The association of HLA-B53 with malaria resistance and the observation that HLA-B53-restricted CTL recognize only LSA-1 of several major pre-erythrocytic antigens from *P. falciparum*, constitute a genetic approach to implicating this antigen in providing protective immunity to malaria, and encourage further assessment of LSA-1 as a component of future subunit vaccines. □

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Astrophysical ^{7}Li as a product of Big Bang nucleosynthesis and galactic cosmic-ray spallation

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RECENTLY measured abundances of beryllium[1–4] and boron[5] in a number of hot population II halo stars are orders of magnitude above the predicted abundances of those elements from standard Big Bang nucleosynthesis[6]. Be and B do not, however, show a plateau of constant abundance over a wide range of low metallicities and high temperatures, as is the case for ^{7}Li (refs 7–15). The implication is that the ^{7}Li abundance is largely primordial, whereas the Be and B abundances are due to galactic cosmic ray (GCR) spallation reactions[16–22] on top of a much smaller Big Bang component[23]. But GCR spallation should also produce ^{7}Li. As a consistency check on the combination of Big Bang nucleosynthesis and GCR spallation, we use the Be and B data to subtract from the measured ^{7}Li abundance an estimate of the amount generated by GCR spallation[21,22] for each star in the sample, and then add to this baseline an estimate of the metallicity-dependent augmentation of ^{7}Li, due to spallation. The slightly reduced primordial ^{7}Li abundance is still consistent with Big Bang nucleosynthesis, and a single GCR spallation model can fit the Be, B and corrected ^{7}Li abundances for all the stars in the sample.

The dominant product of Big Bang nucleosynthesis[6] is ^{4}He, which is produced with a relative abundance by mass of $Y \approx 0.24$ (leaving a primordial hydrogen mass fraction of ~76%). ^{4}He is accompanied by lesser amounts of D and ^{3}He, $(D, {}^3He)/H \approx 10^{-5}$ (by number). In contrast, ^{7}Li is produced with even lower abundances $({}^7Li/H) \approx 10^{-10}$ in the standard model. The fact that the predicted abundances of these light element isotopes can be explained over this range of nearly 10 orders of magnitude is clearly a success for the simplest nucleosynthesis model. Big Bang nucleosynthesis calculations can also predict the primordial abundances of other light element isotopes[23], namely ^{6}Li, ^{9}Be, ^{10}B and ^{11}B. These isotopes are produced in much smaller quantities $({}^6Li/H) \approx 10^{-14}$, $({}^9Be/H) \approx 10^{-18}$, $({}^{10}B/H) \approx 10^{-20}$, $({}^{11}B/H) \approx 10^{-18}$, for a baryon to photon ratio of $\eta \approx 3 \times 10^{-10}$ (the value required to maintain consistency with the light element abundances).

Since the observation of the ^{7}Li plateau[7–9], it has been argued that the plateau value of $({}^7Li/H) \approx 10^{-10}$ corresponds to primordial ^{7}Li. Hence, ^{7}Li has been a key element in tests of consistency for Big Bang nucleosynthesis. The stars making up the plateau (there are nearly 40 of them now) are all population II halo dwarfs. They have low metallicity, $[Fe/H] \leqslant -1.3$ ($[X/H]$ corresponds to the log abundance by number relative to the solar value), with some going as low as $[Fe/H] = -3.5$. They also have high surface temperatures $T > 5{,}500$ K. Cooler halo stars are observed to have considerably less ^{7}Li, confirming stellar models that depict convective depletion at $T \leqslant 5{,}500$ K (see for example ref. 25). Over the entire range ($5{,}500 < T < 6{,}300$ K and $-3.5 \leqslant [Fe/H] \leqslant -1.3$) the ^7Li abundance is remarkably constant. The plateau stars have a well determined mean

$$[^7Li] = 2.08 \pm 0.02 \quad (1)$$

(where we use the astronomical convention $[^7Li] = 12 + [^7Li/H]$) and show a dispersion of ~ 0.12 which is consistent with the observational uncertainty in the measurements. We stress that in equation (1) we have only quoted a statistical error and have not included any systematic errors, which may be sizeable (~ 0.1) and could arise, for example, from the methods of determining the temperatures of these stars. Unfortunately the literature does not supply all the information needed to assess more the systematic errors accurately. Below, all our errors quoted are only statistical; thus the true error is always larger. Furthermore, there are no significant departures from constancy in [Li] in these stars. The dispersion from the mean value, given as χ^2 per degree of freedom, is $\chi^2 = 1.26$. There is no correlation with metallicity: $[Li] = 2.11 \pm 0.09 + (0.02 \pm 0.04)$ [Fe/H], $\chi^2 = 1.26$, $r = -0.056$. The small value of the correlation coefficient, r, shows that the faint hint of a correlation with temperature is not significant: $[Li] = 0.45 \pm 0.62 + (0.0003 \pm 0.0001)T$, $\chi^2 = 1.11$, $r = 0.390$, or $d(Li/H)/dT = 3.6 \times 10^{-14}$, in good agreement with the value given by Hobbs and Thorburn[15]. This lack of trend (the small slope with respect to T leads to a change in Li which is smaller than the error in Li over the entire temperature range) has lent strong credence to the assumption that population II lithium has a primordial origin.

Several halo dwarfs have been shown to have a measurable ^9Be abundance[1-4] (most of these are in the ^7Li data set). Unlike ^7Li, the ^9Be abundance is strongly correlated with metallicity

$$[^9Be] = (-10.19 \pm 0.54) + (1.13 \pm 0.27)[Fe/H] \quad (2)$$

for which $\chi^2 = 0.28$, $r = 0.93$. Thus it is clear that the observed ^9Be is not primordial. As the standard model prediction for primordial[23] $^9Be/H$ is $\sim 10^{-18}$–10^{-17} whereas the observed abundances are 10^{-13}–10^{-12}, the strong correlation is not really a surprise. Unless a ^9Be plateau can be established, the measured ^9Be abundances on their own say very little about standard or even nonstandard nucleosynthesis, as no primordial value can be determined. Unlike the case for ^4He, where the primordial component is dominant and one can determine a definite primordial value by extrapolation to near-zero metallicity, the primordial component of ^9Be is presumably negligible compared with the observed ^9Be.

TABLE 1 Observed Be and Li and extracted Big Bang abundance of ^7Li

Star	[Fe/H]	$(^7Li/Be)_{GCR}$	$[Be]_{obs}$	$[Li]_{obs}$	$[Li]_{BB}$
HD16031	−1.9	80 ± 30	−0.37 ± 0.25	2.03 ± 0.20	1.86 ± 0.32
HD134169	−1.2	11 ± 2	+0.65 ± 0.4	2.21 ± 0.09	2.06 ± 0.22
HD140283	−2.6	234 ± 14	−1.04 ± 0.19	2.09 ± 0.07	2.01 ± 0.09
HD160617	−1.9	38 ± 9	−0.47 ± 0.18	2.20 ± 0.20	2.16 ± 0.22
HD189558	−1.3	26 ± 8	+0.00 ± 0.4	2.04 ± 0.20	1.92 ± 0.30
HD201891	−1.3	12 ± 4	+0.40 ± 0.4	1.98 ± 0.07	1.82 ± 0.22
HD213617	−2.2	161 ± 61	−0.65 ± 0.25	2.17	2.05 ± 0.28
BD23° 3912	−1.5	43 ± 16	+0.30 ± 0.4	2.36 ± 0.10	2.16 ± 0.30

For completeness, we note that there are new observations[5] of B in three halo dwarfs. Again there is a strong correlation with metallicity

$$[B] = (-8.48 \pm 0.67) + (1.42 \pm 0.33)[Fe/H] \quad (3)$$

with $\chi^2 = 0.27$, $r = 0.99$. And as for Be, the measured abundances are orders of magnitude above the Big Bang yields.

These new observations are relevant to our understanding of GCR spallation processes[16-20]: p, α on ^4He, C, N and O. Here, we make the simple set of assumptions used in refs 21 and 22 (the reader is referred there for details). It was found that the abundances of [Be] and [B] are linearly correlated with [Fe]; $[^7Li]$ is less strongly correlated as much of the ^7Li is produced by $\alpha + \alpha$ collisions rather than by spallation on CNO; spallation produces $^6Li/^7Li \approx 0.9$ and predicts $B/Be \approx 7$–17, with the simplest model yielding $B/Be \approx 12$–14.5, which is within 1σ of the observation[5] ~ 10. As ^6Li is depleted much more rapidly than ^7Li and Be, observation of ^6Li in halo dwarfs might only be possible in extreme high-temperature ($T > 6{,}200$ K) dwarfs[25,26], and then only if Li is not depleted by mass loss or diffusion[27]. From the new observation[24] of ^6Li in the halo subdwarf HD84927 with $^6Li/^{total}Li \approx 0.05 \pm 0.02$ at $T \approx 6{,}200$ K, and because of the fragility[26] of ^6Li, one can therefore conclude that the ^7Li observed[7-10] in this star $[Li] = 2.11 \pm 0.07$ is indeed not significantly depleted. As we will see below, this observation has important consequences for nonstandard models.

The consistency of Big Bang nucleosynthesis with the Be and Li abundances has been examined[22]. It was shown that although a sizeable fraction of the total ^7Li may be produced, the observed ^7Li is consistent with the prediction of GCR spallation and a primordial value of $[Li] = 2.00$–2.12. One can go further than the consistency check of Walker *et al.*[22] by systematically

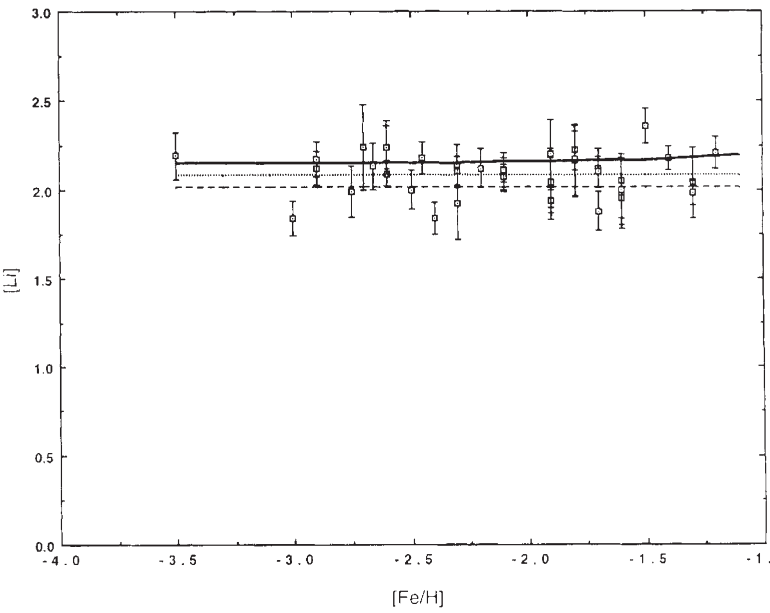

FIG. 1 The ^7Li data as a function of the [Fe/H]. The dotted line corresponds to the mean of the data $[Li] = 2.08$, $\chi^2 = 1.26$. The dashed line corresponds to the extracted primordial value of $[Li] = 2.01$. The solid curve corresponds to the sum of the primordial value and the metallicity-dependent GCR-spallation produced ^7Li with $\chi^2 = 1.75$.

subtracting out the ^{7}Li produced by GCR spallation from the observations. Of the 12 stars with observed ^{9}Be, 10 have measured ^{7}Li. Of these 10 we omit HD76932, which is usually omitted from the ^{7}Li plateau data set because of its high metallicity, and HD34328 which is reported[4] to be a dubious measurement (because of an uncertain spectrographic setting). This leaves us with eight stars from which we attempt to determine the primordial ^{7}Li abundance. These stars are listed in Table 1 along with [Fe/H] (an unweighted mean of measured values), the GCR-spallation ratio ^{7}Li/^{9}Be, the observed ^{9}Be and ^{7}Li abundances and the derived primordial abundances from

$$(^7\text{Li/H})_{\text{BB}} = (^7\text{Li/H})_{\text{obs}} - (^7\text{Li}/^9\text{Be})_{\text{GCR}}(^9\text{Be/H})_{\text{obs}} \quad (4)$$

Where it is available, we use the weighted average of observed C, N and O in these stars, otherwise we use the simple starting point given above in ref. 22 for population II stars. Observational errors in all measurable quantities have been propagated leading to the larger errors for $[^7\text{Li}]_{\text{BB}}$ shown in Table 1. The weighted mean (again ignoring possible systematics) for these eight stars is

$$[\text{Li}]_{\text{BB}} = 2.01 \pm 0.07 \quad (5)$$

Because of the greater uncertainty, the 2σ upper limit is essentially the same as one would obtain from equation (1). The dispersion in observed ^{7}Li of these eight stars is given by a χ^2 per degree of freedom of 1.73, although because of the larger uncertainties the χ^2 per degree of freedom of $[\text{Li}]_{\text{BB}}$ is small, 0.26. The extracted abundance of Li (equation (5)) is not too low to be consistent with standard Big Bang nucleosynthesis.

In principle one can repeat this exercise with the B data shown in Table 2. The implied primordial abundance of ^{7}Li from the B data (by an analogous procedure) is also $[\text{Li}] = 2.01 \pm 0.06$, in perfect (coincidental) agreement with the value derived from Be. We are also encouraged that the B/Be ratios are consistent with the GCR predictions[22].

Given a primordial value of [Li] = 2.01, we can now determine the ^{7}Li abundance as a function of [Fe/H], using [C/H] = [N/H] = [Fe/H] and [O/Fe] = 0.5 so that[22]

$$[\text{Li}]_{\text{GCR}} = 1.59 + \log(1 + 4.53 \times 10^{[\text{Fe/H}]}) \quad (6)$$

and

$$(\text{Li/H})_{\text{total}} = (\text{Li/H})_{\text{BB}} + (\text{Li/H})_{\text{GCR}} \quad (7)$$

(The normalization has been fixed by $(^9\text{Be/H})_{\text{OBS}} = (^9\text{Be})_{\text{GCR}}$ which fixed the exposure time $\Delta t = 10.7$ Gyr.) [Li] total is plotted as a function of [Fe/H] in Fig. 1 along with the baseline $[\text{Li}]_{\text{BB}} = 2.01$ (dashed) the ^{7}Li data set and the mean of the data [Li] = 2.08 (dotted). Given the uncertainties in the measurements and calculations, one cannot identify a discrepancy between the data and the model prediction (solid curve). We are not suggesting that the solid curve in Fig. 1 (from equation (7)) gives a better fit to the data. But one can clearly see that the extracted primordial abundance (equation (5)) and the predicted total abundance of ^{7}Li (equations (6), (7)) can be used to argue for the consistency of the Big Bang and GCR production of ^{7}Li. The χ^2 per degree of freedom is now 1.75. It could be even lower if we make the correction suggested by Hobbs and Thorburn[15] on the left-most discrepant star G238-30. They use a higher surface temperature leading to [Li] = 2.05 rather than [Li] = 1.84 for the same equivalent width. This correction would reduce χ^2 to 1.52. We are not aware of any corrections suggested for the other two discrepant stars. One should note that we have neglected the effects of diffusion (a point we will return to shortly). The models of Deliyannis *et al.*[25] using standard Li isochrones are best fitted with an initial abundance of [Li] = 2.17, close to the model prediction of [Li] ≈ 2.15. GCR models with flatter spectra yield smaller GCR Li corrections for given Be and B abundances.

Finally, we consider the implications of these results for inhomogeneous nucleosynthesis[28-30] and extreme depletion in rotational models[31]. The 'high' Be abundances are sometimes considered to be a signature for inhomogeneous nucleosynthesis[2]. Until a plateau can be established for ^{9}Be, however, there is no signature, standard or not, for any primordial production of ^{9}Be. Furthermore, as the inhomogeneous models cannot alter the conclusions of standard nucleosynthesis significantly when isotope abundance constraints for all light elements $A \leq 7$ are used, it seems unlikely that ^{9}Be will be an exception. Preliminary calculations bear this out[23,32]. In other words, accurate inhomogeneous nucleosynthesis calculations also do not seem to yield Be/H as high as observed in the population II stars.

TABLE 2 Observed B and Li and extracted Big Bang abundance of ^{7}Li

Star	[Fe/H]	$(^7\text{Li/B})_{\text{GCR}}$	$[\text{B}]_{\text{obs}}$	$[\text{Li}]_{\text{obs}}$	$[\text{Li}]_{\text{BB}}$
HD19445	−2.1	7 ± 2	0.4 ± 0.2	2.07 ± 0.07	2.00 ± 0.09
HD140283	−2.6	17 ± 1	−0.1 ± 0.2	2.09 ± 0.07	2.04 ± 0.08
HD201891	−1.3	0.9 ± 0.25	1.7 ± 0.4	1.98 ± 0.07	1.70 ± 0.40

Next we come to the stellar models of Pinsonneault *et al.*[31] with rotation and a reported depletion of primordial ^{7}Li by an order of magnitude. These models consider the possible effects of diffusion beyond standard stellar models arising from large rotationally induced mixing. Pinsonneault *et al.* take a limited high range for stellar angular velocities ranging from 1/20 to 1/2 of the critical break-up value, choose high rotationally induced mixing rates, and find with these assumptions that a primordial value [Li] = 3.1 can be depleted down to a plateau with relatively small dispersion. With such a high value for the primordial abundance, the GCR-produced ^{7}Li would be insignificant. (In the absence of depletion, GCR spallation requires an effective exposure time of ~10 Gyr, so although Be suffers much less depletion than Li (ref. 33), the timescale for producing Be by GCR spallation would have to be correspondingly increased, perhaps by an untenable factor as large as 3.) But this model[31] predicts a dispersion of 0.3 for stellar ages as large as 20 Gyr. For a smaller age of 13 Gyr, the models predict a dispersion of 0.5. Recall that the data show a dispersion, of only 0.12 and this can be accounted for by the observational uncertainties. The chance of this occurring is small for the 20 Gyr model and extremely small for the 13-Gyr model. Clearly, a larger range of angular velocities will produce even more dispersion. An additional failure for these depletion models is that they distinctly predict that the dispersion should be largest at high temperatures; the data do not support this and may contradict it.

In this context, the observation[24] of ^{6}Li in the hot halo dwarf HD84937 is clearly important. The rotation models would not allow for the survival of any observable ^{6}Li in this star. Because of the fragility of ^{6}Li (ref. 26), this observation implies that the ^{7}Li in this star is essentially undepleted.

Finally, we note that the current population I stellar abundances of [Li] ≈ 3 relative to the primordial abundances of [Li] ~ 2 are easily understood to arise from the addition of ^{7}Li from asymptotic giant branch (AGB) stars (as well as ~10% addition of GCR-spallation produced ^{7}Li that accompanies the production of the observed population I ^{6}Li). Considerable enrichments of Li have been observed[34] in certain AGB stars. It has been shown[35] that reasonable estimates of the frequency of such stars and their subsequent mass-loss would naturally result in Li enhancements in the Galaxy that agree with the observed population I abundance. The production of the AGB Li is presumably via the Cameron–Fowler[36] process $^3\text{He}(\alpha,\gamma)^7\text{Be}$(beta-decay)^{7}Li in the outer convective zone. Thus a high initial Li is not only unnecessary but could even cause excesses, because the observed AGB Li would have to be added; little of this could be destroyed without also destroying the ^{6}Li, for which the only known production mechanism is GCR spallation. The population II Li plateau seems to give us a good estimate of the primordial abundance and fits the simplest model fairly well. □

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Counter-rotating gaseous disks in the "Evil Eye" galaxy NGC4826

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SEVERAL elliptical and spheroidal galaxies have been shown, in recent years, to possess kinematically distinct subsystems. These may be in the form of a central stellar component whose rotation is not aligned with the rest of the galaxy[1,2], or of a gaseous disk, often at large radius, which is kinematically distinct from the main stellar component[3,4]. A more unusual case is that of a counter-rotating gaseous component (with some associated stellar absorption) in the inner region of the flattened elliptical NGC4550[5]. All these cases are presumed to be signatures of violently interacting systems, which are the result of galaxy mergers or captures, as in NGC7252[6,7]. Here we report the discovery of two counter-rotating gaseous disks in the otherwise normal early-type spiral (Sab(s)II; ref. 8) NGC4826. This is the most disk-like galaxy in which any kinematic substructure has yet been found, and our discovery raises the possibility, already suggested by Schweizer[7], that even spiral galaxies may have undergone a significant degree of structural evolution due to mergers.

NGC4826 (Messier 64) is both nearby (distance $D = 3.8$ Mpc after correcting for Virgo-centric infall and with $H_0 = 100$ km s^{-1} Mpc^{-1}) and relatively isolated. The galaxy lies at the outskirts of the loose group (CVn I, ref. 9) which includes NGC4736 (M94) and about 15 other possible members. Most of the group members are spirals and irregulars which are spread over an area of 1.9×0.9 Mpc and a velocity range of 300 km s^{-1}. No nearby companions (within a few degrees) of NGC4826 have yet been identified. A distinguishing feature of the galaxy is the prominent dust-lane pattern on the northeastern side which has led to nicknames such as the "Black Eye" or "Evil Eye" galaxy.

We observed neutral hydrogen emission from NGC4826 with the Very Large Array (VLA)[10] between March 1989 and November 1990 in the B, C and D configurations (with effective integration times of 7, 0.5 and 0.5 hours) to image a region 0.5 degree in diameter at 6 arcsec resolution. In addition, a small hexagonal mosaic in the D configuration (with 0.5 hours effective integration on each of seven positions) was used to image a 1-degree diameter field at 65 arcsec resolution. These observations were part of a program to study the properties of 11 nearby galaxies with high spatial resolution (better than ~100 pc) and velocity resolution (6.2 km s^{-1}). Standard calibration and imaging techniques were used to produce a series of narrow-band images separated by 5.15 km s^{-1} over a velocity range of 660 km s^{-1} centred on the nominal (heliocentric) systemic velocity of NGC4826, 415 km s^{-1}.

The dominant velocity component of neutral hydrogen emission was determined at both 65 and 15 arcsec resolution by forming an image of the velocity corresponding to the brightest measured emission along each line-of-sight. The resulting velocity fields were 'blanked' (declared undefined) outside the connected regions where significant emission was detected. The derived velocity field is shown in Fig. 1. An extended disk (of 22 arcmin diameter) is detected in the low-resolution database

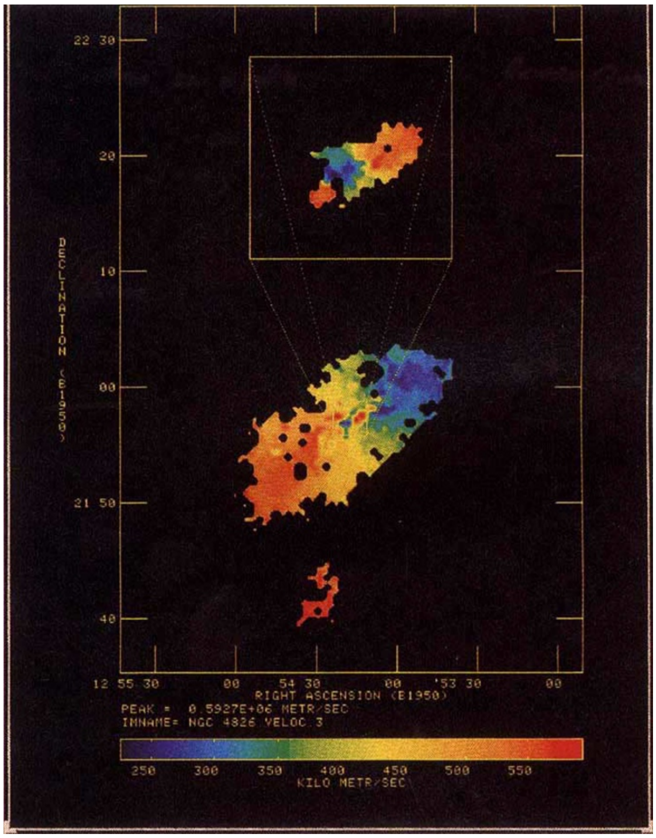

FIG. 1 Line-of-sight velocity of neutral hydrogen emission in the nearby (type Sab(s)II) spiral galaxy, NGC4826. Note the 'spider pattern' characteristic of differential rotation, with the highest receding velocities observed along a position angle of 125° (east of north) in the outer disk. The sense of rotation is observed to reverse within the central region of the galaxy, as seen in the high-resolution inset. These counter-rotating gaseous disks are probably the result of a major merger event during the last billion years. Note also the isolated feature 10 arcmin south of the galaxy, which may well represent a remnant of the galactic collision which is still settling into the disk.