Gemini Multi-Conjugate Adaptive Optics System (GeMS)

Gemini South Adaptive Optics Imager (GSAOI)

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(on behalf of GeMS and GSAOI teams)
GSAOI Data
Calibrations
Image reduction
Distortion correction, mosaic-ing and combining GSAOI images
GSAOI Data
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**INSTNAME** = 'GSAOI' / Instrument used to acquire data

**OBJECT** = 'LMC FIELD 2' / Object Name

**OBSTYPE** = 'OBJECT' / Observation type

**OBSCLASS** = 'science' / Observe class

**GENMPRD** = 'GS-ENG-GEMSGSAOI.COM' / Gemini programme ID

**OBSID** = 'GS-ENG-GEMSGSAOI.COM-797' / Gemini Observation ID

**DATALAB** = 'GS-ENG-GEMSGSAOI.COM-797-017' / Gemini Datalabel

**OBSERVER** = 'P. Persson, B. Neichel' / Observer

**OBSERVAT** = 'Gemini-South' / Observatory (Gemini-North|Gemini-South)

**TELESCOP** = 'Gemini-South' / Name of telescope (Gemini-North|Gemini-South)

**PARALLAX** = 0. / Target Parallax

**RAVEL** = 0. / Target Heliocentric Radial Velocity

**EPICOH** = 2000. / Target Coordinate Epoch

**EQUINOX** = 2000. / Equinox of coordinate system

**TREKQUN** = 2000. / Tracking equinox

**SSA** = 'B. Marin, A. Serlo' / SSA

**RA** = 80.45476667 / Target Right Ascension

**DEC** = -69.49993333 / Target Declination

**ELEVATIO** = 47.317398611111 / Telescope Elevation at the start of exposure

**AZIMUTH** = 165.03995333333 / Telescope Azimuth at the start of exposure

**CRPA** = 154.450127727222 / Case Rotator Position Angle at start

**HA** = 01:59:46.70 / Telescope hour angle at the start of exposure

**LT** = 22:33:16.4 / Local time at start of exposure

**TKFRAME** = 'FK5' / Tracking co-ordinate

**DECTRAK** = 0. / Differential tracking rate Dec

**DKREPOCH** = 56290.037607 / Differential tracking reference epoch

**RATRACK** = 0. / Differential tracking rate RA

**FRAME** = 'FK5' / Target coordinate system

**PMDEC** = 0. / Target proper motion in Declination

**PMRA** = 0. / Target proper motion in RA

**WAVELEN** = 12500. / Effective Target Wavelength (A)
GSAOI Data

GSAOI Sky orientation: N-up, E-right (PA=0.0)

Array 2 - Raw

J-filter

Full frame - Raw

Science Opportunities arising from the new instruments at Gemini and SOAR
Dome flat - J-filter

Array 2 - Raw

Full frame - Raw
GSAOI Data

Bad Pixel Mask

Array 2 - Raw

Array 1 - Raw
Calibrations
Daytime calibrations

- Domeflats → a set of DF for all filters twice per run (beginning and end of each run) → Priority for filters used during the semester.
- Darks → only by request and from the science program

Nighttime calibrations

- Twilight flats → (best effort) TF for broad band filters only (Z, J, H, Kp, Ks and K).
- Photometric Standards → observed every night at three different airmass for all broad band filters used during the night.
  - Standard are observed guiding with PWFS1 – no laser
  - Using ROI of Array 1k x 1k. The star is imaged in each of the 4 arrays – for each filter, four images (one per array)
  - Standards are from Persson et al. (1998) and MKO standard.

All calibrations are taken from shared GS-CALYYYYYMMDD programs.
Image Reduction
Main Tasks
- gapprepare
- gaflat
- gasky
- gareduce

- gamosaic: mosaic images Doesn’t take into account distortion.

Imaging tasks:

- gacalfind - Create a table of calibration information
- gacaltrim - Used to trim full-frame calibration files to the size of the input science image, including ROIs
- gdark - Process and combine GSAOI dark images
- gadmschk - Check supplied statistic section for an image and or the dimensions of two GSAOI images against each other
- gadisplay - Display GSAOI images
- gafastsky - Derive sky image for GSAOI, median or min/max filtering
- gaflat - Derive flat field for GSAOI images
- gaimchk - Check the obstype etc., of input GSAOI images
- gamosaic - Mosaic the 4 GSAOI arrays into one image
- gapprepare - Prepare raw GSAOI data for reductions
- gareduce - Reduce images from GSAOI (trim, dark and flat correct)
- gasky - Derive sky image for GSAOI, includes masking of objects
- gastat - Calculate statistics for a GSAOI image

Information and examples:

- gsaoinfo - Information on GSAOI and data reduction of GSAOI images
- gsaioexample - Print example reduction script to screen
GAPREPAIR: takes raw GSAOI data (4-extensions) and prepares them for reduction

- Trim the input data to remove the boarder of 4 un-illuminated pixels around the outside of each physical array.
- If not present, gain, readnoise (corrected for number of low-noise reads), non-linearity and saturation values will be updated for each array. Values stored in the file “gsaoi$data/gsaoiAMPS.dat”.
- If fl_nlc=yes (the default case), each array is corrected for non-linearity. The following equation is applied to each array for all input ADU ranges:
  \[ Y = X^*(a + bX + cX^**2) \]
  
  Y - linearity corrected pixel value, X - input pixel values; a, b, c - coefficients for different modes (bright, faint and very faint). Coefficients stored in "gsaoi$data/gsaoiNLC.dat"
- If fl_vardq=yes, the variance plane (the sum of the readnoise, corrected for the number of low-reads, and the pixel value in ADU) and the BPM are appended to the images.

• Current example data: J, H and Ks bands science images
  > set rawsci="/my-science-path/RawScience/"
  > unlearn gaprepare> gaprepare 74-77,82-85,90-93 rawpath=rawsci$ rootname=S20121229S fl_vardq+
GAFLAT: takes raw or g-prepared GSAOI flat data (4-extensions), sorts them by unique METACONF keyword values and combines them to form master flats.

- If the input files are raw, GAFLAT call GAPREPARE to prepare the data and add the METACONF keyword.
- If fl_vardq=yes, the variance and data quality extensions created by GEMCOMBINE will be included in the output image. The variance is the square of the output sigma plane from IMCOMBINE divided by the number of contributing pixels for a given pixel, then divided by the square of normalization factor(s).

- Current example data: J, H and Ks bands Domeflat images

```bash
> set calib="/my-calibration-path/RawCalibration/"
> unlearn gaflat> gaflat 148-169,180-189 rawpath=calib$/root=S20121220S fl_vardq+
```
GASKY: takes g-prepared GSAOI data (sky or object; 4 extensions) and creates a combined master sky frame. The individual mask frames created can be kept if requested. Object masks are used during the combining step.

- If fl_vardq=Yes, the variance and data quality planes are propagated and appended to the output images.
- Current example data: Ks bands science gaprepare-d images

```
> gemlist gS20121229S 90-93 > skyKs.lst
> unlearn gasky> gasky @skyKs.lst outimage=SkyKs.fits
fl_vardq \nfl_dqprop+ flatimg=gS20121220S0180_flat.fits
```
GAREDUCE: will reduce raw/g-prepared GSAOI images. It will dark subtract, sky subtract, flat divide and multiply by the GAIN, when asked to and when appropriate. GAREDUCED images can be run through GAREDUCE more than once. GAPREARE is called to prepare all non-prepared inputs.

• If fl_vardq=yes, the variance and data quality planes are propagated.

• Current example data: Ks bands science images

> unlearn gareduce
> gareduce 90-93 rawpath=./ rootname=gS20121229S \ fl_flat+ fl_sky+ fl_vardq+ \
flatimg=gS20121220S0180_flat skyimg=SkyKs.fits
Science Opportunities arising from the new instruments at Gemini and SOAR

Guarujá, August 8 - 10, 2014
Distortion correction, mosaic-ing and combining GSAOI images
Distortion correction

- There is no GSAOI script to correct for distortion and mosaic the images (under construction)

- Most of the distortion can calibrated out (static distortion)
  - Using observation of astrometric field in LMC with accurate coordinates (typical rms ~ 1 mas)

  - Residual distortion due to:
    - Asterism used (distribution of the NGS)
    - Dithering pattern used
    - Can’t be calibrated out.
    - Removal case by case

  - Sparse fields - distortion removal is problematic!!!
The example: LMC astrometric field observed in J, H and Ks-bands (2012 December 29UT)

- distortion correction and mosaicing --> using a catalogue of stars with precise coordinates (~1 mas rms, easiest case)
- Useful programs: scamp, swarp (Terapix) and Theli (http://www.astro.uni-bonn.de/theli/)
- In the example provided we use “mscred” inside IRAF”

Correct the WCS of the images

Transform images to a format that “mscred” package understand: Ks-images

```plaintext
real ra,dec
lrm -r bpm0*
imdelete sciima0???.fits ver-
for(i=90;i<94;i++) {
mkdir("bpm0000"+i)
imcopy("rgS2012122950000"+i+"/.fits[0]","sciima0000"+i+"/.fits")
imget("sciima0000"+i+"/.fits[0]","RA")
ra=real(imget.value)/15.0
imget("sciima0000"+i+,"fits[0]","DEC")
dec=real(imget.value)

for(j=1;j<4;j++) {
imcopy("rgS2012122950000"+i+"/.fits[SCI,"/j","/"],"sciima0000"+i+"/[im,"/j","/",append+]"
imcopy("rgS2012122950000"+i+"/.fits[DO,"/j","/"],"bpm0000"+i+"/[bpmm_im,"/j","/"],pl)
he dit("sciima0000"+i+"/","BPM","bpm0000"+i+"/[bpmm_im,"/j",pl],add+,ver-,show+)
he dit("sciima0000"+i+"/","RA",ra,add+,ver-,show+)
he dit("sciima0000"+i+"/","DEC",dec,add+,ver-,show+)
he dit("sciima0000"+i+"/","EQUINOX",2000.,add+,ver-,show+)
}
```
Distortion correction

- GSAOI WFS is quite good (within 0.3arcsec rms).
- You shouldn’t have problems to find the stars.
- Load packaging “mscred.mscfinder” and working on the 4 extensions

```c
for(j=4;j<=4;j+=1) {
  msctpeak ("skiima0090", "Coordinates.cat", "distortion.db", extname="im"/str(j),
  epoch=2000., update=no, autocenter=no, boxsize=9, projection="tnx",
  fitgeometry="general", function="polynomial", xxorder=4,xyorder=4,
  xxtensor="half", yxorder=4, yorder=4, yxtensor="half",reject=3.,
  interactive=yes, frame=1, marker="circle",omarker="plus", goodcolor="green",
  badcolor="red")
}
```

- Using “tnx” sky projection geometry (add no-linear terms to the solution),
- Using a polynomial fitting of order 4 with cross terms.
- Only for the image at 0,0 position (using as a reference)
**Distortion correction**

- **GSAOI WFS**
  - You should not have problems finding the stars.

- Load package "mscred.mscfinder" and working on the 4 extensions.

- Using "tnxskyprojec" geometry (add non-linear terms to the solution),
  - Using a polynomial fit of order 4 with cross terms.
  - Only for the image at 0,0 position (using as a reference)
Distortion correction

- Propagating the distortion correction to all other images using “mscsetwcs”
- “ccsetwcs” can be used also, but array by array
- Dithering images:
  - Offsets have to be propagated properly

```c
real raoff, decoff
for(i=90; i<=93; i+=1) {
    imgets("sciima0000"+i+"/[0]", "RAOFFSET")
    raoff = (-1)*real(imgets.value)
    imgets("sciima0000"+i+"/[0]", "DECOFFSE")
    decoff = (-1)*real(imgets.value)
    print("RAOFFSET = "/raoff/", DECOFFSET = "/decoff")
    mscsetwcs("sciima0000"+i+".fits", "distortion.db", ra="RA", dec="DEC", equinox="EQUINOX", ra_offset=raoff, dec_offset=decoff)
}
```
Distortion correction

- Propagating the distortion correction to all other images using "mscsetwcs"
- "ccsetwcs" can be used also, but array by array
- Dithering images:
  - Offsets have to be propagated properly

```c
real raoff, decoff
for(i=90; i <= 93; i++) {
    imget("sciima0000"+i+"/[0]", "RAOFFSET")
    raoff = (-1)*real(imget.value)
    imget("sciima0000"+i+"/[0]", "DECOFFSE")
    decoff = (-1)*real(imget.value)
    print("RAOFFSET = "raoff,"DECOFFSET = "decoff)
    mscsetwcs("sciima0000"+i+".fits","distortion.db",ra="RA",dec="DEC",equinox="EQUINOX", ra_offset=raoff,dec_offset=decoff)
}
```
Mosaic-ing

- Build mosaic with “mscimage”
- mscstat is used to calculate the average sky for all array (+ std)

```c
real ave, std
int nima
for(i=90;i<=93;i++) {  
    mscstat("sciima0000"+i,fields="mean",usemask=yes,gmode=no,format=, >> 'tabval')
    type("tabval") | average | scan(ave, std, nima)
    printf("image 94d; Average sky 9.5f; stddev 9.5f; Array 92d\n",i,ave, std, nima)
    mscimage("sciima0000"+i, "mscimage0000"+i,format="image",pixmask=, verbose=, wccsource="image",reference=", RA=INDEF,DEC=INDEF,
    scale=0.02, rotation=INDEF,blank=0.,interpolate="sinc17",interpolate="linear",
    boundary=constant,constant=ave,fluxconserve=-,trim=4,nxblock=4200,
    nyblock=4200,interac=nx=20,ny=20,fitgeometry=general,xorder=4,
    xorder=4, yterms="half",yorder=4, yterms="half",fd_in=",
    fd_ext=",fd_coord=")
    delete('tabval',verify)
}
```

Image  90; Average sky 1981.338; stddev  1.86854; Array  4
WCS reference image is sciima0090[im4]
Resampling sciima0090[im1] ...
Resampling sciima0090[im2] ...
Resampling sciima0090[im3] ...
Resampling sciima0090[im4] ...
Creating image msciima0090 ...

Science Opportunities arising from the new instruments at Gemini and SOAR
Stacking images

- All imagers are aligned to a common reference point
- Before the stacking process, matching intensity scale is recommended.

Using the 2MASS catalog and “mscgetcatalog” to get the catalogue `> mscgetcatalog msciima0090 ima090.cat magmin=12.0 magmax=18.0 cat=" twomass@noao"

- Match intensity using “mscimatch"

```bash
files msciima0090.fits,msciima0091,msciima0092,msciima0093 > inpKs.lst
mscimatch @inpKs.lst ima090.cat bpm="BPM" scale+ zero- box1=21 \ box2=51 lower=0. upper=32000. niterate=4 sigma=2. interac+ \ verbo+ accept+
```

- Stacking can be done with any program (imcombine, combine, gemcombine or mscstack)
- Here we use “mscstack”

```bash
mscstack @inpKs.lst lmcfeld2Ks.fits bpmasks="lmcfeld2Ks_bpm" \ combine=average reject=avsigclip masktype=goodvalue maskval=0. blank=50000. scale=!mscscale zero=!msczeror dnoise=rnoise \ gain=gain
```
Final combined image (Kshort - filter)