Birth, Aging, and Death of Galactic Bars

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Abstract. The life of disk galaxies is likely punctuated with the birth (spontaneous or induced), the aging (quick or slow), and the death (sudden or progressive) of bars. These events are responsible for various major changes of the galaxy which occur both on dynamical (\(\sim 0.1\) Gyr) and cosmological (\(\sim 10\) Gyr) time-scales, as well as both on large- (\(\geq 10\) kpc) and small-scales (\(\leq 1\) kpc). These modifications affect the morphology, the orbital structure, the dynamics, the star formation and central fueling rates, the abundance profiles, etc. As a consequence, remarkable galaxy metamorphoses within the Hubble sequence can be observed. The formation and the fate of gaseous bars are also briefly examined.

1. Introduction

The universe is not rigid or frozen. It is evolving, just like its constituents; galaxies, stars, clusters are all changing with time. Galactic stellar bars or any triaxial systems are not an exception to the rule. But they are not passively undergoing changes, they are actively driving them (Sect. 2.2). Over the last thirty years, mainly due to the development of efficient numerical techniques, the required conditions for a bar to form have become better known (Sect. 2.1). Maybe the recent greatest surprise (but certainly not the last one) about bars is that they can die as well (Sect. 2.3). As a consequence, unbarrered galaxies can either not have yet time to develop a bar, or have hosted one in the past which is now dissolved. An interesting question automatically arises: could a bar be revived a few Gyr after it has been dissolved? Could bars even be recurrent? This is in principle possible, but it is certainly not a straightforward task (e.g. Sellwood & Moore 1999). Anyway, \(\beta\), the ratio of disk galaxies having a stellar bar to the total number of disk galaxies, is absolutely not supposed to be constant with time, and should strongly vary with redshift \(z\). In what way? So far, the answer is widely unknown and will remain so until high resolution deep fields will routinely be available.

Gas distribution inside stellar bars is diverse and complex (Kenney 1997). For instance, numerous gaseous bars are observed; they however seem to be much less common than stellar bars. This might be due to an observational bias, but gaseous bars are certainly not easy to form and/or have short lifetimes (Sect. 3). Gas morphology is clearly strongly dependent on the resolution and the considered scale: a true bar-like shape (Maffei 2) should not be confused with either ring-like plus open arms (IC 342), or “twin peaks” (NGC 3351) morphologies.
2. Stellar Bars

2.1. Birth

Stellar bars seem to be ubiquitous. At $z \approx 0$ this is indisputable since bars are found in $\sim 2/3$ of bright disk galaxies (Sellwood & Wilkinson 1993; Knapen, this volume), and in $\sim 100\%$ of Magellanic type galaxies (Odewahn 1996). At higher $z$, there seems to be very few bars as claimed by van den Bergh et al. (1996) from visual classification of galaxies in HDF-north. But observationally, it is certainly not yet possible to give accurate numbers to $\beta(z)$. First, because of the lack of resolution; for instance at $z=1$, 0.1" corresponds to 1 kpc, meaning that only the largest bars could be detected even with HST or ground-based facilities with adaptive optics. Second, because bars are best detected in near-infrared (NIR) wavelengths, but very rarely in UV; at $z=1$, observations in the visible (respectively NIR) correspond in fact to UV (visible) in the galaxy rest frame and will highly underestimate $\beta$.

Spontaneous bars are formed from unstable and nearly isolated stellar disks (Hohl 1971; Sellwood 1981; Pfenniger & Friedli 1991; Fux 1997). A convenient way to know if the disk will develop a bar is to look at the Toomre (1964) parameter $Q_*$ for the stars. The condition for the instability onset is $Q_* \lesssim 2.0 - 2.5$ at all radii (Athanassoula & Sellwood 1986). This is however true only when the density gradient towards the galactic center is not too steep; galaxies with dense centers can be stable with much lower $Q_*$ values. In this case, the disk might instead suffer from $m=1$ instabilities. Furthermore, supermassive black holes (SBH) can completely prevent the $m=2$ mode from developing when reaching a few percent of the stellar disk mass, even if $Q_* \approx 1.5$ throughout the disk (Friedli 1994).

Induced bars are triggered by close interactions (Noguchi 1988; Gerin et al. 1990; Barnes & Hernquist 1991). In this case, the instability condition is slightly less severe $Q_* \lesssim 2.5 - 3.0$. Induced bars can form in both lighter and hotter stellar disks. Typically, spontaneous stellar bars should only appear $\sim 6$ Gyr after the beginning of the disk build-up (Noguchi 1996), i.e. when $z \approx 0.5$.

According to Noguchi (1996) and Miwa & Noguchi (1998), the properties of spontaneous or induced bars strongly differ: spontaneous ones would essentially form in late-type objects, show an exponential density profile, and be fast-rotating. On the contrary, induced bars would be manufactured in early-type galaxies, present a flat density profile, and rotate slowly. However, this scenario remains to be confirmed; indeed, it is for instance in contradiction with the claim by Combes & Elmegreen (1993) that late-type bars should be slow, i.e. end near their Inner Lindblad Resonance (ILR). Also, Kent (1987) and Merrifield & Kuijken (1995) showed that the bar of the early-type galaxy NGC 936 (SB0) is rotating very quickly.

2.2. Aging

Once they are born, stellar bars are not immutable. They are the scene of numerous evolutionary processes which may affect the whole galaxy (e.g. Martinet 1995). These events occur on dynamical and cosmological time-scales, as well as on large- and small-scales. Below, four selected examples are briefly discussed.
Evolution of Bar Pattern Speed. Since the orbital structure significantly depends on the bar pattern speed $\Omega_p$, it is very important to know its precise value and how it evolves. For instance, a low $\Omega_p$ favors the onset of ILRs and the anti-bar $x_2$, $x_3$ families of periodic orbits. Various numerical simulations have clearly revealed that $\Omega_p$ is generally not constant.

In purely collisionless $N$-body simulations, $\Omega_p$ decreases with a typical time-scale $\tau_\Omega \approx 5 \, \text{Gyr}$ (Combes & Sanders 1981; Little &Carlberg 1991; Pfenniger & Friedli 1991). The decrease is fast during the first few rotations and then stabilizes at a lower level. This behavior can be explained by the presence of many escaping chaotic particles, mainly originated from the corotation radius $R_{\text{CR}}$, which carry away significant angular momentum. A decrease of $\Omega_p$ means that $R_{\text{CR}}$ move outwards. But the system is continuously re-adjusting so that the bar length $a$ also increases. Generally, the ratio $R = R_{\text{CR}}/a$ tends to grow. According to Elmegreen (1996; see also references therein), early-type bars have $R \approx 1.2$, and late-type ones $R \approx 2$. However, Aguerri et al. (1998) found a weaker dependence on morphological type (from $R \approx 1.1$ to $R \approx 1.4$); they showed as well that $R$ slightly increases with bar strength.

When a massive live dark matter halo (DMH) is present as well, the slow down can be even more pronounced due to the dynamical friction generated by the DMH on the bar (Fux et al. 1995; Debattista & Sellwood 1998). $\tau_\Omega$ is inversely proportional to the mass of the DMH and could be as small as a few hundreds of millions years. Furthermore, direct and indirect determinations of $\Omega_p$ in external galaxies show that many bars are likely fast-rotating. This has thus led Debattista & Sellwood (1998) to postulate that there should only be a weak DM contribution in the bar region.

When a dissipative component is present or if the galaxy suffers from a significant interaction, other behaviors may occur. For instance, the central bar-driven gas fueling suppresses the decrease of $\Omega_p$ which then remains nearly constant or can even be accelerated (Friedli & Benz 1993; Berentzen et al. 1998). Gas loses angular momentum in favor of the bar. But this only is a relatively modest and above all temporary effect, at long run $\Omega_p$ decreases or the bar is dissolved (see Sect. 2.3). Close and nearly co-planar interactions may lead $\Omega_p$ to fluctuate by $\sim 10\%$ (Gerin et al. 1990; Miwa & Noguchi 1998). In brief, $\Omega_p$ slightly increases when the perturber leads the bar, and vice-versa.

Dynamical Decoupling (Bars within Bars). Many disk galaxies host not only one primary large-scale bar but also another misaligned secondary (nuclear) one, which is embedded (nested) inside the primary bar (de Vaucouleurs 1974; Buta & Crocker 1993; Wozniak et al. 1995; Friedli et al. 1996; Jungwiert et al. 1997; Mulchaey et al. 1997). So far, the averaged length ratio between both bars $a_p/a_s \approx 7$, and primary bars are on average stronger than secondary ones. But these values might be biased since actual resolution only allows the largest secondary bars to be detected, and tends to underestimate their ellipticities. It is not yet clear if secondary structures are thin bars or rather triaxial bulges. The angle between the two bars $\theta = PA_p − PA_s$ does not take any particular value. This is one of the most decisive evidences of the existence of a dynamical decoupling in the center of these galaxies, i.e. primary and secondary bars should rotate at different speeds. Well-known objects include NGC 1317 (Fig. 1,
Figure 1. I-band images of two galaxy prototypes with bars within bars, NGC 1317 on the left, and NGC 1433 on the right (from Wozniak et al. 1995). The pixel size is 0.38″, and the seeing ~1.1″. The frames are 90″ wide. The contour scale is logarithmic with a spacing of 0.5 mag.

Orbits in galaxies with bars within bars have nicely been investigated by Pfenniger & Norman (1990) and Maciejewski & Sparke (1997) using non-evolving analytical potentials. However, self-consistent numerical simulations remain the only way to study properly the formation and evolution of such non-linear, non-axisymmetric, dissipative and time-dependent systems. Friedli & Martinet (1993) showed that embedded bars with \( \Omega_s/\Omega_p > 1 \) (i.e. \( \theta = \theta(t) \)) can exist and be stable over many rotations. The proper way to proceed is to form first the primary bar which then accumulates gas into the central region. This allows ILRs to be present and to shift gas forward. Then, these great quantities of leading gas naturally trigger the dynamical decoupling and the birth of the secondary bar. A large fraction of the angular momentum continuously lost by the gas is gained by the secondary bar, preventing it to realign quickly. Finally, the fact that \( CR_s \) approximately coincides with \( ILR_p \) minimizes the possible negative effects of resonances like the generation of too much chaos.

While large-scale bars appear to favor the central star formation activity on certain condition (Hawarden et al. 1986; Martinet & Friedli 1997; Ho et al. 1997), they are not directly implicated in the fueling of Active Galactic Nuclei (AGN) according to Ho et al. (1997). In an inspiring paper, Shlosman et al. (1989) suggested that bars within bars might rather play a key role in fueling

\[^{1}\text{With respect to the direction of rotation, the secondary bar can either lead (}\theta > 0\text{), or trail the primary bar (}\theta < 0\text{).}\]
AGN. In their scenario, the secondary bar was a gaseous bar, not a stellar one. While this possibility cannot be ruled out at all, the above-mentioned observations and simulations correspond rather to another mechanism, a “modified” scenario where the gas fueling is driven by the secondary stellar bar. In a single bar, the scale of the compressed (fueled) gas typically is $a_g \approx 0.1 a_p$. In the double-bar case, $a_g \approx 0.1 a_s \approx 0.1 a_p / 7 \approx 71$ pc with $a_p = 5$ kpc. Note that large amounts of gas can be stacked along the nuclear ring so that there is less, but more centrally concentrated, gas in this case. Although packing down gas that deep into the the potential well is already impressive, there is still a long way to the very center and the supermassive black hole. At some point, other stages should follow, e.g. the formation of a tertiary bar, or the Shlosman’s mechanism.

So far, a total of $\sim 40$ unambiguous double-barred galaxies have been discovered. Nearly all have Hubble types earlier than S2Bb, and $\sim 1/3$ are known to be Seyferts. Of course, this global sample is biased and does not allow to infer proper statistics. There are two nearly unbiased NIR surveys, but with only arcsec resolution. The first one by Jungwiert et al. (1997) includes 72 galaxies. The authors found $\sim 24\%$ of S2Bs and $\sim 1/4$ of Seyferts. The other survey by Mulchaey et al. (1997) contains 30 Seyferts and 25 “normal” galaxies. They identified $\sim 16\%$ of S2Bs but did not find any excess of double-bars in the sample of Seyferts with respect to the non-Seyferts one (Mulchaey & Regan 1997).

Clearly, bars within bars represent a very common phenomenon but seem neither a necessary, nor a sufficient condition to create AGN. This does not mean that such systems have nothing to do with central activity. Indeed, the fueling is probably more episodic than continuous. If all galaxies host a SBH in their center, then among S2Bs the ratio of non-Seyferts to Seyferts is a direct measure of the ratio of quiescent to active phases. The existence of Seyferts not of the S2B type means either that the secondary bar is not yet resolved, or other fueling mechanisms ($m = 1$ mode; Shlosman et al. scenario) are at play.

**Bar Thickening (Box-Peanut Formation).** Only young bars are thin ($c/a \approx 0.1$). After a few bar rotations, typically 1 Gyr, their inner parts (up to a few kpc) inflate and become much thicker ($c/a \approx 0.3$), being prone to the formation of box- or peanut-shaped bulges (Fig. 2; Combes & Sanders 1981; Combes et al. 1990; Pfenniger & Friedli 1991; Raha et al. 1991). Berentzen et al. (1998) found that the box-peanut is much less pronounced if the gas mass fraction is significant. Many external galaxies harbor such a central morphology when seen close to edge-on (Jarvis 1986; Shaw et al. 1990; Bureau & Freeman 1997), a property also shared by the Milky Way (e.g. Dwek et al. 1995). This naturally leads to establish a connection between bars and box-peanut bulges; this is amply confirmed by the signatures of gas kinematics either on direct (Kuijken & Merrifield 1995), or on retrograde orbits (Emsellem & Arsenault 1997).

In the literature, this instability received a wide variety of names: bending, box-peanut, buckling or fire-hose instability. There is still some controversy about the nature of this instability: is it a resonant bending fed by vertical diffusion of orbits (Combes et al. 1990; Pfenniger & Friedli 1991) or a collective instability similar to the fire-hose one (Raha et al. 1991; Merritt & Sellwood

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2I suggest to use simply the symbol S2B to denote these objects.
Figure 2. Projected views of some 3D self-consistent collisionless numerical simulations with 720,000 particles, and after an evolution of 2 Gyr. Top left. Purely axisymmetric model. Bottom left. Strongly barred model. Top right. Axisymmetric model with a central black hole with $M_{bh} = 0.02 M_\star$. Bottom right. Weakly barred model including a 2% black hole.

The former possibility is due to the space part (vertical resonances) of the distribution function (DF) while the latter is the result of the velocity part of the DF (critical ratio of vertical to radial velocity dispersions). Unless unrealistically thin stellar disks are built, this critical ratio cannot be reached at distances where box-peanuts are formed, i.e. in rotation-dominated regions. But in central, dispersion-dominated, areas, the fire-hose instability could occur for instance within cold young stellar disks (Griv & Chiueh 1998).

Thus, observed box-peanuts probably result from a 2/1/1 resonant bending (ratio of vertical/radial/circular frequencies). Before the bending, the orbital structure is dominated by the 2D $x_1$ (direct) and $x_4$ (retrograde) periodic orbit families. After the bending, fully 3D families appear, mainly the 2/1/1 banana and anti-banana ones (bifurcation from the $x_1$) and the 1/1/1 anomalous ones (bifurcation from the $x_4$). At least two misconceptions about box-peanuts are widespread: 1) Box-peanuts end at $R_{CR}$. This is wrong! Box-peanuts end near the vertical ILR, i.e. typically at $\sim R_{CR}/2$. 2) Box-peanuts require $z$-symmetry breaking to form. This is also wrong! While in many models, forcing the $z$-symmetry indeed slows down the box-peanut growth rate by a factor of 3–4, it is possible to find models where box-peanuts quickly appear without any macroscopic $z$-asymmetry.

While the addition of a SBH amplifies the bulge inflating (something only observed in barred models), this also highly alleviates or suppresses the box-peanut shape (Fig. 2; Friedli 1994). As a matter of fact, in the bar region broad radial and vertical resonances are unavoidable after the (dissipative) growth of a significant central mass concentration. Stars are then allowed to diffuse into
Abundance Profile Alteration. Outstanding properties of barred systems include the existence of irregular (chaotic) orbits (e.g., Contopoulos & Grosbol 1989), and gravitational torques. These characteristics lead both to large-scale ($\gtrsim$1 kpc) diffusion and mixing of stars, and produce transfer of angular momentum and matter, especially gas (e.g., Athanassoula 1992). This is not harmless for the stellar and gaseous abundance profiles, as discussed in short below (for details see Friedli 1998).

$N$-body or orbit studies have shown that chaos increases if bar strength, central mass concentration, noise, or asymmetries increases. As shown by Pfenniger & Friedli (1991), strong 3D $N$-body bars typically host hot ($\sim$35%, chaotic orbits), bar ($\sim$45%), and disk ($\sim$20%) populations. There is a significant diffusion in both $R$ and $z$ directions as soon as the Lagrangian points $L_{4,5}$ become complex unstable which occurs at some critical bar strength (Ollé & Pfenniger 1998). As a consequence, bar-generated features appear in stellar abundance profiles (Friedli 1998). When a strong bar appears, any smooth and steep initial abundance gradient $d \log A/dR < 0$ is then distorted by a plateau near $R_{CR}$ and a pronounced flattening in the disk region. Models with $d \log A/dz < 0$ quickly develop box-peanut shaped isoabundance contours, whereas models with $d \log A/dz = 0$ become X-shaped and present positive gradient in the disk region.

Bar-generated features also appear in radial gaseous abundance profiles: in the disk region a severe flattening occurs (Friedli et al. 1994) and a break is observed near $R_{CR}$ in young bars (Martinet & Friedli 1997). Indeed, in the bar region during the early phase of its existence, the gradient is maintained since the gas dilution by significant gas inflow is compensating for the heavy-element production by star formation. The oxygen abundances from HII regions in several late-type galaxies have clearly revealed that barred galaxies have weaker gradients (Vila-Costas & Edmunds 1992). Moreover, Martin & Roy (1994) showed that the stronger the bar, the shallower the gradient. Breaks in abundance pro-

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**Table 1. Summary of the bar-induced evolution of stellar and gaseous radial abundance profiles in different regions.**

| Regions | Stellar gradient | Gaseous gradient |
|---------|------------------|------------------|
| Bar     | Weak changes     | Steep $\rightarrow$ Flat |
| Corotation | Plateau         | Break $\rightarrow$ Flat |
| Disk    | Flattening       | Flattening $\rightarrow$ Flat |

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the bulge from the disk (Pfenniger & Norman 1990). The bulge-to-disk ratio increases and secular evolution along the Hubble sequence constitutes a natural outcome of this resonant heating. Of course, the inescapable formation of bar-driven bulges does not preclude other processes to contribute as well. Some mass fraction of the bulges could be primordial, and result from other secular evolution mechanisms like minor mergers or Zhang’s theory (Zhang 1999).
files have been observed in NGC 3359 (Martin & Roy 1995), and NGC 1365 (Roy & Walsh 1997) suggesting that these bars are of the order of 1 Gyr old.

Table 1 summarizes the bar-induced evolution of stellar and gaseous radial abundance profiles in different regions.

2.3. Death

Most bars are probably not perpetual. They might be dissolved by internal or external processes, but the basic reason is the same: significant central mass concentration is always fatal. It generates ILRs which strongly modifies the orbital structure. The bar-supporting $x_1$ orbits are depopulated in favor of chaotic and anti-bar $x_2$ orbits; the bar cannot survive (Pfenniger & Norman 1990; Hasan & Norman 1990). Possible mechanisms of central mass accumulation include bar-driven gas accretion, one could speak of a suicide (Friedli & Benz 1993; Norman et al. 1996; Berentzen et al. 1998), growth of SBHs (Friedli 1994), accretion of satellites (Pfenniger 1991), or the extreme case of mergings (Barnes & Hernquist 1991). Massive nuclear rings also act to weaken or dissolve the bar, mainly exterior to the ring (Heller & Shlosman 1996).

The critical threshold to annihilate the bar can be defined as $\gamma_{\text{anni}} \equiv M_{\text{center}}/M_{\text{total}}$. The bar annihilation time-scale corresponds to the time necessary to reach $\gamma_{\text{anni}}$. It depends on the accretion rate, and probably spans a wide interval, something like 0.2–20 Gyr. In fact, $\gamma_{\text{anni}}$ depends on both mass and concentration. This has not always been underlined properly leading to widely different numbers in the literature, $\gamma_{\text{anni}} \approx 1 - 10\%$. A more accurate but still rough assessment is:

$$\gamma_{\text{anni}} \approx 0.1R + 0.02 \quad 0 < R [\text{kpc}] \leq 1,$$

where $R$ is the radius considered. SBHs are especially efficient bar annihilators with $\gamma_{\text{anni}} \approx 0.02$ (Friedli 1994). A similar value is found for the deletion of triaxiality in ellipticals (Merritt & Quinlan 1998). Note that the strongest bars are the most sensitive to the addition of compact mass in their cores; they quickly become round in the central region, long before $\gamma_{\text{anni}}$ is effectively reached.

Demographic studies of SBHs find a correlation between the mass of the black hole and the one of the bulge (or hot) component (Kormendy & Richstone 1995; Magorrian et al. 1998), $M_{\text{bh}} \approx 0.005 M_{\text{bulge}}$. The scatter is large, with late-type objects having lighter SBHs than early-type ones. The upper limit seems roughly $M_{\text{bh}} \lesssim 0.025 M_{\text{bulge}}$, surprisingly similar to $\gamma_{\text{anni}}$. This might indicate that bars play a role in the SBH growth which is then turned off as soon as the bar has disappeared.

In Sect. 2.2, we have seen that a bar plus a SBH are able to generate a significant bulge. Dissolved bars are thus to be searched for in unbarred early-type galaxies, i.e. S0/Sa’s. The most massive SBHs should be concealed in those objects as well. The proof of the existence of dissolved bars in early-type galaxies seem to have been established by Dutil & Roy (1999) through an abundance study. Indeed, they found that the extrapolated central O/H abundances of early-types (both barred and unbarred) are very similar, whereas that of barred late-types is systematically $\sim$0.5 dex lower than the unbarred ones.
3. Gaseous Bars

A bar-like morphology for the gas is present within some stellar bars (e.g. NGC 7479, Laine et al. 1999). Numerical simulations have shown that young and strong stellar bars without ILRs can host large-scale gaseous and “Hα” bars (Martin & Friedli 1997). Such induced gaseous bars generally lead the stellar bar by a few degrees, $a_g < a$, and $(b/a)_g < (b/a)_s$. Typically, the total gas mass $M_g \lesssim 10^9 M_\odot$, and the (nearly constant) maximum gas surface density $\Sigma_g^{\text{max}} \approx 2.5 \cdot 10^3 M_\odot \text{pc}^{-2}$. With time, both $a_g$ and $M_g$ first decrease very quickly, and then reach an asymptotic value. The evolution of $M_g$ and $\Sigma_g^{\text{max}}$ are essentially controlled by the self-regulated star formation processes, not by dynamics. This might explain why generally $M_g \lesssim 0.3 M_{\text{dyn}}$, where $M_{\text{dyn}}$ is the dynamical mass. The gaseous bar lifetime is of the order of 1 Gyr. For bars within bars systems, a gaseous bar might be present inside the secondary bar as well, but with length, mass, and lifetime scale down by a significant factor.

The galaxy NGC 6946 somewhat represents an issue for this process of stellar bar-driven gaseous bar: it has a gaseous bar, but no (or very weak) stellar bar (Regan & Vogel 1995). Hence, one could imagine that spontaneous gaseous bar instability might occur in some galaxies where significant gas self-gravitation ($M_g \gtrsim 0.3 M_{\text{dyn}}$) is present. Such a critical mass could be reached in primordial galactic discs, mergers, and of course stellar bars. However, spontaneous gaseous bars are very unstable (fragmentation), and gas self-gravity decreases quickly due to furious star formation. A very short lifetime results. Another appealing possibility for NGC 6946 is that the gaseous bar had actually been formed by a strong stellar bar which is now nearly dissolved.

Gaseous bars can also be found in relatively unexpected places, e.g. at the center the giant elliptical Centaurus A (Mirabel et al. 1999). This galaxy harbors an AGN and relativistic jets powering two spectacular large lobes separated by $\sim 350$ kpc. If this $\sim 5$ kpc long bi-symmetric structure (gaseous bar plus spiral arms) serves to fuel the AGN, its lifetime should have been long enough to produce the radio lobes ($\gtrsim 10$ Myr). In the Sb galaxy Circinus, Maiolino et al. (1999) have also found a $\sim 100$ pc nuclear gas bar possibly feeding an AGN. Both gaseous bars seem not to have distinct stellar counterparts.

Table 2. Summary of the main differences between young and old bars.

| Properties                      | Young stellar bars (less than 1–2 Gyr) | Old stellar bars (more than 1–2 Gyr) |
|---------------------------------|---------------------------------------|---------------------------------------|
| Thickness                       | Thin                                  | Thick (box-peanuts)                   |
| Pattern speed                   | High                                  | Low                                   |
| Central decoupling              | Unlikely                              | Likely (S2Bs)                         |
| Radial abundance profile (gas)  | Break near $R_{\text{CR}}$             | Flat                                  |
| Star formation $^a$             | Intense                               | Moderate                              |
|                                 | Along bar $\rightarrow$ Center        | Circumnuclear ring                    |

$^a$ Not discussed here; see Martin & Friedli (1997)
4. Summary and Conclusion

(Galaxies with) bars evolve morphologically, dynamically, chemically, at small- and large-scales, over short and long timescales. Some of their properties change and it is then possible to distinguish young bars from old ones as summarized in Table 2. The bar-induced galaxy evolution along the Hubble sequence definitely tends to transform late-type objects into early-type ones. Clearly, like living beings, bars are born, age, and die! But many fascinating riddles still subsist:

– Could some stellar bars be “eternal”, i.e. be robust over many Hubble times?
– Could stellar bars “revive”, i.e. be recurrent?
– At what $z$ does the first bar appear?
– At what $z$ does $\beta$ reach its maximum?

Although the life cycle of bars is not yet fully understood, it should certainly bear some resemblance with the one depicted in Fig. 3 . . .

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