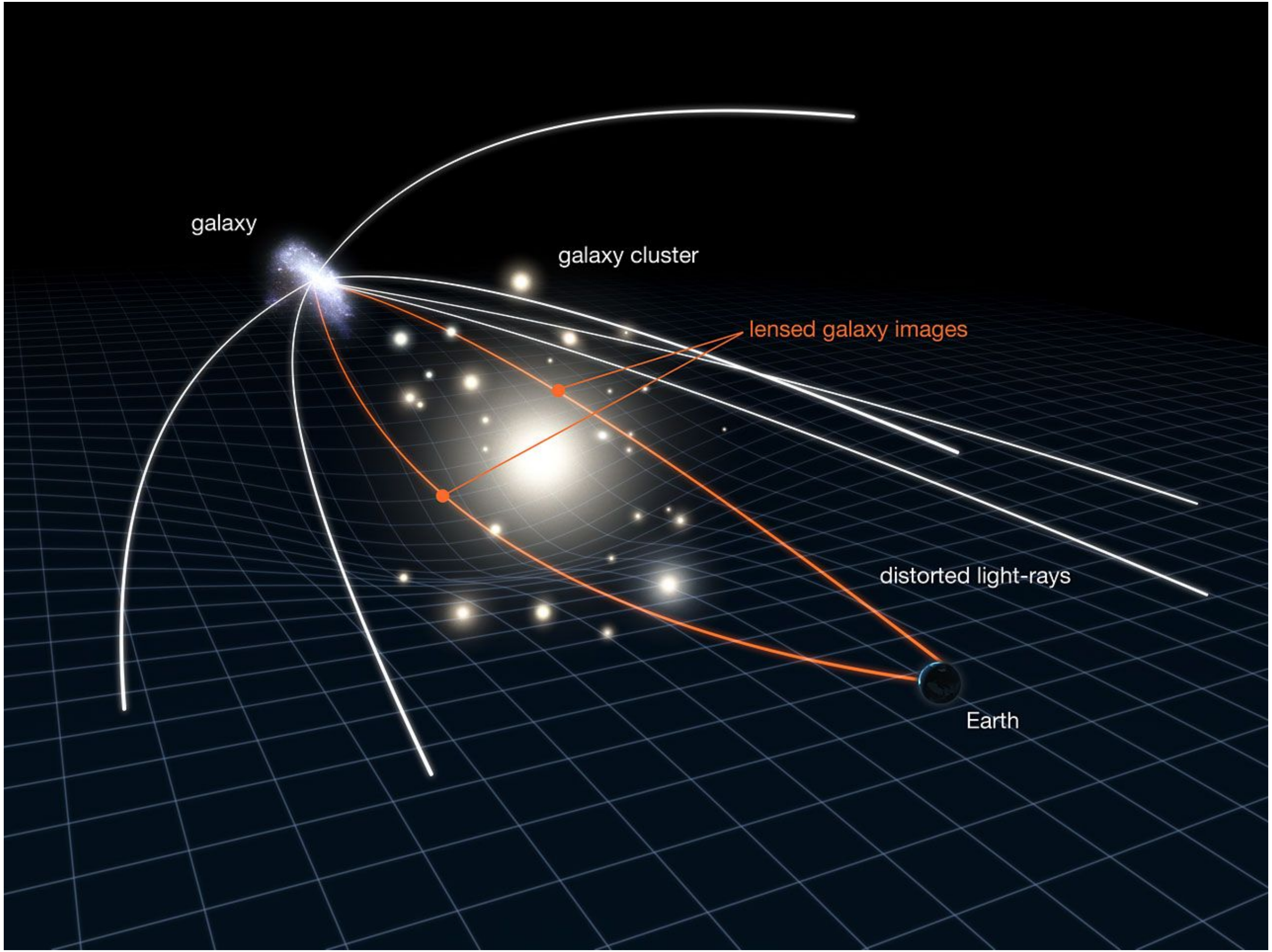
A story of gravitational lensing

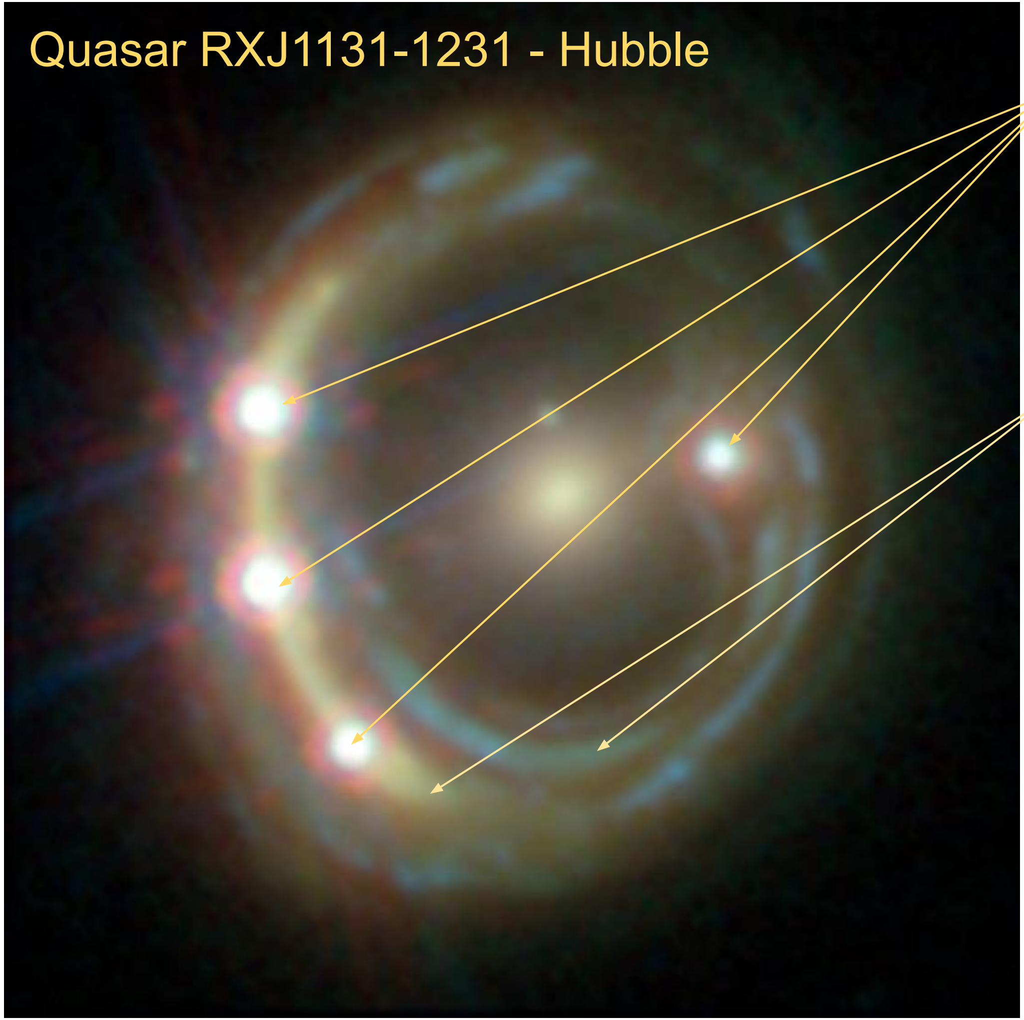
AnimaScience - 27 janvier 2026

Dominique Boutigny

Consequence of General Relativity - Einstein 1915




Abell 2390 - Euclid


Quasar RXJ1131-1231 - Hubble
Quasar
Quasar's host galaxy

Orest Chwolson - 1924

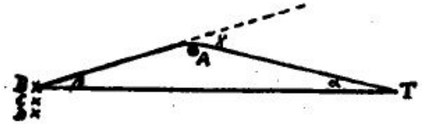
Chwolson, O. (1924). Über eine mögliche Form fiktiver Doppelsterne. Astronomische Nachrichten, 221, 329-330.

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 $\gamma_0 \geq \gamma \geq 0$. Die Größe des Winkels ist bei der Sonne $\gamma_0 = 1\overset{''}{.}7$; 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.

Petrograd, 1924 Jan. 28.

O. Chwolson.

On a possible form of fictitious double stars. By O. Chwolson.

It is currently considered highly probable that a ray of light passing near the surface of a star experiences a deflection. If γ is this deflection and γ_0 is the maximum value at the surface, then $\gamma_0 \geq \gamma \geq 0$. The magnitude of the angle for the Sun is $\gamma_0 = 1.7"$; however, stars likely exist where γ_0 is equal to several arcseconds, perhaps even more. Let A be a large star (giant), T the Earth, and B a distant star; let the angular distance between A and B, as seen from T, be α, and the angle between A and T, as seen from B, be β. It is then:

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

If B is very far away, then γ is approximately equal to α. Thus, α can be equal to several arcseconds, and the maximum value of α would be approximately equal to γ_0. One sees the star B from the Earth in two places: directly in the direction TB and additionally near the surface of A, analogous to a mirror image. If we have several stars B, C, D, their mirror images would be situated in reverse order compared to an ordinary mirror, namely in the order D, C, B when calculated from A (D would be closest to A).

The star A would appear as a **fictitious double star**. Telescopically, it would naturally not be possible to separate them. Its spectrum would consist of the superposition of two, perhaps totally different, types of spectra. By the interference method, it should appear as a double star. All stars that, seen from the Earth, lie in a circle around A at a distance of $\gamma_0 - \beta$, would be, so to speak, "captured" by star A. Should TAB coincidentally be a straight line, then star A, seen from the Earth, would appear **surrounded by a ring**.

Whether the case of a fictitious double star indicated here actually occurs, I cannot judge.

Petrograd, Jan. 28, 1924. O. Chwolson.

Mandl and Einstein - See: https://www.mpiwg-berlin.mpg.de/Preprints/P160.PDF

1936 - Letter from R. D. Potter to A. Einstein

Prof. Albert Einstein
Institute for Advanced Study
Princeton, N.J.

Dear Prof. Einstein:

Last spring an apparently sincere layman in science, Rudi Mandl, came into our offices here in the building of the National Academy of Sciences and discussed a proposed test for the relativity theory based on observations during eclipses of the stars.

We supplied Mr. Mandl with a small sum of money to enable him to visit you at Princeton and discuss it with you. On his return he showed us what were apparently authentic letters from you to him regarding his suggestion.

Mr. Mandl has since moved to New York City (108-11 Roosevelt Ave., Corona, L.I.) but before he left he told us that you had agreed to publish his ideas, or at least incorporate some of them in a technical paper to be prepared by you for some scientific journal.

A letter has today come from Mr. Mandl asking us if this paper has yet been published.

Could you tell us what is the status of the Mandl proposal from your point of view, with the promise that anything you would write would be completely confidential?

beantwortet.

Sincerely yours,

Robert D Potter

Robert D. Potter
Science Service

Einstein, A. (1936)
"Lens-like action of a star by the deviation of light in the gravitational field" - **Science**, **84**, 506–507

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.

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

Letter from Einstein to the Editor of Science

Let me also thank you for your cooperation with the little publication, which Mr. Mandl squeezed out of me. It is of little value, but it makes the poor guy happy.[28]

When Fritz Zwicky gets involved - 1937

Zwicky, F. (1937)
"Nebulae as gravitational lenses"
Physical Review, **51**, 290

Nebulae as Gravitational Lenses

Einstein recently published[1] some calculations concerning a suggestion made by R. W. Mandl, namely, that a star B may act as a "gravitational lens" for light coming from another star A which lies closely enough on the line of sight behind B. As Einstein remarks the chance to observe this effect for stars is extremely small.

Last summer Dr. V. K. Zworykin (to whom the same idea had been suggested by Mr. Mandl) mentioned to me the possibility of an image formation through the action of gravitational fields. As a consequence I made some calculations which show that extragalactic *nebulae* offer a much better chance than *stars* for the observation of gravitational lens effects.

The discovery of images of nebulae which are formed through the gravitational fields of nearby nebulae would be of considerable interest for a number of reasons.

(1) It would furnish an additional test for the general theory of relativity.

(2) It would enable us to see nebulae at distances greater than those ordinarily reached by even the greatest telescopes. Any such *extension* of the known parts of the universe promises to throw very welcome new light on a number of cosmological problems.

(3) The problem of determining nebular masses at present has arrived at a stalemate. The mass of an average nebula until recently was thought to be of the order of $M_N = 10^9 M_\odot$, where $M_\odot$ is the mass of the sun. This estimate is based on certain deductions drawn from data on the intrinsic brightness of nebulae as well as their spectrographic rotations. Some time ago, however, I showed[2] that a straightforward application of the virial theorem to the great cluster of nebulae in Coma leads to an average nebular mass four hundred times greater than the one mentioned, that is, $M_N' = 4 \times 10^{11} M_\odot$. This result has recently been verified by an investigation of the Virgo cluster.[3] Observations on the deflection of light around nebulae may provide the most direct determination of nebular masses and clear up the above-mentioned discrepancy.

Still Zwicky … on detectability of gravitational lensing

Zwicky, F. (1937) *On the Probability of Detecting Nebulae Which Act as Gravitational Lenses*, *Physical Review*, **51**, 679.

On limiting exposures with the 100-inch telescope about 1/400 of the photographic plate is on the average covered by nebular images. Thus for a limiting magnitude of about $m=21.5$ we have approximately $n=400$. With gravitational focusing, nebulae considerably fainter than $m=21.5$ will be observable. Thus around one in about one hundred nebulae B the ring-like image of a distant nebula should be expected, *provided* that the chosen nebula B has an apparent angular radius ρ smaller than the angles γ through which light is deflected on grazing the surface of this nebula. Present estimates of masses and diameters of cluster nebulae are such that the observability of gravitational lens effects among the nebulae would seem insured. In any case, whatever the outcome, the search for such effects will provide us with valuable information regarding the masses of nebulae.

In searching through actual photographs, a number of nebular objects arouse our suspicion. It will, however, be necessary to investigate certain composite objects spectroscopically, since differences in the red shift of the different components of such objects will immediately betray the presence of gravitational lens effects. Until such tests have been made, further discussion of the problem in question may be postponed.

F. Zwicky

California Institute of Technology,
Pasadena, California,
March 18, 1937.

Basis of the theoretical framework

Sachs, R. K. (1961), *“Gravitational waves in general relativity. VI. The outgoing radiation condition”*, *Proceedings of the Royal Society of London A*, **264**, 309

Gravitational waves in general relativity VI. The outgoing radiation condition

BY R. SACHS

Department of Mathematics, King's College, London

(*Communicated by H. Bondi, F.R.S.—Received* 30 *November* 1960—*Revised* 25 *January* 1961)

A covariant formulation of the outgoing radiation condition for gravitational fields is proposed. The condition is based on a detailed examination of the geometry of null lines and of the algebraic and differential properties of the Riemann tensor. It relates the absence of incoming radiation, in a gravitational field with bounded sources and Euclidean topology, to the asymptotic behaviour of the Riemann tensor. Fields that are algebraically special in the Petrov classification are highly special examples of fields obeying the suggested condition.

Experimental discovery - 1987

Soucail, G., Fort, B., Mellier, Y., & Picat, J. P. (1987)
"A blue ring-like structure, in the center of the A370 cluster of galaxies"
Astronomy & Astrophysics, **172**, L14–L16

Astron. Astrophys. 172, L14–L16 (1987)

ASTRONOMY AND ASTROPHYSICS

Letter to the Editor

A blue ring-like structure in the center of the A 370 cluster of galaxies

G. Soucail, B. Fort, Y. Mellier, and J. P. Picat

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Received April 24, accepted August 15, 1986

Summary

We report on a serendipitous observation from our first multispectroscopic run on the distant X-ray emitter Abell cluster A370 (z=0.373). We discovered a very particular ring-like structure of galaxies with a diffuse component lying near one of the very luminous galaxies of the cluster core. A very first analysis suggests that it may be the result of galaxy/galaxy interactions in the dense region or of star formation occuring from a cooling flow of the Intra-Cluster-Medium (hereafter I.C.M.).

Key words : Clusters : of galaxies

the maximum of samples in the CCD field. For this first run we chose to observe the A370 cluster as it was mentioned as an intense X-ray emitter (Henry et al 82) and one of the bluest Butcher-Oemler distant clusters (Butcher and Oemler, 1983). The procedure was fully automatized and we did not examine in great detail the CCD images during the nights of observation.

The data reduction showed a strange ring-like condensation on the R-image very close to a bright elliptical galaxy near the cluster center (fig. 1). The comparison of several images made during the run proved that it was not an artefact. This was confirmed

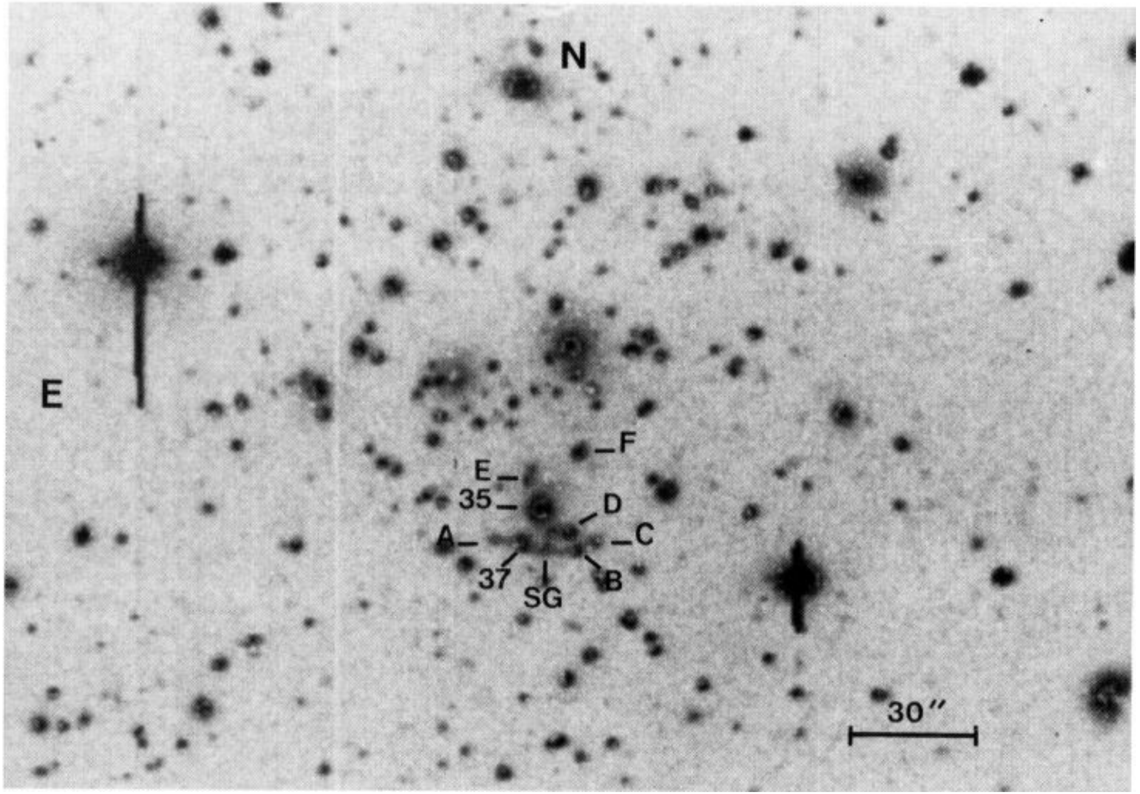
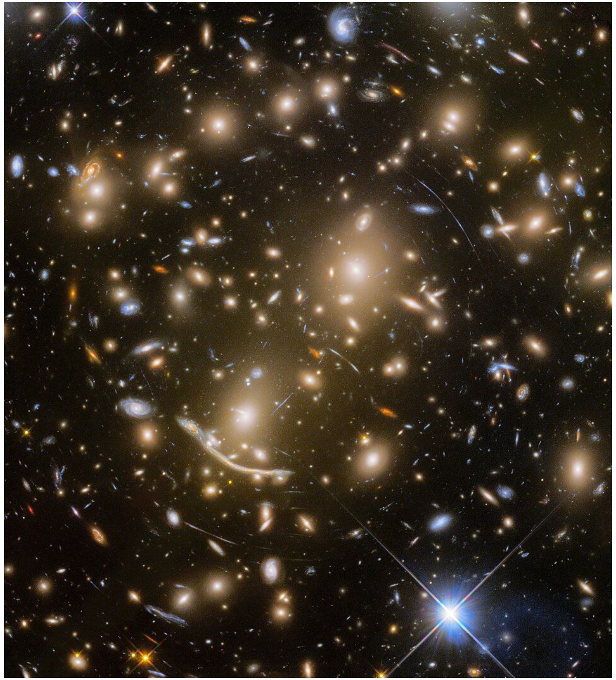


Image from the CFHT (d=3.6m)

One of the very first CCD detector:

- RCA CCD/CEA INAG

320 x 512 pixels (?)



Confirmation that it is a gravitational lens - 1988

Astron. Astrophys. 191, L19–L21 (1988)

ASTRONOMY AND ASTROPHYSICS

Letter to the Editor

The giant arc in A 370: spectroscopic evidence for gravitational lensing from a source at $z = 0.724$

G. Soucail, Y. Mellier, B. Fort, G. Mathez, and M. Cailloux

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Received November 17, accepted December 22, 1987

Summary:

In this Letter we present new spectroscopic data on the giant luminous arc in the distant cluster of galaxies Abell 370 (z = 0.374), obtained at the 3.60 m telescope at ESO with EFOSC/PUMA2. From the spectral analysis of the arc it is now well established that all its segments (including the eastern end) have the same spectrum. Some emission and absorption features identified in the spectrum definitely prove that the arc is the image of a late type galaxy at a redshift of 0.724. Gravitational lensing of a background galaxy by the cluster core results as the most convincing model of the observed configuration.

Key Words: clusters of galaxies – gravitational lensing – arcs.

Introduction:

Since the first discoveries of giant luminous arcs in two distant clusters of galaxies (Soucail *et al.*, 1987a, Lynds and Petrosian, 1986) numerous models have been proposed to explain their nature and origin (Soucail *et al.*, 1987b, Katz, 1987, Milgrom, 1987, Kovner, 1987, etc ...). On the basis of a spectroscopic observation of the eastern end of the arc (referenced as galaxy # 62 in our previous papers, see Fig. 1), we suggested an interpretation in terms of gravitational lensing of a background galaxy at 0.59 aligned with the deflector (in this case the cluster core) (Soucail *et al.*, 1987b). Due to bad weather conditions the spectrum obtained had indeed a poor S/N ratio, making impossible a definitive conclusion about this model. Moreover, it has been argued that the eastern end of the arc could not belong to the arc, beeing a background galaxy superimposed on the structure. Hence, even though the model we described perfectly fitted the arc observed in A370, we found it necessary to reobserve it.

For this peculiar object we used a long slit of 2" width during the first night. In order to collect a maximum of energy from the arc and the superimposed galaxies, we used the PUMA2 system (Fort *et al.*, 1986) to punch a curved slit exactly suited to the arc geometry. In this case, the sky subtraction was ensured using a duplicate curved slit punched on the same mask, close to the arc.

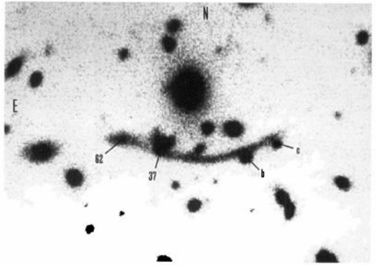

Fig. 1 : *CCD frame of the giant arc in A370. This picture was obtained by J.L.Prieur at the prime focus of the 3.60m Canada-France-Hawaii telescope on October 25th, 1987. The CCD was a 640 × 1024 RCA2: scale 0.2"/pixel - seeing 0.7", with an exposure time of 10 minutes in white light. Note the shape of object #37, which was already suspected to be double on the basis of its spectrum (Soucail et al., 1987b).*

AT CFHT prime focus
CCD: RCA2 640x1024 pixels

Weak lensing and tangential alignment - 1990

THE ASTROPHYSICAL JOURNAL, **349**: L1–L4, 1990 January 20

DETECTION OF SYSTEMATIC GRAVITATIONAL LENS GALAXY IMAGE ALIGNMENTS: MAPPING DARK MATTER IN GALAXY CLUSTERS

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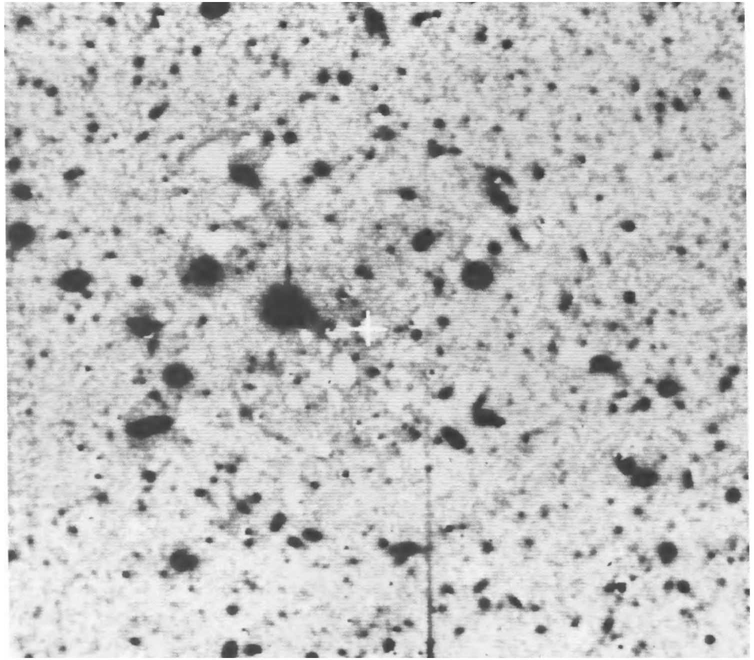
Received 1989 July 19; accepted 1989 October 16

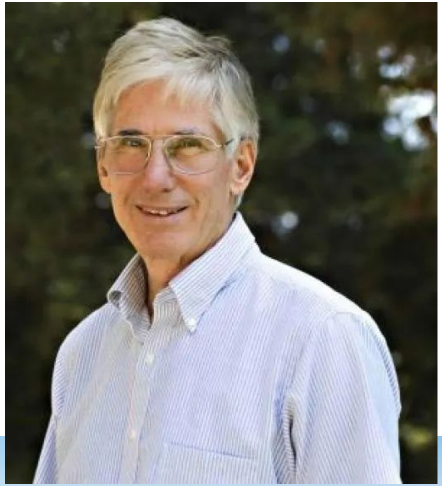
ABSTRACT

A gravitational lens distorts most background galaxies by stretching along a circle centered on the lens. This systematic alignment of 20–60 faint background galaxy images has been detected, centered on foreground galaxy clusters of high velocity dispersion. The background galaxy population is selected by its extreme blue $B-R$ color. At a limiting surface brightness of 29 B mag arcsec^{-2}, there are over 30 background galaxies arcmin^{-2} mag^{-1} anywhere in the sky, which is sufficient to map statistically the dark matter distribution in a foreground cluster. Pattern recognition software generates a two-dimensional lens distortion map. Initial results for the high-velocity dispersion clusters A1689 and CL 1409+52 are presented here. The dark matter is apparently correlated (center and radial extent) with the cluster red light, suggestive of a baryonic origin or dissipative coupling. The existence of a high percentage of lens-distorted faint blue galaxies sets a lower limit of approximately 0.9 to this background galaxy population mean redshift.

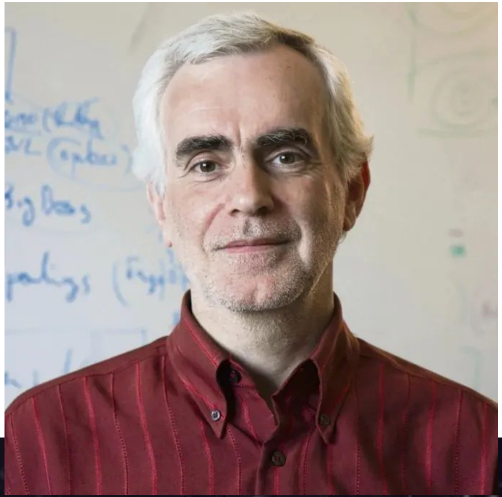
Subject headings: cosmology — dark matter — galaxies: clustering — galaxies: redshifts — gravitation



4m CTIO telescope with unknown CCD ???



Anthony Tyson



Yannick Mellier