Weighing Black Holes with the Australian Dark Energy Survey

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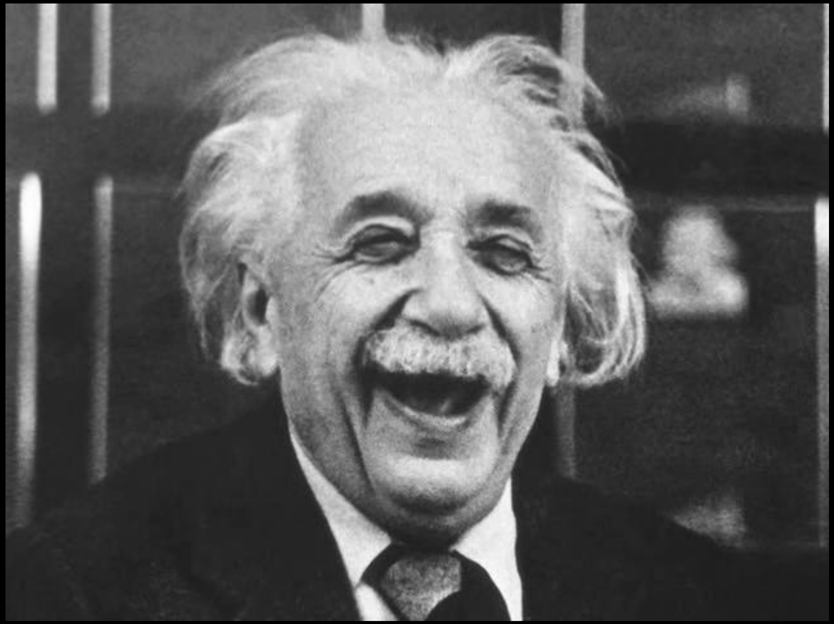
6 October 2017

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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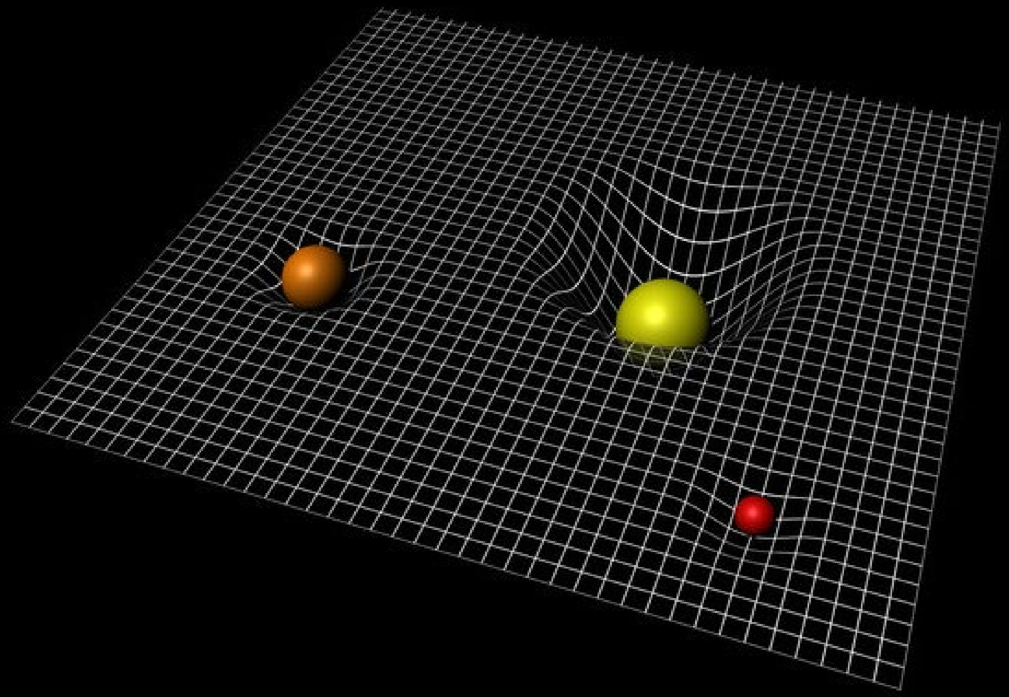
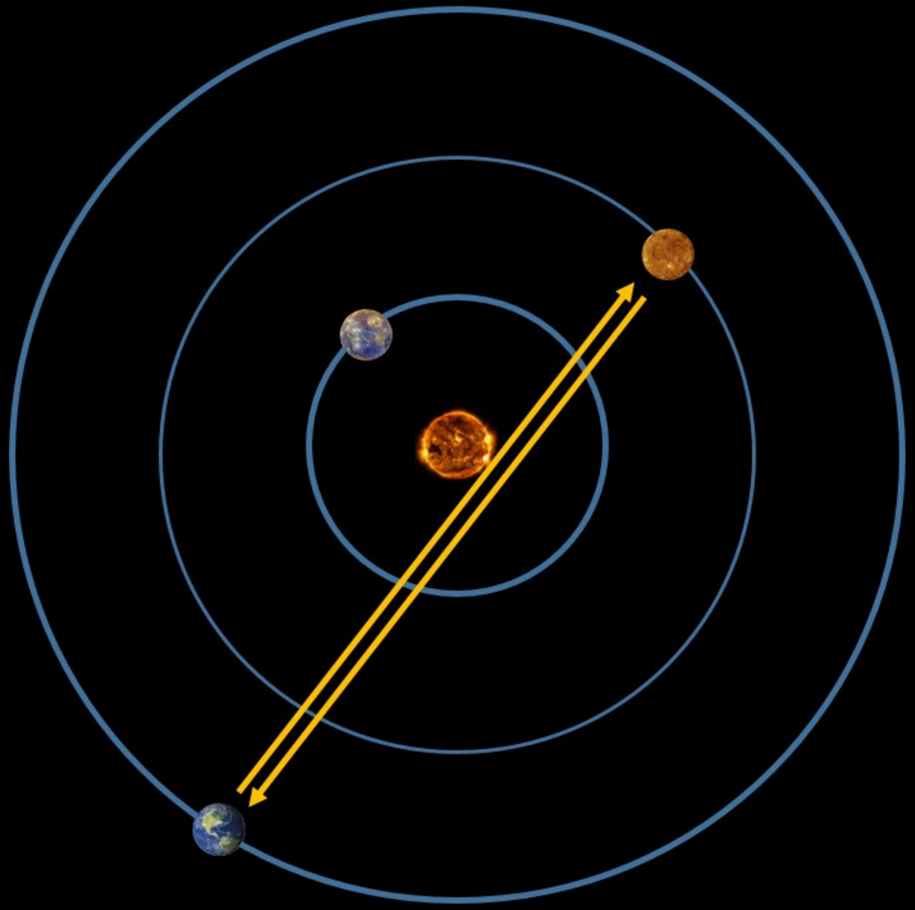


Image Credit: ESA-C.Carreau

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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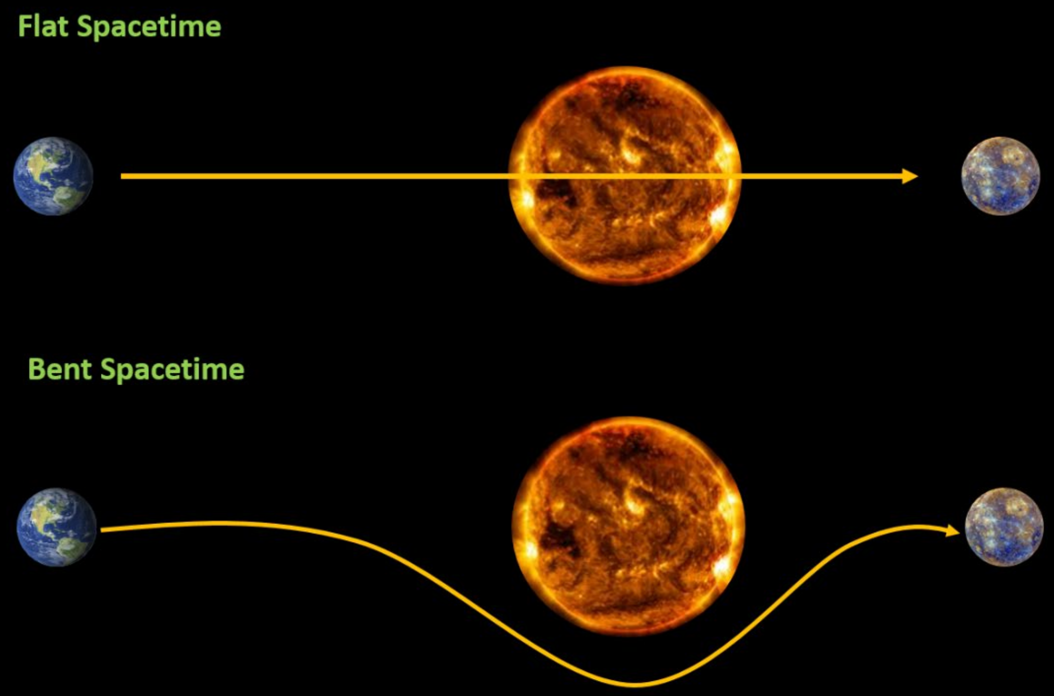

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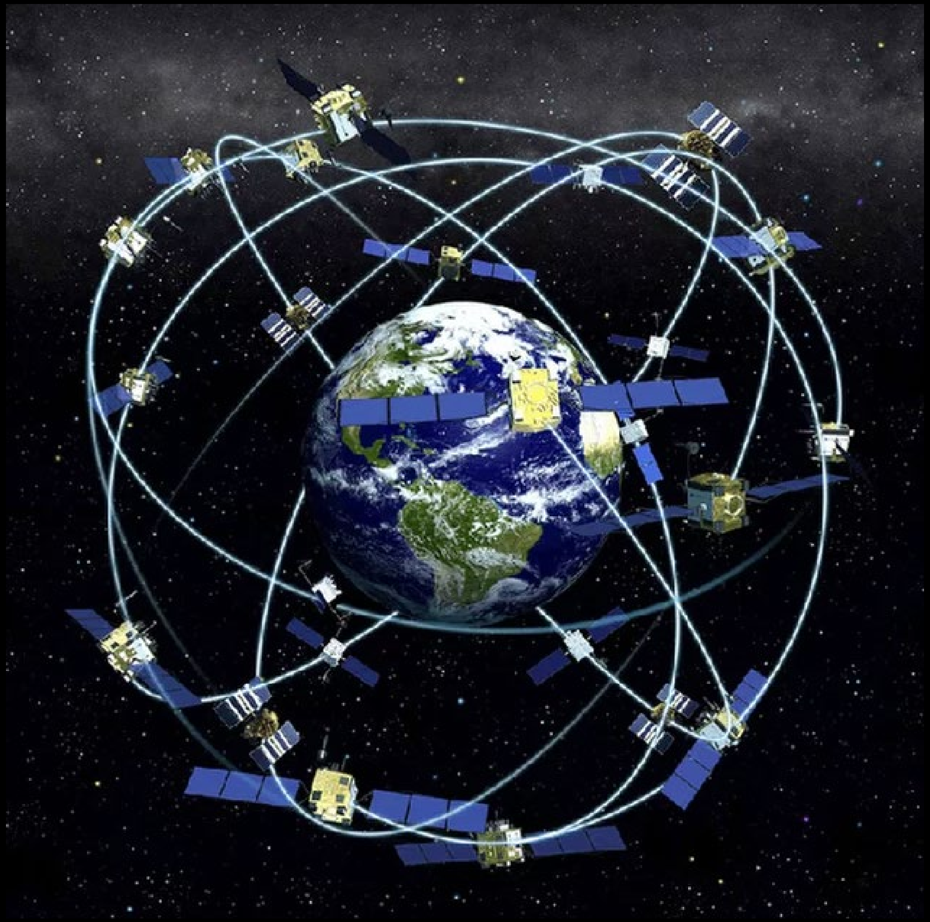

Image Credit: NOAA

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

Gravitational Waves

- Can propagate as ripples in spacetime
- Detectable in dense binary star systems
  - White dwarfs
  - Neutron stars
  - Black holes
- Rainer Weiss (MIT), Kip Thorne and Barry Barish (Caltech) the 2017 Nobel Prize in Physics for the first detection of GWs!

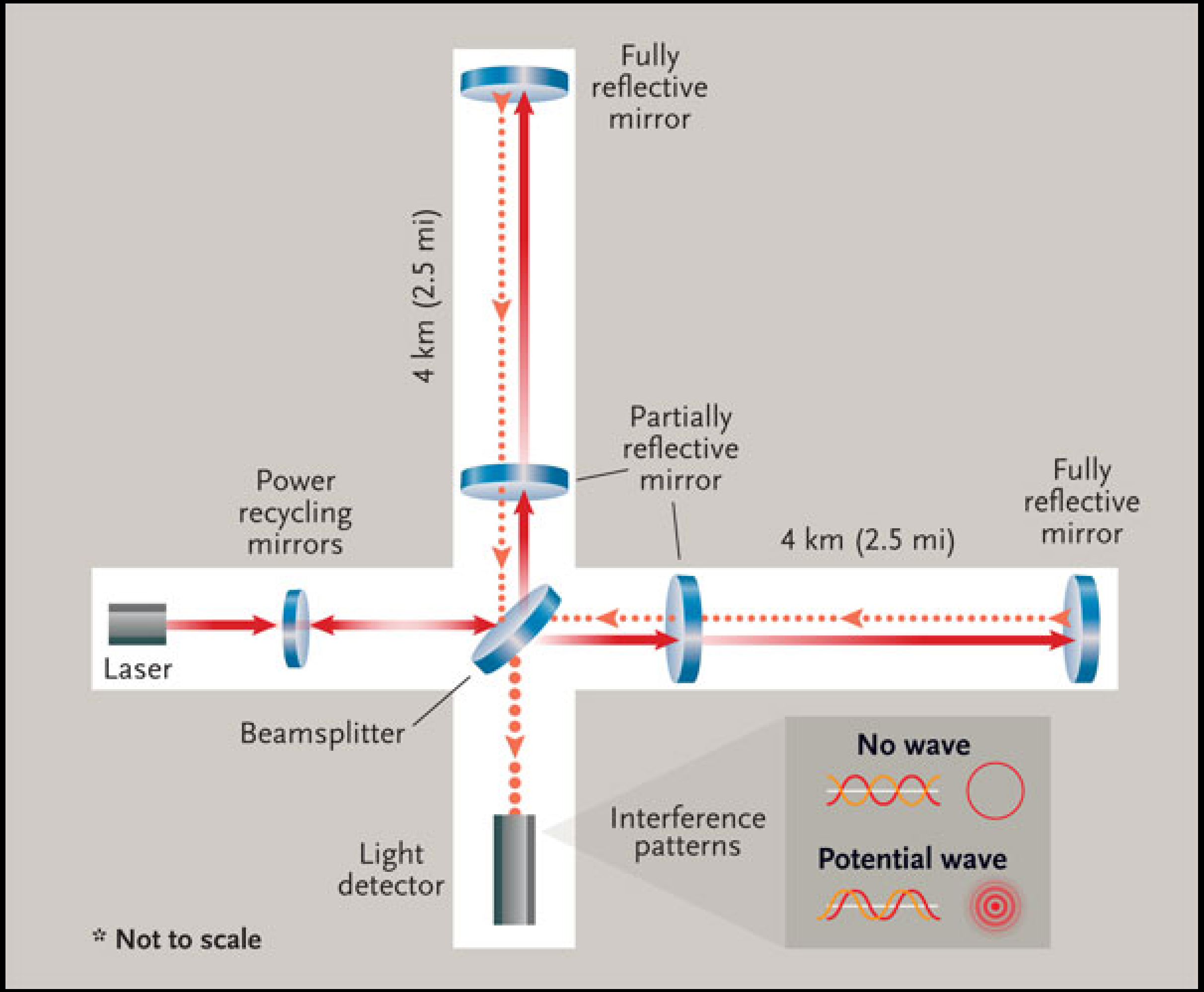

Image Credit: S&T Leah Tiscione

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

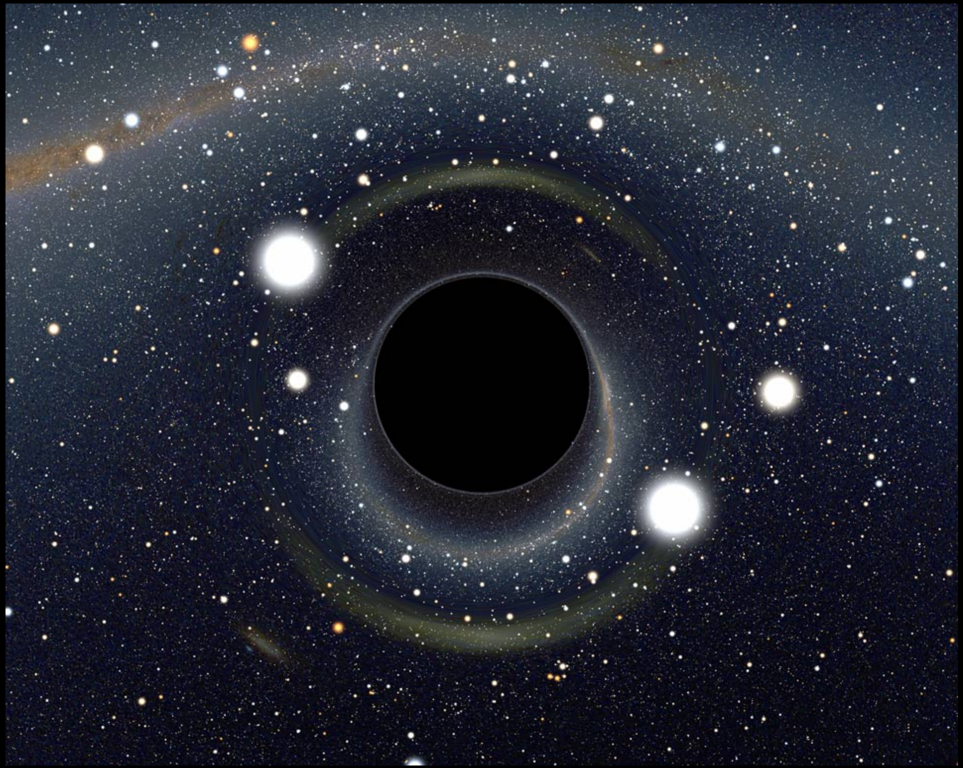

Image Credit: Alain Riazuelo

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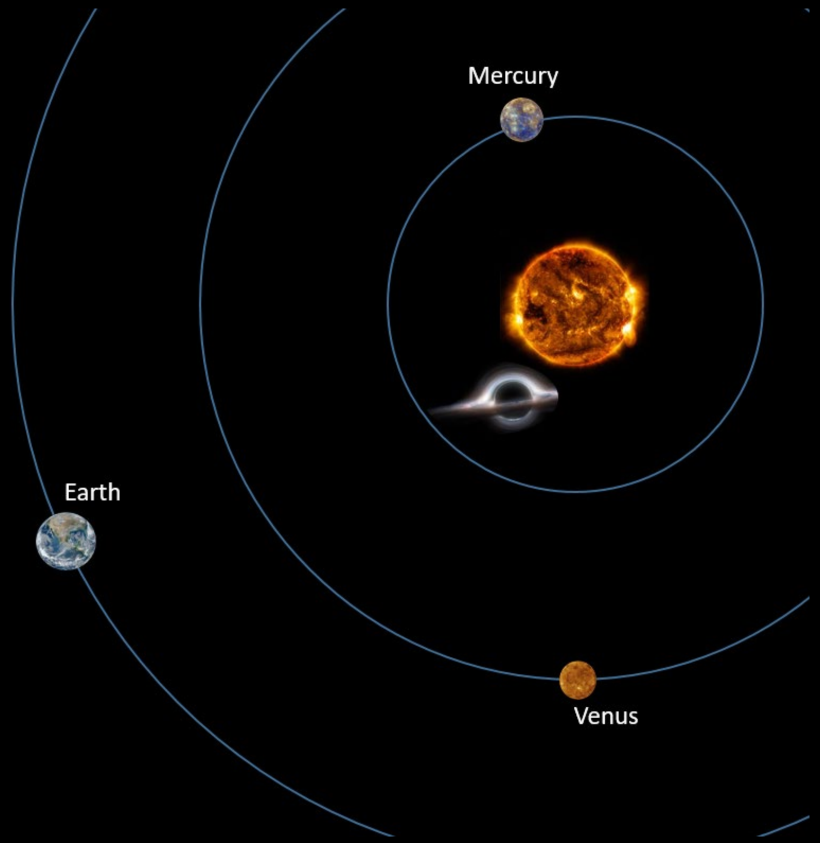


How do we observe something we can’t see?

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

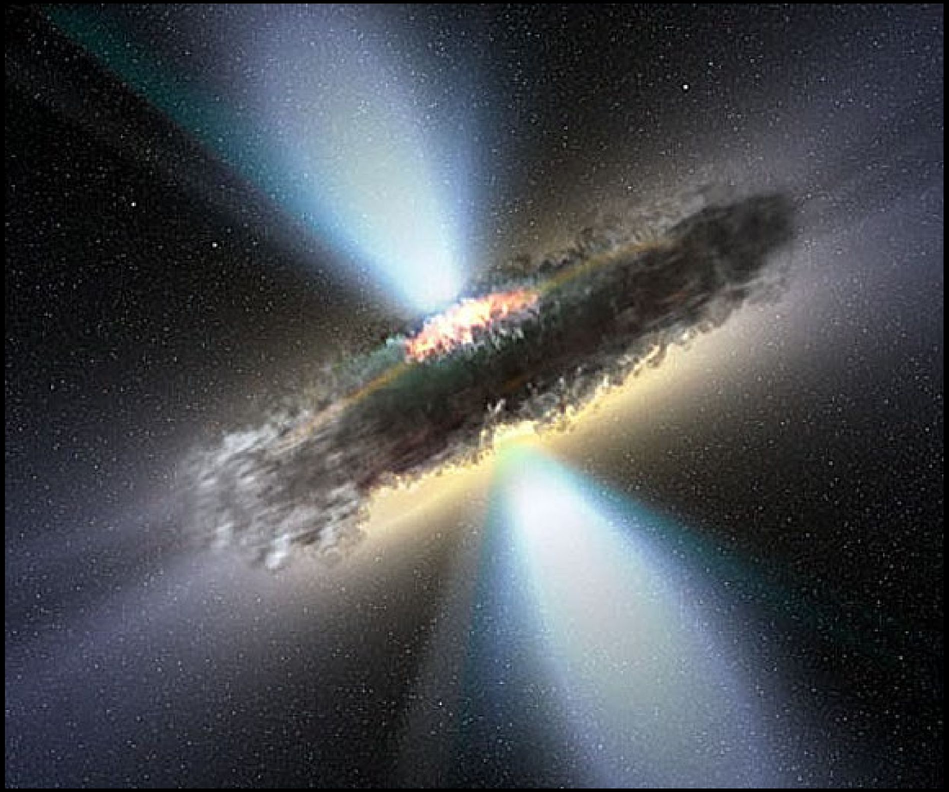
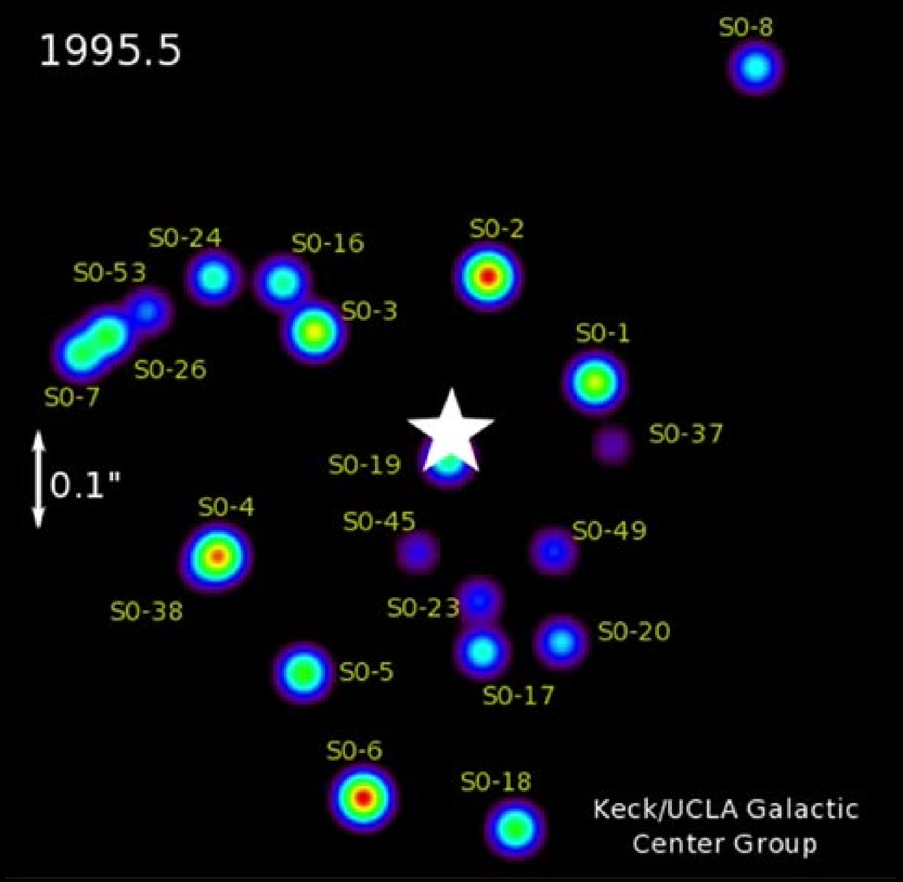


Image Credit: NASA/APOD: V.Veckman

- 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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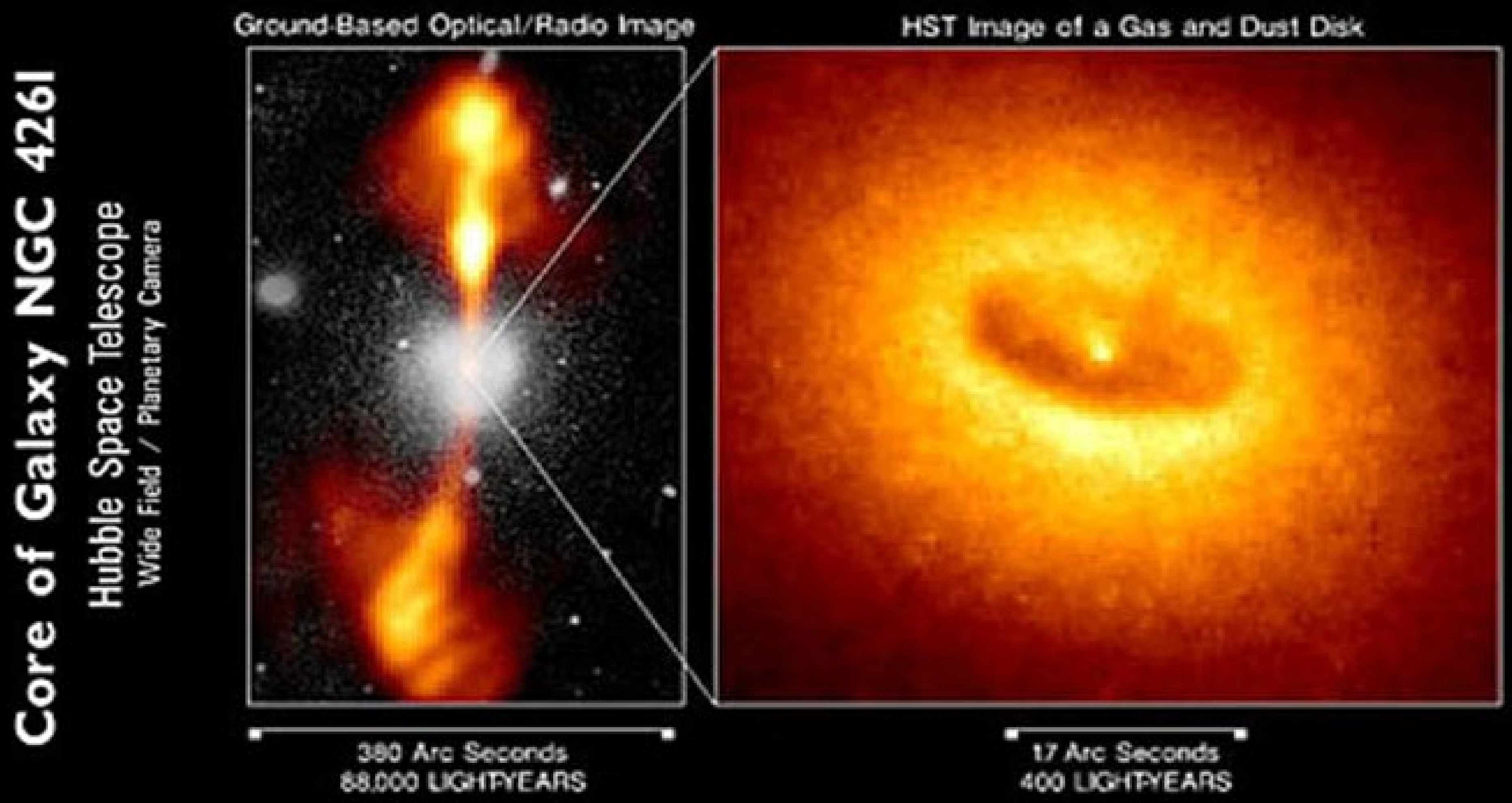


Image Credit: Walter Jaffe/Leiden Observatory, Holland Ford/JHU/STScI, and NASA

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 fast the gas orbiting the black hole is moving

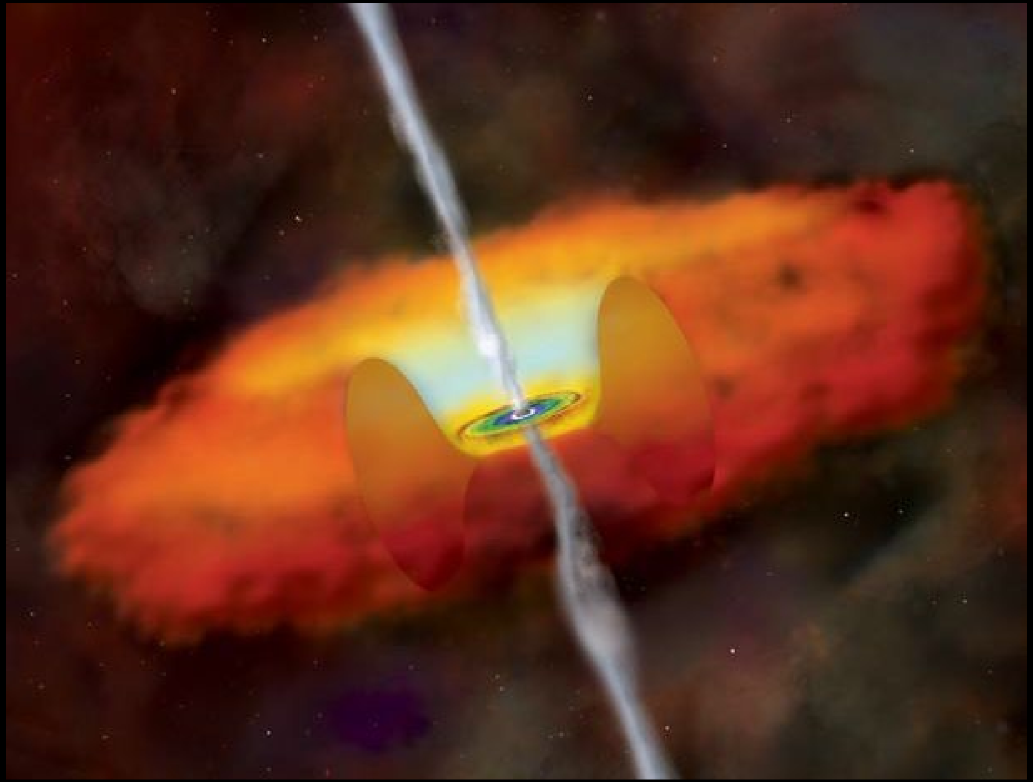


Image Credit: CXC, Melissa Weiss

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

Emission from Gas Clouds

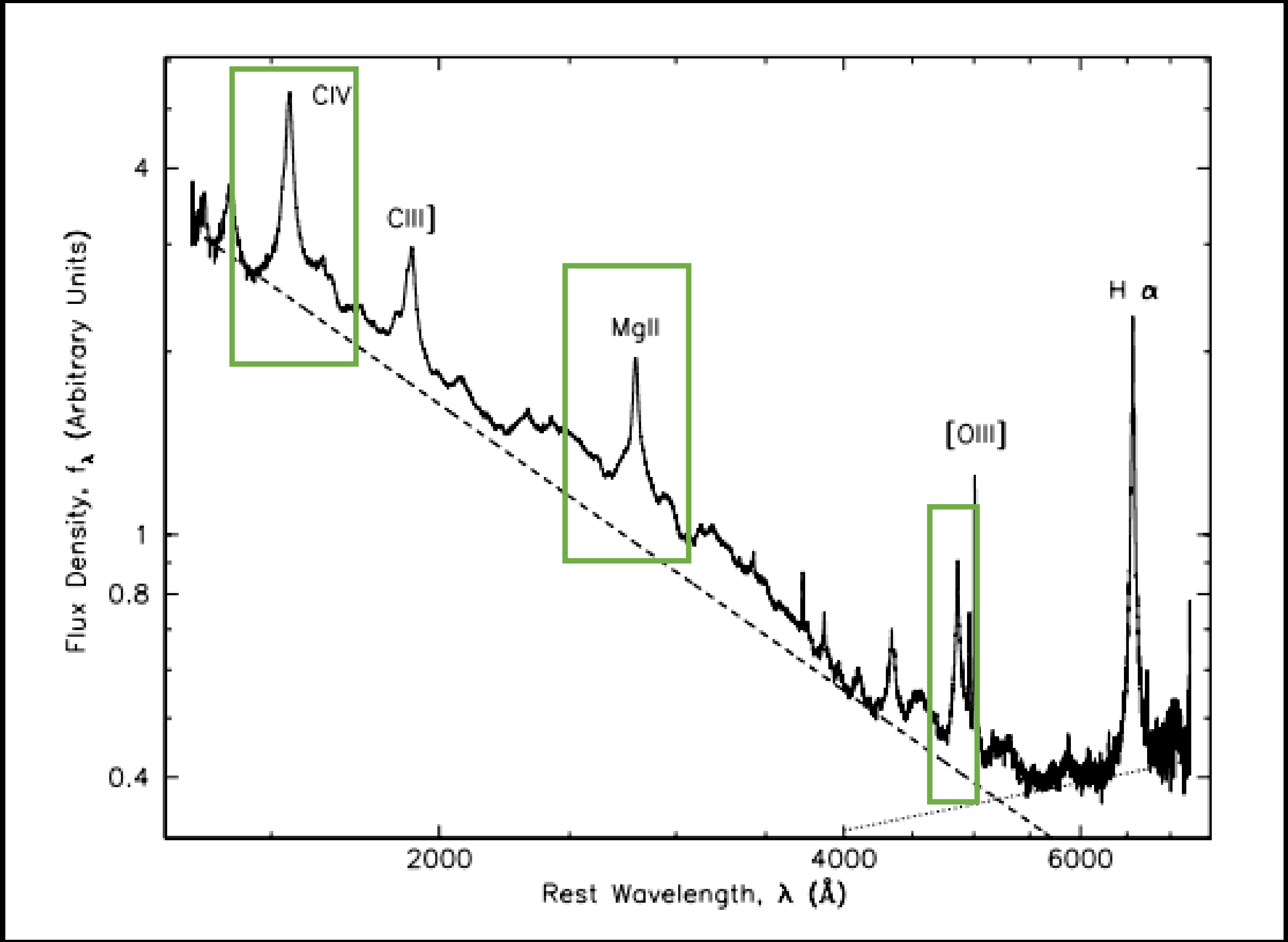
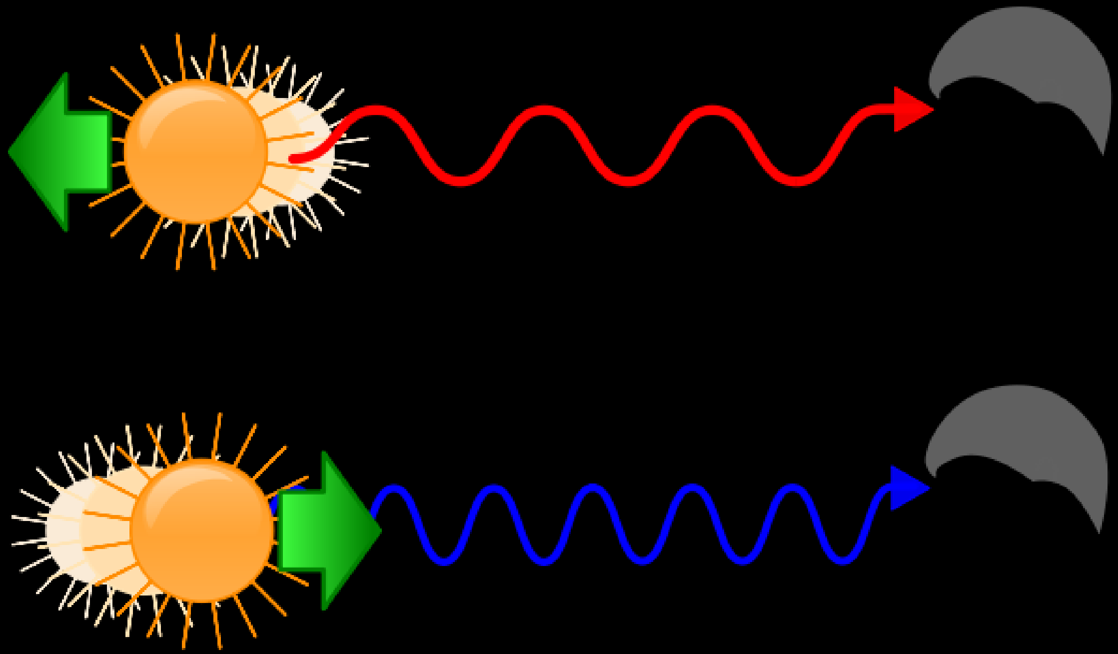


Image Credit: Vanden Berk et al 2001

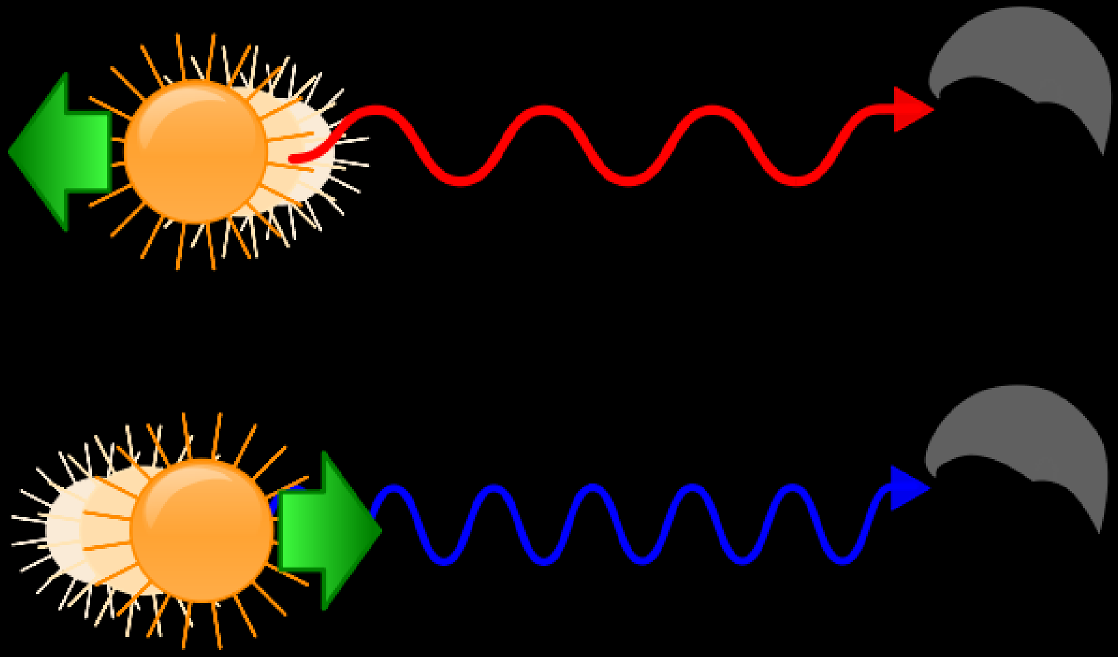
Doppler Effect



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

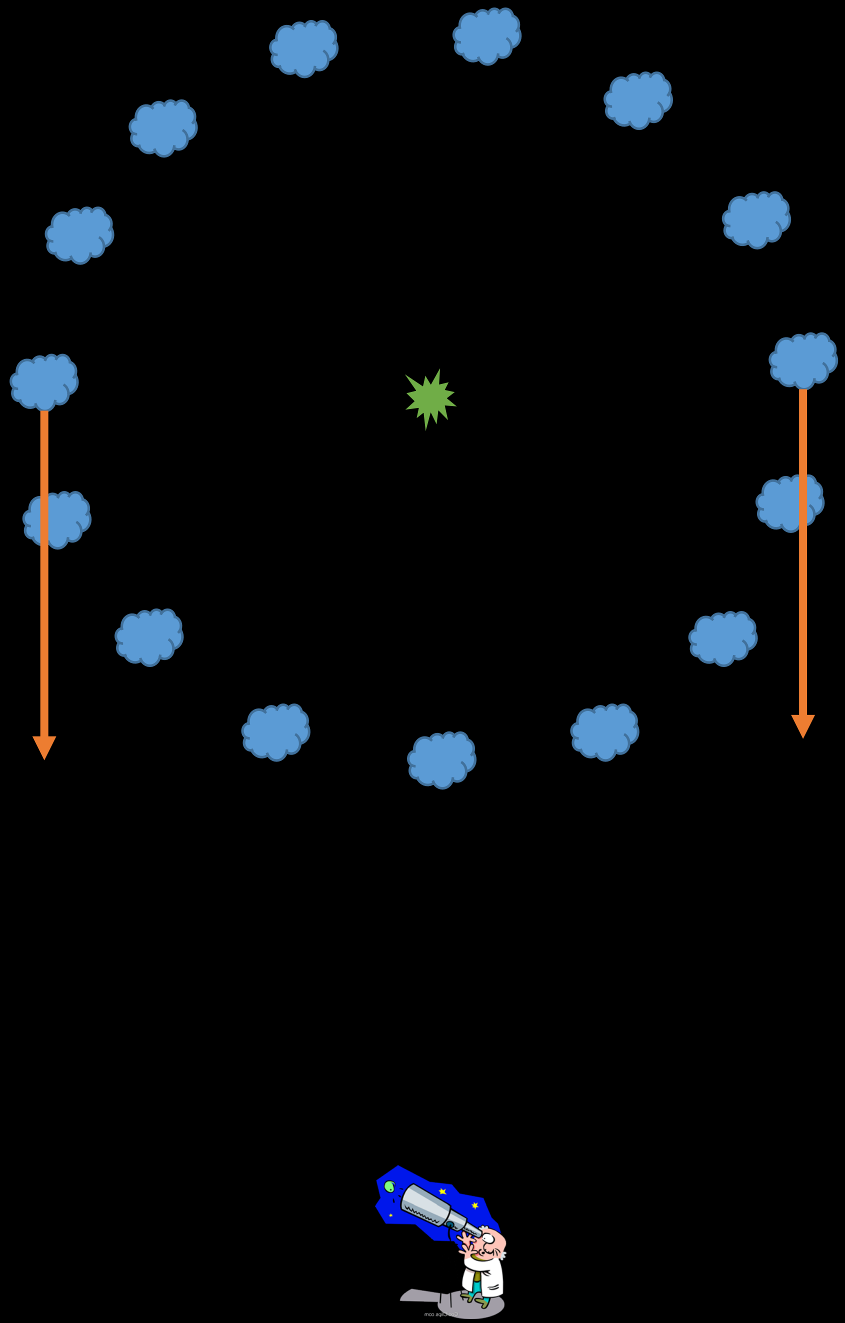
Image Credit: By Aleš Tošovský,
https://commons.wikimedia.org/w/index.php?curid=662534

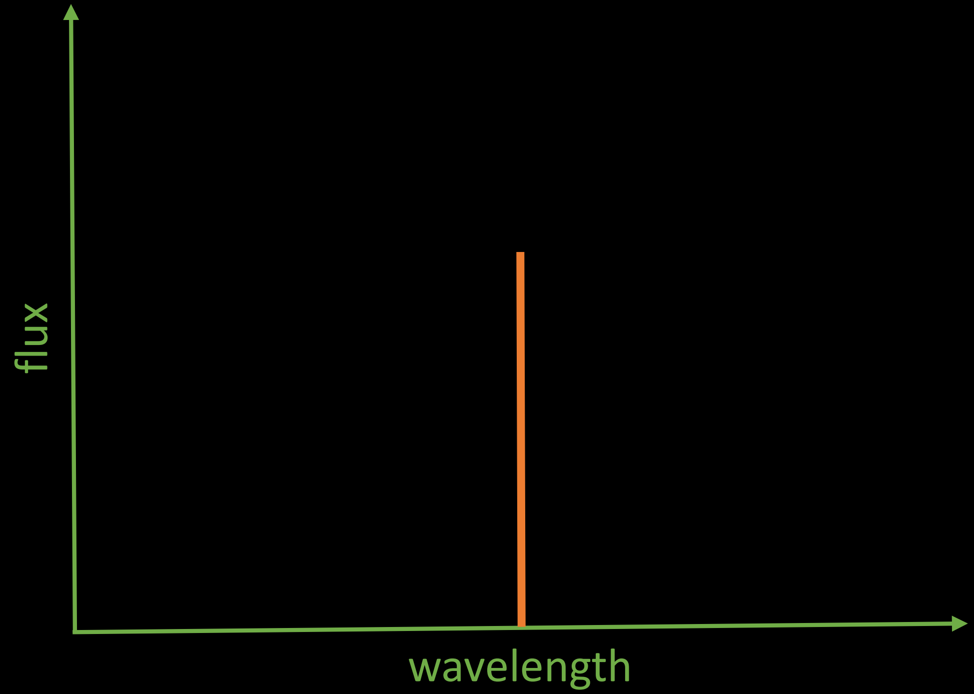
Doppler Effect

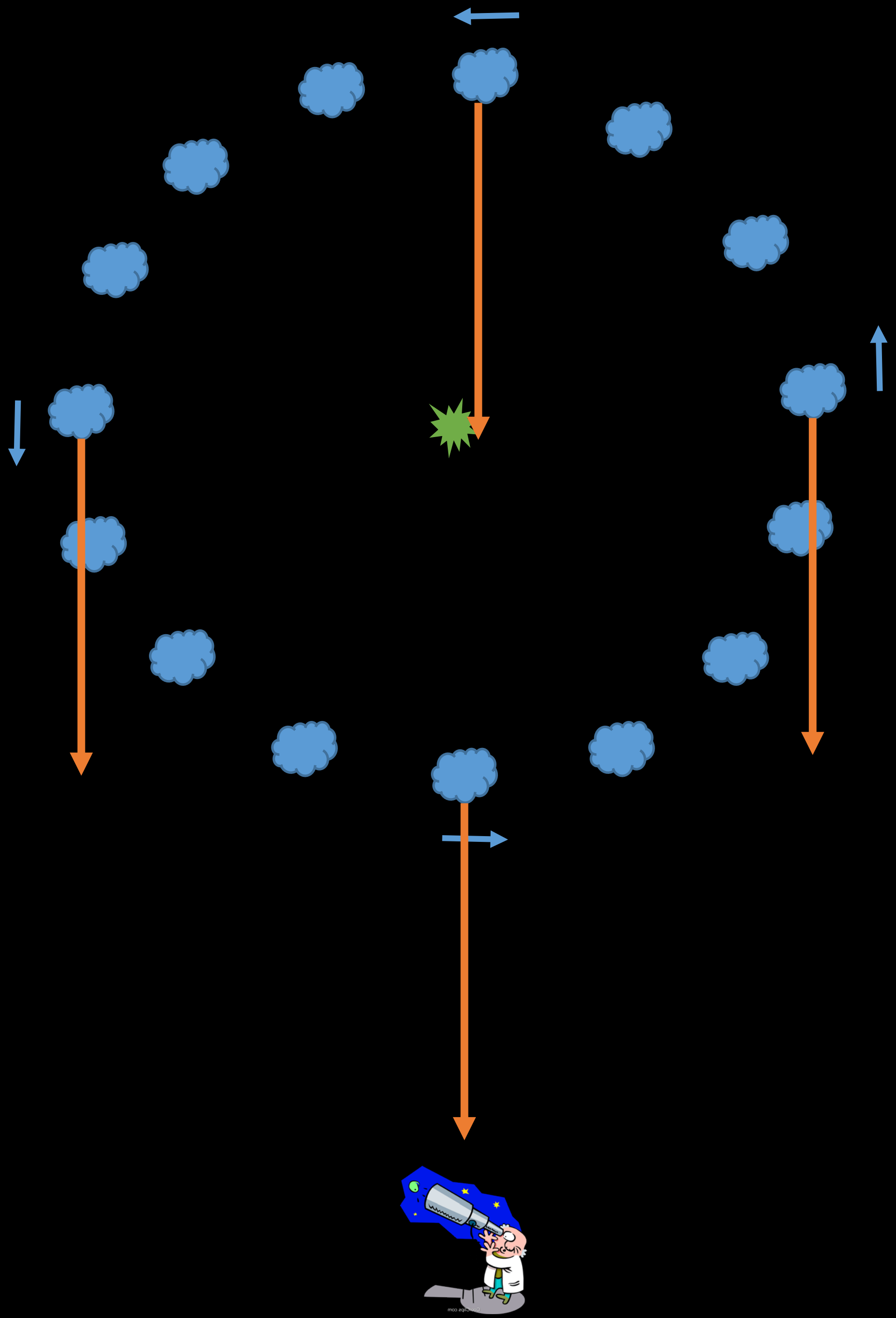


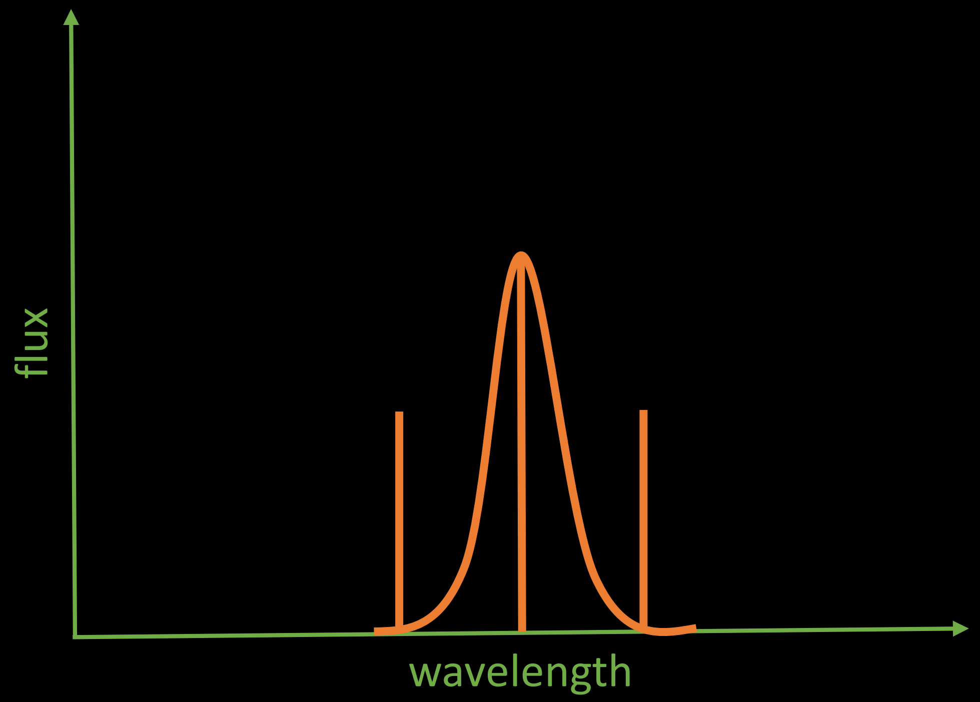
- $\lambda = \lambda' \frac{1}{1 - v/c}$
- Moving towards you
  - v < 0
  - Wavelength decreases
- Moving away from you
  - v > 0
  - Wavelength increases

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




flux
wavelength

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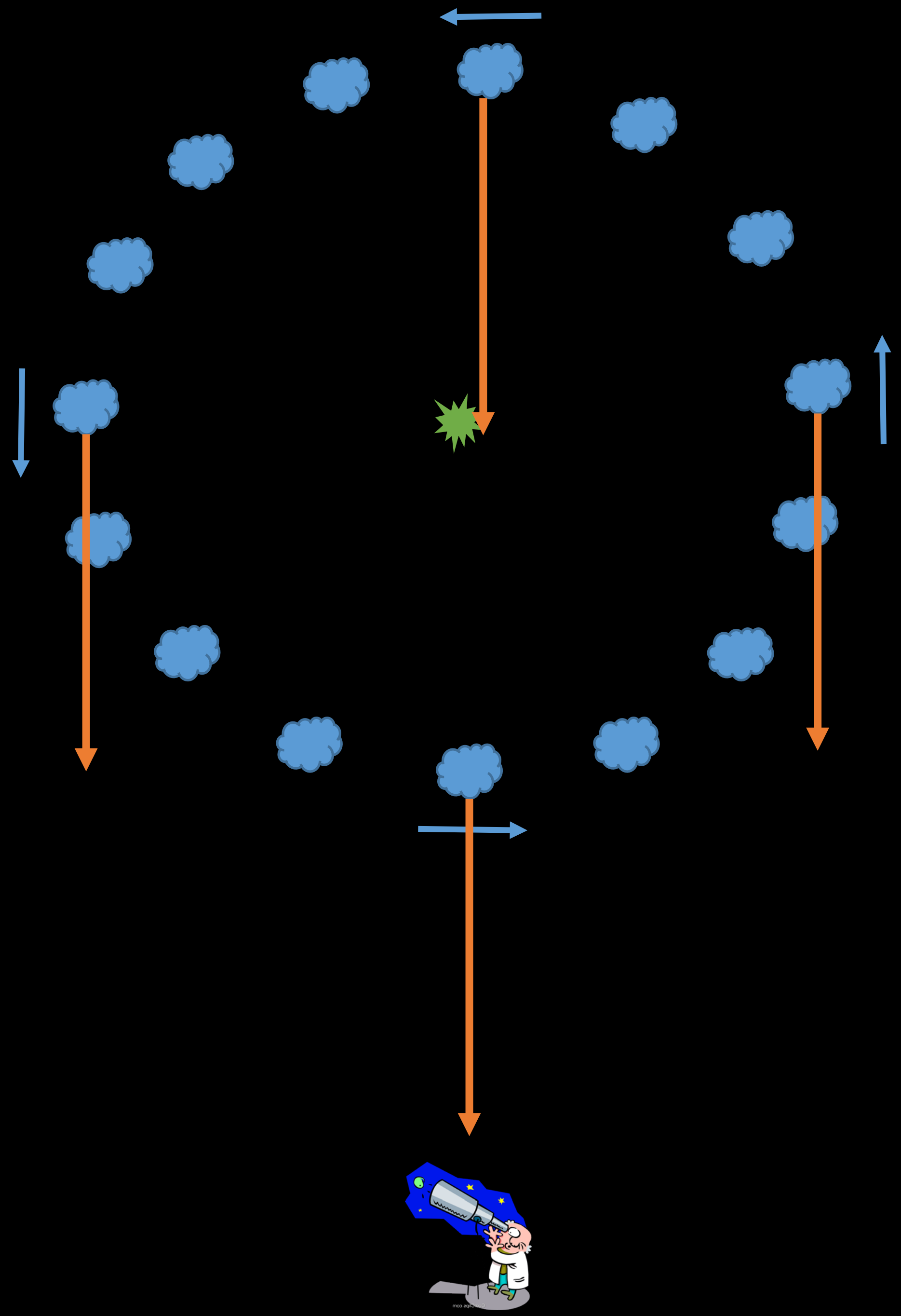
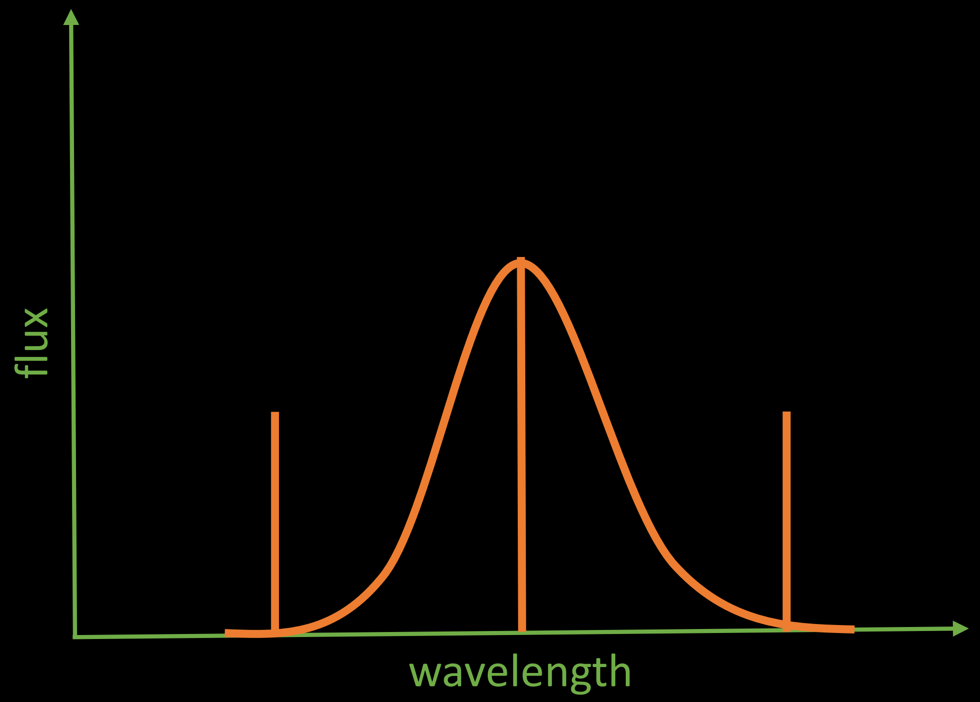
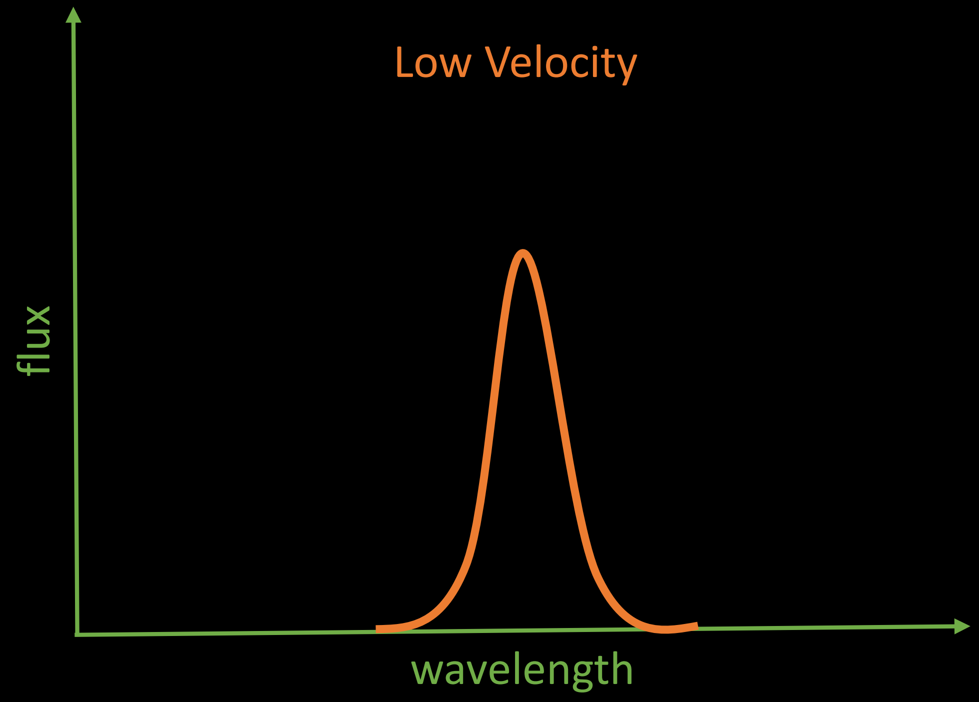
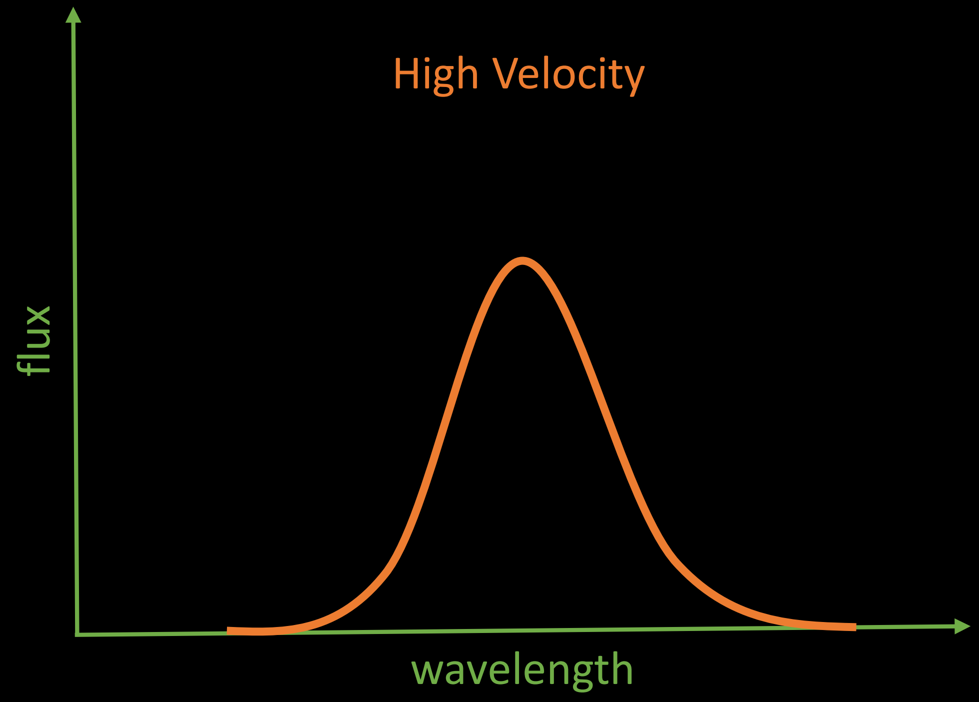


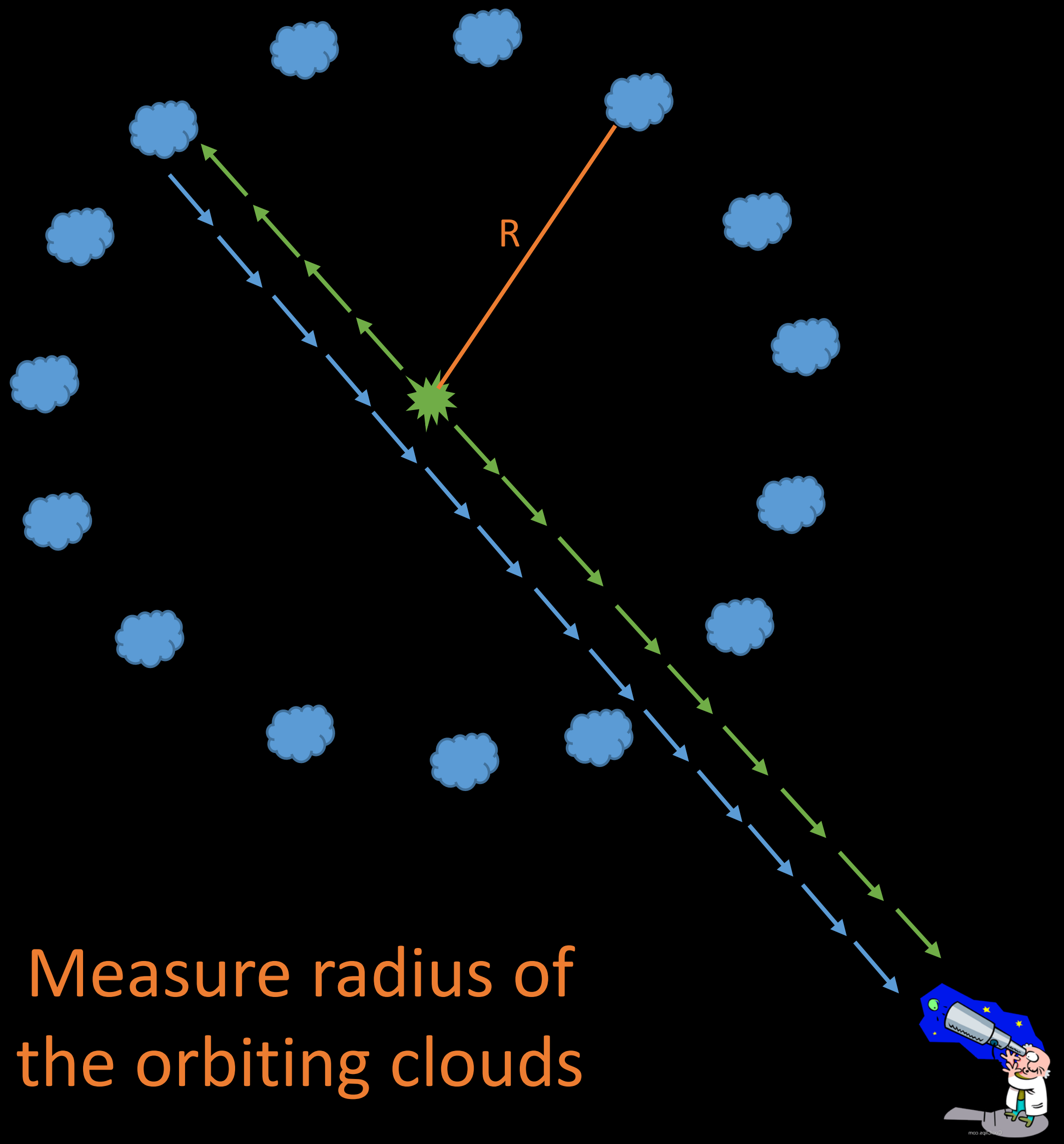

flux
wavelength

Broader the emission line, the faster the gas is moving

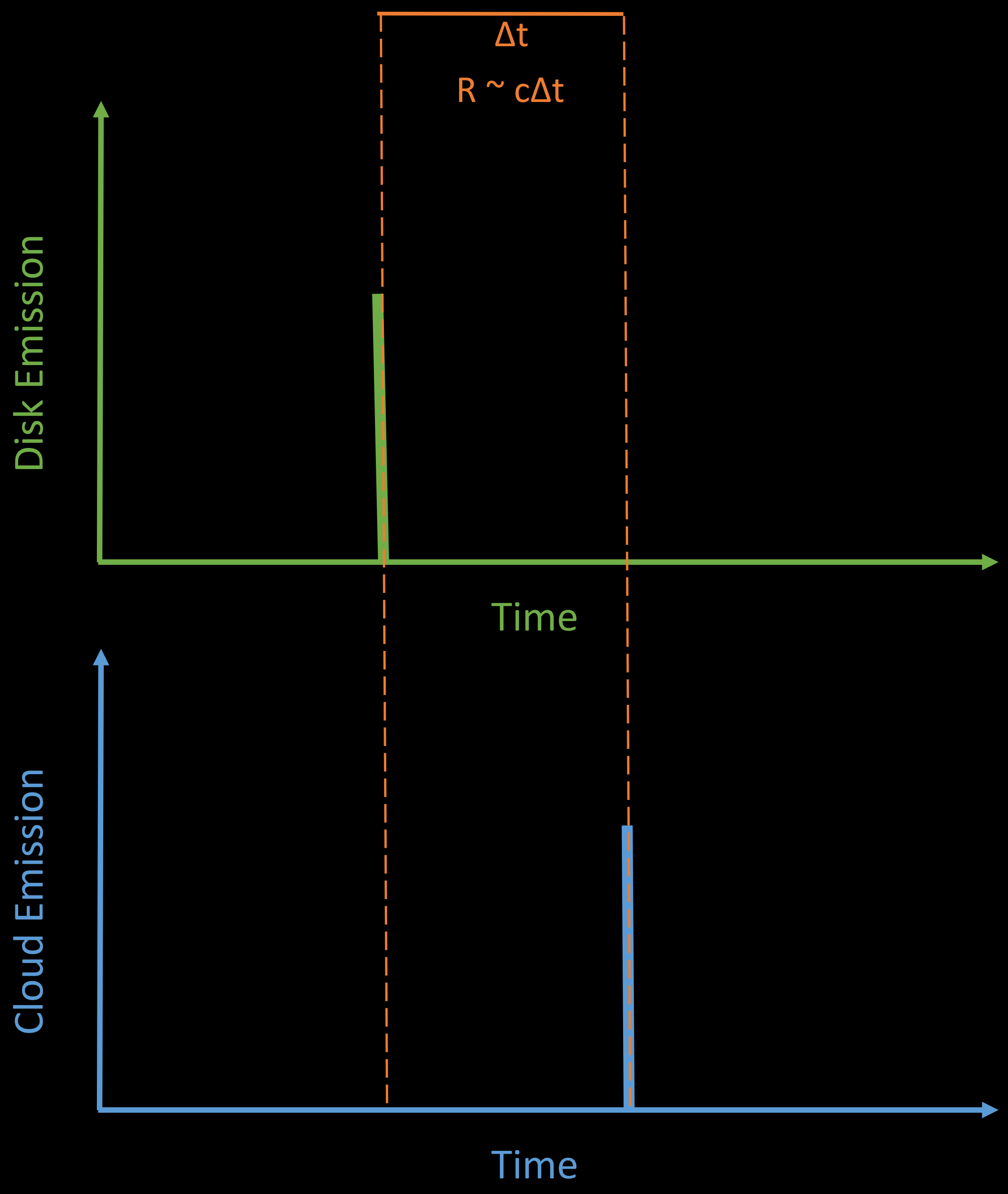




How do we determine how far away the gas clouds are?



Measure radius of the orbiting clouds



Black Hole Masses

- Assume BH and clouds are in viral equilibrium

$$M = \frac{f\ R\ \Delta V^2}{G}$$

- Current state of the art sample has only ~75 BH mass measurements
  - All with z < 0.8

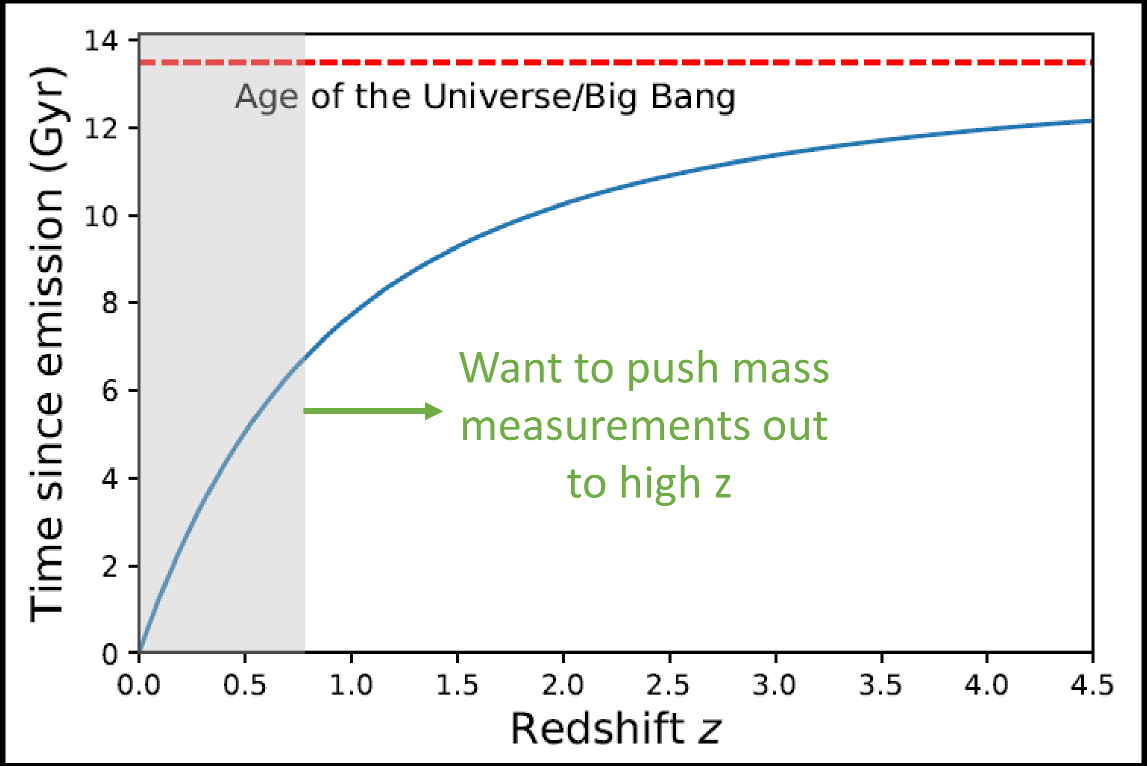


Image Credit: Harry Hobson, UQ

THE DARK ENERGY SURVEY

The Dark Energy Survey

- 5 year survey with the Blanco Telescope
  - 4m telescope in Chili
  - Optical photometry
    - g,r,i,z,Y filters
- Detect supernova and map millions of galaxies to study the expansion of the universe
- Repeatedly observe 10 deep supernova fields

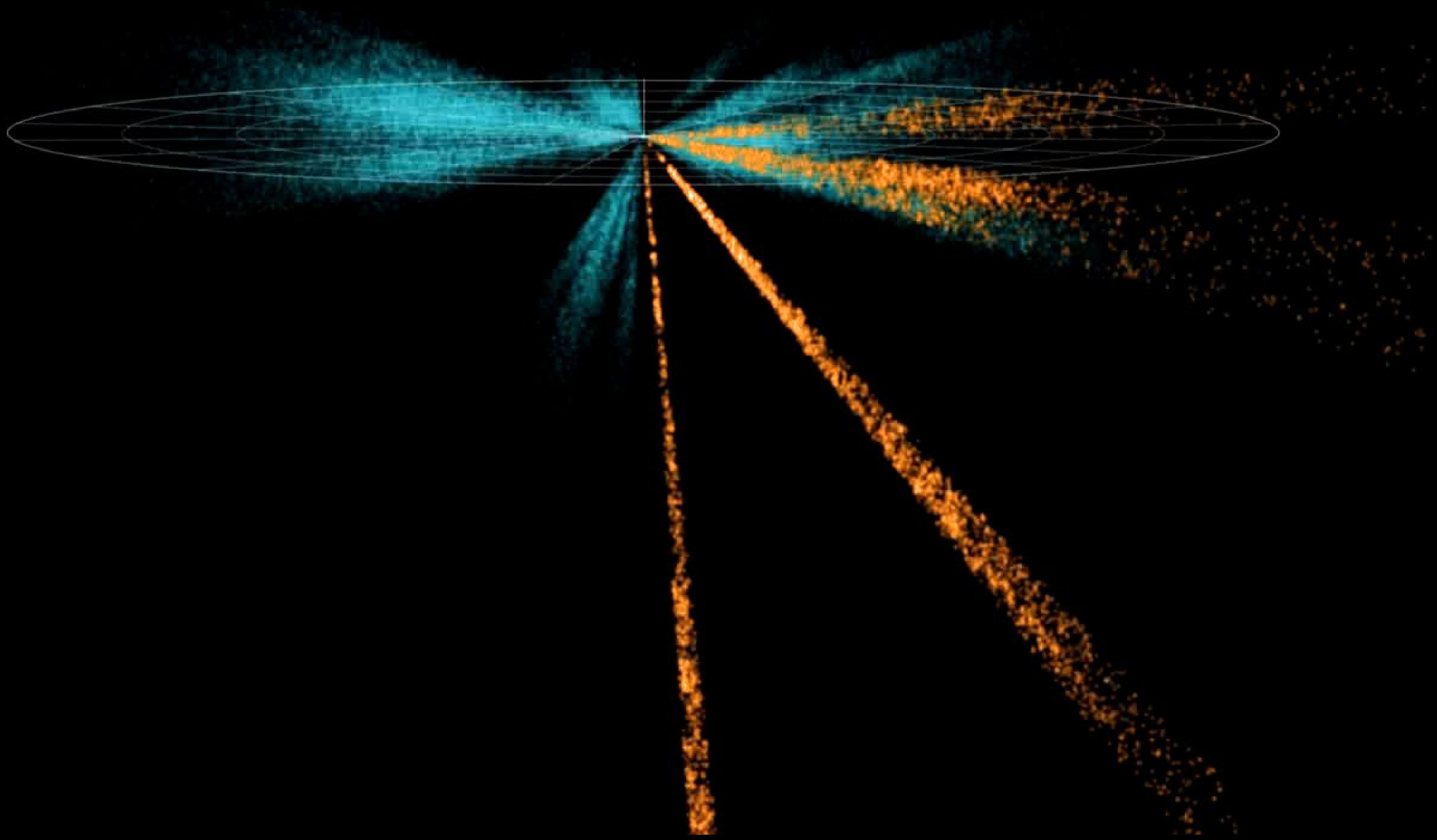
Image Credit: KICP/UChicago

The Australian Dark Energy Survey

The Australian Dark Energy Survey

- 6 year survey with the Anglo-Australian Telescope
  - 4m telescope near Coonabarabran, NSW
  - Optical spectroscopy
- Measure distances to supernova and calculate black hole masses
- Detect more distant galaxies than previous surveys

Image Credit: AAO



Video Credit: Sam Hinton, UQ

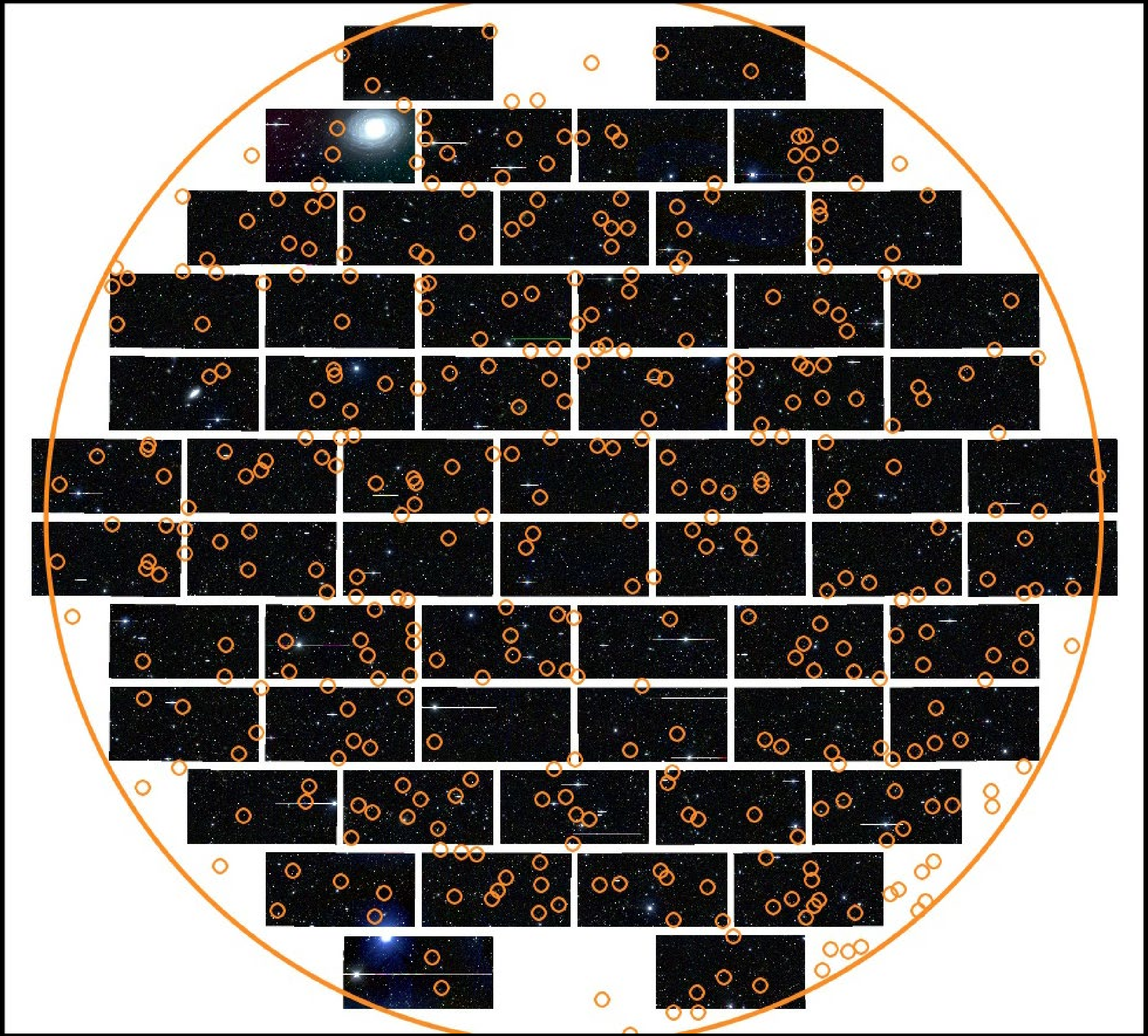
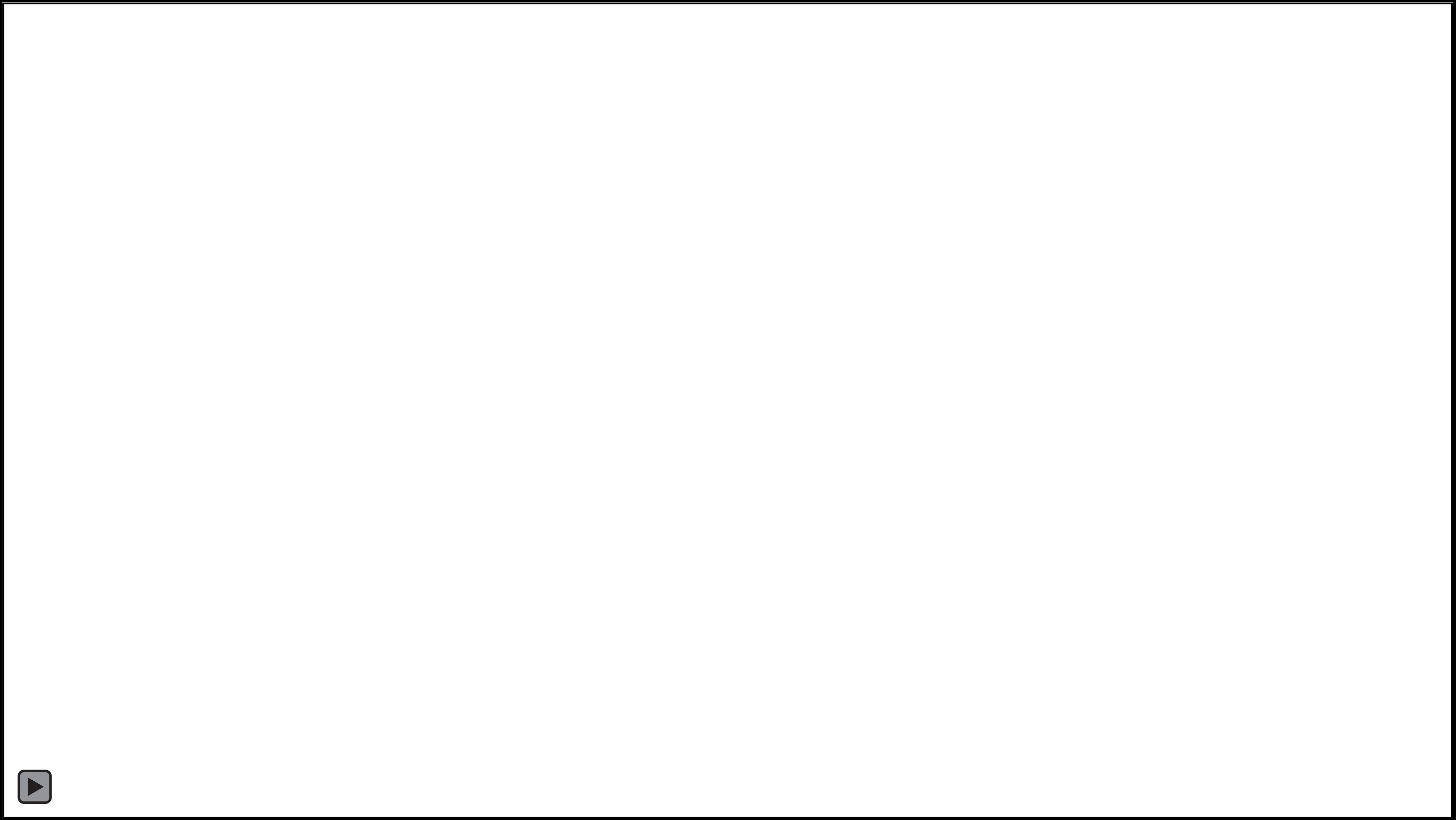


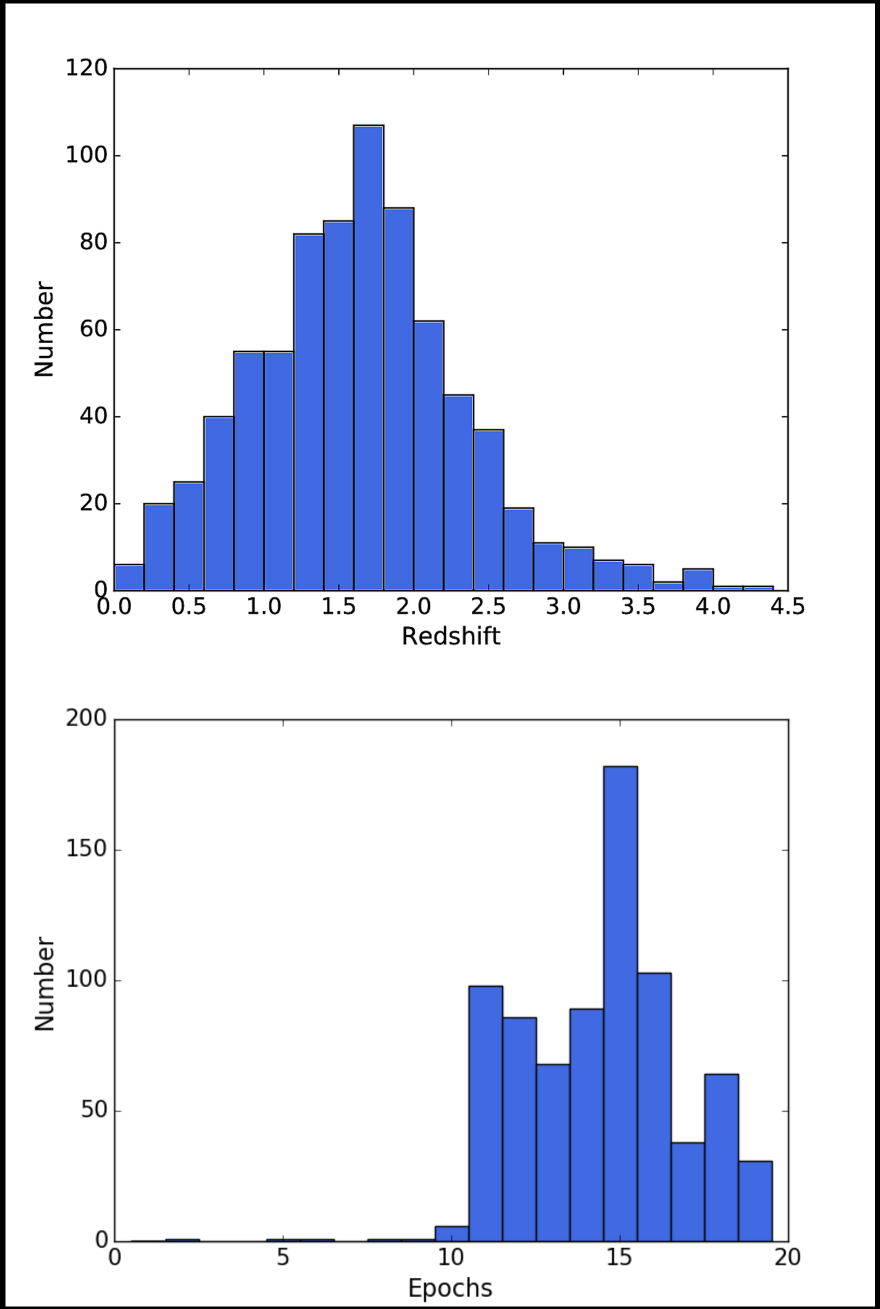
Image Credit: Yuan et al 2015



Video Credit: AAO

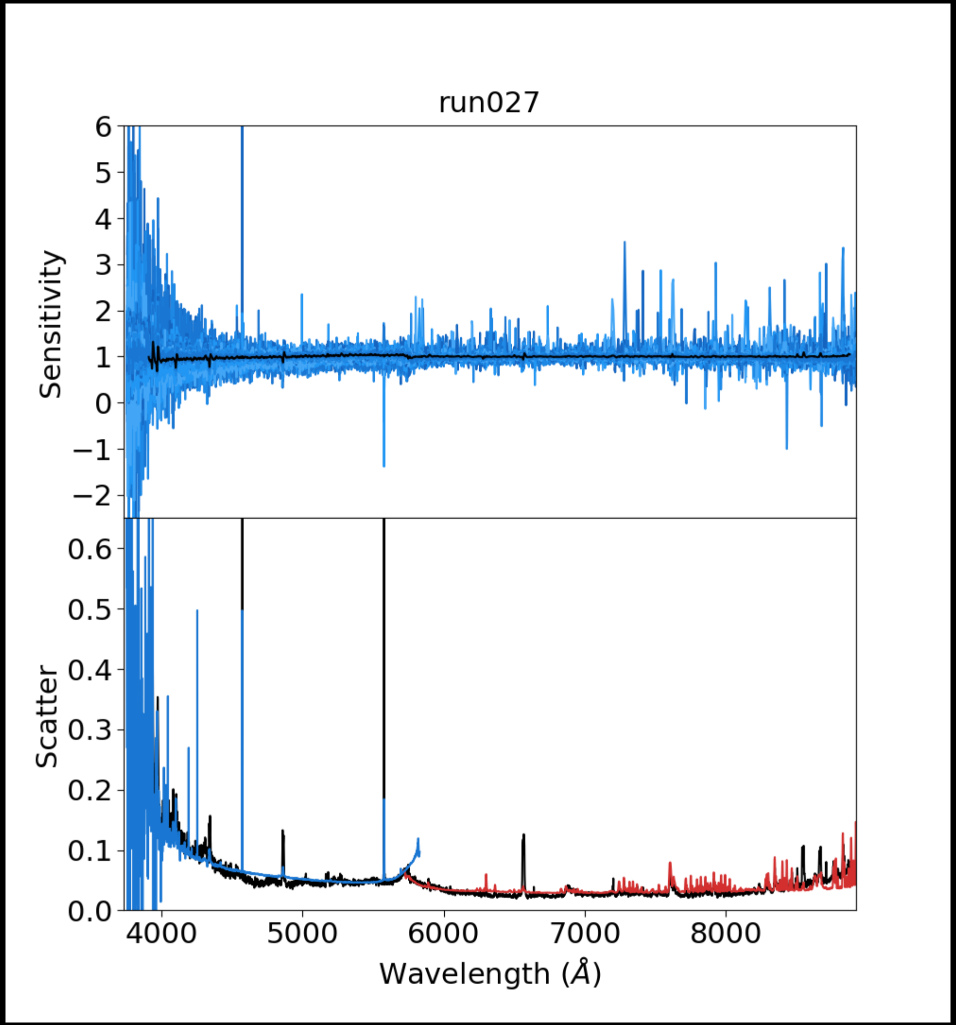
RM Project Overview

- Regular observations of 771 AGN
- z < 4.5
- Continuum
  - DES photometry
  - ~ weekly cadence
- BLR
  - OzDES spectra
  - ~ monthly cadence
  - Hβ, MgII, CIV



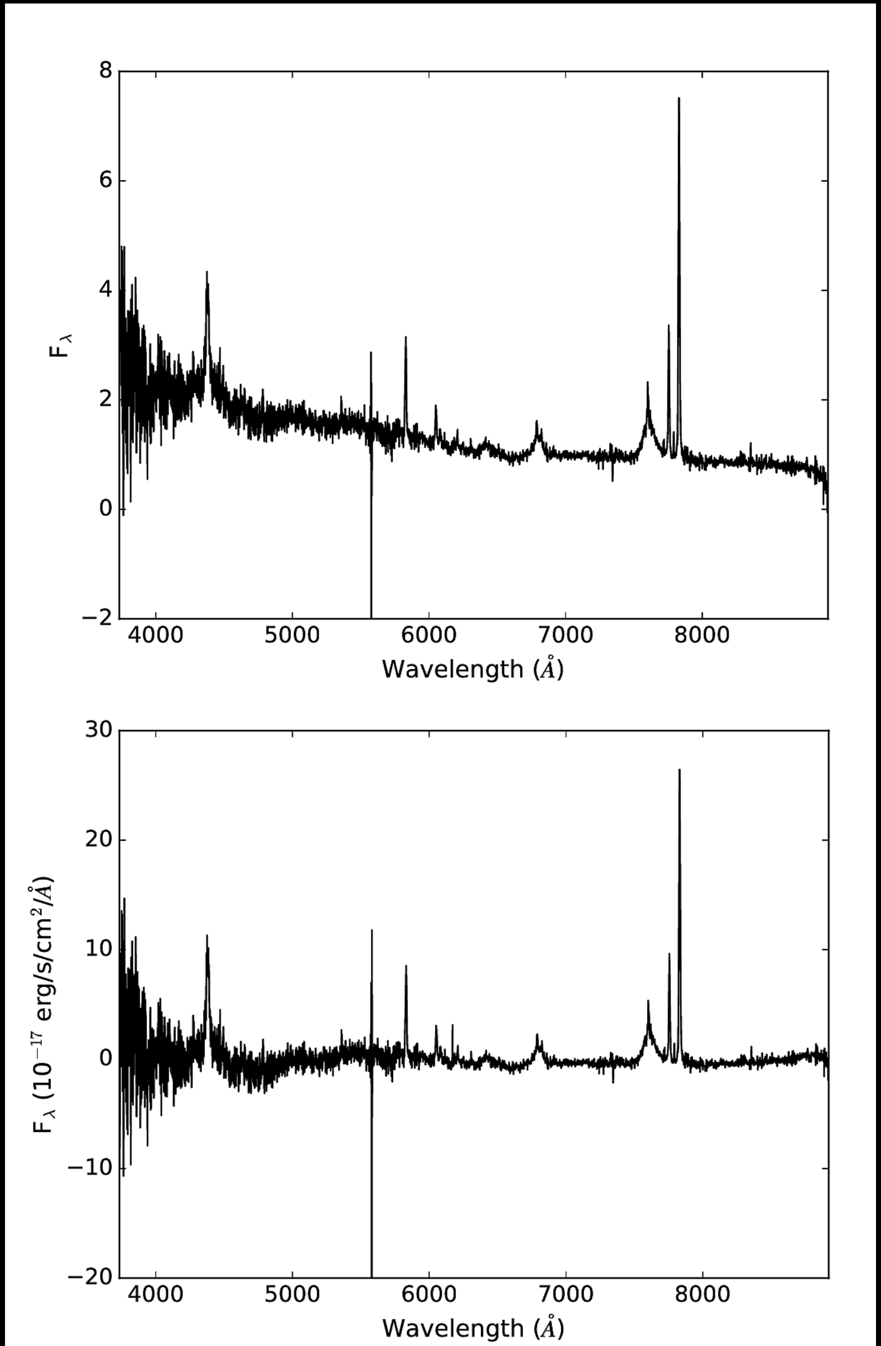
Data Calibration

- Perform spectrophotometric calibration
- Regularly observe F-stars
  - 7000 observed so far
- Median scatter in sensitivity ~ 5%
- Simulations show we expect to recover lags for 35-45% of our AGN
  - ~ 300 new lags!



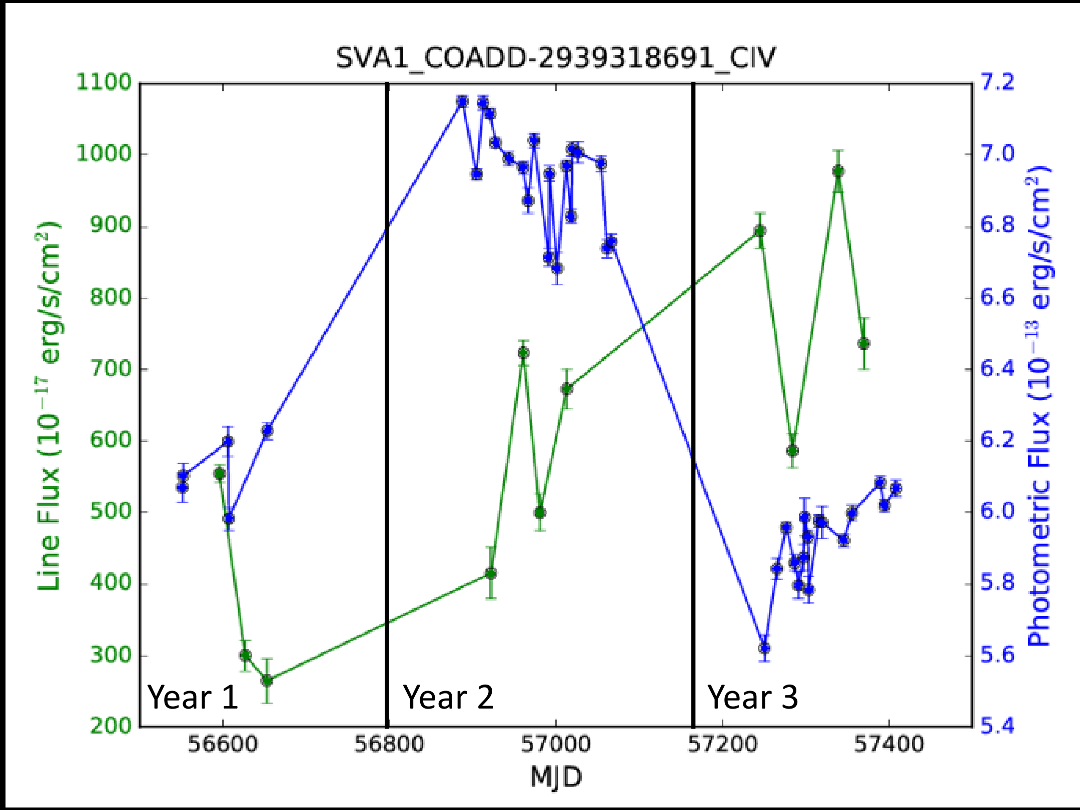
Data Processing

- Calibrate OzDES spectra with DES photometry
- SPAMM is being developed to remove unwanted spectral features
  - Fe contamination
  - Continuum



RM with OzDES

- Line flux of broad emission lines used to calculate line light curves
- Use JAVELIN and cross-correlation to get time lags
- Faint sources can be stacked to obtain lag measurements



Year 4, Year 5, and Year 6 to come!

Science Goals

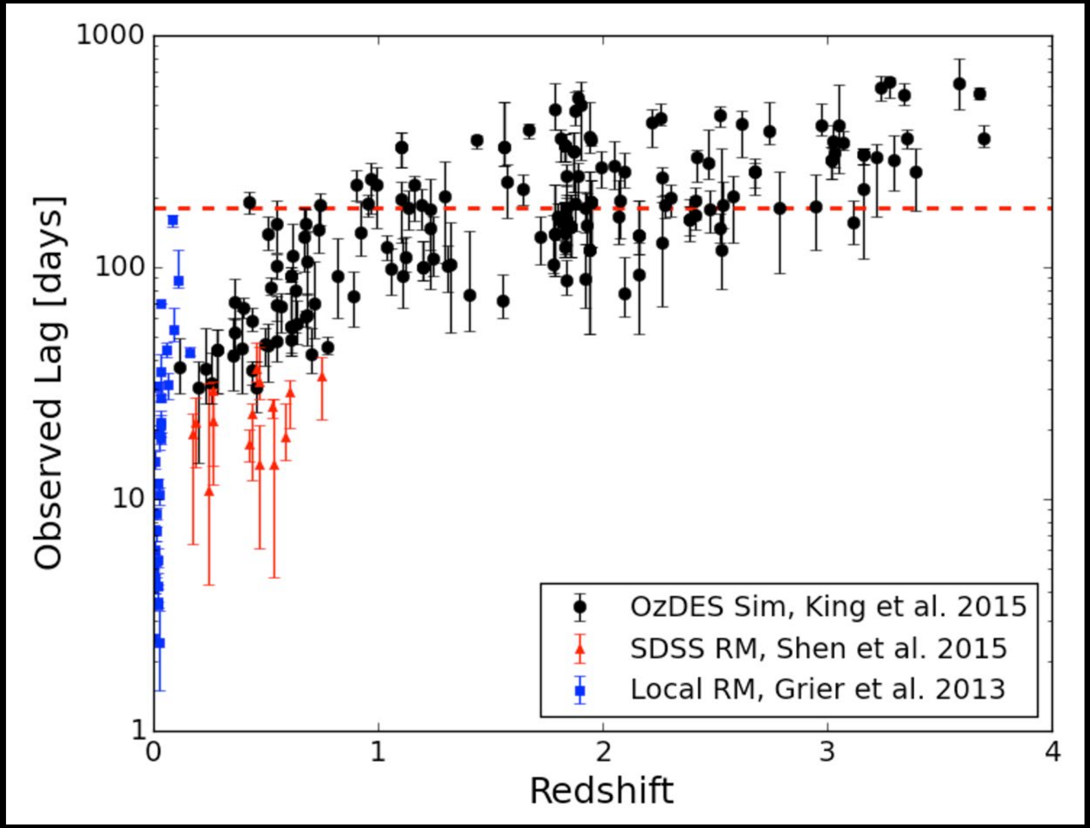


Image Credit: Paul Martini, OSU

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- Verify relationships between the radius of the orbiting gas and galaxy luminosity out to high redshifts
- Test if black holes can be used as standard candles in cosmology

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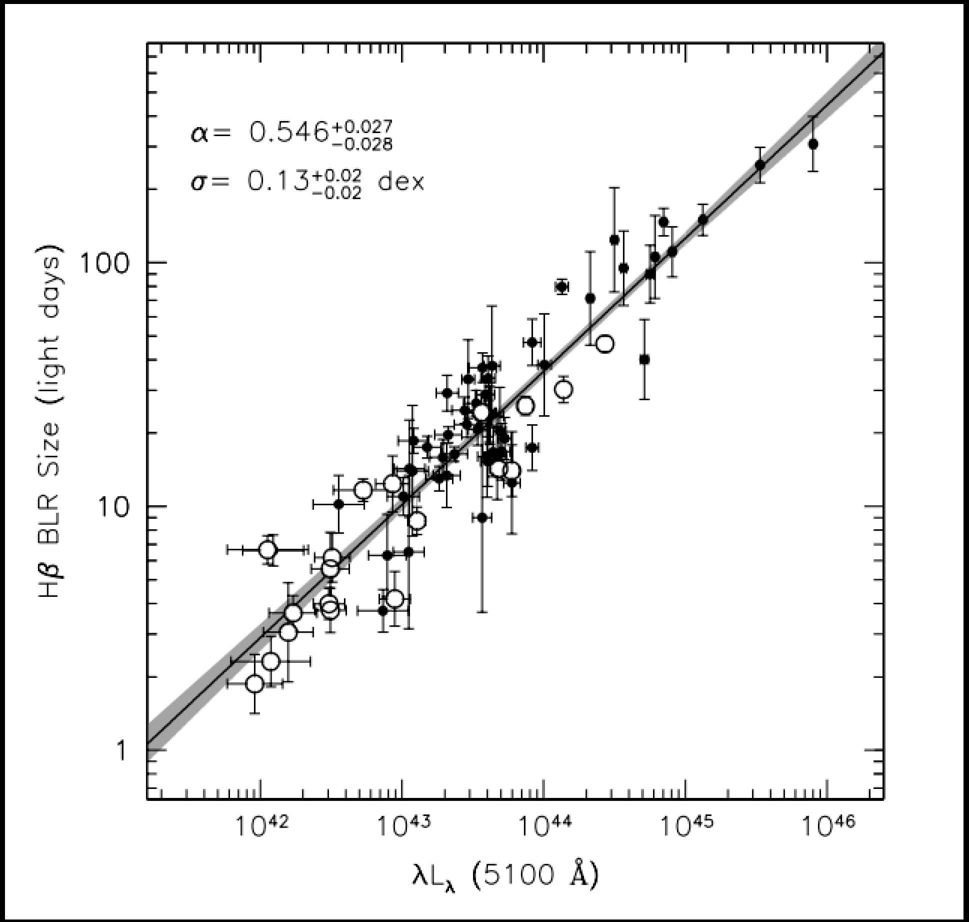

Image Credit: Bentz et. al. 2013

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Thank you, questions?