Compact Imagers Based on MESSENGER's Mercury Dual Imaging System

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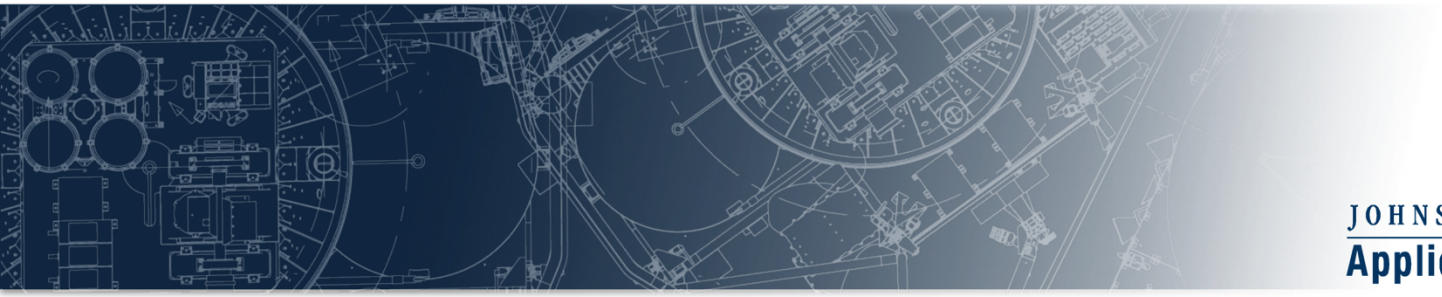

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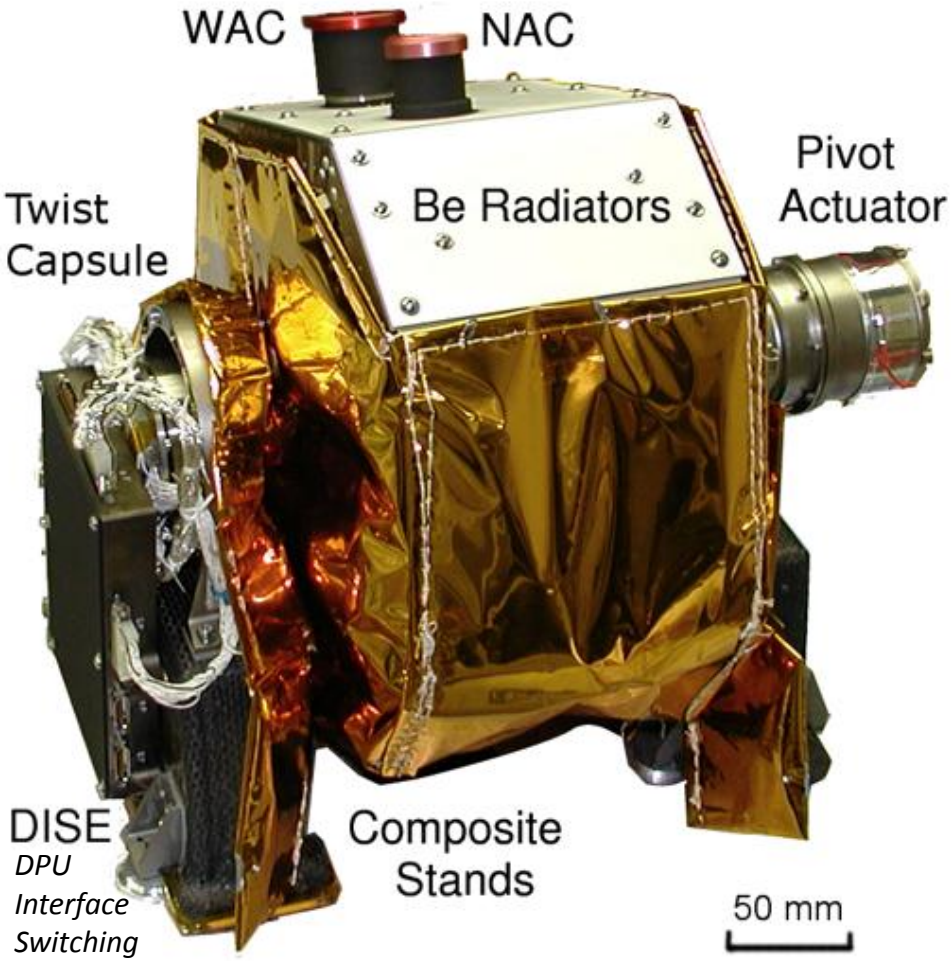
High Level Summary

- Two main goals for planetary imaging are:
  - characterization and mapping of surface morphology
  - determination and mapping of spectral properties
- On the MESSENGER NASA Discovery mission orbiting Mercury, both are accomplished using the **Mercury Dual Imaging System (MDIS)**
- MDIS has been highly successful, acquiring **>150,000 images** during **>8 years of operations** since launch
- With **heritage and known performance**, and with updates to incorporate **new technology**, MDIS is well matched to future planetary missions – especially to small bodies up to 5 AU from the Sun

Mercury Dual Imaging System (MDIS)

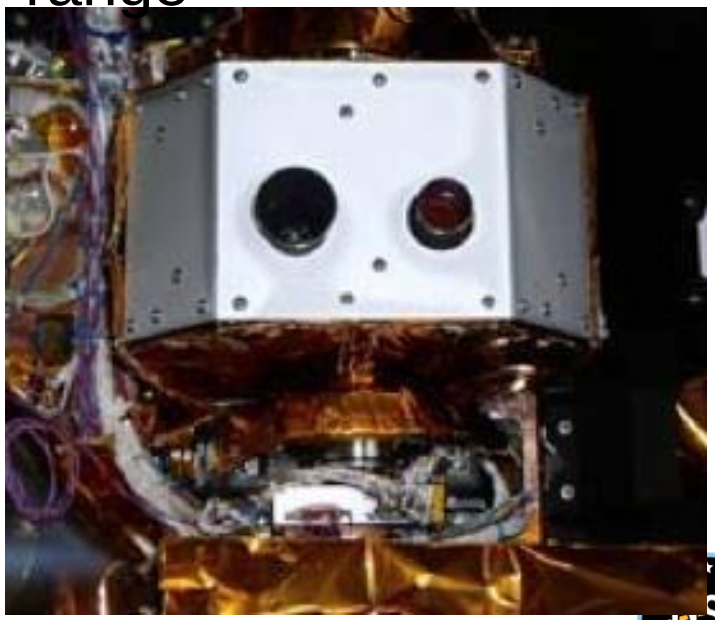
- MDIS is a dual imaging system with two miniature cameras on a pivot
- Monochrome narrow-angle camera (**NAC**)
- Multispectral wide-angle camera (**WAC**)
- Only one camera operates at a time, allowing them to share a common set of control electronics



MDIS Narrow-angle Camera (NAC)

MDIS		
	Narrow angle camera	Wide angle camera
Focal length	550 mm	78 mm
Field of view	1.5º x 1.5º	10.5º x 10.5º
Pixel FOV	5 m at 200-km altitude	35 m at 200-km altitude
Spectral range	725 - 775 nm 1 filter	395 - 1,040 nm 11 spectral filters, 1 clear
CCD	1024 x 1024 Atmel (Thomson) TH7888A	
Pivot range	-40º to +50º	

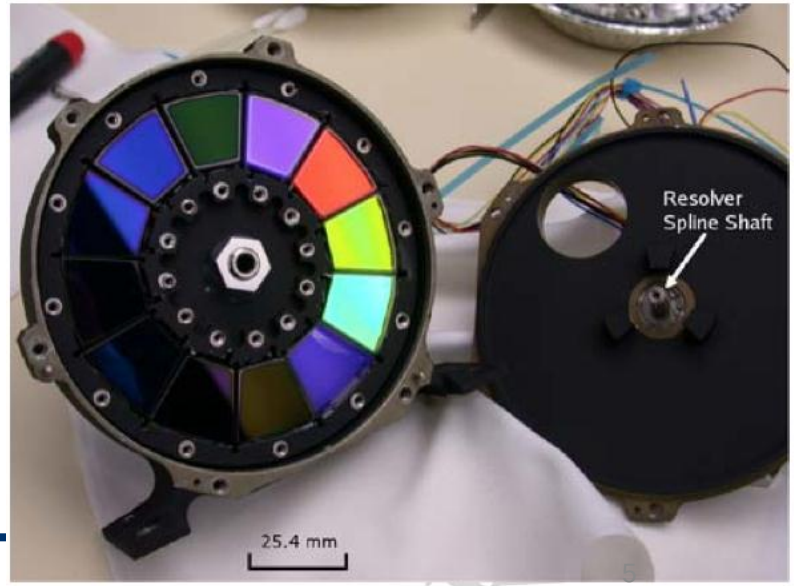
The **NAC** is a 1.5˚ field-of-view off-axis reflector, with 25 µrad/pixel, providing 5 m/pixel from 200 km range



MDIS Wide-angle Camera (WAC)

MDIS		
	Narrow angle camera	**Wide angle camera**
Focal length	550 mm	78 mm
Field of view	1.5º x 1.5º	10.5º x 10.5º
Pixel FOV	5 m at 200-km altitude	35 m at 200-km altitude
Spectral range	725 - 775 nm 1 filter	395 - 1,040 nm 11 spectral filters, 1 clear
CCD	1024 x 1024 Atmel (Thomson) TH7888A	
Pivot range	-40º to +50º	

The **WAC** is a four-element refractor with a 10.5˚ field-of-view; a 12-position filter wheel is equipped with 11 narrow-band color filters and 1 clear filter for star imaging



CS

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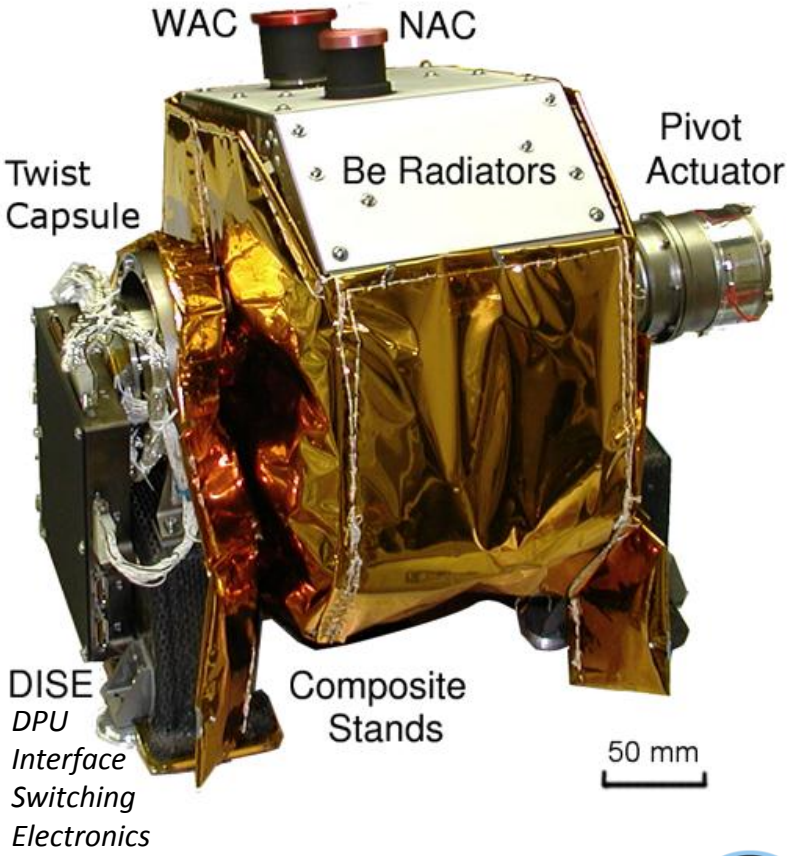
MDIS Instrument Control Electronics

- Both cameras are supported by Instrument Control Electronics that host instrument software
- **Automatic exposure control**, using internal models of filters and pixel-binning states to rapidly switch between filters, cameras, and configurations, **optimizes image exposure**
- Clamping of exposure time by command **prevents image smear**, requiring only orbit predicts to plan the limits



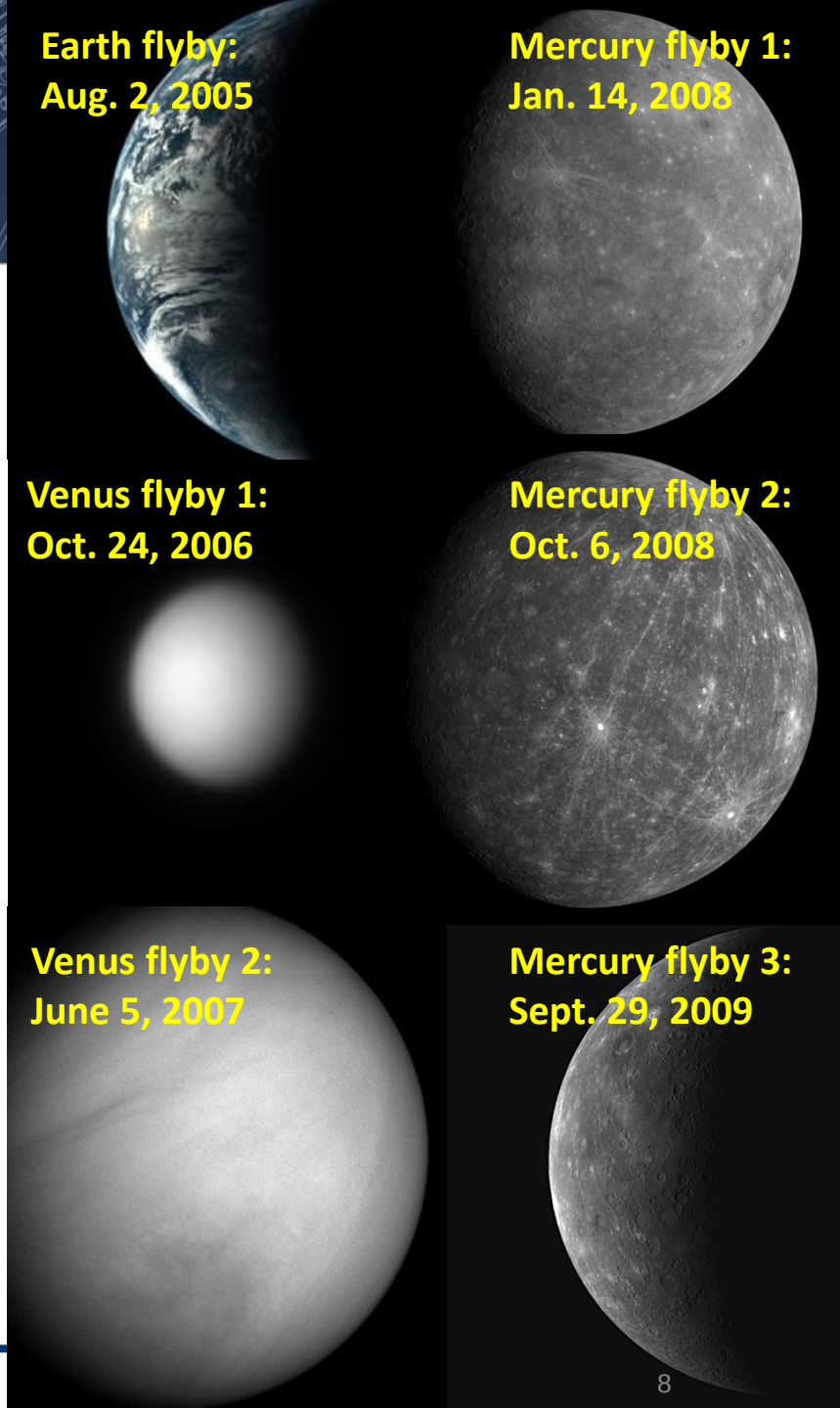
Challenges and Design Solutions for a Mercury-orbiting Imager

Operating in Mercury orbit presents challenges met by design solutions that are applicable to other missions

- The small mass for the payload forced miniaturization and light-weighting of the imagers
- Lack of a gimbaled dish antenna limits downlink; on-board data compression enables comprehensive imaging
  - Options include: pixel binning, 12 to 8 bit conversion, lossless Fast compression, and lossy wavelet compression
- MESSENGER's sunshade limits spacecraft pointing; MDIS is mounted on a pivot platform for pointing flexibility
- It is hot near Mercury! MDIS has a sophisticated thermal control system that keeps the CCDs <-10° C

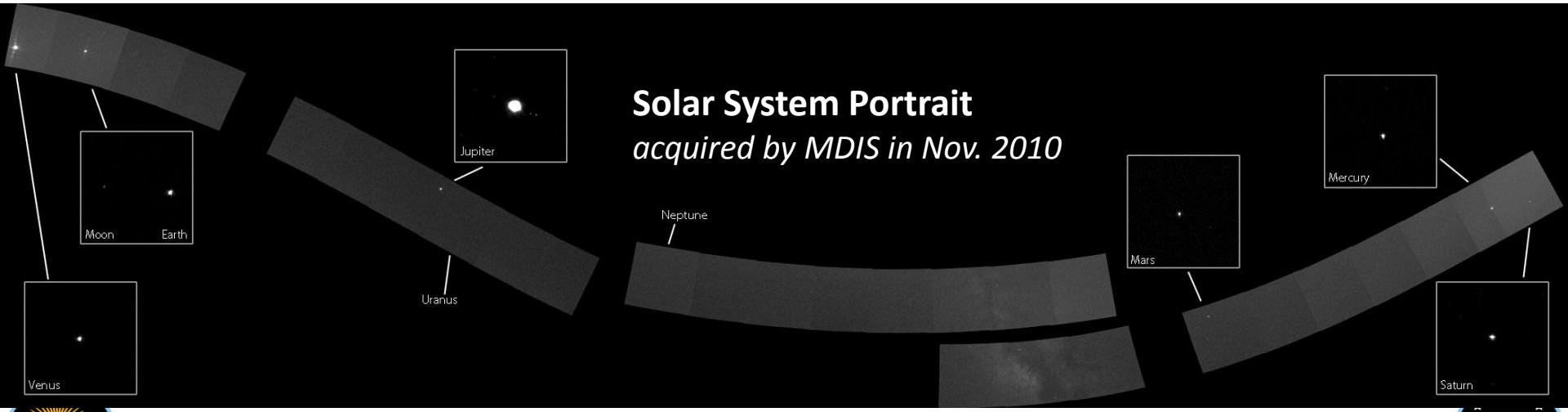
Flyby Tests/Science

- MESSENGER was launched Aug. 3, 2004, and entered Mercury orbit on March 17, 2011
- The cruise phase lasted ~**6.5 years**
- MDIS cruise imaging campaigns during **6 planetary flybys** tested instrument performance
- MDIS images acquired during Mercury flybys were the first spacecraft images of that planet since Mariner 10 in 1974-75
- Mercury flybys yielded new science, helped plan for the orbital mission



Cruise Science and Calibrations

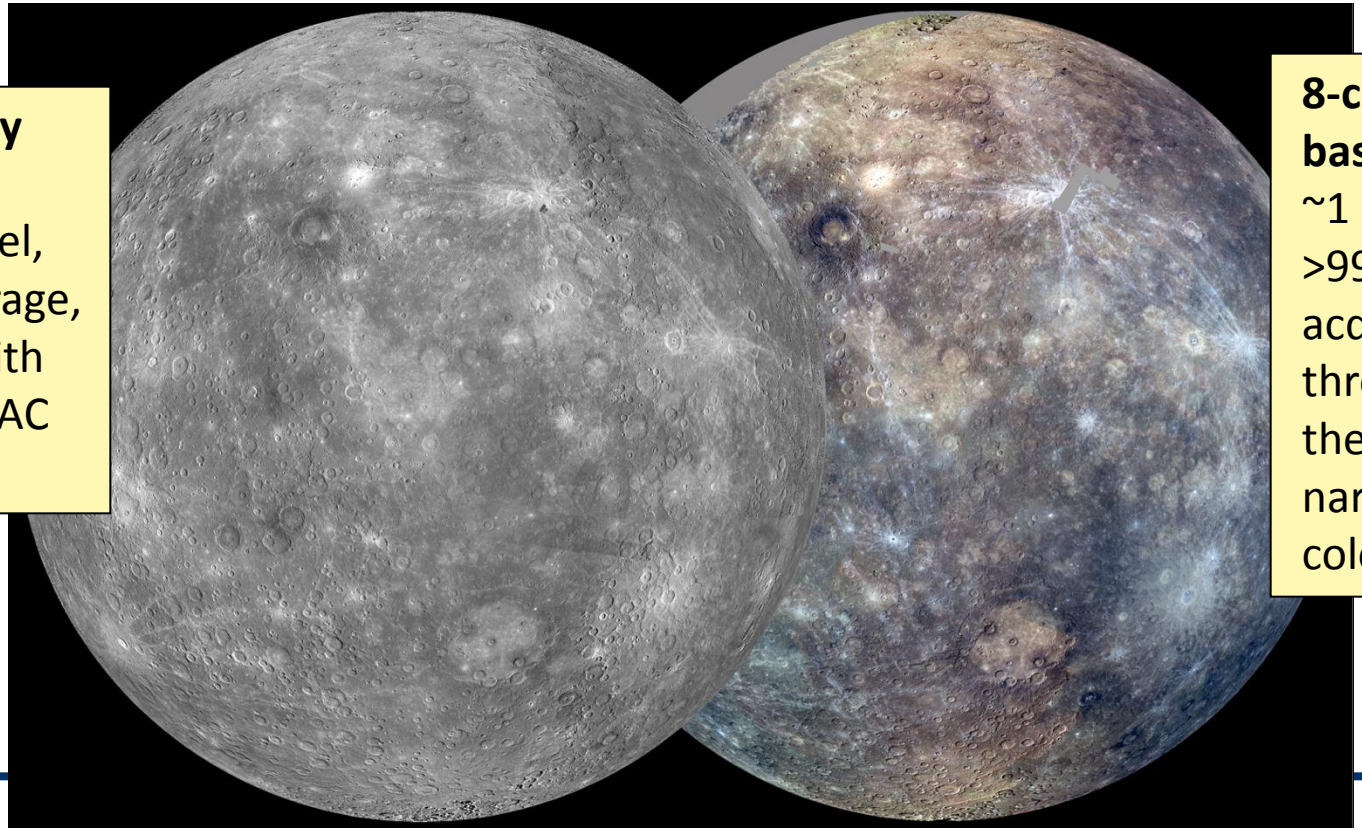
- In addition to planetary flyby imaging, MDIS cruise operations included:
  - Redetermining the WAC and NAC flat-fields by imaging an on-board Spectralon plaque; this removed changes during launch
  - Star images for alignment and geometric calibrations
  - Repeated images to search for and limit the size of vulcanoids
  - A family portrait of the Solar System, from the inside looking out, taken using faint-star imaging capabilities designed for OpNav
- **In total: 13,080 MDIS images acquired during ~6.5 year cruise**



Orbital Global Imaging

- During MESSENGER's one-year primary orbital mission, MDIS acquired the **first global maps of Mercury**
  - Morphology base map and stereo complement with moderate *i*
  - 8-color map with low *i*

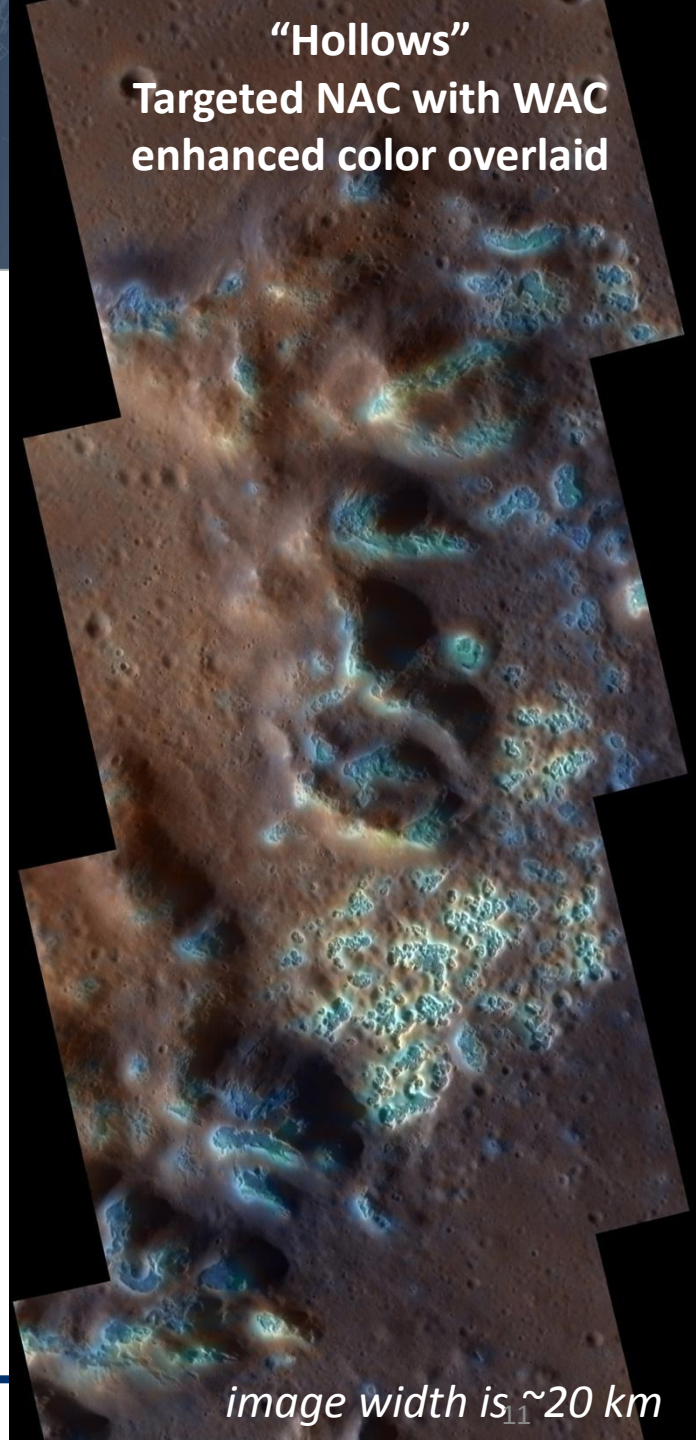
Morphology base map: ~200 m/pixel, >99% coverage, acquired with both the WAC and NAC



8-color base map: ~1 km/pixel, >99% coverage, acquired through 8 of the 11 WAC narrow-band color filters

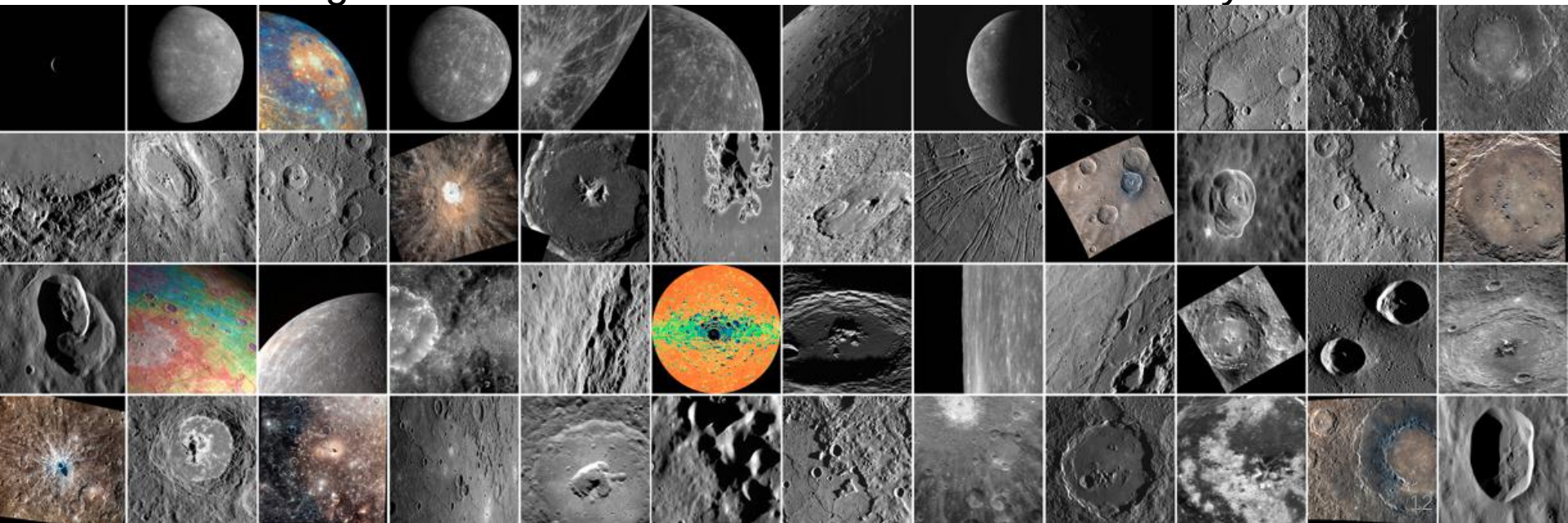
Targeted/Other Images

- Targeted NAC and WAC observations yielded high-resolution views (to ~15 m/pixel) of features of high science interest on Mercury
- Other primary mission image campaigns focused on specific objectives:
  - Repeated south polar imaging to map permanent shadow
  - Limb images to constrain global shape
  - Star images to maintain pointing calibration in an extreme environment
- **MDIS acquired 88,746 images during the one-year primary orbital mission and exceeded all success criteria**



Extended Mission

- MESSENGER's 1-year Extended Mission imaging campaigns build on results from the primary mission:
  - 200 m/pixel global map at high *i* (subdued topography)
  - 200 m/pixel global map and stereo complement at low *i* (albedo features; stereo topography with minimized shadows)
  - High-resolution 3-color map of the northern hemisphere
- **In total, MDIS has acquired >150,000 images to date**
- Mission design shows MESSENGER can remain in Mercury orbit until 2015



Adapting MDIS's WAC and NAC to New Missions

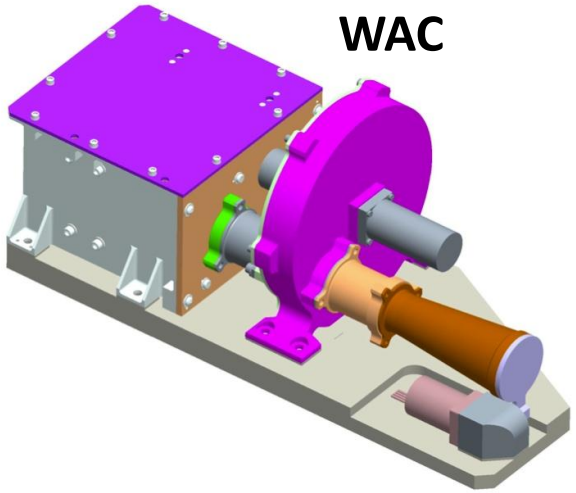
- Without the thermal challenges of orbiting Mercury, the sophisticated thermal control system is not needed
- Some mission profiles include pointing capabilities that remove the need for a pivot
- **MDIS's WAC and NAC can each become free-standing compact imagers**
  - WAC mass: 2.6 kg; NAC mass: 2.3 kg
- Incorporating lessons learned from MDIS in-flight performance, and with new technology developed at APL, the WAC and the NAC are well suited for missions to small bodies at distances to ~5 AU, where downlink bandwidth and recorder size are limitations

Adapting MDIS's WAC and NAC to New Missions

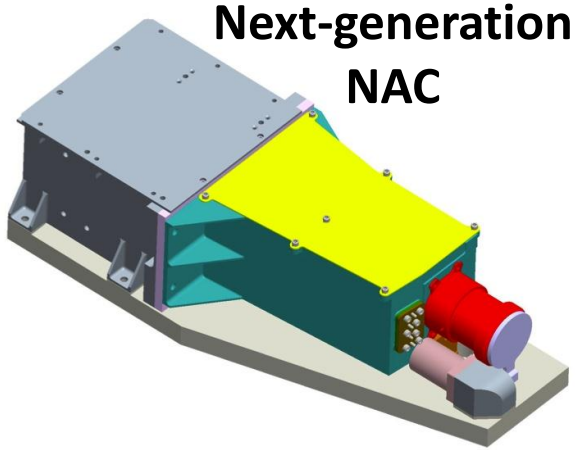
Four Possible Design Updates Adapt the WAC and NAC for Small Body Missions

- 1) Switching the CCD to that used on LORRI* provides a 4x increase in QE, and eliminates scattered light from the CCD structure
- 2) Widening the filter bandpasses enables short exposure times for low-albedo bodies
- 3) An optional re-closeable cover, using the CRISM stepper motor (>400,000 cycles in flight), prevents contamination in dusty conditions and allows in-flight flat-field measurement
- 4) Performance of data compression in real time by enhanced instrument electronics reduces demands for recorder space

Next-generation WAC



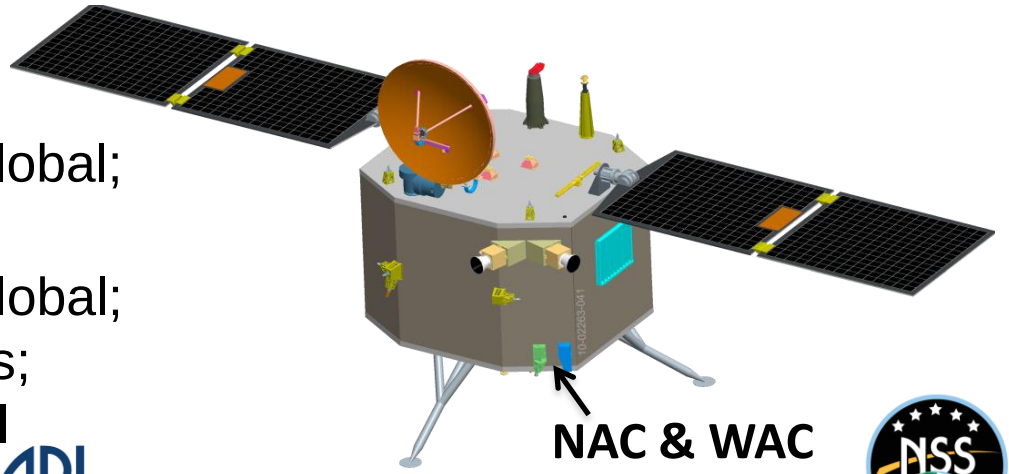
Next-generation NAC



*Long Range Reconnaissance Imager, on New Horizons

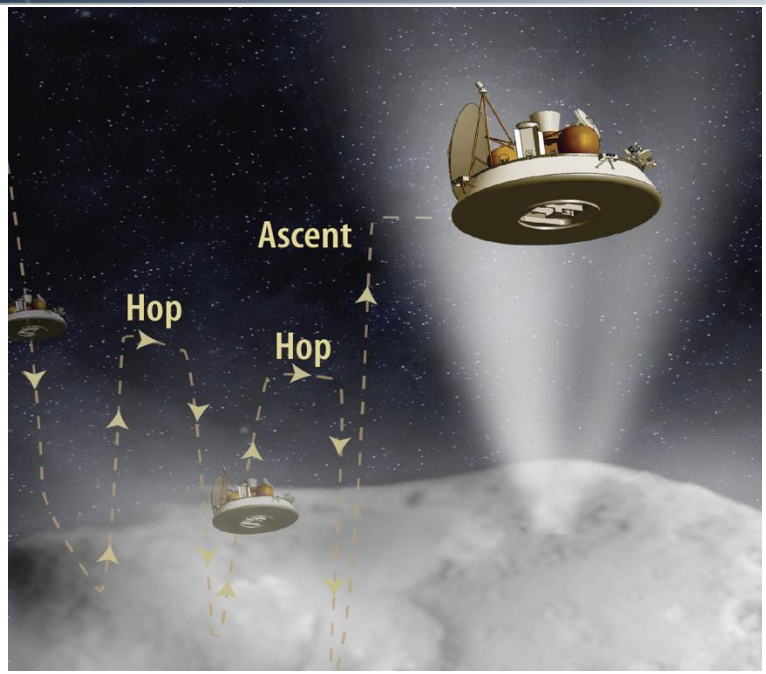
Example 1 of MDIS-heritage Imagers: MERLIN

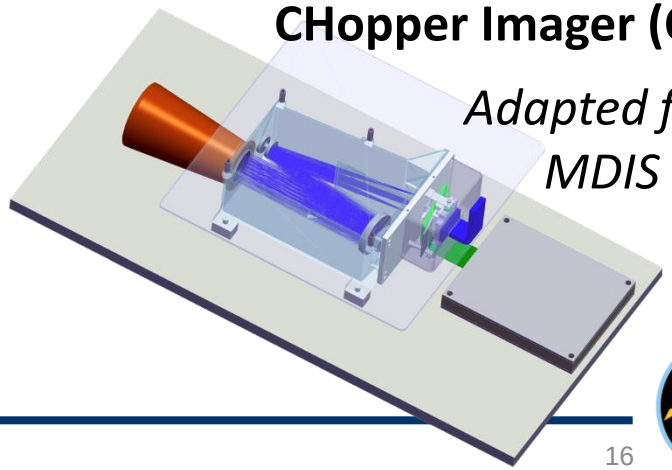
- **MERLIN:** a proposed Discovery-class mission concept to rendezvous with and then land on a martian moon (PI: Murchie, APL)
- Includes a dual imaging system with the updated **NAC & WAC** (without pivot) to conduct:
  - OpNav imaging
  - Stereo mapping at **1 m/pixel** global; **5 cm/pixel** during low flyovers
  - Color mapping at **10 m/pixel** global; **20 cm/pixel** during low flyovers; descent imaging at **1 mm/pixel**



Example 2 of MDIS-heritage Imagers: CHopper

- Comet Hopper (CHopper): One of three finalists in the last Discovery selection (PI: Sunshine, UMD)
- CHopper would characterize and then land on Comet Wirtanen, hopping to other surface locations as the comet approaches the Sun
- The CHopper Imager (CHI) is adapted from the **MDIS NAC**, with the updated LORRI CCD and the aperture increased to **handle the low light conditions expected at 4.5 AU**
- CHI is responsible for first acquiring the comet and then imaging the comet to develop a shape model





CHopper Imager (CHI)

Adapted from MDIS NAC

Compact Imagers Based on MESSENGER's Mercury Dual Imaging System

- MESSENGER's Mercury Dual Imaging System (MDIS) has been and continues to be highly successful
- **Leveraging MDIS's tested design will reduce development and performance risk on future planetary missions**
- For missions not facing challenges of limited pointing, MDIS's NAC and WAC each become free-standing, compact imagers
- Minor design updates allow the incorporation of new technology and provide the flexibility to meet the science needs of future missions, in particular missions to small bodies up to distances of ~5 AU