

Instrument Science Report ACS 2015-01  
Instrument Science Report WFC3 2015-04

# Optimizing pixfrac in Astrodrizzle: An example from the Hubble Frontier Fields

---

R.J. Avila, A. Koekemoer, J. Mack, A. Fruchter

March 31, 2015

---

## ABSTRACT

*We present the results of pixfrac tests conducted for the Hubble Frontier Fields and describe the methodology for optimizing this parameter for any given plate scale. These tests are the final step in the drizzling process and they provide the information necessary for reaching the best possible image resolution using the **AstroDrizzle** task. They are presented as an example for users to follow. Even though most users don't have an exquisite data set like the HFF program, which consists of a large number of optimally dithered frames, these guidelines are still applicable to single visit programs that make use of sub-sampling dither patterns. We also provide code that cycles through some of the relevant parameter space and provides useful statistical analysis for inspection.*

---

## Introduction

The Hubble Frontier Fields (HFF) program is a multi-cycle Director's Discretionary project that is carrying out deep observations of six lensing galaxy clusters. In addition to the program data being made public, an implementation team has been assembled that processes

the data and publishes high level science products (HLSP) on a regular basis. In order to provide the astronomical community with products that have the best possible image resolution, the parameters in the **AstroDrizzle** task, which is used to make the final products, need to be carefully tuned for a data set of this size.

## Drizzle algorithm

**AstroDrizzle** uses the drizzling algorithm (Fruchter and Hook, 2002) to combine images. When the observations have been optimally dithered, this algorithm has the capability to improve the pixel sampling of the final combined image with respect to the input frames, which are undersampled for all HST instruments. This is accomplished by “shrinking” the input pixels before dropping them onto the sub-sampled output image. The shrunken pixels, also called “drops”, rain down on the sub-sampled output frame where each shrunken pixel is averaged into an output pixel, with a weight proportional to the area of overlap between the “drop” and the sub-sampled output grid. The final products have sharper and narrower PSFs than the original input images.

The particular parameters that control the sampling of the final image are *final\_scale* and *final\_pixfrac* (or simply *scale* and *pixfrac*). The *scale* parameter was determined before processing to meet the scientific requirements of the project (more details are provided in the Method section). The *pixfrac* parameter has to be empirically derived for each data set. If *pixfrac* is too small, there could be data missing in some of the pixels of the output frame, caused by pixels that get thrown out in individual frames (e.g., CRs, hot pixels, etc) and the uneven coverage from image distortion. If the value is too big then the input pixels will overlap, causing correlated noise and blurring the output image. The appropriate value for *pixfrac* depends on the number of input images and the dither pattern, and therefore must be tuned for each data set. As recommended in the “Dither Handbook” (Koekemoer et al., 2002) and the “Drizzlepac Handbook” (Gonzaga et al., 2012), statistics performed on the drizzled weight image should yield a RMS/median value of no more than 0.2. This threshold controls the trade-off between improving image resolution versus increasing background noise due to pixel resampling.

In this report we describe the process of determining the optimal value for *pixfrac*, and show results from our tests. Since the observing setup is important to this process, specifically the dither pattern used, we provide a brief description of how the observations were conducted. Finally, we provide the scripts written for these tests so that observers can use them on their own HST images.

## Data

The HFF campaign is observing six lensing galaxy clusters, using seven filters across two instruments (ACS/WFC: F435W, F606W, F814W and WFC3/IR: F105W, F125W, F140W, F160W). Each cluster is observed with one of the instruments on the cluster and the other on a blank, parallel field. Approximately six months later, the cluster is observed again with the position of the instruments on the sky switched. Each epoch of observations requires 70 orbits, for a total of 140 orbits per cluster. Koekemoer et al. (2013) contains a full description

Camera	Filter	Orbits	$N_{img}$	Exptime (s)
ACS/WFC	F435W	18	36	46414.
ACS/WFC	F606W	10	20	25430.
ACS/WFC	F814W	42	84	107766.
WFC3/IR	F105W	24	48	67696.
WFC3/IR	F125W	12	24	33048.
WFC3/IR	F140W	10	20	28140.
WFC3/IR	F160W	24	48	66896.

**Table 1:** Observation log for the data set used in these tests. All the data comes from PID 13495.

of the observing setup and a complete log of the data.

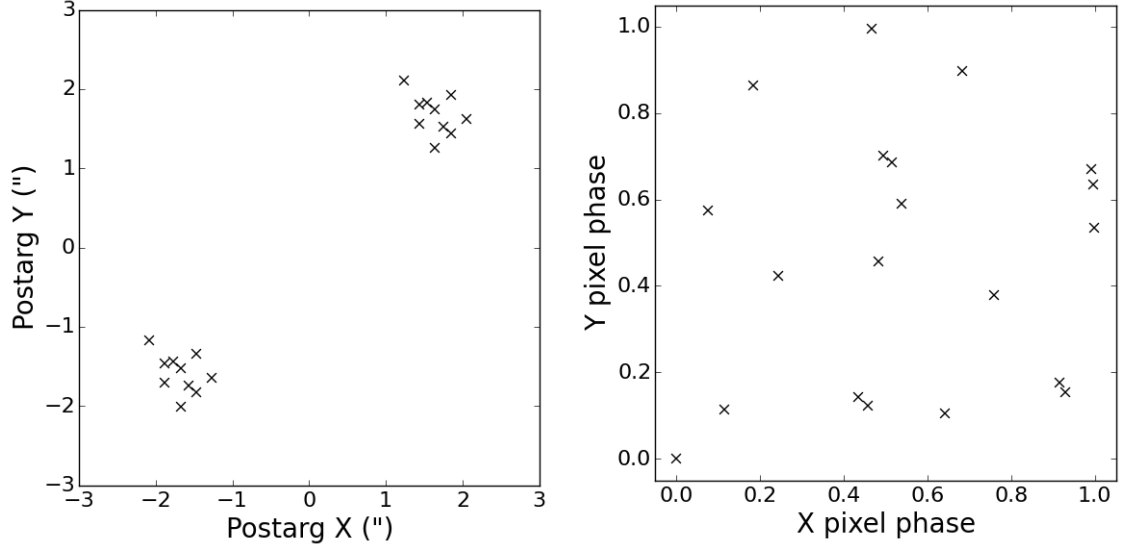
The first cluster for which the first epoch of observations was completed was Abell 2744 (Program ID 13495; PI Lotz, J.). There is extant HST data for this cluster taken by other programs (PID: 11689, 13386, 13389) which is included in the final HLSP mosaic released by the implementation team. Because those images were taken with different offsets and orientations, and because all the clusters in the HFF program will be observed with an identical setup, we chose not to include the extant data in these tests. We only used the images included in the HFF program. Table 1 contains a summary of the data sets.

## Dither pattern

An important aspect of drizzling images to improve the resolution is that the observations must be dithered. Dithering is the process where the telescope is moved in between exposures so that the image is sampled by different parts of the detector each time. This makes it possible to eliminate detector and observational artifacts like hot and warm pixels, bad columns, flat field anomalies, cosmic rays (CRs), etc. Additionally, if the dither pattern includes sub-pixel shifts, the PSF can be well sampled and reconstructed via the drizzle process (Fruchter and Hook, 2002).

HFF observations employed a custom dither pattern that takes into account artifacts in both WFC3/IR and ACS/WFC detectors. Each of the two-orbit HFF visits comprises four half-orbit exposures. Within each of the two orbits, the telescope has a compact ( $\sim$ few WFC3/IR pixels) dither with half-integer pixel phase offsets. Between the two orbits, there is a much larger offset of  $\sim 5''$  offset to step over the WFC3/IR blobs (Pirzkal et al., 2010; Pirzkal and Hilbert, 2012; McCullough et al., 2014) and the ACS/WFC chip gap. This large step eliminates any large holes in the final mosaic. The targeting of the 5–21 visits for any particular filter is modulated by an additional compact ( $< 6$  WFC3/IR pixels) inter-visit dither. The inter-visit pattern is designed to maximally sample WFC3/IR pixel phase and to ensure that no two dithers in the entire pattern are landing within one WFC3/IR pixel of one another.

Figure 1 shows the dither pattern and the pixel phase of the F140W filter. The dither is simply the commanded offset (in arcseconds) for each image. The pixel phase shows the amount of sub-sampling attained with these observations. To estimate these values, we found the sky position of the reference pixel for one of the images in this filter. For the



**Figure 1:** The left hand plot shows the dither pattern used for F140W observations of the HFF program. The *Postarg* header keyword describes the size of the telescope offset in arcseconds. The right shows the pixel phase for this filter. The pixel phase shows how much sub-pixel sampling was achieved in these observations.

rest of the images we then computed the pixel value of that sky position using the header world coordinate system. The phase is the fractional part of that pixel position. Since these images were previously aligned via the `tweakreg` task, this measurement of the realized dither pattern is considerably more accurate than trusting the commanded offsetting across many separate HST visits.

## Method

To conduct these tests, we explored the parameter space of the relevant `AstroDrizzle` options. These options include pre-determined values for the plate scale, weighting scheme, and drizzle kernels. These were pre-determined because of the scientific considerations of the HFF data. The one free parameter in these tests is the *pixfrac* option. Here we explain each of the options. The name of the description is how the options appear in the `AstroDrizzle` task and the values in brackets are the values used.

**final\_scale** {30, 60 mas} This controls the plate scale of the output images. The larger plate scale gives good sampling in IR images, but under-samples ACS images. The smaller plate scale critically samples ACS images and over-samples IR images.

**final\_kernel** {square, gaussian} This parameter describes the form of the kernel function used to drizzle flux in the output images. The gaussian kernel produces well behaved PSFs and is usually used for point source photometry. Square is the classic kernel.

**final\_weight** {EXP, IVM} This instructs the drizzle task what weighting scheme to use when drizzling images. The EXP scheme weights each pixel by the exposure time. This scheme is useful when the objects of interest are dominated by Poisson noise.

The IVM scheme weights each image by an inverse variance map, which is good for objects dominated by sky background and read noise.

**final\_pixfrac** {0.1 - 1.0} This is the free parameter for these tests. It tells drizzle by how much to shrink the input pixels before dropping them into the output image. In general, using a large *pixfrac* increases correlated noise and blurs the image. Using too small of a value causes increased variation in the weight image, blocky PSFs, and possibly holes of missing data in the final image.

For these tests we used the FLT/FLC images that came out of the HFF pipeline (Koeke-moer et al., 2013). This pipeline updates the world coordinate system in the header of the images with the best alignment solution. They are also run through the **AstroDrizzle** to detect and flag cosmic rays and other image artifacts. The data quality arrays (DQ) of these FLT/FLC images contain this information in the form of masks. This facilitates the *pixfrac* tests because one does not need to run through the entire Astrodrizzle process for every permutation of the parameter space, but instead only run the final drizzle step to optimize the relevant parameters. One must be careful to conserve the CR flags in the DQ arrays in each subsequent run. This is done by setting ‘resetbits=0’ so that the flags are retained in each run.

We drizzled each set of images using all the permutations of the options described above. We wrote a python script that facilitates this process by running through the range of *pixfrac* values and automatically analyzing the drizzle products. This script (**pixfrac\_tester.py**) can be downloaded from the DrizzlePac website<sup>1</sup>.

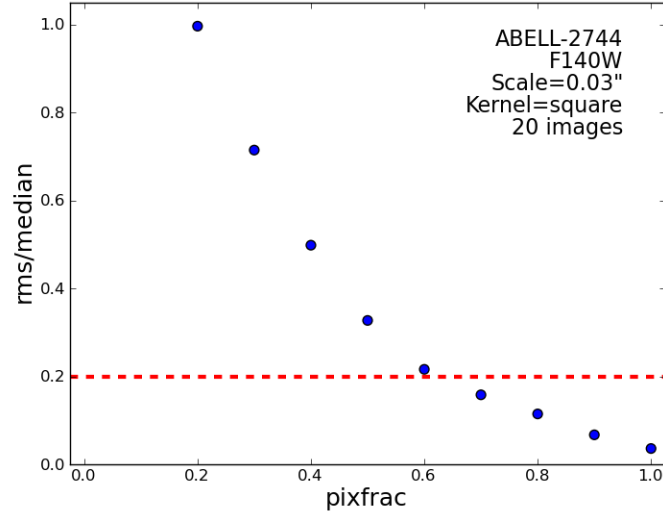
## Results

For the sake of this discussion, we will show the result for only one case; the WFC3/IR F140W filter with EXP weighting, square kernel, and 30mas pixels. We chose this as an example because it is the data set where the *pixfrac* optimization will make the biggest difference: it is an undersampled PSF, the stack contains the fewest exposures, and it is the smallest of the output plate scales. The full set of results for all permutations can be found in the appendix of this document.

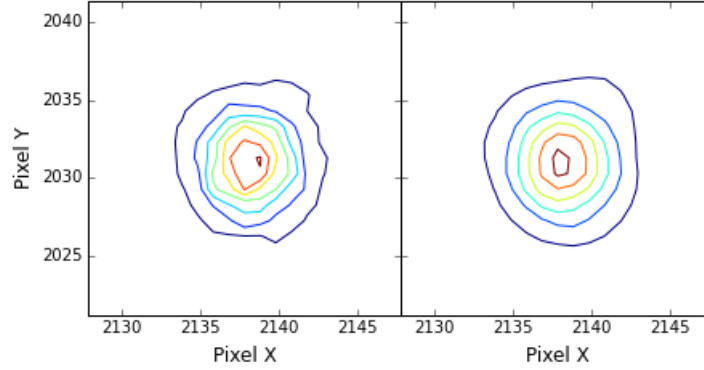
We used the **AstroDrizzle** products to measure statistics of the weight images. The Drizzlepac Handbook (Gonzaga et al., 2012) says that one should use a large area of the weight image and measure the RMS/median of that section. One should take care to use the same region in the weight image as the region where the object of interest is located in the science image. If one is using the entire image for scientific analysis, then one should measure the statistics of the weight image where there is more variance. This statistic should remain below  $\sim 0.2$ . This threshold controls the trade-off between improving image resolution versus increasing background noise due to pixel resampling. We selected a  $500 \times 500$  pixel region of the weight image that avoided blobs (in IR products) and bad columns (in ACS products) that could contaminate the measurements. Figure 2 shows how the RMS/median statistic varies with changing *pixfrac*. The plot indicates that one should choose *pixfrac* = 0.7.

---

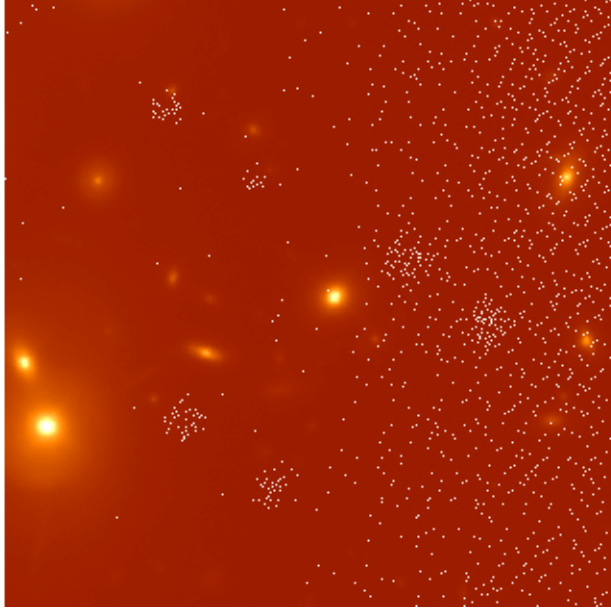
<sup>1</sup><http://drizzlepac.stsci.edu>



**Figure 2:** Example of how RMS/median varies with changing *pixfrac*. The dashed red line marks the threshold recommended in *the DrizzlePac Handbook*.



**Figure 3:** The contours of a star from the example dataset. On the left the *pixfrac* was 0.2, where the RMS/median statistic exceeds the recommended value. The contours look blocky and uneven. On the right is the same star with *pixfrac* = 0.7, the value selected.



**Figure 4:** A  $27'' \times 27''$  section of a poor product, where *pixfrac* was set to 0.2. The white points are output pixels where there was not data. They were marked with very high values so that they could be easily seen in this image. The clusters of points are locations where there are IR blobs in the input images, so half of the input pixels have been flagged and there is insufficient data at this *pixfrac* setting. The more evenly set of points on the right side of the image is caused by geometric distortion. Close to the edges of an image the pixels are distorted enough to cause uneven filling with such a low *pixfrac* value.

The RMS/median statistic is not the only criteria used to choose a value for *pixfrac*. We also inspected the **AstroDrizzle** science products. One should ensure that the PSFs of stars have not been degraded. If *pixfrac* is too small the contours of stars can appear blocky instead of round (figure 3). Another problem that can arise if *pixfrac* is too small is that the image can contain a large number of empty pixels where there was no information (figure 4).

We checked the image with *pixfrac* = 0.7 and found that there were no defects in the contours of stars and no problems of missing data. This confirmed that the value indicated by the RMS/median statistic was good, and we used that for this data set.

The rest of the datasets required the same amount of scrutiny. We found that, in some cases, the value of *pixfrac* obtained from the RMS/median statistic was not adequate due to blocky PSFs, and therefore had to be made larger. Additionally, we tried to maintain some uniformity, for example by using the same value for all the ACS frames. Table 2 summarizes the *pixfrac* values to be used for this and all subsequent data sets in the HFF program.

There is further information to be gained from the aggregate results. For a given case, the results between EXP and IVM weight maps are nearly identical. IVM weight maps contain information about the flat field, which is the main source of the difference. Additionally, the results show that *pixfrac* can be pushed to smaller values by using the square kernel instead of the gaussian kernel. This is because the square kernel distributes light more evenly on the output grid, therefore reducing the variance of the weight map.

Instrument	Filter	Drizzle kernel	$N_{img}$	Pixfrac 0.03"/pix	Pixfrac 0.06"/pix
ACS/WFC	F435W	square	36	0.7	0.6
ACS/WFC	F606W	square	20	0.7	0.6
ACS/WFC	F814W	square	84	0.7	0.6
WFC3/IR	F105W	square	48	0.6	0.5
WFC3/IR	F125W	square	24	0.7	0.6
WFC3/IR	F140W	square	20	0.7	0.6
WFC3/IR	F160W	square	48	0.6	0.5

**Table 2:** The final results from testing. The listed *pixfrac* values will be used in all HFF data.

## Discussion

We presented an example of the recommended method for optimizing the *pixfrac* parameter in the `AstroDrizzle` task. Even though there is no cookbook or straight forward set of rules that users can follow to accomplish this task, the guidelines we show here can be applied even to the simplest observations, as long as they make use of dither patterns that sub-sample the PSF.

The code we provide can be used to make drizzled products with different parameters, or should at least be a good starting point for users to create their own pipeline. It would still be difficult to completely automate the process of selecting the right value for *pixfrac*, since visual inspection is still required even when statistics indicate a desired value. The vagaries of real data do not allow it and therefore a little bit of judgement still comes into play.

## Acknowledgements

We would like to thank Norman Grogan for providing a description of the dither pattern used in this program. We would like to thank Linda Smith, Heather Gunning, Ray Lucas, and David Borncamp for useful comments. This research made use of Astropy, a community-developed core Python package for Astronomy (Astropy Collaboration et al., 2013).

## References

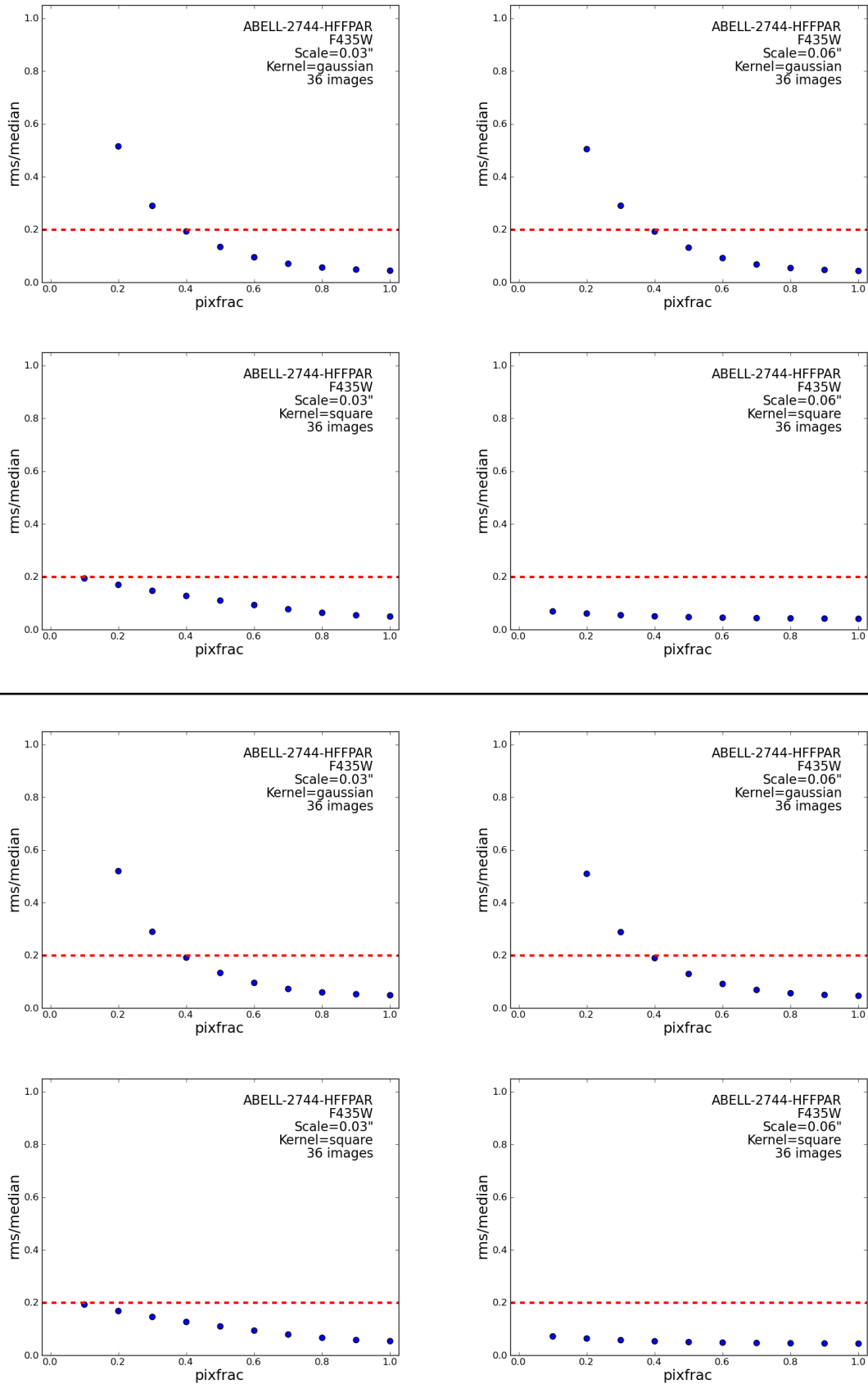
Astropy Collaboration, T. P. Robitaille, E. J. Tollerud, P. Greenfield, M. Droettboom, E. Bray, T. Aldcroft, M. Davis, A. Ginsburg, A. M. Price-Whelan, W. E. Kerzendorf, A. Conley, N. Crighton, K. Barbary, D. Muna, H. Ferguson, F. Grollier, M. M. Parikh, P. H. Nair, H. M. Unther, C. Deil, J. Woillez, S. Conseil, R. Kramer, J. E. H. Turner, L. Singer, R. Fox, B. A. Weaver, V. Zabalza, Z. I. Edwards, K. Azalee Bostroem, D. J. Burke, A. R. Casey, S. M. Crawford, N. Dencheva, J. Ely, T. Jenness, K. Labrie, P. L. Lim, F. Pierfederici, A. Pontzen, A. Ptak, B. Refsdal, M. Servillat, and O. Streicher. Astropy: A community Python package for astronomy. *AAP*, 558:A33, October 2013. doi: 10.1051/0004-6361/201322068.



- A. S. Fruchter and R. N. Hook. Drizzle: A Method for the Linear Reconstruction of Under-sampled Images. *PASP*, 114:144–152, February 2002. doi: 10.1086/338393.
- S. Gonzaga, W. Hack, A. Fruchter, J. Mack, and eds. “*The DrizzlePac Handbook*”. June 2012.
- A. M. Koekemoer, S. Gonzaga, A. Fruchter, J. Biretta, S. Casertano, J. C. Hsu, M. Lallo, and M. Mutchler. “*The HST Dither Handbook*”. 2002.
- A. M. Koekemoer, J. Mack, J. Lotz, J. Anderson, R. Avila, E. Barker, D. Hammer, B. Hilbert, R. A. Lucas, S. Ogaz, M. Robberto, J. Sokol, D. Adler, D. Coe, A. S. Fruchter, S. Gonzaga, N. Grogin, I. Jordan, P. Royle, D. Taylor, A. Welty, B. Workman, K. Levay, S. Fleming, J. Lee, J. MacKenty, L. Smith, M. Mountain, and The Frontier Fields Implementation Team. “The HST Frontier Fields: Science Data Pipeline, Products, and First data release”. [http://archive.stsci.edu/pub/hlsp/frontier/abell12744/images/hst/v1.0-epoch1/hlsp\\_frontier\\_hst\\_wfc3-acs\\_abell12744\\_v1.0\\_readme.pdf](http://archive.stsci.edu/pub/hlsp/frontier/abell12744/images/hst/v1.0-epoch1/hlsp_frontier_hst_wfc3-acs_abell12744_v1.0_readme.pdf), 2013.
- P.R. McCullough, J. Mack, M. Dulude, and B. Hilbert. Infrared Blobs: Time-dependent Flags. Technical Report WFC3 ISR 2014-21, Space Telescope Science Institute, October 2014.
- N. Pirzkal and B. Hilbert. The WFC3 IR “Blobs” Monitoring. Technical Report WFC3 ISR 2012-15, Space Telescope Science Institute, 2012.
- N. Pirzkal, A. Viana, and A. Rajan. The WFC3 IR “Blobs”. Technical Report WFC3 ISR 2010-06, Space Telescope Science Institute, 2010.

# APPENDIX

For completeness, we present the test results for all the filters available in this target.



**Figure 5:** Full results for the F435W filter. The top 4 plots show results for EXP weighting, bottom half shows IVM weighting.

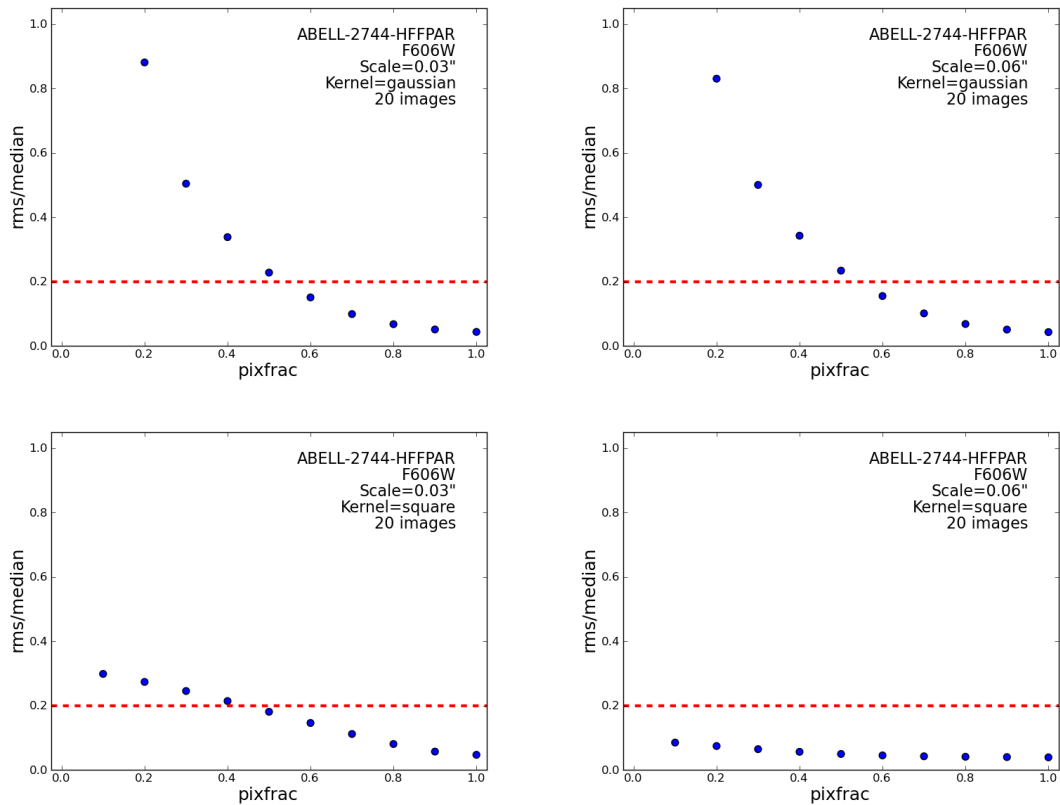
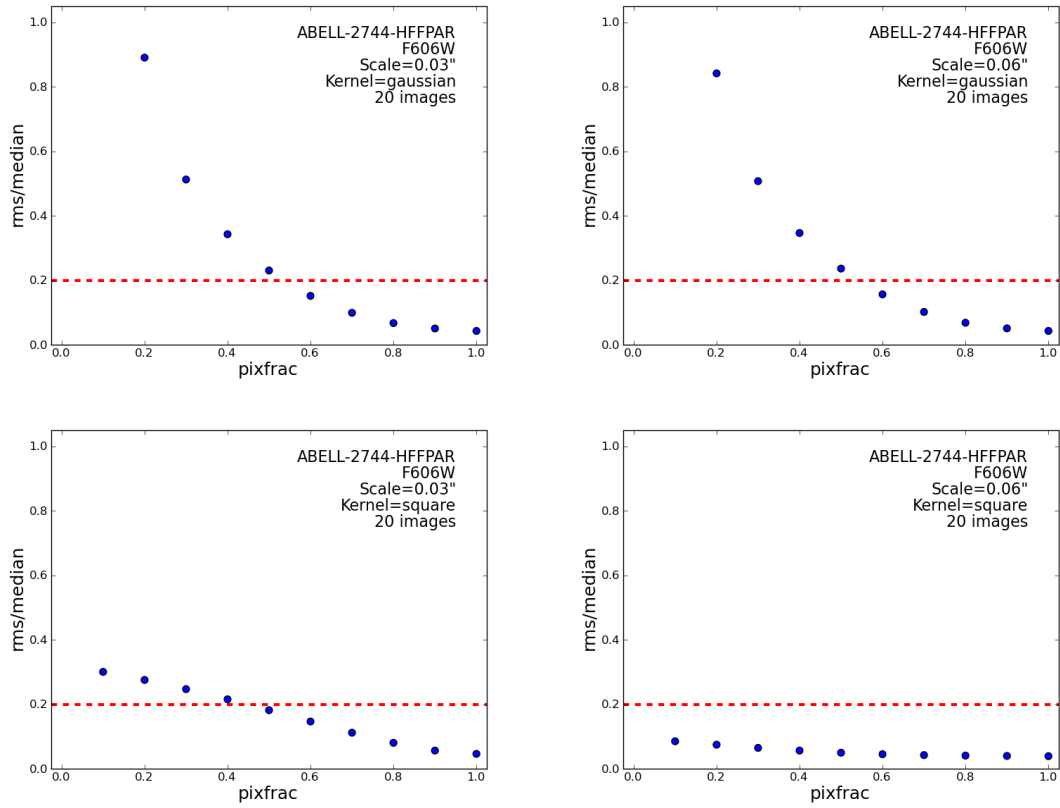


Figure 6: Same as 5 but for F606W.

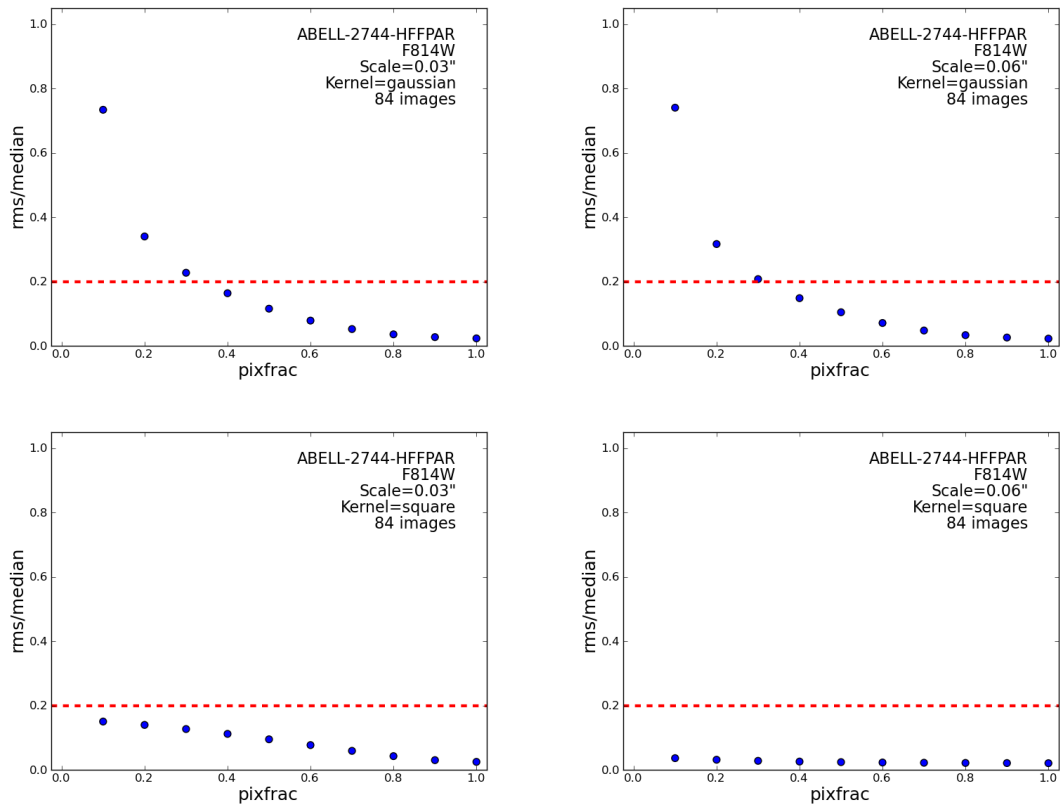
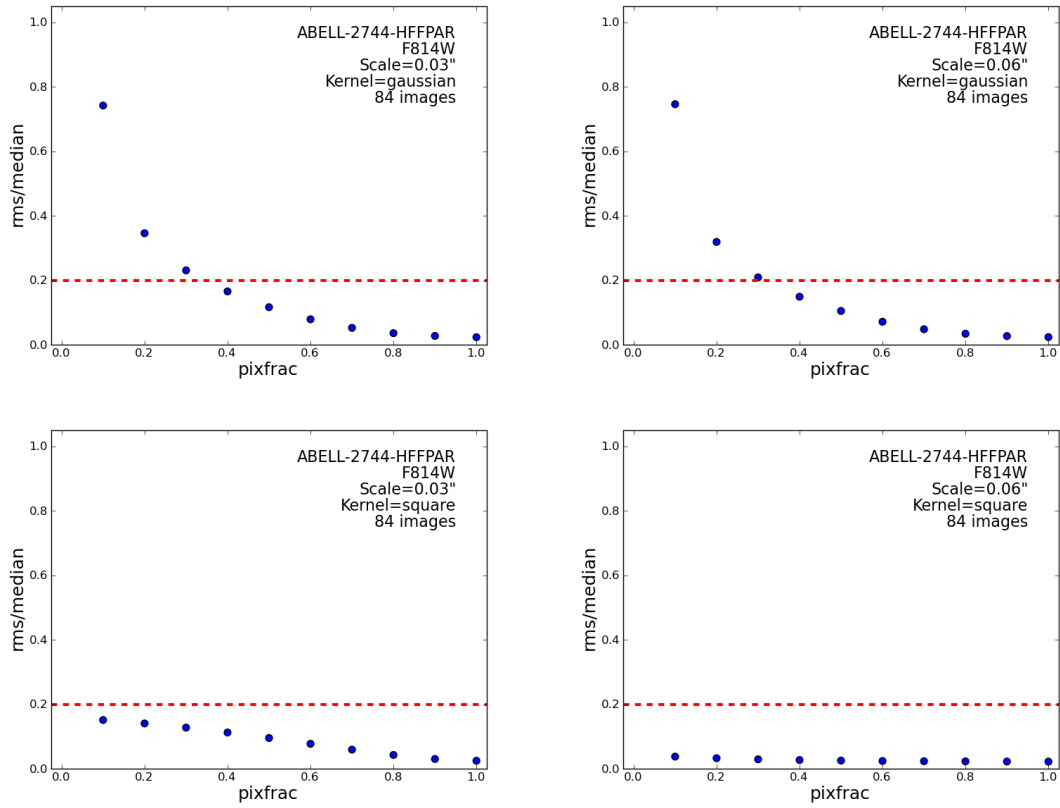


Figure 7: Same as 5 but for F814W.

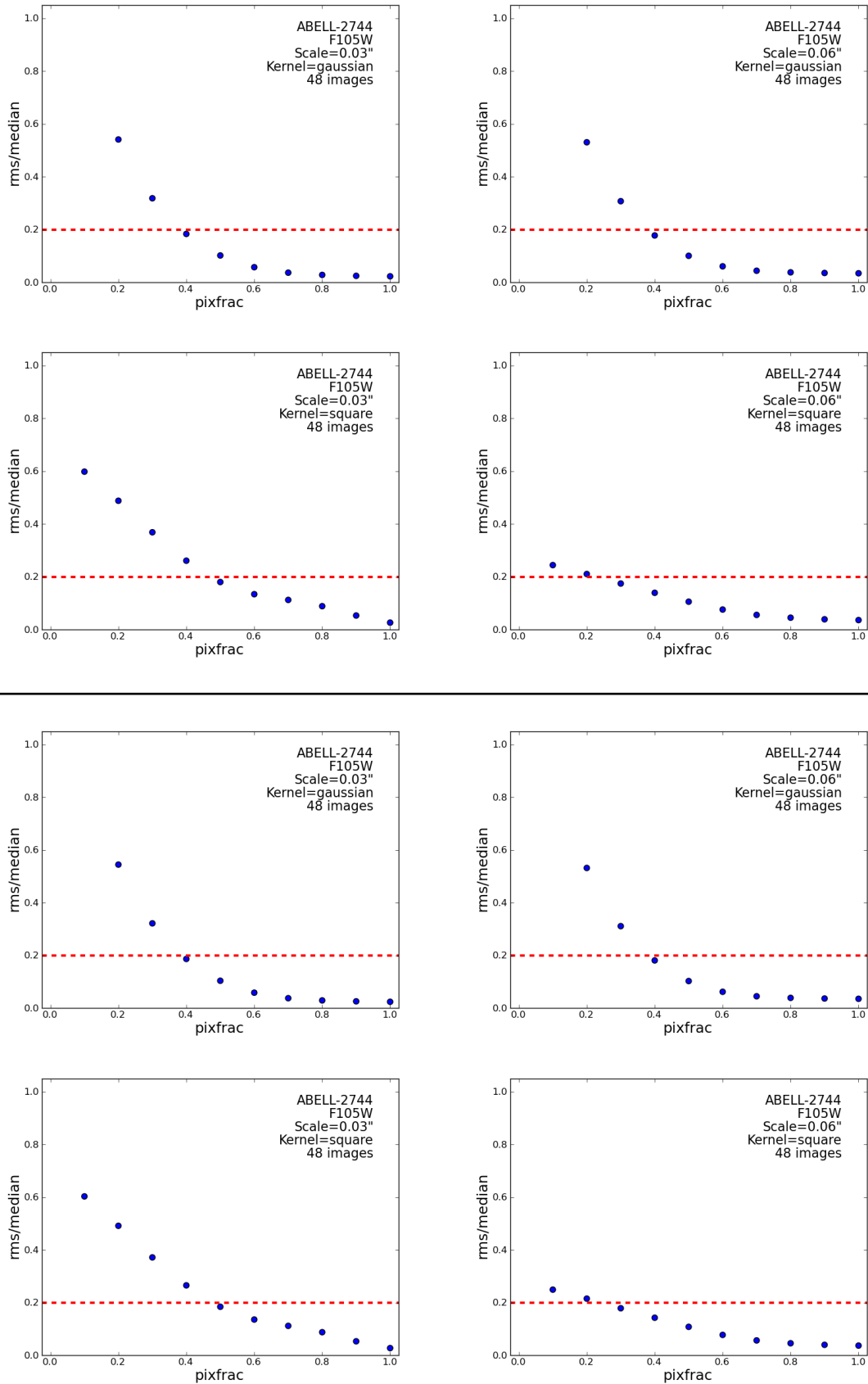


Figure 8: Same as 5 but for F105W.

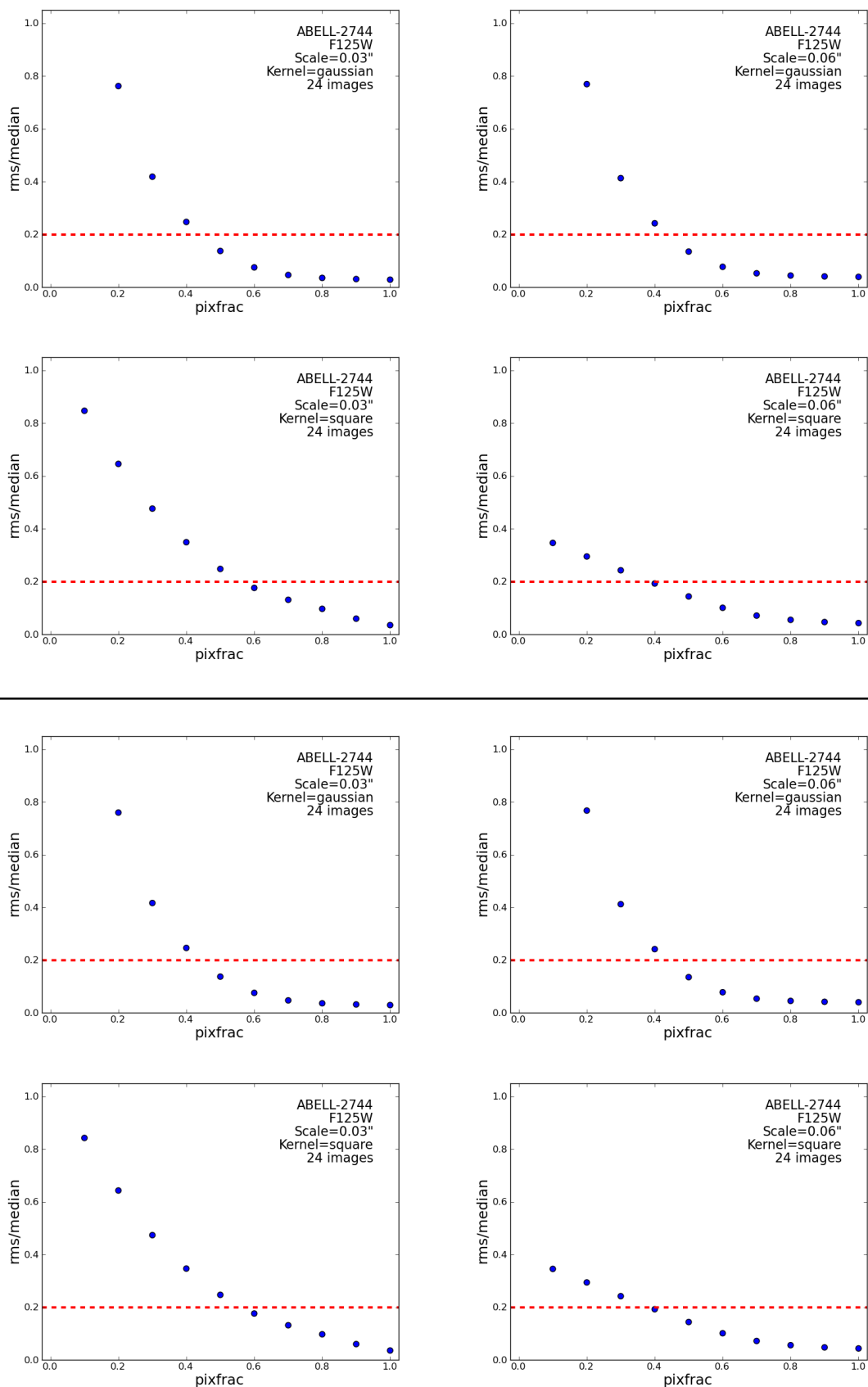


Figure 9: Same as 5 but for F125W.

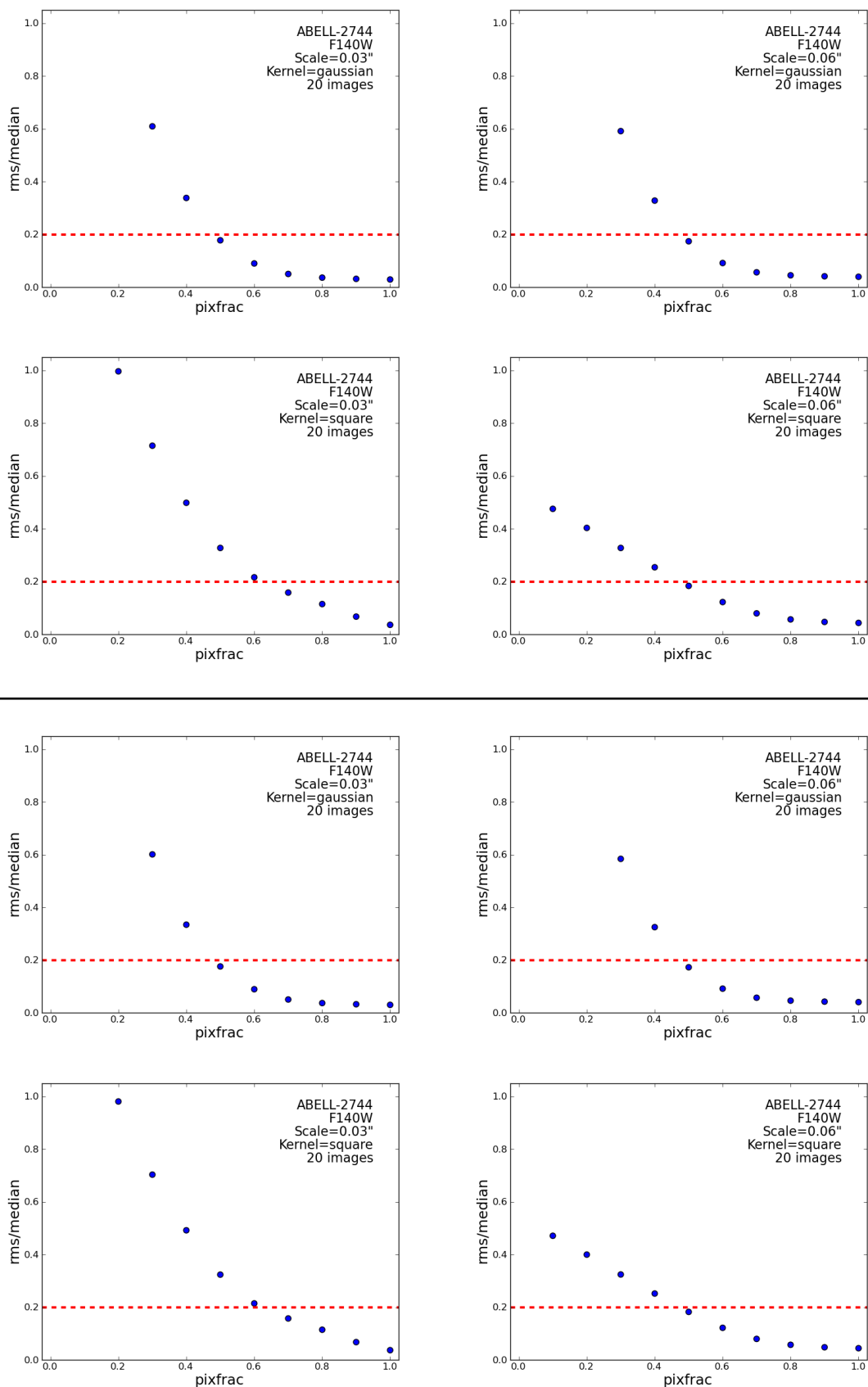


Figure 10: Same as 5 but for F140W.



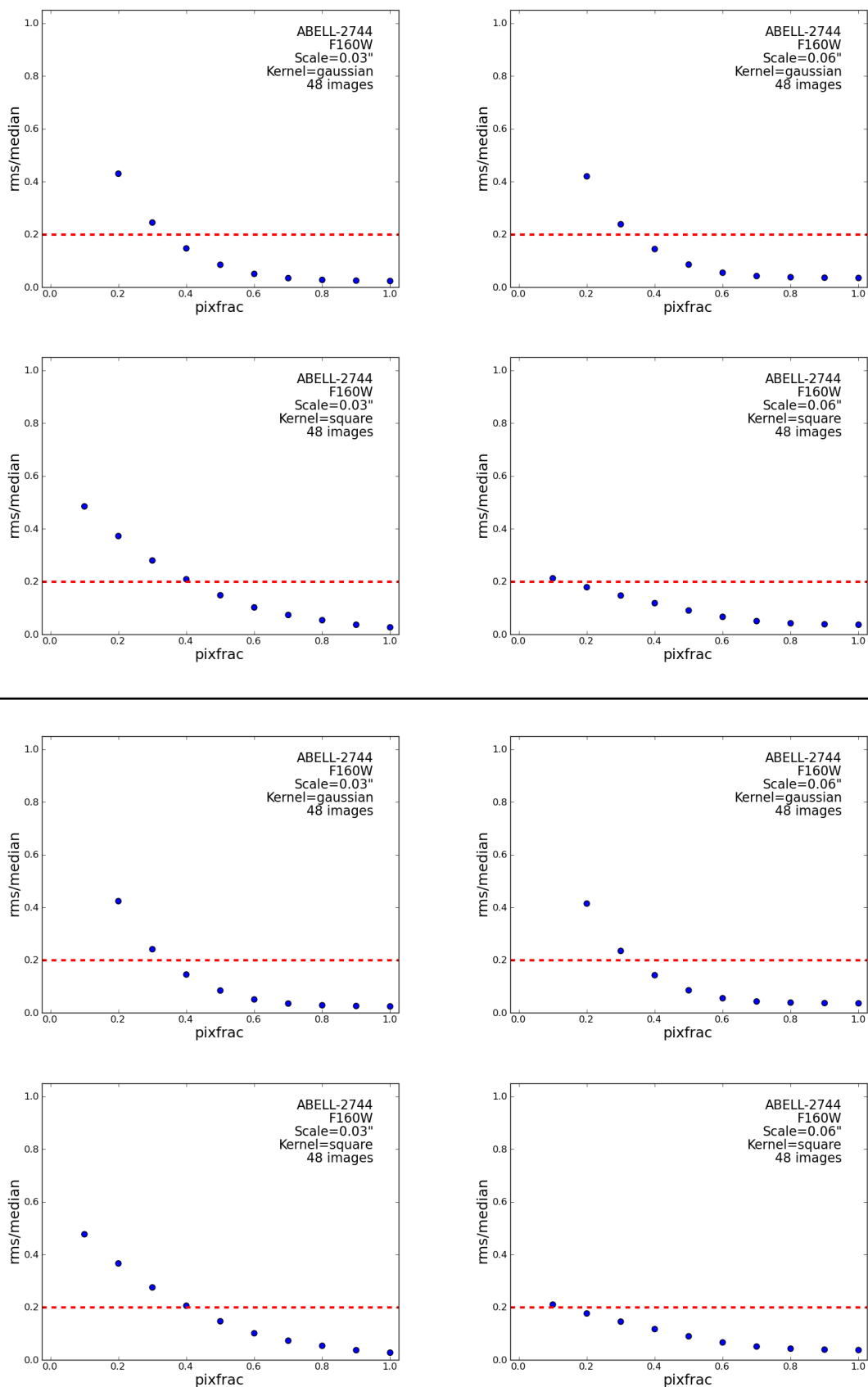


Figure 11: Same as 5 but for F160W.