In gravitational lensing theory, it is predicted that two images which straddle a caustic will have the same magnification. However there are a significant number of well-observed cases where a factor of up to 10 is observed in the magnification ratio – "anomalous lensed quasars". These offer a unique window on the nature of both lens and lensed source. From recent modelling (B+07, C+07) it appears that the size of the emission region convolved with the microlensing pattern is the main reason for the discrepancy. With appropriate modelling, this can be turned around, and a measurement of the emission region of the quasar can be made. This is particularly interesting if a range of observations are made, either at different times (to more highly constrain the probability distribution) or in different wavebands (to constrain the size as a function of \( \lambda \)). We present observations of MG0414+0534, SDSS0924+0219 and WFI2026-4536 as the first part of a multi-band optical IR survey of anomalous lensed quasars. The images demonstrate that the anomalous A2/A1 flux ratio decreases as we move blueward, and we use the results to constrain the size of the r-band AGN emission region of WFI2026-4536 to < 7 light days.

**Background**

### Microlensing

Images are formed at the positions where the optical path length is stationary – minima, maxima and saddle points of the Fermat travel-time surface (Fermat’s principle). Magnification \( \mu \) is determined by convergence \( \kappa \), and the shear \( \gamma \) of the lens at the image locations:

\[
\mu = \frac{1}{\kappa} \left[ 1 + (1 - \kappa)(1 - \gamma) \right]
\]

Maxima and saddles may exhibit demagnification, while minima are always magnified. In a quadrupole system, the brightest image pair are found at a saddle point and a minimum. Images are magnified by a factor of \( \sim 5-20 \).

### Microlensing

As discussed in SW02, the convergence \( \kappa \) can be split into two components: smooth (k), and compact (k'). Introducing small-scale perturbations in the lens potential (microlensing) produces new features in the Fermat surface – see Figure 1. The simple case of one microlens is familiar from planetary transits.

In the macrolens case, each macro-saddle or macro-scale perturbations in the lens potential (microlensing) minima are always magnified by \( \kappa \) and to constrain the emission mechanism for the AGN.

We aim to get multi-band imaging of anomalous lensed QSO’s in a single night with excellent seeing, using PANIC (IR) and IMACS or MagIC (optical) on the Magellan telescopes. There are 6 known anomalous quasars accessible from the south, of which we have observed 3. We fit modified Gaussians to each of quasar image. The pre-existing HST images (CASTLES) are used to constrain the image positions initially. See figs below. MG0414+0534: Observed 2007/11/03 in 0.5" seeing. A1 and A2 clearly resolved. SDSS0924+0219: Observed 2008/05/21 in 0.7" seeing. A1 and A2 clearly resolved.

WFI2026-4536: Observed on 2008/05/21 in 0.7" seeing. A1 and A2 are just resolved.

### Observations & Fitting

Lensed quasars have been used to place upper limits on the size of the emission region (Q2237+0305: WM95, W+05). It has been shown that changing the content of the lens can produce anomalous flux ratios (SW02). However, combining these two effects was only recently attempted (Bate et al. 2007). Our objective is to explore source size with \( \lambda \) and to constrain the emission mechanism for the AGN.

We get multi-band imaging of anomalous lensed QSO’s in a single night with excellent seeing, using PANIC (IR) and IMACS or MagIC (optical) on the Magellan telescopes. There are 6 known anomalous quasars accessible from the south, of which we have observed 3. We fit modified Gaussians to each of quasar image. The pre-existing HST images (CASTLES) are used to constrain the image positions initially. See figs below.

MG0414+0534: Observed 2007/11/03 in 0.5" seeing. A1 and A2 are just resolved. However, it is clear that the A2/A1 ratio becomes more anomalous as we move blueward. SDSS0924+0219: Observed 2008/05/21 in 0.7" seeing. A1 and A2 clearly resolved. WFI2026-4536: Observed on 2008/05/21 in 0.7" seeing. A1 and A2 are just resolved.

### Simulations & Preliminary Results

#### Simulations

Microlensing simulations are conducted using a ray-shooting method (B6; W90). We allow the smooth matter fraction in the lens to vary from 0 to 99% (see Bate et al. 2007 for full details). The model for MG0414+0534 is based on earlier work by SW02. Fig. 3 illustrates the effect of source size and lens model on the magnification probability distribution: Increasing the smoothness of the lens increases the relative probability of a low-magnification saddle point image (right columns in Fig. 3) and thus of an anomalous flux ratio. Increasing source size completely eliminates the flat low-magnification wing, making anomalous fluxes impossible.

#### Results

We have obtained imaging of sufficient quality to detect both members of an anomalous image pair for three sources. It is clear that the A2/A1 ratio gets more anomalous as we get bluer, consistent with a decreasing source size. We fit the observed source size to determine the innermost r-band emission region of 1.9 \( \times \) 70 (h/100) light days. A Shakura–Sunyaev disk (\( \gamma = 1.3 \)) is admitted by the observations. See talk on Tuesday by Nick Bate for more details! The other two cases observed show the same behaviour, although detailed modelling is incomplete.

#### Conclusions

For MG0414+0534, we place an 95% upper limit on the innermost r-band emission region of 1.9 \( \times \) 70 (h/100) light days. A Shakura–Sunyaev disk (\( \gamma = 1.3 \)) is admitted by the observations. See talk on Tuesday by Nick Bate for more details! The other two cases observed show the same behaviour, although detailed modelling is incomplete.

**References**

K+96: Kayser et al. 1986

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**Fig. 1:** Magnification maps showing the magnification with position for a simulation. Darker areas correspond to regions of higher magnification. From left to right we have a clumpier matter content of 26, 30 and 40% conical microlensing due to clumps produces a complicated Fermat travel-time surface and thus magnification map. Anomalous lensed quasars occur when the saddlepoint image is only weakly magnified, but the min image magnified.

**Fig. 2:** Magnified optical IR imaging of WFI2026-4536, SDSS0924+0219 and MG0414+0534. The anomalous flux ratio, \( A_2/A_1 \) increases as we move bluerward. HST image thumbnails are shown for reference.

**Table 1:** Measurements of A2/A1 for the three sources observed (grey = preliminary)

<table>
<thead>
<tr>
<th>Band</th>
<th>MG0414+0534</th>
<th>SDSS0924+0219</th>
<th>WFI2026-4536</th>
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<td>0.20</td>
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<tr>
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</table>

K+96: Kayser et al. 1986

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**Fig. 3:** Differential probability histograms for magnification in case of 95% smooth matter (left) and 0% smooth matter (right). Left and right columns correspond to the "minimum" and "saddle-point" models, respectively (both with \( \gamma = 1.0 \)). Source size (in Einstein radii, \( r_e \)) increases as we move down. Anomalous fluxes demand a narrower probability of low magnification in the saddlepoint image.