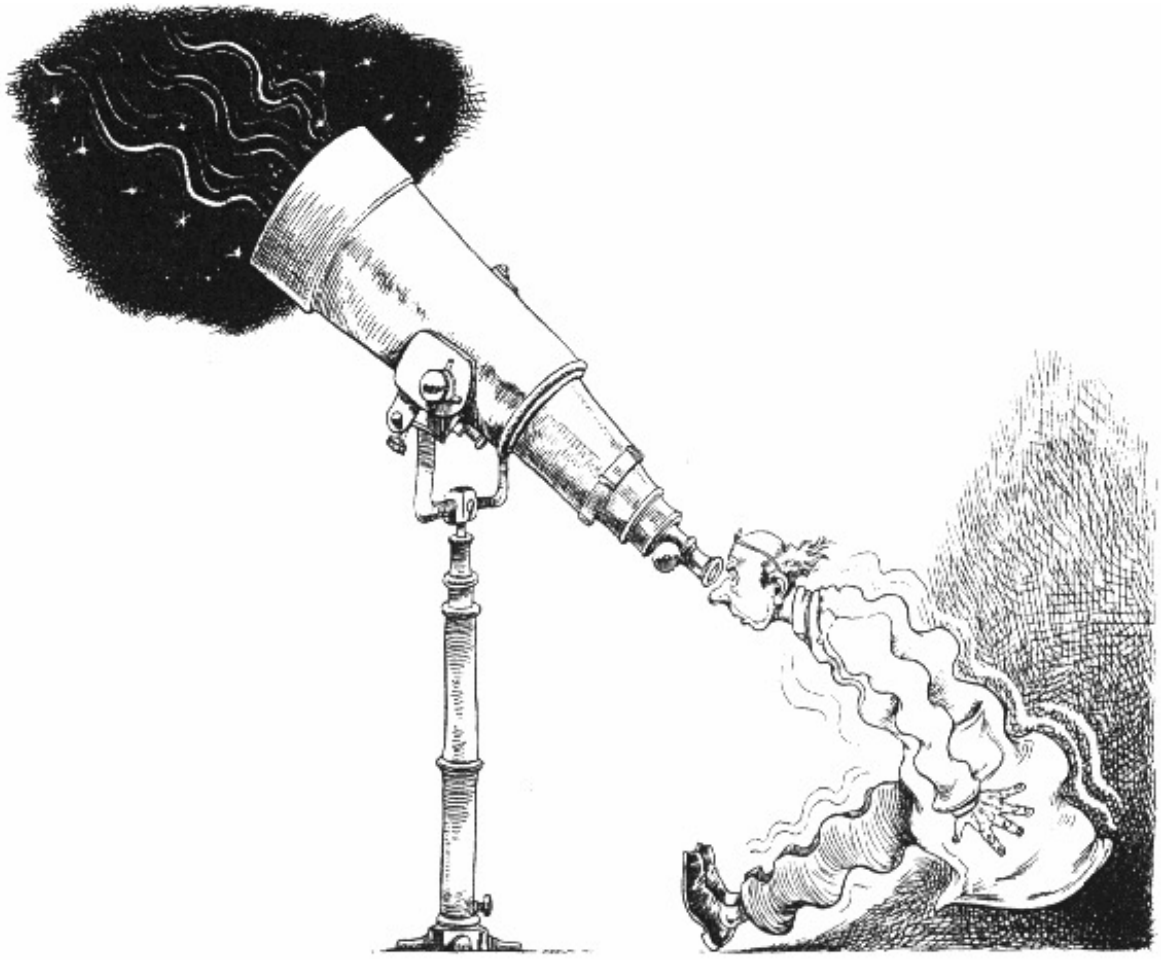
Gravitational Lensing

Alexander Knebe, *Universidad Autonoma de Madrid*



- motivation
- flavours
- history

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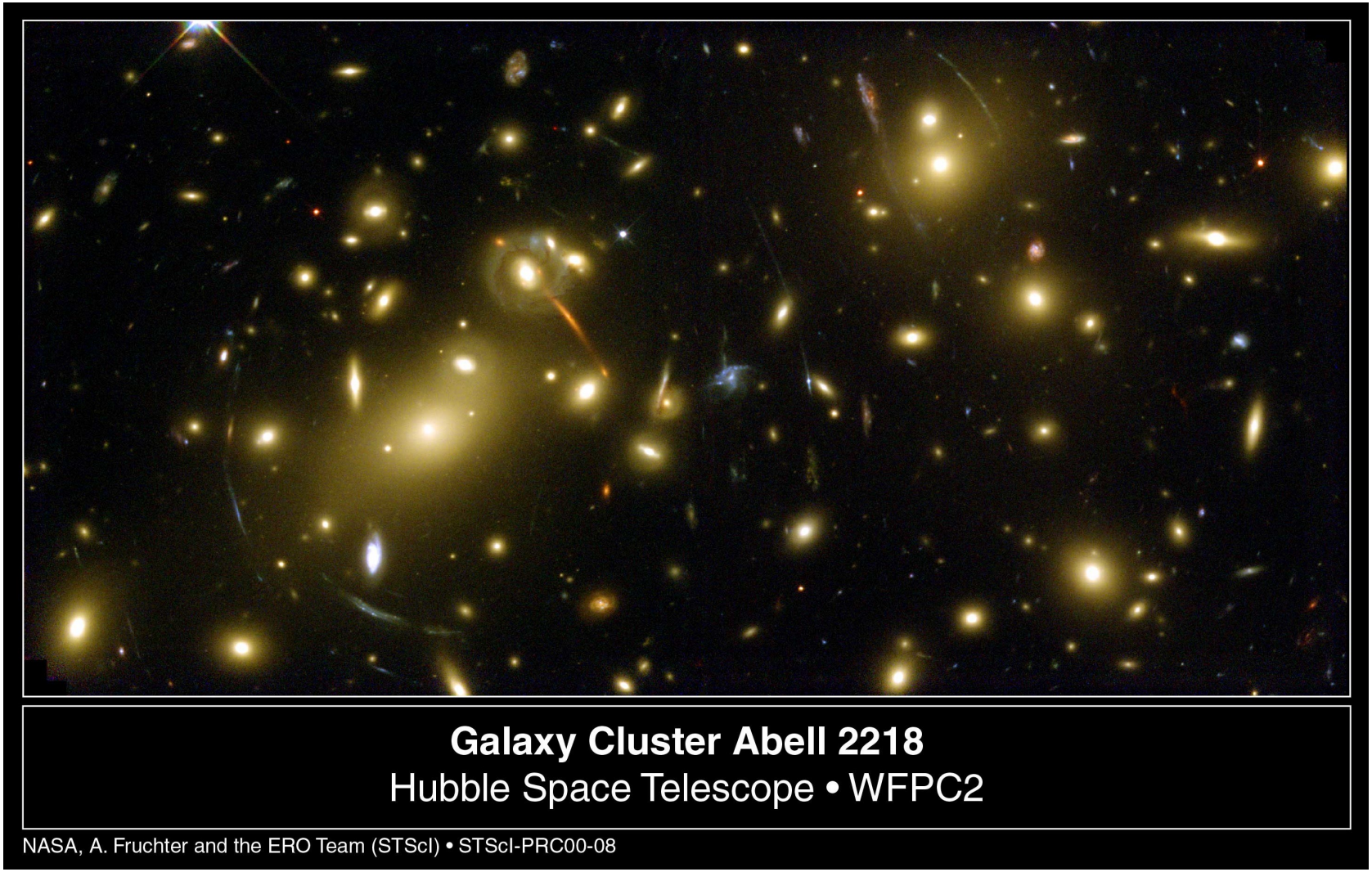
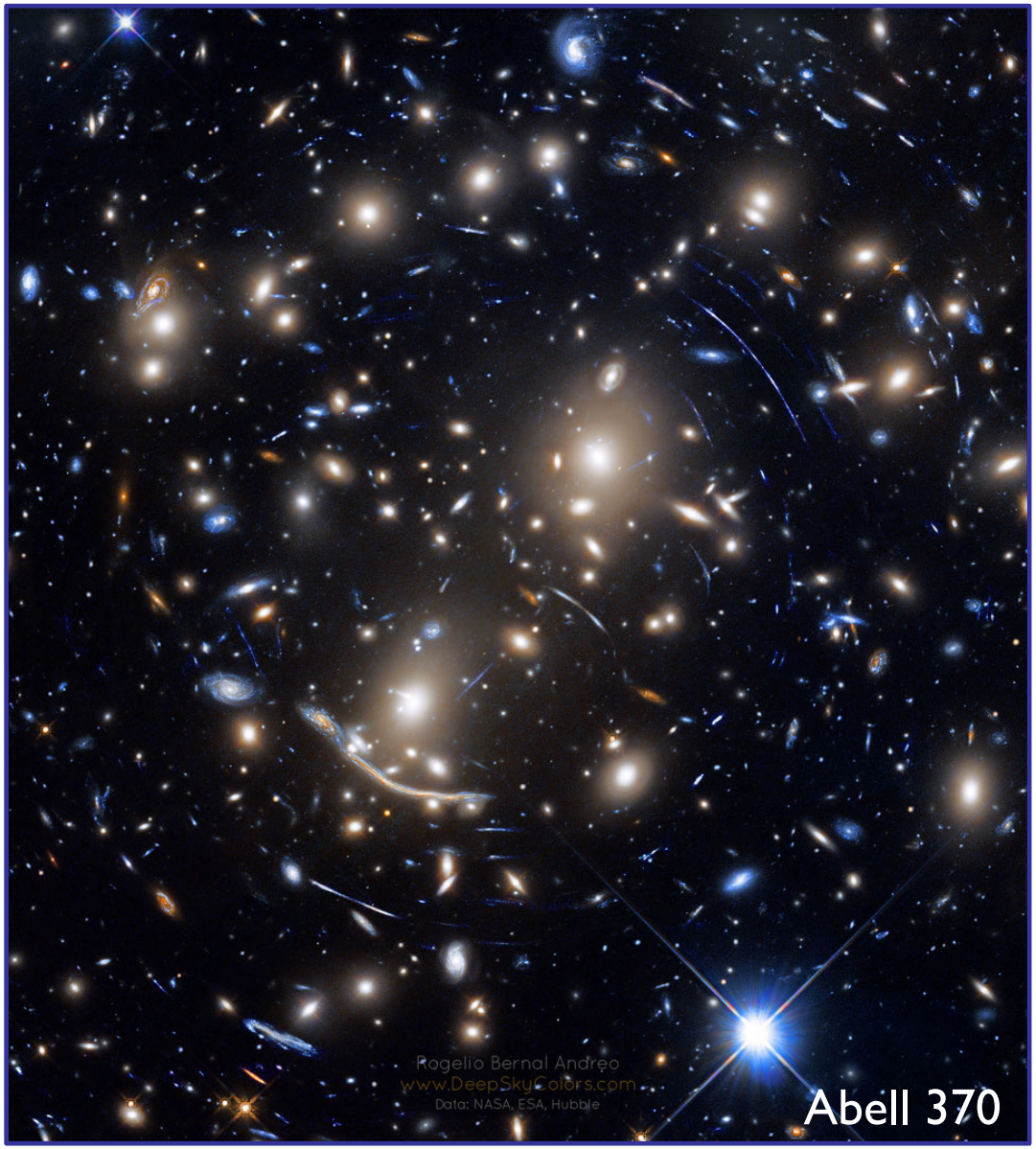
- flavours
- history



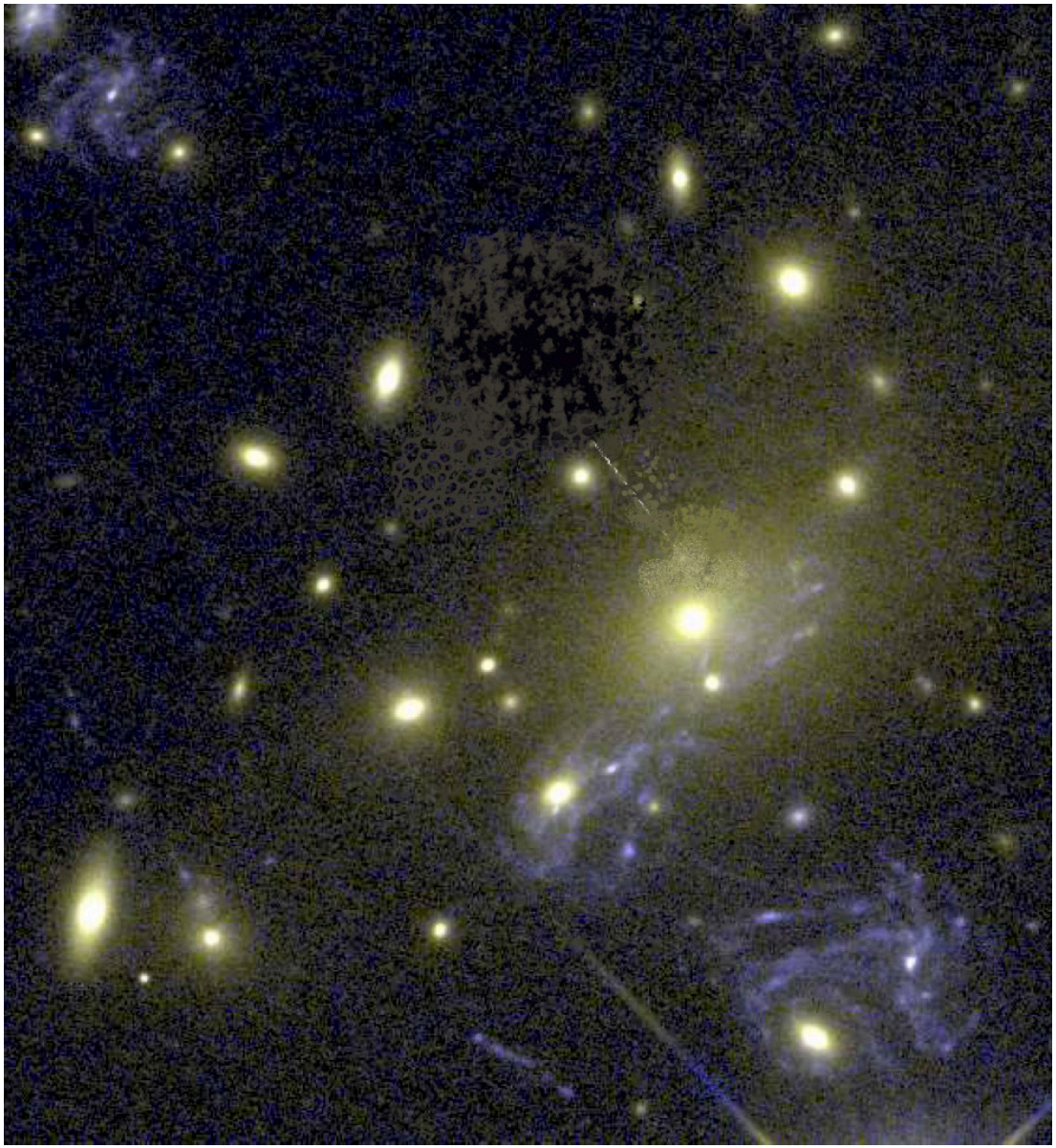
weird shapes and arcs



weird shapes and arcs

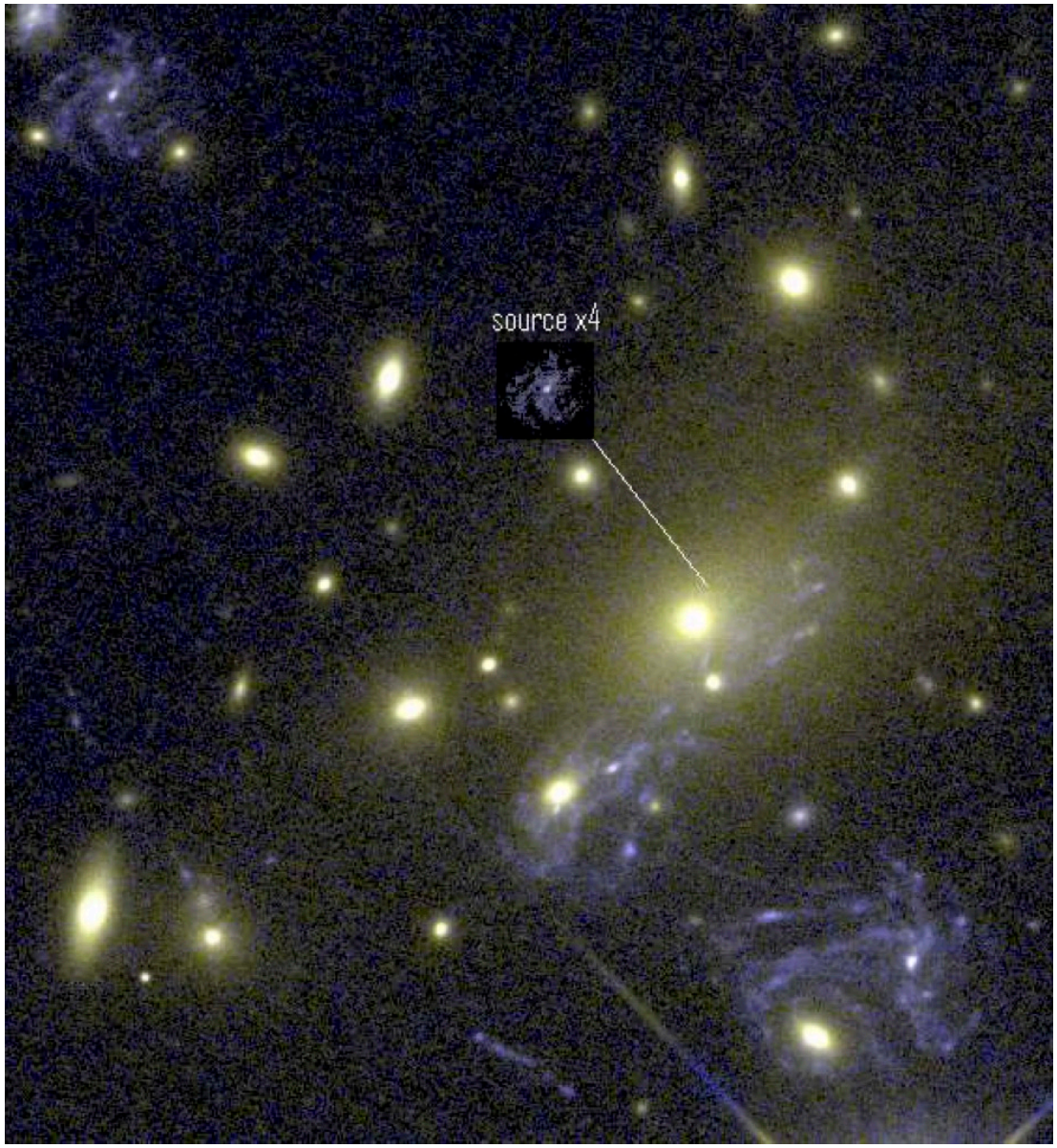
"Cheshire Cat" group of galaxies

...and even faces!?



astro-ph/0906.5079

really weird shapes



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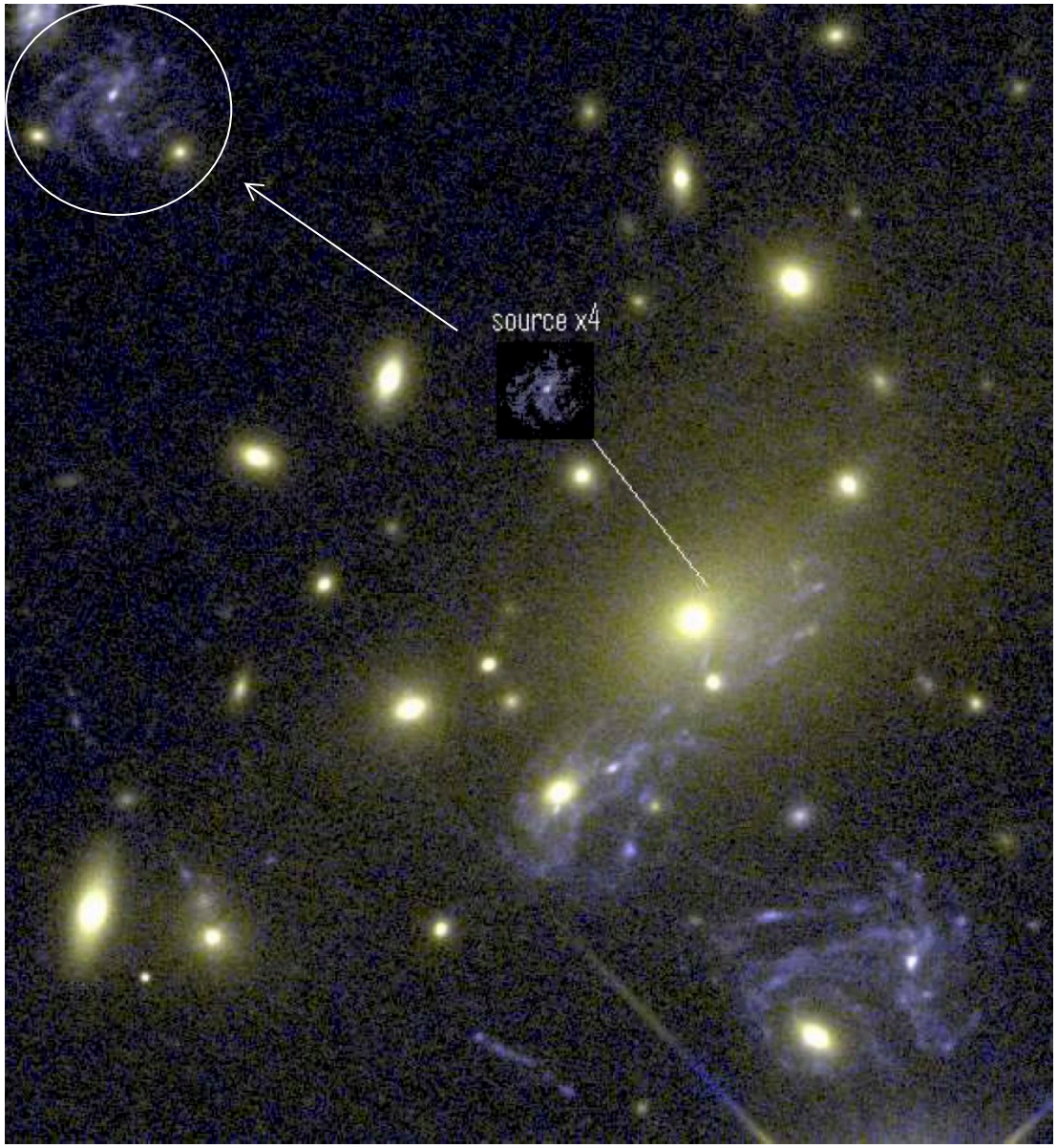

really weird shapes

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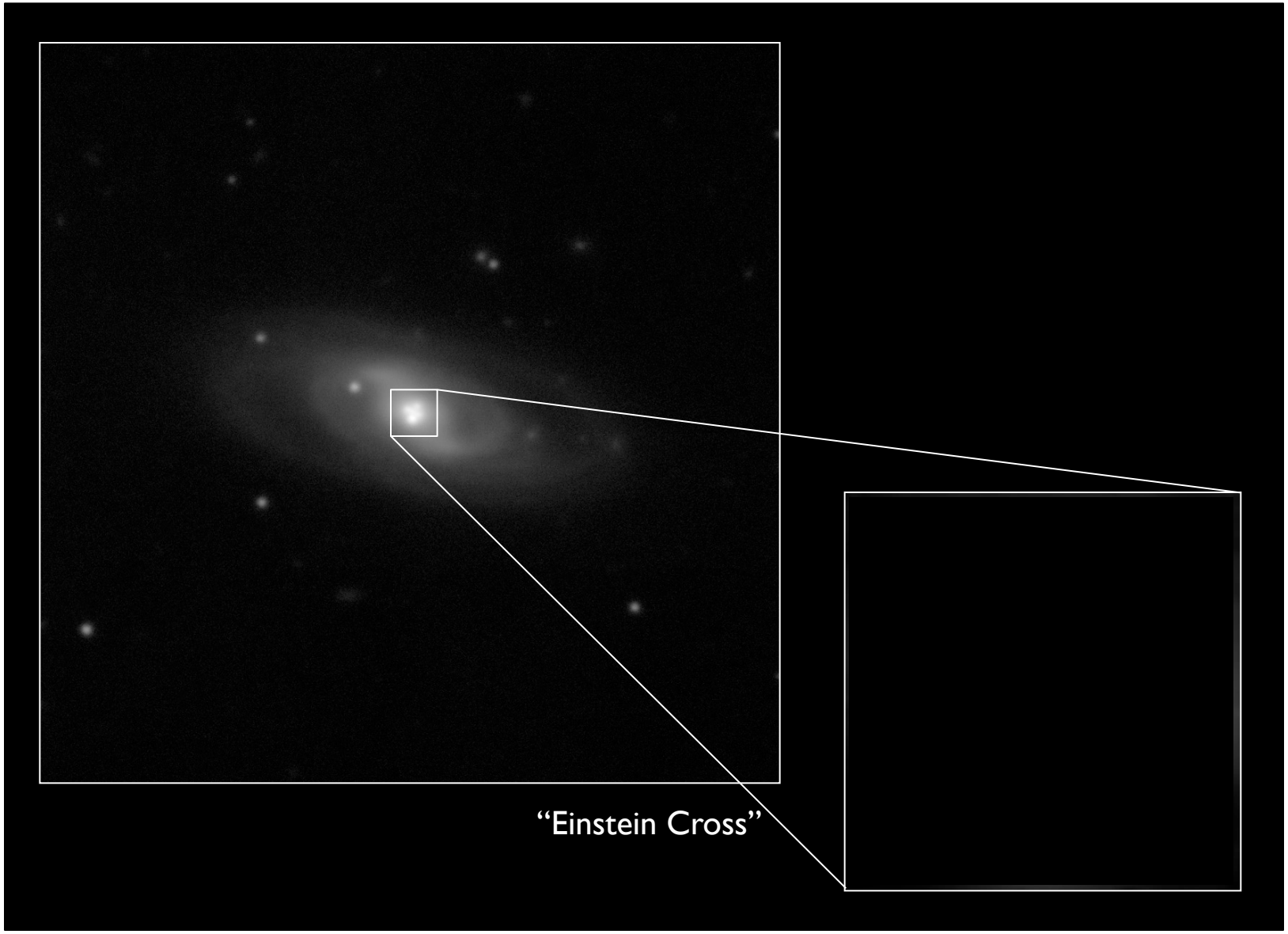
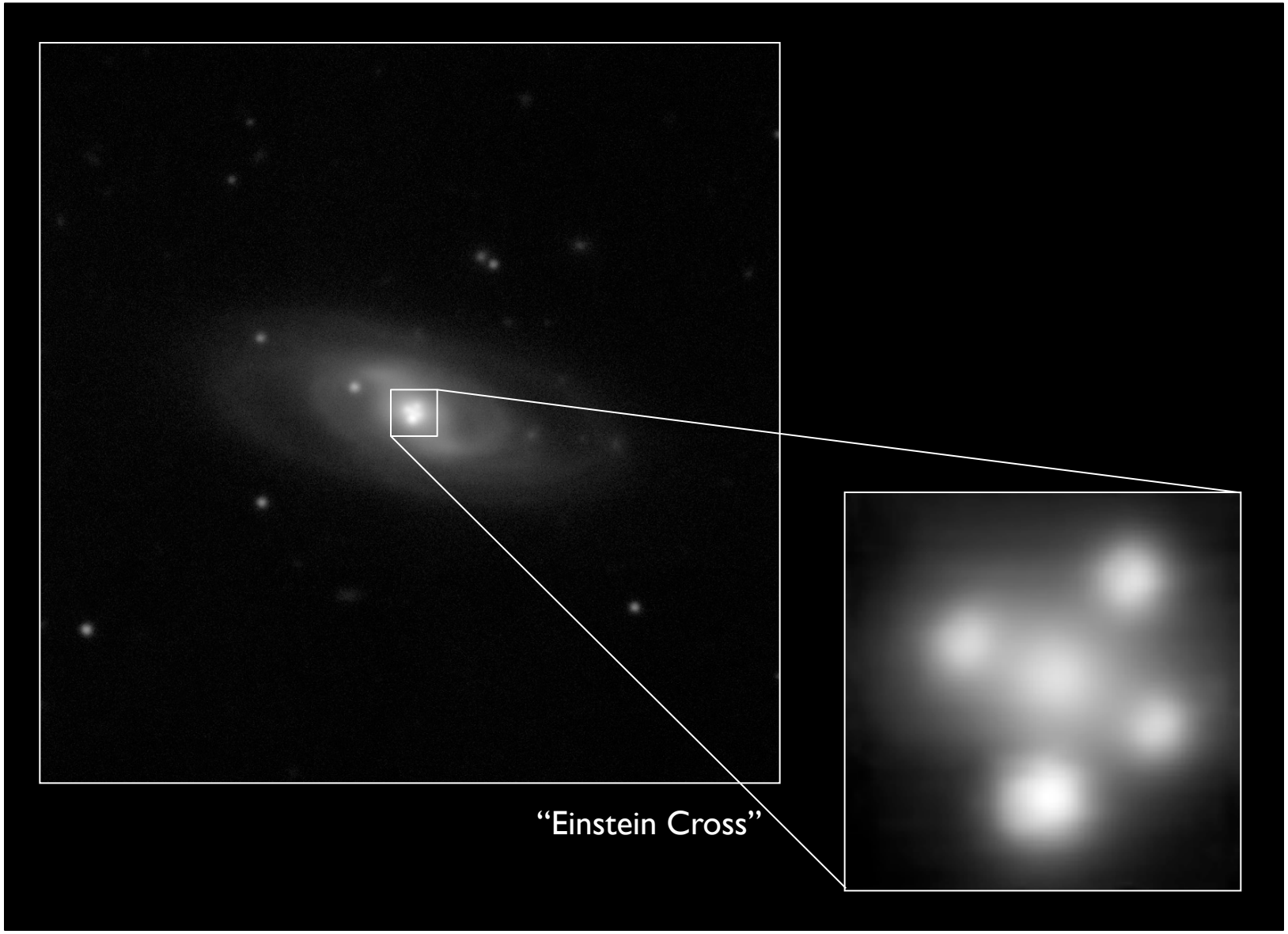

"Einstein Cross"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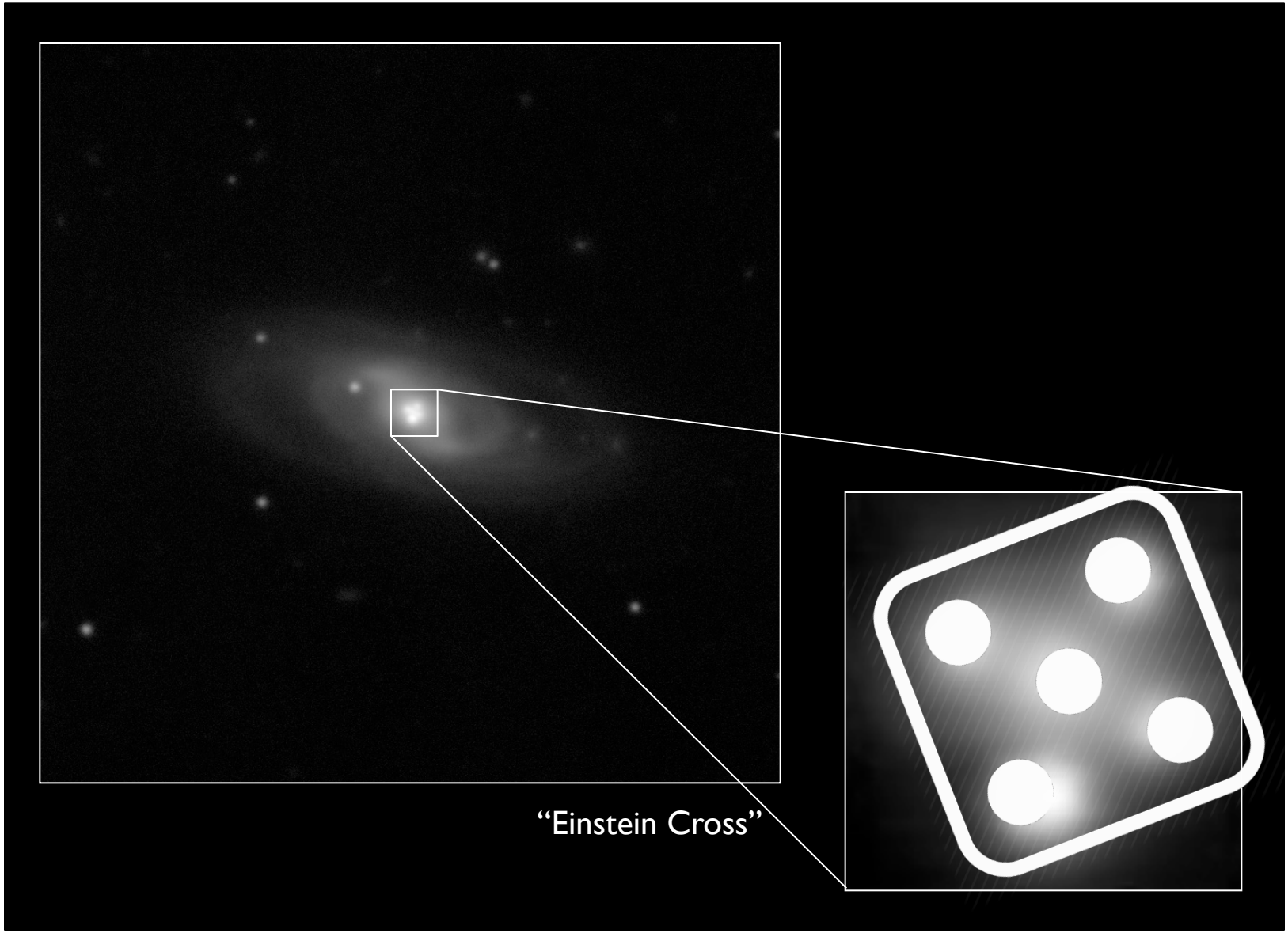
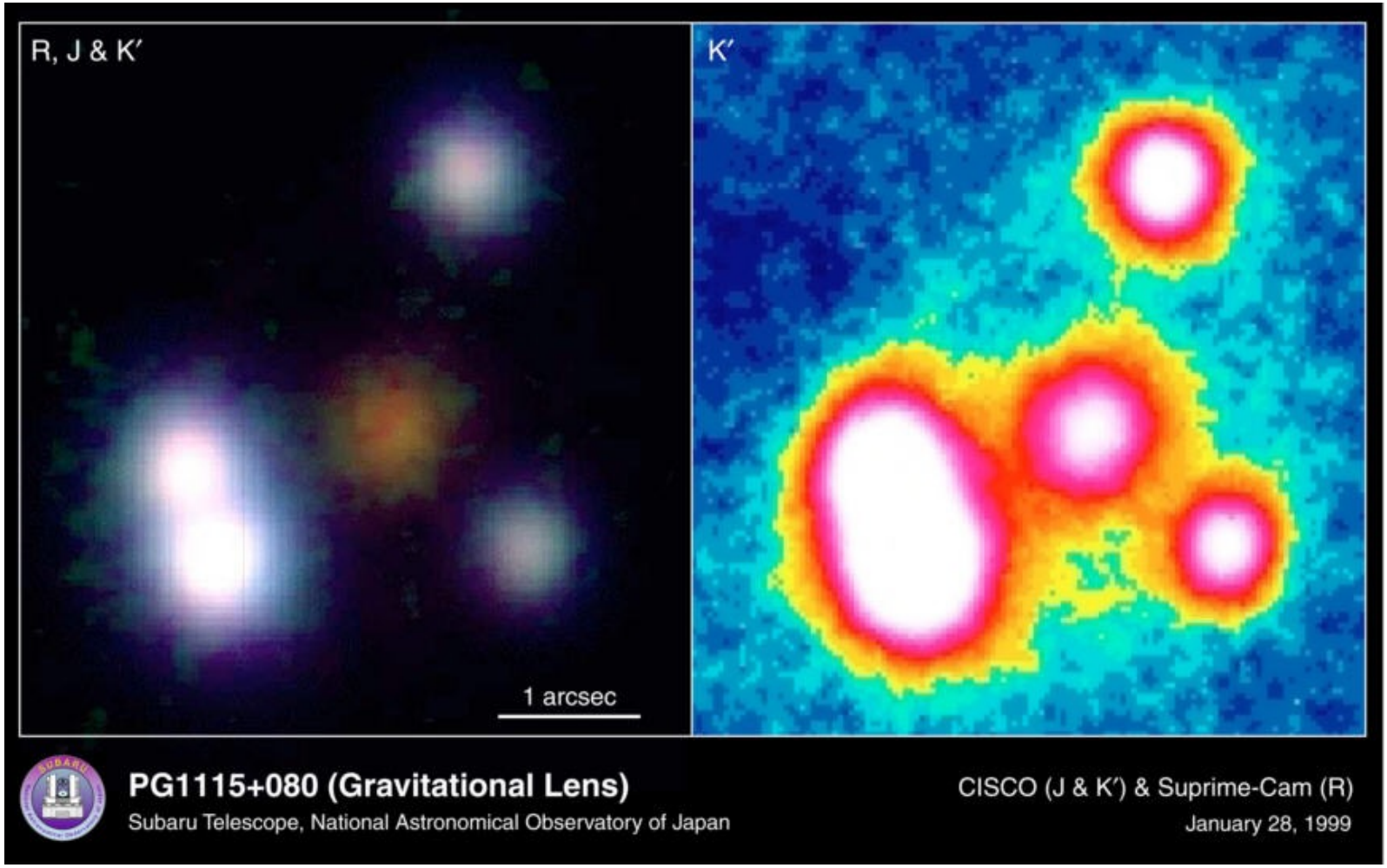
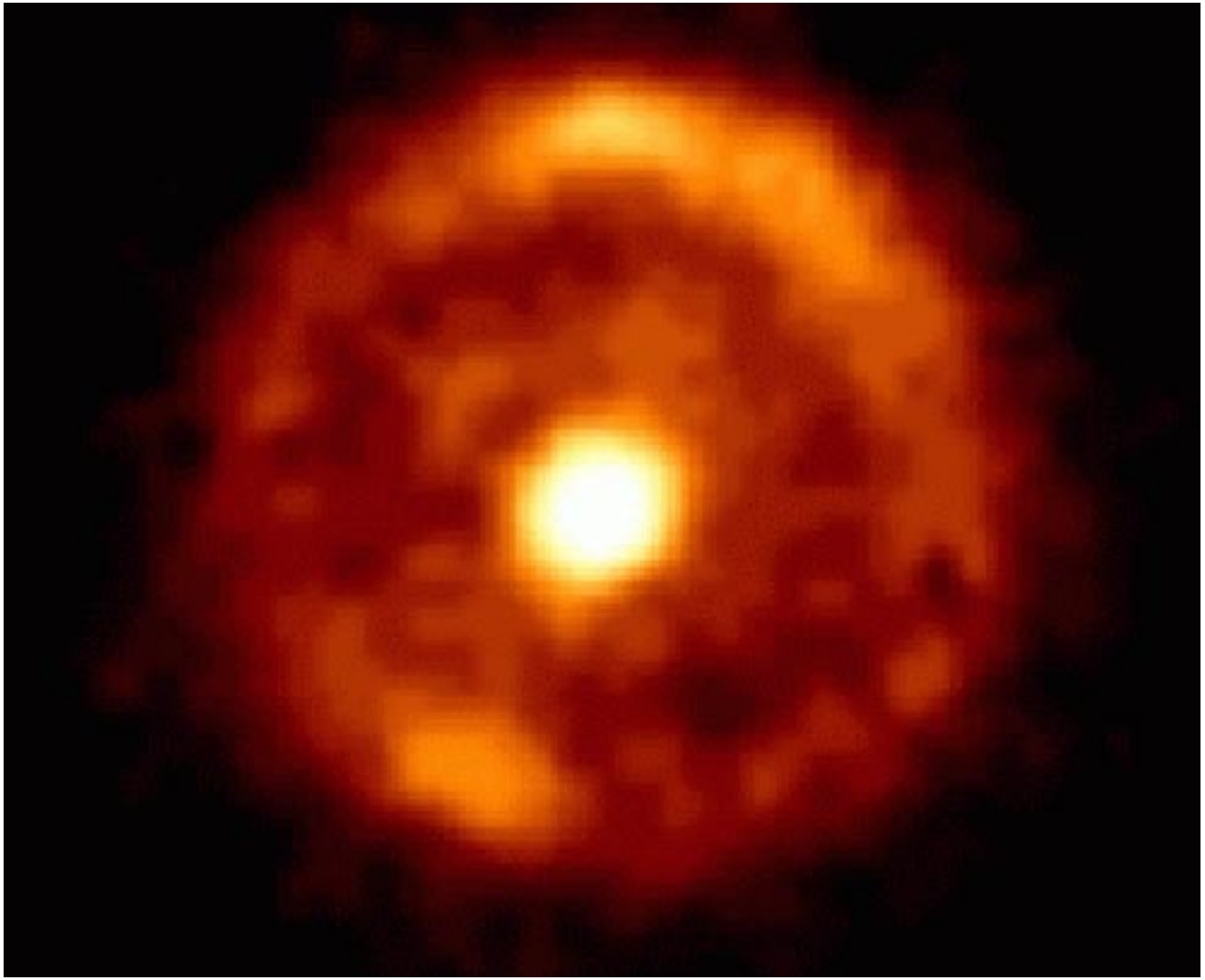


dices?

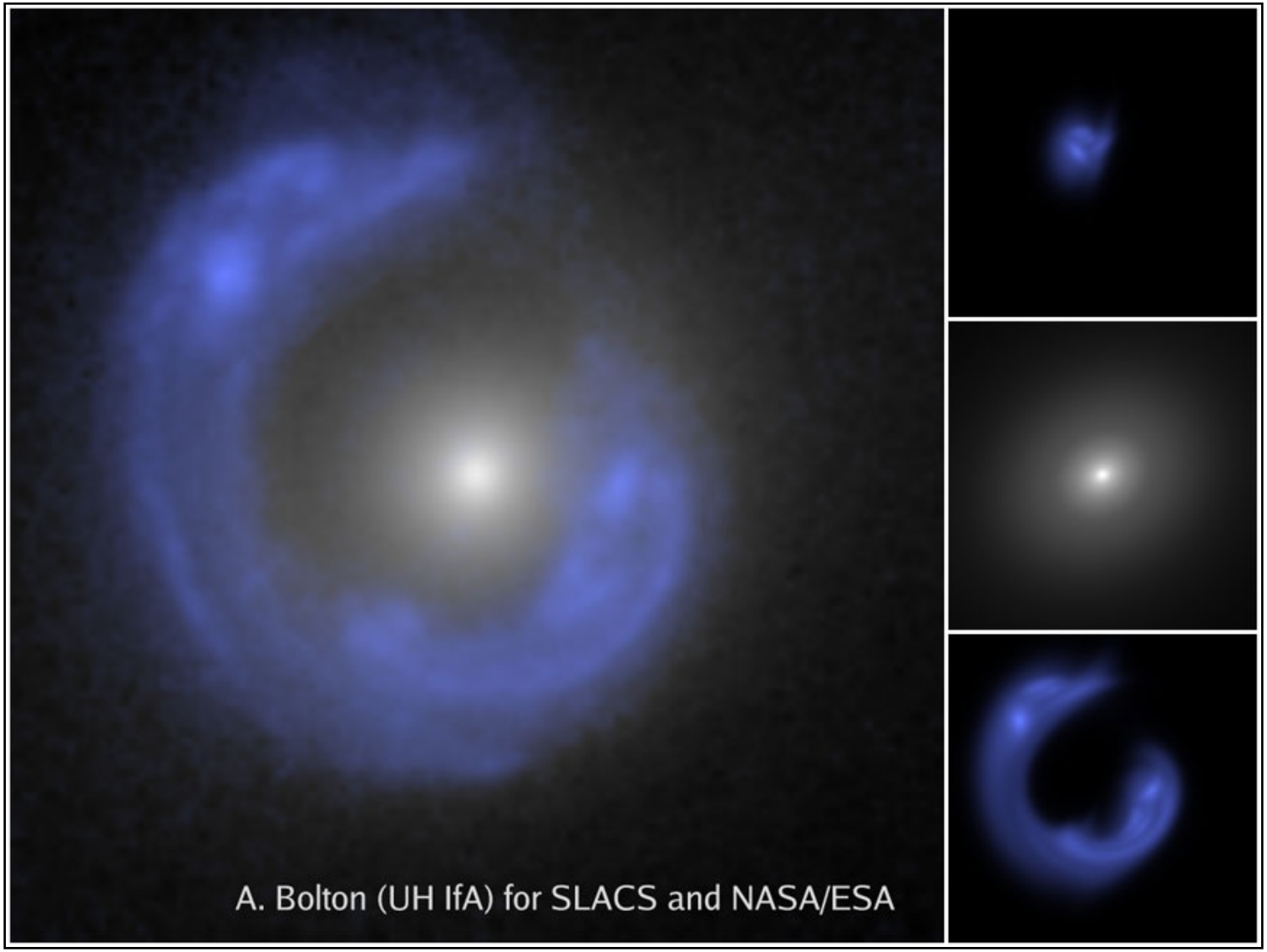


independent of wavelength!



B1938+666

ghostly rings



SDSS J1430

ghostly rings

CL0024+17

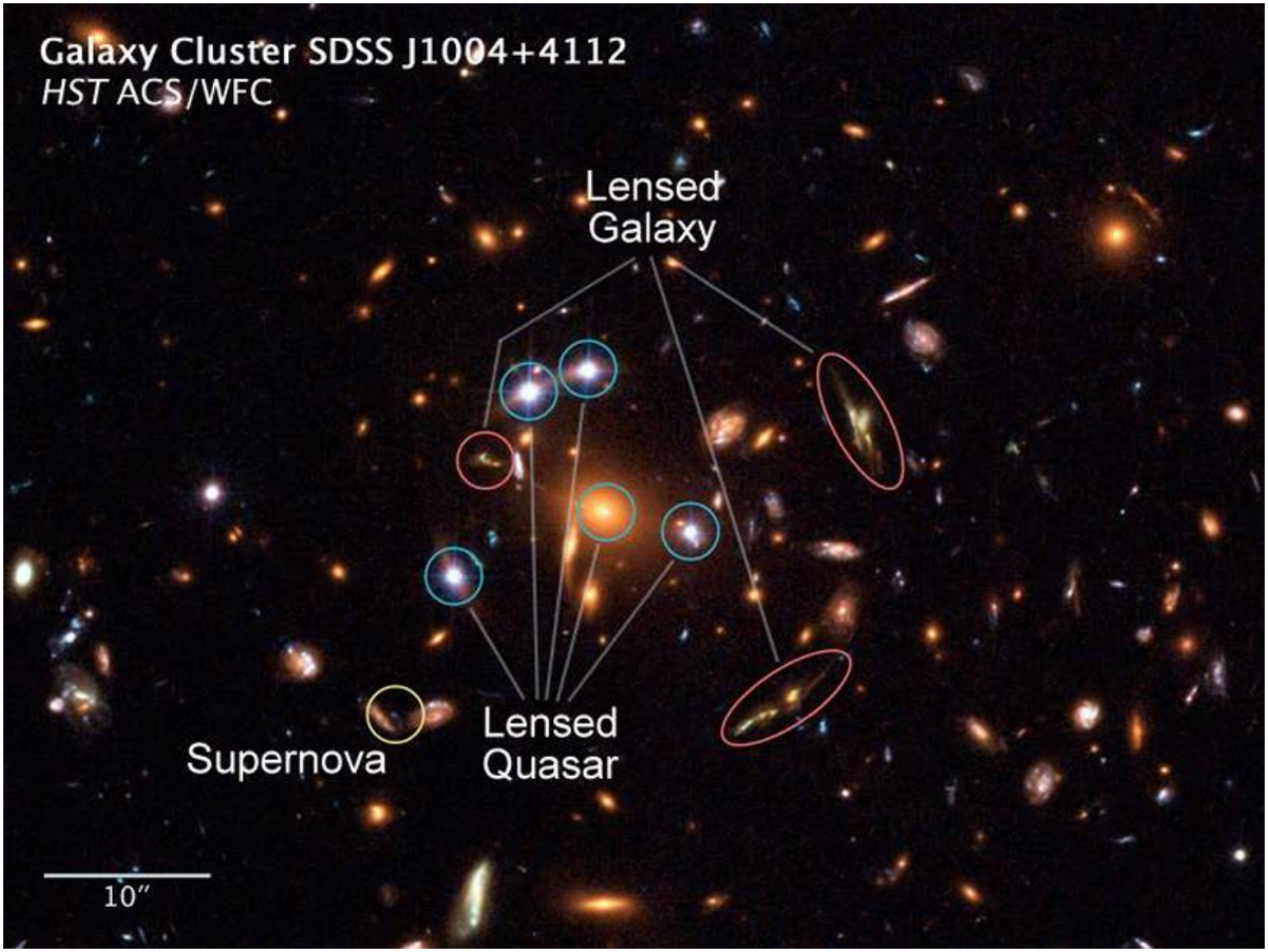
ghostly rings

dark matter ring surrounding galaxy cluster

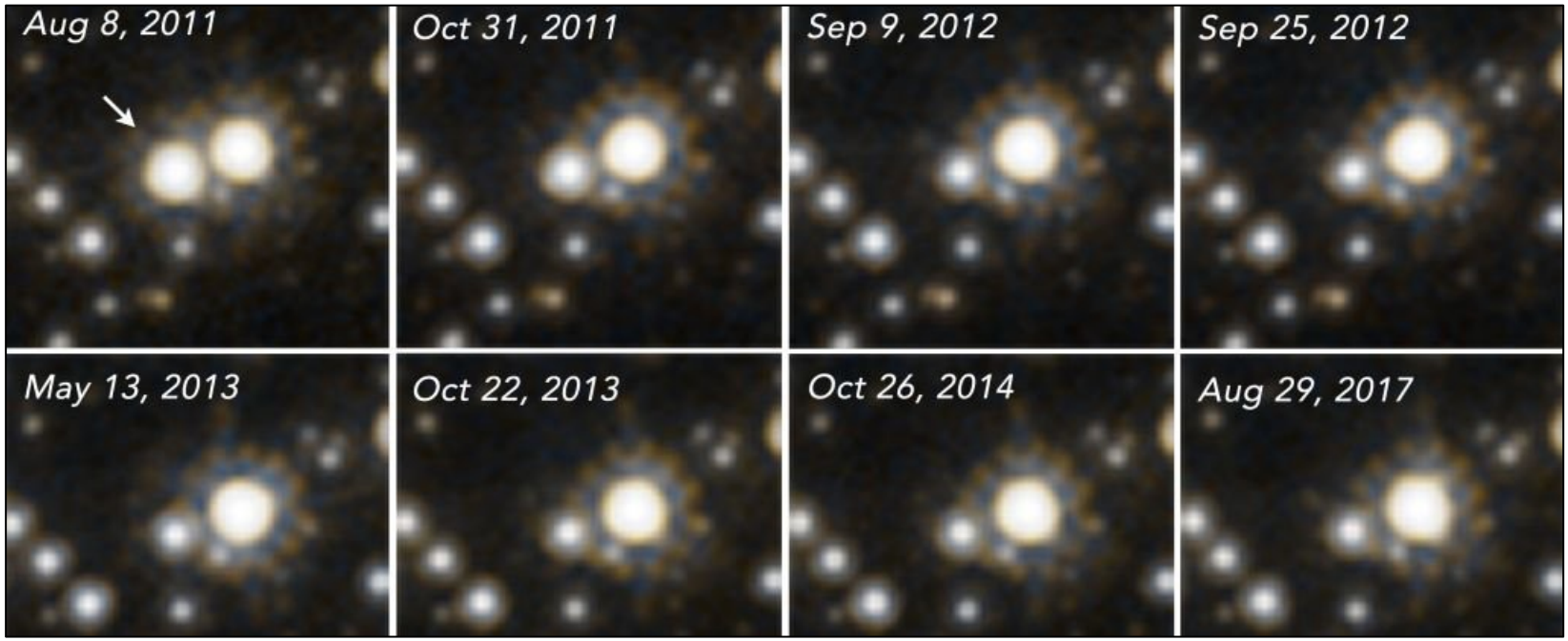
(Lee et al., 2007, ApJ, 661, 728)

CL0024+17

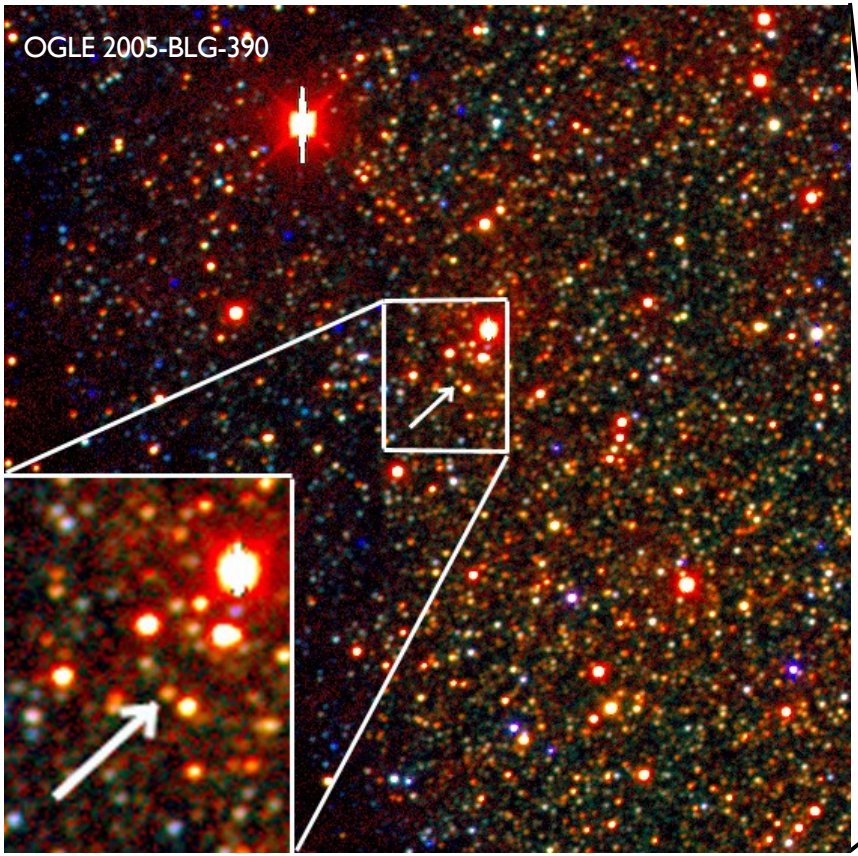
ghostly rings

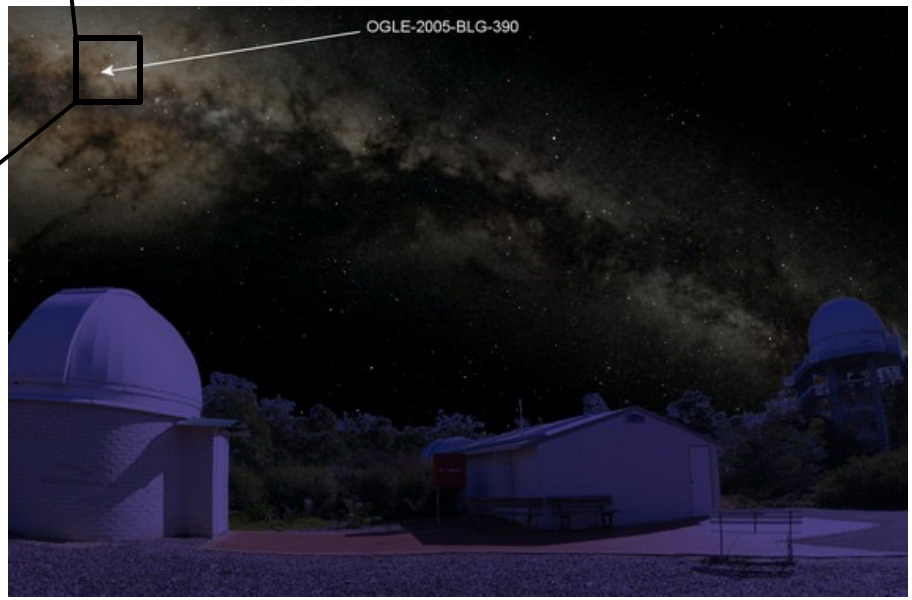


…and all at once!



sudden magnification of stars?





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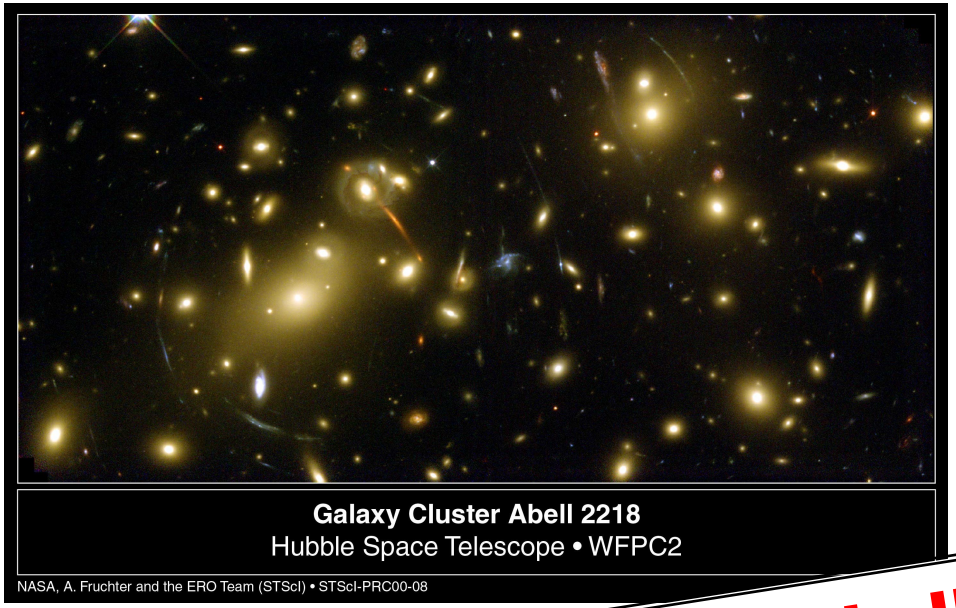
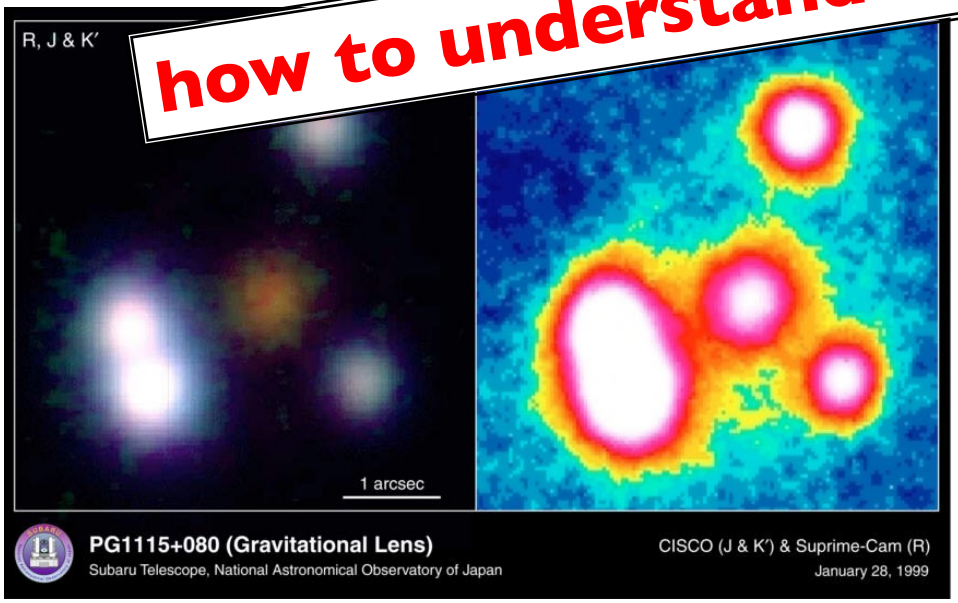
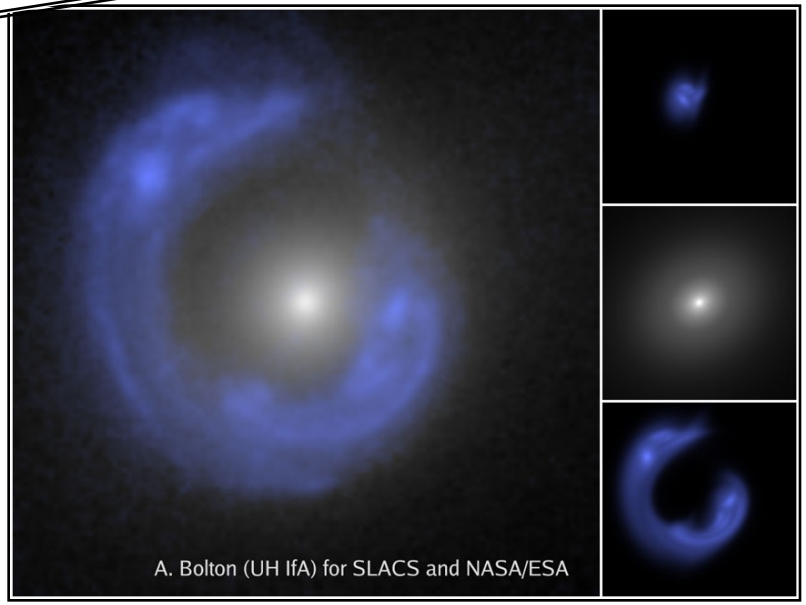


how to understand all these phenomena?





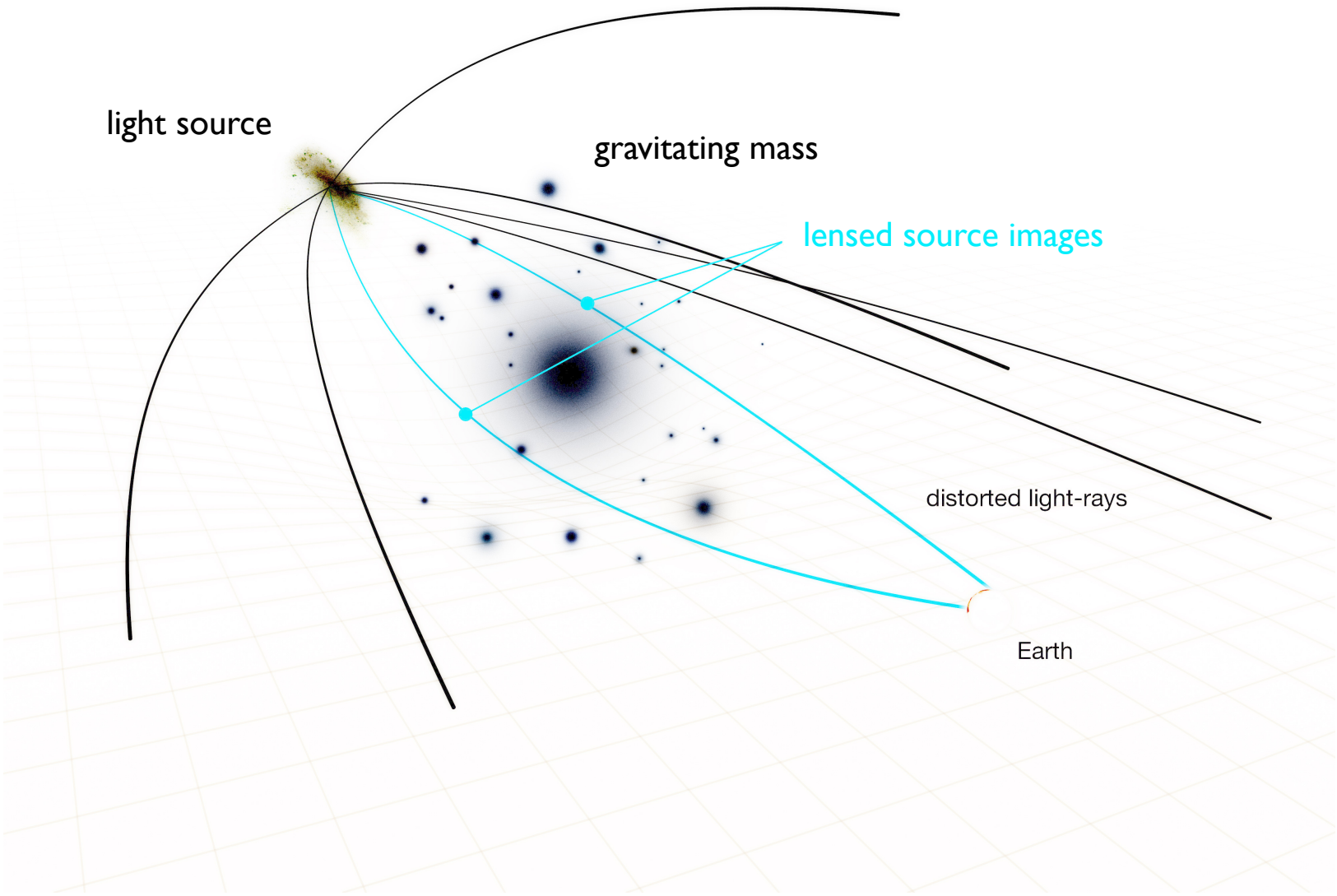
- motivation
- **flavours**
- history

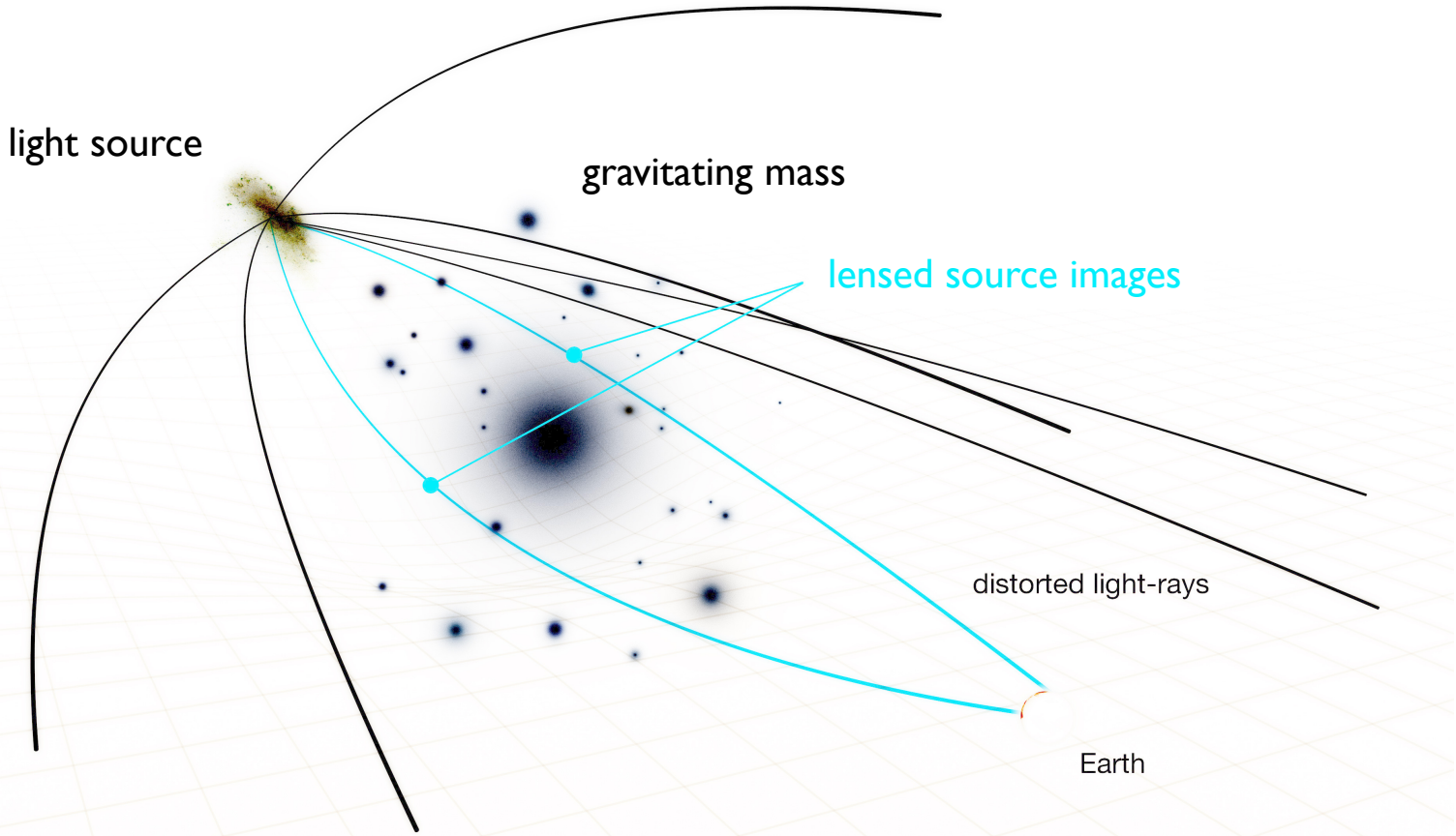
…subtle differences of the same underlying phenomenon!

all these phenomena are "flavours"
of the same underlying physical concept:

gravitational lensing,

i.e. the deflection of light by mass!

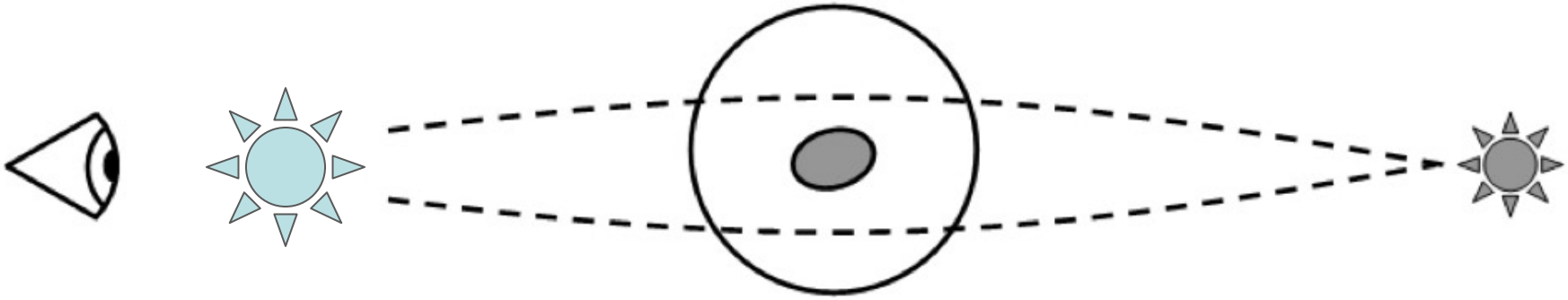

light source
gravitating mass
lensed source images
distorted light-rays
Earth



historically one distinguishes between 3 different flavours…

- microlensing
- strong lensing
- weak lensing

- microlensing
  - mainly referred to as lensing by objects of stellar (point) masses
    ($\rightarrow$ no distortion, mainly magnification)



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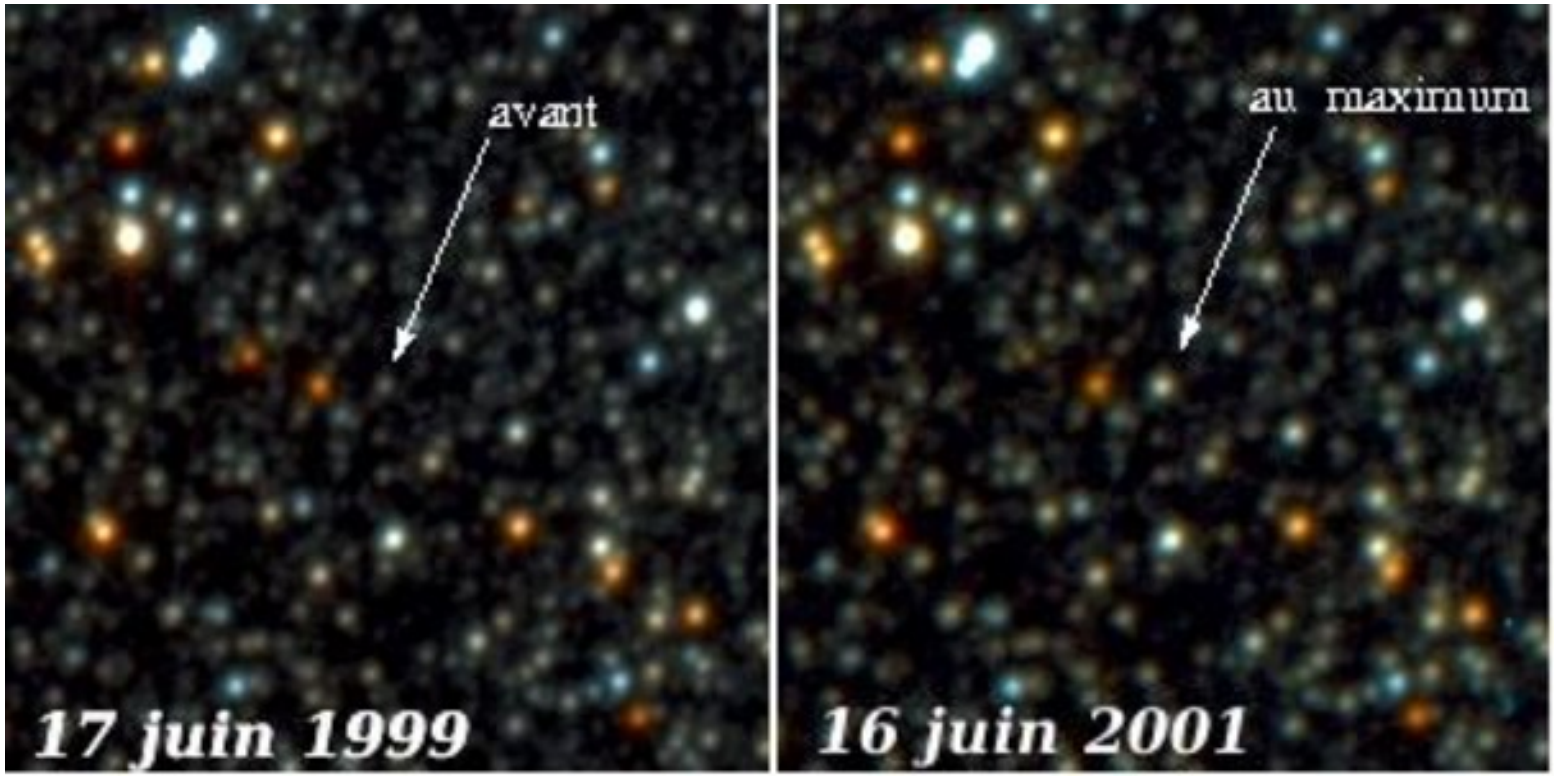
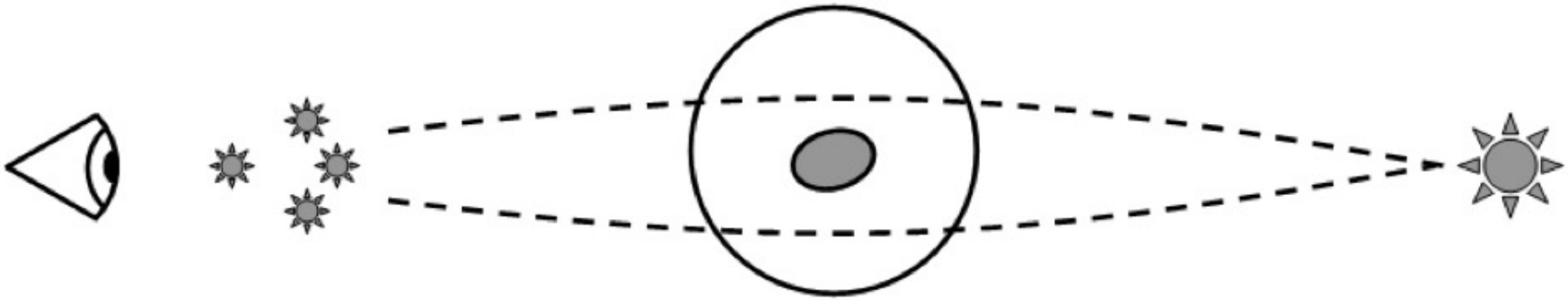


http://eros.in2p3.fr

- microlensing

- strong lensing
  - lensing of background sources by foreground galaxies, clusters, …

  (→ strong distortion, magnification, and multiple images)



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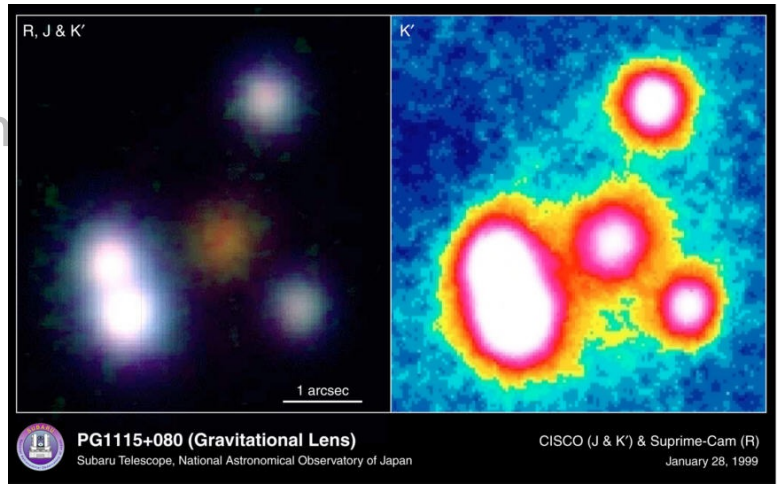
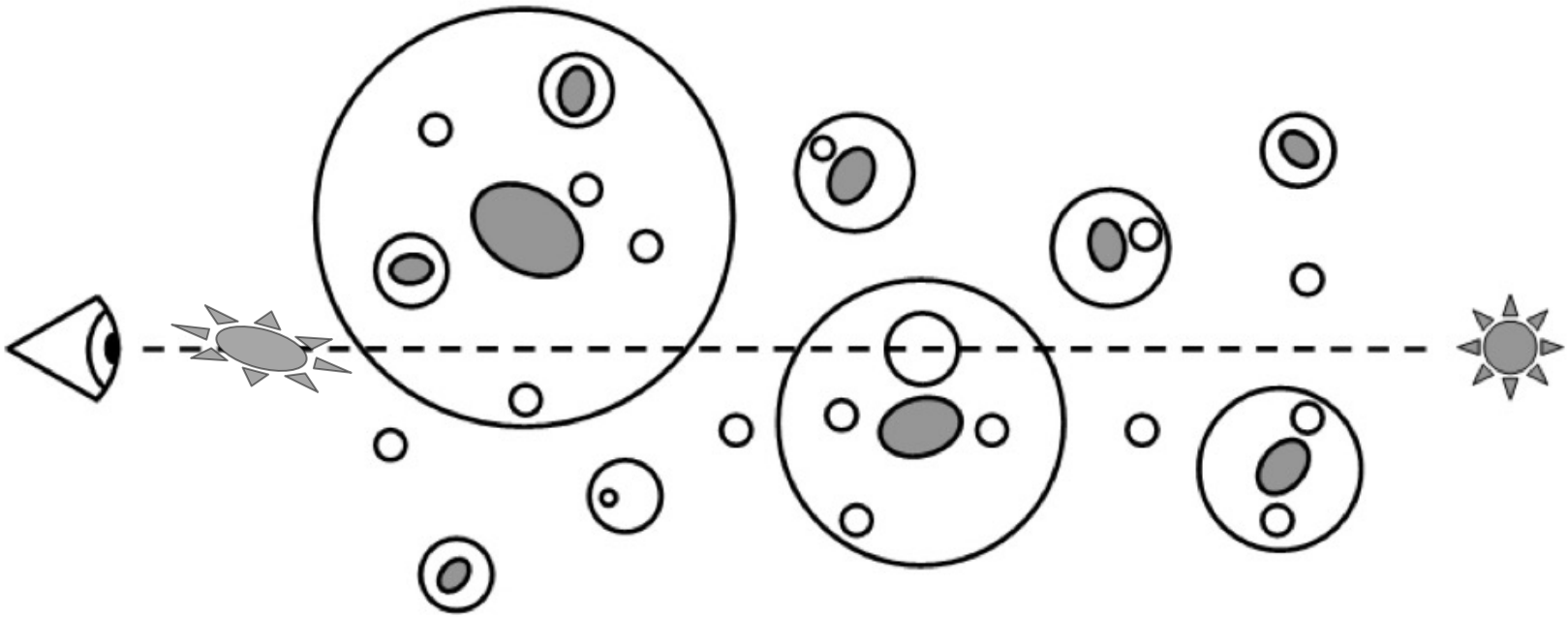
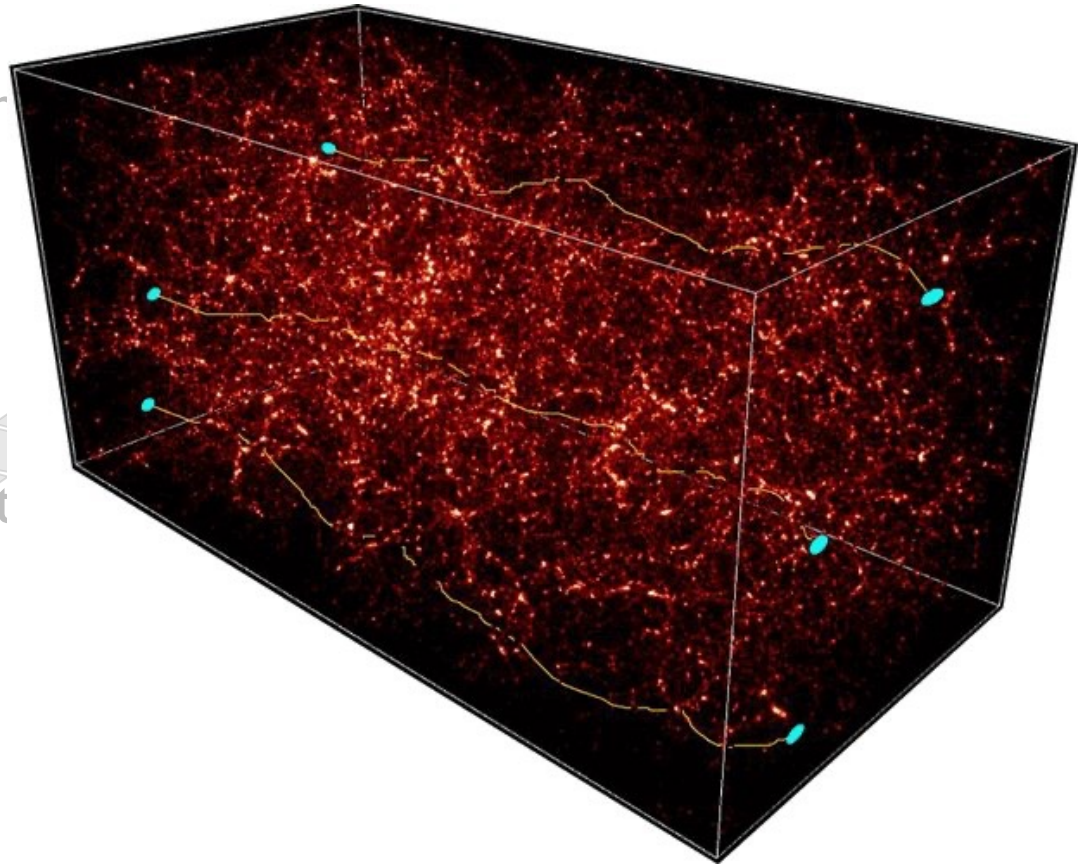




- weak lensing
  - lensing via galaxy clusters and the large-scale structure
    ($\rightarrow$ weak distortion and magnification)



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    ($\rightarrow$ strong distortion, magnification, and multiple images)

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    ($\rightarrow$ weak distortion and magnification)

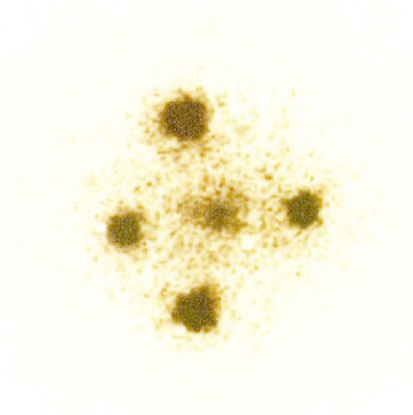
- microlensing
- strong lensing

multiple images

- weak lensing

- microlensing
- strong lensing

multiple images

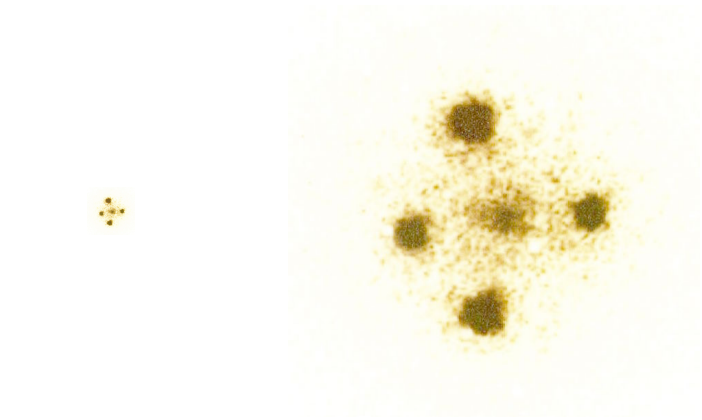


strong lensing

- weak lensing

- microlensing
- strong lensing

multiple images



microlensing strong lensing

- weak lensing

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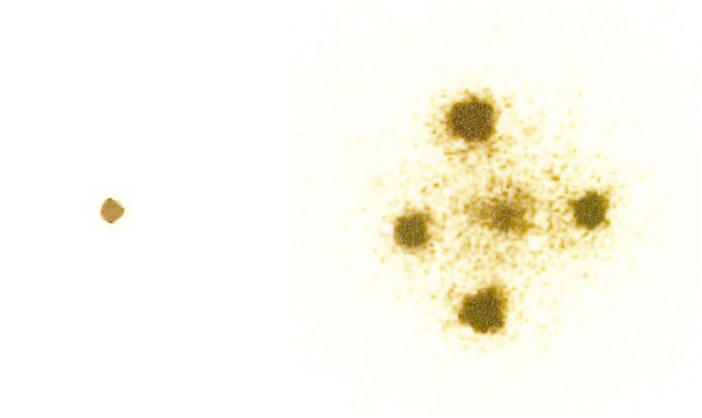
multiple images



microlensing strong lensing

- weak lensing

- microlensing
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multiple images

	image seperation
• nanolensing	~ 10^{-9} arcsec
• ***microlensing***	~ 10^{-6} arcsec
• millilensing	~ 10^{-3} arcsec
• ***strong lensing***	> 0.1 arcsec

- weak lensing

- microlensing
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multiple images

	image seperation
• nanolensing	~ 10^{-9} arcsec
• ***microlensing***	~ 10^{-6} arcsec
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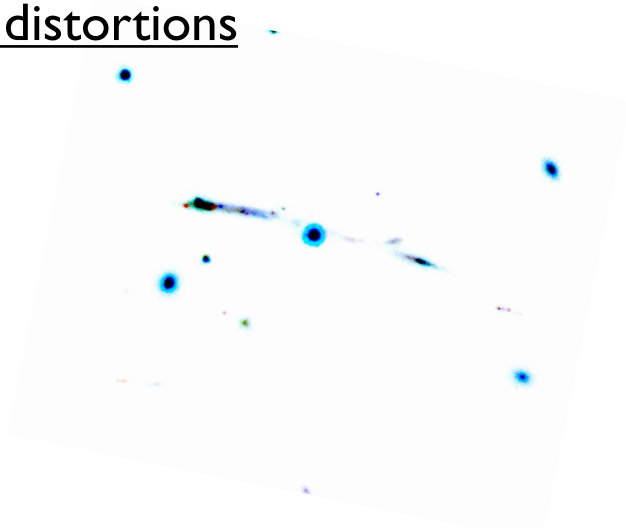
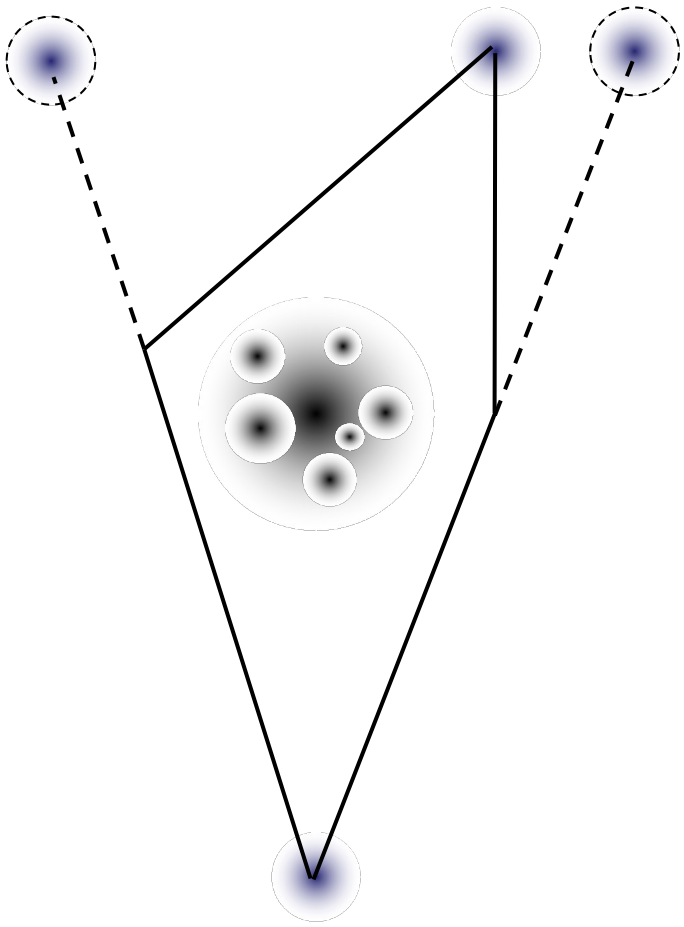
- weak lensing

arcs and distortions

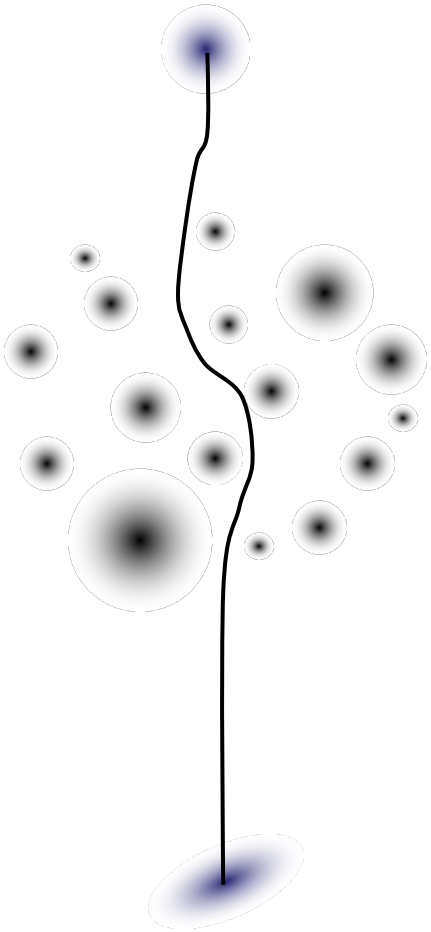
• (cosmic) shear



particle picture



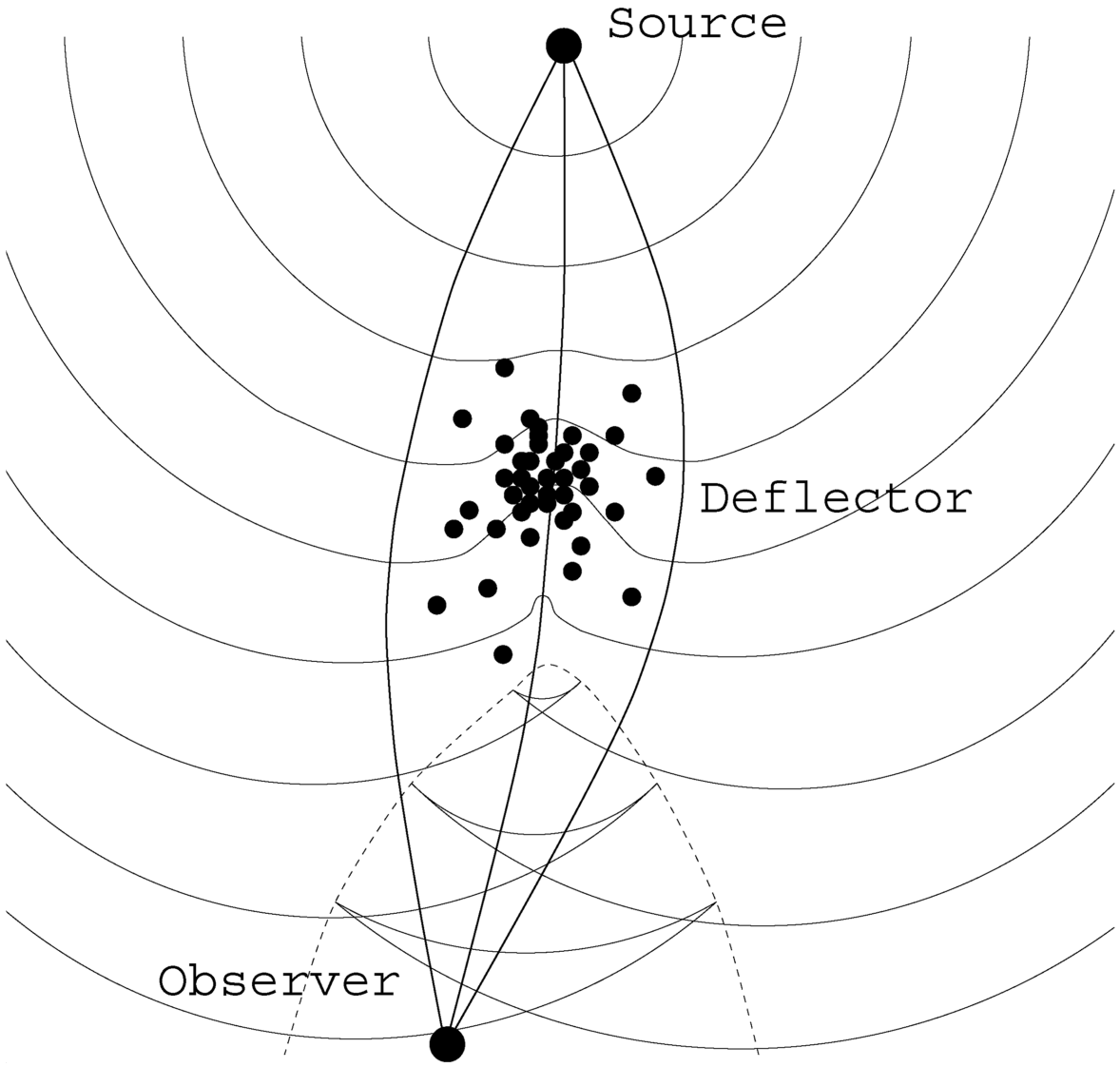
vs.



strong: “angles”

weak: “distortion”

wave picture

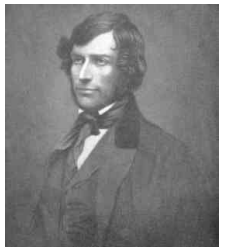


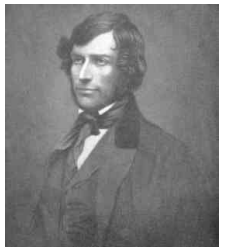
weak lensing regime

strong/micro lensing regime

- motivation
- flavours
- history

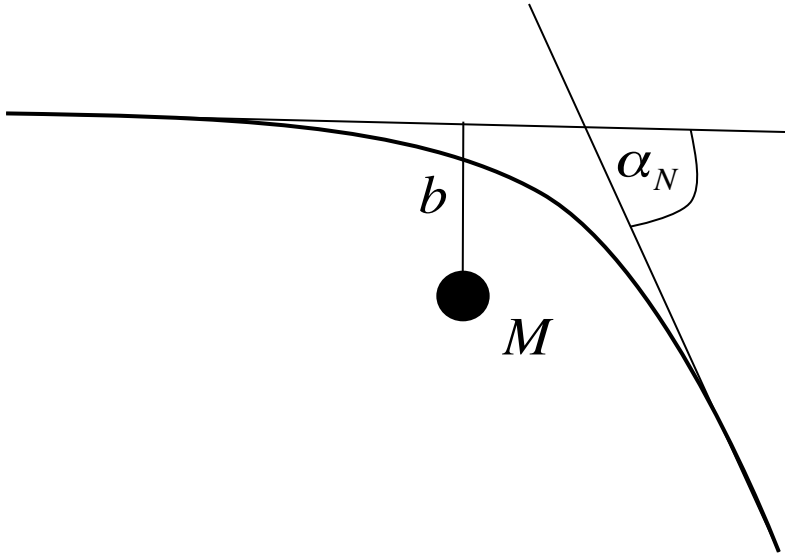
XXXX ?





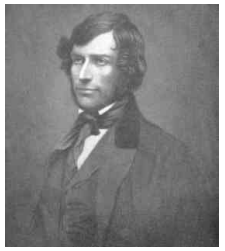
1784 John Michell

letter to Henry Cavendish proposing the idea of light deflection by mass:



$$\alpha_N = \frac{2GM}{c^2}\frac{1}{b}$$ ***(exercise)***

1784 John Michell



letter to Henry Cavendish proposing the idea of light deflection by mass:

<u>further achievements/ideas:</u>

- attempted to measure the radiation pressure of light by focusing sunlight onto one side of a compass needle. *The experiment was not a success: the needle melted.*
- predicted stars should primarily appear in binary systems
- speculated about the existence of black holes
- designed the famous 'Cavendish experiment', but died before accomplishing it...

$$\alpha_N = \frac{2GM}{c^2}\frac{1}{b}$$ ***(exercise)***

1795 Piere-Simon Laplace

escape velocity from massive body vs. speed of light:

$$v_{esc} = \sqrt{\frac{GM}{R}} = c \quad \Rightarrow \quad R_s = \frac{2GM}{c^2}$$

(aka "Schwarzschild radius")

$$\alpha_N = \frac{2GM}{c^2}\frac{1}{b}$$

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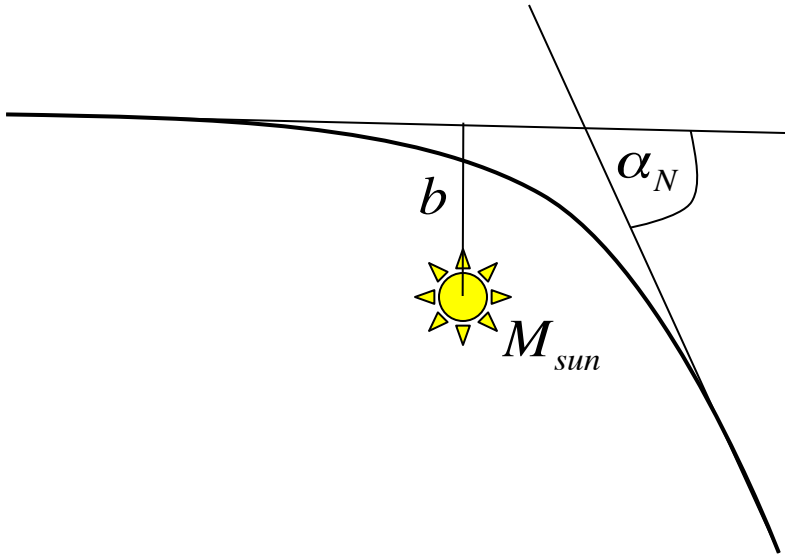
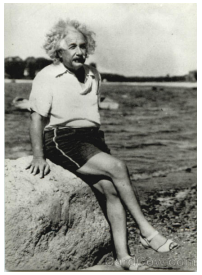
1804 Johann von Soldner

independent derivation for light deflection by sun:



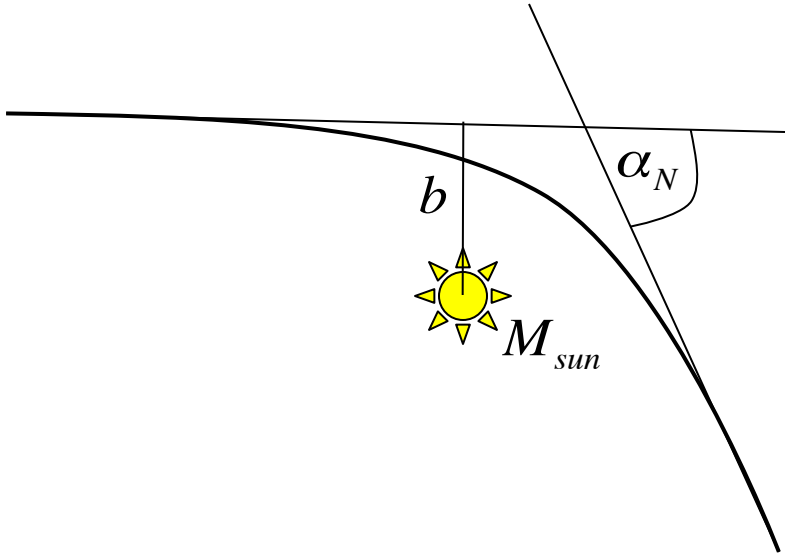
$$\alpha_N = \frac{2GM_{sun}}{c^2}\frac{1}{R_{sun}} \approx 0.87''$$

Note, he apologized for having published such a negligible effect...(https://en.wikisource.org/?curid=755966)



1911 Albert Einstein

yet another independent derivation for light deflection by sun:
(based upon Special Relativity)



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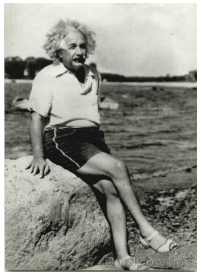
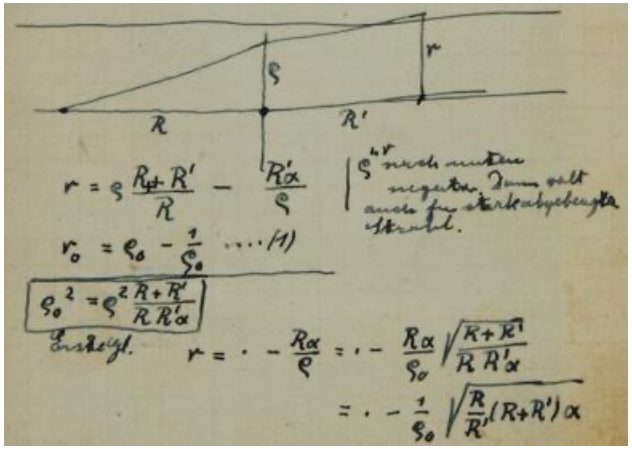
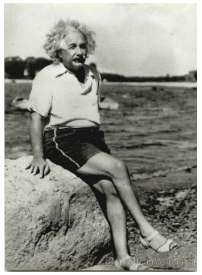


1912 Albert Einstein

unpublished notes about double images, rings, and magnifications





1913 Albert Einstein

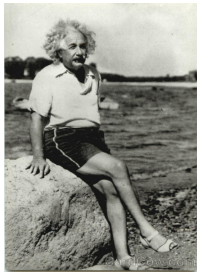
letter to G.E. Hale asking for observing the sun during daytime

1914 Erwin Freundlich

plans to use solar eclipse on Russian Crimea peninsula to test deflection

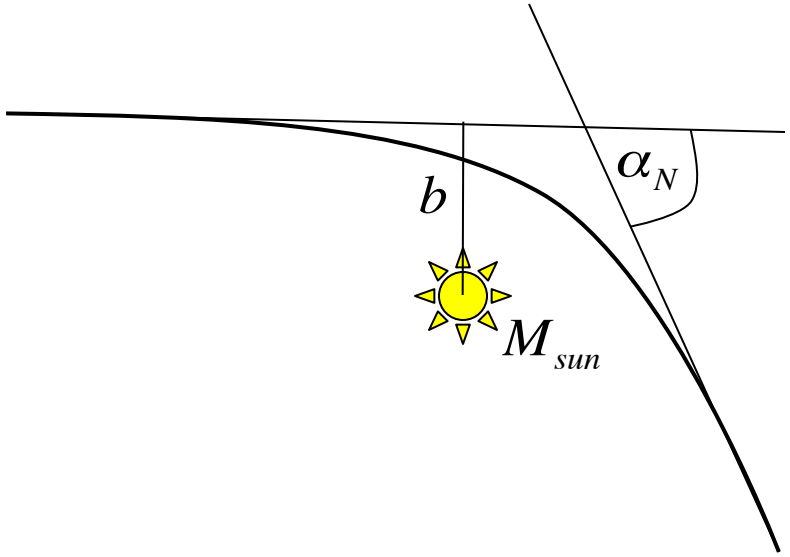
World War I prevented this undertaking!

=> fair enough as α was still the wrong value!



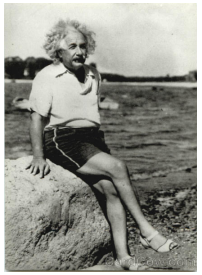
1915 Albert Einstein

yet another independent derivation for light deflection by sun:
(based upon General Relativity)



$$\alpha_{GR} = \frac{4GM_{sun}}{c^2}\frac{1}{R_{sun}} \approx 1.74''$$

=> this time α is the right value!



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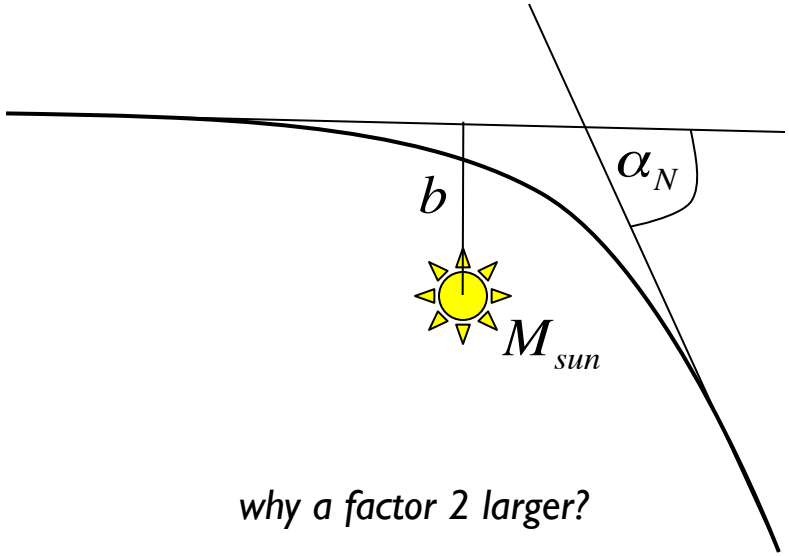

why a factor 2 larger?

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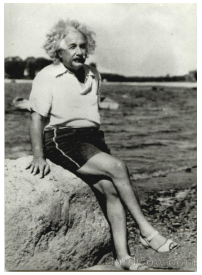
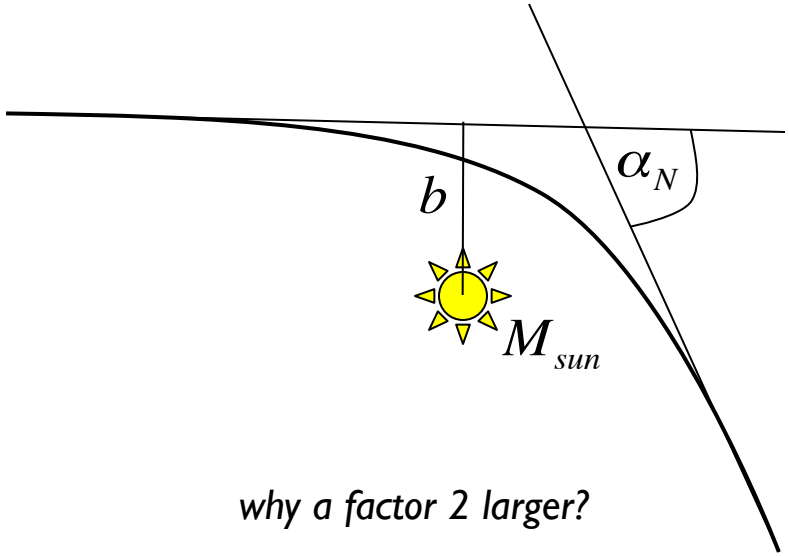
=> this time α is the right value!



1915 Albert Einstein

yet another independent derivation for light deflection by sun:
(based upon General Relativity)



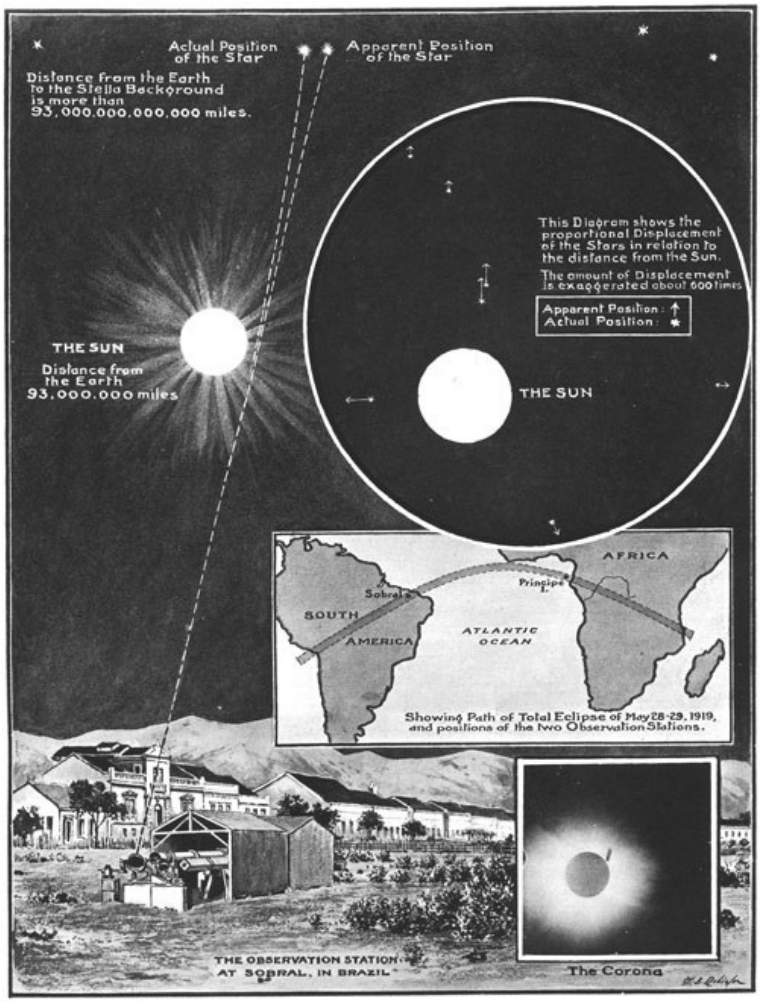
why a factor 2 larger?

the additional factor of 2 comes because GR also considers curvature of space (and not only time)

$$\alpha_{GR} = \frac{4GM_{sun}}{c^2}\frac{1}{R_{sun}} \approx 1.74''$$

=> this time α is the right value!

1919 solar eclipse in Africa & Brazil



Arthur Eddington

1919 solar eclipse in Africa & Brazil

two expeditions:

- Sobral, northern Brazil (Davidson, student of Dyson)
- Island of Principe, west coast of Africa (Eddington & Dyson)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=> earth-shaking confirmation of Einstein's GR!

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Eddington, after return during RAS dinner:
"*Oh leave the Wise our measures to collate*
One thing at least is certain, light has weight
One thing is certain and the rest debate
Light rays, when near the Sun, do not go straight."

1919 Oliver Lodge

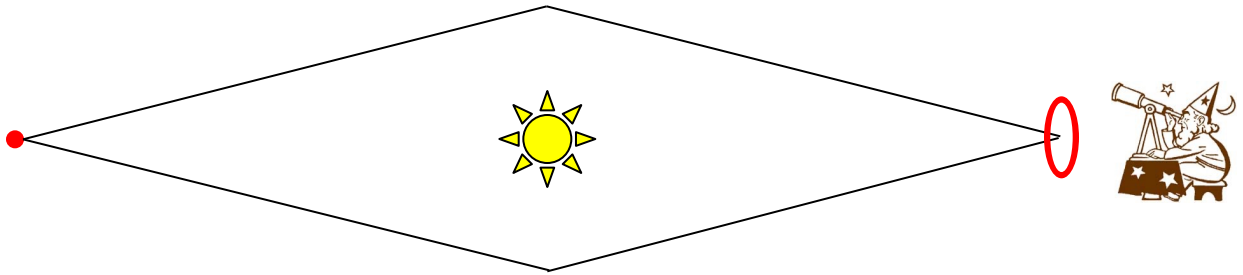
first mentioning of term *gravitational lens*:

"…light could be ***focused*** through a *gravitational lens*"

1924 Orest Chwolson

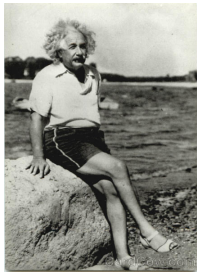
predicts ring-like appearance of aligned lensed star*

(remember the unpublished notes by Einstein in 1912 though…)



distant star sun ring-like feature

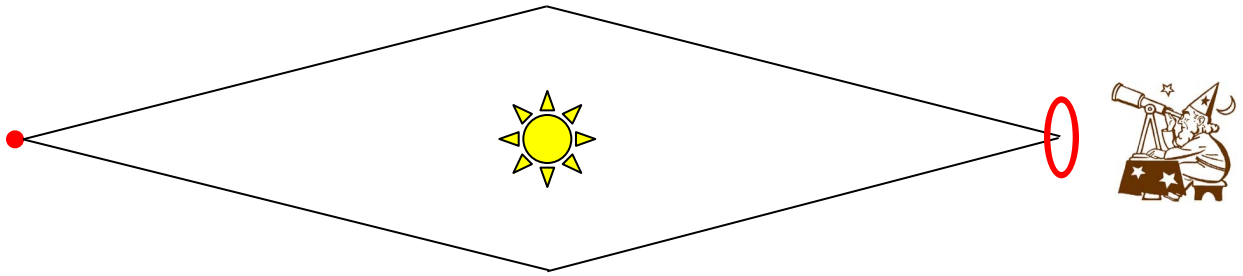
*Chwolson, O (1924). "Über eine mögliche Form fiktiver Doppelsterne". *Astronomische Nachrichten*. **221** (20): 329–330



1936 Albert Einstein

re-calculates ring-feature on request by Czech engineer Rudi Mandl

- phenomenon from now on called *Einstein ring*
- however, too small to be observed !?



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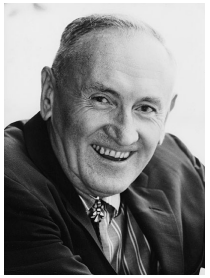
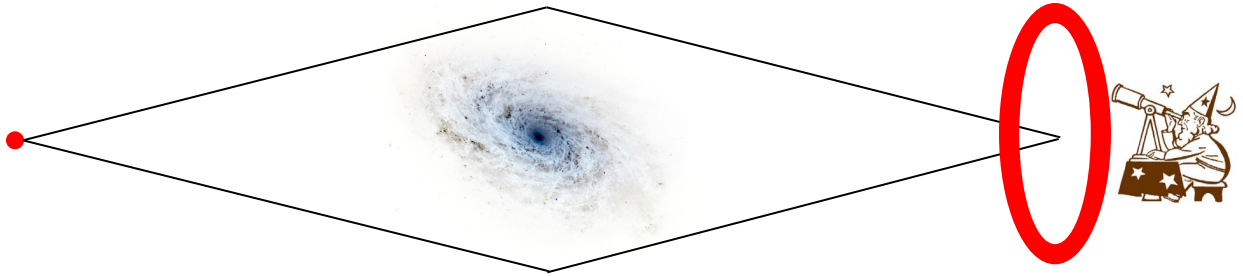


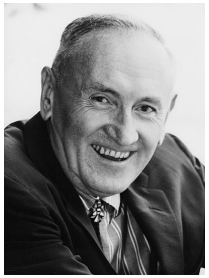
1936 Fritz Zwicky

proposes to consider galaxies rather than stars as lenses

- Einstein rings will be observable!



distant star/quasar galaxy ring-like feature

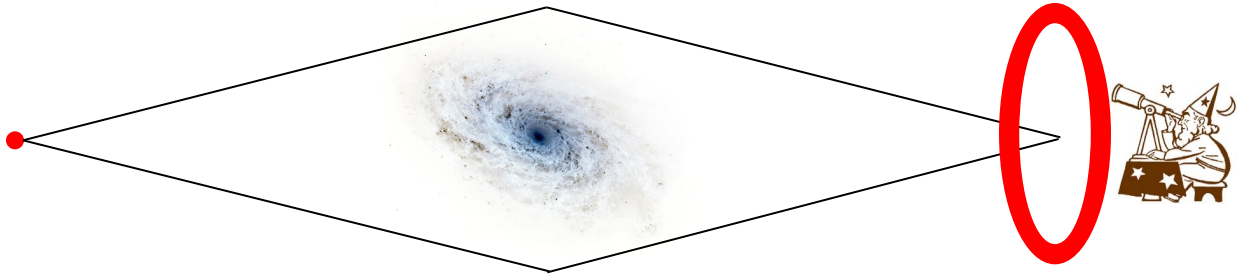


1936 Fritz Zwicky

proposes to consider galaxies rather than stars as lenses

proposes to use "gravitational lensing" as a **tool** to

- observe even more distant galaxies
- determine lens masses



distant star/quasar galaxy ring-like feature

(he actually claimed at a conference in 1950 to have found a lens…but it was a mere plate defect)

1936 ... 1963

1963 Yuri Klimov (3 publications)

1964 Sjur Refsdal (2 publications)

1967 F. Link

1975 Bourassa & Kantowski (3 publications)

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Sjur Refsdal

one paper describes
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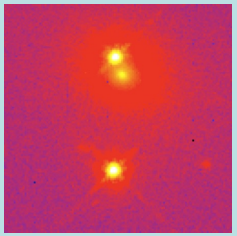
"lensing era"

1979 Walsh, Carswell & Weymann

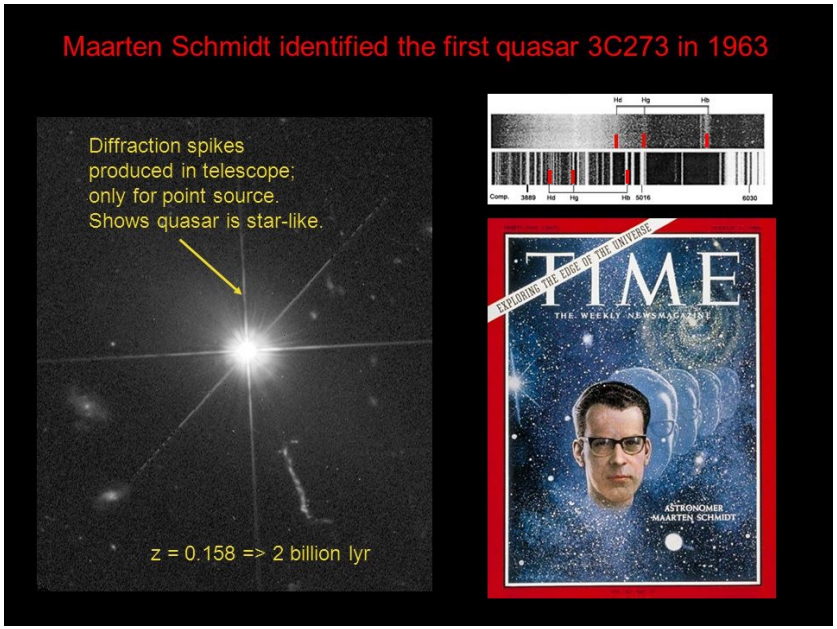
discovery of the very first gravitational lens*:

"0957 + 561 A, B: twin quasistellar objects or gravitational lens"



*other than the sun

1963 Maarten Schmidt



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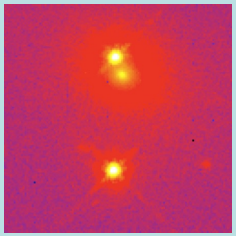


*other than the sun

benefitted from the discovery of quasars by Maarten Schmidt in 1963!

1979 Chang & Refsdal

"Flux variations of QSO 0957+561 A,B and image splitting by stars near the light path"

*=> lensing by stars **inside** the lensing "nebula"!*

Sjur Refsdal

1981 Blandford & Jaroszynski

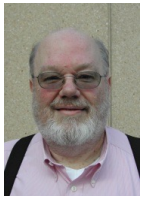
"Gravitational distortion of the images of distant radio sources…"

Roger Blandford

1984 Turner, Ostriker & Gott

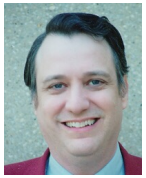
"The statistics of gravitational lenses…"

=> quantifying statistical lensing!



Ed Turner

Jerry Ostriker



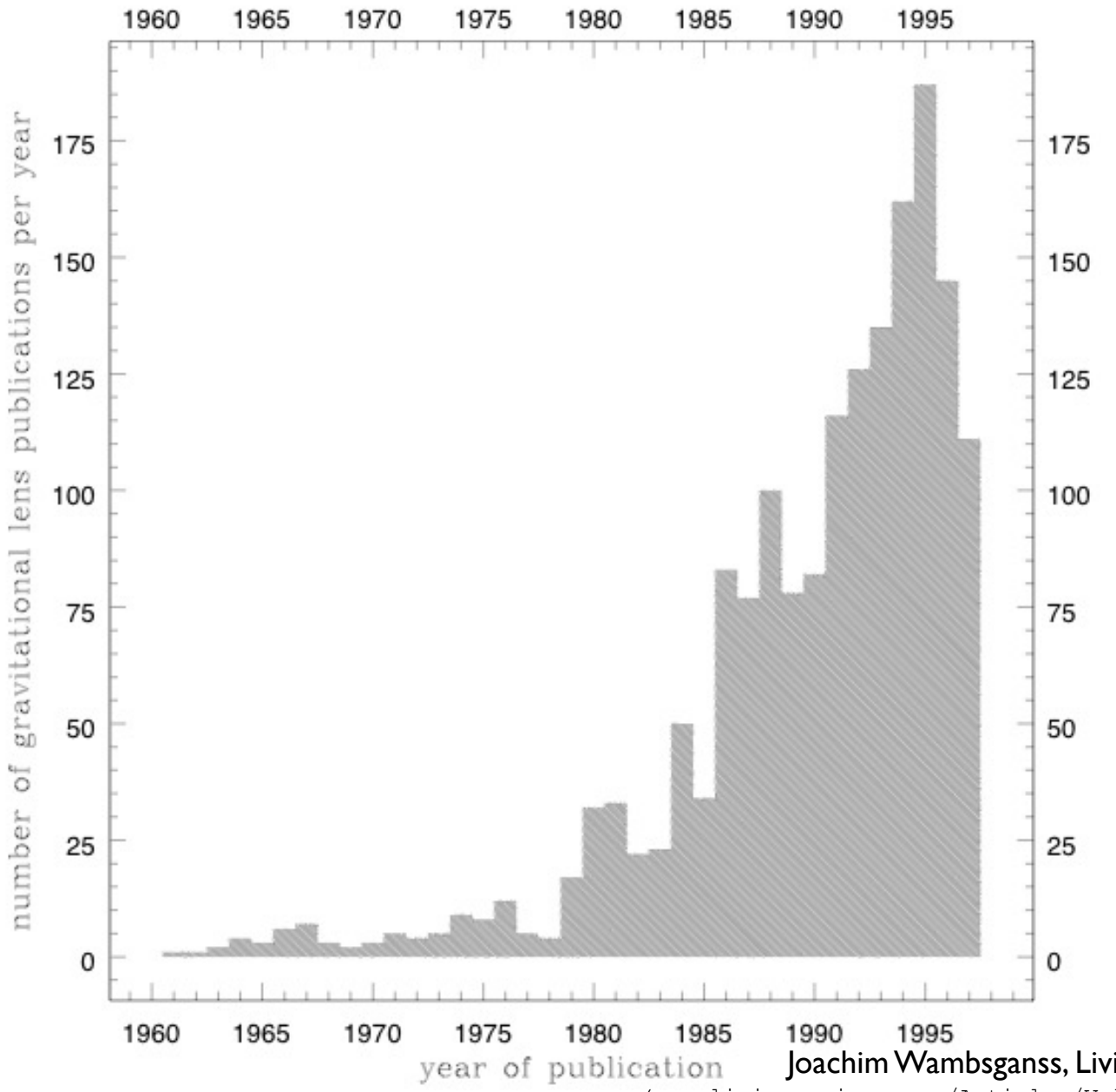
J.R. Gott

1986 Paczynski

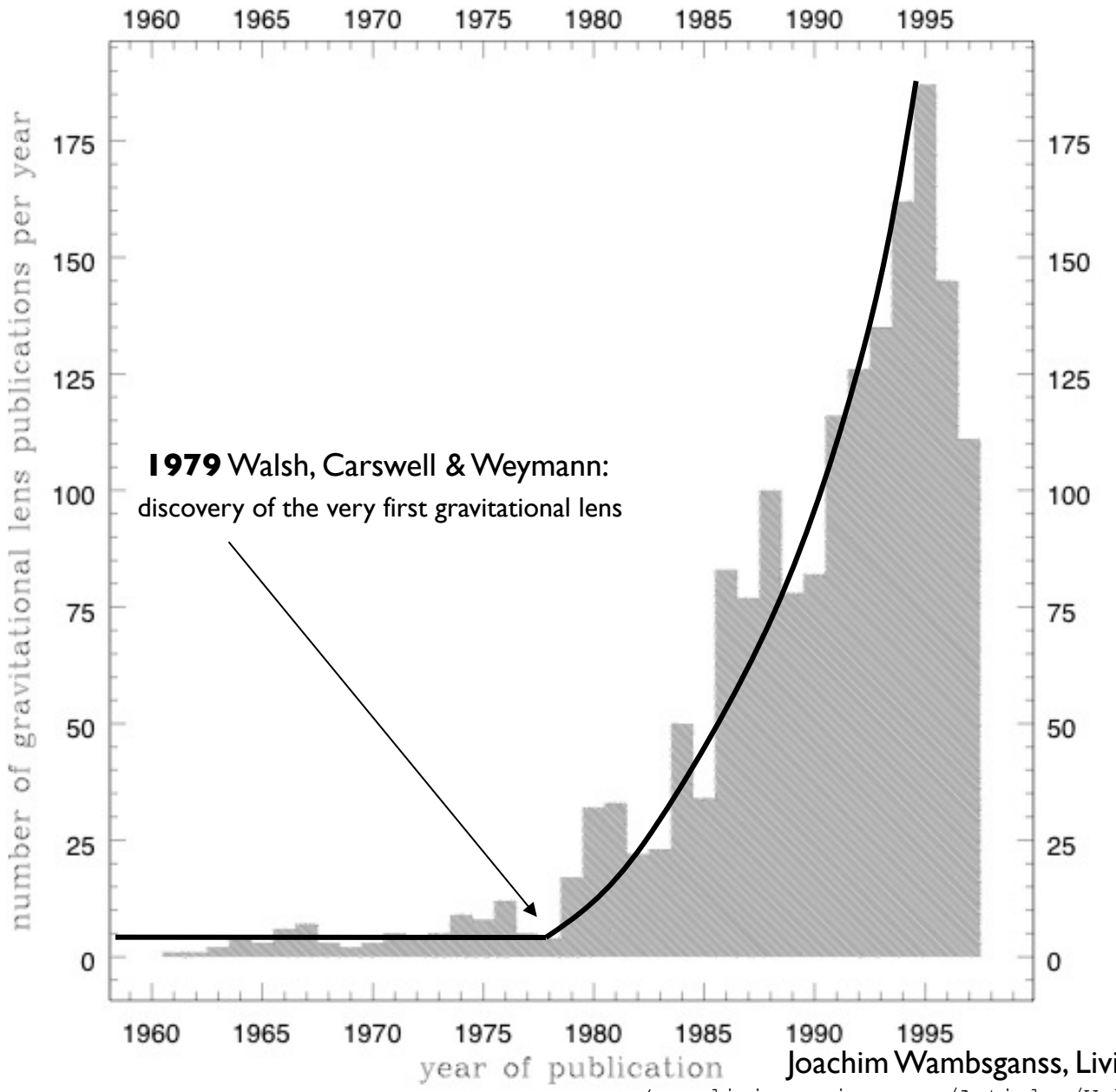
"Gravitational Lensing by the Galactic Halo"

=> triggering MACHO search as possible Dark Matter candidate

Bodhan Paczynski



Joachim Wambsganss, Living Review (1998)
(www.livingreviews.org/Articles/Volume1/1998-12wamb)



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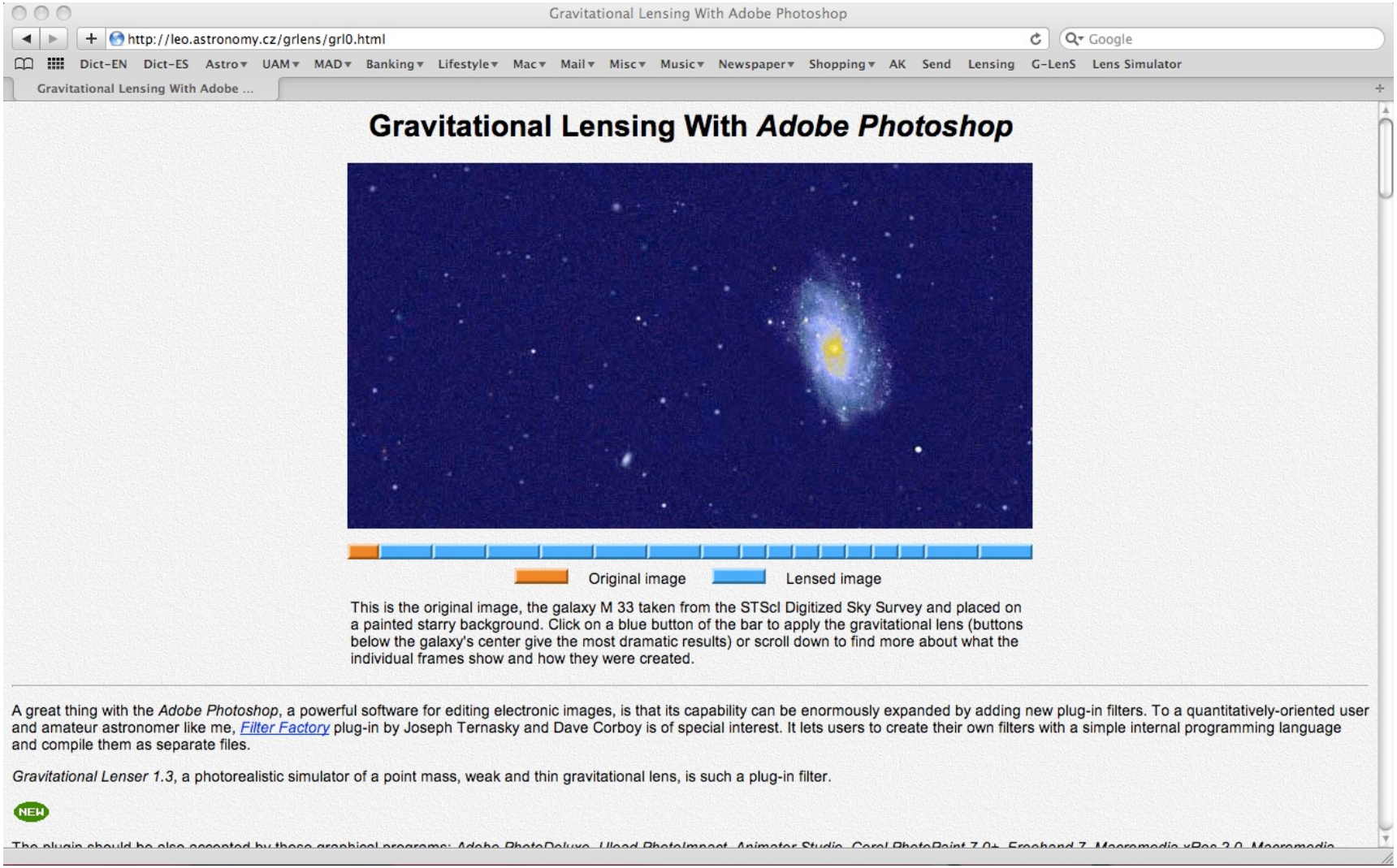
Gravitational Lensing With Adobe Photoshop
http://leo.astronomy.cz/grlens/grl0.html
Google
Dict-EN Dict-ES Astro UAM MAD Banking Lifestyle Mac Mail Misc Music Newspaper Shopping AK Send Lensing G-LenS Lens Simulator
Gravitational Lensing With Adobe ...
Gravitational Lensing With Adobe Photoshop
Original image
Lensed image
This is the original image, the galaxy M 33 taken from the STScI Digitized Sky Survey and placed on a painted starry background. Click on a blue button of the bar to apply the gravitational lens (buttons below the galaxy's center give the most dramatic results) or scroll down to find more about what the individual frames show and how they were created.
A great thing with the Adobe Photoshop, a powerful software for editing electronic images, is that its capability can be enormously expanded by adding new plug-in filters. To a quantitatively-oriented user and amateur astronomer like me, Filter Factory plug-in by Joseph Ternasky and Dave Corboy is of special interest. It lets users to create their own filters with a simple internal programming language and compile them as separate files.
Gravitational Lenser 1.3, a photorealistic simulator of a point mass, weak and thin gravitational lens, is such a plug-in filter.
NEW

An Introduction to Astronomical Image Processing with ImageJ : Microlensing : Simulator

http://www.astro.physik.uni-goettingen.de/~hessman/ImageJ/Book/Gravitational%20Lens%20Simulator/index.html

Google

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Lens Simulator

Constructing a Gravitational Lens Simulator

back

Topics

Introduction

The chapter ▸ Microlensing - Hands-On General Relativity ◂ explains how massive objects can act as cosmic lenses and so produce magnified images of background objects. There is no better way to understand how this works than to produce your own *Gravitational Lens Simulator* which mimicks quite well the gravitational distortions seen in real astronomical images of macrolensing and the effective increase in the size of lensed source objects which causes the amplification effects of microlensing.