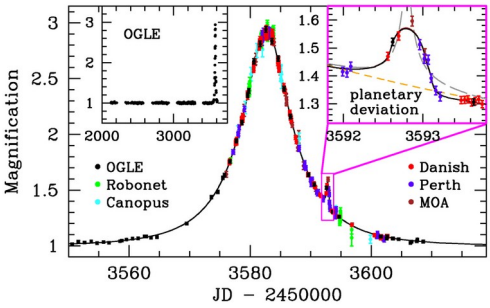
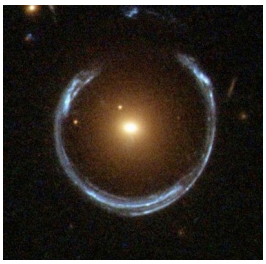
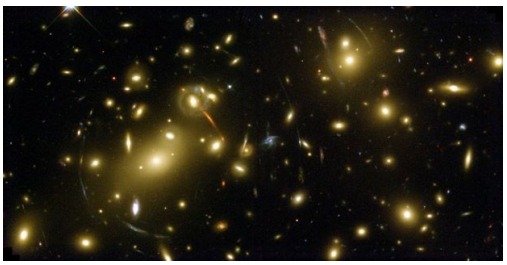
Gravitational lensing: from planets to clusters of galaxies



Gravitational lensing is a very active and highly developed field in astrophysics. Lensing covers all astrophysical scales from the fine details at the scale of planets around stars to the cosmological lensing by large scale structures. This presentation will offer a global review of all these applications of gravitational lensing. The idea is to present the basics for each specific lensing regime or scale. This course will be illustrated by applications and a review of the results obtained by the lensing analysis.

I) General presentation of the course

1.1) *The various applications of gravitational lensing at different scales*

1.1.1) Lensing at the stellar scale
1.1.2) Lensing at the galaxy scale, strong lensing: arcs, galaxy/galaxy lensing
1.1.3) Clusters of galaxies, weak lensing reconstruction of mass, strong lensing: arcs
1.1.4) Gravitational lensing in cosmology

1.2) *The various lensing regimes*

1.2.1) Strong lensing
1.2.2) Weak lensing
1.2.3) Intermediate regime
1.2.4) Illustrations

II) Lensing at stellar scale: microlensing

2.1) *Basics of microlensing by a stellar object*

2.1.1) Lens equation
2.1.2) Equations for the images and amplification
2.1.3) Astrometric effects

2.2) *The microlensing experiments*

2.2.1) Presentation of the experiments
2.2.2) Optical depth
2.2.3) Lensing rates
2.2.4) The results and constraints on dark matter obtained

III) Perturbations at the stellar scale due to planets

3.1) *The double lens*

3.1.1) Basic equations
3.1.2) Caustics and critical lines
3.1.3) A general approach based on libraries with specific examples
3.1.4) The problem of modelisation of double lenses

3.2) *Applications to planets and satellites*

3.2.1) Presentation of the real time experiments
3.2.2) Discussion of applications and results
3.2.3) Some perspective on the distribution of planets in the Milky Way
3.2.4) The future of the experiments dedicated to planets

IV) First cosmological applications: quasars

4.1) *Specific examples of quasars lensing by galaxies*

4.2) *Basic modeling of quasar lensing by galaxies*

4.2.1) The mass-sheet degeneracy
4.2.2) Simple models
4.2.3) Perturbations by dark matter substructures

4.3) *Time delays*

4.3.1) Basic physics of time delays
4.3.2) Specific examples
4.3.3) Constraining cosmological parameters using time delays

4.4) *Perturbation of the lens by local stars: microlensing*

4.4.1) Basic physics of the perturbation
4.4.2) Reconstruction of the local caustics maps
4.4.3) Resolving the fine structure of the quasar source

V) Strong lensing: arcs at the galaxy or small groups of galaxies scale

5.1) *Basic physics of gravitational arcs*

5.1.1) Simple examples using elliptical potentials
5.2.2) Illustrations using real systems
5.2.3) The problem of the degeneracy of the modeling of gravitational arcs

5.2) *What is the information that can be extracted from gravitational arcs ?*

5.2.1) How to overcome the degeneracy issue
5.2.2) Arcs as a perturbation of a singular situation
5.2.3) Description of arcs by fundamental fields

5.3) *Modeling of arcs using the singular perturbative approach*

5.3.1) Geometrical properties of halos related to the singular perturbative approach
5.3.2) Separation of the inner and outer contributions of the lens to the potential
5.3.3) Iterative reconstruction of the fields

5.4) *Practical implementation of the singular perturbative approach*

5.4.1) Basic framework
5.4.2) Application to galactic lenses
5.4.3) Application to small group of galaxies

5.5) *Statistical approach using the singular perturbative approach*

5.5.1) Statistical description of the lenses using the perturbative fields
5.5.2) Associated statistics of the dark matter halo
5.5.3) Prospective application and possibilities offered by Euclid

VI) Cluster of galaxies

6.1) *The weak lensing statistical approach*

6.1.1) Local expansion, Jacobian matrix
6.1.2) Shear, moments and relation to the density of the lens
6.1.3) Shear maps

6.2) *Practical reconstruction of the shear*

6.2.1) Estimation of the moments of local galaxies
6.2.2) Potential difficulties and problems

6.3) *Some practical example of reconstruction using weak lensing*

6.4) *Strong lensing, arcs for clusters of galaxies*

6.4.1) Practical examples
6.4.2) Combination with weak lensing, resolution of the mass-sheet degeneracy

VII) Numerical code, practical implementations, and questions