

Session 10:
Improving support for GNSS and other challenging
missions

17th International Workshop on Laser Ranging
May 2011

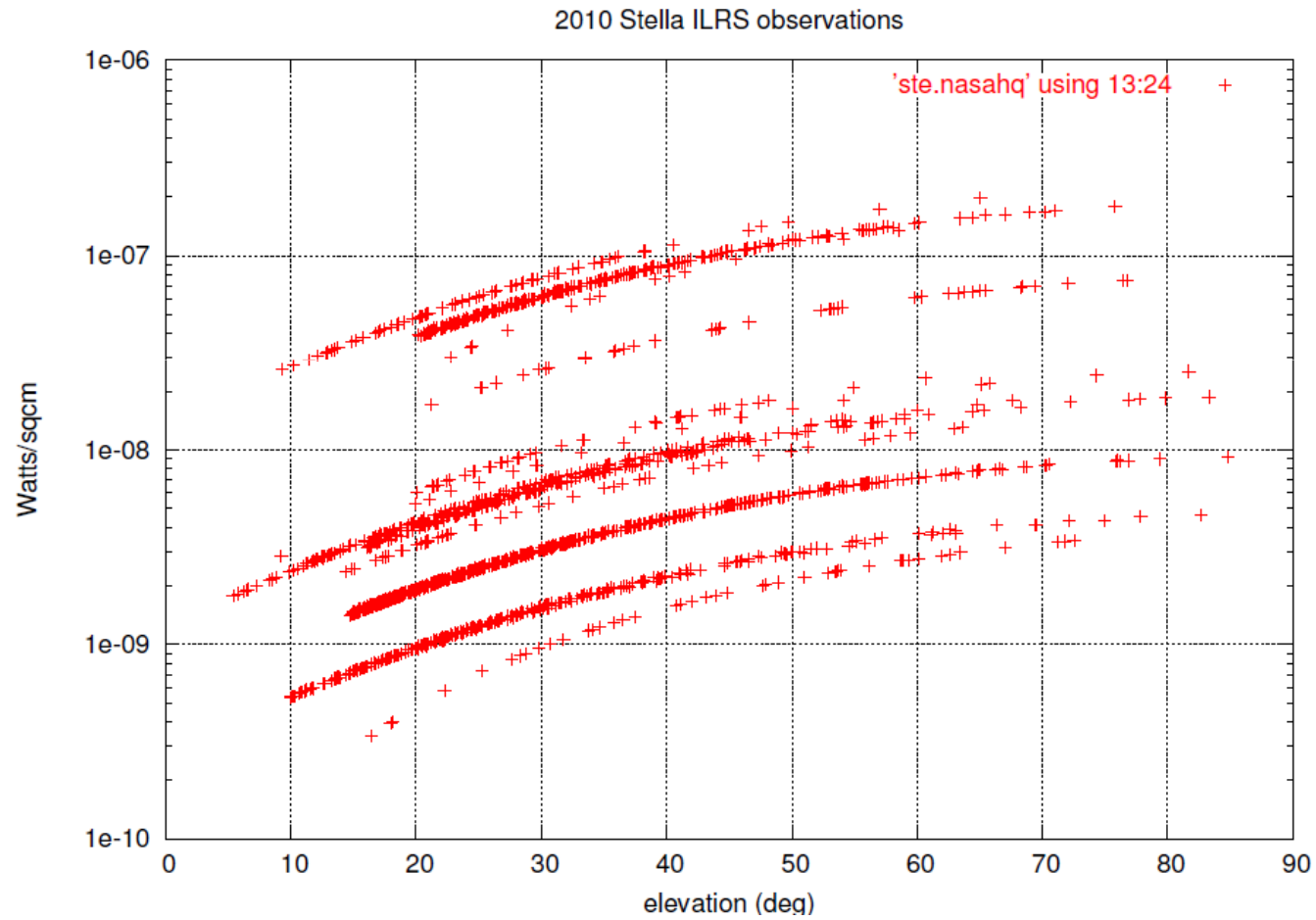
Divergence Estimation procedure for the ILRS Network & Engineering WG

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Why do we need Divergence information?

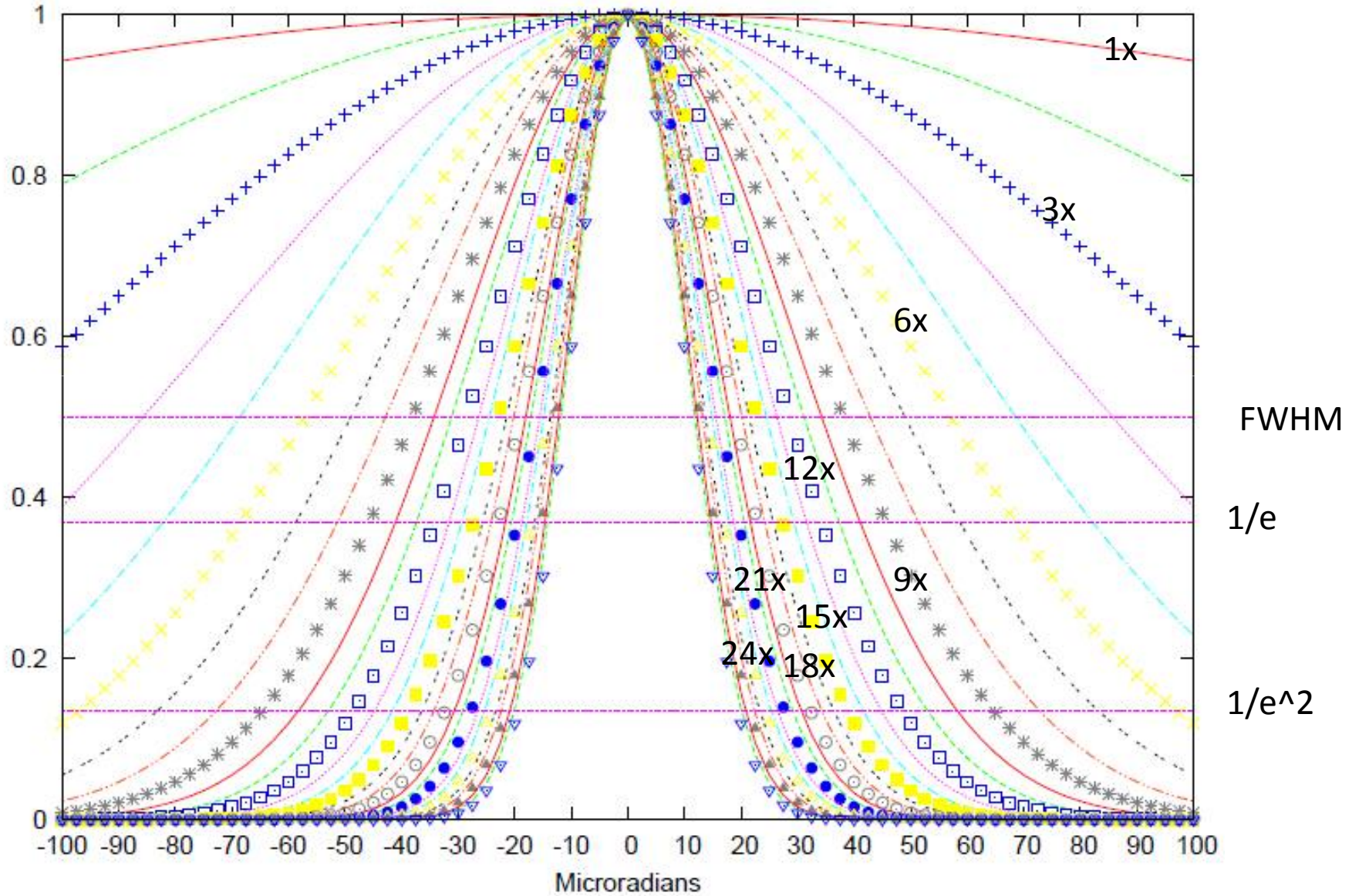
- Link budgets are Estimated using an implied value from the Site Logs
 - Theoretical Data is optimistic / incomplete
- Reliable differences between Day and Night
 - Useful for GNSS Array Requirements and performance prediction
- Missions WG is getting requests by potential new satellites
 - Need reliable W/cm^2 at the satellite for the whole ILRS network
- Estimation of divergence practices today
 - Estimated from diffraction theory from either
 - Full size of the primary mirror for mono static systems
 - Full size of the coude path and beam expander

Example Plots of Flux at Satellite

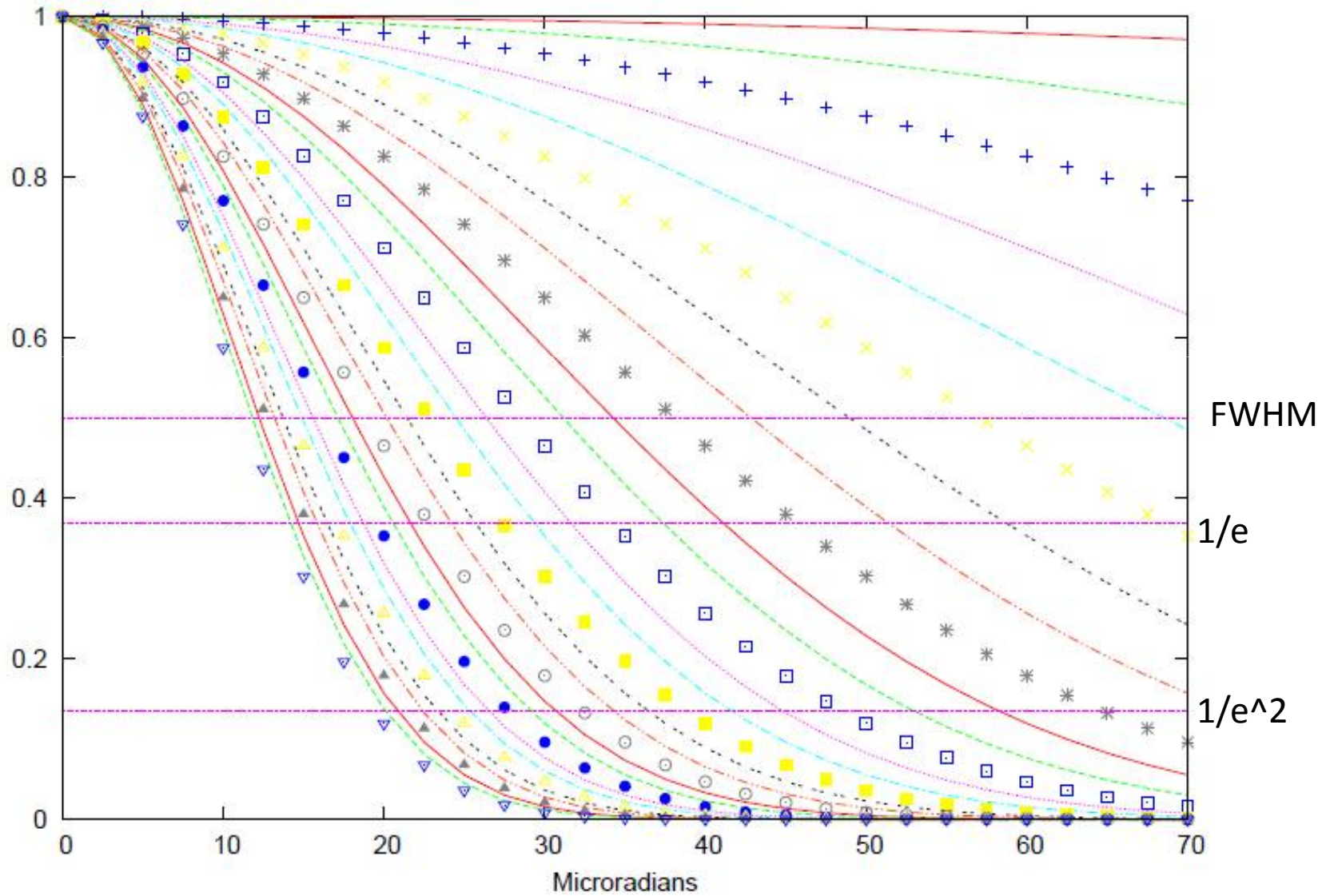


Generic Gaussian Beams

4 mm Waist * Beam Expander Factors



Generic Gaussian Beams



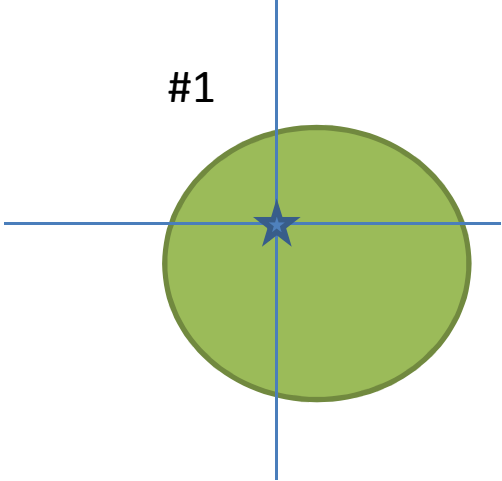
Procedure Setup

- Pick Satellite at > 40 deg elevation pass (on days with different seeing conditions)
 - Ajisai or Starlette /Stella (something very strong)
 - Lageos1/2
 - GNSS or Etalon
- Choose Night conditions
 - No daytime filters
 - No iris
 - No Clouds (in part of sky that's being used)
- Maximize signal
 - Turn off automatic attenuation (10% return rate matching)
 - Open received FOV spatial filter
 - Normal transmit energy
- Step size
 - Make it at least 10 steps
 - 1 arcsec (5 urad / 0.00028 deg) works well
 - Minimum step is half what it takes to lose the signal on a GNSS

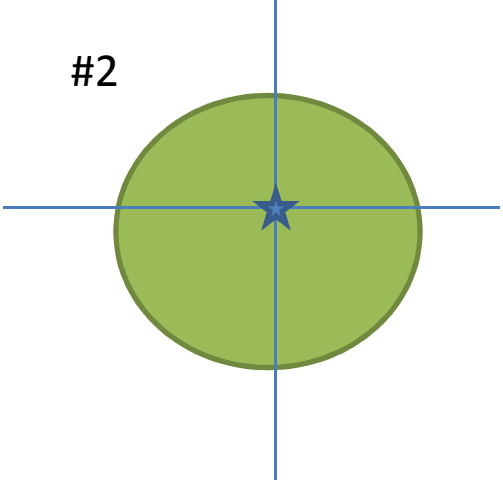
Scanning Procedure

- Acquire
- Scan in azimuth - Initial
 - Find left and right boundary where the signal is barely there
 - go past by 2 or 3 steps to confirm
 - record offsets and center
 - Set to center
- Scan in elevation - Initial
 - Find left and right boundary where the signal is barely there
 - Go past by 2 or 3 steps to confirm
 - record offsets and center
 - Set to center
- Scan in azimuth (left and right) to Boundary where signal is barely present
 - Record offsets and center in azimuth
- Scan in elevation (up and down) to Boundary where signal is barely present
 - Record offsets and center in elevation
- Scan again in Azimuth to boundaries
 - These offsets are the azimuth measurement
 - Center in Azimuth
 - $(\text{right} - \text{left}) * \cos(\text{elevation})$ is the reported measurement
- Scan again in Elevation to boundaries
 - These offsets are the elevation measurement

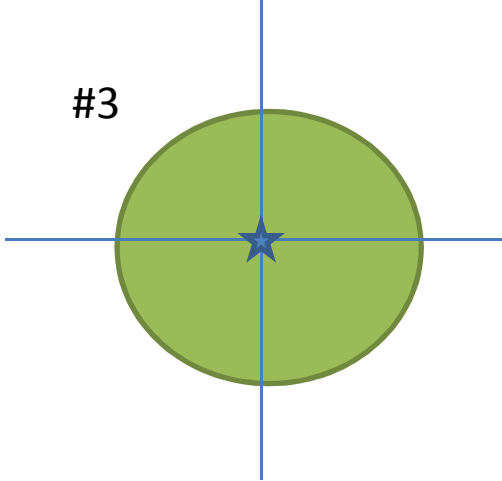
Graphical Measure



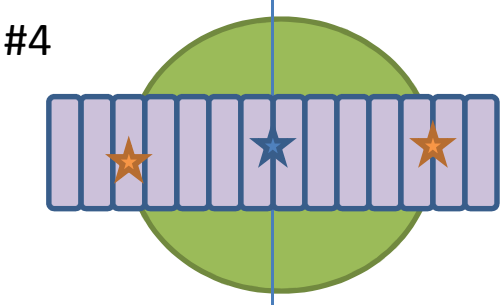
Random initial state



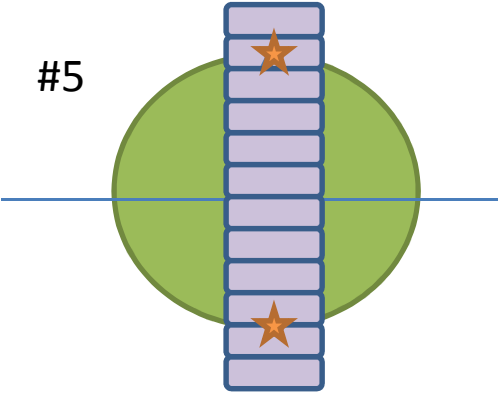
After first azimuth scan



After first elevation scan



Measure Azimuth

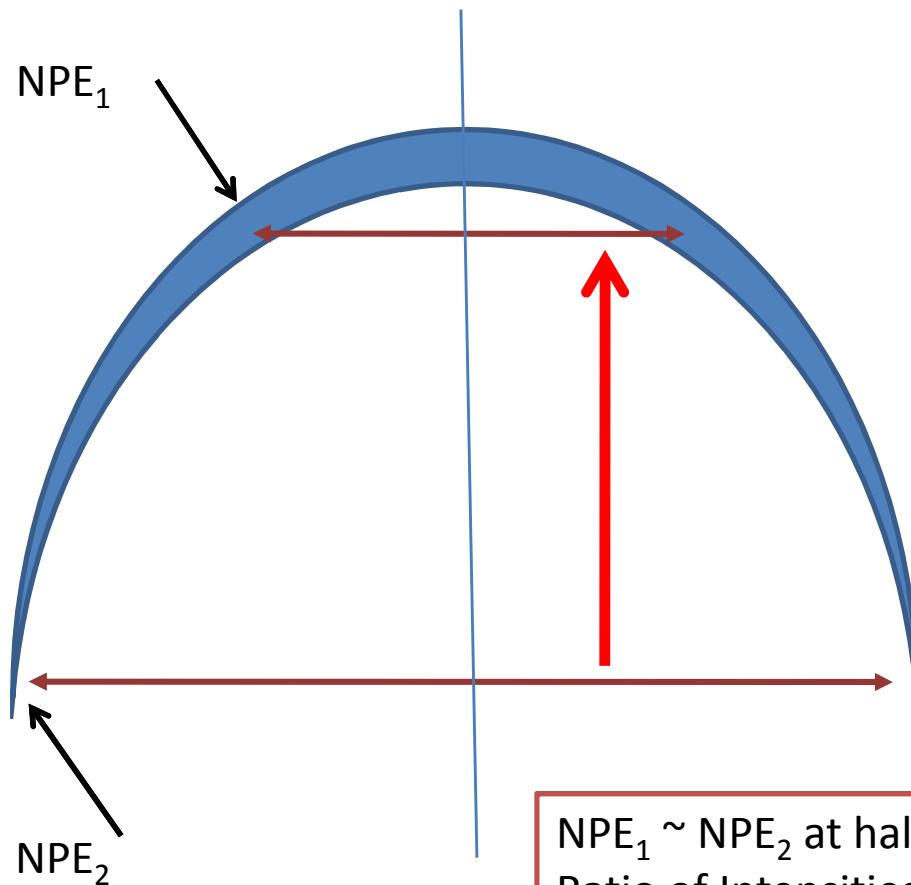


Measure Elevation

Things which affect the measurements

- Seasonal
 - Humidity (0-50, 50-70, 70-100%)
 - Where in the local pressure cycle (High vs Low)
- Sky Conditions (Jitter)
 - Expect 10 to 20 urad of short term (during the measurement)
- Local Seeing
 - If there is access to “waste light”
 - What is the diameter of a typical star (10th Mv – doesn’t really matter – just be consistent) in the same part of the sky
- Thermal Gradients
 - +/- 1 hour of sunrise
- Laser Temperature
 - Thermal lensing effects in the amplifiers
- Sun Proximity to beam
- Operators
 - This is a subjective measurement

Why is Ratio of NPE Important?



Ratio of NPE:

- At two different satellites, scan off in AZ & EL until $NPE \sim 0$
- NPE is proportional to $LRCS/R^4$
- At endpoints of scan, NPE of both are \sim equal
- NPE Ratio = $(\sigma_1/\sigma_2) * (R_2/R_1)^4$
- NPE Ratio defines the ratio of the intensity values where the vertical half angle lines cross the divergence curve

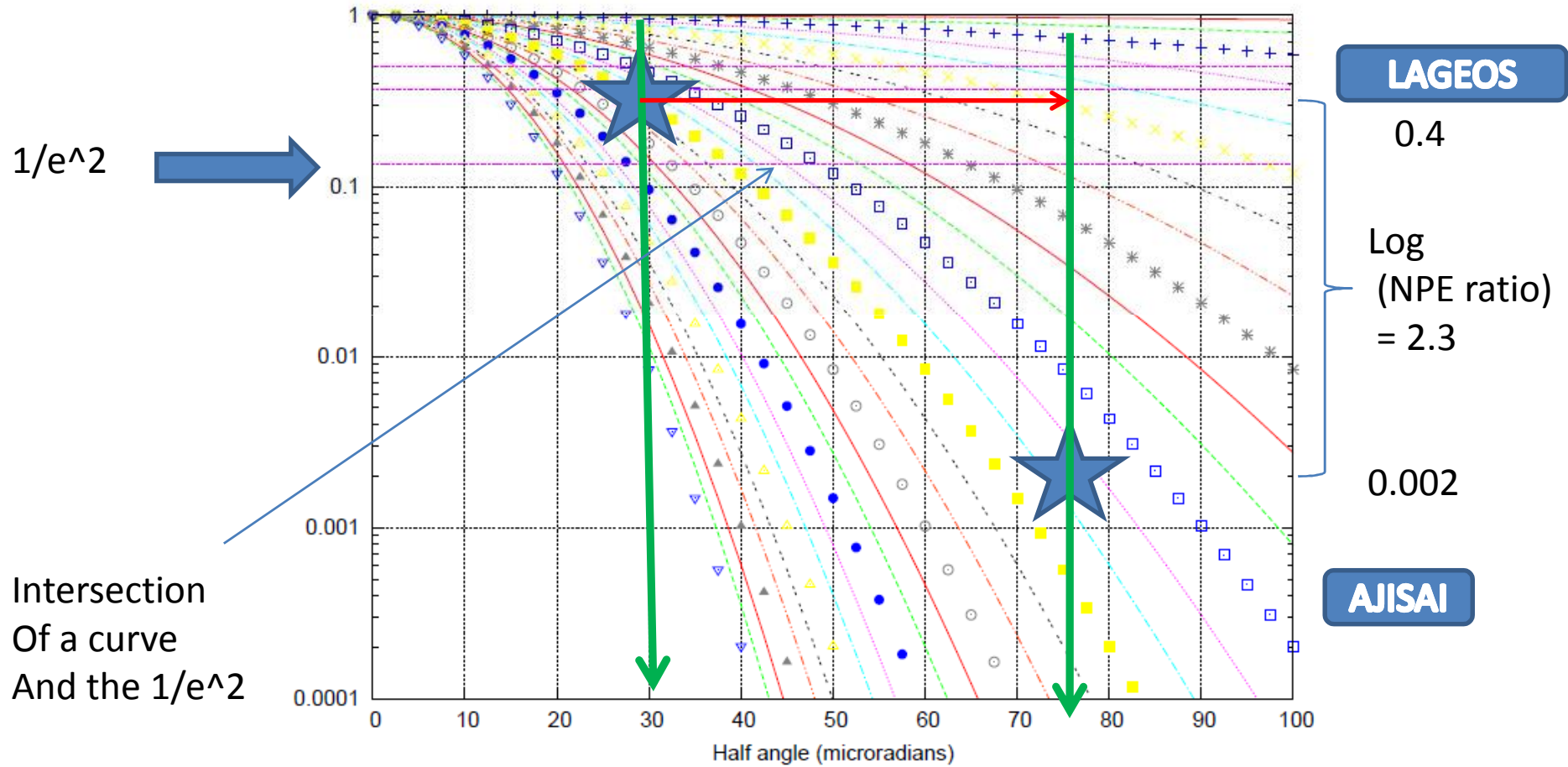
$NPE_1 \sim NPE_2$ at half angle end points
Ratio of Intensities at these points can be determined from known quantities, Range and Cross-section

Link Budget Differences at 40 deg

	Starlette /Stella	Ajisai	Lageos	Etalon	Qzss	
1-way Range (km)	1159	2080	7055	20804	35817	
Range wrt Lageos	6.28	3.43	1.0	0.343	0.200	
Flux wrt Lageos	39.4	11.8	1.0	0.118	0.039	
Log (flux ratio to lag)	1.6	1.05	1.0	-0.93	-1.40	Decade Shift
Avg LRCS (millions sq meters)	1.80	23	15	55	253	
Avg NPE wrt Lageos	185	214	1	0.051	0.028	
→ Log (avg NPE)	2.3	2.3	0	-1.3	-1.6	Decade Shift

* Cross Sections from Arnold – “Cross section of ILRS Satellites”

Graphical Divergence Determination



Station Measured ~ 45 urad (half angle) for
1/e²

Real World Example

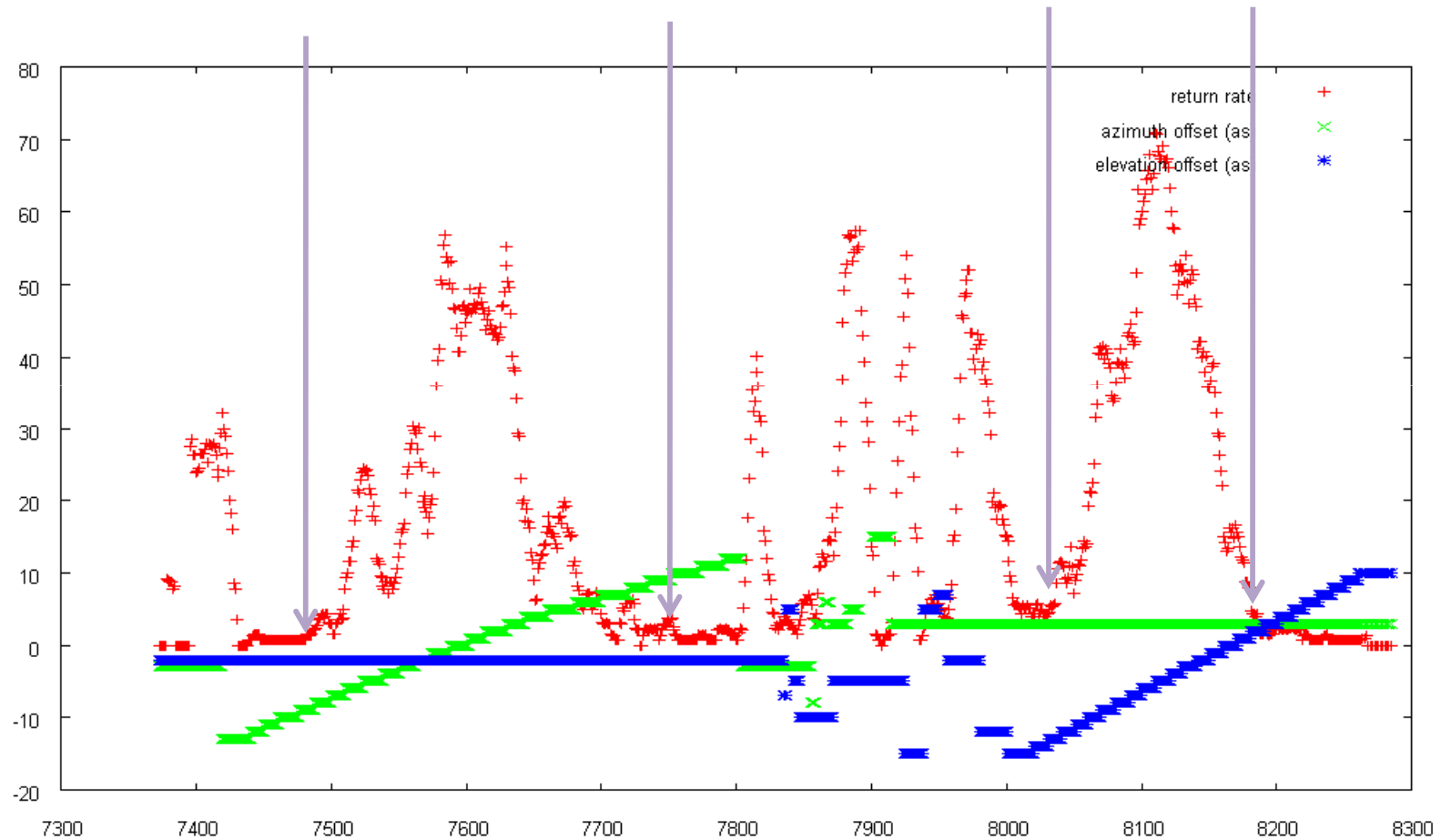
- NRL – Stafford measured using 5 microradian steps
 - Sky conditions were very clear
 - 3 arcsec diameter star and satellite blob diameter
 - Lageos – 12 steps Az, 12 steps El
 - Ajisai – 29 steps Az, 31 steps El
- Interpretation – Plot on graph
 - Ajisai diverge of 150 urad (half 75 urad)
 - Lageos divergence 60 urad (half 30 urad)
 - NPE Ratio = $(\sigma_1/\sigma_2) * (R_2/R_1)^4 = (1.533) * (132.353) = 202.9$
 - $\log(202.9) = 2.3$
 - Find a curve that has 2.3 decades of difference
 - Find the intersection with the $1/e^2$ line (at 0.13 value)

Worksheet / Procedure

Satellite name				
~ Elevation (deg)				
Sky Conditions				
Star diameter				
Daytime Filters out				
Field Stop / IRIS open				
Extra ND's out				
Step size (counts-> microrad)				
Azimuth counts				
Elevation counts				
Beam measurement (microradians)				

First Attempts at Lageos2 from Herstmonceaux

Full Data Logging!



Conclusion

- Procedure establish
- Repeatability (day to day) is good (from Graz and Herstmonceaux)
- Encourage Stations to try and report results
- Spreadsheet to interpret $1/e^2$
- Improve knowledge for the GNSS designs

- Need to get to 1% return rate on 2 satellites at same elevation
 - to get to the “equivalent” components to divide out

Spare Slides

How accurate is needed?

How will the numbers be used?

- The Real world will make these measurements vary from day to day
 - Need average
 - Need worst (biggest) beam for worst case link budget projections
 - Need best case (tightest) beam for MWG assessments
- Flux at satellite / array will vary function of divergence
- Elevation dependence terms in the model
 - Telescope jitter
 - Atmosphere jitter
 - Divergences near these jitter limits need careful models

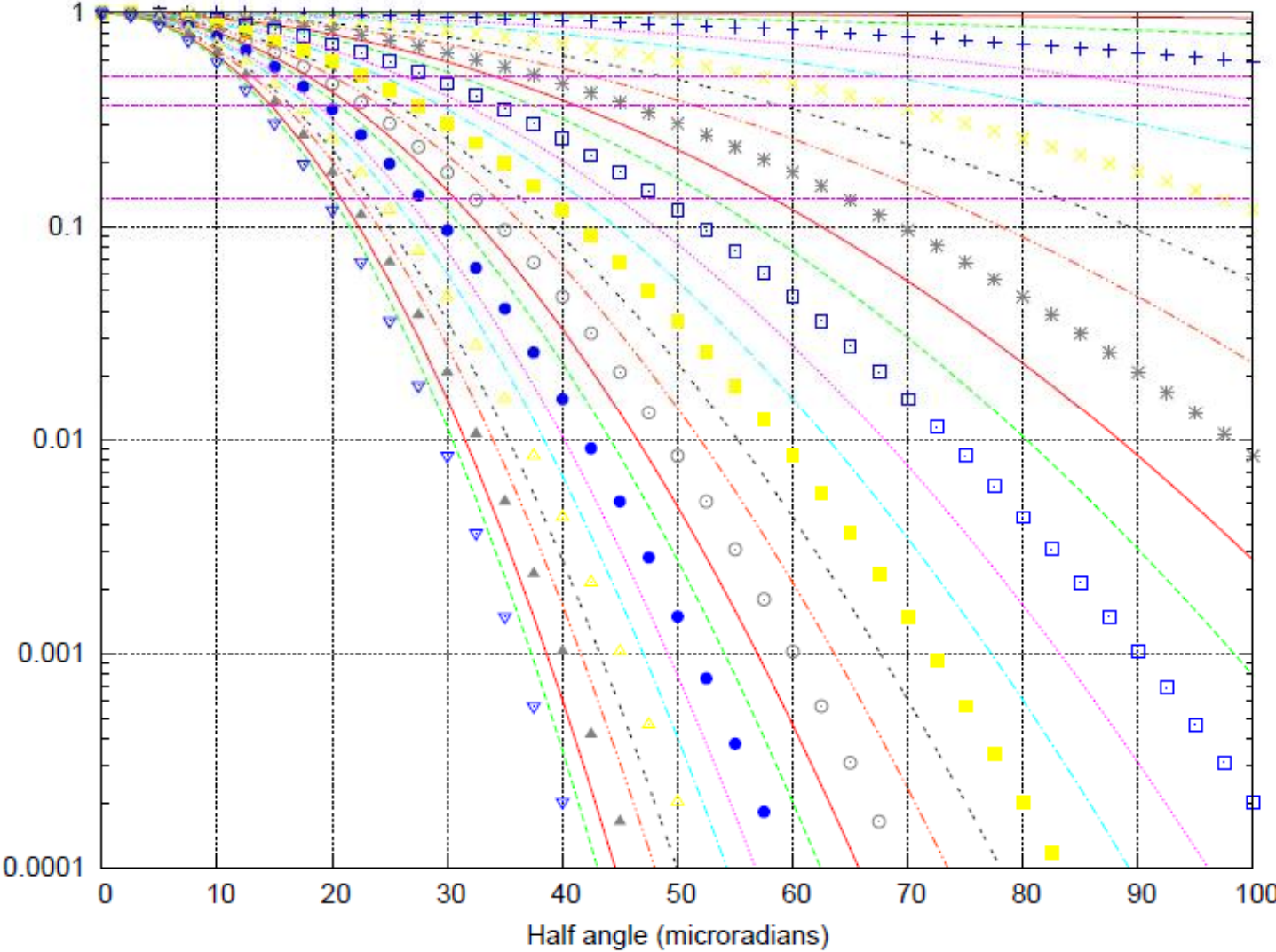
Other Possible Techniques

- Use the procedure above to ensure beam is centered
 - Use ND's on the transmit beam to reduce return rate to very low
 - Ratio of the Ajisai to Lageos ND values
 - Or ND required to reduce signal to equivalent return rate
 - Requires accurate knowledge of cross section
- Generate lots of link budgets with the full range of possible divergences
 - Make similar plots
- Using a single satellite
 - use the measure of beam size at 2 different ranges
 - Requires model for the atmospheric attenuation

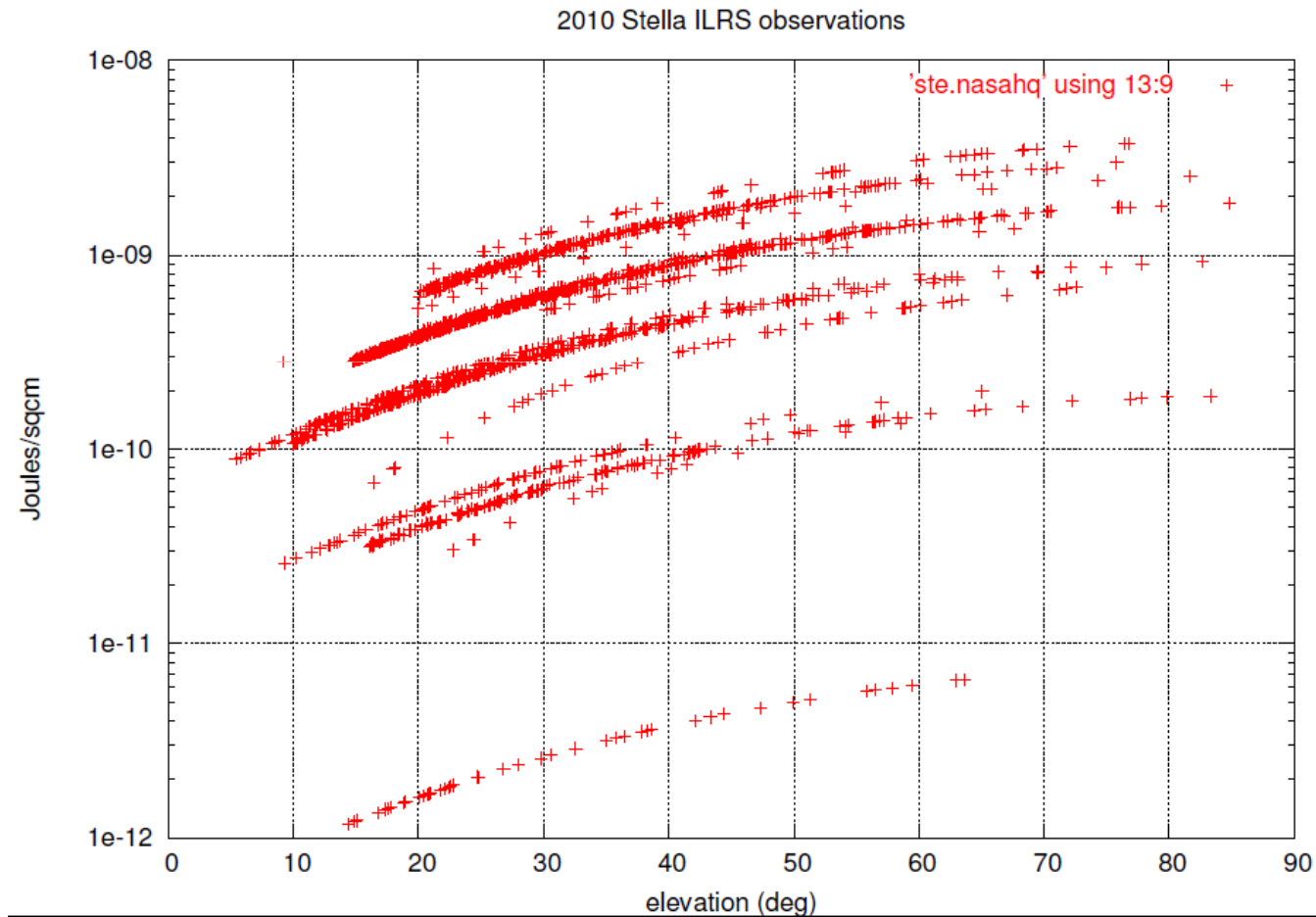
Blank Charts for operators

Arcsec, Degrees, microradians

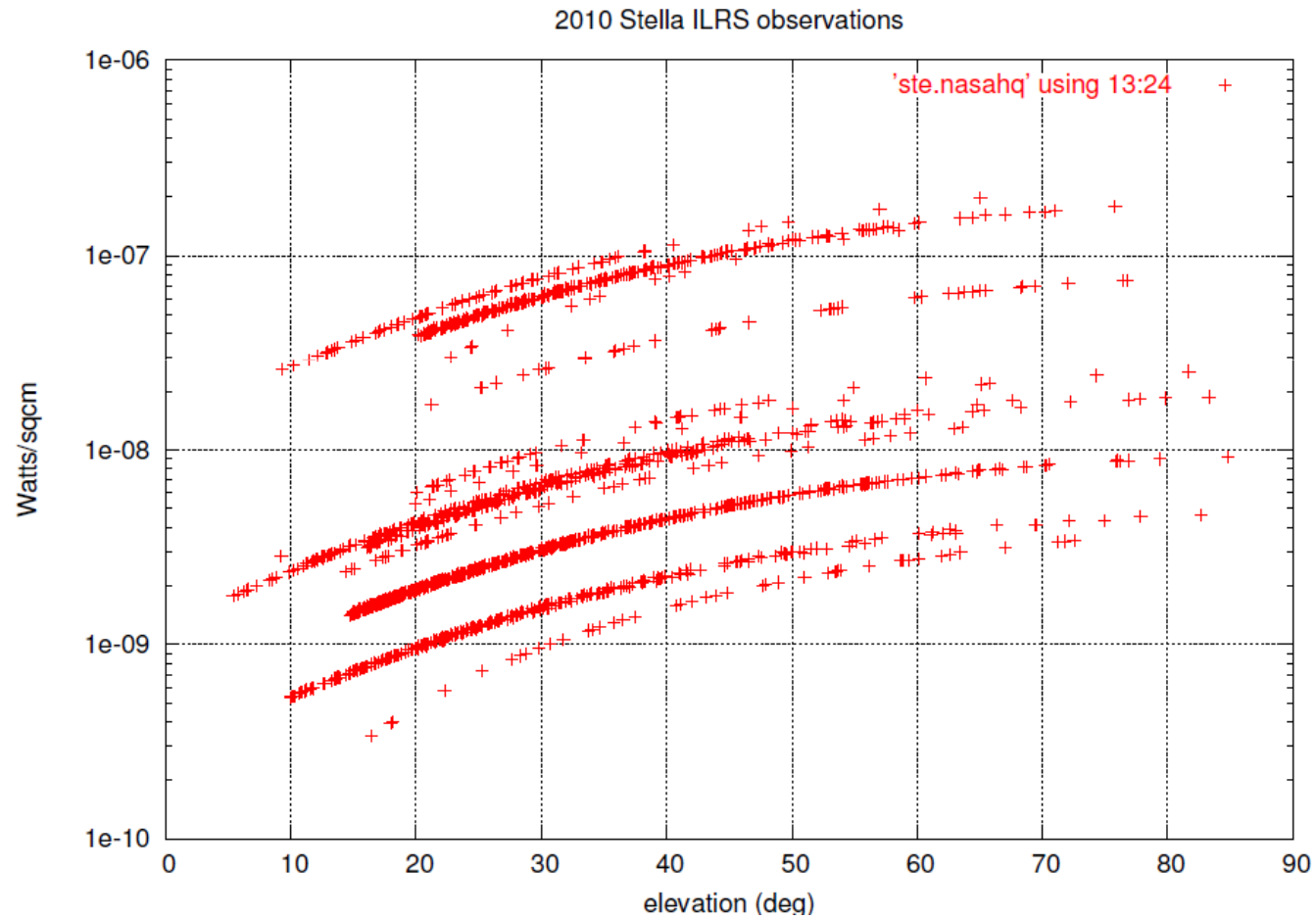
MicroRadians



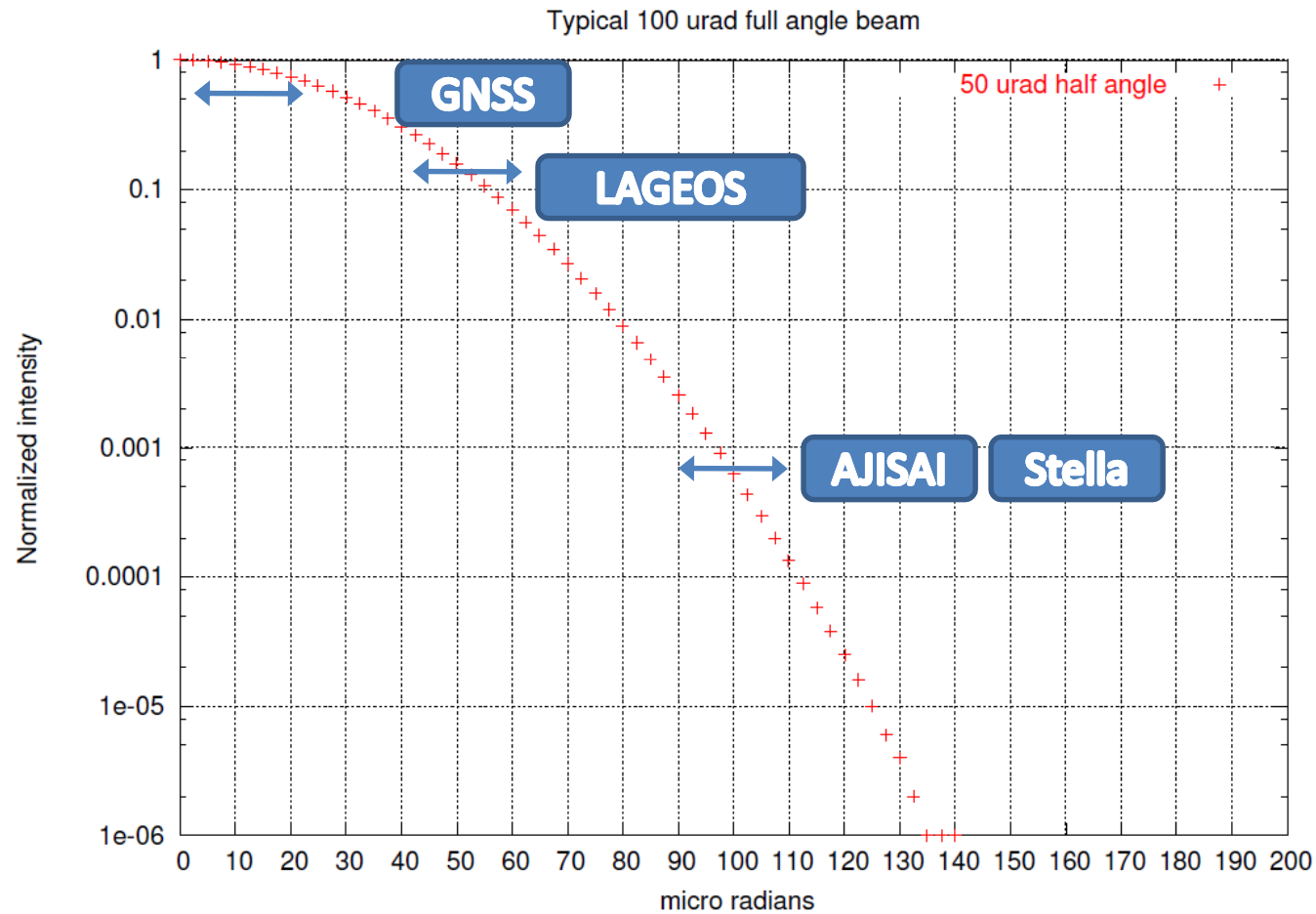
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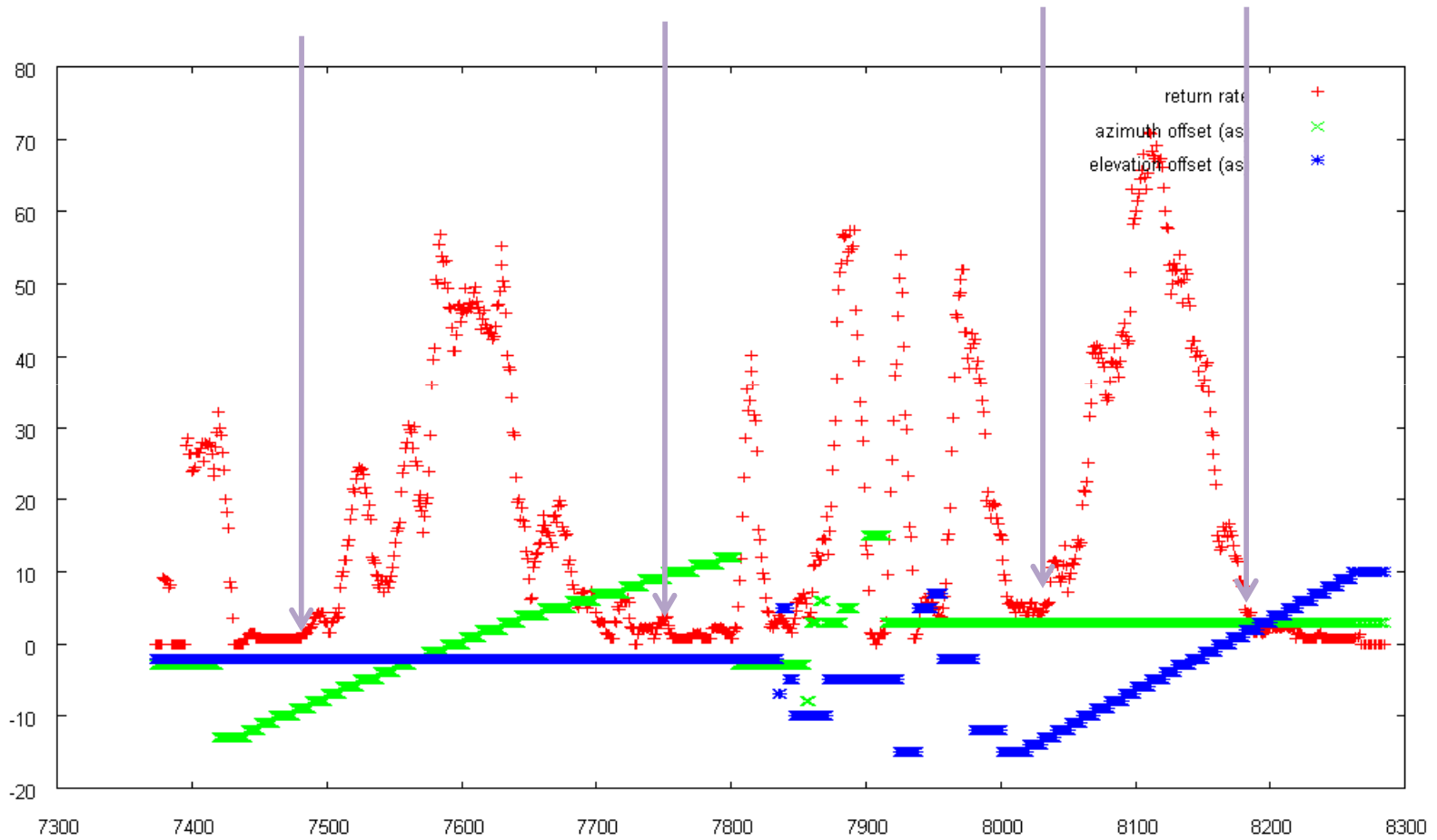
What to expect



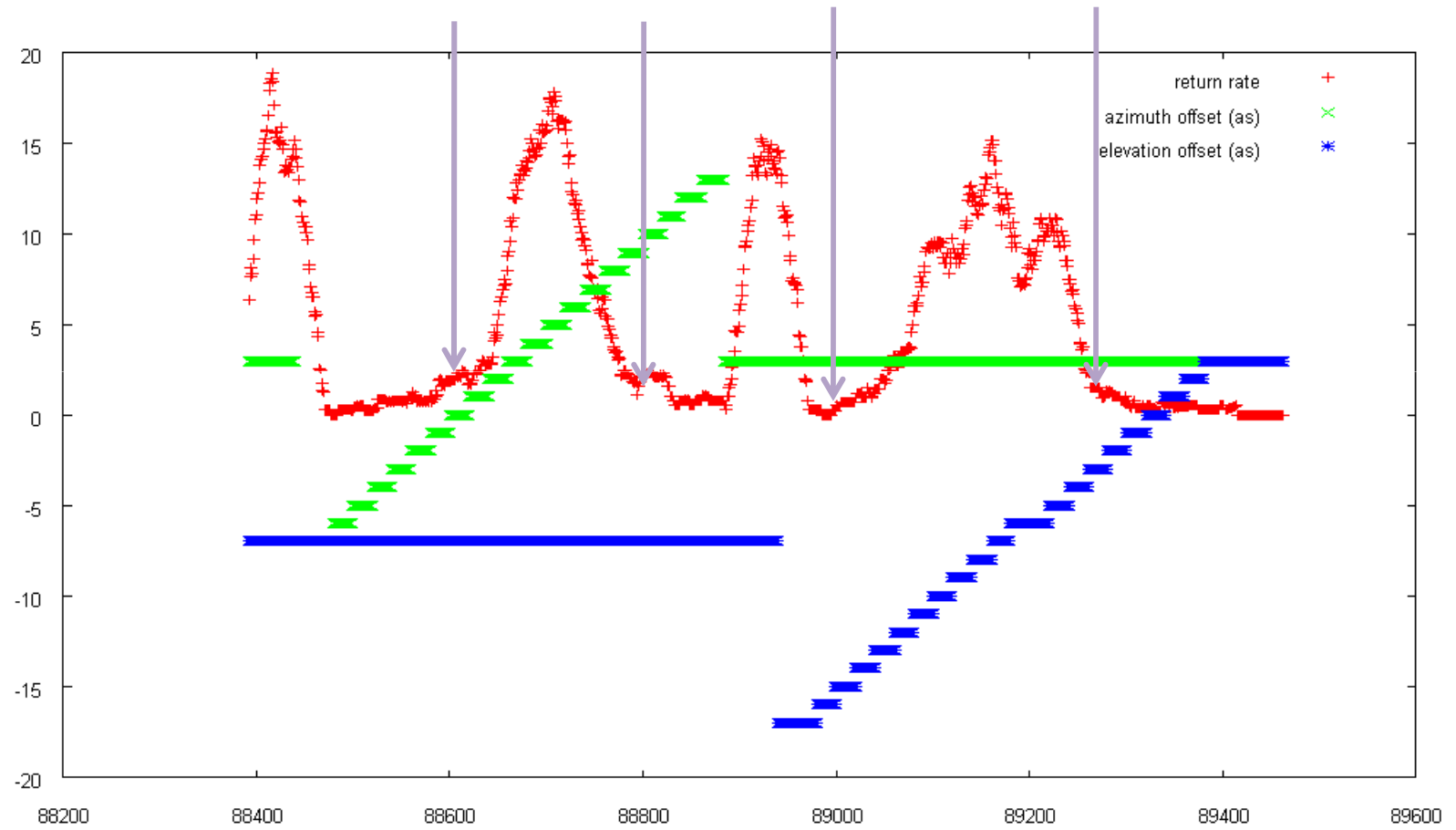
Beam will appear different by satellite / detector sensitivity

NERC beam profile datasets

Lageos2



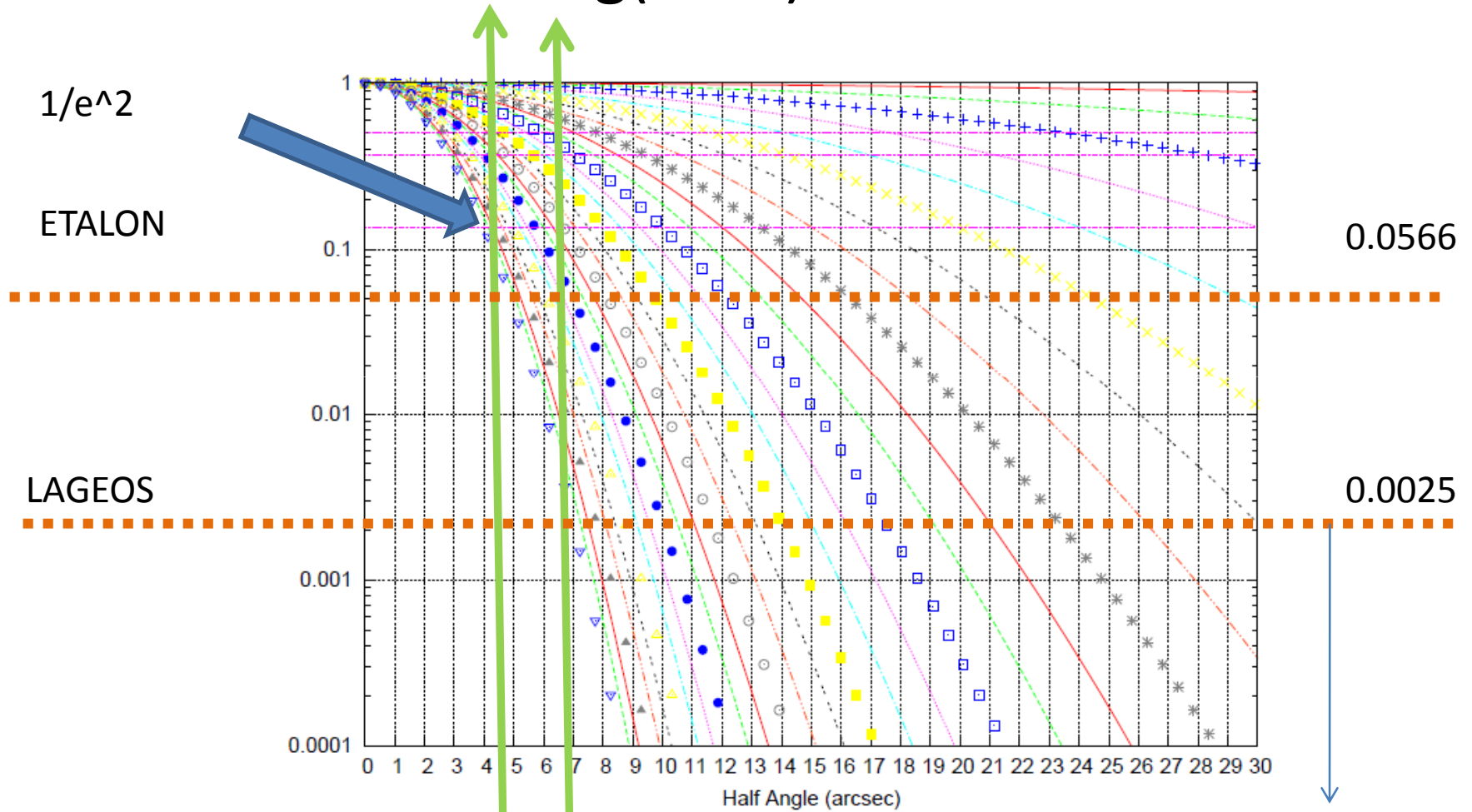
Etalon2



NERC measurements and interpretation

- Measurements at the 1.5 % return rate
 - Lageos2 13 as (full angle)
 - Etalon2 9 to 10 as (full angle)
 - Others –
 - Glonass 100 10 to 11 as
 - Glonass 123 15 to 20 as (did have lots of skewing on the centering and drift)
- From the link budget estimates
 - $\text{Log (Ratio of NPE from Etalon to Lageos) } \Rightarrow -1.3$
- Procedure
 - Draw the Green Lines at the measured half angles
 - Look for a curve that has intercepts at the green lines that has a drop of 1.3
 - Selected the “purple star” or the 9x magnification curve
 - Derive the $1/e^2$ to be 13.3 arcsec half angle

Grey Triangles = MAG=31 case
 $\log(\text{ratio}) \Rightarrow 1.3$



Inner most grey triangle is *30 beam expander magnification

Expect Ajisai to be 2.3 down from lageos line at 0.0000125
 At 10 arcsec half angle