Workshop Ringberg

Destination Mercury

BepiColombo and its payload: Detectors for the X-ray spectrometer MIXS

3.5.2009

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MPI Semiconductor laboratory & MPI for solar system research

Mercury as seen on 16.9.2004

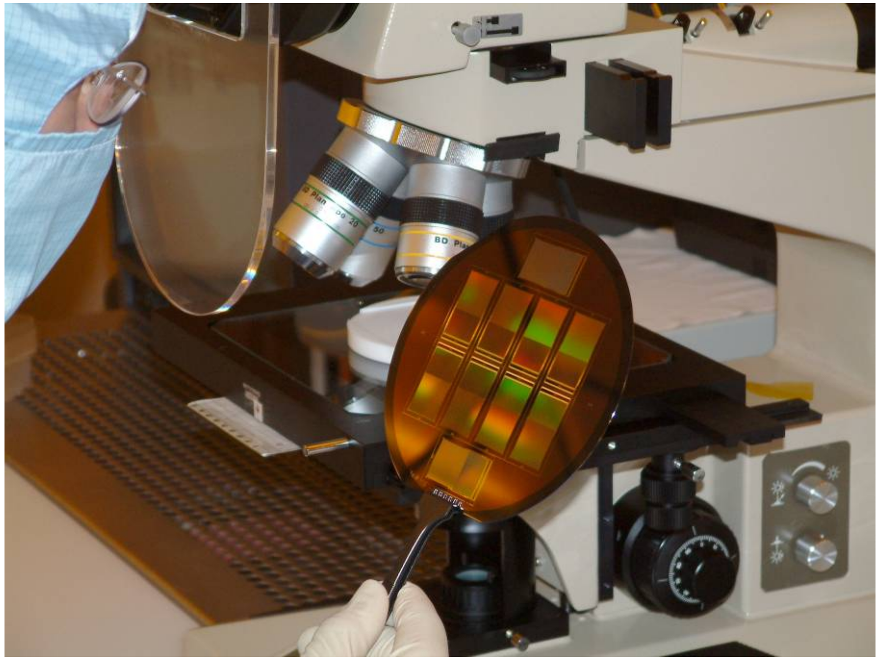
Institutions

esa

BepiColombo

University of Leicester

UNIVERSITY OF HELSINKI



PNSensor

MPS

MPE

Contents

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

History of Mercury observation

Ziggurat of Ur

Babylonian record
of Venus observation

~ 3000 B.C: First known evidence of Mercury observations by sumerian priests in mesopotamia.

~ 1400 B.C: First known records from mercury by assyrian astronomers. Planet known as ***Ubu-idim-gud-ud***

~ 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.

In roman/greek mythology, Mercury/Hermes, son of Jupiter/Zeus and Maja, is the cleverest of the immortals. He is the messenger of gods and the god for travellers nad merchants.

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

History of Mercury observation

Always displayed with the winged herald'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 Würzburg residence (18th century).

History of Mercury observation

But Mercury is, as all greek and roman gods, a somewhat ambiguous figure. On his "bad" side, he is manipulable and, being the progeny of an extramartial affair, he has affairs on his own.

He is also said to have, however unwillingly, contributed to the creation of Pandora. Forced by Zeus, he gave her the ability to arbitrarily lie at any time.

He is also the god of crooks, liars and bandits.

Mercury and Herse by
Paolo Veronese (16th century, Cambridge).

Mercury, god of crooks...

MPI Halbleiterlabor

Groupe Mercure Assurances
Le conseil, c'est capital !
groupemercure.com

EFG - Hermes

EULER HERMES
Kreditversicherung

Mercury Financial Services

HanseMerkur
Versicherungsgruppe

HermesInsurance

FIRST MERCURY FINANCIAL CORPORATION

MERKUR BANK
Meine Bank!

MERKUR
DIE GESUNDHEITS-VERSICHERUNG

MERCURY INSURANCE GROUP

...bandits...

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Mercure MEET THE MERCURES

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...and liars.

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Münchner Merkur

DAS KARRI

Rheinischer MERKUR

Pfälzischer Merkur

webAbo

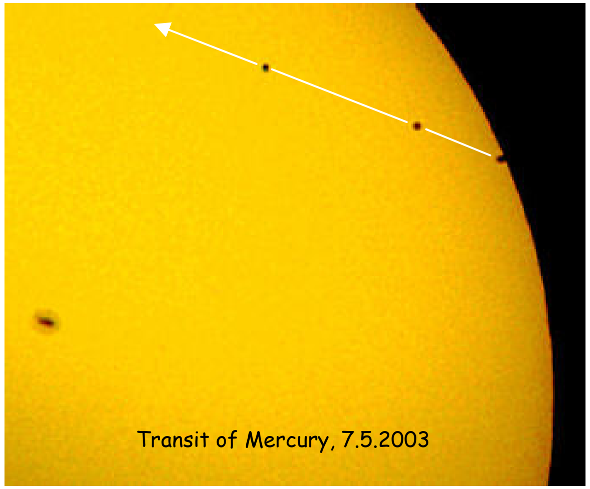
THE VOICE OF TASMANIA

MERCURY

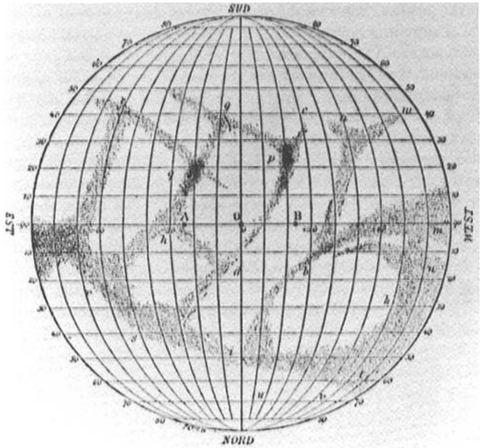
History of Mercury observation

~ **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.


Transit of Mercury, 7.5.2003

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.

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.

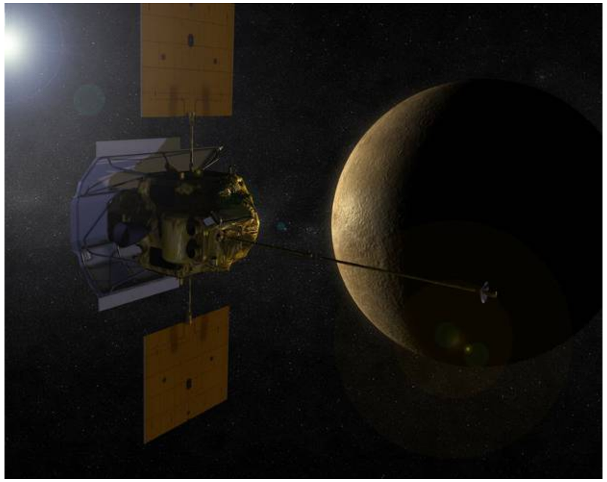
1974: Until 1975, **Mariner 10** passes Mercury 3 times. Flight plan suggested by Bepi Colombo included Venus-Swing-Bys. Unexpectedly, the revolution period of Mariner 10 in this orbit was exactly twice the revolution period of Mercury, so that only ~45 % of mercury could be cartographed.

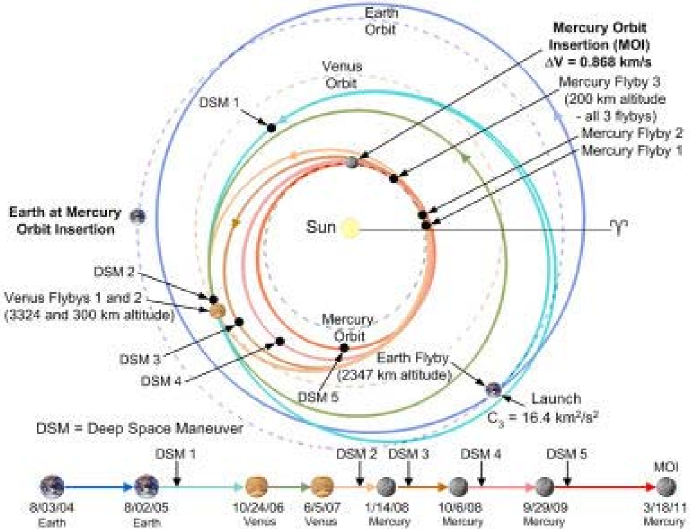
Mariner 10

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

Future of Mercury observation

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



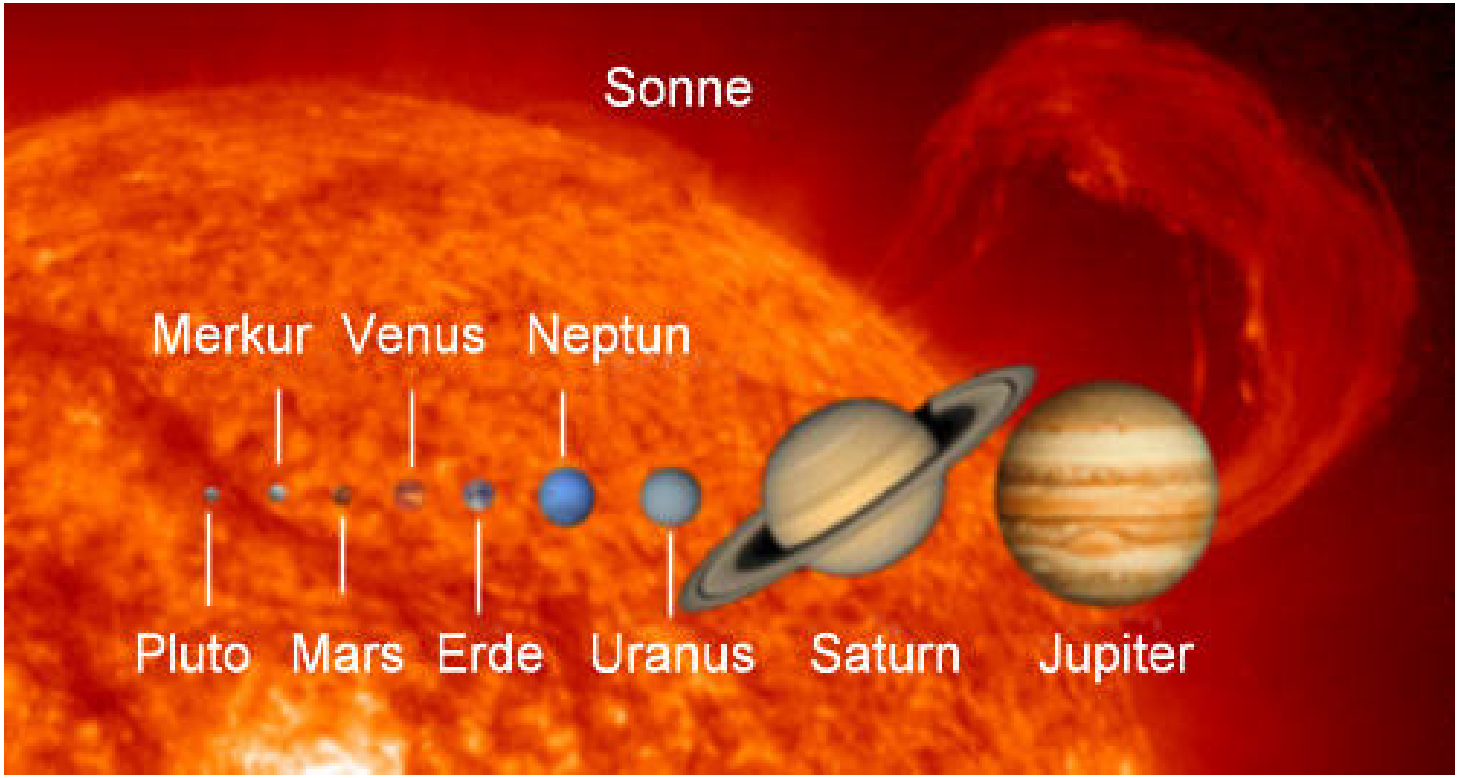


January	**2008:**	First Mercury flyby
October	**2008:**	Second Mercury flyby
September	**2009:**	Third Mercury flyby
March	**2011:**	Entering Mercury orbit

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

Future of Mercury observation

The planet Mercury

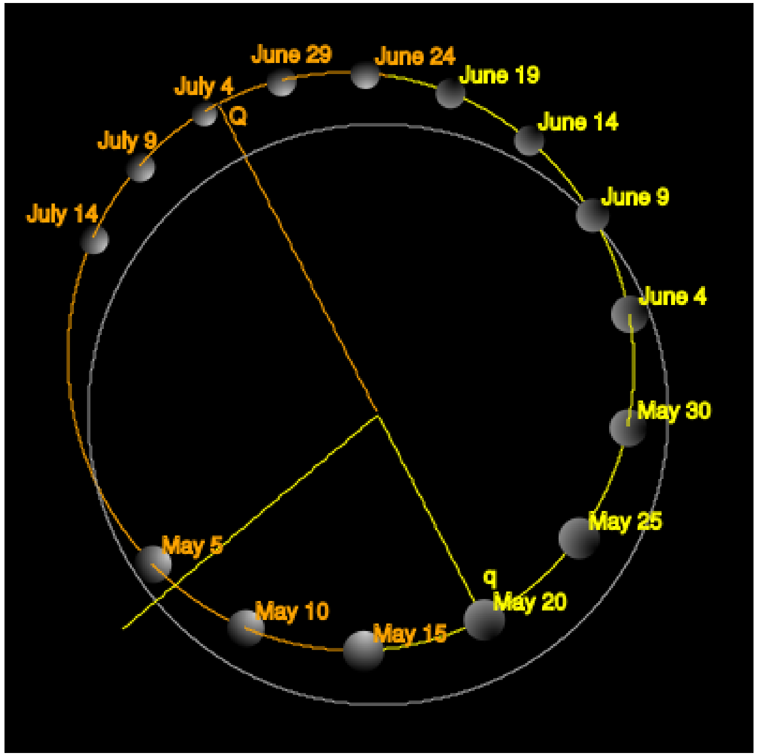


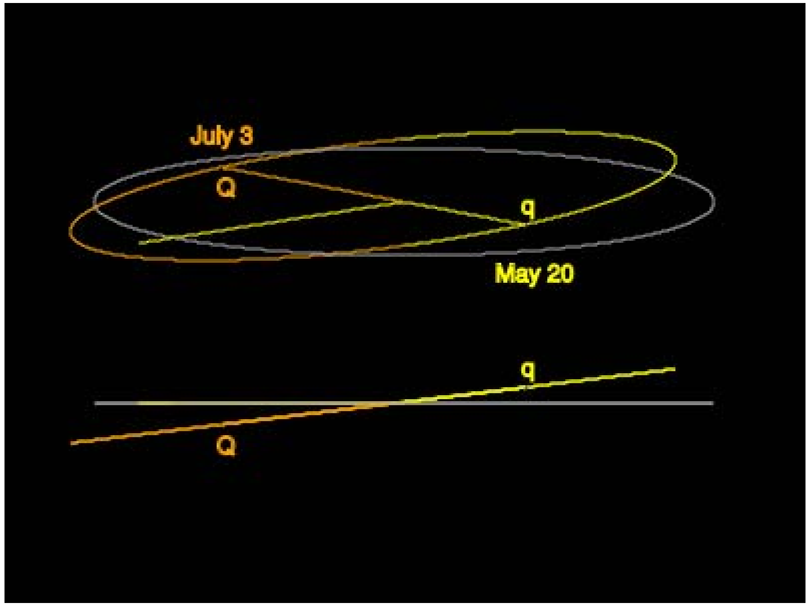
Earth Venus **Mercury** Sun (to scale)

Least well-known of the terrestrial planets

Radii to scale

Mercury Orbit





- Very excentric orbit
- Strong variation of velocity
- Strong perihel rotation

- Strongly tilted from ecliptic
- Incination: ~ 7 °

Mercury fact sheet

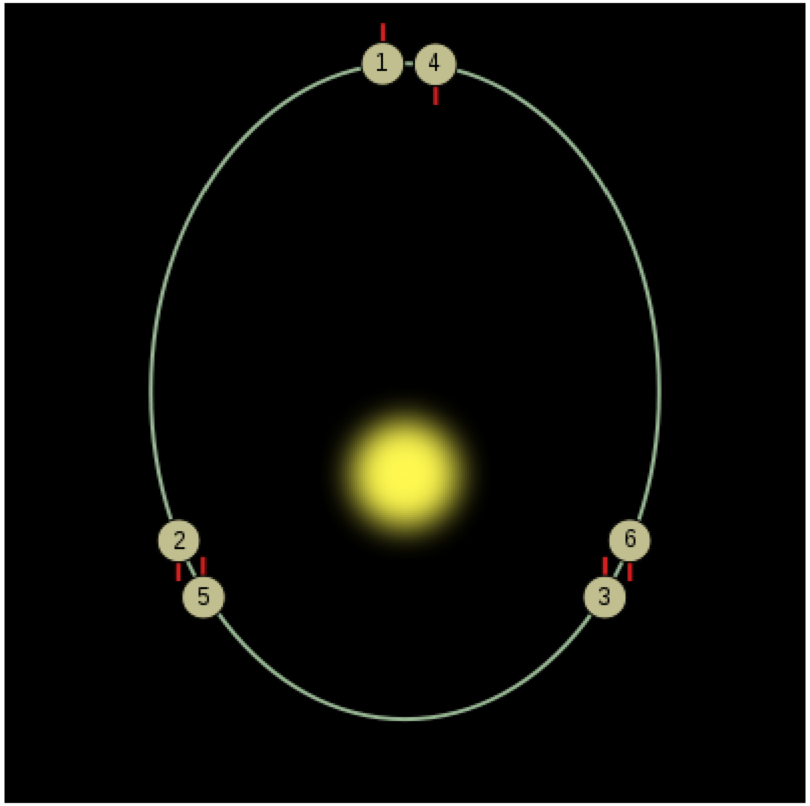
- Orbital radius: 0.46 – 0.3 AU (70 – 46 x10^6 km)
- Radius: ~2440 km (34% of earth)
- Mass: 3.302×10^{23} kg
- Density: 5.43 g / cm^3
- Surface gravity: 3.7 m / s^2
- Very small magnetic field (1% of earth)
- No moons

- Rotation period: ~58 d
- Orbital period: ~85 d
- Axial tilt: 0.01°
- 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

A day on Mercury

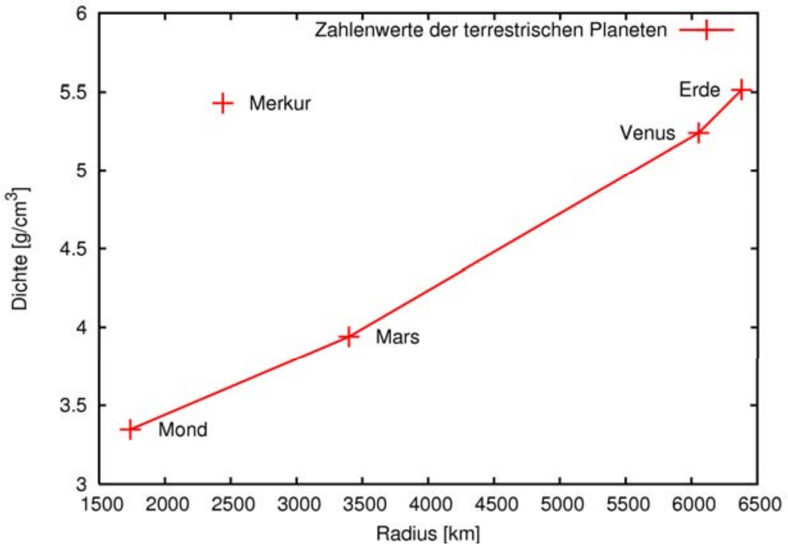


Velocity of revolution greatly varies during one Mercury year.
Angular velocity of rotation remains constant.
Variation causes „day with 2 sunsets and 2 sunrises at perihel.

Mercury mass

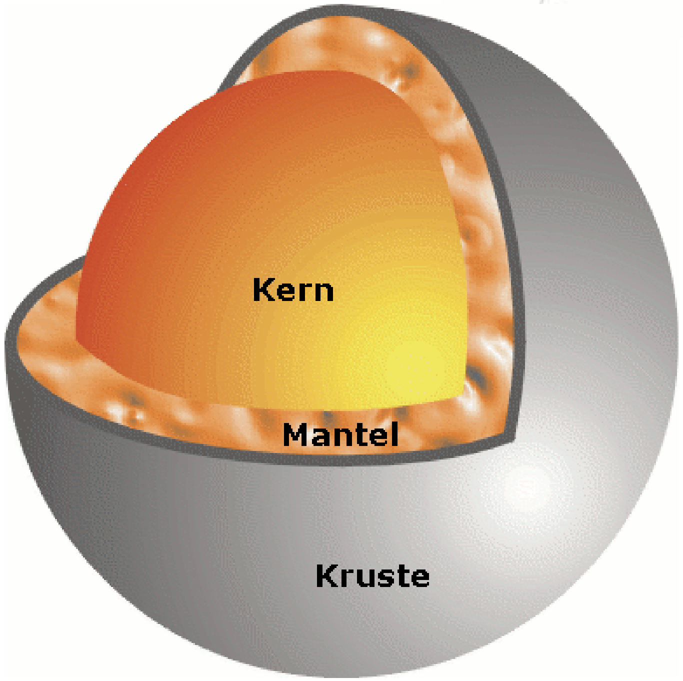
Anomal density!

- Terrestrial planet bulk composition derives from equilibrium condensation from the solar nebula.
- Not for Mercury – unpredicted large uncompressed density



Formation

- Large core – thin mantle
- High Fe content expected.
- Observations imply low Fe in crust.



		Earth values
1: Crust	(100-200 km)	(35)
2: Mantle	(600 km)	(2900)
3: Nucleus	(1800 km)	(3500)

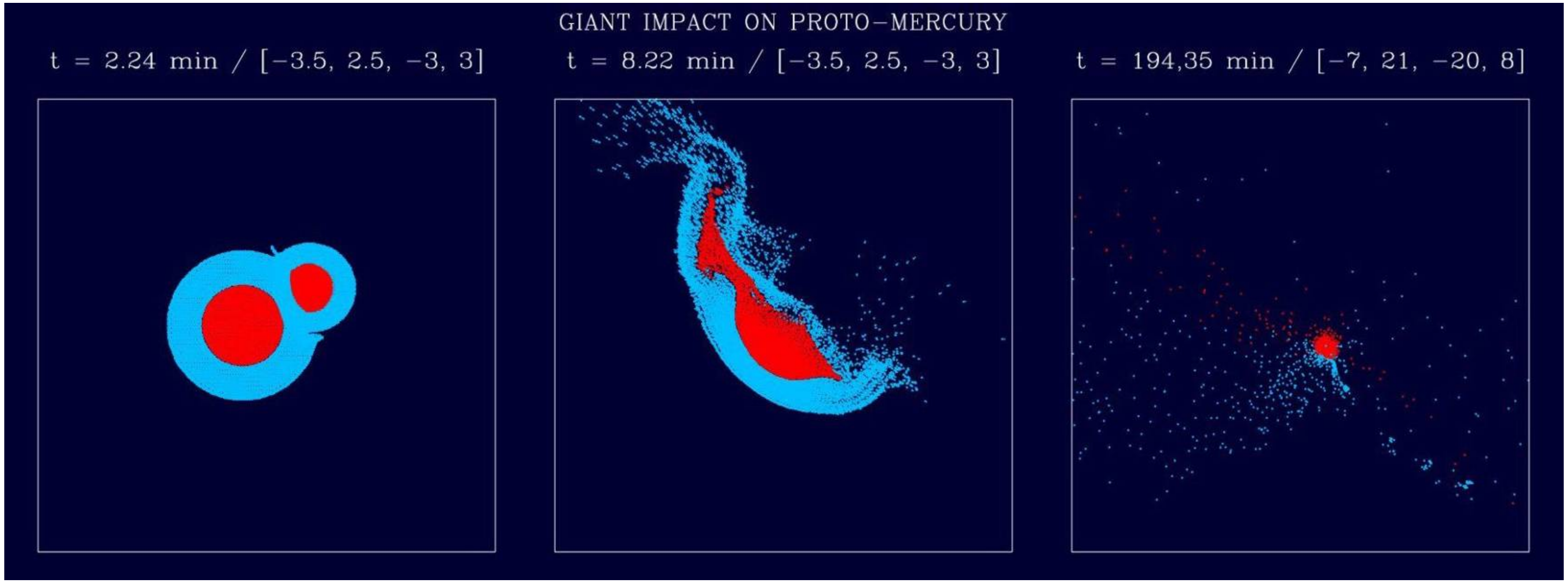
- **But:**
  - Inhomogeneous mass distribution (Mascons, spin-orbit resonance)!

	Element percentage						
Model	**Mg**	**Al**	**Si**	**K**	**Ca**	**Ti**	**Fe**
Equilibrium condensation	30.0	7.1	30.3	0	6.4	0.36	0.04
Dynamically mixed	35.4	3.5	32.3	0	3.0	0	0
Collisionally differentiated	40.5	0	32.3	0	1.3	0	0
Vapourisation	25.6	13.4	23.8	0	10.8	0.52	0

Scenarios:

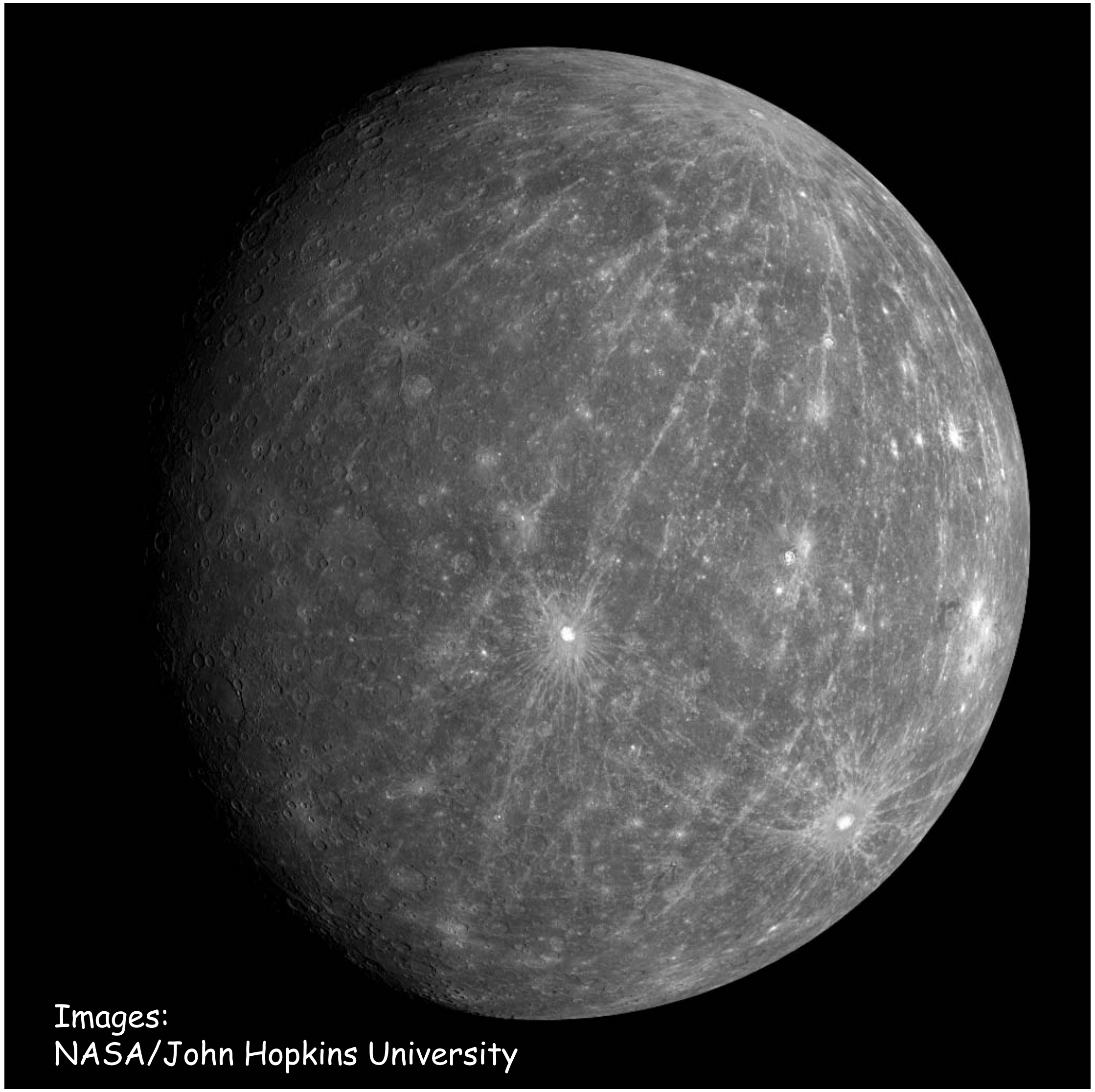
1. Selective accretion
2. Post accretion vaporisation
3. Massive impact (planetesimal)

Massive impact

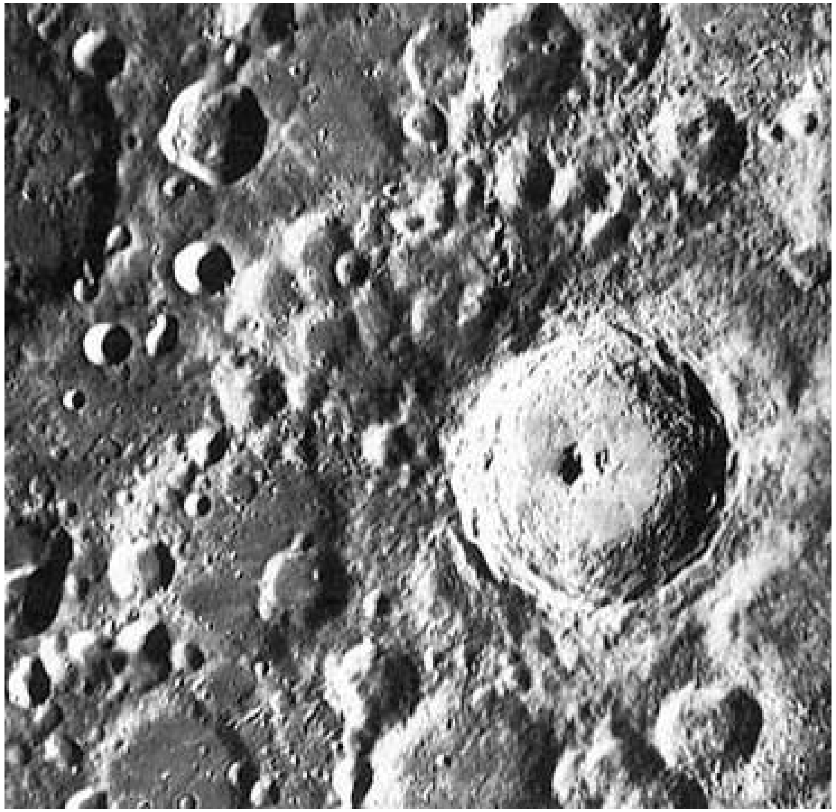


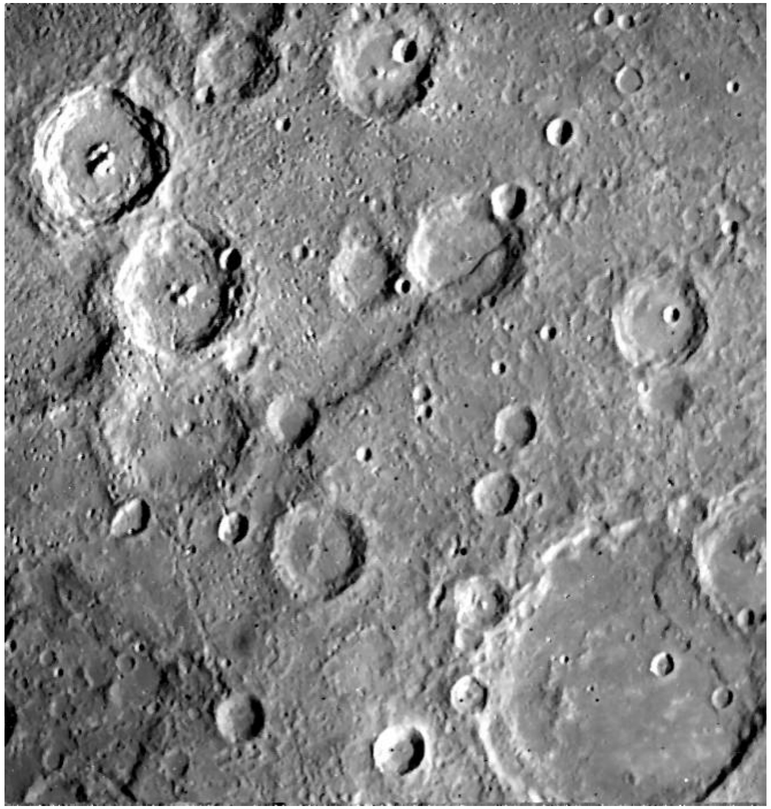
Simulations from Horner et al. (2006)

Mercury surface



Moon vs. Mercury

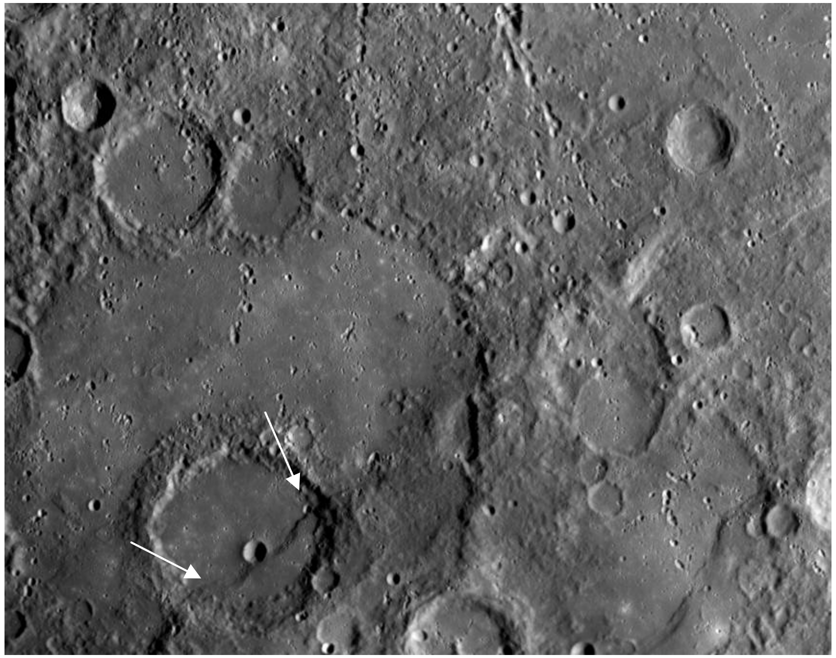


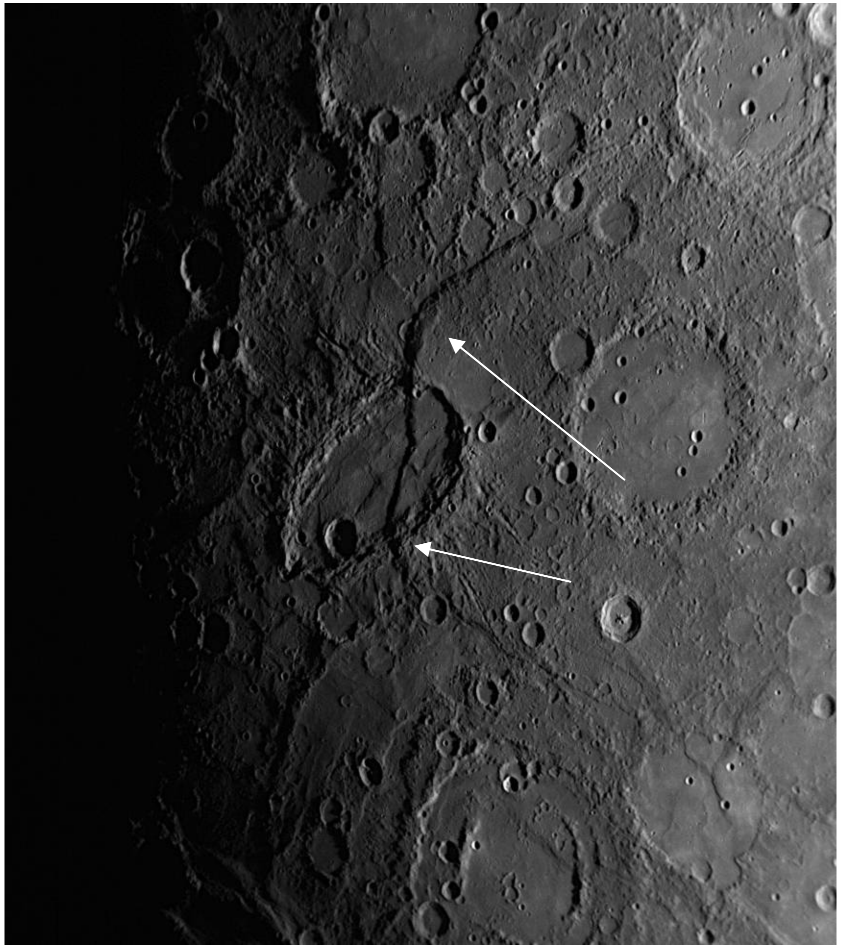


- **Lunar highlands**
  - Oldest features on moon
  - Primary crust
- **Mercury intercrater plains**
  - Not saturated with craters
  - Not primary crust?
  - Lava or ejecta sheets?
  - No signs of recent activity!

Images:
NASA/John Hopkins University

Recent activity?

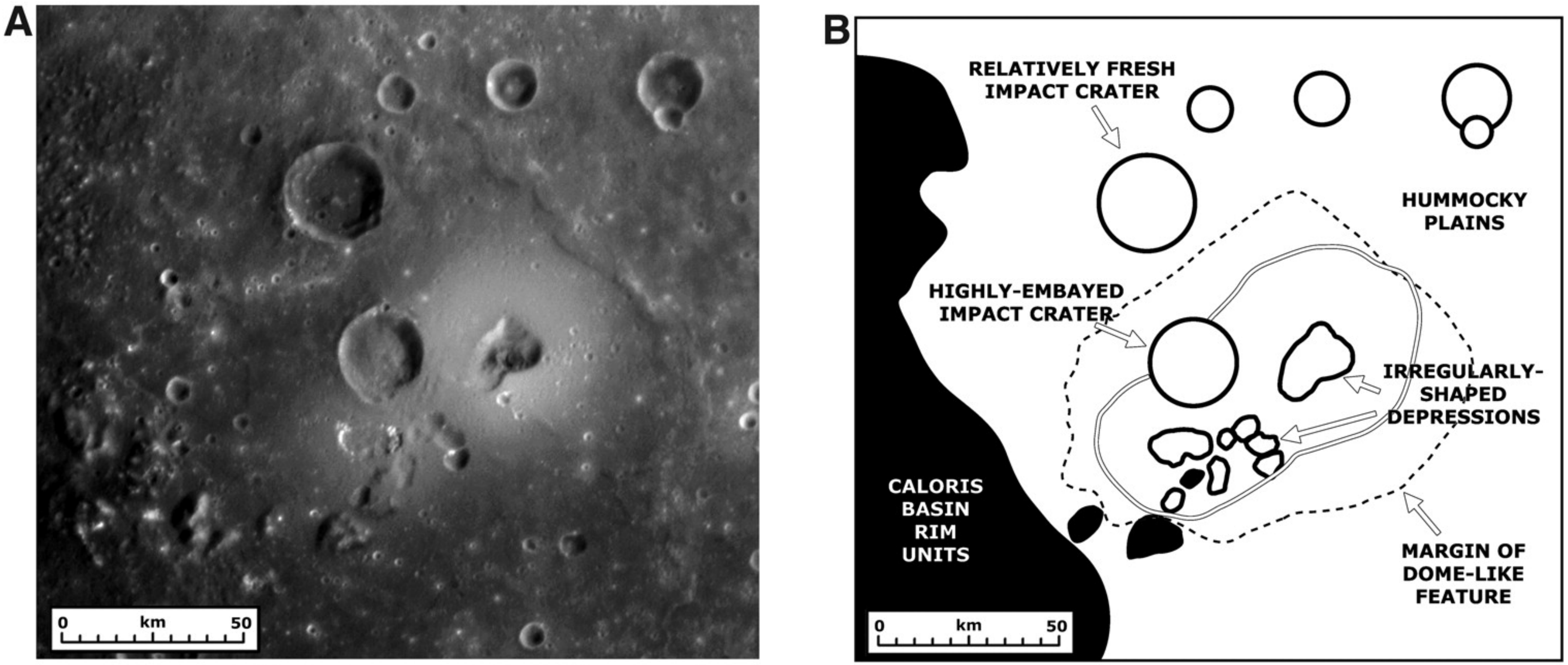




- **Rupes:**
  - Geologically inactive for a long time (700 million years)
  - „Rupes“ are prominent features
  - Indicate „planet shrinkage“ due to solidification
  - But: Observations indicate that core is liquid

Images:
NASA/John Hopkins University

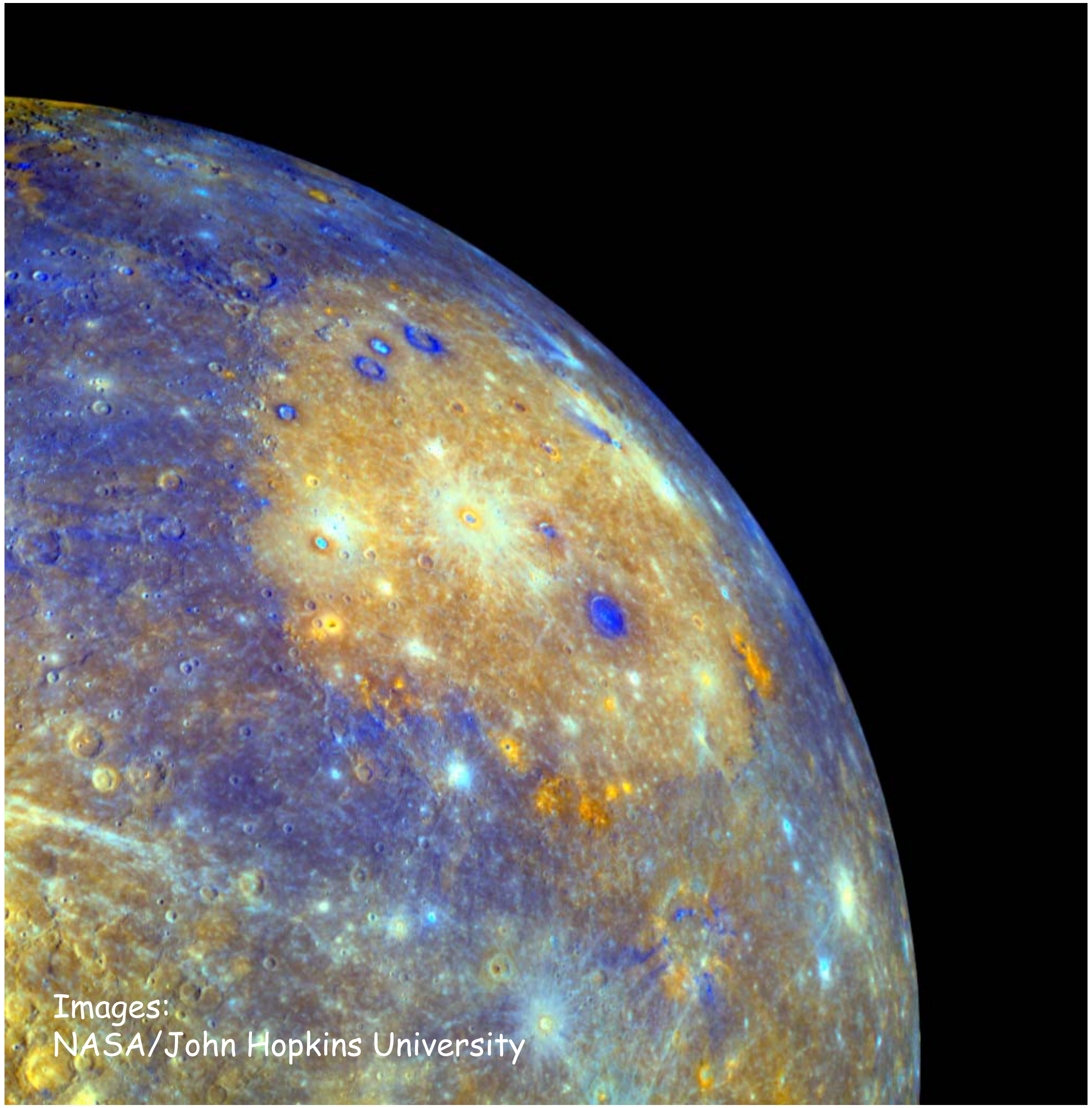
Mercury surface - volcanism



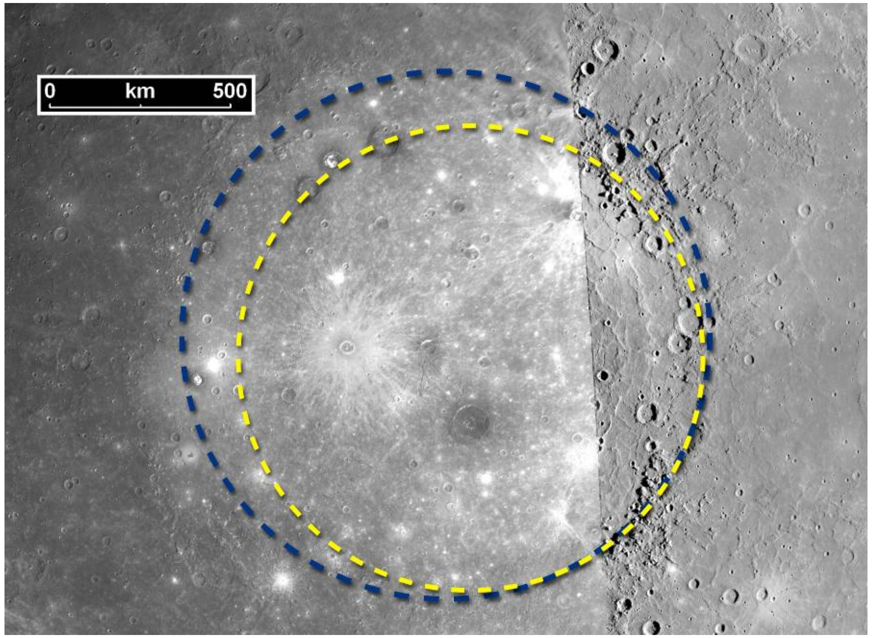
Credit: Figure 1 from Head et al., *Science, 321*, 69-72, 2008.

Images:
NASA/John Hopkins University

Mercury surface

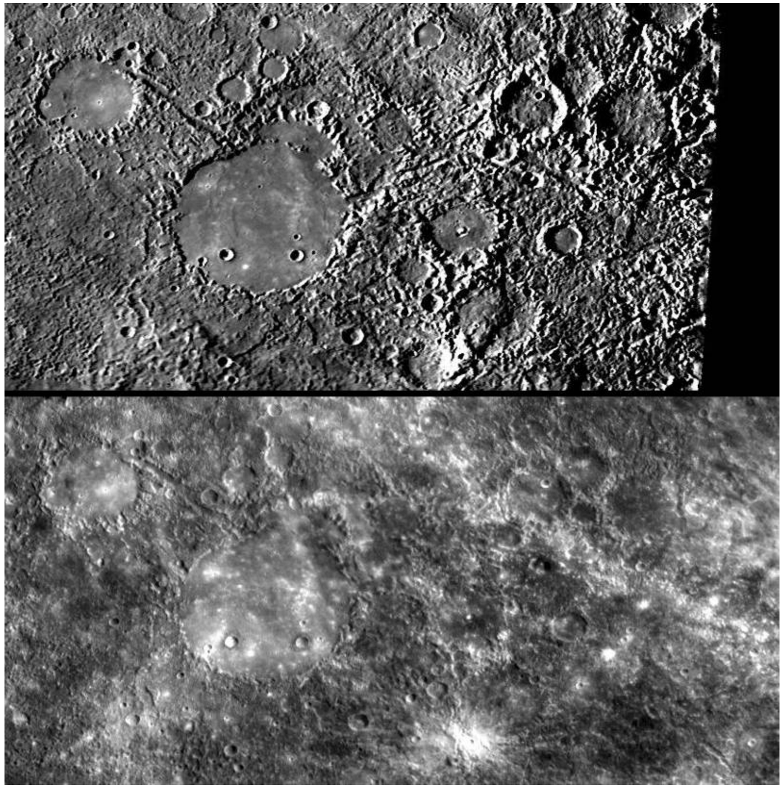


Mercury surface



Caloris platinia

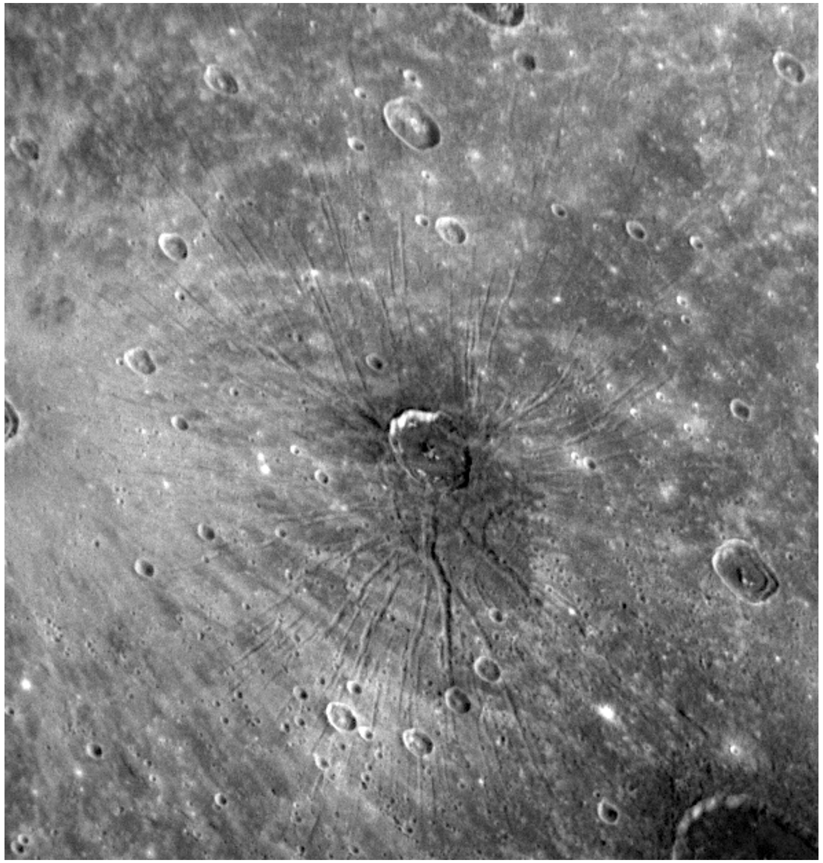
- **Platiniae biggest features on Mercury**
  - Impact craters filled with lava
  - Lava not dark
  - Less Iron and Titan
  - Contradicts Iron-rich core



Weird terrain

Images:
NASA/John Hopkins University

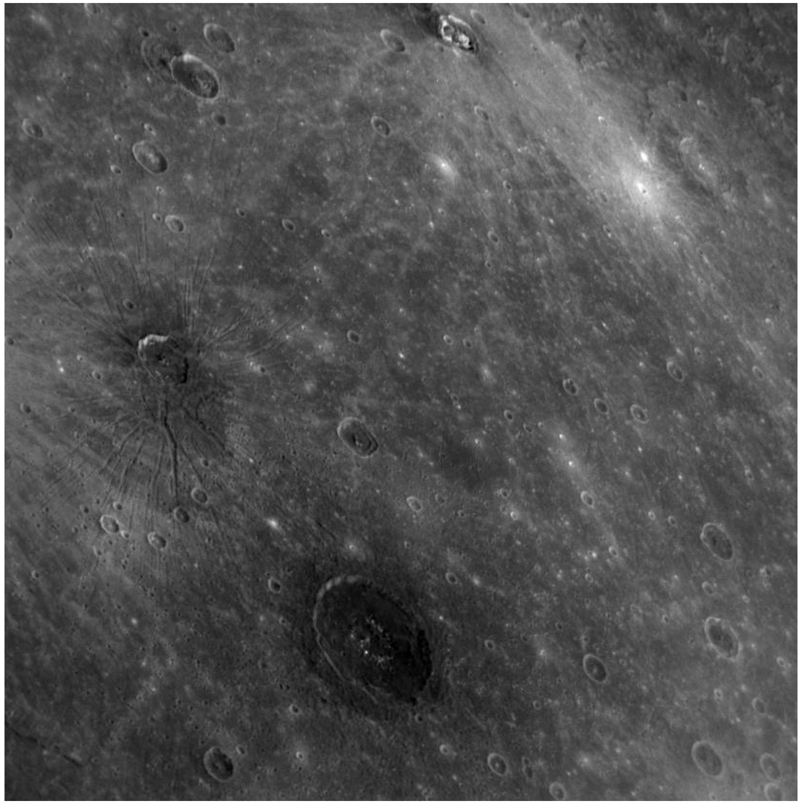
Mercury surface



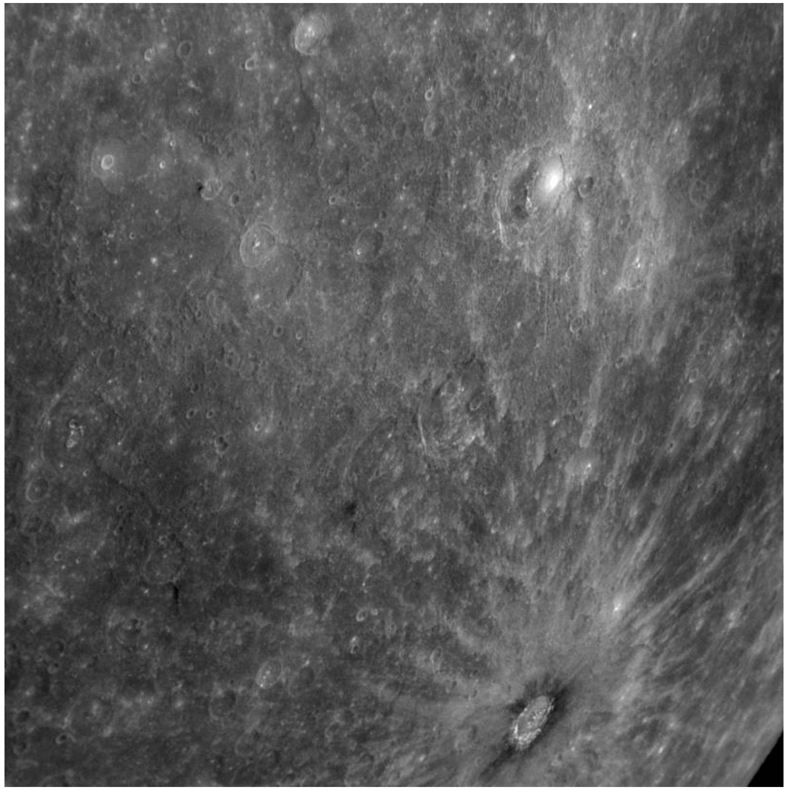
Pantheon fossae

Images:
NASA/John Hopkins University

Mercury surface



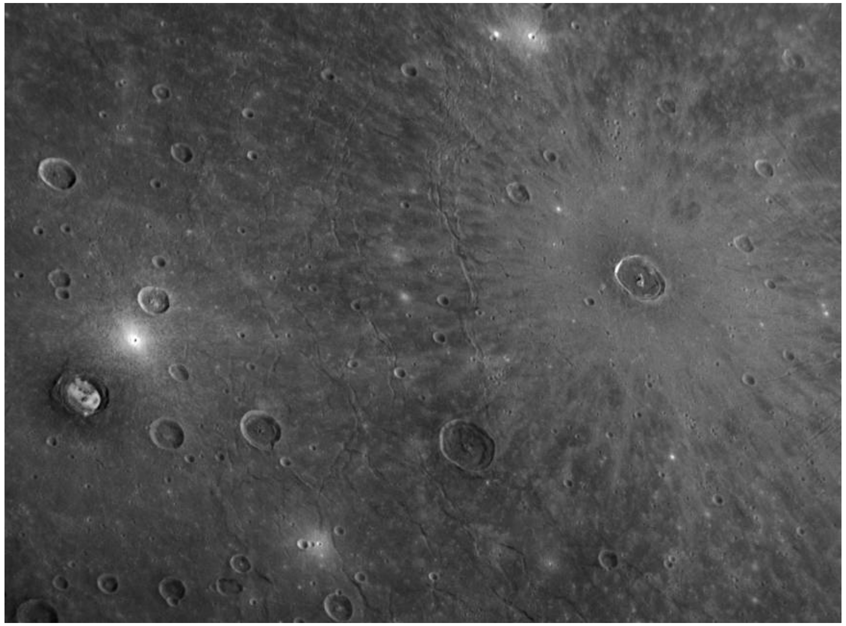
Atget



Basho

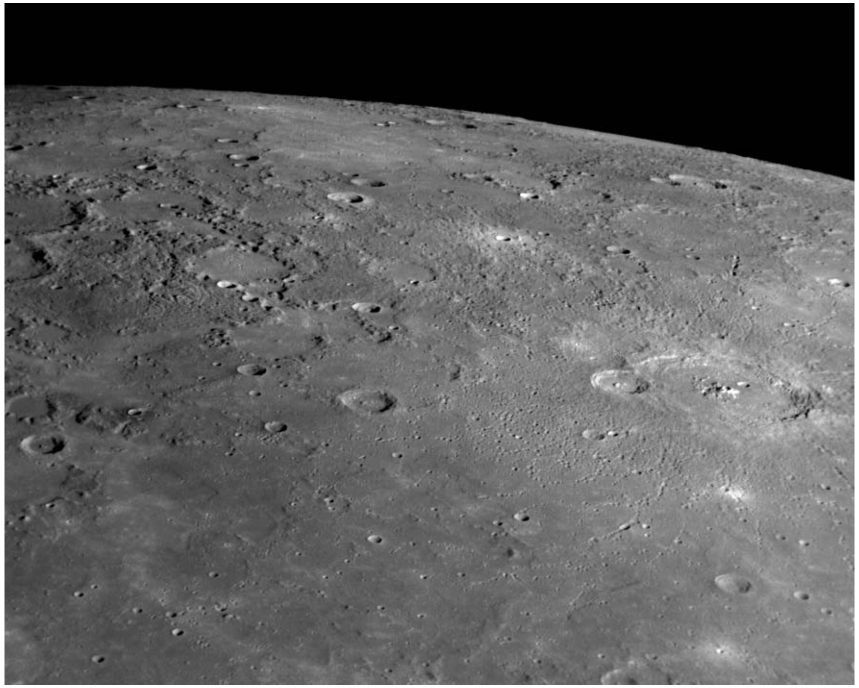
Images:
NASA/John Hopkins University

Mercury surface



Cunningham

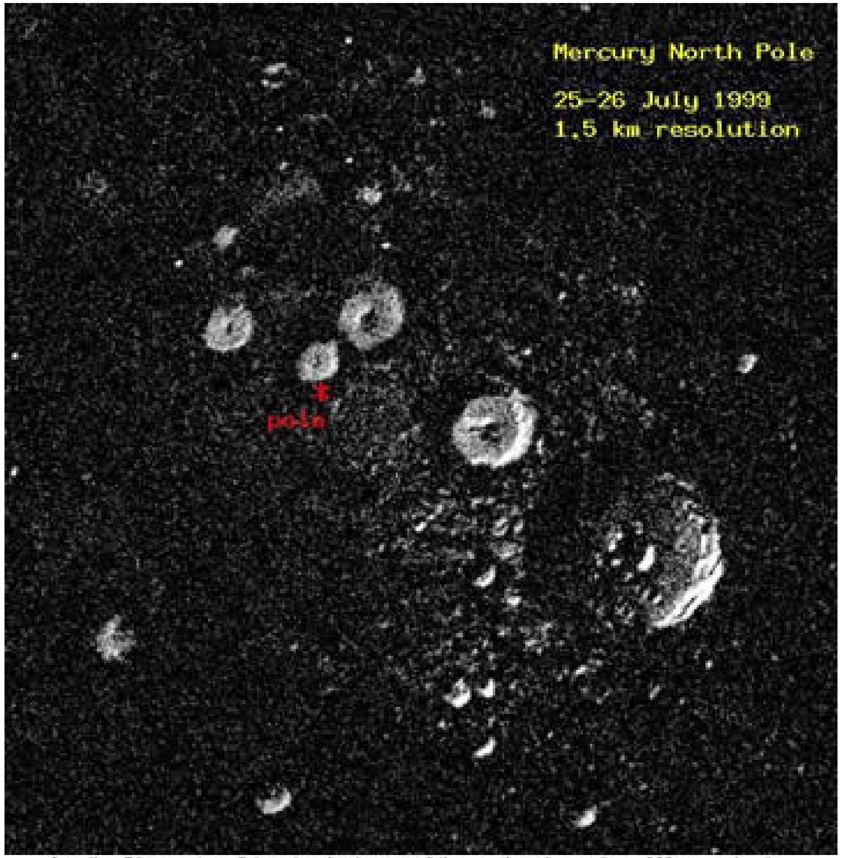
Oshkinson



Images:
NASA/John Hopkins University

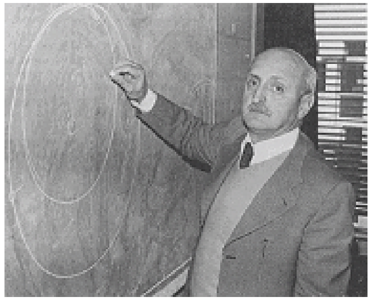
Polar deposits

- Polar deposits
  - Radio band detection
  - Small axial tilt
  - No „seasons“
  - Ice in permanently shadowed craters
  - Sulfites?

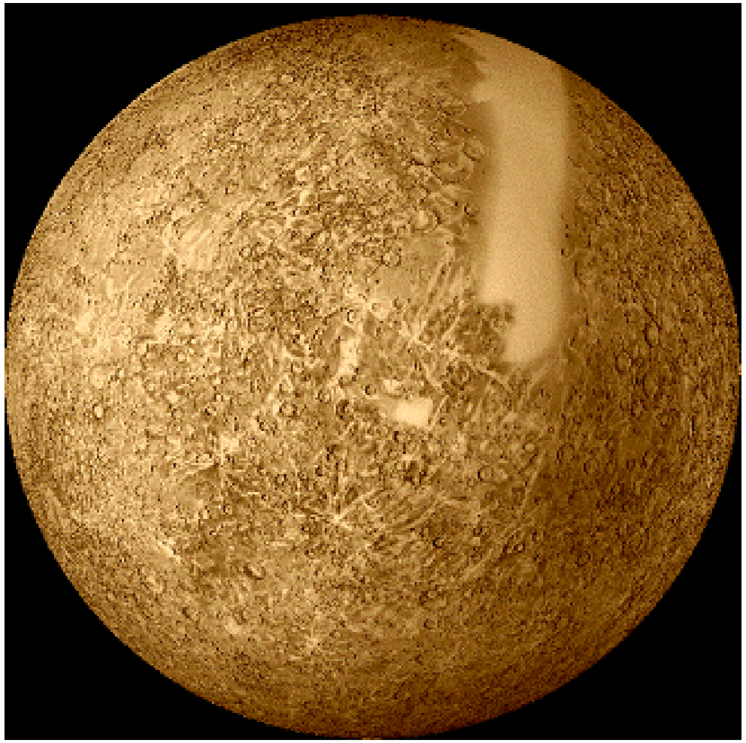


Arecibo Observatory S-band radar image of the north polar region of Mercury by J. Harmon, P. Perrilat, and M. Slade. The resolution is 1.5 kilometers (about 1 mile) and the image measures 450 kilometers on a side. The bright features are thought to be ice deposits on permanently shadowed crater floors.

BepiColombo: Mission targets



Giuseppe "Bepi" Colombo
(2.10.1920 – 20.2.1984)



Mercury surface as seem by Mariner 10

5th 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

...in collaboration with JAXA

BepiColombo

- Launch 8 / 9 2013
- Platform: Soyuz Fregat B
- MCS: Mercury composite spacecraft
- 6 year long journey

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

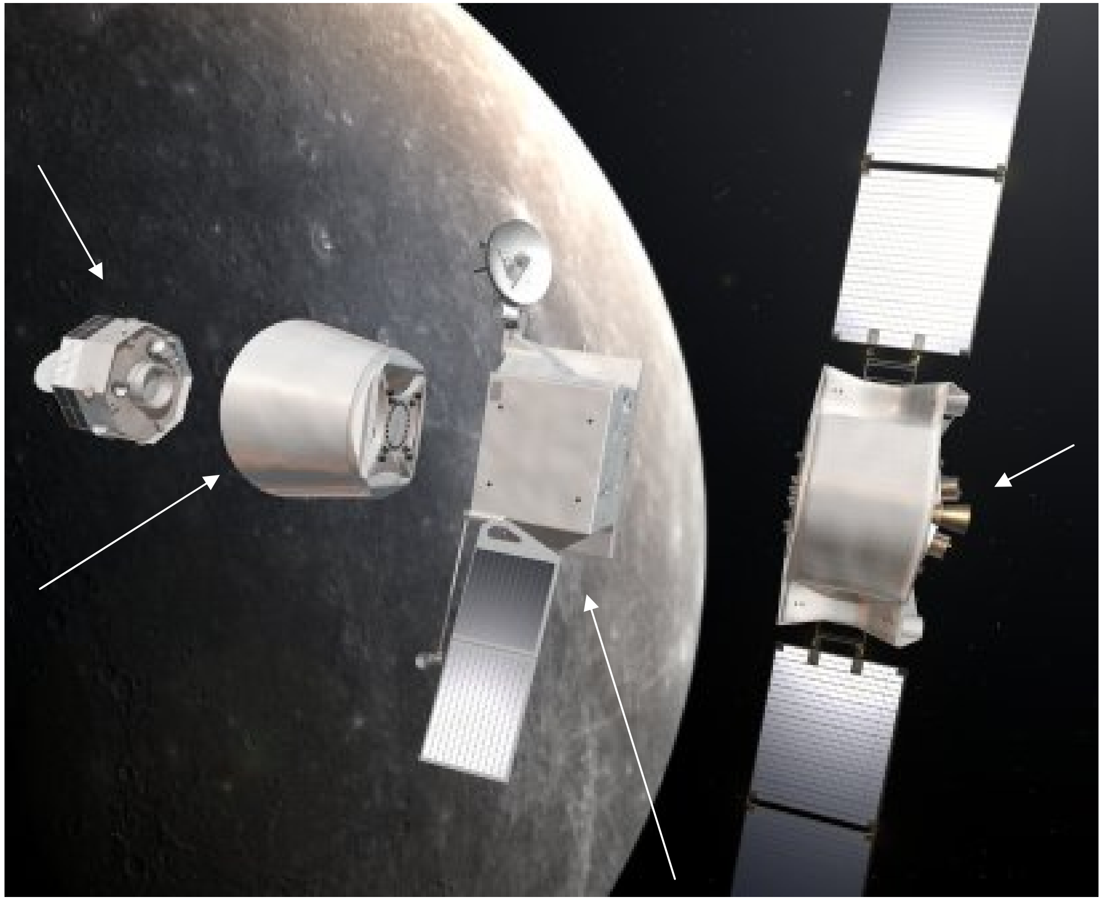
Mercury composite spacecraft (MCS)

BepiColombo

MCS exploded view

Mercury magnetospheric orbiter (MMO)

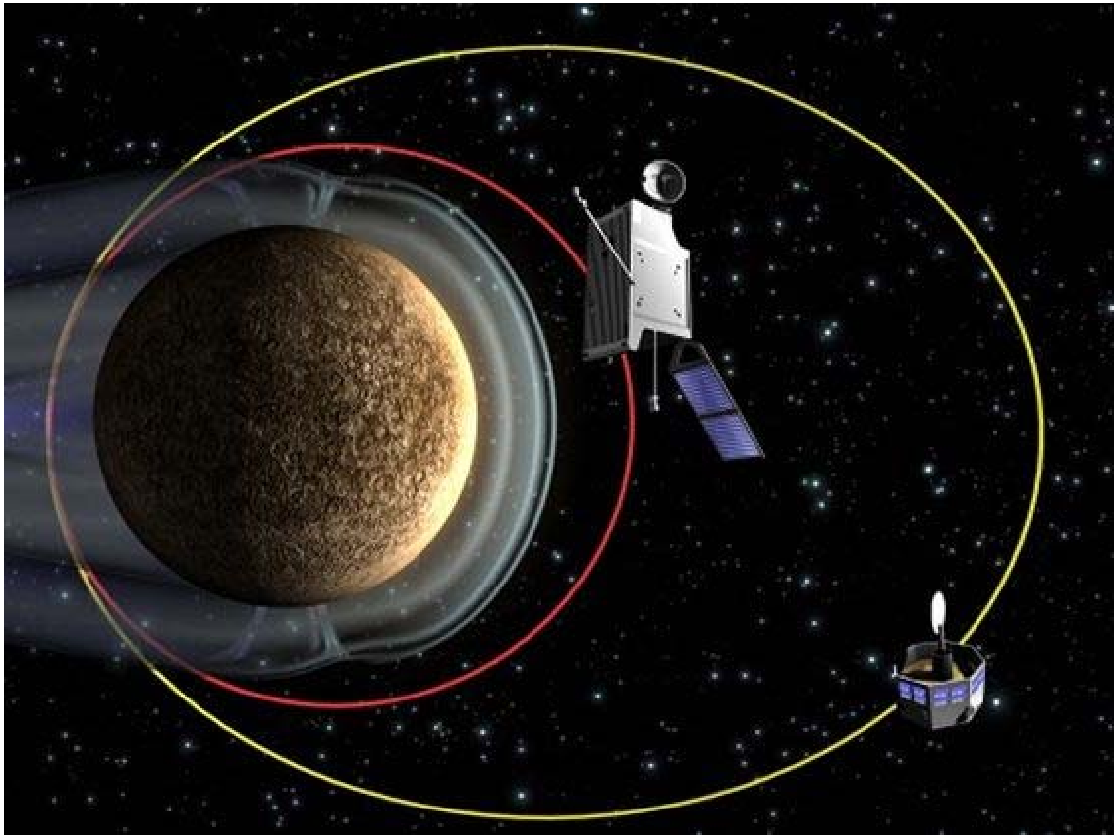
Solar shield (MOSIF)



Mercury transfer module (MTM)

Mercury planetary orbiter (MPO)

BepiColombo

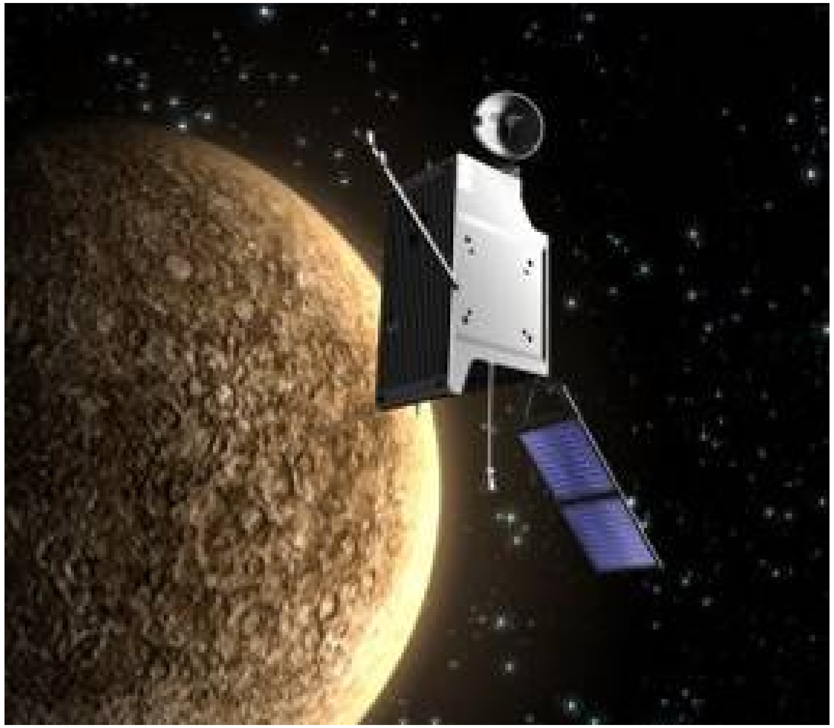


- Scheduled arrival: 2019
- On arrival: Deployment of MPO and MMO in their respective orbits
- 1 year of expected mission lifetime
- Possible prolongation by another year

Mercury planetary orbiter

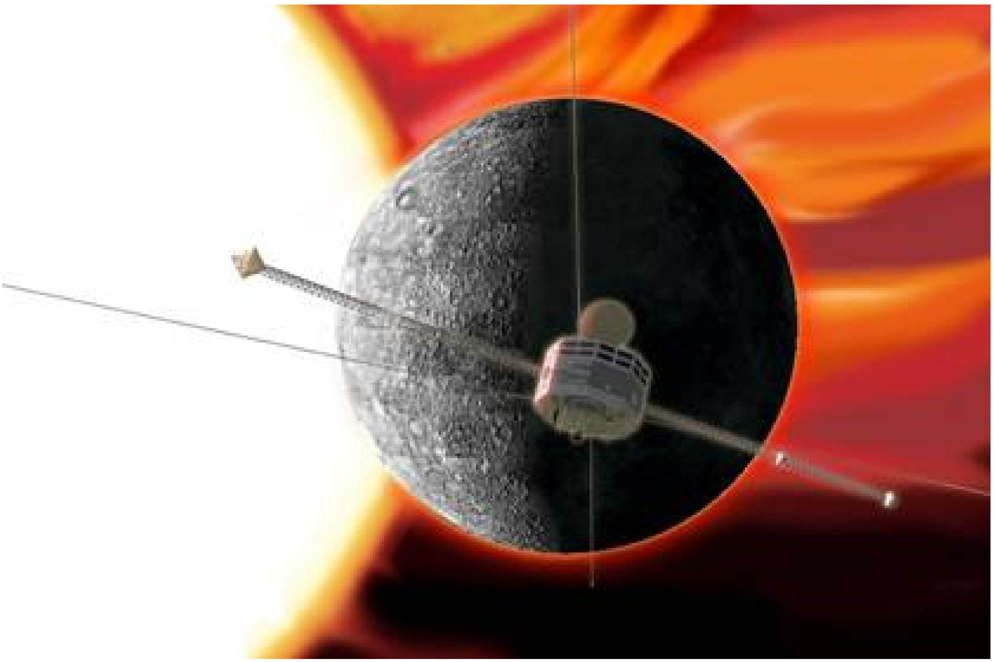
- **Instruments:**

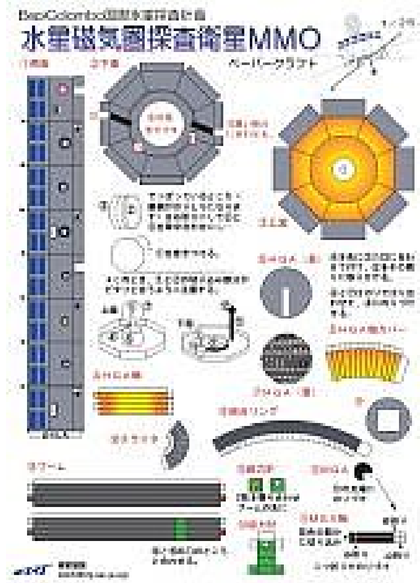
BELA:	Laser altimeter
ISA	Accelerometer
MERMAG:	Magnetometer
MERTIS:	Thermal infrared spectrometer
MGNS:	Gamma-ray and neutron spectrometer
MIXS:	x-ray spectrometer
MORE:	Radio science Ka-Band transponder
PHEBUS:	UV-Spectrometer
VIHI:	Visible Infrared Hyperspectral Imager
SERENA:	Neutral and Ionized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



Mercury magnetospheric orbiter

- **Instruments:**
  - MGF: Magnetometer
  - MPPE: Mercury plasma particle experiment
  - PWI: Plasma wave experiment
  - MSASI: Mercury Sodium Atmospheric Spectral Imager
  - MDM: Mercury dust monitor





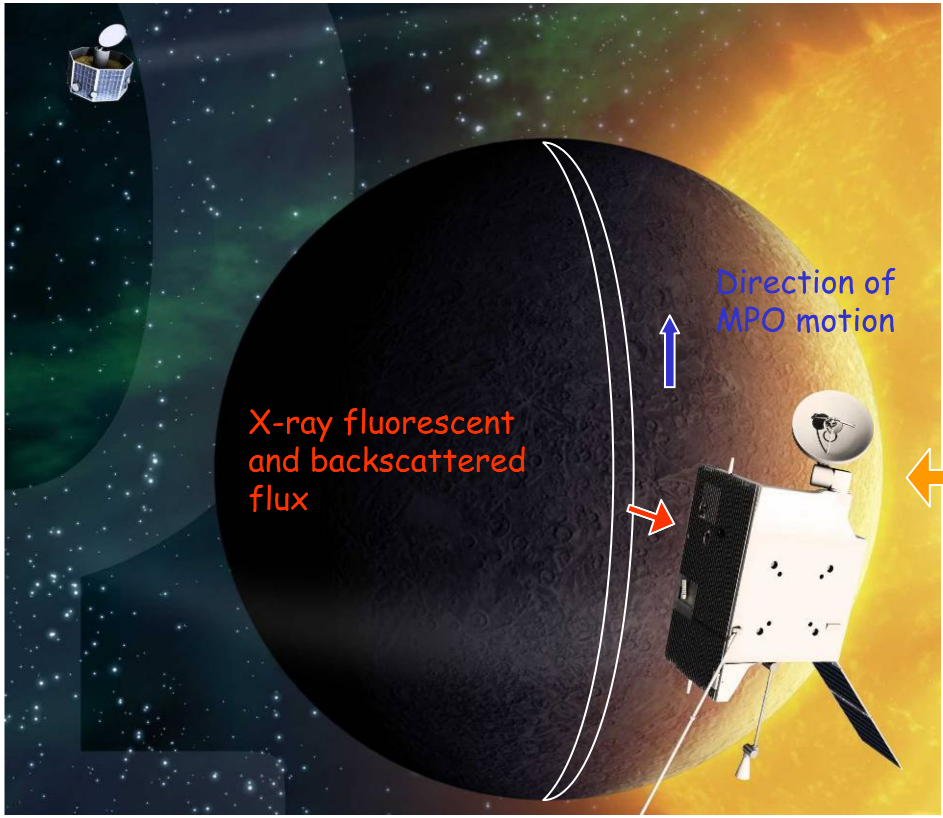
MMO construction kit...

The MIXS Instrument

- **Planetary XRF**
  - Incident solar X-rays induce X-ray fluorescence from the surface

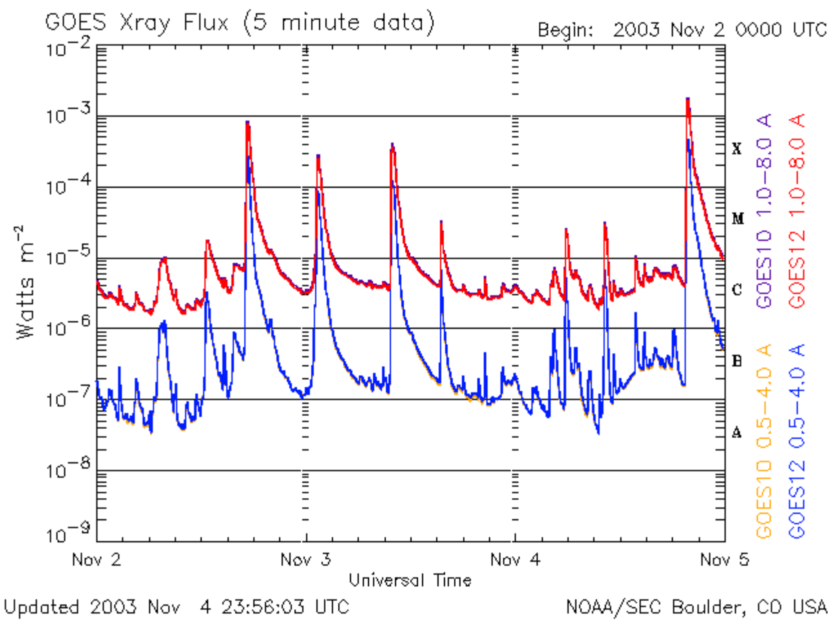
- MIXS : **M**ercury **I**maging **X**-ray **S**pectrometer
- Measure fluorescent X-rays from Mercury surface
- First few micron of depth are explored
- Detection of characteristic lines allows to determine element abundance

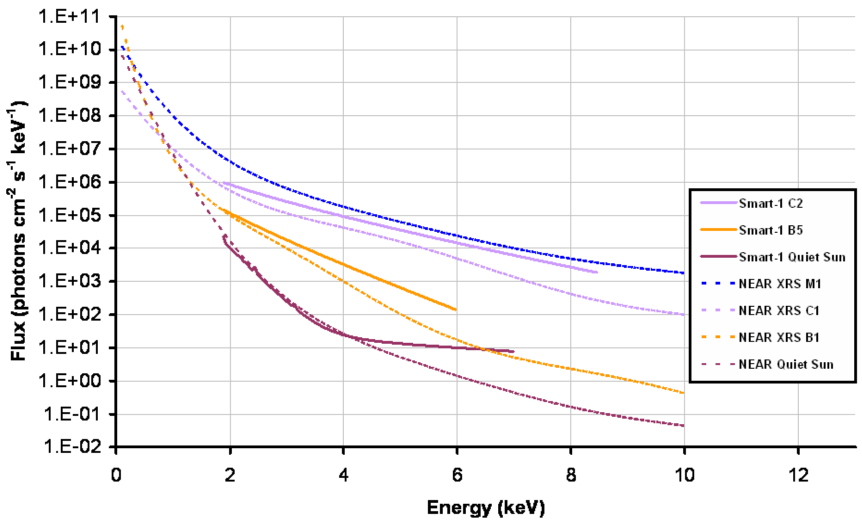
- Combination with thermal IR measurements (MERTIS) yields mineralogy information
- Combination with soft γ-ray measurements (MGNS) yields element abundance in depth of ~1 m



Solar coronal primary X-ray flux

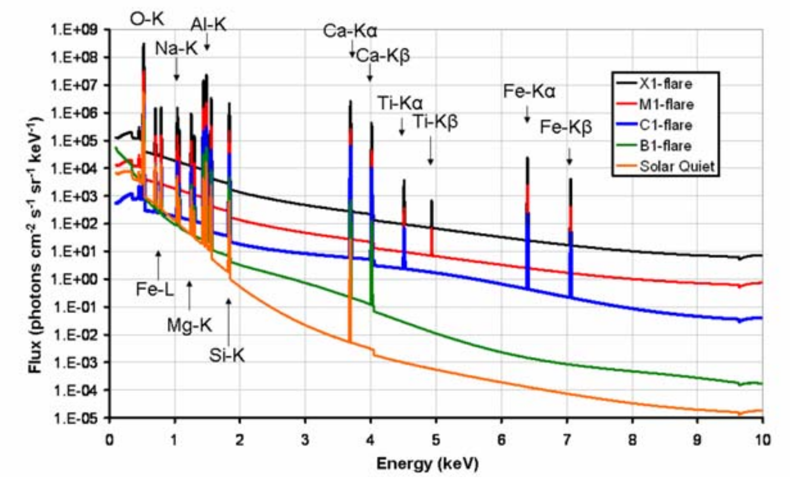
Solar input flux

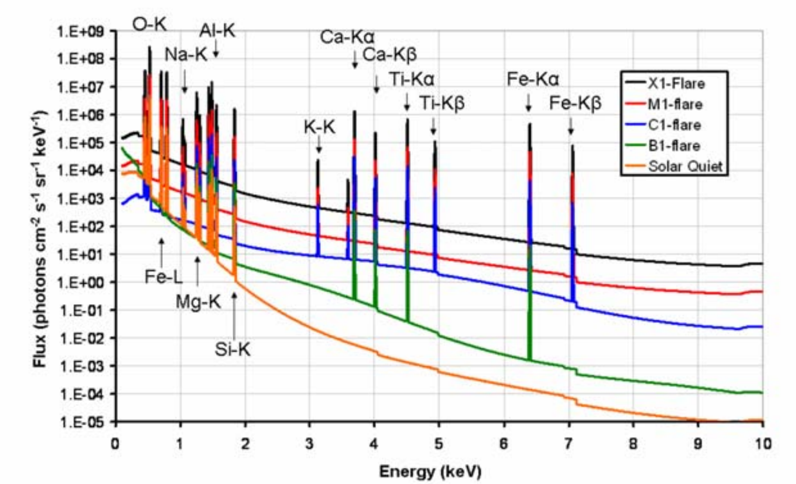




- Solar input changes with time & solar state
- Rapid changes of intensity and spectrum
- Precise intensity monitor needed!
- SIXS (Solar Intensity X-ray Spectrometer)

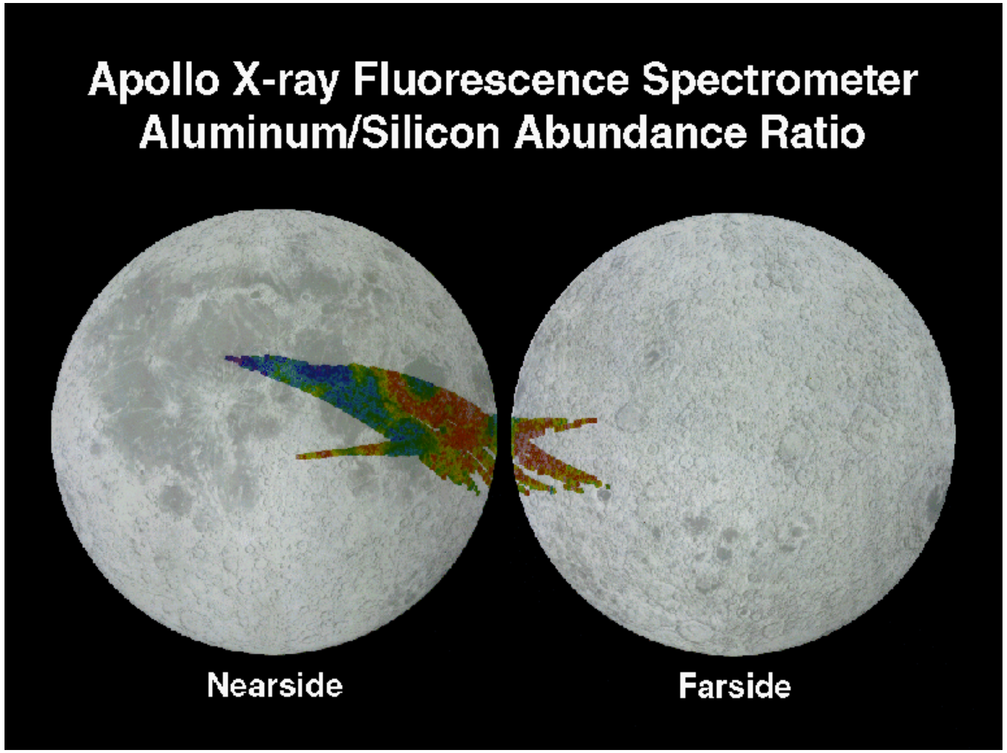
Surface response





Established method

- **Experiments**
  - Apollo 15 and 16 (Moon)
  - NEAR (Eros)
  - Hayabusa (Itokawa)
  - SMART-1 (Moon)
  - Chandrayaan (Moon)
  - Selene (Moon)
  - MESSENGER (Mercury)
- ***All non-imaging***



Example: MESSENGER XRS

Schlemm et al. Space Sci Rev (2007) 131: 393–415

- **X-ray Spectrometer:**
  - Gas proportional counters
  - Sensitive on Mg, Al, Si, S, Ca, Ti Fe
  - Low energy threshold ~800 eV
  - Energy resolution @ 5.9 keV ~14 % (800 eV)
  - 3 channels, differential countrates
  - Beryllium, Magnesium and Aluminum filters
  - Collimated instrument

Whats new with MIXS?

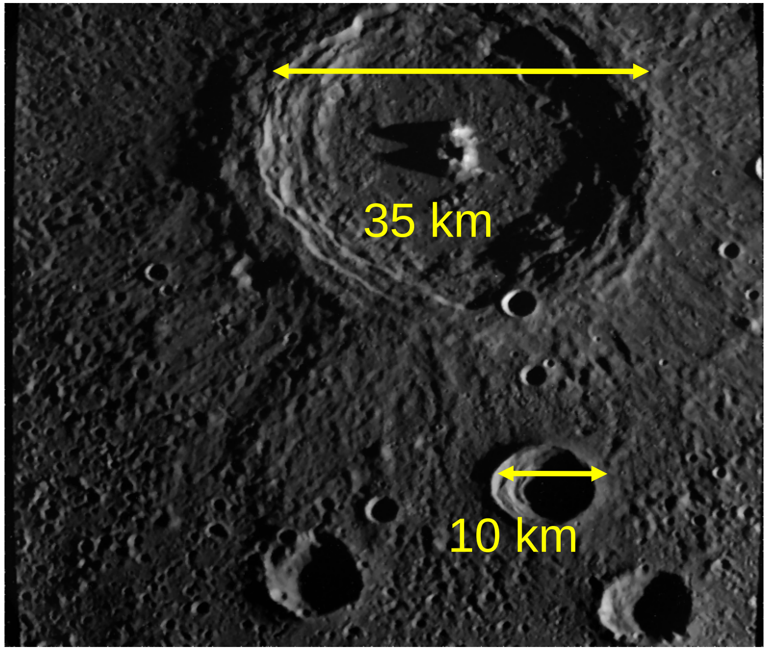
MIXS is the first planetary XRF instrument using an imaging type of optics, not just a collimator
Much better spatial resolution
Look inside craters, identify more features

MIXS is the first planetary XRF instrument using an energy dispersive solid-state detector
Excellent energy resolution
Allows to observe the important lines of Iron, Silicon, Magnesium etc. directly!

MIXS science targets

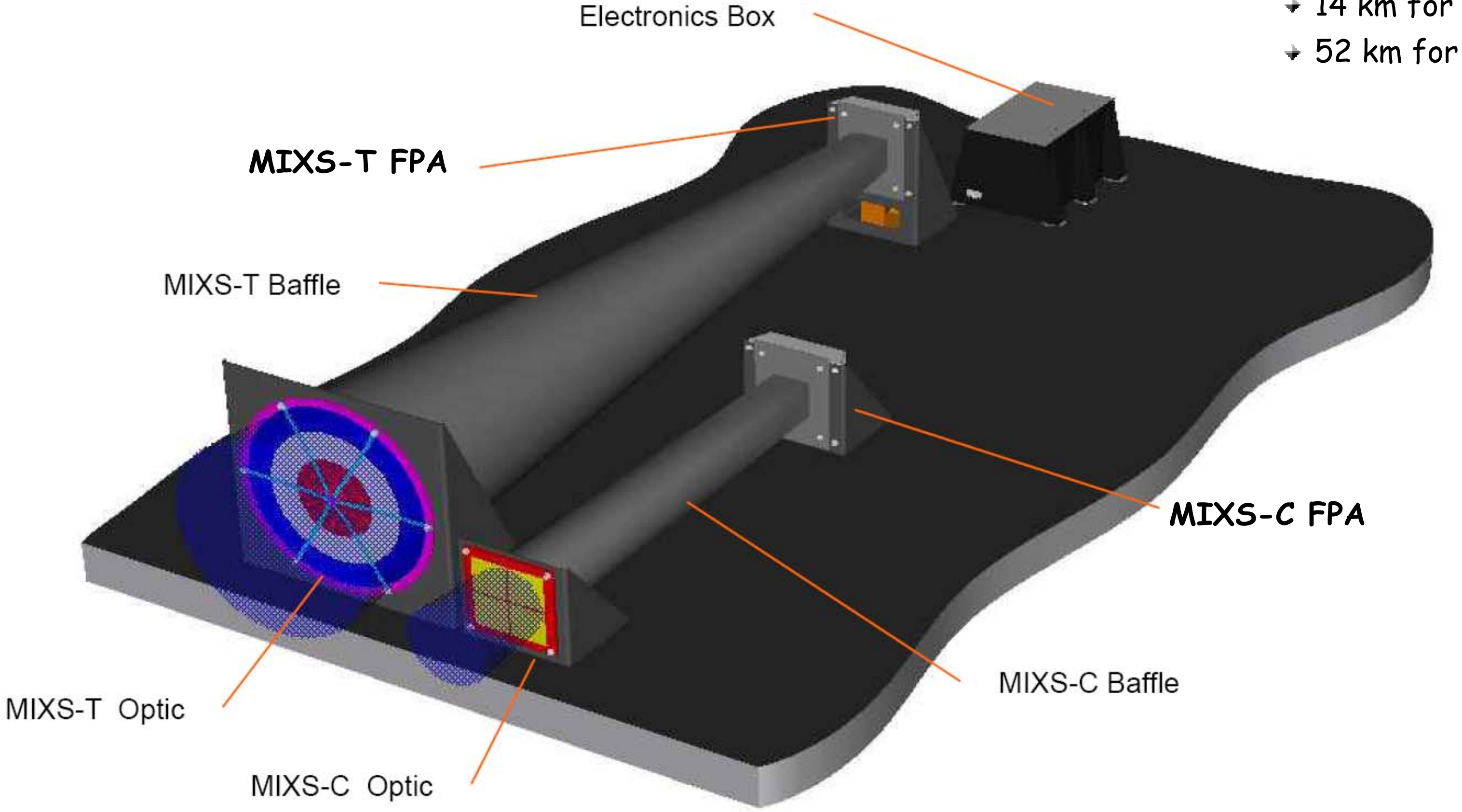
- **Primary targets:**
  - Average composition of Mercury's crust
  - Compositions of the major terrains
  - Composition inside craters and crater structures
  - Detection of iron globally and locally

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

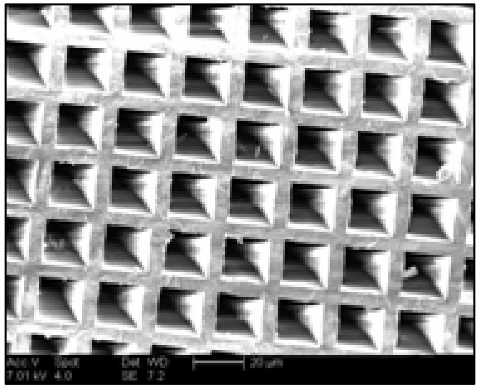


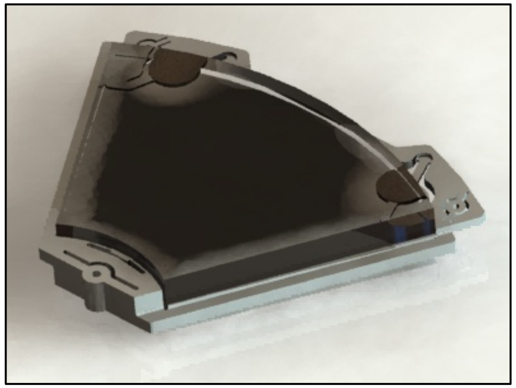
MIXS

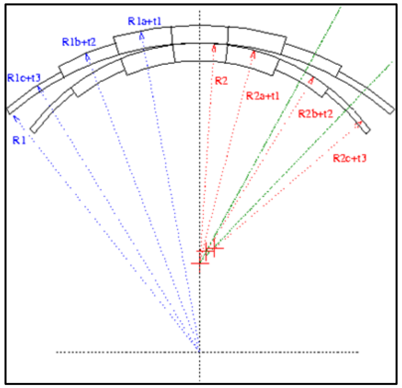
- **Two cameras**
  - Same focal plane detector
  - Different optics
  - Collimator (MIXS-C) and Telescope (MIXS-T)
  - Common electronics box
- Telescope: MPC optics
- MIXS-C: Wide field imaging
- MIXS-T: Precise Mapping
- **Footprint size:**
  - 14 km for periherm
  - 52 km for apoherm



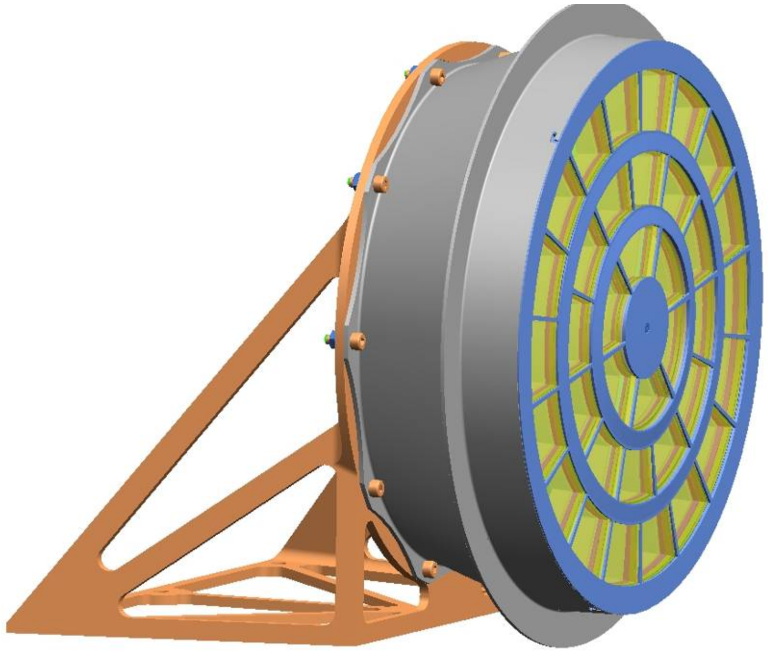
MIXS-T telescope mirror optics



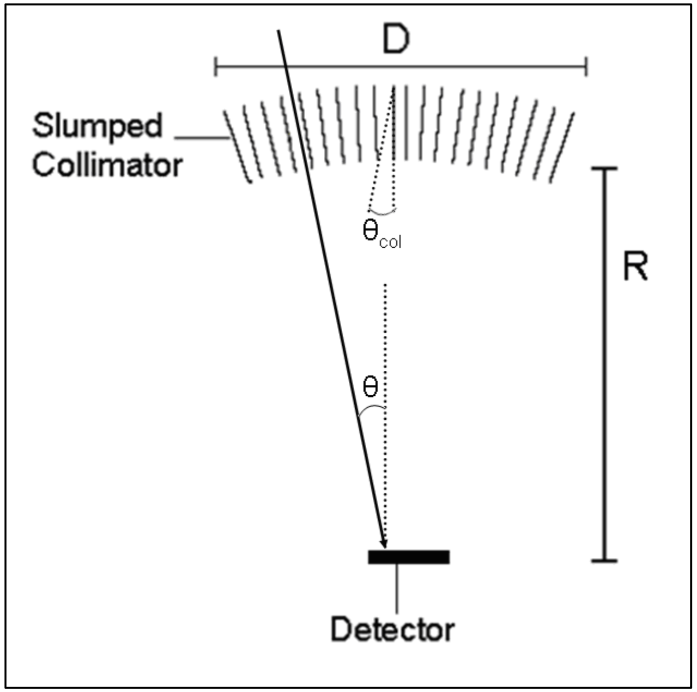


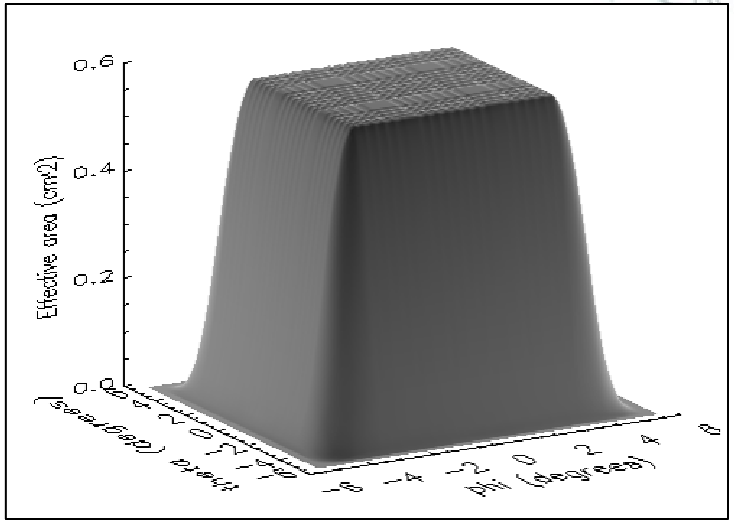


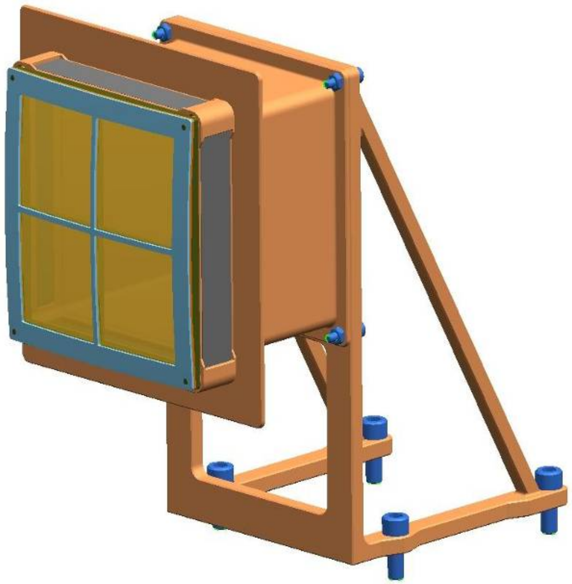
- **MCP mirror**
  - 3 concentrical rings
  - MCP pore width: 20 μm
  - Aperture: 21 cm
  - Focal length: 1 m
  - Effective area : 120 cm^2 @ 1 keV
    15 cm^2 @ 10 keV
  - Wolter type 1 geometry (hyperboloid / paraboloid)
  - Conical approximation
  - Iridium-coated lead silicate glass
  - Angular resolution: ~ 1.7 arcmin FWHM
  - Total FOV: 1° FWZM



MIXS-C collimator Optics







- **MIXS-C collimator:**
  - Much simpler system
  - Radially bent collimator with 8 degree fov
  - Flat response
  - Uses a 2x2 array of square pore square packed MCPs
  - 64mm x 64mm aperture
  - Detector distance 230mm

DEPFETs for MIXS?

MIXS detector key requirements

- *Parameters*
  - Format
    - ↳1.92 x 1.92 cm^2
    - ↳ 64 x 64 pixels
    - ↳ 300 x 300 μm size
  - Energy resolution
    - ↳ 200 eV FWHM @ 1 keV
    - ↳ QE > of 80 % @ 500 eV
  - Time resolution
    - ↳ < 1 ms due to dynamics
  - Radiation hardness
    - ↳ ~ 20 krad ionizing
    - ↳ 3 x 10^{10} 10 MeV p/cm^2

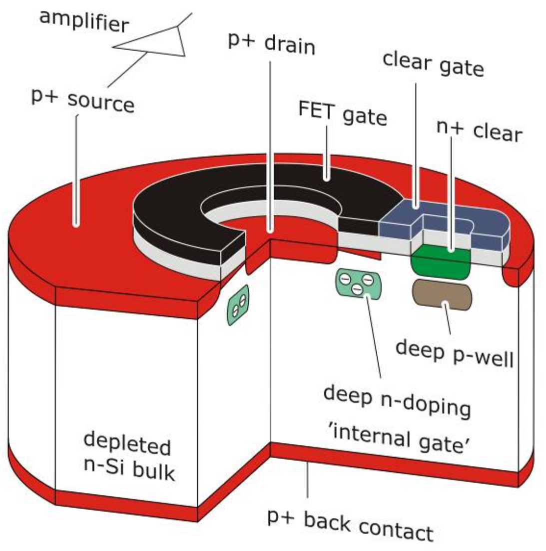
    equivalent to 1.11 x 10^{11} 1 MeV n/cm^2

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

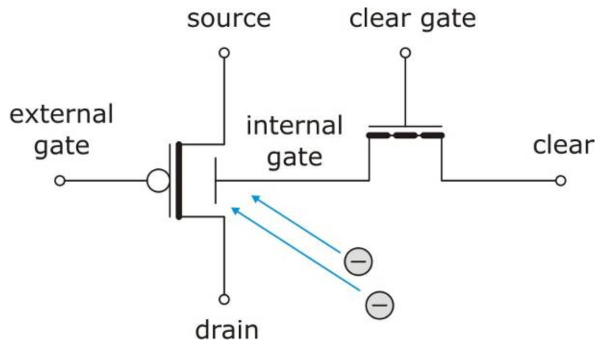
Mercury key element emission lines

DEPFET

- **principle**
  - p-FET on depleted n-bulk
  - circular shape
  - signal charge collected in potential minimum below FET channel
  - transistor current modulation 300 pA/el.
- **combined function of sensor & amplifier**
  - low capacitance (20 fF) and noise
    - ↳ **excellent spectroscopic performance**
  - complete clearing of signal charge
    - ↳ **no reset noise**
  - charge storage capability
    - ↳ **readout on demand**
  - non-destructive readout
    - ↳ **potential of repetitive readout**
  - backside illuminated, fully depleted
    - ↳ **quantum efficiency**

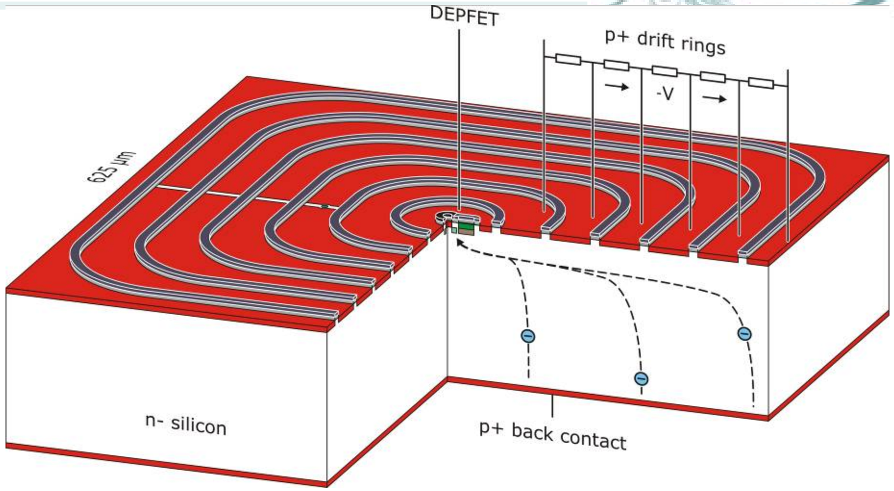


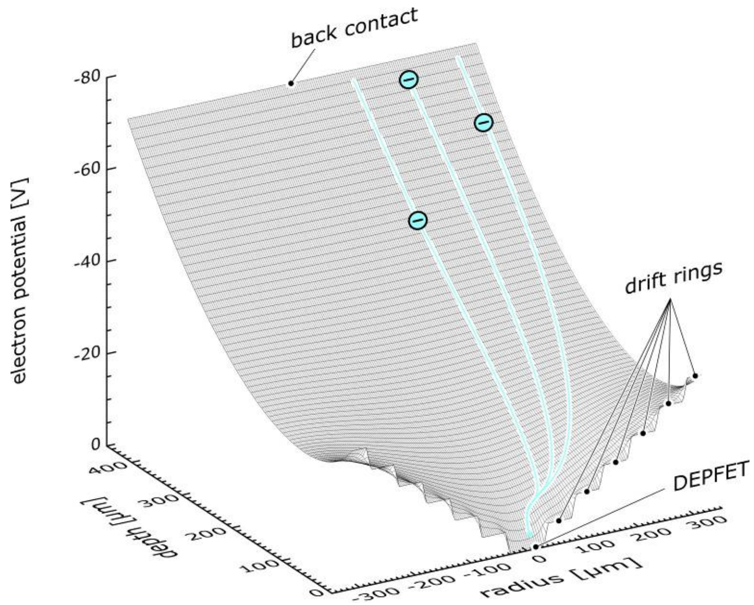
DEPFET: **DE**pleted **P**-channel **F**ield **E**ffect **T**ransistor



DEPFET - pixel size

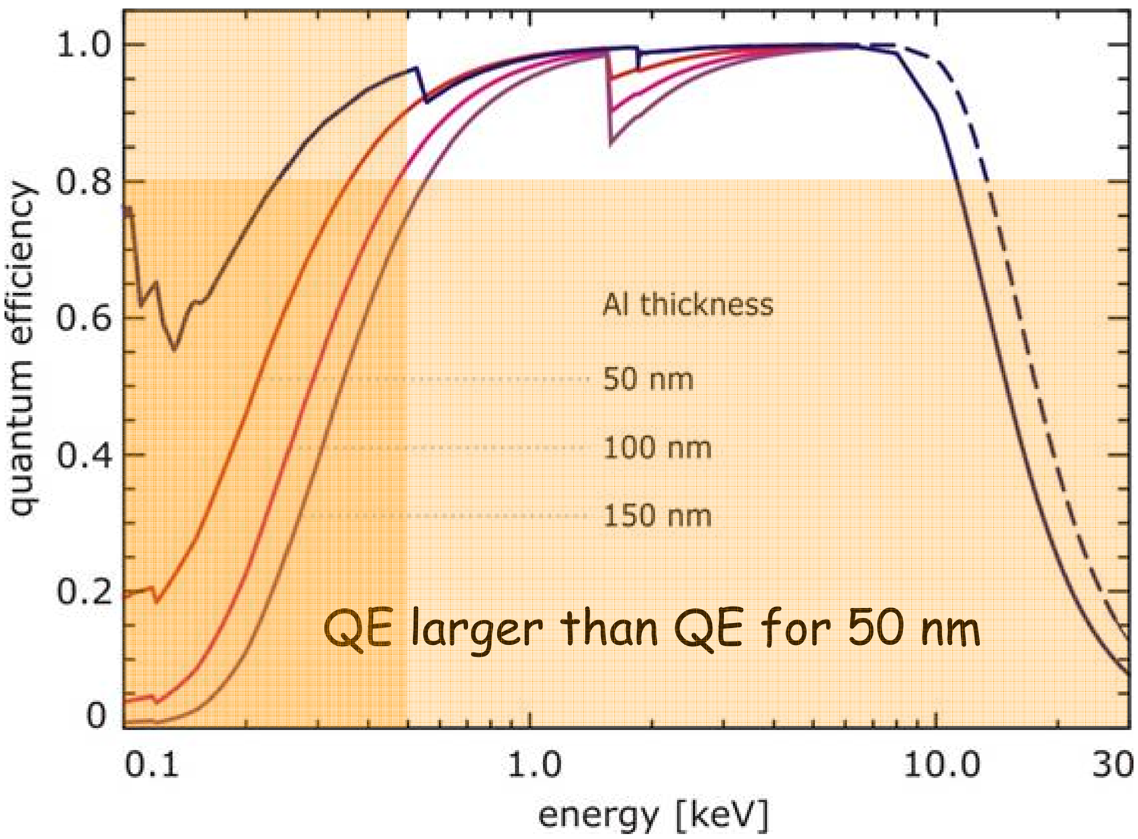
- **Macro Pixel Detector (MPD)**
  - ▷ SDD & DEPFET
    - ↳ large area & low noise
    - ↳ scalable pixel size
      50 µm … 1 cm²
    - ↳ matched to telescope resolution
  - ▷ common backside diode & bulk
    - ↳ thin entrance window
    - ↳ fill factor 1
  - ▷ individually addressable pixels
    - ↳ flexible readout
    - ↳ windowing
  - ▷ 1 active row, other pixels off
    - ↳ low power consumption
  - ▷ column parallel operation
    - ↳ fast processing





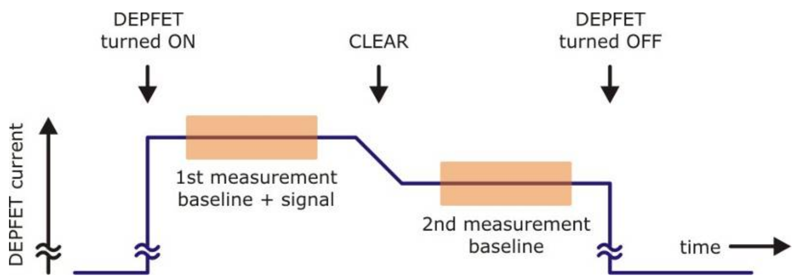
Entrance window configuration

- **Entrance window:**
  - Thin & homogeneous
  - 100% fill factor
  - Thin aluminum layer necessary (~30 nm)
  - Light blocking filter
  - Required for entrance window radiation hardness



DEPFET operation

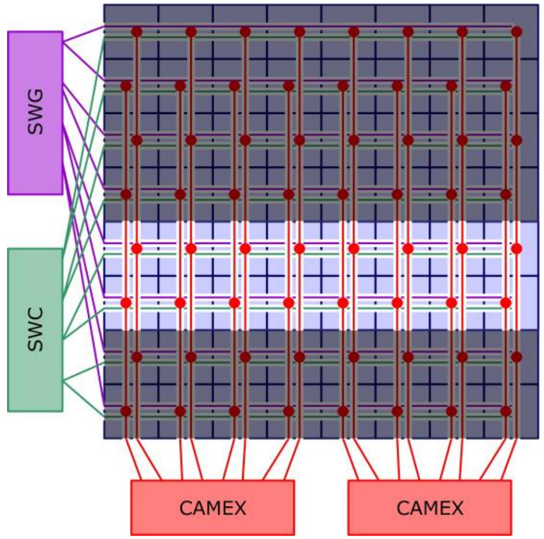
- readout sequence



- ▷ 1st measurement: signal + baseline
- ▷ clear: removal of signal charges
- ▷ 2nd measurement: baseline

- ▷ difference = signal
- ▷ complete clear is mandatory!

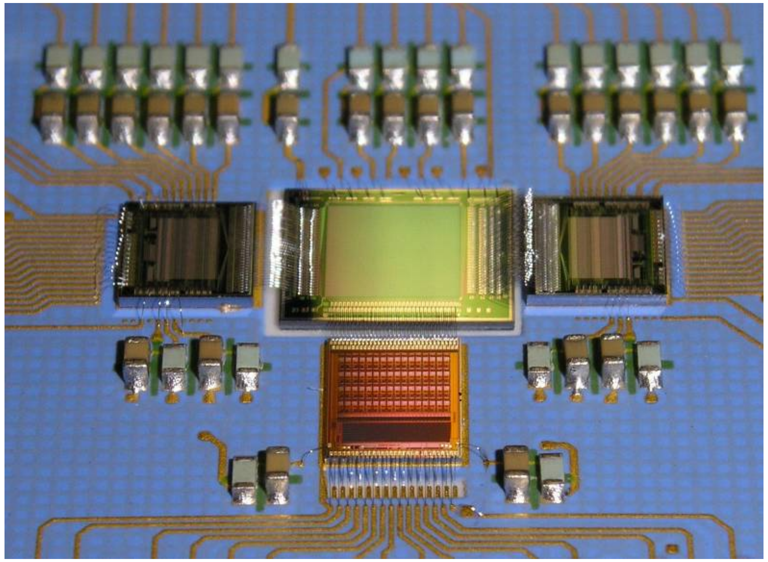
- matrix operation

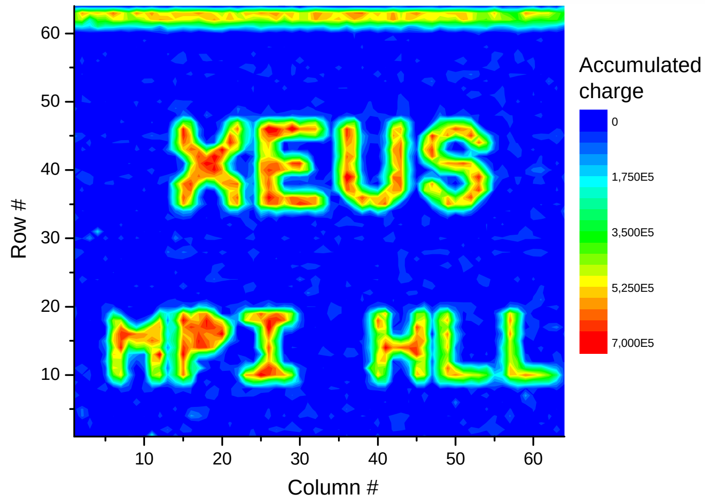


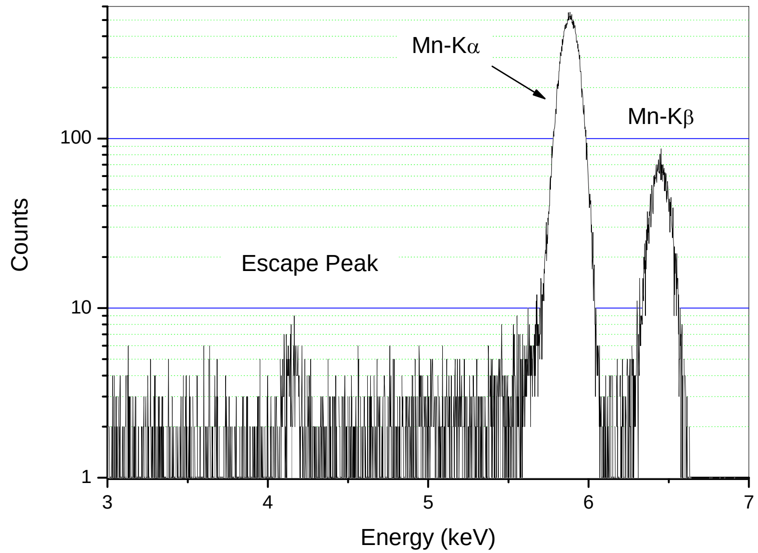
- ▷ horizontal supply lines, row selection
- ▷ vertical signal lines
- ▷ 1 active row, other pixels integrating

- option to speed up (1)
  - ▷ readout parallelisation
  - ▷ 2 x readout channels, 2 active rows

Prototype matrix devices



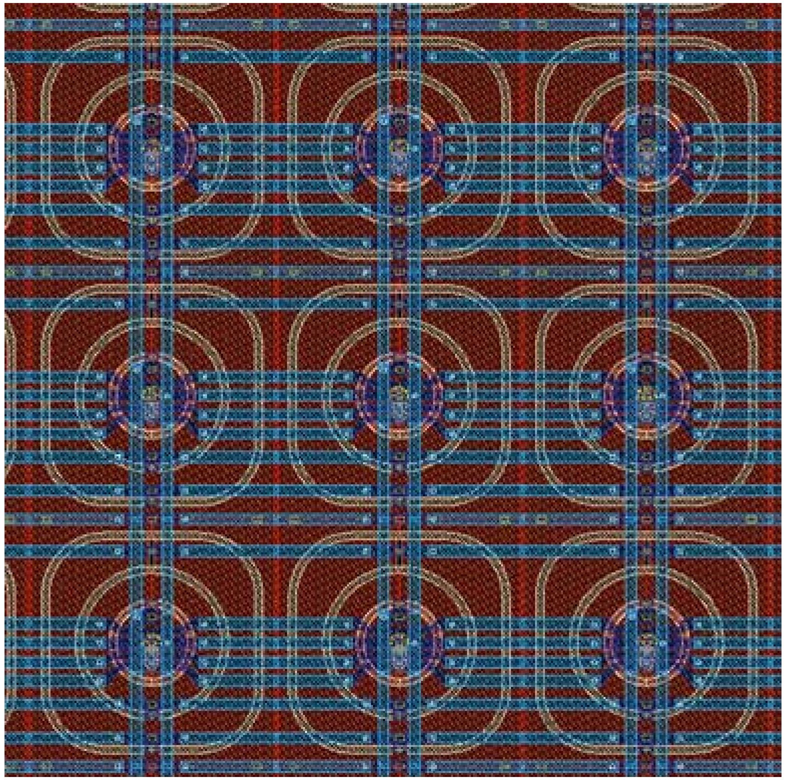




- *Devices:*
  - 64 x 64 pixels
  - Prototypes for XEUS
  - 75 x 75 μm^2 pixels
  - 132 eV FWHM energy resolution @ 5.9 keV

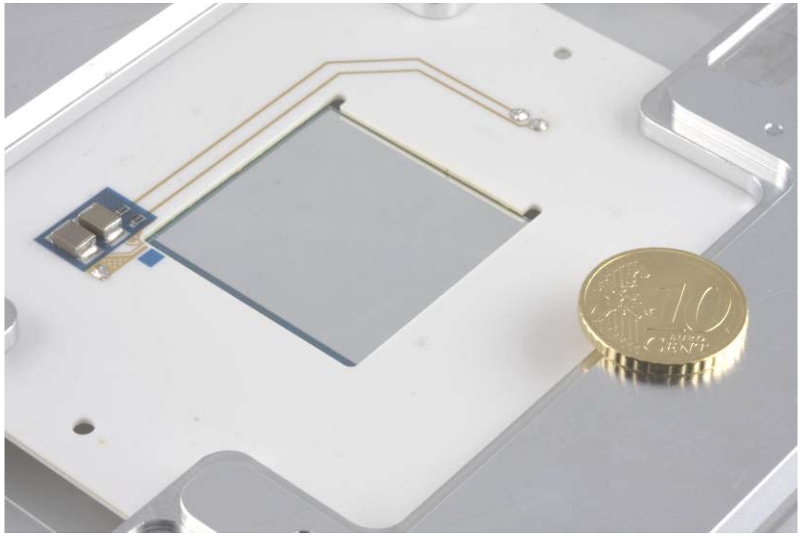
Macropixel layouts

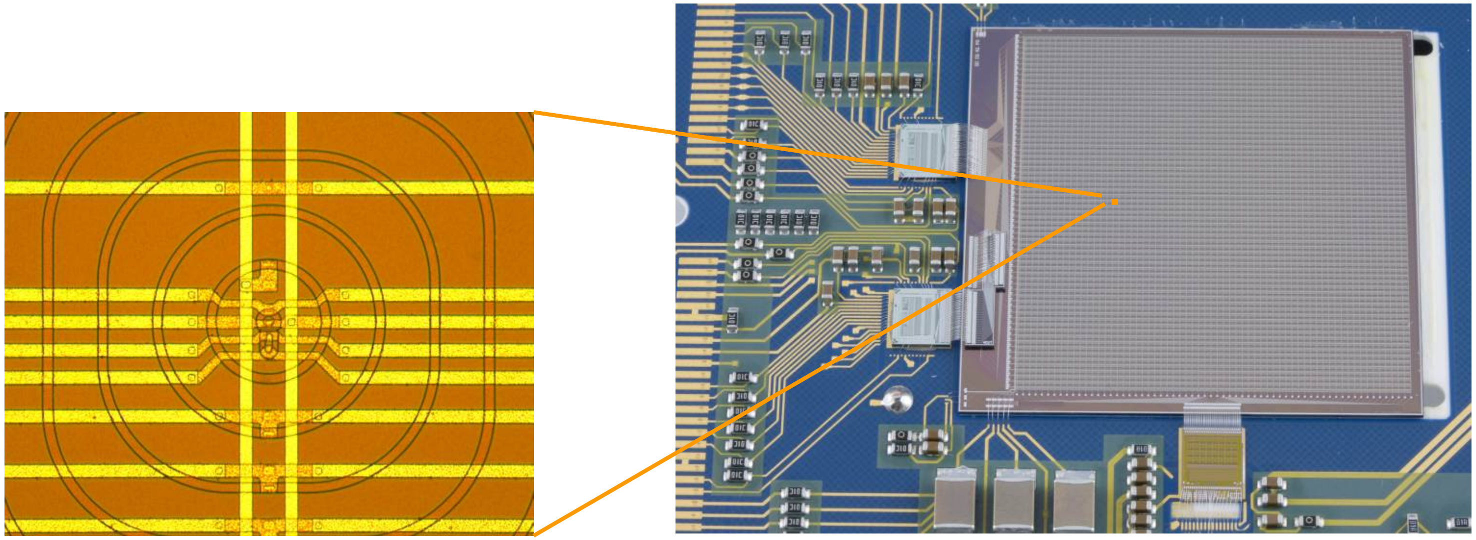
- 300 x 300 μm^2 pixel size
- 3 driftrings per pixel
- Drain & driftring voltage support grid
- Max. driftring voltages ~60-80 V
- No sensitivity gap between pixels
- But: Split events effectively "reduce" QE when sensor is irradiated



Prototype Macropixel devices

- **Demonstrator**
  - ▷ pixel 500 x 500 µm²
  - ▷ format 64 x 64 pixels
    3.2 x 3.2 cm²
  - ▷ frametime 0.45 msec
  - ▷ temperature -80 … -90 °C
  - ▷ representative scalable results





Test results

- **spectroscopy**
  - ▷ flat field illumination
  - ▷ energy resolution

    (FWHM @ 5.9 keV)

    126 eV (singles)

    129 eV (all events)
  - ▷ peak/background ratio

    3.000:1
  - ▷ pattern statistics

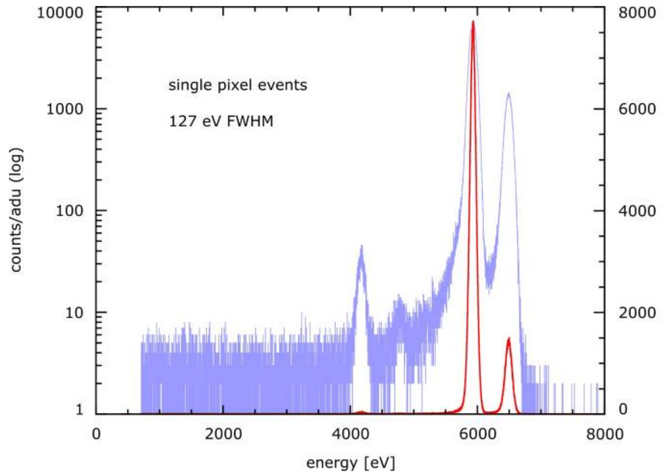
    63 % singles

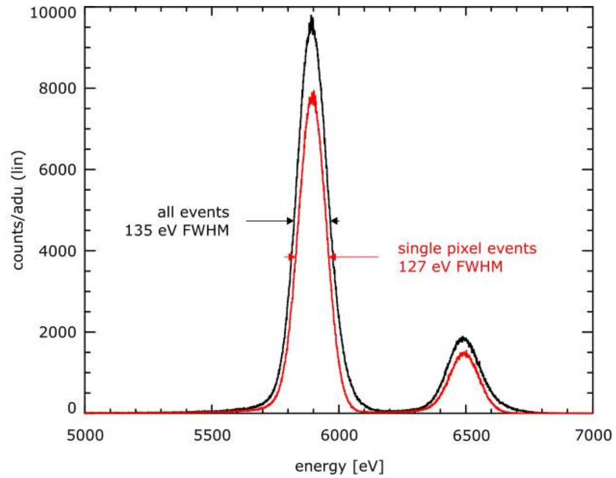
    29 % doubles
  - ▷ (in)homogeneity

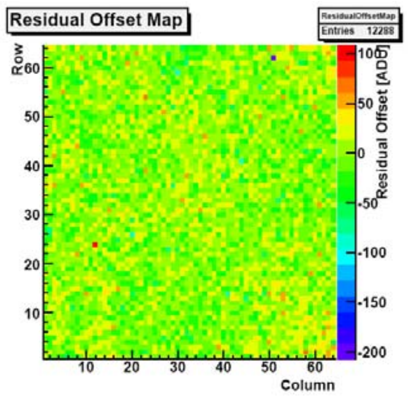
    0.3 % offset

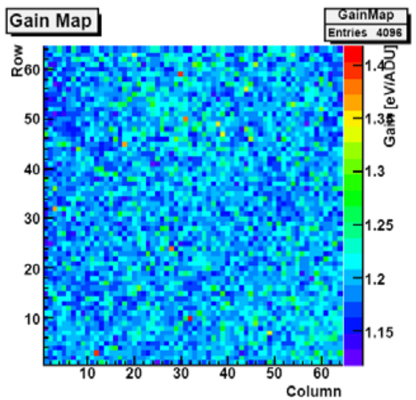
    2.3 % gain

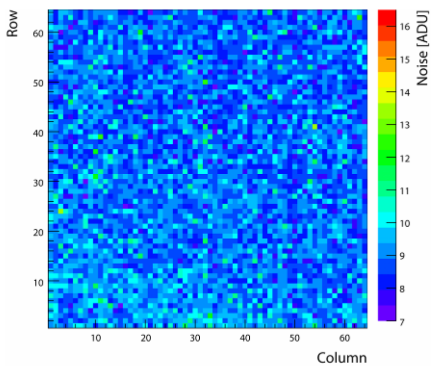
    9.0 % noise









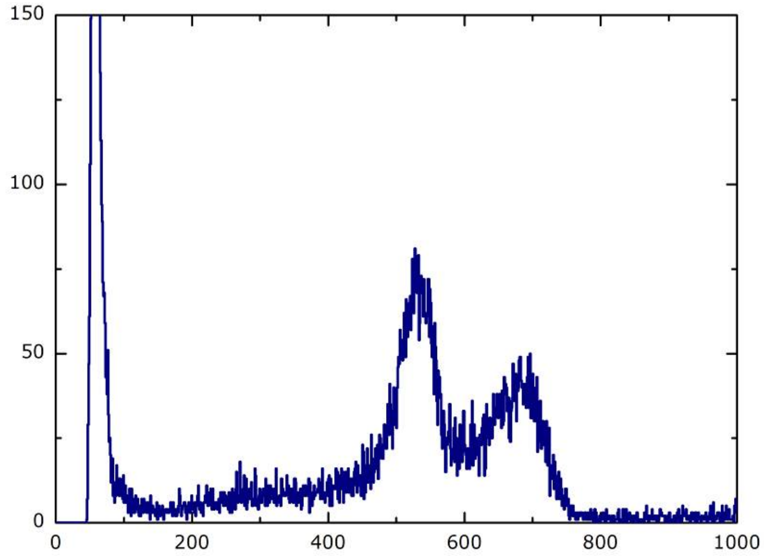


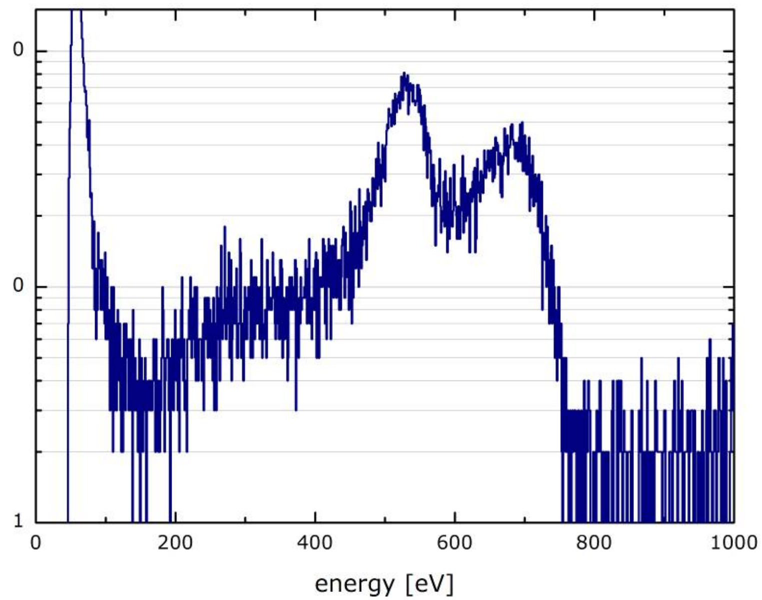
Test results

- **low energy response**
  - ▷ O-K line 525 eV
  - ▷ Fe-L lines 615 eV

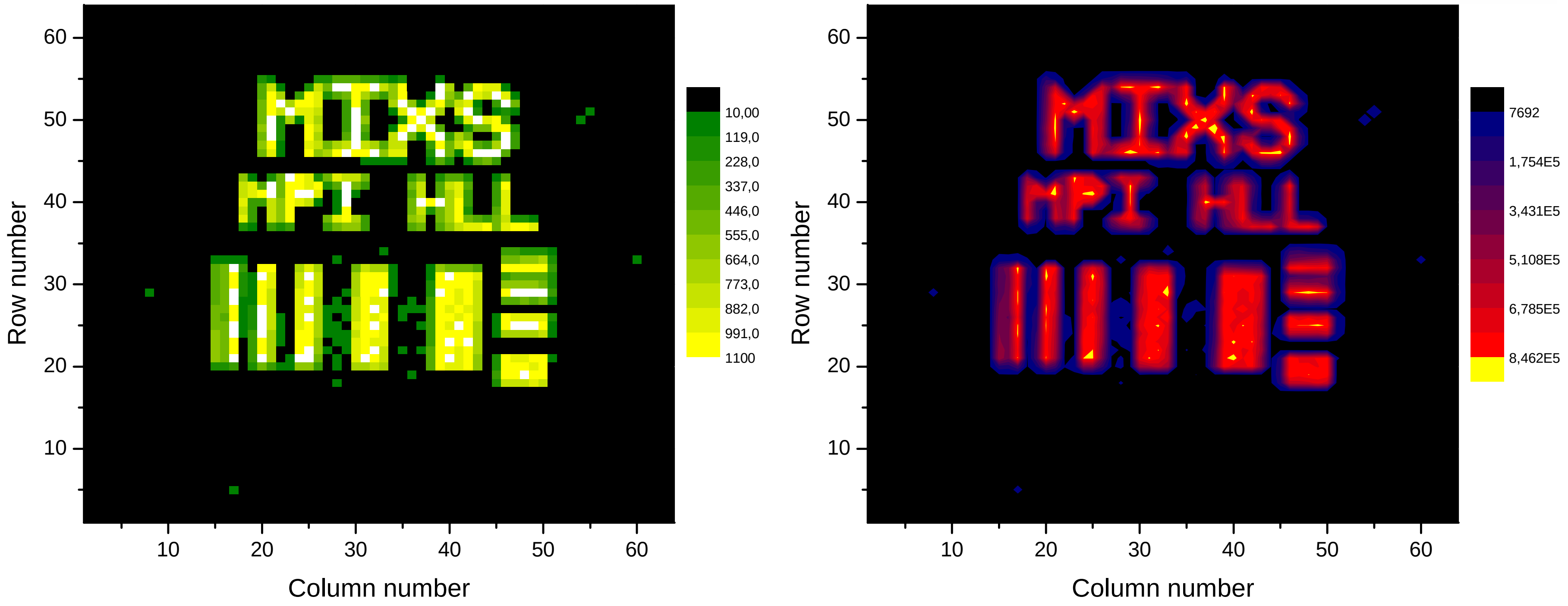
    :

    717 eV



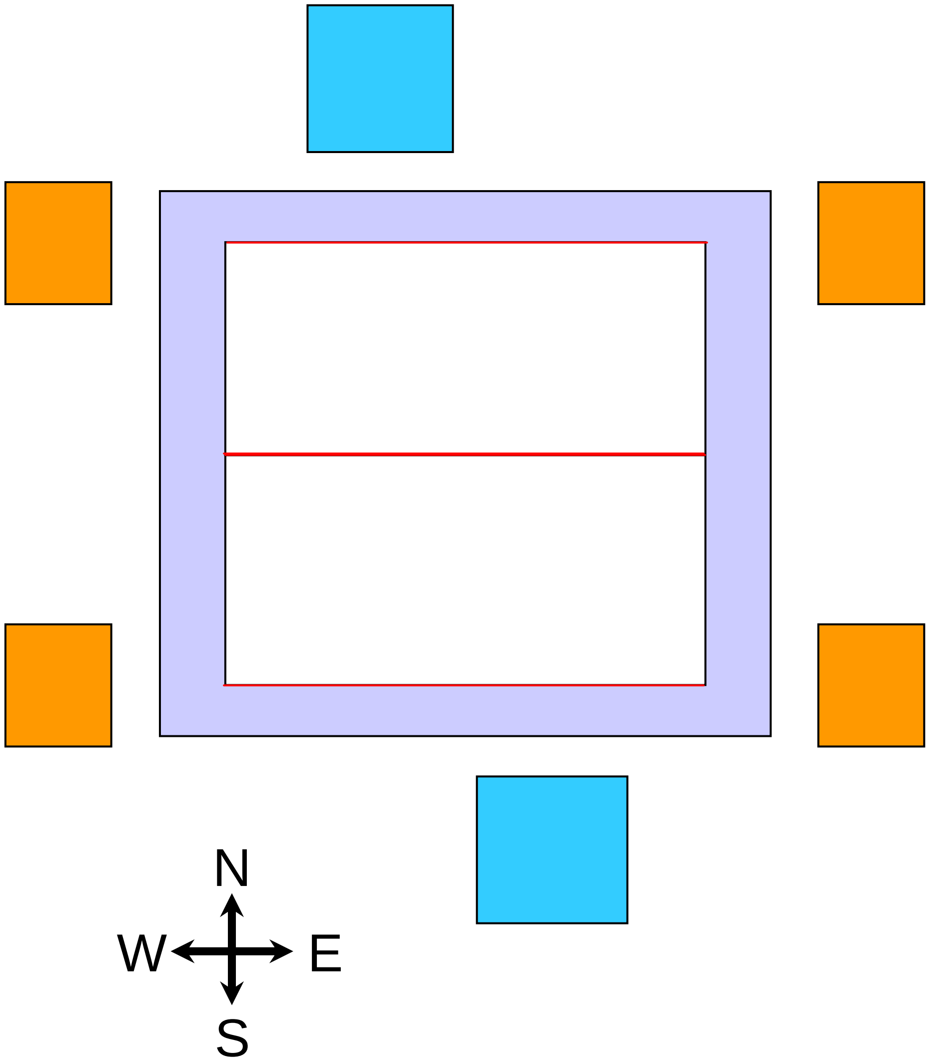


Measurements



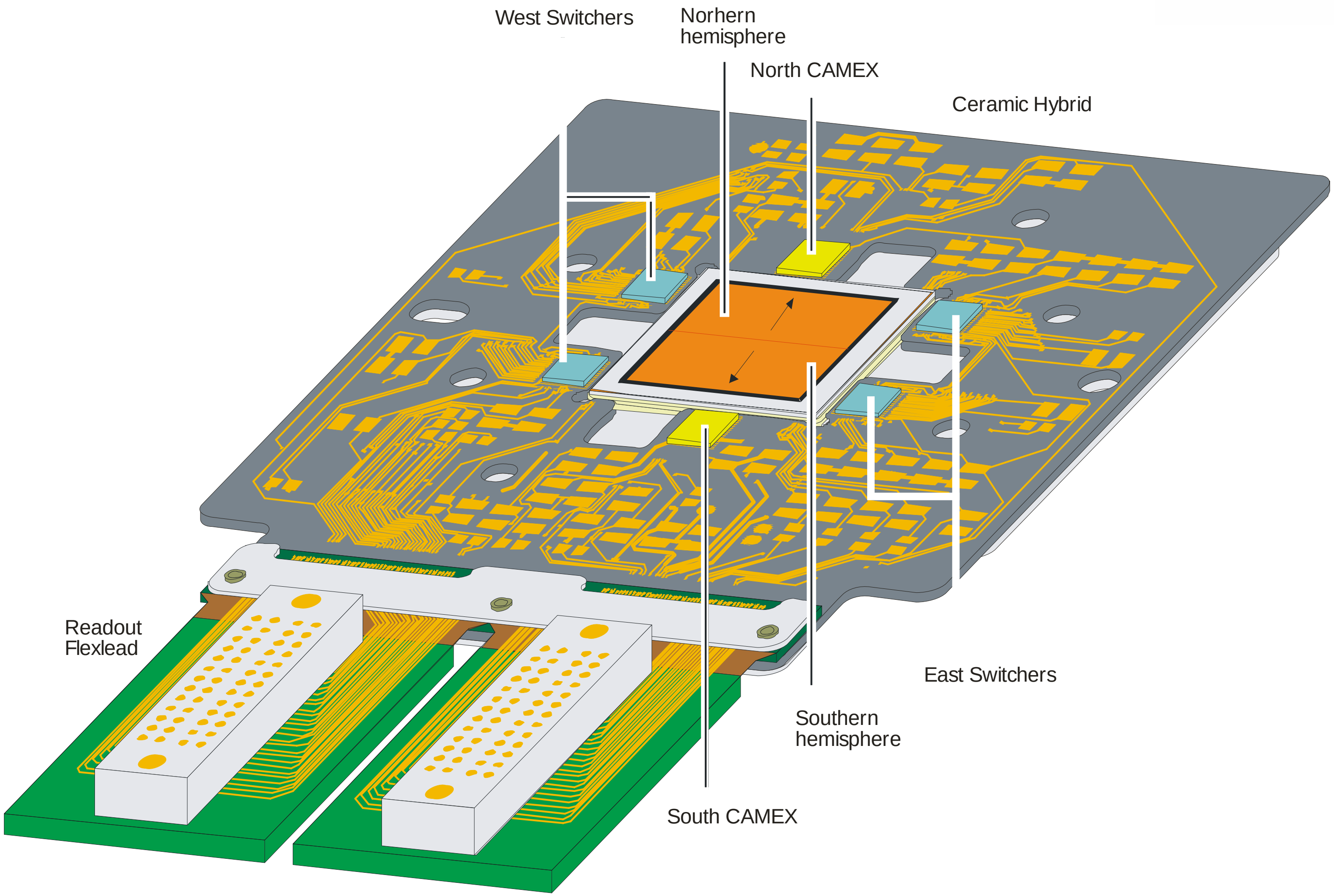
- *Silicon Baffle 450 μm thick*
- *Aluminum-K exposure*
  - *Right: Photon count*
  - *Left: Accumulated energy (contour plot)*

MIXS readout scheme



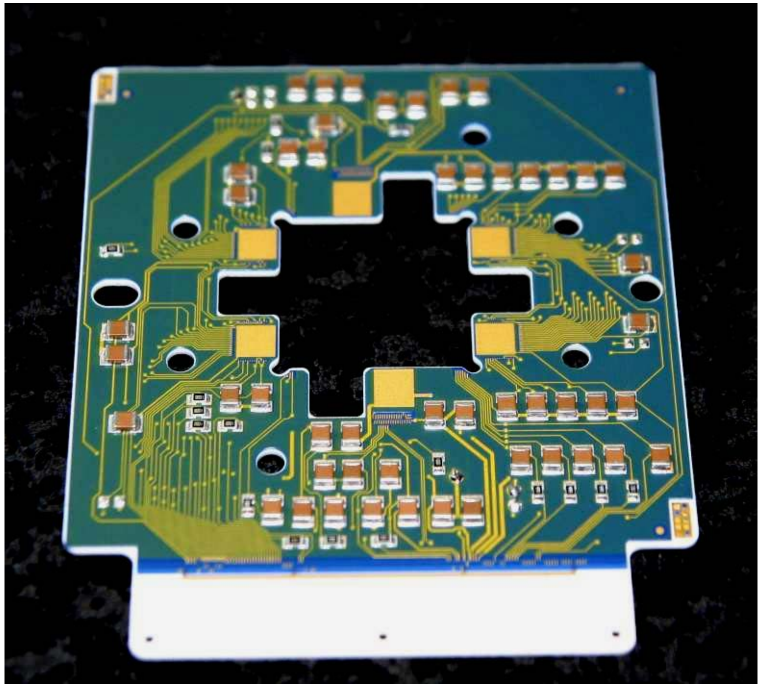
- **Subdivision:**
  - 2 Hemispheres (North and South)
  - 32 x 64 Pixels each
  - Read out by 1 CAMEX each
  - Controlled by 2 Switchers each
  - Readout speed: target 4 µs / row
  - 6 µs / row might be necessary
  - Depends on FE performance, temperature, capacitance...

Hybrid

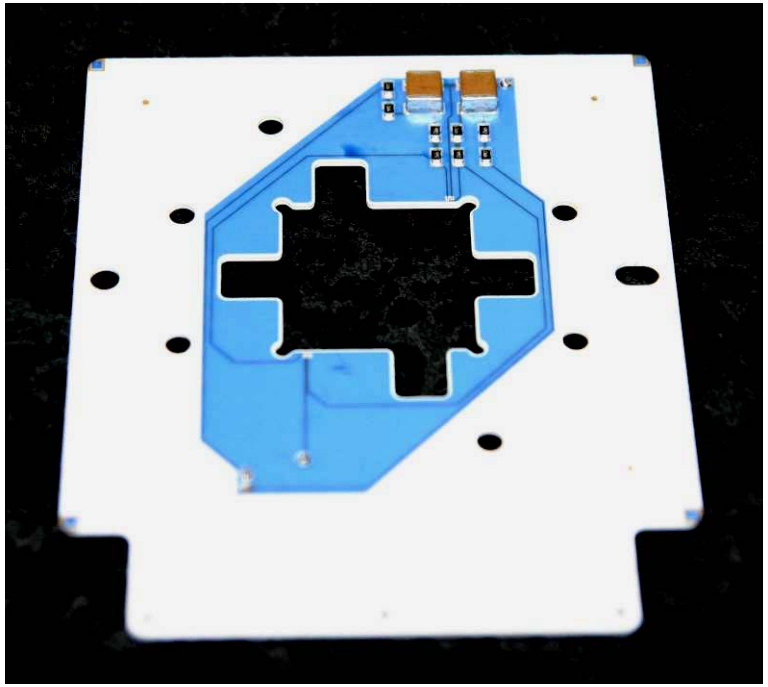


West Switchers
Norhern
hemisphere
North CAMEX
Ceramic Hybrid
Readout
Flexlead
East Switchers
Southern
hemisphere
South CAMEX

Hybrid

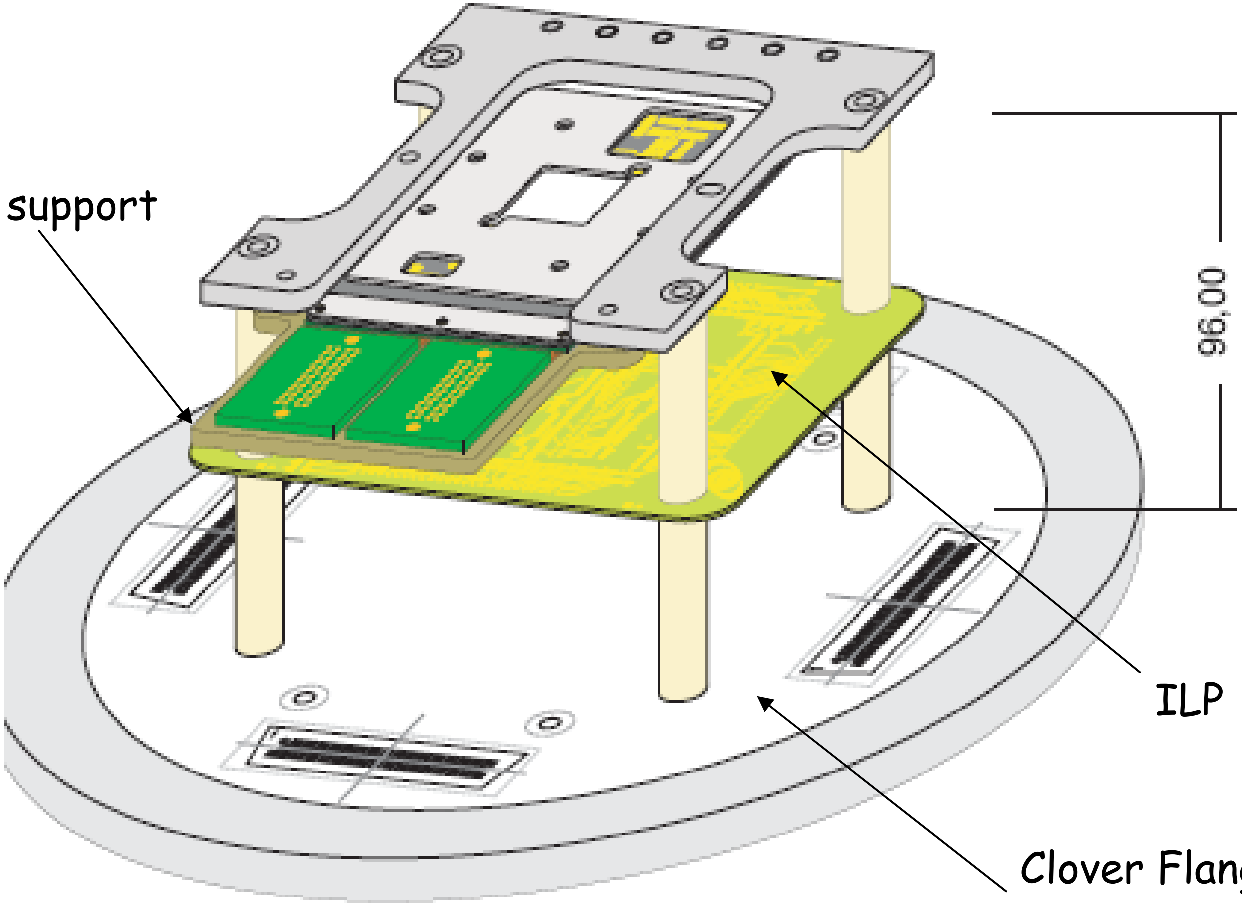


Frontside view



Backside view

Setup


Cooler Horseshoe
Flex support
96,00
ILP
Clover Flange
(Flexleads not shown)

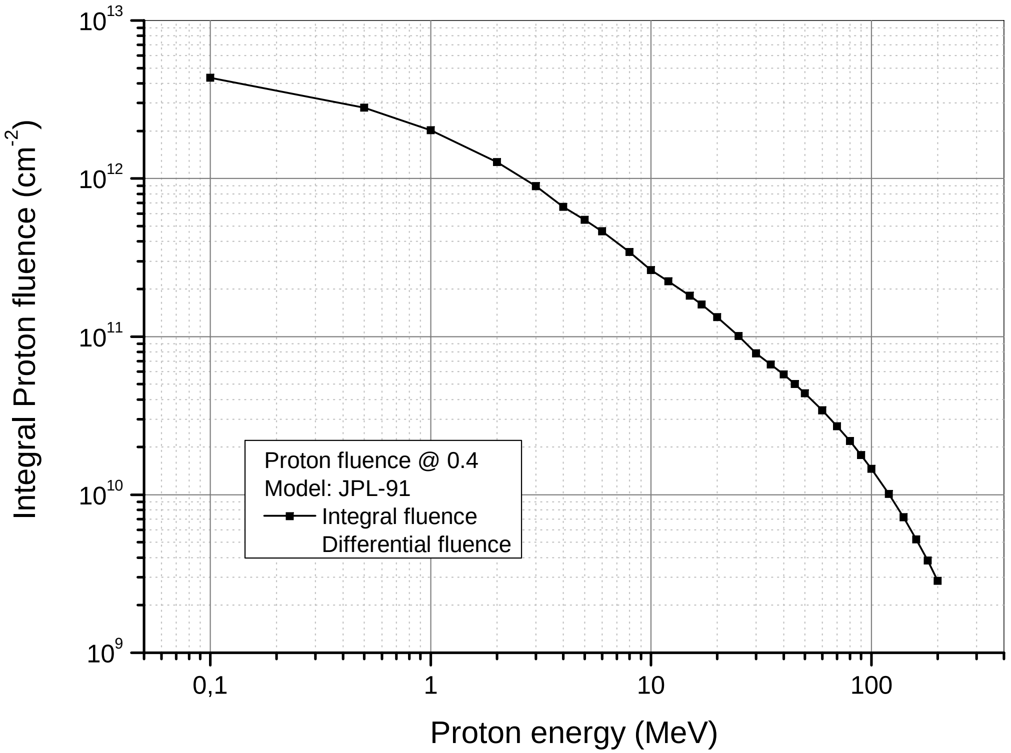
Expected performance

- **Radiation damage** effects will dominate the performance during the entire mission lifetime

- **3 effects are significant:**
  - Threshold voltage shift
    - ↳ Change of operation parameters ✓
  - Increase of interface trap density
    - ↳ Deterioration of DEPFET noise properties ✓
  - Bulk damage (NIEL)
    - ↳ Leakage current increase
    - ↳ Effective doping concentration change
    - ↳ Charge trapping in bulk increases

Radiation damage

The problem: Protons from the solar wind!



Most damage due to protons
Proton spectrum and flux heavily depends on

- Spacecraft design / available shielding (in progress)
- Solar activity (unpredictable)
- Conservative estimates

Bulk damage: NIEL scaling

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

$$\kappa = \frac{\Phi_{eq}}{\Phi_{tot}} \sim 3.8 \longrightarrow$$ Φ_{eq} = **1.14 x 10^{11} 1 MeV neutrons / cm^2**

Resulting leakage current increase:

$$\begin{aligned} I &= \alpha \cdot \Phi_{eq} \cdot V \\ &= \alpha \cdot \kappa \cdot \Phi_{tot} \cdot V \end{aligned}$$

- α is critical parameter:
- Number: α = **4 x 10^{-17} A/cm** (with annealing, ROSE collaboration)
- Number: α = **4.5 x 10^{-17} A/cm** (with annealing, including thickness effects)
- Number: α = **12 x 10^{-17} A/cm** (without annealing, including thickness effects)

How to meet requirements ?

Current increase ***can not*** be prevented, but:

$$\Delta E = 2.355 \cdot \sqrt{\left(\sqrt{F_f \cdot E_{eh} \cdot E}\right)^2 + (E_{eh} \cdot ENC)^2 + \left(E_{eh} \cdot \sqrt{Q_{lk}}\right)^2}$$

Square root of *number* of leakage current electrons per integration cycle

2 options:

Go fast!

4-6 µs processing time per row

128-196 µs overall integration time for frame

Challenge for readout ASICs & DAQ

Power!

Get cold!

Shockley-Read-Hall statistics

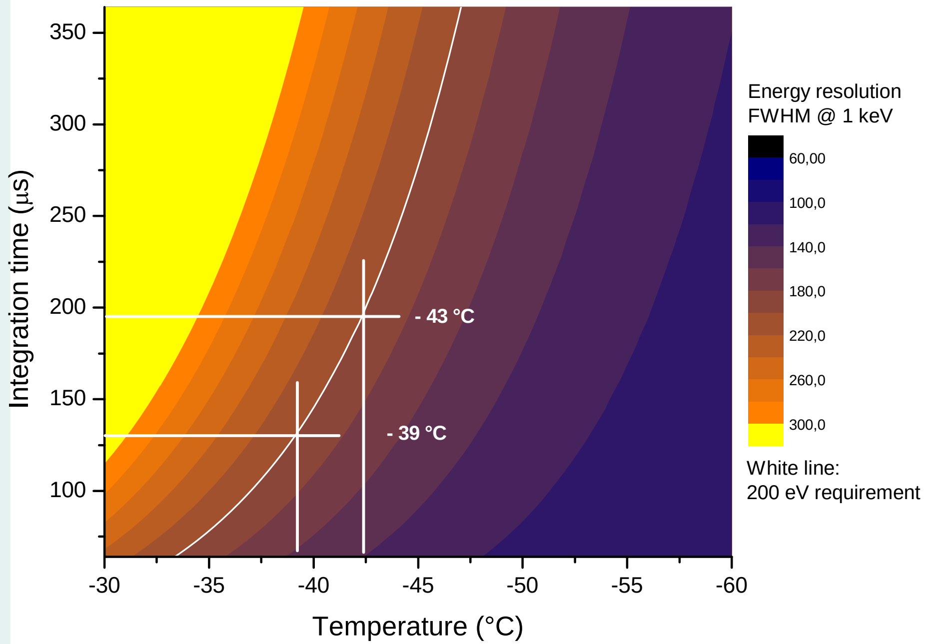
Every 7 degrees of temperature yields factor of 2 in leakage current.

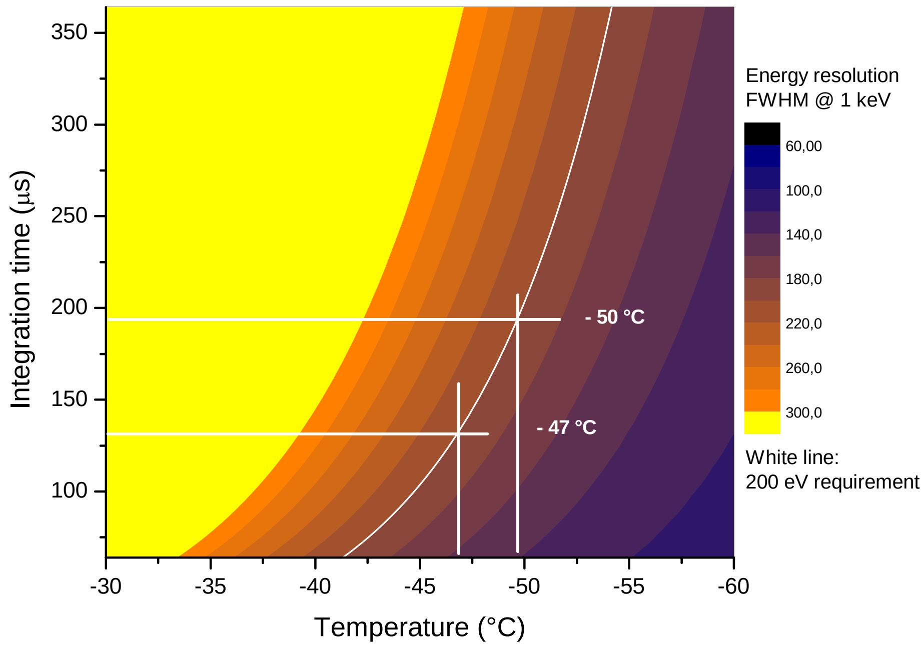
Achieve minimal possible temperature!

Challenge for instrument & spacecraft designers

Do both!

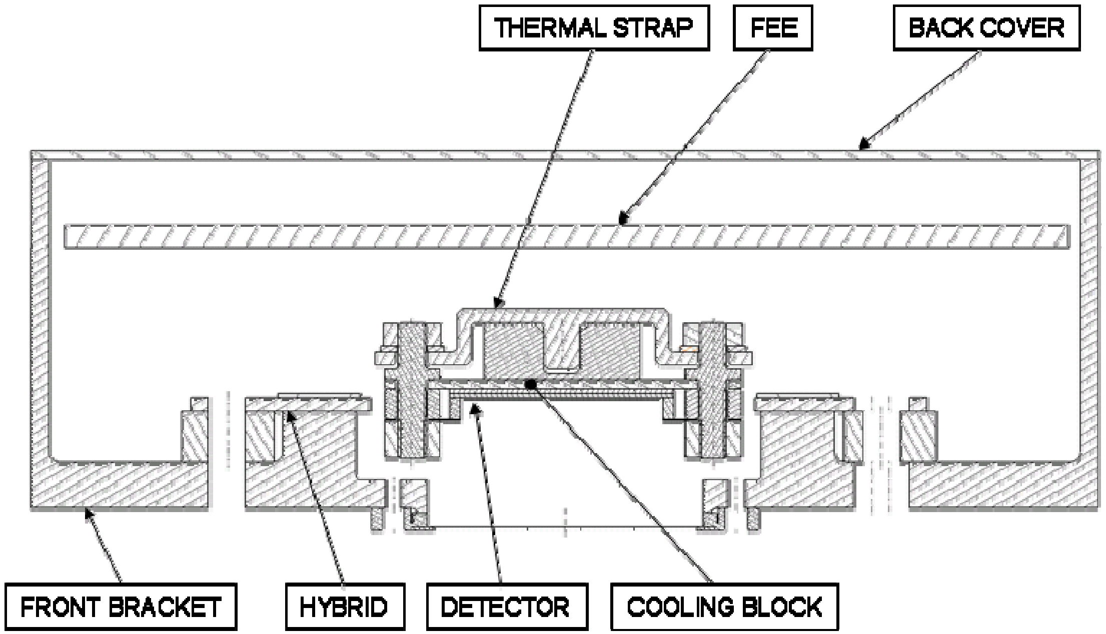
Current model output





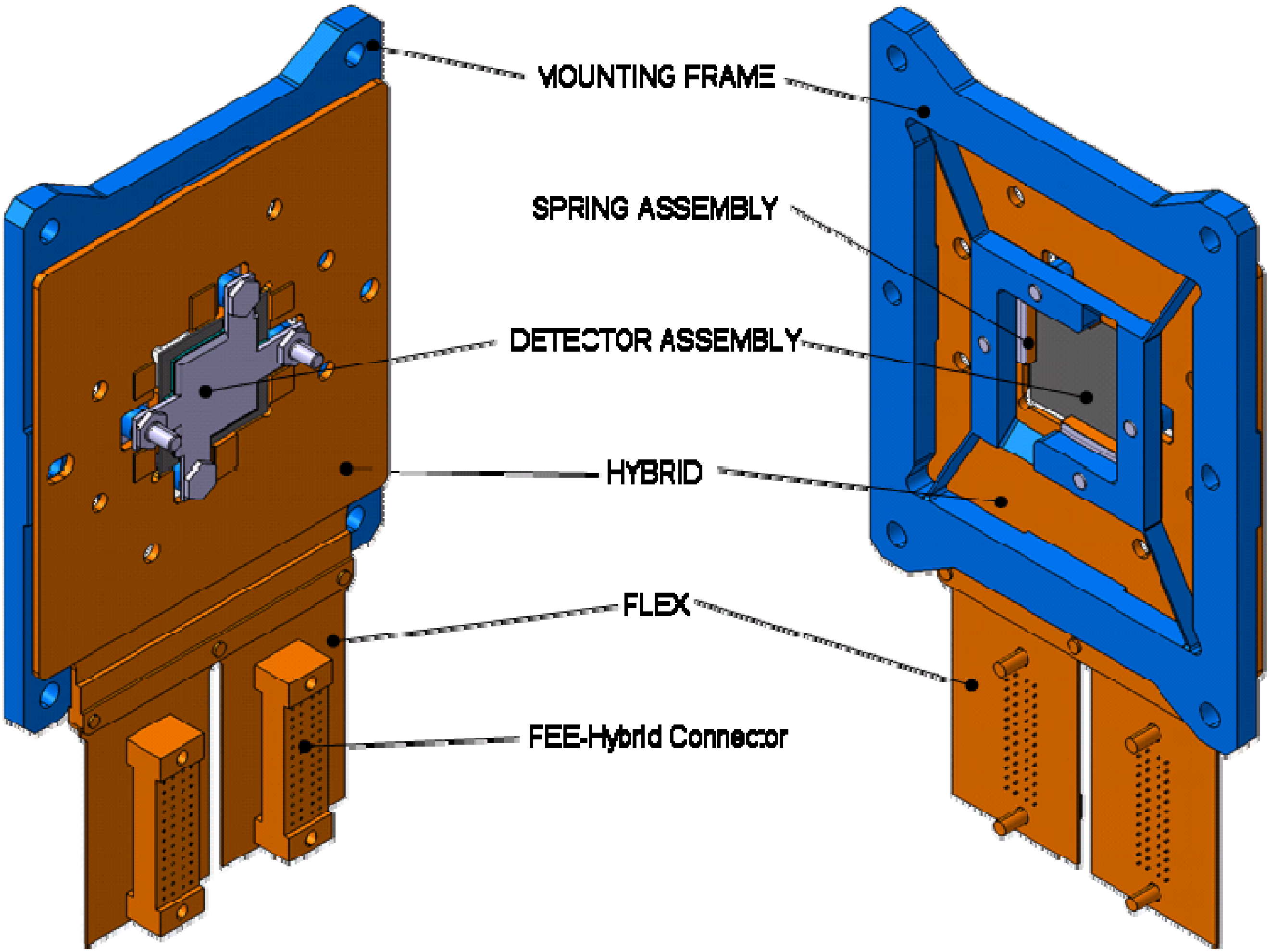
- *Operation scenario:*
  - Annealing brings a down from ~ 12 x 10^{-17} A/cm to 4.5 x 10^{-17} A/cm
  - Lowest required temperature for slow readout - 50°C without annealing
  - Lowest required temperature for slow readout - 43°C without annealing
  - FPA must allow annealing
  - Annealing scenatios are currently examined
  - Radiation analysis is done
  - Make **all** cooling power available for **detector**

FPA concept

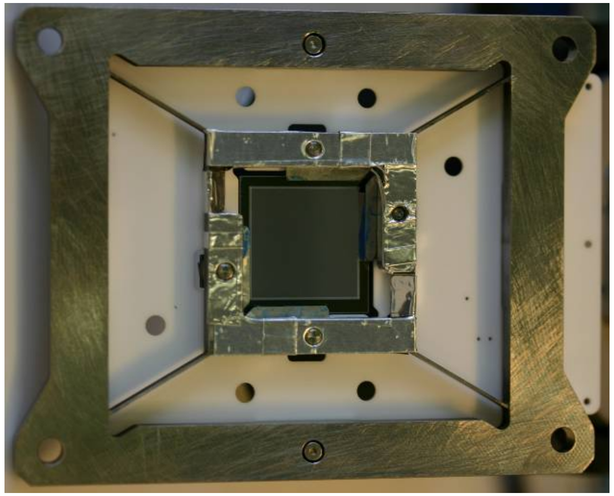


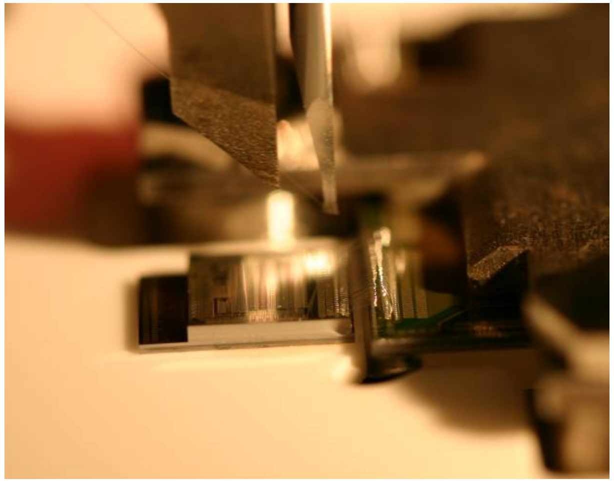
THERMAL STRAP
FEE
BACK COVER
FRONT BRACKET
HYBRID
DETECTOR
COOLING BLOCK

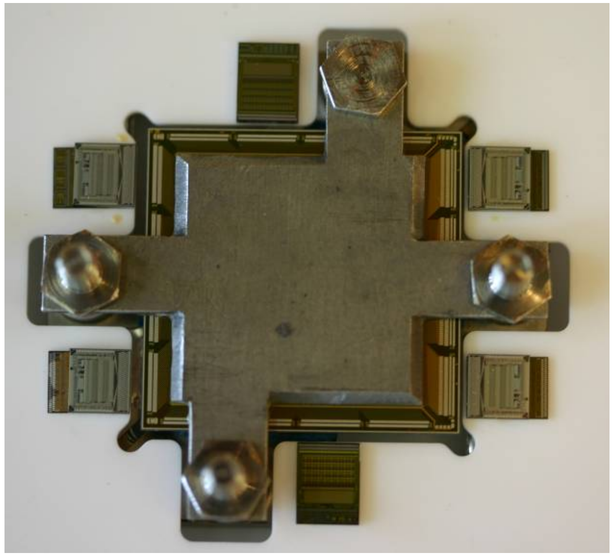
MIXS FPA setup

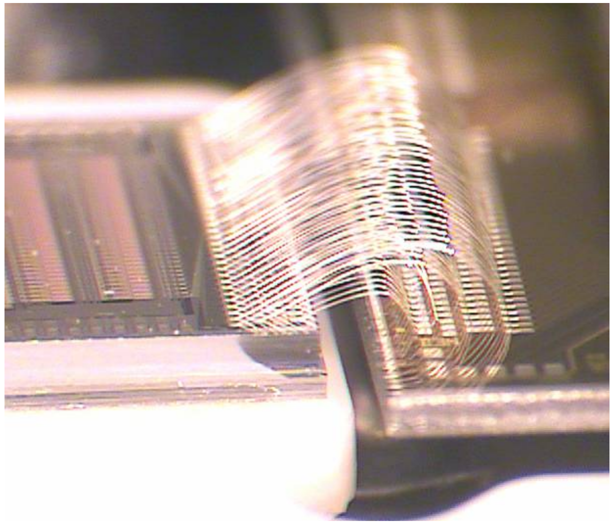


Flight Module demonstrator

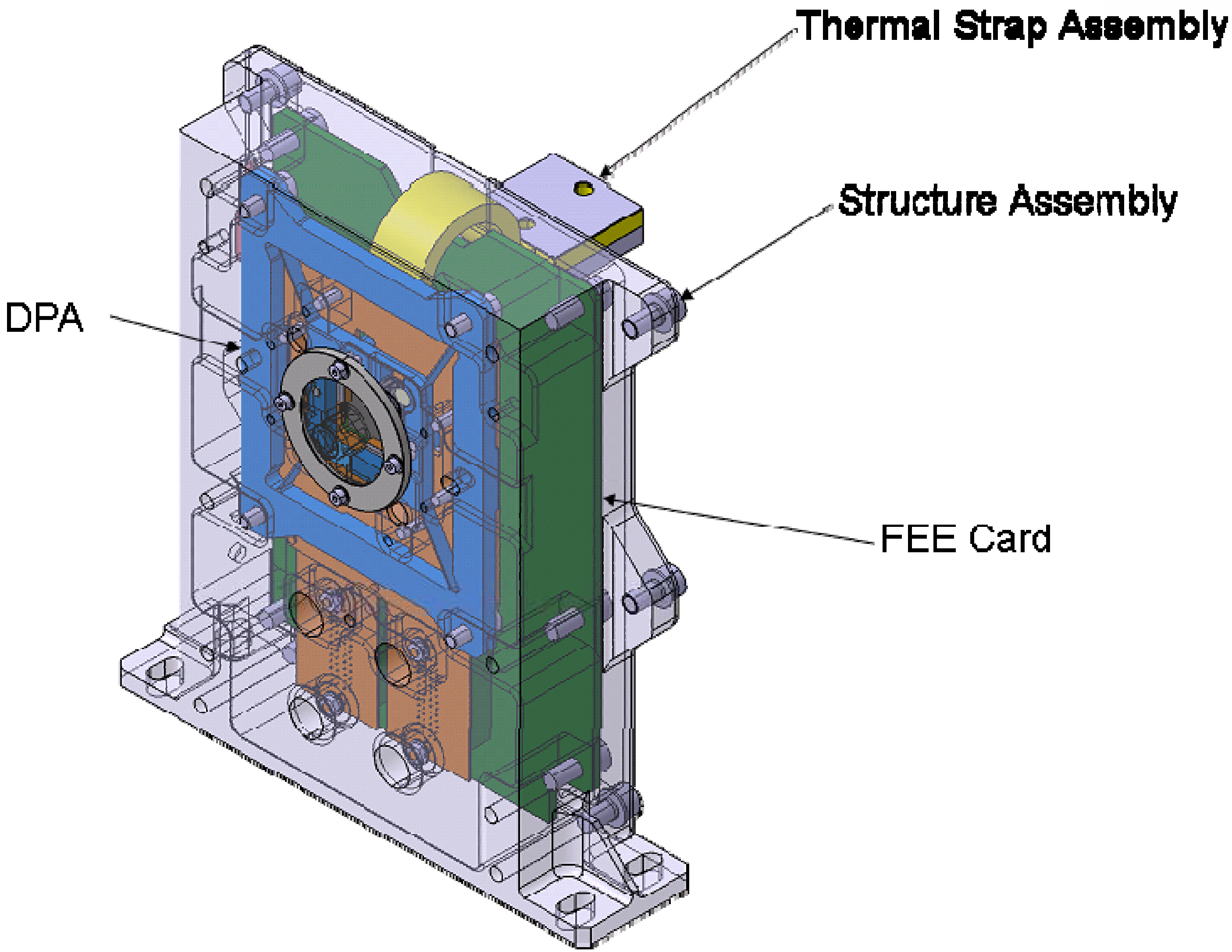






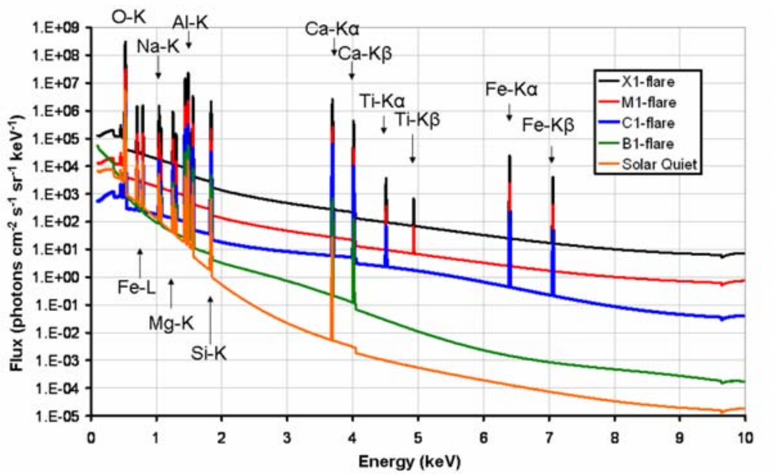


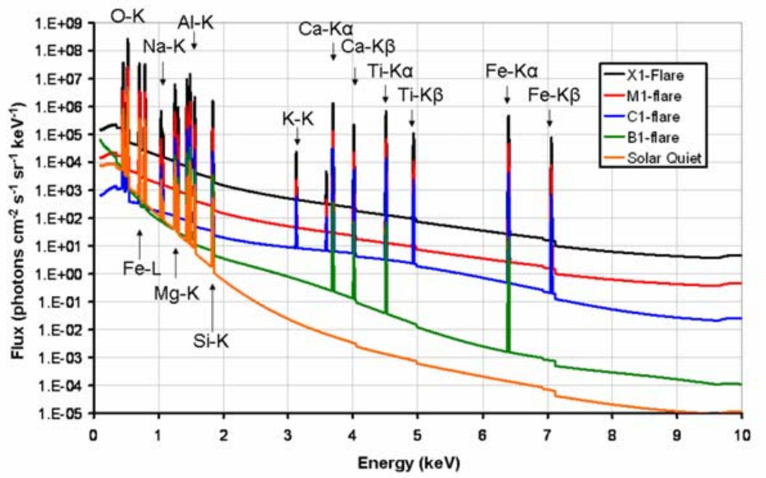
FPA



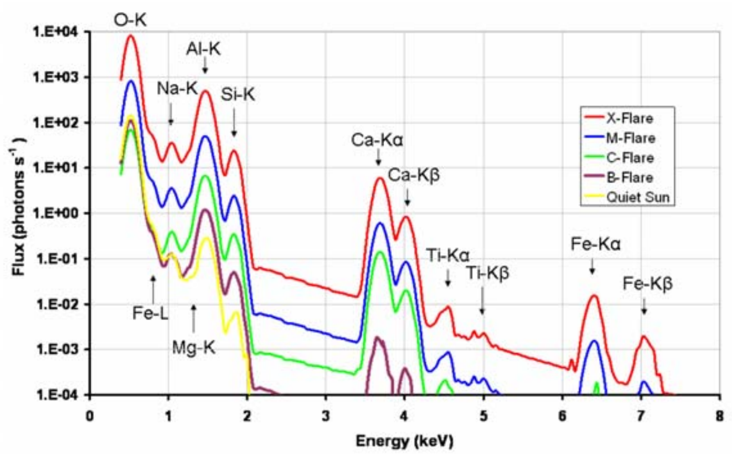
Detector response

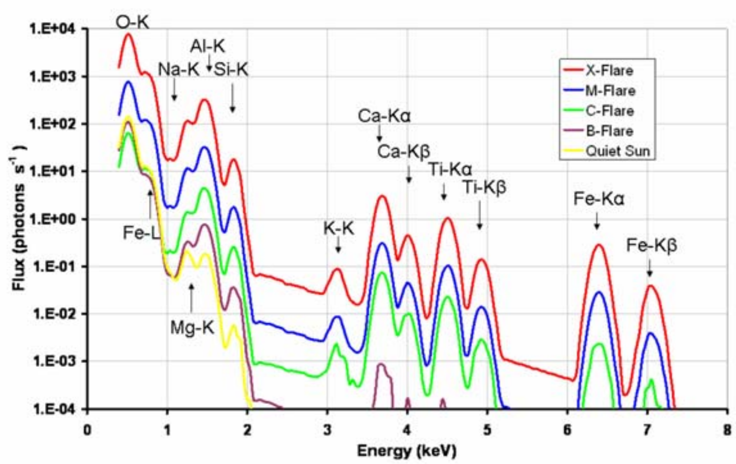
Input flux





Response for 200 eV @1 keV

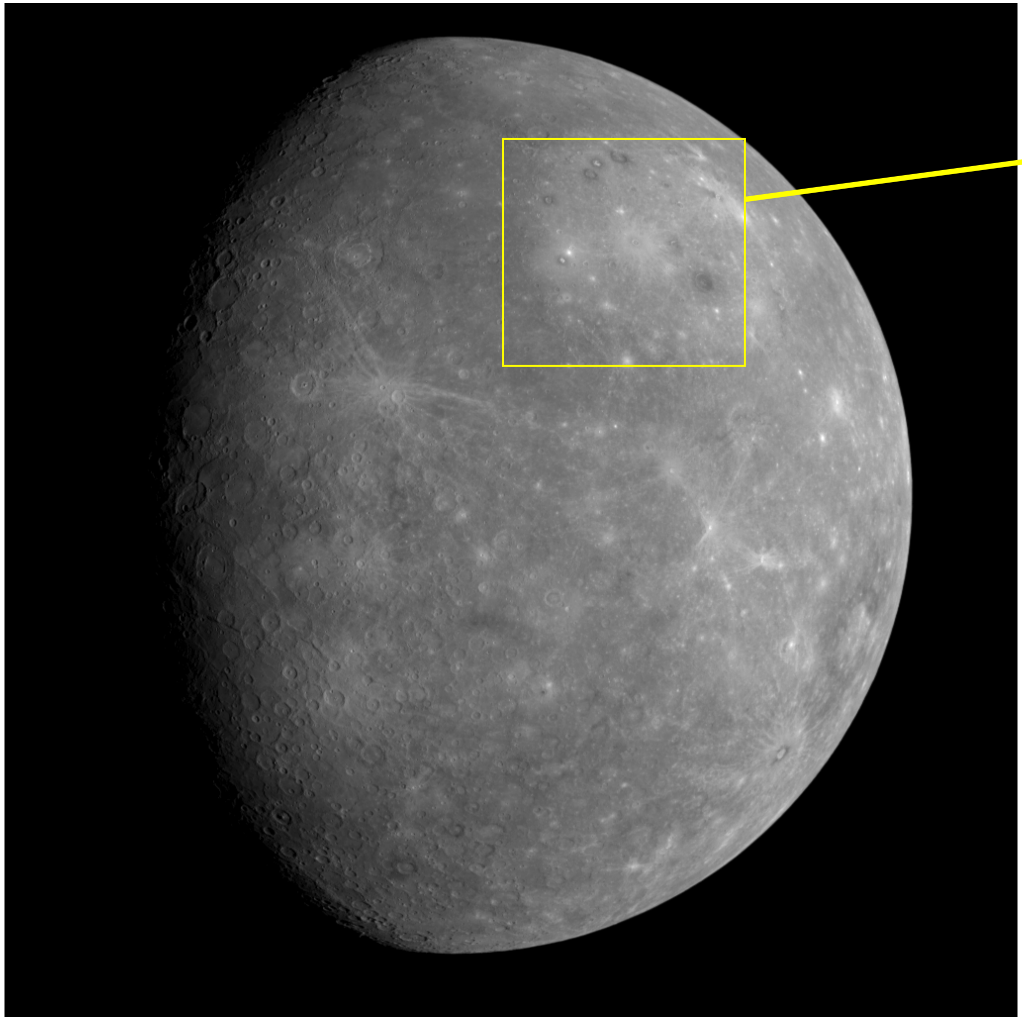


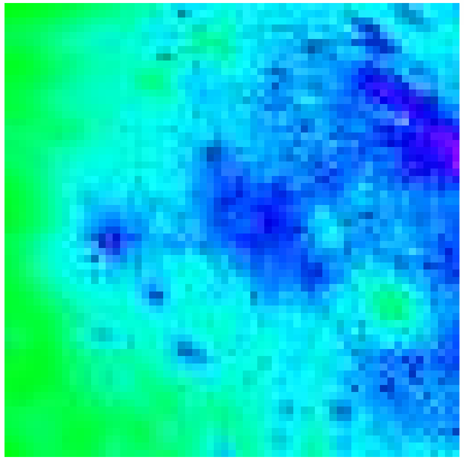


- Similar to lunar anorthosit
- Similar to lunar basalt

Calculations provided by J. Carpenter University of Leicester

Imaging of Mercury surface





MIXS end of mission Fe map

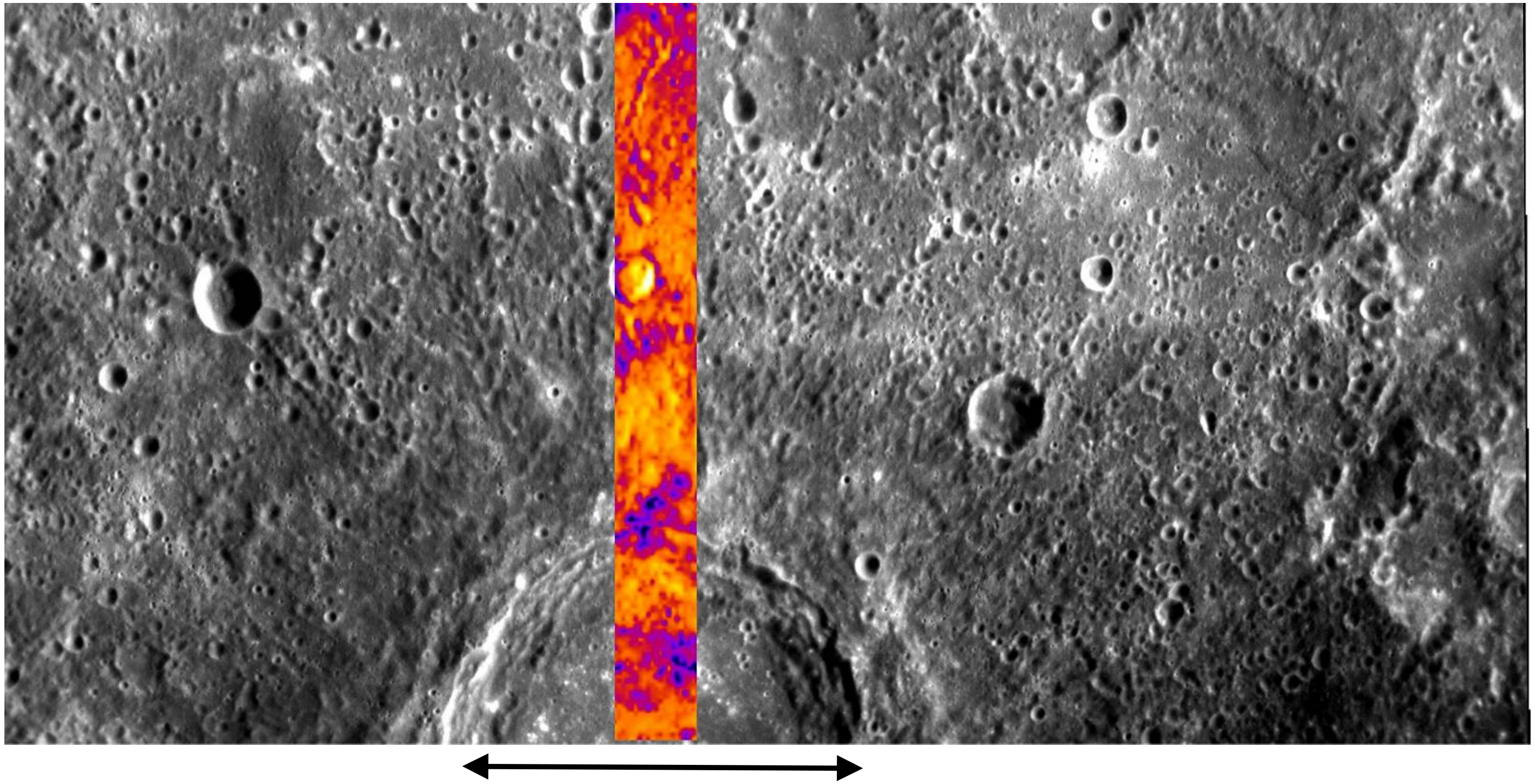
"Quick and dirty" visualisation

- Assume brightness here is proportional to albedo
- Assume albedo at 750 nm is proportional to FeO concentration
- Assume FeO content is proportional to Fe concentration
- Assume Si concentration is ~ homogenous

Simulations provided by J. Carpenter, Leicester University

Imaging of Mercury surface

Scanning during flares



Simulations provided by J. Carpenter, Leicester University

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