
ETH
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Star and Structure Formation:
From First Light to the Milky Way
Talks Abstract
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Session 1

When and where was First Light and how can we look for it?

Probing The First Stars and their Effects on the Universe

Avi Loeb, Harvard University

Abstract The formation of the first stars marks the transformation of the universe from its smooth initial state to its clumpy current state. In popular cosmological models, the first stars began to form at a redshift ~20. The large-scale polarization anisotropies of the microwave background measured recently by the WMAP satellite imply that these stars ionized a significant fraction of the cosmic hydrogen only 200 million years after the big bang. If feedback regulates star formation in early dwarf galaxies as observed in present-day dwarfs, then this early re-ionization requires that the first generation of metal-free stars have a top-heavy (rather than Salpeter) mass function. Despite its importance, there is currently very limited theoretical understanding of the radiative and hydrodynamics feedback of the first stars on their host galaxies. I will describe observational methods to directly probe these effects. In particular, I will show why gamma-ray bursts are much better sources than quasars for probing the first stars and their cosmic habitat.

First Stars and Quasars: What are their Effects on the IGM?

Michael Shull, University of Colorado

Abstract Sometime between redshifts z = 10-30, the first stars and pre-galactic objects formed out of the primordial IGM. I will describe recent theoretical models of the first massive stars, low-mass galaxies, and active galactic nuclei, and speculate about their observable effects on the IGM:

(1) double reionization of the IGM

(2) high-redshift metal pollution

(3) dwarf galaxies and high-z black holes

(4) relics in the cosmic microwave background optical depth

(5) anomalous He II/H I absorption ratios in the voids

The End of the Dark Ages: The Formation of the First Stars and Quasars

Volker Bromm, Harvard University, USA

Abstract How and when did the cosmic dark ages end? I present simulations of the formation of the first stars and quasars, discuss their feedback on the IGM, and describe ways to probe their signature with JWST. The first supernovae are responsible for the initial metal enrichment of the IGM, and I address the impact of this initial enrichment event on the subsequent history of structure formation. Finally, I describe the properties and statistics of high redshift GRBs and SNe that result from the first generation of stars.

Feedback Effects at Cosmic Dawn

Andrea Ferrara, Osservatorio Astrofisico Arcetri, Firenze

Abstract The appearance of the first stars when the universe was only 100 Myr old marked the Cosmic Dawn and the occurrence of a number of physical effects (cosmic reionization, intergalactic medium metal enrichment, black hole formation, magnetic field cosmogenesis and - obviously - galaxy formation) which are now entering the realm of the observability and are strongly governed by so-called `feedback effects'. These feedback effects due to massive stars and supernovae in the first objects are shown to regulate both galaxy formation/evolution and the reionization process.

They are particularly relevant as it is believed that the Initial Mass Function of the first stars was very heavy, thus favouring the formation of massive objects which end their lives as supernovae, or most likely, in even more gigantic explosions which could be connected with high energy events as gamma ray bursts and TeV-neutrino emission. I will review these physical processes at high redshift ($z > 5$) and their detectable imprints, and propose a number of experiments which could yield the first observational signals from the Dark Ages of the universe.

The First Sources of Light

Tom Abel, Center for Astrophysics, USA

Abstract Recent years have led to a watershed in scientific insights gained from direct numerical simulations. In particular our understanding of the formation of primordial proto-stars can be modelled has increased dramatically. However, what sets the final mass of the first stars, and their feedback on subsequent structure formation is currently debated intensely.

First Light - have we found it in Lyman-alpha emitters?

Sangeeta Malhotra, Space Telescope Science Institute

Abstract The Lyman-alpha emitters at z=4.5,5.7 and 6.5 found by the Large Area Lyman Alpha survey show high equivalent width of the line - much higher than can be explained by stellar populations with normal IMFs. Stellar population models with any or all of the following: extremely metal-poor stars, skewed IMFs, young stellar populations can explain the prominent Lyman-alpha emission. AGNs are ruled out by the lack of x-ray emission. Weird geometry is the only other explanation of the high equivalent width that does not favor primitive stars.I will discuss other evidence that might favor or disfavor lyman-alpha emitters as the primitive first light sources.

High z galaxies and AGN

Len Cowie, University of Hawaii

Abstract I will first describe observations of the Lyman alpha forest in a very large sample of z=4-6.4 quasars. These observations show a smooth evolution in the forest transmission which is not particularly supportive of the idea that reionization occurred at z=6.2. The observations determine the required ionization rate over the redshift interval. I will then show using deep field Chandra observations that there are too few AGN to provide this ionization. I will finally compare the required ionization rates with various galaxy searches at these redshifts.

Session 2

When did Reionization occur and what did it?

GRBs versus Quasars: Lyman-alpha Signatures of Reionization versus Cosmological Infall

Rennan Barkana, Tel Aviv University

Abstract Lyman-alpha absorption is a prominent cosmological tool for probing both galactic halos and the intergalactic medium at high redshift. We consider a variety of sources that can be used as the Lyman-alpha emitters for this purpose. We first review our recent demonstration, carried out on two distant quasars, of how to measure the mass of the surrounding dark matter halo based on absorption by infalling hydrogen. We then illustrate how similar measurements on large numbers of quasars will probe the evolution of massive halos. On the other hand, we argue that gamma-ray bursts represent the cleanest sources for studying the reionization of the intergalactic medium.

Probing Reionization History with Topological Tests

James Rhoads, Space Telescope Science Institute, USA

Abstract The most rapid and interesting phase of reionization was the overlap phase, when the ionized bubbles created by individual sources merged. This occurred when the volume-averaged neutral fraction was approximately half, and therefore cannot be probed by Gunn-Peterson troughs that become opaque at much smaller neutral fractions. Overlap is fundamentally a topological transition, and can be detected observationally by using topological statistics. The most promising observational tools for applying such tests are

(a) Lyman alpha galaxy counts, and
(b) 21 cm tomography.

I will review the physics of Lyman alpha radiative transfer in a partly neutral IGM, and discuss the practical issues involved in implementing a topological test of reionization using either Lyman alpha galaxies or 21 cm observations.

The First Stars and Reionization

Jordi Miralda-Escude, The Ohio State University

Abstract I will discuss models of reionization in view of the recent observations of the Gunn-Peterson trough in z>6 QSOs, and the WMAP detection of the electron scattering optical depth to the CMB.

Highest-redshift Quasars: Probing the End of the Reionization Epoch

Xiaohui Fan, University of Arizona

Abstract I will present studies of the highest redshift quasars discovered from the data taken with the Sloan Digital Sky Survey. These most distant quasars provide one of the best probes to the high redshift universe. I will present results on the evolution of their luminosity function, their possible connections to high redshift star formation, and the ionization state of the IGM at $z > 6$ revealed by the quasar absorption lines. I will discuss how to use these objects to probe the end of the reionziation epoch.

Constraints to the evolution of Ly-alpha bright galaxies between z=3 and z=6

Christian Maier, Max-Planck-Institut für Astronomie, Heidelberg, Germany

Abstract Galaxies at high redshift with a strong Ly-alpha emission line trace massive star formation in the absence of dust, and can therefore be regarded as a prime signature of the first major starburst in galaxies. I will report results of the Ly-alpha search within the Calar Alto Deep Imaging Survey (CADIS).

With imaging Fabry-Perot interferometer CADIS detects emission lines in three waveband windows free of night-sky emission lines at 700nm, 820nm, and 920nm with a typical emission flux detection limit of Flim>3X10^(-20)Wm^(-2). Candidate Ly-alpha-emitting galaxies are selected from the total emission line sample, which contains more than 97% of objects at z<1.2, by the absence of flux below the Lyman limit (B-band "dropouts"), and the non-detection of secondary emission lines in narrow band filters.

For four of eight observed Ly-alpha candidates the emission line detected with the Fabry-Perot has been verified spectroscopically at the VLT. When compared to Ly-alpha surveys at z<3.5 even the upper limits set by our list of candidates show that bright Ly-alpha galaxies are significantly rarer at z>5 than the assumption of a non-evolving population would predict. Therefore we conclude that the Ly-alpha bright phase of primeval star formation episodes reached its peak at redshifts 3<z<6.

The Space Density of Redshift 5.7 LyA Emitters from a Deep, Keck Multislit Windows Search

Crystal Martin, University of California, Santa Barbara, USA

Abstract We (C. Martin & M. Sawicki) present results from a deep z=5.7 LyA emission line search with LRIS Keck I. The aim was to push further down the LyA luminosity function than is possible with narrowband imaging surveys while covering more area than surveys restricted to cluster caustics. The multislit windows technique does this by dispersing the light within the atmospheric windows and blocking light outside the window. Though we find many strong emission lines in this blind survey, the number of z=5.7 LyA emitters brighter than 0.6 Lstar is at most two in this (approximately) foursquare arcminute field. We argue that the LyA luminosity of a 'typical' star-forming galaxy cannot brighten much between redshift 3 and 5.7, nor can the number density of such objects increase much. This result raises the interesting question of whether there are enough bright, high-redshift galaxies to maintain the ionization of the intergalactic medium at z=5.7. To make our upper limit on the density of LyA emission consistent with the critical star formation rate would require a LyA escape fraction $f_{LyA} \leq 0.2\ f_Q$, where f_Q is the escape fraction of Lyman continuum photons. While this LyA escape fraction is quite low, it does appear to be plausible given that only 25\% of starburst galaxies at z=3 have LyA in emission (Shapely et 2003). If our candidates are not confirmed to be lyA, however, then it would appear that much fainter galaxies (dwarfs) supply the bulk of the intergalactic radiation field at high redshift. I will also show numerical simulations (with A. Fujita) that explore the star formation efficiency and galactic wind strength required to get substantial leakage of ionizing radiation from high-redshift dwarf galaxies.

Constraints on Reionization from High-z Galaxies

Malcom Bremer, University of Bristol, UK

Abstract I review observations of the most distant galaxies, and how they constrain reionization. Specifically I talk about our deep imaging and spectroscopy programme to find such objects. From deep imaging and spectroscopy we have discovered multiple galaxies at z>5 in a single field. All appear as very recent low metallicity starbursts. Despite the high success rate of discovery, there appear fewer of the galaxies than expected assuming no evolution between z=3 and z>5. The total UV emission from these sources is insufficient to ionize their volume, indicating that such galaxies were unable to reionize the universe (given that they are observed soon after reionization ends).

Observational Constraints on Reionization from High-z Galaxy Studies

Esther Hu, University of Hawaii

Abstract Information on the epoch of reionization can be obtained both from detailed spectroscopic studies of individual high-redshift galaxies and from the number density of confirmed emitters found in wide-field, high-z Lyman alpha galaxy searches. In this talk, I present results from wide-field spectroscopic observations made with the DEIMOS spectrograph on Keck. The luminosity function of Lyman alpha galaxies indicates that star formation rates may remain substantial out to z~5.7. High-resolution spectra of a z=6.56 lensed galaxy shows a kinematic structure with a sharp blue edge, but extended red wings, which is not consistent with a surrounding neutral IGM.

Session 3

How does Metallicity of the Universe develop?

Evolution of the Metallicity of the Universe

James W. Truran, University of Chicago

Abstract The primordial compositions of the first stars reflect that of the Universe as it emerged from the cosmological Big Bang: hydrogen, deuterium, ^{3}He, ^{4}He, and ^{7}Li. Within galaxies, stars and supernovae play the dominant roles in synthesizing the elements from carbon through uranium, and in returning heavy-element-enriched matter to the interstellar gas from which new stars are formed. This abundance history is written in the compositions of stars in our Galaxy (and other galaxies). Observational studies, both with HST and with large aperture ground-based telescopes, are now providing increasing amounts of information concerning both the compositions of stars in our Galaxy and nearby galaxies and the spectroscopic and photometric properties of gas clouds at high red shifts. We review the nuclear processes that participate in heavy element synthesis, identify the astrophysical sites (stars and supernovae) with which they are associated, and note particularly the (production) timescales on which this enrichment is expected to occur. We then demonstrate how observations of distinctive abundance patterns in older stellar populations can be used to trace and to constrain the star formation and nucleosynthesis histories of galaxies and the Universe.

On the constraints on galaxy formation timescales from observed alpha elements overabundance

Laura Greggio, Observatory Padua

Abstract The chemical enrichment timescale of alpha elements and Iron in stellar systems depends on both their Star Formation timescale and on the SN explosion timescale. This dependence is investigated by means of a general analytical formulation, and some conclusions are drawn on the constraints for the formation timescale of Elliptical Galaxies derived by observed alpha element overabundance.

Constraints on Galaxy Formation from Observations of Resolved Fossils

Annette Ferguson, MPA, Germany

Abstract I will discuss observations of the resolved fossil stellar populations in M31 and/or M33 which place constraints on galaxy formation and evolution models, for example constraints on the age/star formation history of disks at large radius and the existence and nature of substructure in the stellar halo.

The Fossil Record of Galaxy Formation observed with SAURON

M. Cappellari, Leiden Observatory

Abstract First results are reported of the study of a representative sample of 48 E/S0 galaxies and 24 early-type spiral bulges with the custom-built integral field spectrograph SAURON, with emphasis on the relations between kinematic structure and the ages and metallicity of the stellar populations.

Chemical Evolution of the ICM

Cesare Chiosi, Department of Astronomy, University of Padova, Italy
(C. Chiosi, A. Moretti, L. Portinari)

Abstract The high metallicity of the intra--cluster medium (ICM) is generally interpreted on the base of the galactic wind scenario for elliptical galaxies. In this framework, we develop a toy--model to follow the chemical evolution of the ICM, formulated in analogy to chemical models for individual galaxies. The chemical evolution model for the cluster computes the Galaxy Formation History (GFH) of cluster galaxies, connecting the final Luminosity Function (LF) to the corresponding metal enrichment history of the ICM. The observed LF can be reproduced with a smooth, Madau--plot like galaxy formation history (peaking at z =1-2 plus a ``burst'' of formation of dwarf galaxies at high redshift. The model is used to test the response of the predicted metal content and abundance evolution of the ICM to varying input galactic models. In our favoured model, chemical enrichment is computed from “galactic yields'' based on models of elliptical galaxies with a variable IMF, favouring the formation of massive stars at high redshift and/or in more massive galaxies. For a given final galactic luminosity, these model ellipticals eject into the ICM a larger quantity of gas and of metals than do standard models based on the Salpeter IMF. Henceforth, the high Iron--Mass--to--Luminosity--Ratio characteristic of the ICM can be reproduced.

New Explorations with DEEP of the Metallicities of Gas and Stars at Intermediate Redshifts

David Koo, University of California

Abstract DEEP is a redshift survey of 50,000 faint field galaxies using the Keck Telescopes. After a brief overview and update of the status of DEEP, this talk will highlight our most recent results in exploring 1) the metallicities and ages of the stellar population within very red field galaxies; and 2) the O/H metallicities and ionization state of the gas as measured from emission lines. Our sample will largely be luminous field galaxies at intermediate redshifts z ~ 0.7 to 0.8, with a particular emphasis on compact galaxies and red galaxies with emission lines.

The Distribution of Metals in the Intergalactic Medium

Joop Schaye, Institute for Advanced Study, Princeton, USA

Abstract We have developed new statistical techniques to search for absorption by various heavy elements and applied these to an unprecedented sample of high-quality quasar spectra. I will present results from this new study, including the first measurements of the distribution of metals in the diffuse intergalactic medium as a function of density and redshift.

The Sources of Intergalactic Metals

Evan Scannapieco, Osservatorio Astrofisico di Arcetri, Florence, Italy

Abstract I will present an analysis of the size distribution and clustering of over 1000 CIV and SiIV systems measured in 19 high signal to noise QSO spectra as part of the ESO Large Program "QSO absorption lines". These results place unique constraints both on the masses of the objects responsible for cosmological enrichment, and the velocities at which this material was ejected. Collaborators involved in this study include Patick Petitjean, Christophe Pichon, Jaqueline Bergeron, and Bastien Aracil.

Evolution of Metals in Galaxies: Clues from the Damped Lyman-alpha Absorbers

Varsha Kulkarni, University of South Carolina, USA

Abstract Absorption lines in quasar spectra provide a unique tool to trace the evolution of galaxies. The damped Lyman-alpha (DLA) absorbers enable us to directly measure the abundances of elements in galaxies at redshifts $0 < z < 5$, and hence probe the chemical evolution of galaxies over > 90% of the age of the Universe. Although cosmic chemical evolution models predict the global metallicity of galaxies to increase with time, it is not clear whether DLAs actually show such a trend. One of the main problems is the small number of measurements, especially at $z < 1.5$. We describe results of our statistical analyses of existing DLA abundance data to address the question of metallicity evolution. We also describe results of two spectroscopic surveys we are currently performing to measure element abundances in DLAs at $0.1 < z < 1.5$. These include an ultraviolet survey with the Hubble Space Telescope and an optical survey with the Multiple Mirror Telescope. These studies are helping to determine the shape of the cosmic metallicity-redshift relation to a much higher accuracy than available so far.

Star Formation and Metal-enrichment History in Clusters and in the Field from SNe

Dan Maoz, Tel Aviv University, Israel

Abstract Being closed boxes, galaxy clusters are excellent laboratories for studying the source of metals. The iron mass in clusters is about 5 times larger than could have been produced by core-collapse SNe, assuming the stars in cluster galaxies formed with a standard IMF. Type-Ia SNe have been proposed as the alternative dominant iron source. We use our HST measurements of the cluster SN-Ia rate at high redshift to study the cluster iron enrichment scenario. The measurements can constrain the star-formation epoch and the SN-Ia progenitor models via the mean delay time between the formation of a stellar population and the explosion of some of its members as SNe-Ia. The low observed rate of cluster SNe-Ia at $z\sim 1$ pushes back the star-formation epoch in clusters to z>2 and argues for a short delay time. Analysis of the redshift distribution of *field* SNe-Ia points to *long* delay times, unless the cosmic star formation history is more constant than many recent determinations. Thus, cluster enrichment by core-collapse SNe from a top-heavy IMF may remain the only viable option.

Session 4

How do Galaxies Grow?

The Evolution of Galaxies from very deep Near-IR imaging

Marijn Franx, University of Leiden

Abstract We discuss the results of our FIRE survey, which is based on very deep Near-Infrared imaging taken with the VLT. We show that the Near-Infrared photometry can be used to identify a significant population of galaxies, which is complementary to the well-known Lyman-break galaxies. We have derived the evolution of the integrated colors of galaxies, and the stellar mass density distribution.

First Results from the Gemini Deep Deep Survey

Bob Abraham, University of Toronto

Abstract Over the course of the last 18 months the Gemini Deep Deep Survey (GDDS) team has proposed, developed, and commissioned a Nod & Shuffle mode for the Gemini GMOS spectrograph in order to undertake the deepest redshift survey ever undertaken. The GDDS spectra are based on an infrared-selected sample, target the so-called "redshift desert" between $1<z<2$, and are deep enough (>30h exposures/field) that we are able to obtain redshifts and measure diagnostic indices for purely quiescent (no emission features whatsoever) L* galaxies out to $z=1.8$. The central goal of the GDDS is direct measurement of the evolving baryonic mass function over the peak epoch of galaxy assembly. On behalf of the GDDS team, I will describe the underlying design of the survey and present some early results on the evolving mass function and ages of galaxies at $1<z<2$.

Early Results from the Great Observatories Origins Deep Survey

Harry Ferguson, MPA, Germany

Abstract The Great Observatories Origins Deep Survey (GOODS) combines deep observations from HST, the ESO VLT and other ground-based telescopes, Chandra, and ultimately SIRTF to provide two deep reference fields for study of faint and distant galaxies. Early results from the survey include measurements of Lyman-break galaxy sizes, luminosities, and number densities out to redshifts $z \sim 6$, investigations of AGN number densities at high redshift, studies of galaxy morphological evolution from $z \sim 0.2$ to $z > 1$, and a measurement of weak tangential shear induced by gravitational lensing. Highlights from these on-going investigations will be presented.

Early results from the VIMOS VLT Deep Survey

Olivier Le Fevre, Laboratoire d'Astrophysique de Marseille

Abstract I will present the first results from the VIMOS-VLT Deep Survey (VVDS), a comprehensive survey aiming to study galaxy evolution over the range $0<z<5+$ from more than 100000 galaxies with spectroscopicaly measured redshifts. The redshift distribution of the sample, as well as luminosity function and clustering analysis will presented and discussed.

Massive Galaxies at High Redshift from K20+GOODS

Alvio Renzini, European Southern Observatory, ESO

Abstract With the aim of tracing the assembly of massive galaxies through cosmic time, spectroscopic redshifts have been measured for a sample of K-band luminous galaxies ($Ks<20$) at $1.7<z<2.3$, selected in a field covered by both the K20 and the GOODS Surveys. Fitting of their multi-color spectral energy distributions indicates stellar masses $M=\sim 10^{11}$ Msun or more for most of the program galaxies, while extinction corrected star formation rates (SFRs) of 100--500 Msun/yr are derived. Their rest-frame UV morphologies from HST/GOODS imaging are highly irregular, suggesting that merging-driven starbursts are going on in these galaxies. Morphologies tend to be more compact in the near-IR, a hint for the possible presence of older stellar populations. Such galaxies are strongly clustered, with the majority belonging to redshift spikes, which indicates a correlation length r_o = (9-17) h Mpc (1 sigma range). Current semianalytical models of galaxy formation appear to underpredict by more than an order of magnitude the number density of such a population of massive and powerful starburst galaxies at z=2. The high masses and SFRs together with the strong clustering suggest that at z=2 we may have started to explore the major formation epoch of massive early-type galaxies.

The Clustering of SDSS Galaxies as a Function of Color

Alex Szalay, Johns Hopkins University

Abstract n/a

Models for disk galaxy formation

Ortwin Gerhard, University of Basle, Switzerland

Abstract I describe multiphase models for the formation and evolution of disk galaxies within a growing dark halo whose mass evolves according to LCDM cosmological simulations. These models predict the star formation history, the photometric and metallicity evolution over redshift, and the distribution of stellar ages and metallicities at z=0. Some comparisons with observations of young galaxies and stellar components in the Milky Way are discussed.

Session 5

When and how are Fundamental Scaling Relations set?

An empirical picture of the evolution of galaxies from the COMBO-17 survey

Hans-Walter Rix, MPA, Germany

Abstract I will present a detailed, empirical picture of the evolution of the galaxy population over the last 8 Gyrs, both in terms of its stellar population and in terms of its structural and dynamical properties. The results are based on ~30,000 faint galaxies with SEDs and redshifts ($0.2<z<1.1$), drawn from the COMBO-17 survey, and complemented by structural parameters and morphologies for ~10,000 of these, drawn from the GEMS mosaic, the larges multicolor image with HST. Results include:

(1) The galaxy color distribution is bi-modal at all redshifts to $z\sim1$, with not only the most massive, but also most luminous (V-band) galaxies being red; at all these redshifts the vast majority of "red sequence" galaxies is red because of a smooth, old stellar population, not because of dust.

(2) The colors, and the luminosity-size relation, of red sequence galaxies are consistent with passive fading; yet, the total mass of stars in early type galaxies doubles since $z\sim1$.

(3) At intermediate redshifts ($z\sim0.5$) about half of all luminous galaxies with blue star-burst spectra are clearly mergers. I will also present preliminary results on the evolution of the merger rate and on the size function of galaxies.

Galaxy Scaling Relations in the SDSS and their Dependence on Environment

Guinevere Kauffmann, Max Planck Institute for Astrophysics

Abstract I will present the relations between stellar mass, star formation history, size and internal structure for a complete sample of 122,808 galaxies drawn from the Sloan Digital Sky Survey. I will also discuss how these relations depend on the environment of the galaxy and the implications of these finding for theoretical models of galaxy formation.

The Host Galaxies of 23,000 AGN

T. M. Heckman, Johns Hopkins University

Abstract I will report on the properties of the host galaxies of 23,000 Active Galactic Nuclei (AGN) selected from the main galaxy sample of the Sloan Digital Sky Survey. We have used the extinction-corrected luminosity of the [OIII]5007 emission line as an indicator of AGN power. The kinematics of the narrow emission-lines in AGN correlate strongly with the measured stellar velocity dispersion. The AGN phenomenon is common-place only in massive galaxies with correspondingly large velocity dispersions. AGN hosts have distributions of sizes, stellar densities, and concentrations similar to normal early-type galaxies. While low-power AGN are hosted by galaxies with old stellar populations, the hosts of powerful AGN have young stellar populations distributed over size-scales of several kpc or more. An unusually large fraction of powerful AGN are in galaxies that have experienced a major burst of star-formation within the past ~Gigayear. The hosts of type 2 Seyferts and quasars with the same redshift and [OIII]5007 luminosity have the same young stellar population. The simplest interpretation is that only massive galaxies contain suitably massive nuclear black holes, and that only galaxies with recent/on-going star-formation have a rich supply of cool interstellar gas to fuel the black hole. This combination is rare today, but must have been more common at early epochs. The connection between star-formation and black hole fuelling is consistent with the close relationship between black hole mass and the properties of the bulge component on galaxies today.

Relationship of Black Hole to Host Galaxy: Properties and Evolution

Karl Gebhardt, The University of Texas at Austin

Abstract The amount of data archived or planned for black hole studies offers an enormous opportunity to fully characterize their relationship to the host galaxy. I will review the present observations and discuss their implications. We are now also able to obtain redshift information for these relations, allowing us to watch how they develop and evolve. I will discuss the evolution of black hole growth relative to the growth of the galaxy.

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Feedback Effects from Growth of Supermassive Black Holes

M. Begelman, University of Colorado

Abstract Accreting black holes probably release as much (or more) energy in kinetic form (via jets and accretion disk winds) as they do in the form of radiation. The total energy liberated during growth of a supermassive black hole is more than enough to unbind all the gas in the surrrounding galaxy and seriously affect the energetics of the nearby intracluster medium. But the impact of this energy is sensitive to the way in which it is deposited. Are the effects concentrated and violent, or more distributed and gentle?

Recent studies of black hole feedback in clusters of galaxies seem to be favoring gentle and widespread heating. X-ray observations suggest that such feedback compensates for radiative cooling (quenching so-called "cooling flows") and may account for the excess entropy inferred in cluster cores. I will discuss the evidence for gentle ("effervescent") heating and recent attempts to model it, as well as its potential for regulating galaxy and/or black hole formation.

Origin of Black Hole Scaling Relations

David Merritt, State University of New Jersey

Abstract Supermassive black holes appear to be universal components of galactic spheroids, and their masses correlate tightly with the global properties of their host galaxies. I review theories for the origin of these scaling relations and discuss the implications for black hole growth.

Session 6

What is the underlying Physics of Disk Formation?

Gas Dynamics in Spiral Galaxies

Daniel Pfenniger, University of Geneva

Abstract The proper modelling and role of interstellar gas still present very serious difficulties, especially in spiral galaxies, where gas is clumpy and gravitationally unstable at different scales. First, observational and theoretical evidences suggest that the visible ISM is probably in a rapid dynamical state, the easily measurable HI being just a short lived phase. Second, evidences exist that stars do form in HI regions displaying no trace of CO or molecular clouds. Third, dynamical models of dark matter dominated galaxies seem to require a heavy disk component. Fourth, several circumstances suggest that the global dynamics of the ISM is better modelled with a weakly collisional or collisionless medium. A synthetic model of the ISM taking into account these constraints will be presented, in which most of the ISM mass is trapped in a very cold molecular phase behaving globally as a collisionless fluid until ambient radiation and cosmic rays evaporate it into visible HI.

Galaxy formation in SPH simulations; physical and numerical effects

Lucio Mayer, University of Zurich

Abstract We discuss the results of recent cosmological simulations which employ smoothed particle hydrodynamics (SPH) to model the baryonic component. We show that disks with sizes not far from those of large spiral galaxies can be achieved with enough mass and force resolution. This opens the possibility that the angular momentum catastrophe might be primarily numerical in nature and that a realistic galaxy formation is not impossible in cold dark matter models. On the other end, when and if convergence of the results can be achieved with SPH is not yet clear. In fact, problems are encountered even in simple tests where the formation of an isolated galaxy is followed at resolutions much higher than those adopted in state-of-the art cosmological runs.

Near and far: Comparing local and high-redshift disk galaxies to constrain their star formation histories.

Ignacio Ferreras, University of Oxford, UK

Abstract A combination of stellar population synthesis and a simple chemical enrichment model is shown to be a robust estimator of the star formation history of galaxies. We use such an approach on disk galaxies, comparing local late-type galaxies with a high-redshift sample from the FORS deep field. The analysis -- which involves optical and NIR broadband photometry -- aims at the estimate of scaling laws of global parameters that control star formation, such as the fraction of gas ejected in ouflows, the infall timescale or the efficiency of star formation.

Constraints on Galaxy Formation from Edge-On Disks

J. Dalcanton, Washington University

Abstract Using a sample of edge-on disks we have identified a sharp transition in the properties of disks at a rotation speed of 120 km/s. We explain the origin of this transition, and its implications for the morphology of the cold ISM, the stability of the disks, the three-dimensional structure of dwarfs, and the metallicity of disks as a function of mass.

HI holes, HI halos and gas infall

Renzo Sancisi, INAF-Osservatorio Astronomico di Bologna

Abstract What is the origin of the HI holes observed in galactic disks and of the high velocity HI observed in galactic halos?

Is there evidence for gas infall onto galactic disks?

Spiral Galaxy Scaling Laws and their Cosmological Application

Riccardo Giovanelli, Cornell University

Abstract not available yet

Forming Young Bulges within Existing Disks: Statistical Evidence for External Drivers

Sheila Kannappan, University of Texas at Austin

Abstract Contrary to traditional models of galaxy formation, recent observations suggest that some bulges form within preexisting disk galaxies. Such late-epoch, *in situ* bulge formation seems to be linked to disk gas inflow and central star formation, caused by either internal secular processes or galaxy mergers and interactions. We identify a population of galaxies likely to be experiencing active *in situ* bulge growth, using the criterion that the color within r_e is bluer than the outer disk color. Such blue-centered galaxies make up >10% of star-forming disk galaxies within the Nearby Field Galaxy Survey, a broad survey designed to represent the natural diversity of the low-z galaxy population over a wide range of luminosities. Blue-centered galaxies correlate at 99% confidence with morphological peculiarities suggestive of minor mergers and interactions. Furthermore, several quantitative plausibility arguments indicate that blue-centered evolutionary phases may represent an important mode of *in situ* bulge growth for many disk galaxies, leading to significant changes in bulge-to-disk ratio. If this view is correct, *in situ* bulge growth may be a natural consequence of the repeated galaxy mergers and interactions inherent in hierarchical galaxy formation.

Dense Disks and Small Bulges

Marcella Carollo, ETH Zurich

Abstract I will report some new numerical and observational results on "small bulges", and discuss implications for the formation of the local disk galaxy population.

Session 7

How does a Dense Environment Affect Galaxies?

Disentangling the high redshift universe.

Carlton Baugh, University of Durham

Abstract Galaxy mergers are thought to play an important role in shaping the high redshift universe. I will use a simulation of hierarchical galaxy formation to interpret the recent detections of seemingly disparate populations of galaxies at high redshifts, through their emission at far UV or sub-mm wavelengths, illustrating how they fit into the galaxy formation scenario in a cold dark matter universe.

Formation and evolution of DM Halos in different environment

Stefan Gottloeber, Astrophysical Institute Potsdam, Germany

Abstract According to the hierarchical scenario, galaxies form in dark matter halos, which grow via merging and accretion of small objects. Using new N-body simulations with very high mass and force resolution we study the clustering of dark matter halos hosting galaxies in LCDM cosmology with Omega = 0.3. We follow the evolution of halos, which end up in such different cosmological environment as the high density environment of clusters and the low density environment of voids. We discuss the formation and merging history of these halos and, using correlation functions, the relation of their spatial distribution to merging history. We discuss the distribution of halos in clusters and voids.

A Case Study of Galaxy Evolution in a Locally Dense Environment

Dennis Zaritsky, University of Arizona

Abstract I present the global star formation history of the Small Magellanic Cloud as derived from an analysis of millions of field stars and from hundreds of stellar clusters. Multiple, coincident, bursts of star formation are identified in both the field and cluster population. I will compare the timing of those burst with orbital models of the Clouds about the Milky Way to draw conclusions regarding the importance and efficiency of tidal triggering of star formation in a close encounter that is not yet a direct merger. The star formation model will also be compared with the derived chemical enrichment history to draw conclusions about the validity of a closed-box model.

The X-Ray Properties of galaxies

G. Fabbiano, Center for Astrophysics

Abstract This talk will summarize some of the Chandra results on the X-ray emission components of galaxies, and will focus on the effects of galaxy interaction on the X-ray emission. The talk will highlight the importance of the X-ray window in framing and answering fundamental questions in galaxy evolution and in suggesting parameters for future X-ray observatories.

The Roles of Environment in Galaxy Evolution

Ann Zabludoff, University of Arizona

Abstract What is the evidence that environment affects galaxy evolution in the nearby Universe? Which environments and environmental mechanisms are the most influential? How might we expand our knowledge to higher redshifts? I will review -- briefly! -- results from recent surveys of rich clusters, poor groups, and the field at z~0 that shed some light on these issues and that raise others.

PRGS and the TF Relation: Implications for the DH Shape

Magda Arnaboldi, INAF, Observatory, Turin, Italy

Abstract We have investigated the Tully-Fisher relation for Polar Ring Galaxies (PRGs), based on near infrared, optical and HI data available for a sample of these peculiar objects. The total K-band luminosity, which mainly comes from the central host galaxy, and the measured HI line width at 20% of the peak line flux density, which traces the potential in the polar plane, place most polar rings of the sample far from the Tully-Fisher relation defined for spiral galaxies, with many PRGs showing larger HI line widths than expected for the observed K band luminosity. This result is confirmed by a larger sample of objects, based on B-band data. This observational evidence may be related to the dark halo shape and orientation in these systems, which we study by numerical modelling of PRG formation and dynamics: the larger rotation velocities observed in PRGs can be explained by a flattened polar halo, aligned with the polar ring.

On the existence of extended dark matter halos around galaxies

Peder Norberg, ETH Zurich

Abstract By carefully selecting isolated bright galaxies and their associated satellites using the full 2dF Galaxy Redshift Survey, we estimate the satellite velocity dispersion of stacked primaries as a function of luminosity. Detailed comparisons with the same selection criteria applied to mock 2dFGRS catalogues, obtained from high resolution N-Body simulations and populated with galaxies from semi-analytic schemes, allow a precise understanding of the different properties of the 2dFGRS satellite sample. Mass estimates of primary systems as a function of luminosity is presented and compared to recent works using either SDSS data or data from the 2dFGRS 100k release.

The fate of cold gas in cluster galaxies

Jaqueline van Gorkom, Columbia University

Abstract How does a dense environment affect the gas in galaxies? I will present preliminary results of an HI imaging survey of clusters in the local universe. By observing the dense cores of clusters and the low density outer parts we can probe the galaxy properties in a wide range of environments and study how they change during the assembly of the clusters.

Old Galaxies at z > 1

Pat McCarthy, Carnegie Observatories

Abstract Deep spectroscopy of red galaxies selected from a large area multi-color survey has probed a population of old galaxies at redshifts beyond one. We describe the statistical properties of the red population, focusing on the number magnitude-relation, the spectral shapes and clustering of the red population. High resolution imaging with ACS on HST reveals that most of these objects have morphologies consistent with early Hubble types. Roughly 20% contain substantial disks. Deep spectroscopy with Gemini reveals little or no evolution in the spectral shapes of the oldest galaxies compared to local templates. We will discuss the implications for the formation epoch and the assembly of early-type galaxies at high redshift.

Session 8

How do Baryons and Dark Matter interact?

Cusps, dynamical friction, and resonances

Anatoly Klypin, New Mexico State University

Abstract We make a detailed study of resonances occurring inside a cuspy dark matter halo when a satellite orbits around it and sinks due to the dynamical friction. Using different numerical techniques we find that resonances strongly affect the response of the halo. The crucial issue for understanding the dynamical friction is appearance of overlapping resonances for trajectories of dark matter particles, which cross the orbit of the satellite.

A Spectroscopic Gravitational Lensing and Limits on the Dark Matter Substructure

Ben Metcalf, University of California at Santa Cruz

Abstract Data from the CIRPASS integral field unit (IFU) is used to measure the gravitational lensing of the 4--image quasar Q2237+0305 on different size scales. A new method for measuring the substructure present in the lens used and demonstrated to be very effective and independent of many of the degeneracies inherent in previous methods. The magnification ratios are compared in multiple wavelengths and within spectroscopic lines to measure the properties of the substructure present in this gravitational lens. We detect both microlensing and lensing by some larger scale substructure. We interpret this substructure in terms of the "missing" small scale structure in the Cold Dark Matter model and put limits on its abundance and mass scale.

The angular momentum problem in CDM halos

Elena D'Onghia, Max-Planck Institute of Astronomy (MPIA)

Abstract Cosmological models of hierarchical clustering predict that galactic disks form as a result of gas infall into cold dark matter (CDM) halos. The disk scale lenghts and rotation curves are determined by the gravitational potential and by the specific angular momentum distribution which the gas acquired from tidal interaction with the cosmological density field and which was modified during the protogalactic collapse phase. Analytical calculations have shown that the observed scale lengths and other properties of galactic disks are reproduced if the disk material retained its initial specific angular momentum when settling into the galactic plane. In the past cosmological N-body/SPH simulations have showed that the scale lengths and specific angular momenta of simulated disks are a factor of 10 smaller than observed (so called angular momentum problem of galaxy formation). We use a set of high-resolution simulations including gas and dark matter to study the formation of disks in a cosmological context. We focus on the following questions: is the halo merging history playing a role in building small disks or increasing the numerical resolution are the simulated disks of the observed size? Is the disk material retained its initial specific angular momentum or is it lost and why?

Galaxy Masses with Strong Lensing

Chuck Keeton, University of Chicago

Abstract not available yet

Resolving the Inner Structure of CDM Clusters

Juerg Diemand, University Zurich-Irchel

Abstract We present first results from a series of new N-body simulations of LCDM clusters. These halos contain up to 30 million particles within the virial radius at redshift zero. Still they are affected by two body relaxation since they are the product of many mergers that started with badly resolved, small N systems. This sets a minimum radius a CDM simulation can resolve if all the numerical parameters a choosen carefully. We find that this resolved radius shrinks slowly with N and that the density profiles at this radius are all clearly steeper than the NFW profile.

The Halo Occupation Distribution of 2dF Galaxies

Cristiano Porciani, ETH Zurich

Abstract The 2-point correlation function of 96,791 galaxies from the 2dFGRS has been used to study how local galaxies are distributed within their host dark-matter haloes. In particular, we estimated the mean number of galaxies which populate a halo of a given mass and the corresponding variance for galaxies with different spectral types. We found strong evidence for morphological segregation, as late-type galaxies appear to be distributed within haloes of mass scales corresponding to galaxy groups and clusters up to about two virial radii, while passive objects show a preference to reside in smaller haloes and closer to the halo centre. As regards the number-density profile of galaxies within a single halo, we found that both early and late-type galaxy distributions can be well described by dark matter profiles found in CDM models. However, while star-forming galaxies can even allow for steeper profiles, this seems to be drastically ruled out in the case of early-type galaxies.

Properties of Dark Matter Halos in Disk Galaxies

Roelof de Jong, Space Telescope Science Institute

Abstract We present a simple technique to estimate mass-to-light (M/L) ratios of stellar populations in local universe galaxies based on two broadband photometry measurements, i.e. a color-M/L relation. We apply the color-M/L relation to galaxy rotation curves, using a large set of galaxies that span a large range in Hubble type, luminosity and scale size and that have accurately measured HI rotation curves. We have obtained new accurate optical and near-IR surface photometry of these galaxies as well as optical rotation curves. Using the color-M/L relation we construct stellar mass models of the galaxies. We subtract all known mass components from the observed rotation curves to reveal the dark matter contribution to the rotation curves. We use these dark matter rotation curves to investigate dark matter scaling relations for our set of galaxies. We compare our dark matter rotation curves with adiabatically contracted Navarro, Frenk & White dark matter halos and with isothermal spheres.

A Dynamical friction and halo densities

Jerry A. Sellwood, University of New Jersey
(and Victor Debattista, ETH Zurich)

Abstract Rotating bars in disk galaxies offer a direct probe of the dark matter halo. The dynamical friction force between the bar and the halo scales with the strength of the bar, the halo density, and the speed of the bar much in the manner predicted by Chandreskhar's formula for test particles; self-gravity in the halo has a minor impact in cases of interest. Bars slow down as they lose angular momentum, while the halo density profile is little affected by the angular momentum gained. The fact that strong bars are not slow yields an important constraint on the central density of the dark matter halo. I present new results on friction between bars and NFW halos, which require a low concentration, index if bars are to remain as fast as those observed today.

How Galaxies Get Their Gas

Neal Katz, University of Massachusetts

Abstract There are two ways that a galaxy can increase its stellar mass, either by accreting a smaller existing galaxy that already contains stars or by converting some of its gas into stars. The global average of this second process gives rise to the Madau plot, the star formation history of the Universe that is observed to decline at low redshift. Where does this gas come from? Once again it has two sources: the accretion of smaller galaxies that contain gas or the smooth accretion of gas not in galaxies. I will use hydrodynamical simulations of a Lambda dominated CDM Universe to investigate these issues. Perhaps suprisingly, most material enters galaxies through smooth accretion and not through merging. It is commonly believed that gas is shock heated to the virial temperature as it enters a dark halo and that the rate that smooth gas accretes onto the galaxy is regulated by the cooling time from the virial temperature. I will show that there are actually two channels by which gas can smoothly accrete onto a galaxy: the standard one just mentioned and one where the gas remains cool and its accretion rate is dominated by dynamical processes. It is this second process that dominates overall, particularly at higher redshifts. The relative importance of these two channels might help to explain both the shape of the Madau plot and the density morphology relation.