Resolving Sirius-like binaries with the Hubble Space Telescope

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Abstract. We have imaged seventeen recently discovered Sirius-like binary systems with HST/WFPC2 and resolved the white dwarf secondary in eight cases. Most of the implied orbital periods are of order several hundred years, but in three cases (56 Per, ζ Cygni and RE J1925−566) the periods are short enough that it may be possible to detect orbital motion within a few years. It will then be possible to derive dynamically determined masses for the white dwarfs, and potentially these stars could be used as stringent tests of the mass-radius relation and initial-final mass relation.

1. Introduction

Although universally accepted, the white dwarf mass-radius relation (Chandrasekhar 1931; Hamada & Salpeter 1961; Wood 1992) has resisted in-depth examination through direct observations for ∼70 years. The difficulty arises mainly from obtaining accurate, model-independent measurements of the masses and radii of known white dwarfs. A combination of spectroscopically derived temperatures and gravities, and accurate parallaxes can provide the independent means of determining $M_{WD}$ and $R_{WD}$, and therefore a new route for examining evolutionary models. The white dwarfs observed by Hipparcos (Vauclair et al. 1997; Provencal et al. 1998) were entirely consistent with expectations, although they were restricted mainly to a narrow range around $0.6M_\odot$. Furthermore, even with these new parallaxes the overall uncertainties are still too large to provide a really thorough examination of the differences between theoretical models which assume a variety of core and envelope compositions.

White dwarfs in resolved binary systems can provide the most stringent tests of evolutionary models, since the mass can be determined from the orbital and physical elements of the system. In practise, though, few such systems are
available to be studied in sufficient detail (they are: Sirius, Procyon, 40 Eri and Stein 2051). However, as reported at previous workshops (e.g. Burleigh 1999) > 20 new Sirius-like binaries have been identified through the ROSAT WFC and EUVE all-sky surveys. Each system consists of a normal or subgiant star plus a hot white dwarf companion, which is responsible for the soft X-ray and EUV flux detected by ROSAT and EUVE. Crucially, in most cases, the bright primary has an accurate Hipparcos parallax, yielding a precise distance for the white dwarf. Thus this new sample of Sirius-like binaries presents a golden opportunity of extending the sample of well-studied white dwarf binary systems. Our first aim, therefore, is to identify those systems that can be resolved and have their orbits measured within an acceptable timescale. Unfortunately, none of these new binaries can be resolved from the ground, due to the huge difference in brightness between the components (> 5 mags.), although we know from radial velocity studies that most of these systems are wide with periods > few years (e.g. Vennes, Christian, & Thorstensen 1998).

The Hubble Space Telescope provides an answer to this problem. Unencumbered by the Earth’s atmosphere, it allows imaging in the UV where the brightness of the hot white dwarf and its companion are similar. It also delivers a diffraction limited resolution of ≈ 0.05″, making it possible to resolve binary components with separations as small as 0.1″. We report here the first results of a snapshot survey with HST/WFPC2 to image these new Sirius-like binary systems.

2. HST/WFPC2 imaging

All the observations have been conducted with the Planetary Camera CCD chip of the WFPC2 instrument aboard HST. A single UV filter was chosen for each system to give approximately equal fluxes between the two components. Exposure times ranged from 8 to 500 seconds, calculated to give the maximum possible signal-to-noise without saturating the chip. Seventeen systems have been imaged thus far, and we have resolved the components in eight cases (Figures 1 & 2). A further ~ ten systems await scheduling.

For the resolved binaries we have calculated the angular separation and, using the known distance to each system, converted this to a physical separation perpendicular to the line of sight (Table 1). Note that these values most likely represent lower limits on the true separation, which will depend on the orbital inclination and current phase. From Kepler’s third law it is then possible to calculate a lower limit on the orbital period, although note we have assumed a mass of 0.6\(M_\odot\) for each white dwarf (the primary masses are estimated from their spectral type).

For the unresolved systems, we can estimate the projected physical separations and orbital periods, assuming a minimum measurable separation on the CCD chip of 0.083″ (Table 2). These results should of course be treated with a certain amount of caution, since such apparently small separations may be observed if the components are close to conjunction or opposition. The true separation and inferred orbital period could be much larger than indicated here.

Of the resolved systems, three immediately stand out. 56 Per, which is in fact a quadruple system (the known visual companion is also resolved into
two components), has a nominal period of \( \approx 47 \) years, similar to Sirius itself. RE J1925–566 may have an orbital period as short as \( \approx 70 \) years. In both these cases it may be possible to detect orbital motion within a few years. In addition, we have resolved the Barium giant + white dwarf system \( \zeta \) Cygni, which has a spectroscopic period of 6489±31 days (i.e. \( \sim 18 \) years). The binary separation (0.11") is consistent with this being the orbital period of the white dwarf.

Among the unresolved systems, it is no surprise that the white dwarfs were not resolved in HR8210 (IK Peg) or HR1608 (63 Eri), since these systems have known binary periods of 21.7 and 903 days respectively. Our failure to resolve these white dwarfs increases the likelihood that the degenerate star is responsible for the radial velocity variations seen in the primary. Conversely, we have confirmed that the white dwarf in 14 Aur C is a wide member of a triple system, and the 2.99 day period seen in this system is most probably due to an M-dwarf companion (Holberg et al. 2000).

Table 1. Estimated separations and orbital periods for the resolved systems

<table>
<thead>
<tr>
<th>System</th>
<th>Distance (pc)</th>
<th>Separation (arcsec)</th>
<th>( P_{(\text{nominal})} ) (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD2133*</td>
<td>F7 V+DA</td>
<td>140</td>
<td>0.602</td>
</tr>
<tr>
<td>HD27483*</td>
<td>F6 V+DA</td>
<td>46</td>
<td>1.276</td>
</tr>
<tr>
<td>14 Aur C*</td>
<td>F4 V+DA</td>
<td>82</td>
<td>2.006</td>
</tr>
<tr>
<td>RE J1925–566</td>
<td>G7 V+DA</td>
<td>110</td>
<td>0.217</td>
</tr>
<tr>
<td>HD223816</td>
<td>F8 V+DA</td>
<td>92</td>
<td>0.574</td>
</tr>
<tr>
<td>56 Per*</td>
<td>F4 V+DA</td>
<td>42</td>
<td>0.390</td>
</tr>
<tr>
<td>MS 0354.6−3650</td>
<td>G2 V+DA</td>
<td>400</td>
<td>0.992</td>
</tr>
<tr>
<td>( \zeta ) Cyg*</td>
<td>G8 IIIp+DA</td>
<td>46</td>
<td>0.11</td>
</tr>
</tbody>
</table>

* Distance from Hipparcos

Table 2. Projected separation limits and implied maximum orbital periods for the unresolved systems

<table>
<thead>
<tr>
<th>System</th>
<th>Distance (pc)</th>
<th>( P_{(\text{upper})} ) (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BD+08°102</td>
<td>F7 V+DA</td>
<td>62</td>
</tr>
<tr>
<td>HD15638*</td>
<td>F6 V+DA</td>
<td>199</td>
</tr>
<tr>
<td>HD18131*</td>
<td>KO IV+DA</td>
<td>104</td>
</tr>
<tr>
<td>HR1608*</td>
<td>KO IV+DA</td>
<td>55</td>
</tr>
<tr>
<td>HR3643*</td>
<td>F7 II+DA</td>
<td>139</td>
</tr>
<tr>
<td>HR8210*</td>
<td>A8 Vm+DA</td>
<td>46</td>
</tr>
<tr>
<td>RE J1309+085</td>
<td>F9 V+?</td>
<td>275</td>
</tr>
<tr>
<td>BD+27°1888</td>
<td>F0 V+DA</td>
<td>250</td>
</tr>
<tr>
<td>( \beta ) Crt</td>
<td>A1 III+DA</td>
<td>82</td>
</tr>
</tbody>
</table>

* Distance from Hipparcos
Figure 1. WFPC2 snapshot images. Each frame is $5''\times5''$ in size, north is at the top and east on the left. The UV filter used is indicated on each image.
Figure 2. Left: WFPC2 image of 14 Aur. The image is 20\arcsec wide. The C component is resolved into the object previously known from the ground, denoted Ca (itself an unresolved binary with a 2.99 day period), and the hot WD, denoted Cb. Right: 56 Per. This image is 10\arcsec × 10\arcsec. The Aa–Ab pair is the F4V primary plus WD companion. The known visual companion, 56 Per B, is also resolved into two components.

3. The next step: FUSE spectroscopy of the white dwarfs

Surprisingly, we know very little about the white dwarfs in these systems. Since they cannot be resolved from the ground, it has thus far been impossible to obtain spectra of the H Balmer series in the optical region, from which the temperature (T\text{eff}) and gravity (log g) are usually derived. Instead, we have had to make do with any information we have been able to obtain from the single H Lyman $\alpha$ line and the shape of the continuum in IUE far-UV spectra. From these features alone it is impossible to unambiguously constrain T\text{eff} and log g. However, now that the Far Ultraviolet Spectroscopic Explorer (FUSE) is fully operational, we can obtain spectra of the entire H Lyman series and use these absorption lines to derive T\text{eff} and log g (and hence mass and radius). We have a GI program with FUSE (PI Burleigh) to obtain these data for many of the new Sirius-like systems. Figure 3 shows the data from the first target to be observed, 14 Aur C. Modelling the Lyman lines with a pure-H atmosphere model, we obtain T\text{eff} \approx 41,000 - 42,500 K and log g \approx 8.10 - 8.45. Hence, M_{WD} \approx 0.75 - 0.90 M_{\odot} and R_{WD} \approx 0.010 - 0.012 R_{\odot}, just about consistent with the lower limit on the Hipparcos distance estimate to the primary (74 pc). We stress that this represents work in progress, and we have some way to go before we will be fully confident in our modelling and understanding of the FUSE data.
Figure 3. *FUSE* spectrum of the white dwarf companion to 14 Aur C. We have been able to model the data with a pure-H atmosphere $T_{\text{eff}} = 41,000\text{ K} - 42,500\text{ K}$ and $\log g = 8.10 - 8.45$.

4. **Prospects from the *GALEX* far-UV all-sky survey and *SIM***

In 2002 NASA will launch *GALEX* (the *Galaxy Evolution Explorer*), a mission designed to survey the whole sky in the UV (Bianchi & Martin 1998). This project is expected to detect $\approx 3 \times 10^5$ hot white dwarfs (as well as $\approx 10^6$ quasars!), and we calculate that $\approx 30,000$ new Sirius-like binary systems will be identified. Obviously this is a huge dataset to follow-up, and so we have applied to the *Space Interferometry Mission (SIM)* (due for launch $\approx 2010$) for Key Project Program status (PI: Holberg) to image, resolve and measure the orbits of many of the systems *GALEX* will identify.

**References**


