A Radiation-Hard Silicon Drift Detector Array for Extraterrestrial Element Mapping

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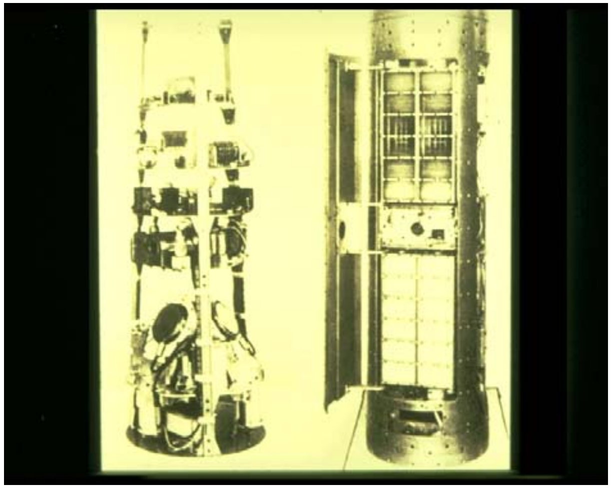
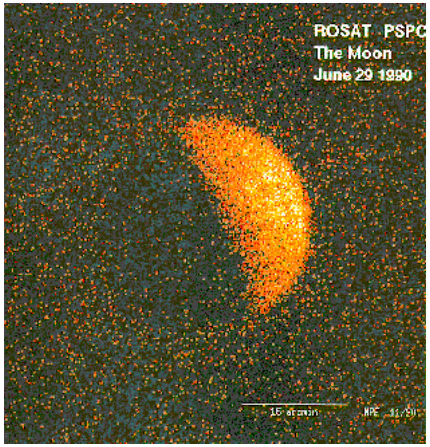
Background

<u>Birth of X-Ray Astronomy</u>

- In 1962, Riccardo Giacconi and colleagues at AS&E flew sounding rocket to look at x-ray fluorescence from the moon
- Lunar signal was overshadowed by very strong emission from the Scorpious region
- Discovered the first extra-solar x-ray source, Sco X-1, and pervasive x-ray background
- This was the effective birth of x-ray astronomy

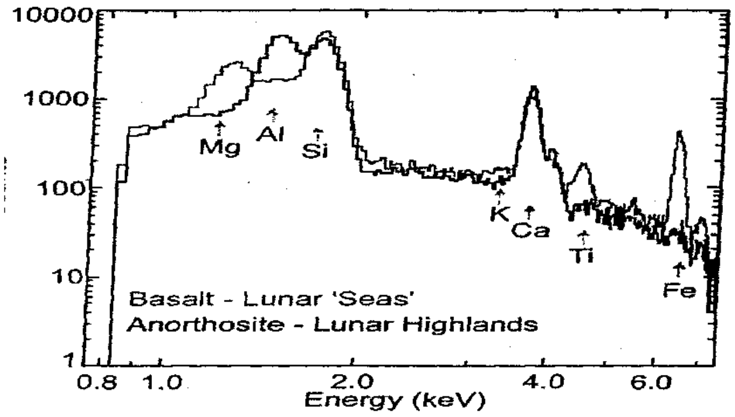




The German-led ROSAT mission took the first x-ray image of the moon in 1990

Introduction

- *Measurement of x-rays from the surface of objects can tell us about the chemical composition*
  - *Absorption of radiation causes characteristic fluorescence from material being irradiated.*
  - *By measuring the spectrum of the radiation and identifying lines in the spectrum, the emitting element (s) can be identified.*

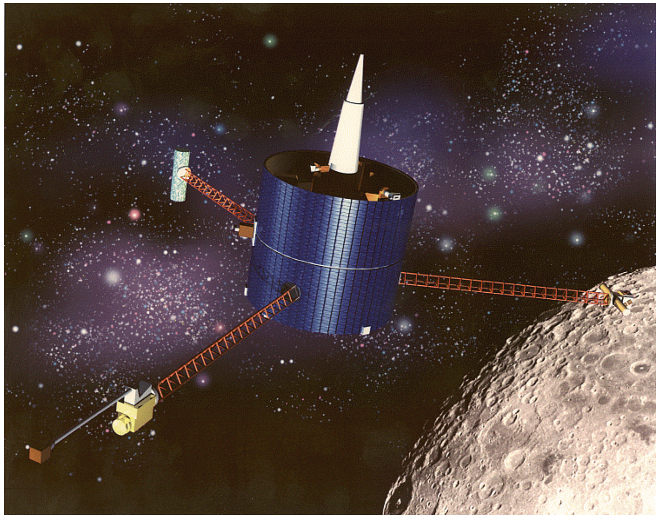


This technique works for any object that has no absorbing atmosphere and significant surface irradiation : Our Moon, the icy moons of Jupiter, the moons of Mars, the planet Mercury, Asteroids and Comets

Lunar Surface Analysis

- On the lunar surface, the fluorescent x rays are produced by solar x-ray irradiation. For surface-element analysis, need an x-ray spectrometer in Lunar orbit.
  - Can use a simply collimated detector looking down at surface. As it scans the surface it records the spectrum in the field of view, as a function of time, to map out the elements

This has already been done (or is being done), originally with proportional counters, with poor spectral resolution, and more recently with CCDs (SMART-1, Kaguya (2007), and Chang'E (2007))

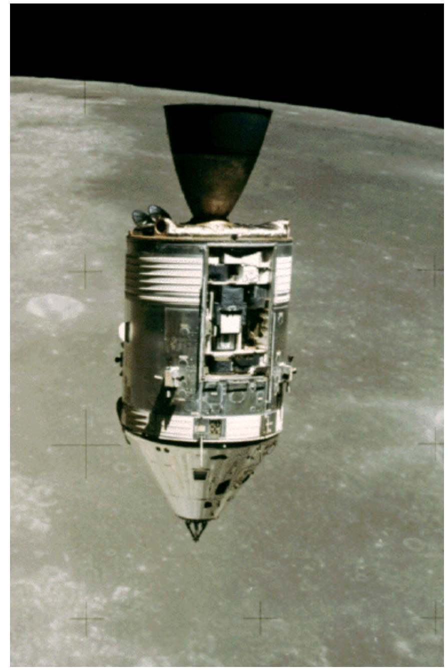


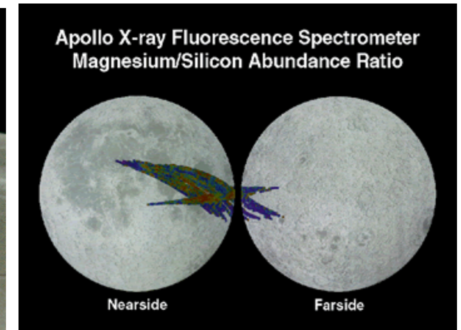
Lunar Prospector

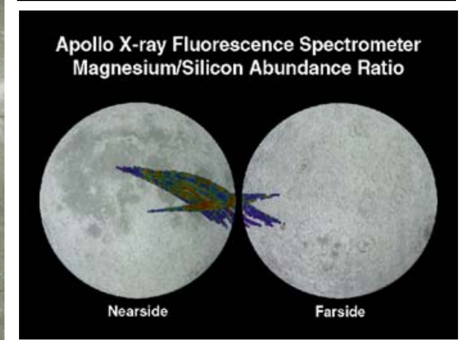
But CCD is very power hungry. This means that the instrument size, and hence sensitivity, is limited. What is needed is a detector with equivalent energy resolution to a CCD, but much lower power requirements

Past Missions

There are several missions (past and present) with the goal of mapping the lunar surface.





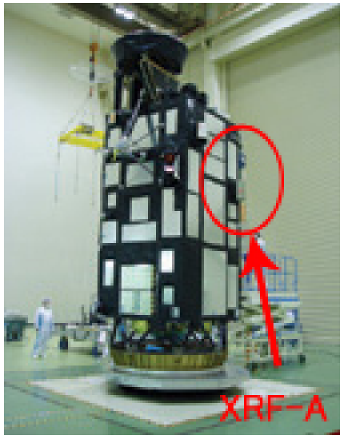


Apollo 15 & Apollo 16: XRS mapped Mg, Al, and Si at the lunar nearside equatorial regions - covered ~9% of the total lunar surface with a resolution of ~100km and energy resolution of ~800eV @ 6.4keV using large area proportional counters (1971).

Clementine Provided global estimates of FeO & TiO_2 based on models fit to spectral reflectance data – and calibrated with lunar samples (1994).

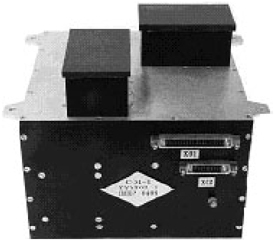
Lunar Prospector: Made global observation of major elemental abundances (Th, K, U, Fe, O, Si, Al, Ca, Mg, Ti) with a resolution of ~150km using a Gamma-Ray spectrometer (bismuth germanate scintillator) (1998).

Past Missions



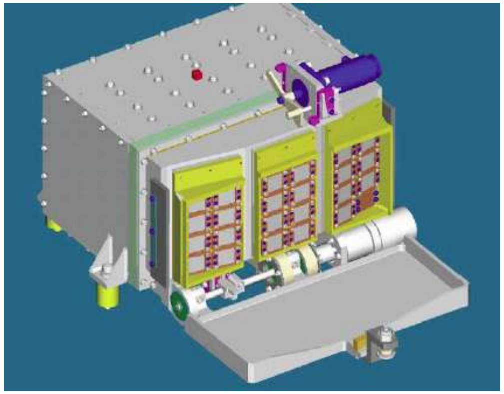
http://www.selene.jaxa.jp/en/

Kaguya (SELENE): Designed to globally map (~90%) the lunar surface elemental composition using a CCD based instrument. The footprint resolution is 20km @100km and the energy resolution is <180eV @ Fe55 & -50°C. Detector area is $100cm^2$ and 0.7 to 10keV (2007).



Chang'E-1: Globally map the lunar surface major elements. Energy resolution is 3.3% @ Fe55 200km orbit (2007).

Chandrayaan-1: During this 2–year mission, CIXS (swept charge device) designed to map the lunar surface elemental composition (0.5-10keV range), and 20x20km FoV @ 100km. Effective area is $25cm^2$. Designed for Mg, Al, and Si during solar quiet and Ca, Ti, and Fe during flares (will launch 2008).



Lunar Surface Science

A lunar orbiting X-Ray fluorescent spectrometer with improved sensitivity and thus, the capability for higher resolution (of a few km) would allow for unique science and a more detailed assessment of global resources.

- **Crater Probing**

  -The number of craters with diameter > d (meters) in a 10^6 km^2 area is given by 5×10^{10} d^{-2} (Cox 2000, Wilhelms *et al* 1978, Cross 1966).

  The number of craters in a 10^6 km^2 area greater than 5km in diameter is 16x the number of craters larger than 20km in diameter.

- **Crater Depth/Diameter Relationship**

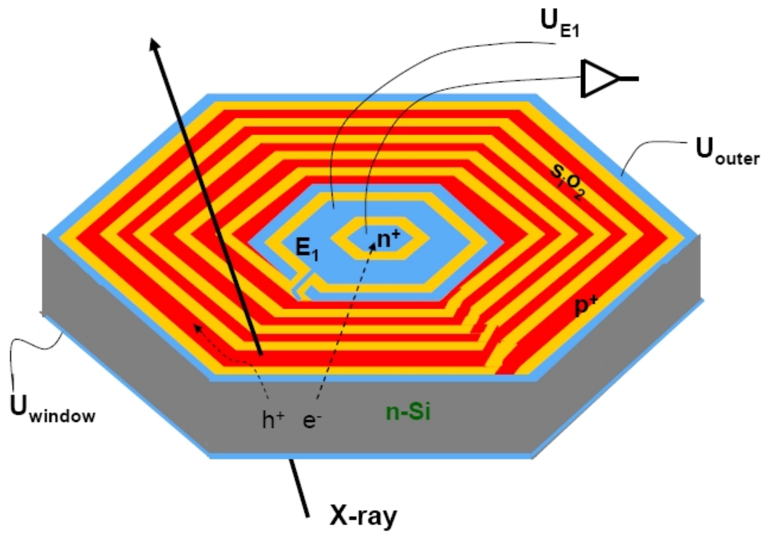
  -Smaller craters are generally shallower – Determine Characteristics
  -Probe deeper/larger craters in detail (e.g. central crater peak, rim, walls, secondary impacts – time evolution of the lunar crust)

- **Defining Potential Landing Sites**

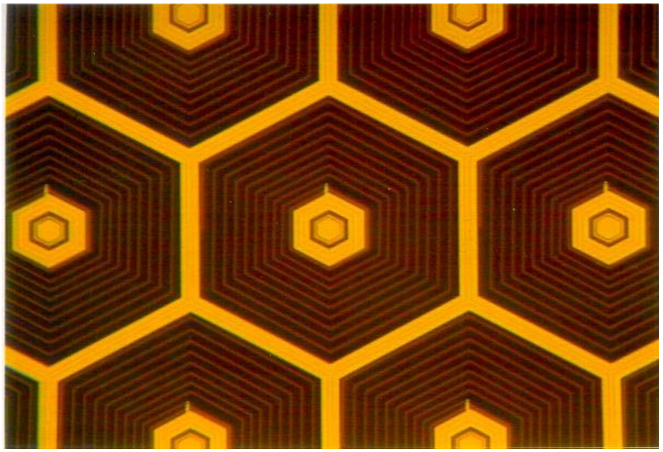
  -The XRS will be able to clearly identify ilmenite ($FeTiO_3$), anorthite ($CaO \cdot Al_2O_3 \cdot 2SiO_2$), pyroxene ($[Fe,Mg,Ca] \cdot SiO_2$), and olivine ($2[Fe,Mg] \cdot SiO_2$) through their abundance ratios. Both ilmenite and anorthite are potential sources for oxygen extraction.

Solution

- ***One type of detector can satisfy all the previous requirements .. An array of silicon drift detectors with custom readout electronics.***
  - *MSFC is working with Brookhaven National Laboratory to develop this type of instrument*
- ***Single silicon wafers contain many individual detector elements (pixels)***
- ***Each detector pixel has its own readout electronics channel – needs custom large scale integrated circuits***
  - *Individual pixel electronics gives very high rate capability*
  - *Low capacitance means good energy resolution*
  - *No clocking of charge packets so very radiation resistant*
- **Chen *et al.*, NSSC Record, IEEE 2007**



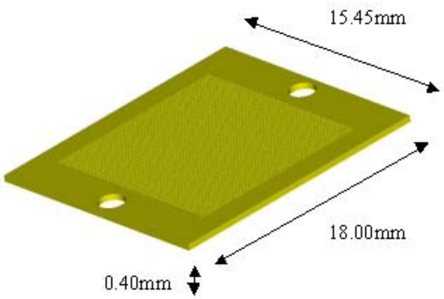
Single pixel silicon drift detector schematic.

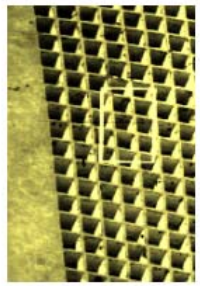


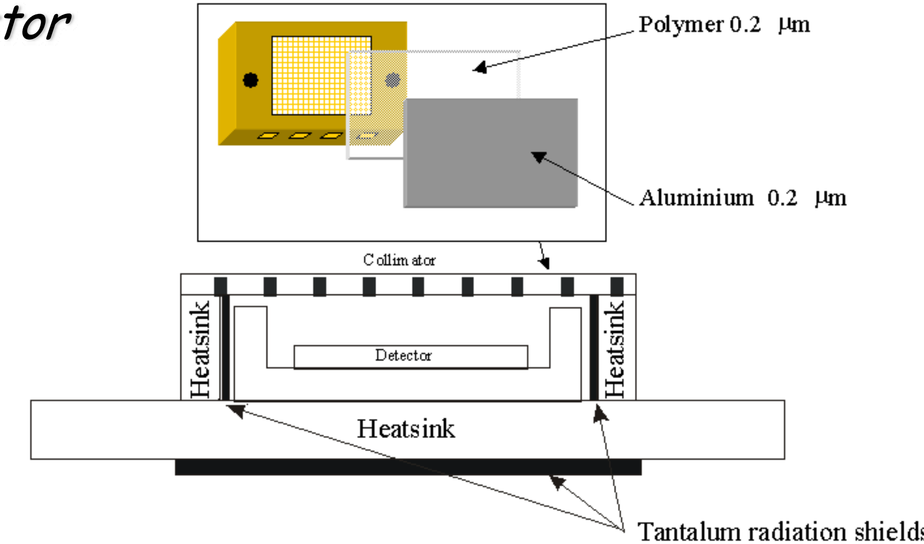
Drift detector array (with hexagonal pixels)

Possible Flight Configurations

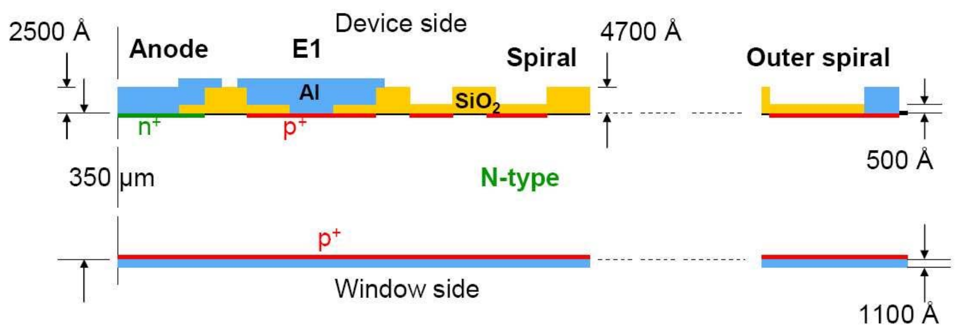
- *Lunar Spectrometer*
  - *Large area, simply collimated detector*







- *Detector Cross-Section*

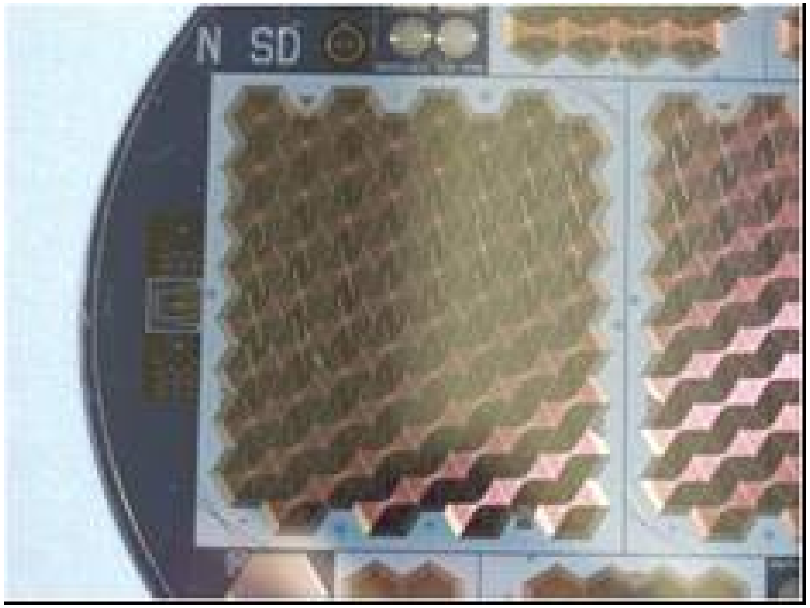


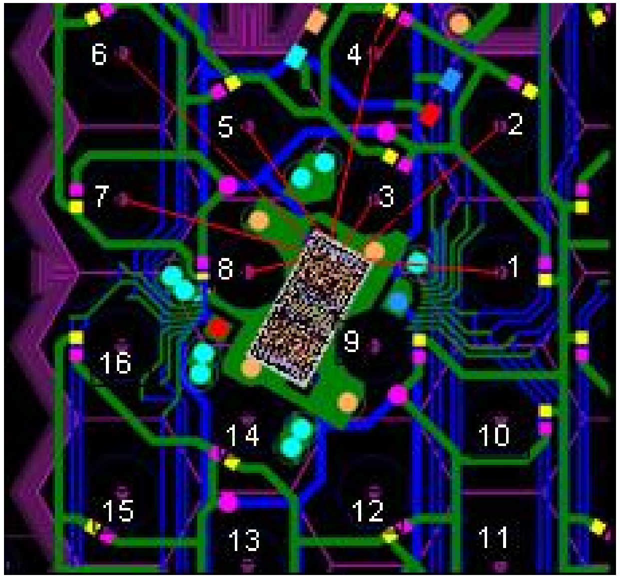
Instrument Configuration

Requirements

Total Detector Area	500cm^2
Effective Lunar Footprint @ 50km	~2km (for X FOV - collimator)
Elements of Interest	Mg, Al, Si, P, Na, Fe, K, Ca, Ti, Cr
Energy Resolution	<200eV FWHM
Single Pixel Size	20mm^2
Single Array Size (unit size)	64 detectors (4 ASICS)

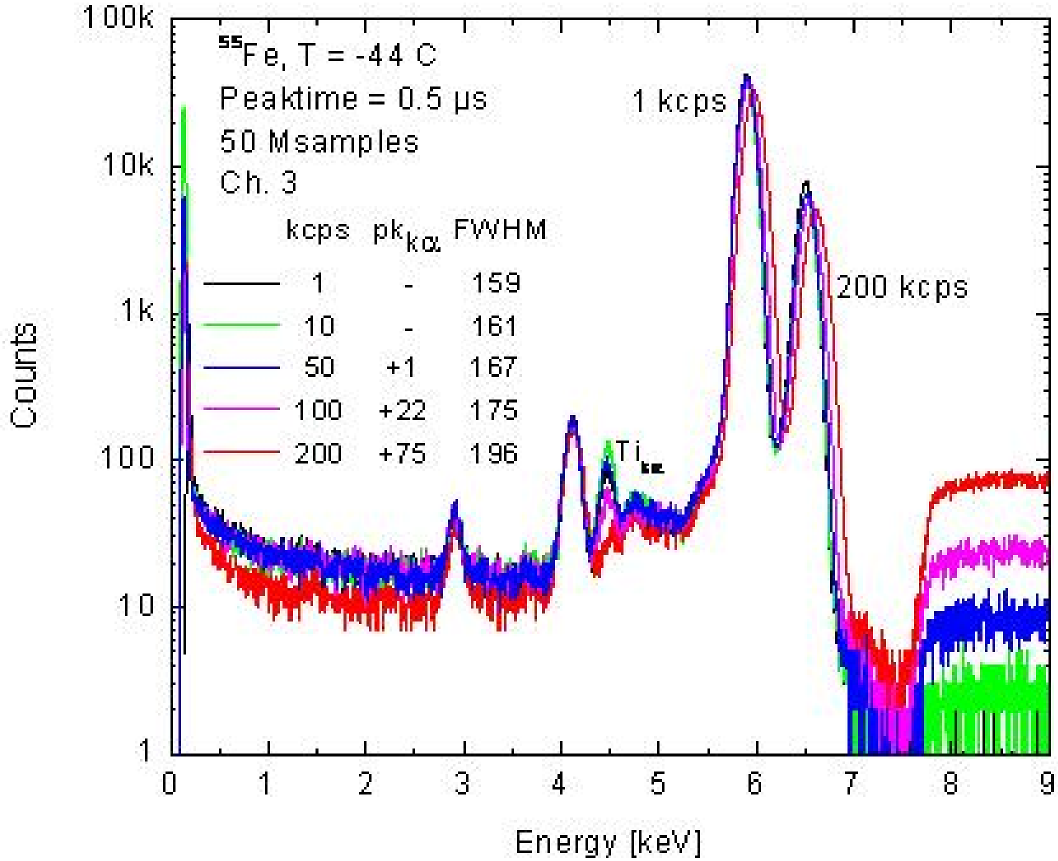
Project Status





Basic 64-channel system developed – read out by 4 custom ASICS. Decvices produced at BNL and by KETEK. This few-square-cm system can then be used to tile any desired area.

Project Status

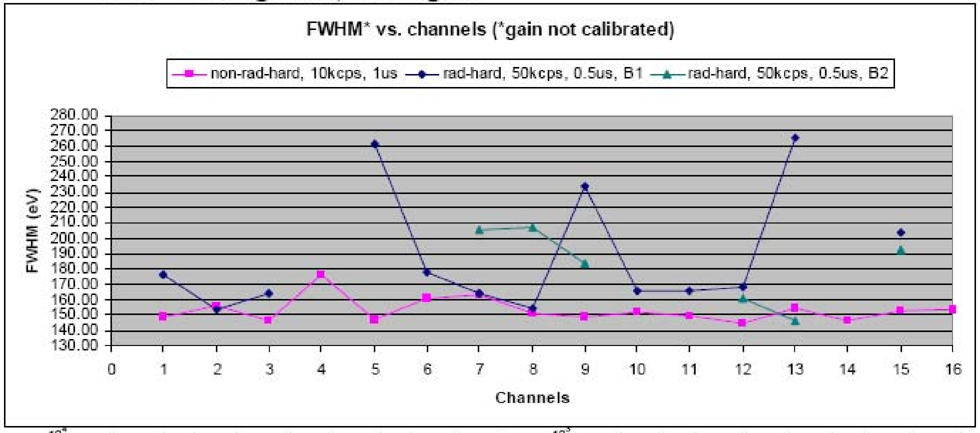


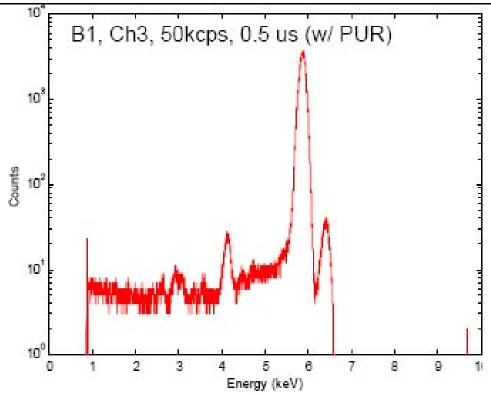
* De Geronimo et al., 2007, NSSC IEEE Proc.

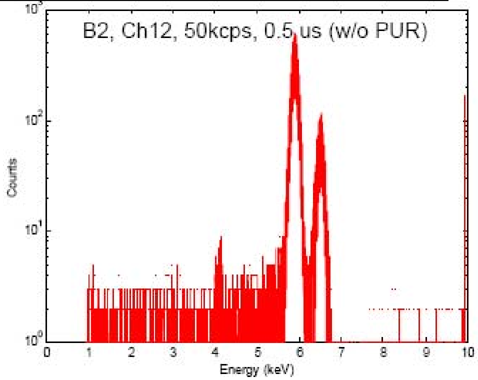
Project Status

Measured Spectra of ASICs with Rad-hard Detector (from a ^{55}Fe source)

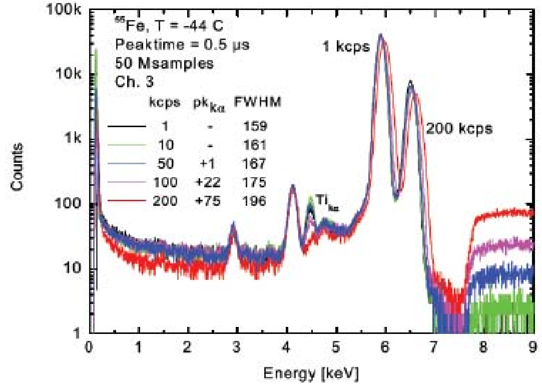
-- A few channels have comparable performance at their optimum biasing conditions, compared to non-rad-hard detectors; other channels show large leakage
-- Corner cells are very sensitive to moisture condensation;
-- Cells are sensitive to biasing condition; large leakage appears at non-optimum biasing condition.
FWHM at counting rate of 50 kcps:
  Board1, Detector #1461
    Ch3 -- 168 eV @ 0.5 us; 164 eV @ 1 us
    Ch12 – 168 eV @ 0.5 us; 180 eV* @ 1 us (*due to larger leakage than in Ch3)
  Board2, Detector #
    Ch12 – 164 eV @ 0.5 us; 164 eV @ 1 us
    Ch13 – 170 eV @ 0.5 us; 170 eV @ 1us

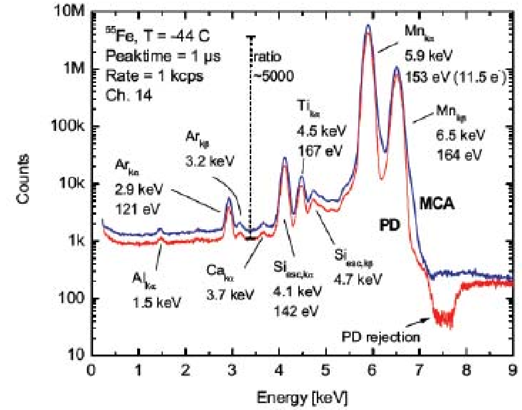






FWHM of non-rad-hard detectors [NSS_2009]:
167 eV @ 0.5 us, 50 kcps
159 eV @ 0.5 us, 153 eV @ 1 us, 1 kcps





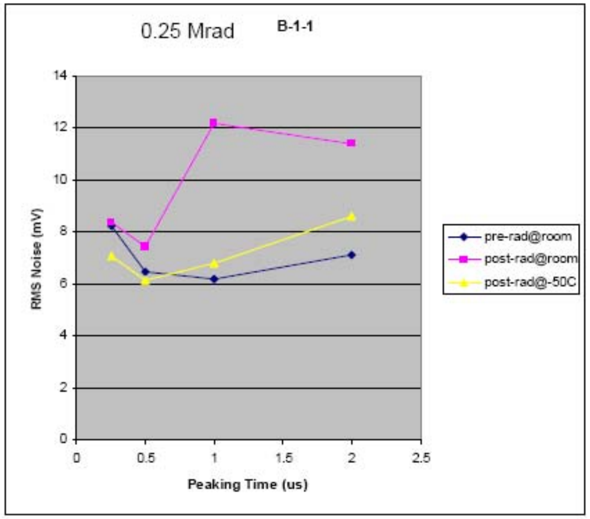
Project Status

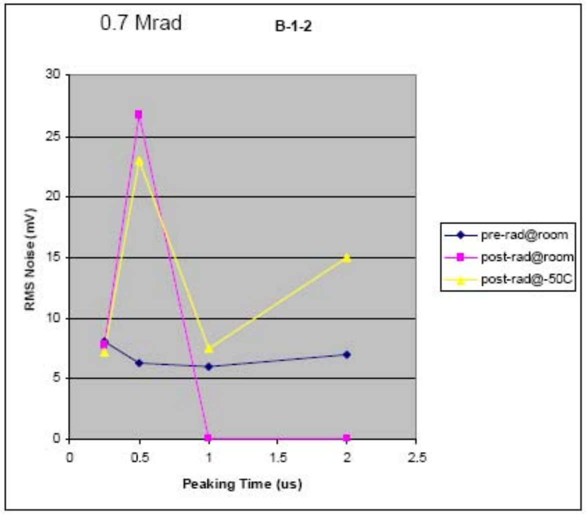
Complete Measurements on Radiated ASICS (w/o detector):

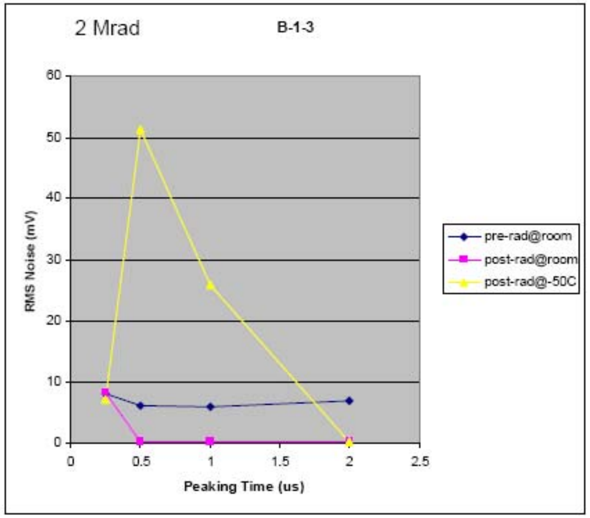
-- worst case at 2 Mrad (NMOS transistor has worst leakage around 2 Mrad in 0.25 um process)
-- radiation-sensitive paths have been located though simulation and analysis, and will be corrected in next fabrication.

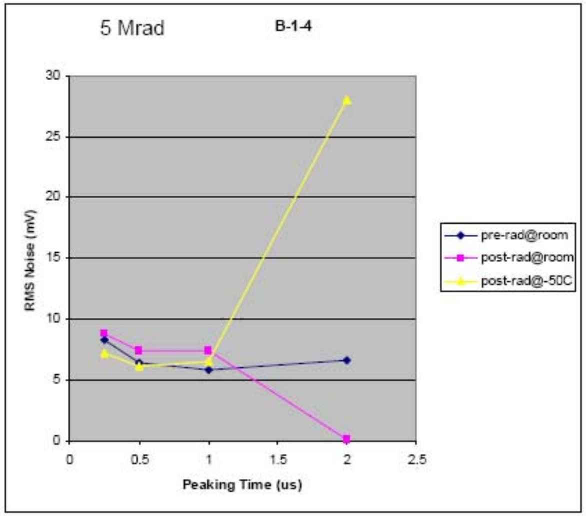
	Rad level (Mrad)	Temperature	Peaking Time	0.25 us	0.5 us	1 us	2 us
	0.25	-50C	ASIC B-1-1	**Good**	**Good**	**Good**	**Good**
	0.6	-50C	ASIC B-2-1	**Good**	**Good**	**Good**	**Noisy**
	0.7	-50C	ASIC B-1-2	**Good**	**Noisy**	**Noisy**	**Noisy**
	1.0	-50C	ASIC B-2-2	**Good**	**Good**	**Noisy**	**Noisy**
w.c. →	**2.0**	-50C	ASIC B-1-3	**Good**	**Noisy**	**Saturated**	**Saturated**
	5.0	-50C	ASIC B-1-4	**Good**	**Good**	**Good**	**Saturated**
	8.0	-50C	ASIC B-2-3	**Good**	**Good**	**Good**	**noisy**
	12.0	-50C	ASIC B-2-4	**Good**	**Good**	**Good**	**Good**
	0.25	Room	ASIC B-1-1	**Good**	**Good**	**Noisy**	**Noisy**
	0.6	Room	ASIC B-2-1	**Good**	**Good**	**Noisy**	**Noisy**
	0.7	Room	ASIC B-1-2	**Good**	**Noisy**	**Saturated**	**Saturated**
	1.0	Room	ASIC B-2-2	**Good**	**Good/Noisy**	**Noisy/Saturated**	**Saturated**
w.c. →	**2.0**	Room	ASIC B-1-3	**Good**	**Saturated**	**Saturated**	**Saturated**
	5.0	Room	ASIC B-1-4	**Good**	**Good**	**Good**	**Saturated**
	8.0	Room	ASIC B-2-3	**Noisy**	**Noisy**	**Noisy**	**Saturated**
	12.0	Room	ASIC B-2-4	**Noisy**	**Noisy**	**Noisy**	**Saturated**

Project Status









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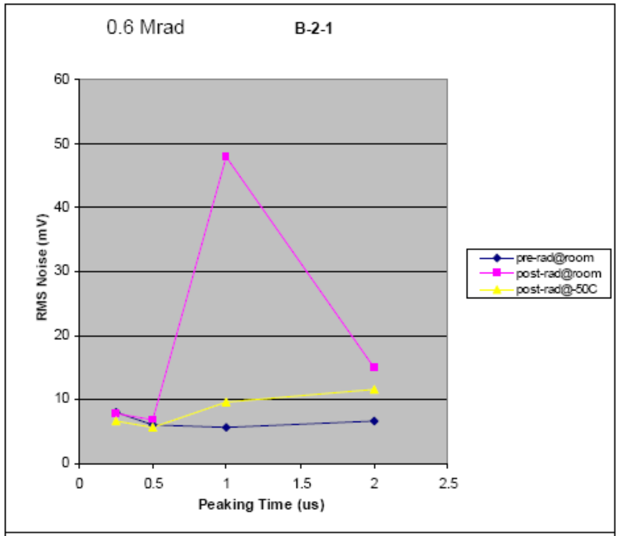
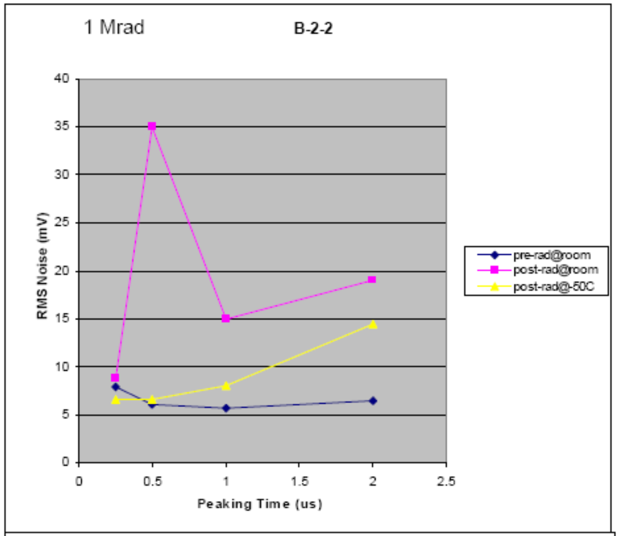
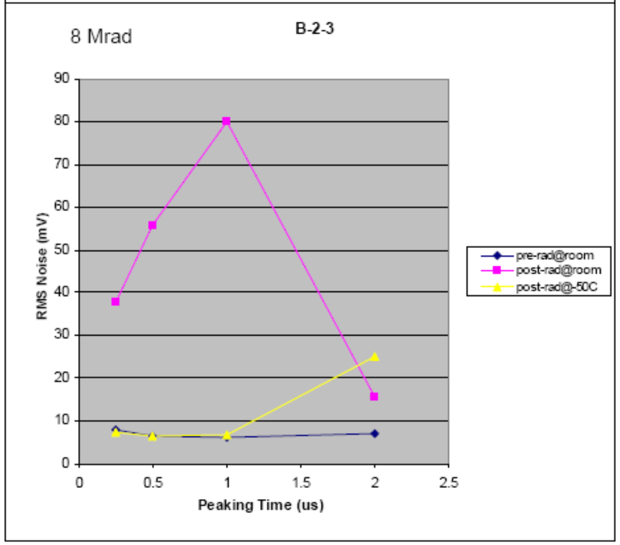
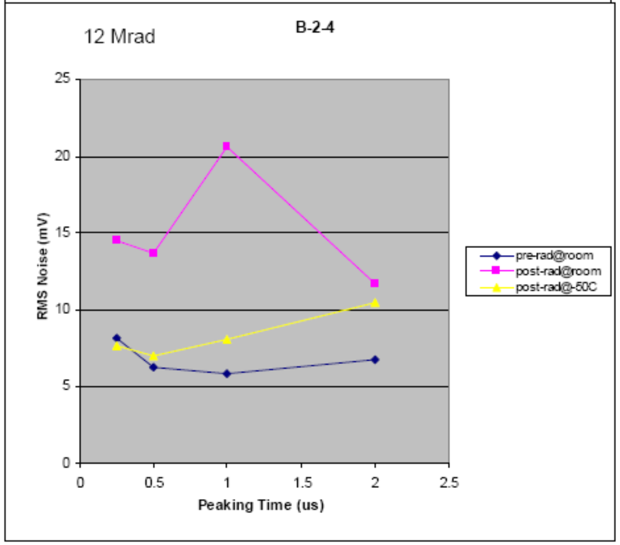


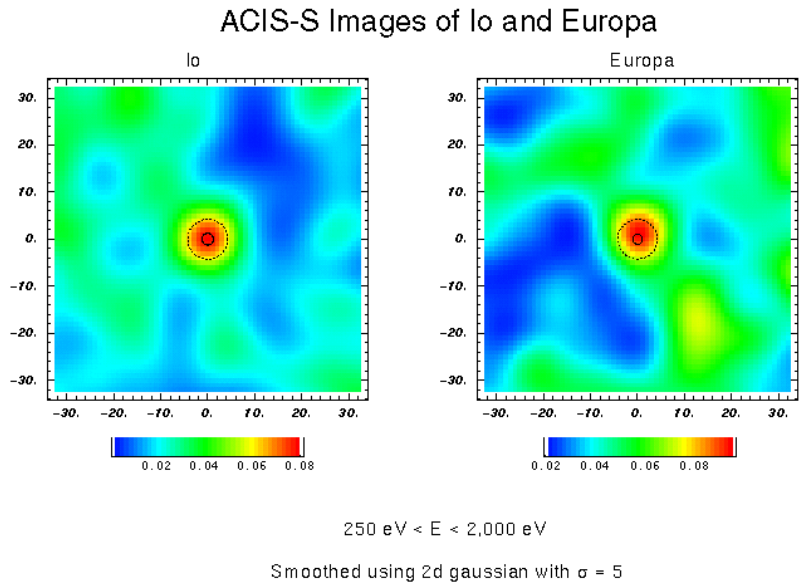






Jupiter Icy Moons Surface Analysis

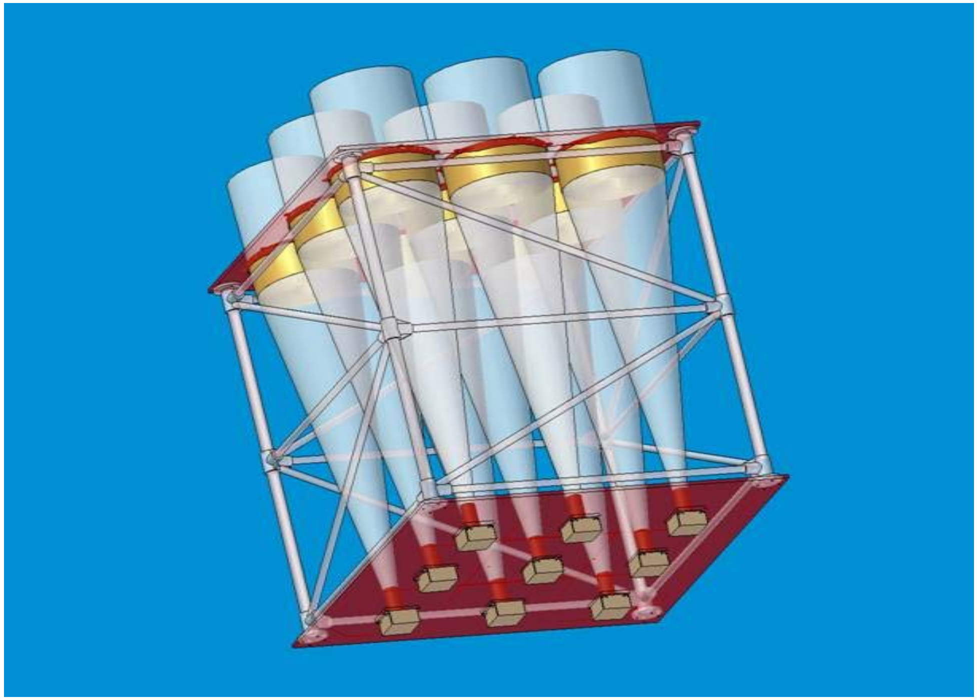
- *For Jupiter's icy moons (Europa, Ganymede and Callisto) the surface fluorescence is stimulated by charged particle irradiation from Jupiter's radiation belts.*



For sensitive measurements, once again need a spectrometer in orbit around the moons. Need low-power, high-spectral-resolution detector as for the lunar application, but also, because you are in radiation belts, need very high rate capability and very high radiation resistance. This completely rules out CCD detector.

Jupiter Icy Moons Surface Analysis

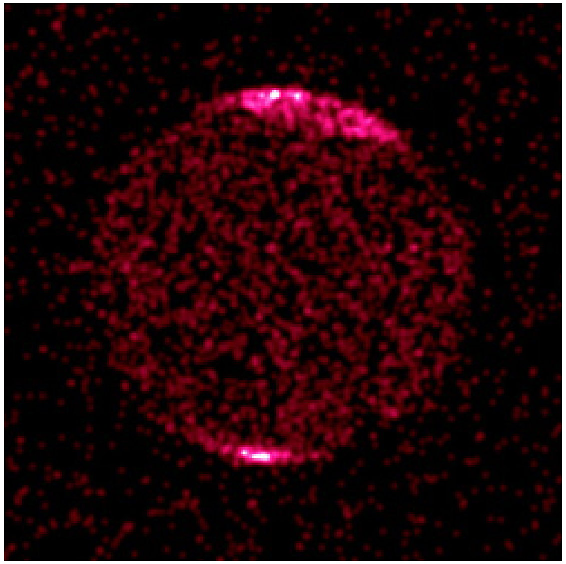
- *Jupiter Icy Moons*
  - *Use focusing x-ray optics to reduce overall data rate and increase signal to noise ration…need array of small detectors*



Jupiter Icy Moons Surface Analysis

X-Ray fluorescence mapping of the Jovian system will help to answer some of these questions regarding the origin and evolution of a potentially habitable planetary system.

- What planetary processes are responsible for generating and sustaining habitable worlds?
- Where are the habitable zones in the solar system?
- How has the suspected ocean varied throughout Europa's history?
- What is keeping the ocean from freezing?
- How do the processes that shape the contemporary character of planetary bodies operate and interact?
- What is the chemical composition of Europa's suspected ocean?



http://chandra.harvard.edu/

Gladstone et al. Nature 415, 1000 (28 Feb 2002)

Possible Applications/Missions

Currently, there is not a specific mission to accommodate this instrument. However, the Lunar Exploration Analysis Group themes/goals includes:

- *Theme 1:*
  - *Pursue scientific activities to address fundamental questions about the solar system, the universe, and our place in them.*
- *Theme 2:*
  - *Use the Moon to prepare for future missions to Mars and other destinations.*
- *Theme 3:*
  - *Extend sustained human presence to the Moon to enable eventual settlement.*

- *Goal 1A: Understand the formation, evolution and current state of the Moon.*
- *Goal 1B: Use the Moon as a "witness plate" for solar system evolution.*
- *Goal 3D: Facilitate development of self-sustaining economic activity.*

**There is a high probability for a future mission with the need for an x-ray fluorescent spectrometer.*

Other Possible Applications

Applications for this instrument other than for the Moon and Jupiter includes:

- *Comet Rendezvous Missions……specific AO*
- *Earth/Sun Interaction Missions*
- *Asteroids and Other Airless Bodies Missions*
- *Mercury and Martian Moons*

Gaspra

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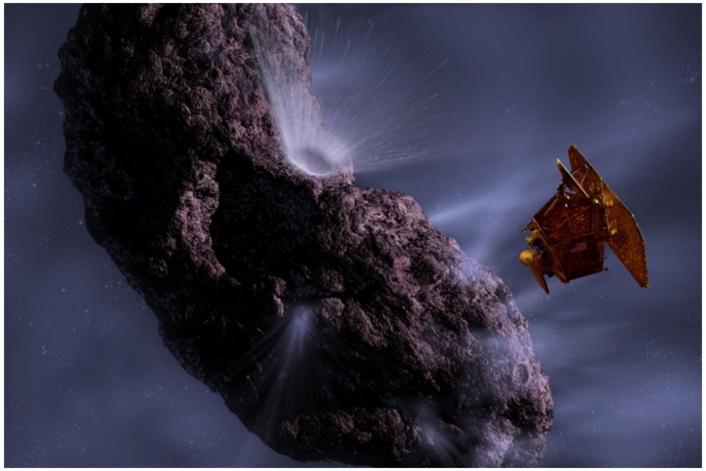
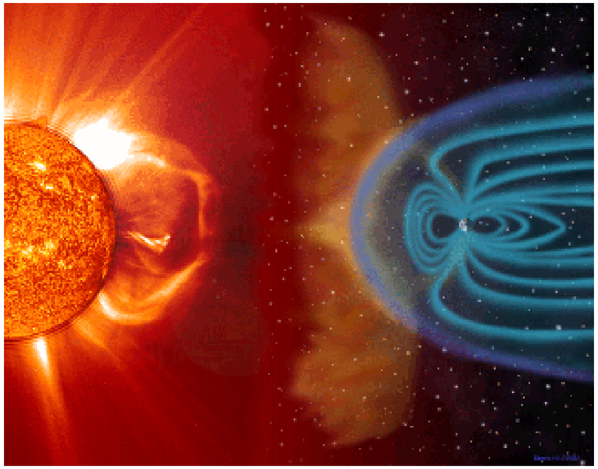
Deep Impact - Tempel 1



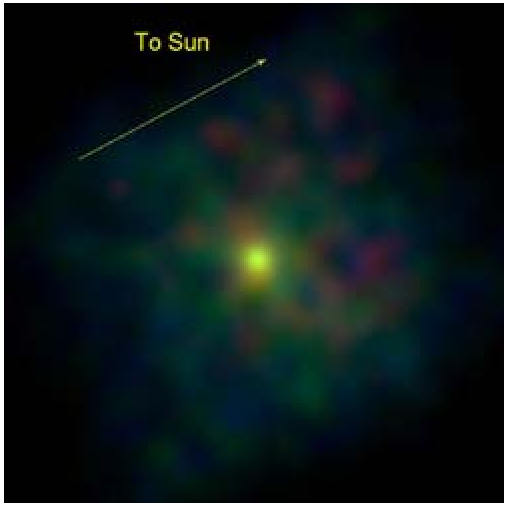
www.nasa.gov/mission_pages/deepimpact

Sun-Earth



www.star.uclan.ac.uk/solar/group

Tempel 1



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