Science Opportunities arising from the new instruments at Gemini and SOAR

- GSAOI Data
- Calibrations
- Image reduction
- Distortion correction, mosaicing and combining GSAOI images
GSAOI Data
**GSAOI Data**

<table>
<thead>
<tr>
<th>EXT#</th>
<th>EXTTYPE</th>
<th>EXTNAME</th>
<th>EXTVE DIMENS</th>
<th>BITPI</th>
<th>INH OBJECT</th>
<th>LMC FIELD 2</th>
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<tbody>
<tr>
<td>0</td>
<td>IMAGE</td>
<td>S20121229S0074.fits</td>
<td>1 2048x2048</td>
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<td>-32</td>
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<td></td>
<td>4 2048x2048</td>
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<table>
<thead>
<tr>
<th>CCDNAME</th>
<th>'G2'</th>
<th>Array name</th>
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<tr>
<td>CCDSIZE</td>
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<td>DEC. in tangent plane projection</td>
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<td>CRVAL2</td>
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<td>partial of first axis coord w.r.t. x</td>
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<td>CD1_2</td>
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<td>Pixel scale in X (in arcsec)</td>
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<tr>
<td>YSCALE</td>
<td>0.0197150286420476</td>
<td>Pixel scale in Y (in arcsec)</td>
</tr>
</tbody>
</table>
GSAOI Data

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

Array 2 - Raw

J-filter

Full frame - Raw

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GSAOI Data

Bad Pixel Mask

Array 2 - Raw

Array 1 - Raw

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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
- gadark - Process and combine GSAOI dark images
- gadimchk - 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
- gamchk - 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:

- gsaoiinfo - Information on GSAOI and data reduction of GSAOI images
- gsaioexamples - Print example reduction script to screen
Reduction

**GAPREPA RE**: 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:

\[ Y = X^*(a + b*X + c*X**2). \]

*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

> 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 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

```bash
> gemlist gS20121229S 90-93 > skyKs.lst
> unlearn gasky> gasky @skyKs.lst
outimage=SkyKs.fits fl_vardq \nfl_dqprop+ flatimg=gS20121220S0180_flat.fits
```

---

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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 ran 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
Reduction

Array 2 - Raw

Kshort-filter

Full frame - Raw

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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!!!
Distortion correction

- 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
!rm -r bpm0*
!rm delete scliama0??.fits ver-
for(i=90;i<=94;i+=1) {
  mkdir("bpm0000"+i)
  imcopy("rgS2012122950000"+i//.fits[0],"scliama0000"+i//.fits")
  imget("scliama0000"+i//.fits[0],",RA")
  ra=real(imget.value)/15.0
  imget("scliama0000"+i//.fits[0],",DEC")
  dec=real(imget.value)
  for(j=1;j<=4;j+=1) {
    imcopy("rgS2012122950000"+i//.fits[SCI,"//j"]",scliama0000"+i//[im"//j","//j",append+])
    imcopy("rgS2012122950000"+i//.fits[DQ,"//j"]",bpm0000"+i//.bpm_m"//j//.pl")
    hedit("scliama0000"+i//["//j","",BPM","bpm0000"+i//.bpm_m"//j//.pl",add+,ver-,show+)
    hedit("scliama0000"+i//["//j","",RA",ra,add+,ver-,show+)
    hedit("scliama0000"+i//["//j","",DEC",dec,add+,ver-,show+)
    hedit("scliama0000"+i//["//j",",EQUINOX",2000.,add+,ver-,show+)
  }
}
```
Distortion correction

GSAOI WFS

- You shouldn't have problems to find the stars.

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

- 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).

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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

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

```plaintext
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)
```
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=0;i<=93;i++) {
    mscstat("sciima0000"+i,fields="mean",usemask=yes,gmode=no,format=, >> "tabval")
    type("tabval") | average | scan(ave,std,nima)
    printf(\"Image %d: Average sky %8.5f; stddev %8.5f; Narray %2d\n",i,ave,std,nima)
    mscimage("sciima0000"+i,"msciima0000"+i,format="image",pixmask=, verbose=,wcssource="image",reference="",ra=INDEF,dec=INDEF,
    scale=0.02,rotation=INDEF,blank=0,interpolant="sinc17",minterpolant="linear",
    boundary="constant",constant=ave,fluxconserve=,ntrim=4,nxblock=4200,
    nyblock=4200,interac=,nx=20,ny=20,fitgeometry="general",xorder=4,
    yorder=4,xterms="half",yorder=4,yxterms="half",fd_in="",
    fd_ext="",fd_coord="")
    delete("tabval",verify-)
}
```

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

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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”

```
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. interact+ \ verbo+ accept+
```

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

```
mscstack @inpKs.lst Imcfield2Ks.fits bpmasks="Imcfield2Ks_bpm" \ combine=average reject=avsigclip masktype=goodvalue maskval=0. blank=50000. scale=!mscscale zero=!msczero rdnoise=rdnoise gain=gain
```