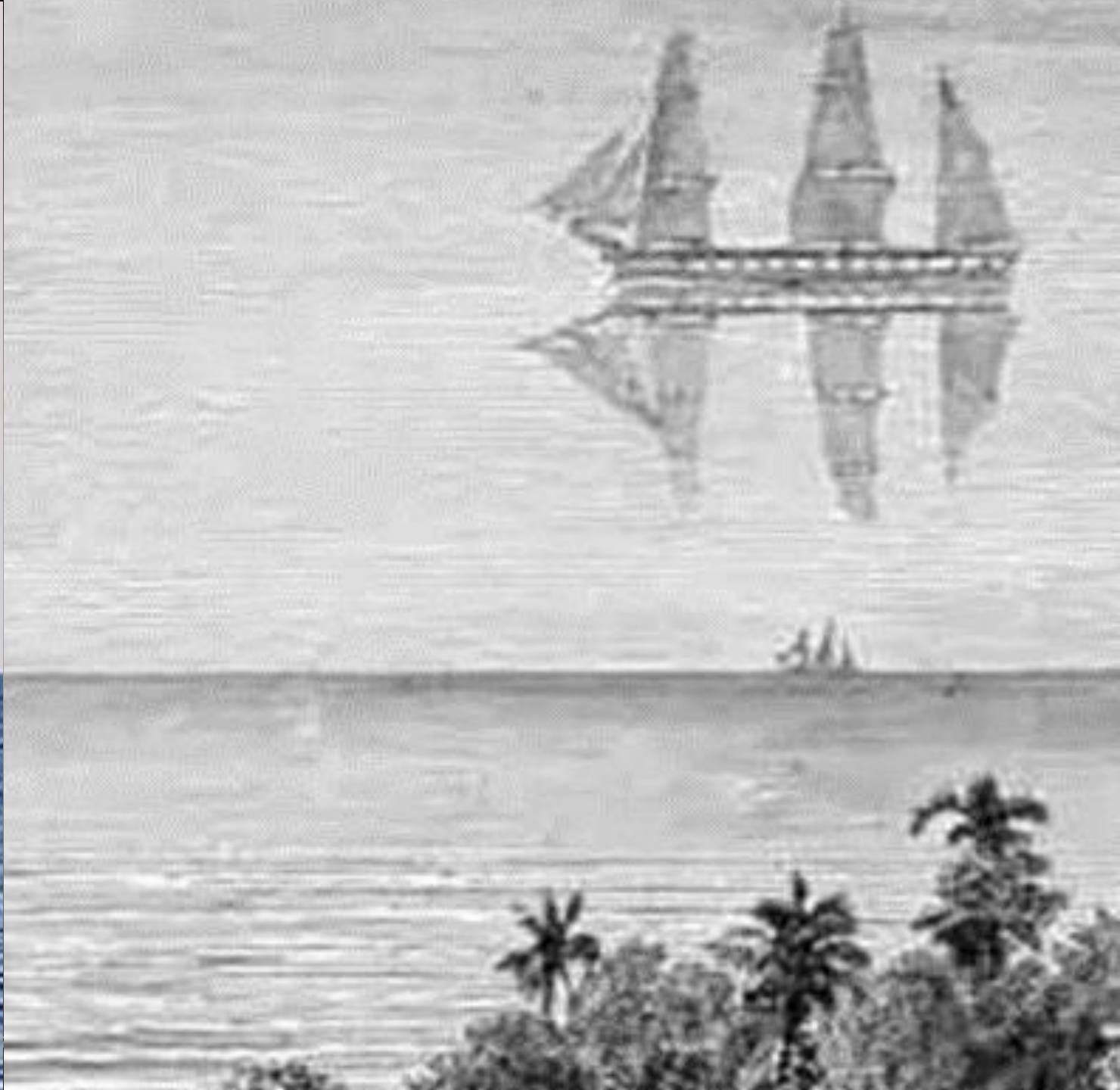


Gravitationslinsen: Fata Morganen in Einsteins Universum

Wissenschaftliche Jahrestagung der Bürger für Technik 2024 (Hannover)

Referent: Carsten Busch

AG Geschichte der Naturwissenschaft und Technik,
Hamburger Sternwarte, Fachbereich Physik (MIN), Universität Hamburg







Linse: SDSS J1226+2149

6,3 Gly Entfernung

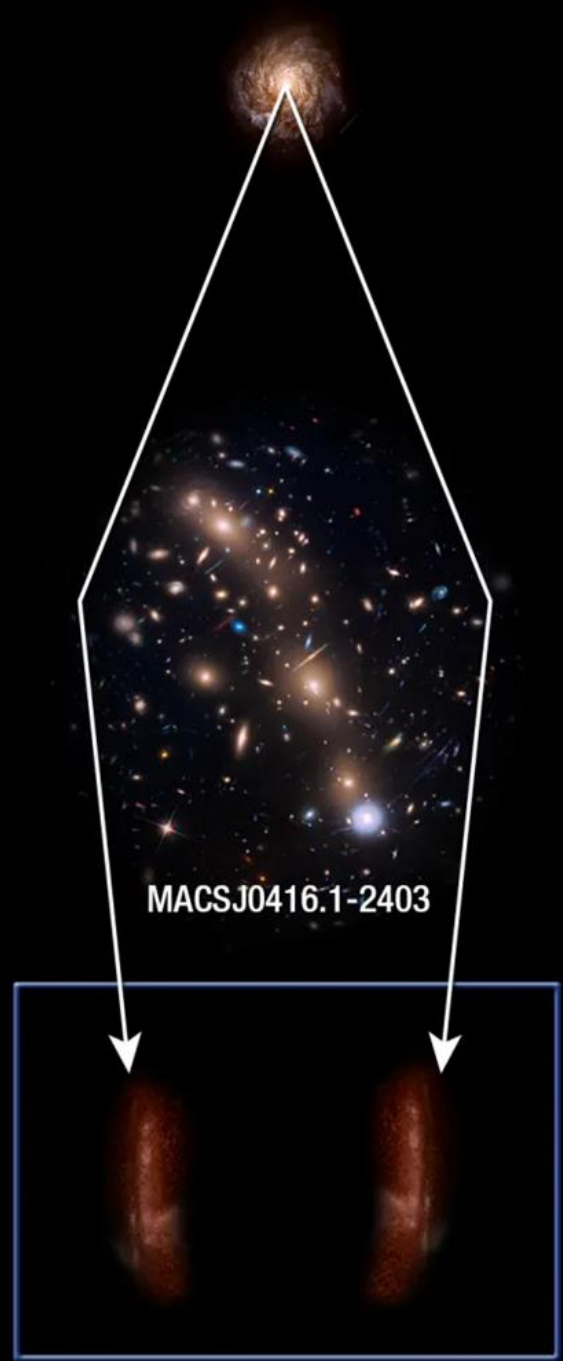
Strong Lensing:

Mehrfachbilder

Positionsverschiebungen

Verzerrung

**Vergrößerung
(„Einsteins Teleskop“)**

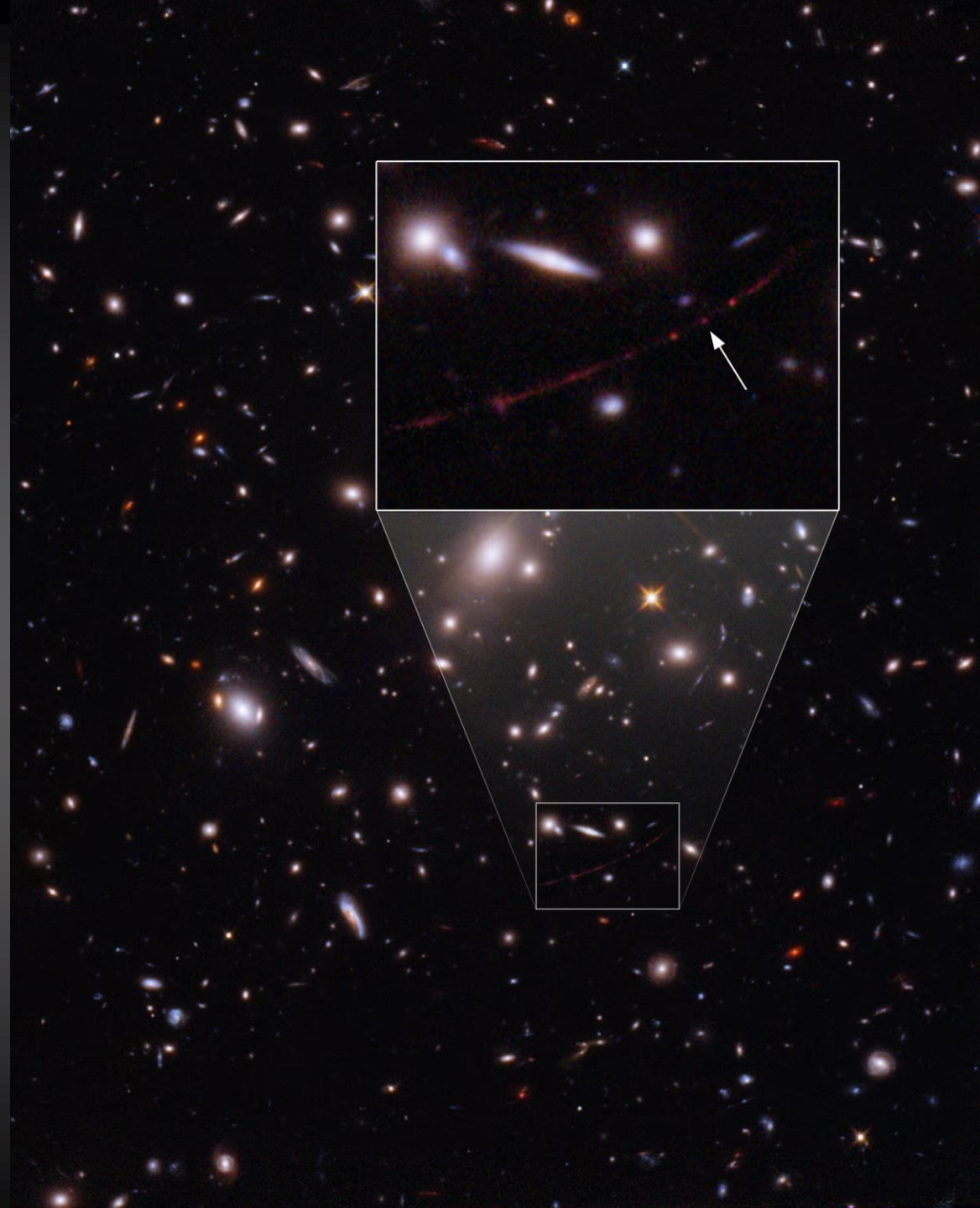


MACSJ0416.1-2403

„*Einsteins Teleskop*“:

Earendel

($z=6,2$;
Vergrößerung Größenordnung 10^3)

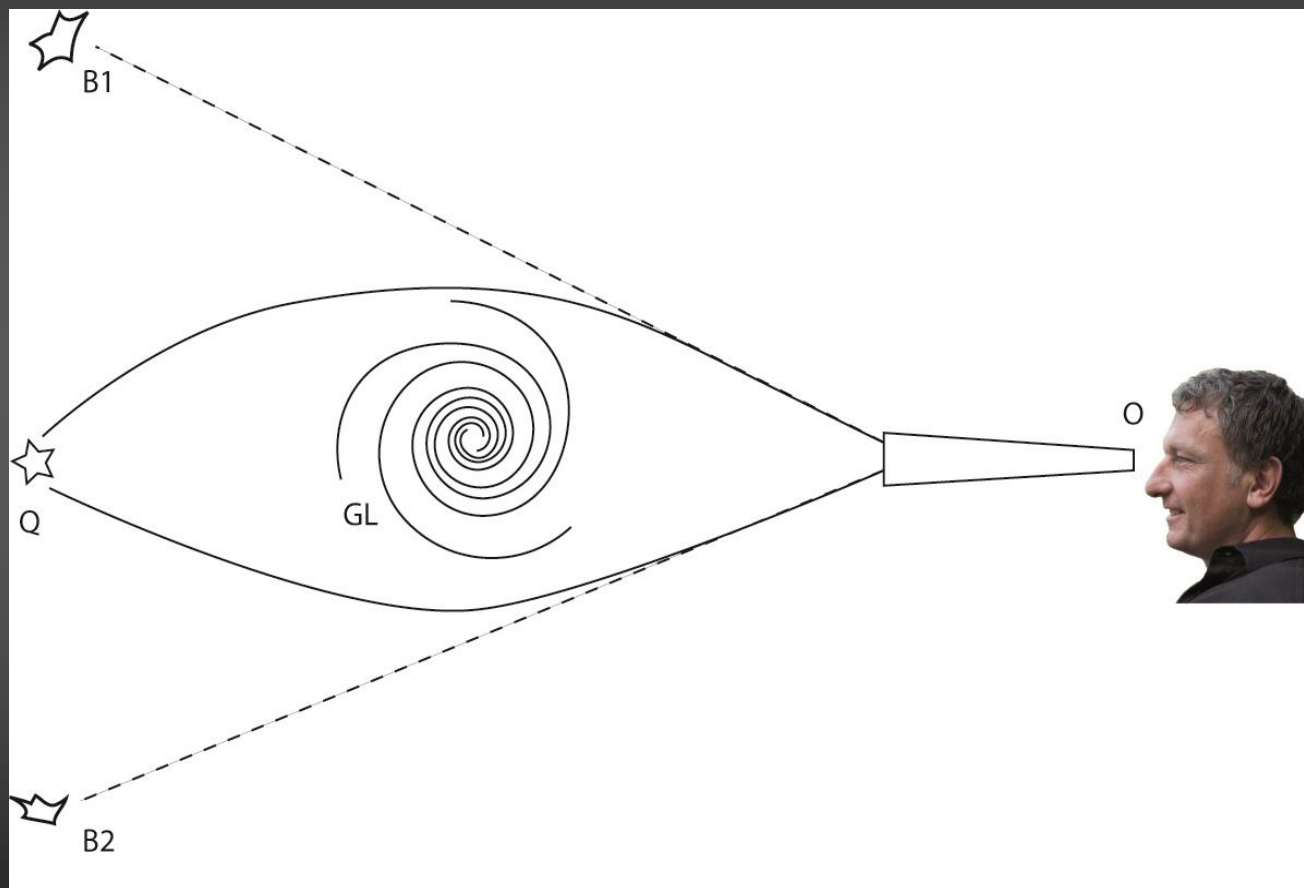


„Erste“ Beobachtung 1979: Q0957+561 A/B

„Difficulties arise in describing them as two distinct objects“



Zwillingsquasar Q0957+561 A/B



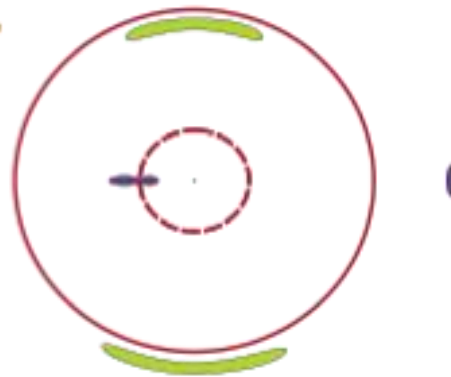
**Ungerade Zahl von Bildern -
Kaustiken und kritische Kurven**

Source Plane



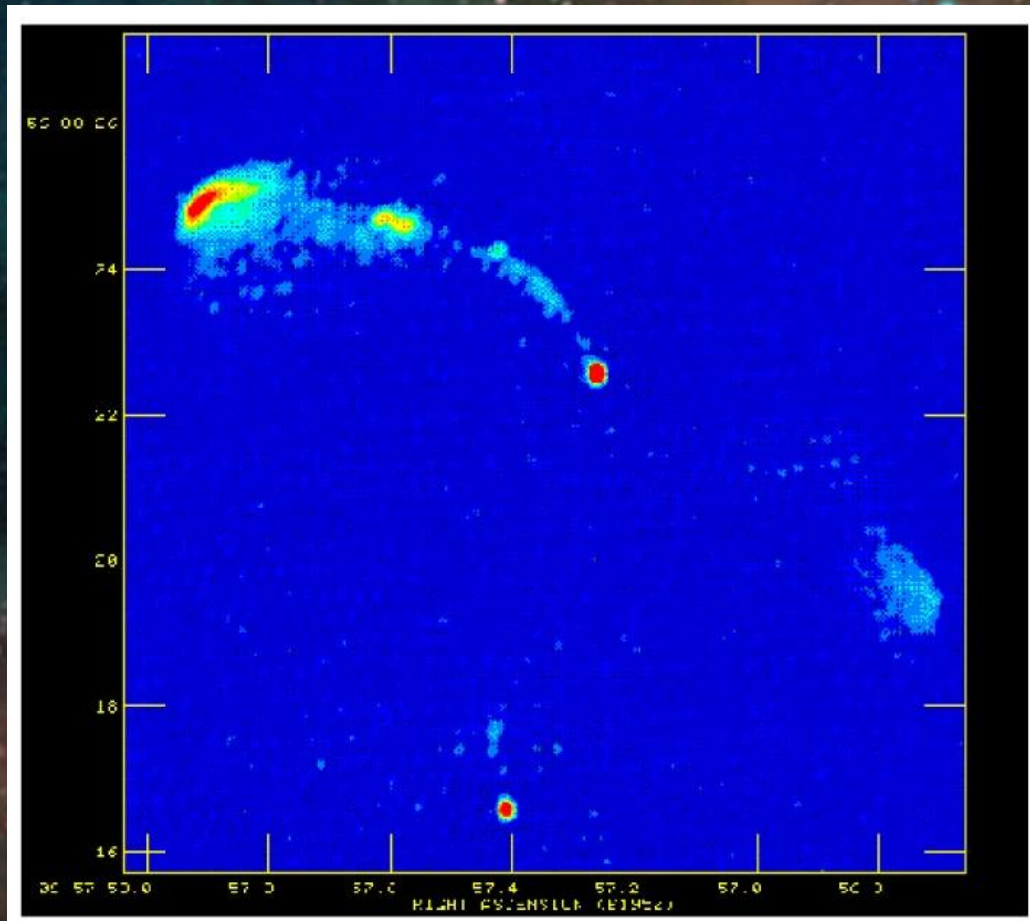
Caustic curves

Image Plane



Critical curves

**(nicht-singuläre
isotherme Sphäre)**



Einstein-Kreuz (1985)



**Einsteinring
(Chwolsonring) (1987)**



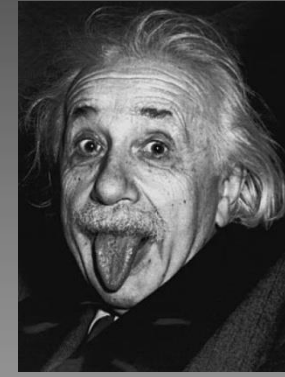
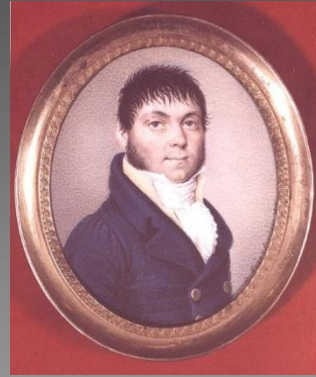
Galaxienhaufen als Linsen (Leuchtende Bögen; 1986)

15.02.2025 12:57

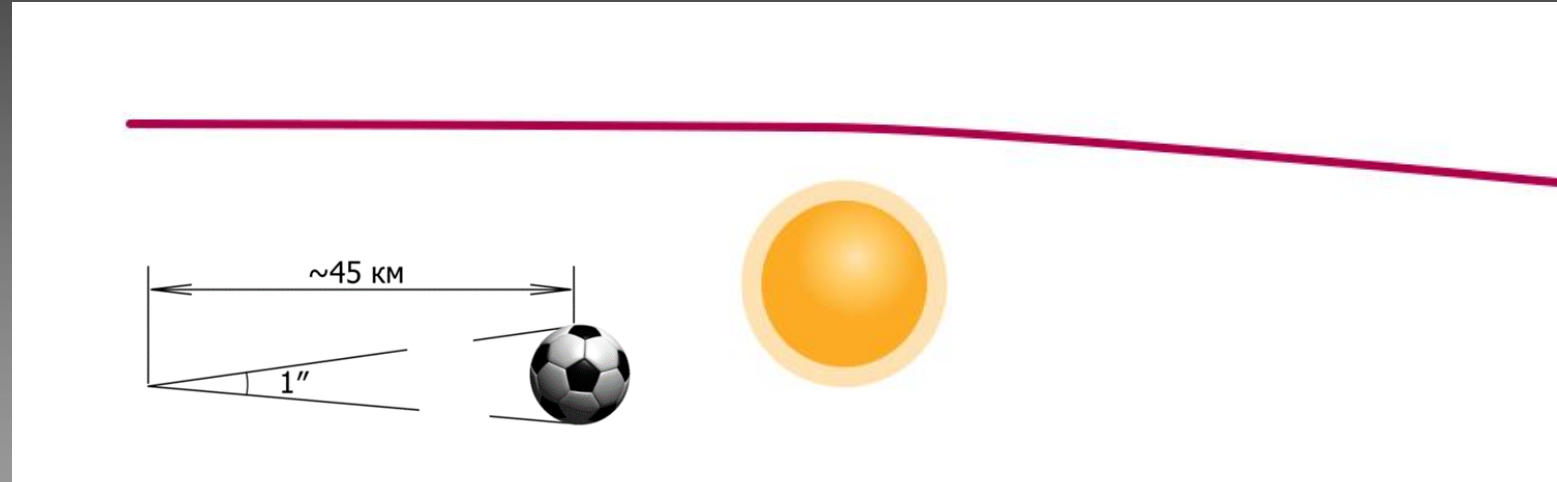
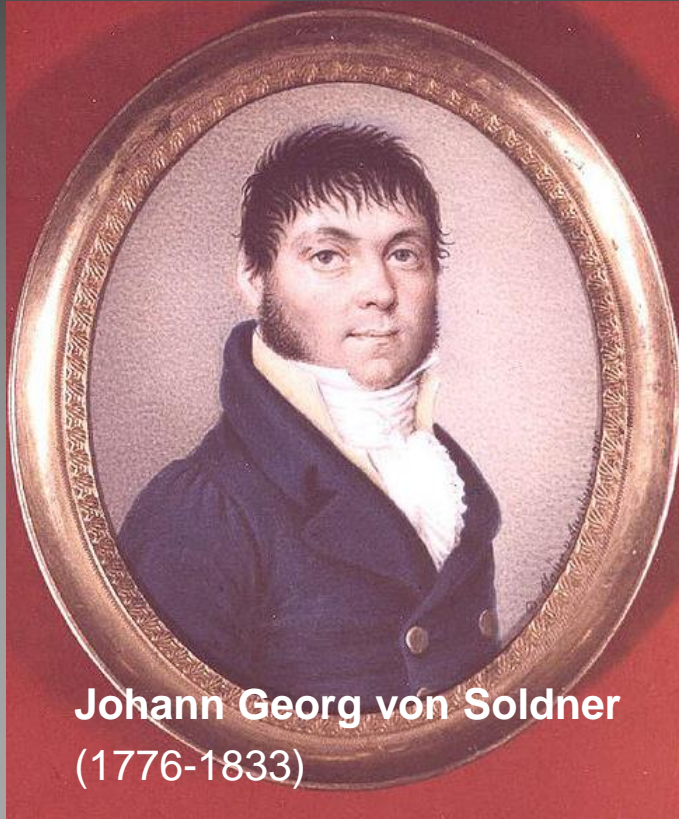
Carsten Busch: Gravitationslinsen



Eine (sehr) kurze Geschichte der Gravitationslinsen

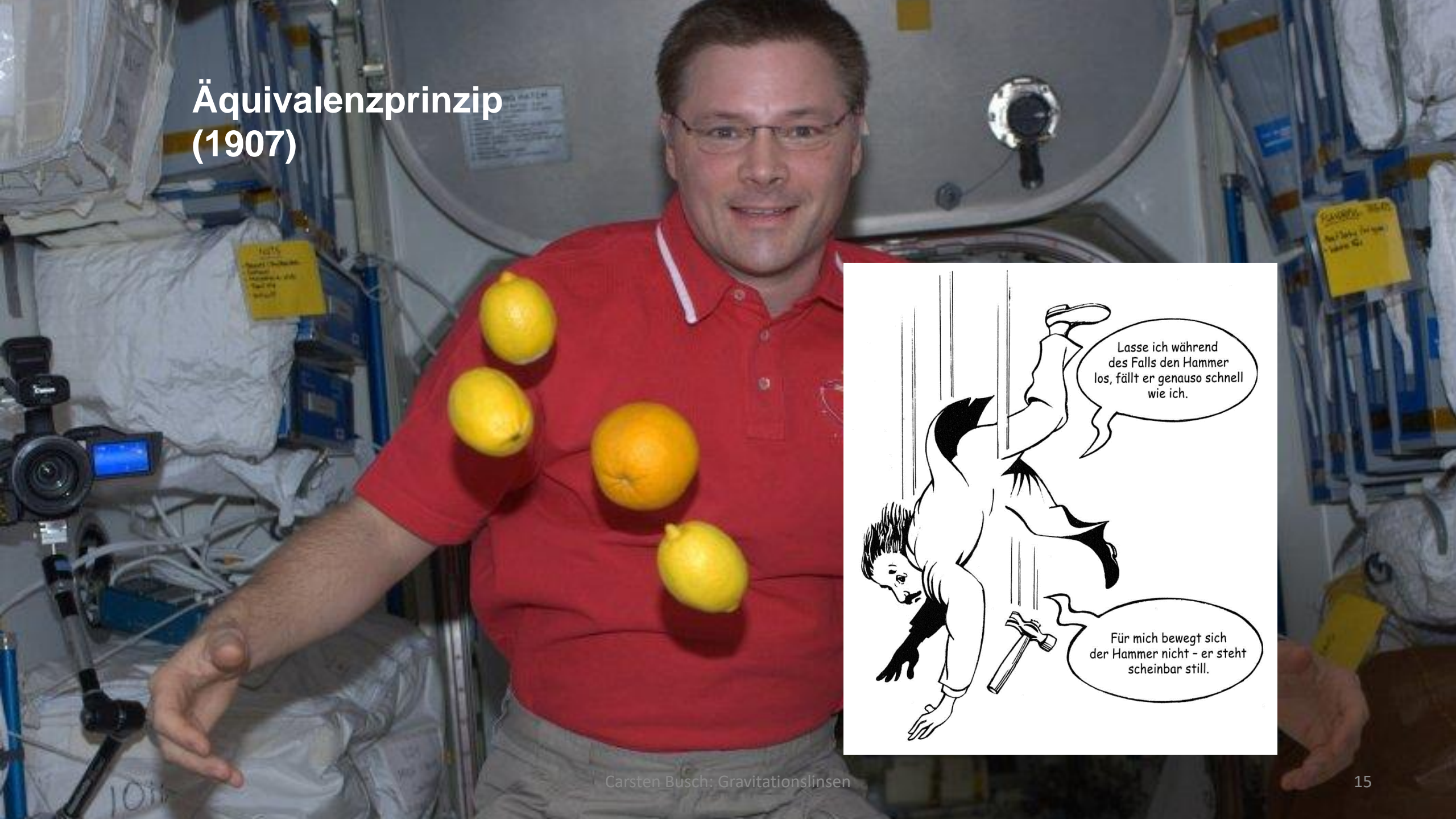


Soldner 1804



*„Ueber die Ablenkung eines Lichtstrals von seiner geradlinigen Bewegung, durch die Attraktion eines Weltkörpers, an welchem er nahe vorbei geht.“
(0,87``)*

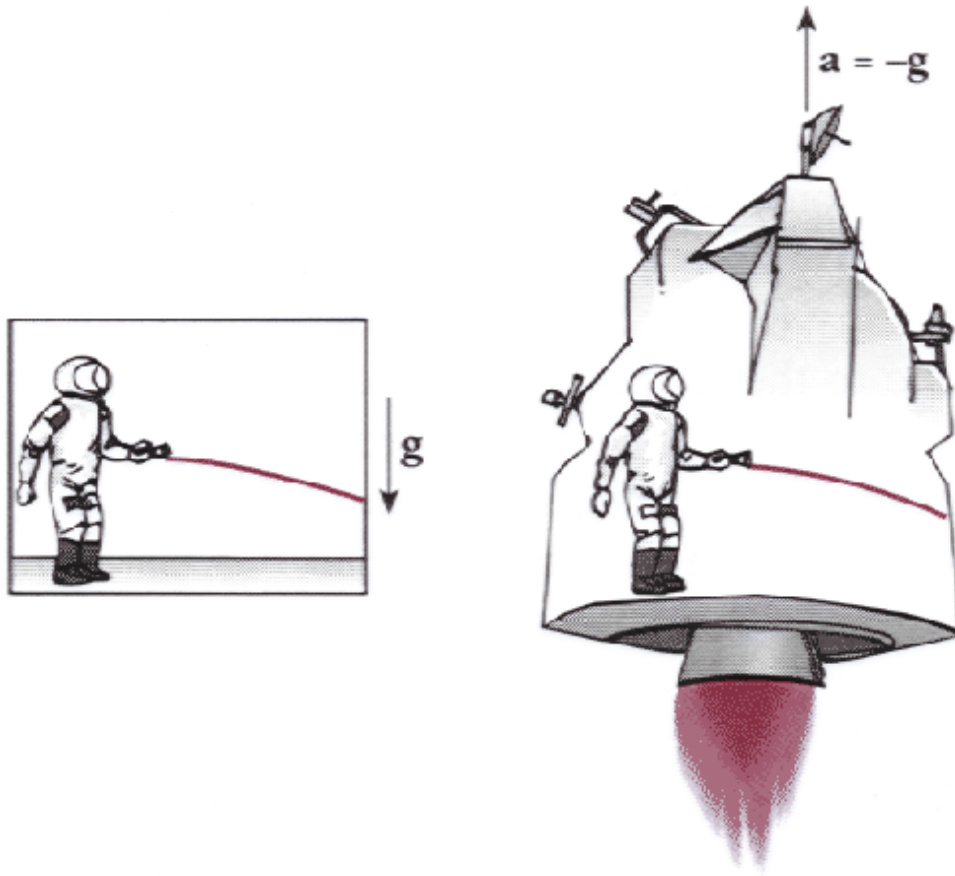
Äquivalenzprinzip (1907)



Einsteins Äquivalenzprinzip 1907



Gravitation krümmt Lichtpfad



Einstein 1911: 0,84''

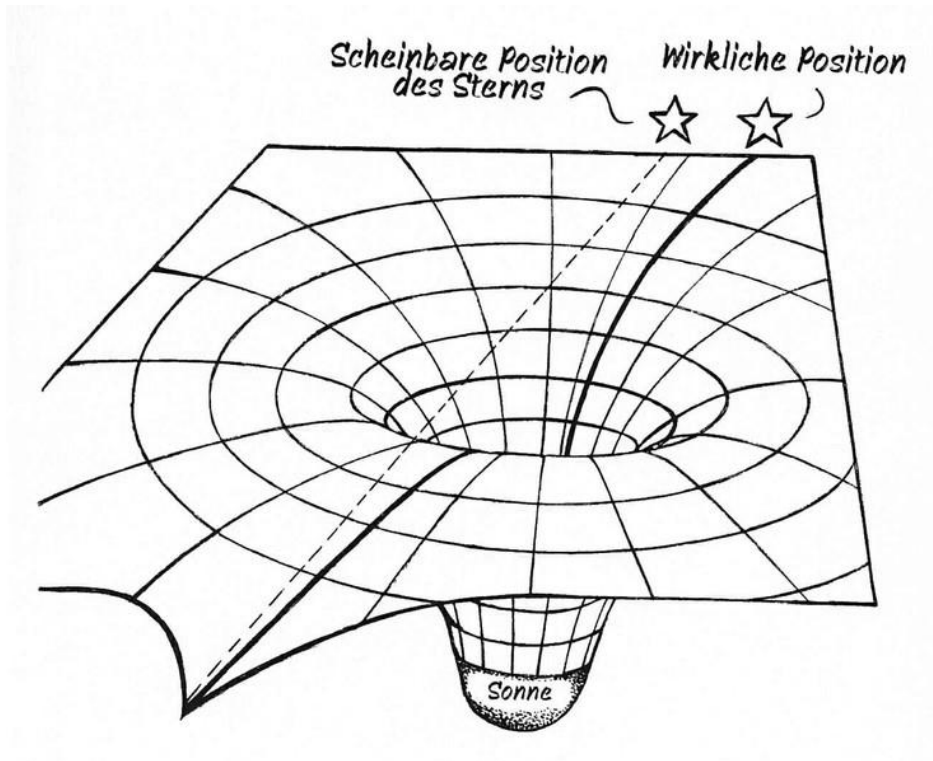
Über den Einfluß der Schwerkraft auf die
Ausbreitung des Lichtes.

Von A. EINSTEIN.¹⁾



*„Es wäre dringend zu wünschen, dass sich
Astronomen der hier aufgerollten Fragen annähmen...“*

Einstein: Lichtablenkung durch Sonne 1,74''



Soldner 1804 (Einstein 1911):

$$\delta_{\text{SOLDNER}} = \frac{2GM_S}{c^2 R_S} \approx 0,87''$$

Einstein 1915:

$$\delta_{\text{EINSTEIN}} = \frac{4GM_S}{c^2 R_S} \approx 1,74''$$

LIGHTS ALL ASKEW IN THE HEAVENS

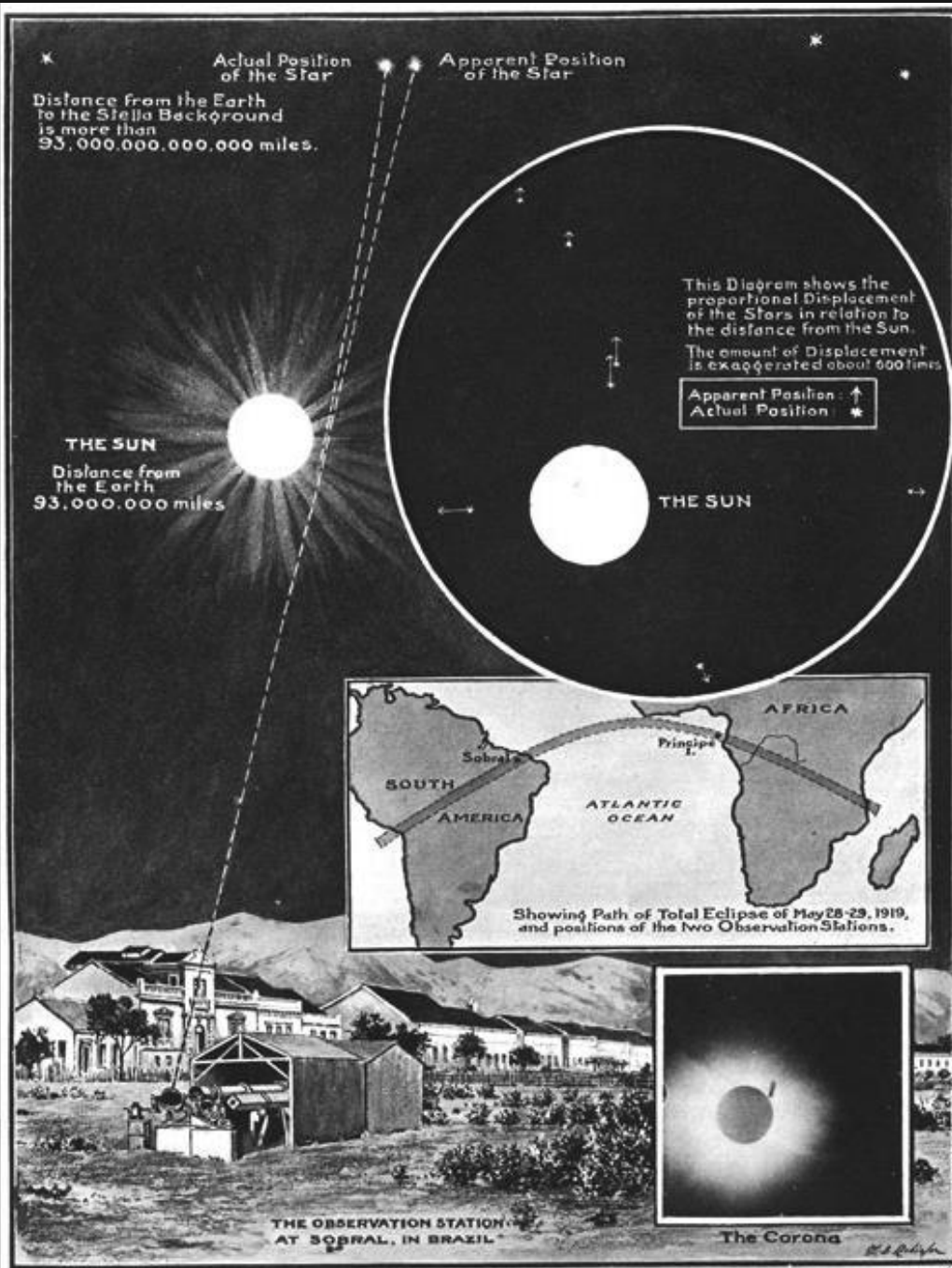
Men of Science More or Less
Agog Over Results of Eclipse
Observations.

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.





Einstein 1936

**LENS-LIKE ACTION OF A STAR BY THE
DEVIATION OF LIGHT IN THE
GRAVITATIONAL FIELD**

SOME time ago, R. W. Mandl paid me a visit and asked me to publish the results of a little calculation, which I had made at his request. This note complies with his wish.

The light coming from a star A traverses the gravitational field of another star B , whose radius is R_0 .

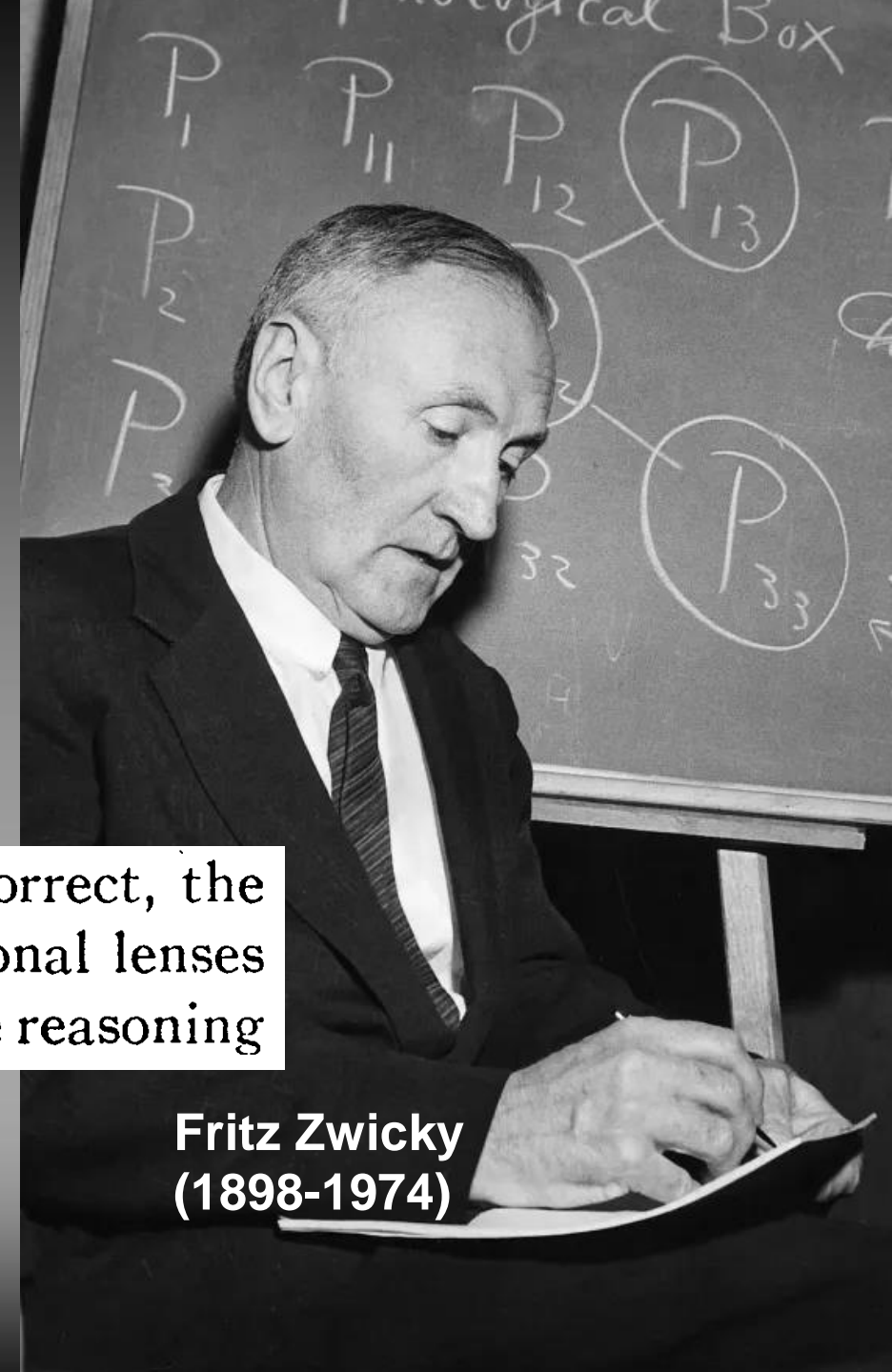
“Of course, there is no hope of observing this phenomenon directly.”

Zwicky 1937

“Nebulae as Gravitational Lenses” (1937)

“On the probability of detecting nebulae which act as gravitational lenses” (1937)

estimates⁵ of the masses of *cluster nebulae* are correct, the probability that nebulae which act as gravitational lenses will be found becomes practically a *certainty*. The reasoning

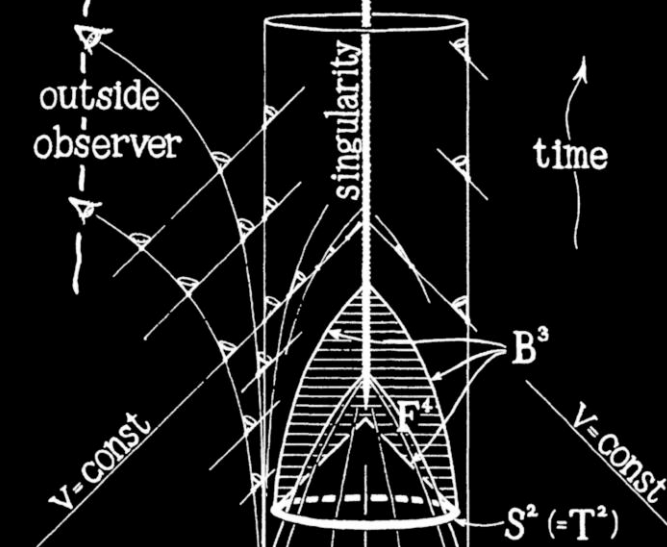


Fritz Zwicky
(1898-1974)

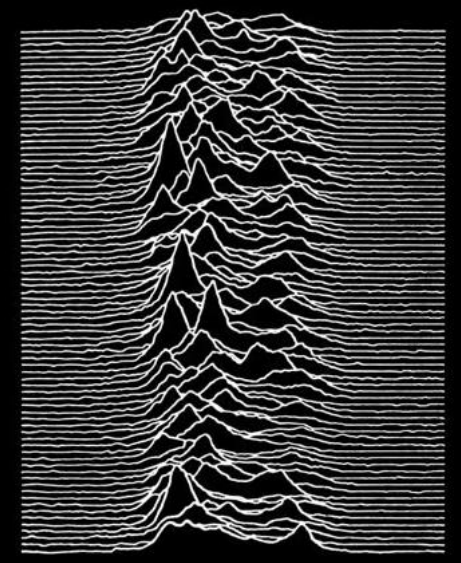


Fritz Zwicky 1933: Galaxien im Coma-Haufen zu schnell

→ Dunkle Materie

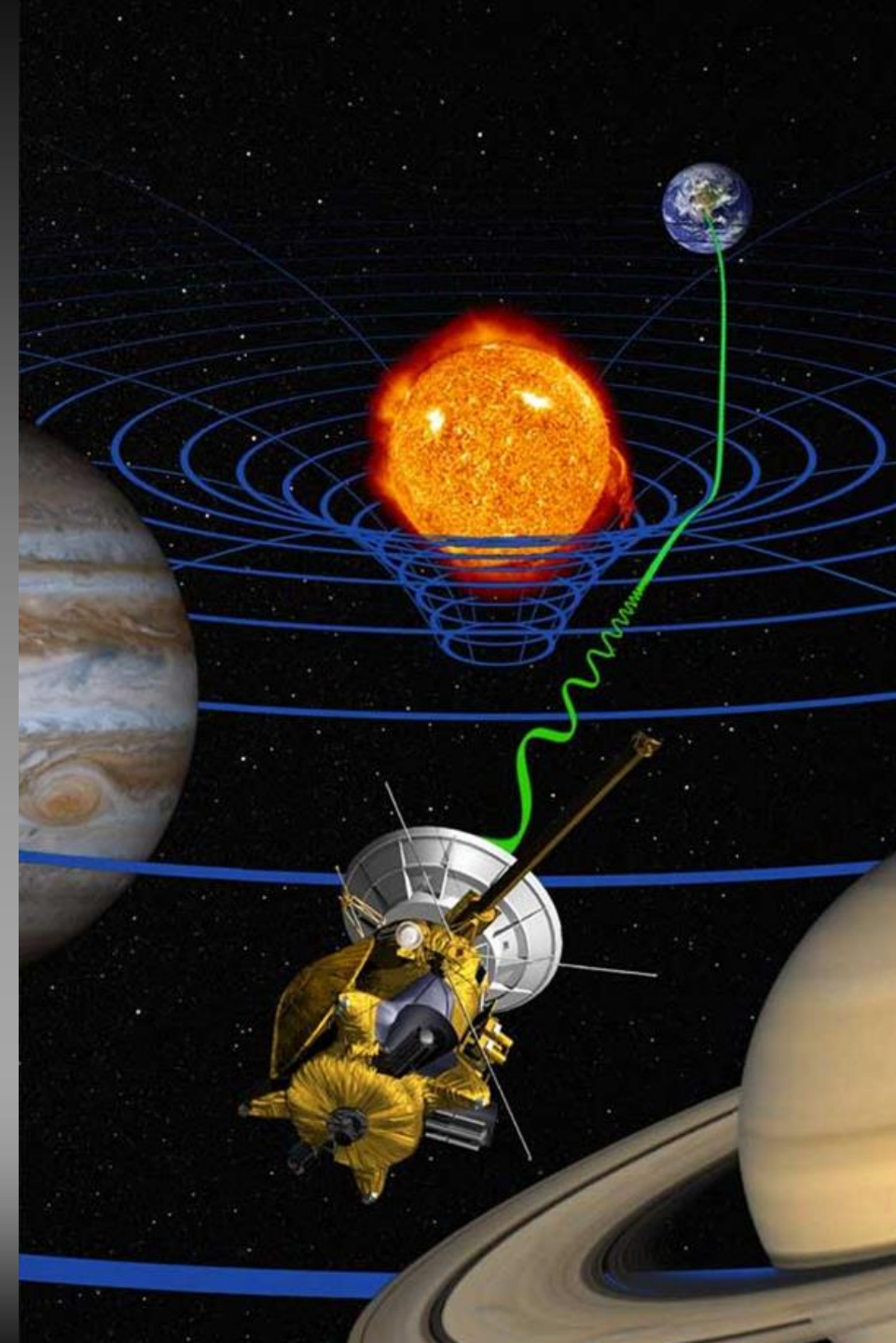
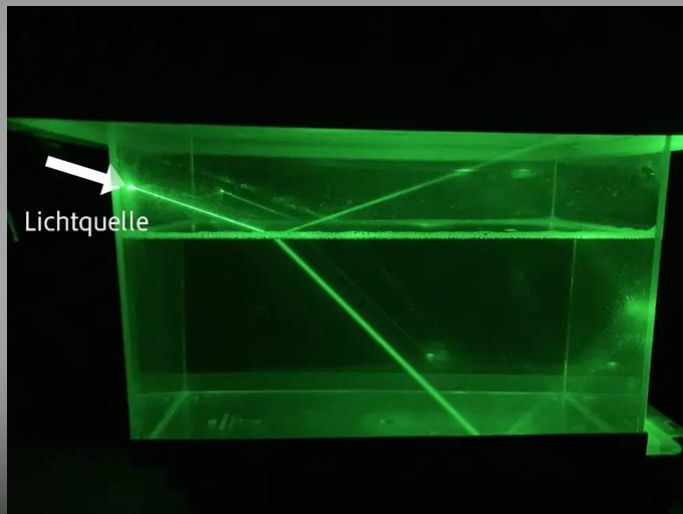


Die Renaissance der ART in den 1950-1960ern



Shapiro 1964

$$c_l = c \left(1 - \frac{R_s}{r} \right) = c \left(1 - \frac{2GM}{c^2 r} \right) = c (1 + 2\phi(x)) < c$$



„The Universe is expanding“



Doctor in Brooklyn: Why are you depressed, Alvy?

Alvy's Mom: Tell Dr. Flicker.

Alvy's Mom: It's something he read.

Doctor in Brooklyn: Something he read, huh?

Alvy at 9: **The universe is expanding.**

Doctor in Brooklyn: **The universe is expanding?**

Alvy at 9: Well, the universe is everything, and if it's expanding, someday it will break apart and that would be the end of everything!

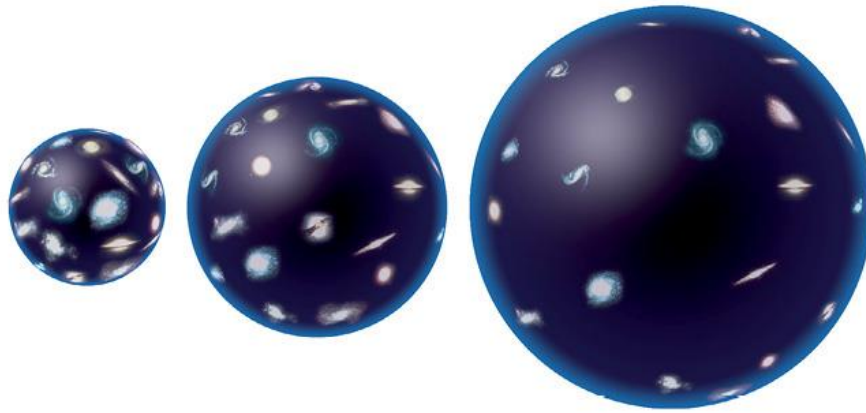
Alvy's Mom: What is that your business?

Alvy's Mom: He stopped doing his homework!

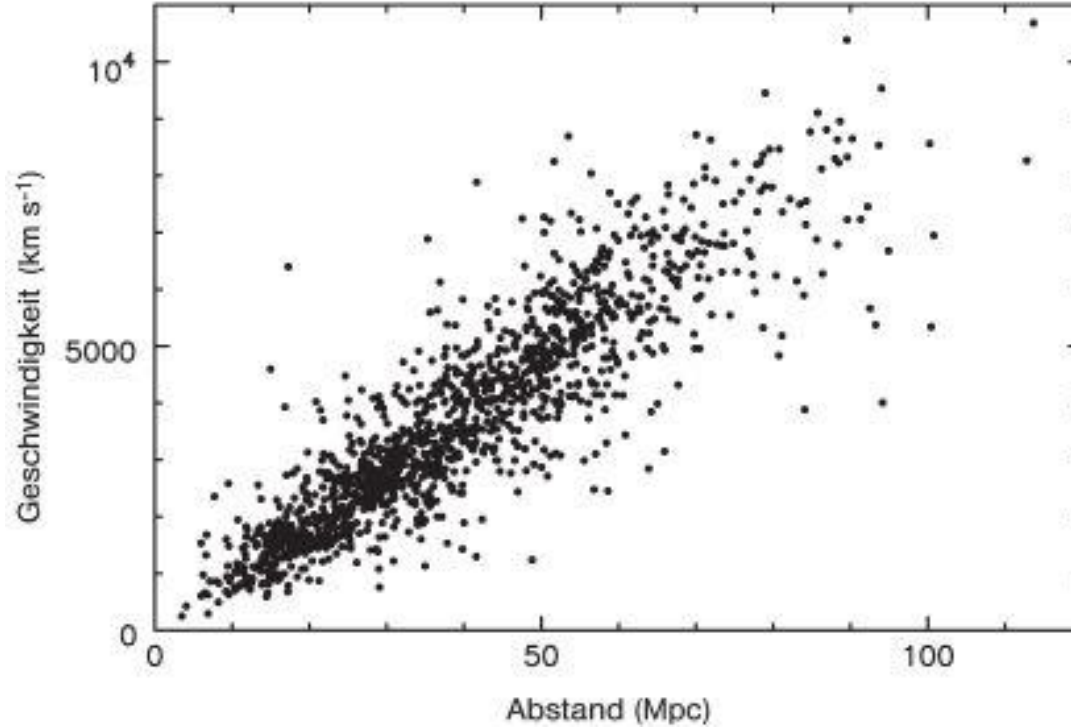
Alvy at 9: What's the point?

Alvy's Mom: What has the universe got to do with it? You're here in Brooklyn! Brooklyn is not expanding!

Doctor in Brooklyn: It won't be expanding for billions of years yet, Alvy. And we've gotta try to enjoy ourselves while we're here!



Hubble-Konstante: Expansionsrate des universums

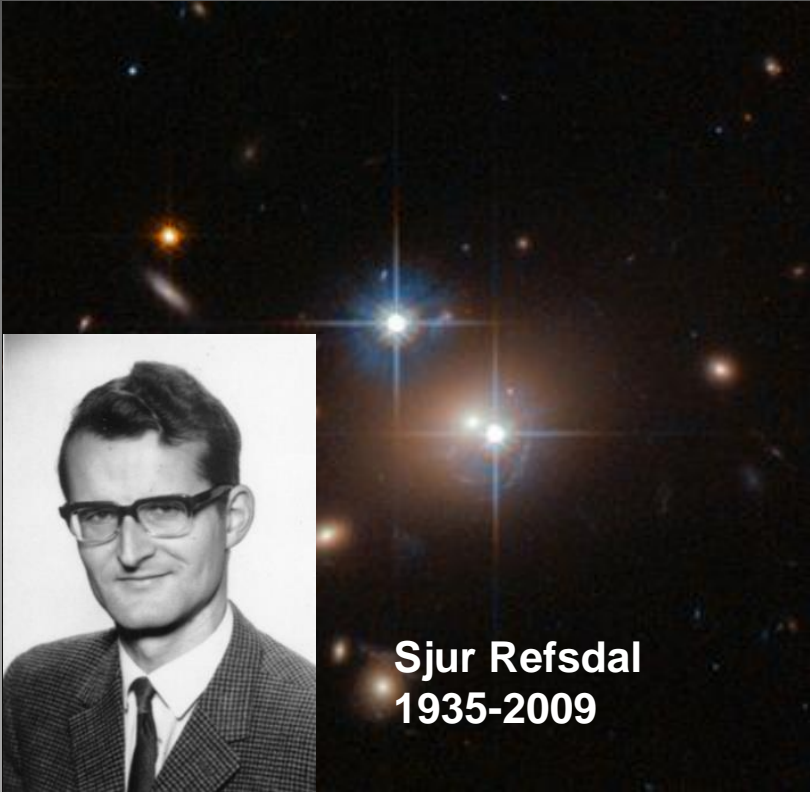


$$H_0 = \frac{\text{Fluchtgeschwindigkeit}}{\text{Entfernung}}$$

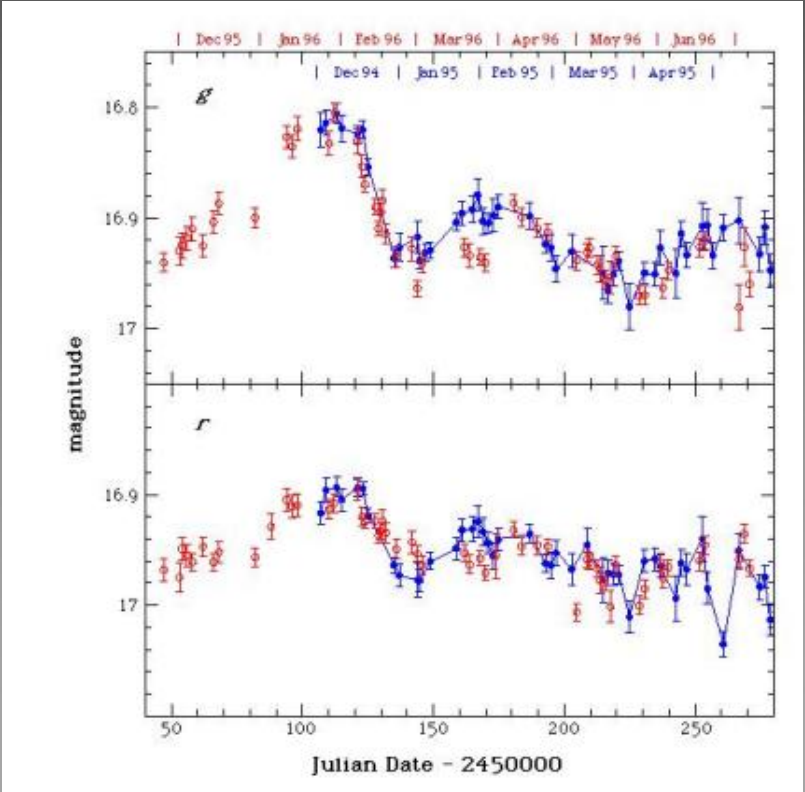
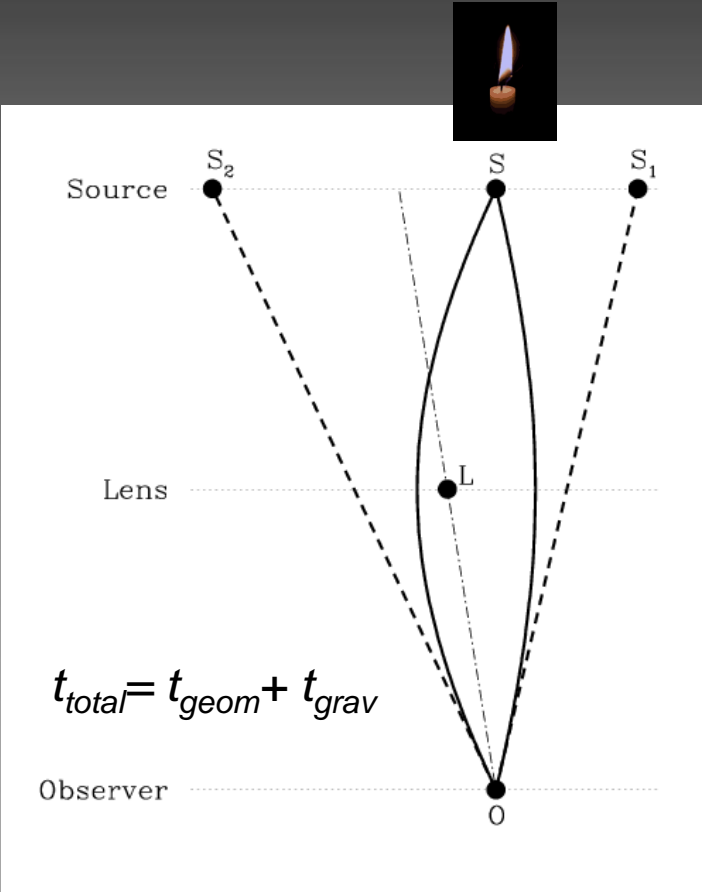
$$t_0 \approx \frac{1}{H_0}$$

$$H_0 = 72 \frac{\text{km}}{\text{s} \cdot \text{Mpc}}$$

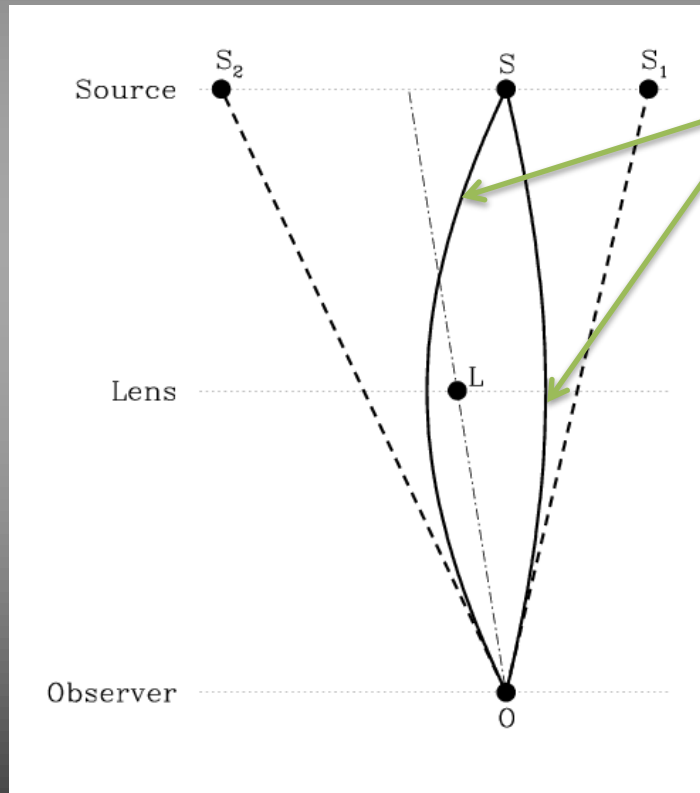
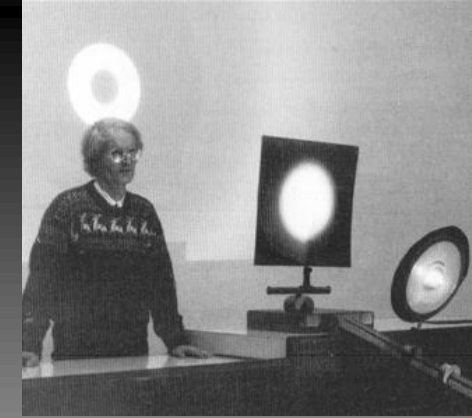
Entfernungsbestimmung mit „Refsdal-Methode“ (1964)



Sjur Refsdal
1935-2009



Entfernungsbestimmung mit „Refsdal-Methode“ (1964)



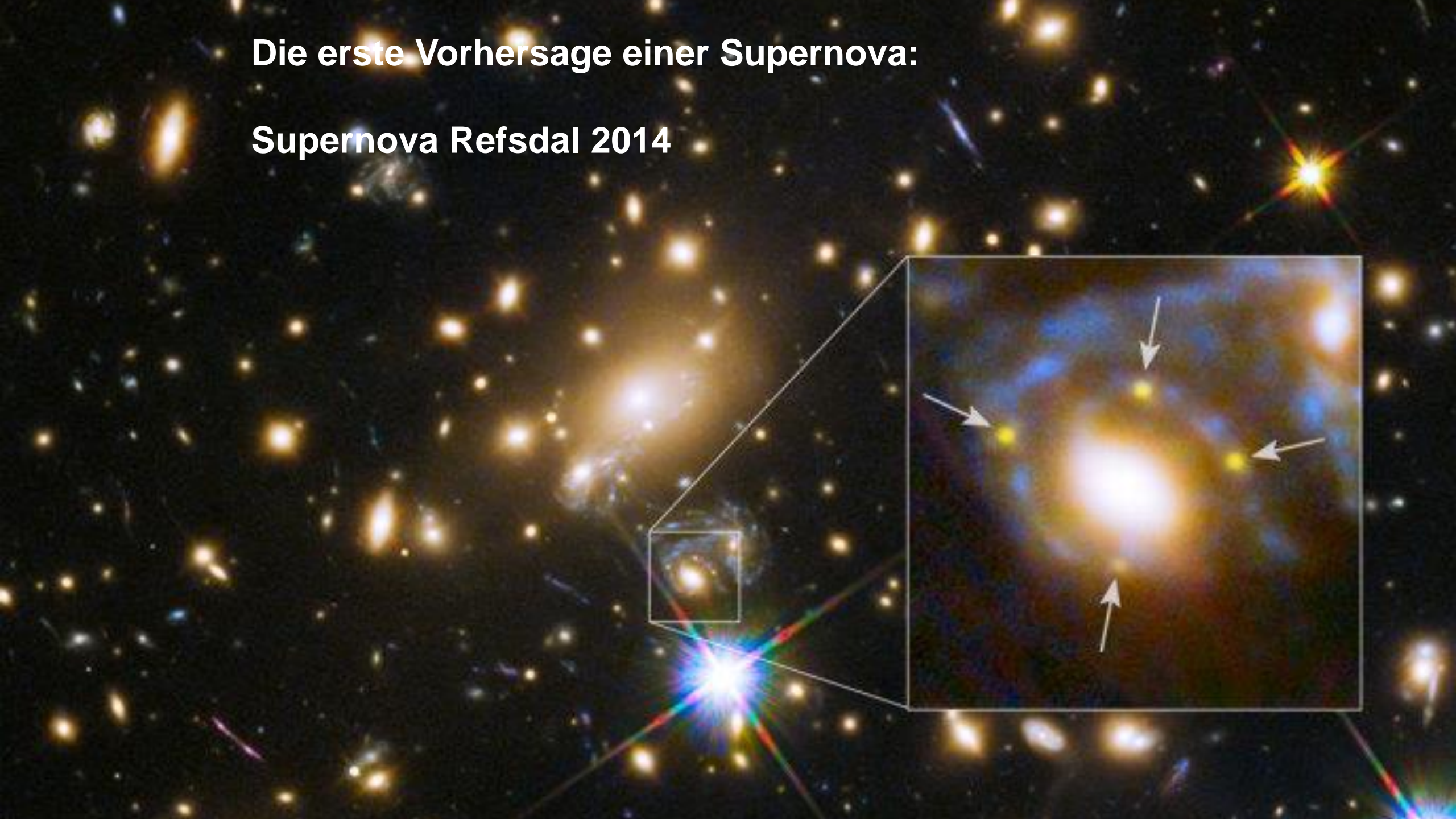
Dauer der Lichtreise unterschiedlich lang:

„Time Delay“ + *Massenprofil* (!)

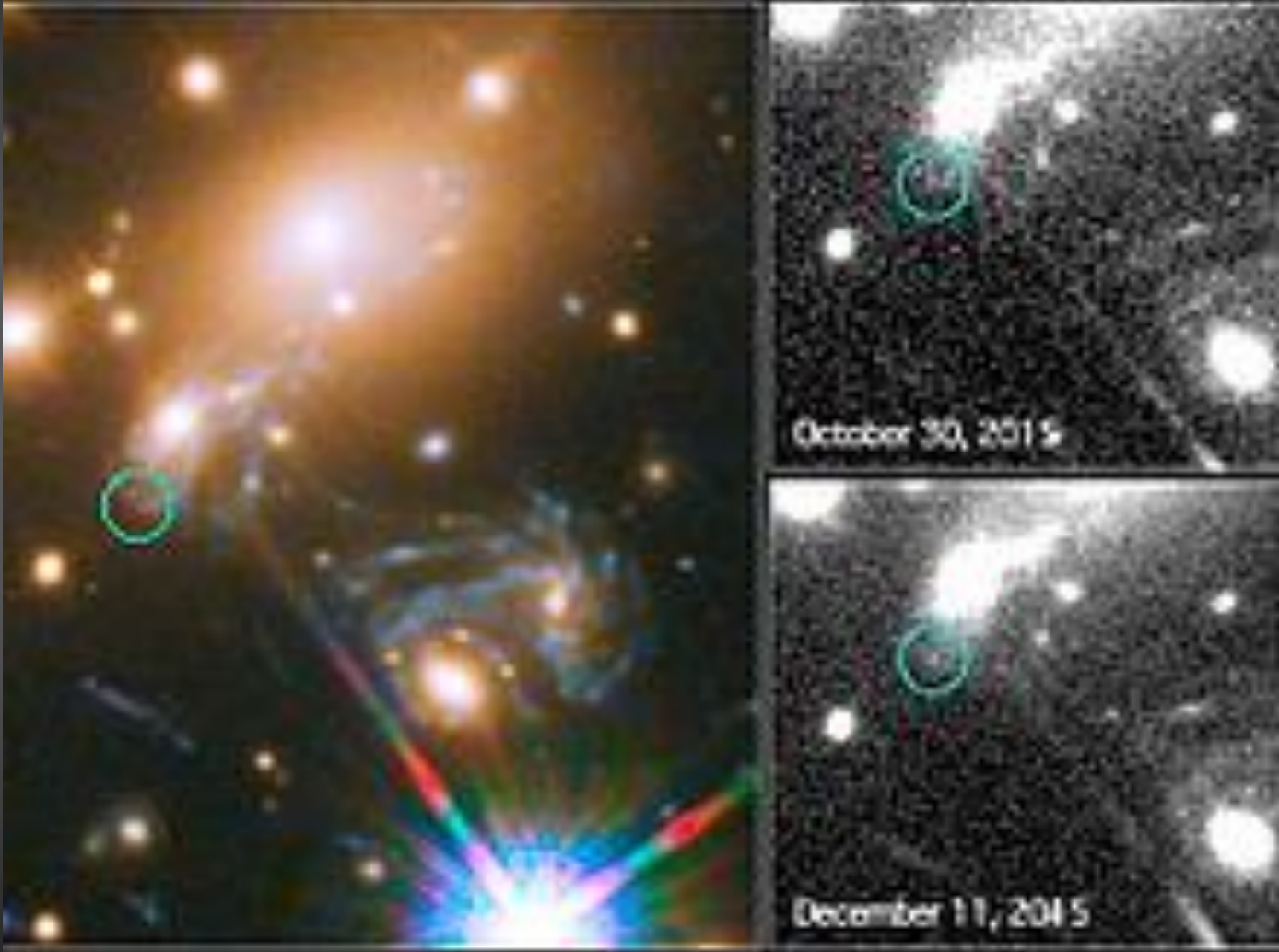
→ **Entfernung** → Hubble-Konstante

Die erste Vorhersage einer Supernova:

Supernova Refsdal 2014



Und ewig grüßt ...
die Supernova Refsdal

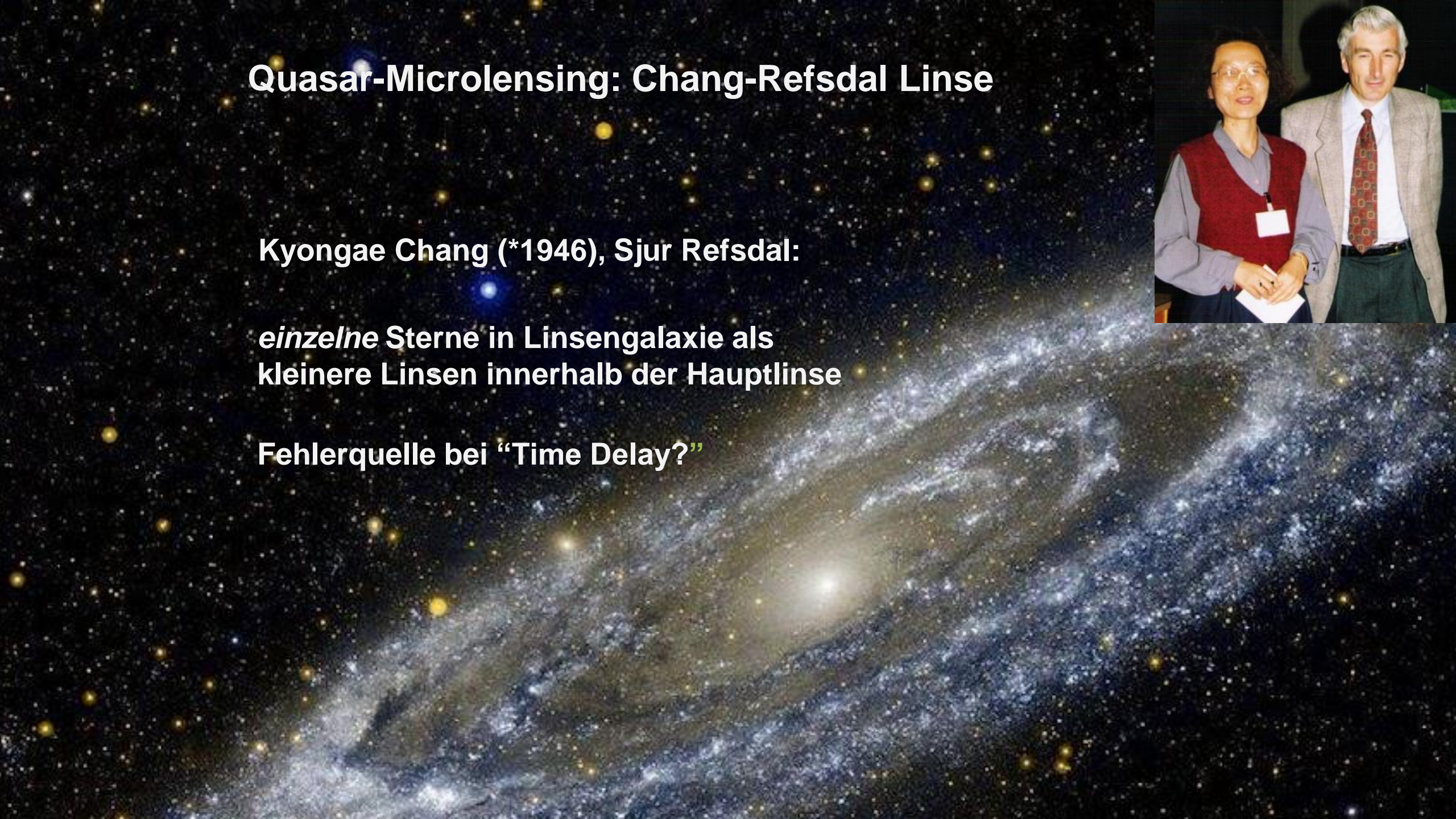


Quasar-Microlensing: Chang-Refsdal Linse

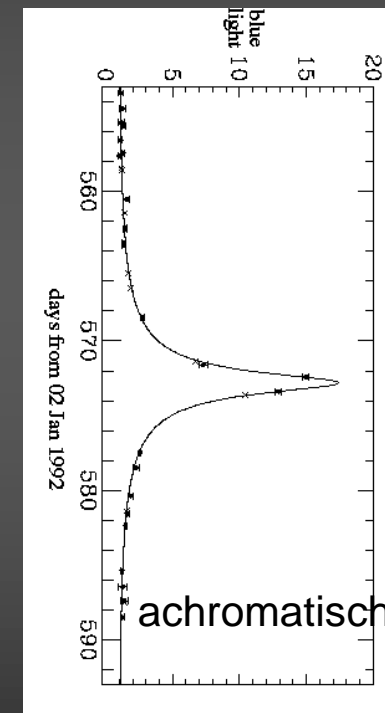
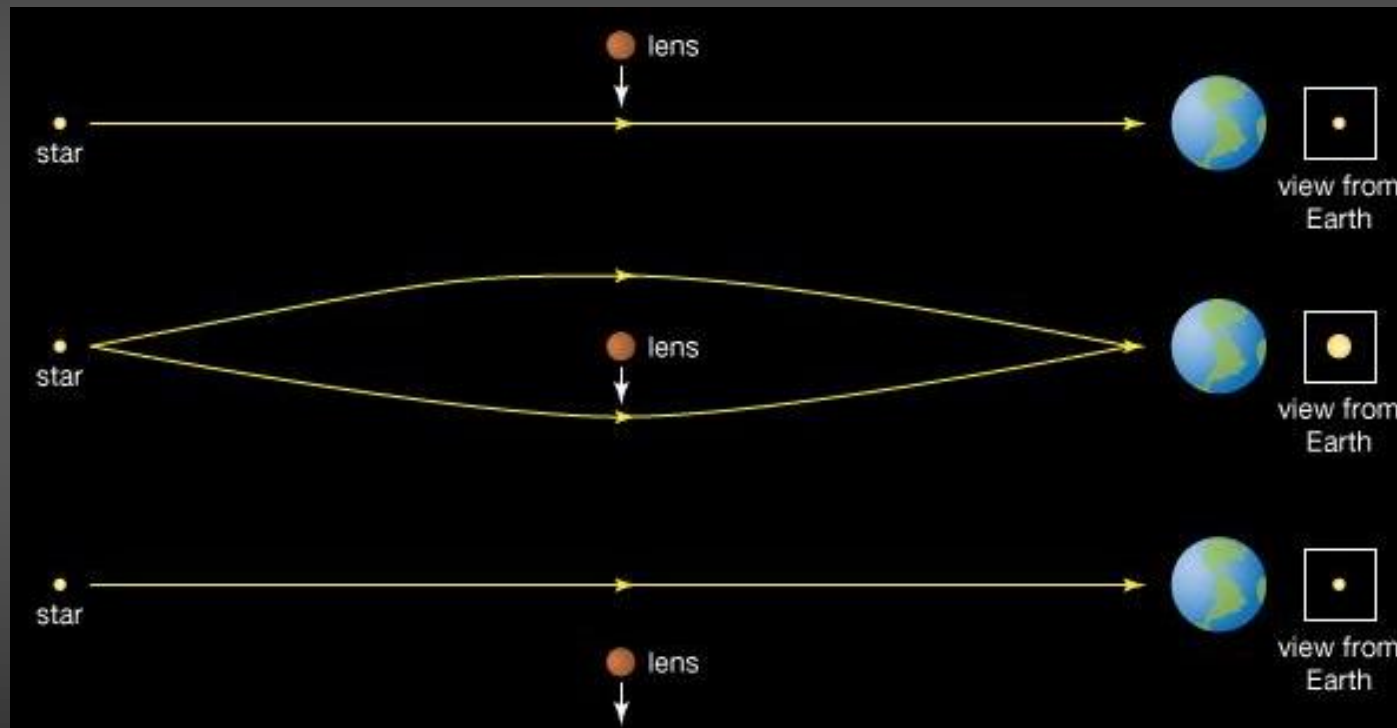
Kyongae Chang (*1946), Sjur Refsdal:

***einzelne* Sterne in Linsengalaxie als
kleinere Linsen innerhalb der Hauptlinse**

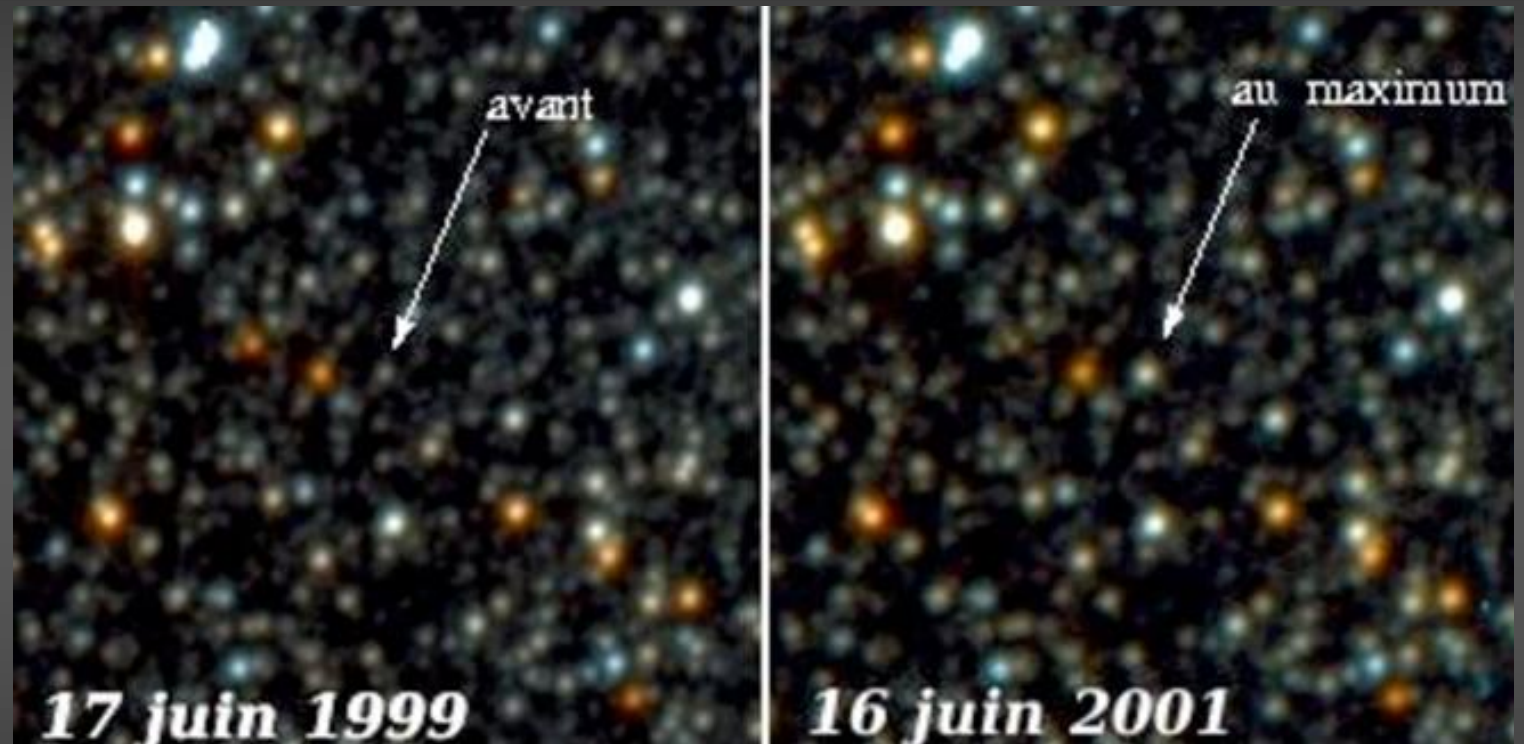
Fehlerquelle bei "Time Delay?"



Galaktisches Microlensing

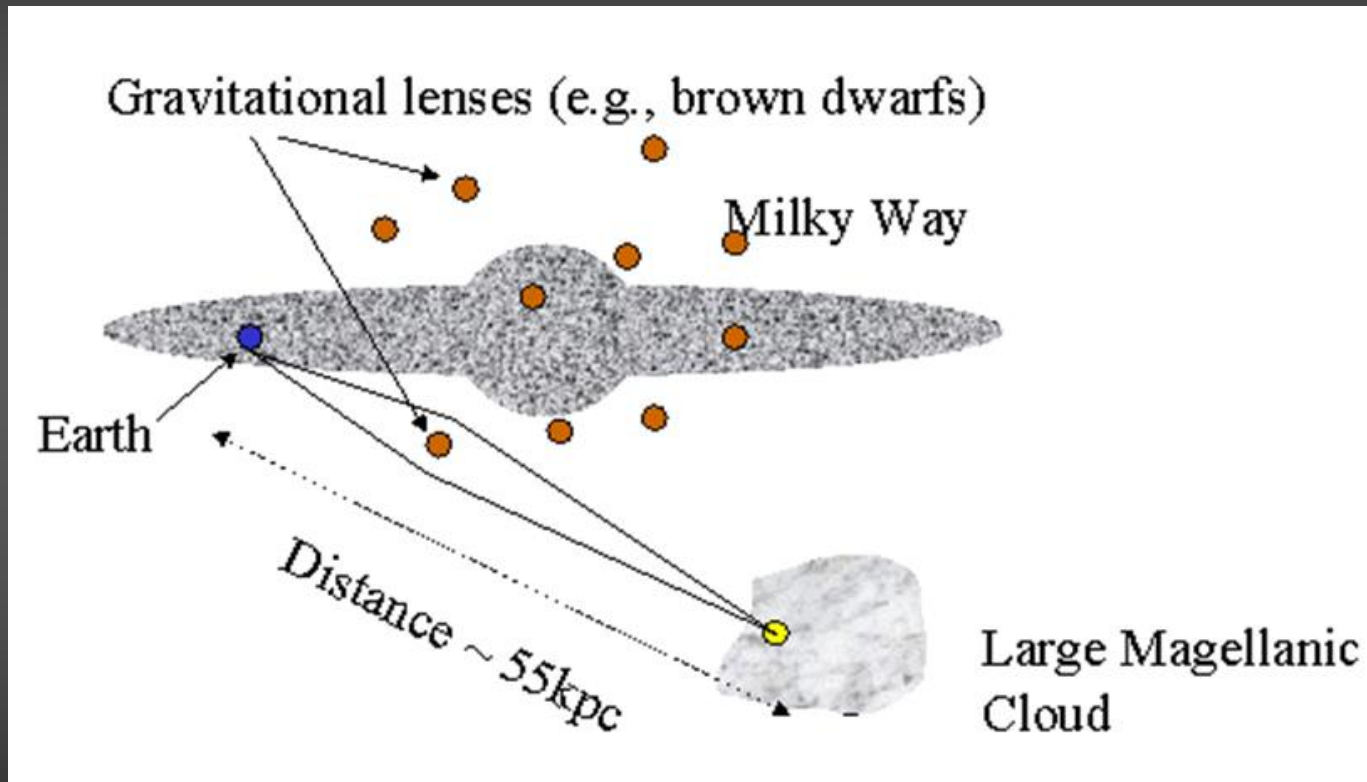


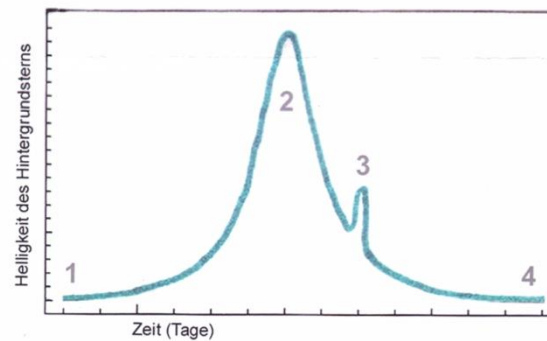
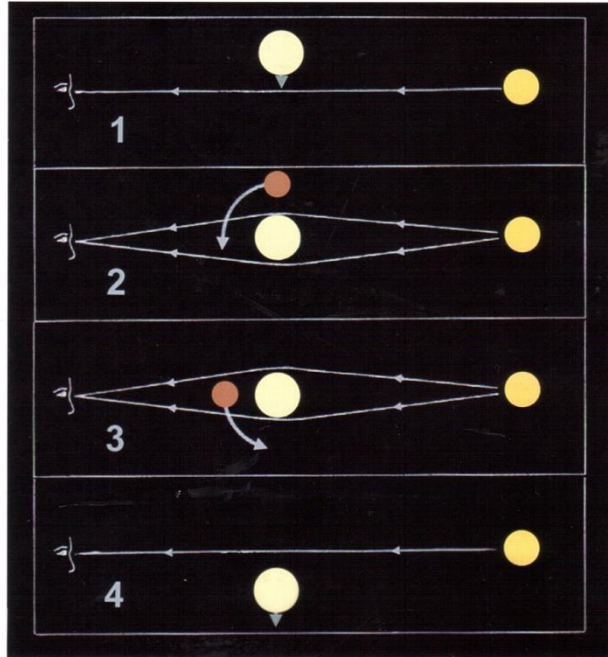
Galaktisches Microlensing



MACHOS im Halo?

(10^6 Sterne)

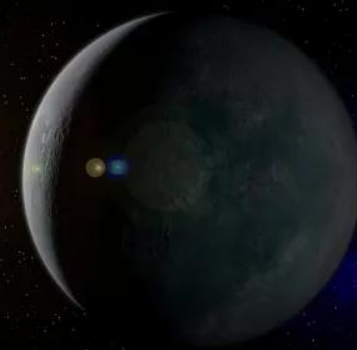




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**Rogue
Planets**





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