

Welcome to the Autumn 2005 edition of 'Through the Lens'.

In this issue we provide informative technical and applications information showing new implementations



of infrared imaging technology in areas of great interest to many - investigating the universe about us and developing new clean sources of energy. The main technology feature details the development of a new coronagraphic interferometric imaging method and illustrates how the technique is offering real benefits to astronomy research. Our application focus looks at how advanced infrared thermography systems are being deployed within nuclear fusion facilities to provide a safer environment through remote monitoring of structures within the reactor facility.

In latest news we report a strategic company acquisition by Cedip, the launch of the Silver 450M an Ultra-fast IR Camera for R&D and Thermography applications, a new 4th generation of the popular JADE family cameras and PHAROS - a new multi-sensor platform for day/night surveillance operations.

We hope you enjoy the hints, tips and information contained within this issue and welcome your comments and feedback on topics you would like discussed in future issues."

Pierre Potet, President

New Literature Corner

CEDIP Infrared Systems has recently released new technical brochures for the following products:

PHAROS Multi-sensor platform

RUBY Night Vision camera

Silver 450 Ultra-fast IR camera

REPLY NOW to Emilie Cornee at

cedip-marketing@cedip-infrared.com to be sent pdf versions of these brochures.

Achromatic Interfero Coronagraphic Imaging – a new technique for astronomy research

Y.Rabbia, J.Gay, J.P. Rivet

Are we alone in the universe and how can we describe its origin are two questions which have intrigued people through the ages. From the time of Epicurus to the late 1980's most commentary on these topics could be no more than speculative, but things changed dramatically in the early 1990's when NASA launched a vast experimental research program "origins". From the technological developments of the "origins" program it became possible to search for "others worlds" – scientifically termed exoplanets (planets orbiting stars other than our sun).

Since the first discovery (51 Peg, Mayor et al., 1995), more than 150 exoplanets have been identified, but only by indirect methods (that is from the perturbation of the light emitted by the mother-star). A step further must be the direct detection (that is recording photons from the planet itself) of earth-like exoplanets, and a spectral analysis so as to find traces of bio-marker gases, such as H₂O, CO₂, O₃, via their absorption lines. For this ambitious endeavour, space-based missions are required however while the planning has started the first launching is probably still at least one decade ahead.

At the present time, a preliminary objective being worked upon is the direct detection of faintly emitting matter and bodies around larger celestial bodies such as stars using techniques including Stellar Coronagraphy.

Coronagraphy is an imaging mode used in Astronomy to study the very close angular environment of stars (and other unresolved sources : asteroids, galaxies with active nuclei, quasars,..). In the stellar domain, studies relate, for example, to the distribution of circumstellar matter, faint companions in binaries and also, ultimately, exoplanets.

Two main problems are to be solved. First, the star is far brighter than the neighbouring features (typical flux ratio spans from 10³ to > 10⁶), and this situation prevents them being detectable by traditional imaging methods. Second, the angular vicinity to explore for these neighbouring features is in the range of a few tens of milli-arcseconds, this corresponds to the diffraction limit of a 4m to 8m class telescopes, depending on the working wavelength.

Thus the two main goals for a workable imaging coronagraph are superior light rejection and close-sensing capabilities. Rejection is needed to eliminate the star's contribution in the recorded image, (like

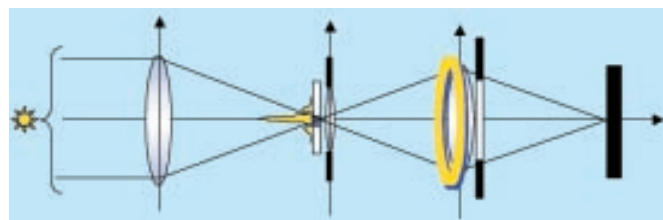


Figure 1. Principle and use of Lyot coronagraph. (Unwanted diffraction effect requires a so-called Lyot stop in exit pupil plane).

obscuring an angular domain around the axis of the telescope). Close-sensing is needed to explore as close to the star as possible, because in the close angular neighbourhood to the star lie the features with the scientific potential currently seen as the most interesting.

Various instrumental approaches for coronagraphs have been devised, the most

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promising of which is the interferometric approach, where rejection is achieved via destructive interference of the light from an on-axis source. The main advantage of the interferometric approach is its close-sensing capability, this enables angular exploration to be done as close as the theoretical diffraction limit (first Airy dark ring) and even closer.

This is not the case with conventional “Lyot coronagraphs” (inspired by the original system devised by B Lyot to make observable solar protuberances by artificially occulting the sun at an intermediate focus of the telescope). An occulting mask, cannot reveal features angularly close-enough to the star because of adverse diffraction effects : the compromise being a mask covering not less than 5 “Airy rings” in the diffraction pattern of a point-like source (assuming degradation from turbulence are compensated for by Adaptive Optics).

The basic principle of the interferometric approach is to split the incoming light into two parts and to insert in one part a phase shift, while accurately maintaining equal optical paths. When recombining the two parts, interference occurs, but in destructive mode: photons from the on-axis source are rejected, and sent back to the sky. By comparison light from off-axis sources bears an extra phase shift causing unbalanced optical paths and interference does not work, photons are

then transmitted.

The Achromatic Interfero Coronagraph (AIC) developed at Observatoire de la Côte d'Azur (France), is an example of the interferometric approach.

The Achromatic Interfero Coronagraph is a Michelson-Fourier interferometer (beamsplitter for separation and recombination) modified so as to achieve destructive interference for an on-axis source. A specific feature of AIC (unshared by other interfero-coronagraphs) is that the phase shift is intrinsically achromatic. This results from the focus-crossing property : when crossing a focus, waves of light experience a π phase shift independent of the wavelength. So, in one arm of the generic Michelson-Fourier interferometer, a cat's eye system is inserted and provides an extra-focus yielding both the wanted π phase shift and a pupil rotation by 180° from which off-axis sources escape the destructive interference process.

The efficiency of the interferometric process (looking to achieve high rejection) depends on the quality of recombined wavefronts from the on-axis source. So that, observing from ground-based telescopes, wavefront distortions caused by atmospheric turbulence must be compensated for and this makes mandatory the help of an adaptive optics system, which performance eventually determines the rejection capability.

Other systems that use the interferometric approach include the Phase

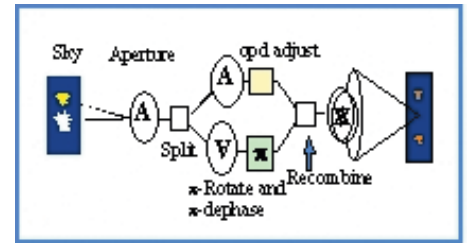


Figure 2. Generic set-up for the chromatic Interfero Coronagraph.

Mask Coronagraph (PMC) (Roddier & Roddier, 1997) and the Sectorised Mask Coronagraph (SMC) (Rouan et al., 2000) (**Figure 3**). In the PMC design, a composite material mask (with two different refractive indexes) splits the Airy pattern in two parts (central and peripheral). In the central part, the mask induces a π phase shift with respect to the other part. In the SMC design, again a composite mask with two different refractive indexes is used but now distributed along a diagonal of a 4 quadrants configuration, thus giving a

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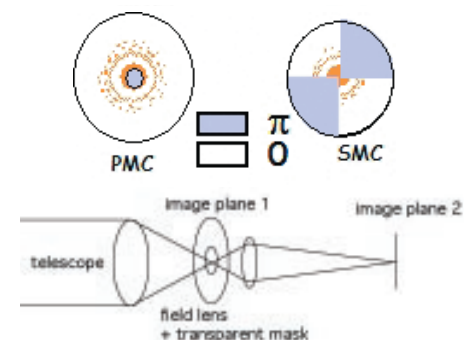


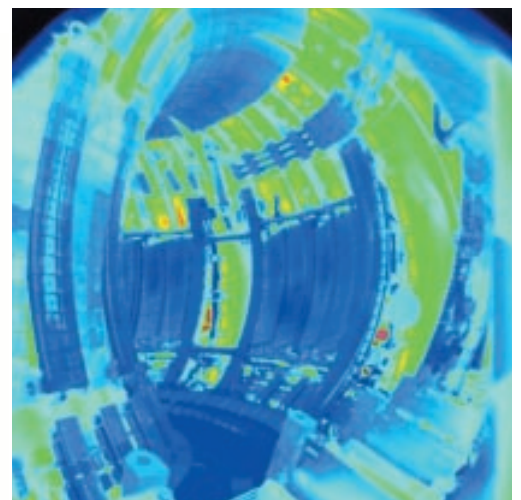
Figure 3. Principle and use of PMC and SMC designs. (Lyot stop on exit pupil plane is non featured).

Image Gallery Competition

Eric Gauthier a researcher from CEA (Cadarache) currently working at the Joint European Torus (JET) research group (Culham, UK) provided us with this attractive image showing the temperature of components inside their Tokamak Fusion reactor facility. Based upon Cedip EMERALD camera technology, operating in the 3-5 micron region, the advanced IR thermography system monitors the plasma temperature inside the reactor through a set of IR endoscopes.

Please email us your images for the next issue of 'Through the Lens' together with a short applications description to support@cedip-infrared.com.

Wide angle system for infrared observation of divertor, ICRH antenna, inner wall and poloidal controller to establish the powerload distribution at the first wall.



Achromatic Interfero Coronagraphic Imaging – a new technique for astronomy research

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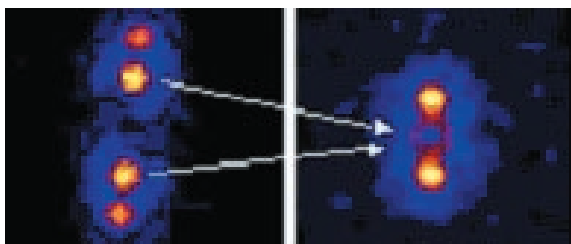
phase shift in quadrants 1 and 3, while giving zero phase shift in quadrants 2 and 4. In both cases, destructive interference occurs in the next image plane.

An interesting feature of the PMC and SMC designs is their small size, making them comparatively easy to insert in the optical train of a telescope, this is not so easy with the AIC design where the entrance and exit beams are perpendicular.

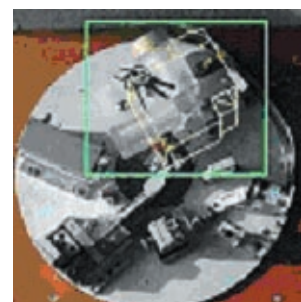
However a substantial disadvantage of the PMC and SMC designs is that they are not achromatic. The key advantages of achromaticity are the subsequent capability to observe at large bandwidth (increasing detectivity via a higher achievable signal to noise ratio), the ability to observe simultaneously in two separate spectral channels (enhancing detectivity by differential analysis) and that the technique offers the flexibility to select a bandwidth according to scientific need.

First results

The Achromatic Interfero Coronagraph has been used at the Observatoire de Haute Provence (OHP) and at the Canada France Hawaii Telescope (CFHT) for preliminary test runs (Figure 4). Close-sensing has been demonstrated and rejection proved to be in agreement with theoretical expectations.



72 Peg, self-adapted brightness scale



(B)



(C)

Figure 4.
(A) First prototype AIC at work showing the extinction of the on-axis source (binary star 72 Peg, observatoire de Haute Provence, 1.52 m diameter);
(B) Compact AIC on its optical interface device for insertion in CFHT optical train;
(C) Result from AIC at CFHT showing imaging of companion (yellow patches) at closer than first Airy dark Ring.

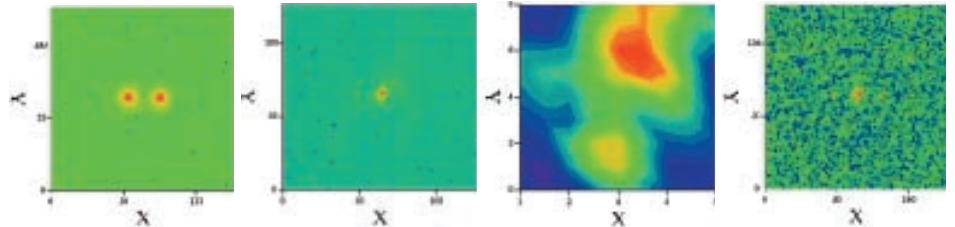


Figure 5.
Images from laboratory tests on AIC using the Cedip Jade SWIR camera.
(from left : artificial star set off-axis (two twin-images); rejection residual with source set on-axis; zoom on distribution of residual ; artificial binary with companion 100 times fainter than main component (5 magnitudes), twin-images of companion can be seen as tiny yellow dots against the noisy background).

Checking & refining the AIC design

To check the performance of the AIC in the spectral domain for which its design is optimised (K band) the Observatoire de la Côte d'Azur invested in a Cedip Jade SWIR camera. Up to this point work in the K band was possible only during observing runs. Laboratory testing with Jade SWIR, yielded images of the residual energy (incomplete rejection) enabling quantification of small optical quality defects within the AIC device as well as providing constraints for internal adjustments and insertion in the telescope optical train.

Up to now, and in non-optimised conditions, rejection at levels of 500 (more than 6 stellar-magnitudes) have been obtained over a large spectral bandwidth (1.9 microns to 2.5 microns) and with a source not totally unresolved.

Figure 5 shows some AIC images (based

upon an artificial star) taken with Jade SWIR camera.

Conclusion

The Achromatic Interfero Coronagraph design has been demonstrated to show rejection and close-sensing performance at experimental limits enabling direct imaging of neighbouring features to stellar objects. The laboratory testing of the AIC using the Jade SWIR camera has enabled identification of optical defects within the device.

For further information: please contact cedip-marketing@cedip-infrared.com or the authors of this article who are researchers at the Observatoire de la Côte d'Azur, Av Copernic, 06130 Grasse F, France and may be contacted on email rabbia@obs-azur.fr; +33.4.93.40.53.59



Corende,
Neuquen City, Argentina
November 2 – 4

Fatigue Design 2005,
Senlis, France
November 16 – 18

CéMOI,
Marseille, France
November 21 – 25

MILIPOL,
Paris, France
November 23 – 25

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IR Thermal cameras add value to the energy of the future.

Modern society depends on access to a ready supply of energy. Energy is used everywhere: for transport, heating, lighting, in industry and in agriculture. At the moment, most of this energy is produced by burning fossil fuels such as coal, oil and gas, some comes from nuclear fission, and a small amount is produced by renewable sources, mostly hydroelectric and biomass. The burning of fossil fuels generates carbon dioxide, a greenhouse gas which traps solar radiation. There are glowing concerns about the resulting global warming and other damaging effects on the environment. Fusion offers the possibility of an emission-free and reliable long-term energy supply with some important advantages.

BASIC SCIENCE OF FUSION

In a fusion reaction, energy is produced when light atoms are fused together to form heavier atoms. This process takes place in the Sun and stars. To utilise fusion reactions as an energy source it is necessary to heat a gaseous fuel to temperatures in excess of 100 million degrees – several times hotter than the centre of the Sun. At these temperatures, the gas becomes a plasma. Under these conditions, the plasma particles, deuterium and tritium, fuse together to form helium and high-speed neutrons, releasing significant amounts of energy. A commercial power station will use the heat generated by the neutrons, slowed down by a blanket of denser material (lithium), to generate electricity. The plasma must be kept away from material surfaces to avoid it being cooled and contaminated; magnetic fields are used for this purpose. The most promising magnetic confinement systems are toroidal (doughnut shaped) and the most advanced is called the Tokamak. The fuels used are virtually inexhaustible. Deuterium and tritium are both isotopes of hydrogen. Deuterium is extracted from water and tritium is manufactured from a light metal, lithium, which is found all over the world. One kilogram of fusion fuel produces the same amount of energy as 10,000,000 kilograms of fossil fuel.

WHY FUSION IS IMPORTANT

Energy demands will increase even more dramatically over the next fifty years as the developing world comes to expect the same standard of living as the industrialised countries. The Kyoto

protocol focused the world's attention to the dangers of global warming from the unrestrained use of fossil fuels. Along with renewable sources nuclear fusion will be an important long-term energy source. Fusion will provide safe and environmentally friendly energy with the advantages of: -

- no atmospheric pollution: the fusion reaction produces helium which is an inert gas; no greenhouse gas is produced
- abundant fuel source
- no long-lived radioactive waste
- an inherently safe system: even the worst conceivable accident would not require evacuation of the surrounding population

This article describes how the world renowned Joint European

Torus (JET) research group based in Abingdon, UK have invested in an advanced IR thermography system from Cedip Infrared Systems for monitoring the temperature of components inside its Tokamak Fusion reactor.

THE IR CAMERAS' ROLE IN THIS EXPERIMENTATION

The JET Tokamak was built to confine and study the behaviour of plasma in conditions and dimensions approaching those required for sustainable fusion. The confinement of plasma in the Tokamak is carried out by an original magnetic configuration obtained by the superposition of a magnetic toroidal field created by the power circulating in the windings and of a magnetic poloidal field,

approximately ten times weaker, created by the toroidal current circulating in plasma.

The objective for the implementation of the IR thermography system was to provide a fail safe system to provide early detection of plasma induced superheated 'hotspots' in the Tokamak Fusion reactor. By doing this through accurate temperature monitoring of components inside the reactor and controlling the Tokamak heating the IR thermography system provides a valuable tool to enhance safety and data to enhance optimisation of the reactor design. Based upon Cedip's proven EMERALD camera technology (**Figure 6**), operating in the 3-5 μm region, the new IR thermography system has been set-up to monitor the plasma temperature inside the reactor through a set of IR endoscopes. Installed inside the reactor facility, an area inaccessible during time of operation, the camera is integrated with the main data processing system of the JET Tokamak

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Figure 6. Emerald infrared camera (Cedip Infrared Systems).

IR Thermal cameras add value to the energy of the future.

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for the setting of parameters, synchronising acquisition and gathering of data. Cedip's advanced 32-bit Altair software is used to remotely control the camera via fibre optics as well as transfer and store acquired data.

Benefiting from the experience of IR thermography installations in nuclear fusion research facilities at the Atomic Energy Commission (Cadarache, France), Cedip has designed a specially adapted version of the EMERALD camera with advantages specific to the extreme environment of a Fusion reactor. The camera system is assembled into a specifically designed housing to protect it against the intense magnetic field generated by the reactors superconducting magnetic coils. A further benefit of the supplied IR thermography system is its ability to measure plasma temperature from 100°C to 2000°C within a single range, whilst operating at 200 images / second in full frame mode.

A NEW IR CAMERA SYSTEM ADAPTED FOR THE NUCLEAR ENVIRONMENT

In an environment of a nuclear reactor, everything has to be remotely situated; otherwise the high level of radiation can corrupt the materials, the data and the data acquisition. To address this problem environment, Cedip Infrared Systems has developed a new protected camera equipped with an endoscope. An endoscope is an instrument that uses fibre optics to remotely visually examine the interior of an inaccessible area (for example in medicine, to observe inside a patients stomach). The Cedip IR thermography system uses a series of 2m long endoscopes, inserted in the Tokamak providing direct contact with the plasma to measure temperature at different points. Using this remote monitoring set-up enables the IR camera to be situated a safe 2.80 metres from the temperature extremes.

The other main challenge has been to protect the camera from the high level of radiation. Working in conjunction with an earlier Fusion reactor customer, AEC Cadarache in France, Cedip Infrared Systems has developed a novel 1cm thick soft iron casing for its camera. When soft pure iron is placed in a magnetic field it becomes magnetic providing protection to the internal components of the camera. Usefully when removed from the intense magnetic field the soft iron ceases to be magnetic, whereas steel keep its magnetization.

CONCLUSION

Initial results from the IR Thermography system installed on the JET Tokamak (example data may be viewed at www.jet.efda.org/images/gallery/index.html) illustrates that a valuable new diagnostic tool has now been developed for safety monitoring in the nuclear industry.

REPLY NOW for further information on this project to cedip-marketing@cedip-infrared.com quoting IR cameras for extreme environments.

HINTS & TIPS

Drawing upon a considerable pool of expertise Cedip's team of experienced technical staff are available to assist you with informed hints and tips. Here is another commonly asked question and answer:-

In this issue we present two definitions widely used for IR signature measurement: the Noise Equivalent Power (NEP) of a detector and the Noise Equivalent Irradiance (NEI) of a system. Both definitions are typically used in range calculation.

NEP (Noise equivalent power)

This quantity gives us the minimum optical power that must be received by the detector to be equal to its noise. Therefore, the NEP unit is Watt.

$$NEP = \frac{\sqrt{A \times \Delta\nu}}{D^*(\lambda)}$$

- D^* is the specific detectivity of the detector. It depends on the integration time. When the light is monochromatic (laser, narrow-band filter, monochromator), D^* value is easy to get. When the light has a larger spectral domain, we usually consider the average specific detectivity. D^* unit is $\text{cm}^2/\text{W}/\sqrt{\text{Hz}}$.
- A is the area of the detector (usually the square of the pitch). Beware, the unit is cm^2 .
- $\Delta\nu$ is the bandpass of the detector. The unit is Hz . It is defined by the following formula:

$$\Delta\nu = \frac{1}{2t_i}$$

It is the integration time of the detector. For the calculation of the NEP, the integration time value is the same one as the one for which the detectivity is measured.

NEI (Noise equivalent irradiance)

This notion is equivalent to the former one expect it takes into account the optics and f number, it is therefore used for estimating the system performance rather than only the detector. The unit is $\text{W}\cdot\text{cm}^{-2}$ since it takes into account the entrance pupil size.

$$NEI = \frac{\sqrt{A \times \Delta\nu}}{S_p D^*(\lambda) \tau_{OP}} = \frac{\sqrt{A \times \Delta\nu}}{\pi \frac{f'^2}{4N^2} D^*(\lambda) \tau_{OP}}$$

- S_p is the entrance pupil diameter of the lens. The unit is cm^2 .
- τ_{OP} is the optical transmission of the lens. It is unitless.
- f' is the focal length of the lens. Beware, the unit is cm .
- N is numerical aperture of the lens. It is unitless.
- The other parameters are described above.

Footnotes is an occasional feature that reports on meetings and conferences around the world that Cedip Infrared Systems has either organised or taken part in. If you have a view on whether or not such reports should feature in future issues of 'Through the Lens' please email us your comments to cedip-marketing@cedip-infrared.com.

Cedip 2005 Distributors Meeting...

Over 40 representatives from around the world attended the recent Cedip Infrared Systems annual global distributors meeting in Croissy-Beaubourg (France). A comprehensive program of technical presentations, practical workshops and open forum discussions drew participants from the USA Australia, Israel, South Africa, Russia, Japan, South Korea, the Netherlands, Belgium, Italy, Spain, Poland as well as from Cedip's 2 subsidiary companies in the UK and Germany. Reflecting upon the meeting Pierre Potet (President) commented 'A key focus of the meeting was for Cedip to transfer

its technological expertise to our representatives'. He added 'Our program of innovative new product introductions coupled with the enthusiasm showed at the meeting bodes well for another good year for Cedip in 2006'.

DSEi visitors respond positively to Cedip...

At the recent Defense Systems & Equipment International (DSEi) exhibition held in London, UK, Cedip Infrared Systems (www.cedip-infrared.com) reported high visitor traffic drawn by its comprehensive range of Thermal IR imaging products. Marking its global debut at DSEi - PHAROS – a high-resolution multi-sensor platform drew consistent attention from visitors interested in applications including ground and vehicle mounted surveillance of sensitive sites such as harbours, borders, airports or industrial production facilities. Particular interest was also shown in the JADE UC family of uncooled IR cameras and the EMERALD LR camera for long-range detection and surveillance applications.

HOT OFF THE PRESS

Hot off The Press brings you breaking news from Cedip Infrared Systems and the world of infrared cameras.

Cedip has announced the launch of **PHAROS** – a high resolution multi-sensor platform specifically designed for short to medium range day/night surveillance applications.

REPLY NOW for further information.

Incorporating the latest ROIC technology **Cedip's** new **SILVER 450M** IR camera's 320 x 240 pixels format InSb detector delivers an outstanding 400 Hz full frame rate while maintaining extraordinary linearity and high sensitivity of typically 15 mK.

REPLY NOW for further information.

Cedip has recently completed the acquisition of **Polytech AB** (www.polytech.se) strengthening its portfolio of products for defence and security. Polytech AB has been focused on development and production of gimbal mounted platforms for airborne applications.

REPLY NOW for further information.

Cedip has announced a new generation of its popular JADE infrared camera family. Key advances in the fourth generation cameras include enhanced sensitivity (< 20mK), faster frame rate and a new windowing mode.

REPLY NOW for further information.

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