Adventures in Classical PSF Subtraction

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Need for Coronagraphy

- Circumstellar Disks, exoplanets, stellar companions are often inconveniently close to a bright object (host star)
- Exposing sufficiently deeply to detect the object of interest can mean that you overexpose the instrument you are using and swamp the signal of interest
- This talk will focus on using a simple coronagraph, and how best to separate the signal of interest from light from the star

The PSF

- Optical systems, and HST is no exception, typically spread the light from an unresolved source due to diffraction, scattering in the telescope, and in the science instrument, and in some cases within the detector system.
- This is termed the point spread function (PSF).
- For the majority of circumstellar disks and exoplanets signal in the wings of the PSF>>signal of interest.

Classical PSF Subtraction

- Simplest of the techniques that will be covered in this hands-on demonstration
- Use a ***suitably chosen*** other observation as an estimate of the light from the star that you want to get rid of.
- Need to match the science observation in terms of factors affecting the shape of the PSF, and those affecting temporal variation in the measured PSF.

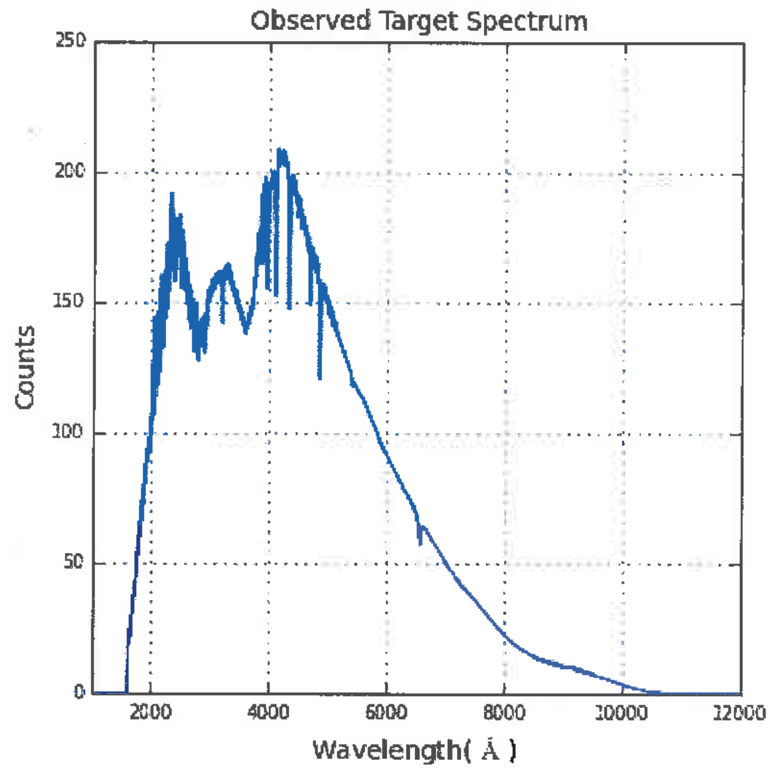
Shape of HST PSF depends on Source Spectral Energy Distribution

Targets for coronagraphic observation are typically on the bright side for direct Imaging.

STIS CCD used for coronagraphic imaging
Has throughput from 0.2-1.0 microns

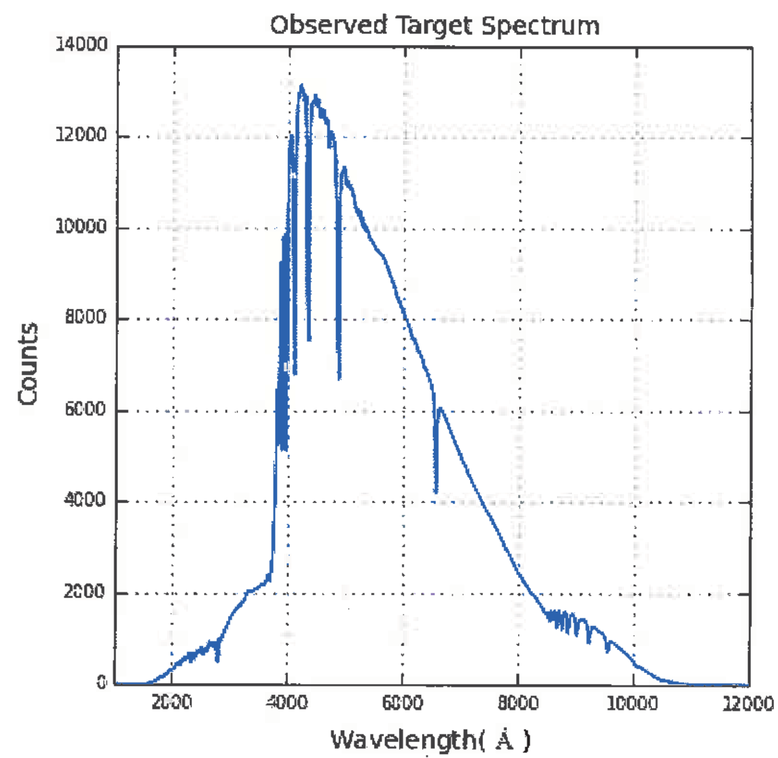
Effective wavelength of the image is a strong function of Teff.

Here we see the observed response for a white dwarf (Feige 110) – bulk of signal is at wavelengths <5000 Å



A1V simulation

By A1V, the bulk of the signal is in the Conventional optical, but with broad Wings.

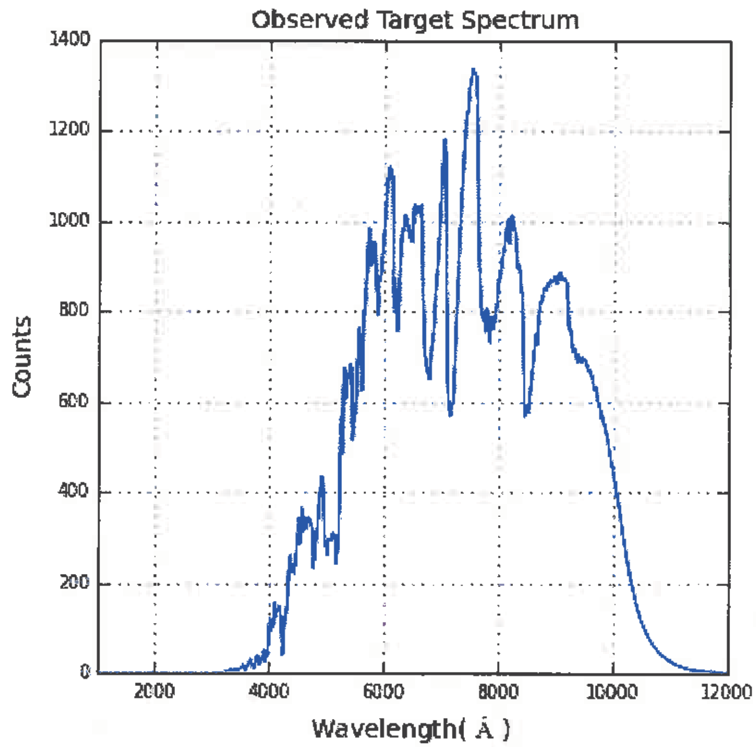


M2 Simulation

By early M, the effective wavelength of the STIS image is 7700 Å.

Sensitivity to color of source decreases as bandwidth decreases, but is typical of all 3 HST coronagraphs.

JWST will have other issues, namely a sensitivity to thermal emission from The inner disk (IR excess), and the fact that diskless stars will be blue compared to any system with an IRE.

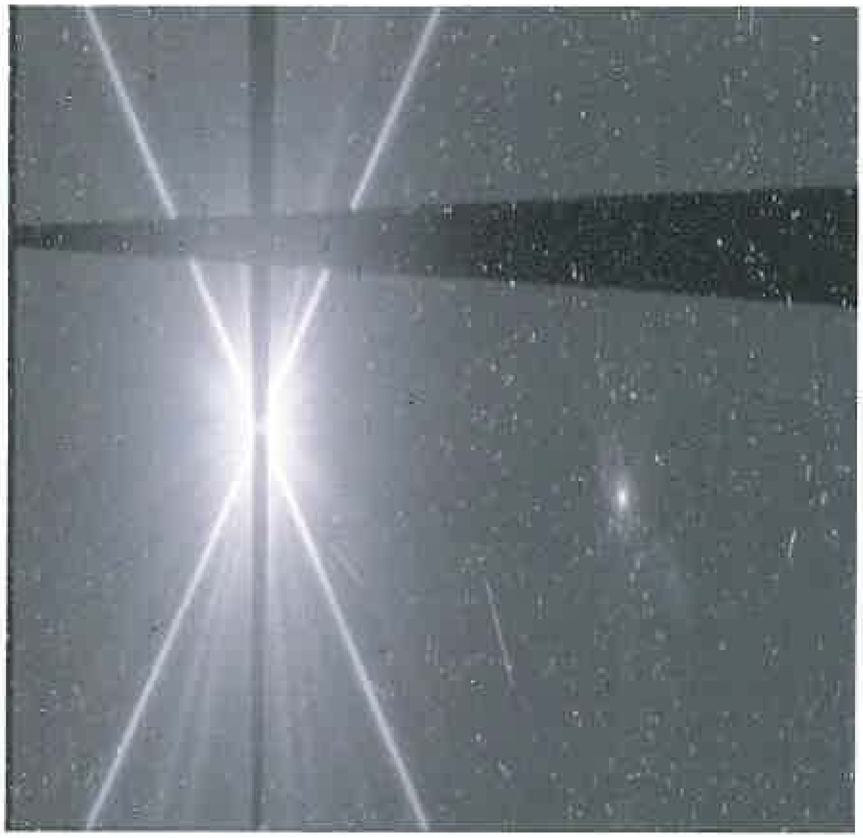


And also on factors affecting focus

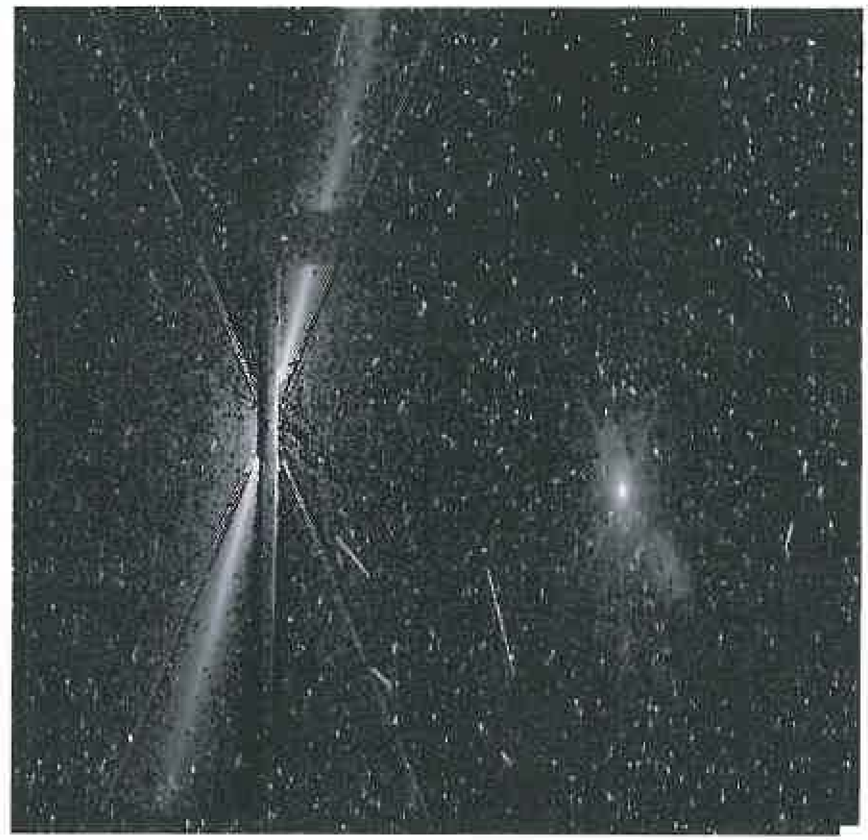
- HST is in a low-Earth orbit and experiences changing thermal conditions.
- Scheduling for HST does not include thermal effects
- differences between focus conditions for the target and what you are using as an estimate of the PSF result in radial streamers – differences in the dispersed speckles

Case 1: Use the same star, different roll of spacecraft on sky

AU Mic – obiw36030_flt.fits



Subtracting obiw35030_flt.fits



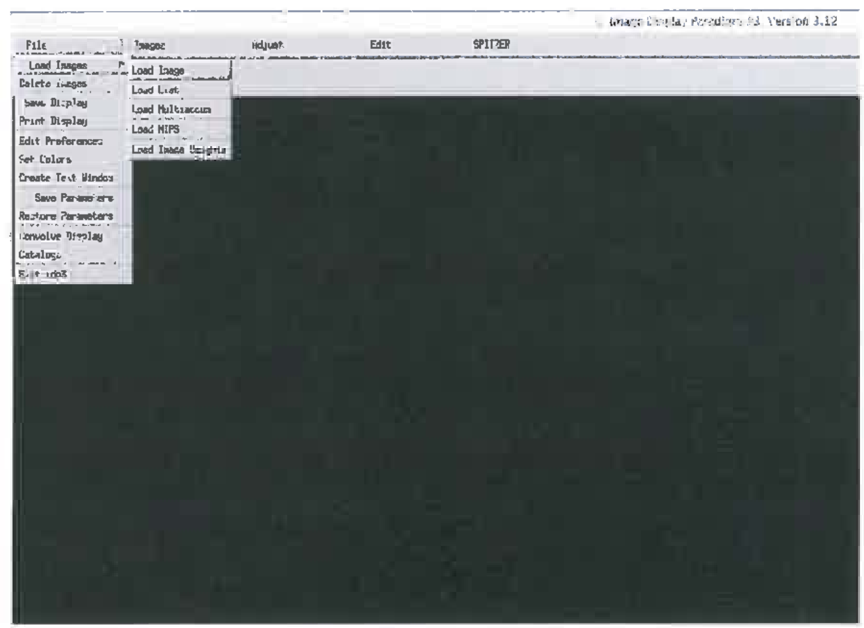
Introduction to IDP3

- For exploring PSF subtraction you need a display-oriented tool that will let you play with registering, scaling, and subtracting one image from another, while allowing you to tweak the display scaling, color, etc. to your preferences.
- Various tools used by the HST IDTs, and other teams, but we have chosen IDP3 developed by the NICMOS team
- Starting point is file *in the detector frame* with NO geometric distortion correction or mapping to the sky.
- Get into IDL, type IDP3
- Large window should appear with File, Images, Adjust, Edit, Spitzer, and Help on menu bar

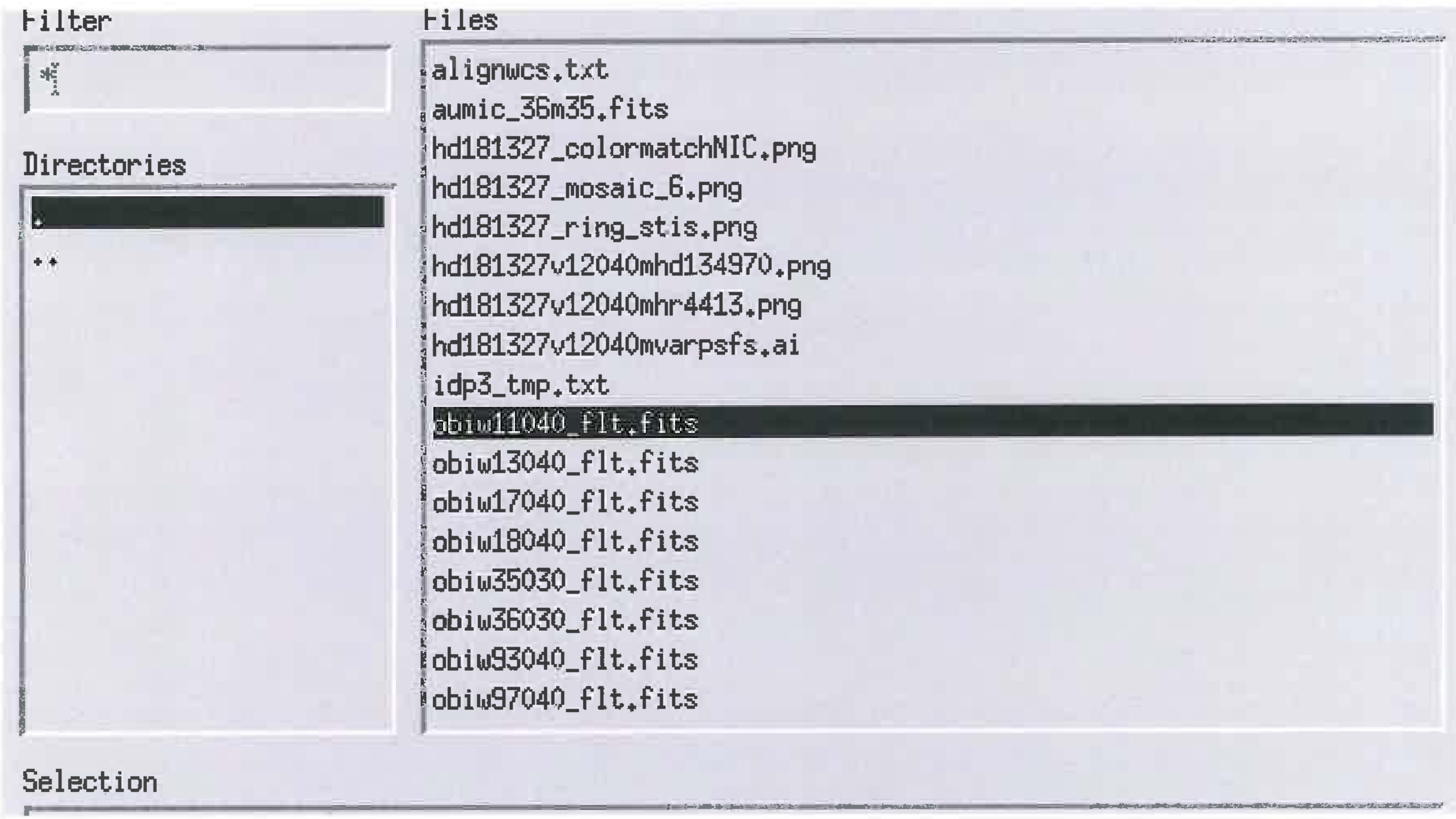
Loading Data

Choices

- STIS data are typically multiple sub-exposures to facilitate cosmic ray removal.
- Can load the first image of a set, or the full set.
- Under file, go to the load images item
- To read the first readout, go to load image on the 2nd menu, to read in a set, go to Load Multiaccum (NICMOS terminology).

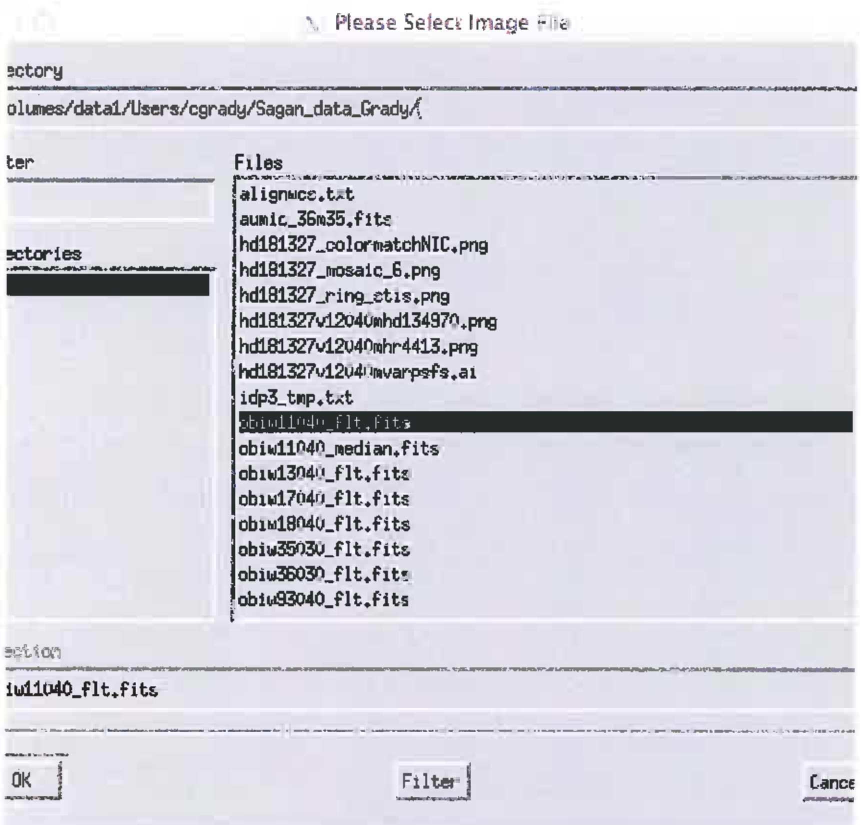


Selecting the file to be loaded

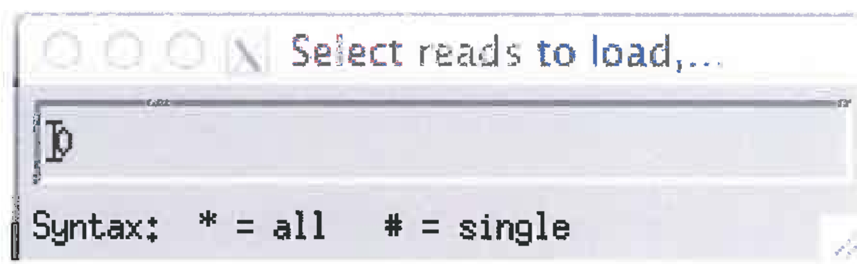


Loading multiple reads

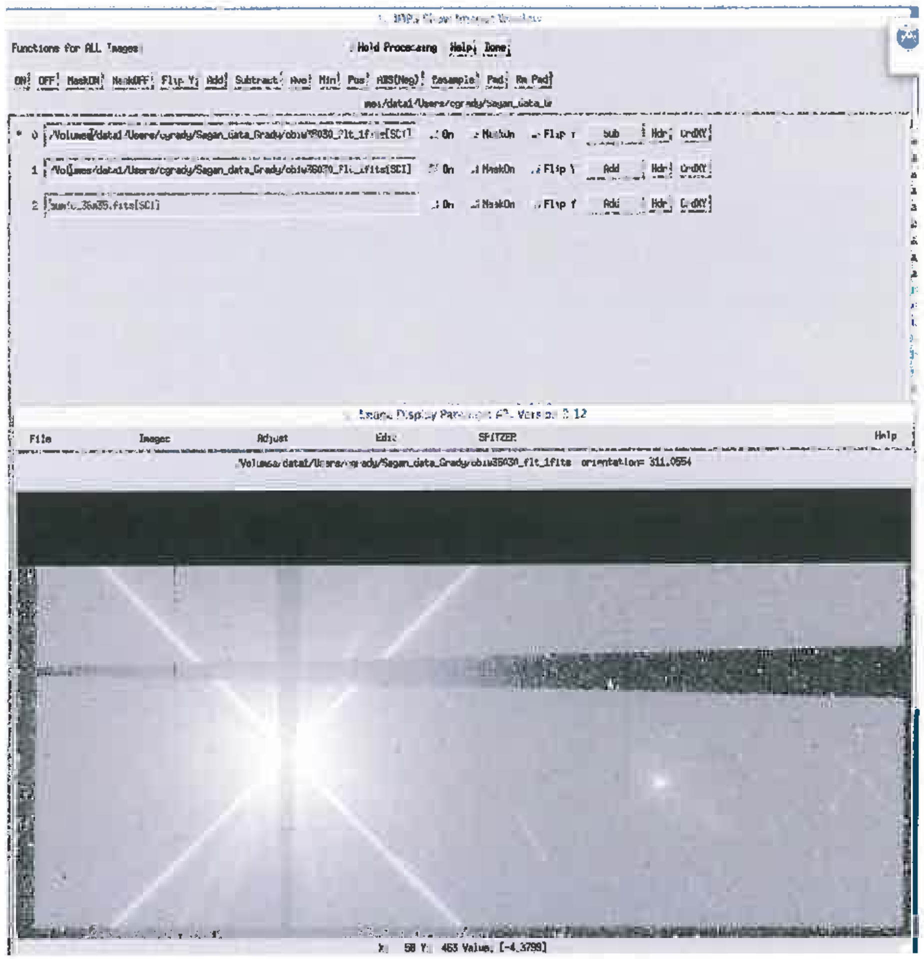
File>load image>load multiaccum



To load all reads from an image, type *; or you can specify individual reads by number



Showing the images



Adjusting the Display

- You can adjust the image dynamic range, color table, and scaling (linear, log, square root) using adjust> display menu item.
- HST coronagraphic images typically have a large dynamic range, so I find log scaling works well.
- You can also shrink the window to the actual data size – IDL increments from the lower left image corner- using the resize display option.

Image registration

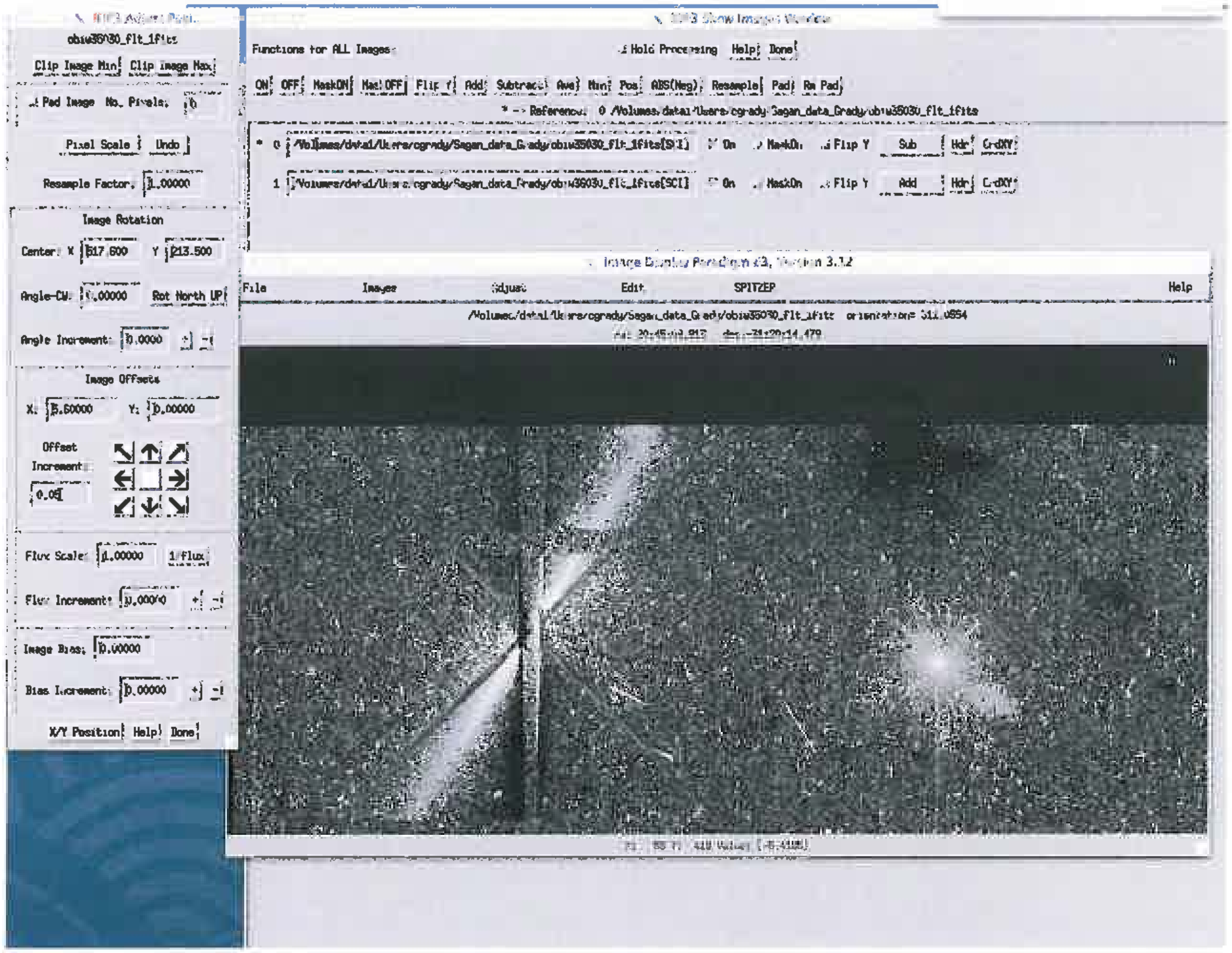
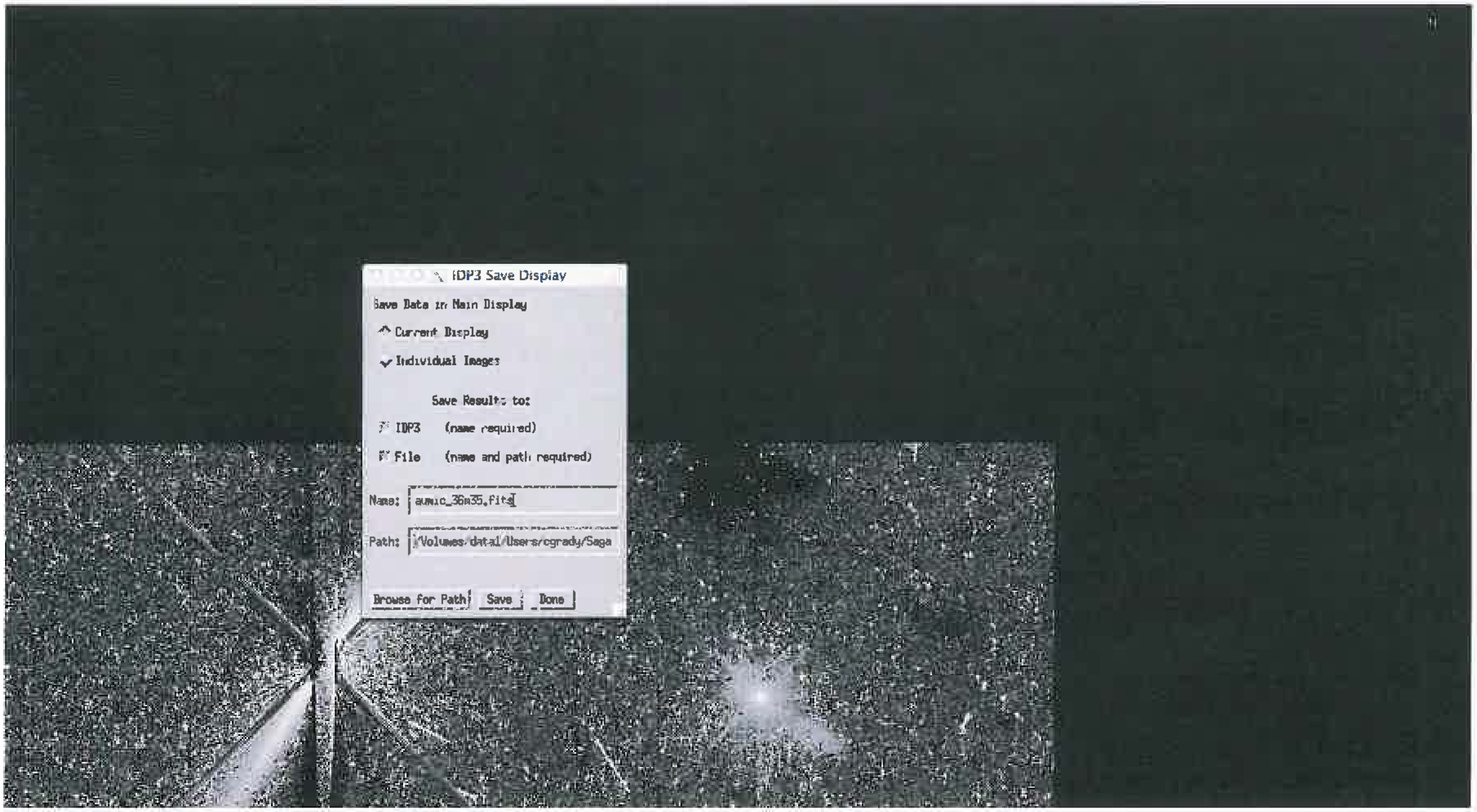


Image Registration

- In show images window select the image to be subtracted as the one with *
- Now go to the Adjust>adjust position menu
- Default increment is 1.0 pixels (0.05" for STIS),
- I find 0.05 pixel works better
- Use the multiple arrow panel to "drive" the image to be subtracted so that there is not a significant dark/light asymmetry in the image and the diffraction spikes are largely nulled
- In this case since we were using data for the same star taken in consecutive orbits, we did not need to adjust the flux scaling for the net image.

Saving Your Image

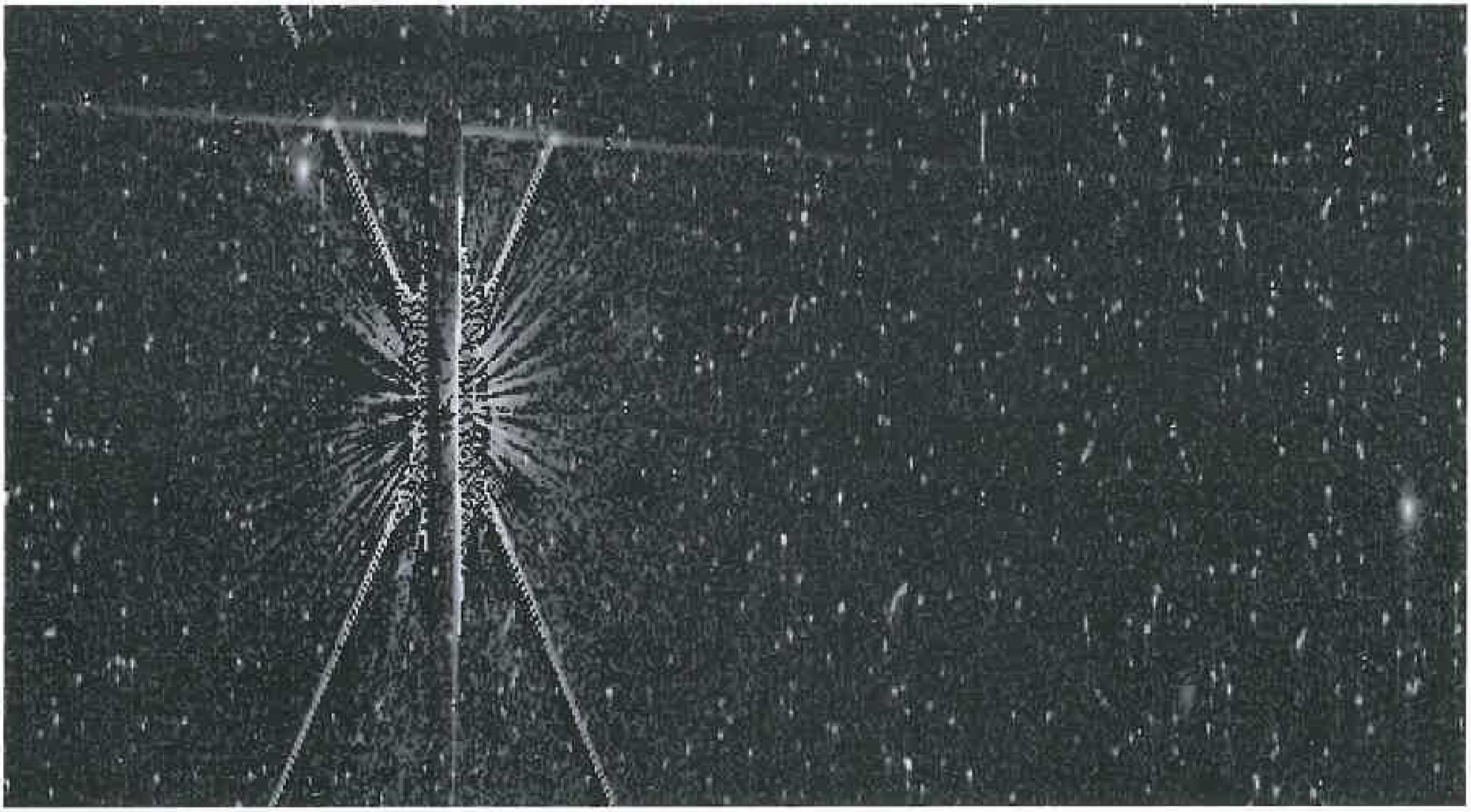


Saving Your image

- You can save for use within IDP3
- Or write a file for external use or both
- Go to File>save display menu, give a file name and path.

- Congratulations you now know the basics of classical PSF subtraction.

Now for a face-on disk…

- 

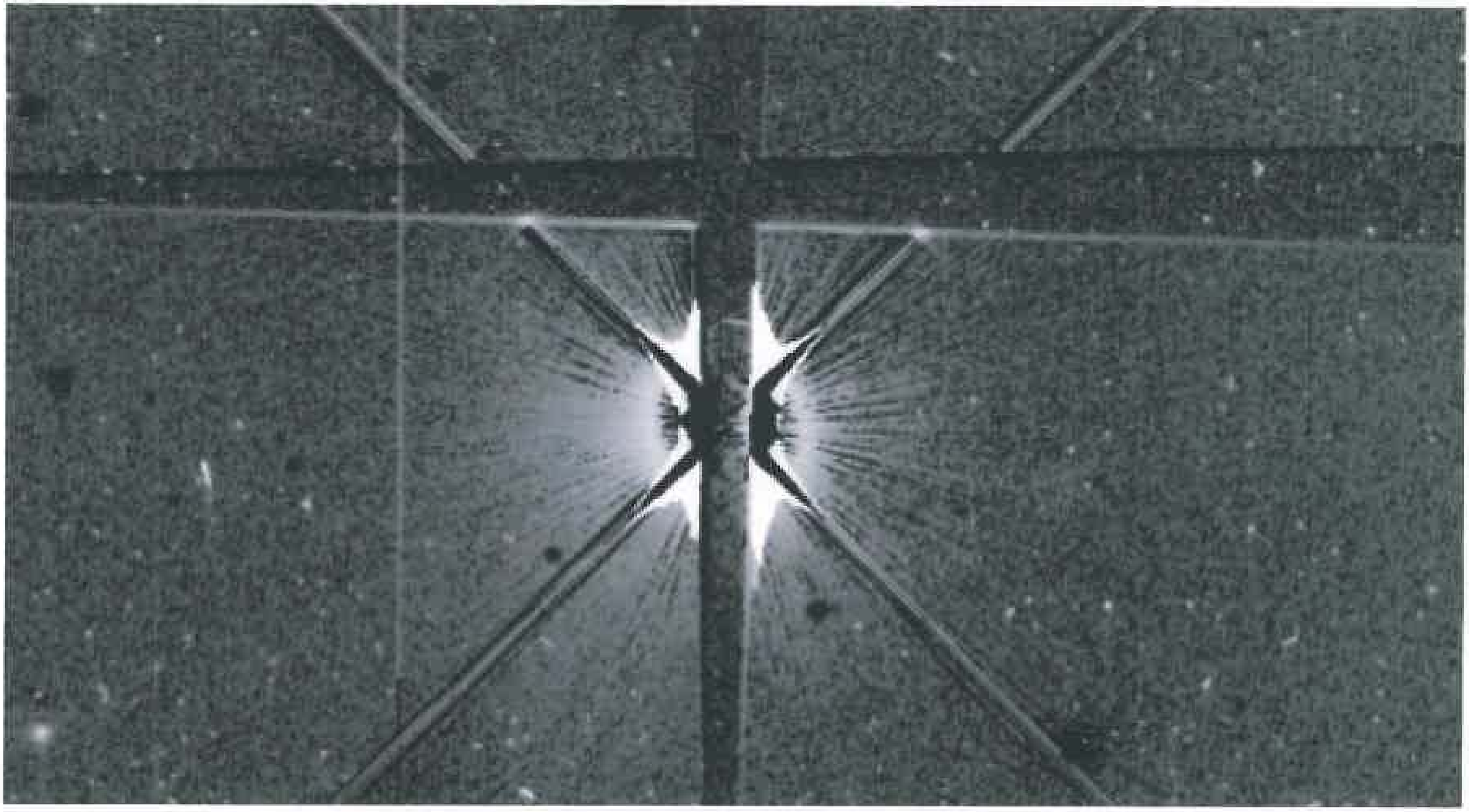
Strengths and Weaknesses of ADI-like strategies

- Best for point source detection and edge-on disks such as AU Mic
- Can eliminate any signal which is azimuthally-symmetric over the roll angle – face on disks can be eliminated.
- Can end up with a mess if the nebulosity is very structured
- Need alternate robust technique for removing the PSF, which conserves flux

Case 2: Non-Contemporaneous PSF template observations

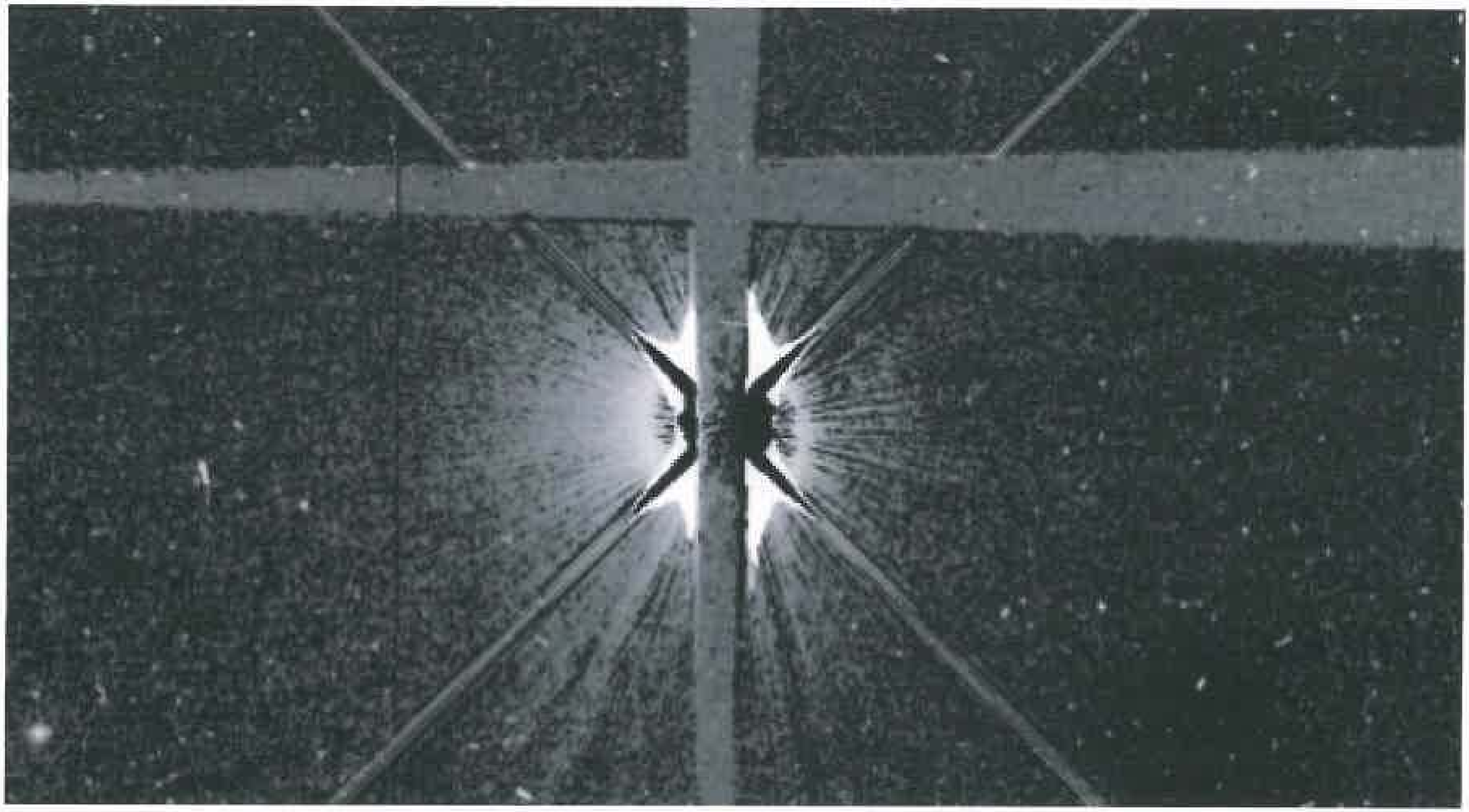
- Science target HD 181327, mid-F member of β Pic moving group
- Disk marginally resolved by Herschel (Lebreton et al. 2012)
- Disk resolved in scattered light by NICMOS and ACS (Schneider et al. 2006)
- Location of bulk of debris constrains SED modeling; asymmetries can constrain planets.

Using archival data for HR 4413 as template



HD 181327v12-hr4413

Using HD 134970 as template



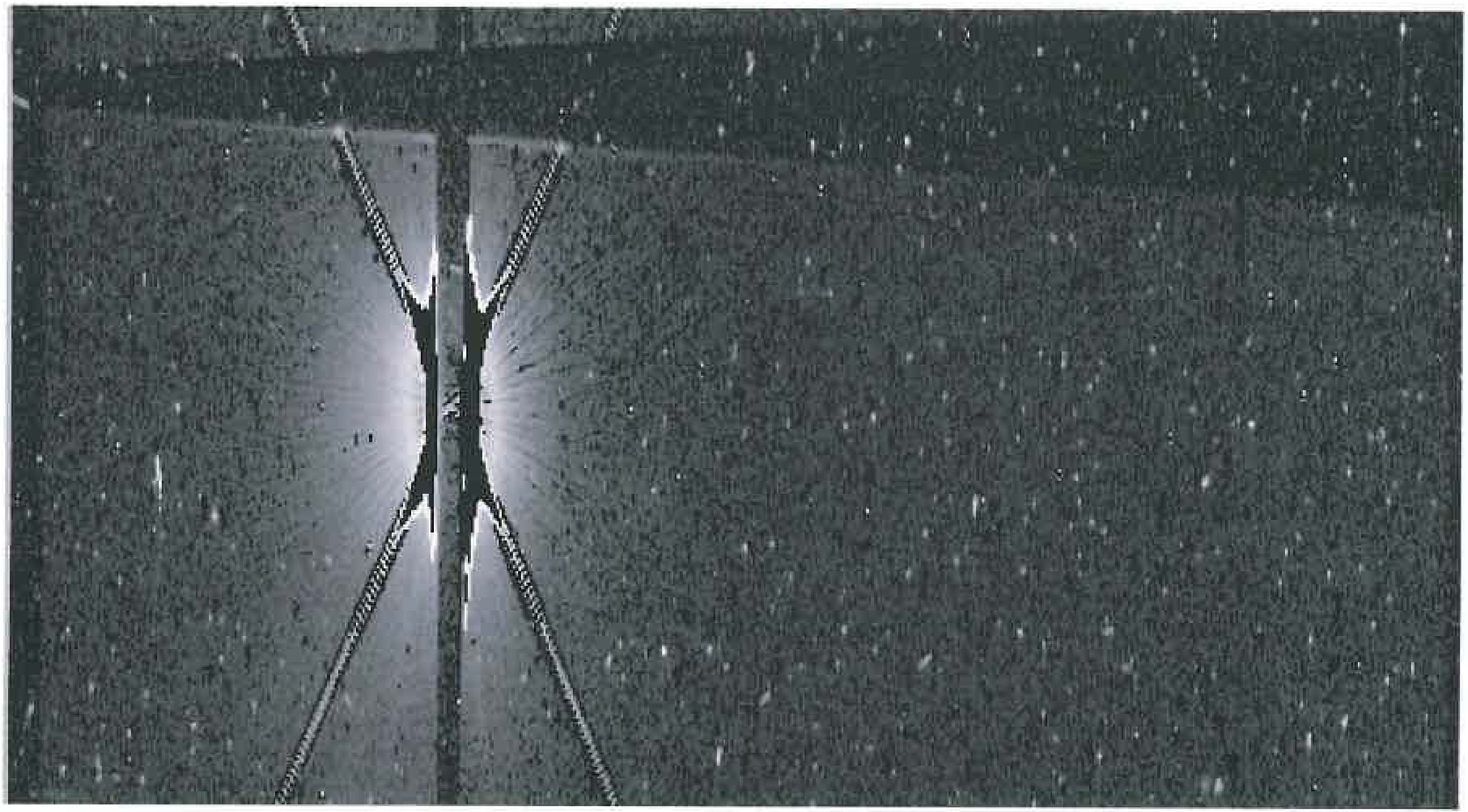
What you get from such processing

- Detection
- Bulk of signal in ring – inner edge, outer edge, inclination, can compare with predictions for location of debris belt from FIR data assuming that the grains are large, compact grains (gray or blackbody).
- Exterior to ring, additional, azimuthally asymmetric nebulosity
- There are residuals which depend on choice of PSF template data, and this is a bright disk. Residuals become more of a nuisance as the surface brightness of the disk decreases.

Case 2 hands-on

- Load files obiw11040_flt.fits
- obiw12040_flt.fits
- obiw13040_flt.fits – psf template
- obiw17040_flt.fits – psf
- obiw93040_flt.fits - psf
- obiw97040_flt.fits - psf
- Now try subtracting 12040 from 11040 and using the PSF template data, some planned and some template used for another target in this program

Case 3: Color-matched, contemporaneous PSF data



Comments on color-matched, contemporary PSF subtraction

- Suppress residuals, since have allowed HST to come to a quasi-equilibrium
- Note large number of hot pixels, cosmic ray events, etc. – these can be removed by combining a suite of science target-PSF data where HST is rolled between observations – reduce STIS wedge to a quasi-circular occulted zone with r=0.35", and can median filter to remove hot pixels.

HD 181327 – smaller obscuration

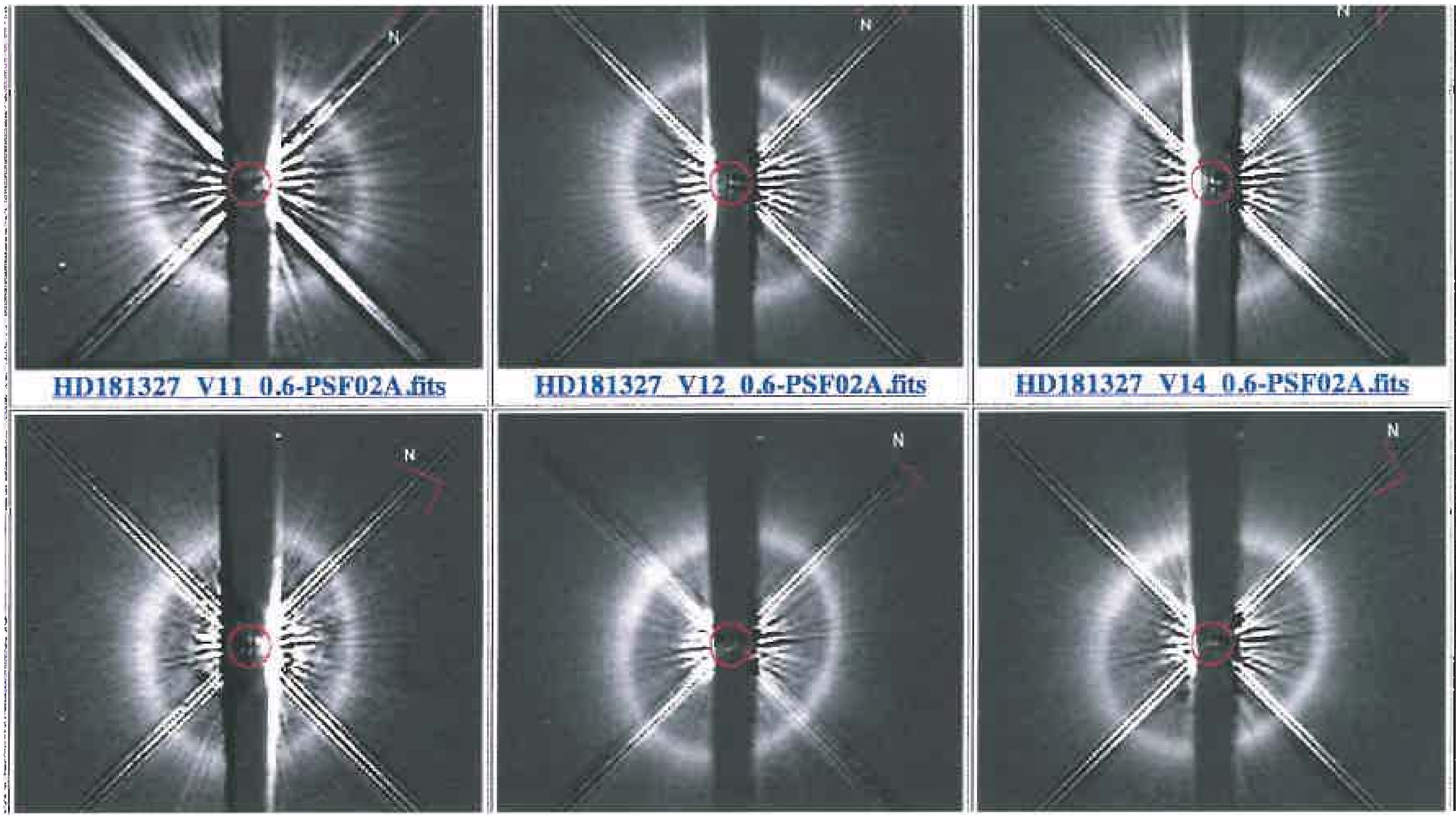
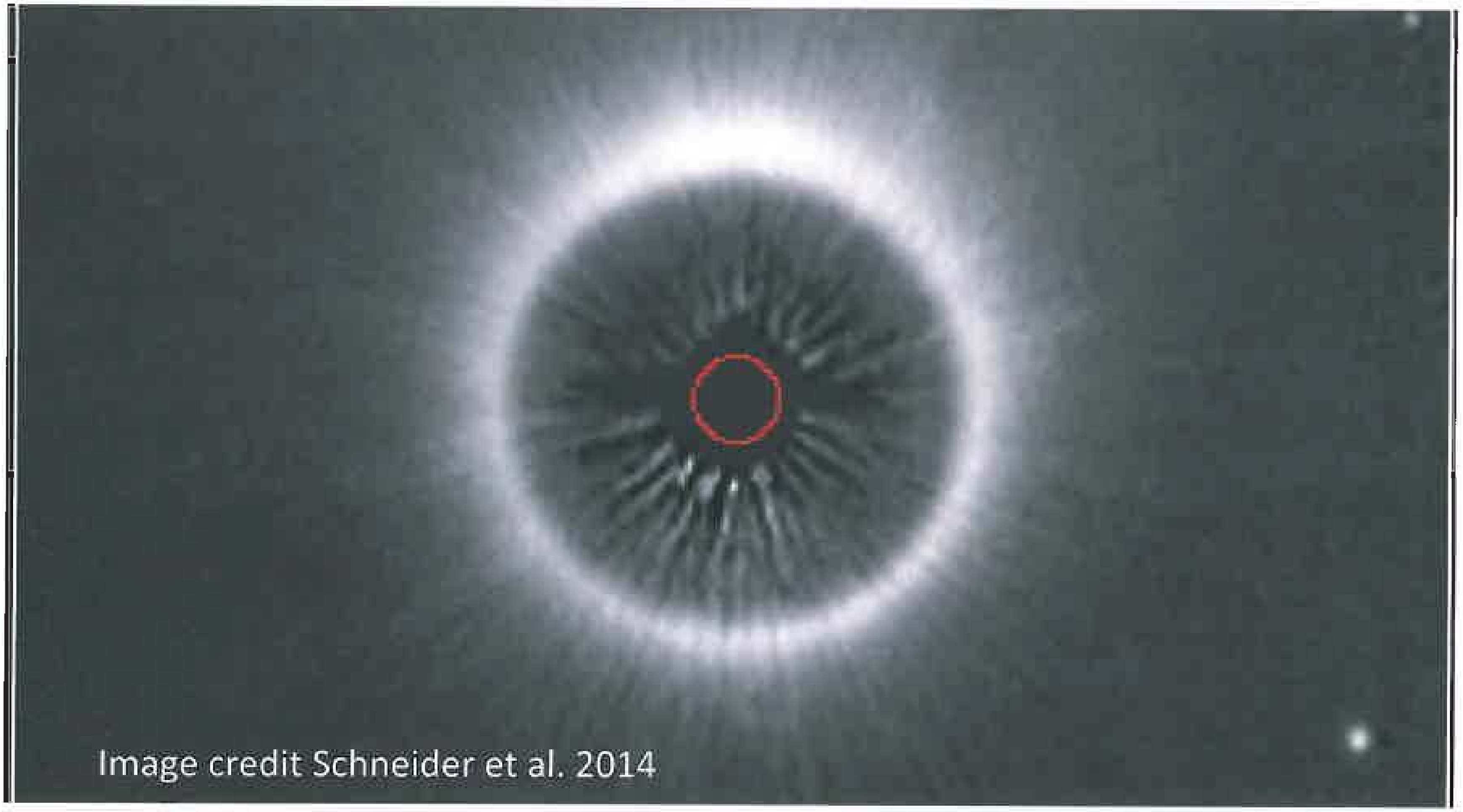


Image Credit Schneider et al. 2014

HD 181327 after merging images

Deprojection and compensation for r^{-2} illumination gradient



Further improvements & Summary

- Can largely remove the remaining residuals using filtering techniques
- Now are at the point that you can begin science
- PSF subtraction with HST requires choice of suitable template targets, planning the observations so that the template is taken as close in time to the science data as feasible, and straightforward data reduction.