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Age and Star Formation of the Radio Galaxy 0902 + 34 at Redshift z = 3.395: Constraints for Primeval Galaxies

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Introduction

Primeval galaxies are among the best test objects of observational cosmology. They will give an estimate of the density parameter of the Universe Ω_0 from a colour-redshift Hubble diagram observed to extreme values of redshifts. They also bring excellent constraints to models of formation and evolution of galaxies. In this sense, searching for distant galaxies becomes one of the first objectives of the new generation of telescopes.

On the basis of recent developments in galactic evolution (see review by Rocca-Volmerange and Guiderdoni, 1988a), it is possible to predict some of the most striking features which will be signatures of young galaxies. Moreover, the present set of observational data of faint galaxies, from deep counts (Tyson, 1988) until the most distant ($z \geq 3$) radio galaxies with a dominant stellar component (Lilly, 1988), is rapidly increasing. It can therefore now be confronted in detail with evolutionary models of galaxies. Due to high redshifts and current activity of these distant galaxies, models have to simulate the galactic evolution in extreme far-UV light, observed in the rest frame through the visible and infrared broad band filters. Scenarios of standard evolution based on a large sample of observations give template spectra. Corrections due to cosmological effect (k-corrections) and to intrinsic evolution of the galaxy (e-correction) are computed from template spectra to predict apparent magnitudes and colours at any redshift and age. Models also predict the nebular component emitted by the Lyman continuum photons N_{Lyc} absorbed by gas and the consequent gas content.

Up to now, to search for primeval galaxies from integrated colours through intermediate or broad band filters as well as from Lyα emission line through narrow band filters gave negative results and only fixed upper detection limits. The infrared and optical counterparts of radio galaxies at high redshifts ($z \geq 1.8$), the oldest stellar populations at about quasar distances, have recently been observed by Djorgovski et al., 1984; Lilly and Longair, 1984; Spinrad et al., 1985; Dunlop and Longair, 1987; Cowie, 1988, and others, from the 3CR or 1 Jy catalogues and the Parkes Selected Region Sample. One of these galaxies, 0902 + 34, was recently discovered by Lilly, 1988 at a redshift $z = 3.395$. According to its fluxes through the VIJK broad-band filters and Bruzual's models, 1983, this galaxy does not appear as a primeval galaxy; however, this result must be confirmed by other models including far-UV ($\leq$ 2000 Å) stellar spectra, nebular component and Asymptotic Giant Branch stars.

With the help of our Atlas of Synthetic Spectra of Galaxies (Rocca-Volmerange and Guiderdoni, 1988b (RVG)), based on the last version of our models (Guiderdoni and Rocca-Volmerange, 1987 (GRV)), we can give a possible age of this galaxy. In the galaxy frame, a burst of star formation is at present taking place but an older burst also happened about 3 Gyrs earlier.

The solution gives an epoch of galaxy formation at a redshift ≥ 10 and a resulting low value of the density parameter $\Omega_0 \leq 0.1$.

Signatures of a Young Galaxy

Due to the extreme distance of galaxies presumed primeval, any interpretation of their observations is a delicate problem. Simultaneous effects interact to modify apparent magnitudes and colours: cosmology, intrinsic evolution and likely environmental influences can affect their appearance in ways which are difficult to estimate with their respective weights. A classical Friedmann-Lemaître cosmological model gives a relation between the redshift z and the cosmic time t(z). This relation essentially depends on the cosmological parameters: the Hubble constant H_0, the density parameter Ω_0 and the cosmological constant Λ_0. Galactic evolutionary models coupled with cosmological models are the key to understand the respective importance of the various effects. For a galaxy observed at redshift z, the age estimated from evolution models constrains the epoch of galaxy formation and then the age of the Universe.

Some principles are used in building our models: limitation to a few free parameters, a time resolution sufficient to follow details of stellar evolution, input data preferentially observational. At least, results must simultaneously fit observational data on a large extent in wavelength range, gaseous content, emission lines, dust, etc. We proposed such models (Rocca-Volmerange et al., 1981, completed with cosmological effects by Guiderdoni and Rocca-Volmerange, 1987 (GRV) which is our present version) in which the star formation parameters are: (i) the start of the star formation process z_{for}, (ii) the time scale

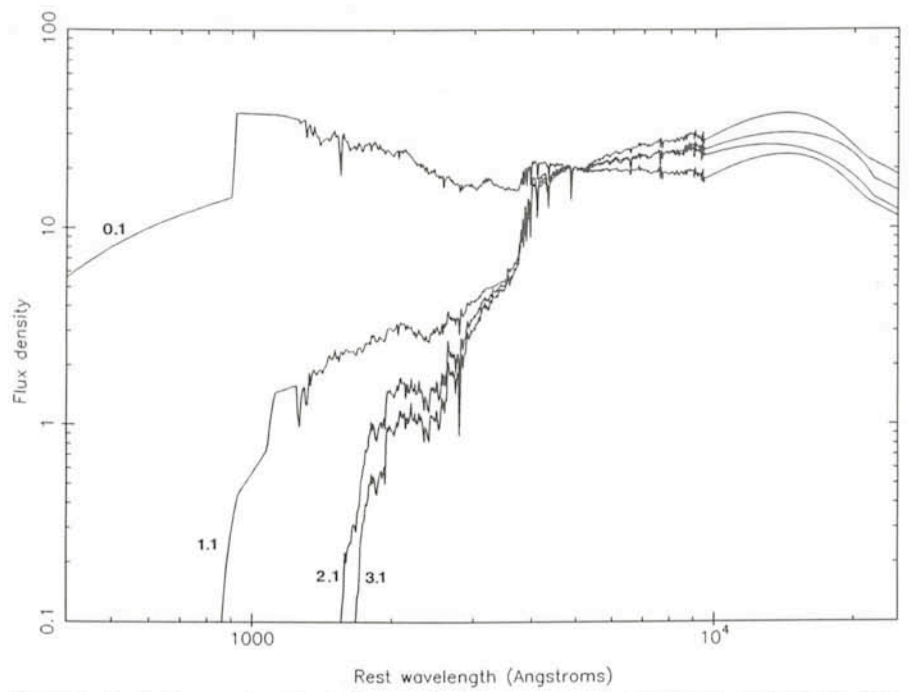

Figure 1: *Synthetic spectra of a 1 Gyr burst at various ages indicated on each line in Gyr. Spectral resolution is 10 Å. Units are arbitrary. Normalization is at 4990 Å.*

of the gas consumption t_*, characteristic of the morphological type when the bulk of stars form. The average metallicity Z is solar or half-solar and the initial mass function (IMF), defining the mass spectrum of stars at birth, is standard (Scalo, 1986). Our models use an observational library of stellar spectra which we compiled from the IUE Atlases and Gunn and Stryker, 1983. The recent results of internal structure models concerning the last phases of evolution (Horizontal Branch and Asymptotic Giant Branch) are taken into account, see GRV for details.

We gathered in two companion papers in press in *Astronomy and Astrophysics Supplement Series* an Atlas of Synthetic Spectra of Galaxies and the predictions of magnitudes and colours of high-redshift galaxies in various photometric systems from z = 0 to 4. The spectra are defined for 8 morphological types from λ = 2000 Å to infrared wavelength bands. Figure 1 gives spectra of our Atlas after a burst of star formation of 1 Gyr duration at various ages. Spectra are in arbitrary units normalized at 4990 Å. In our atlas, we give outputs normalized to the mass of the galaxy. The IMF is a power law $m^{-\varkappa}$ with $\varkappa$ = 0.25, 1.35 and 1.7 respectively between the limits 0.1 $M_\odot$, 1 $M_\odot$, 2 $M_\odot$ and 80 $M_\odot$. Different IMF will be further considered in the starburst galaxies (Larson, 1987).

Nebular Component

At each time step, the nebular emission from a photoionization process is estimated by Stasińska, 1984 models, fitted on a standard H II region in the Magellanic Clouds. The number of ionizing photons is depending on a free parameter *f* which is the effective fraction of N_{Lyc} absorbed by gas. The largest uncertainty affects this parameter. With the limit value *f* = 1, Spinrad, 1988, fits well his sample of Lyα galaxies with our models and finds a redshift of formation z_{for} = 5. Figure 2 (Rocca-Volmerange, 1988) gives a similar comparison calculated with a factor *f* = 0.7 and two redshifts of formation z_{for} = 2 and z_{for} = 5. Such fits, which favour high values of z_{for} = 5 or more, do not impose a large amount of dust as previously thought by many authors. This result is confirmed by a recent and more complete study (Valls-Gabaud et al., in preparation). Emission lines can increase the UV-flux of a burst galaxy by about 50%. The important point is that the predicted nebular component is in agreement with observations sufficiently to be used for further interpretations.

Age of the Radio Galaxy 0902+34

This radio galaxy has been observed by Lilly, 1988. According to recent observations (Lilly, private communication), this example is not unique. The redshift is well estimated at z = 3.395 from Lyα and C IV emission lines which show evidences of a non-thermal component and a metal enrichment. It is important to note that at this redshift the Lyα and Hβ lines coincide with the V and K bands, favouring the detection. It has been selected on the basis of a faint infrared emissivity associated to a very red colour J-K $\geq$ 2.75. Its emissivity in Lyα line ($\simeq 2.1 \times 10^{-18}$ W m^{-2}) and its equivalent width ($\simeq$ 1,000 km s^{-1}) are about similar to those of the 3CR radio galaxies as shown in Figure 2.

The best fit with our models of the integrated VIJK colours, corrected from the Lyα line (Figure 3) is obtained from the sum of two intense bursts of respective ages 0.1 Gyr and $\simeq$ 3 Gyr; the most recent one is going on in the rest frame of the galaxy and the oldest one transformed the galaxy mass in stars for a 1 Gyr duration. The following 2 Gyr correspond to a passive evolution. The Lyα line and the far-UV light detected through the V band are essentially due to massive stars from the recent starburst while a population of asymptotic giant branch stars is essentially emitting in the K band. The two populations are superimposed in the I band. Our scenario is in rough agreement with the images given by Lilly, 1988. In the V image, isophotes show a double component, observed in many bright distant radio galaxies. Except for the most compact one, the V components do not show counterparts in the K band. From the I image, features of both the V and K bands are recognizable. A more detailed analysis is at present going on by varying the star formation parameters into extreme limits for minimizing the start of star formation.

Constraints on the Density Parameter Ω_0

Consequences of the 3 Gyr age on the cosmological parameters z_{for} and Ω_0 are important. The age = $t(z)-t(z_{for})$ gives a value of z_{for}, the start of the galaxy formation in a cosmic time scale fixed by the cosmological model. The following table gives estimates of z_{for} for various values of the density parameter Ω_0. The adopted Hubble constant is 50 km s^{-1} Mpc^{-1} and the cosmological constant $\Lambda_0 = 0$.

	Ω_0 = **0**	Ω_0 = **0.1**	Ω_0 = **1**
Universe Age in Gyr	19.56	17.57	13.04
t(z) in Gyr	4.45	3.13	1.41
$t(z_{for})$ in Gyr for an age 3 Gyr	1.45	0.13	—
z_{for}	**12**	**≥15**	—

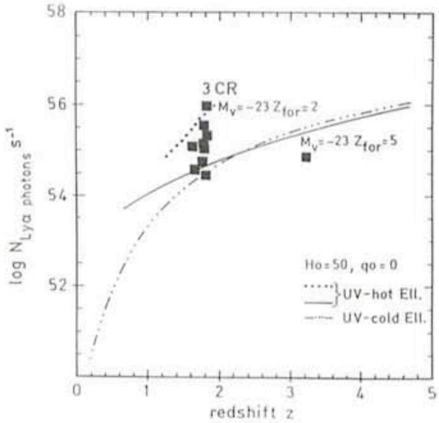

Figure 2: *Number of Lyα photons deduced from observations of Lyα galaxies (Spinrad, 1988) compared to models for two redshifts of formation z_{for} = 2 and 5 (Rocca-Volmerange, 1988). Lyman continuum photons are absorbed by gas at a rate 70%. Normalization is $M_v = -23$.*

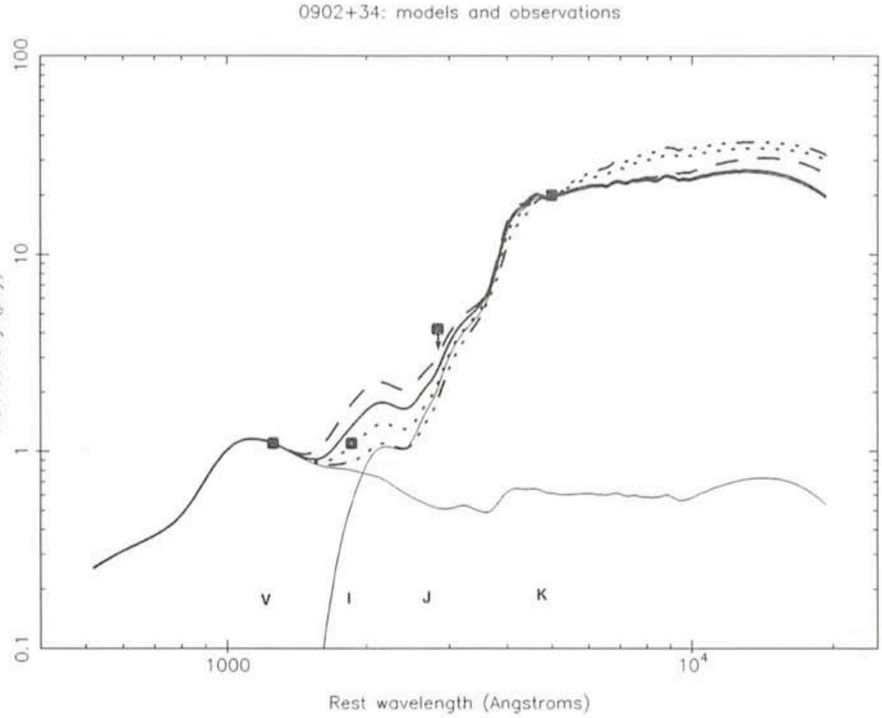

Figure 3: *Comparison of the VIJK fluxes of the radio galaxy 0902+34 (Lilly, 1988) with a model of two bursts: a recent 0.1 Gyr one plus an older one starting at different ages: 2 Gyr (dashed line), 3 Gyr (full line), 4 Gyr (dots), 5 Gyr (dashed-dots). The respective fluxes of the two bursts (0.1 Gyr and 3 Gyr) are also shown (thin lines), see text for details. The IMF is standard and the metallicity is half-solar. Normalization is at 4990 Å (K band in the rest frame).*

To impose an age of the universe long enough to support this 3 Gyr old galaxy, the most plausible values of Ω_0 are very low, likely ≤ 0.1, and the consequent values of z_{for} are high (≥ 10). This result is noticeable since it is full of constraints for the search for primeval galaxies. Also, at a first view, it does not seem quite in agreement with the present models of galaxy formation which favour a redshift of formation peaking at z = 5. Moreover, it is noticeable that similar results are deduced from the Lyα galaxies (Rocca-Volmerange, 1988), Hubble diagrams (GRV) and faint galaxy counts (Guiderdoni and Rocca-Volmerange, 1988c) which are based on independent observational data and in this sense become more confident, even if more complete studies are needed.

Conclusion

The best star formation rate given by evolutionary models for explaining the emission of the radio galaxy 0902+34 in the K band is an intense burst started 3 Gyr earlier with a 1 Gyr duration. Another present (galaxy frame) burst 0.1 Gyr explains the V and partly the I emission. The IMF is standard. The dominant stellar component emitting in the K band is on the Asymptotic Giant Branch. By taking into account uncertainties due to the stellar tracks, the metallicity effects, or changes in IMF, we could slightly improve the accuracy of such results. Anyway, the most important question is to know if this stellar component can be supergiants leading to a recent and possibly primeval burst. The duration of the supergiant phase for massive stars ($\simeq 10^8$ yr) is shorter than the dynamical time scale (10^9 yr) of a burst in these massive galaxies. This means that supergiants evolve from blue to red during the burst and then strongly emit in both the V and K bands. Some shorter bursts will be tested but their dynamical interpretation becomes difficult.

The best detailed analysis to pursue is an estimate of age and star formation parameters (bursts, IMF, metallicity) in each component (as shown in Figure 4) with models in relation with the gas content. More specifically, infrared fluxes of the radio galaxies and their surrounding

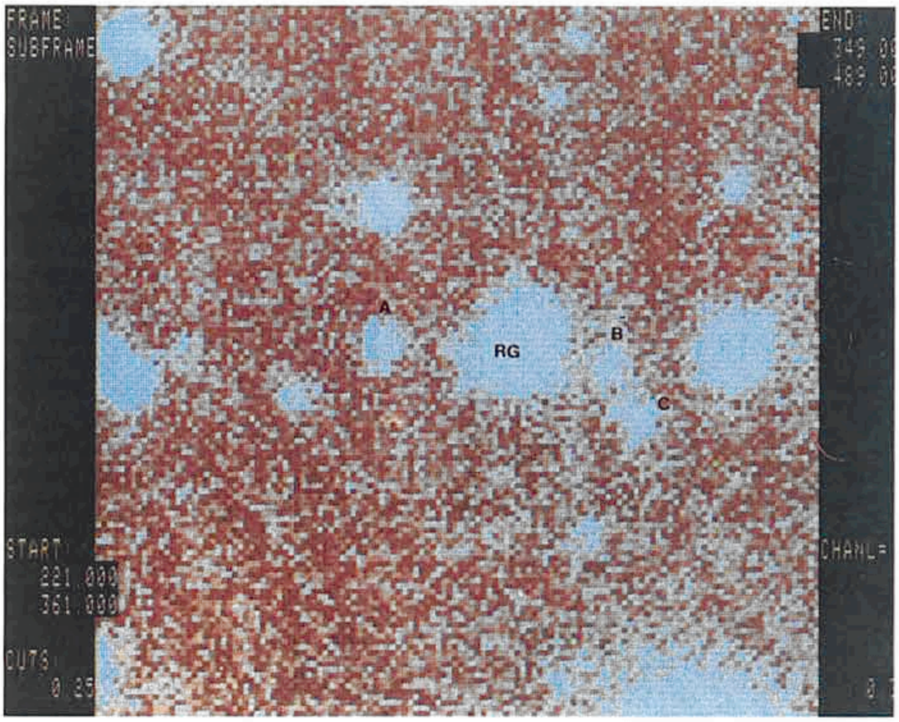

Figure 4: *A 1-hour exposure in September 1987 towards a distant radio galaxy at a redshift z = 0.68 with the ESO 3.6-m telescope and a CCD detector through the R filter. The components have also been observed through the V, I filters.*

components determine the age of the oldest stellar population and, when they are compared to UV fluxes and nebular emission lines, they give information on evolution. Exploring a significant statistical sample of distant radio galaxies with their environment through broad band filters for colours and interference filters for emission lines with the best angular and spectral resolution instrumentation is the best way of understanding the evolution of galaxies and to possibly gain access to primeval galaxies. This programme requires so much exposure time that it can only be realized in the frame of a key-programme of the type recently initiated at ESO.

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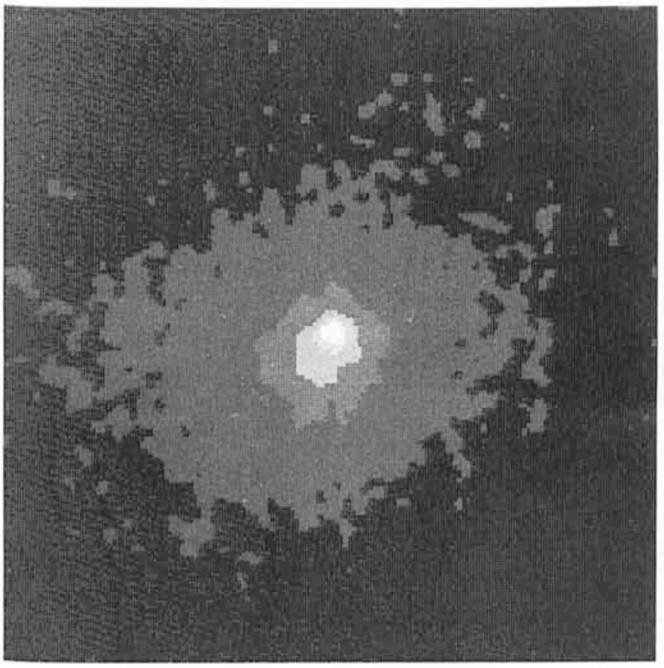
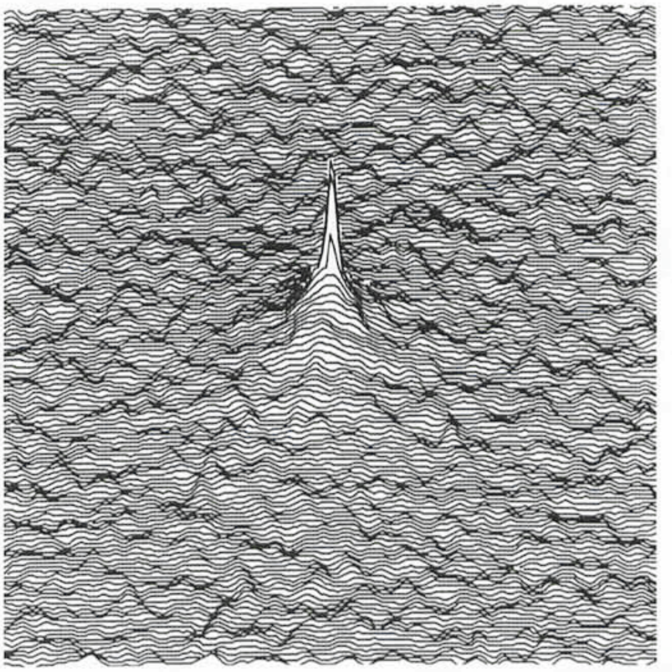
Comet Halley is Still Active





This picture of famous Comet Halley was obtained with the Danish 1.5-m telescope at the ESO La Silla observatory during April-May 1988 (observers: H. Jørgensen, P. Kjærgaard and R.M. West). It was produced by the combination of about 50 CCD frames, obtained during 19 nights, totalling 11 hours 35 minutes exposure. It shows the comet in visual light at a distance of about 1,250 million kilometres, almost as distant as the planet Saturn and demonstrates that the comet still is actively dispensing dust, even at this very large distance from the Sun. The image to the left is smoothed and has 6 light levels, in order to show the 23-mag cometary nucleus in the asymmetric, inner coma and also the much larger, elongated outer coma. To the right is a three-dimensional representation, which illustrates the relative brightness of the nucleus, as compared to the coma. The field of the picture measures 75 arcsec × 75 arcsec; North is up and East is to the left. The direction to the Sun is WNW. Pixel size: 0.47 arcsec = 2,800 km. Johnson V filter. Bias-subtracted, flat-fielded, cleaned for cosmic events, stars and galaxies removed, 3 pix × 3 pix gaussian smoothed.

The ESO Headquarters building in Garching photographed by ESO photographers H.-H. Heyer, C. Madsen and H. Zodet. ▶