Availability of Calibration Stars in Exoplanet Transit Surveys

Avery Bruni
University of Michigan – Ann Arbor

Mentor:
Sagi Ben-Ami
Andrew Szentgyorgi
SAO

Two Projects

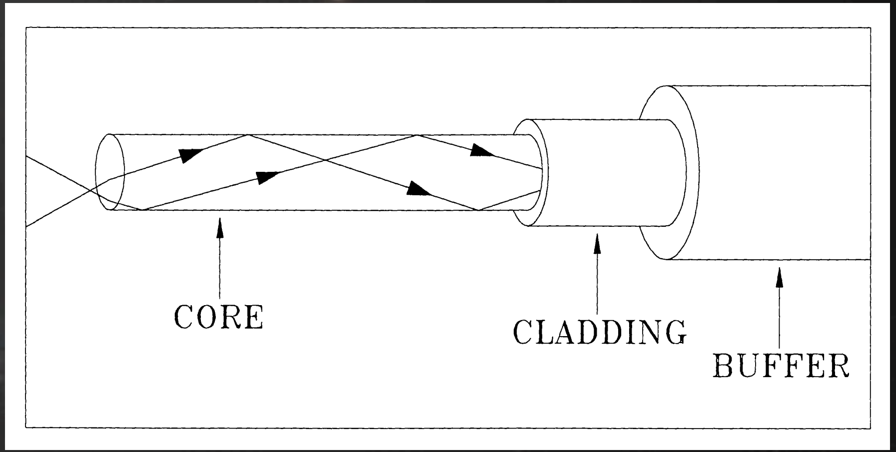
- G-CLEF
- MINERVA

\- http://www.gmto.org/

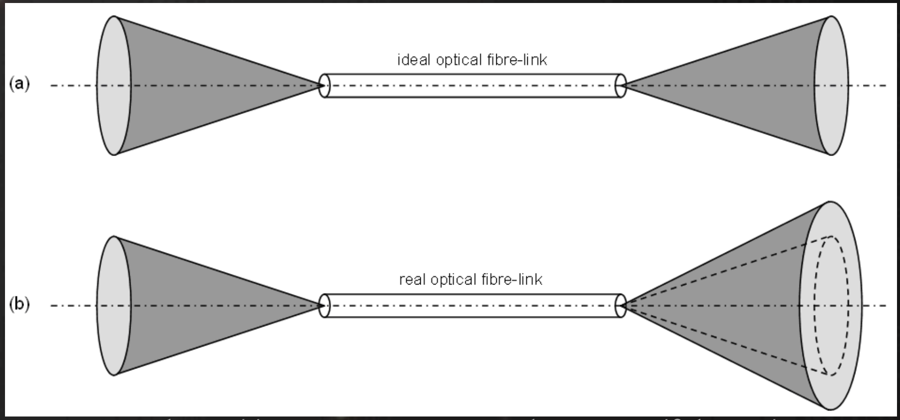
https://www.cfa.harvard.edu/minerva/Images.html#3

G-CLEF

- G-CLEF is on the azimuth platform of the GMT.
  - Gravity invariant.
  - Temperature enclosure.
  - Vacuum cell.
- Fibers channel light from telescope into the spectrograph.
- Fibers introduce error.
  - Throughput losses.
  - Focal Ratio Degradation.
- On-site construction, repairs, maintenance, replacements: How will these affect performance?

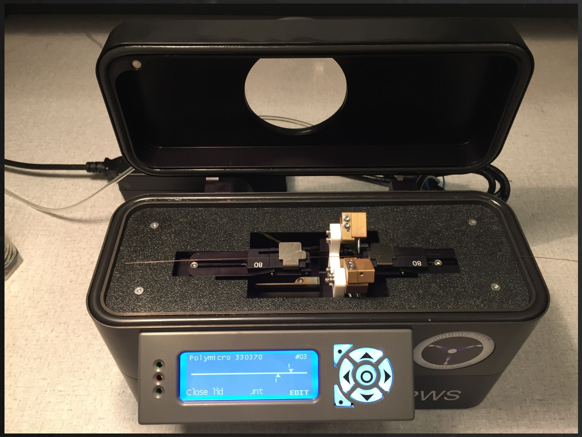


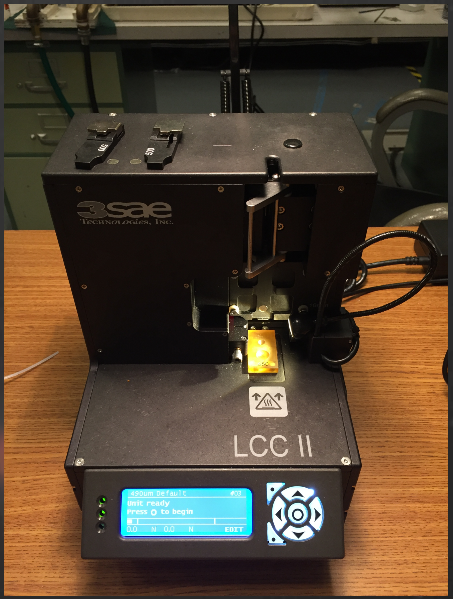
http://articles.adsabs.harvard.edu//full/1998ASPC..152....3P/0000003.000.html



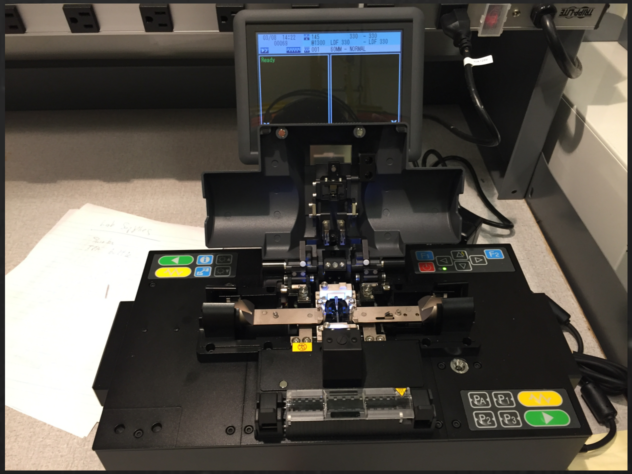
https://astrospectroscopy.wordpress.com/frd-tests/

Process



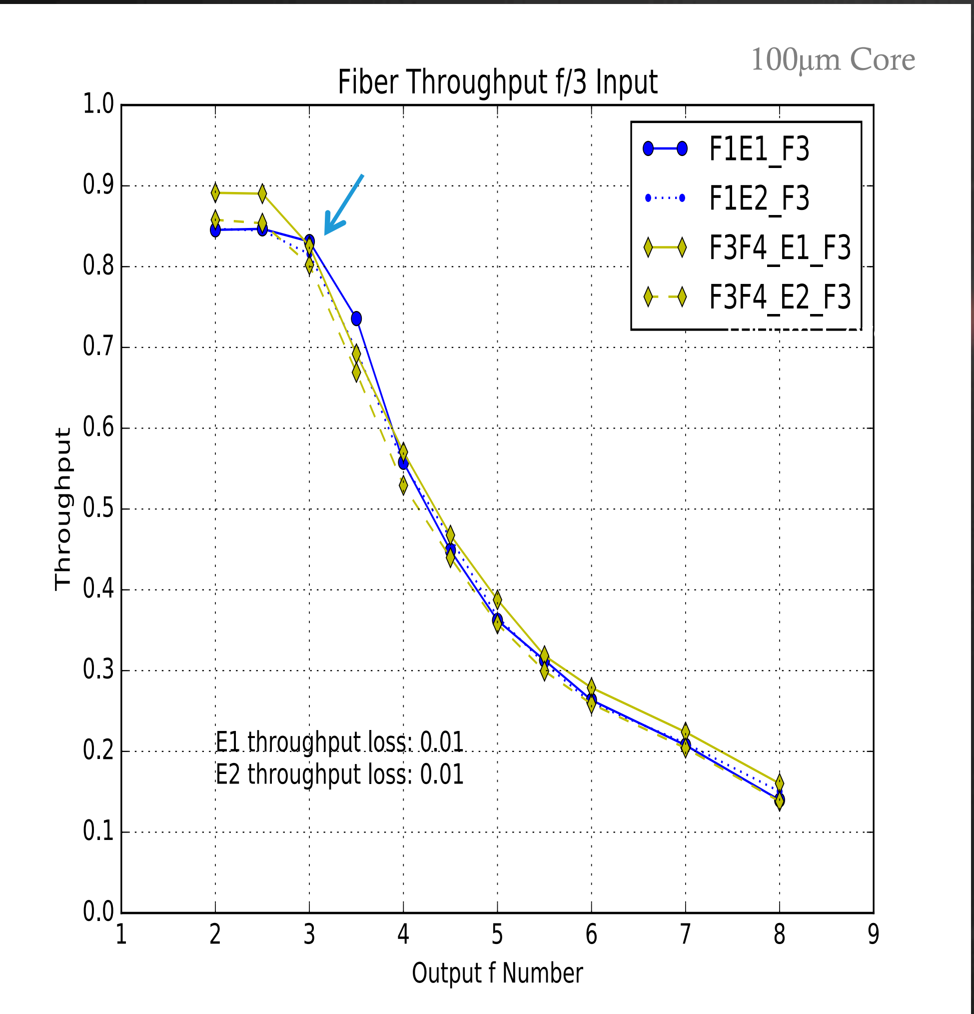


Testing



Testing

After Fusing



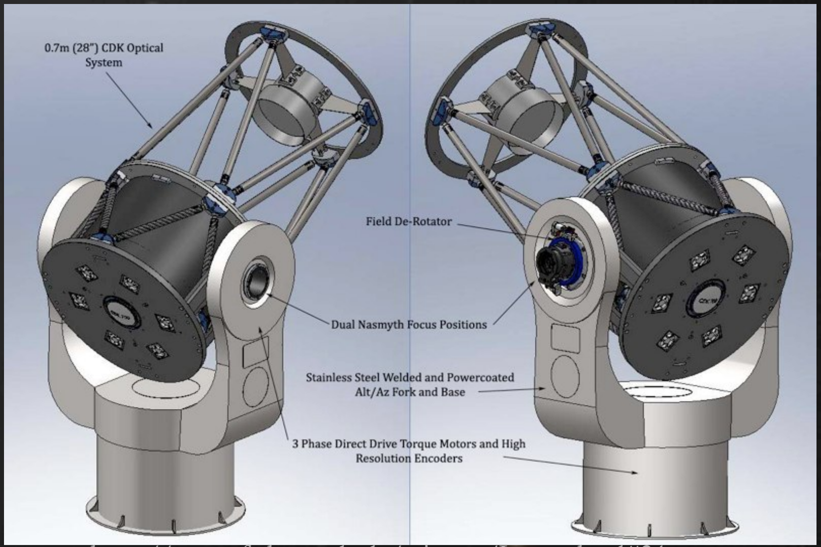
.

- Conclusion:
  - Expected ~2% loss is achievable!
    (But, takes training and time)
  - We have a valid process for servicing the G-CLEF fiber run

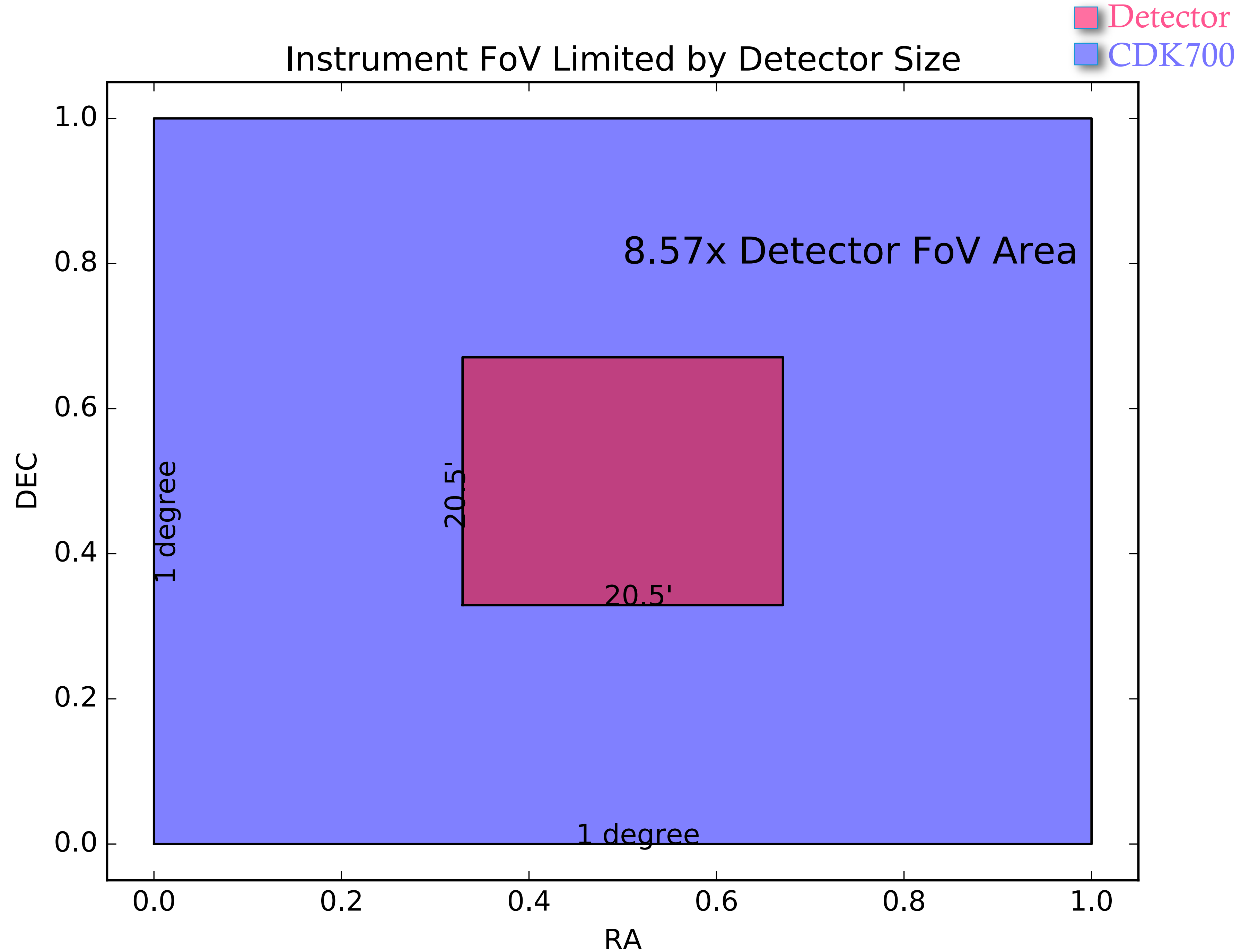
MINERVA Multi-Mirror Feed

https://www.cfa.harvard.edu/minerva/Images.html#23

- MINERVA – MINiature Exoplanet Radial Velocity Array.
  - Four 0.7m telescopes.
  - *Plane Wave* CDK700.
  - Both photometric transits and PRV measurements.
- Mt. Hopkins, Arizona.
- Science Goals:
  - Discover Earth-like exoplanets
    <50 day orbits.
  - Discover super-Earths in
    habitable zones.
  - Measure exoplanet radii and
    internal structure.



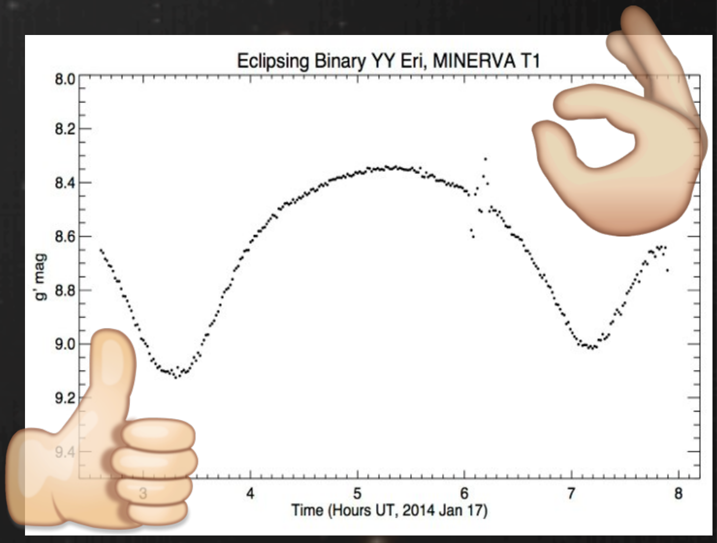
https://www.cfa.harvard.edu/minerva/Images.html#24



Detector
CDK700
Instrument FoV Limited by Detector Size
8.57x Detector FoV Area
20.5'
20.5'
1 degree
1 degree
DEC
RA
0.0
0.2
0.4
0.6
0.8
1.0

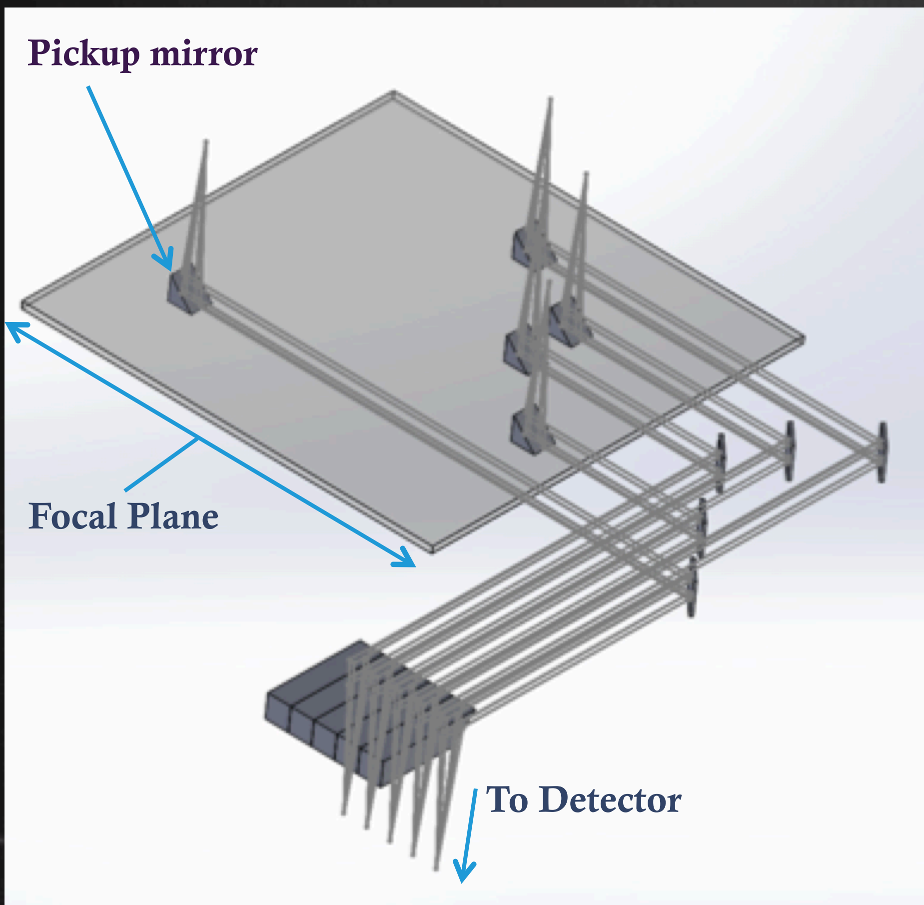
Motivation

- Access to entire focal plane → more available calibration stars, better quality.
  - Stars closer to target in magnitude and color.
- Better quality calibration stars → **more accurate observations!**
- Lower cost.
  - Off-the-shelf components.
  - Smaller CCD → small output port.
- Flexibility.
  - Small output port also allows PMTs as detectors.
    - Low RO noise.
    - Continuous flux measurements.
- Many possible future applications
  - Wide FoV access.
  - Spectrograph feed.



https://www.cfa.harvard.edu/minerva/Images.html#2

MMF Design



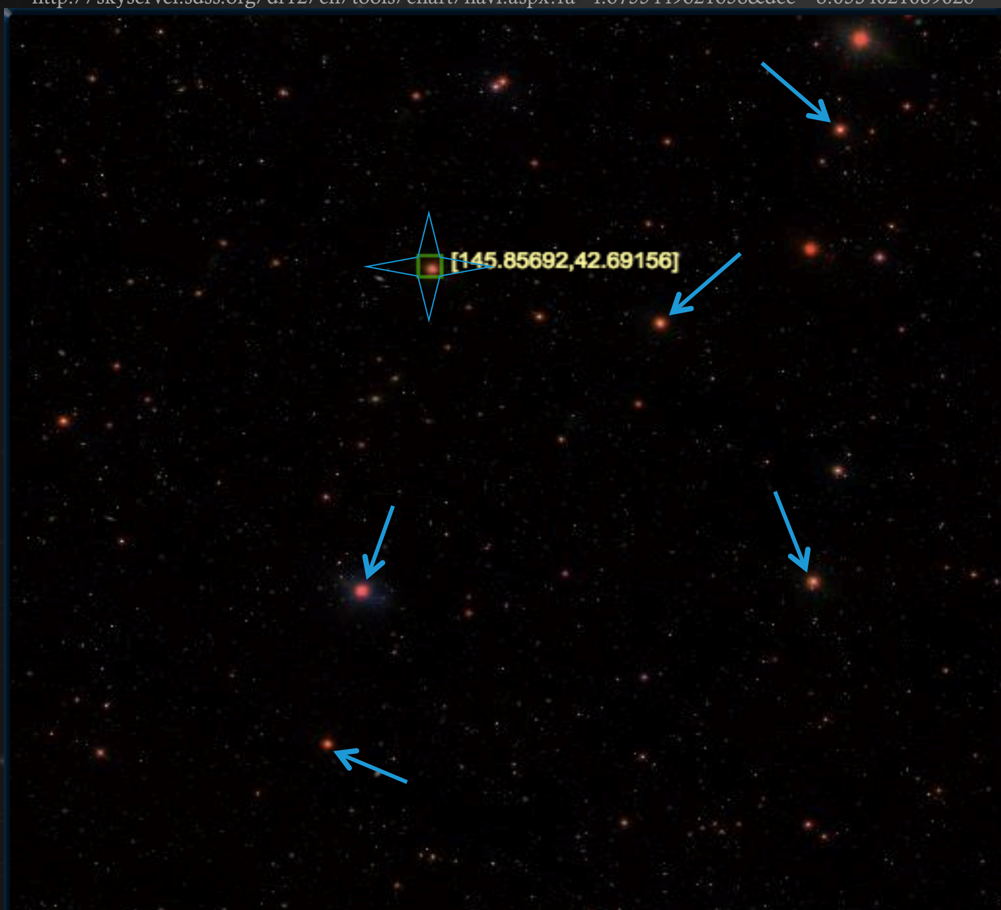
- Moveable Pickup Mirrors.
  - Capture only targets of interest.
- Full access to CDK700 focal plane.
  - 70mm x 70mm.
- Don't need a large 70mm x 70mm CCD.
- Small output port due to collapsing the focal plane.

My Project

Possible Calibration Stars

Target Star

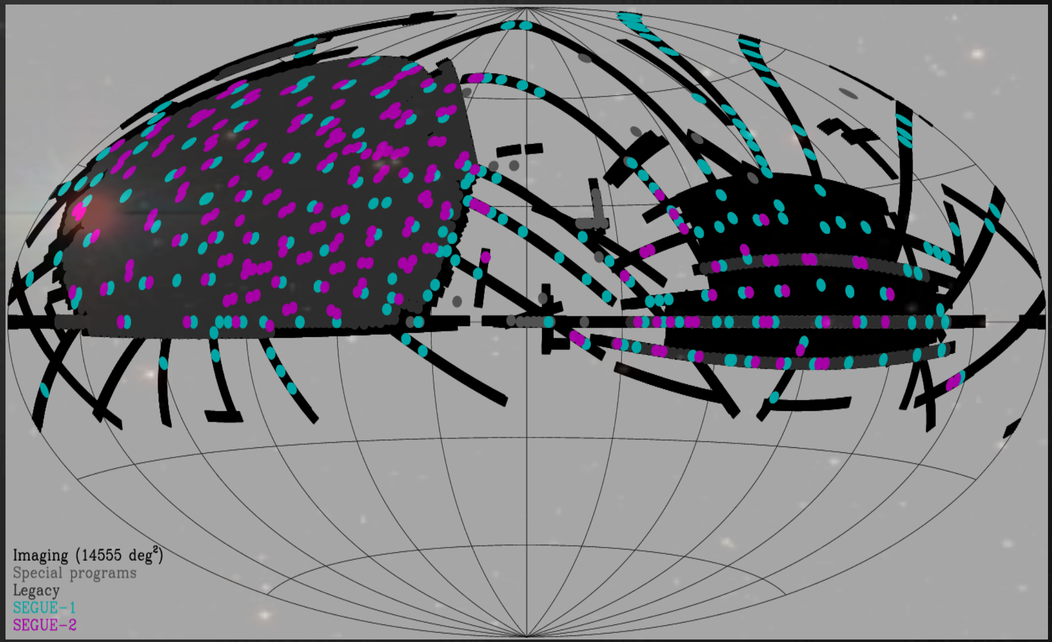
http://skyserver.sdss.org/dr12/en/tools/chart/navi.aspx?ra=4.6755449621658&dec=-8.0534021089026



- Goal:
  - To write software that models the availability and quality of calibration stars near a given target.
  - Use the Sloan Digital Sky Survey (SDSS) to automatically provide the MMF instrument with:
    1. Best possible calibration stars
    2. Best possible 1^{o} x 1^{o} FoV
    3. Fastest track path

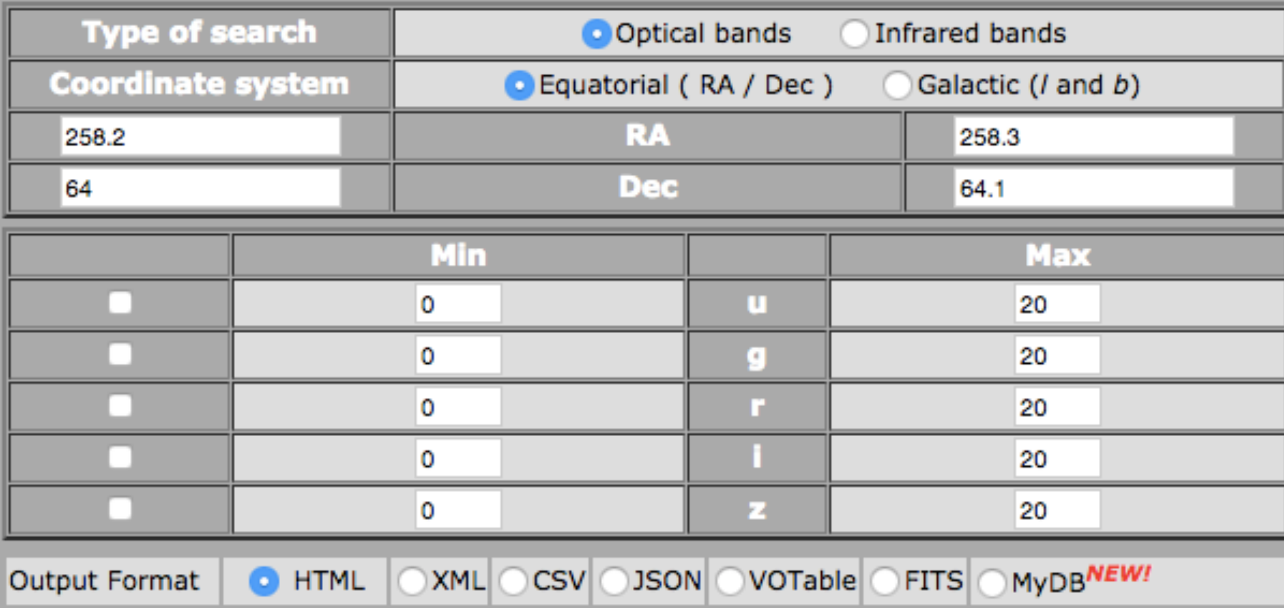
Database

- SDSS – Data Release 12
  - Modifications to work with any database.
  - GAIA catalog, October.
    - More accurate coordinates, better coverage.
- Returns a list with all matching objects.
- Objects contain information on:
  - *u, g, r, i, and z* magnitudes
  - Position.



http://www.sdss.org/dr12/scope/

SDSS



http://skyserver.sdss.org/dr12/en/tools/search/rect.aspx

http://skyserver.sdss.org/dr12/en/tools/chart/navi.aspx?ra=4.6755449621658&dec=-8.0534021089026

- Problem:
  - Bright stars often mislabeled as galaxies
  - Any software filter for stars → missing data
- Solution:
  - Ignore object type
  - Does not affect final output
    - Galaxies are of comparable magnitude to MINERVA targets.

Merit Function

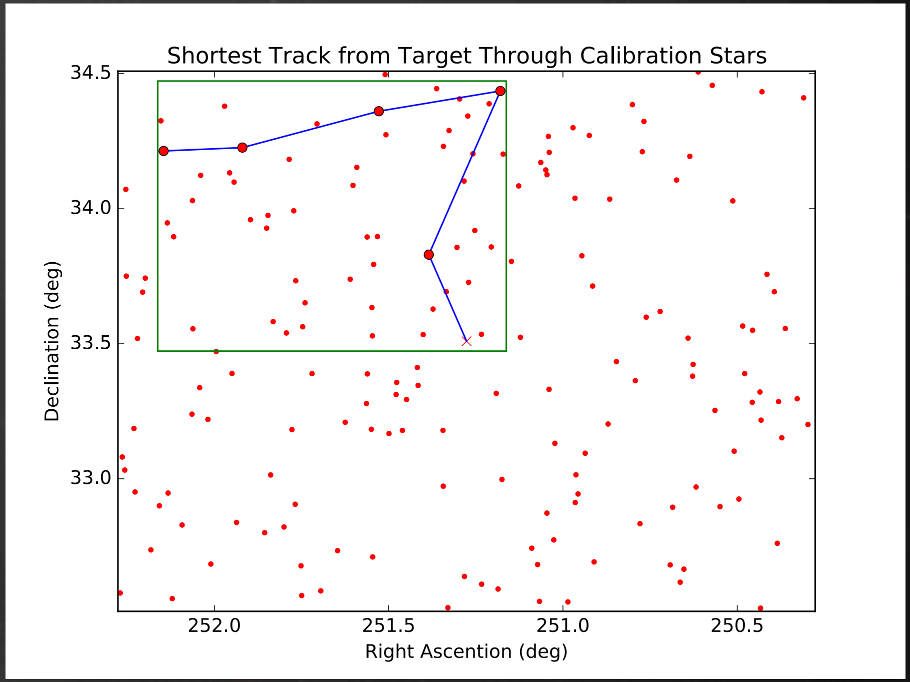
- How to decide what stars are best?

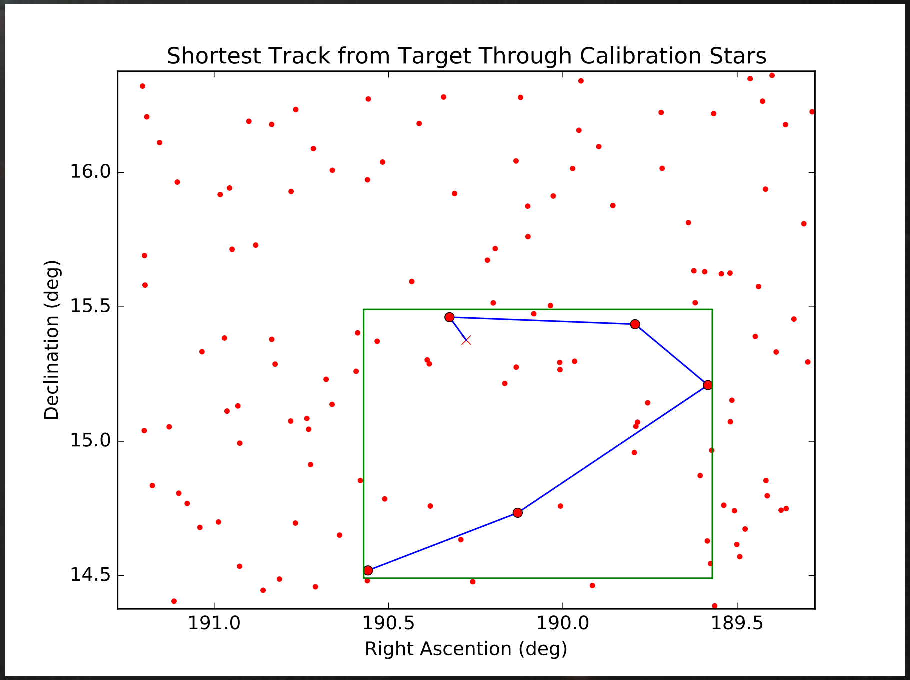
$$w_1 \cdot |\Delta M| + w_2 \cdot |\Delta(g-r)| + w_3 \cdot |\Delta(r-i)| + w_4 \cdot |\Delta D|$$

magnitude — color — color — distance (in focal plane)

- Each star is given a rank based on this function.
- Weights can be configured to be optimal for a particular field of view.
- Stars with **lowest** rank are given preference.

- Choose best 1º x 1º FoV.
  - **Not necessarily centered on target.**
  - Always #1 calibration star.
  - The rest are the best that also fit.
- Fastest Track
  - Telescope time is expensive.
  - One robotic “finger” moves all mirrors.
- The canonical Traveling Salesman Problem.
- Brute force solving method.
  - Number of calibration stars limited to 5.
  - Not computationally expensive.
  - Exact solution.

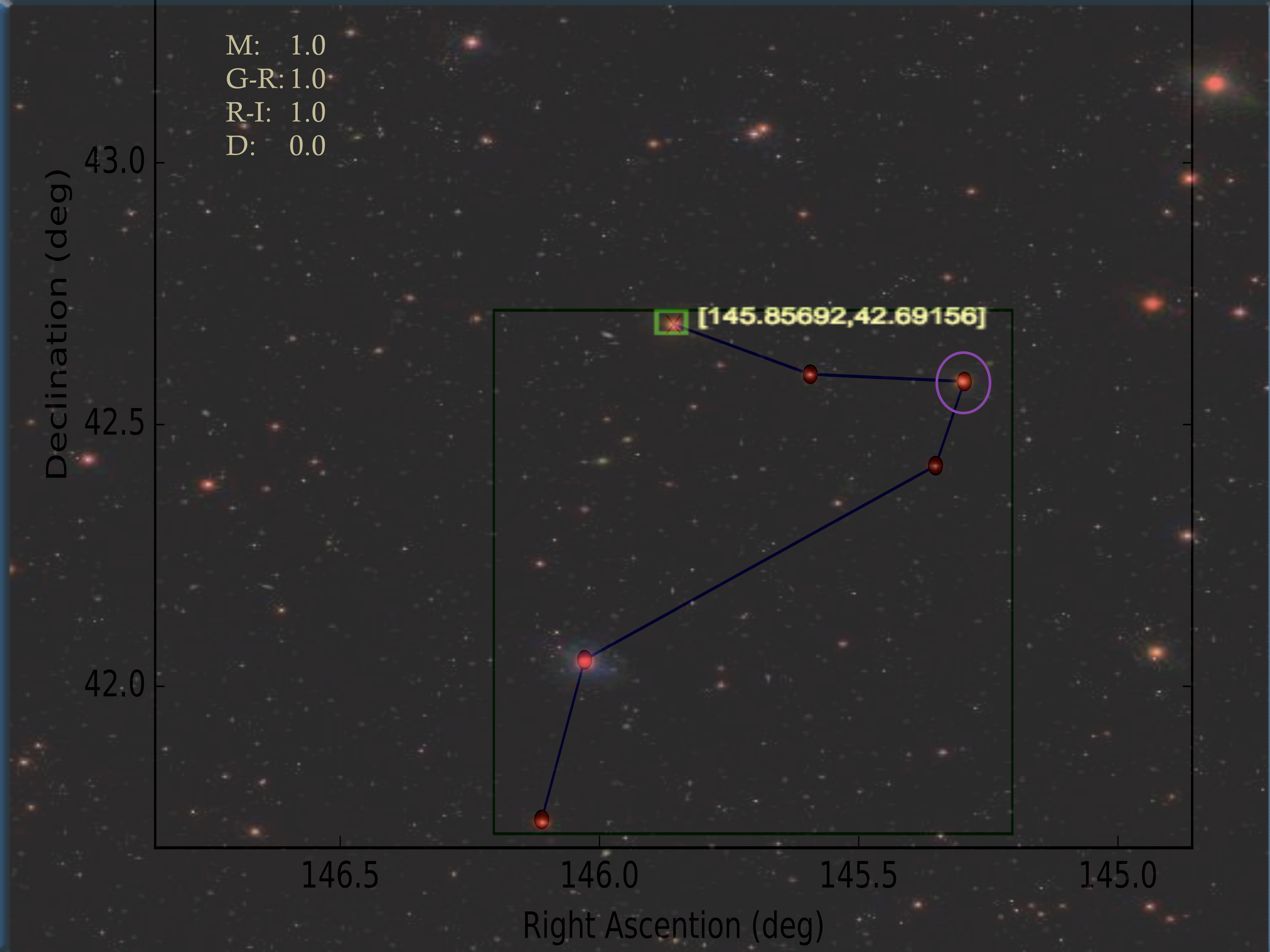




Results

- How do the results from the software stack up against what we chose by hand?

http://skyserver.sdss.org/dr12/en/tools/chart/navi.aspx?ra=4.6755449621658&dec=-8.0534021089026



M: 1.0
G-R: 1.0
R-I: 1.0
D: 0.0
[145.85692,42.69156]
Declination (deg)
43.0
42.5
42.0
146.5
146.0
145.5
145.0
Right Ascention (deg)

Details

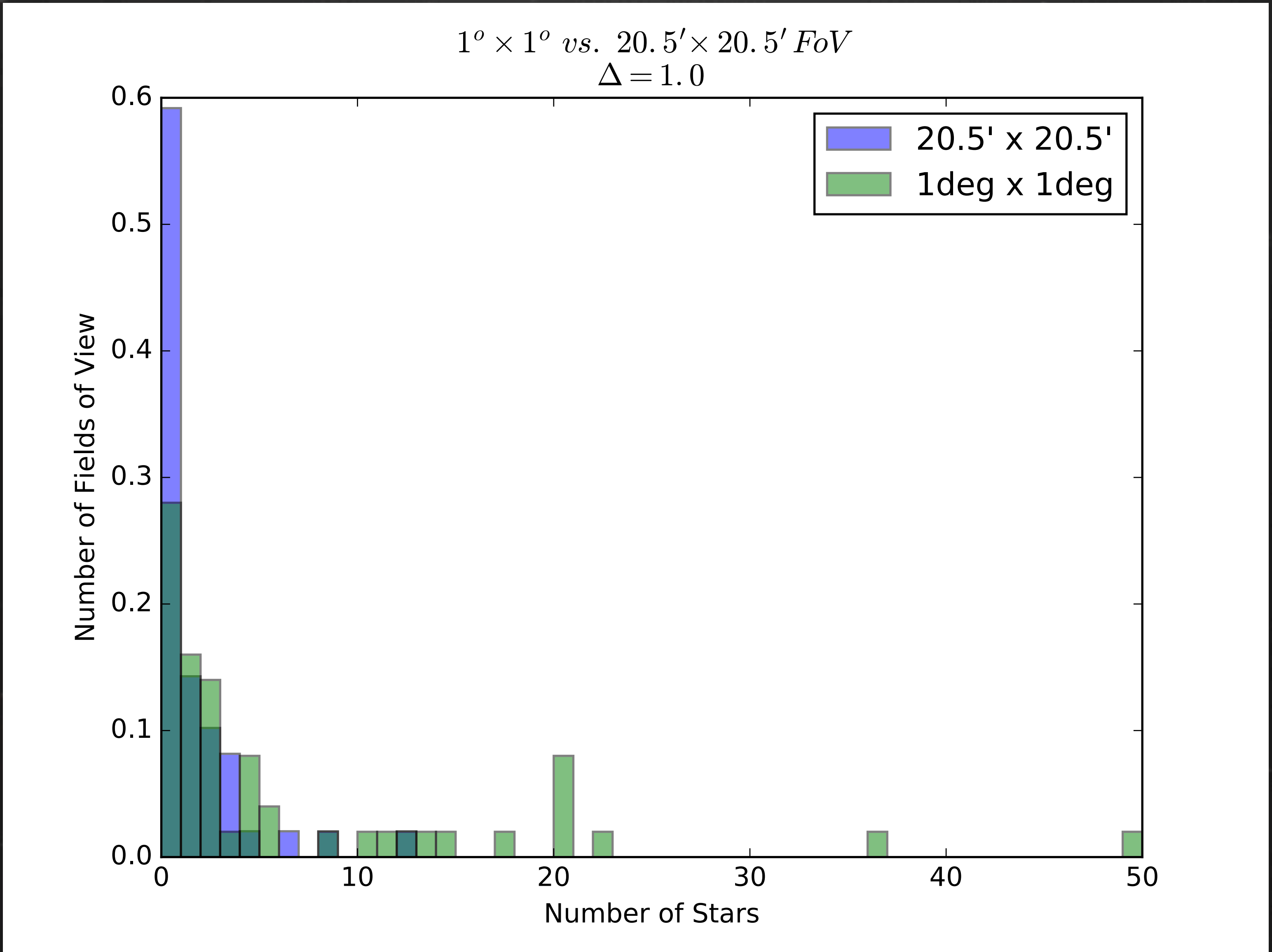
	Position	Magnitude	G-R	R-I	%ΔM	%Δ(G-R)	%Δ(R-I)	Avg%Δ
Target	(145.85698825, 42.6912131564)	7.697868	1.079487	0.297439				
Star 0	(145.593392125349, 42.5960885569766)	9.626675	0.844835	0.290073	25.06%	21.74%	2.48%	16.42%
Star 1	(145.296313187882, 42.5822751253619)	7.885123	1.020387	0.28502	2.43%	5.47%	4.18%	4.03%
Star 2	(145.351687754999, 42.4214740451311)	10.29807	0.84228	0.29092	33.78%	21.97%	2.19%	19.31%
Star 3	(146.028706683397, 42.0507979464548)	7.619718	0.417886	0.237372	1.02%	61.29%	20.19%	27.50%
Star 4	(146.11131960802, 41.7455621646891)	8.920154	1.327716	0.390922	15.88%	23.00%	31.43%	23.43%

- Star 1: Best calibration star in the field (always included).
- Most calibration stars have at lease one parameter very close to the target.
- Star 3: very close in magnitude, but far off in (G-R).
- It works! (At least reasonably well).

Δ -- Range of accepted values for each parameter.

i.e. M ± Δ, (G-R) ± Δ, etc…

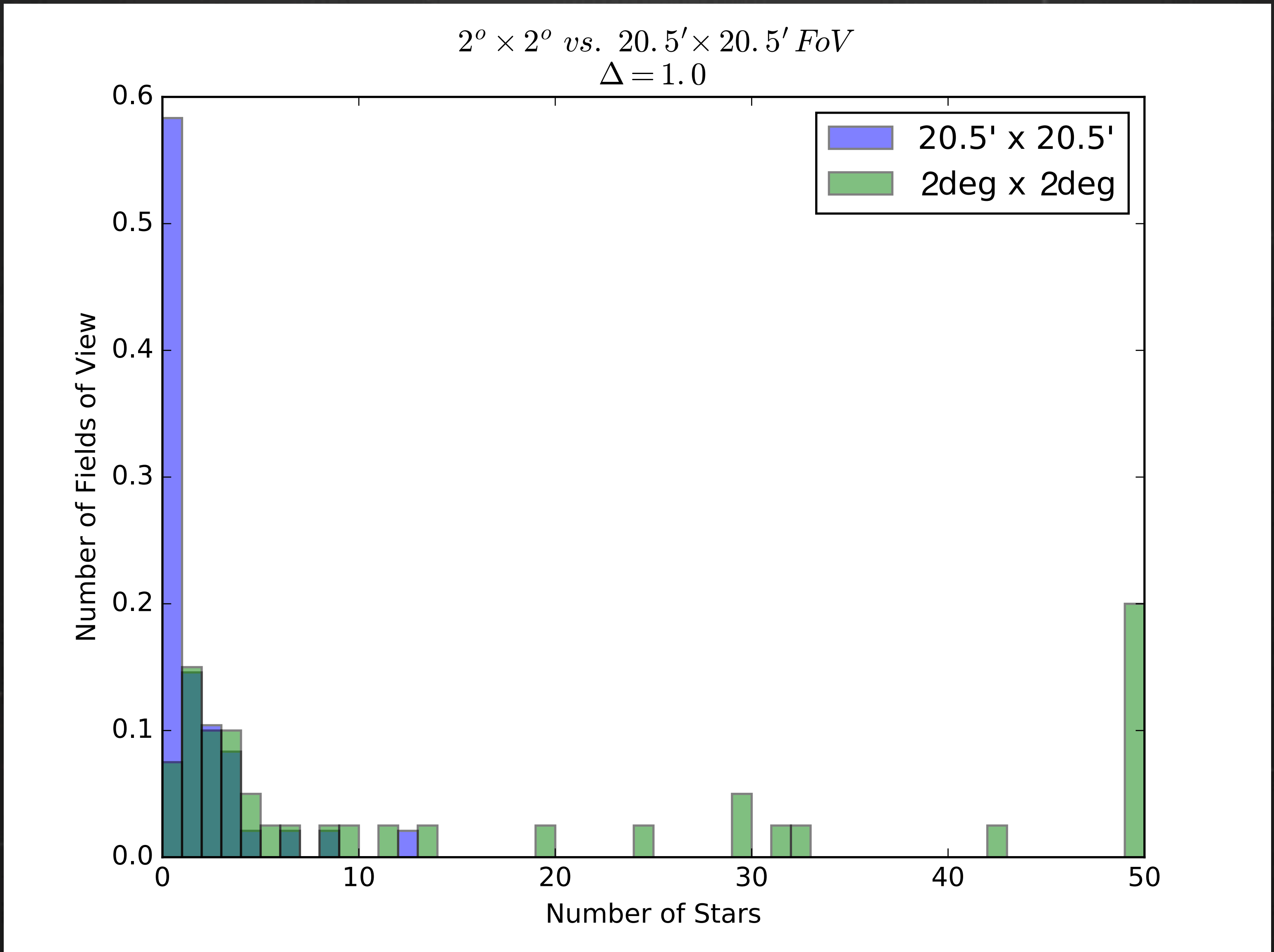
Statistics

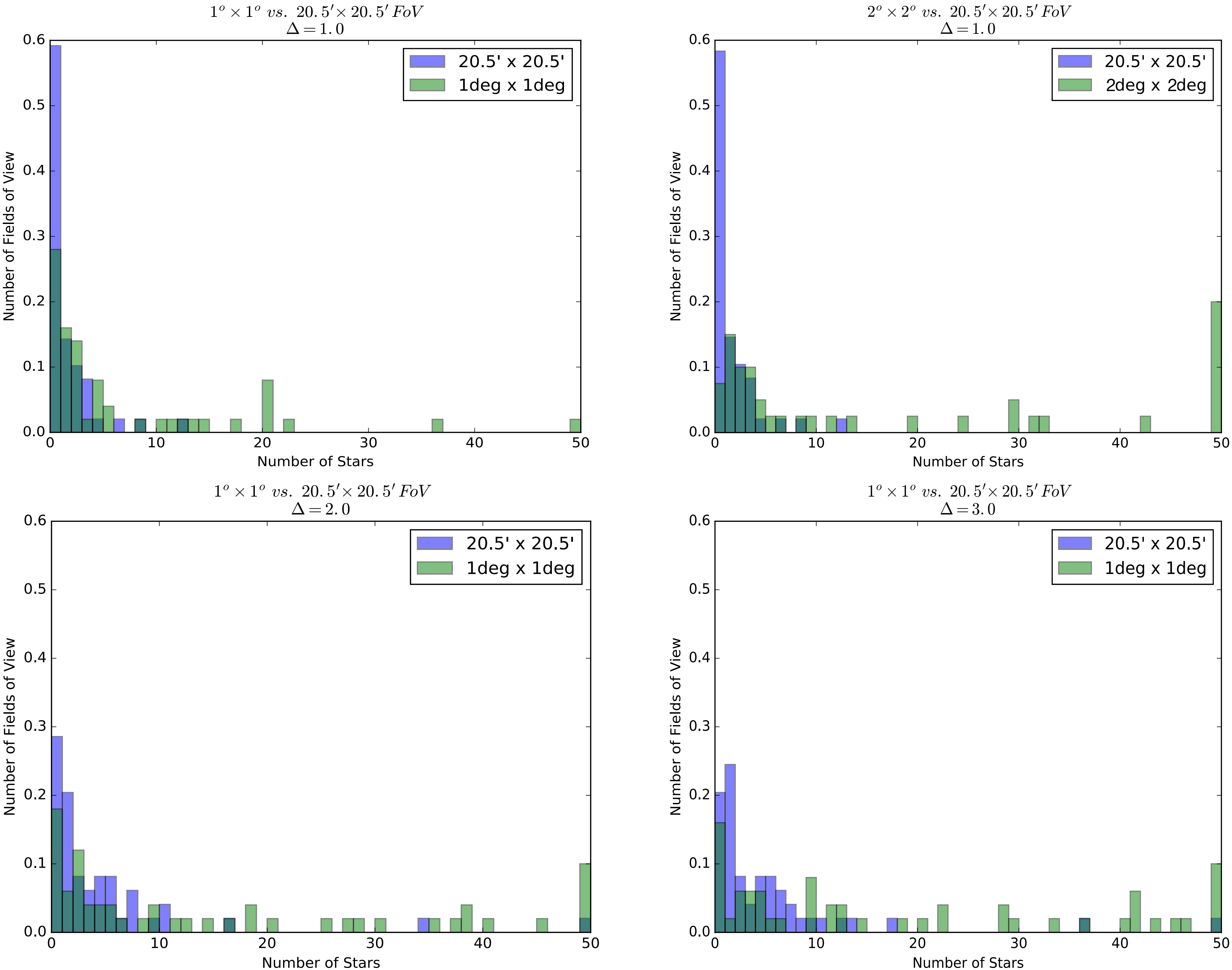


Δ -- Range of accepted values for each parameter.

i.e. M ± Δ, (G-R) ± Δ, etc…

Statistics





$1^o \times 1^o$ $vs.$ $20.5' \times 20.5'$ FoV
$\Delta = 1.0$
20.5' x 20.5'
1deg x 1deg
Number of Fields of View
Number of Stars
$2^o \times 2^o$ $vs.$ $20.5' \times 20.5'$ FoV
$\Delta = 1.0$
20.5' x 20.5'
2deg x 2deg
Number of Fields of View
Number of Stars
$1^o \times 1^o$ $vs.$ $20.5' \times 20.5'$ FoV
$\Delta = 2.0$
20.5' x 20.5'
1deg x 1deg
Number of Fields of View
Number of Stars
$1^o \times 1^o$ $vs.$ $20.5' \times 20.5'$ FoV
$\Delta = 3.0$
20.5' x 20.5'
1deg x 1deg
Number of Fields of View
Number of Stars

Conclusions

- Full access to 1º x 1º does in fact increase quantity and quality of available calibration stars.
  - True for each quality test from Δ = 1, 2, and 3.
- Expanding to 2º x 2º enhances accuracy even further.
- In short:
  - Improve measurement accuracy.
  - Software provides important information to the instrument.
  - Add flexibility.
  - Save money.
  - Save time.

Availability of Calibration Stars in Exoplanet Transit Surveys

Acknowledgements

Sagi Ben-Ami – Advisor and Mentor.
Andrew Szentgyorgi – Advisor, G-CLEF P.I.
Bill Podgorski – Advisor.
Kathy Reeves and Trae Winter – Solar REU coordinators.
The Smithsonian G-CLEF Team
John A. Johnson, MINERVA P.I.
NSF-REU Solar Physics Program at SAO, grant number AGS-1560313.