White Paper concerning Infra-red radiation

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Infra-red (IR) radiation

Infra-red is the electromagnetic (e-m) radiation that has wavelengths longer than the red part of the visible waveband. There are various ranges of the IR that encompasses the wavelengths of 0.7μm to 1000μm (1mm). Sir William Herschel discovered, in the 1800's, that the temperature shown by a thermometer steadily increased as he moved his thermometer across the visual region from the blue (0.4μm) to the red (0.7μm) and into the 'black' region beyond red. This is what we term the thermal, or IR, region. An interesting note is that approximately 50% of our Sun's output is in the IR. Beyond the IR lies microwave and radio e-m radiation.

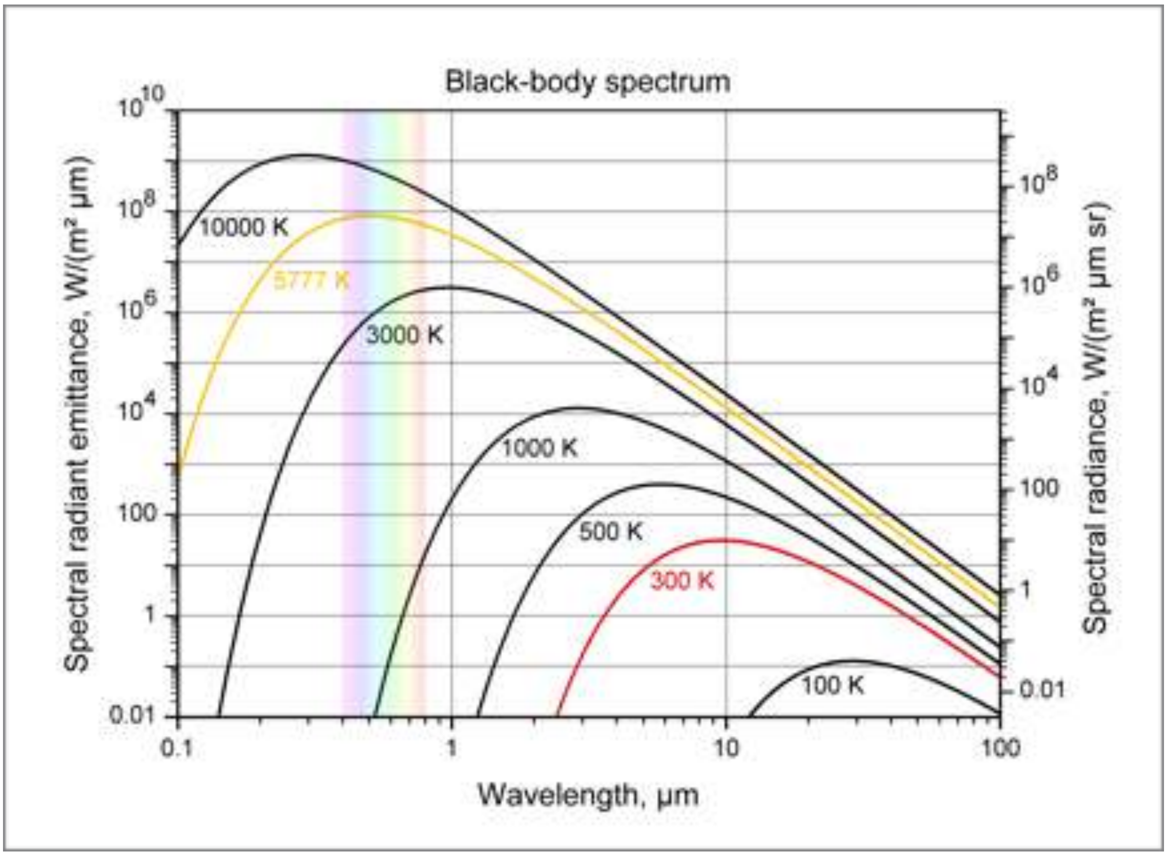

Figure 1. Black-body spectrum. Public Domain

Every object in the known universe emits e-m radiation, for example, the universe itself, stars, planets, and animal life, by the fact that they have there own temperature radiance. The level of this e-m radiation is classified as 'black-body' radiation that has a specific peak and bounding curve calculated by Planck's law. Figure 1 shows the bounding curves for temperature ranges from 100 K to 10000 K. As can be seen from this figure, the higher temperature the objects are at, the higher the e-m output, and conversely for the cooler objects the lower the peak and bounding the curve. The units for the black-body output is the Spectral Radiant Emittance, which is given in W/(m^2 μm), or the Spectral Radiance, which is given in W/(m^2 sr μm).

Planck's law is described by the following equation (1):

$$M_{\lambda}(T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}$$ Equation (1)

where:

M_{λ} denotes the Spectral Radiance,

T is the absolute temperature of the object,

k_B is the Boltzmann Constant,

h is the Planck Constant, and

c is the speed of light in the medium, vacuum or material.

Figure 1 has two curves, yellow and red, that represents the output from our Sun and from our planet Earth respectively. The representation of the visual waveband is shown by the spectrum that is centred near the peak of the Sun's black body curve. As humans, and other wildlife, have outputs similar to the 300 K curve, it is easy to determine that electro-optical equipment operating in the 8 to 12 μm waveband will clearly detect them by their

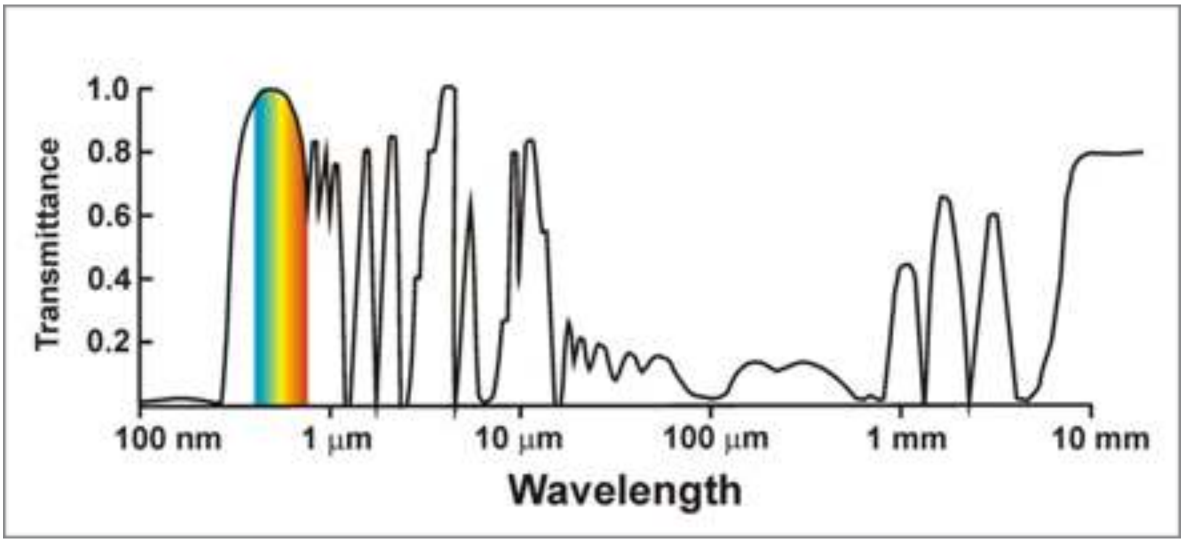

Figure 2. Atmospheric Transmission Public Domain

own radiance. This band is used for equipment that can detect bodies, for example, following a building collapse, or viewing heat loss from homes, and is termed a thermal camera.

The radiance is further modified by absorption by, for example, water in the atmosphere. Figure 2 shows the curve of the transmission of the atmosphere from 100nm to 10mm. The region from 100nm to 400nm is a portion of the ultra-violet waveband, the region from 400nm to 700nm is the visual waveband, the region from 700nm to 1mm is the infra-red waveband, with 1mm to 10mm the millimetric waveband, and radio waves beyond that. The area of interest in this white paper is the infra-red waveband, 700nm to 1mm.

The IR waveband is usually split into sub-bands as shown in the following Table 1:

Table 1: IR wavebands and typical uses.

IR band	Wavelength	Typical uses
Near infra-red (NIR)	0.7 to 1.4μm	Night vision goggles. Fibre optic telecommunication as the materials have low attenuation loss.
Short wave infra-red (SWIR)	1.4 to 3μm	Water absorption in free space. Long range telecommunication at 1.53 to 1.56μm using fibre optics.
Mid wave infra-red (MWIR)	3 to 8μm	Passive heat seeking missiles as the output from a jet engine plume is active. The temperature of the emitter is a little above human body temperature.
Long wave infra-red (LWIR)	8 to 15μm	The thermal imaging region that is used, for example, for body detection, heat loss from houses, and overheating transmission lines.
Far infra-red (FIR)	15 to 1000μm	Infrared astronomy to 750μm. THz imaging for the detection of weapons upon a person at an airport. Plastic explosive detection from a safe distance. Measuring the thermal tiling of,for example, re-entry tiles of returning spacecraft.

The transmission of the e-m radiation through the atmosphere is changed by various constituents, such as water, that absorb at various wavelengths. The atmospheric window for the e-m radiation is shown in Figure 2. This figure shows that the transmission intensity is significantly attenuated in the IR wavebands but with areas of transmission, for example, in the near IR, Mid wave IR, Long wave IR, and a small window in the Far IR. The atmosphere is transparent to e-m radiation beyond 10mm. However, it should be noted that long wavelength radio waves (15m and out to beyond 20km) are blocked by the atmosphere.

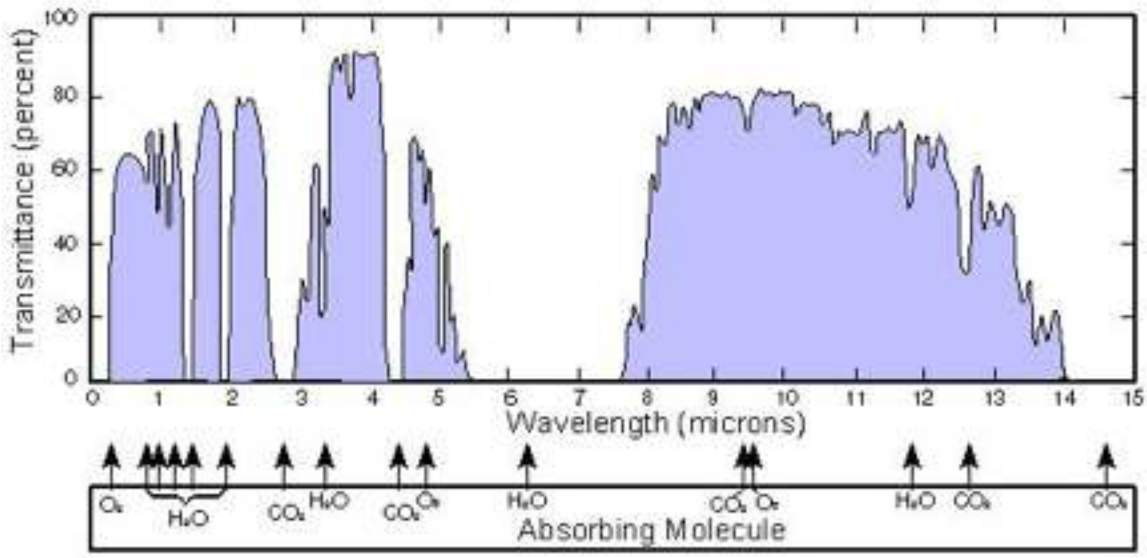

Figure 3. Transmittance and Absorbing molecule. Public Domain

Figure 3 shows the transmission peaks in the IR wavebands from visual to 15μm and the absorbing molecules. The primary absorbers are: H_2O (water), CO_2 (carbon dioxide), O_3 (ozone), and O_2 (oxygen).

- **Near IR (NIR)**

The NIR waveband (0.7 to 1.4μm) has varying transmission given the water absorption peaks. This transmission varies from about 50 to 75% before the blocking at about 1.4μm. Many types of glass are available for the manufacture of, for example, lenses, prisms, windows, fibre-optics, and bespoke electro-optical systems. Suppliers of suitable glass include, Schott, Ohara, Hoya, and other Russian and Chinese manufacturers. Knight Optical supplies various components as stock items and can readily supply bespoke systems to your design. Knight Optical can design and supply fully assembled optical systems, or special elements, to your specification.

- **Short wave IR (SWIR)**

The SWIR waveband (1.4 to 3μm) has two transmission pass band peaks at about 1.6μm and 2.1μm. The transmission at both these peaks is about 80%. The SWIR can use a few of the standard optical glasses and other ones, such as, Calcium Fluoride, Magnesium Fluoride, Silicon, Germanium, Zinc Sulphide, Zinc Selenide, and Sapphire. Knight Optical can supply various optical components, for example, lenses, prisms, and windows made with the various materials stated before.

- **Mid wave IR (MWIR)**

The MWIR waveband (3 to 8μm) also has two primary peaks at about 3.8μm and 4.5μm. The 3.8μm peak has a transmission of about 90% whilst the 4.5μm peak is about 60%. The MWIR waveband has less materials to design with than the standard glass materials. This arises primarily from absorption peaks of the materials that the glass is made from. Consequently, the available glasses are melted from various exotic materials such as Zinc Selenide, Zinc Sulphide, KRS5 (Thalium Bromo-Iodide), Calcium Fluoride, and Barium Fluoride. Knight Optical can supply optical components made from these materials, such as, lenses, prisms, and windows. These components can be stock items or bespoke systems to your, Knight Optical's design.

- **Long wave IR (LWIR)**

The LWIR waveband (8 to 15μm) has a broad peak with several absorption lines. However, the bandwidth peaks at about 80% and is broad with transmission across the majority of the band. This band is also termed the thermal waveband as most living things have a radiance that peaks within this range. The components that Knight Optical can supply in this waveband is limited by the materials available and any design constraints. Typical materials include, Germanium, Zinc Selenide, Zinc Sulphide, and KRS5, with typical components that include, lenses, prisms, and windows.

- **Far IR (FIR), which includes the THz waveband**

The FIR waveband (15 to 1000μm) is primarily a desert with very little radiance at the Earth's surface. However, the waveband is exploited at high altitude, and in space, where there is little atmospheric attenuation, for astronomy. The objects for detection at this waveband are 'cold' sources in our Galaxy and our Universe that were not seen before with ground based telescopes. The THz wave technology covers from about 300μm to 1000μm. The technology using THz waves enables you , for example, to 'see' beneath the clothes of passengers thus enabling staff at airports to determine if that passenger has hidden weapons upon them. Uses are being found for the medical area amongst, for example, further 'new' technology at this waveband. The FIR and THz waveband is a new area that Knight Optical is exploiting by supplying prism, windows, and lenses.

The IR radiation can be considered as the thermal, or heat, waveband. It should be noted that all electromagnetic waves will heat a surface that absorbs it, which means that the absorber will become warmer. Thermal radiation will transmit through a vacuum, whereas heat transmitted by thermal conduction, or convection, cannot. Thermal radiation is spread over many wavelengths, for example, room temperature objects usually cover the 8 to 25μm waveband. Thermal radiation can be emitted from objects at any wavelength that depends on the objects absolute temperature.

Infra-red is extensively used for many varied areas, such as:

1. Heating

   Infra-red heating is used for, for example, removing the ice from the leading edges of wings. It can be used for saunas to warm the occupants, where they have chronic health problems, such as, congestive heart failure, arthritis, and other high blood pressure, provided some benefit. Heat lamps are available for, for example, rheumatoid arthritis warming for some relief of the pain.

2. Astronomy

   Infra-red astronomy began in the 1830's shortly after William Herschel discovered IR in the 1800's. Infra-red astronomy uses the wavebands from 0.75 to 300μm. As water absorbs a large amount of the required bandwidth, the major telescopes are sited on the highest mountains, such as Mauna Kea, several aircraft have been utilised, and in space with various orbits about the earth and sun. The 20th century have made many observations to confirm the use of infra-red for astronomy purposes by finding sources of IR other than the moon and sun. The Herschel Space Observatory (HSO) was launched in May 2009, and died in 2013 following the use of all its helium used to cool the focal pane detectors and scientific instruments. The Observatory used a 3.5m diameter mirror to provide the best view of the Universe at far-infrared and sub-millimetre wavelengths. The HSO had three primary instruments systems, namely: Photodetector Array Camera and Spectrometer (PACS), the Spectral and Photometric Imaging Receiver (SPIRe), and the Heterodyne Instrument for the Far Infrared (HIFI).

   PACS was a camera with low to medium-resolution spectrometer for the infra-red up to 205μm. It used, as the detectors, two bolometric arrays within the camera and two photoconductor arrays for the spectrometer. Figure 4 is a composite image from

Figure 4. Infra-Red image of the Rosette Nebula, a nursery of young stars. The three colours represent: 70μm (blue), 160μm (green), and 250μm (red) from the PACS instruments.

PACS of the young stars in the Rosette Nebula at 70μm, 160μm, and 250μm. SPIRe was another camera system that also had a low to medium-resolution spectrometer for wavelengths longer than 200μm, which means that it continues the spectrometer work of PACS to longer wavelengths. The system uses five detector arrays in the following configuration. Three to take images of infrared sources in three different wavelengths and two to analyse the longer infra-red light that was emitted by a source.

HIFI was a very high resolution spectrometer for obtaining information concerning the chemical composition, kinematics, and physical environment of the infrared objects,

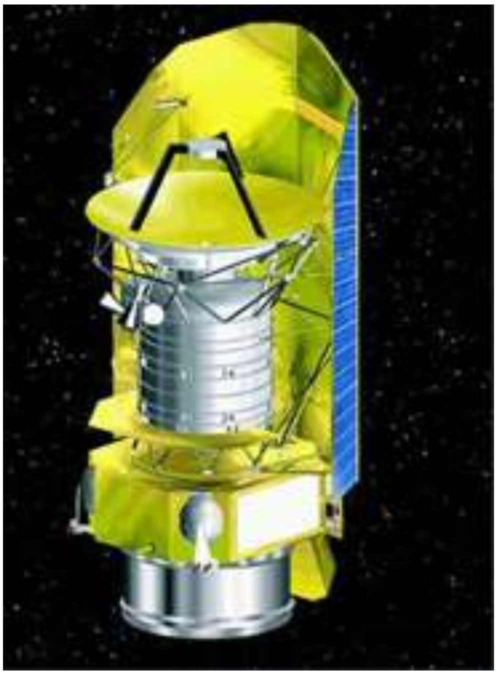

Figure 5. Image of the Herschel Space Observatory. © NASA Public Domain

Figure 5 is an image of the Herschel Space Observatory that had the largest mirror, at 3.5m in diameter, put into orbit. Modern Infrared astronomy is able to observe sources in the Universe that have been red-shifted from the high energy e-m radiation, such as Ultra-violet (UV) and visible wavelengths to the IR wavebands. This allows for more detailed knowledge to be obtained on the present Universe and how objects, and elements, are formed.

3. Night vision

The use of night vision enhancement devices, such as image intensifiers, allow the observation scene to remain in the dark but appear bright enough to see the object. This is done by making use of the reduced number of photons in the NIR and amplifying them by, for example, converting the incoming photons to photo-electrons, amplifying the photo-electrons by using a micro-channel plate, and converting them back into photons for the observer to see the scene much amplified without

Figure 6. Soldiers seen through a Night Vision Device. © DoD Public Domain

illuminating the scene by artificial light, such as a torch or laser illuminator. Figure 6 is a view taken through an Night Vision Device (NVD). The green image is the result of the multiplied photo-electrons being converted back to visible light. A phosphor does this conversion and is green as the dark adapted eye is more sensitive to the blue-green part of the spectrum. Also, colour blind people can see the green but not the red part of the visual spectrum. Figure 7 shows a NVD mounted on the helmet of a US pilot who is adjusting it prior to his flight.

Figure 7 US pilot adjusts his Night Vision Device before flying. ©DoD Public Domain

4. Hyper-spectral imaging

Hyper-spectral imaging aims to get the e-m spectrum of a point (pixel) that forms the image of the scene. The purpose of this type of imaging is to find objects, such as tanks, identifying the materials of the scene, or detecting what is happening. The way to accomplish the need of spectral and spatial processes in one 'image' is to consider the requirement as a cube. The cube contains an x-y view of, for example, a landscape from space with the third axis, the z-axis, as containing similar images of the landscape but at a slightly different wavelength from the first image. The imaging continues for different wavelengths, from, for example, UV to Far IR, and this builds up a cube of data. It is known that different minerals have different 'signatures' and thus the scene can be analysed to detect hidden tanks, finding oil, or finding certain mineral deposits. This method is very effective at locating the target.

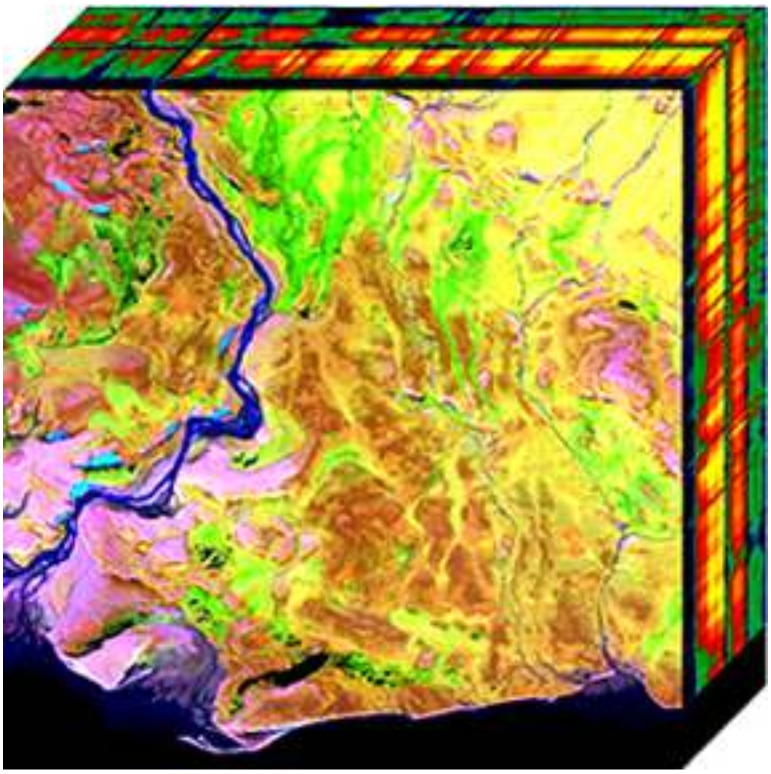

Figure 8. Hyper-spectral cube. ©NASA Public Domain

Figure 8 shows how each monochromatic image is stacked along the z-axis to form a cube of data. The x and y axis represent the distance on the ground of the image at a monochromatic wavelength. As each image at a different wavelength is added to the cube a file of image and wavelength is built up for subsequent processing.

5. Spectroscopy

Spectroscopy is a method for the measurement of e-m radiation intensity as a function of wavelength. Energy that is absorbed by, for example, a dye of a material, will show as a line in the spectrum of e-m radiation. This line will be at certain wavelengths that depend upon the transmission, or reflection, characteristics of the dye. Figure 9 is a typical spectrum of white light using a dispersion prism.

Figure 9. White light analysis by dispersion using a prism. Public Domain

Near infra-red spectroscopy uses the 0.8 to 2.5μm wavelength range and is typically used for medical diagnostics, such as neurology, blood sugar, and pulse oximetry. Fourier Transform Infra-Red spectroscopy (FTIR) is a way to obtain an infra-red spectrum of absorption, emission, photoconductivity, or Raman scattering of a solid, liquid, or gas. The FTIR collects spectral data simultaneously over a wide spectral range. The Fourier transform of the raw data gives the output of the absorption lines simultaneously and is making the dispersive spectroscope redundant.

6. Far infrared imaging, including T waves (Terahertz imaging)

   The UK's James Clerk Maxwell Telescope (JCMT) is the largest telescope that operates in the far-infrared to millimetre wavebands and is located at the Mauna Kea Observatory in Hawaii. The primary mirror is 15m in diameter.

   The far infra-red radiation is used for saunas where the person will get warm, but the emitter will feel cold, as will the air. As neither will get hot they are therefore safe to be used by vulnerable people, such as the disabled.

Conclusion.

The foregoing paper briefly discussions the Infra-Red section of the electromagnetic spectrum, 0.7μm to 1000μm. The bandwidth is used for various products, ranging from, for example, optical fibre telecommunications, thermal detection, and night vision equipment. New areas are being exploited, such as the 'desert' region 15 to 1000μm, for example, that is used to scan people for concealed weapons. Further advances will be made in the coming years and Knight Optical will be here to assist you with your optical needs, such as, lenses, prisms, windows, and bespoke electro-optical systems.