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**Recommended Citation**

D. A. Forbes, A. Cortesi, V. Pota, C. Foster, Aaron J. Romanowsky, M. R. Merrifield, J. P. Strader, L. Coccato, and N. Napolitano. "Radially extended kinematics in the S0 galaxy NGC 2768 from planetary nebulae, globular clusters and starlight" *Monthly Notices of the Royal Astronomical Society* (2012): 975-982.  
https://doi.org/10.1111/j.1365-2966.2012.21877.x

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Radially extended kinematics in the S0 galaxy NGC 2768 from planetary nebulae, globular clusters and starlight

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Accepted 2012 August 7. Received 2012 August 2; in original form 2012 June 12

ABSTRACT
There are only a few tracers available to probe the kinematics of individual early-type galaxies beyond one effective radius. Here we directly compare a sample of planetary nebulae (PNe), globular clusters (GCs) and galaxy starlight velocities out to approximately four effective radii, in the S0 galaxy NGC 2768. Using a bulge-to-disc decomposition of a K-band image we assign PNe and starlight to either the disc or the bulge. We show that the bulge PNe and bulge starlight follow the same radial density distribution as the red subpopulation of GCs, whereas the disc PNe and disc starlight are distinct components. We find good kinematic agreement between the three tracers to several effective radii (and with stellar data in the inner regions). Further support for the distinct nature of the two galaxy components comes from our kinematic analysis. After separating the tracers into bulge and disc components we find the bulge to be a slowly rotating pressure-supported system, whereas the disc reveals a rapidly rising rotation curve with a declining velocity dispersion profile. The resulting $V_{rot}/\sigma$ ratio for the disc resembles that of a spiral galaxy and hints at an origin for NGC 2768 as a transformed late-type galaxy. A two-component kinematic analysis for a sample of S0s will help to elucidate the nature of this class of galaxy.

Key words: galaxies: elliptical and lenticular, cD – galaxies: individual: NGC 2768 – galaxies: kinematics and dynamics.

1 INTRODUCTION
Based on studies of the morphology-density relation in clusters (Dressler 1980) and groups (Wilman et al. 2009), it has been suggested that lenticular (S0) galaxies may be the descendants of spirals that have undergone some evolutionary process (e.g. ram pressure stripping, galaxy harassment, gas starvation and/or mergers). Recent investigations of S0s have studied their metallicity gradients (Bedregal et al. 2011), Tully–Fisher relation (Bedregal, Aragón-Salamanca & Merrifield 2006) and stellar populations (Aragón-Salamanca, Bedregal & Merrifield 2006). However, the origin of S0s is still a subject of much debate (e.g. Kormendy & Bender 2012). The internal kinematics of galaxies are a key tool to understanding their structure and formation histories, and S0s are no exception. For example, the kinematics will be largely unaffected if S0s are formerly spirals that have been simply stripped of gas or if they are involved in a relatively minor merger.

Although half of the stellar mass within a galaxy lies within one effective radius ($R_e$), more than 90 per cent of the total mass and angular momentum does not (Romanowsky & Fall 2012). Thus in order to examine the internal kinematics and total mass of early-type galaxies one must probe well beyond $1 R_e$. Elliptical and S0 (early-type) galaxies often lack the significant quantities of extended HI gas commonly found in spirals, so the kinematic tracers are the galaxy starlight themselves, planetary nebulae (PNe) and globular clusters (GCs).

Using the underlying starlight of a galaxy to probe its stellar kinematics is perhaps the preferred method; however, the surface brightness of a galaxy declines rapidly with increasing radius so
it is very difficult to obtain high quality spectra beyond a few effective radii without a large investment of 8-m-class telescope time (Coccato et al. 2010) or using deep single pointings (Weijmans et al. 2009). PNe and GCs have the advantage that they are ubiquitous in the haloes of early-type galaxies out to large galactocentric radii (5–10 $R_e$). Although there have been several studies of PNe and GC system kinematics in early-type galaxies, very few studies have directly compared them to each other, or to results from galaxy starlight over a common radial range.

Luminous PNe are the end product of low mass stars. However, there is still debate as to whether they arise from normal single-star evolutionary processes or from mass transfer in a binary star system (Ciardullo et al. 2005). In the former case, the PNe observed in early-type galaxies would have an age of $\sim 1.5$ Gyr, and in the latter case they could be as old as 10 Gyr. Coccato et al. (2009) showed that the radial surface density of PNe follows the galaxy starlight in early-type galaxies and that they are useful probes of galaxy kinematics. However, ellipticals with embedded thick discs and S0 galaxies may contain two subpopulations of PNe, one associated with the disc and one with the bulge, as seen for spiral galaxies (Nolthenius & Ford 1987; Hurley-Keller et al. 2004). Not accounting for the different kinematics of these distinct PNe subpopulations could lead to misleading results as illustrated recently by Cortesi et al. (2011) for the lenticular galaxy NGC 1023. Furthermore, Dekel et al. (2005) suggested that an intermediate-aged population of PNe may have ‘contaminated’ the PNe velocity dispersions of some galaxies in the early-type sample of Romanowsky et al. (2003) and hence impacted the resulting mass analysis.

The globular cluster (GC) systems of all large galaxies, irrespective of Hubble type, generally consist of two subpopulations – blue (or metal-poor) and red (or metal-rich). Both of these subpopulations are thought to have ages $\geq 10$ Gyr and hence trace old stellar populations (for a review of GC system properties see Brodie & Strader 2006). The blue subpopulation is associated with galaxy haloes (Forte et al. 2005; Forbes et al. 2012), whereas the red subpopulation has been shown to share many properties with the spheroid/bulge stars of early-type galaxies (Strader et al. 2011; Forbes et al. 2012), including their kinematics (Pota et al. 2012). We note that the association of red GCs with the bulge and not with a thin disc component extends to spiral galaxies, including our own (Minniti 1995; Côté 1999) and the Sombrero (Forbes, Brodie & Larsen 2001).

To better understand the issues discussed above it is important to directly compare different kinematic tracers for the same galaxy. Here we combine starlight, PNe and GC data for an arche-type lenticular galaxy NGC 2768 and directly compare these different kinematic tracers in the same galaxy. The galaxy is a nearby, near edge-on S0 (Sandage, Tammann & van den Bergh 1981), although we note that it was originally classified as an E6 in the RC3 catalogue. According to Wikland et al. (1995) it is an isolated galaxy; however, it has also been classified as part of the Lyon Group of Galaxies 167 (Garcia 1993). It reveals ionized gas and a minor axis dust lane (Kim 1989). The central ionized gas and stars are known to have different kinematics (Fried & Illingworth 1994) suggesting an external origin for the gas. NGC 2768 is a rare example of an early-type galaxy with detectable CO emission (Wikland et al. 1995) and the host of a calcium-rich supernova type Ib (Filippenko & Chornock 2000). The effective radius of the galaxy is 1.06 arcmin (Proctor et al. 2009; Cappellari et al. 2011). For a distance of 21.8 Mpc (Cappellari et al. 2011), this corresponds to 6.7 kpc.

2 KINEMATIC TRACERS

2.1 Galaxy starlight data

Using a new technique to extract integrated kinematic information of the underlying galaxy starlight from a multi-slit spectrograph, Proctor et al. (2009) presented 2D stellar kinematics for NGC 2768 out to $\sim 3 R_e$. Here we have carried out a re-analysis of the Proctor et al. galaxy data after re-defining the sky scaling index continuum passbands to avoid any strong spectral features associated with the galaxy, as well as any skylines in order to refine the sky subtraction (see Foster et al. 2009 for more details). The resulting velocity and velocity dispersion profiles are similar to those published in Proctor et al. (2009). The total number of positions with stellar kinematics available is 104 and our full data set is given in Table A1 of Appendix A.

2.2 Planetary nebulae (PNe) data

Velocity data for 315 PNe in NGC 2768 were acquired using the PNS spectrograph (Douglas et al. 2002) in 2007 and are available at www.strw.leidenuniv.nl/pns/. Details of the data reduction procedure and analysis can be found in Cortesi et al. (2012, in preparation). Following Coccato et al. (2009), a uniform magnitude cut has been applied and radial incompleteness tests have been carried out. Thus each bin of the PNe surface density distribution is complete to a given magnitude and has been statistically corrected for any radial incompleteness. All are spectroscopically confirmed. The PNe data reach out to $\sim 5 R_e$.

2.3 Globular cluster (GC) data

The radial surface density distribution and velocity data for GCs come from the imaging and spectroscopy of Pota et al. (2012). Briefly, imaging from Hubble Space Telescope (HST) allows us to model and subtract the galaxy light, and hence detect GCs in the galaxy inner regions with little or no radial incompleteness. The resulting surface density distribution for over 500 GCs is a combination of HST data in the inner regions and Subaru data in the outer regions, with a background level subtracted. Blue and red GCs were separated according to the local minimum of their radial surface density distribution and velocity data in the inner regions and Subaru data in the outer regions, which have been statistically corrected for any radial incompleteness. All are spectroscopically confirmed. The GCs data reach out to $\sim 4 R_e$ and we henceforth assume that they are all associated with the bulge of the galaxy.

3 RESULTS AND DISCUSSION

3.1 Spatial distributions

The locations of the 481 starlight, PNe and red GC positions with kinematic data in NGC 2768 are shown in Fig. 1. The kinematic data points are well distributed across the surface of the galaxy. In some cases the GC and starlight velocities come from the same position on the sky.
Before examining the kinematic data, we compare the 1D radial distribution of the PNe and red GCs with the galaxy starlight. We use the results of the starlight decomposition into bulge and disc components from Cortesi et al. (2012, in preparation). The general method is to create a model that can be used to assign a probability that a given position is associated with either the disc or bulge component as described in Cortesi et al. (2011). Briefly, it involves a 2D decomposition of a $K$-band image of NGC 2768 from the Two Micron All Sky Survey (2MASS) survey. From this, parameters for the disc and bulge, assuming an exponential and Sérsic light profile, respectively, are obtained. The resulting major axis scale lengths, Sérsic indices, $K$-band magnitudes and axial ratios are given in Table 1. The 2D disc/bulge probability map is shown in Fig. 1.

The bulge has a position angle that is consistent with the major axis of the disc. We also find the bulge and disc to have similar scale sizes. Using a distance of 21.8 Mpc and the $K$-band magnitudes quoted in Table 1 (assuming a solar value of $K = 3.28$) we can calculate the luminosity in each component. To calculate masses, we need to assume a mass-to-light ratio that depends on both age and metallicity. The advantage of working in the $K$ band is that it is relatively insensitive to metallicity and we simply assume solar. In a study of age gradients in S0 galaxies, Bedregal et al. (2011) found age gradients to be positive (with discs younger than bulges) or flat. The typical mean age was around 5 Gyr. Although NGC 2768 shows some indication of recent star formation (e.g. a type Ib supernova in 2000), we assume that a mean age of 5 Gyr is more appropriate. The mass-to-light ratio in the $K$ band for a near solar 5 Gyr population is 0.6 (e.g. Forbes et al. 2008). This gives the mass of the disc to be $3.1 \times 10^{10} M_{\odot}$ and $7.5 \times 10^{10} M_{\odot}$ for the bulge. Thus the bulge-to-total mass ratio is 0.7.

Fig. 2 shows the 1D radial surface density distribution of disc and bulge PNe and the red (bulge) GCs with the galaxy starlight profiles. The radial bins, using geometric circular radii, are chosen to have similar numbers of objects in each bin with Poisson errors shown. Our assumption of associating the red GCs with the bulge is supported by the similarity between their surface density profile and that of the bulge starlight.

### Table 1. Bulge-to-disc decomposition of NGC 2768.

| Parameter | Disc | Bulge |
|-----------|------|-------|
| $R_d, R_e$ (arcmin) | 0.72 | 0.84 |
| Sérsic $n$ | 1 | 4.65 |
| $K$ (mag) | 8.19 | 7.23 |
| $b/a$ | 0.29 | 0.66 |

Figure 1. Distribution of planetary nebulae (PNe, solid dots), red globular clusters (GCs, open circles) and starlight positions (stars) for which velocity information is available for NGC 2768. Also shown is a grey-scale corresponding to the probability of association with the bulge component (high values in the grey-scale bar shown below). The effective radius of the galaxy is 1.06 arcmin.

Figure 2. Surface density of planetary nebulae (PNe) and globular clusters (GCs) in NGC 2768 as a function of the galaxy major axis. The surface density of red GCs is shown as red open circles. The surface density of PNe assigned to the disc and bulge components is shown as blue and red dots, respectively. The combined total PNe surface density is shown as black dots. The disc, bulge and total galaxy starlight profiles from a bulge-to-disc decomposition are given as blue, red and black dashed lines. The normalization in the vertical direction is arbitrary (i.e. the disc and bulge distributions have been offset for clarity; in reality the bulge dominates at small and large radii). A good correspondence is seen between the bulge PNe, bulge starlight and red GCs.
Thus for the kinematic modelling all of the red GCs are assigned to the bulge.

Unlike our two discrete tracers, the starlight data are integrated quantities for which the rotation velocity and velocity dispersion come directly from the measurements. Ideally, with full wavelength coverage and a high signal-to-noise 2D spectrum we could attempt to decompose the starlight into disc and bulge components (Johnston et al. 2012). However for our data, which are modest signal-to-noise data from a restricted wavelength range around the Ca triplet lines, we adopt a simpler approach. We assign each starlight position to either the disc or the bulge based on the probability map of Fig. 1. The rotation amplitude is fit by an inclined disc model rotating along the major axis using equation 3 from Foster et al. (2011) which fits the rotation velocity and velocity dispersion simultaneously.

In Fig. 3 we show how the starlight and PNe rotation velocity depend on the disc/bulge probability. In both cases the rotation velocity declines smoothly from the disc-dominated regime to the bulge-dominated regime. We note that the velocity dispersion (not shown) does not depend strongly on the disc/bulge probability. The figure also gives the azimuthal dependence on the probability. This shows that low (disc-like) probabilities are exclusively associated with position angles about the major axis (90° and 270°) as expected. For the starlight data we have chosen a probability cut of 63 per cent. This combined with a restriction of velocity expected. For the starlight data we have chosen a probability cut with position angles about the major axis (90°) shows that low (disc-like) probabilities are exclusively associated with position angles about the major axis (90°) which fits the rotation velocity and velocity dispersion simultaneously.

In Figs 4 and 5 we show the disc and bulge kinematic profiles from our two-component decomposition. Each radial bin is chosen to have similar numbers in each bin with 289 (disc and bulge) PNe in six radial bins, 122 red (bulge only) GCs in two bins and 45 (disc and bulge) starlight data points in two bins. As detailed above the rotation velocity and velocity dispersion in each radial bin are computed following Cortesi et al. (2011) for the PNe and red GCs and Foster et al. (2011) for the starlight data. For the stellar velocity dispersion we show a continuous profile. We also include the inner region stellar kinematic profiles from the SAURON instrument (Emsellem et al. 2004). For the latter we have simply extracted profiles ±30° about the major and ±60° about the minor axes to approximate the disc and bulge profiles, respectively. The resulting disc and bulge data are both plotted as a function of a generalized radius, i.e.

\[ R = \sqrt{R_{\text{maj}}^2/q + R_{\text{min}}^2/q}, \] (1)

where \( R_{\text{maj}} \) is the semi-major axis, \( R_{\text{min}} \) is the semi-minor axis and \( q \) is the axial ratio of 0.46 from 2MASS.

Figs 4 and 5 shows generally good agreement between the PNe kinematics and the kinematics probed by red GCs and direct starlight to large radii for NGC 2768. We also see reasonable consistency in the inner regions with the SAURON stellar kinematic data. We support the earlier work by Cortesi et al. (2011), on the S0 galaxy NGC 1023, finding evidence for distinct populations of disc and bulge PNe.

The disc component reveals a rapid rise reaching a maximum velocity of \( \sim 270 \, \text{km} \, \text{s}^{-1} \) at a few scale lengths. We note that the true circular velocity may be closer to \( 311 \, \text{km} \, \text{s}^{-1} \) given by Davis et al. (2011) from their modelling of molecular gas kinematics which is unaffected by the asymmetric drift that may influence the kinematics derived from stars. Beyond the very inner regions, we find a continuously declining velocity dispersion profile to very low values. In a sample of late-type spiral galaxies, Bottema (1993) found the velocity dispersion to decline exponentially with radius reaching very low values at a few scale lengths. The bulge reveals mild rotation with a near constant velocity of \( \sim 100 \, \text{km} \, \text{s}^{-1} \) and a mean velocity dispersion of \( \sim 120 \, \text{km} \, \text{s}^{-1} \) at large radii.

Fig. 4 also shows that \( V_{\text{rad}}/R \) for the disc rises continuously with radius. Such a trend suggests that NGC 2768 could be descended from a galaxy with an extended disc. The simulations of Bournaud et al. (2005) showed that such high values of \( V_{\text{rad}}/R \) are maintained after a minor merger. Minor mergers may also help to build up the bulge mass. We note that an isotropic oblate rotator of \( b/a = 0.66 \) (see Table 1) would be expected to have \( V_{\text{rad}}/R \sim 0.7 \) (Davies et al. 1983), similar to our average value. The bulge of NGC 2768 (Fig. 5) resembles a pressure-supported system similar to those seen for the bulges of other spiral galaxies (MacArthur, González & Courteau 2009). Thus we find NGC 2768 to have kinematic properties that resemble those of a spiral galaxy (although with a dominant bulge). We note that determining the exact differences and testing the various evolutionary processes suggested for S0 formation would require a detailed analysis beyond the scope of this paper.

4 CONCLUSIONS

By combining galaxy starlight, PNe and red GC data for NGC 2768 we have shown that the red subpopulation of GCs and a subpopulation of PNe follow the same radial surface density profile as the bulge component of the galaxy starlight. An additional distinct,
Figure 4. Disc kinematic profiles for NGC 2768. Symbols are solid dots for PNe, open circles for GCs and blue stars for starlight data. The stellar velocity dispersion is shown as a continuous blue line. The continuous orange lines at small radii show the SAURON data along the major (disc) and minor (bulge) axes. The upper panels show the rotation velocity ($V_{rot}$), the middle panels the velocity dispersion ($\sigma$) and the lower panels the $V_{rot}/\sigma$ ratio (note the different scales on the left- and right-hand sides). The outermost disc $V_{rot}/\sigma$ data point is off scale. The x-axis shows the generalized radius as given by equation (1). Generally good agreement is seen between the different kinematic tracers.

Figure 5. Bulge kinematic profiles for NGC 2768. Symbols are the same as Fig. 4. The continuous orange lines at small radii show the SAURON data along the major (disc) and minor (bulge) axes. The upper panels show the rotation velocity ($V_{rot}$), the middle panels the velocity dispersion ($\sigma$) and the lower panels the $V_{rot}/\sigma$ ratio (note the different scales on the left- and right-hand sides). The x-axis shows the generalized radius as given by equation 1. Generally good agreement is seen between the different kinematic tracers.

ACKNOWLEDGMENTS

We thank C. Blom, J. Arnold, L. Spitler for their help with the Keck observations. We also thank the referee for several useful comments. CF acknowledges co-funding under the Marie Curie Actions of the European Commission (FP7-COFUND). LC has received funding from the European Community’s Seventh Framework Programme (FP7/2007-2013) under grant agreement no 229517. JB and AR acknowledge support from the NSF through grants AST-0808099, AST-0909237 and AST-1109878.

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APPENDIX A:

Table A1. Galaxy kinematic data. Columns 1 and 2 give the position in right ascension and declination (J2000), respectively. Columns 3 and 4 give the galactocentric radius. The measured kinematic moments are given in km s⁻¹. The data for two individual masks are included (Y and Z); however, mask Y has been observed twice independently and is labelled Y1 and Y2.

| α (hh:mm:ss) | δ (°′′′) | r (arcsec) | PA (deg) | V_{obs} (km s⁻¹) | σ (km s⁻¹) | h₃ | h₄ |
|--------------|----------|------------|----------|----------------|-------------|-----|-----|
| 09:11:28:703 60:02:48:06 | 92.5 | 297 | 1205 ± 11 | 143 ± 18 | 0.08 ± 0.09 | −0.02 ± 0.12 |
| 09:11:39:886 60:01:37:87 | 81.5 | 153 | 1343 ± 14 | 178 ± 19 | −0.02 ± 0.06 | 0.02 ± 0.09 |
| 09:11:20:931 60:02:07:85 | 126.4 | 267 | 1148 ± 8 | 126 ± 12 | 0.01 ± 0.07 | −0.12 ± 0.13 |
| 09:11:23:223 60:02:24:78 | 106.9 | 275 | 1122 ± 7 | 107 ± 18 | 0.07 ± 0.07 | 0.10 ± 0.08 |
| 09:11:33:407 60:02:16:73 | 29.9 | 273 | 1228 ± 5 | 171 ± 8 | 0.02 ± 0.02 | 0.01 ± 0.02 |
| 09:11:25:877 60:03:16:79 | 152.8 | 306 | 1209 ± 55 | 110 ± 65 | 0.05 ± 0.09 | −0.03 ± 0.13 |
| 09:11:24:979 60:01:32:49 | 137.4 | 245 | 1218 ± 15 | 113 ± 20 | 0.06 ± 0.07 | −0.08 ± 0.10 |
| 09:11:22:204 60:02:08:74 | 116.5 | 267 | 1127 ± 9 | 96 ± 16 | 0.10 ± 0.08 | 0.05 ± 0.13 |
| 09:11:28:835 60:01:58:20 | 77.1 | 255 | 1217 ± 8 | 142 ± 10 | 0.03 ± 0.05 | 0.01 ± 0.05 |
| 09:11:30:367 60:02:41:56 | 74.4 | 297 | 1240 ± 7 | 130 ± 11 | −0.02 ± 0.06 | −0.05 ± 0.06 |
| 09:11:19:758 60:01:45:71 | 152.5 | 257 | 1197 ± 13 | 123 ± 11 | −0.01 ± 0.05 | −0.06 ± 0.07 |
| 09:11:21:916 60:00:13:79 | 297.6 | 224 | 1306 ± 123 | 211 ± 117 | 0.01 ± 0.07 | −0.02 ± 0.10 |
| 09:11:38:854 60:02:07:47 | 19.2 | 125 | 1376 ± 5 | 196 ± 8 | 0.01 ± 0.01 | −0.02 ± 0.03 |
| 09:11:36:253 60:01:59:28 | 36.3 | 208 | 1309 ± 5 | 180 ± 8 | 0.00 ± 0.02 | 0.02 ± 0.02 |
| 09:11:37:409 60:01:32:92 | 91.8 | 180 | 1314 ± 22 | 212 ± 26 | −0.12 ± 0.08 | 0.07 ± 0.17 |
| 09:11:35:694 60:02:12:86 | 14.2 | 260 | 1270 ± 5 | 203 ± 8 | 0.03 ± 0.01 | 0.01 ± 0.02 |
| 09:11:19:269 60:03:04:43 | 165.7 | 290 | 1152 ± 70 | 65 ± 84 | 0.08 ± 0.10 | 0.01 ± 0.16 |
| 09:11:41:096 60:01:58:14 | 44.3 | 122 | 1400 ± 5 | 174 ± 8 | −0.04 ± 0.02 | 0.02 ± 0.06 |
| 09:11:24:573 59:59:56:42 | 324.5 | 215 | 1132 ± 85 | 106 ± 54 | 0.00 ± 0.06 | −0.03 ± 0.06 |
| 09:11:34:314 60:01:54:53 | 52.3 | 228 | 1274 ± 5 | 155 ± 8 | 0.00 ± 0.02 | 0.01 ± 0.03 |
| 09:11:39:822 60:02:19:25 | 21.0 | 77 | 1403 ± 5 | 194 ± 8 | −0.02 ± 0.01 | 0.00 ± 0.02 |
| 09:11:31:048 60:02:31:14 | 56.5 | 289 | 1221 ± 6 | 172 ± 9 | 0.04 ± 0.04 | 0.05 ± 0.04 |
| 09:11:36:752 60:01:38:21 | 80.9 | 187 | 1329 ± 16 | 184 ± 20 | −0.08 ± 0.07 | 0.02 ± 0.12 |
| 09:11:19:078 60:01:59:02 | 145.3 | 263 | 1136 ± 13 | 91 ± 28 | 0.17 ± 0.08 | 0.00 ± 0.12 |
| 09:12:10:561 60:01:39:79 | 254.6 | 98 | 1329 ± 144 | 170 ± 144 | 0.02 ± 0.08 | −0.02 ± 0.12 |
| 09:12:02:699 59:59:31:30 | 388.4 | 131 | 1325 ± 164 | 228 ± 153 | 0.01 ± 0.11 | 0.00 ± 0.19 |
| 09:11:59:272 60:02:23:17 | 132.0 | 87 | 1560 ± 53 | 131 ± 102 | −0.01 ± 0.10 | 0.05 ± 0.12 |
| 09:11:59:744 60:01:45:39 | 217.6 | 113 | 1481 ± 79 | 164 ± 107 | −0.05 ± 0.06 | −0.01 ± 0.05 |
| 09:11:57:921 60:01:54:50 | 157.0 | 98 | 1500 ± 27 | 149 ± 63 | −0.12 ± 0.11 | 0.03 ± 0.12 |
| 09:11:57:142 60:02:35:58 | 158.9 | 82 | 1506 ± 45 | 125 ± 86 | −0.09 ± 0.10 | −0.05 ± 0.12 |
| 09:11:56:449 60:02:48:83 | 166.7 | 77 | 1523 ± 47 | 148 ± 87 | −0.01 ± 0.12 | −0.07 ± 0.11 |
| 09:11:53:358 60:02:10:14 | 119.7 | 92 | 1523 ± 11 | 127 ± 15 | −0.14 ± 0.06 | −0.07 ± 0.12 |
| 09:11:53:195 60:01:00:13 | 193.0 | 122 | 1289 ± 41 | 168 ± 65 | −0.01 ± 0.06 | 0.00 ± 0.04 |
| 09:11:51:588 60:01:40:84 | 124.7 | 108 | 1445 ± 19 | 159 ± 18 | −0.18 ± 0.05 | −0.09 ± 0.11 |
| $\alpha$ (hh:mm:ss) | $\delta$ (°: ') | $r$ (arcsec) | PA (deg) | $V_{\text{obs}}$ (km s$^{-1}$) | $\sigma$ (km s$^{-1}$) | $h_3$ | $h_4$ |
|------------------|----------------|-------------|---------|-------------------------------|----------------------|-------|-------|
| 09:11:50.723     | 60:02:07.76    | 100.2       | 94      | 1500 ± 9                       | 141 ± 12              | -0.07 ± 0.04 | 0.01 ± 0.09 |
| 09:11:49.342     | 60:01:38.98    | 114.1       | 112     | 1456 ± 15                      | 175 ± 16              | -0.11 ± 0.04 | 0.00 ± 0.10 |
| 09:11:48.534     | 60:02:05.28    | 84.7        | 97      | 1490 ± 8                       | 155 ± 8               | -0.11 ± 0.03 | -0.06 ± 0.07 |
| 09:11:48.180     | 60:02:46.95    | 111.1       | 69      | 1460 ± 22                      | 141 ± 57              | 0.04 ± 0.07  | 0.08 ± 0.08 |
| 09:11:46.500     | 60:01:52.47    | 80.8        | 108     | 1457 ± 7                       | 152 ± 8               | -0.05 ± 0.03 | -0.09 ± 0.05 |
| 09:11:44.879     | 60:02:19.45    | 57.9        | 86      | 1463 ± 6                       | 167 ± 8               | -0.06 ± 0.02 | -0.04 ± 0.04 |
| 09:11:17.066     | 60:03:14.92    | 191.6       | 291     | 1131 ± 102                     | 35 ± 114              | 0.03 ± 0.09  | -0.03 ± 0.11 |
| 09:11:14.309     | 60:02:18.90    | 173.3       | 271     | 1182 ± 20                      | 98 ± 31               | 0.10 ± 0.07  | -0.03 ± 0.08 |
| 09:11:13.660     | 60:00:43.19    | 279.7       | 243     | 1163 ± 97                      | 92 ± 90               | 0.03 ± 0.06  | -0.02 ± 0.12 |
| 09:11:12.873     | 60:02:39.49    | 187.5       | 278     | 1109 ± 40                      | 34 ± 60               | 0.02 ± 0.07  | -0.01 ± 0.06 |
| 09:11:11.932     | 60:00:52.67    | 273.9       | 247     | 1202 ± 76                      | 76 ± 84               | 0.01 ± 0.07  | -0.04 ± 0.10 |
| 09:11:11.256     | 60:02:01.23    | 201.8       | 266     | 1200 ± 34                      | 80 ± 40               | 0.04 ± 0.06  | -0.02 ± 0.07 |
| 09:11:10.340     | 60:01:53.13    | 213.4       | 264     | 1187 ± 55                      | 92 ± 56               | 0.03 ± 0.07  | -0.03 ± 0.11 |
| 09:11:10.815     | 60:00:38.63    | 354.6       | 250     | 1175 ± 116                     | 81 ± 107              | 0.01 ± 0.07  | -0.03 ± 0.12 |
| 09:11:00.672     | 60:01:46.55    | 288.8       | 264     | 1224 ± 93                      | 69 ± 84               | -0.01 ± 0.02 | -0.01 ± 0.03 |
| 09:12:03.148     | 60:01:07.31    | 232.9       | 109     | 1406 ± 66                      | 247 ± 79              | -0.06 ± 0.07 | -0.05 ± 0.07 |
| 09:10:56.037     | 60:03:10.99    | 323.9       | 280     | 1194 ± 130                     | 68 ± 117              | 0.01 ± 0.05  | -0.02 ± 0.06 |

*Mask Y2*
| $\alpha$ (hh:mm:ss) | $\delta$ (°: ′) | $r$ (arcsec) | PA (degree) | $V_{\text{obs}}$ (km s$^{-1}$) | $\sigma$ (km s$^{-1}$) | $h_3$ | $h_4$ |
|---------------------|----------------|-------------|------------|-----------------|----------------|------|------|
| 09:11:06.573 | 60:02:29.59 | 231.4 | 274 | 1173 ± 173 | 49 ± 136 | 0.03 ± 0.09 | −0.01 ± 0.09 |
| 09:10:36.037 | 60:03:10.99 | 323.9 | 280 | 1227 ± 163 | 76 ± 129 | 0.01 ± 0.09 | −0.01 ± 0.10 |

Mask Z

| $r$ (degree) | $\text{PA}$ (km s$^{-1}$) | $\text{V}_{\text{obs}}$ (km s$^{-1}$) | $\sigma$ (km s$^{-1}$) | $h_3$ | $h_4$ |
|---------------|----------------|-----------------|----------------|------|------|
| 274 | 127 | 1173 | 49 | 0.03 | −0.01 |
| 280 | 122 | 1227 | 76 | 0.01 | −0.01 |

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