# Radio Waves

**Jigsaw Card**





Intensity of the radio continuum emission from the disk of the Milky Way at 408 MHz (top) and 2.4-2.7 GHz (bottom). These radio wavelengths show astronomers where electrons are being accelerated through a variety of processes. (Credit: Haslam, et. al (1982), A&AS, 47, 1; Duncan, et. al (1995) MNRAS, 277, 36; Fuerst, et. al (1990) A&AS, 85, 691; Reich, et al. (1990), A&AS, 85, 633)

Radio emission reveals a few different things about the Milky Way depending on which part of the radio spectrum we observe. Parts of the radio continuum tell us about where electrons are being accelerated in the galaxy. Other parts tell us about where hydrogen lies in the Milky Way.

Radio continuum emission comes from electrons accelerated through one of two different processes. The 408MHz continuum, shown above, primarily shows us places in the Milky Way where electrons are accelerated by the interstellar magnetic field at nearly the speed of light. As the electrons are accelerated, they spiral around the magnetic field lines and emit radiation at radio wavelengths. In the 2.4-2.7 GHz range, some of the bright spots also show where electrons are accelerated in magnetic fields. In that part of the continuum, though, we also see light emitted by electrons accelerated by protons in the hot, ionized gases of emission nebula.

NASA Imagine the Universe. (2016). *Multiwavelength Milky Way*. Retrieved from https://imagine.gsfc.nasa.gov/science/objects/milkyway2.html

Explore *Radio Astronomy*. Start by looking at <https://public.nrao.edu/radio-astronomy/> and then do some exploring on your own.

Jot down some information about radio astronomy, including what scientists have learned about our galaxy and universe from the field and objects that emit radio waves.

# Infrared Light

**Jigsaw Card**







Infrared views of the plane of the Milky Way. The top image shows a composite of mid- and far-infrared observed by IRAS (3,000-25,000 GHz). The middle image is mid-infrared observed by the MSX satellite (28,000-44,000 GHz). The bottom image shows near-infrared as observed by COBE (86,000-240,000 GHz). (Credit: Wheelock (1994) IRAS Sky Survey Atlas Explanatory Supplement, JPL Publication 94-11; Price (2001) AJ, 121, 2819; Hauser (1995) COBE Diffuse Infrared Background Experiment Explanatory Supplement, Version 2.0, COBE Ref. Pub. No. 95-A (Greenbelt, MD: NASA/GSFC))

Infrared light does not get absorbed as easily as optical light, so infrared observations peer farther into the plane of the Milky Way than optical telescopes. Shorter wavelengths of infrared light reveal stars in the Milky Way while longer wavelengths show interstellar dust warmed by starlight.

Infrared light can help us find young stars that are embedded in their parental molecular clouds – these clouds obscure our view in visible light, but are nearly transparent to infrared light. These are visible in the images above as small bright spots.

When light from stars encounters interstellar dust, it warms it, making it shine in infrared light. By observing longer infrared wavelengths, we can trace clouds of interstellar dust. This is seen in the images above by diffuse emission throughout the plane of the Milky Way.

NASA Imagine the Universe. (2016). *Multiwavelength Milky Way*. Retrieved from https://imagine.gsfc.nasa.gov/science/objects/milkyway2.html

Explore *Infrared Astronomy*. Start by looking at <http://coolcosmos.ipac.caltech.edu/infrared_universe> and then do some exploring on your own.

Jot down some information about infrared astronomy, including what scientists have learned about our galaxy and universe from the field and objects that emit infrared light.

# Visible Light

**Jigsaw Card**



Optical view (0.4 - 0.6 micron) of the plane of the Milky Way. (Image courtesy of Mellinger, A., Milky Way Panorama)

Optical observations of the Milky Way are probably the most familiar. One challenge, though, is that optical light is absorbed quickly by interstellar gas and dust, so we can't see as far as we can in some other wavelengths.

Due to the strong obscuring effect of interstellar dust, the optical light shown above is primarily from stars within a few thousand light-years of the Sun, nearby on the scale of the Milky Way. We can also see bright red regions produced by glowing gas. The dark patches are due to absorbing clouds of gas and dust, which can be see in the molecular hydrogen and infrared maps as emission regions.

NASA Imagine the Universe. (2016). *Multiwavelength Milky Way*. Retrieved from https://imagine.gsfc.nasa.gov/science/objects/milkyway2.html

Explore *Optical Astronomy*. Start by looking at <https://www.noao.edu/about-noao.php> and then do some exploring on your own.

Jot down some information about optical astronomy, including what scientists have learned about our galaxy and universe from the field and objects that emit optical (visible) light.

# Ultraviolet Light

**Jigsaw Card**



Ultraviolet view of the plane of the Milky Way from GALEX data. The black bands are places where there is no data. (Credit: D. Schiminovich (Columbia), M. Seibert (OCIW) and GALEX science team, led by Prof. C. Martin at Caltech)

The ultraviolet band is where we see the stars that heat up the interstellar medium and star forming regions that are present in the maps of the other wavebands.

Young, hot stars emit light in ultraviolet wavelengths which, in turn, heats the surrounding hydrogen gas. Visible in the image above are stellar clusters, wisps of emission from supernova remnants, and pronounced dusty absorption features surrounding star-forming regions and molecular clouds in the Milky Way's disk.

NASA Imagine the Universe. (2016). *Multiwavelength Milky Way*. Retrieved from https://imagine.gsfc.nasa.gov/science/objects/milkyway2.html

Explore *Ultraviolet Astronomy*. Start by looking at <http://www.galex.caltech.edu/index.html> and then do some exploring on your own.

Jot down some information about ultraviolet astronomy, including what scientists have learned about our galaxy and universe from the field and objects that emit ultraviolet light.

# X Rays

**Jigsaw Card**



Soft X-ray view (0.25, 0.75, and 1.5 keV) of the plane of the Milky Way from ROSAT observations. (Credit: Snowden (1997) ApJ, 485, 125)

In the Milky Way, we see X-rays from hot gas, binary star systems, young stars and stellar clusters, supernova remnants, and matter falling into our galaxy's central black hole.

Soft (lower energy) X-ray emission is detected from hot, shocked gas. At the lower energies especially, the interstellar medium strongly absorbs X-rays, and we see cold clouds of interstellar gas as shadows against background X-ray emission. Color variations indicate variations of absorption or of the temperatures of the emitting regions.

NASA Imagine the Universe. (2016). *Multiwavelength Milky Way*. Retrieved from https://imagine.gsfc.nasa.gov/science/objects/milkyway2.html

Explore *X-Ray Astronomy*. Start by looking at <http://chandra.harvard.edu/field_guide.html> and then do some exploring on your own.

Jot down some information about x-ray astronomy, including what scientists have learned about our galaxy and universe from the field and objects that emit x-ray light.

# Gamma Rays

**Jigsaw Card**



Gamma-ray view (500 GeV - 2 TeV) of the plane of the Milky Way from 6 years of Fermi data. (Credit: NASA/DOE/Fermi LAT Collaboration)

Most of the gamma-ray objects we detect originate from outside the Milky Way. However, we do see gamma-ray background emission from collisions of cosmic rays with hydrogen nuclei in interstellar clouds and emission associated with a few bright compact objects like pulsars.

The above shows gamma-rays observed by the Fermi Gamma-ray Space Telescope with energies between 500 GeV and 2 TeV. Most of the gamma rays shown are from collisions between cosmic rays and hydrogen nuclei. However, a few bright sources can be seen as well. These pulsar wind nebulae and supernova remnants.

In addition to seeing a gamma-rays from the disk of the Milky Way, the Fermi Gamma-ray Space Telescope also discovered huge lobes of gamma-ray emission above and below the plane of the Milky Way. These lobes of gamma-ray emitting gas extend more than 25,000 light years above and below the plane of the Milky Way and astronomers are still working to figure out their nature and origin.

NASA Imagine the Universe. (2016). *Multiwavelength Milky Way*. Retrieved from https://imagine.gsfc.nasa.gov/science/objects/milkyway2.html

Explore *Gamma-Ray Astronomy*. Start by looking at <https://fermi.gsfc.nasa.gov/> and then do some exploring on your own.

Jot down some information about gamma-ray astronomy, including what scientists have learned about our galaxy and universe from the field and objects that emit gamma-ray light.