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Galaxy Evolution: Theory and Observations (Cozumel, Quintana Roo, México, 8-12 April 2002)
Editors: Vladimir Avila-Reese, Claudio Firmani, Carlos S. Frenk & Christine Allen

JOINT FORMATION OF QSOS AND SPHEROIDS

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RESUMEN

En vista de la abundante evidencia en favor de la relación entre las galaxias esferoidales (y los bulbos galácticos) y los hoyos negros masivos en sus centros, un modelo congruente debe considerar conjuntamente la evolución de ambas componentes. Describimos un modelo que explica con éxito la función de luminosidad local de las galaxias esferoidales, sus propiedades fotométricas y químicas, los conteos de galaxias en distintas bandas de frecuencia (incluyendo las de la banda submilimétrica que han demostrado ser críticas para los modelos semianalíticos actuales, que surgen de la visión estandar del agrupamiento jerárquico), las propiedades de agrupamiento de las galaxias SCUBA, los EROs y las LBgs, así como la función de masa local de los hoyos negros masivos y la evolución de los cuasares. Se presentan algunas predicciones que pueden ser comprobadas mediante sondeos SIRTF.

ABSTRACT

In view of the extensive evidence of tight inter-relationships between spheroidal galaxies (and galactic bulges) with massive black holes hosted at their centers, a consistent model must deal jointly with the evolution of the two components. We describe one such model, which successfully accounts for the local luminosity function of spheroidal galaxies, for their photometric and chemical properties, for deep galaxy counts in different wavebands, including those in the (sub)-mm region which proved to be critical for current semi-analytic models stemming from the standard hierarchical clustering picture, for clustering properties of SCUBA galaxies, of EROs, and of LBGs, as well as for the local mass function of massive black holes and for quasar evolution. Predictions that can be tested by surveys carried out by SIRTF are presented.

Key Words: **DUST,EXTINCTION — GALAXIES: FORMATION — QUASARS: GENERAL — INFRARED: GALAXIES — COSMOLOGY: THEORY**

1. INTRODUCTION

The hierarchical clustering model with a scale invariant spectrum of density perturbations in a Cold Dark Matter (CDM) dominated universe has proven to be remarkably successful in matching the observed large-scale structure as well as a broad variety of properties of galaxies of the different morphological types (Granato et al. 2000 and references therein). However, serious shortcomings of this scenario have also become evident in recent years.

The critical point can be traced back to the relatively large amount of power on small scales predicted by this model, which would imply far more dwarf galaxies or substructure clumps within galactic and cluster mass halos than are observed (the so-called "small-scale crisis"), unless star formation in small objects is strongly suppressed (or the small scale power is reduced by modifying the standard model). At the other extreme of the galaxy mass function, we have another strong discrepancy with model predictions, that we might call "the massive galaxy crisis". Even the best semi-analytic models hinging upon the standard picture for structure formation in the framework of the hierarchical clustering paradigm, are stubbornly unable to account for the (sub)-mm (SCUBA and MAMBO, Figure 1) counts of galaxies, most of which are probably massive objects undergoing a very intense starburst (with star formation rates $\sim 1000\,\mathrm{M_\odot\,yr^{-1}}$) at $z > 2$. Recent optical data confirm that most massive ellipticals were already in place and (almost) passively evolving up to $z \simeq 1$–1.5. These data are more consistent with the traditional "monolithic" approach whereby giant ellipticals formed most of their stars in a single gigantic starburst at substantial redshifts, and underwent essentially passive evolution thereafter. In the canonical hierarchical clustering paradigm the smallest objects collapse first and most star formation occurs, at relatively low rates, within relatively small proto-galaxies, that later merged to form larger galaxies. Thus the expected number of galaxies with very intense star formation is far less than detected in SCUBA and MAMBO surveys and

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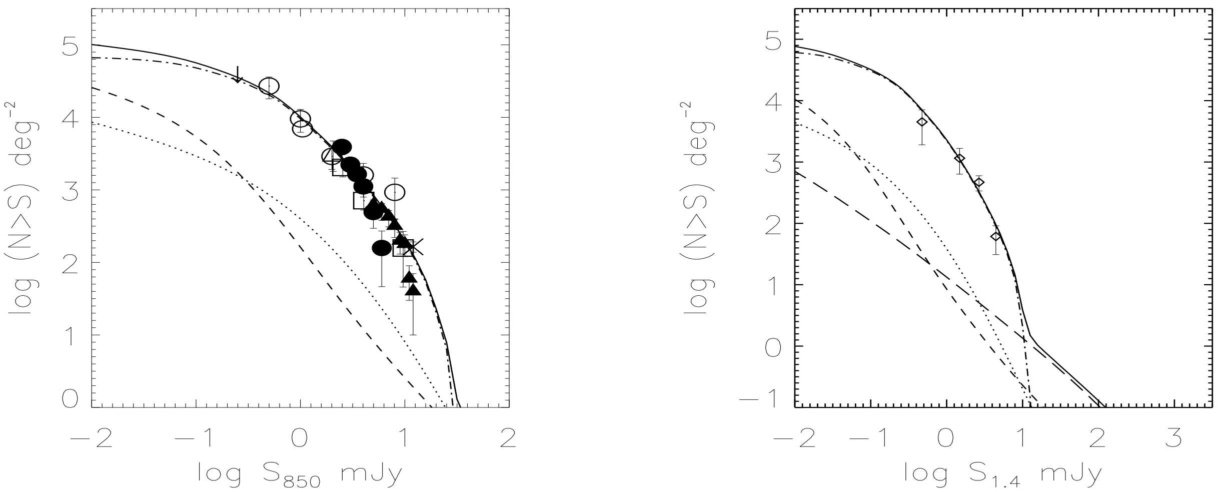

Fig. 1. Integral source counts at 850 μm and 1.4 mm predicted by the model by Granato et al. (2001) compared with observations. The dotted, dashed, dot-dashed lines show the contributions of starburst, spiral, and forming elliptical galaxies respectively. The long-dashed (at 1.4 mm only) gives the counts of radio sources (Toffolatti et al. 1998).

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the surface density of massive evolved ellipticals at $z \gtrsim 1$ is also smaller than observed. The "monolithic" approach, however, is inadequate to the extent that it cannot be fitted in a consistent scenario for structure formation from primordial density fluctuations.

2. RELATIONSHIPS BETWEEN QUASAR AND GALAXY EVOLUTION

The above difficulties, affecting even the best current recipes, may indicate that new ingredients need to be taken into account. A key new ingredient may be the mutual feedback between formation and evolution of spheroidal galaxies and of active nuclei residing at their centers. In this framework, Granato et al. (2001) elaborated the following scheme.

Feed-back effects, from supernova explosions and from active nuclei (note that supernova feedback alone falls short of solving the dearth of dwarf galaxies, but photo-ionization by the UV background reionizing the inter-galactic medium (IGM) could do the job) delay the collapse of baryons in smaller clumps, while large ellipticals form their stars as soon as their potential wells are in place; *the canonical hierarchical CDM scheme – small clumps collapse first – is therefore reversed for baryons.* Large spheroidal galaxies therefore undergo a phase of high (sub)-mm luminosity.

At the same time, the central black-hole (BH) grows by accretion and the quasar luminosity increases; when it reaches a high enough value, its action (ionization and heating of the gas) stops the star formation and eventually expels the residual gas. This explains the observed correlation between BH and host spheroidal masses. The same mechanism distributes in the IGM a substantial fraction of metals and may pre-heat the IGM. The onset of quasar activity (and the corresponding end of star formation) occurs earlier for more massive objects. The duration of the starburst increases with decreasing mass from ~ 0.5 to ~ 2 Gyr. This implies that the star formation activity of the most massive galaxies quickly declines for $z \lesssim 3$, i.e. that the redshift distribution of SCUBA/MAMBO galaxies should peak at $z \gtrsim 3$, as quasars reach their maximum luminosity (at $z \simeq 2.5$). This explains why very luminous quasars are more easily detected at (sub)-mm wavelengths for $z \gtrsim 2.5$.

A "quasar phase" follows, lasting 10^7–10^8 yrs, and a long phase of passive evolution of galaxies ensues, with their colors becoming rapidly very red [Extremely Red Object (ERO) phase]. Intermediate- and low-mass spheroids have lower Star Formation Rates (SFRs) and less extreme optical depths. They show up as Lyman-Break Galaxies (LBGs).

Therefore, in this scenario, large ellipticals evolve essentially as in the "monolithic" scenario, yet in the framework of the standard hierarchical clustering picture. Many aspects and implications of this compound scheme have been addressed by our group in a series of papers (Granato et al. 2001, Magliocchetti et al. 2001, Perrotta et al. 2002, Romano et al. 2002). Here we only summarize how the scenario compares with sub-mm counts.

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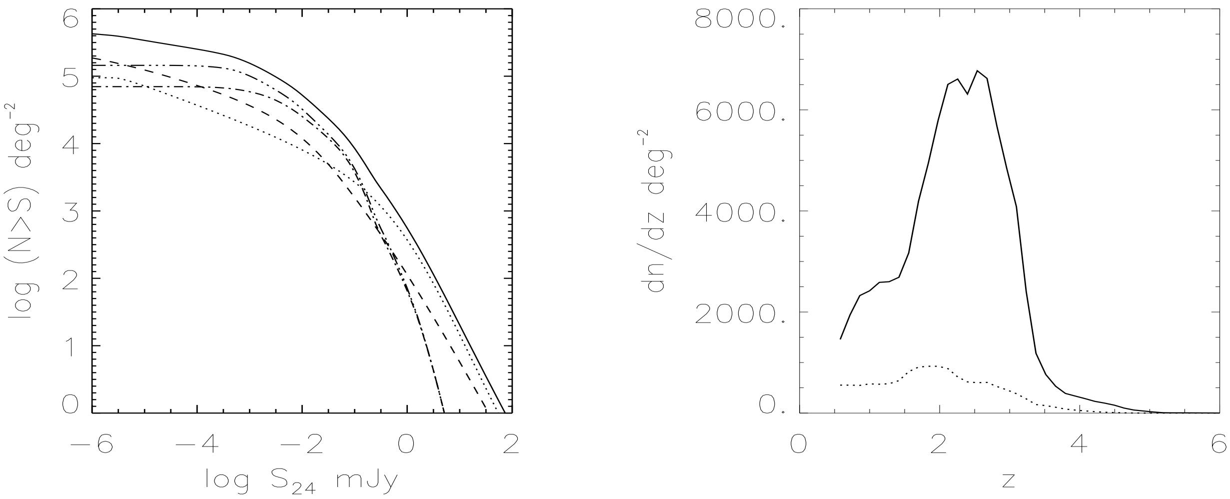

Fig. 2. Integral counts and z distribution for a flux limit of 30 μJy at 24 μm by the model by Granato et al. (2001). Symbols for counts as in Figure 1. The three-dots/dashed line shows the total counts of ellipticals, including also those where the star formation has ended. In the right-hand panel, the solid and the dotted lines show the z distributions of ellipticals during and after the star formation phase, respectively.

2.1. *Counts at (sub)-mm wavelengths*

The (sub)-mm counts are expected to be very steep because of the combined effect of the strong cosmological evolution of dust emission in spheroidal galaxies and of the strongly negative K-correction (the dust emission spectrum steeply rises with increasing frequency). The model by Granato et al. (2001) has extreme properties in this respect: above several mJy its 850 μm counts reflect the high-mass exponential decline of the mass function of dark halos. In this model, SCUBA/MAMBO galaxies correspond to the phase when massive spheroids formed most of their stars at $z \gtrsim 2.5$; such objects essentially disappear at lower redshifts. On the contrary, the counts predicted by alternative models (which are essentially phenomenological) while steep, still have a power law shape, and the redshift distribution has an extensive low-z tail. As illustrated by Figure 1, the recent relatively large area surveys are indeed suggestive of an exponential decline of the 850 μm counts above several mJy. Further evidence in this direction comes from MAMBO surveys at 1.2 mm.

2.2. *Predictions for SIRTF surveys*

SIRTF surveys have the potential of providing further tests of the model. In particular, the 24 μm survey to be carried out as a part of the GOODS (http://www.stsci.edu/science/goods) Legacy Science project should reach a flux limit of 100 μJy. According to the model, about 50% of detected galaxies should be spheroidal galaxies forming their stars at $z \gtrsim 2$. About 400–600 such objects are expected over an area of 0.1 square degree (Figure 2). Their redshift distribution is predicted to peak at z slightly above 2, with a significant tail extending up to $z \simeq 3$.

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