100 Years of Not Finding a Planet with Astrometry

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100 Years of Not Finding a Planet with Astrometry

Introduction

The Early Years

van de Kamp and Barnard's Star

HST

The Value of Low-mass Binaries

The Glorious Future

Summary

100 Years of Not Finding a Planet with Astrometry

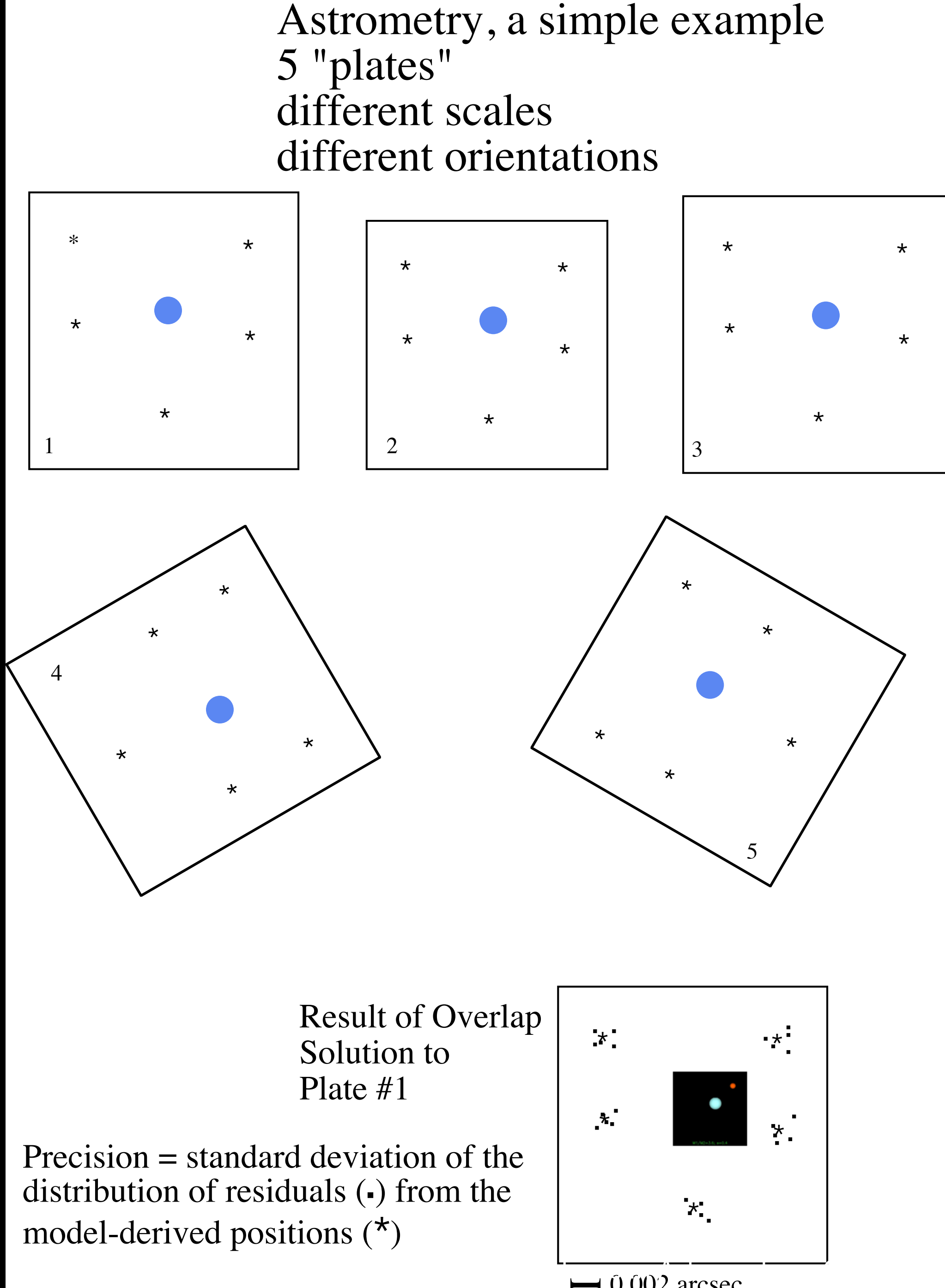
Introduction

Typical response to the word

Astrometry

Not anymore. 109 refereed papers with Gaia in the title since end of April.

Astrometry and orbital motion



Star Positions to Astrometry

Modeling, scale, rotation, and offset

xi = ax + by + c
eta = -bx + ay + f

The resulting six (xi, eta) pairs are a catalog with associated errors. Also get the residuals to the fit.

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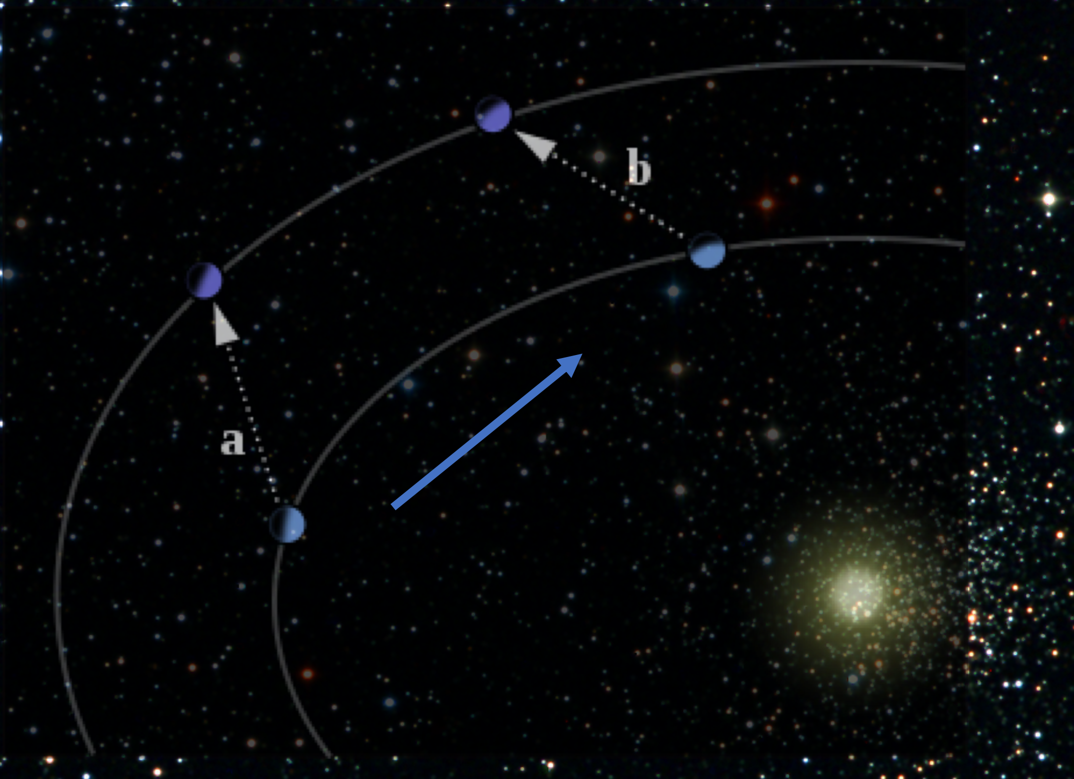
The Early Years

The Discovery of Neptune in 1846

by Le Verrier,

with ASTROMETRY



172 Years of Not Finding a Planet with Astrometry

van de Kamp and Barnard's Star

50 & 25 YEARS AGO

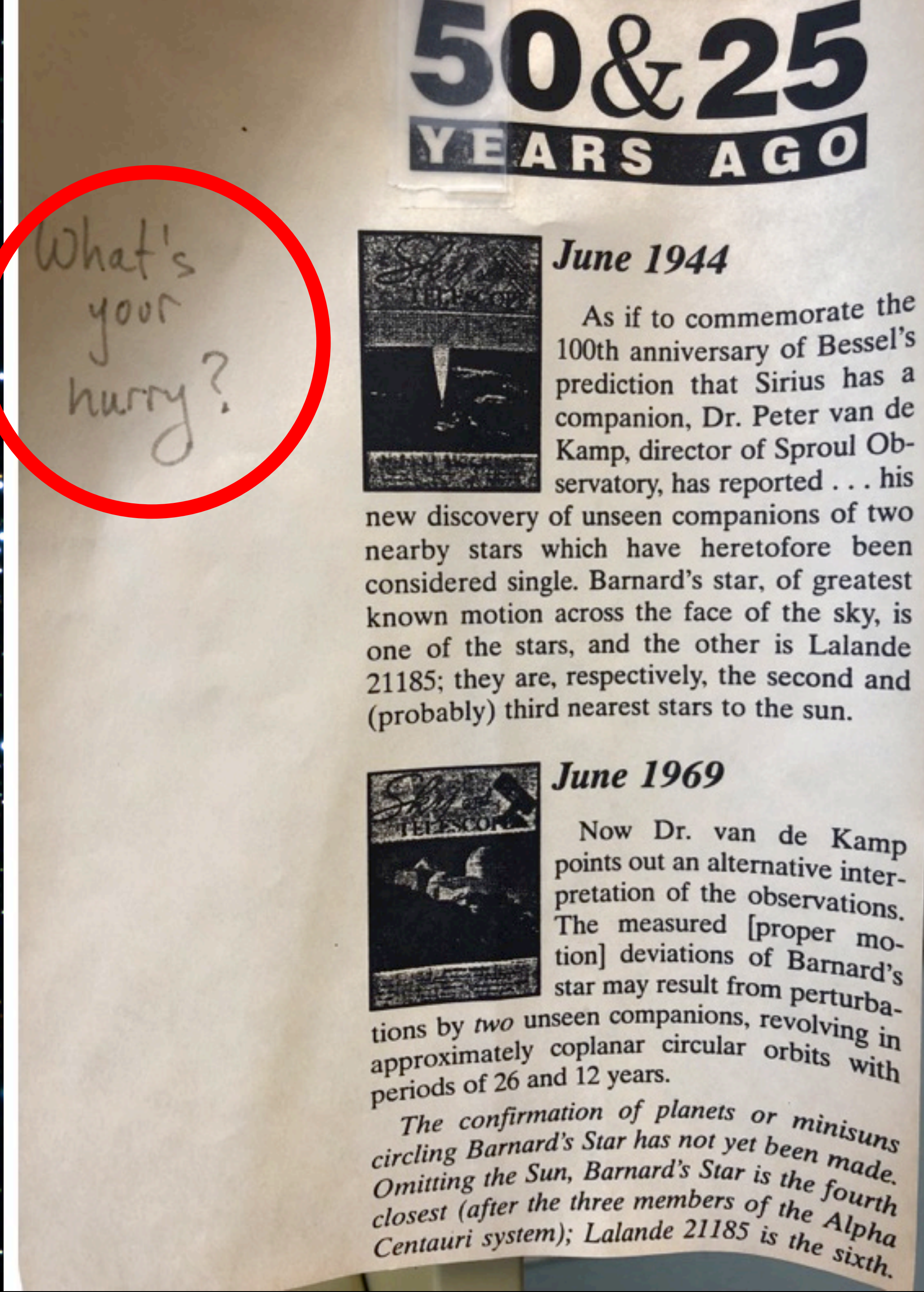
June 1944

As if to commemorate the 100th anniversary of Bessel's prediction that Sirius has a companion, Dr. Peter van de Kamp, director of Sproul Observatory, has reported . . . his new discovery of unseen companions of two nearby stars which have heretofore been considered single. Barnard's star, of greatest known motion across the face of the sky, is one of the stars, and the other is Lalande 21185; they are, respectively, the second and (probably) third nearest stars to the sun.

June 1969

Now Dr. van de Kamp points out an alternative interpretation of the observations. The measured [proper motion] deviations of Barnard's star may result from perturbations by *two* unseen companions, revolving in approximately coplanar circular orbits with periods of 26 and 12 years.

The confirmation of planets or minisuns circling Barnard's Star has not yet been made. Omitting the Sun, Barnard's Star is the fourth closest (after the three members of the Alpha Centauri system); Lalande 21185 is the sixth.



What's your hurry?

50 & 25 YEARS AGO

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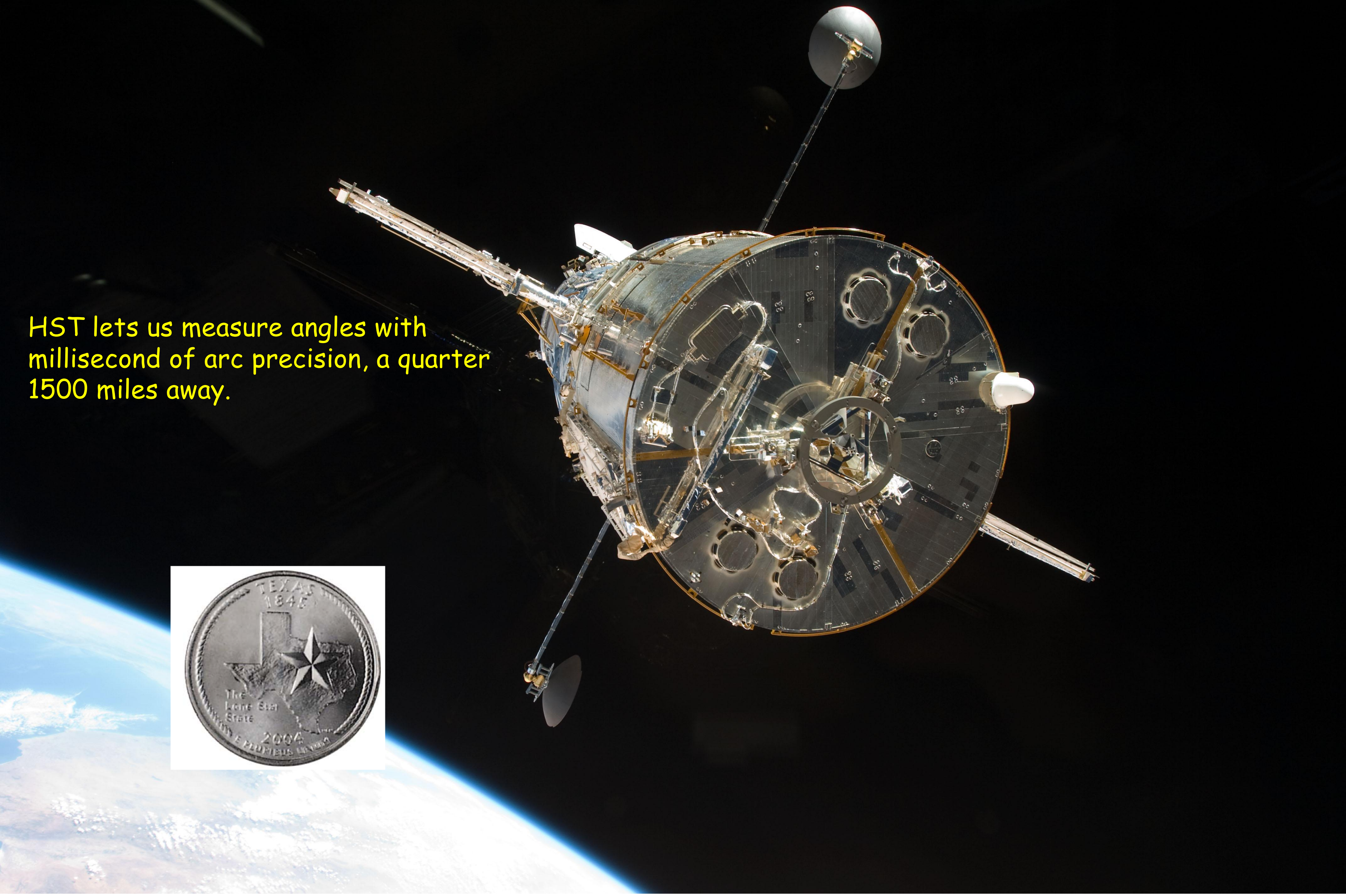
Investigations at observatories other than Sproul, however, failed to confirm the existence of a perturbation in the Barnard's star path (Gatewood and Eichhorn 1973; Fredrick and Ianna 1985; Harrington and Harrington 1987). Infrared, speckle, and radial velocity searches of Barnard's star similarly have been negative (e.g. Skrutskie, Forrest, and Shure 1989; Henry and McCarthy 1990; Marcy and Benitz 1989).

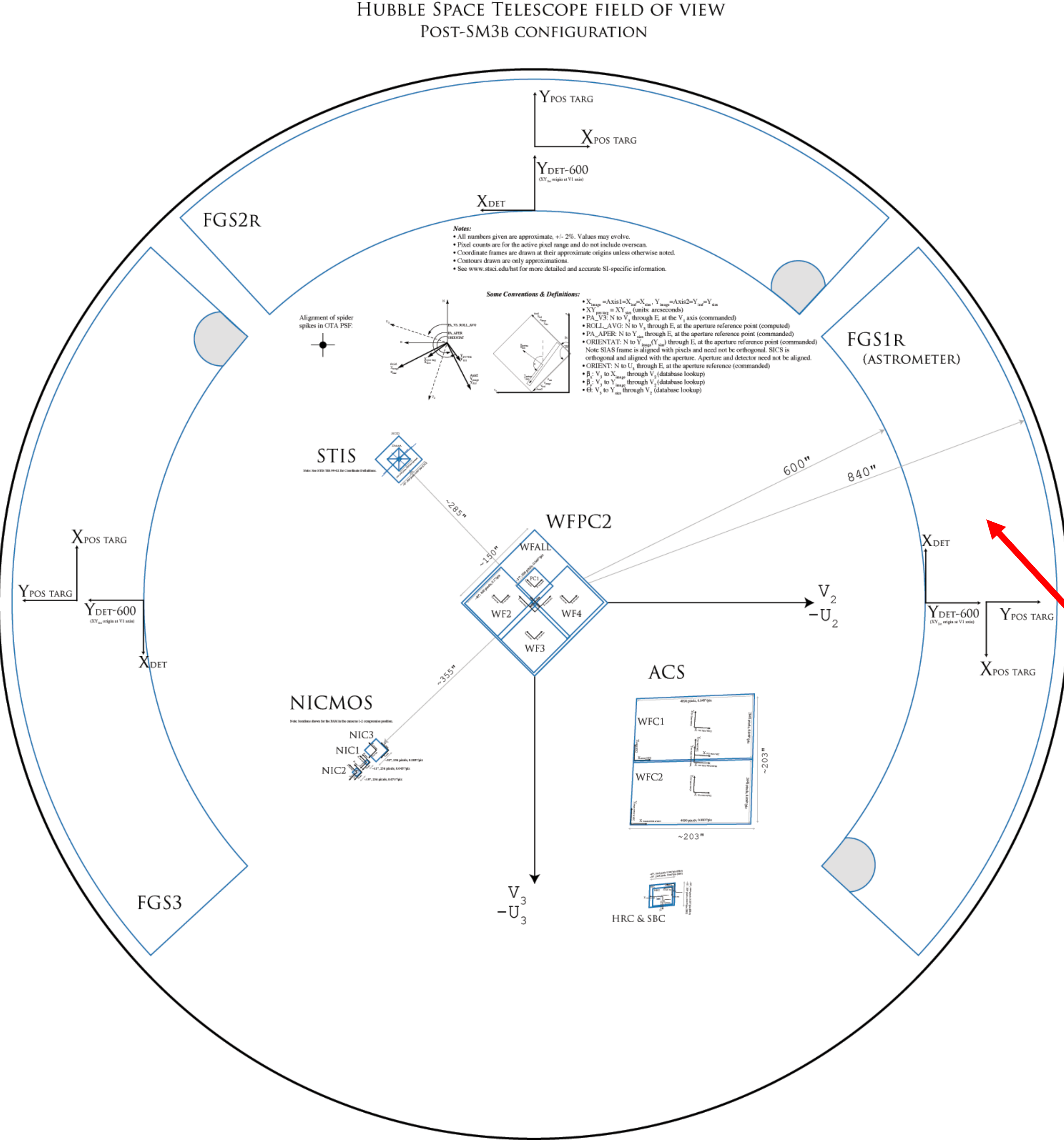
P. A. Ianna, 1995, Ap&SS, 223, 161

172 Years of Not Finding a Planet with Astrometry



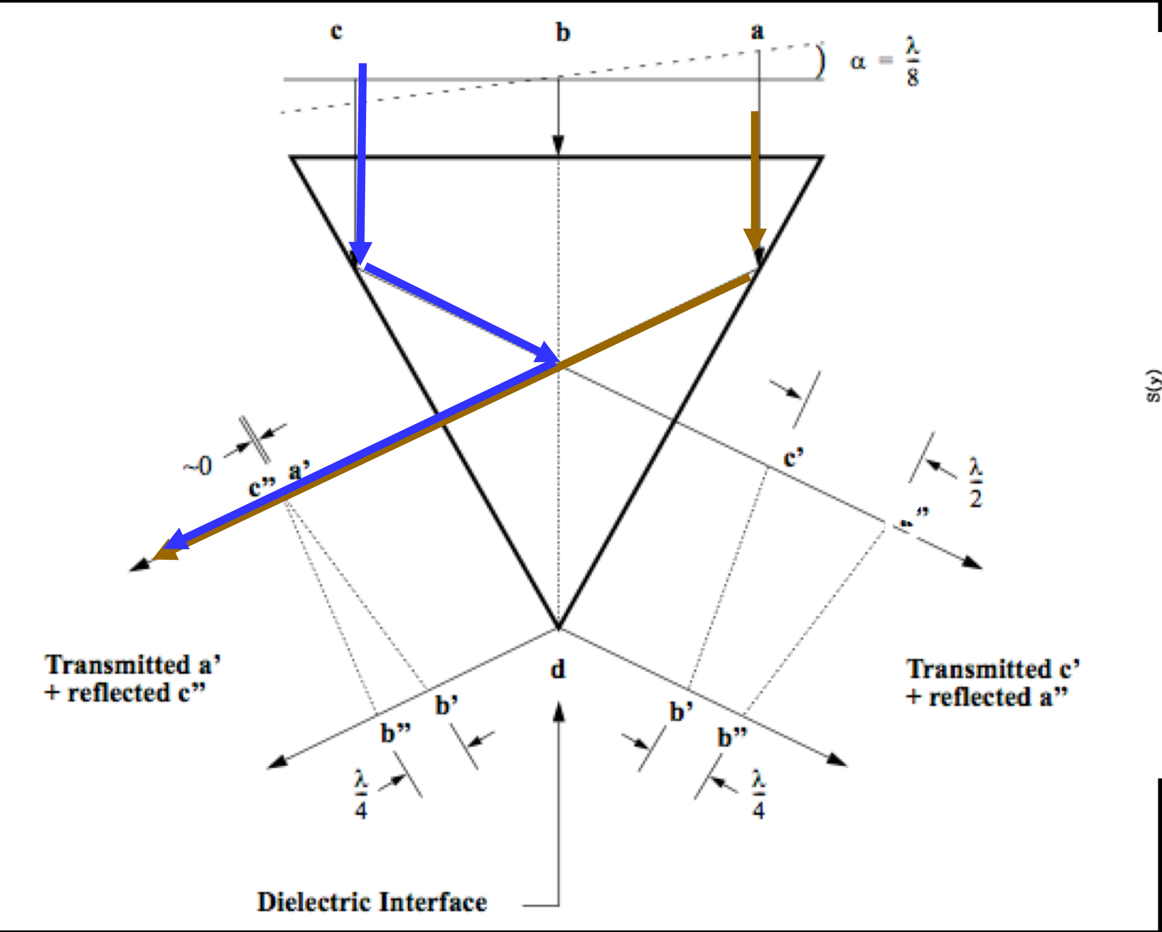
S125E011810

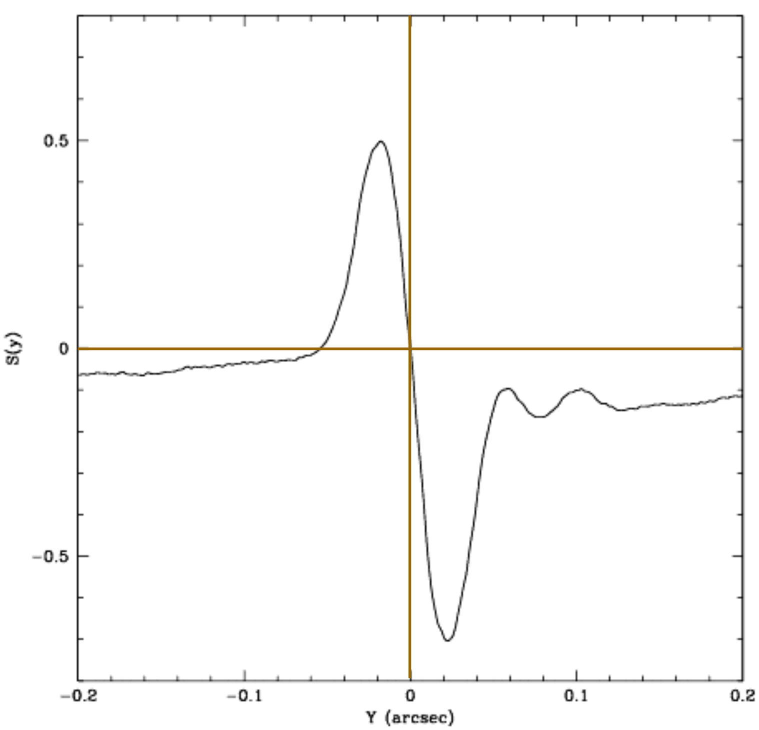
HST Focal Plane



Space Astrometry with an Interferometer on Hubble Space Telescope

The Koester's Prism - the Interferometric Heart of a Fine Guidance Sensor (FGS)





$$S = (A-B)/(A+B)$$

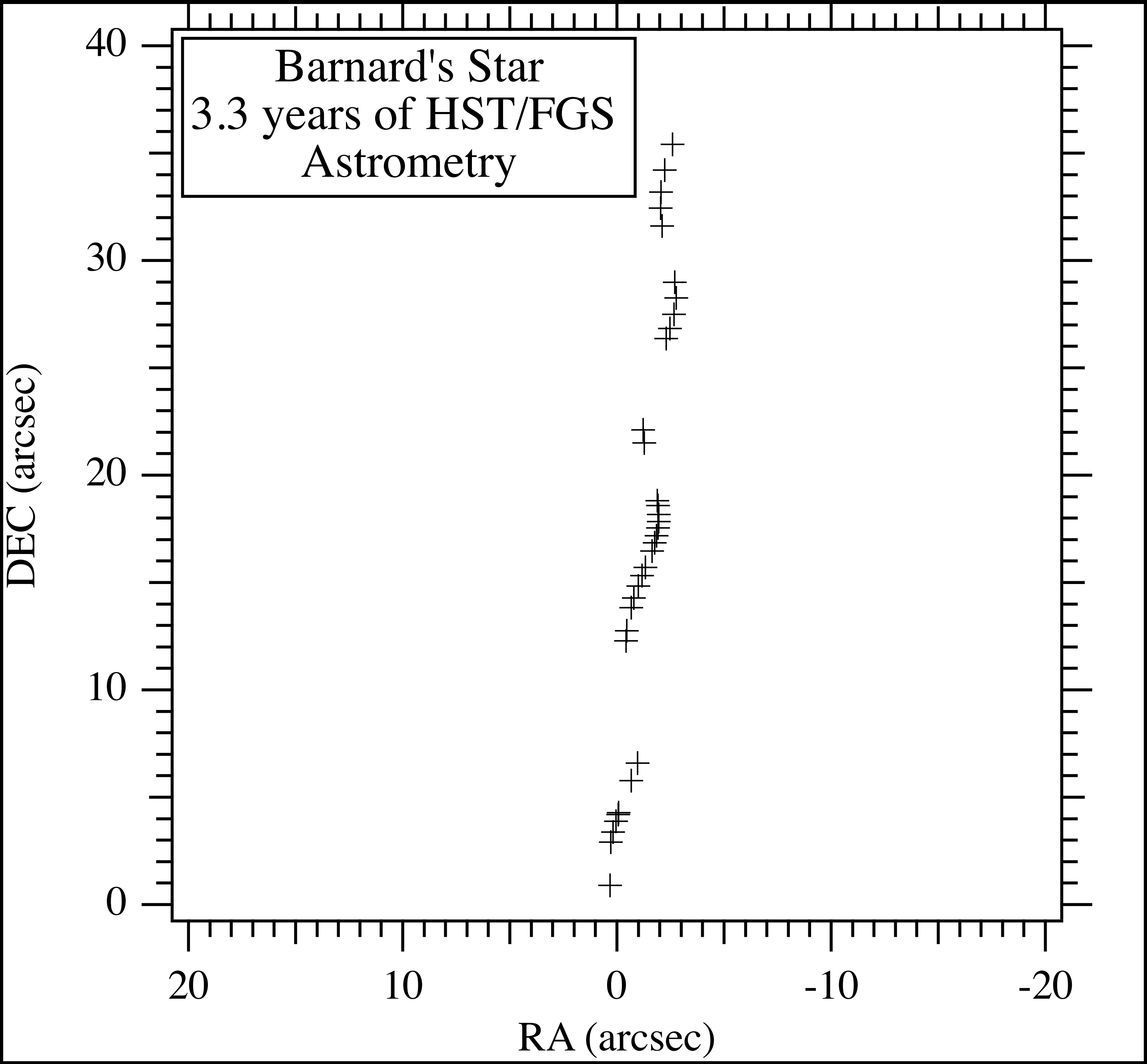
Effectively, a 2.4m baseline interferometer

TABLE 7

Parallax and Proper Motion

Parameter	Proxima Cen	Barnard's Star
HST study duration	5.6 yr	3.3 yr
Observation sets	59	34
Reference stars' ⟨*V*⟩	14.5	14.2
Reference stars' ⟨*B*−*V*⟩	+0.87	+0.85
Relative parallax	767.7 ± 0.2 mas	544.2 ± 0.2 mas
Correction to absolute	1.0 ± 0.2 mas	1.2 ± 0.2 mas
HST absolute parallax	768.7 ± 0.3 mas	545.4 ± 0.3 mas
Yale parallax catalog[a]	769.8 ± 6.1 mas	545.6 ± 1.3 mas
Hipparcos parallax	772.3 ± 2.4 mas	549.3 ± 1.6 mas
HST proper motion	3851.7 ± 0.1 mas yr^{-1}	10370.0 ± 0.3 mas yr^{-1}
In P.A.	78°.46 ± 0°.03	4°.45 ± 0°.1
HST secular acceleration......	...	12 ± 4 mas yr^{-2}
Hipparcos proper motion......	3852.9 ± 2.3 mas yr^{-1}	10368.6 ± 2.1 mas yr^{-1}
In P.A.	78°.50 ± 0°.03	4°.42 ± 0°.07

[a] Van Altena et al. 1995.



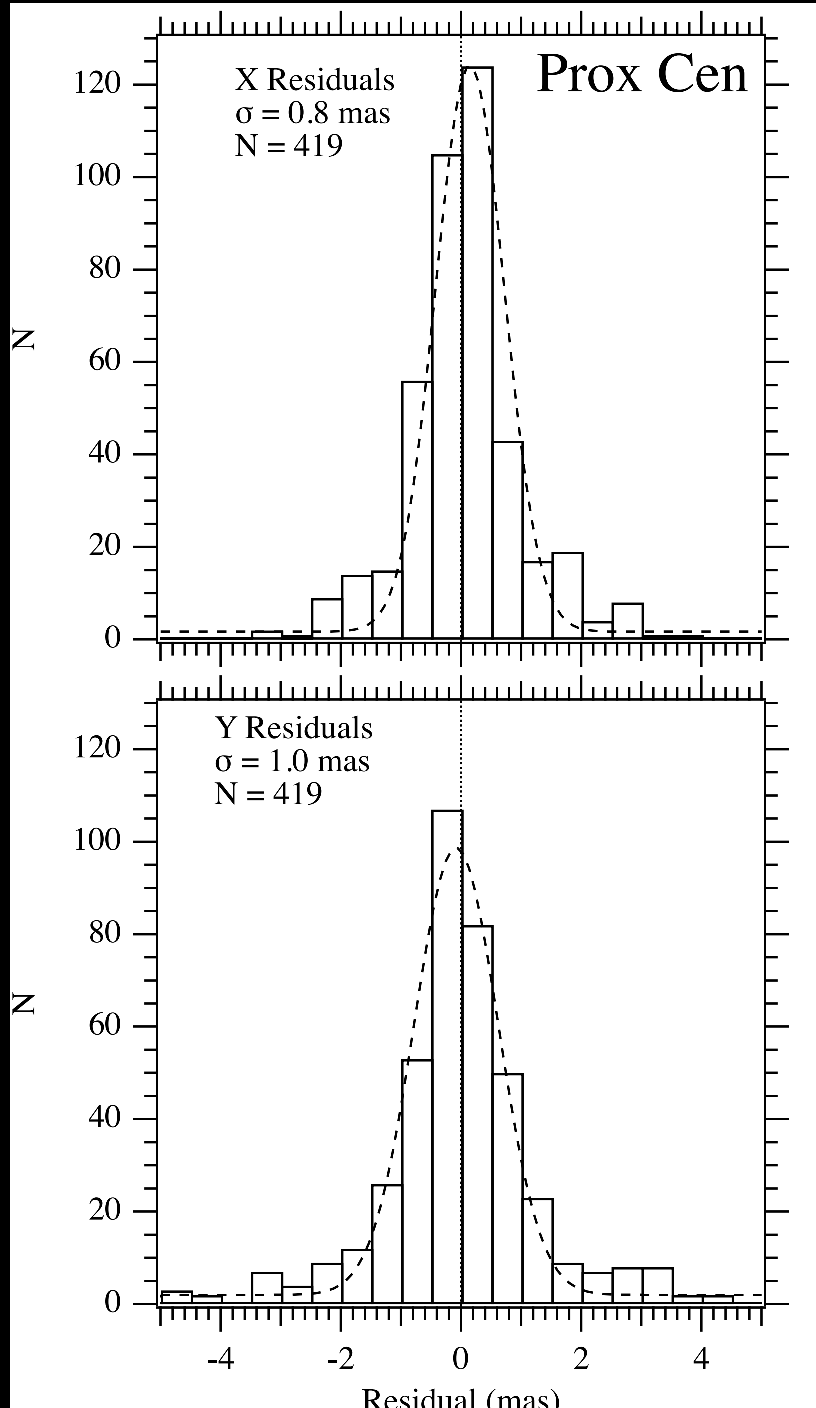
Barnard's Star
3.3 years of HST/FGS
Astrometry
DEC (arcsec)
40
30
20
10
0
20
10
0
-10
-20
RA (arcsec)

FOR WITH SLIGHT EFFORTS, HOW SHOULD ONE OBTAIN GREAT RESULTS? IT IS FOOLISH EVEN TO DESIRE IT

– EURIPIDES

The first principle is that you *must not fool* yourself - and you are the easiest person to fool.

- R. Feynman


Prox Cen
X Residuals
σ = 0.8 mas
N = 419
Y Residuals
σ = 1.0 mas
N = 419
N
Residual (mas)
120
100
80
60
40
20
0
-4
-2
0
2
4

We missed this one.*
No shame.
Would require 1 μasec measurement precision, not the 1 mas we had.

*Anglada-Escude, 2016, Nature, 536, 437
RV detection

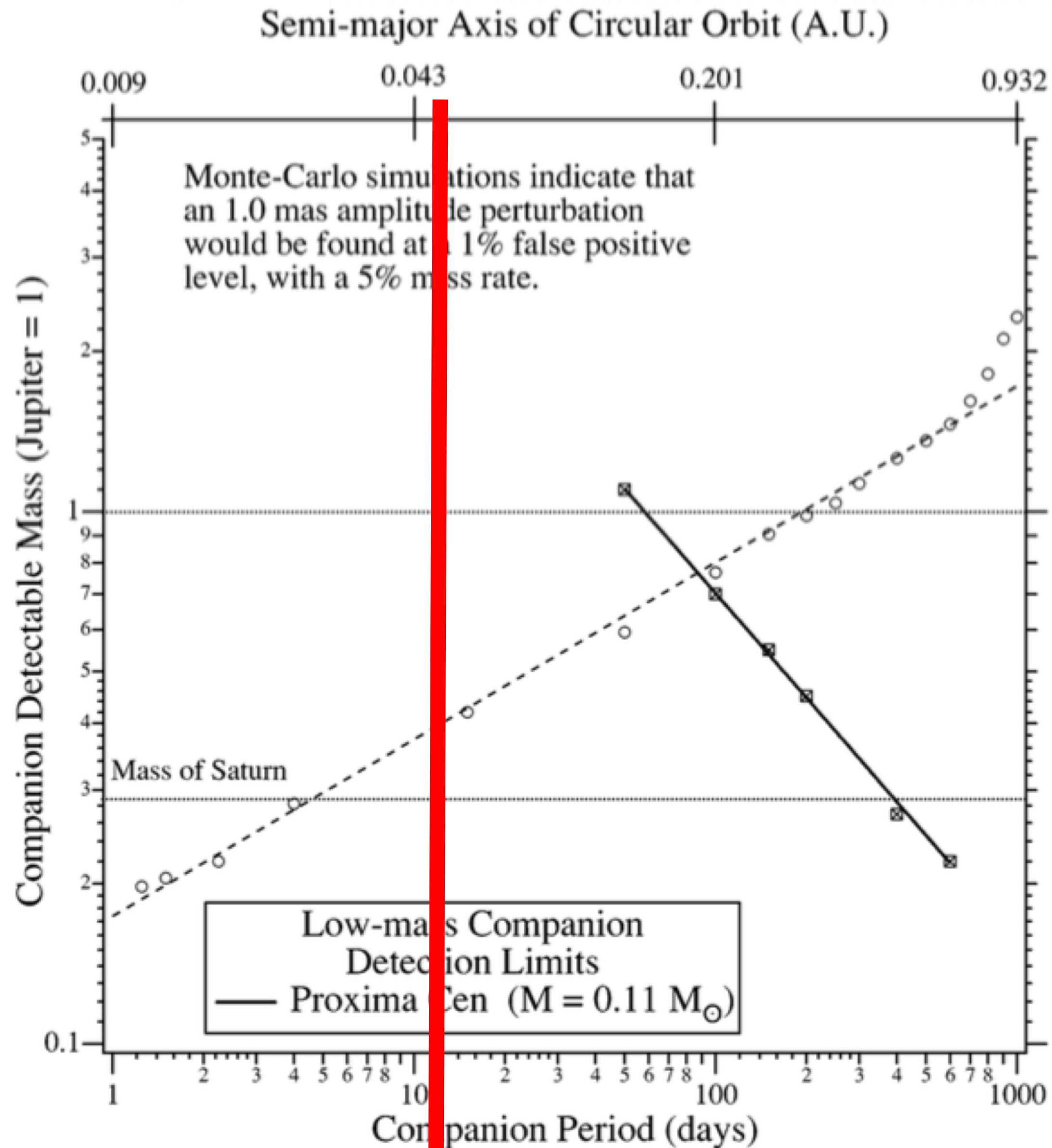


FIG. 17.—Same as Fig. 16, but for Proxima Cen. Monte Carlo simulations indicate that a 1.0 mas amplitude perturbation would be found at a 1% false-positive level, with a 5% miss rate. The dashed line presents the limits determined by the radial velocity program of Kürster et al. (1999).

Tasting Note by The Producer

Nose: Lots of fruit with a mixture of grapefruit peel, dried tropical fruits, wine gums and a touch of cassis.

Palate: Orange peel, honeycomb, brandy snaps, black pepper and tobacco leaf.

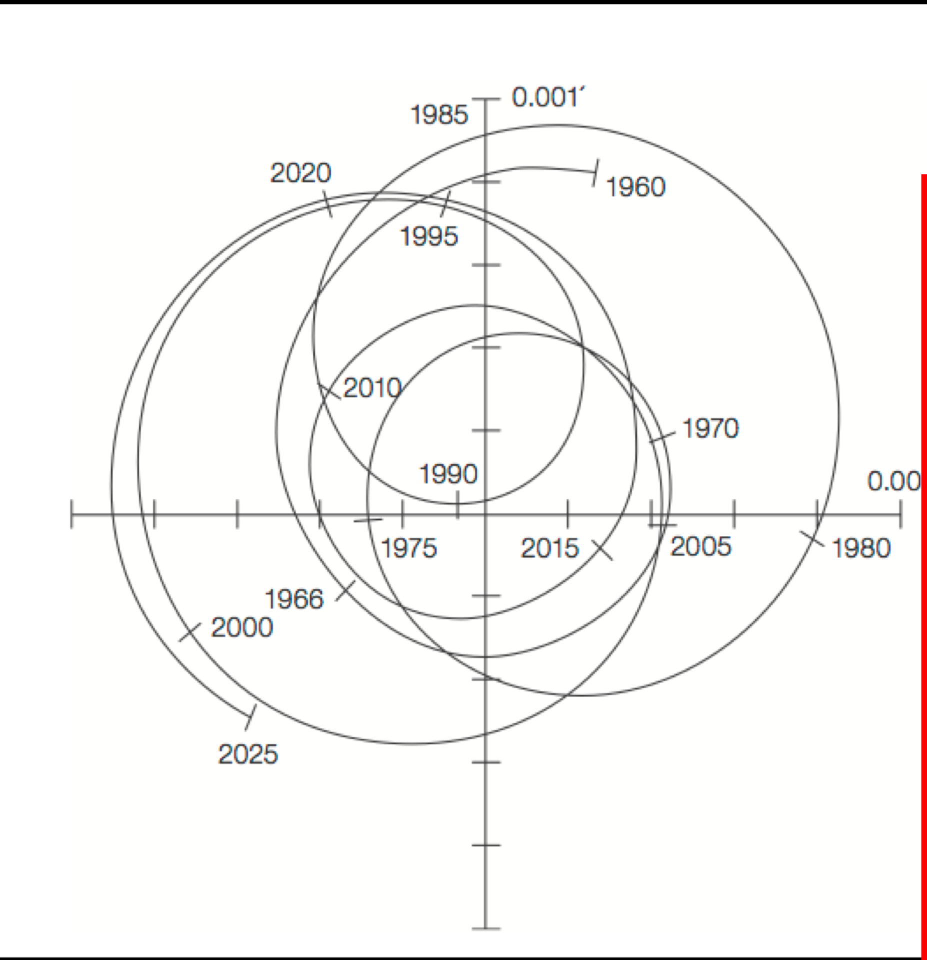
Finish: Mineral notes combining with fennel, tea leaf and leather against a background of soft burning embers.

What We* Did
Not FIND, but Measure

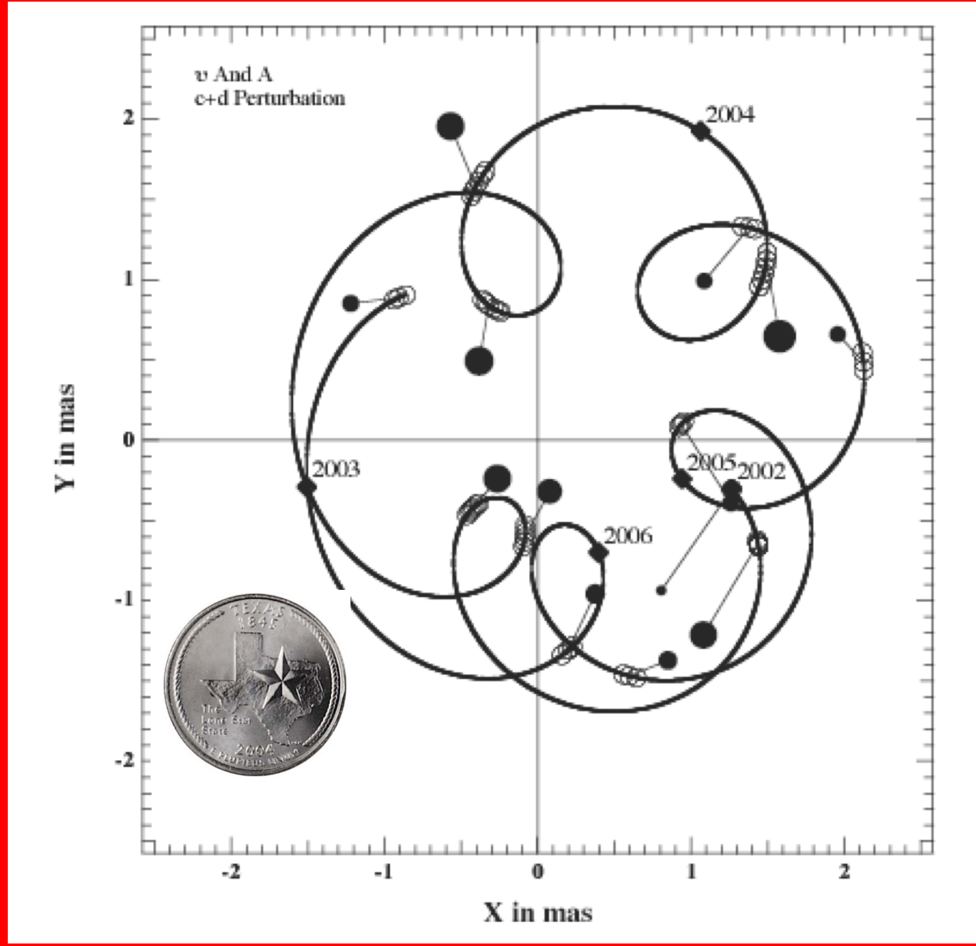
HST/FGS Exoplanetary Astrometric Results									
Companion	M_* ($M_\odot$)	[Fe/H]	Sp.T.	d(pc)	ecc	M (M_{Jup})	α (mas)	inc(°)	P(d)
υ And c	1.31	+0.15	F8 V	13.5	0.25	14 ± 4	0.62	8±1	241
υ And d	|	|	|	|	0.32	10 ± 2	1.4	24±1	1282
GJ 876 b	0.32	+0.17	M4 V	4.7	0.1	1.9±0.5	0.25	84±6	61
55 Cnc d	1.21	+0.32	G8 V	12.5	0.33	4.9±1.1	1.9	53±7	4517
ε Eri b	0.83	-0.03	K2 V	3.2	0.7	1.6±0.2	1.9	30±4	2502
HD 33636 B	1.02	-0.13	G0 V	28.1	0.48	142±11	14.2	4.0±0.1	2117
HD 136118 b	1.24	-0.01	F9 V	52.3	0.35	42±15	1.5	163±3	1191
HD 38529 c	1.48	+0.27	G4 IV	40.0	0.36	17.6±1.4	1.1	48±4	2136
HD 128311 c	0.83	+0.2	K0 V	16.5	0.154	3.8±0.7	0.5	56±14	922
HD 202206 B	1.07	+0.35	G6V	45.5	0.432	94±7	18.2	11±1	256
HD 202206 c	|	|	|	|	0.22	17.9±2	52.9	8±1	1260
γ Cep Ab	1.18	0	K1 III-IV	13.5	0.4	9.4±1	1.1	170±1	905

*Benedict, McArthur, Harrison, Martioli, Bean

A Triumph - Architecture of the υ And System (Analysis by Barbara McArthur)



υ And like ours?

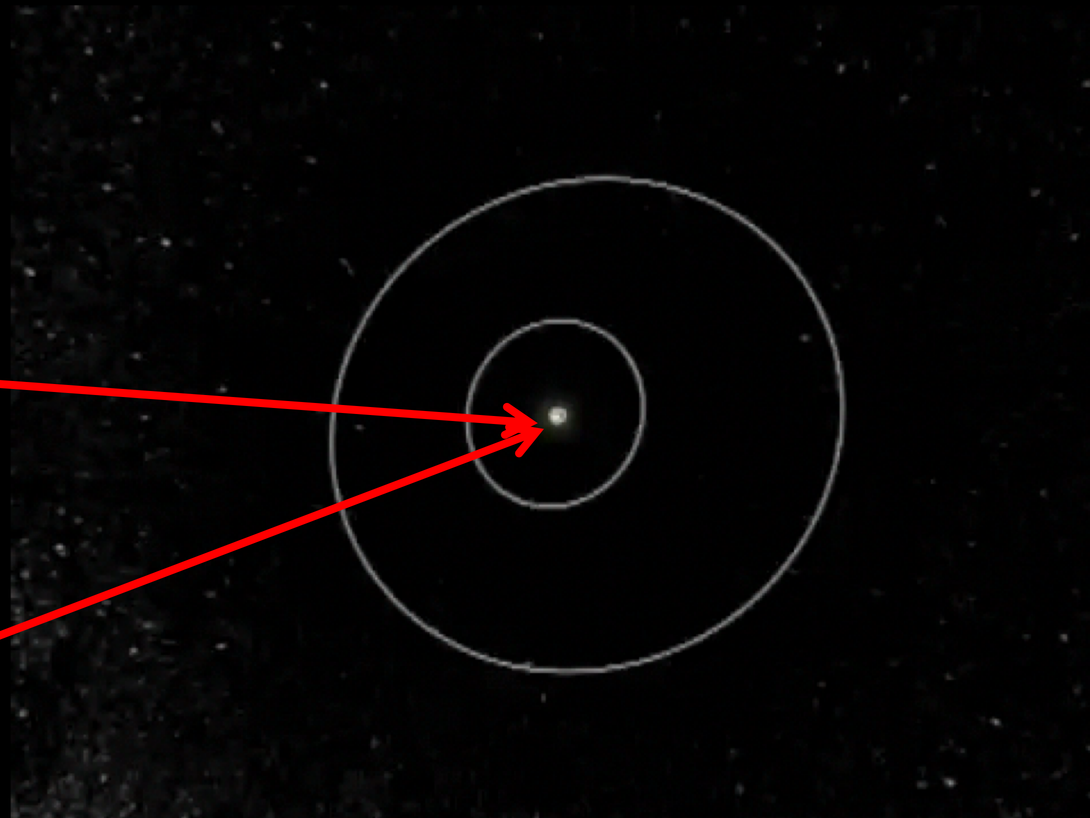


υ And system not so much like ours

What could have 'screwed up' the υ And system?

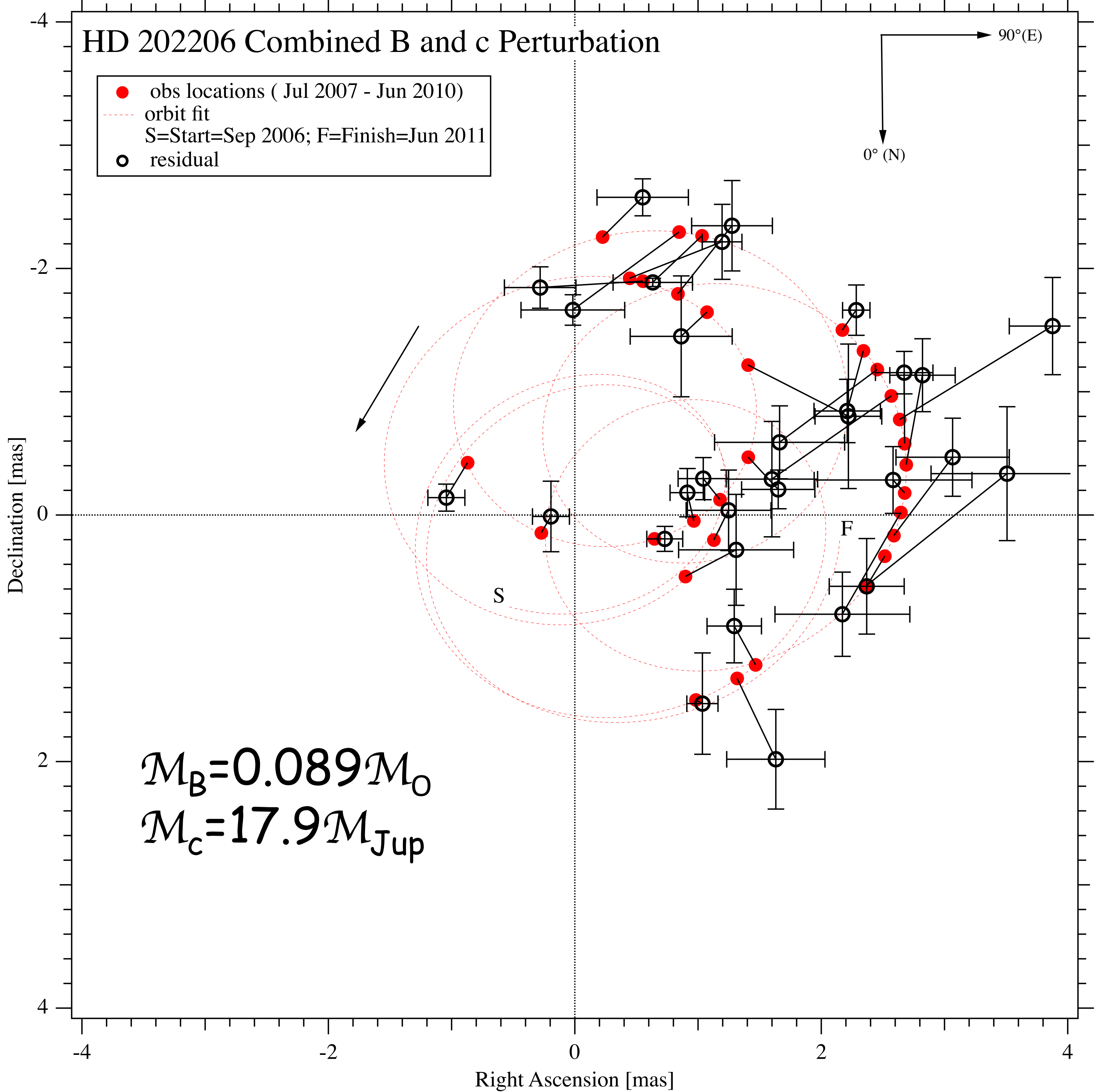
The migration of this hot Jupiter

…



… and/or this distant companion is not always so distant?

Another System Dissected



HD 202206 System Nearly Coplanar

The Astronomical Journal, 153:258 (12pp), 2017 June Benedict & Harrison

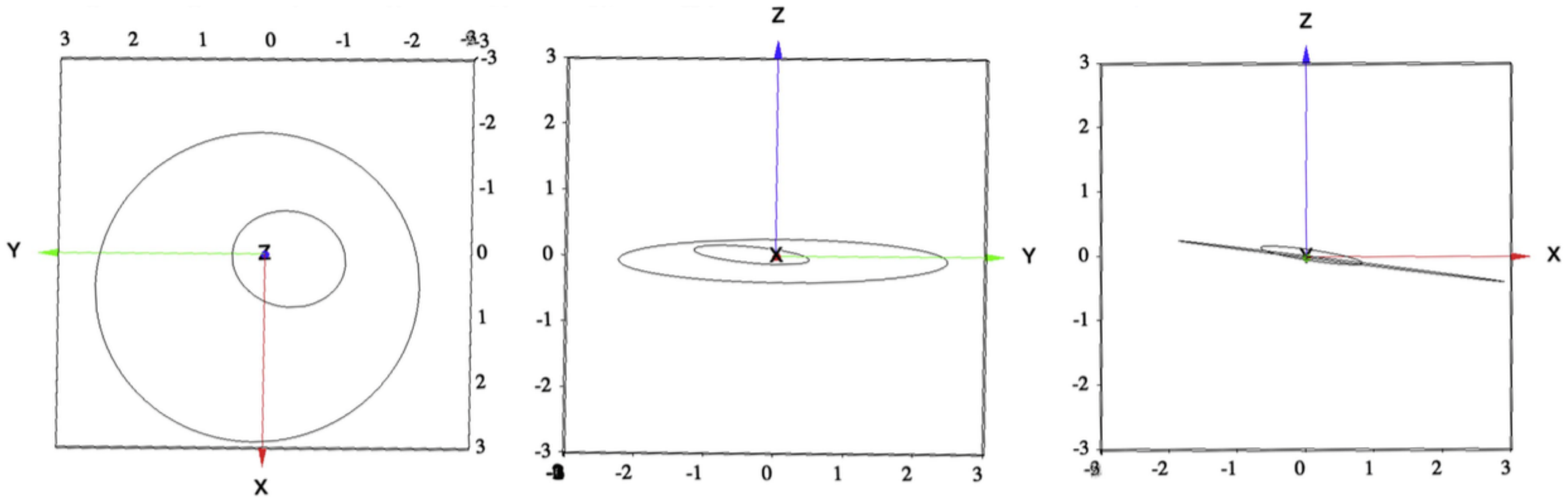


Figure 10. Component *B* (inner) and *c* (outer) orbits as observed (left to right panels) toward the $-z$ (looking at the HD 202206 system with $+y$ to the south and $+x$ pointing west), toward $-x$ (east in R.A.), and $-y$ (north in decl.) axes. Axes units are au.

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SCARCE Astrometry and Discovery (and follow-up RV) tied together through this constraint

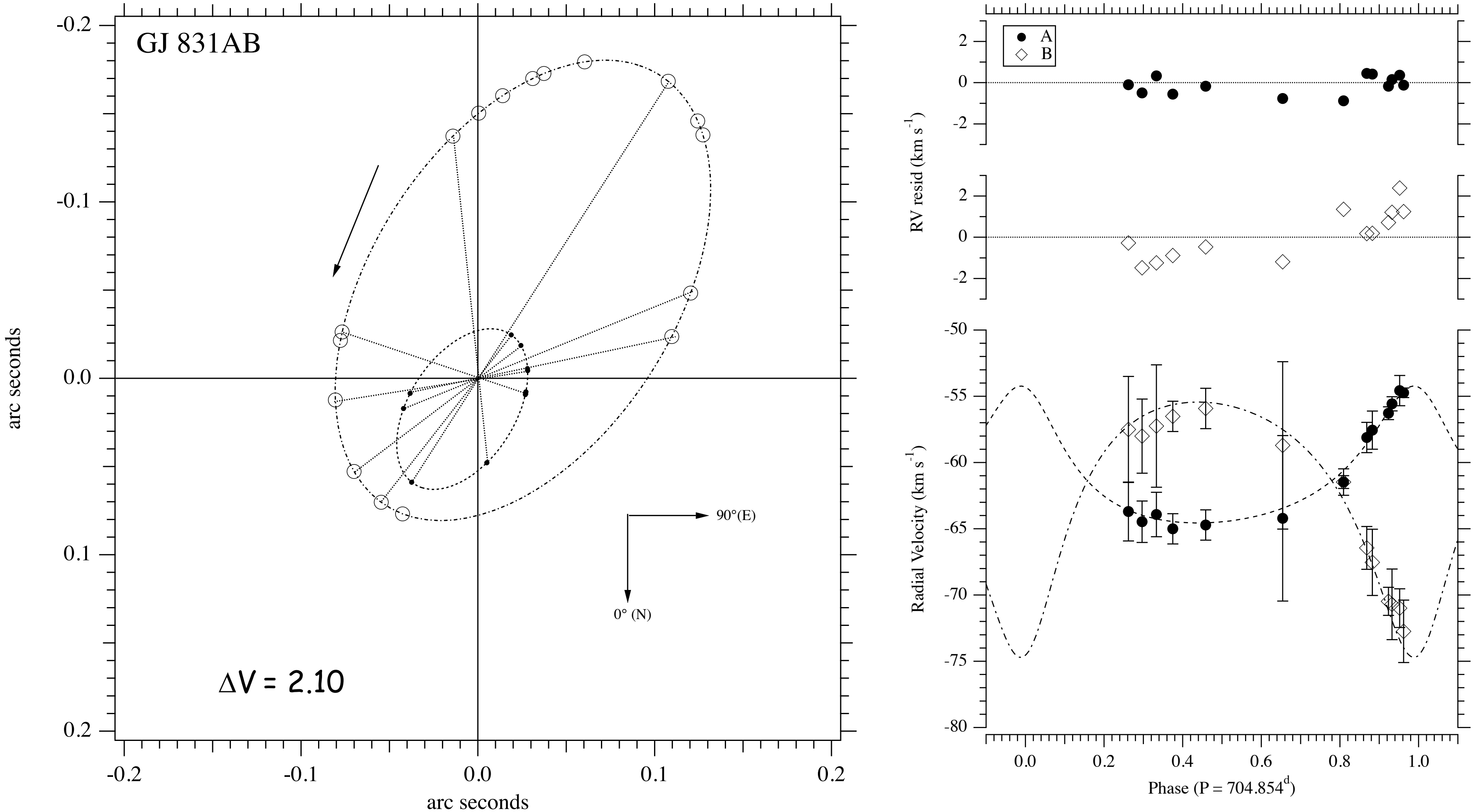
$$\frac{\alpha_{\mathrm{A}}\, sin\, i}{\pi_{\mathrm{abs}}} = \frac{P K_{\mathrm{A}} sqrt(1 - e^2)}{2\pi \times 4.7405}$$

Pourbaix & Jorissen, 2000, A&A 145, 161

172 Years of Not Finding a Planet with Astrometry

Astrometry can Assist the Exoplanet Game in Other Ways

Low-mass Binaries and the Lower Main Sequence Mass-Luminosity Relation



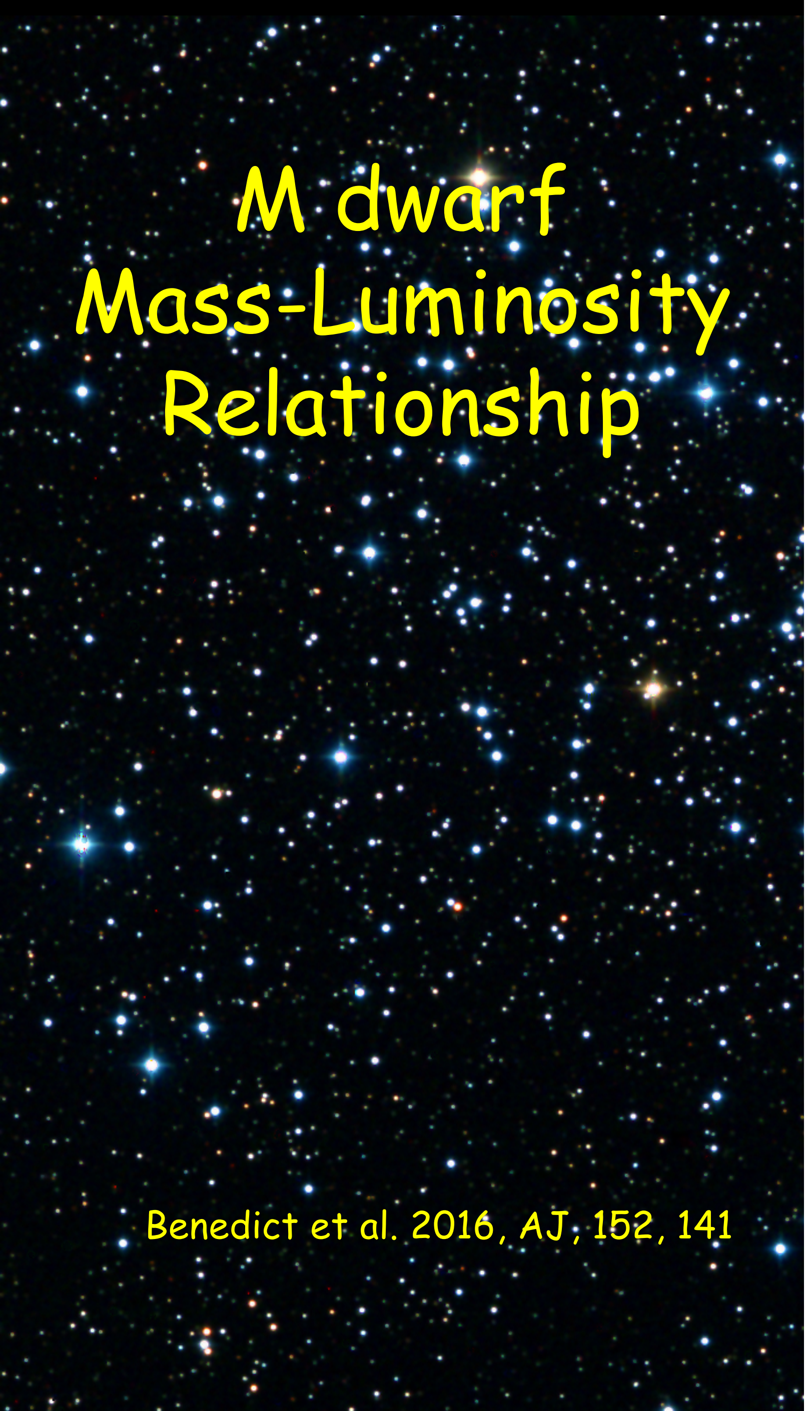
Left: GJ 831A (dots, POS orbit predicted positions) and component B (open circles, TRANS orbit predicted positions). All observations, POS and TRANS and A and B component radial velocities, were used to derive the final orbital elements. POS and TRANS astrometric residuals are smaller than the symbols. The arrow indicates the direction of orbital motion. Right: RV measurements from the CE, phased to the orbital period determined from a combined solution including astrometry and RV. We obtain an absolute parallax π_{abs} = 125.3±0.3 mas, yielding $\mathcal{M}_A$ = 0.270 ± 0.004$\mathcal{M}_\odot$ and $\mathcal{M}_B$ = 0.145 ± 0.002$\mathcal{M}_\odot$. Mass error ~ 1.5%

Again, Astrometry and RV tied together through this constraint

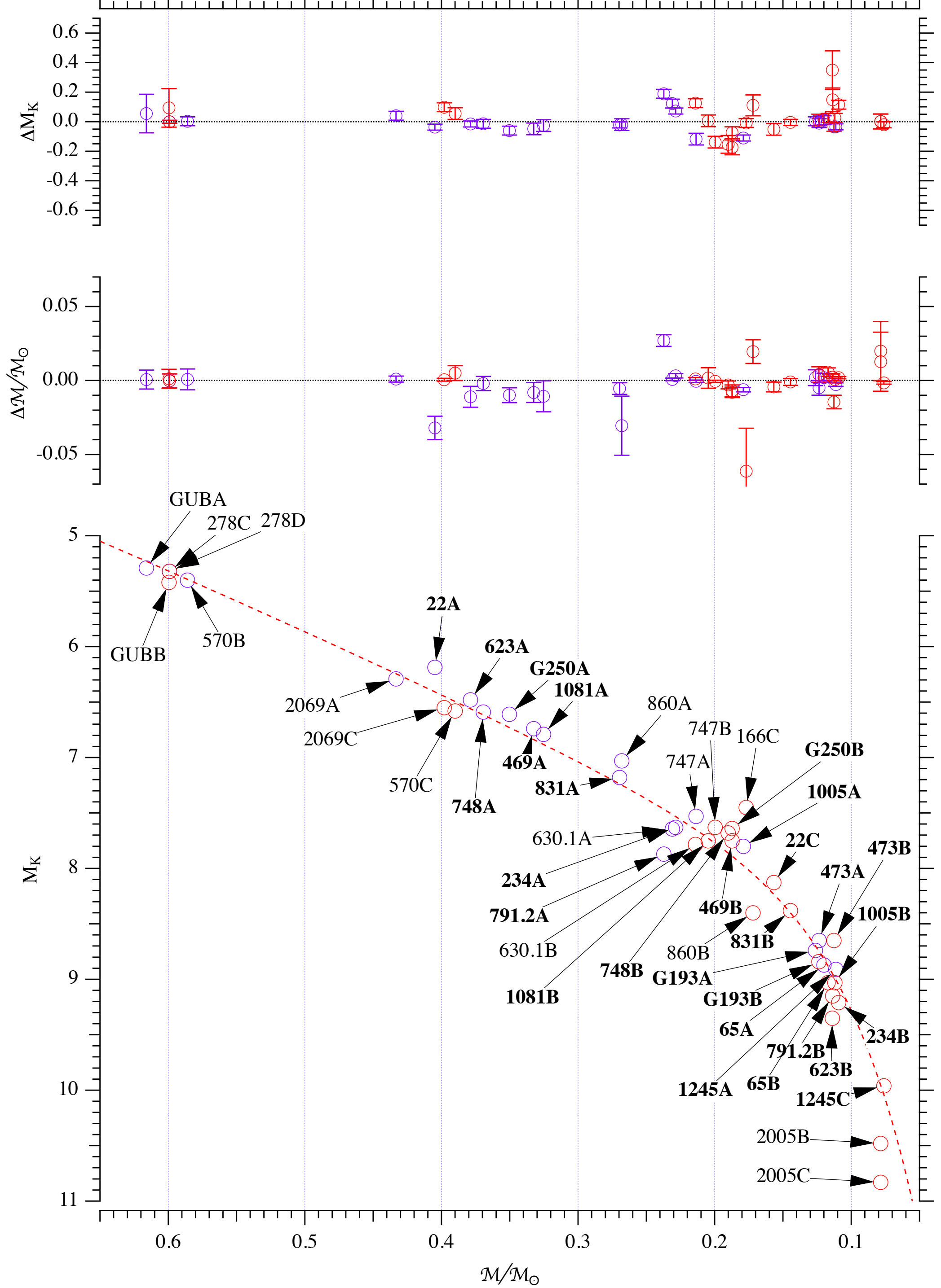
$$\frac{\alpha_{\mathrm{A}}\, sin\, i}{\pi_{\mathrm{abs}}} = \frac{PK_{\mathrm{A}} sqrt(1-e^2)}{2\pi \times 4.7405}$$

Pourbaix & Jorissen, 2000, A&A 145, 161

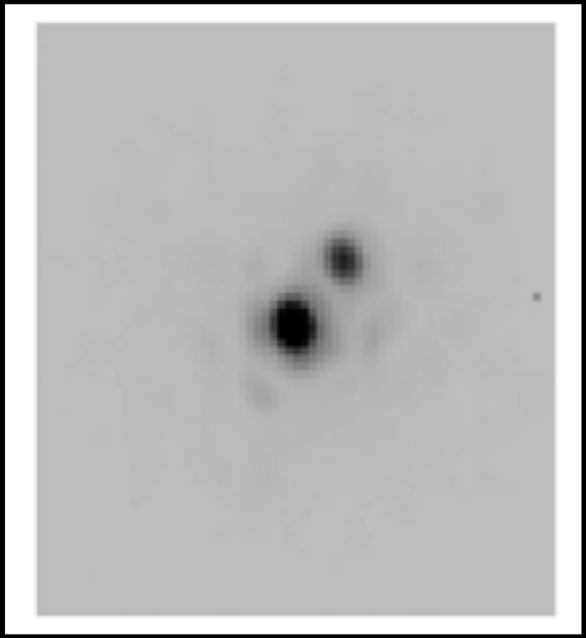
M dwarf Mass-Luminosity Relationship



Benedict et al. 2016, AJ, 152, 141



Where do we get most ΔK?
Gemini AO.



Dieterich, S., Ph. D. Thesis 2012 GSU and
Dieterich+ 2012 AJ, 144, 64

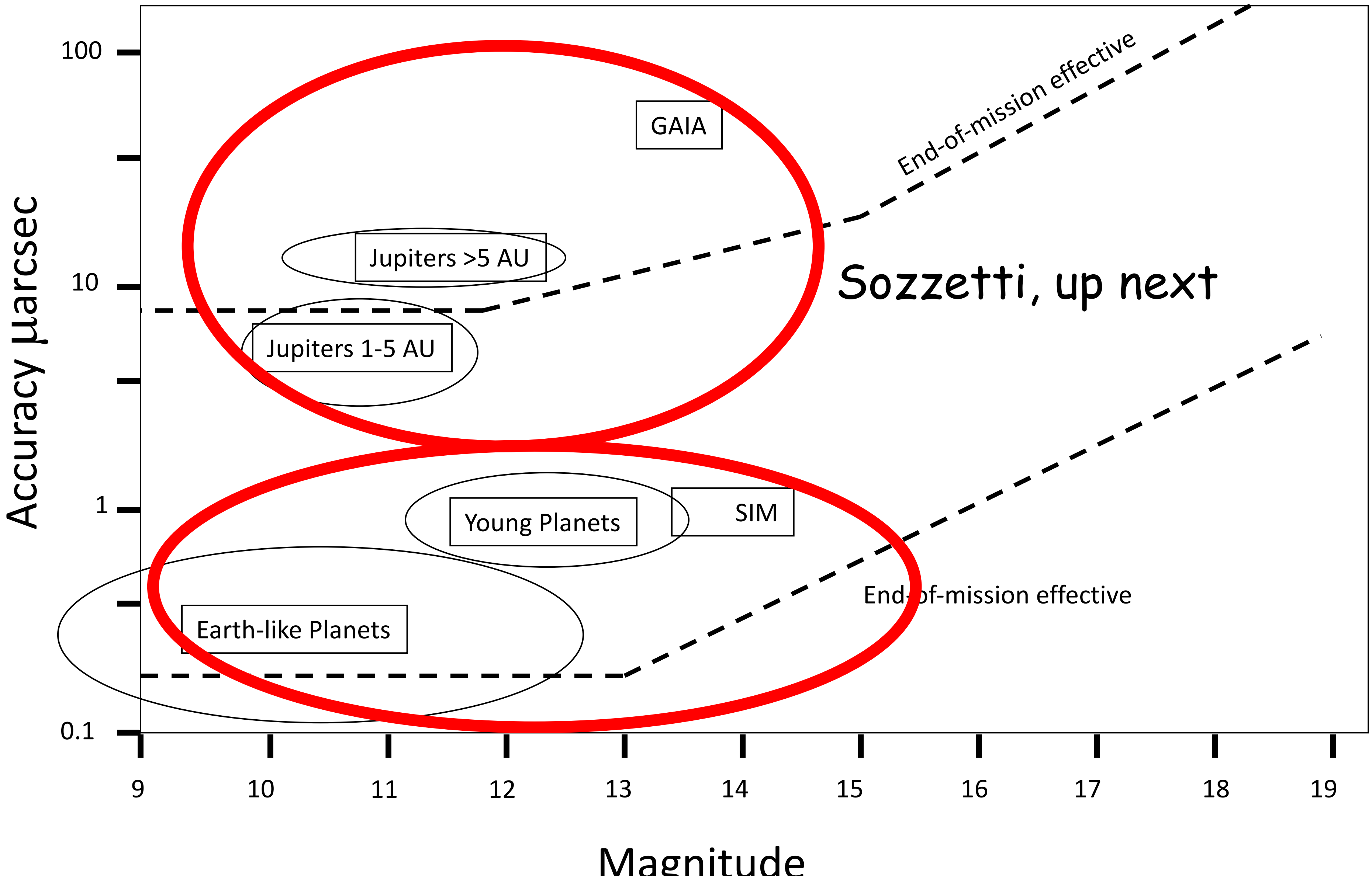
Also Henry & McCarthy 1993 (!)

172 Years of Not Finding a Planet with Astrometry

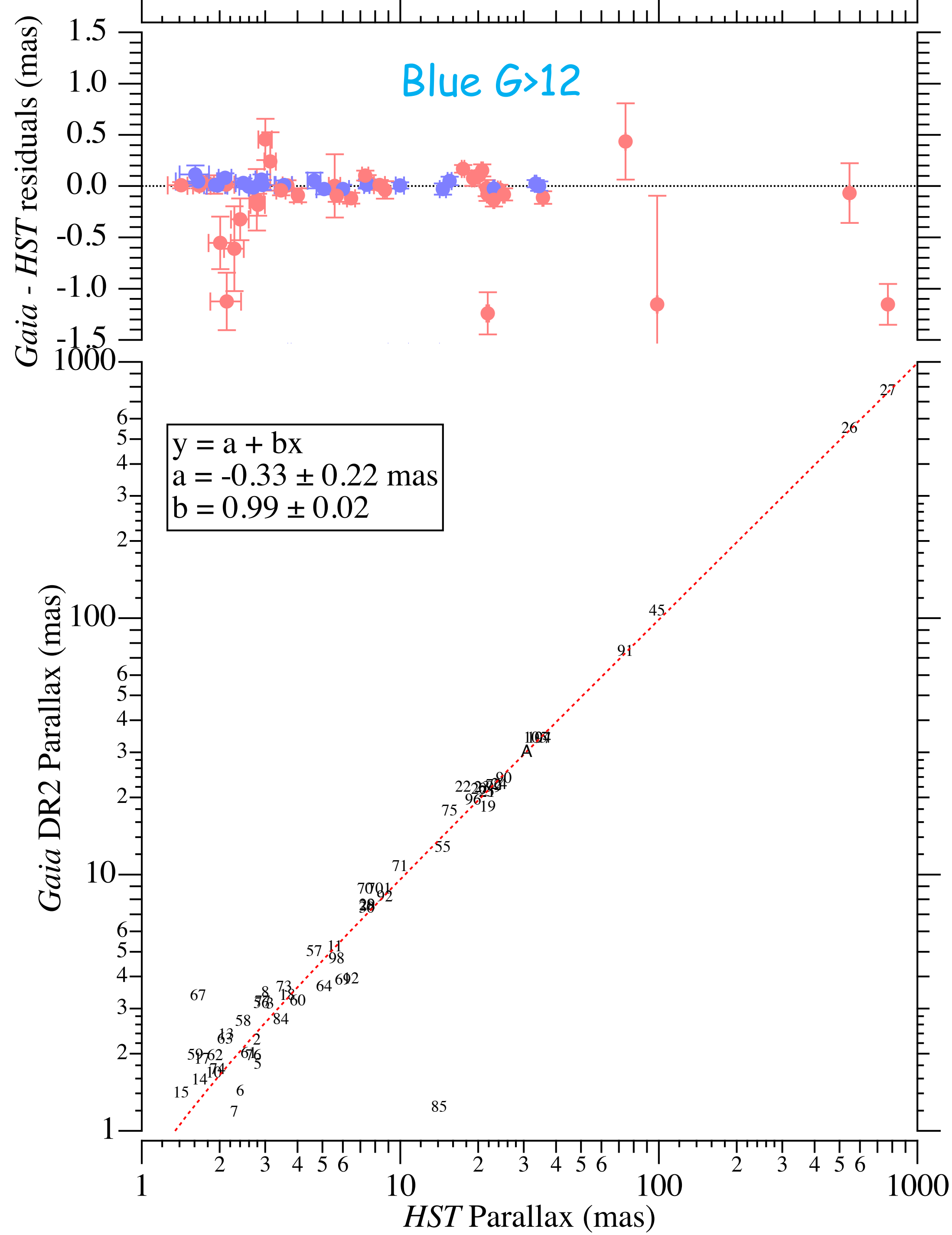
The Glorious Future

This is DEAD

SIM and GAIA - Exo-Planet Detection Capability

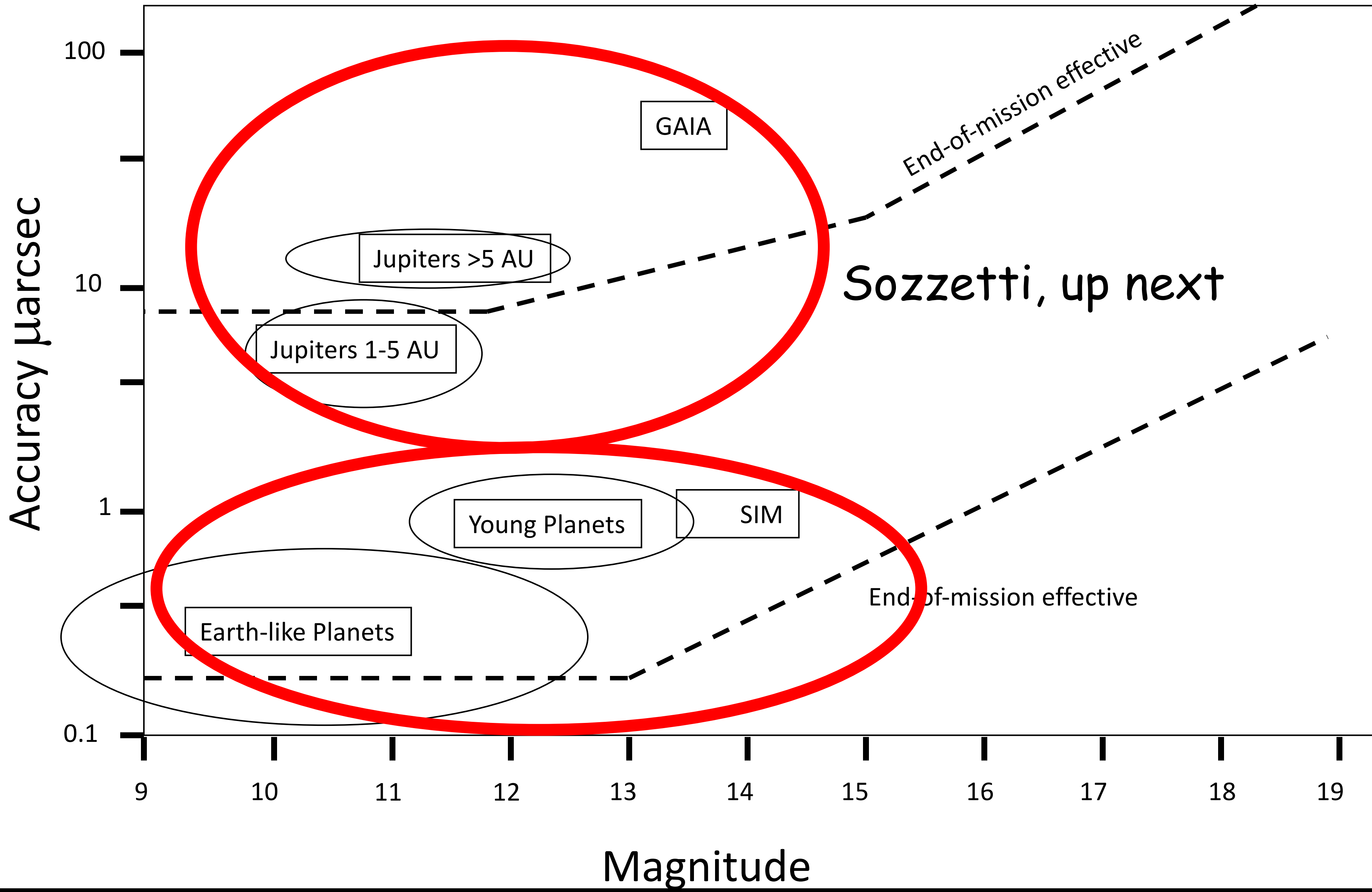


Gaia Passes My Test



Benedict+ 2018 Res. Notes AAS 2, 22

SIM and GAIA - Exo-Planet Detection Capability

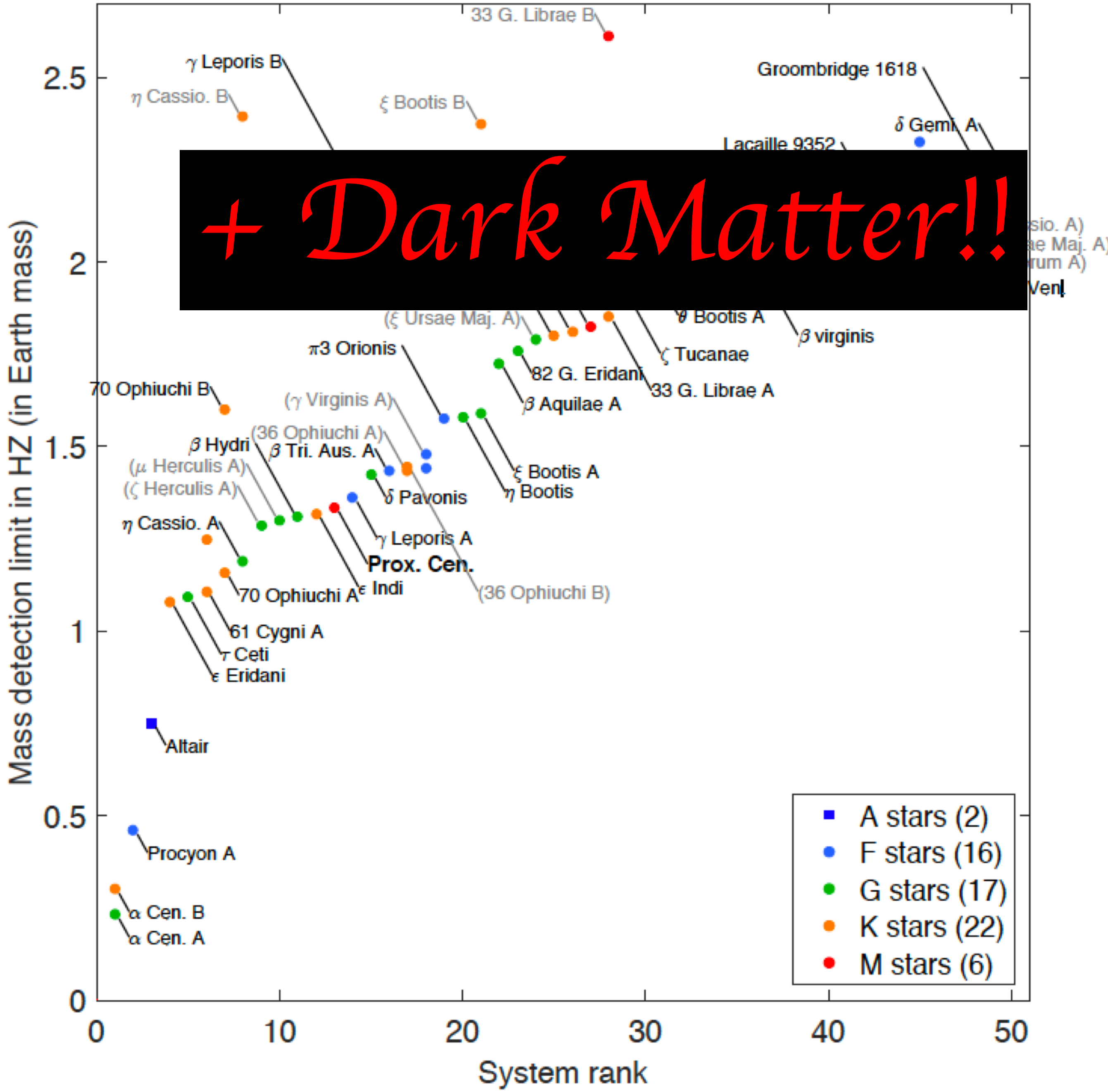


Theia

A New Hope?

ESA and Japan?

Theia

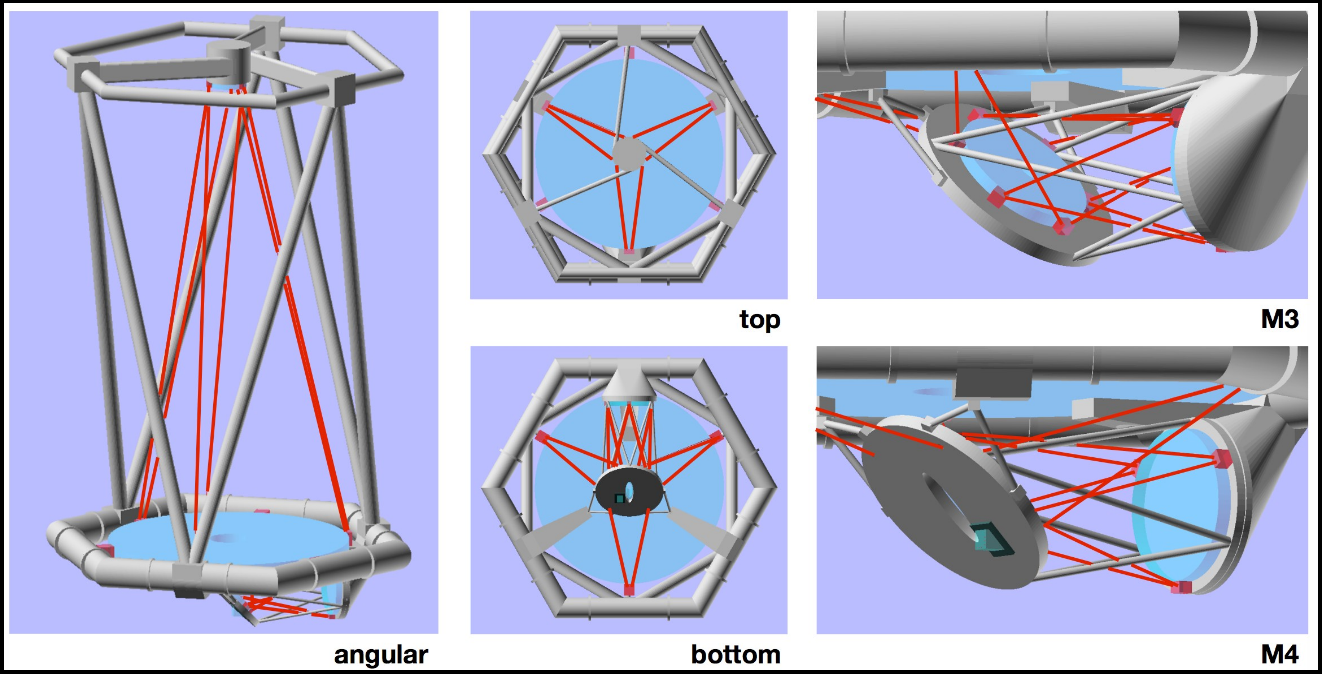


Earths and super-E
be detected and ch

All Super-Earths w
can be detected ar
stars.

Independent Linear Interferometers

Lesson from Gaia (and HST/FGS): monitor, monitor, monitor



Independent linear interferometers : monitoring for corrections on ground. In red all the independent baselines forming laser hexapods. Retroreflectors are at M2 and M3. Microinterferometers at M1 and M4.

Funding an issue to be resolved ~December 2018

An Astrometric Search for Planets Orbiting in the Alpha Centauri System

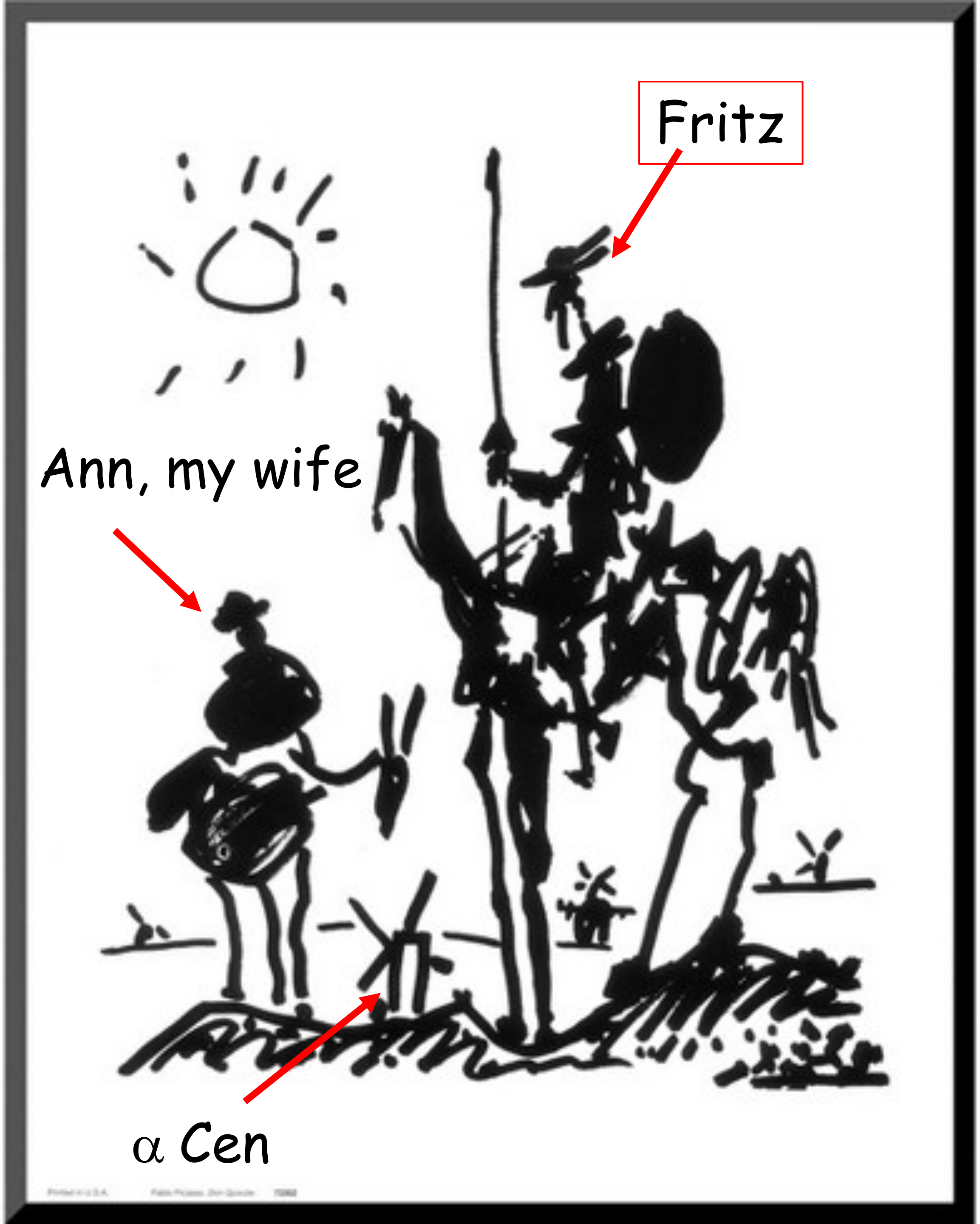
None Assigned

ABSTRACT

We propose a pilot study consisting of a series of high signal-to-noise (SNR) observations of the nearby stellar binary alpha Cen A and B to make precise measurements of their relative orbit. In addition to probing the limits of ALMA's differential astrometric precision, these measurements will improve our knowledge of the orbit of the alpha Cen AB system by factors of two to five in just a few years and will form the start of a search for exoplanets in this system.

APPROVED!

PI NAME:	Rachel Akeson			**SCIENCE CATEGORY:**	Circumstellar disks, exoplanets and the solar system
ESTIMATED 12M TIME:	18.0 h	**ESTIMATED ACA TIME:**	0.0 h	**ESTIMATED NON-STANDARD MODE TIME (12-M):**	18.0 h
CO-PI NAME(S): (Large & VLBI Proposals only)					
CO-INVESTIGATOR NAME(S):	Chas Beichman; Pierre Kervella; Ed Fomalont; George Benedict				


Fritz
Ann, my wife
α Cen

172 Years of Not Finding a Planet with Astrometry

Summary

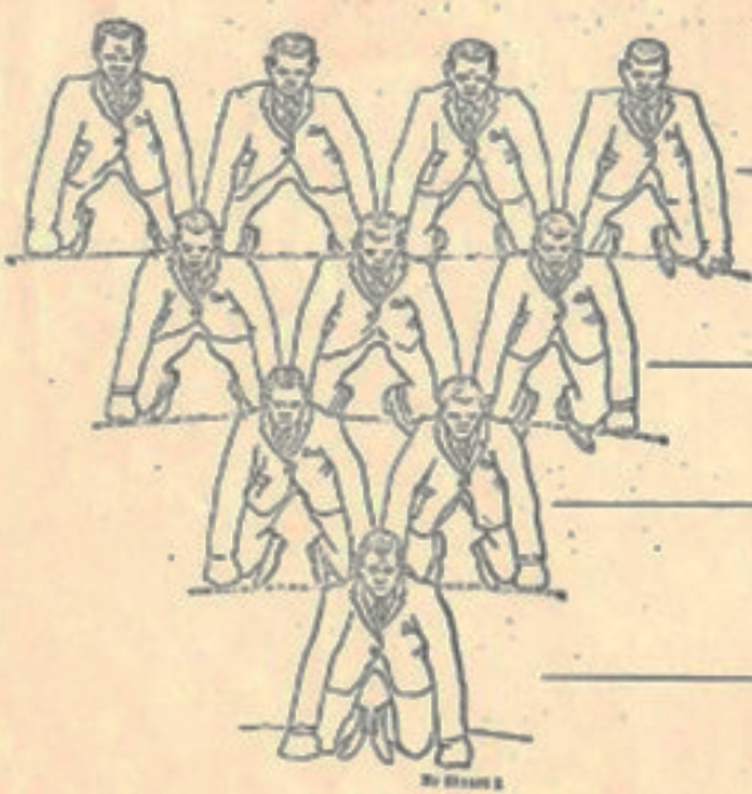
Astrometry has yet to independently discover an exoplanet

Astrometry has made useful contributions- exoplanet masses, system architecture, host star characterization

The future is seemingly bright, although true Earth analogs just out of reach (Like fusion power? Always a few years off in the future?)

THE ASTRONOMICAL PYRAMID

ILLUSTRATING THE INTERDEPENDENCE OF THE VARIOUS AREAS OF STUDY



GET BACK TO BASICS -- SUPPORT ASTROMETRY