UPCOMING AND FUTURE MISSIONS IN THE AREA OF INFRARED ASTRONOMY: SPACECRAFT AND GROUND BASED OBSERVATIONS

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ABSTRACT

The IRIS instrument on the Voyager spacecrafts (Hanel et al., 1977) made major discoveries with regard to the giant planets, their moons and rings (Hanel et al., 1979a,b; Hanel et al., 1981, 1982; Hanel et al., 1986; Conrath et al., 1989) and paved the way for future infrared observations for planetary missions within our solar system. The CIRS instrument of Cassini with much greater spectral-spatial resolution and sensitivity than that provided by IRIS is now rapidly approaching the Saturnian system with orbit insertion on July 1, 2004, for which CIRS is expected to provide an order of magnitude advance beyond that provided by IRIS (Kunde et al., 2003). The Mars program is also presently dominated by infrared observations in the near to mid-infrared spectral bands for missions such as Mars Global Surveyor and its TES instrument and Odyssey with its THEMIS instrument. In the case of Earth science we have such missions as TIMED, which makes infrared observations of the thermosphere using the SABER instrument. With the newly formed New Frontiers Program we have the opportunity for $650M missions such as Kuiper Belt-Pluto Explorer and Jupiter Polar Orbiter with Probes. Under the Flagship line, once per decade, we have the opportunity for $1B missions for which Europa is presently being considered; for this mission infrared measurements could look for hot spots within the maze of cracks and faults on Europa's surface. On Kuiper Belt-Pluto there is an imaging near-IR spectrometer called LEISA. Another mission on the horizon is Titan Orbiter Aerorover Mission (TOAM) for which there is planned a state-of-art version of CIRS called TIRS on the orbiter that will map out the atmospheric composition with unprecedented wavelength coverage and spectral-spatial resolution. This instrument will also provide temperature maps of the surface of Titan to look for hot spots where life may form. On the same mission there will be a descent imager on the Aerorover (i.e., balloon) similar to that provided by LEISA on the Pluto mission to provide compositional-topographical maps of Titan's surface. Other future mission will also be discussed. Improved thermal detectors could have important applications in solar physics, specifically in the detection of far-IR synchrotron emission from energetic electrons in solar flares. For infrared astronomy we have missions like SIRTF and JWST, which will cover the spectral range from near-IR to far-IR in the search and probing of both new and old planetary systems in our galaxy and the measurement of the most distant galaxies of our universe. SIRTF is scheduled to be launched in August 2003, while JWST will be launched next decade. Another mission is TPF, which will use interferometer techniques at infrared wavelengths to search for planetary systems beyond 2010. With regard to ground based telescopes we have, for example, the twin 10 meter Keck telescopes and the IRTF telescope at Mauna Kea. The Keck telescopes are presently using interferometer techniques. Over the next several decades there are plans for 50 meter to 200 meter telescopes providing near-IR to far-IR measurements with the eventual plan to combine all telescopes using interferometer techniques to provide unprecedented spectral-spatial resolution and sensitivity.

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INTRODUCTION

We will review the future missions on the near horizon to those that will not occur until after 2013. These missions will fall under four major categories or sub-headings: 1.) Astrophysics, 2.) Planetary Science, 3.) Earth Science and 4.) Sun Earth Connection (SEC) or Living with a Star (LWS). The list is very comprehensive in the first three categories. It will become clear that there is a very bright but challenging future in the area of infrared astronomy from NIR to FIR wavelengths to as high as microwave wavelengths. In the area of astrophysics the primary mission over the next decade is the James Webb Space Telescope (JWST), which will be looking for distant galaxies of very high red-shifts so that visible emissions will be shifted to FIR wavelengths. Also, up to 50% of the radiated energy in the universe is in the infrared (John Mathers, private communication 2003). In the area of planetary sciences we have the Jupiter Icy Moons Orbiter (JIMO) mission, which is also called Prometheus. This is a technology demonstration mission using a space fission reactor. This mission will provide ~ 500 kg total instrument payload mass with total instrument power in excess of 10 kwatts. This mission favors large high power instrument concepts with the potential for major scientific breakthroughs using measurements at infrared wavelengths. With this amount of mass and power one can design infrared spectrometers using large focal plane arrays for high spatial resolution and cryogenic refrigeration systems that will cool detector arrays to mK temperatures and thus high spectral and spatial resolution. Heterodyne techniques will also probably be used. Although JIMO could indicate a new paradigm in the area of spacecraft instrumentation, cost constraints will not go away and there will always be pressures to make instruments lighter, smaller in volume and lower in power. At an international level funding and facilities development in the area of nanotechnology is growing at leaps and bounds and major advances in this area are expected over the next decade. In this same arena we see significant progress in the field called MEMS, which stands for Micro Electro-Mechanical System. Both areas provide the potential for miniature low power infrared spectrometers, which could be flown on miniature spacecraft and landers for future planetary missions. In the area of Earth science the future in infrared astronomy is very bright. Over the next decade major advances in instrument capability are expected in the Earth science arena. This includes the next generation of Landsat missions and the NPOESS missions, which will start demonstration mission NPP and main phase beginning around 2009. Finally, we will discuss missions in the SEC/LWS sector and future developments in the area of ground based telescopic missions using interferometer techniques.

FUTURE MISSIONS USING INFRARED REMOTE SENSING INSTRUMENTS

Astrophysical Infrared Missions

In Table 1 we summarize future astrophysical infrared missions. As an example of these we show the JWST spacecraft in Figure 1, which will use a seven meter telescope with radiative cooling to achieve detector temperatures ~ 35°K, but could achieve 6°K temperatures or lower using a refrigeration system (see Stockman and Mather, 1999). The SIRTF 85 cm Beryllium telescope will operate at T < 5°K, operate for wavelengths 3-180 μm and will study star formation, centers of galaxies, extrasolar planets and giant molecular clouds (see Gallagher et al., 2003). SOFIA will be the largest airborne observatory in the world using a Cassegrain System with 2.7 m telescope with wavelength coverage from 0.3 μm to 1.6 mm with main science goals of studying molecular clouds, infrared galaxies, low dust extinction and study formation of stars and galaxies (Becklin, 1997). ASTRO-F, built by the Japanese will have its telescope cooled to 6°K using superfluid liquid helium and Stirling-cycle coolers. It will search for primeval galaxies, infrared galaxies, protostars, brown dwarfs and protoplanetary disks. NGSS will look for IR galaxies, brown dwarfs near the Sun and detect ~ 500,000 asteroids using IR observations. The Astrobiology telescope will be cooled to < 10°K using cryogen solid hydrogen with InSb and SiAs detectors. Herschel will have a 3.5 m SiC telescope cooled to 70°K, SIRCE will combine radiative cooled shields and helium cooled telescope with ADR cooled TES bolometer arrays. The Japanese SPICA has 3.5 m actively cooled telescope at 4.5°K. SAFIR is a passively cooled 8 meter telescope that will build on JWST technology. The Terrestrial Planet Finder (TPF) mission will use a formation-flying interferometer of infrared telescopes that use large passively cooled optics, nulling interferometry, precision wavefront control, coronagraphs and cryocoolers. The SPIRIT mission uses a deployed linear array of telescopes using a common heat shield, while SPECS uses a separated spacecraft array similar to that used by TPF and the possible combined use of tethers and rotation (separation distances ~ 1 km. The missions SAFIR, TPF, SPIRIT and SPECS are all planned for launches after 2013.

Planetary Infrared Missions

With regard to planetary missions (see Table 2) the first New Frontiers mission will be New Horizons, which will take images of Kuiper Belt objects and the Pluto-Charon system using an imaging NIR spectrometer called LEISA. This imaging spectrometer is also being considered for TOAM on the Aerorover (i.e., powered balloon) for surface maps of Titan in the NIR, which is expected to provide surface compositional information. Regarding JIMO one of the main goals will be to provide high sensitivity, high spectral resolution and high spatial resolution measurements of icy moon surfaces to look for localized hot spots or hydrothermal vents where aqueous solutions may be extruding out from below due to tidal heating and radiogenic heating of their interiors where subsurface oceans may exist. For these measurements to be successful experimenters will have to shield against the large thermal radiators for the space fission reactor and provide active cryogenic cooling below 4°K so that large TES arrays can be constructed using SQUID switches at the focal plane. Heterodyne spectroscopy will also play an important role regarding icy moon exospheres. Here we note that the JIMO/Prometheus mission is setting a new paradigm in instrument development for which one can use instrumentation only reserved to ground based telescopes. The SPA-SR mission will take a sample of the moons surface at the South Pole-Aitken Basin where infrared measurements by Clementine showed permanently shadowed regions at the bottom of deep craters with temperatures less than 100°K and that frozen water lasting more than 10^9 years probably resides (Ingersoll et al., 1992). Bi-static radar measurements by Clementine gave further evidence for permanently frozen ice in these polar regions (Nozette et al., 1996). The Lunar Prospector Neutron Spectrometer measuring thermal and epithermal neutrons showed unequivocally evidence for water ice in these polar regions (Feldman et al., 1998). This was first predicted back in 1961 (Watson et al., 1961), though their stability is in question (Arnold, 1979). We expect an infrared imager to be part of the SPA-SR mission with regard to global surface temperature and composition measurements of these regions of permanently stored regions of water ice. Here, measurements in the NIR to MIR are recommended. For JPOP one of the primary objectives will be images of the polar aurora at Jupiter. In the past ground based observations have been made between 3-4 μm (Connereny et al., 1998, Satoh and Connerney, 1999) and most recently during the Cassini flyby the CIRS instrument measured emissions in the 7-14 μm range in the polar regions of Saturn at upper stratospheric depths and are believed to be associated with Jupiter's polar cusp (Flasar et al., 2003). Therefore, we expect these spectral regions to be covered by JPOP. In the case of CSSR the need for infrared observations of a comet at close quarters cannot be overstated considering the expected high abundance of water products and complicated organic chemistry. The recommended spectral range is 1-1000 μm. For MRO the CRISM instrument will provide high spatial and spectral resolution measurements over an extended wavelength range from 1.05-4.0 μm with a primary objective of detecting aqueous and/or hydrothermal activity regions on the surface of Mars and to map and characterize the composition, geology and stratigraphy of surface features (Murchie et al., 2003). This instrument uses doubly redundant cryogenic coolers and side-facing radiative cooler. For TOAM the orbiter will have a Titan Infrared Spectrometer (TIRS) covering the spectral range from 7 to 1000 μm (see Coustenis et al., 1993) and the LEISA instrument (1.0 – 3.5 μm) with both using passive radiative coolers for their detectors. A modified version of LEISA would also be used for the Aerorover part of TOAM for which it would use the ambient cryogenically cold atmosphere to cool its detectors.

Earth Science Infrared Missions

For the Earth Science infrared missions we refer you to Table 3, which is not a complete list when one considers other international funded missions. There are also a large number of missions without infrared remote sensing instruments for which they instead do altimetry or radar observations of the Earth system. The Aura spacecraft makes measurements of the upper troposphere and lower stratosphere. It has two major remote sensing instruments, the High Resolution Dynamics Limb Sounder (HIRDLS) which has an infrared limb scanning radiometer to measure atmospheric temperature and concentration of various gases and aerosols and a Tropospheric Emission Spectrometer (TES) which is a high-resolution infrared imaging fourier spectrometer for both limb and nadir viewing in the spectral band from 3.2 to 15.4 μm. The SAGE III spacecraft makes stratospheric aerosol and gas measurements using the Sage-3 spectrometer, which makes measurements from 280 nm to 1040 nm and at 1550 nm with spectral resolution of 1-2 nm. It uses a combination of a CCD detector and photodetector. The NMP/EO-3 spacecraft has what is called a GIFTS Imager, which has a Fourier Transform Spectrometer with Michelson Interferometer. The sensor module is cryogenically cooled and makes measurements in the visible to infrared wavelengths. It uses a Large Area Format Focal Plane Detector Array (LFPA). One of its science objectives is to measure the greenhouse gases that may play an important role with regard to global warming. Landsat-7 is the next launch for the Landsat Data Continuity Mission (LDCM). It is a polar orbiting spacecraft with an imaging system called the Enhanced Thematic Sensor, which covers the wavelength range of 0.45 to 12.5 μm. It uses 8 spectral filters, a scan mirror assembly and radiative coolers. The detector technology is SiPD, InSb and HgCdTe. The spatial resolution is 30 to 1000 meters. The NPOESS spacecraft, for which NPP is a precurser, will make remote sensing images of the Earth system using wavelengths from the visible to infrared to microwave. The infrared measurements are provided by the Visible/Infrared Imager/Radiometer Suite (VIIRS) instrument and the Crosstrack Infrared Sounder (CrIS). Lastly, we have the DSCVR (Triana) spacecraft which uses the Scripps-NISTAR Imager. This imager covers the wavelength range from 0.2 to 100 μm and will make continuous global measurements of the Earth where the spacecraft is at the L-1 Lagrange point between the Earth and the Sun. The launch date is undetermined, since it was meant to be launched by the shuttle, but since the Columbia accident is in a holding state. For detectors they use heat sink receivers cooled to 40°K and SiPD photodiodes.

Solar Physics Infrared Missions

In the area of solar physics or SEC/LWS we have the recently proposed MIRAGES (France) mission proposed by Gerard Trottet and collaborators under the microsatellite programme of CNES. They propose to measure synchrotron emissions in the far infrared and γ-rays (bremsstrahlung) from relativistic 10 MeV electrons with $\tau \leq 1$ second time resolution during acceleration events such as solar flares.

Ground Based Infrared Missions

We now come to ground based observations. Here, most of the future efforts are being made to develop a very high tech interferometer capability using even larger telescopes than we have now. Sizes as big as 200 meter telescopes are being discussed. The science that is driving this capability falls under the heading of origins and the desire to detect terrestrial planets in other solar systems and ascertain whether such bodies can harbor life. Several technologies need to be developed to achieve this capability. We do not have the space to discuss such technologies other than to mention them. For example, the Palomar Testbed Interferometer's main purpose is to develop future fringe trackers, star trackers and active delay lines (Colavita et al., 1999). In most of these cases the measurements will be made at infrared wavelengths. To follow the Palomar effort we have the Keck Interferometer (Keck-I) on top of Mauna Kea, Hawaii, which is composed of two 10 Meter Keck Telescopes (see Figure 4) with four 1.8 meter outrigger telescopes. Here they want to develop planet detection, synthesis imaging, precision narrow-angle astrometry and detection of exozodiacal dust near stars. Will use cryogenic nulling interferometry, laser metrology (Gursel, 1993) and automation. Also, uses cascaded achromatic nulling interferometer to null central star. Alongside the Keck telescopes we have the University of Arizona's Large Binocular Telescope, which is made of two 8.4 meter mirrors on a beam. In the southern sky, the Very Large Telescope Array is being constructed by the Europeans in Chile and we have the U.S. version also based in Chile which is made of a pair of 6.5 meter telescopes. Using Heterodyne spectroscopy the Keck telescopes can also be used to measure winds on the Saturn moon Titan (Kostiuk et al., 2001).

Conclusions

In summary we can say there are a lot of missions in the next ten years that will use infrared detectors and that the field of Infrared Astronomy has a bright future and challenging future with applications in the area of astrophysics, planetary physics, Earth science and solar physics. The platforms for these various missions will be spacecraft, balloons, rovers, airplanes and ground based telescopes. Finally, the use of nanotechnology and MEMS technology will allow one to miniaturize future instrument concepts, while the Prometheus project could be a paradigm changing force toward the development of larger more power hungry instrument concepts with correspondingly greater spatial and spectral resolution, higher telemetry rate capabilities and order of magnitude advancements in science.

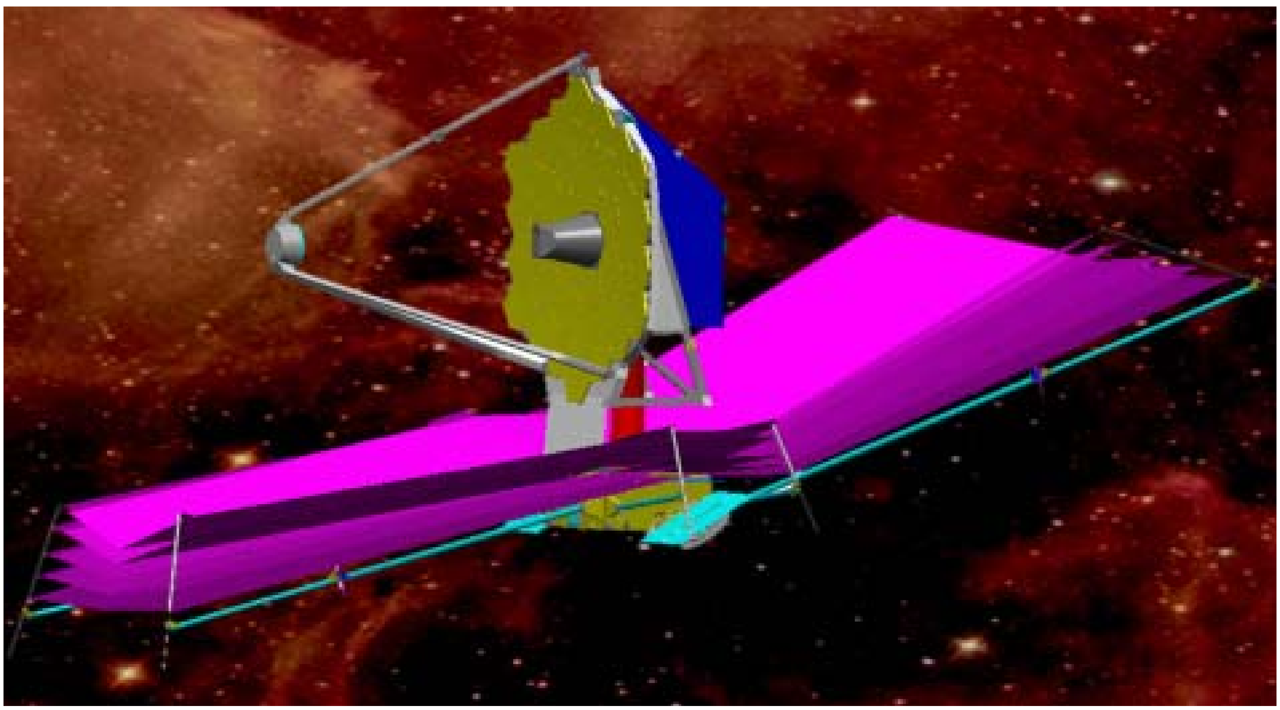

Figure 1. Artist rendition of James Webb Space Telescope showing heat shield to eliminate thermal input from Sun and Earth. Figure also shows 7 meter telescope composed of a network of smaller hexagonal mirrors.

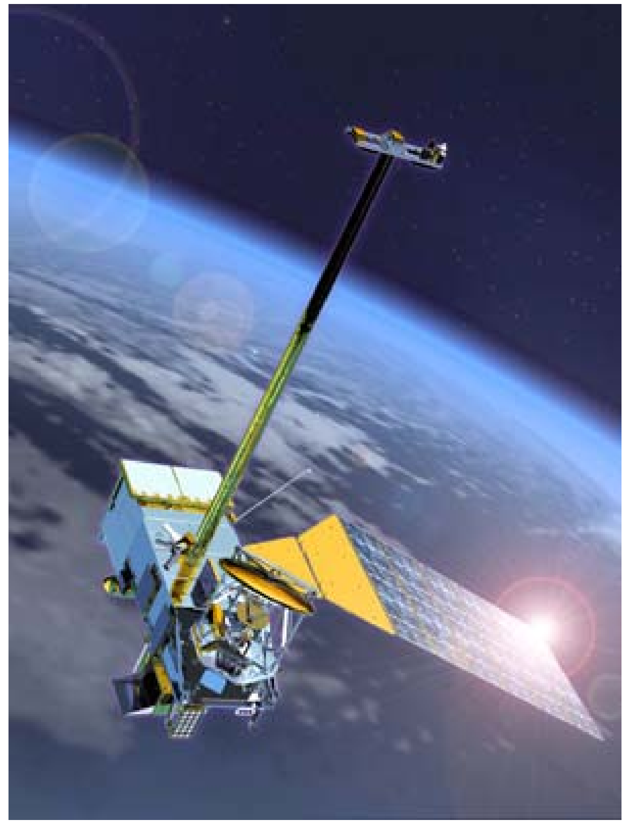

Figure 2. Artist rendition of the Jupiter Icy Moon Orbiter (JIMO) mission. The space fission reactor is at the tip far from the spacecraft body. Large radiators are used to dissipate excess heat. The ion enaine clusters are shown.

Figure 3. National Polar-Orbiting Operational Environmental System (NPOESS). Will use VIIRS = Visible / Infrared Imager / Radiometer Suite Instrument.

Figure 4. The two 10 Meter Keck Telescopes on Mauna Kea, Hawaii.

Table 1. ASTROPHYSICAL INFRARED MISSIONS

Launch Date	Mission Name	λ Coverage
2003	SIRTF = Space Infrared Telescope Facility	3-180 μm
2004	SOFIA = Stratospheric Observatory for Infrared Astronomy	5-20 μm
2004	IRIS – ASTRO-F (Japanese)	50-200 μm
2007	NGSS – Next Generation Sky Survey	3.5-23 μm
2007	ABE – Astrobiology Explorer	2.5-20 μm
2007	Planck – Measure the Microwave Background Radiation	300μm – 1.2 cm
2007	Herschel = Far Infrared and Submillimeter Telescope	60-670 μm
2010	JWST = James Webb Space Telescope (was NGST)	1-27 μm
TBD	SIRCE – Survey of Infrared Cosmic Evolution	Not yet defined
2010	SPICA – Japanese proposed mission	5-200 μm
TBD	SAFIR – Single Aperture Far IR Observatory	Not yet defined
TBD	SPIRIT – Space Infrared Interferometric Telescope	Not yet defined
TBD	TPF – Terrestrial Planet Finder	7 – 20 μm
TBD	SPECS – Submm Probe of the Evolution of Cosmic Structure	Not yet defined

Table 2. PLANETARY INFRARED MISSIONS

Launch Date	Mission Name	λ Coverage
2005	New Horizons (Kuiper Belt-Pluto Express)	1.25-3.5 μm
2006	DAWN (Vesta-Ceres)	1-5 μm
2008	South Pole-Aitken Basin Sample Return (SPA-SR)	1.25-2.5, 5-50 μm
2011	Jupiter Polar Orbiter with Probes (JPOP)	3-4, 7-14 μm
2014	Venus In Situ Explorer (VISE)	Not yet defined
2017	Comet Surface Sample Return (CSSR)	1-1000 μm
2012	Jupiter Icy Moons Orbiter (JIMO) or Prometheus	1-5, 5-50, 50-100 μm
2007	Mars Reconnaissance Orbiter (MRO)	1.05-40 μm
2009	Mars Smart Lander (MSL)	Not yet defined
2013	Titan Orbiter Aerorover Mission (TOAM)	1.25-3.5, 7-1000 μm

Table 3. EARTH SCIENCE INFRARED MISSIONS

Launch Year	Mission Name	λ Coverage
2004	Aura – Upper Troposphere and Lower Stratosphere	3.2-15.4 μm
2005	ESSP/CALIPSO-Cloud Aerosol Lidar and Infrared Satellite Obs.	0.532-1.064, 8.7, 10.5, 12.0 μm
2005	Stratospheric Aerosol and Gas Experiment (SAGE-3)	0.28-1.04 μm, 1.55 μm
2005	New Millenium Program/Earth Observing-3 (NMP/EO-3)	NIR Lines
2007	Landsat Data Continuity Mission (LDCM)	0.45 – 12.5 μm
2006	NPOES Preparatory Project (NPP)	0.405 – 2.155 μm
TBD	DSCVR (Triana) – Global Earth Imaging	0.2 – 100 μm
2009	National Polar-Orbiting Operational Environmental Satellite System (NPOESS)	0.405 – 2.155 μm

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