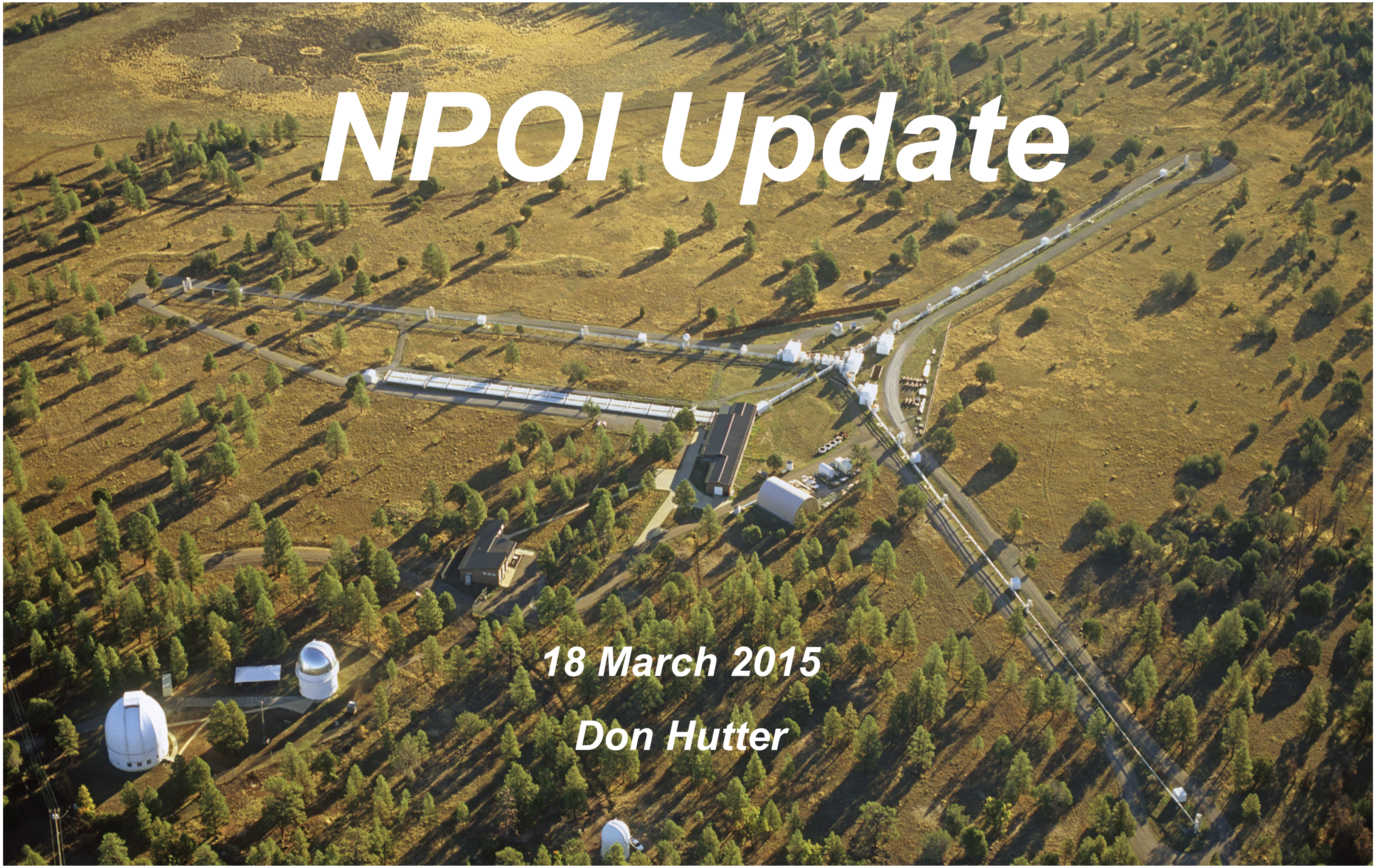


# NPOI Update

18 March 2015

Don Hutter

# The “Basics”

- NPOI = Navy Precision Optical Interferometer
- Major funding by Oceanographer of the Navy and Office of Naval Research
- NPOI is collaboration b/w USNO, NRL & Lowell Observatory
- Lowell is science partner & contractor to USNO (infrastructure & ops)
- Several external collaborators, some with independent funding (NMT, TSU)

# The NPOI Team

**USNO:**

Brian Luzum
Paul Shankland
Don Hutter
Jim Benson
Mike DiVittorio
Bob Zavala

**AZES:**

Tim Buschmann
David Allen

**NRL:**

Richard Bevilacqua
Sergio Restaino
Tom Armstrong
Ellyn Baines
Jim Clark
Henrique Schmitt

**ONR:**

12 Navy Reservists

**TSU:**

Matt Muterspaugh

**Lowell:**

Jeff Hall
Gerard van Belle
Bill DeGroff
Jacob Gannon
Victor Garcia
Jim Gorney
Teznie Pugh
Michael Sakosky
Jason Sanborn
Susan Strosahl
Steve Winchester
Stephen Zawicki

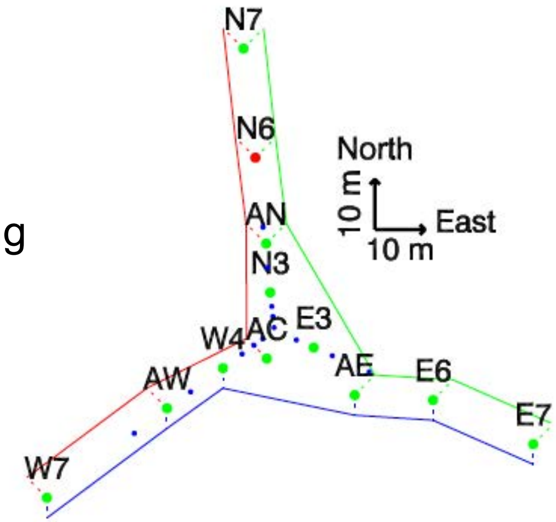
**NMT:**

Anders Jorgensen
Matt Landavaso

# Imaging Array Expansion

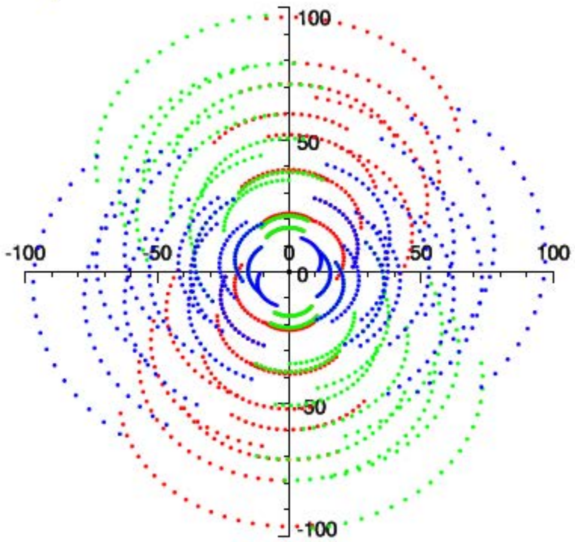
*Goals:*

- Infrastructure @ 10 stations (8 complete, 2 partial)
  - Shelters & cabling for siderostat, acquisition & angle tracking
  - Enables 9 – 432 m baselines
- 6 portable siderostats (functional, mostly)
  - In addition to 4 fixed astrometric stations

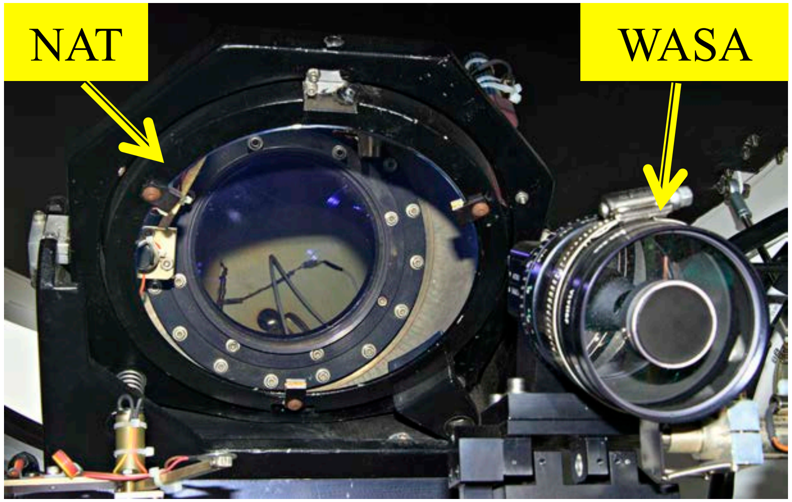



*Enables:*

- Geosatellite imaging techniques
  - Observe stars & satellites w/short, bootstrapped baselines
  (See also Gerard van Belle's presentation)
- High precision imaging
  - Observe O stars, solar analogs with baselines up to 432 m



# "Imaging" Station

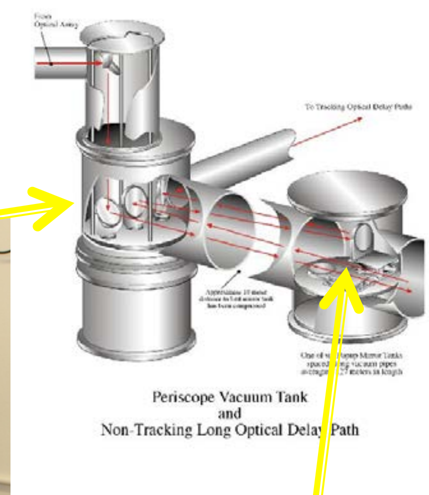


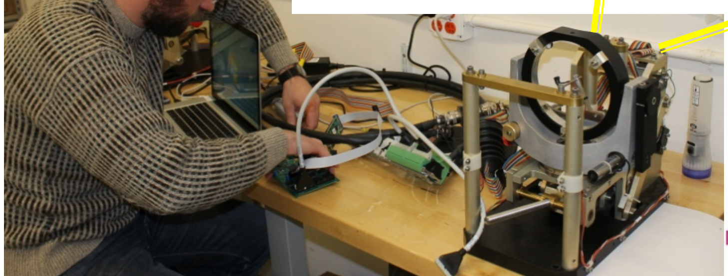

Siderostat


# View down East Arm

# Long Delay Lines (LDLs):

- Alignment of 72 “Popup” Mirrors in progress
- Integration to “Periscopes” to start this summer.



# Beam Combiners

VISION:

- NSF funded (TSU)
- 6-beam, visible-light analog of MIRC
  - 16 Dec 2013: First bootstrapped fringe tracking (5 stations).
  - Currently fringe tracking to $4^{th}$ magnitude
  - "Big" stars, rotators, binary observations underway (3 baselines, closure phase)

New Fringe Engine for NPOI "classic" beam combiner

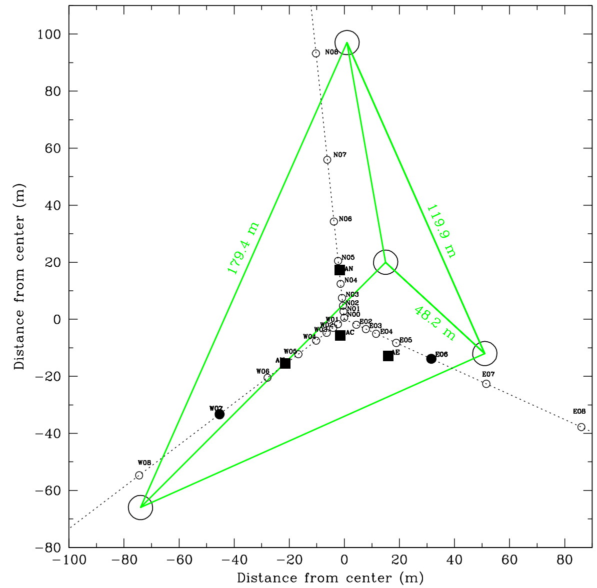
- Hardware finished (AZES)
- Firmware & software (NMT), undergoing on site tests.

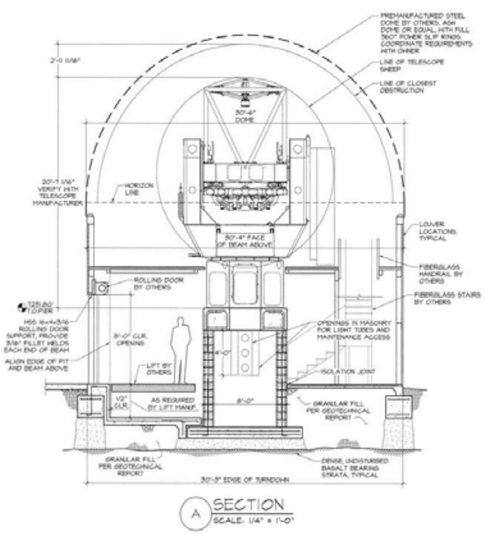
# 1.8m Telescopes

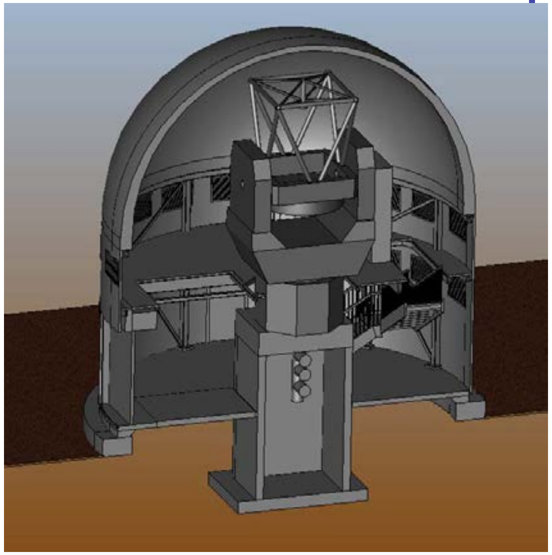
- **Goal:** large aperture array for wide-angle astrometry & visible/near-IR imaging

- **History:**
  - Nov 2010: gifted to Navy (USNO Flagstaff) by CARA
  - May 2012: Infrastructure (construction ready) plans finished
  - July 2012: Special Use Permit from US Forest Service

- **Currently:**
  - Infrastructure construction contract for 3 telescopes – Summer 2015
  - Current funding: $11.6M through 2019



# UNAC Update *(Jim Benson)*

UNAC = "USNO – NPOI Astrometric Catalog"

- Goal: Catalog of ~ 1000 stars with positions accurate to < 16 mas (tied to ICRF).

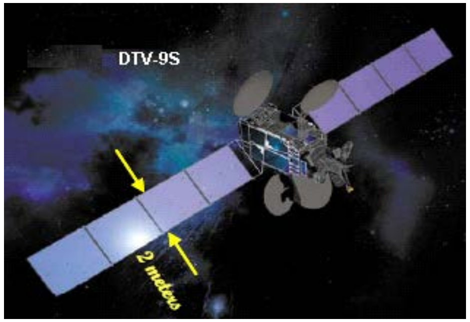
- 4 August 2014: internal USNO release of UNAC ver. 1.1
  - 59 stars (60 nights data)
  - $-11° \leq \delta \leq +72°$
  - Median position error ≈ 13 mas
  - Improved error distribution calc., only data from "locked" baselines, up to 5th-order thermal modeling

- From UNAC 1.1 to UNAC 1.2 ("publishable")
  - More QA work & tests of whether solid-earth tides are significant

# GEOsat Imaging

- 2009: 1st Interferometric detection of GEOsat during "glint"

Hindsley et al. 2011, Applied Optics, 50, 2692



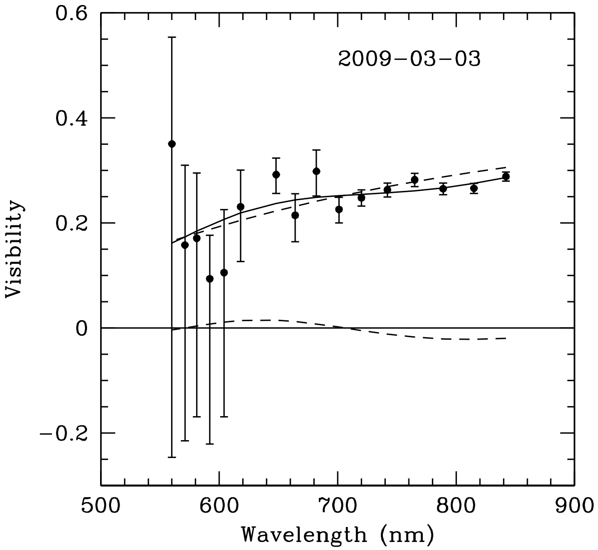




Fig. 5. Calibrated visibilities as a function of wavelength from 3 March 2009 data and from a two-component model fit to the data. The solid curve shows the flux-weighted sum of the two components from the first of the 3 March models shown in Table 1. This model consists of a smaller circular component of size 1.1 m (6.2 mas at geostationary distance) with 46% of the flux (upper dashed curve) and a larger component of 7 m (40 mas) with 54% of the flux (lower dashed curve). This larger, resolved component has a visibility amplitude of almost zero.

16

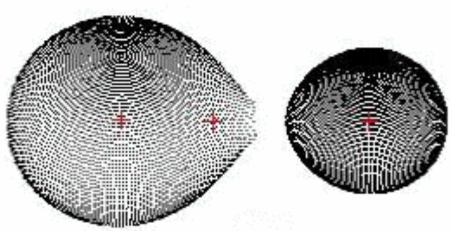
- March 2015: New multi-baseline observations

See Henrique Schmitt's presentation tomorrow

# *b Persei* *(Bob Zavala)*

- J. Sanborn (Lowell) and D. Collins (Warren Wilson College)
- Pioneer object for photo-electric photometry (Stebbins 1923)
- Ellipsoidal binary, SB1 triple system
- Radio star

(Hjellming & Wade)



0.2500

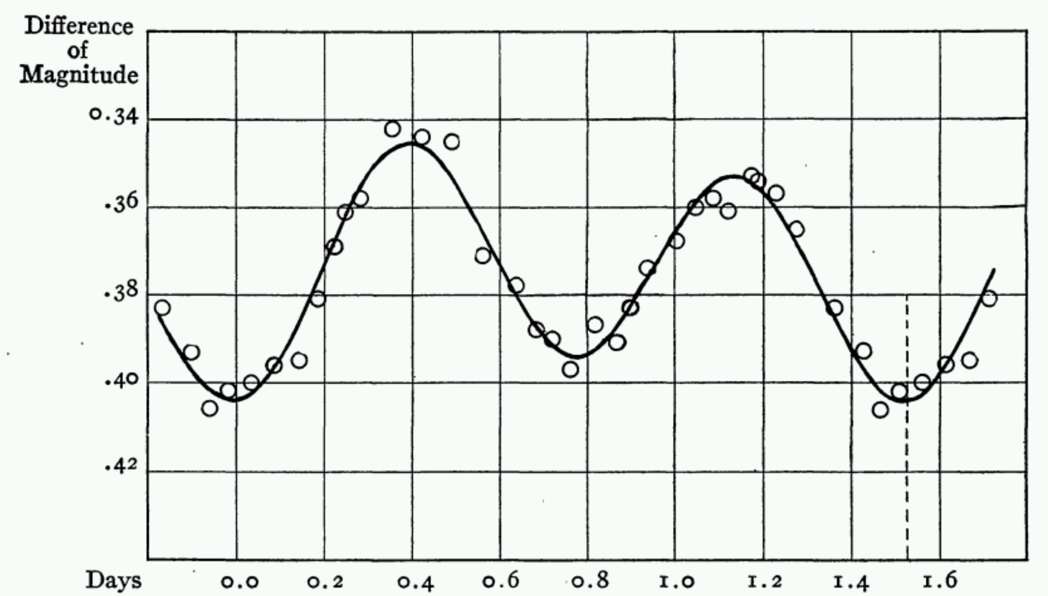
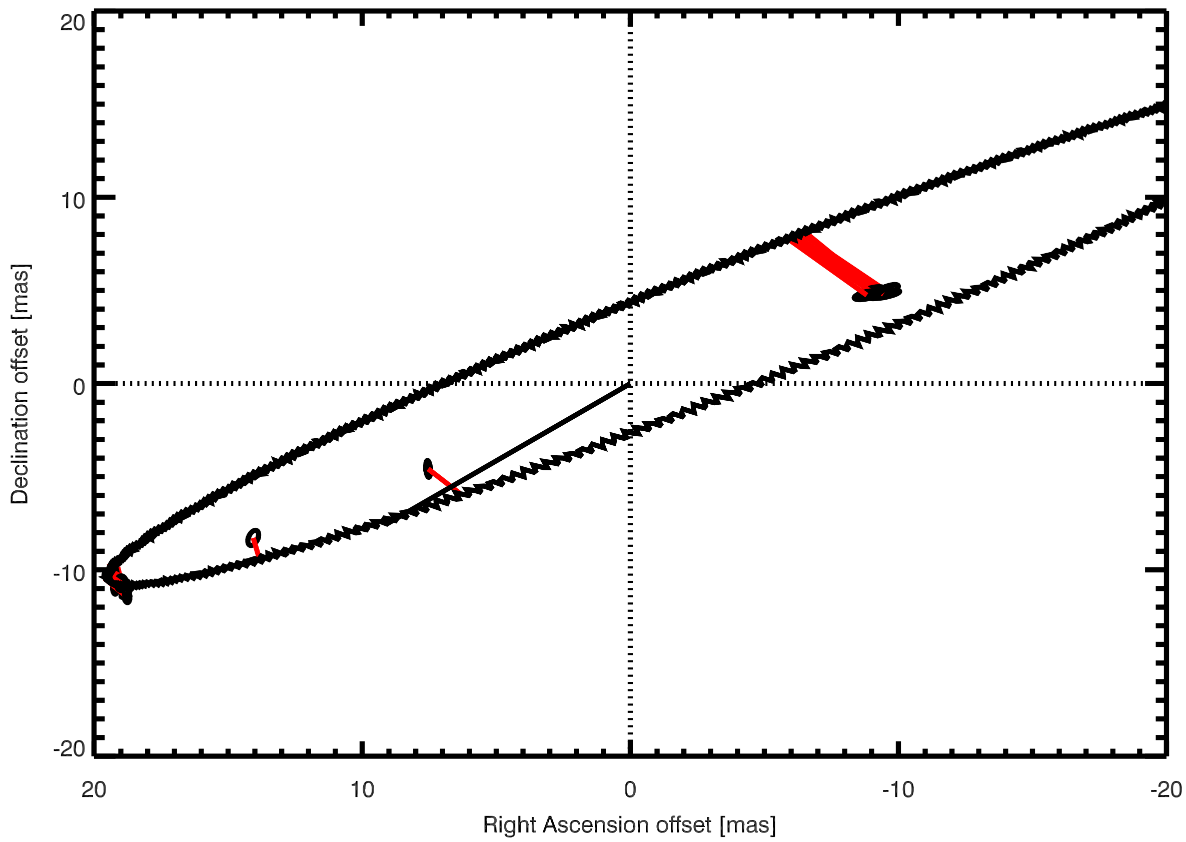
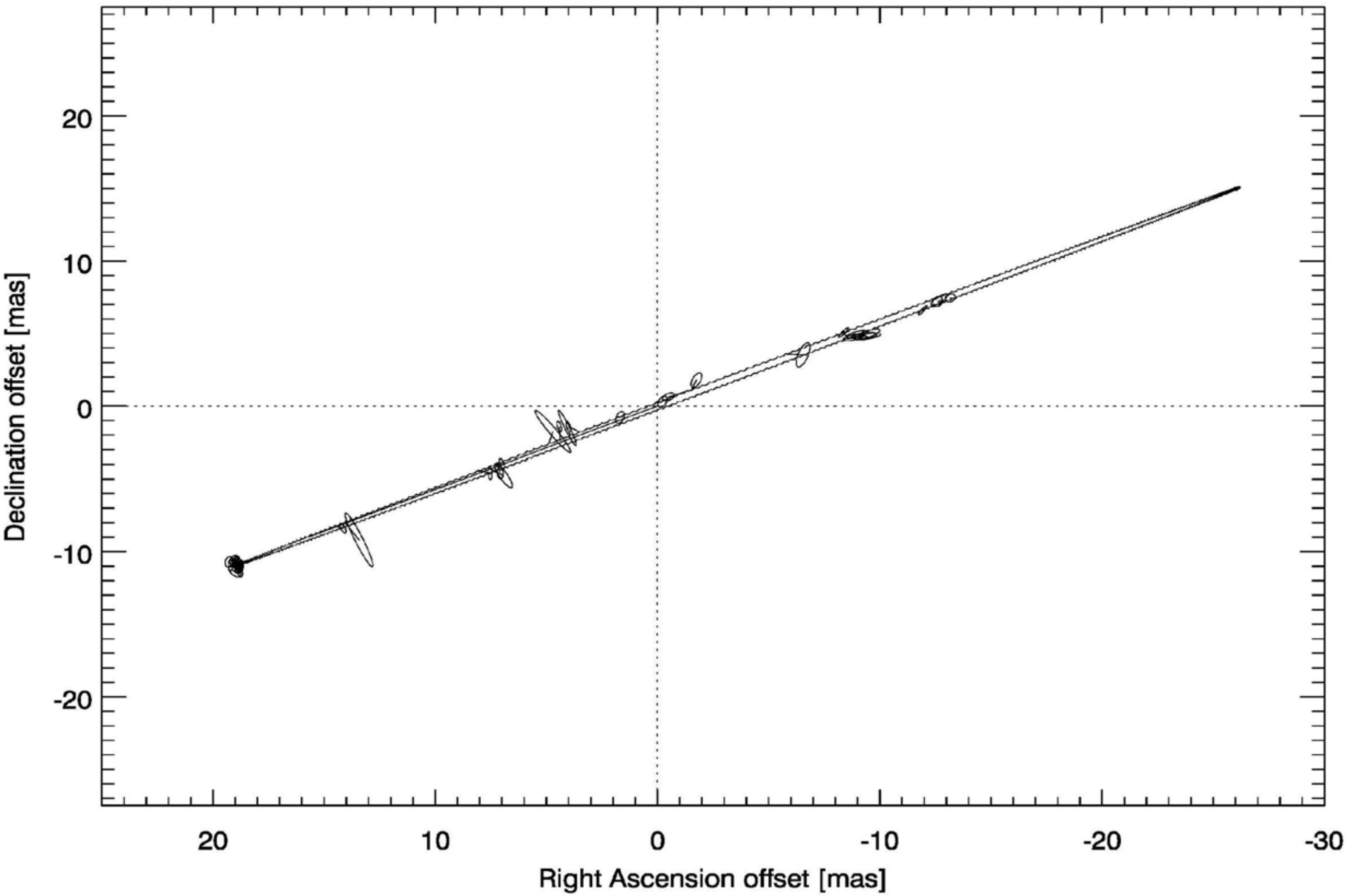



FIG. 1.—The light-curve of *b* Persei

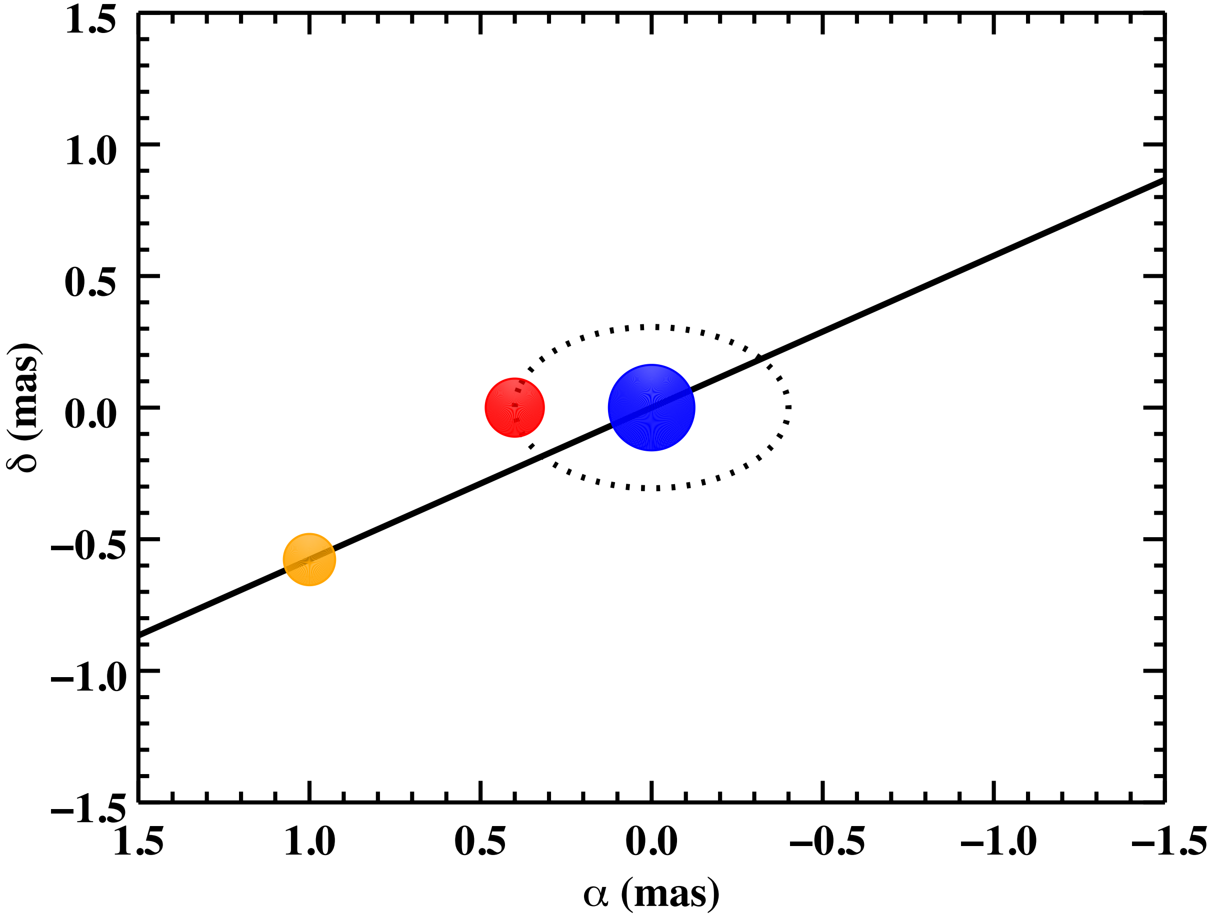
# HIPPARCOS: inclination close, within the 10 degree uncertainty



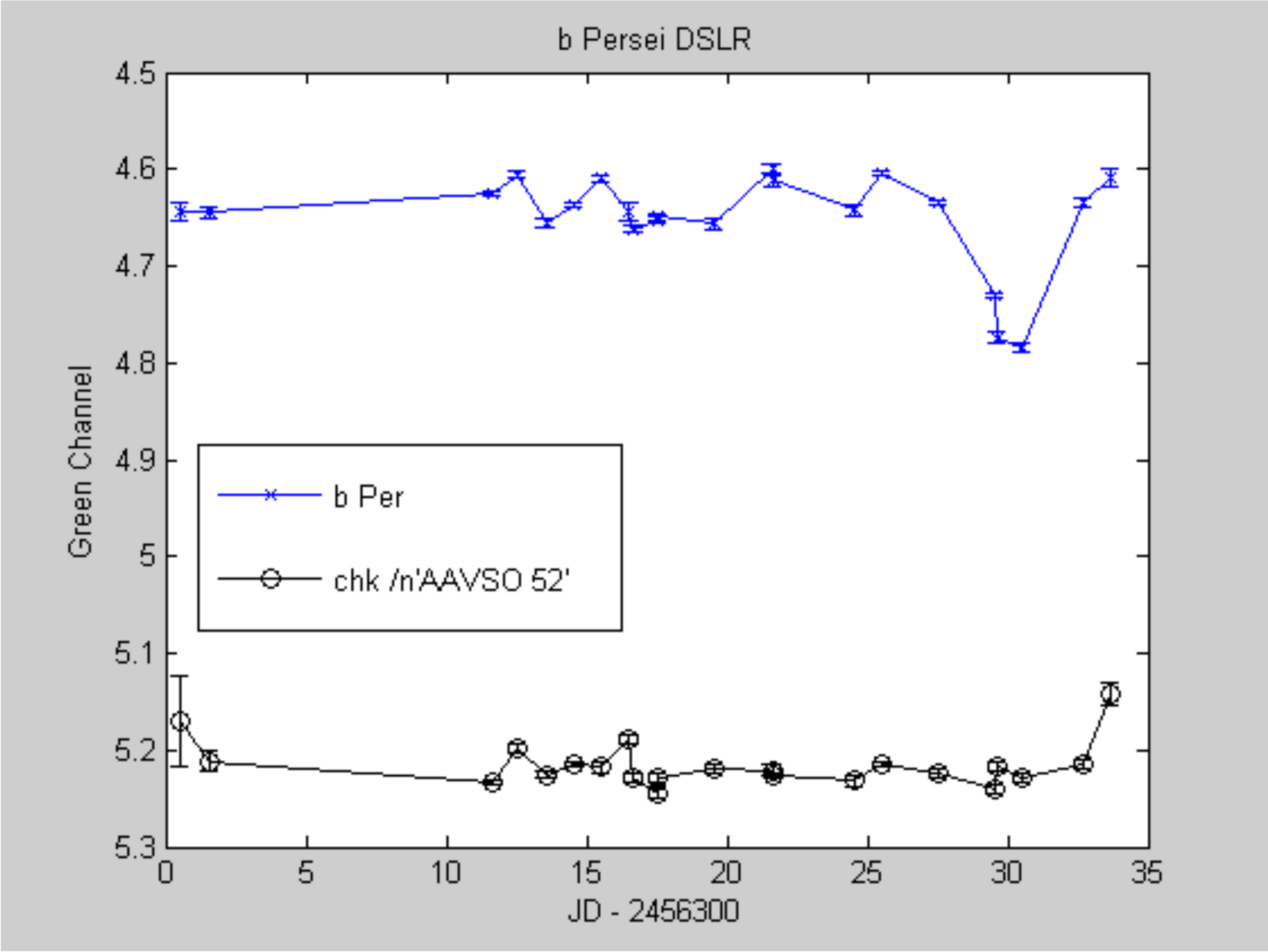
# b Per C orbit ~edge on



# *b Per eclipse prediction*
# *Jan 24-Feb 4, 2014*



# DSLR photometry 2013 eclipse detected



# *b Persei*

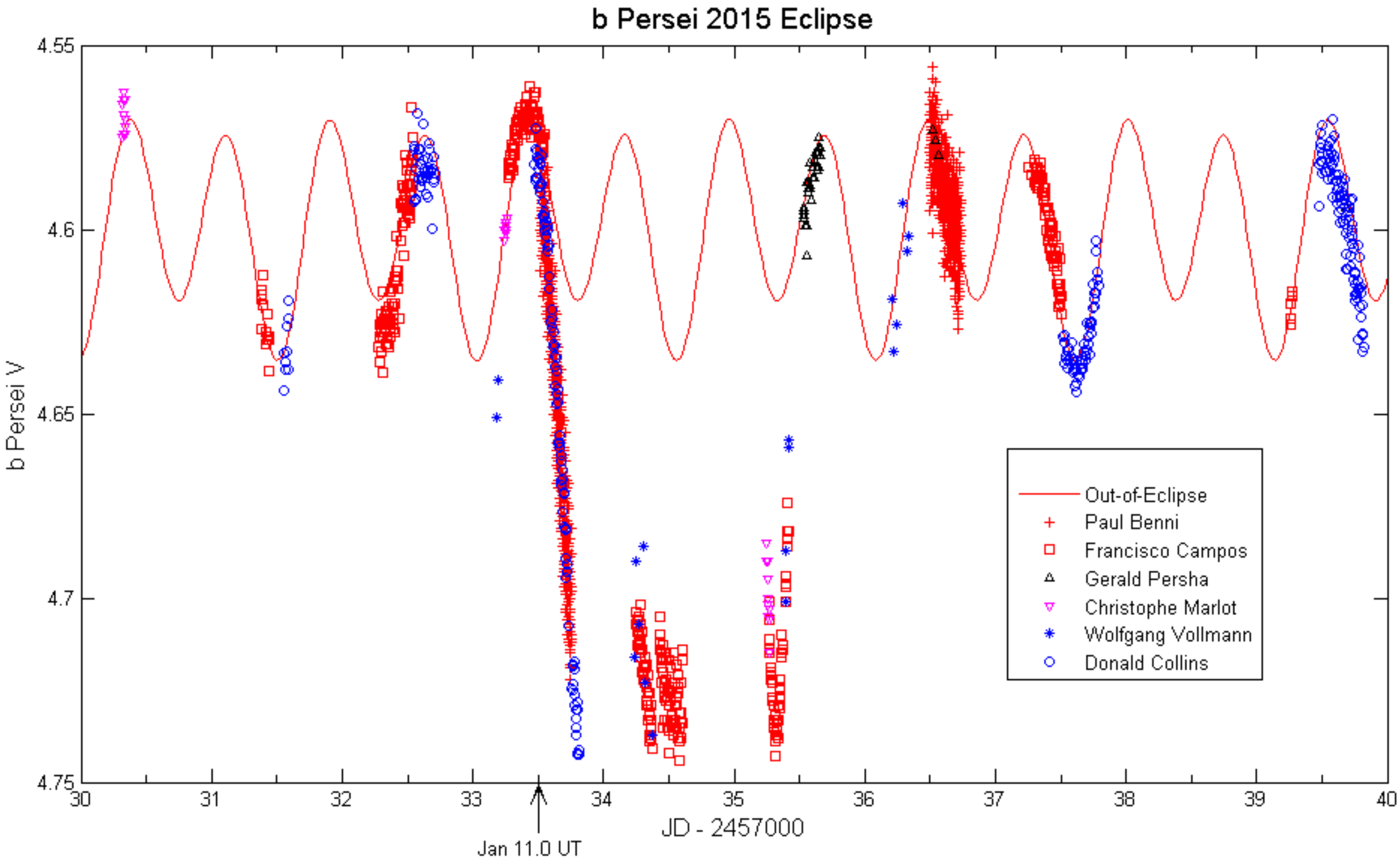
- Eclipse confirmed
- Next eclipse prediction Jan 15, 2015
- NPOI observations to refine prediction
- High time resolution, multi-color, detect eclipses against A and B components

http://inside.warren-wilson.edu/~dcollins/bPersei/

NOFS: 1.3m + Hartmann mask (Murison, DiVittorio)

Bright star photometry (IR too, e.g. Delta Sco)

# Jan 2015 b Per multi-eclipse preliminary AAVSO data



# Binaries: 47 Oph

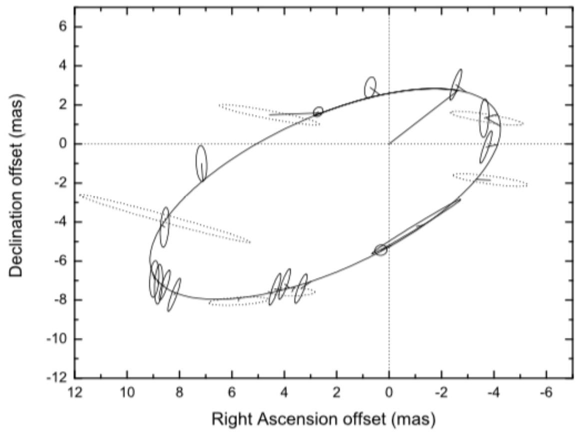



Fig. 1.— Apparent orbit and the interferometric data of 47 Oph. The ellipses indicate the astrometric uncertainty. The data with dot ellipses observed by the Mark III have already been published by Hummel (1997), and the data with solid ellipses are new data observed by the NPOI. The straight solid line indicates the periastron.

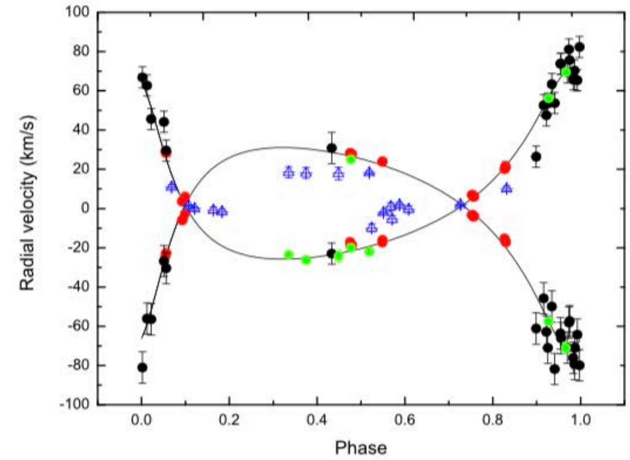
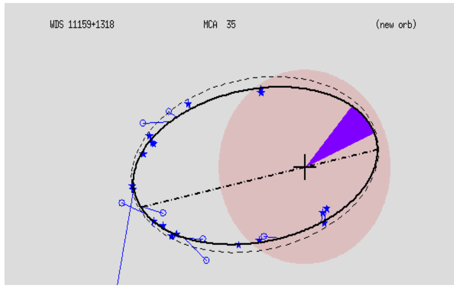



Fig. 2.— Radial velocity curve and the observed RV data. The black, green and red filled circles denote the RV data supplied by Parker (1915), Abt & Levy (1976) and measured by the present work, respectively. The blue triangles represent the RV data which were not used to fit the orbit.

- Wang, Hummel, Ren & Fu 2015, AJ, accepted.
  - masses, orbital parallax, luminosities, radii & age derived

# Updating Double Star Orbits with the NPOI




New Orbit (solid curve) vs. Old Orbit (dashed curve) for star **73 LEO** derived from newly collected data points (blue asterisks)

**Project Dates:** 23 June – 15 August 2014

**SEAP Student:**
Jonathan Hurowitz
The Altamont School
Senior

**Mentor:**
Dr. Brian Mason
US Naval Observatory
Astrometry Department
brian.mason@usno.navy.mil

**Project Objective:**

- Reduce data taken by the Navy Precision Optical Interferometer (NPOI) in Flagstaff, AZ to update orbits of bright binary star systems with recent, highly accurate data.

**Methods:**

- Used OYSTER, a program written by former USNO employee Christian Hummel, that reduces NPOI data to find position angle and separation of binary star systems.

**Results:**

- Obtained 52 data points on five binary star systems: HR 233, τ PER, 36 TAU, 73 LEO, δ SGE, with an average of 5 measures per data point, accounting for over 100 nights of data dating back 6 years.
- Computed new orbital elements and errors for said systems.

# Stellar Shakers & Movers

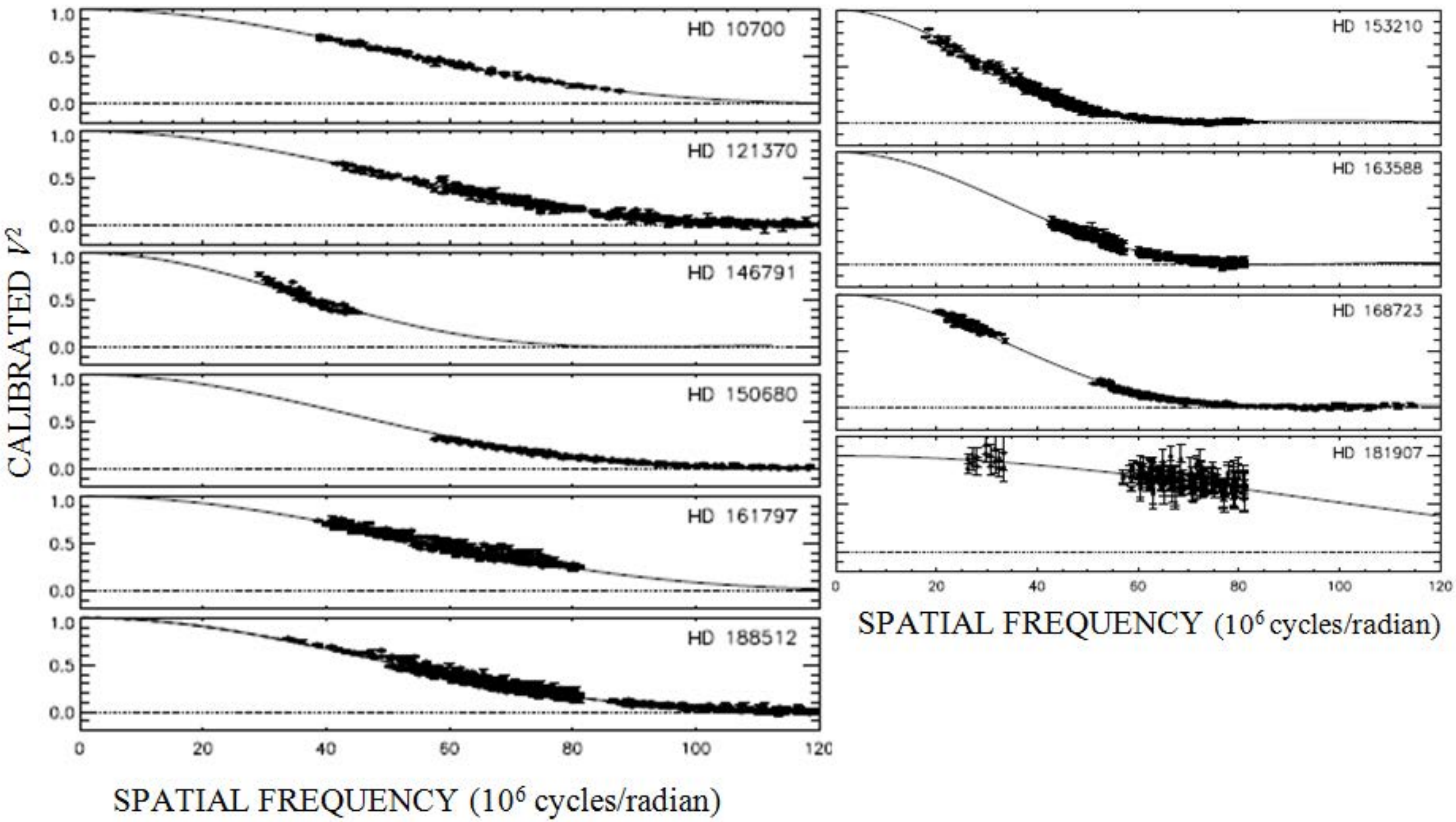
- 10 stellar oscillators observed using the NPOI
  - Included new and archival data
  - 1 dwarf, 4 subgiant, 5 giant stars
- Measured/calculated $\theta_{LD}$, $R$, $T_{eff}$, $F_{BOL}$, $L$
- Usually asteroseismologists measure frequencies $\nu$ and calculate $R$ using

$$\Delta\nu \propto M^{\frac{1}{2}} R^{-\frac{3}{2}} \quad \text{and} \quad \nu_{max} \propto M R^{-2} T_{eff}^{-\frac{1}{2}}$$

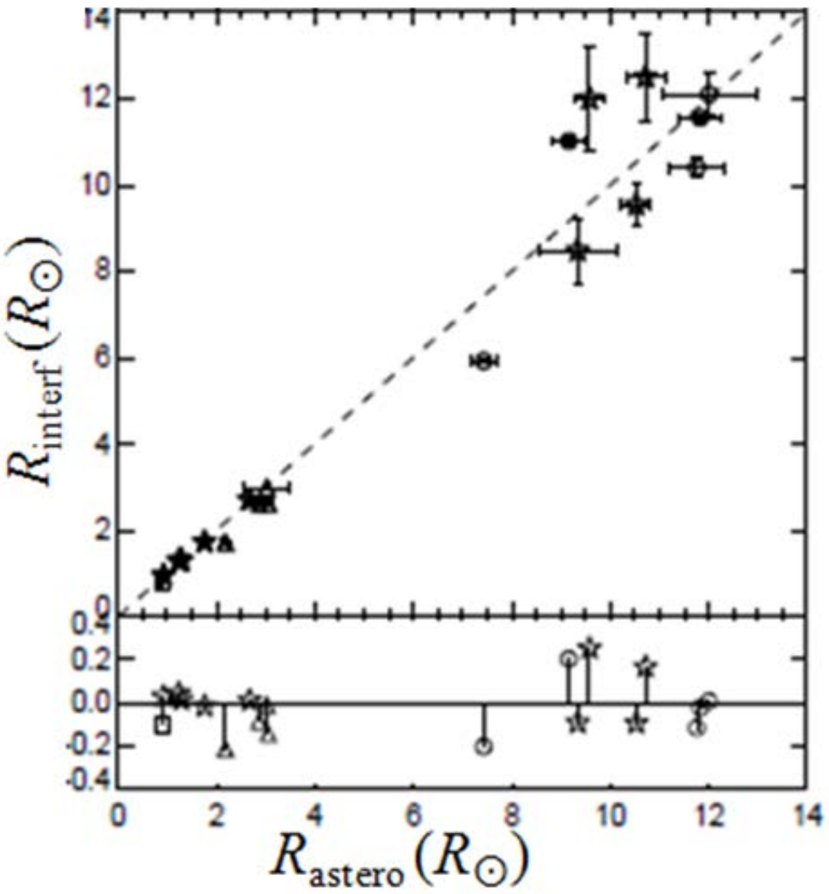
- Here we measured $R$ and compared them to oscillation results to test the relationships.

Baines et al. 2014, ApJ, 781, 90

# Visibility Measurements



# Radii Comparison




□ is the dwarf, △ are subgiants, ○ are giants, ☆ are 10 oscillators from Huber et al. (2012).

The largest outliers (HDs 153210, 161797, 168723) agree with other $R_{interf}$ to within 1% (the latter two) and to the SED fit to within 2-σ (HD 153210).

The relationships work best for M-S stars but have limited precision for giant stars. Chorus: More observations needed.