

# Gemini Multi-Conjugate Adaptive Optics System (GeMS)

## Gemini South Adaptive Optics Imager (GSAOI)

Rodrigo Carrasco  
Gemini Observatory  
(on behalf of GeMS and GSAOI teams)

- \* GSAOI Data
- \* Calibrations
- \* Image reduction
- \* Distortion correction, mosaic-ing and combining GSAOI images

# GSAOI Data

EXT#	EXTTYPE	EXTNAME	EXTVE	DIMENS	BITPI	INH	OBJECT
0	S20121229S0074.fits				16		LMC FIELD 2
1	IMAGE		1	2048x2048	-32	F	
2	IMAGE		2	2048x2048	-32	F	
3	IMAGE		3	2048x2048	-32	F	
4	IMAGE		4	2048x2048	-32	F	

```

INSTRUME= 'GSAOI' / Instrument used to acquire data
OBJECT = 'LMC FIELD 2' / Object Name
OBSTYPE = 'OBJECT' / Observation type
OBSCCLASS= 'science' / Observe class
GEMPRGID= '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.Peshev, 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
RADVEL = 0. / Target Heliocentric Radial Velocity
EPOCH = 2000. / Target Coordinate Epoch
EQUINOX = 2000. / Equinox of coordinate system
TRKEQUIN= 2000. / Tracking equinox
SSA = 'E.Marin, A.Serio' / SSA
RA = 80.45476667 / Target Right Ascension
DEC = -69.49993333 / Target Declination
ELEVATIO= 47.317398611111 / Telescope Elevation at the start of exposure
AZIMUTH = 165.03995833333 / Telescope Azimuth at the start of exposure
CRPA = -141.254012724721 / Cass 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
TRKFRAME= 'FK5' / Tracking co-ordinate
DECTRACK= 0. / Differential tracking rate Dec
TRKEPOCH= 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
WAVELENG= 12500. / Effective Target Wavelength (A)

```

```

CCDNAME = 'G2' / Array name
CCDSIZE = '[1:2048,1:2048]' / Array dimensions
CCDSUM = '1 1' / Array binning
CCDSEC = '[1:2048,1:2048]' / Array section
AMPNAME1= 'A' / Amplifier 1 name
AMPSEC1 = '[1:512,1:2048]' / Amplifier 1 section
DETSEC = '[1:2048,1:2048]' / Detector section (wrt mosaic)
DATASEC = '[1:2048,1:2048]' / Current datasection of the frame
AMPNAME2= 'B' / Amplifier 2 name
AMPSEC2 = '[1024:513,1:2048]' / Amplifier 2 section
AMPNAME3= 'C' / Amplifier 3 name
AMPSEC3 = '[1025:1536,1:2048]' / Amplifier 3 section
AMPNAME4= 'C' / Amplifier 4 name
AMPSEC4 = '[2048:1537,1:2048]' / Amplifier 4 section
CTYPE1 = 'RA---TAN' / R.A. in tangent plane projection
CTYPE2 = 'DEC---TAN' / DEC. in tangent plane projection
CRPIX1 = 2089.10192892564 / Ref pix of axis 1
CRPIX2 = 2948.33028843773 / Ref pix of axis 2
CRVAL1 = 80.4500672028297 / RA at Ref pix in decimal degrees
CRVAL2 = -69.4968304826112 / DEC. at Ref pix in decimal degrees
CD1_1 = 5.56513472905115E-06 / partial of first axis coord w.r.t. x
CD1_2 = 6.31907796408907E-08 / partial of first axis coord w.r.t. y
CD2_1 = 3.20736737540113E-08 / partial of second axis coord w.r.t. x
CD2_2 = 5.47996465229383E-06 / partial of second axis coord w.r.t. y
RADECSYS= 'FK5' / R.A./DEC. coordinate system reference
XSCALE = 0.0200210572443785 / Pixel scale in X (in arcsec)
YSCALE = 0.0197150286424076 / Pixel scale in Y (in arcsec)

```

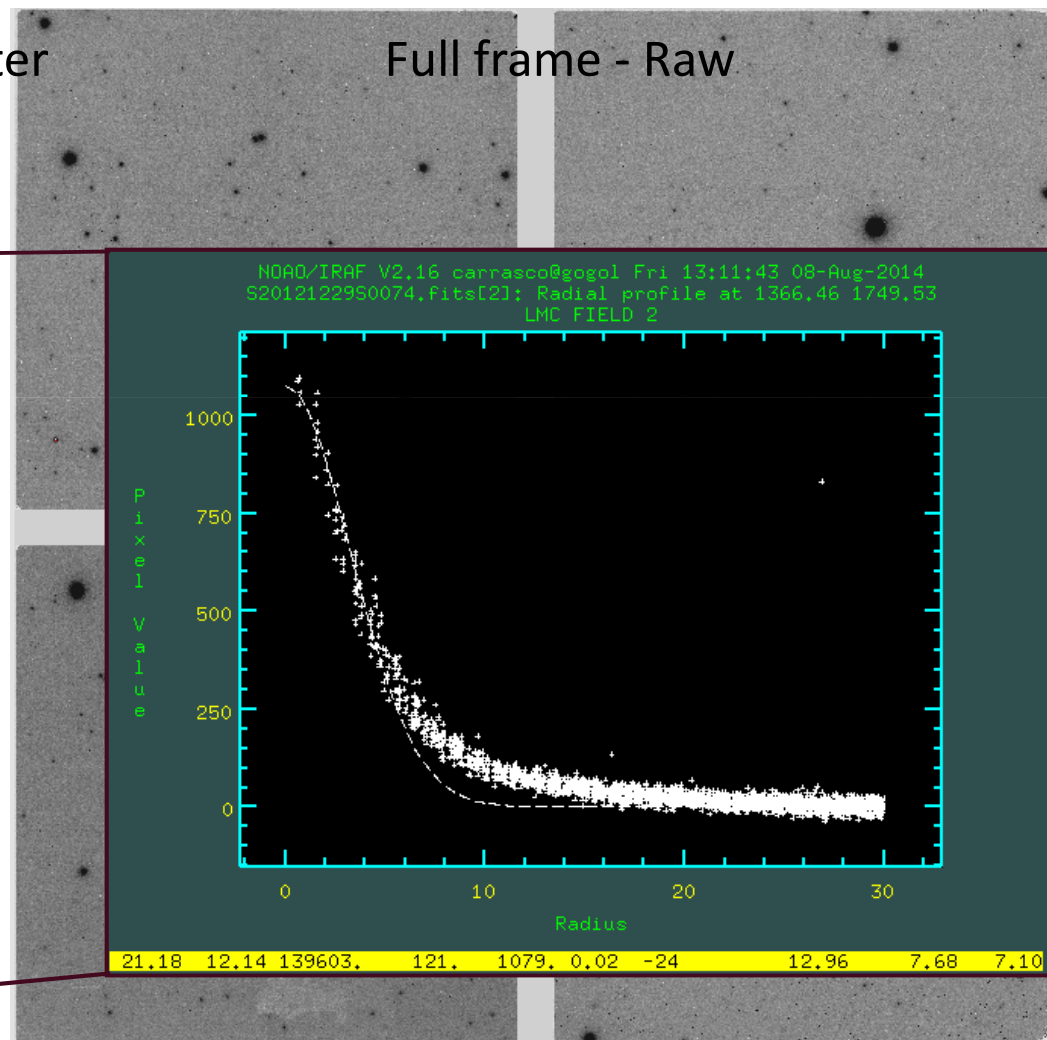
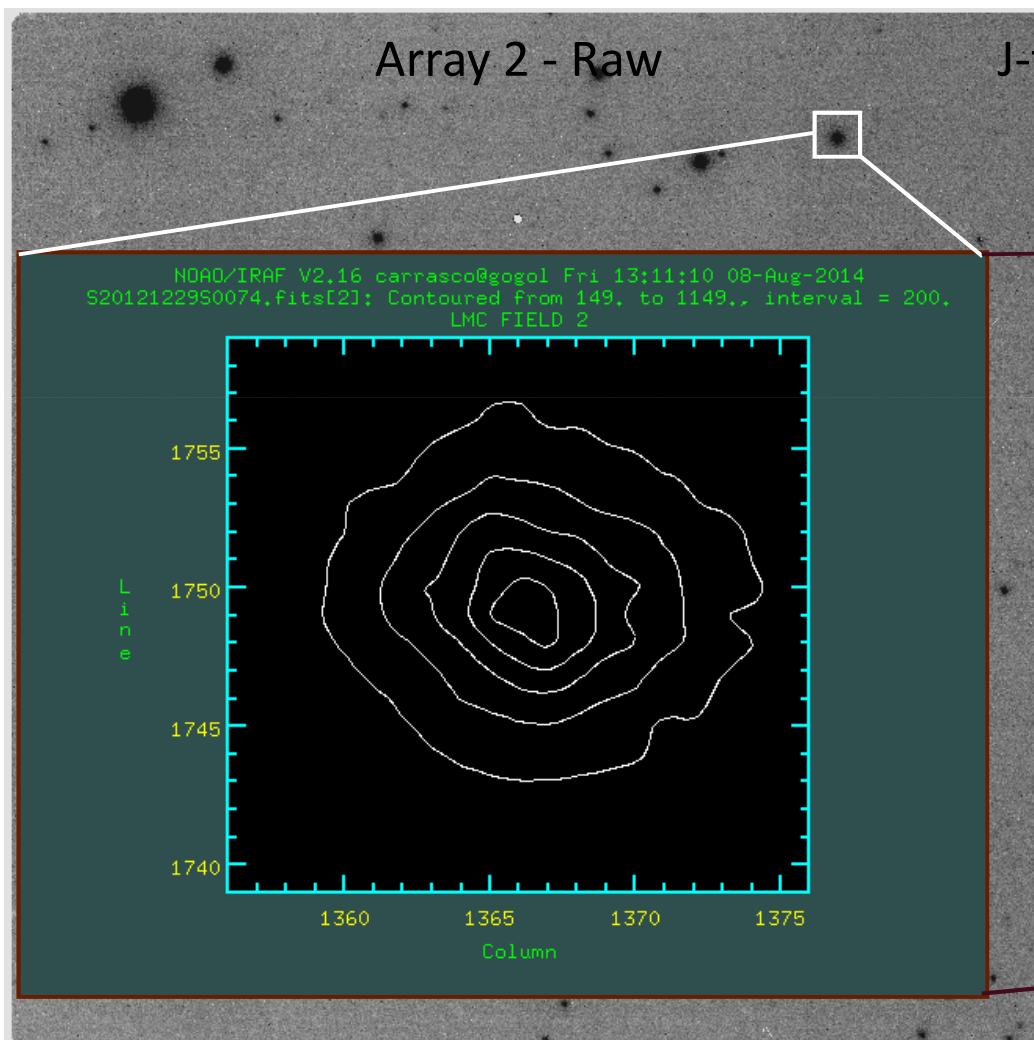


GSAOI Sky orientation: N-up, E-right (PA=0.0)

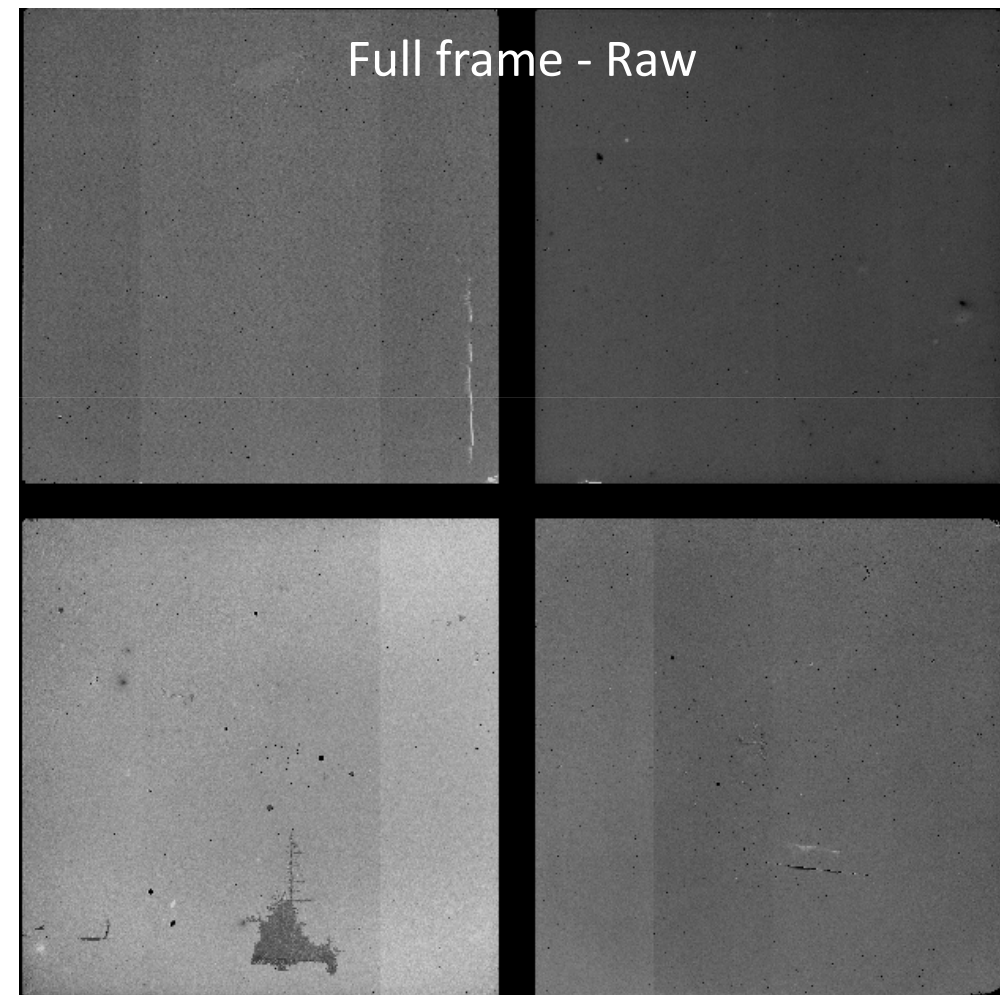
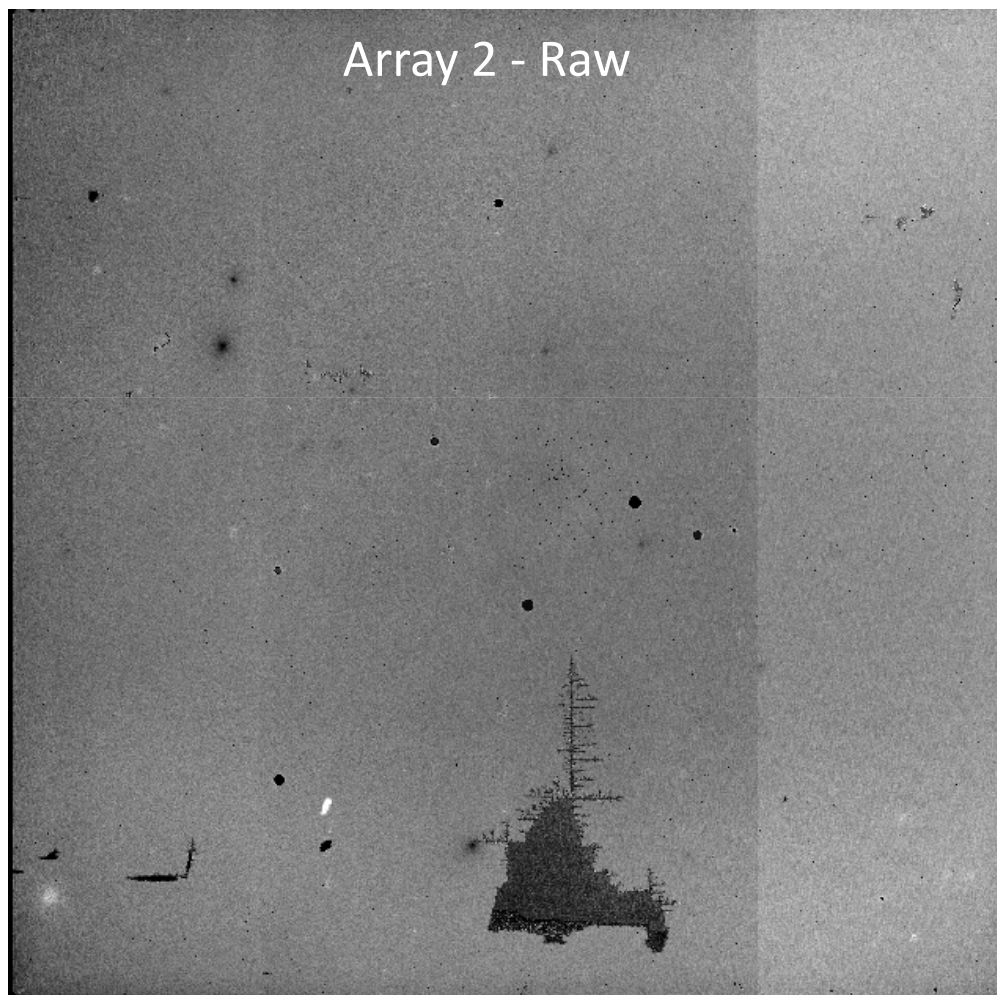
Array 2 - Raw

J-filter

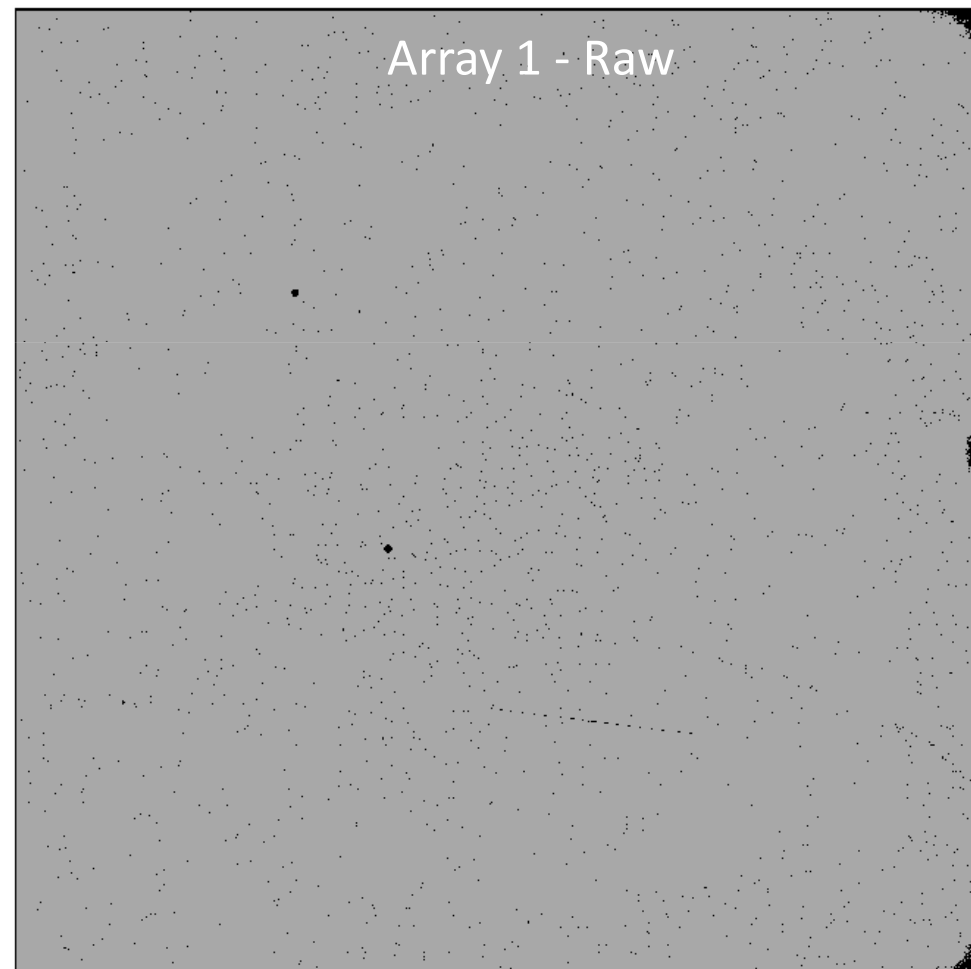
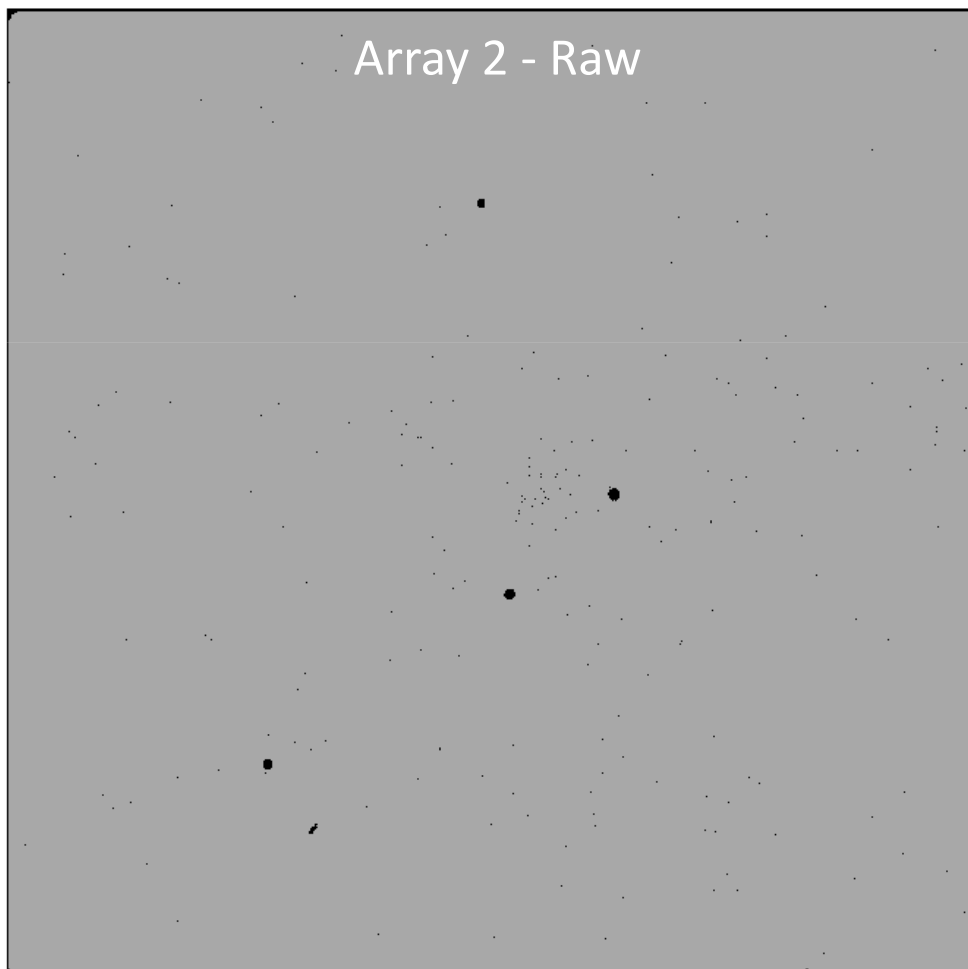
Full frame - Raw



## Dome flat - J-filter



## Bad Pixel Mask



# 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-CALYYYYMMDD 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  
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:

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

**GAPREPRE:** 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\_var dq=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 gapprepare> gapprepare 74-77,82-85,90-93 rawpath=rawsci$ rootname=S20121229S fl_var dq+
```



**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_var dq=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\_var dq+

<code>inimages = ""</code>	Input GSAOI images
<code>(rawpath = "...")</code>	Path for raw input images
<code>(outsufx = "flat")</code>	Suffix for output flat
<code>(rootname = "...")</code>	Root name for images; blank=today UT
<code>(minflat = 5)</code>	Minimum number of flat images to combine
<code>(ignore_exp = "default")</code>	Ignore exposure times when combining
<code>(stattype = "mean")</code>	Type of statistics to compute for normalization
<code>(statextn = "ARRAY")</code>	How to calculate normalization. (DETECTOR ARRAY)
<code>(statsec = "[*,*]")</code>	Statistics section for scaling when combining
<code>(fl_mask = yes)</code>	Mask non-good pixels when calculating normalization
<code>(badpix = "gsaoi\$data/gsaobpm_high_full.fits")</code>	Static Bad Pixel Mask - n
<code>(fl_var dq = no)</code>	Create variance and data quality frames
<code>(maxtime = INDEF)</code>	Maximum time interval from first image in the l
<code>(datename = "DATE-OBS")</code>	Date header keyword
<code>(timename = "UT")</code>	Time stamp header keyword
<code>(ignore_nlc = no)</code>	Ignore NLC state of the input files?
<code>(use_offs = "default")</code>	Use off flats?
<code>(gaprep_pref = "g")</code>	Prefix for GAPREPARE output images
<code>(fl_trim = yes)</code>	Trim the images?
<code>(fl_nlc = yes)</code>	Apply non-linear correction to each array?
<code>(fl_sat = yes)</code>	Include non-linear and saturated pixels in data
<code>(arraysdb = "gsaoi\$data/gsaoiAMPS.dat")</code>	Database file for characteristics o
<code>(non_lcdb = "gsaoi\$data/gsaoinLC.dat")</code>	Database file for non-linearity corr
<code>(combine = "default")</code>	Combination operation
<code>(reject = "avsigclip")</code>	Rejection algorithm
<code>(masktype = "goodvalue")</code>	Bad Pixel Mask type
<code>(maskvalue = 0.)</code>	Good pixel value in the BPM
<code>(zero = "none")</code>	Image zero point offset (none mode median mean
<code>(weight = "none")</code>	Image weights (none mode median mean exposure @
<code>(expname = "EXPTIME")</code>	Exposure time header keyword
<code>(lthreshold = INDEF)</code>	Lower threshold
<code>(hthreshold = INDEF)</code>	Upper threshold
<code>(nlow = 1)</code>	minmax: Number of low pixels to reject
<code>(nhigh = 1)</code>	minmax: Number of high pixels to reject
<code>(nkeep = 1)</code>	Minimum to keep or maximum to reject
<code>(mclip = yes)</code>	Use median in sigma clipping algorithms?
<code>(lsigma = 3.)</code>	Lower sigma clipping factor
<code>(hsigma = 3.)</code>	Upper sigma clipping factor
<code>(key_ron = "RDNOISE")</code>	Keyword for readout noise in e-
<code>(key_gain = "GAIN")</code>	Keyword for gain in electrons/ADU
<code>(ron = 0.)</code>	Readout noise rms in electrons
<code>(gain = 1.)</code>	Gain in e-/ADU
<code>(snoise = "0.0")</code>	ccdclip: Sensitivity noise (electrons)
<code>(sigscale = 0.1)</code>	Tolerance for sigma clipping scaling correction
<code>(pclip = -0.5)</code>	pclip: Percentile clipping parameter
<code>(grow = 0.)</code>	Radius (pixels) for neighbor rejection
<code>(fl_dqprop = no)</code>	Propagate all DQ values?

# Reduction

**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_var dq=yes`, the variance and data quality planes are propagated and appended to the output images.

- Current example data: Ks bands science gapprepare-d images

```
> gemlist gS20121229S 90-93 > skyKs.lst
```

```
> unlearn gasky> gasky @skyKs.lst
```

```
outimage=SkyKs.fits fl_var dq \
```

```
fl_dqprop+ flatimg=gS20121220S0180_flat.fits
```

<code>inimages =</code>	GSAOI sky images to combine
<code>(outimages = "")</code>	Output sky images
<code>(outsufx = "sky")</code>	Output suffix if <code>outimages=""</code>
<code>(combine = "default")</code>	Type of combine operation (default median average)
<code>(reject = "minmax")</code>	Type of rejection (none minmax avsigclip)
<code>(nlow = 0)</code>	<code>minmax</code> : Number of low pixels to reject
<code>(nhigh = 1)</code>	<code>minmax</code> : Number of high pixels to reject
<code>(statsec = "[5%]")</code>	Statistics section
<code>(masktype = "goodvalue")</code>	Bad Pixel Mask type (none goodvalue)
<code>(maskvalue = 0.)</code>	Good pixel value in the BPM
<code>(badpix = "gsaoi\$data/gsaobpm high full.fits")</code>	Static Bad Pixel Mask
<code>(key_exptime = "EXPTIME")</code>	Keyword for exposure time
<code>(key_ron = "RDNOISE")</code>	Header keyword for read noise (e-)
<code>(key_gain = "GAIN")</code>	Header keyword for gain (e-/ADU)
<code>(fl_var dq = no)</code>	Create variance and data quality frames in <code>outp</code>
<code>(fl_dqprop = no)</code>	Propagate data quality information?
<code>(fl_keepmasks = no)</code>	Keep object masks for each input image?
<code>(masksuffix = "msk")</code>	Mask name suffix
<code>(threshold = 3.)</code>	Threshold in sigma for object detection
<code>(ngrow = 3)</code>	Number of iterations to grow objects into the w
<code>(agrow = 3.)</code>	Area limit for growing objects into the wings
<code>(minpix = 6)</code>	Minimum number of pixels to be identified as an
<code>(fl_mask = yes)</code>	Mask non-good pixels during source detection &
<code>(greduce = yes)</code>	Quickly reduce images, with sky from GAFASTSKY
<code>(gred_msktype = "goodvalue")</code>	Bad Pixel Mask type (none goodvalue) for GAFAST
<code>(flatimg = "...")</code>	Flat field image, for use when <code>greduce=yes</code> ("...")
<code>(minflat_val = 1.0000000000000000E-6)</code>	Minimum allowed pixel value in flat image;
<code>(sci_ext = "SCI")</code>	Name for science extensions
<code>(var_ext = "VAR")</code>	Name for variance extensions
<code>(dq_ext = "DQ")</code>	Name for data quality extensions
<code>(logfile = "...")</code>	Name of log file
<code>(verbose = yes)</code>	Verbose?
<code>(status = 0)</code>	Exit status (0=good)
<code>(scanfile = "...")</code>	Internal use only
<code>(scanfile2 = "...")</code>	Internal use only
<code>(scanfile3 = "...")</code>	Internal use only
<code>(mode = "ql")</code>	



# Reduction

**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

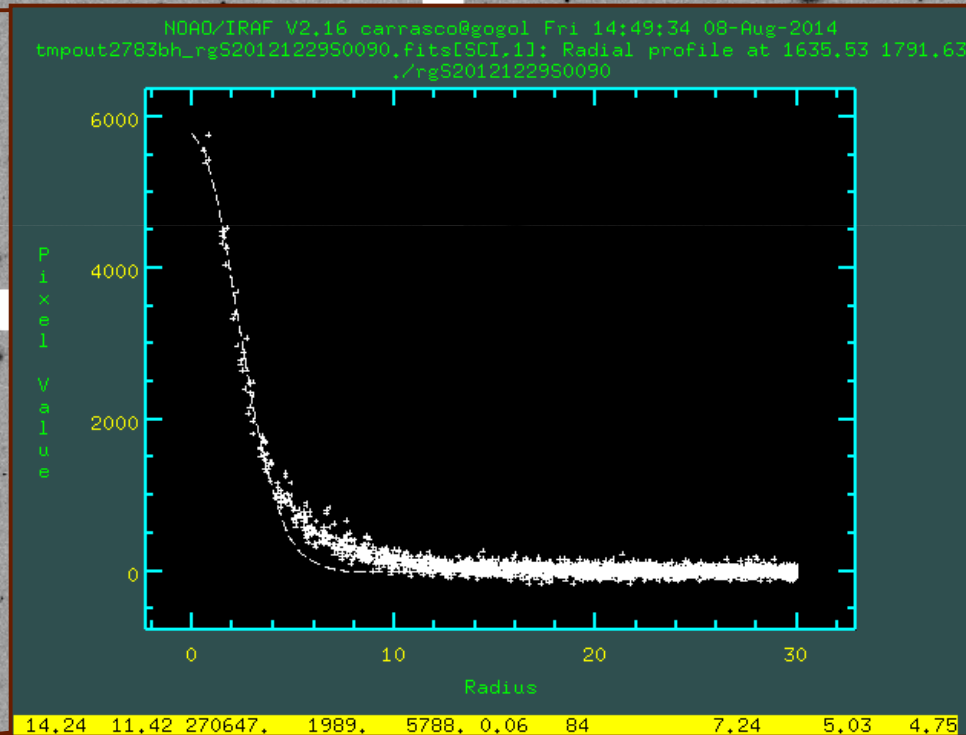
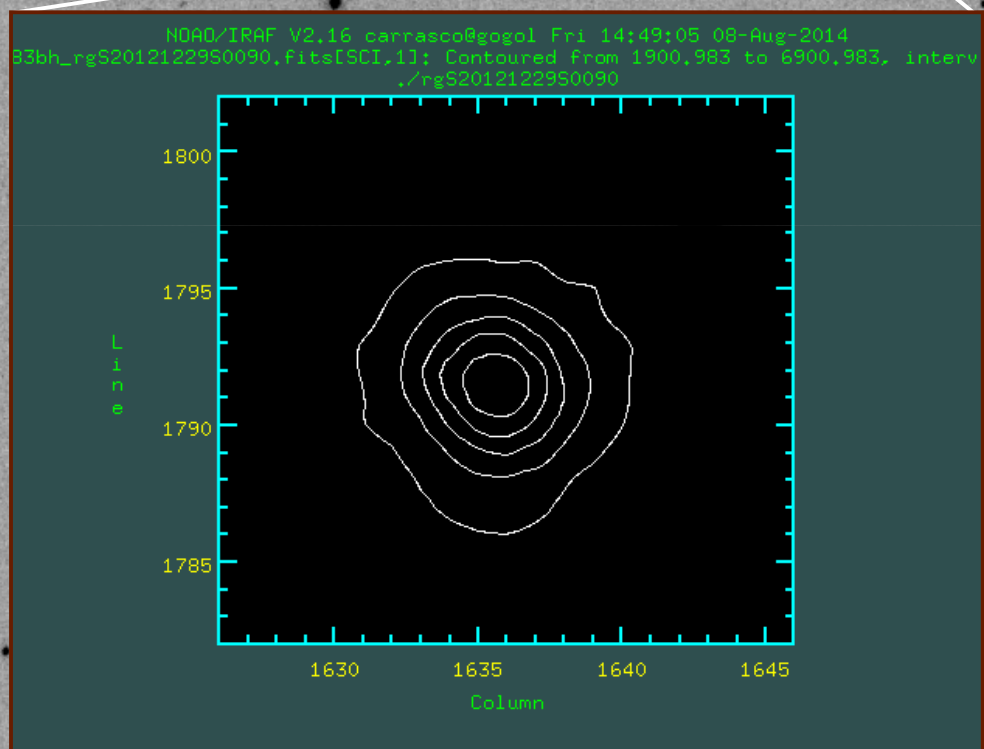
<code>inimages =</code>	Input GSAOI images
<code>(rawpath = ".")</code>	Path for input images
<code>(outpref = "r")</code>	Prefix for output processed images
<code>(rootname = ".")</code>	Root name for images, blank=today UT
<code>(fl_dark = no)</code>	Subtract dark image?
<code>(fl_flat = no)</code>	Do flat field correction?
<code>(fl_sky = no)</code>	Subtract sky image?
<code>(fl_autosky = yes)</code>	Use median of the sky to add back constant to p
<code>(fl_mult = yes)</code>	Multiply by gain to convert to electrons?
<code>(fl_vardq = no)</code>	Create variance and data quality frames
<code>(darkimg = ".")</code>	Dark image to be used ("." find <filename>)
<code>(flatimg = ".")</code>	Flat field image to be used ("." find <DOE TWT
<code>(skyimg = ".")</code>	Sky image to be used ("." time distance both <fi
<code>(calpath = ".")</code>	Path for calibration images
<code>(caltable = "gsaoical.fits")</code>	Name of table with calibration information (fr
<code>(fl_calrun = no)</code>	When looking for calibrations, first re-create
<code>(cal_maxtime = INDEF)</code>	Maximum time difference between calibration and
<code>(badpix = "gsaoi\$data/gsaobpm_high_full.fits")</code>	Static bad pixel mask
<code>(lsigma = 3.)</code>	Lower sigma clipping factor when fl_autosky=yes
<code>(hsigma = 3.)</code>	Upper sigma clipping factor when fl_autosky=yes
<code>(gaprep_pref = "g")</code>	Prefix for gapprepare output images
<code>(fl_trim = yes)</code>	Trim the images?
<code>(fl_nlc = yes)</code>	Apply non-linear correction to each array?
<code>(fl_sat = yes)</code>	Include non-linear and saturated pixels in DQ
<code>(arraysdb = "gsaoi\$data/gsaoiAMPS.dat")</code>	Database file containing array info
<code>(non_lcdb = "gsaoi\$data/gsaoinLC.dat")</code>	Database file containing non-linear
<code>(sky_sufx = "sky")</code>	Output suffix if creating sky frames from input
<code>(maxtime = 900.)</code>	For sky="time", combine frames within this time
<code>(minoffs = 90.)</code>	For sky="distance", combine frames with offsets
<code>(minsky = 5)</code>	Minimum number of sky images to combine
<code>(combine = "default")</code>	Combination operation for sky frames (default a
<code>(reject = "minmax")</code>	Rejection algorithm for sky frames (none minmax
<code>(nlow = 1)</code>	minmax: Number of low pixels to reject
<code>(nhigh = 1)</code>	minmax: Number of high pixels to reject
<code>(statsec = "[5%]")</code>	Statistics section
<code>(masktype = "goodvalue")</code>	Bad Pixel Mask type (none goodvalue)
<code>(maskvalue = 0.)</code>	Good pixel value in the BPM
<code>(datetime = "DATE-OBS")</code>	Date header keyword
<code>(timebase = "UT")</code>	Time stamp header keyword
<code>(expname = "EXPTIME")</code>	Exposure time header keyword
<code>(key_ron = "RDNOISE")</code>	Keyword for readout noise in e-
<code>(key_gain = "GAIN")</code>	Keyword for gain in electrons/ADU
<code>(ron = 0.)</code>	Readout noise rms in electrons
<code>(gain = 1.)</code>	Gain in e-/ADU
<code>(lthreshold = 3.)</code>	Threshold in sigma for object detection
<code>(ngrow = 3)</code>	Number of iterations to grow objects into the w
<code>(agrow = 3.)</code>	Area limit for growing objects into the wings

# Reduction

Array 2 - Raw

Kshort-filter

Full frame - Raw





# Distortion correction, mosaic-ing and combining GSAOI images

- \* There is no GSAOI script to correct for distortion and mosaic the images (under construction)
- \* Most of the distortion can be calibrated out (static distortion)
  - \* Using observation of astrometric field in LMC with accurate coordinates (typical rms  $\sim 1$  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

```
real ra,dec
!rm -r bpm0*
imdelete sciima0???.fits ver-
for(i=90;i<=94;i+=1) {
  mkdir("bpm0000"+i)
  imcopy("rgS20121229S0000"+i//".fits[0]","sciima0000"+i//".fits")
  imgets("sciima0000"+i//".fits[0]","RA")
  ra=real(imgets.value)/15.0
  imgets("sciima0000"+i//".fits[0]","DEC")
  dec=real(imgets.value)
  for(j=1;j<=4;j+=1) {
    imcopy("rgS20121229S0000"+i//".fits[SCI,///j//"]","sciima0000"+i//"[im"///j//",///j//",append+]")
    imcopy("rgS20121229S0000"+i//".fits[DQ,///j//"]","bpm0000"+i//"/bpmmm_im"///j//".pl")
    hedit("sciima0000"+i//"[///j//"]","BPM","bpm0000"+i//"/bpmmm_im"///j//".pl",add+,ver-,show+)
    hedit("sciima0000"+i//"[///j//"]","RA",ra,add+,ver-,show+)
    hedit("sciima0000"+i//"[///j//"]","DEC",dec,add+,ver-,show+)
    hedit("sciima0000"+i//"[///j//"]","EQUINOX",2000.,add+,ver-,show+)
  }
}
```

# Distortion correction

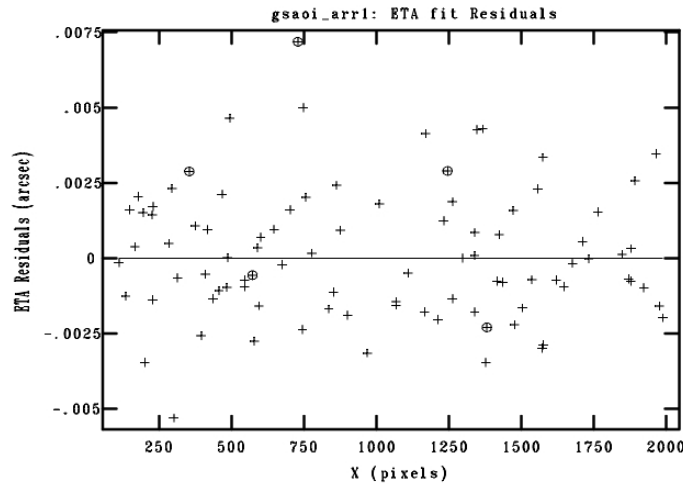
## GSAOI W

- You sh
- Load pac
- the 4 ext

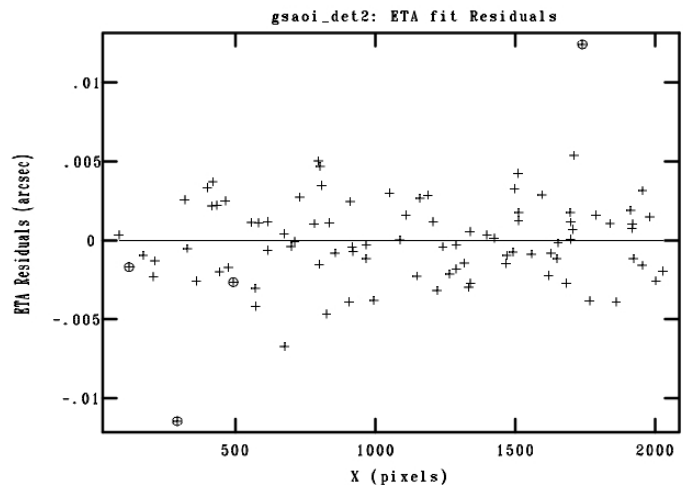
```
for(j=4;j<=4;j++)
msctpeak ("sc
epoch=2000.,
fitgeometry="
xxterms="half
interactive=yes
badcolor="red"
}
```

- Using "tr
- terms to
- Using a p
- terms.
- Only for
- reference

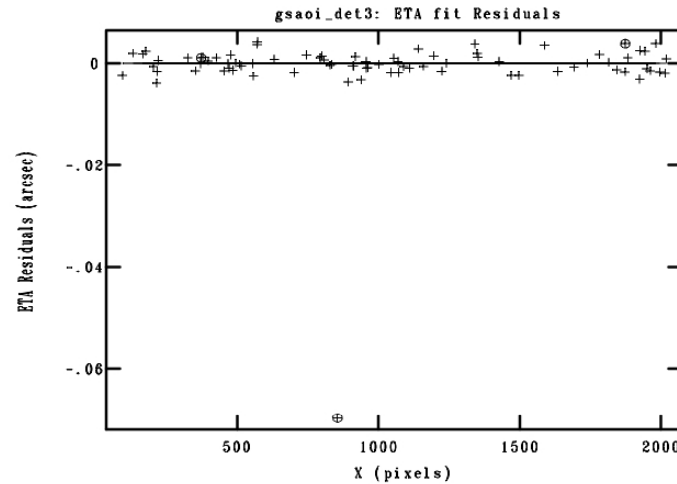
NOAO/IRAF V2.16 carrasco@intti.cl.gemini.edu Wed 13:53:50 05-Feb-2014  
CCMAP: function = polynomial npts = 91 reject = 3. nrej = 5  
ETA fit: xorder = 4 yorder = 4 xterms = half rms = 0.00202 arcsec



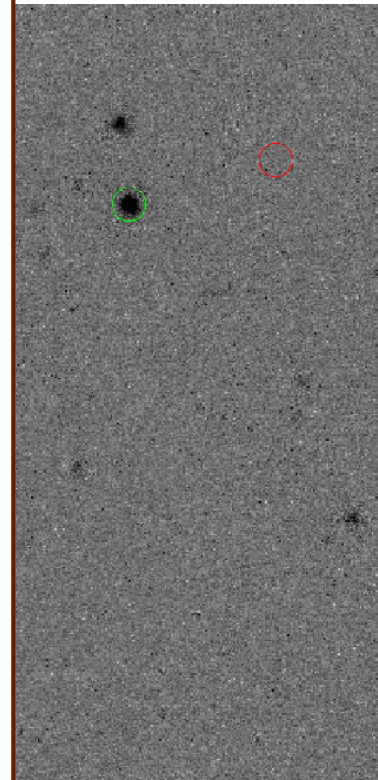
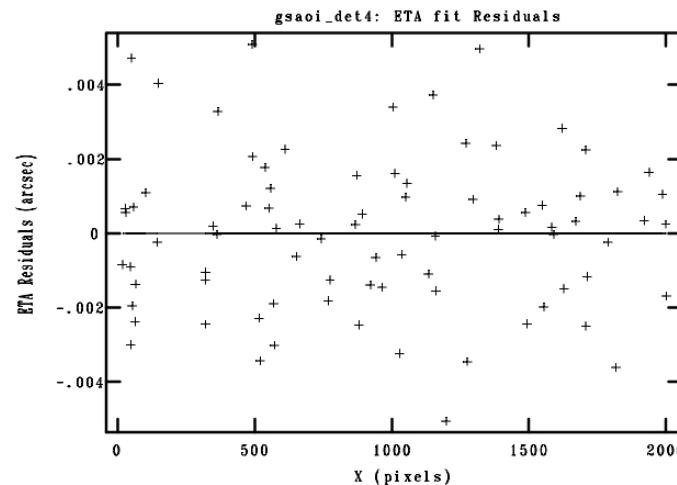
NOAO/IRAF V2.16 carrasco@intti.cl.gemini.edu Wed 16:08:09 05-Feb-2014  
CCMAP: function = polynomial npts = 94 reject = 3. nrej = 4  
ETA fit: xorder = 4 yorder = 4 xterms = half rms = 0.00239 arcsec



NOAO/IRAF V2.16 carrasco@intti.cl.gemini.edu Wed 16:14:55 05-Feb-2014  
CCMAP: function = polynomial npts = 81 reject = 3. nrej = 3  
ETA fit: xorder = 4 yorder = 4 xterms = half rms = 0.00181 arcsec



NOAO/IRAF V2.16 carrasco@intti.cl.gemini.edu Wed 16:16:37 05-Feb-2014  
CCMAP: function = polynomial npts = 82 reject = 3. nrej = 0  
ETA fit: xorder = 4 yorder = 4 xterms = half rms = 0.00207 arcsec





- \* 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

```
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)
}
```

- \* 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

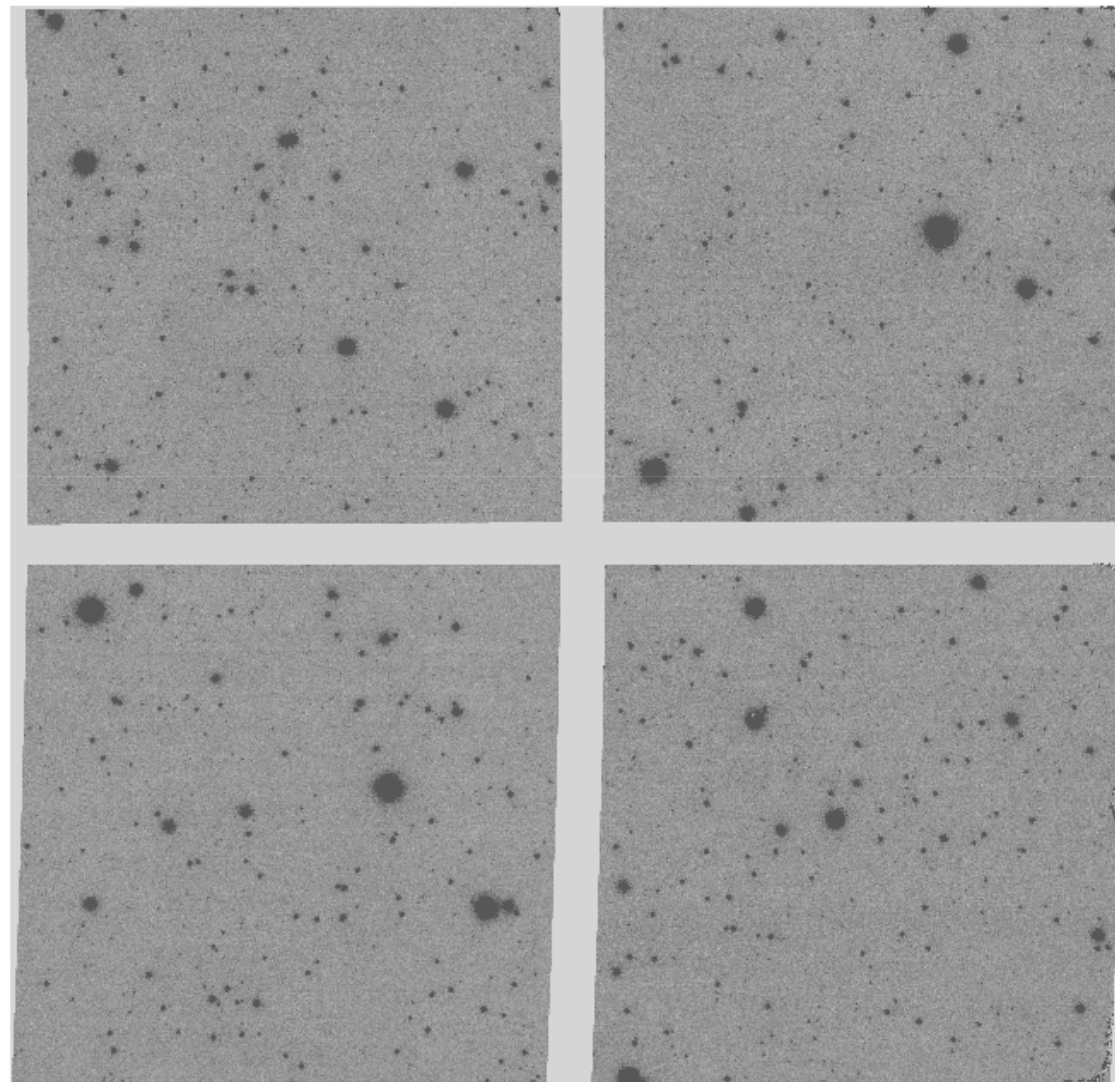
```
real raoff,decoff
for(i=90;i<=93;i+=1) {
  imgets("sciima0000"+i//"[0]","RAOFFSET")
  raoff=(-1)*real(imgets.value)
  imgets("sciima0000"+i//"[0]","DECOFFSE")
  decoff=(-1)*real(imgets.value)
  print("RAOFFSET = "//raoff//", DECOFFSET = "//decoff)
  mscsetwcs("sciima0000"+i//".fits","distortion.db",ra="RA",dec="DEC",equinox="EQUINOX",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

# Mosaic-ing

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

```
real ave, std
int nima
for(i=90;i<=93;i+=1) {
  mscstat("sciima0000"+i,fields="mean",usemask=yes,gmode=no,format-, >> "tabval")
  type("tabval") | average | scan(ave,std,nima)
  printf("Image %4d; 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",xxorder=4,
  xyorder=4,xxterms="half",yxorder=4,yyorder=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 ...
```



# 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 “mscismatch”

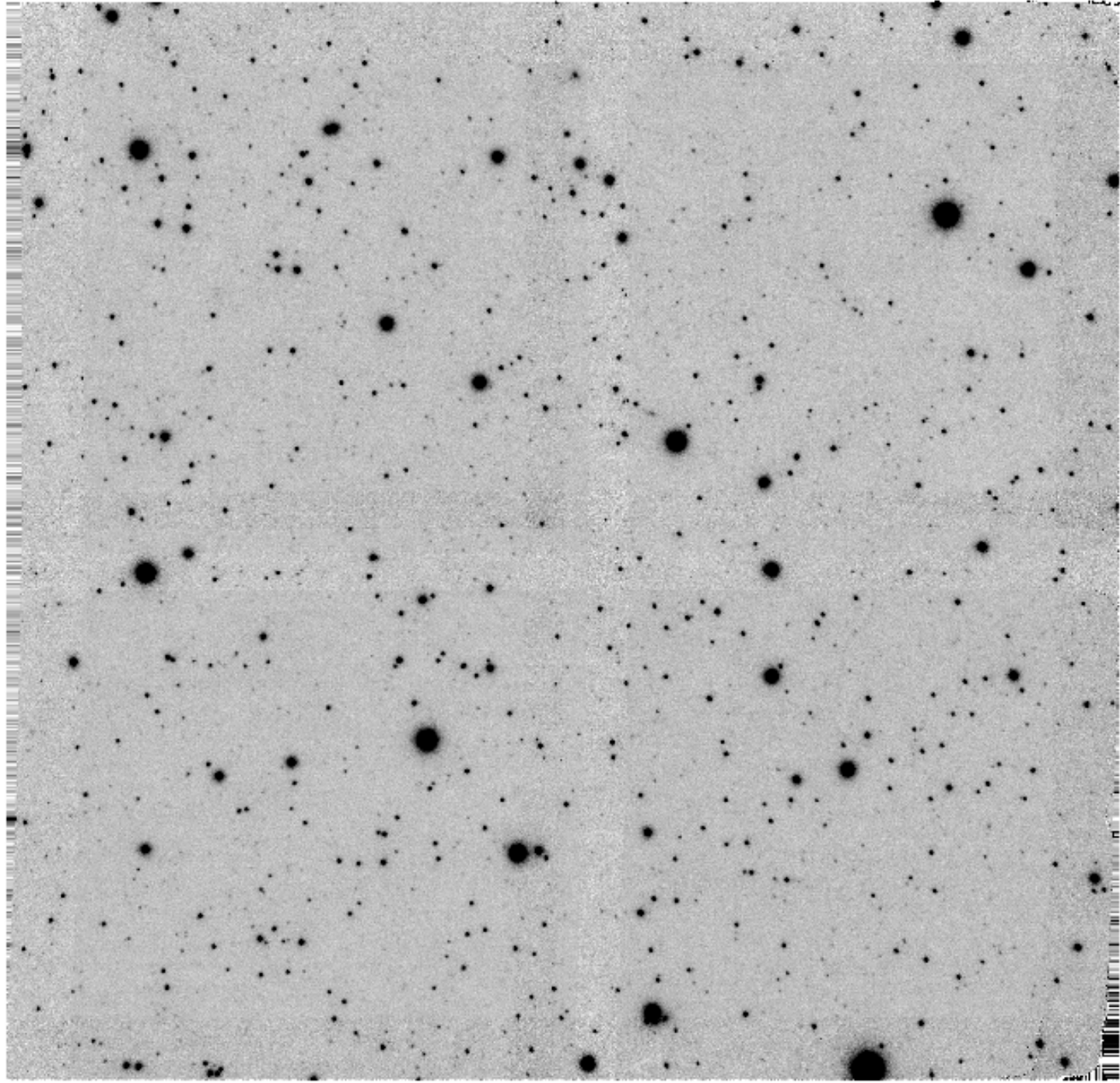
```
files msciima0090.fits,msciima0091,msciima0092,msciima0093 > inpKs.lst
mscismatch @inpKs.lst ima090.cat bpm="BPM" scale+ zero- box1=21 \
box2=51 lower=0. upper=32000. niterate=4 sigma=2. interac+ \
verbo+ accept+
```

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

```
mscstack @inpKs.lst lmcfield2Ks.fits bpmasks="lmcfield2Ks_bpm" \
combine=average reject=avsigclip masktype=goodvalue maskval=0.
blank=50000. scale=!mscscale zero=!msczero rdnoise=rdnoise
gain=gain
:
```



Final combined image  
(Kshort - filter)



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