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Letter to the Editor

First spectroscopic evidence of microlensing on a BAL quasar? The case of H 1413+117 *

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Abstract:

We have obtained, under optimal seeing conditions ($\simeq$ 0.6" FWHM), new data for the quadruply lensed quasar *H* 1413 + 117 using the bidimensional spectrograph SILFID at the C.F.H. telescope. The spectra recorded for each of the four individual images turn out to be quite similar, except for the narrow absorption line systems (probably related to the lenses) seen in images A and B and for marked differences in the spectrum of image D. When compared to the 3 other images, the spectrum of D shows smaller values for the emission lines/continuum ratio and a larger equivalent width for absorption features located in the blueshifted P Cygni profile.

We discuss briefly the possible explanations of these observations in terms of micro-lensing and/or intrinsic variability of the source.

Key-words:
Quasars (*H* 1413 + 117), gravitation, observational methods, spectroscopy.

1. Introduction:

The BAL quasar *H* 1413 + 117 has been resolved at optical wavelengths in 4 images having comparable brightness and forming a tight, nearly square, configuration (hence the nickname "clover leaf"). The great similarity existing between the spectra of the 2 most separated images (B, C) and the global spectrum strongly suggested that it is a new case of gravitational lensing (Magain et al., 1988) . However, the compactness of the "clover leaf" has precluded to obtain until now uncontaminated spectra of the 4 images.

We tried to resolve this problem with the help of the bidimensional spectrograph SILFID (Vanderriest et al., 1987; Vanderriest and Lemonnier, 1988) at the Cassegrain focus of the Canada-France-Hawaii telescope. The aim of this letter is to present and discuss the data obtained under optimal seeing conditions with this instrumentation.

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(*) Based on observations made at the Canada-France-Hawaii telescope (Hawaii).

2. Observations:

With SILFID, transforming the 2 spatial dimensions of the focal image of the telescope into a single one (the slit of the spectrograph) is achieved by means of a short fibre optics device: in the focal plane, about 400 fibres are closely packed into an hexagonal array and, at the other end of the device, they are just set in line to form a pseudo "slit". Following the dispersion, we may apply the exactly inverse geometrical transformation in order to reconstruct crude pictures of the object at any chosen wavelength.

Our spectra were obtained on 7 March 1989 during a period of strong wind, but very good seeing. Just in front of the fibre device, a small lens extended the focal length of the telescope so that each 100μm diameter fibre subtended 0.33 arcsec on the sky. The scale is 60μm per fibre on the detector (a Ford CCD with $(512)^2$ pixels of 20μm).

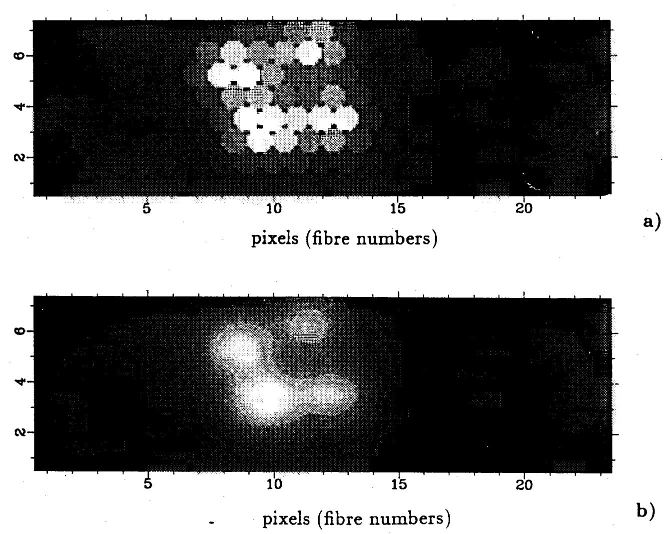

Figure 1:
The field of *H* 1413 + 117 reconstructed from bidimensional spectroscopic data (30 min. exposure at 235 Å/mm).
-*a)* Direct reconstruction in the wavelength range 4800 - 6600 Å showing the fibre array.
-*b)* The same picture smoothed with a gaussian filter (FWHM $\simeq$ 0.15").

Fig. 1*a* displays a reconstructed picture in the wavelength range $\simeq$ 4800 – 6600 Å and shows how the fibres were lightened by the object in the focal plane of the telescope. As the size of the CCD did not allow to cover the whole slit length, only about 1/3 of the initial hexagonal field could be reconstructed (160 useful fibres). We see that, even at 0.33" per fibre, the spatial sampling is still too coarse. On the smoothed picture (fig. 1*b*), the average size of the images is about 0.6" (FWHM), corresponding to an initial seeing of the order of 0.5".

Analysing the reconstructed picture, we could select those fibres whose data can be safely added for obtaining the spectra of each of the 4 images A, B, C and D with a minimum of contamination (<10%). This led to disregard many fibres fed with "mixed" light from 2 or more images. The possibility of such an *a posteriori* choice provides the best S/N ratio for a given seeing. Fig. 2 displays the spectra obtained in this way from the sum of two 30 min. exposures at 235 Å/mm. The spectrophotometric standard Feige 67 (Massey et al., 1988), observed in the same conditions with SILFID, provided the flux calibration. Multiplying by a V filter response, one find a global magnitude for the system of 4 images: V = 17.10 $\pm$ 0.05.

3. Results:

First of all, we see that the overall shapes of the spectra extracted for each single image are very similar to each other, strengthening the gravitational lensing interpretation for the clover-leaf. The narrow absorption lines, already recognized by Magain et al. (1988) as belonging to two systems at redshifts 1.438 and 1.661, are seen with different intensities in the 4 spectra. Within the limit of accuracy fixed by the data noise, they are absent in image C and hardly significant in D. If we interpret these absorptions as arising in two lensing galaxies, our present data may help in locating these with respect to the 4 images. But direct imaging of the lenses would certainly be more secure.

In hope of detecting the deflectors, we tried to take advantage of the deep C IV absorption trough that reduces the intensity of the quasar almost to zero near 5400 Å. We have thus reconstructed an image within a 32 Å bandwidth around this wavelength but could set only an upper limit to the flux of the deflector corresponding to V $\geq$ 23.5. This is not a very stringent constraint since at z $\simeq$ 1.5, the deflectors could be 1 or 2 magnitudes fainter than this limit, their masses being of the order of $10^{11} M_{\odot}$ (Magain et al., 1988; Kayser et al., 1989).

Another major spectral difference between the four images may be noticed after inspection of Fig. 2. Indeed, with respect to images A, B and C, the continuum of D is found to be marginally bluer and its ratio to the emission line fluxes is greater. Moreover, specific absorption features in the BAL line profiles appear to be significantly stronger in image D than in the three other images (see the arrows in Fig. 2). One of these features corresponds certainly to the C IV absorption component located at about -8500 km/s from the center of the emission line and reported to be possibly variable, in the integrated spectrum of *H* 1413 + 117 over a 4-year period, by Turnshek et al. (1988). This absorption feature is also seen at the same relative velocity in the Si IV and Al III 1857 Å P Cygni profiles.

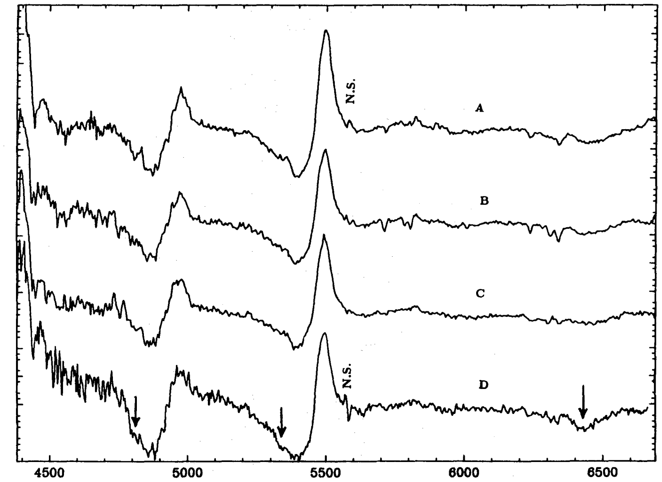

Figure 2:
Spectra of the 4 images extracted from the low dispersion data (sum of two 30 min. exposures, 235 Å/mm, resolution $\simeq$ 12 Å). The vertical scale has been shifted for clarity between each spectrum. N.S. stands for poor Night Sky line subtraction. Note the differences in the structure of the BAL troughs for image D (arrows).

4. Discussion:

There are at least two obvious ways to account for these observed spectral differences.

-a) If real, the difference in the slope of the continuum of D suggests a possible intrinsic variation of the source. The spectral difference observed in the BAL trough between images D and A, B, C could also be explained this way. The equivalent widths of similar features (Al III 1857 Å and high velocity components due to Si IV and C IV) have also been found to be variable in another BAL quasar, UM 232 (Barlow et al.,1989), in apparent correlation with the ionizing flux of the central source. In such a scenario, the characteristics observed for D should be exactly reproduced in the spectra of the other images, with shifts in time characterizing the geometry and mass distribution of the lensing system. For *H* 1413 + 117, these time delays are expected to be of the order of a few days or weeks, but their exact values and even their signs are very much model dependent (see Kayser et al., 1989).

The flux of image D seems to be indeed variable. Kayser et al. (1990) have reported a fading of D, with respect to the other images, of $\simeq$ 0.15 mag between their observations and those of Magain et al. (1988), recorded 6 weeks earlier. Prior to the bidimensional spectroscopy described above, we also took a 5 min. direct R CCD frame of *H* 1413 + 117 on the night of 7 march 1989. This CCD frame is essentially of good quality and it was straightforward to fit, in the least squares sense, the observed images of the clover leaf system using a four-component Moffat star profile. Fortunately, we could make use of a nearby and well exposed star image in order to determine the three unknown parameters of the single Moffat PSF. Furthermore, the finite size of the pixels was taken into account in the present fitting procedure (Remy and Magain, in preparation).

Table 1: Photometric data:
Intensity ratios of the B, C and D images relative to A. The 08/03/1988 and 07/03/1989 data have been obtained in the R band; the values taken on 27/04/1988 refer to the average of 3 colours B, R and I.

image :	08/03/1988 (*Magain et al.*)	27/04/1988 (*Kayser et al.*)	07/03/1989 (*this work*)
B	0.87	0.87	0.88 ± 0.02
C	0.76	0.77	0.78 ± 0.02
D	0.69	0.60	0.66 ± 0.02

The derived flux ratios for images B, C and D with respect to A are reported in Table 1 and may be compared with previous determinations. The flux level observed for D on 7 march 1989 appears to lie between the two previous measurements by Magain et al. (1988) and Kayser et al. (1990).

In any case, these observed variations seem to be too small for inducing appreciable changes in the ionization level of the BAL clouds.

-b) As already suggested by Kayser et al. (1990) on the sole basis of photometric variations, it is more likely that micro-lensing effects do exist in image D. We suggest that they could be responsible for the observed departures from the spectra of the other images. Knowing that micro-lensing effects are highly dependent on the source's size (see e.g. Kayser et al., 1986), we understand easily that if a star or group of stars, located in one of the lensing galaxies, come in front of the QSO's nucleus, it will lead to a significant magnification of the quasi-stellar continuum without (almost) affecting the broad spectral emission lines formed in the much larger BEL region. This now "classical" effect (see e.g. Rees, 1981) is suspected to be at work in several gravitational lenses and provides a straightforward explanation for the different equivalent widths of similar BELs observed in the spectra of the four lensed images of $H\,1413+117$ (cf. Fig. 2). The same explanation holds for the BALs: if the continuum source is being "resolved" by the microlens and if the BAL region is highly inhomogeneous on such scales, the star will then preferentially magnify one of the BAL components that happens to occult only a part of the continuum core.

Let R_c be the angular critical radius of the microlens. This represents also the typical length of the microlensing magnification gradient. An observable differential effect will take place if two conditions are fulfilled:

-(1) $\quad d_{cont} \not\ll R_c$

-(2) $\quad d_{abs} < d_{cont}$

where d_{cont} is the diameter of the continuum source and d_{abs} the equivalent diameter of the part heavily absorbed by the BAL clouds at the considered wavelength.

For a star of 1 $M_\odot$ in the lensing galaxy (supposed to be at z $\simeq$ 1.5), R_c is found to be about 3.10^{-2} pc at the distance of the source. According to the different models, the order of magnitude of d_{cont} is only roughly estimated, from a few 10^{-3} pc to about 1 pc (see for instance Drew and Giddings, 1982), so that inequality (1) is more or less fulfilled; on the other hand, the diameter of the absorbing clouds is not believed to be much larger than d_{cont}, making easy to also fulfill (2) in a random projection of such clouds over the continuum core.

A good way of testing the likelihood of the differential absorption mechanism due to microlensing is to investigate whether the spectrum of image D may be reproduced by a straightforward combination of both a macro-lensing and micro-lensing contributions. In order to check this, we built a "synthetic" spectrum $F_S(\lambda)$ (with S equal to the sum A+B+C cleared of the narrow absorption lines) and, neglecting completely microlensing for the emission lines, we can represent the spectrum $F_D(\lambda)$ of D by:

$$F_D(\lambda) = k\,F_S(\lambda) + k'\,I_c(\lambda)\,R(\lambda)\,e^{-\tau'(\lambda)} \qquad (3)$$

where k (resp. k') is a constant representing an effective amplification of image D due to macro-lensing (resp. micro-lensing), $I_c(\lambda)$ is the underlying QSO continuum observed in spectrum S, $R(\lambda)$ is a wavelength dependent factor correcting for the possibly different shape of the continuum spectrum emitted by the region of the QSO which is magnified by the micro-lens and $\tau'(\lambda)$ is the opacity of this particular region as a function of wavelength. Similarly, we assume that the spectrum of S may be described by the following expression:

$$F_S(\lambda) = I_c(\lambda)\,e^{-\tau(\lambda)} + E(\lambda) \qquad (4)$$

where $\tau(\lambda)$ stands for the opacity, at wavelength λ, of the expanding envelope projected against the whole QSO core along the line-of-sight and where $E(\lambda)$ is the profile of the emission line component. Fitting the spectra of D and S by means of Eqs. (3) and (4) leads to the following best parameter estimates: k = 0.15, k' = 0.07 and $R(\lambda)$ is found to be an almost linear function of λ such that R(5500) = 1 and R(4500) = 2.1. Such values correspond to a moderate differential magnification: with respect to the macro-lensing contribution, it is as if micro-lensing brightens the QSO continuum of D by $\simeq$ 0.4 mag. The resulting attenuation factor $e^{-\tau'(\lambda)}$ derived from this spectral decomposition is illustrated in Fig. 3. For comparison, we have also plotted in this figure the profile $F_S(\lambda)/I_c(\lambda)$. Referring to the absorption line profiles in Fig. 3, we see that at least three discrete absorption components located at about $-3\,870$ (C IV and Si IV), $-7\,750$ (C IV, Si IV and Al III) and $-12\,330$ km/s (just C IV) from the center of their corresponding emission line have been enhanced by micro-lensing effects in the spectrum of image D. More details about these observations and the spectral decomposition will be published elsewhere.

So, the hypothesis of differential microlensing is a viable interpretation of the observed spectral differences between the faintest and the three other lensed images of $H\,1413+117$. However, a definite proof is yet to be found. In broad band photometry, image D should display a light curve characteristic of micro-lensing events. We may also predict that the continuum of image D shoud be differently (probably more) polarized than that of the other three images. An even better proof would be to detect spectral variability in the BAL troughs, reflecting the star(s) motion in front of the BAL clouds. It is quite possible that Turnshek et al. (1988) have witnessed such an event between 1981 and 1985, even if centering of the 4 images (not yet resolved at that time) in the spectrograph slit can also be partly incriminated. We may of course predict that the enhancement of the blue component(s) should not last during the whole transit of the lensing star(s); at some phase, it should be replaced by a weakening.

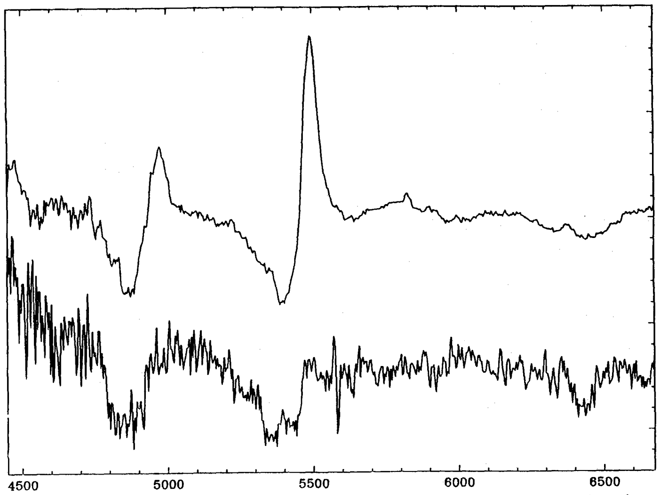

Figure 3:
Because of micro-lensing effects, the attenuation factor $e^{-\tau'(\lambda)}$, calculated by means of Eqs. (3) and (4), accounts for the additional absorption components seen in the P Cygni profiles of image D. It is represented here as a function of λ. We have also illustrated in this figure the profile $F_S(\lambda)/I_c$ whose blue wing gives a good representation of the attenuation factor $e^{-\tau(\lambda)}$ (cf. Eq(4)).

5. Conclusions:

Our bidimensional spectroscopic data strengthen the interpretation of $H\,1413+117$ as a gravitational mirage. The differences observed in the spectrum of image D are either due to intrinsic variations of the source, or to a differential microlensing effect operating on the BAL clouds. We personally favour this second interpretation. In this context, it is therefore quite possible that the spectroscopic variations reported in the integrated image of $H\,1413+117$ by Turnshek et al. (1988) are not intrinsic to the BAL quasar but caused by a mirage effect. Spectroscopic monitoring of the 4 images will help in discriminating between these various possible scenarios.

Detailed modeling of this gravitational lens system was of course beyond the scope of the present letter; it would even be premature to do so considering the paucity of the relevant data (cf. the still unknown precise location(s) and type of the lenses, etc.). We just wished to present here new high angular resolution spectroscopic observations of the clover leaf and to attract the attention of potential observers on the interest and importance of getting further bidimensional spectroscopy of this object, with comparable or better spectral and spatial resolutions.

$H\,1413+117$ has an unprecedented status, being at the same time a BAL quasar and a gravitational mirage. While it is believed that gravitational mirages of "normal" QSOs could help to improve our knowledge on their structure, we bet that the clover leaf will turn out to be a unique tool in order to better understand the BAL phenomenon itself.

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