4 The discovery power of modern astronomical instruments

Observation:
① light is collected by telescope
② corrected by AO system
③ enter on detector

Contents:
① abstract of measurements
② underlying principles of instruments and detectors
③ expand discussion about ② to other bands

4.1 Imaging the sky; more than pictures

Mapping the distribution of sources:
① Identify the locate the position of sources precisely
② Provide information of form and local environment

Example of purpose:
1. Detect positional change of faint nearby sources
2. Observe and identify binary systems
3. Deep, large-scale photometric surveys of the sky with statistical properties of stars and galaxies

First measurement of stellar parallax (1838)

Observed the positional shift of 61Cygni
⇒ Detected 0.3” shift (by Earth’s motion)

Measurement of distance with parallax:

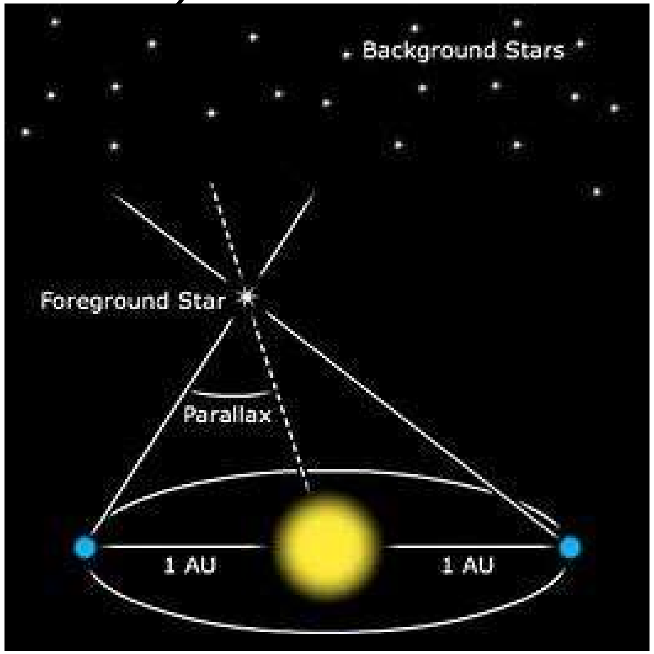
$$d(AU, distance) = 206265/p(arcsec, parallax)$$

$$d(pc) = 1/p$$

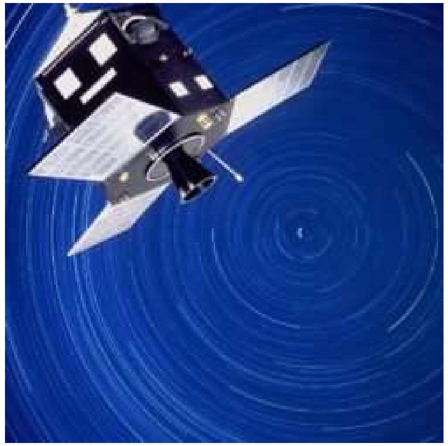
Example(61 Cygni):

$$1/0.3 = 4.33(pc)$$

(p=0.287”, d=4.48pc, modern value)



Astrometry before the appearance of CCD, computers and plate-measuring machines



- **Hipparcos satellite (ESA)**
  - Obtained the **positions, parallaxes and proper motions** of 118,218 stars(mm-arcsec accuracy)
  - Additional catalogs (“Tycho”) appeared later
  - Type of Detector: **image dissector tube, photomultiplier tube**
- **U.S. Naval Observatory B1.0 Catalog**
  - Tabulation of digitized plates
  - 1 billions of stellar object (~0.2 arcsec)

Factors for progress of astrometry

- **Increased accuracy of measurement with VLBI**

  Positional accuracy of extragalactic source: less than 1mas
  ⇒New reference system（ICRF）

- **GPS satellite**

  Profits:
  - Accurate and continuous time transfer
  - Geodesy observation of polar motion and Earth rotation （sub-mas level）

Radiometry (Photometry)

Measure the brightness of sources

Magnitude system: proposed in 2c (Hipparchus, Ptolemy)

- 1st magnitude: brightest stars
- 6th magnitude: barely discernible to the naked eye

After the invention of telescope, Herschels developed this system

Norman Pogson's Magnitude system

1st mag star: 100 times brighter than 6th mag star

Magnitude system (Radio)

m_1, m_2: magnitude of two stars
S_1, S_2: fluxes of stars

$$log(S_1/S_2) = log\left(2.5119^{(m_2-m_1)}\right) = (m_2 - m_1)log(2.5119)$$
$$m_1 - m_2 = -2.5log(S_1/S_2)$$

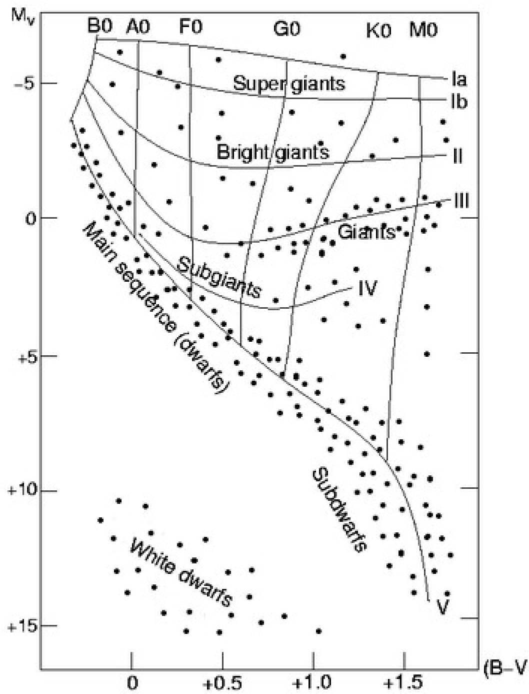
Magnitude is defined only by flux ratio
(discussed in S9.6)

Utilization of (relatively) magnitude/radiometry

- **"Color"** = brightness ratio between two bands
  - Measure the temperature of the object
  - Making HR diagnosis (luminosity-temperature relation)

- **Color-Color relation**
  - Classifying objects (especially important in optical/IR)

- **Measuring distance to high-z galaxy(phot-z)**



- **Comparing with other wavelength data**
  - Brightest region in a band should be different from that in other bands

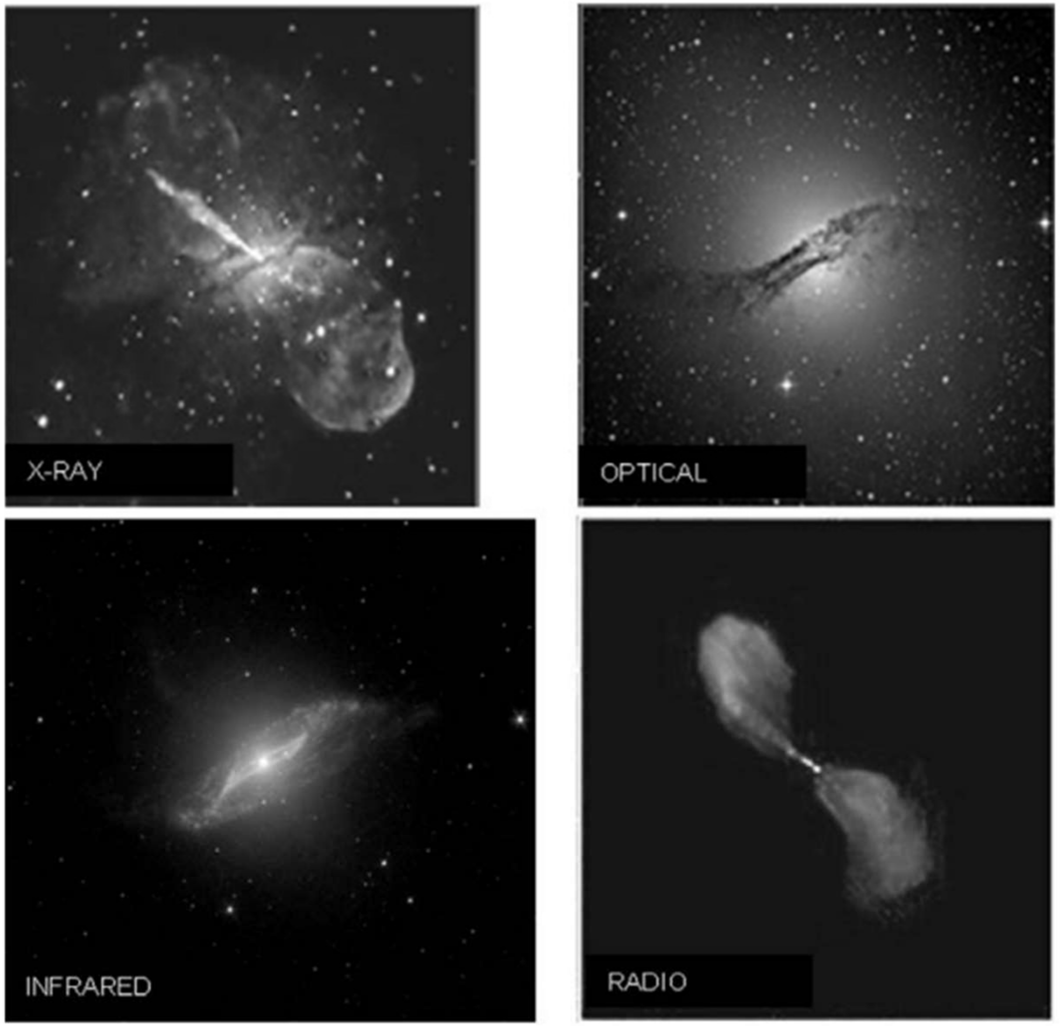


Figure 4.1. Images of the galaxy Centaurus A (Cen A) in X-rays, visible light, infrared, and radio (see also Plate 4) illustrate a dramatic change in appearance with wavelength. Credits: NASA/NSF/NRAO/ESO. See book cover credits.

Variation of brightness with time

Useful to get information about objects

- Periodic variation:
  Reveal the existence of eclipsing binary system, pulsting star

- Non-periodic:
  Unusual stellar activity（Nova, AGN, SN）

4.1.1 Early surveys of the sky

All-sky survey: time-consuming task
Whole sky: 41,254 square degrees
Typical FoV of telescope: <1 square degree
⇒**Use Telescopes with wide FoV**

Example: Schmidt telescope(FoV: 42.25 square degrees)
- **At least 977 image to cover the entire sky**
- **need long exp time to detect faint sources, and to reach uniformly good image quality**

At least two telescopes (for northern & southern hemisphere) are needed for all-sky survey

Past all-sky survey project (before CCD)

- **POSS(1950-57):**

Survey with 1.2m Schmidt telescope(Mt. Palomar, California) and photographic plates

Copy of plates in POSS (Palomar chart)

- **POSSII(1985-2000):**
  - Survey with 3 telescopes(California, Australia and Chili)
  - Observed in 3 wavelength regions(B, R and IR)

Advantage of CCD survey:

- **Have gains in longer wavelength**
- **High quantum efficiency**

4.1.2 Digitized survey

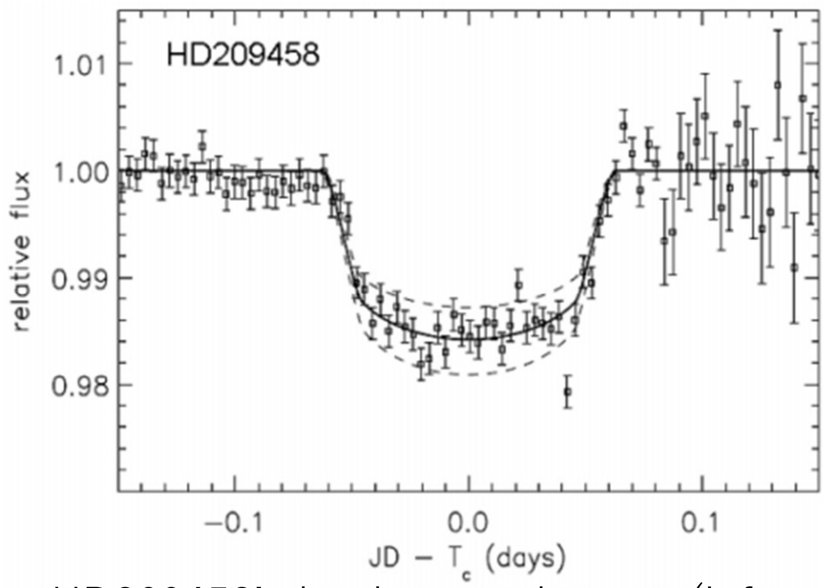
Observation digital data (with CCD)

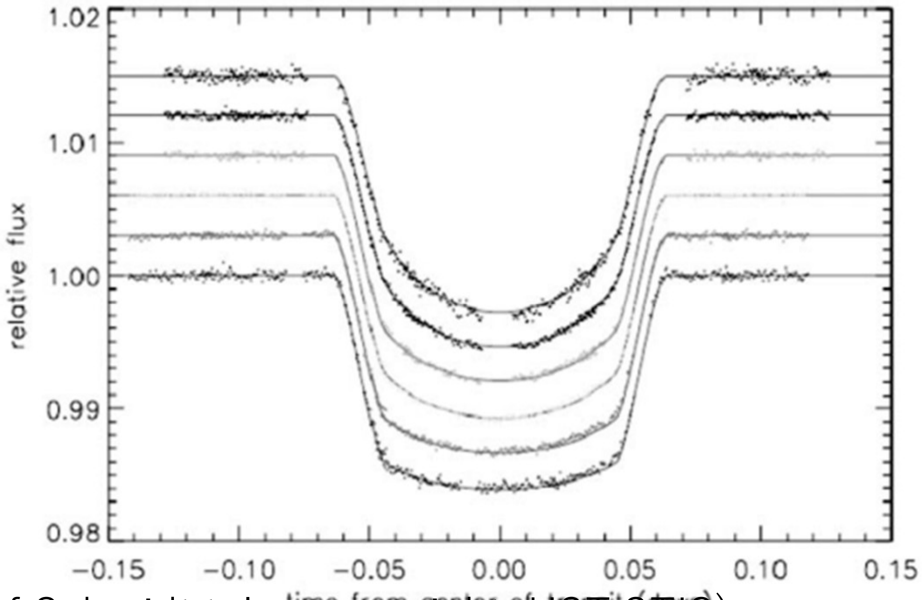
Benefits (compared to plates)

1. **High sensitivity**
   Possible to convert to measurable quantity
2. **Greater coverage of the spectrum**
   CCD is sensitive to light from UV to near-IR
3. **Immediate compatibility with computers**
   output of the CCD is suitable for computer
4. **Instant display of the image on a screen**
5. **Stable and quantitative brightness measurement**

Utilization of small telescope with CCD camera
①Discovery & observation of extrasolar planets:

- **Utilize tiny brightness variation of the parent star when the planet transit across the face of the star**





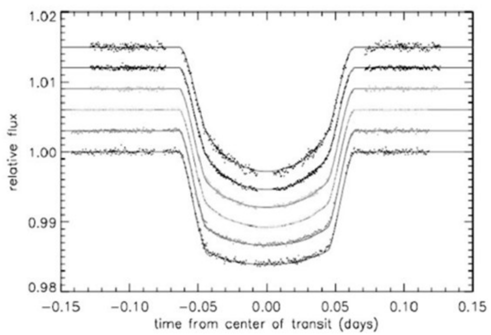
HD209458's brightness changes (left: result of Schmidt telescope, right: HST STIS)

Measurement accuracy of CCD: ~0.0015mag

Observation of extrasolar planets

- **Deduction of distance between planet and parent star**
  (with transit photometry and radial velocity spectroscopy)
- **Probe the atmospheric composition**
  (obtained with absorbed lines, transit spectroscopy)
- **Estimation of planet's radius**
  (use variation of brightness (transit depth) by transit)

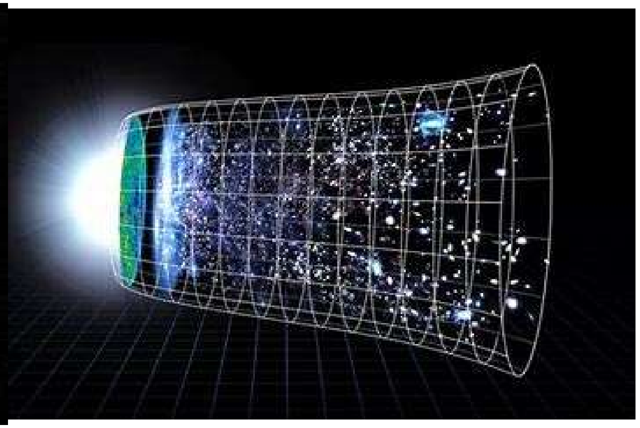
- **Detection of thermal radiation from HD209458b directly**
  (subtract radiation from parent star, 2005/3, with Spitzer)



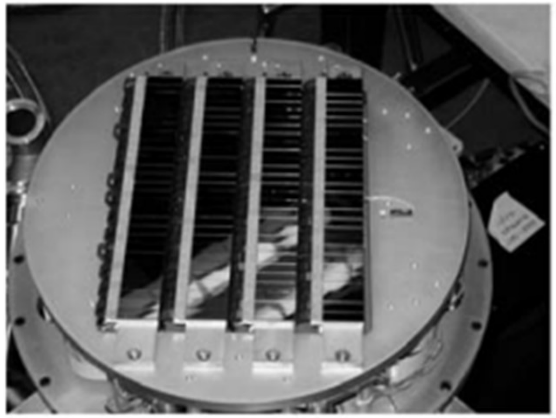
②Type Ia supernova and cosmology

Brightness of Ia is known
⇒**we can determine distance with observed brightness of Ia**
Comparing with spec-z⇒**Study for cosmic expansion**
(Standard model: Accelerated by Dark Energy?)

Discovery of SN: **IR CCD camera** in space telescope and ground-based observatory



Structure of CCD camera



- **The chip is mounted in a vacuum chamber**
  (to be cooled by liquid nitrogen or cooler)

- **"Box of electronics" with circuit for operation (like ADC)**

- **Entire CCD camera can be quite large**
  (single CCD chip is small, but we sometimes use multiple CCD)

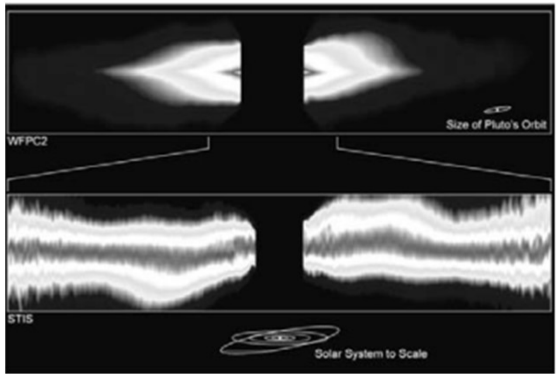
(Upper):112 CCDs in Palomar telescope
(lower): mosaiced image with 40 CCD (CFHT MegaCam)

Device in CCD camera

Light from bright sources:

- Scattered by the edge of the primary mirror, and vanes secondary mirror
- **Covers close, faint sources⇒Cut down scattering**

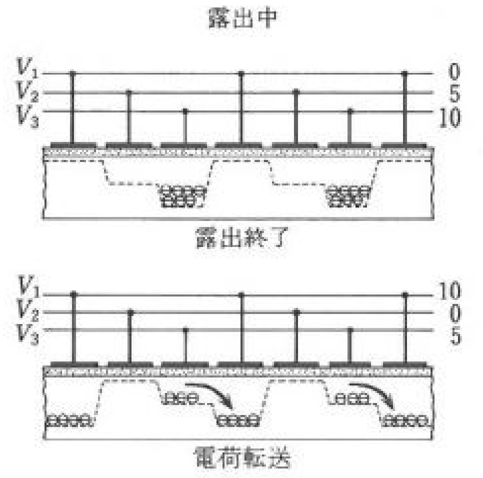
1. **Opaque finger or disk** (on focal plane)
   (blot out or occult the bright source)
2. **Blackened mask** (on position of vane’s image)
   (block scattered light from vanes)
3. **Coronagraphs**
   (hide bright sources)

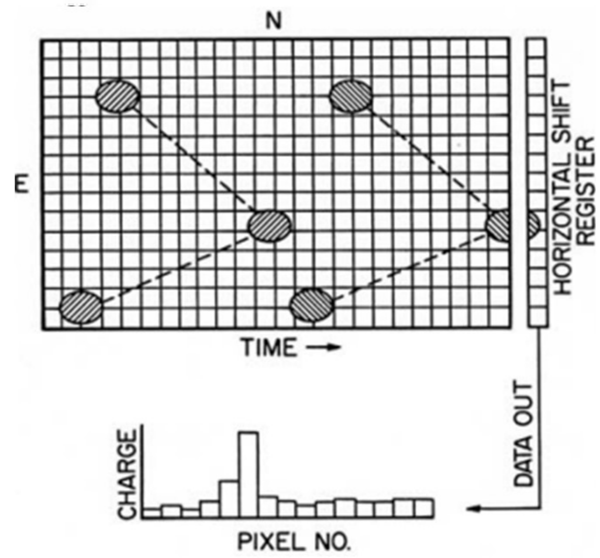


S4.1.3 Drift scanning and Sloan Digital Sky Survey

CCD: Obtain image with transferring electronic charge packet accumulated by photoelectric effect

Early CCD: **nonuniformity of sensitivity**
⇒**Drift Scanning**
(Use every pixel along column direction by shifting telescope synchronize with transferring electronic charge)
(take data without tracking, but shifting charges to follow image of stellar body)
⇒**deeper level of observation**





Abstract and advantage of SDSS

SDSS 2nd phase: provided all-digital survey (50% of the northern sky)
(Drift-scanning technique is used)

Benefits of digital survey(compared to plates)

① **High sensitivity(possible to detect 21-22mag)**
Use larger telescope(1.2m⇒2.5m)

② **Provide 5 color bands(near-IR and Optical)**
Powerful diagnostics for extracting different type of sources

③ **Follow-up, spectroscopic observation**
Over 9,583 square degrees of sky had been surveyed (2007/6)