# The impact of bars on disk breaks as probed by $S^4G$

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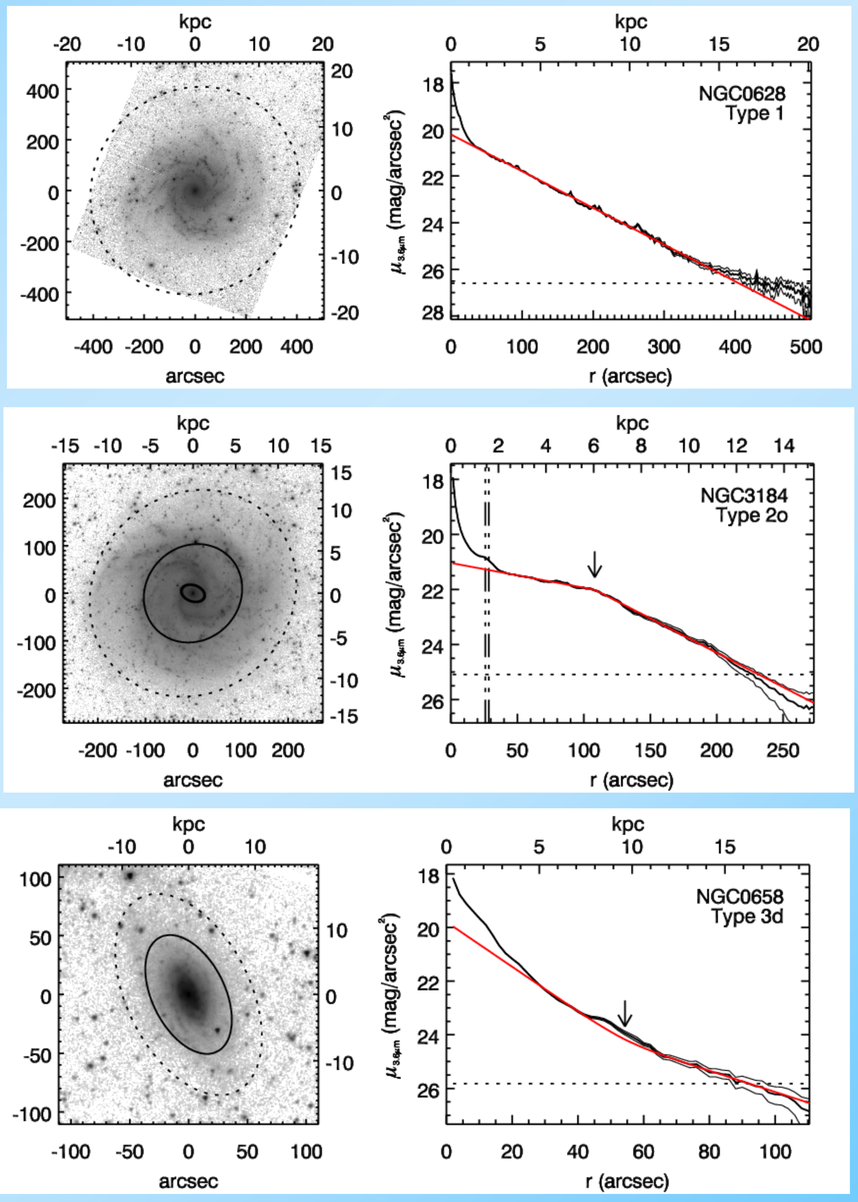
## Three types of disks

The traditional textbook description of spiral galaxies depicts them as composed of a bulge and an exponential disk. However, we now know that only 10% of nearby disks exhibit a single exponential profile [1,2]. Most disks, around 60%, present a broken or down-bending profile, with an inner exponential disk followed by a steeper outer one. The remaining 30% have an up-bending profile, where the outer exponential is flatter than the inner one. Multi-sloped profiles are also found up to z~1 [3,4,5].

The ubiquity of these features implies that they are key probes of disk assembly and evolution. Are breaks due to star formation thresholds? Do resonances with bars and spiral arms play a role? In brief, **is the present-day distribution of old stars in disks determined by in-situ star formation or by radial stellar migration?** To answer these questions, here we use deep Spitzer images to study, for the first time, the properties of breaks in the infrared, thus mapping the old stellar backbone of galaxies.



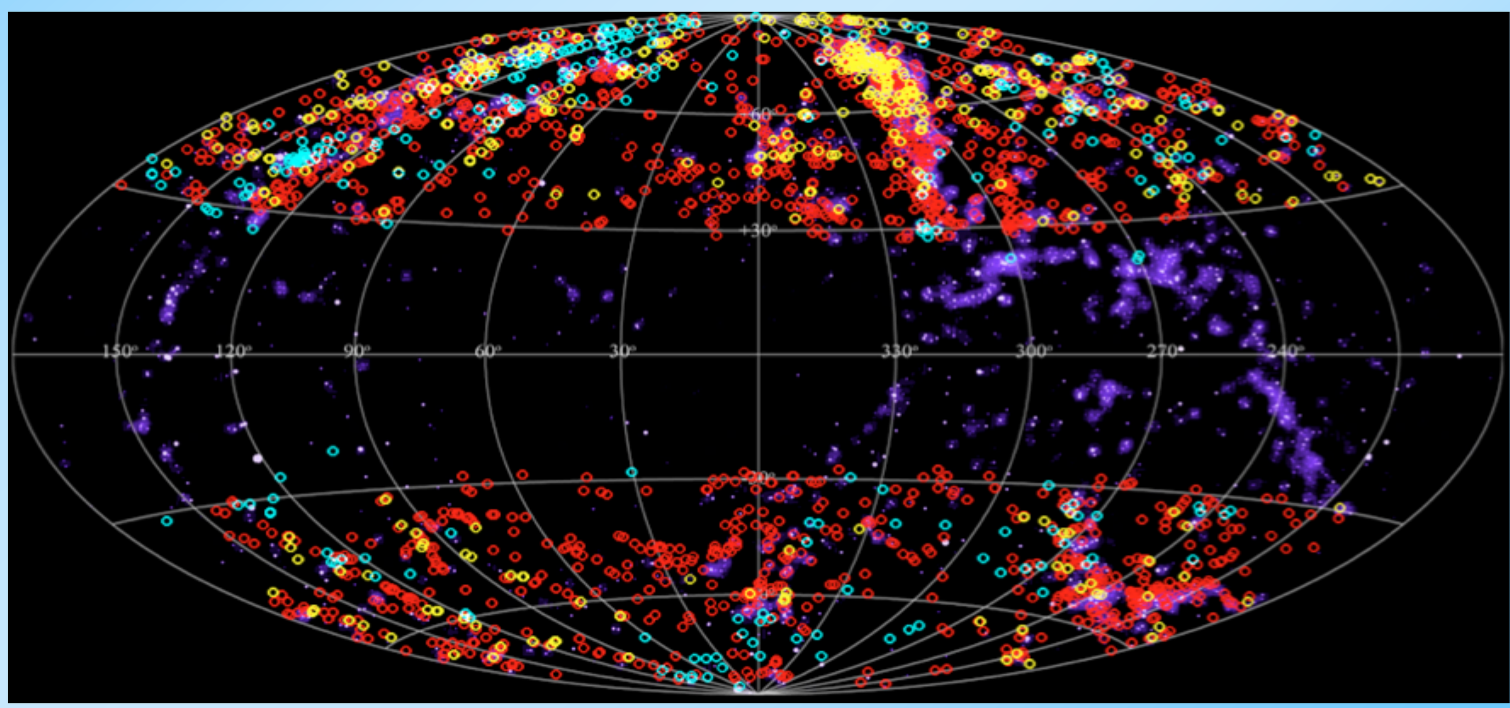

*Images and radial profiles at 3.6 μm of three galaxies with a single exponential profile (top), a down-bending one (middle) and an up-bending one (bottom). The break is marked with an arrow and a solid ellipse.*

## The Spitzer Survey of Stellar Structure in Galaxies ($S^4G$)

$S^4G$ is an Exploration Science Legacy Program carried out during Spitzer's warm mission [6]. It comprises very deep 3.6 and 4.5μm images of more than 2300 nearby galaxies of all Hubble types. These bands trace old stellar populations and are insensitive to internal dust extinction. **Therefore, $S^4G$ provides an unprecedented inventory of the stellar structure in nearby galaxies.**

***Survey details:***

- Observing time: 637.2 hours
- 4 min/pixel
- $\mu \sim 27$ AB mag/arcsec$^2$ at 3.6μm ($\sim 1\ M_\odot\ pc^{-2}$)
- D < 40 Mpc
- $|b| > 30°$
- $m_{Bcorr} < 15.5$
- $D_{25} > 1$ arcmin



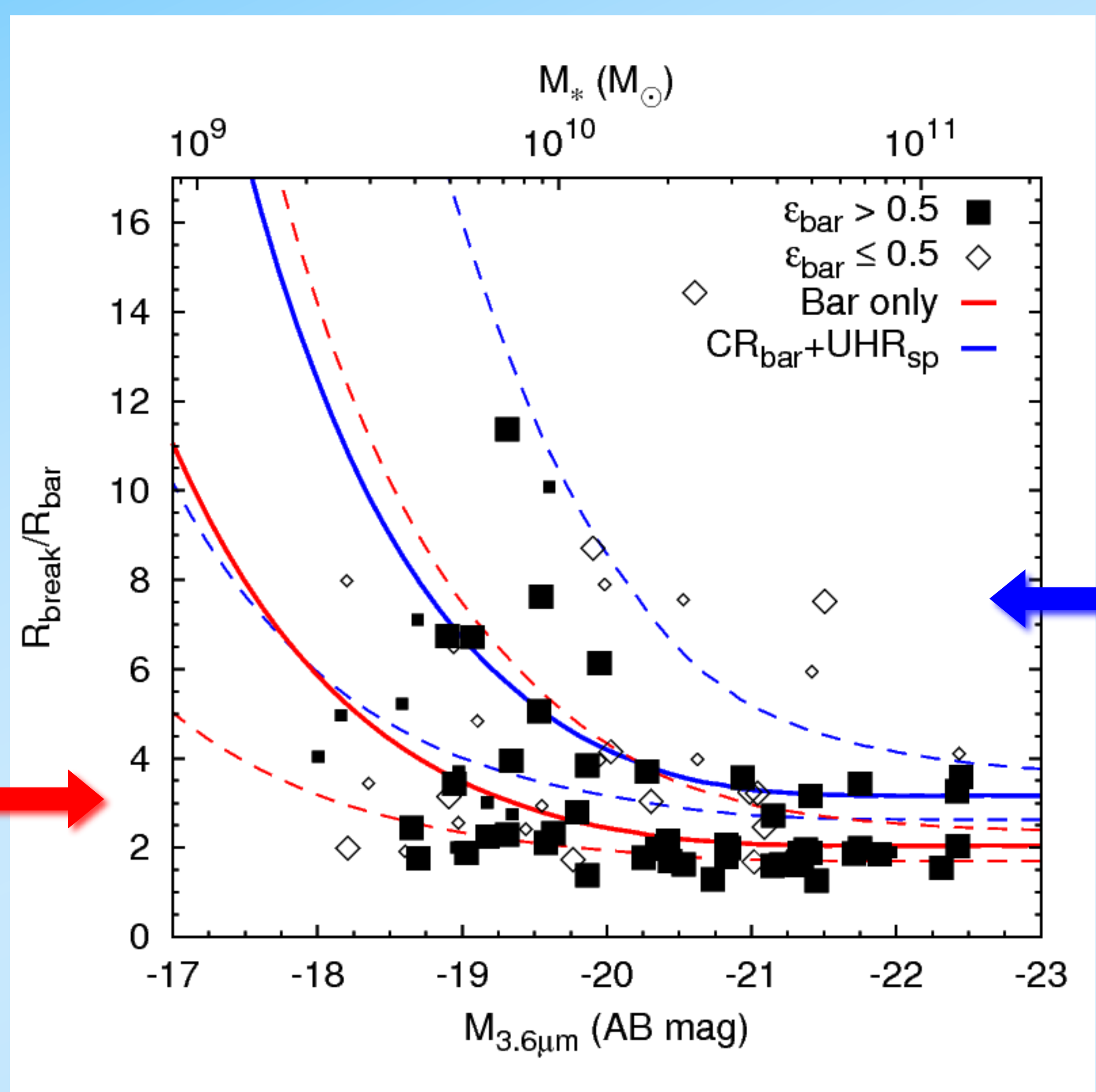
*Cyan: LVL galaxies. Yellow: other GO/GTO archival galaxies. Red: new galaxies observed as part of $S^4G$. Purple: local large scale structure from the 2MASS XSC [7], showing that $S^4G$ covers a wide variety of environments.*

## The link between breaks and bars

The plot to the right shows the break radius, relative to the bar radius, for a subsample of barred face-on $S^4G$ galaxies. Low-mass disks have breaks lying between 2 and 10 times $R_{bar}$, but the range of $R_{break}/R_{bar}$ values becomes considerably narrower in more massive disks.

**Most disks present a break at $2\times R_{bar}$.** Assuming that rotation curves are flat, this is the expected locus of the Outer Lindblad Resonance (OLR) of the bar [2]. This means that this kind of breaks results most likely from a secular rearrangement of stars, through a dynamical interaction with the bar.

It has been often argued that breaks found much further out must be unrelated to bars, being perhaps due to star formation thresholds. However, the OLR is at $2\times R_{bar}$ only when the rotation curve is flat. But the rotational velocity in low-mass disks rises gently with radius, thus pushing the OLR outwards [8]. The red curves result from a model that incorporates realistic rotation curves as a function of the galaxy's stellar mass. **This model can account for the observed distribution of $R_{break}/R_{bar}$ relying on dynamical considerations alone, without appealing to star formation thresholds.**




*Ratio between the break and bar radii as a function of the total stellar mass of our galaxies. Solid squares correspond to elongated bars, and open diamonds mark rounder ones. Small symbols mark galaxies in which the presence of a bar is unclear.*

There is another well-defined family of disks having breaks at $3.5\times R_{bar}$, and this had been overlooked in previous studies of disk breaks.

**We propose that these breaks may happen when certain resonances of the bar and the spiral arms overlap;** that is, when stars at certain radii are simultaneously in resonance with both the bar and the spiral pattern [9]. In particular, the blue curves mark the expected break-to-bar ratio when the corotation radius of the bar overlaps with the inner 4:1 resonance of the spiral arms (also called the Ultra Harmonic Resonance).

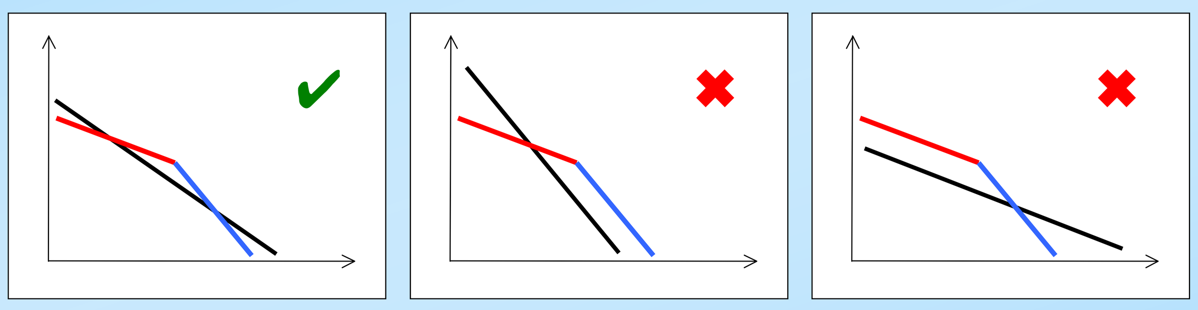
Such a coupling has been found in numerical simulations [10], and analysis of the pattern speed in some real galaxies are also suggestive of coupling [11]. Moreover, it has been shown that **when the bar and the spiral arms are dynamically coupled in this way, radial stellar migration is much more efficient**, taking only a few Gyr to achieve a complete mixing of stars within the disk [12].

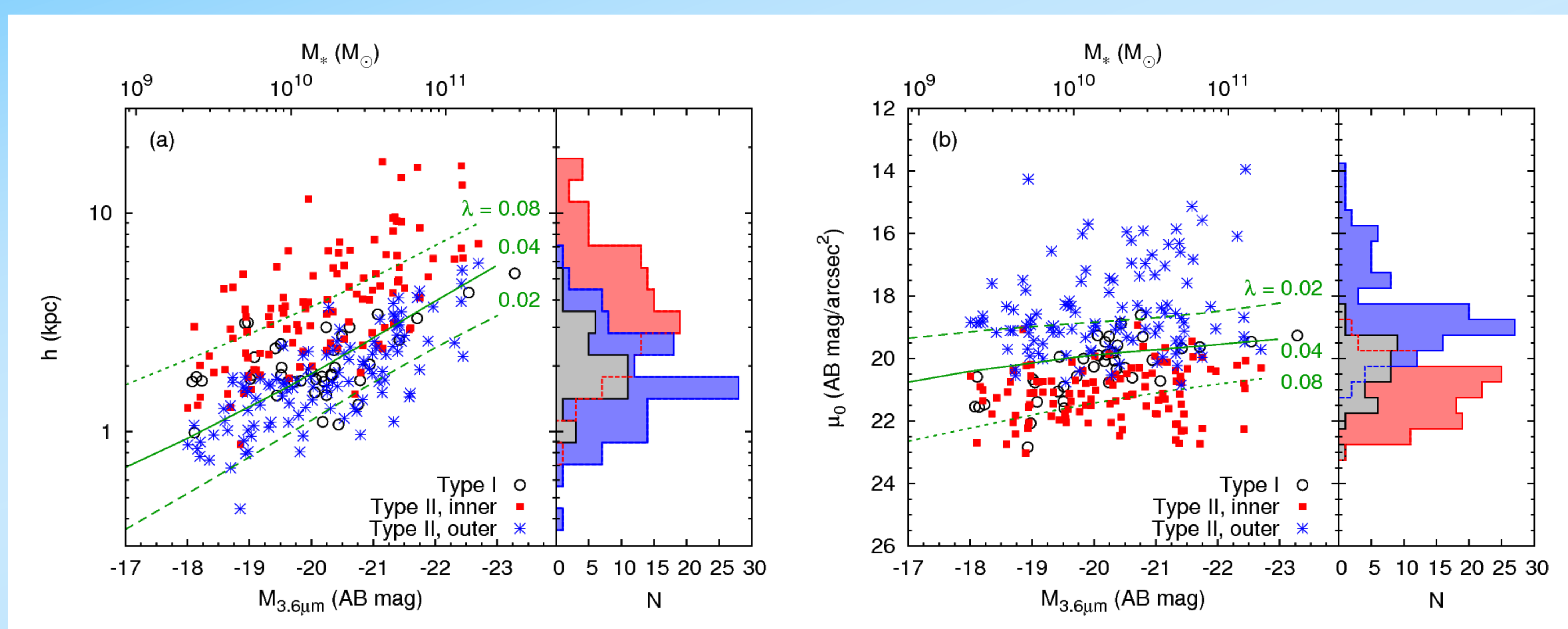
Therefore, identifying the relative position of breaks and bars is a powerful way to study the processes governing the secular evolution of disks.

## The scaling laws of broken disks

Scaling laws are empirical trends between different global properties of galaxies (mass, luminosity, circular velocity, size…), that any successful model of galaxy formation must be able to reproduce.

The plots to the right show that, **on average and for the same total stellar mass, the inner disk of a down-bending profile is flatter than the slope of a disk with a genuine single exponential profile, and the outer disk is steeper.** In theory, there is an infinite number of down-bending profiles with the same total stellar mass as a single exponential one, so the fact that Nature has chosen a particular shape for broken profiles strongly constrains models of break formation.






*Radial scale-length (left) and extrapolated central surface brightness (right) as a function of the total stellar mass. Galaxies with single exponential profiles are marked with an open circle. Those with down-bending profiles are shown with two points: a red square (inner disk) and a blue star (outer disk). Barred and unbarred galaxies are plotted together. The green curves show the predictions of ΛCDM models [13], for different values of the spin parameter λ.*

## References

[1] Pohlen & Trujillo (2006)
[2] Erwin et al. (2008)
[3] Pérez (2004)
[4] Trujillo & Pohlen (2005)
[5] Azzollini et al. (2008)
[6] Sheth et al. (2010)
[7] Jarrett (2004)
[8] Athanassoula et al. (1982)
[9] Tagger et al. (1987)
[10] Debattista et al. (2006)
[11] Meidt et al. (2009)
[12] Minchev et al. (2010)
[13] Boissier & Prantzos (2000)