The optical appearance of B0218+357 from WFPC2 images

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ABSTRACT

I here present an analysis of archive WFPC2 images of B0218+357 and relate the results obtained to our previous ground-based study of this system (Grundahl & Hjorth 1995). It is found that the Grundahl–Hjorth analysis is essentially confirmed by the HST data, but the more precise image positions and intensity ratios derived seem to further complicate the interpretation of the optical appearance of B0218+357.

1. Background

Grundahl & Hjorth (1995) presented ground-based optical observations of the gravitational lens system B0218+357. They suggested, based on V and I images obtained at the Nordic Optical Telescope (NOT), that the optical appearance is that of two point sources A and B with $4 < B/A < 8$ and an extended (face-on disk) lens galaxy. They also presented calibrated photometry of the system and its nearby surroundings. The archive HST data may shed further light on this system which has known source ($z = 0.96$) (Lawrence 1996) and lens ($z = 0.68$) redshifts (Stickel & Kühr 1993; Browne et al. 1993) and a measured time delay of 12 ± 3 days (Corbett et al. 1996; Biggs et al. 1997).

2. Reductions

The data (see Table 1) were cosmic-ray (CR) cleaned by intercomparison of the two 500 sec exposures in each band. Only star 2 (Grundahl & Hjorth 1995) in the combined F814W image is not saturated and only star 1 in the 60 sec F555W exposure in unsaturated and unaffected by CR hits. The reduced images are shown in Fig. 1.

Table 1. WFPC2 B0218+357 data analysed[a]

Dataset	Start time	Exposure time	Filter
U2QK0101T	22 Jul 95 17:29:16	60.000	F555W
U2QK0102T	22 Jul 95 17:32:17	500.000	F555W
U2QK0103T	22 Jul 95 17:43:17	500.000	F555W
U2QK0104T	22 Jul 95 17:55:17	500.000	F814W
U2QK0105T	22 Jul 95 18:06:17	500.000	F814W

[a] The data consists of 5 images of the HST target QSO–022105+355613 located at RA = 02 21 05.47, Dec = +35 56 13.7 (J2000), obtained with the WFPC2 camera under program ID 5965 (PI Ian Browne)

2.1. Photometric calibration

The data were standard calibrated according to Holtzman et al. (1995). A CTE ramp correction (0.02 mag) was applied to the zero-point of the 60 sec image and a long-exposure-time correction (0.05 mag) was applied to the 500 sec images (Hill et al. 1997).

For the stars 1 and 2 we find V($\star$1) = 17.24 and I($\star$2) = 17.88 (using the $V - I$ values reported in Grundahl & Hjorth as colour terms in the transformation equations). These values are in excellent agreement with the ground-based values V($\star$1) = 17.24 ± 0.05 and I($\star$2) = 17.86 ± 0.05 which gives confidence in the Grundahl–Hjorth results as well as the photometric calibration of the HST results.

2.2. Aperture photometry

In an aperture radius of 2.2 arcsec we find for the HST data:

F814W: B0218 $- \star 2 = 0.87$ mag

F555W: B0218 $- \star 1 = 3.26$ mag

This may be compared with the published NOT results (with a similar effective outer aperture of 2.2 arcsec):

I: B0218 $- \star 2 = 0.68$ mag

V: B0218 $- \star 1 = 3.11$ mag

We conclude that B0218+357 has faded by 0.19 ± 0.05 mag in I and 0.15 ± 0.05 in V since the NOT images were taken. The main uncertainty in these numbers come from the region in which the sky background is determined, the standard calibration and the CTE corrections of the HST data. However, the F555W and F814W filters are very well mapped onto the V and Cousins I standard system, and so these are genuine variations and not an artifact of the pass bands used. We conclude that B0218+357 has faded by 0.17 ± 0.07 mag between August 14 1993 and July 22 1995.

2.3. PSF photometry

Using Tiny Tim v4.0 generated PSFs we performed PSF photometry of the system using DAOPHOT/ALLSTAR II. We find:

- Intensity ratios:

  F814W: $B - A = 2.09$ or $B/A = 6.86$
  F555W: $B - A = 1.92$ or $B/A = 5.85$

  These values are in good agreement with the NOT observations for which we found $4 < B/A < 8$ (Grundahl & Hjorth 1995).

- Separation:

  F814W: $|AB|$= 6.557 px = 0.299 arcsec
  F555W: $|AB|$= 6.510 px = 0.296 arcsec

using a pixel scale of 0."4554 pixel^{-1} (Holtzman et al. 1995).

These values are significantly smaller than the 0."335 obtained in the radio.

- Orientation:

  We find position angles of

  PA(F814W) = 68.02 deg
  PA(F555W) = 67.73 deg

  The position angle inferred from the VLBA map (Fig. 1 in Patnaik et al. 1995) is 67.60 ± 0.03 deg. This is in excellent agreement with the optical value.

3. The lens galaxy

The residuals after the two point sources have been subtracted (Fig. 1) show interesting substructure independently in the two bands. The galaxy subtends several arcsec and shows effects of substructure such as spiral or tidal 'arms' or 'shells' (to the North). There does not seem to be optical emission at the location of the hotspot 2″ to the south-east seen in the radio by O'Dea et al. (1992) and Menten & Reid (1996). See Fig. 1. The optical appearance in consistent with a gas-rich spiral (Patnaik et al. 1993; Browne et al. 1993; Grundahl & Hjorth 1995).

For the galaxy we find

$$\mathrm{V} = 22.08,\ \mathrm{I} = 20.00 \text{ and } V - I = 2.08.$$

This coulour suggests that the lens is an Sbc galaxy (Fukugita et al. 1995). Using the method of van Dokkum & Franx (1996) and the spectral energy distribution for Sbc galaxies of Coleman, Wu, & Weedman (1980) the V and I magnitudes can then be converted to an absolute restframe B magnitude of $M_B = -21.99$ ($L_B = 9.2\,10^{10}$ L$_\odot$) for $q_0 = h = 0.5$.

4. Additional checks

Using gaussian fits the derived positions are consistent within 0.1 px with those found by ALLSTAR. The relative positions cannot be wrong by almost 1 pixel.

Subtraction of a hypothetical optical component 1/3 or 1/4 of the intensity of A 335 mas from A can only change the derived separation between the two point sources by about 2 mas.

B appears to be a point source when compared to the stars on WF4 There are however indications that the A component is more extended than B and it appears in fact to be tangentially elongated (Fig. 1).

5. Interpretations

The bright images could be identified with the radio A and B because of the excellent agreement between the position angles. This is consistent with the interpretation of Grundahl & Hjorth (1995). The shorter separation found here could then be due to the extendedness of A. What we see then is what is not covered by the molecular cloud (Grundahl & Hjorth 1995; Wiklind & Combes 1995). This explains why the

A/B ration does not follow that expected from extinction and complicates attempts to determine the N_{H_2} value from the optical A/B ratio (Menten & Reid 1996). The extent of A then is at least $335 - 296$ mas = 40 mas in the optical. A potential problem with this interpretation is that the bright image appears to be a point source whereas it is expected to be extended, albeit with a magnification that is 4 times smaller than that of B.

Alternatively the bright optical point source is the core of the lensing galaxy and the optical counterpart to image B is either absorbed or swamped in the light of the galaxy core. This would explain the short separation which is consistent with the separation between the lens centre and A inferred from the radio Einstein ring (290 ± 10 mas). The lens core would then have to be located exactly on the line joining A and B to explain the observed optical position angle. Problems with this interpretations are that the bright point source is the dominant source of optical light and there is quite deep MgII absorption at $z = 0.68$ (Browne et al. 1993). This would then have to be associated absorption with the BL Lac. Furthermore, we would also expect to see a radio source at the location of the lens BL Lac (Urry & Padovani 1995) which we do not.

6. Summary

The HST observations essentially confirm the findings of Grundahl & Hjorth (1995) regarding

- the detection of two point sources and an extended galaxy
- the B/A value
- a face-on late-type lens galaxy (Sbc)

The superior resolution attained with HST allows some new conclusions:

- B/A does not follow the expected extinction law
- $|AB|$ differs from the radio value
- PA is identical to the radio value
- there is substructure in galaxy

The new epoch shows that the system is optically variable (0.2 mag in 2 years).

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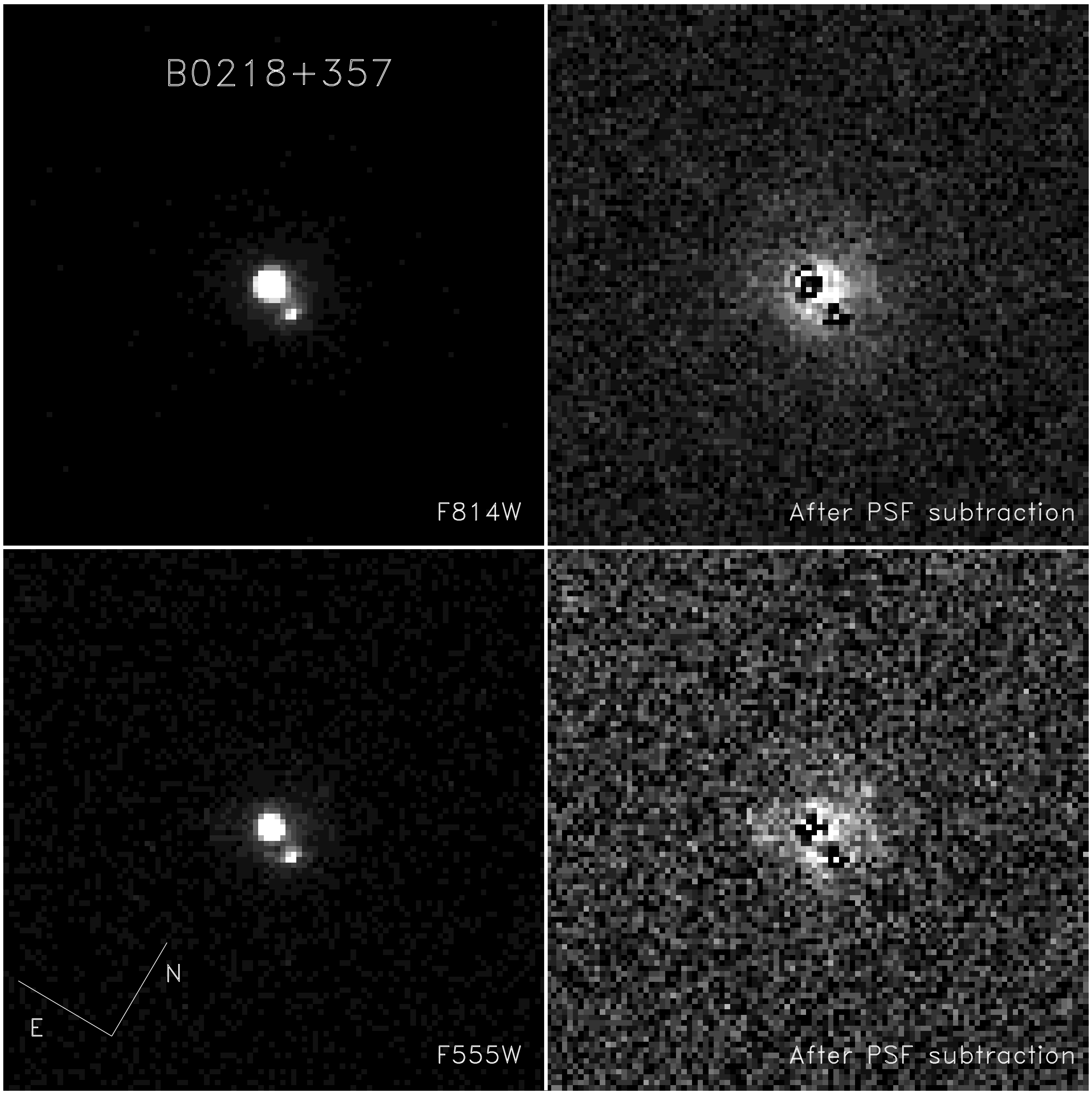

Fig. 1.— B0218+357 before (left) and after (right) PSF subtraction. The upper panels are F814W (I) images, the lower panels are F555W (V) images. The individual frames are $4\farcs6 \times 4\farcs6$.