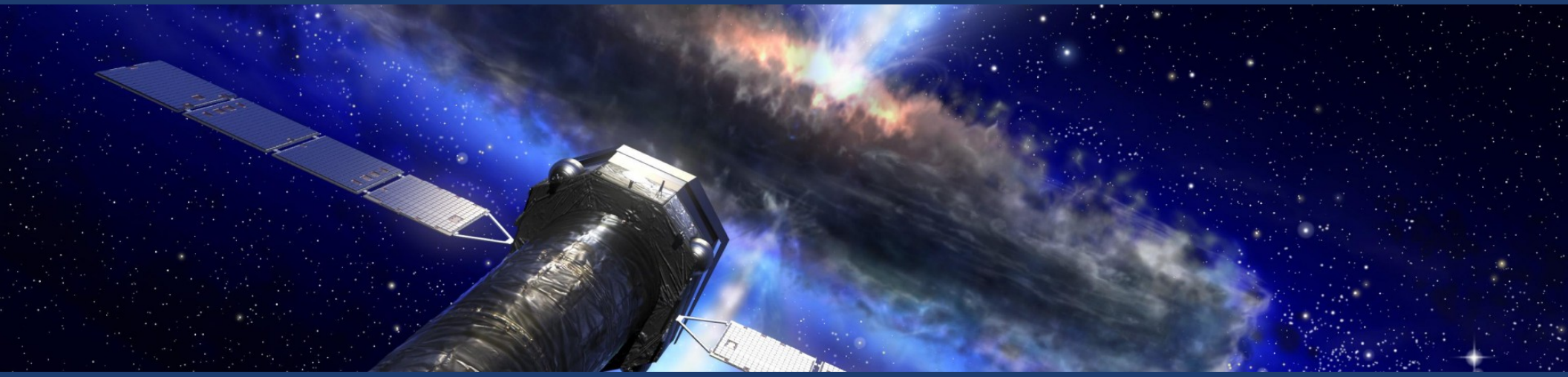
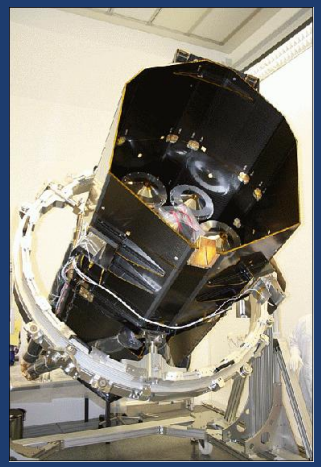


Other Instruments

J. Wilms, T. Dauser, P. Peille



Gendetsim

Generalized model for pixel-based detectors: gendetsim

Parameters:

```
1   ImpactList = impacts.fits      impact list input file
2       RawData = raw.fits          raw data output file
3       Mission = SRG               mission name: Chandra, GRAVITAS, IXO,
          ATHENA, SRG, XMM
4    Instrument = eROSITA           instrument name
5          Mode = none              instrument mode (including filter)
6     (XMLFile = none)              XML input file with detector
        definition (overwrites Mission, Instrument, and Mode)
7      (MJDREF = 55000.0)           reference Modified Julian Date
8      (TSTART = 0.0)               start time (s)
9     Exposure = 1000.0             simulated exposure time (s)
10       (Seed = -1)                seed for random number generator (-1:
           initialize with system time)
11    (chatter = 3)                 verbosity
12    (clobber = no)                overwrite output files if exist?
13    (history = true)              write a history block with program
        parameters to each FITS file?
```

XMLFile: generalized language allowing to model most pixel-based detectors

Example: CCDs for Arcus

Example: CCDs for ARCUS project

Start with field of view and imaging information:

```
<?xml version="1.0"?>
<!-- ARCUS Gratings CCD -->
<instrument type="ARCUS">
  <telescope>
    <fov diameter="0.5"/>
    <focallength value="12.000"/>
  </telescope>
```

More complicated instruments also have a PSF definition for the imaging.

Example: CCDs for Arcus

Detector specification:

General pixel information (for imaging):

```
  <detector>

    <dimensions xwidth="2048" ywidth="1024"/>

    <pixelborder x="0." y="0."/>
    <wcs xrpix="0.0" yrpix="0.0"
         xrval="0.0" yrval="0.0"
         xdelt="24e-6" ydelt="24e-6"
         rota="0."/>
```

Example: CCDs for Arcus

Detector specification:

General pixel information (for imaging):

```
  <detector>

    <dimensions xwidth="2048" ywidth="1024"/>

    <pixelborder x="0." y="0."/>
    <wcs xrpix="0.0" yrpix="0.0"
         xrval="0.0" yrval="0.0"
         xdelt="24e-6" ydelt="24e-6"
         rota="0."/>
```

Detection process: use RMF and ARF (generated externally):

```
    <rmf filename="arcus_ccd.rmf"/>
    <arf filename="arcus_ccd.arf"/>
```

Example: CCDs for Arcus

Detector specification:

General pixel information (for imaging):

```
  <detector>

    <dimensions xwidth="2048" ywidth="1024"/>

    <pixelborder x="0." y="0."/>
    <wcs xrpix="0.0" yrpix="0.0"
         xrval="0.0" yrval="0.0"
         xdelt="24e-6" ydelt="24e-6"
         rota="0."/>
```

Detection process: use RMF and ARF (generated externally):

```
    <rmf filename="arcus_ccd.rmf"/>
    <arf filename="arcus_ccd.arf"/>
```

Charge cloud and digitization information:

```
    <cte value="1"/>

    <split type="gauss" par1="5e-6"/>

    <threshold_readout_lo_keV value="0.050"/>
    <threshold_event_lo_keV value="0.050"/>
    <threshold_split_lo_keV value="0.050"/>
```

Example: CCDs for Arcus

Detector specification (cont'd):

Reading out a pixel detector:

```
28      <readout mode="time">
29        <wait time="0.98976"/>
30        <loop start="0" end="1023" increment="1" variable="$i">
31          <readoutline lineindex="0" readoutindex="$i"/>
32          <lineshift/>
33          <wait time="1e-5"/>
34        </loop>
35        <newframe/>
36
37      </readout>
```

That's it:

```
38
39    </detector>
40  </instrument>
```

Example: CCDs for Arcus

Modification: binning in *y*-direction:

Reading out a pixel detector:

```
26      <readout mode="time">
27        <wait time="0.1"/>
28        <!-- read out 1023 rows in 10ms, binning 16 rows at a time -->
29        <!-- NB: 9.76562e-6 = 10ms/1024                             -->
30        <loop start="0" end="1023" increment="16" variable="$i">
31          <loop start="0" end="15" increment="1">
32            <lineshift/>
33            <wait time="9.76562e-6"/>
34          </loop>
35          <readoutline lineindex="0" readoutindex="$i"/>
36        </loop>
37        <newframe/>
38
39      </readout>
```

Suzaku

A more complex example: *Suzaku* burst mode:

1. Wait for $8\,\mathrm{s} - b$
2. flush whole CCD w/charge injection, takes 156 ms
3. expose for $b\,\mathrm{s}$
4. read into framestore w/o charge injection (25 ms)

Suzaku

A more complex example: *Suzaku* burst mode:

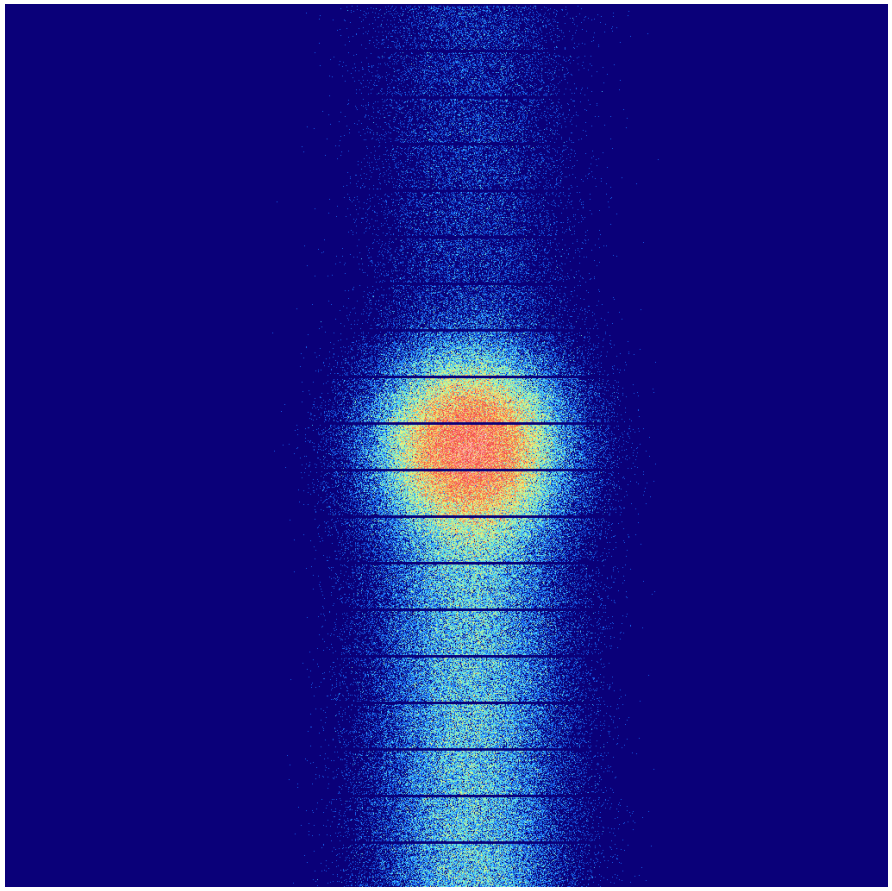
1. Wait for 8 s − b
2. flush whole CCD w/charge injection, takes 156 ms
3. expose for b s
4. read into framestore w/o charge injection (25 ms)

Example: b = 0.94 s

```
<readout mode="time">
  <wait time="7.906"/>
  <loop start="0" end="1023"
        increment="1">
    <clearline lineindex="0"/>
    <lineshift/>
    <wait time="0.000152"/>
  </loop>
  <wait time="0.094"/>
  <loop start="0" end="1023"
        increment="1" variable="$i
          ">
    <readoutline lineindex="0"
                 readoutindex="$i
                   "/>
    <lineshift/>
    <wait time="0.0000244"/>
  </loop>
  <newframe/>
</readout>
```

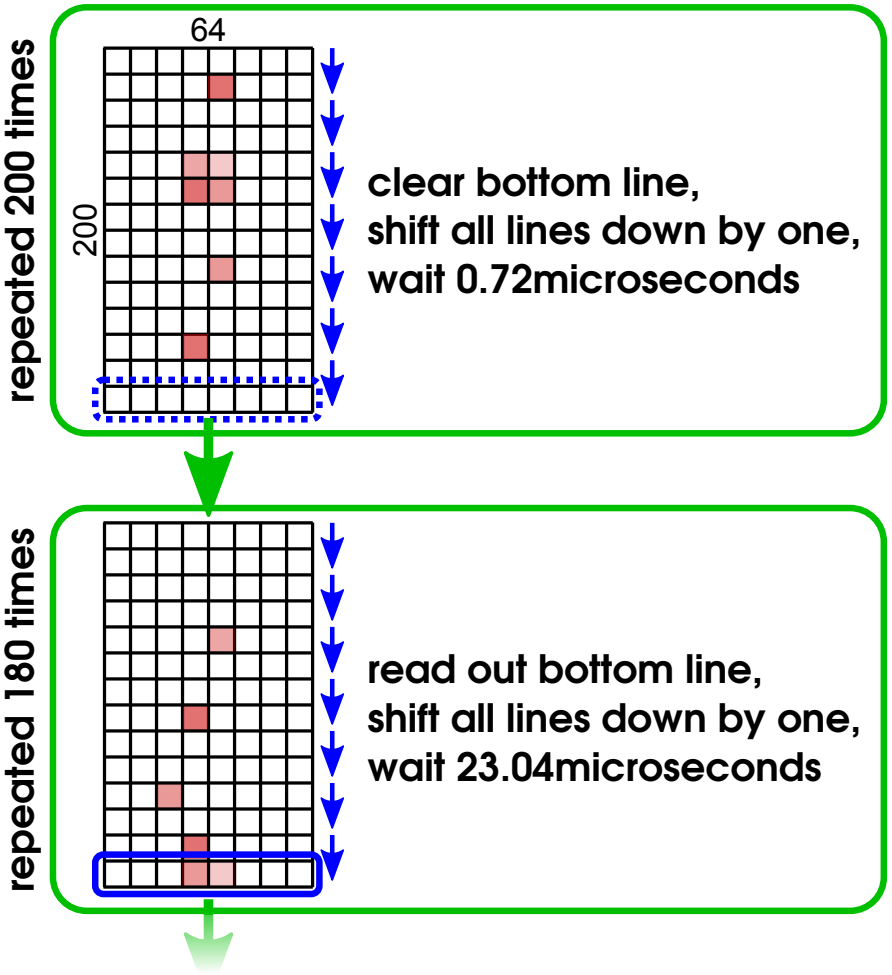
Suzaku

A more complex example: *Suzaku* burst mode:



```
<readout mode="time">
  <wait time="7.906"/>
  <loop start="0" end="1023"
        increment="1">
    <clearline lineindex="0"/>
    <lineshift/>
    <wait time="0.000152"/>
  </loop>
  <wait time="0.094"/>
  <loop start="0" end="1023"
        increment="1" variable="$i
          ">
    <readoutline lineindex="0"
                 readoutindex="$i
                   "/>
    <lineshift/>
    <wait time="0.0000244"/>
  </loop>
  <newframe/>
</readout>
```

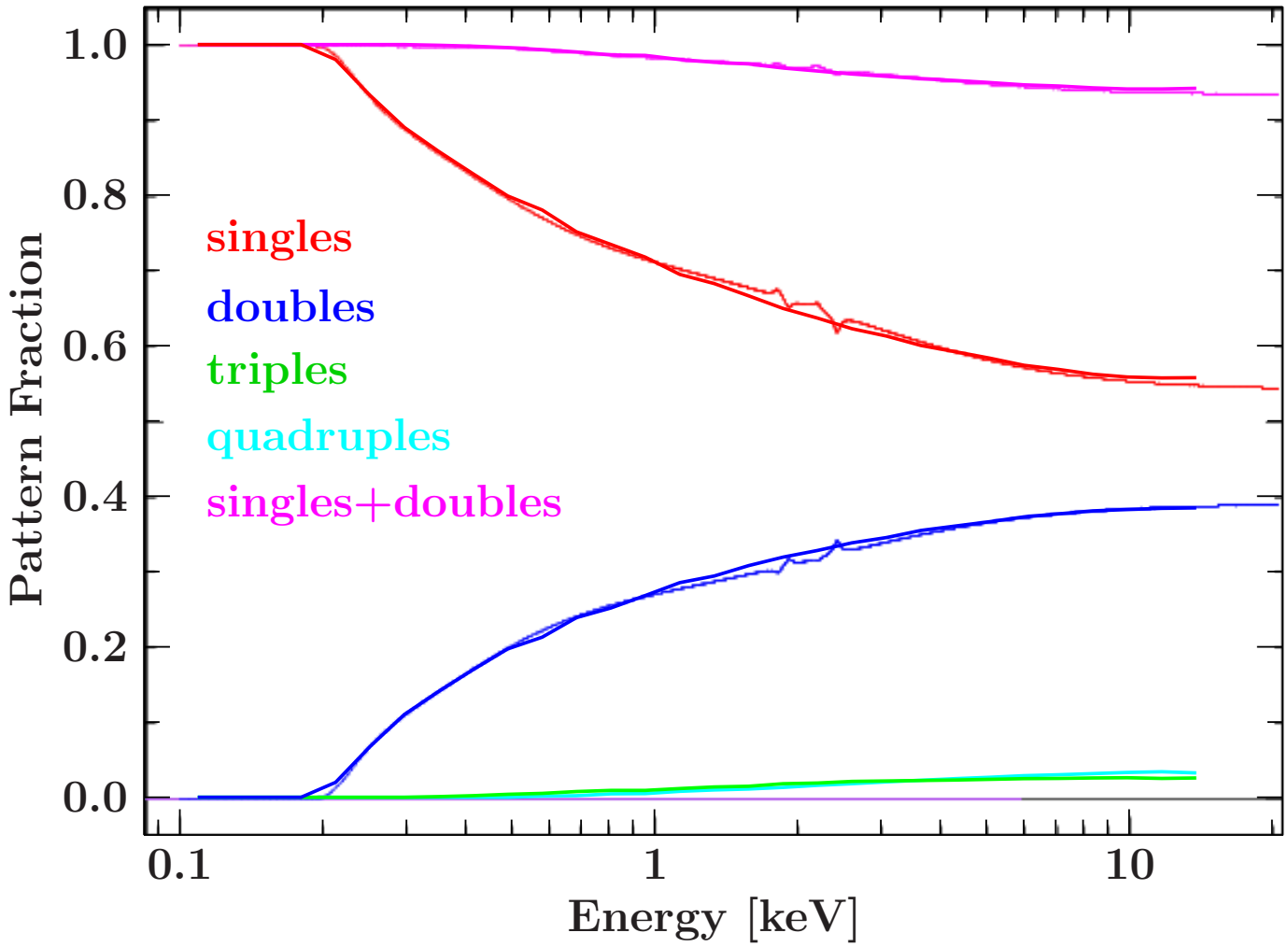
XMM-Newton




```
<readout mode="time">
  <loop start="0" end="199" increment="1">
    <clearline lineindex="0"/>
    <lineshift/>
    <wait time="0.72e-6"/>
  </loop>
  <loop start="0" end="179" increment="1"
        variable="$i">
    <readoutline lineindex="0"
                 readoutindex="$i"/>
    <newframe/>
    <lineshift/>
    <wait time="23.04e-6"/>
  </loop>
</readout>
```

Verification: XMM-Newton EPIC-pn (example: burst mode readout)

XMM-Newton

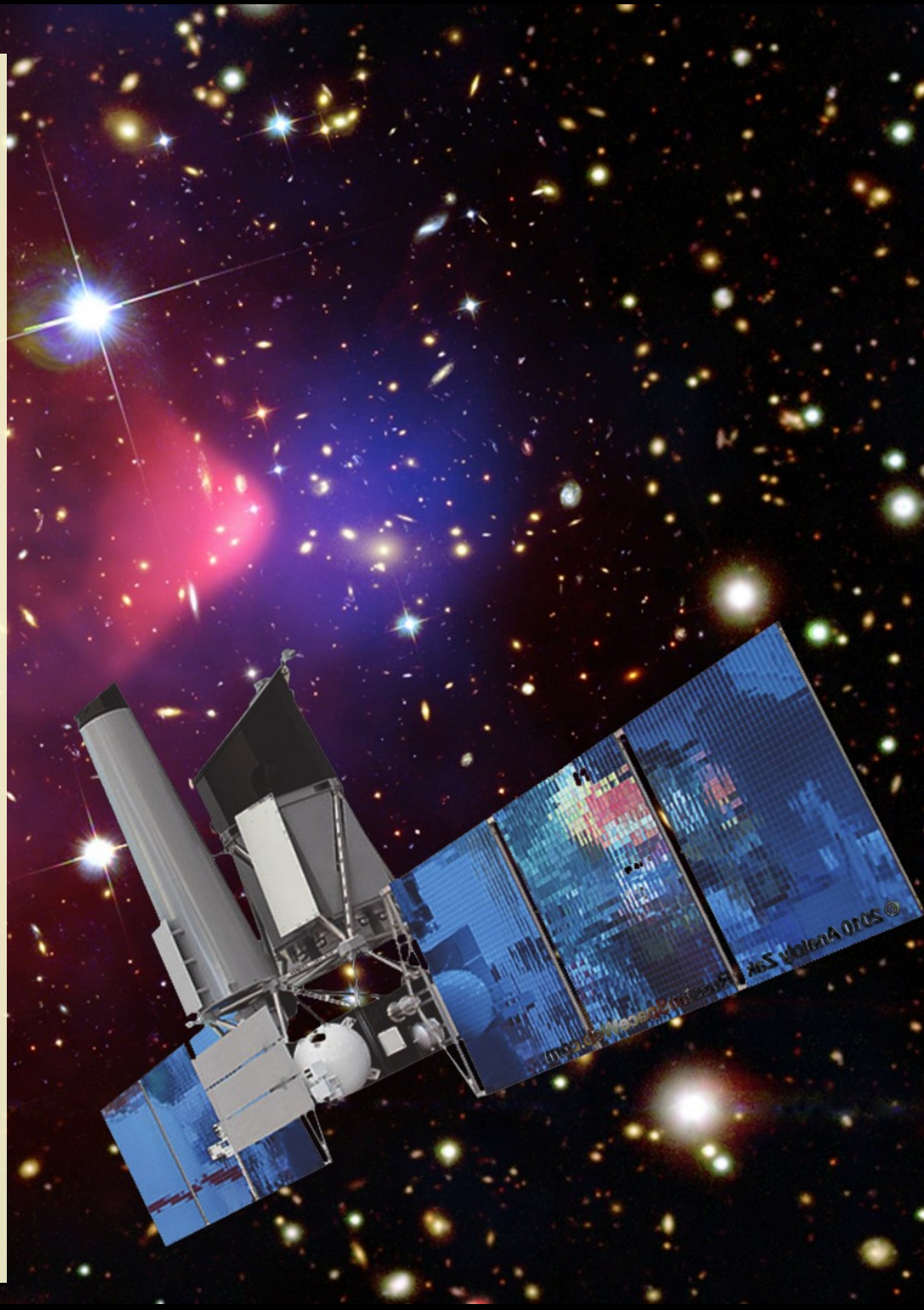


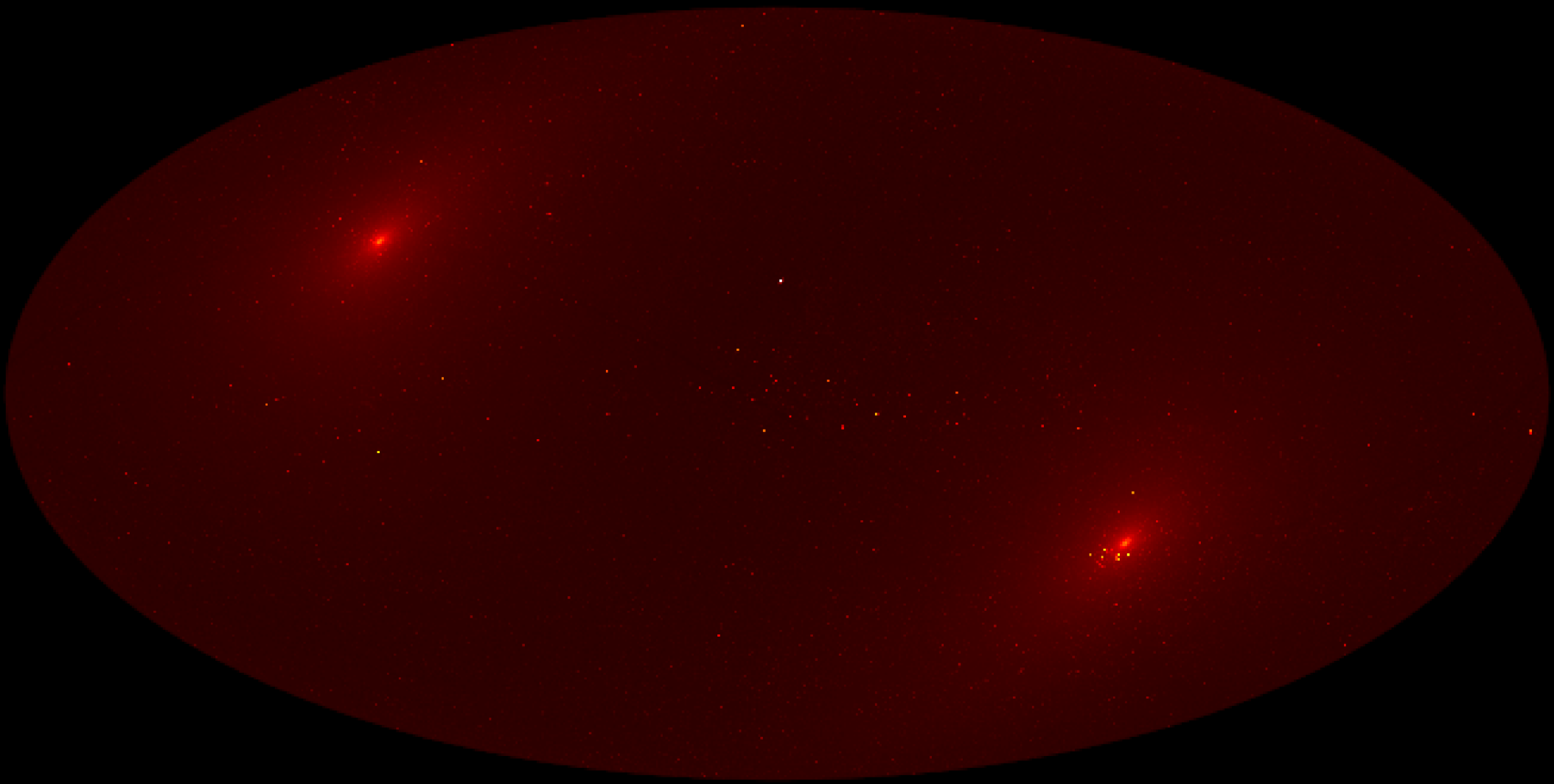
Charge cloud model in XMM-Newton EPIC-pn:

smooth lines: calibrated model, ragged lines: simulation

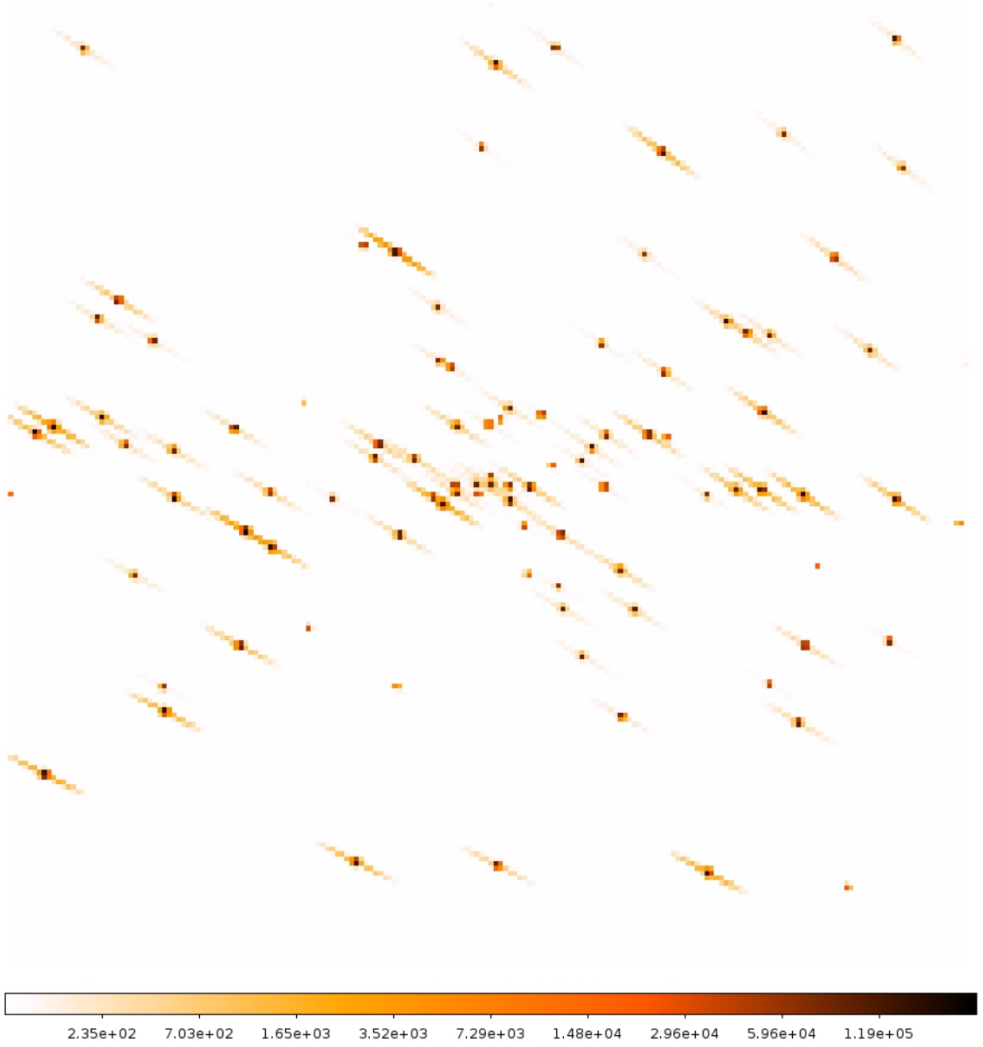
eROSITA:

- Slew survey, attitude!
- Simulation needed for 7 telescopes/detectors
- Frame store readout
- Simulation tools:
  - `erosim`: simulate survey
  - `ero_vis`: determine visibility of X-ray sources from attitude
  - `ero_rawevents`, `ero_calevents`: convert simulator output to internal eROSITA SASS formats
- Also have tool to produce telemetry stream (and FITS from telemetry) – available upon request



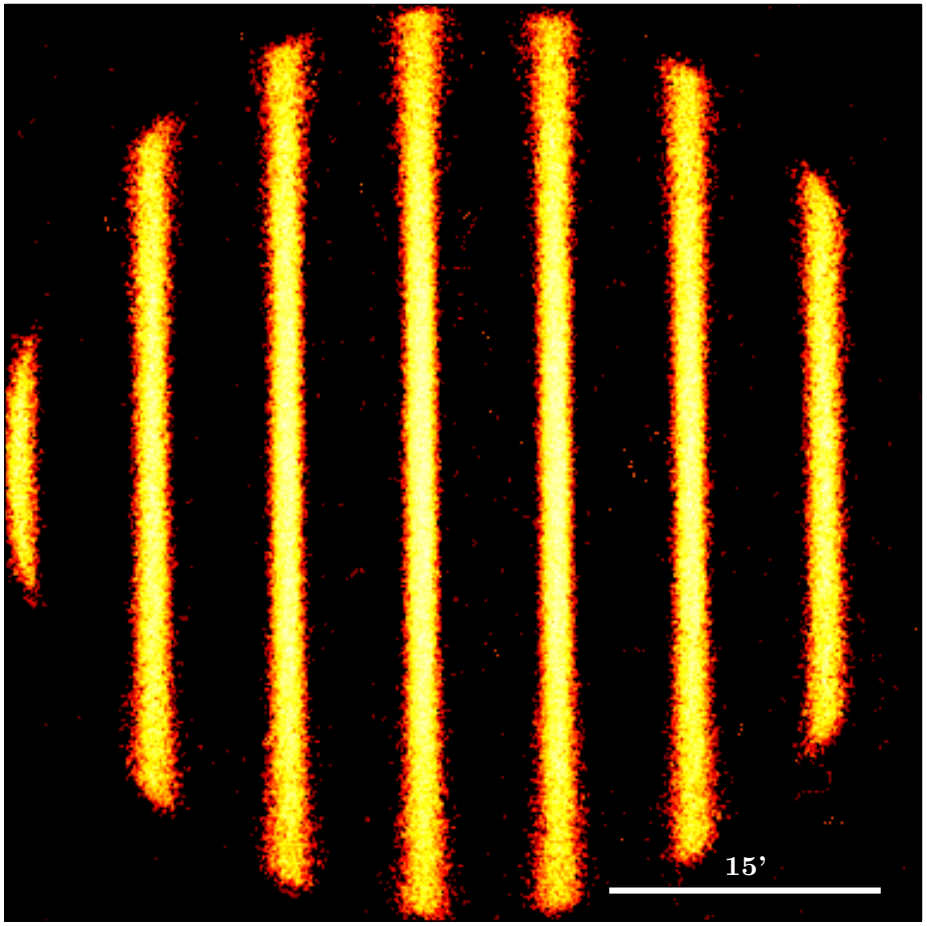


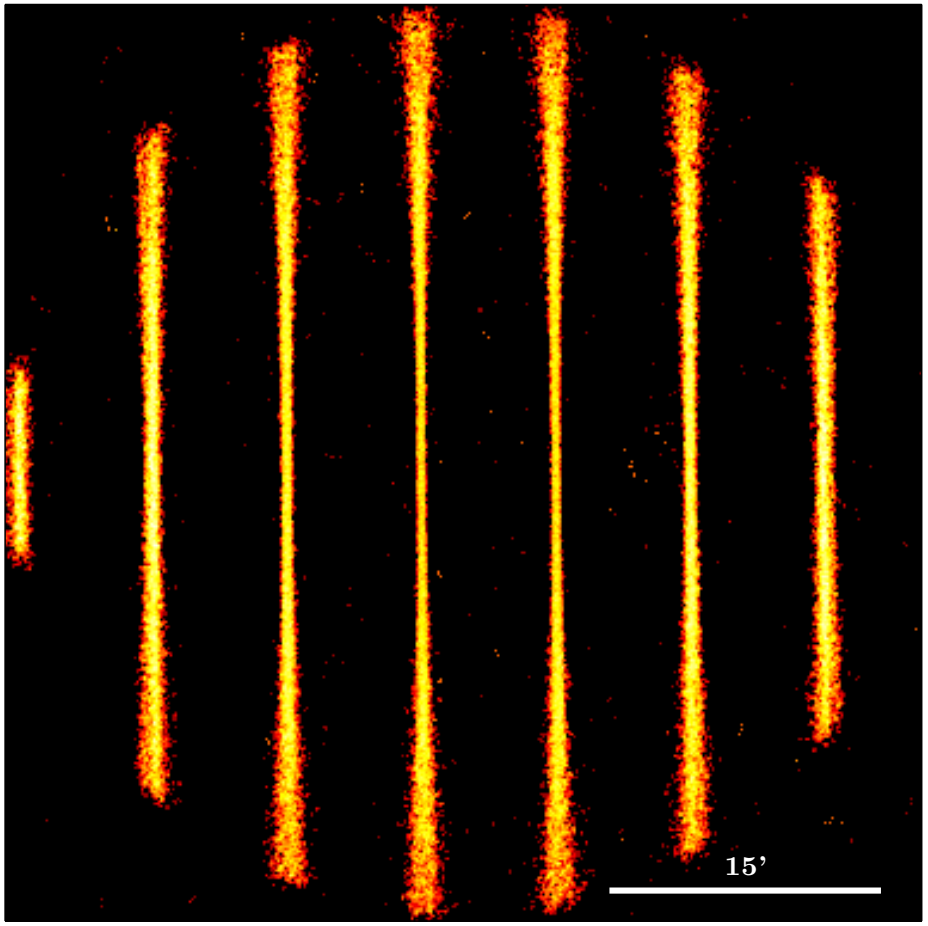
Galactic Center



Inner $20^\circ \times 20^\circ$ of the Galaxy

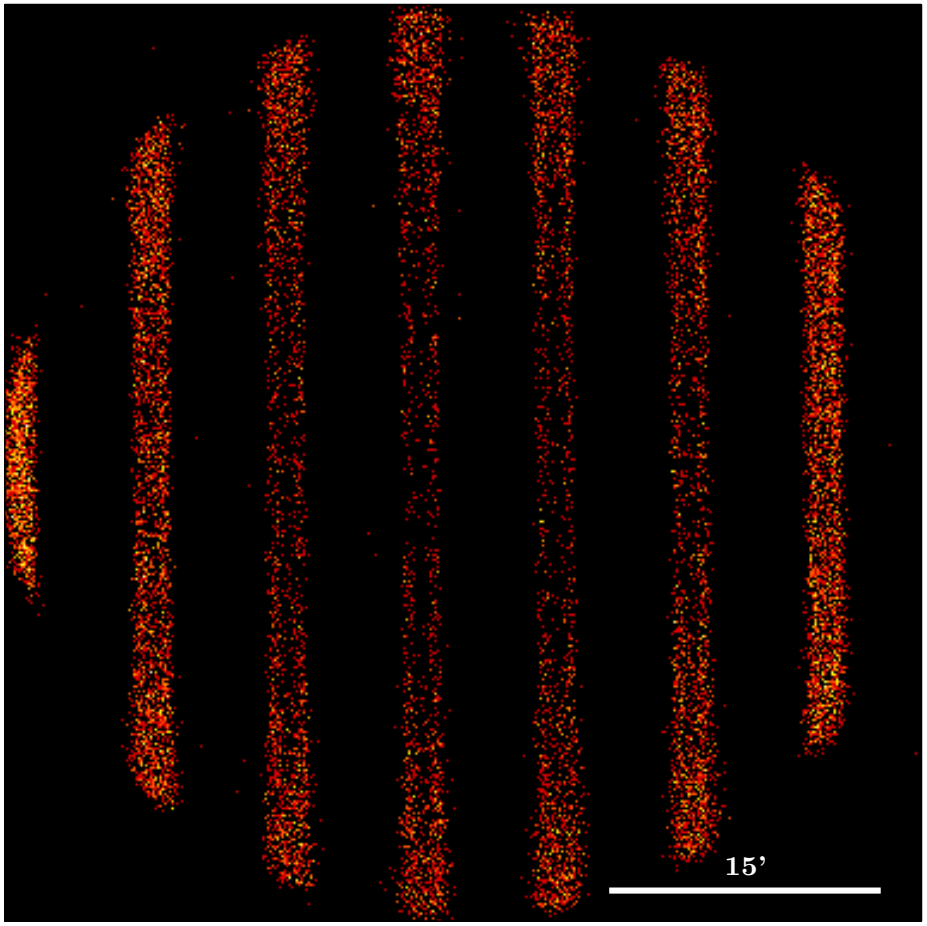
PSF effects

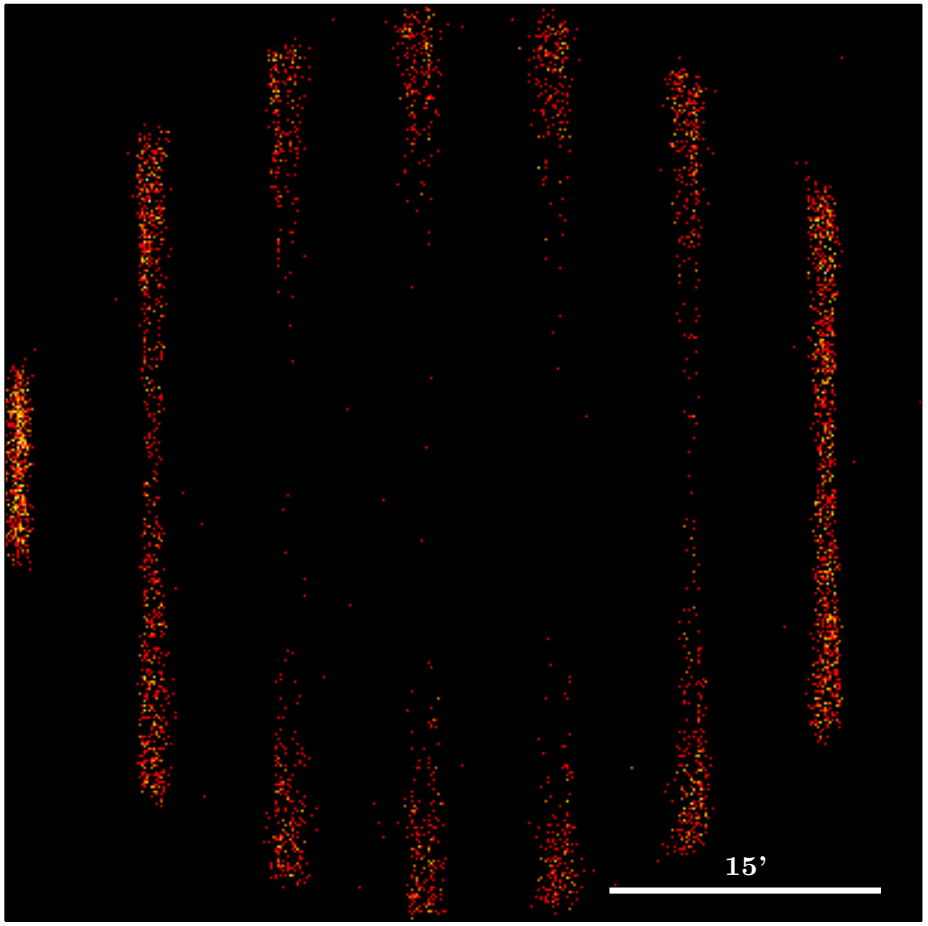




slew observation over the Crab and Vela X-1 (all evts)

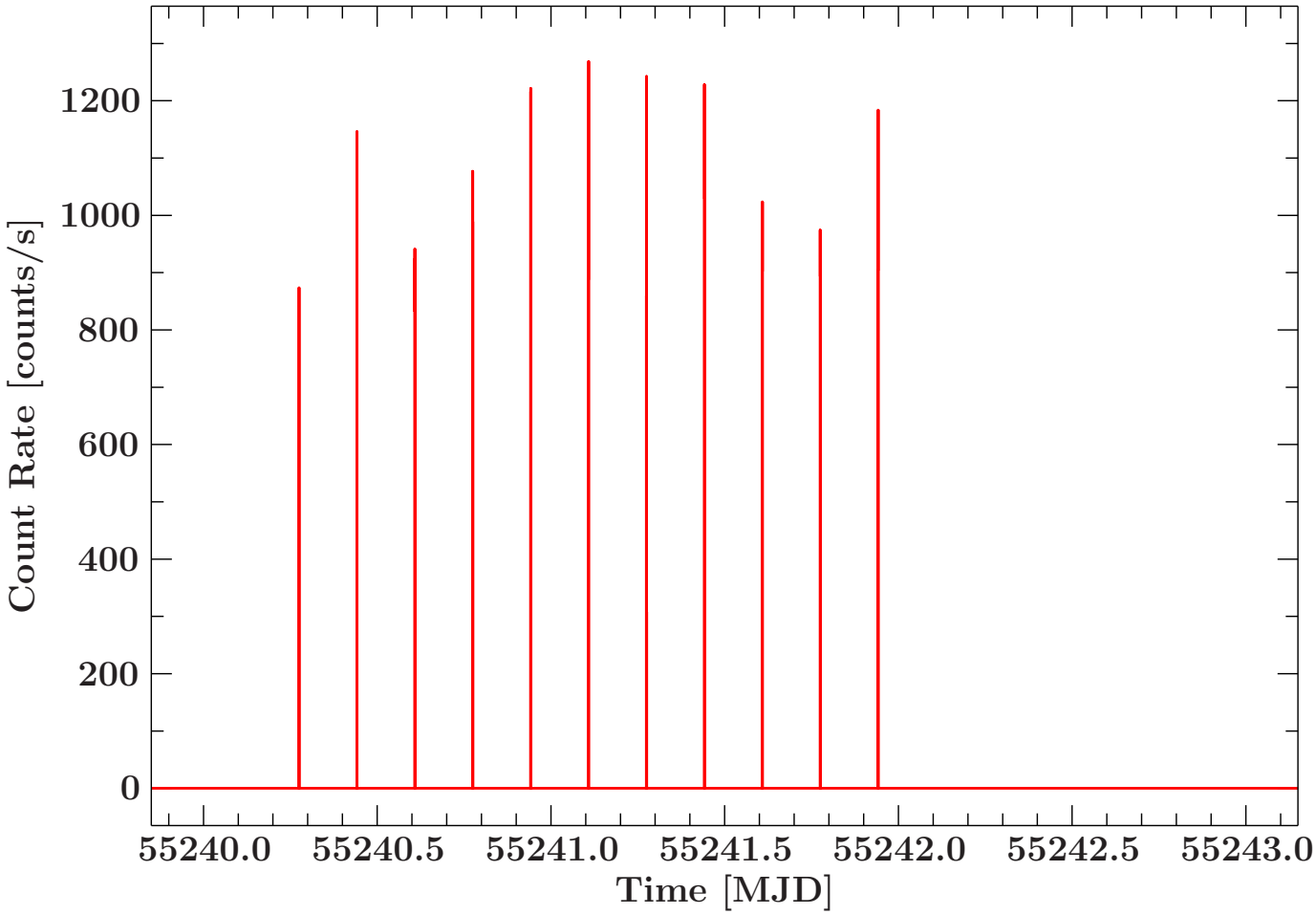
PSF effects





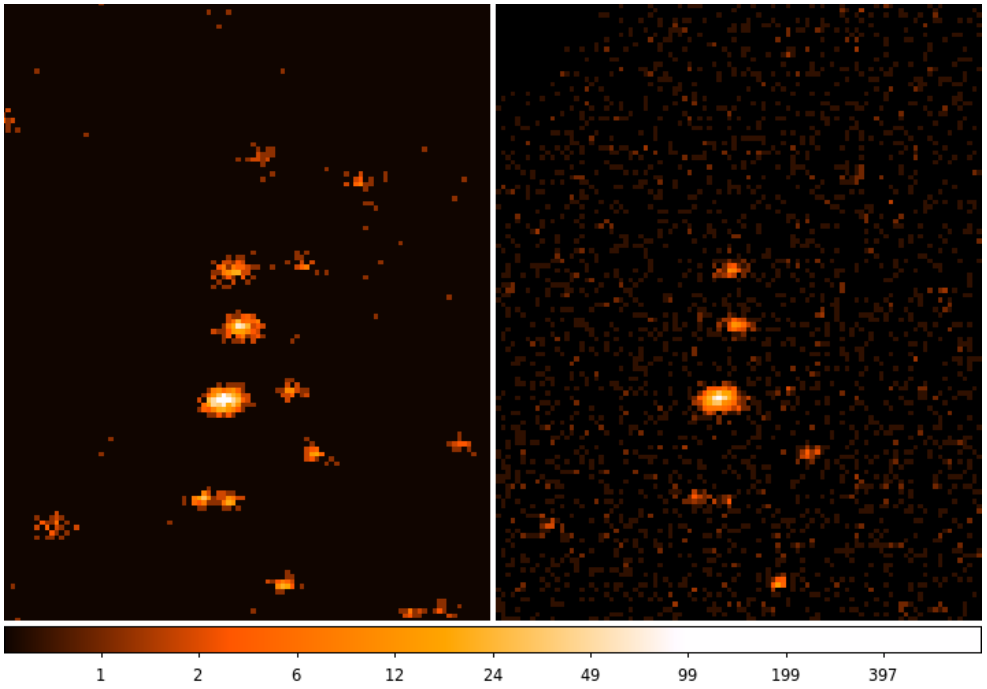
slew observation over the Crab and Vela X-1 (good evts only)

PSF effects



Daily light curve of Cyg X-1

Chandra, Suzaku, XMM,. . .



CDFS: Simulation Observation

Courtesy Hans Moritz Günther (MIT)

Chandra: As of MARX 5.3, MARX can work with SIMPUT files

`http://space.mit.edu/cxc/marx/`

MARX parameters: `SourceType=SIMPUT S-SIMPUT-Source=CDFS_cat_giacconi.fits S-SIMPUT-Library=/path/to/libsimput.so`

The simulator `simx` for Suzaku, XMM-Newton, Hitomi, Athena can also read and write SIMPUT

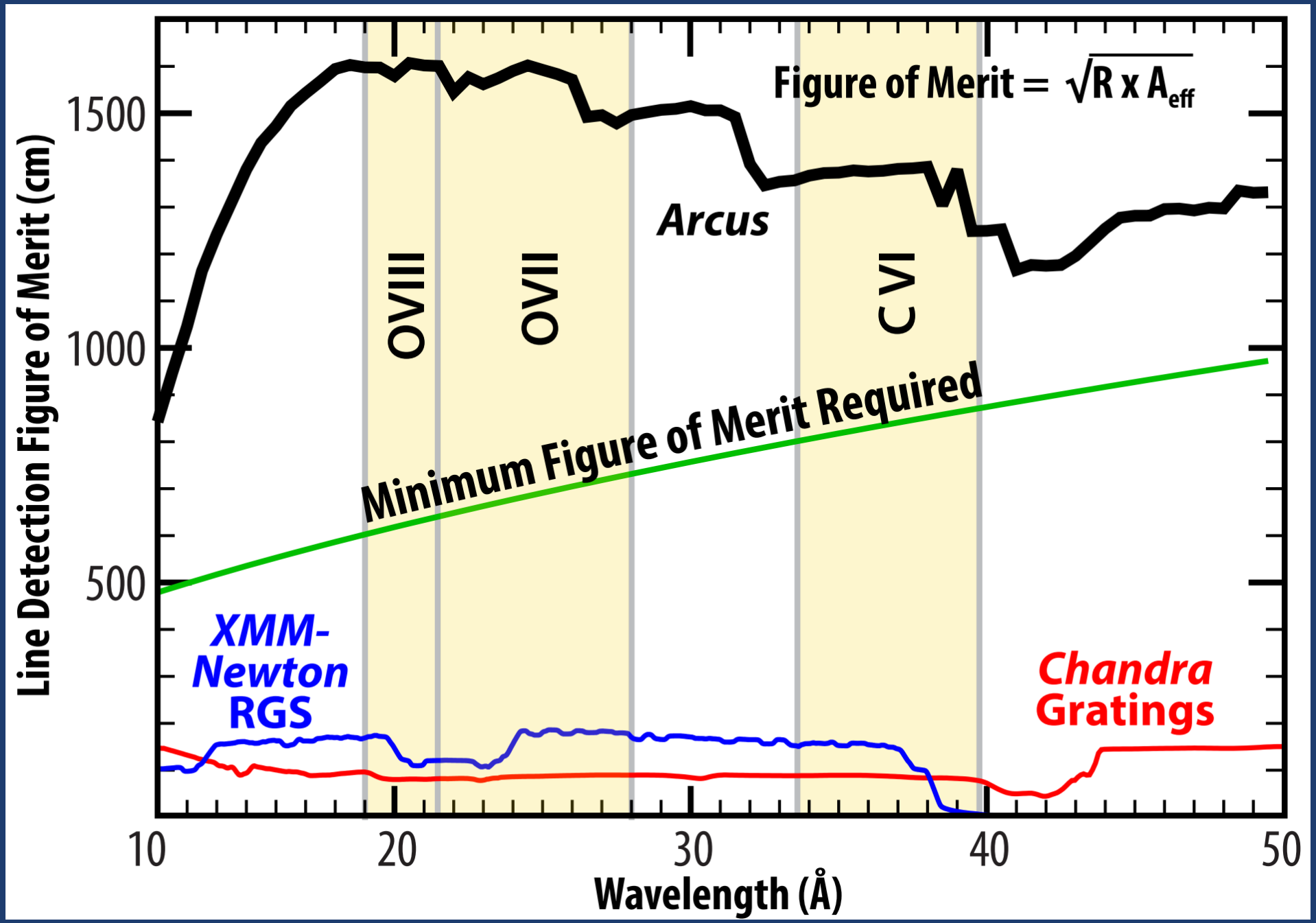
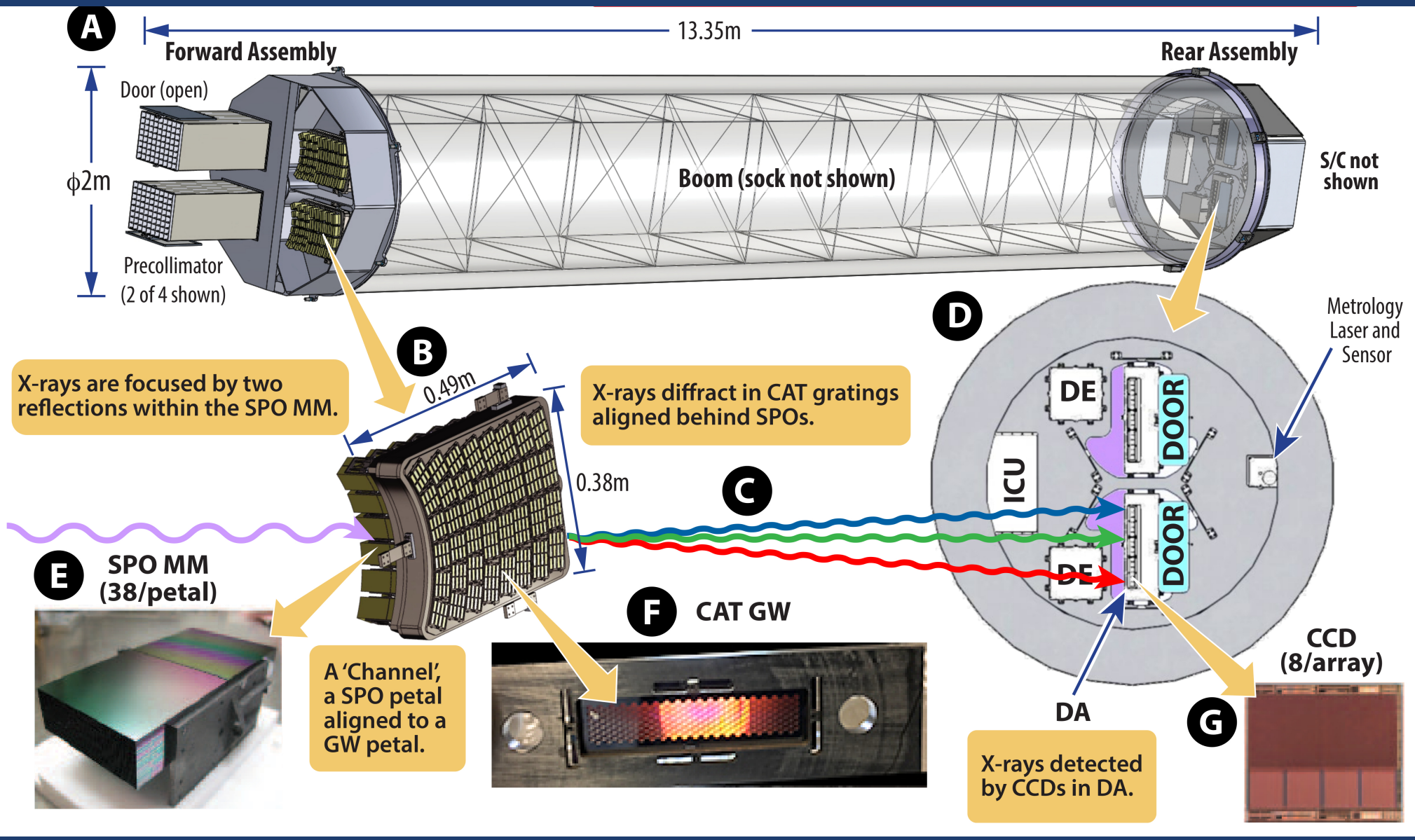
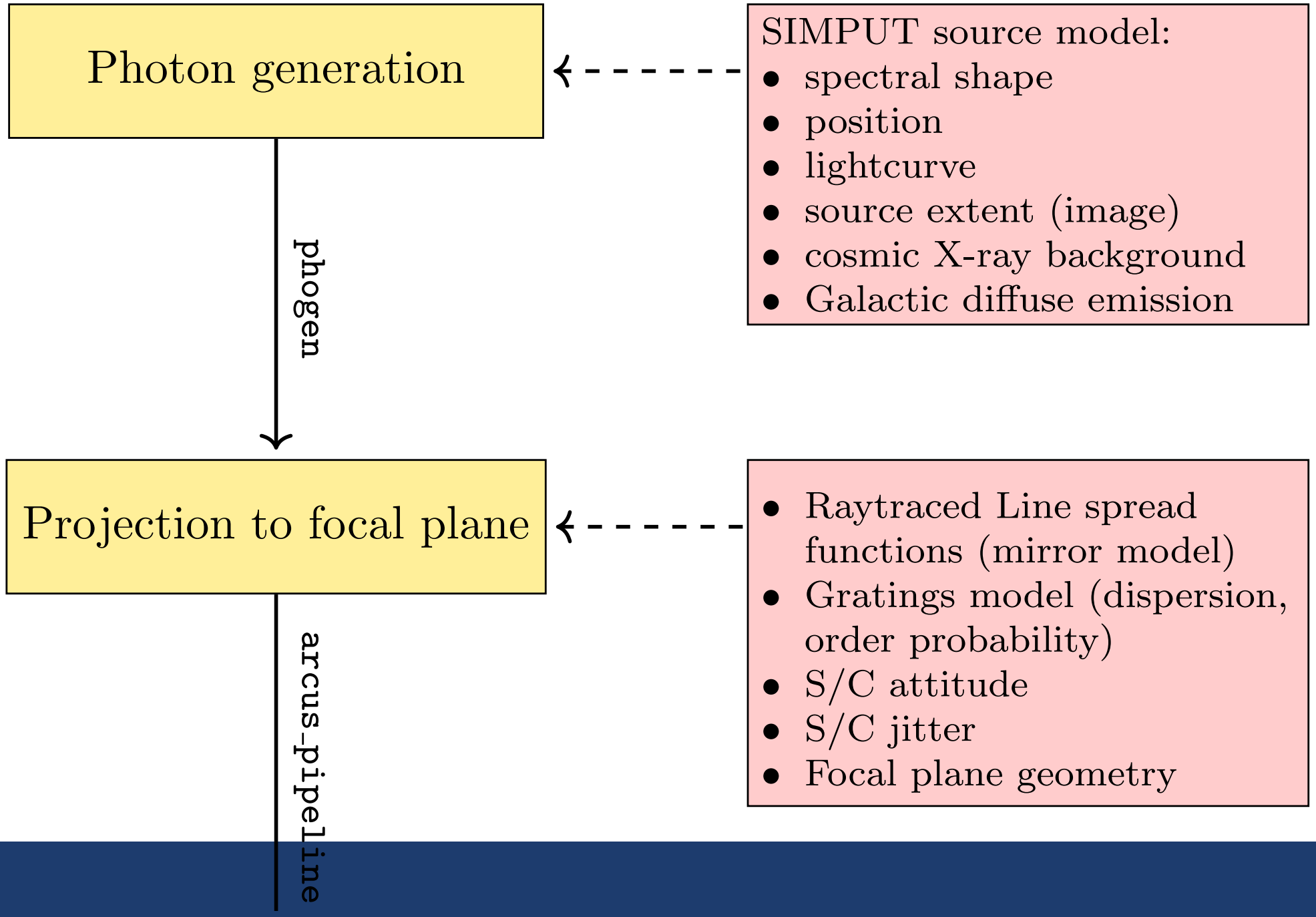


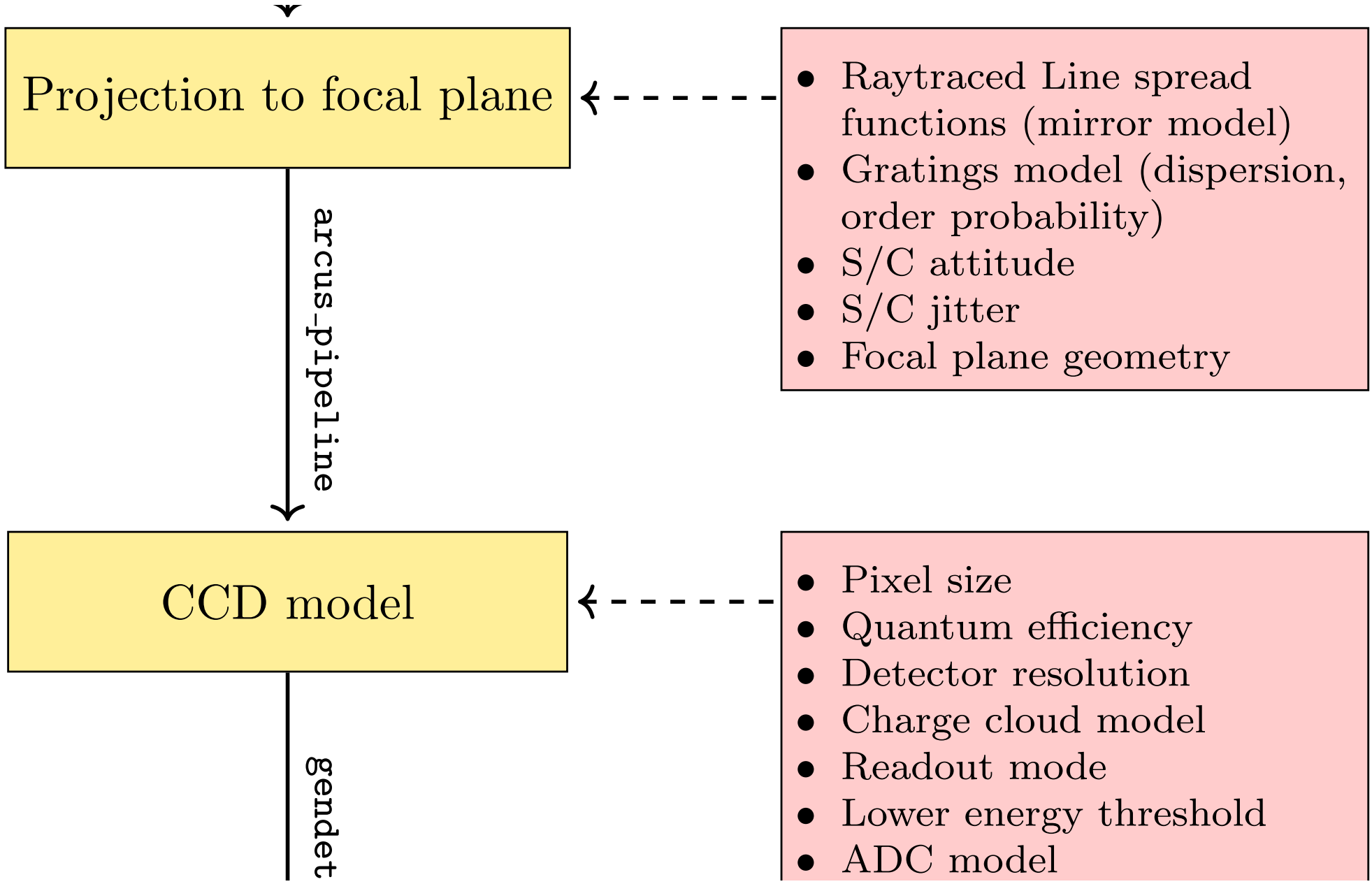
Figure of Merit = $\sqrt{R \times A_{eff}}$
Arcus
OVIII
OVII
C VI
Minimum Figure of Merit Required
XMM-Newton RGS
Chandra Gratings
Line Detection Figure of Merit (cm)
1500
1000
500
10
20
30
40
50
Wavelength (Å)

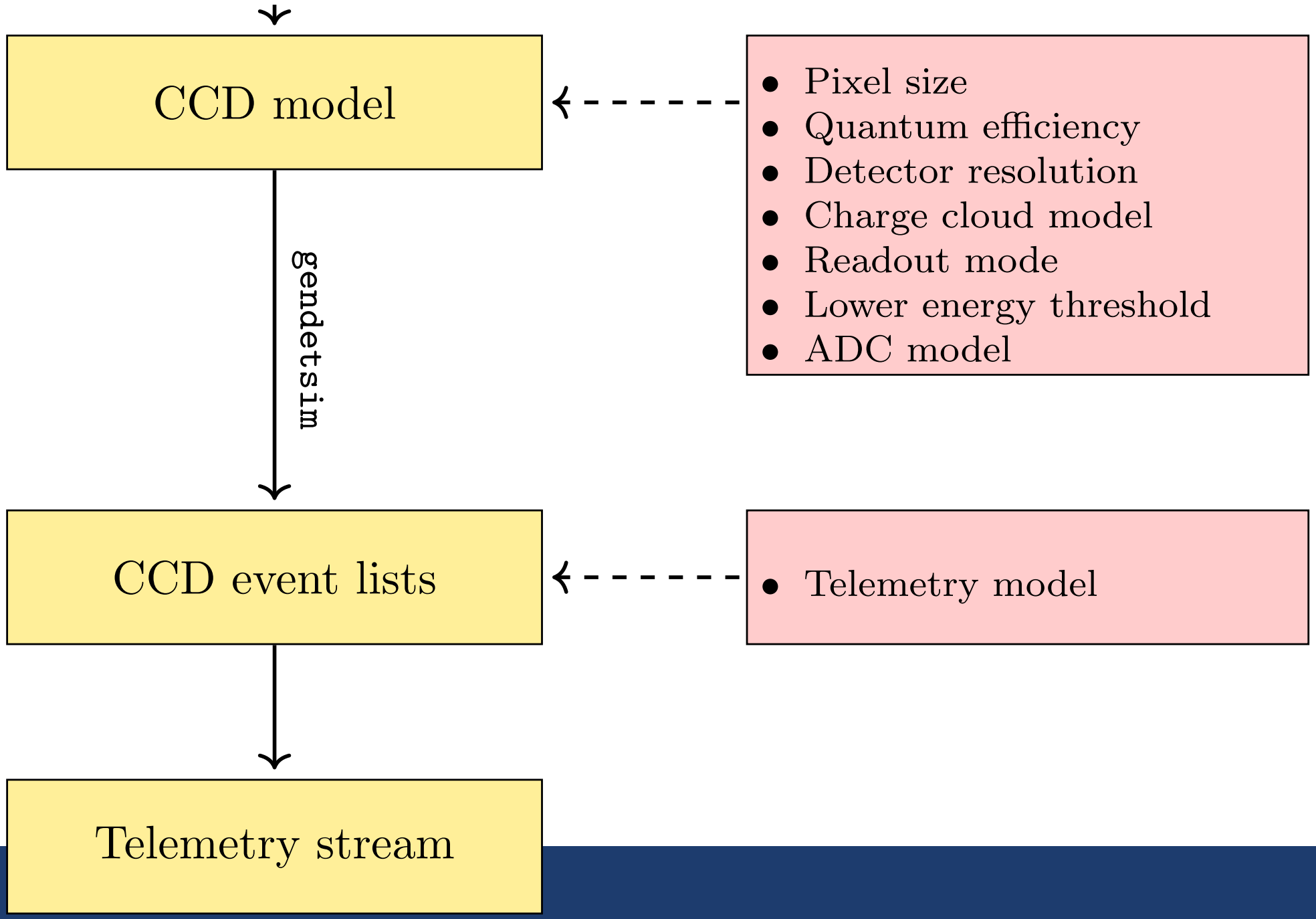

A
13.35m
Forward Assembly
Rear Assembly
Door (open)
ϕ2m
Precollimator
(2 of 4 shown)
Boom (sock not shown)
S/C not shown
B
0.49m
0.38m
X-rays are focused by two reflections within the SPO MM.
X-rays diffract in CAT gratings aligned behind SPOs.
C
D
Metrology Laser and Sensor
DE
DOOR
ICU
DOOR
DE
E
SPO MM (38/petal)
A 'Channel', a SPO petal aligned to a GW petal.
F
CAT GW
DA
X-rays detected by CCDs in DA.
G
CCD (8/array)

Arcus

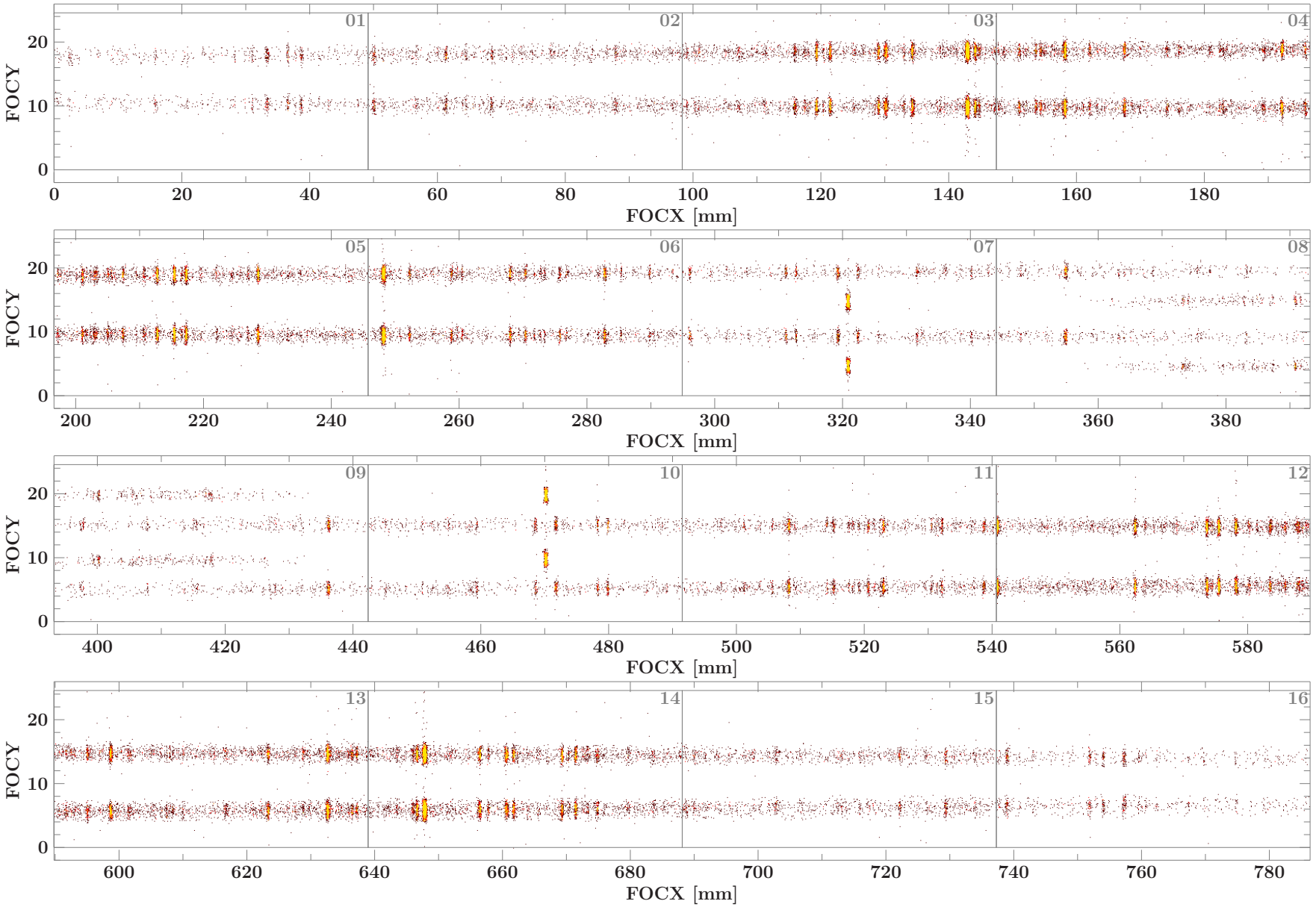

Photon generation
SIMPUT source model:
• spectral shape
• position
• lightcurve
• source extent (image)
• cosmic X-ray background
• Galactic diffuse emission
photon
Projection to focal plane
• Raytraced Line spread functions (mirror model)
• Gratings model (dispersion, order probability)
• S/C attitude
• S/C jitter
• Focal plane geometry
arcus-pipeline

Arcus

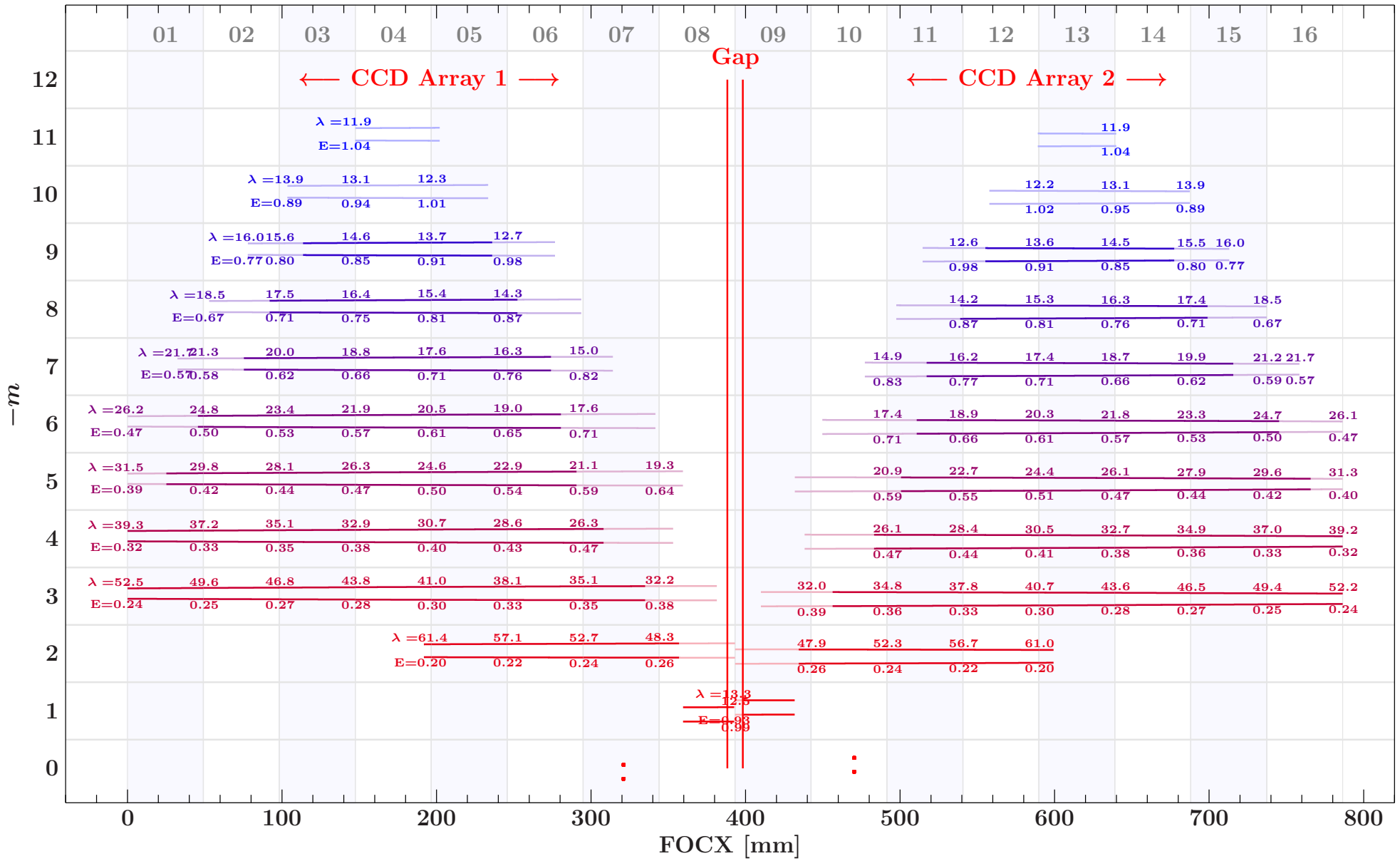

Projection to focal plane
arcus-pipeline
CCD model
gendet
• Raytraced Line spread functions (mirror model)
• Gratings model (dispersion, order probability)
• S/C attitude
• S/C jitter
• Focal plane geometry
• Pixel size
• Quantum efficiency
• Detector resolution
• Charge cloud model
• Readout mode
• Lower energy threshold
• ADC model


CCD model
Pixel size
Quantum efficiency
Detector resolution
Charge cloud model
Readout mode
Lower energy threshold
ADC model
gendetsim
CCD event lists
Telemetry model
Telemetry stream

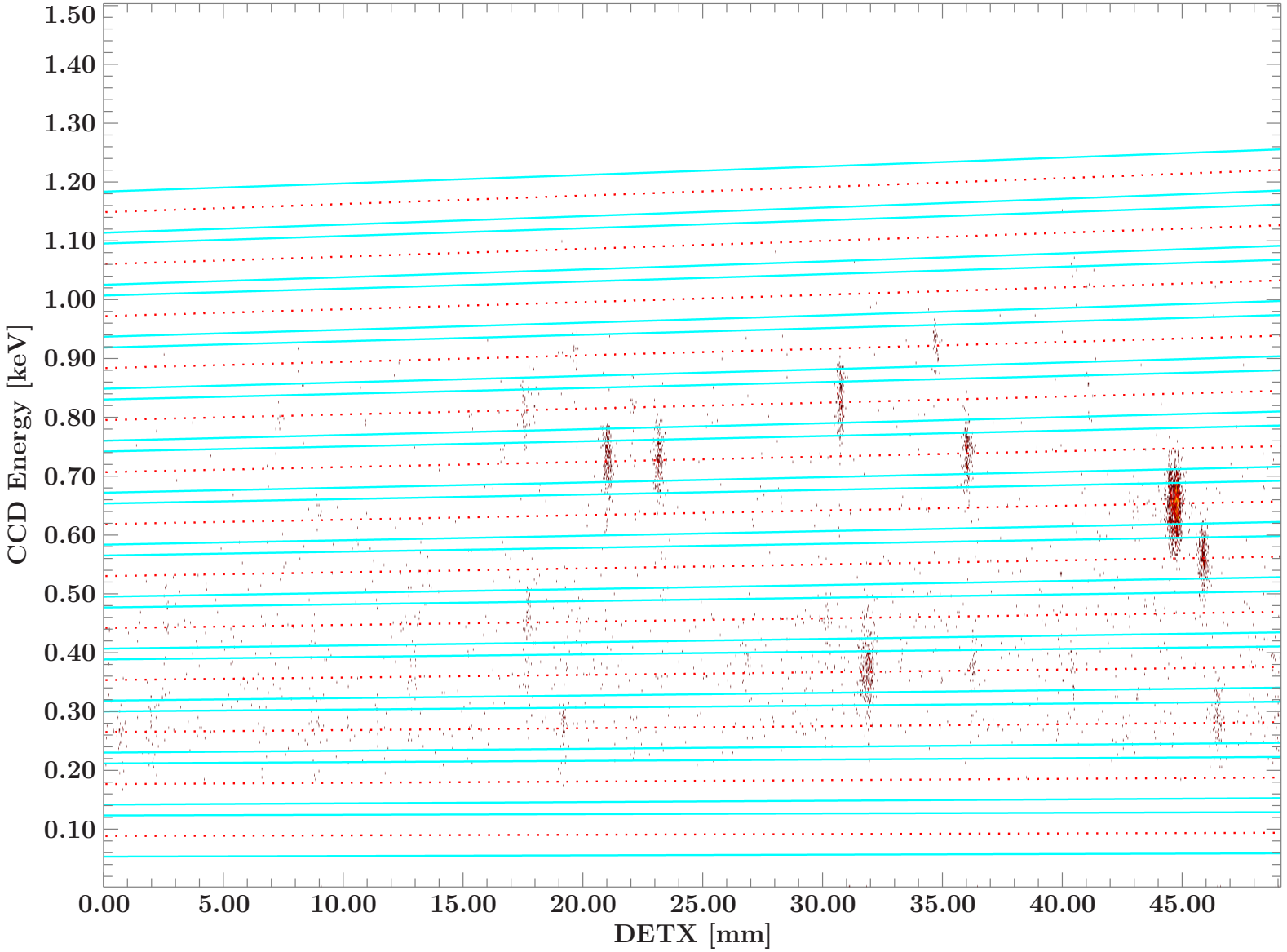
Arcus


01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
FOCY
FOCX [mm]
0
10
20
0 20 40 60 80 100 120 140 160 180
200 220 240 260 280 300 320 340 360 380
400 420 440 460 480 500 520 540 560 580
600 620 640 660 680 700 720 740 760 780

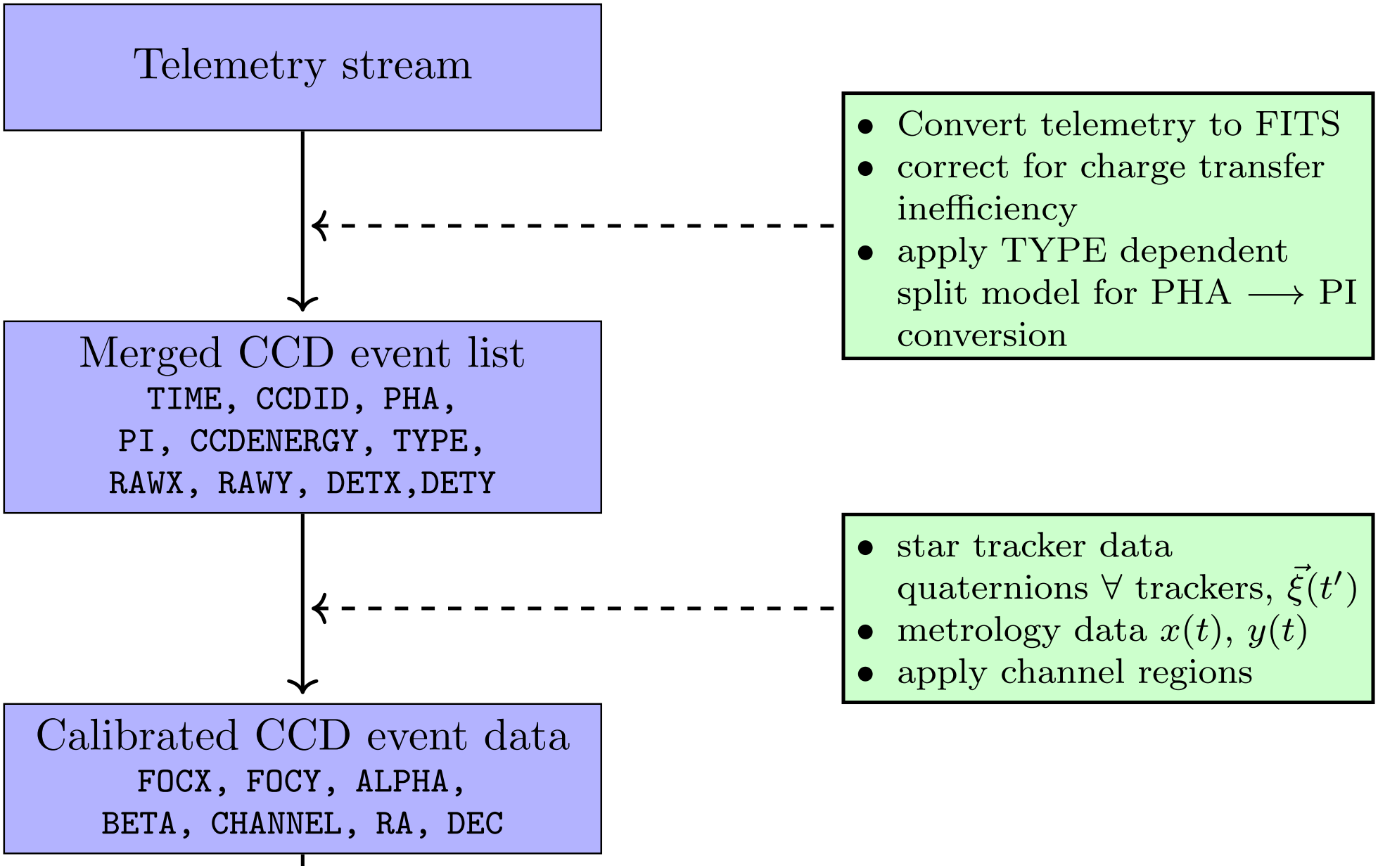
Arcus


01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16
Gap
⟵ CCD Array 1 ⟶
⟵ CCD Array 2 ⟶
−m
FOCX [mm]
0 100 200 300 400 500 600 700 800
0 1 2 3 4 5 6 7 8 9 10 11 12
λ =11.9
E=1.04
λ =13.9 13.1 12.3
E=0.89 0.94 1.01
λ =16.0 15.6 14.6 13.7 12.7
E=0.77 0.80 0.85 0.91 0.98
λ =18.5 17.5 16.4 15.4 14.3
E=0.67 0.71 0.75 0.81 0.87
λ =21.7 21.3 20.0 18.8 17.6 16.3 15.0
E=0.57 0.58 0.62 0.66 0.71 0.76 0.82
λ =26.2 24.8 23.4 21.9 20.5 19.0 17.6
E=0.47 0.50 0.53 0.57 0.61 0.65 0.71
λ =31.5 29.8 28.1 26.3 24.6 22.9 21.1 19.3
E=0.39 0.42 0.44 0.47 0.50 0.54 0.59 0.64
λ =39.3 37.2 35.1 32.9 30.7 28.6 26.3
E=0.32 0.33 0.35 0.38 0.40 0.43 0.47
λ =52.5 49.6 46.8 43.8 41.0 38.1 35.1 32.2
E=0.24 0.25 0.27 0.28 0.30 0.33 0.35 0.38
λ =61.4 57.1 52.7 48.3
E=0.20 0.22 0.24 0.26
11.9
1.04
12.2 13.1 13.9
1.02 0.95 0.89
12.6 13.6 14.5 15.5 16.0
0.98 0.91 0.85 0.80 0.77
14.2 15.3 16.3 17.4 18.5
0.87 0.81 0.76 0.71 0.67
14.9 16.2 17.4 18.7 19.9 21.2 21.7
0.83 0.77 0.71 0.66 0.62 0.59 0.57
17.4 18.9 20.3 21.8 23.3 24.7 26.1
0.71 0.66 0.61 0.57 0.53 0.50 0.47
20.9 22.7 24.4 26.1 27.9 29.6 31.3
0.59 0.55 0.51 0.47 0.44 0.42 0.40
26.1 28.4 30.5 32.7 34.9 37.0 39.2
0.47 0.44 0.41 0.38 0.36 0.33 0.32
32.0 34.8 37.8 40.7 43.6 46.5 49.4 52.2
0.39 0.36 0.33 0.30 0.28 0.27 0.25 0.24
47.9 52.3 56.7 61.0
0.26 0.24 0.22 0.20

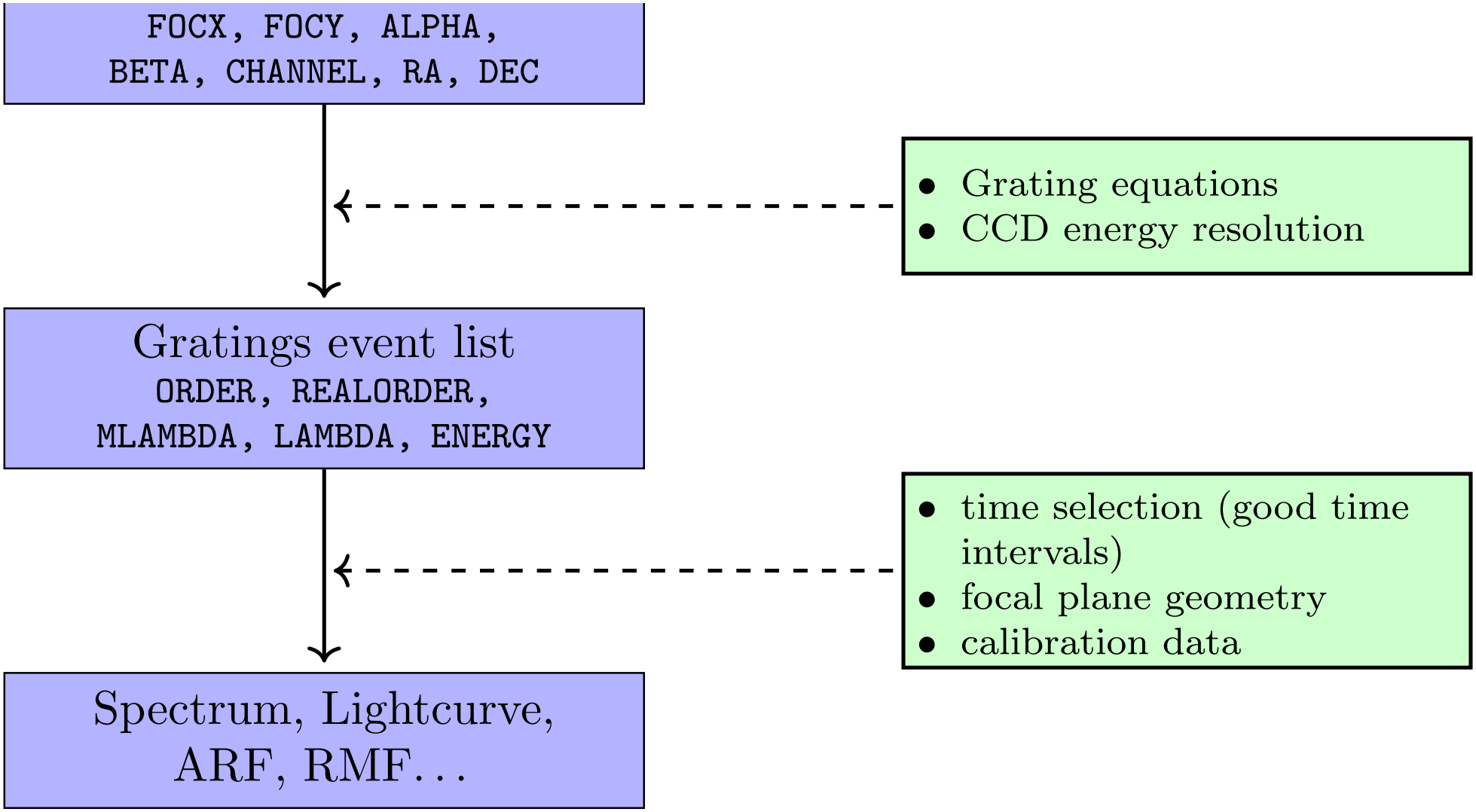
Arcus


CCD Energy [keV]
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
DETX [mm]

Arcus


Telemetry stream
Merged CCD event list
TIME, CCDID, PHA,
PI, CCDENERGY, TYPE,
RAWX, RAWY, DETX,DETY
Calibrated CCD event data
FOCX, FOCY, ALPHA,
BETA, CHANNEL, RA, DEC
• Convert telemetry to FITS
• correct for charge transfer inefficiency
• apply TYPE dependent split model for PHA ⟶ PI conversion
• star tracker data quaternions ∀ trackers, $\vec{\xi}(t')$
• metrology data $x(t)$, $y(t)$
• apply channel regions

Arcus


FOCX, FOCY, ALPHA,
BETA, CHANNEL, RA, DEC
Grating equations
CCD energy resolution
Gratings event list
ORDER, REALORDER,
MLAMBDA, LAMBDA, ENERGY
time selection (good time intervals)
focal plane geometry
calibration data
Spectrum, Lightcurve,
ARF, RMF...