FORCAST Commissioning and Upgrade Status

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Detector Upgrade

Some background…

- There was interest in upgrading the arrays in FORCAST (starting with the LWC)
- The main concern with the original arrays was that the dark current was high (1e7 e-/s!)
- This would potentially push the spectroscopic modes out of being background-limited
- We contracted DRS Tech (only company available) to create new arrays (best effort basis)
- A new array (Si:Sb, LWC) was delivered mid-2012 and testing began in the lab at Cornell

New Detector Tests Results

- After much fiddling, it was determined that the new array would not be a viable replacement for the present LWC array
- Of the many reasons some are:
  - Dark current was still high
  - Cosmetically there were too many dead and hot pixels
  - The switchable well depths were not useful for FORCAST
  - No gain in sensitivity
- Based on these results, it was decided that we would stick with the original arrays

Grism Mode Upgrade

There has been an ongoing effort to develop grisms for use in FORCAST

About two years ago it was decided to officially pursue the addition of the grisms as a fully supported facility mode

Long slit R~100 grism suite was developed:

- "G1": 5-8um coverage
- "G3": 8-13um coverage
- "G5": 17-29um coverage
- "G6": 28-37um coverage

As well as a cross-dispersed R~1000 grisms:

- "G2xG1": 5-8um coverage
- "G4xG3": 8-13um coverage

The G4 grism problem

- The G3 and G4 grisms are made from KRS-5 material
- After multiple cryo-cycles without issue, suddenly the G4 grism clouded, affecting performance
- It was determined that the cause of the issue may have been thermally induced stress on the grism by the grism mount
- The grism mounts have been re-designed, analysis of the stresses have been independently measured by a group at Lockheed and found to be adequate
- A new G4 grism was ordered and has already been delivered
- As of yesterday, the new G4 grism is now in FORCAST and ready to undergo lab testing

Phase 1 Commissioning

FORCAST commissioning is split into two phases:

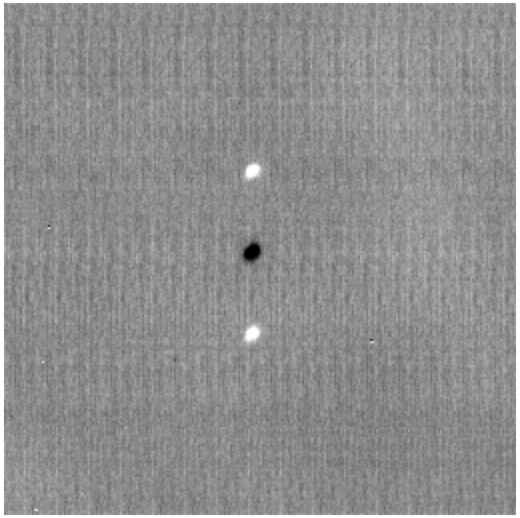
- Phase 1:
  - Lyot stop tests for optimal S/N (these stops must be removed and the filters to be used for Cycle 1 observing installed)
  - Basic grism checkout
- Phase 2:
  - Tests are mostly concerned with optimizing FORCAST performance in-flight
- Phase 1 concluded the end of the first week of April
- We were able to get all of our Lyot stop tests done, and due to a relatively stable MCCS build, we had a significant amount of time to perform other commissioning tests.
- The MCCS build on these flight was rev37, and these were the first flight with this build. As a result, some of the tests we performed not only yielded information on the performance of FORCAST, but also yielded information on the performance of the telescope under this new rev37.

FORCAST’s First Grism Observations

- We gathered spectra of a bright stars in all grism available grism modes in Phase 1
  - Excludes the G4xG3 cross dispersed mode

Wide Slit Spectrum (G5 Grism: 17-28um)

Alpha Boo



Source on field at wide slit boresight
File 171 (swc, 19.7um)

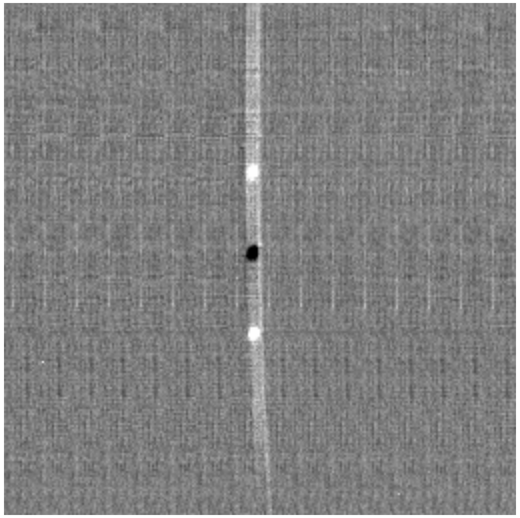
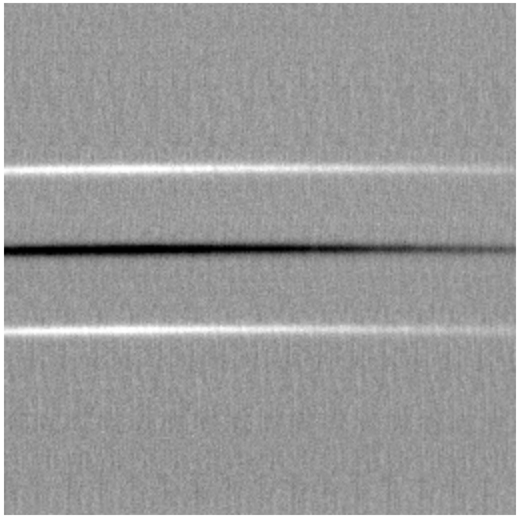


Image of source through slit
File 172 (swc, 19.7um)

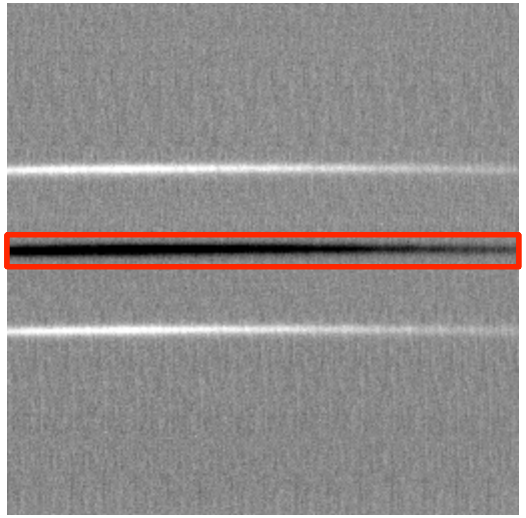


Spectrum of source
File 174 (lwc, G5)

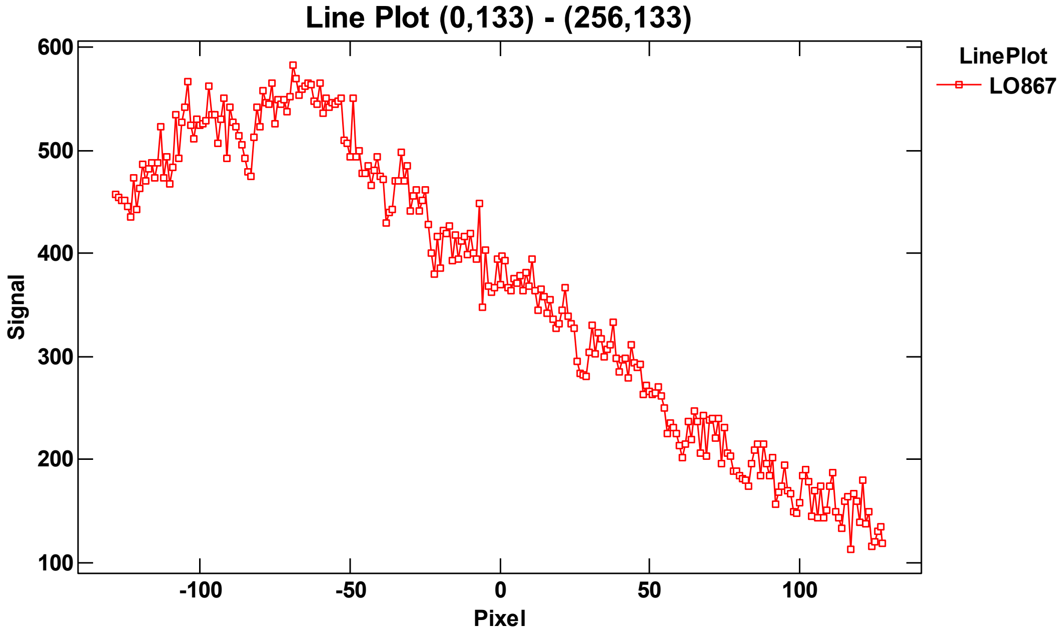
- Alpha Boo was imaged first to make sure it was at the proper boresight (left).
- Then the slit was put into the optical path and the source was image through the slit (center). This reconfirmed that the source indeed was properly centered in the slit.
- Then the grism was placed into the optical path and the resultant spectrum can be seen on the right. This is the first G5 spectrum ever taken by FORCAST

Wide Slit Spectrum (G5 Grism: 17-28um)

Alpha Boo

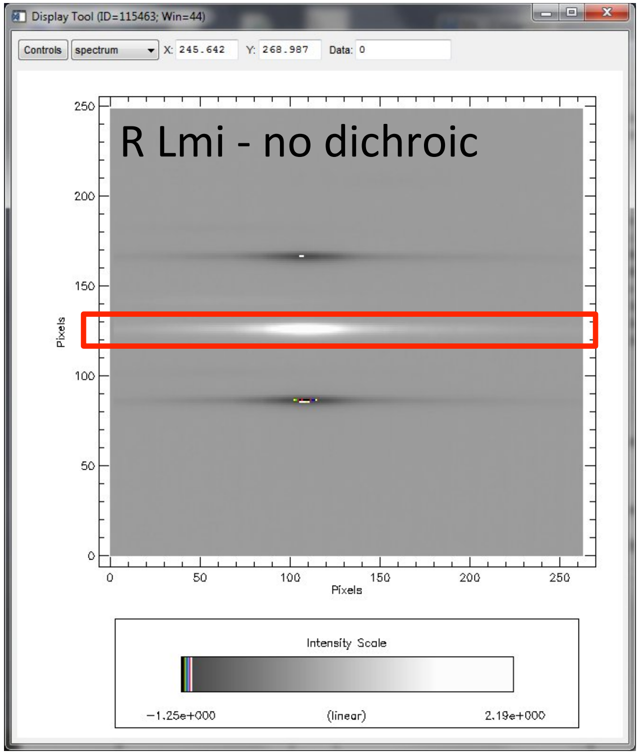


File 177 (lwc)



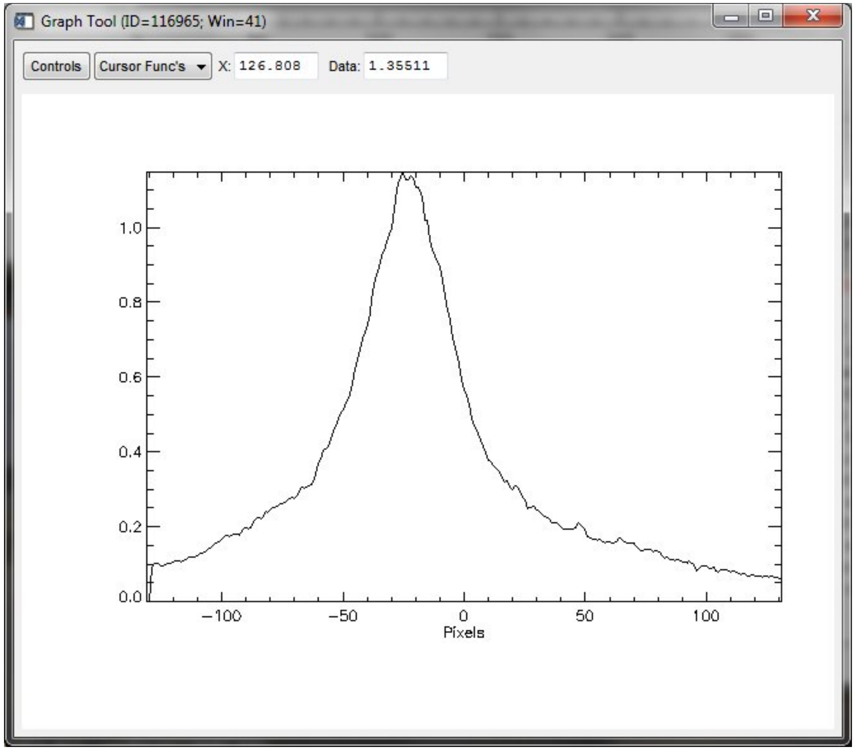
- A simple line cut was made through the data (left)
- The plot on the right shows the crude spectrum of the source (with no flux calibration (y-axis), no wavelength solution (x-axis)).

Wide Slit Spectrum (G6 Grism: 28-37um)


Display Tool (ID=115463; Win=44)

X: 245.642 Y: 268.987 Data: 0

R Lmi - no dichroic

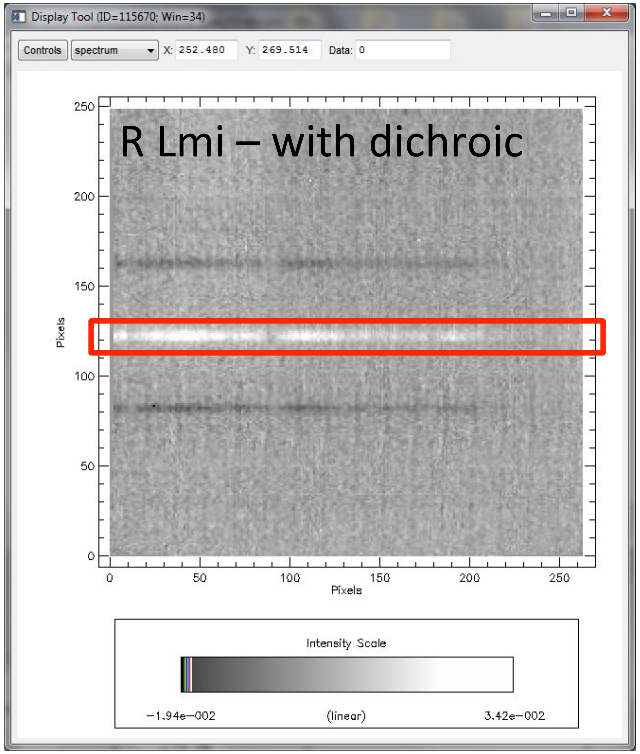

Graph Tool (ID=116965; Win=41)

X: 126.808 Data: 1.35511

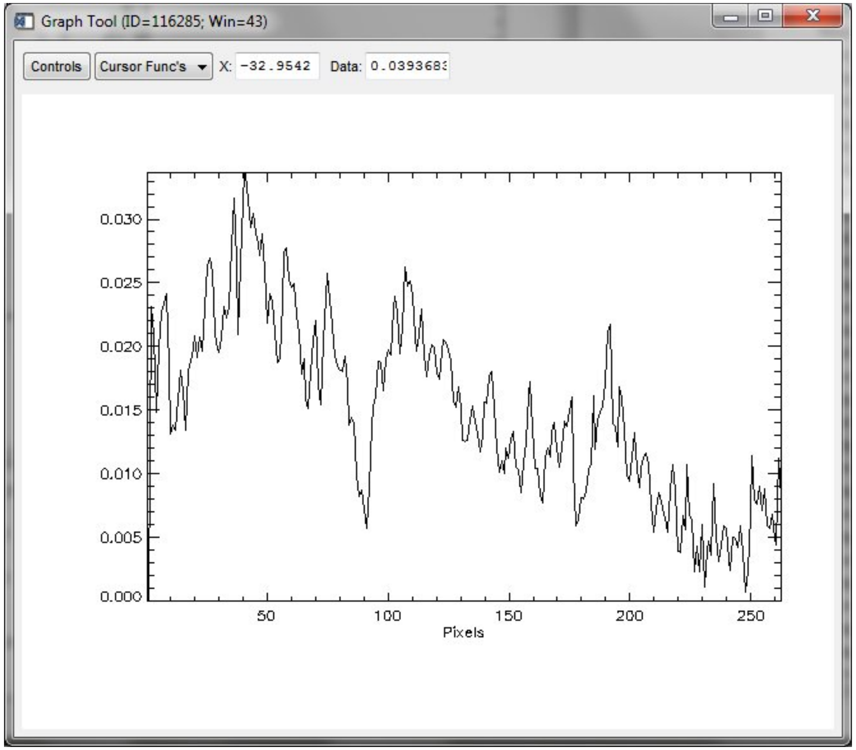
File 382 (lwc)

- The G5 grism was moved out of the optical path and the G6 was then inserted. On the left is the resultant G6 spectral image, and on the right is another line plot to crudely show the spectrum.
- As can be seen in the data, there is a strange behavior in the G6 grism, with a very bright lenticular structure with a peak around 34um. This is not a real spectral feature of the astronomical target.

Wide Slit Spectrum (G6 Grism: 28-37um)


Display Tool (ID=115670; Win=34)

X: 252.480 Y: 269.514 Data: 0

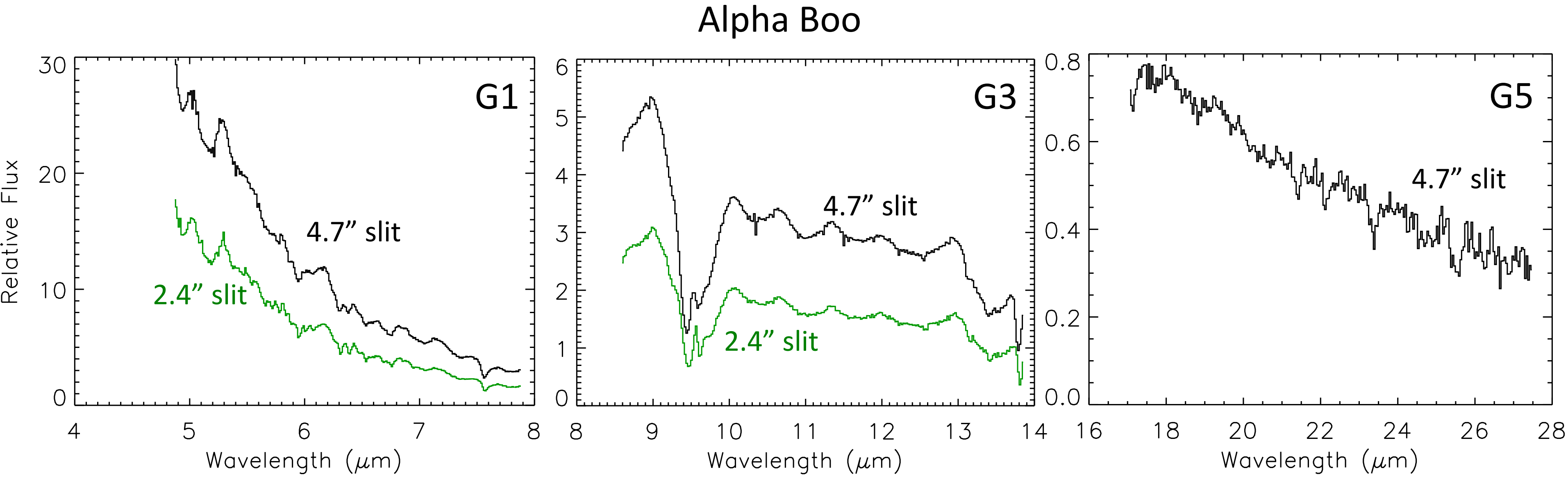

Graph Tool (ID=116285; Win=43)

X: −32.9542 Data: 0.0393683

File 372 (lwc)

- The above data is the same star through the same G6 grism, but in this case we put the dichroic in the optical path.
- As can be seen in the data, the presence of the dichroic eliminates the bright lenticular feature at 34um from the spectrum. It is for this reason that we believe that the G6 behavior is due to a bad blocking/order sorting filter paired with the G6 grism. We plan on replacing this filter for Phase 2 commissioning and Cycle 1.

Example of the pipeline-extraction of spectral data



- This was our first opportunity to tests the effectiveness of the data pipeline code on real grism data
- As can be seen in the data, long slit spectra can be produced from the data using the pipeline.
- Only the data from 4-28um are shown here (data were taken in the 28-37um G6 grism, but it is not shown here due to problems associated with the 34um feature shown earlier)

Grsim Spectroscopy Modes Summary

- We now have spectra in all grism modes. Except for G6, which appears to have a failed or faulty blocking filter, all modes work according to the following specifications that we can measure with from the stellar spectrum we observed:
  - Resolving power: G1 (R=200 @ 6 mm, narrow slit), G3 (no narrow features to measure), G5 (R=118 @ 23 mm)
  - Spectral range: G1 (4.9 – 7.9 mm), G3 (8.6 – 13.9 mm), G5 (17.1 – 27.5 mm)
- Wavelength calibrations in all modes need slight adjustment as existing calibration used the lab point source simulator.
- The data reduction pipeline and quick-look tool are able to reduce and display wavelength-calibrated spectra

In-flight Image Quality

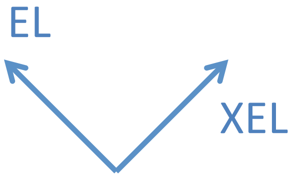
- Image quality was overall poor on the Phase 1 flight, though things did get better at higher altitudes
- The psf was elongated at all wavelengths, typically in the approximate direction of telescope cross-elevation
  - Elongation was NOT due to chop-nod smear/synching issues, as the elongation angle did not change as a function of chop or nod angle
  - The baffle plate was thought to be responsible for a portion of the cross-elevation elongation seen in previous flights, and was removed for this flight
  - The fact that the effect seemed to get better with higher altitude, suggests that the elongation is unlikely due to secondary control issues.
- The AMDs were not operable for this flight and may have been part of the reason for the elongated image quality
- The following slides show some example images at different wavelengths

Alpha Tau 5.4

Image Quality*

PA= -44.9°
FWHM_{maj}=4.21”
FWHM_{min}=3.24”
Eccentricity=0.231

TA Elevation=30°



39,000 ft
Leg 6

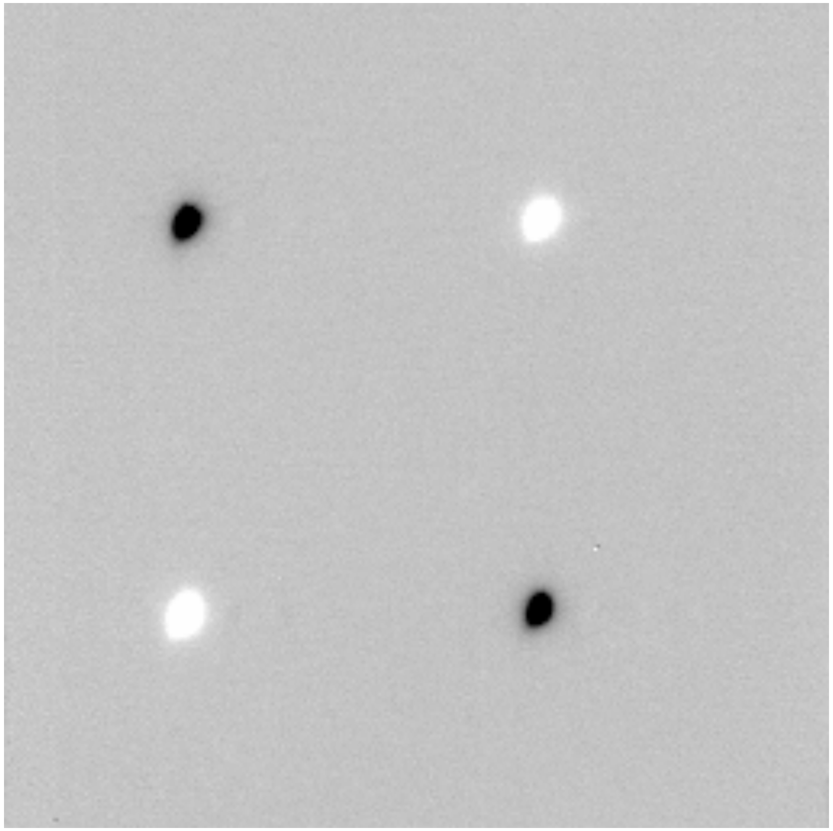
*averaged over all four sources

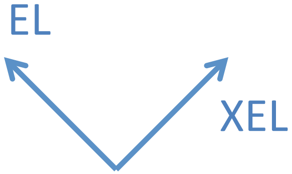
R Leo 7.7

Image Quality*

PA= -25.7°
FWHM$_{maj}$=4.37”
FWHM$_{min}$=3.25”
Eccentricity=0.257

TA Elevation=57°





39,000 ft
Leg 5

*averaged over all four sources

RS Cnc 31.5

Image Quality*

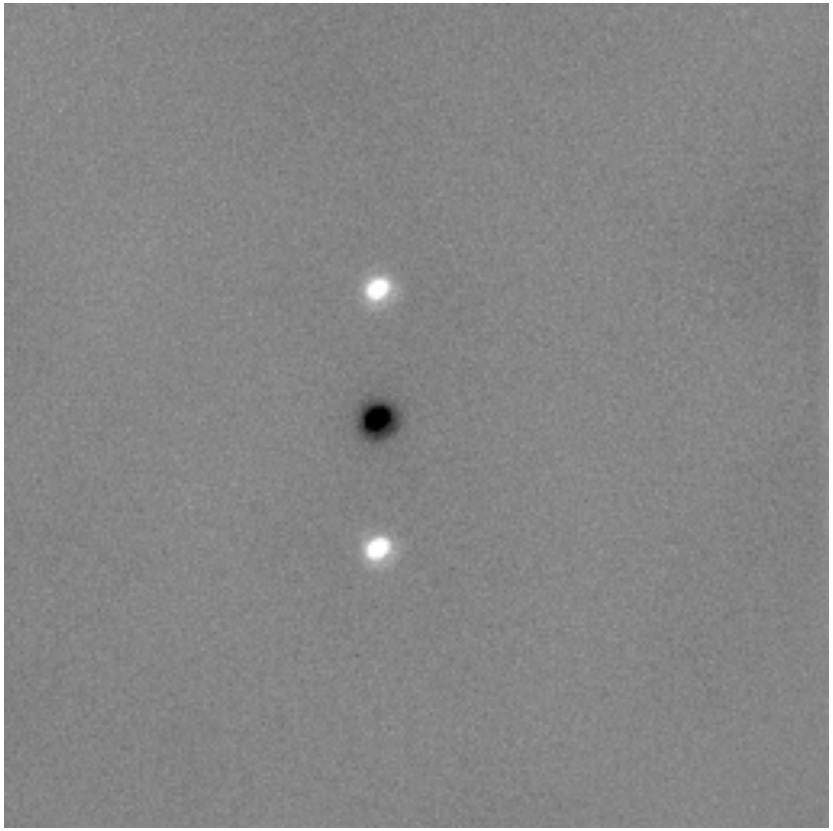
PA= -61.7^o

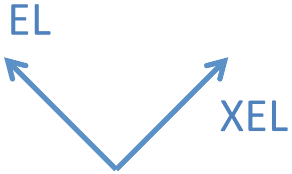
FWHM$_{maj}$=4.08”

FWHM$_{min}$=3.31”

Eccentricity=0.187

TA Elevation=50^o





43,000 ft

Leg 10

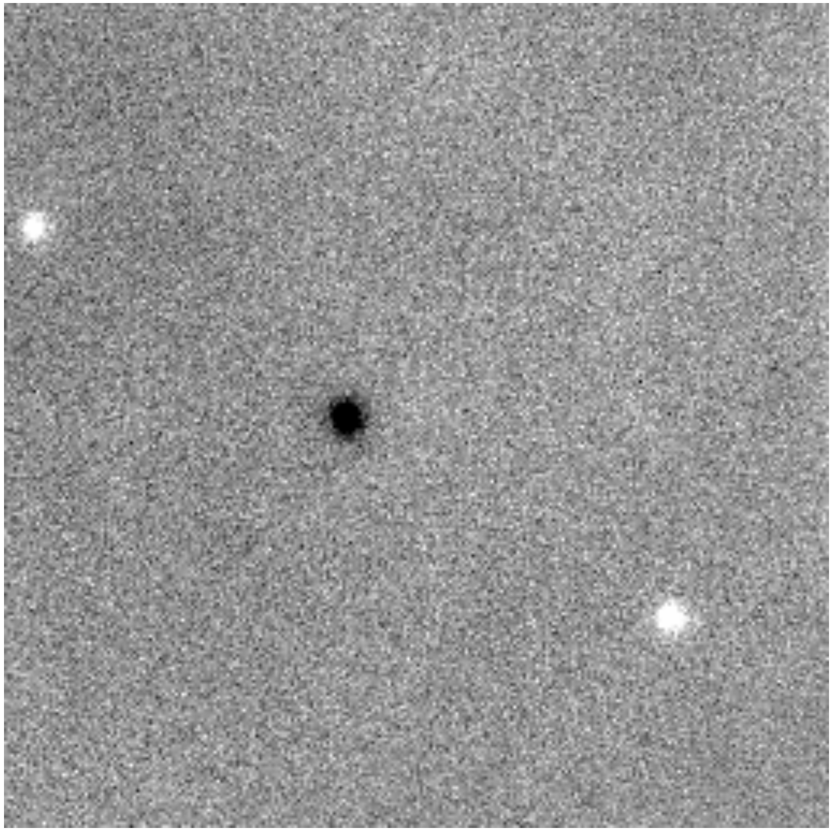
*averaged over all four sources

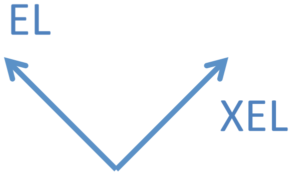
S Cep 37.1

Image Quality*

PA= 12.2°
FWHM_{maj}=5.39”
FWHM_{min}=4.50”
Eccentricity=0.165

TA Elevation=38°





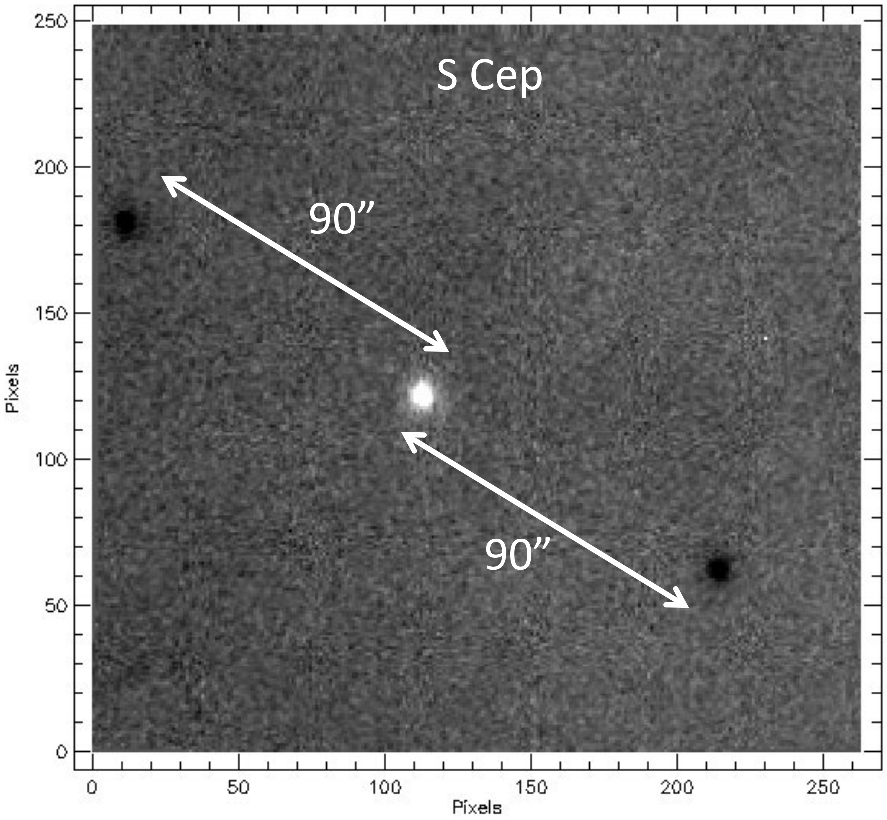
43,000 ft
Leg 14

*averaged over all four sources

Image Quality Analysis Summary

- It appears that the image quality was less elongated at higher altitudes (i.e. 43K ft as opposed to 39K ft)
- When image quality is poor, it tends to be elongated in (approximately) the cross-elevation direction
- This elongation was at times very high (i.e., eccentricities of 0.3)

Chop/Nod Accuracy and Precision Tests



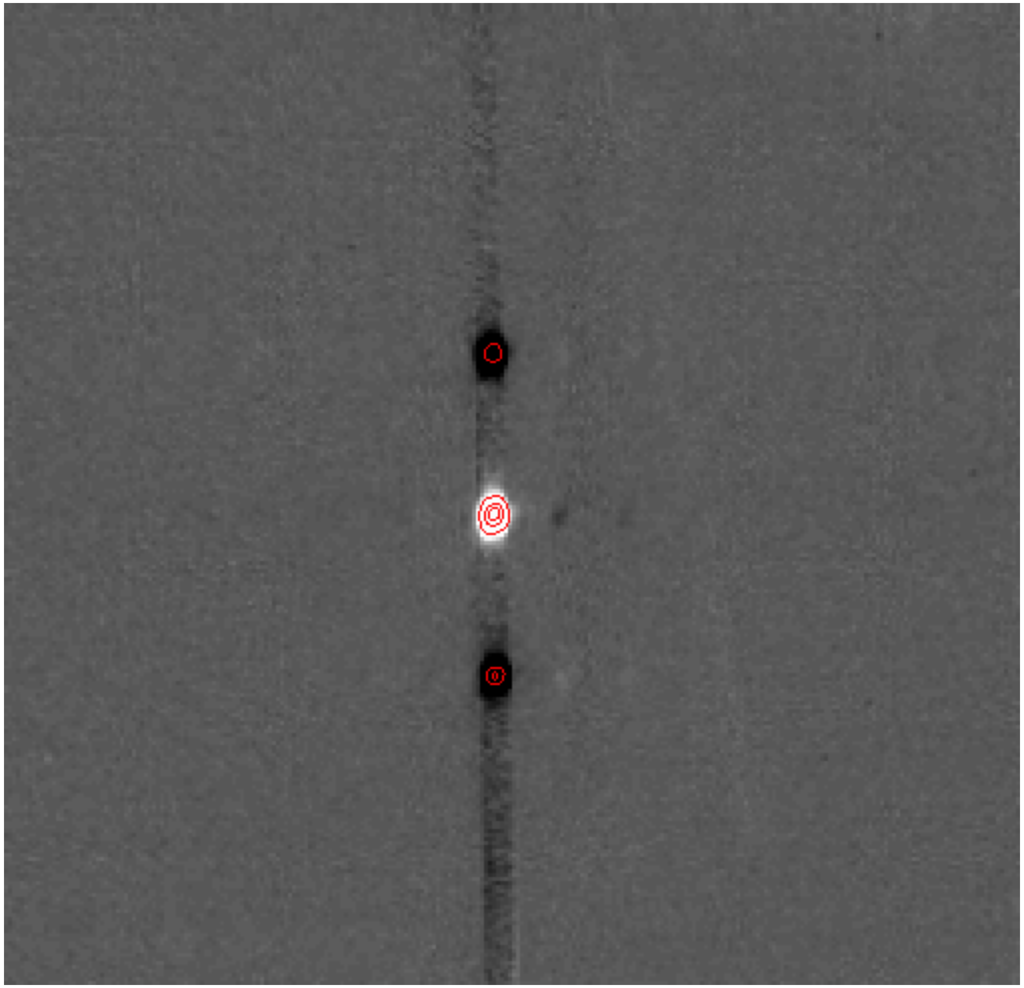
Nod Matched to Chop (NMC) Case

NMC affect on image quality

- Another way of testing how well the nods and chops align is to look at the FWHM of the source in the chop differenced only frames, and compare it to the FWHM in the chop-nod double differenced final image
- For S Cep data:
  - "Nod A Chop 1" => FWHM(pixels) = 6.43+/-0.36
  - "Nod A Chop 2" => FWHM(pixels) = 5.81+/-0.38
  - "Nod B Chop 1" => FWHM(pixels) = 6.39+/-0.64
  - "Nod B Chop 2" => FWHM(pixels) = 5.92+/-0.46
- In the final double differenced frame, the central source with the matched beams has FWHM(pixels) = 6.19+/-0.31.
- The final image therefore has a FWHM that is about 1-standard deviation of the pointing precision found earlier and certainly no larger than the average FWHMs found in the chop differenced-only frames.
- In conclusion, the level of misalignment of the chops and nods (after a ***nod-chop align procedure***) does not significantly deteriorate final image quality.

Chop-Nod Centroid Analysis

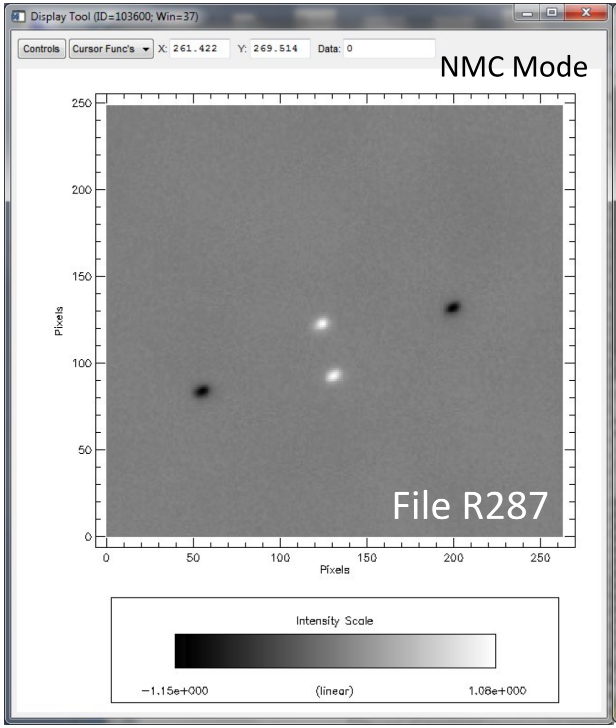
- The **precision** of the chopping and nodding look to be pretty good in both the ERF and SIRF coordinate systems, with 1-sigma errors being a fraction of a FORCAST pixel (with or without the alignment procedure prior)
- The **accuracy** of the chopping and nodding are a little off when the TOs do not explicitly run the alignment procedure that increases the accuracy of matching the chop and nod throws.
  - With no alignment procedure, even though the chop and nod throws were requested to be the same, they were off in both cases (tests i. and ii.) by about 2”.
  - With an alignment procedure, the chops and nods matched to better than 0.15”.
- It appears that the commanded chop and nod angles are accurate and precise whether or not there is an alignment procedure prior to observations.
- Chops and nods can be made to match precisely enough so that there is no significant affect on final delivered image quality on FORCAST.



This is an animated gif (must be in presentation mode to see) of 10 images taken in the SWC of a star in the 4.7” FORCAST slit, while spectra are being taken in the LWC with the G6 grism. This observation is set up so that the chop throw matches the nod throw and the throw angles are set up to be in the direction of the slit in SIRF (hence the three instances of the source, one positive and two negative). It can be seen in this animation that the star centroids (positive and negative) stay very constant in location in the slit, showing the pointing of the telescope to be quite good. Furthermore after every second image we performed an LOS rewind, and no motion is perceptible in the source centroid positions from before to after the rewind. The animation is looped, but total real time elapsed for the 12 images and 6 LOS rewindsis about 10 minutes. **Tracking was on-source.**

“Wild” Nods and Missed Dithers

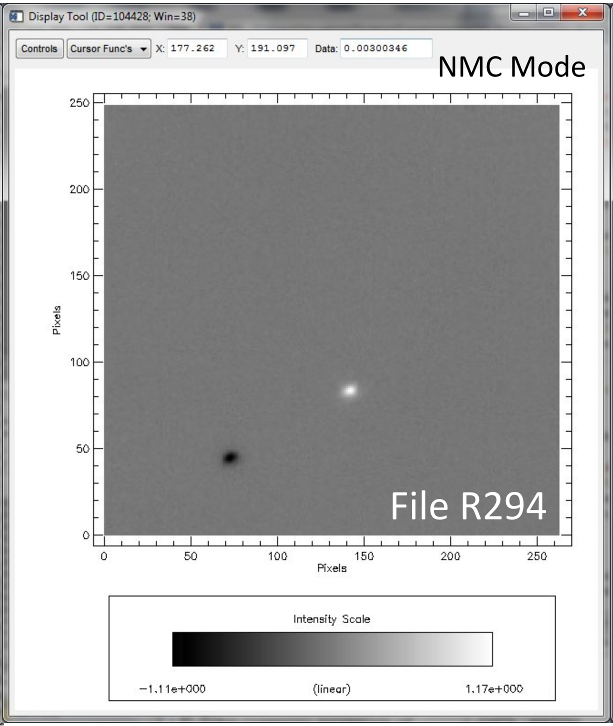
- In the normal course or observing on the Phase 1 flight we encountered a few strange nod/dither behaviors
- It is unclear if the problems with the nods and dithers are related
- Below are the examples of the strange nods seen.


Display Tool (ID=103600; Win=37)

X: 261.422 Y: 269.514 Data: 0

NMC Mode

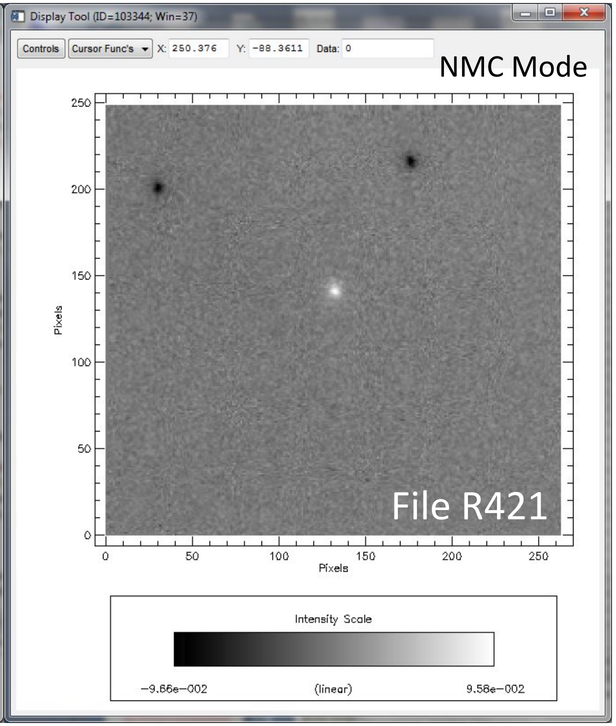
File R287


Display Tool (ID=104428; Win=38)

X: 177.262 Y: 191.097 Data: 0.00300346

NMC Mode

File R294


Display Tool (ID=103344; Win=37)

X: 250.376 Y: -88.3611 Data: 0

NMC Mode

File R421

Wild Nod/Dither Summary

- For as yet unknown reasons, we encounter poor or missed nods on three occasions
- Dithers positions were skipped several times when running through scripts configured to do repeated cycles of multiple element dither patterns. Why some dither patterns successfully completely while others did not is not yet clear.
- A “wild nod”-like behavior was reported to be seen by GREAT on their flights following ours

Plans for Phase 2 commissioning

- Commissioning Phase 2 Line Ops: 20 hrs over 5 nights
  - May 20-23, and May 28
- Commissioning Phase 2 Flights: 27 hrs over 4 flights
  - May 30, June 4, June 6, June 11

Phase 2 Tests include:

- Optimal detector biases at altitude
- Optimal chop/nod settle times
- Optimal nod frequency as a function of filter/grisms
- Imaging and spectral flat tests
- First test data of G4 grism, test of new G6 blocker
- Data mode efficiencies

Cycle 1 observations begin June 13 and continue throughout the month