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Kinds of Astronomy-5

Astronomers study light and basically, almost everything we know about the universe has been figured out through the study of light gathered by telescopes on the earth, in the earth's atmosphere, and in space.

This light comes in many different colors, the sum of which comprises what is commonly known as the electromagnetic (EM) spectrum. Unfortunately, the earth's atmosphere blocks almost all of wavelengths in the EM spectrum. Only the visible (400-700nm) and radio (~1-150m) "windows" are accessible from the ground, and thus have the longest observational "history." These early restrictions on the observational astronomer also gave rise to classifying "kinds" of astronomy based on their respective EM portion, such as the term "radio astronomy."

Over the past few decades, parts of the infrared (1-30μm) and sub-mm (300μm-1mm) have become accessible to astronomers from the ground, but the telescopes required have to be placed in high altitude (>14,000ft) locations or at the South Pole where water absorption is minimal. Other options have included balloon experiments, airborne telescopes, and short-lived rocket experiments.

Presently, the field of astronomy is enriched immensely by the accessibility of several high caliber airborne (e.g., Kuiper Airborne Observatory (KAO), Stratospheric Observatory For Infrared Astronomy (SOFIA)) and space telescopes, all which are opening up the other, previously blocked windows (gamma ray, X-ray, ultra-violet, far infrared, millimeter, microwave) of the EM spectrum. Additionally, modern astronomers often need to piece together information from different parts of the EM spectrum to build up a picture of the physics/chemistry of their object(s) of interest. Table 1 summarizes some links between wavelength, objects/physics of interest, and a few examples of current/planned observing platforms. It is by no means complete, but can give the reader a flavor of how the field of astronomy today varies across wavelength, and hence, the energy of the object sampled.

The field of astronomy itself is also quite vast in terms of the physical nature, location, and frequency of object types to study. We can perhaps break down the field into four large "kinds" or categories:

1. solar & (recently) extra-solar planets and planet formation, star formation and the interstellar medium;
2. stars (including our Sun) and stellar evolution;
3. galaxies (including the Milky Way) and stellar systems (clusters, superclusters, large scale structure, dark matter); and
4. cosmology and fundamental physics.

One of the most important developments in the first category over the past few years has been the detection of several planets orbiting other stars along with the detections of sub-stellar objects (brown dwarfs) through deep infrared sky surveys (e.g., Sloan Digital Sky

Survey) whose spectral characteristics have been found to be similar to that of giant planets (e.g., methane, water vapor). Additionally with superb Hubble Space Telescope (HST) imaging with its infrared (IR) camera and IR instruments on large ground based telescopes, astronomers have started to observe directly the proto-stellar disks out of which planets are forming.

We have learned that the formation of stars and these disks start in the interstellar medium (ISM), the vast "vacuum" of gas and dust between the stars, but we are only just learning what the structure of the ISM really is and how it affects and is affected by stellar birth (dust enshrouded stars) and death (planetary nebulae and supernovae). Another step forward is to understand star formation in other galaxies, for we readily see active star formation in the arms of spiral galaxies and in the collisions of galaxies.

The study of stars and their evolution (Category 2) is perhaps one of the oldest sub-fields of astronomy, and has benefited greatly from observational evidence dating back over hundreds of years. It is the core of astronomy as since stars are truly the fundamental blocks of the universe, creating and destroying chemical elements, acting as light posts in galaxies, and giving insights into understanding mysterious phenomena such as black-holes and gamma-ray bursts. The Chandra X-ray satellite, for example, has recently detected new classes of black holes and is giving astronomers new information about exploding stars. Understanding such exotic and high energy events are critical to the advancement of astronomy and fundamental physics, where such "events" occur in conditions impossible to create on Earth. We are even continuing to learn new things about the nearest star, our Sun, through recent amazing images (e.g., solar storm activity) from the Solar and Heliospheric Observatory (SOHO) satellite.

In so much as stars are the building blocks of galaxies, galaxies are the building blocks of the universe, and the study of their types, sizes, distribution, and interactions with neighbors (Category 3) is essential to understanding the nature and future of our universe. The study of the earliest galaxies, or "seeds" of galaxies is the main driver behind building larger ground based telescopes and more sensitive IR space telescopes such as the Space InfraRed Telescope Facility (SIRTF) and the Next Generation Space Telescope (NGST). We know from the deepest HST images (e.g., Hubble Deep Field), that the early universe is composed of many irregular, active, star formation rich galaxies. We do not know however, is how such a chaotic early universe could have evolved to what we see in our local group, whose component galaxies are quite different.

Among the many mysteries in the universe, astronomers are still sketchy about dark matter in galaxies and clusters. We know little about its amount (speculated to be about 10-100x greater than the observed mass), structure, location, and make-up, despite evidence from beautiful HST pictures of gravitational lenses and X-ray observations detecting hot gasses in galaxy clusters by recent sensitive X-ray telescopes (e.g., German Röntgensatellit (ROSAT), Japanese Advanced Satellite for Cosmology and Astrophysics (ASCA), American Chandra).

Another very active field in Category 3 is the study of elusive quasars, observed out to a redshift of 5, when the universe was less than 10% of its present age. Recent far infrared and X-ray data have revealed a large population of these objects, indicating that many of these objects might be heavily obscured by dust, and therefore not previously seen by earlier visible light surveys. We know very little about the power mechanisms of these objects, and this field is very "active" topic for today's radio, X-ray, and gamma ray astronomers.

The fourth category is perhaps the most elusive and yet also the most important aspect of astronomy as since it encompasses all the other three categories. Cosmology literally means "the study of the beginning of the universe." However, cosmologists strive to answer questions not only about the universe's origin, but its evolution, contents, and its future or perhaps, end.

It is now widely believed that the universe started with a "big bang," with the most conclusive evidence being the detection of the predicted 3K cosmic background by the Cosmic Background Explorer (COBE) satellite in 1997, perhaps one of the greatest astronomical measurements this century. Other recent advances in this sub-field have been through 1) all-sky IR surveys (e.g., InfraRed Astronomical Satellite (IRAS)) which have mapped out the distribution of galaxies across the sky (to investigate structure development), 2) more observational evidence (from HST, X-ray observations of gas, and discovery of very distant supernovae) in tying down the rate of expansion of the universe

(Hubble's constant) and its deceleration parameter, and 3) increased computing power for numerical simulations which attempt the solve the ever present many-bodied problem.

We only can comprehend our universe through what we can see (limited by our instrument's sensitivity), what we can infer from observational data and numerical simulations, and what is supported by theory. As time as progressed, so has the toolkit of the astronomer, from easier access to satellites, large ground based telescopes, arrays of telescopes around the world working as one, computing power, and more sensitive cameras and spectrometers. As long as there is a way to improve our detection techniques and strategies, astronomers will never run out of new discoveries or re-discoveries on different scales or wavelengths among the many "kinds" of astronomy.

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**Infrared Astronomy**

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**Microwave & Radio Astronomy**

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| Approximate Wavelengths (m) | Wavelengths Other units | Photon energies greater than | Frequency | Name for spectral band | Produced by temperatures in region of (K) | Examples of astrophysical objects of interest | Examples of present/planned telescopes to use for observations |
|---|---|---|---|---|---|---|---|
| $10^{-13}$<br>$10^{-12}$<br>$10^{-11}$ | | 80.6MeV<br>8.06MeV<br>0.8MeV | | Gamma-ray | $10^{8}$ | Cosmic rays, gamma-ray bursters | Space only: CGRO (1991-2000), INTEGRAL (2002-), GLAST (2005-) |
| $10^{-10}$<br>$10^{-9}$ | 1Å, 0.1nm<br>10Å, 1nm | 80.6keV<br>8.06keV | | Hard X-ray | $10^{7}$ | Accretion disks in binaries, black holes, hot gas in galaxy clusters, Seyfert galaxies | Space only: ROSAT (1990-99), ASCA (1993-), Chandra (1999-), XMM (2000-) |
| $10^{-8}$ | 100Å, 10nm | 0.806keV | | Soft X-ray | $10^{6}$ | Supernovae remnants, neutron stars, X-ray stars, superbubbles | |
| $10^{-7}$ | 1000Å, 100nm | 80eV | | XUV/EUV Far UV | $10^{5}$ | White dwarfs, flare stars, O stars, plasmas | Space only: EUVE (1992-), FUSE (1999-) |
| $2 \times 10^{-7}$ | 200nm | | | Ultraviolet | $10^{5}$ | Hot/young stars, Orion-like star nurseries, interstellar gas, helium from the big bang, solar corona, Ly alpha forest sources | Space only: HST (1990-), Astro-1/2 (1990, 1995), SOHO (1996-) |
| $4 \times 10^{-7}$ | 400nm | | | Violet / Visible | $10^{4}$ | B stars, spiral galaxies, nebulae, Cepheids, QSOs | Ground: Keck, Gemini (1999-), Magellan (1999-), Subaru (1999-), VLT (1999-), MMT (2000-)<br>Space: HST |
| $7 \times 10^{-7}$ | 700nm | | | Red | $10^{4}$ | K, M stars, globular clusters, galaxy mass | |
| $8\text{–}50 \times 10^{-7}$ | 0.8-5μm | | | Near Infrared | $10^{3}$ | Circumstellar dust shells, comets, asteroids, high z galaxies, brown dwarfs | Ground: CHFT, CTIO, IRTF, Keck, Magellan, Subaru, UKIRT, VLT<br>Space: HST |
| $5\text{-}30 \times 10^{-6}$ | 5-30μm | | | Mid-infrared | | Cool interstellar dust, PAHs, organic molecules, planetary nebulae, molecular hydrogen | Ground: IR optimized telescopes: IRTF, UKIRT, Gemini<br>Airborne: SOFIA (2005-)<br>Space: ISO (1995-98), SIRTF (2002-) |
| $3\text{-}20 \times 10^{-5}$ | 30-200μm | | | Far infrared | | Ultraluminous/starburst galaxies, debris disks, Kuiper Belt Objects | Airborne: SOFIA<br>Space: ISO, SIRTF |
| $3.5\text{-}10 \times 10^{-4}$ | 350μm-1mm | | | Sub-millimeter | 100 | High z galaxies/proto-galaxies; molecular clouds; interstellar dust | Ground: HHT, JCMT, SMA (1999-)<br>Space: SWAS (1998-) |
| $10^{-3}$ | 1mm | | 300,000MHz, 300GHz | Millimeter | | Molecules in dark dense interstellar clouds (CO) | Ground: IRAM |
| $10^{-2}$ | 1cm | | 30,000MHz, 30GHz | Microwave | 10 | Cosmic microwave background | Space: COBE (1989-), MAP (2001-) |
| $10^{-1}$ | 10cm | | 3000MHz, 3GHz | | 1 | Galaxy studies, Hydrogen clouds (21cm), masers | |
| 1 | 1m | | 300MHz | Radio | <1 | Quasars, radio galaxies, hot gasses in nebulae | Ground: Arecibo, VLA, VLBA, MERLIN<br>Space: VSOP (1997-) |
| 10 | 10m | | 30MHz | | | Synchroton radiation (electronics spiraling in magnetic fields) from supernovae remnants, magnetic lobes of radio galaxies | |
| $10^{2}$ | 100m | | 3MHz | | | | |
| $10^{3}$ | 1km | | 300kHz | Long wave | | We don't have any data yet. We could explore cosmic ray origins, pulsars, supernovae remnants, look for coherent emission. | No missions planned, space only due to opaqueness of earth's ionosphere. Lunar telescope(s) perhaps? |
| $10^{4}$ | 10km & greater | | <30kHz | Very long wave/very low frequency | | | |

Table 1. Different "kinds" of astronomy separated by wavelength. Adapted and expanded from J.K. Davies, Astronomy from Space, 1997, Table 1.1, p. 2.