Astrometric Stability and Precision of Fine Guidance Sensor #3: The Parallax and Proper Motion of Proxima Centauri

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Abstract

Demonstrating the utility of *HST* for astrometry, we obtain $\pi = 0.7692 \pm 0.0004$ arcsec and $\mu = 3.8531 \pm 0.0005$ arcsec per year, for Proxima Centauri. Achieving this precision required 42 observation sets spaced over 1.5 years. Parallaxes with precision slightly better than 0.001 arcsec can be obtained with 11 observations spanning one year.

I. Observations

We present a progress report on astrometry of Proxima Centauri with the *HST* FGS 3. Proxima Cen (α Cen C; V645 Cen) is a known flare star. The spectral type is M5Ve and $M_V = 15.45$, V = 11.22 (Walker 1981). The mass of Proxima Cen is estimated to be $0.11 M_{Sun}$ (Kirkpatrick and McCarthy, 1993). An early assessment of astrometry with FGS 3 can be found in Benedict et al. (1992). Benedict et al. (1993) presents a more detailed discussion of the astrometry of the reference stars. The scientific motivation for these observations is the determination of an upper limit for non-stellar companions to Proxima Cen. Since our monitoring is incomplete, we will discuss the planet search at a later time.

Our astrometric results thus far are based on 42 observation sets (orbits) acquired between 23 March 1992 to 5 October 1993. Figure 1 shows the field containing Proxima Cen and the reference stars. We attempted 49 data sets. Six were lost or fatally corrupted due to jitter and/or loss of lock. One GTO set was lost to safe-mode. We have experienced no losses of lock since January 1993, after a significant modification to the Pointing Control System software. We suffered one GS Acquisition failure. Since this is a monitoring project, we would prefer no gaps in coverage. We have experienced several. One is natural, due to the *HST* sun constraint. A second gap occurred due to FGS 2 bearing difficulties.

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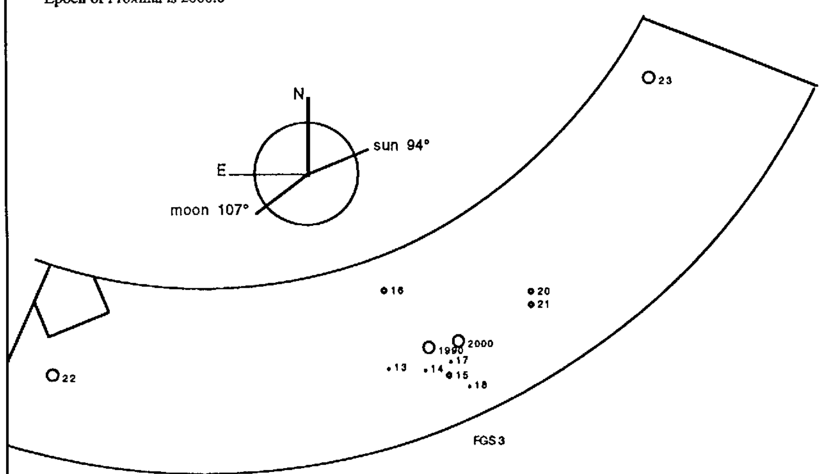
File : Fig. 1 Pickles 3.55, by James McCartney, docs: Barbara McArthur, Univ. of Texas at Austin
V1: Ra: 14h 30m 27.358s Dec: -62° 29' 31.793" Roll: 0.00° Orient: 112.15° Veh.Roll: 67.85°
AntiSun: 85° Moon: 107° Plate Roll: 0° Tobs: 92/08/15.808 Tcat: 0/01/01.500 Now: 92/12/15 16:21:29

Reference Stars in the Proxima Centauri Field

Star ID	RA				DEC				V		B-V	
Proxima	14h	29m	43.003s	± 0.008s	-62°	40'	46.1"	± 0.08"	11.02	± 0.08	1.94 ±	0.08
13	14	29	55.664	0.004	-62	41	21.3	0.08	15.10	0.07	0.72	0.10
14	14	29	49.109	0.024	-62	41	21.6	0.17	15.76	0.06	0.87	0.17
15	14	29	44.491	0.006	-62	41	28.8	0.08	14.36	0.11	0.66	0.14
16	14	29	56.659	0.003	-62	39	44.5	0.07	14.58	0.09	0.52	0.12
17	14	29	44.281	0.006	-62	41	12.8	0.08	15.32	0.08	0.73	0.12
18	14	29	40.875	0.012	-62	41	41.5	0.15	15.14	0.05	1.53	0.07
20	14	29	29.567	0.007	-62	39	45.6	0.10	14.30	0.11	1.05	0.15
21	14	29	29.423	0.006	-62	40	2.3	0.07	14.43	0.09	0.69	0.13
22	14	30	55.728	0.033	-62	41	26.3	0.50	11.83	0.6	-	-
23	14	29	8.998	0.033	-62	35	23.9	0.50	11.19	0.6	-	-

Positions are J2000.0

Epoch of Proxima is 2000.0



Proxima Cen and reference stars within FGS #3. Positions for Proxima Cen are shown for epoch 1990.0 and 2000.0. Orientation is nominal for 15 August 1992 (JD 2448849).

Figure 1

What have we done to pre-process these data?

- median filtered to reduce jitter
- secondary mirror breathing treated as linear drift
- known encoder bit-error pattern (LSB) included
- asphere and pick-off corrections included
- our best Optical Field Angle Distortion mapping (Jefferys et al., this volume)

These interim results do not include corrections for field dependent k-factors, de-jittering, and possible color effects. Hence, there is room for improvement.

II. The Astrometric Model, Resulting Precision, and Scale Stability

Every astrometry observation is an act of calibration. With our 42 observation sets (with 5 - 7 reference stars per set) we solve for

- plate (set) constants: *a, b, c, d, e, f*
- star parameters: proper motion, μ; and parallax, π
- R, roll orientation of the constraint plate with respect to RA and DEC

in the system of equations:

$$\xi = aX + bY + c - \mu_x t - (p_x \times \cos(R) - p_y \times \sin(R))\pi$$

$$\eta = dX + eY + f - \mu_y t - (p_x \times \sin(R) + p_y \times \cos(R))$$

where the X, Y are positions of the stars in each data set, p_x and p_y are parallax factors. The ξ and η are x, y positions for the plate (observation set) chosen as our constraint, 1992, day 135.

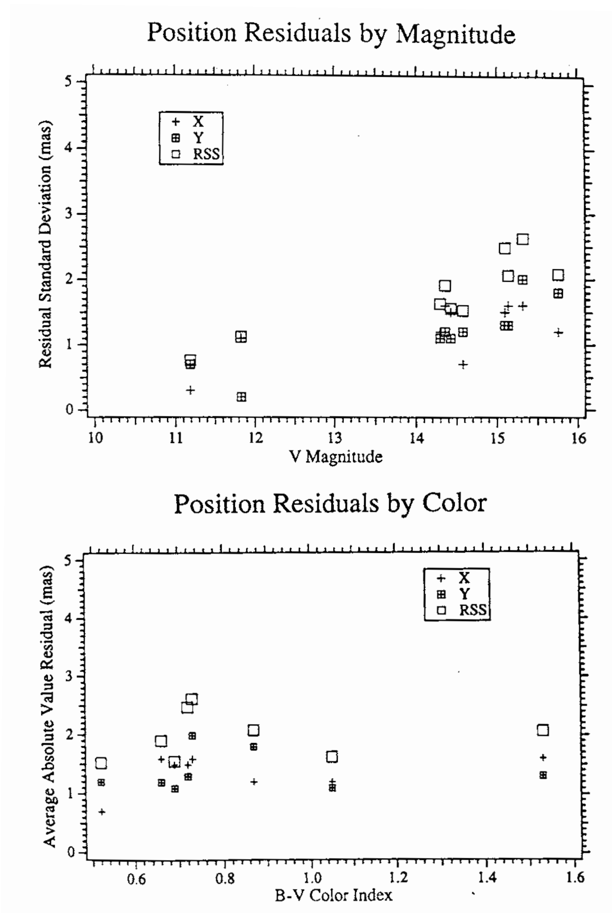


Figure 2

From Figure 1 we see that the average magnitude of our reference frame is V~15. Hence, parallax and galactic rotation effects would be at a level of ~0.5 millisecond of arc per year level (van Altena, 1993). Nonetheless, one reference star (18) is found to have a parallax π = 0.0031±0.0005 arcsec. After 3σ rejection, reference frame RSS average absolute value residual is 2.0 mas. The 3σ rejection resulted in 6 percent of the reference stars being rejected. Figure 2 shows the run of residual against star ID and against star color. Note that there are no statistically significant color terms for 0.52 < B – V < 1.53.

We next explore the scale stability of the Proxima Cen reference frame by defining a global scale:

$$S = (ae - bd)^{1/2}$$

Figure 3 plots these values against time. We see significant variations. However, these variations are not typical scale variations due to primary-secondary mirror despace changes. They are most likely due to optical component shifts internal to FGS 3. See Whipple et al. in this volume for a discussion. The quality of the scale-like change is more important to *HST* FGS Astrometry than the quantity of the change. The gradual scale-like changes seen will be monitored, eventually understood, and removed. For now, the changes are absorbed into the astrometry coefficients. Lastly, note (Figure 3) that our totally independent long-term stability (LTSTAB) field shows quantitative agreement (Whipple et al., this volume).

III. Astrometric Results

The following table compares our interim Proxima Cen parallax and proper motion with a long-duration ground-based campaign. Errors are internal.

	HST	Ground
Study duration	1.5y	45y
# plates	41	130
Ref. stars <V>	14.9	12.3
Parallax	0.7692 ± 0.0004	0.773 ± 0.004 arcsec
Proper Motion	3.8531 ± 0.0005	3.8473 ± 0.0008 arcsec/year

The ground-based study is described in Kamper and Wesselink (1978). We can expect differences in proper motion due to motions in the reference frame. Ours, being fainter, has less motion and likely yields a more accurate proper motion for Proxima Cen. In a ground-based redetermination of the proper motion including more recent plate material van Altena & Yang (1992) get 3.8527 arcsec/year for the proper motion. Reference star 18 is included in the solution with its parallax.

We next discuss astrometry with a realistic set of observations. What does a one year campaign yield? We analyze an 11 observation set sub-set of the Proxima Cen data, representing one observation per month and find π = 0.7699±0.0007 arcsec and

μ = 3.8561±0.0013 arcsec/year. Modern ground-based CCD astrometry yields 0.001 arcsec precision parallaxes and 0.0006 arcsec/year precision proper motions for 3-5 year baselines (Monet et al. 1992). If you are in a hurry, use *HST*.

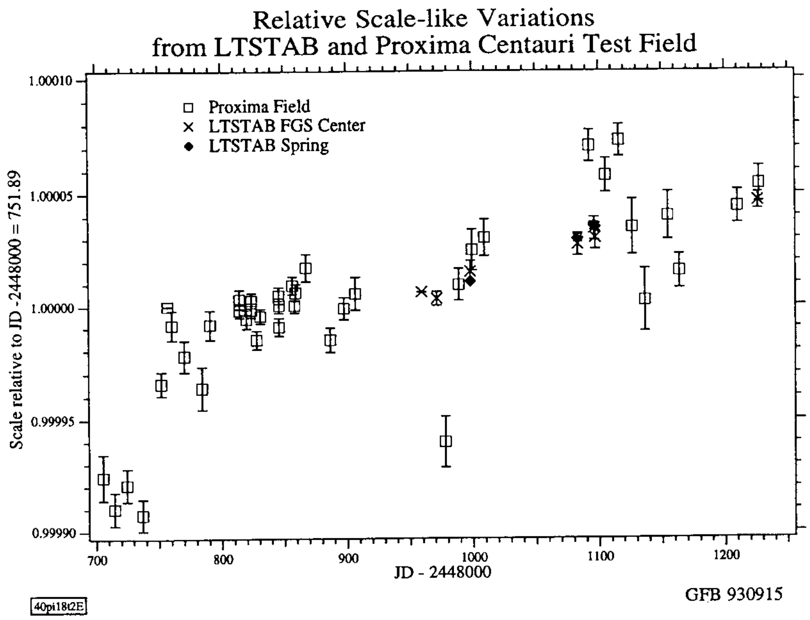


Figure 3

Conclusions

- We obtain astrometric precision of 0.0020 arcsec RSS per observation in the pickle center, better than pre-launch estimates.
- Scale-like variations seen in the Proxima Cen astrometry do not adversely affect our astrometry. The variations agree with the LTSTAB monitoring results (Whipple et al., this volume).
- A 1.5 year campaign with *HST* produces a parallax precise to 0.0004 arcsec, and agrees with a 45 year ground-based effort.
- Two parallax determinations from a single field with *HST* have precisions similar to the best ground-based techniques, but required one quarter the time.

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