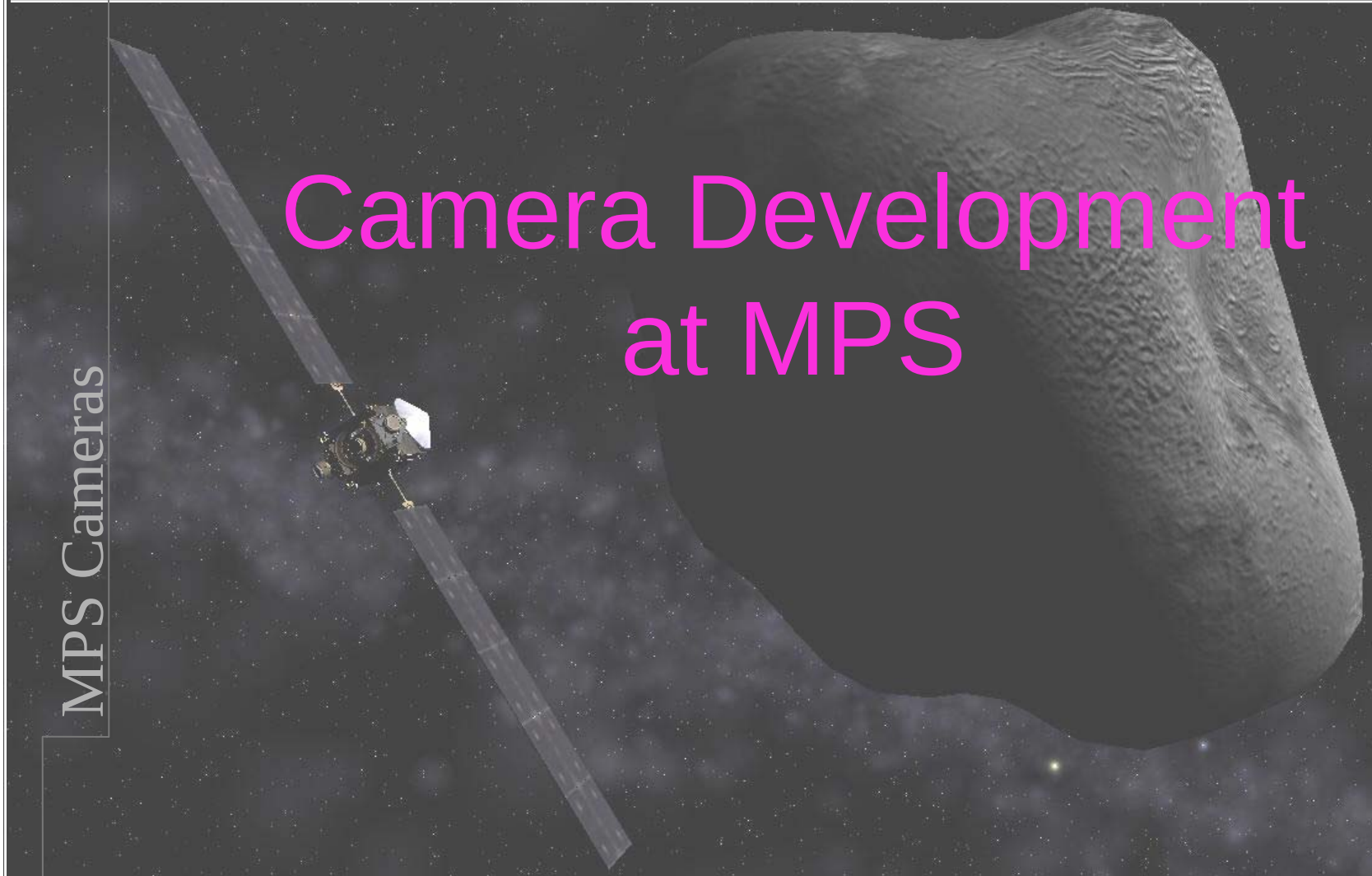


Camera Development at MPS

MPS Cameras

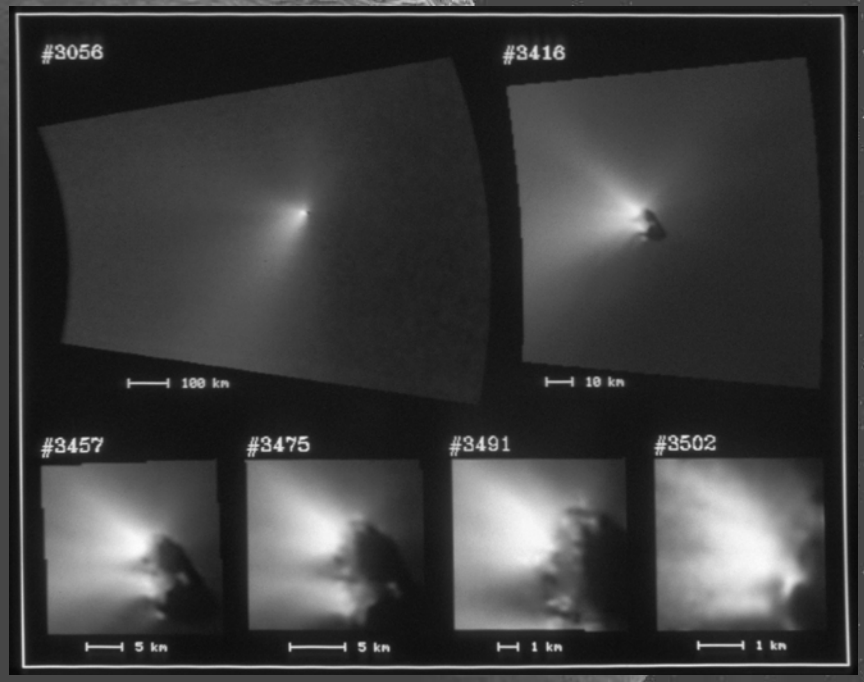
Outline

- Past- and present projects
- Scientific goals that can be addressed by a camera system
- Camera schematics
- Examples: OSIRIS and Framing Cameras
- Optics
- Filters
- Detectors
- Electronics
- Thermal
- In-flight constraints
- Software
- Image and instrument calibration
- Operations
- Data Flow
- Results

Past and Present Projects

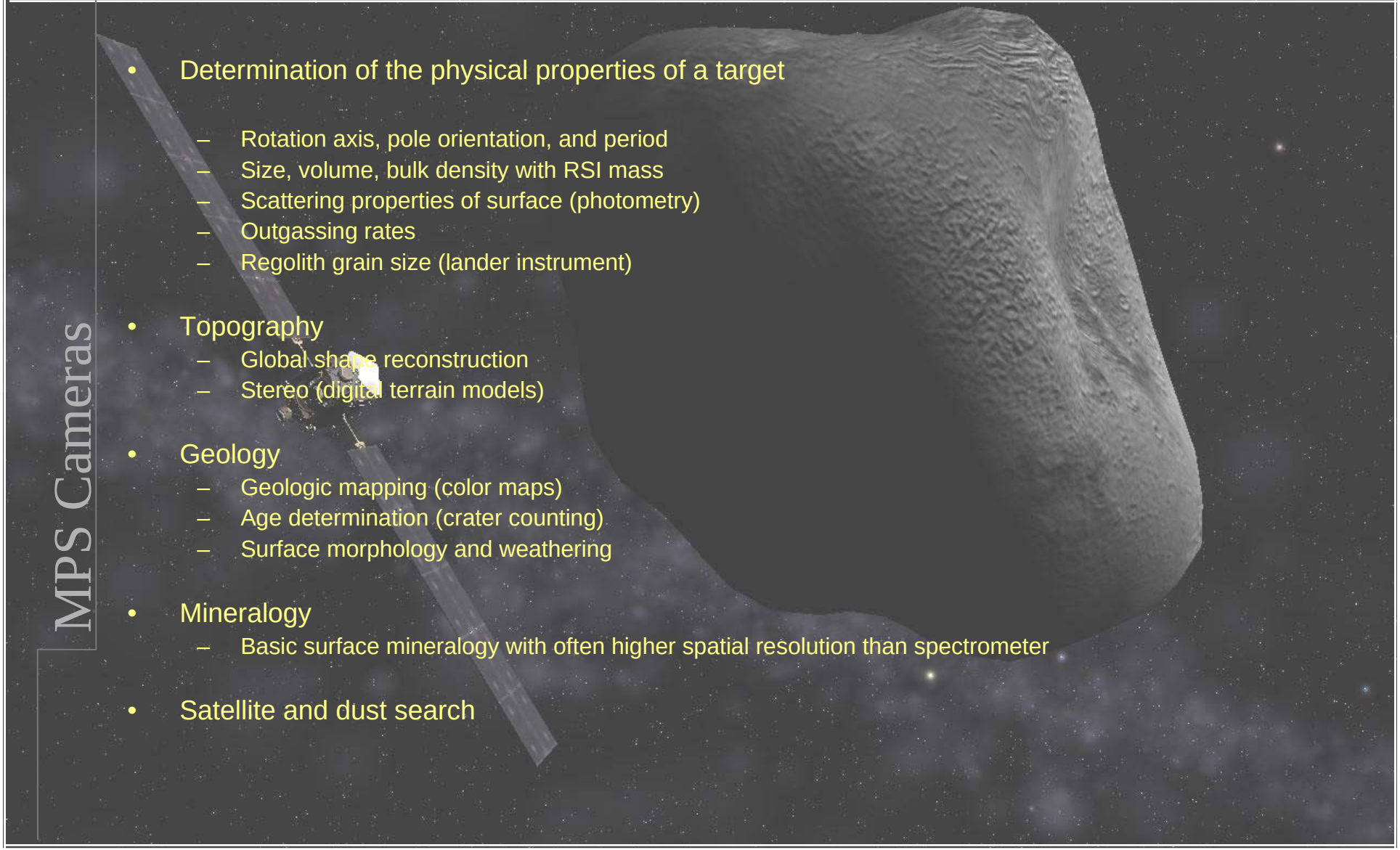
MPS Cameras

- HMC (Giotto) – completed in 1986
- RAC (Phoenix) – completed in 2008
- OSIRIS (Rosetta) – ongoing
- VMC (Venus Express) – ongoing
- FC (DAWN) – ongoing



Six examples of HMC images (original frame sizes) that are filtered, calibrated and deconvolved by the point spread function (PSF) (except image 3502). The Sun is on the left side.

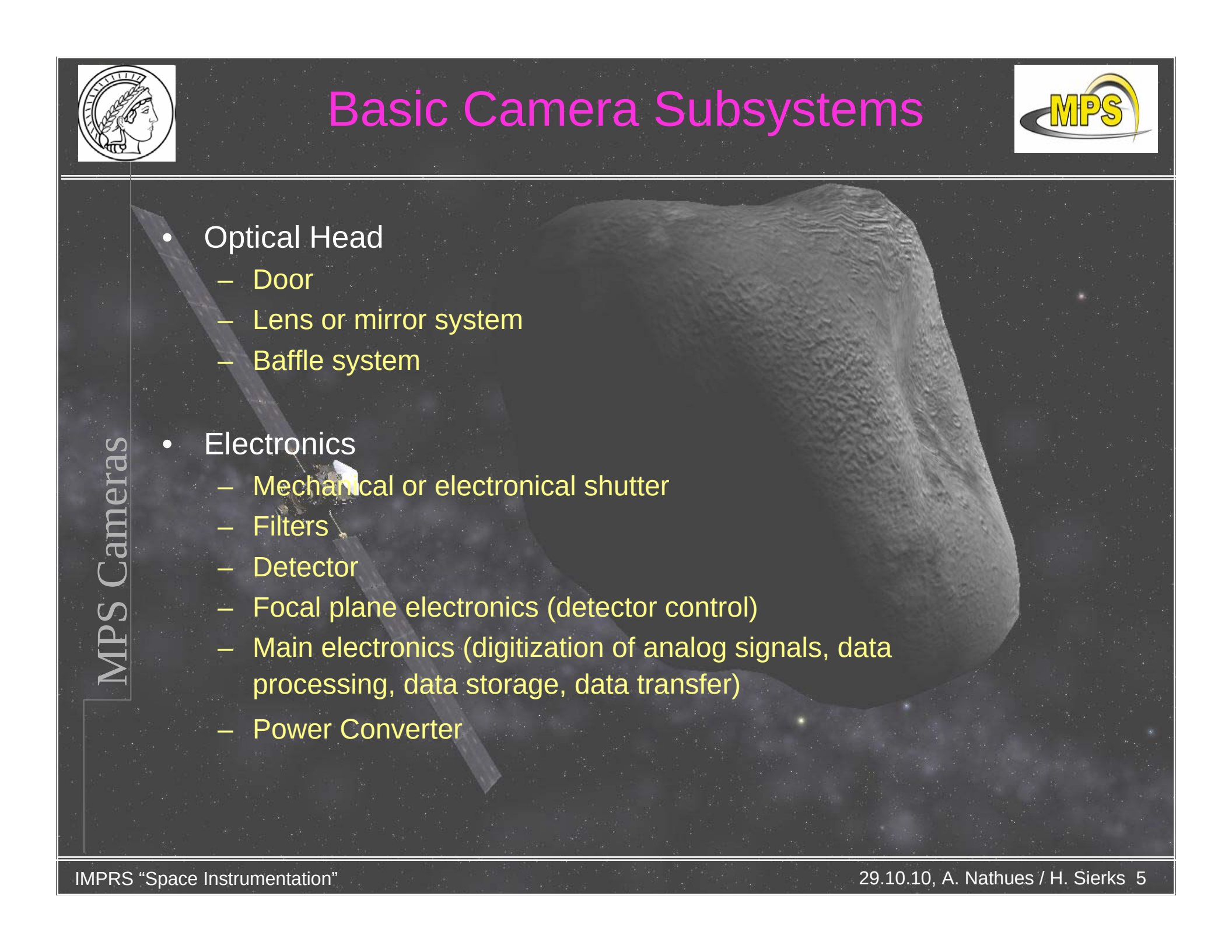
Scientific Goals



- Determination of the physical properties of a target
  - Rotation axis, pole orientation, and period
  - Size, volume, bulk density with RSI mass
  - Scattering properties of surface (photometry)
  - Outgassing rates
  - Regolith grain size (lander instrument)
- Topography
  - Global shape reconstruction
  - Stereo (digital terrain models)
- Geology
  - Geologic mapping (color maps)
  - Age determination (crater counting)
  - Surface morphology and weathering
- Mineralogy
  - Basic surface mineralogy with often higher spatial resolution than spectrometer
- Satellite and dust search

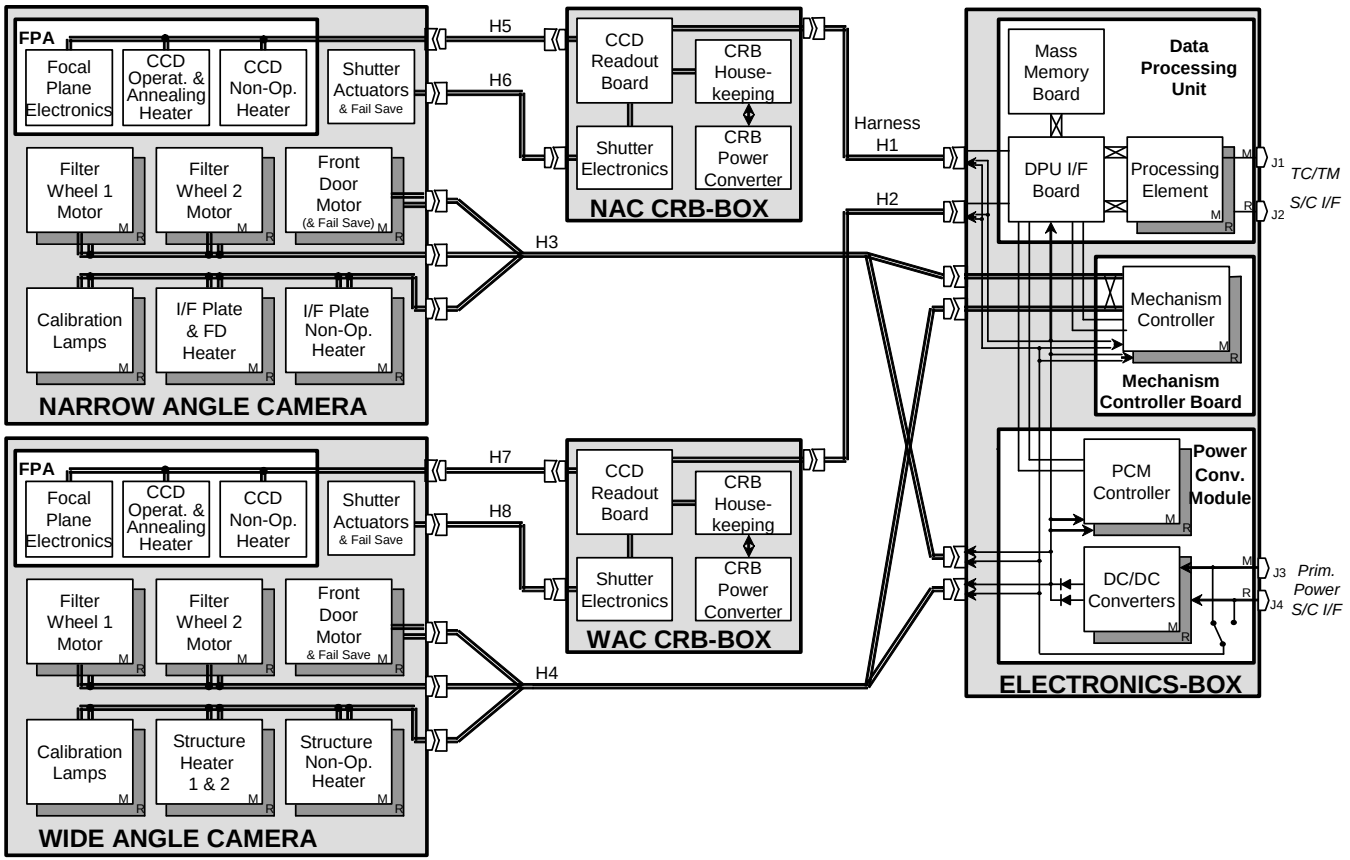
MPS Cameras

Basic Camera Subsystems



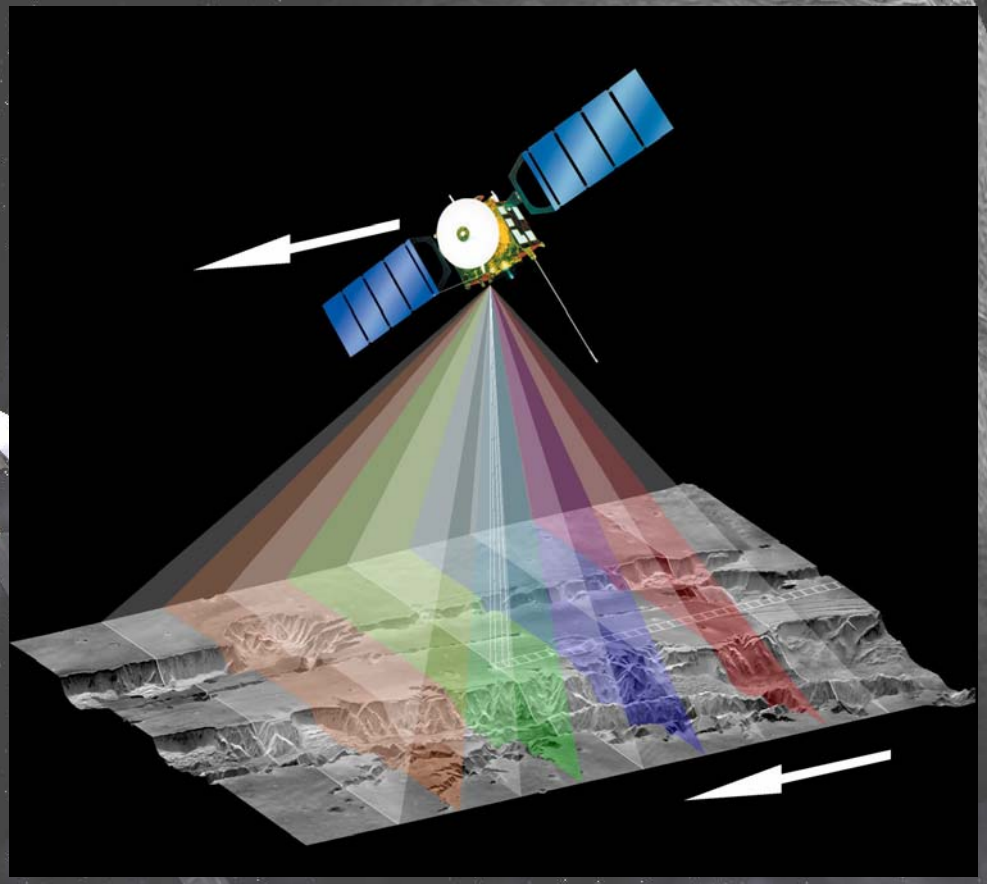
- Optical Head
  - Door
  - Lens or mirror system
  - Baffle system
- Electronics
  - Mechanical or electronical shutter
  - Filters
  - Detector
  - Focal plane electronics (detector control)
  - Main electronics (digitization of analog signals, data processing, data storage, data transfer)
  - Power Converter

Detailed Camera Schematics (OSIRIS)



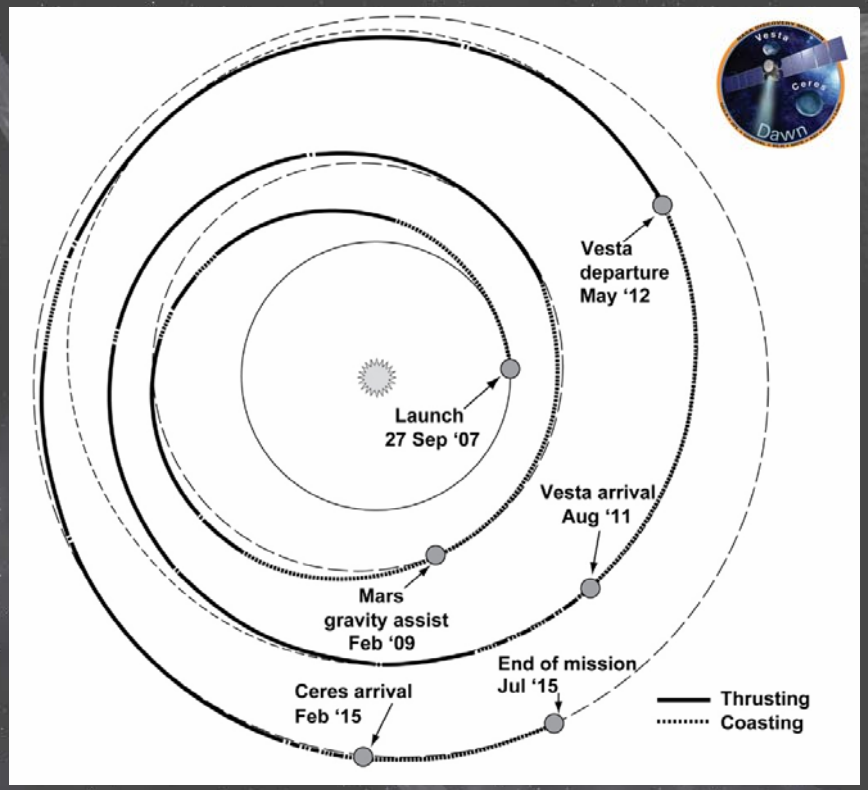
MPS Cameras

Mode of Operation



Operation principle of a scanning camera (HRSC / Mars Express).
Several line sensors in series are scanning the surface.

Example (1) – DAWN Mission



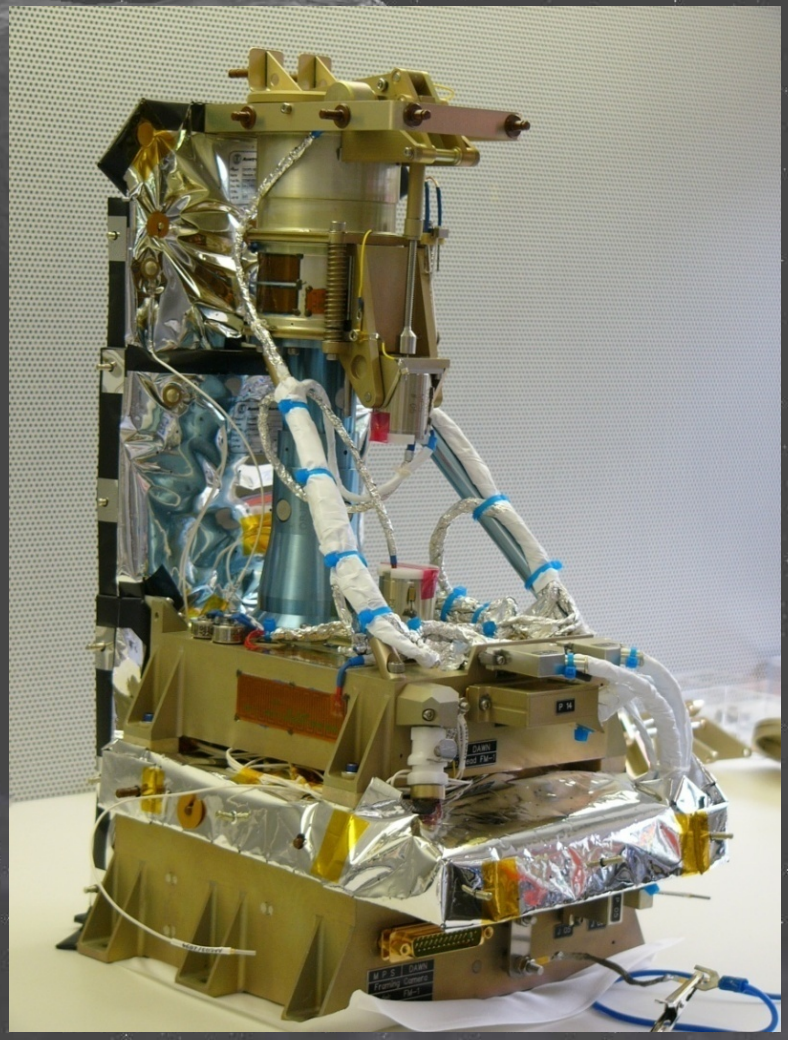
DAWN Mission Phases

DAWN Spacecraft

Example (1) – DAWN FC

MPS Cameras

- Two Framing Cameras (FCs) are onboard DAWN, one main (FC2) and one redundant system (FC1).
- The FCs have been built at MPS with contributions from DLR-PF (CCD and proximity electronics) and IDA (DPU).
- On-ground calibration was performed at MPS.



Example (1) – DAWN FC

- Used as navigation camera
- Optimized for low distortion (<0.1%) for OpNav
- Declared as “mission critical”
- Redundant, one camera always in clear filter mode and closed
- Carries in part class A software (bootstrap loader)

MPS Cameras

Example (1) – DAWN FC

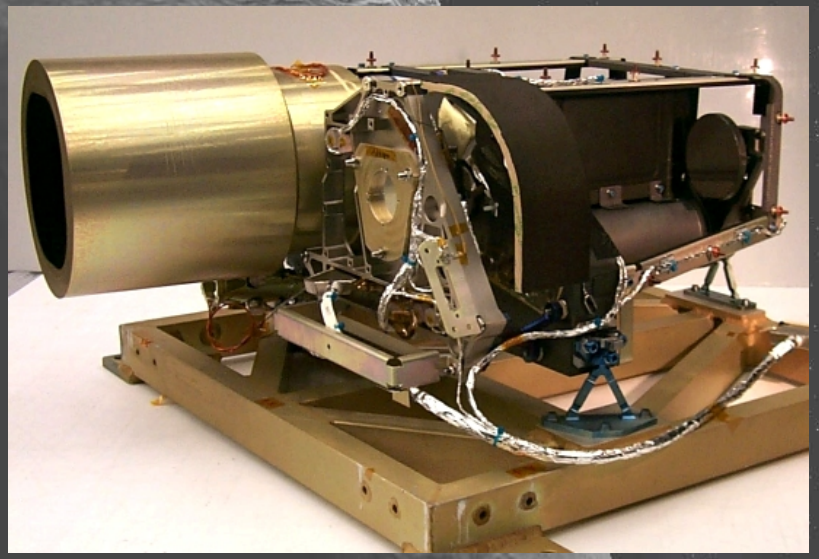
MPS Cameras

Mass	5.5 kg
Size	423 x 192 x 215 mm
Power consumption	18 W during imaging peak
Angular resolution	93.7 µrad/px
Spectral range	360 - 1050 nm
Filters	7 color + 1 clear
Dynamic	14 bit
Focal length	150 mm
Focal ratio	f/7.5
FoV	5.5° x 5.5°

Example (2) – Rosetta OSIRIS

MPS Cameras

NAC – Narrow Angle Camera
FOV 2.2°, IFOV 18.6 µrad/px
2k x 2k BI E2V CCD, AB
60m px scale @ CA, f/8, 717mm



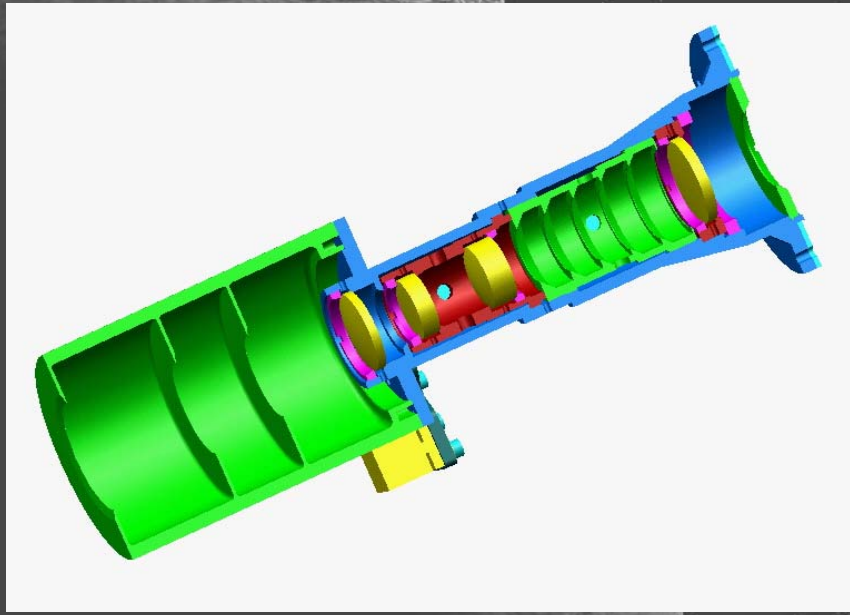
WAC – Wide Angle Camera
FOV 12°, IFOV 100 µrad/px
2k x 2k BI E2V CCD, AB
300m px scale @ CA, f/5.6, 140mm

Optics – Refractor –

MPS Cameras

DAWN FC

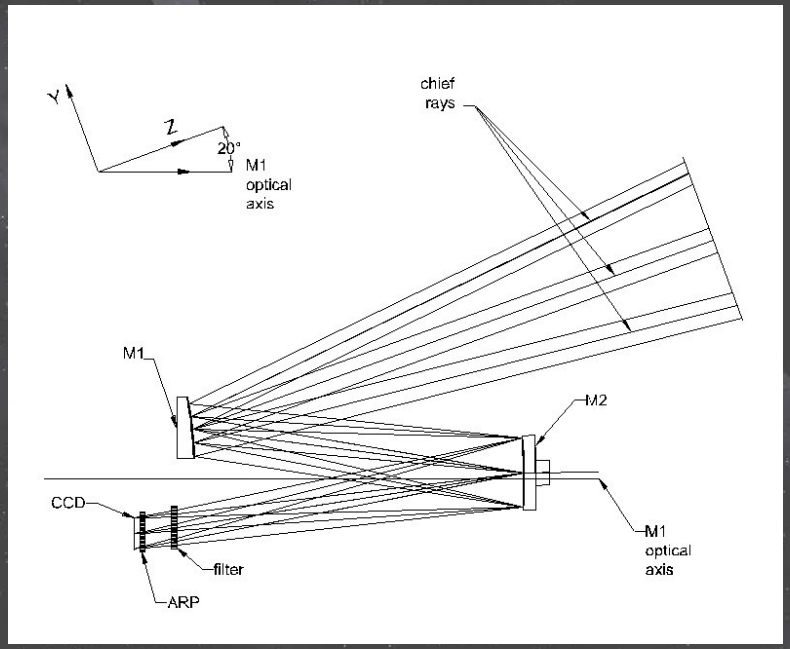
- Four-lens optics
- 150 mm focal length
- 20 mm aperture (f/7.5)
- 1 m/px res from 10 km
- thermally compensated
- tele-centric
- 5.5° x 5.5° field of view
- > 80 % encircled energy per pixel
- > 75 % spectral transmission
- in focus down to 300 m
  - < 0.7 px deformation

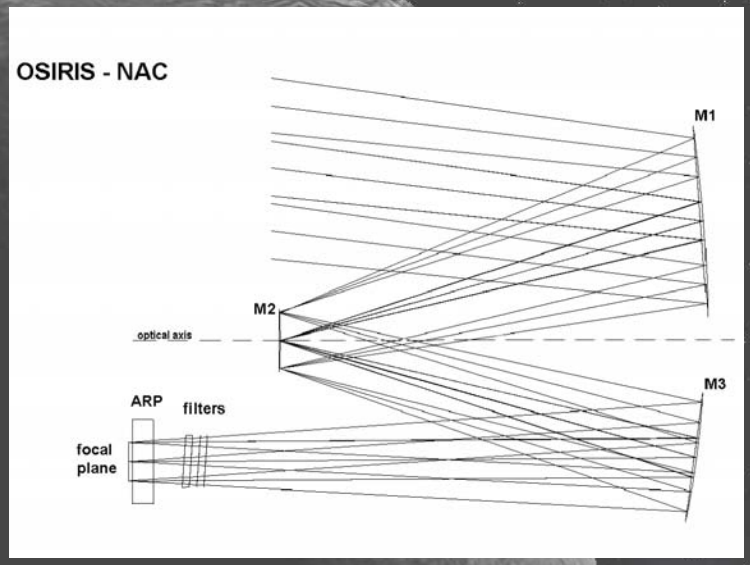


Optics – Reflector –

MPS Cameras

OSIRIS NAC – Narrow Angle Camera
3 mirror off-axis system →



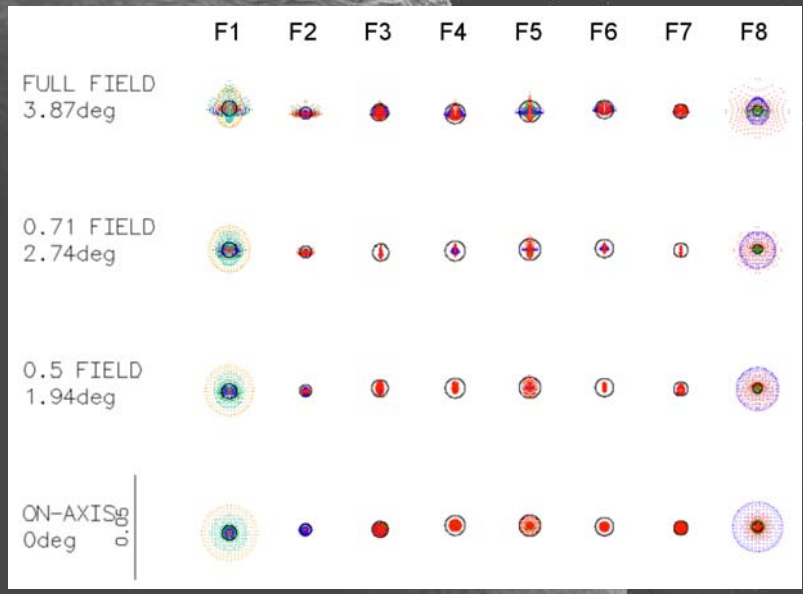


OSIRIS WAC – Wide Angle Camera
← 2 mirror off-axis system

Optical Performance (PSF)

MPS Cameras

- Spot diagrams (right) as a function of distance to the center of the FC CCD. The colors represent different wavelengths of light.
- Spatial resolutions on Vesta:
  - Survey: ~ 260 m
  - HAMO: ~ 60 m
  - LAMO: ~ 20 m (de-smear correction required)
- Expected S/N:
  - > 50 (typically ~200 for brightest pixels) in each filter



Filter	F1	F2	F3	F4	F5	F6	F7	F8
Size (0°)	1.7	0.9	1.1	1.0	1.3	0.9	1.2	2.3
Size (3.6°)	1.8	1.1	1.2	1.4	1.6	1.3	1.1	1.9
Airy disk	-	0.69	0.94	1.15	1.22	1.04	0.81	0.54

Optical Performance (other)

- Geometric distortion
- Chromatic aberration
- Field curvature
- Transmission range
- Stray light
  - Infield stray light
  - Out of field stray light

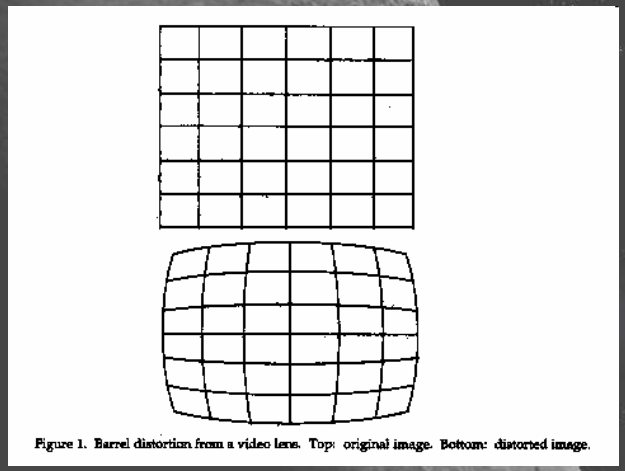
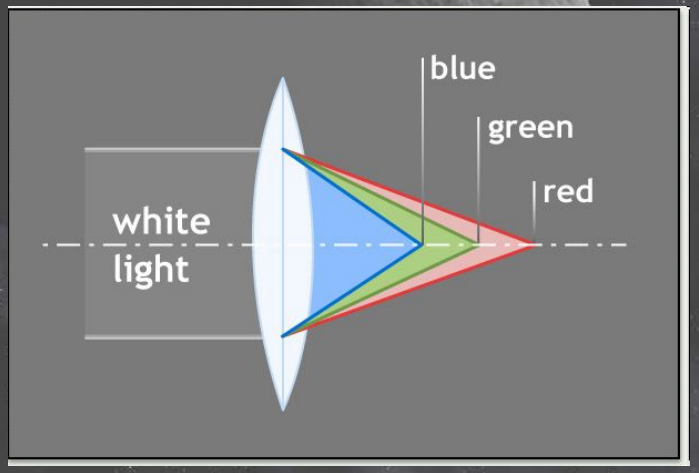


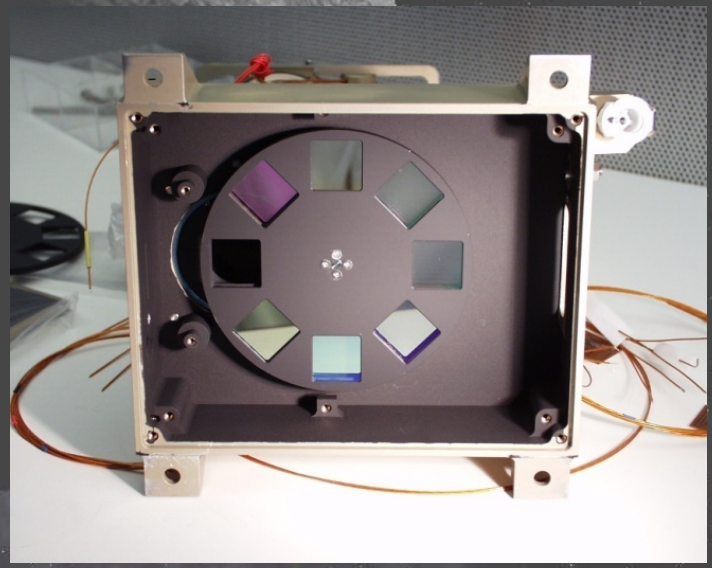
Figure 1. Barrel distortion from a video lens. Top: original image. Bottom: distorted image.



Spectral Bands – FC –

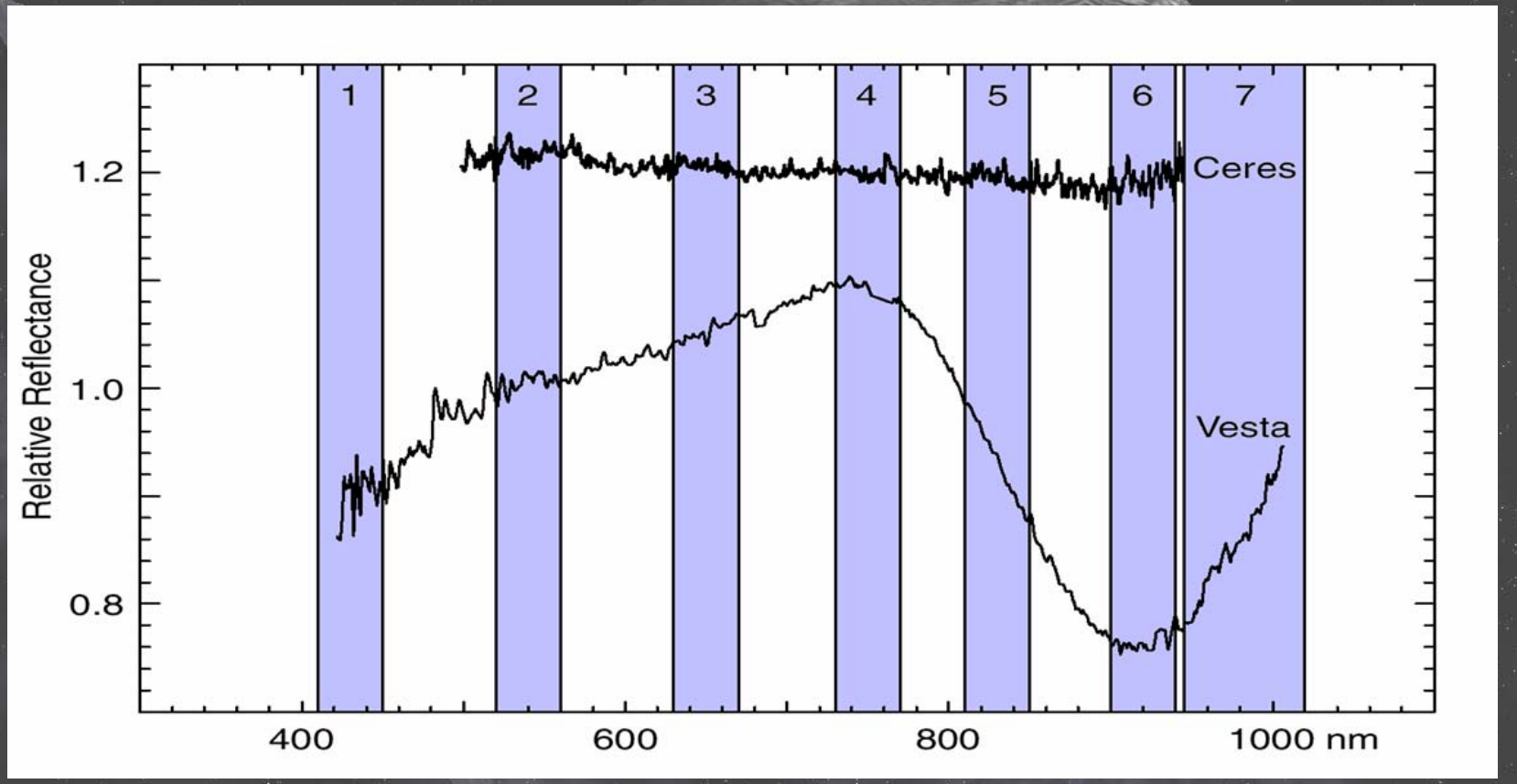
Channel No.	Center wavelength [nm]	Bandwidth [nm]	Trans-mission [%]	Filter wheel position	Thickness [mm]
1	polychromatic	450 ±10 to 920 ±10	98	1	6.00 ±0.05
2	430 ±2	40 ±5	> 75	8	2.00 ±0.05
3	550 ±2	40 ±5	> 75	2	5.90 ±0.05
4	650 ±2	40 ±5	> 75	7	6.60 ±0.05
5	750 ±2	40 ±5	> 75	3	6.40 ±0.05
6	830 ±2	40 ±5	> 75	6	5.90 ±0.05
7	920 ±2	40 ±5	> 75	4	5.30 ±0.05
8	980 ±2	80 ±5	> 75	5	4.80 ±0.05

FC carries one polychromatic and 7 color filters. Minimum wavelength tested down to 360 nm, maximum wavelength 1050 nm.



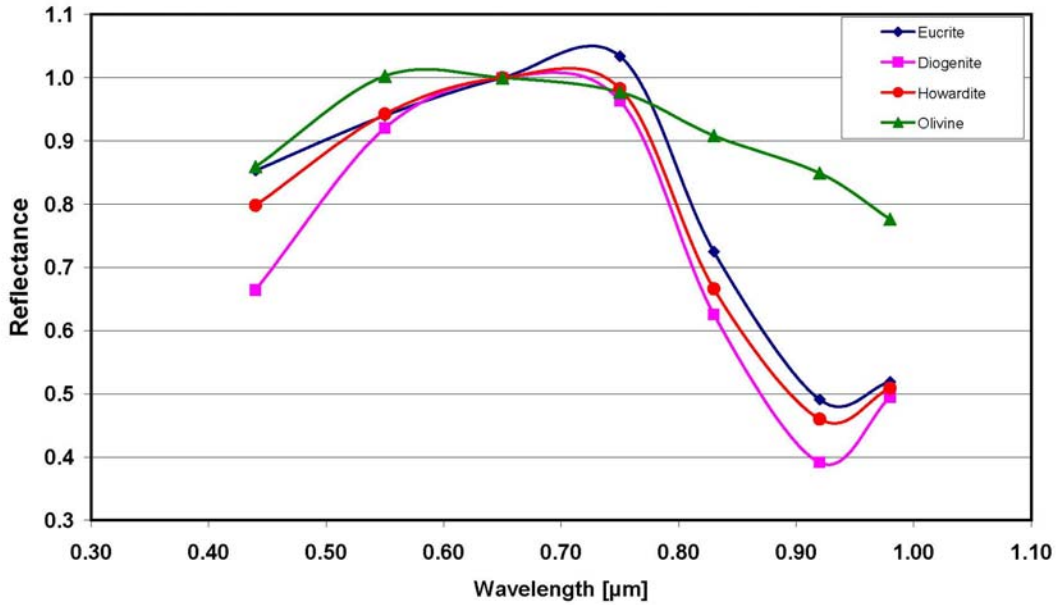
MPS Cameras

Spectral Bands – FC –



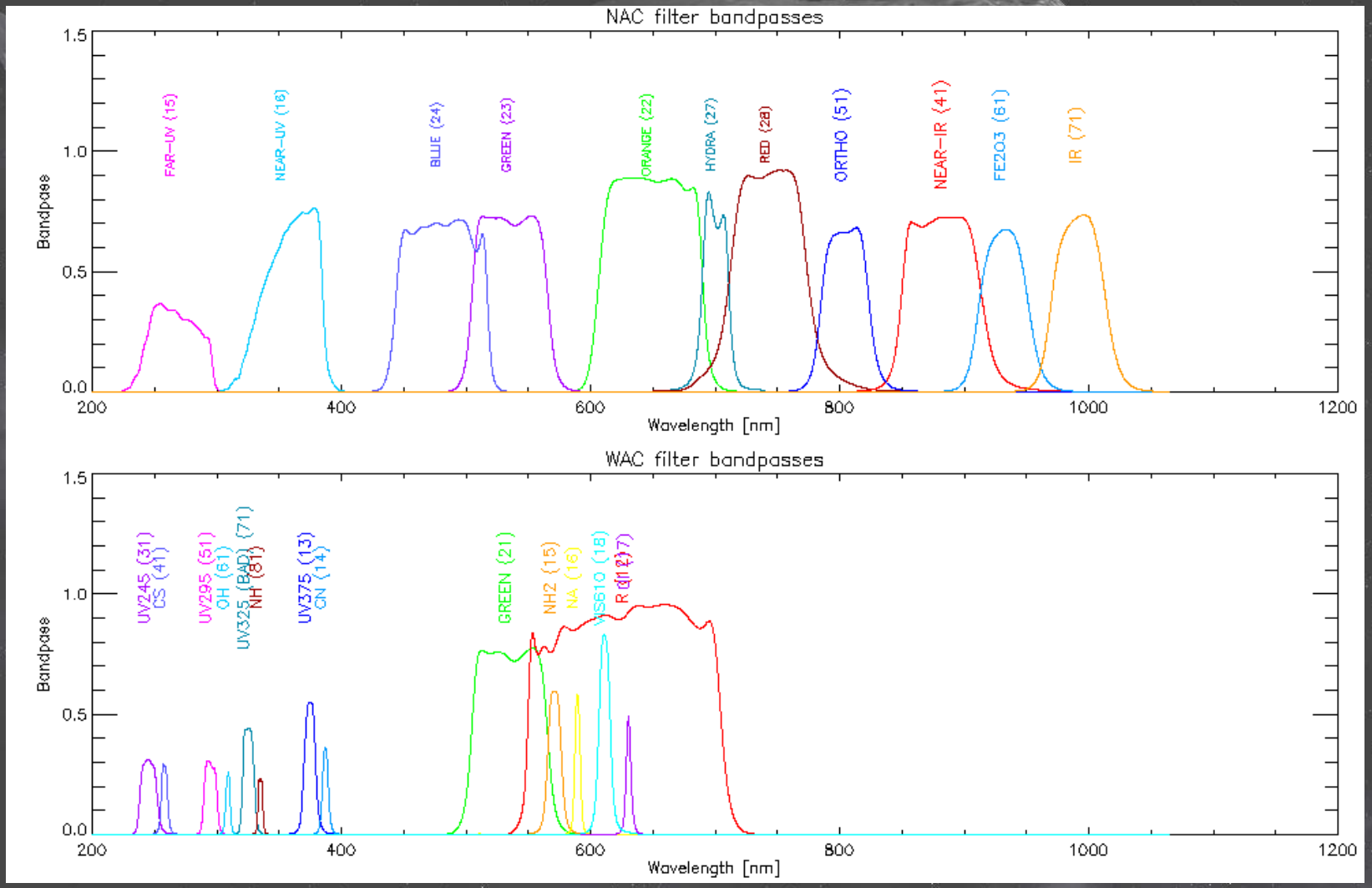
MPS Cameras

Spectral Bands – FC –



Spectra of selected HED meteorites and olivine as would be seen by FC.

Spectral Bands – OSIRIS –



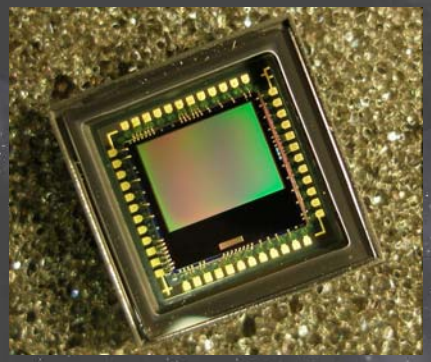
MPS Cameras

Detectors

- CCDs (Charge-Coupled Device)
  - 2D matrix of photosensitive pixels
  - After exposure the charges generated are shifted to a common output structure that coverts charges to voltages.

FC frame transfer CCD and proximity electronics.

- APS (Active Pixel Sensor)
  - 2D matrix of photosensitive pixels
  - Amplification stage is implemented in every pixel
  - Each pixel can be addressed



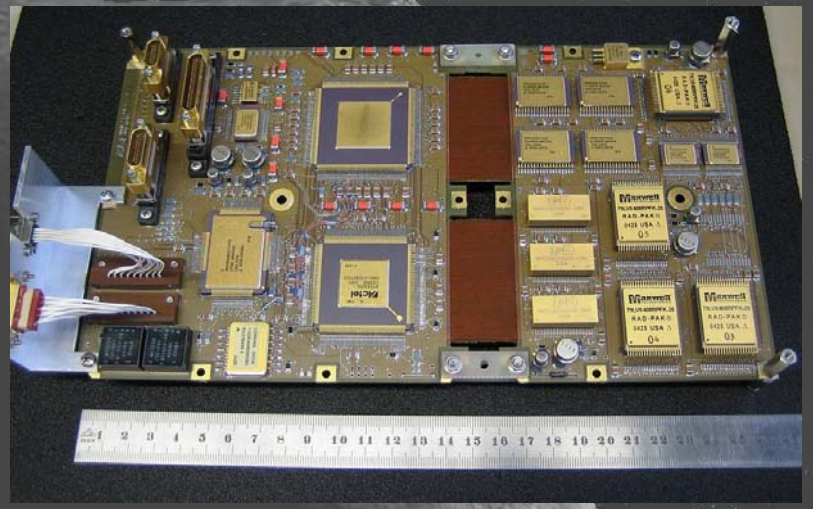
APS

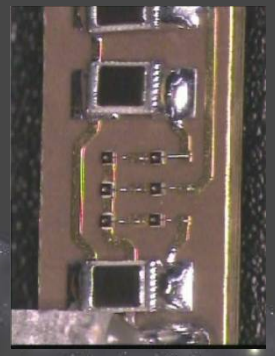
MPS Cameras

FC Main Electronics

MPS Cameras

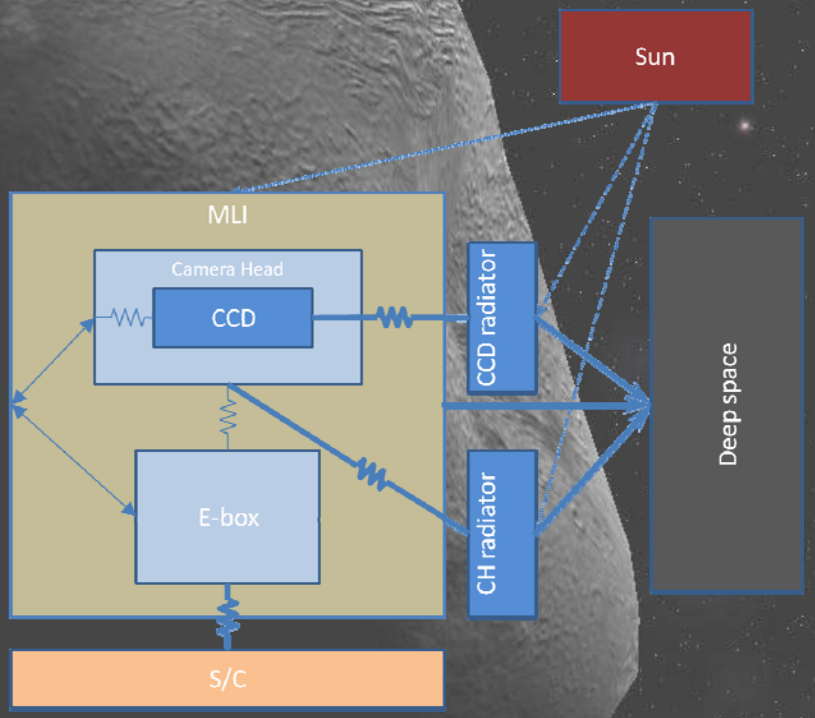
- 14-bit ADC for readout
  - ~ 20 e⁻ rms noise
- 5 s image repetition time
  - 2 s in same filter
- 8 GBit internal mass memory
  - Holds ~1000 compressed images (1:1.8)
- Set of 6 LEDs for inflight calibration
- 152 kbps data transmission
- MIL-STD 1553B data and command interface
- 22 – 35 V unregulated power





Mass, Power and Thermal – FC –

- Flight mass: 5.5 kg
- Power consumption
  - 6 W non-op heaters
  - 11 W standby/process
  - 18 W imaging peak + thermal control
- Thermal load
  - 10 W to S/C deck
  - Rest to deep space

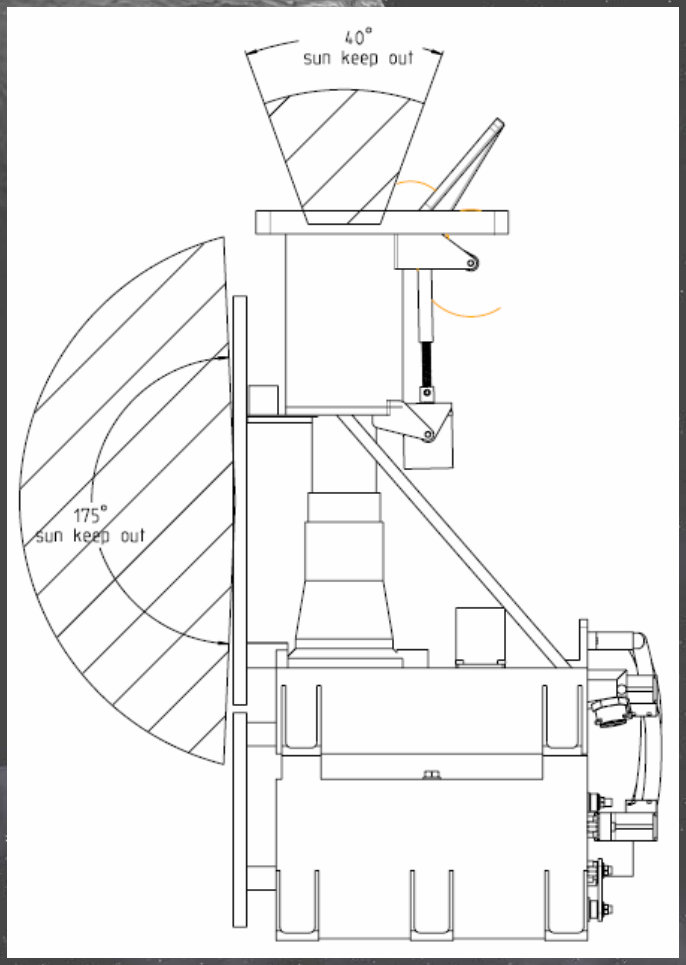


Thermal couplings

MPS Cameras

Constraints During Flight – FC –

- Sun keep out zones
  - 175° Sun exclusion around radiator
  - +/- 20° around boresight



MPS Cameras

Software (DPU Example)

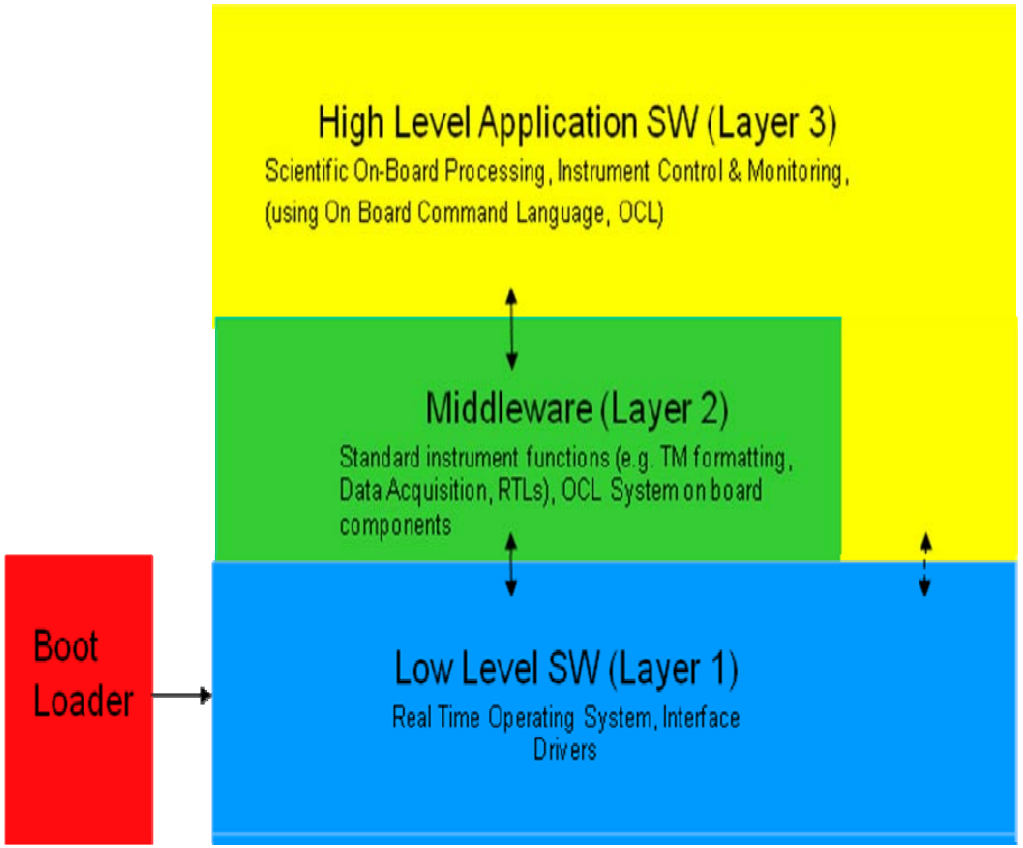
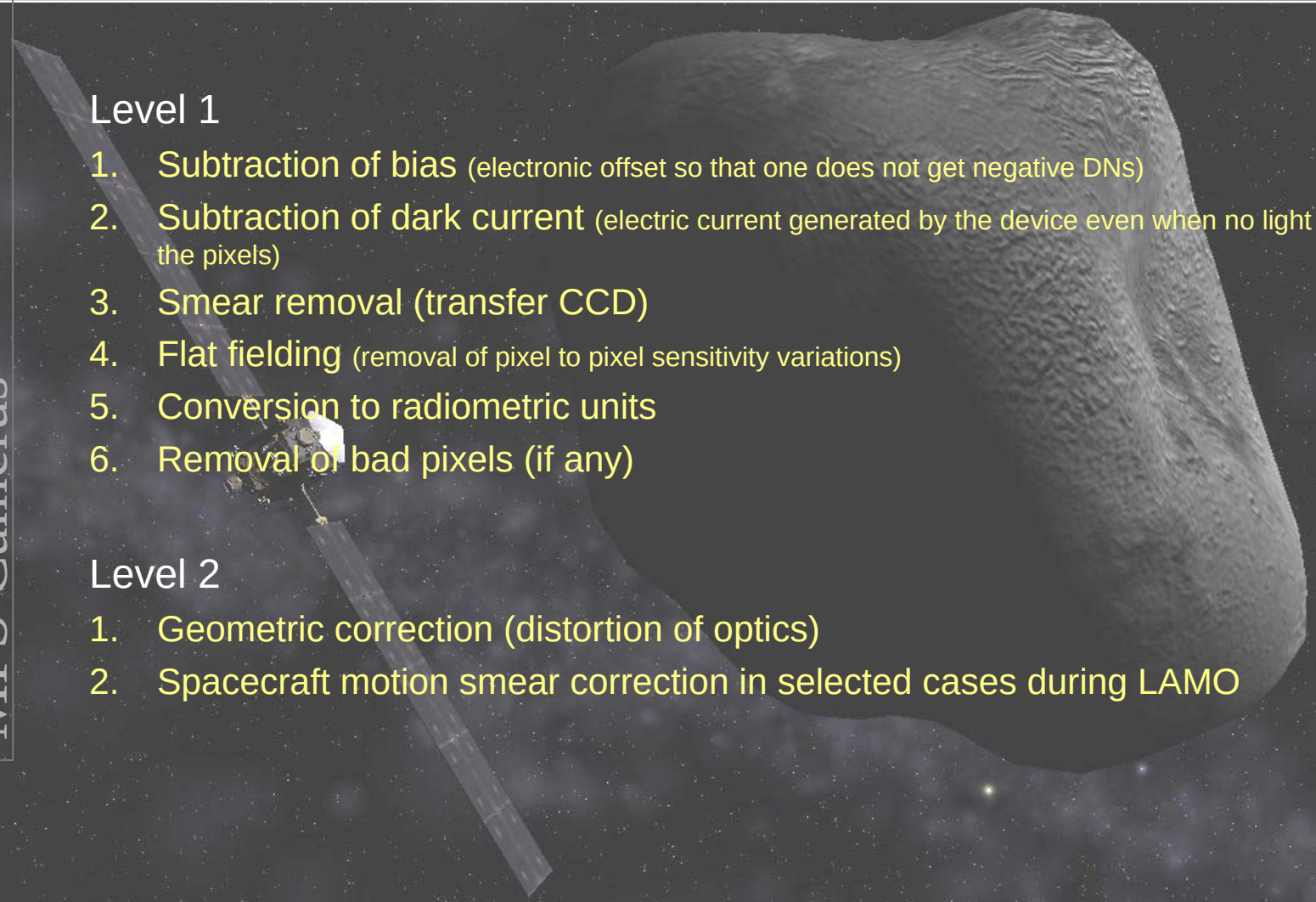


Image Calibration



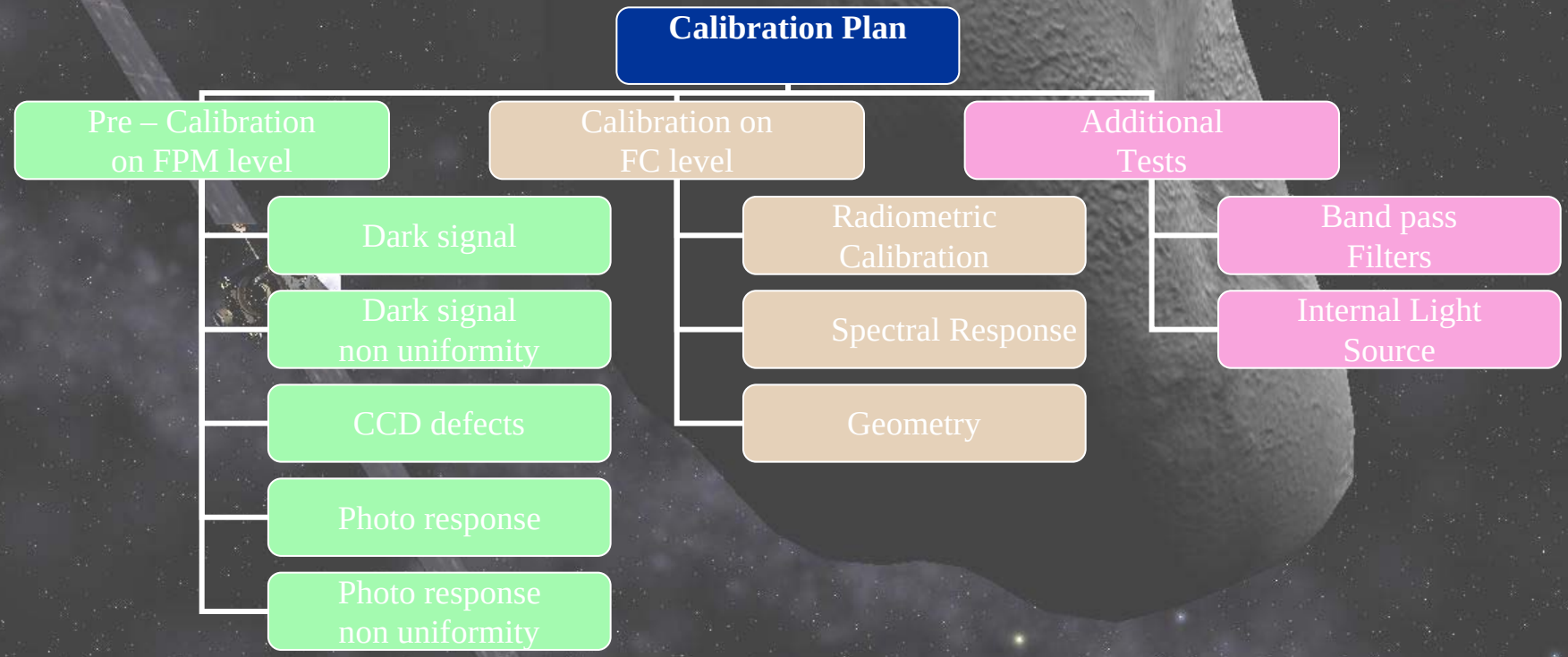
Level 1

1. Subtraction of bias (electronic offset so that one does not get negative DNs)
2. Subtraction of dark current (electric current generated by the device even when no light reaches the pixels)
3. Smear removal (transfer CCD)
4. Flat fielding (removal of pixel to pixel sensitivity variations)
5. Conversion to radiometric units
6. Removal of bad pixels (if any)

Level 2

1. Geometric correction (distortion of optics)
2. Spacecraft motion smear correction in selected cases during LAMO

On-Ground Calibration

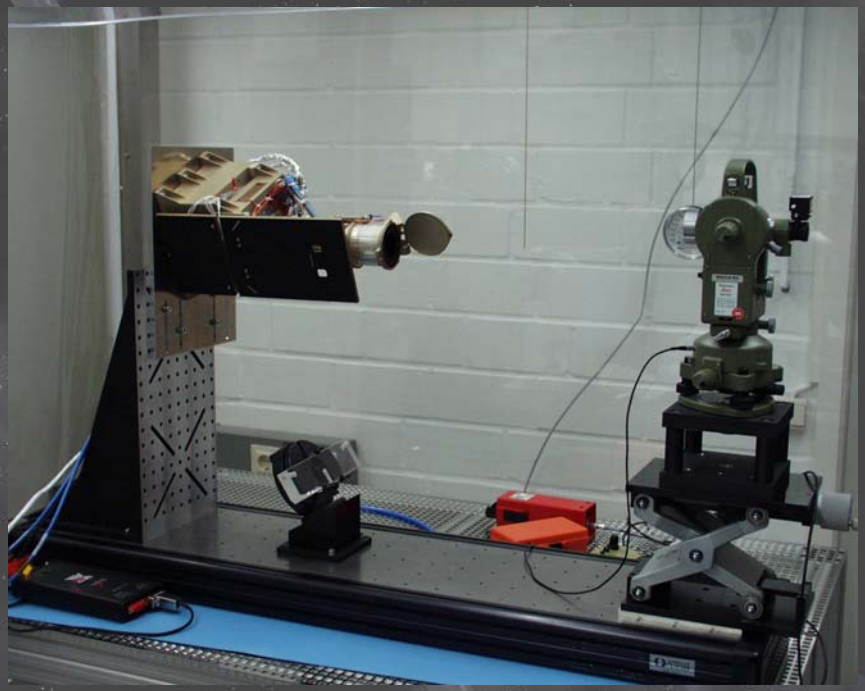


MPS Cameras

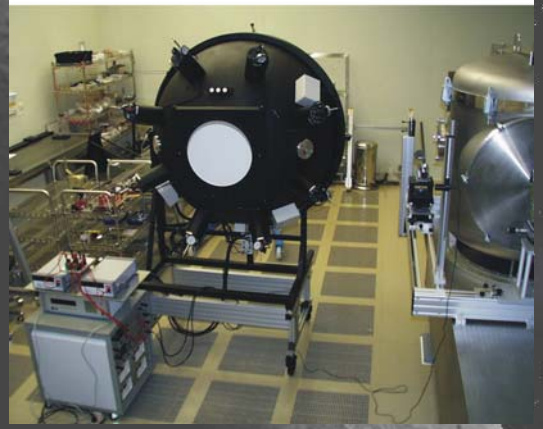
On-Ground Calibration

MPS Cameras

Test Set – Up Optical Alignment



Integrating Sphere in MPAE clean room

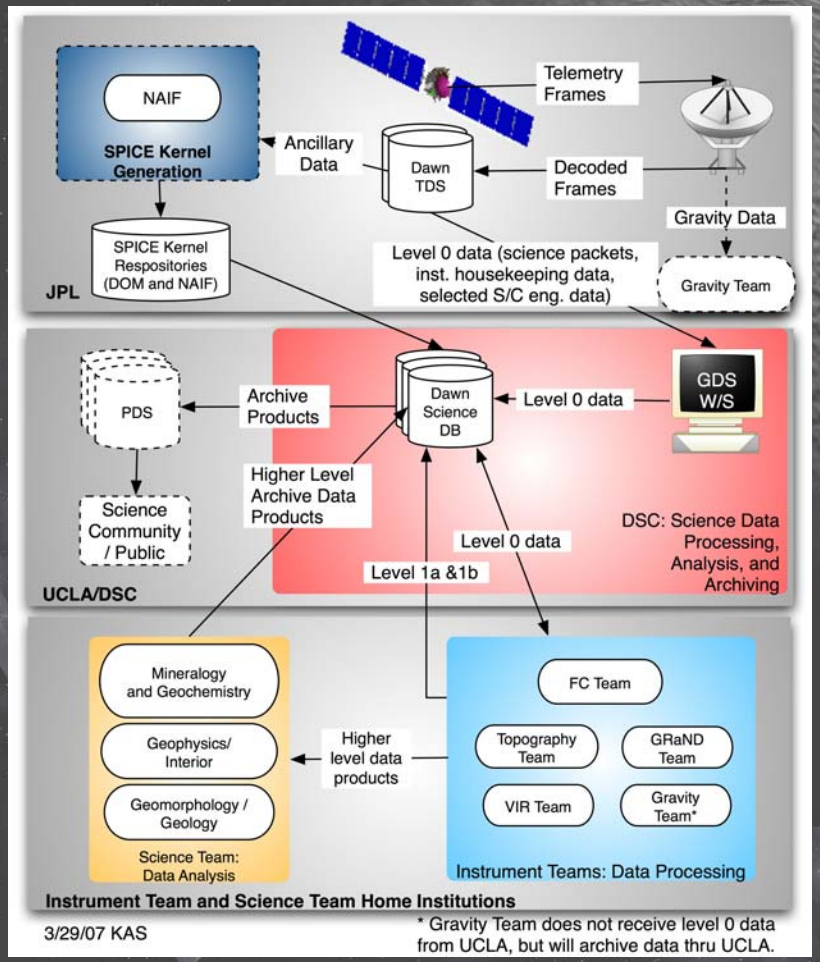


Calibration Set-up in MPAe clean room

Operations

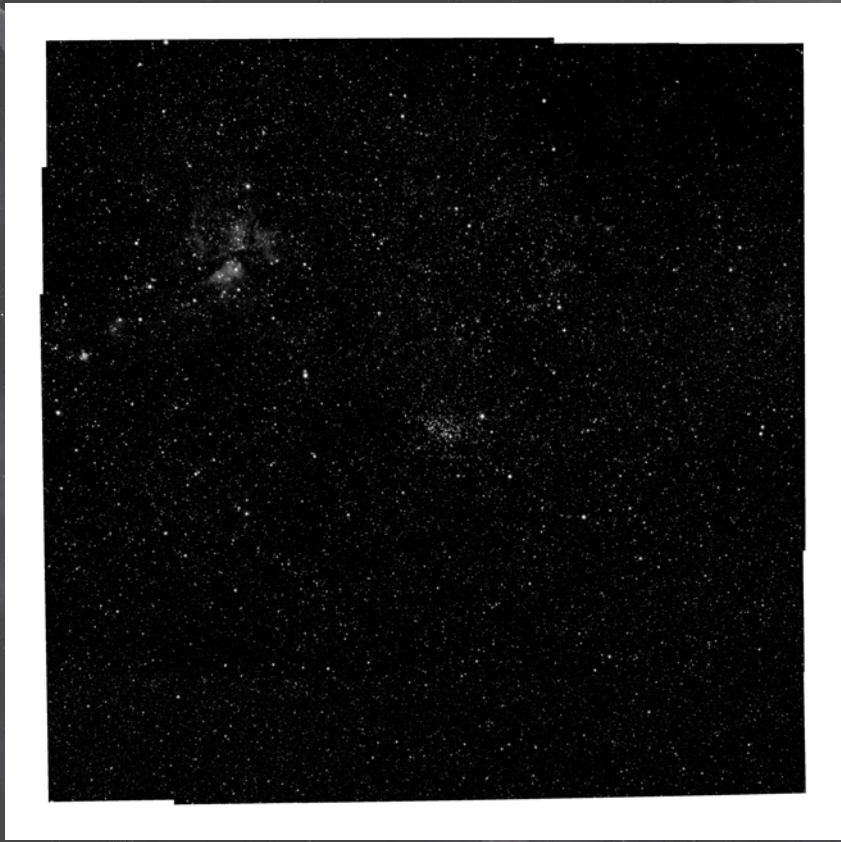
- FC command sequencing is performed at MPS by means of the actual mission TOL using the Damocles software tool.
- Prepared FC sequences are sent to the DSC for inclusion in the overall P/L sequences.
- Sequences are executed on testbeds at MPS and JPL before uplink.
- Conflicts are reported by DSC/JPL and changes on the sequences are performed by MPS.

Data Flow



MPS Cameras

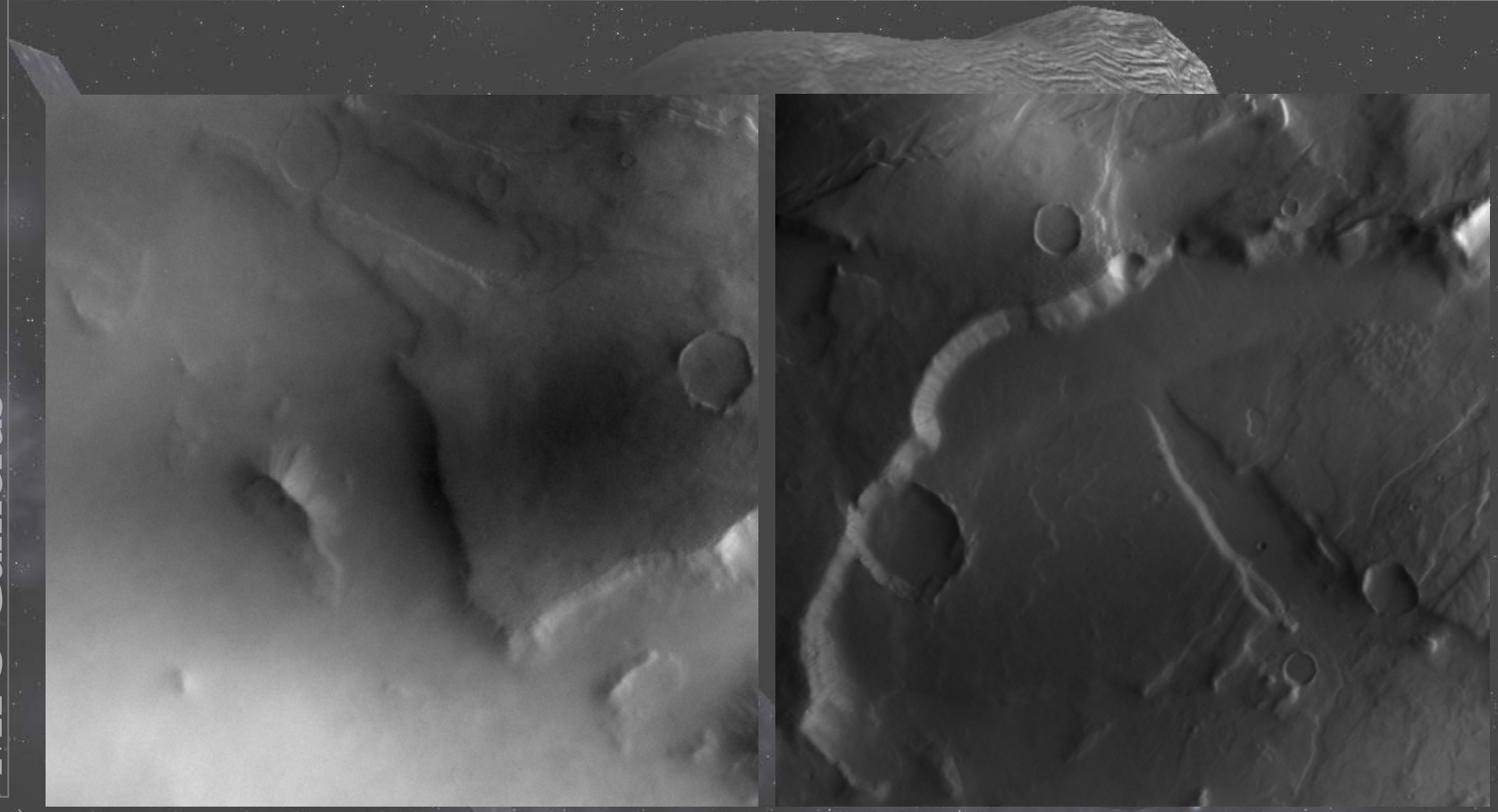
Results



Mosaic of 9 FC images of the star cluster NGC 3532 (center) and the Eta Carinae Nebula (upper left corner) in clear filter.

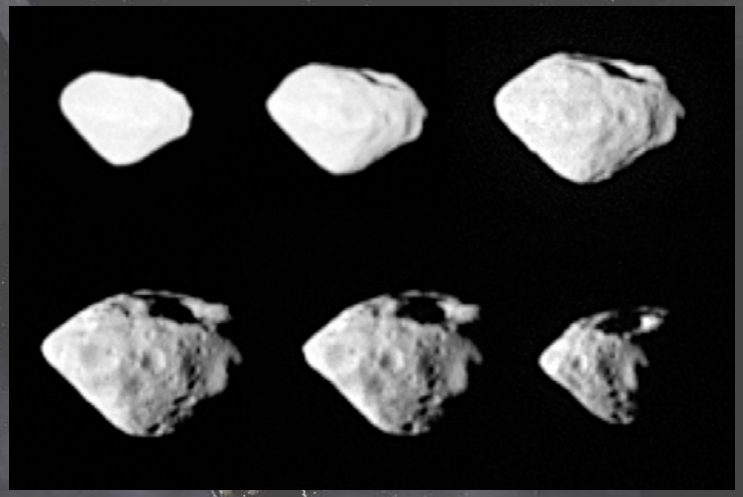
Image detail of three FC false-color images of the Eta Carinae Nebula (NGC 3372).

Results

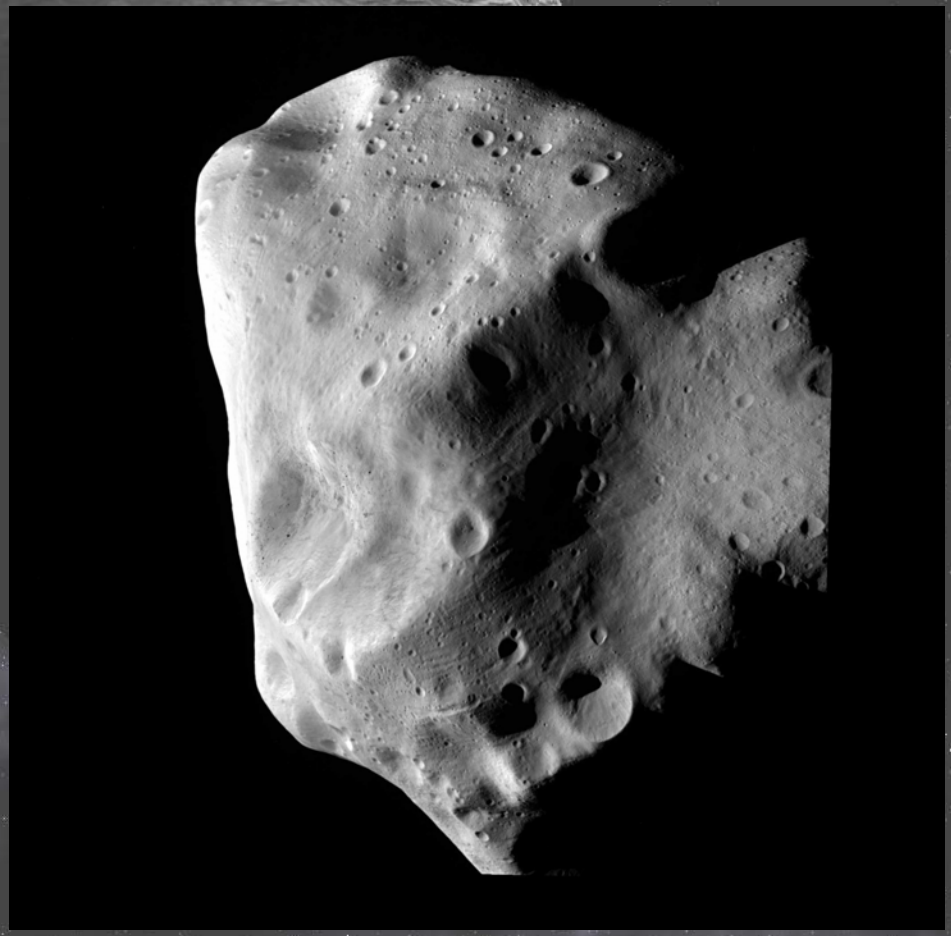


FC calibration images of Mars taken near the point of closest approach on Feb. 17, 2009, during Dawn's gravity assist flyby. The right image shows a portion of the cratered northwest margin of Tempe Terra. The scarp of the highlands/lowlands boundary is illuminated by the light of dusk. Traces of fog appear in the left image. The area covered by one image is about 55 kilometers across.

Results



E-Type main-belt asteroid 2867 Steins; images obtained by OSIRIS during the flyby in Sept 2008.



M-Type main-belt asteroid 21 Lutetia; image obtained by OSIRIS during the flyby in July 2010.