Remote Sensing Instrument Technologies

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Remote Sensing Trends

- Emphasis is technology trends for scientific observations around small bodies throughout the solar system
  - NEO's, asteroids, comets, small satellites, Trojans, Centaurs, TNO's
  - Highlight instrument technologies expected to be important over the next 10-20 years.
- Universal goals of higher performance, smaller and lighter, lower power, and especially lower cost
- There are many types of instruments for remote sensing of many parameters
  - Talk will try to show the technology trends and point out some advanced technology needs

Electronics

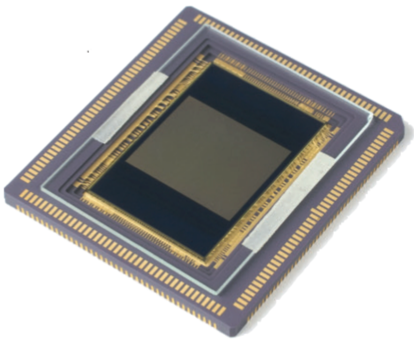
- General trend in electronics is moving the analog to digital transition closer to the toward front end of instruments
  - Almost all scientific measurements start as analog signals
  - Putting more into digital regime improves performance while often reducing size and power, plus adding programming flexibility
    - The capacity of FPGAs is still increasing rapidly so there is more capability to do refined processing
    - This trend is expected to continue over next decade and beyond
- Radiation-hard integrated circuits are in ever decreasing supply

Imagers and Spectrometers

- Imagers are the most ubiquitous instruments for small body missions
  - Several technology trends are changing the imager landscape
    - Sensors – CMOS vs CCD focal plane arrays
    - Optics – Advances in both refractive and reflective
    - Electronics – Readouts and digital processors
- Optical spectrometers and imaging spectrographs are planned on most new small body missions
  - Reflectance spectroscopy for mineralogy covers wide range of wavelengths from UV through IR
  - UV spectroscopy for cometary comas and exospheres

Imager - Sensors

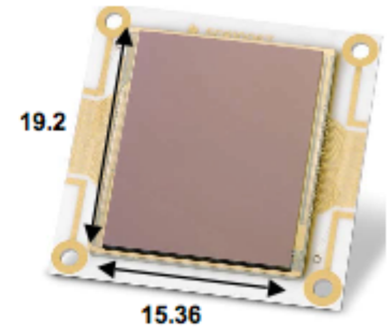
- There is a trend away from CCD sensors to CMOS
- CCDs require very pure silicon, are not very radiation hard, and are inflexible
  - CCD must transfer photoelectrons in bucket brigade fashion across the full chip.
    - Very small errors in charge transfer efficiency have a dramatic effect after 1000 transfers ($0.999^{1024} = 0.359$)
- CMOS sensors are made of "standard" integrated circuit silicon
  - They address each pixel individually, no bucket brigade
  - CMOS sensors can have processing electronics on the same chip
  - CMOS technology is being driven by cell phone and digital camera industries
  - Easier to radiation harden
  - Non-uniformity requires active correction



2560 x 2160 CMOS Sensor

Thermal Imager - Sensors

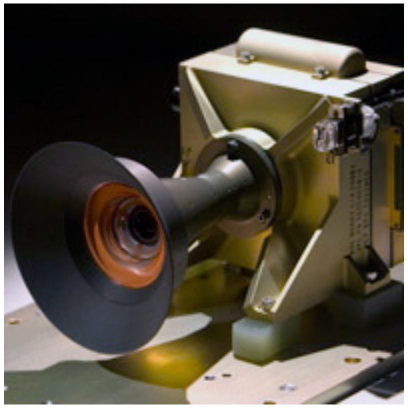
- HgCdTe cooled focal plane arrays can be made to cover Near, Mid, or Far IR by varying the composition
  - Array sizes continue to grow, now reaching $(1024)^2$ and $(2048)^2$ sizes
  - Sensors must be cooled to cryogenic temperatures, so availability of long-life cryocoolers is also a limiting constraint
- Uncooled bolometric array sensors are also reaching large sizes
  - Vanadium Oxide sensors are most popular, but Barium Strontium Titanate and amorphous Silicon are still contenders



Sofradir 1280x1024 bolometer

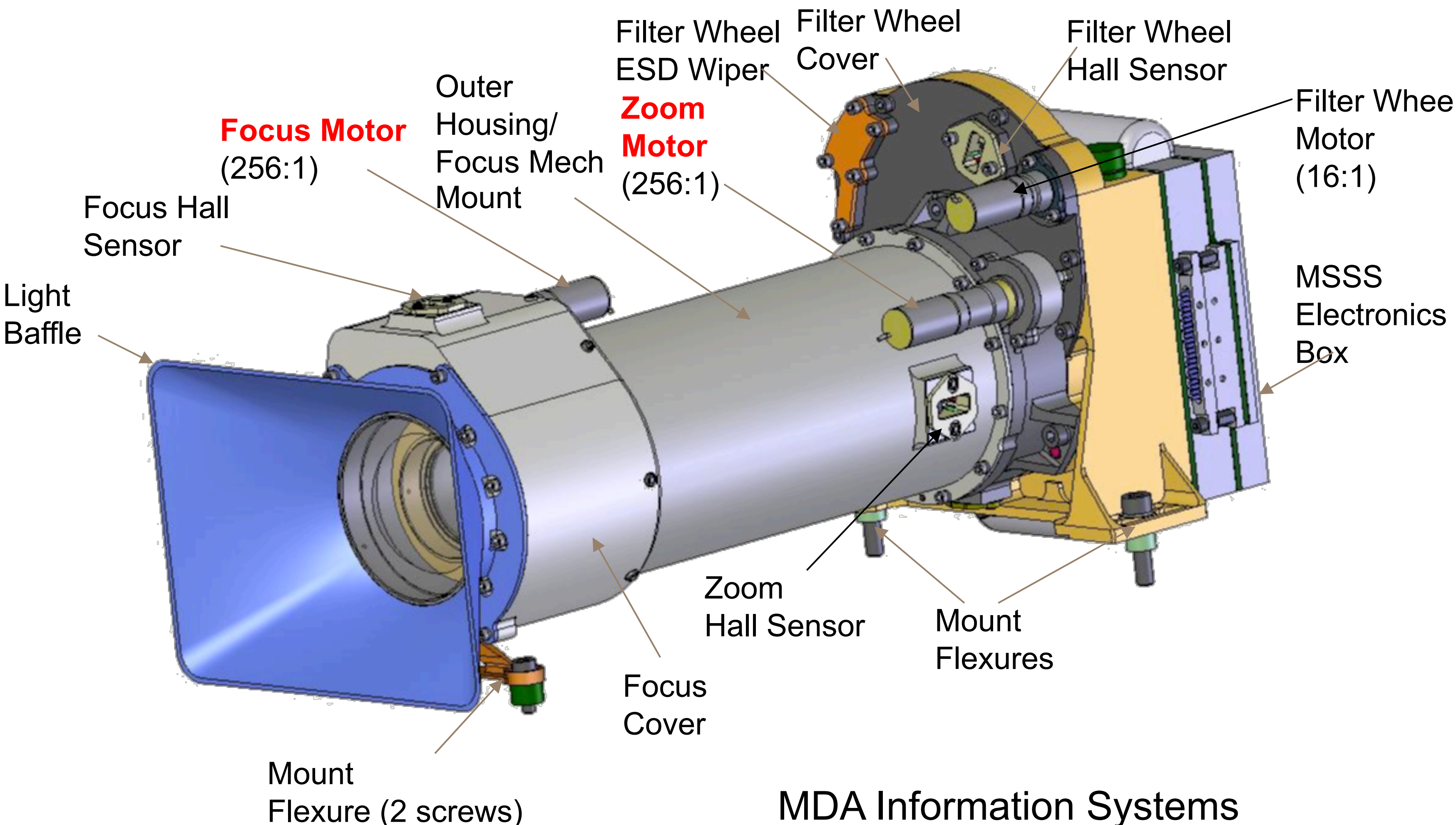
Imagers - Lenses

- Optics sizes are mostly determined by the physics of the observations, however lenses and reflective optics are steadily improving
  - Lenses-
    - Aspheric elements can improve performance and reduce the number of elements in the lens
    - Graded-index elements use a gradient in the index of refraction to eliminate aberrations in spherical lens elements
  - Focus and zoom mechanisms are starting to appear in space missions



Malin Space Science Systems

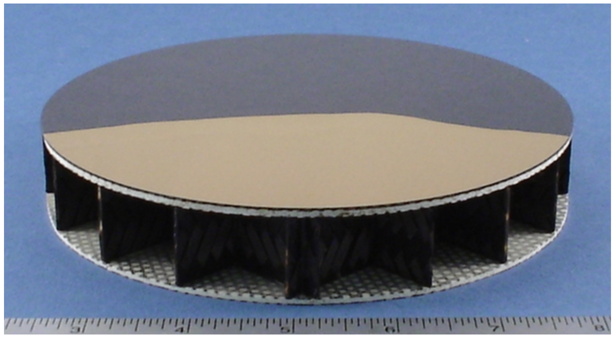
Zoom Mastcam



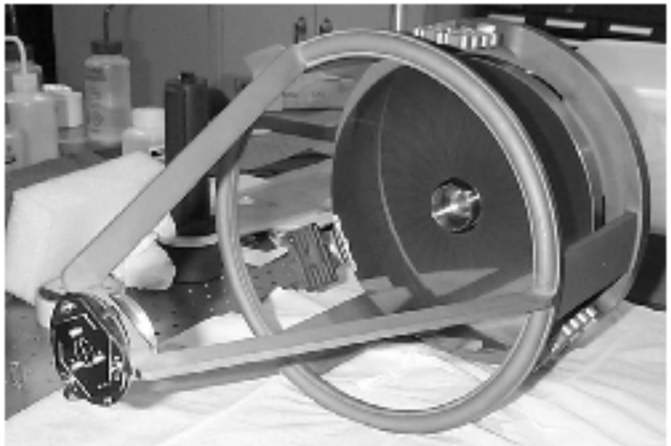
MDA Information Systems

Imagers – Reflective Optics

- Trends toward new mirror materials that are thinner, stiffer, and lighter weight
- Beryllium is very stiff and light, but quite expensive
- Silicon carbide technology is improving and is becoming commonplace
- Carbon fiber replica optics are steadily advancing and are likely to be much lighter for large mirrors
  - Will enable meter class mirrors with sub kg mass



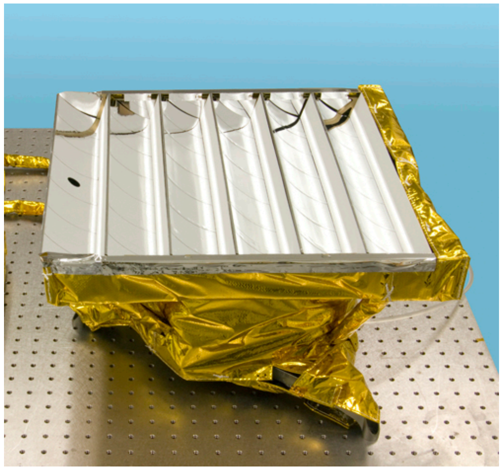
Carbon fiber replica mirror CRC inc.



New Horizons LORRI SiC JHU/APL

Spectrometers and Spectrographs

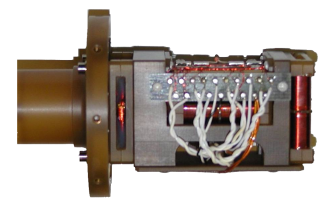
- Sensor array improvements continue to be as important for spectrometers as for imagers, often using the same array
- Diffraction grating technology improvements are helping to improve resolution and reduce aberrations
- Silicon carbide and carbon fiber composites for the optical bench are making the spectrographs lighter



Moon Mineralogy Mapper (M^3)   JPL

Magnetometers

- **Traditional fluxgate magnetometers are filled with delicate analog electronics**
- **Digital magnetometers reduce this to a probe head, A/D converter, D/A converter and digital electronics**
  - **Replace a 4 kg instrument with a 0.4 kg magnetometer**
- **Scalar magnetometers usually depend on optical pumping of a spectral line**
  - **They require a high intensity, precisely tuned source**
  - **Improvements in diode lasers are making these instruments much smaller and more rugged**

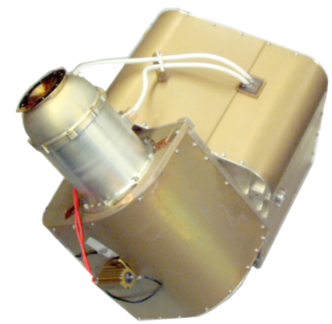


Magnetometer head

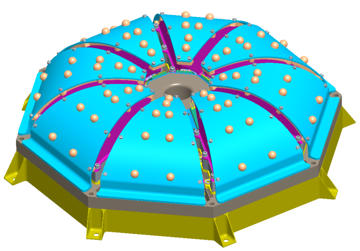
Analog Magnetometer has many delicate tuned circuits

Plasma and Energetic Particles

- While these are some of the oldest forms of space instrumentation, there are important trends in instrument configuration
- Plasma and energetic particles want full 4π coverage
  - Observing spacecraft are usually 3-axis oriented so very wide field of view instruments are needed
  - Hemispherical plasma and energetic particle instrument are emerging
- Solid state detectors and avalanche photodiodes with very thin dead layers are enabling lower energy thresholds



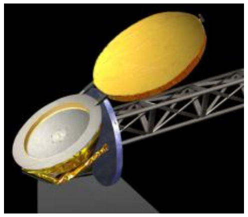
Plasma instrument with ~2π fov U Mich



Particle instrument with ~2π fov APL

Gamma-Ray, X-Ray, and Neutron Spectrometers

- These are the primary instruments for remote atomic composition measurements need significant technology developments
- Traditional gamma-ray scintillation detectors have poor energy resolution
  - High-purity germanium (HPGe) has excellent resolution, but requires cryocooling
  - Mars Odyssey (passive cooling) and MESSENGER (active cooling) have demonstrated HPGe for planetary missions
  - New long-life cryocoolers are needed
- X-ray instruments are still reliant on gas proportional counter for large area detectors
  - Large area solid state detectors with better than 250 eV resolution are needed
- Neutron sensors are excellent for detecting water and ice, but existing neutron sensors also have very poor energy resolution. New detectors needed



Mars Odyssey GRS U AZ

Radars and Lidars

- Radar technology is limited by the size of antennas
  - Low frequency radars for examining internal structure require very large antennas
  - Future trends are likely to have electrically steered, sparse phased array antennas
- Lasers suitable for lidars are evolving rapidly. Diode-pumped solid-state slab lasers are being challenged by fiber optic lasers and disk lasers
  - Laser altimeters have operated at the Nd:YAG wavelength of 1064 nm, but newer designs are expected to operate at wavelengths that are better matched to their detectors
  - Flash and multi-beam lidars can generate a topo-map with each laser pulse

MESSENGER Laser Altimeter GSFC

Technology Improvements Needed

- Large, low noise focal planes and readout circuits
- Very light weight reflective optics
- High performance, rad-hard, refractive optics
- Analog and mixed signal rad-hard integrated circuits
  - A/D and D/A converters, Field Programmable Analog Array
- Small, high efficiency, long-life, cryocoolers
- Miniaturized vector and scalar magnetometers
- Low energy solid state particle detectors
- Hemispherical plasma spectrometers
- Miniaturized HPGe gamma-ray detectors
- Large area, high resolution, X-ray sensors
- Improved neutron detectors
- Small, high efficiency, pulsed lasers
- Multi-beam, mapping lidar
- Active-pixel phased array radars

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New Technology Concepts Required

- Ability to sense internal structure of a small body remotely
  - Differentiation
  - Internal layering
  - Identify subsurface ice concentrations
- Remote Raman spectrometer for mineralogy
- Remote APXS for atomic composition (alpha particle beam generator)
- Measure small body gravity during flybys
  - High accuracy accelerometers and gravity gradient instrument
  - Improved Doppler tracking
- Measure atomic composition during flybys
  - Active gamma-ray instrument (neutron beam generator)
  - Active X-ray instrument (X-ray beam generator)