天文狗仔的報告裝備：望遠鏡
(observations, not too many lab works)

辜品高
師大地科系
中研院天文所
visible & invisible

\[ \approx 10^6 \text{ degrees} \]

\[ \approx 5500 \text{ degrees} \]
Prism (三棱鏡) & Spectrum

A prism breaks white light into its component colors or spectrum

refraction (折射) → 色散(分光)

First prism breaks light into its spectrum

Screen lets only one color pass through

Second prism only changes light's direction

Figure 3-1
Discovering the Universe, Seventh Edition
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Sunlight comes from the other side of the rainbow

2005/10/7  my home in Taipei

West

East

2006/10/18  星星・月亮・太陽
Examples of Refraction

折射率(index of refraction)越大，光速越低

Index of refraction = 1.33

Index of refraction = 2.41

Diamond Action

4 C's

http://sol.sci.uop.edu/~jfalward/refraction/refraction.html

Light is Electromagnetic Radiation

Magnetic field  Electric field

Direction of motion

\[ \text{wavelength} = \text{speed of light} \times \text{period} \]
\[ = \frac{\text{speed of light}}{\text{frequency}} \]

speed of light in vacuum = \(3 \times 10^8\) m/s
speed of light is slower in other media determined by index of refraction

Figure 3-3
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2006/10/18

*Literally translated: 電磁波*
Music & Sound waves

Note that sound waves require a medium to propagate.

Hertz (Hz, 赫) = how many vibration per second

Frequencies compiled from Wikipedia
Spectrum of light

Astronomers don’t like water and ozone 😞

Remark: how does a microwave oven work?

Taiwan major contribution: Millimeter & Sub-millimeter 毫米以及 次毫米
wavelength & frequency

Hertz (Hz, 赫) = how many vibration per second

手機頻率 ~ 1 GHz=10^9 Hz
=1000 MHz
=1000 兆赫？
refraction

Figure 3-16ab
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Parallel light rays from distant objects

But do you remember “parallax” (視差)?
Extended objects \rightarrow extended image
Essentials of a refracting telescope (折射式望遠鏡)

![Diagram of a refracting telescope showing the objective lens and eyepiece lens, along with their focal lengths.]

Figure 3-18
*Discovering the Universe, Seventh Edition*
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3 basics for a telescope

• Light-gathering power (集光率) $\propto \text{口径}^2$

• Angular resolution (鑑別角度) $\propto \frac{波長}{口径}$

• Magnification (放大率) = \frac{\text{focal length of the objective}}{\text{focal length of the eyepiece}}

Angular Resolution:
1 circle = 360°
1° (度) = 60’ (角分)
1’ = 60” (角秒)

brighten, resolve, & magnify $\rightarrow$ bigger is better!
Light-gathering power
Angular resolution (worse)
Angular resolution (better)
Sunday Afternoon on the Island of Grand Jatte by Georges Seurat
81x120 inches; 2 years to complete; ~ 4 megadots (Pointillism)

Seurat uses the viewer’s eyes to create the colors of his art.

http://psych.hanover.edu/krantz/art/spatial.html
Chromatic (色差) & Spherical (球面差) aberration
Yerkes observatory 102 cm in diameter 19.33 m long

Nowadays, people don’t build refracting telescopes for professional uses: difficult to deal with a big lens (hard to make, aberration, distortion due to weight), too long....

Bid made for Yerkes Observatory: Aurora University’s bid to buy the historic Wisconsin observatory would yield an astronomy outreach center and expand AU’s campus.

Reflection

反射
Reflect incident radar signals up and down, rather than back to the radar station.
Spherical aberration

鏡子有球面差但無色差

Figure 3-21
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Reflecting telescopes (反射式望遠鏡)

(a) Newtonian focus  (b) Cassegrain focus  (c) Coudé focus  (d) Prime focus

反射式的鏡筒比折射式的短
聚光力因2nd mirror的遮擋稍微減弱
2nd mirror does not create a hole in the image

Just reduce the amount of light coming into the telescope tube.

Figure 3-20
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鹿林山的光学望远镜(可见光)

鹿林一米望远镜(台湾最大)
http://www.lulin.ncu.edu.tw

中央大学计划兴建二米(五年五百亿)
scientific goal?

台湾-美国掩星计划 (Taiwan-America Occultation Survey, a.k.a. TAOS):
http://taos.asiaa.sinica.edu.tw/

中央研究院
中央大学
美国劳伦斯利物摩国家实验室
美国賓州大学
韩国延世大学

4 telescopes
0.5m in diameter
Search for Kuiper belt objects(the source of comets)
Light pollution (光害)
Effects of twinkling (turbulence)

Ground-based

Hubble (哈伯) Space telescope

Stars twinkle, but planets don’t.

坐過飛機嗎？
防手震 (anti-shape, image stabilizer)
Adaptive Optics (調適光學)

Gemini telescope animation (http://www.tmt.org/tmt/adaptive-optics)

Use a known object as a reference to correct the distortion due to atmospheric turbulence

Ground, no adaptive optics  Hubble space telescope

Ground, with adaptive optics

Figure 3-26
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two 10-m Keck telescopes

Mauna Kea, Hawaii

Dome: protect telescopes from rain/snow, dusts. & reduce day-night temperature variation

36 hexagonal mirrors
Easy to build
Less expensive

telemes on the top of mountains:
less light & air pollution
less twinkling
good weather
less CO₂ & H₂O
→ can see infrared

Air pressure is low
Inside is pressurized
Charge-coupled devices (CCD)

A series of CCD images with different colored filters
Can do day-time observation because of longer wavelength, needs bigger mirror to achieve better resolution.

Golden Eyes (007 Movie)

Arecibo 305m Telescope Puerto Rico
Interferometer (干涉儀)

Can reach the same resolution, even though the light-gathering power is not significantly improved.
Very Large Array (VLA)

27 dishes
26m in diameter
36km

Figure 3-30
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A message from deep space.
Who will be the first to go?
A journey to the heart of the universe.

織女星 (Vega)
25.3 lyrs away
1.5 solar masses
385 million year old
T=9600 K
Sub-millimeter Array (SMA)

Smithsonian institution (6) + 中央研究院天文所 (2)
Mauna Kea, Hawaii
Observe dust & molecular emissions in star forming regions or dying (evolving) star regions.
**ALMA**

Cover wavelength: 0.3 - 9 mm
angular resolution: 0.004"

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**Atacama Large Millimeter Array (ALMA)** is one of the largest ground-based astronomy projects of the next decade. It will be comprised of some sixty-four 12-meter (North America & Europe) and 12 7-meter + 4 12 meter (Japan & Taiwan), submillimeter-quality antennas at the high-altitude (5000 m) Llano de Chajnantor, possibly the world's best site for millimeter astronomy, close to San Pedro de Atacama in northern Chile.

ALMA-T (T here means Taiwan)

http://alma.asiaa.sinica.edu.tw/

invest 16M USD (5% of Japanese contribution)

What are we doing now?
1) Integration center
2) circuit
3) data archive

President Lee just stepped down

Signing Ceremony of the Agreement concerning Enhanced ALMA between NINS and AS

Sep, 2005
East Asia VLBI? Japan+Korea+China

Can Taiwan participate in? Ishigakijima or build one in South China Sea?
Radio telescope larger than the Earth!

VSOP

http://www.vsop.isas.ac.jp/
Orion in UV, IR, & visible

- Hot (ionized) gas & stars
- Dust
- Infrared (actually everything glows in dark)
Focusing X-ray

X-ray is so energetic that it can penetrate a normal surface.

X-ray from high energy sources: Supernova remnant, black hole, cluster of galaxies
X-Rays From Tycho's Supernova Remnant

7,500 light-years in the constellation Cassiopeia (仙后座)

T=10^7 degrees

Image taken by Chandra X-ray observatory
Multi-wavelength investigation

Remember that some wavelengths cannot be seen on the ground.
Light & energy level of atoms

Gives line spectra

Figure 4-12
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Energy level of H atom

You don’t have worry about “eV” in this class.
Different atoms have different line spectra

請區別我們平常所看的顏色哦：
不是溫度造成的 (黑暗中就看不到了)。
Stars have colors!

The higher the temperature of a blackbody, the shorter the wavelength of maximum emission (the wavelength at which the curve peaks).

The higher the temperature of a blackbody, the more light it emits at all wavelengths.

Figure 4-2
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Continuous & Line Spectra

Hot blackbody

Cloud of cooler gas

Continuous spectrum (blackbody emits light at all wavelengths)

Absorption line spectrum (atoms in gas cloud absorb light of certain specific wavelengths, producing dark lines in spectrum)

Emission line spectrum (atoms in gas cloud re-emit absorbed light energy at the same wavelengths at which they absorbed it)
Diffraction Grating (光柵)

In reality, people don’t use a prism but a grating to get spectra. Prism is more difficult to make.
radial & proper motions of a star

Can you recall “Barnard’s Star” in the “astrometry” lecture?
Doppler effect

Examples:
- rotating astronomical disks
- binaries
- distant galaxies

This observer sees blueshift
Frequency increases

This observer sees redshift
Frequency decreases

Figure 3-6
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Summary

- 什麼是波? 什麼是光譜?
- 地球大氣對所有的光都是透明的嗎?
- 為什麼有彩虹?
- 為什麼星星月亮老是跟著我走?
- 為什麼望遠鏡口徑越大越好?
- 為什麼當代大型天文望遠鏡都採反射式而非折射式?
- 為什麼天文望遠鏡總是要建在高山上?
- 為什麼要有adaptive optics?
- 為什麼無線電望遠鏡都很巨大?
- 許多天文望遠鏡形成陣列有什麼好處?
- 一座可見光望遠鏡可以用來觀測無線電波或x-ray嗎?
- 為什麼線光譜告訴我們是何原子或分子?
- 線光譜和連續光譜有何不同?
- 溫度和顏色有關嗎?
- 什麼是都卜勒效應?
- 觀測由一天體發射出不同波段的光有必要嗎?