8. Infrared Sky Surveys and Space Missions

Digital sky surveys are now a large part of modern astronomy and the trend is toward ever larger sky surveys. This due to great technical advances in array detectors (optical and IR) and even greater advances in computing and data storage.

Sky surveys are needed to attack problems in cosmology and to identify transient objects. A great example of the latter is the recent identification of the gravitational wave source GW170817.

I will discuss sky surveys and space missions that have surveyed the sky at IR wavelengths as well provided pointed observations.

Notes:

8.1 Infrared sky surveys from the ground.

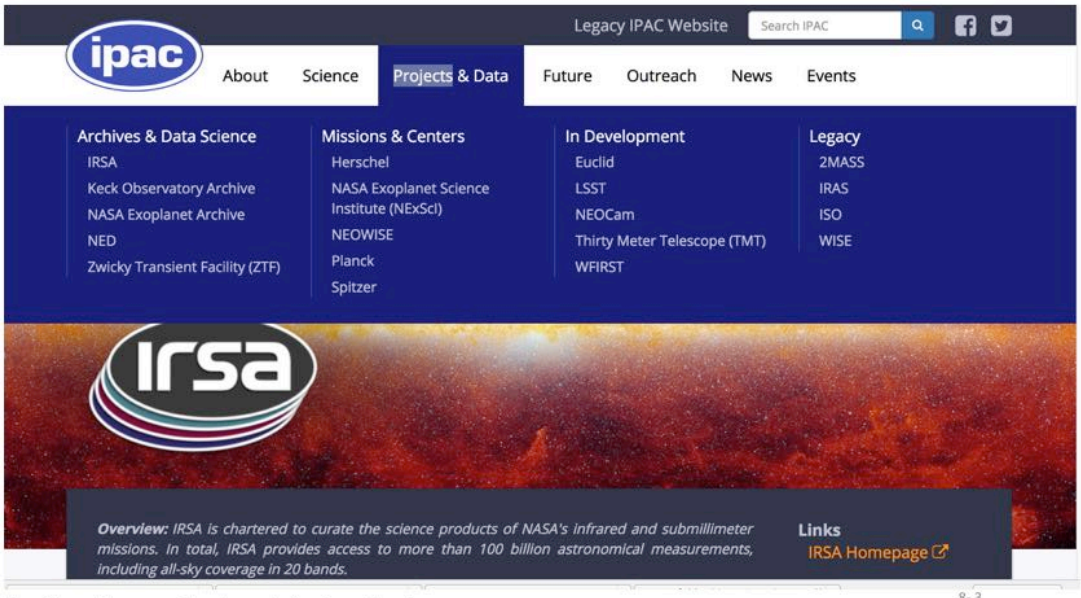
- **2 Micron All Sky Survey (2MASS).** The entire sky was surveyed at J, H, and Ks between 1997 and 2001 (Skrutskie et al. 2006). The uniformity, accessibility, and quality of the data has made it and indispensable resource for observing and research especially in regions that are highly obscured by interstellar extinction. The 2MASS near-IR images are available through the NASA/IPAC Infrared Science Archive (IRSA). Home page:

  https://www.ipac.caltech.edu/project/irsa

Notes:
http://irsa.ipac.caltech.edu/index.html also provides access to an extensive set of databases, including IRAS, ISO, Akari, Midcourse Space Experiment
(MSX), Spitzer, WISE, Herschel, and Planck.

References:
Skrutskie, M. F. et al. (2006). "The Two Micron All Sky Survey (2MASS)." The Astronomical Journal **131**: 1163-1183
Hewett, P. C. et al. (2006). "The UKIRT Infrared Deep Sky Survey ZY JHK photometric system: passbands and synthetic colours." Monthly Notices of the Royal Astronomical Society **367**: 454-468.
Hodgkin, S. T. et al. (2009). "The UKIRT wide field camera ZYJHK photometric system: calibration from 2MASS." Monthly Notices of the Royal Astronomical Society **394**: 675-692.

IPAC Infrared Science Archive (IRSA) home page:



http://irsa.ipac.caltech.edu/index.html

Notes: Infrared Processing and Analysis Center (IPAC). IPAC was founded to process IRAS data and has been expanded to other space observatories.

http://irsa.ipac.caltech.edu/index.html also provides access to an extensive set of databases, including IRAS, ISO, Akari, Midcourse Space Experiment
(MSX), Spitzer, WISE, Herschel, and Planck.

References:

Skrutskie, M. F. et al. (2006). "The Two Micron All Sky Survey (2MASS)." The Astronomical Journal **131**: 1163-1183
Hewett, P. C. et al. (2006). "The UKIRT Infrared Deep Sky Survey ZY JHK photometric system: passbands and synthetic colours." Monthly Notices of the Royal Astronomical Society **367**: 454-468.
Hodgkin, S. T. et al. (2009). "The UKIRT wide field camera ZYJHK photometric system: calibration from 2MASS." Monthly Notices of the Royal Astronomical Society **394**: 675-692.

IRSA front page for searching for objects.

Most useful for making finding charts in the IR.

8- 4

Notes: Infrared Processing and Analysis Center (IPAC). Started processing data from the IRAS mission.

http://irsa.ipac.caltech.edu/index.html also provides access to an extensive set of databases, including IRAS, ISO, Akari, Midcourse Space Experiment
(MSX), Spitzer, WISE, Herschel, and Planck.

References:

Skrutskie, M. F. et al. (2006). "The Two Micron All Sky Survey (2MASS)." The Astronomical Journal **131**: 1163-1183
Hewett, P. C. et al. (2006). "The UKIRT Infrared Deep Sky Survey ZY JHK photometric system: passbands and synthetic colours." Monthly Notices of the Royal Astronomical Society **367**: 454-468.
Hodgkin, S. T. et al. (2009). "The UKIRT wide field camera ZYJHK photometric system: calibration from 2MASS." Monthly Notices of the Royal Astronomical Society **394**: 675-692.

8.1 Sky surveys from the ground (continued)

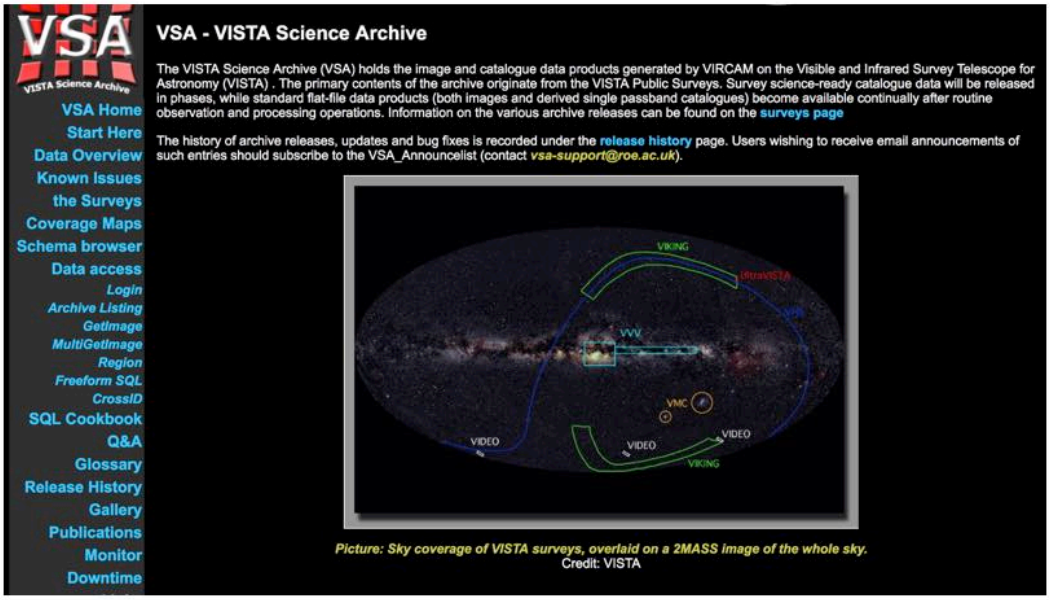
- UKIRT Infrared Deep Sky Survey (UKIDSS). Started in 2005 and consists of five filters: Z, Y, J, H, and K. The JHK filters are identical to the MKO near-IR filter set (Hewett et al. 2006). The UKIDSS photometric system was established using the 2MASS photometry (Hodgkin et al. 2009). Images from this this survey can be found at: http://www.ukidss.org/

- Visible and Infrared Survey Telescope for Astronomy (VISTA). It consists of a dedicated wide-field telescope with a 67 million pixel IR camera. It has a set of filters similar to that used by UKIDSS. The survey programs started in 2010 (Emerson and Sutherland 2010). Information on VISTA:
  http://www.eso.org/public/teles-instr/paranal-observatory/surveytelescopes/vista/
  The science archive for VISTA is at: http://vsa.roe.ac.uk/

Notes:
http://irsa.ipac.caltech.edu/index.html also provides access to an extensive set of databases, including IRAS, ISO, Akari, Midcourse Space Experiment
(MSX), Spitzer, WISE, Herschel, and Planck.

References:
Skrutskie, M. F. et al. (2006). "The Two Micron All Sky Survey (2MASS)." The Astronomical Journal **131**: 1163-1183
Hewett, P. C. et al. (2006). "The UKIRT Infrared Deep Sky Survey ZY JHK photometric system: passbands and synthetic colours." Monthly Notices of the Royal Astronomical Society **367**: 454-468.
Hodgkin, S. T. et al. (2009). "The UKIRT wide field camera ZYJHK photometric system: calibration from 2MASS." Monthly Notices of the Royal Astronomical Society **394**: 675-692.

Vista Science Archive page:



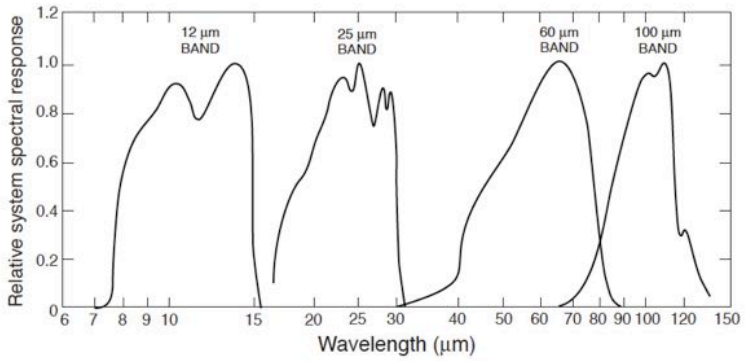
Notes:
http://irsa.ipac.caltech.edu/index.html also provides access to an extensive set of databases, including IRAS, ISO, Akari, Midcourse Space Experiment
(MSX), Spitzer, WISE, Herschel, and Planck.

References:
Skrutskie, M. F. et al. (2006). "The Two Micron All Sky Survey (2MASS)." The Astronomical Journal **131**: 1163-1183
Hewett, P. C. et al. (2006). "The UKIRT Infrared Deep Sky Survey ZY JHK photometric system: passbands and synthetic colours." Monthly Notices of the Royal Astronomical Society **367**: 454-468.
Hodgkin, S. T. et al. (2009). "The UKIRT wide field camera ZYJHK photometric system: calibration from 2MASS." Monthly Notices of the Royal Astronomical Society **394**: 675-692.

8.2 Sky surveys from space.

IRAS (Infrared Astronomical Satellite)

The first all sky survey in the IR was accomplished with IRAS in 1983.



Imaging was accomplished in 4 bands: 12, 25, 60, 100 μm as shown to the left. The filters are very broad, and so the effective wavelength of the filters depends on the spectral energy distribution of the source. **Color corrections have to applied depending on whether you have a hot or cold source.**

Notes: Comprehensive history of infrared sky surveys is given by Price, S. D. (2009). "Infrared Sky Surveys." Space Science Reviews **142**: 233-321.

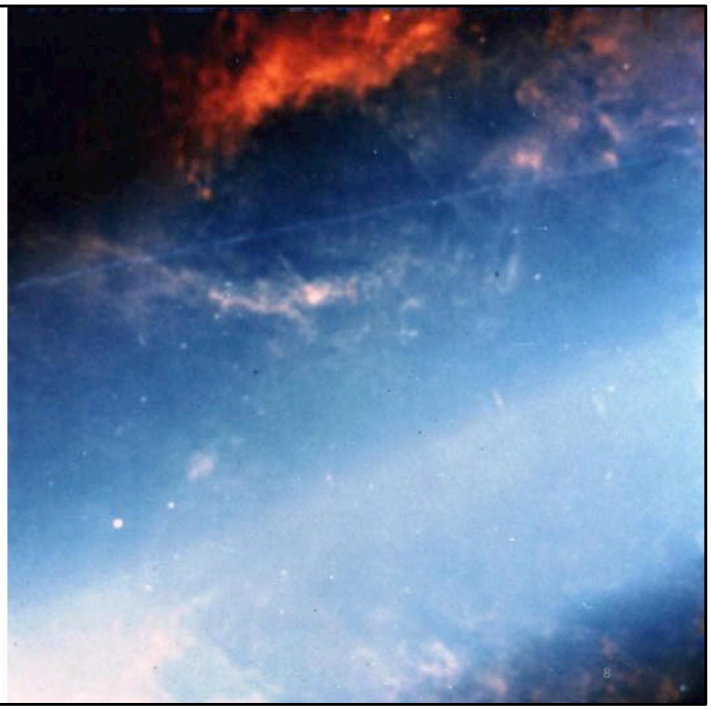
Webpage: http://irsa.ipac.caltech.edu/Missions/iras.html

Archive: http://irsa.ipac.caltech.edu/Missions/iras.html

References:

Description of the observatory: Neugebauer, G., H. et al. (1984). "The Infrared Astronomical Satellite (IRAS) mission." The Astrophysical Journal Letters **278**: L1-L6.

False color map with the 12 μm image as blue and 100 μm image as red. The comet Temple 2 dust trail is seen across the top half of the image. The light blue emission is from the zodiacal light at 12 μm along the ecliptic plane. The complex structure is emission from cold dust in the Galaxy at 100 μm.



Notes: Image from: Price, S. D. (2009). "Infrared Sky Surveys." Space Science Reviews **142**: 233-321.

MSX (Midcourse Space Experiment)

Operated from 1996-1997 at 4.29, 4.35, 8.28 μm, 12.13 μm, 14.65 μm, and 21.3 μm and it mapped the galactic plane as well as areas of the sky missed by IRAS. One focus of this telescope was to provide an absolute calibration of standard stars in the IR (Cohen et al. 2000; Cohen et al. 2001). The absolute calibration of Akari and the Spitzer Space Telescope is based on this work.

False-color Midcourse Space Experiment (MSX) composite with the 8.28 μm band (blue), 12.13 μm band and 14.65 μm band (green), and 21.3 μm band (red). Covers about 4.5 x 4.5 degrees.

From:
http://coolcosmos.ipac.caltech.edu/image_galleries/MSX/hourglass_nebula.html

8- 9

Notes:
Webpage: http://irsa.ipac.caltech.edu/Missions/msx.html

Archive: http://irsa.ipac.caltech.edu/Missions/msx.html

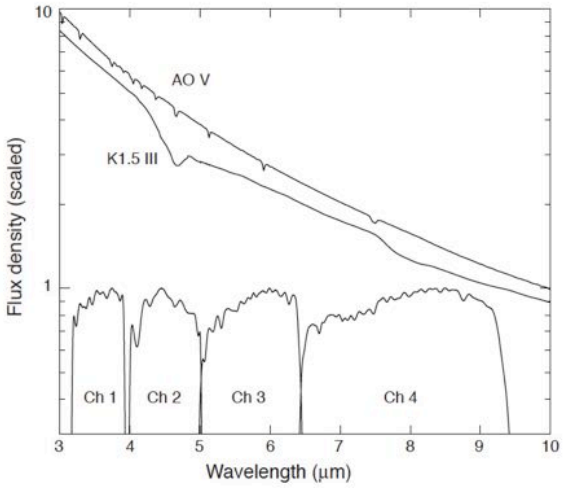
References:
Description of the observatory: Price, S. D. et al. (2001). "Midcourse Space Experiment Survey of the Galactic Plane." The Astronomical Journal **121**: 2819-2842.

Description of absolute calibration: Price, S. D. et al. (2004). "Spectral Irradiance Calibration in the Infrared. XV. Absolute Calibration of Standard Stars by Experiments on the Midcourse Space Experiment." Astronomical Journal **128**: 889-910.

More detailed info on the filters used: http://irsa.ipac.caltech.edu/applications/MSX/MSX/imageDescriptions.htm

Spitzer Space Telescope (SST)

Operated from 2003 to the present, Spitzer has provided a wealth of new discoveries.



The Infrared Array Camera (IRAC) is a 4-channel camera operating at 3.6, 4.5, 5.8, and 8.0 μm (Fazio et al. 2004). When the cryogens ran out in 2009, the observatory was operated using only the near-IR instrument at 3.6 and 4.5 μm.

Figure shows the scaled spectra an A dwarf and a K giant star compared to the normalized spectral response of the 4 IRAC channels. InSb arrays were used for 3.6 and 4.5 μm and a Si:As arrays for 5.8 and 8.0 μm.

8- 10

Notes:
Webpage: https://www.nasa.gov/mission_pages/spitzer/main/index.html
http://www.spitzer.caltech.edu/

Archive: http://irsa.ipac.caltech.edu/Missions/spitzer.html

References:
Description of the observatory: Werner, M. W. et al. (2004). "The Spitzer Space Telescope Mission." The Astrophysical Journal Supplement Series **154**: 1-9.
Scientific case for the Spitzer warm mission: McCarthy, P. J. and N. A. Silbermann (2007). Spitzer Science in the Post Cryogen Era. The Science Opportunities of the Warm Spitzer Mission Workshop, AIP Conf. Ser. L. J. Storrie-Lombardi. **943:** 3-26.
Description of IRAC: Fazio, G. G. et al. (2004). "The Infrared Array Camera (IRAC) for the Spitzer Space Telescope." The Astrophysical Journal Supplement Series 154: 10-17.

The Multiband Imaging Photometer for Spitzer (MIPS) had three camera modes and one spectrometer mode (Rieke et al. 2004).

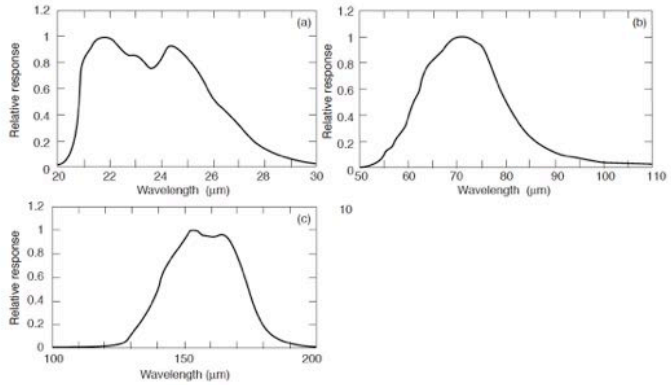


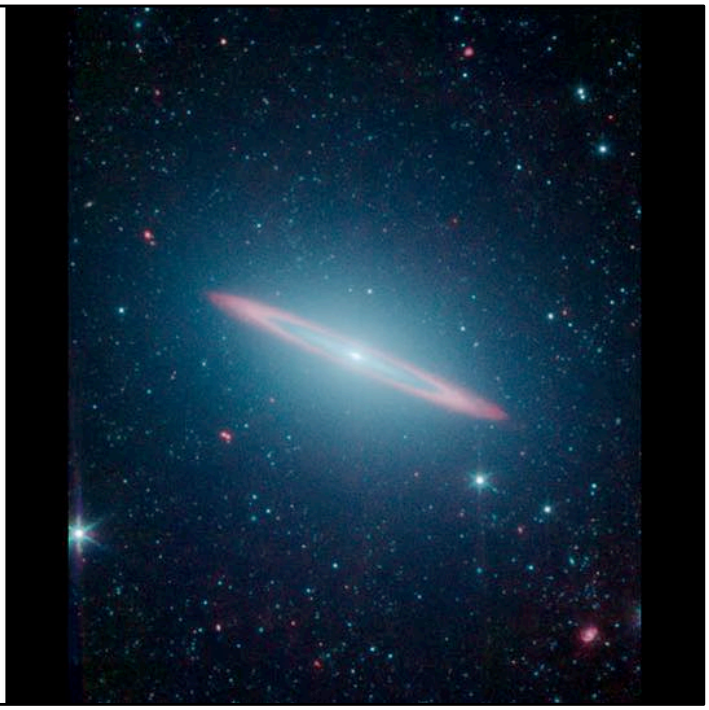
Figure shows the filters used for MIPS. Three types of detectors were used: a Si:As impurity band conduction array at 24 μm (Rieke et al. 2008), a Ge:Ga photoconductor array at 70 μm (Gordon et al. 2007), and a stressed Ge:Ga array at 160 μm (Stansberry et al. 2007).

Notes:
Webpage: https://www.nasa.gov/mission_pages/spitzer/main/index.html
http://www.spitzer.caltech.edu/

References:
Description of MIPS: Rieke, G. H. et al. (2004). "The Multiband Imaging Photometer for Spitzer (MIPS)." The Astrophysical Journal Supplement Series 154: 25-29.
24 μιχρον calibration: Rieke, G. H. et al. (2008). "Absolute Physical Calibration in the Infrared." The Astronomical Journal **135**: 2245-2263.
70 micron calibration: Gordon, K. D. et al. (2007). "Absolute Calibration and Characterization of the Multiband Imaging Photometer for Spitzer. II. 70 μm Imaging." Publications of the Astronomical Society of the Pacific 119: 1019-1037.
160 μicron calibration: Stansberry, J. A. et al. (2007). "Absolute Calibration and Characterization of the Multiband Imaging Photometer for Spitzer. III. An Asteroid-based Calibration of MIPS at 160 μm." Publications of the Astronomical Society of the Pacific 119: 1038-1051.

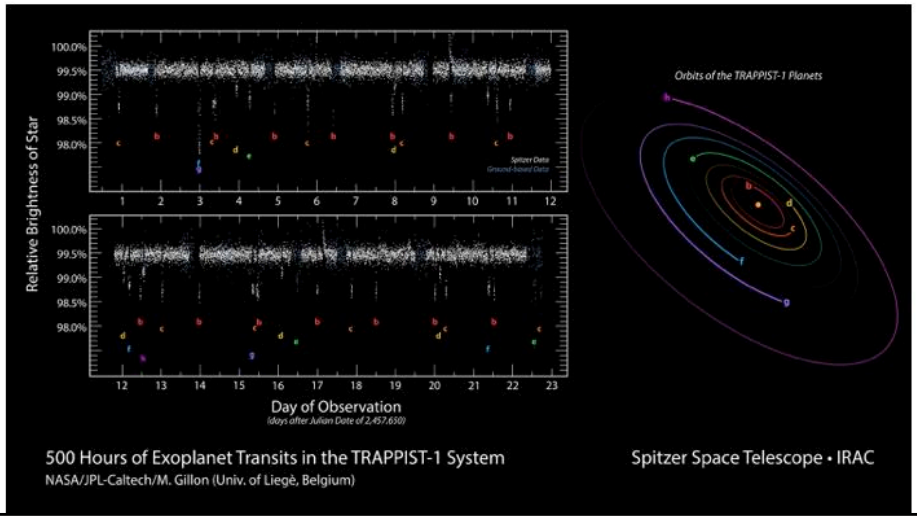
Some science highlights from Spitzer:

This Spitzer image shows that the Sombero galaxy is composed of an elliptical component and a thin disk galaxy embedded within. The starlight detected at 3.5 and 4.6 μm is shown as a blue-green color while the dust detected at 8.0 μm is shown in red.



Notes:
From: http://www.spitzer.caltech.edu/search/image_set/20?by_type=astronomical&tabs=hidden

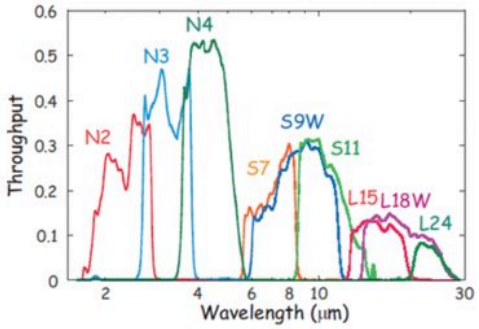
Spitzer observations of a system of seven planets orbiting TRAPPIST-1, an ultracool dwarf star located only 40 light years from the Earth. The transits were observed over a period of 21 days. Seven rocky planets were found, including three in the habitable zone where liquid water might be found. All of the planets are probably tidally locked to the star.

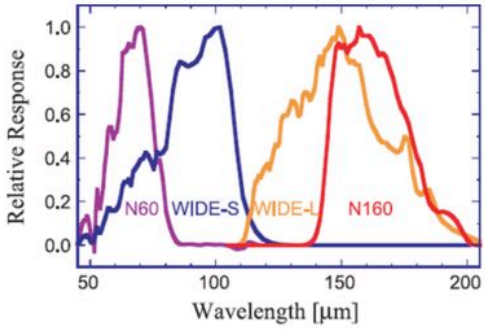


Notes:
From: http://www.spitzer.caltech.edu/search/image_set/20?by_type=astronomical&tabs=hidden

AKARI

AKARI was launched in 2006 by JAXA (Murakami et al. 2007). The liquid helium ran out in Aug. 2007 after 1.5 years of observations. The near-IR camera could still operate due to a mechanical cryo-cooler and observations continued with a "warm mission" until May 2011 when problems with the satellite power supply caused the end of the mission.





The figures show the filters for the Infrared Camera (IRC) on AKARI (Onaka et al. 2007) and the filters for the Far-Infrared Surveyor (FIS; Kawada et al. 2007).

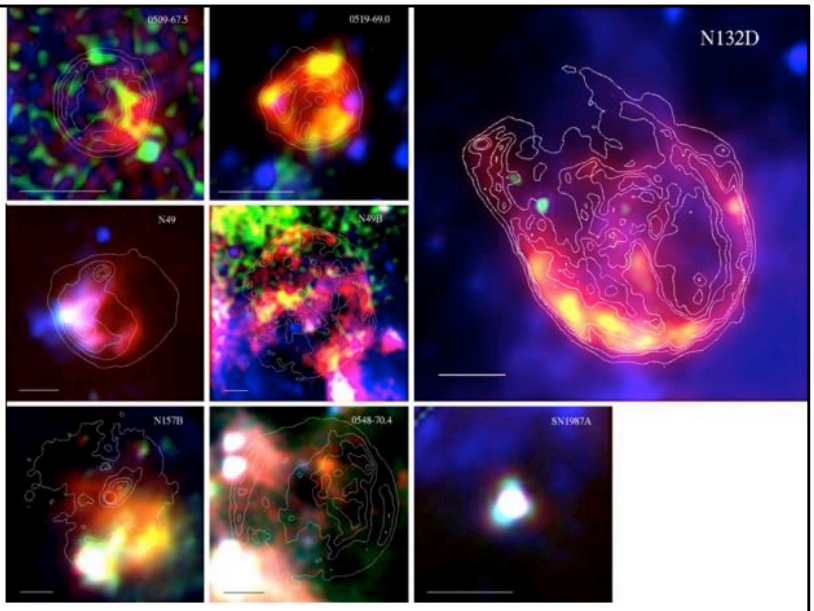
8.14

Notes:
Webpage: http://www.ir.isas.jaxa.jp/AKARI/

Data archive: http://darts.jaxa.jp/astro/akari/

References: Murakami, H. et al. (2007). "The Infrared Astronomical Mission AKARI." Publications of the Astronomical Society of Japan 59: 369.
Onaka, T. et al. (2007). "The Infrared Camera (IRC) for AKARI -- Design and Imaging Performance." Publications of the Astronomical Society of Japan 59: S401.
Kawada, M. et al. (2007). "The Far-Infrared Surveyor (FIS) for AKARI." Publications of the Astronomical Society of Japan 59: S389.

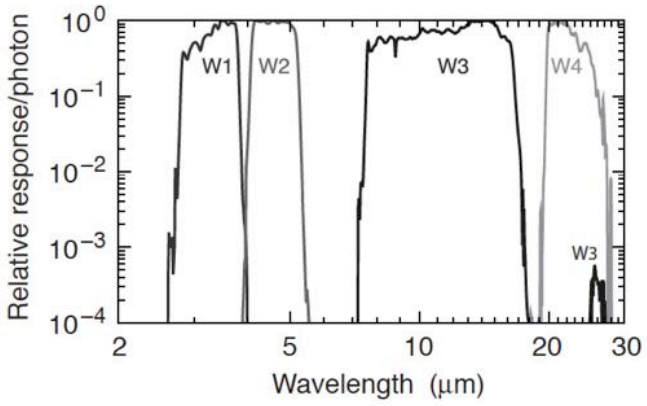
Three-color composite images of eight supernova remnants in the Large Magellanic Cloud composed of images taken at 7 (blue), 11 (green) and 15 (red) micrometers, with the near- and mid-Infrared Camera (IRC) onboard Akari. Contours indicate the intensity of the X-ray emission observed by the NASA's Chandra X-ray observatory. The line at the bottom of each image indicates a distance of 20 light-years. This study quantified the dust production in the metal poor galaxy.



Notes:
http://m.esa.int/spaceinimages/Images/2008/11/Supernova_remnants_in_the_Large_Magellanic_Cloud

Wide-field Infrared Survey Explorer (WISE)

WISE was launched in 2009 and it performed an all-sky survey at 3.4, 4.6, 12 and 22 μm (Wright et al. 2010). At the end of the survey the telescope was put into hibernation and then reactivated in 2013 to conduct as search for near-Earth objects (NEOs). This new program is called NEOWISE and it was actually started before the hibernation of the spacecraft.



Normalized relative system response curves on a log scale. The absolute calibration is based on the Spitzer calibration (Cohen 2007).

8- 16

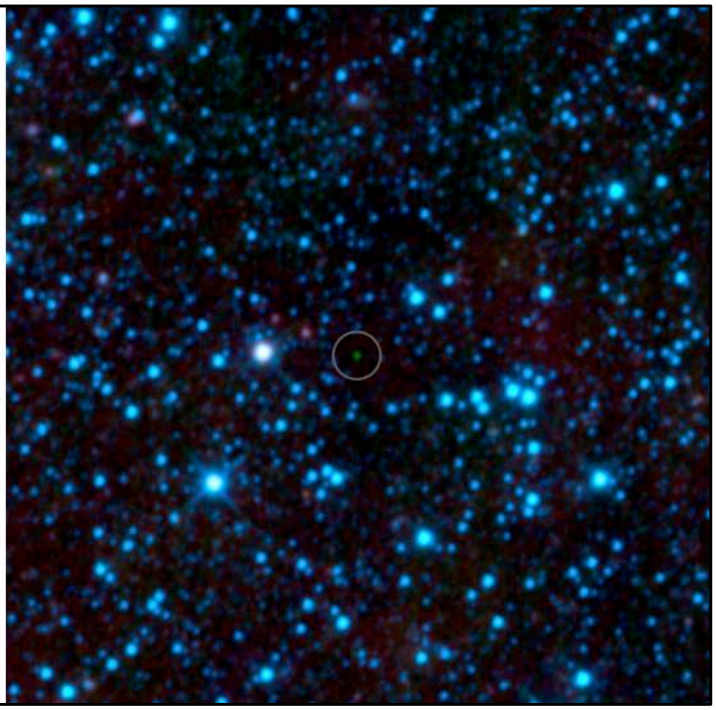
Notes:
Webpage: https://www.jpl.nasa.gov/wise/index.cfm
NEOWISE webpage: https://neowise.ipac.caltech.edu/

Data archive: https://www.ipac.caltech.edu/project/irsa

References: Wright, E.L. et al. (2010). "The Wide-field Infrared Survey Explorer (WISE): Mission Description and Initial On-orbit Performance." The Astronomical Journal 140: 1868-1881.
Cohen, M. (2007). Networks of Absolute Calibration Stars for SST, AKARI, and WISE. The Future of Photometric, Spectrophotometric and Polarimetric Standardization. C. Sterken. Blankenberge, Belgium, Astronomical Society of the Pacific. **364:** 333.

Discovered the object WISE 1828+2650, one of the coolest object yet discovered with a temperature of about 300 K. It is classified as a Y brown dwarf. The image shows three of WISE's four infrared channels, color-coded blue, green and red, with blue showing the shortest infrared wavelengths and red, the longest.

It is about 14 pc from the sun and has a mass of about 3-6 times the mass of Jupiter.

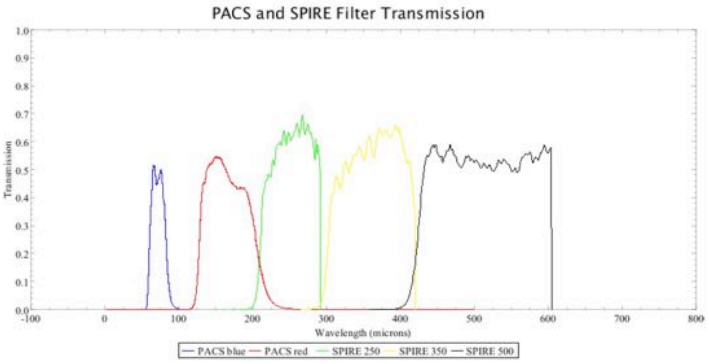


Notes:
https://www.jpl.nasa.gov/news/news.php?feature=3113

Herschel Space Observatory (Herschel)

Herschel was launched in 2009 by ESA and had a 3.5-m primary mirror that made it the largest infrared telescope launched at that time. The mission ended when the liquid helium ran out. It had three instruments:

- PACS - imaging at 120-210 μm, spectroscopy at 55-210 μm.
- SPIRE - imaging at 208-583 μm, spectroscopy at 200-570 μm.
- HIFI - high resolution spectroscopy at 480-1910 GHz (257-625 μm).



PACS AND SPIRE filters for imaging. The calibration of PACS is based on stars (Balog et al. 2014) while that for SPIRE is based on Neptune (Bendo et al. 2013). Figure is from Marston & Puga (2012).

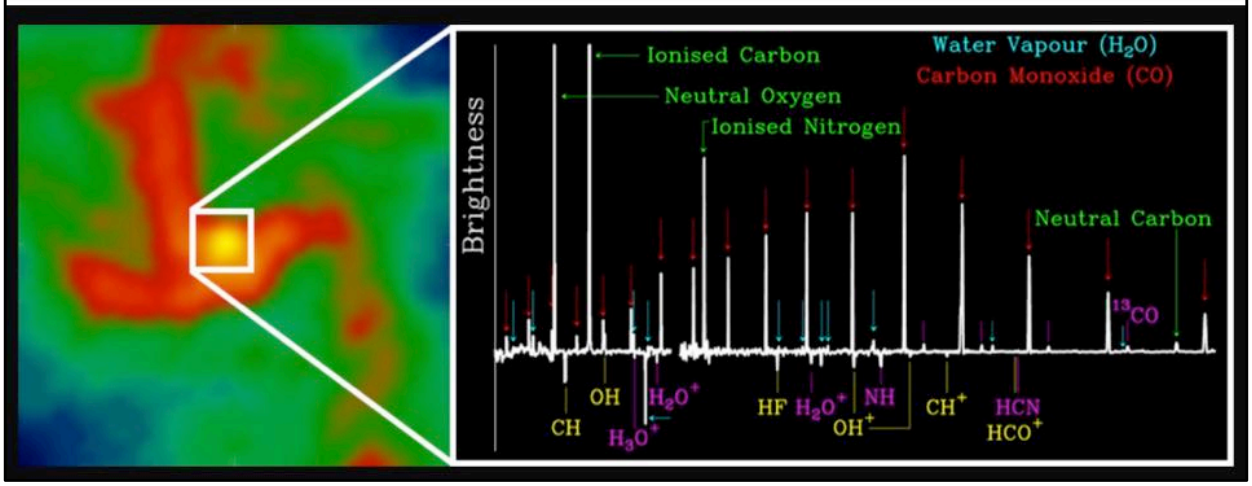
8- 18

Notes:
Webpage: https://www.cosmos.esa.int/web/herschel

Archive: http://archives.esac.esa.int/hsa/whsa/

References:
Observatory description: Pilbratt, G. L. et al. (2010). "Herschel Space Observatory. An ESA facility for far-infrared and submillimetre astronomy." Astronomy and Astrophysics **518**: L1.
Balog, Z., T. et al. (2014). "The Herschel-PACS photometer calibration. Point-source flux calibration for scan maps." Experimental Astronomy **37**: 129-160.
Bendo, G. J. et al. (2013). "Flux calibration of the Herschel★-SPIRE photometer." Monthly Notices of the Royal Astronomical Society 433: 3062-3078.
Marston, A.P. & Puga, E. 2012, Herschel Cross-Calibration Report, Version 2, Document Number HERSCHEL-HSC-REP-1935, Herschel Science Centre.

Herschel observations of hot molecular gas within 1 light year of the black hole at the center of the Galaxy. The black hole (known as Sgr A*) has a mass of 4 million solar masses. The temperature of the gas is as high as 1,300 K, much hotter than typical interstellar clouds with temperatures of about 20K. The high temperatures arise from heating by uv radiation and shocks in colliding material.



Notes:
http://m.esa.int/Our_Activities/Space_Science/Herschel/Herschel_finds_hot_gas_on_the_menu_for_Milky_Way_s_black_hole

PLANCK

The Planck spacecraft was launched in 2009 and it operated until 2013. The primary was 1.9m x 1.5m and this provided the highest resolution image of the Cosmic Microwave Background. The primary goal was to map the intensity and polarization of the CMB. It had two instruments, the Low Frequency Instrument (LFI) operating in three bands at 28 to 70 GHz and the High Frequency Instrument (HFI) operating at 100 to 857 GHz.

Instrument	LFI			HFI					
Characteristic									
Frequency (GHz)	28.4	44.1	70.4	100	143	217	353	545	857
FWHM (arcmin)	32.3	27.0	13.2	9.7	7.2	4.9	4.9	4.7	4.2
Bandwidth (%)	20	20	22	33	30	33	28	31	30
Sensitivity (μK_{CMB} deg)	2.5	2.7	3.5	1.29	0.55	0.78	2.56	0.78*	0.72*

Table 1. *Planck* instrument performance. Figures taken from the 2015 full mission data release [26]. * The sensitivity values for the 545 and 857 GHz channels, which are not sensitive to the CMB, are given in kJy sr^{-1}.

Table is from Clements (2017).

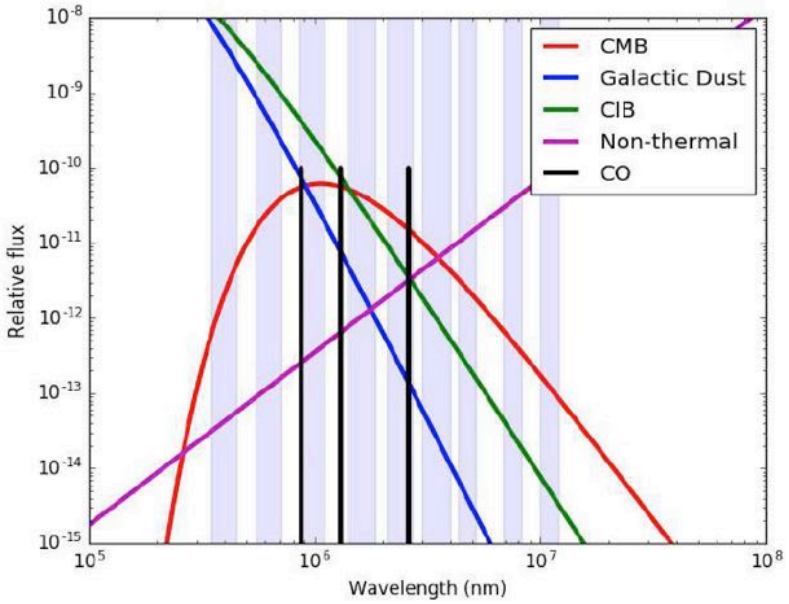
Notes:
Webpage: https://www.cosmos.esa.int/web/planck

Archive: https://www.cosmos.esa.int/web/planck/pla

References:
Planck_Collaboration, P. A. R. Ade, et al. (2011). "Planck early results. I. The Planck mission." Astronomy and Astrophysics 536: A1.
Clements, D. L. (2017). "An introduction to the Planck mission." Contemporary Physics **58**: 331-348.

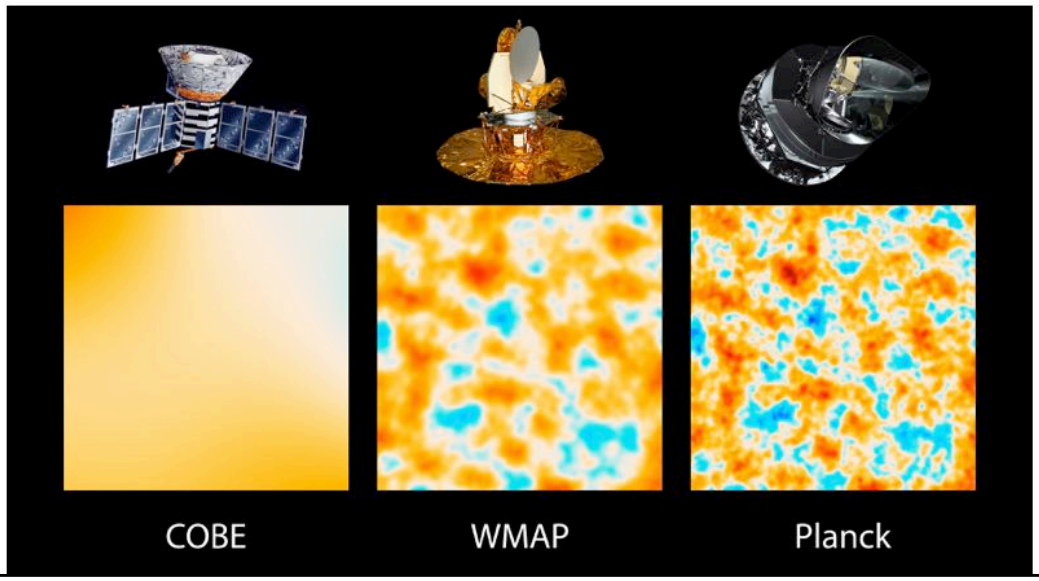
Planck detector bandpasses (grey) compared to the Cosmic Microwave Background (CMB), Galactic Dust emission, Cosmic Infrared Backbround (CIB), non-thermal emission, and CO line emission. The CIB dominates away from the plane of the Galaxy and originates from faint galaxies.

From Clements (2017).



Notes:

The panels show 10 deg x 10 deg maps of the cosmic microwave background. COBE was launched in 1989, WMAP in 2001, and Planck in 2009. The spatial resolution of Planck map is about 0.08 degree.



Notes:
Webpage:

References:
Planck_Collaboration, P. A. R. Ade, et al. (2011). "Planck early results. I. The Planck mission." Astronomy and Astrophysics 536: A1.
Clements, D. L. (2017). "An introduction to the Planck mission." Contemporary Physics **58**: 331-348.