Sec 4.1.4 – 4.2.2

McLean seminar
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Sec 4.1.4 The Two Micron All Sky Survey (2MASS)

- **In 1960s: survey of about 70% of the sky at 2.2 μm**
- Using only a small telescope and single-element detectors -> reveal 5,700 sources

- **In mid-1980s, digital infrared array cameras + a pair of 1.3m telescopes**
  -> Two Micron All Sky Survey (2MASS),
  - equipped with a three-channel infrared camera
  - three infrared bands: J (1.25 μm), H (1.65 μm), and Ks (2.17 μm).
  - Pixel resolution of about 2 seconds of arc

- **All-Sky Release data:**
  - Point Source Catalog: positions and brightness for over 470 million objects
  - Extended Source Catalog: positions, magnitude, and basic shape information for nearly 1.6 million resolved sources
  - Image Atlas: nearly 5 million J, H, and Ks image

Sec 4.1.4 The Two Micron All Sky Survey (2MASS)

Importance of 2MASS:

- free from the obscuring effects of interstellar dust
- reveled the true distribution of luminous mass
- first all-sky photometric census of galaxies brighter than Ks = 14.5 mag
- including galaxies in the 60° wide "Zone of avoidance"
    - Zone of avoidance: dust within the Milky Way renders optical galaxy surveys incomplete
- provides a rich statistical data base (> 1,000,000 galaxies)
- including photometric measurements and structural parameters
- statistical basis to search for rare but important objects
- previously unknown galaxies were revealed by the survey

Sec 4.1.4 The Two Micron All Sky Survey (2MASS)

At longer infrared wavelength, use space telescope

➔ In 1980s, the Infrared Astronomical Satellite (IRAS):

- low-resolution all-sky survey at 12 μm, 20 μm, 60 μm, and 100 μm
- realization that faint emitting clouds covered much of the Galaxy
- some distant galaxies were extremely luminous

- Now we have all-sky survey from radio (73.5 cm) to gamma rays (<1.2 x 10^{-12} cm)

Sec 4.1.5 Deep imaging in selected fields

- **Hubble Deep field (HDF):**
  - digital image of a very small patch of sky observed with and extremely long exposure
  - 10 consecutive days
  - assembled from 342 separate CCD exposures using the Wide Field and Planetary Camera 2
  - Four broad filters to cover the ultraviolet to near-infrared: F300W, F450W, F606W, and F814W

Sec 4.1.6 Diffraction-limited imaging

- Space telescopes: provide diffraction-limited images from the near-UV to far-IR

➔ Advent of adaptive optics changed this advantage

- adaptive optics : carried out motion of stars located close to the physical center of our Galaxy
  - it is difficult to distinguish individual stars in seeing-limited images
  - adaptive optics: overcome atmospheric turbulence
  - largest possible telescopes to get the smallest angular resolution
  - AO images can be used to rack the motions of the stars
  - classical orbital mechanics of Newton can be used to derive the enclosed mass

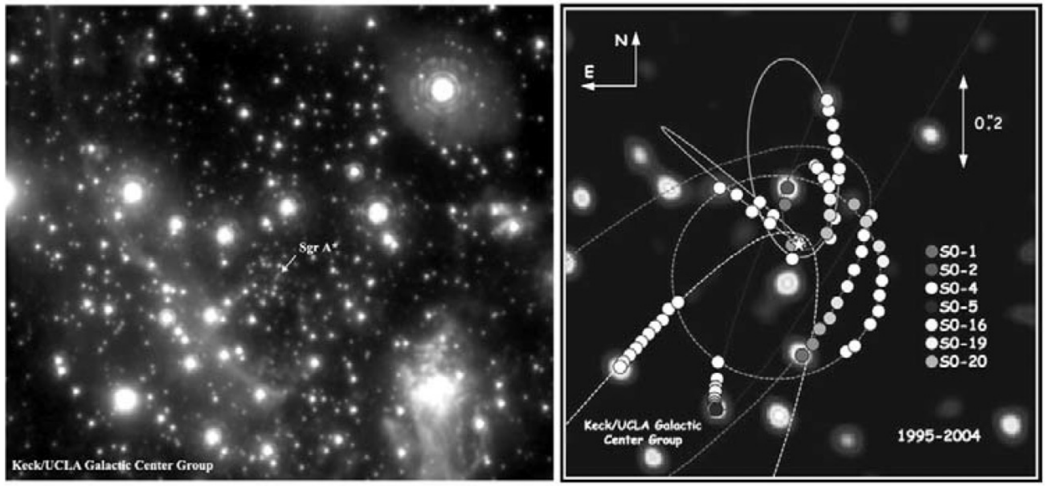


Figure 4.8. Left: a diffraction-limited infrared image of the Galactic Center using laser guide star adaptive optics on the Keck II telescope (see also Plate 10); the image is 10 × 10 arcsec. Right: the orbits of stars revolving around the central black hole; scale 1 × 1 arcsec centered on Sgr A*. Credit: Andrea Ghez.

Sec 4.1.7 Interferometers; expanding the baseline

- **Optical and infrared interferometers:**
  - contributions to the study of stellar diameters and binary star orbits
  - new generation of instruments in the optical and infrared
  - associated with large telescopes
  - contributing to non-stellar science by mapping the pre-planetary accretion disks
  - these techniques are in their infancy and rapidly improving

Sec 4.2 Spectroscopy; Atomic Fingerprints

4.2.1 Introduction

- Spectrometers:
  - provide fundamental physical information on the chemical composition, temperatures, densities, and velocities of objects
  - Almost all astronomical spectrometers use CCD detectors

- Astronomers always use spectrographs

- Classes depending on the amount of fine detail or spectral resolution achieved

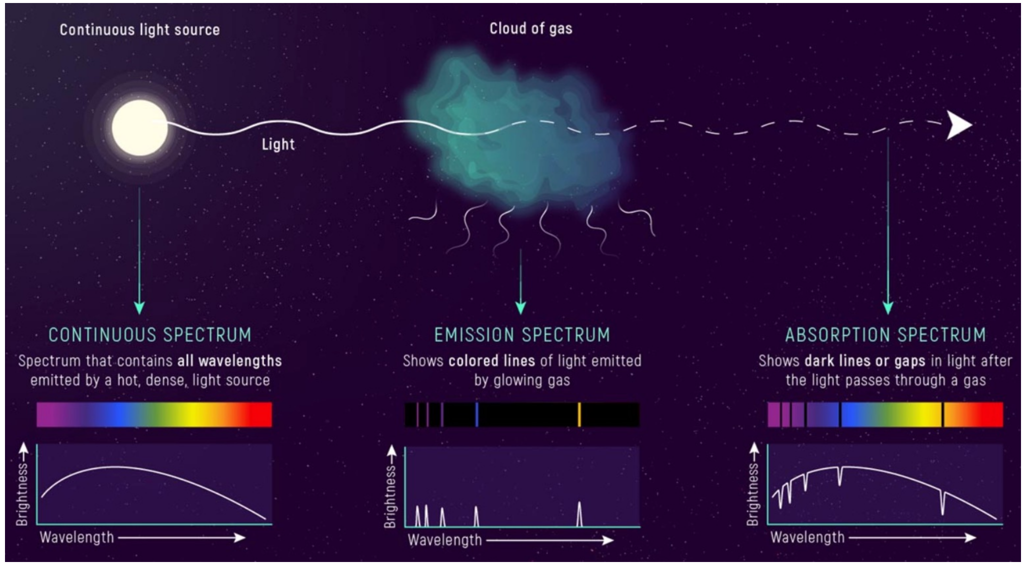
- Resolving power (R) is defined by the ratio of the wavelength divided by the smallest discernible change in wavelength
  - Faint object spectrographs (R ~ 500)
  - Intermediate dispersion spectrographs (R ~ 5000)
  - High resolution spectrographs (R > 25,000)
  - Imaging spectrometers (depends on technique)

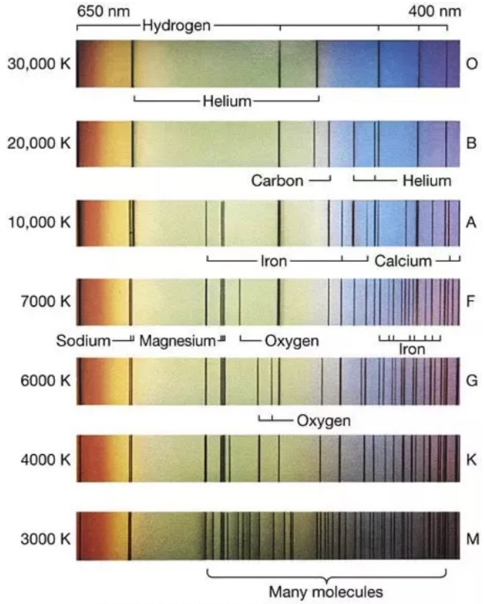
Sec 4.2 Spectroscopy; Atomic Fingerprints

4.2.1 Introduction

- Spectra types: continuous, emission, absorption
- Natural width of a spectral line is very narrow
- Many processes can broaden spectral lines
  - random thermal motions of the emitting atom
  - rotation of entire stars
  - pressure (collisions) in the stellar atmosphere
  - effects due to strong magnetic fields

- Spectral appearance depended on the temperature and ionization state
- discovery of brown dwarf led to two further letters (L and T) in recent years to describe much cooler objects





Sec 4.2 Spectroscopy; Atomic Fingerprints

4.2.1 Introduction

- component of the velocity (V) of the emitting object along the line of sight (the radial velocity) is given by
  $V/c = [\lambda_{obs} - \lambda_{em}] / \lambda_{em}$
  Where obs: observed wavelength, em: emitted wavelength

- The smallest velocity that can be detected corresponds to matching the Doppler change
  $V/c = \Delta\lambda / \lambda = 1/R$
  ➔ Taking c=300,000 km/s then R=10,000 is sufficient to detect a motion of 30 km/s

- For cosmological studies, it is customary to define the redshift factor: $z = [\lambda_{obs} - \lambda_{em}] / \lambda_{em}$

4.2.2 High resolution, from cosmic abundances to planet hunting

- high-resolution spectrographs tend to be very large instruments

➔ usually located at a stationary focus on the telescope **(-> Nasmyth: gravity always in the same direction // vs. Cassegrain, etc. (other focus))**

- primordial deuterium to hydrogen (D/H) abundance ratio:
  - Give a sensitive estimate of the ratio of baryons to photons
  - Derive the density of photons then yields the density of baryonic matter

- Distant quasar: provide luminous sources to probe the hydrogen gas clouds in the outer halos of unseen galaxies
  - Strongest spectral line is usually the ultraviolet Lyman-alpha line of normal hydrogen
  - For redshift $z > 2.5$, Lyman series moves from the UV to the visible
  - To properly resolve the weak deuterium line requires high resolution (R=30,000 – 60,000)

4.2.2 High resolution, from cosmic abundances to planet hunting

- First planet to be found orbiting another star in 1995
    - exceedingly short period of 4.2 days
    - small orbital radius of 0.05 AU
    - The basis of the measurement is the reflex motion on the star being orbited
        - From Kepler's third law: $a^3 = (GM_{\text{star}}/4\pi^2)P^2$

          a: semi-major axis, P: period of the planet's orbit

          By the Doppler shifts of spectral lines, we can derive P

- Spectroscopic measurement are challenging. To solve this problem:
    - Step 1. Precise calibration of the wavelength scale by allowing the incoming starlight to pass through a **chamber include translucent gas**
        - **Gas absorb line -> calibrate spectra**
    - Step 2. utilizing in a cross-correlation technique for thousands of lines

    - **Check example of this process (ex. Keck telescope)**

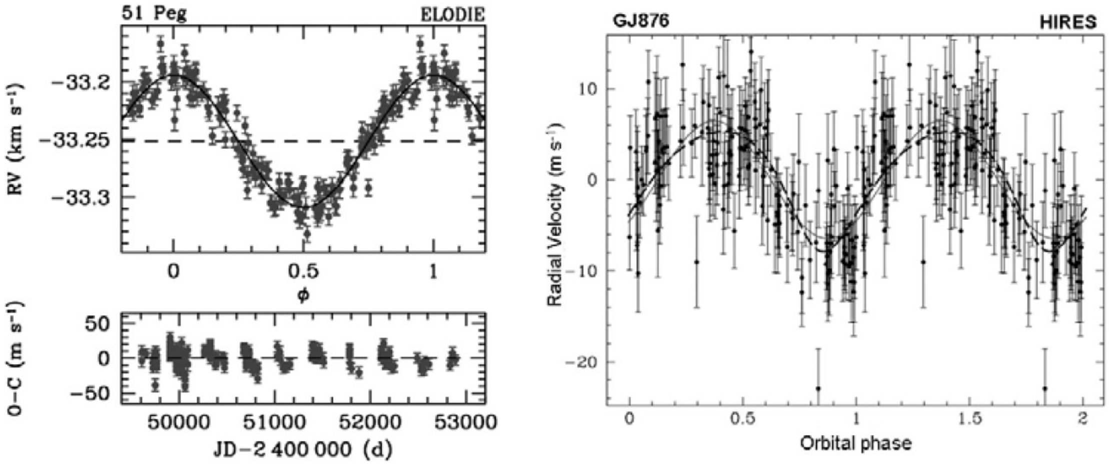


Figure 4.11. Left: the radial velocity curve of 51 Peg obtained using the ELODIE spectrograph by Mayor and Queloz. Right: a radial velocity curve obtained with HIRES on Keck I, showing the Doppler reflex motion of GJ 876 due to a planet with a mass of at least 7.5 Earth masses. Credit: California and Carnegie Planet Search.