MPI Project Review

BepiColombo-a planetary mission to Mercury

Focal plane instrumentation for the MIXS instrument

Ringberg, 24.4.2007

Mercury as seen on 16.9.2004

Institutions

esa

BepiColombo

University of Leicester

UNIVERSITY OF HELSINKI

MPI
Halbleiterlabor

MPS

MPE

PNSensor

Contents

- History of Mercury observation
- The Planet Mercury
- BepiColombo
- The MIXS Instrument
- The FPA detector for MIXS

History of mercury observation

Ziggurat of Ur

~ 3000 B.C: First known evidence of Mercury observations by sumerian priests in mesopotamia.
Planet known as ***Ubu-idim-gud-ud***

Babylonian record
of Venus observation

~ 1000 B.C: Detailed recordings of Mercury observations by babylonian astronomers
Planet known as ***Nabu*** or ***Nebu***, referring to the babylonian messenger of gods, due to its swift movement and partial visibility.

History of Mercury observation

~ 500 B.C: Greek astronomers give Mercury two names, ***Stilbon*** and ***Hermaon***, depending whether it is visible in the morning or evening. **Pythagoras of Samos** proposes that the two observations refer to a common body, which is then called Hermes, after the greek messenger of gods, which is later identified with the roman god Mercury.

Statue of Mercury by Giambologna (16th century, Florence)

In roman/greek mythology, Mercury is not only the messenger of gods and the god of travellers, but also the god of merchants, of crooks, liars and highwaymen.

History of Mercury observation

Always displayed with the winged herlad's staff wound by two snakes (caducaeus), winged sandals (talaria) and winged traveller's hat (petasos), which inspired the astronomical symbol for Mercury: ☿

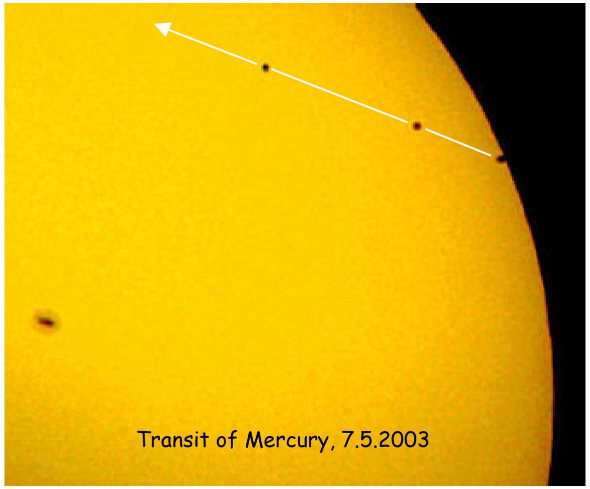
Rarely displayed alone, but either participating on assemblies of gods (mostly just arriving or leaving) or while delivering a message to a recipient. Is also said to explain the somewhat obscure messages of the gods to the mortals.

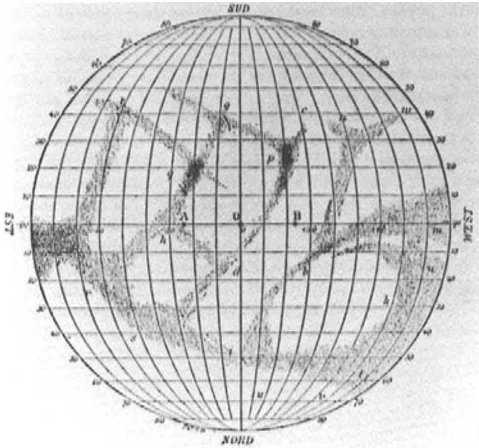
Engl.:	***French:***
Merchant	*Merci*
Commerce	*Mercredi*
Mercury (Hg)	
Mercenary	
Wednesday	

Mercury in the staircase fresco by Gianbattista Tiepolo at the Wuerzburg residence (18th century).

History of mercury observation

~ 1610:	First **telescopic observations** of Mercury by Galileo Galilei
1631:	The **Mercury transit** predicted by Johannes Kepler is observed by Pierre Gassendi, which is the first known observation of a planetary transit.
1639:	Giovanni Zulpi discovers **Mercury's phases** by telescopic observation, which proves that mercury orbits around the sun.
1737:	John Bevis records the first historically observed **Mercury occultation** by Venus (28.5.1737) Next: 2133.
1800:	First observation of **surface features** by Johann Schroeter.
1881:	First **surface map** of mercury by Giovanni Schiaparelli.


Transit of Mercury, 7.5.2003



History of Mercury observation

~ 1930: Mercury’s orbit irregularities are explained by GRT!

~ 1960: Discovery of anomalous tidal locking of orbital period to rotational period by radio observations

1965: Precise measurement of the planet’s orbital period. **Guiseppe** (Bepi) **Colombo** suggests an anomalous resonant tidal locking with a 3:2 ratio, i.e. Mercury rotates three times for every two revolutions round the sun.

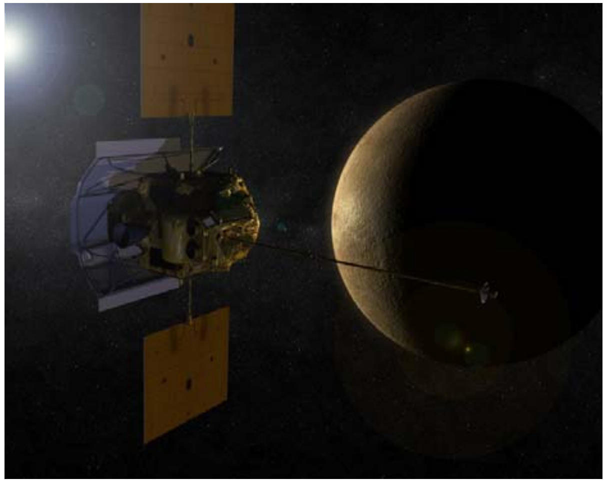
1974: Until 1975, **Mariner 10** passes Mercury 3 times. Flight plan suggested by Bepi Colombo included Venus-Swing-Bys. Unexpectedly, the revolution period of Mariner 10 in this orbit was exactly twice the revolution period of Mercury, so that only ~45 % of mercury could be cartographed.

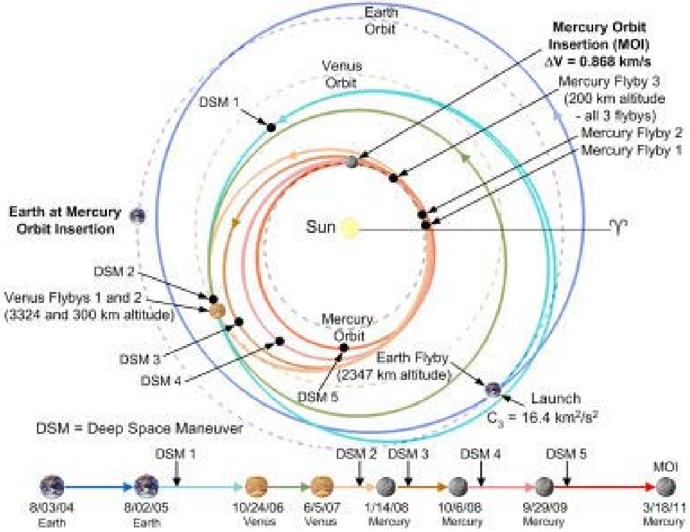
Mariner 10

2000: **Lucky imaging** observations at Mount Wilson reveal details of the uncartographed region. Observation with x-ray satellites.

Future of Mercury observation

2004: Launch of the MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) probe by NASA.

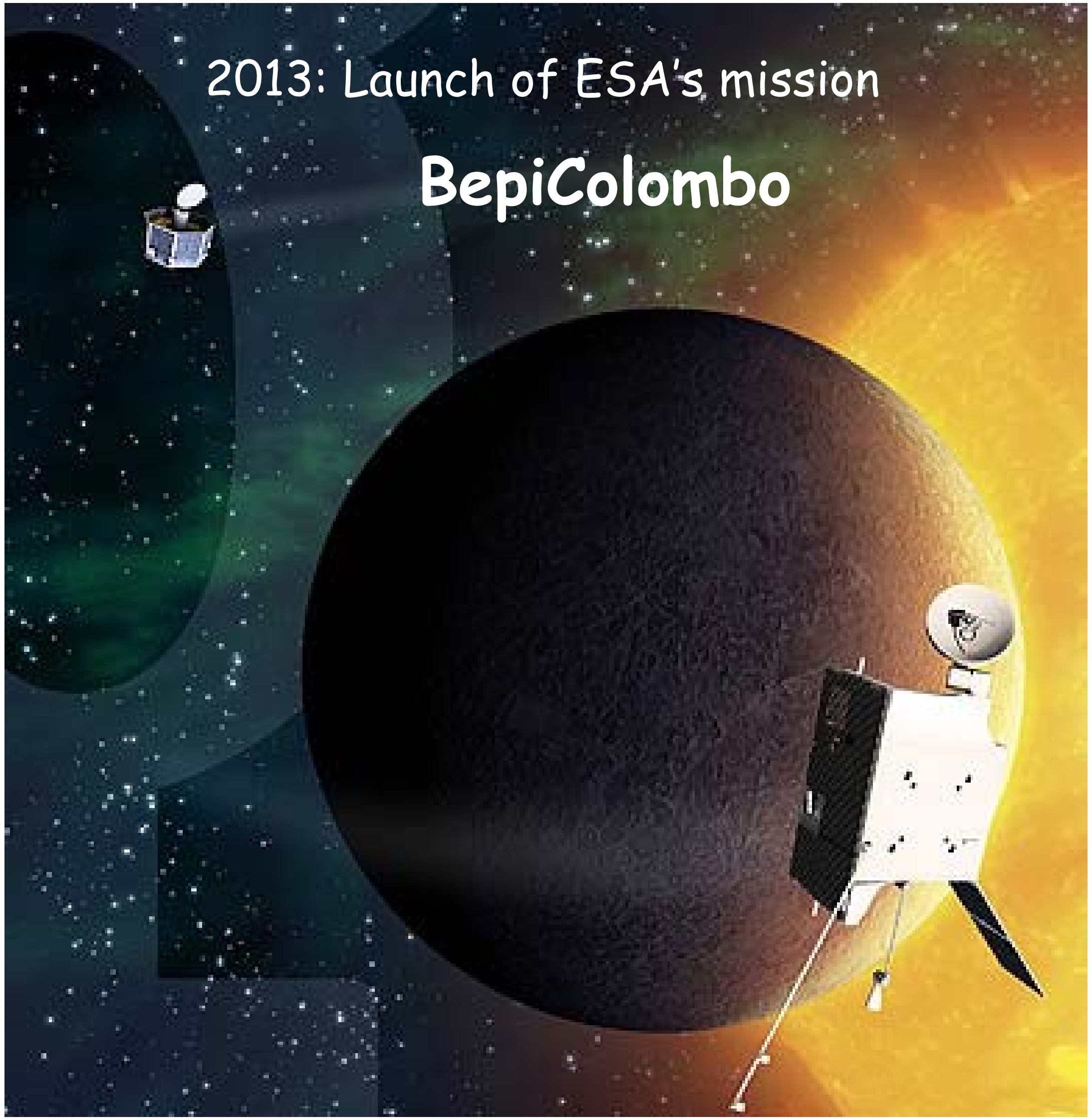




January **2008**:	First Mercury flyby
October **2008**:	Second Mercury flyby
September **2009**:	Third Mercury flyby
March **2011**:	Entering Mercury orbit

1 year of mission lifetime
Payload similar to BC, but simpler
Pathfinder for BC

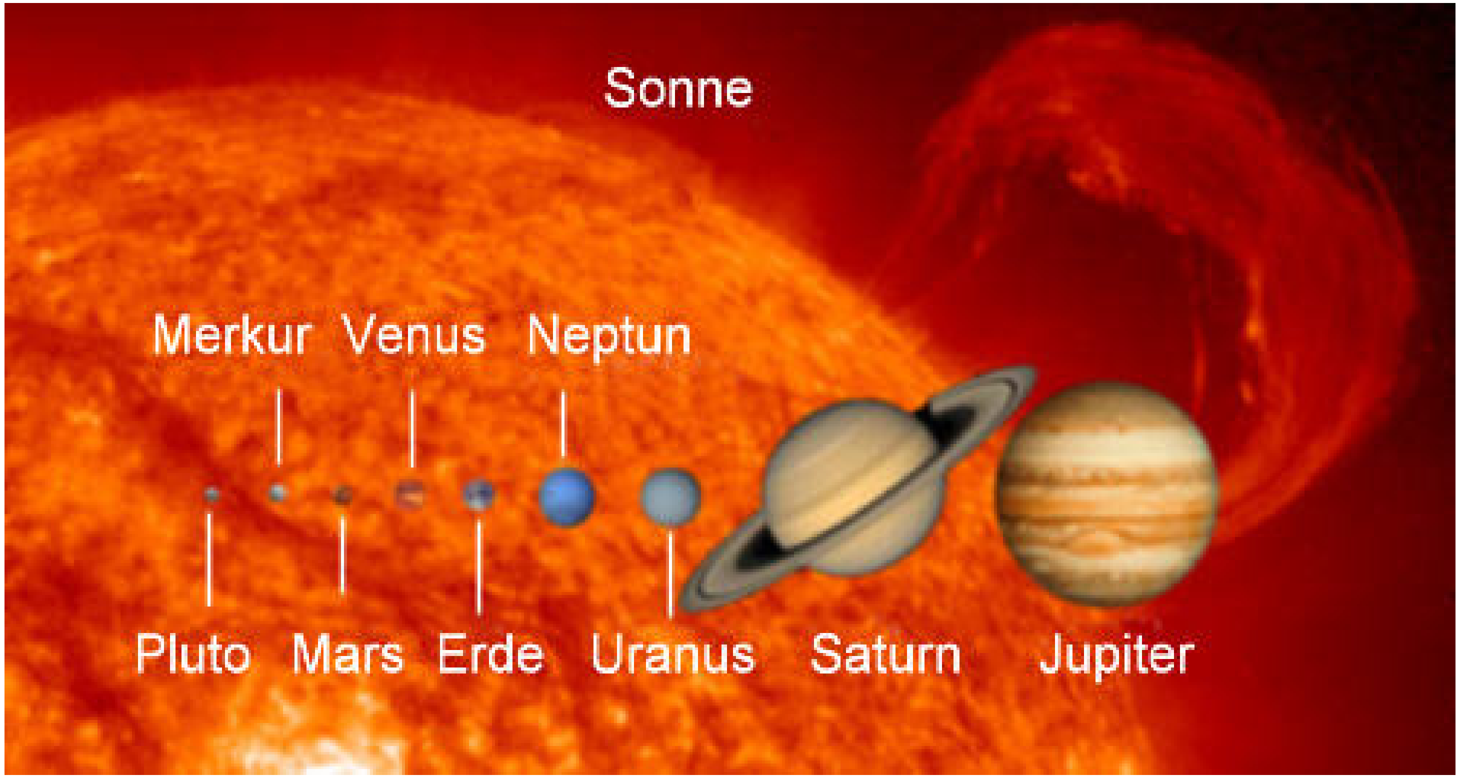
Future of Mercury observation



2013: Launch of ESA's mission

BepiColombo

The planet Mercury



Radii to scale

Mercury fact sheet

Orbital radius:	0.46 – 0.3 AU (70 – 46 x10^6 km)
Radius:	~2440 km (34% of earth)
Mass:	3.302×10^{23} kg
Density:	5.43 g / cm^3
Surface gravity:	3.7 m / s^2
Rotation period:	~58 d
Orbital period:	~85 d
Axial tilt:	0.01°
Incination:	~ 7 °
Albedo:	0.1
Atmosphere:	Traces (H, He, O, K, Na, Ca)

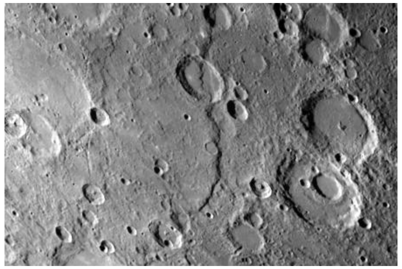
Surface temperatures:

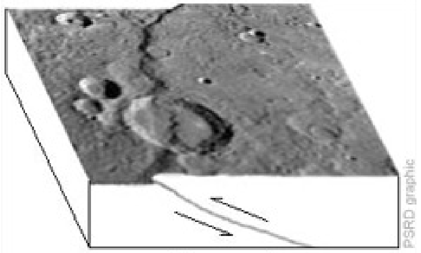
	Equator	North pole
Mean:	70 °C	-70 °C
Min:	-170 °C	-190 °C
Max:	430 °C	107 °C

Least well-known of the terrestrial planets

- Very small magnetic field (1% of earth)
- No moons
- Ice? Sulphur?

Mercury surface

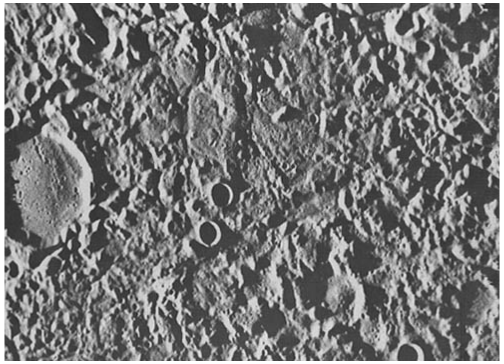




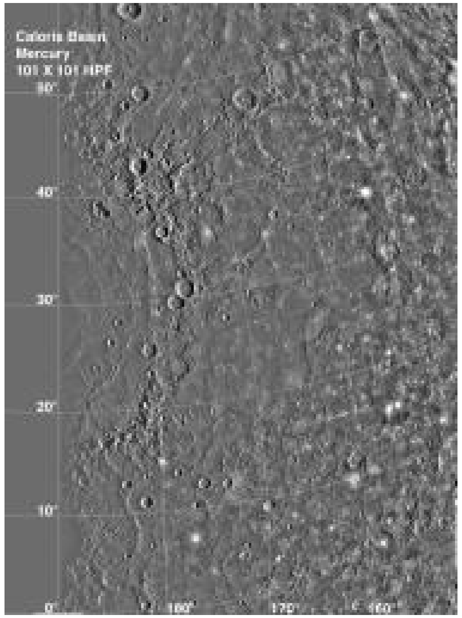
Discovery Rupes
schematic

- Moon-like surface, heavily cratered
- Basins (volcanism)
- Geologically inactive for a long time
- Weird morphologhic features

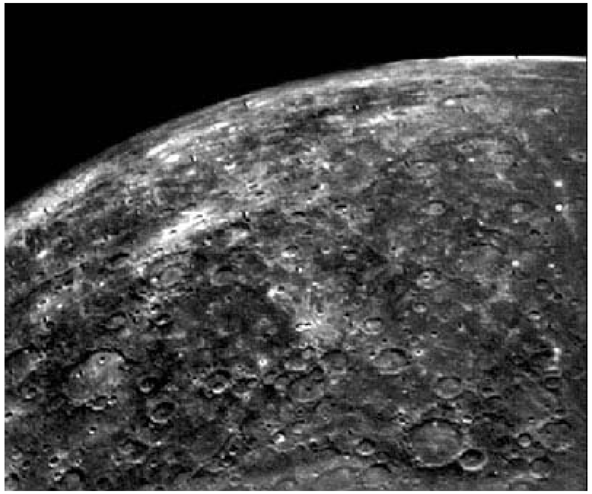
Rupes

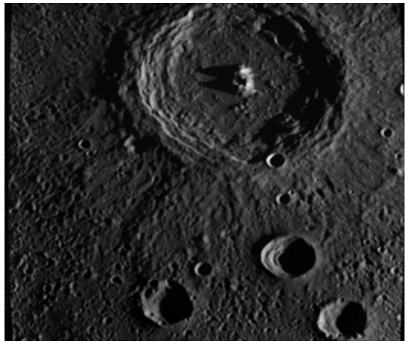


Weird terrain



Caloris basin



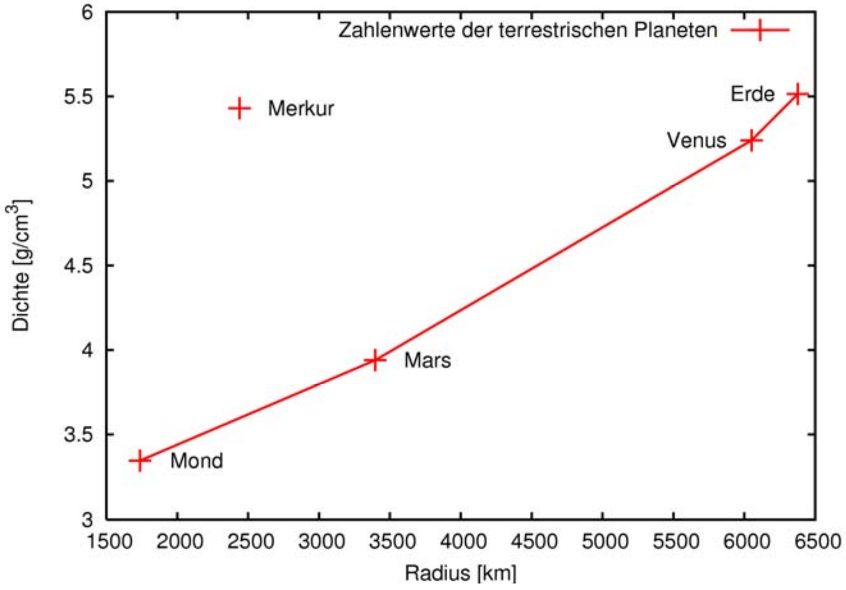


Mercury mass

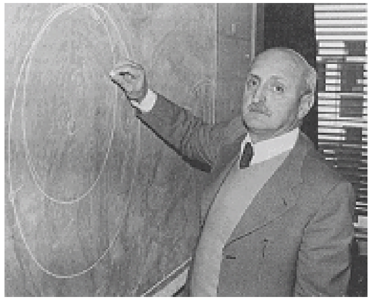
Anomal density!

- Terrestrial planet bulk composition derives from equilibrium condensation from the solar nebula.
- Not for Mercury – unpredicted large uncompressed density
- Large core – thin mantle – high Fe content, observations imply low Fe.
- Possibilities
  1. Selective accretion
  2. Post Accretion Vaporisation
  3. Massive Impact

Inhomogeneous mass distribution (spin-orbit resonance)!



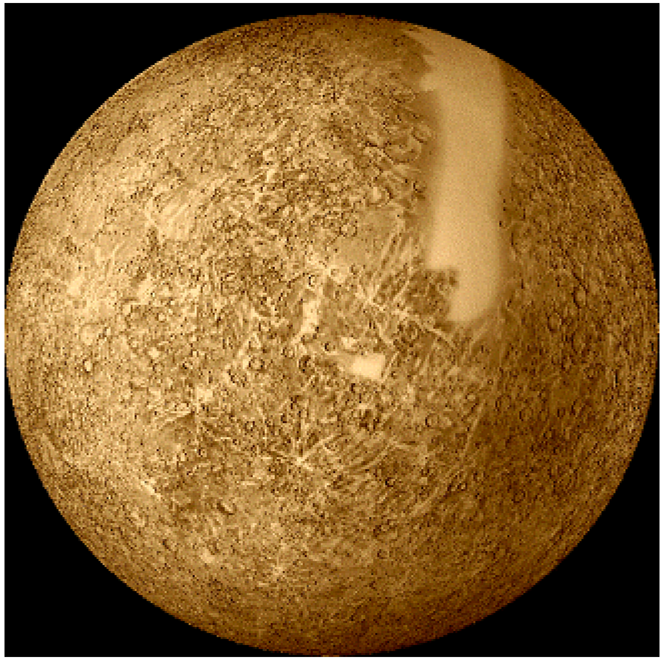
Mission targets



Giuseppe "Bepi" Colombo
(2.10.1920 – 20.2.1984)

ESA cornerstone mission:

- Origin and evolution of a planet close to the parent star
- Mercury as a planet: form, interior, structure, geology, composition and craters
- Detect traces of Mercury's vestigial atmosphere (exosphere): composition and dynamics
- Mercury's magnetized envelope (magnetosphere): structure and dynamics
- Origin of Mercury's magnetic field
- Test of Einstein's theory of general relativity



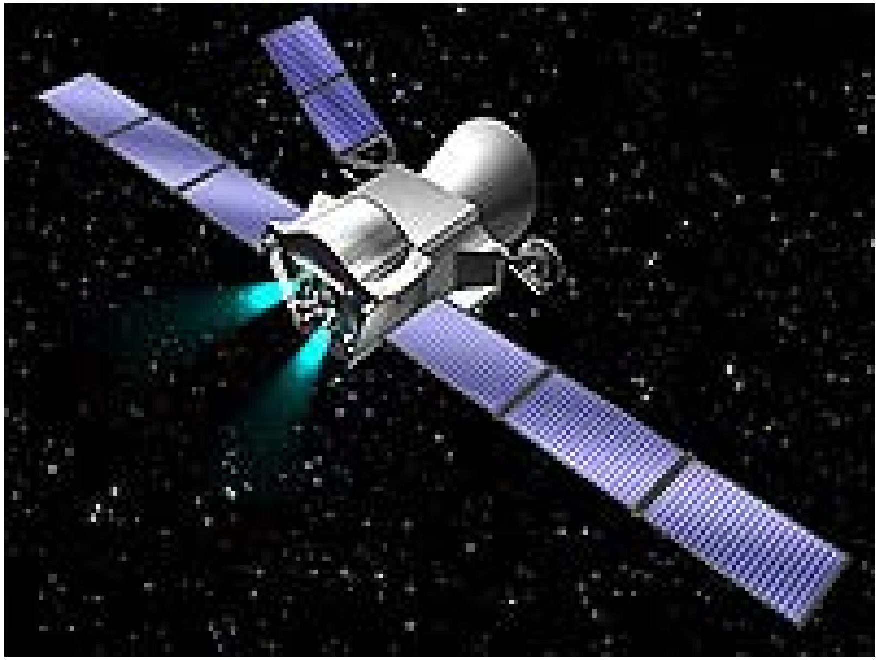
Mercury surface as seem by Mariner 10

...collaboration with JAXA

BepiColombo

- Launch 2013
- Platform: Soyuz Fregat B
- MCS: Mercury composite spacecraft
- 6 year long journey

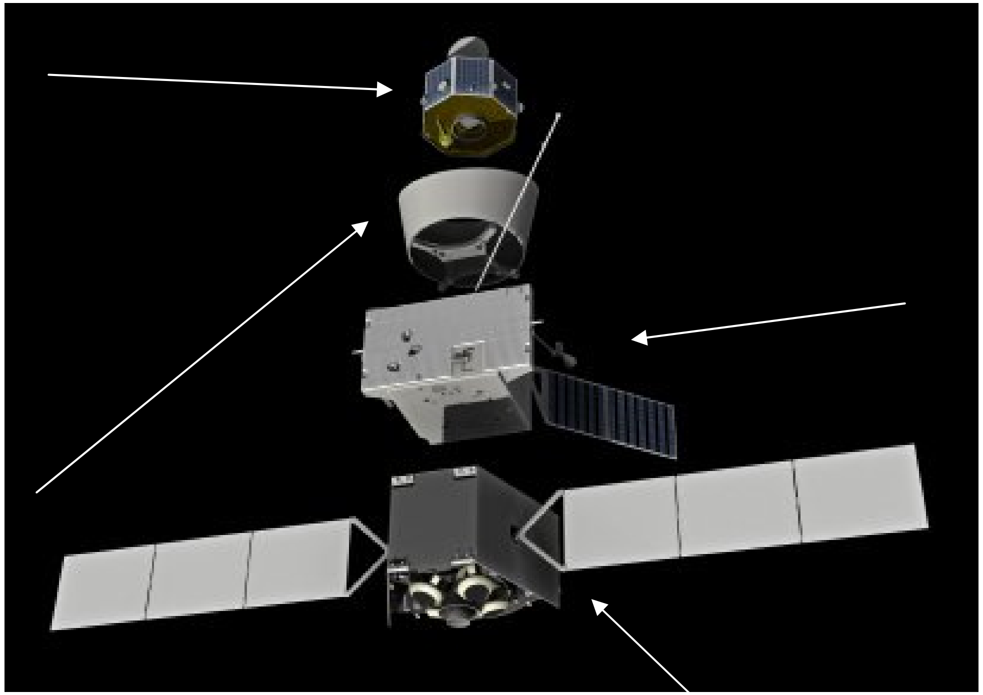
- **Main challenges:**
  - Thermal management
  - Power (!)
  - Radiation damage
  - Flight plan



Mercury composite spacecraft (MCS)

BepiColombo

MCS exploded view



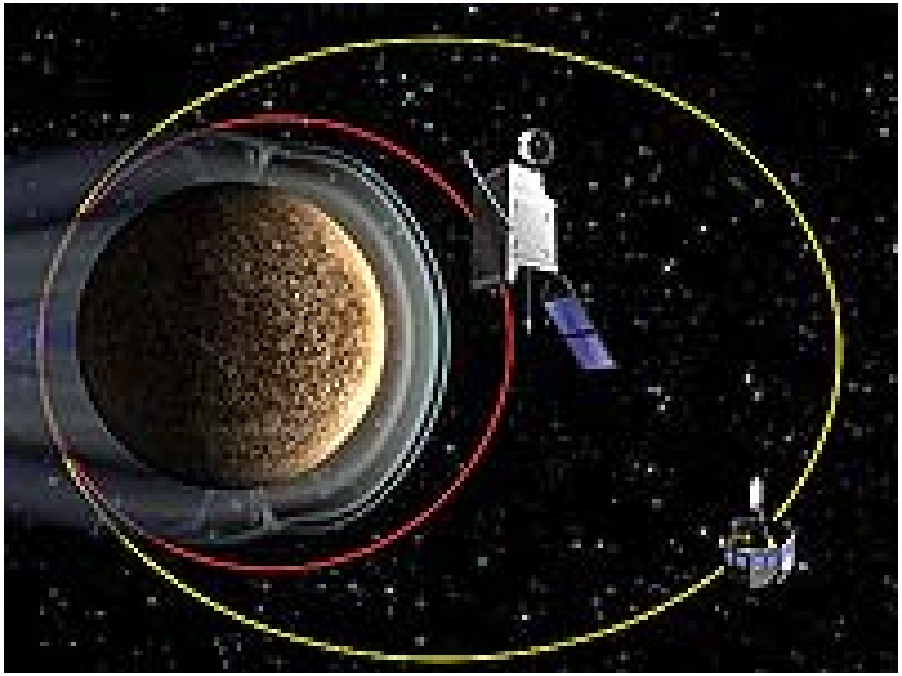
Mercury magnetospheric orbiter (MMO)

Mercury planetary orbiter (MPO)

Solar shield

Mercury transfer module (MTM)

BepiColombo

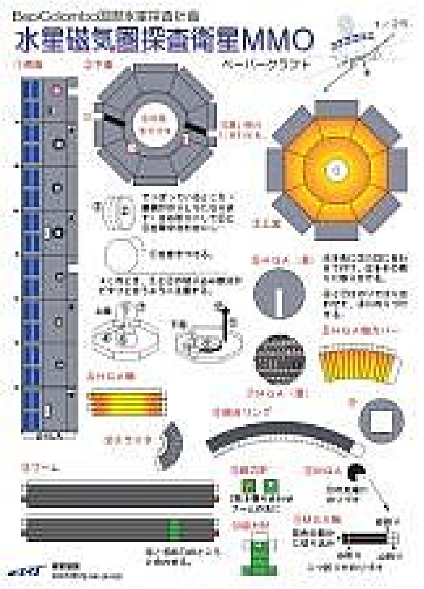


- Scheduled arrival: 2019
- On arrival: Deployment of MPO and MMO in their respective orbits
- 1 year of expected mission lifetime
- Possible prolongation by another year

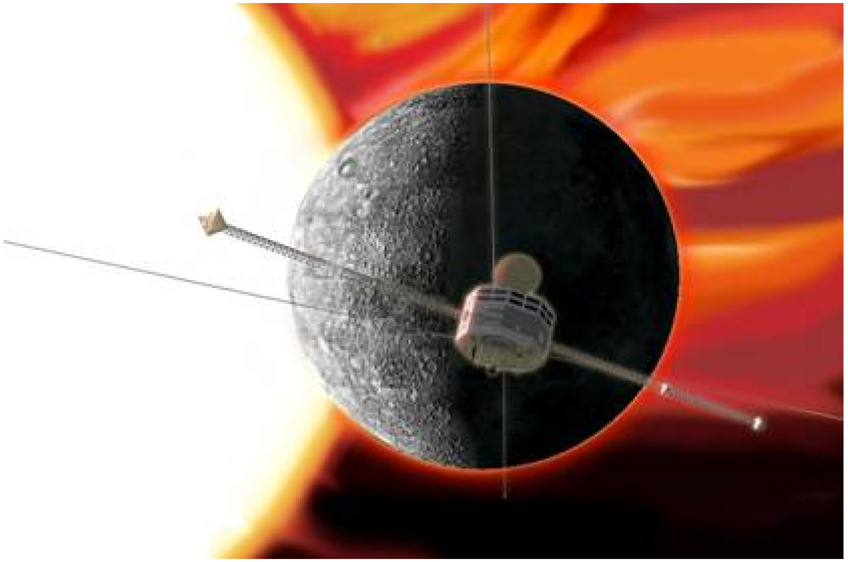
Mercury magnetospheric orbiter

Instruments:

MERMAG-M:	Magnetometer
MPPE:	Mercury plasma particle experiment
PWI:	Plasma wave experiment
MSASI:	Mercury Sodium Atmospheric Spectral Imager
MDM:	Mercury dust monitor



zum Selberbasteln...



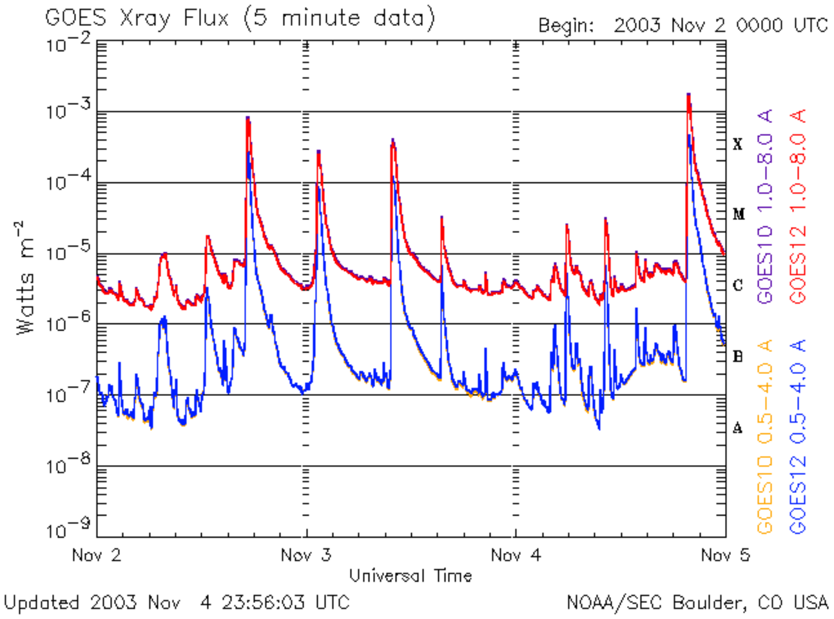
Mercury planetary orbiter

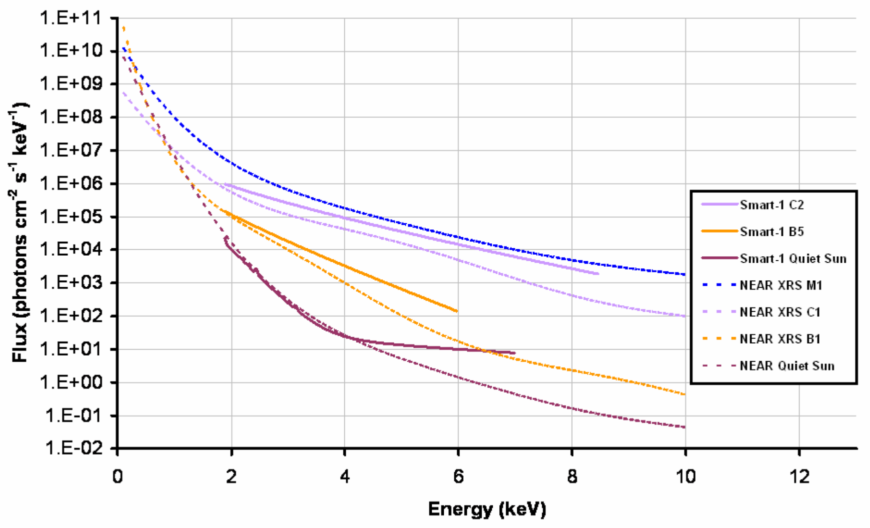
Instruments:

BELA:	Laser altimeter
ISA	Accelerometer
MERMAG:	Magnetometer
MERTIS:	Thermal infrared spectrometer
MGNS:	Gamma-ray and neutron spectrometer
MIXS:	x-ray spectrometer
MORE:	Radio science Ka-Band transponder
PHEBUS:	UV-Spectrometer
SERENA:	Neutral and Ionized particle analyzer
SIMBIO:	High resolution and stereo camera, visible and NIR spectrometer
SIXS:	Solar monitor

The MIXS Instrument

- Incident solar X-rays induce X-ray fluorescence from the surface
- Potentially an additional component induced by incident protons and electrons
- Precise intensity monitor needed!





The MIXS Instrument

- MIXS : **M**ercury **I**maging **X**-ray **S**pectrometer
- Measure fluorescent X-rays from Mercury surface
- First few micron of depth are explored
- Solar Intensity X-ray Spectrometer (SIXS) provides reference information
- Detection of characteristic lines allows to determine element abundance

- Combination with IR measurements (MERTIS) yields mineralogy information
- Combination with soft γ-ray measurements (MGNS) yields element abundance in depth of ~1 m

- Average composition of Mercury's crust
- Compositions of the major terrains
- Composition inside craters and crater structures
- Detection of iron globally and locally

- Correlation of surface Na, K and Ca with complementary measurements of exosphere
- probe of the surface-magnetosphere-exosphere system
- Sulphur at the poles and in the crust globally
- Chromium to Nickel ratio globally to constrain formation models

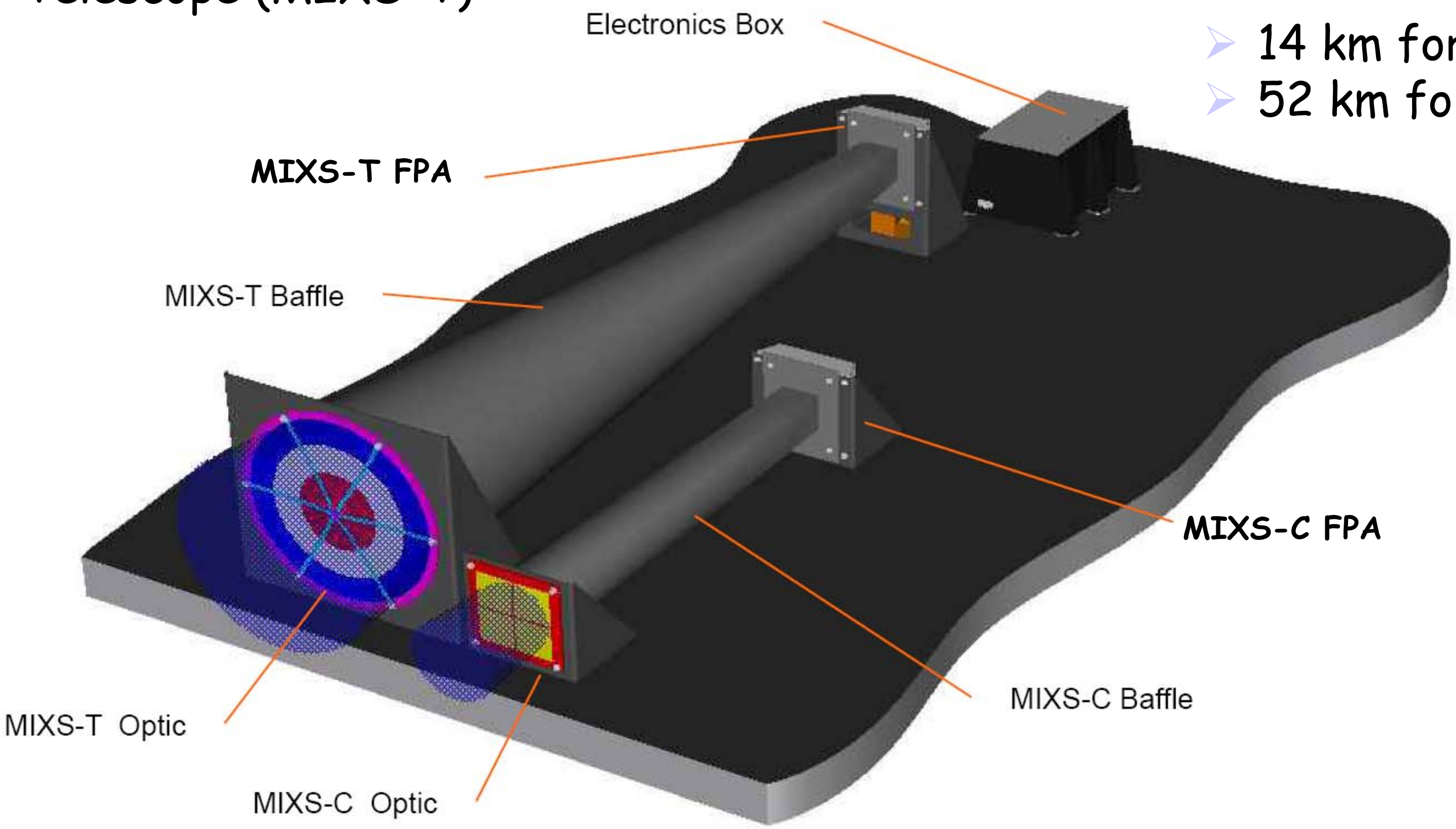
MIXS

- Two cameras
- Same focal plane detector
- Different optics
- Collimator (MIXS-C) and Telescope (MIXS-T)

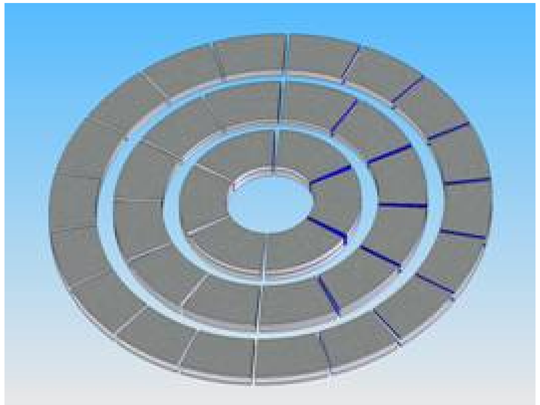
- Telescope: MPC optics
- MIXS-C: Wide field imaging
- MIXS-T: Precise Mapping

Footprint size:

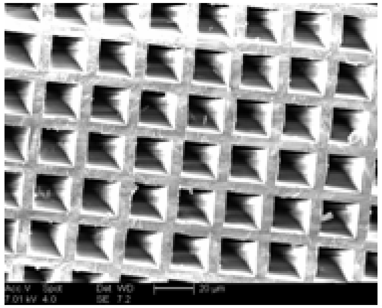
- 14 km for periherm
- 52 km for apoherm



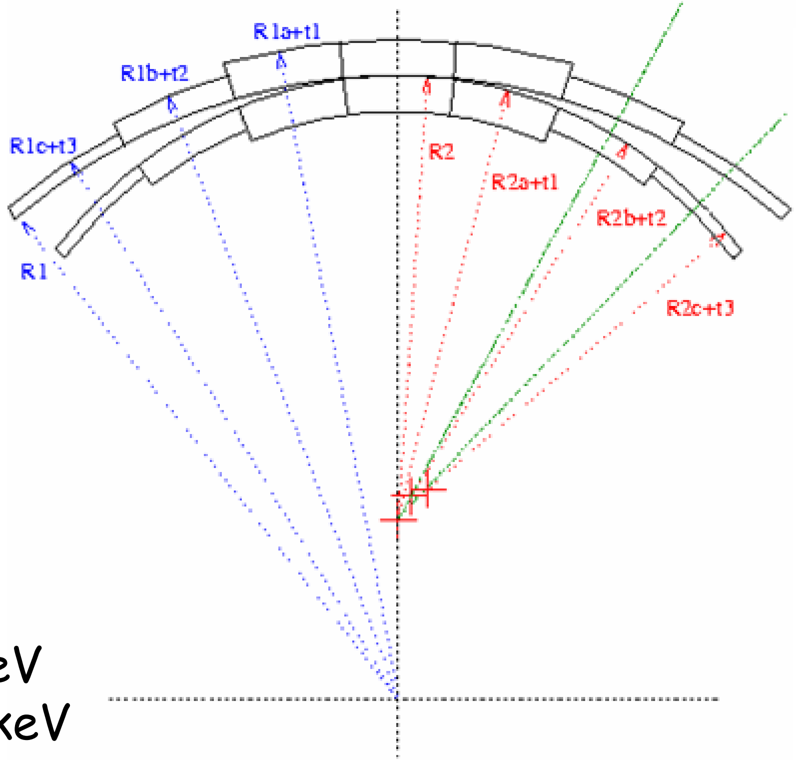
MIXS-T Optics



- MCP optics (3 concentrical rings)
- MCP pore width: 20 μm
- Aperture: 21 cm
- Focal length: 1 m
- Effective area : 120 cm^2 @ 1 keV
  15 cm^2 @ 10 keV



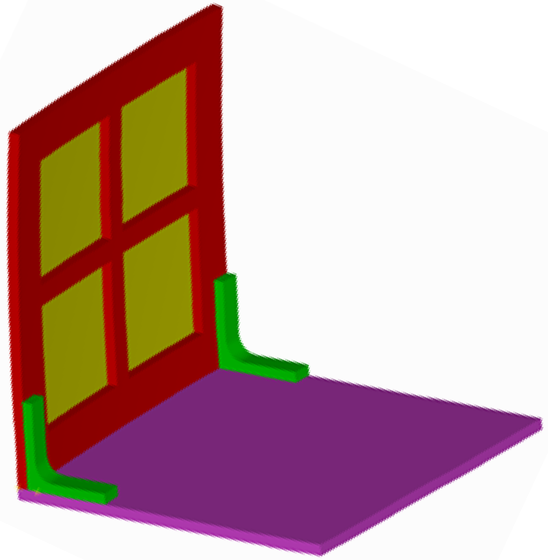
Prototype



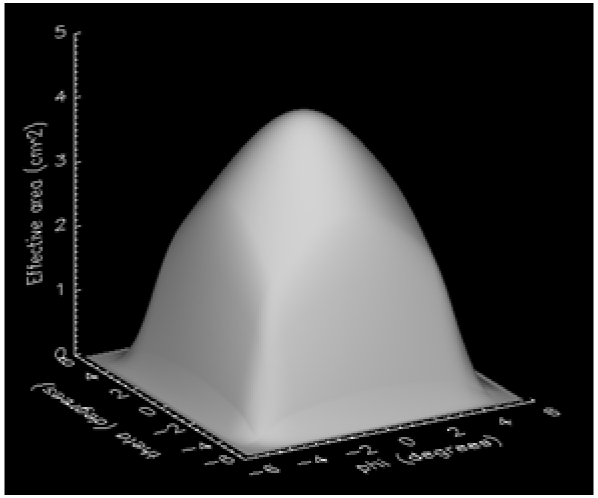
- Wolter type 1 geometry
- Conical approximation
- Iridium-coated lead silicate glass
- Angular resolution: ~ 1.7 arcmin FWHM
- Total FOV: 1° FWZM

MIXS-C Optics

- Much simpler system
- Radially bent collimator with 8 degree fov
- Uses a 2x2 array of square pore square packed MCPs
- 64mm by 64mm aperture
- Detector distance 230mm

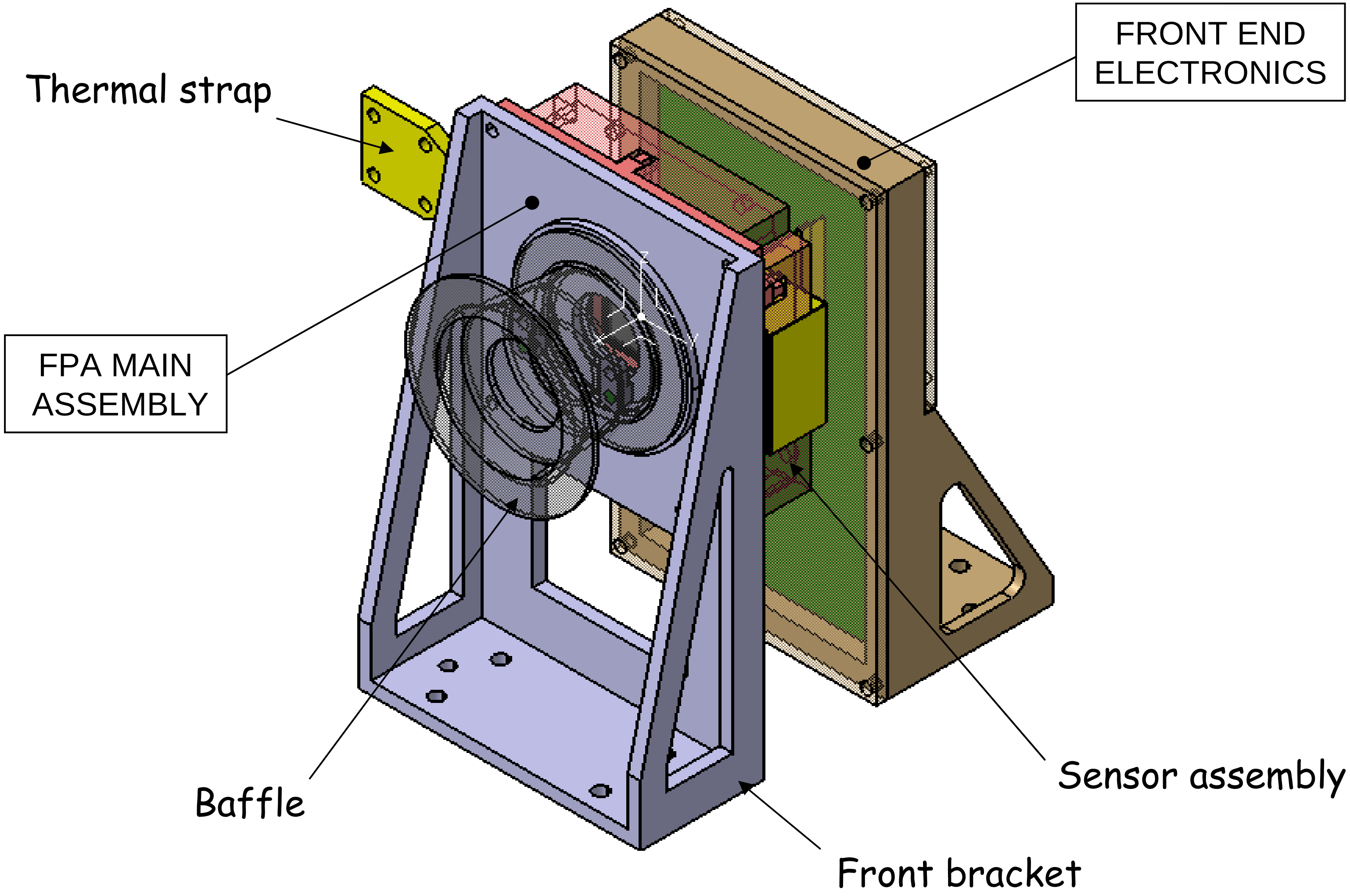


- Collimator setup drawing



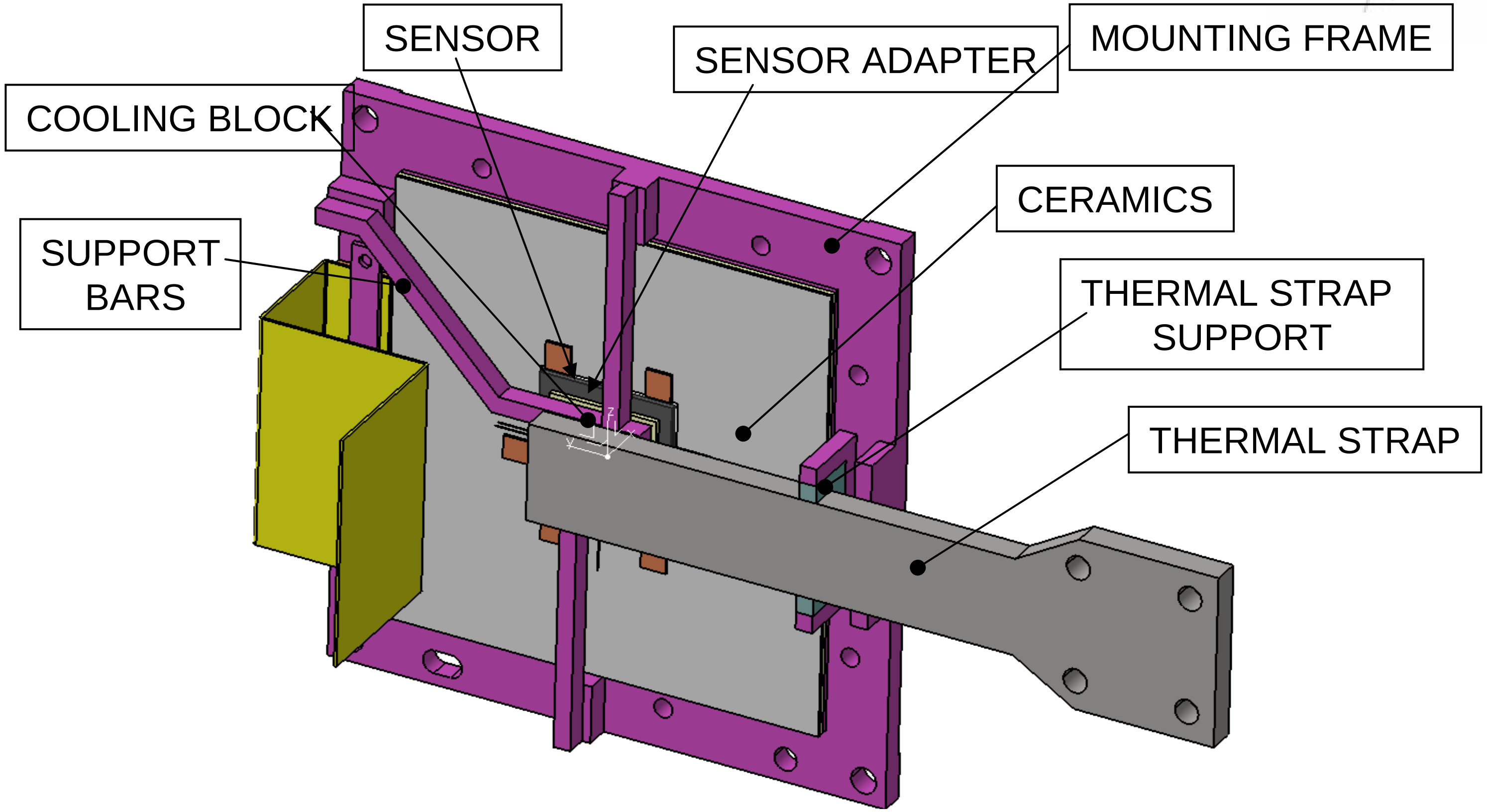
- Collimator angular response

FPA design



Thermal strap
FRONT END ELECTRONICS
FPA MAIN ASSEMBLY
Baffle
Sensor assembly
Front bracket

Sensor assembly



- Radiation enters from backside
- Frame and cooling block are made of high-perfromance beryllium alloy
- Support bars of composite carbon fiber material
- Details need to be fixed

Detector characteristics I

Sensor and pixel size

- **FOV & focal length:**
  Minimum sensor area 1.75 x 1.75 cm^2

- **Tradeoff between:**
  - Spotsize in focal plane (~1 mm)
  - Oversampling PSF
  - Angular resolution
  - Number of readout channels
  - Resolution & charge splitting
  - Spectral purity

2 Alternatives:

- 64 x 64 pixels of 500 x 500 μm^2
- Sensor size: 3.2 x 3.2 cm^2
- 96 x 96 pixels of 500 x 500 μm^2
- Sensor size 2.8 x 2.8 cm^2

- Resolution element size:
  - 0.2 km (periherm) and 0.8 km (apoherm) @ 300 μ pixel size
  - 0.3 km (periherm) and 1.3 km (apoherm) @ 500 μ pixel size

Detector characteristics II

Energy range

- Energy range:
  < 0.5 keV to > 7.0 keV
- Detection of Fe using the Fe-L line

Fe	L	0.71 keV		K	K	3.31 keV 3.59 keV
Na	K	1.04 keV 1.07 keV		Ca	K	3.69 keV 4.01 keV
Mg	K	1.25 keV 1.30 keV		Ti	K	4.51 keV 4.93 keV
Al	K	1.49 keV 1.55 keV		V	K	4.95 keV 5.43 keV
Si	K	1.74 keV 1.84 keV		Cr	K	5.41 keV 5.95 keV
P	K	2.02 keV 2.14 keV		Mn	K	5.90 keV 6.49 keV
S	K	2.31 keV 2.47 keV		Fe	K	6.40 keV 7.06 keV

Mercury key element emission lines

Detector properties

Parameter	**Value**	**Comments**
Format	1.92 x 1.92 cm^2 sensitive area	O.K.
Array dimension	64 x 64 pixels	O.K.
Pixel size	300 x 300 mm^2	O.K.
Energy resolution	≤ 200 eV FWHM @ 1 keV	Depends on temperature
QE	≥ 80 % @ 500 eV	O.K.
Time resolution	128 µs (192 µs)	Depends on FE speed
Radiation hardness - Ionizing - Non-Ionizing (10 MeV p)	 20 krad 3 x 10^{10} p/cm^2	Depends on temperature
Operation temperature	-40 °C (-45 °C)	Depends on annealing scenario
Power consumption	≤ 2.5 W	Detector plus FEs

Temperature
most critical
issue!

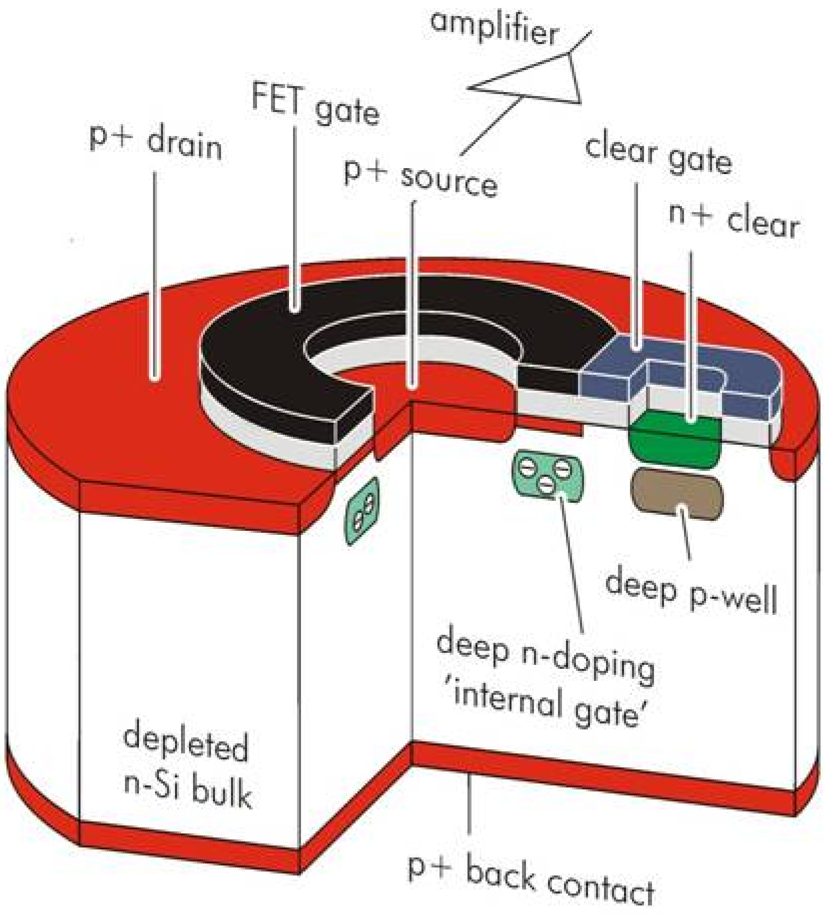
Detector concept

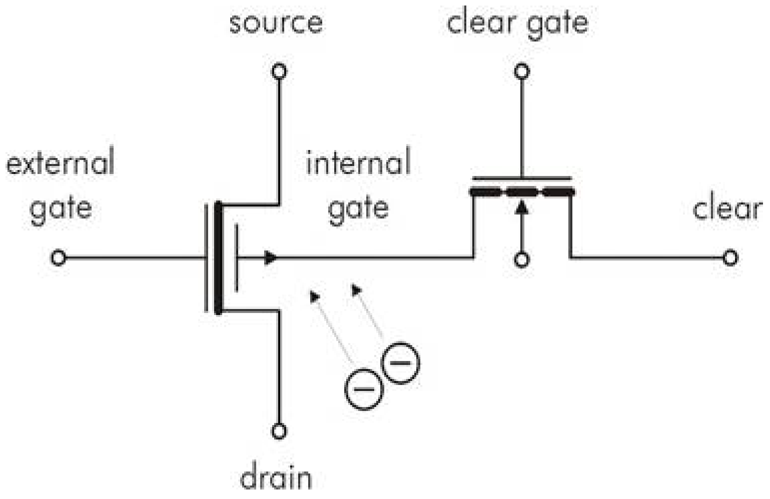
FPA detector:

DEPMOSFET Macropixel array

- Monolithic Array of silicon drift chambers
- DEPMOSFET devices as readout nodes
- Scalable pixel size
- High QE due to high fill factor
- Bidirectional row-wise readout
- High readout speed
- Low power consumption

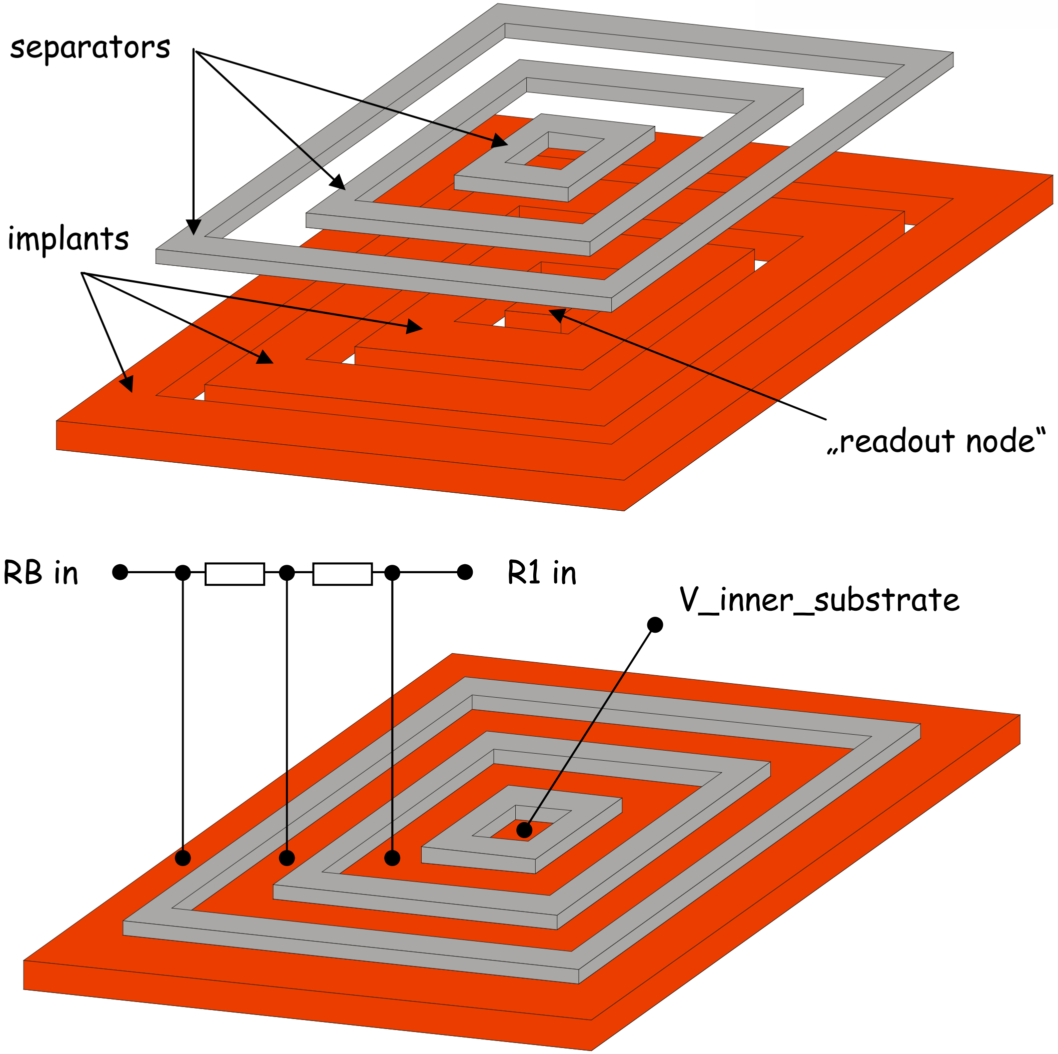
X-type DEPMOSFET device



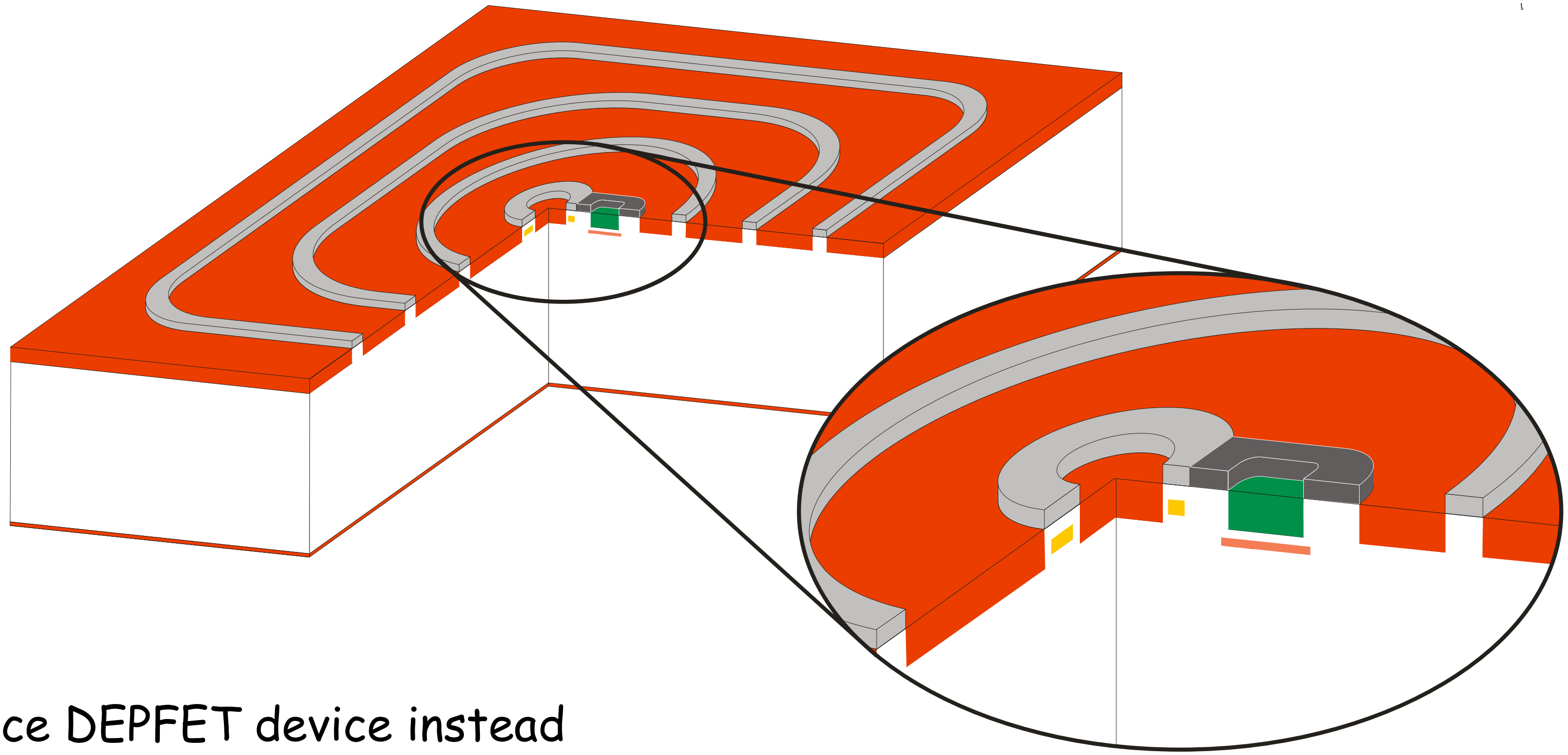


Implementation: Pixel substructure

- MIXS-T requirement: 300 x 300 μm^2 pixels
- Can be implemented using 3 driftrings per pixel
- Driftring voltage cascade applied externally or generated by integrated resistive voltage divider

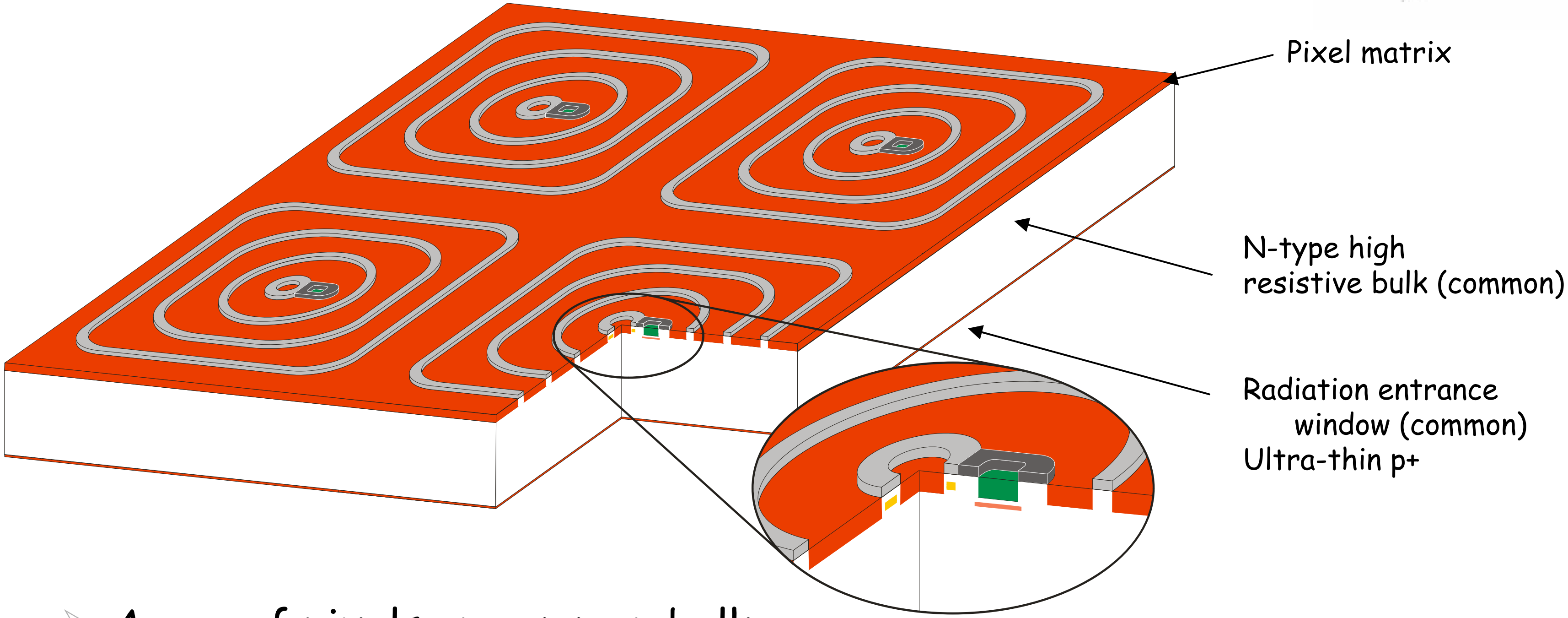


Implementation: Central readout node



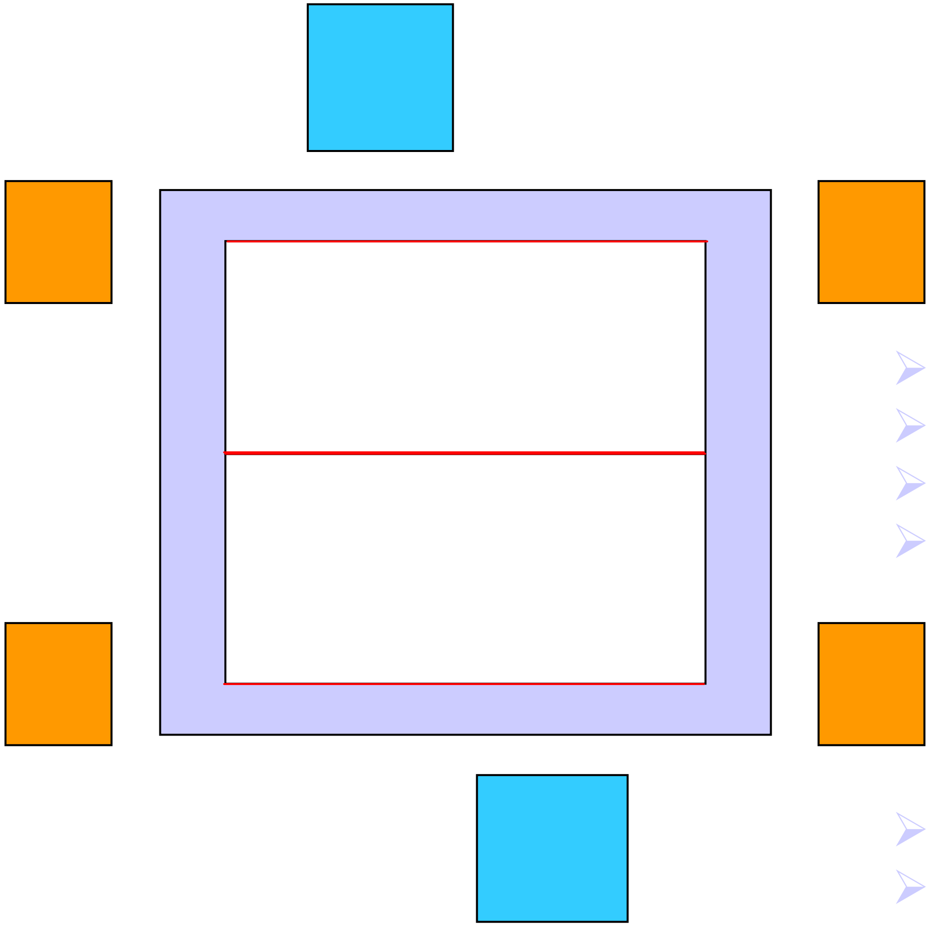
- Place DEPFET device instead of„conventional" readout anode or JFET
- Charge integration capability for every cell

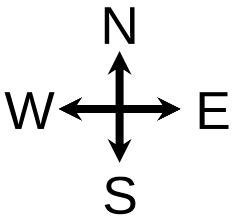
Implementation: Matrix arrangement



- Array of pixels on common bulk
- Common outermost drift ring (RB)
- Common thin homogeneous entrance window
- Common backside contact voltage
- Shared driftring voltages
- No insensitive inter-pixel gaps
- But: charge sharing between pixels possible

Readout scheme

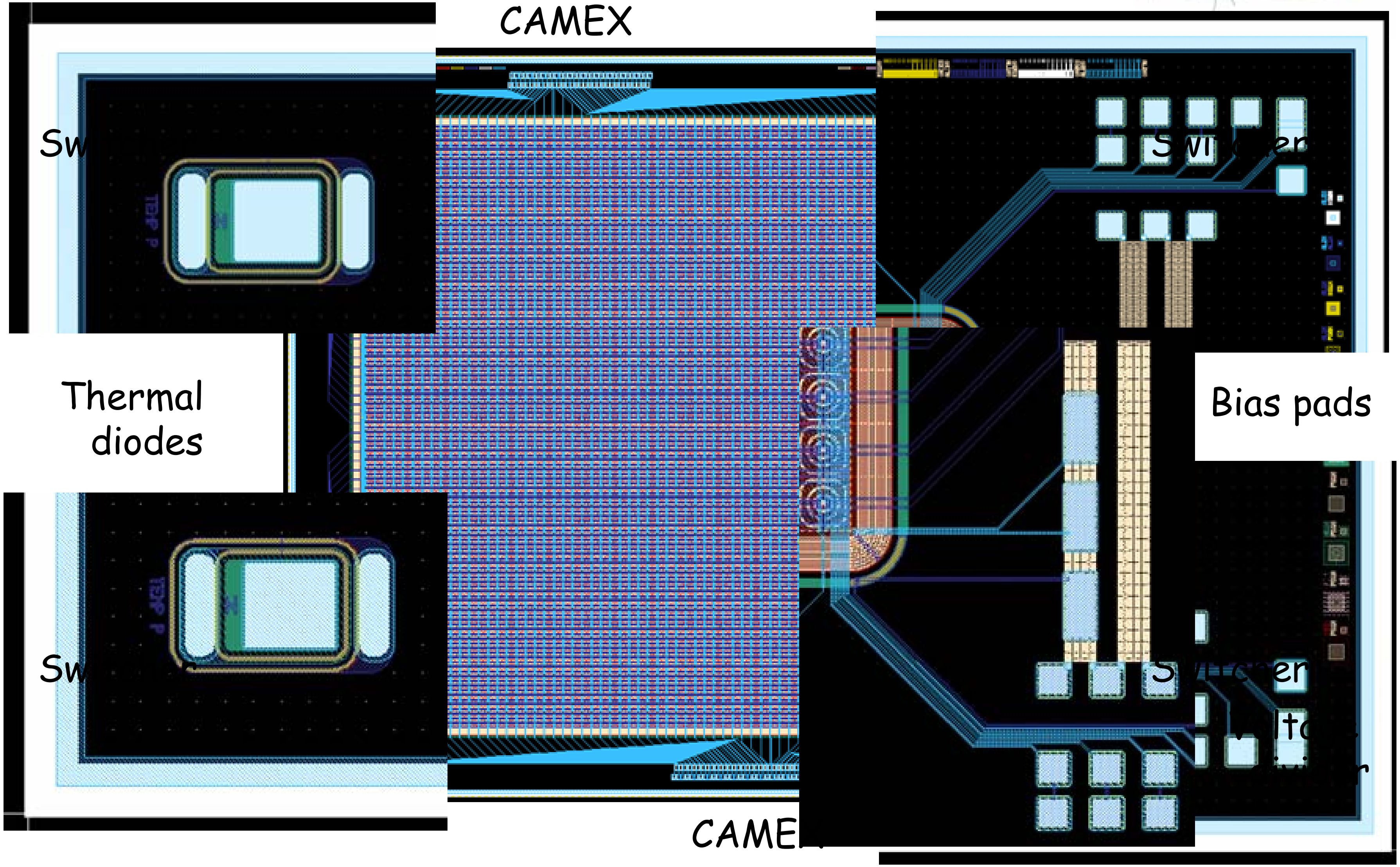




- 2 Hemispheres (North and South)
- 32 x 64 Pixels each
- Read out by 1 CAMEX each
- Controlled by 2 Switchers each

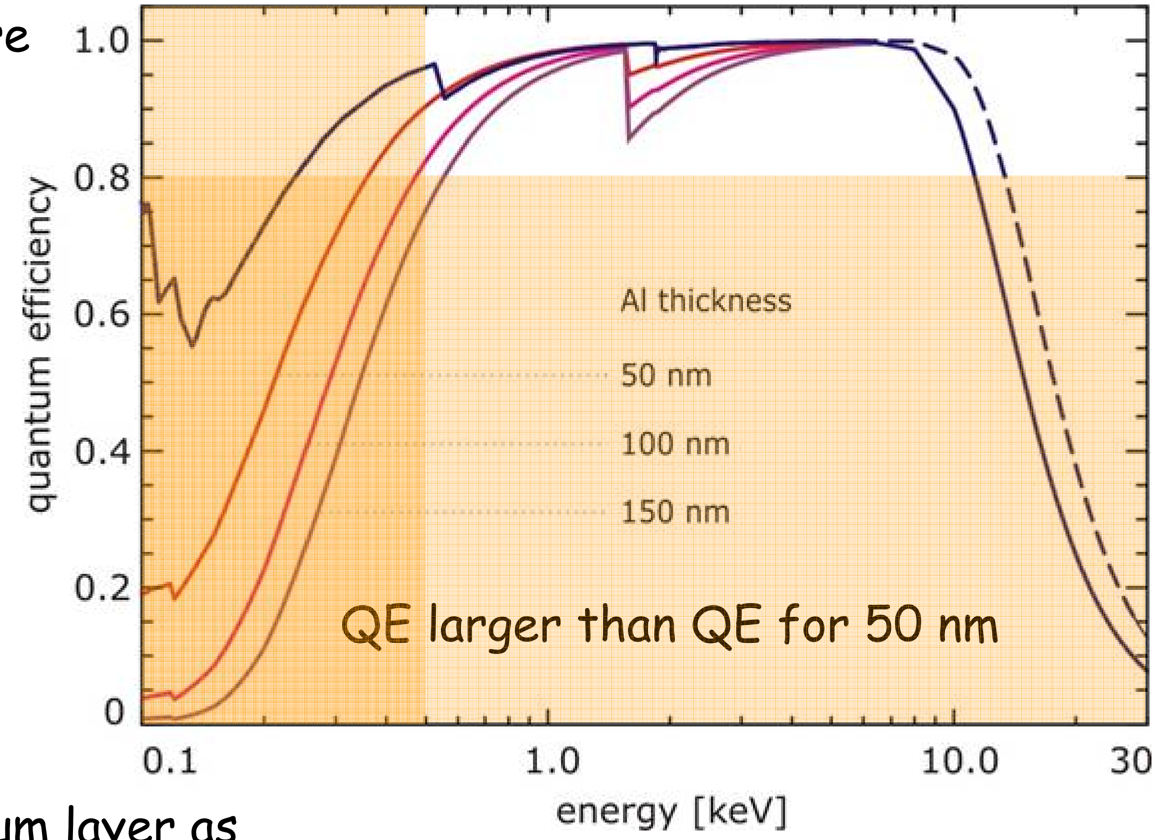
- Readout speed: target 4 µs / row
- 6 µs / row might be necessary
- Depends on FE performance, temperature, capacitance...

Detector overview



Entrance window configuration

- Thermal reasons require external optical filter
- Incorporates also UV-filtering properties



QE larger than QE for 50 nm

Entrance window:

- No UV-Filter
- As thin an aluminum layer as necessary (~30 nm)
- Required for entrance window radiation hardness

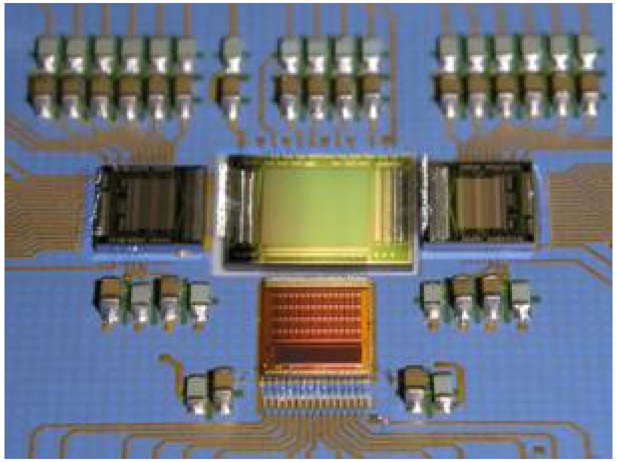
Front End ICs

Switcher ICs:

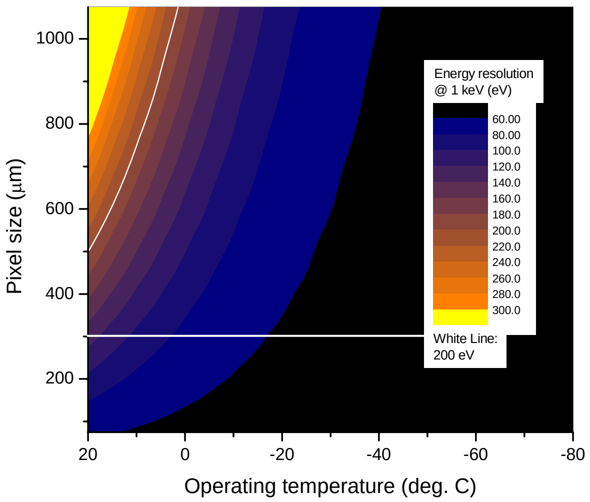
- Vital control element of detector
- Present technology radiation tolerant
- Design not radiation tolerant
- Esp. digital part
- New radiation tolerant design is going to be submitted after first tests of PXD 05 devices
- Radiation tests required

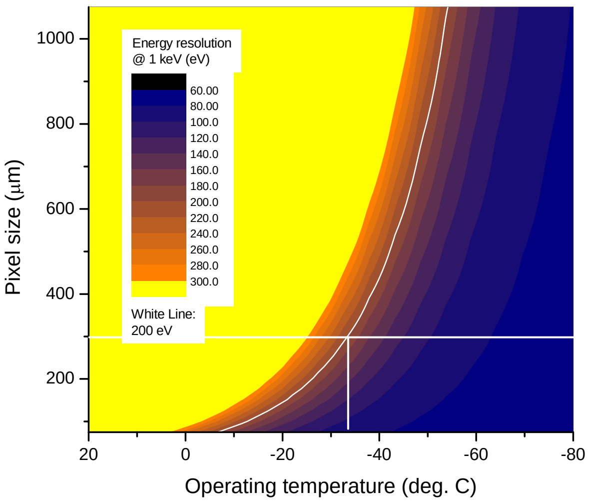
CAMEX / VELA ICs:

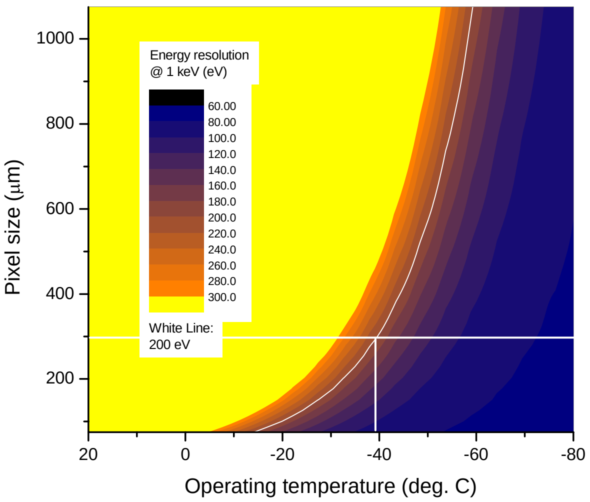
- Readout mode has been decided.
- Source follower is baseline in spite of intrinsic speed limit
- Design to be submitted ~02/07
- Devices ready ~ 07/07
- Speed is critical issue
- Radiation test to be done



Radiation damage





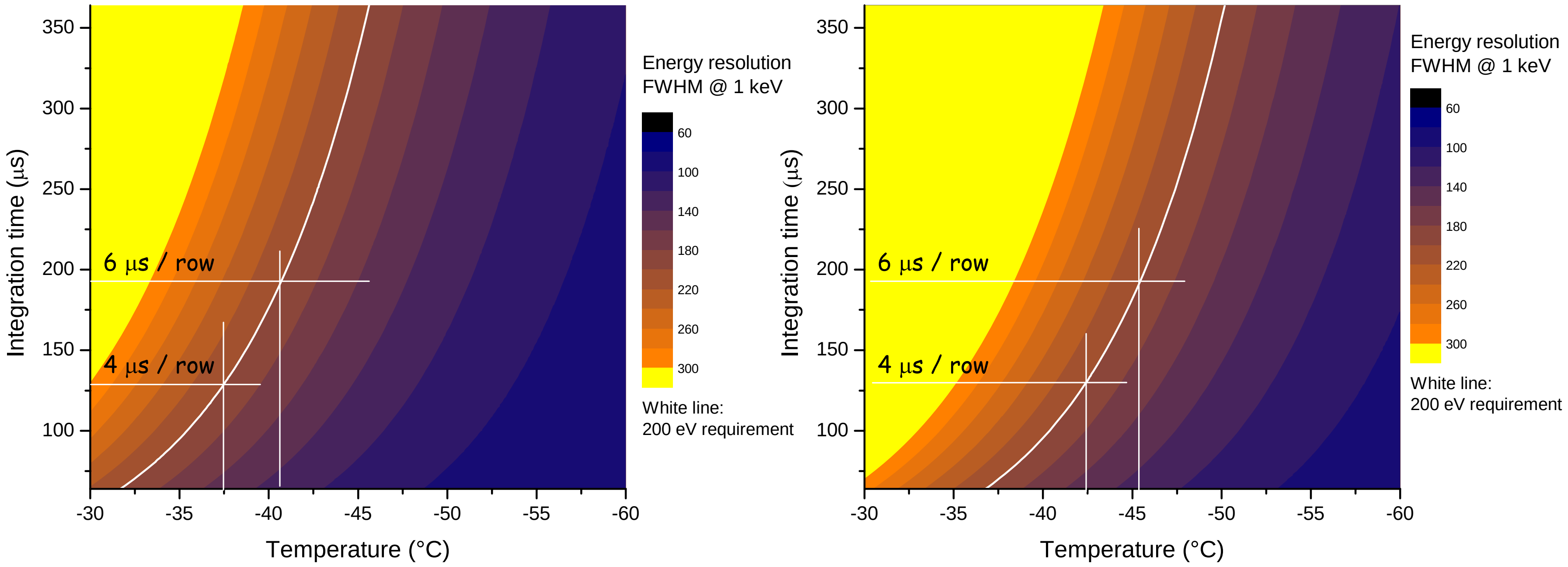


- Start of mission
- Mission halftime (half of the dose)
- Full mission lifetime (full dose)

Φ_{tot} = 3 x 10^{10} 10 MeV protons /cm^2

Calculations based on experimental results both of ROSE and operating experience with XEUS devices

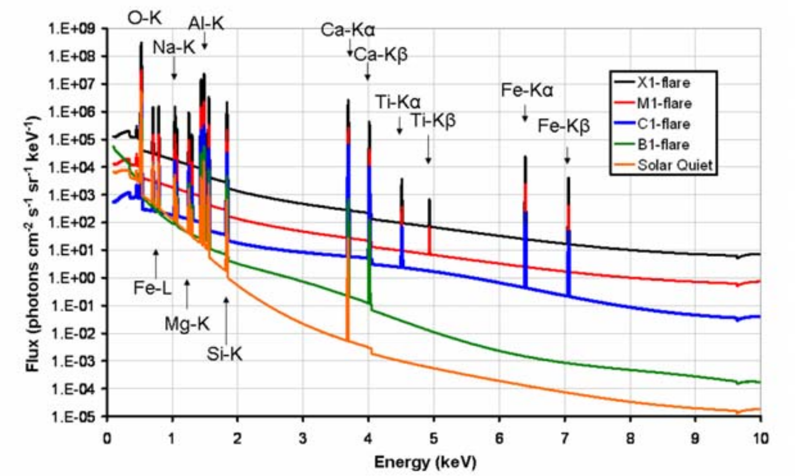
Comparison: Annealing vs. no annealing

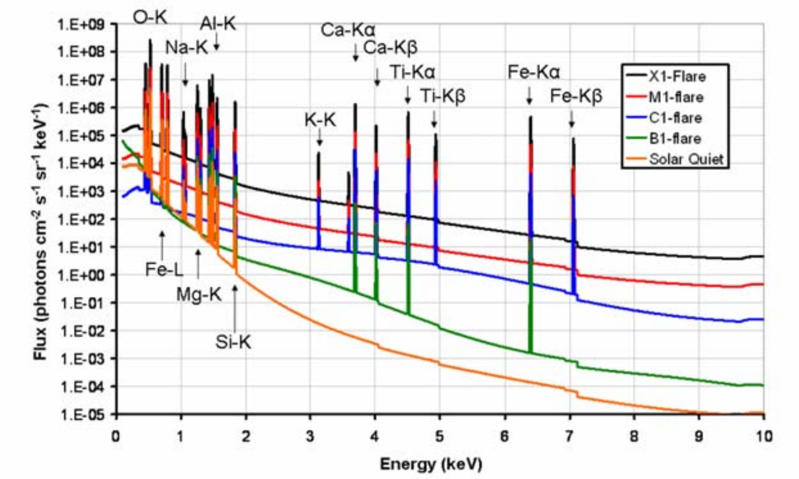


- Operating temperature of -41 ° C requires regular annealing cycle to remedy bulk damage and reduce leakage current
- Operation without annealing requires lower operation temperature, depending on speed ~ -46 ° C

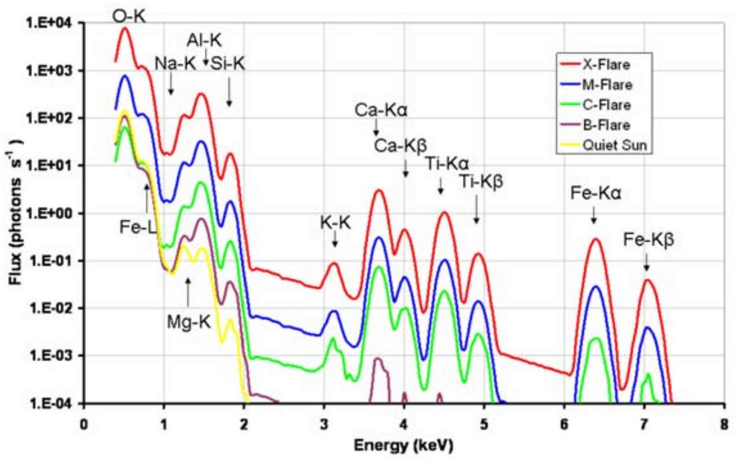
Detector response

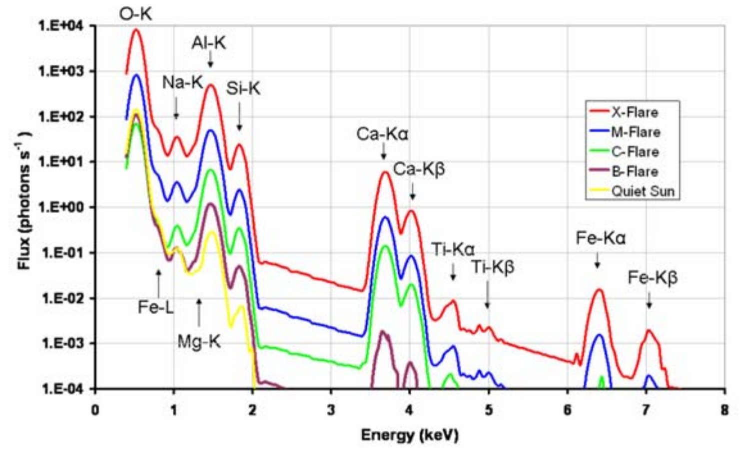
Input flux





Response for 200 eV @1 keV





- Similar to lunar anorthosit
- Similar to lunar basalt

Calculations provided by J. Carpenter University of Leicester