QUASAR SPECTROSCOPY
WITH THE SLOAN DIGITAL SKY SURVEY

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Runnoe Lab

QuarkNet Workshop
June 20, 2022

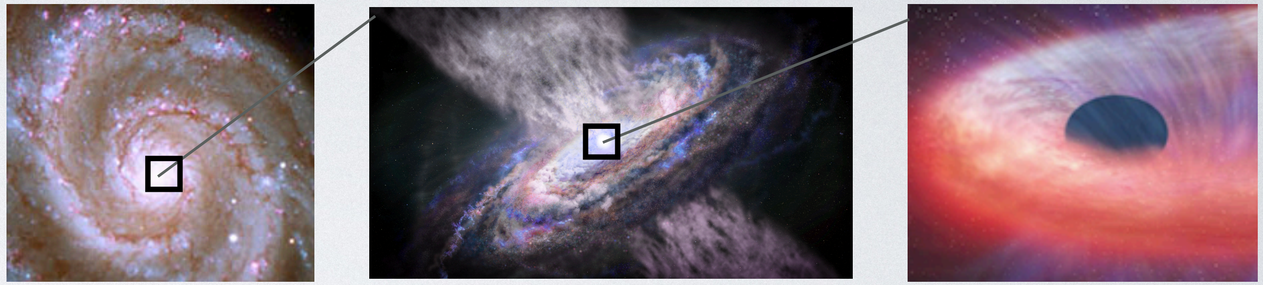
SDSS

NASA/STScI

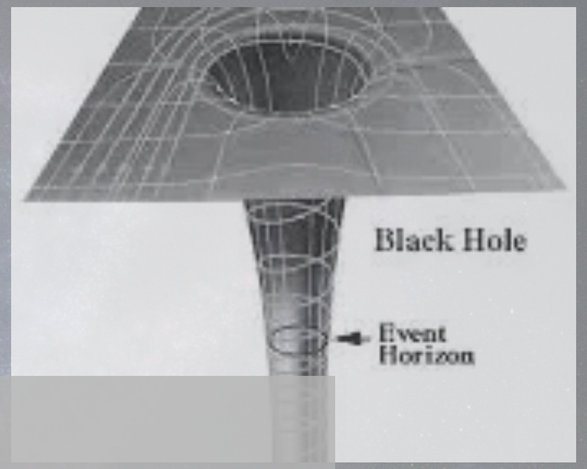
OBJECTIVES

By the end of this talk you will be able to…

- (1)…visualize and demonstrate various approximate scales of the universe.
- (2)…reconcile "differences" between gravity on earth and in space.
- (3)…define and identify features of a quasar and its spectrum.

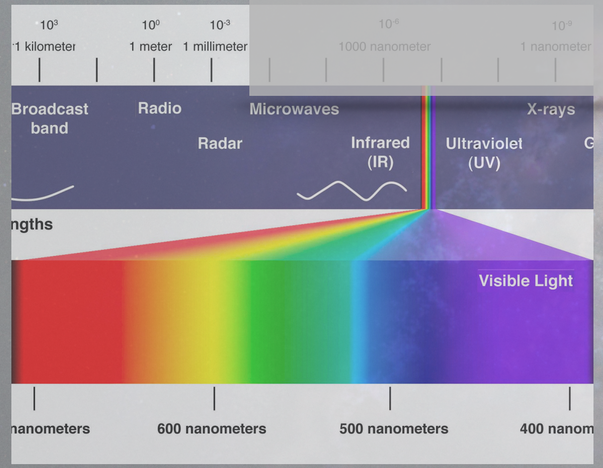


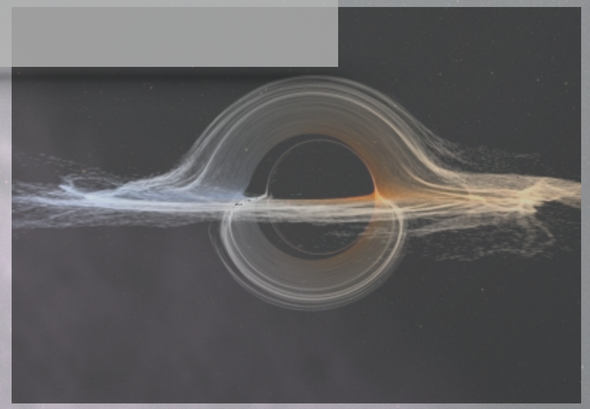
- (4)…apply the concept of the doppler effect to the observed signature of material consumed by a black hole.
- (5)…explain how the Sloan Digital Sky Survey and other telescopes are mapping black holes.



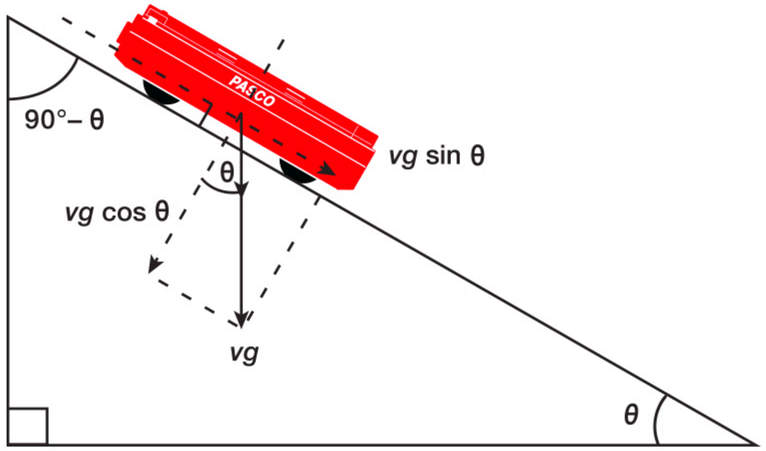
BACKGROUND:

TERMINOLOGY & SCALES



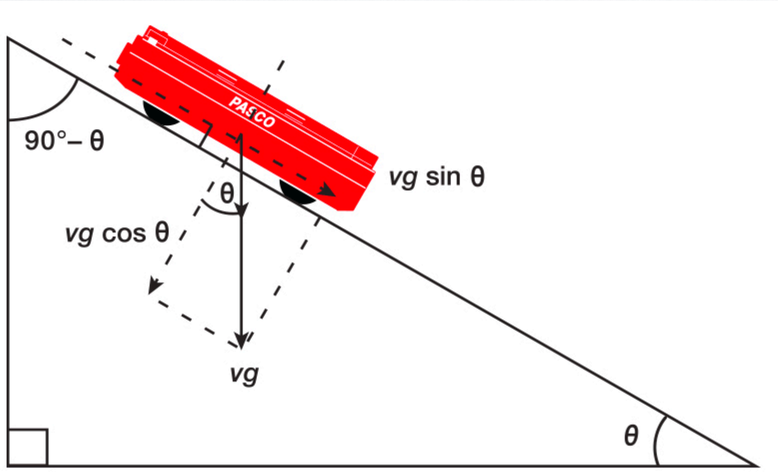


GRAVITY



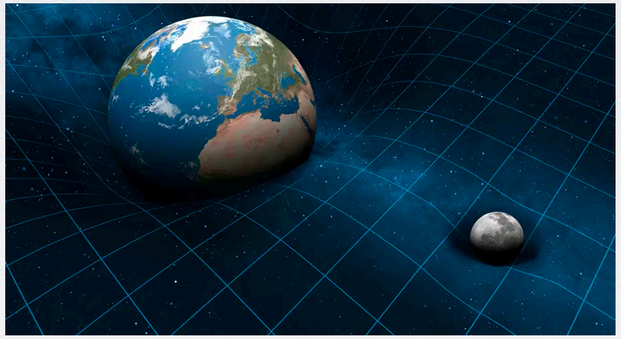
Racing a Smart Cart down a ramp.

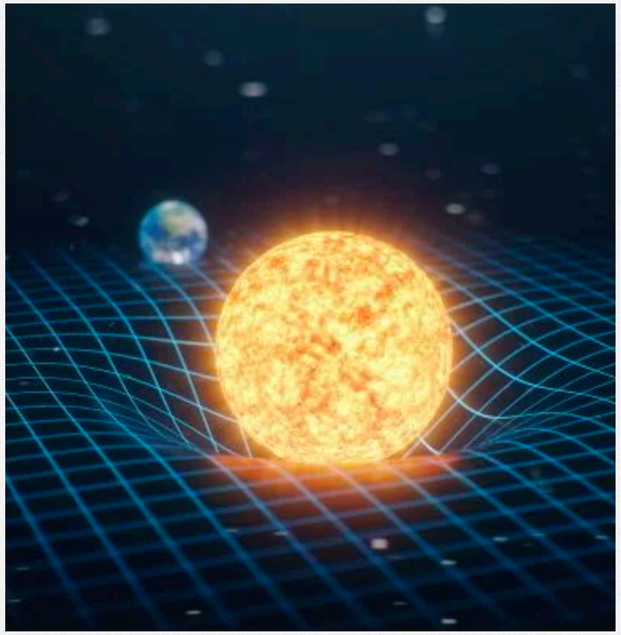
GRAVITY



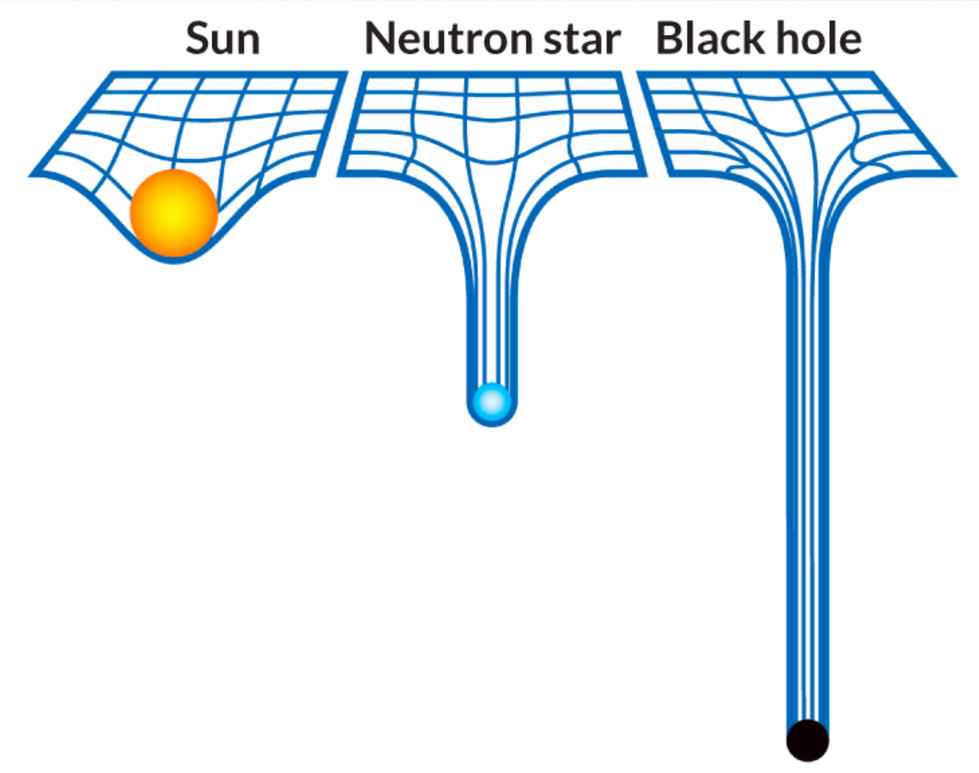
Racing a Smart Cart down a ramp.

- Zoom out, reconceptualize





SPACE-TIME

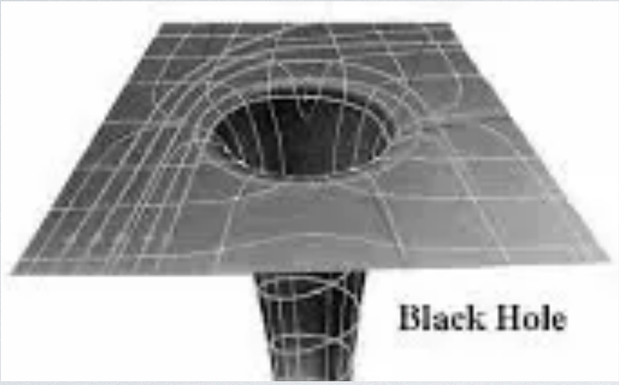


GALAXIES

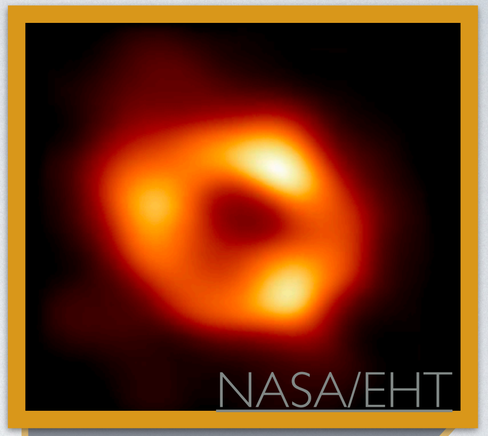
- Gravitationally bound collections of billions of stars
- Many types e.g. Milky Way spiral galaxy

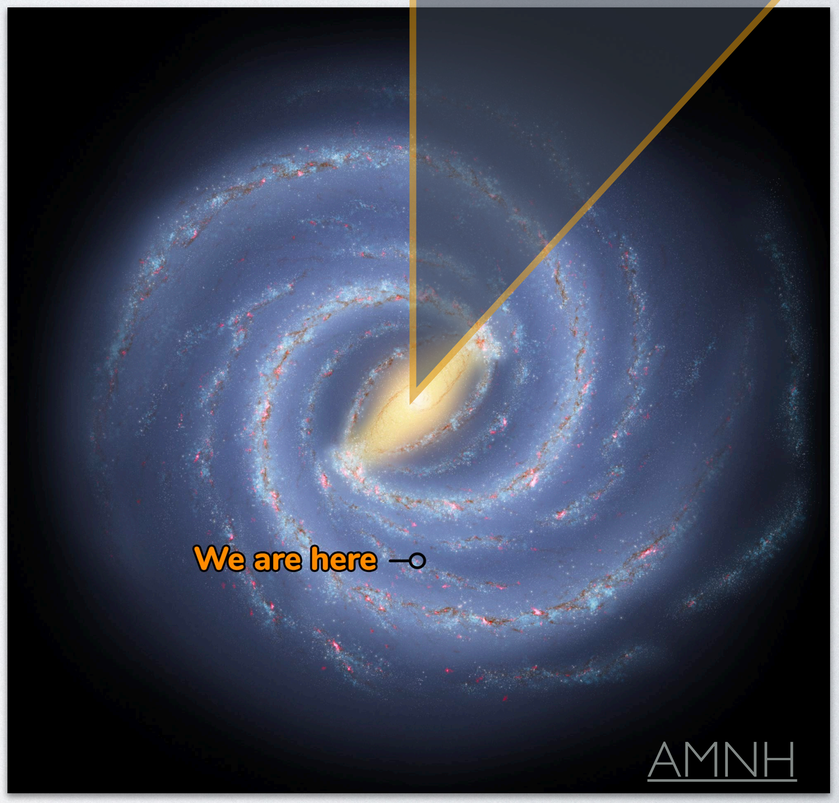
AMNH

TN State Parks



BLACK HOLES





- Singularities in spacetime described by mass, spin
- End states of massive star death / collapse
- May be dormant or actively accreting
- Interactions help feed supermassive BHs
- Difficult to (directly) observe

BLACK HOLES

- Singularities in spacetime
- End states of massive star death / collapse
- Galaxy mergers create supermassive BHs
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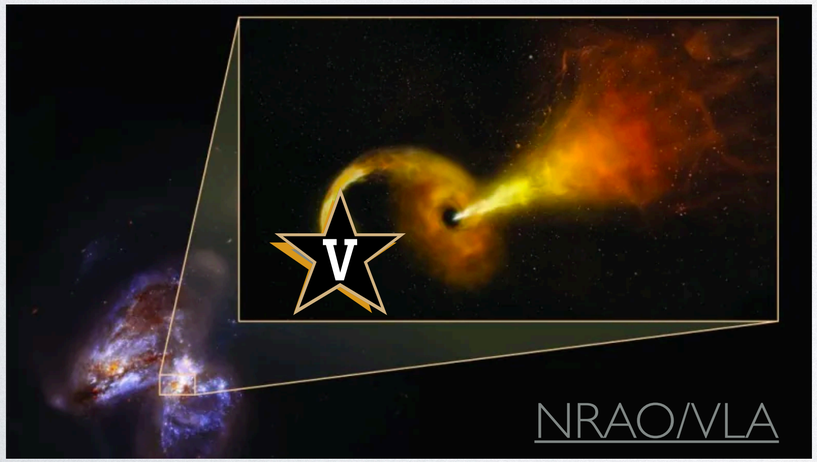
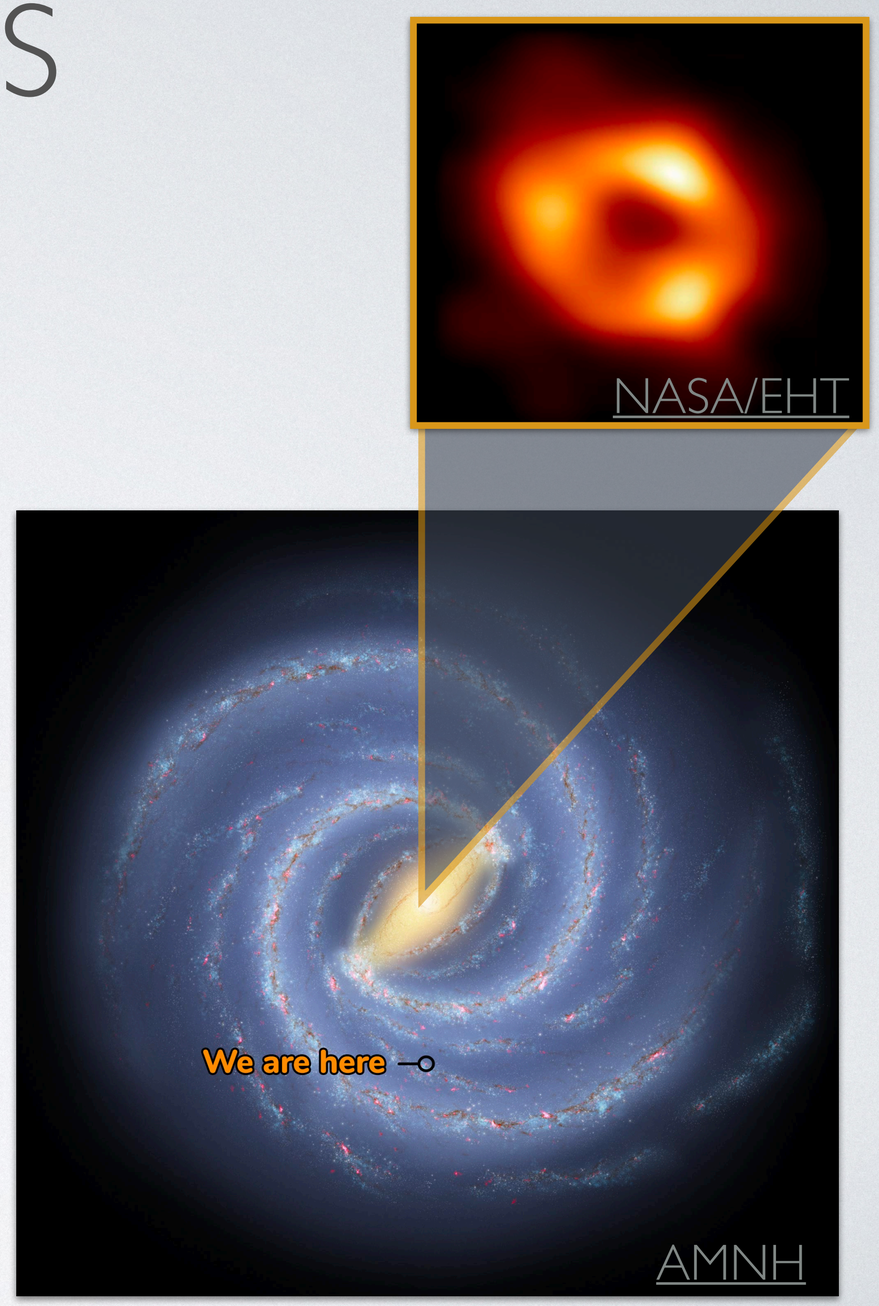
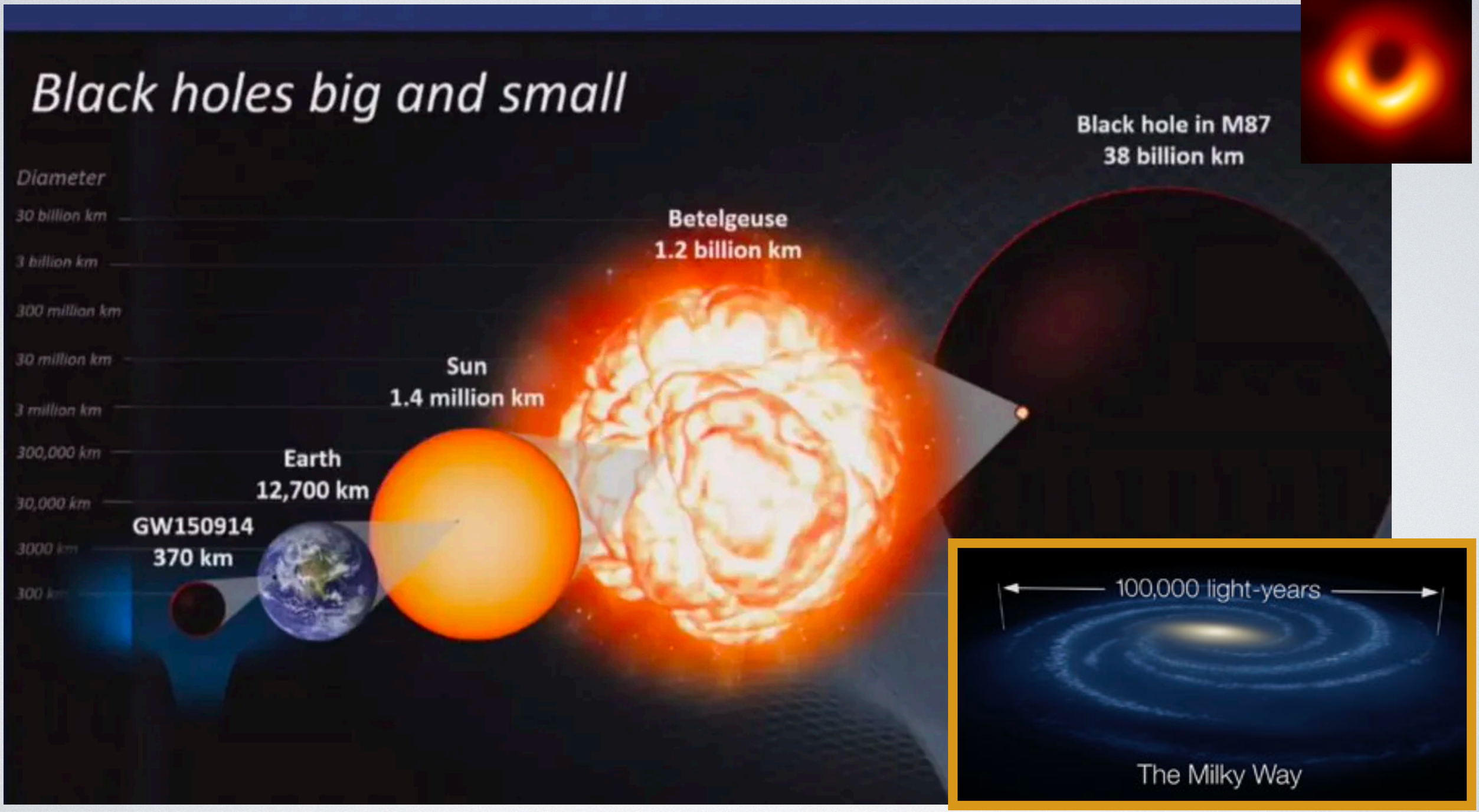


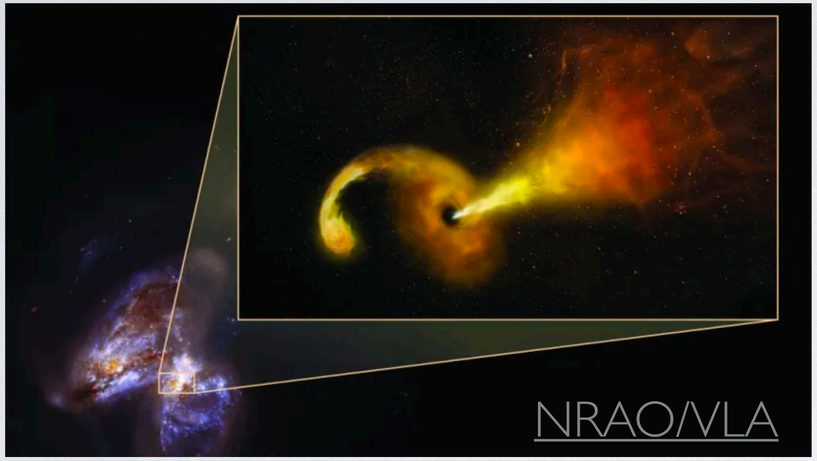
NRAO/VLA

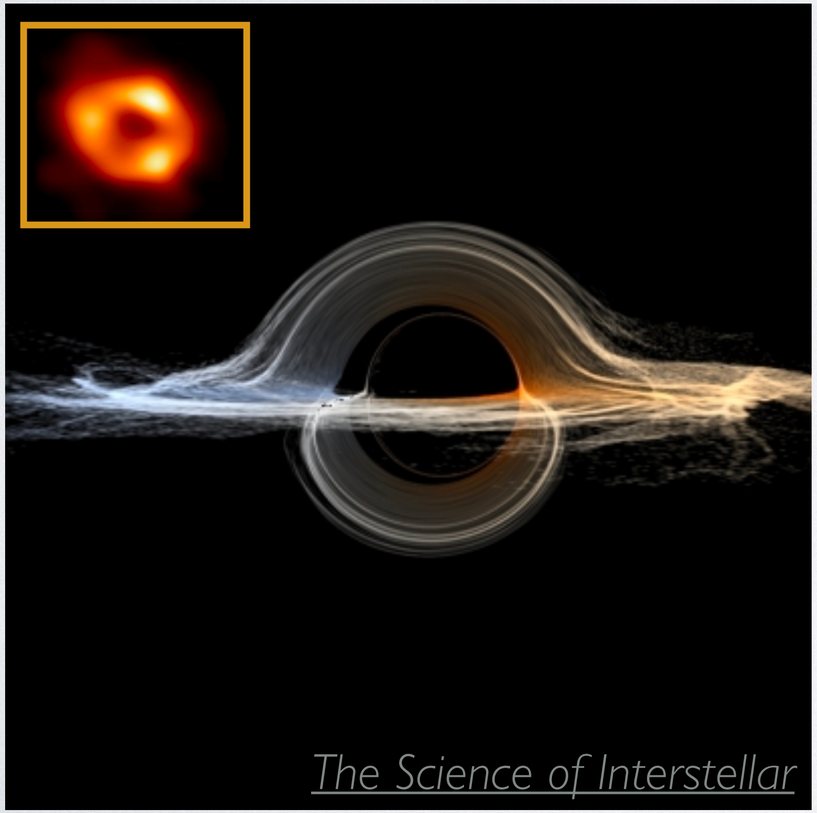


NASA/EHT

AMNH

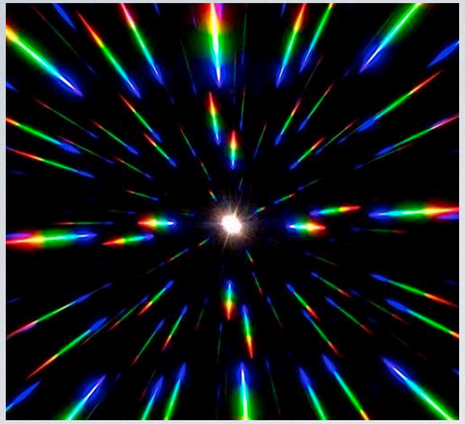

Black holes big and small
Diameter
30 billion km
3 billion km
300 million km
30 million km
3 million km
300,000 km
30,000 km
3000 km
300 km
GW150914
370 km
Earth
12,700 km
Sun
1.4 million km
Betelgeuse
1.2 billion km
Black hole in M87
38 billion km
100,000 light-years
The Milky Way



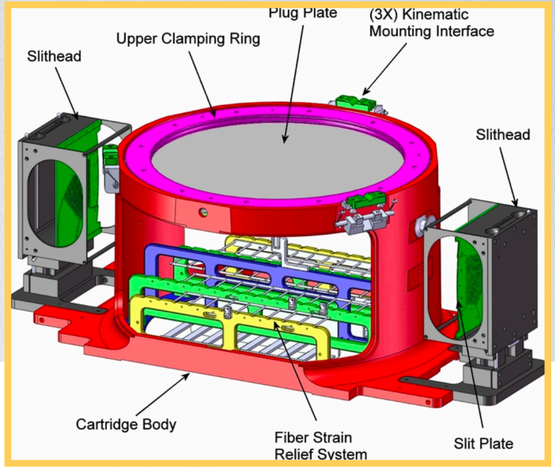


ACCRETION

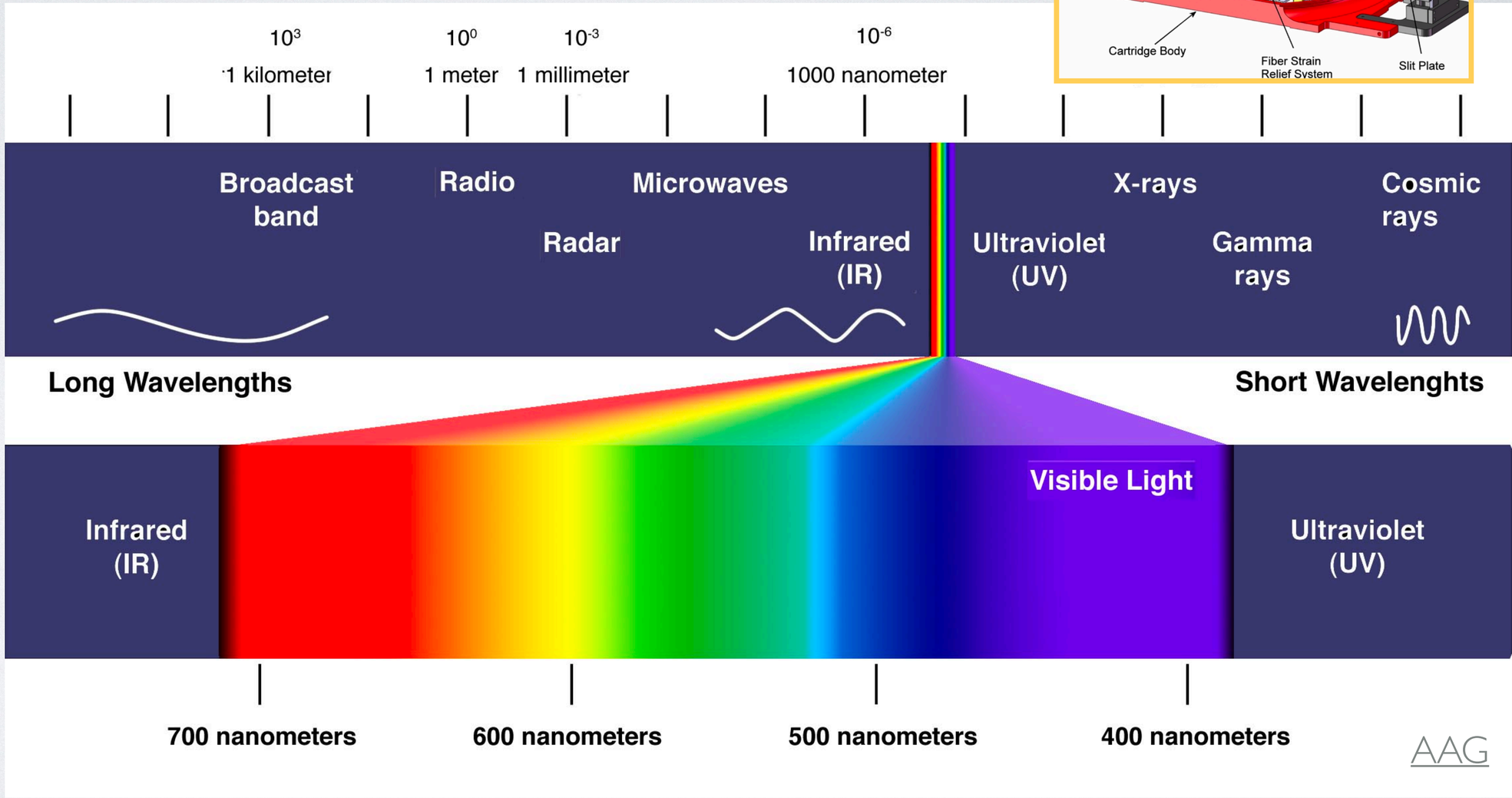
- Disks form through conservation of angular momentum
- Ubiquitous in astronomy
- The process by which BHs "feed", release energy, and become visible
- Fluid dynamics, magnetism



SPECTROSCOPY



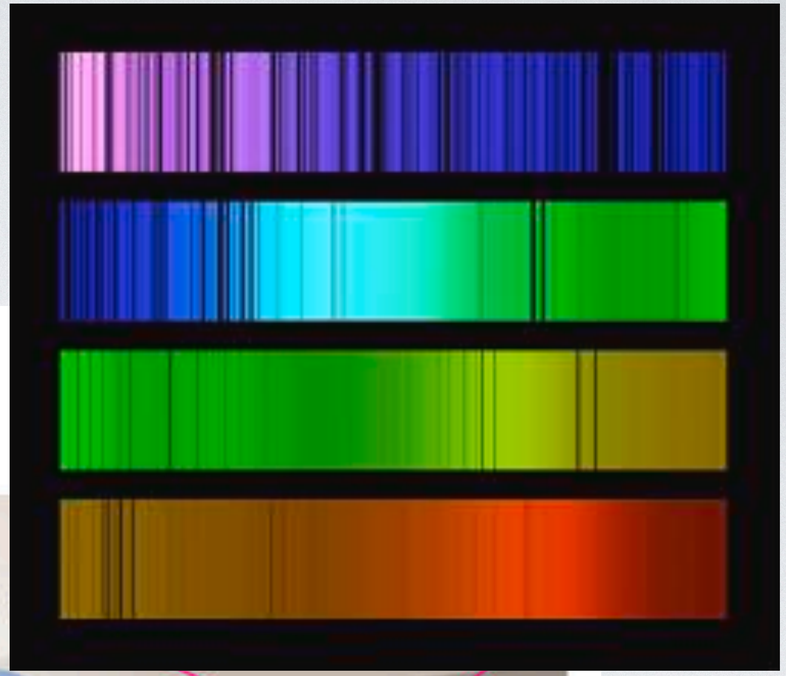
- Dispersal of light into component wavelengths of EM spectrum



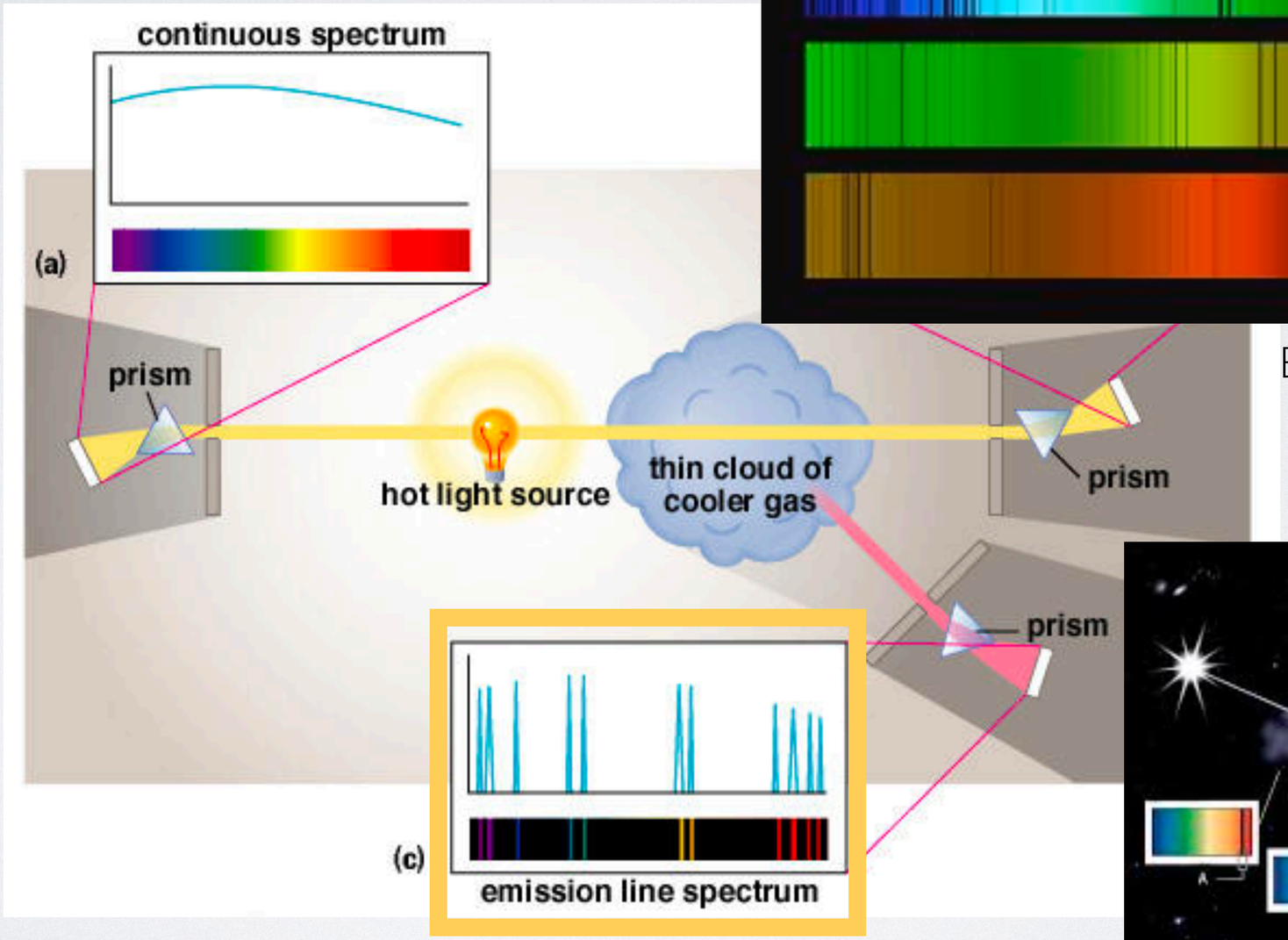
AAG

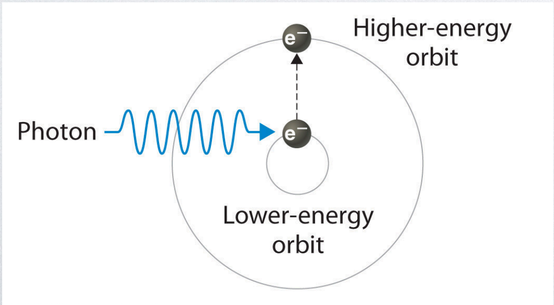
SPECTROSCOPY

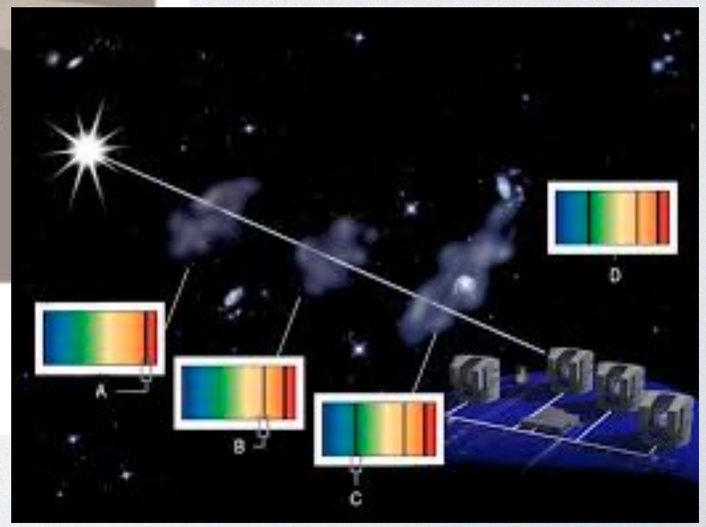
- Structure of an atom
- Emission line "spikes''



ESO/VLT

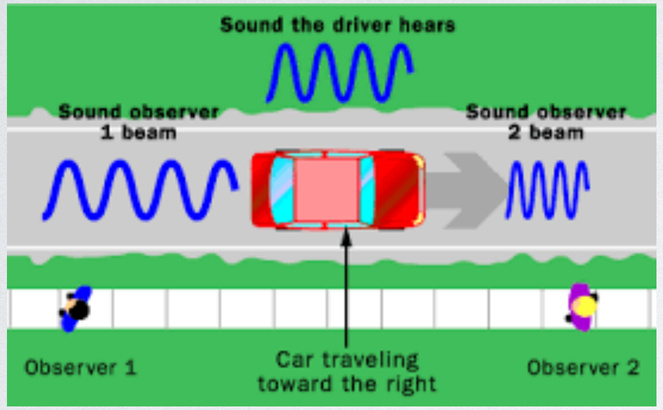






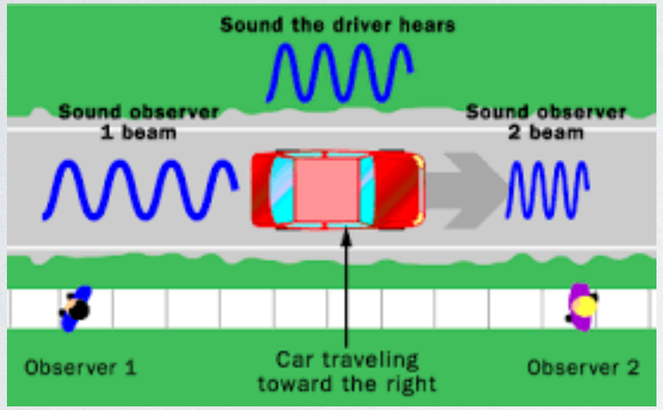
LINE BROADENING

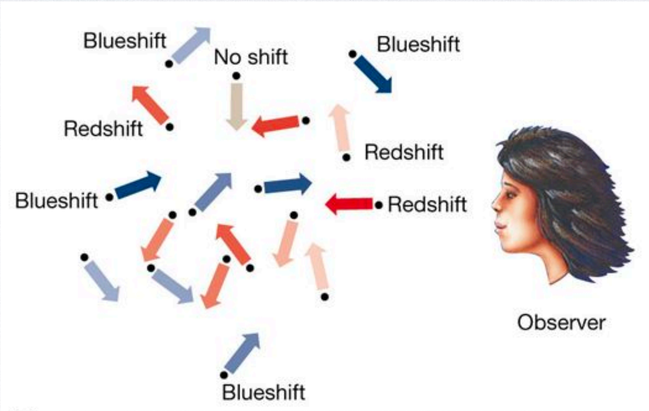
- Doppler boosting

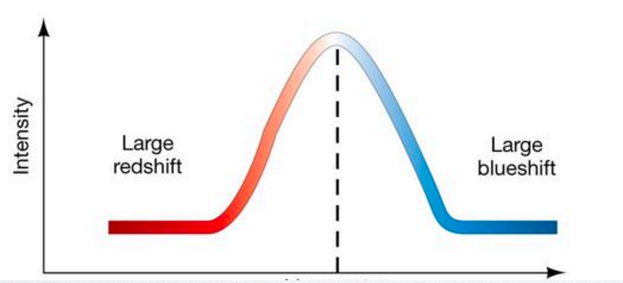


LINE BROADENING

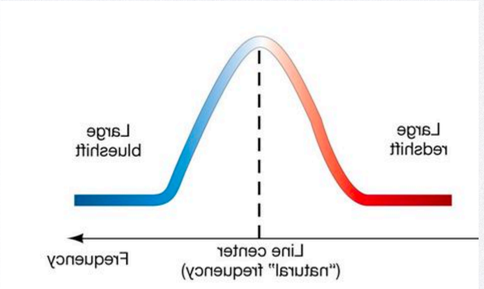
- Doppler boosting, feature smearing







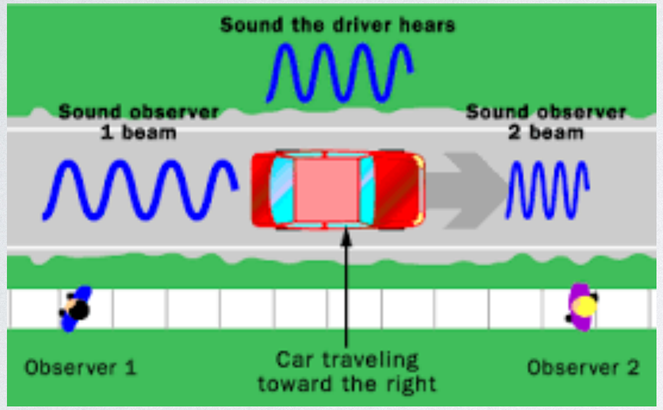
Frequency

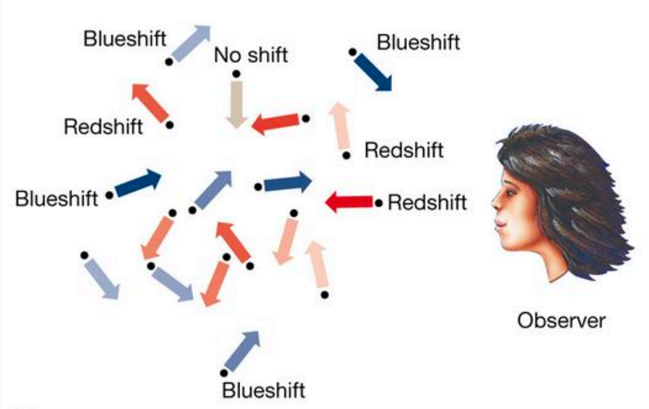


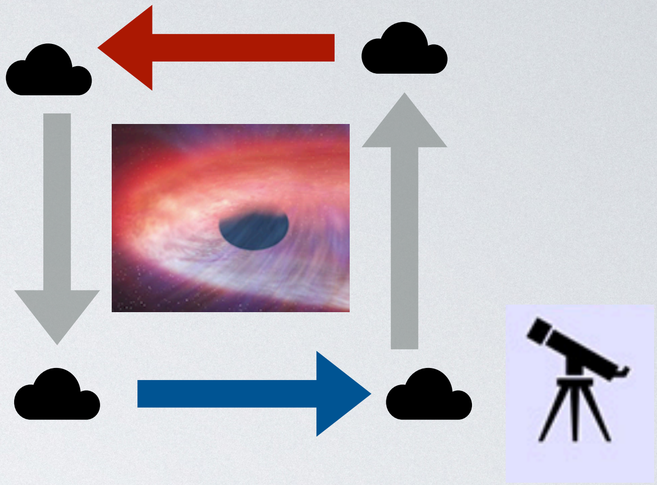
Wavelength

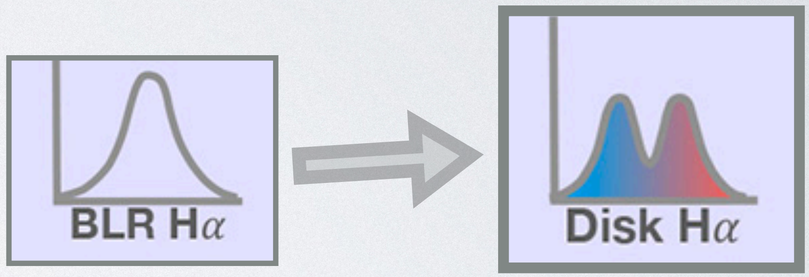
LINE BROADENING

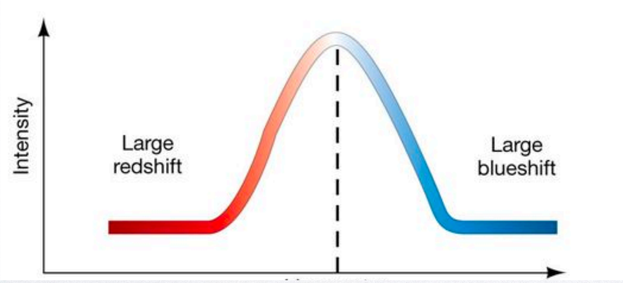
- Doppler boosting, feature smearing, relativistic effects











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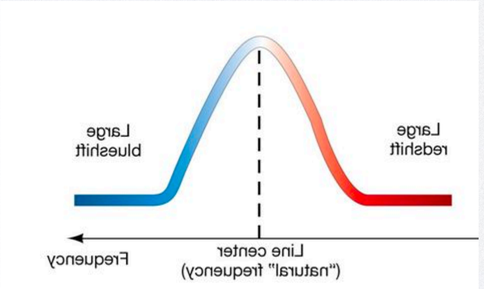
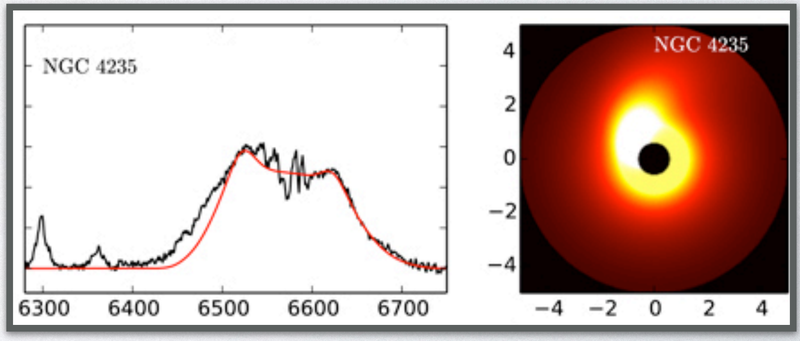


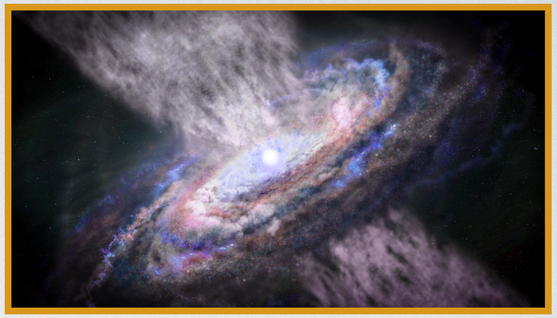
Wavelength



Storchi-Bergmann+2017

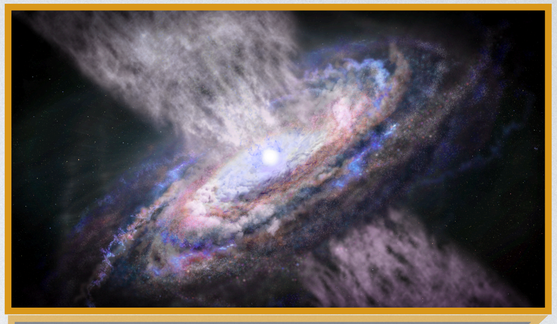
QUASARS

(A.K.A. QUASI-STELLAR OBJECTS, SEYFERTS, AGN)



- Supermassive black hole feeding on host galaxy
- Most luminous persistent sources in the universe!
- Emit across full electromagnetic spectrum

QUASARS



eCUIP

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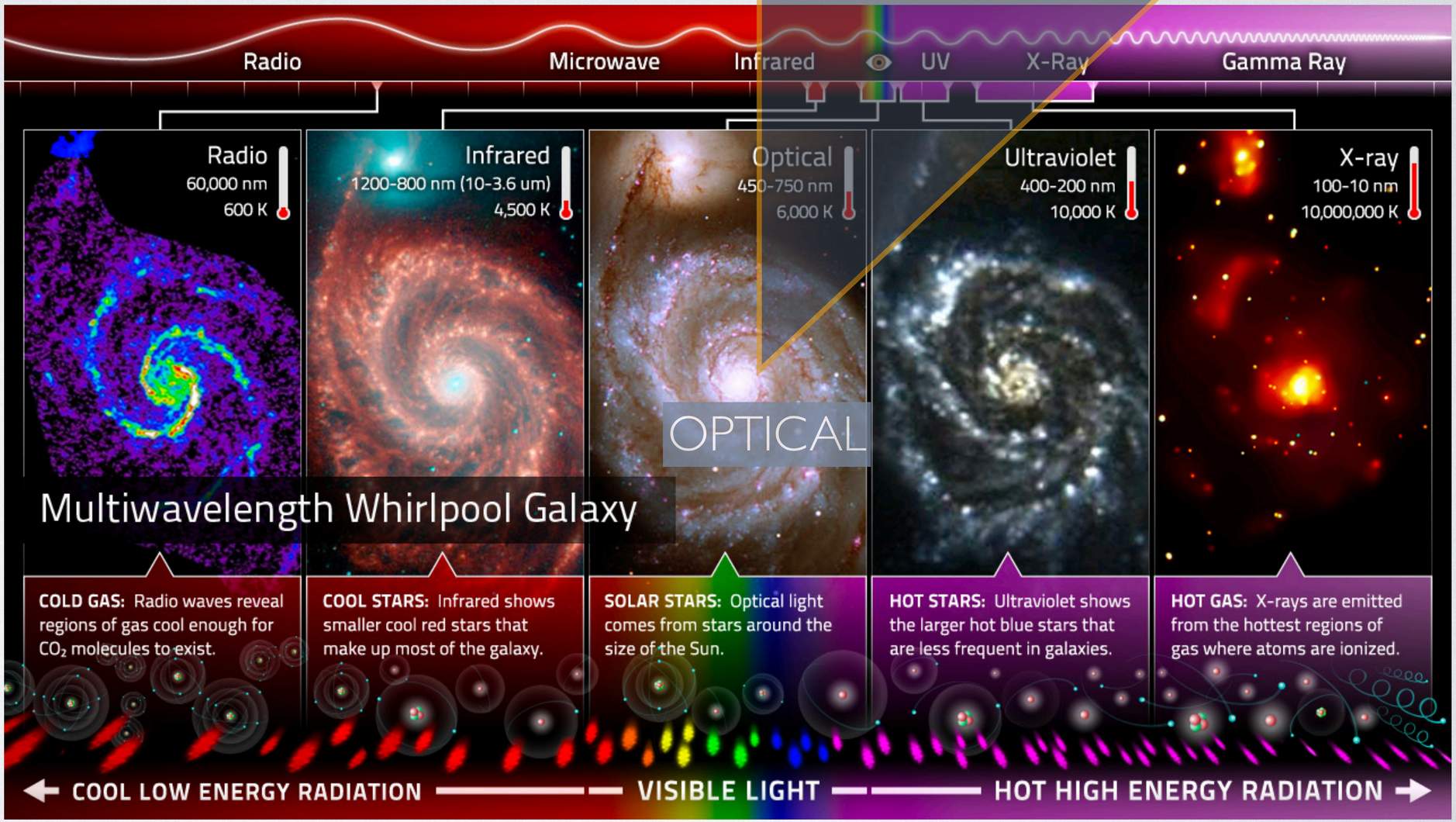
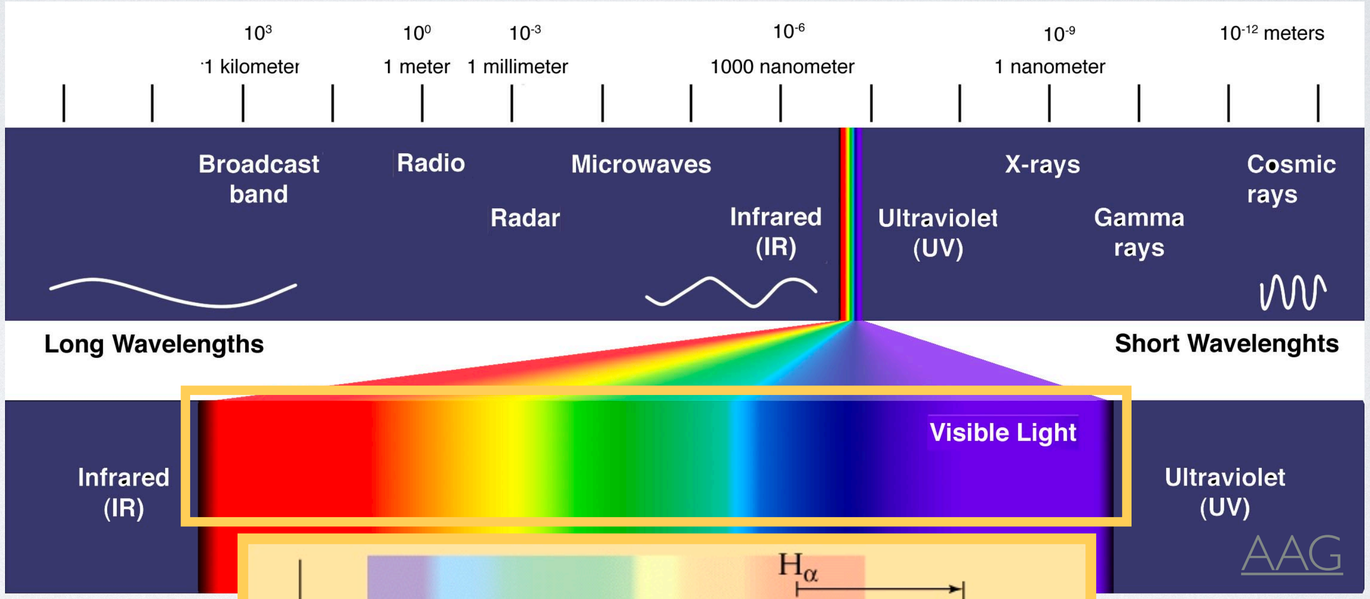
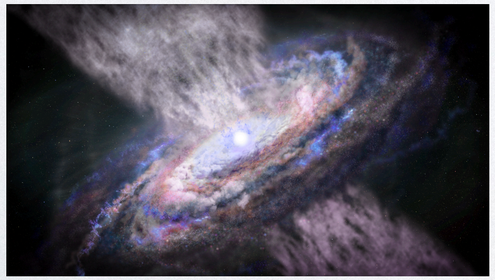
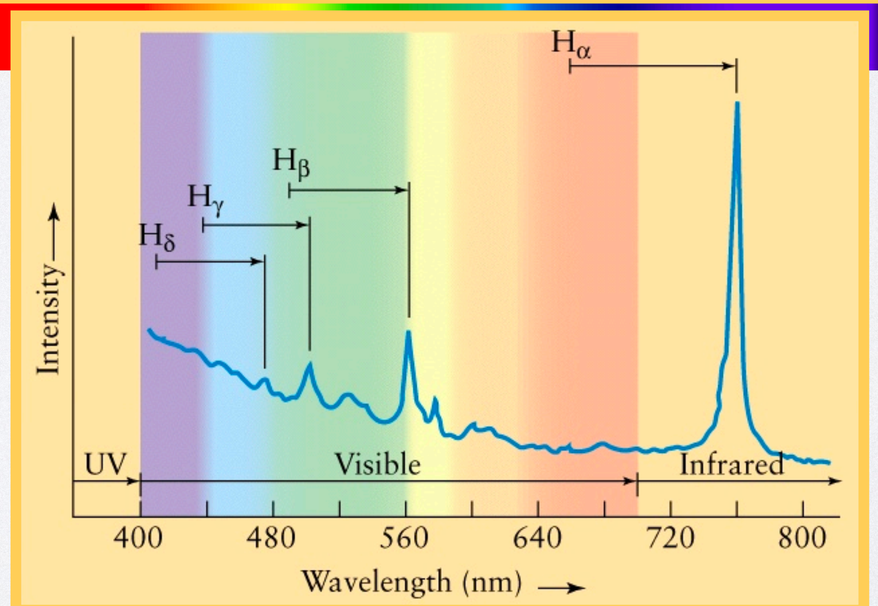


QUASAR SPECTROSCOPY



- Emission Features of Hydrogen





QUASAR SPECTROSCOPY

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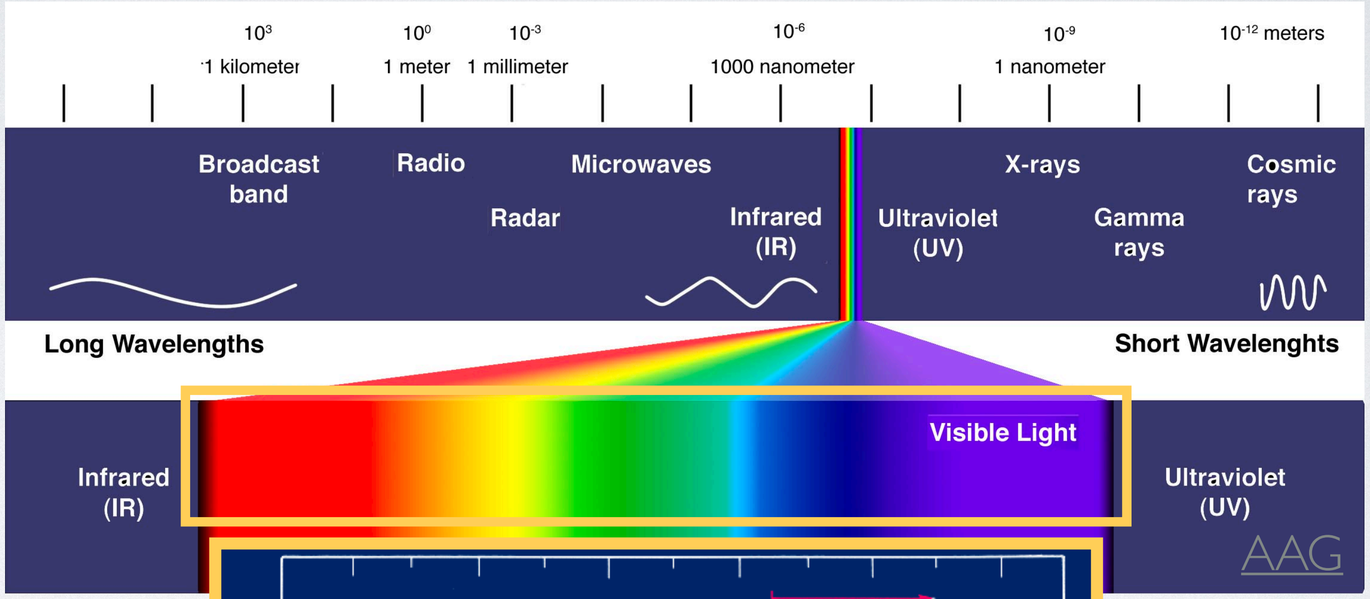
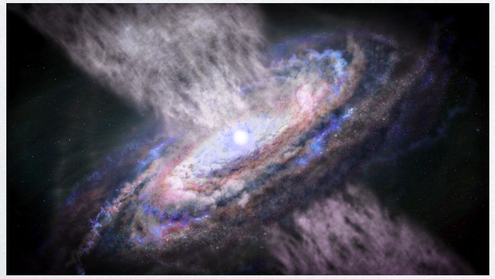
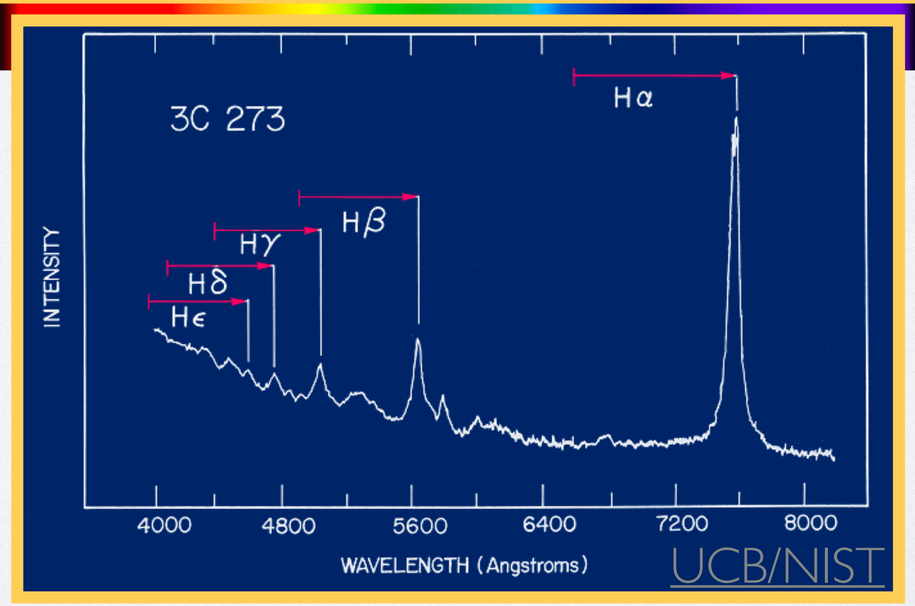
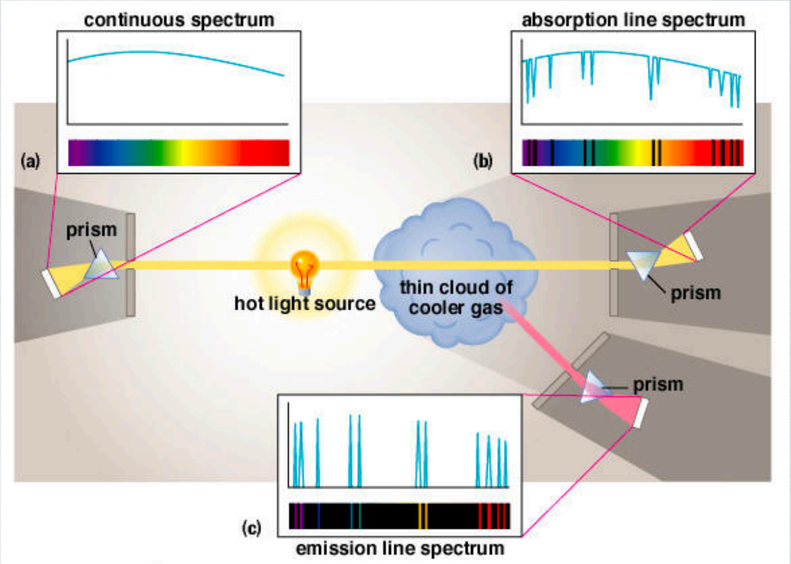
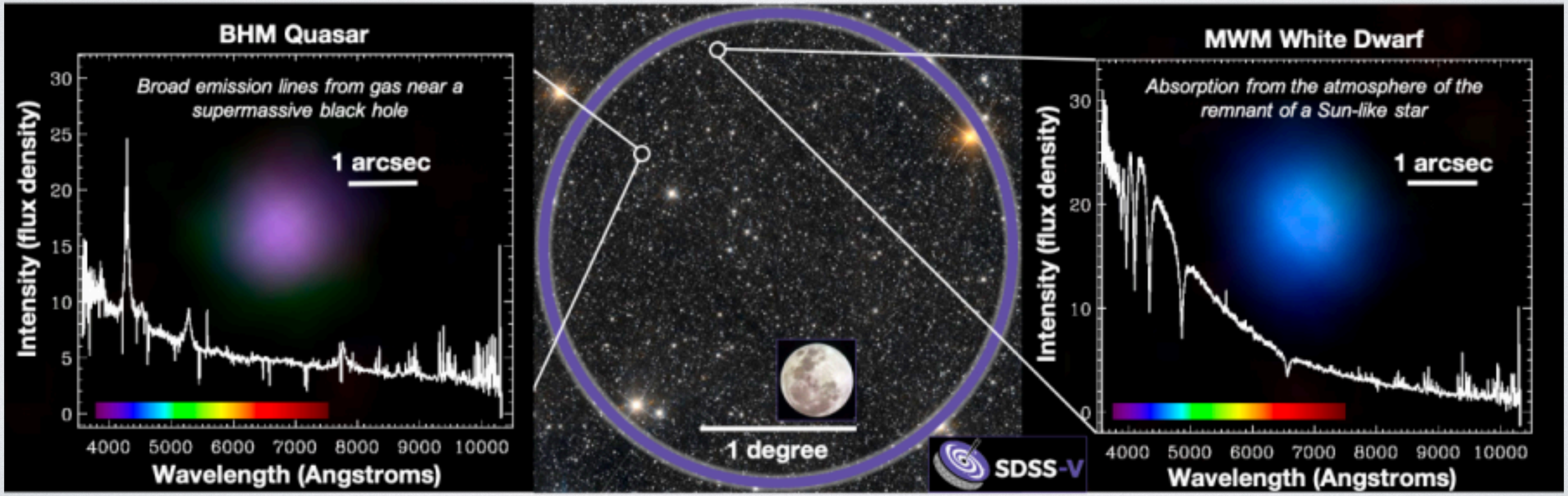






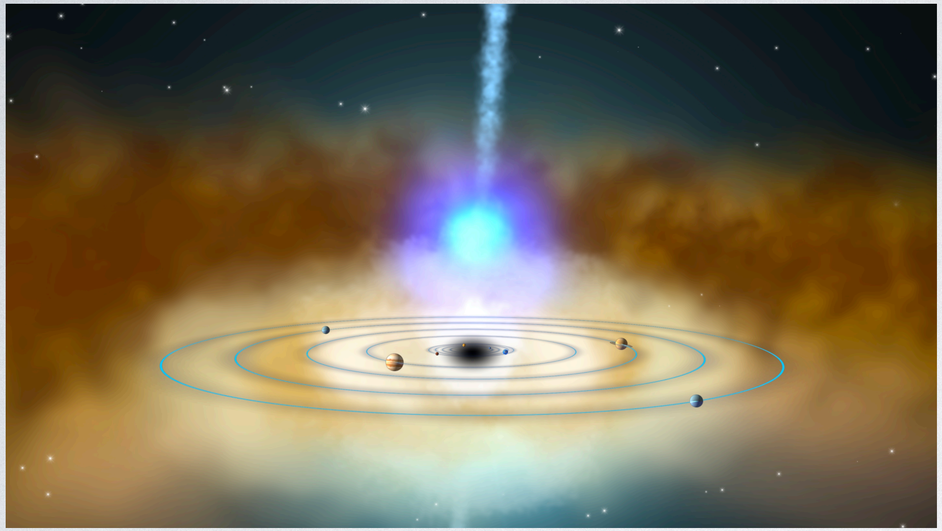
QUASAR VS. STAR SPECTRUM

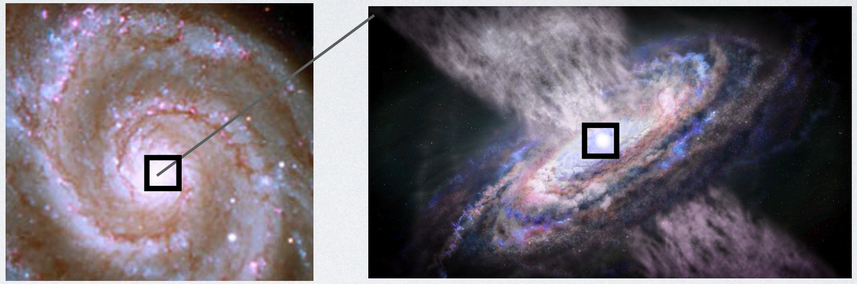




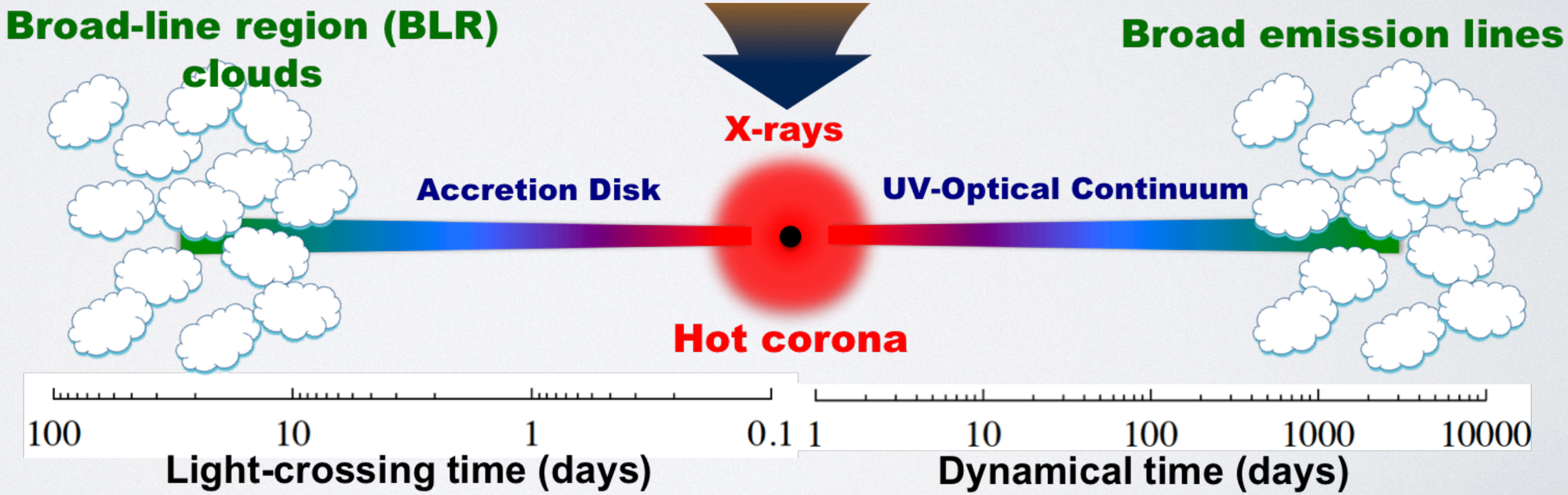
Carnegie

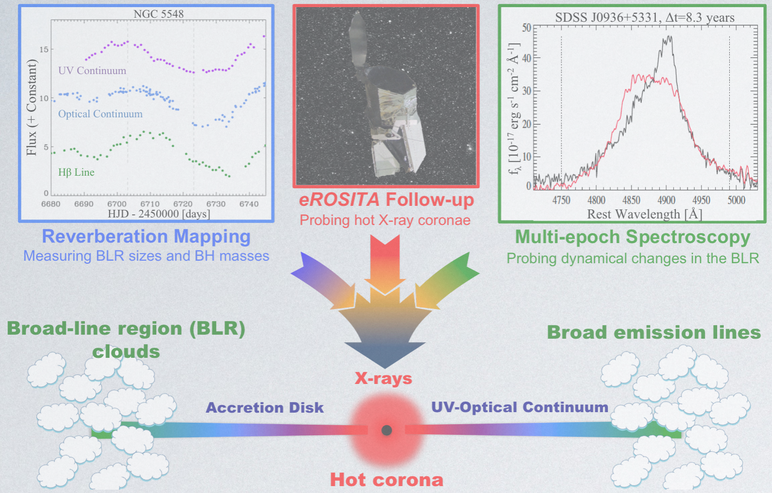
QUASAR COMPONENTS

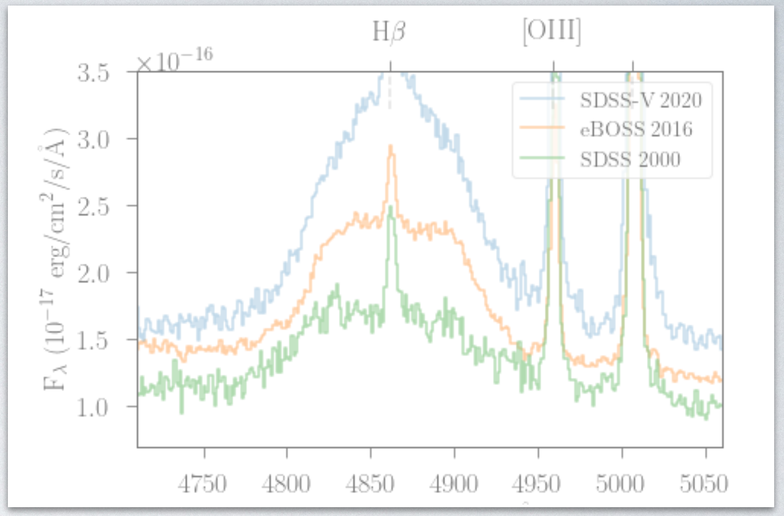




- Size scales comparable to Solar system!
- Accretion flow can be complex

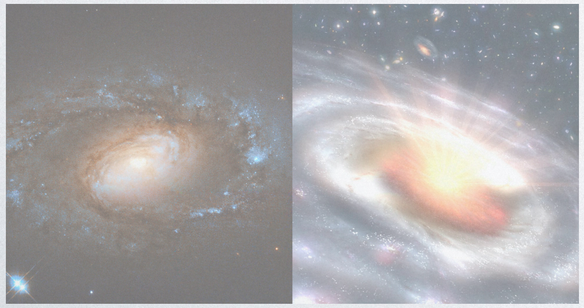


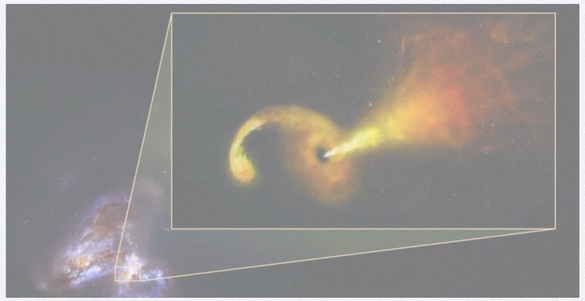


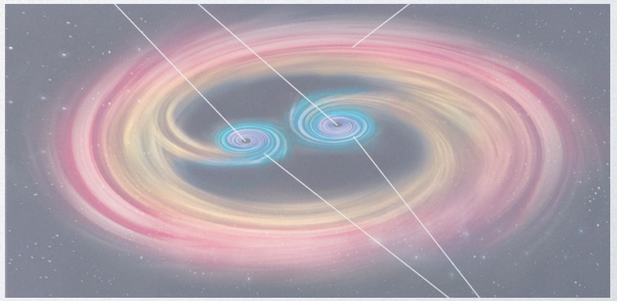


SCIENCE WITH QUASAR SPECTROSCOPY:

THE LEGACY OF THE SLOAN DIGITAL SKY SURVEY

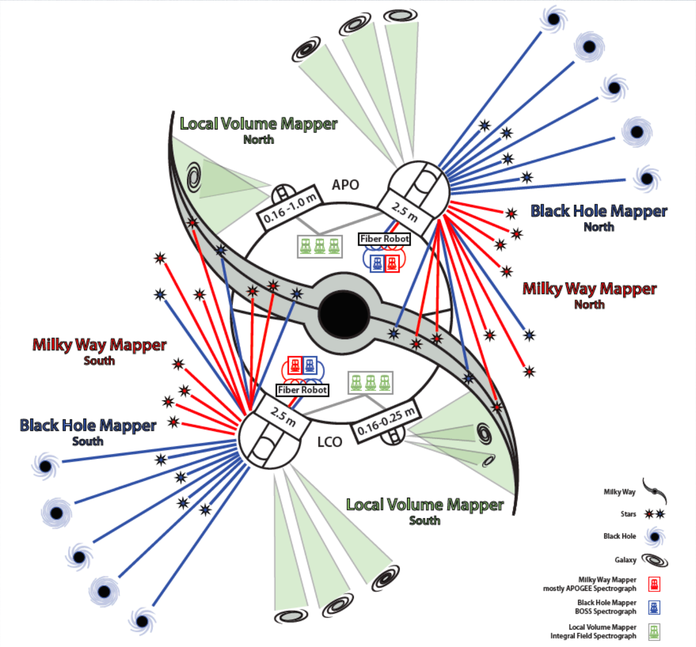


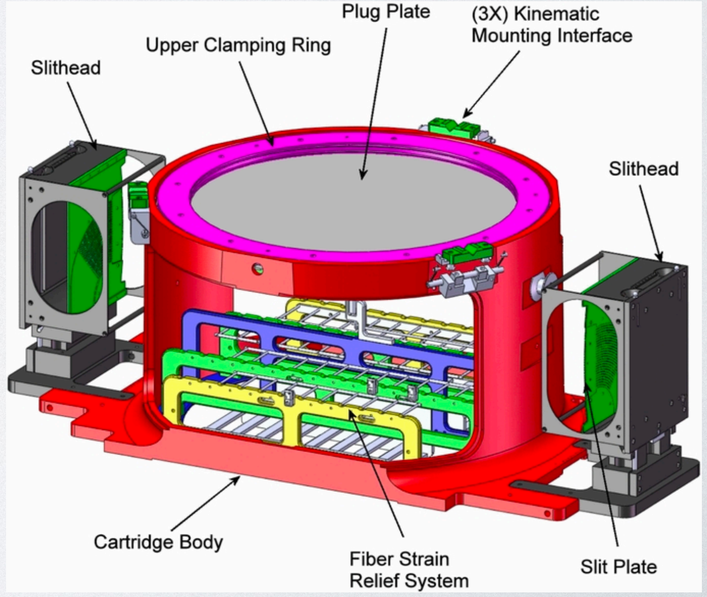




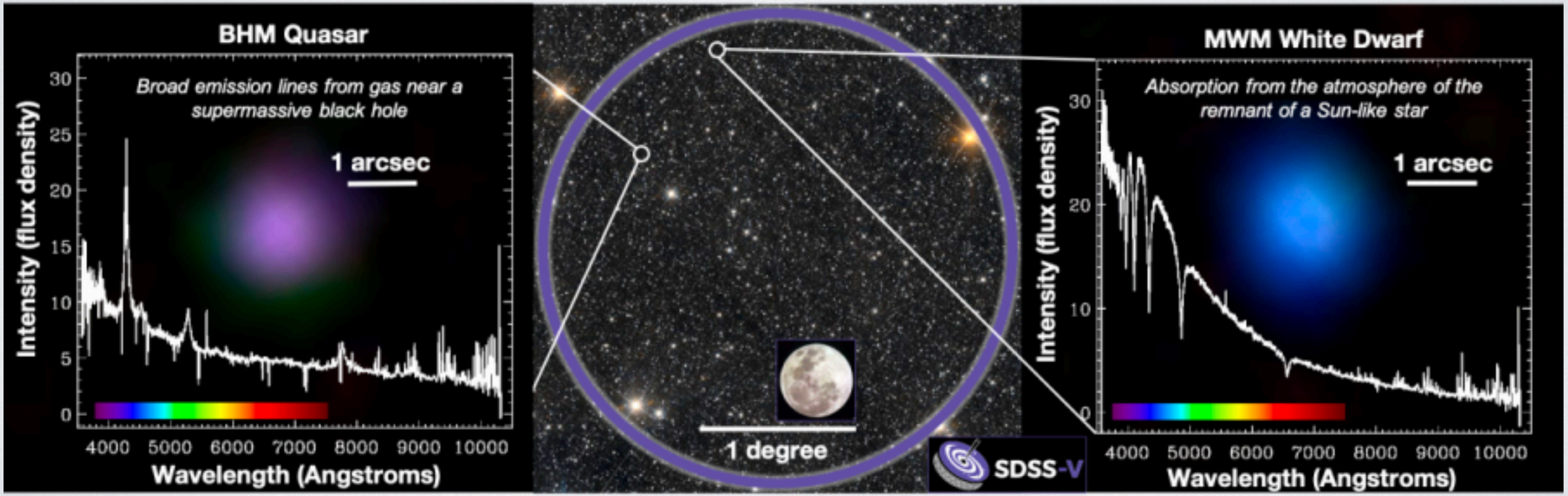
SLOAN DIGITAL SKY SURVEY

- Fifth iteration, All sky, Instrument upgrades
- Black Hole Mapper Project,
  BOSS Spectrograph
- Will also survey stars in Milky Way,
  ISM of Local Group
- Huge volume of data generated over decades



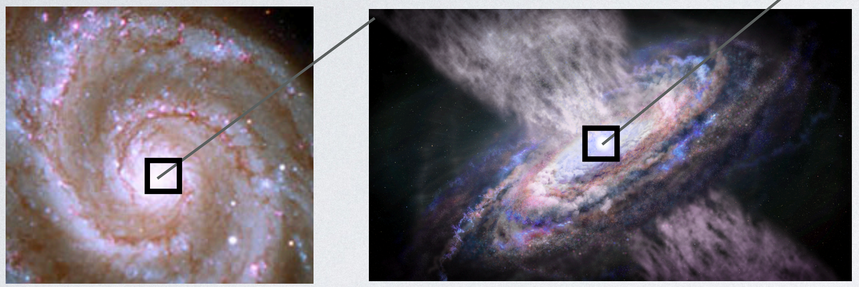


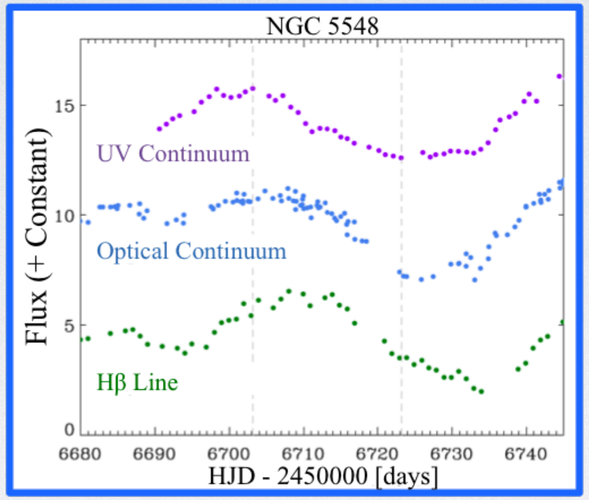
SLOAN DIGITAL SKY SURVEY



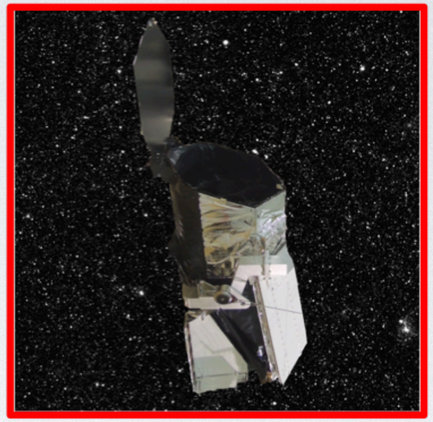
Carnegie

BLACK HOLE MAPPER

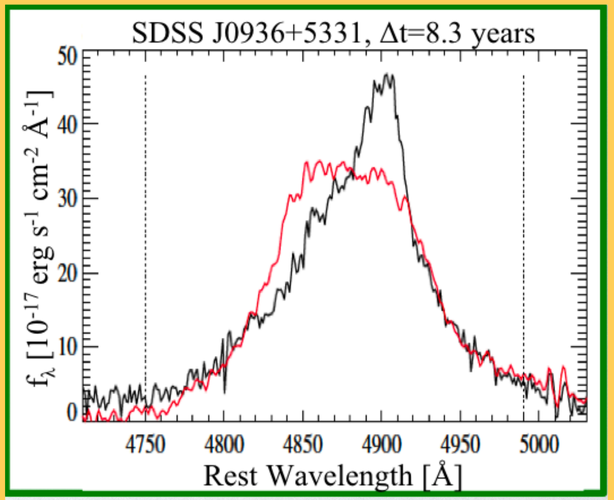




Reverberation Mapping
Measuring BLR sizes and BH masses

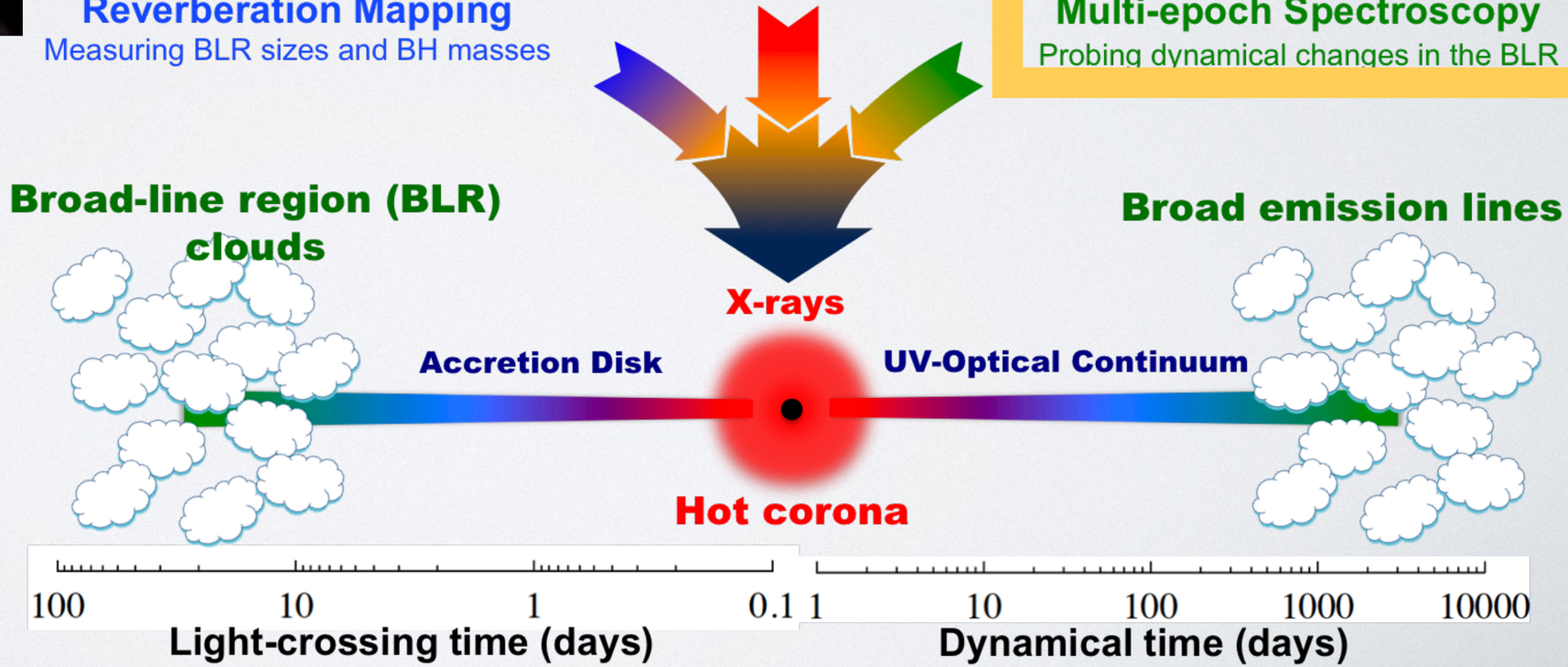


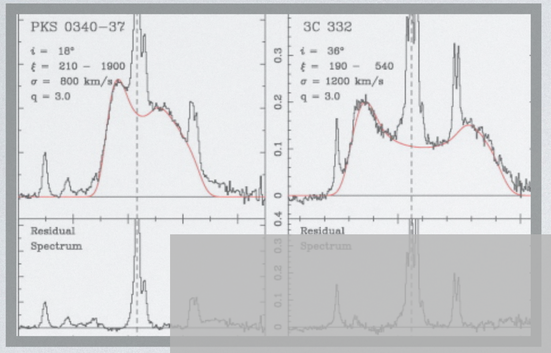
***eROSITA* Follow-up**
Probing hot X-ray coronae

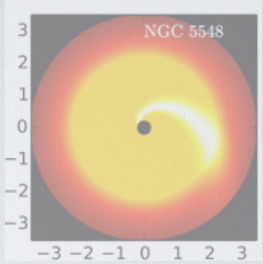


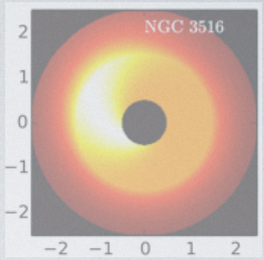
Multi-epoch Spectroscopy
Probing dynamical changes in the BLR

- Accretion flow can be complex
- Changes on fast & long timescales





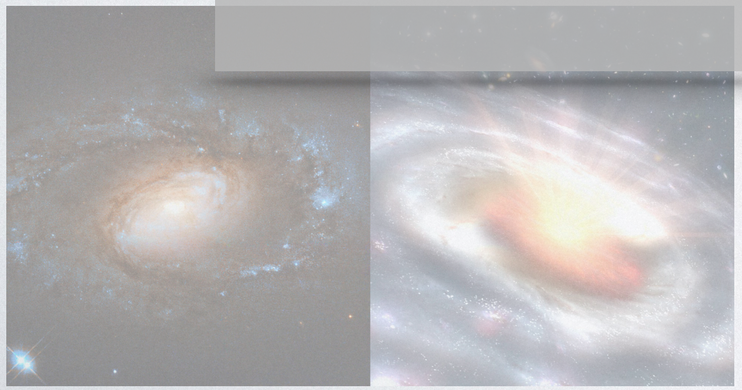


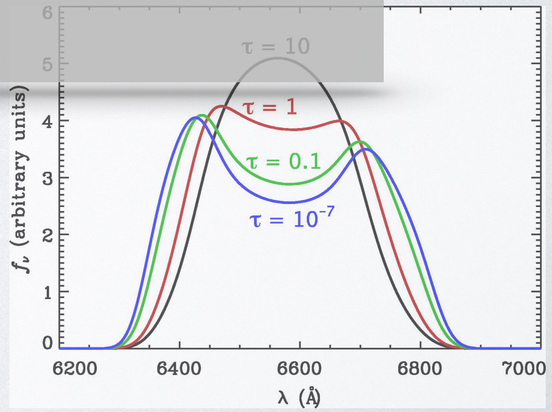


OBJECTIVES:

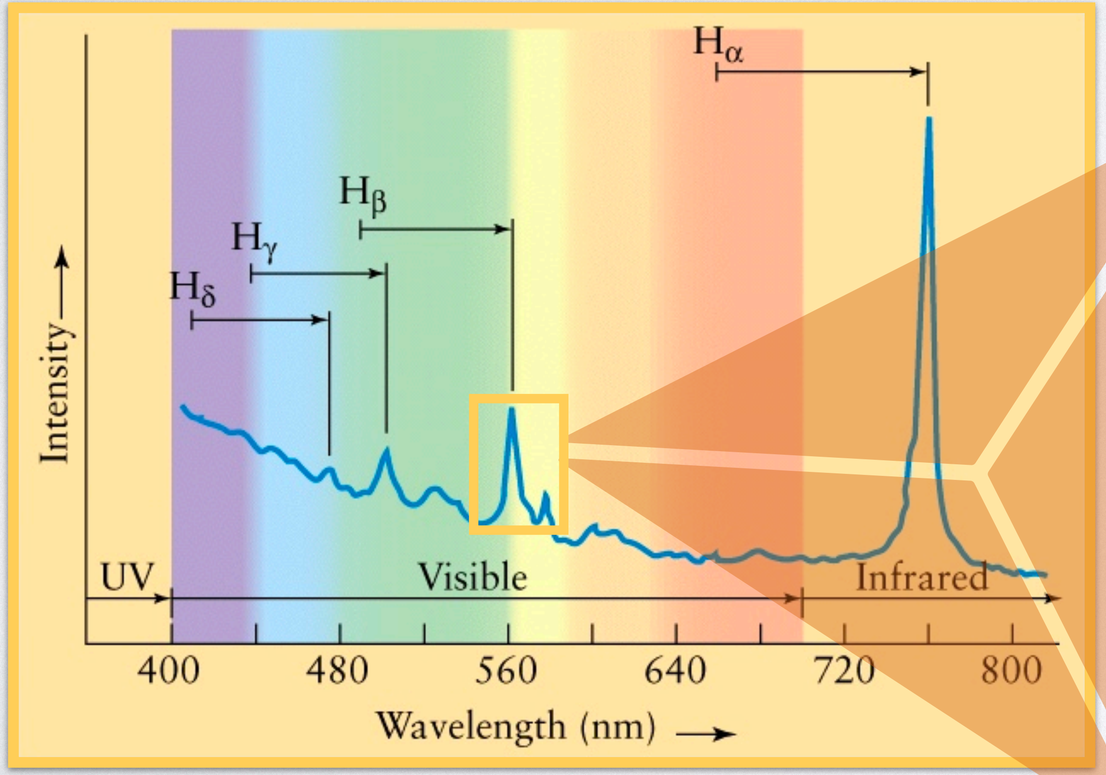
1) MONITOR CHANGES IN BROAD LINE PROFILE SHAPES IN SDSS V QUASAR SPECTRA

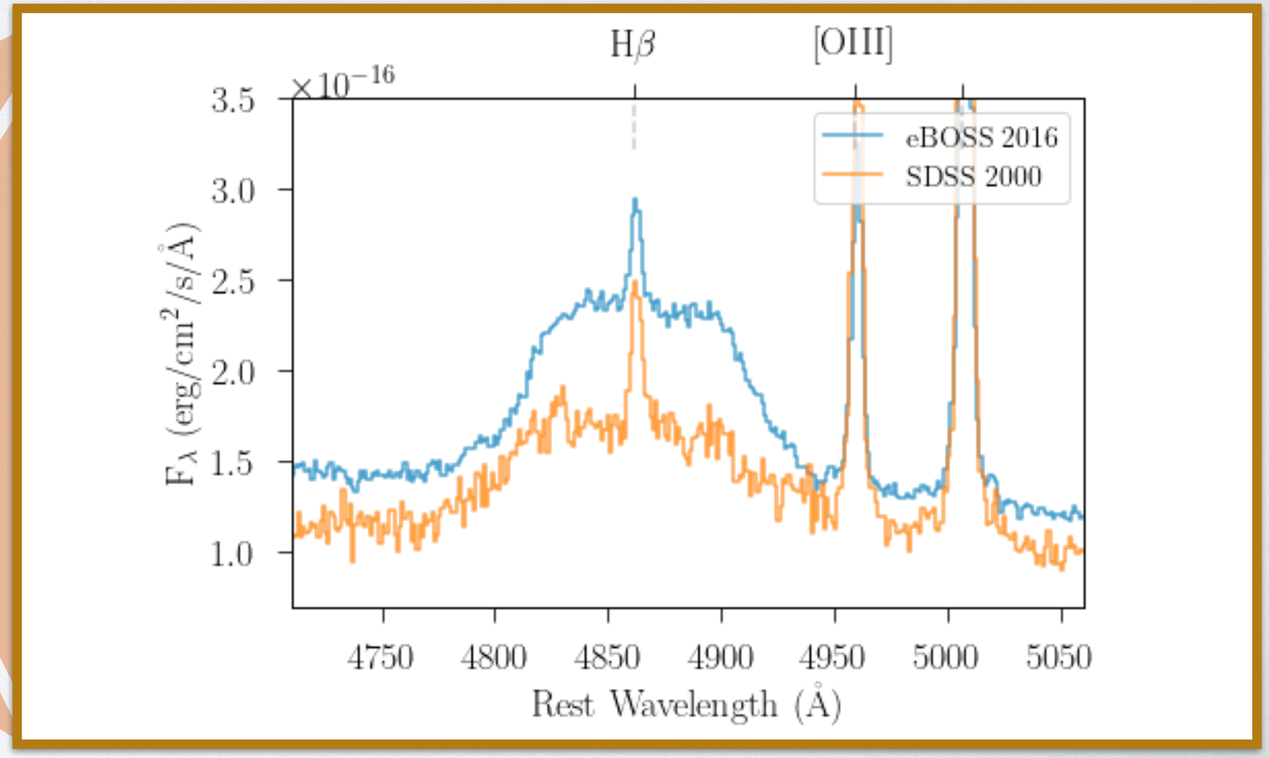
2) MODEL THE PHYSICAL PROCESSES RESPONSIBLE





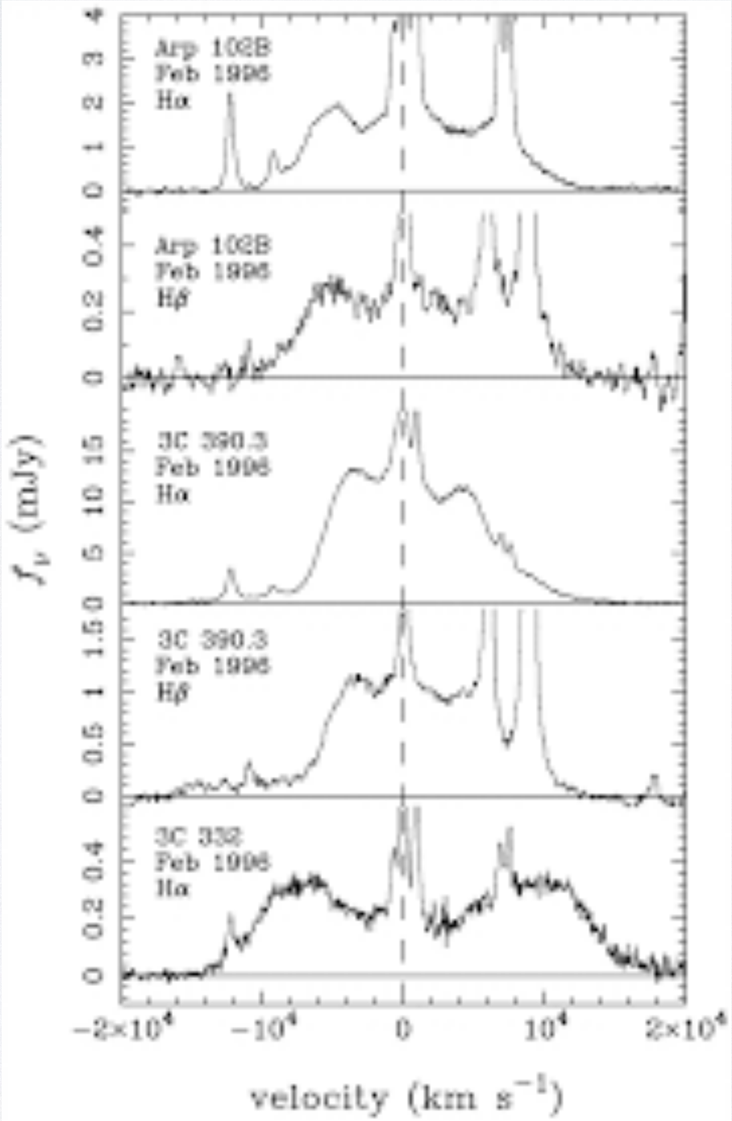
EXAMPLES OF BHM OBSERVATIONS SO FAR

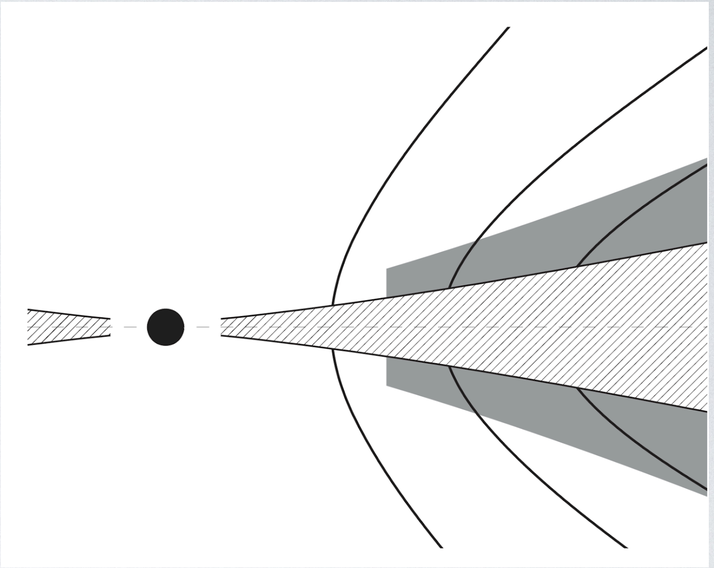


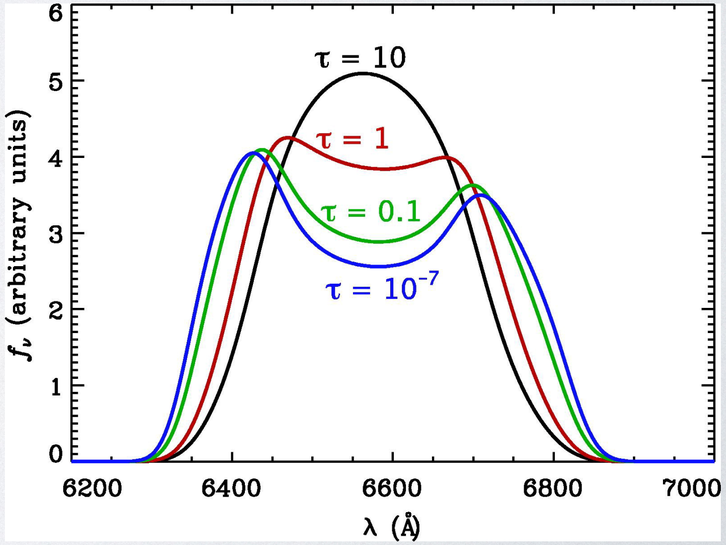


ACCRETION DISK WIND

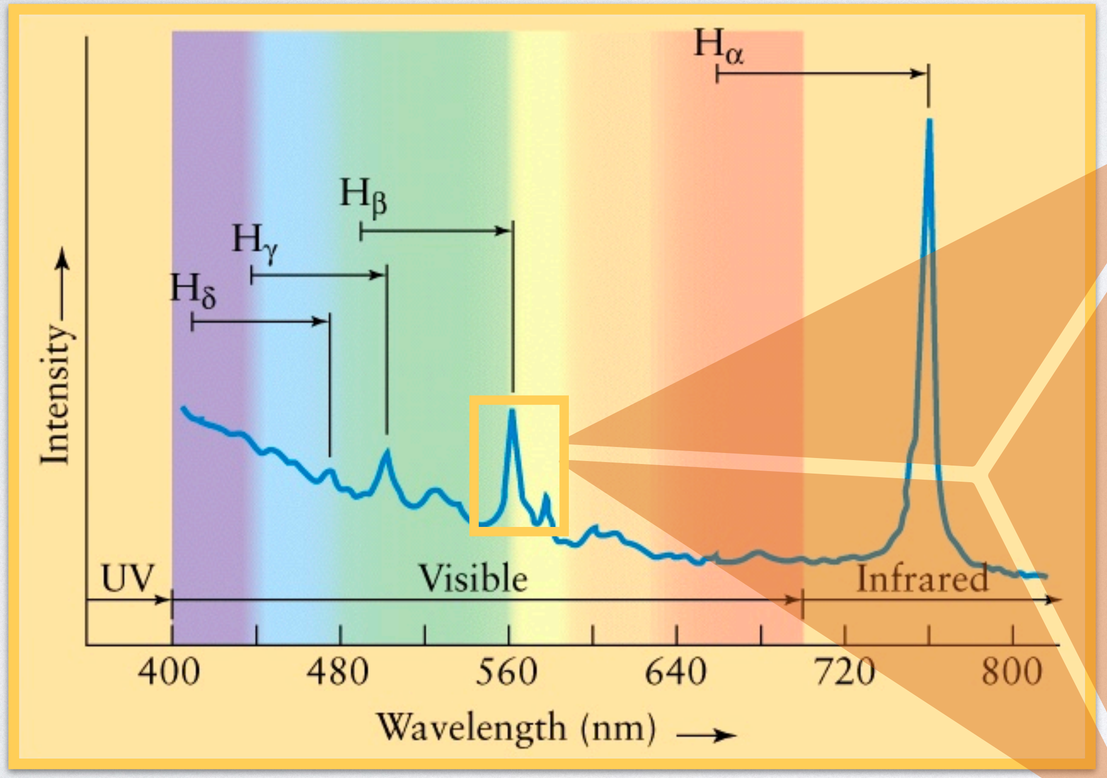
- Accretion components: Disk BLR, Disk Wind
- Properties, such as how opaque gas is to light, can alter how emission lines appear

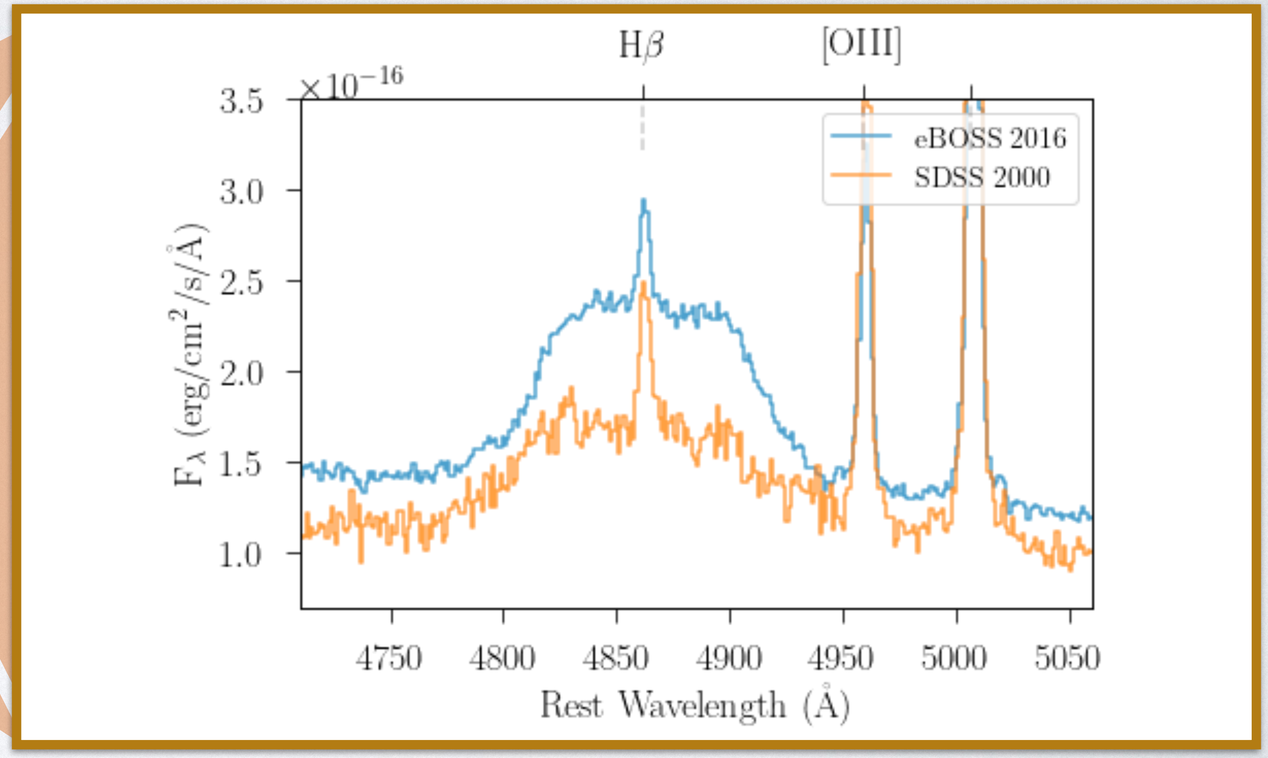






EXAMPLES OF BHM OBSERVATIONS

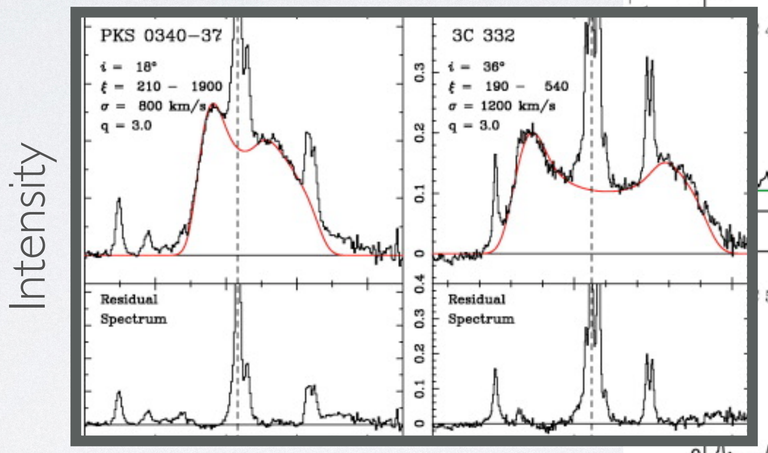


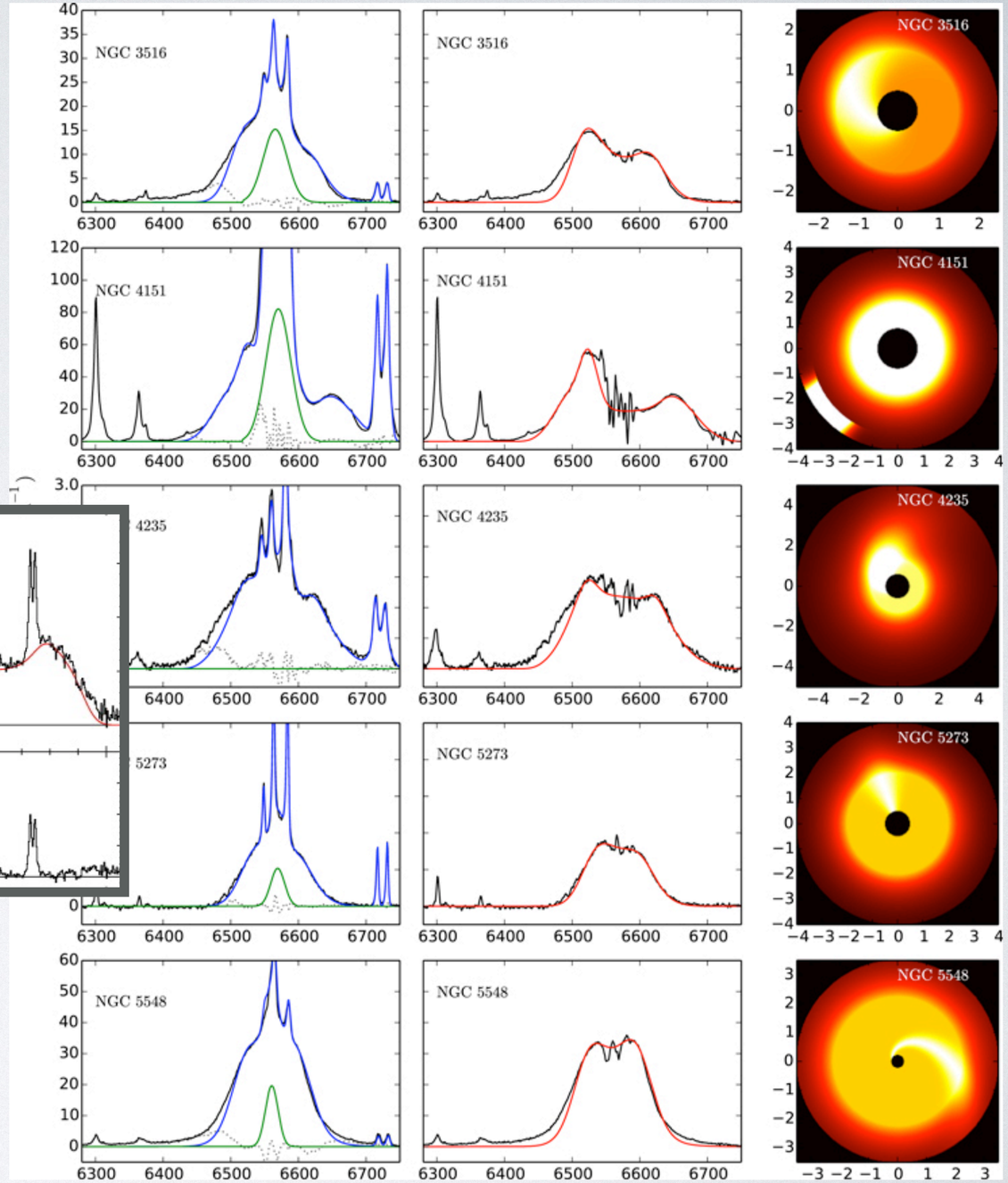


- Changes in BLR, disk wind?

PHYSICAL DISK MODELS FOR EMISSION LINES

- Rotating gas velocity profiles *(Storchi-Bergmann+2017)*
- Some changes due to clumpy, precessing spiral arms
- Binary hypothesis ruled out in a subset of candidate DPE sources *(Eracleous+1997)*



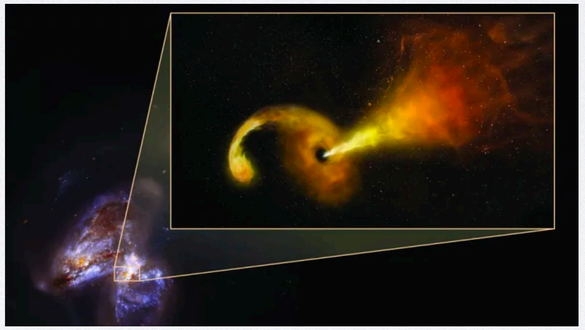


RARE TRANSIENT EVENTS

- Changing look AGN

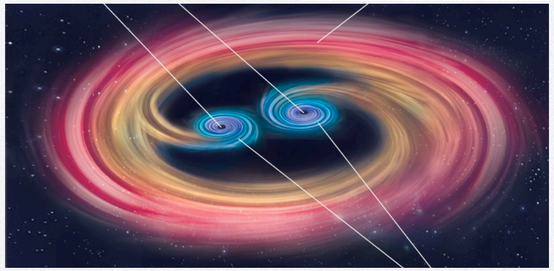
Frederick et al. 2018

- Tidal Disruption Events

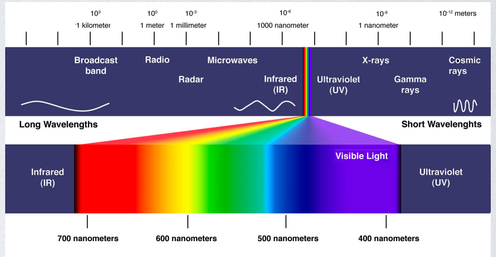


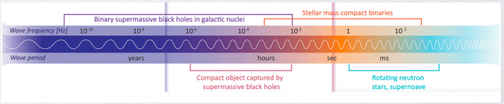
NRAO/VLA

- Binary Supermassive BHs

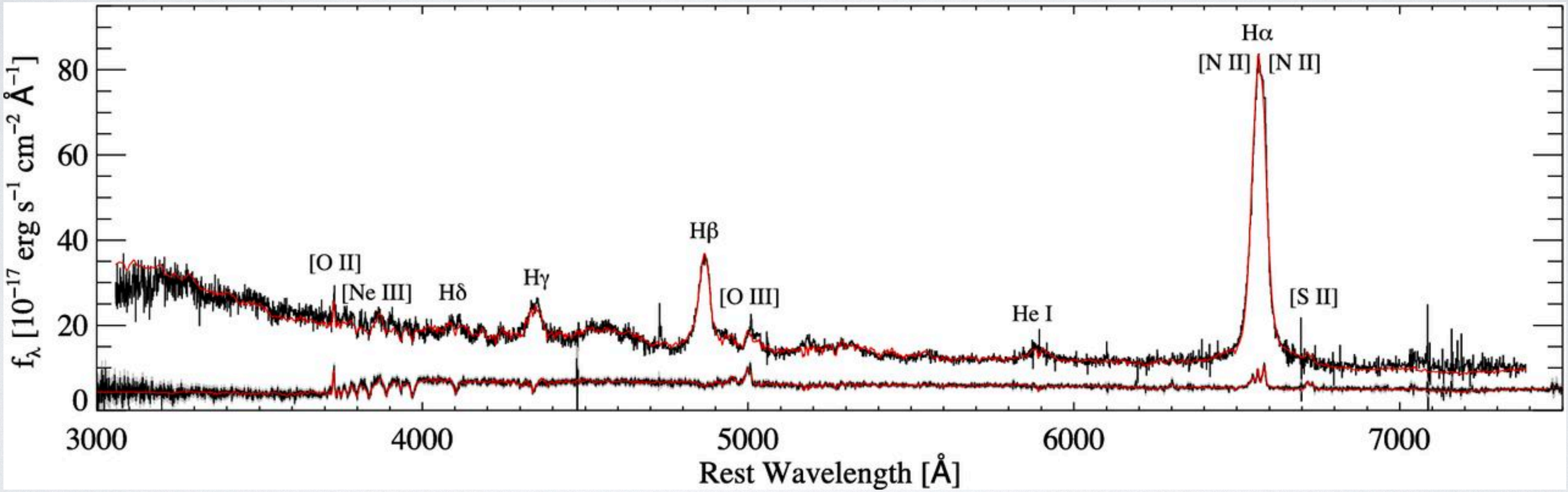


Hayasaki/Morimoto, 2008





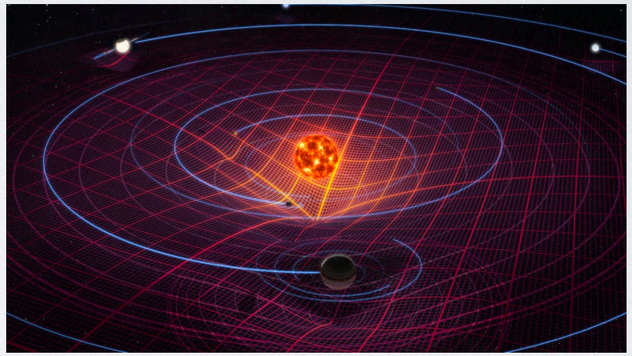
CHANGING LOOK QUASARS

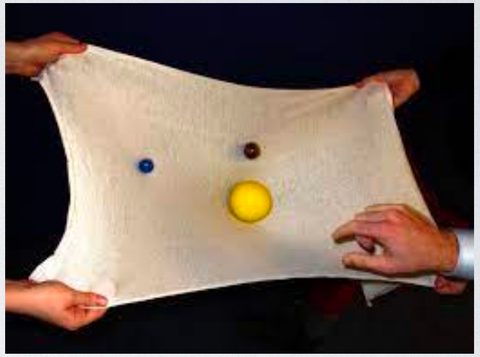


Runnoe et al. 2016

CLASSROOM ACTIVITIES & RESOURCES

- Fabric Sheet Demonstration of Space Time / Gravity





- Journey to a Black Hole Demonstration Manual

- Zoom in to a Black Hole (EM Spectrum, Scales)

CLASSROOM ACTIVITIES & RESOURCES

- Fabric Sheet Demonstration of Space Time / Gravity
- Journey to a Black Hole Demonstration Manual
- Zoom in to a Black Hole (EM Spectrum, Scales)

1905 - 2005

INSIDE EINSTEIN'S UNIVERSE

"Journey to a Black Hole" Demonstration Manual

What is a black hole? How are they made? Where can you find them? How do they influence the space and time around them? Using hands-on activities and visual resources from NASA's exploration of the universe, these activities take audiences on a mind-bending adventure through our universe.

1. How to Make a Black Hole [Stage Demo, Audience Participation] (Page 3)
2. The Little Black Hole That Couldn't [Stage Demo, Audience Participation] (Page 6)
3. It's A Bird! It's a Plane! It's a Supernova! [Stage Demo] (Page 10)
4. Where Are the Black Holes? [Stage Demo, Audience Participation] (Page 14)
5. Black Holes for Breakfast [Make-and-Take…and eat!] (Page 17)
6. Modeling a Black Hole [Cart Activity] (Page 19)
7. How to Spot a Black Hole [Stage Demo, Audience Participation] (Page 25)
8. Black Hole Hide and Seek [Cart Activity] (Page 29)
9. Black Hole Lensing [Stage Demo, Audience Participation] (Page 32)
10. Spaghettification [Make-and-Take] (Page 35)

CFA

CLASSROOM ACTIVITIES & RESOURCES

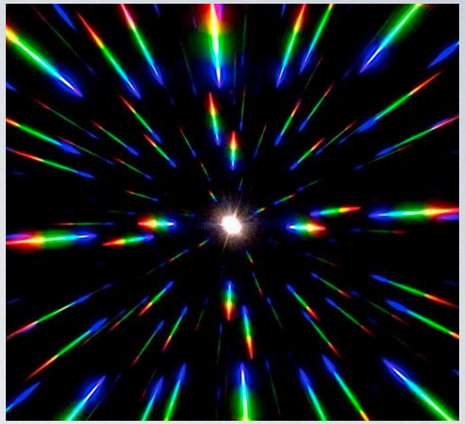
- Fabric Sheet Demonstration of Space Time / Gravity

- Journey to a Black Hole Demonstration Manual

- Zoom in to a Black Hole (EM Spectrum, Scales)

ESO

DIFFRACTION GRATING GLASSES



- Hands-on spectroscopy experiment
- Diffract light sources into visible spectrum

Fisher Scientific

MORE RESOURCES

astrobites

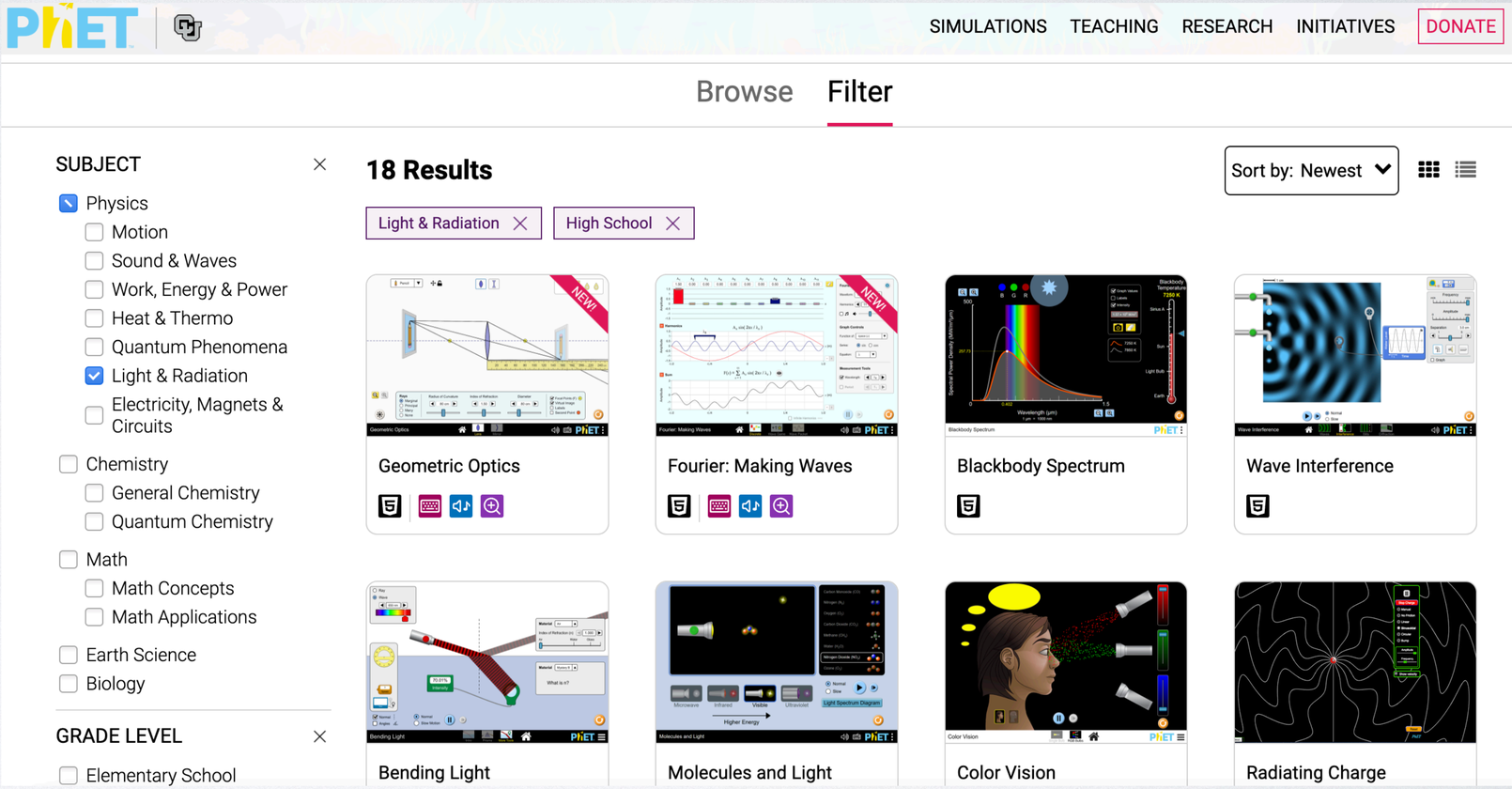
THE ASTRO-PH READER'S DIGEST | SUPPORTED BY THE AAS

- AstroBites https://astrobites.org/
- APOD, NASA's Astronomy Pic of the Day https://apod.nasa.gov/apod/astropix.html

ONLINE ACTIVITIES

- Physics simulations
  - Gravity / Orbits
  - EM / Radiation
  - Spectroscopy

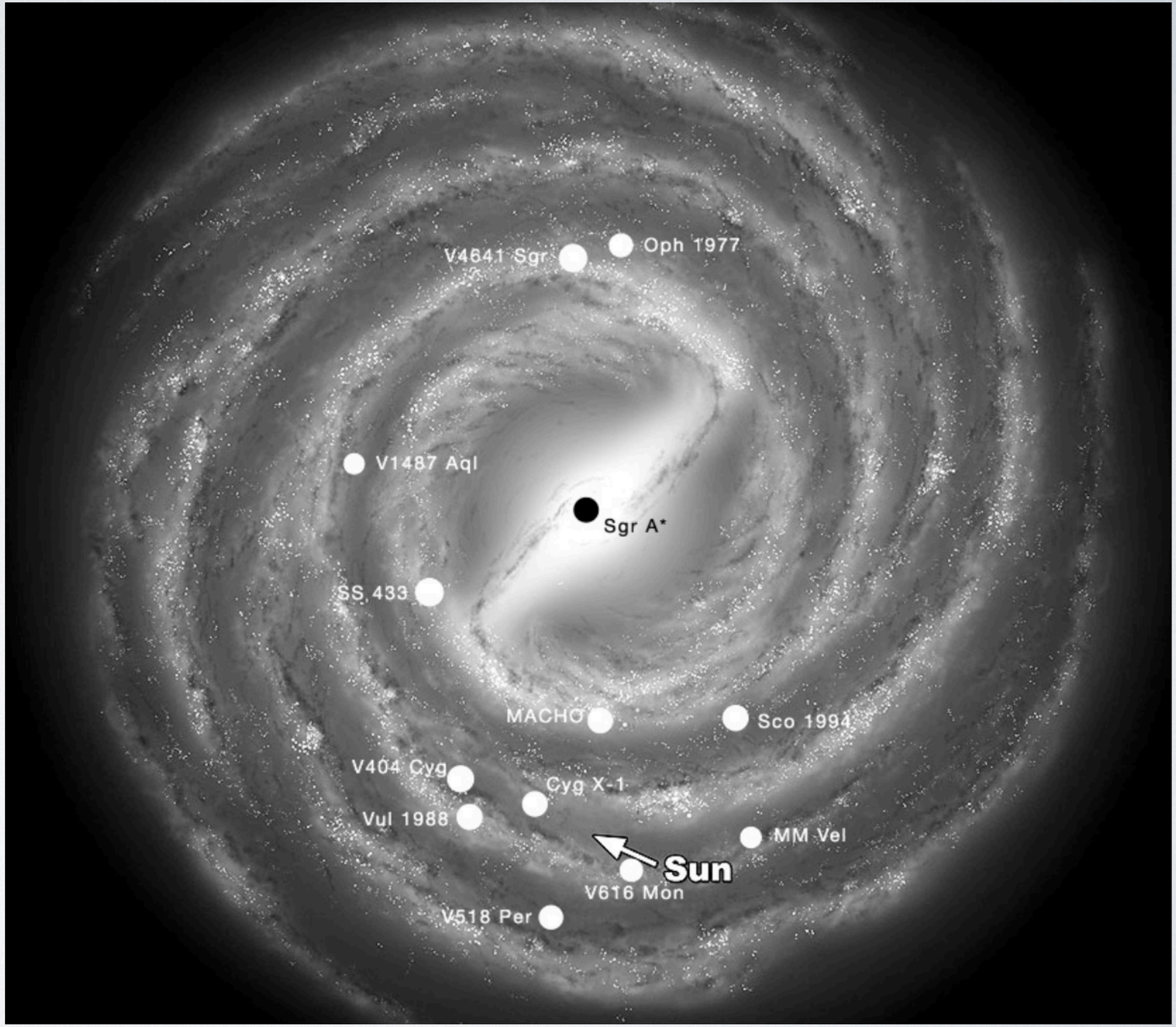
…and many more!



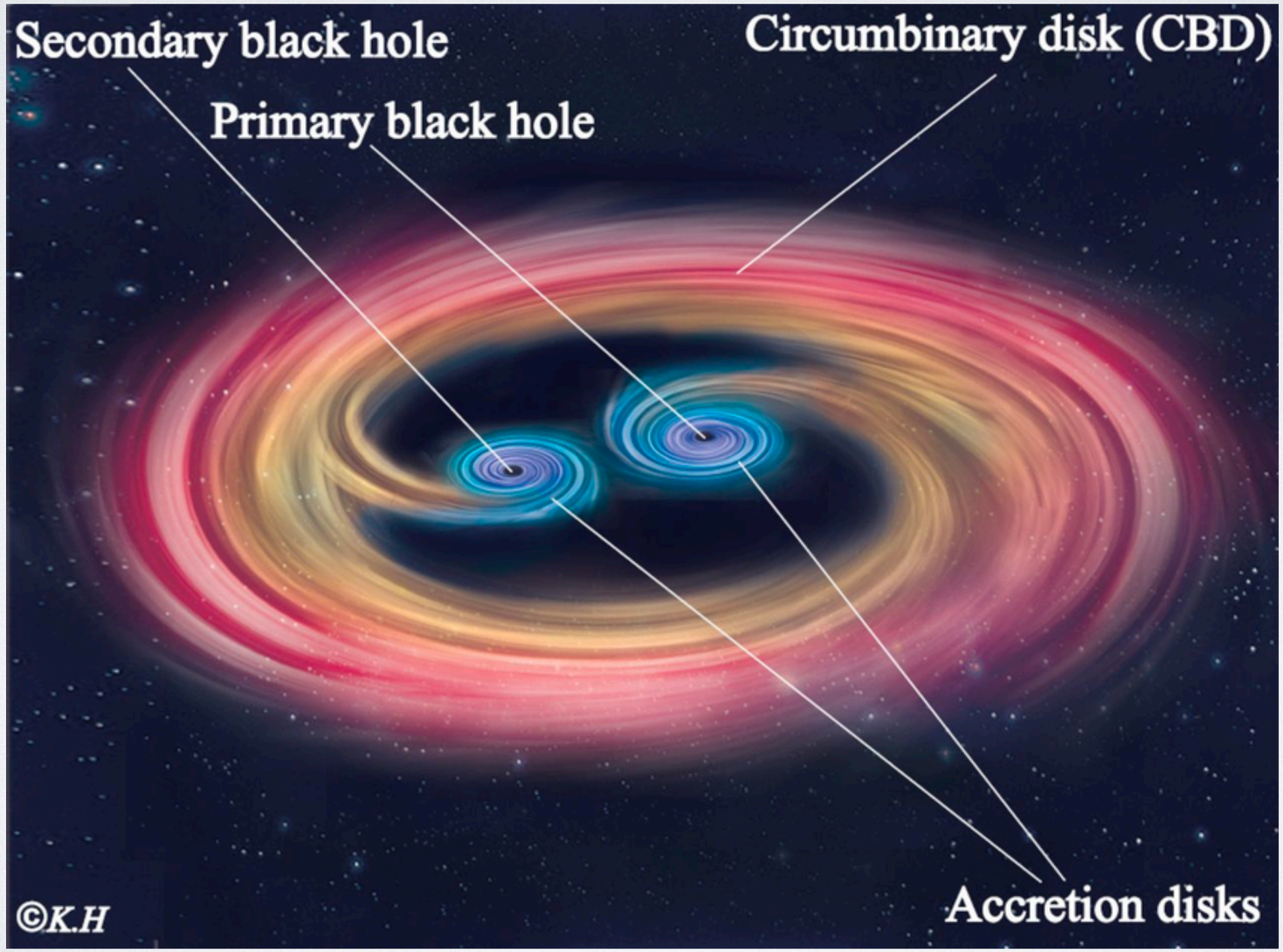
PHET/CU Boulder

ADDITIONAL SLIDES

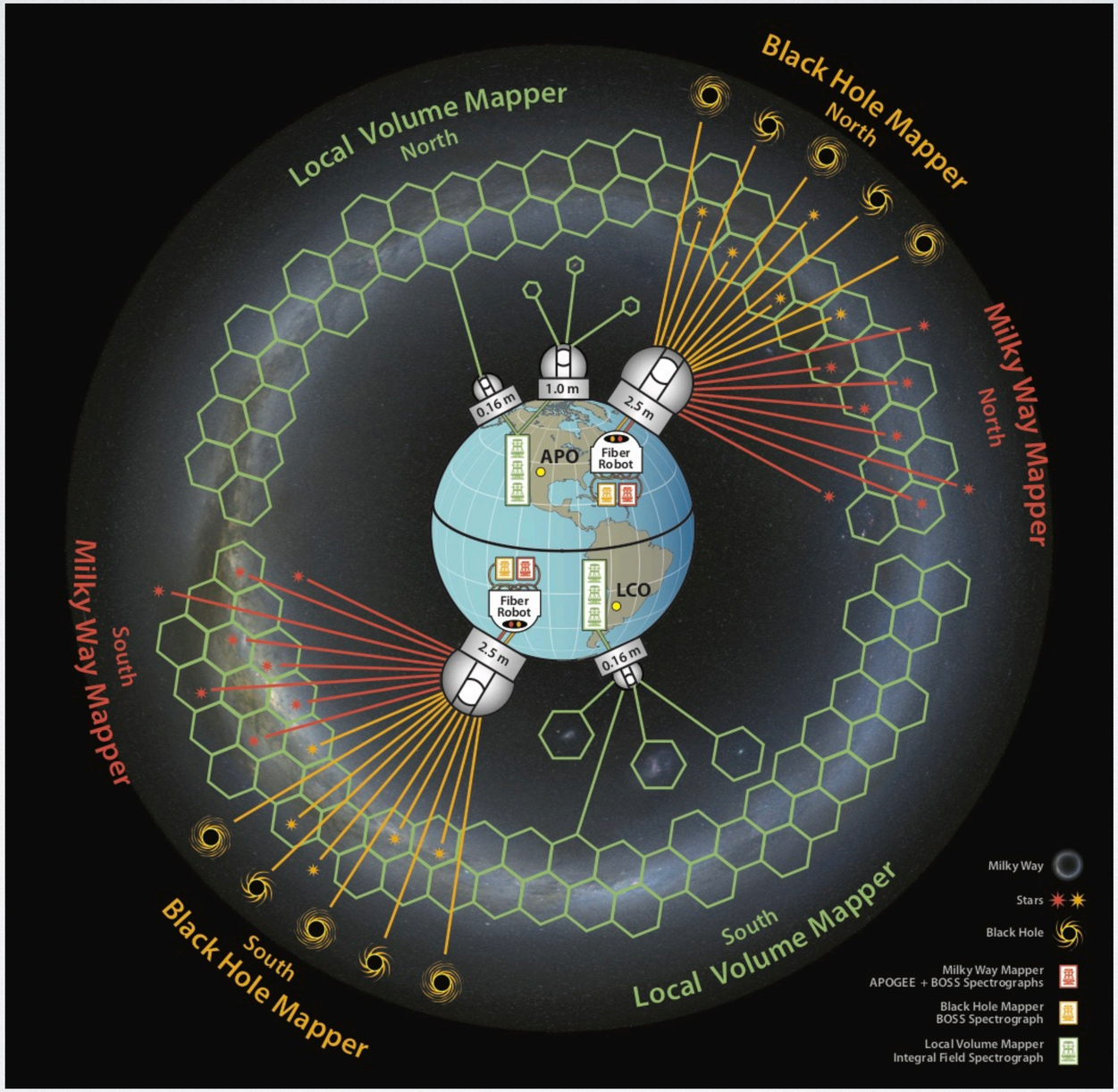
OTHER BHS IN OUR MW GALAXY



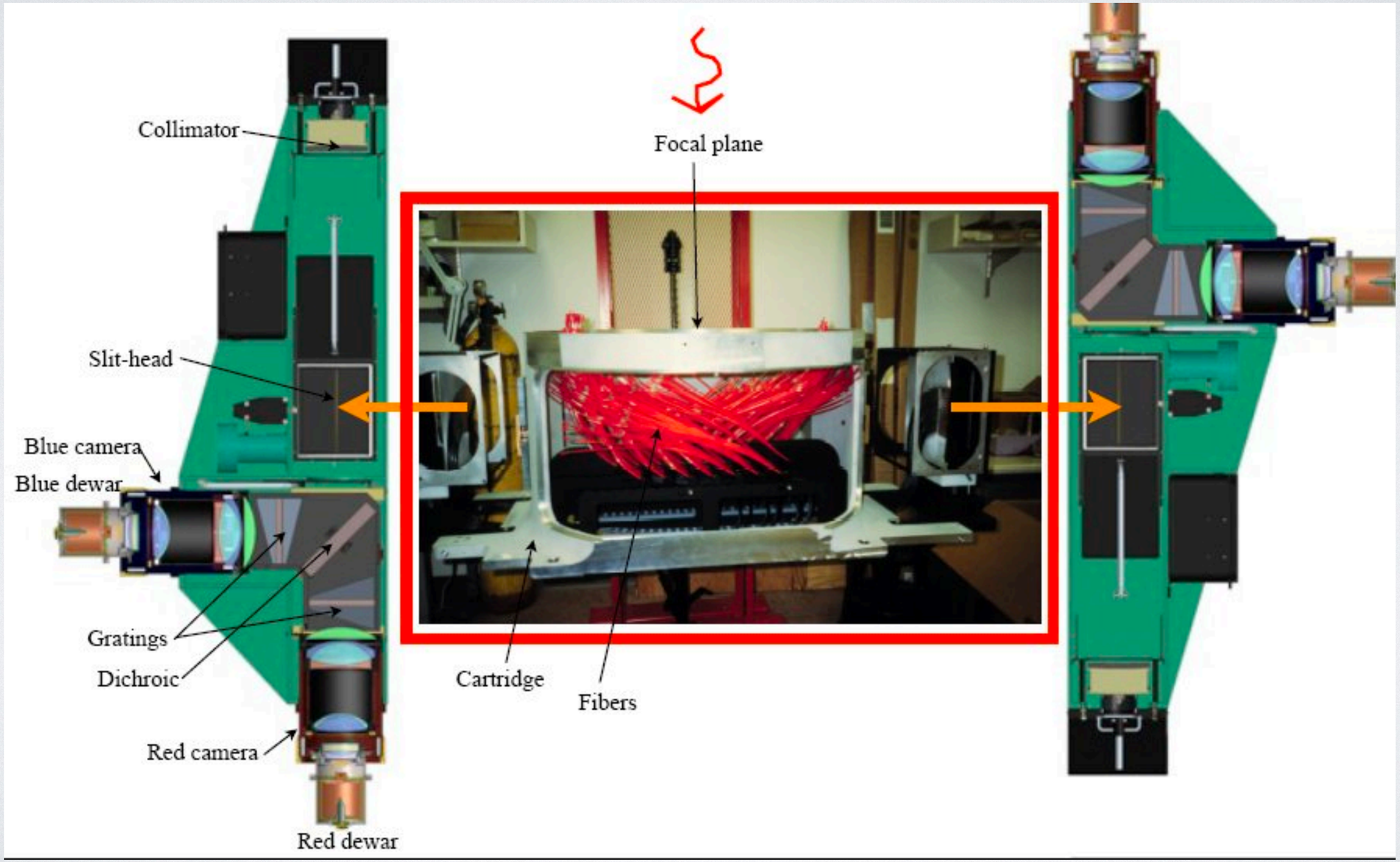
SUPERMASSIVE BLACK HOLE BINARIES



SDSS INSTRUMENTS

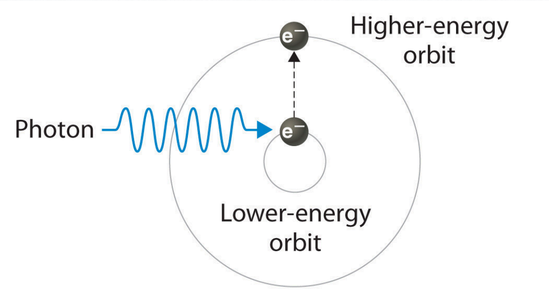


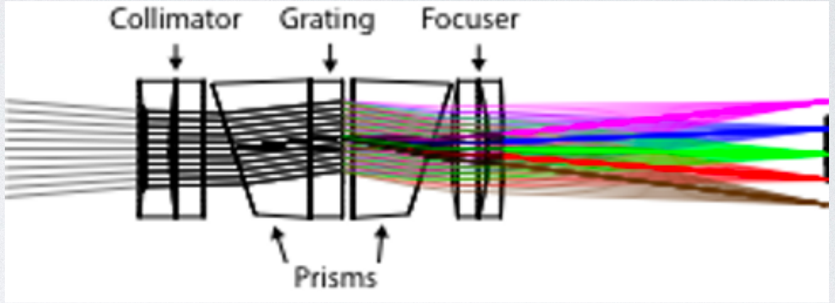
BOSS SPECTROGRAPH SETUP

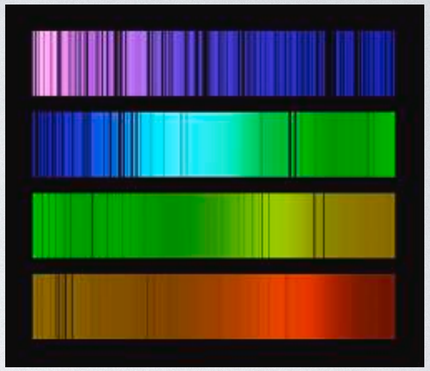


MORE ON SPECTROSCOPY

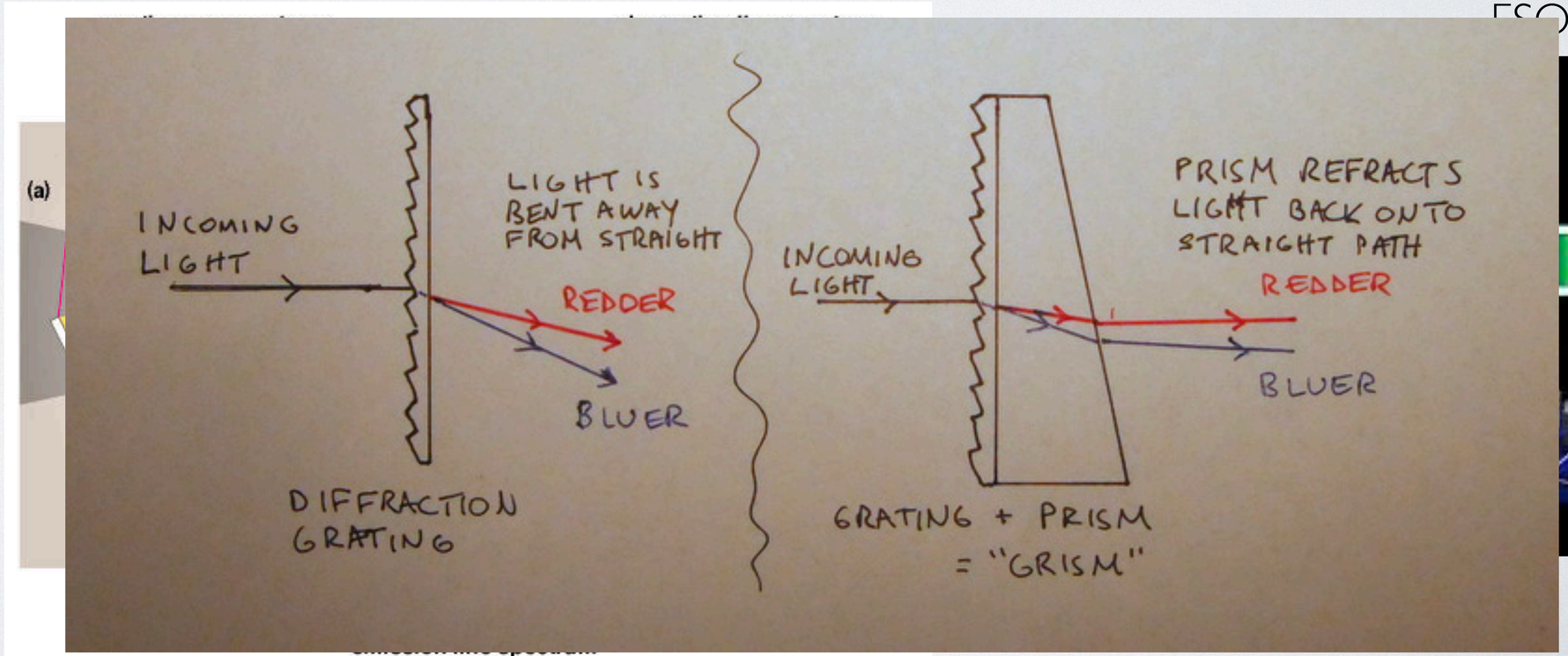
- Structure of an atom
- Emission vs. Absorption
- Grism vs Prism

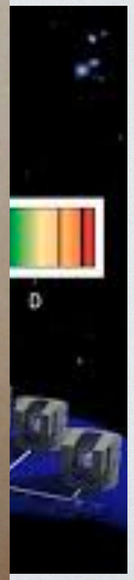






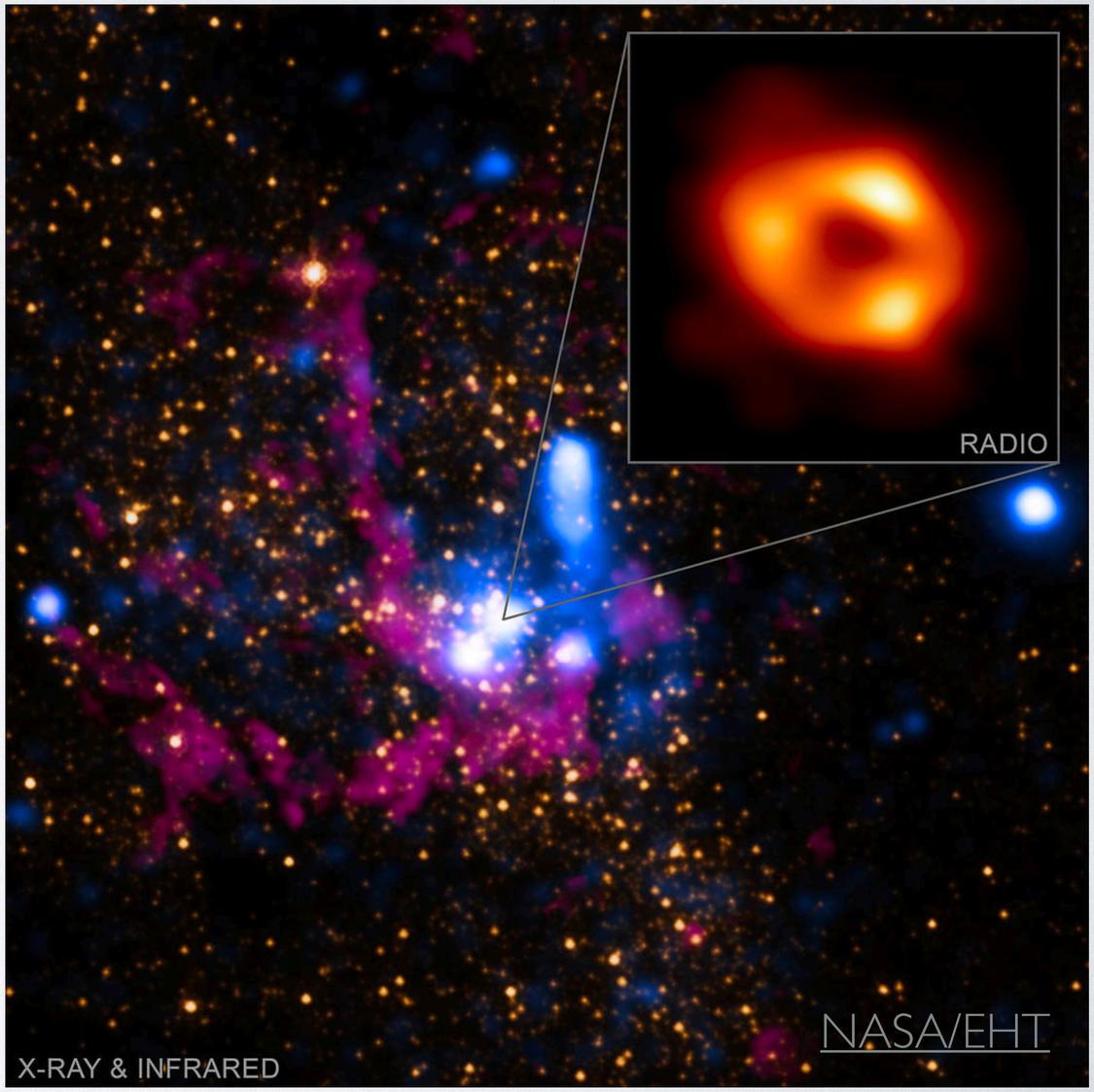
ESO/VLT





EVENT HORIZON TELESCOPE

- Global Network of Radio Telescopes
- Sagittarius A*
- M87



NASA/EHT