e2v high performance imagers and systems for AO & Astronomy

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WE PARTNER WITH OUR CUSTOMERS TO IMPROVE, SAVE AND PROTECT PEOPLE’S LIVES
Introduction: e2v capability

Heritage / Experience in Astronomy & Space:
• More than 50% of ground based professional astronomy telescopes are equipped with e2v sensors

Cutting edge CCD & CMOS technology:
• High-sensitivity: Associated technologies
  Low read-noise and high QE from UV to NIR
  Custom AR coatings (single & multi-layer, graded)
  Precision packages and assemblies

Systems capability:
• Sensors and systems together; cryogenics and electronics

Overall supply chain management: from design to production
• e2v CCD and CMOS Sensors

• Space and Astronomy Imaging Systems
# Popular astronomy sensors-1

**High QE, low noise**


<table>
<thead>
<tr>
<th>Type</th>
<th>X</th>
<th>Y</th>
<th>μm</th>
<th>Special</th>
<th>Primary Use</th>
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<tbody>
<tr>
<td>CCD39</td>
<td>80</td>
<td>80</td>
<td>24</td>
<td>FT</td>
<td>Wavefront sensing</td>
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<tr>
<td>CCD220</td>
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<td>FT, EMCCD</td>
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<td>CCD47-20</td>
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<td>13</td>
<td>FT</td>
<td>Acquisition &amp; guiding</td>
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<tr>
<td>CCD42-40</td>
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<td>13.5</td>
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<td>CCD44-82</td>
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</table>
## Custom sensors/ in development

<table>
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<tr>
<th>Type</th>
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<th>Primary Use</th>
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<td>CIS113 (CMOS)</td>
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<td>4608</td>
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<td>700 fps</td>
<td>WFS/AO (NGSD)</td>
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<td>CIS112 (CMOS)</td>
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<td>1680</td>
<td>24</td>
<td>700 fps</td>
<td>WFS (LGSD)</td>
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<td>CIS115 (CMOS)</td>
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<td>7</td>
<td>Space use</td>
<td>demonstrator</td>
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</table>
e2v sensor capability
Graded anti-reflection coating

High Quantum Efficiency requires AR coating
A simple coating is only optimised for one wavelength
Graded coatings have spatial gradient to match spectrograph
Spatial pattern can be based on spectrograph design
Optimised spectral response
Ideal for fixed-format spectrographs
Reflection also minimised (ghosts and fringes)

Example of 2 single coatings together with graded AR coating
Custom CCD packages
CCD sensors for J-PAS

CCD290-99 science sensors
9216 X 9232 format, 10 µm pixels
92 X 92 mm image area

• All at 20.00 mm height
• All have same spectral response
• All used with differential outputs
• Flex cables for FPA assembly

CCD47-20 guiders
1024 X 1024 Frame-transfer
11 X 13 mm image area

CCD44-82 wavefront sensors
2048 X 2048 Frame-transfer
31 X 31 mm image area
Main features

- 4k X 4k image area
- 12 µm pixels
- Split frame transfer sections
- 8 EMCCD outputs
- Sub-electron readout noise
- Real and dummy outputs
- Min. 4 fps at 10 MHz pixel rates
- Designed for photon counting
- Non-inverted (non-MPP) operation at cryo temperatures
- Backthinned for high spectral response; 90% peak
- Alternate formats possible; TBC
CCD282 -2

103 mm die length

Preliminary performance:
- Full images recorded
- Very low Clock-induced-charge
- CTE good with unit gain; lower serial CTE with gain (as usual)
- Gain characteristics being measured

Status
- Design complete
- Frontside devices characterised
- Backside devices in progress; shown to be functional broadly as expected
- Production test camera in use
- Eight EM outputs tricky to setup for good operating window; being investigated
- Some CTE & FWC variation

Ref: Jean-Luc Gach, Development of EM CCD282, SPIE 9154, 2014
CCDs with high red sensitivity

**CCD261**

- 2k X 4k, 15 µm pixels
- 200 µm thick
- 2.5 e- noise floor
- Precision Buttable package

**CCD261-84**

- Deep depletion together with inverted mode operation (patent)

Picture courtesy: Andor iDus 416 spectroscopy camera
**Sensor**: 1920 x 4608 16 µm square pixels.

8 segments for parallel read-out

Independent access of left and right sides

Multiple ROI mode for 20 fps sampling rate

Noise floor < $5e^{-\text{RMS}}$ and low dark current.

Backthinned for 90% QE

Saturation signal (node) ~ 18 ke-
CMOS imagers-2
NGSD/LGSD  CIS112 sensor

- Designed for AO WFS
- 20X20 pixel sub-arrays
- 24 um pixels
- Backthinned for high QE
- < 3 e- read-noise target
- LGSD (later) & NGSD (“1/4”-size)

See next slide
STATUS

- First NGSD samples have been tested
  - Pixel functions well; low noise
- A design iteration has been made to correct digital signal path mainly
- Backthinned Rev-B devices are packaged and being tested
- Most of performance is achieved; some issues being addressed with e2v and ESO testing devices

Ref: Mark Downing, NGSD CMOS imager for E-ELT, SPIE 9154, 2014
LGSD Peltier Package Concept

Window not shown for clarity
• e2v CCD and CMOS Sensors

• Space and Astronomy Imaging Systems
e2v ambition

• Be a leading supplier of custom complex imaging systems for ground based and space based applications

e2v value proposition

• Based on e2v sensors, optimize design of camera systems to deliver effective and efficient solutions,

• Save our customers development time and cost by simplifying the management of the project and of the supply chain

• Leverage synergies between systems for Astronomy and Space (experience, skills, tools,...)

• Industrial approach, aiming at fulfilling schedule and budget objectives, without compromising performance and quality.
e2v Space Imaging System Strategy (2/2): Building on our sensor technology to provide customers with system integrated solutions

- **Unique** CCD/CMOS detector and packaging in-house capability (design, manufacturing, Test)
- Growing experience in detection assemblies and focal planes.
- Significant experience in cameras for industrial, defence and science
- Synergy in camera subsystems for Space and ground based applications
- e2v in-house expertise covers **system engineering disciplines**. It encompasses design, development, integration and test & qualification of the complete system covering:
  - **CCD/CMOS detectors** design & development
  - **Packages** including hermetic packages, Thermo-Electric Coolers, windows, flexi
  - **Optical filters** specification, procurement and assembly
  - **Opto-mechanical** skills incl. Mechanical & Thermal design, verification & Test
  - **Electronics, FPGA, Software** capabilities
  - Cryogenics, vacuum, radiation aspects
  - Development of **test equipment** and assembly & test infrastructure
The e2v 1.2 Giga-pixel camera produces high-quality images and a unique spectral resolution.

The 2.5m mirror of the main telescope, combined with the e2v camera will, over the whole area of the 5 year survey, cast a new picture of the cosmos. The innovative designs of the J-PAS camera and filter system will allow, for the first time, to map not only the positions of hundreds of millions of galaxies in the sky, but their individual distances to us as well, providing the first complete 3D map of the Universe in 59 colours.

- CCD operational performance: 14x 290-99 CCDs flat to 40 μm
- Bespoke cooling design in a bespoke Cryostat to maintain CCDs at -110°C
- Readout electronics: 22 CCD drive modules, power and data handling electronics, 50 FPGAs to handle the 2.4 GBytes of data per frame (every 20 seconds), 1.2kW dissipation
- Cryogenic cooler using a custom mixed phase LN2 cooling system and including the control electronics for the cooling and vacuum systems

Camera Delivery: Q2/16
The FPA consists of four CCD290-99 devices arranged in a 2 by 2 matrix and four CCD47-20 devices, one on each side of the CCD290-99 matrix. The CCDs are mounted on a silicon carbide Detector Mounting Plate.

Three FPAs delivered early 2014

Flatness ~ 30µm from peak to valley
Diameter ~ 30 cm
e2v are responsible for this complete detector assembly with design, assembly, validation and test of the MTG FCI VisDA

- The MTG FCI VisDA is a custom CMOS Image Sensor for use in the Meteosat Third Generation meteorological satellite.
- Challenging sensor design due to:
  - Novel large area rhombus shaped pixels (~100μm x 100 μm).
  - 5 custom channels each specific to different wavelengths of light in the range 414 to 924nm.
  - On chip sequencer.
  - Needs to operate in a high radiation environment.
- The CMOS Image Sensor is assembled into a package that includes a ribbon flex, custom optical filters and a permanent window.
  - First CMOS Image Sensor that e2v have been fully responsible for a space application
- The CMOS Image Sensor is fabricated at an external foundry,
- There is a system aspect to the project as the optical filters are being procured as part of subcontract.
  - The subcontractor is responsible for the design, manufacture, validation and test of the filter to ensure that it meets the requirements defined by e2v.
  - First time e2v have used a subcontractor on an ESA backed project.
- In-house capability for filter alignment (TRL5 achieved)
  - Process qualified end 15
e2v is developing a focal plane to study the universe in Ultraviolet

WSO-UV space mission is to study the Universe in the 120 - 310 nm ultraviolet (UV) wavelengths range, which is beyond the reach of ground-based instruments. WSO-UV is a major international collaboration with Russia playing the leading role as part of the Federal Space Program of Russia.

The Focal Plane system Instrument comprises:
- Three vacuum cryostat enclosures each containing a CCD optimised for different wavelengths
- Three electronic drive modules
- Cabling for interconnection

Key challenges:
- Maintain CCD at -100°C while contributing no more than 3W heat into the cooling system
- Outgassing – need to maintain a high vacuum for up to 9 years to prevent condensation
- Shock and vibration – Needs to survive launch while maintaining alignment

Enclosure composed of a window, a cold finger, ION pump and getter pump with a CCD central support

Three different Anti Reflection (AR) coating variants. High guaranteed QE below 200 nm, High CTE Low Dark Current and Readout noise.
e2v acts as a *thin prime* to export the Multi Port CCD (MPCDD) system to the Pohang Accelerator Laboratory (PAL) X-ray Free Electron Laser (XFEL)

For a number of years e2v have supplied CCD’s to the *Spring 8* facility at Riken. These are used in either single or dual MPCCD systems within the X-ray Free Electron Laser (XFEL) beam line to capture experiment results.

Pohang Accelerator Laboratory in South Korea are currently in the process of building a fourth generation XFEL and wish to use the MPCCD system. Majority of the work is conducted by Meisei who designed sections of original MPCCD

**Key Challenge:**

- Generate the technical specification the MPCCD system will meet ensuring sign off from both supplier and customer
- Provide engineering governance and supervision of the Meisei subcontractor for the industrialisation and certification
- Technical point of contact between PAL and Meisei incl. Installation at site, Requirements for test acceptance, regulatory and EMC compliance,…

**Deliveries:**

- 2 single device systems: Aug/Sept 15
- 3 Dual device systems: Oct/Nov/Dec 15

**Images:**

- MPCCD Head
- Camera Head
- PAL Experiment Hall
Test Systems: 25 years of experience

More than 20 test systems are operational in e2v for the characterisation, test and acceptance of CCD/CMOS devices for Space, Science and Astronomy devices.

They have been design, manufactured and commissioned by e2v

Key Challenges:

- Adaptability to different and new products versions
- High performance and low noise measurement
- Software and data management
- Low temperature (up to -120°C) in Vacuum
- Stable optical source
Thank you for your attention

e2v offers-

- Science imaging, spectroscopy, & WFS/AO sensors
- Sub-assemblies, cryogenic cameras, electronics, systems
- Complete in-house capability for supply

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Examples of Space CCD applications

[in reserve]
Space CCD examples: GAIA Astrometry satellite

**GAIA** CCD91-72, 106 FM$s$
4500 x 1966 10 x 30 μm pixels
TDI mode operation

**Operational:** Largest focal plane in space
Euclid CCD273-84

4096 X 4096 12 µm pixels

Development phase complete

Qualification phase in progress (sample devices)

Two year Flight phase to follow in 2015 (36+ spare FMs)
Plato CCD270
4510 X 4510 18 µm pixels; 4 CCDs per FPA
34 FPAs. Will be largest focal plane area

Development phase complete
Validation phase soon (24 devices)
Flight phase to follow (152 FMs)
Rosetta-1: the mission


Has now covered 6 billion km.

Pictures courtesy ESA

Landing site Agilkia chosen for Philae lander on 12 November 2014. Uses NavCam images.
Landed 2014; now returning some data.
Rosetta-2: The orbiter
Navcam, two OSIRIS imagers, VIRTIS spectrometer

Navcam CCD47-20

www.rosetta.ac.uk
Rosetta-3: the lander, Philae
ROLIS and CIVA imaging systems (TH7888)

www.rosetta.ac.uk
New Horizons was launched on 19th January 2006

July 2015 flies past Pluto and records images
New Horizons instruments

Science Payload

- Ralph: Ultraviolet imaging spectrometer; provides compositional mapping.
- Alice: Ultraviolet imaging spectrometer; analyzes composition and structure of Pluto’s atmosphere and looks for atmospheres around Charon and Kuiper Belt Objects (KBOs).
- REX (Radio Science Experiment): Measures atmospheric composition and temperature; passive radiometer.
- LORRI (Long Range Reconnaissance Imager): Telescopic camera; obtains enhanced spatial resolution images of Pluto and its moons; maps Pluto’s far side and provides high-resolution images of Charon.
- SWAP (Solar Wind Around Pluto): Solar wind and plasma spectrometer; measures atmospheric “escape rate” and observes Pluto’s interaction with solar wind.
- PEPSSI (Pluto Energetic Particle Spectrometer Science Investigation): Energetic particle spectrometer; measures the composition and density of plasma (ions) escaping from Pluto’s atmosphere.
- VBSDC (Venetia Burney Student Dust Counter): Built and operated by students at University of Colorado; measures the space dust peppering New Horizons during its voyage across the solar system.

For scale the main dish has a diameter of 2.1 meters.
LORRI

- **LORRI** - short for Long Range Reconnaissance Imager - provides the highest spatial resolution.

- LORRI consists of a telescope with a 8.2-inch (20.8-centimeter) aperture that focuses visible light onto a charge-coupled device (CCD). LORRI has a very simple design; there are no filters or moving parts. Near the time of closest approach, LORRI will take images of Pluto's surface at football-field size resolution, resolving features approximately 100 yards or 100 meters across.

- Uses a standard monochrome CCD47 (like so many other missions!)
Ralph – CCD96

• This a multi TDI imager – each of the 6 TDI sensors operates at a different wavelength to give detailed colour information about the surface

• A TDI sensor is similar to a scanner and creates an image as it scans the surface. This has to be very quick and efficient as the fly-by will be quick
New Horizons Instruments

Scanning Images ~ 1 minute
   (Ralph)

Scan Direction

Spacecraft Rotation about Z-Axis

Staring Images ~ 100 milliseconds
   (LORRI, Ralph, Alice)
A Portrait from the Final Approach to Pluto and Charon

A portrait from the final approach. Pluto and Charon display striking color and brightness contrast in this composite image from July 11, showing high-resolution black-and-white LORRI images.
A portrait from the final approach. Pluto and Charon display striking color and brightness contrast in this composite image from July 11, showing high-resolution black-and-white LORRI images colorized with Ralph data collected from the last rotation of Pluto. Color data being returned by the spacecraft now will update these images, bringing color contrast into sharper focus.
New close-up images of a region near Pluto’s equator reveal a range of youthful mountains rising as high as 11,000 feet (3,500 meters) above the surface of the icy body. The image was taken about 1.5 hours before New Horizons closest approach to Pluto, when the craft was 47,800 miles (77,000 kilometers) from the surface of the planet. The image easily resolves structures smaller than a mile across.
A view of Pluto and Charon as they would appear if placed slightly above Earth's surface and viewed from a great distance.

Recent measurements obtained by New Horizons indicate that Pluto has a diameter of 2370 km, 18.5% that of Earth's, while Charon has a diameter of 1208 km, 9.5% that of Earth's.
Unused sensor slides
Stitching
Large area devices- “stitched” from blocks

Four side track blocks

Image pixels block

Amp-A LHS & Register LHS

Amp-B LHS & Register LHS

Amp-A RHS & Register RHS

Amp-B RHS & Register RHS

Register Large blocks

Register Small blocks

Nikon reticle (~ 100 X 100 mm) with multiple elements
On-wafer stitching

Part number conventions-
Eg

Device design #  CCD203-82-G-abc  [4k4k sensor]
Y,X # of stitch blocks  grade  part descriptor

For CCD203-82 design:  8 vertical blocks of 512K, 2 horizontal blocks of 2k

Ultracech stepper  1½ D blocks  X1 projection
\ multiple blocks in Y; 2 blocks max in X
Eg CCD44-82, CCD203-82
Quoted alignment precision:  250 nm

Nikon stepper  Full 2D block stitching  X5 demagnification
\ multiple blocks in X and Y
Eg CCD231-84, CCD290-99
Quoted alignment precision:  90 nm

Each block is located relative to the stepper reference frame

Newer devices are designed for Nikon use and are more accurate
Stitch boundaries [UT & NK steppers]

1000nm QE image CCD203-82

Photographs of CCD203-82 wafers
CCDs with high red sensitivity-1

**LSST CCD250**

- 4k X 4k 10 µm format
- 189 science sensors
- 100 µm thick; 5 µm flat
- High precision SiC buttable package
- 16 outputs; 2 s readout
- 5 e- read-noise

21 “science rafts” make up the 3.2Gpix focal plane

4K x 4K CCD
- 10µm pixels = 0''.2
- extended red response
- 16 outputs
- 5µm flatness

FOCAL PLANE WITH 21 SCIENCE RAFTS

RAFT
- 9 CCDs
- coplanarity 6.5µm

TOWER
- CCDs + front end electronics
- 180K operation
- An autonomous, fully-testable and serviceable 144 Mpixel camera

Pictures courtesy: LSST
STATUS

• Frontside samples tested in 2014
• Devices match predictions (lag OK)
• 1st Backthinned devices tested 1H 2015
• Devices work well except for lag [foundry fault]
• New wafers under manufacture- due Nov 2015
• 2nd set Backthinned devices to be tested in 1H 2016
• Customer deliveries (of 40) due 2016-2017.

Each focal plane:

10 buttable image sensors per focal plane
3 focal planes to be built for three telescopes

Matt Lehner, *TAOS-II survey status*, SPIE 9145, 2014