Eilat Glikman, PhD   http://www.astro.yale.edu/people/eilat-glikman/
NSF Astronomy & Astrophysics Fellow   eilat.glikman@yale.edu
Yale Center for Astronomy & Astrophysics

Source Detection and Sensitivity Map Generation for XMM Archival Data

I. Set up SAS:

Go to http://xmm.esac.esa.int/sas/current/downloadandinstall.shtml
Click `Download SAS` and determine the `File to download` from the table.
For MacOS X Snow Leopard, choose `sas_11.0.0-Darwin-10.6.0-32.tgz`
Click on the link that says here which takes you to this webpage:
http://xmm.esac.esa.int/sas/current/download/download_form.php
You must fill out the form and `submit` it to get to this page
http://xmm.esac.esa.int//sas/11.0.0/download/process_form.php and choose the mirror site to
download the file. This will take you to a new window (and may open a new browser entirely!)
ftp://legacy.gsfc.nasa.gov/xmm/software/sas/ (if you need to do this more than once, you may
just skip to this part).

Now you need to find your download file based on your OS and graphics needs:
11.0.0
32 (64 is probably also OK for snow leopard, but I have been advised that 32 usually works
more consistently, so if you want to avoid issues go for 32)
MacOSX
Darwin-10.6.0
And finally sas_11.0.0-Darwin-10.6.0-32.tgz

A. Install the software:
Go back to the main page, http://xmm.esac.esa.int/sas/current/downloadandinstall.shtml and
click on `Install SAS` and follow the directions on the page, up until Initialization. You may
need to make a symbolic link to perl in /usr/local/bin for the `configure_install` shell
script to work properly.
Do not yet initialize, since you will need the HEASOFT software to run.

B. Install supportive software:
Go back to the main page, http://xmm.esac.esa.int/sas/current/downloadandinstall.shtml and
click on `Software requirements`. You will need ds9 and HEASOFT. Grace is only
important for plotting with the SAS GUI. It is not crucial and may already come with the main
SAS install, or the Mac X11 distribution. If you want to get it, feel free, but it is not needed and
I cannot help with installation or problems relating to Grace.

1. Get ds9:
Go to http://hea-www.harvard.edu/RD/ds9/ and select the download appropriate to your OS level
(Mac OS X 10.6 Snow Leopard binaries of the highest version).

2. Get HEASOFT:
Go to http://heasarc.gsfc.nasa.gov/docs/software/lheasoft/ and click on Download.
STEP 1: Select your OS (just get the binaries. Do not obtain the source code distribution! Unless
you want to do other X-ray stuff later, in which case, you are on your own.)

Eilat Glikman, PhD

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STEP 2: select `All` and `Submit`. Put the file in your home directory.

STEP 3: Follow the instructions only in the last bullet for binary installations. unzip and untar the file and follow the instructions in the `HEASOFT-INSTALL` link.

This is a big busy file, so here are the main steps in the HEASOFT installation:

- Scroll down to `STEP BY STEP INSTALLATION INSTRUCTIONS`
- Only follow the binary installation steps (skip SOURCE DISTIBUTIONS steps) 1, 2, 3(partial) and 8.
- Follow the `INITIALIZATION AND SETUP` and make sure you know what shell you are in bash or tcsh, etc.
- Type `heainit` to initialize HEASOFT so it is running where SAS will need it.

C. Finishing the SAS installation:

Go back to the main page, http://xmm.esac.esa.int/sas/current/downloadandinstall.shtml and click on `Install SAS` and proceed to the initialization step.

II. Getting the data:

Create a directory where all the observations will be stored

`/Volumes/Data/Stripe82X/XMM_analysis/`

If you know the `obsid` of your observation (e.g, `0403760301`) go to the main HEASARC web page.

Click on `XMM-Newton` from the list of `Guest Observer Facilities & Science Centers` on the left.

Click on `Archive` button in the top banner.

Then, under `GOF Mirror Archive (Browse)` click on `HEASARC Browse facility`.

Unclick the `Select All` button and click on the box next to `XMM-Newton Master Log & Public Archive` (the first one).

Then scroll to the bottom and press the `Specify Additional Parameters` button.

In the table that loads, enter the obsid (`0403760301`) in the first box at the top of the table and click on the `Start Search` button at the bottom of the page.

Now you will get a table with the observation and all its details.

	Related Links	Services	obsid ⇩⇧ Dataset ID	status ⇩⇧	name ⇩⇧	ra ⇩⇧	dec ⇩⇧	time ⇩⇧	duration ⇩⇧ [s]	pi lname ⇩⇧	pi fname ⇩⇧	public date ⇩⇧	data in heasarc ⇩⇧
Select ☐All													
⊕☐	Chan ROSAT RXTE ASCA Abstract	O R N S D H B	0403760301	archived	UVLG03	00 11 11.62	+00 51 37.1	2006-07-10 22:21:37	25910	Hornschemeier	Ann	2007-08-07	Y

1 row retrieved from xmmmaster

In the `Services` column, click on `D` for data.

At the bottom of the page, select the `XMM Complete Data Set`, by clicking the boxes near `XMM ODF Basic Data (ODF)` and `XMM Pipeline Products (PPS)`, and click the `Create Download Script` button.

Create a directory in your observations directory for the obsid.

`mkdir 0403760301`

Now you can copy and paste the `wget` commands into your command line. Be sure to be in the directory that you just created. This will also take a long time, and should create two subdirectories called `PPS` and `ODF` which contain the pipeline reduced data and the raw data, respectively.

Eilat Glikman, PhD   http://www.astro.yale.edu/people/eilat-glikman/
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III. Getting the calibration files:
You should place the calibration database in the top level directory where all your xmm data are grouped together, `/Volumes/Data/Stripe82X/XMM_analysis/`

Go to http://heasarc.gsfc.nasa.gov/docs/xmm/xmmgof_mirror.html to obtain the US mirror of the calibration files and download **only** the CCF files using `wget`:
`wget -m -nH --cut-dirs=3 -l 2 -np`
`ftp://legacy.gsfc.nasa.gov/xmm/data/CCF &`
Note that this will take a long time to obtain (30-90 minutes, or more, depending on the connection speed) and is larger than the statsed 1.9 GB (more like 2.4GB).

Once you have the calibration files, you need to get a `Current Calibration File (CCF)` index file, for each of your observations. Go to http://xmm2.esac.esa.int/external/xmm_sw_cal/calib/ccf.shtml
Under The Calibration Archive you need to click on `cifbuild` link (there are a bunch of links on this page called cifbuild, but they don't all work or go to the same place!)
This link will take you to http://xmm2.esac.esa.int/external/xmm_sw_cal/calib/cifbuild.shtml
Enter the observation dates and create a CCF file (keep the default boxes checked) and save it as in the `ODF` directory as `ccf.cif`

Now SAS and the data should be set up and ready to follow the ABC Guide instructions.
And, in particular, the source detection thread that should reproduce the XMM point source catalog objects and the background and sensitivity map.

Useful things in the ABC guide that are worth having open or printed out:

Section 3.3 – The naming conventions of files.
http://heasarc.gsfc.nasa.gov/docs/xmm/abc/node5.html

Section 4.3 – Particular points in the setup of SAS that were not covered so far.
Go to http://heasarc.gsfc.nasa.gov/docs/xmm/abc/node6.html
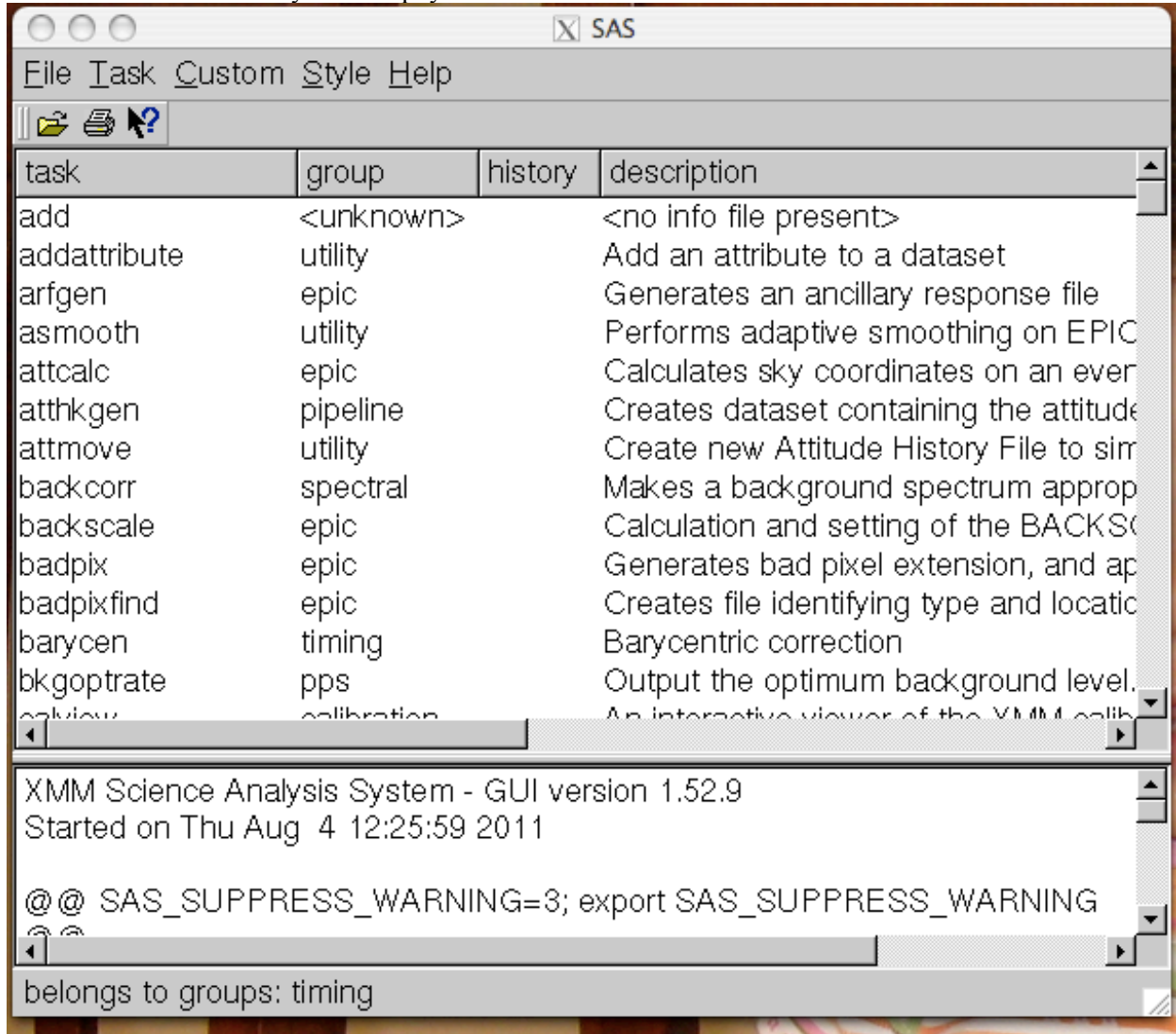Set the environment variables as described in the section.

```
setenv SAS_CCFPATH /full/path/to/CCF         Sets the directory
                                             path to the CCF data.
setenv SAS_ODF /full/path/to/ODF             Sets the directory
                                             path to the ODF data.
setenv SAS_CCF /full/path/to/ODF/ccf.cif     Sets the Calibration
                                             Index File (CIF) path
                                             and file name.
```
Note that for bash shell you need to say:
`export SES_CCFPATH=/full/path/to/CCF        etc...`

Try opening sas GUI by typing `sas &`

Eilat Glikman, PhD http://www.astro.yale.edu/people/eilat-glikman/
NSF Astronomy & Astrophysics Fellow eilat.glikman@yale.edu
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Follow the online `SAS Startup Thread`
http://xmm.esac.esa.int/sas/current/documentation/threads/sas_startup_thread.shtml
Much of which has already been covered here (and in Chapter 5 of the ABC Guide, which is worth looking at), but otherwise it will assign a single observation to the calibration files. Make sure all the steps have been completed.
Here you are basically taken through the steps of running `cifbuild` and `odfingest`.

Be sure to gunzip all the data in the `ODF` directory. (If there is a *.SAS file there before you run `odfingest`, you must remove it!)

Once you reach the end of this thread, you can move on to the `EPIC source finding thread: edetect_chain`
Go to http://xmm.esac.esa.int/sas/documentation/threads/src_find_thread.shtml
Note that in this thread, we will use the calibrated and concatenated event lists from the pipeline products (`PPS` directory).

Eilat Glikman, PhD   http://www.astro.yale.edu/people/eilat-glikman/
NSF Astronomy & Astrophysics Fellow   eilat.glikman@yale.edu
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The following notes are modifications or clarifications to the online thread document. These are important to follow because the threads are incomplete and have some bugs.

As Section 3.3 of the ABC Guide describes, files with these extensions are the event files.

EEVLIS	MIEVLI	MOS imaging mode event list	Zipped FITS	*xmmselect, fv, Xselect*
	PIEVLI	PN imaging mode event list	Zipped FITS	*xmmselect, fv, Xselect*

They can be found in the `PPS` diretory.
The start of Chapter 6 of the ABC Guide also explains how to set up the event files for processing:

For example, an MOS1 event list
`cp PPS/PiiiiiijjkkM1SlllMIEVLI0000.FTZ PROC/mos1.fits`
where
`iiiiiijjkk` - observation number
`lll` - exposure number within the observation
(I call the `mos1.evt` file `mos1.fits`, etc.)

2. In bash `export DATRED=path_to_my_reduced_data_directory`

3. Cut and paste the commands into the command line, eliminating the forward slash, \, so that everything is on one line.

4. If you do not have Grace installed, then read the output lightcurves into TOPCAT or IDL or some other fits reading/plotting tool. The countrate vs. time is in the first extension of the file.

5. After examining my images I used:
```
tabgtigen table=m1_back_lightc.fits expression="RATE<0.35"
gtiset=m1_back_gti.fits

tabgtigen table=m2_back_lightc.fits expression="RATE<0.35"
gtiset=m2_back_gti.fits

tabgtigen table=pn_back_lightc.fits expression="RATE<1.0"
gtiset=pn_back_gti.fits
```

Steps 6-9 are straightforward cut & paste tasks.
Before step 10, you will need to produce an `attitude file`.

Section 6.6 explains how to create an attitude file. For the sake of consistency, give the output file an extension of .ds:
`atthkgen atthkset=AttHk.ds timestep=1`

You will also need to know which filter was used for each detector, open, thin, medium, or thick, in order to select the appropriate count-rate to flux conversion factors, provided below.

Eilat Glikman, PhD   http://www.astro.yale.edu/people/eilat-glikman/

NSF Astronomy & Astrophysics Fellow   eilat.glikman@yale.edu

Yale Center for Astronomy & Astrophysics

The filter information is in the events file header. Use fv to view the header of the MIEVLI.FTZ and PIEVLI.FTZ files and find the FILTER keyword.

Before running `edetect_chain` to get the sources and sensitivity maps, you need to provide Energy Conversion Factors (ECFs) that convert count-rate to flux for each detector, energy band, and filter. Spend some time on the WebPIMMS tool to create a table that you can use for all the pointings.

http://heasarc.nasa.gov/Tools/w3pimms.html

WebPIMMS

A Mission Count Rate Simulator
Powered by PIMMS v4.3

Access the multiple component model interface.

Convert From:	Into:
XMM/MOS Med Count Rate 15" region	FLUX

Examples of Common FLUX Input/Output Ranges

		Units
Input Energy Range (low-high): 0.2-0.5	⊙ keV ○ Angstroms	Units
Output Energy Range (low-high): 0.2-0.5	⊙ keV ○ Angstroms	Units

Source: Flux / Count Rate	1	(erg/cm²/s) (counts/s)

Galactic nH	Redshift	Intrinsic nH	
1e20 (cm⁻²)	none	none	(cm⁻²)

Model of Source:	Model Parameters
⊙ Power Law	Photon index: 1.7
○ Black Body	keV:
○ Therm. Bremss.	kT:
○ APEC	1.0 Solar Abundance LogT | keV

(Estimate Count Rate) (Reset)

Select to convert from the detector (MOS, PN) + filter (Med, Thick, Thin) in a 15" region into FLUX. The input and output energy ranges are the same and reflect the different energy bands. The example shows band 1, 0.2-0.5 keV. Select a value for the Galactic N_H absorption by going to http://heasarc.gsfc.nasa.gov/cgi-bin/Tools/w3nh/w3nh.pl and entering the coordinates of your pointing (2.8e20 for `0403760301`).

Use a power-law photon index of 1.7, which is what Watson et al. (2009) used in producing the XMMi serendipitous survey point source catalog (which is the base catalog for our science).

Eilat Glikman, PhD   http://www.astro.yale.edu/people/eilat-glikman/
NSF Astronomy & Astrophysics Fellow   eilat.glikman@yale.edu
Yale Center for Astronomy & Astrophysics

Use a count-rate of 1 for a direct conversion of counts to flux and click the `Estimate Count Rate` button. Scroll down and find that:
PIMMS predicts a flux (0.200- 0.500keV) of 7.011E-12 ergs/cm/cm/s
or an ecf of 0.74 (ecfs are in units of 1e-11 erg/s/cm^2).

Energy	MOS	PN
Band 1: 0.2 – 0.5 keV	0.7011	0.1064
Band 2: 0.5 – 2.0 keV	0.5351	0.1399
Band 3: 2.0 – 4.5 keV	1.371	0.4975
Band 4: 4.5 – 7.5 keV	3.763	1.075
Band 5: 7.5 – 12 keV	34.35	4.243

Now we are ready to run `edetect_chain` on the individual band images for each detector. The output file will provide all the detections in all the bands as well as background and sensitivity maps.
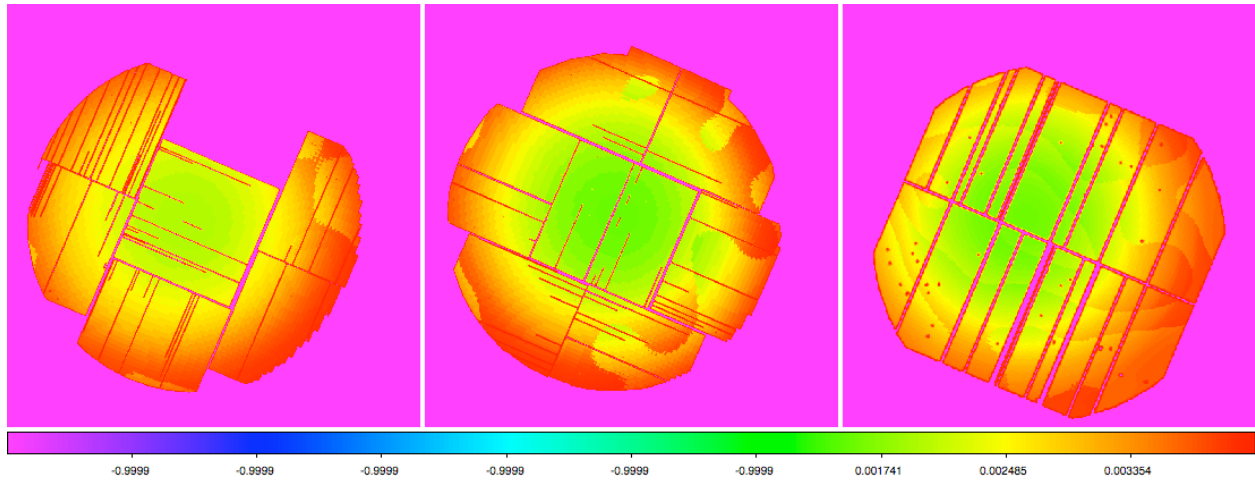
```
edetect_chain imagesets='"m1_image_b1.fits" "m1_image_b2.fits"
"m1_image_b3.fits" "m1_image_b4.fits" "m1_image_b5.fits"'
eventsets=$DATRED/MOS1.evt:EVENTS attitudeset=$DATRED/AttHk.ds:ATTHK
pimin='200 500 1000 2000 4500' pimax='500 1000 2000 4500 12000'
ecf='0.7011 0.5351 1.371 3.763 34.35' eboxl_list='m1_eboxlist_l.fits'
eboxm_list='m1_eboxlist_m.fits' esp_nsplinenodes=16
eml_list='m1_emllist.fits' esen_mlmin=15

edetect_chain imagesets='"m2_image_b1.fits" "m2_image_b2.fits"
"m2_image_b3.fits" "m2_image_b4.fits" "m2_image_b5.fits"'
eventsets=$DATRED/MOS2.evt:EVENTS attitudeset=$DATRED/AttHk.ds:ATTHK
pimin='200 500 1000 2000 4500' pimax='500 1000 2000 4500 12000'
ecf='0.7011 0.5351 1.371 3.763 34.35' eboxl_list='m2_eboxlist_l.fits'
eboxm_list='m2_eboxlist_m.fits' esp_nsplinenodes=16
eml_list='m2_emllist.fits' esen_mlmin=15

edetect_chain imagesets='"pn_image_b1.fits" "pn_image_b2.fits"
"pn_image_b3.fits" "pn_image_b4.fits" "pn_image_b5.fits"'
eventsets=$DATRED/PN.evt:EVENTS attitudeset=$DATRED/AttHk.ds:ATTHK
pimin='300 500 1000 2000 4500' pimax='500 1000 2000 4500 12000'
ecf='0.1064 0.1399 0.4975 1.075 4.243' eboxl_list='pn_eboxlist_l.fits'
eboxm_list='pn_eboxlist_m.fits' esp_nsplinenodes=16
eml_list='pn_emllist.fits' esen_mlmin=15
```

A step-by step version of this process (with figures and explanations) is found here:
http://xmm.esac.esa.int/sas/documentation/threads/src_find_thread_stepbystep.shtml

Eilat Glikman, PhD
NSF Astronomy & Astrophysics Fellow
Yale Center for Astronomy & Astrophysics

http://www.astro.yale.edu/people/eilat-glikman/
eilat.glikman@yale.edu

Here are the resultant sensitivity maps for Band 1 0.2-0.5 keV for MOS1,2 and PN (left to right).

And for Band 5 7.5-12 keV for MOS1,2 and PN (left to right).
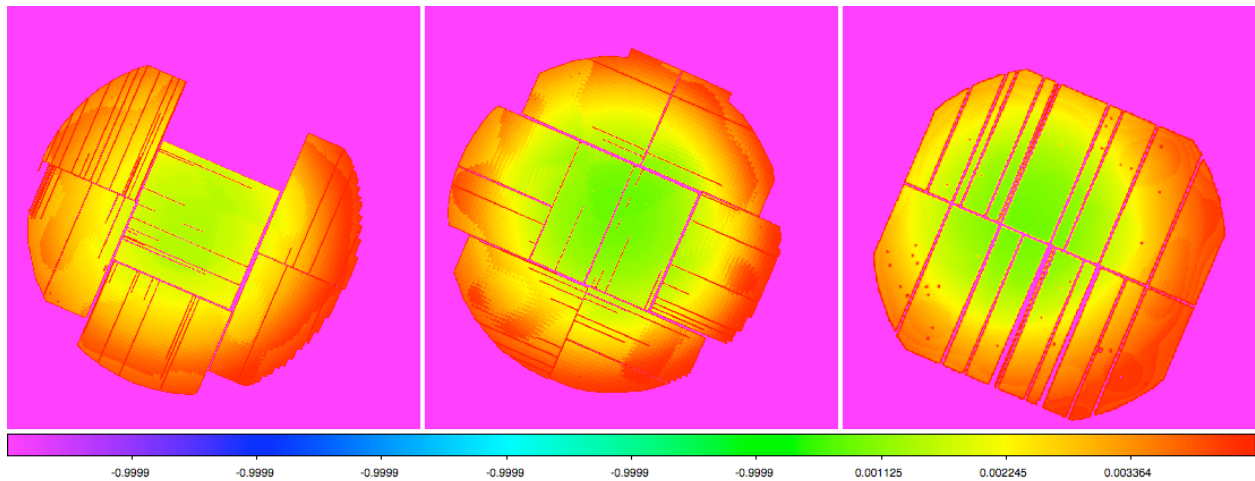
Sanity checks:

- Compare the detected sources to the XMMi serendipitous catalog as well as the PPS pipeline output table of sources.
- Is the number of sources the same? If not, what is missed? (Faint? Bright? Edge?)
- Compare the fluxes of the extracted sources. Are they similar? At what level (%age)?
- Make a radial profile of the sensitivity limit. How does it compare to Felipe's 0th order efforts?
- Make an Area vs. Depth curve for your field. Does it make sense?

Now repeat for another pointing, until you are done.