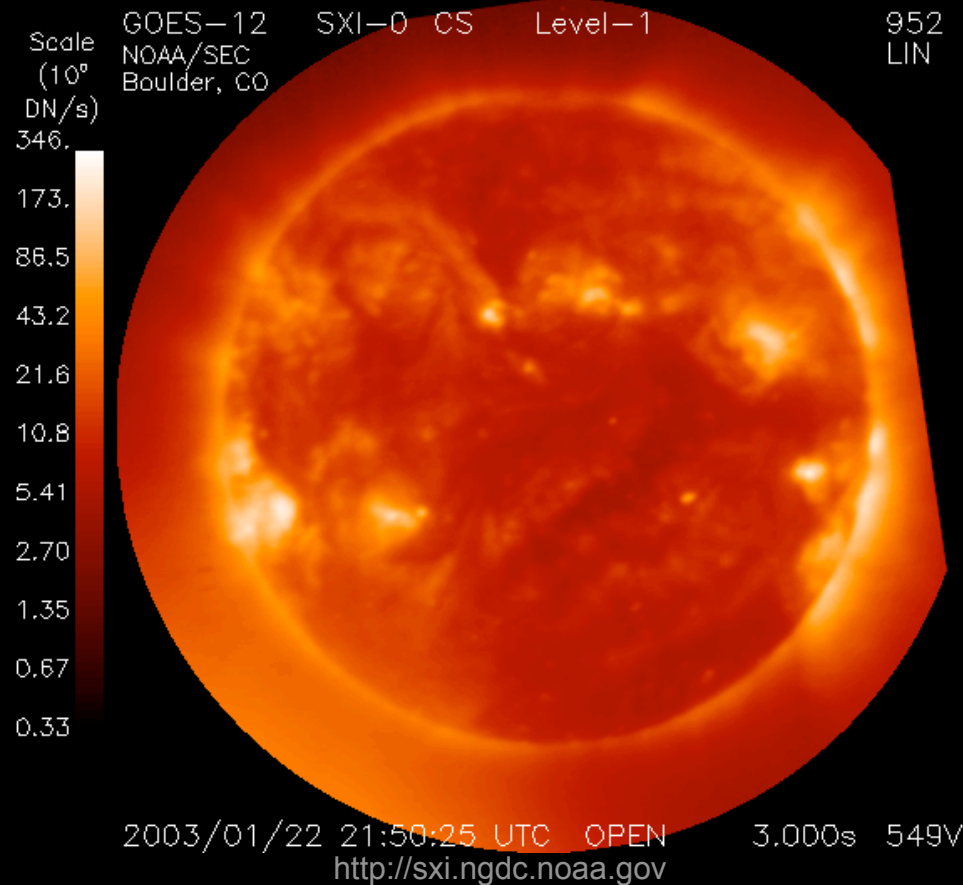


GOES-12 SXI Pointing Refinement



Ellen Pettigrew

NOAA Space Environment Center

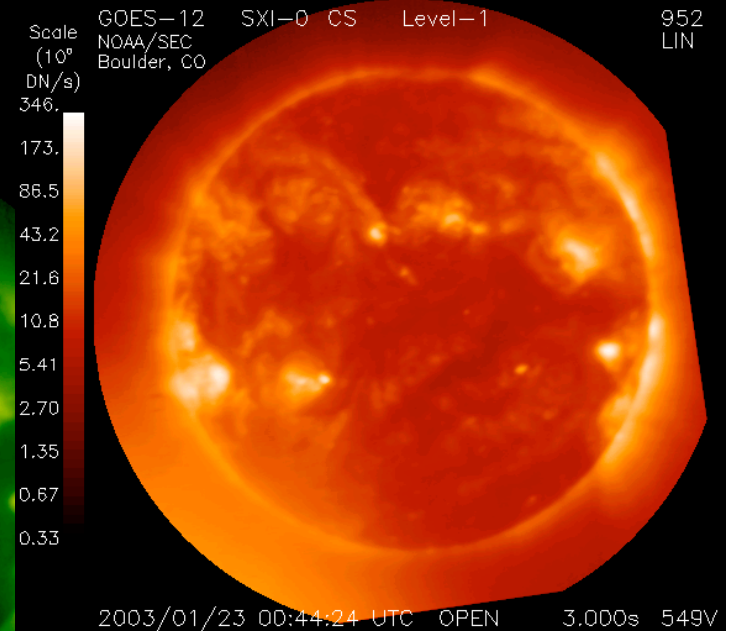
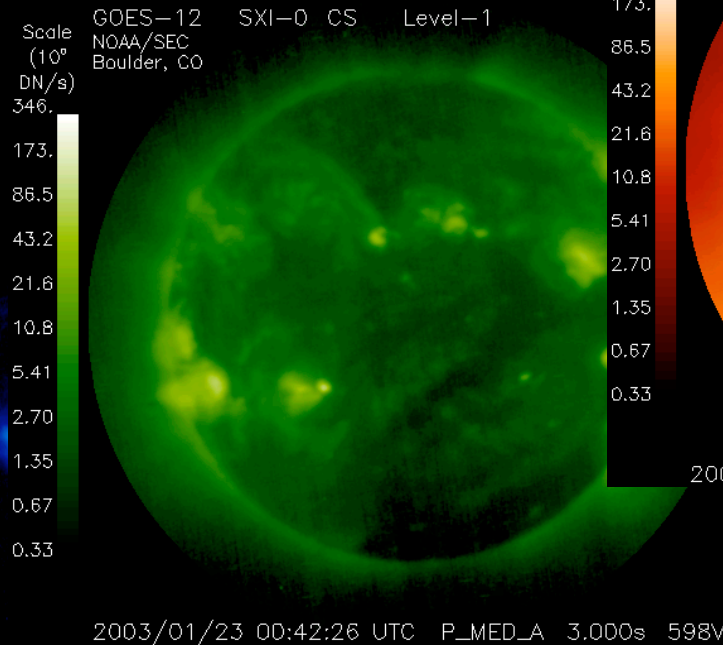
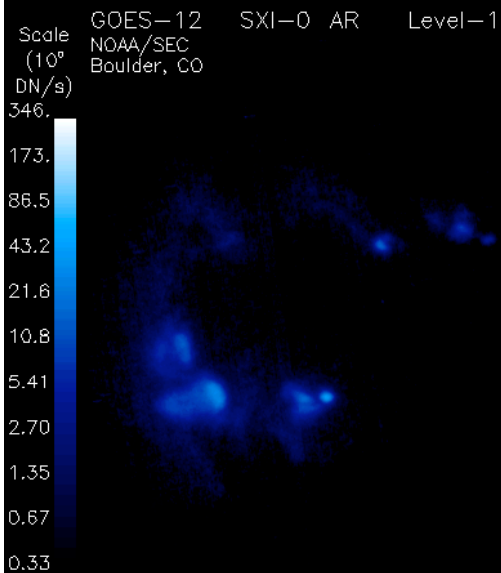
Mentor: Steven Hill

Other advisors: Vic Pizzo, Doug Biesecker



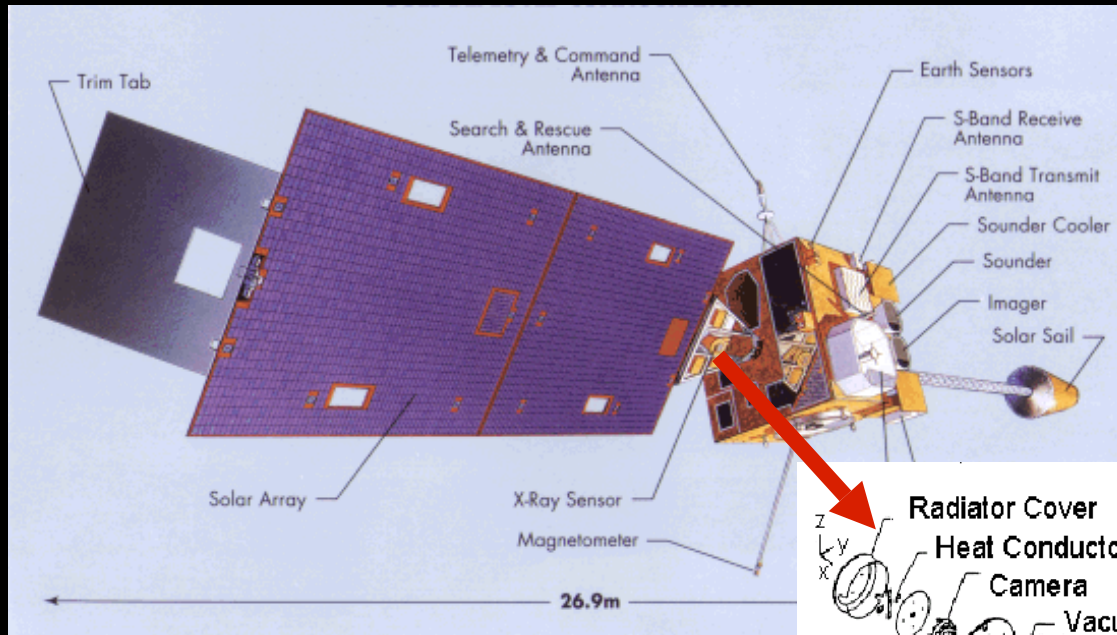
Intro to GOES-12 SXI

- **Solar X-ray Imager (SXI)**
 - X-ray telescope with several different filters
 - New image approximately once a minute
 - Over 2 million images in database



<http://sxi.ngdc.noaa.gov>

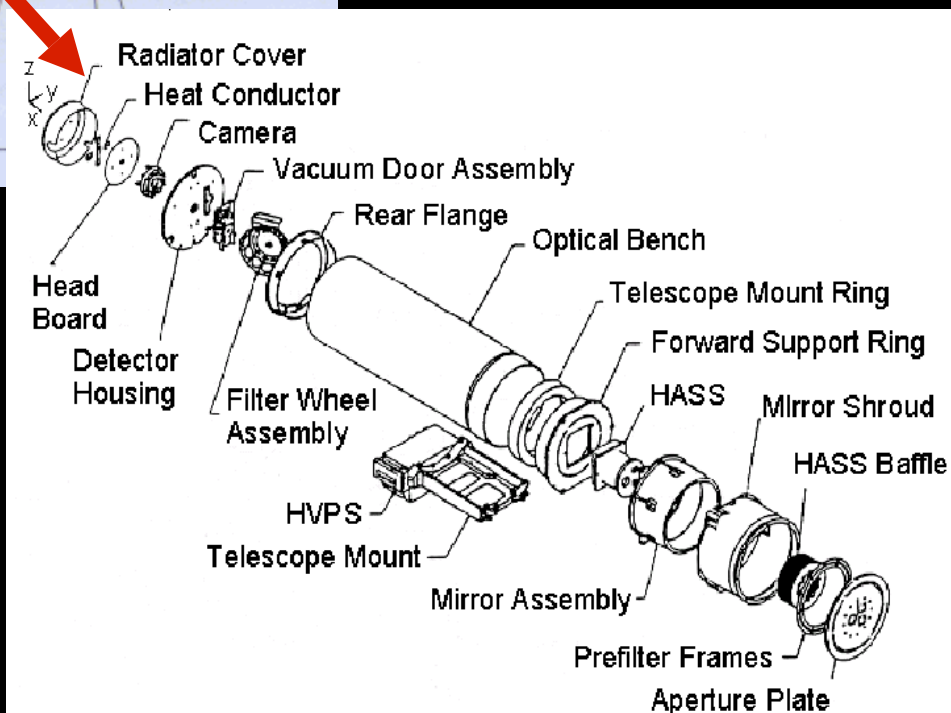
Intro to GOES-12 SXI



http://rst.gsfc.nasa.gov/Sect14/Sect14_7.html

Telescope Assembly:

- Mass \approx 15 kg
- Length \approx 0.7 m
- Radius = 8.0 cm



<http://sec.noaa.gov/sxi/info/InstrumentAndOperations/InstrumentAndOperations.html>

The Problem

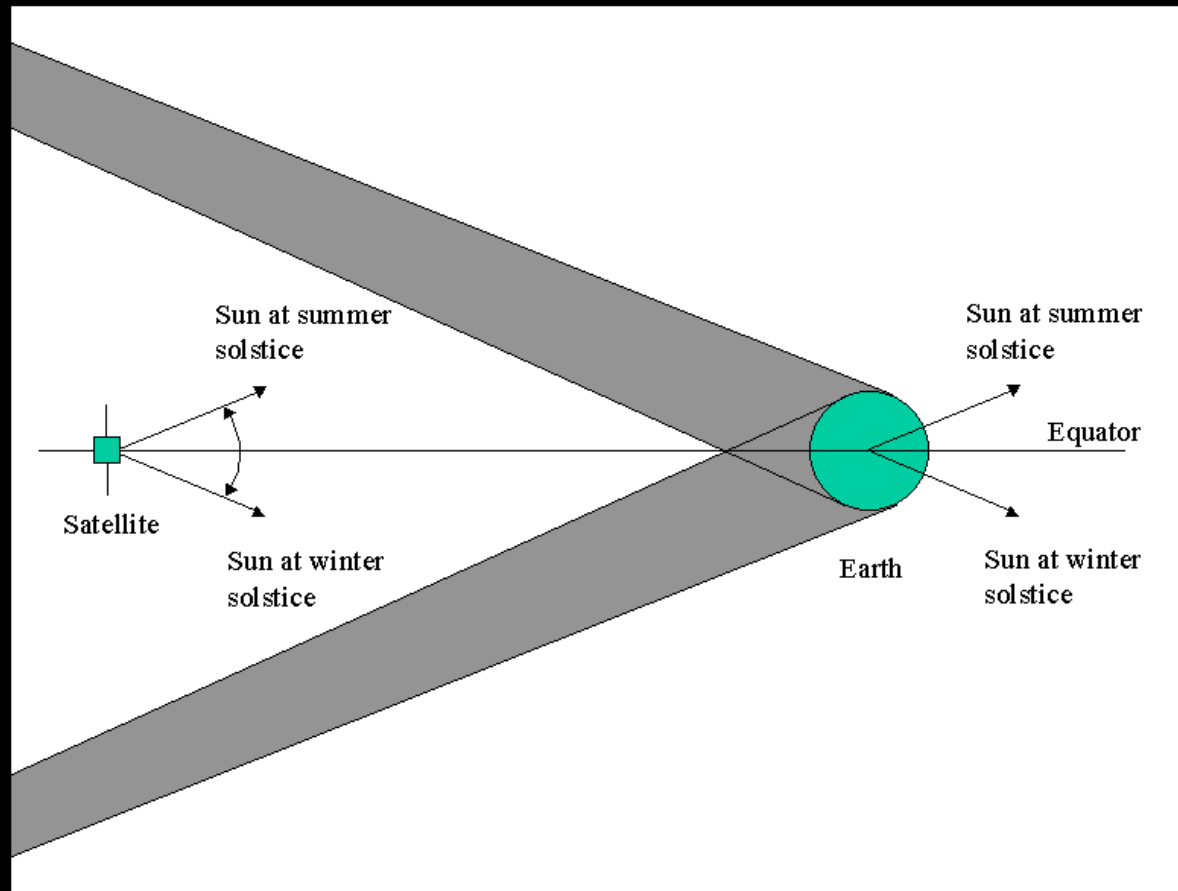
- **Significant errors in pointing data for a large portion of the SXI images**
- **Errors have magnitudes of up to 30 arcseconds**
- **Reduces utility of image database**

Causes of Pointing Errors

- Pointing data provided by High Accuracy Sun Sensor (HASS)
 - Accuracy is sensitive to thermal distortions in instrument
- Thermal distortions arise:
 - After eclipses
 - Due to seasonal changes

Eclipse Season

- 45 days symmetrically centered around equinoxes
- Satellite is in the Earth's shadow for up to ~1 hour each night
 - Causes thermal distortions in instruments



Eclipse Season

Possible Solution

- Correct for pointing errors by determining an empirical relationship between the errors and recorded temperatures

True Center = Reported Center + Correction

Correction = $f(T_1, T_2, \dots)$

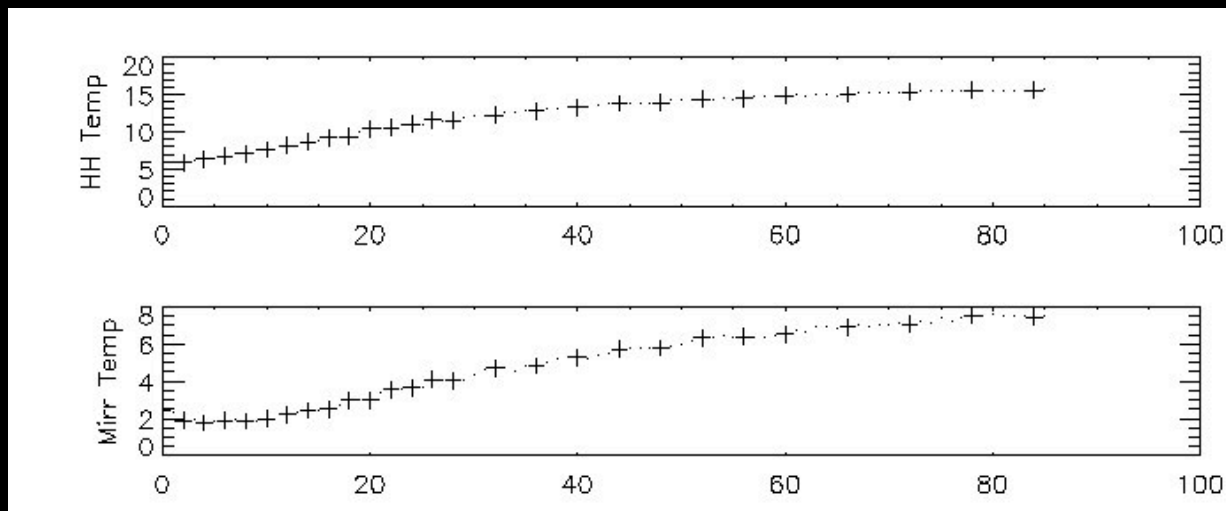
- Simple because many temperature measurements that are made on-board in real-time are included in image headers

Methodology

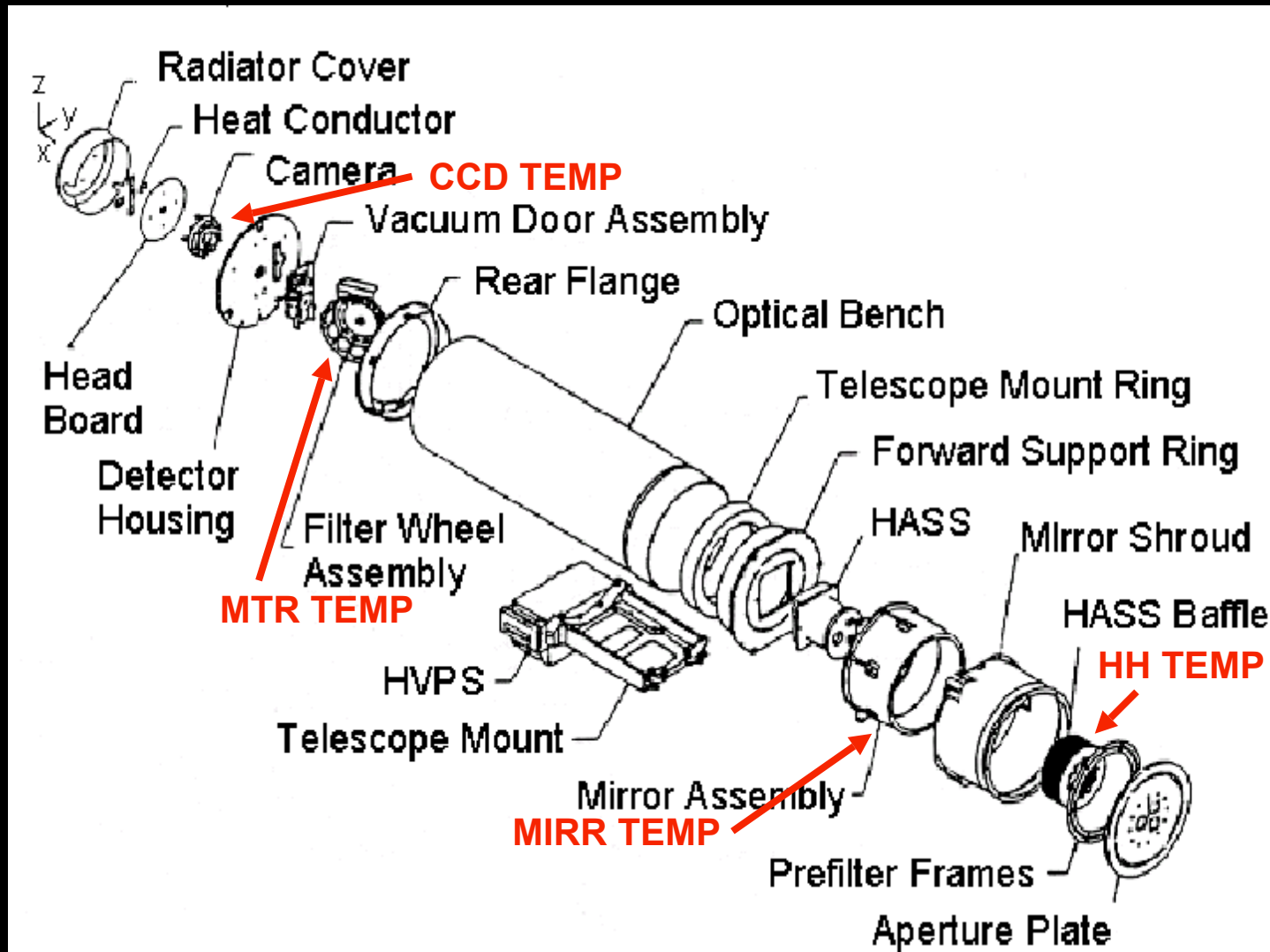
- Select representative data set
- Determine pointing error in each image
- Statistically analyze data set

Methodology

- **Select representative data set**
 - Several eclipse seasons spread throughout instrument life
 - Several days spread throughout eclipse season
 - Several hours from immediately after eclipse until thermal equilibrium is reached
 - Select image set which emphasizes time periods when the temperature values were rapidly changing

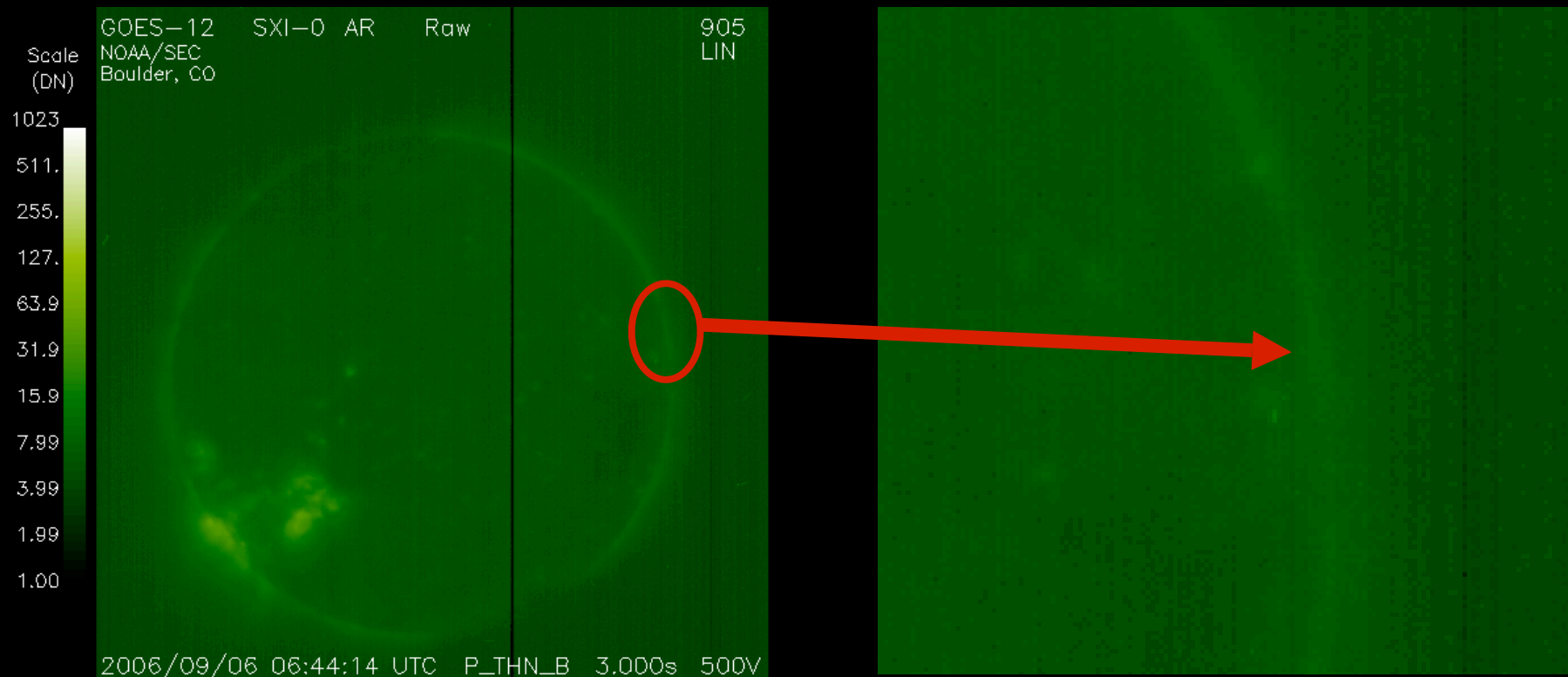


A Note on Temperatures



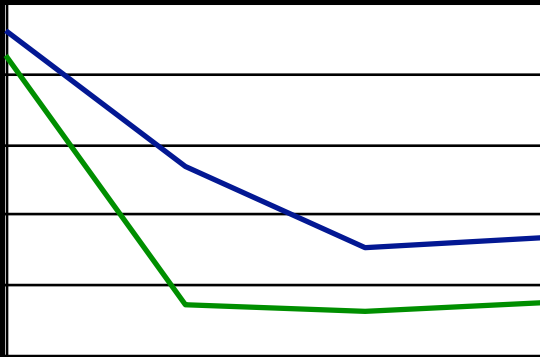
Methodology

- Determine pointing error in each image
 - IDL routine involves manually selecting points on the solar limb in each image
 - Need to perform routine more than once for each image to reduce effect of errors in finding solar limb

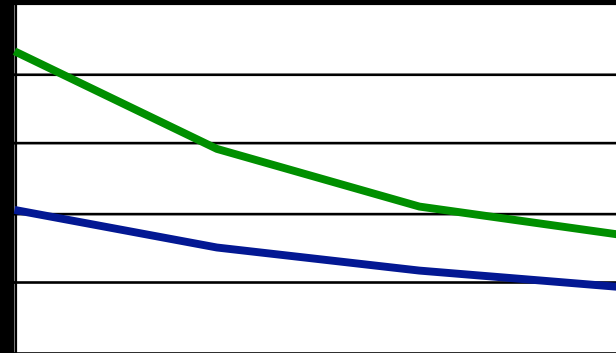


Methodology

- Variance Study on Limb-Fitting Procedure
 - Use average of 3 limb-fitting results for each “true” coordinate



— Image 1 — Image 2



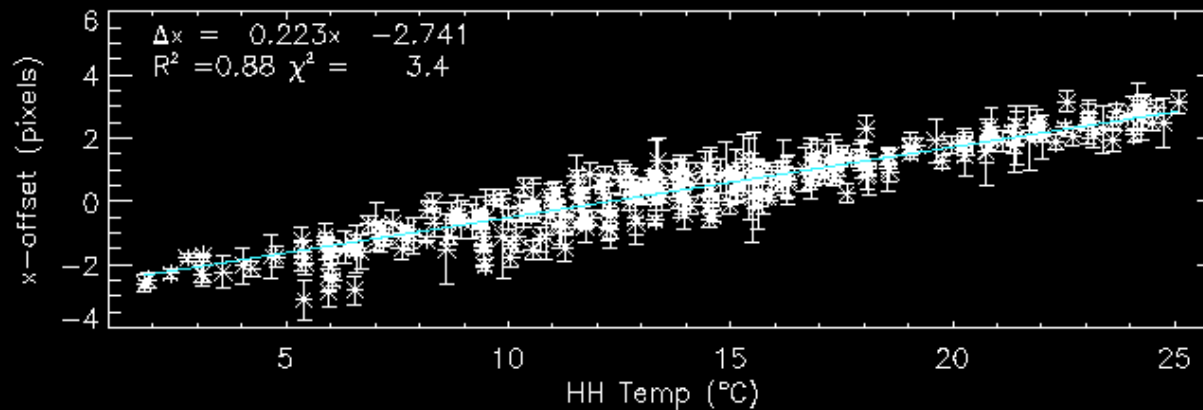
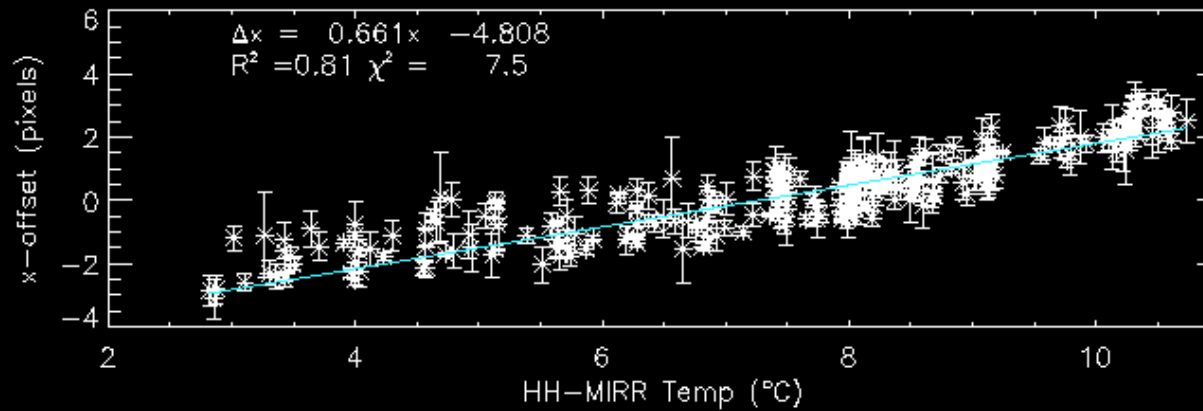
— Image 1 — Image 2

Methodology

- **Statistically analyze data set**
 - Find a function which best describes behavior of pointing errors with changes in temperature
- **Questions:**
 - Which parameter has the strongest correlation to errors?
 - Linear or quadratic fit?
 - Possible improvements to fit by:
 - analyzing residuals?
 - using multiple linear regression?

Analysis of Eclipse Data

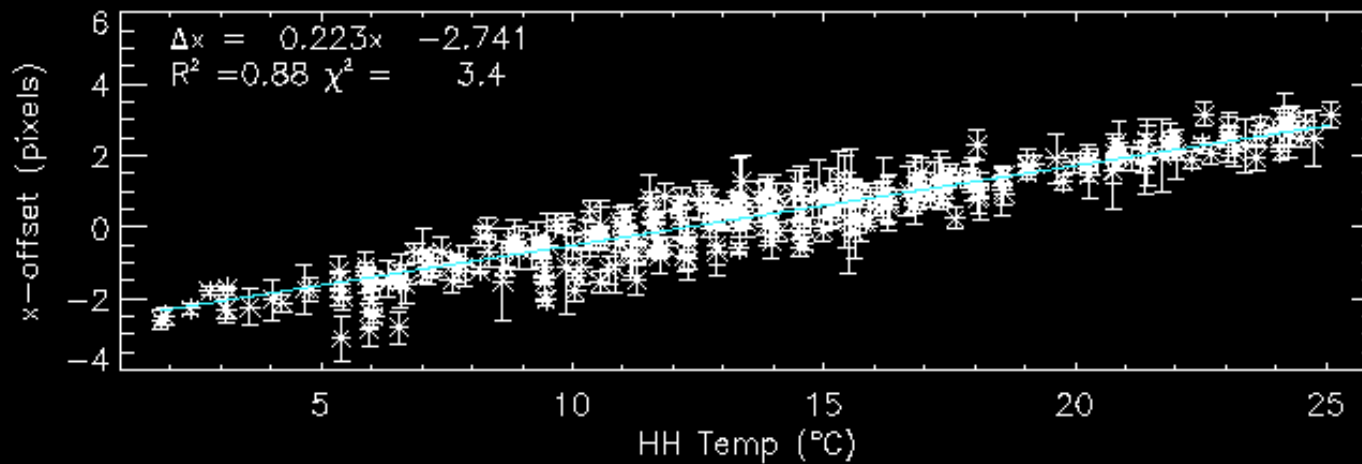
- Which parameter has the strongest correlation to errors?



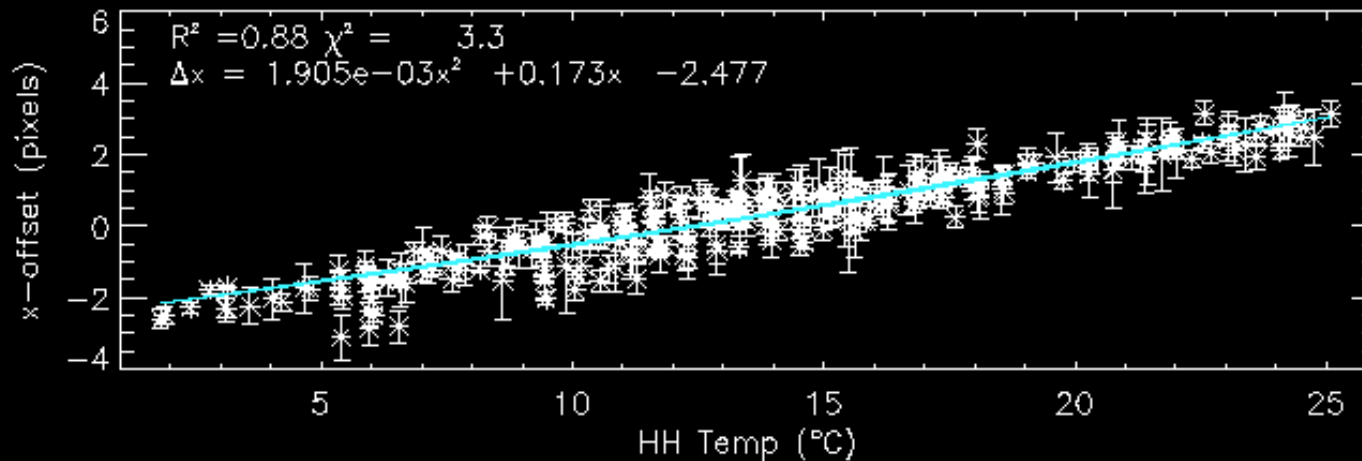
Analysis of Eclipse Data

- Linear or quadratic fit?

Linear

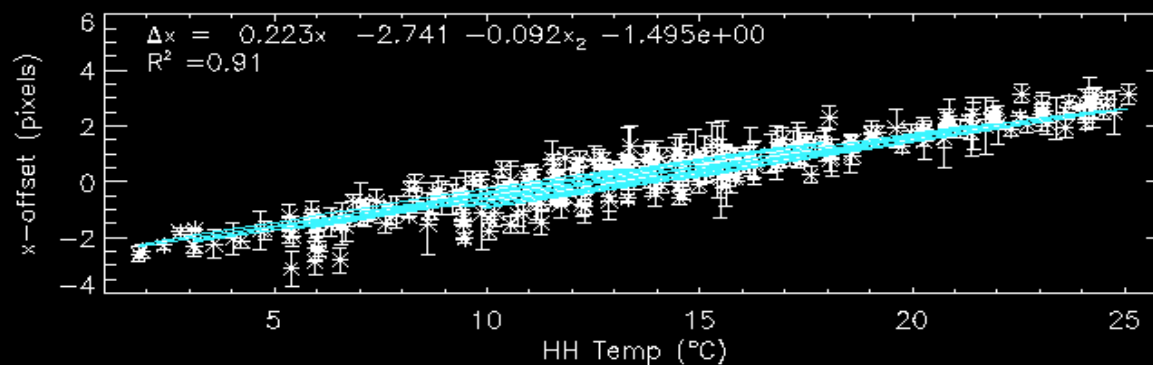
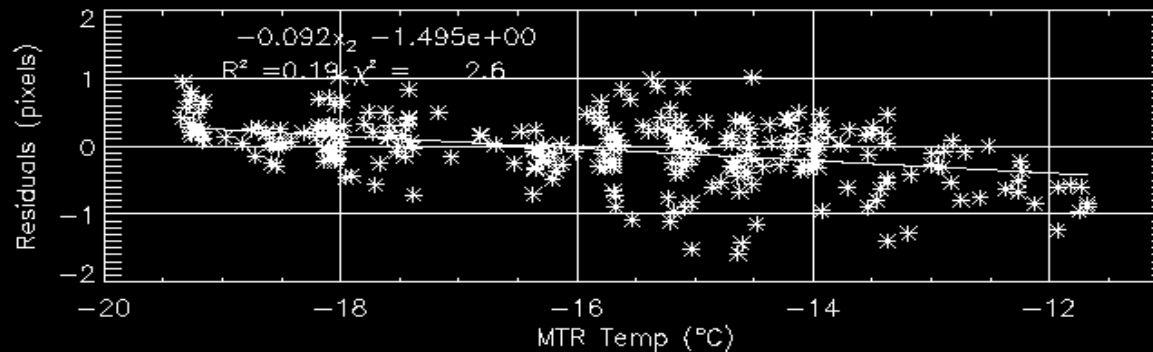
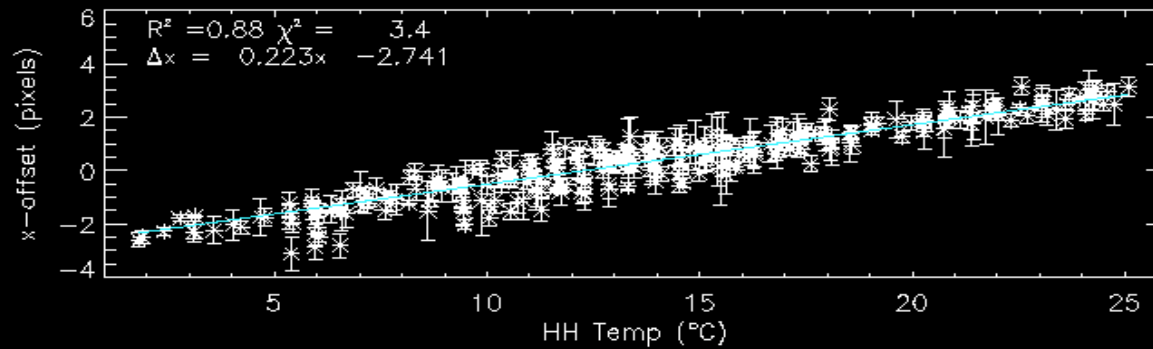


Quadratic



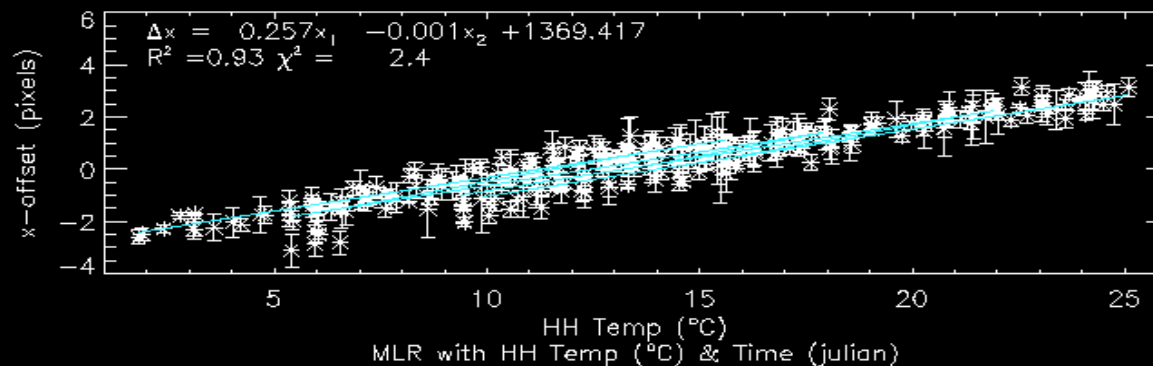
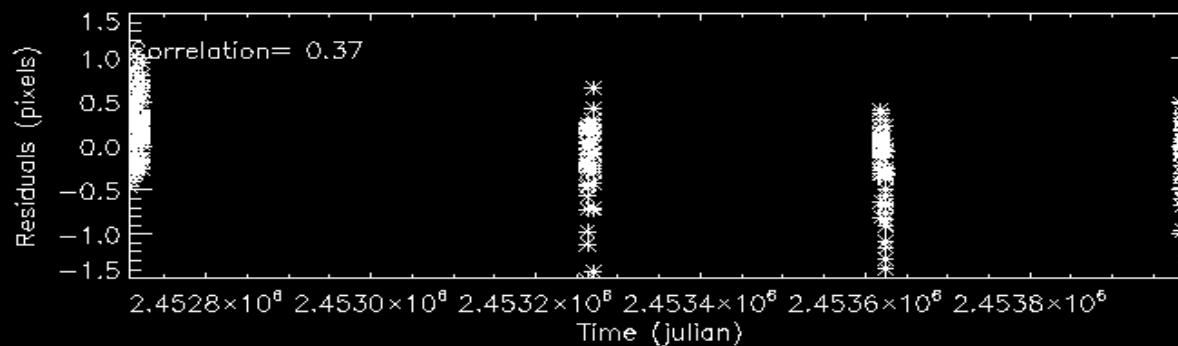
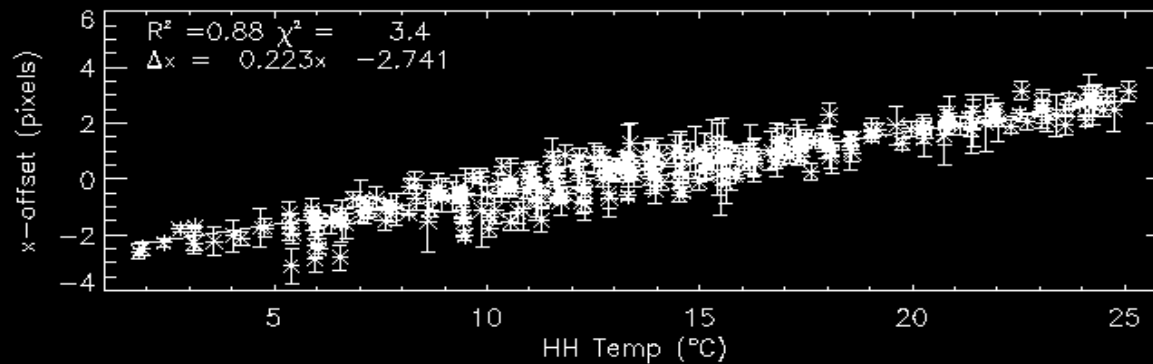
Analysis of Eclipse Data

- Possible improvements to fit by analyzing residuals?



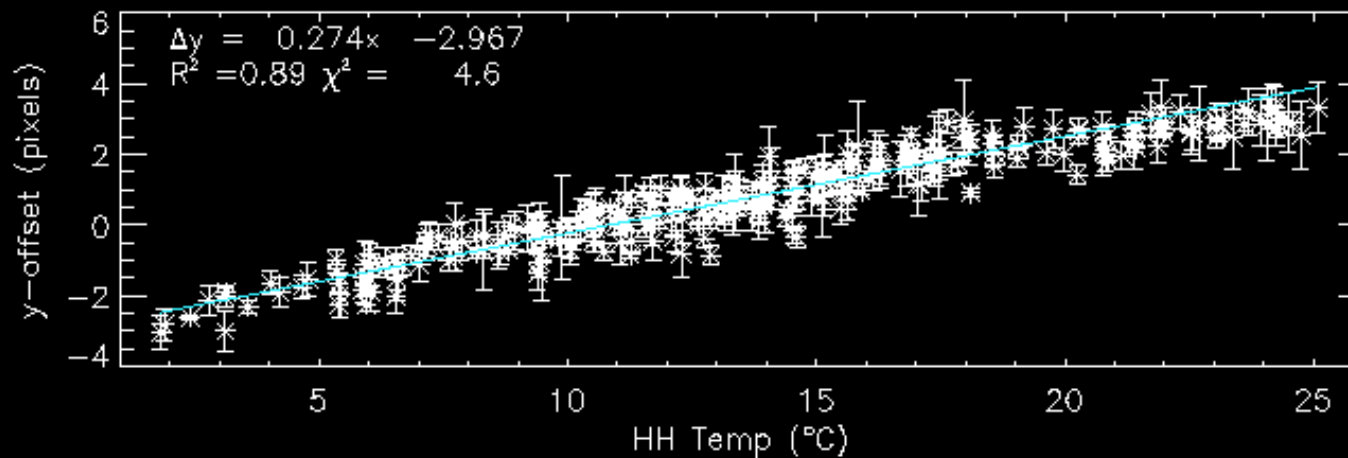
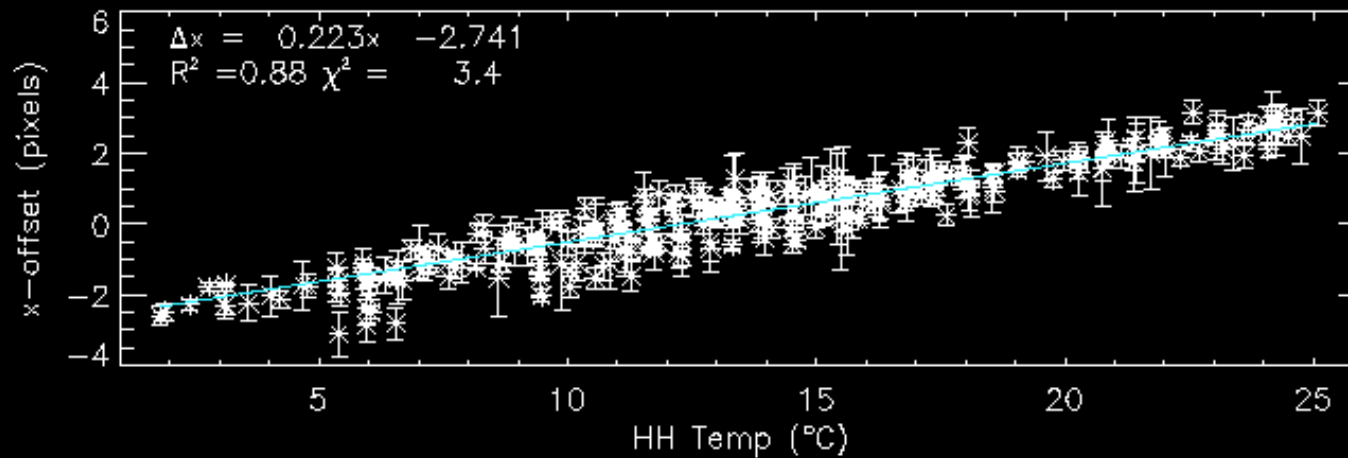
Analysis of Eclipse Data

- Possible improvements to fit by using multiple linear regression?



Analysis of Eclipse Data

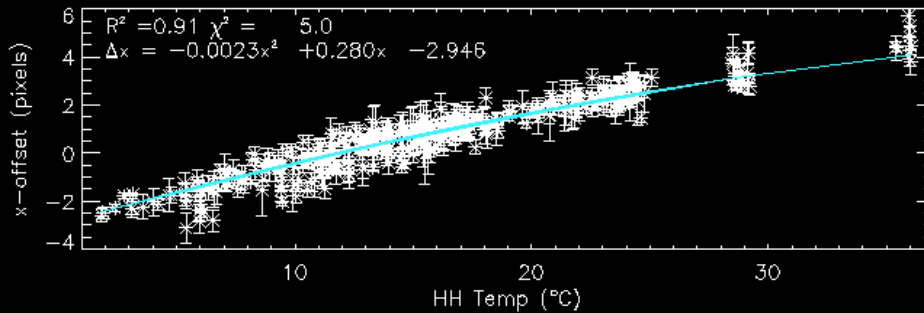
- Best model is simple linear fit to HH Temp



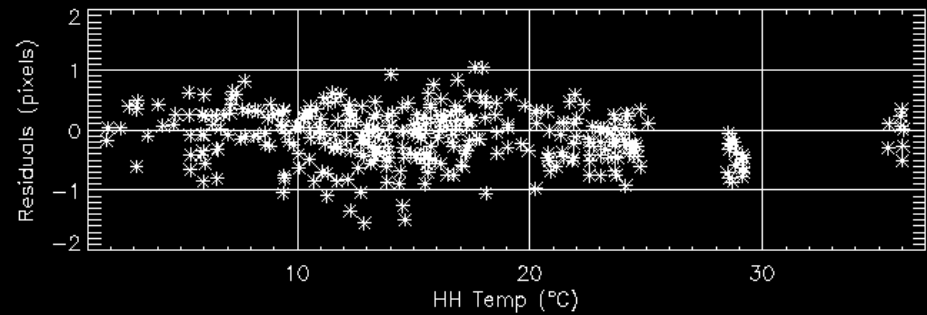
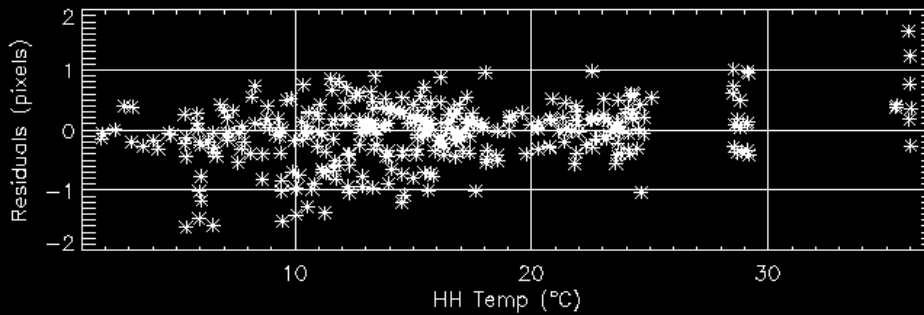
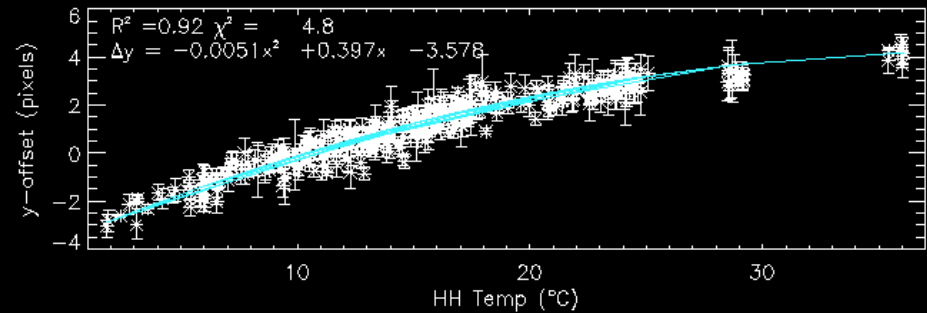
Global Data Set

- Global fit for data outside of eclipse season?

x – offset model

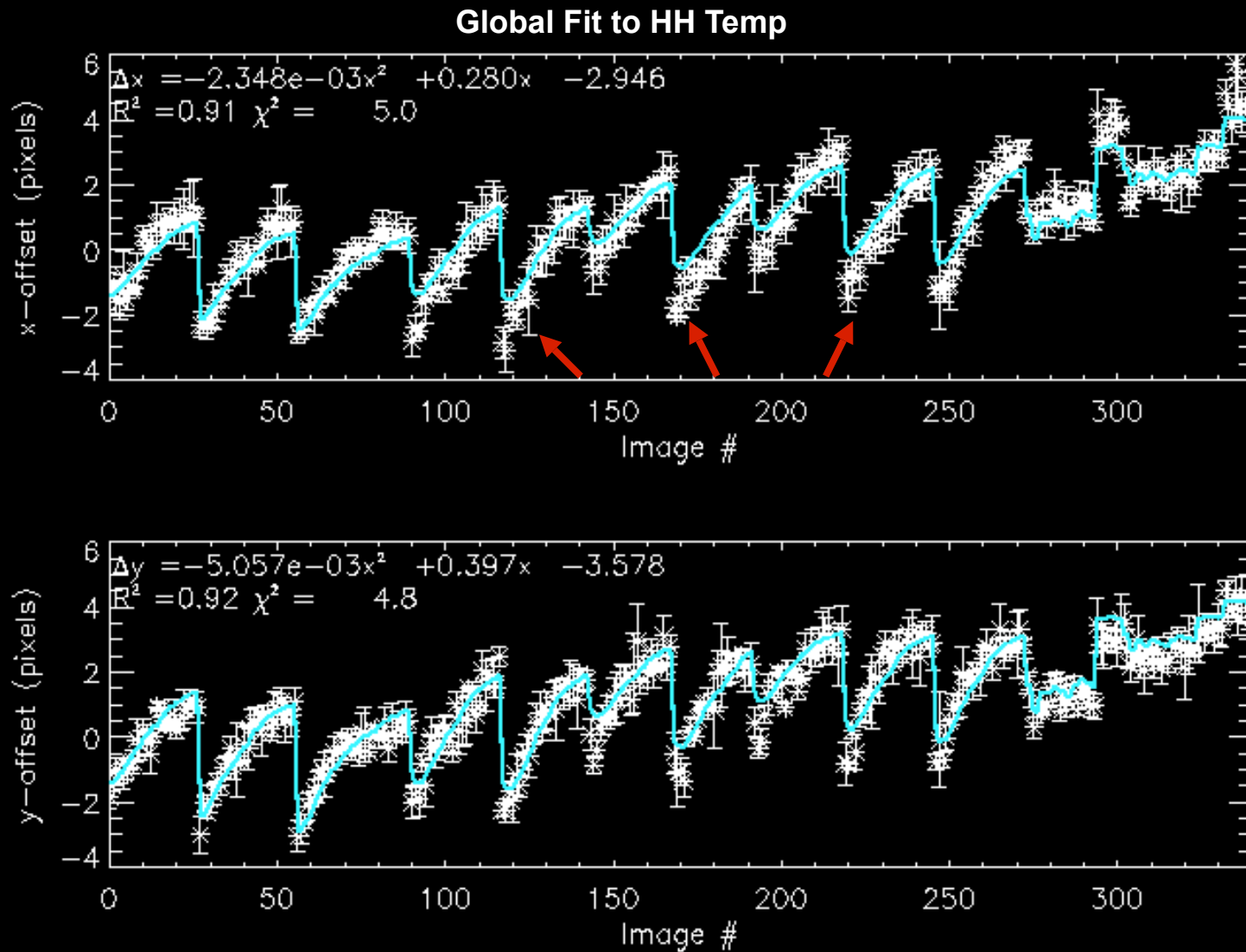


y – offset model



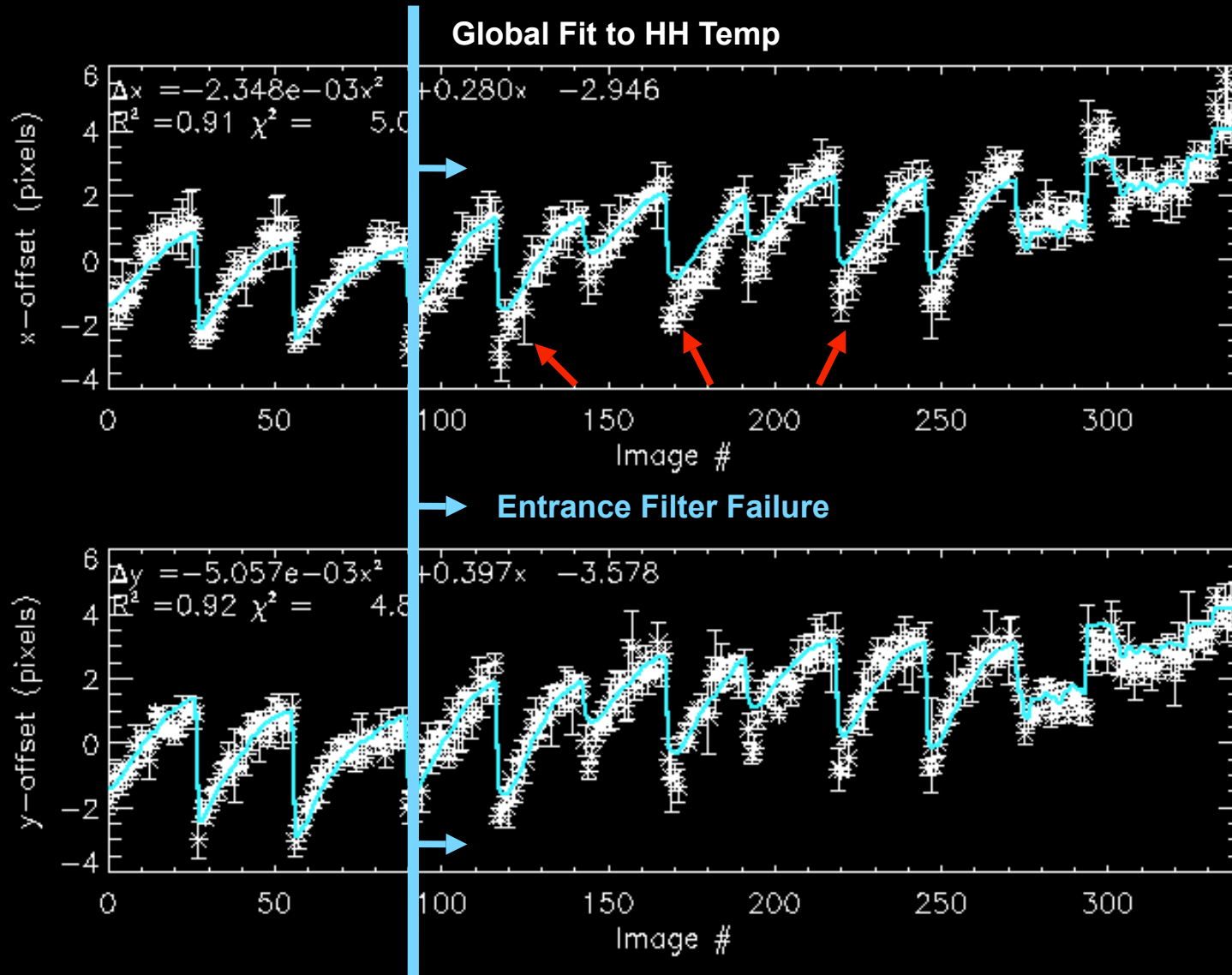
Global Data Set

- Global fit for data outside of eclipse season?



Global Data Set

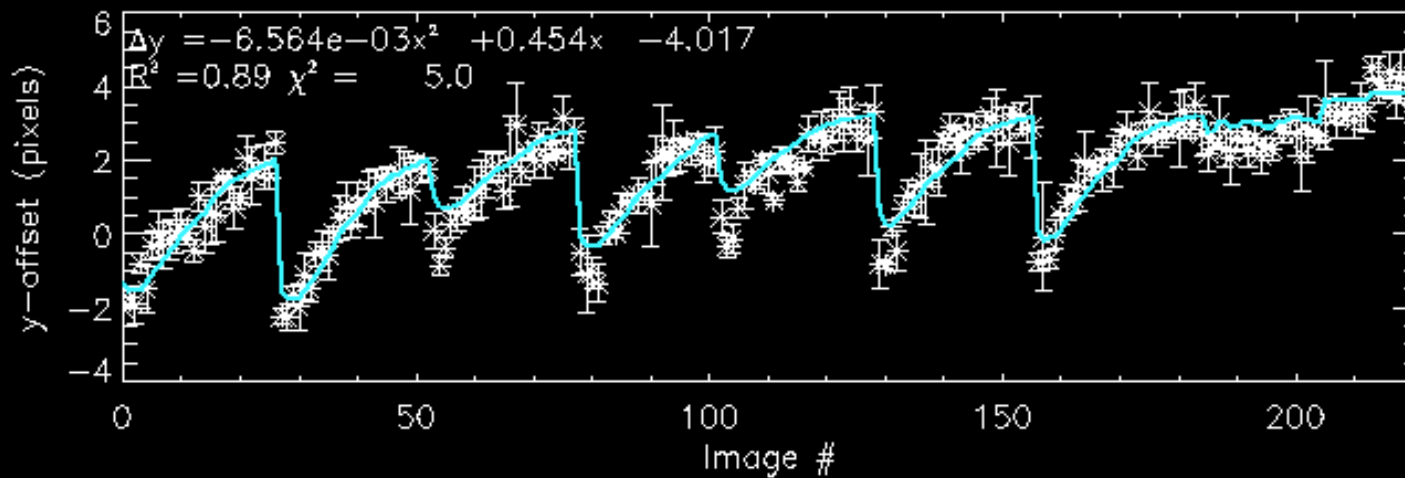
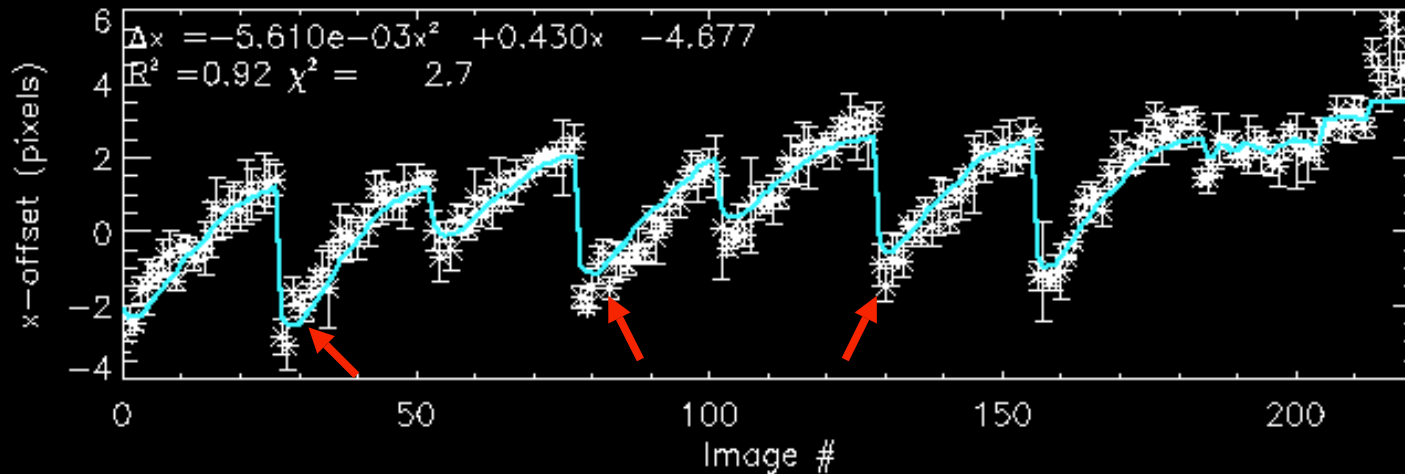
- Global fit for data outside of eclipse season?



Global Data Set

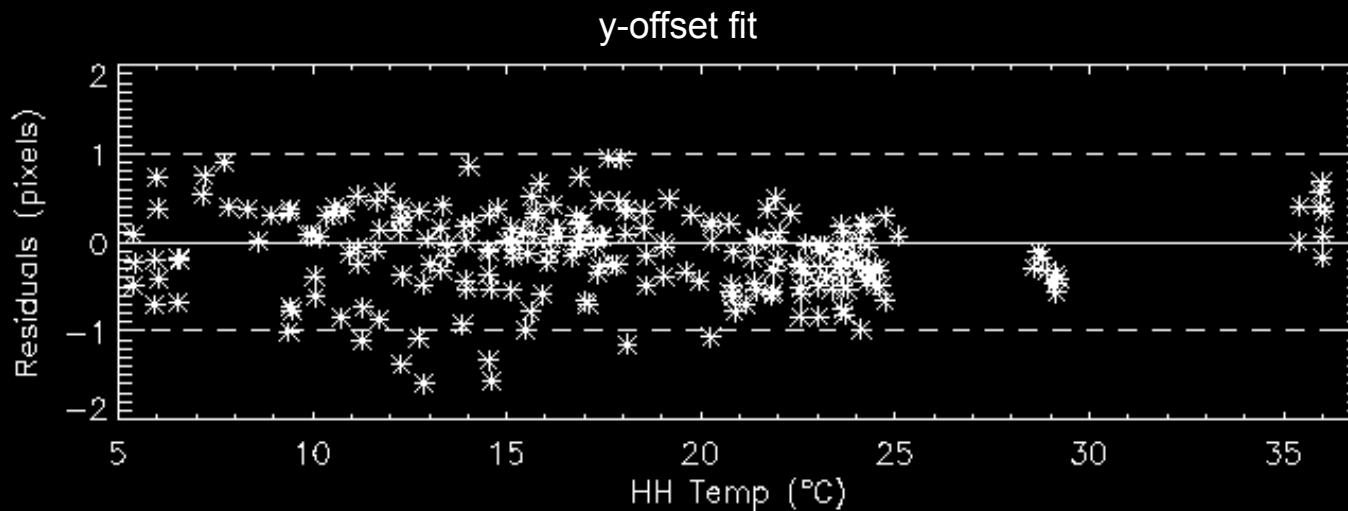
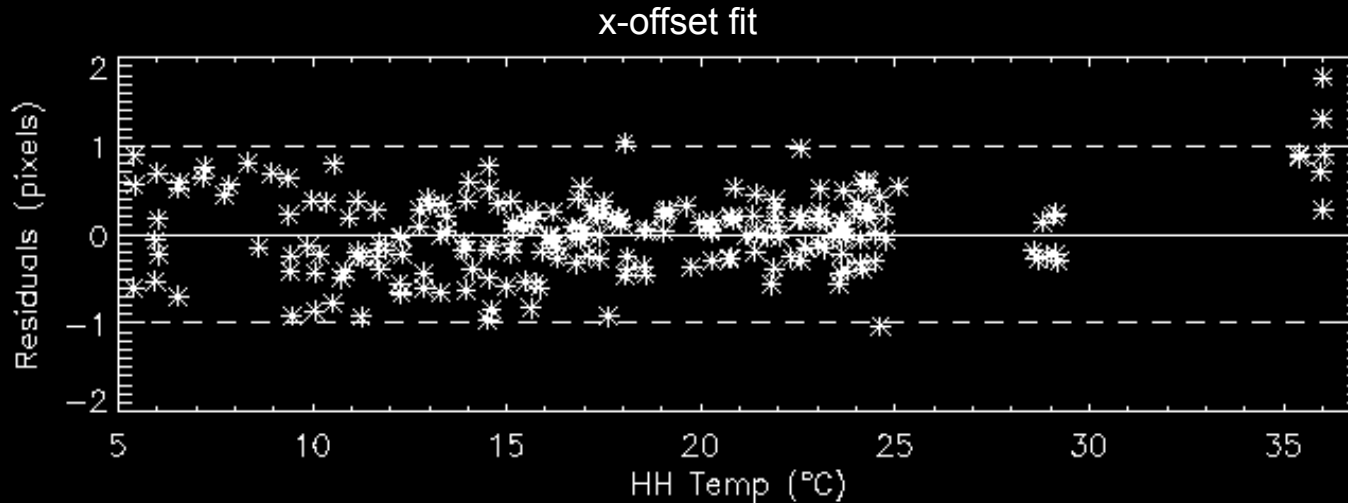
- Use two fits, one pre- and one post- entrance filter failure

Post-failure data only



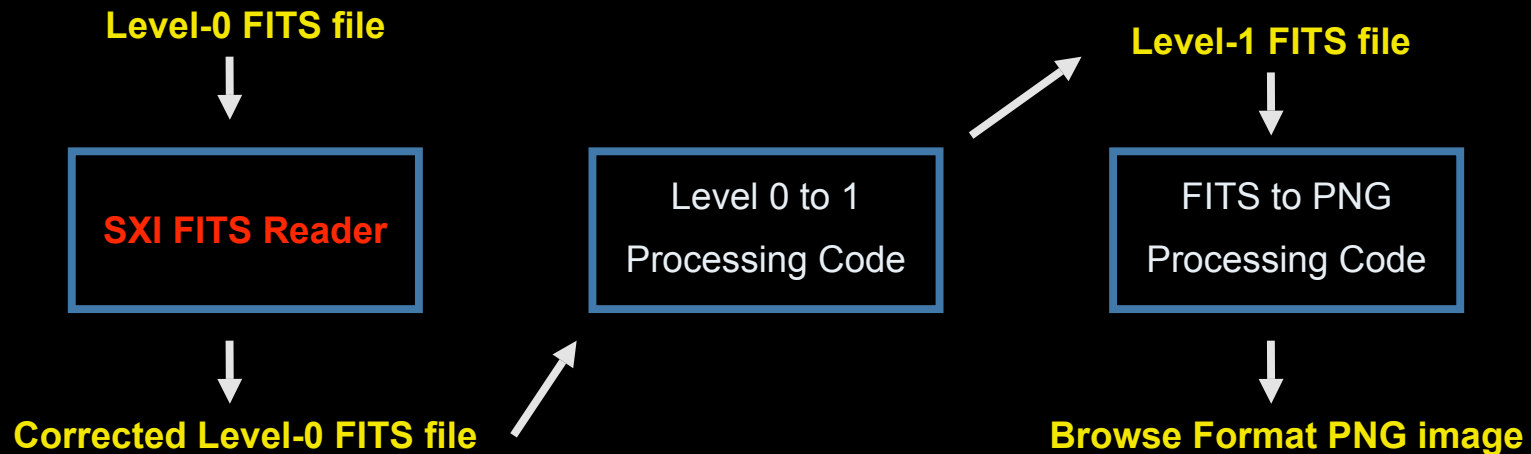
Global Data Set

- Residuals are now almost all < 1 pixel (5 arcseconds)



Implementation

- **Requirements:**
 - Easily applicable
 - Change affects all levels of image processing
- **Solution:**
 - Add correction factor to existing SXI-specific FITS reader



Implementation

```
x1 = index.HH_TMP          ; Parameter for calculating offsets
yr = fix(strmid(index.DATE,0,4))
mnth = fix(strmid(index.DATE,5,2))

; Offset equations for before and after Nov-2003 entrance filter failure
if (yr lt 2003) or (yr eq 2003 and mnth lt 11) then begin
  index.CRPIX1 = index.CRPIX1 - 1.991e-3*x1^2 + .289*x1 - 2.883
  index.CRPIX2 = index.CRPIX2 - 5.466e-3*x1^2 + .367*x1 - 3.344
endif else begin
  index.CRPIX1 = index.CRPIX1 - 5.610e-3*x1^2 + .430*x1 - 4.677
  index.CRPIX2 = index.CRPIX2 - 6.564e-3*x1^2 + .454*x1 - 4.017
endelse

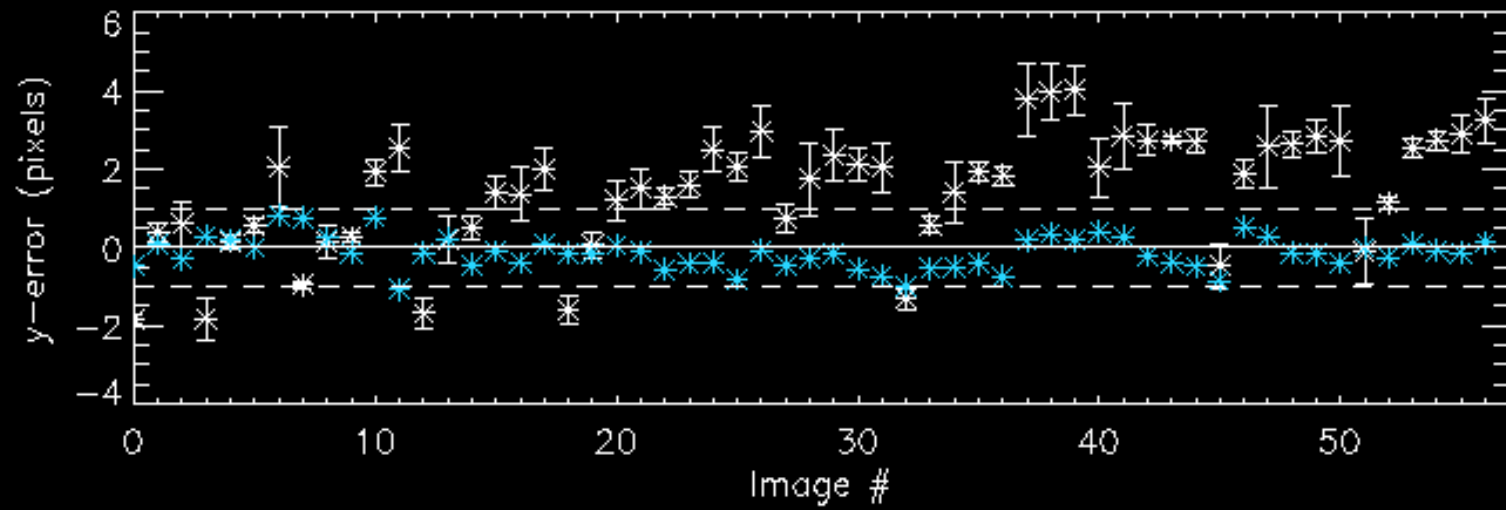
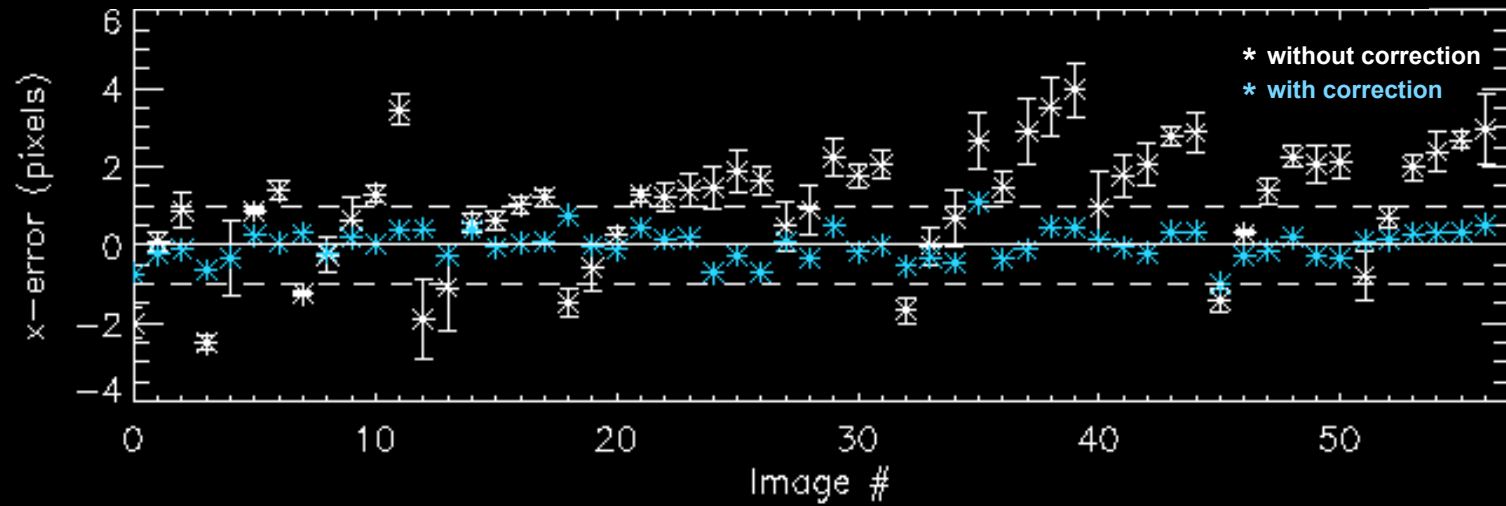
; Calculate XCEN and YCEN (in pixels) based on new CRPIX1 and CRPIX2
index.XCEN = index.CRVAL1 + ((index.NAXIS1+1)/2.0 - index.CRPIX1)*index.CDELTA1
index.YCEN = index.CRVAL2 + ((index.NAXIS2+1)/2.0 - index.CRPIX2)*index.CDELTA2

; Record new values in image header
header = sxi_sxmodpar(header, 'CRPIX1', index.CRPIX1)
header = sxi_sxmodpar(header, 'CRPIX2', index.CRPIX2)

header = sxi_sxmodpar(header, 'XCEN', index.XCEN)
header = sxi_sxmodpar(header, 'YCEN', index.YCEN)
```

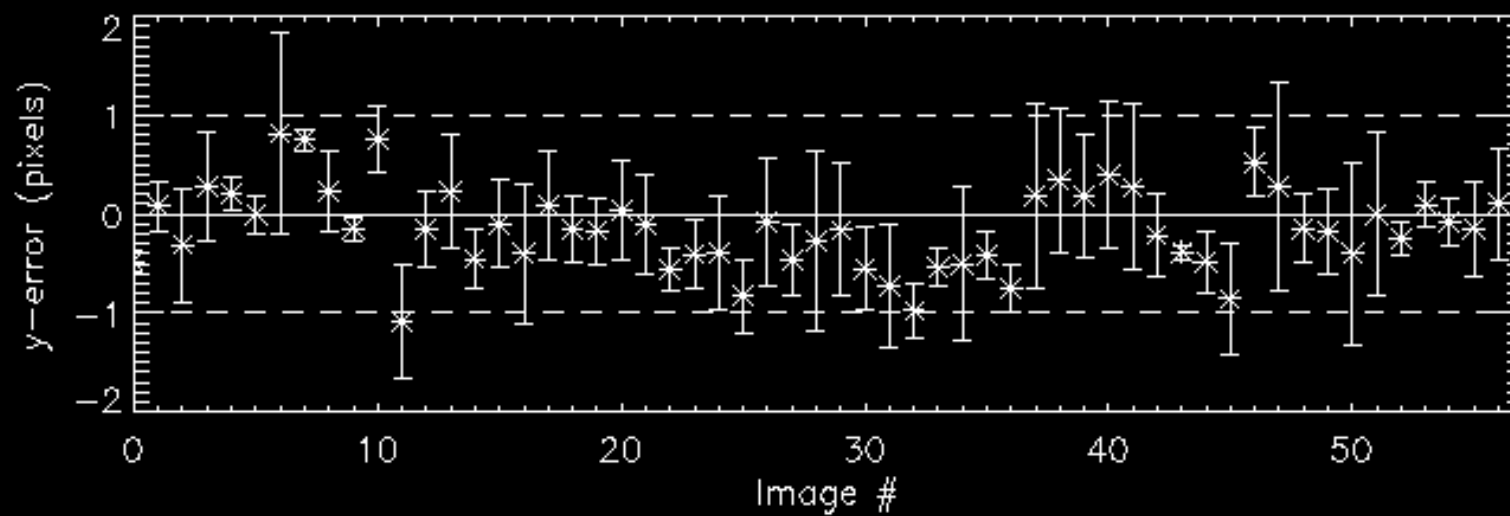
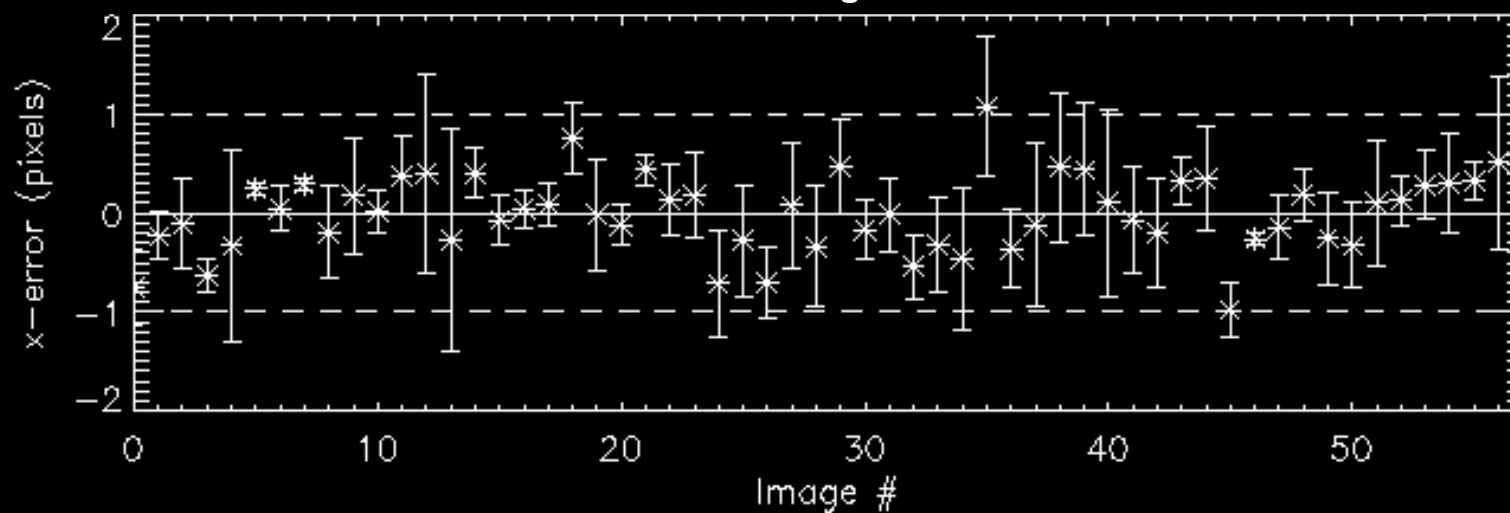
Validation

Pointing Errors



Validation

Corrected Pointing Errors



Final Result

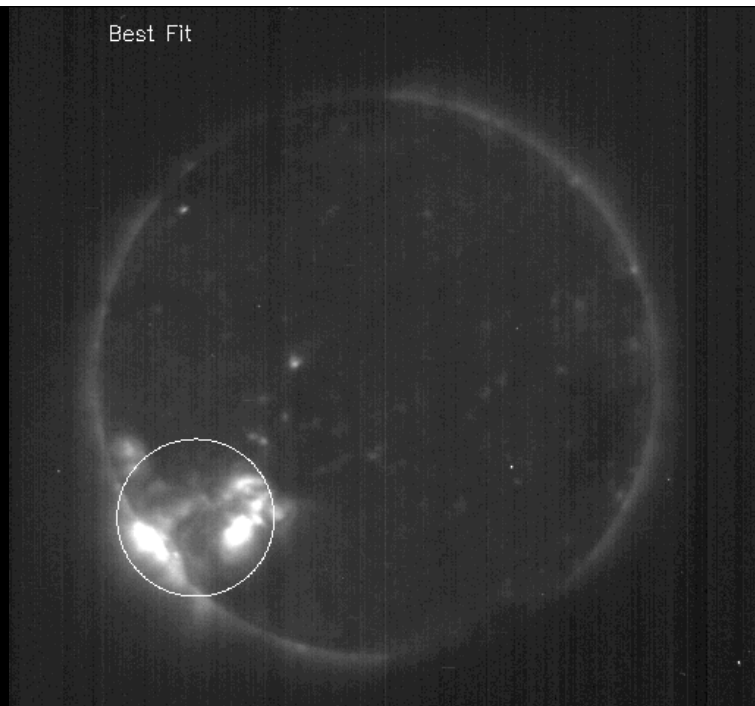
Before

After

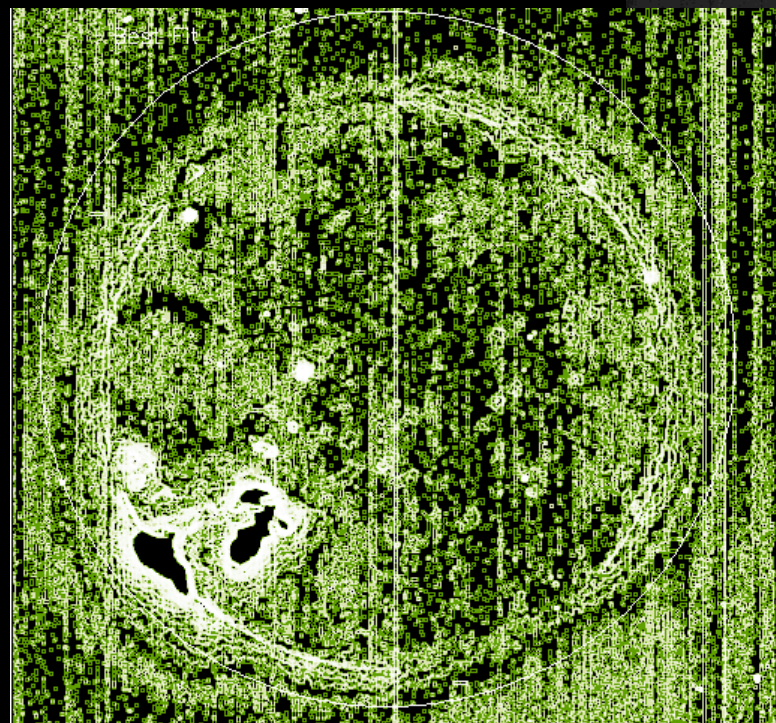
References

- Hill, Steven et al. “The NOAA GOES-12 Solar X-Ray Imager (SXI) 1. Instrument, Operations, and Data.” *Solar Physics* 226 (2005): 225-281
- Pizzo, Vic et al. “The NOAA GOES-12 Solar X-Ray Imager (SXI) 2. Performance.” *Solar Physics* 226 (2005): 283-315
- GOES 12 Science User Guide. <<http://www.sec.noaa.gov/sxi/info/ScienceUserGuide.html>>
- GOES I-M DataBook. NASA Goddard Space Flight Center, Greenbelt, MD: 1996. <<http://rsd.gsfc.nasa.gov/goes/text/goes.databook.html>>

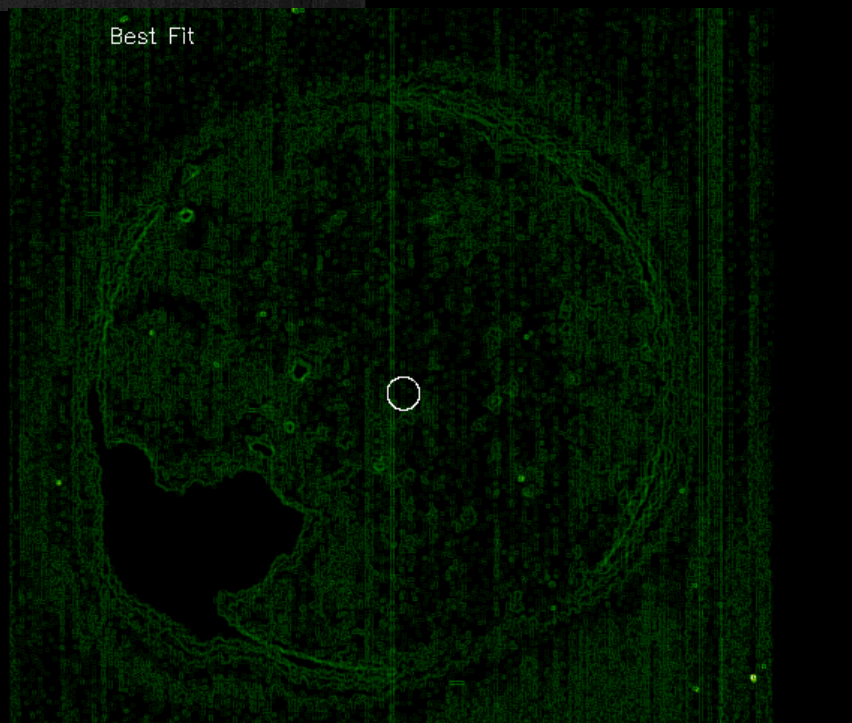
Best Fit



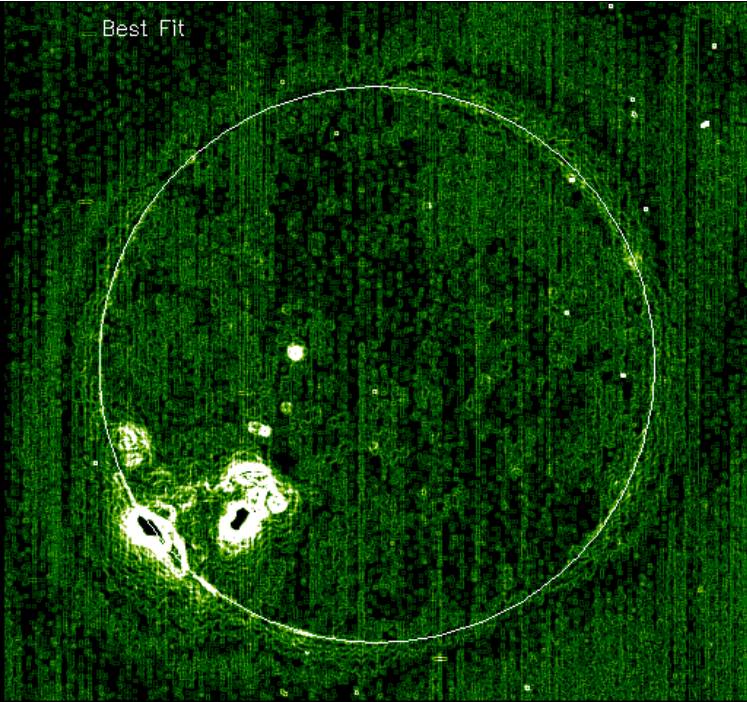
Best Fit



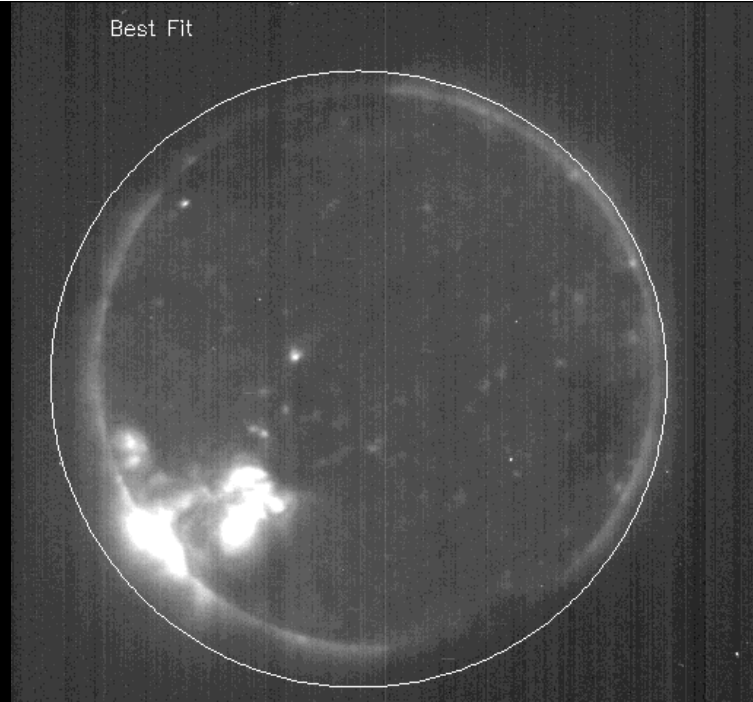
Best Fit



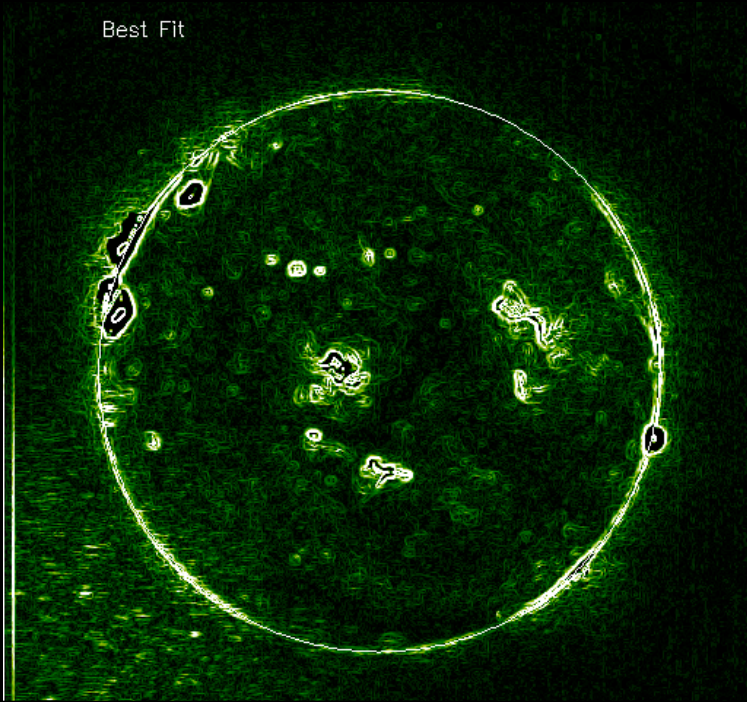
Best Fit



Best Fit



Best Fit



Best Fit

