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Research Note

First results of a spectroscopic search for gravitational mirages★

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Summary. We present the first results of a systematic search for gravitational mirages among close pairs of blue objects and we discuss some representative cases.

The spectroscopic study of 15 candidates did not yield new gravitational mirages but revealed ~40% of extragalactic physical systems including a large proportion of quasars, active galaxies or H II regions.

Key words: quasars – active galactic nuclei – spectroscopy – gravitational mirages – blue objects

1. Introduction

Most of the known cases of gravitational mirages[1] have been discovered by chance. In fact, only 2016 + 112 may be considered as the result of a successful systematic search (Lawrence et al., 1984) starting from a catalogue of radio-sources. Different optical methods can be tried on selected high-redshift quasars. The selection criterium may be for instance anomalous brightness or existence of low redshift absorption lines.

Our team has adopted another approach which has been exposed at the 24th Liège Colloquium (Fringant et al., 1983).

The 9010 faint blue objects at high galactic latitude of the Berger-Fringant catalogue (Berger and Fringant, 1977, 1980, 1984) are the starting point of our program. This catalogue should contain about 20–30% of quasars or active galatic nuclei (Berger and Fringant, 1985; Zotov, 1985) i.e. a total number comparable to the presently available set of these objects (Veron-Cetty and Veron, 1985). Its 2-point auto-correlation function shows a strong excess of pairs at separations lower than 100″. More than a half of these 333 pairs must be physical.

That percentage becomes higher than 90% at separations lower than 8″. As these objects have colours and magnitudes typical of quasars we proposed at Liège the close pairs of blue objects as good gravitational mirages candidates.

We extended our selection to other similar catalogues as the ones of Haro and Luyten (1962), Luyten (1967–68, Usher (1981, 1982a, 1982b) and Richter (1965, 1966, 1967, 1968). We extracted in that way a sample of 46 definitely blue pairs (classes I, II or III as defined in Berger and Fringant, 1977) separated by less than 9″. 16 pairs containing only one definitely blue object have been added to our initial sample to take into account the possibility of reddening along one of the light paths through the matter of the deflecting galaxy.

The spectroscopic study of our candidates has been undertaken but was somewhat impaired by bad weather conditions. At this time, 15 pairs have been more or less investigated, some of the spectra having a rather poor S/N ratio.

The aim of this paper is to show the first striking results of this beginning program.

2. Observations

Most of the observations have been made with the ESO 3.6 m telescope and the Image Dissector Scanner (IDS) in September 1984. In this case, only 1 spectrum is available at a time. So, in order to save observing time, when the spectrum of the first component (the brightest one) of a pair revealed a stellar nature, we moved to the next pair of the list.

Some objects have also been observed with other telescopes and spectrographs allowing to record simultaneously the 2 spectra of the pairs, but often with a poor S/N ratio for the fainter component. Moreover, the medium to bad seeing encountered biased our choice against the closest pairs.

Up to now, among the 15 pairs investigated, 7 objects revealed at least one extragalactic component and 8 showed at least one stellar component (halo star or white dwarf).

[1] Gravitational lensing effects (distorsion of the wave-front by density inhomogeneities resulting in displacement and magnification of the images of distant sources) are very common in our locally inhomogeneous Universe. Only in rare cases is the wave front so disturbed that a folding occurs, allowing the observer to see several images of a single source. We call this "catastrophic" splitting a gravitational mirage by analogy with atmospheric mirages (Vanderriest, 1985).

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★ Based on observations collected at the European Southern Observatory (Chile), the Canada-France-Hawaï Telescope (Hawaï) and at the Observatoire de Haute-Provence (France)

We discuss now the observations of some representative pairs involving extragalactic objects.

2.1. P.B. 4053

We have there a mixed pair with only one blue object, P.B. 4053, extracted from the Berger-Fringant catalogue (Berger and Fringant, 1977). The object ($B = 16.5$, class I) is noted as "compact and associated with a red companion at 12″ W". Direct imagery revealed a separation of $\sim 8''$. The companion has a colour similar to that of a K star and a B magnitude ~ 18.

The spectrum has been obtained with the 1.93 m telescope of the Observatoire de Haute Provence equipped with the SILFID fibre spectrograph at 250 Å mm^{-1} and a photon counting camera. The hexagonal primary of the optical fibres interface allowed to record the two spectra simultaneously. But the short available exposure time (10 min) and poor transparency gave only a useful spectrum of the brightest component. It shows Hα, Hβ and [O III] in emission at a redshift $z = 0.0880 \pm 0.0005$. The FWHM is 1700 km s^{-1} for Hβ, while the [O III] lines remain unresolved.

The [O III] 5007/Hβ ratio is about 0.2. Thus, P.B. 4053 is a bona fide Sy I nucleus. The (noisy) spectrum of the companion does not show any emission lines and it could be an elliptical galaxy at a projected distance of 18 kpc. Taking into account a random projection effect, the real separation remains lower than 60 kpc at the 0.95 level of confidence if the pair is physical. The separations have been computed with $H_0 = 50$ km s^{-1} Mpc^{-1}. This value supplies upper limits for the real separations and will be adopted thereafter.

2.2. P.H.L. 6657–6658

This pair has been found in the catalogue of Haro and Luyten (1962), where it is described as a pair of 18.1 and 18.2 B magnitude objects of colour class II separated by 4″.

The observation of the pair has been achieved in 30 min at the 2.2 m telescope of ESO with a dispersion of 114 Å mm^{-1} and a CCD receptor. The slit had been previously orientated according to the position angle of the pair.

The total spectrum of the pair is displayed in Fig. 1. The emission lines of [O II] 3727, H_γ, H_β, [O III] 4959 and [O III] 5007 all show a redshift $z = 0.07894 \pm 0.00007$. From the observed profiles of the lines, their intrinsic width is less than 150 km s^{-1} (FWHM).

This spectrum could be that of a pair of extragalactic H II regions (see e.g. Shaver and Chen, 1985). Nevertheless, the relatively strong continuum could imply an important stellar component.

The absolute magnitude of each component is about $M_B = -20.5$ and the projected separation of the 2 objects is 8 kpc.

2.3. P.B. 7348

This object is a mixed pair. P.B. 7348 is in the third part of the Berger-Fringant catalogue (1984), where it appears with a 17.5 B magnitude and a class II colour. A note precises that it has a companion at 5″ towards North with a B magnitude 18.5 and a colour compatible with that of an A star.

The spectra of the two components have been obtained with the 3.6 m telescope of ESO, a dispersion of 171 Å mm^{-1} and the Image Dissector Scanner. A 20 minutes exposure on P.B. 7348 revealed a quasar with two emission-lines identified as [C III] 1909 and Mg II 2798 at redshift $z = 1.33$ (Fig. 2).

In the available 30 minutes, the spectrum of the northern component revealed no reliable feature neither in emission nor in absorption.

For a mixed pair the a priori probability of the physical character of the association is not easy to estimate but seems to remain high for a class II-colour A system.

In the physical association hypothesis, we can calculate the real linear separation for a given angle on the line of sight (taken at random) and a given Friedmann model with a deceleration parameter q_0 (taken between 0. and 0.5). We find a separation between 40 and 200 kpc at the 0.95 confidence level.

The absolute magnitude of the quasar (P.B. 7348) is about $M_B = -28$ and, if the association is real, the companion would be a bright starlike object ($M_B \sim -27$).

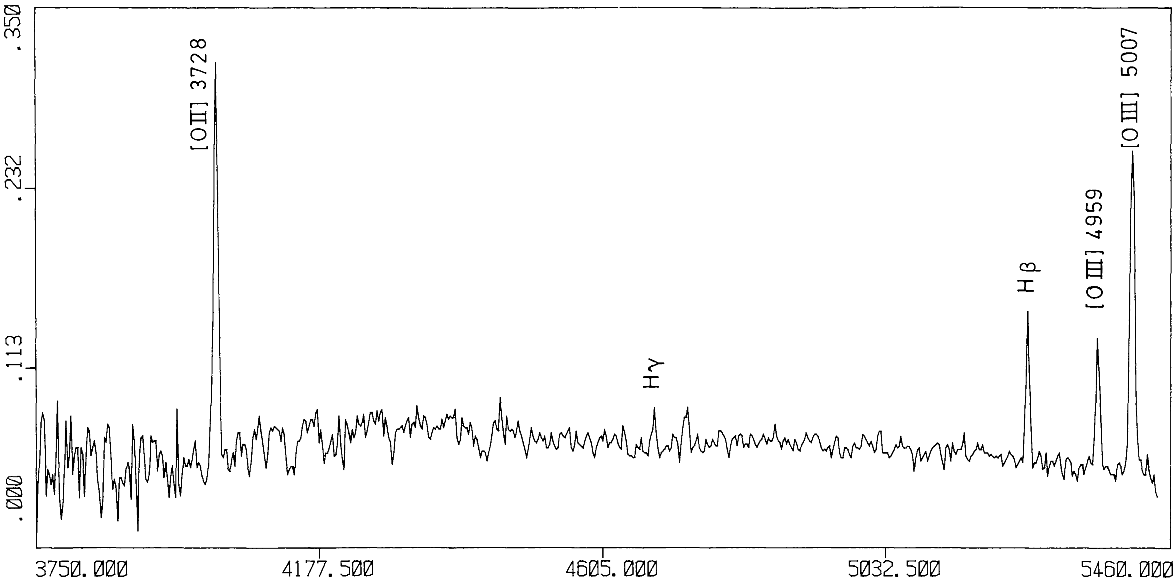

Fig. 1. Total spectrum of PHL 6657–6658. Arbitrary units in ordinate

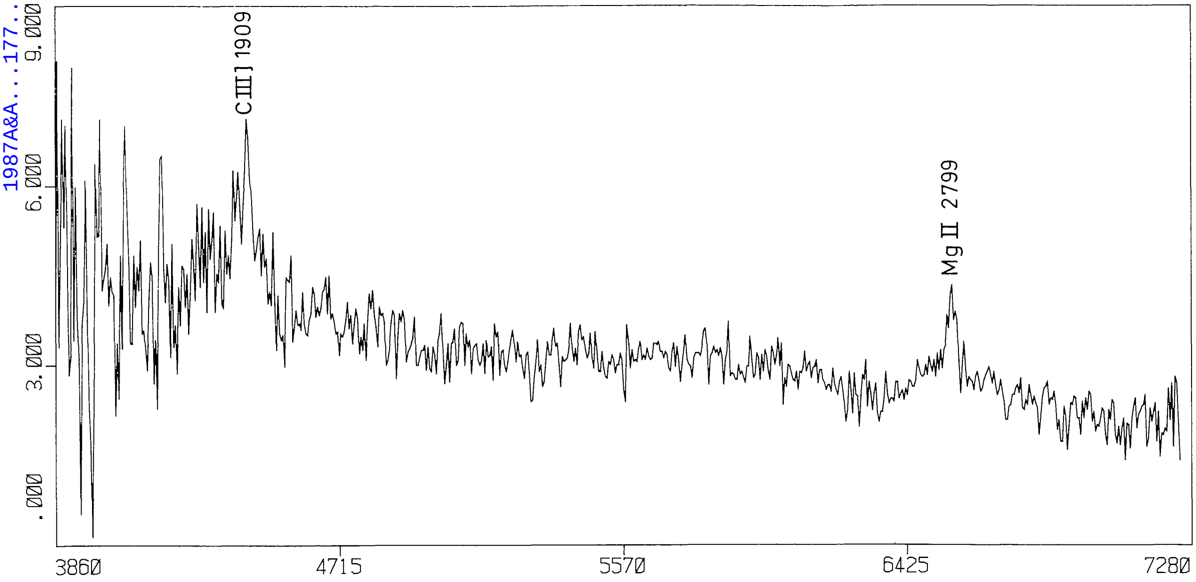

Fig. 2. Spectrum of P.B. 7348 (Bright Southern component). Units in ordinate are 10^{-19} W m^{-2} Å^{-1} but the calibration is very poor

2.4. P.B. 5062

This object is again a mixed pair from the Berger-Fringant catalogue (1980) where it is described as a 17.5 class II object with a faint companion (colour G, magnitude 19", 3 southward).

A 60 minutes exposure has been made with the same equipment than for P.H.L. 6657–58. The spectrum of P.B. 5062 (Fig. 3) shows a broad emission feature. The most likely identification is C IV 1549 at a redshift of 1.77 which would affect to this quasar an absolute magnitude $M_B \sim -28.5$.

The companion is found at a distance of about 5".5 and exhibit the spectrum of a G-type subdwarf star. It is the only proved optical pair among the 15 we have investigated.

3. Discussion

Those preliminary observations could seem disappointing, because no new gravitational mirage has been found, but they are not in disagreement with the a priori expectations of our program.

The complete list of the 15 investigated candidates is given elsewhere (Reboul et al., 1986). The statistical properties of this observed sample are summarized in Table 1, which deserves some comments:

(1) The mean values of separation, magnitude of the brightest component and difference of magnitudes are:

$$\langle\theta\rangle = 4''.9\,, \quad \langle B_1\rangle = 17.5\,, \quad \langle B_2 - B_1\rangle = 0.9$$

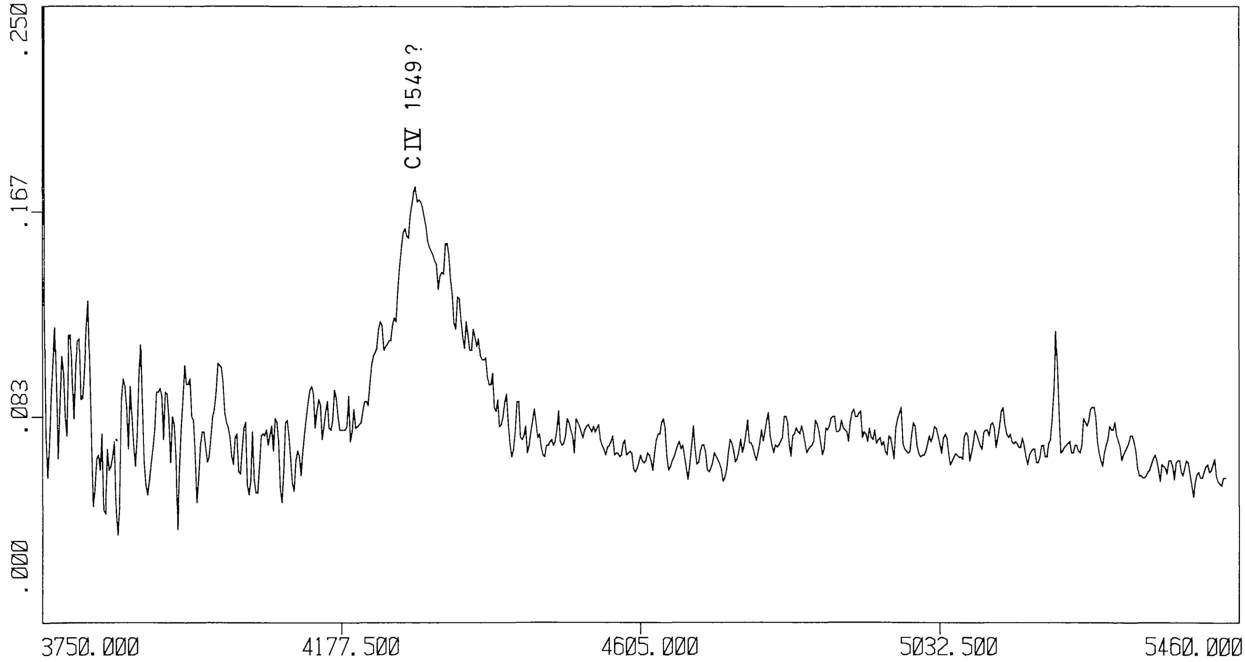

Fig. 3. Spectrum of P.B. 5062 (Bright Northern component). Arbitrary units in ordinate

Table 1. Statistics of observed pairs. N_0 is the number of observed pairs for each class. N_{B-B} restricts to pairs of blue objects (classes I, II or III). N_{SC} further restricts to pairs of separately catalogued blue objects. By "Nature of the components" we mean "nature of at least the brightest component" but see point 2 of the discussion. A star locates the optical pair (P.B. 5062)

Nature of the components		N_0		N_{B-B}		N_{SC}	
Galactic	White dwarf	8	3	8	3	5	3
	Halo star		5		5		2
Extragalactic	H II	7	1	4	1	2	1
	AGN		4		3		1
	QSO		2*		0		0
Character of the pair							
Proved physical		5		5		5	
Proved optical		1*		0		0	

(2) Unless direct observational evidence of the contrary, the 2 components of a physical pair are very likely to belong to the same class, because of the small differences of apparent magnitude between components and of the large differences in magnitude between classes. In other words, the companion of a detected white dwarf has the absolute magnitude of a white dwarf, and the companion of a detected quasar has the absolute magnitude of a quasar. In only one case (P.B. 3424–3425), the spectrum of the companion of a stellar object has been obtained. The association turned to be a physical pair of hot white dwarfs with a separation of 2.″75 (the projected linear separation could be in the range 1 or a few 100 AU).

(3) The proportion of extragalactic objects is comforting: the selection of presumed physical pairs among a general population of faint blue objects was able to catch preferably binary stars if binary blue stars were much more common than binary blue extragalactic objects. We note that our proportion ($\sim$40%) is essentially comparable with that of unpaired UVX objects (see e.g. Zotov, 1985). A first-but approximate-result of these observations is then that extragalactic and galactic objects have similar tendencies for pairing (in the range of magnitudes and separations defined in the point 1 of this discussion).

(4) Among the extragalactic objects, a high proportion – if not the totality – is AGNs, quasars or H II regions. 4 extragalactic systems are proved physical, with projected separations such that gravitational interactions would be important. This may raise hope to find really double quasars or pairs of "interactivating" AGNs (Reboul et al., 1986).

(5) Among the galactic pairs, the white dwarfs are less numerous than we thought. The main galactic contamination comes from halo stars. The interest for the stellar by-products was known previously to the observations. Pairs of halo stars or white dwarfs may increase our knowledge of these objects.

It would thus be interesting to observe also the second component of these pairs, "neglected" up to now.

(6) Even the optical pairs found in the survey may be interesting: pairs of quasars at different redshifts can be used for the study of absorbing regions (Shaver and Robertson, 1983).

(7) Finally, recent works suggest that gravitational mirages can also be found at separations larger than our selection limit (Surdej et al., 1983; Vilenkin, 1984, Turner et al., 1986). The reinterpretation of the proposed candidates in terms of real pairs of distinct quasars in the same cluster (Surdej et al., 1986, Shaver and Christiani 1986) provides us with a new class of nevertheless interesting objects, justifying by themselves a broader systematic search.

4. Conclusions

The reported preliminary results are an encouragement for carrying out our observational program of 62 mirage candidates, even if none was found among the 15 observed pairs.

The poor available observational data allow to precise the products that may be expected from that observation of close pairs of faint blue objects at high galactic latitude: one half of our sample is probably formed with binary halo stars or white dwarfs. The 40% of extragalactic pairs are preferently H II regions, interacting galaxies, AGNs (including quasars)... or mirages. The 10% of optical pairs may include pairs of quasars.

The scarcity of gravitational mirages is common to all presently known methods of systematic search. Our procedure compensates this drawback by the high interest of quite all its by-products. These by-products remain interesting even at larger angular separations ($\sim 1'$), where the probability of physical pairing in the catalogues we use is still high.

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References

Berger, J., Fringant, A.M.: 1977, *Astron. Astrophys. Suppl.* **28**, 123

Berger, J., Fringant, A.M.: 1980, **39**, 39

Berger, J., Fringant, A.M.: 1984, **58**, 565

Berger, J., Fringant, A.M.: 1985, **61**, 191

Fringant, A.M., Reboul, H., Vanderriest, C.: 1983, *Proc. 24th Liège Int. Astrophys. Coll.* Université de Liège, p. 155

Haro, G., Luyten, W.J.: 1962, *Bol. Obs. Tonantzintlay Tacubaya* **22**, 37

Lawrence, C.R., Schneider, D.P., Schmidt, M., Bennett, C.L., Hewitt, J.N., Burke, B.F., Turner, E.L., Gum, J.F.: 1984, *Science* **223**, 46

Luyten, W.J.: 1967–1968, A search for faint blue stars, Minneapolis, Univ. of Minnesota

Reboul, H., Fringant, A.M., Vanderriest, C.: 1986, in *Quasars*, Proc. IAU Symp. **119**, Bangalore, Reidel, Dordrecht, p. 547

Richter, N: 1965, 1966, 1967, 1968, *Mitt. Obs. Tautenburg* Nr 24, 25, 31, 38

Shaver, P.A., Chen, J.S.: 1985, *Astron. Astrophys.* **148**, 443

Shaver, P.A., Cristiani, S.: 1986, (preprint)

Surdej, J., Swings, J.P., Henry, A., Arp, H., Kruszewski, A., Pedersen, H.: 1983, in *Quasars and Gravitational Lenses*, 24th Liège Int. Astrophys. Coll., Institut d'Astrophysique, Liège, p. 355

Surdej, J., Arp, H., Gosset, E., Kruszewski, A., Robertson, J.G., Shaver, P.A., Swings, J.P.: 1986, *Astron. Astrophys.* (in press)

Turner, E.L., Schneider, D.P., Burke, B.F., Hewitt, J.N., Langston, G.I., Gunn, J.E., Lawrence, C.R., Schmidt, M.: 1986, *Nature* **321**, 142
Usher, P.D.,: 1981, *Astrophys. J. Suppl.* **46**, 117
Usher, P.D., Mattson, D., Warnock, III A.: 1982a, *Astrophys. J. Suppl.* **48**, 51
Usher, P.D., Mitchell, K.J.: 1982b, *Astrophys. J. Suppl.* **49**, 27
Vanderriest, C.: 1985, *Lecture Notes* Phys **212**, 265
Véron-Cetty, M.P., Véron, P.: 1985, ESO Scientific Report N° 4
Vilenkin, A.: 1984, *Astrophys. J.* **282**, L51
Zotov, N.: 1985, *Astrophys. J.* **295**, 94