Calibrator Selection

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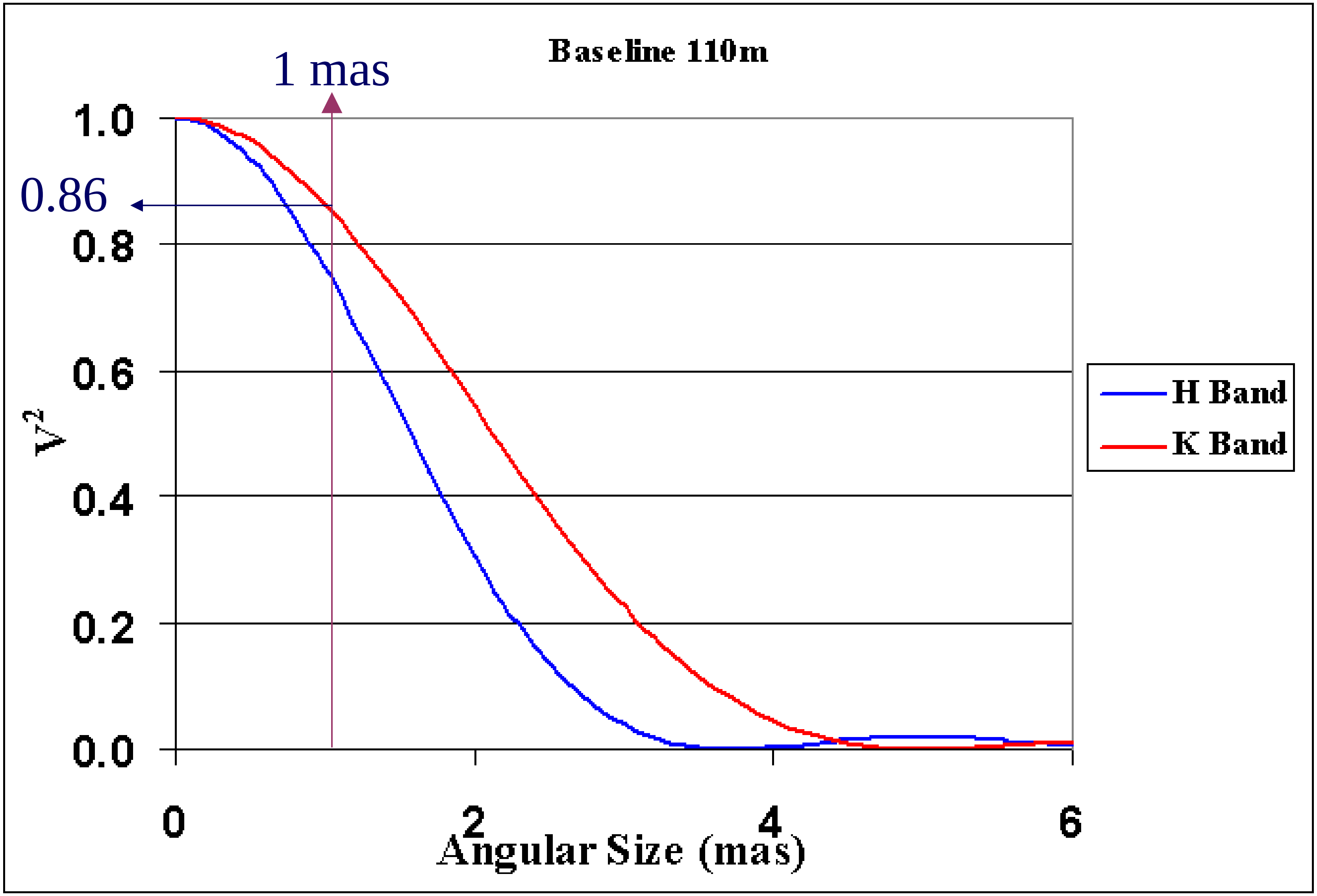
Brief Overview

- Why and how to pick a calibrator?
- MSC calibration tools
  - PTI, KI, CHARA, NPOI and VLTI
- Target vetting criteria
- Special cases and other considerations

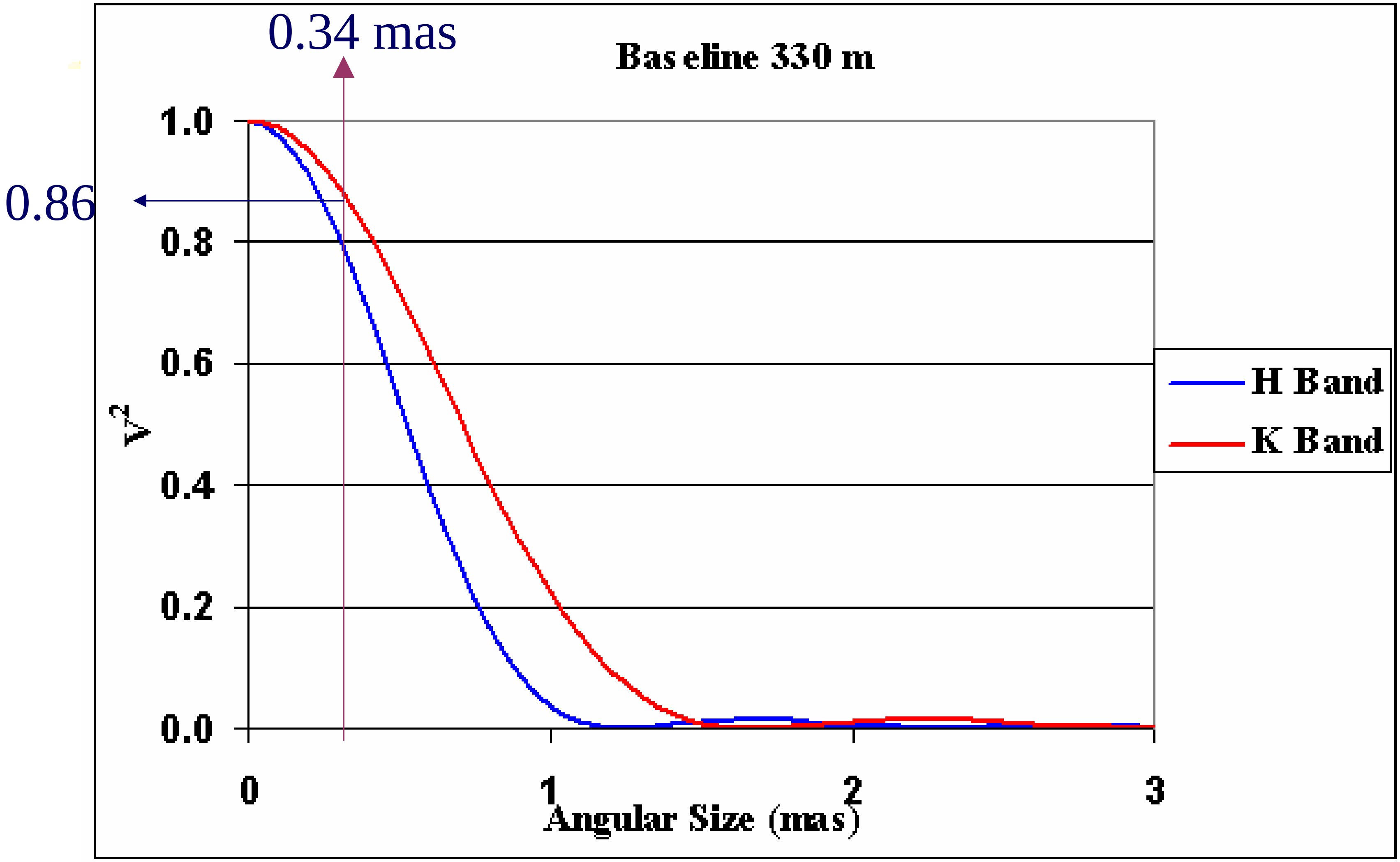
What exactly is calibration?

- Interferometer system response to an unresolved source is system visibility
  - Perfect Interferometer $V^2 = 1$
  - Real Interferometer System $V^2 \sim 0.75$
    $\Rightarrow$ ***Pick only unresolved calibrators to first order***
- This may not be possible in practice
  - e.g. PTI calibrators, CHARA calibrators

Unresolved sources for PTI



Unresolved sources for CHARA



Comparison from getCal

- PTI
  - 1.0 mas K band size (for 110 m baseline)
    - 63 potential calibrators all LC in randomly chosen 20º FOV
  - This assumes limiting K mag of 5.0
- CHARA
  - 0.34 mas K band size (for 330 m baseline)
    - 4 potential calibrators all LC in same randomly chosen 20º FOV using K mag of 5.0
    - 47 potential calibrators in same FOV if K mag is raised to 7.0

Why do we care about calibration?

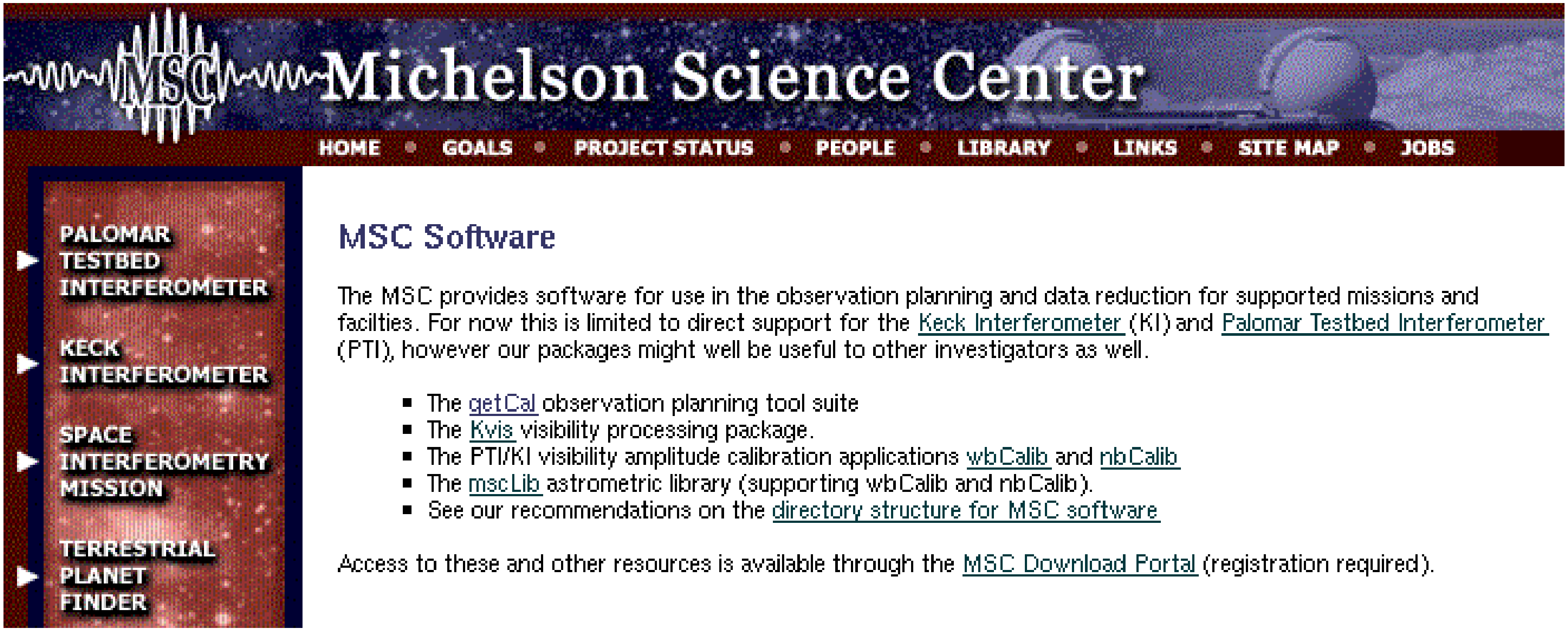
- Interferometer response function
  - system visibility - uniform disk model
  - $|V|^2 = (2 J_1(x) / x)^2$ where $x = \pi B \vartheta / \lambda$
- System response
  - geometry with respect to target
  - brightness
  - color (spectral type)
  - bolometric flux - $F_{bol} = \pi\sigma T^4/m$ where m - best fit factor

What helps us?

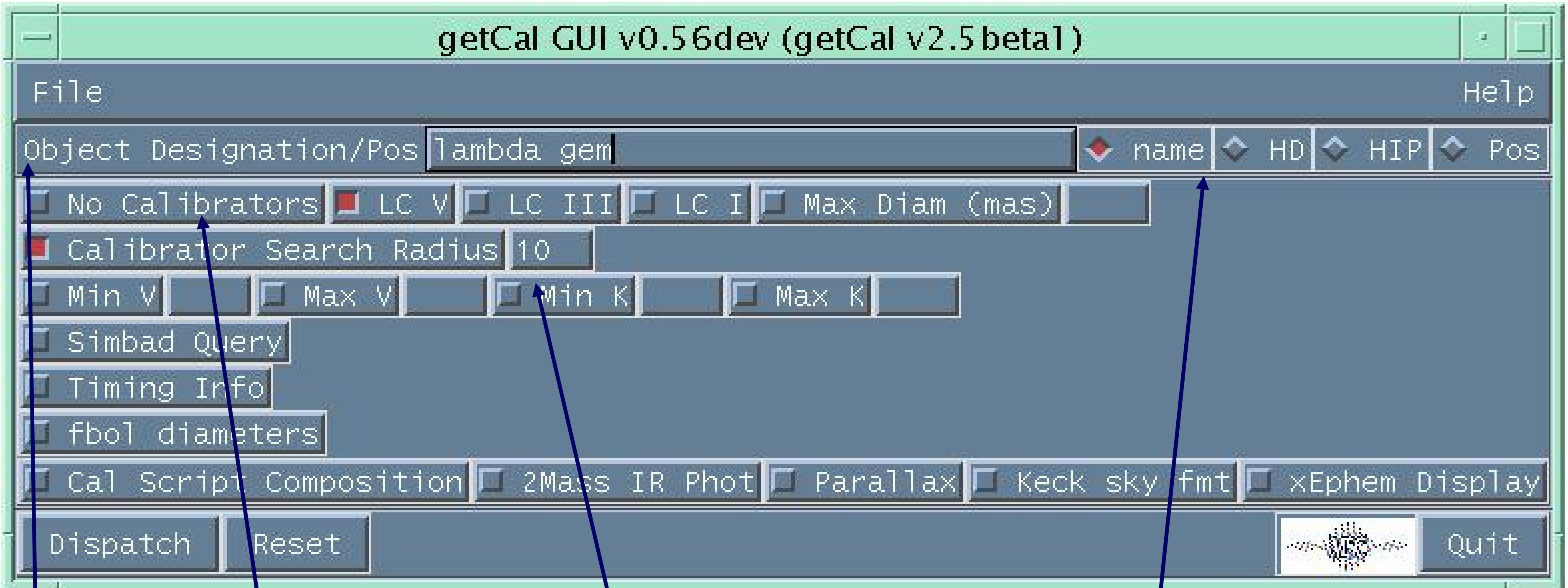
- Known Solutions
  - binaries, resolved stars, circularly symmetric, simple geometry, limb-darkening, etc.
- Peripheral Knowledge
  - estimated angular diameter
  - astrophysics of source (e.g. variability, lines)
  - spectral energy distribution (SED)
  - Hipparcos/SIMBAD/ADS classifications
- Scientific Experiment - clear goals

Tools - getCal and gcGui

- Written by A. Boden as part of PTI/KI reduction tools suite. Now upgraded and maintained by MSC at IPAC/Caltech for use with several interferometers.
  - getCal is original command line interface
  - gcGui is updated GUI with most common functions and additional modules for added functionality



getCal GUI: The Basics



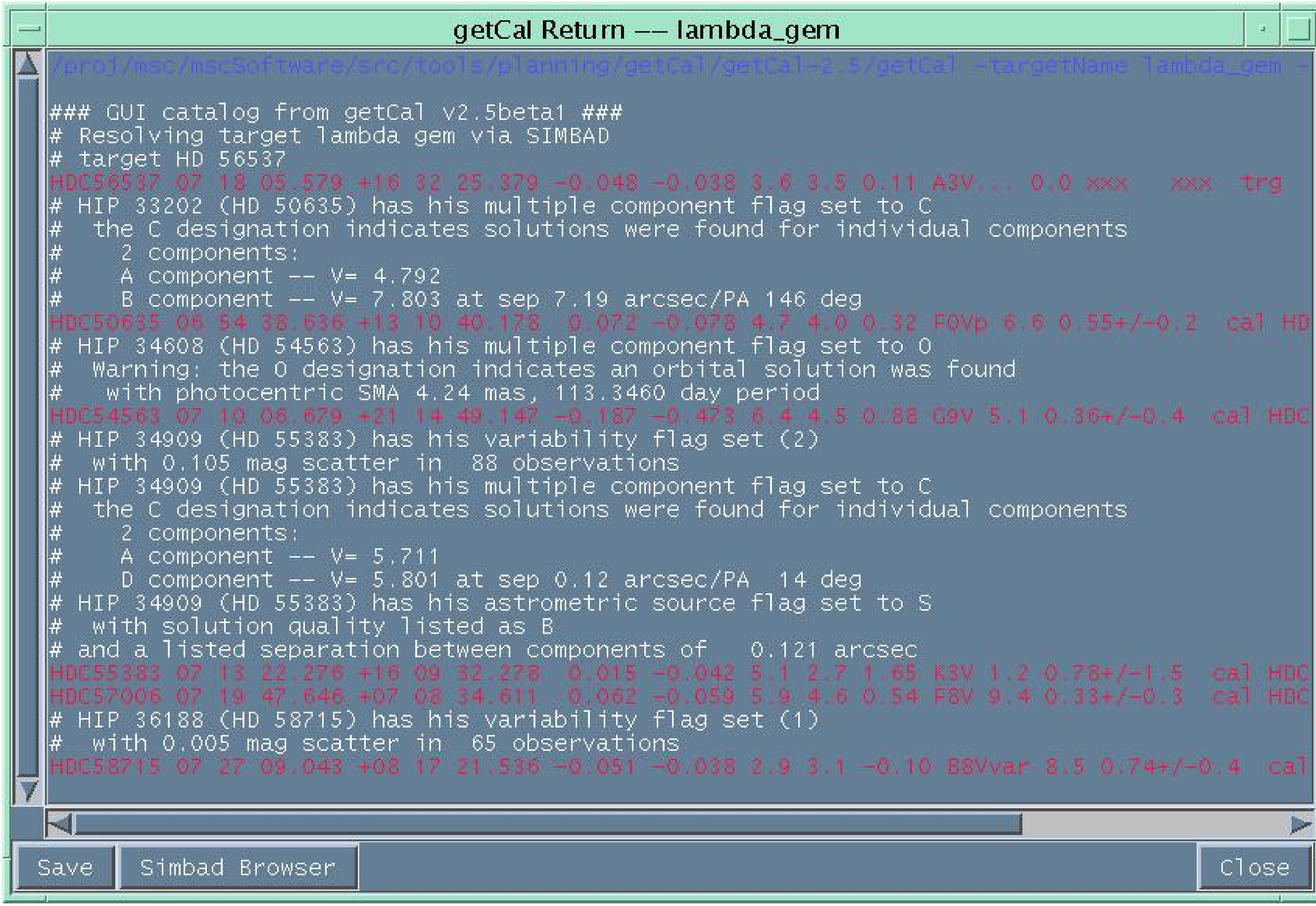
max search radius

Do you want calibrators for it?

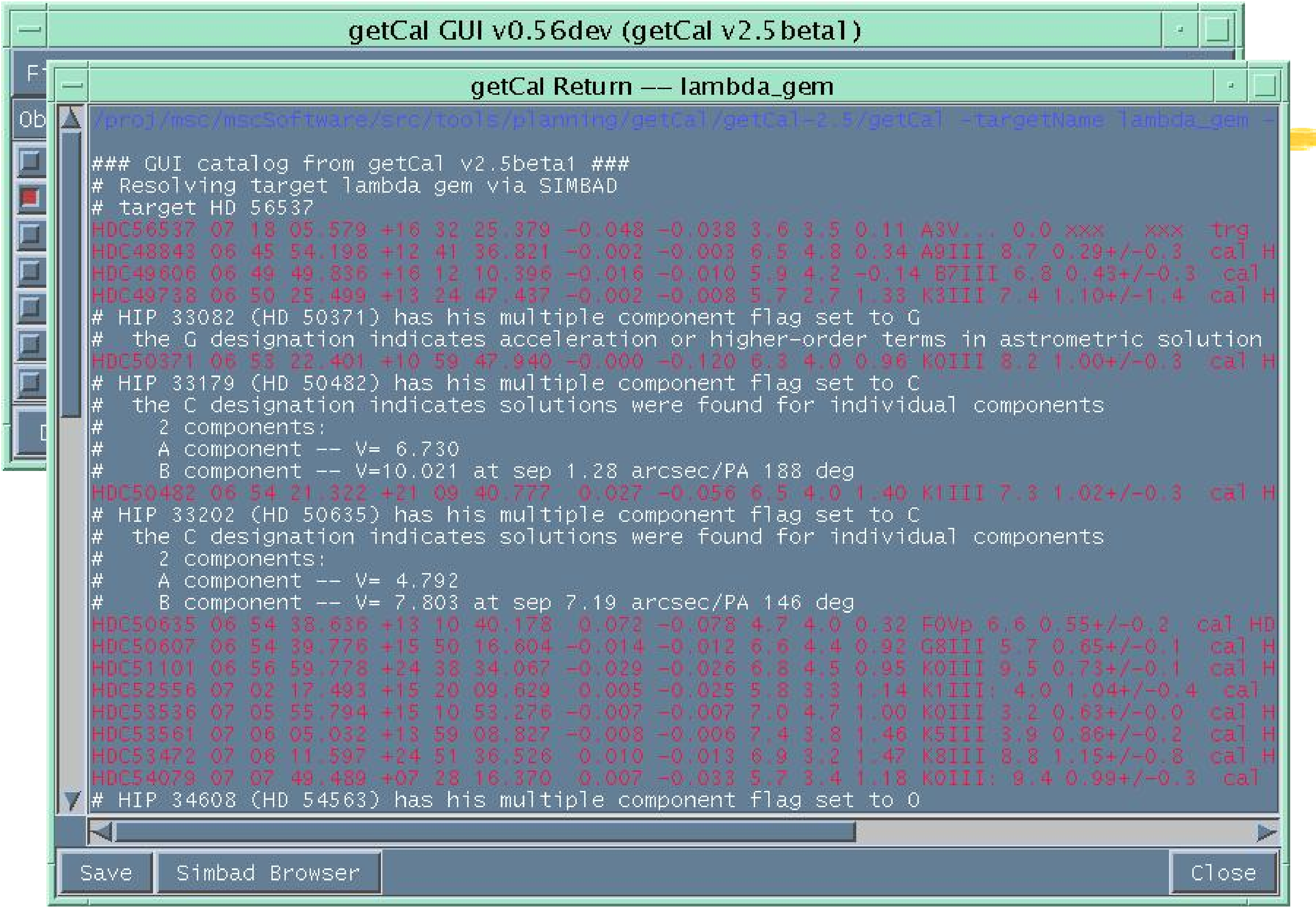
name type/position

name of object

List of potential calibrators



List of potential calibrators



List of potential calibrators

getCal Return -- lambda_gem

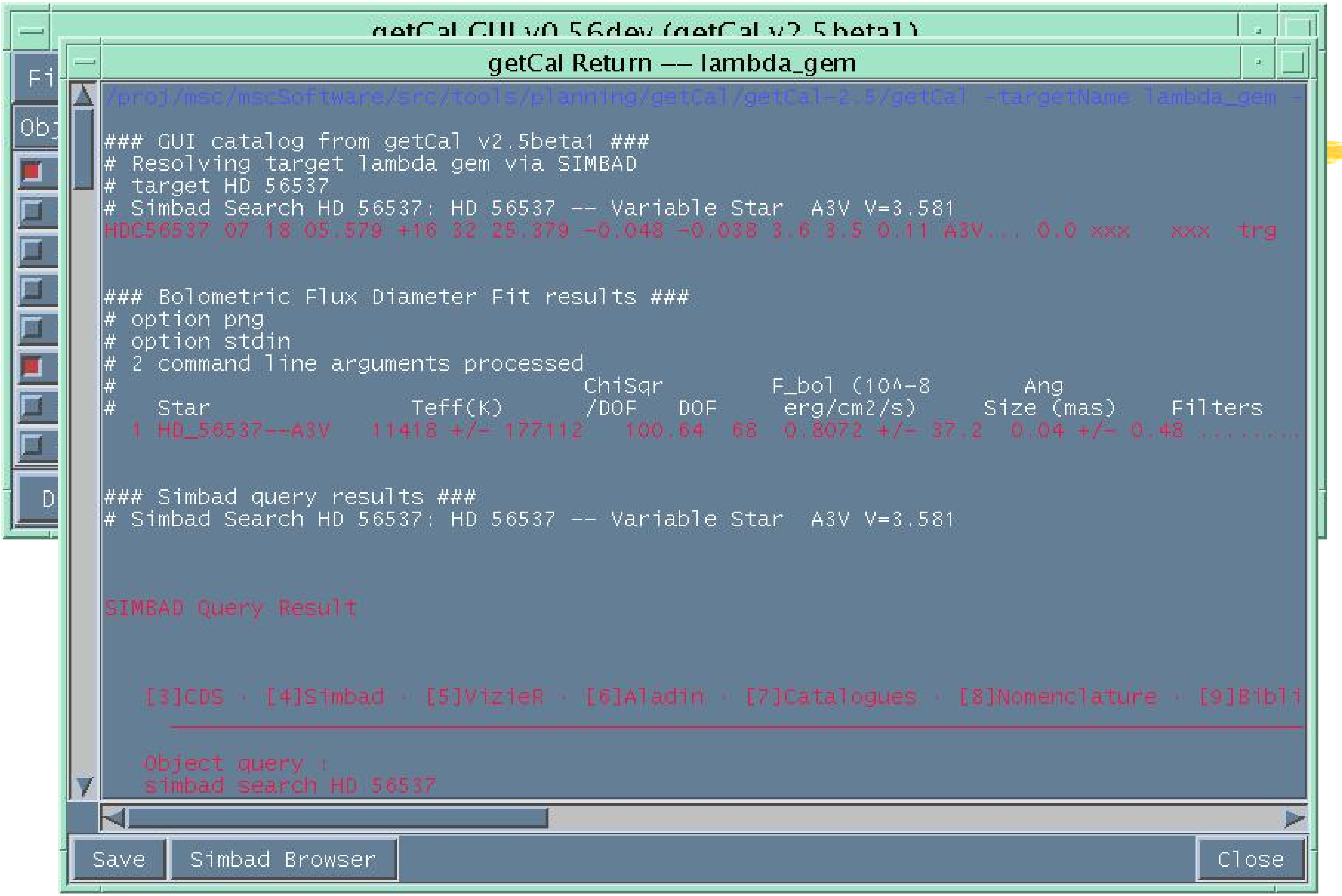
```
/proj/msc/mscSoftware/src/tools/planning/getCal/getCal-2.5/getCal -targetName lambda_gem -

### GUI catalog from getCal v2.5beta1 ###
# Resolving target lambda gem via SIMBAD
# target HD 56537
HDC56537 07 18 05.579 +16 32 25.379 -0.048 -0.038 3.6 3.5 0.11 A3V... 0.0 xxx   xxx  trg
# HIP 33202 (HD 50635) has his multiple component flag set to C
#  the C designation indicates solutions were found for individual components
#    2 components:
#    A component -- V= 4.792
#    B component -- V= 7.803 at sep 7.19 arcsec/PA 146 deg
HDC50635 06 54 38.636 +13 10 40.178  0.072 -0.078 4.7 4.0 0.32 F0Vp 6.6 0.55+/-0.2  cal HD
# HIP 34608 (HD 54563) has his multiple component flag set to O
#  Warning: the O designation indicates an orbital solution was found
#   with photocentric SMA 4.24 mas, 113.3460 day period
HDC54563 07 10 06.679 +21 14 49.147 -0.187 -0.473 6.4 4.5 0.88 G9V 5.1 0.36+/-0.4  cal HDC
# HIP 34909 (HD 55383) has his variability flag set (2)
#  with 0.105 mag scatter in  88 observations
# HIP 34909 (HD 55383) has his multiple component flag set to C
#  the C designation indicates solutions were found for individual components
#    2 components:
#    A component -- V= 5.711
#    D component -- V= 5.801 at sep 0.12 arcsec/PA  14 deg
# HIP 34909 (HD 55383) has his astrometric source flag set to S
#  with solution quality listed as B
# and a listed separation between components of   0.121 arcsec
HDC55383 07 13 22.276 +16 09 32.278  0.015 -0.042 5.1 2.7 1.65 K3V 1.2 0.78+/-1.5  cal HDC
HDC57006 07 19 47.646 +07 08 34.611  0.062 -0.059 5.9 4.6 0.54 F8V 9.4 0.33+/-0.3  cal HDC
# HIP 36188 (HD 58715) has his variability flag set (1)
#  with 0.005 mag scatter in  65 observations
HDC58715 07 27 09.043 +08 17 21.536 -0.051 -0.038 2.9 3.1 -0.10 B8Vvar 8.5 0.74+/-0.4  cal
```

Save | Simbad Browser | Close

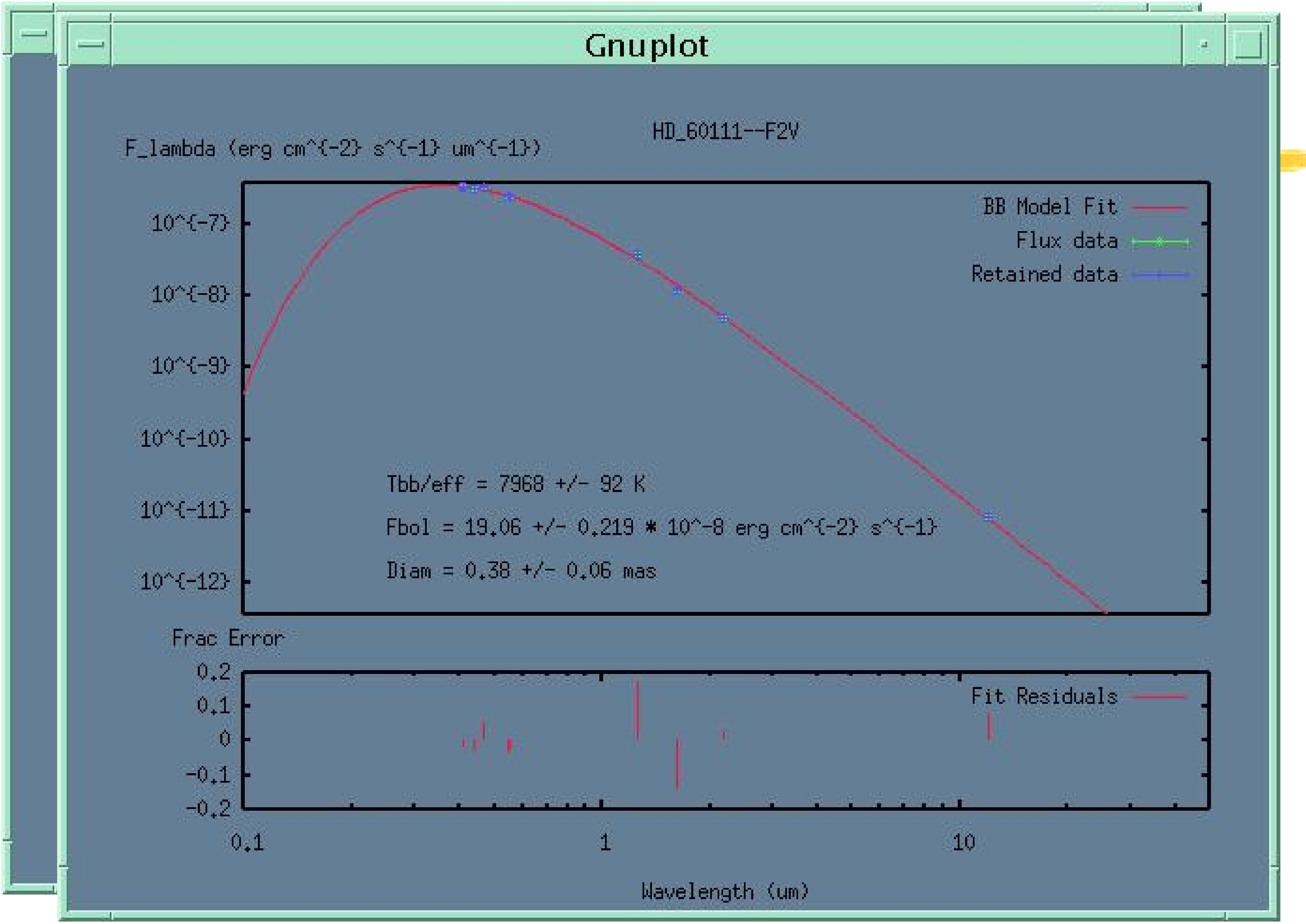
Hipparcos Flags

- Variability (V) - classed as a number depending upon mag. of variations
- Orbital solution (O) - orbital solution found with SMA separation and period
- Components solution (C) - individual components in multiple system resolved and separated with PA
- Stochastic Motion (X)
- Acceleration or higher order terms (G)

Bolometric flux information

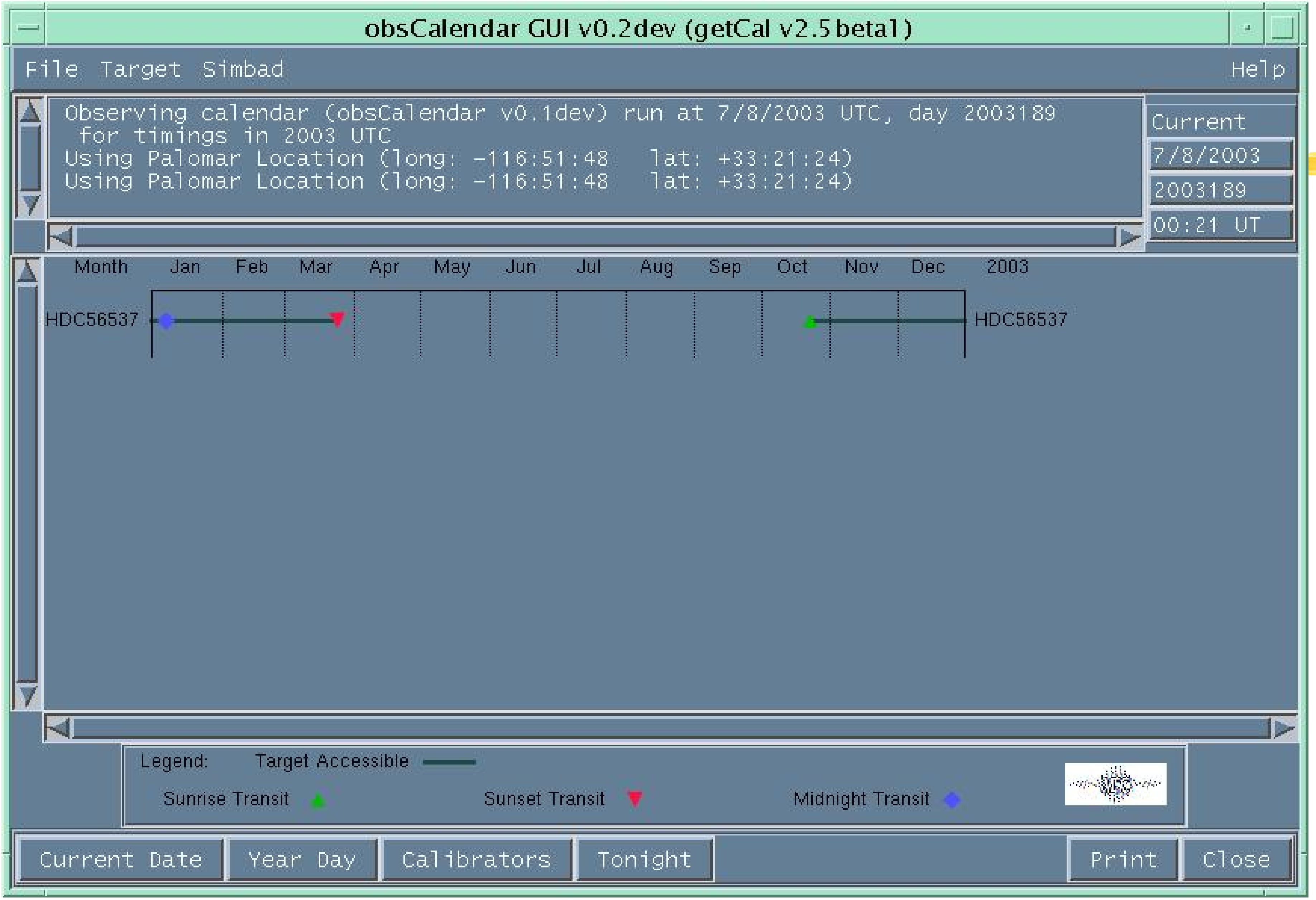


Photometric fits...

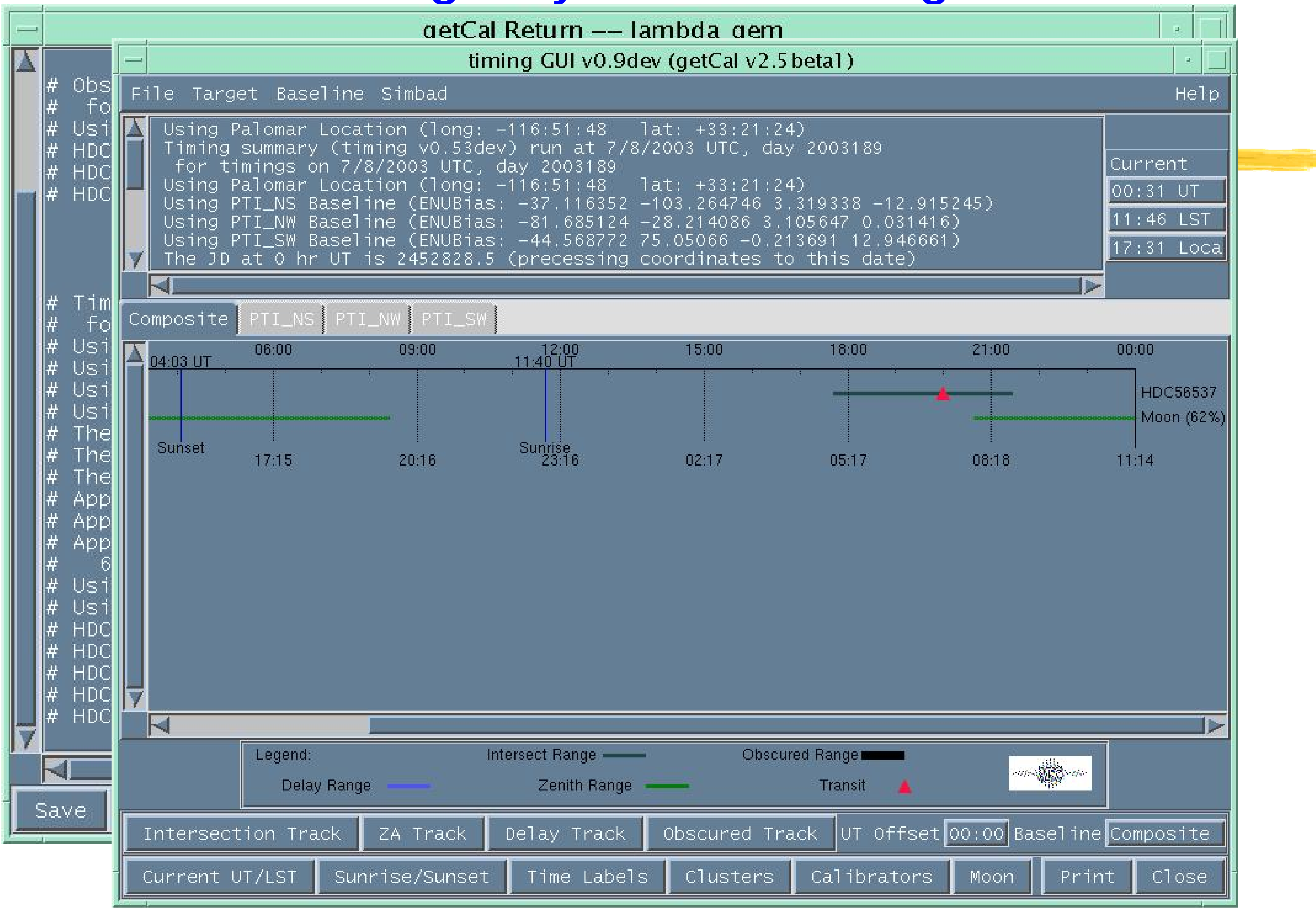


Sky coverage - annually and nightly

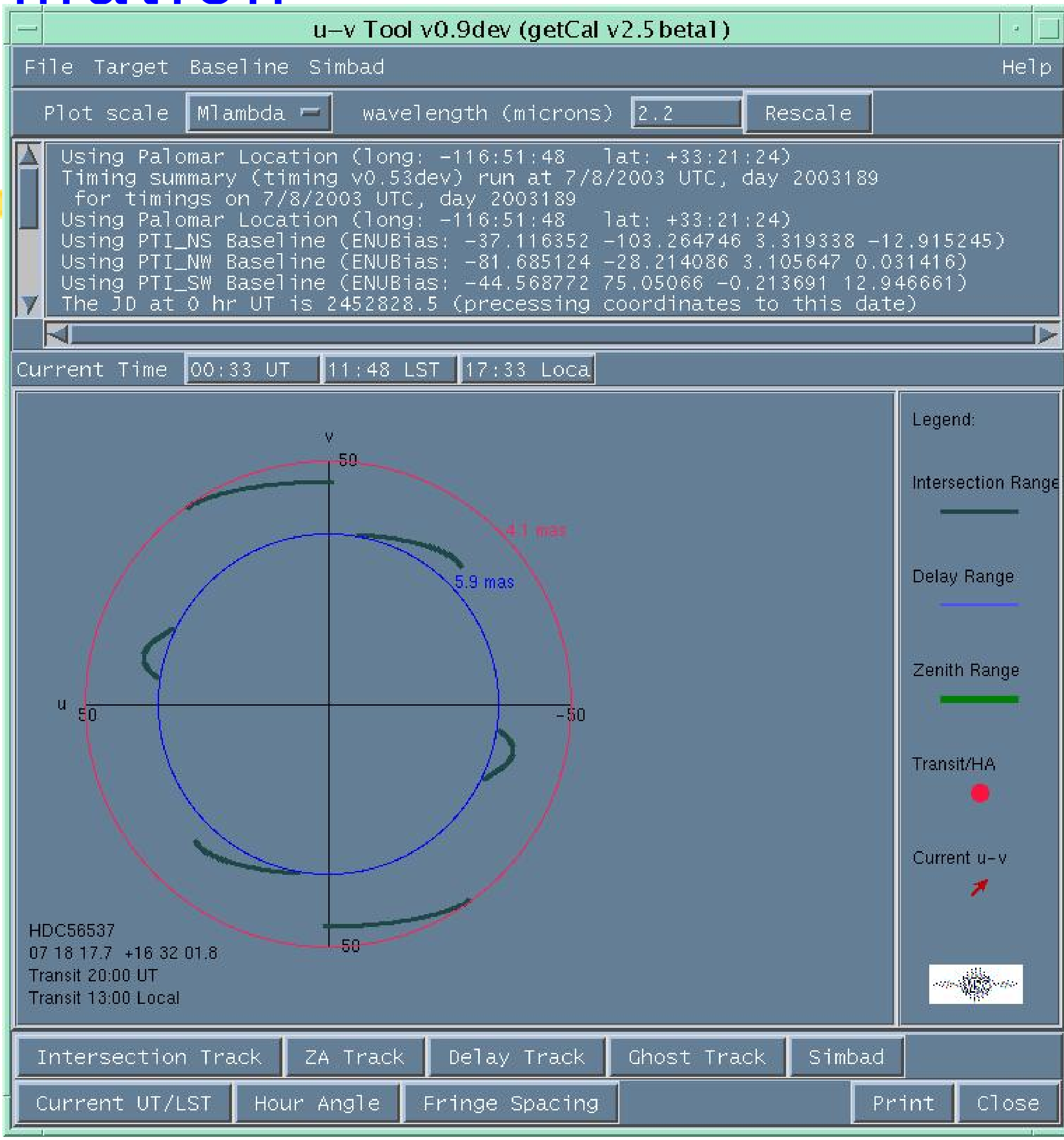
Annual calendar



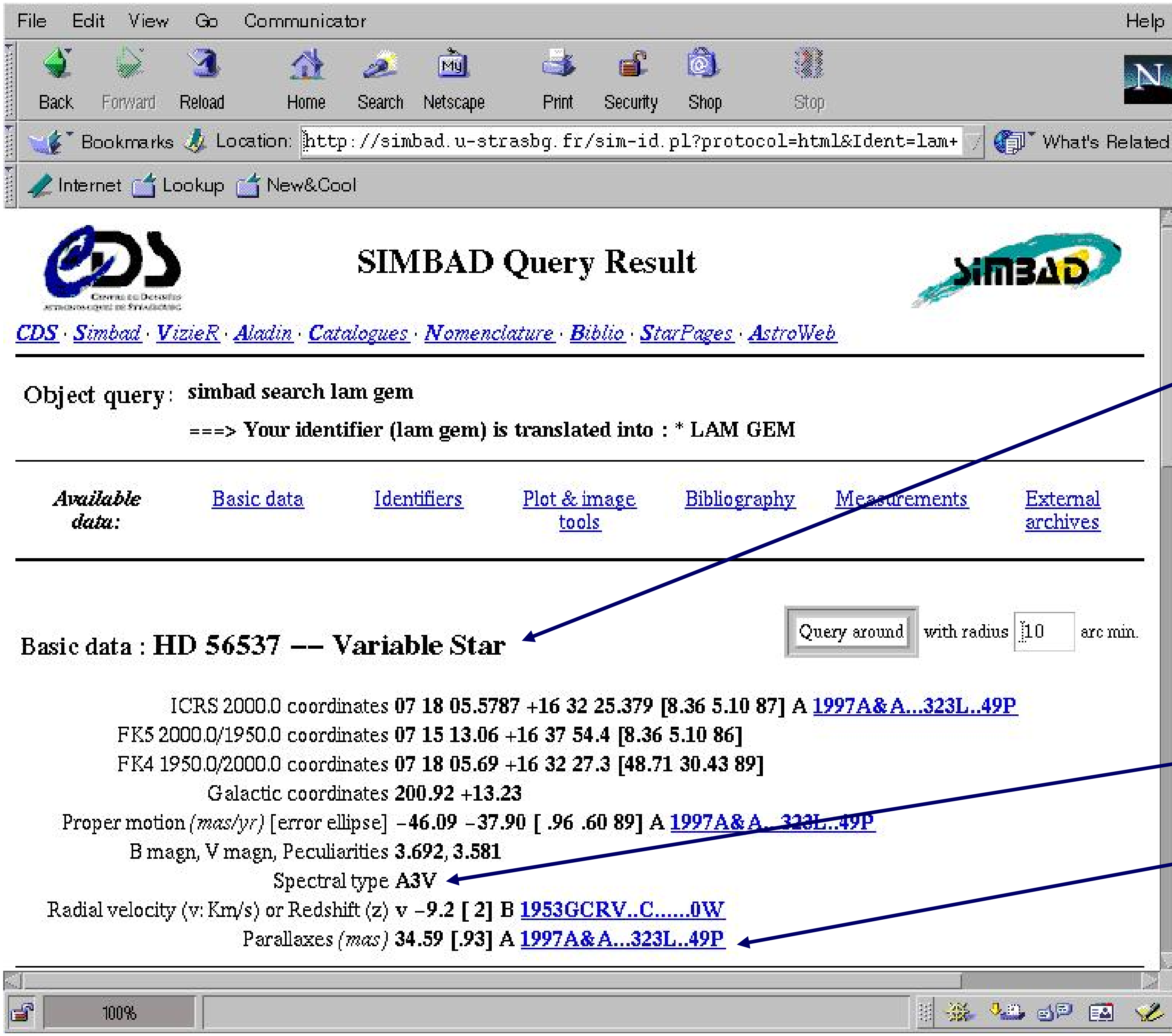
Nightly scheduling



UV Information



Check your target



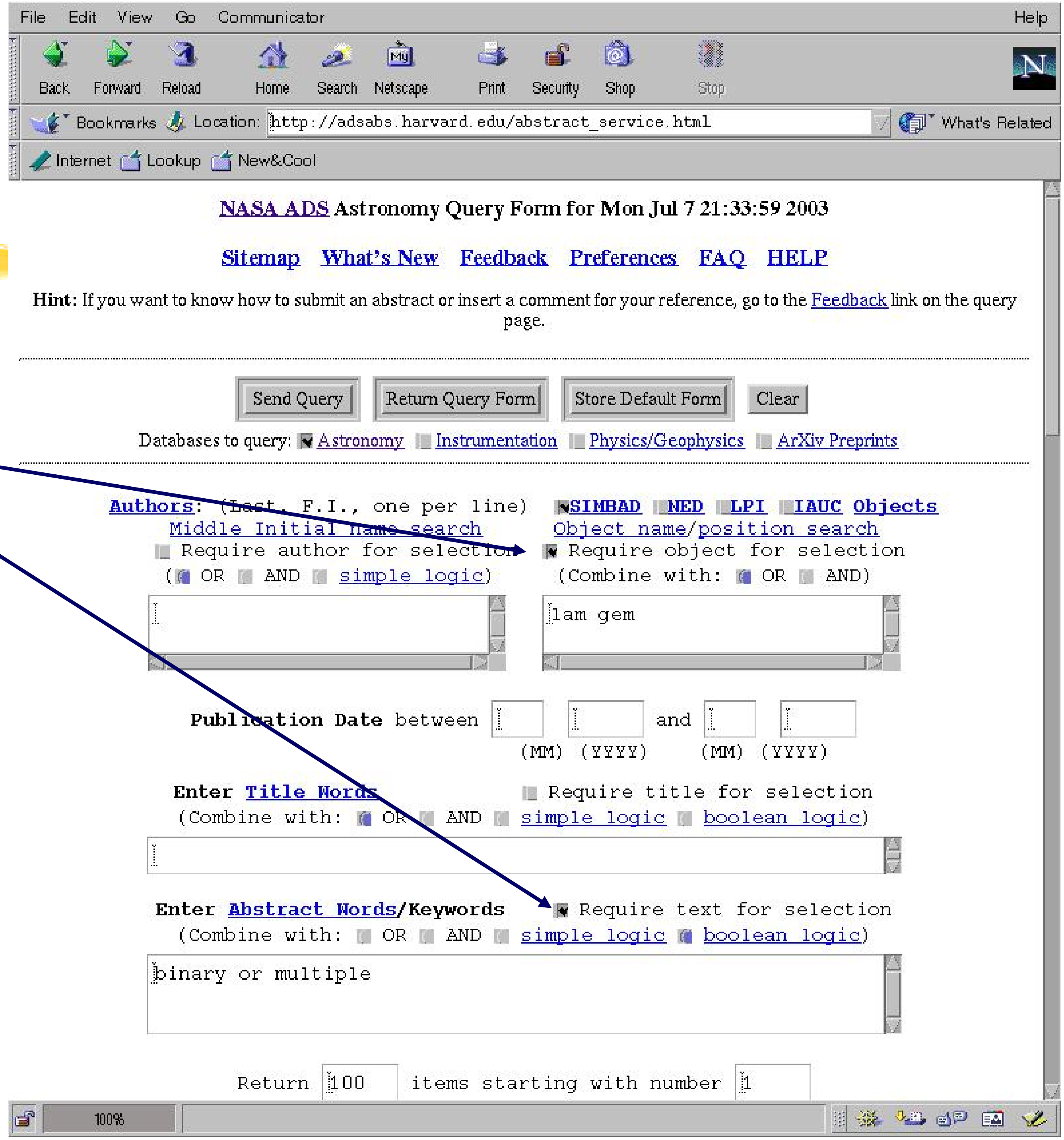
category

spectral type

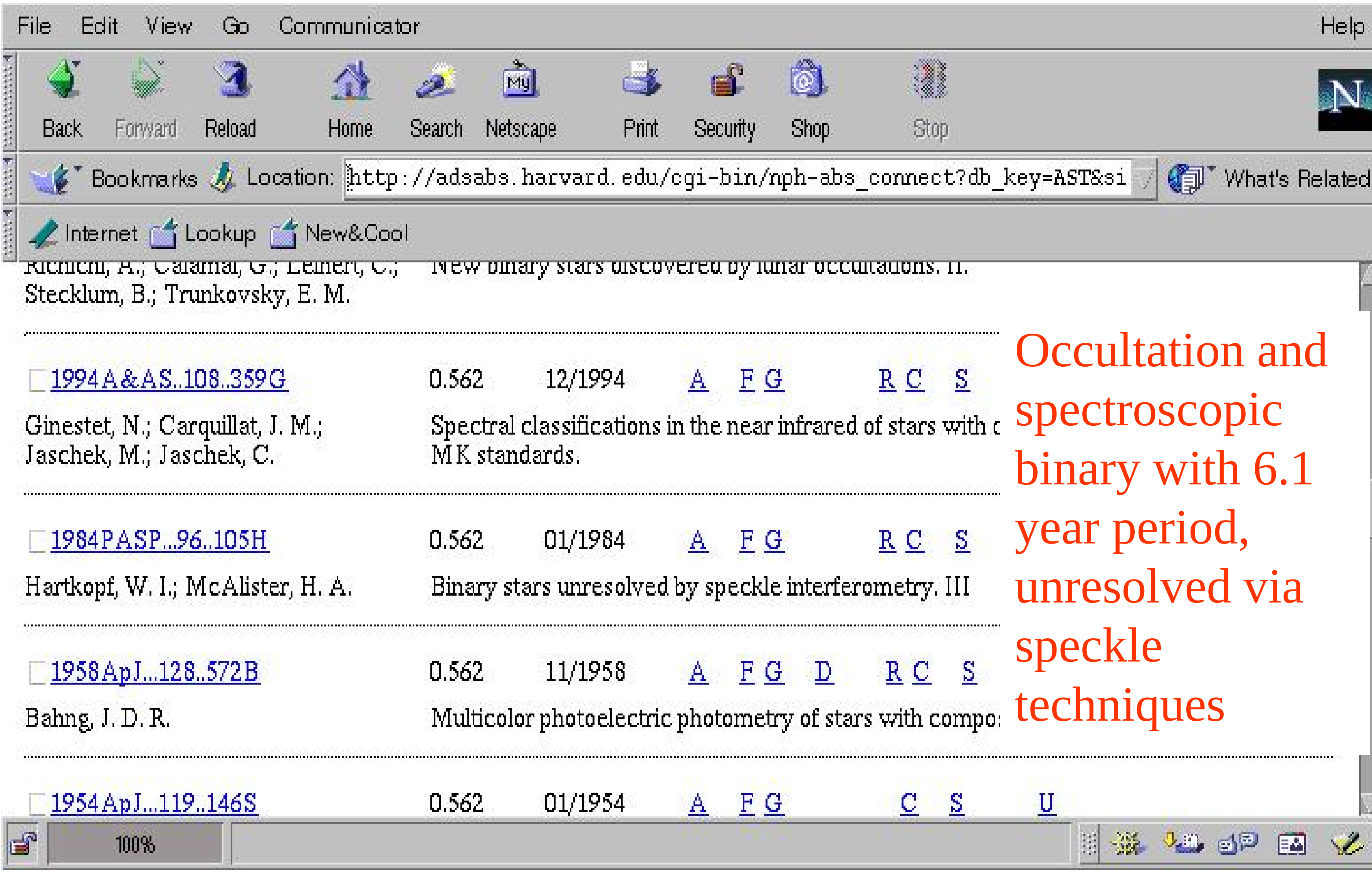
distance

Do your homework...

Use this feature!



Beware certain results!



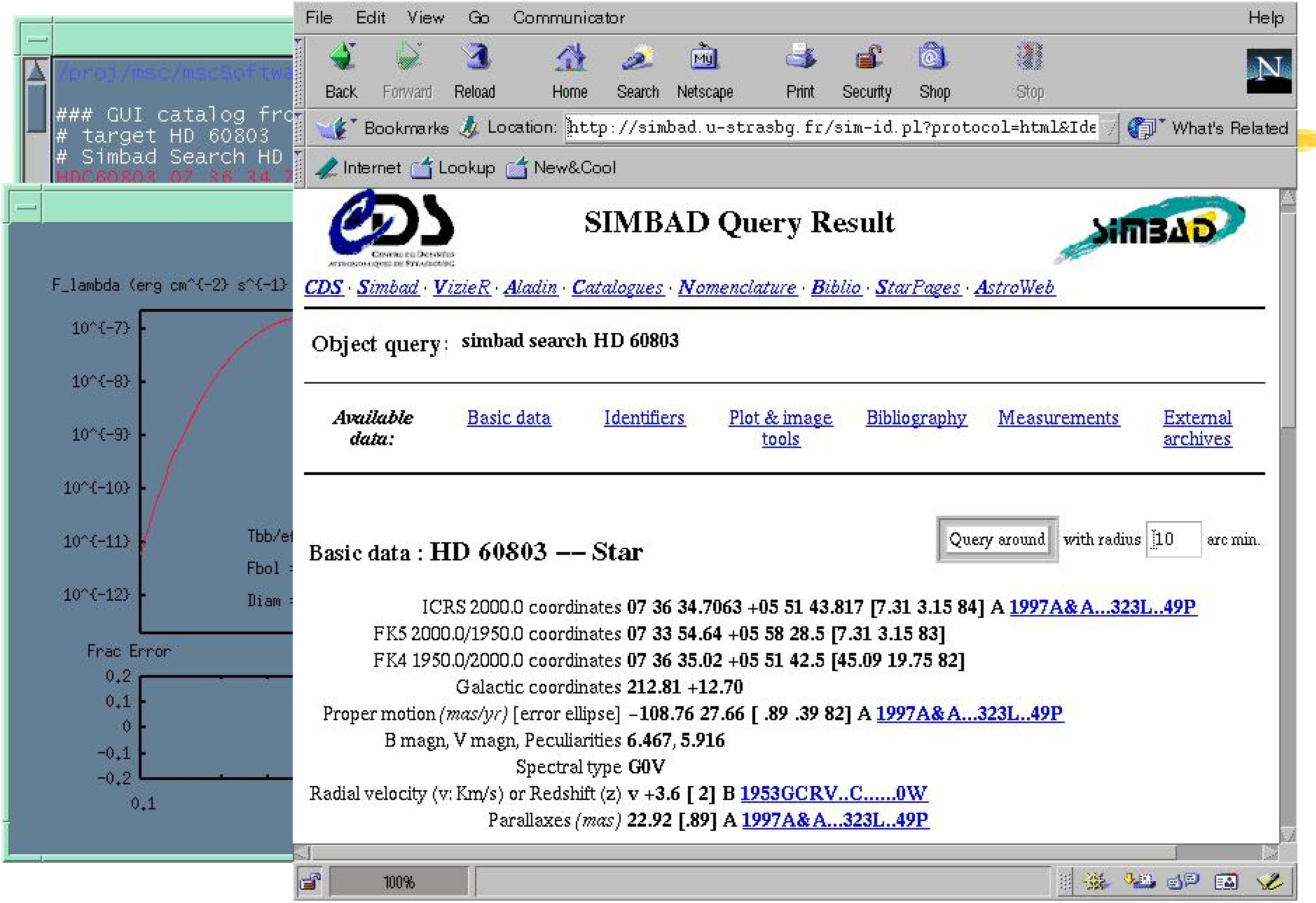
Occultation and spectroscopic binary with 6.1 year period, unresolved via speckle techniques

Calibrator Vetting Criteria

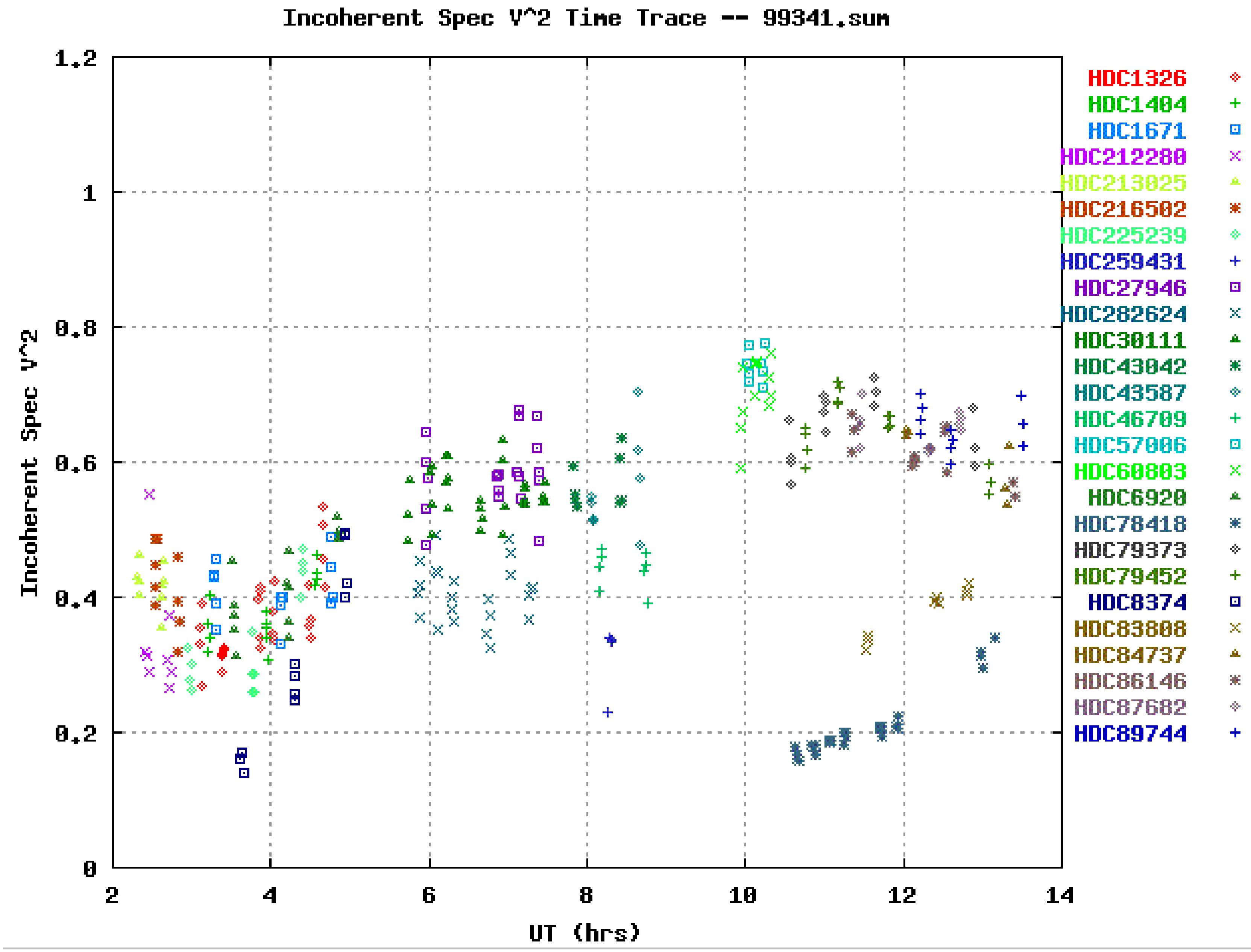
- Basic Information
  - Resolved/Unresolved
    - Spectral Type, SED & distance
  - Singular or apparently so (Hipparcos/Simbad)
  - Sky coverage - compatibility with target(s)
    - UV Track & Annual availability
  - Magnitude (SNR)
    - Different if fringe tracking or scanning

- Estimated Angular Diameter
  - Spectral Type
  - Estimated bolometric flux
- SIMBAD/ADS - Red Flags
  - Sanity check (SpTy, distance, magnitudes)
  - Variability
  - Double/confused
  - Fast rotator
  - Calibration standard
  - Papers - how many, what types, anything odd
- Real data - acid test
  - (un)resolved nature from data
  - nightly and long-term variations
  - SNR, color, other “gotchas”

Real world example



Take some data



I didn't do my homework...

NASA Astrophysics Data System (ADS)

Query Results from the Astronomy Database

Selected and retrieved **10** abstracts.

Bibcode / Authors	Score / Title	Date	List of Links / Access Control Help
1999Obs...119..272G	1.000	10/1999	F G R C S O U
Griffin, R. F.	Spectroscopic binary orbits from photoelectric radial velocities. Paper 148: HR 7955		
1999Obs...119...81G	1.000	04/1999	F G R S O U
Griffin, R. F.	Spectroscopic binary orbits from photoelectric radial velocities. Paper 145: HR 6797		
1997Obs...117..288G	1.000	10/1997	F G R C S O U
Griffin, R. F.; Mayor, M.; Pont, F.; Udry, S.	Spectroscopic binary orbits from photoelectric radial velocities. Paper 136: HD 7000		
1997Obs...117..208G	1.000	08/1997	F G R C S O U
Griffin, R. F.	Spectroscopic binary orbits from photoelectric radial velocities. Paper 135: HR 2918		

Next Steps

- Collect and verify integrity of data
- Have at least two calibrators
  - estimate angular sizes to get system visibility
  - check for consistency
- Choose a model for your target observation (uniform disk, gaussian, binary system, etc.)
- Reduce, analyze & publish!

How do you resolve conflicts in calibrator sizes?

$$\chi^2 = \sum_i \left[\frac{\theta_i - \hat{\theta}_i}{\sigma_{\hat{\theta}_i}}\right]^2 + \sum_i \sum_{j<i} \left\langle \frac{V^2_{sys,i}(\theta_i) - V^2_{sys,j}(\theta_j)}{\sigma_{V_{sys}}} \right\rangle^2$$

system visibilities on calibrators derived from observations

working diameter estimates

estimated uncertainties

a priori diameter estimates

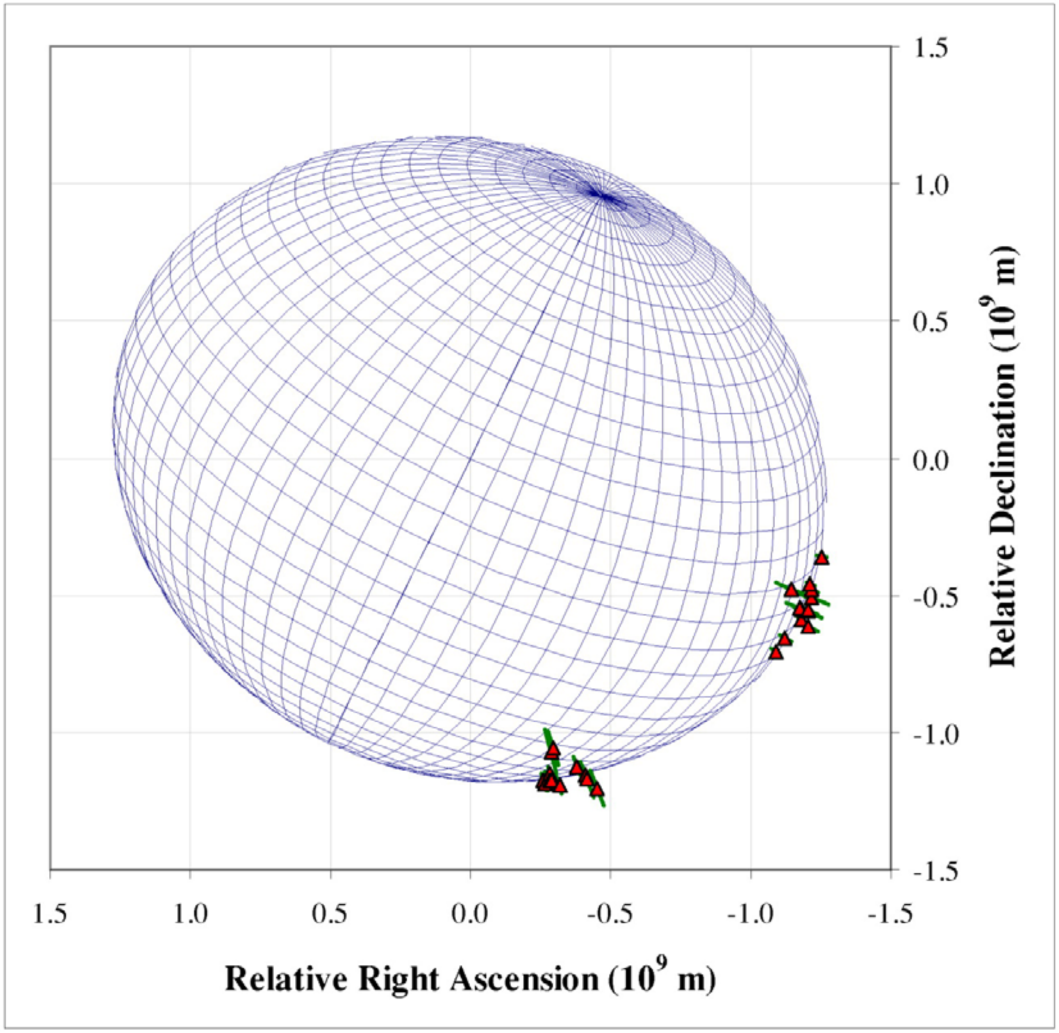
- Minimize chisquared function for all calibrators

Special Circumstances

- Sometimes to do the experiment correctly you need a calibrator (control star) that lacks some special feature you expect your target has
  - non-spherically symmetric (resolved) stars (e.g. Altair, stars with outflows)
  - pulsating (e.g. miras, cepheids)
  - line emission or spectral features (e.g. P Cyg, narrow-band studies)

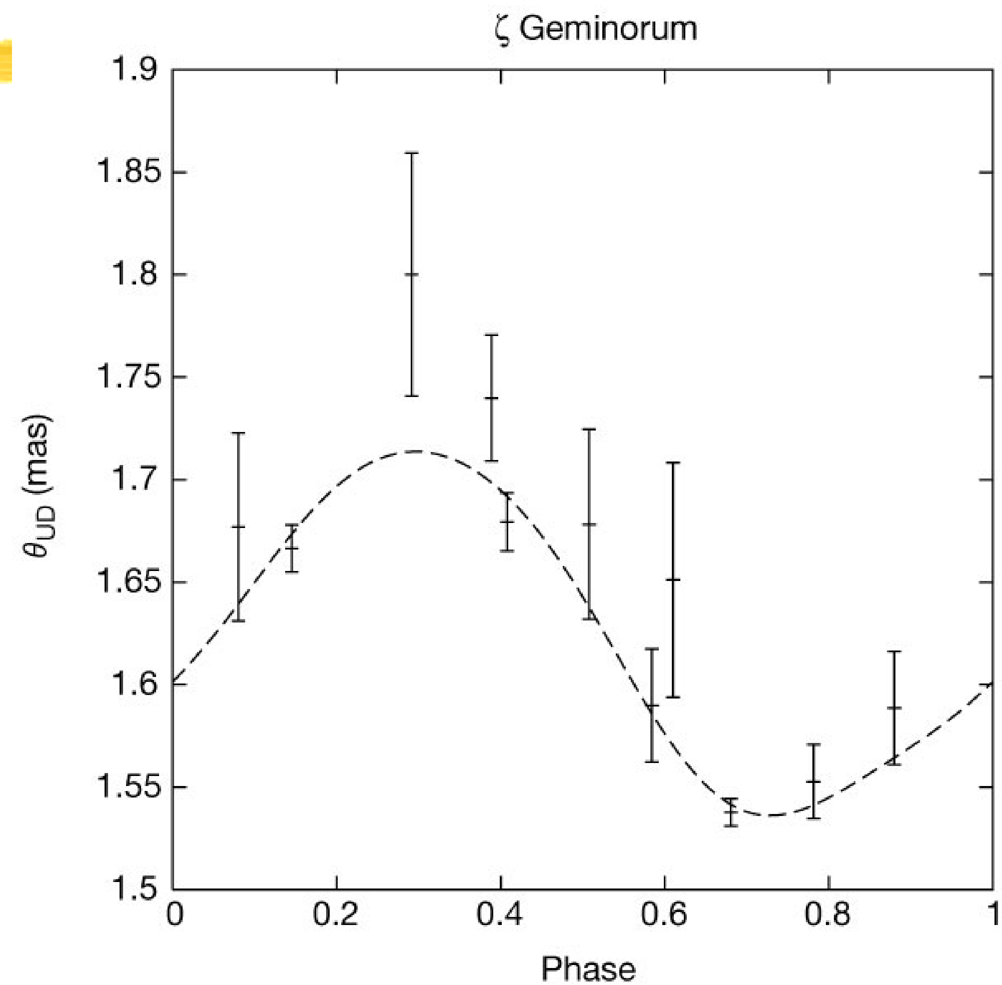
Altair

- HD187691 - F8V @ 1.6° sep. and about 0.72 mas in diameter
- HD187923 - G0V @ 2.8° sep. and about 0.55 mas in diameter
- Comparison to Vega as a bright, nearby, resolved calibrator
- van Belle et al., 2001, ApJ, 559, 1155.



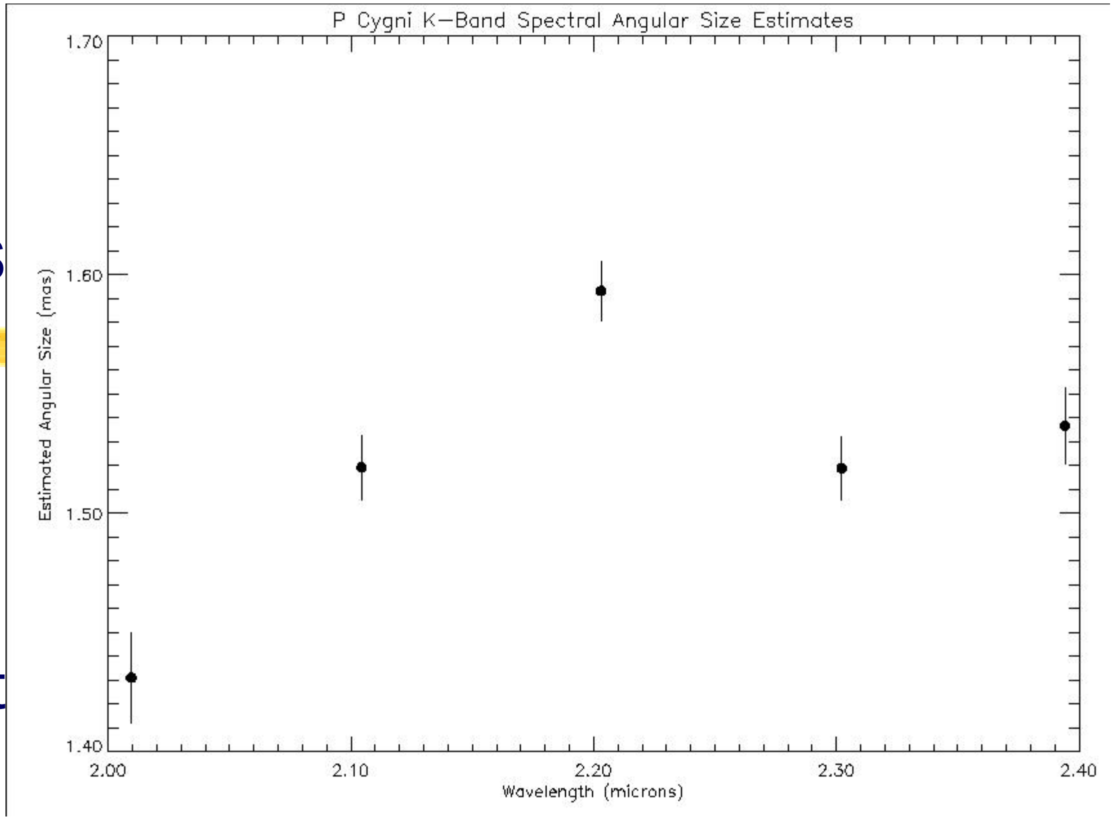
Zeta Geminorum

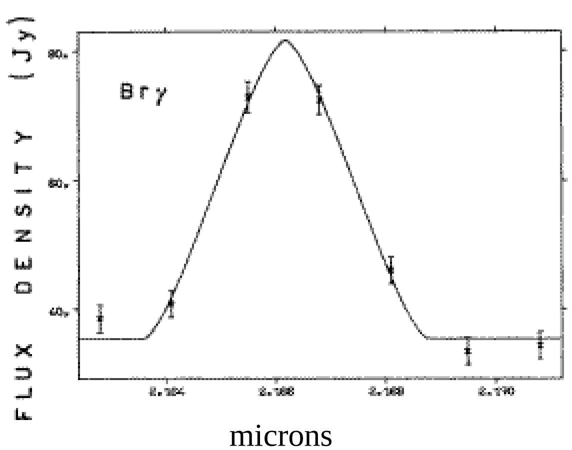
- Classical GOIbvar cepheid
  - clear evidence for pulsation
  - possibly want to use a resolved calibrator of similar size to show interferometric stability
  - Lane et al., 2000, Nature, 407.



P Cygni

- Prototypical Luminous Blue Variable - B2pe
  - shows clear signs for emission in the narrow-band data
  - used control stars that were slightly larger and smaller than the expected 2.17um size to bracket the observation
  - Serabyn & Creech-Eakman, 2000 AAS, 197, 4505.





Summary

- Choose calibrators carefully
  - Use physical information (distance, spectral type, SED) and literature search to determine best calibrators for experiment
- Consider goals of experiment
  - spectral or spatial resolution may require control stars
- Reduce data in a timely fashion
- Publish, publish, publish!

Software:

- This work has made the use of software produced by the Michelson Science Center at the California Institute of Technology

Thank you for your attention!