Physics 133: Extragalactic Astronomy and Cosmology

Lecture 13; February 26 2014
Previously

• Mass concentrations distort the images of objects in on the sky in a way similar to that of optical images.

• Strong and weak lensing provide very accurate mass maps of objects (in projection)

• Gravitational field “slows down” light. Strong lensing can be formulated in terms of Fermat’s principle
Outline:

• Cool things you can do with lensing (applications):
  – Cosmography (Hubble Constant)

• Useful link:
  – Saas Fee Lectures on gravitational lensing
  – (Particularly the first one by Peter Schneider)
Cosmography with time-delays
Time delay distance in practice

\[ \Delta t \propto D_{\Delta t}(z_s, z_d) \propto H_0^{-1} f(\Omega_m, w, ...) \]

Steps:
1. Measure the time-delay between two images
2. Measure and model the potential
3. Infer the time-delay distance
4. Convert it into cosmological parameters

Riess et al. 2011
Cosmography with strong lenses: the 4 problems solved

• Time delay – 2-3 %
  – Tenacious monitoring (e.g. Fassnacht et al. 2002); COSMOGRAIL (Meylan/Courbin)

• Astrometry – 10-20 mas
  – Hubble/VLA/(Adaptive Optics?)

• Lens potential (2-3%)
  – Stellar kinematics/Extended sources (Treu & Koopmans 2002; Suyu et al. 2009)

• Structure along the line of sight (2-3%) and the mass-sheet degeneracy,
  – Galaxy counts and numerical simulations (Suyu et al. 2009)
  – Stellar kinematics (Koopmans et al. 2003)
Gravitational Lens Time Delays

B1608+656 Variability in Radio Observations

Credits: S. H. Suyu, C. D. Fassnacht, NRAO/AUI/NSF
COSMOGRAIL: the COSmological MOonitoring of GRAvItational Lenses

- time delays of lensed quasars from optical monitoring
- expect to have delays with a few percent error for ~20 lenses
The slope-$H_0$ degeneracy

- Uncertainty of the mass density profile of the main lens is the single largest source of uncertainty.
- If mass density profile is a power law $\rho \sim r^{-\gamma}$ then $H_0(\gamma') \sim H_0(2)(\gamma'-1)$ (Wucknitz 2002)
- Can be broken using lensing (Suyu et al. 2010) and stellar kinematic data (Treu & Koopmans 2002)
- We need to know the slope of the mass density profile to break this degeneracy!
- The degeneracy can be broken using multiple time delays, extended rings, and external information such as stellar kinematics
Lens Model

Observed Image
Lens Model

light distribution of extended source

mass distribution of lens
Lens Model

light distribution of extended source

mass distribution of lens

light of lensed AGN
Lens Model

- Light distribution of extended source
- Mass distribution of lens
- Light of lensed AGN (Sersic)
Lens Model

light distribution of extended source

mass distribution of lens

light of lens (Sersic)

light of lensed AGN

+ time delays
Lens Model
Time delays vs other probes

WMAP7owCDM prior

[Suyu et al. 2012]

- contour orientations are different: complementarity b/w probes
- contour sizes are similar: lensing is a competitive probe
Summary. Applications of lensing

• Measure mass of galaxies, clusters, planets.
• Test the cosmological model by measuring substructure.
• Cosmography.
• Test gravity.
• Properties of dark matter.
The End

See you on monday!