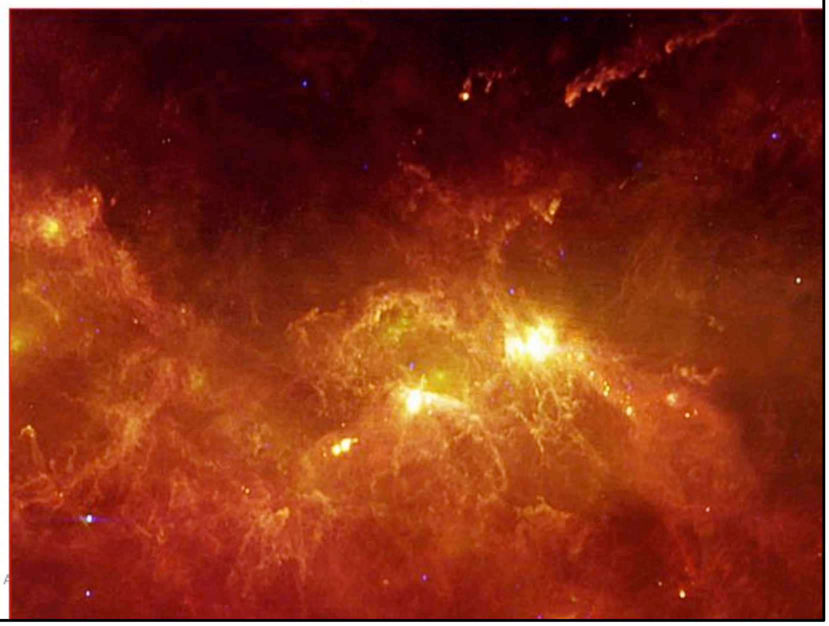
4. Background Emission from Space

The background emission from space is about 10^6 times smaller than from the ground. Therefore the first spacecraft to observe it, the InfraRed Astronomical Spacecraft (IRAS) made a number of important discoveries. One discovery was the numerous fine structure of the dust emission throughout the Galaxy as shown in the image to the right. This is an image of the constellation Orion, covering an area of 30°x24°.

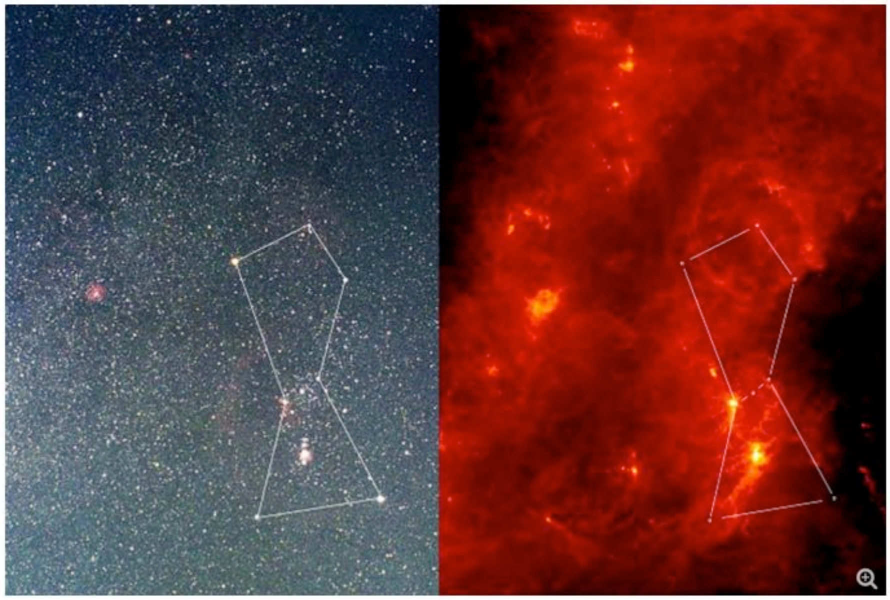


Notes: Image from https://apod.nasa.gov/apod/ap050419.html.

The fine structure is called the “infrared cirrus” since it resembles terrestrial clouds.

The IRAS satellite was launched in 1983 and accomplished a sensitive all sky survey at 12, 25, 60 and 100 μm.

Comparison of the Orion region in the visible and a 140 μm image from the AKARI spacecraft of the the Orion nebula region. The images show a region of about 30x40 square degrees.



Notes:
http://m.esa.int/spaceinimages/Images/2007/07/The_constellation_Orion_and_the_winter_Milky_Way

An image of the Orion A star-formation cloud made by the Herschel space observatory. This is a region were massive star formation taking place. Cooler gas and dust is seen in red and yellow, The point-like sources shows where new stars are forming. The image is a composite of images made at 70 μm (blue), 160 μm (green) and 250 μm (red). The region covered is about 1.3° x 2.4°. North is up and east is to the left.

The Herschel space craft was launched in 2009 by ESA and was designed to operate from 55-672 μm.

Notes: Image is from: http://www.esa.int/Our_Activities/Space_Science/Highlights/Herschel_images

References: http://www.esa.int/Our_Activities/Space_Science/Herschel; https://en.wikipedia.org/wiki/Herschel_Space_Observatory

Detailed view of the Orion nebula (to the right) observed by the Herschel spacecraft. The image is a composite of images made at 70 microns (blue), 160 microns (green) and 250 microns (red). It covers a region of 4.5x1.5 degrees. The image is oriented with northeast towards the left of the image and southwest towards the right. To the left are the regions of NGC 2068 and NGC 2071.

Notes:

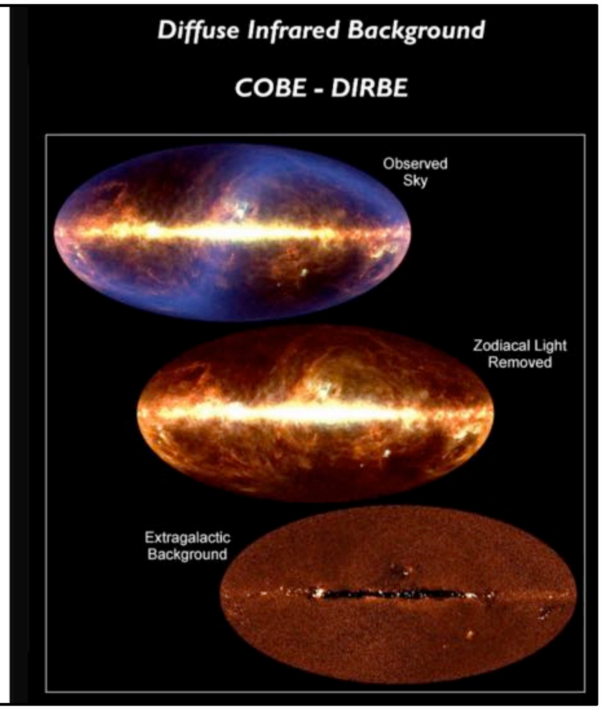
http://m.esa.int/var/esa/storage/images/esa_multimedia/images/2013/04/herschel_s_view_of_the_horsehead_nebula/12631139-1-eng-GB/Herschel_s_view_of_the_Horsehead_Nebula_article_mob.jpg

An illustration of the foreground emission subtraction process using sky maps from the DIRBE instrument on the COBE spacecraft. The map at the top is a false-color image showing the observed infrared sky brightness at wavelengths of 60 (blue), 100 (green) and 240 μm (red).

The background is a minimum at the ecliptic poles.

The subtraction of the zodiacal light and the Milky Way emission shows the Cosmic Infrared Background ("Diffuse Infrared Background) at 240 μm, which arises from unresolved background galaxies.

A. Tokunaga, Introduction to Infrared Astronomy, Univ. of Tokyo Visiting Professor Lecture, Feb. 2018



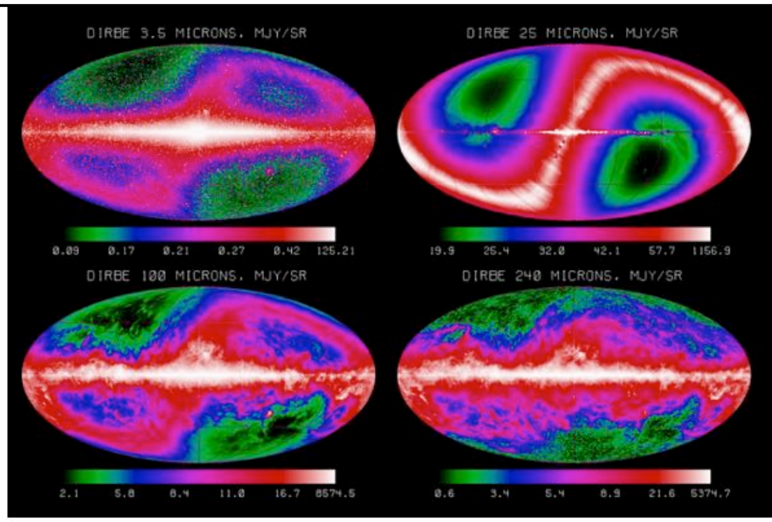
Notes: Image from: https://lambda.gsfc.nasa.gov/product/cobe/cobe_image_table.cfm

The Cosmic Background Observer (COBE) was launched in 1989 and was designed to measure the cosmic background radiation that resulted from the Big Bang.

Diffuse InfraRed Background Experiment (DIRBE) was a multi-wavelength infrared imager on COBE to observe dust emission. It observed at 1.25, 2.2, 3.5, 4.9, 12, 25, 60, 100, 140, 240 μicrometers.

Reference: https://lambda.gsfc.nasa.gov/product/cobe/; https://en.wikipedia.org/wiki/Cosmic_Background_Explorer

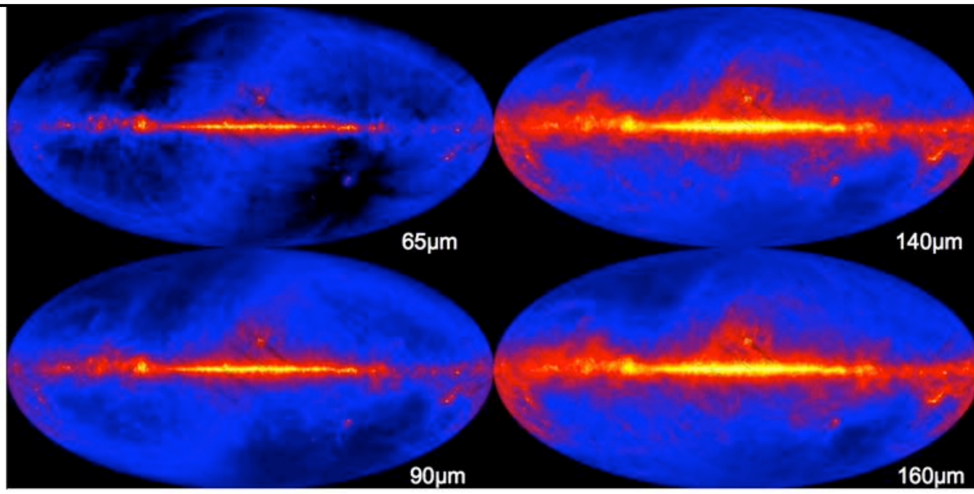
This is a Mollweide projection map, where relative areas of the sky is preserved but there is some distortion.



Zodaical light emission from interplanetary dust particles as measured by the DIRBE instrument on the COBE spacecraft. The S-shaped feature is the ecliptic plane. Note that the dust emission from the Milky Way galaxy is increasing with longer wavelength.

Notes: Image from: https://lambda.gsfc.nasa.gov/product/cobe/dirbe_image.cfm

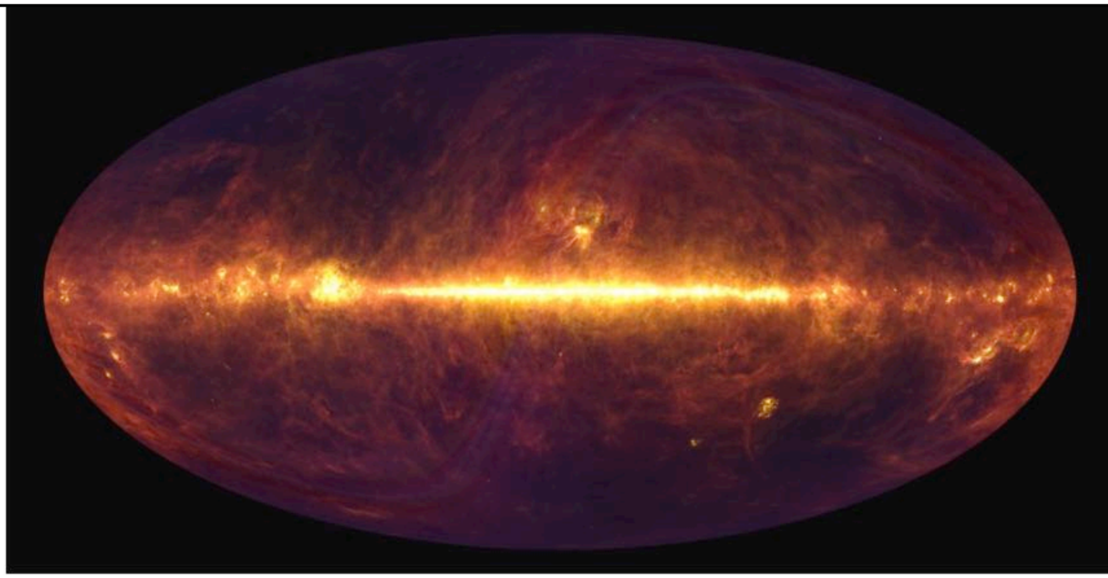
See also: Kelsall, T. et al. (1998). "The COBE Diffuse Infrared Background Experiment Search for the Cosmic Infrared Background. II. Model of the Interplanetary Dust Cloud." The Astrophysical Journal **508**: 44-73.



AKARI images of the galaxy. At these wavelengths the dust emission in the Milky Way galaxy dominates. The zodiacal light emission is most apparent at 65 μm.

Notes: Image is from: http://www.ir.isas.jaxa.jp/AKARI/Observation/support/WS/20150320_ASJ/FISmap_Doi_150320.pdf

References: http://www.ir.isas.jaxa.jp/AKARI/;



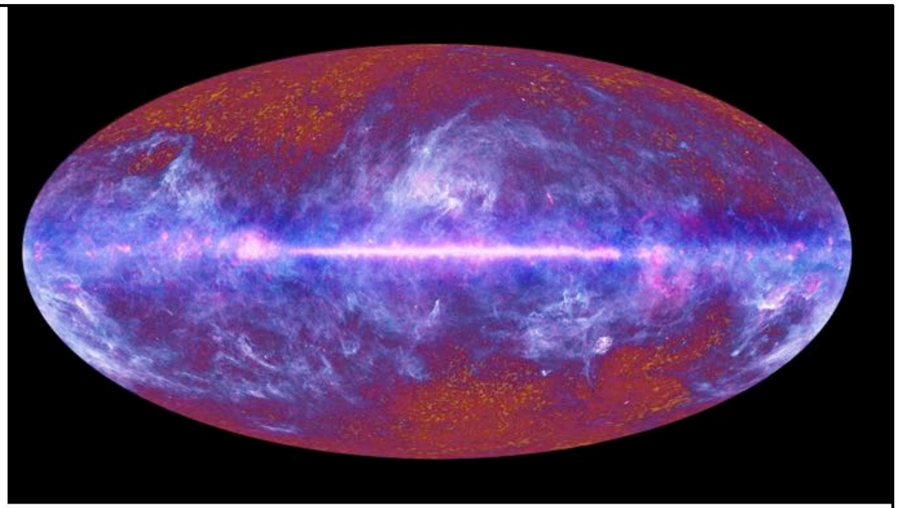
IRAS view of the interstellar dust emission.

Notes: Image from: https://lambda.gsfc.nasa.gov/product/foreground/f_images.cfm

IRAS 25, 60, and 100 um Composite Map Logarithmic scale

Maps from the Improved Reprocessing of the IRAS Survey (IRIS) were used to produce this 3-color composite image of the infrared sky. The 25, 60 and 100 um data are represented as blue, green, and red, respectively. Low-level residuals from removal of the zodiacal light show as stripes parallel to the ecliptic.

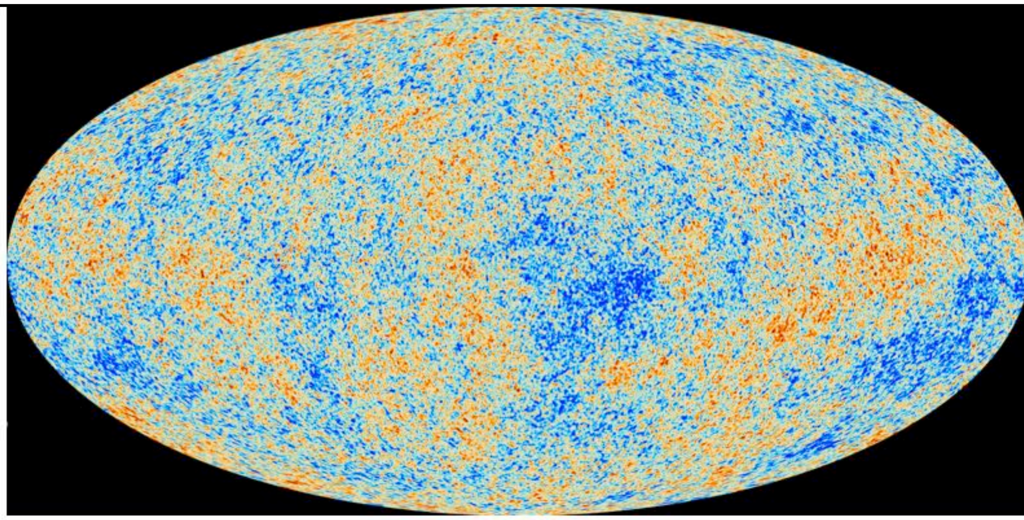
All-sky image of the sky was made from images obtained with the Planck spacecraft from 30 GHz to 857 GHz (350 μm to 10 mm). The central plane of the Milky Way galaxy goes across the center of this map. Diffuse emission from gas and dust show up in a bluish color. The Cosmic Microwave Background can be seen at high galactic latitudes where the gas and dust emission is very small.



The Planck spacecraft was launched by ESA in 2009 and it was designed to map the Cosmic Microwave Background following the initial measurements by COBE.

Notes: Image from: http://www.esa.int/spaceinimages/Images/2010/07/The_microwave_sky_as_seen_by_Planck3

References: http://www.esa.int/Our_Activities/Space_Science/Planck; https://en.wikipedia.org/wiki/Planck_(spacecraft)



The anisotropies of the Cosmic Microwave Background (CMB) as observed by Planck. Temperature fluctuations in the Cosmic Microwave Background (CMB) as observed by Planck. The fluctuations correspond to regions of slightly different densities that gave rise to the large scale structures in our universe. The CMB shows radiation emitted when the Universe was just 380,000 years old.

Notes: Image is from: http://www.esa.int/spaceinimages/Images/2013/04/Planck_CMB_black_background

The thermal infrared background in space

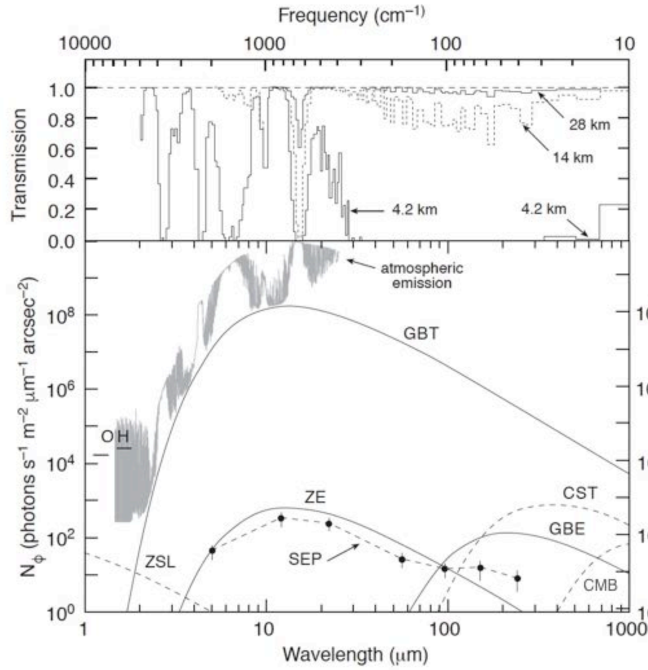
There are four primary sources of diffuse emission exists:

- Solar System – thermal emission from interplanetary dust particles. In the near-IR there is scattered sunlight from interplanetary dust particles.
- Galactic – interstellar dust emission with much fine structure
- Extragalactic – emission from unresolved sources
- Cosmic microwave background

Notes:

The main background emission sources are shown in this figure. Where specified they are blackbody functions reduced by the emissivity ε. In most cases, only the minimum background levels are plotted.

Figure caption. Transmission of the Earth's atmosphere at Mauna Kea (4.2 km), airborne (14 km), and balloon altitudes (28 km). Bottom: Background emission sources. The surface brightness is calculated from $N_\phi = \varepsilon\lambda B_\lambda/(hc) = 1.41\text{x}10^{16}\,\varepsilon\lambda^{-4} / (e^{14387.7/\lambda T} - 1)$ photons s^{-1} m^{-2} μm^{-1} $arcsec^{-2}$ (λ in μm, T in K). The intensity is derived from $\lambda B_\lambda = 8.45\text{x}10^{-9} N_\phi$ W m^{-2} sr^{-1} .



4- 12

Notes: The background in space comes from the solar system (zodiacal light), interstellar dust emission from the galaxy, emission from unresolved galaxies, and the cosmic microwave background.

GBT=Ground-Based Telescope; ZSL=Zodiacal Scattered Light, ZE=Zodiacal Emission, SEP=South Ecliptic Pole, CST=Cooled Space Telescope, GBE=Galactic Background Emission, CMB=Cosmic Microwave Background

Reference: Tokunaga, A. T. (2000). Infrared Astronomy. Allen's Astrophysical Quantities, 4th edition. A. N. Cox. New York, Springer-Verlag**:** 143.

Key to previous slide.

OH airglow	Average OH emission of 15.6 and 13.8 mag arcsec^{-2} at J and H, respectively (see slides 3.2-3.5, 3.10).
GBT	Ground-based telescope thermal emission, optimized for the thermal infrared and approximated as a 273-K blackbody with e = 0.02. Emission from the Earth's atmosphere at 1.5-25 μm is shown (see slides 3.18 - 3.19.
ZSL	Zodiacal scattered light at the ecliptic pole, approximated as a 5800-K blackbody with e = 3x10^{-14} ; see also Kelsall et al. (1998), Tsumura et al. (2010).
ZE	Zodiacal emission from interplanetary dust at the ecliptic pole, approximated as a 275-K blackbody with e = 7.1x10^{-8}. Based on observations from the Infrared Astronomical Satellite (IRAS); Kelsall et al. (1998), Leinert et al. (1998).
GBE	Galactic background emission from interstellar dust in the plane of the galaxy. In regions away from the Galactic Center, it can be approximated by a 17-K blackbody and e = 10^{-3}; Sodroski et al. (1994), Cox and Mezger (1989).
SEP	South ecliptic pole emission as measured by the Cosmic Background Explorer (COBE) spacecraft; Wright (1993).
CST	Cryogenic space telescope, cooled to 10 K with e = 0.05.
CMB	Cosmic Microwave Background, 2.73-K blackbody with e = 1.0; Mather et al. (1994).

References:

Roche, P. F. (2004). "Mid-infrared instruments on the Gemini 8-m telescopes." Advances in Space Research **34**: 583-588.

Kelsall, T. et al. (1998). "The COBE Diffuse Infrared Background Experiment Search for the Cosmic Infrared Background. II. Model of the Interplanetary Dust Cloud." The Astrophysical Journal **508**: 44-73.

Tsumura, K. et al. (2010). "Observations of the Near-infrared Spectrum of the Zodiacal Light with CIBER." The Astrophysical Journal **719**: 394-402.

Leinert, C. et al. (1998). "The 1997 reference of diffuse night sky brightness." Astronomy and Astrophysics Supplement Series **127**: 1-99.

Sodroski, T. J. et al. (1994). "Large-scale characteristics of interstellar dust from COBE DIRBE observations." The Astrophysical Journal **428**: 638-646.

Cox, P. and P. G. Mezger (1989). "The Galactic infrared/submillimeter dust radiation." Astronomy and Astrophysics Review **1**: 49-83.

Wright, E. L. (1993). COBE experience. Infrared Spaceborne Remote Sensing, SPIE, **2019:** 158-166.

Mather, J. C. et al. (1994). "Measurement of the cosmic microwave background spectrum by the COBE FIRAS instrument." The Astrophysical Journal **420**: 439-444.

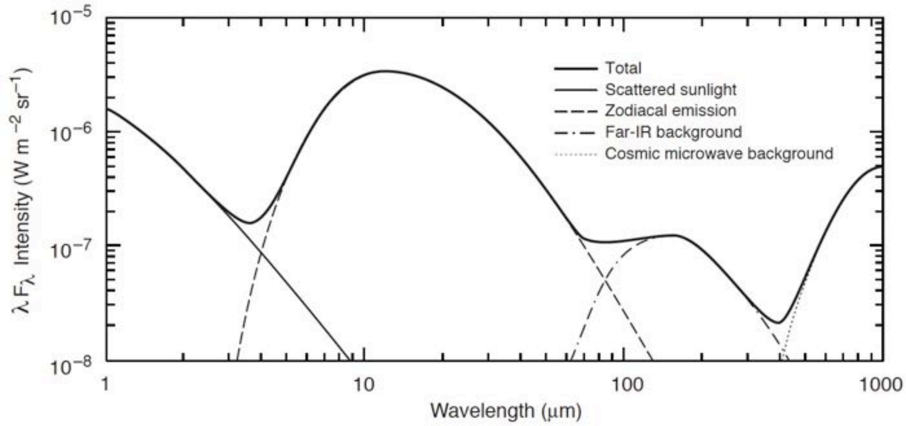
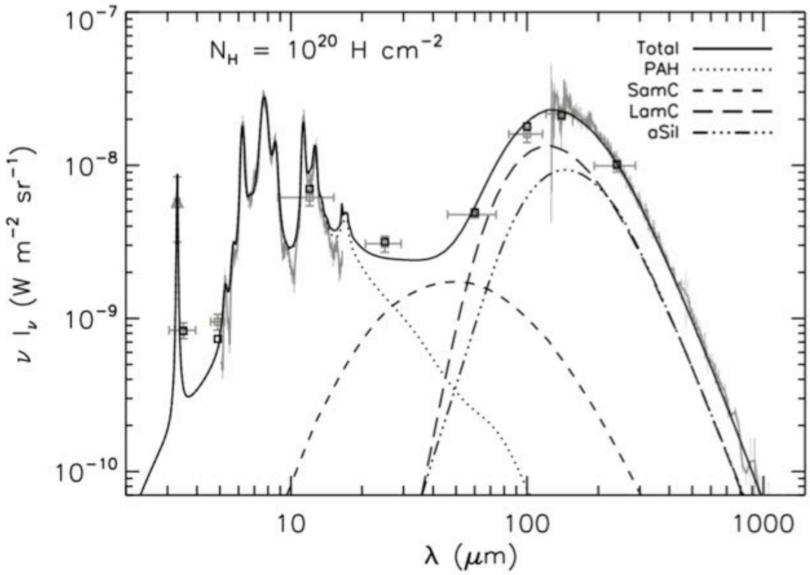


Illustration of the infrared background in the direction of the ecliptic pole. Scattered sunlight from interplanetary dust particles (zodiacal light) dominate at wavelengths less than 3 μm. Between 3 and 100 μm, emission from interplanetary dust particles (zodiacal light) dominate. The minimum in background near 3 μm has been exploited with the IRAC camera on the Spitzer spacecraft. The far-infrared background is roughly due half to background galaxies and half due to interstellar dust.

Notes: This is a very simplified plot. It shows that the background in space has three main components: (1) scattered light and emission from dust particles in the solar system (zodiacal light), (2) far-infrared emission from cold dust in the interstellar medium and unresolved background galaxies, and (3) the cosmic microwave background from the Big Bang.

The background varies greatly depending on where you are looking relative to the ecliptic and the plane of the Milky Way galaxy as can be seen from the slides 3.1 - 3.7.

The dust emission from the galaxy has a complicated spectrum arising from the carbonaceous and silicate components (Compiegne et al. 2011).



Notes: Reference: Compiègne, M., L. et al. (2011). "The global dust SED: tracing the nature and evolution of dust with DustEM." Astronomy and Astrophysics **525**: A103.

Strong emission bands at 8-20 micrometers from carbonaceous material in the interstellar medium (PAH or UIR emission) are seen. Carbon and silicate dust particles also contribute to the total emission spectrum.

List of IR space observatories:

1983 Infrared Astronomy Satellite (IRAS; 0.57m)
1989 Cosmic Background Explorer (COBE; 0.19m)
1995 Infrared Space Observatory (ISO; 0.60m)
1995 Infrared Telescope in Space (IRTS; 0.15m)
1996 Midcourse Space Experiment (MSX; 0.35m)
1998 Submillimeter Wave Astronomy Telescope (SWAS; 0.55m x 0.71m)
2001 Wilkinson Microwave Anisotropy Probe (WMAP; 1.4m x 1.6m)
2003 Spitzer Space Telescope (SST; 0.85m)
2006 Akari (0.67m)
2009 Wide-field Infrared Survey Explorer (WISE; 0.40m)
2009 Herschel Space Observatory (3.5m)
2009 Planck (1.9m x 1.5m)

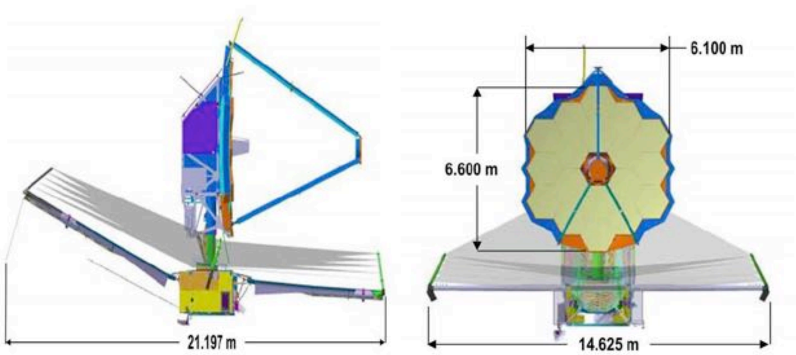
2019 James Webb Space Telescope (JWST; 6 m)

Notes: This slide was presented earlier. Reminder of the long heritage of space observatories and the data that is available in the archives.

Now I will discuss the backgrounds in space in the context of JWST, Herschel, and SPICA (a possible future space observatory).

James Webb Space Telescope (JWST; 6 m)

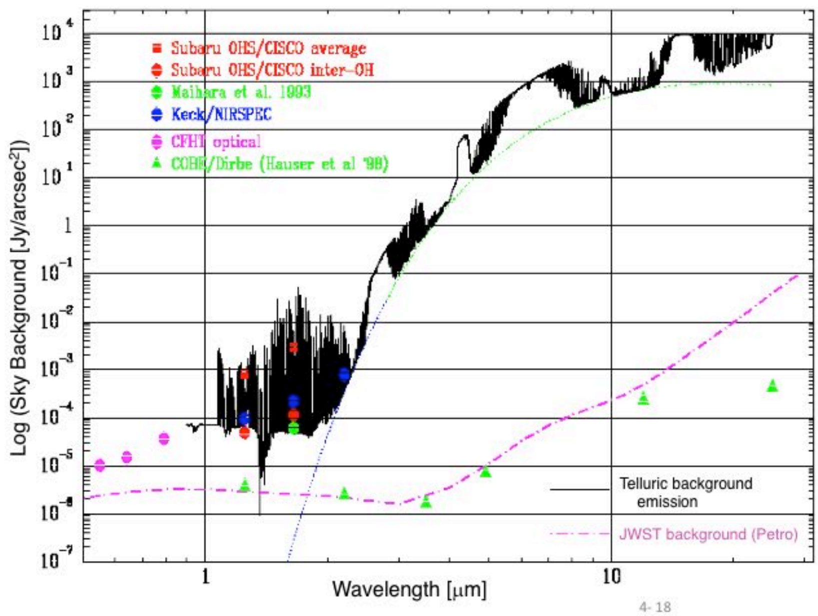
- 25 m^2 collecting area (equivalent to a 5.6 m diameter mirror)
- Mirror operating temperature ~50K
- Diffraction limited at 2 μm
- Imaging, coronagraphy, multi-object spectroscopy at 0.6-5.0 μm
- Imaging, coronagraphy, integral field spectroscopy at 5-29 μm



Notes: Brief overview of JWST. More detailed description in a later lecture.

JWST background compared to ground-based telescopes.

Note that the thermal background from the ground-based telescope crosses over the background from space at about 1.7 μm. Therefore at wavelengths shorter than 1.7 μm a ground-based telescope has more sensitivity in between the OH lines. Stated in another way, for resolving power higher than about 1000, a ground-based telescope is more sensitive in between the OH lines. Figure is from Greenhouse (2009).

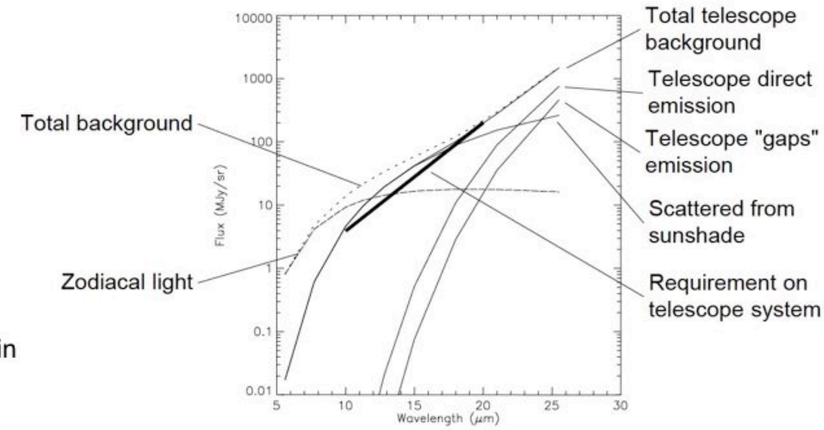


Notes: M. Greenhouse, 2009, presentation on "James Webb Space Telescope (JWST) Mission Overview".

Thermal background for JWST is dominated by zodiacal light emission and scattered light from the sunshade (figure from Swinyard et al. 2004).

At wavelengths less than 5 μm, the background is dominated by the zodiacal light (scattered light and emission from dust particles in the solar system).

Note that the telescope mirror is cooled to about 50K and it is a significant contributor at wavelengths greater than 18 μm.

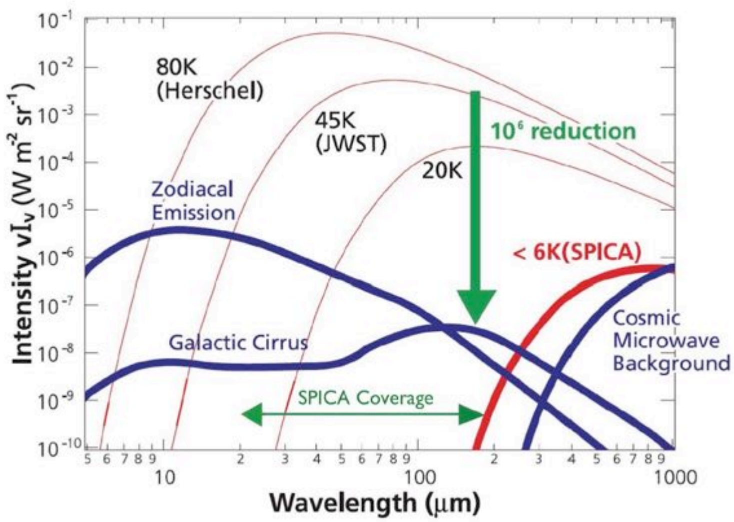


Notes:

Swinyard, B. M. et al. (2004). Sensitivity estimates for the mid-infrared instrument (MIRI) on the JWST. Optical, Infrared, and Millimeter Space Telescopes, SPIE, **5487:** 785-793.

This figure shows the cosmic background emission sources (zodiacal, galactic, microwave background) compared to the telescope thermal emission from Herschel, JWST, and SPICA (Nakagawa et al. 2014). This figure shows a 10^6 reduction in background can be achieved with a cooled telescope.

SPICA is a cooled space telescope that achieves background limited observations to be made at 20-200 μm. It is currently under study by Japan and the European Space Agency.



Notes: Both Herschel and JWST are passively cooled by letting the telescope come to equilibrium with space background emission.
JWST comes to a cooler temperature because it has a large sunshield. The operational temperature of the Herschel telescope mirror was about 85K. The operational temperature of the JWST mirror is planned to be about 50K.

SPICA = Space Infrared Telescope for Cosmology and Astrophysics
The current goal is that SPICA will have an aperture of 2.5 m, the same as Herschel but actively cooled to 4-6 K.

Nakagawa, T. et al. (2014). The next-generation infrared astronomy mission SPICA under the new framework. Space Telescopes and Instrumentation, SPIE, **9143**.
Pilbratt, G. L. et al. (2010). "Herschel Space Observatory. An ESA facility for far-infrared and submillimetre astronomy." Astronomy and Astrophysics **518**: L1.

For a discussion on the background emission in space, see Denny, S. P. et al. (2013). "Fundamental limits of detection in the far infrared." New Astronomy **25**: 114-129.

Links to archives from space missions

IRSA - overplotting data sets
http://irsa.ipac.caltech.edu/Missions/missions.html : list of all missions in IRSA
http://irsa.ipac.caltech.edu/applications/finderchart/ : making finder charts
http://irsa.ipac.caltech.edu/Missions/2mass.html : making 2MASS finder charts

ESA
https://www.cosmos.esa.int/web/esdc

Data ARchives and Transmission System (DARTS)
http://darts.isas.jaxa.jp/astro/akari/cas/tools/index.html
http://darts.isas.jaxa.jp/about.html.en

STScI object search tools
https://mast.stsci.edu/portal/Mashup/Clients/Mast/Portal.html : main portal
http://archive.stsci.edu/panstarrs/search.php : Pan-STARRS all sky images

Aladin Sky Atlas
http://aladin.u-strasbg.fr/

Notes:
There is a tremendous amount of data that can be retrieved from online databases. Perusing these databases will be useful in future work.