Weighing Black Holes

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School of Mathematics and Physics
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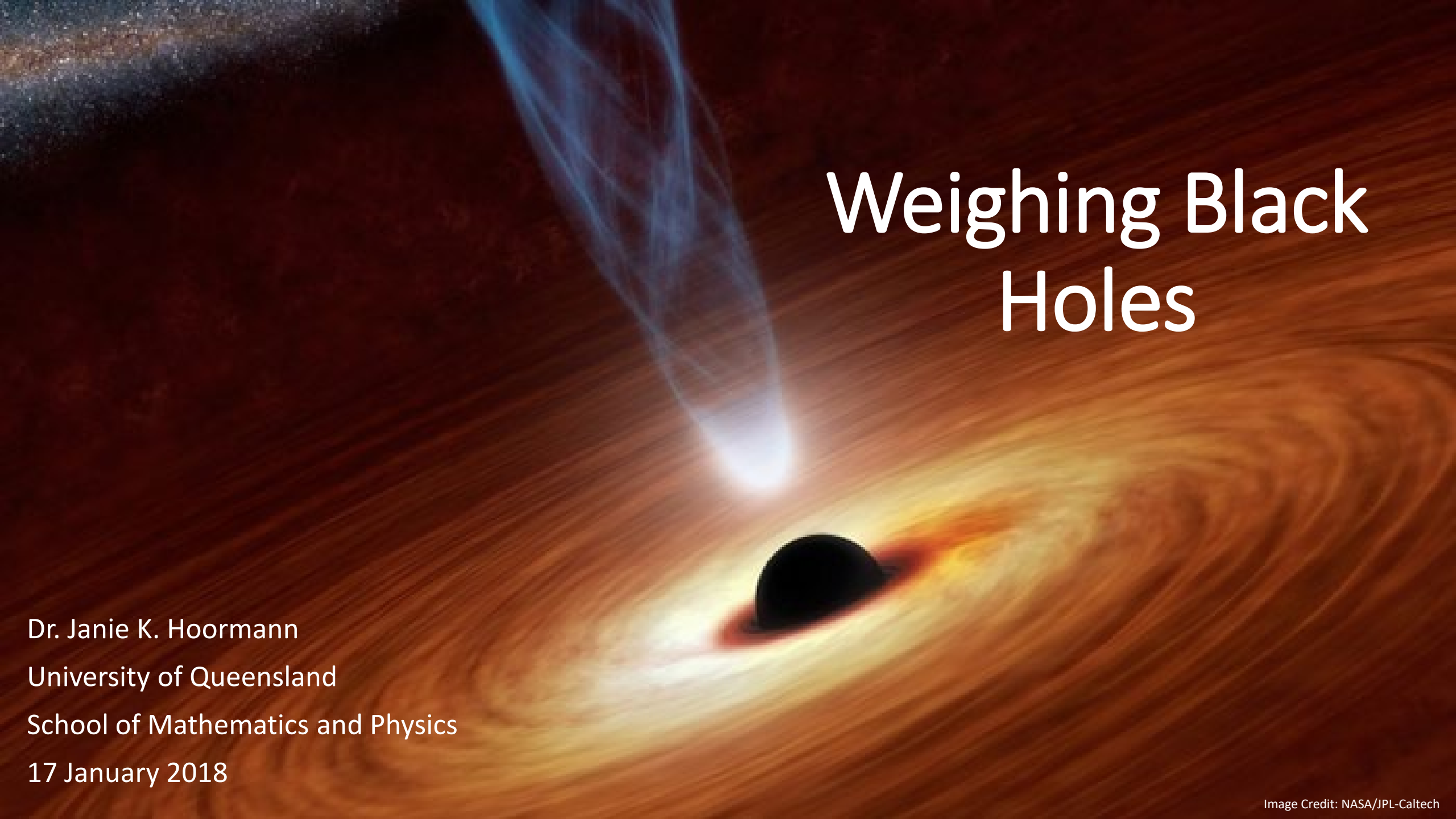
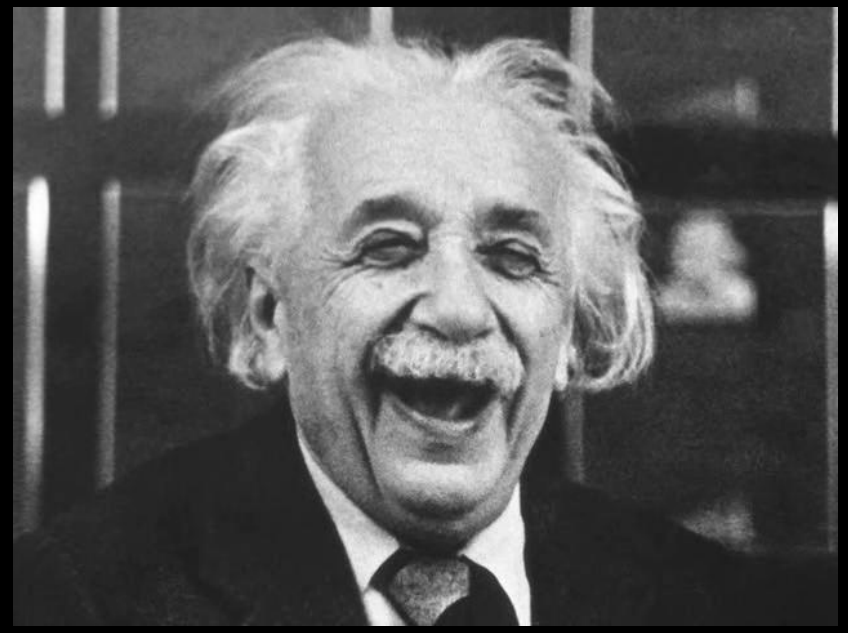


Image Credit: NASA/JPL-Caltech

Q: What is gravity?

What is Gravity?

- General Relativity proposed by Albert Einstein in 1915
- Gravity caused by a warping in spacetime
- Has been extensively tested inside and outside our solar system



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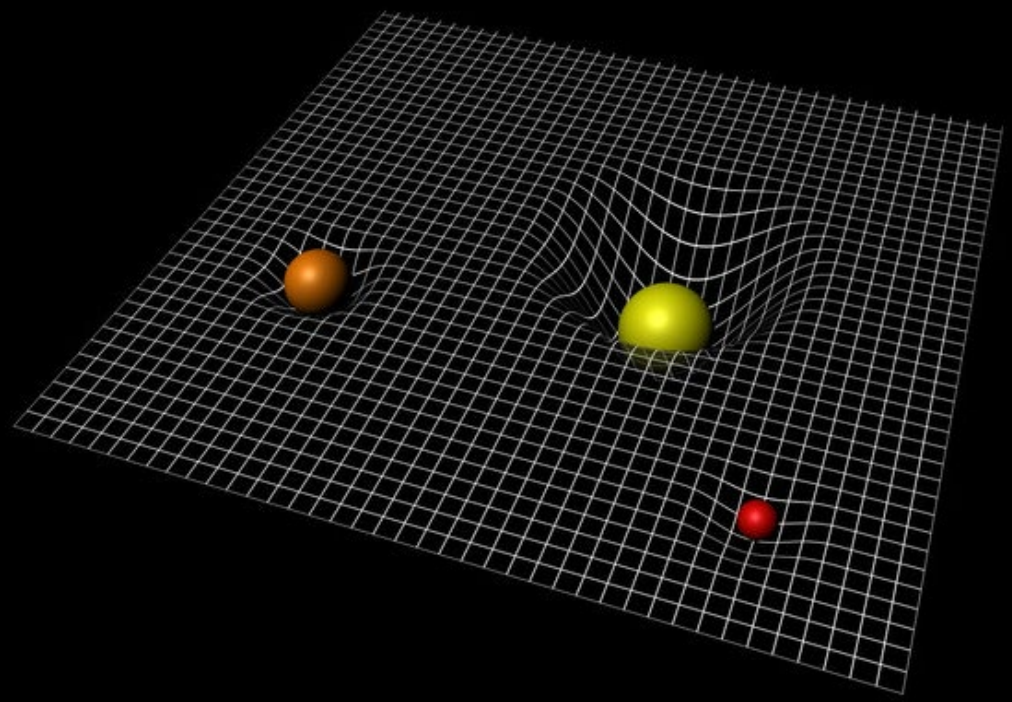
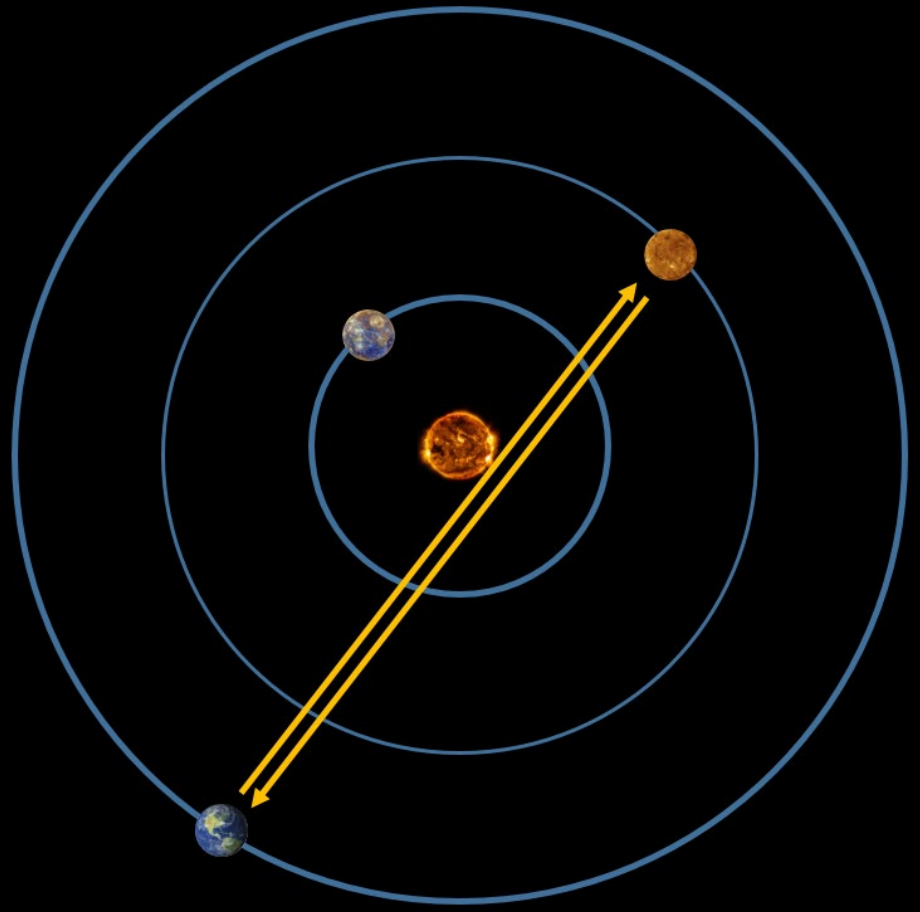


Image Credit: ESA-C.Carreau

Warping Spacetime

- Light takes longer to travel in warped spacetime
- Tested by bouncing radar signals off Venus
- Without understanding this GPS wouldn’t work



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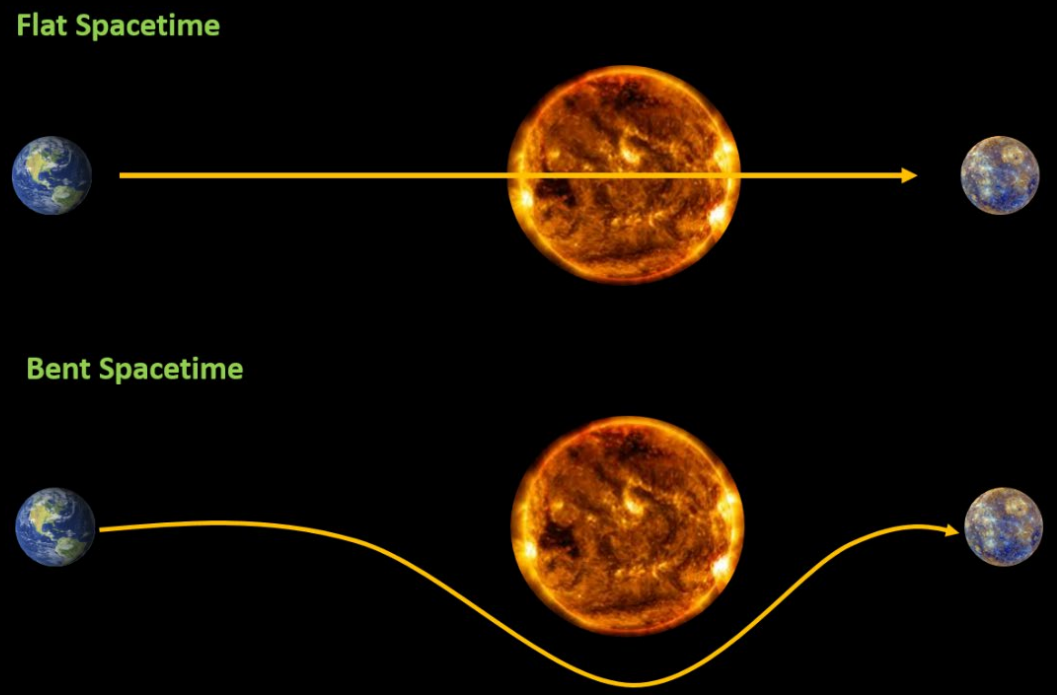

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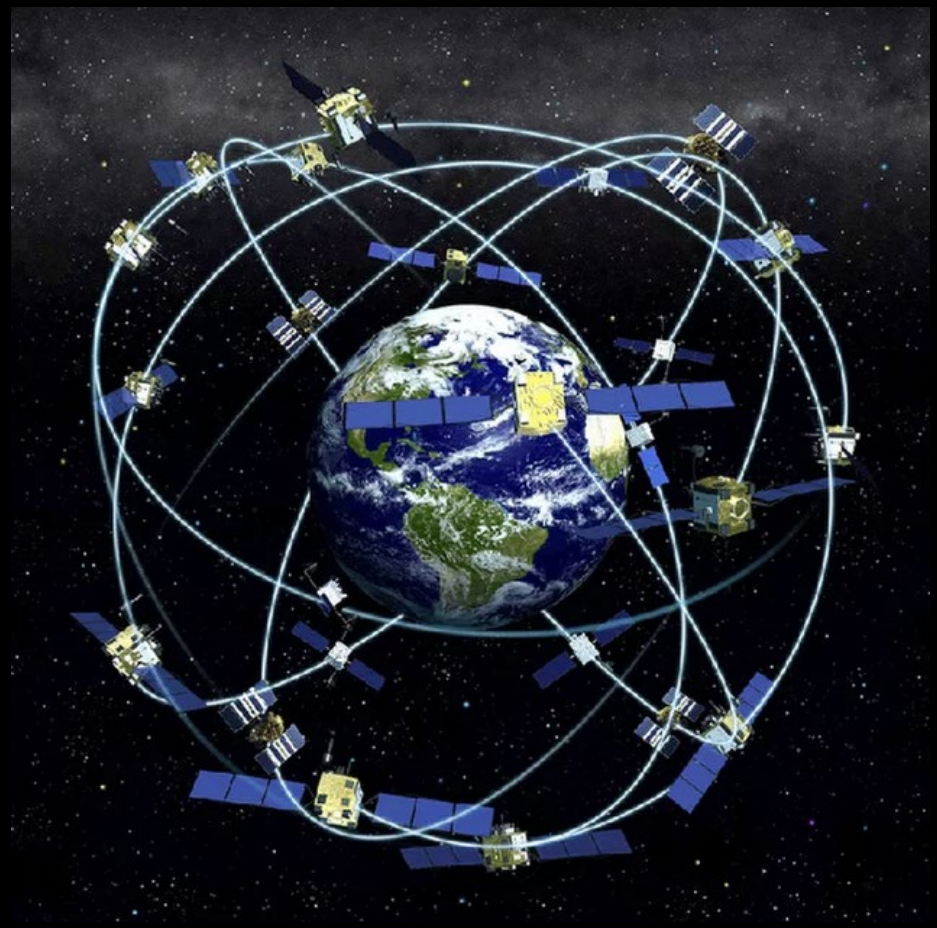

Image Credit: NOAA

Q: What are black holes?

Black holes can form when massive stars die

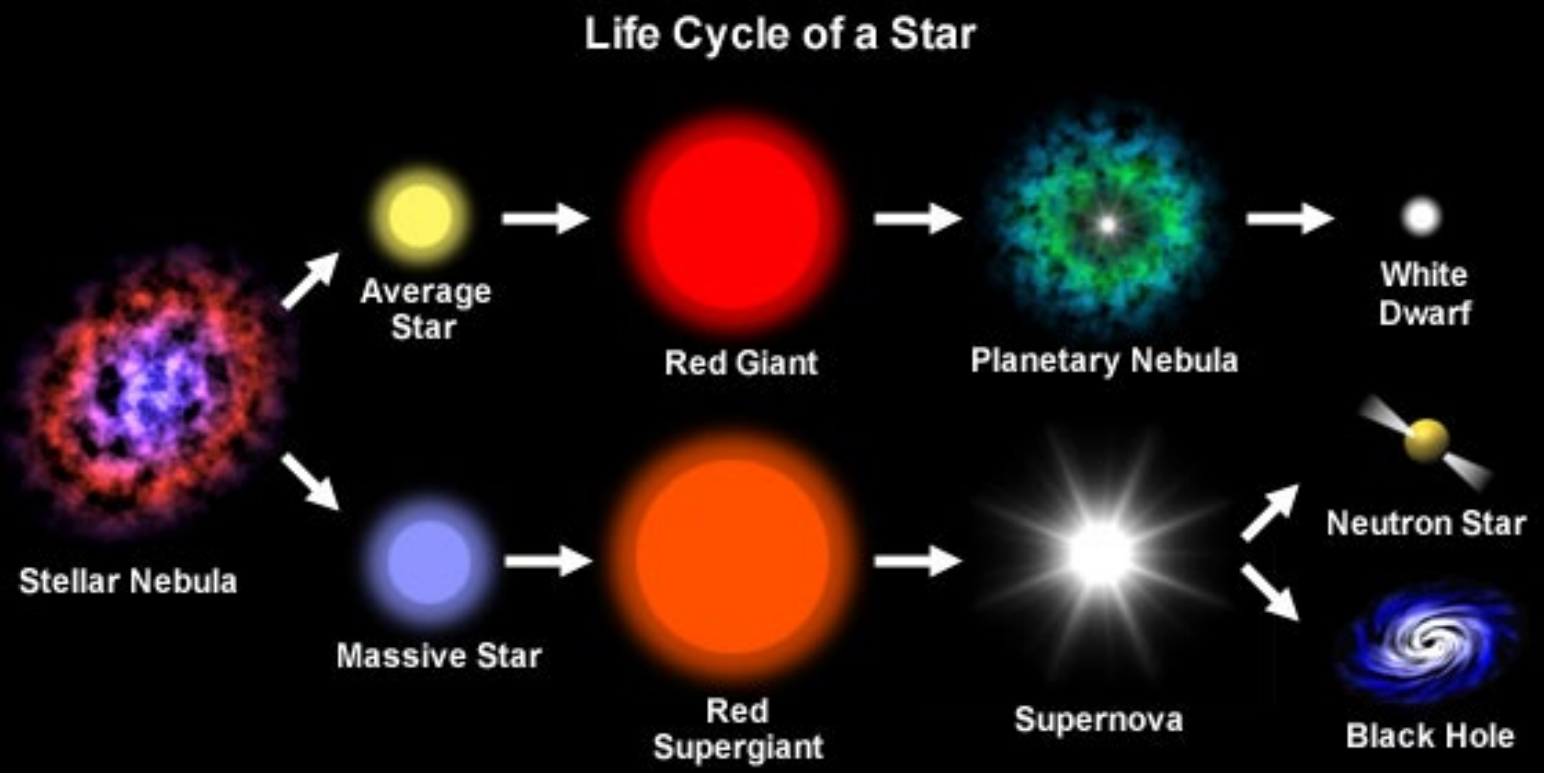

Image Credit: https://scioly.org/wiki/index.php/File:Star_cycle.png

Black Holes

Image Credit: Interstellar

- GR predicts the existence of black holes
- Gravitational pull so strong that light can’t escape
- Strongest gravitational fields that we know of

Q: How big are black holes?

How Big are Black Holes?

- Size defined by the size of the event horizon
  - Point of no return
  - Related to the mass of the black hole
- Earth
  - Diameter -> 1.8 cm
- Sagittarius A*
  - Diameter -> 23,600,000 km

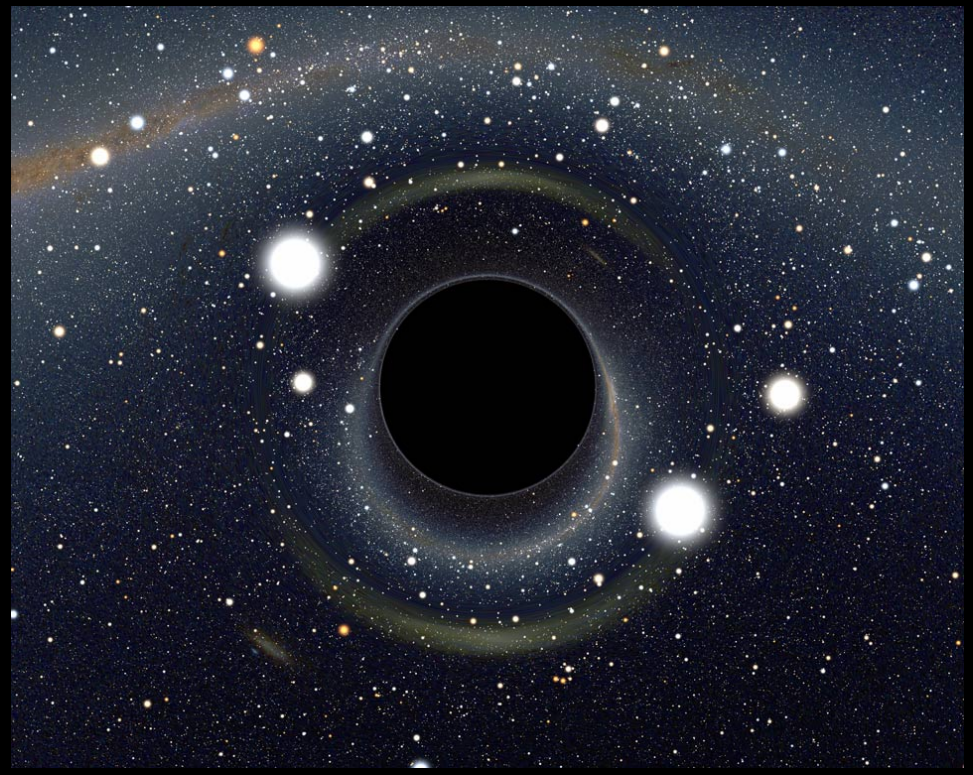

Image Credit: Alain Riazuelo

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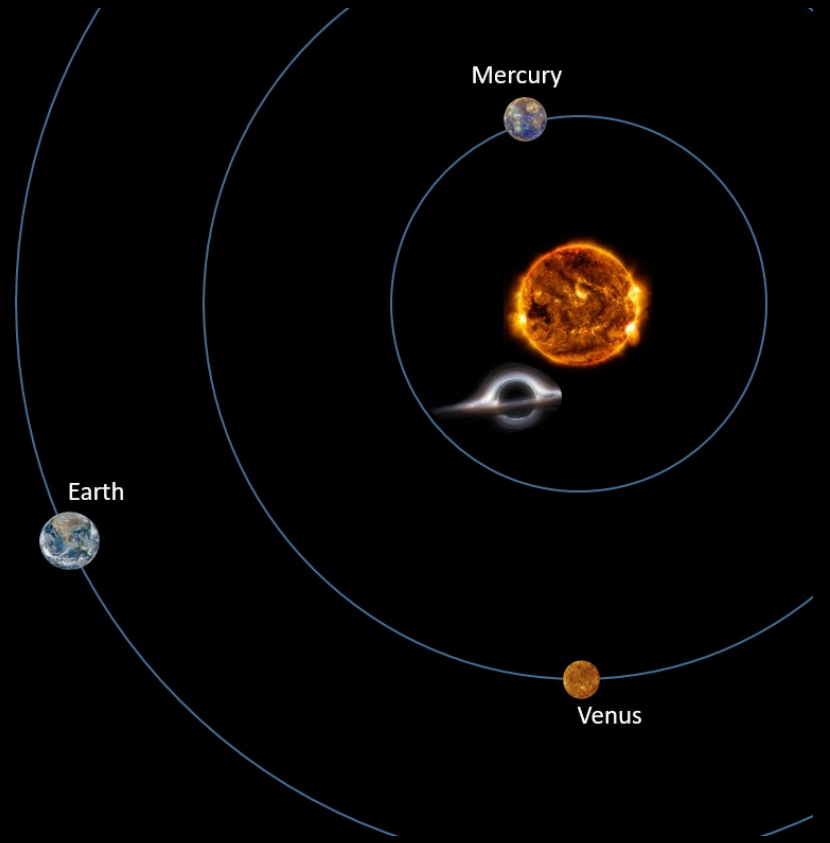


Q: How do we observe something we can’t see?

What do we see?

- Look at the effect the black hole has on its surrounding
- Paths of stars and gas orbiting the black hole far out
- Look at the hot gas getting sucked into the black hole forming

Image Credit: NASA/JPL

Orbits around Supermassive Black Holes

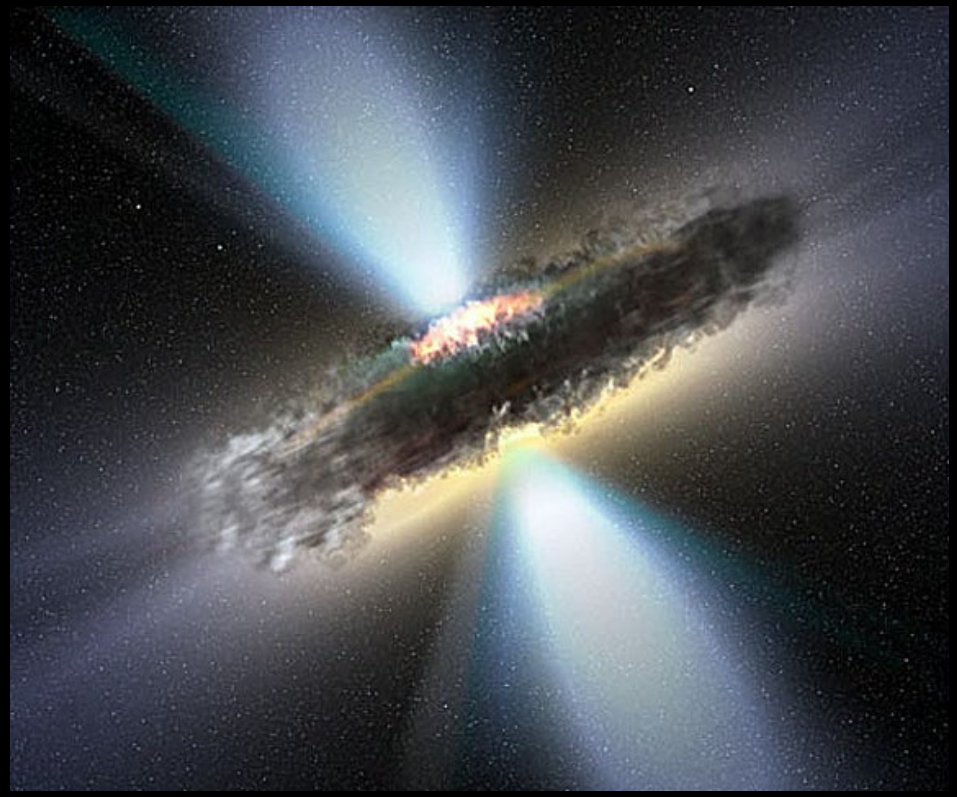
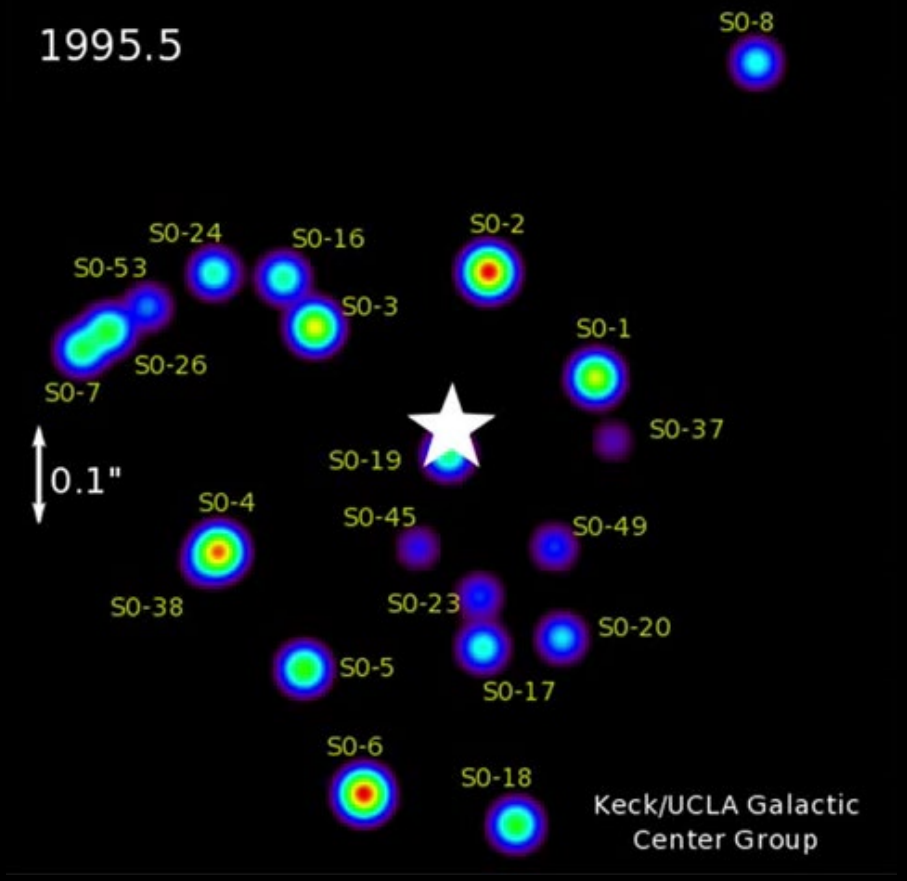


Image Credit: NASA/APOD: V.Veckman

- Look at orbit of stars around the galactic centre
- Found Sagittarius A* has a mass 4 millions times that of the sun
- Only works for very close black holes
- Use timing data to look at gas orbiting supermassive black holes further away

Orbits around Supermassive Black Holes



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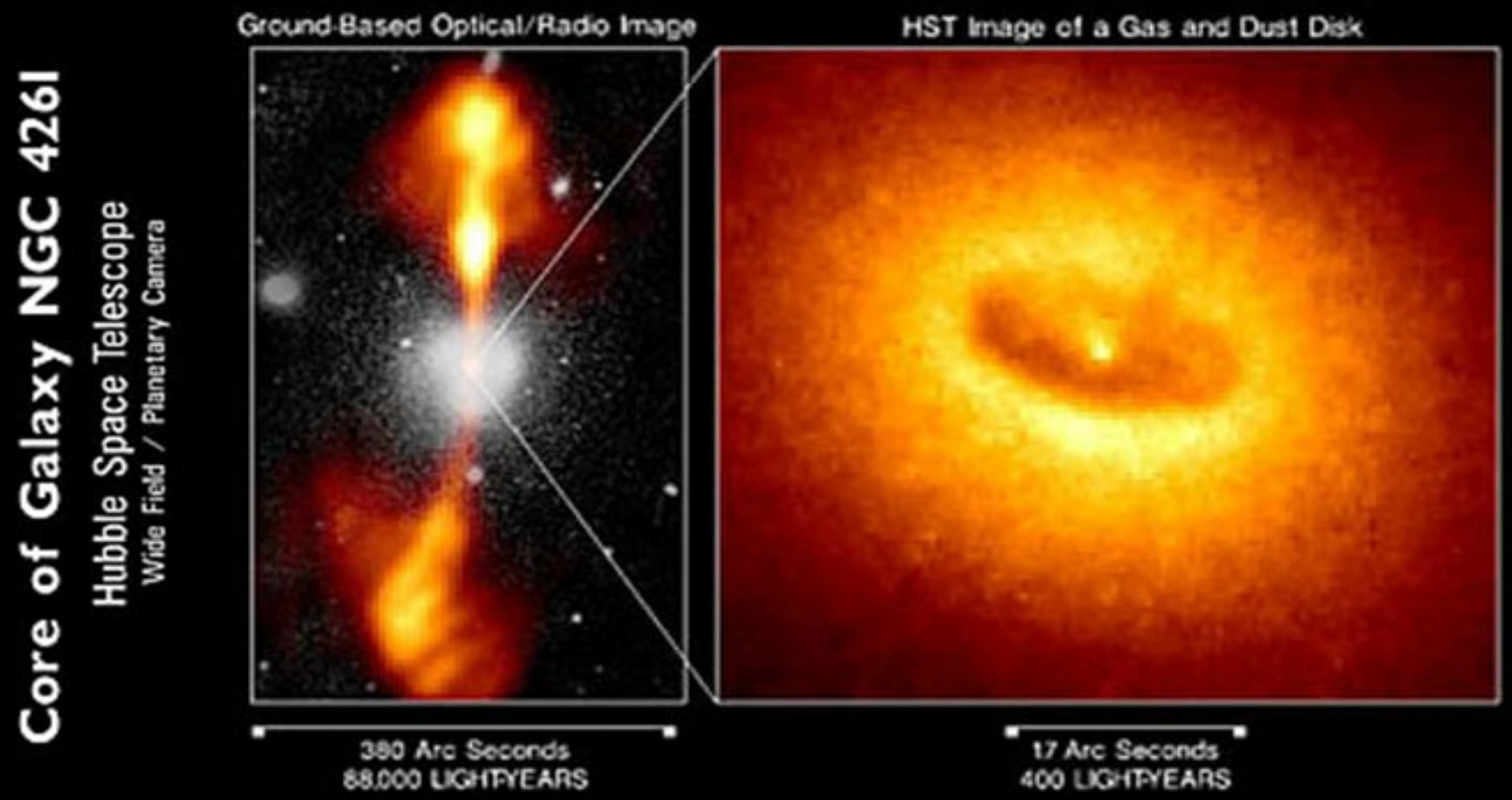


Image Credit: Walter Jaffe/Leiden Observatory, Holland Ford/JHU/STScI, and NASA

Masses of Supermassive Black Holes

- Use a technique called Reverberation Mapping
- Look at how light echoes around the most central region of the galaxy
- Use that to determine how far away the gas clouds are and how fast they are orbiting

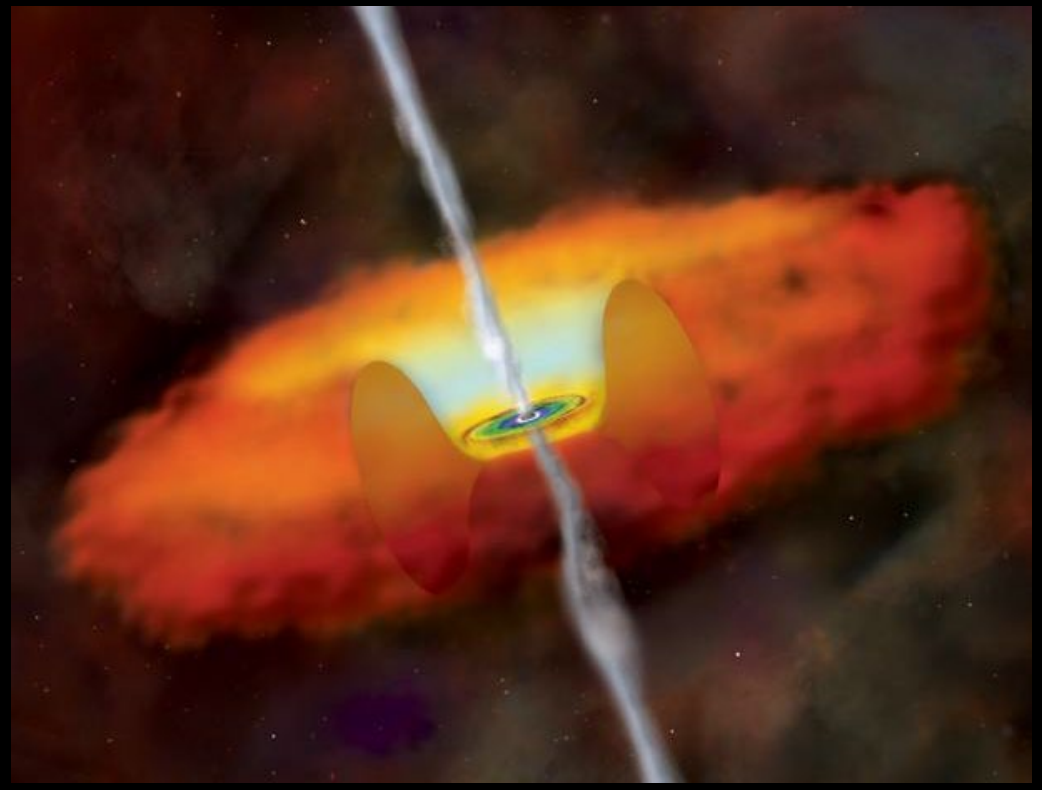


Image Credit: CXC, Melissa Weiss

Q: How do we measure how fast the gas clouds are orbiting the black hole?

Emission from Gas Clouds

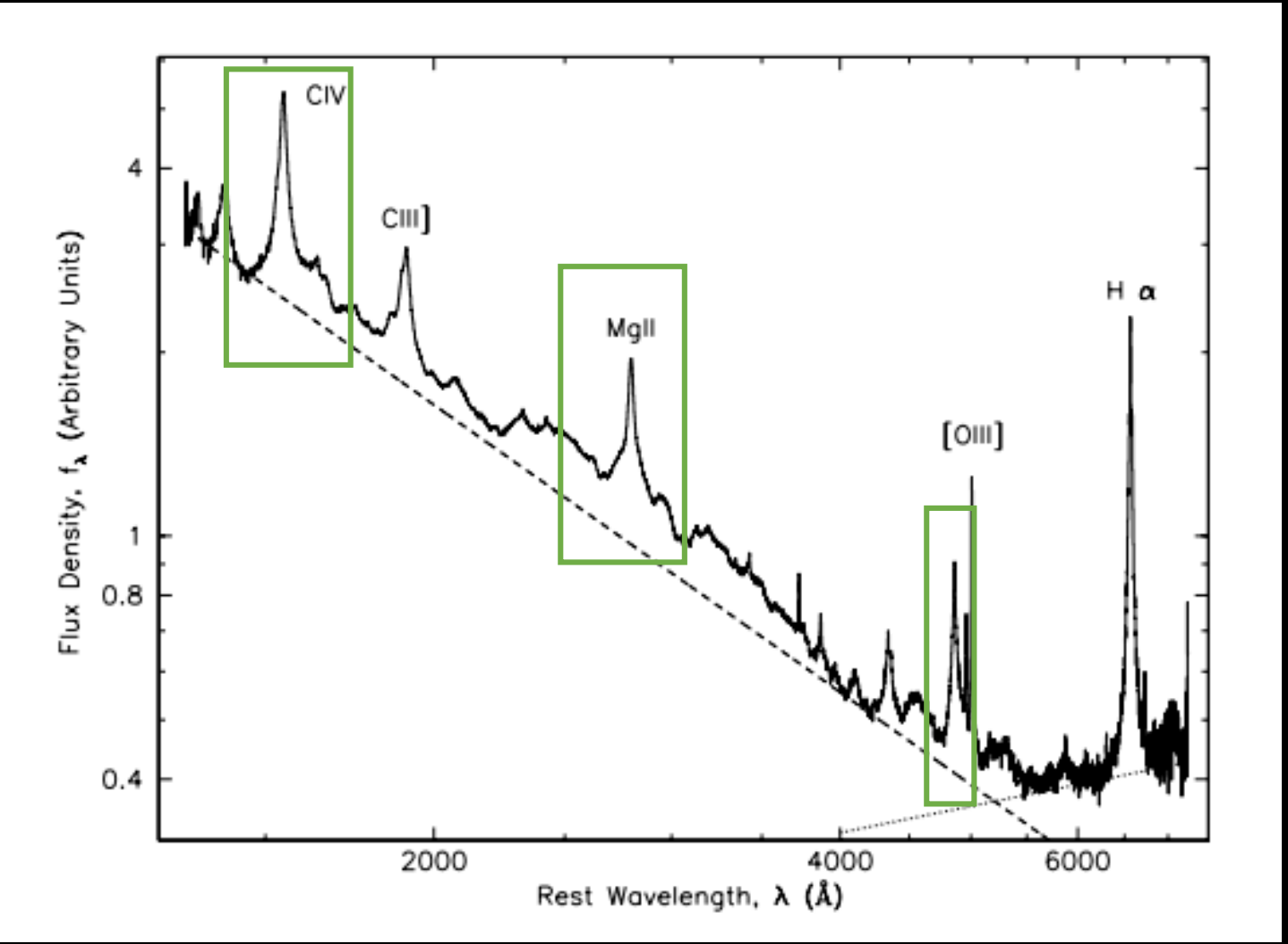
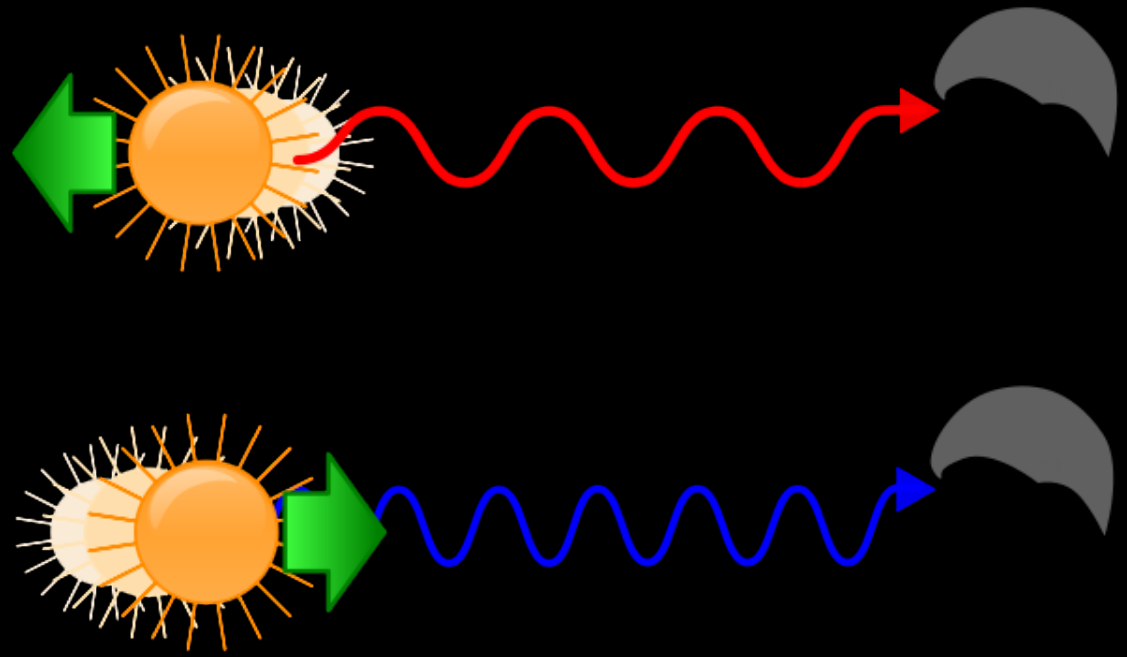


Image Credit: Vanden Berk et al 2001

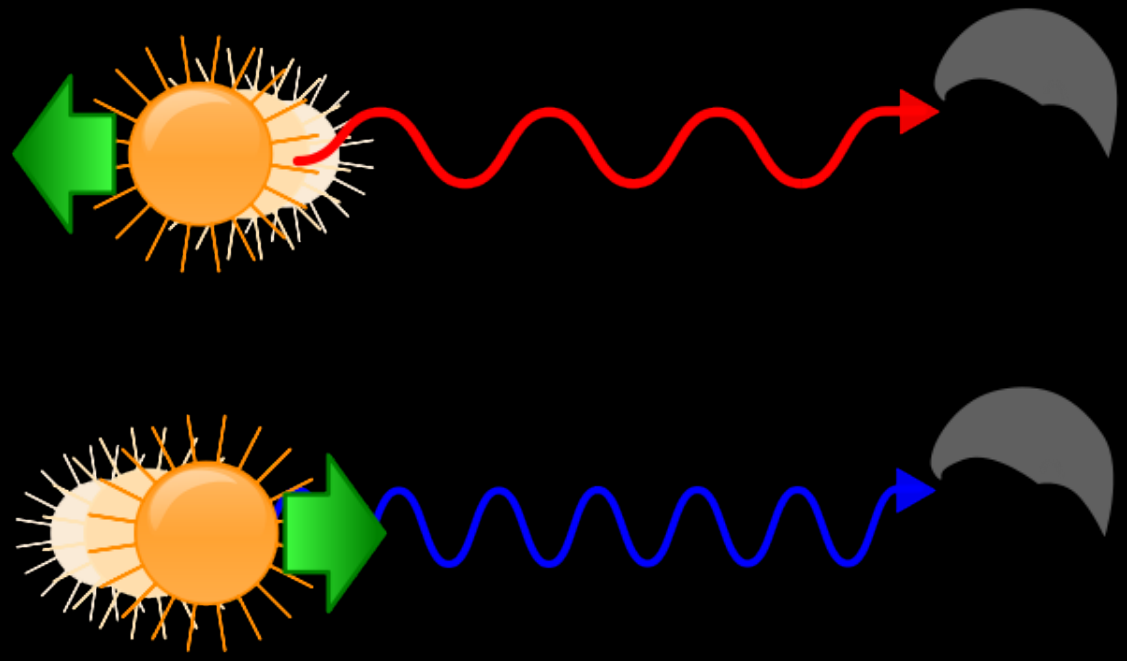
Doppler Effect



- $\lambda = \lambda' \frac{1}{1 - v/c}$
  - λ' = original wavelength
  - λ= new wavelength
  - v = velocity of source
  - c = speed of light

Image Credit: By Aleš Tošovský, https://commons.wikimedia.org/w/index.php?curid=662534

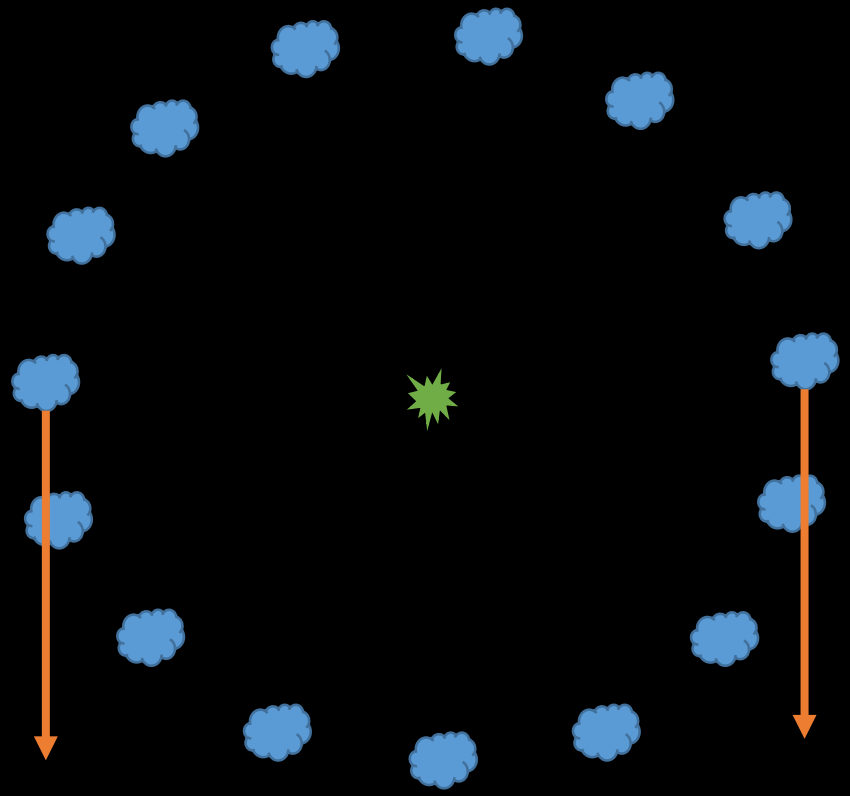
Doppler Effect

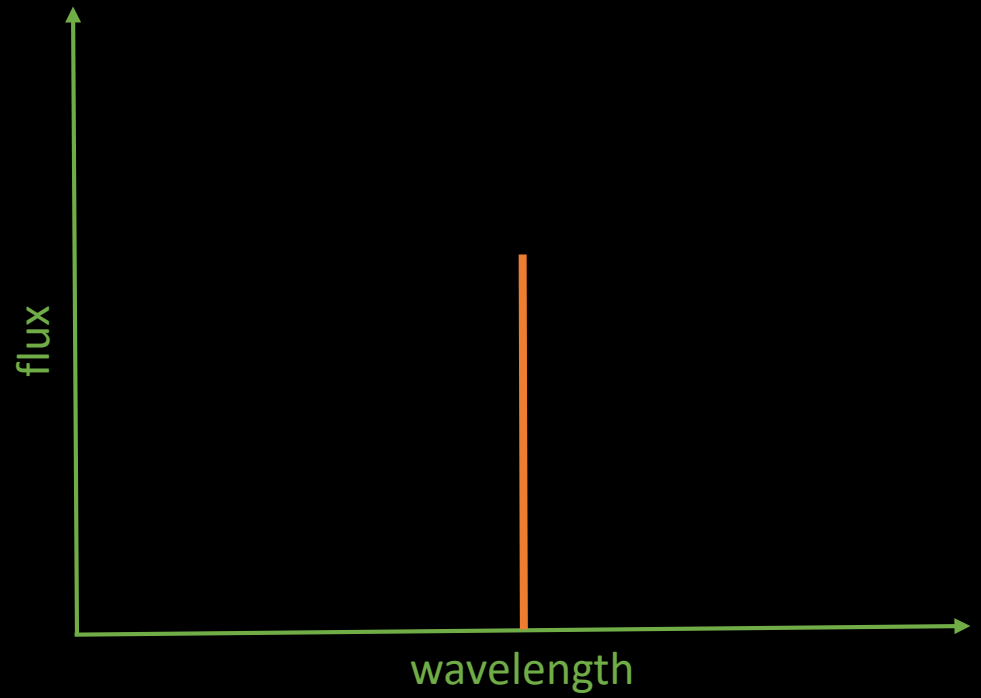


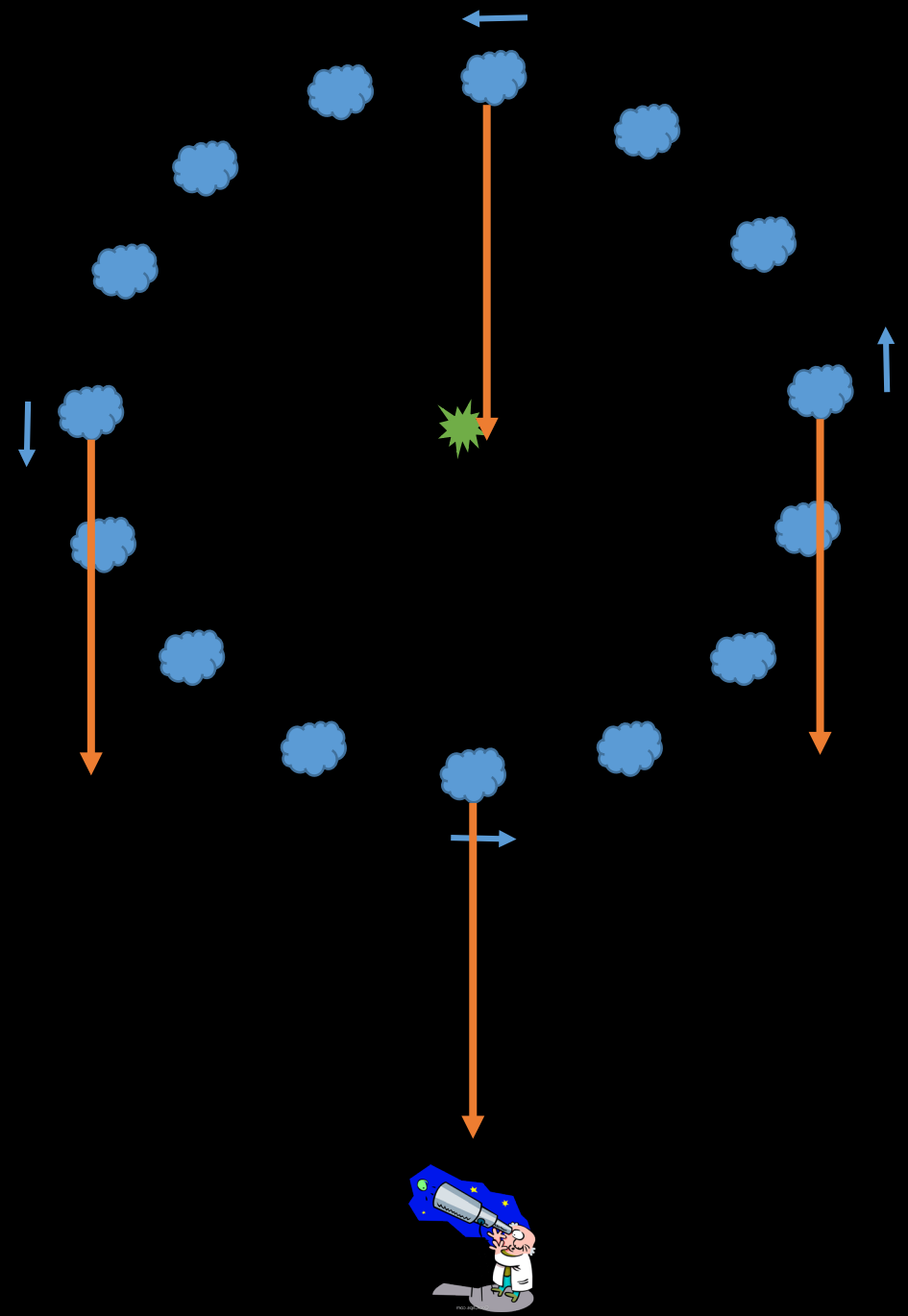
- $\lambda = \lambda' \frac{1}{1 - v/c}$

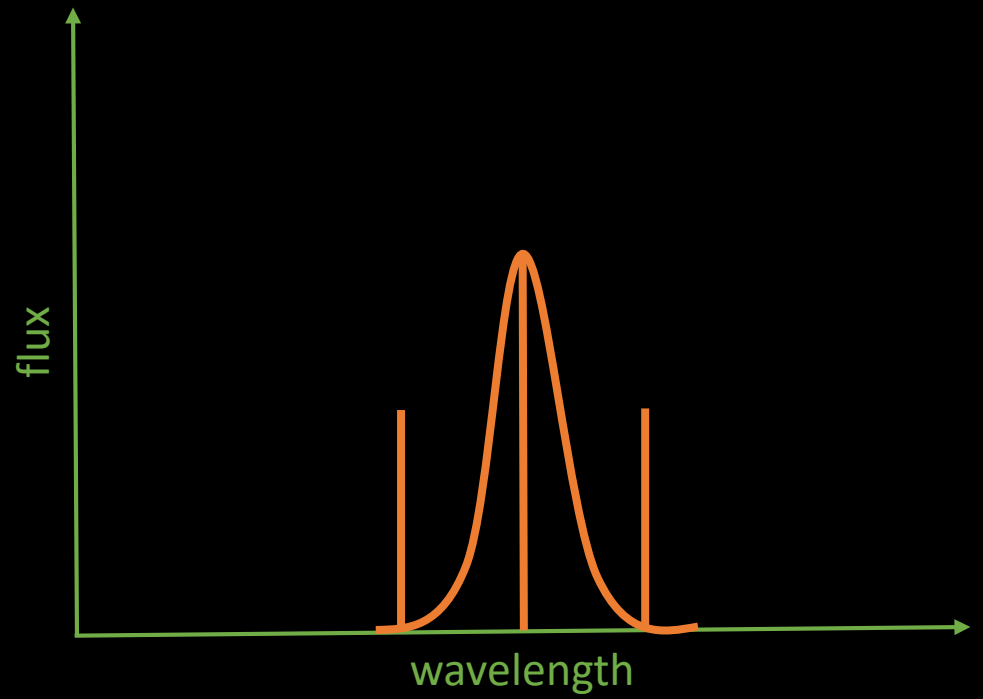
- Moving towards you
  - v < 0
  - Wavelength decreases
- Moving away from you
  - v > 0
  - Wavelength increases

Image Credit: By Aleš Tošovský, https://commons.wikimedia.org/w/index.php?curid=662534




flux
wavelength

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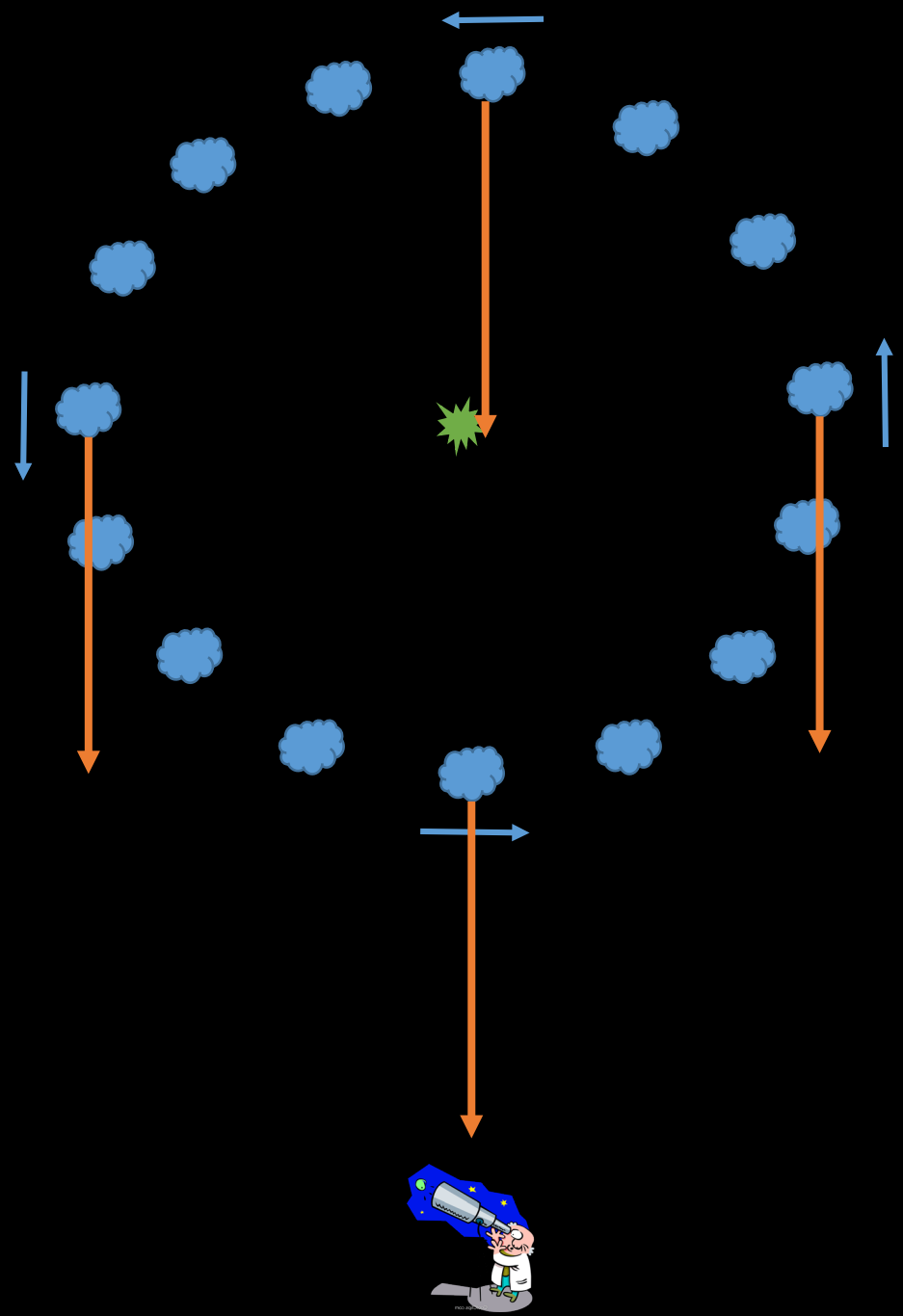
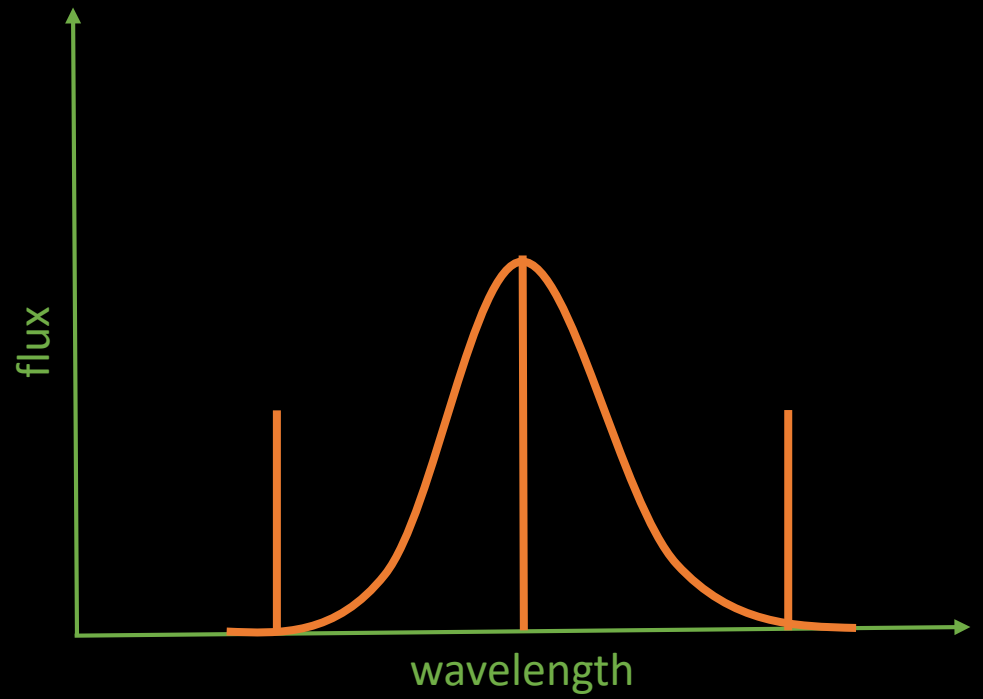
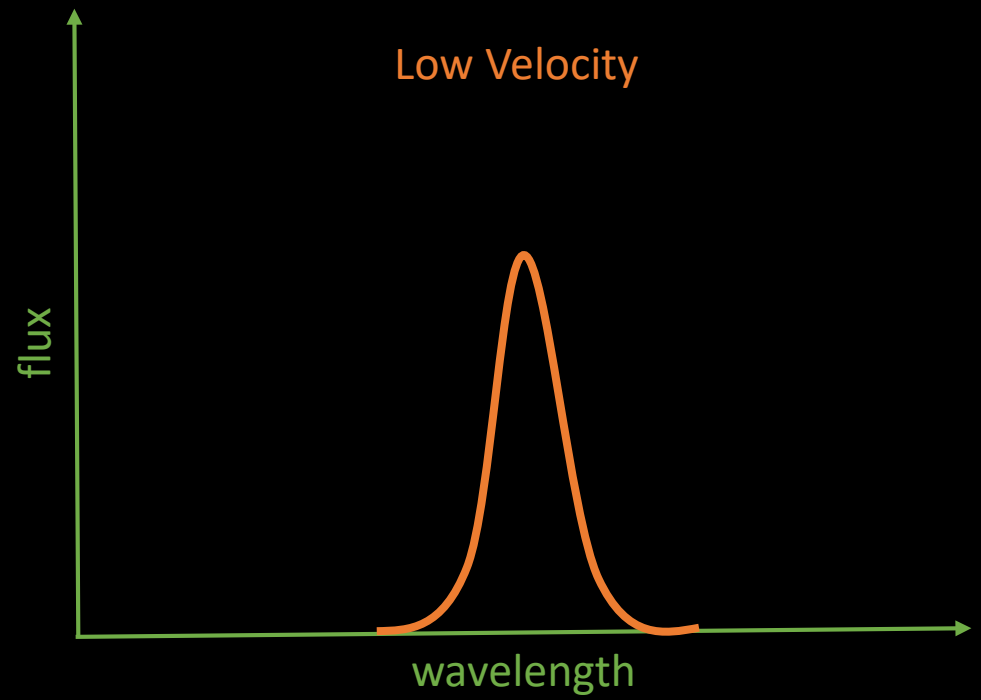
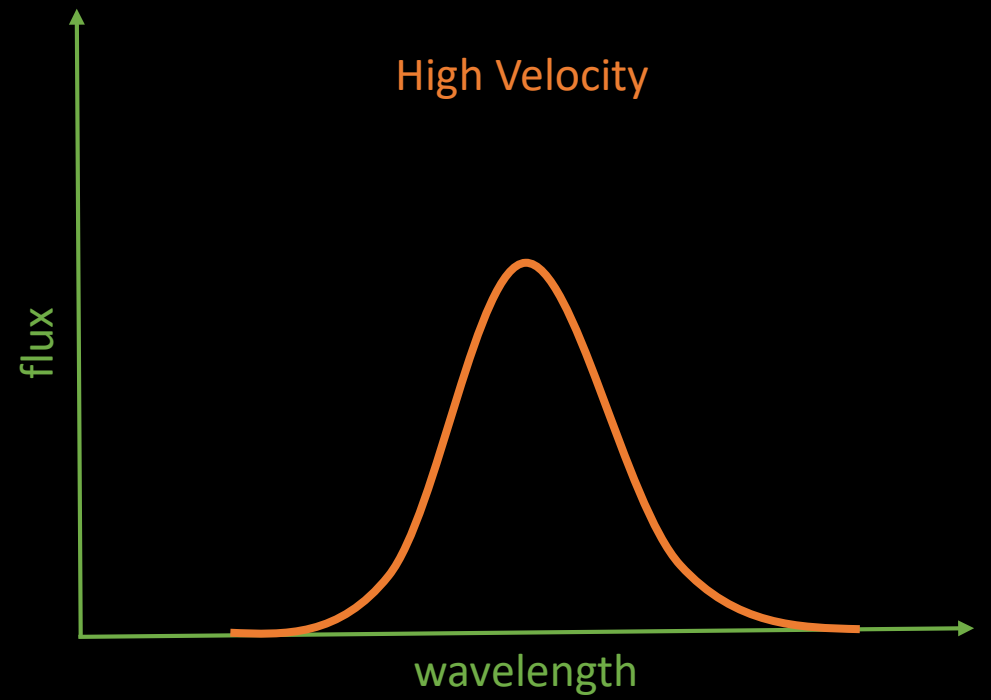


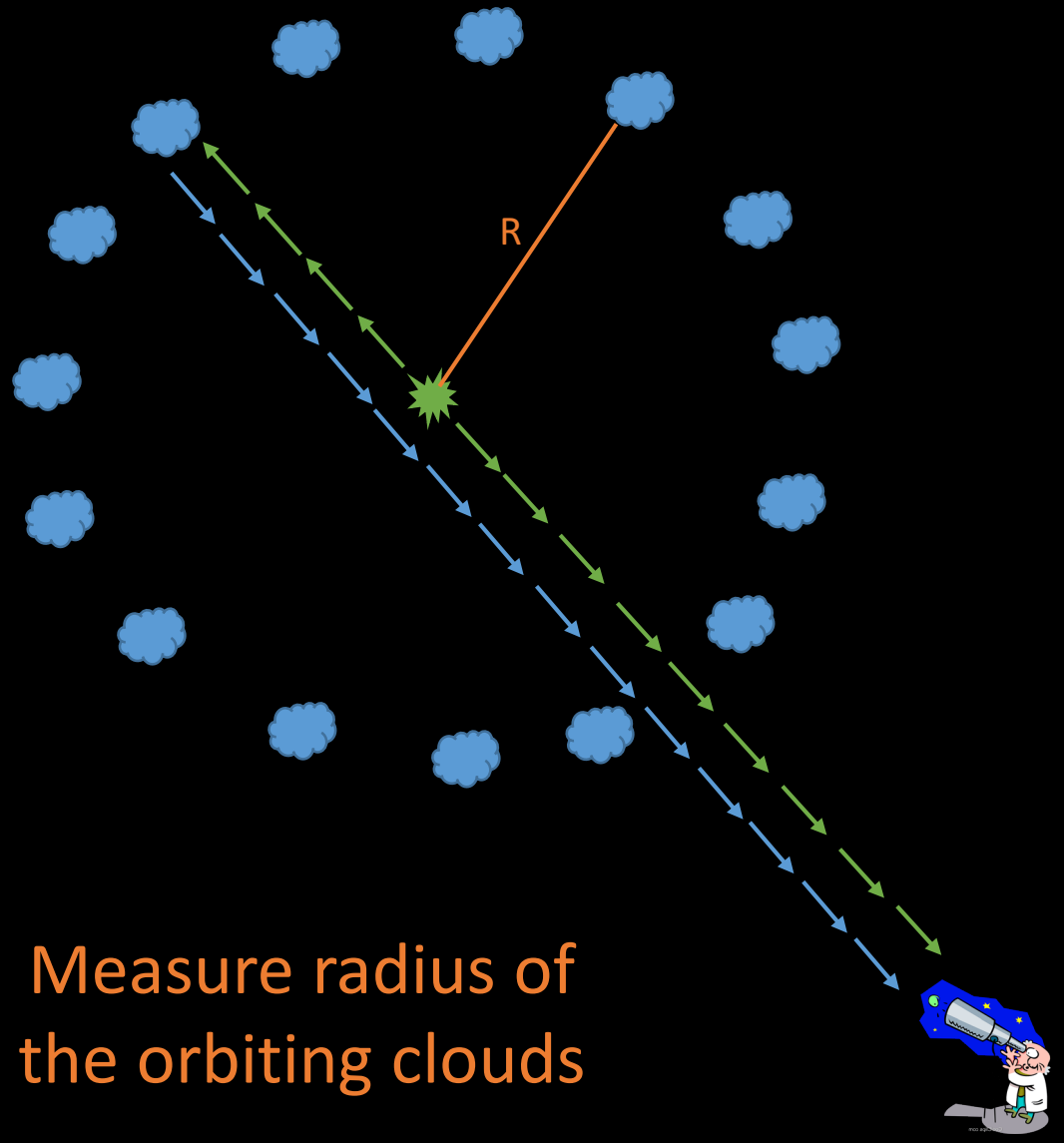

flux
wavelength

Broader the emission line, the faster the gas is moving

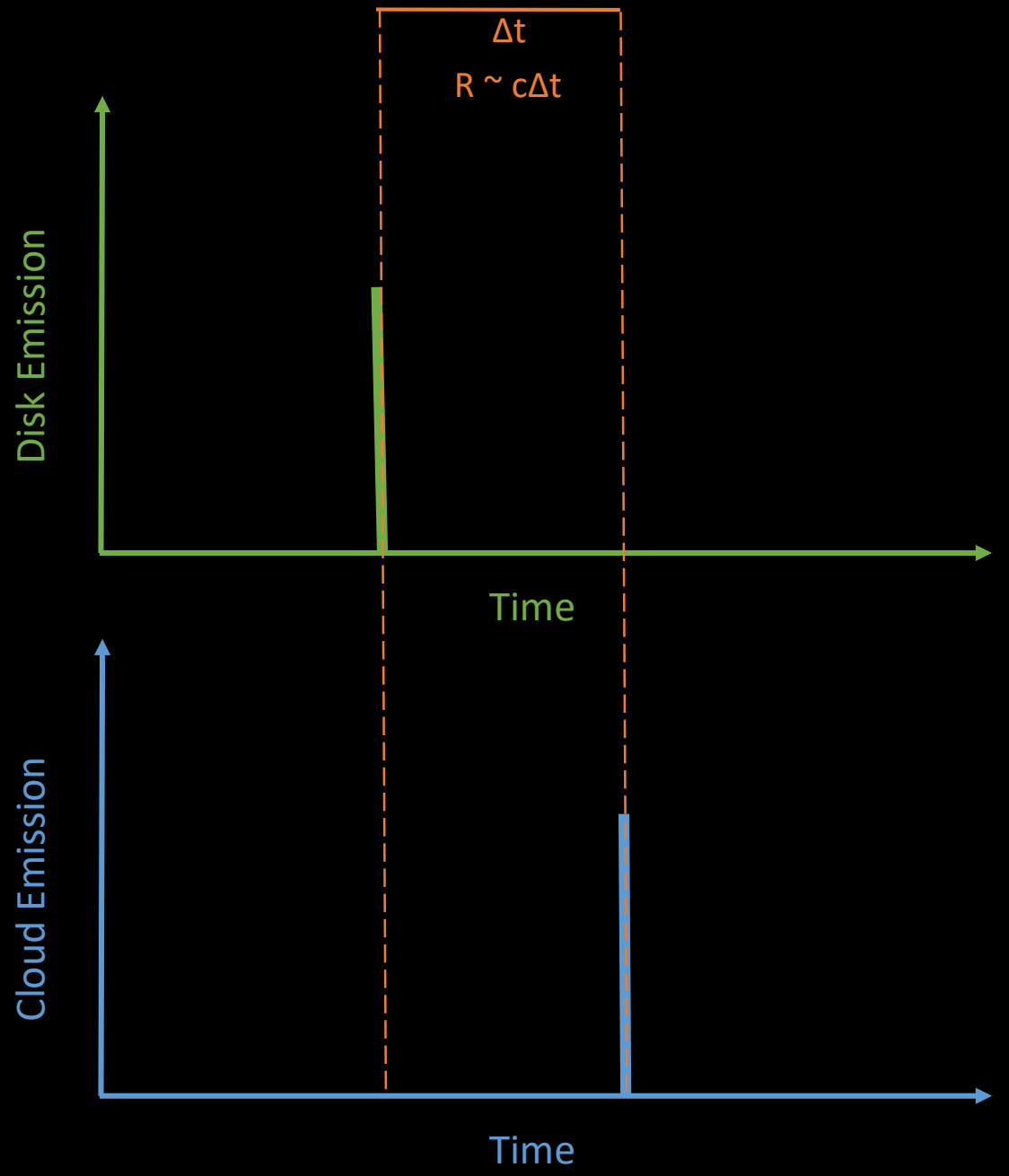




Q: How do we determine how far away the gas clouds are orbiting?



Measure radius of the orbiting clouds



Q: How do you observe black holes and measure their mass?

THE DARK ENERGY SURVEY

The Dark Energy Survey

- 5 year survey with the Blanco Telescope
  - 4m telescope in Chile
  - Take photos with an optical camera
- Detect supernova and map millions of galaxies to study the expansion of the universe
- Repeatedly observe 10 regions of the sky

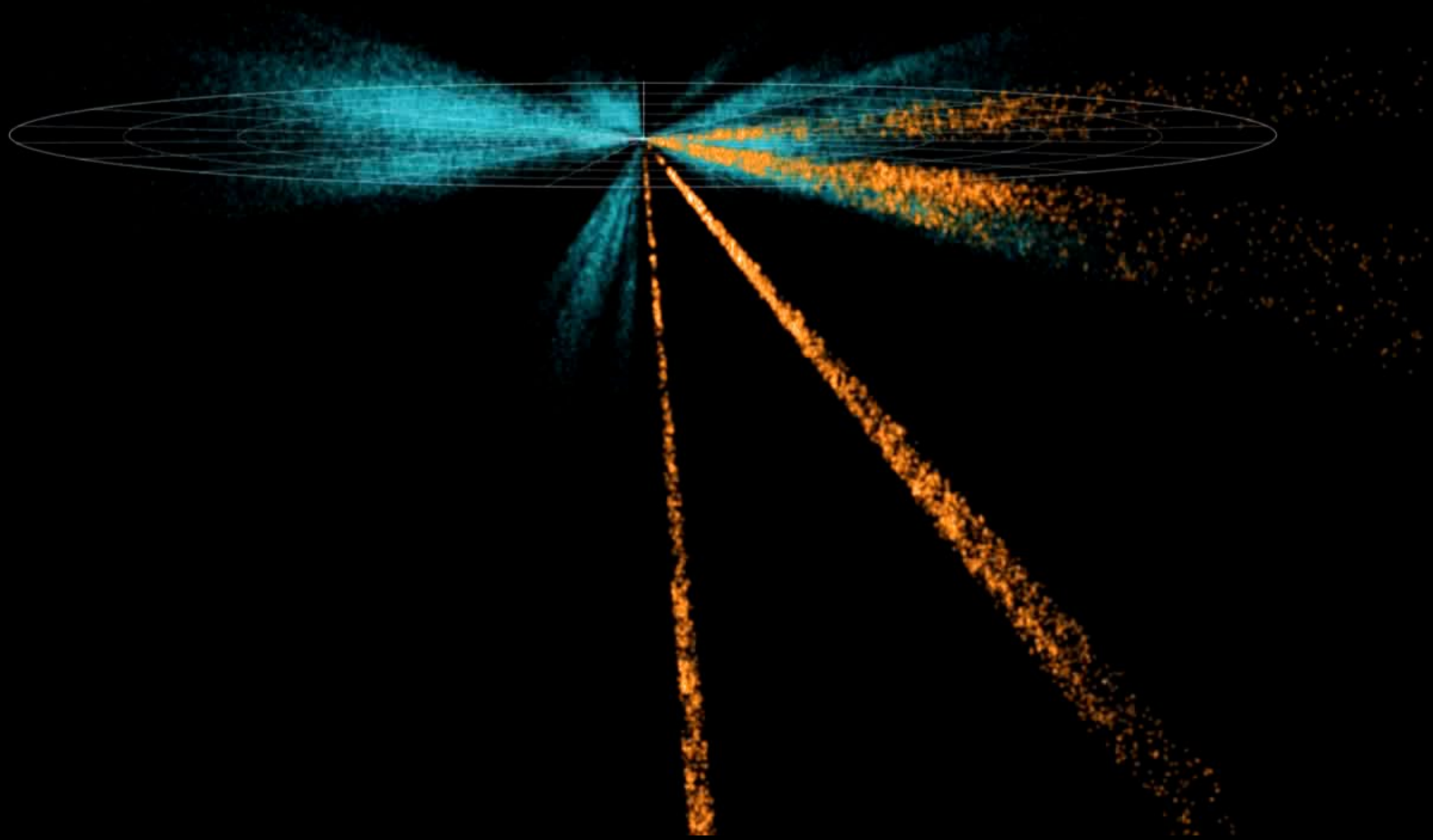
Image Credit: KICP/UChicago

The Australian Dark Energy Survey

The Australian Dark Energy Survey

- 6 year survey with the Anglo-Australian Telescope
  - 4m telescope near Coonabarabran, NSW
  - Takes spectra of the galaxies
- Measure distances to supernova and calculate black hole masses
  - Regularly look at 771 galaxies with black holes in the centre
- Detect more distant galaxies than previous surveys

Image Credit: AAO



Video Credit: Sam Hinton, UQ

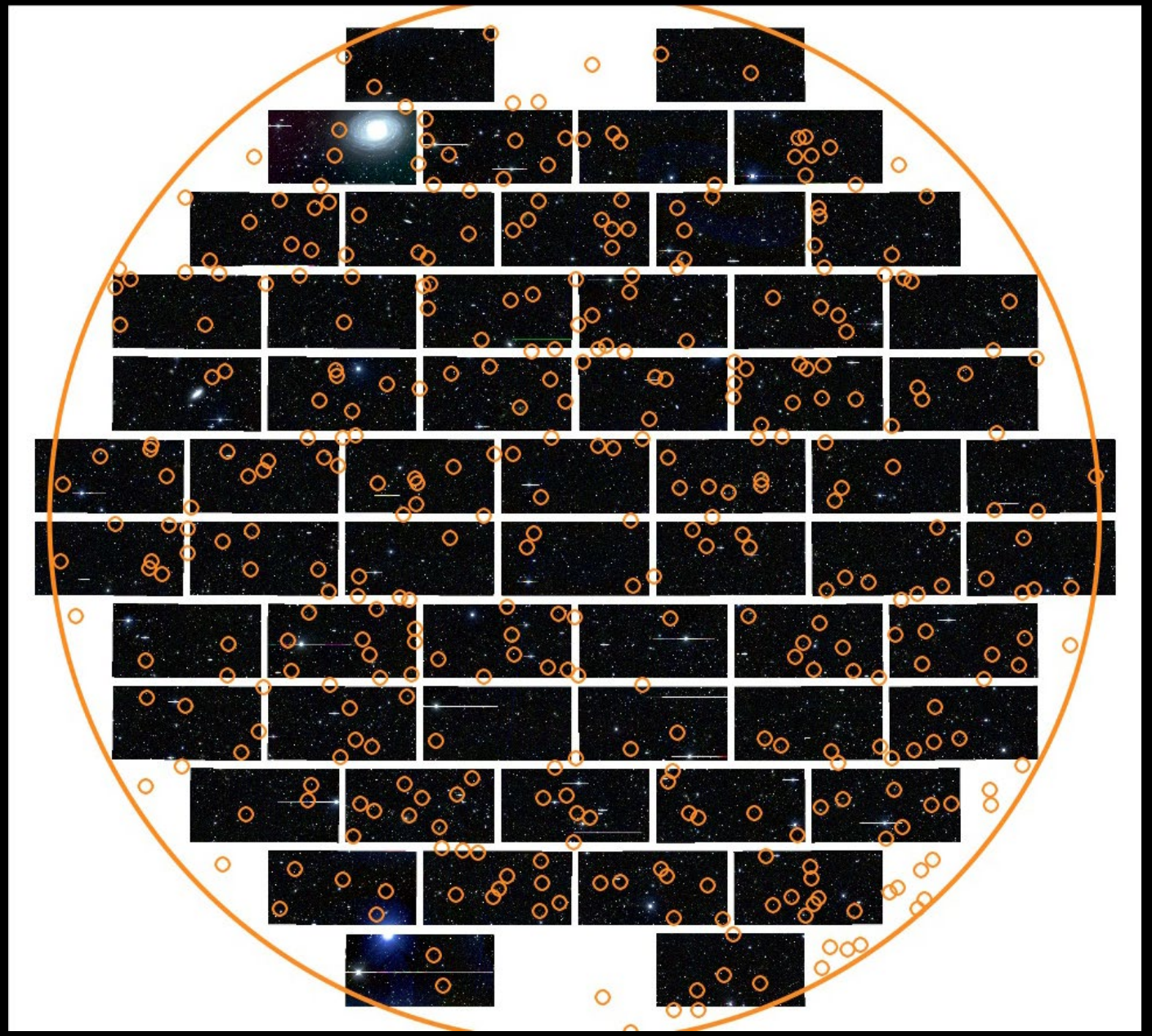


Image Credit: Yuan et al 2015

Video Credit: AAO

Q: Why do I care about how much black holes weigh?

The Big Questions

Q: Did black holes get so big just by eating space junk?

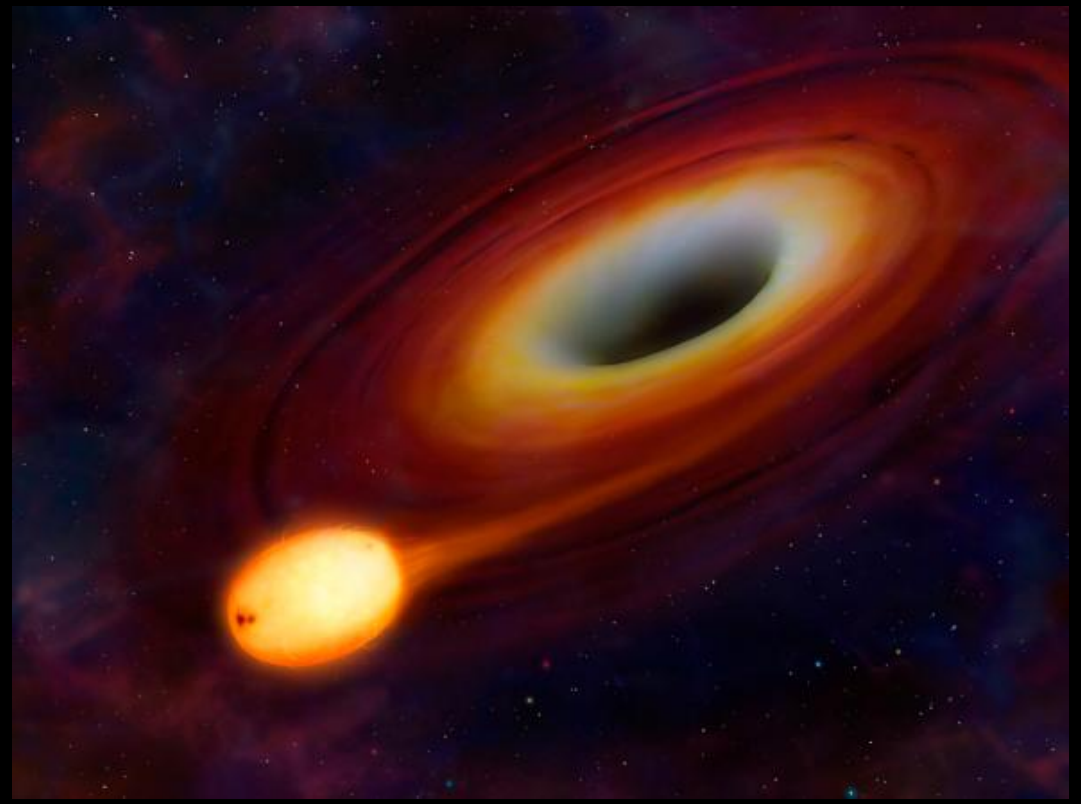


Image Credit: M.A. Garlick

The Big Questions

Q: Did black holes get big by crashing into other black holes to create one big black hole?

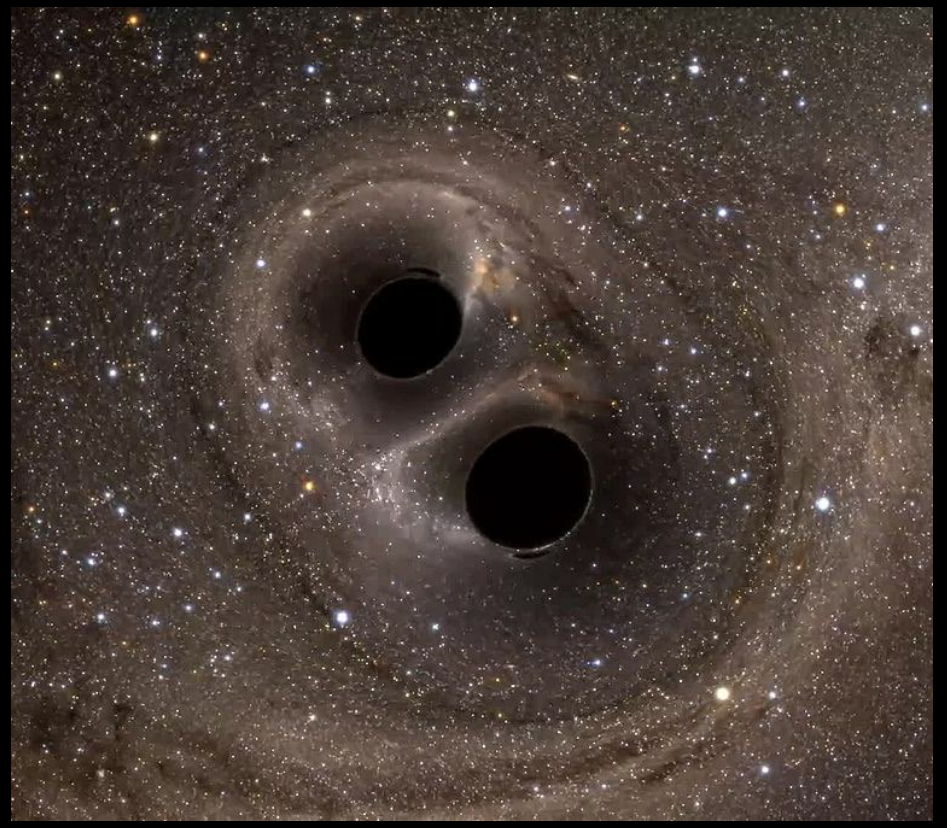


Image Credit: SXS

The Big Questions

Q: How have galaxies grown over time?

Image Credit: NASA

Thank you, questions?