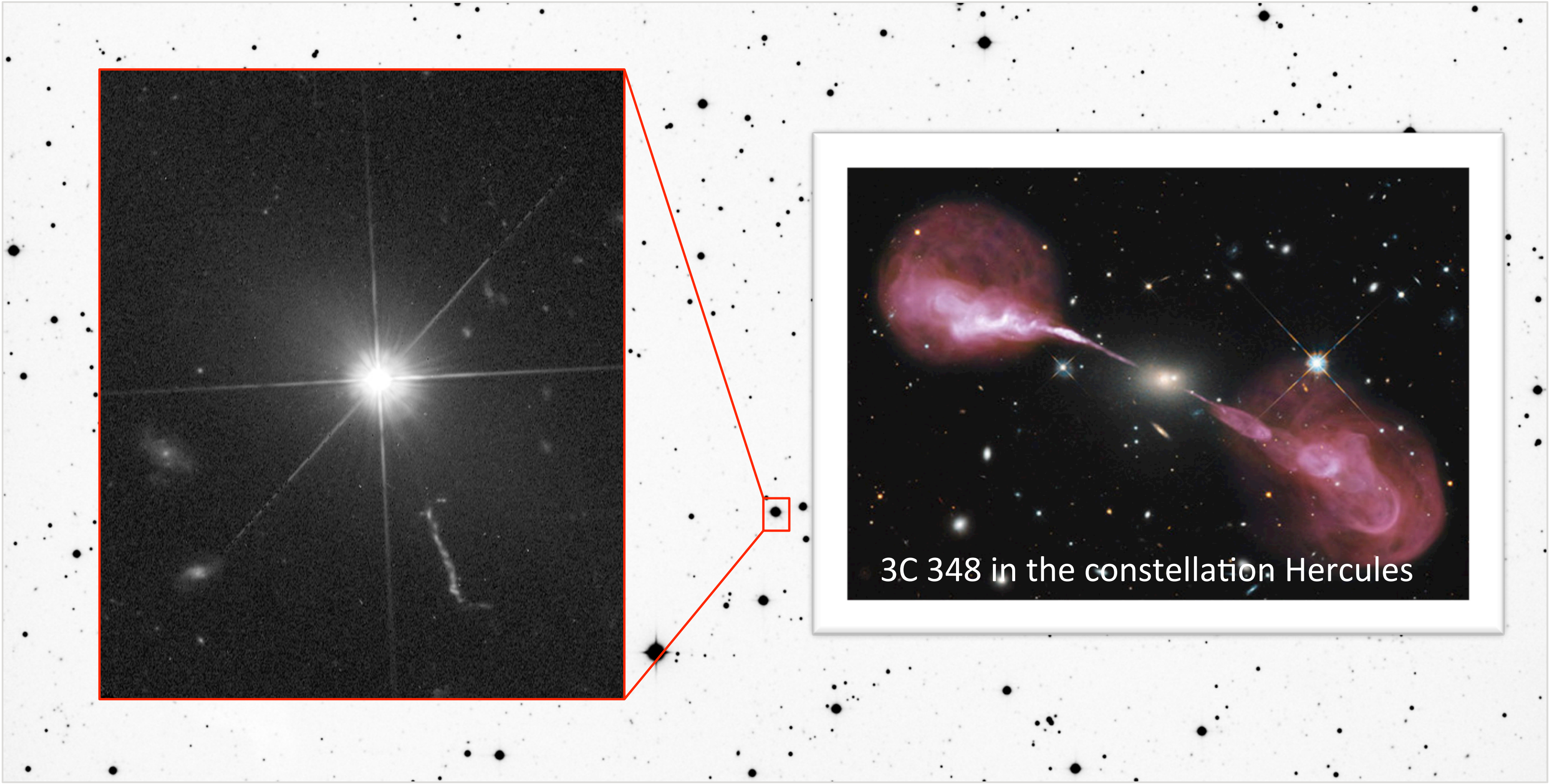
Where Does This Light Come From?



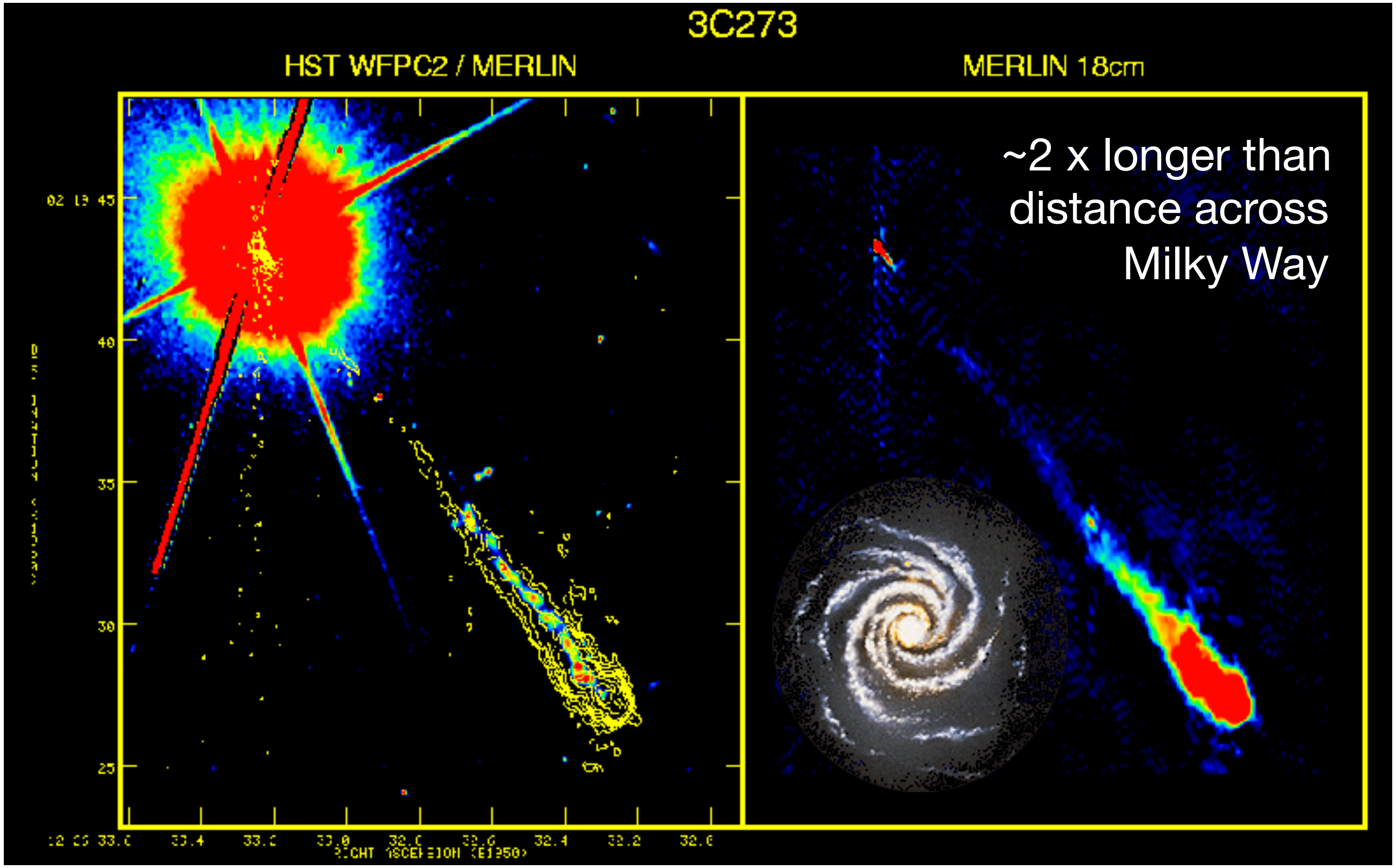
- Cold material close to black hole forms an accretion disc
- Accretion disc heats up scatters photons up to X-ray energies
- Radiation obscured by dust is re-radiated at longer wavelengths
- Particles accelerated to speeds approaching that of light and emerge from the poles as radio jets

http://www.iaa.es/~jlgomez/Jose_L._Gomez/Animations.html

Multi-Wavelength View of 3C 273

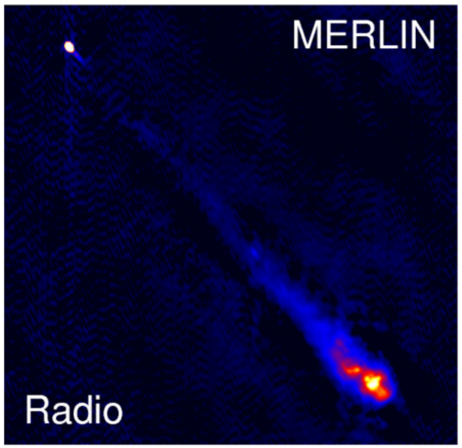


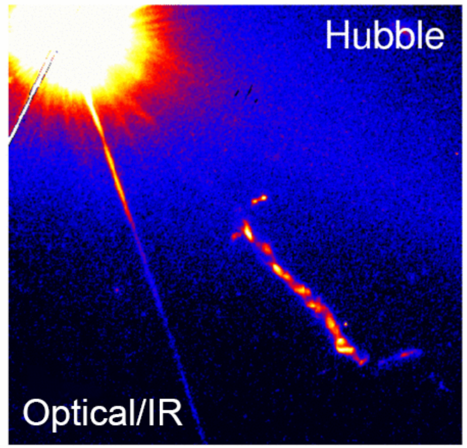
Quasar 3C 273 Radio Jet

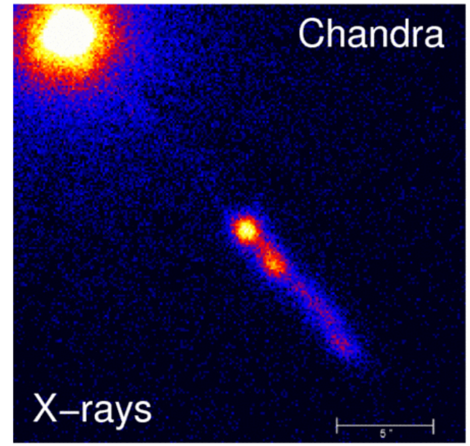


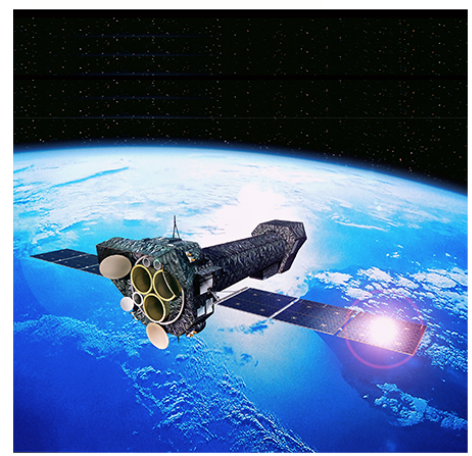
Credit: Hubble Space Telescope (WFPC2) / MERLIN

Multi-Wavelength View of 3C 273









MACQUARIE University SYDNEY·AUSTRALIA

AAO

ZFOURGE

FourStar Galaxy Evolution Survey

- Consortium with ~20 astronomers
- 50 nights on Magellan Telescope
- FourStar Infrared Camera
- 5 filters (J1, J2, J3, Hs ,Hl, Ks)
- Observe more than 30,000 galaxies
- Lookback time of 12.7 billi

Carnegie Institution for Science

Sterrewacht Leiden

CSIRO

Texas A&M University

Swinburne — Centre for Astrophysics and Supercomputing

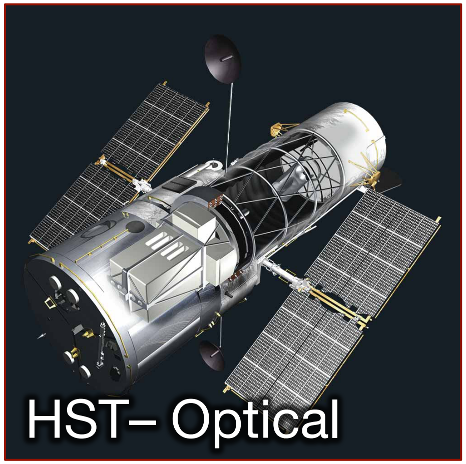
Macquarie University Sydney · Australia

Australian Government Department of Industry

AAO

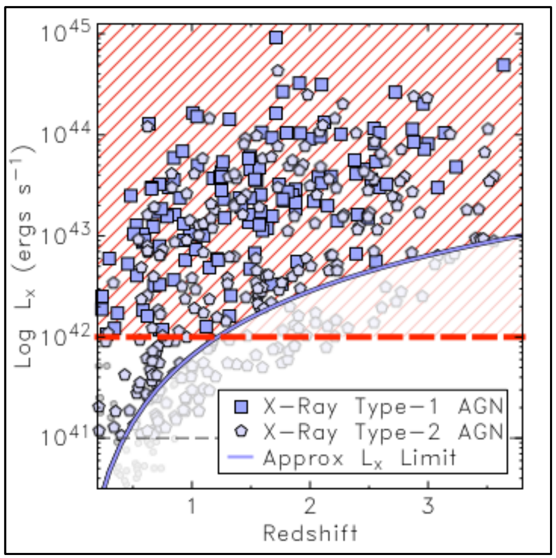
Credit: Yuri Beletsky

Searching for AGN in ZFOURGE

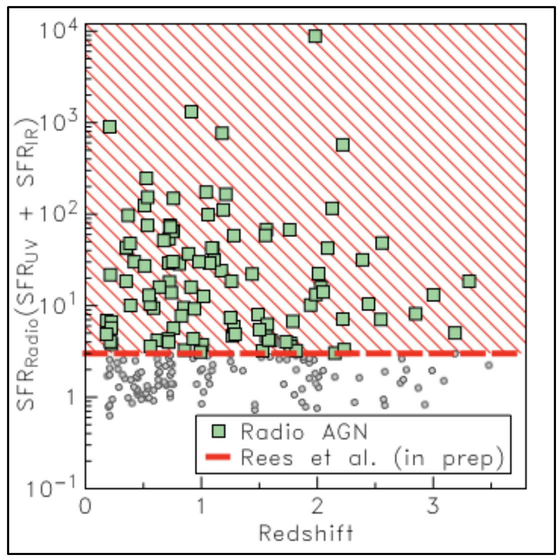


Searching for AGN in ZFOURGE

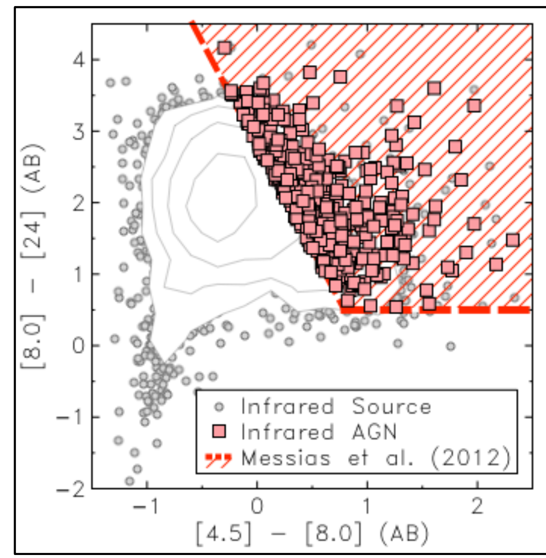
X-RAY



RADIO



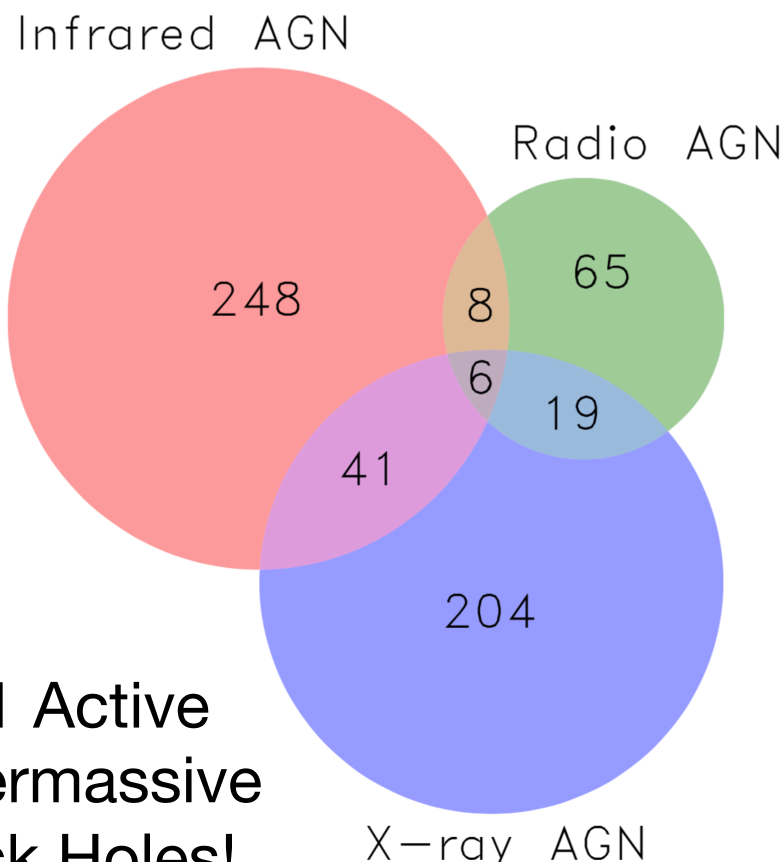
INFRARED



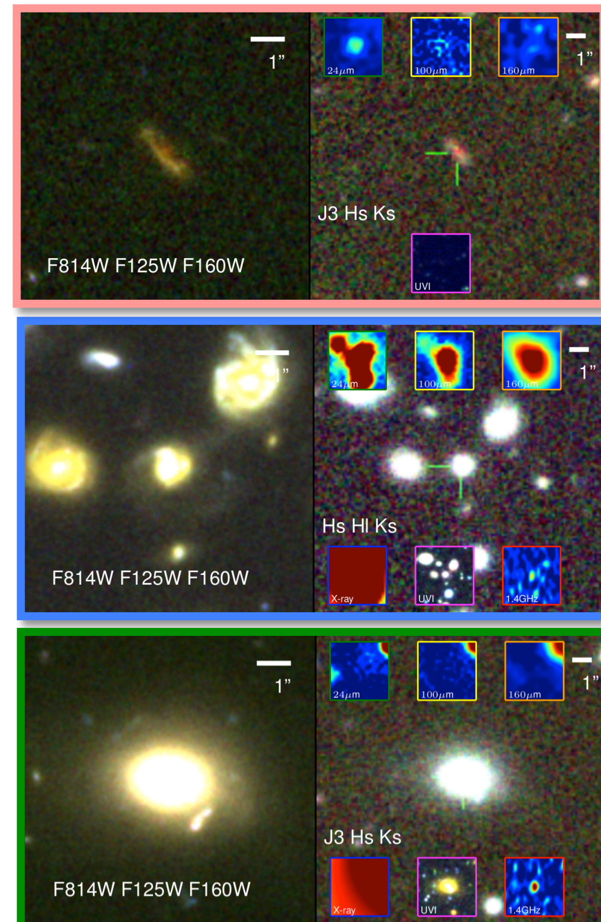
MACQUARIE University SYDNEY · AUSTRALIA

AAO

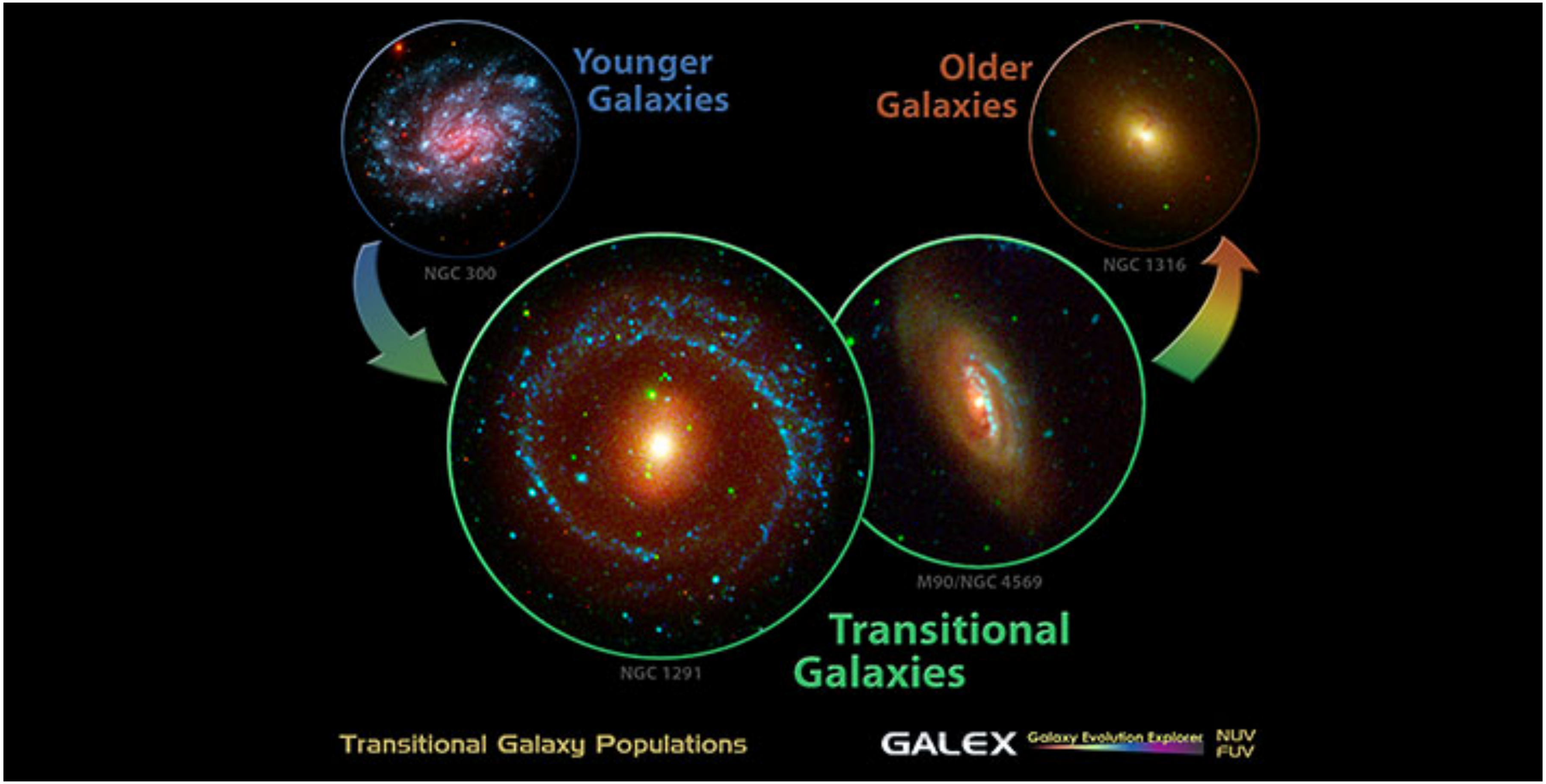
Searching for AGN in ZFOURGE



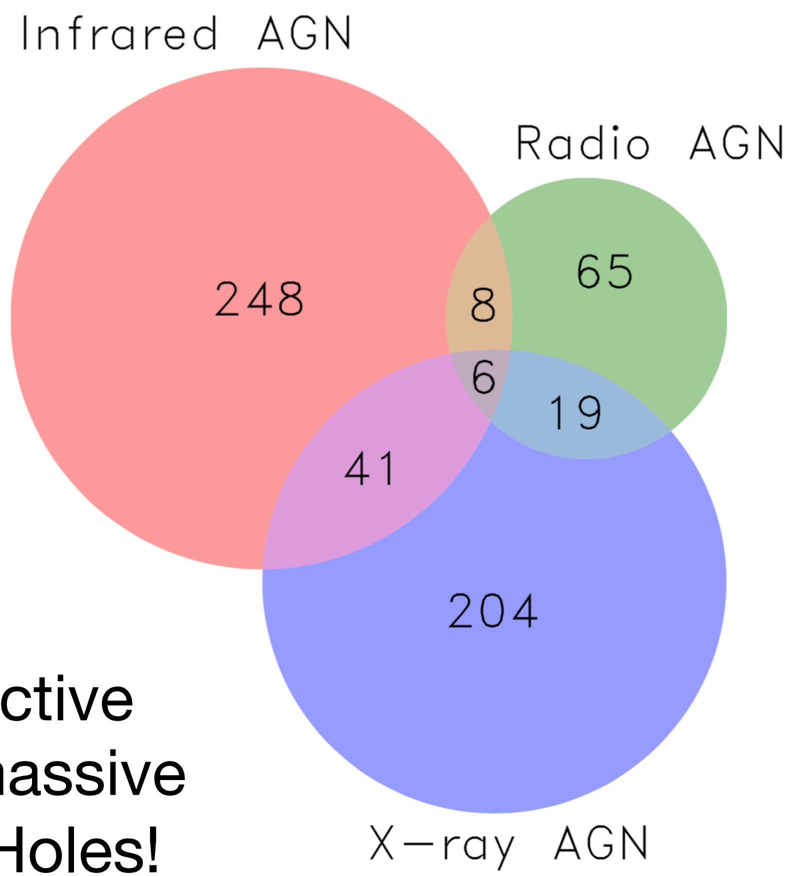
591 Active Supermassive Black Holes!



Galaxy Evolution



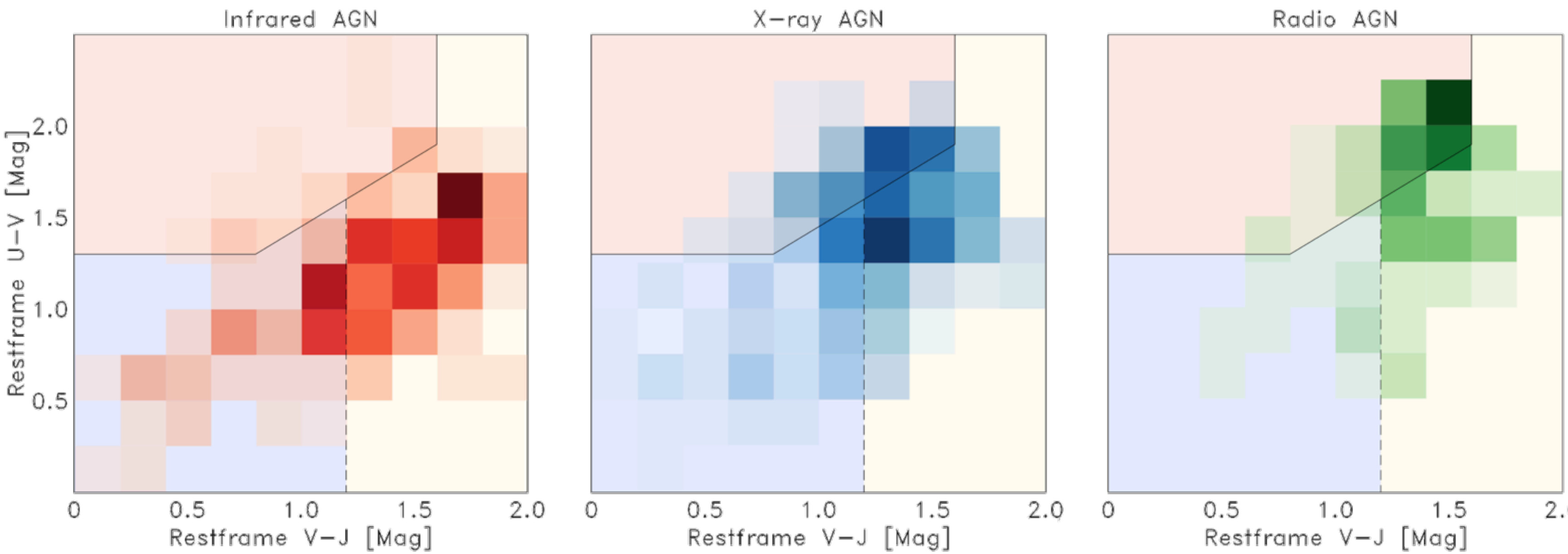
What Galaxy Type do AGN Prefer?



591 Active Supermassive Black Holes!

Classifying our AGN

Infrared AGN | **X-ray AGN** | **Radio AGN**



INFARED AGN: Dusty, young, late-type galaxies

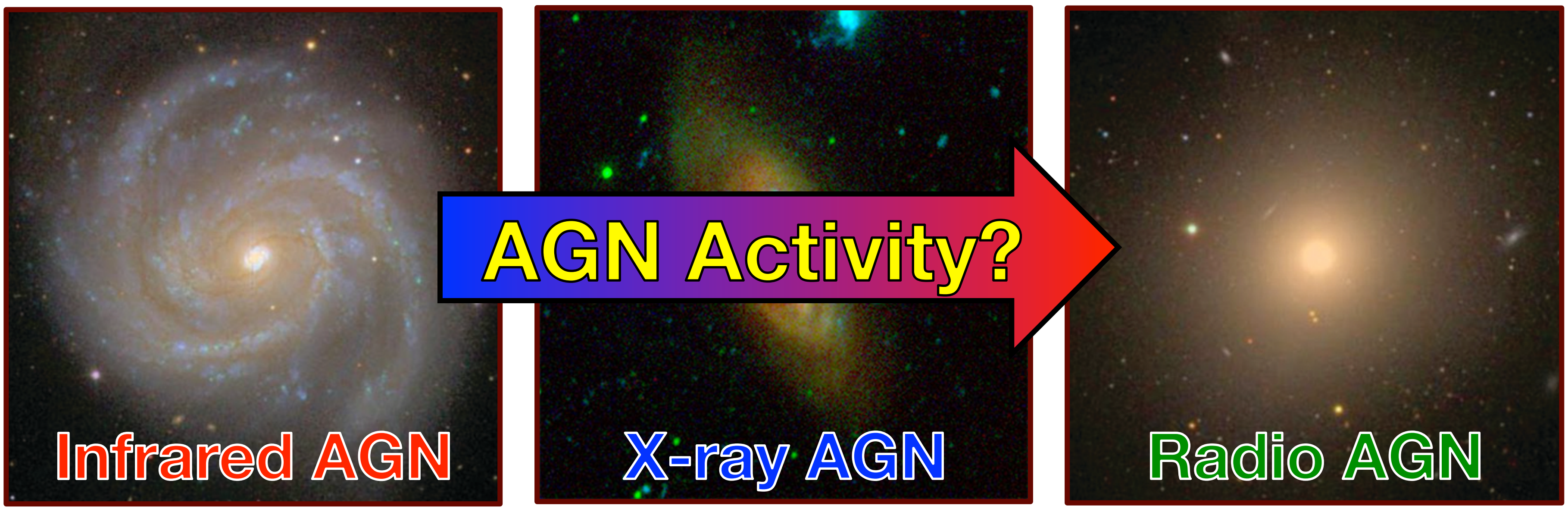
RADIO AGN: Old, late-type galaxies

X-RAY AGN: Straddle between the two

MACQUARIE University SYDNEY·AUSTRALIA

Classifying our AGN

Late Type | Transitional Type | Early Type

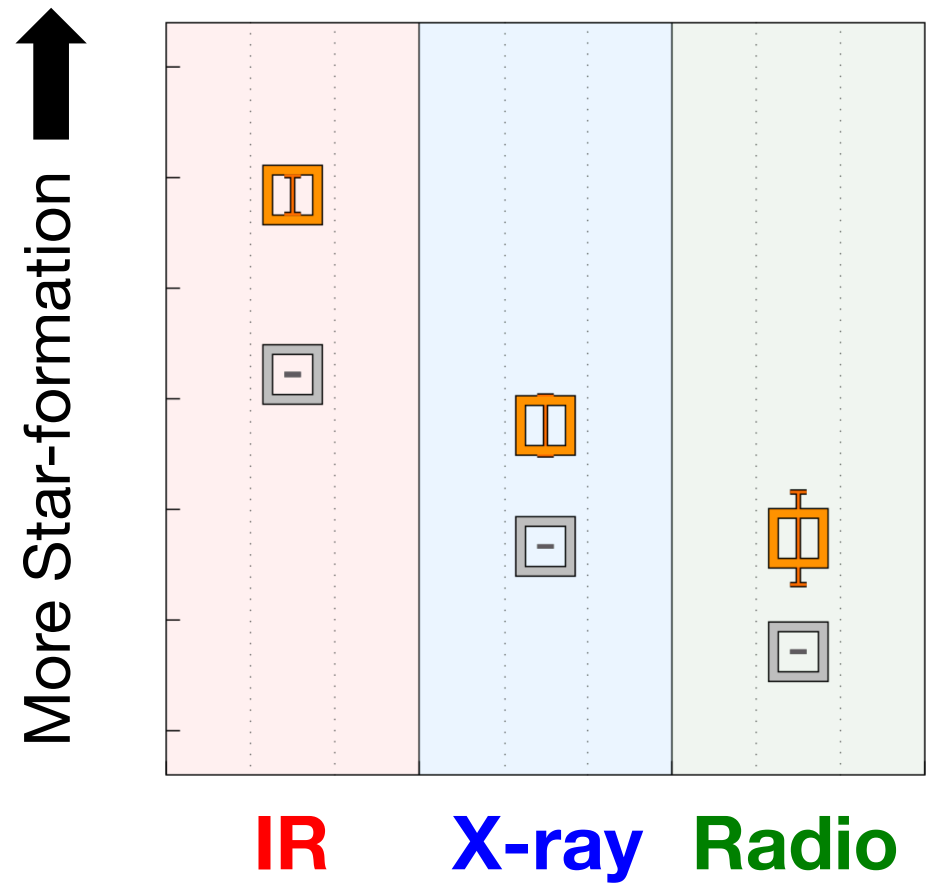


Younger Galaxies | Middle-Aged Galaxies | Old Galaxies

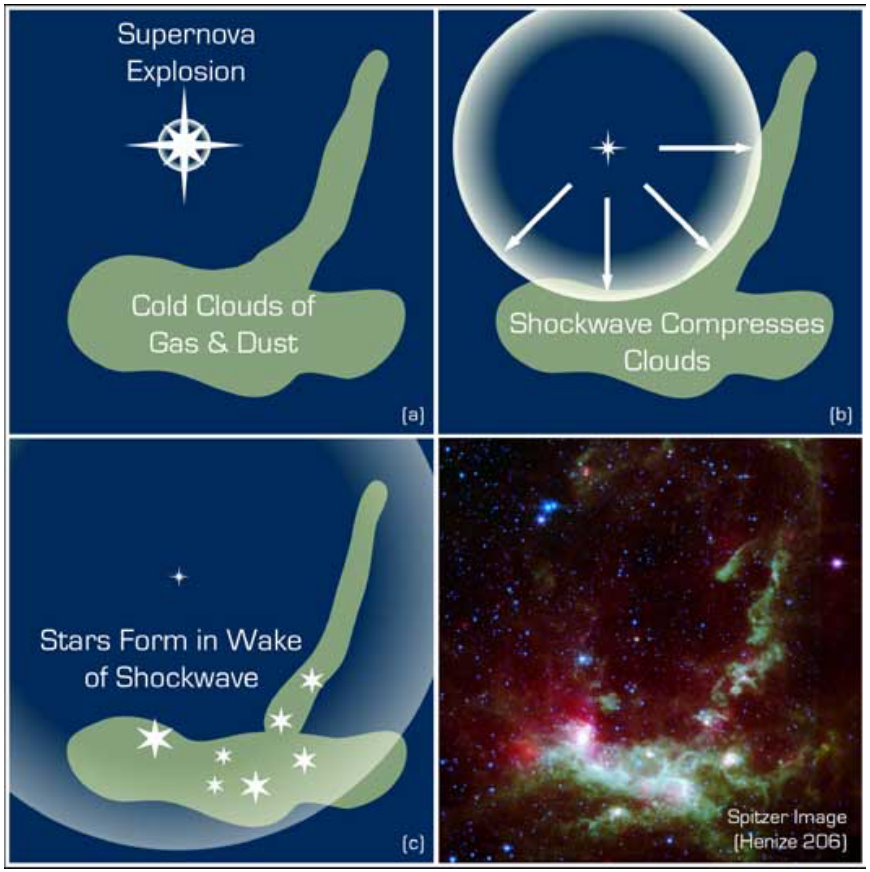
How Much Star-Formation?

Active Galaxies

Non-active Galaxies



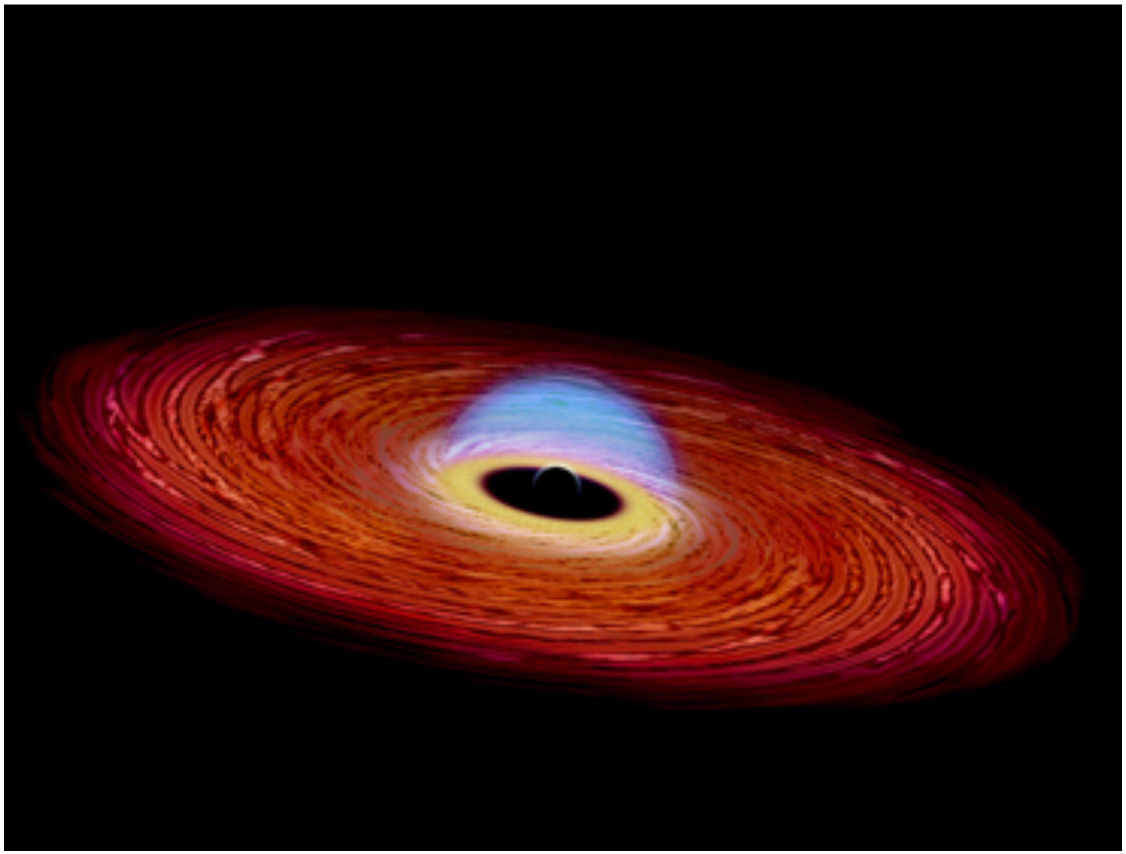
Recipe for Star-Formation?



- Start with some cold interstellar gas and dust
- Add a supernova explosion
- Use a shockwave to compress the cold gas and dust
- Leave for approximately 10 million years
- Your stars are ready!

MACQUARIE University SYDNEY·AUSTRALIA AAO

Watch the Temperature!



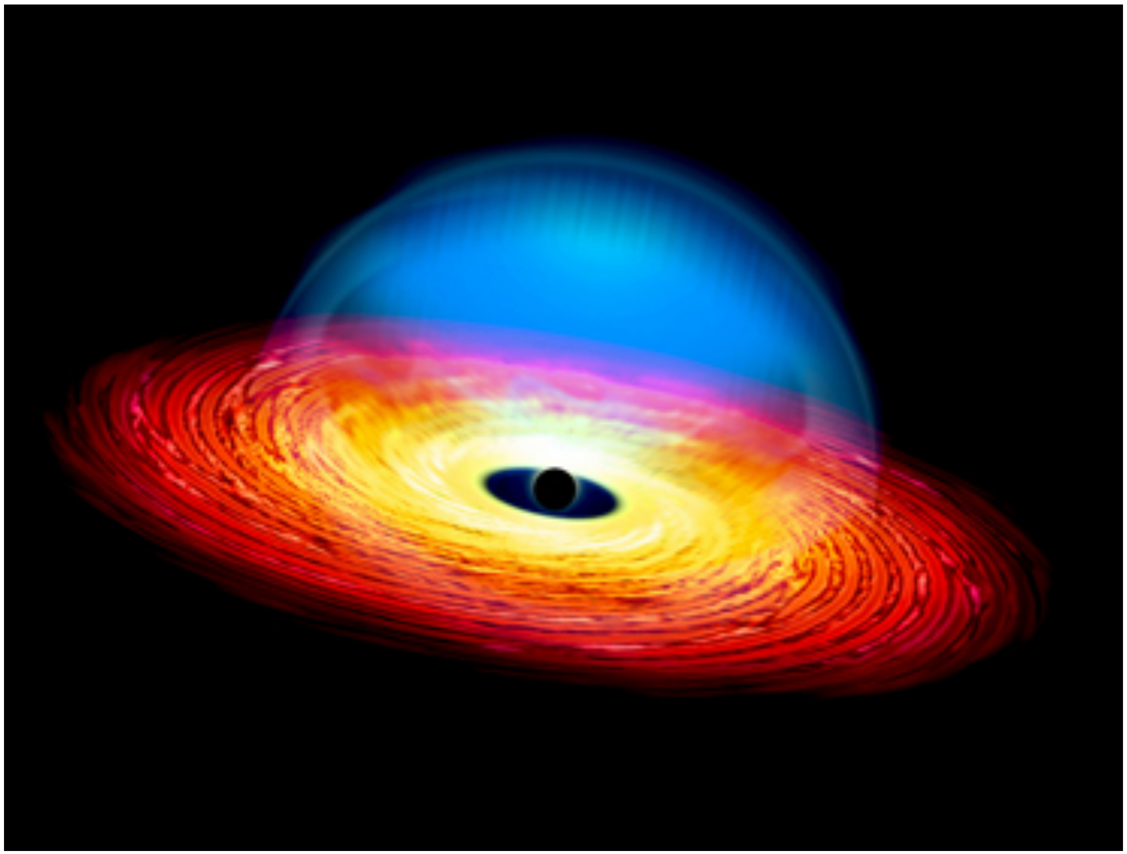
Credit: Michael S. Helfenbein / Yale University

- We know AGN produce enormous amounts of energy
- Energy = heat
- Hot gas is not good for making stars

MACQUARIE University SYDNEY·AUSTRALIA

AAO

AGN Shockwaves!



Credit: Michael S. Helfenbein / Yale University

- We know AGN produce enormous amounts of energy
- Energy = heat
- Hot gas is not good for making stars
- However, an AGN shockwave can also compress existing cold gas
- **What's the correct answer?**

Thank You!

If you'd like to know more, please visit my website www.mjcowley.com