Observational aspects of gravitational lensing

Jean Surdej

Institut d'Astrophysique, Université de Liège

Chercheur Qualifié au FNRS (Belgique)

Abstract

In this review on the recent observational aspects of gravitational lensing, I first present the various systematic optical surveys for multiply lensed extragalactic objects that are being carried out at several observatories enjoying good seeing conditions. I then summarize the updated observational status of all proposed gravitational lens candidates, concentrating mainly on multiply lensed QSOs (the cases of giant luminous arcs, radio rings and distant 3C radio galaxies are described elsewhere in this volume). Finally, I give a general outline of all the additional pieces of observational evidence suggesting that gravitational lensing may (i) perturb significantly our view of the distant Universe and (ii) affect our physical understanding of various classes of extragalactic objects.

1. Introduction

The possible perturbations of our view of the distant Universe by gravitational lensing effects are strongly linked to the detailed distribution of matter at various scales. A theoreticians' approach usually consists in making use of all our present (but of course, limited) knowledge on the distribution of matter to predict the importance of such perturbations. Given all the modelling complications, limitations, as well as all yet unknown biases in our observations of distant objects, it is not surprising that the conclusions of such studies do oscillate between various degrees of pessimism or of optimism. There is a citation by Peebles, quoted in Blandford and Kochanek (1987), saying that: "Gravitational lenses provide a theorists' heaven and an observers' hell". I rather believe that the contrary is true and that the path through the examples will always remain shorter and more secure than that through the theories. This is also probably why, at least recently, observers have been more optimistic about the possible importance of gravitational lensing than theoreticians. Of course, there are exceptions and in this context, it is only fair to consider Sjur Refsdal as the leader of the optimistic supporters of gravitational lensing. The situation about "gravitational lensing" is a bit reminiscent of that associated with "atmospheric mirages". What does the average man think about the importance of atmospheric lensing effects on our view of distant earth-sources? (cf. the distant car lights seen along a straight road in Figure 1).

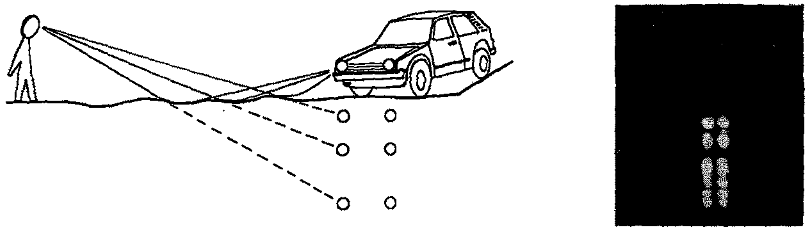

Figure 1: The figure at left gives a schematic representation of the light ray paths from a distant car when the ground turns out to be somewhat hotter than the ambiant air. Because air refraction always leads to a bending of light rays towards regions of colder air, several lower and somewhat deformed images of a distant source (the car lights in this example) may result. The figure at right represents the multiple images due to the lights from a distant car, as photographed by J. Lehár and the author, along the US 60 road, between Magdalena and Datil near the VLA (New Mexico) on the night of 19 January 1989. The distance between the car and the observers was estimated to be about 10 miles. Such terrestrial mirages, usually made of two single images, can actually be seen everyday, almost from anywhere. In addition to significantly affect our view (image deformation, multiplication, etc.) of distant resolved earth-sources, atmospheric lensing is also often responsible for the light magnification of distant unresolved objects located along straight and long roads or across flat countrysides. Other examples of terrestrial mirages are illustrated in Surdej et al. (1989).

The answer to the analogous question for "gravitational lensing" is of course not so trivial. Ten years after the serendipitous discovery of the double quasar Q0957+561 A and B by Walsh, Carswell and Weymann (1979), both theoretical and observational researches on gravitational lensing have led to a formidable burst of published work. Partly guided by this monument of information but also trying not to cover topics already addressed in recent reviews on the subject of gravitational lensing (e.g. Canizares (1987), Blandford and Kochanek (1987), Nottale (1988), Turner (1989a, b), Barnothy (1989) and references therein), I have decided to focus the present paper on a general discussion of the various known (or only hypothesized) pieces of observational evidence which suggest that gravitational lensing may affect significantly our view and physical understanding of the distant Universe, and of its major constituents.

In section 2, I present an overview of the various systematic optical surveys that are presently being carried out all over the world in order to search for multiply lensed distant objects. In section 3, I have listed the updated observational status of the best recognized cases of multiply lensed objects. I also discuss individually the objects for which recent and outstanding observations have led to a better understanding of the gravitational lenses. Suggestions are also given as to which complementary observations shoud be carried out in order to still improve some of the lens models. Section 4 summarizes all the additional observational evidence on statistical effects due to gravitational lensing and I also discuss there the various classes of extragalactic objects which may actually consist of lensed sources. The last section deals with general conclusions.

Before closing this introduction, let me recall the challenging goals of studying known gravitational lens systems as well as of discovering new ones. First of all, it is known that a statistical evaluation of the occurrence of gravitational lensing within well defined samples of extragalactic objects is of prime importance in order to improve our knowledge on quasars and distant radio galaxies (luminosity function, source counts, true part of their cosmic evolution). Detailed studies of identified gravitational lens systems are also important to test cosmological models (Refsdal 1964, 1966), to set constraints on the size and structure of the lensed source (Grieger et al. 1986, 1988) and to probe the luminous and dark matter distributions on various scales in the Universe (Refsdal 1964, 1966). In particular, gravitational lens studies can be used to set limits on populations of dark massive objects (Press and Gunn, 1973; Hewitt et al. 1987a; Webster et al., 1988a). Finally, analysis of narrow absorption lines observed in the spectrum of multiply lensed QSO images are of considerable interest for studies of the spatial structure of the inter-galactic medium (cf. Foltz et al. 1984 and the paper by Smette et al. in these proceedings).

2. Optical surveys for multiply lensed extragalactic objects

Whereas the first gravitational lens systems have been discovered by chance, systematic searches for lenses have proved to be very successful in identifying new systems. I shall describe hereafter several of the on-going optical surveys for multiply lensed extragalactic objects (I refer to the article by B. Burke in this volume for a description of the radio surveys).

2.1 Highly Luminous Quasars as gravitationally lensed objects

Considering the canonical log(N)-B relation for the count number of quasars per unit area brighter than a given magnitude B (cf. Boyle et al. 1988), it is easy to calculate the number density enhancement q(M,B_0) of quasars in a flux limited sample (B_0) subject to a magnification M. Following Narayan (1989), one finds that q(M,B_0) = (N($<B_0+2.5\log M$)/N($<B_0$))/M. Referring to Figure 1 in Narayan (1989) where the author has illustrated the dependence of q versus both M and B_0, one immediately sees that the magnification bias works preferentially well for a bright flux limited sample of QSOs. There are at least three optical surveys for multiply lensed QSO images which benefit from this magnification bias:

1. The Liège/ESO/Hamburg survey, initiated in November 1986 and terminated in November 1988. A description may be found in Surdej et al. (1988a-c) and an update is presented in these proceedings by Swings et al. and Magain et al. I briefly recall that it has consisted in a high resolution imaging of apparently ($m_V < 18.5$) and intrinsically (M < -29) bright quasars observable from ESO (Chile). Out of 111 quasars observed under an average seeing FWHM = 1.2″, 25 turned out to be interesting candidates (i.e. 23% of HLQs showing elongated, multiple, or fuzzy images), 5 of which constitute very good lens candidates. The cases of UM673 and H1413+117 are described in Surdej et al. (1987) and Magain et al. (1988), respectively.

2. The Djorgovski and Meylan (1989a, b) optical survey for bright distant quasars that has been carried out during the past few years. It also consists in an optical (CCD) imaging search for gravitational lenses among a sample of (≈ 300) high redshift QSOs having an apparently large absolute luminosity. So far, they found one new gravitational lens candidate UM425 (Meylan and Djorgovski, 1989), two probable binary quasars PKS1145-071 (Djorgovski et al., 1987) and PHL1222 (Meylan and Djorgovski, these proceedings), and several other promising candidates. As in the Liège/ESO/Hamburg survey, they also identified several cases of QSOs with foreground galaxies within a few arcsec. I refer to the paper by Meylan and Djorgovski in this volume for more detailed information on their survey.

3. The Crampton et al. (1989) optical survey. Using a new-image stabilizing camera at the CFHT, these authors have also made a direct imaging search for closely spaced gravitationally lensed QSO components. Out of 32 quasars with $z > 1.6$, $m_V < 19$ (i.e. $M < -27.8$), seven were found to be good gravitational lens candidates, two of these having sub-arcsec. angular separations. This fraction (22%) of interesting HLQs is essentially the same as the one (23%) reported by Surdej et al. (1988c).

2.2 Quasars as gravitationally lensed objects

Whereas it is expected that for a fainter limiting magnitude survey the quasar number-density enhancement $q(M,B_0)$ will get smaller, such surveys have the advantage of dealing with a much larger number of objects. One such sample of fainter quasars ($m_B < 19$) has been used as a basis for the automated survey for gravitational lenses described by Webster et al. (1988a). With the help of the Automated Plate Measuring (APM) facility at Cambridge, these authors have scanned both broadband direct and objective-prism Schmidt plates resulting in a survey of 2500 quasars, covering 130 sq. deg. of sky. Whereas this technique is only effective for separations greater than 2 - 3″, it enables one to quantify different parameters (separation, magnitude difference, lens brightness, etc.) in the lens survey. Since the frequency of lensing for a given separation of lensed QSO images may be predicted, it allows one to set interesting constraints on the mass distribution in the Universe. The new wide separation gravitational lens candidate Q1429-008 recently reported by Hewett et al. (1989) has been found via this survey. The detection of statistical gravitational lensing by foreground mass distributions described in Webster et al. (1988b) is also based upon this survey. It is discussed at length by R. Webster in this volume.

2.3 Distant 3C radio sources as gravitationally lensed objects

The magnification bias has also motivated Hammer, Nottale and Le Fèvre (1986) to assume that the distant ($z > 1$) and powerful ($P(178MHz) > 10^{28}$ W/Hz) radio sources (hereafter DPRSs) constitute some of the best extragalactic candidates to search for the presence of gravitationally lensed images at arcsec./sub-arcsec. angular scale resolutions and/or for an excess of foreground objects (galaxies, clusters) in the vicinity of the relevant targets. Approximately 75% of the high redshift 3C sources observed by Hammer and Le Fèvre (1989) in optimal seeing conditions with the CFHT at Mauna Kea have been resolved into multiple (2 to 6) components. Strong arguments supporting the mirage hypothesis have been obtained for 3C324, by high resolution imagery through narrow band filters (Le Fèvre et al. 1987; Hammer and Le Fèvre 1989). High spatial resolution imaging and spectroscopy obtained for 3C208.1 definitely prove that the optical appearance of this source is due to the close projection (3.9″) of the optical counterpart of a radio loud quasar at $z = 1.01$ and a foreground AGN at $z = 0.159$ which gravitationally magnifies, by more than 0.5 mag., the background object (Le Fèvre and Hammer, 1989). Of special interest is that a detailed comparison between CCD frames obtained from a sample of 27 3C distant radio sources with $z > 1$ and selected blank fields indicates a significant excess of foreground bright galaxies (up to $m_R \approx 21$) and Abell/Zwicky clusters near the 3C sources (Hammer and Le Fèvre, 1989). It therefore seems that gravitational magnification by foreground galaxies and rich clusters is at least partly responsible for the observed radio and optical luminosities of the bright 3C sources. In particular, the following DPRSs: 3C194 and 3C225A (Le Fèvre and Hammer, 1988), 3C238, 3C241, 3C266 and 3C305.1 (Le Fèvre et al. 1988b), 3C13 and 3C256 (Le Fèvre et al. 1988a), 3C239, 3C252, 3C267, 3C322, 3C230, 3C297 and 3C469.1 (Hammer and Le Fèvre, 1989) have been proposed to be either gravitationally magnified and/or multiply imaged. High spatial resolution narrow band imaging and/or deep 2D spectroscopy of most of these candidates are badly needed in order to further test the lensing hypothesis.

In closing I wish to mention here that the surveys described in 2.1.1, 2.1.2 and 2.3 constitute parts of an ESO key-programme that is being presently conducted at ESO-La Silla (see the description of the programme as well as the names of all participants in Surdej et al. 1989).

3. Gravitational lens candidates

Table 1 (see the appendix at the end of these proceedings) presents an updated list of the accepted and proposed candidates of multiply lensed extragalactic objects. Separate comments on individual gravitational lens systems follow:

1. 0957+561: The most extensive photometric monitoring of a gravitationally lensed quasar has of course been carried out for this famous double quasar. Tentative time delays of 1.55 +/- 0.1 years by Florentin-Nielsen (1984), 1.2 years by Schild and his collaborators and, very recently, 1.14 +/- 0.06 years by Vanderriest et al. (1989) have been reported. The radio time delay of < 500 days derived by Lehár et al. (1989) essentially corroborates the optical value. Both the groups of Vanderriest and of Schild find however that the observed lightcurves of 0957+561 A and B cannot be fully interpreted in terms of intrinsic brightness variations of the quasar alone. Micro-lensing seems to contribute to the variations of the B component. Note however that Falco et al. (cf. these proceedings) cast some doubt on this whole interpretation. A spectrophotometric monitoring of the two image components of 0957+561 would certainly help in disentangling the effects due to intrinsic and/or extrinsic variability. Whereas the estimate of the mass of the lensing galaxy is fairly secure (cf. Borgeest, 1986; see Table 1), a more precise modelling of the mass distribution in the lensing galaxy and its attendant cluster is necessary to derive a safe estimate for the Hubble parameter. A deep mapping in luminosity and velocity (velocity dispersion + redshift) of most of the foreground galaxies is necessary in order to better constrain the free parameters of the mass distribution. Very high angular resolution radio observations of images A and B at several epochs would also be extremely valuable.

2. 1115+080: Following the photometric variability study reported by Vanderriest et al. (1986), it is likely that micro-lensing effects are responsible for the brightness variations observed between the A1 and A2 image components. Spectrophotometry of the whole system at various epochs should provide us with a definite answer as to the reality of these effects. Note that in addition to the lensing galaxy detected by Shaklan and Hege (1987) between the A and B images, Henry and Heasley (1986) found that there was also a galaxy centred approximately midway between the two A components. These authors find that the properties of this galaxy (G4, $M_V \approx -23.3$) are consistent with it being the brightest member of a small group at $z = 0.305$ (cf. galaxies G1 and G2 in Young et al. 1981). If real, this would lend support to the micro-lensing induced variability suspected for the A twin components. By means of the pupil segmentation technique used with the CFHT (see Lelièvre et al. 1988), high angular resolution observations supporting this picture for PG1115+080 have been obtained by Arnaud et al. (1989). However, using speckle interferometric observations, Foy et al. (1985) have detected an elongation of image A2 and they suggested that it was caused by a fifth lensed QSO image, located at 0.04" from A2. It is therefore clear that image A is made of more than simply two lensed QSO images and it is likely that further high angular resolution imaging will be necessary in order to definitely settle this point. Although the redshift of the galaxy detected between the A and B images has not yet been directly measured, it is quite possible that for $z = 0.305$, the observed reddening of the B component relative to A, as seen in the spectra published by Young et al. (1981), is actually due to the contamination by the foreground galaxy. In any case, any serious modelling of this lens should take into account the several (5?) galaxies detected in the nearby field.

3. 2345+007: Nieto et al. (1988) have obtained very high angular resolution images of this system using a photon counting detector in its resolved imaging mode. By using recentring and selection algorithms plus image restoration techniques, they have achieved good S/N images with resolution of $FWHM \approx 0.25''$. These observations lend a good support to the gravitational lensing hypothesis of 2345+007 A and B because they reveal that the fainter (B) component actually consists of a double image (B1, B2 with roughly equal brightnesses), separated by 0.36" and roughly aligned along the same direction as the A and B images, and that there is also good evidence for the outer of these two sub-images to be resolved along a direction perpendicular to the line between B1 and B2. Furthermore, comparison of the ratio A/B at the time of their observations with previously reported values suggests some variability in this system. A spectrophotometric monitoring of the A and B components would also be of great scientific interest to search for micro-lensing effects and/or for a measurable time delay between the two brighter image components.

4. 2016+112: This gravitational lens system appears to be very complex because it consists of at least three detected lensed images A-C', two foreground galaxies C and D, including one with a measured redshift $z = 1.01$ and two diffuse narrow line emission regions, that appear to be physically distinct, and located near images A and B (see Figure 1 in Schneider et al. 1986). Observational evidence for the possible occurrence of micro-lensing effects has also been reported for this system and a spectrophotometric follow-up of the lensed QSO images would be of great value. See the contribution in this volume by Heflin et al. related to the interesting constraints that their VLBI observations impose on the proposed gravitational lens models (cf. those by Narasimha et al. 1987).

5. 1635+267: The detailed spectroscopic study of 1635+267 A and B by Turner et al. (1988) has led to the good conviction that this double quasar constitutes a good case of gravitational lensing. Indeed, not only were they able to show that the wavelengths, strengths, widths and profiles of different lines were the same, after a proper scaling and to within measuring errors, in the two image spectra but they also found that the excess of red light in the bright component ressembles the continuum emission of a $z \approx 0.57$ galaxy. Independently, the modelling of this system by Narasimha and Chitre (1988) also led to the prediction that a lensing galaxy should be located at 0.75" from component A. One should of course try to image this system in red light and under very good seeing conditions in order to confirm the presence of the lensing galaxy ... nearly on top of the A (multiple?) image(s).

6. 2237+0305: First of all, superb high angular resolution imagery (Yee, 1988 and Schneider et al. 1988) and spectroscopy (De Robertis and Yee, 1988 and Adam et al. 1989) have convincingly demonstrated that the Einstein cross consists of four lensed images plus a central galaxy nucleus. Kayser and Refsdal (1989) have pointed out the uniqueness of this gravitational lens system to display micro-lensing effects. Indeed, i) because the expected time delays are so short, intrinsi variability should show up almost simultaneously in the four images so that any difference may be attributed to micro-lensing, ii) due to the large distance ratio between the lens and the source, micro-lensing should lead to more frequent and rapid high amplification events (HAEs) and iii) the expected number of HAEs should be large (about 0.3 events per year and per image). It was therefore not a surprise when Irwin et al. (1989) announced the brightening by 0.5 mag. of component A on CCD frames obtained during the 1988 summer. CCD frames taken at La Silla by Remy et al. (1989) in april 1989 in the framework of the "Gravitational Lensing" ESO key-programme indicate that the relative brightening of image A was still about 0.3 mag. in blue light. Integral field spectrophotometric monitoring of this system, similar to the *one epoch* observations reported by Adam et al. (1989) with the TIGER spectrograph (Courtès et al. 1987), would also be extremely valuable. Such observations would present the additional potential of measuring simultaneously the rotational velocity field of the deflecting spiral galaxy. Note that simulations of micro-lensing effects for 2237+0305 by Wambsganss et al. (1989) predict unfortunately that the time scale and the amplitude of HAEs should not only depend on the source size and the relative transverse velocity between the source, the lens and the observer but that, due to the very strong effect of the shear by the galaxy, it should also depend on the direction of this velocity.

7. 0142-100: Since the lens of this system appears to be made of a single isolated galaxy at a redshift $z = 0.49$ (the redshift of the galaxy D in Surdej et al. 1987 has been measured to be $z = 0.17$), it constitutes a very good candidate to attempt an independent measurement of H_0 . A photometric monitoring of 0142-100 A and B has been initiated two years ago at ESO. It should nevertheless be mentioned that we have failed to detect the A and B images with the VLA at 6cm in the A configuration (0.3 mJy r.m.s. noise).

8. 3C324: Spectroscopic confirmation of this first galaxy-galaxy gravitational lens system is strongly awaited. This optical source should also be monitored photometrically for the possible detection of a SN event in the different images.

9. 1413+117: This gravitational lens system has been resolved at 3.6 cm with the VLA in the A configuration. A detailed modelling of these observations has been made by Kayser et al. (1989) and supports very nicely the optical observations. High angular resolution integral spectroscopy of this system with the integral field spectrograph SILPHID (Vanderriest and Lemonnier, 1987) has enabled us to resolve the spectra of the four individual images (Angonin et al., these proceedings). Spectroscopic and photometric indications of micro-lensing effects in the D component have possibly been found.

10. 1120+019: Except for images A and B, no spectra have yet been obtained for the many other objects in the field of this gravitational lens candidate (see Meylan and Djorgovski, 1989).

11. 0414+0534: It would be very important to make a new attempt to determine the redshift of the optically detected object (source?). All four components of this system have been detected with VLBI to show compact flux at 18cm (Hewitt, 1989). There is no doubt that this gravitational lens system turns out to be a very interesting one.

12. 1429-008: Because of the slight, although probably real, spectroscopic differences seen between the two image components, better S/N spectra are mandatory in order to confirm or reject the lensing hypothesis for this system.

13. M82 quasars: This is just one example of QSO images with large separations and all general remarks which follow could apply equally well to many other cases of quasars having very similar redshifts and spectra but large angular separations. Paczynski and Gorski (1981) did actually first suggest that the unusual grouping of quasars near M82 (Burbidge et al. 1980) may consist of another case of gravitational lensing. In the lensing scenario, one or several of the observed QSO images could actually be multiple (due to macro-lensing by a galaxy located in one of the two hypothetical clusters) and one could try to detect i) the presence of a cluster by direct imaging (direct detection or search for distorted background galaxies), ii) the possible multiplicity of the QSO images, iii) the presence of additional magnified QSOs, iv) the similarity or, on the contrary, noticeable differences between the redshifts of the three identified quasars.

4. Further observational evidence for gravitational lensing

4.1 Statistical gravitational lensing

4.1.1 Galaxies near flat radio spectrum quasars: using an automatic search and classification technique for counting galaxies on CCD frames, Fugmann (1988, 1989) has reported, at typically a 97.5% significance level, an increase in the number density of relatively bright ($r < 21.5$) galaxies towards distant ($z > 1.7$) quasars. The increased number of galaxies seems to pertain mainly to fields of (12) flat-spectrum quasars with a much smaller increase near steep-spectrum and radio-quiet quasars. Fugmann invokes gravitational lensing effects, specially micro-lensing to account for these observations and he concludes that gravitational lensing contributes strongly to observed counts of distant sources, particularly to the statistics of flat-spectrum quasars. Whereas Tyson (1986) had also reported a QSO-galaxy correlation for moderately distant quasars ($1 < z < 1.5$), Yee and Green (1984) did not. It is most likely that these different results arise because of the different fractions of radio quiet, steep and flat spectrum quasars constituting those different samples. Fugmann further postulates that gravitational lensing may be responsible for the appearance of different sub-classes of quasars (e.g. the optically quiet compact radio sources (OQCRSs) including objects such as AO0235+164, 0406+121, 0500+01, 1413+135, etc.). Since X-rays detected from selected quasars are supposedly emitted from a very compact core, one may naturally wonder whether X-ray selected quasars could also reveal observational evidence for statistical gravitational lensing.

4.1.2 Galaxies near X-ray selected quasars: during the course of an extensive program of spectroscopic identification of faint X-ray sources discovered serendipitously with the Einstein satellite, 10 X-ray selected AGNs have been discovered by Stocke et al. (1987) to lie within three optical diameters of bright ($m_V < 18$) foreground galaxies . These authors report that, at a confidence level > 97.5%, these AGNs have significantly higher redshifts than X-ray selected ones in general. Stocke and his collaborators have interpreted their findings in terms of micro-lensing in which stars in the foreground galaxy significantly brighten the X-ray emission from these higher redshift AGNs, allowing them to be detected. However, Rix and Hogan (1989) have recently reinvestigated this problem by taking deeper CCD frames of the complete sample of the 56 X-ray flux limited AGN fields (MSS initial sample) in order to enlarge the subsample of AGNs with foreground galaxies ($R < 20.5$) from 3 to a total of 8. On the basis of these new data, Rix and Hogan conclude that there is no longer any evidence for lensing effect by the galaxies. The presence of an excess of high redshift X-ray selected quasars near bright foreground galaxies remain still a subject of debate.

4.1.3 Galaxies near APM quasars: at a significance level greater than 99.99%, Webster et al. (1988b) have presented evidence for the detection of an excess of distant quasars ($z > 0.5$, $B_J < 18.7$) associated with foreground galaxies ($r < 6''$, $B_J < 21$) and they invoke gravitational lensing effects in order to account for such a large number of associations. However, they report that the mass of the foreground galaxies must be substantially greater than is conventionally attributed to a luminous galaxy and its halo. I believe that this apparent problem could be easily overcome if one could prove that the principal deflector lies much closer to the line-of-sight (e.g. $r < 1.5''$) than it has been claimed. Several such tight associations have been identified in the HLQ samples described above (see Magain et al. in these proceedings and also section 4.1.12). Given the excess of 4.4 times more APM quasars near galaxies, which corresponds to an average magnification of 2.7, Narayan (1989) has shown that, if this effect is really caused by gravitational lensing, then the quasar-galaxy correlation found by Webster et al. must be smaller than the reported one by a factor of about 2 and/or the magnitude limit of their survey should be brighter by a few tenths of magnitude than the one reported ($B_J = 18.7$). Narayan also demonstrates that the observed effect does not require halos of foreground galaxies to be composed of micro-lenses (stars, black holes, etc.); the quasar-galaxy correlation works equally well with smooth halos. All these conclusions directly follow from the quasar luminosity function and are independent of the lens structure. This result shows how important it is to know accurately what the unlensed luminosity function of quasars is (see the contribution in this volume by R. Webster for an update of their findings on the APM QSO-galaxy associations).

4.1.4 The giant luminous arcs: see the updated report by B. Fort in these proceedings.

4.1.5 Distorted background galaxies: using a similar technique to that of Tyson and his collaborators, Elston et al. (1989) have carried out searches for statistical gravitational lensing effects using background galaxies projected on selected rich, massive clusters. They found that the background galaxies are preferentially aligned at 90° to a radial vector from the cluster center. Some good agreement is reached between the observed distributions of position angles and those of lensing models. They consider this finding as evidence that the background galaxies are being lensed by the foreground clusters (see also the contributions by Tyson and Grossman in these proceedings).

4.1.6 Anomalous quintets of galaxies: Hammer and Nottale (1986a) have shown that the well known quintets of galaxies such as VV172, VV115, etc. which contain a discrepant redshift member may be fully understood in terms of the effects of gravitational magnification by the halo of the foreground quartet on the more distant galaxy.

4.1.7 Gravitational lensing magnification of the bright cluster galaxies (BCGs): Hammer and Nottale (1986b) have presented good evidence that the BCGs of the Kristian et al. (1978) sample lie in regions of the sky containing about two times more foreground Zwicky clusters, the latter clusters being approximately 5 times richer than the mean value for the whole sky. The authors suggest that the gravitational lens magnification of the BCGs by the foreground clusters has induced a strong selection effect in defining the Kristian et al. sample, artificially increasing the deceleration parameter q_0 from 0.2 to about 1.7, as measured from the Hubble diagram of these objects.

4.1.8 The Arp QSO-galaxy associations: Nottale (1988) also presents good evidence that the Arp QSO-galaxy associations may be the result of the combined lensing effects of several superposed galaxies, groups and clusters near their lines-of-sight.

4.1.9 Quasars with 2.45 < z < 3.8: speculations have been made by Ph. Véron that the second observed rise in the space comoving density of quasars from $z = 2.45$ up to at least $z = 3.8$ (Véron, 1986) could be due to statistical gravitational lensing effects by foreground objects located along their lines-of-sight.

4.1.10 Gravitationally magnified narrow absorption line quasars: to my knowledge, Nottale (1987) has reported the first observational evidence for gravitational lensing magnification within a sample of absorption line quasars. His conclusions are based upon a comparison between observational data on absorption line quasars with $1.6 < z < 2.2$ from the catalogue of Barbieri et al. (1982) with predictions from the theory of multiple gravitational lensing (Nottale and Chauvineau, 1986). Nottale finds that the luminosity of a large fraction of known quasars with a redshift $z > 1.6$ is enhanced by a factor up to about 10 because of the action of intervening matter (clusters of galaxies, superclusters) along their lines-of-sight. More recently, Thomas and Webster (1989, see also their contribution in these proceedings) have presented tests of both evolution and bias due to gravitational lensing in the number density of QSO metal absorption line systems. Their study is mainly based on sets of CIV and MgII absorption line systems observed and compiled by Sargent et al. (1988a-c). They do not find any evidence for evolution except perhaps in the high equivalent width systems, where gravitational lensing may affect the statistics. They rather propose a model in which the distribution of high equivalent width systems reflects clustering of an unevolving low equivalent width population. Note however that, unlike Nottale (1987), Thomas and Webster assume that gravitational lensing resulting from two or more independent systems is unlikely.

4.1.11 Gravitationally magnified quasars with damped Lyα absorption line(s): in studies of the formation of disk galaxies at high redshift, various authors have carried out a search for damped Lyα absorption in the spectra of high redshift QSOs. Smith et al. (1987) report that the observed number of those absorption lines is at least a factor five in excess of the number of galaxy disks expected to be intercepted by lines-of-sight to this sample of QSOs (cf. their Fig. 3). The derived column densities of those damped Lyα lines are found to be well in excess of $10^{21} cm^{-2}$ (cf. their Fig. 4). Although these authors suggested that gaseous disks may form relatively early in galaxies and that they may be considerably larger at early epochs, I naturally suggest that gravitational lensing magnification could as well account for these observations in terms of induced observational biases, i.e. the quasars from this sample have been observed because they are preferentially magnified due to galaxy disks intercepting their lines-of-sight.

4.1.12 Quasar-galaxy superpositions: among the 23% of interesting HLQs found in the above surveys for gravitational lenses, quite a few of these objects turned out to show that a bright galaxy is superimposed on the central image of the QSO (see also the contribution by Magain et al. in these proceedings). We believe that this form of gravitational lensing magnification of background quasars (HLQs, etc.) could actually be more common than the formation of multiple images. One should note that a lensing galaxy has been identified on top, or very near to one of the lensed images in the cases of 0957+561, PG1115+080, 2016+112, and UM673. Recently, Arnaud et al. (1988) have published another nice case of a galaxy superimposed on an HLQ image. These authors report the detection of a galaxy (z = 0.63, M_R = -21.7) at 1.3″ from the line-of-sight to the QSO 1209+107 (z = 2.19). Another galaxy (z = 0.39), lying at 7″ from the QSO had previously been identified by Cristiani (1987). Arnaud et al. conclude that the QSO is certainly gravitationally magnified by the first and second galaxy. One should also note that the distant flat-spectrum (Fugmann, 1988) and APM (Webster et al., 1988b) quasars are also good candidates to this form of lensing. In any case, one should derive the redshifts of the galaxies found in the vicinity of those distant quasars in order to have a definite proof that they constitute foreground objects. Indeed, at low redshifts (up to about z = 0.7), most of us would tend to agree that a galaxy superimposed on a QSO image does actually consist of its host galaxy or a galaxy in interaction whereas for higher redshifts, we would be tempted to call it a foreground (lensing) object. Could it be for instance that some of the reported low redshift host galaxies are in fact foreground objects, and vice-versa at high redshifts?

4.2 Gravitational lensing and AGN segregation

4.2.1 Gravitationally lensed high luminosity AGNs: in a spectrophotometric monitoring of high luminosity AGNs, Pérez et al. (1989) report that significant emission line variations take place in high luminosity, high redshift objects (cf. 3C 446, PKS 2134+004, etc.). These variations are found to occur on timescales much shorter than those expected from ionization models and therefore the authors invoke beaming of the optical and ultraviolet continuum towards the observer, leading to an anisotropic broad line emission region and a selection effect in favour of cases in which the axis of this anisotropy is close to the line-of-sight (cf. their Fig. 7). Since the phenomenological effects of gravitational lensing are very similar to those expected from beaming, it is equally plausible that the spectroscopic variations observed in high luminosity AGNs are caused by (micro-?) lensing effects. Let us mention that metal absorption line systems, at optimal redshifts for a lens, have been detected in the spectrum of most these objects.

4.2.2 *Rapid variability of extragalactic sources due to lensing effects:* Quirrenbach et al. (1989) have reported radio variability of several flat-spectrum compact sources with amplitudes in the range 10-20% and timescales of hours (cf. their Fig. 1). Although they discuss intrinsic effects and scattering in the interstellar medium as possible explanations for the observed rapid variability, they also mention that it could be due to micro-lensing effects in a foreground object. They searched for the presence of a lensing galaxy in the fields of 0716+71 and 0917+62 but did not find any object on the POSS plates. They conclude on this basis that the other interpretations are more likely to be the right ones. Besides taking deeper CCD frames of the above fields ... one should certainly postpone any sound and firm conclusion.

4.2.3 OVVs as micro-lensed objects: Chang and Refsdal (1979, 1984) have first proposed that the main observable effect of lensing by stars or compact objects in galaxies and their halos will be a noticeable photometric variability of the distant source, due to the passage of the micro-lens in front of its line-of-sight. Ostriker and Vietri (1985), Nottale (1986) and Schneider and Weiss (1987) have independently proposed that micro-lensed objects were to be searched among the Optically Violently Variable (OVV) extragalactic objects, particularly those behaving like BL Lac objects at maximum brightness and like quasars when fainter. In the case of 0846+51w1, Nottale (1986) has shown that all its observed properties (sudden brightening by 4 mag. in less than one month, changes of its spectrum between that of a BL Lac object and that of a QSO, etc.) could be explained by the effects of gravitational lensing due to a compact -Jupiter like- object (10^{-2} M_o), located within a galaxy at z = 0.072 near the line-of-sight and that the core size of the central region emitting the QSO continuum is about $2.10^{-4}\,pc$. Stickel et al. (1989) recently reported that this BL Lac object displays a noticeable elongated appearance due to an intervening galaxy at z = 0.235 located nearly exactly on the line-of-sight. This observation therefore strengthens the hypothesis by Nottale (1986) that the observed properties of 0846+51w1 are markedly influenced by gravitational micro-lensing.

Stickel et al. (1988a) have also suggested that the correlated dramatic flux variability in the optical and radio wavebands of the BL Lac object AO0235+164 (z = 0.94) are most likely the result of gravitational lensing of the compact non thermal BL Lac core in the intervening galaxies at z = 0.524, seen at 2" to the south and at 0.5" to the east from the background source. Note that Yanni et al. (1989) locate this second newly detected foreground object at 1.3" east of AO0235+164. Surdej and his collaborators found recently good evidence that these two claimed galaxies are actually forming a single object. Kayser (1988) has analysed the plausibility of a micro-lensing model to explain the observed characteristics of AO0235+164. Although he finds that several observational data are in apparent contradiction with the micro-lensing hypothesis, he does not totally exclude that micro-lensing may contribute in part to the observed variability of AO0235+164. More investigations on this particular object are badly needed.

Stickel et al. (1988b) have presented convincing arguments that the southern blazar PKS0537-441 could be another example of a gravitationally lensed object. This blazar has been found by these authors to have an extended, spatially resolved appearance, despite its high redshift of z = 0.894. Using image decomposition techniques, Stickel and his collaborators have shown that a foreground disk galaxy (z = 0.186?), seen nearly face on, lies very near the line-of-sight to the blazar (cf. their Figure 2). Stickel et al. derive $M \approx -22.7$ and an exponential disk scale length of 4.3 kpc for the foreground galaxy. These authors propose that micro-lensing effects are responsible for the rapid and large optical variations (up to 5 mag.) previously observed for this object and that macro-lensing magnification by the foreground galaxy could account for the large luminosity radiated by this blazar. During an active state of the object in february 1985, Tanzi et al. (1986) found that PKS 0537-441 brightened by a similar factor ($\approx$ 2) in the IR, optical, UV and X-ray frequencies, suggesting that a same spatial region may be responsible for the emission in the whole spectral range observed. It is of course not difficult to account for these observational trends with a micro-lensing model that magnifies a very compact and distant source.

3C279, as one of the most variable ($\delta B > 6.7$) and possibly most luminous QSO yet observed (M = -31.4), constitutes another excellent candidate for micro- and/or macro- lensing effects (see the historical lightcurve of 3C279 in Figs. 1 and 2 of Eachus and Liller, 1975). Additional good micro-lensed candidates may be found among the following OVVs: PKS0215+015, 0420-014, 0454-234, 0511-220, 0735+178, PKS0823-23, 1308+326, 1638+398, 3C345 (1641+399) and 3C446 (2223-052). Some of these candidates are known during different brightness phases to have a spectrum turning from that of a QSO to that of a BL Lac object. Others undergo sudden light brightening reminiscent of magnification by micro-lensing effects, and some are located very near a diffuse object and/or show narrow metallic absorption lines at an optimal redshift for a lens.

4.2.4 Variability of some BAL profiles induced by micro-lensing effects: variability of some broad absorption line (BAL) profiles have been reported for several objects: UM232 (Barlow et al., 1989), Q1246-057 (Smith and Penston, 1988), Q1303+308 (Foltz et al., 1987) and the well known cloverleaf H1413+117 (Turnshek et al., 1988). In the latter case, it has been recently possible to obtain with the CFHT + SILFID spectrograph very high angular resolution spectra of each of the four QSO lensed images (cf. Angonin et al. in this volume). The spectrum of component D turns out to be markedly different from the other ones and I suggest that micro-lensing might be responsible for this. Other evidence for this effect comes from the photometric variability observed for that same image (see Kayser et al. 1989). The possible implication of this is that if an observer takes an integrated spectrum of H1413+117 under average seeing conditions (FWHM > 1″), he may detect variability in the trough or emission line component(s) of the SiIV, CIV, etc. BAL profiles not only depending on when (time dependence of micro-lensing) he took the spectrum but also on how he set the instrument (width, orientation and exact location of the slit with respect to each of the four image components). It could therefore very well be that some of the variability of BAL profiles reported for other BAL QSOs is induced by micro-lensing effects ... and that, maybe, the BAL phenomenon itself could be closely related to gravitational lensing effects.

5. Conclusions

From an observational point of view, it has been shown in the previous sections that the challenge of further studying "gravitational lenses" is great, essential and manifold. Indeed, observations taken with the best performing instruments, and under the best seeing conditions, will certainly contribute: (i) to a better understanding of the already known examples of gravitational lensed objects (cf. section 3), (ii) to the discovery of new interesting cases (cf. section 2), (iii) to test the various proposed suggestions that gravitational lensing may significantly perturb our view of the distant Universe (cf. section 4.1) as well as to check how much gravitational lensing has induced an apparent segregation among the various specific classes of extragalactic objects (cf. section 4.2). In summary, there is no doubt that future observations of very remote objects will help us in assessing the real importance of the various known, recently hypothesized or yet unknown gravitational lens effects which seem to condition our view of the distant Universe (see Figure 2).

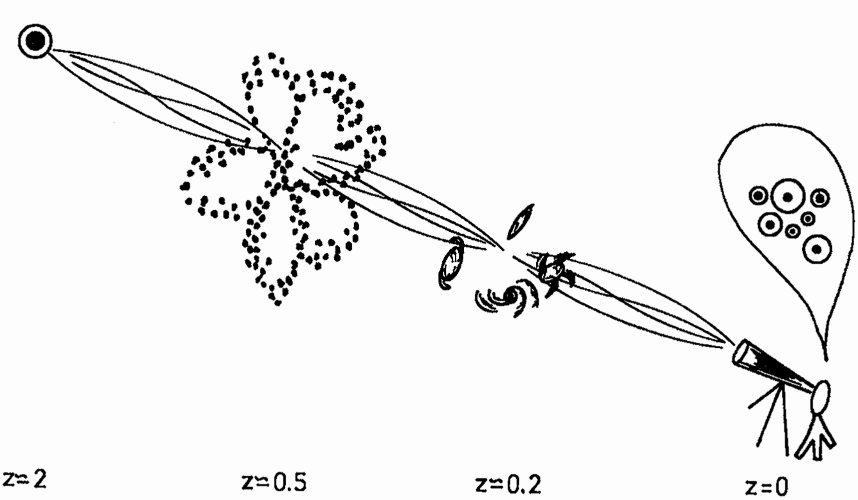

Figure 2: About the possible importance of gravitational lensing effects in our Universe.

Acknowledgements: It is a pleasure to thank my friends and colleagues Pierre Magain, Alain Smette and Jean-Pierre Swings for their careful reading of the manuscript. I also wish to thank them as well as George Djorgovski, François Hammer, Géo Meylan, Laurent Nottale, Olivier Le Fèvre, Sjur Refsdal and Peter Schneider for interesting discussions. Finally, my thanks also go to Armand Kransvelt for drawing the figures.

References:

- Adam, G., Bacon, R., Courtès, G. et al.: 1989, Astron. Astrophys 208, L15.
- Arnaud, J., Hammer, F., Jones, J., Le Fèvre, O.: 1988, Astron. Astrophys. 206, L5.
- Arnaud et al.: 1989, private communication.
- Barbieri, C., Capaccioli, M., Cristiani, S. et al.: 1982, Mem. S. A. It. 53, 511.
- Barlow, T.A., Junkkarinen, V.T., Burbidge, E.M.: 1989, preprint.
- Barnothy, J.M.: 1989, in "Gravitational Lenses", eds. J.M. Moran et al., (New York: Springer-Verlag), p. 23.
- Blandford, R.D., Kochanek, C.S.: 1987, in "Jerusalem Winter School for Theoretical Physics": Vol. 4, "Dark Matter in the Universe", (World Scientific), Singapore, eds. J. Bahcall et al., p. 133.
- Borgeest, U.: 1986, Astrophys. J. 309, 467.
- Boyle, B.J., Shanks, T., Peterson, B.A.: 1988, Mon. Not. Roy. Astr. Soc. 235, 935.
- Burbidge, E.M., Junkkarinen, V.T., Koski, A.T. et al.: 1980, Astrophys. J. 242, L55.
- Canizares, C.R.: 1987, in "Observational Cosmology": Proceedings of IAU Symp. N° 124, eds. A. Hewitt et al. (Reidel: Dordrecht), p. 729.
- Chang, K., Refsdal, S.: 1979, Nature 282, 561.
- Chang, K., Refsdal, S.: 1984, Astron. Astrophys. 132, 168.
- Courtès, G., Georgelin, Y., Bacon, R. et al.: 1987, in "Instrumentation in Astronomy": Proceedings of the 1987 Santa Cruz Workshop, p. 266.
- Cowie, L.L., Hu, E.M.: 1987, Astrophys. J. 318, L33.
- Crampton, D., McClure, R.D., Fletcher, J.M. et al.: 1989, DAO preprint.
- Cristiani, S.: 1987, Astron. Astrophys. 175, L1.
- De Robertis, M.M., Yee, H.K.C.: 1988, Astrophys. J. 332, L49.
- Djorgovski, S., Spinrad, H.: 1984, Astrophys. J. 282, L1.
- Djorgovski, S., Perley, R., Meylan, G. et al.: 1987, Astrophys. J. 321, L17.
- Djorgovski, S., Meylan, G.: 1989a, in "Active Galactic Nuclei": Proceedings of the IAU Symp. N° 134, eds. D. Osterbrock and J. Miller, (Dordrecht: Kluwer), p. 269.
- Djorgovski, S., Meylan, G.: 1989b, in "Gravitational Lenses", eds. J.M. Moran et al., (New York: Springer-Verlag), p. 173.
- Eachus, L.J., Liller, W.: 1975, Astrophys. J. 200, L61.
- Elston, R., Grossman, S., Zaritsky, D.: 1989, preprint.
- Florentin-Nielsen, R.: 1984, Astron. Astrophys. 138, L19.
- Foltz, C.B., Weymann, R.J., Röser, H.-J. et al.: 1984, Astrophys. J. 281, L1.
- Foltz, C.B., Weymann, R.J., Simon, L.M. et al.: 1987, Astrophys. J. 317, 450.
- Foy, R., Bonneau, D., Blazit, A.: 1985, Astron. Astrophys. 149, L13.
- Fugmann, W.: 1988, Astron. Astrophys. 204, 73.
- Fugmann, W.: 1989, preprint.
- Grieger, B., Kayser, R., Refsdal, S.: 1986, Nature 324, 126.
- Grieger, B., Kayser, R., Refsdal, S.: 1988, Astron. Astrophys. 194, 54.
- Hammer, F., Nottale, L.: 1986a, Astron. Astrophys. 155, 420.
- Hammer, F., Nottale, L.: 1986b, Astron. Astrophys. 167, 1.
- Hammer, F., Nottale, L., Le Fèvre, O.: 1986, Astron. Astrophys. 169, L1.
- Hammer, F., Le Fèvre, O.: 1989, CFH preprint.
- Henry, J.P., Heasley, J.N.: 1986, Nature 321, 139.
- Hewett, P.C., Webster, R.L., Harding, M.E. et al.: 1989, preprint.
- Hewitt, J.N., Turner, E.L., Burke, B.F. et al.: 1987a, in "Observational Cosmology": Proceedings of IAU Symp. N° 124, eds. A. Hewitt et al. (Dordrecht: D. Reidel), p. 751.
- Hewitt, J.N., Turner, E.L., Lawrence, C.R. et al.: 1987b, Astrophys. J. 321, 706.
- Hewitt, J.N., Turner, E.L., Schneider, D.P. et al.: 1988, Nature 333, 537.

- Hewitt, J.N., Burke, B.F., Turner, E.L. et al.: 1989, in "Gravitational Lenses", Eds. J.M. Moran et al. (New York: Springer-Verlag), p. 147.
- Hewitt, J.N.: 1989, private communication.
- Huchra, J.P., Gorenstein, M., Kent, S. et al.: 1985, Astron. J. 90, 691.
- Irwin, M.J., Webster, R.L., Hewett, P.C. et al.: 1989, CITA preprint.
- Kayser, R.: 1988, Astron. Astrophys. 206, L8.
- Kayser, R., Surdej, J., Condon, J.J. et al.: 1989, preprint.
- Kayser, R., Refsdal, S.: 1989, Nature 338, 745.
- Kristian, J., Sandage, A., Westphal, J.A.: 1978, Astrophys. J. 221, 383.
- Langston, G.I., Schneider, D.P., Conner, S.: 1989, preprint N° 346 from the MPI für Radioastronomie.
- Lawrence, C.R., Schneider, D.P., Schmidt, M. et al.: 1984, Science 223, 46.
- Le Fèvre, O., Hammer, F., Nottale, L. et al.: 1987, Nature 326, 268.
- Le Fèvre, O., Hammer, F., Nottale, L. et al.: 1988a, Astrophys. J. 324, L1.
- Le Fèvre, O., Hammer, F., Jones, J.: 1988b, Astrophys. J. 331, L73.
- Le Fèvre, O., Hammer, F.: 1988, Astrophys. J. 333, L37.
- Le Fèvre, O., Hammer, F.: 1989, CFH preprint.
- Lehár, J., Hewitt, J.N., Roberts, D.H.: 1989, in "Gravitational Lenses", eds. J.M. Moran et al. (New York: Springer-Verlag), p. 84.
- Lelièvre, G., Nieto, J.L., Salmon, D. et al.: 1988, Astron. Astrophys. 200, 301.
- Magain, P., Surdej, J., Swings, J.-P. et al.: 1988, Nature 334, 325.
- Meylan, G., Djorgovski, S.: 1989, Astrophys. J. 338, L1.
- Narasimha, D., Subramanian, K., Chitre, S.M.: 1987, Astrophys. J. 315, 434.
- Narasimha, D., Chitre, S.M.: 1988, preprint.
- Narayan, R.: 1989, Astrophys. J. 339, L53.
- Nieto, J.-L., Roques, S., Llebaria, A. et al.: 1988, Astrophys. J. 325, 644.
- Nottale, L., Chauvineau, B.: 1986, Astron. Astrophys. 162, 1.
- Nottale, L.: 1986, Astron. Astrophys. 157, 383.
- Nottale, L.: 1987, Ann. Phys. Fr. 12, 241.
- Nottale, L.: 1988, Ann. Phys. Fr. 13, 223.
- Ostriker, J.P., Vietri, M.: 1985, Nature 318, 446.
- Paczynski, B., Gorski, K.: 1981, Astrophys. J. 248, L101.
- Paczynski, B.: 1986, Astrophys. J. 308, L43.
- Pérez, E., Penston, M.V., Moles, M.: 1989, preprint.
- Press, W.H., Gunn, J.E.: 1973, Astrophys. J. 185, 397.
- Quirrenbach, A., Witzel, A., Krichbaum, T. et al.: 1989, Nature 337, 442.
- Refsdal, S.: 1964, Mon. Not. Roy. Astr. Soc. 128, 295 and 307.
- Refsdal, S.: 1966, Mon. Not. Roy. Astr. Soc. 132, 101.
- Remy et al.: 1989, private communication.
- Rix, H.-W., Hogan, C.J.: 1989, preprint N° 883 of the Steward Observatory.
- Sargent, W.L.W., Boksenberg, A., Steidel, C.C.: 1988a, Astrophys. J. Suppl. 68, 539.
- Sargent, W.L.W., Steidel, C.C., Boksenberg, A.: 1988b, Astrophys. J. 334, 22.
- Sargent, W.L.W., Steidel, C.C., Boksenberg, A.: 1988c, RGO preprint.
- Schneider, D.P., Gunn, J.E., Turner, E.L. et al.: 1986, Astron. J. 91, 991.
- Schneider, D.P., Turner, E.L., Gunn, J.E. et al.: 1988, Astron. J. 95, 1619; plus erratum in Astron. J. 96, 1755.
- Schneider, P., Weiss, A.: 1987, Astron. Astrophys. 171, 49.
- Shaklan, S.B., Hege, E.K.: 1987, preprint N° 609 of the Steward Observatory.
- Smith, H.E., Cohen, R.D., Bradley, S.E.: 1987, preprint.
- Smith, L.J., Penston, M.V.: 1988, Mon. Not. Roy. Astr. Soc. 235, 551.
- Stickel, M., Fried, J.W., Kühr, H.: 1988a, Astron. Astrophys. 198, L13.
- Stickel, M., Fried, J.W., Kühr, H.: 1988b, Astron. Astrophys. 206, L30.
- Stickel, M., Fried, J.W., Kühr, H.: 1989, preprint.
- Stocke, J.T., Schneider, P., Morris, S.L. et al.: 1987, Astrophys. J. 315, L11.
- Surdej, J., Magain, P., Swings, J.-P. et al.: 1987, Nature 329, 695.
- Surdej, J., Magain, P., Swings, J.-P. et al.: 1988a, Astron. Astrophys. 198, 49.
- Surdej, J., Magain, P., Swings, J.-P. et al.: 1988b, in "Large Scale Structures: Observations and Instrumentation": Proceedings of the First DAEC Workshop (Paris-Meudon), eds. C. Balkowski and S. Gordon, p. 95.
- Surdej, J., Swings, J.-P., Magain, P. et al.: 1988c, Astr. Soc. Pac. Conf. Ser. 2, 183.

- Surdej, J., Arnaud, J., Borgeest, U. et al.: 1989, The Messenger 55, 8.
- Tanzi, E.G., Barr, P., Bouchet, P. et al.: 1986, Astrophys. J. 311, L13.
- Thomas, P.A., Webster, R.L.: 1989, CITA preprint.
- Turner, E.L., Hillenbrand, L.A., Schneider, D.P. et al.: 1988, Astron.J. 96,1682.
- Turner, E.L.: 1989a, in "Gravitational Lenses", eds. J.M. Moran et al. (New York: Springer-Verlag), p. 69.
- Turner, E.L.: 1989b, in "The 14th Texas Symp. on Relativistic Astrophysics", preprint.
- Turnshek, D.A., Foltz, C.B., Grillmair, C.J. et al.: 1988, Astrophys. J. 325, 651.
- Tyson, J.A.: 1986, in "Quasars", Proceedings of the IAU Symp. N° 119, eds. G. Swarup and V.K. Kapahi (Dordrecht: Reidel), p. 551.
- Vanderriest, C., Wlérick, G., Lelièvre, G. et al.: 1986, Astron. Astrophys. 158, L5.
- Vanderriest, C., Lemonnier, J.P.: 1987, in "Instrumentation in Astronomy": Proceedings of the 1987 Santa Cruz Workshop, p. 304.
- Vanderriest, C., Schneider, J., Herpe, G. et al.: 1989, Astron. Astrophys. 215, 1.
- Véron, P.: 1986, Astron. Astrophys. 170, 37.
- Walsh, D., Carswell, R.F., Weymann, R.J.: 1979, Nature 279, 381.
- Wambsganss, J., Paczynski, B., Katz, N.: 1989, Preprint POP-315.
- Webster, R.L., Hewett, P.C., Irwin, M.J.: 1988a, Astron. J. 95, 19.
- Webster, R.L., Hewett, P.C., Harding, M.E. et al.: 1988b, Nature 336, 358.
- Weedman, D.W., Weymann, R.J., Green, R.topet al.: 1982, Astrophys. J. 255, L5.
- Weymann, R.J., Latham, D., Angel, J.R.P. et al.: 1980, Nature 285, 641.
- Yanny, B., York, D.G., Gallagher, J.S.: 1989, Astrophys. J. 338, 735.
- Yee, H.K.C.: 1988, Astron. J. 95, 1331.
- Yee, H.K.C., Green, R.F.: 1984, Astrophys. J. 280, 79.
- Young, P., Deverill, R.S., Gunn, J.E. et al.: 1981, Astrophys. J. 244, 723.