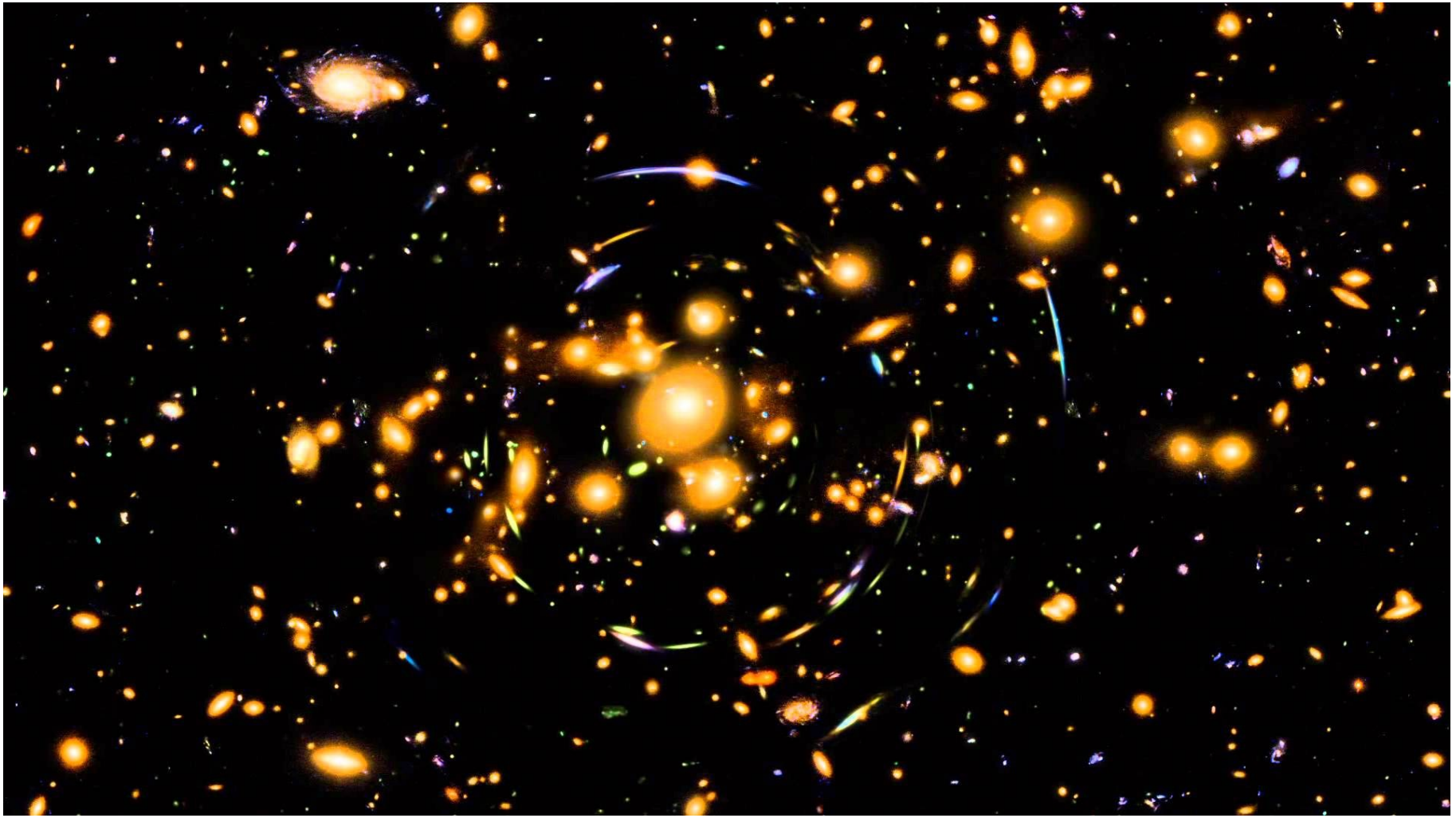
Viewing the Universe in Light of Gravitational Lensing

James Nightingale



Overview

- **What is gravitational lensing?**
  - The bending of light due to gravity.
- **Why do we care?**
  - It allows us to study essential **everything** in the Universe.

Overview

Microlensing:

- Weigh stars.

- Find Earth-like planets.

- Detect Dark Matter.

Overview

Strong Lensing:

- Dissect the contents galaxies.

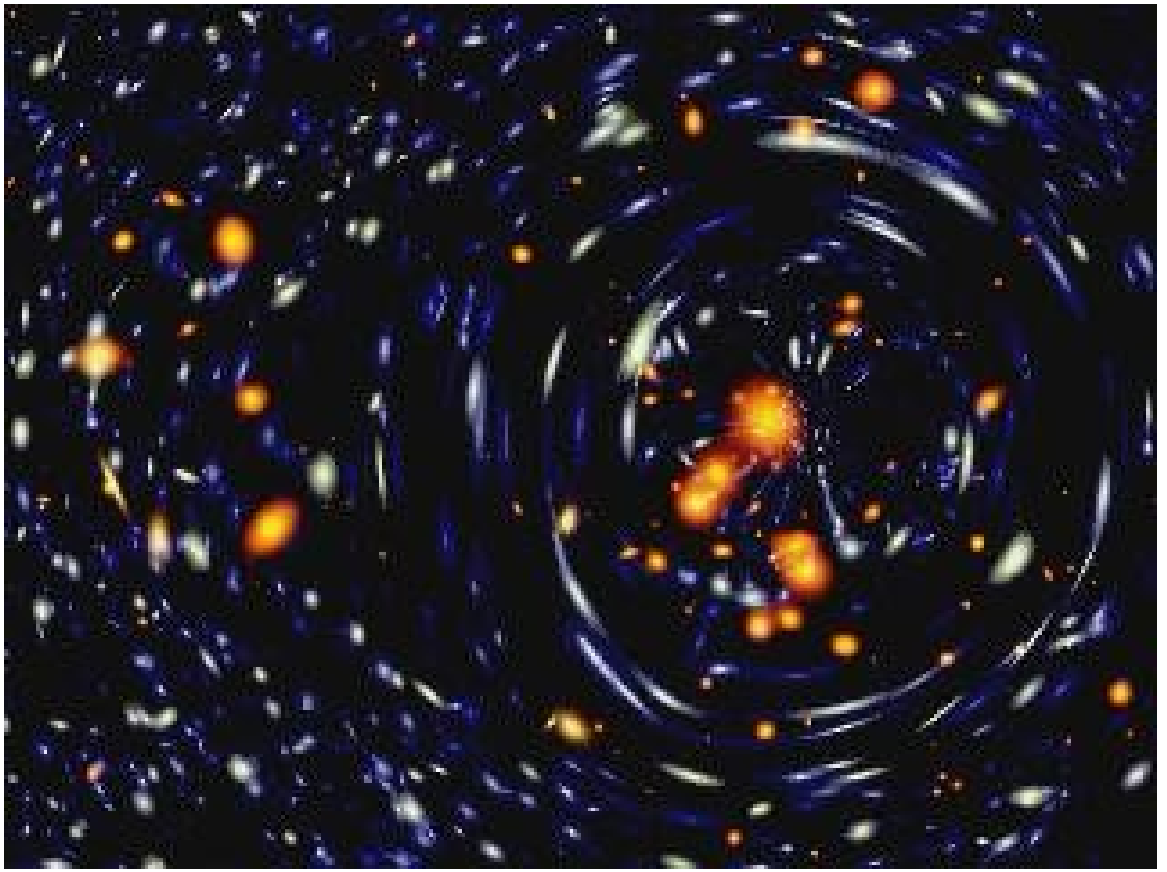
- See the furthest epochs of the Universe.

Overview

- **Weak lensing:**

  - Measure the expansion of the Universe.

  - Weigh *billions* of galaxies.



What is Gravitational Lensing?

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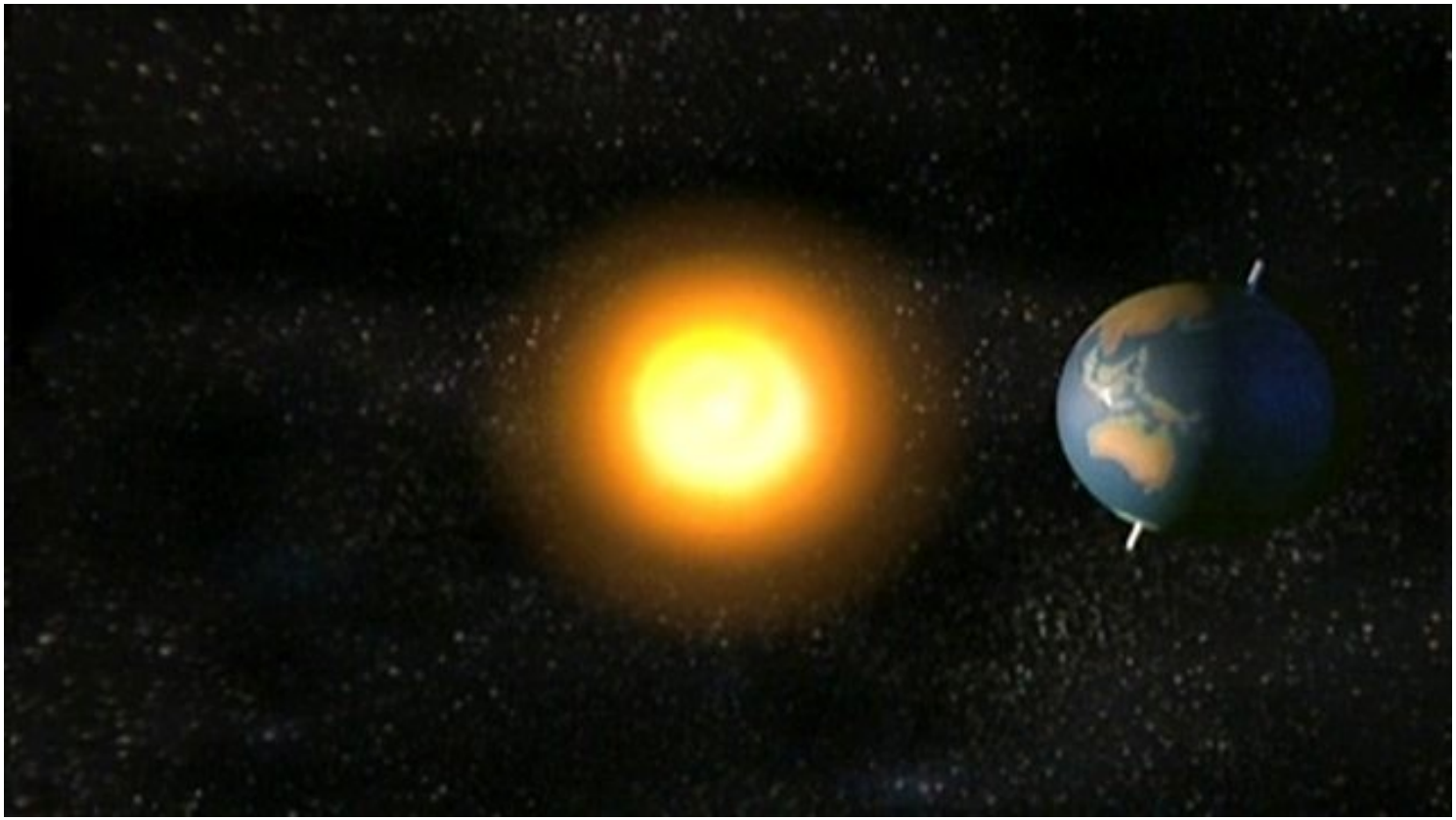
  THIS IS WRONG!

An Analogy…

- **Is it analogous to the Sun – Earth orbit?**
  - The Sun's Mass, therefore gravity, pulls the Earth toward it.



An Analogy…

- **Is the analogous to the Sun – Earth orbit?**
  - The Sun's Mass, therefore gravity, pulls the Earth toward it.

$M_{earth} = 6 \times 10^{24}$ Kg

$M_{sun} = 2 \times 10^{30}$ Kg

$r = 1.5 \times 10^{8}$ m

$G = 6.67 \times 10^{-11}$ N $(kg/m)^2$

$$F_g = G\frac{m_1 m_2}{r^2}$$

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$F_g = 3.5 \times 10^{22}$ N

$$F_g = G\frac{m_1 m_2}{r^2}$$

An Incorrect Analogy

- **Is the analogous to the Sun – Earth orbit?**
  - The Sun's Mass, therefore gravity, pulls the Earth toward it.
- **But... Light has no mass?**

$M_{light} = 0$ Kg ?

$M_{sun} = 2 \times 10^{30}$ Kg

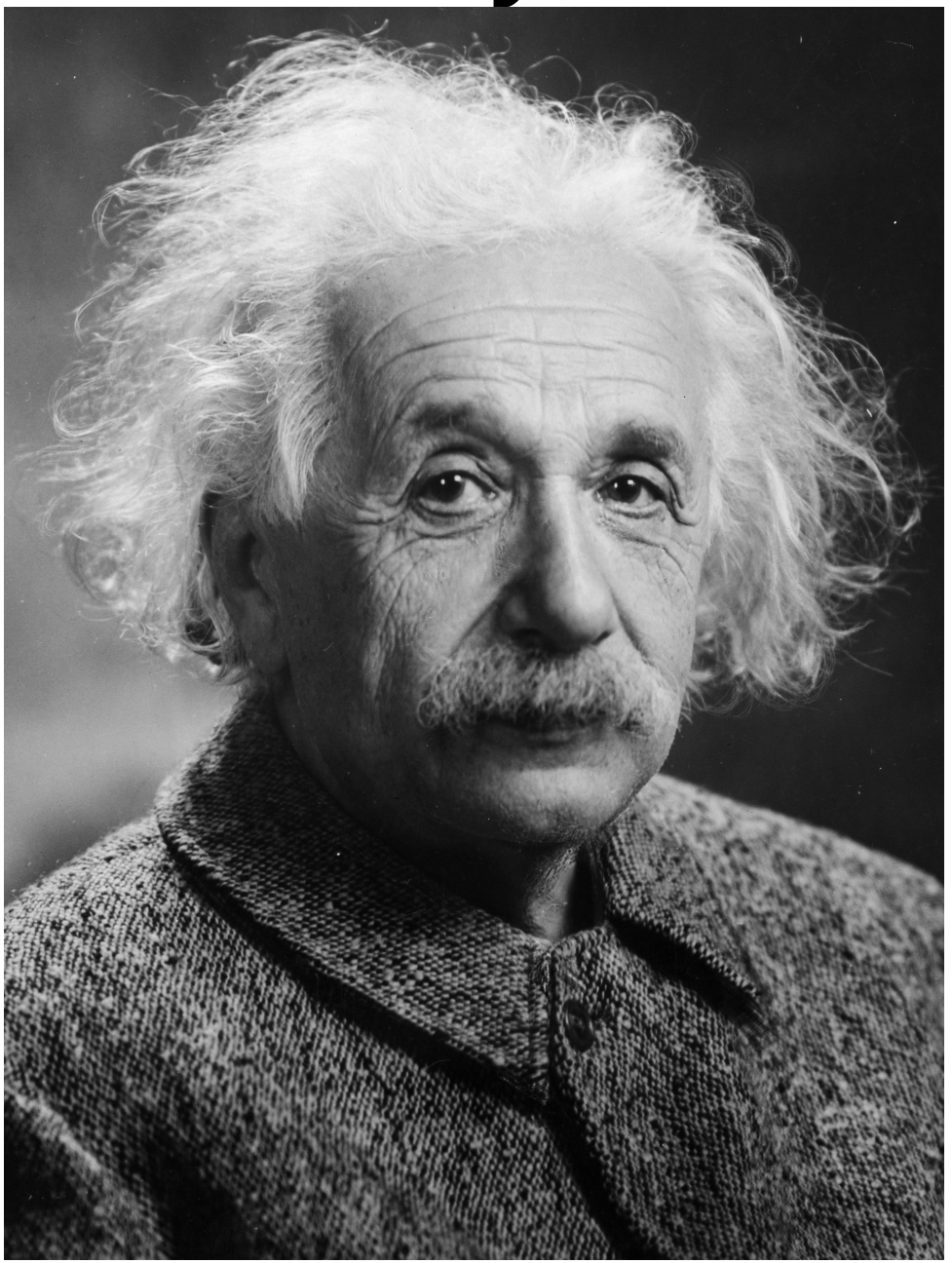
$G = 6.67 \times 10^{-11}$ N $(kg/m)^2$

$F_g = 0$ N

$$F_g = G\frac{m_1 m_2}{r^2}$$

General Relativity

- **Unified space and time into one geometry – 'space time'.**



General Relativity

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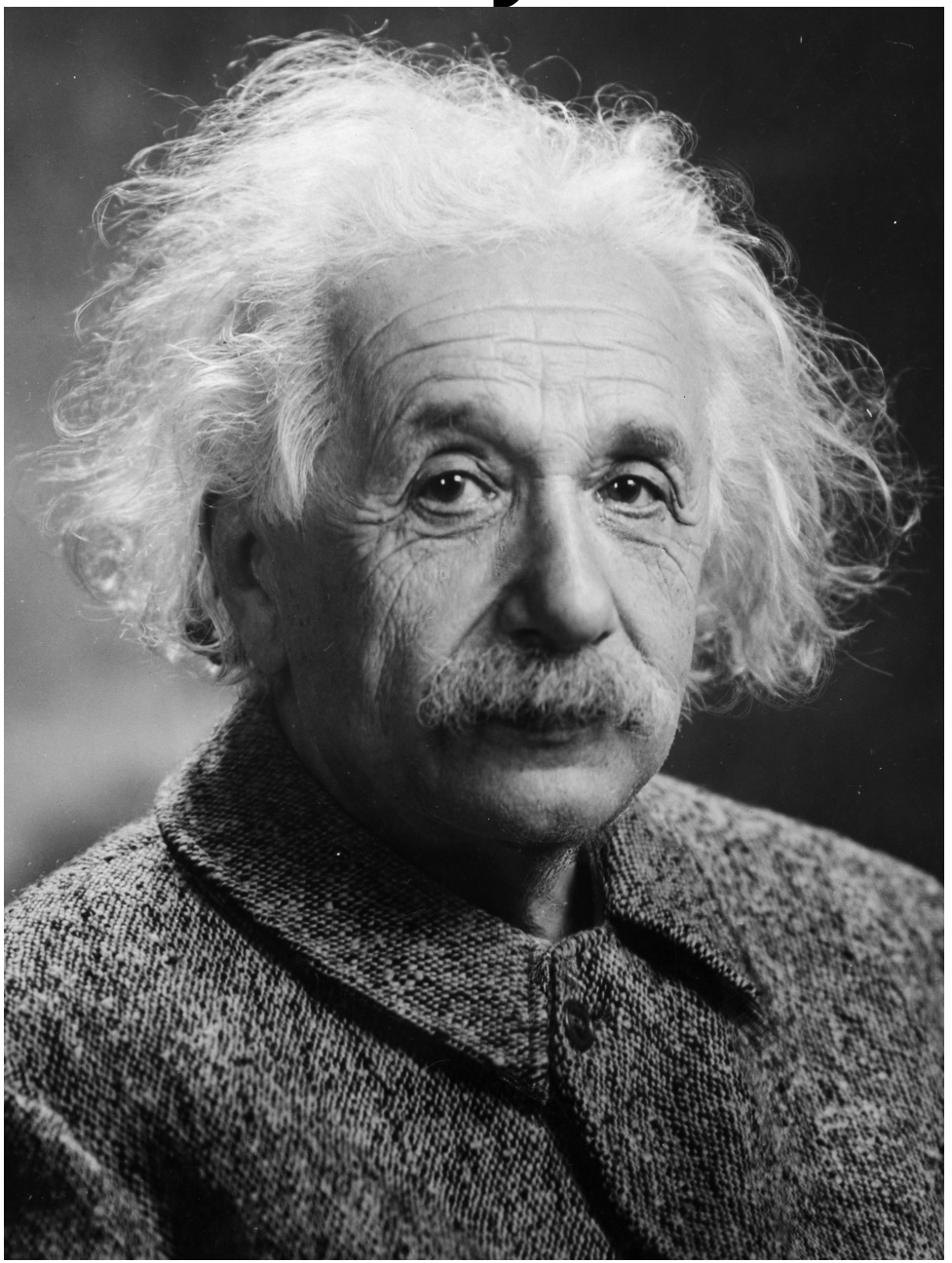
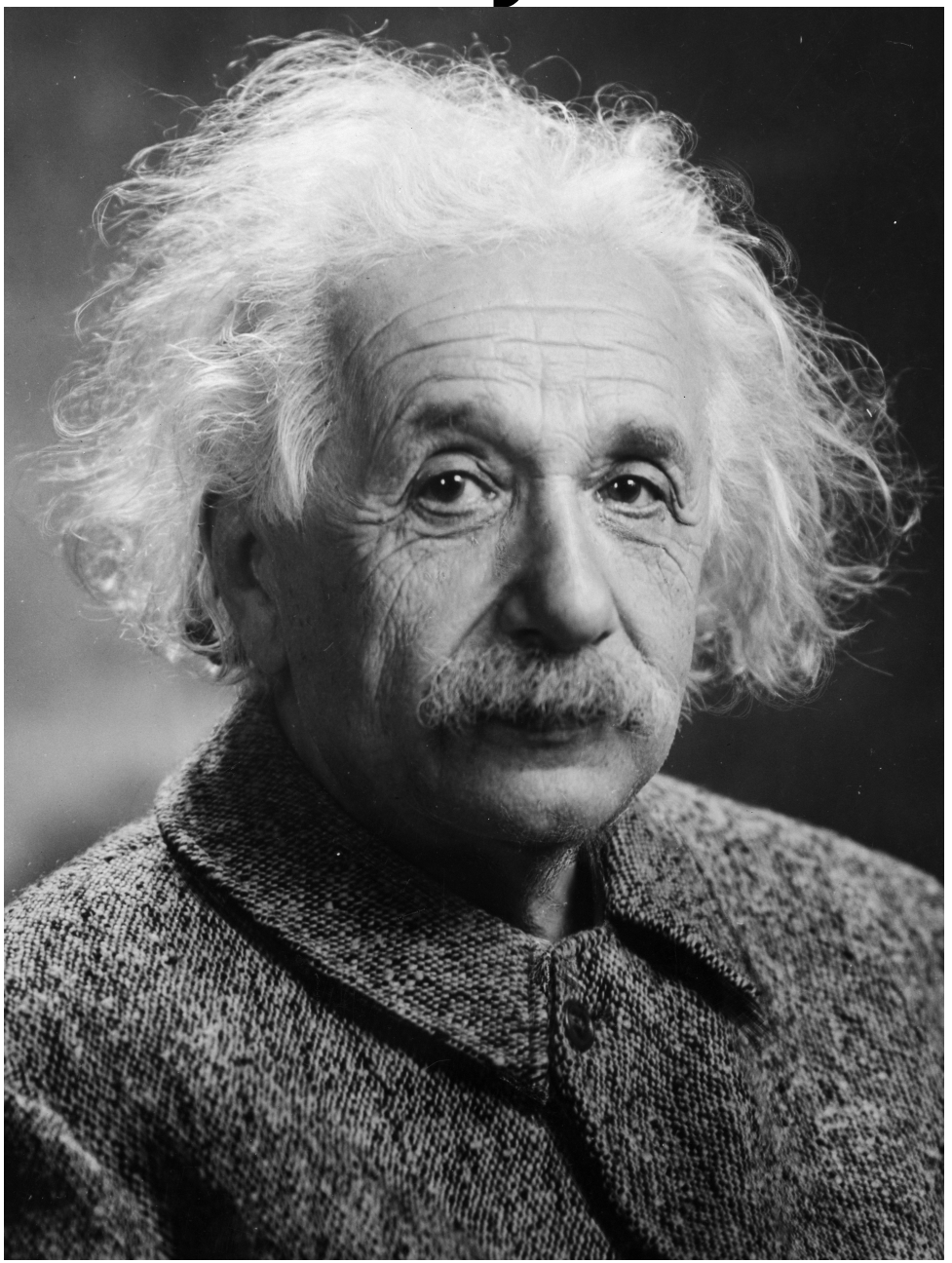
- **Showed light always travels in straight lines in '*spacetime'.***



General Relativity

- **Unified space and time into one geometry – 'space time'.**
- **Showed light always travels in straight lines in *spacetime.***
- **HOWEVER, spacetime is bent by gravity.**



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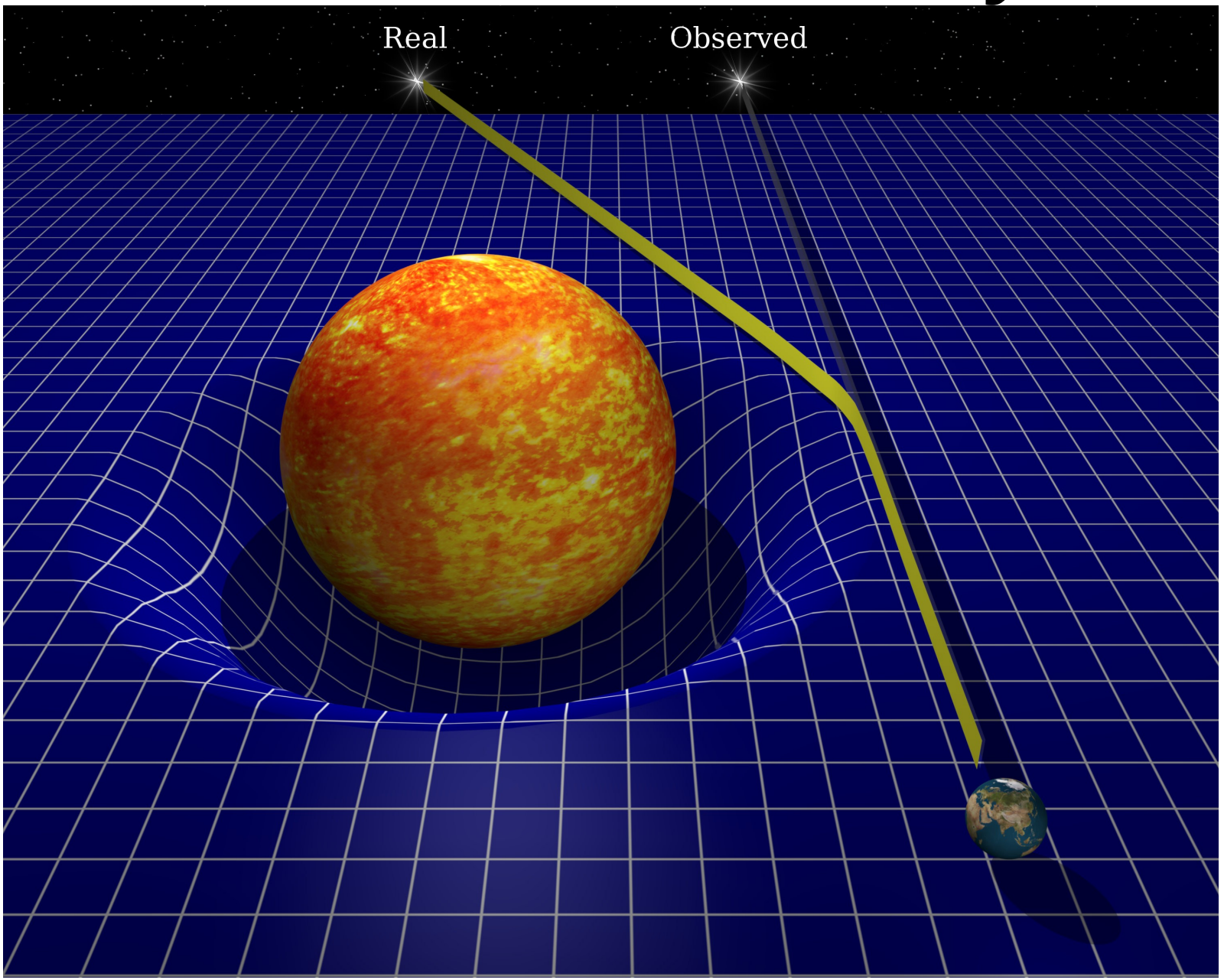

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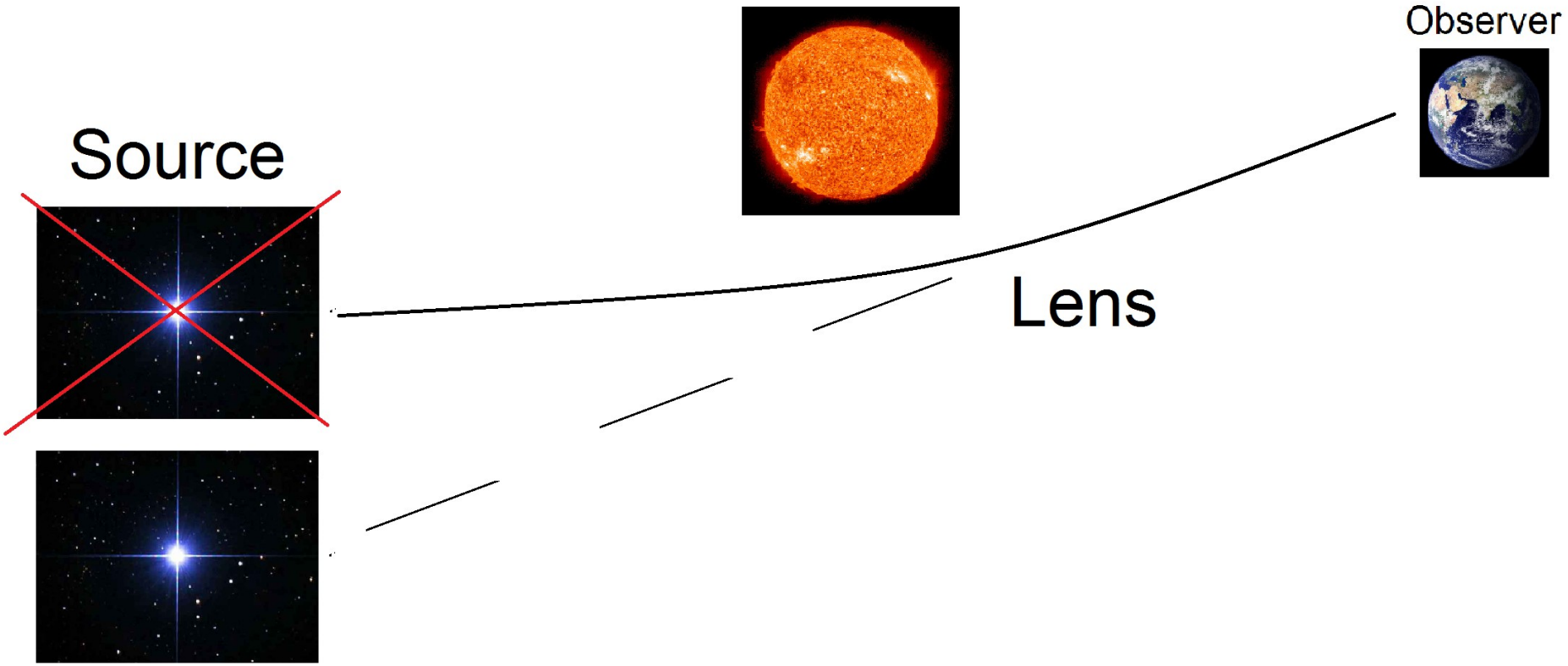
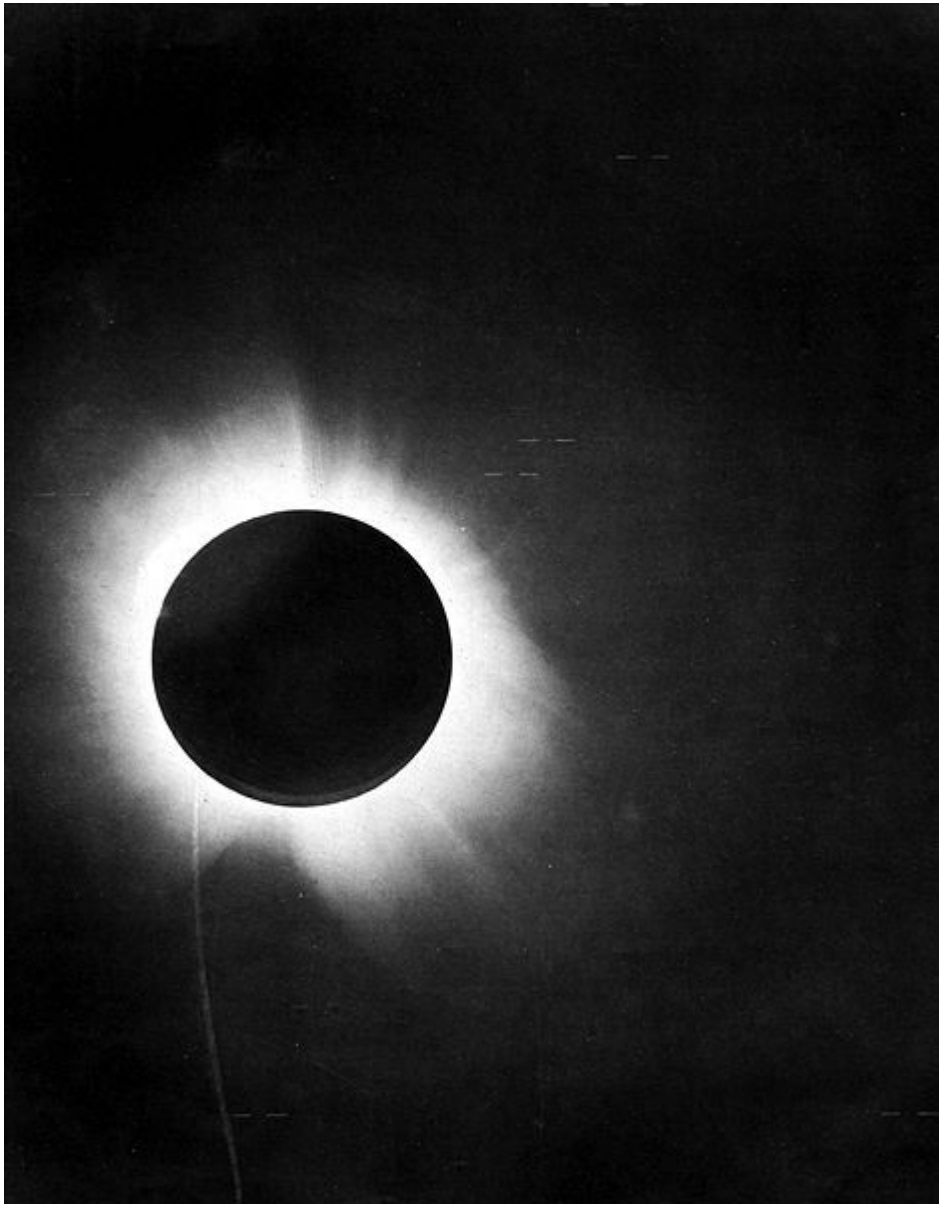


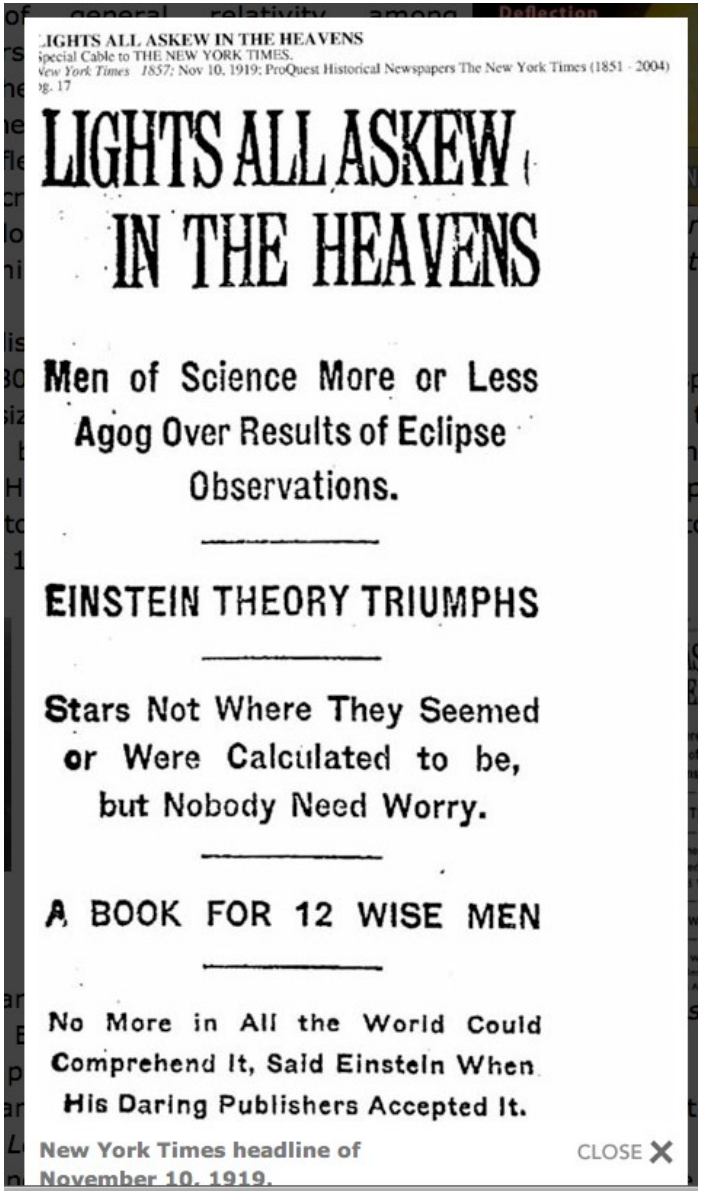
Observing General Relativity

- **Eddington photographed the sun in a solar eclipse in 1919.**



Observing General Relativity

- **Eddington photographed the sun in a solar eclipse in 1919.**
- **First observational evidence for General Relativity.**



LIGHTS ALL ASKEW IN THE HEAVENS
Special Cable to THE NEW YORK TIMES.
New York Times 1857; Nov 10, 1919; ProQuest Historical Newspapers The New York Times (1851 - 2004)
pg. 17

LIGHTS ALL ASKEW IN THE HEAVENS

Men of Science More or Less Agog Over Results of Eclipse Observations.

EINSTEIN THEORY TRIUMPHS

Stars Not Where They Seemed or Were Calculated to be, but Nobody Need Worry.

A BOOK FOR 12 WISE MEN

No More in All the World Could Comprehend It, Said Einstein When His Daring Publishers Accepted It.

New York Times headline of November 10, 1919.

CLOSE ✕

So... What is Gravitational Lensing?

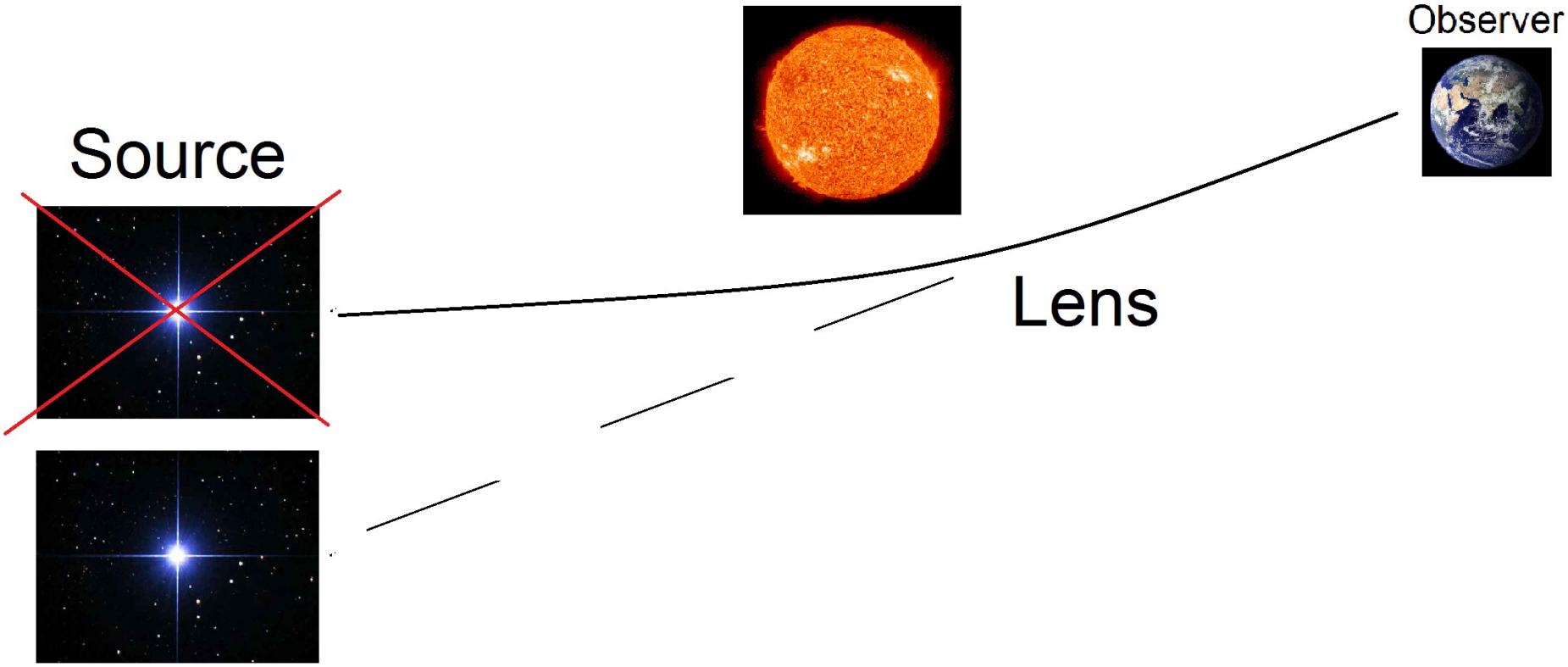
- **Light bending around massive objects due to their gravity.**

  THIS IS WRONG!

- **Light travelling in straight lines through curved space time.**

Microlensing

Microlensing



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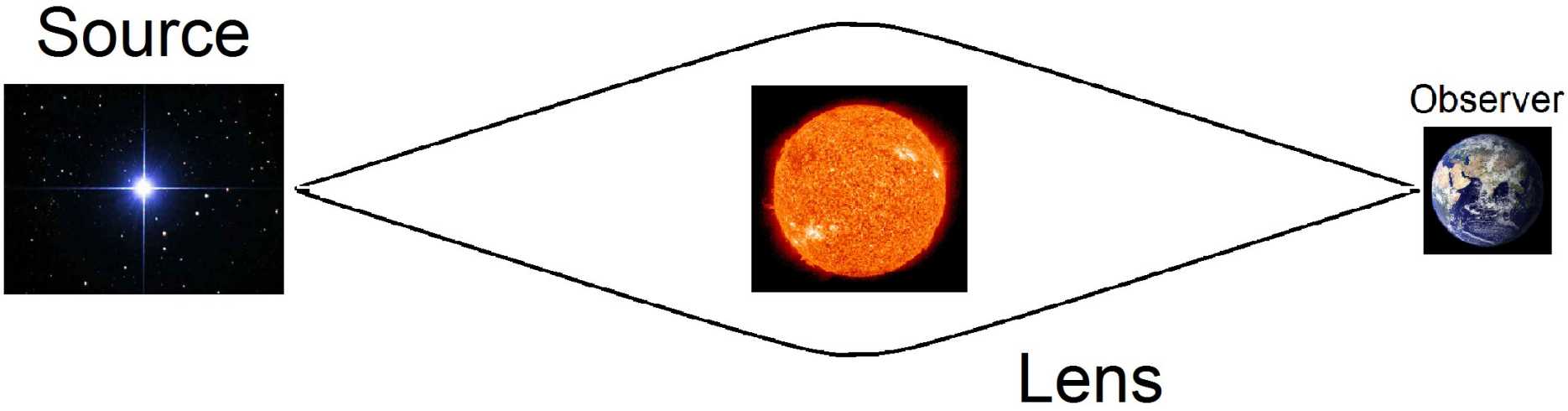

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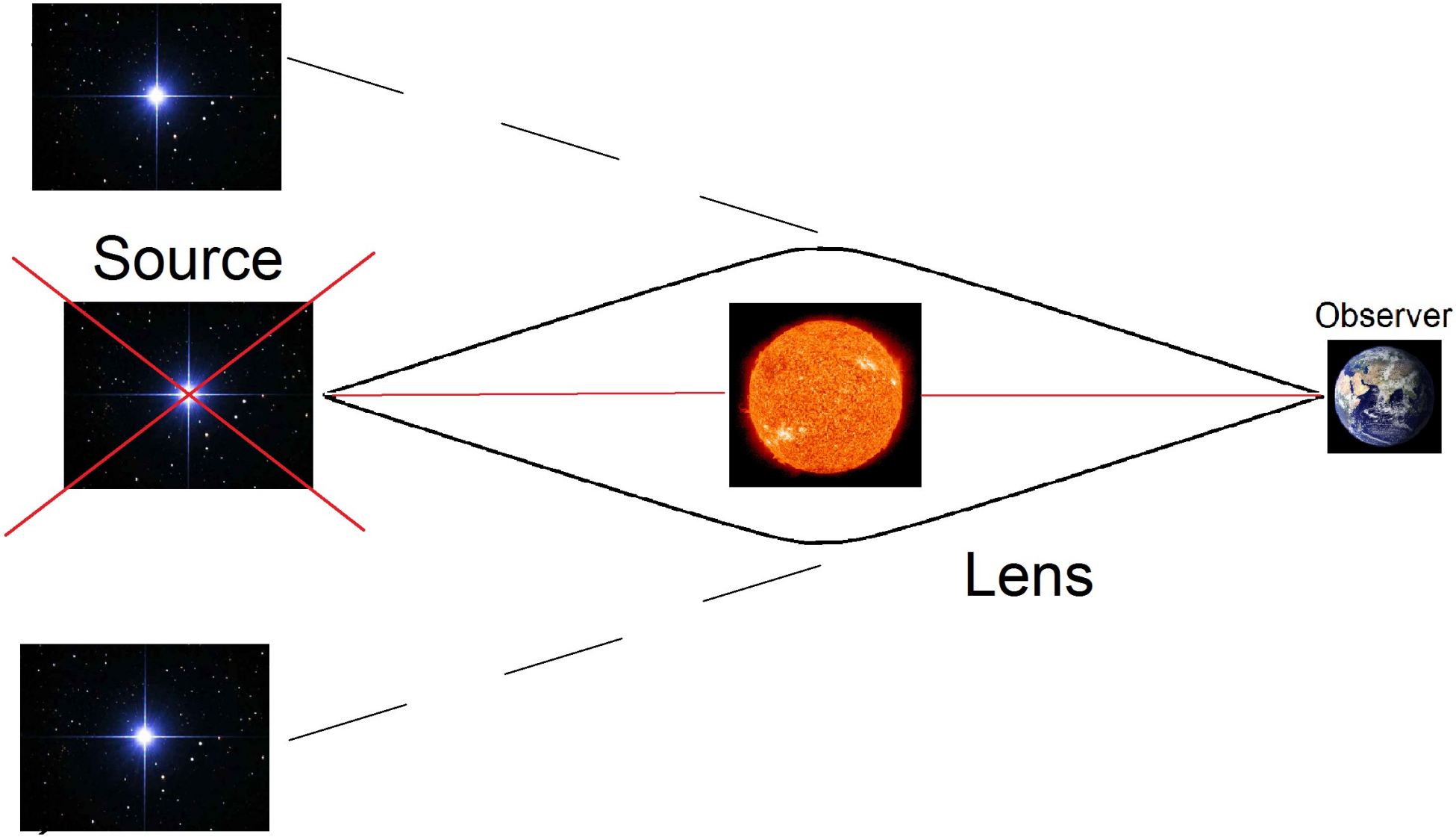
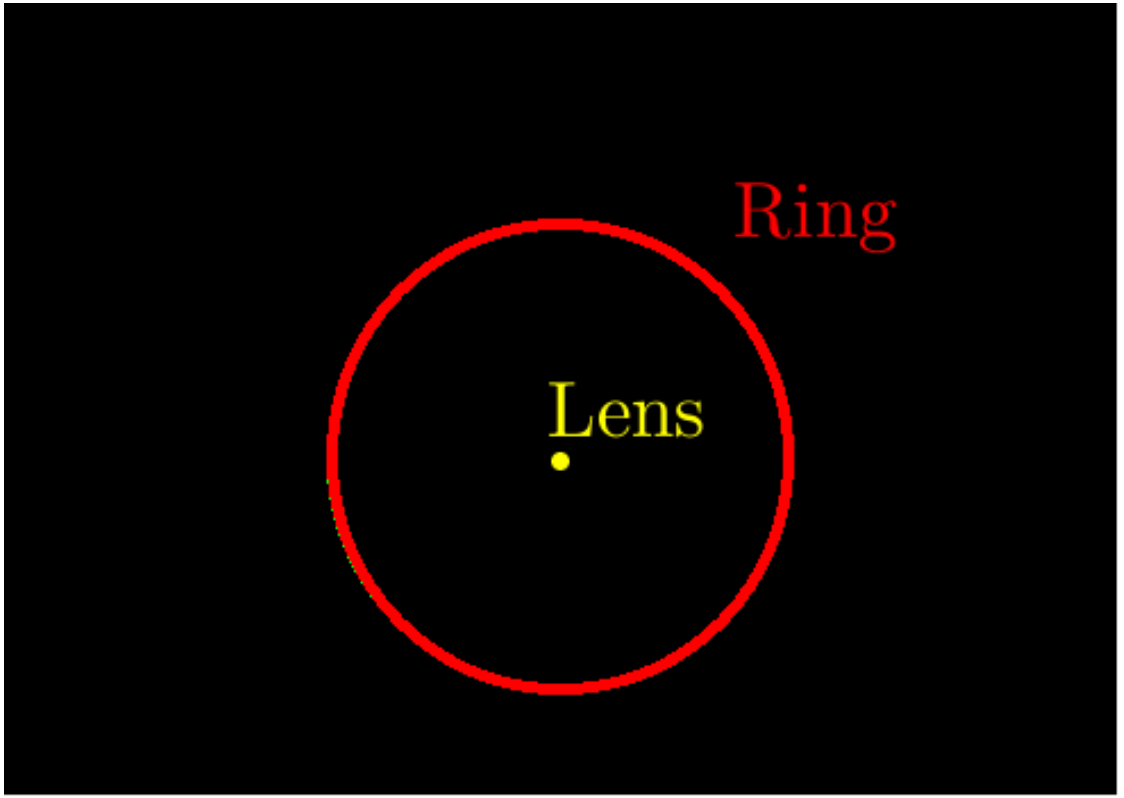


Microlensing – Einstein Ring



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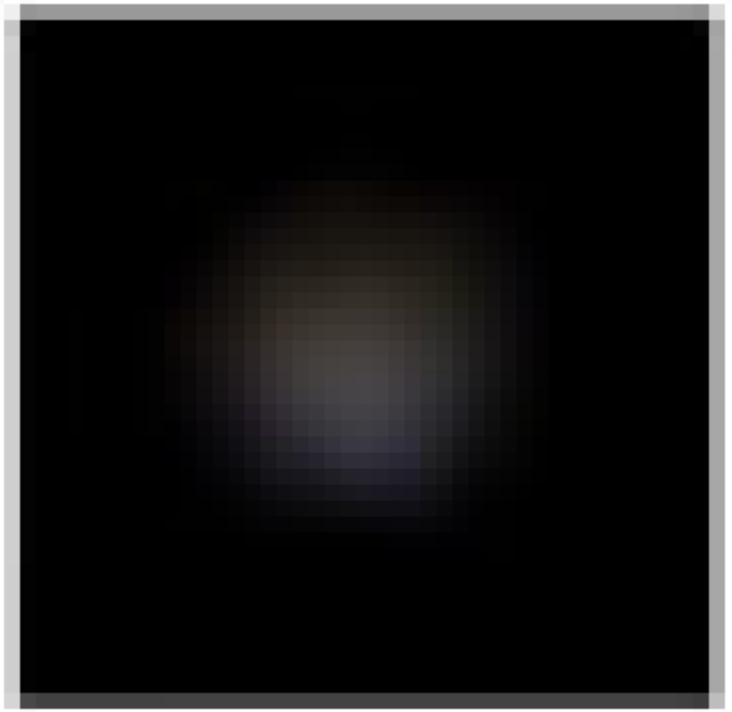
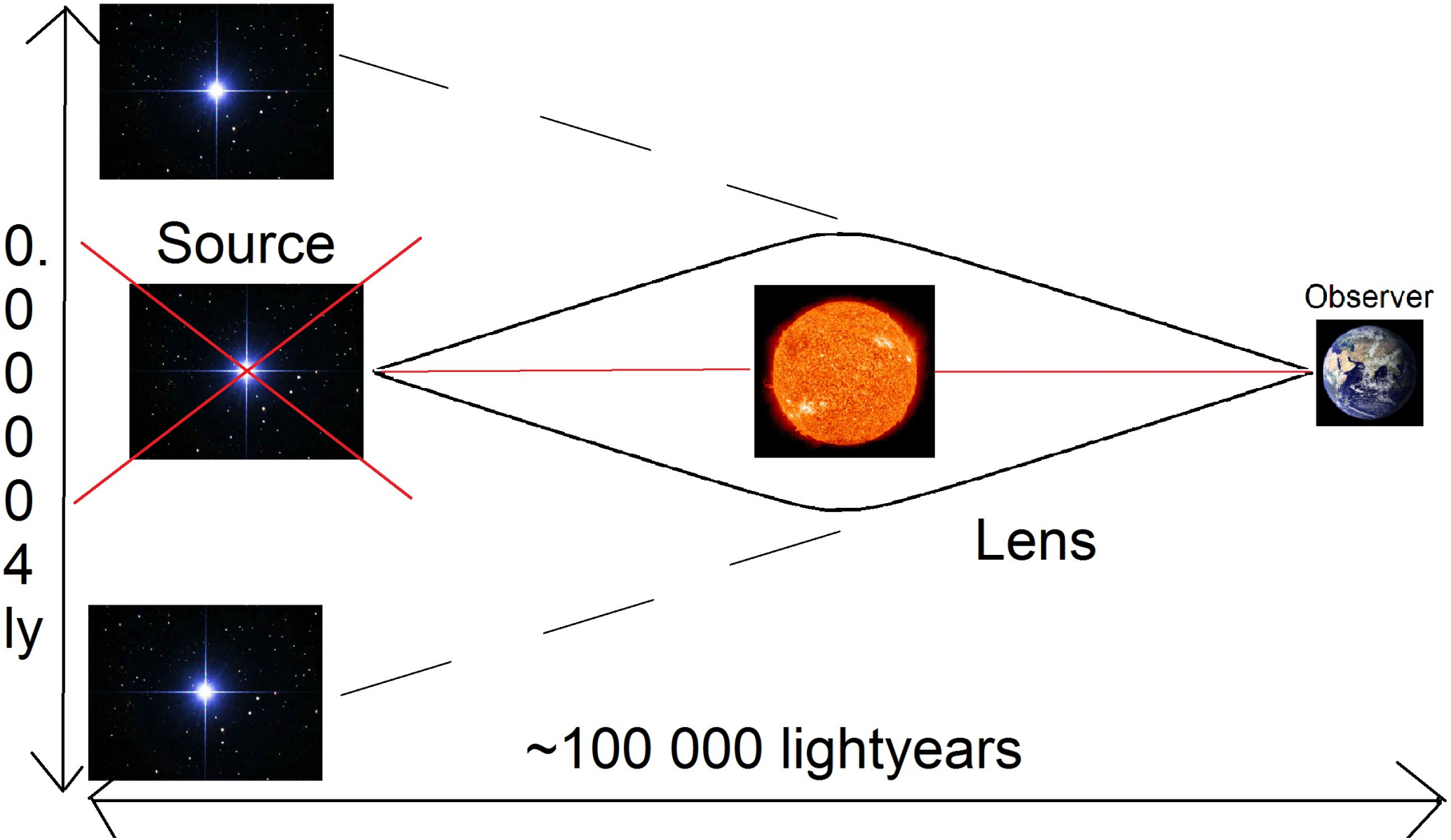
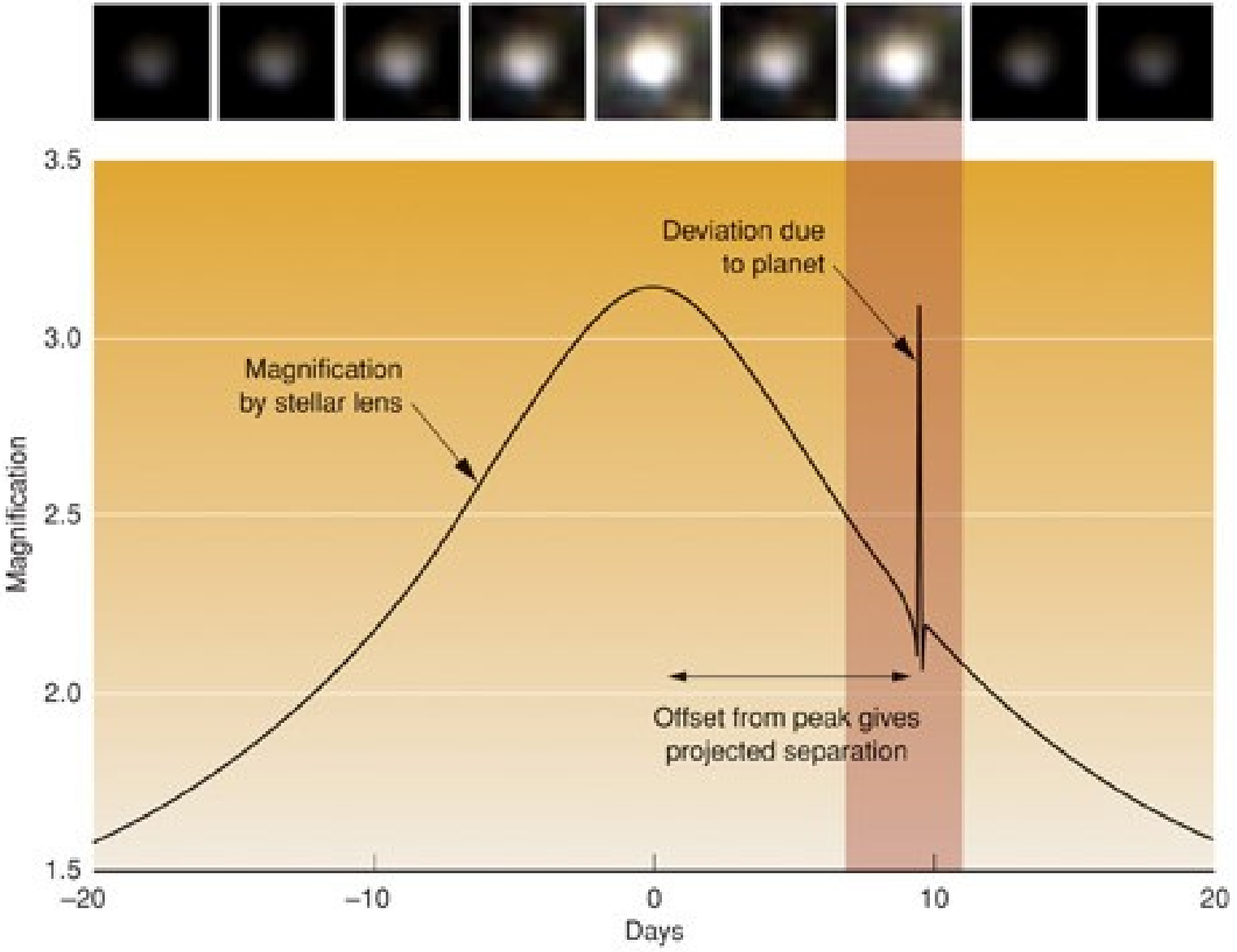


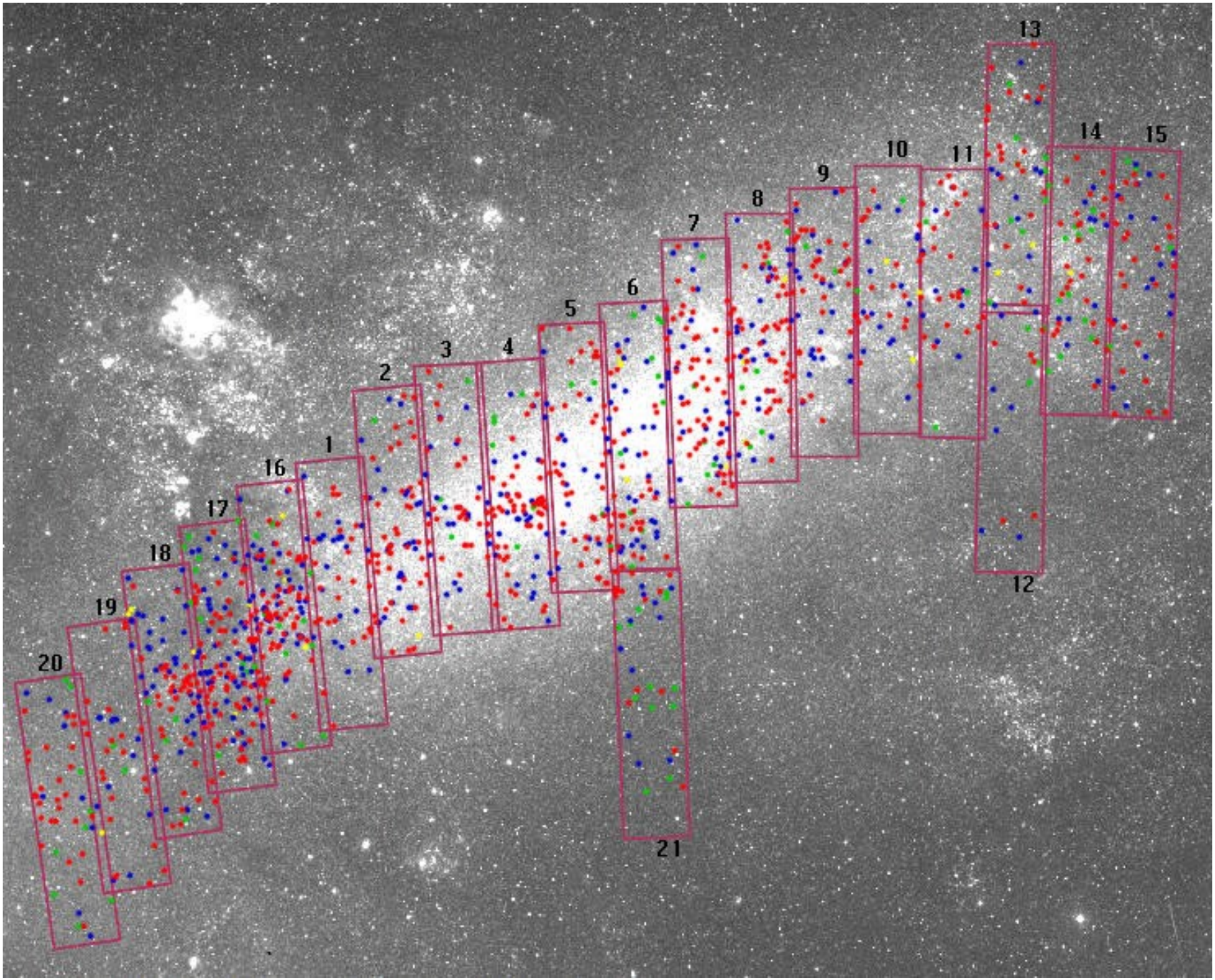
Microlensing – Einstein Ring

Microlensing - Distances



Microlensing - Transience

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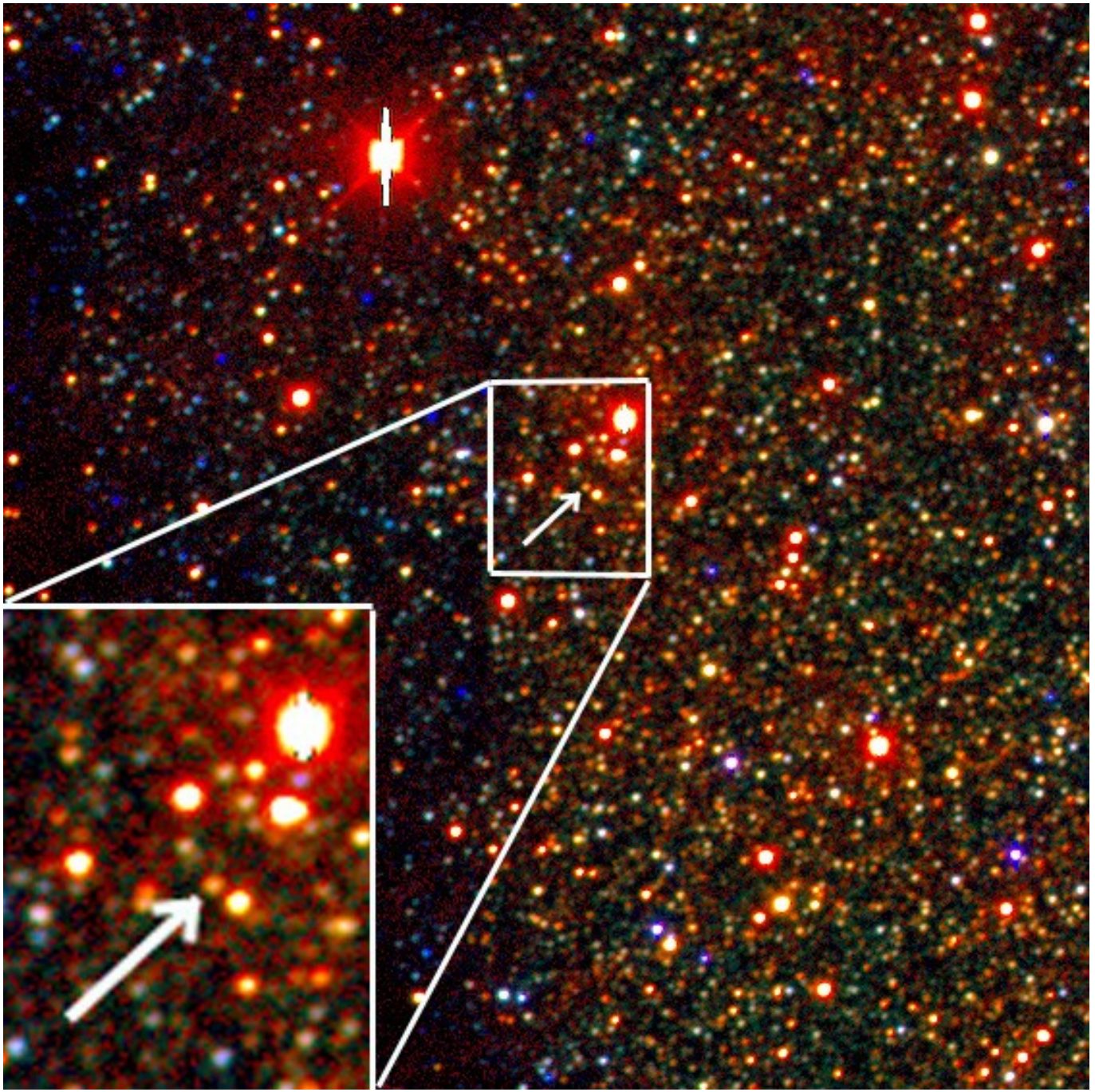
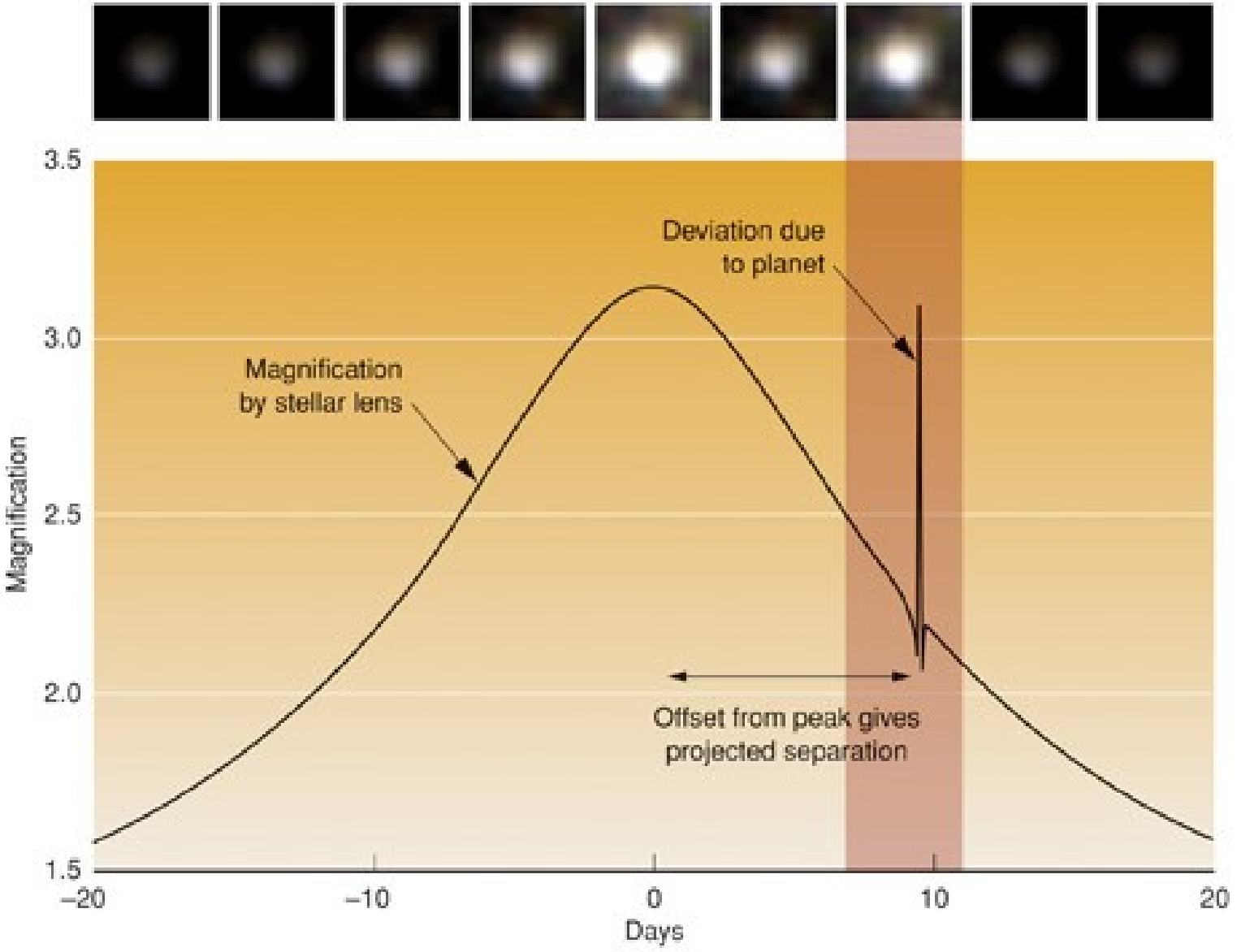


Microlensing - Telescopes

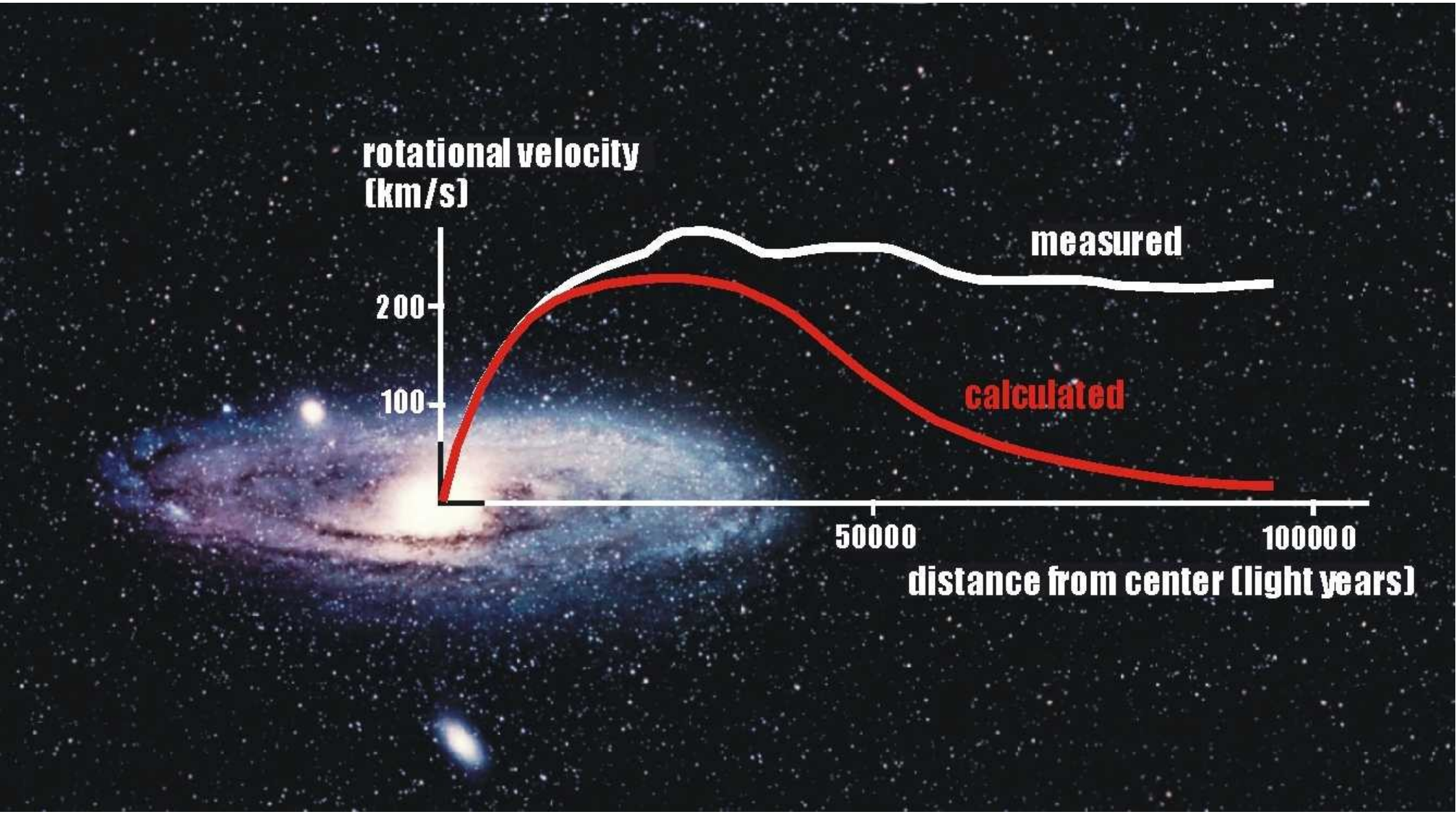
OGLE – Optical Gravitational Lensing Experiment in Chile.

Mt John Obervatory – New Zealand

Microlensing – Exoplanets



Microlensing – Dark Matter



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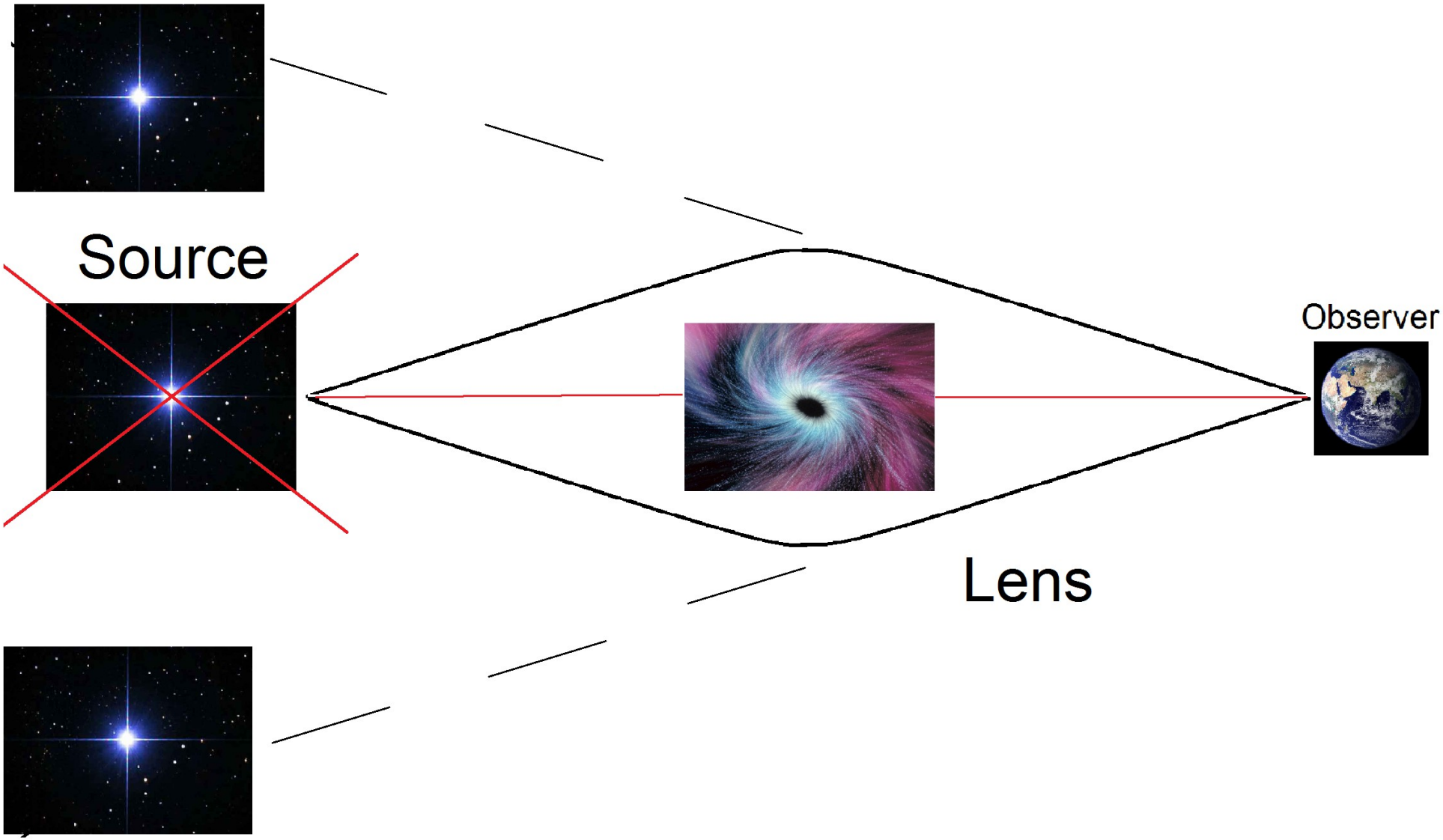

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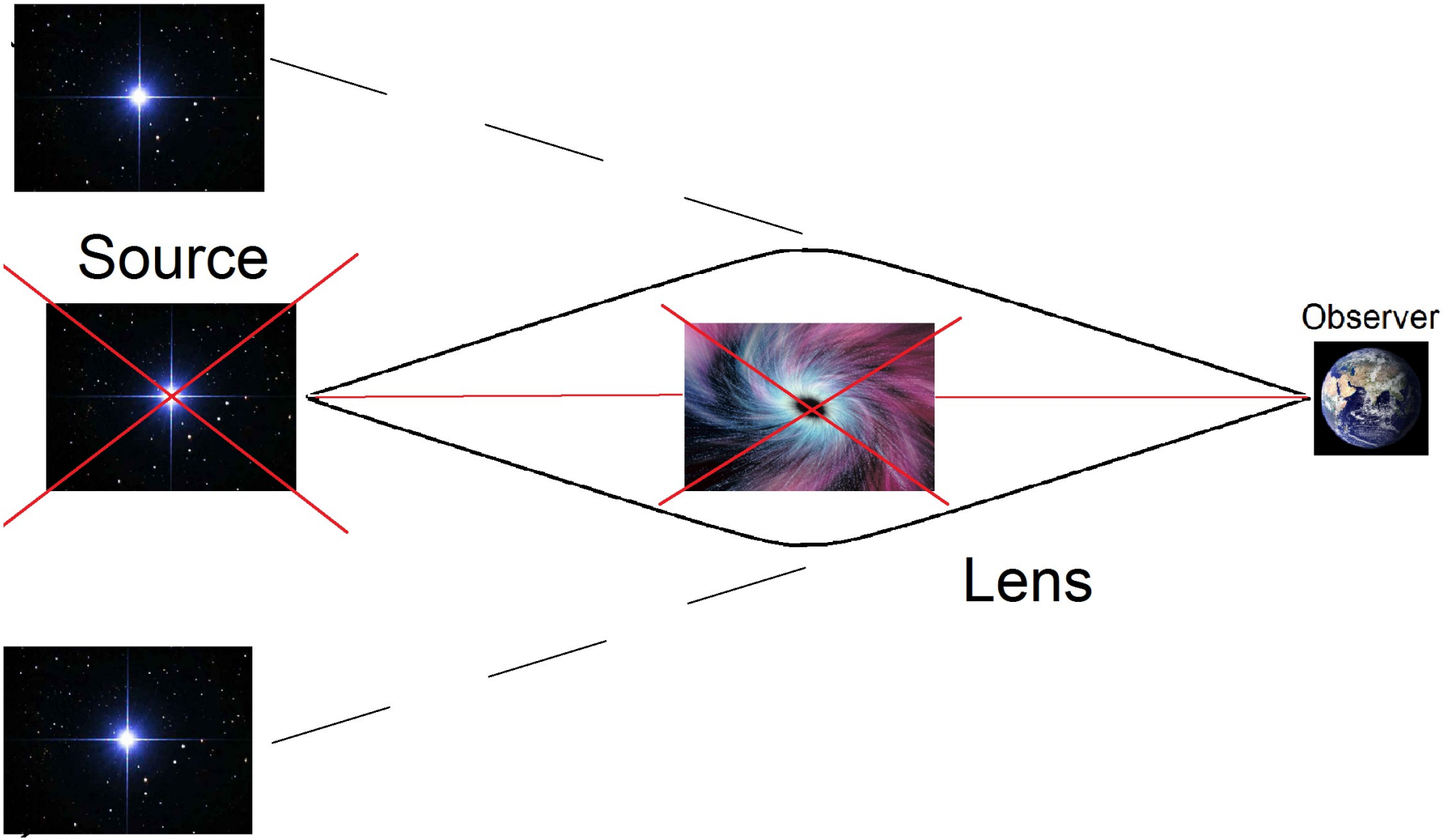
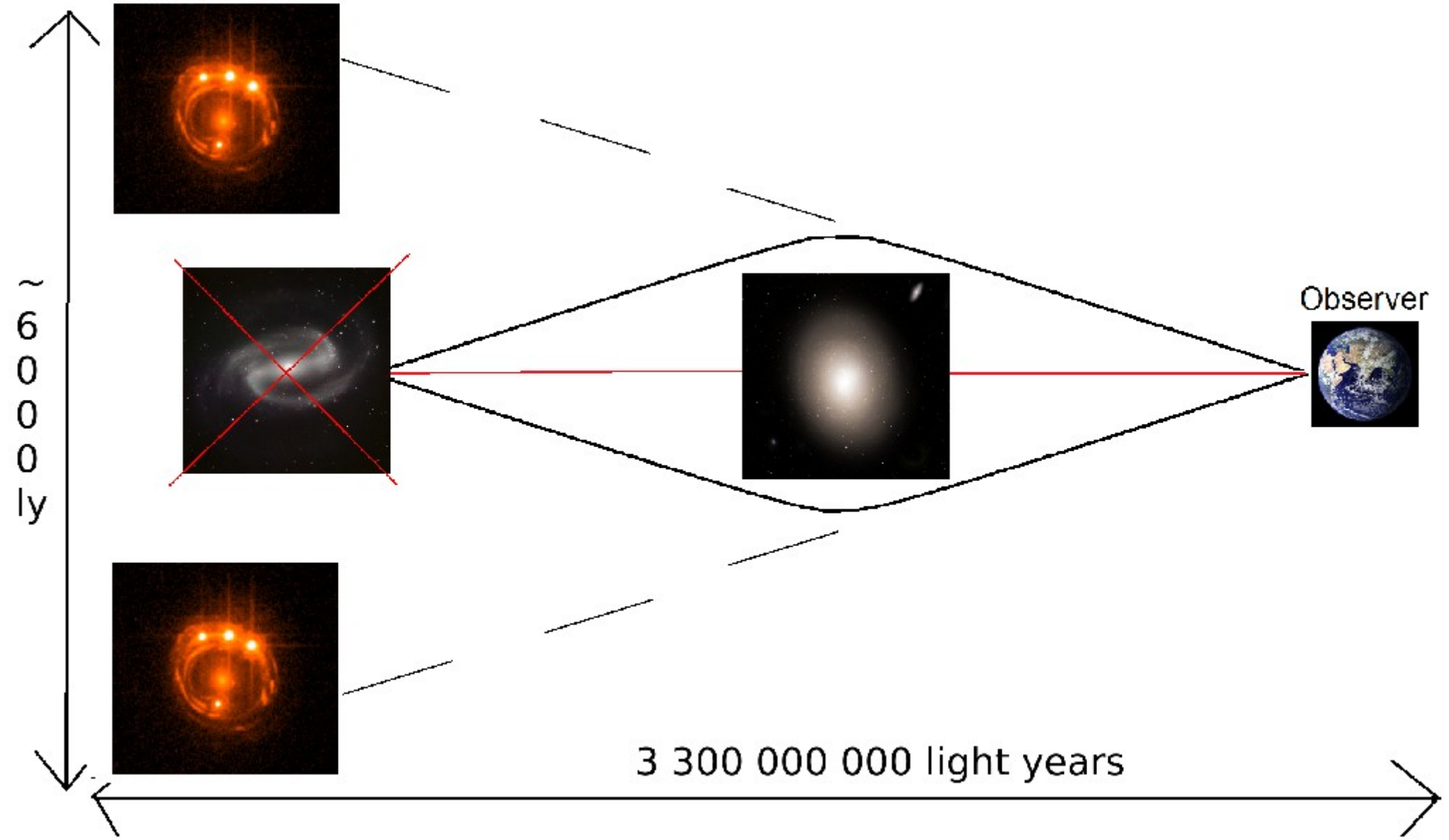
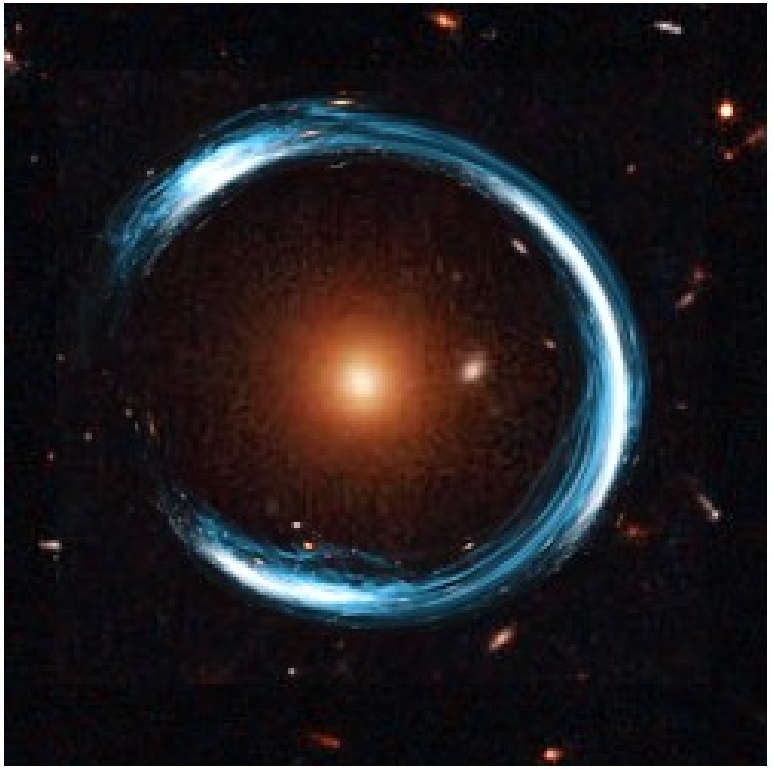


Strong Lensing
(The best lensing)

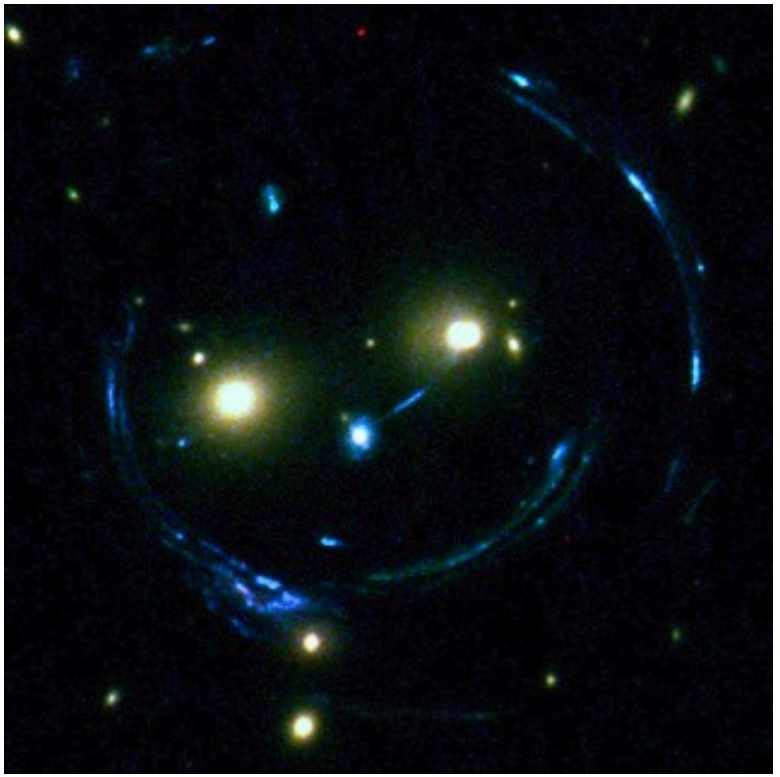
Strong Lensing



Strong Lensing – One Lens Galaxy



Strong Lensing – Two Lens Galaxies



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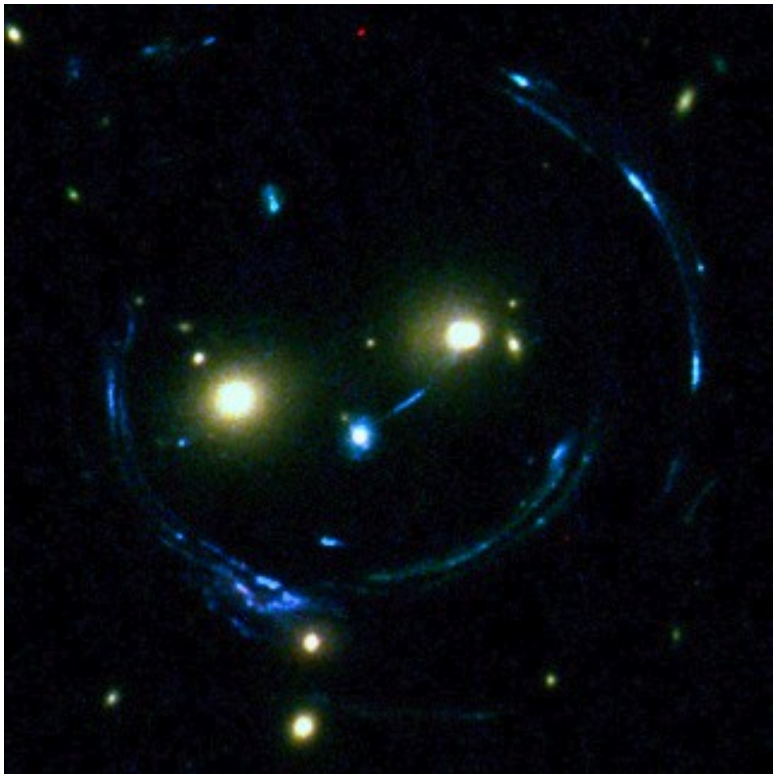

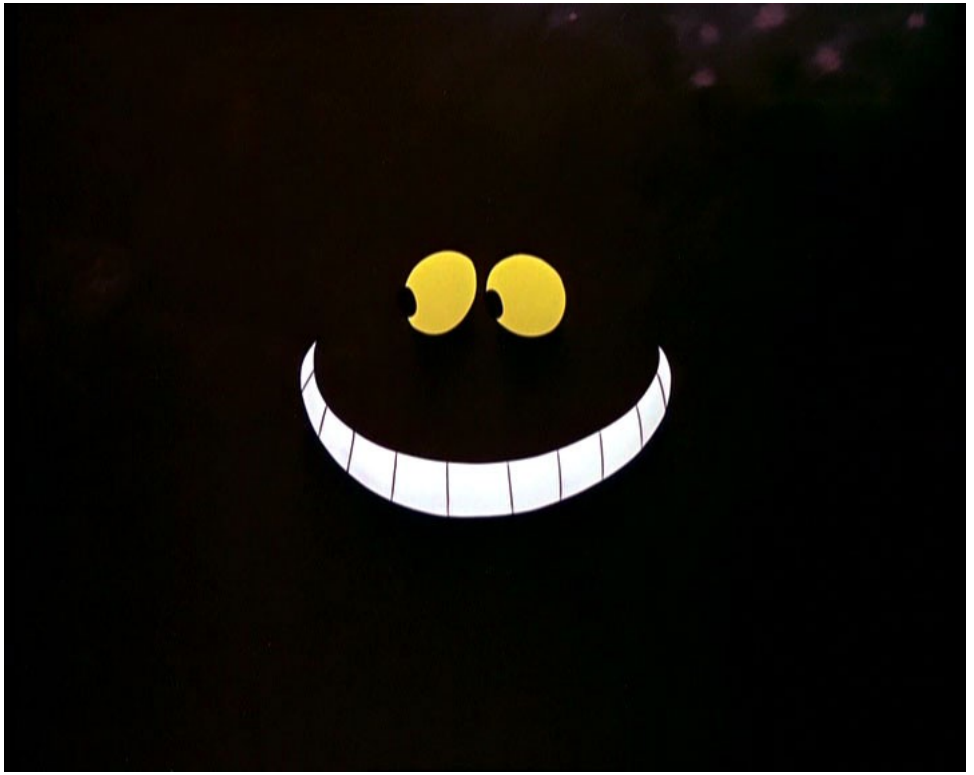

Finding Strong Lenses Is Tough...

- The probability of an object in modern surveys being a strong lens is around 0.01%

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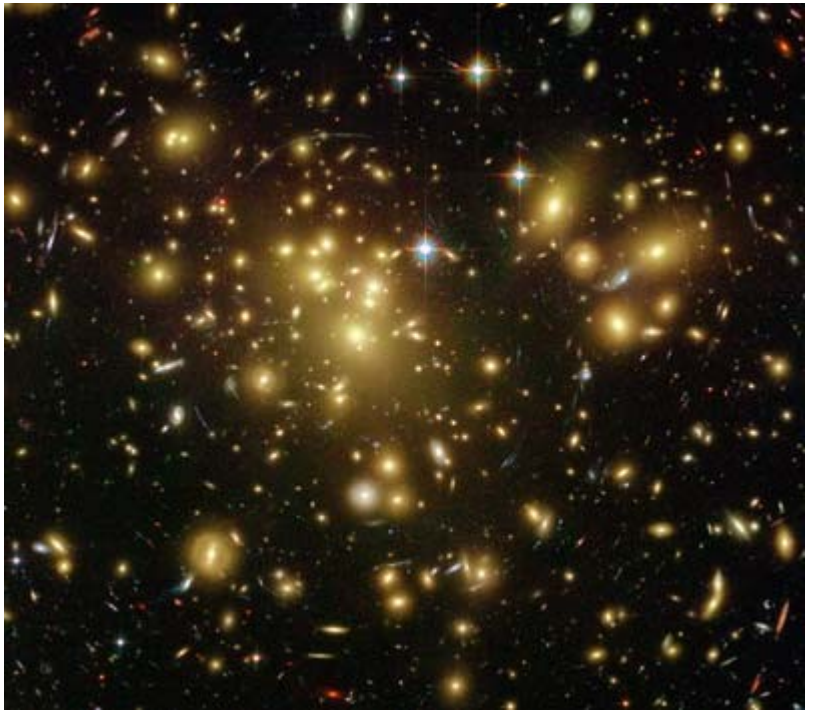
  … and there are **a lot** of galaxies.



Finding Strong Lenses Is Tough...

- The probability of an object in modern surveys being a strong lens is around 0.01%

  … and there are **a lot** of galaxies.

- **How do we find the needle in the haystack?**

You Could Look For...

- (Near) Perfect Ring.

You Could Look For...

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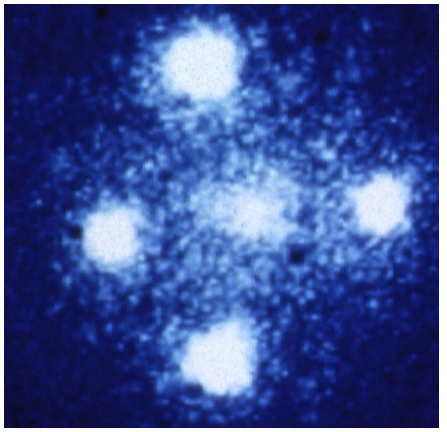
- 2 or 4 Multiple Images.



You Could Look For...

- (Near) Perfect Ring.
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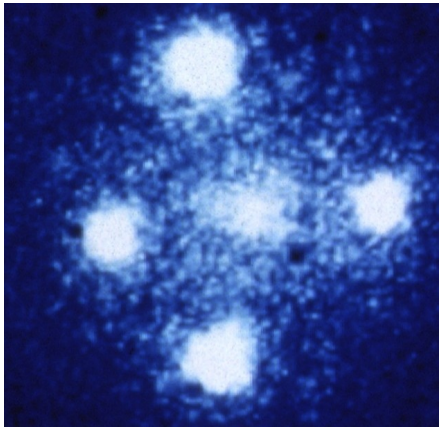
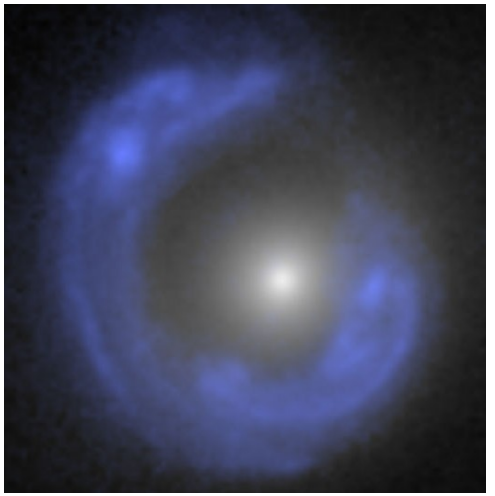
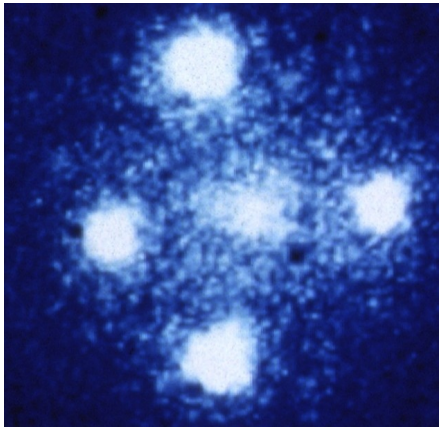
- Giant Arcs

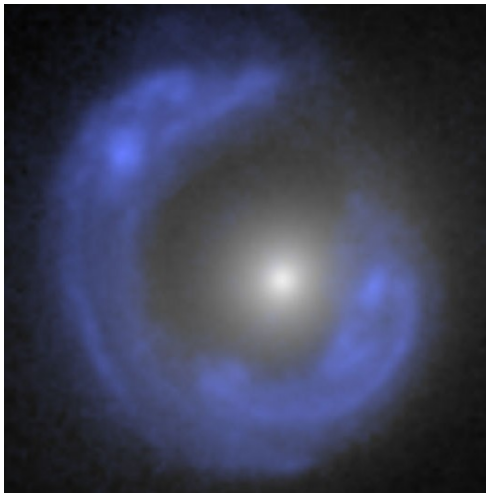




You Could Look For...

- A (Near) Perfect Ring.
- 2 or 4 Multiple Images.
- Giant Arcs
- **Its really hard to get a computer to do this!**



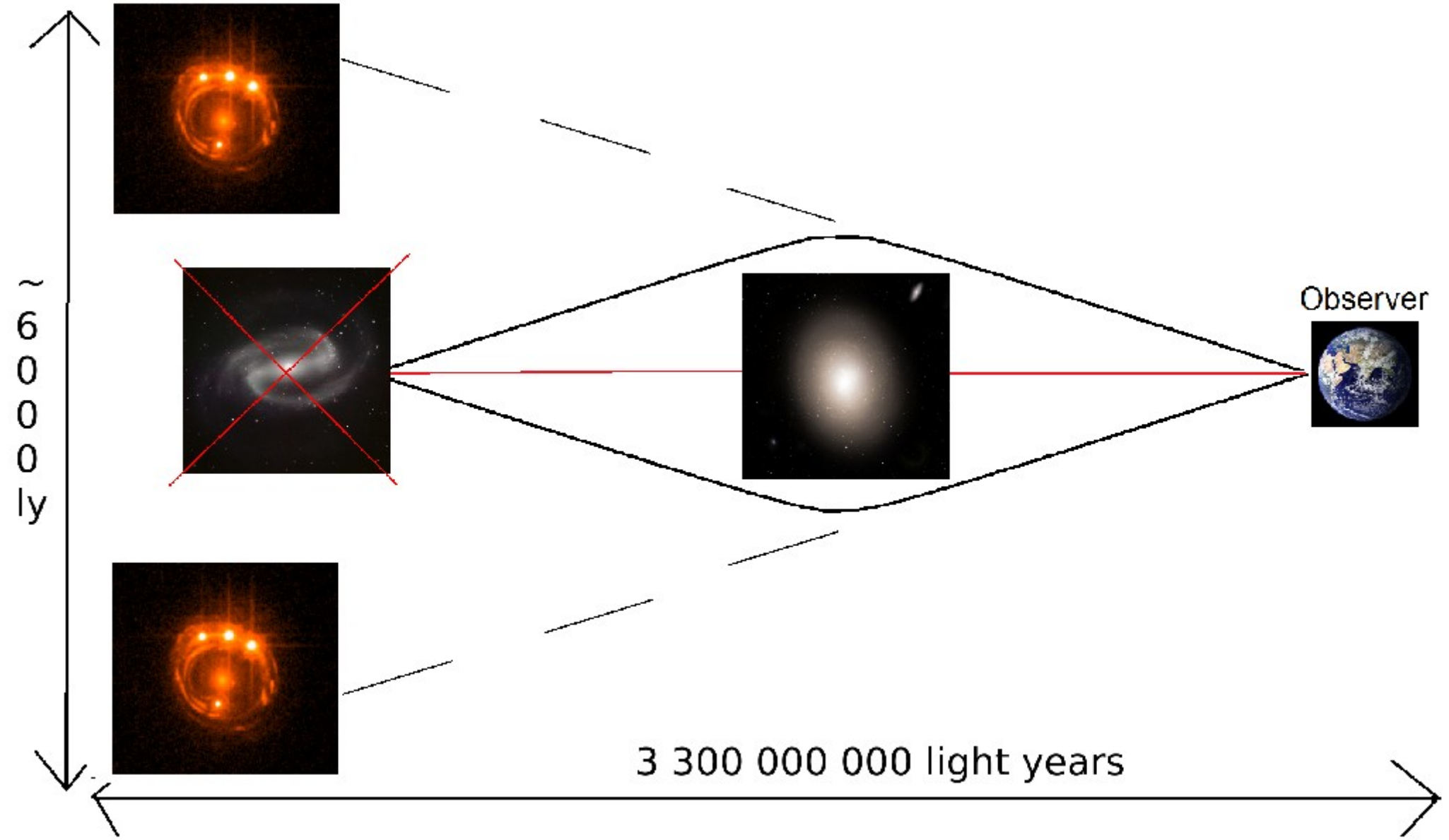


Can Humans?

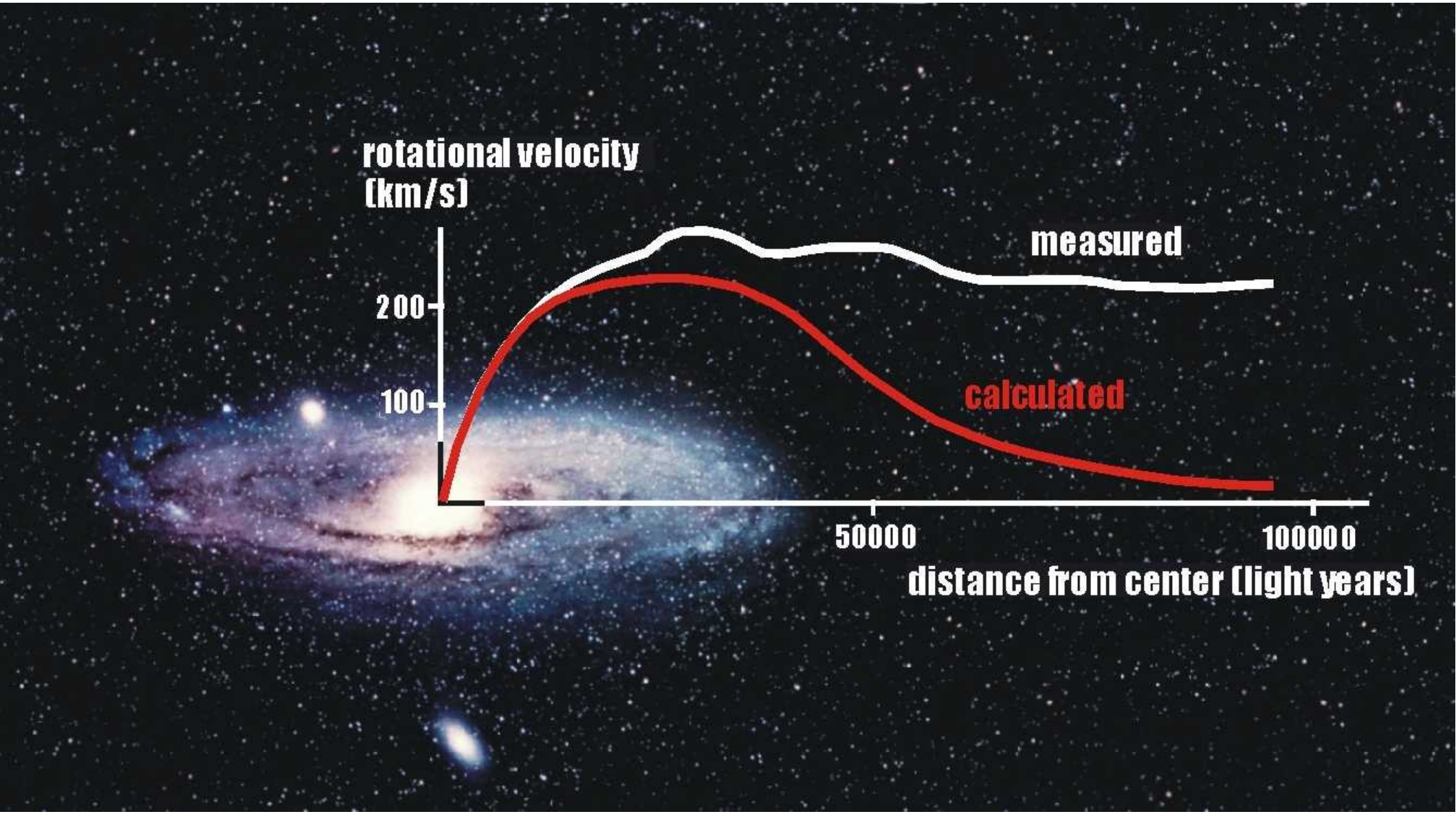
Space Warps

- www.spacewarps.org
- Citizen Science – finding the strong lenses in 3 million galaxies.

Strong Lensing – Whats in a Galaxy?



Strong Lensing – Dark Matter



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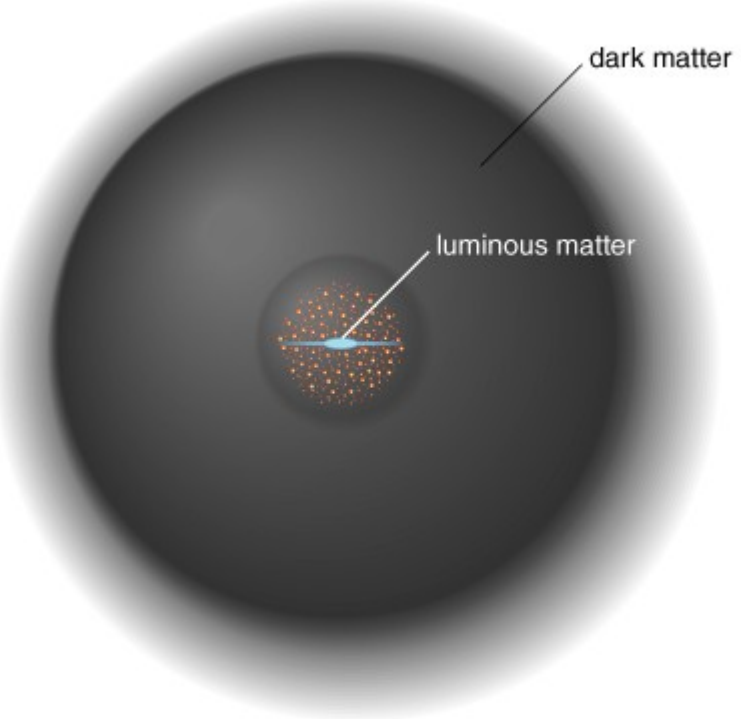

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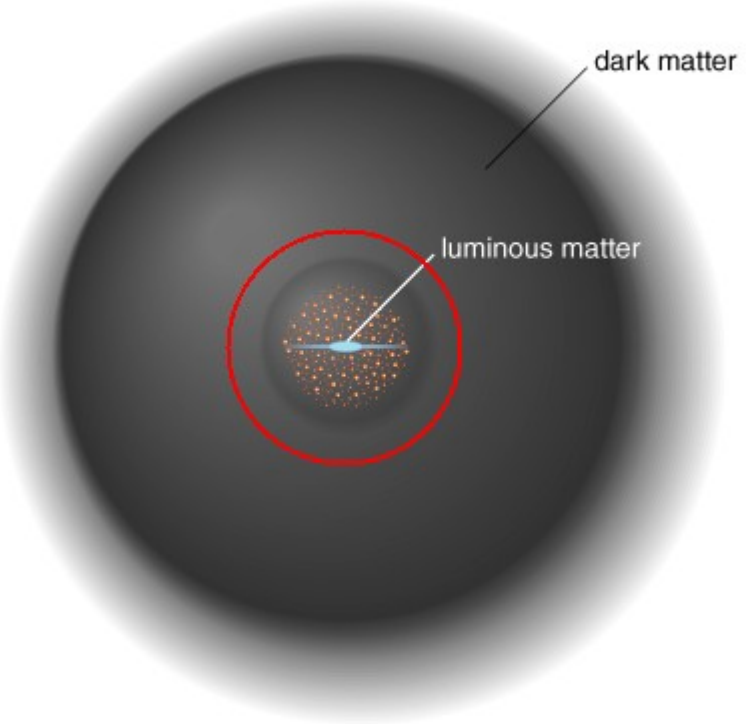
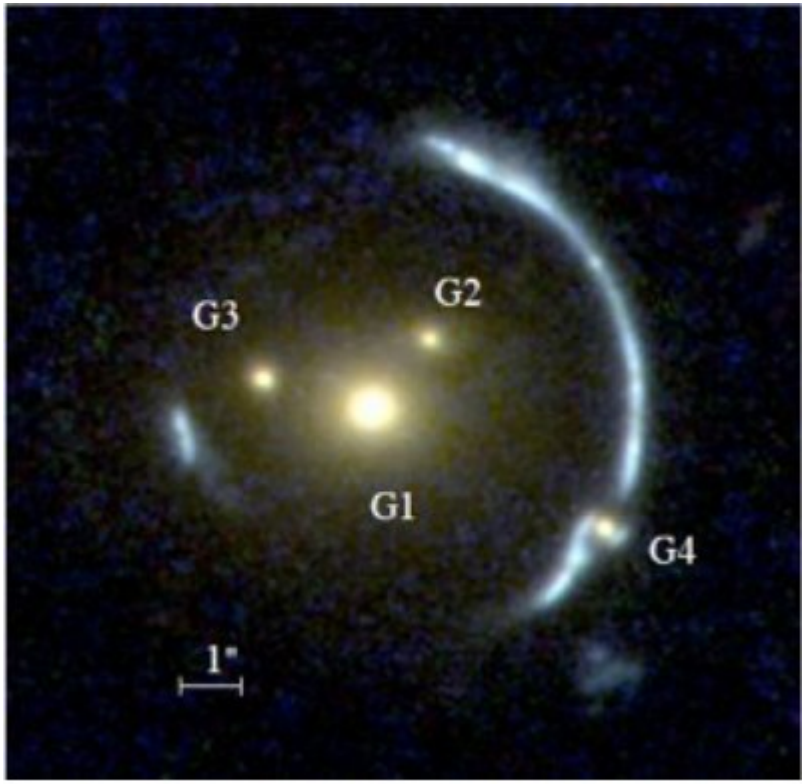


Strong Lensing – Viewing The Past

- If one Galaxy is a Lens the lensed source arc is around 1 “
- This gives a magnification of around 5-50.

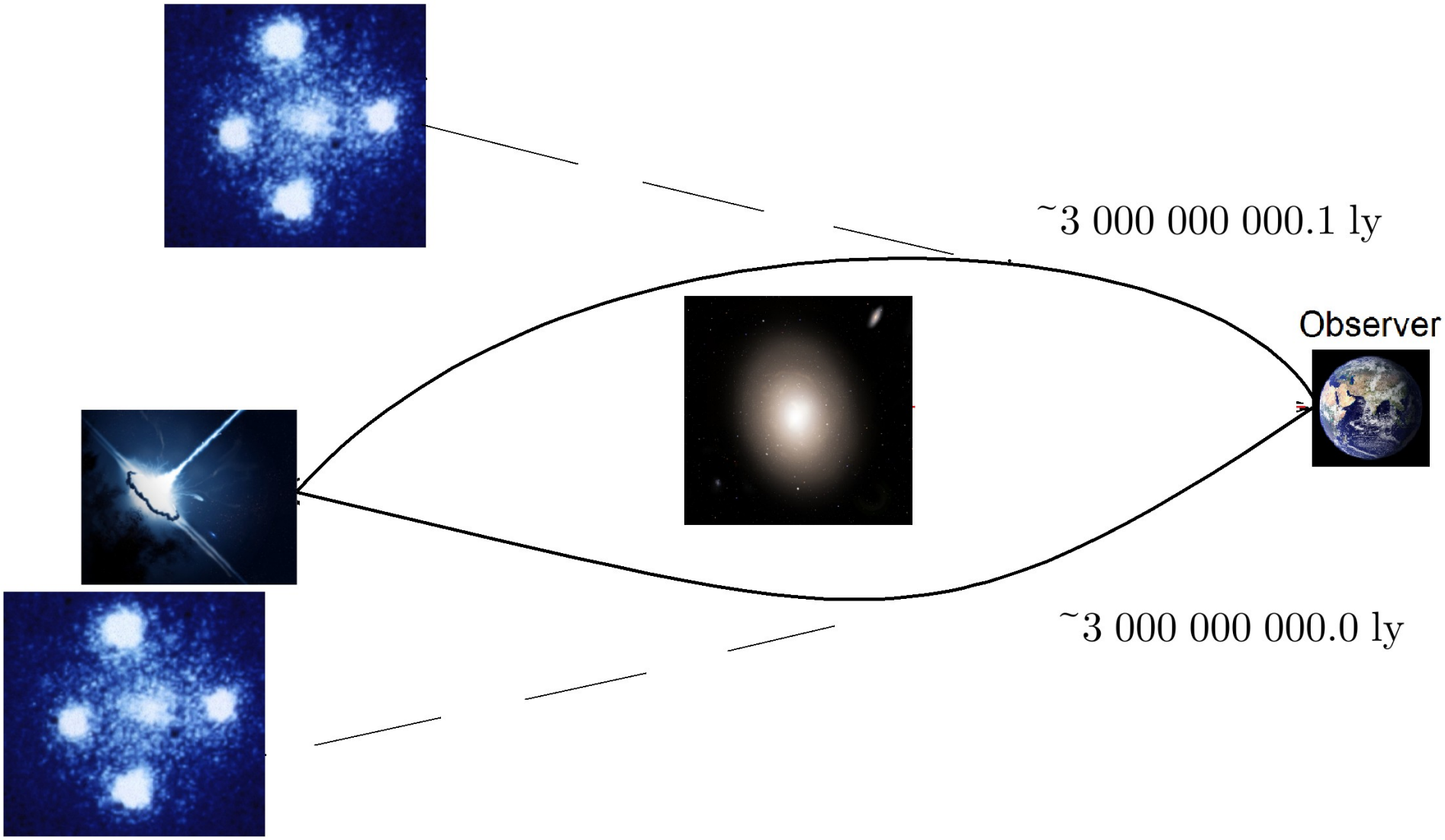
Strong Lensing – Viewing The Past

- For two galaxies the arc is around 2 – 5”
- This gives a magnification of around 50-200.

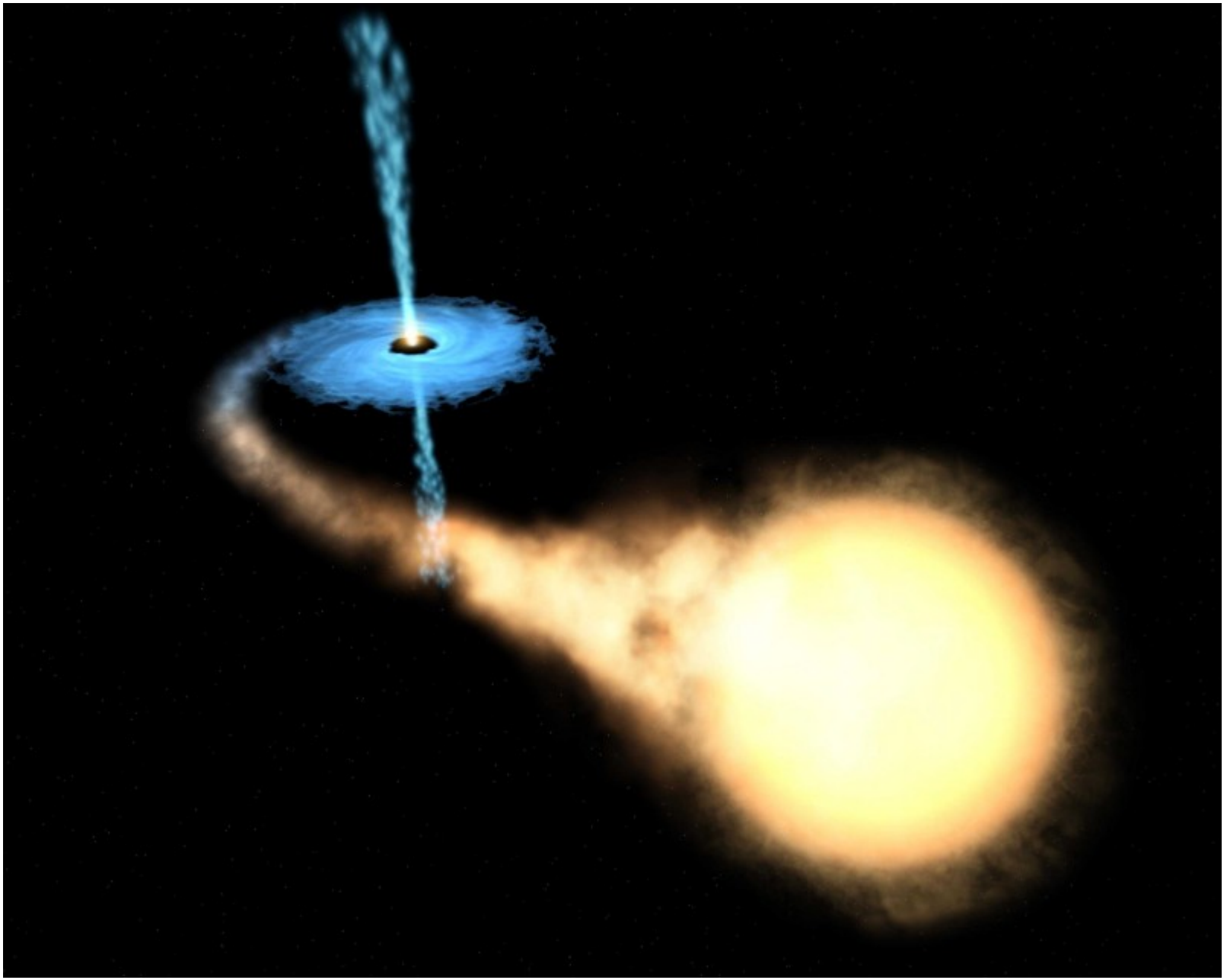


Strong Lensing – Frontier Fields

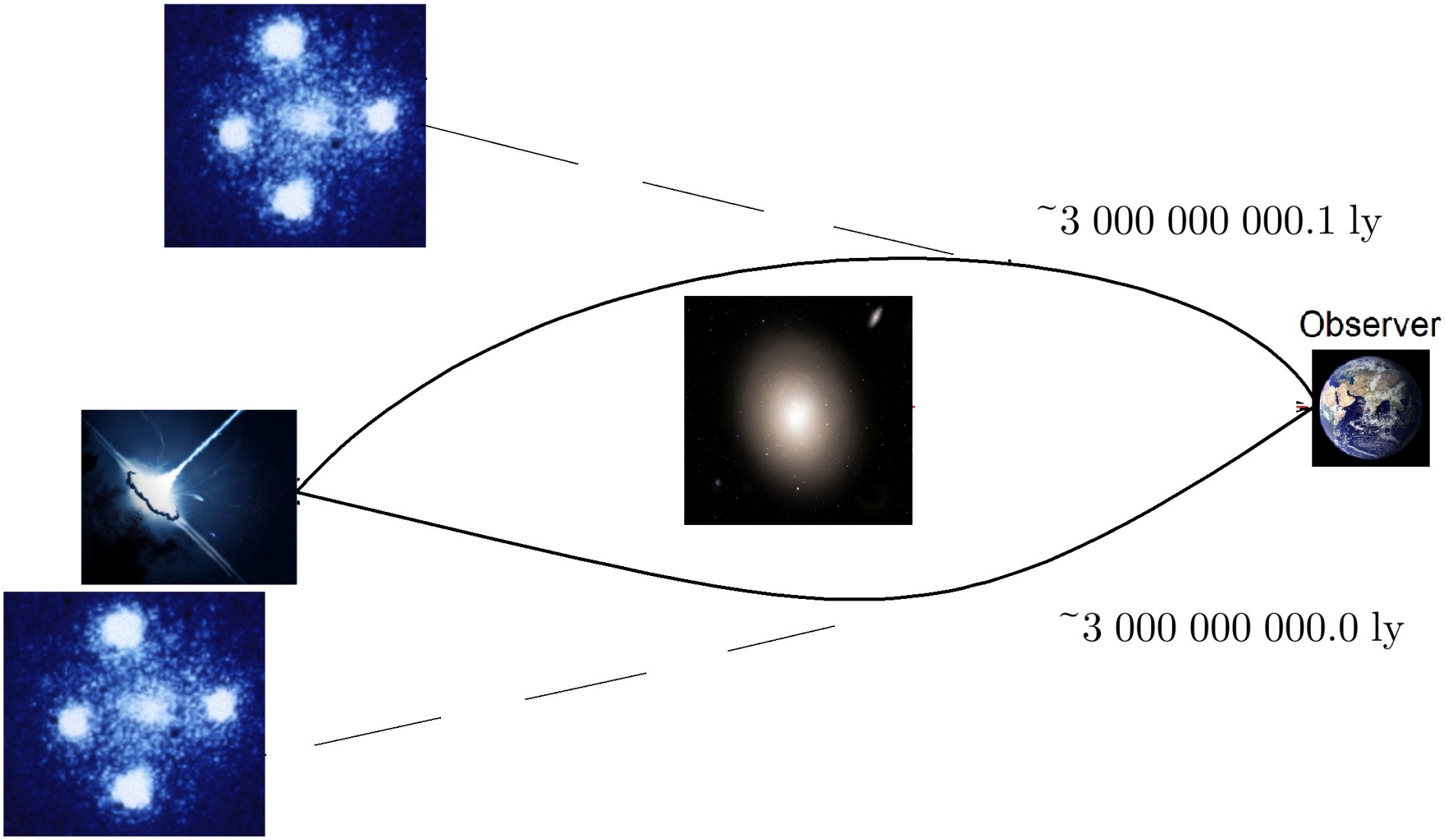
Strong Lensing – Time Delays



Strong Lensing - Quasar



Strong Lensing – Time Delays



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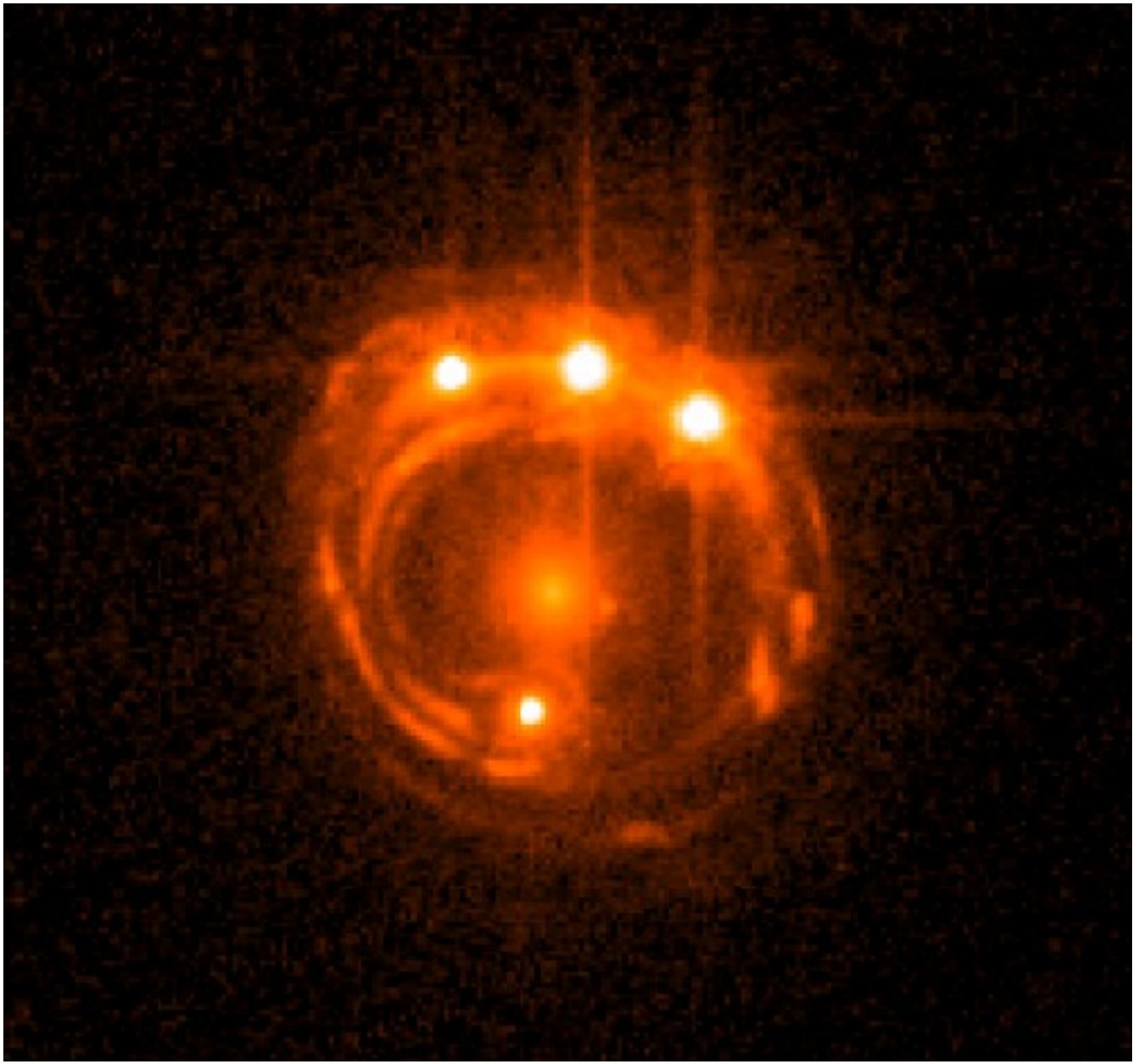
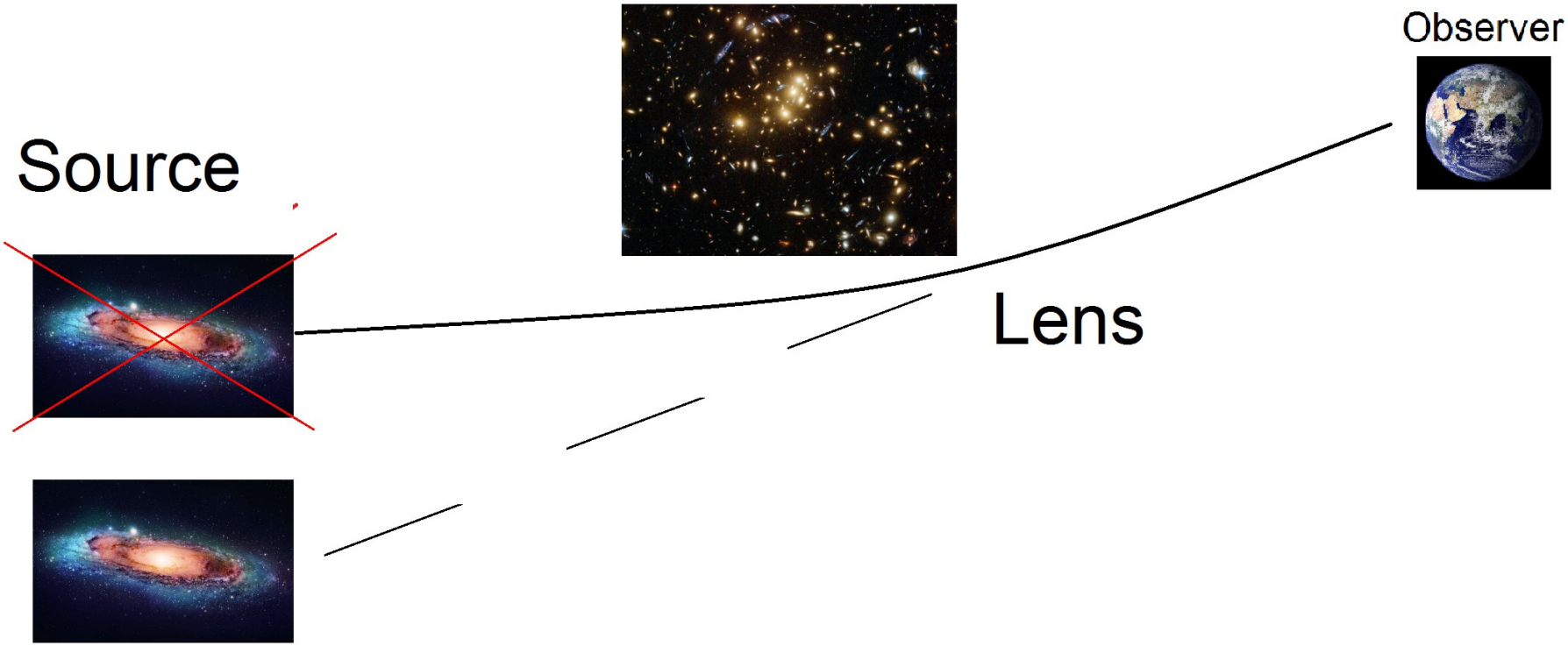
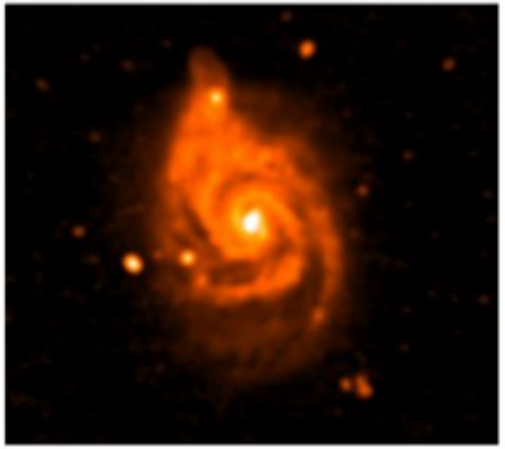
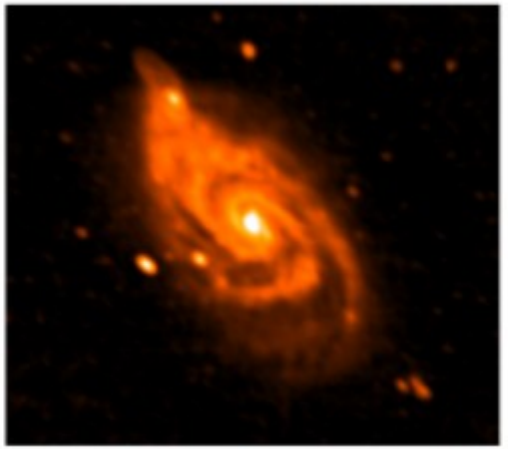
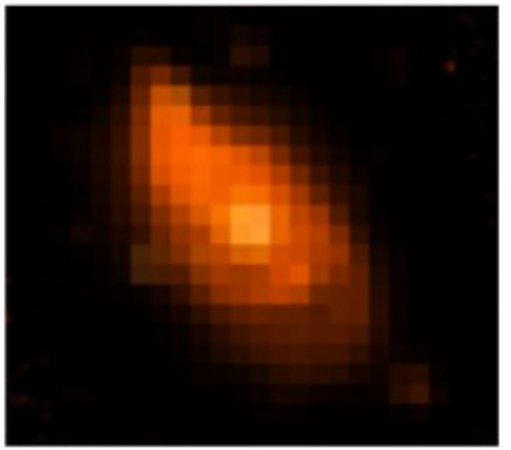


Weak Lensing

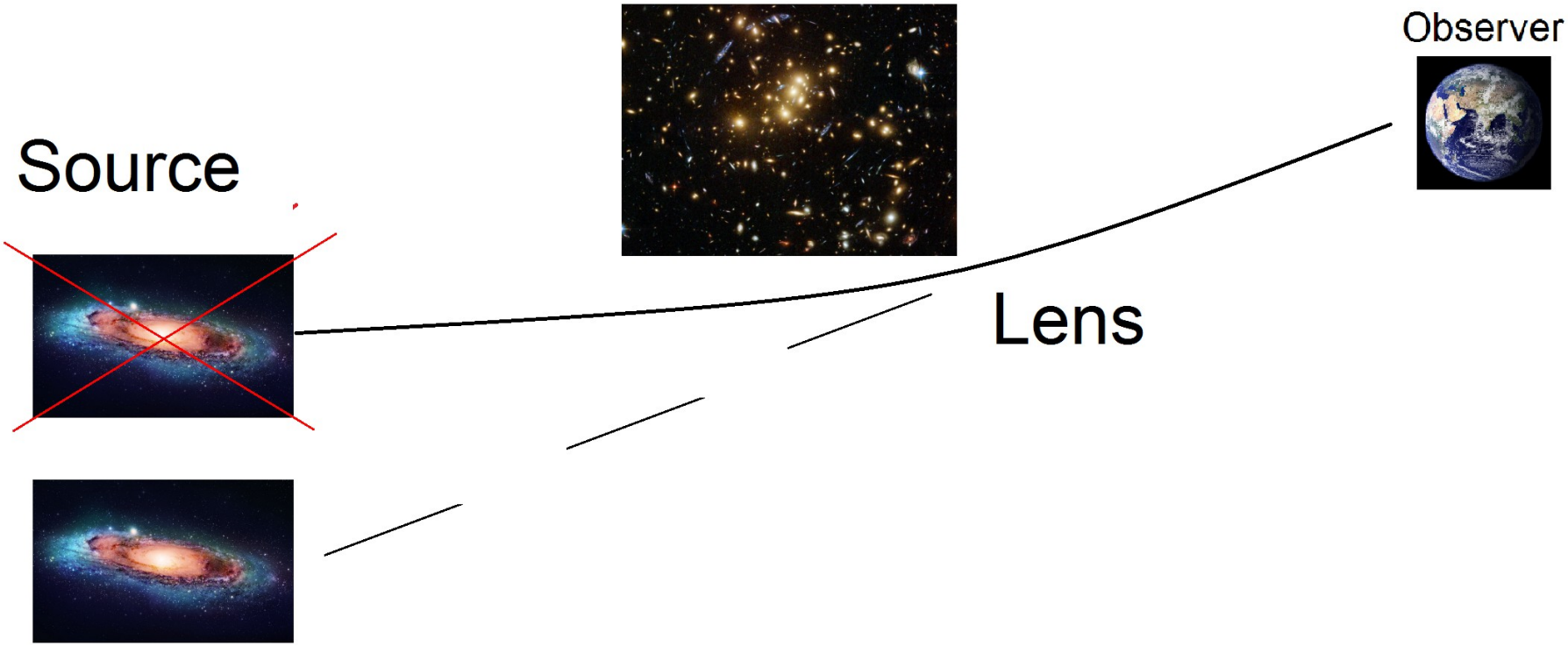
Weak Lensing



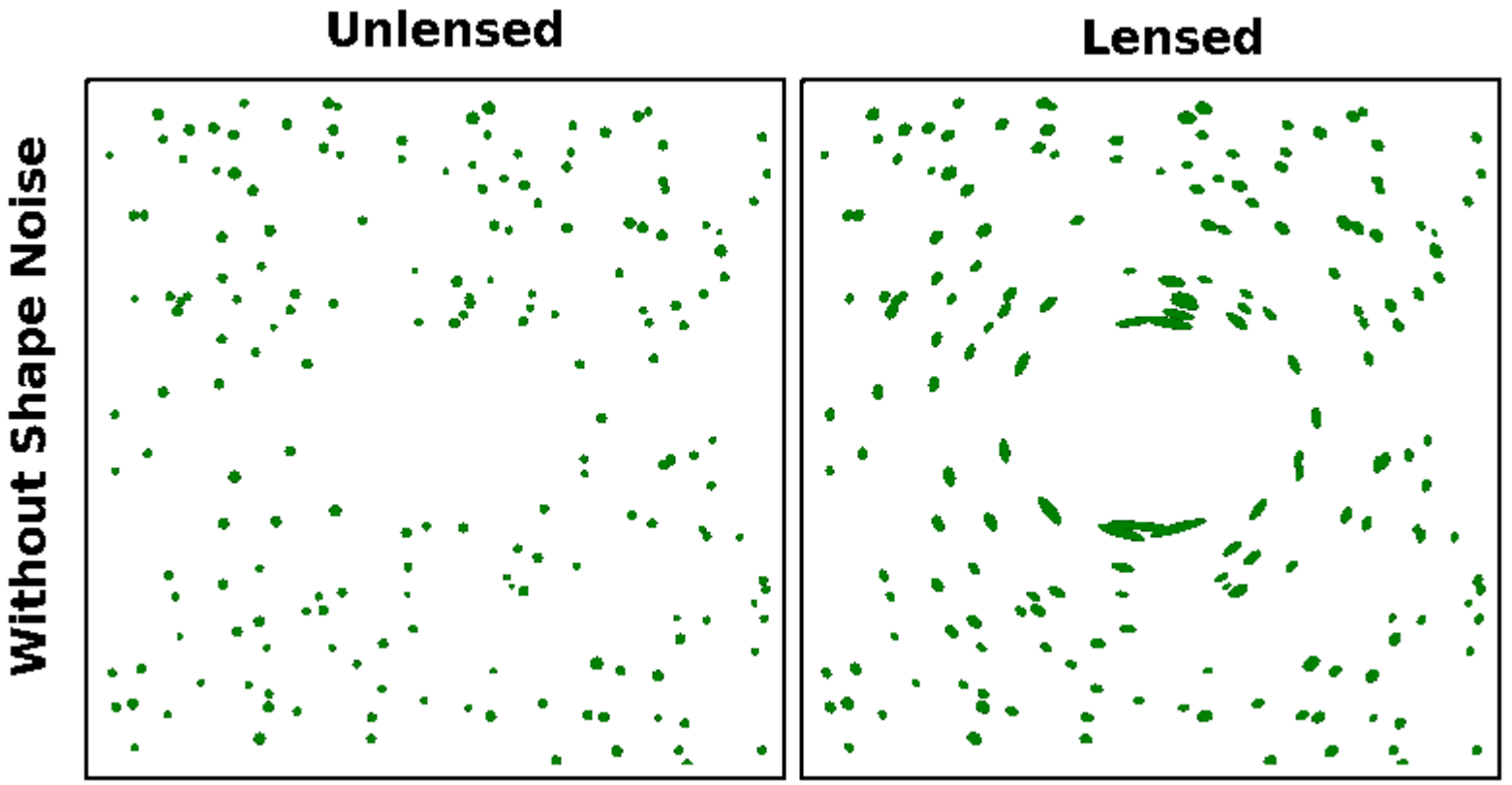
Weak Lensing

Weak Lensing



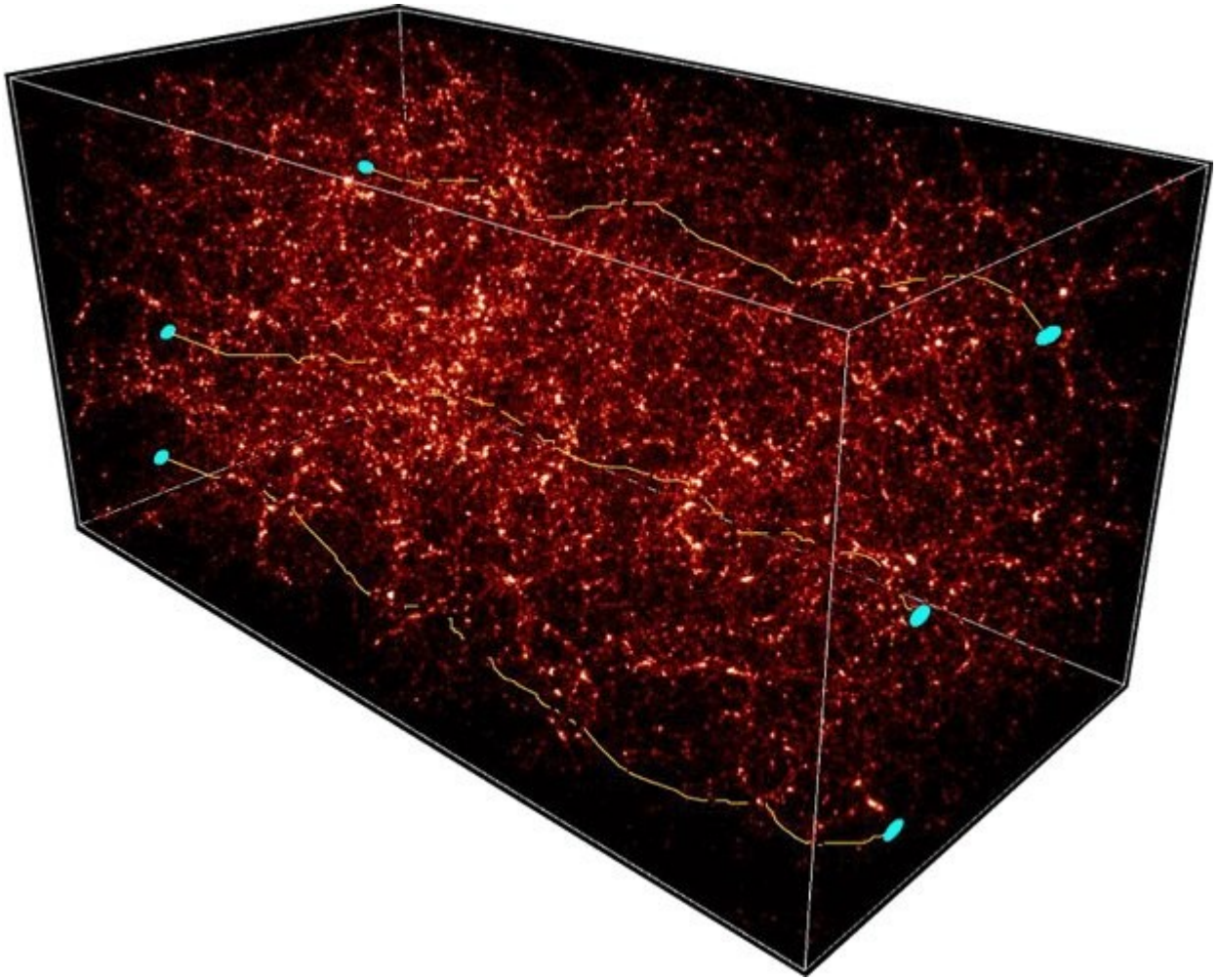
Weak Lensing



Weak Lensing – Bullet Cluster

Weak Lensing – DES

Mapping The Universe

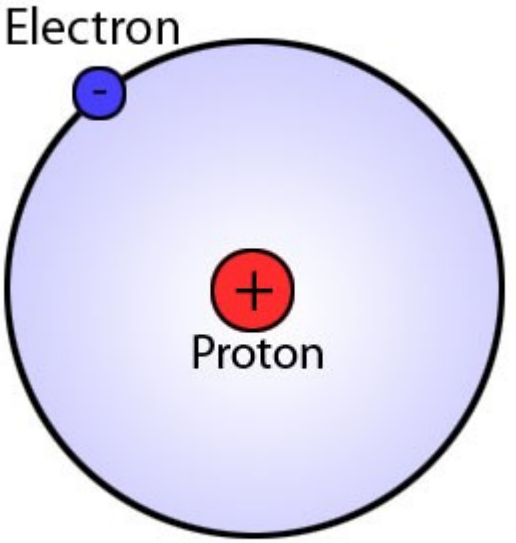


Thank You and Questions!

Microlensing – Dark Matter

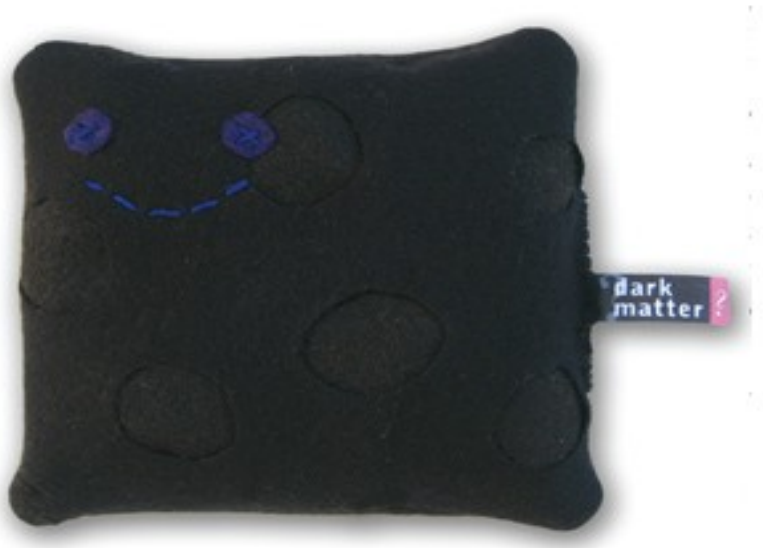
Baryonic Matter

- **Baryonic matter primarily interacts via the Coloumbic force.**
- **Negative and positives forces attract and repel one another.**
- **Gravity, although present, is insignificant.**

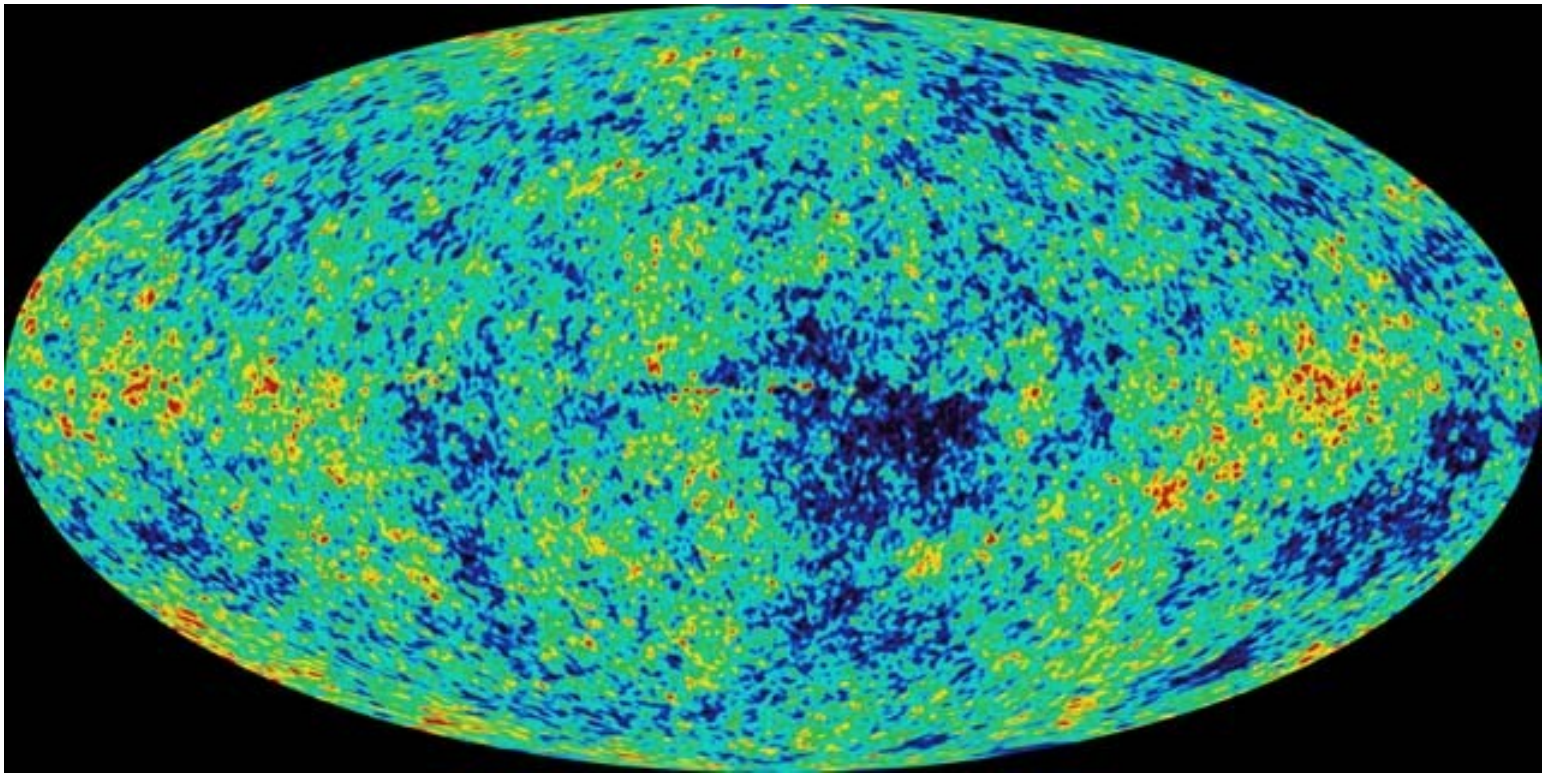


Dark Matter

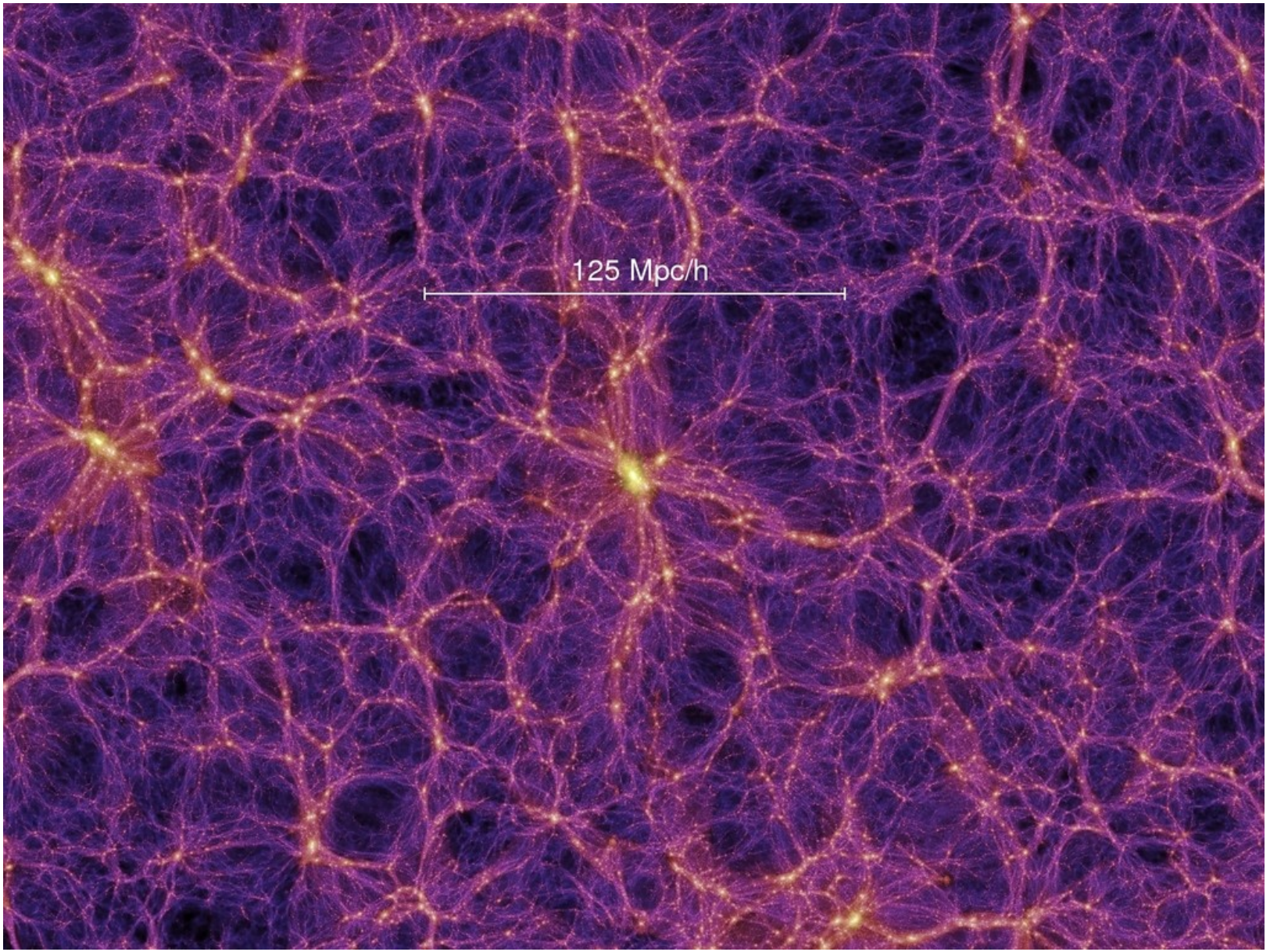
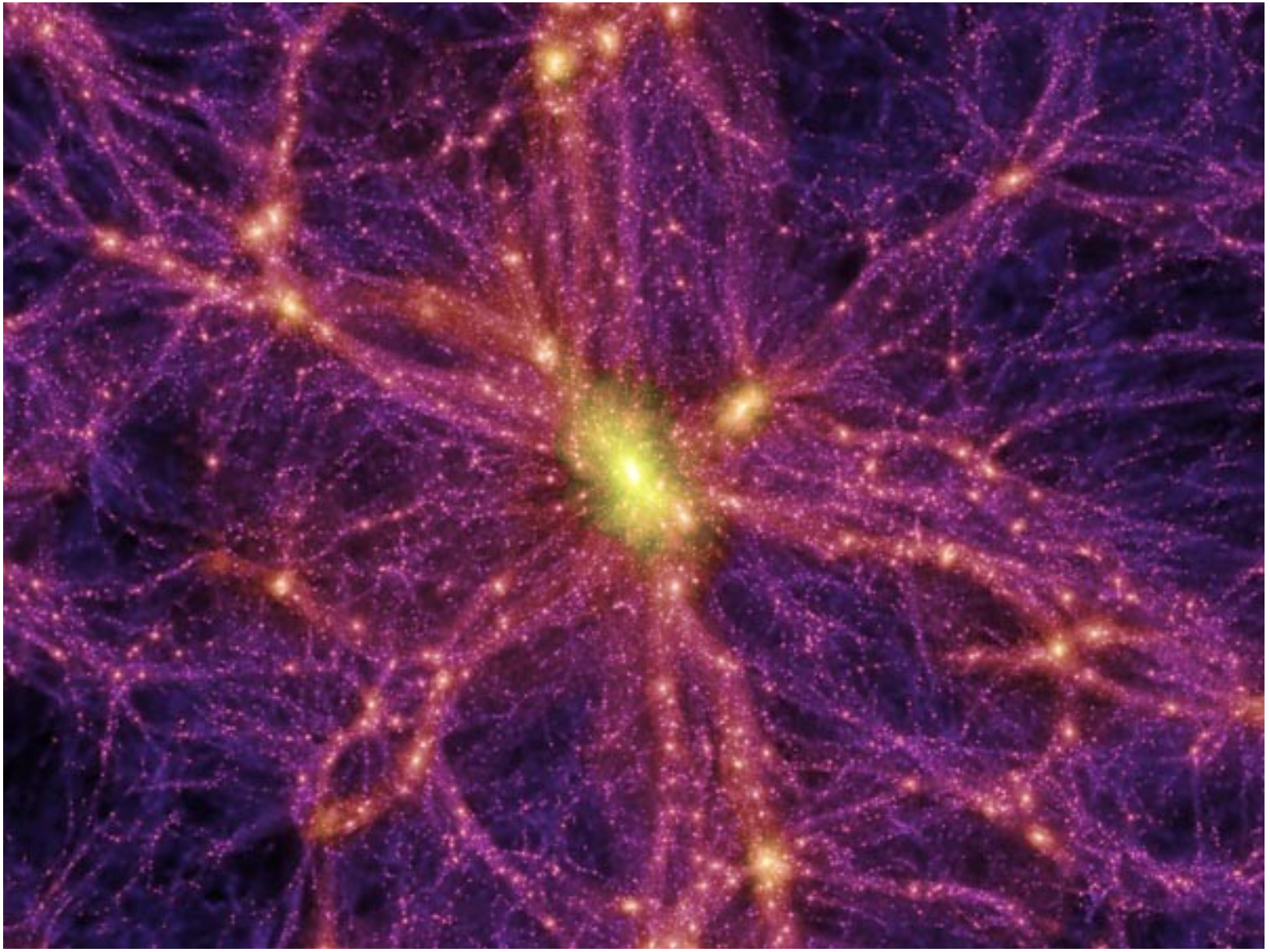
- **The dark matter particles interacts only via gravity.**



Cosmic Microwave Background



Weak Lensing – Dark Matter Simulations



Weak Lensing – Dark Matter