NICI Python Data Reduction

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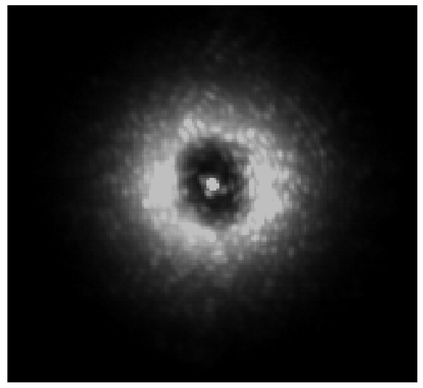
ABSTRACT

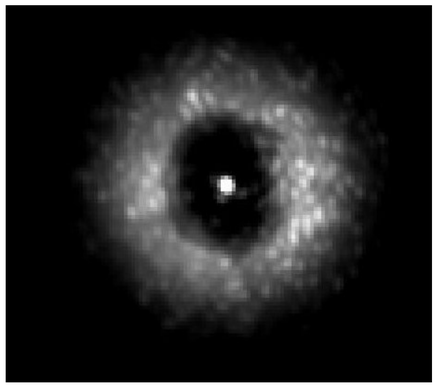
NICI, the new adaptive-optics supported Near Infrared Coronagraphic Imager of the Gemini Observatory (South), has recently been commissioned and offered to the astronomical community.

We describe its reduction package and design of the different modules. The software has been written in Python using numerical routines from Numpy, Scipy and Ndimage, as well as the Gemini module Astrodata dealing with Gemini's fits-file structure.

We discuss science data preparation, and basic reduction steps as well as the implementation of the Angular and Spectral Differential Imaging (ADI/SDI) reduction algorithm, and the LOCI method (Locally Optimized Combination of Images) producing the final set of reduced science FITS files for high-contrast imaging.



Original Red Frame (flat-fielded)

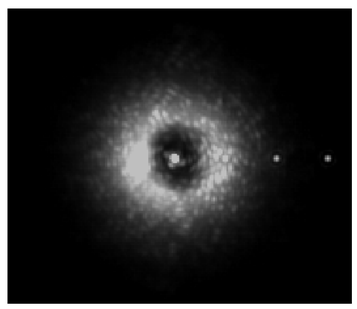


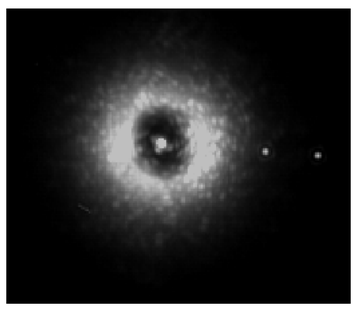
Original Blue Frame (flat-fielded)

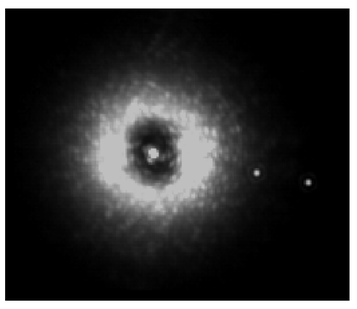
In this example the selected semitransparent coronagraphic mask dampens the flux of the center star by approximately 6.5 magnitudes.

NICI INSTRUMENT

NICI (Ref. 3) combines an 85-element curvature adaptive optics system, a dedicated Lyot coronagraph, and a specialized dual-channel camera into a single instrument optimized to detect large Jovian-type planets around nearby stars. Sensitivity is enhanced by spectrally differencing two images taken simultaneously inside and outside the strong near-infrared methane absorption features found in substellar objects cooler than 1400 K. Integrating the three major subsystems into a single instrument keeps non-common path aberrations small, limited only by the residual atmospheric wavefront and scattering. Optical scattering and ghosts are minimized by using off-axis paraboloids of lenses. Both channels are equipped with a 1024x1024 ALADDIN InSb array (1 -5 µm), with an imaging scale of 18 mas/pix and field of view of 18x18 arcsec. A variety of broad- and narrow-band filters are available, including AO-quality filters to sample the methane absorption band at 1.6 µm.







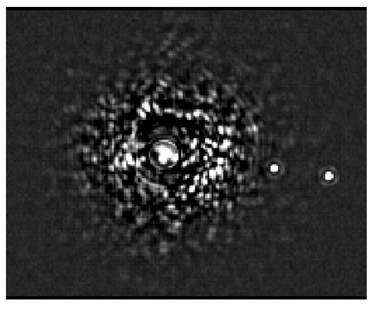
To demonstrate the field rotation and contrast gain three artificial objects are introduced (0.5", 1.0", 1.5" from the central star under the semi-transparent mask) . The exposure time (60 sec) is small enough to keep smearing of potential objects closer than 2” negligible. The shown frames are taken 5 minutes apart.

NICI Reduction

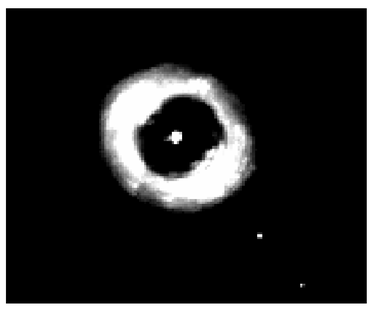
Pure Python (v2.5) code. Runs where Python runs (in principle) . The external public modules needed are *scipy, matplotlib and numpy.*

The reduction sequence is:

- n*cqlook* -- Quick look statistics for an observation sequence. It creates lists of calibration files, science files and logs. Useful for the next scripts.
- n*cprepare* -- Find mask center and update header of science data.
- n*cmkflats* -- Produces calibration fits files *flats_red, flats_blue, sky_red and sky_blue.*
- n*cscience* -- Analysis of the science dataset.



The Median of the frames of one cube (flat fielded) observed with the instrument rotator fixed. The radius fromthe center to the outside simulated source is 1.5 arcsec.

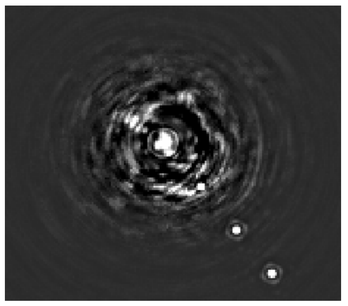


After rotating each frame of the cube to a common angle the median across the cube shows smearing due to rotation. Small scale features (static speckles) are averaged out, while the object signal is enhanced.

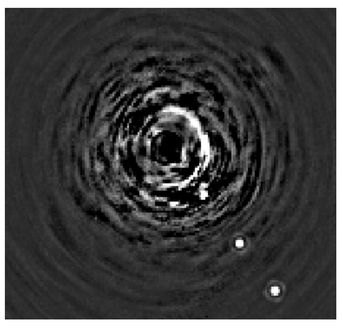
NICI SCIENCE DATA PRODUCTS

cube_[red,blue].fits
Flat fielded cube. Each slice is 1024x1024. Input for next steps.
medcrunchp[red,blue].fits
Median reduce thru the slices of the input cube.
sumcrunch[red,blue].fits
Sum reduce thru the slices of the input cube.
cube_rotate[red,blue].fits
Rotated cube using the parallactic angles to a common angle.
medcrunch_rotate[red.blue].fits
Median reduced of the cube_rotate.
sumcrunch_rotate[red,blue].fits
Sum reduced of the cube_rotate.
cube_medfilter[red,blue].fits
Median filtering of cube slices. This image is the initial cube minus the median-smoothed image. This is sort-of-an-unsharp-mask but we use a median instead of boxcar smooth.
medfilter_medcrunch_rotate[red,blue].fits
Rotated median reduced of cube_medfilter.
cube_shift_medfilter[red,blue].fits
Scales the two channels to a common 'speckle' size. This is done using the ratio of the central wavelengths of the filter bandpasses.
cube_sdi.fits
Differential imaging result or plainly is red-blue cubes.
sdi_medcrunch.fits
Median reduced of cube_sdi.
cube_loci_sdi.fits
LOCI subtraction of cube_sdi.
loci_sdi_medcrunch.fits
Median reduced of the cube_loci_sdi.
loci_sdi_sumcrunch.fits
Sum reduced of the cube_loci_sdi.
loci_medfilter_medcrunch[red,blue].fits
Median reduced of cube_loci_medfilter.
loci_medfilter_sumcrunch[red,blue].fits
Sum reduced of cube_loci_medfilter.
cube_loci_medfilter[red,blue].fits
Median filtering of the cube_medfilter.
cube_asdi.fits
'Super' Loci subtraction using the red channel as a cube and the blue channel as an additional sample of images.
asdi_medcrunch.fits
Rotation and median reduced of the cube_asdi.
asdi_counter_medcrunch.fits
Counter rotation and median reduced of the cube_asdi.

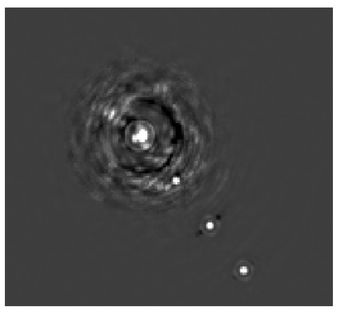
High-pass filtering of all frames in the initial cube to remove low frequency components leaving spatial scales similar to those of points sources.



After doing the steps described above for both channels, the contrast for methane containing objects can be further improved by differencing the red & blue channel pipeline output frames (SDI technique, see Ref. 1 & 2). Therefore, the frames are aligned with sub-pix accuracy and scaled according the wavelength difference to match the static speckles.



Taking the high-pass filtered output frame and applying the LOCI algorithm (Ref. 4) will even further increase the contrast. After reduction the innermost object (0.5”) can easily be identified.



References:

(1) Artigau et al. , 2008, SPIE, “NICI: combining coronagraphy, ADI and SDI”

(2) Biller et al., 2008, SPIE, “Observing strategies for the NICI campaigne to directly image extrasolar planets”

(3) Toomey et al., 2003, SPIE, “Near Infrared Coronagraphic Imager for Gemini South”

(4) Lafreniere et al., 2007, Astroph. Journal, “A New Algorithm for Point-Spread Function Subtraction in High-Contrast Imaging: A Demonstration with Angular Differential Imaging”