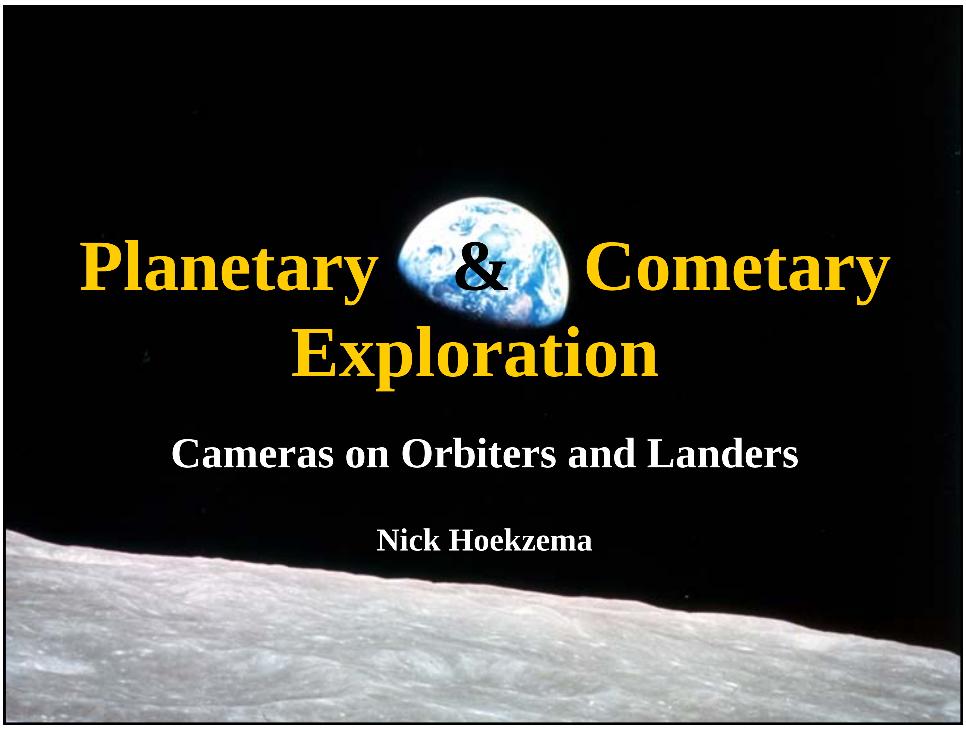


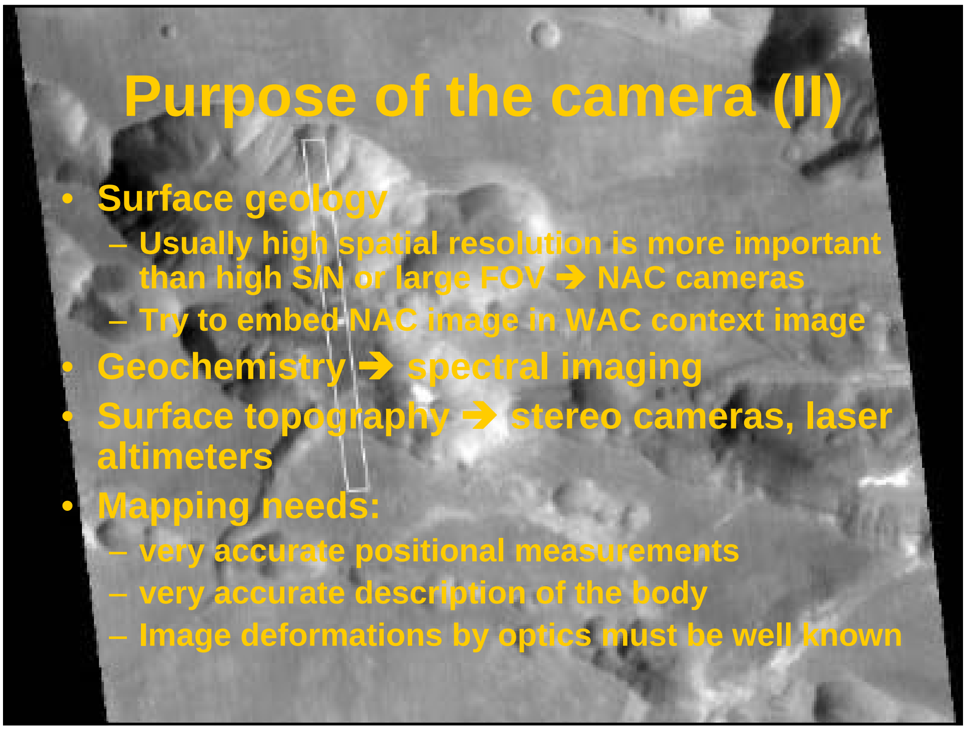
Planetary & Cometary Exploration

Cameras on Orbiters and Landers

Nick Hoekzema

Purpose of the camera (I)

- Navigation, orientation ➔
  - Solar sensors ➔ orientation with ~ 0.5º accuracy
  - Star trackers to recognize constellations ➔ accuracy up to the `` range
  - Feedback between cameras and gyros/rockets
- Atmospheric research
  - Usually large FOV (Field Of View) and high S/N is more important than high spatial resolution. Usually a few km/pixel is quite sufficient ➔ WAC (Wide Angle Camera)
  - E.g., weather, cloud, and aerosol studies



Purpose of the camera (II)

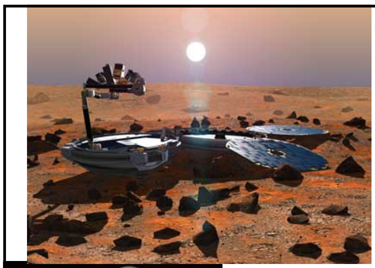
- Surface geology
  - Usually high spatial resolution is more important than high S/N or large FOV ➔ NAC cameras
  - Try to embed NAC image in WAC context image
- Geochemistry ➔ spectral imaging
- Surface topography ➔ stereo cameras, laser altimeters
- Mapping needs:
  - very accurate positional measurements
  - very accurate description of the body
  - Image deformations by optics must be well known

Border conditions (I)

- Data rate
  - Earth remote sensing: many Gbytes/day if needed
  - Deep space: be happy with a Gbyte/day
- Weight, how much payload does a camera take?
  - Simple WAC & navigational cameras nowadays: few kg or even few hundred grams
  - Some Earth observers have cameras of hundreds of kg
  - Old fashioned pre CCD era cameras: tens of kg
  - Omega (spectral imager) ~20—25 kg
- Temperature environment
  - Dark current changes with temperature ➔ unstable temperature environment ruins calibration
  - Spectral imagers, IR cameras often need cooling

Border conditions (II)

- Power consumption
  - Small WAC cameras: few W or even less
  - Old fashioned pre CCD era camera: tens of W
  - Active system like MOLA laser altimeter: tens of W
  - Huge, cooled, IR telescopes: hundreds of W
- Weathering: CCDs don’t like cosmic rays, fast solar wind protons, etc
- Dimensions
  - some positional cameras and WACs fit into a matchbox
  - High resolution cameras need a telescope ➔ much larger e.g., MOC ~ 0.5 X 0.5 X 0.9 m
  - Some spy satellites had telescopes of several meters



Lander Stereo Cameras

- Most landers have stereo cameras
- Stereo information is needed to manouvre vehicle or manipulators

Past

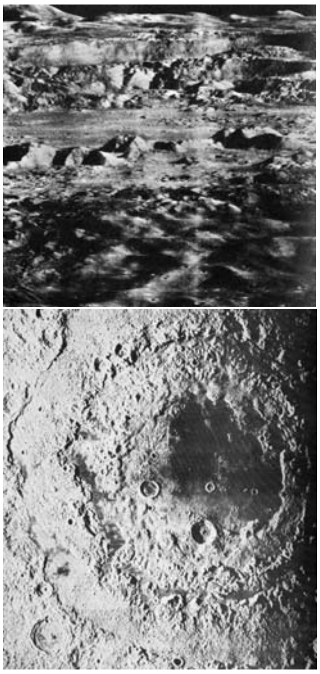
sixties & seventies

Extremely high resolution space images from spy satellites. E.g., US Samos

- Use television system for targeting
- Register high resolution images on film
- Drop film in capsule to Earth surface
- (Panic when capsule lands on wrong spot)

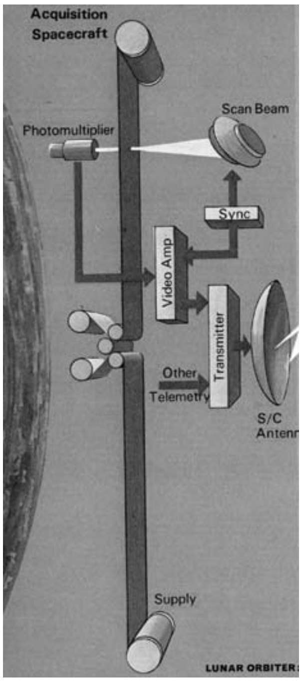
Obvious problems when you want to have pictures from planets other than Earth, then use television ➔ quality not so good

Lunar Orbiter



- 1966-1967
- Great images (but the reproduction shown here is less than optimal)
- Although the optics were not impressive, objects of only a few meters are visible…
- and intensities are extremely well calibrated
- …because the S/C could be put into low lunar orbit…
- …and, most of all, because it exposed onto a 70 mm film!

Lunar orbiter (II)



- Essentially used a normal photo-camera
- The spacecraft developed and digitized its own films onboard
- Drawbacks
  - Many moving parts
  - System is really heavy ➔ ~65 kg for some simple black and white pictures
- Not used for interplanetary missions such as Viking or Voyager

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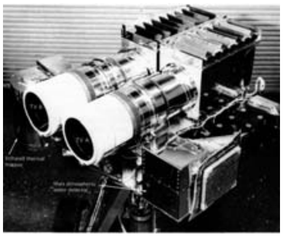
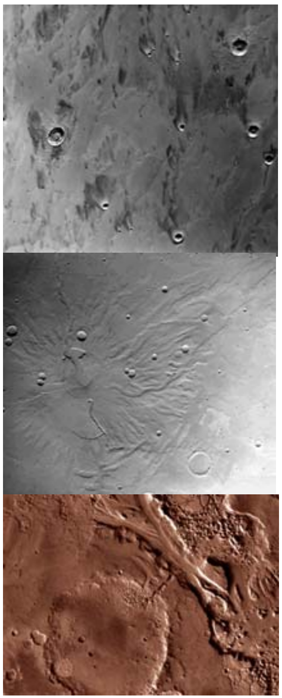
Vidicon

- Telescope focuses images on a Vidicon
- Image is an imprint of variable electrostatic charge on the faceplate of the Vidicon
- Faceplate is then scanned and neutralized with an electron beam and variations in charge are read in parallel into a tape recorder
- They flew on numerous missions (Mariners, Voyagers, etc)
- They were heavy (➔Voyager camera system ~40 kg)

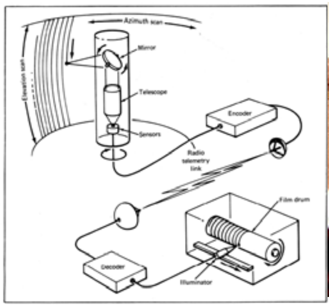


VIS:

Viking orbiter vidicon cameras as an example



- But for many over/under exposed pixels, intensities are ~1% reliable
- Bit slow (i.e., the readout and digitization)
- Moving parts (shutter, filter wheel)
- Consume upto 35 watts



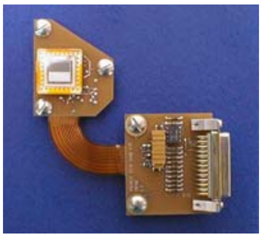
Facsimile Viking lander cameras

- Very different from vidicon principle
- Intensities from a small solid angle are measured by one or more photodiodes (viking facsimiles had 12)
- A nodding mirror is used to build an image pixel by pixel
- Advantage: extremely accurate intensity measurements
- Drawback: slow, very slow, and contains moving parts

Present

- And then miniaturization gave birth to the CCD
- Each pixel stores a charge that is determined by the incident illumination
- End of exposure ➔
  - charge is transferred to a storage register
  - the CCD is freed up for the next exposure
- First interplanetary use:

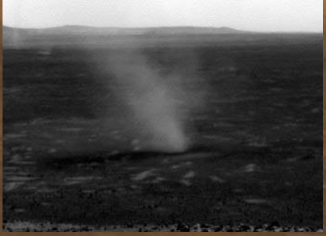
  1986 Halley flyby of
  - Giotto **CCD from MPAE!**
  - Vega



CCD: good and bad

- Few or no moving parts • Extremely lightweight
- Fast • Reliable • Small power consumption
- Can handle large contrasts
- Measured intensities are not too accurate
  - Originally ~5%
  - Nowadays ~0.5% or better
- Sensitive to damage from e.g., cosmic rays
- In short: If time, weight, maintenance, data transfer rates, and transport were no problem then old fashioned facsimile and film cameras would often still be the better choice

Framing cameras

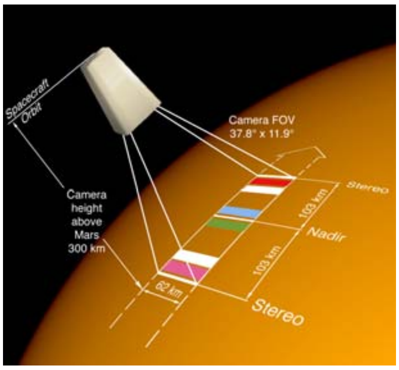


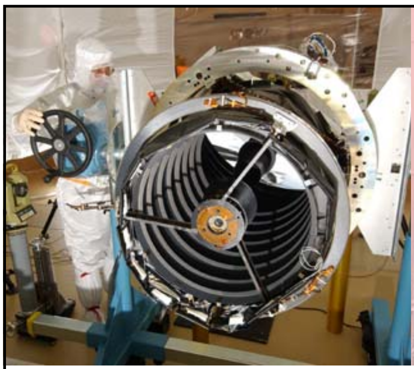
- Use rectangular CCD to take pictures
- No Viking-like problems with fast phenomena like these dust-devils
- Since nowadays CCD may easily have several million pixels…
- …observing at high spatial resolution usually is less of a problem than…
- …sending images of a few Mbyte each in a reasonable amount of time
- Therefore add pixels prior to transmitting the image ➔
  - Higher S/N ratios
  - Lower spatial resolution
- This procedure is called macro pixeling

Push broom scanners

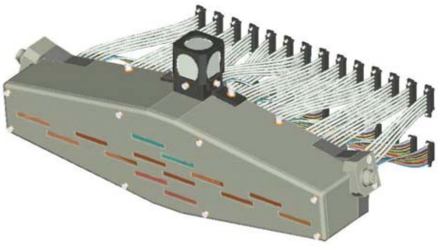
Examples:	MOC	(on Mars Global Surveyor)
	MISR	(on Terra)
	HRSC	(on Mars Express)
	((Omega	(on Mars Express)))
compare	Sumer	(on SOHO)

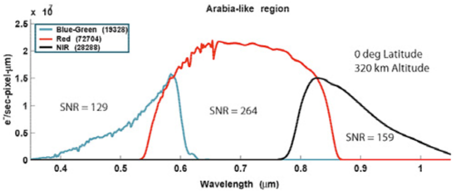
- Push broom cameras scan the surface with line CCDs
- Images are built line after line as the spacecraft moves along its orbit
- Line CCDs may have many thousands of pixels
- Biggest problems usually:
  - Data rate
  - Need for accurate correction for S/C movements and vibrations

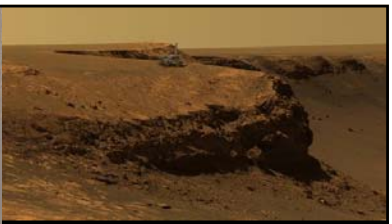




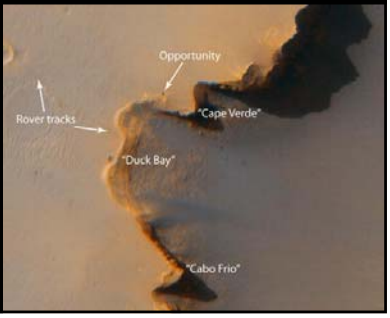
HiRise camera on board Mars Reconnaissance orbiter
14 line CCDs yield upto 30 cm per pixel from orbit!





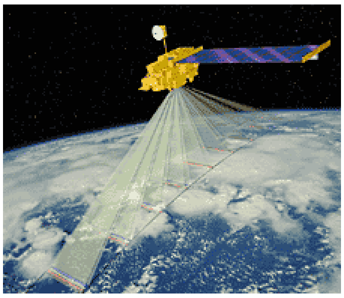


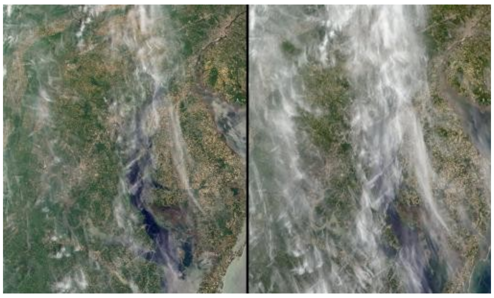
HiRise



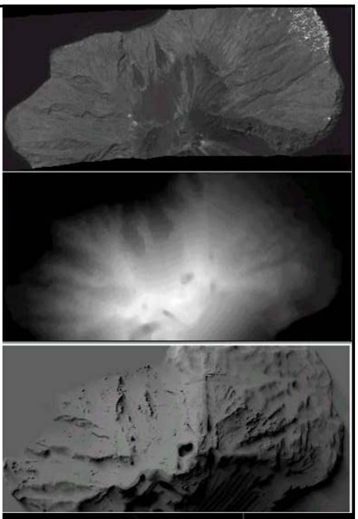
Multiple line push broom scanners

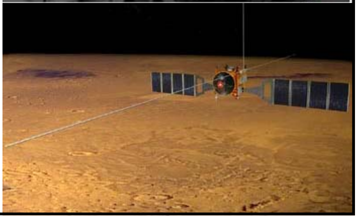
- Examples, MISR and HRSC
- Several line CCDs are mounted in parallel
- Each observe in different colors and/or angles ➔ stereo view in color
- Note the difference in optical depth between 0º and 60º





Stereo Remote Sensing



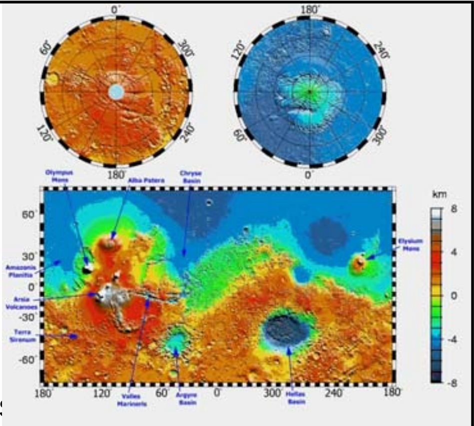


- Gives DEMs
- Very useful for aerosol and other atmospheric studies
- Useful for separating atmosphere from surface
- Some stereo cameras fly onboard airplanes are Air Misr and HRSCa
- Stereo remote sensing of Earth:
  - ATSR-2 onboard ERS
  - POLDER onboard ADEOS
  - MISR onboard TERRA
- Stereo remote sensing of Mars from 2004 with HRSC on Mars Express

So what about the future? Scanning with a rectangular CCD?

- In fact a 1000 X 1000 pixel CCD is a set of 1000 line CCDs in parallel
- You might put a grating in front of it so that a spectrum is projected on the CCD
- Scan the surface with each of these ‘line CCDs’
- This is a form of ‘spectral imaging’
- Largest drawback: the data rate is enormous if done at high resolution
- Mars Climate observer was to use a simple, low data rate version of this principle (pity it was lost)

Laser altimeters



- MOLA (Mars Orbiting Laser Altimeter) gave a superb topographic map of Mars
- However, it also:
  - Probes the atmosphere
  - Measures surface albedos
  - Measures surface roughness
  - Can look at dark surfaces
    - E.g., study of clouds over the polar cap during winter darkness
- Will be a valuable tool on missions to e.g., asteroids Jovian moons, Mercury

Resolution:
Horizontal ~100 m
Vertical > 40 cm
However, future instruments may do much better

‘Our’ laser altimeter will go to Mercury!

BELA The BepiColombo Laser Altimeter

- Launch: 2013, the primary mission begins 2019
- Mass: 12 kg, including a DPU, and radiation shielding
- Power: 43 W average operational power
- Near Mercury you of course need sophisticated thermal control
- Surface spot size: 20—50 m, up to 30 cm resolution in measured altitudes, sampling every ~250 m along track
- topographic variations
- Sensitive enough (we hope) to measure tidal deformations
  - **May tell about interior (liquid core?)**
- surface roughness, local slopes
- albedo variations, also in permanently shaded craters near the poles ➔
  - **What is in the so called cold traps (Ice?, Sulfer?, ?)**