Seeing The Universe Through A Gravitational Lens

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What we're going to do in the next hour

- First, we'll introduce a phenomenon called GRAVITATIONAL LENSING and explain what (astro)physicists use it for
- Then, we'll be astrophysicists ourselves and use a (model of a) gravitational lens to figure out properties of black holes (Oooooh!)
- And the best part – you can take this activity back to your classroom and get the students to play with their very own 'black holes' to discover what real scientists do – great activity for inquiry-based learning

Do you notice anything strange in this picture?

Image: NASA/ESA, K Sharon (Tel Aviv University), E. Ofek (Caltech)

These five bright objects are actually one and the same quasar!

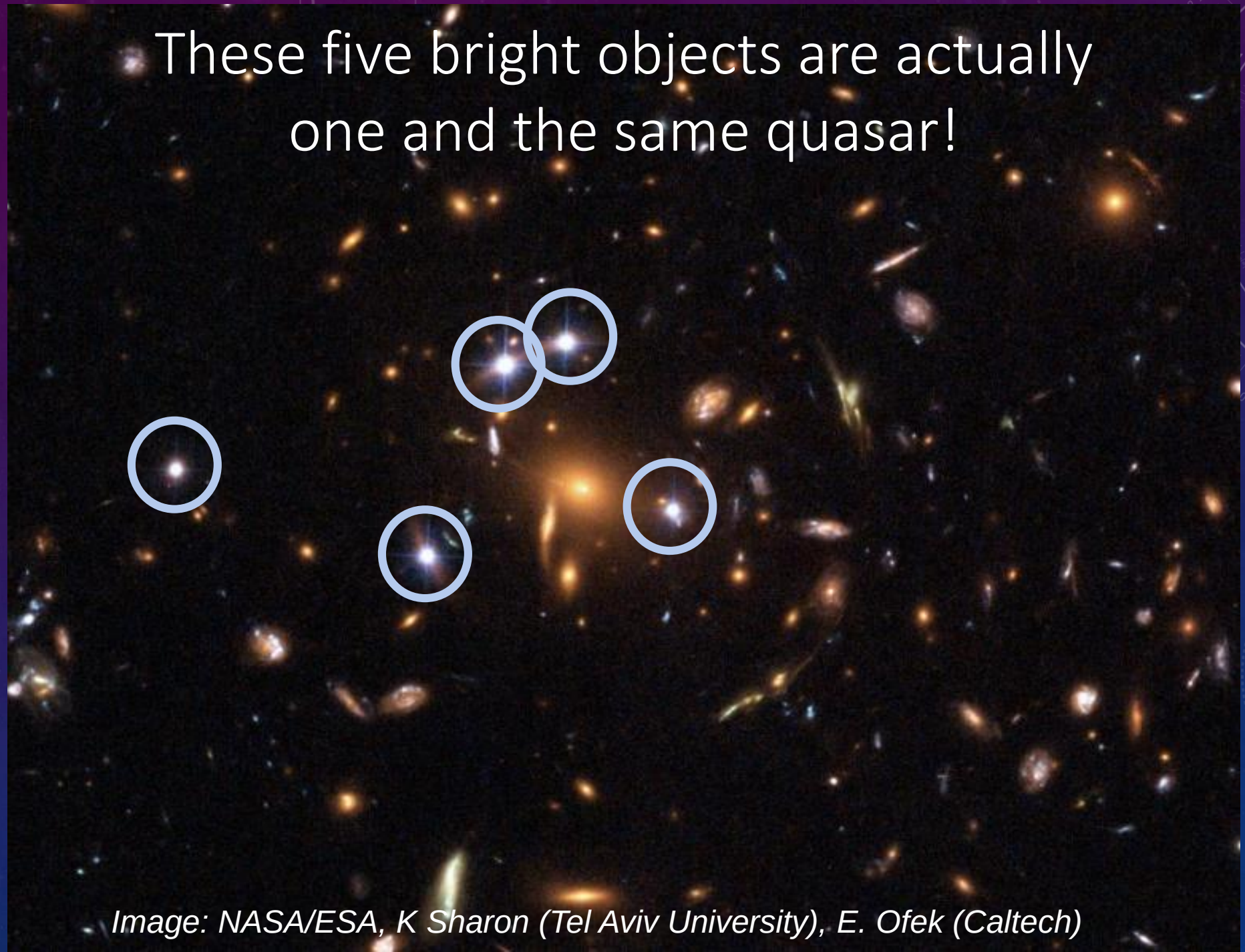
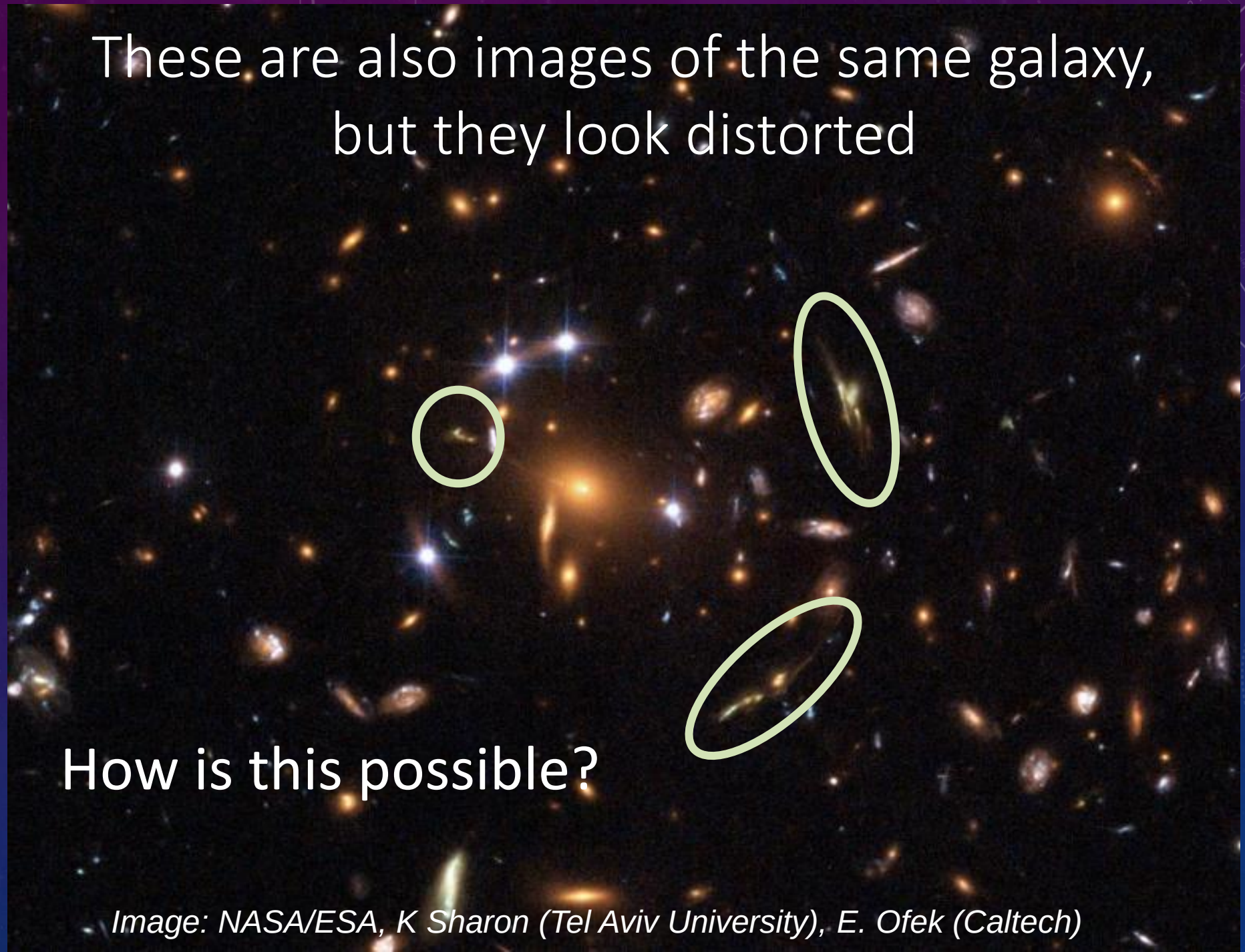


Image: NASA/ESA, K Sharon (Tel Aviv University), E. Ofek (Caltech)

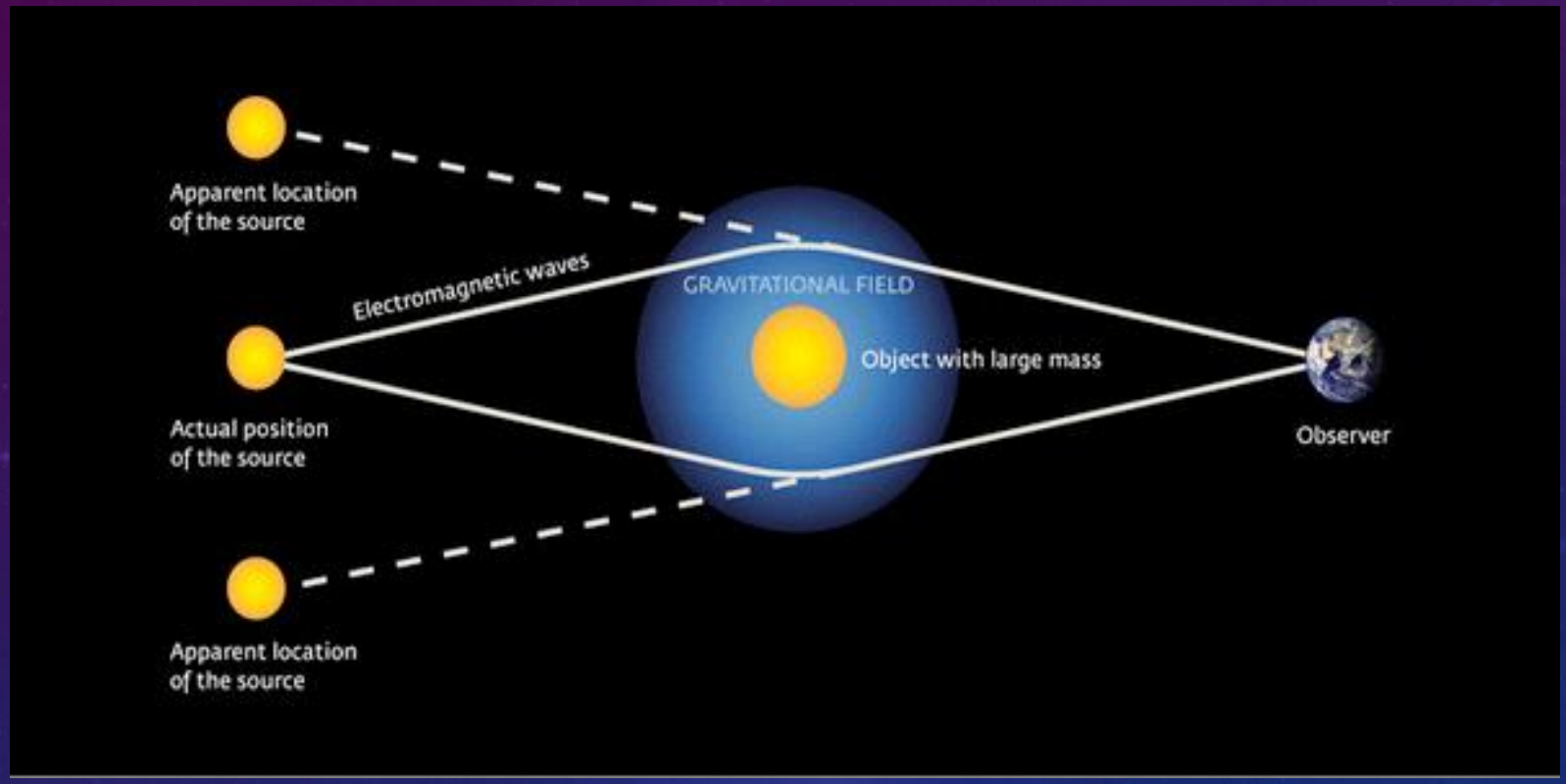
These are also images of the same galaxy, but they look distorted



How is this possible?

Image: NASA/ESA, K Sharon (Tel Aviv University), E. Ofek (Caltech)

Light bends around massive objects!

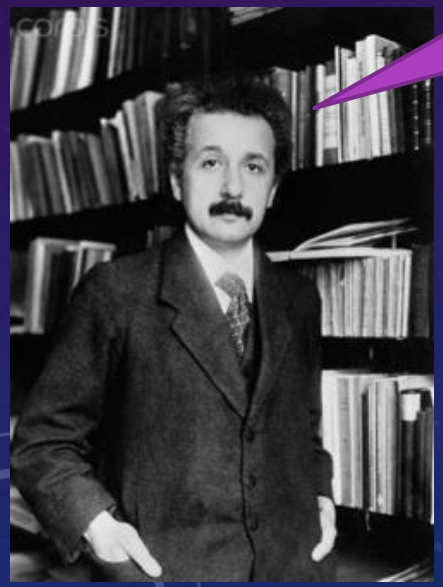


We call this effect **gravitational lensing.**

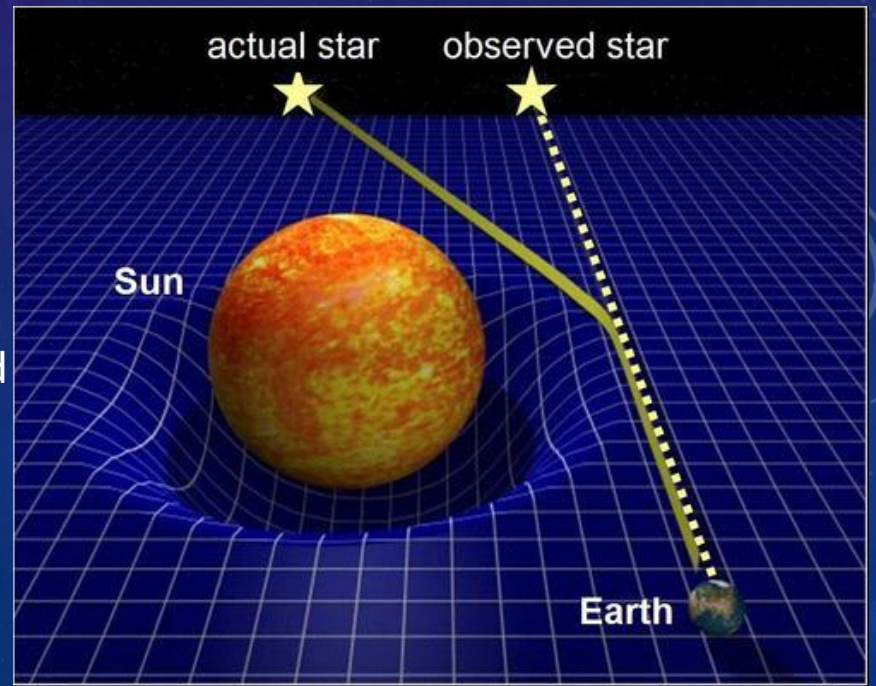
This is weird – according to Newton, light should travel in straight lines in empty space.

To understand why light bends this way, we need to call upon Mr. Einstein to explain his theory of gravity

Gravity is caused by the warping of time and space. Objects distort space, as if sitting on a trampoline. The more massive an object, the more distorted spacetime is around it.

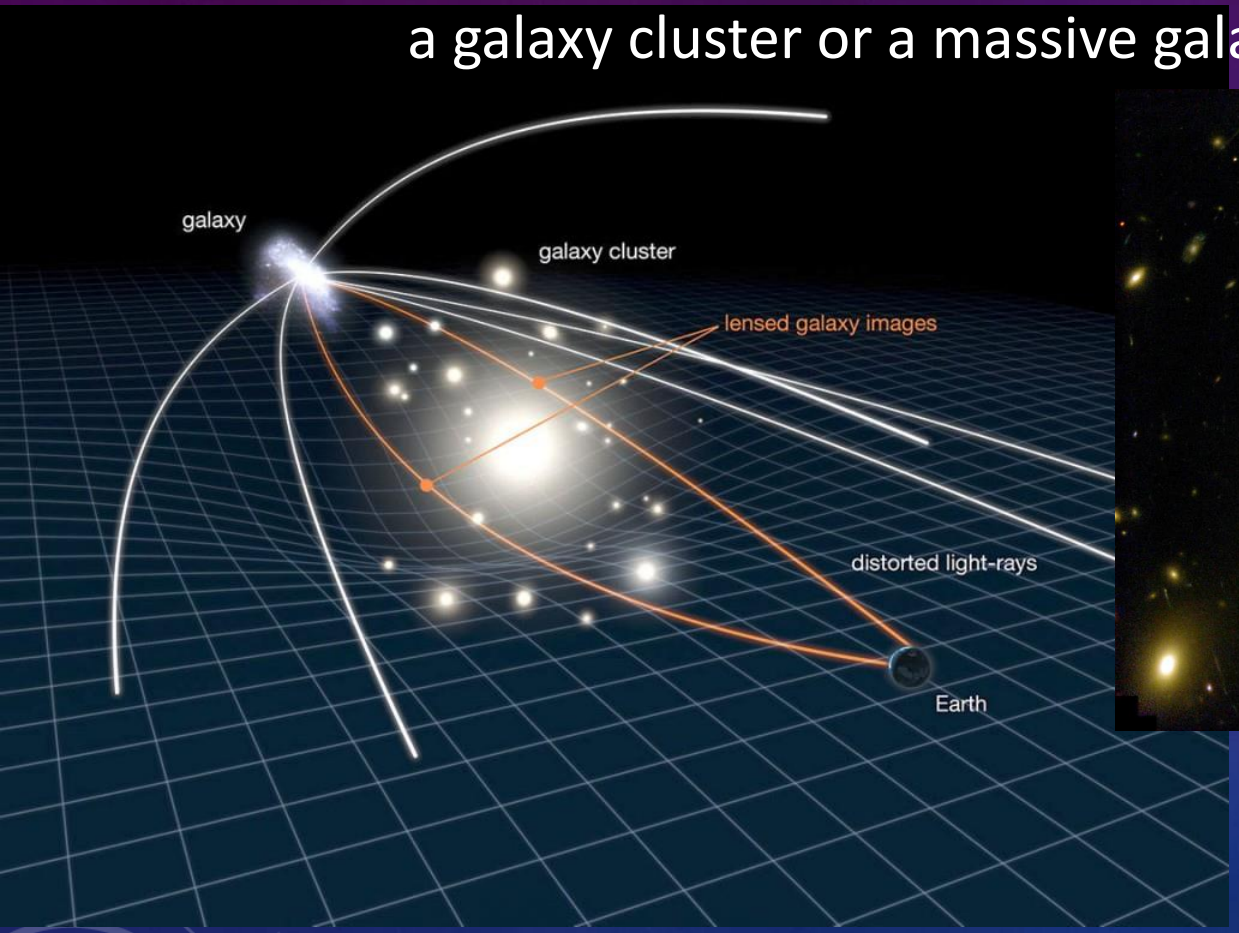


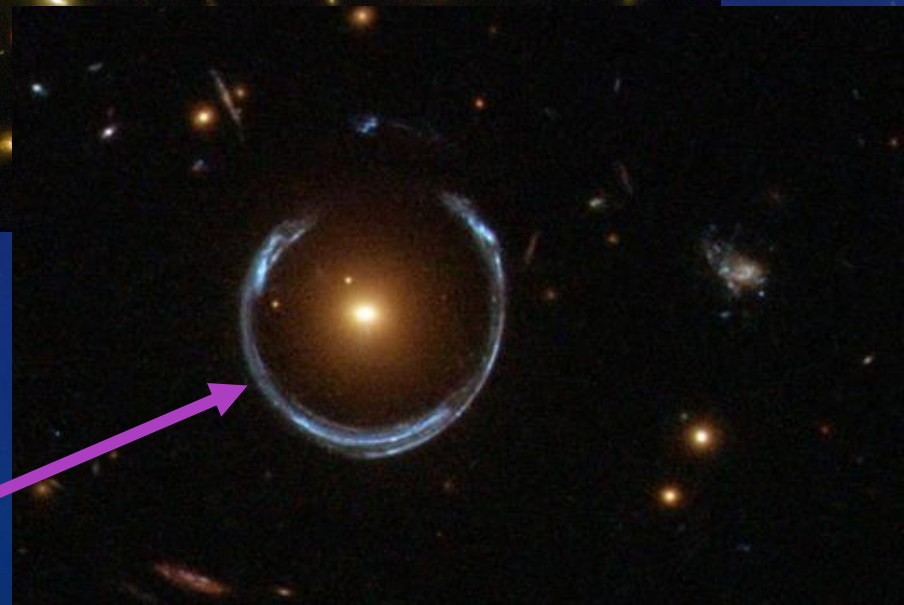
Things not too heavy (like humans) also bend light around them, but the effect is too small to be measurable.



Distortion of Light

Distant galaxies appear distorted when the light from them goes around a galaxy cluster or a massive galaxy on the way to our telescopes

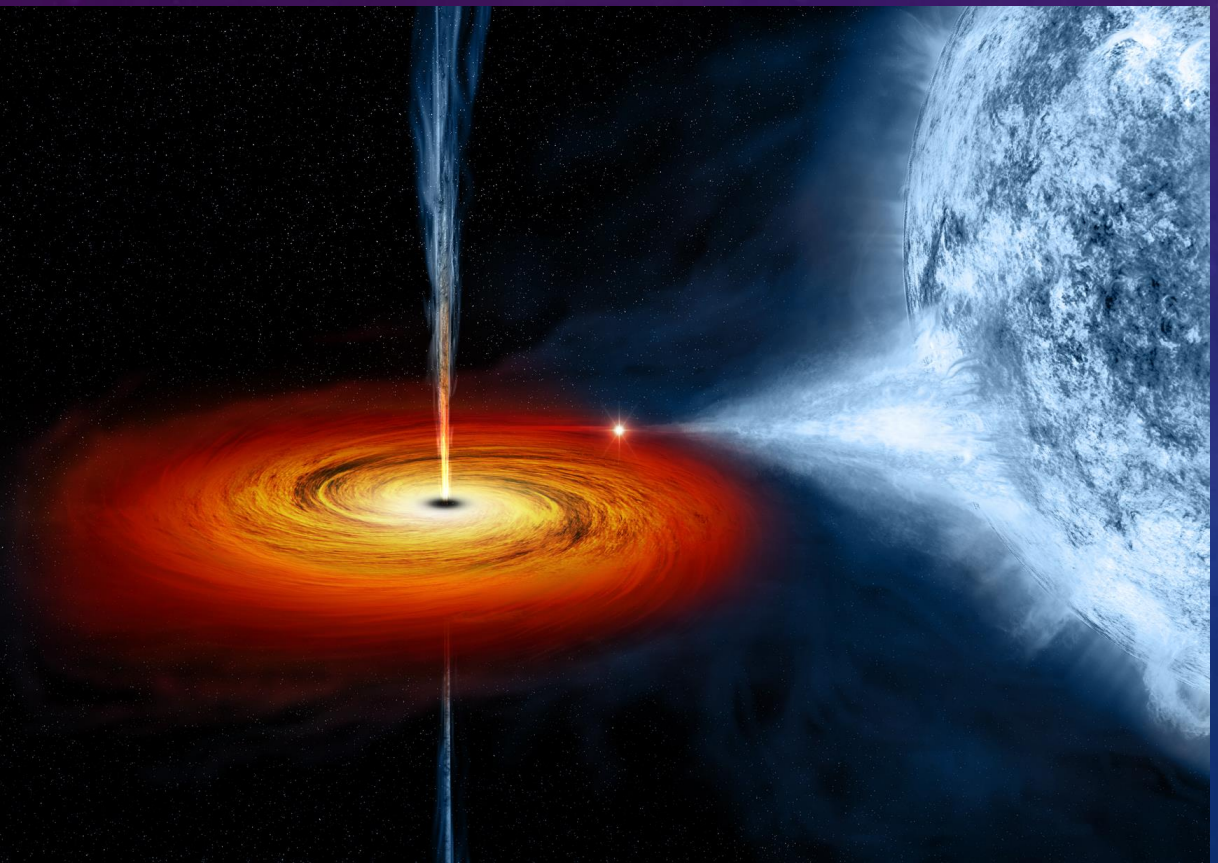




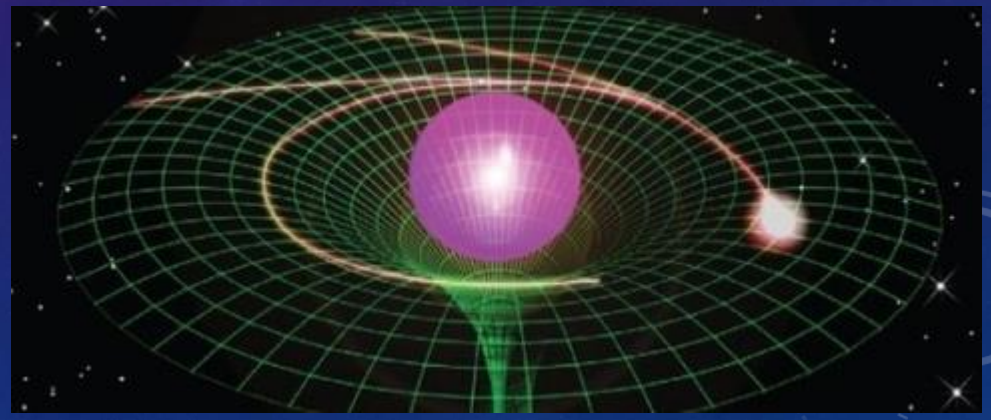
Einstein ring

The most extreme lensing occurs near black holes

Black holes:
a) stellar – when very massive stars collapse
b) supermassive – thought to be in centres of galaxies



Gravity is so strong,
no light can escape!



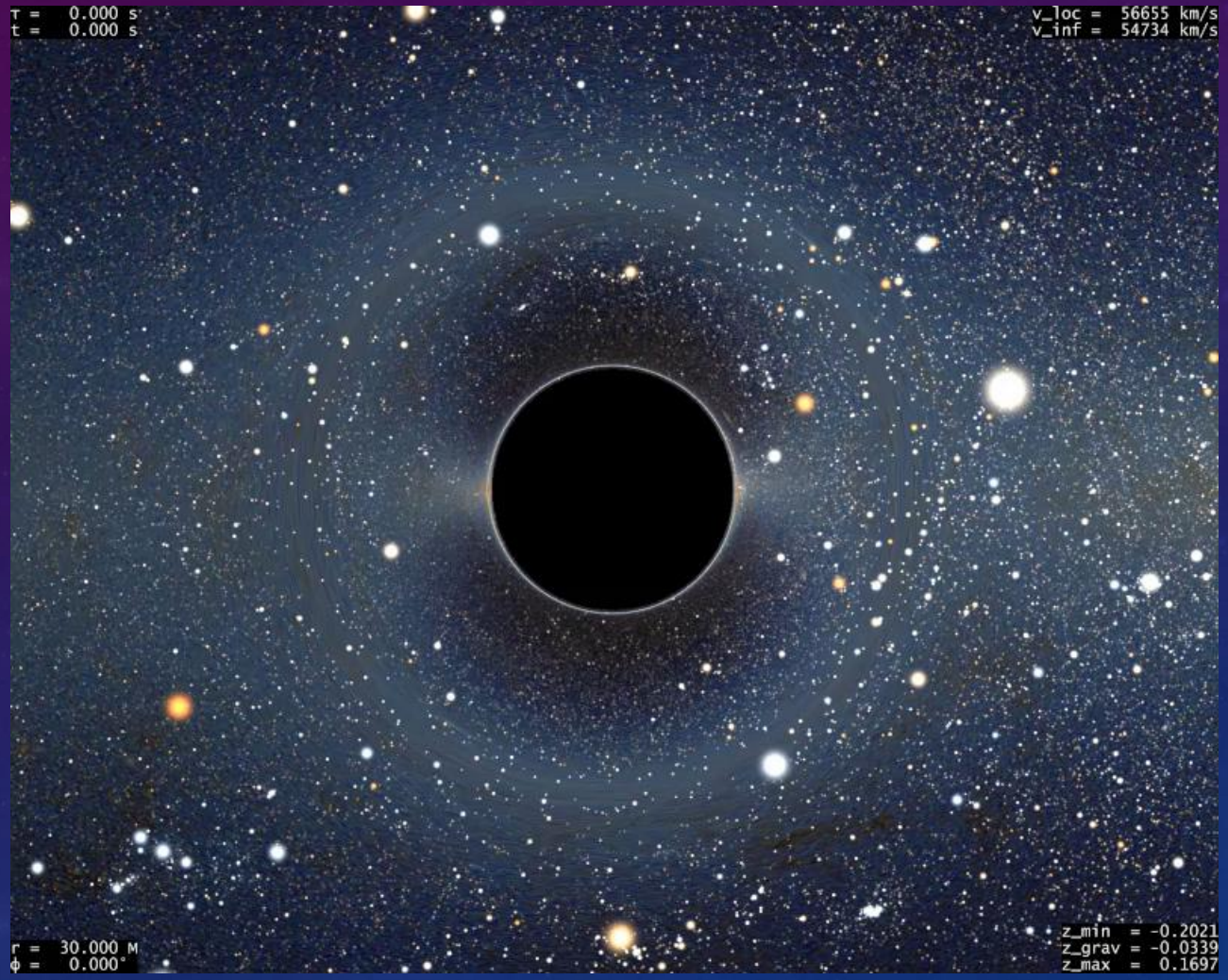
Space around a black hole
is like a trampoline
with a bottomless pit!

Action!

- Your team has been given its own black hole lens, a laser pointer, an image of objects in space and some supplementary info/equation sheet

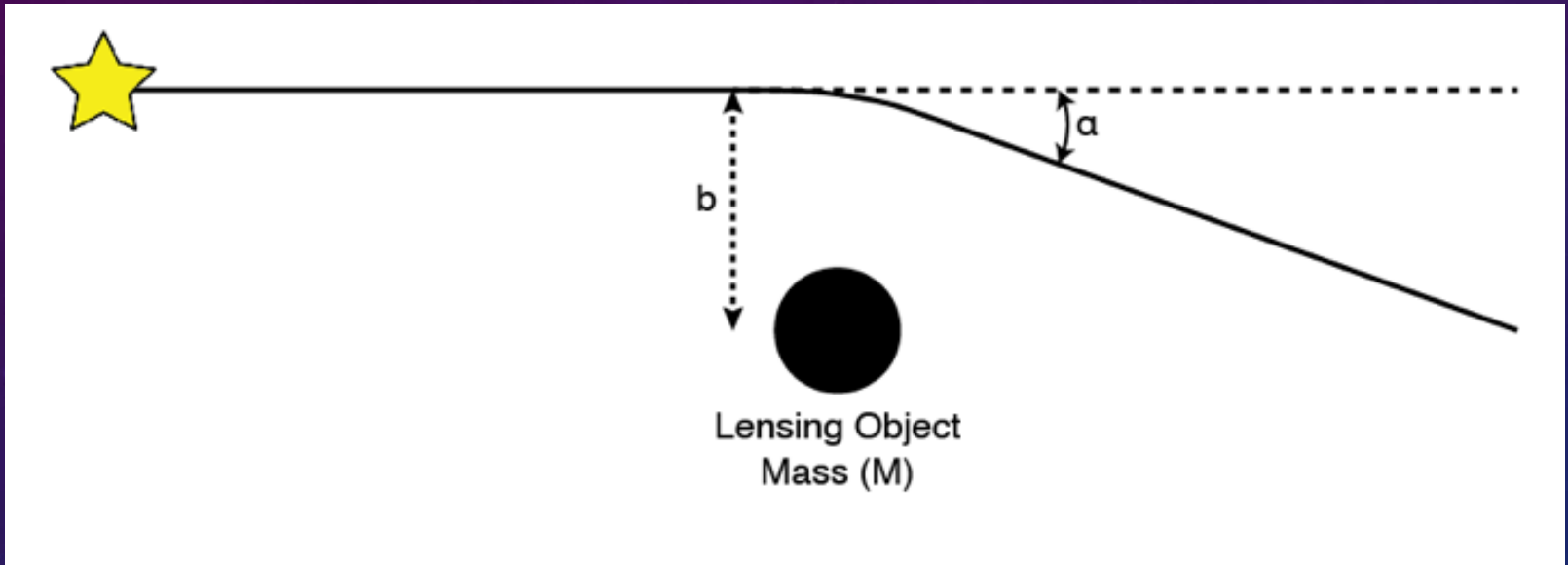
- Work through Section A: How Warped? on your handout to explore the ways that black holes warp light (5 mins)

What would it look like if a black hole moved across the night sky?



Alain Riazuelo (Institut d'Astrophysique de Paris)

By how much does the light bend?



Based on Einstein's theory,
a light ray that passes within
a distance b
of an object of mass M
will be deflected by an angle α

$$\alpha = \frac{4GM}{bc^2}$$

Let's use gravitational lensing to determine the mass of a black hole

- Now that you are familiar with how your black hole distorts images of more distant objects, here is your next mission:

- Work through Section B: How Massive? on your handout to find the mass of your black hole (20 mins)

- Then as a group, consider questions in Section C: How'd You Do It?

What did we learn?

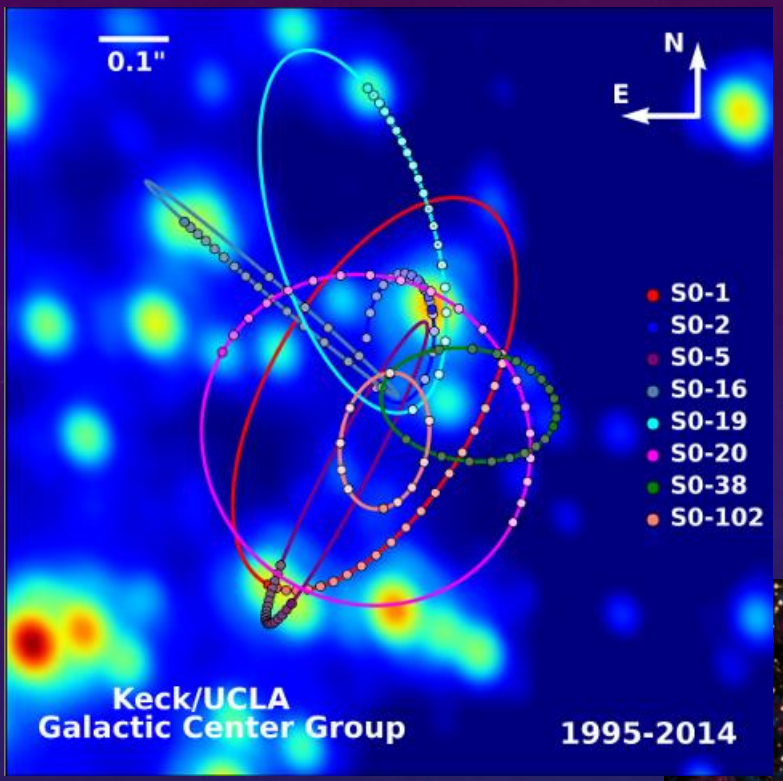
- Massive objects warp space around them causing light to bend and the images to look distorted
- We can use gravitational lensing to find the unknown mass of objects in space
- Black holes cause the most extreme bending of light because they are very massive, but also very small (check your equation – large M, small *b*

If you want to do it at home…

- First, sip some nice wine…

- Then, cut the foot of the glass off!
- The rest of the supplies are from your local $ store.

Current Research



- Gravitational lensing is commonly used to:
  - Measure the mass of large galaxies
  - Measure the mass of galaxy clusters
  - Discover unknown extrasolar planets

- Black hole in the centre of our Galaxy has been found by observing the stars rotating around the centre

- Scientists have been trying to find black holes via gravitational lensing, but have been unsuccessful so far
  - Maybe some of your students will detect them?

Credits: NASA/UMass/D.Wang et al., IR: NASA/STScI

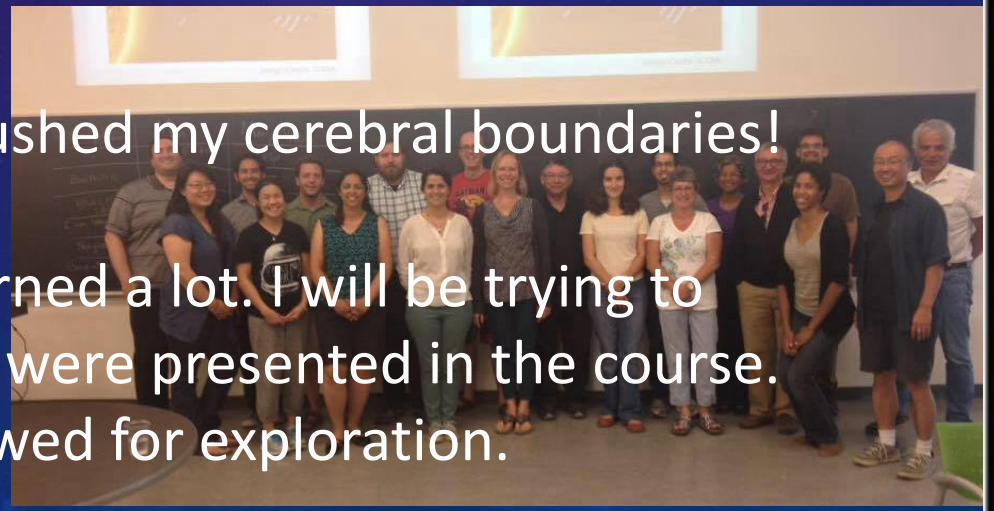
Want More Astronomy?
Come to Teachers Workshop at YorkU this July

3-day workshop – get a Certificate from YorkU Faculty of Ed (Toronto)

- Created and led by astronomers at UofT and YorkU
- Activities: black hole lensing, exoplanets, cosmology, gravitational waves…
- Happening the week of 11th – 15th July 2016 (exact dates TBD)
- Sign up here if you want to get more info when it becomes available

Participant quotes:

- It messed with my brain! It pushed my cerebral boundaries! And it also made sense.
- It was a great course and I learned a lot. I will be trying to use most of the activities that were presented in the course.
- Completely open ended - allowed for exploration.



From 2015 workshop