# OBSERVATIONS AND PREDICTIONS OF THE RATIO OF 3-IMAGE TO 5-IMAGE SYSTEMS IN JVAS


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**Abstract.** In JVAS we find more 5–image systems than 3–image systems. On conventional assumptions, we predict the ratio to be ∼5:1.


## 1. Introduction

The analysis of gravitational lensing events gives unique information about the distribution of matter in the Universe. JVAS (Jodrell/VLA Astrometric Survey; Patnaik et al. (1992)) has examined ∼2500 compact flat spectrum radio sources and is complete to within well–defined limits. We quantify the biases in JVAS and compare the predicted ratio of 3–image to 5–image systems with the observed. In this way we can check if our assumptions about the properties of lensing masses are correct.

## 2. The biases that might affect the 3:5 image ratio in JVAS

1 **Magnification bias**: The radio luminosity function of quasars shows that there are progressively fewer sources at higher luminosities. When quasars are lensed (magnified) they appear further up the luminosity function and lensed objects are thus over–represented in the high luminosity population (Turner 1980). Average magnifications for 5–image systems are higher than for 3–image systems. Hence when magnifica-




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tion bias is high, i.e. when the quasar luminosity function is steep, one expects proportionately more 5–image systems than 3–image systems.

**2 Bias due to finite source size**: Intrinsic 5–image cross–sections are much smaller than 3–image cross–sections. If the lensed object sizes are comparable to the 5–image cross-section then this significantly increases the number of 5–image systems expected but leaves the number of 3–image systems substantially unaltered (Kochanek & Lawrence 1990).

**3 Bias due to finite core radii**: The cross–section for the production of 3–image systems is reduced when the core radius for lensing galaxies is increased, but the 5–image cross–section remains largely unaffected.

## 2.1. MAGNIFICATION BIAS

We assume that lensing galaxies have elliptical potentials of the form:

$$\Psi(x,y) = \frac{A}{2\alpha_s}\left(\left[1+(1-\epsilon)\left(\frac{x}{s}\right)^2+(1+\epsilon)\left(\frac{y}{s}\right)^2\right]^{\alpha_s}-1\right) \qquad (1)$$

with parameters (i) ellipticity of the potential ($\epsilon$), (ii) core radius ($s$), (iii) softness of the potential ($\alpha_s$) and (iv) depth of the potential well ($A$) which is proportional to $\sigma^2$ (eg. Blandford & Kochanek 1987). The core radii of lensing galaxies are assumed to be small ($\leq$ a few hundred parsecs), as shown by the observations of Lauer (1985) and supported by the "missing" central images in lens systems (eg. Wallington & Narayan 1993). For the source population, we use the Dunlop & Peacock (1990) luminosity function. We use approximations for the probability distributions of magnification (M) associated with 3 and 5 image systems (Kochanek 1992, private communication):

$$P_3(M)dM \propto M^{-3.5}dM \quad and \quad P_5(M)dM \propto M^{-3}dM. \qquad (2)$$

The intrinsic cross–sections for the productions of three– and five–images are roughly in the ratio $1 : 1.5\epsilon^2$ (Kochanek 1991). The flat spectrum radio luminosity function is shallower than the luminosity function for optically selected sources, so the bias factors and ratio between the bias for 5–image systems as opposed to 3–image systems is smaller.

## 2.2. SIZE BIAS.

The JVAS lensed systems are all selected from flat spectrum radio sources which are invariably compact. The systems under discussion have multiple

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images of this compact emission. VLBI observations of a subset of these sources show that they are typically much less than 10mas (Taylor et al. 1994) so that the size bias enhancement of the production of 5–image systems relative to 3–image systems is expected to be small; assuming each source has an extent 10 mas × 10 mas only leads to ~ 10% enhancement.

### 2.3. FINITE CORE RADII

An isothermal lens potential with a softened core (Equation 1) results in a reduction in the total lensing optical depth by a factor of about two when the core radius is increased from zero to several hundred pc. Although this enhances the number of 5–image systems *relative* to 3–image systems, the expected number of 5–image systems is not increased. There are two reasons to think that finite core radii are not affecting the relative numbers of 3–image to 5–image systems by a large factor. The first is that the observed lensing frequencies (see below) indicate an enhancement of the number of 5–image systems rather than a depletion of 3–image systems. The second is that the existing observational evidence, both from lensing and for elliptical galaxies in general, gives no support for large core radii (Wallington & Narayan 1993; Lauer 1985).

### 2.4. RESULTS OF OUR PREDICTIONS

Without magnification bias, and assuming $\epsilon = 0.1$, the expected ratio is 66:1; with magnification bias, size bias and core radii effects, the expected ratio is decreased to ~ 5:1.

## 3. JVAS results

In JVAS, five confirmed lens systems, and one strong candidate, have been identified. Of the five secure systems, there are four 5–image systems and only one 3–image system. The strong candidate is a 3–image system. The 1938+666 system probably gets into the sample by virtue of lensed extended radio emission rather than core emission and thus should excluded from the statistics. The conclusion is, however, that 5-image systems are found in radio surveys at least as frequently as 3–image systems – about a factor of five times more frequently than the predictions.

## 4. A possible resolution?

If the lensing masses were more elliptical than we have assumed, this would result in more 5–image systems relative to 3–image systems (Nair 1993). Some of the known radio selected systems (eg. 1422+231, 1608+654,

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2016+12) require highly elliptical or multiple component lenses to reproduce the observed image properties. Thus there may be more higher ellipticity galaxies capable of multiple imaging than has hitherto been assumed, or lensing by multiple (merging?) galaxies may be more common than expected. We may already have clues as to the possible properties of these lenses with the discovery that some lenses are very dusty (Larkin et al. 1993) and that others are likely to be gas rich and dusty disk systems (Patnaik et al. 1993, Myers et al. 1995). The presence of dust biases optical lens surveys against detection of such objects.

## 5. Conclusions

**1** Bias effects amongst lensed systems selected from samples of flat spectrum radio sources are smaller than optically selected sources.

**2** Assuming ellipticities of 0.1, our predictions indicate that 3–image systems should outnumber 5–image systems by $\sim$ 5:1.

**3** In JVAS, which is the most complete radio radio survey to date, 5–image systems outnumber 3–image systems.

**4** The preponderance of 5–image systems is unlikely to be due to 3–image systems being missed. This is because the observed lensing frequency is already as high as expected ($\sim$ 1:500). If the discrepancy were to be removed by a population of missing 3–image systems this would imply a rate of $\geq$ 3:500.

**5** A possible resolution may be that some lenses may be much more elliptical than previously thought or may consist of multiple (merging) galaxies.

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