Astrometry of Extra-Solar Systems with HST/FGS

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Abstract

We present here an overview of our program of astrometric measurements of extra-solar systems using a Fine Guidance Sensor on HST. We briefly describe the instrument and our interferometric techniques for attaining high precision astrometry. Then we introduce some basic concepts used to combine astrometry and spectroscopy to characterize the planetary orbit and determine the actual companion mass. We highlight three systems as examples of recent results from our group. These results highlight the importance of astrometric follow-up to determine the actual nature of companions discovered by radial velocity techniques.

Figure 1: Hubble Space Telescope.

Fine Guidance Sensor

The FGS is a two-axis white-light optical interferometer aboard Hubble Space Telescope (HST). A schematic view of its optical train is shown on Figure 2. This instrument has been designed to work as a guider for the Space Telescope, requiring a remarkable astrometric precision which makes it suitable for scientific research as well. The whole instrument has three FGSs operating at the same time, of which two (FGS2 and FGS3) are used for guiding. FGS1r is currently being used for science. A detailed description about the FGS can be found in Nelan & Makidon (2003). In Figure 3 there is a scheme of the field-of-view (FOV) of the three FGSs on the focal plane of the telescope.

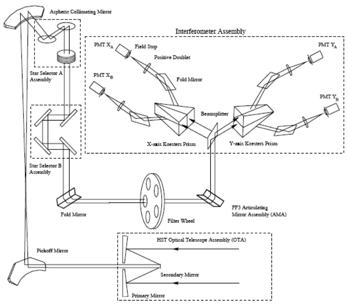

Figure 2: FGS1r optical train schematic.

Astrometry with an FGS

As an interferometer working with a 2.4 m telescope in space, the FGS has a potential capability for measuring relative stellar positions with sub-millisecond of arc precision (~0.3 mas), with a dynamical range up to 12 magnitudes.

Figure 3 shows the Koester prism, the device responsible for the interference of light collected by the telescope. The light coming outward from each side of the prism is focused by a lens into photomultiplier tubes (PMT-A and PMT-B). Their measured photon counts (A and B) can be combined by the following expression S = (A-B)/(A+B), which gives the response of the interferometer. The read position can be changed by performing slight rotations on a secondary mirror, which is read by an encoder. Then the angles are translated to the telescope focal plane coordinates (X or Y). This gives the position in one direction. However the light beam is split into two identical prisms rotated by 90 degrees, providing positions in two orthogonal directions. Astrometric measurements are made by scanning S over a range of positions. For example, the response S(X or Y) for a point-like source is given by the curve shown in Figure 4.b. This is the FGS interferometric fringe. Extended sources like resolved stellar disks or binary stars show different patterns for the S-curve. These can be modeled giving direct measurements of the light distribution of these objects. In our work we are particularly interested in highly accurate measurements of relative stellar positions in a field which only requires the measurement of the photo-center of each star (POSITION mode) and not the morphology of the entire S-curve (TRANSFER mode).

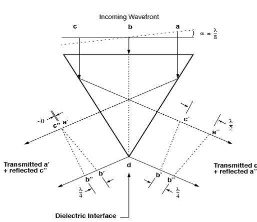

Figure 3: Constructive and destructive interference in the Koester prism.

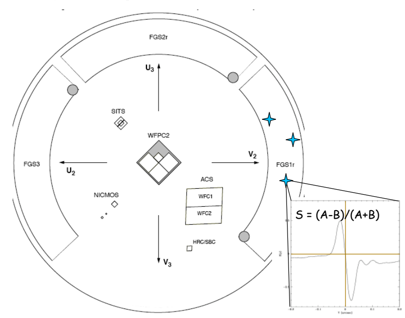

Figure 4: a. (great circle) FGSs in the HST focal plane (projected onto the sky). b. (right panel) FGS1r S-curve response for a point-like source.

HET Spectroscopy: More than a follow-up!

Although the FGS provides high astrometric precision, the measuring of stellar reflex motion due to surrounding planetary bodies can require astrometric precisions at or below our instrumental limit of ~1 mas per observation. We make use of stellar radial velocities provided by spectroscopic time series to supplement and support our astrometric measurements. We augment the already published results from other groups by obtaining additional spectroscopic data with the Hobby Eberly Telescope (HET) at McDonald Observatory (see Figure 5). This is a 9.2 m telescope with a High Resolution Spectrograph (HRS), nominally R = 60,000. This instrument is equipped with an I_2 gas cell for a contemporaneous wavelength calibration, providing relative radial velocities with precision down to ~3 m/s. The high precision together with the high cadence make it not only a good follow-up to increase orbital parameter precision but also a tool for discovering additional companions that could be hidden in the noise of previous data (e.g. McArthur et al., 2004). The discovery of new planets within known systems has great value. Any newly revealed as multi-planet systems provide useful dynamical laboratories . They are also good places to test planetary formation theories.

Figure 5: Hobby Eberly Telescope, McDonald Observatory located in west Texas, USA.

Astrometry and Radial Velocity: the perfect combination!

Radial velocity alone is not sufficient to describe completely the orbit of a planet around a star. This is because we are only measuring the velocity component in the radial direction. Astrometry provides two components of the orbital positions on the plane of the sky, which is orthogonal to the radial direction. Hence by combining both techniques it becomes possible to describe the orbit thoroughly. One remarkable issue is that even by adopting a value for the stellar mass obtained from other means (e.g. atmospheric models), the planetary mass, which is considered a key parameter to claim the body as a planet, is still undetermined only by radial velocity measurements. However it is possible to determine its projected mass $M_p\sin(i)$, which represents at best a lower limit, depending on the value of the inclination angle i of the orbital axis with respect to the radial direction. Most of the announced extra-solar planet candidates do not have their actual mass known. Figure 6 shows the two components of the orbital motion of HD136118 measured by astrometry with FGS and the radial velocity component measured by HET. Its complete orbit is also shown, and its measured mass is described on Table 1.

HD 136118

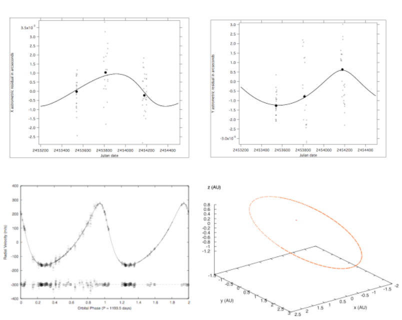

Figure 6. Top panels: orbital position components of HD136118 reflex motion projected onto the plane of the sky given by FGS astrometry. Bottom left panel: Radial velocity HET and Lick data, model and residuals for HD136118. Bottom right panel: complete orbital model for HD136118b.

Weighing "Planets"- A Giant Planet, a Brown Dwarf and a M Dwarf Star

The astrometric determination of companion's mass can be decisive to characterize it as a planet. A good illustration of this fact can be seen from our results for three objects that were previously listed as extra-solar planet candidates: Gliese 876b, HD136118b and HD33636b. Surprisingly each object has been found to belong to a different class: a giant planet, a brown dwarf and a dwarf star, respectively (Benedict et al., 2002, Martioli et al., 2008, and Bean et al., 2007). These results demonstrate the importance of considering further applications of complementary techniques in observing extra-solar planetary systems.

Table 1: Objects observed by astrometry and radial velocity.

PLANET CANDIDATE	$M_p\sin(i)$ (M_{Jup})	Actual Mass (M_{Jup})	Orbital Period (days)	Class
Gliese 876 b	2.0	1.9 ± 0.5	61.02 ± 0.03	Giant Planet
HD 136118 b	11.9	28^{+29}_{-9}	1193.5 ± 1.2	Brown Dwarf
HD 33636 b	9.3	142 ± 11	2117.3 ± 0.8	M6V Star

References

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