An old quasar in a young dark energy-dominated universe?

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ABSTRACT

Dark energy is the invisible fuel that seems to drive the current acceleration of the Universe. Its presence, which is inferred from an impressive convergence of high-quality observational results along with some apparently successful theoretical predictions, is also supported by the current estimates of the age of the Universe from dating of local and high-z objects. In this paper we test the viability of several dark energy scenarios in the light of the age estimates of the high redshift (z = 3.91) quasar APM 08279+5255. Using a chemodinamical model for the evolution of spheroids, we first reevaluate its current estimated age, as given by Hasinger et al. (2002). An age of 2.1 Gyr is set by the condition that Fe/O abundance ratio (normalized to solar values) of the model reaches 3.3, which is the best fit value obtained in the above reference. In the detailed chemodynamical modelling, the iron enrichment defines three relevant time scales: (i) \( \sim 0.3 \) Gyr for the central region of the galaxy housing the quasar to reach a solar iron abundance; (ii) \( \sim 1 \) Gyr for the Fe/O abundance ratio to reach the solar value; (iii) \( \sim 2 \) Gyr for a highly supersolar Fe/O abundance ratio (Fe/O=2.5, suggested by the quasar APM 08279+5255). Therefore, a high value of the Fe/O abundance ratio for a quasar is a strong evidence that the quasar is old, which represents a severe constraint for cosmological scenarios. It is shown that for the currently accepted value of the matter density parameter, most of the existing dark energy scenarios cannot accommodate this old high redshift object unless the Hubble parameter is as low as \( H_0 = 58 \text{ km.s}^{-1}.\text{Mpc}^{-1} \), as recently advocated by Sandage and collaborators. Even considering less stringent age limits, only cosmological models that predicts a considerably old Universe at high-z can be compatible with the existence of this object. This is the case of the conventional ΛCDM scenario and some specific classes of brane world cosmologies.

Key words: cosmology: theory – cosmology: observations – dark matter – distance scale – quasars: general – galaxies: evolution

1 INTRODUCTION

The idea of a dark energy-dominated universe is a direct consequence of an impressive convergence of independent observational results. Along with distance measurements from high-redshift type Ia supernovae (SNe Ia), CMB anisotropies and clustering estimates, one of the most pressing piece of data which motivated such an idea involves the estimates of the age of the Universe \( (t_U) \). Since \( t_U \) at any stage of the evolution of the Universe must necessarily be greater than the age of any object within it, dark energy helps explain the current dating of globular clusters, which indicates \( t_U \geq 13 \) Gyr, by allowing a period of cosmic acceleration and leading to a larger expansion age. For the widely accepted current value of the Hubble parameter, i.e., \( H_0 = 72 \pm 8 \text{ km.s}^{-1}.\text{Mpc}^{-1} \) (Freedman et al. 2001), no flat CDM model without dark energy (whose age prediction is \( t_U = \frac{2}{3}H_0^{-1} \)) may be compatible either with the direct age estimates from globular clusters or with the indirect age estimates, as provided by SNe Ia and CMB measurements (Tonry 2002; Spergel et al. 2003).

On the other hand, it also well known that the evolution of the age of the Universe with redshift \( (dt_U/dz) \) differs from scenario to scenario, which means that models that are old enough to explain the total expanding age at \( z = 0 \) may not be compatible with age estimates of high-redshift objects.
This in turn reinforces the idea that dating of objects at high-redshift constitutes one of the most powerful methods for constraining the age of the Universe at different stages of its evolution (Dunlop et al. 1996; Kennicutt Jr. 1996; Spinrad et al. 1997), and the first epoch of galaxy/quasar formation (Alcaniz & Lima 2001; Alcaniz et al. 2003) as well as for discriminating among different dark energy scenarios (Krauss 1996; Alcaniz & Lima 1999; Jimenez & Loeb 2002; Jimenez et al. 2003).

In this concern, the recent discovery of an old quasar at a redshift of \( z = 3.91 \) is of particular interest (Hasinger et al. 2002; Komossa & Hasinger 2002). Given its location at very high redshift, the existence of APM 08279+5255, whose age was firstly estimated to lie within the range of 2-3 Gyr (Hasinger et al. 2002), it is of fundamental importance to study the effect of any dark energy candidate and/or of the main cosmological parameters on the age of the Universe at the early stages of the cosmological evolution (Komossa & Hasinger 2002; Alcaniz et al. 2003; Cunha & Santos 2004). In principle, provided that reliable and converging estimates on the inferred age of APM 08279+5255 system are obtained, one may combine such estimates with independent determinations of the matter density parameter, \( \Omega_m \), compare the predictions of different scenarios and, possibly, explore new alternatives to better describe the Universe. This is our primary objective in this paper. Firstly, by using a chemodynamical model for the evolution of spheroids proposed by Friaça & Terlevich (1998) [hereafter FT98], we re-estimate the age for APM 0879+5255. Further, by considering the current value of the matter density parameter as given by WMAP team (Spergel et al. 2003), i.e., \( \Omega_m = 0.27 \pm 0.04 \) (1\( \sigma \)), and the latest measurements of the Hubble parameter from the HST key project, this new age estimate is used to test the viability of several cosmological scenarios. It is shown that for these widely accepted values of the matter density parameter (\( \Omega_m = 0.27 \pm 0.04 \)) and of the Hubble parameter (\( H_0 = 72 \pm 8 \text{ km s}^{-1} \text{ Mpc}^{-1} \)) no dark energy scenario may explain the estimated age for the APM 0879+5255 system.

2 THE AGE OF APM 08279+5255 REVISITED

2.1 Chemical abundances constraints on the ages of high redshift objects

It seems natural to consider the metallicity of a galaxy as an age indicator. During its evolution, the galactic system becomes more metal-rich in virtue of the metal injection by evolved stars, and, therefore, a more metal-rich system would be expected to be older. However, the star formation rate (SFR) affects the relation between metallicity and age of a system, because a higher SFR implies a faster rise of the metal abundance. In this case, a relatively young object, that has been formed at a very high SFR (\( \sim 10 \text{ Gyr}^{-1} \)) could have high metallicities. In particular, this explains why even the highest redshift quasars have strong metal lines in their spectrum.

Abundance ratios would be a better probe of galaxy age in chemical evolution studies. Unlike absolute values, abundance ratios do not strongly depend on particular model parameters and on details of the star formation history, but mainly on the stellar nucleosynthesis and the adopted initial mass function (IMF). In particular, the \( \alpha/\text{Fe} \) abundance ratio can be used to place constraints on time scales for star formation and metal production. While the \( \alpha \) elements (O, Ne, Mg, Si, S) are mainly produced in type II Supernovae (SNe II) in short time scales (\( \lesssim 0.1 \text{ Gyr} \)), the Fe-peak elements are produced in type Ia Supernovae (SNe Ia) in a longer time scale (\( \sim 0.3 - 1 \text{ Gyr} \)). A slow (long time scale) star formation corresponds to nearly solar values of \( \alpha/\text{Fe} \) while suprasolar values may indicate shorter time scales for the star formation, which is dominated by SNe II. Conversely, suprasolar values of the Fe/\( \alpha \) ratio indicate that the system is probably older than 1 Gyr.

Using an Fe/O=3 abundance ratio (here the abundance ratio has been normalized to the solar value), derived from X-ray observations, Komossa and Hasinger (2002) estimated the age of the quasar APM 0879+5255 to lie within the interval 2-3 Gyr. An age of 3 Gyr is inferred from the temporal evolution of the Fe/O ratio in the giant elliptical model (M4a) of Hamman & Ferland (1993, hereafter HF93). For the “extreme model” M6a of HF93, the Fe/O evolution would be faster, and Fe/O=3 is already reached after 2 Gyr.

It is worth to notice that the HF93 models are one-zone chemical evolution models based on the classical monolithic scenario of formation of elliptical galaxies. However, this scenario does not account for internal variations in the SFR, which are required to explain the metallicity (and colour) gradients of elliptical galaxies (Saglia et al. 2000; La Barbera et al. 2003), and the internal variations of colours of spheroids (Menanteau, Abrahams & Ellis 2001; Menanteau, Jimenez & Matteucci 2001). In addition, the one-zone chemical evolution models that attempt to explain the high metal content in high redshift QSOs tend to overproduce metals (averaged over the entire galaxy) and predict an excessively high luminosity for the parent galaxy of the QSO. For example, the HF93 model M4a predicts luminosities of up to \( 10^{15} \text{ L}_{\odot} \) during the formation of a present-day \( \sim L^* \) elliptical.

In what follows, we reevaluate the ages for APM 0879+5255 by using a chemodynamical model for the evolution of spheroids (FT98). We assume the scenario (which is the same adopted by HF93) in which luminous quasars at high redshifts (\( z \lesssim 3 \)) are hosted in young elliptical galaxies or massive spheroids (Dunlop et al. 2003).

2.2 The chemodynamical model

We investigate the joint chemical evolution of the quasar and its host galaxy with the chemodynamical model of FT98, in which a single massive dark halo hosts baryonic gas that will fall toward the centre of dark halo and will subsequently form stars. The code combines a multi-zone chemical evolution solver and a 1D hydrodynamical code. The system, assumed to be spherical, is subdivided in several spherical zones and the hydrodynamical evolution of its ISM is calculated. The equations of chemical evolution for each zone are then solved taking into account the gas flow, and the evolution of the chemical abundances is obtained. A total of \( \approx 100 \) star generations are stored during 13 Gyr for chemical evolution calculations. We assume that at a given radius \( r \) and the time \( t \), the specific SFR \( \nu_{SF} \) follows a power-law function of gas density \( \rho \): \( \nu_{SF}(r,t) = \nu_0(\rho/\rho_0)^{1/2} \), where \( \rho_0 \) is the initial average gas density inside the core radius of
Figure 1. Top panel: evolution of the Fe/O ratio averaged over the $r = 0 - 1$ kpc and $r = 1 - 3$ kpc spherical zones. The top panel exhibits the predictions of the model with $M_G = 10^{12} \, M_\odot$, and the lower panel those for $M_G = 10^{11} \, M_\odot$. The horizontal lines denote the iron overabundance of Fe/O of 3.3 ± 0.9 found by Hasinger et al. 2002. Also shown the Fe/O ratio in the halo of the galaxies, at $r = 100$ kpc. In addition, the top panel exhibits the evolution of the Fe/O ratio in the reference one-zone model of FT98 for a $M_G = 10^{12} \, M_\odot$ elliptical galaxy (dotted line).

the dark halo ($r_h$), and $\nu$ is the normalization of the star formation law.

The stars formed follow a Salpeter IMF between 0.1 and 100 $M_\odot$. Chemical evolution occurs as the stars formed out of the ISM evolve and eject gas back into the ISM. The stars are assumed to die either as supernovae (SNe) or as planetary nebulae, when instantaneous ejection of mass, metals and energy occurs. The evolution of the abundances of He, C, N, O, Mg, Si, S, Ca and Fe is calculated by solving the basic equations of chemical evolution. We do not assume instantaneous recycling approximation for the chemical enrichment, but instead we take into account the delays for gas restoring from the stars due to the main-sequence lifetimes. Instantaneous mixing with the ISM is assumed for the stellar ejecta. The models start with an entirely gaseous protogalaxy with primordial chemical abundances ($Y = 0.24$, $Z = 0$). In this work, we use metallicity dependent yields for SNe II, SNe Ia, and intermediate mass stars ($0.8 - 8 \, M_\odot$). For more details of the nucleosynthesis prescriptions, see FT98 and Lanfranchi & Friaça (2003).

With the aid of this model, FT98 investigated the relation between young elliptical galaxies and QSO activity. It was used a sequence of galaxy models parameterized according to the initial total baryonic mass $M_0 = M_g + M_\ast$ (i.e. the stellar and the gas components). The parameters of the model were set in order to reproduce the present-day elliptical galaxy properties. The relevant mass range for massive elliptical hosting luminous quasar is $M_G = 10^{11} - 2 \times 10^{12} \, M_\odot$. Due to inflow and galactic wind episodes occurring during the galaxy evolution, the present stellar mass of the galaxy is ~ 20% higher.

### 2.3 Dating APM 0879+5255 with the chemodynamical model

The chemodynamical model has been used to derive ages for a variety of high redshift objects – quasars (FT98), elliptical galaxies in deep surveys (Jimenez et al. 1999), Lyman Break Galaxies (Friaça & Terlevich 1999), Blue Core Spheroids (Friaça & Terlevich 2001), radiogalaxies/submm sources (Archibald et al. 2002), and damped Lyman alpha systems (Lanfranchi & Friaça 2003) – using several age indices: overall metallicity, level of QSO activity IR-visible colours, colour gradients, IR-submm colours, abundance ratios. Here we use the abundance ratio Fe/O as a clock of the evolution of the galaxy.

From XMM-Newton observations of the high-redshift ($z = 3.91$), lensed, broad absorption line (BAL) QSO APM 0879+5255, Hasinger et al. (2002) have derived an iron overabundance of Fe/O of 3.3 ± 0.9 (relative to solar abundances) for the BAL system. The BAL system should be located near the centre of the galaxy, where a supermassive black hole is driving the quasar activity. Figure 1 shows, at several radii, the evolution of the Fe/O ratio (normalized to the solar abundances) for the models with $M_G = 10^{12} \, M_\odot$ and $M_G = 10^{11} \, M_\odot$. This interval brackets most of the masses of galaxy hosts of radio-loud and luminous QSOs (FT98, Archibald et al. 2002). An age for the QSO of 2.11 Gyr is set by the condition that Fe/O abundance ratio of the model reaches 3.3, which corresponds to the best fit value given by Hasinger et al. (2002). As we see from Figure 1, the age implied by Fe/O=3.3 could be smaller in the outer regions of the galaxy, since in the very centre ($r \lesssim 1$ kpc), there is ongoing star formation for ~ 2 Gyr that gives rise to α element ejecta from SNe II, while in the outer regions (e.g $r = 1 - 3$ kpc), most of the star formation has ceased before 1 Gyr and there is metal ejection only from SNe Ia, leading to a faster rise of the Fe/O ratio. However, the outer regions could not host BALs, which are located only very close to the central supermassive black hole. Note that the model with $M_G = 10^{12} \, M_\odot$ never reaches Fe/O=3.3. However, the peak Fe/O abundance ratio (=2.77) also occurs at 2.1 Gyr.

The age predictions of one-zone models, as represented by the HF93 models, are also in agreement with the results of the present, more elaborated model, since Fe/O ~ 3 is reached at ~ 2 and ~ 3 Gyr by their models M6a and M4a, respectively. Model M4 is the favorite QSO model of HF93, whereas M6 is characterized as “extreme”, since its IMF has a lower mass cutoff of 2.5 $M_\odot$. In order to make a more detailed comparison of the chemodynamical model to the one-zone model, Figure 1 also exhibits the predicted Fe/O evolution of the reference one-zone model for elliptical galaxies of FT98. This model represents an initially gaseous galaxy with mass $M_G = 10^{12} \, M_\odot$, and no dark halo. It is assumed a linear star formation law, i.e. $\nu_{SF} = \nu_0 = \text{constant}$, with $\nu_0 = 9 \, \text{Gyr}^{-1}$. The model belongs to the class of SN-driven galactic wind models, in which a galactic wind is established at a time $t_{gw}$. At this time, the gas is swept from the galaxy and the star formation is turned off forever. The condition for the onset of the galactic wind is that the thermal content of the SN remnants of the galaxy equals the
gravitational binding energy of the galaxy ISM. This model is similar to the model M4 of the HF93, with the main differences being the lower \( v_0 = 0.7 \, \text{Gyr}^{-1} \) and the flatter IMF (IMF power law slope \( \alpha = 1.1 \)) of HF93. In the FT98 one-zone reference model, the evolution of the Fe/O is typical of the classic galactic wind models: Fe/O is initially low, due to the predominant \( \alpha \)-element enrichment by SNe II. When the SN Ia appear, their Fe-rich ejecta boost the Fe/O ratio which becomes solar at 0.7 Gyr. The Fe/O ratio keeps rising and, at \( t_{gw} = 0.81 \, \text{Gyr} \), the galactic wind is established. At later times, Fe/O reaches a plateau, with a slight decrease as the model evolves, due to an increasing contribution of mass-loss from intermediate mass stars. In this model, Fe/O=3.3 is reached at 1.93 Gyr, somewhat before the plateau phase of Fe/O evolution.

It is outstanding that both the chemodynamical and the one-zone models predict that Fe/O \( \sim 3 \) is reached at \( \sim 2 \) Gyr, even though the evolution of the Fe/O ratio is very different in the two models. In order to address the issue of the coincidence of time scales for high iron enrichment in both models and the evolution of the Fe/O ratio in the chemodynamical model, we compare the central (\( r < 1 \, \text{kpc} \)) iron enrichment to the evolution of the SN Ia rate. The first SN Ia appear at \( 3 \times 10^7 \, \text{yr} \), but the SN Ia rate reaches its peak only at 0.78 Gyr for model with \( M_G = 10^{11} \, M_\odot \) and at 0.86 Gyr for that with \( M_G = 10^{12} \, M_\odot \). After the maximum, the decrease of the SN Ia rate is slow until \( \sim 2 \) Gyr, when it is halved with respect to the peak value. This behaviour is what is expected from a continuous star formation lasting for \( \sim 1 \) Gyr. In contrast, an instantaneous starburst exhibits the maximum of SN Ia rate only \( \sim 0.3 \) Gyr after the burst.

As it appears, a continuous star formation history (for \( \sim 1 \) Gyr) describes better the early evolution of the elliptical galaxy than an instantaneous burst, since in our model the main body of the galaxy is formed in \( \sim 0.5 \) Gyr, but there is residual star formation in the central region extending for the first \( 2 - 3 \) Gyr of the galaxy evolution. This is an important characteristic of the FT98 model, namely, that the global star formation history of the elliptical galaxy is not coordinated with the central star formation.

Not only the star formation, but also the gas flow is uncoordinated along the galaxy radius. Some stages of the galaxy evolution are characterized by a complex flow pattern, with inflow in some regions and outflow in other regions. All models, however, exhibit during their late evolution a galactic wind at the outer boundary and, during their early evolution, an inflow towards the galaxy nucleus. The central inflow maintains an extended star formation period in the center and at the same time promotes the growth of the QSO supermassive black hole and feeds its activity. The length of the central inflow episode (\( 2 - 3 \) Gyr) regulates the duration of the QSO activity and of the central star formation.

As a consequence of the extended central star formation period, our elliptical galaxy model exhibits three star formation stages: stage (1) during which the bulk of the stellar population is formed (half of the present day stellar population inside 10 kpc is formed in 0.40 and 0.30 Gyr for the galaxies with \( 10^{11} \) and \( 10^{12} \, M_\odot \), respectively); stage (2), which corresponds to an extended (2-3 Gyr) period of star formation in the core maintained by the inner cooling flow. This stage exhibits more modest star-formation rates than stage (1) and explains the central blue colours of some spheroids at \( z = 0.5 - 1 \) (Friaça & Terlevich 2001) and the absence of very red elliptical galaxies in deep optical and near-infrared surveys (Jimenez et al. 1999). Finally, during stage (3) after \( \sim 3 \) Gyr, the galaxy evolves passively (i.e. with very low levels of star formation).

The relatively slow evolution of the SN rate (peak rate at \( 0.7 - 0.9 \) Gyr) is not inconsistent with short time scales for element enrichment as required by the conspicuous metal lines in the spectra of high redshift QSOs. In fact, in the chemodynamical model, a high-metallicity core (\( r < 1 \, \text{kpc} \)) is rapidly built-up. For the gas, solar metallicities are reached in \( 10^8 \, \text{yr} \) for oxygen, and \( 3 \times 10^6 \, \text{yr} \) for iron. However, central Fe/O solar values are reached only at \( \sim 1 \) Gyr (at 1.0 and 1.1 Gyr for the \( M_G = 10^{11} \) and \( 10^{12} \, M_\odot \) models, respectively). The continuing star formation in the central regions of the galaxies injects, via SNe II, \( \alpha \)-elements in the ISM, which tend to lower the [Fe/O] ratio. In the outer regions of the galaxy, where the star formation has ceased sooner, the SN Ia are more effective in enriching the ISM in iron, and the Fe/O rises faster and to higher values. Note that the galactic wind, which reaches \( r = 100 \, \text{kpc} \) at 1.1 - 1.3 Gyr, initially carries only the metal products of the early enrichment of the ISM, predominantly \( \alpha \) elements, but after 1.7 - 2.5 Gyr, the iron produced by SNe Ia arrives to the outer boundary of the galaxy and is expelled into the intergalactic medium.

As noted above, not all models exhibit a central Fe/O as high as 3.3. However, all the models reach Fe/O=2.5, and it would be more useful for dating purposes, to focus on the rising part of the Fe/O ratio evolution and establish a lower limit for the age of APM 0879+5255 by considering when the Fe/O abundance ratio reaches 2.5. This happens at 1.83 and 2.03 Gyr, for the models with \( 10^{11} \) and \( 10^{12} \, M_\odot \), respectively. In addition, due to the later decrease of the Fe/O ratio, there is only a temporal window during which the QSO will be seen as very iron-rich (Fe/O=2.5 or higher): 1.8-4.3 Gyr, and 2.0-3.4 Gyr for the \( M_G = 10^{11} \) and \( 10^{12} \, M_\odot \) models, respectively. In fact, this temporal window could be narrower, because the later time would rather be given by the condition that the QSO is being fed by the inner cooling flow, i.e. \( t \lesssim 3 \, \text{Gyr} \) (FT98, Archibald et al. 2002). On the other hand, the lower limit for the age of the QSO is more interesting for cosmological purposes. As we will see in the next section, both our “best estimate” of 2.1 Gyr for the age of APM 0879+5255, and the lower limits 1.8-2.0 Gyr impose strict constraints on cosmological models.

3 TESTING COSMOLOGICAL SCENARIOS WITH APM 0879+5255

To what extent does this novel determination of the age of APM 0879+5255 provide new constraints on dark energy scenarios? To answer this question, we first take for granted that the age of the Universe at any redshift must be greater than or at least equal to the age of its oldest objects. Such a condition naturally introduces the following ratio (Alcaniz & Lima 1999)

\[
\frac{t_w}{t_g} = \frac{f(z; P)}{H_0 t_g} \geq 1,
\]

(1)
where \( t_z = H_0^{-1} f(z; \mathbf{P}) \) is the predicted age of a particular cosmological model, \( t_0 \) is the age of an arbitrary object, say, a quasar or a galaxy at a given redshift \( z \) and \( f(z; \mathbf{P}) \) is a dimensionless function of the cosmological parameters \( \mathbf{P} \). For a given object, the denominator of the above equation defines a dimensionless age parameter \( T_\star = H_0 t_\star \), which involves two quantities measured or estimated from completely independent methods. In particular, the 2.1-Gyr-old quasar at \( z = 3.91 \) yields \( T_\star = 2.1 H_0 \) Gyr which, for the most recent determinations of the Hubble parameter, \( H_0 = 72 \pm 8 \) kms\(^{-1}\)Mpc\(^{-1}\) (Freedman et al. 2001), takes values on the interval \( 0.137 \leq T_\star \leq 0.172 \). In order to assure the robustness of our analysis, we will adopt in our computations the 1\( \sigma \) lower bound for the above mentioned value of the Hubble parameter, i.e., \( H_0 = 64 \) kms\(^{-1}\)Mpc\(^{-1}\), which implies \( T_\star \geq 0.131 \). Therefore, only models providing an age parameter larger than this value at \( z = 3.91 \) will be compatible with the existence of this object.

Figures 2 and 3 show the dimensionless age parameter \( T_\star = H_0 t_\star \) as a function of the redshift for several dark energy models, namely, the current concordance scenario, i.e., a flat model with a cosmological constant (ACDM), the so-called generalized Chaplygin gas [GC\(_g\)] (Kamenshchik et al. 2001; Bilić et al. 2001; Bento et al. 2002; Dev et al. 2003), two different parameterizations for the redshift-dependence of the dark energy equation of state (EOS), i.e., \( \omega(z) = \omega + \omega_z z \) [P1] (Cooray & Huterer 2000; Goliah et al. 2001) and \( \omega(z) = \omega + \omega_1 (z/1 + z) \) [P2] (Linder 2003; Padmanabhan & Choudhury 2003), and a 5-dimensional brane world scenario, which we refer to it as DGP model (Dvali et al. 2000; Deffayet et al. 2002; Alcaniz 2002). For the GC\(_g\) model we assume \( \alpha = 0.96 \) and \( A_1 = 0.98 \), the best-fit values provided by the latest SNe Ia data (Alcaniz & Lima 2004) while for the \( \omega(z) \) scenarios we fix \( \omega = -1.31 \) and \( \omega_1 = 1.48 \), in agreement with the SNe Ia analysis of Riess et al. (2004). The shadowed regions in the graphs are determined from the minimal value of \( T_\star \), which means that any model crossing the rectangles yields an age parameter smaller than the minimal value required by the existence of the quasar APM 08279+5255.

By adopting the central value of the matter density parameter as given by WMAP team, i.e., \( \Omega_m = 0.27 \), we see from Figure 2a that no dark energy or brane world scenario is compatible with the age estimate of 2.1 Gyr for this object, even considering the 1\( \sigma \) lower bound for the Hubble parameter given by the HST key project. Note also that the same happens for the central value, \( H_0 = 58 \) kms\(^{-1}\)Mpc\(^{-1}\), as recently advocated by Sandage and collaborators (right panel).

![Image of dimensionless age parameter](image.png)

**Figure 2.** Dimensionless age parameter as a function of redshift for dark energy and brane world models. As explained in the text, all curves crossing the shadowed area yield an age parameter smaller than the value 2.1 Gyr required by the quasar APM 08279+5255. The two thin horizontal lines in the shadowed areas, correspond to the ages 1.8 and 2 Gyr, required for the models with \( 10^{11} \) M\(_\odot\) and \( 10^{12} \) M\(_\odot\) to reach Fe/O=2.5\( \times \) solar. On the left panel, we see that none dark energy or brane world scenario is compatible with the age estimate of 2.1 Gyr for this object, even considering the 1\( \sigma \) lower bound of the Hubble parameter given by the HST key project. Note also that the same happens for the central value, \( H_0 = 58 \) kms\(^{-1}\)Mpc\(^{-1}\), as recently advocated by Sandage and collaborators (right panel).
value of $H_0$, the age parameter at $z = 3.91$ is $T_9 > 0.124$ and both $\Lambda$CDM and DGP models are compatible with the existence of the APM 08279$+5255$ system. By considering $H_0 = 72$ km s$^{-1}$ Mpc$^{-1}$, the central value of the HST key project (Freedman et al. 2001) and no prior on the value of $\Omega_m$, we find $\Omega_\Lambda \geq 0.85$ ($\Omega_m \leq 0.15$). Such values are in disagreement with the results inferred from an elementary combination of CMB measurements pointing to $\Omega_{\text{Total}} \geq 1.0$ (de Bernardis et al. 2000; Spergel et al. 2003) and clustering estimates giving $\Omega_m = 0.3 \pm 0.1$ (Ciberg et al. 1996; Dekel et al. 1997) or from a rigorous statistical analysis involving many astrophysical constraints (see, for example, Peebles & Ratra 2002, Padmanabhan 2002 and Lima 2004 for recent reviews). For the other three scenarios considered in this paper (excluding P1), we obtain: $\Omega_m < 0.1$ (P2), $\Omega_m < 0.16$ (Cg) [for values of $A_\pm = 1.0$, $\alpha = 0$, which correspond to the maximum age] and $\Omega_m < 0.15$ (DGP).

4 SUMMARY AND CONCLUSIONS

As widely known, the determination of the total age of the universe (the expanding time from the big-bang to $z = 0$) has been since the early thirties one of the major questions as well as a real source of progress for cosmology. Similarly, the age estimates of old high redshift objects may play a prominent role to discriminate among the existing dark energy or brane world models by constraining the basic cosmological parameters. In reality, the so-called high redshift “age crisis” seems to be even more restrictive than the total age, and is now becoming an important complement to other independent cosmological tests (Alcaniz & Lima 1999; Jimenez & Loeb 2002).

In this paper we have reestimated the age of the APM 08279$+5255$ quasar, and constrained some basic cosmological parameters of a large class of cosmological scenarios. In the first place, using a chemodynamical model for the evolution of spheroids, we reevaluate its current estimated age, as given by Hasinger et al. (2002). An age of 2.1 Gyr is set by the condition that Fe/O abundance ratio (normalized to solar values) of the model reaches 3.3, which is the best fit value given in Hasinger et al. (2002). In the detailed chemodynamical modelling, although the central region of the galaxy housing the QSO reaches a solar iron abundance in $\sim 0.3$ Gyr, the Fe/O abundance ratio reaches the solar value at $\sim 1$ Gyr, and Fe/O$=2.5$ only at $\sim 2$ Gyr. Therefore, a highly suprasolar value of the Fe/O abundance ratio for a QSO is a strong evidence that the QSO is old, which constrains severely cosmological scenarios.

As we have seen (Figures 2 and 3), assuming $t_9 = 2.1$ Gyr for APM 08279$+5255$, for the current accepted values of $\Omega_m$, the main class of world models (dark energy or brane inspired universes) cannot accommodate the existence of this object. $\Lambda$CDM and DGP brane world models pass the test only if one considers the low value of $H_0$ obtained by Sandage and collaborators (Figure 3). Even less stringent age limits, derived from a Fe/O ratio of 2.5, which is allowed by the X-ray data, are consistent with only a few cosmological scenarios, namely, those favoring an older high-redshift Universe. The models with $10^{11}$ $M_\odot$ and $10^{12}$ $M_\odot$ reach Fe/O$=2.5$ x solar at 1.8 and 2.0 Gyr, respectively. In this case (see Figures 2 and 3), also the $\Lambda$CDM and DGP brane world models are favored by the age estimates. In addition, $H_0 = 64$ km s$^{-1}$ Mpc$^{-1}$ could be acceptable if $\Omega_m = 0.23$.

In general grounds, two aspects should be emphasized.
First, by using an independent chemodynamical evolution code, we have confirmed the earlier age estimates of this object set by Hasinger et al. (2002). Second, we have shown the importance of the dating of high redshift objects as an independent test. This is more evident, for instance, in the case of $\omega(z)$ (P1) scenario which predicts a total expanding age compatible with the current dating of globular clusters (Asantha & Huterer 1999), but which present a very small age at moderate and high $z$ (see the dashed line in Figures 2 and 3). Our results, therefore, rule out the model as a realistic description of our Universe.

The present work highlights the cosmological interest on the observational search for quasars, galaxies and other old collapsed objects at high redshifts. In particular, we emphasize that chemical modelling of high redshift quasar evolution can be a valuable tool for dating the high redshift Universe, providing much needed constraints on cosmological models.

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An old quasar in a young dark energy-dominated universe?