Gravitational Lensing

from Einstein's ring to probes of dark matter and extra-solar planets

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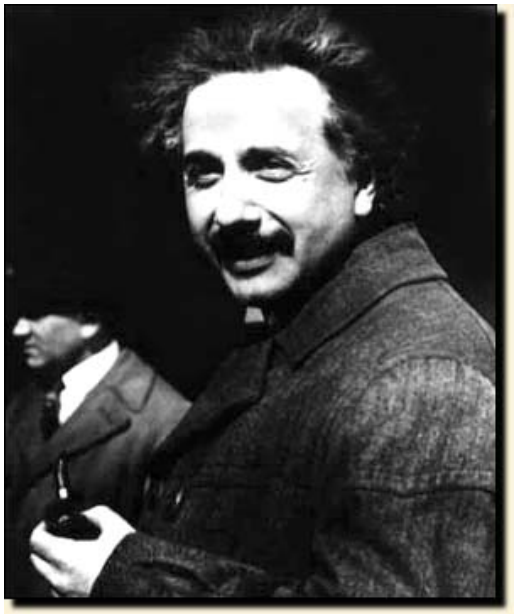


All masses fall at the same rate, so light must fall as well…

Bending of starlight by the sun will be around 1.75 seconds of arc.

Zürich, 14. X. 13.

Hochgeehrter Herr Kollege!

Eine einfache theoretische Überlegung macht die Annahme plausibel, dass Lichtstrahlen in einem Gravitationsfelde eine Deviation erfahren.

Grav. Feld Lichtstrahl

Am Sonnenrande müsste diese Ablenkung 0,84" betragen und wie $\frac{1}{}$ abnehmen (R = Entfernung vom Sonnen- Mittelpunkt)

0.84" Sonne

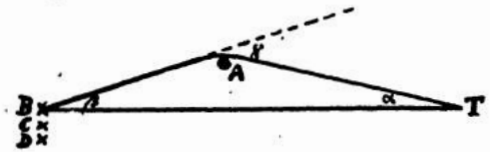
Es wäre deshalb von grösstem Interesse, bis zu wie grossen Sonnennähe helle Fixsterne bei Anwendung der stärksten Vergrösserungen bei Tage (ohne Sonnenfinsternis) gesehen werden können.

Über eine mögliche Form fiktiver Doppelsterne. Von *O. Chwolson.*

Es ist gegenwärtig wohl als höchst wahrscheinlich anzunehmen, daß ein Lichtstrahl, der in der Nähe der Oberfläche eines Sternes vorbeigeht, eine Ablenkung erfährt. Ist γ diese Ablenkung und γ_0 der Maximumwert an der Oberfläche, so ist $\gamma_0 \geqq \gamma \geqq 0$. Die Größe des Winkels ist bei der Sonne $\gamma_0 = 1''.7$; es dürften aber wohl Sterne existieren, bei denen γ_0 gleich mehreren Bogensekunden ist; vielleicht auch noch mehr. Es sei A ein großer Stern (Gigant), T die Erde, B ein entfernter Stern; die Winkeldistanz zwischen A und B, von T aus gesehen, sei α, und der Winkel zwischen A und T, von B aus gesehen, sei β. Es ist dann

$$\gamma = \alpha + \beta .$$

Ist B sehr weit entfernt, so ist annähernd $\gamma = \alpha$. Es kann also α gleich mehreren Bogensekunden sein, und der Maximumwert von α wäre etwa gleich γ_0. Man sieht den Stern B von der Erde aus an zwei Stellen: direkt in der Richtung TB und außerdem nahe der Oberfläche von A, analog einem Spiegelbild. Haben wir mehrere Sterne B, C, D, so würden die Spiegelbilder umgekehrt gelegen sein wie in einem gewöhnlichen Spiegel, nämlich in der Reihenfolge D, C, B, wenn von A aus gerechnet wird (D wäre am nächsten zu A).



Der Stern A würde als fiktiver Doppelstern erscheinen. Teleskopisch wäre er selbstverständlich nicht zu trennen. Sein Spektrum bestände aus der Übereinanderlagerung zweier, vielleicht total verschiedenartiger Spektren. Nach der Interferenzmethode müßte er als Doppelstern erscheinen. Alle Sterne, die von der Erde aus gesehen rings um A in der Entfernung $\gamma_0 - \beta$ liegen, würden von dem Stern A gleichsam eingefangen werden. Sollte zufällig TAB eine gerade Linie sein, so würde, von der Erde aus gesehen, der Stern A von einem Ring umgeben erscheinen.

Ob der hier angegebene Fall eines fiktiven Doppelsternes auch wirklich vorkommt, kann ich nicht beurteilen.

O. Chwolson.

Petrograd, 1924 Jan. 28.

(Dated one week after Lenin's death.
The city had already been renamed
"Leningrad" on Jan. 24, 1924.)

DISCUSSION

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. Let there be an observer at a distance D from B and at a distance x, small compared with D, from the extended central line $\overline{AB}$. According to the general theory of relativity, let α_0 be the deviation of the light ray passing the star B at a distance R_0 from its center. If we are interested mainly in the case $q \gg 1$, the formula

$$q = \frac{l}{x}$$

is a sufficient approximation, since $\frac{x^2}{l^2}$ may be neglected. Even in the most favorable cases the length l is only a few light-seconds, and x must be small compared with this, if an appreciable increase of the apparent brightness of A is to be produced by the lens-like action of B.

Therefore, there is no great chance of observing this phenomenon, even if dazzling by the light of the much nearer star B is disregarded. This apparent amplification of q by the lens-like action of the star B is a most curious effect, not so much for its becoming infinite, with x vanishing, but since with increasing distance D of the observer not only does it not decrease, but even increases proportionally to $\sqrt{D}$.

Albert Einstein

Institute for Advanced Study,
Princeton, N. J.

Of course, there is no hope of observing this phenomenon directly. First, we shall scarcely ever approach closely enough to such a central line. Second, the angle β will defy the resolving power of our instruments. For, α_0 being of the order of magnitude of one second of arc, the angle R_0/D, under which the deviating star B is seen, is much smaller. Therefore, the light coming from the luminous circle can not be distinguished by an observer as geometrically different from that coming from the star B, but simply will manifest itself as increased apparent brightness of B.

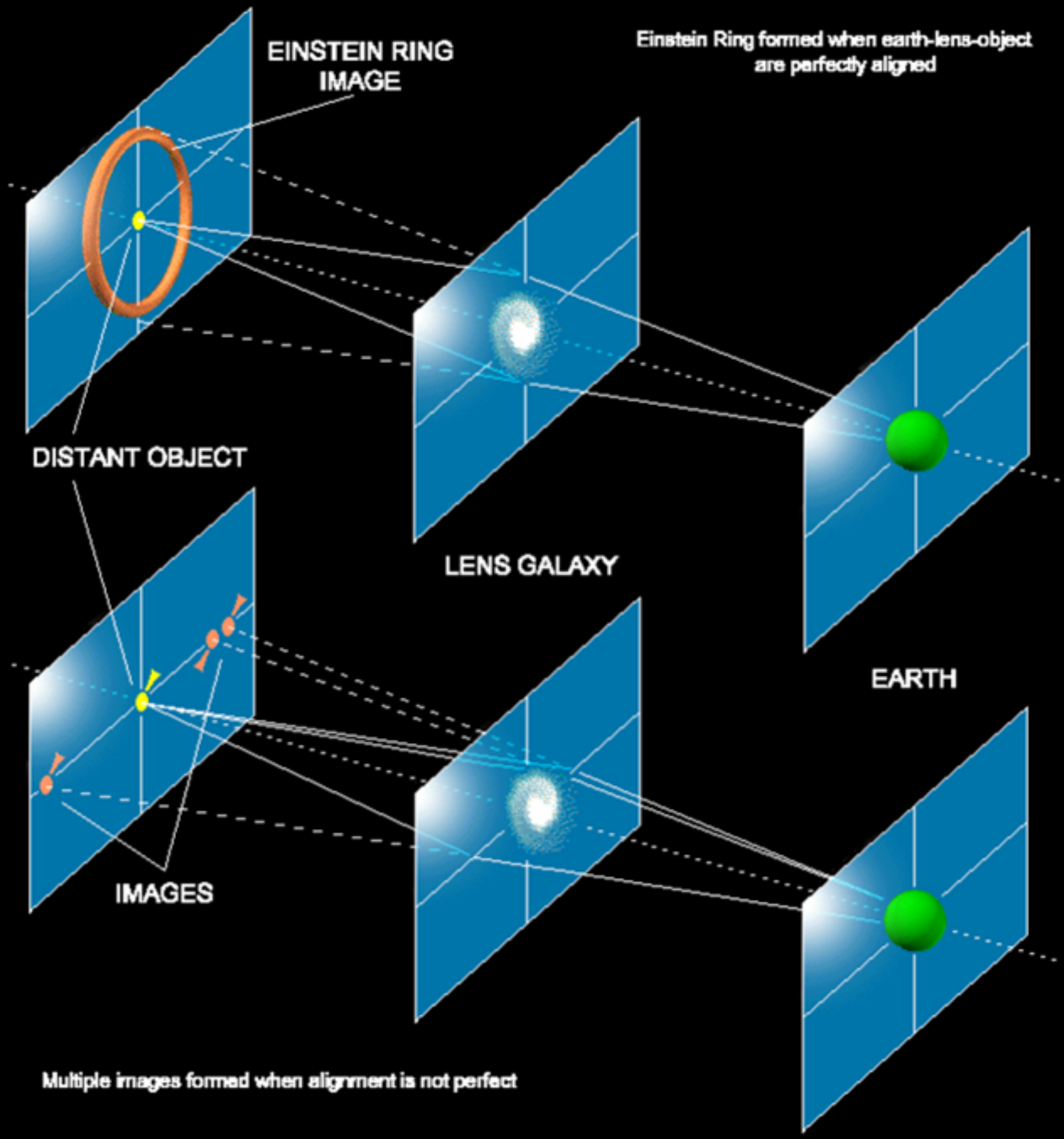
The same will happen, if the observer is situated at not decrease like $1/D$, but like $1/\sqrt{D}$, as the distance D increases.

PLEISTOCENE MAN IN SOUTHERN CALIFORNIA

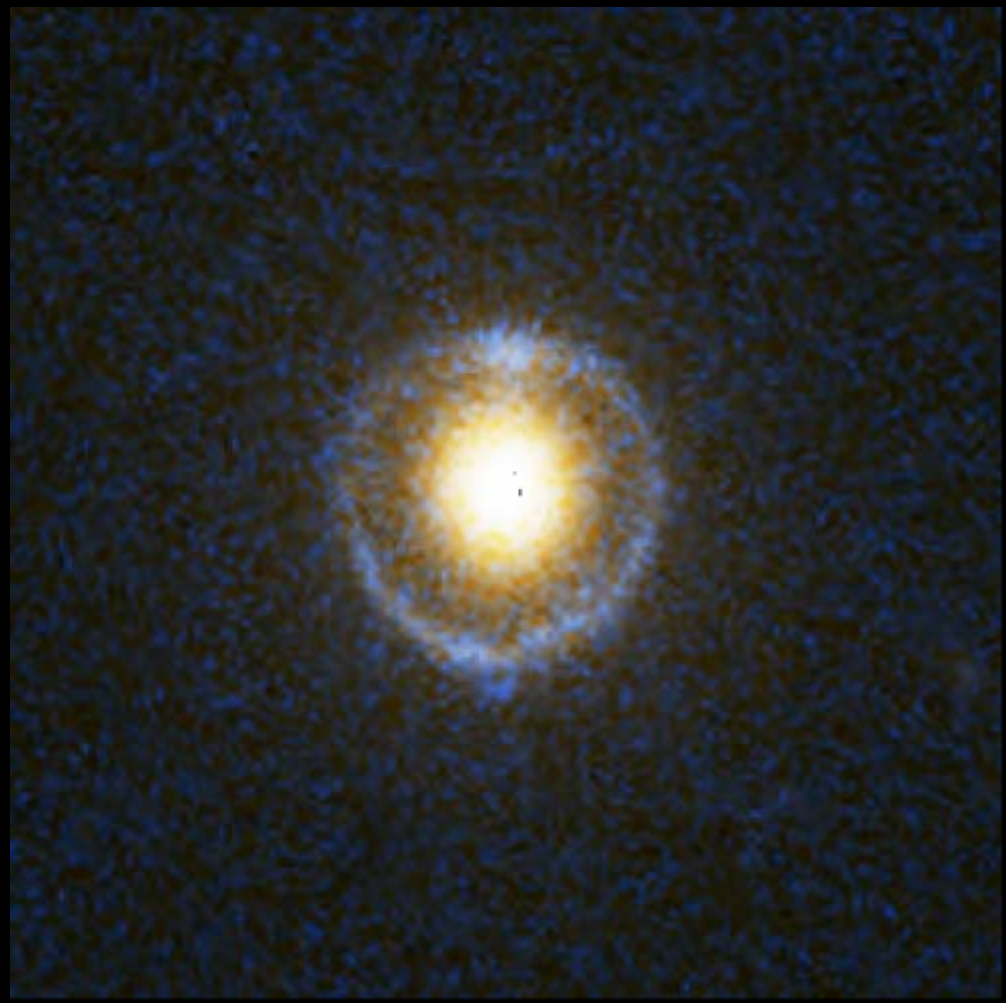
On the twenty-third of January of this year the Federal PWA Project, C-642, in an excavation project to build a storm drain from Los Angeles to the sea, unearthed what has proved to be a very interesting and doubtless significant discovery of early man in America. The chief engineer, Mr. J. J. Ryan, of the strata. All the deposits on the walls of this trench appear to be fairly well bedded, and even to a casual observer they are very clear. The strata run almost horizontally, thus making them easy to trace for hundreds of feet. Over these skeletal remains were four strata. Beginning at bottom the stratum was gravel, about four feet thick. Over that was a gray clay two feet thick, which covered the human remains; then three feet of very dark clay. The fourth stratum from the bottom was gray clay, three to four feet thick, with boulders enmeshed. The top stratum was three feet of yellow clay; no loam soil on top.

For several weeks the site was watched by Dr. Lopatin and the workers, with the hope that other discoveries of the kind would be made, and on the thirteenth of March about one thousand feet from the site where the human remains were found, several bones of a large animal were discovered. Four large teeth and some fragments of tusks came to light in close proximity to the large bones. For identification, Dr. Thomas Clements, of the geology department of the University of Southern California, was called in consultation. He identified these bones as those of the mammoth (*Archidiskodon imperator* Leidy).

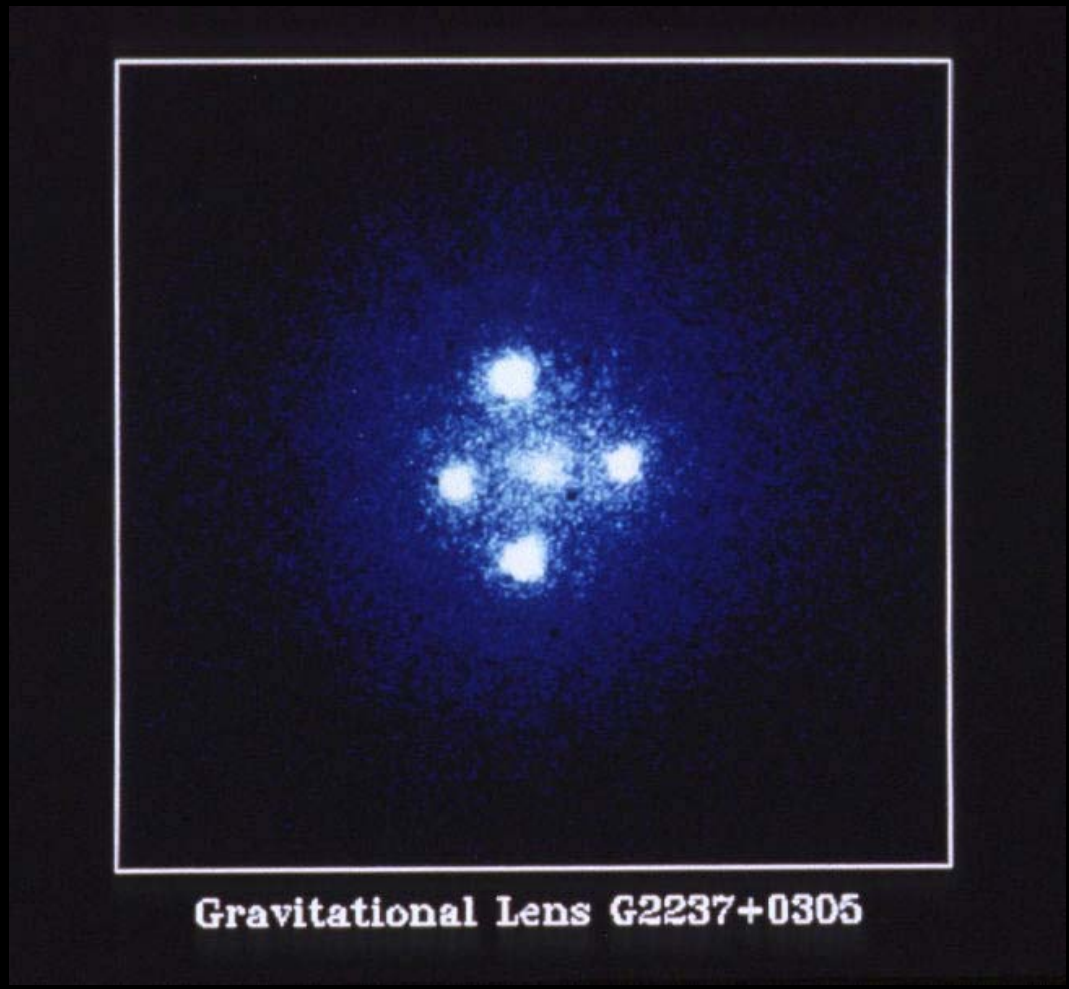
Due to the extended and thorough excavation of the government project a thorough examination of the stratification could be made, and it was found that the mammoth bones were in the same stratum as that of the human remains and were covered to a depth of about 12 feet. Likewise there were five strata in-


EINSTEIN RING
IMAGE
Einstein Ring formed when earth-lens-object
are perfectly aligned
DISTANT OBJECT
LENS GALAXY
EARTH
IMAGES
Multiple images formed when alignment is not perfect

Einstein Ring



Giant elliptical galaxy roughly 3 billion light-years away lensing galaxy twice as far away.

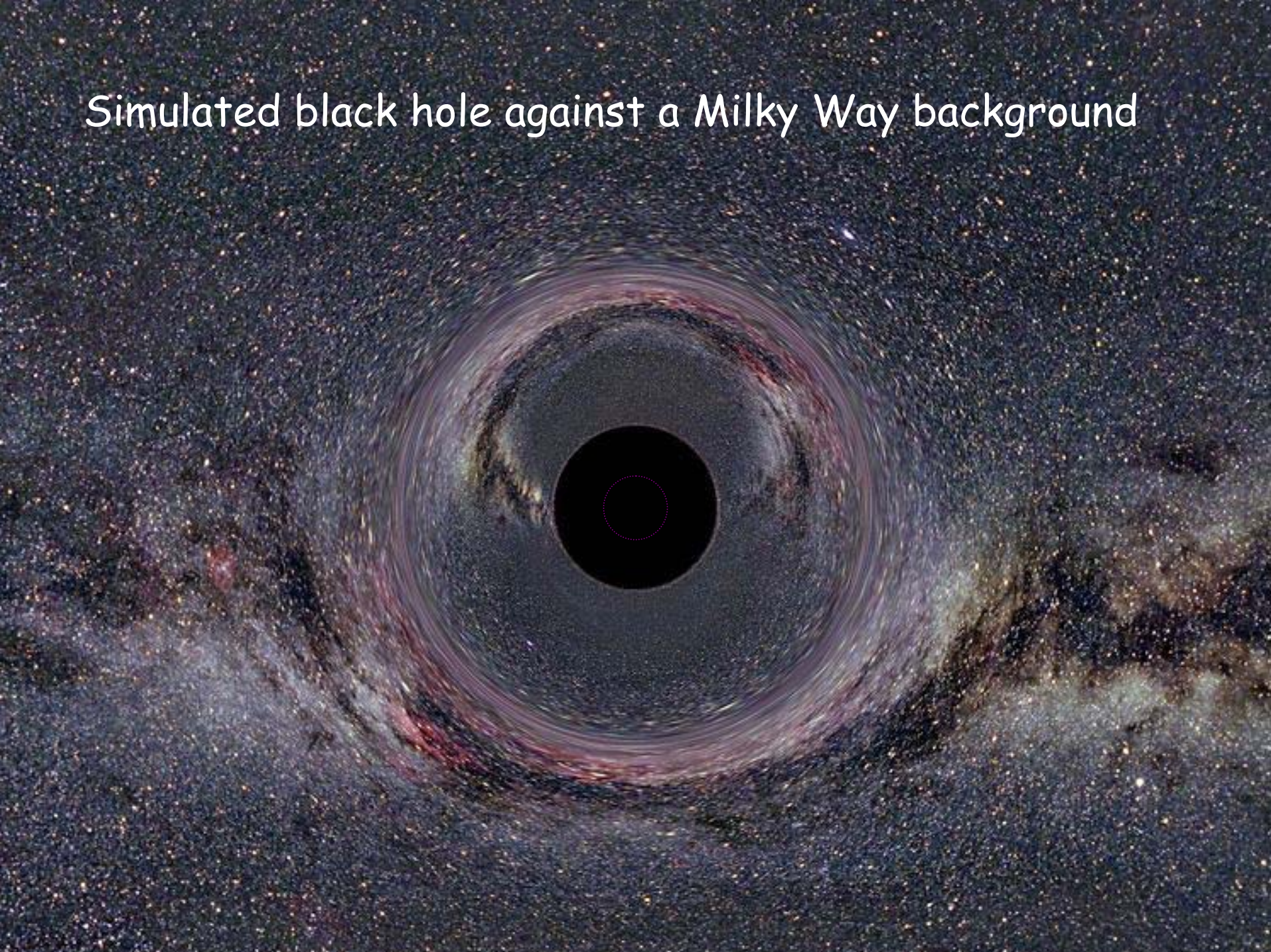


Quasar 8 billion light years away, lense galaxy 400 million light years: 20 times closer.

Time delays of multiple images:

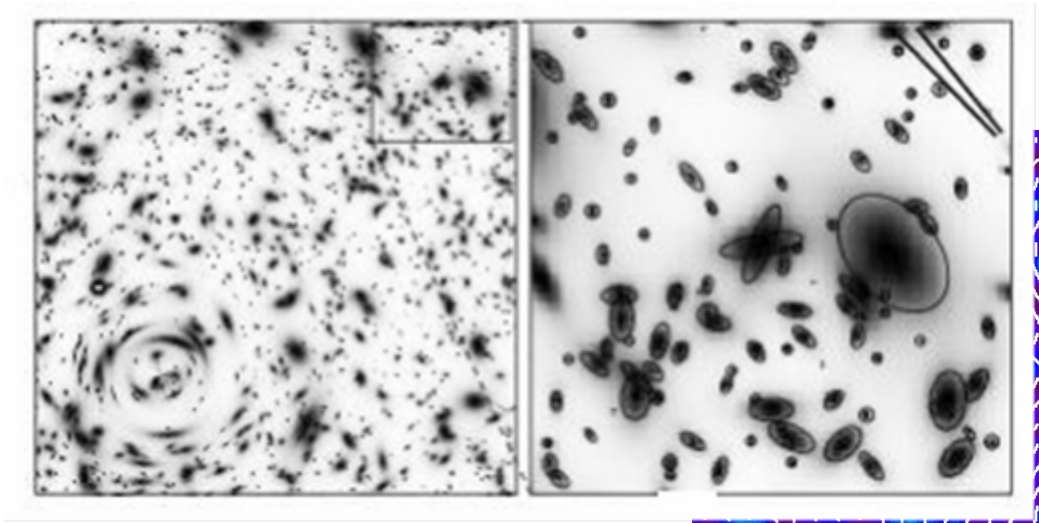
~ 14, 8, and 2 days among the four images of intrinsic quasar variations.

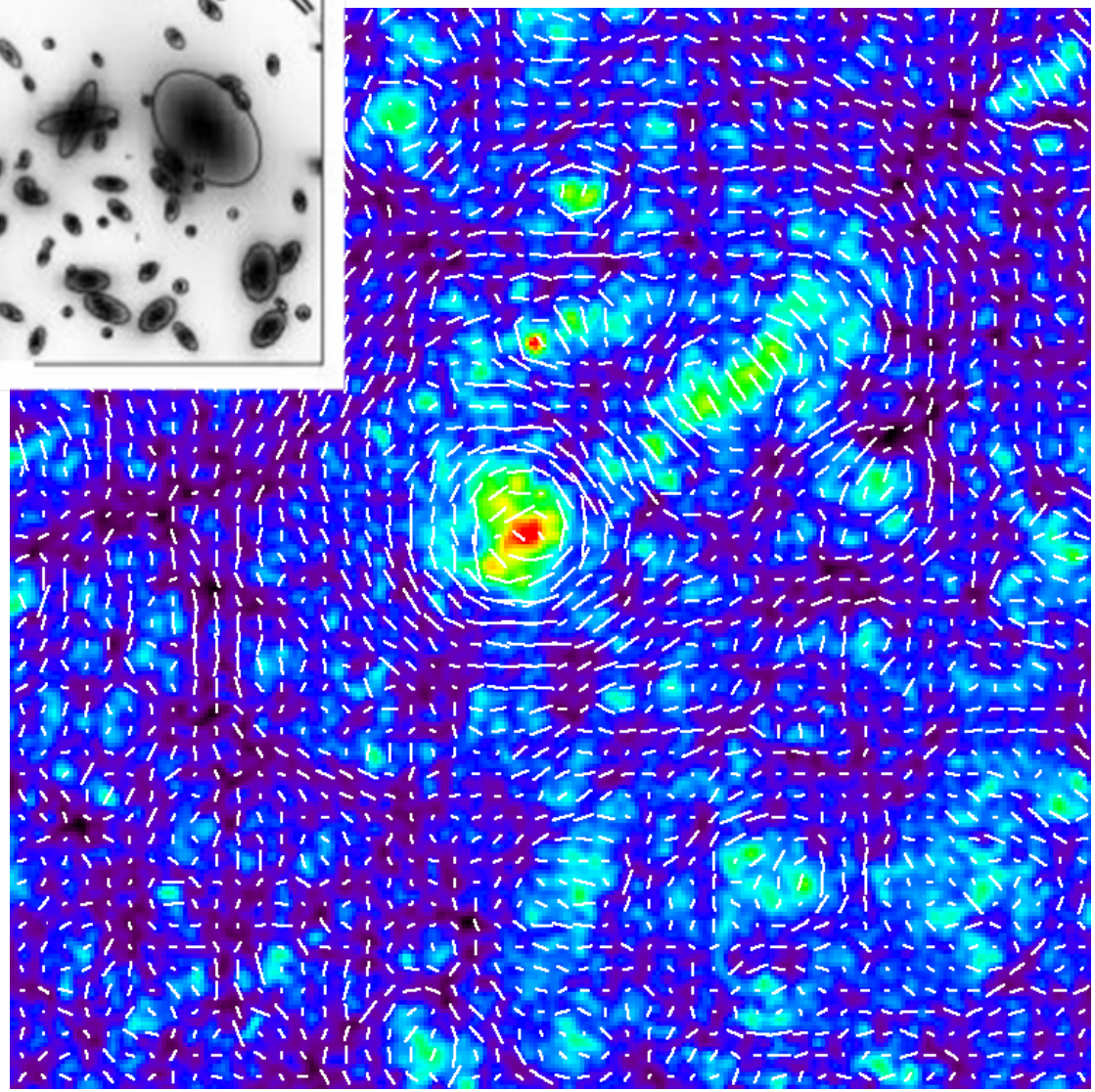
Non-intrinsic variations of 9% per year are attributed to microlensing.


Simulated black hole against a Milky Way background

Galaxy Cluster Abell 2218 **HST • WFPC2**

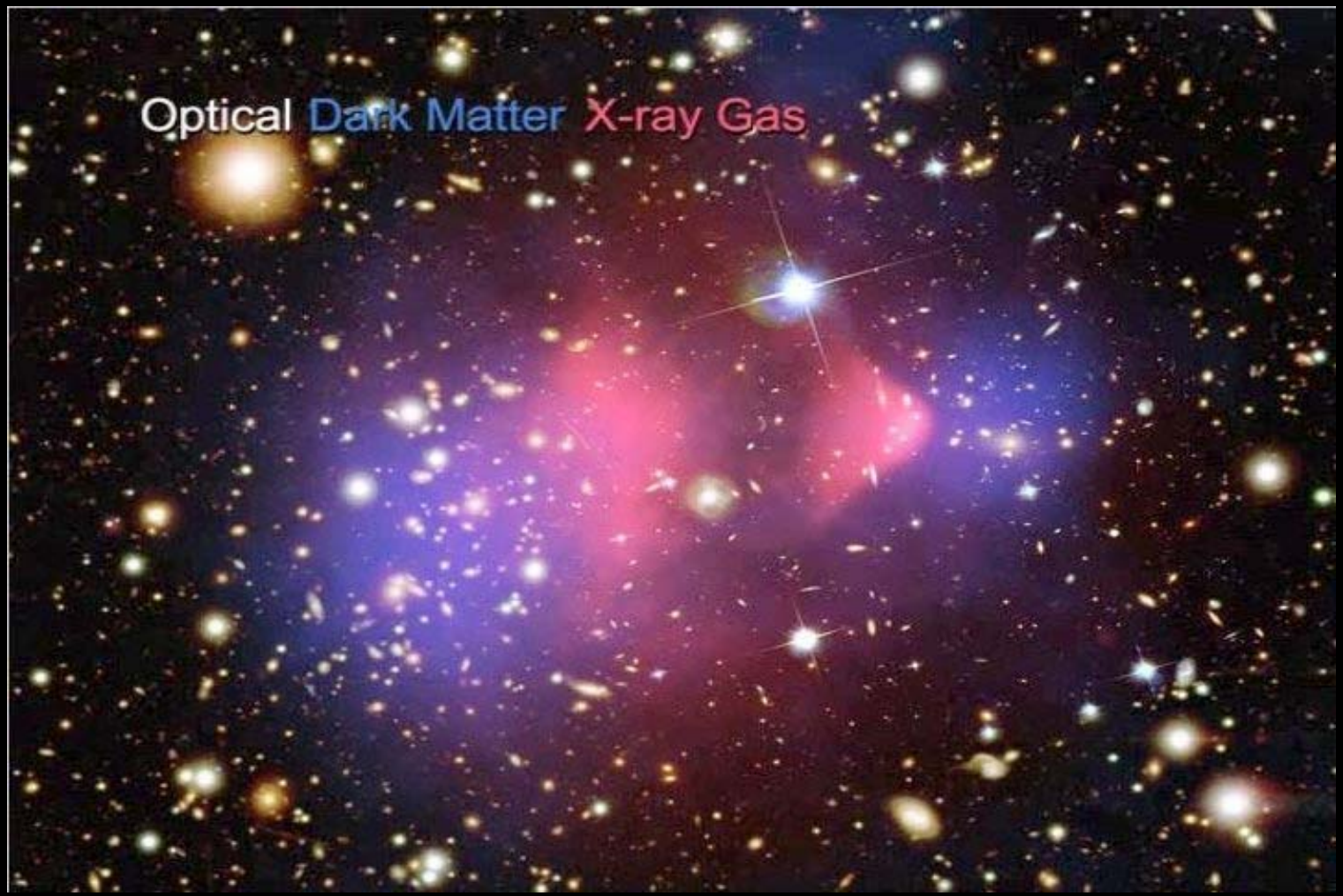
NASA, A. Fruchter and the ERO Team (STScI, ST-ECF) • STScI-PRC00-08





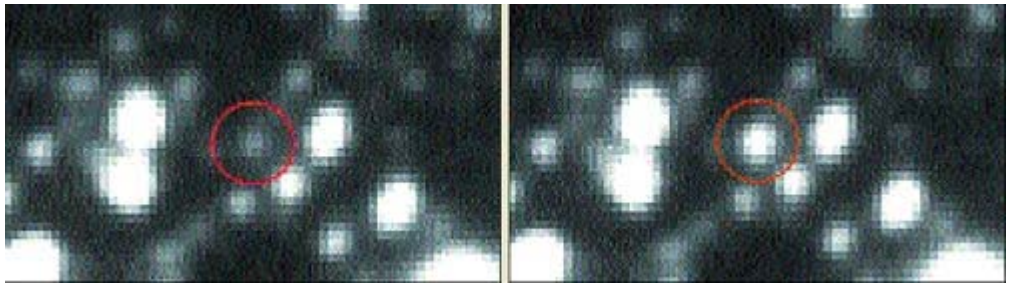
"Weak lensing" of background galaxies produces a 'map' of gravity field of a foreground galaxy cluster.

When clusters of galaxies collide…



Luminous and dark matter sail through, but gas is trapped.

Extrasolar planets have been detected by "microlensing"!



Credit:

Ian Bond et al, 2004

Figure from physicsworld.com