

High Precision Photometry of Quasars using the Andor FI iXon

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Dr. Aidan O'Connor

Mr. Alan Giltinan

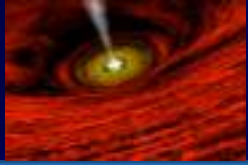
Mr. Stephen O'Driscoll

Cork Institute of Technology

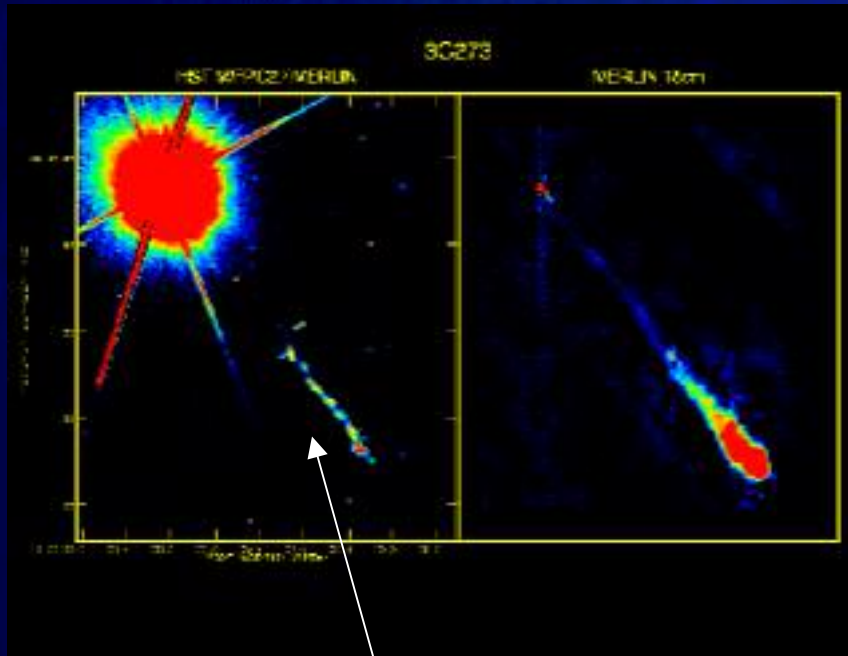
Prof. Stefan Wagner

Mr. Marcus Hauser

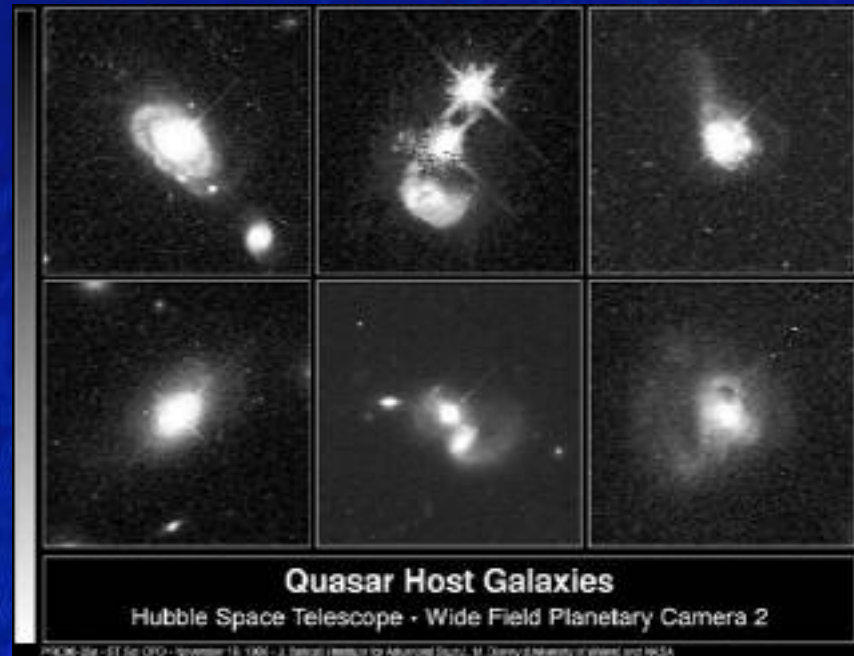
LSW, Heidelberg

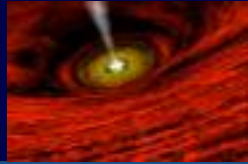


What are Quasars?



Optical Jet



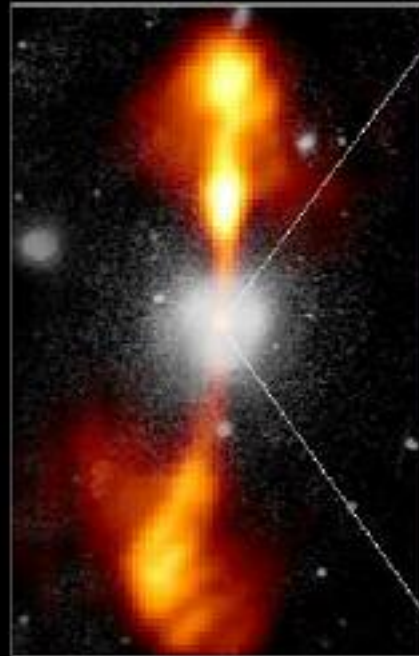


What if we zoom into the core?

Core of Galaxy NGC 4261

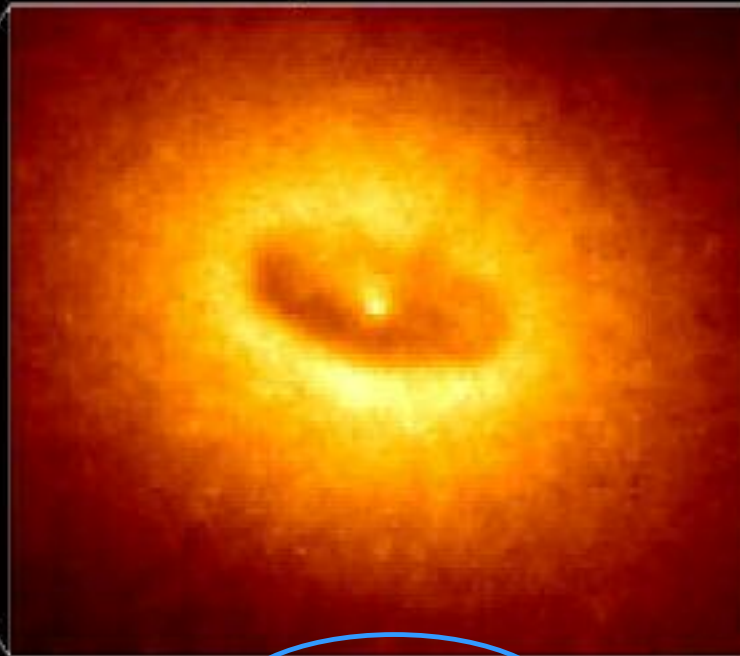
Hubble Space Telescope
Wide Field / Planetary Camera

Ground-Based Optical/Radio Image

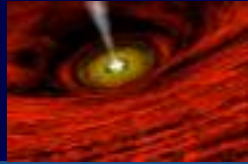


380 Arc Seconds
88,000 LIGHTYEARS

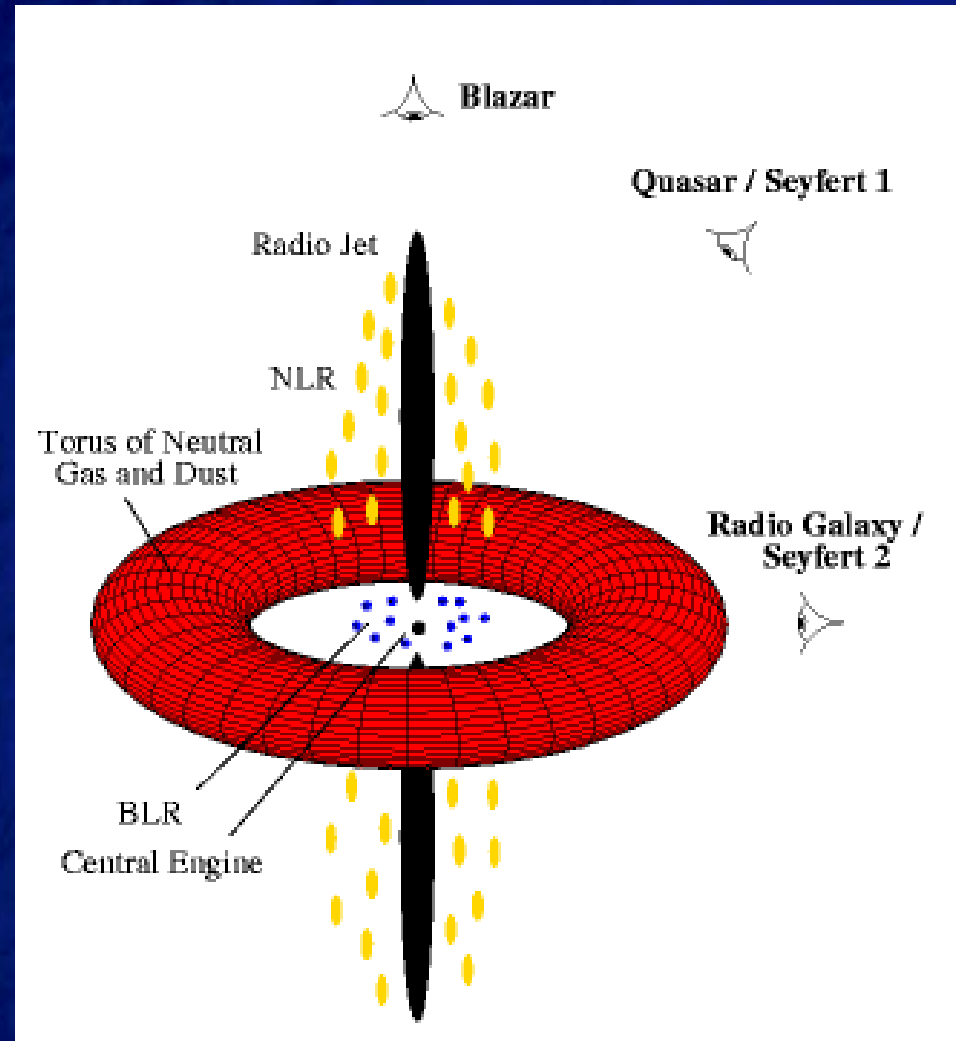
HST Image of a Gas and Dust Disk

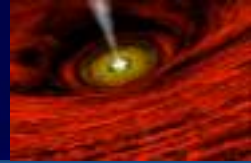


17 Arc Seconds
400 LIGHTYEARS



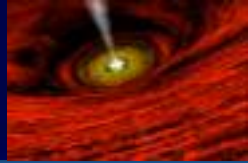
Standard Model for Quasars





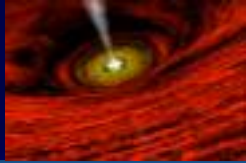
Optical Variability Characteristics

- Most quasars do not appear to have jets. They show only low amplitude optical variability on long timescales (days to years).
- Jets emitted by quasars which point directly at us give rise to the most rapidly variable objects and are called *blazars*.
- In both cases we need high precision, high **reliability photometry**.
- In the case of blazars we need effective time resolutions of minutes or better.

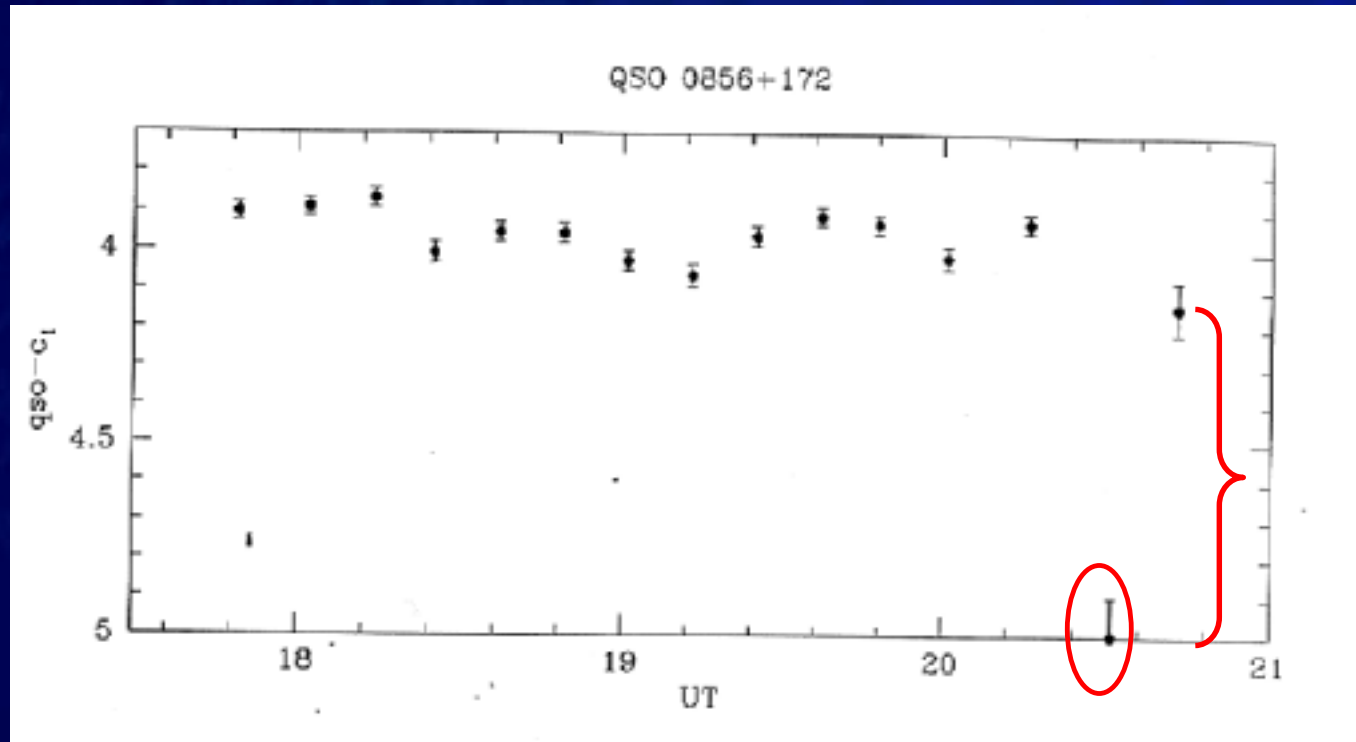


Why Optical Variability Studies?

- Data is most easily gathered at optical wavelengths
- High time resolution photometry is the ONLY way to search for small scale structures and provides orders-of-magnitude more resolution than even NGST
- Tantalising hints of rapid, small-amplitude events which formally breach General Relativity

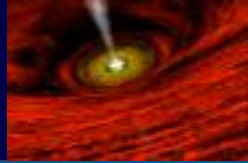


Real Events?



Anapuma
1998

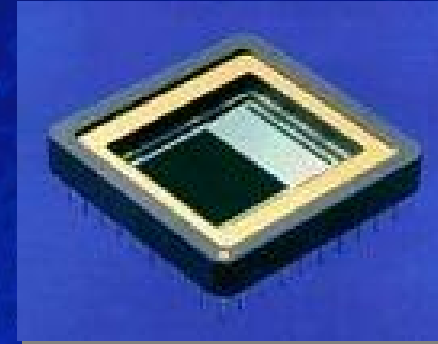
A change in brightness
equivalent to 250 Milky
Way galaxies!



L3 ENIGMA Campaign

DV887A (Andor Technology)

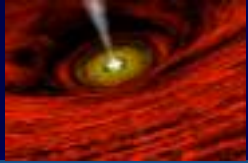
- 512x512 pixels, 16 μ m/pixel
- Well depth \sim 250,000 e⁻
- Readout noise 30 at G=1
<1 at G=200!
- 5MHz readout rate @ 14 bit resolution
- Single-stage thermoelectric cooling to -50 °C





L3 ENIGMA Campaign

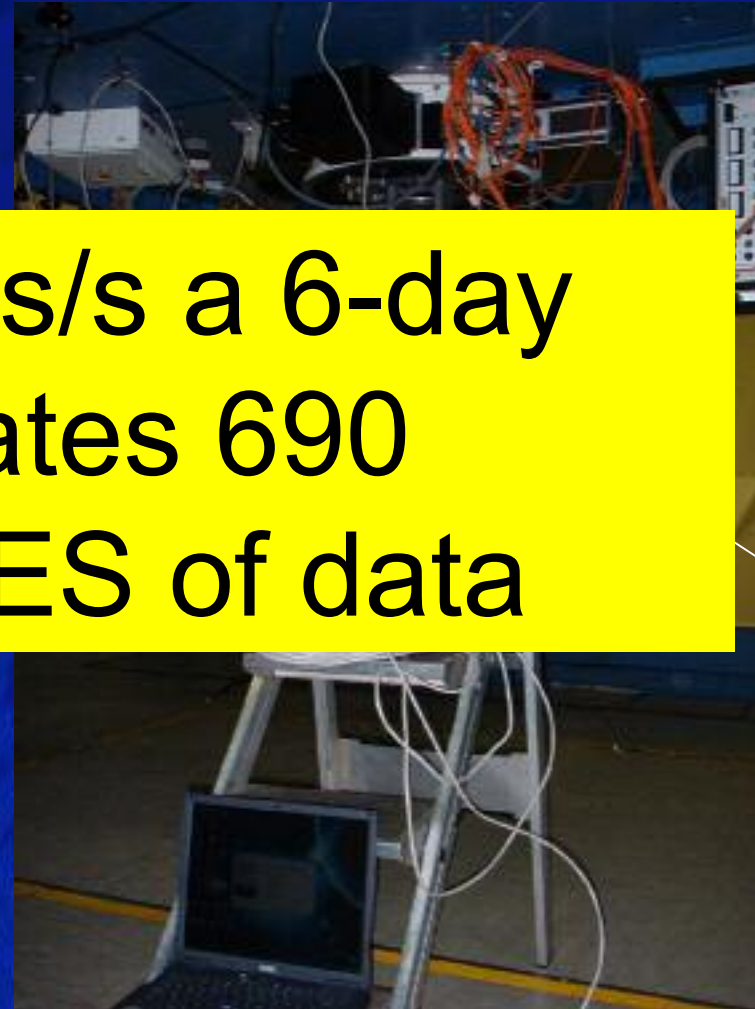




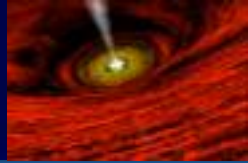
L3 ENIGMA Campaign

- 2.2m telescope at Calar Alto
- 7 nights (Jan/Feb 2002)
- Operated by US researchers
- Approximately 39,655 science frames on QSO 0716+74

At 4 frames/s a 6-day run generates 690 **GIGABYTES** of data

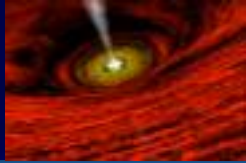


L3 (!)



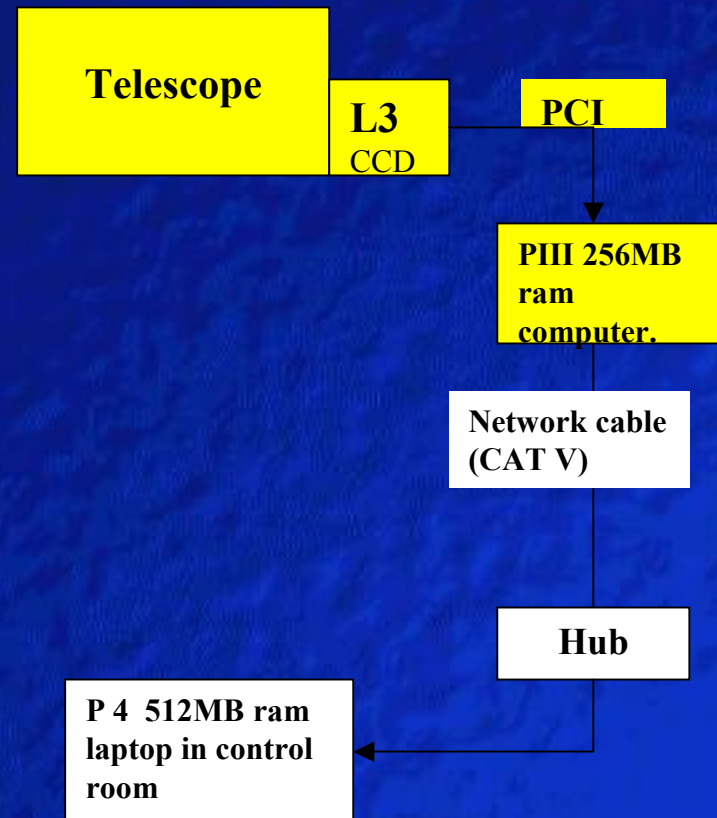
L3 ENIGMA Campaign

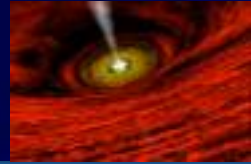
At 4 frames/s a 6-day
run generates 690
GIGABYTES of data



Schematic of Connections

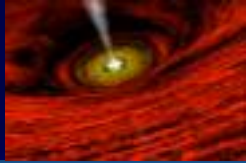
- Windows XP
- LabView drivers
- Full frame readout only
- Realtime aperture photometry





Not all fun and games





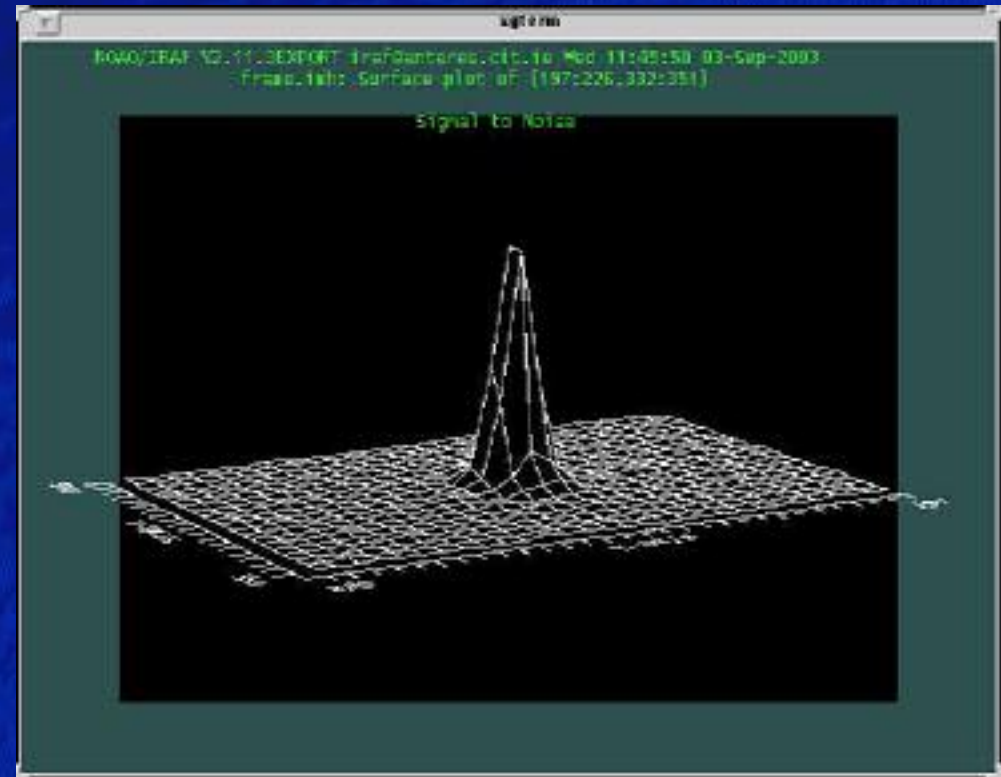
Field of QSO 0954+51

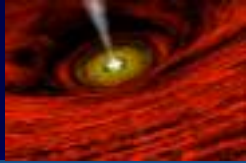


Gain = 200

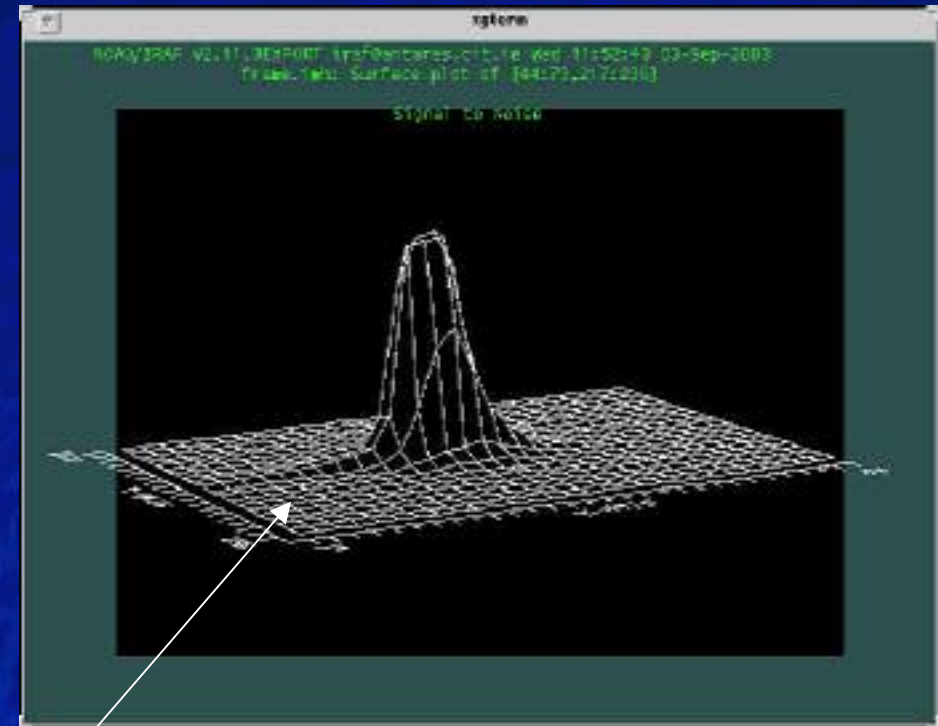
Exp. = 1.5s

Uncrowded fields





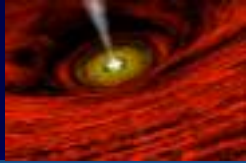
Field of QSO 0716+74



Gain = 200

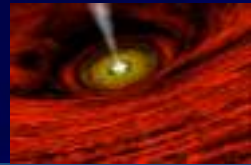
Exp. = 0.3 s

Saturation effects

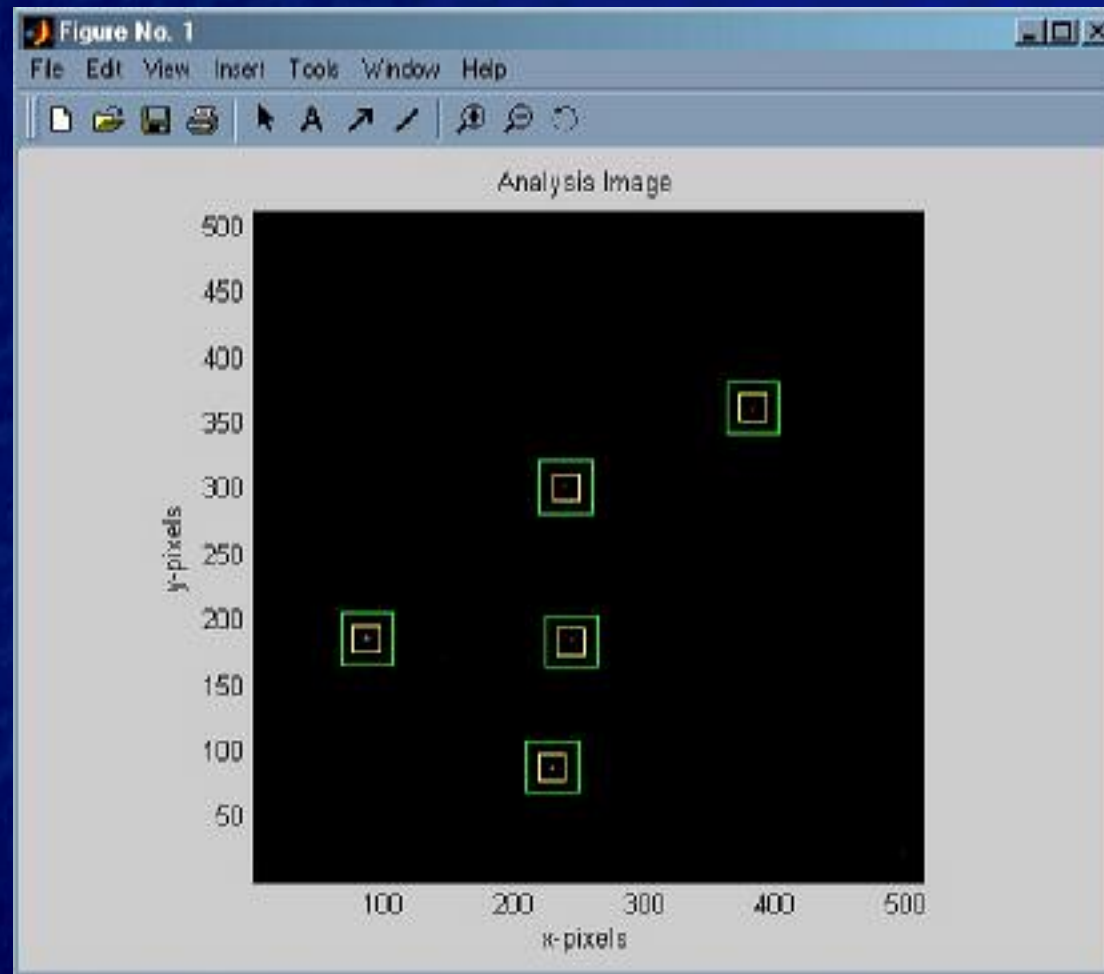


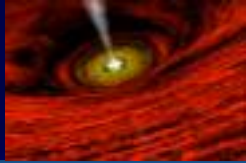
Aside Image Sharpening

- Distance to 0716+714 is unknown, despite ground-based spectroscopic observations and imaging with HST (too bright).
- Using frames with smallest FWHM we are constructing a deep image of the 0716+714 field to search for a possible host galaxy.
- Host galaxies of this type of quasar have reasonably defined parameters.



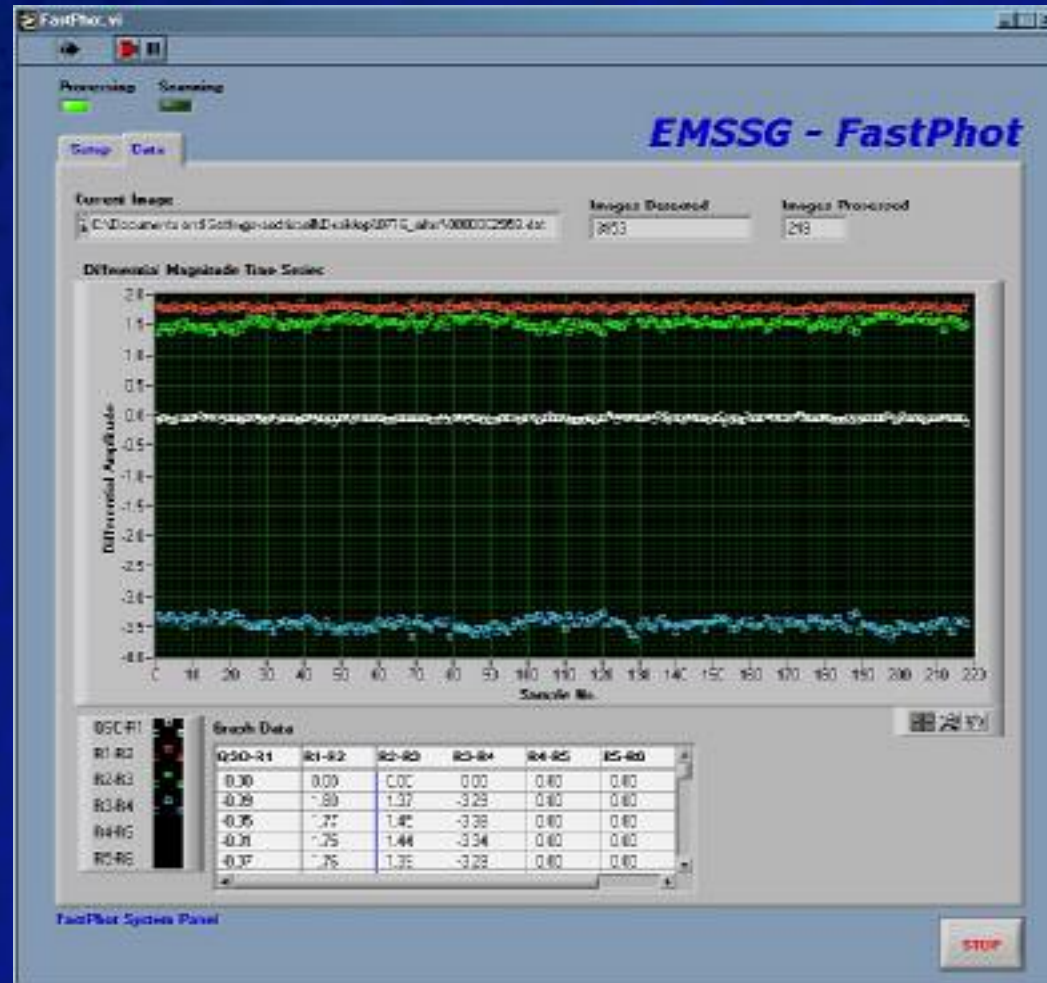
Quick-look Aperture Photometry

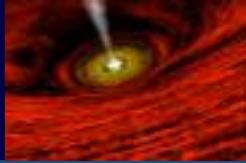




Differential Lightcurves

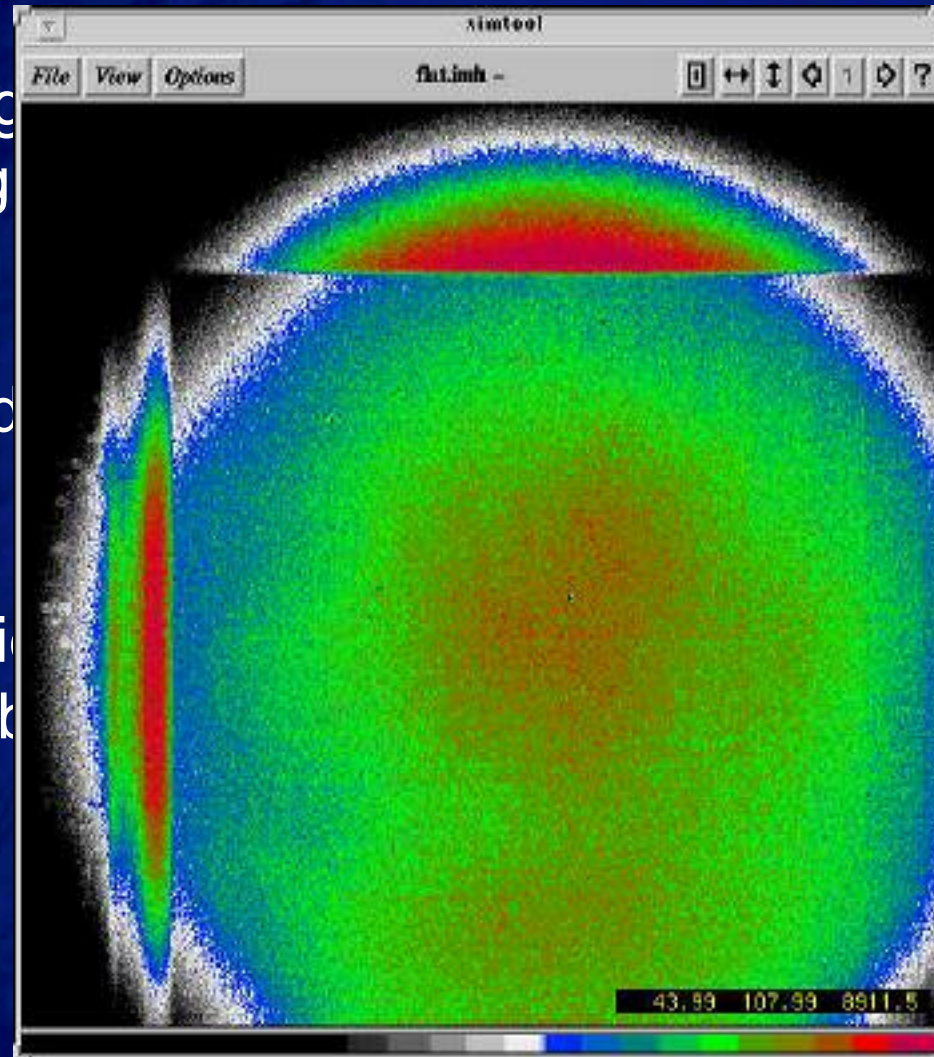
- Realtime photometry allows decisions to be made about the gross variability state of a quasar.





Calibration Data

- For each g image
- Generated
- Need sufficient zero

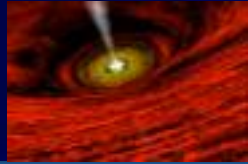


ook flatfield

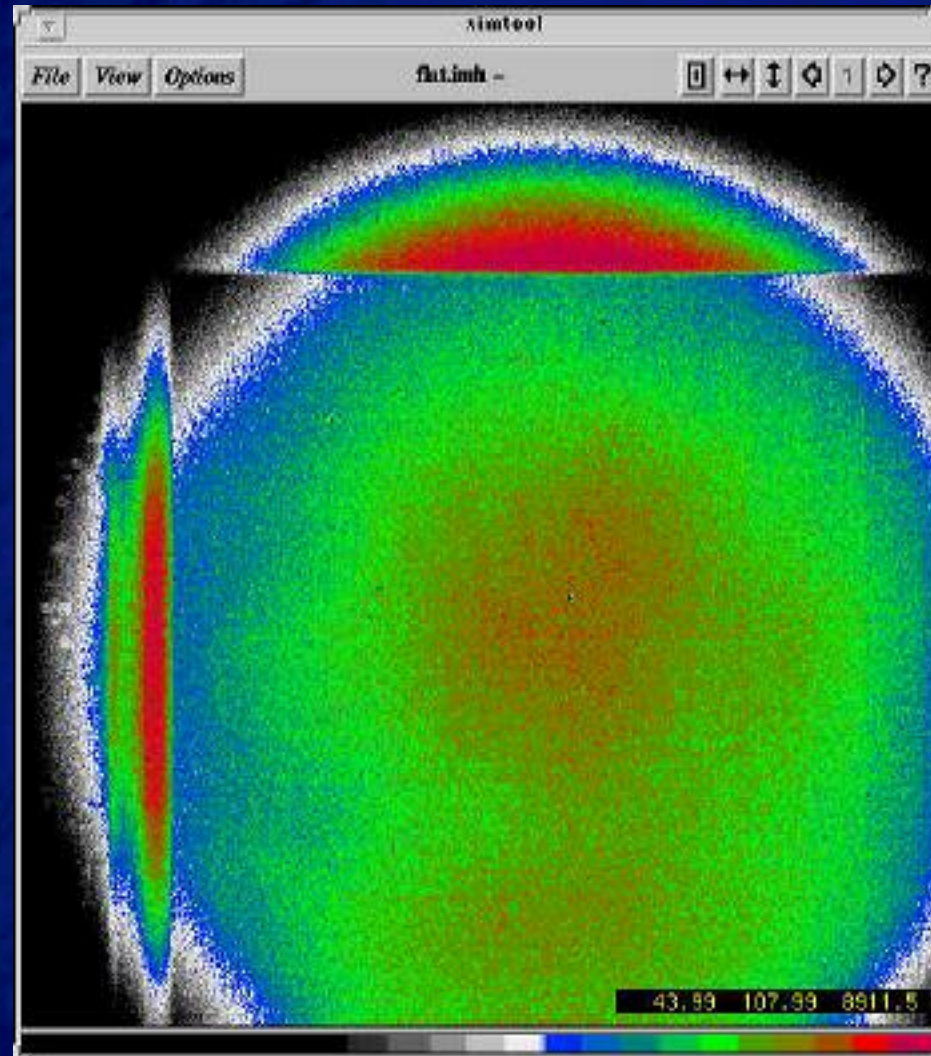
om these.

he flatfield and

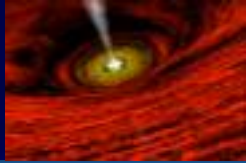
Using the
LSW Focal
Reducer



Calibration Data

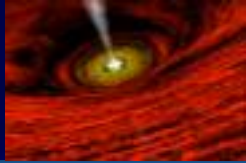


Using the
LSW Focal
Reducer



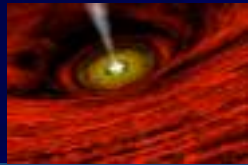
Data Reduction

- Automated IRAF *apphot* routines
 - Applies flatfield and zero-bias correction.
 - Identify objects in the field.
 - Record the integrated flux in apertures of increasing radius.
 - Flag objects with counts in the non-linear response region of the L3.

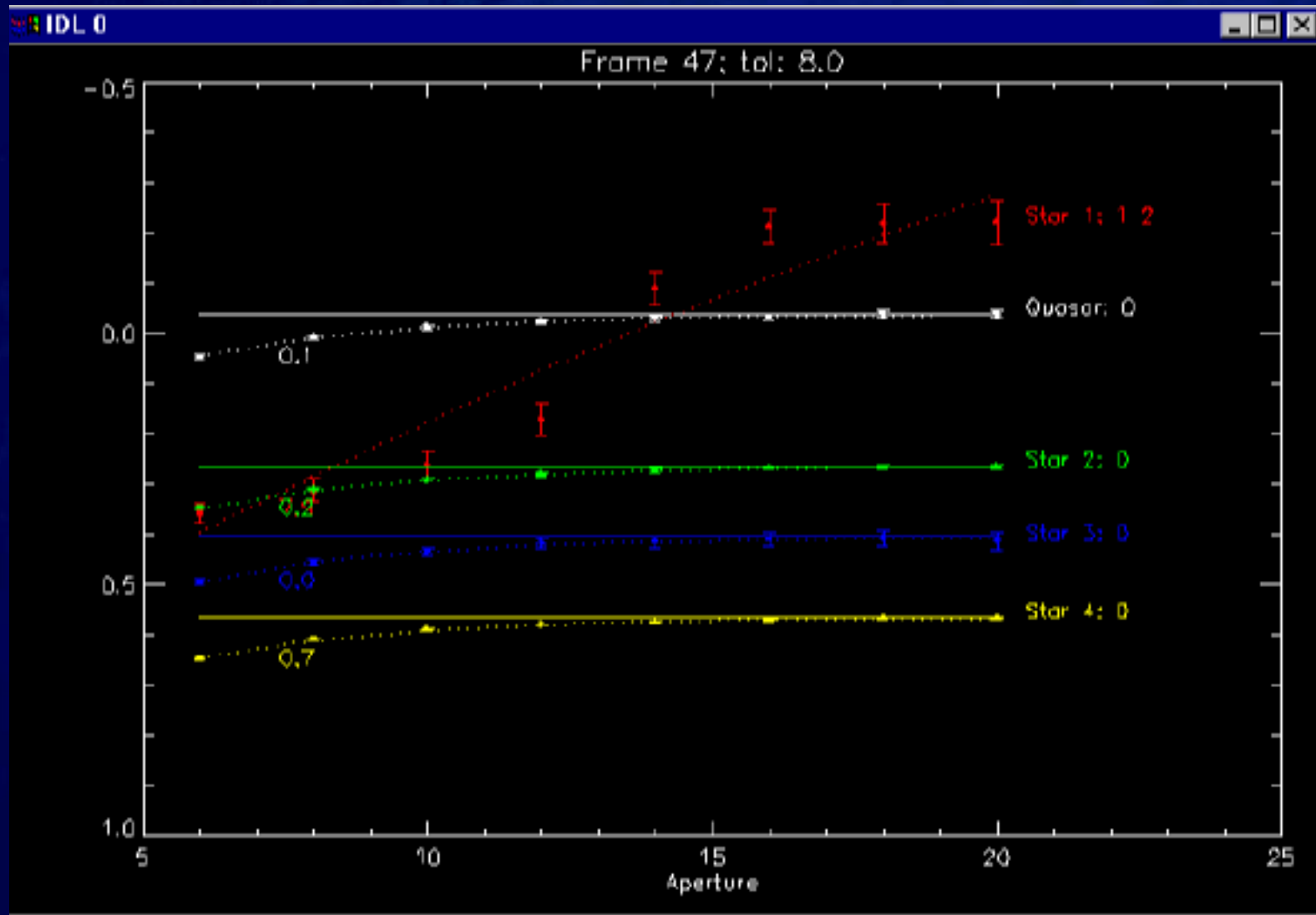


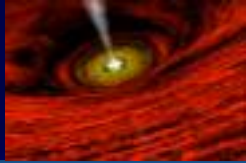
Generation of Lightcurves

- Output is piped to IDL program “qvar”
 - performs differential photometry using a master reference star (composed of 4-8 stars typically)
 - provides statistical tests of variability
 - allows different background determination methods to be used
 - tracks variations in fwhm, position, apparent magnitude, airmass
 - allows rejection of variable stars or data points affected by cosmic rays



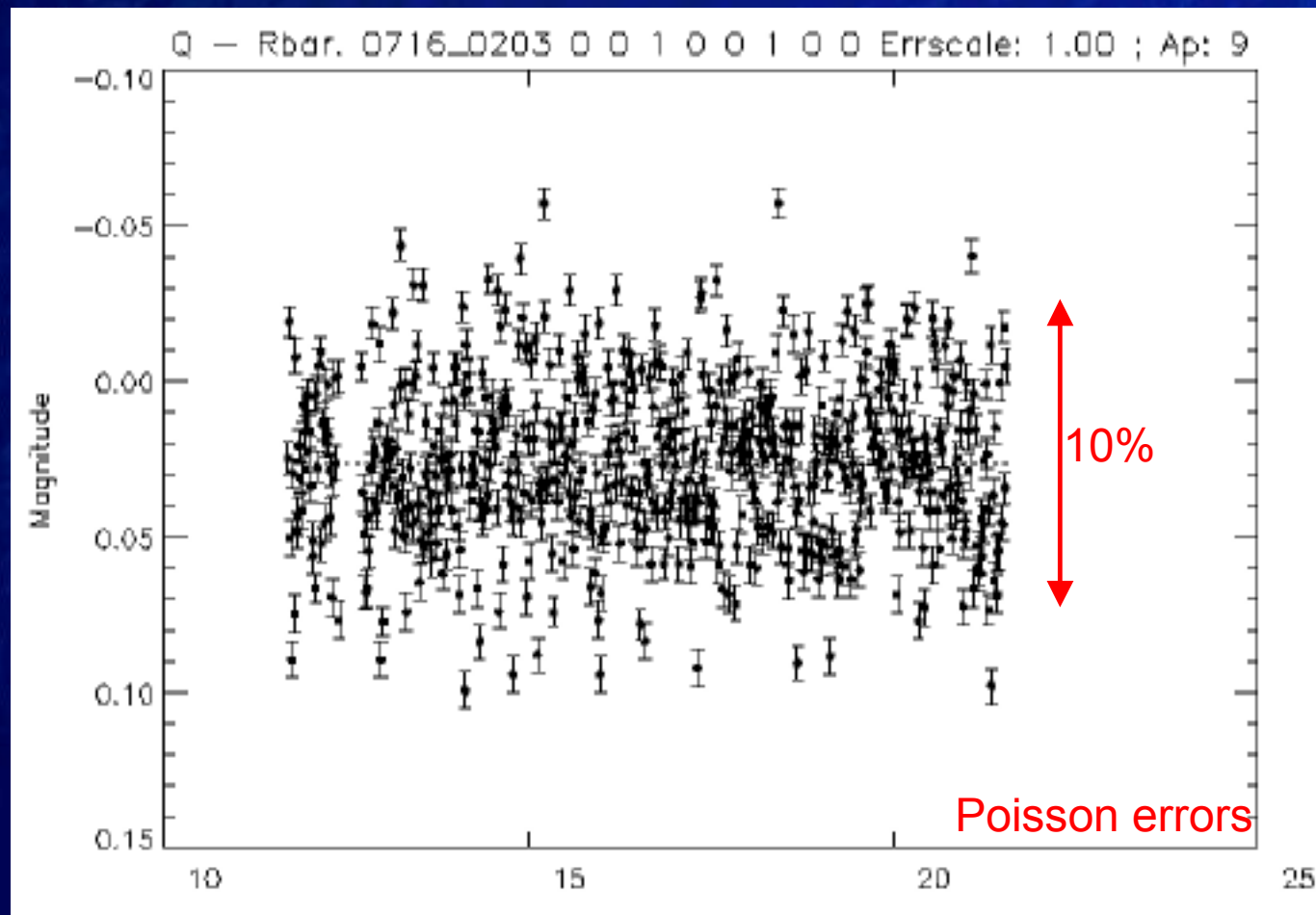
Growth Curves

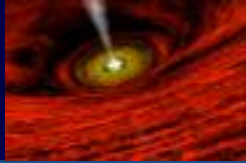




Subsample of Results

Differential Lightcurve of 0716+714 over 10 minutes

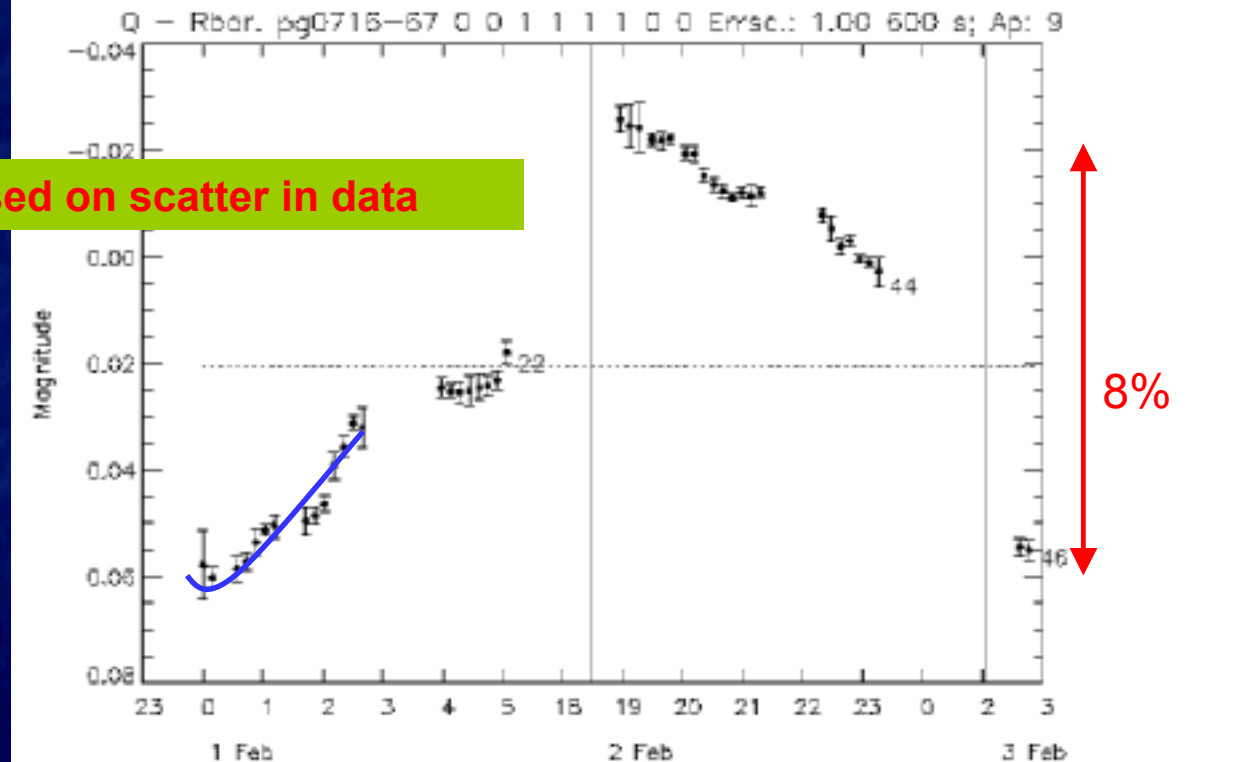


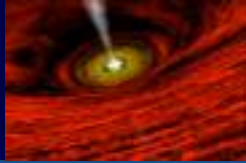


Subsample of Results

26,493 frames of 0716+714

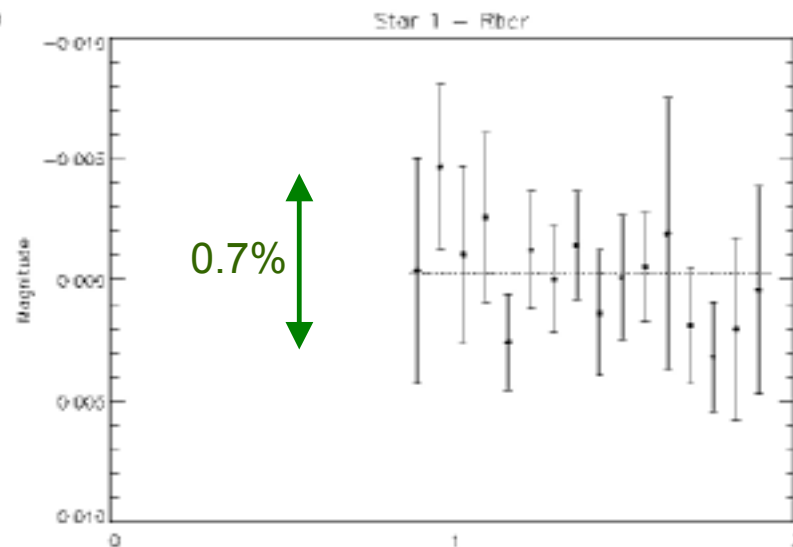
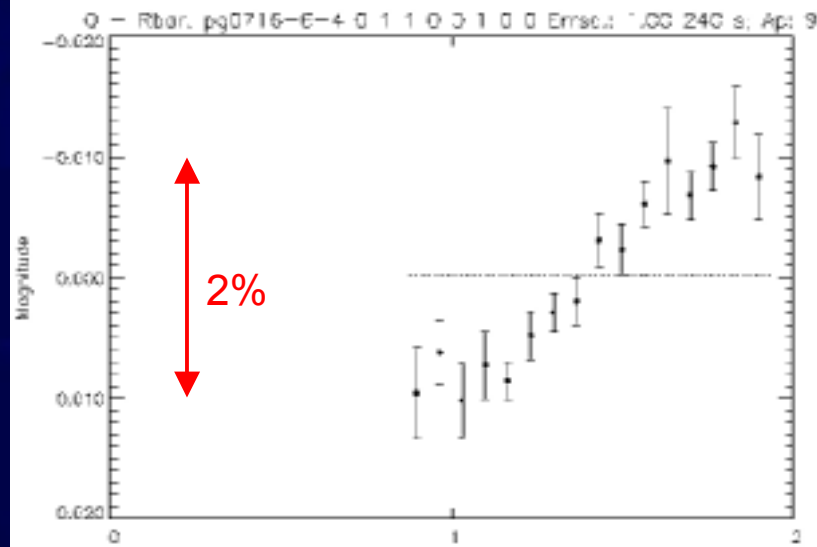
Errors based on scatter in data



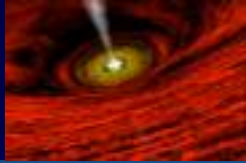


Subsample of Results

Stability of Reference Stars

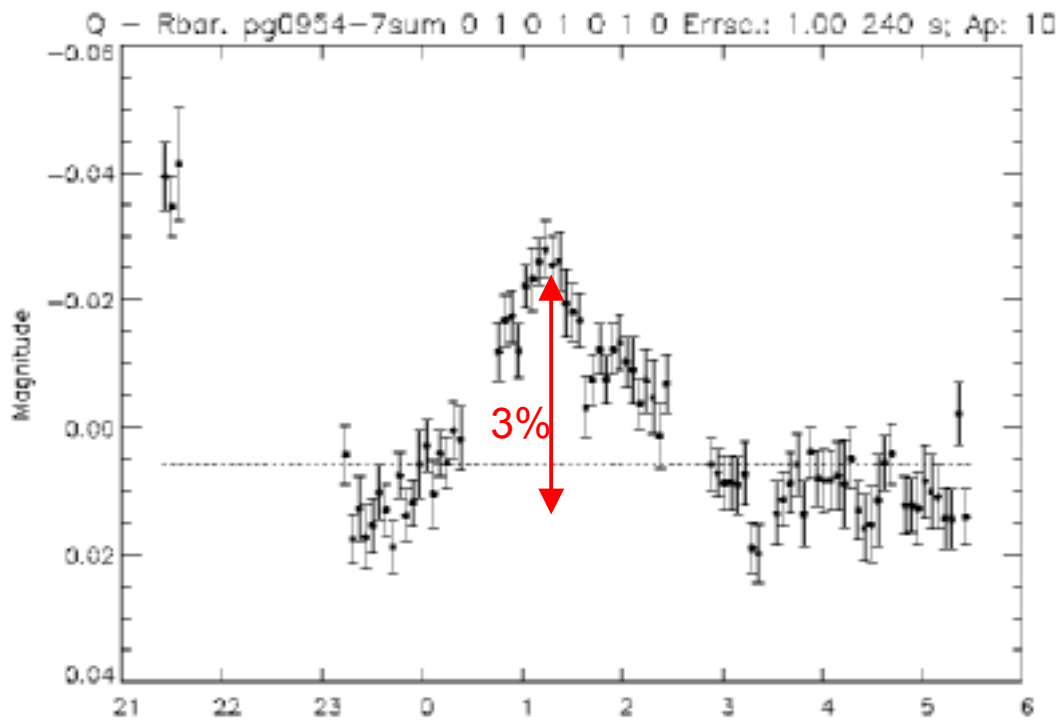


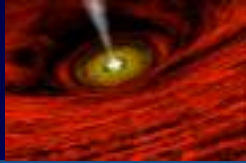
Scatter = 1.7mmag



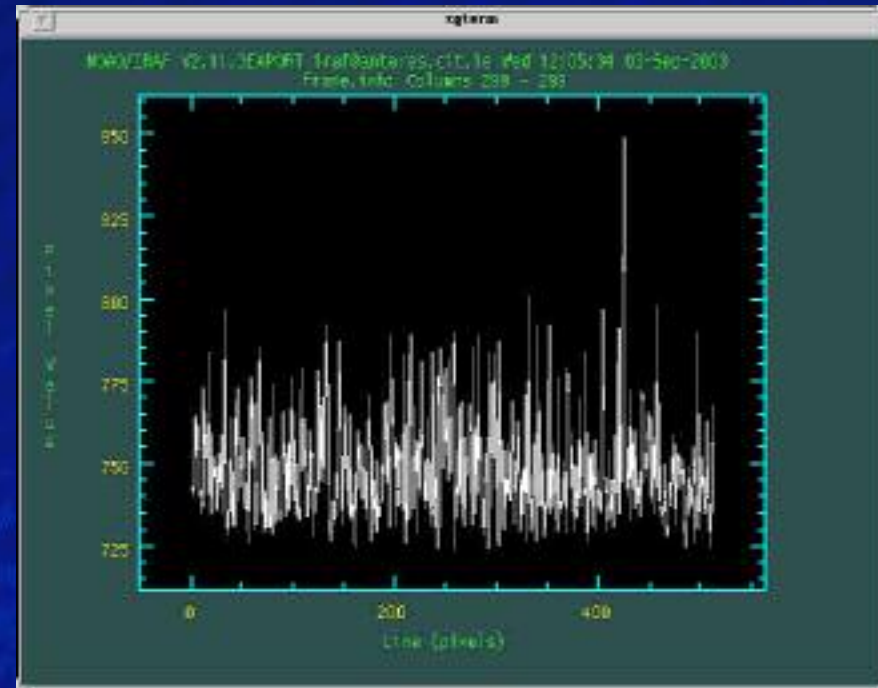
Subsample of Results

Mini-flare in QSO 0954+51





CIC

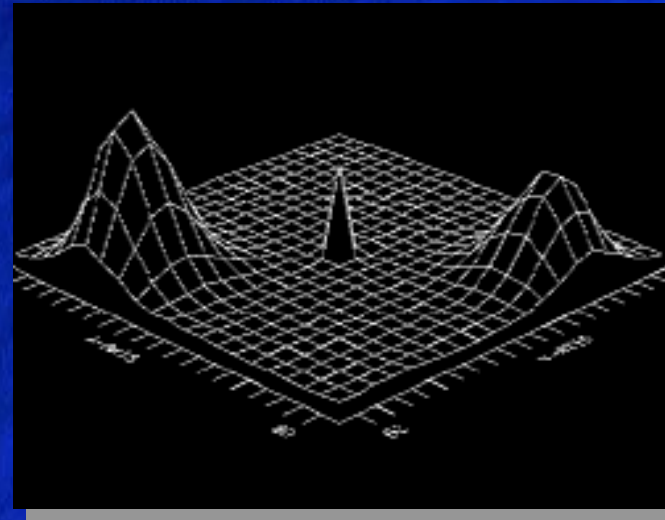
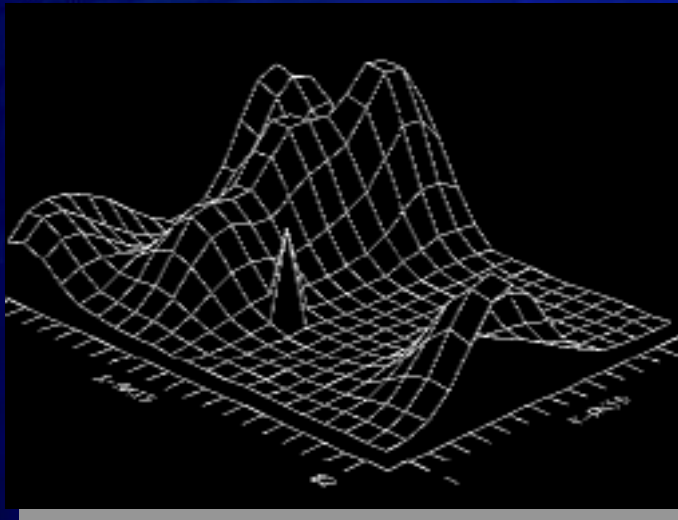


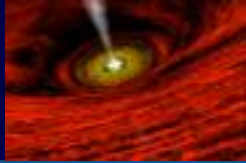
How is the photometry affected by CIC?



Rejection of CIC?

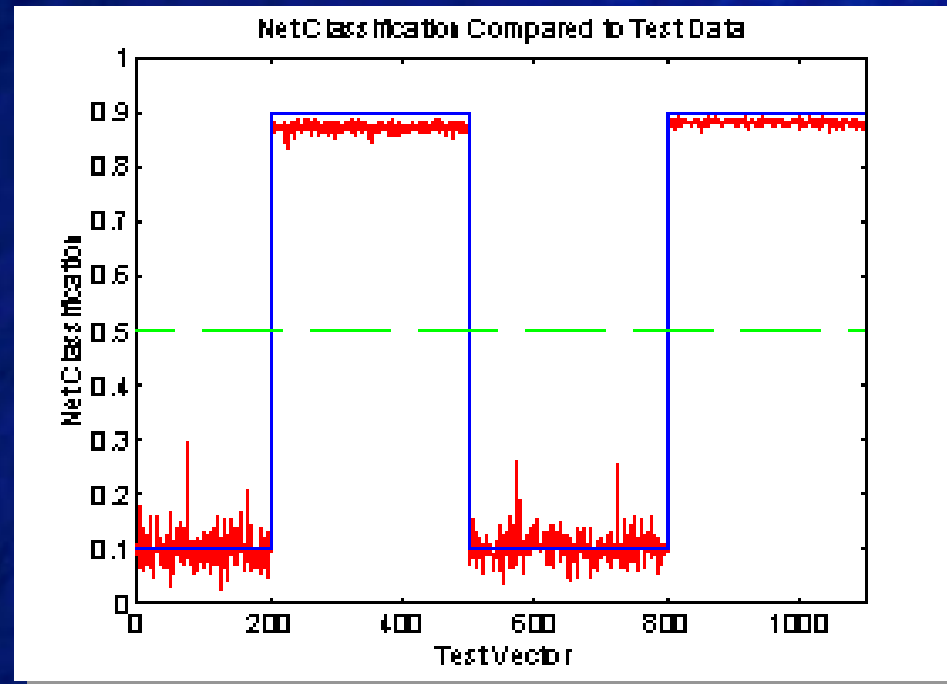
- In our application we trained a simulated artificial neural network to classify detected objects in an image as either stars or noise artifacts (cosmic rays).
- A training set consisting of 1000 image sections classified by human experts was used.

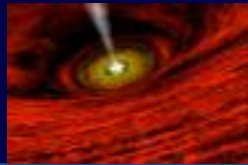




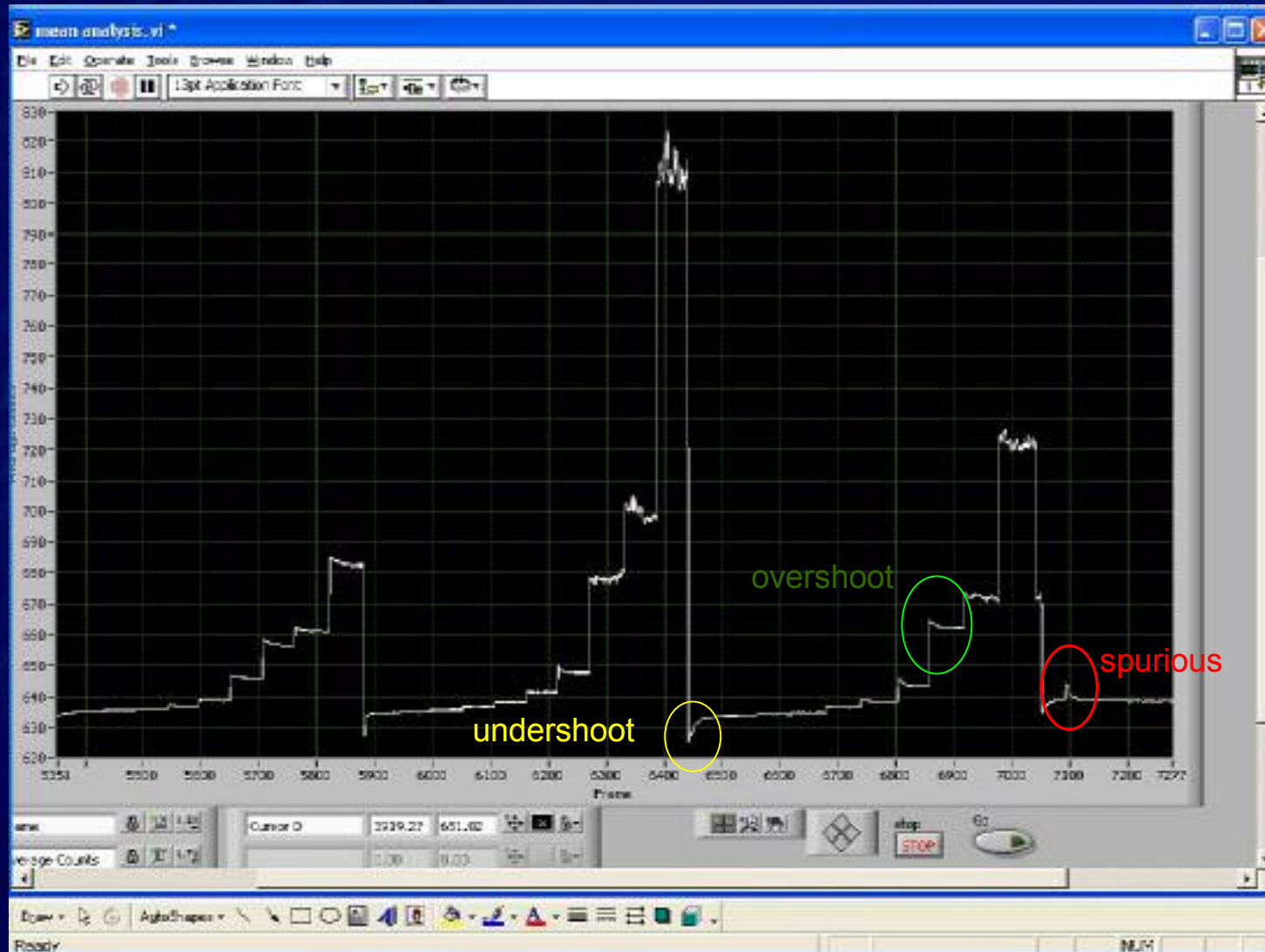
Neural Networks Might Work

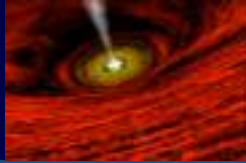
- Experimental results show that the neural network was very successful at this classification task.





Gain Changes





Conclusions

- Preliminary results suggest L3 has good prospects for use in high precision photometry
- Did not achieve photon-limited photometry from individual frames
- Potential to generate enormous quantities of data very quickly
- Multiple windowing
- Accurate timing