e2v imaging and the cubesat revolution

Cubesat Developer's Workshop

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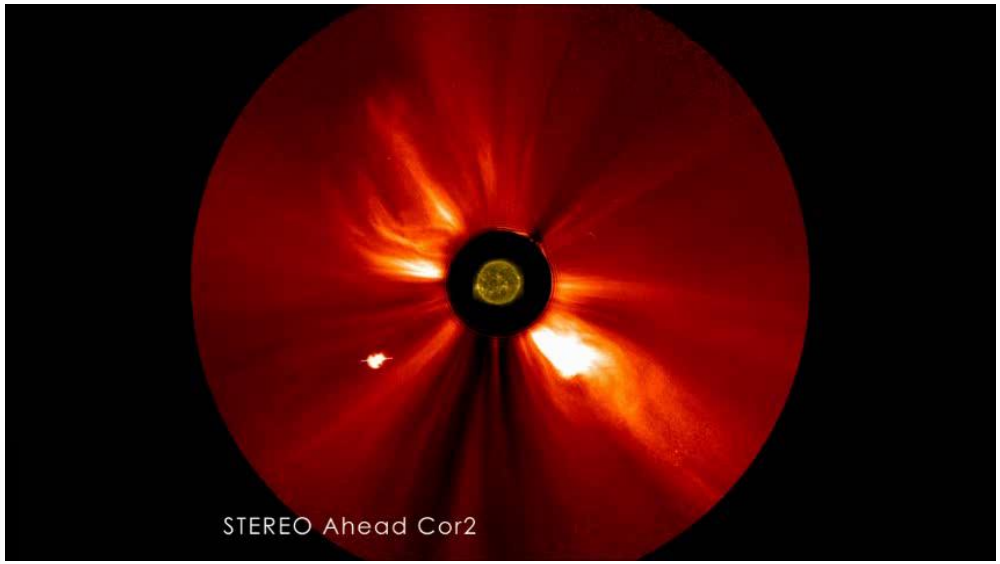
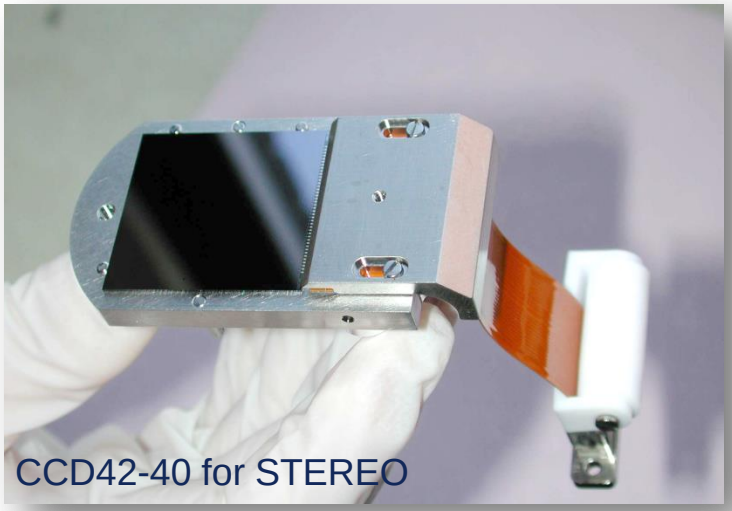
WE PARTNER WITH OUR CUSTOMERS TO IMPROVE, SAVE AND PROTECT PEOPLE'S LIVES

Outline

1. **Introduction – who is e2v?**
2. **Silicon image sensors**
3. **Systems expertise**
4. **Applied imaging**
5. **e2v imaging in cubesats**



e2v imaging example
Comet Ison perihelion
Image Courtesy of NASA



CCD42-40 for STEREO

e2v – about us

Founded in 1947

Annual sales of $350M

1700 employees

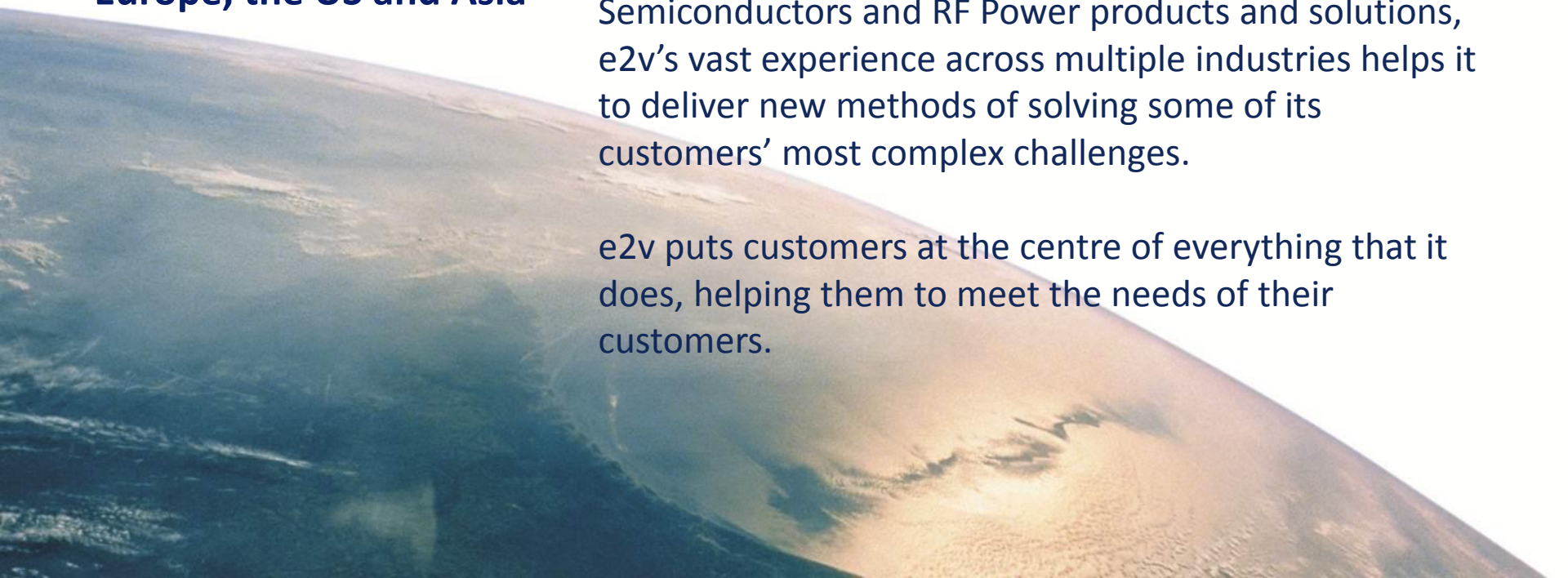
500+ engineers & scientists

Operational facilities in Europe, the US and Asia

Bringing life to technology, e2v partners with its customers to improve, save and protect people's lives. Delivering innovative technology for high performance systems and equipment, e2v leads developments in communications, automation, discovery, healthcare and the environment.

With a business built on core technologies in Imaging, Semiconductors and RF Power products and solutions, e2v's vast experience across multiple industries helps it to deliver new methods of solving some of its customers' most complex challenges.

e2v puts customers at the centre of everything that it does, helping them to meet the needs of their customers.



Who is e2v?

e2v Bringing life to technology

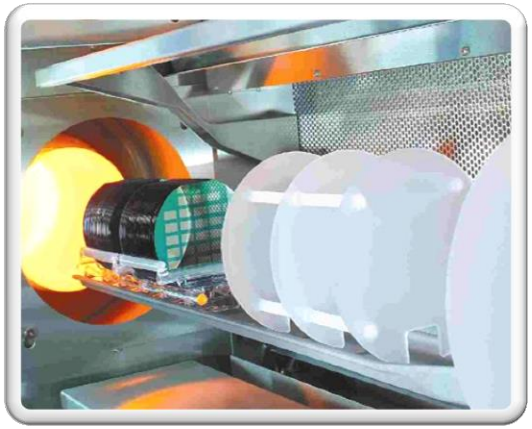
We are a leading supplier of high performance image sensors for space applications

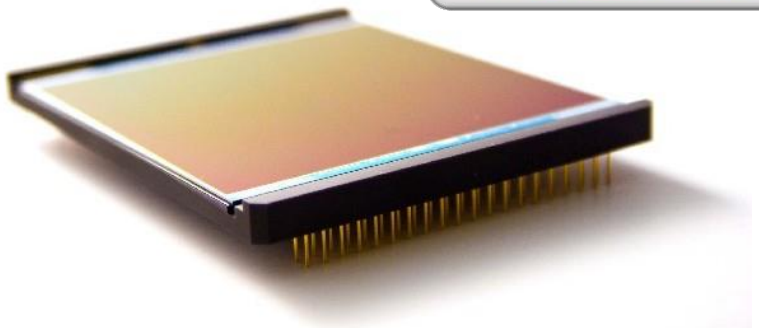
- e2v image sensors enable missions flown by all of the world's major space agencies

- Over 150 missions have flown using e2v image sensors

We are uniquely suited for the task

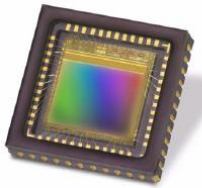
- Over 35 years experience in the design and qualification of image sensors for space
- Own CCD fab (Chelmsford, England) – back thinning CMOS image sensors and CCDs
- In-house start to finish design teams
  - Systems engineering
  - CIS / CCD design engineering
  - Package engineering
  - Project and quality management
  - Test and project engineering
- Custom designs and standard products





Silicon image sensors

e2v state of the art after 35 years…



- Wavelength range
  - Visible: ~400-700 nm
  - Near IR: ~700-1100 nm
  - UV: ~200 – 400 nm
  - VUV: ~100 – 200 nm
  - EUV: ~10 – 100 nm
  - Soft X-ray: ~0.1 – 10 nm (~100eV – 10 keV)
- Pixel sizes
  - 2.2 µm - ~100 µm
- Array sizes
  - ~4mm x 6mm – ~90mm x 90mm
- Read noise
  - < 1 e-, photon counting with EMCCDs
  - < 2 e- with standard designs
- Quantum efficiency
  - Back-illumination is our specialty
  - > 95% peak
  - > 85% over 400 – 825 nm

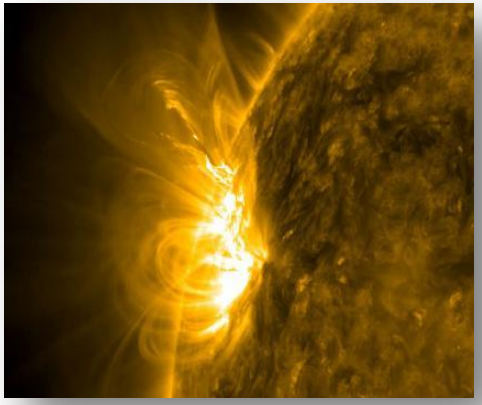
- CMOS Image Sensors
  - Charge to voltage converter in every pixel
  - Low voltage CMOS process
    - = low power
  - May have integrated ADCs and other logic on-chip
  - Lends itself to the highest frame rates
  - Limited dynamic range
  - Design intensive
- Charge-Coupled Devices - CCDs
  - Must shift charge to a limited number of outputs
  - No on-chip integration of ADCs or logic
  - High dynamic range, linear response
  - Well known performance
  - Long heritage

Space qualification where appropriate

e2v provides screening and radiation testing as required by the program

Space screening to modified ESCC 9020 standards

- Production control
  - Lot acceptance
  - In-process control
- Screening tests
  - Temperature cycling
  - Burn-in
  - Visual inspections
- Qualification tests
  - Mechanical
  - Environmental
  - Endurance
  - Assembly capability
  - Solderability
  - Controls
- Deliverable paperwork



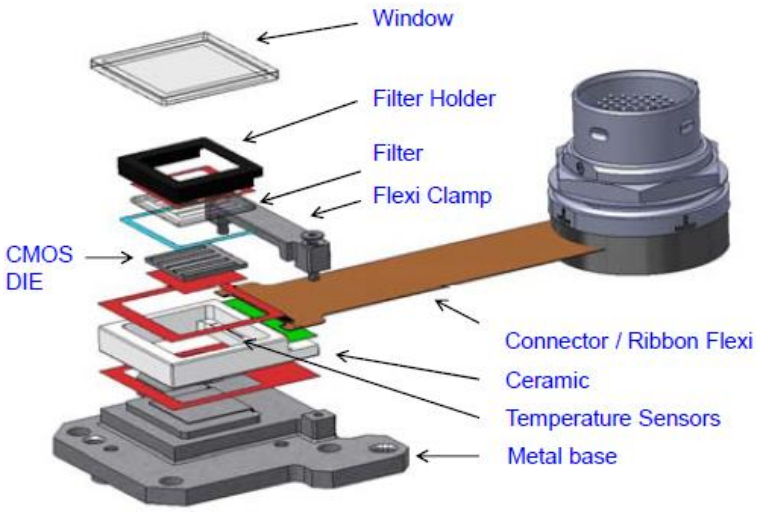
SDO AIA -- Solar flare in EUV
Image Courtesy of NASA

Radiation testing

- CCDs
  - Ionizing radiation (Co60 gamma)
    - Increased dark signal
    - Flatband voltage shift
  - Proton dose (10-60 MeV protons)
    - Dark current spikes
    - Traps / poor charge transfer efficiency
    - RTS dark signal
- CMOS Image Sensors
  - Ionizing radiation (Co60 gamma)
    - Increased dark signal
    - Flatband voltage shift
  - Proton dose
    - Dark current spikes
    - RTS dark level shift
  - Heavy ion
    - SEU (single event upset)
    - SEL (single event latch-up)

Detector sub-systems capability

- We produce **flat focal planes** that remain flat at low operating temperatures
- We integrate **electronics** and achieve sensor-limited performance in a focal plane array
- We produce **mechanical and thermal designs** with extremely tight tolerances of alignment with the customer's optics
- We produce stable, uniform and controlled **cooling** over a large area for a long time
- We **assemble, integrate, verify and test** - including doing operational low temperature metrology



MTG Flexible Combined Imager for Meteosat Third Generation meteorological satellite

A few space imaging applications

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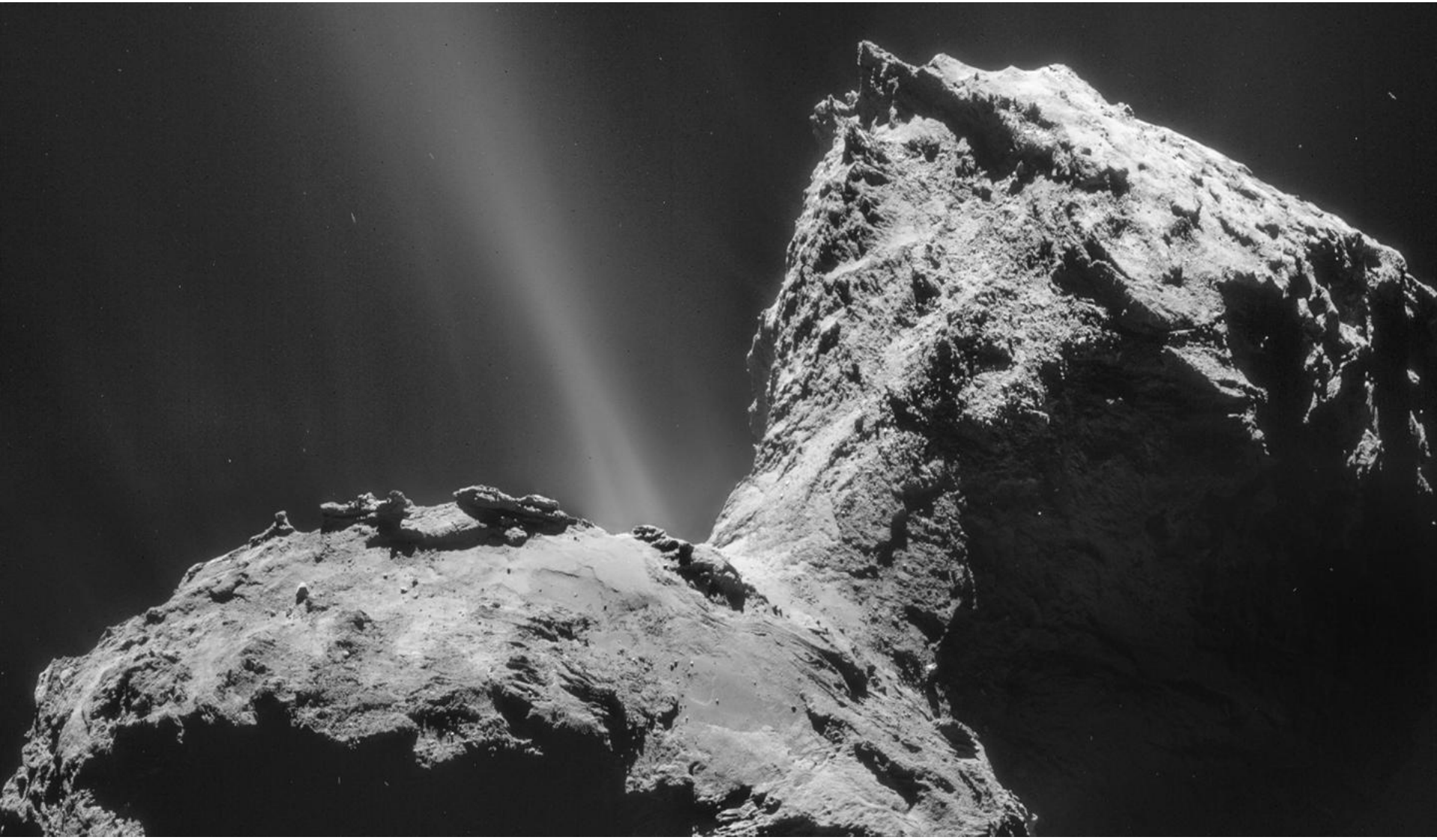

Visible Imaging

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What makes a good visible imaging detector?

- High resolution
- High quantum efficiency (back-illumination)
- Optimized AR coating

Examples

- Hubble - Wide Field Camera 3
- New Horizons – LORRI
- Rosetta – OSIRIS, NAVCAM (orbiter) ROLIS (lander)

CCD42-40 in Rosetta OSIRIS

Image courtesy ESA

Planet Observation

What makes a good detector?

- Ability to do Time Domain Integration (TDI) scanning for high sensitivity
- Multiple bands on the same silicon
- Anti-blooming
- High resolution

Examples

- Sentinal 3
- Pleiades
- Mars Reconnaissance Orbiter – HIRISE
- New Horizons - RALPH

Pan and multi-spectral image sensors for Pleiades

Image courtesy Airbus

Photometry and Astrometry

GAIA -- 1 billion pixels mapping the Milky Way – First year of science operations complete Aug 2015

What makes a good detector?

- High dynamic range
- Linear response
- High spatial uniformity
- Large areas for surveys

Examples

- Kepler – Photometer
- Gaia - ASTRO

Image courtesy ESA

Spectroscopy
Hyperspectral Imaging

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What makes a good detector for spectroscopy?

- High resolution in spectral dimension
- High dynamic range

Example

- Curiosity - ChemCam

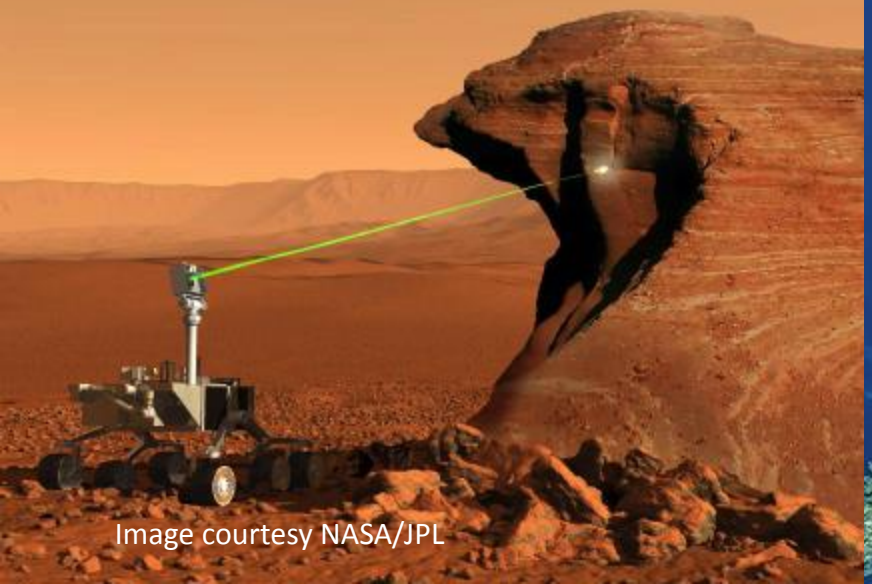


Image courtesy NASA/JPL

What makes a good detector for hyperspectral imaging?

- High resolution in spatial dimension
- High dynamic range
- High cadence

Example

- Envisat – MERIS
- PROBA - CHRIS

Image courtesy ESA

Extreme UV and X-ray Imaging

What makes a good EUV imager?

- High resolution
- Back-illumination, no AR coating for EUV and soft X-ray sensitivity
- Good radiation tolerance

Examples

- STEREO – SECCHI
- Solar Dynamics Observatory – AIA
- Curiosity – Chemin (X-ray diffraction focal plane)

CCD203-82 for SDO AIA

Image courtesy NASA

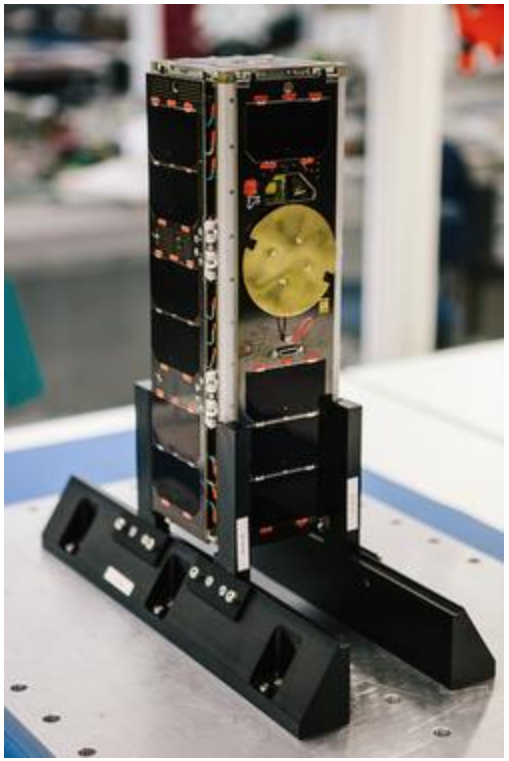
Tech Demonstrator - UKube-1

e2v COTS image sensor flown in XCAM's CD3 camera

Developed in partnership with Open University

EV76C560 (Sapphire)

- Number of pixels 1280(H) × 1024 (V)
- Pixel size 5.3 µm square
- Output Digital, 10 bits parallel
- Pixel architecture 5T, rolling or global shutter
- Pixel illumination Color/monochrome with microlens
- Frame rate Up to 60 fps
- Read noise ~9 e- in rolling shutter
- Pixel charge capacity 12 ke-



UKube-1

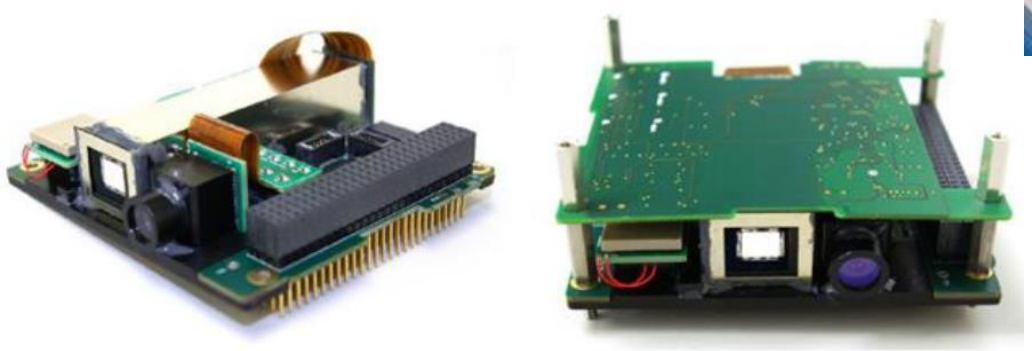
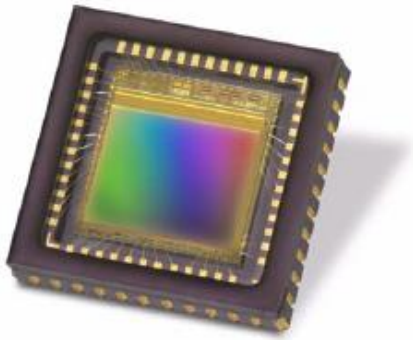


Figure 18 : Images of the C3D flight model prior to shipment, with the optics, sensors and control system on the left, and fully assembled with the ESS on the right. The completed size is 90x90x20 mm^3 with a mass of 175g.

CD3 image courtesy XCAM



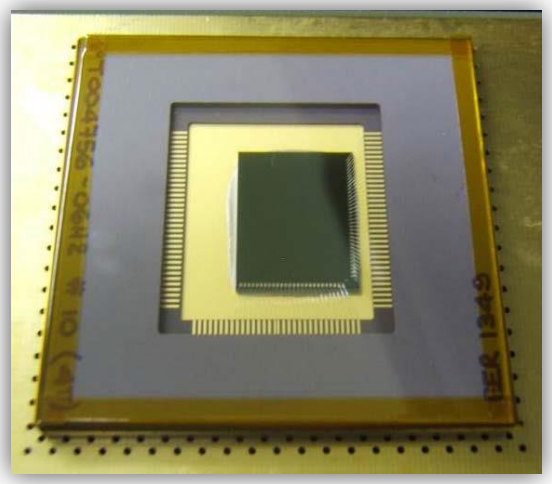
EV76C560

CIS for Space - CIS115

Radiation tolerant design – baselined for JUICE (JUpiter ICy moons Explorer) / JANUS Camera system

SUMMARY PERFORMANCE (Typical)

- Number of pixels 1504(H) × 2000(V)
- Pixel size 7.0 µm square
- Outputs **4 analog**
- Pixel architecture 4T, rolling shutter
- Readout noise 5 e- at 6.2 MP/s per channel
- Maximum data rate 10 MP/s per channel
- Max full frame rate 7.5 fps
- Pixel charge capacity 39,000 e-
- Dark signal 25 e-/pixel/s (at 21°C)



CIS115 with temporary window taped on

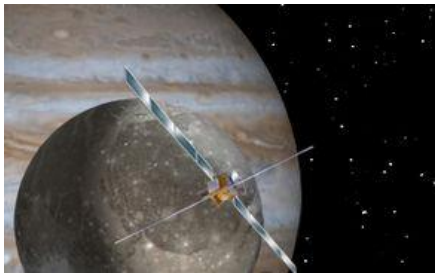
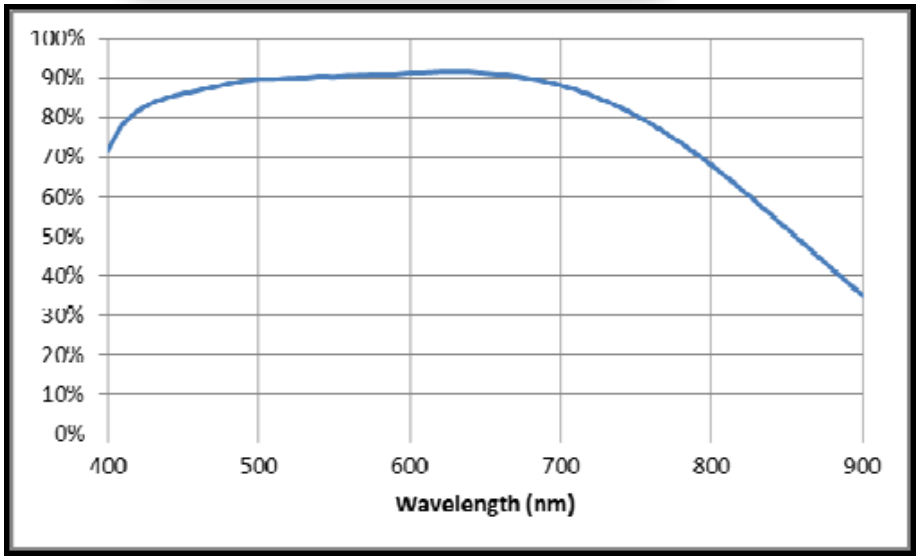


image credit: NASA



Typical spectral response (multi-2)

Other options are available

COTS Imaging Products

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Industrial CMOS image sensors

Name	Part #	Versions	Resolution	Pixel size	Bit depth	Frame rate (max)
Sapphire*	EV76C560	Color/mono RS/GS	1280 x 1024	5.3 µm	10b	60 fps
Sapphire 2Mp	EV76C570	Color/mono RS/GS	1600 x 1200	4.5 µm	10b	50/60 fps
Ruby	EV76C660 EV76C661	Color/mono Red enhanced RS/GS	1280 x 1024	5.3 µm	10b	60 fps
Onyx	EV76C664	Mono Red enhanced RS/GS/DDS	1280 x 1024	10 µm	8/10 12/14 bits	100/ 60 fps
Lince5M	Anafocus anafocus.com	Color/mono GS	2560 x 2048	5 µm	12b	250 fps
LS4k	Anafocus anafocus.com	2 linear sensors on a single chip GS	1 x 4096 1 x 2048 (may be binned to 1x1024 or 1x512)	7 µm 14 µm (28 or 56 µm when binned)	12b	Up to 82k lps binned to 0.5k resolution

* Some radiation data available

And a variety of CCD imaging products…

e2v imaging in cubesats

What we can offer…

1. **We have extensive experience in delivering space qualified projects to well defined standards**
2. **We offer CMOS image sensors designed for use in space**
3. **We offer COTS image sensors which have some characterization data available**
4. **We partner with e2v Centre for Electronic Imaging at Open University who provide expertise in radiation effects in image sensors**

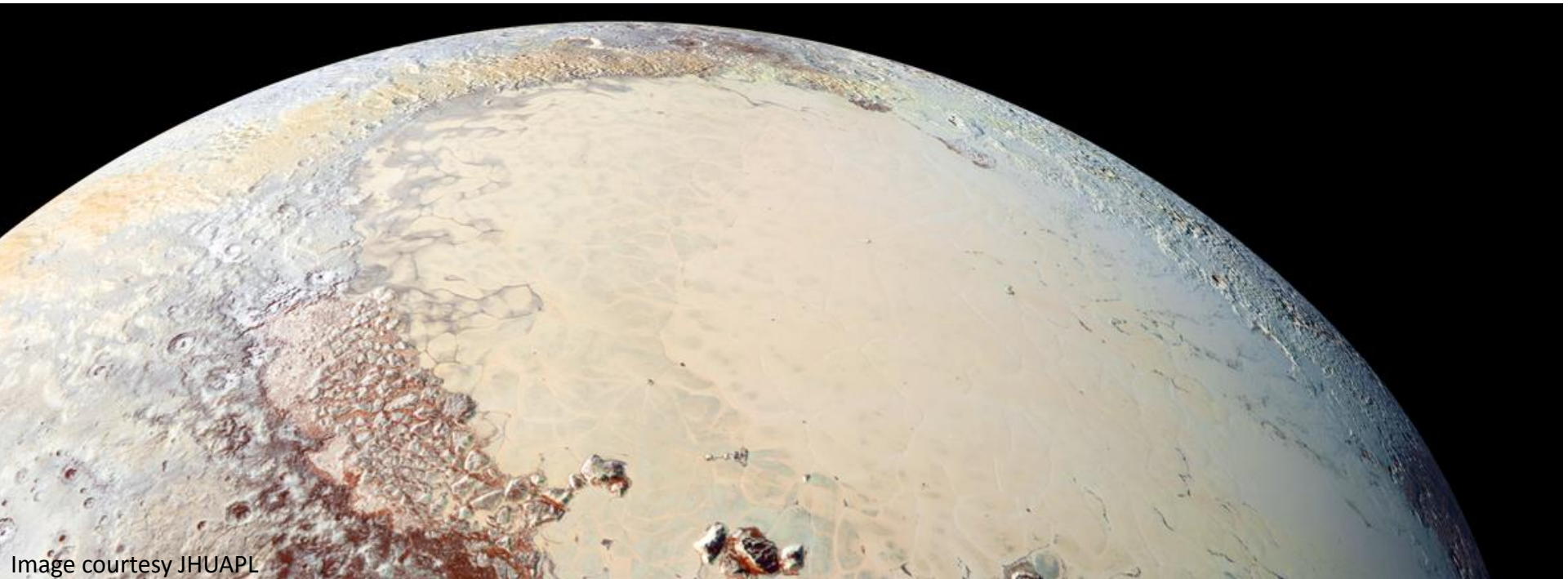

Image courtesy JHUAPL

Thank you for your attention

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Questions?

Image courtesy STSci

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