VIGO PHOTONICS

Infrared Detectors

For Space Application

Several projects led by space agencies were built to expand our ability to observe many phenomena in space. Those projects are not limited only to the earth's surface and earth's atmosphere which have a direct impact on human beings and the environment. Those are also extended farther away to observe nebulae, young stars, gas and dust in other galaxies, planets, and active galactic nuclei which need much effort to collect the data.

The techniques of infrared astronomy make it possible to investigate many astronomical phenomena. The character of the near-infrared spectrum is dust transparent so it is able to see cool stars and other celestial objects. In far-infrared, the emission of the dust itself becomes observable. Relatively cold objects also emit most strongly in the infrared spectrum. Many gaseous molecules are readily visible in the infrared range which have their unique ways of rotation and vibration. Thus, many infrared spectroscopy from space or near space with high altitude aircraft or remote objects, and also earth-based and earth-orbiting telescopes have been included in many space missions.

Different astronomical phenomena in the infrared range correspond with different methods of observation and require specific detection. VIGO Photonics is an expert in providing infrared (IR) detectors and detector arrays from the short-wave infrared (SWIR) to long-wave infrared (LWIR) that support the space application. This paper describes some examples of the application of infrared detectors for space missions and the way to choose the best detectors provided by VIGO Photonics that suit your space exploration.

NIR	0.7-1 µm	Star observing telescope
SWIR	1-3 µm	Characterizing the spectral features of ground formations, Environmental mapping
MWIR	3-6 µm	Tracking the thermal emission
LWIR	6-12 µm	Weather and climate monitoring from on-board satellites
VLWIR	12-30 µm	Weather and climate monitoring from on-board satellites
FIR	30-100 µm	Observing cold stellar objects in deep space

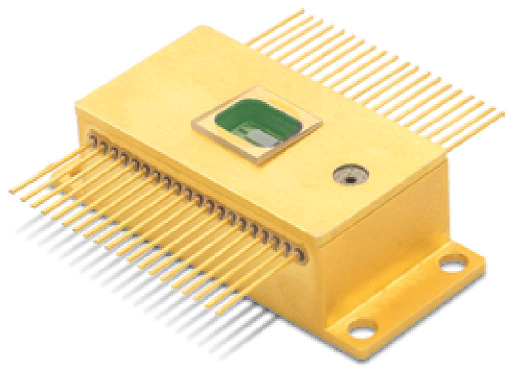
DETECTOR APPROPRIATE FOR SPACE APPLICATION

The detector appropriate for space application needs to have a wide spectral range with a small tolerance (+/- 1 µm) and the ability to enhance the optical signal. The detector also should pass several standard evaluations subjected to environmental screening, including thermal cycling, radiation, vacuum compatibility, burn-in, and vibration testing. Harsh environmental conditions in space by high-temperature fluctuations (-40°C to +85°C), shock, and vibration decrease the signal-to-noise ratio of the detectors. Thus, the detectors need to be cooled to give a stable measurement result at a high range of ambient temperature and have a low power operation. The detectors also need to have a short response time (< 6 s) for fast data acquisition and a long lifetime. To compromise with the small area of spacecraft and space satellites, the dimensions of the detectors also should be small and compact. Specifically for thermal sensing, the detector needs to be able to detect both cold and hot objects and be able to operate either sunlit or in shadow in a far distance.

The comparison of main materials of detectors offered by VIGO for space application:

	HgCdTe	InAs / InAsSb / InGaAs
FEATURES	• Can be operated in PC and PV mode	• Mostly operated in PV mode
+	• Best performance among all discovered materials • Tunable band-gap energy (2-30 μm) • High quantum efficiency in LWIR • Broad spectral range	• Higher stability and uniformity across large area wafers • Advance growth technology and manufacturability • Temperature stable up to 300 °C • Possibility of designing advanced structure as superlattices (SLs)
-	• High cost of wafer growth and processing • Less uniform across large area wafers	• Cut-off wavelength at 7 μm • Slightly worse performance than HgCdTe

The main challenge for IR detectors for space application is to compete with the size of photographic film. Array technology made it possible to use larger numbers of detectors in a compact size in space focal plane arrays. The detectors can be arranged as linear sensor arrays or two-dimensional sensor arrays. VIGO Photonics provides detector arrays in the customized mode which consist of multiple spectral ranges that are appropriate for space application.

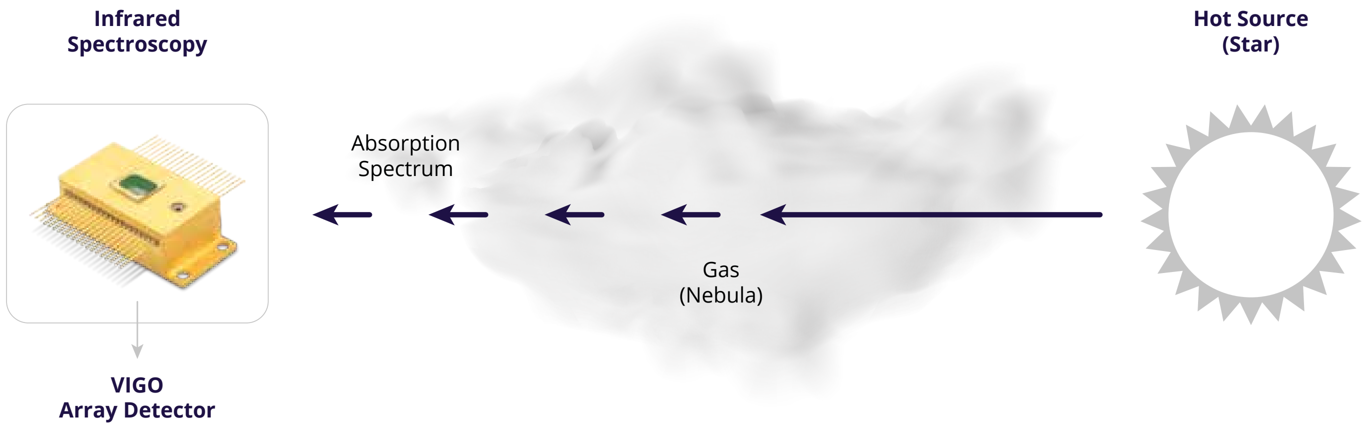


VIGO Detector Array Specification

Parameter	Value
Detector material	HgCdTe or InAsSb
Detector type	PV, PC
Operating wavelength	MWIR (3-6 μm), LWIR (6-12 μm); Can be optimized upon request
Pixel size	To be defined by the application; Minimum 25 μm sensor size
Pixel pattern	To be defined by the application; Array or bi-array; Minimum 20 μm between pixels; Maximum 6 mm array length
Enclosure/dimensions	TO8-16 pin, butterfly 40-pin
TEC type	2TE, 3TE
Active elements temperature	210 - 270 K
Temperature sensor	Thermistor or diode (accuracy up to +/- 1 K)
Cooler power	1-4 W
Time constant	1 ns - 500 ns
Window	Si/Al2O3/Ge with anti-reflection coating
Ambient temperature	0 to 70°C
Storage temperature, °C	-40 to 85°C
Detector array available with:	
TEC controller	Onboard analogue controller
Preamplifier	Ultralow noise, selectable bandwidth
DAQ	SPI or USB HS

Infrared (IR) Spectroscopy

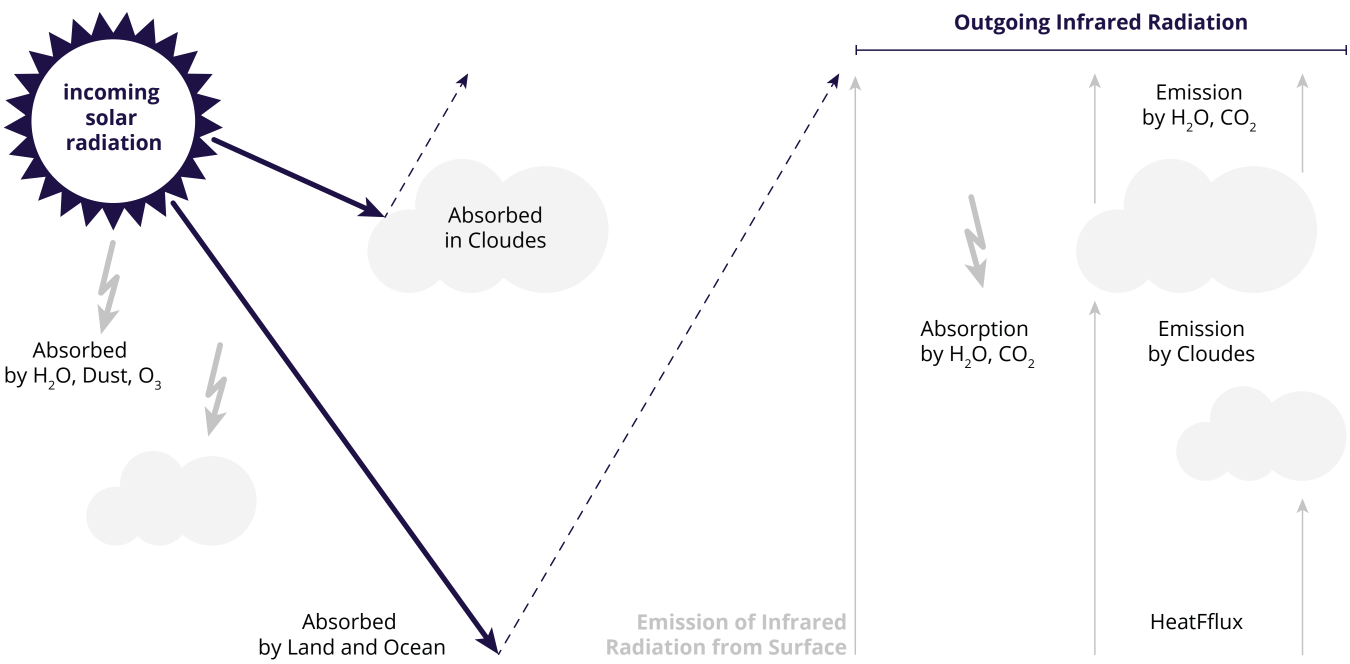
Spectrometers and imaging spectrometers are now flying in many spacecraft throughout the solar system, providing a wealth of new data that has led to many discoveries. Infrared spectroscopy is one of the spectroscopy techniques to measure the spectrum of infrared radiation that radiates from stars or other objects. The object is emitting broadband IR radiation which is passing through the space dust and other gasses. The light then finally is detected by infrared detectors to probe the characteristics of the source or the gasses depending on the spectral range and sensitivity of the detectors.

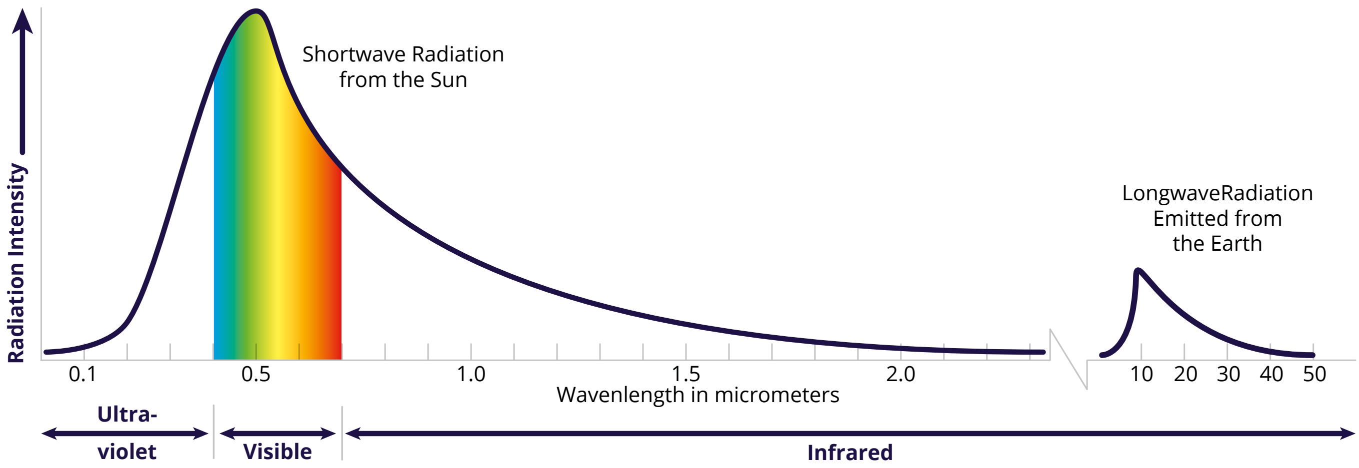


The infrared spectrum can provide many properties of the space objects, such as chemical composition, temperature, density, mass, distance, motion, luminosity, etc. The chemical composition can be obtained by probing the characteristic of vibrational and rotational modes of chemical bonds in molecules. Thus, the choice of detectors needs to be matched to the application and specifically to the molecular characteristics from the space objects under observation.

IR ABSORPTION SPECTROSCOPY

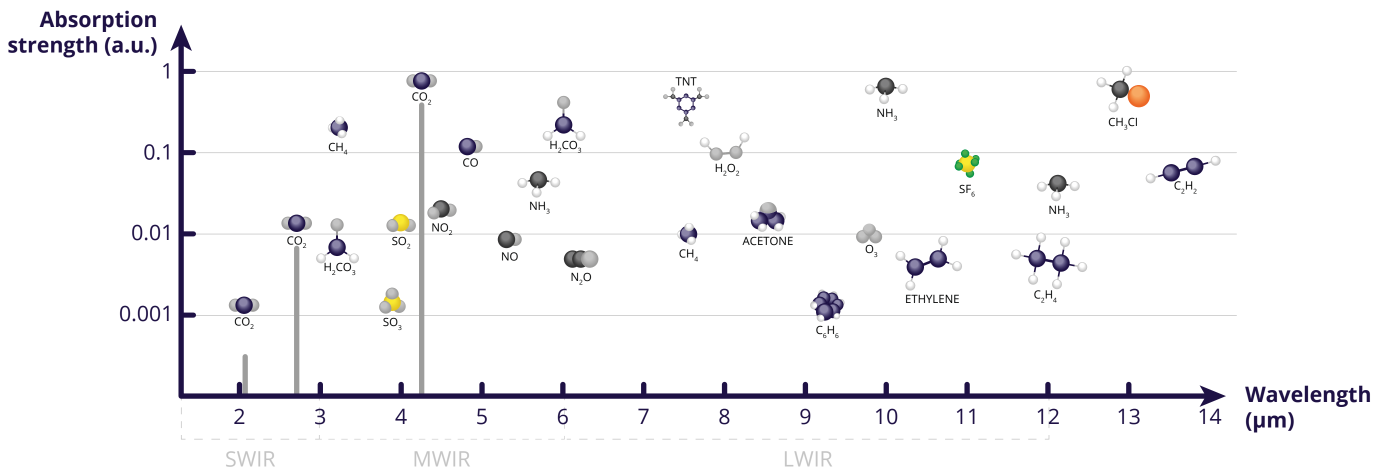
Approximately, 70% of the incoming solar radiation is absorbed by the earth's surface and atmosphere and re-emitted as thermal radiation primarily in the range of infrared radiation.





The atmosphere generally behaves as a selective absorber. Gasses absorb at some wavelengths and not others because of the energy gap between various vibrational and rotational states of the molecules. When radiation is absorbed, it is re-emitted in all directions where the amount of energy is dependent on the temperature and emissivity of the earth's surface, clouds, aerosols, and gasses. Outgoing infrared radiation is attenuated by atmospheric gasses, such as CO_2, H_2O, and O_3.

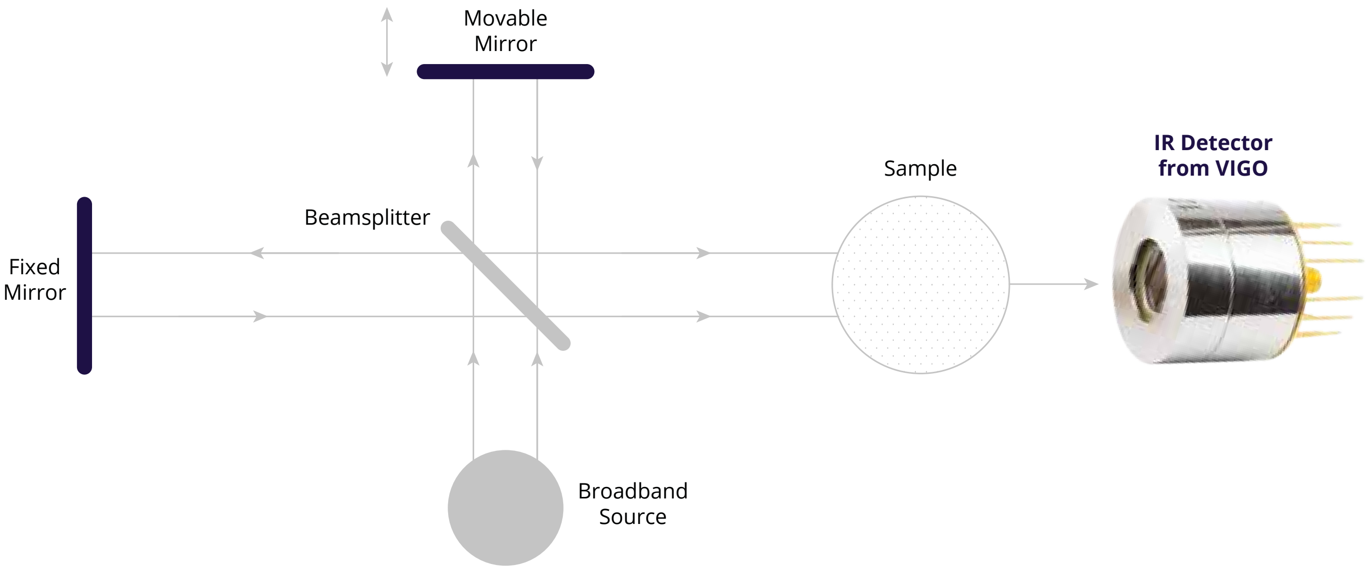
The attenuation of infrared radiation comes from the absorption of electromagnetic radiation by the atmospheric gasses in the IR spectral region. IR spectroscopy is a method to measure the absorption of an IR beam that has been passed through a sample. The position of the absorption peaks in an IR spectrum are characteristic of the chemical composition and the intensity of an absorption peak is proportional to the concentration of the samples. The absorption spectrum of a molecule provides a unique "fingerprint" of the absorbances that can be used to deduce the chemical composition and concentrations of the atmospheric gasses.



The level of absorption by various gasses is described by Beer-Lambert law, it depends on the optical path of light to the gasses, concentration of the gasses, and absorption cross-section. The concentration of the gasses in the atmosphere has some lifetime and varies with the altitude from the earth's surface. For example, CO_2 has altitude ranges of about 10 to 100 km and H_2O has altitude ranges of about 10 to 80 km from the earth's surface. Thus, generally, the detection of IR radiation from the atmospheric gasses is done from space using satellites with variant altitudes. These satellites consist of various techniques of infrared spectroscopy and are used to predict the climate, weather, pollution and natural hazards on the planets. The benefit of detection in the MWIR and LWIR range is that many atmospheric gasses have an absorption spectrum in this range and it is possible to optimize the sensitivity of the detection specifically for each gasses. IR spectroscopy in satellites is also applied for outer space investigation to observe stars, planets, and other space objects. The observation from outer space is useful to not overlap the spectrum of the objects with the absorption spectrum of earth's atmospheric gasses.

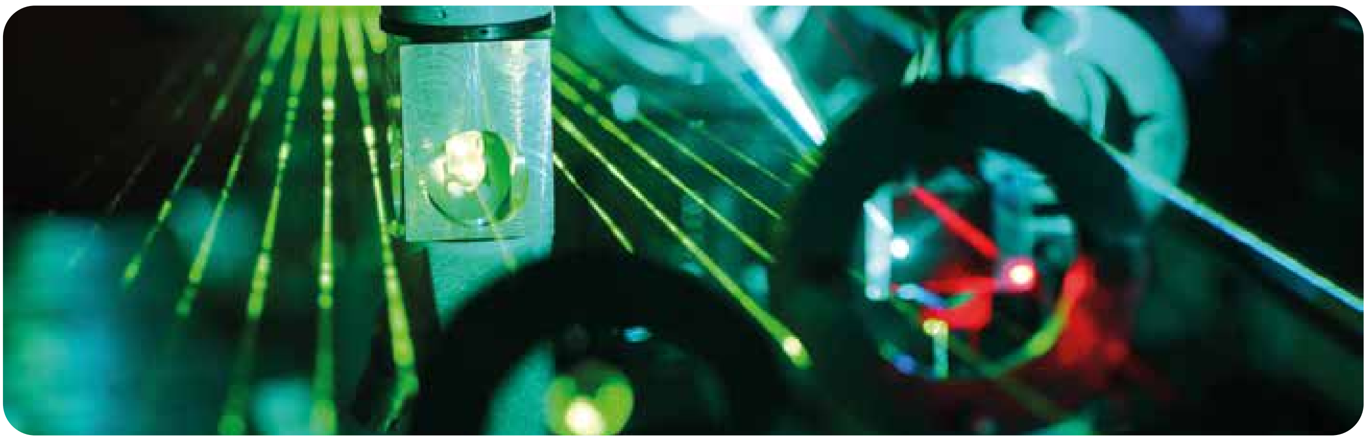
FOURIER-TRANSFORM INFRARED SPECTROSCOPY (FTIR SPECTROSCOPY)

Fourier-transform infrared (FTIR) spectroscopy has been successfully employed in space for various IR spectroscopy applications. Minerals, ices, liquids, and other materials have been detected and mapped from many planets and satellites where the surface can be observed from space.



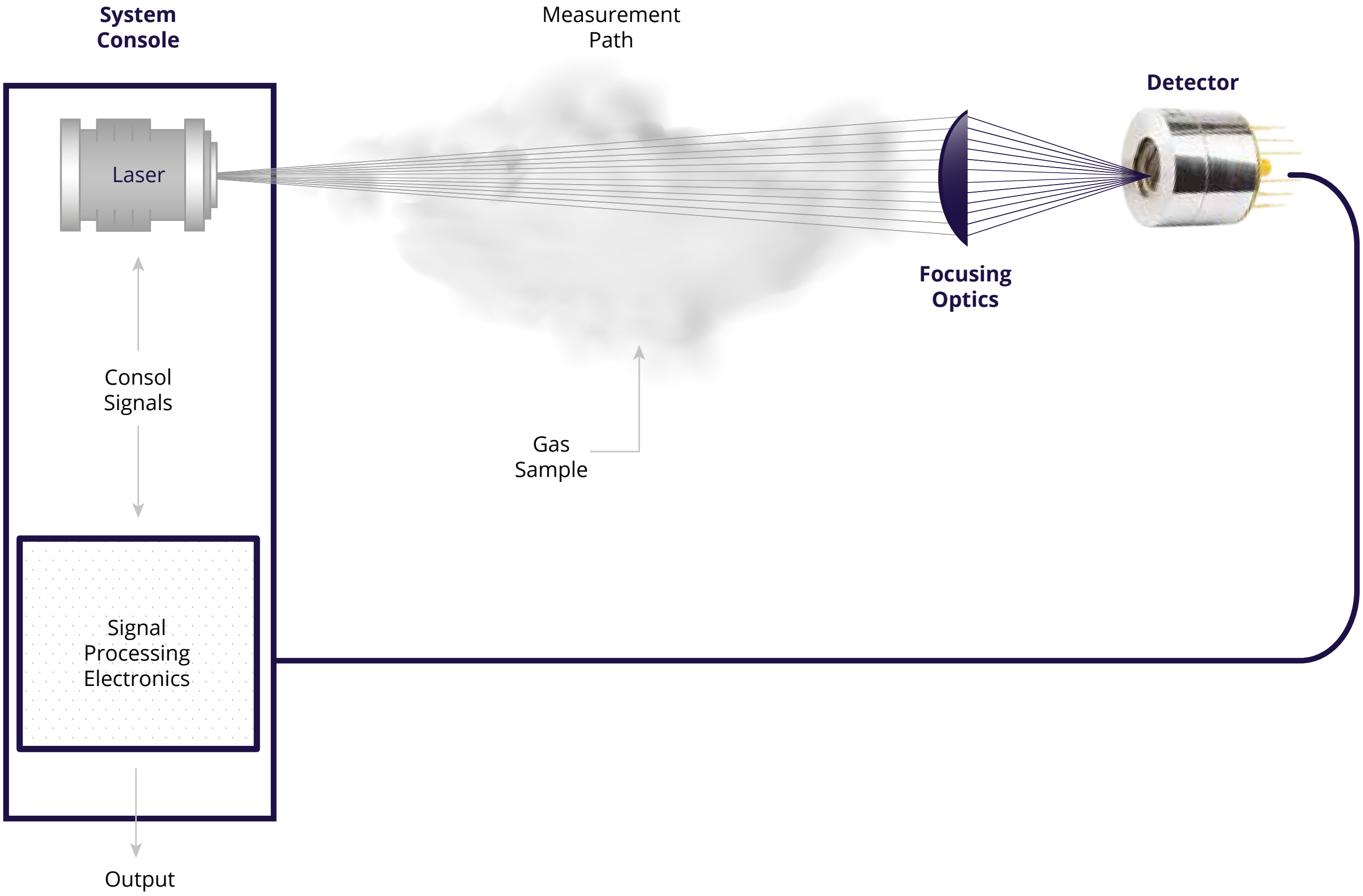
An FTIR spectrometer generates a spectrum by modulating the IR radiation in the time domain interference to produce an interferogram that is then subjected to a Fourier transform. Thus, the central component of an FTIR spectrometer is the Michelson interferometer. A beam of broadband radiation is directed on a semitransparent beam splitter. Half of the beam is reflected in a fixed mirror and the other half of the beam is transmitted to a moving mirror. The path difference, the different distances travelled by each beam, creates a phase difference between the beams. The two beams recombine at the beam splitter, travel through the sample, and are detected by the detector. The detected signal is proportional to the intensity of the interference beam. For imaging spectroscopy, the scanning parameter is the optical path difference (OPD) existing between two arms and the plot of intensity versus OPD in real space is the interferogram.

FTIR spectroscopy can provide fast measurements over a wide wavelength range. The waveband limitations of FTIR comes from the sensitivity of the detectors and the transmittance and reflectance of the optics. Thus, the option of IR detectors becomes a crucial part of FTIR spectroscopy. VIGO Photonics is an expert in providing detectors in MWIR and LWIR with high sensitivity and low noise performance which can detect many materials in space. FTIR spectroscopy also produces a good resolution, wavelength precision, and stability that can enhance the signal-to-noise ratio.



TUNABLE DIODE LASER (TDL) SPECTROSCOPY

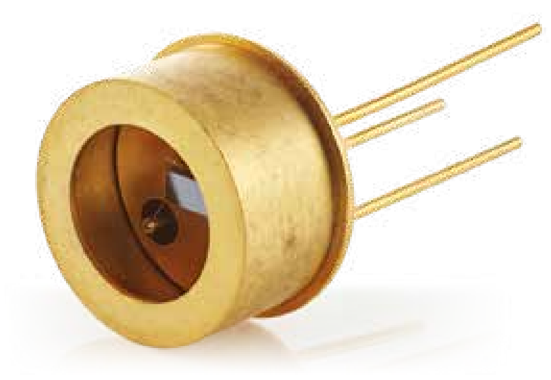
Tunable diode laser (TDL) spectroscopy enables sensing trace concentrations of many gases in many space applications. The technology has emerged from the laboratory to become reliable in space missions for continuously detecting and measuring small concentrations of selected gas analytes.



TDL spectroscopy has a tunable light source by the steering console with appropriate electronics to control and modulate the beam. The light source is commonly a quantum cascade laser (QCL). The laser wavelength is tuned to a particular absorption feature of the target gas molecule. The emitted light goes through the sample where part of the beam is absorbed and attenuated by the analyzed gasses. Then, the light is passed through an objective and focused on the detector. TDL is built with a specific design wavelength chosen to optimize the sensitivity to a particular target gas and free of interfering absorption from other molecules. The tuned laser is exploited to rapidly and repeatedly scan the wavelength across the selected gas absorption line and VIGO detector is used to detect the absorption spectrum of atmospheric gasses in LWIR and MWIR range with fast response and high sensitivity. After going through some electronic processing, the signal is ready to be interpreted.

DETECTORS WITH ANTI-FRINGING TECHNOLOGY

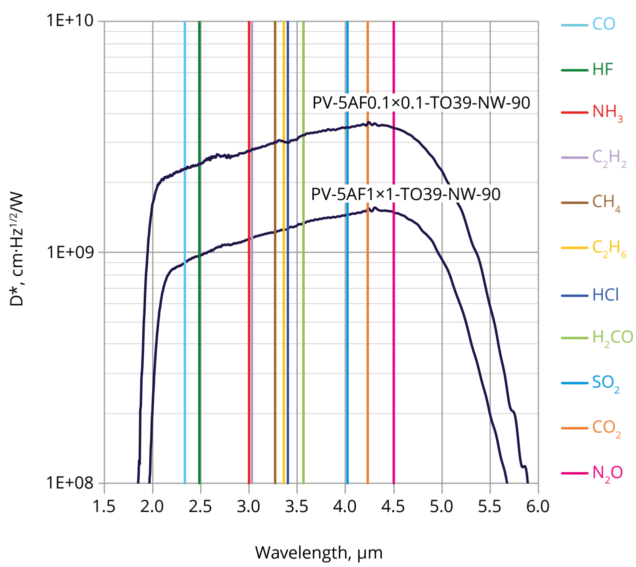
Detectivity of various spectroscopy techniques is usually severely limited by the presence of optical fringing effects (etalon effects). Optical fringing is a result of the interference of reflected or scattered radiation on the optical elements like a Febry-Perot etalon such as mirror, lenses, optical fibre end faces, components of multiple cells, detector and laser package windows and semiconductor structure surfaces. The optical fringing can be determined as the local signal amplitude to its mean value ratio:



$$F = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

In VIGO Photonics detectors, optical fringing effects are mainly generated in GaAs substrate due to its high refractive index (n = 3.3). Fringing significantly increases for the wavelengths above the λ_{peak} in which the detectors are optimized. To overcome this problem, VIGO Photonics introduced a solution called Anti-fringing Technology. VIGO modifies and specially processes the detector structure so that the fringing effects decrease 10-40 times smaller than the standard IR detectors.

Sample of spectral response for PV-5 with anti-fringing solution (Ta = 20°C)



VIGO PHOTONICS WITH NASA FOR MARS SCIENCE LABORATORY MISSION-CURIOSITY ROVER

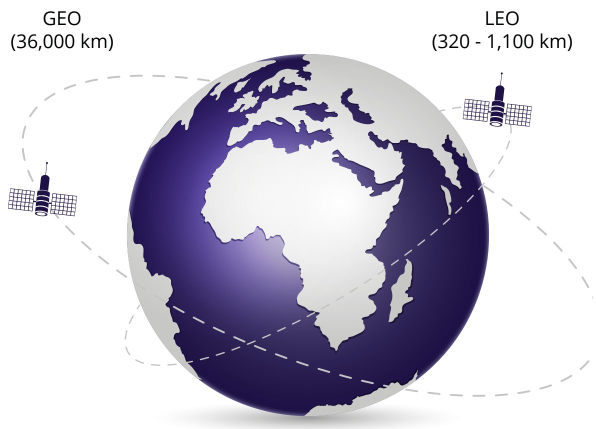
In 2012, the Curiosity rover from NASA was successfully landing on the red planet for the Mars Science Laboratory Mission. The purpose of the mission was to measure the concentration of methane, carbon dioxide, and water vapour from heated samples taken from the Martian surface. Thus, the curiosity rover was built as a TDL spectroscopy with a cascade laser and cooperates with infrared detectors manufactured by VIGO Photonics.

Infrared Satellites

Infrared satellites consist of spectroscopy and sometimes with telescope systems which have many applications both for earth or outer space observation. For earth observing systems, satellites are very effective in providing wide coverage because of the high position above the planet. By gathering the data at multiple wavelengths, we gain a more complete picture of the state of the planet's surface and atmosphere. Thanks to the technology we can observe climate variability and change, atmospheric composition, carbon cycle and ecosystems, water cycle, weather, and natural hazards. While for the outer space observation, it can provide a more clear image without interfering with the absorption spectrum from earth's atmospheric gasses.

For earth observation, infrared satellites detect heat energy in the infrared range from the earth and atmosphere. The satellite image displays objects, such as: clouds, water, and land surface, based on the temperature of the object. So, the image of the object can be obtained day and night, since it is independent of sunlight. The altitude of the object is in the function of their temperature since the temperature in general decreases with increasing height.

One application of infrared satellites is weather satellites which differentiate by height, it is geostationary (GEO) satellite - earth-orbiting 36,000 km from the earth and low earth orbit (LEO) satellite - earth-orbiting up to 1,100 km. GEOS satellites orbit in the equatorial plane at the same rate as the earth's spins, thus maintaining a constant position over one location on earth. The satellites provide constant coverage of their view of weather conditions with updates every minute. LEO satellites are typically in an orbit that is sun-synchronous and in the distance of 750 km from the earth. The satellites get two views per day of the entire earth. Each view has the same solar illumination so that day-to-day changes can be compared.

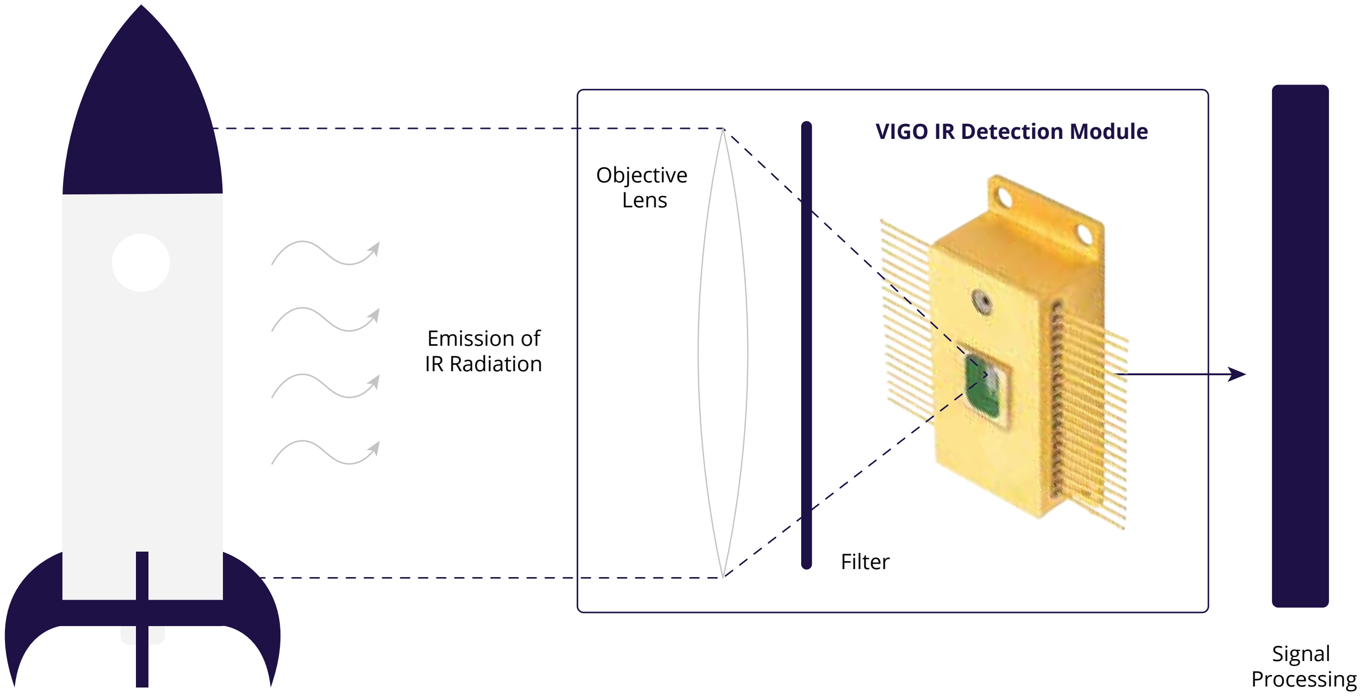


Our recommendation of VIGO Photonics detectors for atmospheric gas sensing

VIGO detector for atmospheric sensing	Gaseous species	Absorption peak (µm)	Recommendation	Description
MCT photovoltaic (PV) or InAs/InAsSb photovoltaic (PVA) or MCT photoconductor (PC) detectors with immersion lens technology (PVI/PVIA/PCI) and multiple stage thermoelectric cooling (2TE/3TE/4TE) that optimized for absorption peak of the specific gases	**H_2O**	2.7	PV-5-AF	MCT-PV detector with anti-fringing technology for MWIR
		6.2		
	CO_2	4.3		
		9.4	LabM-I-4/5/6/10.6	Programmable MCT-PV detection module for MWIR and LWIR
	CO	4.75		
	CH_4	3.25		
		7.66		
	NO	2.67	MicroM-10.6	Micro-size detection module optimized for LWIR
		5.24		
	N_2O	2.86		
		4.5		
		7.78	4EF-5	Four-channel InAsSb detection module with spectral filter for specific gases
	NO_2	3.46		
		6.17		

Infrared Thermal Sensors

IR thermal sensors work by converting the emitted thermal radiation of an object into electrical signals expressed as voltages or currents, which is proportional to the infrared energy emitted by the object. Thermal sensors detect the thermal radiation emitted by the object and compare the thermal energy either with the background temperature or internal temperature reference. The performance of thermal sensors are described by the temperature resolution which is the ability of the sensors to differentiate small temperature differences of the object. The temperature resolution of current sensors can reach 0.1°C which corresponds directly with the detectivity of the detector. Additionally, thermal sensors are also able to detect the emission of thermal radiation during the day or night.



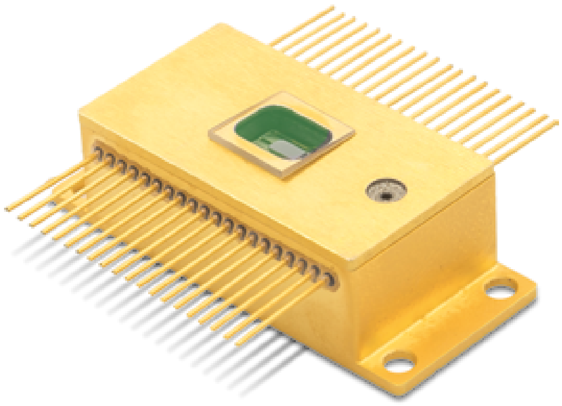
Thermal sensors have the ability to measure a moving object and give more details by pointing to different spots on the object. IR sensors can be used to detect motion by measuring the fluctuation in temperature in the field of view (FOV). Naturally, the thermal sensor has a large FOV to ensure enough energy reaches the detector. Thermal sensors have several applications for space application, such as ground-based remote sensors, space and ground-based telescopes, attitude determination of space objects, monitoring space system from overheating, forest fires and volcano activities observation, and environmental mapping.

The essential design of the thermal sensor consists of an objective lens to focus the infrared thermal radiation on the photosensitive element of the infrared detectors. The thermal radiation emitted by the object is converted by the thermal sensor to different colours corresponding to different temperatures of the measured objects.

Compared to visible radiation, thermal radiation has longer wavelengths so it minimizes atmospheric scattering. A high level of thermal radiation is observed in the wavelength of beyond 8 μm (LWIR to VLWIR range). However, the bands also contain a high level of earth-limb background and off-axis radiation from the earth. Thus, MWIR sensors are employed. Even though the MWIR band has a lower thermal signature, the earth-limb and off-axis earth-radiation components of the background are also significantly lower. Therefore, based on background-noise-limited performance, the MWIR sensors offer sensitivity performance levels comparable to those of the LWIR. Moreover, MWIR operation provides the inherent advantage of the improved diffraction-limited resolution.

Our recommendation of VIGO Photonics detectors for thermal sensors in space

To cover a wider view of observation and to create a more compact sensor, the thermal sensor can be built as linear arrays which consist of pixels lined up in a row or two-dimensional sensor arrays. Linear arrays require a scanning mirror or an along-track scanner to sweep the spatially extended object. VIGO Photonics offer 32-channel detection modules with MCT photovoltaic detector optimized for MWIR integrated with transimpedance preamplifier.



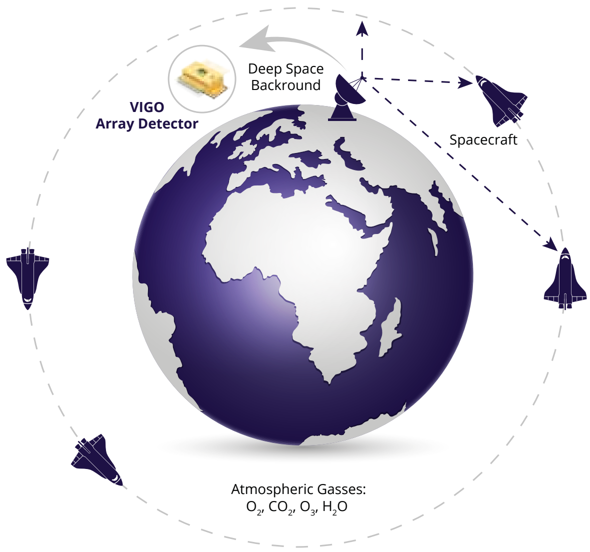
Detector type	32EM-5
Active element materials	epitaxial HgCdTe heterostructure
Number of elements	1x32 linear array
Active area of single element, mm x mm	0.125x1
Distance between active elements (μm)	25
Window	pAl_2O_3AR
Acceptance angle	70°
Working temperature (°C)	10 to 30
Spectral range (μm)	2 to 5
Detectivity (cm×$Hz^{1/2}$/W)	~1E+9
Voltage responsivity (V/W)	~1E+4
Working frequency (kHz),	DC to 400
Output voltage (V)	-1
Output impedance (Ω)	50
Power supply voltage (V)	+5

GROUND-BASED REMOTE SENSOR

The aircraft can maintain operation in space for several months and can then return to the earth's atmosphere. During that mission, it is essential to track the vehicle's trajectory and flight behaviour. The application of ground-based remote sensing detectors has become an important method of accessing the information on trajectories, positions and flight conditions in space technology.

Thermal infrared (TIR) remote sensing technology is widely used for monitoring the background environment and the real targets.

During the flight, the air around the aircraft is heated to an extremely high temperature. Under this condition, there are two TIR radiation sources: hot air components and gaseous products from dissociation, ionization, and recombination chemical reactions, and the aircraft surfaces. For the air around the aircraft, the flows are hypersonic and in chemical and thermal nonequilibrium due to the drastic environmental changes. For the vehicle surface, the wall temperature depends on the aero-heating, structure heat condition, radiation, and so on.



These TIR radiations can be received by an IR detection system after being attenuated by passing the earth's atmosphere. Thus the flight path of the aircraft and altitude-varying thermal and chemical properties can be monitored.

VIGO PHOTONICS WITH ESA FOR EXOMARS MISSION - SCHIAPARELLI LANDER

The Schiaparelli module or landing demonstrator will examine meteorological conditions during the planetary landing and will test a number of technological innovations to be used in future interplanetary missions by ESA. One part is a test of the ablative shield which protects against high temperature during passing through the planet's atmosphere and rocket engine braking technology. So, the lander is expected to prove the feasibility of landing with controlled orientation and touchdown speed. VIGO Photonics detectors were used for the ICOTOM radiometer embedded in the Comars+ system for measuring the heat in the outer shell of the lander during planet atmospheric entry.

LIGO-NOBEL WINNING PROJECT

The gravitational wave measurements consist of two detectors with a separation of 3,000 km apart which provides isolation from unwanted interference by earthquakes, human activities, etc. Each of the gravitational wave detectors consists of a Michelson interferometer whose each arm has a 4 km in length. By the reflection in those tubes, light travels a total of 1,120 km before reaching the detector. By the distances, it is possible to measure minute strains of space-time on the order of 1E-21.

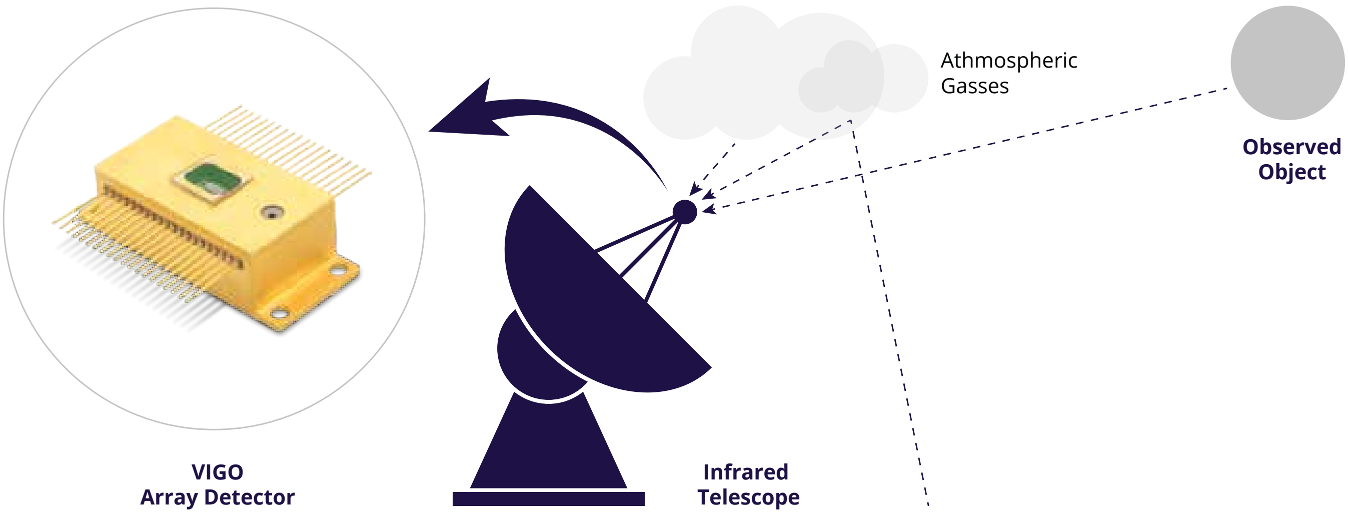
The mirrors in the interferometers are the best-polished mirrors in the world with 40 kg weight and suspended on thin glass fibres. The laser used to measure gravitational waves has the power of nearly 1 MW. Such great optical power leads to the heating of the mirrors and results in the deformation of the mirrors. To avoid this problem, the temperature of mirrors need to be monitored continuously using VIGO Photonics detectors. VIGO Photonics detectors are essential components of thermal compensating systems. These active compensation systems heat up the opposite parts of the mirrors and compensate for the losses caused by the laser.

Infrared Telescope

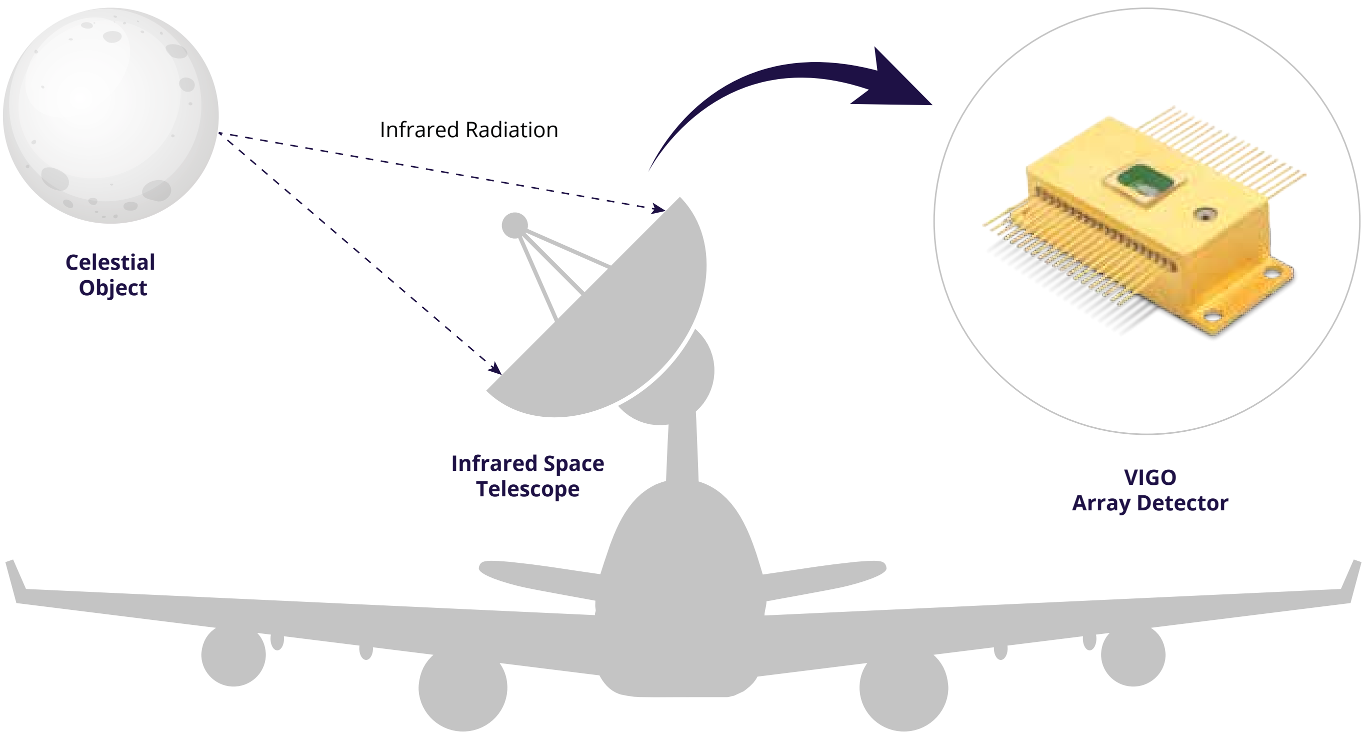
An infrared telescope is a telescope that uses infrared light to detect celestial objects. Any objects in space surrounded by dust are not visible by optical telescopes but are observable by infrared light since infrared can penetrate thick dust. Infrared telescopes may be ground-based, airborne, or space telescopes. They contain an infrared camera with infrared detectors which must be cooled. Additionally, they also can contain an interferometer for observing the spectrum of the objects.

Ground-based telescopes were the first to be used to observe outer space and provide information from spatially resolved temperature maps. However, this telescope has a limitation due to the absorption of infrared radiation by the water vapour in the earth's atmosphere. Thus, ground-based infrared telescopes need to be placed on high mountains and in very dry climates to improve visibility.

The presence of adaptive optics has improved the performance of ground-based telescopes. Adaptive optics is a technology that is able to compensate for the fast-changing optical distortions arising during the imaging process and reduce optical aberrations. The distortion comes from the turbulent nature of the atmosphere caused by e.g., the temperature fluctuations and wind conditions resulting in a blurring effect. Adaptive optics works by measuring the distortions in a wavefront and correcting those errors by a compensator such as a deformable mirror or liquid crystal array controller by computer. Thus, the resolution of the images is enhanced significantly by corrections from the adaptive optics in real-time.



The development of the space telescope opens the possibility to observe the solar system in distant and early Universe. Our solar system contains a population of dust particles, created by evaporating comets and colliding asteroids which are brightest at infrared wavelengths. However, the radiation of the infrared spectrum is absorbed by water vapour in the atmosphere, so telescopes have to be carried to high altitudes above most of the absorbing molecules to clearly see the spectrum of the solar system. By the space telescopes, there are many types of stars with different surface temperatures and other celestial objects can be observed in the infrared wavelength.

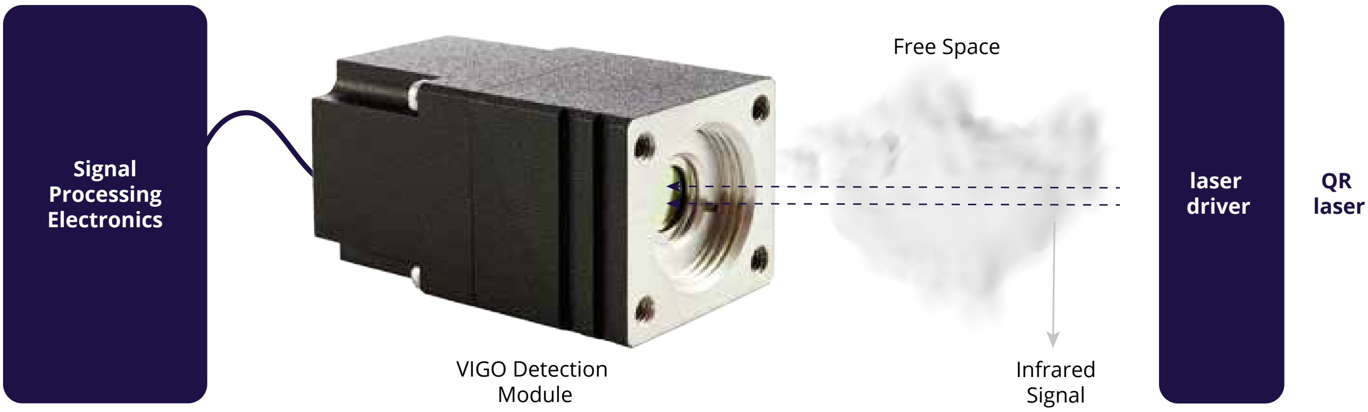


Many stars and space objects emit a lot of electromagnetic radiation in the short-IR range and it can pass through the thick space dust. For a longer IR range, the dust itself can be detected. VIGO Photonics detectors have a high sensitivity, wide linear range, and fast response in the range of MWIR and LWIR that are suitable for either ground-based or space telescopes. The application of some spectral bands in space observation using infrared telescopes and the recommendation of VIGO Photonics detectors:

Band (μm)	Application	VIGO detector
3.4	Stars and galaxies observation	MCT-PVI-3TE-3.4 InAs/InAsSb-PVIA-2TE-3
4.6	Thermal radiation detection from the internal heat sources of sub-stellar objects like brown dwarfs	MCT-PVI-2TE-5 InAs/InAsSb-PVA-2TE-4.5
12	Thermal radiation detection from asteroids	MCT-PCI-3TE-12 InAs/InAsSb T2SL-PCIAS-3TE-12

Free-space optics communication

Free space optics communication (FSO) uses infrared lasers to send data to and from space, then receive the data using an infrared detector. The advantage of FSO is the high-speed connections with energy efficiency, high levels of data transmission security, compact size, and low cost for installation and maintenance. However, the transmission efficiency is reduced due to several factors, such as rain, physical obstructions, temperature fluctuations, geometric losses, absorption, atmospheric turbulence, and atmosphere attenuation and scattering.



FSO link operating at wavelength 8-12 μm has more advantages because of less attenuation caused by aerosol particles and is also safe for eyesight. The main setup consists of quantum cascade (QC) lasers operating in the long-wave infrared radiation and highly sensitive MCT detectors in the type of photoconductive (PC) and photovoltaic (PV) that can be provided by VIGO Photonics.

Our recommendation of VIGO Photonics detectors for optics communication:

Detector type	Spectral range (μm)	Detectivity, D* (cm×Hz$^{1/2}$/W)
PVI-4TE-10.6	3-12	2E+9
PVMI-4TE-10.6	2-14	2.5E+9
PCI-4TE-12	1-13	2E+9
	Detection module	
SM-I-12	2-13	1.3E+9
UHSM-I-10.6	3-12	1E+9

CONTACT US

VIGOPHOTONICS.COM
INFO@VIGOPHOTONICS.COM

VIGO PHOTONICS