Astro 210
Lecture 15
Feb 23, 2011

Announcements

- HW4 due at start of class Friday
- Night Observing tonite, tomorrow, next week – *Dress warmly!*
  report forms, info online
- HW3 back today
- Hour Exam: grading elves hard at work
  but takes time

Last time: telescopes

The Division of Labor in Astronomy/Astrophysics

Working astronomers/astrophysicists generally spend their time in *one* of these roles

- **observer**: collect, analyze, and interpret telescope data

- **theorist/simulator**: use physics to make models/predictions

- **instrumentalist**: design/build new scopes/detectors

A few very talented people do more than one of these well

Beware! each comes with its own biases and "culture"!

iClicker Poll: Instructor Culture of Origin

Vote your conscience!

Which of these is your instructor?

A observer

B theorist

C instrumentalist

Last time: telescopes

- light collection: refractors vs reflectors
  Q: what's the diff? Which is your eye?
  Q: What do the pros use nowadays?
- scopes as "light buckets"
  light gathering power $\propto D^2$

⋆ **Angular Resolution**

ang res = smallest angular separation distinguishable

→ sets *angular size* of *finest detail* in image

wave nature of light:

passing through finite telescope aperture (non-infinite diameter)

light rays diffract: bent

→ pointlike source image smeared into blob (Airy disk)

point spread "blob" size: smallest angular size measurable

diffraction limit:

$$\theta_{\rm obs} \geq \theta_{\rm min,obs} = \theta_{\rm diff} = 1.22\frac{\lambda}{D} \tag{1}$$

objects separated by $\theta < \theta_{\rm obs}$ smeared into one blob

Keck: $\theta_{\rm diff} = 0.01$ arc sec at 500 nm diffraction limit sets optimal telescope resolution

but: Earth atmosphere is turbulent – fluctuating density
→ light path distorted
and distortion rapidly fluctuates
→ light path rapidly fluctuates
→ point sources appear to jiggle: "twinkling"
`www: twinkle animation`

twinkling further smears out point source image
$\rightarrow \theta_{\rm obs,Keck} = \theta_{\rm atm} \geq 1 \ {\rm arcsec} \gg \theta_{\rm diff}$

Q: so obviously, the solution is?

go to space! $\rightarrow$ HST $\theta_{\text{diff}} = 0.05$ arc sec at 500 nm
this is the main motivation for Hubble Telescope!
$\rightarrow$ unprecedented angular resolution

⋆ **Magnification**

only worthwhile if enough light gathering power & resolution
$\rightarrow$ need to have a sharp image to magnify!
magnification set by focal lengths of objective (i.e., main mirror) and eyepiece: magnification $= f_{\text{obj}}/f_{\text{eye}}$

Telescopes: Detectors

Once light collected, focused, need to detect

- **naked eye** – just look!

Q: Problems? other means of detection?

naked eye as photodetector

benefits:

- readily available, and cheap!

problems:

- only $\sim$ 1% of photons detected!
- can't store image
- only sensitive to small portion of EM spectrum (visible λs)

photographic film

better!

- can collect light $\rightarrow$ see much dimmer objects
- stores image

but: efficiency still small

only $\sim$ few% of incoming γs registered on film

• **Charged-Coupled Device (CCD)**

same technology as digital camera, camcorder!

photons $\rightarrow$ silicon wafer $\rightarrow$ e knocked out (photoelectric effect)

• moving charges = current

$\Rightarrow$ CCD converts light $\rightarrow$ electrical signal

to make image: create *grid/array* of picture elements ("pixels")

great!

⋆ digital data $\rightarrow$ good for computers

⋆ efficiency: $> 80\%$ of incident photons detected

downside: expen$ive, hard to make large CCD's

⋆ essentially all modern telescopes – HST, Keck – use CCD's

Field of View

key telescope property: *field of view*

$\rightarrow$ angular area $\Omega_{\rm fov}$ of celestial sphere visible in each pointing

- naked eye: see almost a full hemisphere
  $\Omega_{\rm fov} \approx 2\pi$ steradian $= 2\pi$ rad^2
- typical modern telescopes, e.g., Hubble, Keck:
  $\Omega_{\rm fov} \approx 1$ arcmin $\times$ 1 arcmin $=$ 1 arcmin^2

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iClicker Poll: Rank these from *largest* to *smallest* field of view

A paper towel tube, drinking straw, Hubble telescope

B paper towel tube, Hubble telescope, drinking straw,

C Hubble telescope, paper towel tube, drinking straw

Field of View and LSST

typical modern telescopes: $\Omega_{\rm scope} \approx 1$ arcmin^2
drinking straw: $\Omega_{\rm straw} \approx 1$ deg$^2 = 3600$ arcmin$^2 \approx 3600\, \Omega_{\rm scope}$!
$\Rightarrow$ modern telescopes (so far!) have *tiny* fields of view!

Large Synoptic Survey Telescope `www: LSST`

- site: Cerro Pachón ridge, Andes mountains, Chile
- primary mirror diameter $D = 8.4$ m: large but not unusual
- field of view $\Omega_{\rm fov} = 10$ deg^2 **enormous!**
  requires 3.2 Gigapixel camera!
  first telescope to have such a large field of view
- Illinois is LSST member; Astronomy, Physics, NCSA involved

Q: why is such a large field of view useful? what does this allow?

Coming Soon–Cosmic Movie & Wallpaper

thanks to large field of view
LSST can **scan entire night sky** in a few days!
and then **repeat** this scan for ≈ 10 years

result: ≈ 1000 deep digital images of *every point* on the southern celestial sphere, spanning 10 years!

Strategy: *compare* images of *same* region

- some things won't show any change *Q: like?*
  add exposures to get *very* deep images
  "The Sky: The Wallpaper"
- other things *will* show change! *Q: like?*
  subtract exposures to find & monitor changes
  $\rightarrow$ reveal celestial variability over timescales $\sim$hours to years
  "The Sky: The Movie"
  $\Rightarrow$ this has never been done on such a huge scale!

Invisible Astronomy

before 20th century: astronomy = optical astronomy
visible waveband only known form of light

Now: want to take advantage of full EM spectrum
$\rightarrow$ radio, IR, UV, X-ray, γ-ray

key issue: atmosphere is *not* transparent
to all wavelengths
`www: atmospheric transmittance`
Q: implications?

radio: large antennas
since λ very large
$\rightarrow$ need huge collecting area for angular res.
$\rightarrow$ arrays of antennae
`www: VLA, Arecibo`

X-ray: don't penetrate atmosphere
$\rightarrow$ must go to space
to focus: scatter at glancing angle
detectors: measure energy deposited

`www: Chandra, XMM`

Also: the cosmos contains more than photons!
particles from space already detected
⋆ neutrinos
⋆ cosmic rays (relativistic nuclei and electrons)
confidently expected but only indirect evidence so far:
▷ gravitational radiation ("gravity waves")

The Solar System

The Solar System

`www: Place in the Big Picture`

Why study the Solar System?
▷ it's home!
▷ use present to learn about past
  → clues for origins of Earth & Sun
▷ help understand origin of exoplanets: compare/contrast

Sociology: traditionally, astronomy divided into study of solar system vs extrasolar objects
boundary is artificial, and somewhat loosening now...

Basic Organization `www: SS lineup`

Terrestrial planets (Earth-like): smaller, rocky
Mercury, Venus, Earth/Moon, Mars

Asteroid Belt: rocky debris

Jovian planets (Jupiter-like): large, gaseous
Jupiter, Saturn, Uranus, Neptune

Kuiper Belt & Oort Cloud: Icy debris

Pluto: in summer 2006, demoted to "dwarf planet"
→ will discuss what's behind this

Orbital dynamics show clear patterns

all planets & asteroids:

- move in same direction/sense: counterclockwise as seen from north
- move in planes close to ecliptic plane ...except Pluto
- move in orbits that are almost circular biggest exception is Pluto

But could it have been otherwise?
Q: What rules does Newton impose on bound orbits?
And note the near-circularity of orbits:
imaging placing a planet at distance $\vec{r}_{\rm init}$
and releasing it with velocity $\vec{v}_{\rm init}$
Q: how does orbit depend on $\vec{v}$ magnitude, direction?
Q: how to adjust $\vec{v}$ to get a circular orbit?

Newton/Kepler Motion and Initial Conditions

Given initial position $\vec{r}_{\rm init}$ and velocity $\vec{v}_{\rm init}$
trajectory (orbit) completely determined by Newton's laws

- if $v_{\rm init} \geq v_{\rm esc}$, orbit is *unbound*
  $\rightarrow$ leaves solar system on parabolic or hyperbolic orbit

- for $v_{\rm init} < v_{\rm esc}$, a *bound* orbit: ellipse or circle...but which one?

if $\vec{v}_{\rm init}$ has *any* component along $\vec{r}_{\rm init}$
i.e., if the velocity is not purely tangential
then orbit *must* be an ellipse
but even if $\vec{v}_{\rm init} \perp \vec{r}$, circle not guaranteed
if $v_{\rm init} \neq v_{\rm circ} = \sqrt{GM/r}$, orbit *must* be an ellipse
a circular orbit results if and *only if* speed is *exactly* $v_{\rm init} = v_{\rm circ}$!

Lesson: ellipse is "generic" bound orbit
circular orbits are "fine tuned" and special
$\Rightarrow$ the near-circularity of planet orbits cries out for explanation!