Telescope Arrays & Related Topics

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Gravic Labs Workshop October 8, 2011

Topics

- The case for telescope arrays: SNR
- Gravic's array plans
- IOTA Array & "Nano?"

This talk is dedicated to the memory of
Robert H. Koch 1929-2010

Research Interests

- Occultations
- Stellar Intensity Interferometry
- High-precision photometry
- Spectroscopy
- Polarimetry
- And others

Signal-to-Noise-Ratio Dependencies

- How do the factors affect the Signal-to-Noise-Ratio (SNR) of program measures?

$$SNR = \frac{N_{Star+Sky} - N_{Sky}}{\sqrt{N_{Star+Sky} + N_{Sky} + N_{Detector} + S^2}}$$

,

where *Ns* are counts and *S* models atmospheric scintillation

- Alt-Az Initiative members are focused on improving various parts of the SNR equation

Dependency: Sky and Star

- Objective: Increase program object signal, decrease sky
  - Need large, affordable, and portable scopes
- New mirror making technologies
  - Balance needs, e.g. light bucket diaphragm size vs. aberrations
- Mounts & Controllers
  - Alt, az, fov rotation

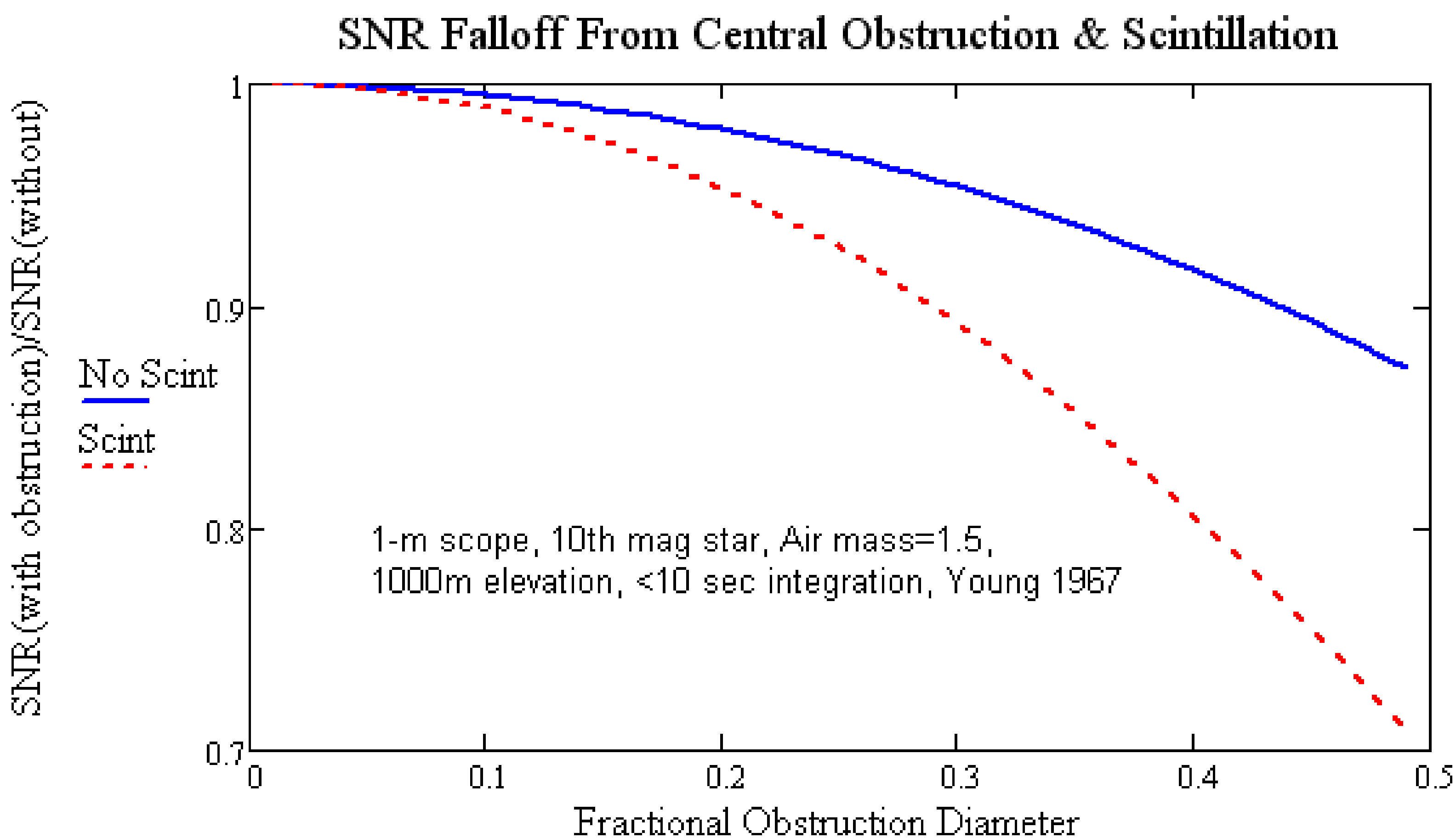
42-inch pneumatic mirror prototype at Gravic Labs

Dependency: Scintillation

- Can’t increase integration duration
  - Need about 200+ fps in visible for lunar occultation diffraction patterns
- Mitigate it
  - Increase objective diameter to a point
    - About 2-meters max (for lunar occultations).
  - Move to a higher altitude
  - Watch central obstruction size
- Arrays of light bucket scopes (future)

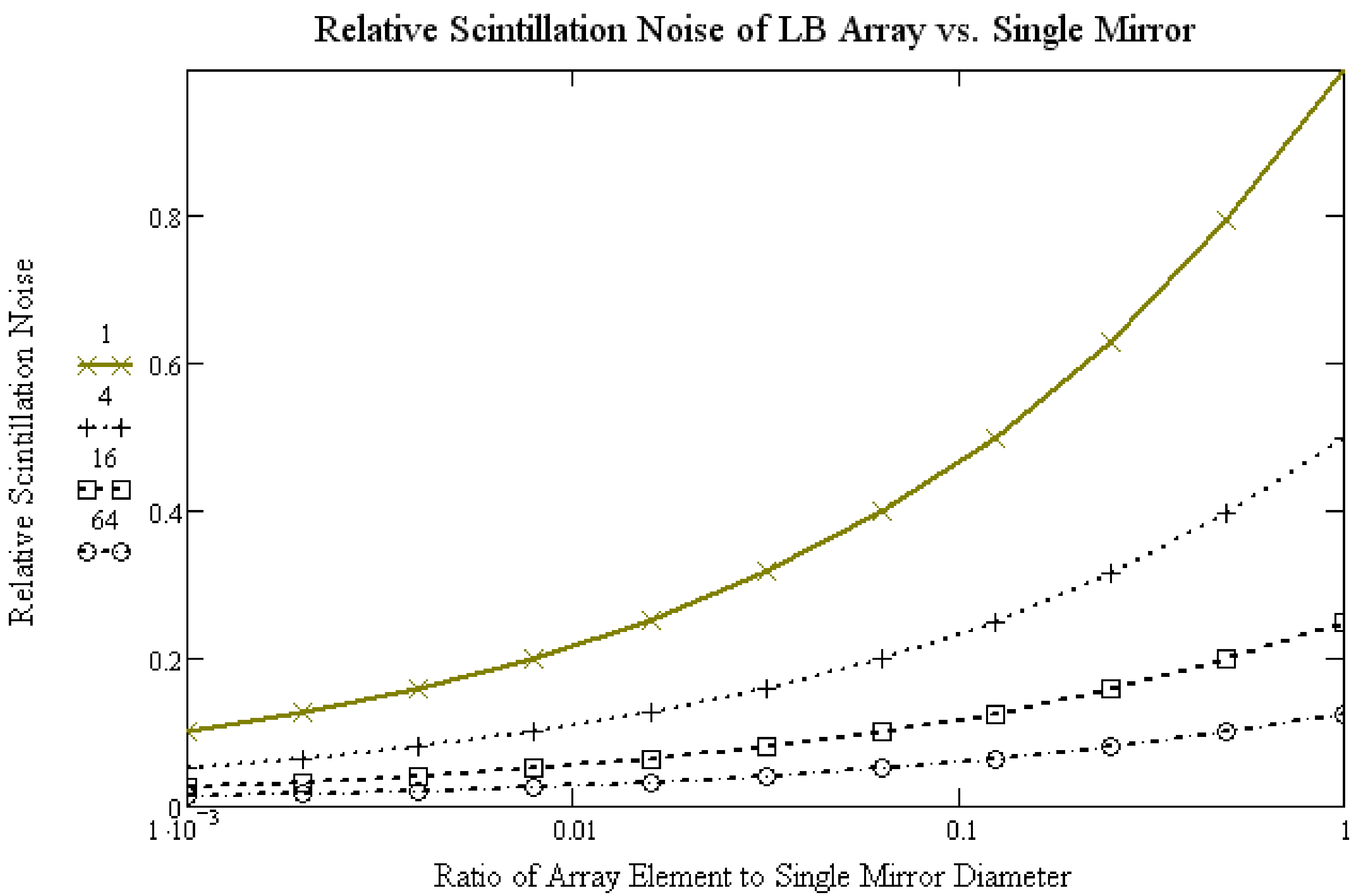
Central Obstruction SNR Falloff

Shot noise only (blue), plus extra scintillation due to obstruction (red).



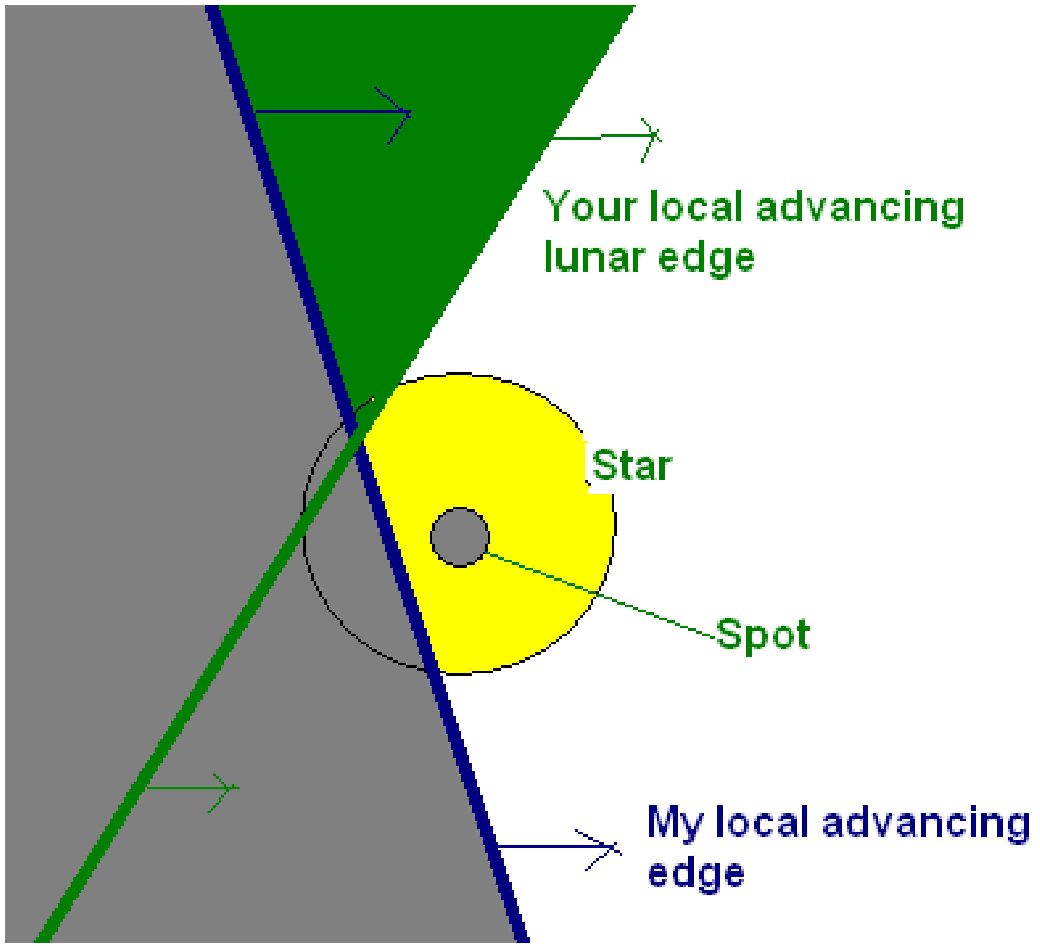
Arrays – Scintillation Reduction

- Top curve: same effective aperture of single mirror and array
- Array elements spread out



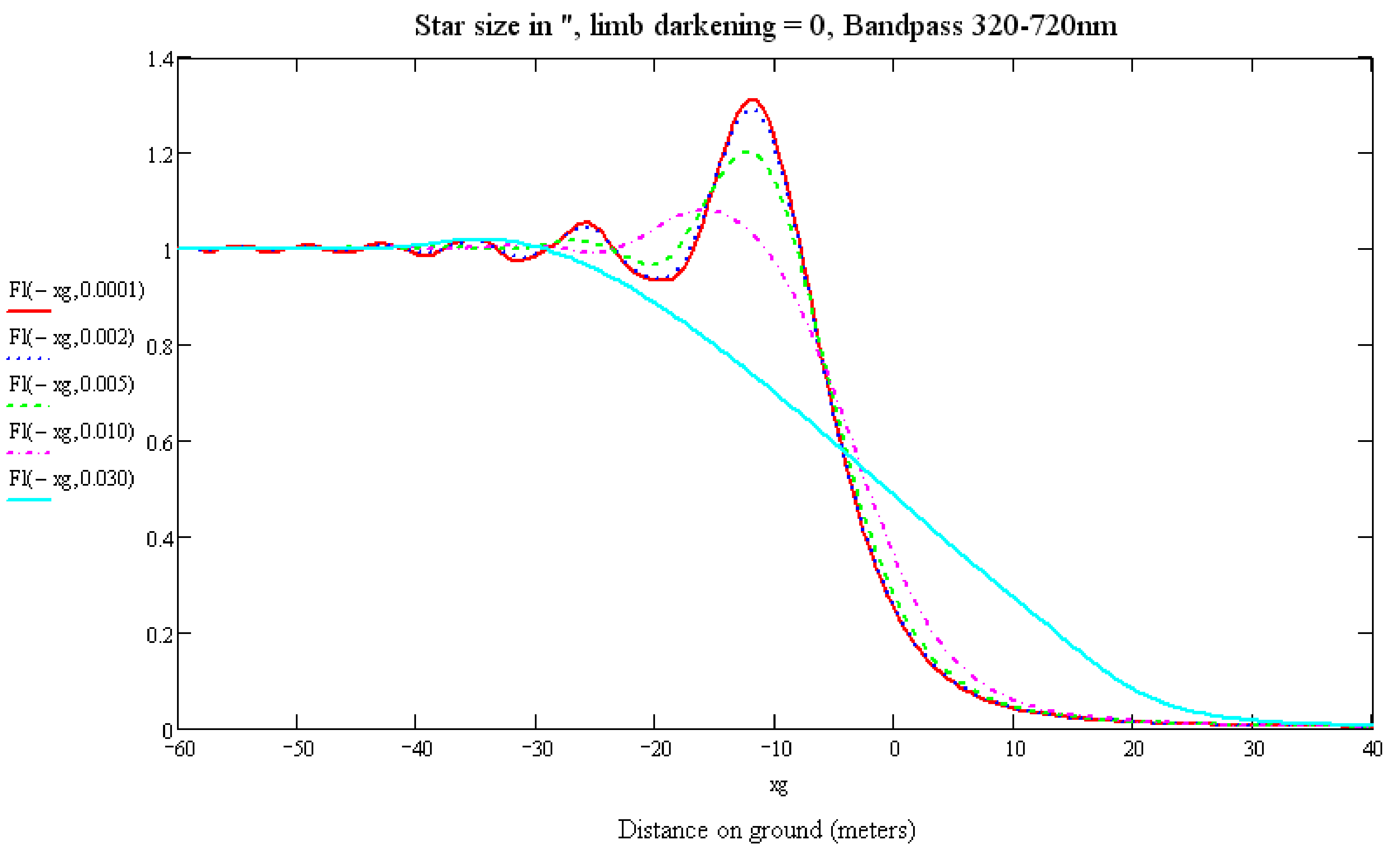
Occulted Object Science Potentials with a Sufficient SNR

- Presence/absence of stellar companions
  - Separations, PA, relative luminosity
- Stellar sizes
- Limb darkening laws
- Presence of plages and spots
- Circumstellar disks
- Detection of hot Jupiters



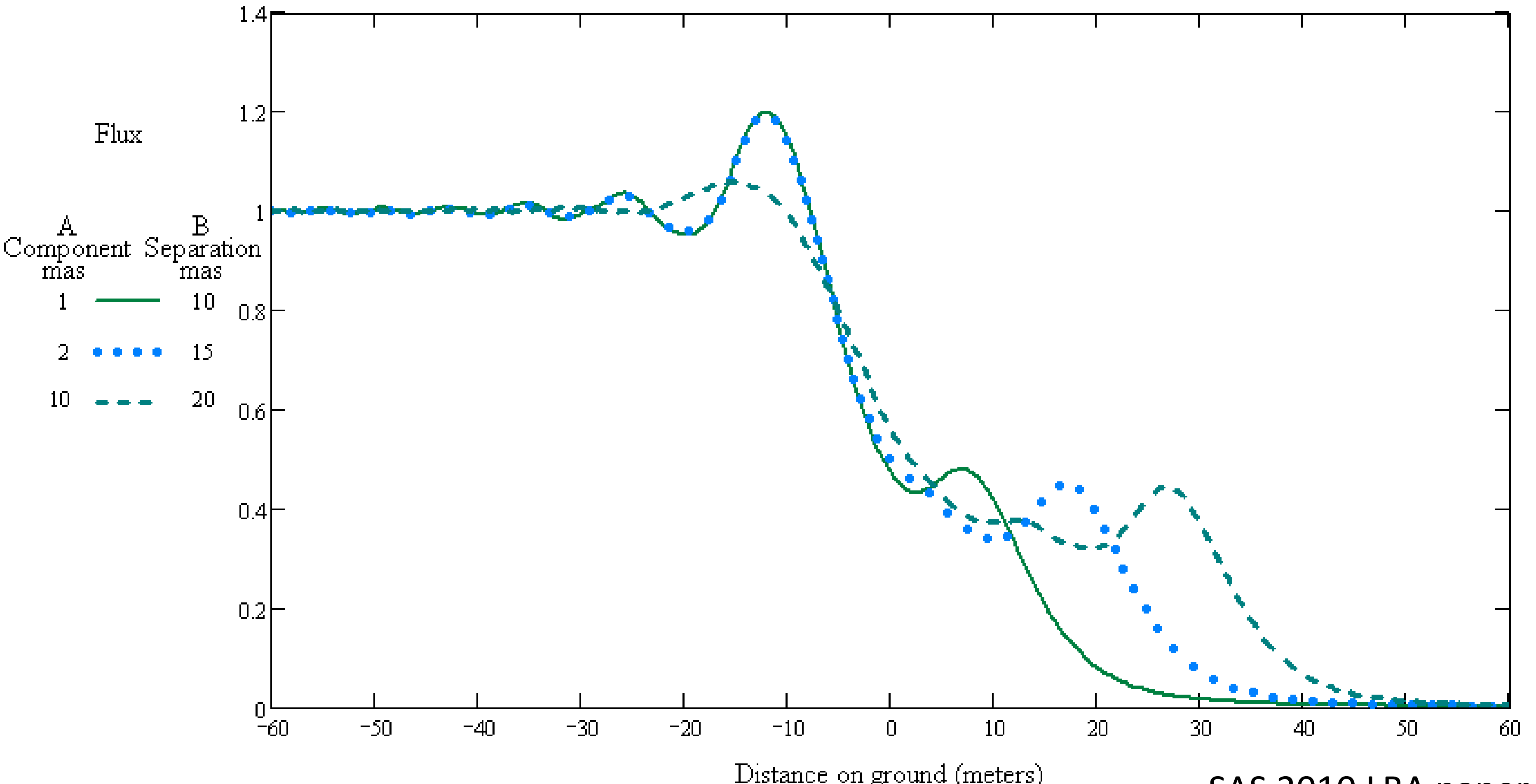
Lunar Occultations Examples

Theoretical diffraction light curves for different sized stars (0.1 to 30-mas)



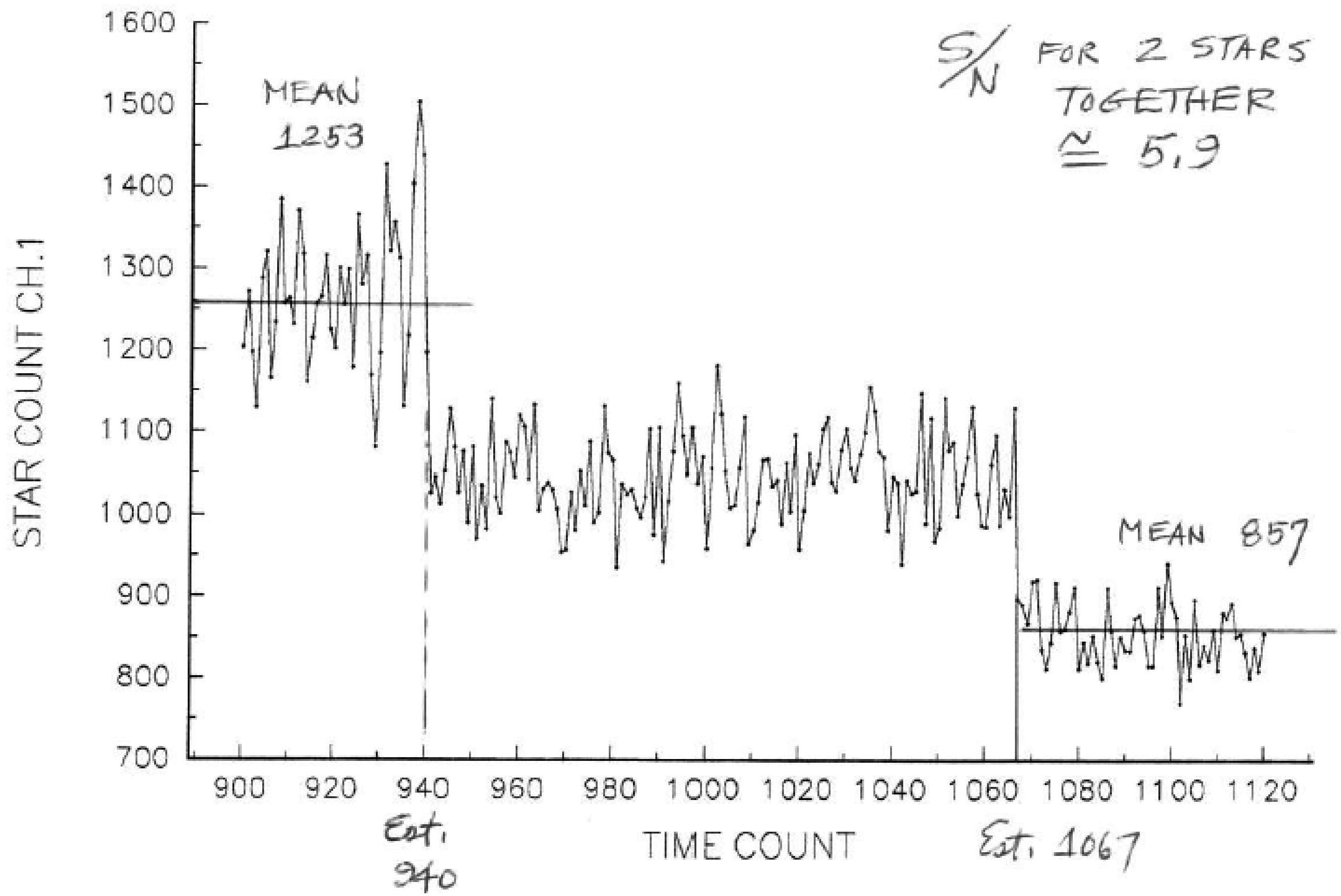
Lunar Occultations - Binaries

Theoretical diffraction light curves for three different binary systems



SAS 2010 LBA paper

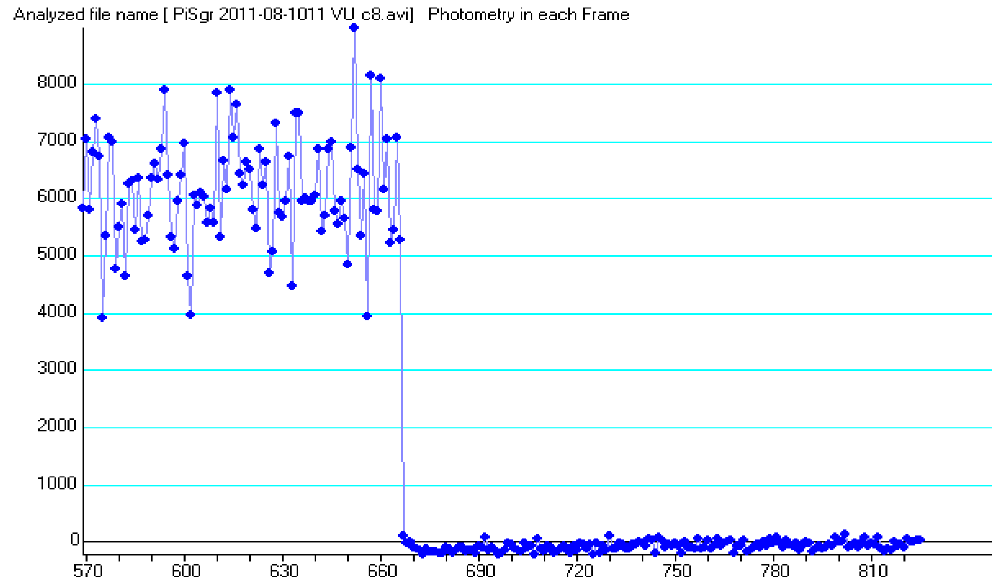
LUNAR OCCULTATION ZC 944(double star)
2/3 APRIL 1998 file:ZC944OCC



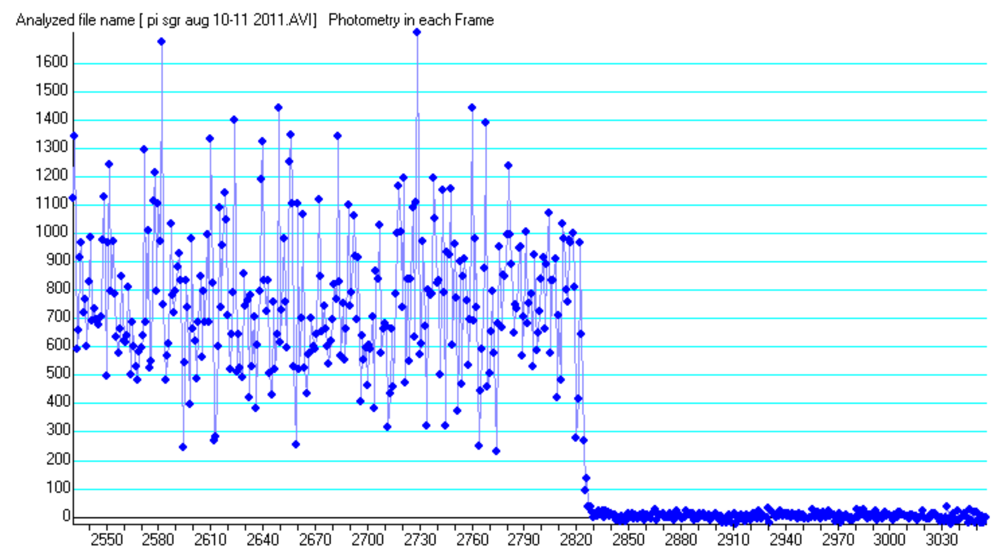
- 15” Siderostat at Flower and Cook Observatory, Malvern, PA by R. H. Koch, R. J. Mitchell and W. J. Blitzstein
- Occult4 lists close double 0.39”, Limb=0.190”/sec
- 127 15-ms samples = 0.362” separation

FPS (speed) - Pi Sgr at Villanova, August 10, 2011

- Villanova C8, 164CEX-2 CCD, no filter, 30fps
- 9.4mas per datum

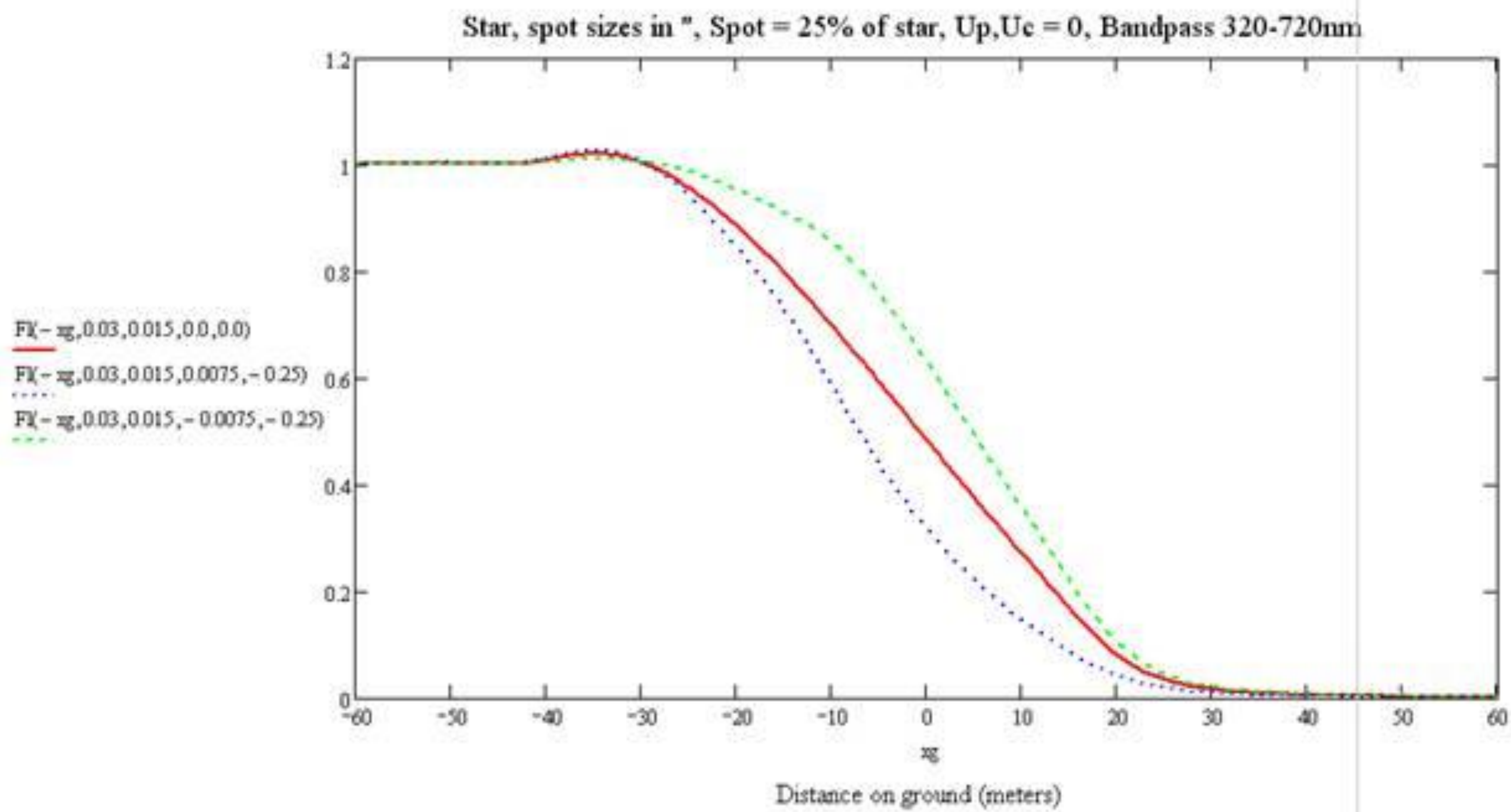


- Gravic C8, Andor Luca-S emCCD, Sloan r filter, 120fps
- 2.4 mas per datum



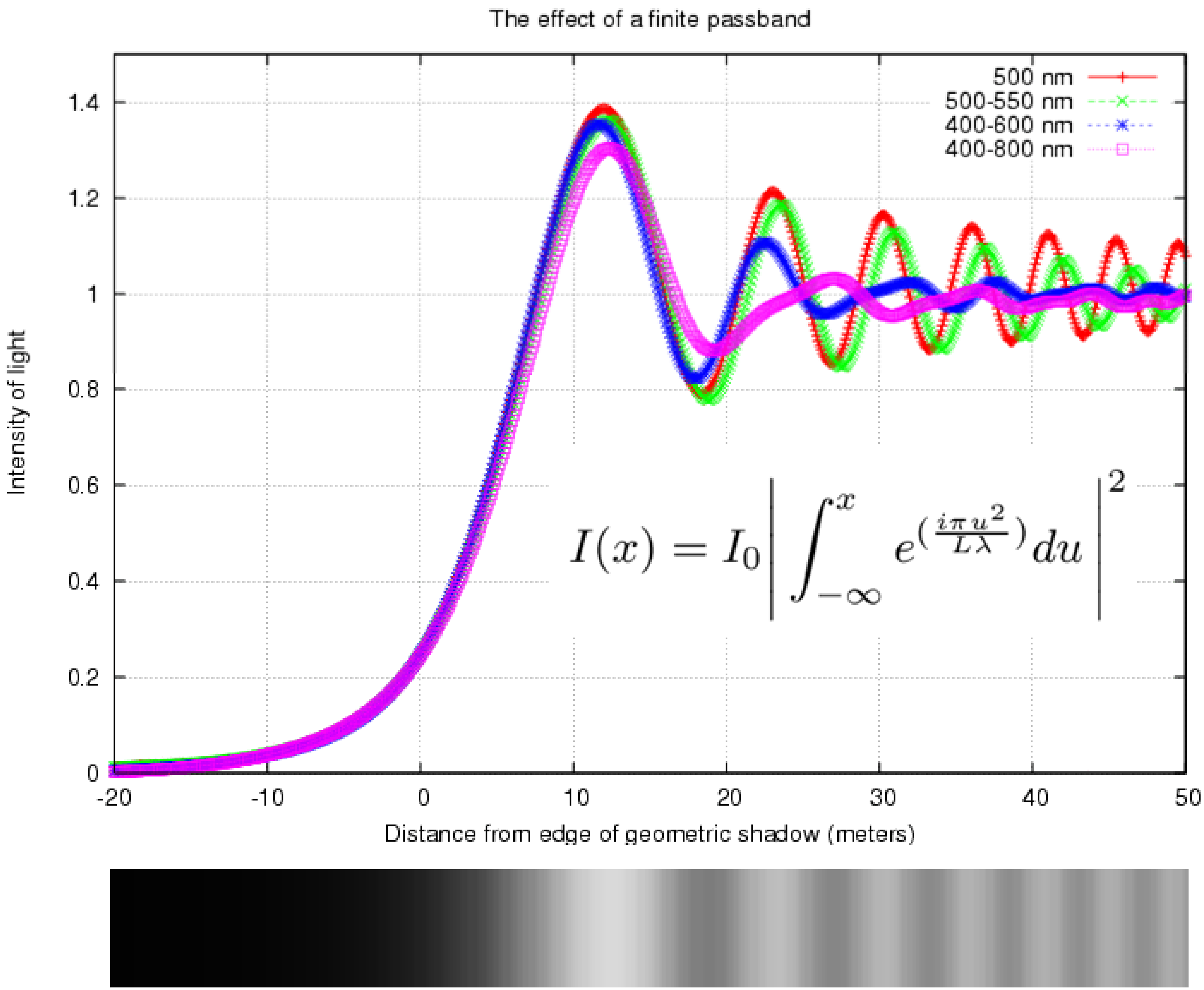
Lunar Occultations - Spots

Theoretical diffraction light curves for a 30-mas star lacking spots(red), and a dark spot (25%) leading (blue) and trailing (green) by 7.5-mas.



Fresnel Diffraction

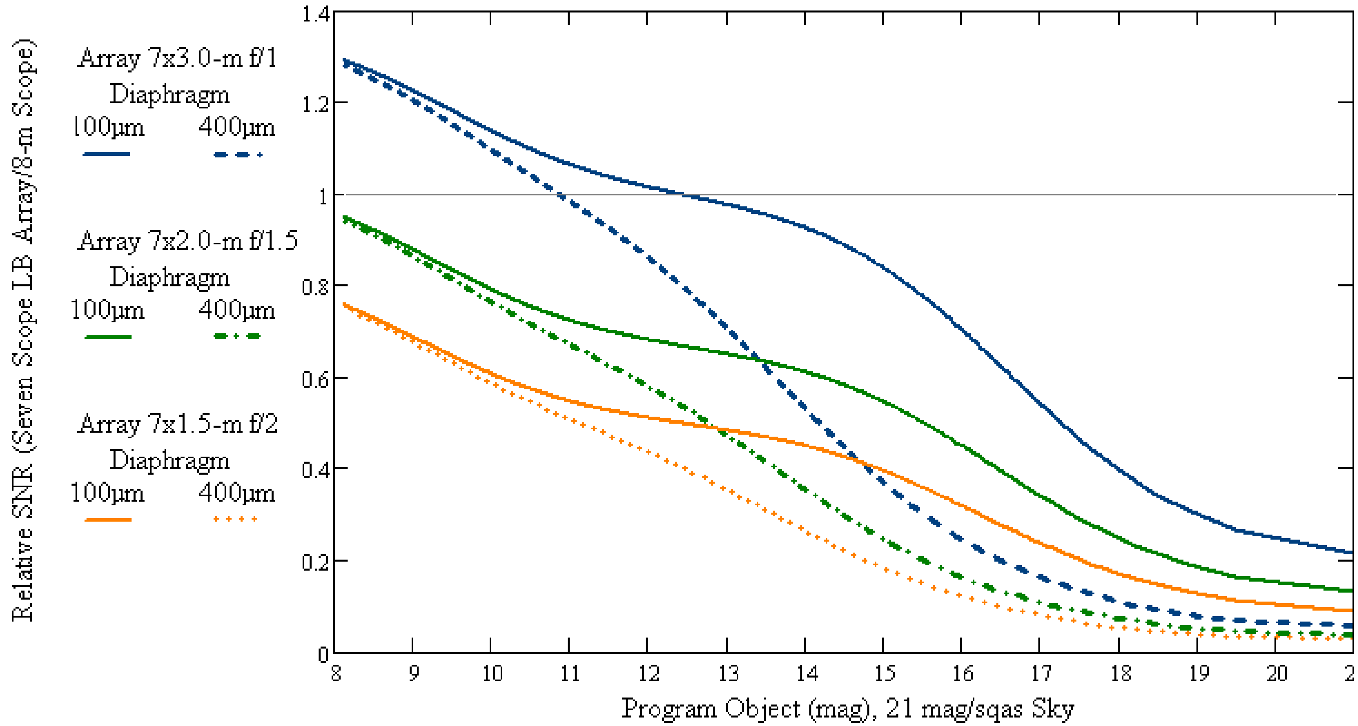
Dependencies on bandpass and geometry



Adapted from: Michael Richmond, 2005, http://spiff.rit.edu/richmond/occult/bessel/bessel.html

Light Bucket Arrays

- 7 LBT arrays vs 8-m f/1 scope
- 2 relative diaphragm diameters (400, 100 vs 40 micron on 8-m)
- Scintillation at 3000-m, air-mass 1.5

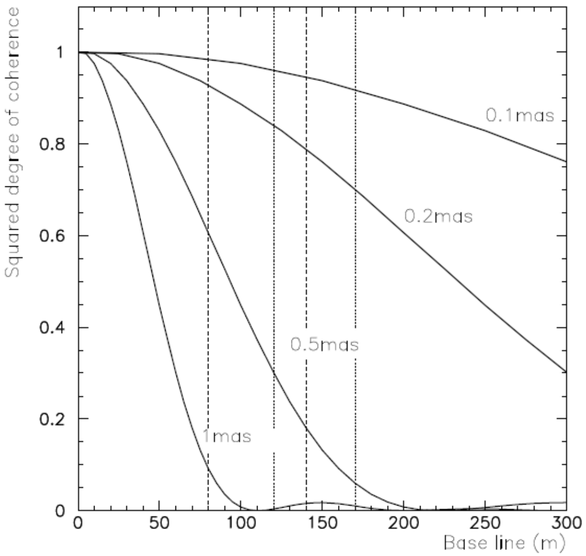


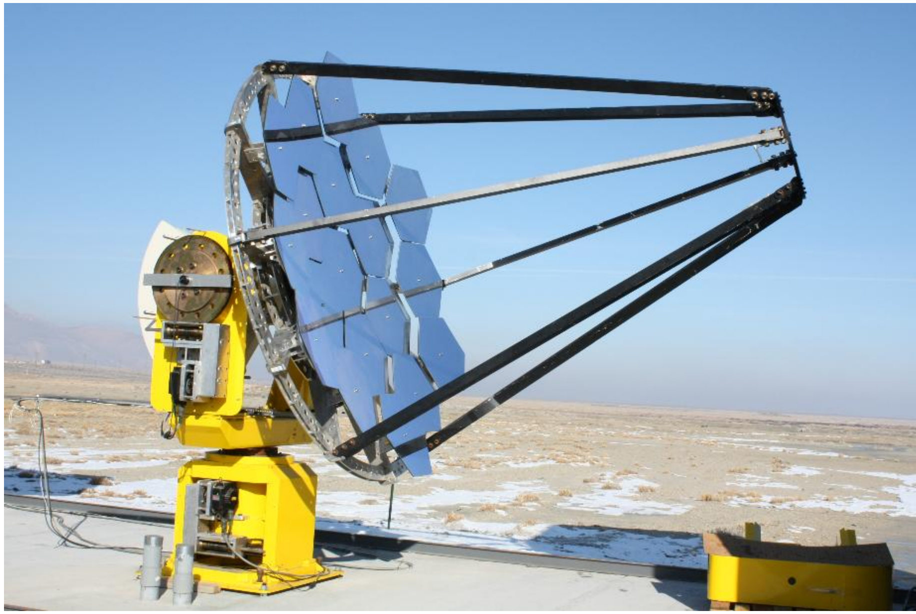
Other Array Benefits

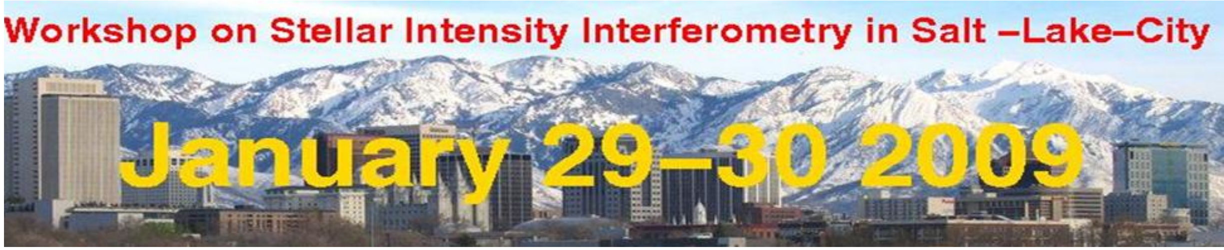
- *Reliability. Immediate and independent confirmation of rare, transient events*
- *Availability. Graceful failure rather than all at once*
- *Independence. Geographic area avoids clouding out the array*
- *Transportability. Moveable elements to avoid bad weather or seek advantageous observing locations*
- *Expandability. Add more array elements later as funds allow.*

Stellar Intensity Interferometry Arrays

- Hanbury-Brown in 60's measured diameters of 32 stars
- <I1 * I2>/<I1><I2>
- LeBohec *et. al.* revival







Intensity Interferometry LBT Potential

$$SNR_{Hanbury\ Brown} = A\alpha\, n\, |\gamma| \left[\Delta f\ \frac{T}{2}\right]^{1/2}$$

A is the telescope area, α is the photomultiplier quantum efficiency; n is the number of photons incident on the telescope per unit area, per unit time, and optical bandwidth; γ is the degree of coherence of the flux; Δf is the bandpass of the electronics, and T is the observing period.

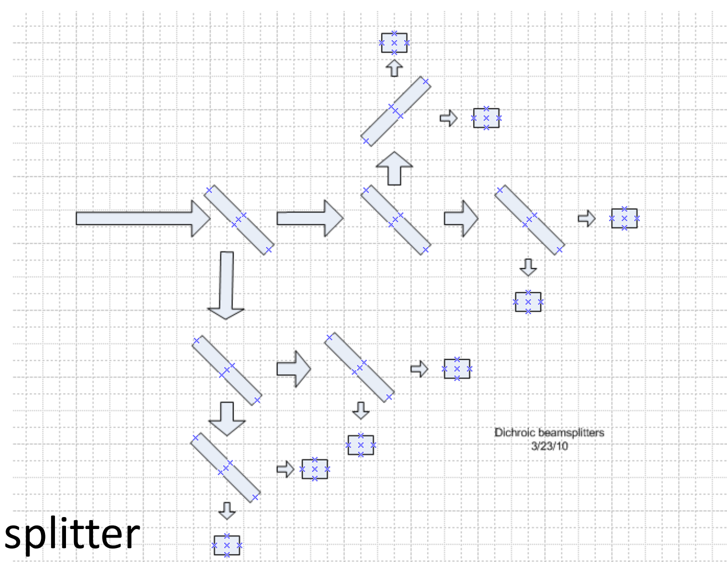
$$SNR_{Overall} = \left[\binom{N_{Array}}{2} N_{Channels}\right]^{1/2} SNR_{Hanbury\ Brown}$$

N_{Array} is the number of elements in the array, and $N_{Channels}$ is the number of simultaneous channels measured, and the noise is modeled as adding in quadrature.

Modern Electronics with pair of 2-m LBTs = 3 magnitudes better than Narrabri - 4.5 mag. with seven 2-m LBTs

Future HTRA experiments

- Three 12-cell Hamamatsu R1463P PMTs
- LeCroy 6100A samples at 10GS/s
- NVIDEA CUDA GPU for photon correlation



8-band dichroic beam splitter

Future experiments

- Oriel M125 Spectrograph (1/8 m) vs. dichroics

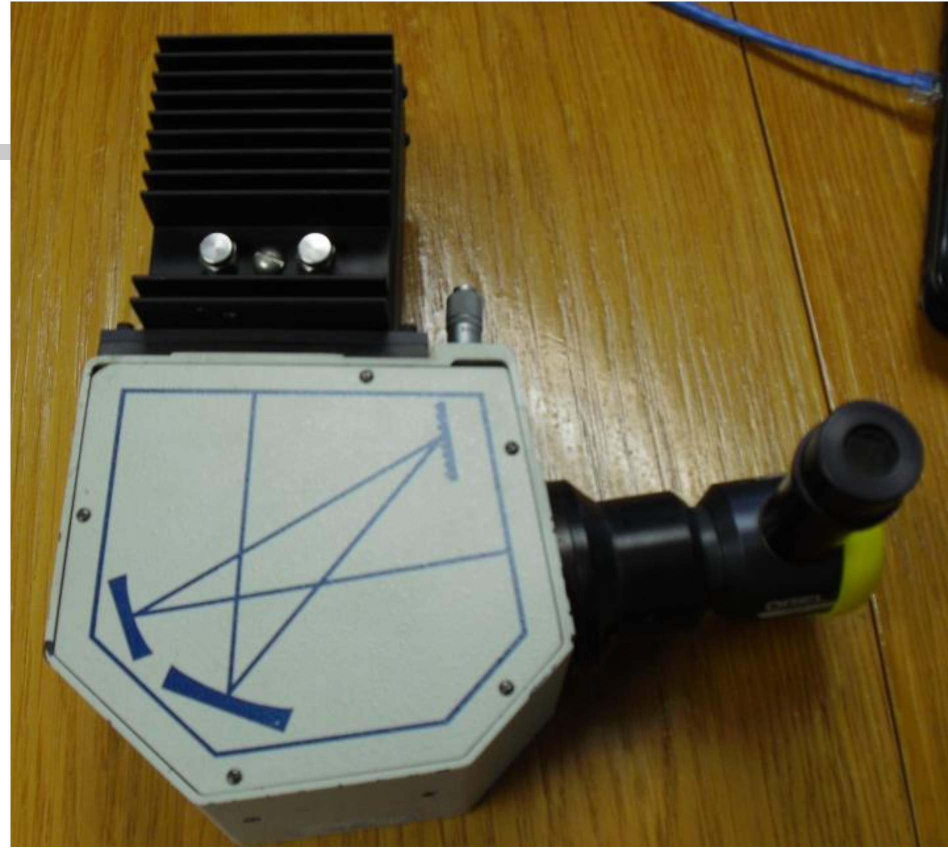


Table 1 Grating Options for LineSpec InGaAs Linear Array Spectrometers

Line Density (l/mm)	Blaze Wavelength	Type	Spectral Resolution (nm)*	Array Bandpass (nm)*	Primary Wavelength Region (nm)**	Grating Model
1200	1000	Ruled	0.44	160	550 - 1600	77463
1200	750	Ruled	0.44	160	450 - 1000	77412
600	1000	Ruled	0.86	338	600 - 2500	77465
600	1250	Ruled	0.86	333	750 - 2000	77455
600	1600	Ruled	0.86	325	900 - 2000	77456
400	1600	Ruled	1.3	505	900 - 2900	77457
300	1000	Ruled	1.72	675	575 - 2500	77458

* Measured with 10 µm x 2 mm slit and 512 array detector.

** The primary wavelength region is where the grating efficiency is ≥20%. System efficiency will also be affected by the reflectivity of the spectrograph's mirrors and the grating angle, at any wavelength.

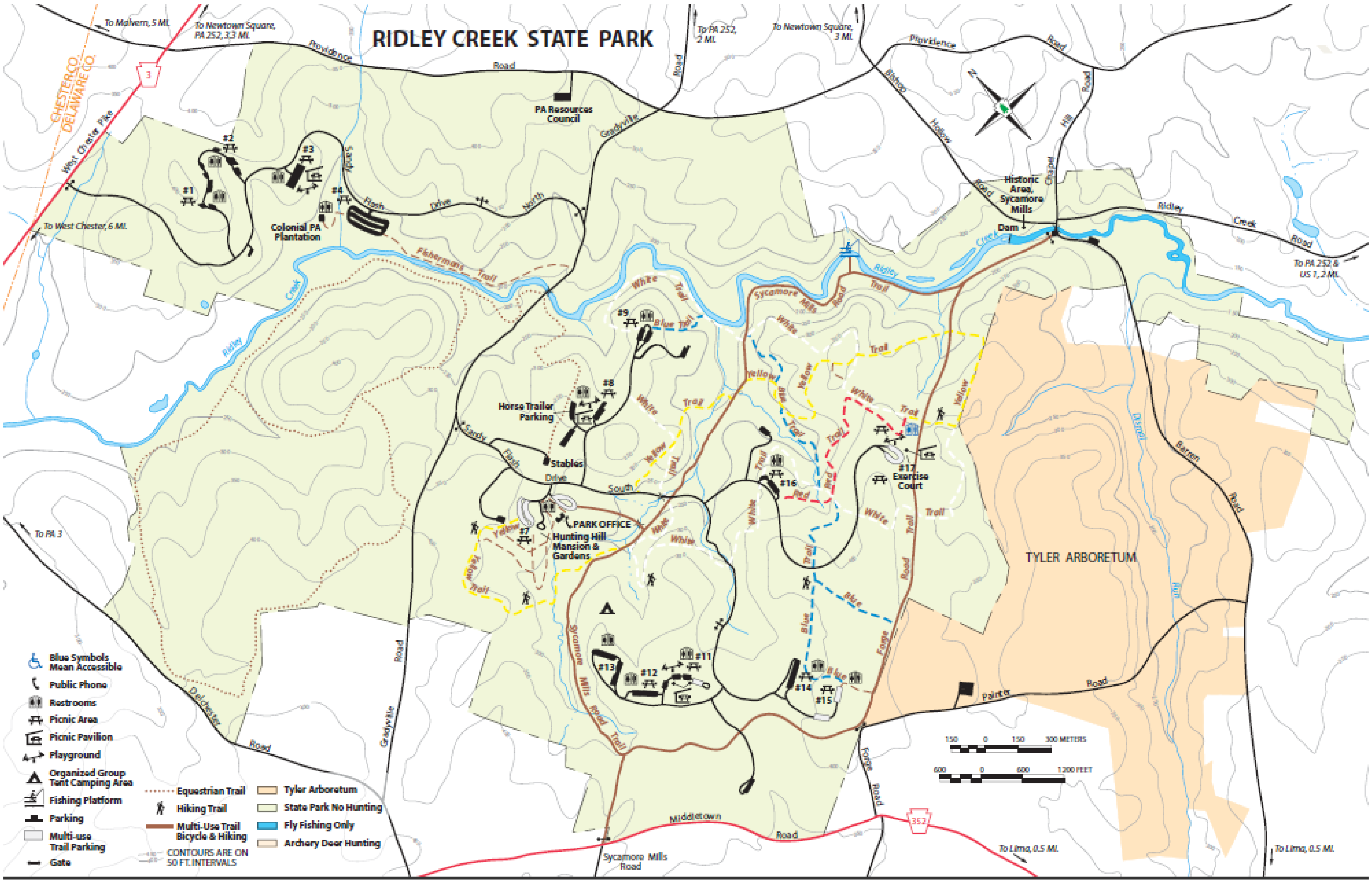
Newport
Experience | Solutions

Gravic's Array Plans

- 7 to 10 elements 0.75 to 1.25-m aperture
- Configurable
  - Minimize scintillation
  - Maximize coverage
- East Coast location
  - <2500 ft. elevation typical
  - 1-2 arc second seeing
- Automated, Queue Scheduling
- Minimum 3 astronomers, 1 technician

Gravic's Array Location Possibilities

- Ridley Creek State Park (5 min.)
- Chester County (30 min.)



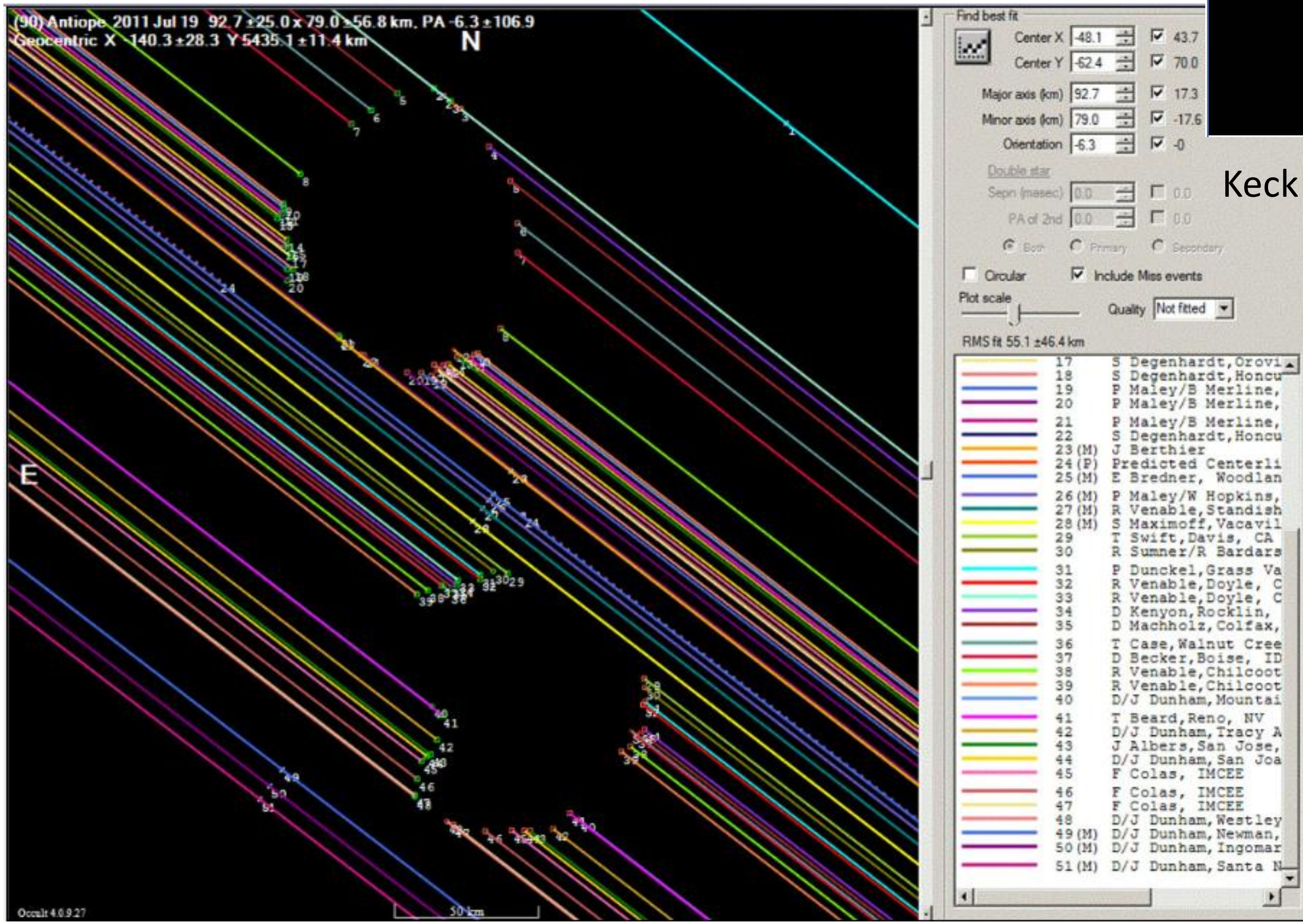
Gravic's Array Location Possibilities

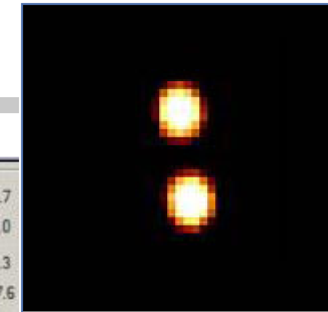
- Poconos (2 hrs.)

Gravic's Array Location Possibilities

- Cloudersport, PA (5 hrs.)
- International Dark Sky Park

IOTA Successes





Keck (Sky & Tel)

- Antiope success – July 19, 2011

"IOTA Nano?"

- Potential opportunity is to involve the masses
  - 1000's of chords for publicized events
  - Build interest in IOTA and occultation studies
- Will it work?
  - Some tests with a iPhone4 & inexpensive iPhone telephoto

15mm f/1.1 lens 6.5^0 field on iPhone4

Moon

Vega

"IOTA Nano?"

- IPhone4S camera
  - Back Illuminated
  - HAD technology
  - 5MP, 8MP (4s)
- 125M sold since 2007
- Functions
  - Compass
  - GPS
  - Gyros
  - Networking

"IOTA Nano?"

FOR THE MASSES?

- Alerts via Occult Watcher
- Alarm & instructions
- Pre-pointing guide (theodolite)
  - Up/down/left/right, etc., camera used to avoid trees
- Automatic recording of event
  - Time, GPS location, 30fps HD video
- Automatic transmission of raw video
- Automatic reception of results
- Other:
  - Instant messages for coordination
  - 50mm Telephoto and adapters for 1.25" eyepieces

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