A Local Reference for Bar Studies in the Distant Universe
Bar Properties as a function of wavelength

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Why do we care about bars?

*Disks like forming bars!*
- A galaxy disk will naturally form a bar in a couple of Gyrs unless it is dynamically hot or is dominated by dark matter (Athanassoula+)
- The presence of a bar allows us to gauge disk “maturity”

*Bars transform their hosts!*
- The gas transport triggered by a bar can affect significantly its host
  - wash out metallicity gradient across galaxy (Martin & Roy 2004; but Sánchez-Blázquez+11 (e.g., Sheth+05)
  - central accumulation of molecular gas
  - triggering nuclear starbursts
  - leading to the formation of pseudobulges (e.g., Kormendy & Kennicutt 04)
  - perhaps even feeding an AGN
Morphological classification of local galaxies – it all started in the optical...

- Morphological classification of galaxies in the optical
  - ~2/3 of spirals are barred (de Vaucouleurs+63)
Morphological classification of local galaxies – look in the infrared!

• Morphological classification of galaxies in the optical
  → ~2/3 of spirals are barred (de Vaucouleurs+63)
• Case studies in the IR showed bars unseen in the optical
  – IR traces old, low-mass stars
  – Bars are dominated by old stars

→ Are all galaxies barred and we just need to look in the IR?

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The quest for the bar fraction

• The *Two-Micron All-Sky Survey* (2MASS; Skrutskie+05)
  – Large Galaxy Atlas (LGA; Jarrett+03)
    • > 500 large (~2’ to 2°) galaxies
    • J, H, Ks
  – The bar fraction stays constant across wavelengths from optical to near-IR
    (e.g., Menéndez-Delmestre+07)

  – Why is this interesting?
    • We can trace the evolution of the bar fraction with redshift (→ disk maturity!), safe from band-shifting effects!
Redshift Evolution of the Bar Fraction

![Graph showing the bar fraction evolution with redshift](image)

[Based on HST restframe optical]

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Redshift Karín Menéndez-Delmestre
Redshift Evolution of the Bar Fraction:
Decreases beyond $z \sim 0.4$

@ $z=0$: 65%

@ $z=0.8$: 15%

[based on HST restframe optical]
The quest for bar characterization – do bars change over cosmic time?

- Band-shifting from near-IR to optical does not hamper (significantly) the ability to **recognize** bars

→ So we can trace the evolution of the bar fraction based on the huge amount of high-resolution optical imaging available (HST)

**How about our ability to trace bar properties?**

- Several studies have looked at bar properties locally (e.g., Erwin+05+13, Laurikainen+07, Gadotti+08, Hoyle+11)

<table>
<thead>
<tr>
<th>2MASS median bar:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• $a_{\text{bar}} = 4.2\text{kpc}$</td>
</tr>
<tr>
<td>• $\epsilon_{\text{bar}} = 0.5$</td>
</tr>
</tbody>
</table>

Menéndez-Delmestre+07

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The quest for bar characterization – do bars change over cosmic time?

• Band-shifting from near-IR to optical does not hamper (significantly) the ability to recognize bars

→ So we can trace the evolution of the bar fraction based on the huge amount of high-resolution optical imaging available (HST)

How about our ability to trace bar properties?

• Several studies have looked at bar properties locally (e.g., Erwin+05+13, Menéndez-Delmestre+07, Laurikainen+07, Gadotti+08, Hoyle+11)

• Although some studies on bar properties have ventured to higher redshifts (Barazza et al. 2009), band-shifting effects on the bar morphology have not been explored. (Q_b: Speltincx+08)
Bar Morphology at high z: need a local reference on how bar properties change with wavelength.

We look at bar properties as a function of waveband in a sample of 16 local barred spirals with deep multi-band imaging from UV–opt–IR, based on GALEX, SINGS and S^4G imaging.

NGC1097

Spitzer Survey of Stellar Structures in Galaxies (PI Kartik Sheth)
Legacy Survey of the Warm Spitzer Mission
IRAC 3.6/4.5um of >2300 local galaxies

http://s4g.caltech.edu

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Bar Morphology at high z: need a local reference on how bar properties change with wavelength

mid-IR: optimal window for stellar structure → provides a “canonical measure” of bar properties

UV: explore band-shift out to z>0.8

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Measuring bar properties – our approach

- widely-used ellipse-fit technique

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KMD+15
Bars properties: from optical through IR

- Based on SINGS ancillary B, R and S^4G 3.6μm IRAC/Spitzer images
- Angular resolution ~1-2"

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Bars properties: from UV through IR

- Including GALEX NUV [2267 Å] and FUV [1516 Å]
  - To address high-z (z>0.8) studies based on optical imaging
  - Angular resolution ~6"

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1st result: we lose bars in the $\text{UV}_{\text{rest}}$

- We lose $\sim$50% of all bars in the NUV/FUV bands

- Band shifting is an issue when going shortwards of the Balmer break (Sheth+08)

→ Studies of bars at high redshift – beware!

→ HST optical data beyond $z \sim 0.8$ traces emission bluewards of the Balmer break

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2nd result: bars look thinner in bluer bands

- $\varepsilon_{\text{max}}$ is higher in the optical bands, compared to the mid-IR

$\varepsilon_{\text{band1}}/\varepsilon_{\text{band2}} > 1$

→ Bar measured to be more elliptical in the bluer band
2nd result: bars look thinner in bluer bands

- $\varepsilon_{\text{max}}$ is higher in the optical bands, compared to the mid-IR
- This result extends to the UV

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2nd result: bars look thinner in bluer bands

- Driven by bulge sizes:
  - Bulge looks bigger in redder bands → smaller in the blue
    - Limits the size of the bar semi-minor axis
    → Bar looks thinner

Speltincx+08:
- Similar increase of ~25% in bar strength from H to B
  - OSUBSG survey
- $Q_b$: gravitational bar torque method
  - the maximum tangential force normalized by the radial force

The bluer the restframe band, the thinner the bar!

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3rd result: bars look longer in bluer bands

- SMA where $\varepsilon = \varepsilon_{\text{max}}$ is larger in the optical bands, compared to the mid-IR

$$\frac{a_{\text{band1}}}{a_{\text{band2}}} > 1$$

→ Bar measured to be longer in the bluer band
3\textsuperscript{rd} result: bars look longer in bluer bands

This result also extends to UV

The bluer the restframe band, the longer the bar!

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3rd result: bars look longer in bluer bands

Star-forming knots at the end of bars become more prominent and drive maximum ellipticity out to larger radii.

The bluer the restframe band, the longer the bar!

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3rd result: bars look longer in bluer bands

How significant? Comparable to reported differences with respect to:
- environment (e.g., Barazza+09)
- AGN content (e.g., Laurikainen+02)
- Hubble type (e.g., Menéndez-Delmestre+07)

\[ \Delta l_{\text{bar, band-shifting}} \approx 20-30\% \text{ longer} \]

\[ <\text{B} \rightarrow 3.6\mu m>: 13\% \]
\[ <\text{NUV} \rightarrow \text{B}>: 9\% \]
Take away points…

• As we extend bar studies out to high redshifts, our single-band studies are inevitably subject to band-shifting effects:
  
  – We lose 50% of bars in the UV → need to stick to the red side of the Balmer break in order to reliably detect bars
  – Bars change in shape as we go bluer; even in the restframe opt:
    • *Bars look thinner*, due to apparent bulge size
    • *Bars look longer*, as star-forming knots become prominent
  – Need to consider this when comparing bar morphologies as a function of galaxy properties!
  – These band-shifting effects may affect the “ease” to detect bars

• Refraining from going bluer than B-band may be good enough to study bar fraction out to z~0.8… but not bar properties!
  – Need to correct for band-shifting effects even in the optical!