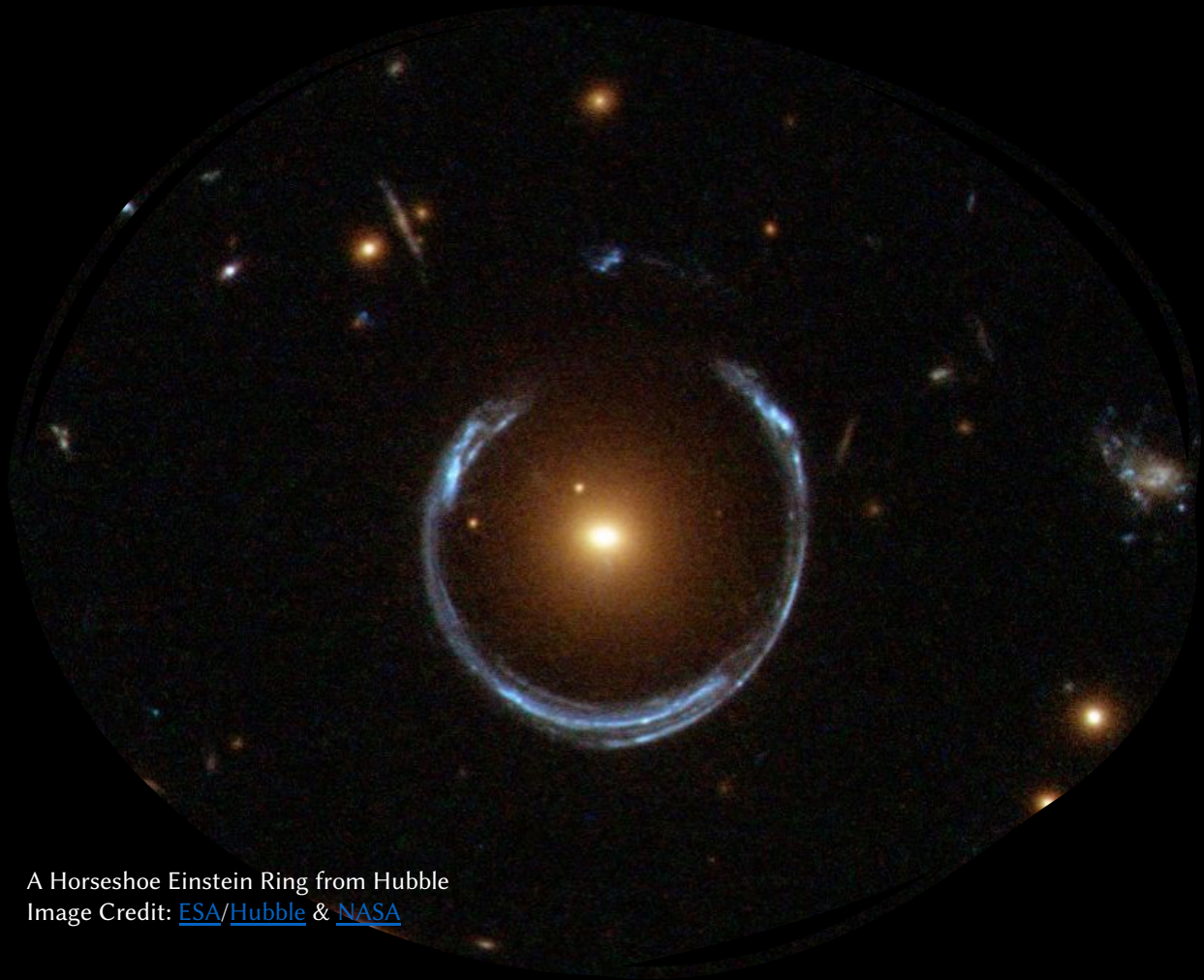# What Can Gravitational Lenses Teach Us About Nature?

Andi Gu

A Horseshoe Einstein Ring from Hubble
Image Credit: ESA/Hubble & NASA

A Little About Me

- My interests coming out of high school:
  - Applied math
  - Theoretical physics
  - CS
  - ML/AI
  - Statistics
  - ...
- Physics/CS major at Cal – just graduated 🎉
- Next step: graduate degree in physics

Toronto

Research at Berkeley

- Joined the Supernova Cosmology Project at the beginning of sophomore year – they do it all!
  - Theoretical physics
  - CS + ML/AI

computer science

applied mathematics

SCP

theoretical science
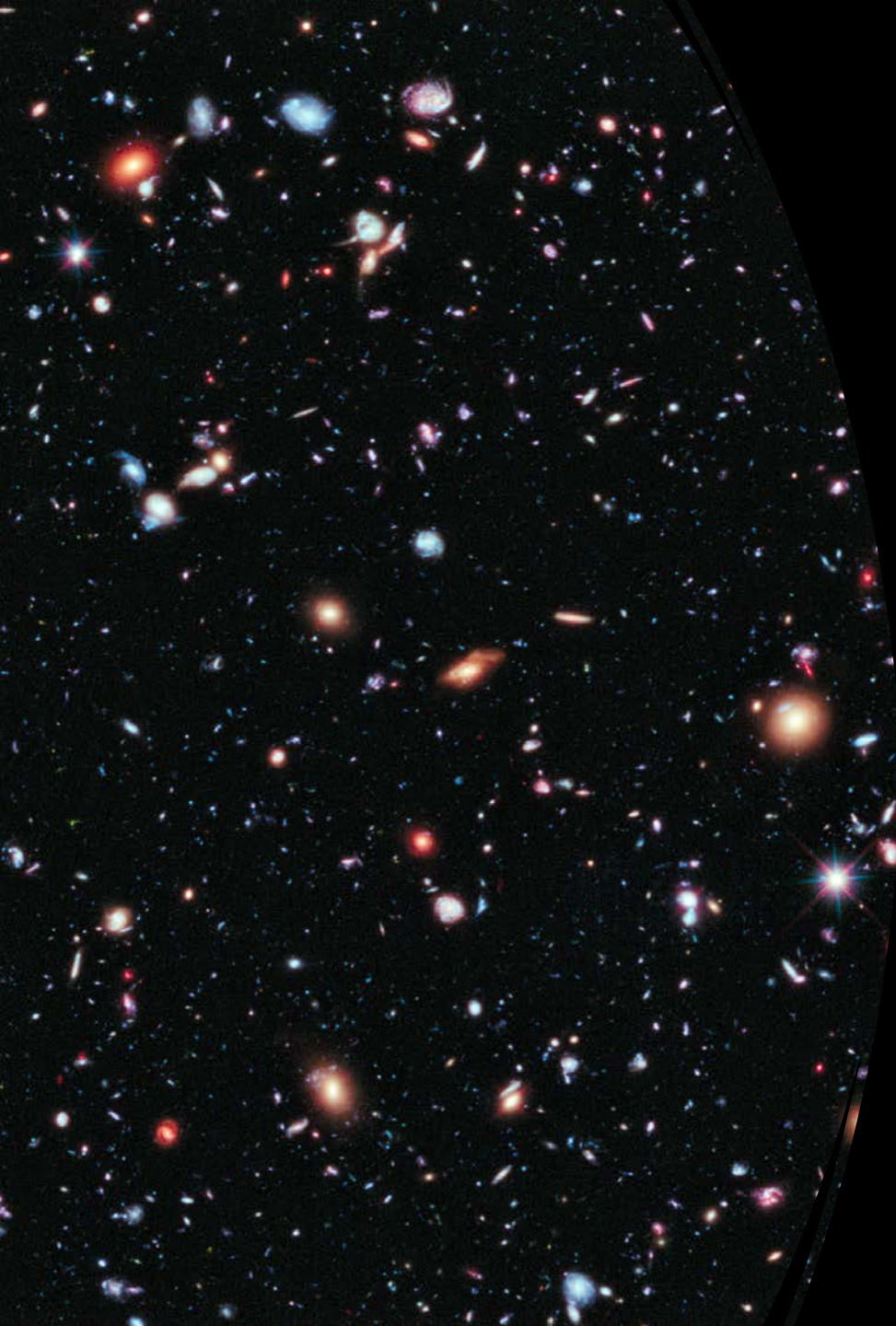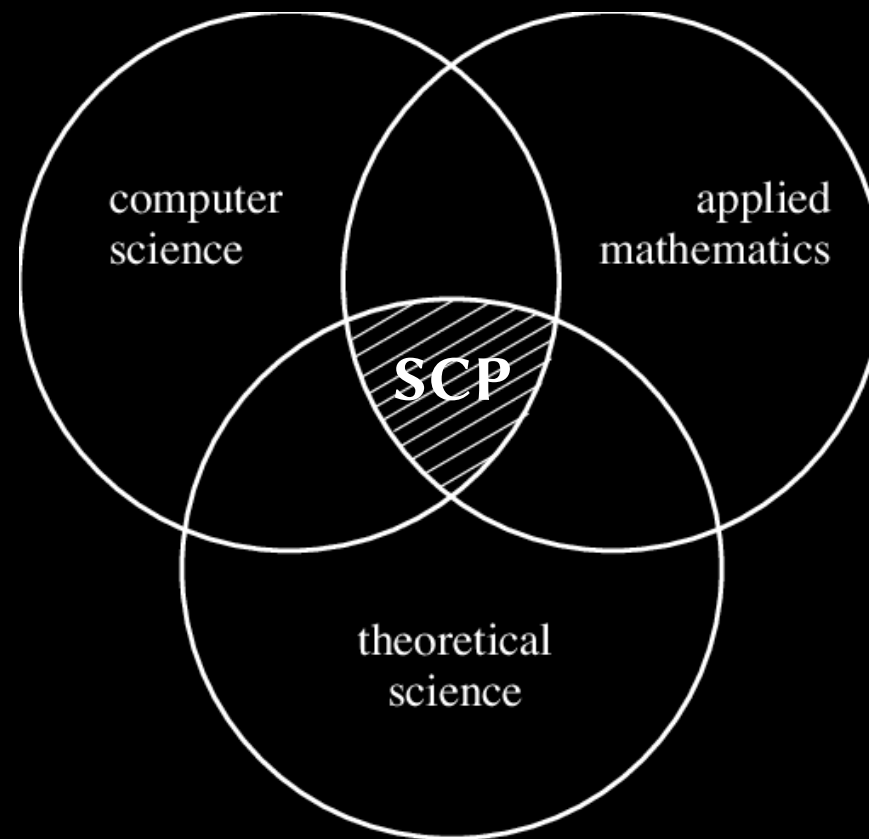
Supernovae

- Supernova: powerful explosion of a massive star/white dwarf

- Played a key role in Prof. Perlmutter's 2011 Nobel Prize-winning research

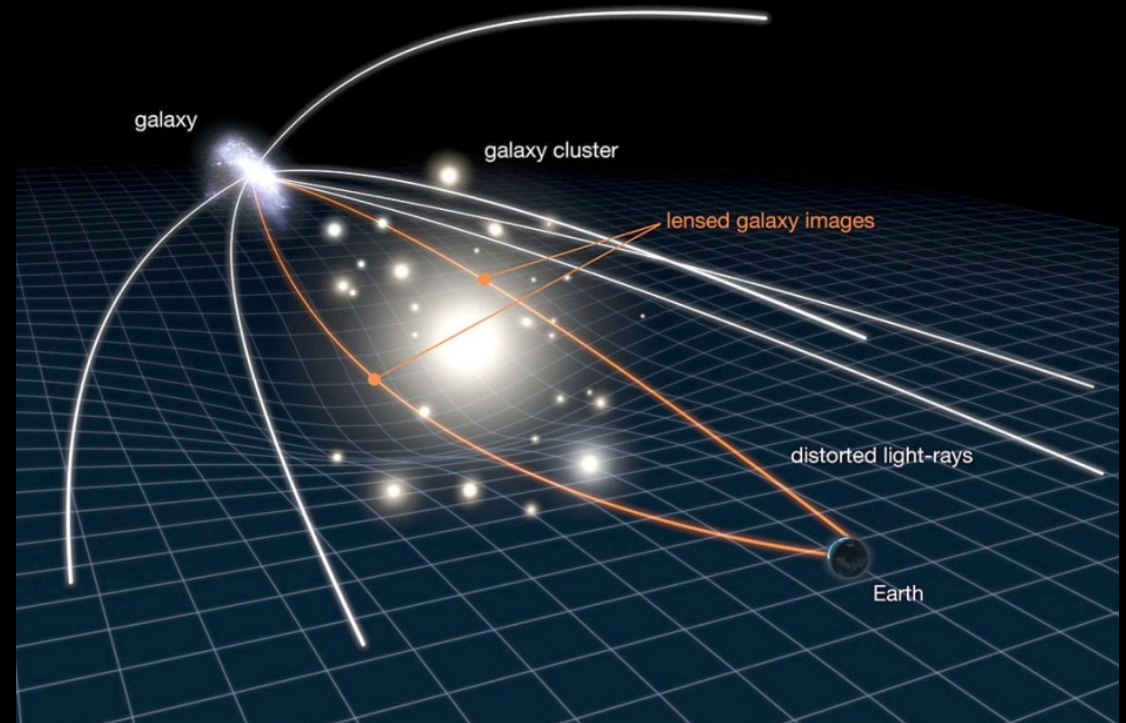# **Cosmology**: studying the universe on the *largest* scales

1. How fast is the universe expanding? (H_0)

2. What is the nature of dark matter?

3. What is the distribution of matter in the universe?
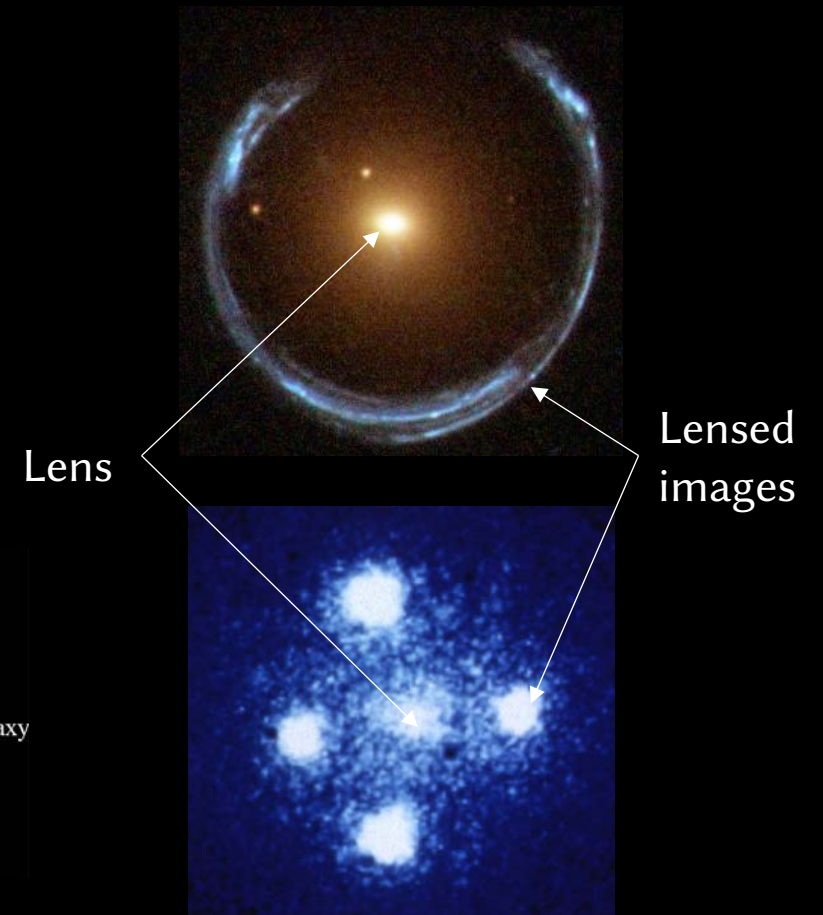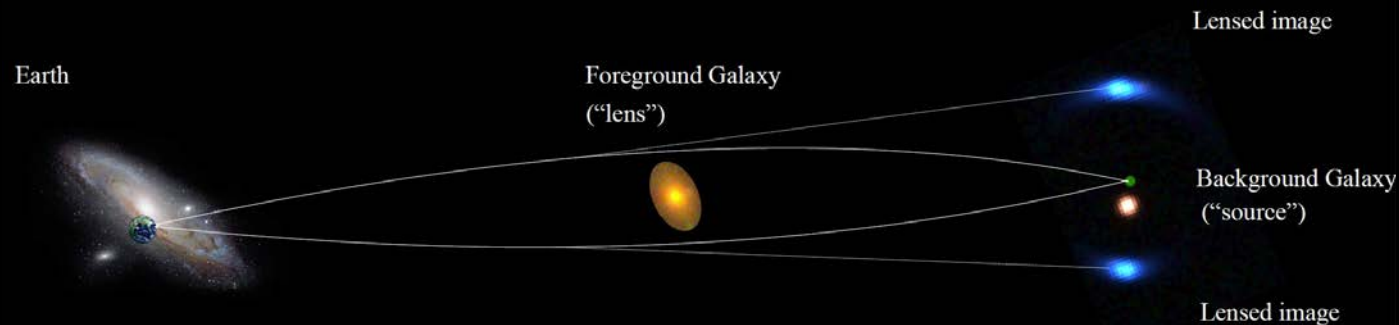
4. … and many more

Does Light Bend?

- Einstein proposes general relativity in 1915
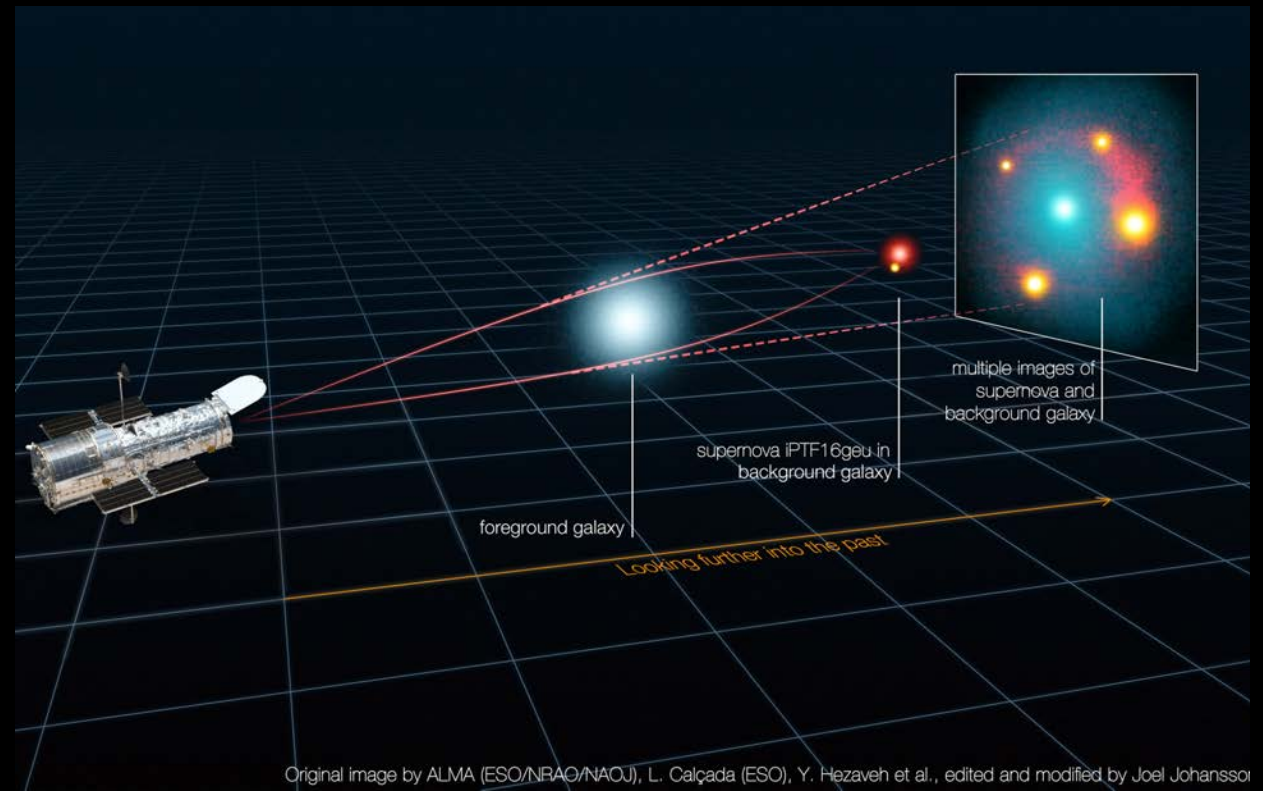   - Light is affected by gravity, too!

Strong Gravitational Lensing

- Warping of space-time by the mass of the foreground galaxy

- Large arcs & multiple images

- Chance alignment (1 in 10000)

Lens

Lensed images

Earth

Foreground Galaxy ("lens")

Lensed image

Background Galaxy ("source")

Lensed image

Applications of Lenses

- Probe for dark matter/energy
- Infer mass distribution of lensing galaxy
- Sensitive measurement of H_0

multiple images of supernova and background galaxy

supernova iPTF16geu in background galaxy

foreground galaxy

Looking further into the past

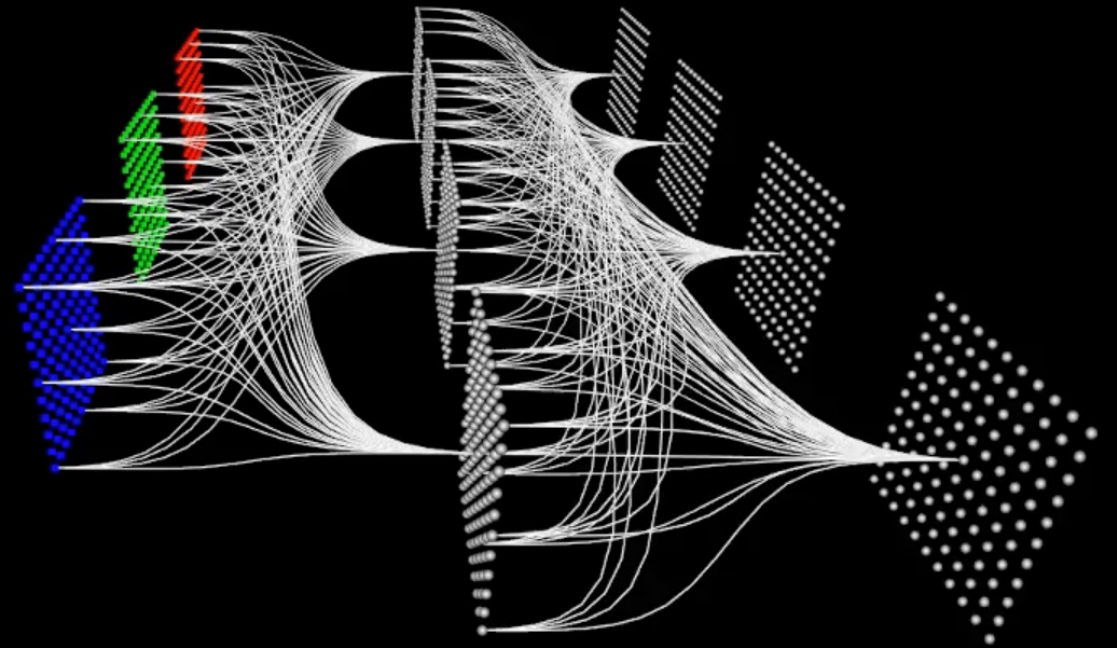Original image by ALMA (ESO/NRAO/NAOJ), L. Calçada (ESO), Y. Hezaveh et al., edited and modified by Joel Johansson
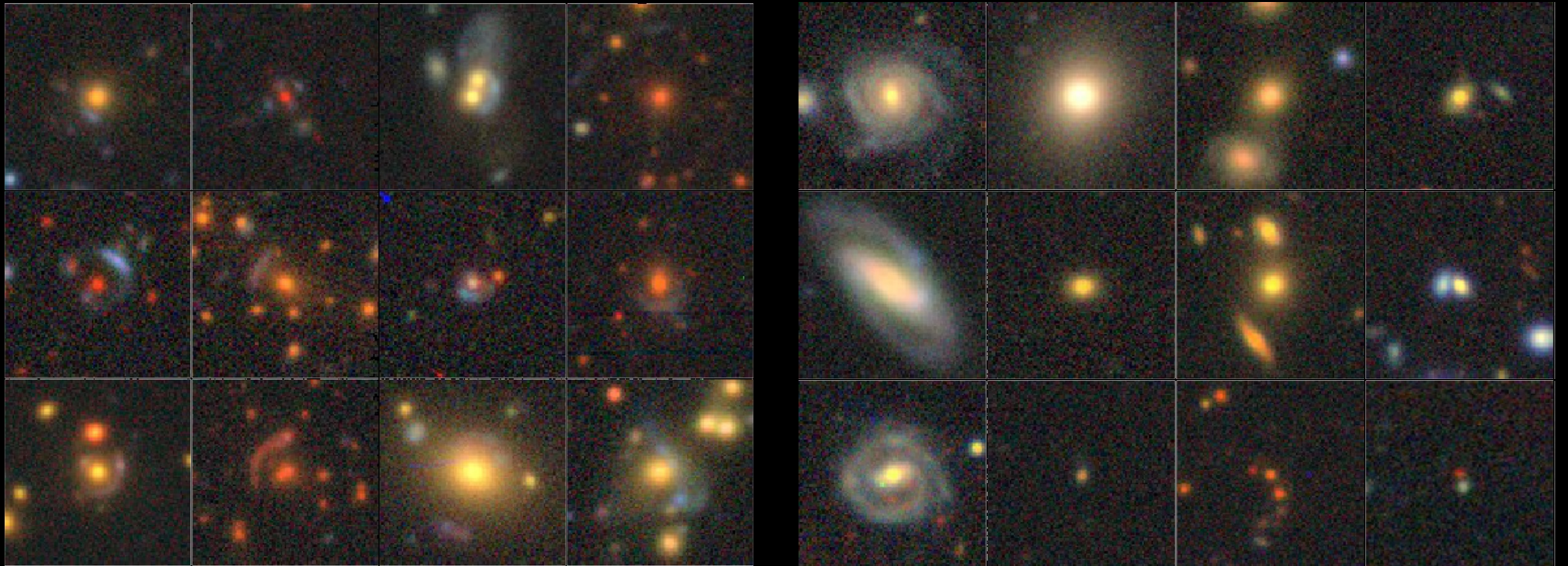
Step 1: Finding Lenses

- Problem: lenses are a ~1/10000 occurrence

- Solution: use artificial intelligence (convolutional neural networks)

Lenses and Non-lenses
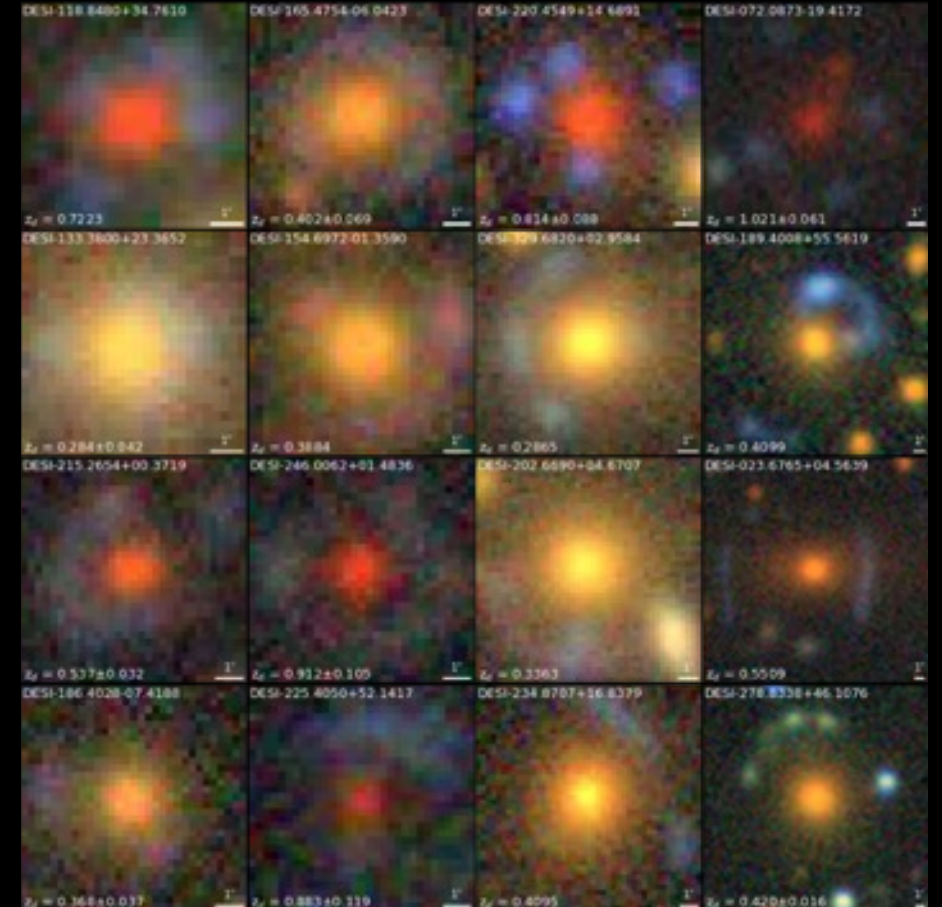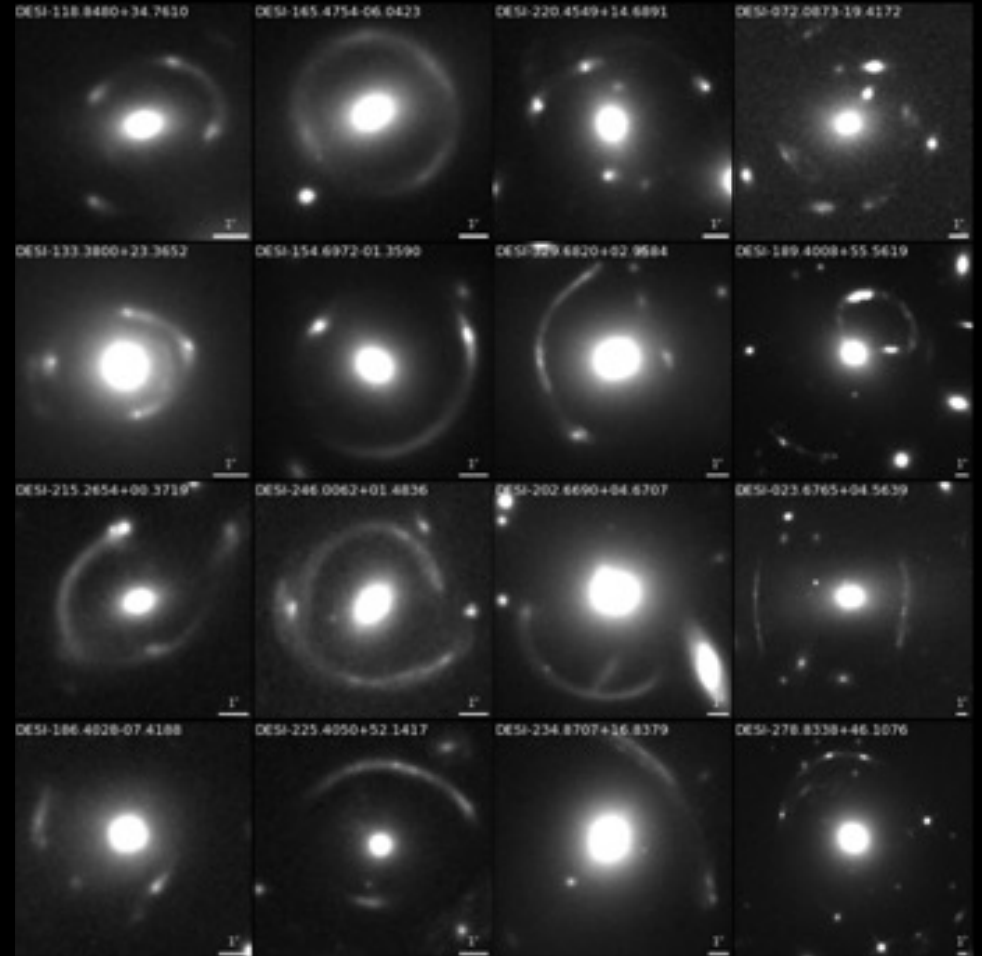
Step 1: Finding Lenses

- Our success rate: 1/30 recommendations is a lens
- Discovered over 3000 new lenses
- Open questions: can we get the AI to **explain** why it makes its recommendations?

Step 2: Modelling Lenses

1. Acquire high quality images of lenses

2. Infer properties about the lensing system ('modelling')
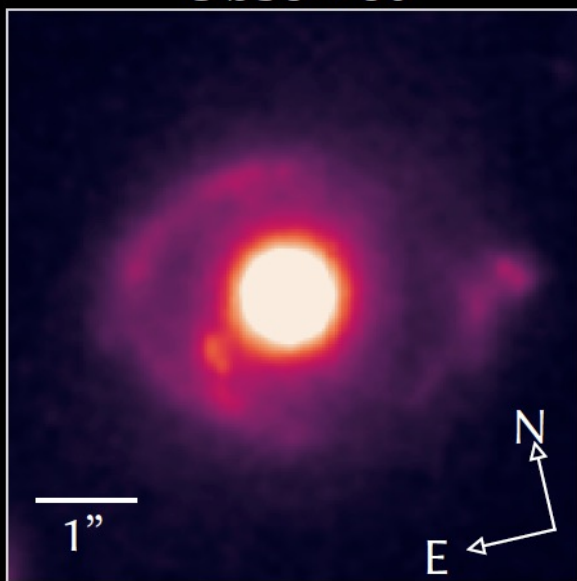
3. Apply inferences to scientific questions
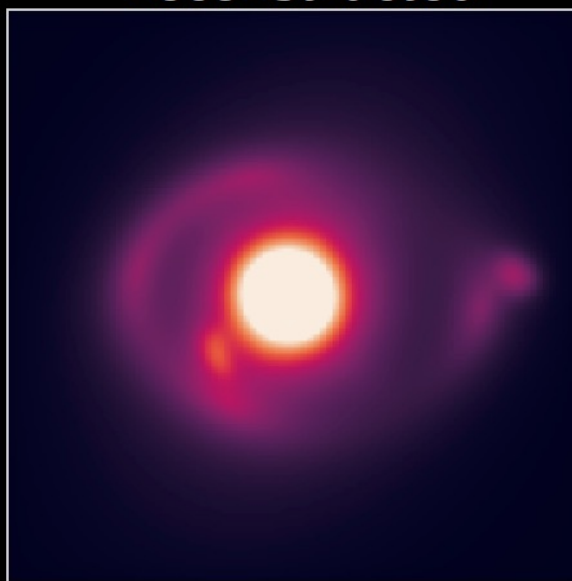
How to Model a Lens

Adjust

1. Parameterize the system
2. Guess parameters
3. Calculate the consequences of the guess (**simulate**)
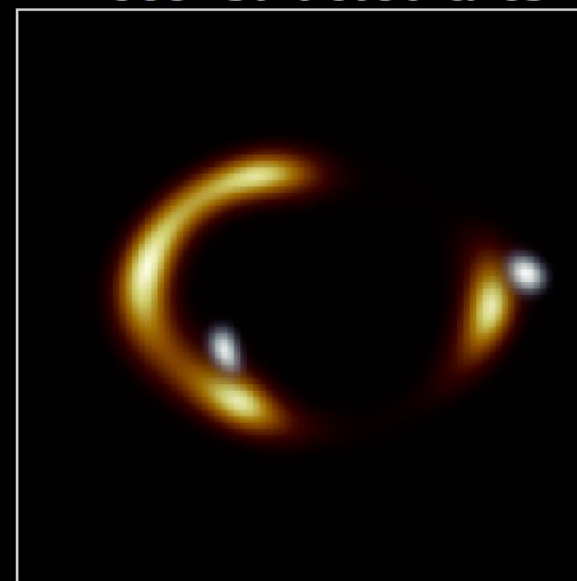4. Compare simulation with observation

Observed | Reconstructed | Reconstructed arcs

Conclusion

- Only advice: explore broadly

- If you do explore… cosmology is a great option!
  - Ask hefty and interesting physics questions
  - Apply cutting edge techniques from other fields
  - Work closely with data