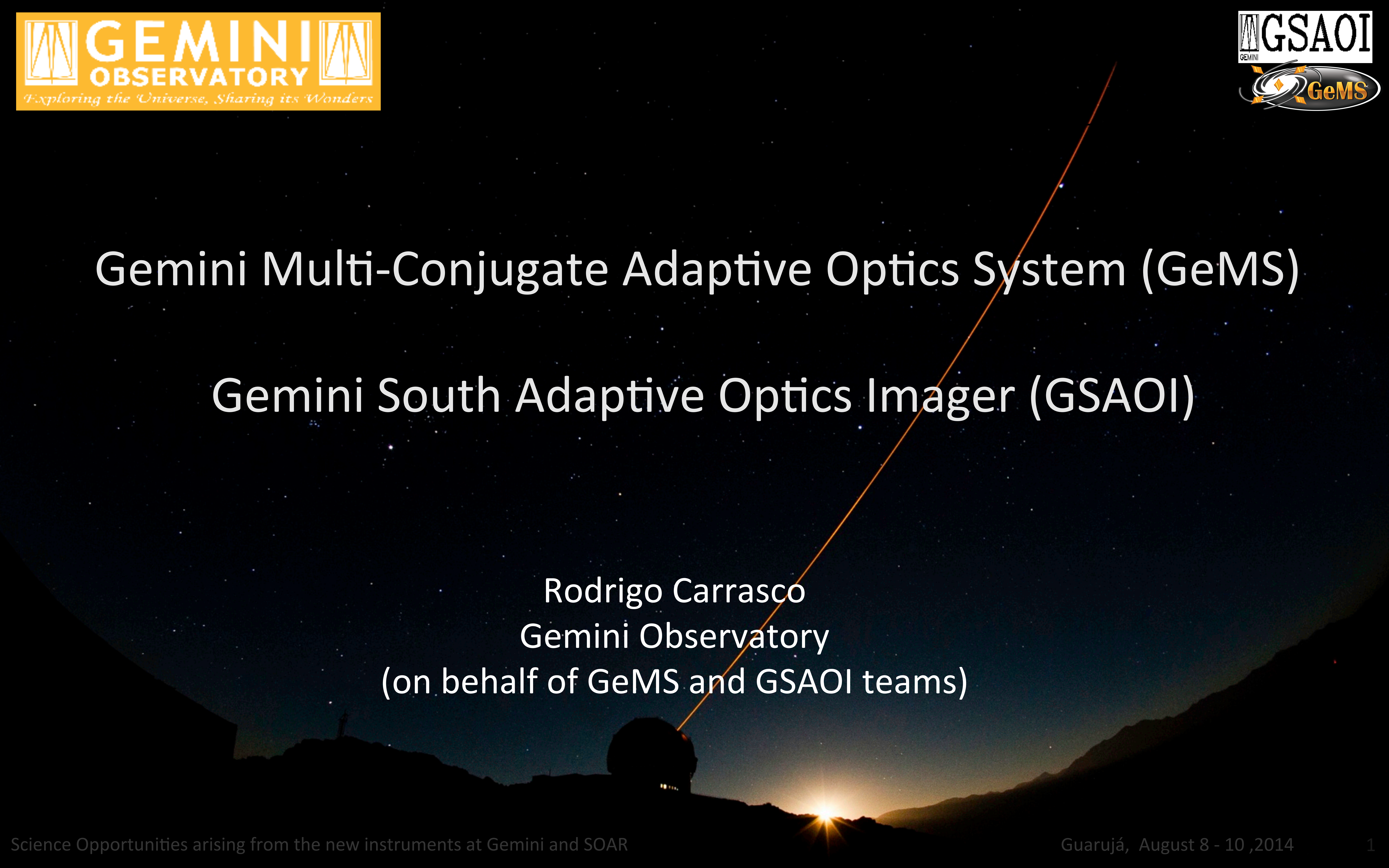


Gemini Multi-Conjugate Adaptive Optics System (GeMS)

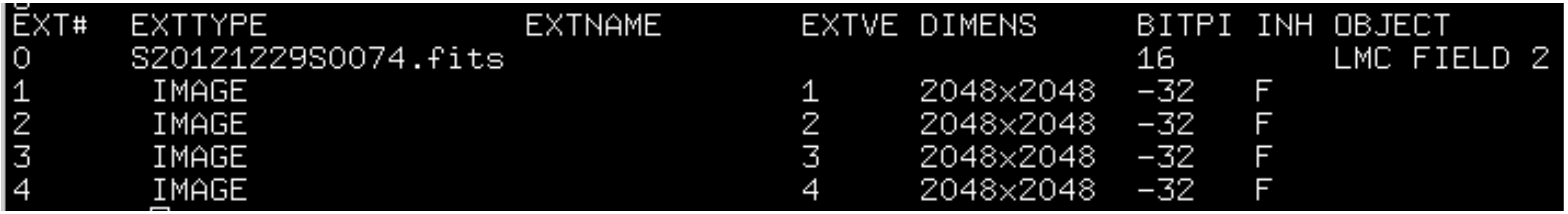
Gemini South Adaptive Optics Imager (GSAOI)

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

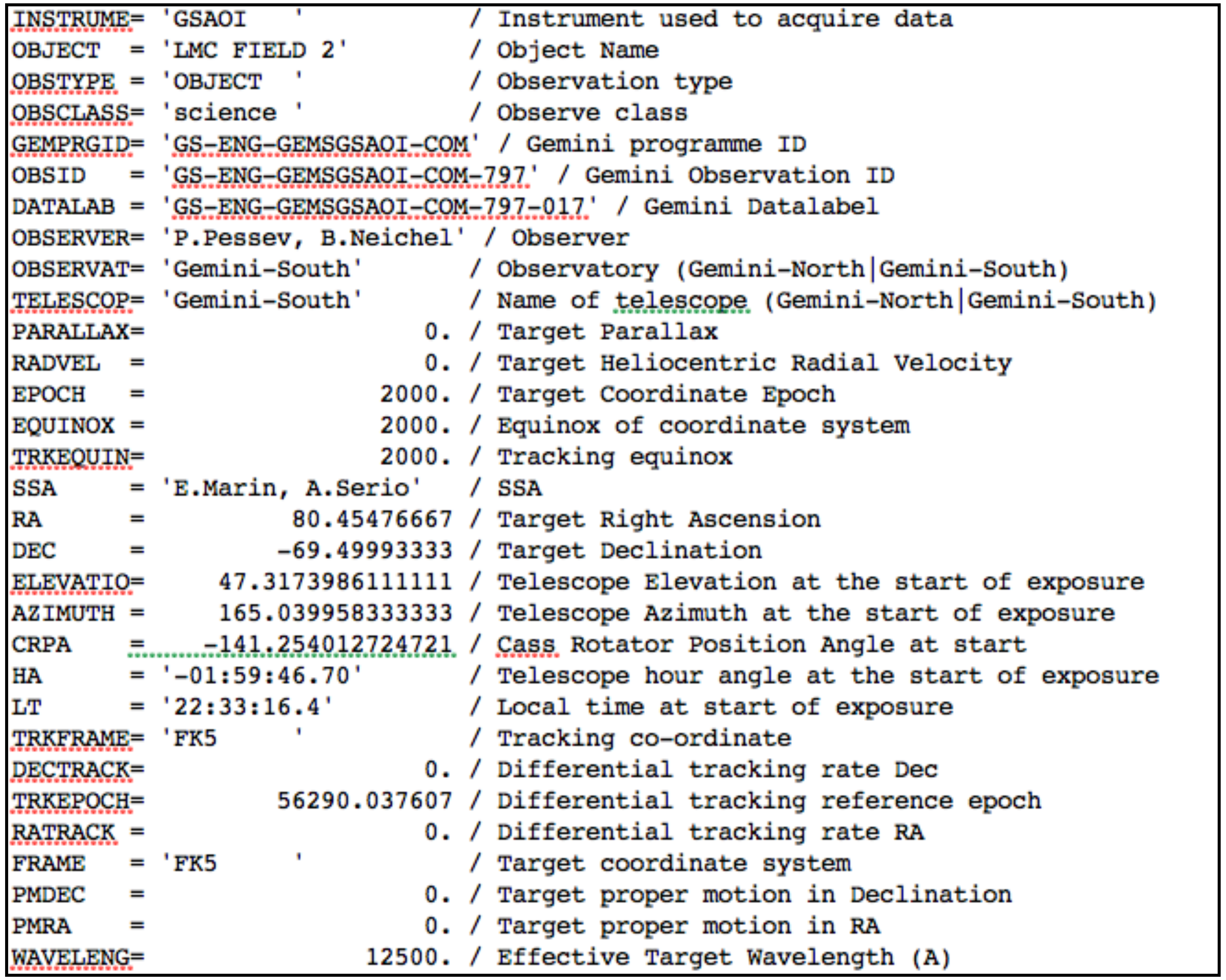
- GSAOI Data
- Calibrations
- Image reduction
- Distortion correction, mosaic-ing and combining GSAOI images

GSAOI Data

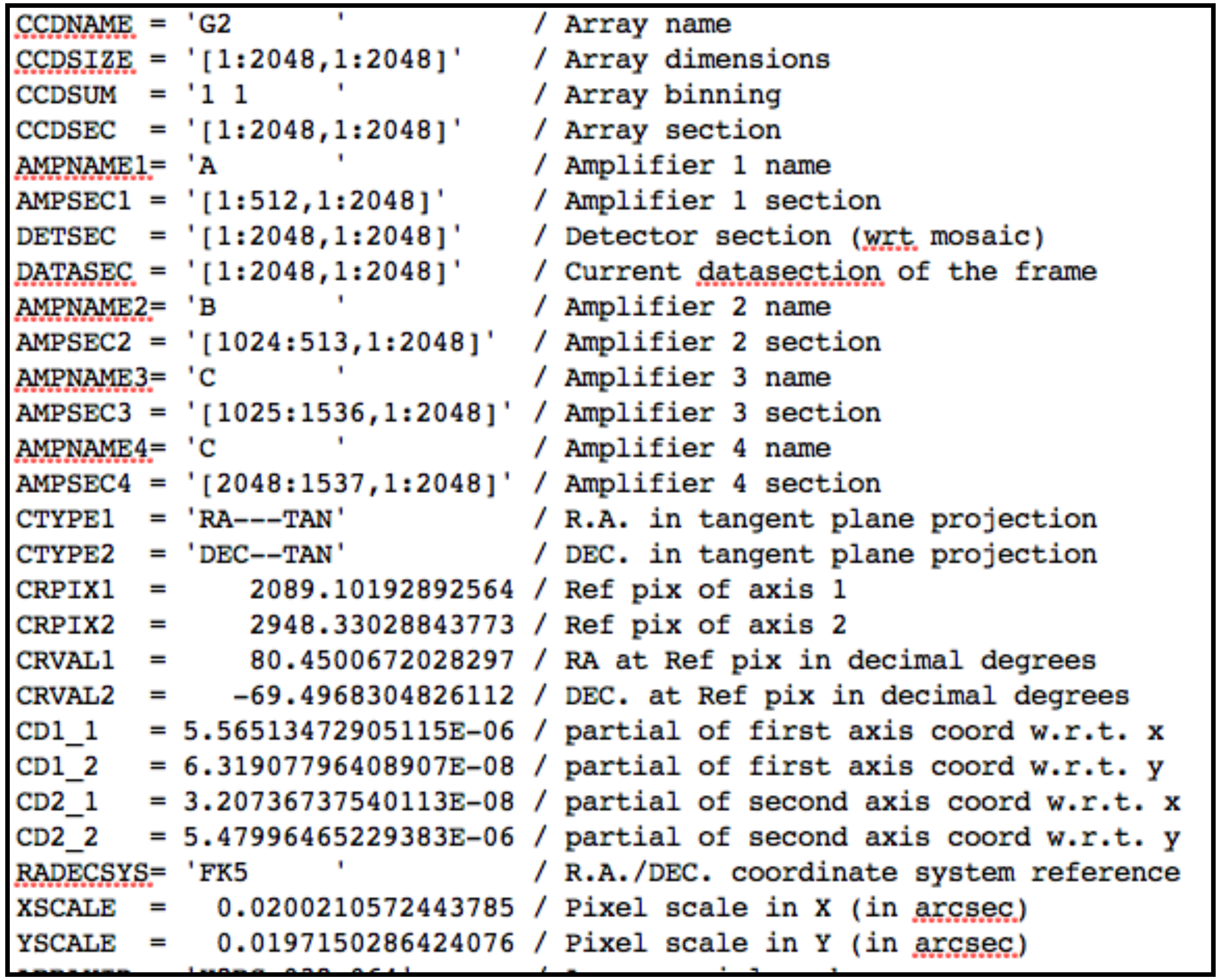
GSAOI Data



```
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
OBSCLASS= '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.Pessev, 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=     47.3173986111111 / Telescope Elevation at the start of exposure
AZIMUTH =     165.039958333333 / 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)
```

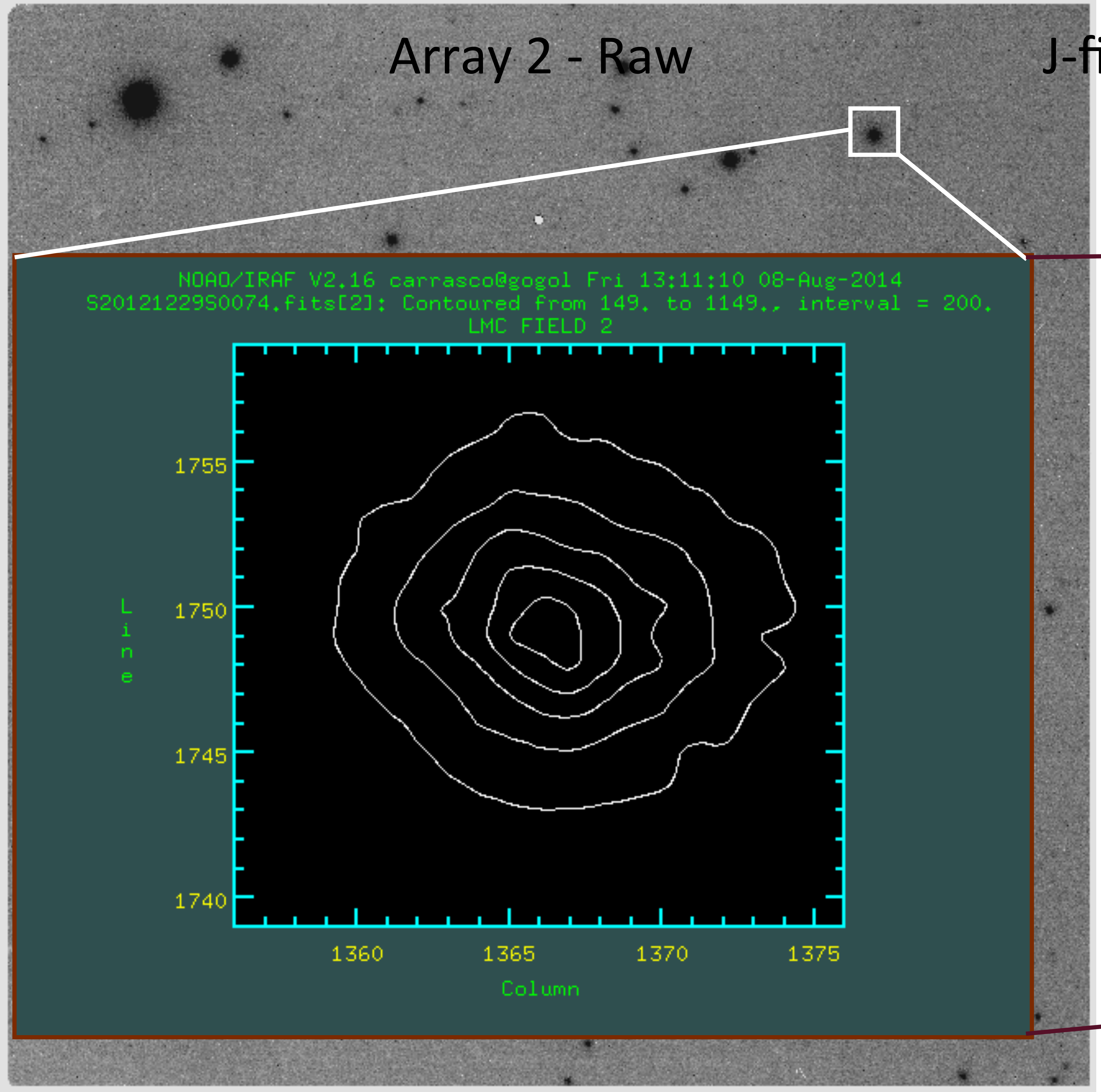


```
CCDNAME  = 'G2      '            / Array name
CCDSIZE  = '[1:2048,1:2048]'     / Array dimensions
CCDSUM   = '1 1     '            / Array binning
CCDSEC   = '[1:2048,1:2048]'     / Array section
AMPNAME1= 'A       '             / Amplifier 1 name
AMPSEC1  = '[1:512,1:2048]'      / Amplifier 1 section
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 Data

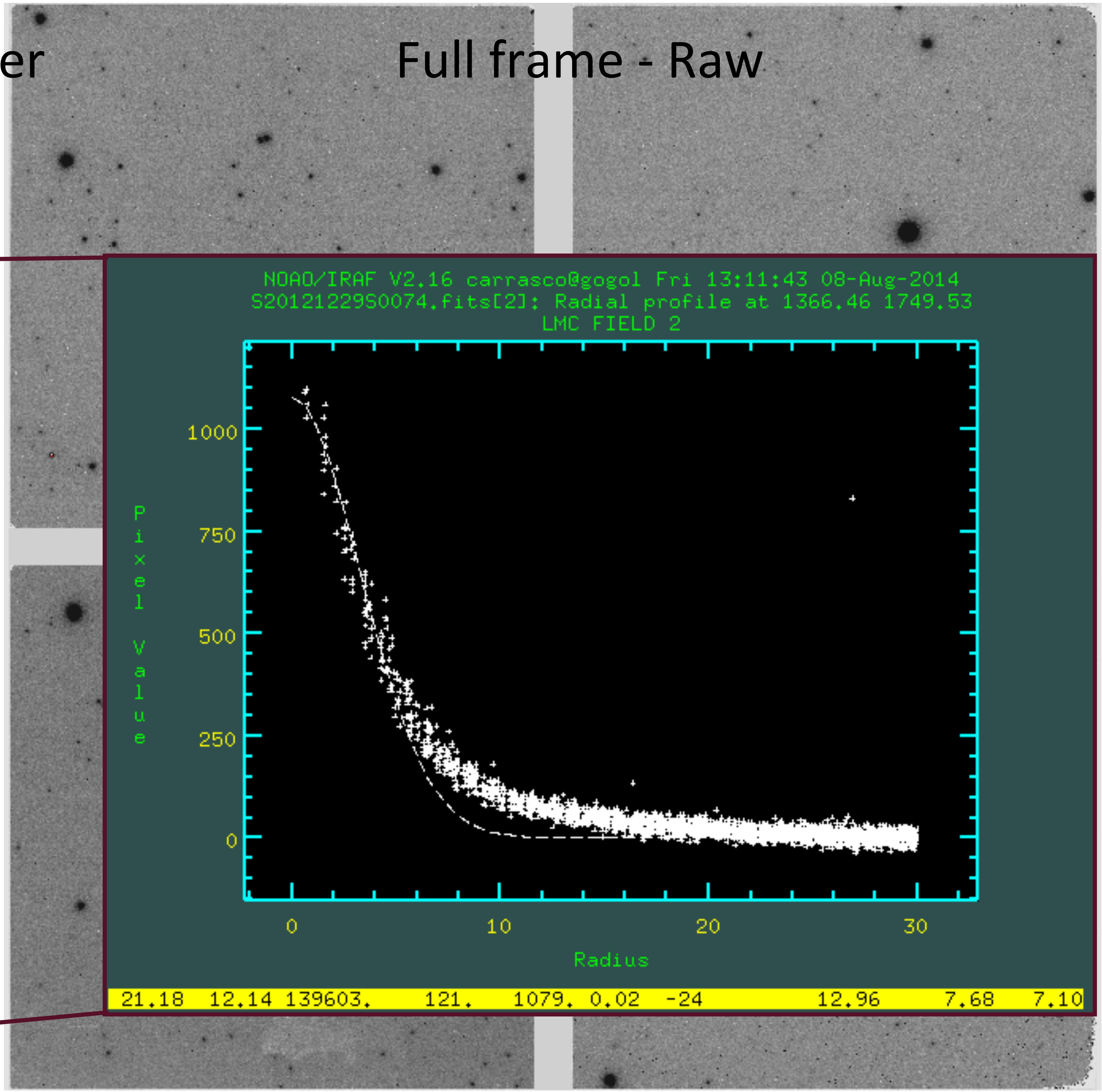
GSAOI Sky orientation: N-up, E-right (PA=0.0)

J-filter



Array 2 - Raw

```
NOAO/IRAF V2.16 carrasco@gogol Fri 13:11:10 08-Aug-2014
S20121229S0074.fits[2]: Contoured from 149. to 1149., interval = 200.
LMC FIELD 2
```



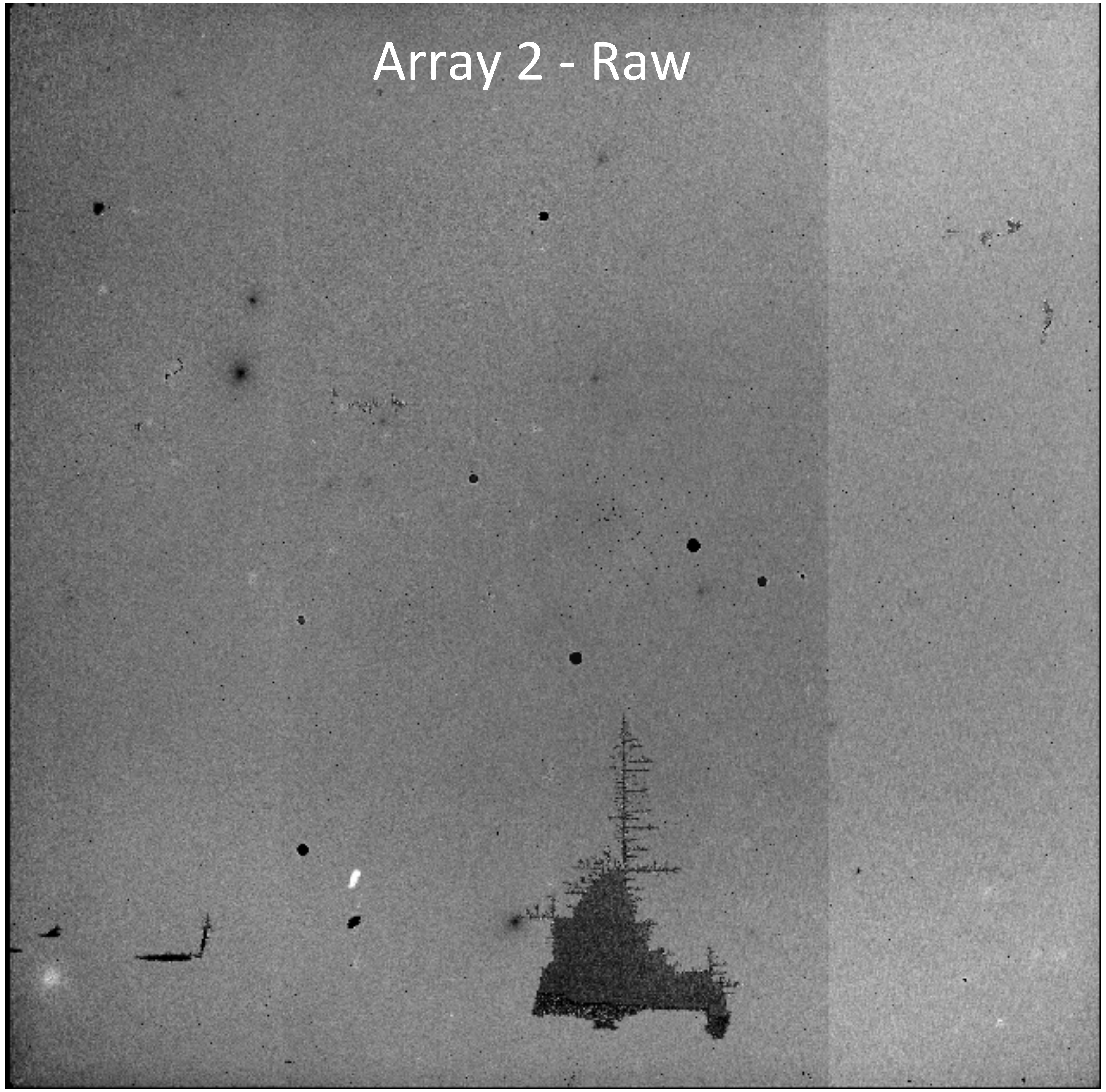
Full frame - Raw

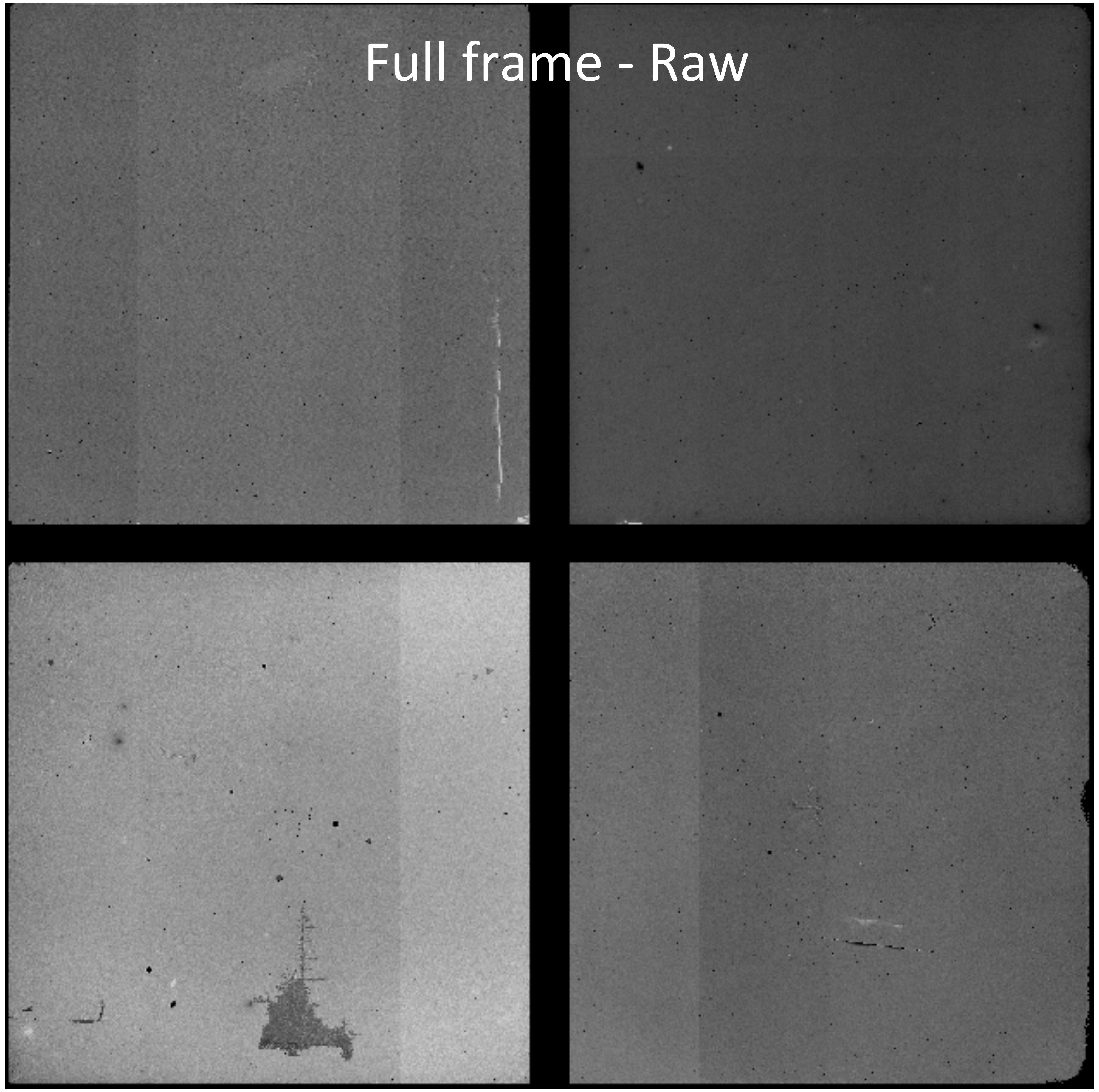
```
NOAO/IRAF V2.16 carrasco@gogol Fri 13:11:43 08-Aug-2014
S20121229S0074.fits[2]: Radial profile at 1366.46 1749.53
LMC FIELD 2
```

```
 21.18  12.14 139603.     121.    1079. 0.02  -24          12.96     7.68   7.10
```

GSAOI Data

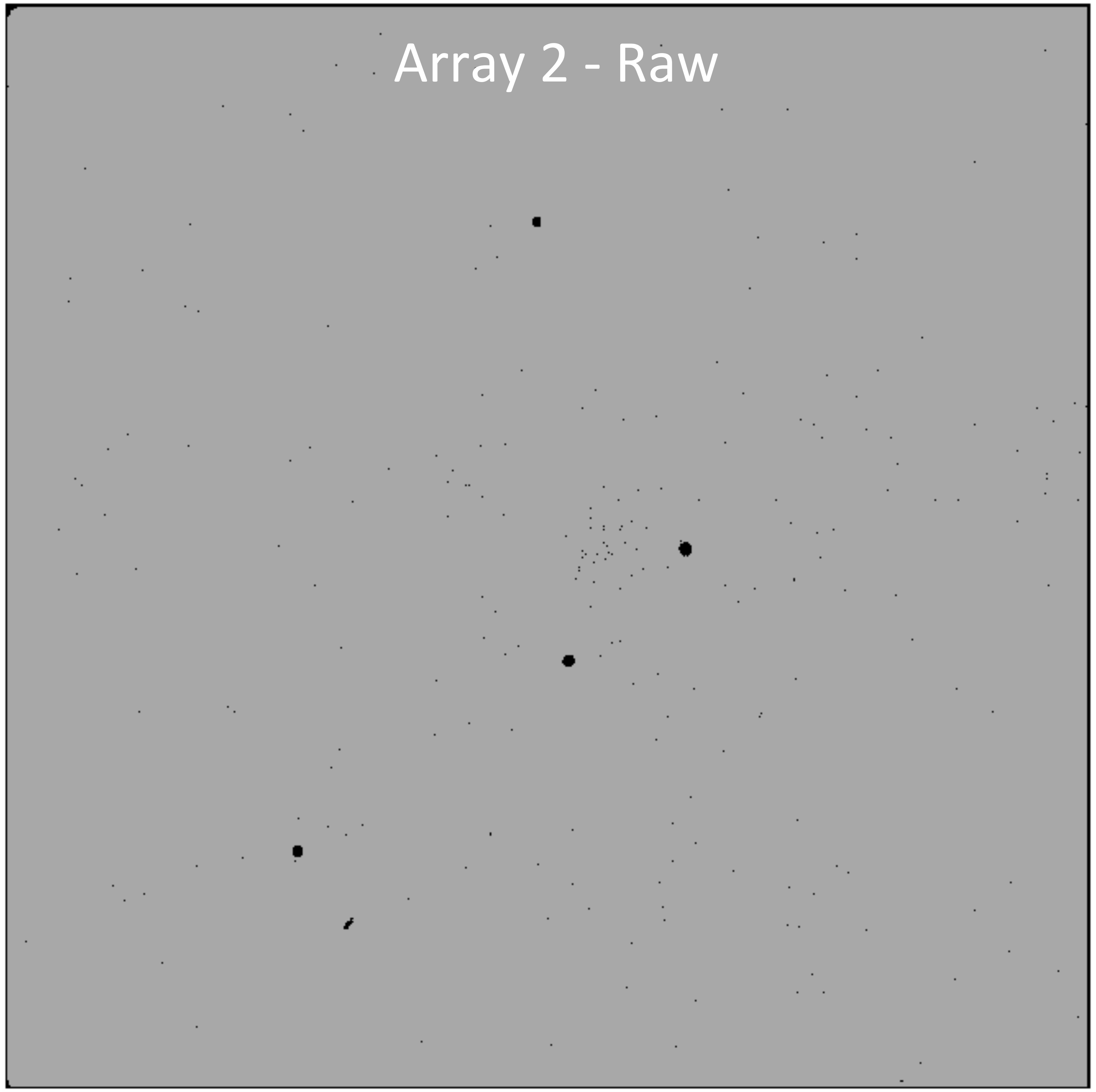
Dome flat - J-filter

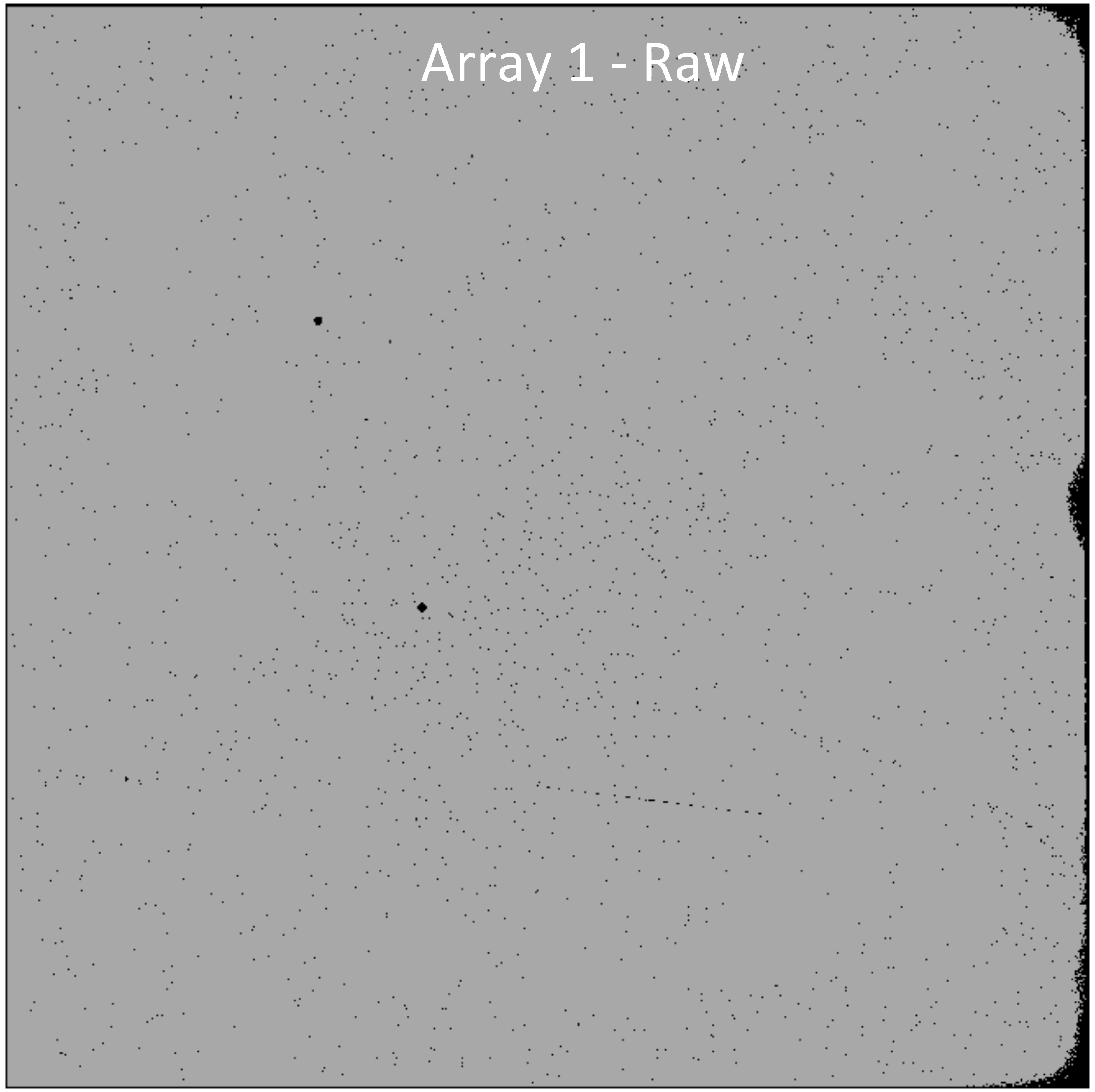




GSAOI Data

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 semeter.

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.

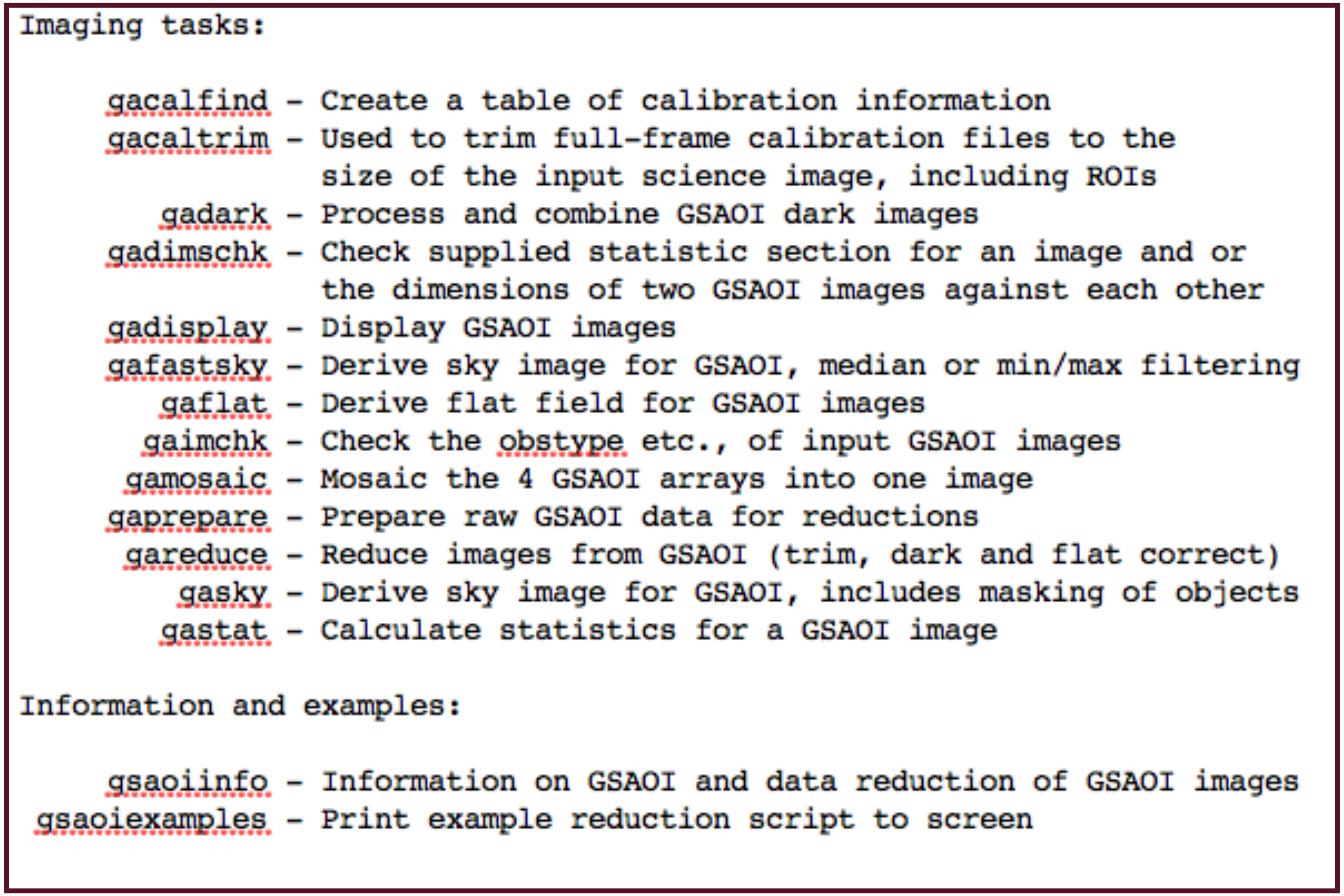
Image Reduction

Reduction

Main Tasks

- gaprepare
- 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
     gadimschk - 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
     gaprepare - 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
```

Reduction

GAPREPARE: 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+
```

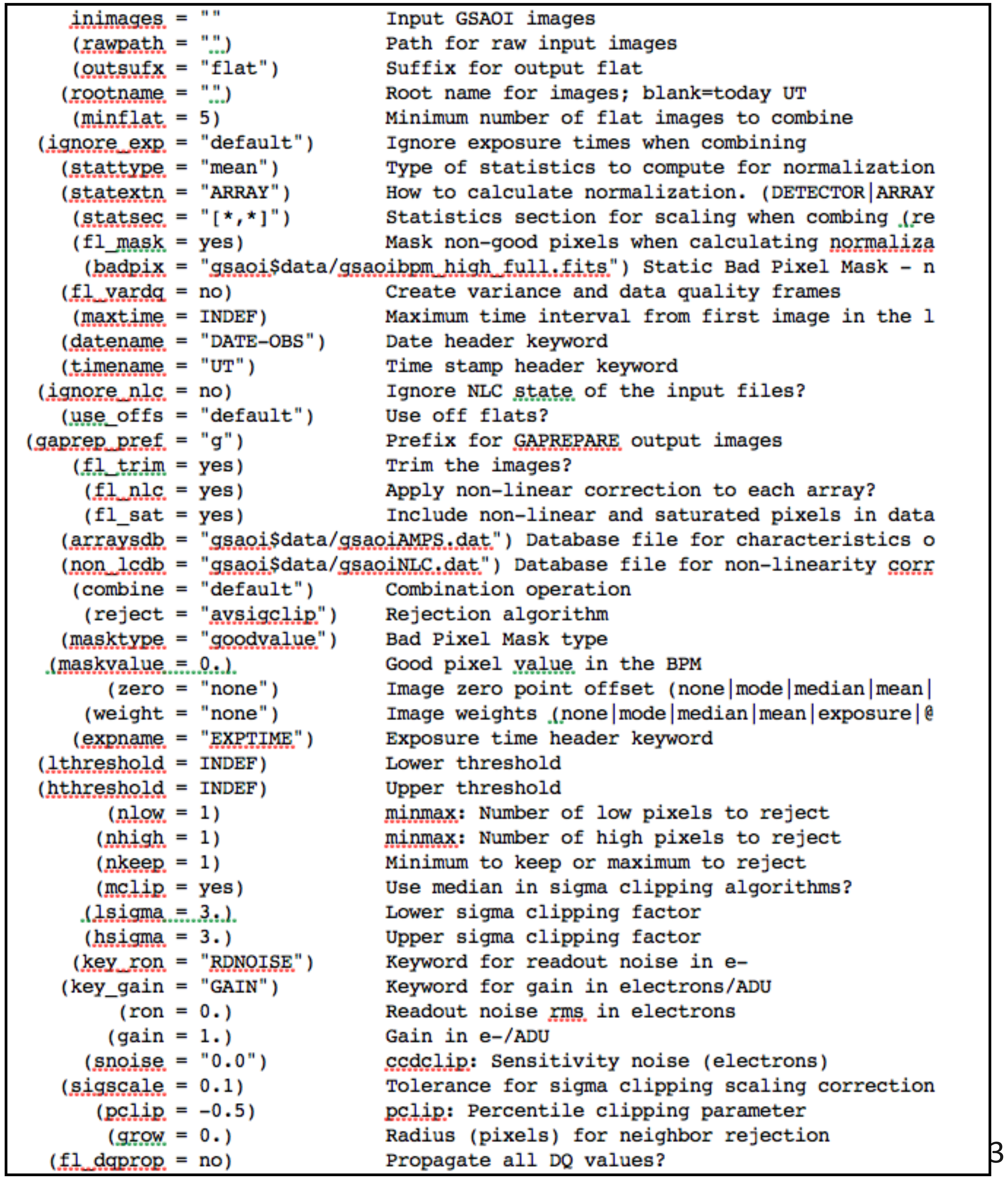
Reduction

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 images

```
> set calib=”/my-calibration-path/RawCalibration/”
> unlearn gaflat> gaflat 148-169,180-189 rawpath=calib$ \
  root=S20121220S fl_vardq+
```



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

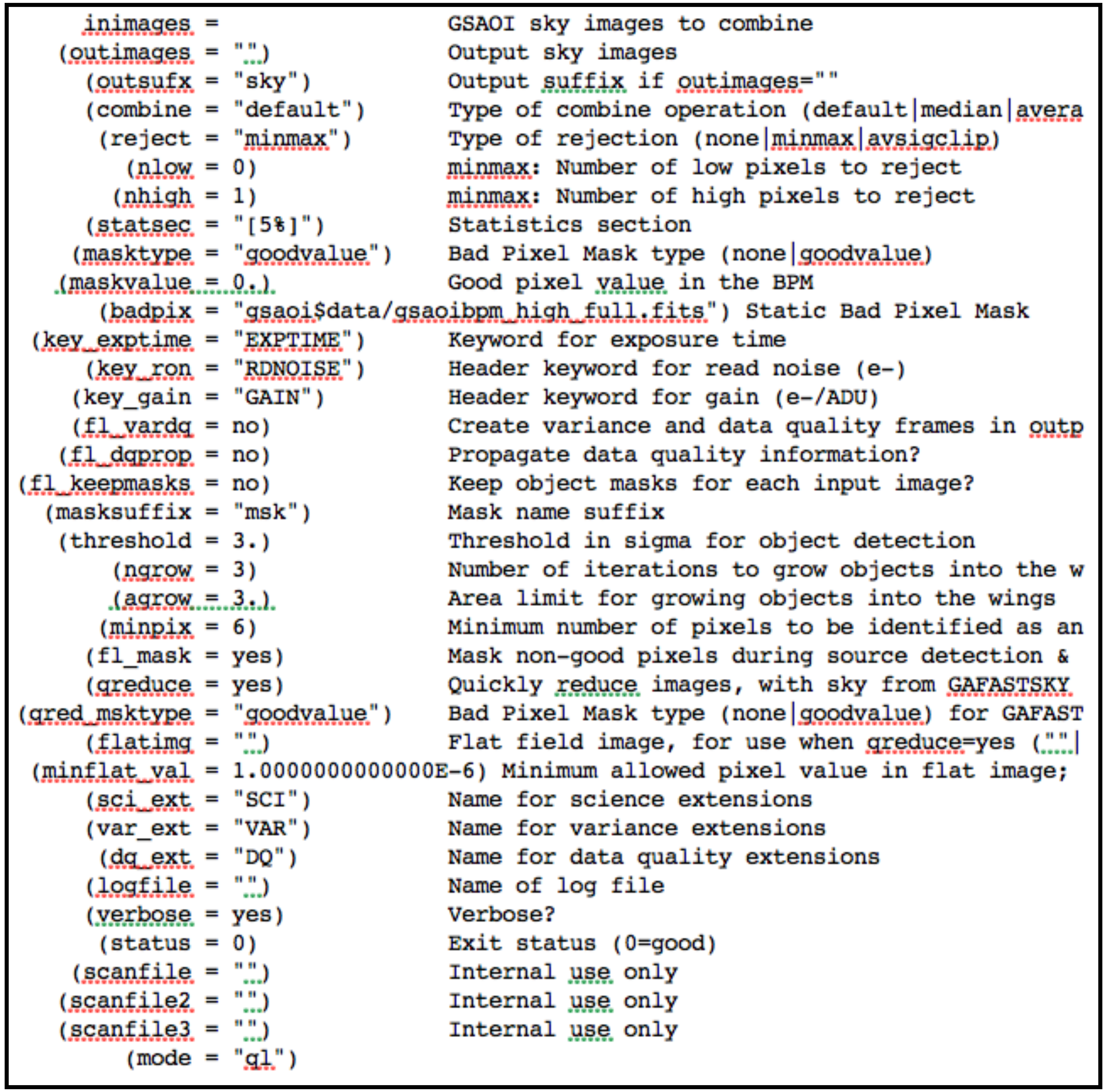
Reduction

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_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 \
fl_dqprop+ flatimg=gS20121220S0180_flat.fits



```
     inimages =                      GSAOI sky images to combine
   (outimages = "")                  Output sky images
     (outsufx = "sky")               Output suffix if outimages=""
     (combine = "default")           Type of combine operation (default|median|avera
      (reject = "minmax")            Type of rejection (none|minmax|avsigclip)
        (nlow = 0)                   minmax: Number of low pixels to reject
       (nhigh = 1)                   minmax: Number of high pixels to reject
     (statsec = "[5%]")              Statistics section
    (masktype = "goodvalue")         Bad Pixel Mask type (none|goodvalue)
   (maskvalue = 0.)                  Good pixel value in the BPM
      (badpix = "gsaoi$data/gsaoibpm_high_full.fits") Static Bad Pixel Mask
  (key_exptime = "EXPTIME")          Keyword for exposure time
     (key_ron = "RDNOISE")           Header keyword for read noise (e-)
    (key_gain = "GAIN")              Header keyword for gain (e-/ADU)
    (fl_vardq = no)                  Create variance and data quality frames in outp
   (fl_dqprop = no)                  Propagate data quality information?
(fl_keepmasks = no)                  Keep object masks for each input image?
  (masksuffix = "msk")               Mask name suffix
   (threshold = 3.)                  Threshold in sigma for object detection
       (ngrow = 3)                   Number of iterations to grow objects into the w
       (agrow = 3.)                  Area limit for growing objects into the wings
      (minpix = 6)                   Minimum number of pixels to be identified as an
     (fl_mask = yes)                 Mask non-good pixels during source detection &
     (greduce = yes)                 Quickly reduce images, with sky from GAFASTSKY
(gred_msktype = "goodvalue")         Bad Pixel Mask type (none|goodvalue) for GAFAST
     (flatimg = "")                  Flat field image, for use when greduce=yes (""|
 (minflat_val = 1.0000000000000E-6) Minimum allowed pixel value in flat image;
     (sci_ext = "SCI")               Name for science extensions
     (var_ext = "VAR")               Name for variance extensions
      (dq_ext = "DQ")                Name for data quality extensions
     (logfile = "")                  Name of log file
     (verbose = yes)                 Verbose?
      (status = 0)                   Exit status (0=good)
    (scanfile = "")                  Internal use only
   (scanfile2 = "")                  Internal use only
   (scanfile3 = "")                  Internal use only
        (mode = "ql")
```

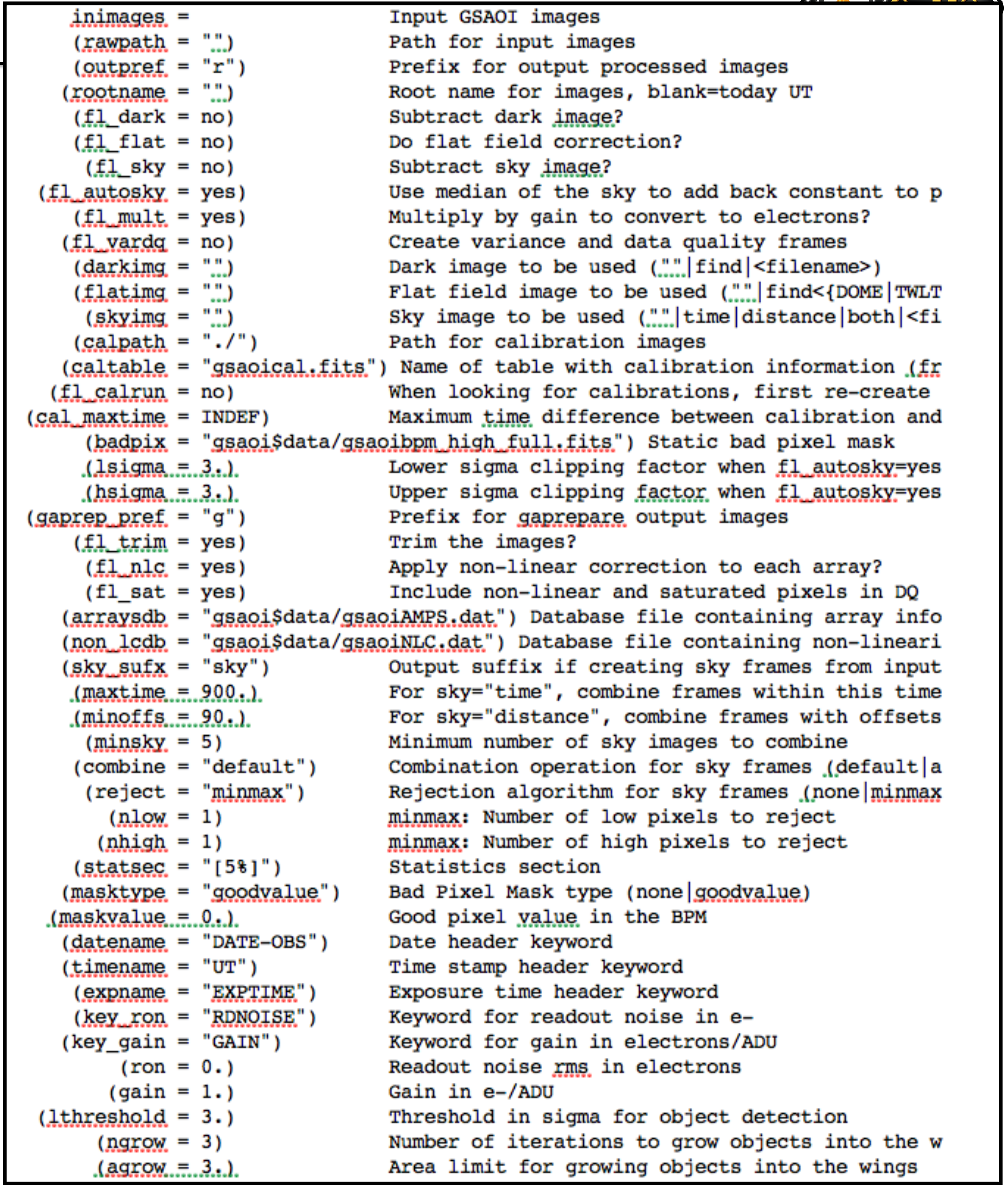
Reduction

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.

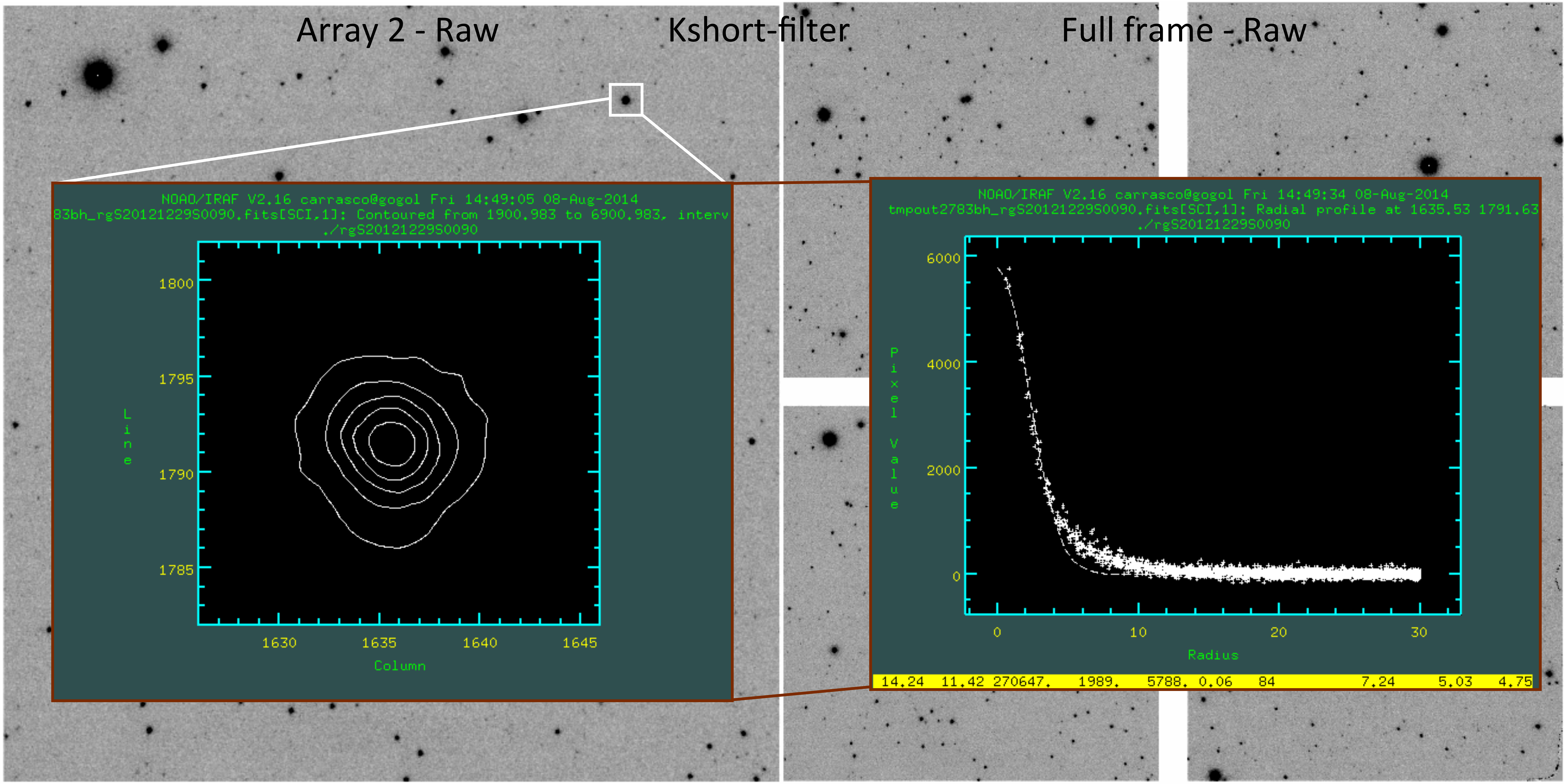
- Current example data: Ks bands science images

```
> unlearn gareduce
> gareduce 90-93 rawpath=./ rootname=gS20121229S \
fl_flat+ fl_sky+ fl_vardq+ \
flatimg=gS20121220S0180_flat skyimg=SkyKs.fits
```



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

Reduction



Array 2 - Raw

Kshort-filter

Full frame - Raw

```
NOAO/IRAF V2.16 carrasco@gogol Fri 14:49:05 08-Aug-2014
83bh_rgS20121229S0090.fits[SCI,1]: Contoured from 1900.983 to 6900.983, interv
./rgS20121229S0090
```

```
NOAO/IRAF V2.16 carrasco@gogol Fri 14:49:34 08-Aug-2014
tmpout2783bh_rgS20121229S0090.fits[SCI,1]: Radial profile at 1635.53 1791.63
./rgS20121229S0090
```

```
14.24   11.42 270647.     1989.    5788. 0.06    84             7.24       5.03    4.75
```

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)

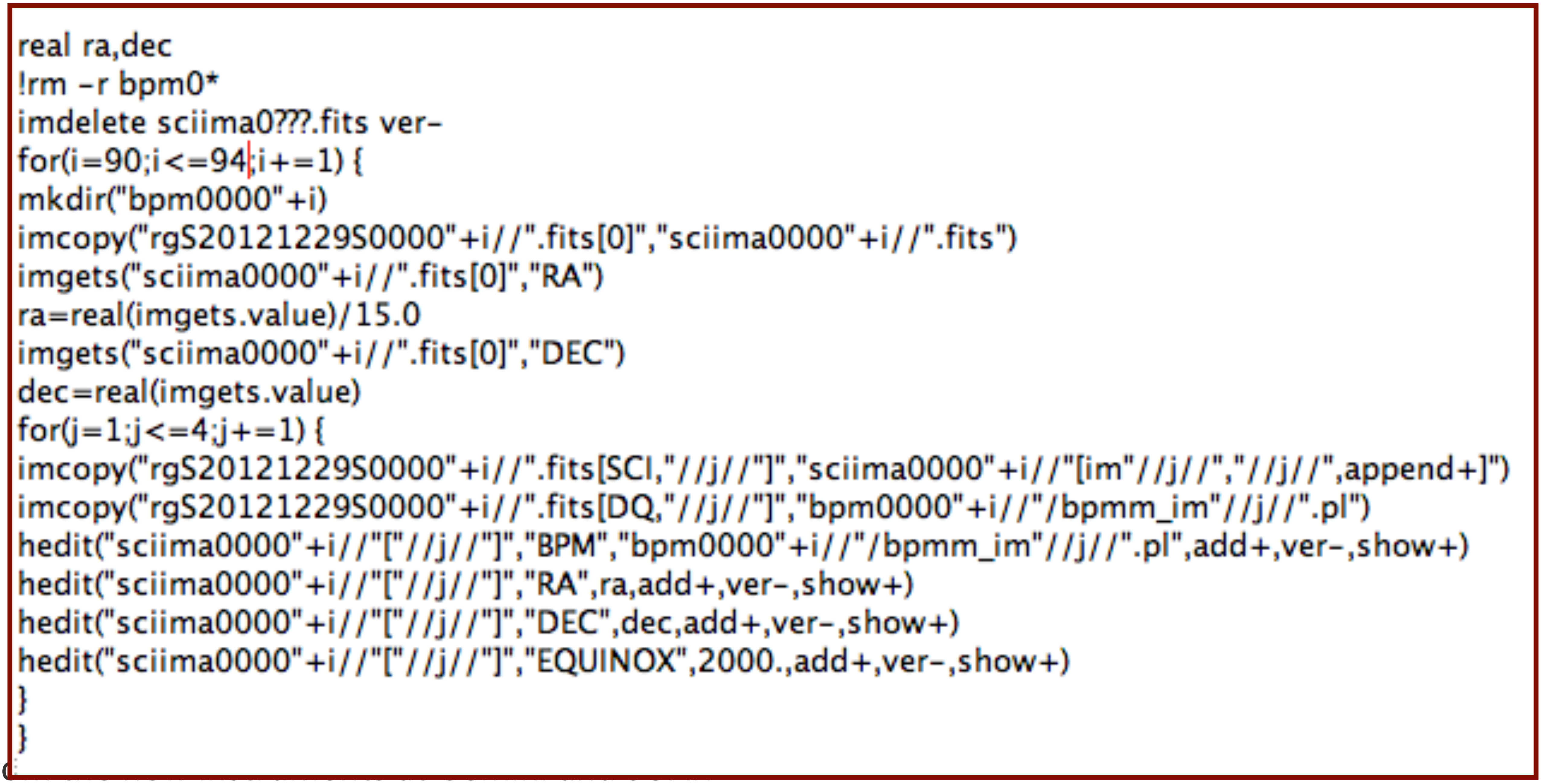
- Most of the distortion can calibrated out (static distortion)
  - Using observation of astrometric field in LMC with accurate coordinates (typical rms ~ 1 mas)

- 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

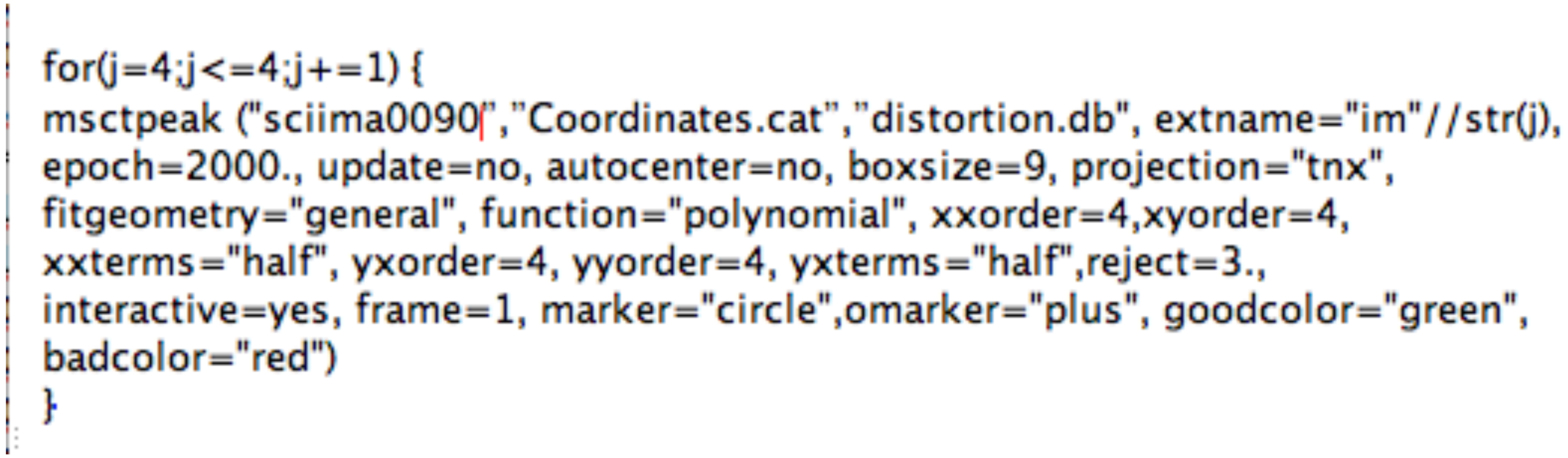
- The example: LMC astrometric field observed in J, H and Ks-bands (2012 December 29UT)
  - distortion correction and mosaicing --> using a catalogue of stars with precise coordinates (~1 mas rms, easiest case)
  - Useful programs: scamp, swarp (Terapix) and Theli (http://www.astro.uni-bonn.de/theli/)
  - 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



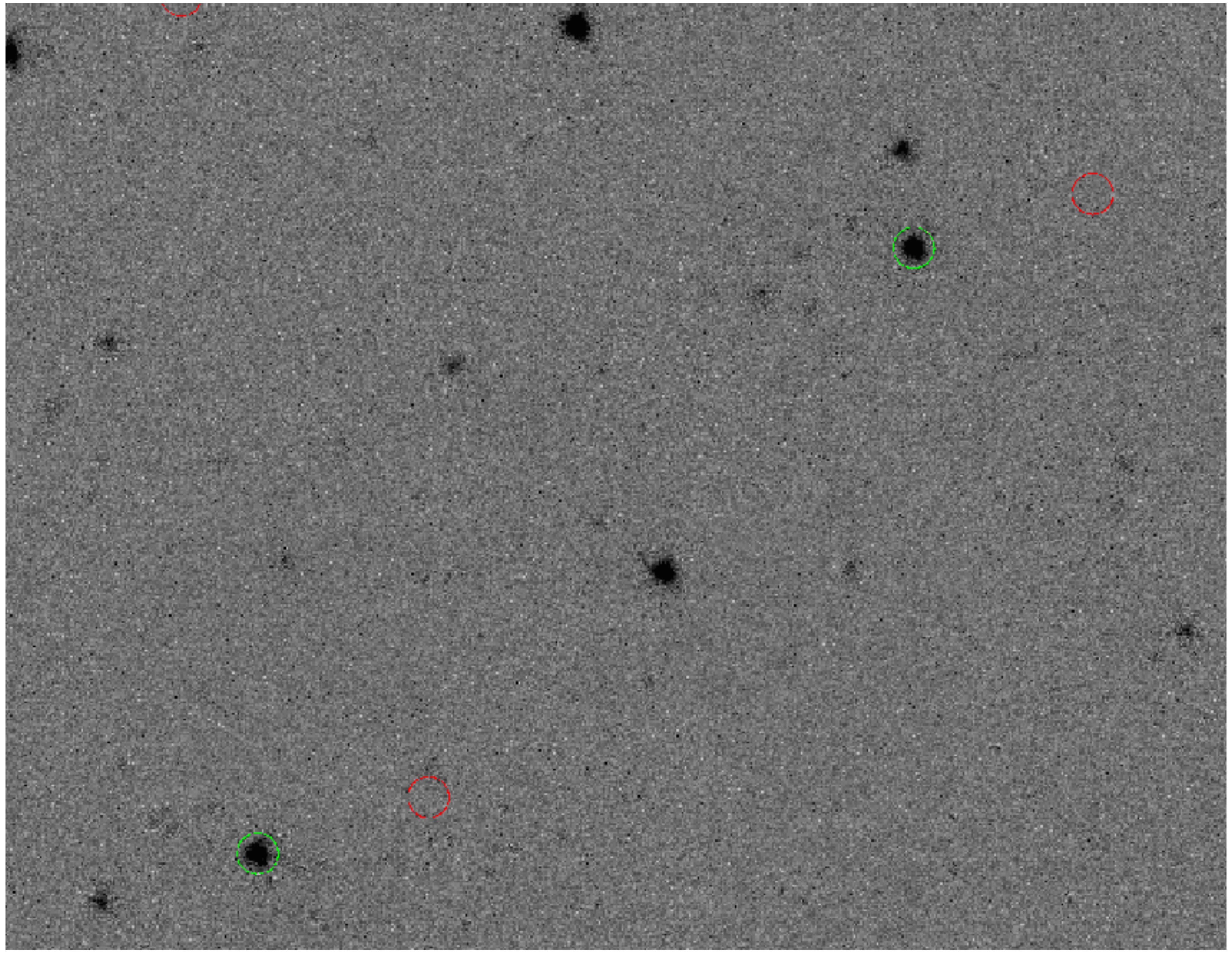
```
real ra,dec
!rm -r bpm0*
imdelete sciima0???.fits ver-
for(i=90;i<=94;i+=1) {
mkdir("bpm0000"+i)
imcopy("rgS20121229S0000"+i//".fits[0]","sciima0000"+i//".fits")
imgets("sciima0000"+i//".fits[0]","RA")
ra=real(imgets.value)/15.0
imgets("sciima0000"+i//".fits[0]","DEC")
dec=real(imgets.value)
for(j=1;j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



```
for(j=4;j<=4;j+=1) {
msctpeak ("sciima0090","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,
xxterms="half", yxorder=4, yyorder=4, yxterms="half",reject=3.,
interactive=yes, frame=1, marker="circle",omarker="plus", goodcolor="green",
badcolor="red")
}
```



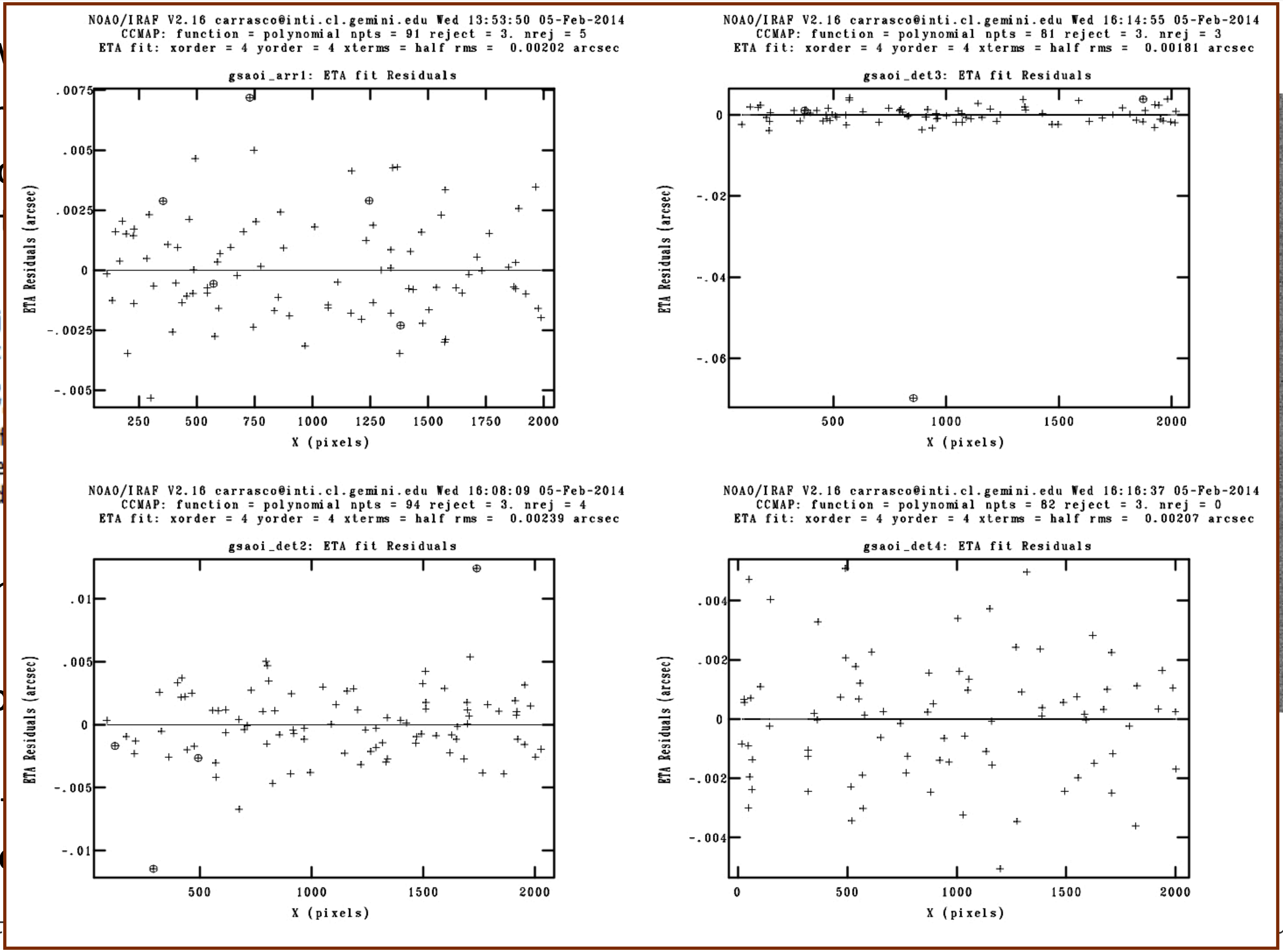
- Using “tnx” sky projection geometry (add no-linear terms to the solution),
- Using a polynomial fitting of order 4 with cross terms.
- Only for the image at 0,0 position (using as a reference)

Distortion correction

- GSAOI W
  - You sh
- Load pac
  the 4 ext

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

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



```
NOAO/IRAF V2.16 carrasco@inti.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
```

gsaoi_arr1: ETA fit Residuals

```
NOAO/IRAF V2.16 carrasco@inti.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
```

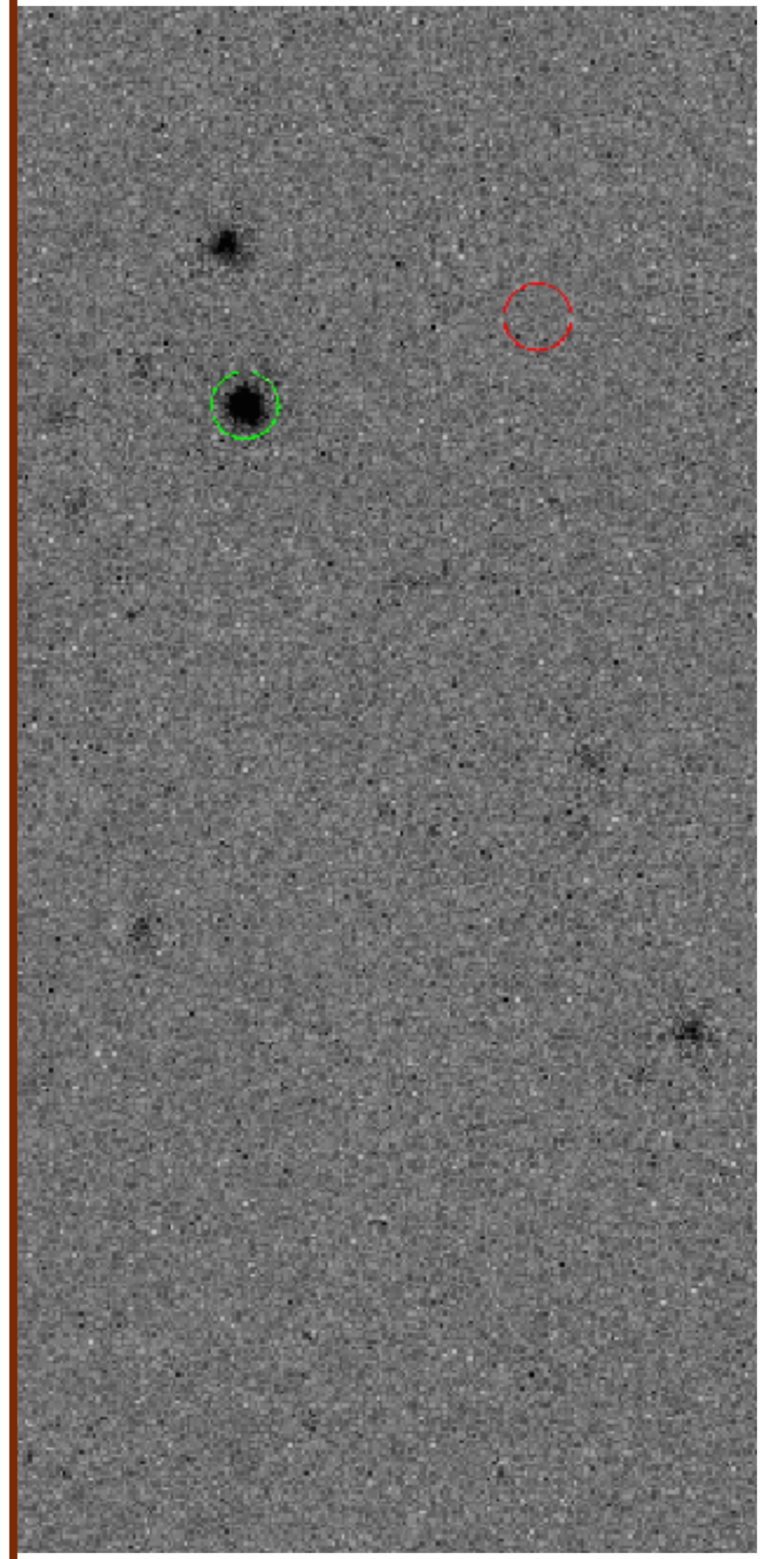
gsaoi_det3: ETA fit Residuals

```
NOAO/IRAF V2.16 carrasco@inti.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
```

gsaoi_det2: ETA fit Residuals

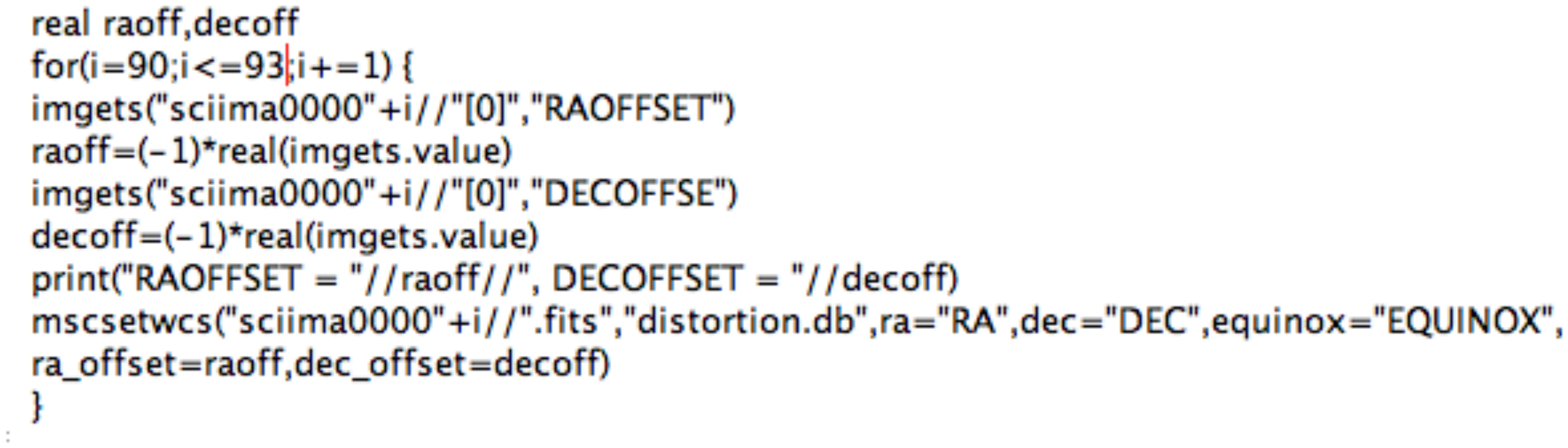
```
NOAO/IRAF V2.16 carrasco@inti.cl.gemini.edu Wed 16:16:37 05-Feb-2014
CCMAP: function = polynomial npts = 82 reject = 3. nrej = 0
ETA fit: xorder = 4 yorder = 4 xterms = half rms =  0.00207 arcsec
```

gsaoi_det4: ETA fit Residuals



Distortion correction

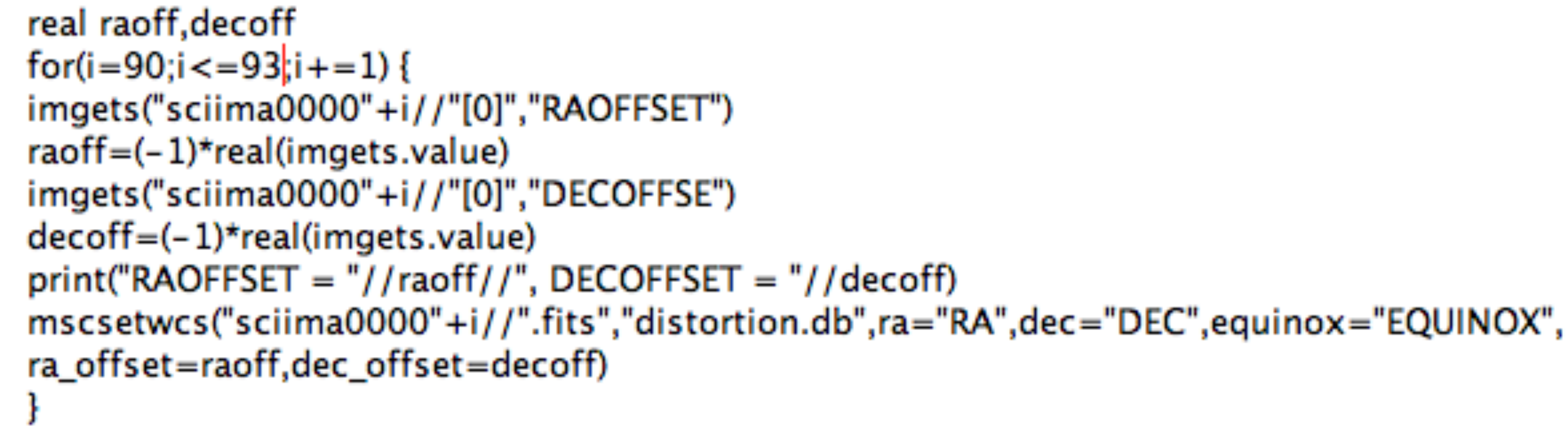
- Propagating the distortion correction to all other images using “mscsetwcs”
  - “ccsetwcs” can be used also, but array by array
- Dithering images:
  - Offsets have to be propagated properly



```
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

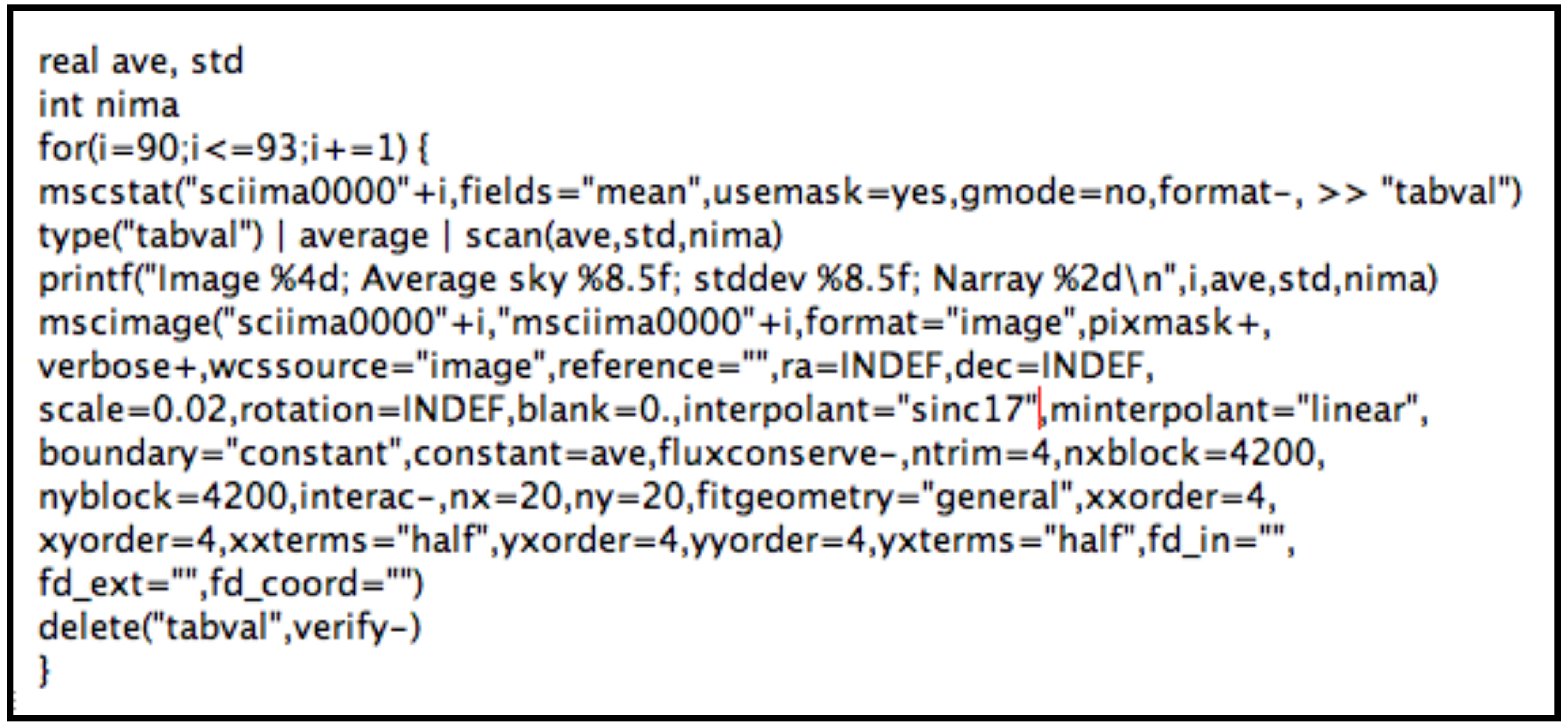
- Propagating the distortion correction to all other images using “mscsetwcs”
  - “ccsetwcs” can be used also, but array by array
- Dithering images:
  - Offsets have to be propagated properly



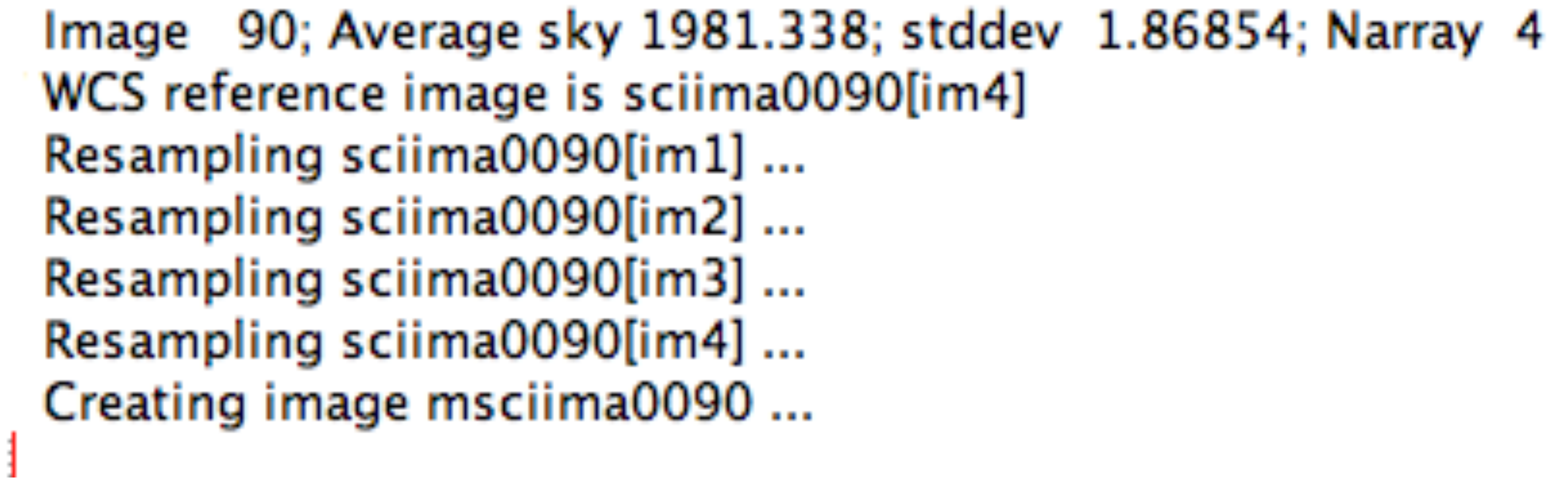
```
real raoff,decoff
for(i=90;i<=93;i+=1) {
imgets("sciima0000"+i//"[0]","RAOFFSET")
raoff=(-1)*real(imgets.value)
imgets("sciima0000"+i//"[0]","DECOFFSE")
decoff=(-1)*real(imgets.value)
print("RAOFFSET = "//raoff//", DECOFFSET = "//decoff)
mscsetwcs("sciima0000"+i//".fits","distortion.db",ra="RA",dec="DEC",equinox="EQUINOX",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

Mosaic-ing

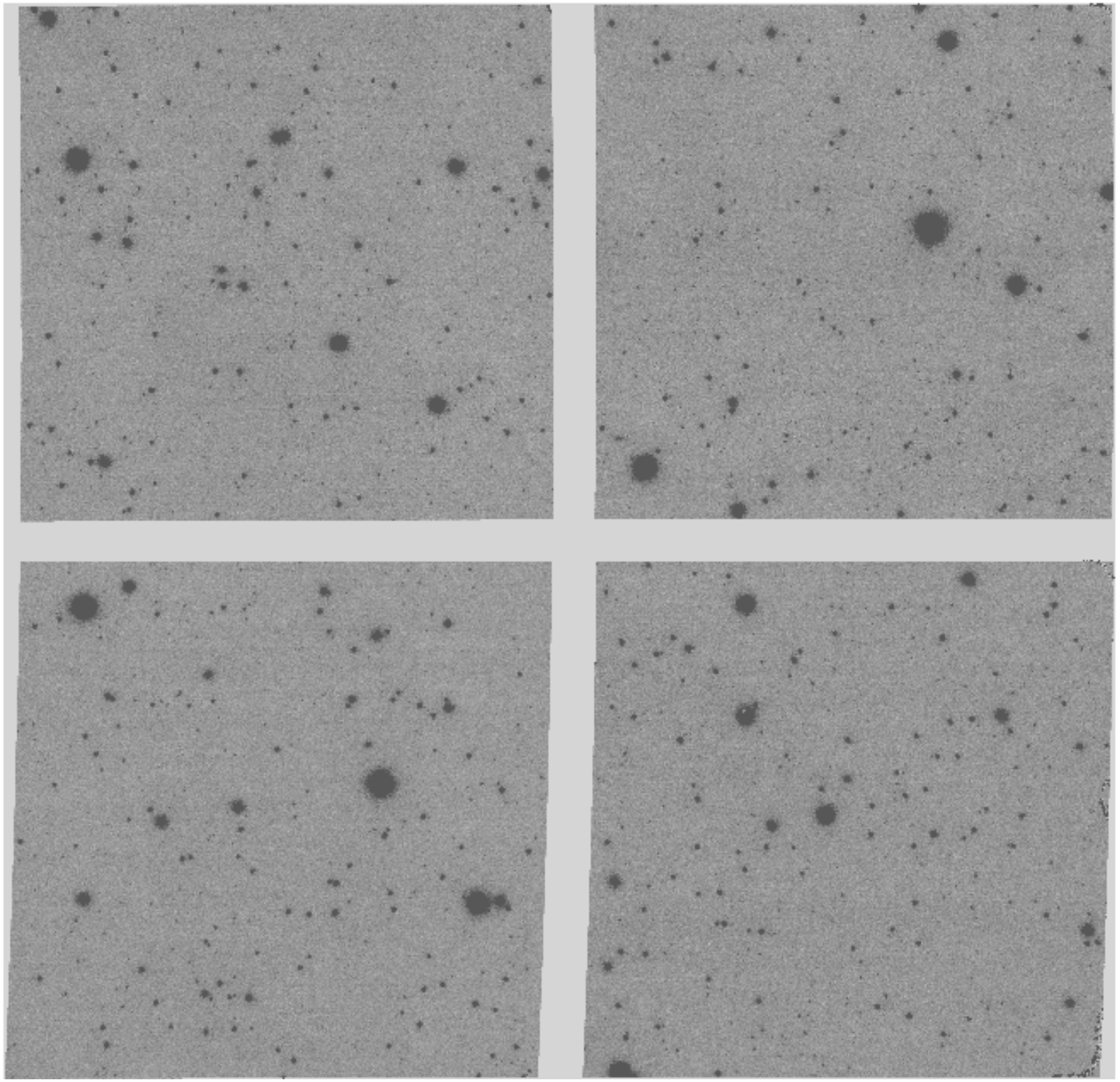
- Build mosaic with "mscimage"
- mscstat is used to calculate the average sky for all array (+ std)



```
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 ...
```

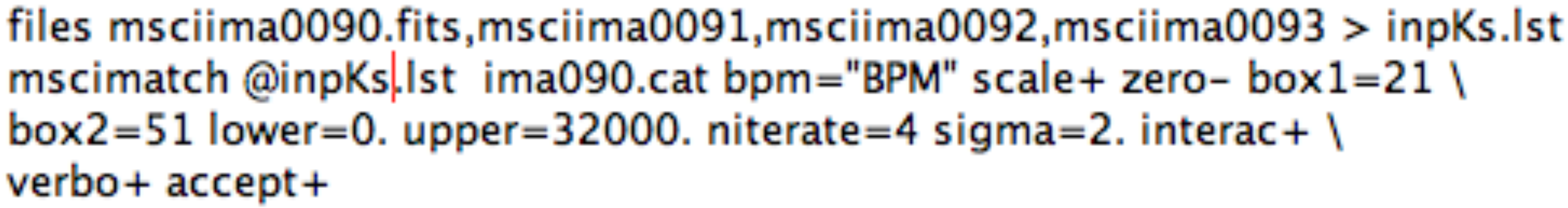


Stacking images

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

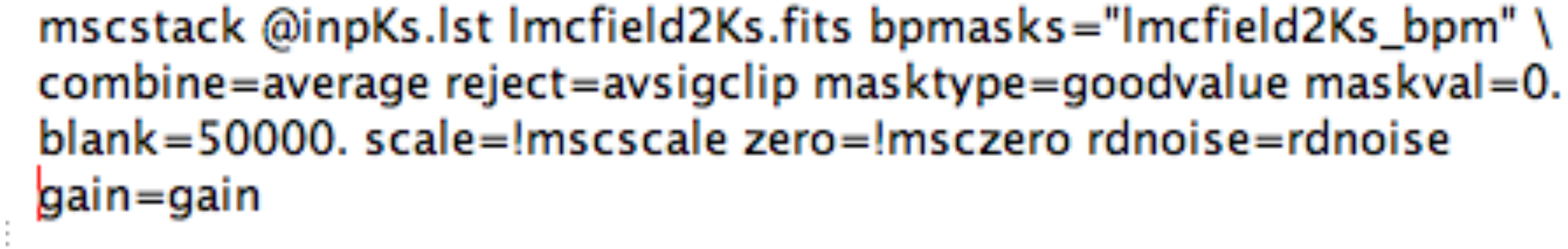
Using the 2MASS catalog and “mscgetcatalog” to get the catalogue > mscgetcatalog msciima0090 ima090.cat magmin=12.0 magmax=18.0 cat=” twomass@noao"

- Match intensity using “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. 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)