The Optical Field Angle Distortion Calibration of HST Fine Guidance Sensors 1R

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The usual suspects

last meeting of the STAT, 10/96

The OFAD

- **Geometric distortion** in the FGS is referred to as the Optical Field Angle Distortion (OFAD)
- Distortion alters the measured positions of stars in the FGS FOV by more than 1.0" (scale-like) and 0. 5" (non-linear components).
  - For comparison, typical science objective is to obtain parallaxes accurate to 0.3 mas or better.
- **How to calibrate?** Use a star field in M35

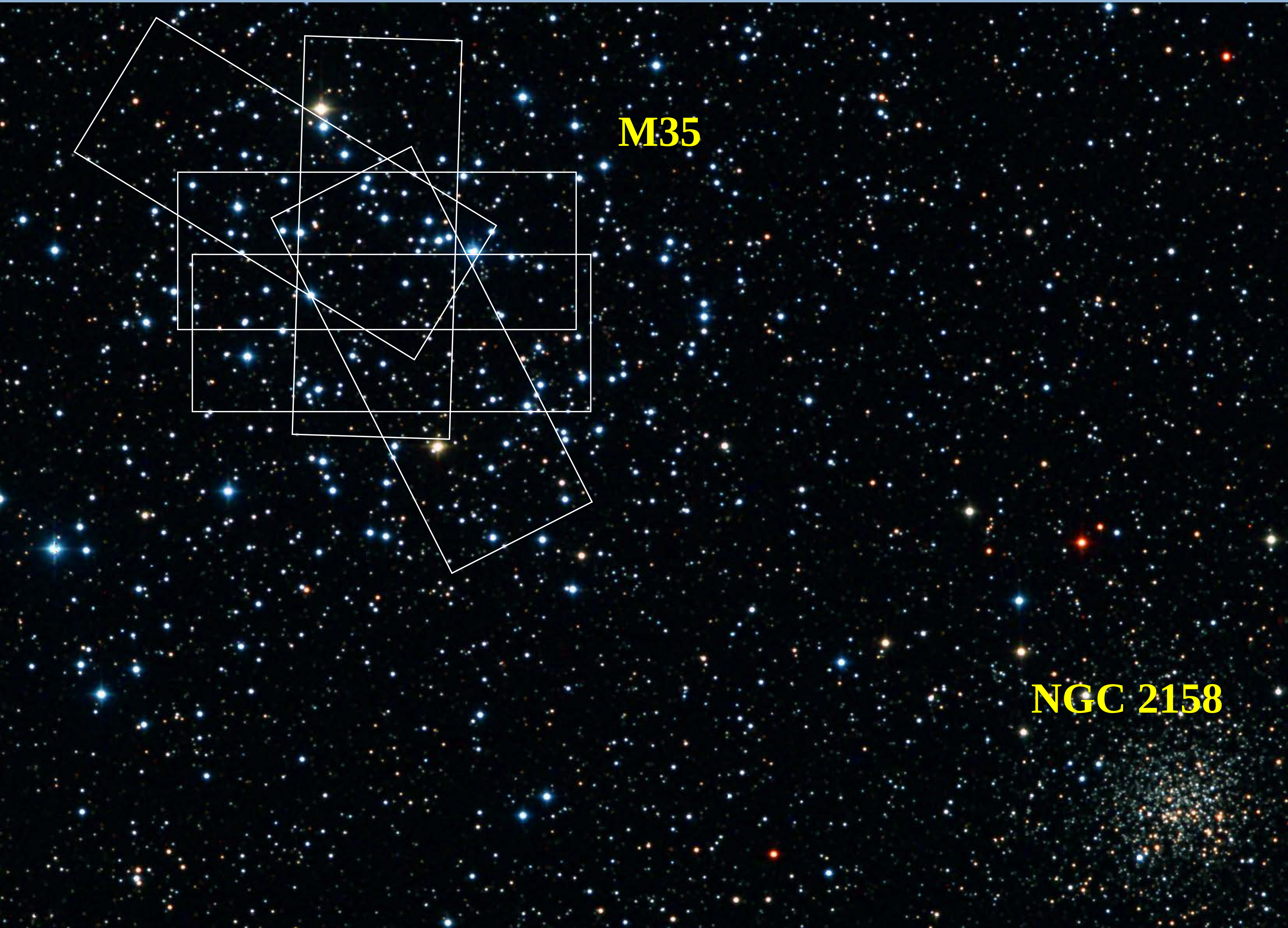
Calibration Field --- Open Cluster M35

- M35 contains many stars with 8 < V < 14, ideal for the FGS calibration.

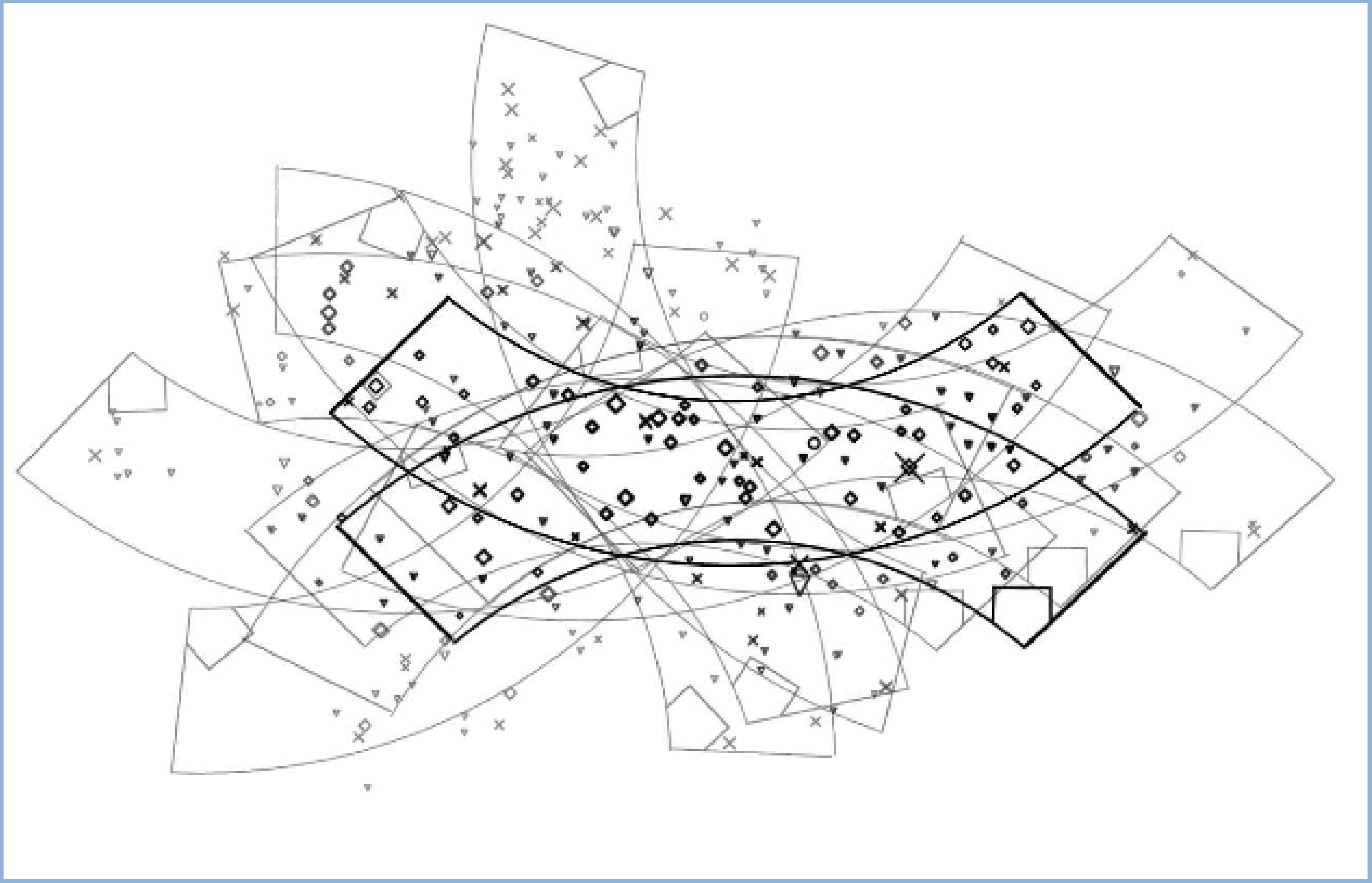
- M35 is near the ecliptic (Dec = +24^{o} 25'). It can be observed nearly year round (in 3-gyro mode), which makes it suitable to monitor FGS1r performance over time.

- FGS1r calibration data acquired in December 2000, while M35 was at "anti-sun" (proposals FGS/CAL 8469, AR 9190)

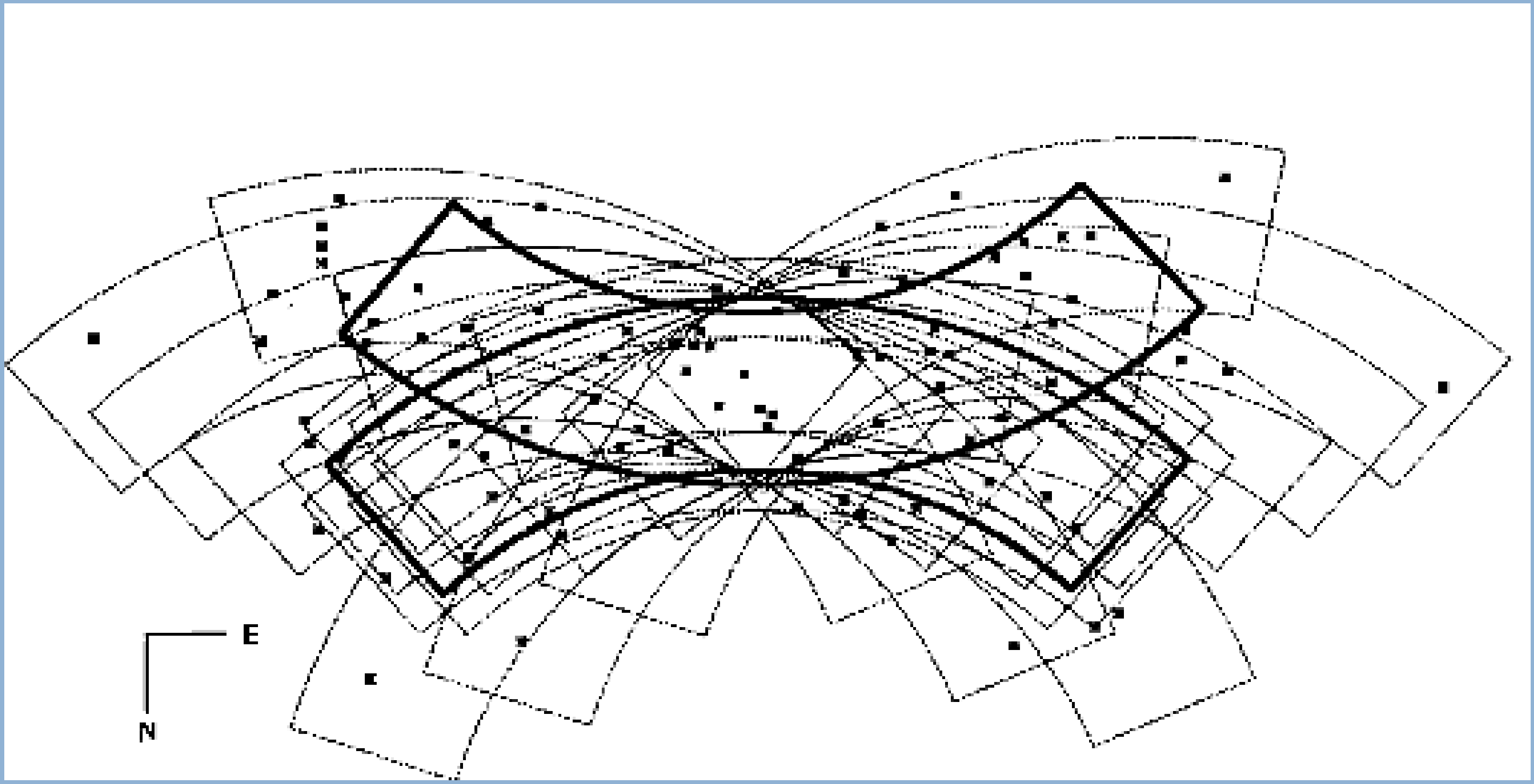
- Analysis of FGS1r was assisted by having a 1 mas catalog of this region from earlier calibrations of FGS3.


M35
NGC 2158

FGS1r OFAD Calibration



FGS3 OFAD Calibration



Analysis

We employed GaussFit[1] to ***simultaneously*** estimate the

- **relative star positions (generate a catalog)**
- **pointing & roll** of the HST during each orbit
- **magnification** of the telescope
- **OFAD polynomial coefficients**
- ρ**A**, k**A**, two parameters that describe the star selector optics[2]

1. Jefferys, Fitzpatrick, & McArthur 1987, Celestial Mechanics, 41, 39
2. McArthur et al. Proc 1997. Calibration Workshop

The Distortion Model

$$x' = a_{00} + a_{10}x + a_{01}y + a_{20}x^2 + a_{02}y^2 + a_{11}xy$$
$$+ a_{30}x(x^2+y^2) + a_{21}x(x^2-y^2) + a_{12}y(y^2-x^2)$$
$$+ a_{03}y(y^2+x^2) + a_{50}x(x^2+y^2)^2 + a_{41}y(y^2+x^2)^2$$
$$+ a_{32}x(x^4-y^4) + a_{23}y(y^4-x^4) + a_{14}x(x^2-y^2)^2$$
$$+ a_{05}y(y^2-x^2)^2$$

$$y' = b_{00} + b_{10}x + b_{01}y + b_{20}x^2 + b_{02}y^2 + b_{11}xy$$
$$+ b_{30}x(x^2+y^2) + b_{21}x(x^2-y^2) + b_{12}y((y^2-x^2)$$
$$+ b_{03}y(y^2+x^2) + b_{50}x(x^2+y^2)^2 + b_{41}y(y^2+x^2)^2$$
$$+ b_{32}x((x^4-y^4) + b_{23}y(y^4-x^4) + b_{14}x(x^2-y^2)^2$$
$$+ b_{05}y(y^2-x^2)^2$$

Motions M35 Proper

In 2004 we determined the *internal* proper motions of selected stars in M35 based upon 12 years of HST FGS data.

- *Previously we had used ground-based determinations from the McNamara catalog.*
- Only stars that have been observed at more than 4 epochs over the course of the 12 years were included in the analysis.
- Proper motion amplitudes ranged from 0 to ~20 mas/yr.

A new OFAD in both FGS3 &FGS1r and a new M35 catalog were recalculated using the more accurate proper motions.

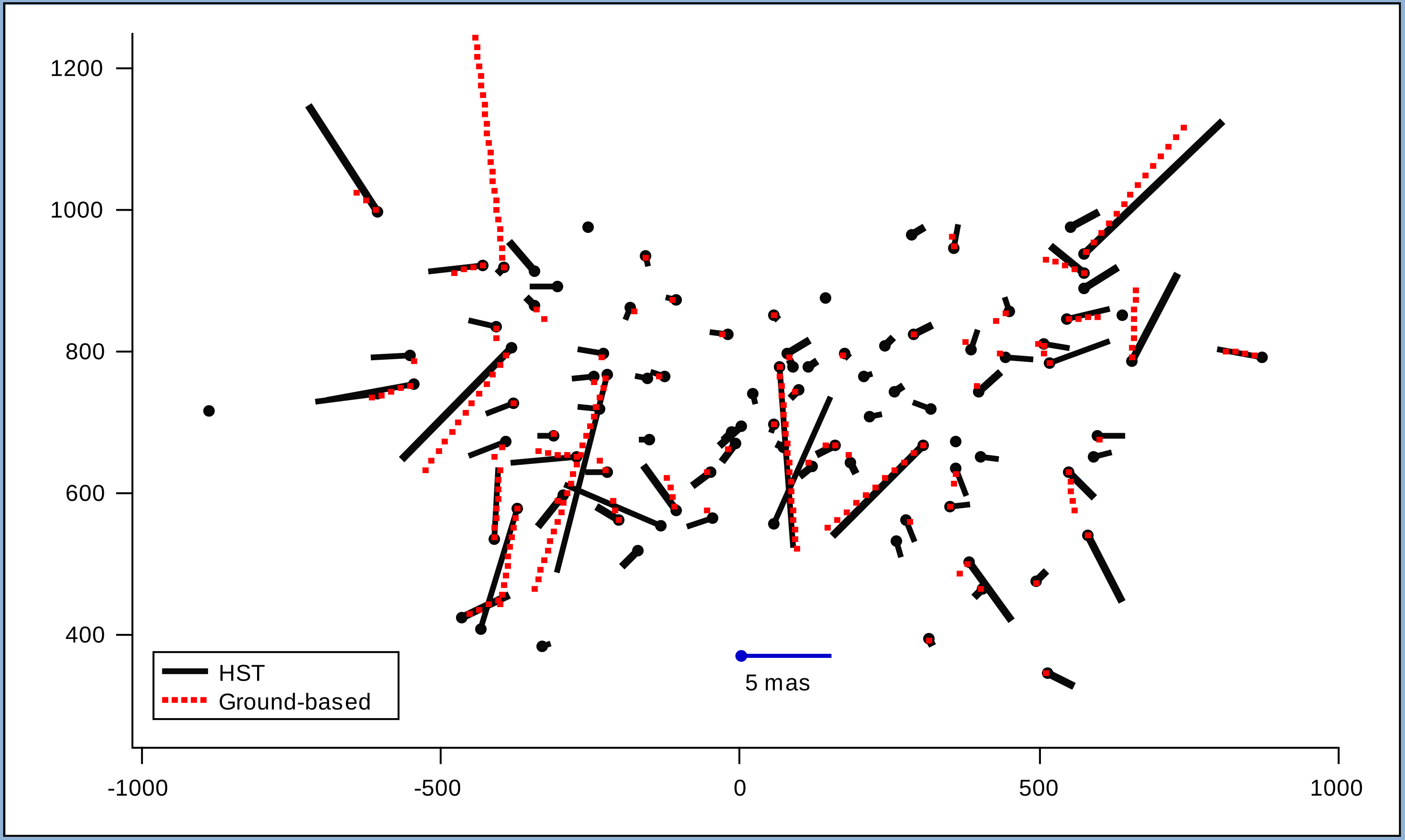
Epochs of FGS OFAD calibrations in M35

FGS	date	# HST orbits
3	12/90	5
3	01/93	20
3	09/95	5
1	12/00	12

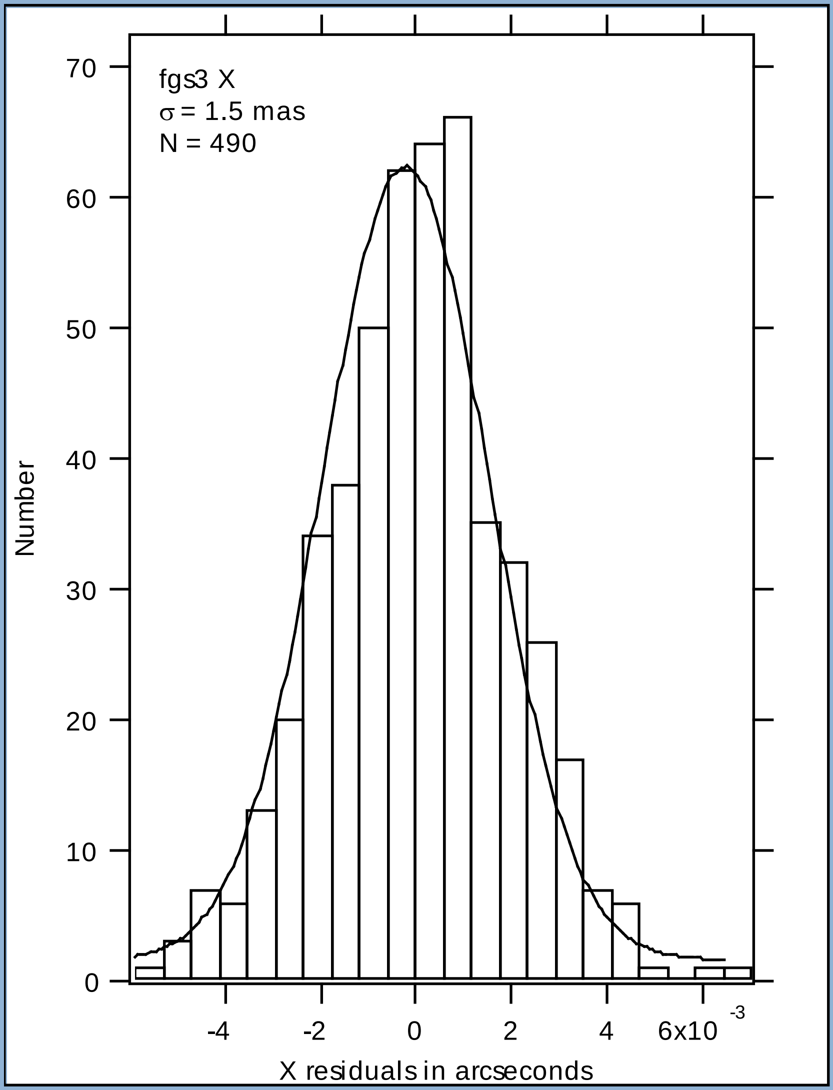
In addition, there have been ~6 observations / year of a field in M35 to monitor OFAD calibration.

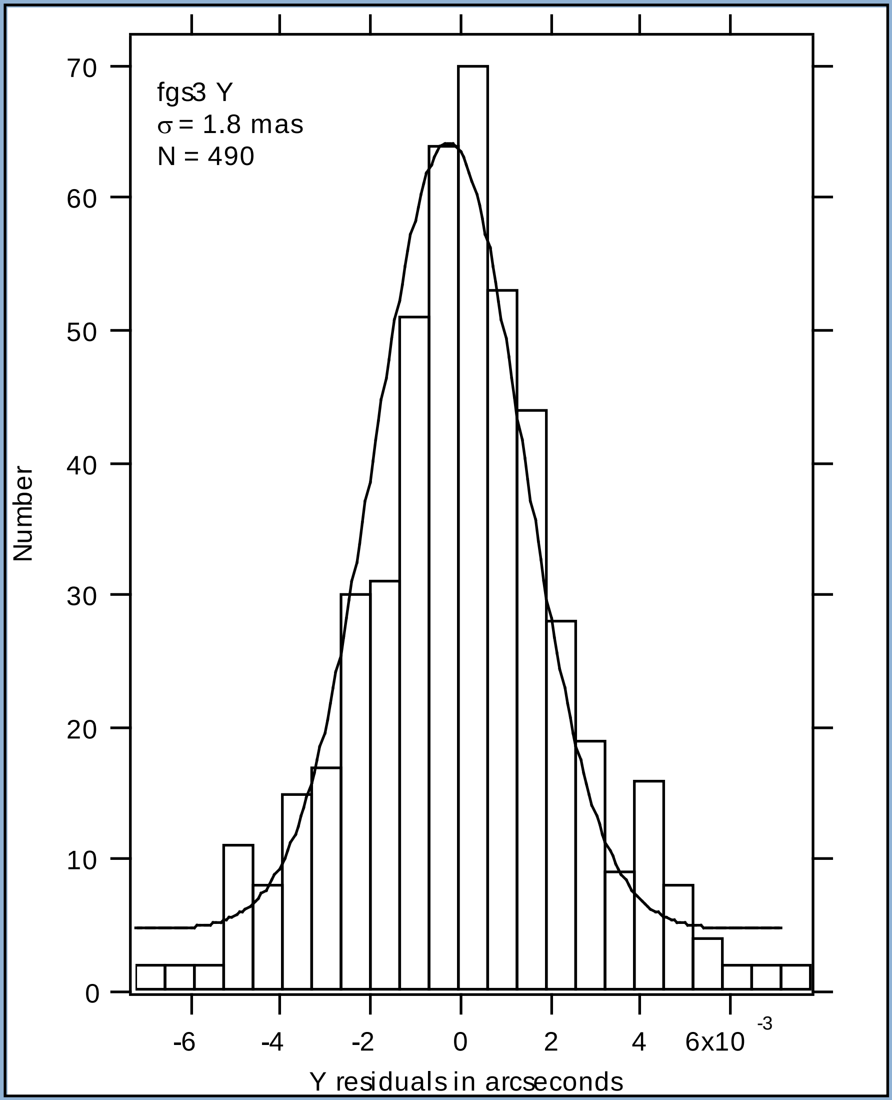
M35 Proper Motions

milli-arcseconds per year

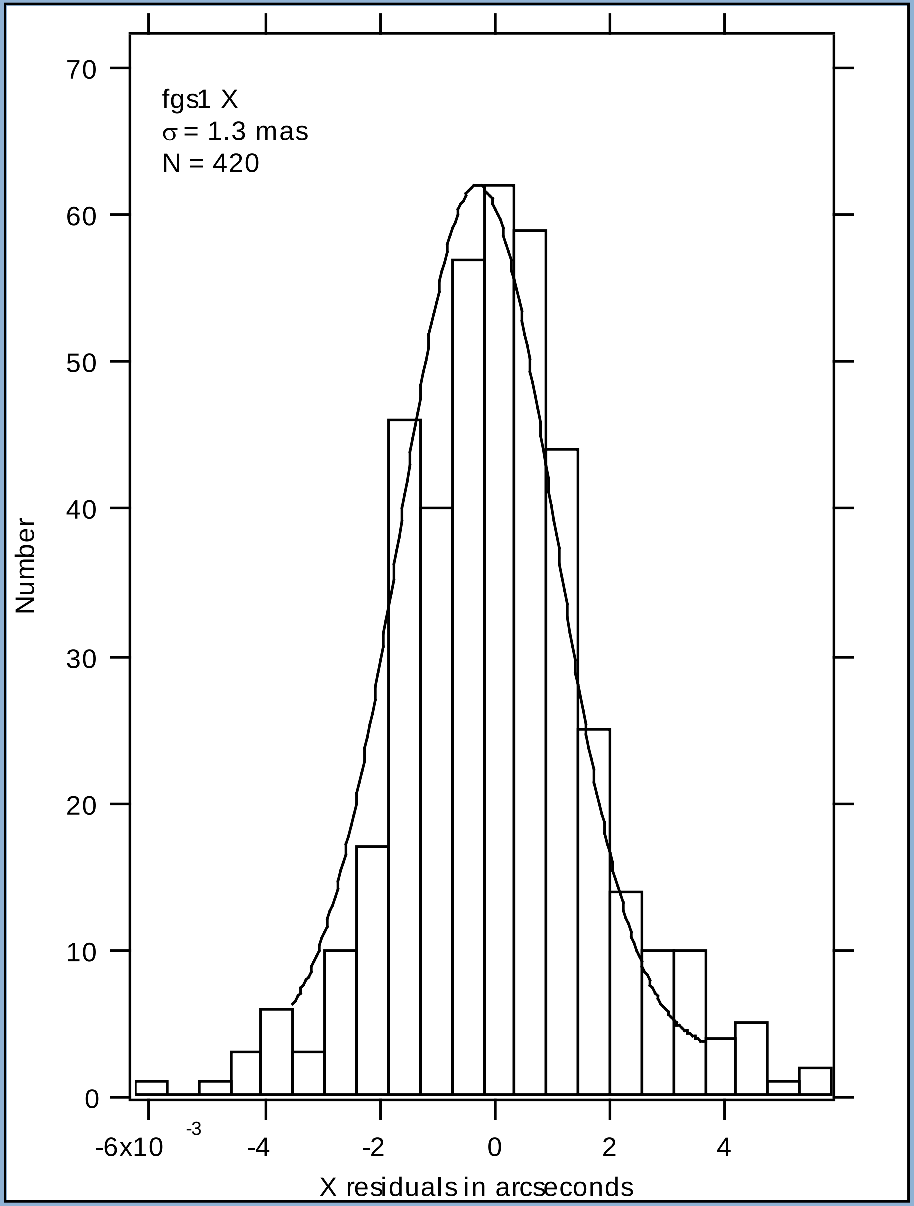


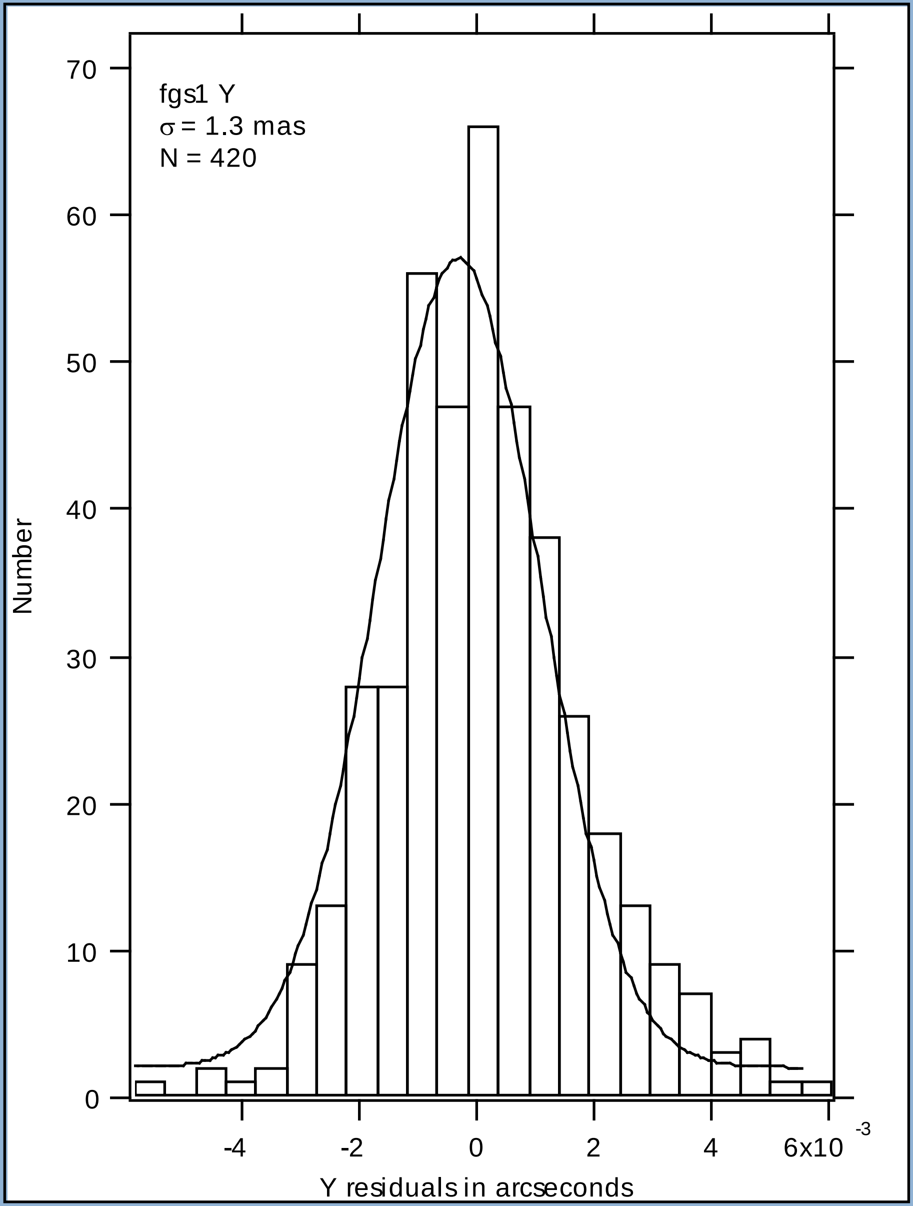
New FGS3 OFAD





New FGS1 OFAD





OFAD Calibration Improvement with M35 Proper Motions

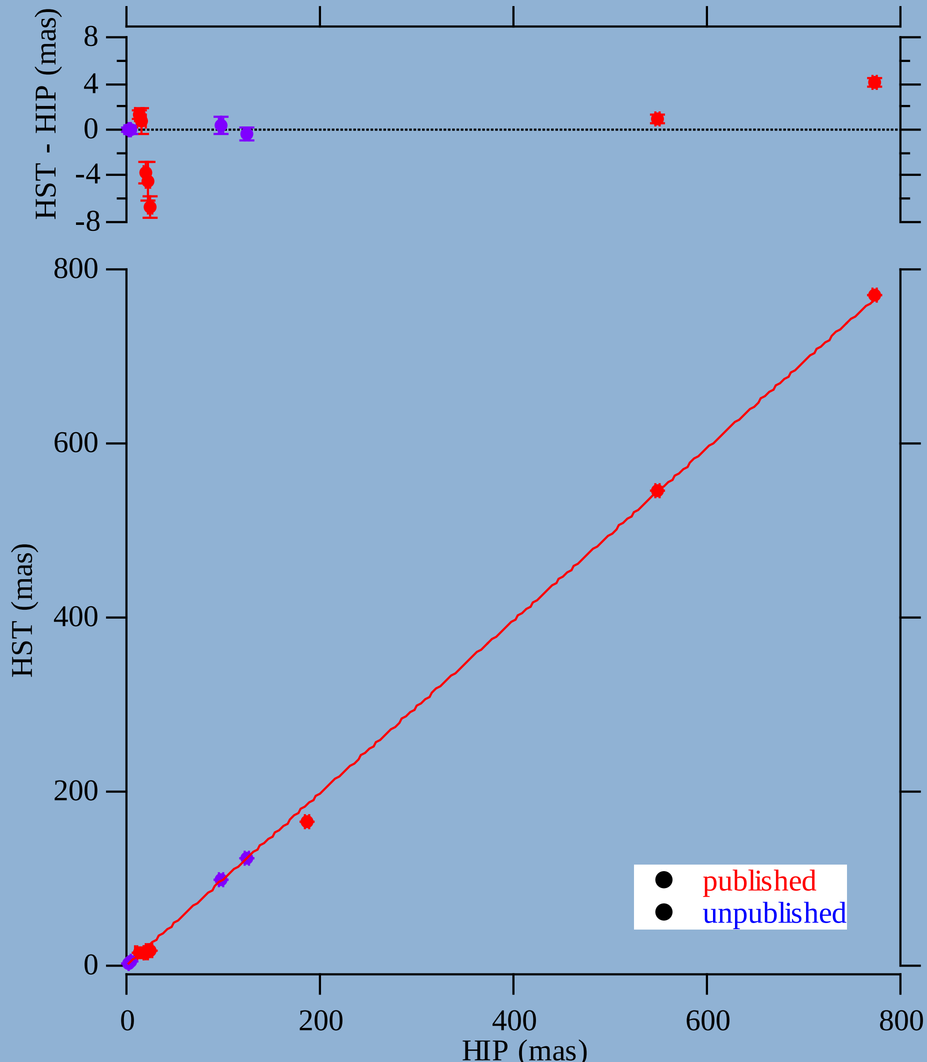
With the determination of the proper motion of the M35 field we have significant improvement in the quality of the OFAD calibration in both FGS1r & FGS3.

	Previous OFAD	**New OFAD**
FGS 3	σ X = 2.3 mas	σ X = 1.5 mas
	σ Y = 2.2 mas	σ Y = 1.8 mas
FGS1r	σ X = 1.6 mas	σ X = 1.3 mas
	σ Y = 1.7 mas	σ Y = 1.3 mas

HST/FGS and Hipparcos

Object	π_{HST} (mas)	π_{Hip} (mas)	*HST* Reference
Proxima Cen...	769.7 ± 0.3	772.33 ± 2.42	1
Barnard's Star...	545.5 ± 0.3	549.3 ± 1.58	1
Gliese 876...	214.6 ± 0.2	212.7 ± 2.1	2
Feige 24...	14.6 ± 0.4	13.44 ± 3.62	3
Wolf 1062...	98.0 ± 0.4	98.56 ± 2.66	4
Pleiades...	7.43 ± 0.17	8.45 ± 0.25	5
RR Lyrae...	3.60 ± 0.20	4.38 ± 0.59	6
δ Cephei...	3.66 ± 0.15	3.32 ± 0.58	7
HD 213307...	3.65 ± 0.15	3.43 ± 0.64	7

Parallaxes - HST vs HIPPARCOS



Absolute Parallaxes
HST = 0.991 ± 0.006 HIP

THE ASTRONOMICAL JOURNAL, 121:1607-1613, 2001 March

PRECISE MASSES FOR WOLF 1062 AB FROM *HUBBLE SPACE TELESCOPE* INTERFEROMETRIC ASTROMETRY AND McDONALD OBSERVATORY RADIAL VELOCITIES

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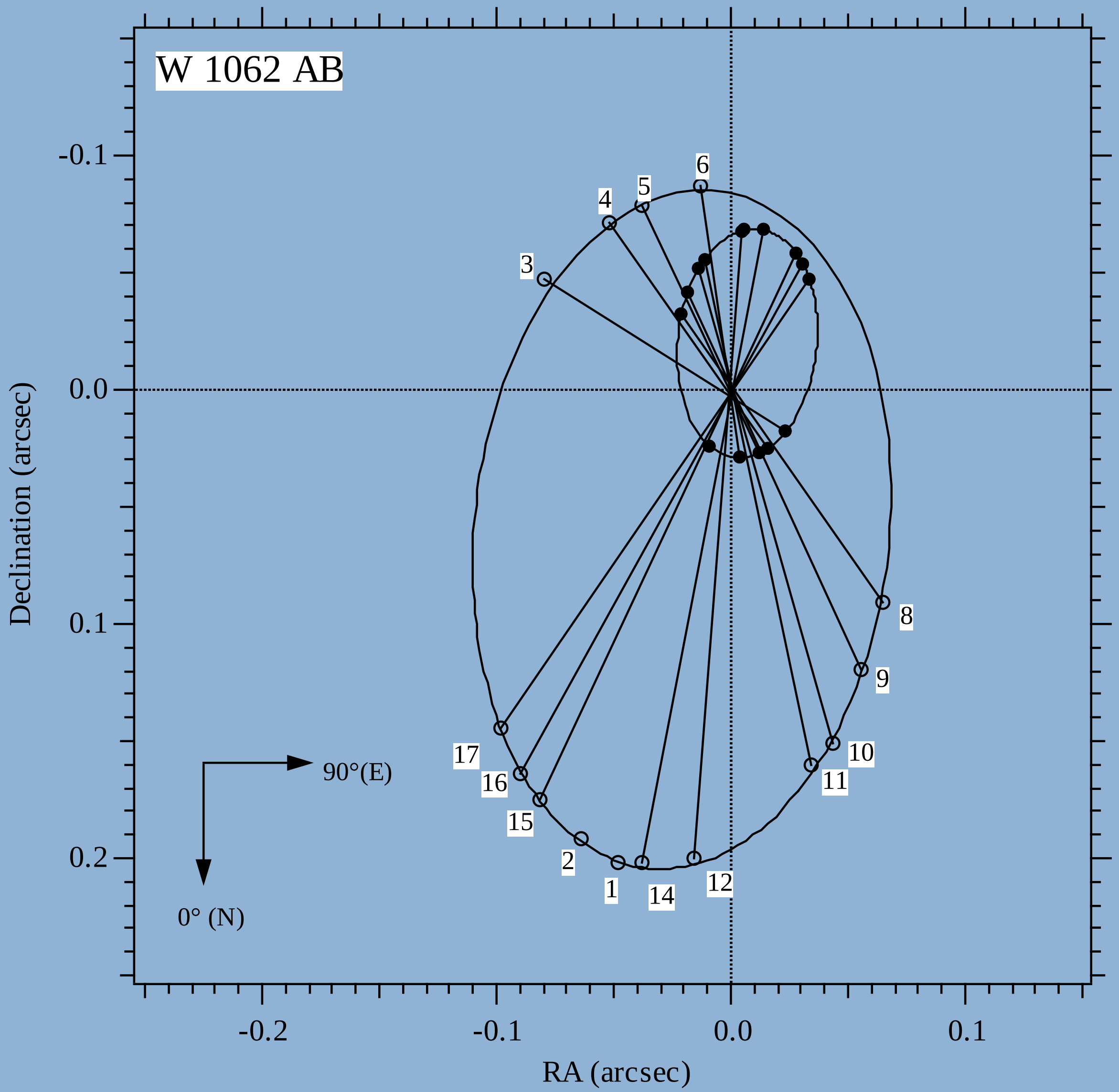
Received 2000 August 28; accepted 2000 December 1

ABSTRACT

We present an analysis of astrometric data from Fine Guidance Sensor 3 (FGS 3), a white-light interferometer on *HST*, and of radial velocity data from two ground-based campaigns. We model the astrometric and radial velocity measurements simultaneously to obtain parallax, proper motion, and component masses for Wolf 1062 (Gl 748; M3.5 V). To derive the mass fraction, we relate FGS 3 fringe scanning observations of the science target to a reference frame provided by fringe tracking observations of a surrounding star field. We obtain an absolute parallax (abs = 98.0 ± 0.4 mas) yielding *MA* = 0.379 ± 0.005 *M* and *MB* = 0.192 ± 0.003 *M*, high-quality component masses with errors of only 1.5%.

Wolf 1062 - Orbits and RV



M_{Tot} = 0.568 ± 0.008M_O
M_A = 0.381 ± 0.006M_O
M_B = 0.187 ± 0.003M_O
π_{abs} = 98.1 ± 0.4 mas

The Astrophysical Journal, 581:L115-L118, 2002 December 20

A Mass for the Extrasolar Planet Gliese 876b Determined from *Hubble Space Telescope* Fine Guidance Sensor 3 Astrometry and High-Precision Radial Velocities

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Received 2002 September 24; accepted 2002 November 11; published 2002 November 25

ABSTRACT

We report the first astrometrically determined mass of an extrasolar planet, a companion previously detected by Doppler spectroscopy. Radial velocities first provided an ephemeris with which to schedule a significant fraction of the *Hubble Space Telescope* (*HST*) observations near companion peri- and apastron. The astrometry residuals at these orbital phases exhibit a systematic deviation consistent with a perturbation due to a planetary mass companion. Combining *HST* astrometry with radial velocities, we solve for the proper motion, parallax, perturbation size, inclination, and position angle of the line of nodes, while constraining period, velocity amplitude, longitude of periastron, and eccentricity to values determined from radial velocities. We find a perturbation semimajor axis and inclination, = 0.25 ± 0.06 mas, i = 84 ± 6, and Gl 876 absolute parallax, abs = 214.6 ± 0.2 mas. Assuming that the mass of the primary star is M* = 0.32 M, we find the mass of the planet, Gl 876b, Mb = 1.89 ± 0.34 MJup.

Orbital Elements of Perturbation Due to Gl 876b

Parameter	Value
a	*0.25 ± 0.06 mas...*
a	*0.0012 ± 0.0003 AU* *(± 28,000 miles!)*
i	*84° ± 6°*
P	*61.02 ± 0.03 days*
T0 (JD)	*2,450,107.87 ± 1.9*
E	*0.10 ± 0.02*
ω	*25°± 4°*
Ω	*338.96 ± 036*
K1	*0.210 ± 0.005 km s-1*

What's coming for Position Mode?

- Inclination & mass of the ε Eridani and υ Andromeda planetary systems (nearly all data collected)
- Inclinations and masses of 6 more extrasolar planets
- Parallaxes:
    - 13 Galactic Cepheids
    - 3 PN
    - 1 CV
    - 1 brown dwarf
    - 3 Pop II Sub-Giants (to determine the age of the Halo)
    - (and masses) of 7 white dwarfs.