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Alignment of Light and Mass in Lensing Galaxies

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ABSTRACT
Abstract here.

Key words:

1 INTRODUCTION

1.1 Context/Background/Motivation

- Why interesting (lensing can constrain mass distribution (enclosed mass constraint independent from model with only few percent uncertainty e.g. Kochanek 1991?, Wambsganss & Paczyski 1994?), insights into structure formation)
- What is to be expected from theory (dm, alternative gravity)

1.2 Anything done before?

- Surely cite: Keeton et al. (1997, 1998); Koopmans et al. (2006); Treu et al. (2009); Gavazzi et al. (2012)

1.3 New here

- Statistics
- Free-form modelling
- group versus stellar misalignment with dm halo

2 DATA

- SPS (Ignacio Ferreras, Dominik, etc. (Leier et al. 2011))
- Write why specifically these lenses were chosen, where they're from

The pixelated stellar mass maps we use, were reconstructed by Leier (2011). For each pixel the surface brightness was compared with stellar mass-to-light ratios, which were determined by stellar population synthesis models. This technique allows estimating the stellar mass in these pixels. Further details on this method can be found in Leier (2011), Ferreras et al. (2005), Ferreras et al. (2008).

Our sample consists of 20 galaxies. The sample is identical to the one as in Leier (2011) and Leier et al. (2011) except that *HS0818+1227* proved too difficult to reconstruct and therefore was left out. Most of the lens galaxies are early-type galaxies, except *B1030+074*, *B1152+200*, *B1600+434*, *B1608+656*, and *Q2237+030*. All lenses can also be found in the gravitational lens database *CASTLES*. Characteristics and references of each lens in the sample are listed below. Table 1 contains of all the redshifts and the type of the lenses, Table 2 lenses with environment information, and Table 3 lenses with measured time delays.

Lens	z_L	z_S	Type	Lens	z_L	z_S	Type
Q0047	0.48	3.60	Quad	HE1104	0.73	2.32	Double
Q0142	0.49	2.72	Double	PG1115	0.31	1.72	Quad
MG0414	0.96	2.64	Quad	B1152	0.44	1.02	Double
B0712	0.41	1.34	Quad	B1422	0.34	3.62	Quad
RXJ0911	0.77	2.80	Quad	B1608	0.63	1.39	Quad
BRI0952	0.63	4.50	Double	MG2016	1.01	3.27	Quad[1]
Q0957	0.36	1.41	Double	B2045	0.87	1.28	Quad
LBQS1009	0.87	2.74	Double	HE2149	0.60	2.03	Double
B1030	0.60	1.54	Double	Q2237	0.04	1.69	Quad

Table 1. List of all the lenses in the sample and their properties. Data is taken from *CASTLES* and Leier (2011). The angles are measured north-through-east.
[1] Two images merge, thus only three images can be resolved.

Q0047-2808 (hereafter *Q0047*) is a luminous early-type galaxy (Warren et al. 1996). Wong et al. (2011) find a group of 9 members all of which they spectroscopically confirm.

Q0142-100 (hereafter *Q0142*) is a passively evolving early-type galaxy according to (Lehár et al. 2000; Eigenbrod et al. 2007).

MG0414+0534 (hereafter *MG0414*) is a passively evolving early-type galaxy (Tonry & Kochanek 1999). Schechter & Moore (1993) find a very close luminous satellite galaxy north-west of the lens. Due to the proximity of this satellite, we include it as a point mass in our analysis.

B0712+472 (hereafter *B0712*) is an early-type galaxy (Fassnacht & Cohen 1998). Another galaxy, 102" to the south-east seems to be at a similar redshift (Fassnacht & Lubin 2002). There is also a group of 10 galaxies at a lower redshift.

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2*Lens	2*Environment[a]	Group/Cluster centroid[b]		Other galaxy		2*References[c]
		Δα ["]	Δδ ["]	Δα ["]	Δδ ["]	
Q0047	G(9)	3.6 ± 15.6	43.2 ± 28.8	...	...	1
MG0414	2	...	...	-0.4	1.5	2
B0712	2	...	...	47	-91	3
RXJ0911	C	-12.0	-39.8	...	...	4
Q0957	C	...	...	...	...	5
B1030	2	...	...	-9.8	8.5	6
PG1115	G(13)	-10.8 ± 21.0	-3.6 ± 15.6	...	...	1
B1422	G(17)	61.2 ± 25.2	-10.8 ± 23.4	...	...	1
B1608	G(8)	-0.7	8.0	...	...	9
MG2016	C(69)	...	...	...	...	10
HE2149	G	-36.6	14.2	...	...	11

Table 2. List of lenses lying in a group or cluster environment, or that have a companion.
[a] G stands for group, C for cluster, and 2 means that the lens has a companion galaxy. If known, the number of member galaxies including the lens is given.
[b] If not stated differently, the centroid positions are luminosity-weighted estimates.
[c] References for the centroid estimates we used.
[d] Only number-weighted estimates are available.
1: Wong et al. (2011); 2: Schechter & Moore (1993); 3: Fassnacht & Lubin (2002); 4: Morgan et al. (2001); 5: Chartas et al. (1998); 6: Lehár et al. (2000); 7: Auger et al. (2008); 8: Auger et al. (2007); 9: Toft et al. (2003); 10: Williams et al. (2006); 11: Williams et al. (2006)

Lens	Time delays [d]			References
RXJ0911	$\Delta t_{BA} = 146 \pm 4$	...	...	1
Q0957	$\Delta t_{BA} = 416.5 \pm 1.0^a$	$\Delta t_{BA} = 420.6 \pm 1.9^b$	...	2
HE1104	$\Delta t_{BA} = 162.2^{+6.3}_{-5.9}$	...	...	3
PG1115	$\Delta t_{BA} = 12.0^{+2.4}_{-2.0}$	$\Delta t_{DC} = 4.4^{+3.2}_{-2.4}$	...	4
B1608	$\Delta t_{BA} = 31.5^{+2}_{-1}$	$\Delta t_{CA} = 36.0 \pm 1.5$	$\Delta t_{DA} = 77.0^{+2}_{-1}$	7
HE2149	$\Delta t_{BA} = 103 \pm 12$	...	...	8

Table 3. Lenses with measured time delays. Δt_{BA} corresponds to the time delay between the images A and B with A leading.
[a] measured in the g-band
[b] measured in the r-band
1: Hjorth et al. (2002); 2: Shalyapin et al. (2012); 3: Morgan et al. (2008); 4: Tsvetkova et al. (2010); 5: Eulaers & Magain (2011); 6: Burud et al. (2000); 7: Fassnacht et al. (2002); 8: Burud et al. (2002)

RXJ0911+0551 (hereafter *RXJ0911*) is an almost circular early-type galaxy (Sluse et al. 2012). It has measured time delays (Hjorth et al. 2002). It lies on the outskirts of a cluster (Morgan et al. 2001). This cluster seems to be rather complex and especially it is not spherical. Possibly it is not dynamically relaxed, although X-ray emission can be detected. Analysis of this emission yields a temperature of 2.3 keV. There is also a satellite galaxy to the north-west direction (Kneib et al. 2000).

BRI0952-0115 (hereafter *BRI0952*) is an early-type galaxy (Lehár et al. 2000; Eigenbrod et al. 2007). Momcheva et al. (2006) find that the lens lies in a poor group of 5 members. However, a redshift of $z = 0.41$ was used. According to Eigenbrod et al. (2007), the redshift is more likely to be $z = 0.632$. They also find a system of 2 or 3 other galaxies at a slightly higher redshift of which the lens could be part of. The required external shear could be explained easily by a cosmic contribution (Lehár et al. 2000). Therefore, we treat this lens as an isolated object.

Q0957+561 (hereafter *Q0957*) is a cD galaxy lying close to the center of a cluster with a high sprial galaxy-fraction (e.g. Garrett et al. (1992); Angonin-Willaime et al. (1994); Chartas et al. (1998)). Due to the large image separation, large physical scales are probed. As listed in Table 3 of Keeton et al. (2000), the position angles to the center of the cluster of earlier lens reconstructions range between 51.8 deg and 67.8 deg measured north-through-east. These results are consistent with the center of the X-ray emission from the cluster (Chartas et al. 1998). The lens has a measured time delay, e.g. (Shalyapin et al. 2012). They however also find a three-day lag between the g- and r-bands, and the estimates do not agree at the 2σ-level. They argue that this effect can be accounted for by the presence of a substructure and chromatic dispersion. We find that the results do not change significantly for either estimate and choose therefore the g-band measurement.

LBQS1009-0252 (hereafter *LBQS1009*) is probably an early-type galaxy (Lehár et al. 2000). Faure et al. (2004) find no significant galaxy overdensity near the lens.

B1030+074 (hereafter *B1030*) appears to have some substructure (Xanthopoulos et al. 1998). Lehár et al. (2000) conclude that there are two distinct galaxies. The main one is a red, early-type galaxy. The other component seems to be fitted well by an exponential disk galaxy. They also conclude that no firm statements about the environment can be made. Although there is another galaxy nearby, it is too blue to be an early-type galaxy and thus they cannot estimate its shear contribution.

HE1104-1805 (hereafter *HE1104*) is probably an early-type galaxy (Lehár et al. 2000; Courbin et al. 2000). It has measured time delays (Morgan et al. 2008). Lehár et al. (2000) also seem to find a group environment. Faure et al. (2004) however conclude that the photometric redshift measurements of these galaxies indicate that they are at a higher redshift and rather associated with the source. Nonetheless, their lens models, parametric and free-form, all require strong external shear.

PG1115+080 (hereafter *PG1115*) is an early-type galaxy (Yoo et al. 2005). It has measured time delays. We use recent estimates of the time delays by Tsvetkova et al. (2010) which differ significantly from traditional values by e.g. Barkana (1997). Momcheva et al. (2006) and Wong et al. (2011) analyzed the environment of the lens thouroughly. It is part of a small group of 13 members. Grant et al. (2004) detect also X-ray emission from the corresponding group, which yields a temperature of 0.8 keV.

B1152+200 (hereafter *B1152*) seems to have a color consistent with a late-type or an irregular galaxy (Toft et al. 2000). Not much seems to be known about the environment of the lens.

B1422+231 (hereafter *B1422*) is an early-type galaxy (Impey et al. 1996). Although there are measured time delays by Patnaik & Narasimha (2001), they are probably not to be trusted too much as they deviate significantly from theoretical expectations in Raychaudhury et al. (2003). An accurate measurement of the time delays would require time delay measurements on the scale of hours. Momcheva et al. (2006) find a group environment with 16 spectroscopically confirmed member galaxies. Using newer data, Wong et al. (2011) find an additional member. Grant et al. (2004) also detect X-ray emission from the corresponding group at a temperature of 1.0 keV.

B1608+656 (hereafter *B1608*) consists of two merging galaxies. The main galaxy is an early-type galaxy which is disrupted by a smaller, probably late-type galaxy (Surpi & Blandford 2003). The system has measured time delays (Fassnacht et al. 2002). The environment and the mass distribution along the line of sight have been analyzed by Fassnacht et al. (2006). They find a group with 8 resp. 9 members if the merging galaxies are counted as 2. No significant X-ray emission was detected from the surrounding group (Dai & Kochanek 2005). Along the line of sight seem to be four other groups.

MG2016+112 (hereafter *MG2016*) is a giant elliptical galaxy (Lawrence et al. 1984; Schneider et al. 1986). It is the farthest lens we consider in this sample. It lies in a cluster which consists of 69 probable galaxies (Toft et al. 2003). The clusters shows a high density of galaxies close to the lens in a south-east direction.

B2045+265 (hereafter *B2045*) is probably an elliptical galaxy (McKean et al. 2007). Fassnacht et al. (1999) initially classified the galaxy as a late-type Sa galaxy, the velocity dispersion however seems too high. As the source redshift is rather low, a large lens mass is needed. McKean et al. (2007) therefore conclude that it is more likely an elliptical galaxy. To the west of the lens, Fassnacht et al. (1999) find that a group at a similar redshift as the lens. McKean et al. (2007) also find evidence for a dwarf satellite galaxy.

HE2149-2745 (hereafter *HE2149*) is an early-type galaxy (Eigenbrod et al. 2007). It has a measured time delay (Burud et al. 2002). There is some uncertainty in estimating the lens' redshift. Initial estimates by Wisotzki et al. (1996); Kochanek et al. (2000) found a probable redshift range of $\sim 0.2 - 0.5$. By cross-correlating the lens spectrum with a template spectrum of an elliptical galaxy, Burud et al. (2002) find that the redshift probably lies in the range $0.49 \leqslant z \leqslant 0.60$, with the most likely redshift $z = 0.495 \pm 0.01$. Eigenbrod et al. (2007) however find that the redshift is more likely to be $z = 0.603 \pm 0.001$. This would probably make the lens part of a poor group found by Momcheva et al. (2006) and Williams et al. (2006). They also find two other groups at lower redshifts.

Q2237+030 (hereafter *Q2237* or *2237*) is a barred spiral (Yee 1988). With only a redshift of $z = 0.04$, it is the closest lens of the sample. Due to the low redshift, the probed physical scales are quite small. No further inquiries into the environment were made.

Further information about the sample can be found in Leier (2011), Leier et al. (2011), and Sluse et al. (2012).

NOTE: Cannot use B1608, but I still left it in the sample as Fei probably will use the lens.

3 METHODS

3.1 GLASS

- Explain GLASS briefly and link to fake data tests

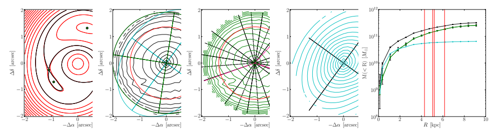

Figure 1. Reconstruction of lens *PG1115*

3.2 Priors and assumptions

- Explain what priors were chosen to model the lenses

Basically always pixrad 12, shear left free for quads, shear limited for doubles to 0.01, local gradient 50 degrees, smoothening prior 2, time delays if known. Exceptions are few. For some quads symmetry prior, for one double 0.01 was not possible therefore chose 0.1.

3.3 Shape measure

- Explain shape measure
- Link to tests on fake data
- Include one plot of fake data test -¿ Jonathan
- Illustrate everything with example lens PG1115.

4 RESULTS

- Show some examples (stellar and dm contour plots, image of lens, arrival time surface, included mass)
- Show money plots
- Comment on a few lenses special lenses
- Environmental effect?

5 CONCLUSION

- Recapitulate what were the main results
- Answer whether this method is promising
- What is needed to understand such misalignments better (-¿ Surely need to understand environment effects better, ...)

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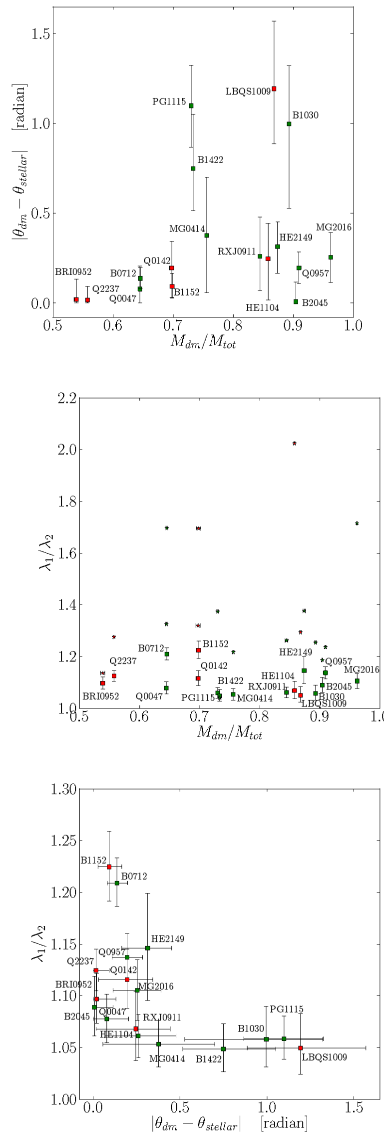

Figure 2. Plots of stellar and dark matter misalignments, ellipticities and composed plot.

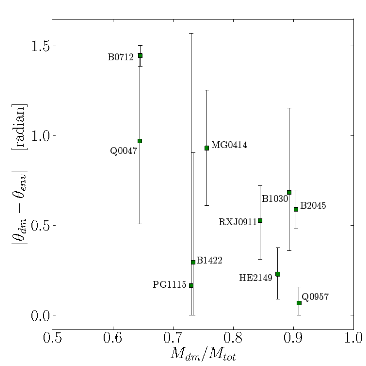

Figure 3. Plots of stellar and dark matter misalignments, ellipticities and composed plot.

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