PHD Thesis

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Prologue

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Abstract

After this fourth paragraph, we start a new paragraph sequence. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text gives you information about the selected font, how the letters are written and an impression of the look. This text should contain and it should be written in of the original language. There is no need for special content, but the length of words should match the language. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text gives you information about the selected font, how the letters are written and an impression of the look. This text should contain and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

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1 Introduction

Why UGC11680NED01 spiral galaxy is red?

With this simple question began work presented in this thesis.

In any textbook we learn that elliptical galaxies are red and spiral galaxies are blue, Two morphologies, two colors. We can distinguish between these types of galaxies without really studying very thoroughly, and go with something else. However, not everything is so easy, people have discovered red spiral galaxies (Bundy) in the local universe. This simplification is justified because most galaxies follow a relationship strictest Color-morphology. To study the nature of the red spiral, we will have many preconception off on their star formation. This has certain advantages in the analysis. Thus we will take the spiral of the catalog, and try to analyze their stellar populations.

The advent of large galaxy surveys like the Sloan Digital Sky Survey (SDSS) in which photometry (and therefore color) is readily available to millions of objects has led to use of optical colors to define "early" galaxies "tardias“ (Eg Cooray 2005; Bundy et al 2006 ;. Croton Lee et al 2007 ;. And pen 2007; Salimbeni et al. 2008; Simon et al. 2009). This method is particularly favored because obtaining morphologies for a large number of galaxies has been impossible until recently. This simplification is justified because it has been shown many times that Most galaxies follow a color ratio - strict morphology. For example, Mignoli et al. (2009) showed that 85 percent of galaxies to z *approx* 1 are either, red galaxies dominated by its bulb or blue galaxies dominated by its disc; while Conselice (2006) showed Similar result 22 000 galaxies of low redshift (both using automated methods for morphological classification). However, the clear correlation between the color and morphology surprising given that the colors of the galaxies are determined primarily for its stellar content (and therefore their recent star formation, especially within the last Gyr), while morphology is mainly driven by the dynamic history. The clear link between color and morphology gives a strong indication that the time scales and the processes that drive morphological transformation and cessation of star formation are related (at least in most cases). In this paper, however, we consider a class of object (red spiral) where it seems that the relationship described above seems to be fulfilled.

Since the morphology-density relation quantified first (Dressler, 1980), many mechanisms have been proposed for Blue transformation, disk galaxies forming stars at low density regions of the Universe, a, passive red galaxies in clusters first type. A recent review of many of the proposed mechanisms and the evidence supporting them, can be found at Boselli and Gavazzi (2006). Clearly two things must happen for a blue star-forming spiral Galaxy becomes a passive early red type. Education First Star You must cease (which can alter the morphology indirectly cause spiral arms and the disc generally disappear, possibly producing a S0 lenticular or a spiral). Secondly, in order to produce a bona fide elliptical, the same or a different process must also dynamically alter the stellar kinematics of the galaxy.

The presence of an unusual red colored or passive (ie, not forming star) population of spiral galaxies in clusters of galaxies was first said Van den Bergh (1976) in the Virgo cluster. later studies distant cluster of galaxies in the Hubble Space Telescope (HST) images also revealed a number of so-called "passive" spiral galaxies with a lack of ongoing star formation (Couch et al. 1998; Dressler et al. 1,999; Poggianti et al. 1,999). Passive delayed type galaxies were identified on the move to lower red outside SDSS clusters of Goto et al. (2003) using the concentration as a proxy for morphology. Spirals liabilities of a cluster at z 0.4 were studied by Moran et al. (2006) who found stories of star formation in the Galaxy Evolution Explorer (GALEX) consistent with observations closing of star formation choke (as described by Bekki, sofa and Shioya 2002). Spirals liabilities have also revealed in a cluster at z 0.1 in the A9012 / Galaxy Space Telescope Evolution Survey (STAGES) using HST morphologies Wolf et al. Spectral energy distributions (2009), rest-frame near-ultraviolet optical (SED; Wolf, Gray & Meisenheimer 2005) and data from 24 microns Spitzer (Gallazzi et al. 2009). In this series of papers, 'dusty are red late types "and" optically passive final rates "to be largely the same, with a non-zero (but reduced significantly) rate of star formation revealed by infrared data. Spiral red / final year types have been studied in several recent articles (Lee et al 2008 ;. Cortese and Hughes 2009; Deng et al 2009 ;. Hughes And Cortese 2009) and Mahajan and Raychaudhury (2009) who speak passive blue galaxies (ie, galaxies with blue, but showing signs of recent star formation in their spectra) most of which seem to have late-type morphologies and have very Recently off star formation. These could be the progenitors red spirals. Bundy et al. (2010) studied the redshift evolution of disk galaxies red string as components in the Cosmic Evolution Survey (COSMOS) and use it to estimate that up to 60 percent of spiral galaxies must go through this phase on the way to the red string - making it an important evolutionary step.

It is clear that all spiral galaxies can be affected by various physical processes as they evolve - in this paper seeks to identify that they are most important for red spirals, asking how are able to shut down star formation, keeping their spiral morphology. A list of possible mechanisms include processes It will depend on the environment. (1) galaxy-galaxy interactions: high density regions, there is a greater probability of interaction with other galaxies. Most major mergers destroy spiral structure (Toomre and Toomre 1972) unless they involve parents in rich gas (Hopkins et al. 2009), but some interactions can be quite soft (for example, Walker and Hernquist Mihos 1996), for example minormergers, tidal interactions, etc. (2) The interaction with the cluster itself also it produced and can be removed form the gas reservoir star formation. This may be due to tidal effects (eg Gnedin 2003) or interaction with the intercluster hot gas, either through thermal evaporation (Cowie and Songaila 1977) or ram pressure extraction (Gunn and Gott 1972). (3) The processes as harassment (Moore et al. 1999) and the starvation and strangulation (Larson, Tinsley and Caldwell 1,980; Bekki et al. 2002) have also shown to have a significant cant effect in late-type galaxies. Harassment refers to heating gas for many small interactions, while hunger or strangulation It refers to the gradual depletion of disk after the hot gas has halo It has been stripped away. Both of these mechanisms occur in much greater radios cluster (ie, lower densities) than the "classic environmental effects. Internal mechanisms may be more important. For instance, (4) the last semi-analytic models of galaxy formation invoke all feedback from a massive black hole active center [or galactic nuclei (AGN)] to explain the most massive elliptical galaxies red (Granato et al. 2004; Silk 2005; Schawinski et al. 2006; Croton et al. 2006; Bower et al. 2,006), although the effect of this process on disk galaxies has been studied less, you can still have some effect (Okamoto, Nemmen and Bower 2008). (5) Another cause could be the instability bar in spiral galaxies that lead the gas into (eg Combes Sanders 1981), and may trigger the AGN activity and / or central star training (eg Shlosman, Peletier and Knapen 2000), perhaps using the gas reservoir in the outer disk and spirals making red. (6) Finally, spirals Red spirals could simply be old who have exhausted all its gas in normal star-forming activities without any basic interaction. In normal spirals, gas supplying current star formation comes from material falling from a reservoir in the outer halo (Boselli and Gavazzi 2006). As first it suggested by Larson, Tinsley and Caldwell (1980) and expanded by Bekki et al. (2002), extracting gas from this outer halo ('throttle' or 'hungry') will cause the gradual cessation of star formation proceeding more several Gyr.

The quenching of star-formation in massive galaxies is one of the most fundamental aspects of galaxy evolution in the last 8 Gyrs that is still poorly understood. It should involve both a ?switching-off? of the star formation and a morphological transformation: (1) To reconcile the predicted and observed massive end of the galaxy luminosity function; (2) To understand why during this cosmological time (from z 1 to the present time), most of the stars are formed in late-type (blue-cloud) galaxies (e.g., Wolf et al. 2005), but the mass is accumulated in early-type (red-sequence) ones (e.g., McIntosh et al. 2005). (3) To reproduce the observed ratio of red-sequence to blue-cloud galaxies at different cosmological times. Standard explanations invoke galaxy mergers which can drive inflows of cold gas that fuel central starbursts and AGNs (e.g., Hopkins et al., 2008). The gas is then consumed by the starburst, and subsequent outflows from the AGN (and the starburst itself), can heat (and spell-out) the remaining gas, quenching the starformation and switching off the nuclear activity. The cosmological co-evolution of the black-hole/bulge masses (eg., Cisternas et al. 2011), and the location of the AGN hosts in the so-called transition Green-Valley region of the CM-diagram (e.g., Kauffman et al. 2003; Sanchez et al. 2004), support this scenario. However, observations have struggled to test the details of this ?self-regulated? hypothesis. On one hand there is a lack of direct evidence of the relation between the merging processes and the AGN activity in general. This may be related to the differences in the time-scale associated with both processes. On the other hand, there are some puzzle examples of apparently ?quenched? galaxies that does not fit with this scenario. One example is the significant population of bar-dominated (face-on) disk galaxies on (or above) the red-sequence observed at different redshifts (e.g, Masters et al. 2010; Bundy et al. 2010): How can a merger shut off star-formation without destroying the disk? Host these galaxies and active nuclei? Could they fit within the standard explanations at all? Three complementary scenarios have been proposed: (a) Disks are re-grown in gas-rich mergers before quenching completes, perhaps during the starburst phase (e.g., Robertson et al. 2006); (b) Quenching may also be driven by ?starvation? in average high-density environments (e.g., Bekki, 2009); (c) Star-formation is suppressed by internal structural changes (e.g., ?morphological quenching?, Martig et al. 2009).

Integrated measures cannot distinguish between a truncated disk model in which SFH has gradually ended over 2 Gyrs (scenario b and c), and a 2-component model in which a central starburst (20% by mass) lead to a rapid quenching (scenario a). However, spatially resolved star-formation histories and gas metallicity enrichment gradients, like the ones provided by CALIFA, are a robust measure of the burst fraction in these proposed transitioning galaxies.

Due to the scarce number of face-on red spiral galaxies most probably CALIFA will not sample a representative number of them. However, in the first observing run we observe one: UGC11680. This galaxies is a M51-like galaxy, with a nearby companion under interaction. It has a Seyfer 2 nuclei spectra, and it has been clasified as one of the reddest Seyfert galaxies in different NIR surveys. It u-z color place is above the red-sequence.

Although it is just one object, we can test on it the different scenarios proposed for face-on spiral red objects, by performing a comparison of its spatilly resolved spectroscopic properties with those of face-on spiral galaxies of a similar luminosite (mass). This is an unique property of CALIFA, the capability of providing suitable comparison samples for ?rare? objects.

The insight that our Milky Way is just one of many galaxies in the Universe is less than 100 years old, despite the fact that many had already been known for a long time. The catalog by Charles Messier (1730-1817), for instance, lists 103 diffuse objects. Among them M31, the Andromeda galaxy, is listed as the 31st entry in the Messier catalog. Later, this catalogue was extended to 110 objects. John Dreyer (1852-1926) published the New General Catalog (NGC) that contains nearly 8000 objects, most of them galaxies. Spiral structure in some of the nebulae was discovered in 1845 by William Parsons, and in 1912, Vesto Slipher found that the spiral nebulae are rotating, using spectroscopic analysis. But the nature of these extended sources, then called nebulæ, was still unknown at that time; it was unclear whether they are part of our Milky Way or outside it.

1.1 The nature of the nebulæ

. The year 1920 saw a public debate (the Great Debate) between Harlow Shapley and Heber Curtis. Shapley believed that the nebulæare part of our Milky Way, whereas Curtis was convinced that the nebulæmust be objects located outside the Galaxy. The arguments which the two opponents brought forward were partly based on assumptions which later turned out to be invalid, as well as on incorrect data. Much of the controversy can be traced back to the fact that at that time it was not known that dust in the Galactic disk leads to an extinction of distant objects. We will not go into the details of their arguments which were partially linked to the assumed size of the Milky Way since, only a few years later, the question of the nature of the nebulæwas resolved.

In 1925, Edwin Hubble discovered Cepheids in Andromeda (M31). Using the period-luminosity relation for these pulsating stars he derived a distance of 285 kpc. This value is a factor of 3 smaller than the distance of M31 known today, but it provided clear evidence that M31, and thus also other spiral nebulæ, must be extragalactic. This then immediately implied that they consist of innumerable stars, like our Milky Way. Hubble's results were considered conclusive by his contemporaries and marked the beginning of extragalactic astronomy. It is not coincidental that at this time George Hale began to arrange the funding for an ambitious project. In 1928 he obtained six million dollars for the construction of the 5 m telescope on Mt. Palomar which was completed in 1949.

The road to understanding the processes that lead to the evolution of galaxies has It has been arduous. It is surprising that until the 1920s did not know of the existence of other galaxies than the Milky Way. The hitherto prevailing view was that the universe consisted of the Milky Way and a vacuum around it. Four hundred years ago, Galileo Galilei turned his telescope on the Milky Way and discovered that consisted of countless faint stars that are not visible to the naked eye. Nearly 150 years later, the philosopher Immanuel Kant speculated that gravity should act between stars of the Milky Way in the same way that gravity is responsible for movements Solar System planets, and other observed nebulae could be similar to ours but far away (i.e., would be island Universes).

More than 90 years since the so-called Great Debate between Harlow Shapley and Heber Curtis settled the true nature gaseous nebulae. The debate was finally ended by Edwin Hubble in 1923, measuring the distance to Andromeda using the Cepheid distance and that has proved that these spiral nebulae are in Indeed, entire galaxies outside our Milky Way (Hubble 1925).Since then, the concept of these objects, galaxies or universes island located beyond the Milky Way, began to spread.

Moreover, it is worth mentioning that until the 1980s were considered the stars as the dominant form of matter in the Universe. Thus, new theoretical ideas put to It is shown that dark matter originally discovered by Zwicky (1933) could be neutral elementary particles not baryonic (Cowsik & McClelland 1973; Peebles, 1982) while X-ray images showed that most baryons in rich clusters is in the form of hot intergalactic gas (Forman & Jones 1982). The result of our best knowledge the properties of galaxies became clear that the baryons are not the dominant form of matter in our universe, and that the stars represent only a small fraction of the baryons (eg Fukugita, Hogan & Peebles 1998) .Despite the significant progress in recent years in our understanding of the baryon physics, formation and evolution of galactic discs still remain as two of the most important aspects to understand in full, within the field of astronomy extragalactic.

The current image on the formation of galaxies in general is based on the model Hierarchical clustering of Cold Dark Matter (within the standard paradigm of Λ CDM), the which attempts to explain how the structures we see today were formed as a result the growth of primordial fluctuations (gravitational instabilities) after a period when the Universe was extremely homogeneous, as it exemplifies the Cosmic Background Microwave. According to the model Λ CDM most of the matter in the universe is in the form of (non-relativistic) cold baryonic matter not subject to gravitational interactions and whose virialization cooling process takes place without the emission of photons. The latest results of the Planck project confirms that our universe has an age of $13,798\pm$ 0.037 million years and it consists for $4.82\pm$ 0.05 % ordinary baryonic matter, 25 $\pm$ 4 % dark matter and $69\pm$ 1 % dark energy (Planck Collaboration et al. 2015). Of particular interest is the fact that, paradigm Λ CDM galaxies represent only the tip of the iceberg of a Universe dominated for some unknown dark matter, and an even harder way to study: dark energy. Thus, understanding the wealth of morphologies, sizes and luminosities of the galaxies within a cosmological context is a task of great importance but of no less difficulty (Mo, Mao & White 1998 onwards MMW).

Most of the visible matter in the Universe is concentrated in galaxies, which are the basic ecosystems in astronomy in which stars form, evolve and die for a process which keeps in constant interaction with the interstellar medium (ISM). Galaxies also they represent beacons that allow us to explore our Universe to cosmological scales. From the pioneering work of Edwin Hubble (1926b, 1936), which was who first proposed morphological classification system (called the Hubble diagram) for galaxies, knows- we that the universe is populated by different types of galaxies are arranged in three categories General according to the form presented (originally on photographic plates): elliptical, spiral and irregular; the first type galaxies are relatively rounded in shape and are made by a large number of stars with a distribution of triaxial movement, while the pins ral flat discs are dominated almost entirely by the prescribed rotations.

Today, this has a more complex classification taxonomy and continuously updated using not only the information of the optical bands, but also other wavelengths. Other types of galaxies galaxies are low surface brightness dwarf galaxies, ultra-faint galaxies, spheroidal and galaxies in transition between subclasses (often due to environmental effects). Figure 1.1 illustrates how the Hubble diagram for classifying galaxies would be at different times history of the Universe.

The standard model Λ CDM (Springel et al. 2006) provides a framework that can scale to understand the main mechanisms of formation and evolution of structure the universe. However, the formation of disk galaxies has proved particularly hard to understand. In the context Λ CDM galaxies are systems consisting of a structure star embedded in a halo of dark matter mass growing from hierarchical clustering lower mass halos. However, understanding the evolution of the baryonic component under this scenario for hierarchical dark matter it is not yet complete. Thus, it is well known that photometric, chemical, and kinematics of galaxies today are the result of properties more complex mechanisms such as the initial conditions that were formed and the interaction between internal and external processes, both fast and secular. Although difficult separate the effects of all these mechanisms, any theory that seeks to explain satisfactorily factory formation and evolution of galaxies disk must be able to account for all these processes.

The most common types of galaxies in a limited exploration in magnitude within the Universe Local would spiral galaxies. These represent about 77 % of all galaxies obtained servadas (20 % are elliptical and 3 % irregular, Li & White 2009). In this doctoral thesis we will pay special attention to the spiral discs observed within exploration CALIFA (Calar Alto Legacy Integral Field Area Survey) 1 which also represents the most common type of ob- I ject observed as part of this project (see Chapter §4 and §5). Disk galaxies consist a disk component made up of stars, dust and cold gas (both atomic and molecular) a central component of bulb, a stellar halo, and a halo of dark matter. Often they appreciated spiral arms and also a high percentage of spirals also have a component bar-shaped core. Their typical stellar masses ranging from 10^9 and 10^12 $M_\odot$, their luminosities between 10^8 and $10^11 L_\odot$, sizes between 5 and 100 kpc in diameter, rotation speeds of about 200-300 km / s scales disc of about 4 ksi. His records often can be separated into a Thin and thick component. The small disc is composed of young stars, while the thick disc contains significantly less mass and their stars are older, richer in metals and are dynamically hotter. Since our own galaxy is a spiral (barred) most of our understanding of the formation of spiral galaxies comes from studies made on the various components of the Milky Way.

As mentioned previously, many aspects of the formation and evolution galaxy and especially on the evolution of spiral galaxies remain unexplained. They were White & Rees (1978) who first raised in the formation of these galaxies as a two-step process whereby disk galaxies form by contraction dissipate tory within halos of dark matter. On the one hand, the structures of dark matter would hierarchically grown collapsing in individual halos with a certain amount of time prior acquired regulate tidal pairs. Furthermore, the gas initially follow the same evolution dark matter until dissipation emission light of the first stars let their virialization contraction and increasingly smaller sizes provided that could transfer total angular momentum of the object (which is not altered by light emission) to a component relatively large disk. This process virialization increasingly smaller radii and training a thin disk help to increase both the gas density, facilitating a process of fragmentation and star formation in the resulting molecular clouds. Historically, pro- They put two scenarios for the formation of the component disc (see White & Rees 1978; Fall & Efstathiou 1980). The first contemplated a monolithic collapse of a large gas cloud Tama No, where the disc is formed by conservation of angular momentum (Eggen et al. 1962), while the second mechanism is based on the coalescence of smaller progenitors with some total angular momentum also end up stored in a stellar disk (Searle & Zinn 1978).

Today the most widely accepted scenario for the formation of discs (White & Frenk 1991; MMW) It is known as the inside-out stage collapsing combining some initial spherical with a stage hierarchical mergers of halos which would further lead to the formation of a thick disk and an effective redistribution of angular momentum component in the thin disk. This scenario predicts a direct sequence of events beginning with the initial formation of a bulge due to high densities and times of rapid cooling of the innermost part of a galaxy. Basically, a halo of dark matter that provides a potential gas cloud protoga- rotating lactic increase its density and collapses by gravity. During the collapse, gas is cooled through radiative processes until equilibrium is reached and virializa. By Furthermore, the dark matter halo gains angular momentum through tidal pairs generated by the large-scale structure around it and the numerous mergers that take place during this first stage. Due to conservation of angular momentum that results in the formation of a relatively thick disk. But until that it does not diminish the pace of mergers (a $z < 1$) is not I began to form a thin disk where the bulk of star formation occurs (due Jeans instabilities in which the balance between self-gravity and thermal pressure breaks) and further wherein the transfer of angular momentum is more effective because of its abundance of gas.

The conservation of angular momentum in this case leads to the formation of surface profiles exponential mass density (Freeman 1970). A quantitative analysis of this model and different theories on the formation of discs described below, although the details of their modeling going beyond the scope of this thesis and the reader is referred to the original papers and / or the classic book of Binney & Tremaine (1987 or subsequent updates) for review Detailed.

Qualitatively, according to inside-out stage, a disc is formed with properties similar to those observed only if the gas retains most of its angular momentum; in a first mere stage halos non-baryonic dark matter are formed from primordial fluctuations, then it condenses the gas cools in these halos. Its main assumptions are: (I) mass and angular momentum of the disk represent a fixed fraction of the mass and angular momentum halo of dark matter; (II) it is a thin disc structure supported by rotation and with a profile exponentially surface gloss; (III) only dynamically stable systems may correspond to discs real galaxies; (IV) the internal structure of the halo is assumed to follow a profile of dental sity Navarro, Frenck & White (1997); (V) halo assuming ball is maintained during the collapse. In this context, it would be forming stars from gas from the beginning of the disk formation, from gravitational instabilities that lead to cloud formation molecular giants (Elmegreen & Elmegreen 1983). Disc stability can be ensured and either through the pressure when the local dynamic time scale is larger than the scale of associated with the velocity of sound in the gas, or by the velocity dispersion time the stars when the period of epicycles is less than the time scale of local dynamics. This It is known as the stability criterion Toomre (1964), which establishes a relationship between parameters of a gaseous disk with differential rotation and which is applicable in linear approximation, it is ie, away from the resonances between the spiral pattern and the rotational motion (co-rotation) and epi- cyclical (ILR and OLR) of stars. This criterion applies only to the stability against perturbations axisymmetric and is also used to explain the presence of thresholds star formation the outer regions of the disks of galaxies.

2 Telling a History: Setting the inductive Scenario

in this chapter we will develop the story that will lead us to understand UGC11680. First, we explain the historical context and the study of physical processes extragalactic objects. Second, we exemplify our peculiar galaxy and try to see that part of this "history" fits into the overall framework. This will allow us to tell a story, step by step, without being redundant in the subsequent analysis.

2.1 Tracers of star formation

Star formation is an important facet of galaxy evolution caught "in the act". Much of the history of a galaxy is written through changes in its stellar population, inextricably linked through the processes of starbirth and stellar evolution. We can ask whether the current level of star formation is comparable with its past level, or has increased or decreased markedly. There are several disparate tracers from various wavelength regimes which give insight to the rate of star formation averaged over different timescales. In fact, the optical and near-infrared regimes are distinguished by being the only parts of the electromagnetic spectrum in which we can easily see any but the youngest stars in galaxies.

The first tracer of star formation to be developed and extensively used involves optical emission lines. The recombination lines from hydrogen have a particularly straightforward relationship to the number of ionizing photons from the hottest stars, which yields a star-formation rate (SFR) when coupled with stellar models and an initial-mass function.

In equilibrium, the number of photoionizations over the whole volume of gas ionized by a star will equal the number of recombinations as the liberated electrons become bound to protons again. This generally happens only after many weaker Coulomb encounters, which have the helpful effect of making the velocity distribution of the electrons thermal (Maxwellian) even though it would have been quite different immediately upon their ejection from neutral atoms. During recombination, most electrons will be initially captured into an excited (high-n) state, and decay to the ground level by a cascade of photon emissions. The number of recombinations can thus be measured starting with the intensity of some emission line. This is usually one of the optical hydrogen lines (H, H), although instrumental advances have started to allow signifficant surveys using the infrared lines from transitions between higher pairs of n-values. These lines are intrinsically weaker in both energy and photon ux, but have the enormous advantage of being much less sensitive to dust extinction. Using the notation in Osterbrock and Ferland's treatment, a balance between recombination and ionization requires that the number N LC of ionizing photons per second satisfy where y is the frequency at the Lyman limit of hydrogen and is the recombination coefficient, calculated including effects of resonent scattering which can keep essentially all atoms in n 2 in extensive nebulæ. For comparison with observations, we use the calculations of what fraction of decay cascades leads to a given emission line, which may either be derived from a full cascade matrix incorporating all processes between the various levels, or using emissivities so derived for various lines at the relevant electron temperature. An effective recombination eff rate can be defined, such that the emission rate of photons in the relevant emission line is simply n p n eeff .(For example, at a typical electron temperature 10 4 K, each H photon stands in for 8.5 recombinations, while an H photon results on average from nearly half of all recombinations.) The line luminosity will be this quantity, integrated over the nebular volume, as diminished by distance (via 4D 2 for small enough distances to be Euclidean):

A set of young stars will give o a number N LC of photons below the Lyman limit, and if the surrounding gas has sufcient column density, all these will be absorbed and eventually lead to recombinations (the ionization-bounded case). If we have a model of the stars' spectra in this region (which is unobservable because of this very absorption), we can calculate the number of ionizing phtons per second (also known as Q) as

in which the spectrum is converted to photons from the more usual energy units. A widely-used relation was derived by Kennicutt (1998), using models for the ionizing continuum of hot stars. Extrapolating to the entire mass in stars with a Salpeter (1955) initial mass function of power-law form, it is:

in solar masses per year, while counting only those stars with masses above 10 solarmasses, which actually ionize surrounding hydrogen, it becomes:

2.2 Population Sinthesis

The light of normal galaxies originates from stars. Stellar evolution is largely understood, and the spectral radiation of stars can be calculated from the theory of stellar atmospheres. If the distribution of the number density of stars is known as a function of their mass, chemical composition, and evolutionary stage, we can compute the light emitted by them. The theory of population synthesis aims at interpreting the spectrum of galaxies as a superposition of stellar spectra. We have to take into account the fact that the distribution of stars changes over time; e.g., massive stars leave the main sequence after several 10 6 yr, the number of luminous blue stars thus decreases, which means that the spectral distribution of the population also changes in time. The spectral energy distribution of a galaxy thus reflects its his- tory of star formation and stellar evolution. For this reason, simulating different star formation histories and comparing them with observed galaxy spectra provides important clues for understanding the evolution of galaxies. In this section, we will discuss some aspects of the theory of population synthesis; this subject is of tremendous importance for our understanding of galaxy spectra.

The processes of star formation are not understood in detail; for instance, it is currently impossible to compute the mass spectrum of a group of stars that jointly formed in a molec- ular cloud. Obviously, high-mass and low-mass stars are born together and form young (open) star clusters. The mass spectra of these stars are determined empirically from observations. The initial mass function (IMF) is defined as the initial mass distribution at the time of birth of the stars, such that m/ dm specifies the fraction of stars in the mass interval of width dm around m, where the distribution is normalized,

The integration limits are not well defined. Typically, one uses m L 0:1M because stars less massive than 008M do not ignite their hydrogen (and are thus brown dwarfs), and m U 100M , because considerably more massive stars are not observed. Whereas such very massive stars would in any case be difficult to observe because of their very short lifetime, the theory of stellar structure tells us that more massive stars can probably not form a stable configuration due to excessive radiation pressure. The shape of the IMF is also subject to uncertainties; in most cases, the Salpeter-IMF is used,

as obtained from investigating the stellar mass spectrum in young star clusters. It is by no means clear whether a universal IMF exists, or whether it depends on specific conditions like metallicity, the mass of the galaxy, cosmic epoch, or other parameters. Given the difficulties of deter- mining the shape of the IMF, apparent variations of the IMF with epoch or environment may be attributed to other effect, such as the specifics of the star-formation history in galaxies. Therefore, there seems to be no clear direct indica- tion that the IMF varies with environment. However, as will be discussed in Chap. 10, some properties of high-redshift galaxies are very difficult to understand if their IMF would be the same as in our neighborhood. It has therefore been suggested that the IMF in starbursts is different from that of quiescent star formation such as we are experiencing in the Milky Way. The Salpeter-IMF seems to be a good description for stars with M 1M , whereas the IMF for less massive stars is flatter. Note that, due to the steep slope of the IMF, most of the stellar mass is contained in low-mass stars. However, since the luminosity of main-sequence stars depends strongly on mass, approximately as L / M 3 , most of the luminosity comes from high-mass stars (see Problem 3.2). The star-formation rate is the gas mass that is converted into stars per unit time,

The metallicity Z of the ISM defines the metallicity of the newborn stars, and the stellar properties in turn depend on Z. During stellar evolution, metal-enriched matter is ejected into the ISM by stellar winds, planetary nebulae, and SNe, so that Z.t/ is an increasing function of time. This chemical enrichment must be taken into account in population synthesis studies in a self-consistent form. Let S ;Z .t 0 / be the emitted energy per wavelength and time interval, normalized to an initial total mass of 1M , emitted by a group of stars of initial metallicity Z and age t 0 . The function S;Z.t t 0 / .t 0 /, which describes this emission at any point t in time, accounts for the different evolution- ary tracks of the stars in the Hertzsprung?Russell diagram (HRD)?see Appendix B.2. It also accounts for their initial metallicity (i.e., at time t t 0), where the latter follows from the chemical evolution of the ISM of the corresponding galaxy. Then the total spectral luminosity of this galaxy at a time t is given by

thus by the convolution of the star formation rate with the spectral energy distribution of the stellar population. In particular, F.t/ depends on the star formation history. In order to compute S;Z.t t 0 / .t 0 /, models for stellar evolution and stellar atmospheresneeded. As a reminder

Fig. 3.32a displays the evolutionary tracks in the HRD. Each track shows the position of a star with specified mass in the HRD and is parametrized by the time since its formation. Positions of equal time in the HRD are called isochrones and are shown in Fig. 3.32b. As time proceeds, fewer and fewer massive stars exist because they quickly leave the main sequence and end up as supernovae or white dwarfs. The number density of stars along the isochrones depends on the IMF. The spectrum S ;Z.t t 0 / .t 0 / is then the sum over all spectra of the stars on an isochrone?see Fig. 3.33b. In the beginning, the spectrum and luminosity of a stellar population are dominated by the most massive stars, which emit intense UV radiation. But after 10 7 yr, the flux below 1000 Å is diminished significantly, and after 10 8 yr, it hardly exists any more. At the same time, the flux in the NIR increases because the massive stars evolve into red supergiants. For 10 8 yr . t 10 9 yr, the emission in the NIR remains high, whereas short-wavelength radiation is more and more diminished. After 10 9 yr, red giant stars (RGB stars) account for most of the NIR production. After 3 10 9 yr, the UV radiation increases again slightly, due to blue stars on the horizontal branch into which stars evolve after the AGB phase, and due to white dwarfs which are hot when they are born. Between an age of 4 and 13 billion years, the spectrum of a stellar population evolves fairly little. Of particular importance is the spectral break located at about 4000 a which becomes visible in the spectrum after a few 10 7 yr. This break is caused by a strongly changing opacity of stellar atmospheres at this wavelength, mainly due to strong transitions of singly ionized calcium and the Balmer lines of hydrogen. This 4000 a-break is one of the most important spectral properties of the continuum stellar emission in galaxies; as we will discuss in Sect. 9.1.2, it allows us to estimate the redshifts of early-type galaxies from their photometric properties?so-called photometric redshift estimates.

2.3 Color Evolution

Detailed spectra of galaxies are often not available. Instead we have photometric images in different broadband filters, since the observing time required for spectroscopy is substantially larger than for photometry. In addition, modern wide-field cameras can obtain photometric data of numer- ous galaxies simultaneously. From the theory of popula- tion synthesis we can derive photometric magnitudes by multiplying model spectra with the filter functions, i.e., the transmission curves of the color filters used in observations, and then integrating over wavelength (A.25). Hence the spectral evolution implies a color evolution, as is illustrated in Fig. 3.34a. For a young stellar population the color evolution is rapid and the population becomes redder, again because the hot blue stars have a higher mass and thus evolve quickly in the HRD. For the same reason, the evolution is faster in B V than in V K. It should be mentioned that this color evolution is also observed in star clusters of different ages. The mass-to-light ratio M=L also increases with time because M remains constant while L decreases. As shown in Fig. 3.34b, the blue light of a stellar popula- tion is always dominated by main sequence stars, although at later stages a noticeable contribution also comes from horizontal branch stars. The NIR radiation is first dominated by stars burning helium in their center (this class includes the supergiant phase of massive stars), later by AGB stars, and after 10 9 yr by red giants. Main sequence stars never contribute more than 20 % of the light in the K-band. The fact that M=L K varies only little with time implies that the NIR luminosity is a good indicator for the total stellar mass: the NIR mass-to-light ratio is much less dependent on the age of the stellar population than that for bluer filters.

2.4 star Formation History and galaxy colors

Up to now, we have considered the evolution of a stellar population of a common age (called an instantaneous burst of star formation). However, star formation in a galaxy takes place over a finite period of time. We expect that the star formation rate decreases over time because more and more matter is bound in stars and thus no longer available to form new stars. Since the star formation history of a galaxy is a priori unknown, it needs to be parametrized in a suitable manner. A ?standard model? of an exponentially decreasing star formation rate was established for this,

where is the characteristic duration and t f the onset of star formation. The last factor in (3.38) is the Heaviside step function, Hx D1 for x 0, H.x/ D 0 for x < 0. This Heaviside step function accounts for the fact that .t/ D 0 for t < t f . We may hope that this simple model describes the basic aspects of a stellar population. Results of this model are plotted in Fig. 3.35a in a color-color diagram. From the diagram we find that the colors of the population depend strongly on Specifically, galaxies do not become very red if is large because their star formation rate, and thus the fraction of massive blue stars, does not decrease sufficiently. The colors of Sb spirals, for example, are not compatible with a constant star formation rate?except if the total light of spirals is strongly reddened by dust absorption (but there are good reasons why this is not the case). To explain the colors of early-type galaxies we need . 4 10 9 yr. In general, one deduces from these models that a substantial evolution to redder colors occurs for t . Since the luminosity of a stellar population in the blue spectral range decreases quickly with the age of the population, whereas increasing age affects the red luminosity much less, we conclude

The spectral distribution of galaxies is mainly deter- mined by the ratio of the star formation rate today to the mean star formation rate in the past, today= h i.

One of the achievements of this standard model is that it explains the colors of present day galaxies, which have an age 10 billion years. However, this model is not unambiguous because other star formation histories .t/ can be constructed with which the colors of galaxies can be modeled as well.

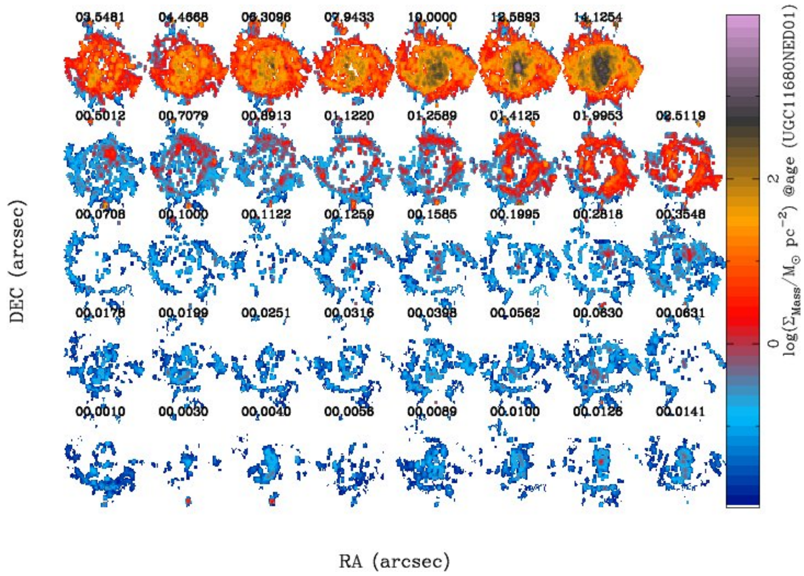

Figure 2.1: Spatially resolved Star formation history (SFH) for the stellar surface density. each map represent a time slice and run from upper-right corner, reads from right to left and ends the bottom-left corner. Also, Each map color represents the stellar mass assembly for each slice, following the colormap. Notice that each map is not cummulative

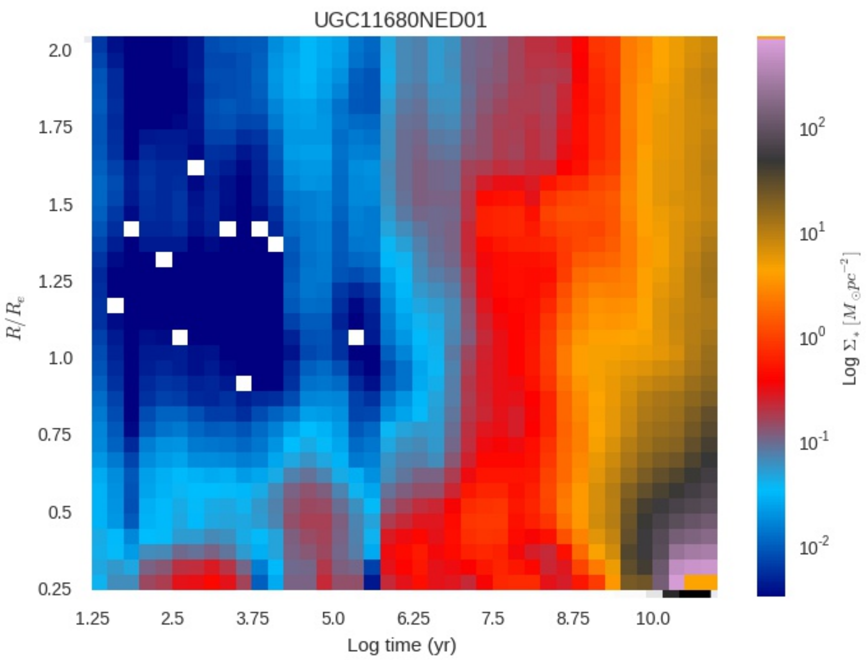

Figure 2.2: Final Historiogram for UGC11680NED01

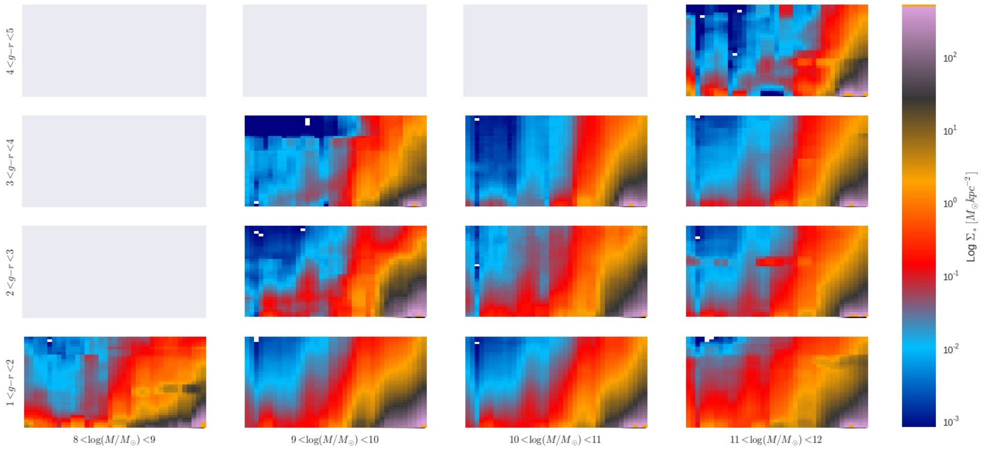

Figure 2.3: Color-Mass Diagram for the CALIFA survey historiograms. Each bin is the average historiogram for each group.

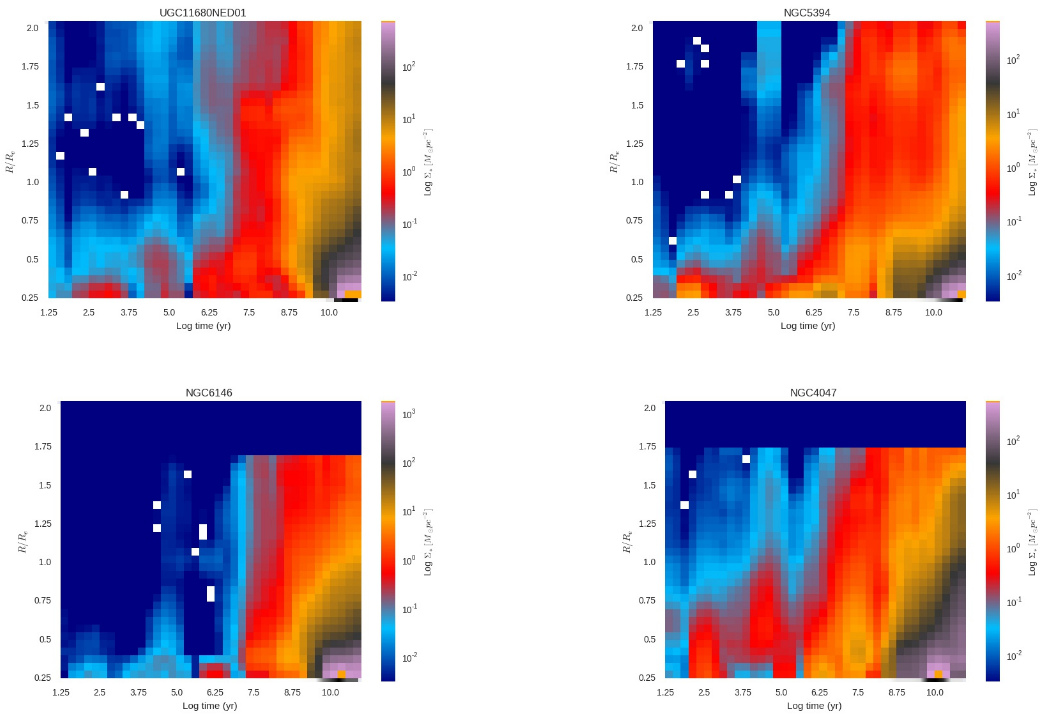

Figure 2.4: Four Historiograms for different galaxies:UGC11680NED01,the red spiral. NGC5394,a interacting starburst galaxy.NGC6146,a typical elliptical galaxy and NGC4047,a face-on blue spiral.

3 Dude (looks like an AGN)

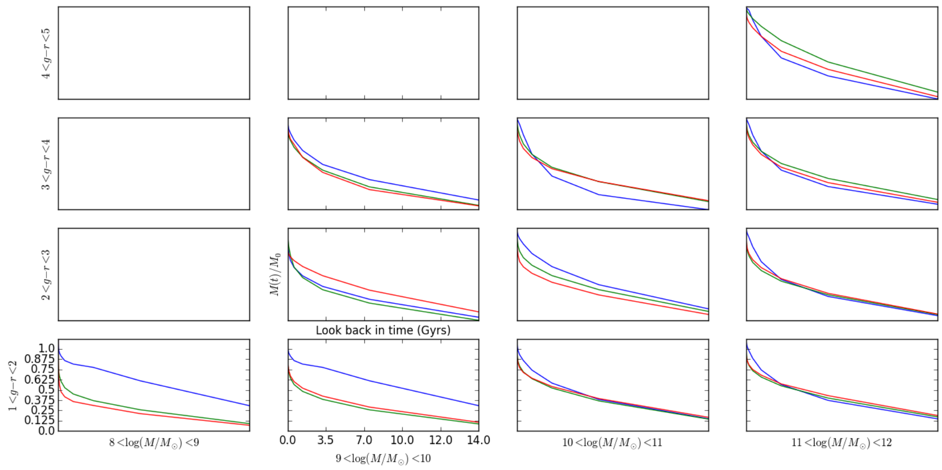

Figure 3.1: Color-Mass Diagram for the CALIFA survey. Each bin includes the mass assembly history tracks for different effective radius (nucleus, middle range and outskirts) The time scale is linear. Notice the inside-out grow in stellar mass.

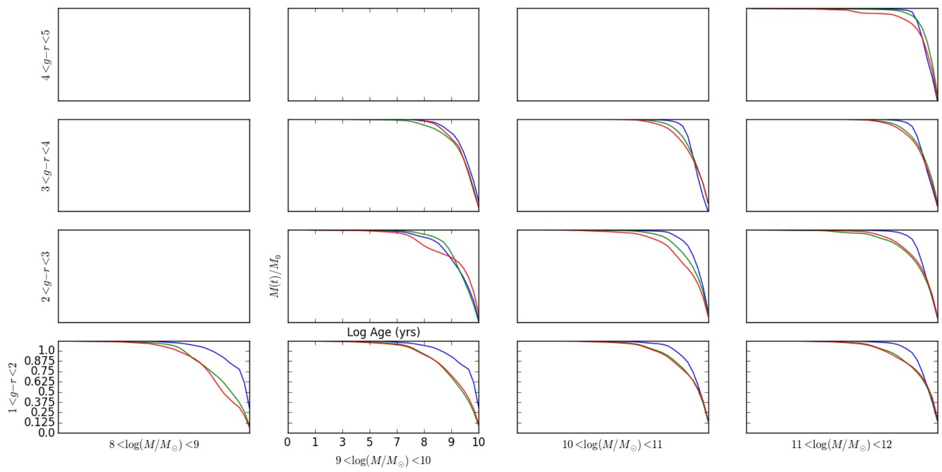

Figure 3.2: Color-Mass Diagram for the CALIFA survey. Each bin includes the mass assembly history tracks for different effective radius (nucleus, middle range and outskirts) The time scale is logarithmic. Notice the inside-out grow in stellar mass.

4 The χ^2 Measure

For a > 0, the gamma function G(a) is defined by

The most important properties of the gamma function are the following:

A continuous random variable X is said to have a gamma distribution if the pdf of X is

Figure 4.26(a) illustrates the graphs of the gamma pdf for several (a, b) pairs, whereas Figure 4.26(b) presents graphs of the standard gamma pdf. For the standard pdf, when a 1, f(x; a) is strictly decreasing as x increases; when a $>$ 1, f(x; a) rises to a maximum and then decreases. The parameter b in (4.7) is called the scale parameter because values other than 1 either stretch or compress the pdf in the x direction.

DEFINITION Let n be a positive integer. Then a random variable X is said to have a chi squared distribution with parameter n if the pdf of X is the gamma density with a 1?4 n/2 and b 1?4 2. The pdf of a chi-squared rv is thus

The chi-squared distribution is important because it is the basis for a number of procedures in statistical inference. The reason for this is that chi-squared distributions are intimately related to normal distributions

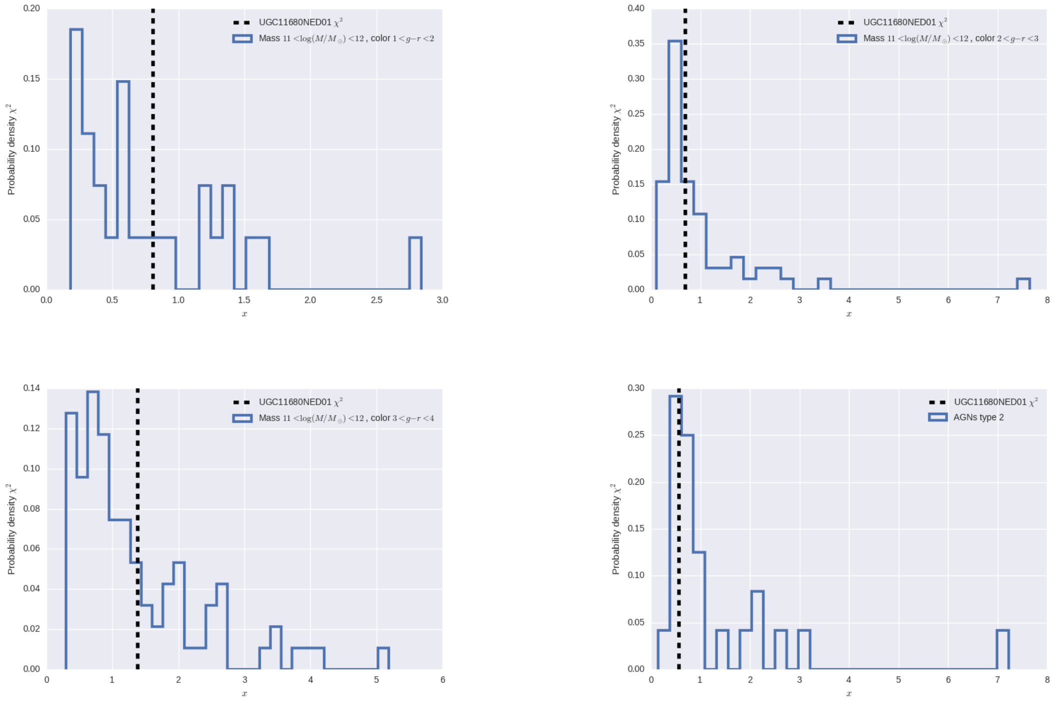

Figure 4.1: χ^2 reducided distribution for all galaxies in the mass range $11 < \log(M/M_{\odot}) < 12$ in the CALIFA survey, subdivided by color $g-r$ bins. The Black dashed line represents the χ^2 reducided value of UGC11680NED01 compared with each mass bin average. The bootom-right figure is the all AGNS χ^2 reducided distribution

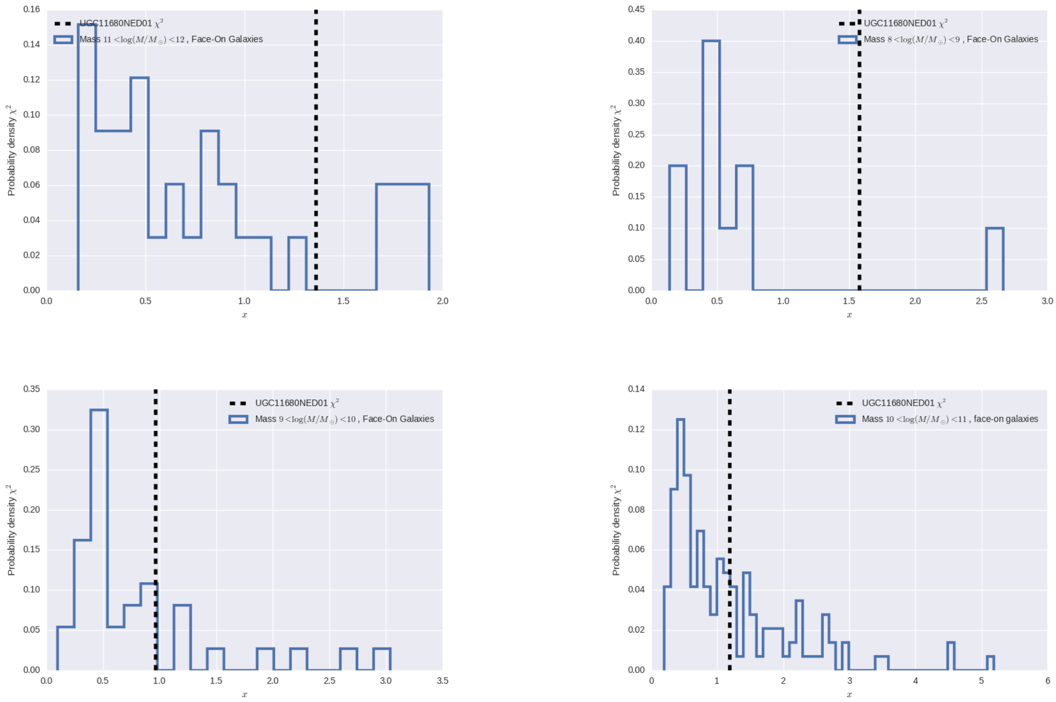

Figure 4.2: χ^2 reducided distribution for all Face-On Spiral Galaxies in the CALIFA survey, subdivided in mass bins. The Black dashed line represents the χ^2 reducided value of UGC11680NED01 compared with each mass bin average

5 Final Thoughts

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A Appendix Chapter

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A.1 Appendix Section

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A.1.1 Appendix Sub-Section

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B Another Appendix Chapter

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