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ASTRONOMY AND ASTROPHYSICS

CLASS B0827+525: ‘Dark lens’ or binary radio-loud quasar?

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Abstract. We present radio, optical, near-infrared and spectroscopic observations of the source B0827+525. We consider this source as the best candidate from the *Cosmic Lens All-Sky Survey* (CLASS) for a ‘dark lens’ system or binary radio-loud quasar. The system consists of two radio components with somewhat different spectral indices, separated by 2.815 arcsec. VLBA observations show that each component has substructure on a scale of a few mas. A deep *K*–band exposure with the W.M. Keck–II Telescope reveals emission near both radio components. The *K*–band emission of the weaker radio component appears extended, whereas the emission from the brighter radio component is consistent with a point source. *Hubble Space Telescope F160W*–band observations with the NICMOS instrument confirms this. A redshift of 2.064 is found for the brighter component, using the LRIS instrument on the W.M. Keck–II Telescope. The probability that B0827+525 consists of two unrelated compact flat-spectrum radio sources is ∼3%, although the presence of similar substructure in both component might reduce this.

We discuss two scenarios to explain this system: (i) CLASS B0827+525 is a ‘dark lens’ system or (ii) B0827+525 is a binary radio-loud quasar. B0827+525 has met *all* criteria that thus far have in 100% of the cases confirmed a source as an indisputable gravitational lens system. Despite this, no lens galaxy has been detected with $m_{\rm F160W} \leq 23$ mag. Hence, we might have found the first binary radio-loud quasar. At this moment, however, we feel that the ‘dark lens’ hypothesis cannot yet be fully excluded.

Key words: Cosmology: gravitational lensing – Cosmology: dark matter – quasars: individual: B0827+525

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1. Introduction

There are several indirect ways to detect the presence of dark matter in galaxies at relatively low redshifts (e.g. microlensing, rotation curves of spiral galaxies, polar-ring galaxies, etc.). However, at intermediate and high redshifts, weak and strong gravitational lensing is the only method of detecting the presence of dark matter on galaxy scales.

Gravitational lensing does not depend on the luminosity or color of the lensing mass distribution. One can therefore expect to find ‘dark-lens’ galaxies in large gravitational-lens surveys, *if* they make up a significant fraction of massive galaxies (e.g. Hawkins 1997). On the basis of confirmed and candidate large-separation ($\gtrsim$3 arcsec) gravitational-lens systems, which were all optically selected, Hawkins (1997) concludes that around 75% of all galaxies could be ‘dark’ (i.e. extremely underluminous). This high fraction was shown to be inconsistent with observational results (Jackson et al. 1998) from the *Cosmic Lens All-Sky Survey* (CLASS; Browne et al. 1999; Myers et al. 1999) and also very unlikely on the basis of a number of statistical arguments (e.g. Kochanek, Falco & Muñoz 1999; Peng et al. 1999). A very high fraction of dark galaxies therefore seems to be excluded, although a much smaller fraction ($\leq$10%) cannot yet be ruled out. The detection of only a single dark-lens galaxy would already have severe consequences for the standard picture of galaxy formation (e.g. White & Rees 1978). Such systems would have allowed dark matter to collapse in structures massive enough to create multiple images through gravitational lensing, but at the same time prohibit baryonic matter to settle in the dark-matter halo and initiate star formation. Clearly, one has to be careful in dismissing any candidate dark-lens galaxy as being either a binary quasar or a chance alignment of unrelated quasars or AGNs, although undoubtedly for the majority of candidates this will be the case.

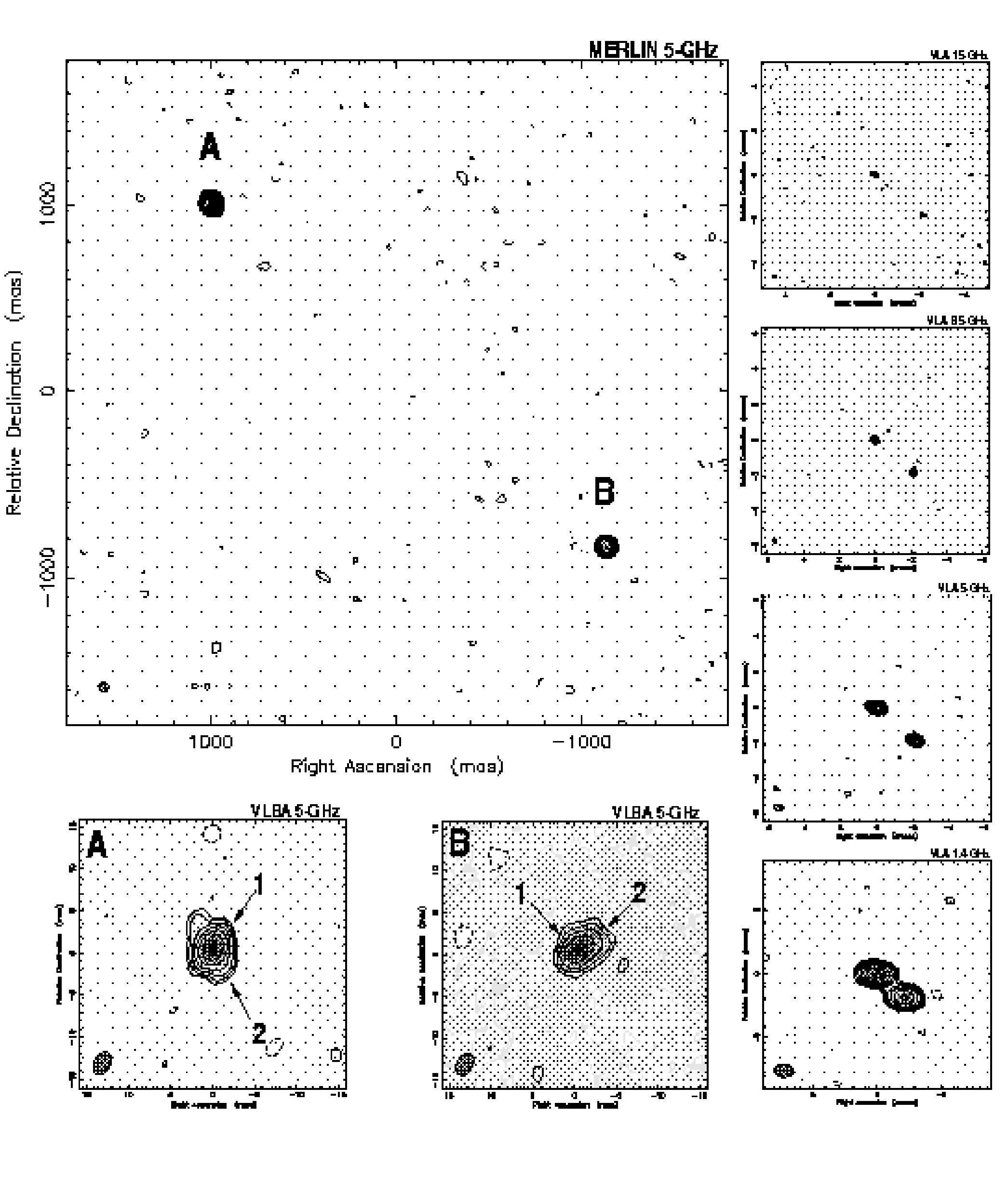

Fig. 1. Summary of the VLA, MERLIN and VLBA radio images of B0827+525 (see text for more details). Contours start at the 3–σ level and increase by factors of 2. The first contours are 0.19 mJy beam^{-1}, 0.37 mJy beam^{-1}, 0.37 mJy beam^{-1}, 1.15 mJy beam^{-1}, 0.88 mJy beam^{-1}, 0.40 mJy beam^{-1}, 0.77 mJy beam^{-1}, for the MERLIN 5–GHz, VLBA 5–GHz (A), VLBA 5–GHz (B), VLA 15–GHz, 8.5–GHz (discovery image), 5–GHZ and 1.4–GHz images, respectively

In this paper, we present the strongest ‘dark-lens’ candidate found in the CLASS survey: CLASS B0827+525[1]. In Section 2, we present radio, optical, near-infrared and spectroscopic observations of this system. In Section 3, we derive constraints on the lens-galaxy mass-to-light ratio and compare those with observations of ‘luminous-lens’ galaxies. In Section 4, we summarize our results and suggest future work on this system.

2. Observations

The CLASS survey aims to find all multiply-imaged flat-spectrum ($\alpha \leq 0.5$ for $S_\nu \propto \nu^{-\alpha}$) radio sources in the northern hemisphere with a total flux density of $S_{\rm 5GHz} \geq 30$ mJy, a flux-density ratio between lens images ≤ 10, a Galactic latitude $|b| > 10^\circ$ and a component separation ≥ 0.3 arc-

[1] Not to be confused with the gravitational-lens system APM 08279+5255 (Irwin et al. 1998).

sec. The scientific goal of the survey is to create a sample of GL systems, that can be used to study the structure and evolution of lens galaxies at intermediate redshifts *and* constrain the cosmological parameters, in particular the Hubble parameter (H_0). At present CLASS has discovered at least 17 new GL systems (Browne et al. 1999; Myers et al. 1999).

2.1. Radio observations

If not specified otherwise, the radio data presented in this section are flux-calibrated in the NRAO data-reduction package AIPS and self-calibrated, imaged and model-fitted in DIFMAP (Shepherd 1997). To obtain flux-densities of the two radio components of B0827+525, the uv-data was fitted by typically two Gaussian components.

As part of the CLASS sample of around 15 200 flat-spectrum radio sources observed during the 1994, 1995 and 1998 *Very-Large-Array* (VLA) A–array seasons (Myers et al. 1999), a 30–sec snapshot of B0827+525 was made at 8.5 GHz on 1995 August 13. The calibrated VLA image (Fig.1) shows two unresolved components that are separated by 2.8 arcsec and have a flux-density ratio of 2.7 [i.e. $S_{\rm A}{\approx}24$ mJy and $S_{\rm B}{\approx}9$ mJy].

With an average source density in the CLASS survey of ≈1 per sq. deg, the probability of chance alignment of two unrelated compact radio-loud quasars within ≤2.8 arcsec is around $2{\cdot}10^{-6}$, whereas the lensing rate is around 10^{-3}. In a sample of 15 200 sources the occurrence of such a close alignment has a probability of only 3%. B0827+525 was therefore regarded as a candidate GL system.

To improve the resolution and obtain a two-point spectral index between the radio components, a snapshot image of B0827+525 was made on 1997 January 3 with the *Multi-Element Radio Linked Interferometer Network* (MERLIN) at 5 GHz. A flux-density ratio of 2.5 was found [i.e. $S_{\rm A}{\approx}34$ mJy and $S_{\rm B}{\approx}14$ mJy] and a component separation of 2.8 arcsec, very similar to the VLA 8.5–GHz observations. Subsequent long-track MERLIN 5–GHz observations were made on 1997 December 8, with a total integration time on the source of ≈10 hours. The calibrated image (Fig.1) has an rms-noise level of 60 μJy beam^{-1} and a resolution of ≈50 mas. Both components remain unresolved. The flux-densities are $S_{\rm A}{\approx}34.0$ mJy and $S_{\rm B}{\approx}14.8$ mJy, respectively. No sign of extended emission is detected in the image above a level of 0.6%. The similarity in flux-density ratio at 8.5 and 5 GHz strengthened the case for a lensing explanation of this system.

To improve the resolution by another order of magnitude, B0827+525 was observed with the *Very-Long-Baseline-Array* (VLBA) at 5 GHz on 1997 August 2. Snapshots were obtained over a range of hour angles to improve the uv-coverage. Phase referencing was done by rapid switching between the nearby strong calibrator B0828+493 (2 min) and B0827+525 (5–7 min). The total integration time on B0827+525 was 35 min. The final calibrated image (Fig.1) has a resolution of 2.5 mas and an rms-noise level of 0.1 mJy beam^{-1}. The two radio components were each modeled by two Gaussian subcomponents. Component A shows a NE–SW extension, whereas component B shows an area of weak extended emission in the NW–direction. The low SNRs of the NE–component in image A and the NW–extension of image B does not warrant modeling them by more than two subcomponents. The positions of the best-fit Gaussians and their respective flux densities are listed in Table 1.

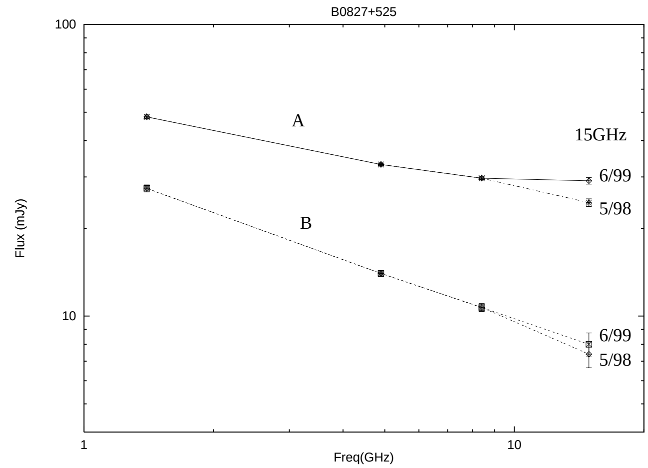

Fig. 2. Radio spectra of B0827+525 A and B, determined with the VLA in A–array at 1.4, 4.9, 8.5 and 14.9 GHz on 1999 June 27

Both radio components show fairly flat spectra from 4.9 to 8.5 GHz. The integrated flux density of B0827+525 (A+B) in the WENSS survey, (70±5 mJy at 325 MHz, mean epoch 1992.2), is about equal to the flux density at 1.4 GHz in the NVSS, FIRST and WSRT observations taken in the summer of 1997. This suggests that the individual component spectra must flatten to a spectral index of zero below 1.4 GHz. Alternatively, one of the component spectra could become inverted leaving room for the other to remain straight. High resolution low frequency data are needed to distinguish between these possibilities.

A 2–month monitoring campaign (8 epochs) with the WSRT at 1.4 GHz (with 15–arcsec resolution) in the period July-September 1997 indicates variability in the total flux density: the source flux density slowly decreased from 71 to 58 mJy with a typical error of about 1 mJy in individual measurements. It is not clear to which component these variations should be attributed. The variation time scale is rather short even though both components are compact. It is perhaps more likely that the 1.4–GHz variations are due to refractive interstellar scattering (RISS; e.g. Rickett et al. 1984), an explanation requiring a less extreme size for the components.

To examine the radio spectra of both components in more detail, near-simultaneous VLA 1.4, 4.9, 8.5 and 14.9–

	A1	A2	B1	B2
Δx (mas)	1064.02	1063.18	−1074.16	−1076.43
Δy (mas)	930.74	929.89	−900.40	−899.78
maj. (mas)	–	–	1.75	2.23
min/maj	–	–	0.65	0.55
θ (°)	–	–	-31.40	5.80
$S_{4.9}$ (mJy)	24.8±0.1	6.8±0.1	9.3±0.1	3.6±0.1

Table 1. VLBA 5–GHz data on B0827+525 (1997 Aug. 2) The VLBA phase-center was RA $08^{h}31^{m}5\overset{s}{.}36200$, DEC $52°25'20\overset{''}{.}24100$. Positions ($\Delta x$, Δy) are given with respect to to this phase-center. The 4.9–GHz flux-density ($S_{4.9}$) of the sub-components and their deconvolved major axis, axial ratio and position angle (N→E) are also given. The sub-components of component A are unresolved. The positional error is 2.5 mas divided by twice the SNR of the components. The errors on the major and minor axes of the subcomponents in B are roughly 25%

ν (GHz)	$S_{\rm A}$ (mJy)	$S_{\rm B}$ (mJy)
14.9	29.1±0.4	8.0±0.4
8.5	29.7±0.1	10.7±0.1
4.9	33.1±0.1	14.0±0.1
1.4	48.2±0.3	27.4±0.3

Table 2. VLA multi-frequency data on B0827+525, taken near-simultaneously on 1999 June 27. The internal errors are indicated.

GHz (L, C, X and U–band) observations in A–array were done on 1999 June 27 (Table 2). The radio spectra for both components are shown in Fig.2. Components A and B have fairly different radio spectra with spectral indices $\alpha^{8.5}_{1.4} = 0.27 \pm 0.01$ (A) and $\alpha^{8.5}_{1.4} = 0.52 \pm 0.01$ (B) (where $S_\nu \propto \nu^{-\alpha}$). Also variability in component A at 14.9 GHz was detected from the 1998 May 15 and 1999 June 27 VLA observations, which is more likely to be intrinsic and not RISS, because the rms variability due to RISS decreases rapidly towards higher frequencies (e.g. Rickett et al. 1995; Walker et al. 1998; see also Koopmans & de Bruyn 2000).

Variability at both lower (1.4 GHz) and higher (15 GHz) frequencies makes a direct comparison of the spectral indices difficult. The formal difference in spectral index does not disqualify the source as possible GL candidate, but complicates the argumentation in a ‘dark lens’ hypothesis. We will return to this issue in Sect.4.

2.2. Optical and near-infrared observations

Hubble Space Telescope (HST) observations were made on 1998 April 18 with the *Near-Infrared Camera and Multi-Object Spectrometer* (NICMOS) at 1.6 μm (F160W), roughly corresponding to ground-based *H*–band. The NIC1 camera was used which provides a detector scale of 43 mas pixel^{-1} and a field-of-view of $11'' \times 11''$. The total exposure time was 2624 sec. The data were subjected to the standard NICMOS calibration pipeline in IRAF[1] which (i) corrects for known instrumental effects (i.e. flat field and dark current), (ii) performs gain and flux calibration and (iii) removes cosmic rays and flags degraded and suspect data values[2]. The image was cut around B0827+525 and rotated to correct to standard orientation. The final calibrated image is shown in Fig.3 (middle). The primary northern component (A) is unresolved and clearly detected ($m_{\rm F160W}$=19.6±0.2 mag). Component B is just barely detected as a region of extended emission ($m_{\rm F160W}$=22.6±0.2 mag). No sign of a lensing galaxy is seen in the image to $m_{\rm F160W}$=23 mag, although the extended emission near image B could partly be from a possible lens galaxy. No optical correction (i.e. deconvolution) was applied to the image, because the PSF distortion[2] is not expected to change appreciably over the image separation of only 2.8 arcsec.

Similarly, B0827+525 was observed in *K*–band on 1998 May 9 with the *Near InfraRed Camera* (NIRC) at Keck. A total of 25 frames, each having a 60–sec integration time, were obtained of the field. The telescope was moved by approximately 10–15 arcsec between individual integrations. The seeing at the time of the observations was 0.6–0.75 arcsec (FWHM). The exposures were combined and rotated to correct the orientation and the resulting image is shown in Fig.3 (right). The observations confirm the conclusions drawn from the *HST* exposure, that image A is consistent with a point source and image B seems somewhat extended.

An *R*–band image was taken on 1998 May 19 on the WHT. Two 600-sec exposures were obtained with a seeing of 1.4–1.5 arcsec (FWHM). It was re-observed on 1998 May 20 with two exposures of 600–sec and one of 300–sec exposure, respectively. The seeing was around 1.0 arcsec (FWHM). All exposures were combined and reduced in the standard way in the data-reduction package IRAF. The resulting image (Fig.3, left) only show image A, whereas image B is not detected above the noise

[1] IRAF (Image Reduction and Analysis Facility) is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy under cooperative agreement with the National Science Foundation.

[2] A detailed description of the NICMOS calibration pipeline process, zero-point fluxes and PSF can be found in the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) handbook for Cycle 10, available at the STScI web page.

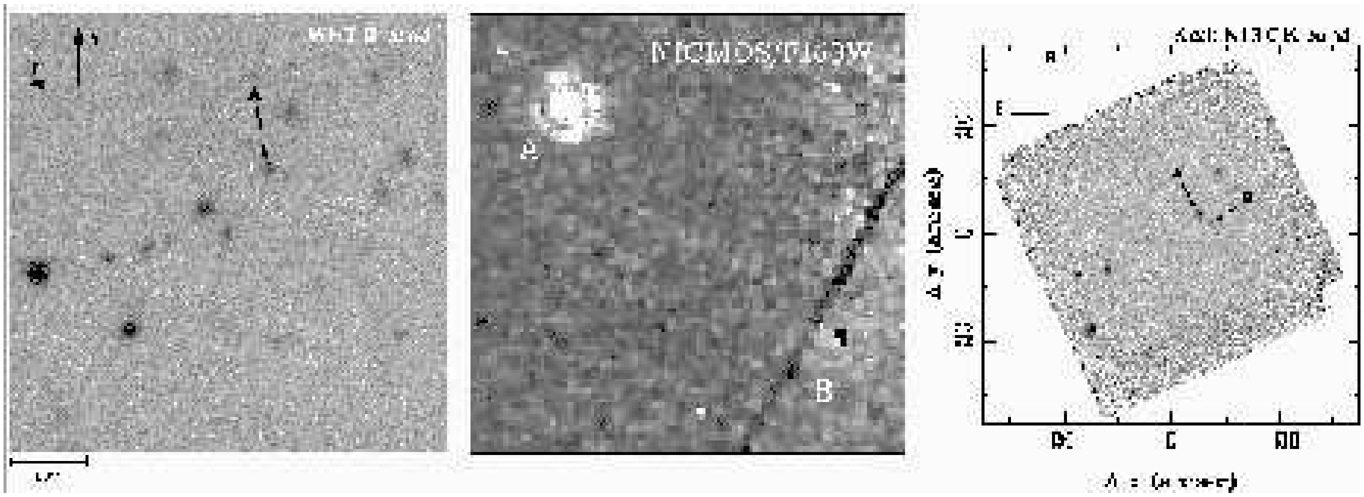

Fig. 3. Left: R–band image of B0827+525, observed 1998 May 19 with the WHT on La Palma. Middle: HST F160W NICMOS image of B0827+525, observed on 1998 April 18. The separation between components A and B is 2.8 arcsec. Right: NIRC K–band image of B0827+525, observed with the W.M Keck–II Telescope on 1998 May 9

level. Unfortunately no useful calibration was obtained, but based on the exposure time and expected noise-level, we roughly estimate for component A an apparent magnitude of $m_{\rm R}{\approx}22.0$–22.5 mag and for component B a lower limit $m_{\rm R}{\gtrsim}24.0$ mag.

2.3. Spectroscopic observations

B0827+525 was observed with the *Low Resolution Imaging Spectrograph* (LRIS; Oke et al. 1995) on the W. M. Keck II Telescope on the night of 1998 April 21. Three exposures were taken in longslit mode with a total exposure time of 4500 sec. The 300 grooves mm^{-1} grating was used, giving a dispersion of 2.44 Å per pixel. The slit was placed along both components, with a position angle of 50°. The final spectrum covers a wavelength range of 4024–9012 Å. The spectra were reduced using standard IRAF tasks. A correction for the response of the CCD was determined from observations of the Oke standard star BD332642 (Oke 1990). The corrected spectra were weighted by the squares of their SNRs and co-added to produce the final B0827+525 spectrum. Fig.4 shows the spectrum of component A, which has been smoothed using a boxcar kernel with a width of five pixels. Emission lines associated with Si-IV λ1397, C-IV λ1549, He-II λ1641, and possibly C-III] λ1909 are seen, establishing a source redshift of 2.064. No emission at the position of component B is detected. We also find no evidence in the spectrum of component A for a second redshift, possibly from a lens galaxy.

3. Analysis

Before proceeding with our analysis, let us summarize the most important observational results. We have found that B0827+525 consists of two radio components, separated by 2.8 arcsec. At least component A is variable, and both components have substructure at a scale of a few mas. The integrated radio spectra of both components from 1.4 to 14.9 GHz are somewhat different. The redshift for the brightest radio component (A) is 2.064. Optical counterparts for both radio components are found in H and K–band observations. The emission associated with the fainter radio component appears extended, which could suggest that it is very faint galaxy emission.

3.1. The ‘dark lens’ hypothesis

To compare the observed limits on the mass-to-light ratio of a possible lens galaxy with those found for typical lens galaxies, we first calculate the velocity dispersion of the lensing mass, using the Singular-Isothermal-Sphere (SIS) mass model (Binney & Tremaine 1987). This model relates the lens-image separation ($\Delta\theta$) to a line-of-sight velocity dispersion (σ), given the cosmological model and the source- and lens redshifts:

$$\Delta\theta = 8\pi \cdot \left(\frac{\sigma}{c}\right)^2 \left(\frac{D_{\rm ds}}{D_{\rm s}}\right), \qquad (1)$$

where c is the velocity of light, and $D_{\rm ds}$ and $D_{\rm s}$ are the angular-diameter distances between lens-source and observer-source, respectively (e.g. Schneider, Ehlers and Falco 1992). The angular-diameter distance is a function of redshifts and cosmological model. Using the component separation, we can furthermore calculate the mass contained inside the Einstein radius

$$M(\Delta\theta) = 3.1 \cdot 10^{10} \times \left(\frac{\Delta\theta}{1''}\right)^2 \left(\frac{D}{\rm Gpc}\right) \ \ {\rm M}_{\odot}, \qquad (2)$$

where $D{\equiv}D_{\rm d}D_{\rm s}/D_{\rm ds}$ and $D_{\rm d}$ is the angular-diameter distance to the lens galaxy. To calculate the luminosity of the

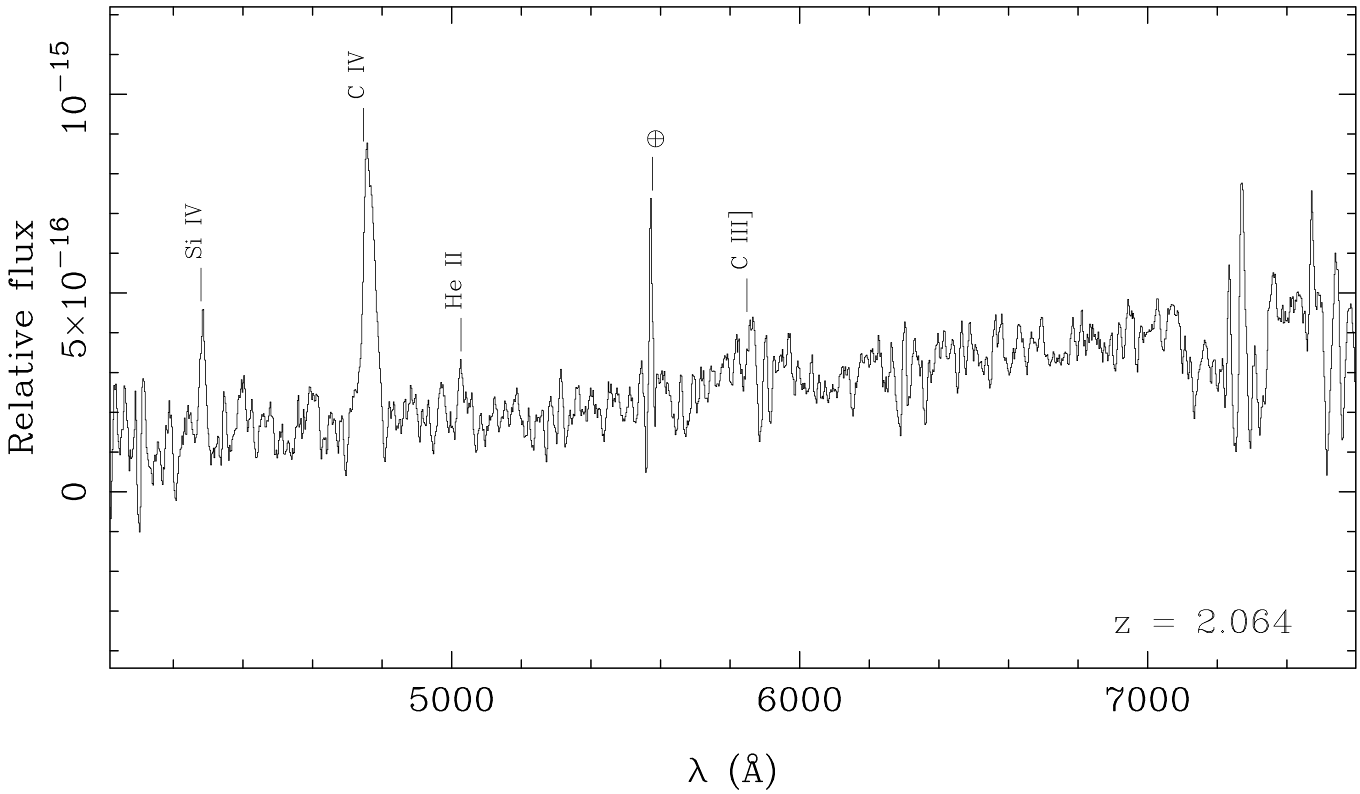

Fig. 4. LRIS spectrum of B0827+525, observed with the W.M Keck II Telescope on 1998 April 21

lens galaxy, using the filter band λ (e.g. *U, B, V, ...*), we subsequently use the relation

$$L_\lambda/\mathrm{L}_{\lambda,\odot} = 10^{0.4\cdot(M_{\lambda,\odot}-m_\lambda+\mathrm{DM}+\mathrm{K}_\lambda)}, \quad (3)$$

where DM is the distance modulus of the lens galaxy, $\mathrm{M}_{\lambda,\odot}$ is the absolute magnitude of the sun, m_λ is the apparent magnitude of the lens galaxy and K_λ is the K–correction for the filter band λ. We use the lower limit of $m_{\mathrm{F160W}}>23$ mag on the lens galaxy, found from the HST exposure (Fig.3) to constrain the mass-to-light ratio in *H*–band. We use the *H*–band observations, because K corrections are relatively small (<0.2 mag for $z\leq1$ and <0.5 mag for $z\leq2$; Poggianti 1997). We do not use evolutionary corrections and assume $M_{\mathrm{H},\odot}$=3.46 mag.

For a source redshift of 2.064, we have plotted the *H*–band mass-to-light ratio in Fig.5 for two different cosmologies (A: Ω_{m}=1 and Ω_Λ=0; B: Ω_{m}=0.3 and Ω_Λ=0.7) and H_0=65 km s^{-1} Mpc^{-1}. We assume a Friedmann-Robertson-Walker universe. A minimum mass-to-light ratio around 100 is found, using cosmology B. This mass-to-light ratio implies a lens-galaxy redshift around 1.5 and a high velocity dispersion of 400–500 km/s. For cosmology A, the minimum mass-to-light ratio would increase to about 200. From Jackson et al. (1998) we find that the mass-to-light ratio in *H*–band for B0827+525 is a factor 15–100 larger than the *H*–band mass-to-light ratios of typical lens galaxies in the CLASS survey.

In Fig.6, we have plotted the expected *H*–band magnitude of the lens galaxy as function of redshift, galaxy type and cosmology. We used (i) the velocity dispersion determined from eqn.1, (ii) the relation between velocity dispersion and *B*–band magnitude of elliptical and spiral galaxies from Fukugita et al. (1991) and (iii) the colors and K–corrections from Poggianti (1997). From Fig.6 an upper limit on m_{H} of 17 mag is found, nearly independent of galaxy type. If evolutionary corrections are applied (Poggianti 1997), we find no significant differences in these results. The upper limit is at least 6 mag brighter than the lower limit on the *H*–band magnitude of the possible lens galaxy, whereas for all confirmed GL systems (Jackson et al. 1998), for which the lens and source redshifts are known, differences between the observations and the model are $\lesssim$1 mag.

Hence, if B0827+525 is a lens system then the object is indeed a 'dark lens' system. However, also image B must be darkened and reddened by the 'dark lens' galaxy. For further discussion of this possibility we refer to Sect.4.

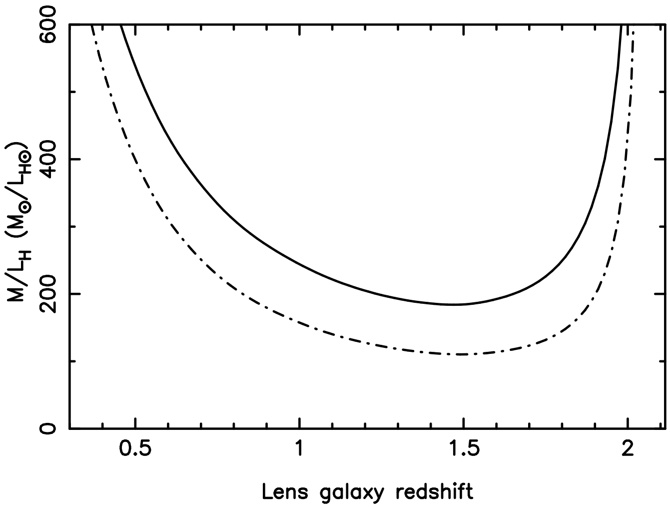

Fig. 5. Estimated lower limit on the H–band mass-to-light ratio of the lens galaxy, as function of redshift (see text). The solid line is for a ($\Omega_{\rm m}$=1, Ω_Λ=0) cosmology, the dot-dashed line for a ($\Omega_{\rm m}$=0.3, Ω_Λ=0.7) cosmology. We assume H_0=65 km s^{-1} Mpc^{-1}

3.2. The binary quasar hypothesis

As argued in Sect.2.1 the probability of a chance alignment of two radio-loud quasars is rather small. Hence, if the source is *not* a lens systems it is most likely a pair of physically close quasars. We call this the 'binary quasar' hypothesis even though we have no evidence for the quasar nature of component B in the optical.

The compact flat-spectrum radio source population selected via CLASS is generally believed to emit its radio emission in a highly non-isotropic manner (e.g. Orr & Browne 1982) with the radio axis pointed in our direction within a small angle. As first argued by Scheuer & Readhead (1979) there should then be many radio-quiet quasars (QSO) for every radio-loud quasar (QSR). It is then obvious that the probability of finding two related radio-loud quasars pointed at us is rather small. In fact we can probably state that for every QSR–QSR pair there should be around 20 QSR-QSO pairs in the CLASS survey, if ≈5% of all QSOs are also radio-loud, i.e. ≥30 mJy at 8.5 GHz (e.g. Hooper et al. 1995; Bischof & Becker 1997).

Under the assumption that B0827+525 is the only QSR–QSR pair (i.e. binary radio-loud quasar) in CLASS, the probability that a flat-spectrum radio source is part of a QSR–QSR pair is around 1 in 15 000. This means that the probability that a CLASS source is part of a QSR–QSO pair is around 1 in 750. In the Large Bright Quasar Survey (LBQS; Hewett et al. 1998) two QSO–QSO pairs were found from a sample of around 1000 optically selected quasars, hence 1 in 500. This number is very close to that found from the CLASS survey, which means that the presence of one QSR–QSR pair in the CLASS survey is consistent with the rate of QSO–QSO pairs in optical quasar surveys (see also Kochanek et al. 1999).

However, if B0827+525 is a binary radio-loud quasar and we compare it with the list of wide separation quasar pairs in Kochanek et al. (1999), we notice two things: First, B0827+525, has the smallest separation (2.8 arcsec or 23 kpc/h_{50}) of all quasar pairs. Second, only 2 out of 13 non-lens quasar pairs have higher redshifts (i.e. LBQS 1429-008 and Q2345+007). On the other hand, B0827+525 would also be one of the largest separation lens systems (e.g. Browne et al. 1999; Myers et al. 1999; CASTLES survey[2]). B0827+525 thus appears to be at the parameter-space border delineated by the optical quasar pairs listed by Kochanek et al. (1999) and the confirmed GL systems. It is difficult to see how significant these issues are in the context of binary quasars and how it possibly relates to the fact that both quasars are radio-loud.

4. Discussion & Conclusions

If taken at face value, most of the observational evidence seems to be in favor of B0827+525 being a binary radio-loud quasar: (i) somewhat different radio spectra from 1.4 to 14.9 GHz for the two components, (ii) a different radio and optical brightness ratio, (iii) the weaker radio component appears slightly resolved, (iv) the extended nature of the optical and near-infrared emission near component B, whereas that of image A is compact and (v) the agreement with the number statistics of binary radio-loud quasars in the CLASS survey with those of optical surveys.

However, the most interesting explanation of B0827+525, a "dark lens" system, cannot convincingly be excluded and in view of the cosmological importance of the presence of galaxy-sized concentrations of dark matter – even though they must be rare (e.g. Jackson et al. 1998) – we now discuss why we believe the 'dark lens' hypothesis can not yet be discarded: (1) We have seen that at least one of the radio components is variable. If they are lens images, a time delay between them combined with variability of the source can result in a difference in simultaneously measured spectral indices, especially if the time delay is of the order of the variability time scale. (2) If we place a massive 'dark lens' galaxy near component B, containing a large amount of dust, this galaxy would obscure most optical and a significant fraction of the near-infrared emission from component B. In the secure lens system B0218+357 a similarly large discrepancy has been observed between the optical and radio brightness ratios of the lens images (e.g. CASTLES survey), which can also be explained in terms of obscuration by the high-column density of the rich ISM in the lens galaxy (e.g. Wiklind & Combes 1995; Menten & Reid 1996; Combes Wiklind & Nakai 1997; Combes & Wiklind 1997; Gerin et al. 1997; Combes & Wiklind

[2] http://cfa-www.harvard.edu/glensdata/

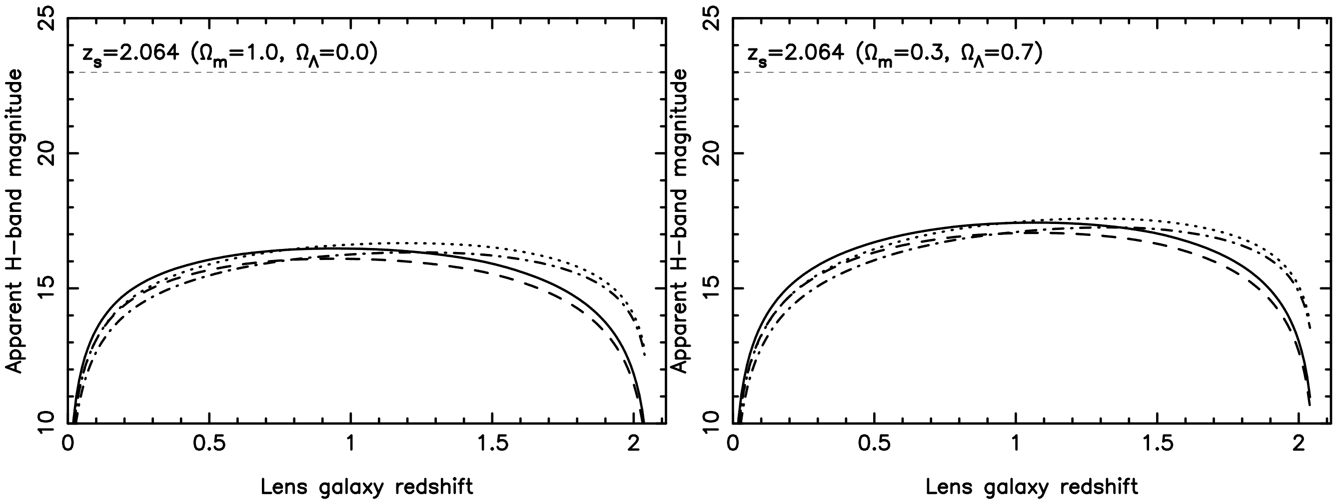

Fig. 6. The estimated *H*–band magnitude of the lensing galaxy for 4 galaxy types – E (solid), S0 (dash), Sa (dot-dash) and Sc (dot) –, plotted as function of redshift (see text). The horizontal dashed line indicates the observed lower limit of 23 mag on the *H*–band magnitude. Two cosmologies are shown

1998). This dust, however, would probably not block all of the lens-galaxy emission. In fact, most of the extended emission seen near radio component B could be coming from the lens galaxy itself and not from the quasar. (3) The optical brightness of image B is surprisingly low for a radio-loud quasar, which might suggest some form of extinction. (4) A high scattering measure, associated with the ionized component of the ISM in the lens galaxy (see for example Marlow et al. 1999; Jones et al. 1996), could furthermore scatter-broaden radio component B, explaining why it appears somewhat resolved.

So far in the 'dark lens' hypothesis we have assumed that the lensing mass is a single galaxy dominated by non-baryonic matter in its inner parts and therefore extremely underluminous. If the lensing mass distribution is a high-redshift ($z \gtrsim 1$) group or cluster, the constraints on the mass-to-light ratio, which is usually an order of magnitude larger in clusters and groups of galaxies than in the inner parts of galaxies (e.g. van der Marel 1991; Carlberg, Yee & Ellingson 1997), is somewhat alleviated. However, for most of the lens galaxies from the CLASS survey, the *H*–band mass-to-light ratios are around unity (Jackson et al. 1998). This is two orders of magnitude smaller than the minimum *H*–band mass-to-light ratio found in Sect.3.1 and can therefore not entirely account for the high mass-to-light ratio within the context of a 'normal' galaxy evolution. Hence also in the case that the lensing mass is a group or cluster, it must be underluminous. A possible candidate for this type of mass concentration was recently found by Erben et al. (2000).

Thus, although the binary quasar hypothesis seems more likely at face value, the 'dark lens' hypothesis can not be ruled out convincingly. However, the latter hypothesis does give concrete predictions: First, the substructure in both radio components should be related, although distorted by the intervening gravitational potential. We have obtained multi-frequency global VLBI data on B0827+525 at three frequencies to test this. (2) If the variability of the radio components is intrinsic, one should be able to correlate their light-curves to find a time-delay. This could definitively prove or disprove whether B0827+525 is a 'dark lens' system. (3) If the extended *H* and *K*–band emission seen near component B is partly from a lens galaxy, it should have a redshift smaller than 2.064. Near-infrared spectroscopy of this emission should therefore be attempted.

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