Tentative Lecture Outlines

1. Luis Aguilar 3-4 hours,
Dynamics in Clusters of Galaxies

Cluster of galaxies are small *N* dynamical systems where interactions are further exacerbated by the non-negligible size of galaxies compared to mean separations. Contrary to the classical idea of galaxies as "island universes", it is essential to understand the various dynamical mechanisms that shape galaxies within clusters, in order to understand their structure and history. In this series of lectures, we will explore the various dynamical effects to which galaxies in clusters are subjected. The emphasis won't be in depth, but on a clear and wide understanding of the dynamics involved.

1) Clusters as Dynamical Laboratories: Why interactions are important?
2) Close encounters: relaxation and mass segregation
3) The effect of the environment: Dynamical friction
4) A closer look at tides: tidal truncation, tidal stripping and the formation of shells
5) Putting everything together: what to expect in a cluster?

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2. Craig Sarazin 4 hours
Gas Dynamics in Clusters

1. Properties of the Intracluster Medium (ICM)
2. X-ray Emission from the ICM
    - Emission Processes
    - Diagnostics
3. The ICM as a Fluid
    - Mean Free Paths, Equilibration Time-Scales
    - Transport Properties, Thermal Conduction and Viscosity
4. Magnetic Fields
5. Heating and Cooling of the ICM
    - Heating
        - Gravitational Heating
        - Nongravitational Processes
            - Star Formation and Supernovae
            - AGNs
    - Radiative Cooling
    - Is the ICM Homogeneous or Inhomogeneous?
6. Hydrostatic Equilibrium Distributions in the ICM
    - Isothermal and Adiabatic Models
    - Cooling Cores
7. Masses of Clusters from Hydrostatic Equilibrium
    - Gas Masses
    - Total Masses
    - Baryon Fractions

8. Dynamics of Clusters -- Accretion and Mergers
9. Hydrodynamics of the ICM - Large Scale
    Numerical Simulations
    Merger Shocks
    Accretion Shocks
    Cold Fronts
10. Hydrodynamics of the ICM – Non-central Galaxies
    Stripping Processes for Interstellar Gas
11. Hydrodynamics of the ICM - Central Galaxies
    Cooling Cores
    The "Cooling Flow" Problem
    Interactions with Central AGNs
    Thermal Conduction
    Other Processes
12. Abundance Distributions in the ICM
    Type Ia vs. Type II SNe
    Mixing Processes
    Settling Processes
    The Role of Central cD Galaxies
13. Connections to the Diffuse Intergalactic Medium

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3. L.Feretti (4 hours)
Non Thermal emission

Lecture 1 (0.5 h)
Theoretical background related to radio emission:
    Synchrotron radiation from an ensemble of particles
    Synchrotron spectrum
    Evolution of synchrotron spectrum with time
    Age of a radio source
    Energy content in a radio source
    Minimum energy density and equipartition magnetic field
    Limitations of the classical approach
    Polarization of synchrotron emission
Lecture 2. (1.5 h)
Non thermal components of the intracluster medium:
    Diffuse radio emission: Radio halos and relics
    Radio spectra and their implications
    Physical conditions
    Correlation between radio and X-ray emission
    Connection to cluster mergers
    Origin and reacceleration of the radio emitting particles
    Mini-halos and connection to cooling flows
    Hard X-ray emission
Lecture 3. (1 h)
Magnetic fields in clusters:
    Polarization of diffuse radio sources
    Rotation Measure studies
    Interpretation of Rotation Measure data

Field structure (power spectrum) and radial profile
Reconciling magnetic fields from different methods
Numerical simulations
Connection between magnetic field strength and cluster properties
Constraints on the origin and evolution of cosmological magnetic fields
Amplification by cluster mergers

Lecture 4. (1 h)

Radio emission from cluster galaxies:

Classical radio galaxies
Distorted structures: NAT and WAT
Radio galaxies in the center of cooling core clusters
Radio – X-ray interaction
Confinement
Trigger of radio emission: radio luminosity function
Enhancement of star formation

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4. J.VanGorkom (3 hours)

Galaxy Populations-Nature vs Nuture, Gas Content

Lecture 1: The Evolution of Galaxy Populations in Clusters

Overview of the local density morphology relation and its existence over 5 orders of magnitude in galaxy density. A similar relation may exist between star formation rate and galaxy density. A summary of the evolution of the density morphology relation out to redshifts of 0.5, and of the increased star formation rate with redshift.
Enter the nature versus nurture debate.
At least 3 questions can be posed:
Are galaxies different because they are formed in different environments, i.e. is it the depth of the global potential well at formation that determines morphology, or does the environment affect the evolution?
Are the galaxy populations in clusters at intermediate redshift different because of cluster driven evolution, or does the field population evolve and do we see different kinds of galaxies fall into clusters?

How do the environmental trends of star formation rate depend on galaxy mass? Are we mainly witnessing a down sizing effect, where at lower redshift star formation mostly occurs in smaller galaxies, or is the correlation between density and star formation rate a separate effect that exists in addition to the mass - star formation rate correlation?
Having set the observational stage I will then discuss the different mechanisms that can drive environmental evolution:

Gravitational effects:
a) slow interactions and mergers.. result in galaxy transformation
b) galaxy harassment, i.e. the cumulative effect of many fast encounters result in truncation of smaller galaxies and possibly thickening of disks
c) galaxy - cluster potential interaction. This will result in collective phenomena, where galaxies falling in as groups will all be affected in similar ways.

Gas-gas interactions
d) Ram pressure stripping.. removes cold gas in outer parts of disks
e) Turbulent viscous stripping.. removes gas along surfaces, especially efficient when there are

holes in disks
f) Evaporation.. removes gas from surface of disks.. efficiency depends strongly on orientation of magnetic fields
g) starvation.. removal of pre existing hot gas reservoir around galaxies. Mechanism not completely understood, could be shock heating.

Lecture 2 Content and distribution of cold gas in cluster galaxies
First I will summarize what kind of data can in principle be obtained. The difference between filled aperture telescopes and interferometers. The difference between pointed observations and volume limited surveys. Summary of content and distribution of cold gas in non cluster galaxies.

Results of single dish pointed observations. Definition of gas deficiency. Summary of most recent work on cold gas content in cluster galaxies. I will try to cover HI and CO wherever possible. Discuss possible correlation of gas content with global cluster properties. Discuss possible correlation with orbital structure of galaxies and gas content. Compare observational results with predictions of various gas removal mechanisms.

Summary of HI imaging of cluster galaxies. Discussion of environmental dependence of HI morphology. Compare statistical results with predictions of various gas removal mechanisms.
Does change in gas content affect the star formation rate?
Summary of different tracers of star formation, H alpha, UV, FIR, radio continuum.
Comparison of global gas content with star formation rate.
Main question to address: does removal of gas lead to reduced star formation?

Lecture 3 Theory confronts observations
Here I want to compare high resolution, high sentivity observations of the gas distribution and kinematics in selected systems with state of the art simulations of gravitational and hydrodynamical interactions between cluster environment and galaxies.
Main topics:

- what kind of information can we derive from the data
- what kind of data do we need to constrain the simulations
- how do we distinguish between gravitational and gas gas interactions
- how do we distinguish between galaxy galaxy and galaxy cluster interaction
- what is the impact of the dynamical state of the cluster, the role of cluster-subcluster merging and its impact on galaxy evolution.

To summarize: what is the evidence for environmentally driven morphological transformation of galaxies and what will the end products be.

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5. C.Jones (4 hours)
X-ray Emission from Groups and Clusters of Galaxies

Lecture 1
I. Optical and X-ray views
II. Cluster mass measurements
  a. Visible, X-ray and dark matter in clusters
  b. Mass measurements through lensing
III. X-ray observations of clusters

a. Description of Chandra observatory
b. Why study clusters with X-rays
c. X-ray emission mechanisms
d. X-ray properties of galaxies, groups, and clusters
   1. X-ray luminosities, temperatures, and abundances
e. X-ray morphology (relaxed, merging, filaments)
f. Superclusters
g. X-ray mass measurements from surface brightness and gas temperature
h. Gas mass, total baryonic mass, and total (dark plus luminous) mass

Lecture 2
Cluster Mergers
I. Infall amd motion of galaxies in clusters
   a. Virgo galaxies
   b. NGC1404 in Fornax
II. Cluster mergers
   a. A3667 merger
   b. A3266 merger
   c. The "Bullet" cluster
III. Origin of radio halos

Lecture 3
The Impact of AGN outbursts on the Gas in Galaxies and Clusters
I. Cooling flows
   a. History
   b. X-ray spectroscopy
II. Reheating mechanisms
III. X-ray cavities (e.g.M84, Hydra A, A478)
IV. Shocks and ripples in Perseus
V. Reflections of outbursts in M87
VI. Cen A jet and lobes
VII. Chandra sample of 100 early-type galaxies

Lecture 4
Using Clusters for Cosmology
I. Distant clusters
II. Cluster scaling relations
III. Cosmological constraints from CMB, SNIa and clusters (e.g. Dark Energy)

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6. Alvio Renzini (4.5 hours)
Metal Content & Production in Clusters

Lecture 1: The observed metal content of galaxy clusters (ICM and galaxies). Metal transfer from galaxies to the ICM (ejection vs extraction).

Lecture 2: Metal production in clusters. The star formation history of cluster galaxies. The production of alpha elements by Type II supernovae and the IMF. The iron production by Type Ia supernovae. Metals in the ICM and ICM pre-heating.

Lecture 3: Beyond galaxy clusters: the chemical evolution of the universe. Star formation in clusters vs field. The global metallicity of the universe, locally and at high redshift. Chemical evolution of the Milky Way and of clusters: are the two pictures consistent?

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7. Mark Birkinshaw (5 hours)

The Sunyaev-Zel'dovich effect in cosmology and cluster physics

Lecture 1: The physics of the SZ effect
- Inverse-Compton scattering --- the Kompaneets equation and the non-relativistic limit, high-temperature gas scattering, the relativistic limit.
- The SZ thermal and non-thermal effects and the Compton y parameter.
- The kinematic effect.
- Brightness temperature, specific intensity, flux density of the SZ effects.
- Polarization signals

Lecture 2: Observing the SZ effect
- Fundamental considerations in observation design
- Basic observation types: radiometers, interferometers, bolometers
- Sensitivity requirements and limits
- Sources of noise
- Systematic errors in different types of study

Lecture 3: Cluster science from the SZ effect
- Linear and non-linear probes of structure
- Baryon content of clusters
- Energy content of clusters
- Approaches to virial equilibrium
- Gravitational lensing and cluster SZ effects
- Thermal substructure in clusters: X-ray and SZ effect evidence
- Velocity structure and the growth of clusters
- Supercluster gas

Lecture 4: Cosmology from the SZ effect
- Clusters at high redshift: X-ray and SZ effect sensitivities
- SZ effect confusion and the primordial background
- The cluster Hubble diagram
- Microwave background quadrupole sampling
- Evolution of the microwave background

Lecture 5: The next generation of instruments for SZ effect science
- Need for SZ effect instruments: science drivers
- Possibilities and realities
- Interferometers: AMI, AMiBA, SZA, etc
- Bolometer arrays: SPT, ACT, APEX, Planck, BOLOCAM, etc
- Radiometer arrays: OCRA, Planck, etc
- Performance comparisons
- X-ray telescope complementarity
- A step further

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8. Stefano Borgani (4 hours)

Precision Cosmology with Clusters

Lecture 1: Introduction - Different ways of constraining cosmological parameters using galaxy clusters.
Basics of evolution of cosmological density perturbations.
The Spherical top-hat collapse.
The Press-Schechter Theory: comparison with N-body simulations and extensions.
Models for the power spectrum and correlation function of dark matter halos.

Lecture 2: Methods to estimate the mass of galaxy clusters:
X-ray methods and the equation of hydrostatic equilibrium;
Dynamics of galaxies within clusters: the Jeans equation and the virial theorem;
Elements of mass estimates from gravitational lensing.
Cosmological constraints from the baryon fraction in clusters:
Constraints on the density parameter from low-redshift clusters;
Constraints on Dark Energy from distant clusters;
Calibrating the method with with hydrodynamic simulations.

Lecture 3: Observational measurements of the cluster mass function:
Building cluster samples at different wavelengths: efficiency of cluster identification and the survey selection function.
Overview of surveys in the optical band: the distribution of the cluster velocity dispersions and its evolution.
Overview of surveys in the X-ray band: the X-ray luminosity function, the temperature function and the baryon mass function.
Critical review of the cosmological constraints so-far obtained.
Observational measurement of the power spectrum and correlation function of galaxy clusters: Results in the optical and X-ray bands.

Lecture 4. The future of cosmology with galaxy clusters:
Precision cosmology: non-Gaussianity and Dark Energy from galaxy clusters?
Lensing and SZ blind cluster searches;
Perspectives for deep wide-field X-ray surveys.

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9. Rien van de Weygaert (6 hours) substituting also for Dick Bond
Clusters and the Cosmic Web

1) **Census of the Cosmic Web**: surrounding large scale structure: nearby superclusters and clusters, location within surrounding weblike structure (e.g. 2MASS), the 2dFGRS and SDSS: walls and filaments, voids and clusters, the web at high redshifts: pencil-beam redshift surveys. Subaru deep field, clusters and the web: comparison REFLEX clusters and galaxy distribution.

2) **Formation of the Cosmic Web:**

- Linear Theory: Linear Density and Velocity Perturbations (definitions, linear growth density and velocity perturbations), Gaussian random density and velocity perturbations, definition Gaussian distribution, Fourier definitions, Power spectrum definition, Filtering: Gaussian and Tophat, generating primordial perturbation fields, Peaks in Gaussian random fields: description (height, shape, ...), peak bias description, Constrained Random Field theory
- Nonlinear Structure Growth**:** Anisotropic Collapse, Hierarchical Clustering:

Excursion Set theory (Press-Schechter): Clumps and Voids, Quasi-linear perturbation theory (Lagrangian perturb. theory): Zeldovich formalism, Least Action Principle, Web Constraints: tidal constraints, filaments, voids and clusters (theory of how clusters tie in with weblike features, CRF of tidal shear). Formation filaments and voids.

- N-body experiments: cluster, filament and void growth in different cosmologies, sensitivity power spectrum slope n(k), cluster virialization, infall and substructure, void hierarchy

3) Analyzing the Cosmic Web

(A) superclustering:

correlation function analysis cluster distribution and cluster bias

(B) measures for weblike topologies

- filaments: percolation measures, MST, ...
- topology, Minkowski functionals, local MF (SURFGEN)
- DTFE

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10. Carlos Frenk (2 hours)

Background Cosmology & N-body Simulations

Lecture 1: Introduction to large-scale structure I: origin of fluctuations, linear theory, power spectra, microwave background radiation

Lecture 2: Introduction to large-scale structure II: the spherical top hat model, Press-Schechter model, tidal torques, N-body simulations

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11. Jean-Paul Kneib (4 hours)

Cluster Lensing

I. Introduction: gravitational lensing - the tool

- historical perspective
- lensing equations: deflection, amplification, time delay
- angular distances
- simple mass models
- strong lensing: Einstein ring, multiple images, giant arcs
- weak lensing: shape measurements, averaging

II. Strong gravitational lensing: Exploring cluster cores

- strong lensing observations
- strong lensing methods
- parametric approach
- non-parametric approach
- X-ray vs strong lensing
- M/L in cluster core
- inner dark matter slope (velocity dispersion of cD)

III. Weak lensing in clusters

- shear measurements, PSF corrections

- 1D mass reconstructions: shear/mass profiles
  parametric/non-parametric methods
- 2D mass reconstructions:
  parametric/non-parametric methods
- strong + weak constraints on cluster mass profile
- X-ray vs lensing mass comparison
- M/L as a function of radius
- Dynamical mass estimate of clusters - 3D picture.
- Mass distribution of cluster samples - cosmological implications

IV. Other Applications

* Galaxy-galaxy lensing
- statistical direct approach
- maximum likelihood methods
- physical constraints

* Clusters as telescope
- motivation, benefits
- example of distant lens galaxies.

* Cluster Cosmography

* Future of Cluster Lensing.

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12. George Djorgovski, Roy Gal and Omar Lopez-Cruz (4 hours)
Global Properties of Clusters and Cluster Searches

1. General optical properties of clusters - an introduction (1.5 hours)
   What optical cluster measurements do we make? What physics do they address, and what is hard to do?
   - Richness - is this a useful property? Relation to mass?
   - Integrated luminosities, cluster luminosity (mass) functions
   - Morphology, structure, radial profiles, concentration, substructure. How do these impact detection and measurement of physical properties? Relation to dynamical ages and numerical simulations. Schemes for the morphological classification of clusters; do they make sense?
   - Spectroscopy, for both redshifts and galaxy properties (but leaving the details of galaxy properties to other speakers).
   - Velocity dispersions. What's needed for a "reliable" velocity dispersion? Relation to x-ray temperature. Kinematical substructure correlated with density substructure.
2. Cluster finding techniques (0.5 hours)
   - Detection techniques in the optical/NIR: matched filters, adaptive kernel, red sequence, Voronoi tesselation, etc. Drawbacks and advantages of each. How do they compare to other techniques (x-ray, radio, SZ, lensing)?
3. Galaxies and light within clusters (1 hour)
   - The effects of the environment on galaxy cluster populations. Various physical mechanisms and possible observables.
   - Disruption of galaxies and the formation of cD galaxies.
   - The non-universality of the LF.
   - The morphology of cluster galaxies and the density-morphology relationship.

- The color-magnitude relation, red sequence, and its implications for galaxy formation and evolution. The size-magnitude relation and passive evolution. A brief overview of Fundamental Plane results.
- Intracluster light: just a brief discussion of what is known, what it might be, difficulty of measuring.

4. Cluster scaling relations (1 hour).
    - Known correlations: optical, x-ray, and their interpretations. Comparison with theoretical expectations.
    - Difficulties in measuring cluster radii, possible approaches.
    - Consistency of r_vir, r_200, r_500, etc., and comparing of observations and simulations.
    - Fundamental plane of clusters: preliminary results, future prospects.