The Relevance of HST Observations for Studies of Quasars, Gravitational Lenses and Intervening Gas Clouds

J. Surdej[3] - J. -F. Claeskens[4] - C. Jean - D. -W. Lee - A. Pospieszalska-Surdej M. Remy[5] - D. Sluse - A. Smette[6] - J.-P. Swings

Surdej@astro.ulg.ac.be

Institut d'Astrophysique et de Géophysique
Université de Liège,
Avenue de Cointe 5,
Liège, 4000, Belgium

ABSTRACT

During the period 1994-2000, we have made use of the WFPC2 camera and the FOS and STIS spectrographs onboard the Hubble Space Telescope (HST) to obtain observations of close pairs of quasars and to identify new cases of multiply imaged quasars and gravitational lenses. Our main findings concern the identification of J03.13 A & B as a new case of doubly imaged quasar, the direct detection of the lensing galaxy for the doubly imaged quasar HE 1104-1805 A & B and the determination of upper mass limits for the foreground quasars among the QSO pairs Q1548+114 A & B and Q1148+0055 A & B. HST observations have also been used in the context of the photometric monitoring of multiply imaged quasars and in various studies of gravitational lensing statistics, of intervening Damped Lyman Alpha and narrow absorption line clouds and of dust obscuration in lensing galaxies. Finally, didactical papers and experiments simulating HST observations of multiply imaged quasars, a non exhaustive bibliography on gravitational lensing and a list of observational and physical parameters, plus direct images, of all known multiply imaged sources are available on the web via the URL address: http://vela.astro.ulg.ac.be/grav_lens.

INTRODUCTION

Gravitational lensing may perturb our view of the distant Universe and affect our physical understanding of various classes of extragalactic objects (see reference I.1 in the 1994-2000 bibliography for a general review on gravitational lensing). The great interest in gravitational lensing comes from the fact that this phenomenon can be used as an astrophysical and cosmological tool (cf. ref. I.2). Indeed, gravitational lensing may help in deriving (i) the distance scale of the Universe, via the determination of the Hubble constant H_0 based upon the measurement of the time delay Δt between the observed lightcurves of multiply imaged quasars, (ii) the values of other cosmological parameters (Ω_0 and λ_0), (iii) the mass distribution M(r) of the lens, (iv) the extinction law in the deflector usually located at high redshift, (v) the nature and distribution of luminous and dark matter in the Universe, (vi) the size and structure of quasars, (vii) the size of absorbing intergalactic gas clouds and (viii) upper limits on the density of a cosmological population of massive compact objects.

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[3] Directeur de Recherches FNRS
[4] Chargé de Recherches FNRS
[5] until May, 1999
[6] Chercheur Qualifié FNRS as of October 1, 2000; until then: NASA postdoctoral fellow

In this article covering the period 1994-2000, we describe some of our theoretical and observational contributions to these endeavors, mostly based upon HST data.

SEARCH FOR MULTIPLY IMAGED QUASARS AND DETECTION OF THE LENSES

Extragalactic gravitational lensing has first been mentioned by Zwicky in 1937. He realized that, due to their large mass, external galaxies could in fact "lens" more distant ones into several *observable* images. However, such mirages are still difficult to identify because galaxies are faint, diffuse and extended objects whose apparent size can be large (compared to the Einstein ring of the lens).

In 1963, the first quasar was discovered by Schmidt. Quasars are the beacons of the Universe. Thanks to their huge luminosity, they can be seen at very large distances so that the probability to find a foreground lensing galaxy close to their line-of-sight is larger than for normal galaxies. On the other hand, multiple lensed images of quasars can be more easily identified because the source is bright and point-like. In 1979, the first cosmic mirage was found by chance as a double image of a radio-loud quasar (Walsh et al. 1979), with identical spectral properties all the way from UV (measured with the IUE satellite by Gondhalekar and Wilson in 1980) to radio through optical and infrared wavelengths. This discovery opened new interests in gravitational lensing. A large number of applications became possible and motivated several independent teams to find more and more gravitational lenses among selected Highly Luminous Quasars (hereafter HLQs). HLQs are indeed more likely to be lensed because they are distant and appear very bright: their brightness is partially due to light amplification by gravitational lensing (the so-called amplification bias). However, the probability to be lensed is only about 1%, so that large samples must be observed with optical ground-based, space or radio telescopes.

Due to the arcsec scale (or less) of the angular separation between the lensed images of QSOs, the HST is often needed to confirm the nature of lens candidates. This is illustrated in the case of the doubly imaged QSO J03.13 A & B ($z_s = 2.55$, $\Delta\theta = 0.84''$), which was discovered at the European Southern Observatory, La Silla, Chile (Figure 1a) to be a good candidate, then confirmed with HST to consist of 2 point-like images (Figure 1b) having identical spectra (Figure 1c). See refs. I.3, I.7, II.6 and II.11 for a detailed report on these observations.

At present, more than 50 multiply imaged quasars have been identified (see ref. I.15 for a complete list). Hereafter, we present some of the most interesting applications and results obtained from gravitational lensing effects in quasar samples.

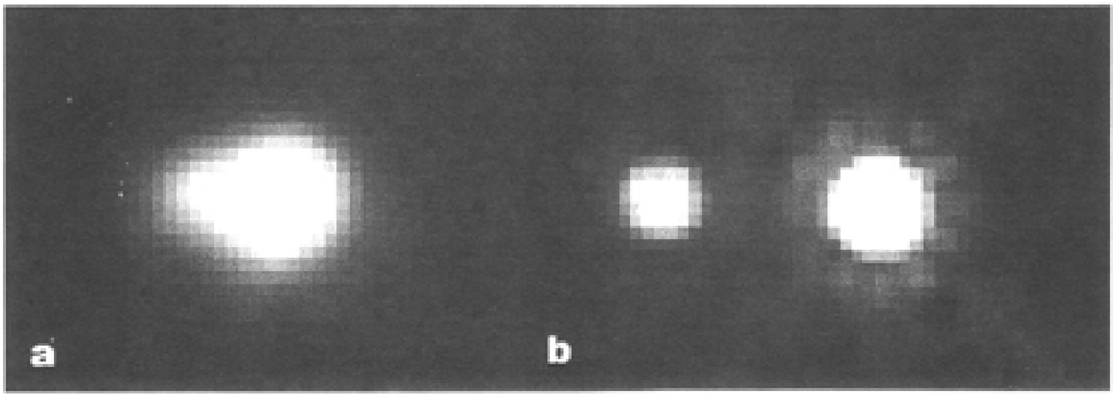

Figure 1: (a) Identification of a gravitational lens candidate based on ground-based direct CCD imagery. On this CCD frame obtained with the ESO New Technology Telescope (NTT) at La Silla (Chile), the image of QSO J03.13 looks somewhat elongated. The seeing was about 0.7". Claeskens et al. (1996, ref. I.3) suspected that J03.13 was composed of two nearby point-like images. (b) Subsequently, the WFPC2 camera onboard the Hubble Space Telescope was used to confirm the image structure of J03.13. This WFPC2 R CCD frame clearly reveals a double image, with an angular separation of 0.84".

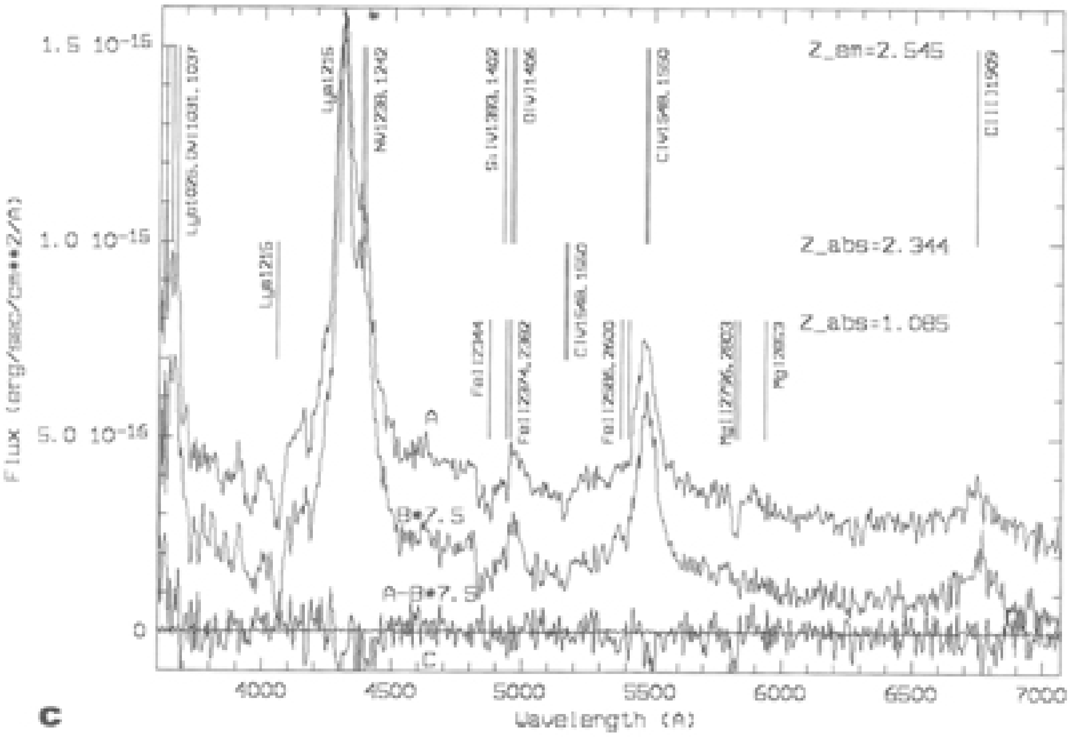

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Figure 1: (c) For such a small angular separation, it is impossible to obtain individual spectra of the resolved components from the ground. This is an easy task for the Hubble Space Telescope. Spectra obtained with the FOS instrument clearly show that the fingerprints of J03.13 A & B cannot be distinguished one from another, except for a few narrow absorption lines due to distinct intervening clouds located along the two lines-of-sight. These two spectra show that the quasar is at a redshift z_s = 2.55 (Surdej et al. 1997, ref. I.7). Courtesy of the European Southern Observatory (ESO) and the Space Telescope Science Institute (STScI) operated for NASA by AURA.

The lensing galaxies

Multiply imaged QSOs provide general constraints on the mass distribution of the lensing galaxies. For example, if the value of the Hubble constant H_0 and the lens and source redshifts are known, the total mass can be derived from the angular separation between the lensed QSO images. This is the simplest and most direct astrophysical application of gravitational lensing.

If a time delay is also measured, the lensing mass can be obtained independently of the cosmological parameters H_0, Ω_0, λ_0 and the source redshift. The inferred values for the mass are typical of elliptical galaxies (see ref. I.15 for a summary of mass and mass-to-light ratio estimates).

The Hubble Space Telescope plays a crucial role in detecting the main lenses, which are faint, extended, high redshift objects located between bright and angularly close (~1 arcsec) images of the background quasars. Careful subtraction of the HST Point Spread Function and/or deconvolution is often mandatory (cf. refs. II.9, II.10, II.12 and II.16). As an example, Figure 2 illustrates the easy detection of the lens galaxy for the doubly imaged quasar HE 1104-1805 A & B, based upon direct imagery with the WFPC2 camera onboard HST (see refs. I.8 and II.11 for a complete discussion of these observations). Close associations between background quasars and foreground galaxies reflecting the magnification bias have been studied in ref. I.9.

Finally, multiply imaged quasars deserve very special investigations to determine the extinction law in the lensing galaxies. Indeed, when the lines-of-sight corresponding to the different images probe different dust optical depths in the lens, a differential reddening is observed between the lensed images (cf. refs. I.11, II.17). Until now, only Galactic parametric curves have been fitted from photometric data but high quality spectrophotometry should allow to directly determine the extinction law at high redshift and compare it with that observed in the Milky Way, in the Magellanic Clouds and in a few local galaxies.

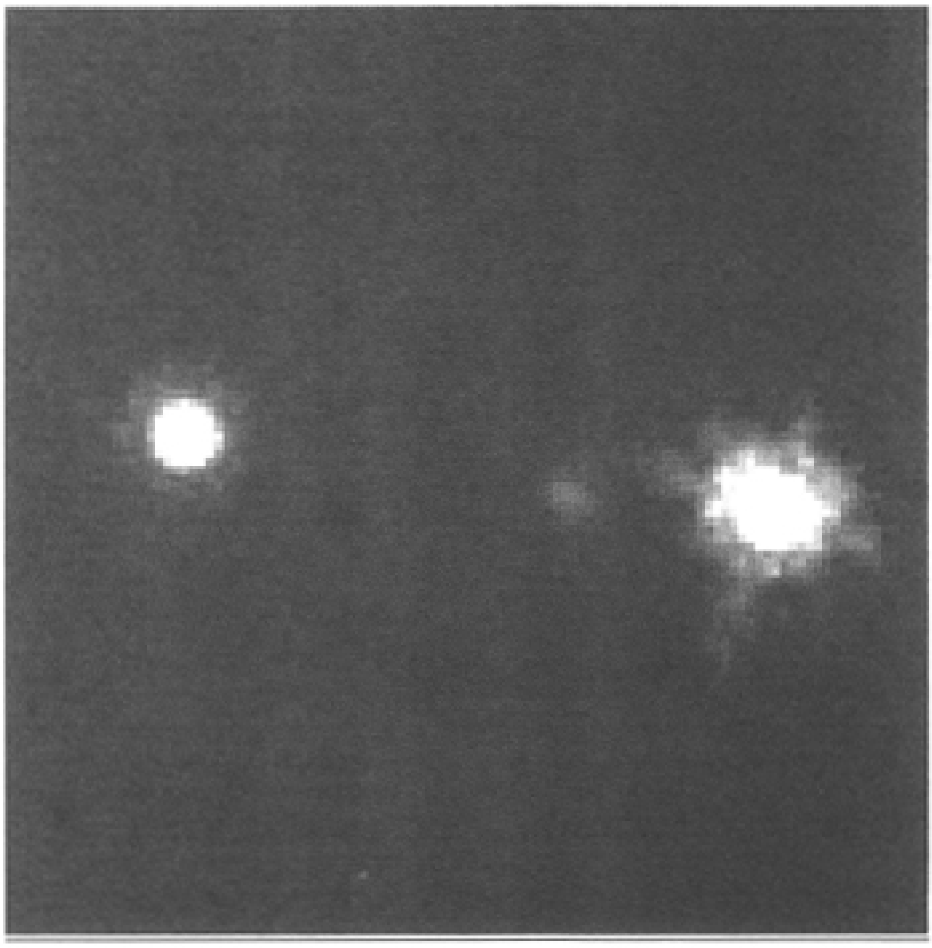

Figure 2: Direct WFPC2 CCD frame of HE 1104-1805 showing very clearly the lens galaxy between images A and B (Remy et al. 1998, ref. I.8).

Cosmological parameters

Extragalactic gravitational lensing provides us with an optical experiment whose optical bench has a size comparable to that of the observable Universe. Since this size is directly related to the values of the cosmological parameters, it is not surprising that the latter can be constrained from gravitational lensing observations. We refer the reader to refs. I.1, I.2, I.12, I.15 and I.16 for extended reviews on the general determination of the cosmological parameters.

The Hubble constant H_0

The Hubble constant fixes the actual expansion rate of the Universe. Its determination from the observation of a multiply imaged extragalactic source consists in a very original application of gravitational lensing. It was proposed in 1964 by Refsdal and it is based on the observation of a time delay between flux variations in the lensed images. The major interest of this method is to get rid of the traditional issue of flux calibrations relying on the -difficult to prove- existence of standard candles (such as Type Ia supernovae). Direct images of gravitational lens systems observed with HST usually provide good astrometric constraints which are implicitly used to derive accurate photometric lightcurves for each component of multiply imaged quasars. Refs. I.5 and II.7 describe the application of this technique for the case of the Cloverleaf H1413+117 A-D. Estimates of H_0 from gravitational lens studies are summarized in ref. I.15.

The cosmological constant λ_0

The fate of the Universe is intimately related to the values of the cosmological density parameter Ω_0 and of the cosmological constant λ_0. Their determination constitutes one of the most important challenges in present observational cosmology.
Since the spatial volume of a sphere extending to a given redshift increases with lower values of Ω_0 or with larger values of λ_0, the resulting number of multiply imaged QSOs in a large sample of HLQs also increases for such values of the cosmological parameters, assuming the comoving density of galaxies is constant. The influence of λ_0 is much stronger than that of Ω_0: whatever a reasonable value of Ω_0, values of λ_0 close to 1 lead to the prediction of detecting at least twice as many lenses than is actually observed in optical samples. Gravitational lensing statistical studies thus yield a natural *upper* limit to the value of the cosmological constant but no significant constraint on Ω_0. Statistical analyses based on the concept of lensing optical depth may be found in refs. I.6, II.1 and II.2.

The cosmological density of dark compact objects

Press and Gunn had already noted in 1973 that counting gravitational lensing events in a sample of distant sources may help in constraining the contribution (Ω_L) to the critical density of the Universe due to a putative cosmological population of dark compact objects with a mass M_L. Ground-based optical telescopes can reveal the multiple images produced by dark compact objects with a mass M_L between $10^{10.5}$ and 10^{15} solar masses. Thanks to its higher angular resolution, HST is sensitive to masses down to 10^9 $M_\odot$. Radio observations with the VLBI allow to reach the level of $M_L = 10^6$ $M_\odot$. Below that mass range, the lensed images cannot be resolved any longer and constraints only come from the observed statistical variability of the QSO flux or of the equivalent width of their emission lines due to (micro)lensing by the putative dark compact object population (Canizares 1982). The available constraints are summarized in Figure 3 and the conclusion is that there is no cosmological population of dark compact objects with mass M_L in the range 10^{-3} - 10^{15} $M_\odot$ capable of closing the Universe (see refs. II.2 and II.5 for a more detailed presentation).

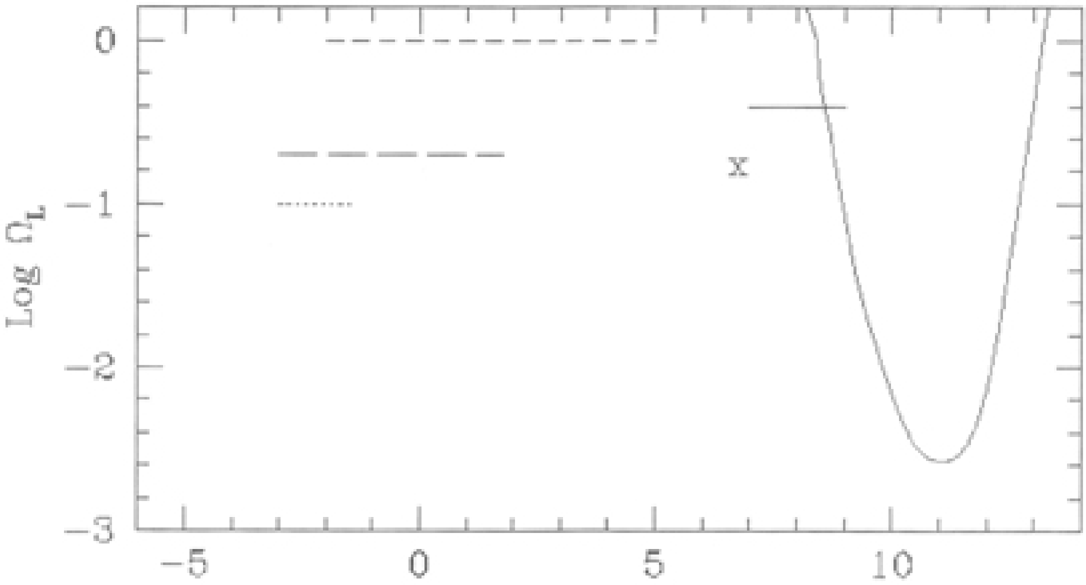

Figure 3: Current constraints from gravitational lens studies on the cosmological density of dark compact objects (in unit of the critical density Ω_c) as a function of their mass. Thick full line: Claeskens (1999; 99.7% confidence level - CL); straight full line: Kassiola et al. (1991; 99.7% CL); short dashed line: Canizares (1982); dotted line: Schneider (1993; ~ 97% CL); long dashed line: Dalcanton et al. (1994); 'X': Marani et al. (1999; 90% CL).

Size of intergalactic clouds

Cold intergalactic clouds, which may be connected to galaxy formation (e.g. Wolfe 1988), are revealed by their Lyα and/or metallic absorption lines (CIV, MgII, ...) seen in the spectra of distant quasars. If such a distant QSO is multiply imaged by gravitational lensing, the different lines-of-sight probe the clouds at various impact parameters. The large number of coincident absorption lines found in the spectra of several multiply imaged QSOs implies that most of the intervening clouds extend over both lines-of-sight. A lower limit on their size was derived to be 50 h^{-1} kpc ($h = H_0 / 100$), in agreement with even larger estimates of about 300 h^{-1} kpc recently found from spectroscopic studies of QSO pairs (d'Odorico et al. 1998). A detailed study of absorption lines in pairs of quasars is presented in refs. I.10 and II.13.

DLA clouds

Gravitational lensing may also affect the determination of the cosmological density of Ω_{HI} of neutral hydrogen based on Damped Lyα Absorptions (DLAs) surveys in quasar spectra. Indeed, lensing by the halo of the associated spiral galaxies may cause the light rays from the background QSOs to avoid the densest central parts of the disk, while the amplification bias increases the chance that a QSO with a DLA be included in a flux limited sample of quasars. The competition between these two effects results in a slight overestimation of Ω_{HI} in existing high redshift surveys but the latter could be more significant at lower redshift in bright QSO samples, although the influence of dust extinction could balance that of the amplification bias (cf. refs. I.4, I.14, I.17, II.4, II.14 and II.15).

QSO MASS CONSTRAINTS

Constraints on the mass of quasars have been derived from gravitational lens studies of the QSO pairs Q 1548+114 A & B and Q 1148+0055 A & B, for which new ground-based and Hubble Space Telescope direct imagery have been obtained (see ref. I.13). In the case of Q 1548+114 A & B, QSO A has been resolved into its host galaxy and a close companion. The non-detection with HST of a secondary lensed image of the background QSO in the close vicinity of the foreground one and the modeling of the host of QSO A, of the companion and of field galaxies with Singular Isothermal Spheres yield a robust upper limit on the central compact mass of 4.5 10^{11} $M_{\odot}$. On the other hand, the combined mass of Q 1148+0055 B plus host must be smaller than 6.5 10^{11} $M_{\odot}$ since no secondary lensed image has been detected with HST.

OPTICAL LENS SIMULATOR AND GRAVITATIONAL LENS BIBLIOGRAPHY

Several optical lens simulators made of plexiglass have been produced by some of us (JS & A P-S) and used to simulate the formation of multiply imaged quasars by a foreground lens galaxy. Such didactictal experiments enable one to reproduce all image configurations (cf. double or quadruple lensed images, Einstein ring, giant luminous arcs, arclets, etc.) that have been observed with the Hubble Space Telescope (see refs. II.3 and II.18). One of these simulators is being use in the 'Cosmology' exhibition organized at the National Air and Space Museum in Washington from 2000 until 2015.
A non exhaustive, although quite complete, bibliography dedicated to theoretical and observational studies of gravitational lens systems as well as a database summarizing the main observational and physical parameters of multiply imaged sources, including a set of color images of most of these cosmic mirages, are available on the web at the following URL address (see refs. II.8 and II.19):
http://vela.astro.ulg.ac.be/grav_lens/.

CONCLUSIONS

Observations of gravitational lenses are very demanding in terms of spatial resolution and collecting power, but also in time sampling for flux monitoring or in data handling while searching for these. All this has motivated much work in image processing, such as Point Spread Function (PSF) subtraction or deconvolution, in lightcurve analysis and in team organization to get good data. In this context, space observations, especially with HST, have played a crucial role with respect to the angular resolution issue. Most gravitational lenses have been discovered with ground-based telescopes or radio-telescopes, but HST has enlightened us with the confirmation of several cases with small angular separations (like J03.13 in

Figure 1), with the precise determination of all the lensed image positions, with the discoveries of new luminous arcs and with first detection of several lensing galaxies.
Strong lensing events (multiply imaged sources, giant arcs, ...) are rare (approximately 50 cases are presently known), but automated surveys with (nearly) full sky coverage (SDSS, ILMT, CLASS, GAIA, ...) will find them more and more systematically. Thus, gravitational lenses will become very common and there is little doubt that in the near future, the present and next generation of astronomical space satellites (HST, Chandra, XMM, MAP, FIRST, Planck, NGST, GAIA, …) will contribute even more significantly to the astrophysical and cosmological applications of gravitational lensing that have been described in the previous sections.

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REFERENCES

Canizares, C R, 1982. Manifestations of a cosmological density of compact objects in quasar light. Astrophys. J., 263, 508

Claeskens, J-F, 1999. Thèse de Doctorat. Soc. Roy. Sci. Liège, 68, 1-305

Dalcanton, J J, Canizares, C R, Granados, A, Steidel, C C, Stocke, J T, 1994. Observational limits on Omega in stars, brown dwarfs, and stellar remnants from gravitational microlensing. Astrophys. J. 424, 550

d'Odorico, V, Cristiani, S, d'Odorico, S, Fontana, A, Giallongo, E, Shaver, P, 1998. The size and geometry of the Lyα clouds. Astron. Astrophys., 339, 678

Gondhalekar, P M, Wilson, R, 1980. UV spectra of the twin QSOs 0957+561 A, B. Nature, 285, 461

Kassiola, A, Kovner, I, Blandford, R D, 1991. Bounds on intergalatic compact objects from observations of compact radio sources. Astrophys. J., 381, 6

Marani, G F, Nemiroff, R J, Norris, J-P, Hurley, K, Bonnell, J T, 1999. Gravitationally lensed gamma-ray bursts as probes of dark compact objects. Astrophys. J., 512, L13

Press, W H, Gunn, J E, 1973. Method for detecting a cosmological density of condensed objects. Astrophys. J., 185, 397

Refsdal, S, 1964a. The gravitational lens effect. Monthly Notices Roy. Astron. Soc., 128, 295

Refsdal, S, 1964b. On the possibility of determining Hubble's parameter and the masses of galaxies from the gravitational lens effect. Monthly Notices Roy. Astron. Soc., 128, 307

Schmidt, M, 1963. 3C 273: a star-like object with large red-shift. Nature, 197, 1040

Schneider, P, 1993. Upper bounds on the cosmological density of compact objects with sub-solar masses from the variability of QSOs. Astron. Astrophys., 279, 1

Walsh, D, Carswell, R F, Weymann, R J, 1979. 0957+561 A, B: twin quasistellar objects or gravitational lens? Nature, 279, 381

Wolfe, A M, 1988. Damped Ly-alpha absorption systems. In: QSO absorption lines: Probing the universe; Proceedings of the QSO Absorption Line Meeting, Baltimore, MD, May 19-21, 1987, p. 297-306; Cambridge University Press.

Zwicky, F, 1937a. Nebulae as gravitational lenses. Phys. Rev. Let., 51, 290

Zwicky, F, 1937b. On the probability of detecting nebulae which act as gravitational lenses. Phys. Rev. Let., 51, 679

Zwicky, F, 1957. Morphological Astronomy. Berlin: Springer

BIBLIOGRAPHY

Peer-Reviewed Articles and Invited Conference Talks

Gravitational Lenses
Refsdal, S., Surdej, J.: 1994, Reports on Progress in Physics 57, 117-185.

Gravitational lensing as a tool: future observational prospects
Surdej, J., Refsdal, S.: 1994, review paper delivered during the 27th ESLAB Symposium 'Frontiers of space and ground-based astronomy', in the series 'Astrophysics and Space Science Library', pp. 409-419, (eds. W. Wamsteker, M.S. Longair and Y. Kondo).

J03.13 A and B: a new multiply imaged QSO candidate
Claeskens, J.-F., Surdej, J., Remy, M.: 1996, Astron. Astrophys. Letters 305, L9-L12.

Gravitational lensing by damped Ly-α absorbers
Smette, A., Claeskens, J.-F., Surdej, J.: 1997, New Astronomy 2, 53-76.

ESO & NOT Photometric Monitoring of the Cloverleaf quasar
R. Østensen, M. Remy, P.O. Lindblad, S. Refsdal, R. Stabell, J. Surdej, P.D. Barthel, P.I. Emanuelsen, L. Festin, E. Gosset, O. Hainaut, P. Hakala, M. Hjelm, D. Hutsemékers, M. Jablonski, A.A. Kaas, H. Kristen, S. Larsson, P. Magain, B. Pettersson, A. Pospieszalska-Surdej, A. Smette, J. Teuber, B. Thomsen, E. Van Drom: 1997, Astron. Astrophys. Suppl. 126, 393-400.

Gravitational lens studies with a LMT
Surdej, J., Claeskens, J.-F.: 1998, invited paper presented during the international workshop "Science with Liquid Mirror Telescopes" in Marseille Observatory, 14-15 April 1997, proceedings published by M. Ferrari., pp. 1-8, paper available at the URL: http://wood.phy.ulaval.ca/lmt/Surdej.ps

HST confirmation of the lensed quasar J03.13
Surdej, J., Claeskens, J.-F., Remy, M., Refsdal, S., Pirenne, B., Prieto, A., Vanderriest, Ch.: 1997, Astron. Astrophys. Letters 327, L1-L4.

Detection of the lensing galaxy for the double QSO HE 1104-1805
Remy, M., Claeskens, J.-F., Surdej, J., Hjorth, J., Refsdal, S., Wucknitz, O., Sorensen, A.N., Grundhal, F.: 1998, New Astronomy 3, 379-390.

Close projected QSO-galaxy associations: are they real?
Claeskens, J.-F., Surdej, J.: 1998, Astron. Astrophys. 335, 69-84.

HST observations of the QSO pair Q1026-0045 A, B
Petitjean, P., Surdej, J., Smette, A., Shaver, P., Mucket, J., Remy, M.: 1998, Astron. Astrophys. Letters 334, L45-L48.

Redshift estimate of a gravitational lens from the observed reddening of a multiply imaged quasar
Jean, C., Surdej, J.: 1998, Astron. Astrophys. 339, 729-736.

Concluding remarks on the Oslo workshop "Gravitational lensing
Surdej, J.: 1998, talk presented during the Oslo workshop "Gravitational lensing", 10-12 June 1998

QSO mass constraints from gravitational lensing studies of quasar pairs: the cases of Q1548+114 A & B and Q1148+0055 A & B
Claeskens, J.-F., Lee, D.-W., Remy, M., Sluse, D., Surdej, J.: 2000, Astron. & Astrophys. 356, 840.

A NICMOS search for multiple imaging by damped Ly-α absorbers
Smette, A., Claeskens, J.-F., Surdej, J., Le Brun, V.: 2000, Ap.J., in preparation.

Gravitational Lensing in Quasar Samples
Claeskens, J.-F., Surdej, J.: 2000, Astron. & Astrophys. Review, in press

Gravitational Lensing
Surdej, J., Claeskens, J.-F.: 2000, chapter for the book 'The Century of Space Science', Eds. J. Bleeker, J. Geiss & M.C.E. Huber, Kluwer Academic Publishers, in press

Lensing properties of 7 damped Ly-α absorbing galaxy-QSO pairs
Le Brun, V., Smette, A., Surdej, J., Claeskens, J.-F.: 2000, Astron. Astrophys., in press.

Conference Papers

Ground-based and HST direct imaging of HLQs
Surdej, J., Jaunsen, A.O., Claeskens, J.-F., Gonzaga, S., Pospieszalska-Surdej, A., Pirenne, B., Prieto, A.: 1996, in the proceedings of IAU Symposium 173, "Gravitational Lensing", Melbourne, July 1995, eds. C. Kochanek and J. Hewitt, pp. 387-392.

Gravitational lenses among highly luminous quasars: large optical surveys
Claeskens, J.-F., Jaunsen, A., Surdej, J.: 1996, in the proceedings of IAU Symposium 173, "Gravitational Lensing", Melbourne, July 1995, eds. C. Kochanek and J. Hewitt, pp. 13-20.

Formation of giant luminous arcs and arclets using an optical gravitational lens experiment
Surdej, J., Refsdal, S., Pospieszalska-Surdej, A.: 1996, in the proceedings of IAU Symposium 173, "Gravitational Lensing", Melbourne, July 1995, eds. C. Kochanek and J. Hewitt, pp. 417-418.

Gravitational lenses and damped Ly-α systems
Smette, A., Claeskens, J.-F., Surdej, J.: 1996, in the proceedings of IAU Symposium 173, "Gravitational Lensing", Melbourne, July 1995, eds. C. Kochanek and J. Hewitt, pp. 99-100.

Determination of the cosmological density of compact objects using gravitational lensing and the HST
Claeskens, J.-F., Surdej, J.: 1996, in the proceedings of "Science with the HST-II", Paris, eds. P. Benvenuti, F.D. Macchetto, E.J. Schreier, pp. 96-100.

J03.13 A & B: a new multiply imaged QSO candidate
Claeskens, J.-F., Surdej, J., Remy, M.: 1996, in the proceedings of IAU Symposium 173, "Gravitational Lensing", Melbourne, July 1995, eds. C. Kochanek and J. Hewitt, pp. 337-338.

The Clover Leaf quasar H1413+117: new photometric lightcurves
Remy, M., Gosset, E., Hutsemékers, D., Revenaz, B., Surdej, J.: 1996, in the proceedings of IAU Symposium 173, "Gravitational Lensing", Melbourne, July 1995, eds. C. Kochanek and J. Hewitt, pp. 261-262.

The 'Gravitational Lensing' bibliography
Pospieszalska-Surdej, A., Surdej, J., Véron, P.: 1996, in the proceedings of IAU Symposium 173, "Gravitational Lensing", Melbourne, July 1995, eds. C. Kochanek and J. Hewitt, pp. 415-416.

WFPC2 photometry from subtraction of TinyTim PSFs
Remy, M., Surdej, J., Baggett, S., Wiggs, M.: 1997, in the proceedings of the "1997 HST Calibration Workshop", eds. S. Casertano et al., pp. 374-377.

WFPC2 photometry from subtraction of observed PSFs
Surdej, J., Baggett, S., Remy, M., Wiggs, M.: 1997, in the proceedings of the "1997 HST Calibration Workshop", eds. S. Casertano et al., pp. 386-391.

HST observations of the gravitational lens systems HE 1104-1805 and J03.13
Remy, M., Claeskens, J.-F., Surdej, J.: 1997, in the proceedings of the "1997 HST Calibration Workshop", eds. S. Casertano et al., pp. 368-373.

The WFPC2 PSF library
Wiggs, M., Baggett, S., Surdej, J., Tullos, C.: 1997, in the proceedings of the "1997 HST Calibration Workshop", eds. S. Casertano et al., pp. 392-397.

Spatial distribution of the Ly-α forest
Petitjean, P., Surdej, J., Remy, M., Smette, A., Mucket, J., Shaver, P.: 1998, in the proceedings of the conference "The Young Universe: Galaxy Formation and Evolution at Intermediate and High Redshift", Eds. S. D'Odorico, A. Fontana, and E. Giallongo, ASP Conference Series, Vol. 146, p. 383

Gravitational lenses and Damped Ly-α systems
Smette, A., Claeskens, J.-F., Surdej, J.: 1997, in 13th IAP Workshop "Structure and evolution of the intergalactic medium from QSO absorption line systems", Eds. P. Petitjean and S. Charlot, Editions Frontières, 313-316.

Gravitational Lensing by Damped Ly-α Absorbers
A. Smette, J.-F. Claeskens, and J. Surdej, in "Highly Redshifted Radio Lines", Proceedings of a Conference held in Green Bank, WV, USA, October 9-11, 1997; Edited by C.L. Carilli, S.J.E. Radford, K.M. Menten, and G.I. Langston, 1999, ASP Conf. Series Vol. 156, p. 147-151.

WFPC2 PSF subtractions

Baggett, S., Remy, M., Surdej, J., Wiggs, M.: 1998, to appear in the abstracts of Bulletin of the American Astronomical Society (meeting held in January 1998, Washington DC, USA)

Determination of the redshift of an invisible lens based upon the observed reddening of multiply imaged quasars

Jean, C., Surdej, J.: 1998, paper presented during the Oslo workshop "Gravitational lensing", 10-12 June 1998

Gravitational Lensing by a Wine Glass"

Surdej, J.: 1999, in the journal "The Universe in the Classroom", published by the Astronomical Society of the Pacific, 46 (Second Quarter 1999), 5.

The GL bibliography and an interactive database

Pospieszalska-Surdej, A., Surdej, J., Detal, A., Jean, C.: 1999, to appear in the proceddings of the Conference 'Gravitational lensing: recent progress and future goals', Boston University 1999, eds. T.G. Brainerd and C.S. Kochanek