



DRAGONS Science Quality Verification: Imaging

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The first public release of Gemini's new Python-based data reduction platform, DRAGONS (Data Reduction for Astronomy from Gemini Observatory North and South), occurred late in 2019 and supports imaging for current facility instruments. Here we present some reduction examples with GMOS, FLAMINGOS-2 (F2), NIRI, and GSAOI, and compare with an equivalent Gemini IRAF reduction for the purpose of demonstrating similar photometric accuracy. DRAGONS and Gemini IRAF do not have the same default options so it is important to consider certain parameters carefully as will be shown for each instrument.

Comparison Process

The reduction is done with both DRAGONS and PyRAF in a standard way as described in the [DRAGONS tutorials](#) and the [Gemini IRAF examples](#). When something differs between the two versions of the reduction, this is mentioned in the text. The output units for Gemini IRAF are either ADUs (F2, NIRI) or electrons (GMOS, GSAOI) whereas DRAGONS' output is always in electrons.

Sources are detected in the stacked images, using DRAGONS' detectSources primitives which runs SExtractor. A reference catalog is added to the stacked files, either from the SDSS¹ catalog in the optical (GMOS), or from the 2MASS² catalog in the infrared. The reference

¹ Funding for SDSS-III has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, and the U.S. Department of Energy Office of Science. The SDSS-III web site is <http://www.sdss3.org/>. SDSS-III is managed by the Astrophysical Research Consortium for the Participating Institutions of the SDSS-III Collaboration including the University of Arizona, the Brazilian Participation Group, Brookhaven National Laboratory, Carnegie Mellon University, University of Florida, the French Participation Group, the German Participation Group, Harvard University, the Instituto de Astrofísica de Canarias, the Michigan State/Notre Dame/JINA Participation Group, Johns Hopkins University, Lawrence Berkeley National Laboratory, Max Planck Institute for Astrophysics, Max Planck Institute for Extraterrestrial Physics, New Mexico State University, New York University, Ohio State University, Pennsylvania State University, University of Portsmouth, Princeton University, the Spanish Participation Group, University of Tokyo, University of Utah, Vanderbilt University, University of Virginia, University of Washington, and Yale University.

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catalog is matched to the sources detected in the image and it is used to determine the astrometric solution, and can then be used to measure the magnitude zeropoint. This is very similar to the procedure used by the Quality Assessment Pipeline (QAP, an internal Observatory tool used by Observers to assess the observing conditions) and can be reproduced with the following custom DRAGONS recipe:

```
def findSources(p):
    p.detectSources()
    # source must be "sdss9" or "2mass"
    p.addReferenceCatalog()
    # initial radius is 5" by default but a larger radius was needed for F2, 10" was used
    p.determineAstrometricSolution()
    p.measureIQ()
    p.measureBG()
    p.measureCC()
    p.writeOutputs()
```

After putting this code in a “myrecipes.py” file, it can be run with the “reduce” command with the appropriate parameters, for example:

```
reduce -r myrecipes.findSources -p addReferenceCatalog:source=2mass
determineAstrometricSolution:initial=10
```

The addReferenceCatalog primitive currently does not work outside the Observatory network due to a bug that will be addressed in the next release.

Sources without measured instrumental magnitudes or reference magnitudes are removed. The sources that are saturated or that have more than 2% of their pixels flagged by DRAGONS (for bad or non-linear pixels) during the reduction are plotted with a star symbol below.

In the analysis below, two types of plots are shown to compare the source magnitudes:

- A plot comparing with the reference catalog. This plot usually has fewer sources, especially with 2MASS, because the reference magnitudes that are available are usually not as deep measured with Gemini data. We compute a mean error for the magnitude difference, weighted by the magnitude errors. The sources that are excluded in DRAGONS due to the reasons mentioned above are also excluded from the IRAF results in order to use the same sources
- A plot comparing DRAGONS and IRAF, with all the sources that have been detected and matched in the two images.

I - GMOS

The reduction is done with both DRAGONS and PyRAF in a standard way, computing the master bias and flat with the default parameters. Then the science images are processed and stacked. For the purpose of this comparison, the stacking parameters are adjusted to use a similar method. IRAF's "imcoadd" uses a scaling according to the signal in the objects, so this was disabled (fl_scale-) to be consistent with DRAGONS. And to be consistent with a lack of sigma-clipping on sources in imcoadd, the DRAGONS rejection thresholds were set conservatively (hsigma and lsigma parameters for the stackFrames primitive) to 20.

Of the ~1900 sources detected in both DRAGONS and IRAF stacked images, we get ~250 sources with a reference magnitude (due to lack of catalog depth) and ~130 sources after removing the flagged ones.

Program	Band(s)	Number of exposures	Exposure time (s)
GN-2018A-LP-15	r	9	180



Figure 1: Comparison of the images reduced with DRAGONS (left) and IRAF (right). The under-illuminated horizontal stripes in the IRAF image, near the bright and saturated stars, are due to an effect present in the raw files, where saturated pixels would depress the whole amp in that row; this is virtually eliminated in DRAGONS by an overscan subtraction method that is more appropriate for the Hamamatsu detectors.

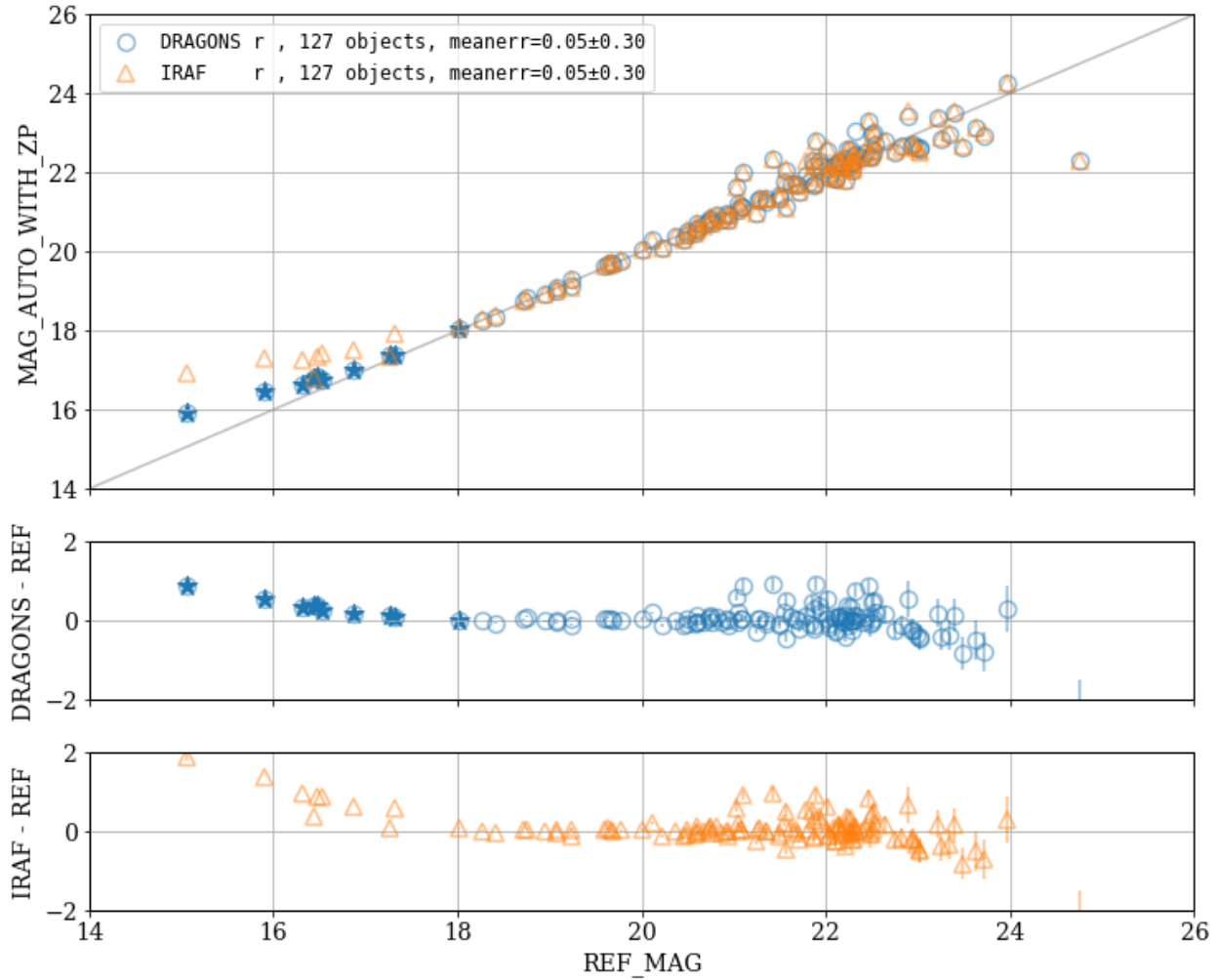


Figure 2: Top panel plots the SExtractor calculated magnitude (using the MAG_AUTO parameter that uses an adaptively scaled aperture) versus the SDSS9 catalog reference magnitude. Bottom panels show the magnitude difference, MAG_AUTO - REF_MAG, for DRAGONS and IRAF. The sources represented with star symbols have saturated, non-linear, or bad pixels and are excluded from the mean error calculations.

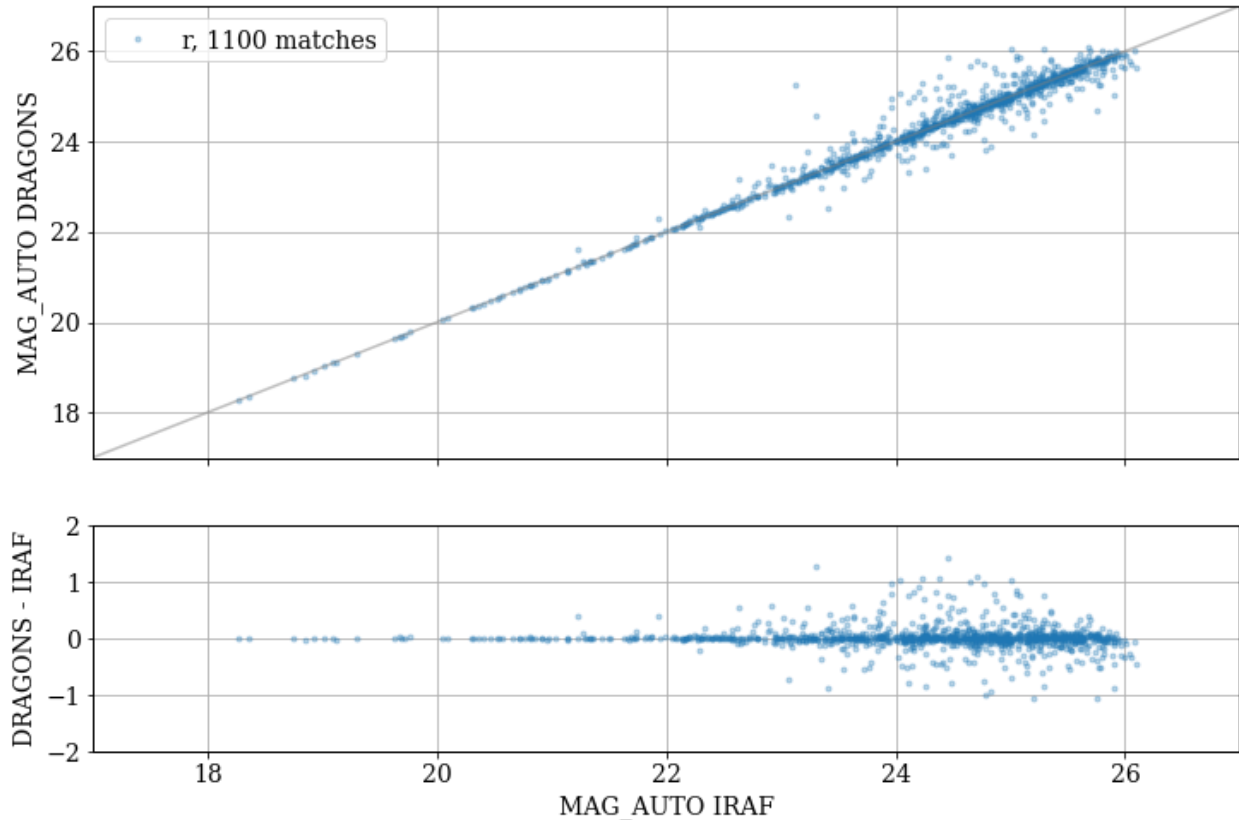


Figure 3: Comparison of DRAGONS and IRAF magnitudes (MAG_AUTO).

II- Flamingos 2

For Flamingos 2 we used a large dataset with eight fields observed over three bands (J, H, Ks). In this case, the PyRAF reduction was done previously for a different purpose (and as a best effort by a new DRAGONS user wanting to make a comparison) and therefore, the parameters were not ideal to maximize the equivalence with DRAGONS default options. This is a good example of the importance of examining these default choices carefully.

The sky subtraction is a bit different between DRAGONS and PyRAF. In Gemini IRAF, `nisky` is used to combine all the frames with a median and a sigma-clipping rejection, and with default parameters except for `statsec` which was limited to the central 600 pixels. With DRAGONS, only the frames within a time range of 600s and a distance of 3 arcsec are used, and those are combined with a median with minmax rejection. In both cases objects are masked before stacking the sky frames.

Additionally the stacking with `imcoadd` used the flux-source scaling option (`fl_scale+`) with a custom list of sources to minimize the influence of the vignetting of the peripheral wavefront sensor. Stacking in DRAGONS uses only scaling by the background levels and therefore, is not

affected by the vignetting. However, to have a true comparison, it would be better to turn off the `fl_scale` in the call to `imcoadd` in IRAF.

These differences in reduction appear to affect the background sky levels, primarily in H and Ks. Figure 4 shows a histogram of these background values for both reductions and we can see that the noise for the J band is similar for DRAGONS and IRAF, whereas for the H and Ks band DRAGONS does significantly better.

Name	Band	Exptime	Date	QA	Raw CC	Nobj OBJCAT	Nobj REFCAT
J0007+1951	J	10.0	2018-10-03	Pass	50	313	9
J0007+1951	H	10.0	2018-10-03	Pass	50	688	9
J0007+1951	Ks	10.0	2018-10-03	Pass	50	781	9
J0109-1901	J	10.0	2018-10-03	Pass	50	414	2
J0109-1901	H	10.0	2018-10-03	Pass	50	489	2
J0109-1901	Ks	10.0	2018-10-03	Pass	50	572	2
J0347+1624	J	10.0	2018-10-17	Pass	50	175	17
J0347+1624	H	10.0	2018-10-17	Pass	50	669	17
J0347+1624	Ks	10.0	2018-10-17	Pass	50	615	17
J0508+0535	J	10.0	2018-10-17	Pass	50	518	14
J0508+0535	H	10.0	2018-10-17	Pass	50	745	14
J0508+0535	Ks	10.0	2018-10-17	Pass	50	716	14
J0622+0142	J	10.0	2018-10-16	Pass	50	795	60
J0622+0142	H	10.0	2018-10-16	Pass	50	1413	60
J0622+0142	Ks	10.0	2018-10-16	Pass	50	1172	60
J0644-0352	J	10.0	2018-10-17	Pass	50	1108	82
J0644-0352	H	10.0	2018-10-17	Pass	50	1912	80
J0644-0352	Ks	10.0	2018-10-20	Undefined	50	1323	80
J0734-6011	J	10.0	2018-10-20	Pass	50	364	24
J0734-6011	H	10.0	2018-10-20	Pass	50	952	25
J0734-6011	Ks	10.0	2018-10-20	Pass	50	705	25
J1909-7938	J	10.0	2018-10-03	Pass	50	533	18
J1909-7938	H	10.0	2018-10-03	Pass	50	926	18
J1909-7938	Ks	10.0	2018-10-03	Pass	50	828	18

Table 1: Summary of the data, with the number of detected sources for each target and band, as well as the number of sources in the reference catalog.

Program	Band(s)	Number of exposures	Exposure time (s)
GS-2018B-FT-204	J, H, Ks	5 (J) or 19 (H, Ks)	10.0

J0007+1951

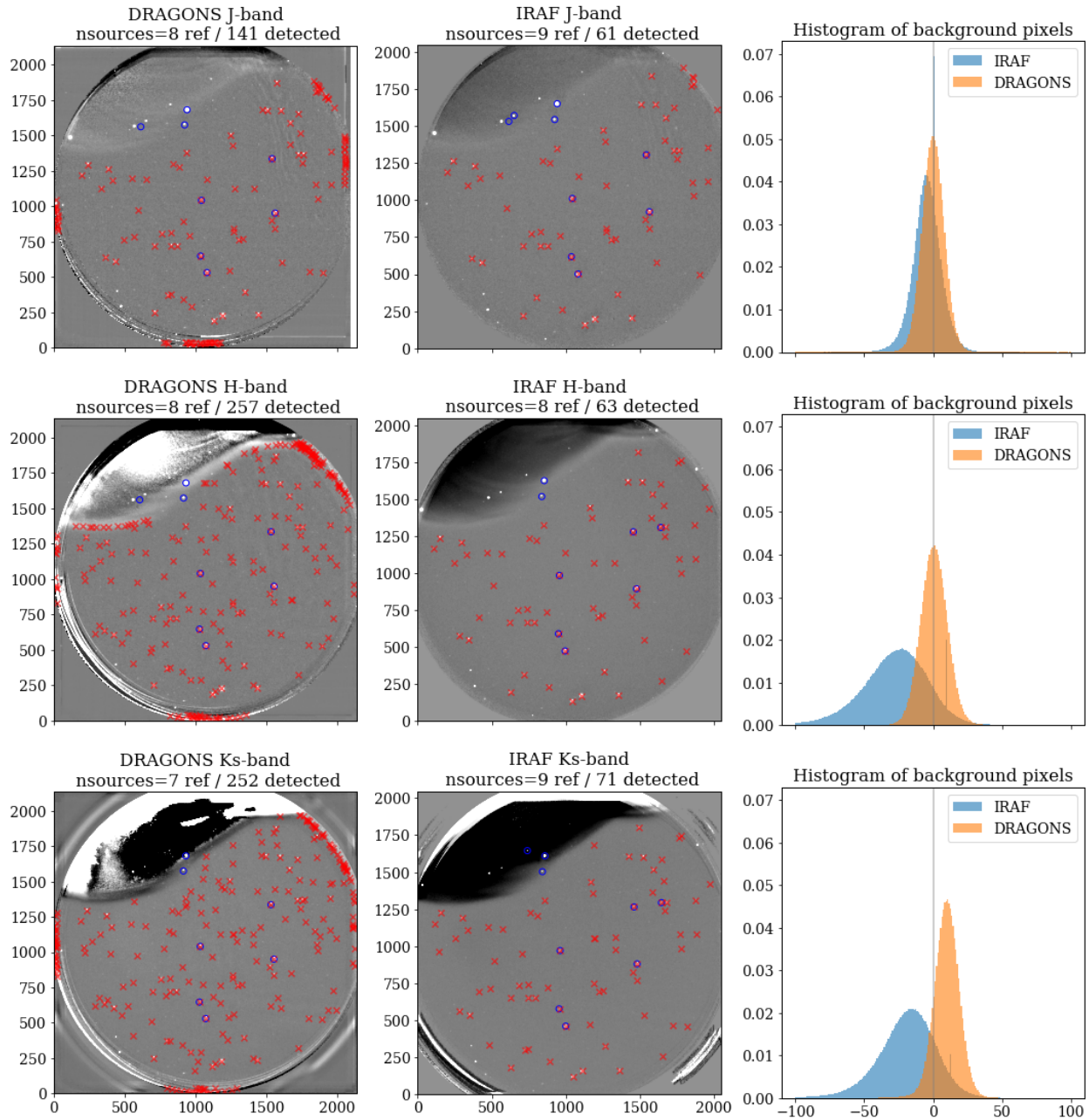


Figure 4: Comparison of the images reduced with DRAGONS (left) and IRAF (middle) for one of the targets, with the detected sources in red, and the ones in the reference catalog in blue. Right column shows the histogram of background values for both images.

For the purposes of source detection, a mask is computed for the region of the vignetting, using a positive and negative thresholding, followed by a binary dilatation, and identifying the biggest detected region.

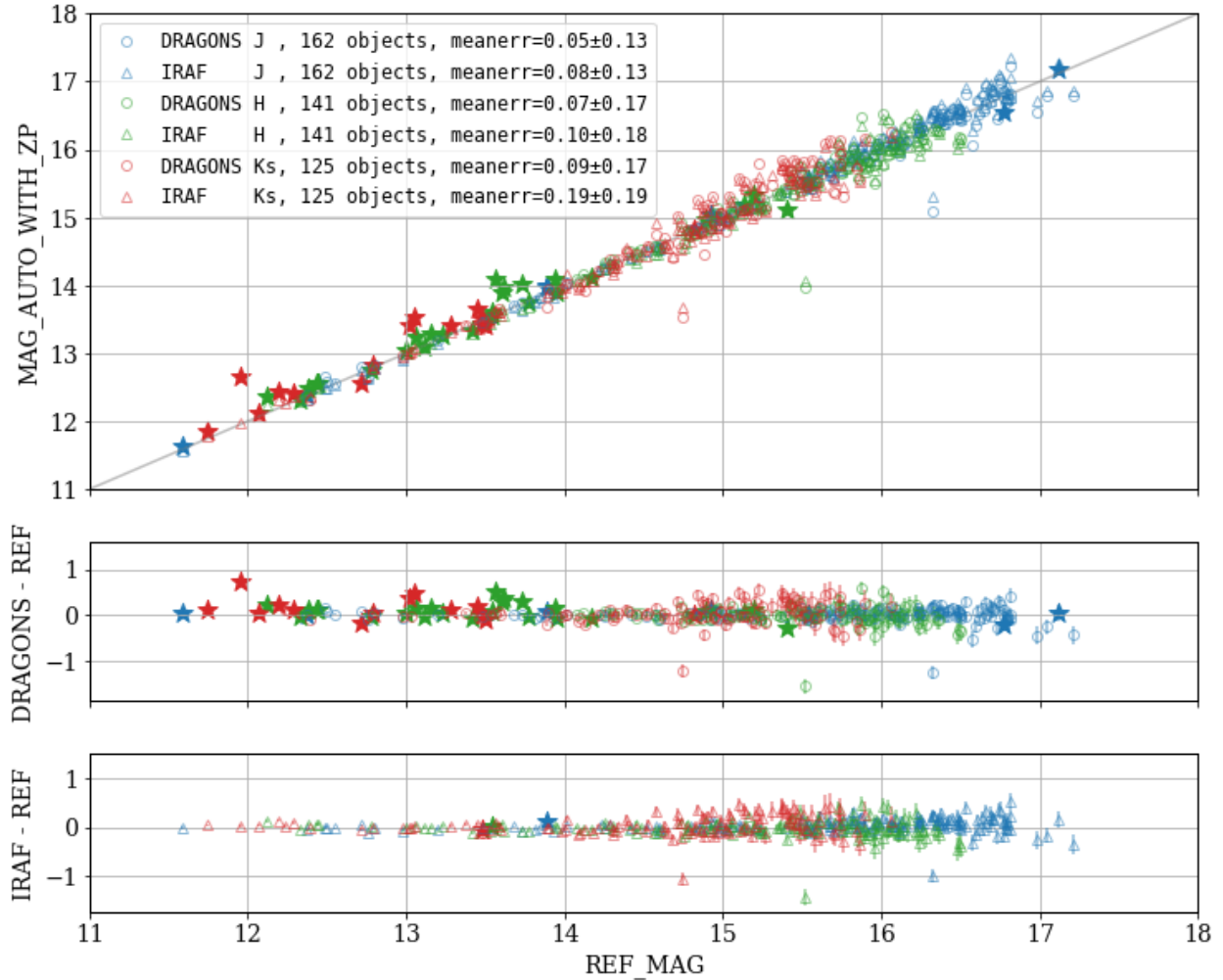


Figure 5: Top panel plots the SExtractor calculated magnitude (using the MAG_AUTO parameter that uses an adaptively scaled aperture) versus the 2MASS catalog reference magnitude. Bottom panels show the magnitude difference, MAG_AUTO - REF_MAG, for DRAGONS and IRAF. The sources represented with star symbols have saturated, non-linear, or bad pixels and are excluded from the mean error calculations.

Comparison of DRAGONS and IRAF magnitudes (MAG_AUTO)

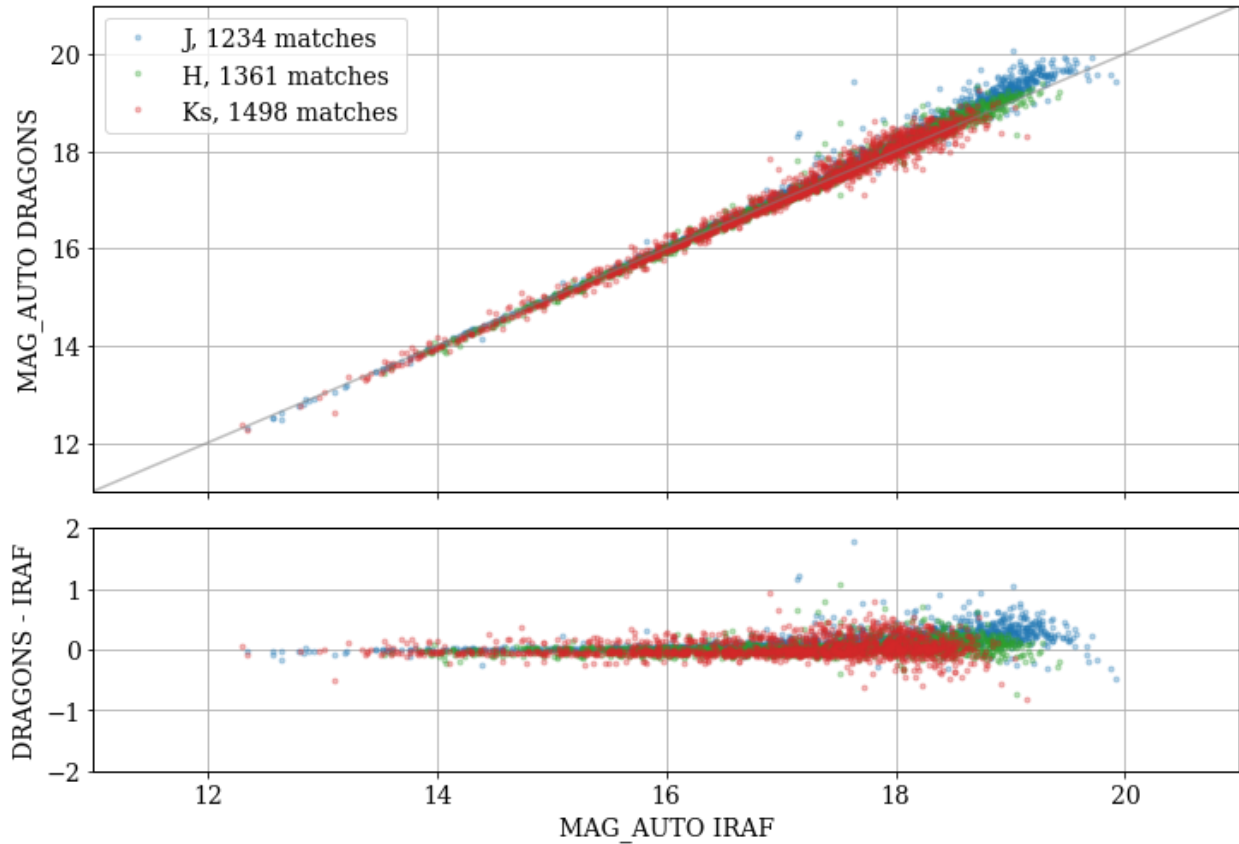


Figure 6: Comparison of DRAGONS and IRAF magnitudes (MAG_AUTO) for the J (blue), H (green) and Ks (red) bands.

III- NIRI

The dataset was taken with NIRI's f/6 camera without AO, and consists of two sets of observations, N20180711 (epoch 1 below) and N20181112 (epoch 2), and three bands (J, H, Ks). The data is available in [the archive](#).

As for F2, the sky frames are computed differently, risky (IRAF) uses by default an average with sigma-clipping (lsigma=3.0 and hsigma=3.0), and DRAGONS uses a median with minmax rejection. Also DRAGONS excludes the processed frame from the sky stack, whereas risky uses all frames to compute a sky frame.

[NIRLIN](#) was used to do a non-linearity correction on all raw frames for the IRAF reduction. The `nonlinearityCorrect()` primitive is used by default for DRAGONS. [CLEANIR.py](#), a script to remove pattern noise, was not used (it was not necessary in this case), and DRAGONS does not use its equivalent `removePatternNoise()` by default.

Program	Band(s)	Number of exposures	Exposure time (s)
GN-2018A-DD-109-15	J, H, Ks	10	15

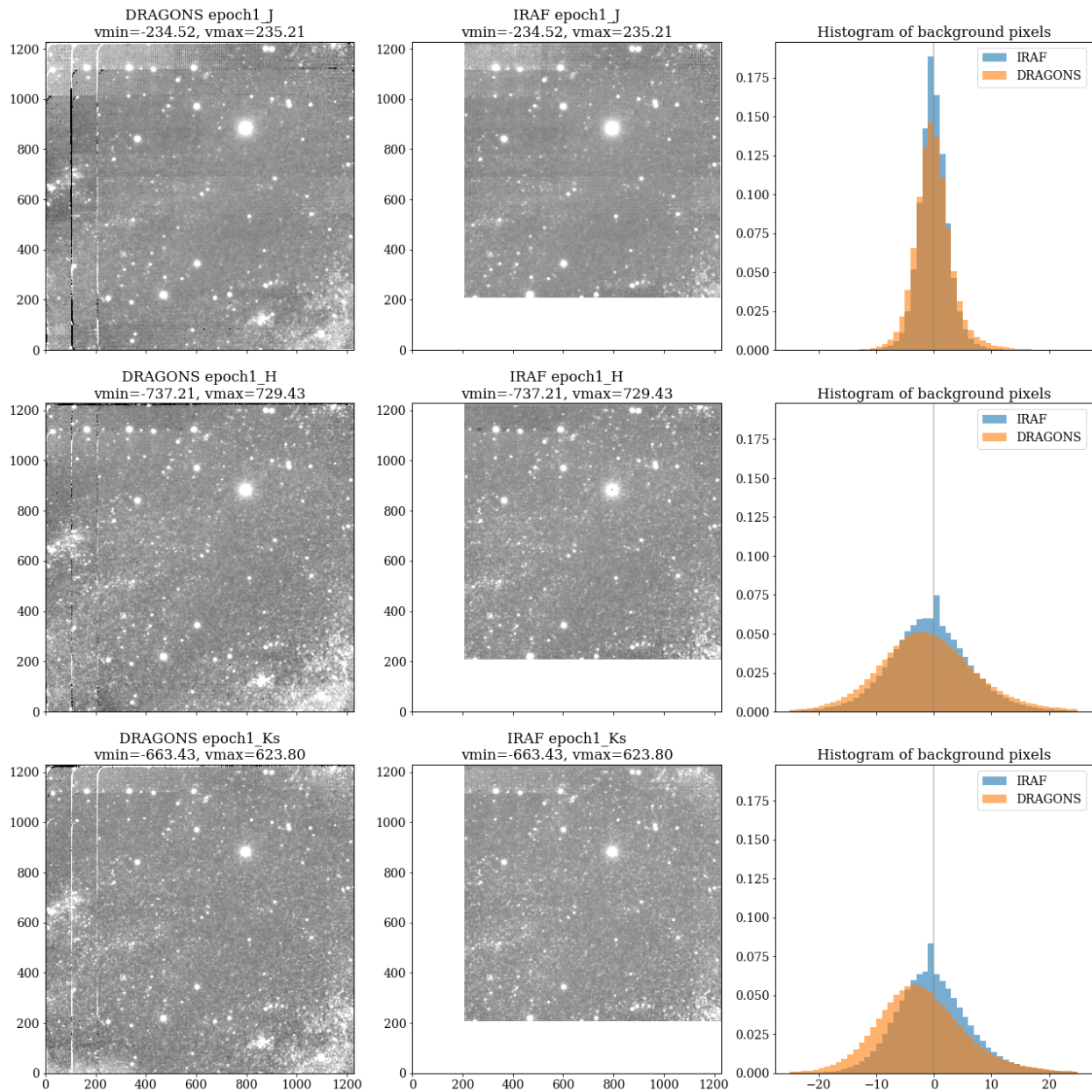


Figure 7: Comparison of the images reduced with DRAGONS (left) and IRAF (middle) for the three bands and for “epoch 1”. The image stacked with IRAF is smaller because it uses the first image footprint whereas DRAGONS computes the combined footprint of all images. Right column shows the histogram of background values.

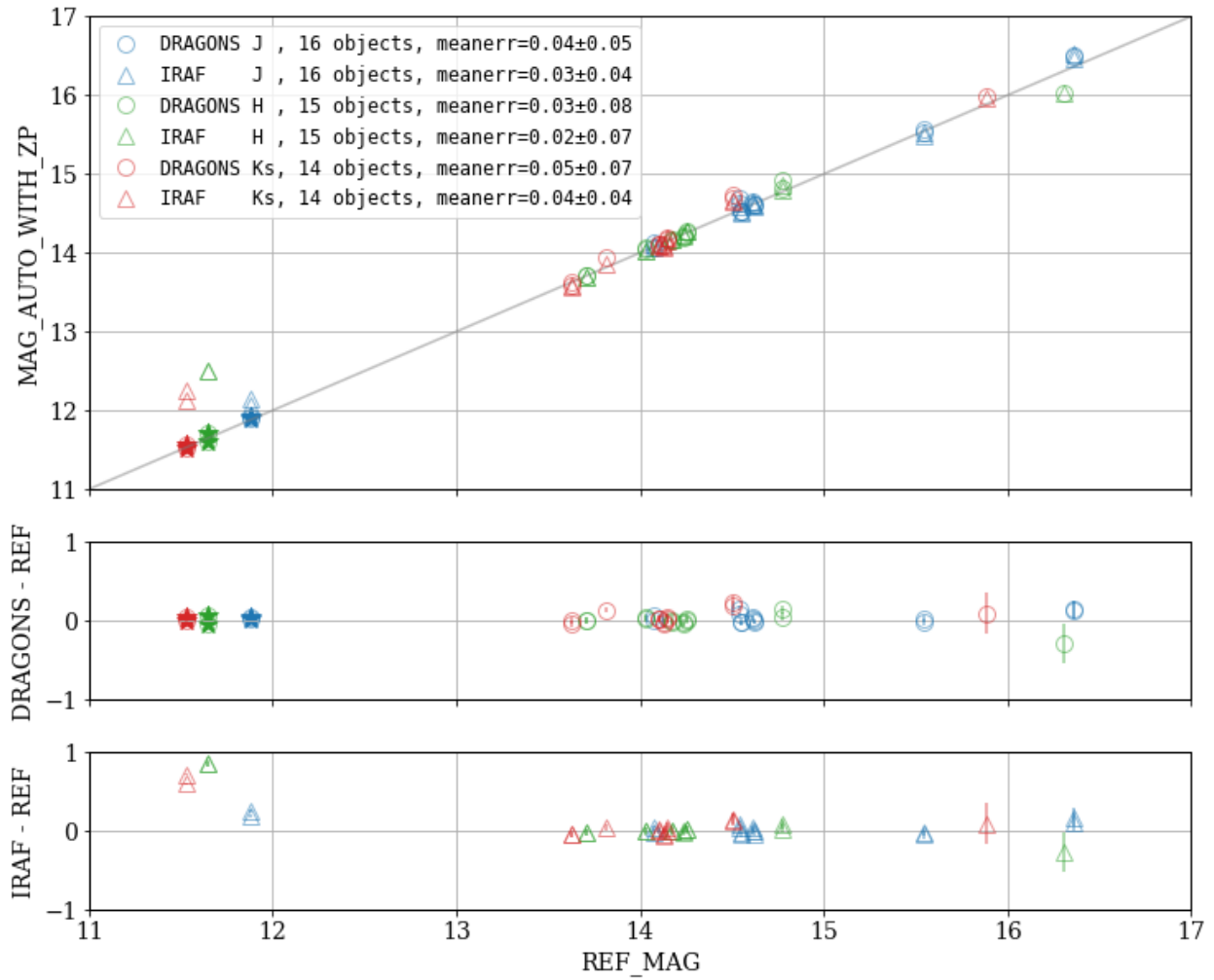


Figure 8: Top panel plots the SExtractor calculated magnitude (using the MAG_AUTO parameter that uses an adaptively scaled aperture) versus the 2MASS catalog reference magnitude. Bottom panels show the magnitude difference, MAG_AUTO - REF_MAG, for DRAGONS and IRAF. The sources represented with star symbols have saturated, non-linear, or bad pixels and are excluded from the mean error calculations.

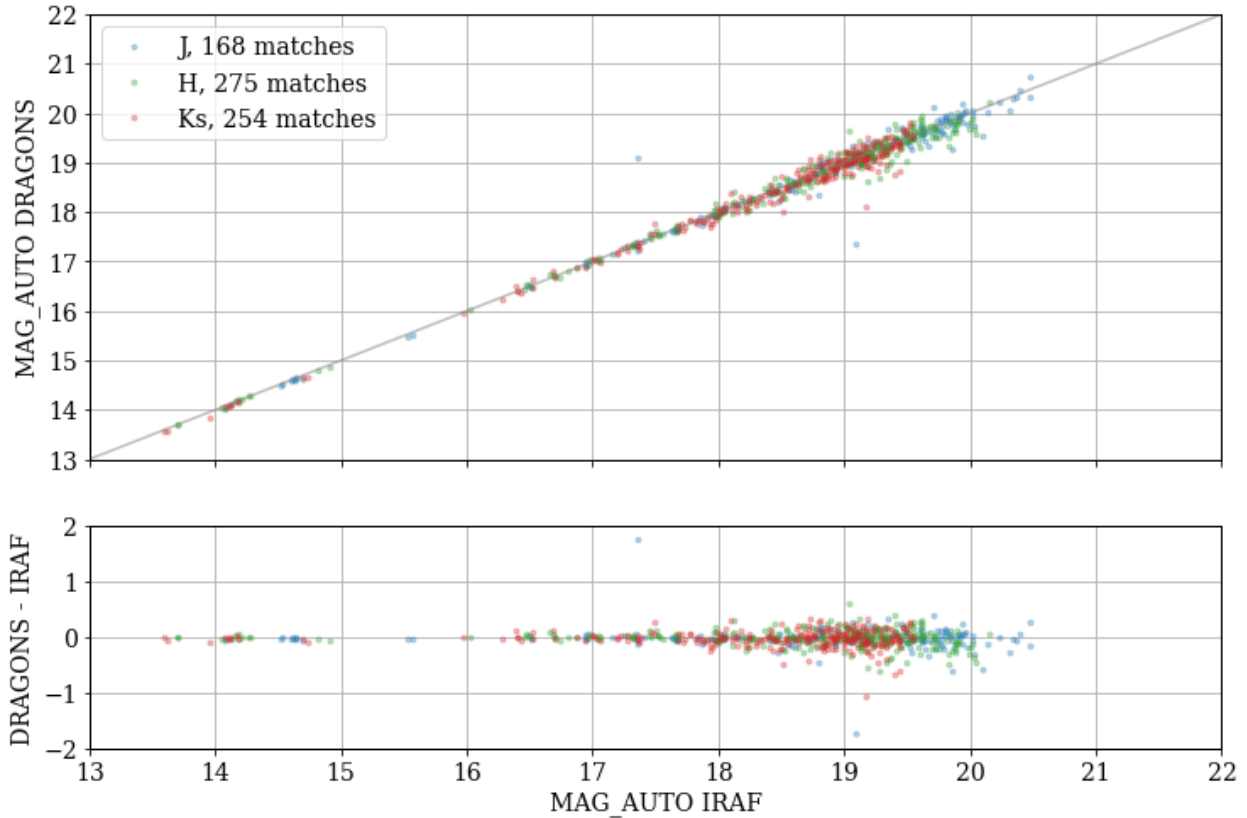


Figure 9: Comparison of DRAGONS and IRAF magnitudes (MAG_AUTO) for the J (blue), H (green) and Ks (red) bands.

IV- GSAOI

As for F2 and NIR1 the GSAOI dataset covers three bands (J, H, Ks). In both cases, PyRAF and DRAGONS, the reduced frames are corrected from the distortions and stacked with disco-stu. Before running disco-stu, the mean background level has been manually subtracted both for DRAGONS and IRAF. The “skysub” option in disco-stu did not work in this case because it was not using the objects mask and was using a less robust fitting method. This has been fixed and will be available in a future release.

Program	Band(s)	Number of exposures	Exposure time (s)
GS-2016B-Q-62	J, H, Ks	24	60

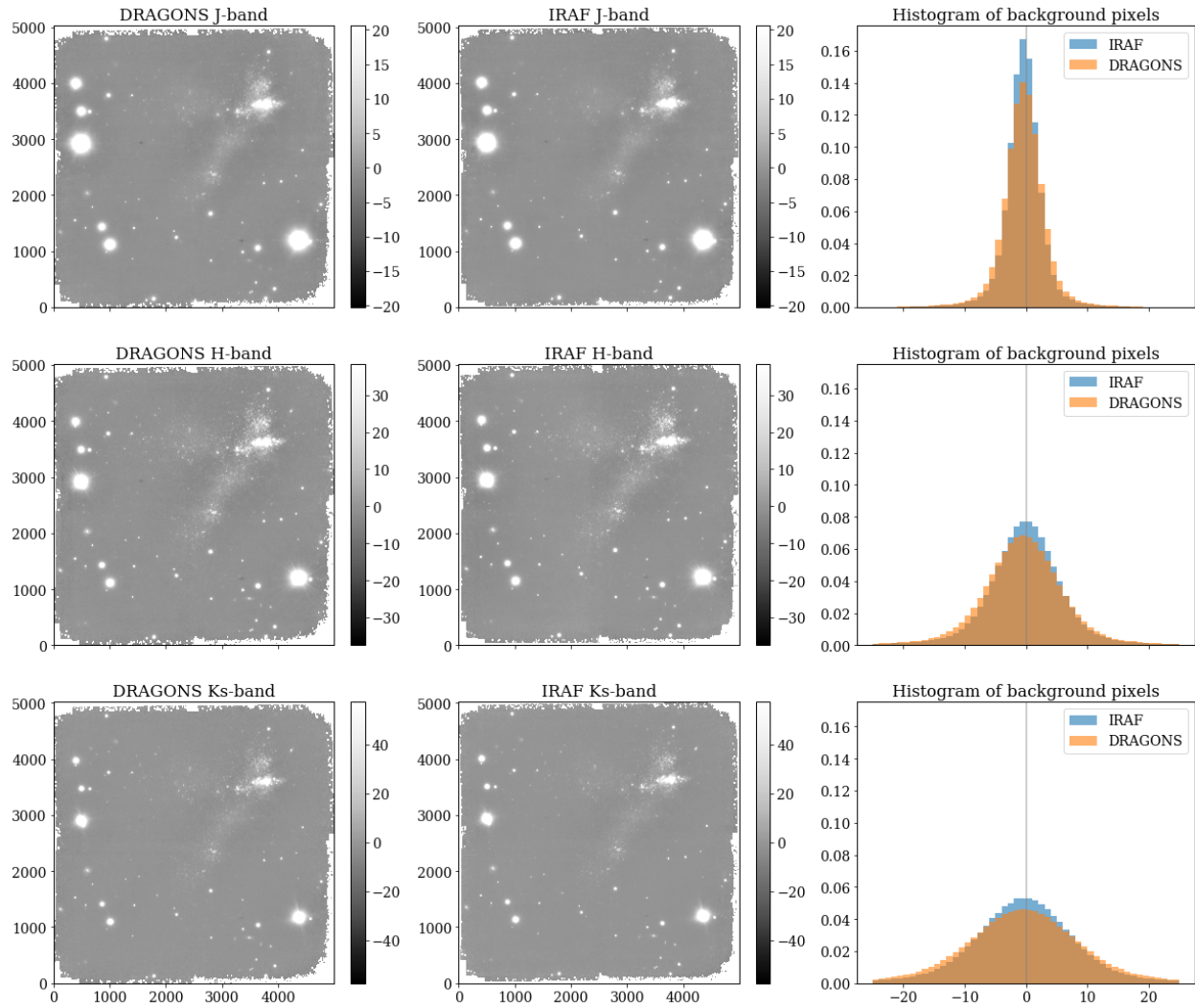


Figure 10: Comparison of the images reduced with DRAGONS (left) and IRAF (middle), and stacked with disco-stu, for the three bands. Right column shows the histogram of background values.

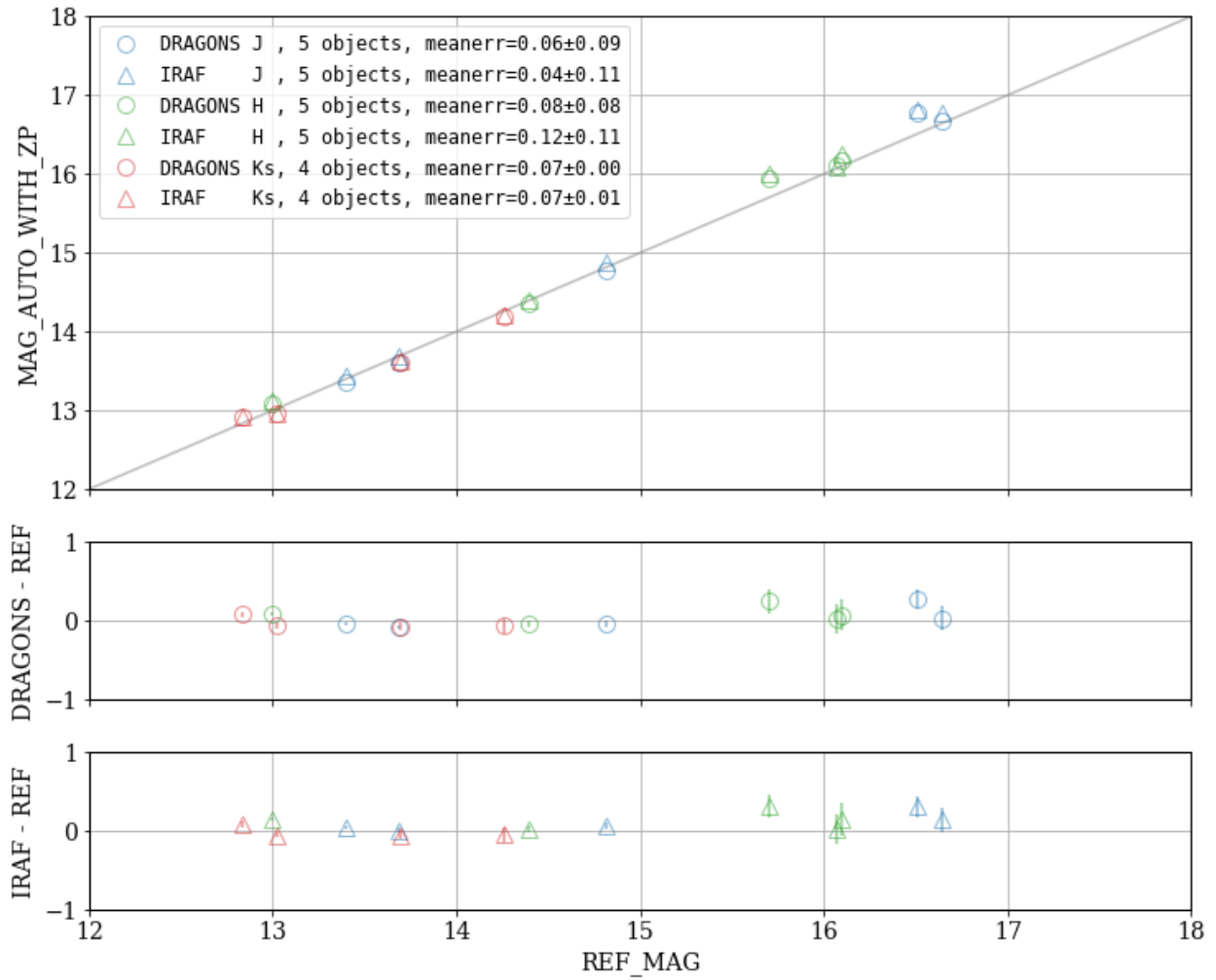


Figure 11: Top panel plots the SExtractor calculated magnitude (using the MAG_AUTO parameter that uses an adaptively scaled aperture) versus the 2MASS catalog reference magnitude. Bottom panels show the magnitude difference, MAG_AUTO - REF_MAG, for DRAGONS and IRAF. The sources represented with star symbols have saturated, non-linear, or bad pixels and are excluded from the mean error calculations.

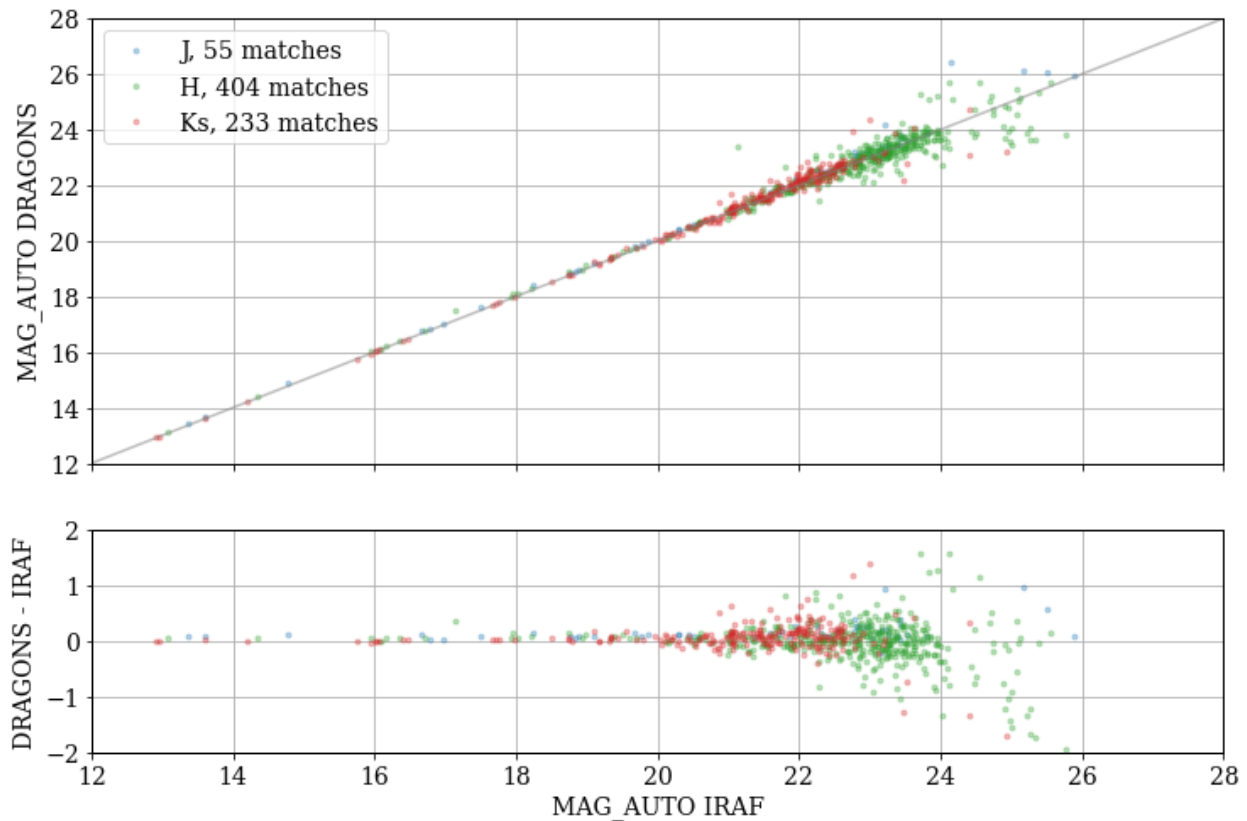


Figure 12: Comparison of DRAGONS and IRAF magnitudes (MAG_AUTO) for the J (blue), H (green) and Ks (red) bands.

Detailed reduction example

For each band, J, H and Ks, we have 24 raw images, as well as lamp-on and lamp-off dome exposures (only lamp-on for the J band). The data is available in [the archive](#). Once downloaded the data has been organized with directories for each band and data type:

```

> ls
Dflats_H/  Dflats_J/  Dflats_Ks/  H-band/  J-band/  Ks-band/

```

The reduction process is similar for all bands, we will show below an example for the Ks-band.

With DRAGONS

The first step is to create the master flat field:

```
reduce Dflats_Ks/*.fits
```

```
caldb add S20170113S0061_flat.fits
```

Then we can process the science exposures:

```
reduce Ks-band/*.fits
```

This command will generate flat corrected and sky subtracted files but will not stack them, because of the high level of distortion in the GSAOI images. The tool `disco_stu` must be used to stack GSAOI science data :

```
flist=$(dataselect *_skySubtracted.fits --expr 'filter_name=="Ks"')
disco -o stacked_Ks_dragons.fits $flist
```

With IRAF

We start by loading the required packages and building file lists:

```
gemini
gsaoi
gemlist "S20170113S" "61-75" > on.lis
gemlist "S20170113S" "122-135" > off.lis
gemlist "S20170112S" "48-71" > sci.lis
concat ("on.lis,off.lis", "flat.lis")
```

Then we create a master flat field with `gaflat` (which also calls `gaprep`):

```
gaflat ("@flat.lis", fl_var dq=yes, fl_dqprop=yes, rawpath="./Dflats_Ks")
```

To reduce the science images we use the `skyimg="time"` option to compute the sky image in a way similar to DRAGONS, filtering the current list for images that are within `maxtime=900s` of the image currently being reduced. `fl_mult=no` is used to keep the values in ADUs, and `fl_autosky=no` to avoid adding back the median sky level which makes it easier to compare the images with DRAGONS.

```
gaprep ("@sci.lis", fl_var dq=yes, rawpath="./Ks-band")
gareduce ("g@sci.lis", fl_var dq=yes, fl_dqprop=yes, fl_mult=no, \
          flatimg="gS20170113S0061_flat.fits", fl_sky=yes, \
          fl_flat=yes, skyimg="time", fl_autosky=no, minsky=3)
```

Finally we stack the images with `disco-stu`, with the `--reference` option to use the same WCS for the purpose of the comparison:


```
disco -o stacked_Ks_iraf.fits --wcs stacked_Ks_dragons.fits rgS*.fits
```

Summary and future ideas

With this comparison of various datasets, instruments and filters, reduced with DRAGONS and IRAF, we have shown that the magnitudes obtained from the two software packages are consistent. The mean difference with the reference magnitudes is usually less than 0.05 to 0.1 mag and DRAGONS performs at least as well as IRAF.

DRAGONS has a better handling of bad, non-linear, and saturated pixels, with data quality flags that are propagated through the reduction and to SExtractor, and then used to exclude these problematic sources. It also provides a much faster and simpler reduction compared to IRAF.

To improve the comparison several points could be of interest:

- The IRAF sky subtraction for NIRI and F2 (with risky) computes a unique sky frame for the full dataset, whereas DRAGONS always use a matching by time and distance, and excludes the current frame, similar to gareduce for GSAOI.
- A more controlled comparison for the F2 verification would investigate the difference in the mean background between the DRAGONS and IRAF reductions, especially in H and Ks, and the difference in the magnitudes at the high magnitude end.
- The reference catalogs, SDSS and 2MASS, are not deep enough which drastically limits the number of sources that can be used for the comparison. It would be interesting to use other catalogs, such as the GAIA one instead of 2MASS, to improve the depth of the photometry comparison. For the NIR images, UKIDSS (North) and Vista-VHS (South) surveys could also provide better reference catalogs.