An introduction to XMM-Newton data analysis and the SAS grand-scheme

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Outline

- **Basic principles of X-ray astronomy**
- **SAS grand-scheme**
- **Introduction to X-ray spectroscopy**
- **What you should do even *before* you install the SAS**

Basics of X-ray analysis

X-ray detectors are photon-counting → two main consequences:

- **X-ray astronomy is an intrinsically Poissonian science**
  - Scientific products can have a few or even zero events in large ranges of their parameter spaces

- **The "king" in the X-ray realm is the event, characterised by:**
  - position on the detector
  - "pulse height", which is related to the X-ray energy of the incoming photon in a complex and generally non-linear way
  - arrival time at the spacecraft
  - event "shape" (used to separate X-ray events from particles)
  - CCD number, and other secondary attributes (you don't generally have to worry about)

Event list

When? **Where [position]?** **Who [energy]?** **What [X-ray or particle]?**

	TIME D s	X J 0.05 ARCSECONDS	Y J 0.05 ARCSECONDS	PHA I CHAN	PI I CHAN	PATTERN B	CCDNR B
1	9.506202266412E+07	23743	21330	423	1447	2	1
2	9.506202266412E+07	28728	21990	25	98	0	1
3	9.506202527717E+07	28176	31623	25	97	0	1
4	9.506202527717E+07	29829	30841	327	1131	0	1
5	9.506202527717E+07	23686	19319	541	1854	0	1
6	9.506203046611E+07	25510	32711	1810	6171	0	1
7	9.506203566620E+07	29814	28823	102	360	0	1
8	9.506203826626E+07	26635	30601	2062	7028	0	1
9	9.506204346625E+07	26429	20314	443	1519	4	1
10	9.506204606629E+07	20691	28728	1608	5471	3	1
11	9.506204606629E+07	27989	29777	202	700	0	1
12	9.506204606629E+07	21937	25667	117	402	2	1
13	9.506204866632E+07	28132	32491	462	1589	0	1
14	9.506204866632E+07	27204	29741	904	3095	0	1
15	9.506205126638E+07	22124	20257	290	994	0	1
16	9.506205906643E+07	23193	18795	1398	4771	0	1
17	9.506206166646E+07	23224	19326	276	950	0	1
18	9.506206946653E+07	27755	28979	183	637	0	1
19	9.506207206939E+07	22533	29563	33	118	0	1

The FITS format

- **Almost all XMM-Newton data are in FITS (*Flexible Image Transport System*) - standard format for astronomical images since the 80s and the documents of the Vatican Library since 2011**

- **FITS files are constituted by *extensions***

  - **Each extension contains a *header* (list of readable strings) and a binary data block, either as an *image* or as a *table* (*e.g.*: `EVENTS`)**

  - **For historical reasons, the first block (`PRIMARY`) must contain image data, and is frequently left blank**

Example of a FITS header (event list)

```
XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                   18 / width of table in bytes
NAXIS2  =                42549 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group (required keyword)
TFIELDS =                    9 / number of fields in each row
EXTNAME = 'M1IME1  '           / Extension name
EXTVER  =                    1 / Extension Version
TELESCOP= 'XMM     '           / XMM mission
INSTRUME= 'EMOS1   '           / EPIC MOS Instrument
DATATYPE= 'IMAGE.EL'           / Type of data
OBS_ID  = '0002940401'         / Observation Identifier
EXP_ID  = '0002940401001'      / Exposure Identifier
CCDID   =                    1 / Numerical identifier of the CCD
CCDNODE =                    0 / CCD Node
WINDOWX0=                    0 / X-Coordinate of bottom left corner of window
WINDOWY0=                    0 / Y-Coordinate of bottom left corner of window
WINDOWDX=                  610 / Size, along x-axis, of window
WINDOWDY=                  602 / Size, along y-axis, of window
EDUID   =                    0 / EDU Identifier
EDUMODE =                    3 / EDU Mode
EDUTHR  =                   25 / EDU Threshold
FRMTIME =                   26 / Frame Integration Time
EMDHLOW =                    0 / EMDH Lower Threshold
EMDHUPP =                 4095 / EMDH Upper Threshold
DATE-OBS= '2002-01-28T20:33:20' / Start time of exposure
```

To work with FITS: LHEASOFT (a.k.a. FTOOLS):

http://heasarc.gsfc.nasa.gov/ftools/

Science as projection

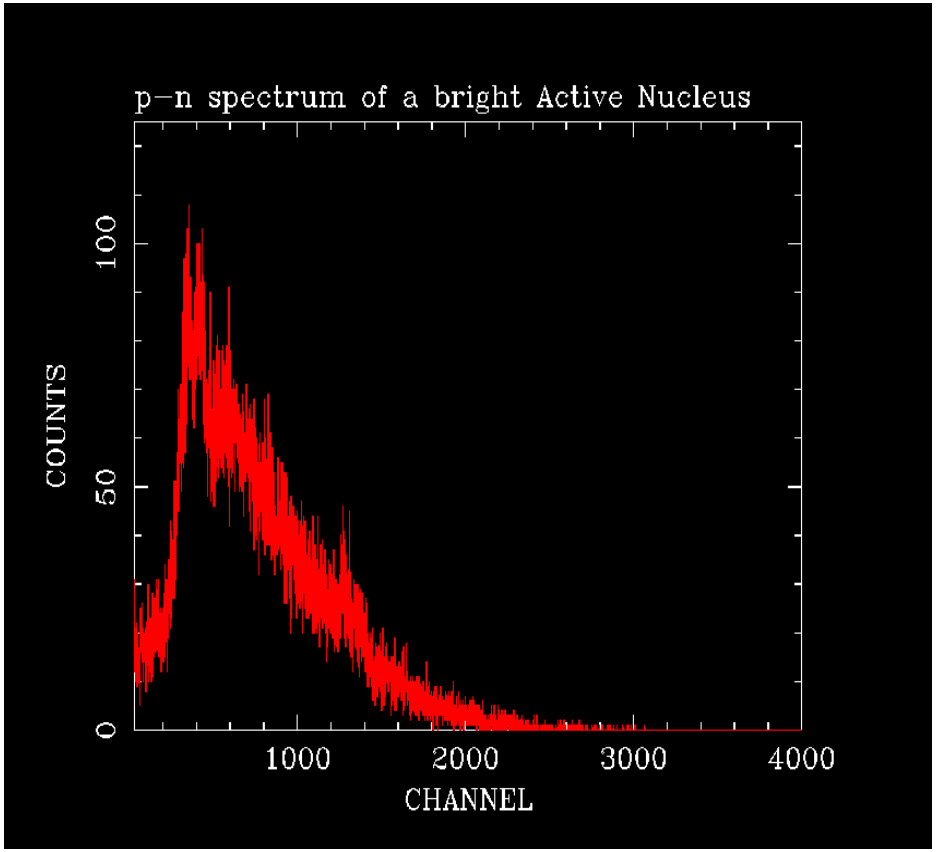
The X-ray scientific products can be seen as *projections* onto the sub-spaces defined by the event physical quantities

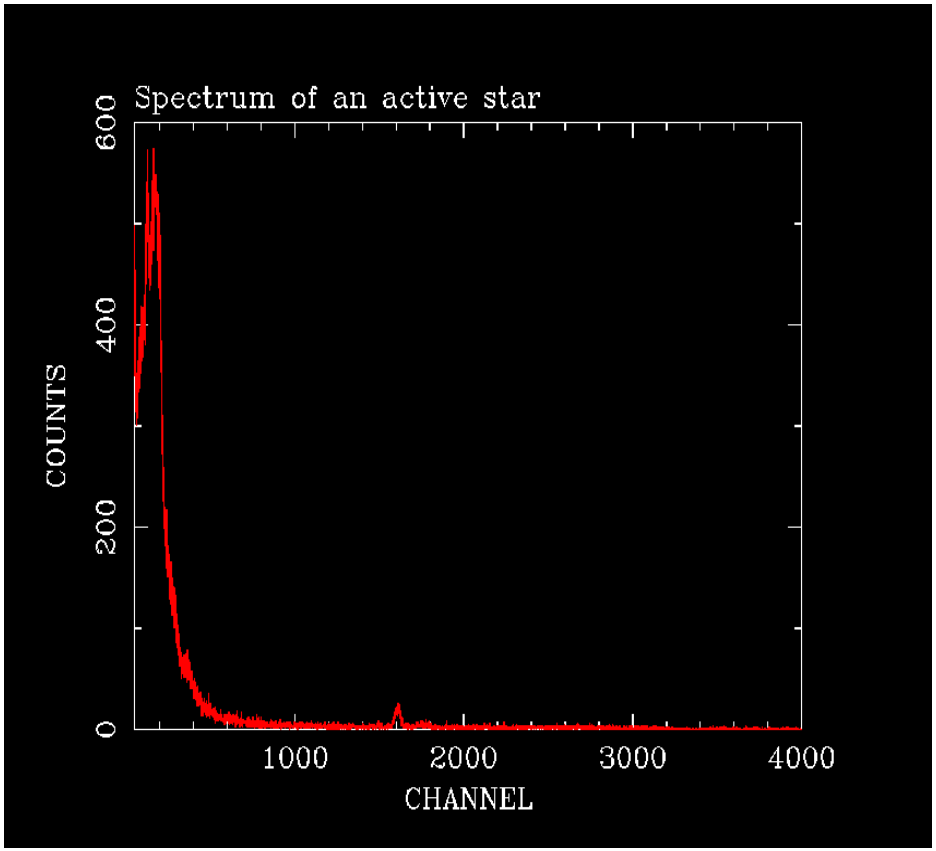
- **By collapsing time and space, one gets an energy distribution function (*spectrum*) in units of *counts per energy bin***
- **By collapsing time and energy, one gets a 2-D *image* in units of *counts per pixel***
- **By collapsing space and energy, one gets an intensity *time series* in units of *counts per time bin***

These scientific products are expressed in units that are *in*directly related to the intrinsic properties of celestial sources

Transfer function

When all candles be out, all cats be gray.





SAS scope

SAS makes two things for you, which no other software can do

- **Apply all the transformations, which allow to convert instrument into physical quantities (whence astrophysical quantities can be derived) → CALIBRATION**

- **Optimally screen the data (remove noise, keep source signal only)**

In practical terms …

Before SAS → **After SAS**

(frame number) **FRAME** → **TIME** (UTC time)

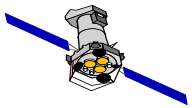
(EPIC raw coordinates) **RAW[XY]** → **[X,Y]** (sky coordinates)

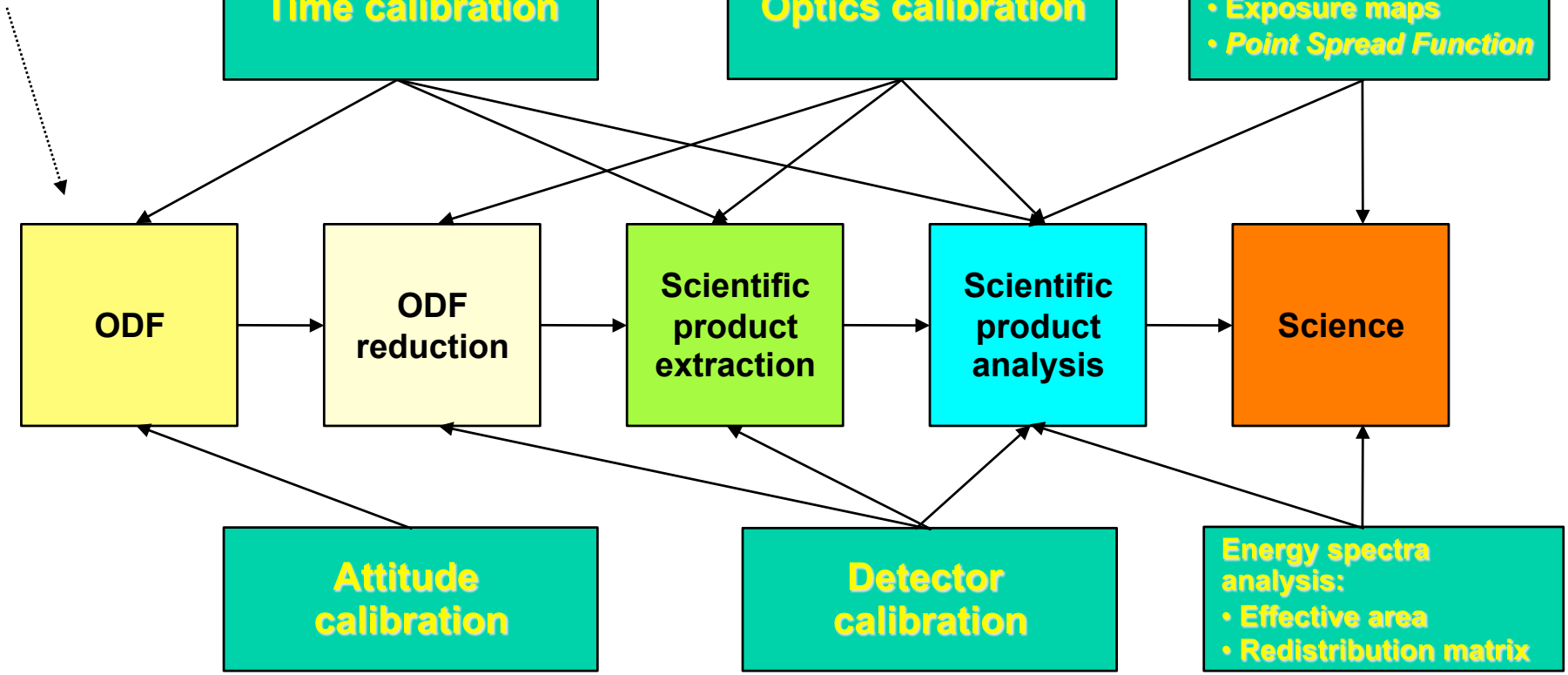
(RGS raw coordinates) **RAW[XY]** → **BETA_CORR, XDSP_CORR** (dispersion and cross-disprsion angles)

(Energy channel) **PHA** → **PI** (energy)

(Name of the column in the event list)

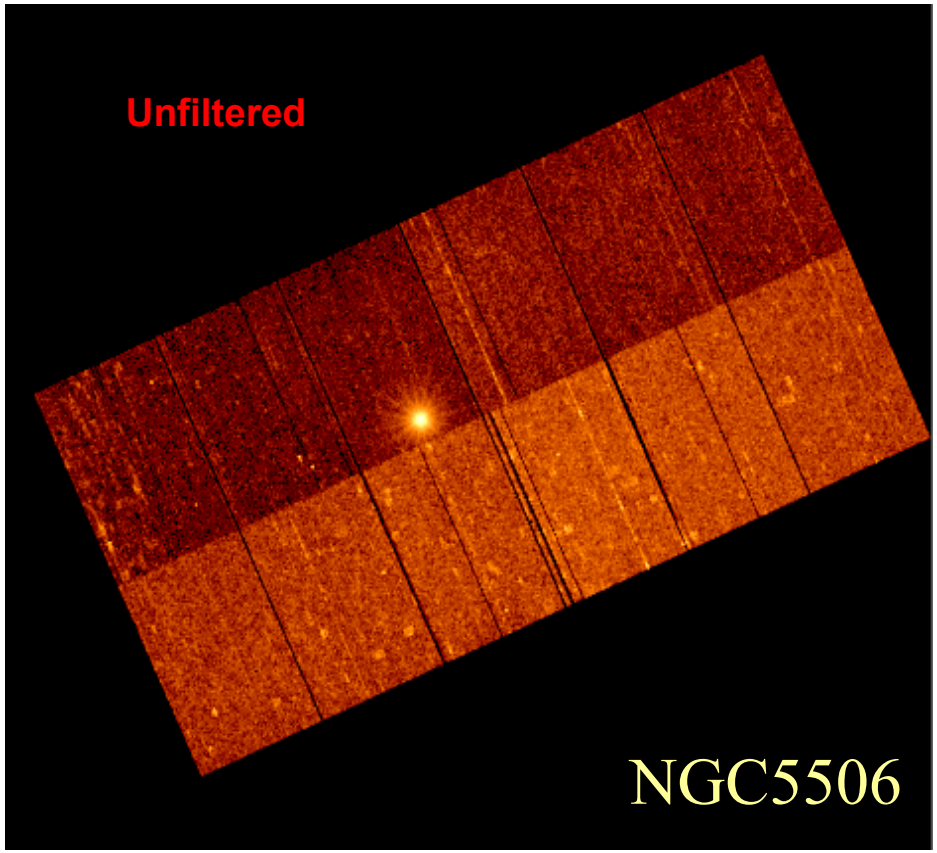
Removing transfer function = **calibration**

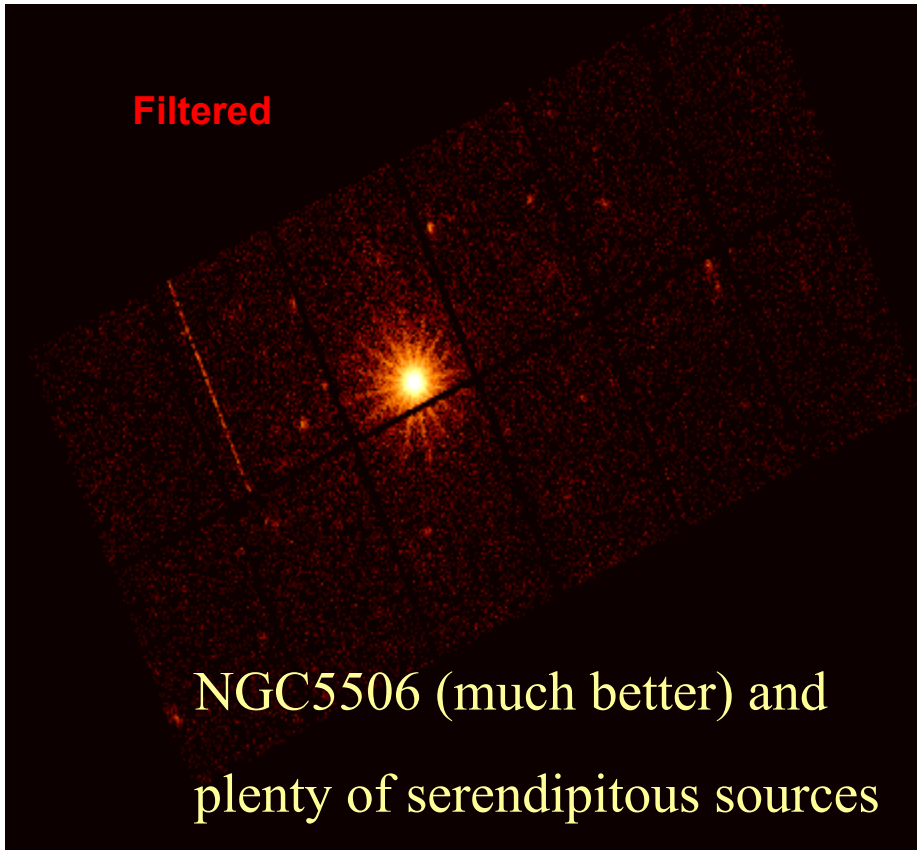




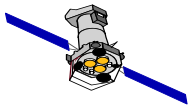
Importance of data screening

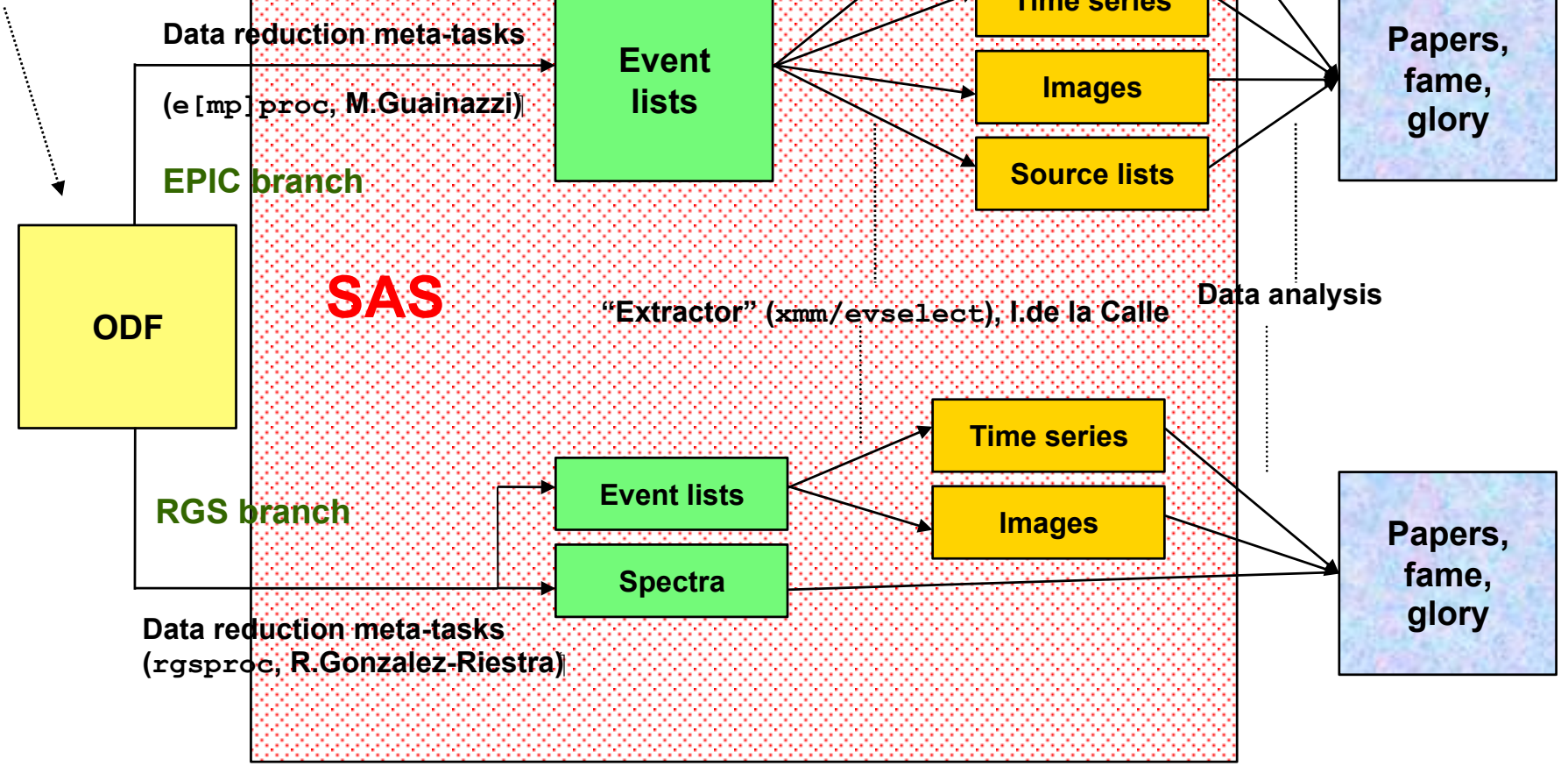
Not only the *quality* but also the *quantity* of you X-ray science depend on efficiently removing noise





XMM-Newton grand-scheme





What I need to do ...

… before starting analysing data of an XMM-Newton observation:

1. Know the systematic uncertainties of your instruments

- Instrument calibration status reports (see talks by M.Guainazzi, R.Gonzalez-Riestra, J.U.Ness)
- SAS Science Validation Reports (see talk by C.Gabriel)
- Current Calibration File (CCF) Release Notes (see talk by C.Gabriel)

2. Make sure that you are using the latest calibrations

- Install an automatic mirror of the calibration files (*e.g.*, `rsync`)
- Reduce the data again if you are unsure on the calibrations on which your data were reduced. Always stay on the safe side!

3. Make sure that SAS does not surprise you

- Check the SAS "watchout and evergreen" SAS pages, which contain known caveats or bugs
- Make use the threads (see E.Ojero's talk), would you like to learn something new

4. If everything else fails …

- Contact the HelpDesk: **xmmhelp@xmm.esac.esa.int**

To know more

- **What is SAS:** `http://xmm.esac.esa.int/sas/current/documentation/sas_concise.shtml`
- **FITS data format:** `http://heasarc.nasa.gov/docs/heasarc/fits.html`
- **XMM-Newton calibration portal:** `http://xmm2.esac.esa.int/external/xmm_sw_cal/calib/index.shtml`
- **Basics of spectral fitting:** `http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec/manual/XspecSpectralFitting.html`
- **SAS watchout:** `http://xmm.esac.esa.int/sas/current/watchout/`
- **XMM-Newton HelpDesk:** `http://xmm.esac.esa.int/external/xmm_user_support/helpdesk.shtml`