Bar morphology as a function of wavelength: a local baseline for high-redshift studies

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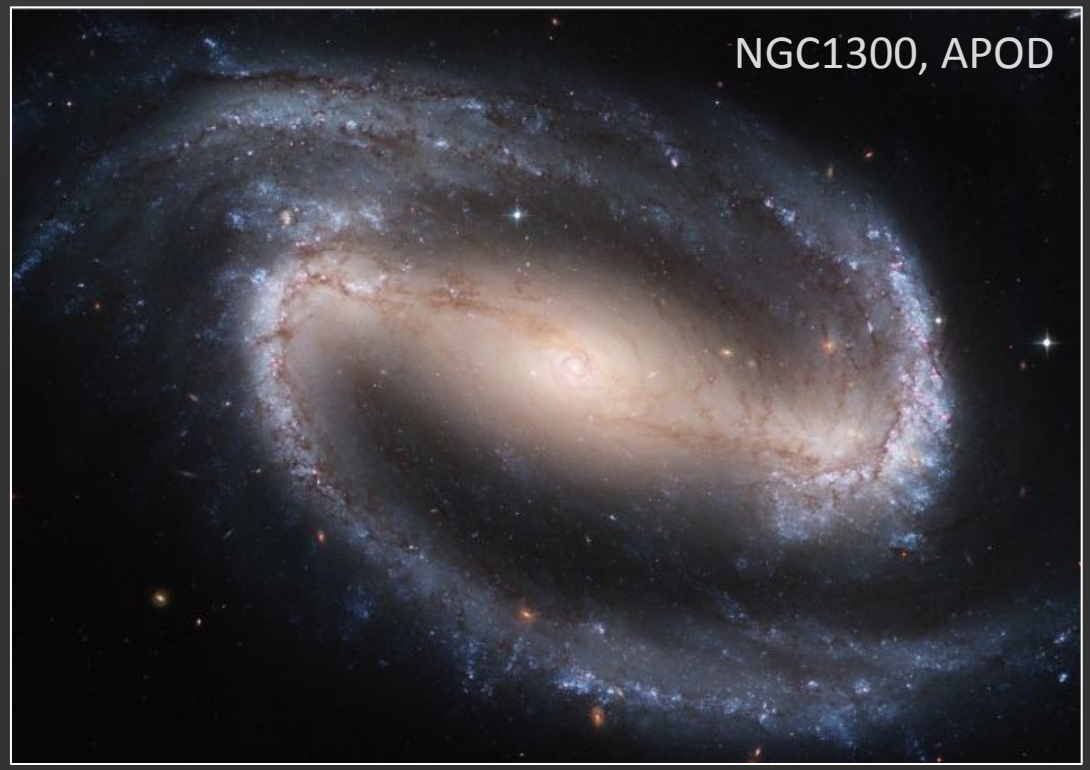
Spitzer Survey of Stellar Structure in Galaxies

Bars, bars, bars

- Bars are everywhere!
- A galaxy disk will naturally form a bar in a couple of Gyrs unless it is dynamically hot or is dominated by dark matter.

→ *Bars are very important cosmological signposts for inferring disk assembly*

→ *gauge disk "maturity"*



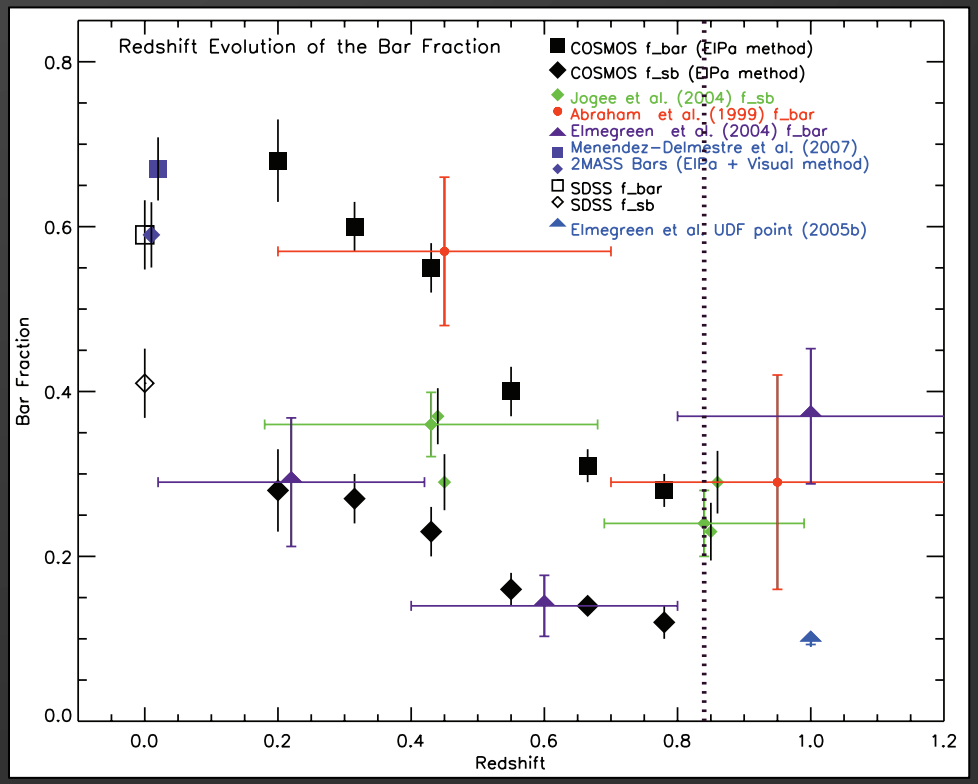
Local Bars

- What we know about bars in the local universe:
  - 2/3 of all local spirals have a bar
  - The bar fraction stays pretty constant across wavelengths from optical to near-IR (e.g., Menéndez-Delmestre+07)
    - Why is this interesting?…
      - Bars are dominated by old stellar pop
      - Worry that we may lose track of them due to band-shifting! (e.g., Sheth+03)

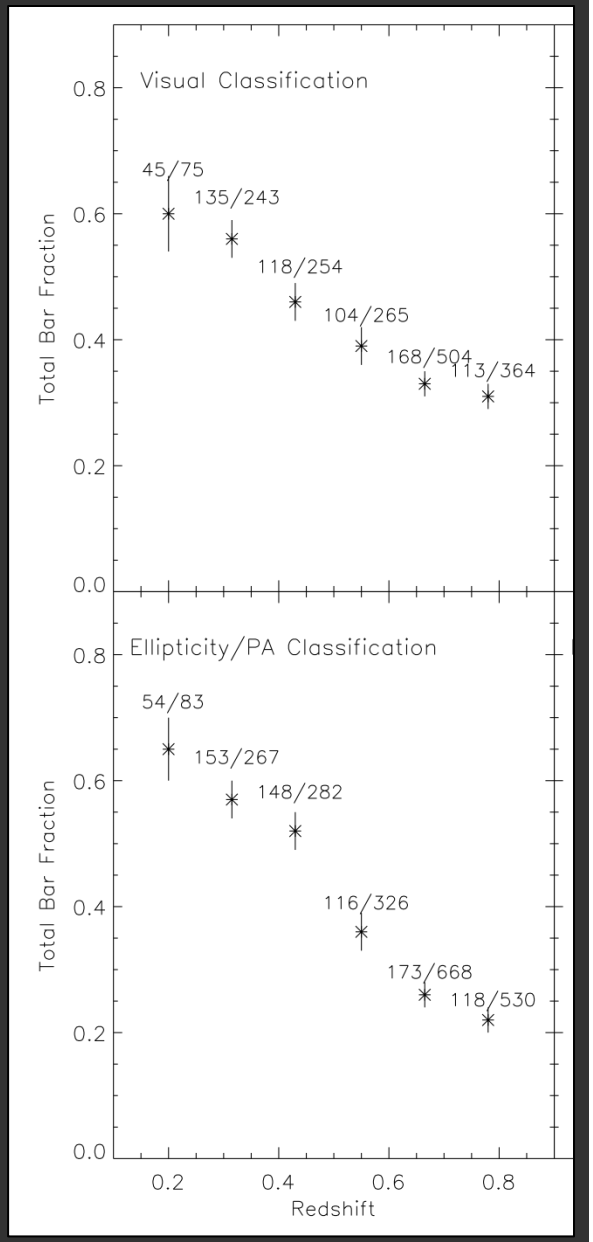
  →So, band-shifting from near-IR to optical does not hamper (significantly) the ability to recognize bars, which becomes important in high-z studies

Bar studies at high-redshift

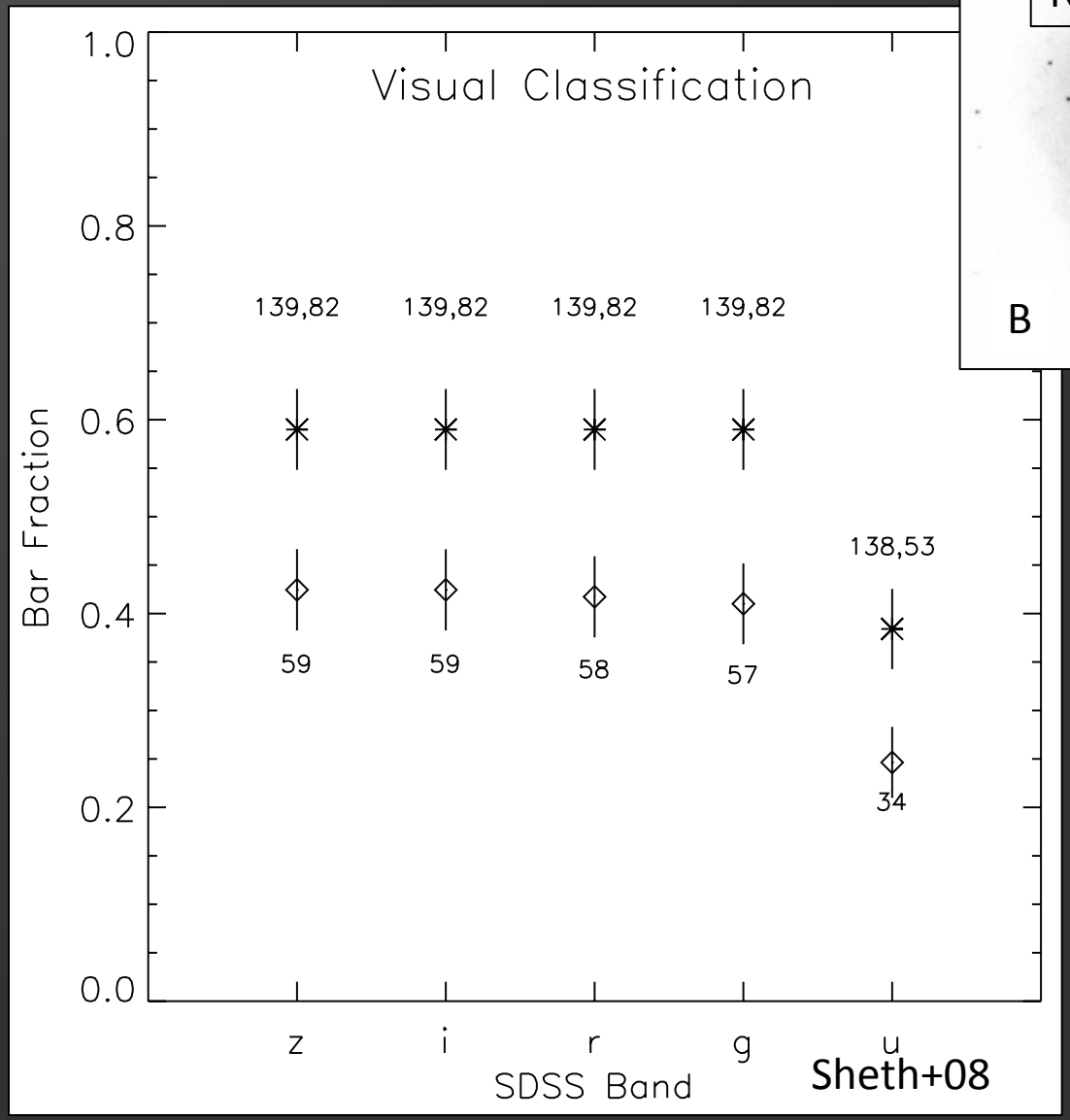
- Bar fraction declines at high redshift

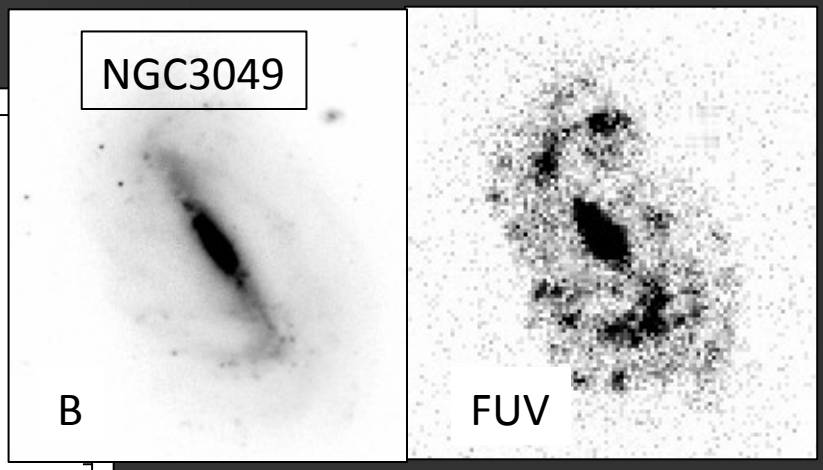


Sheth+08



Band-shifting matters! We lose bars in the UV





KMD+14

- Bars are dominated by old stellar popuplation
- Band shifting is an issue when going to shortwards of the Balmer break

Bar Morphology

- Several studies have looked at the distribution in 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 have not been explored.
  - Bar *length*:
    - the galactic radius out to which the bar potential may dominate gas and stellar motions
  - Bar *strength*:
    - measure of the non-axisymmetric influence of the bar's gravity on the otherwise axisymmetric gravitational potential of the galactic disk
    - Many ways of quantifiying this → we pick the simplest one that can be easily implemented at high-z
- QUESTION: evolution of bar properties with redshift?

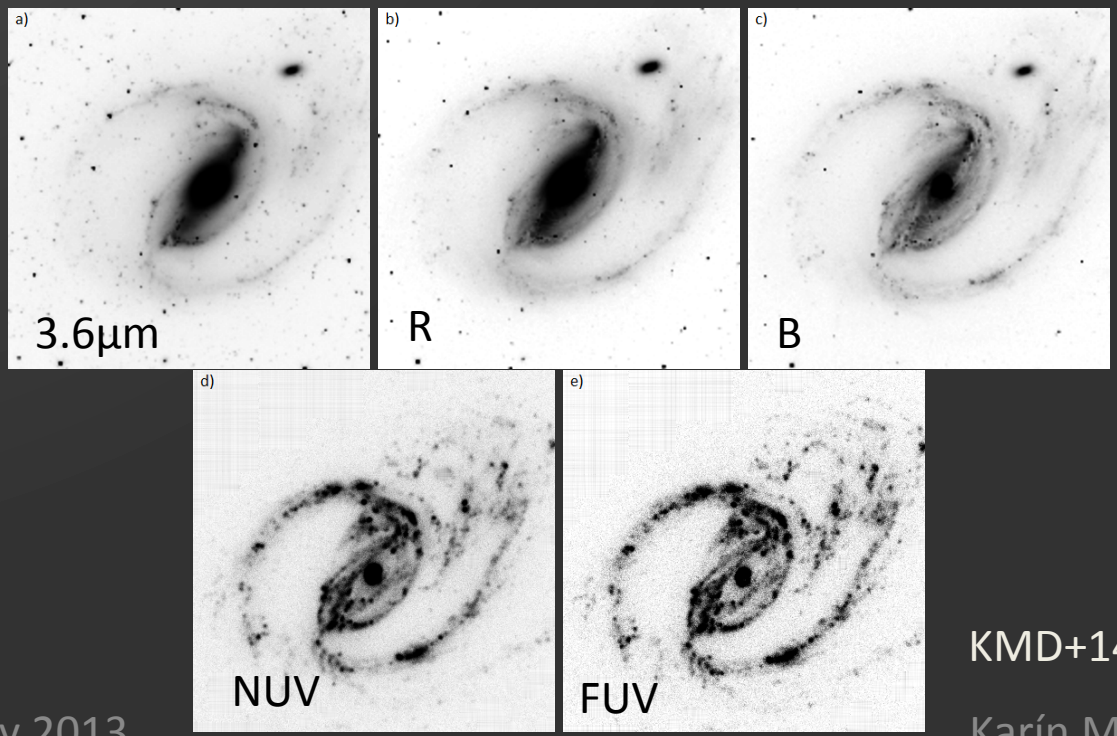
Bar Morphology

need a local reference to extend studies to high redshift

- Need to know how the bar properties change with waveband!

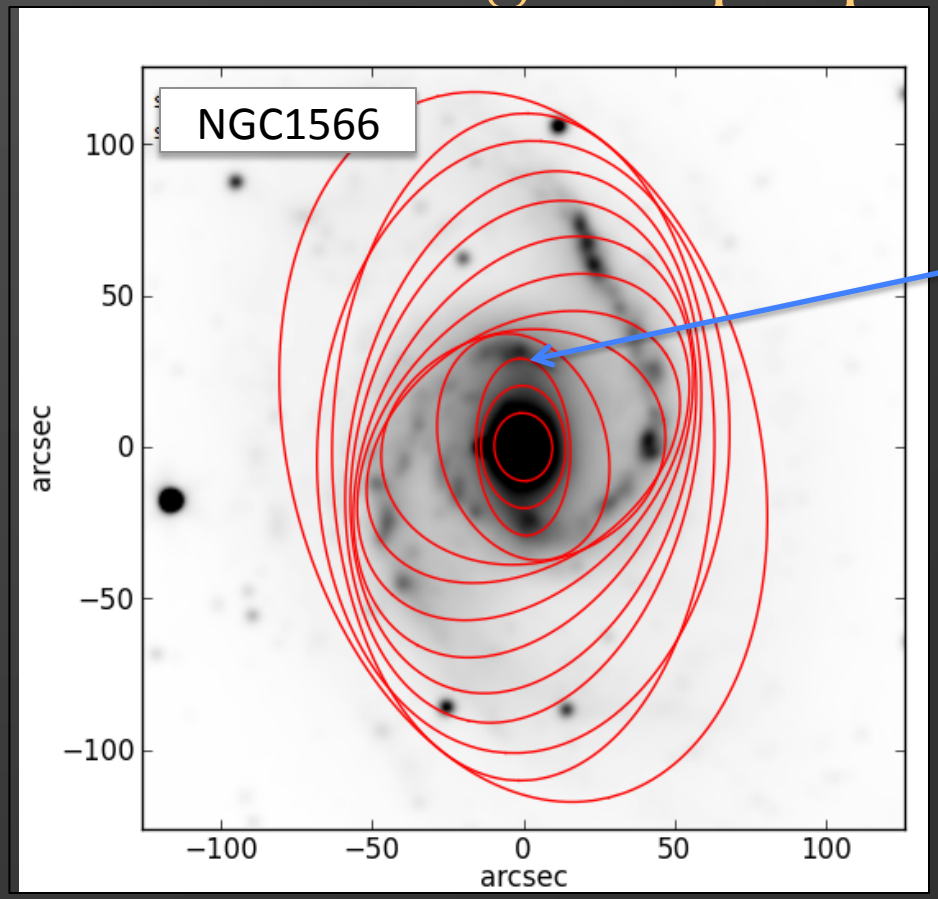
We look at bar properties as a function of waveband in a sample of 16 local barred spirals with deep multi-band imaging from UV – opt – IR, based on GALEX, SINGS and S^{4}G imaging.

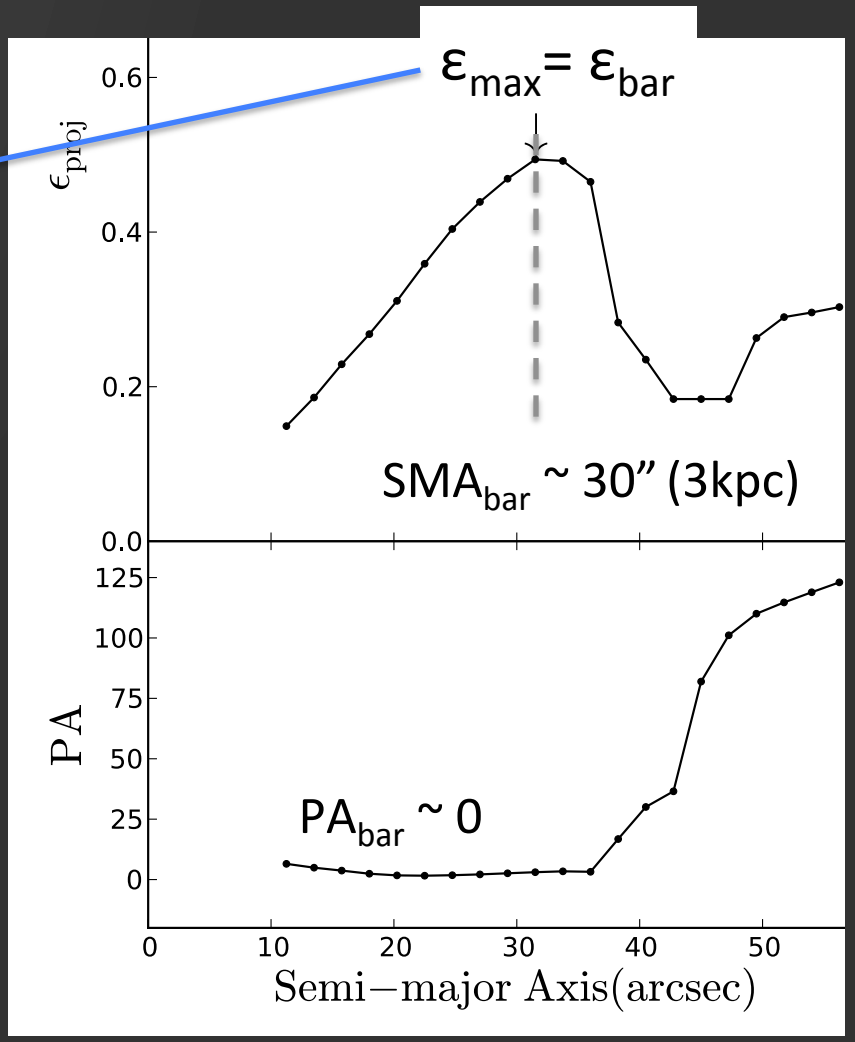
NGC1097



KMD+14

Measuring bar properties – our approach

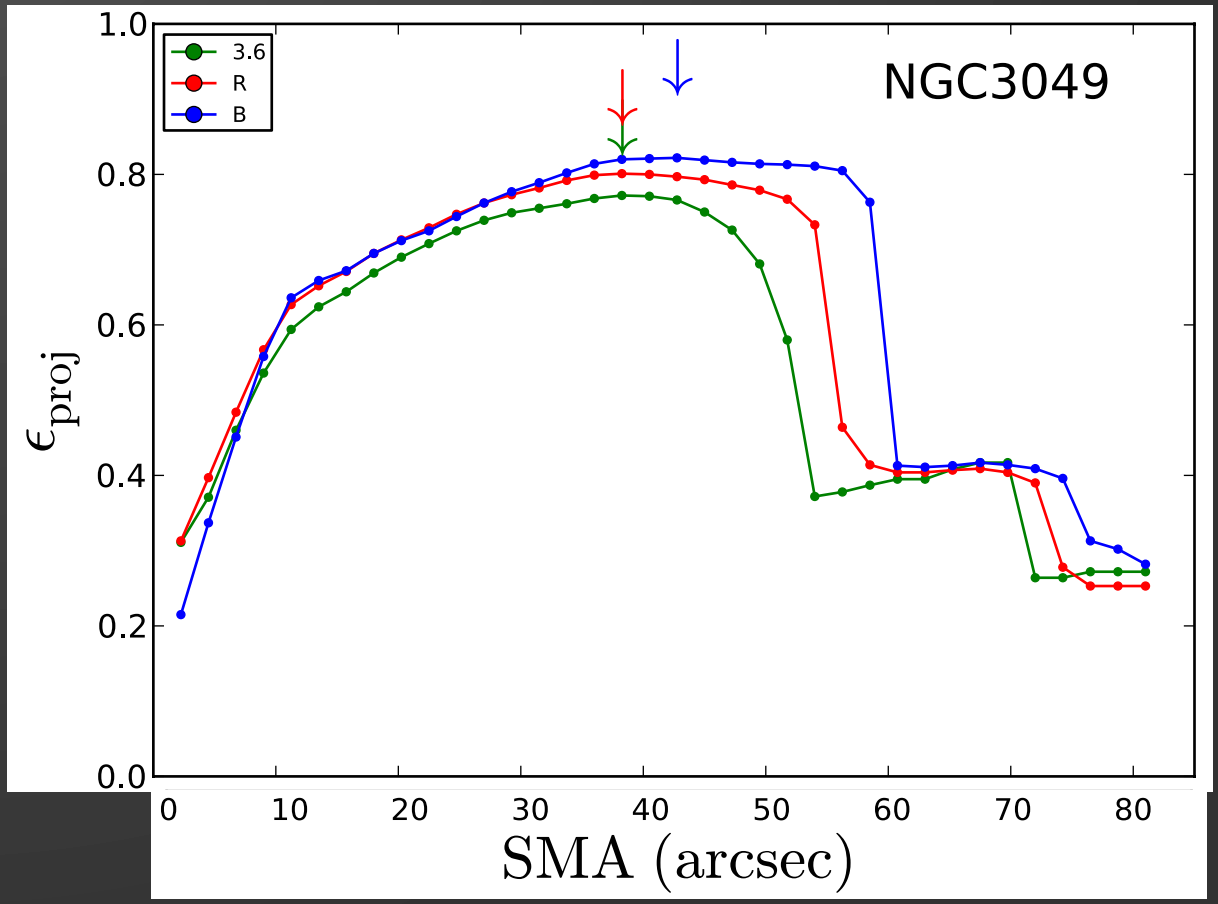


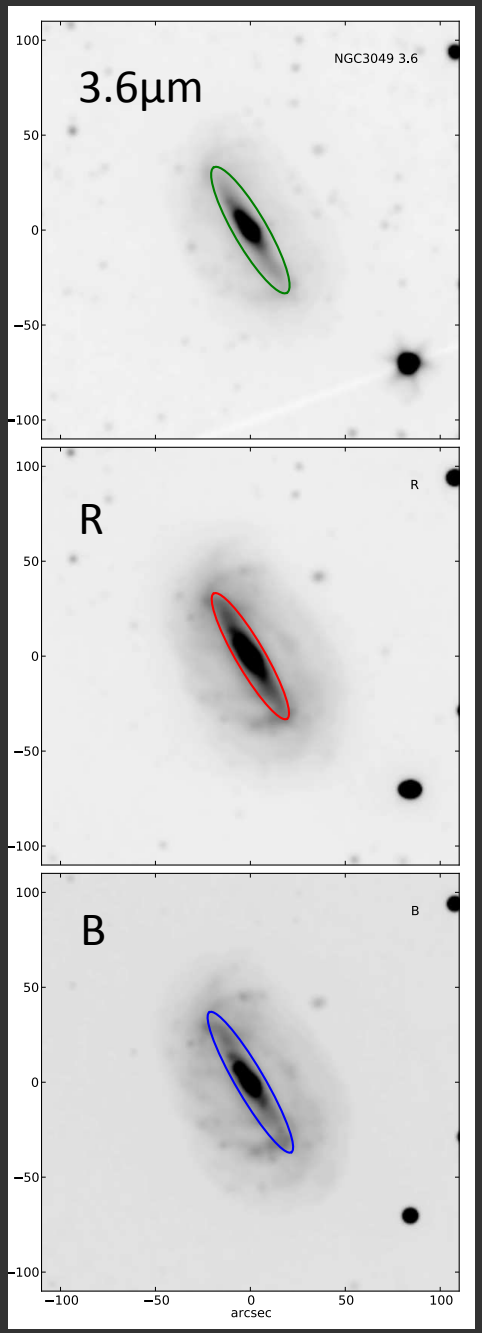


- widely-used ellipse-fit technique

KMD+14

Bars properties: from optical through IR

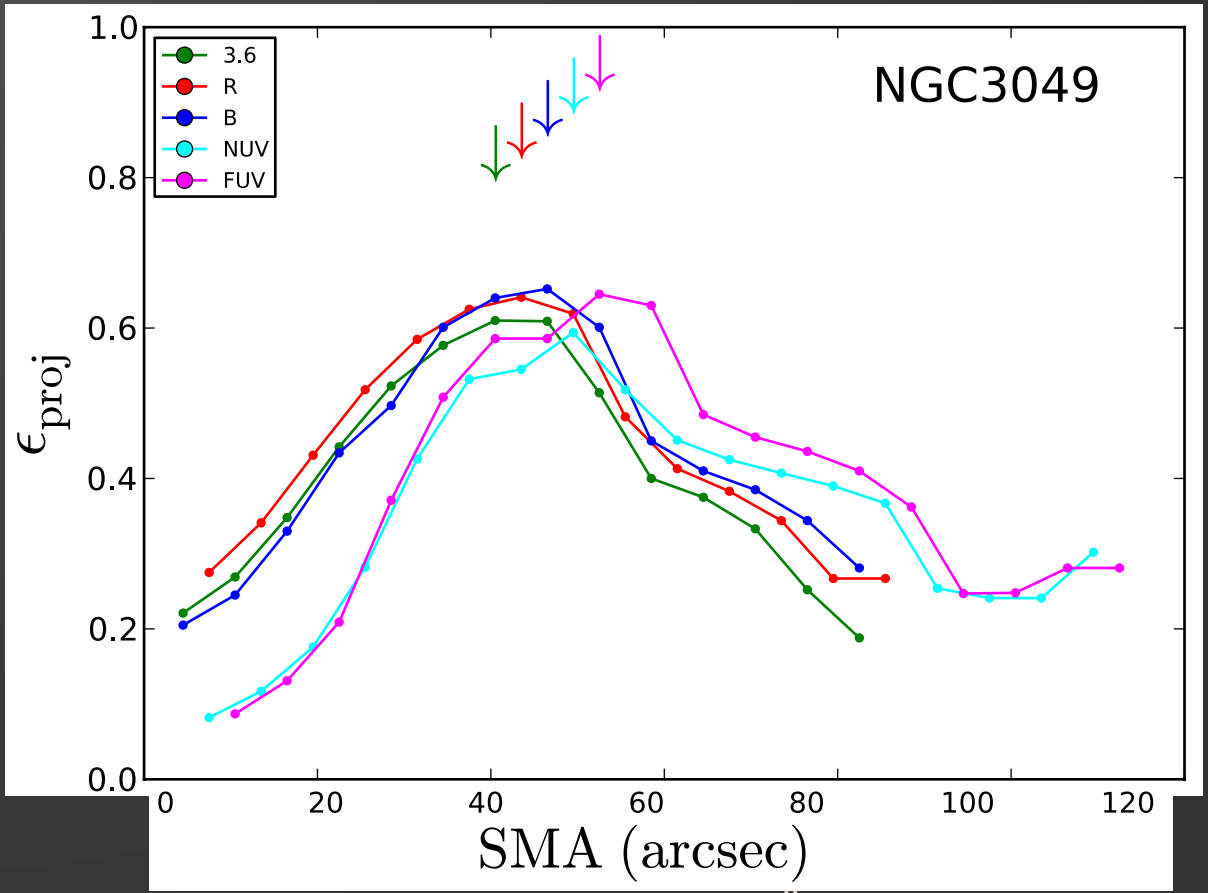


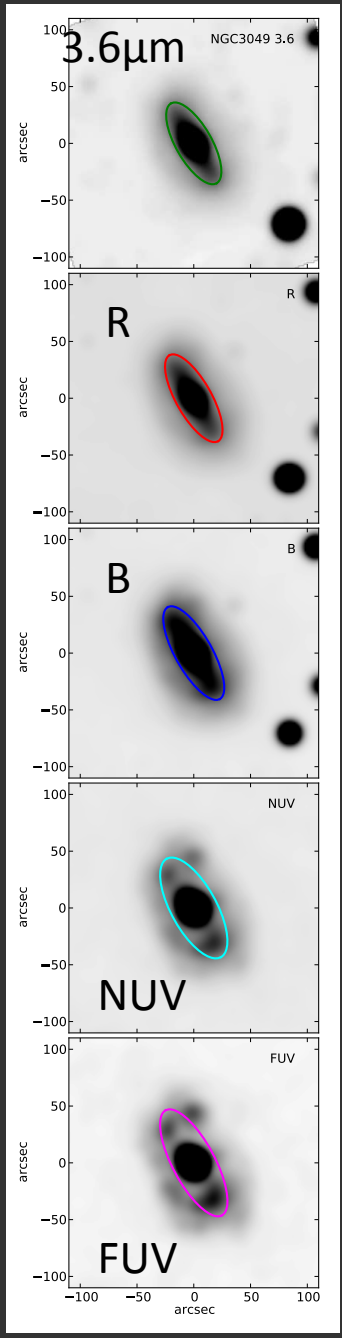


- Based on SINGs ancillary B, R and S^{4}G 3.6µm IRAC/Spitzer images

Karín Menéndez-Delmestre

Bars properties: from UV through IR

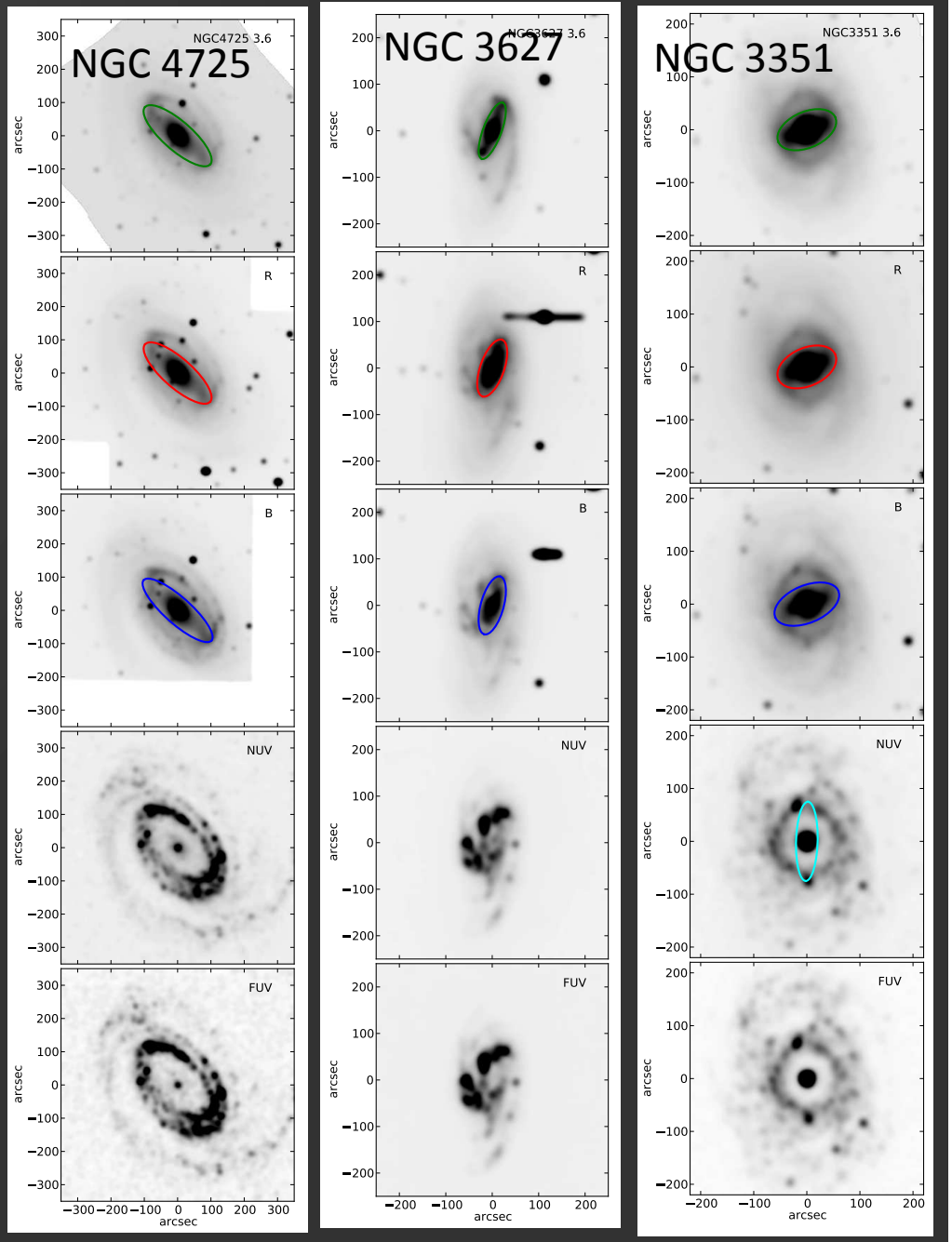




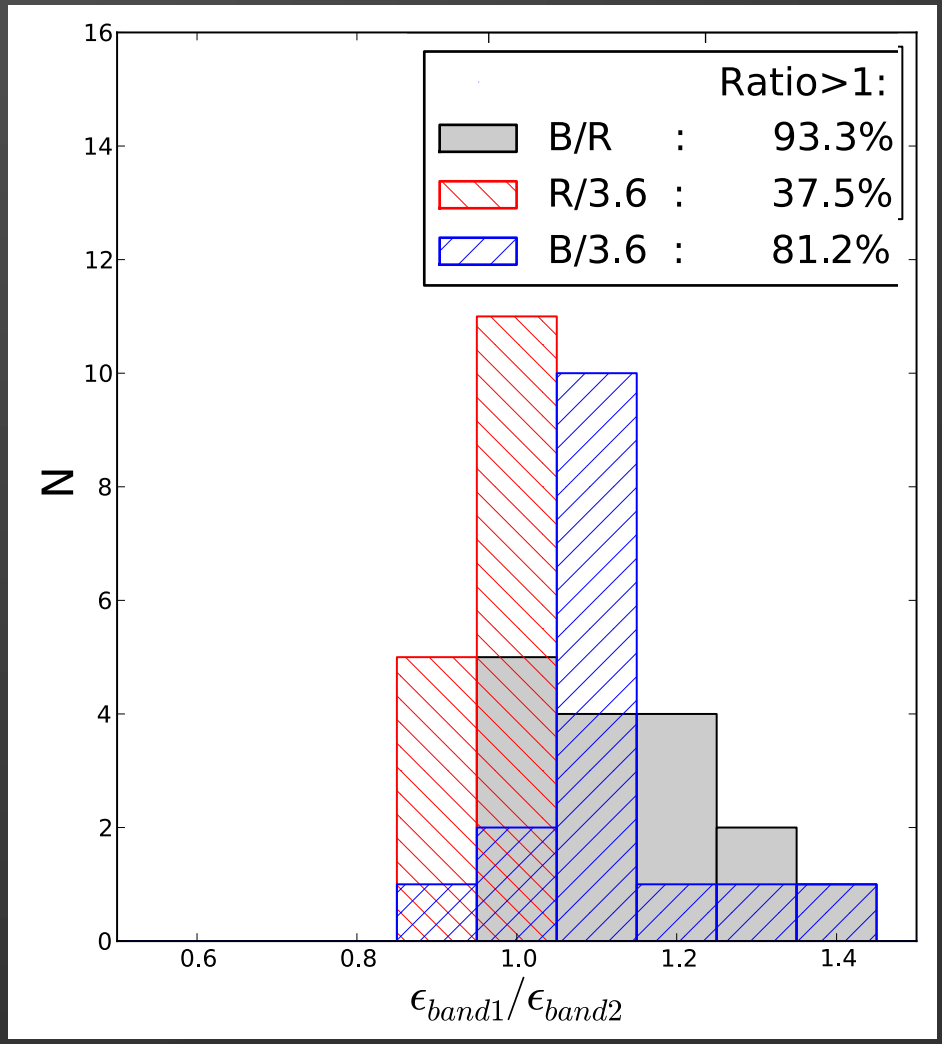
- Including GALEX NUV [2267 Å] and FUV [1516 Å]
  - To address high-z studies based on optical imaging (for instance, I-band studies beyond z~0.8)

1st result:
we lose bars in the UV_{rest}

- We lose half of all bars in the NUV/FUV bands
- No surprise, but worth emphasizing:
  - Studies of bars at high redshift – beware!

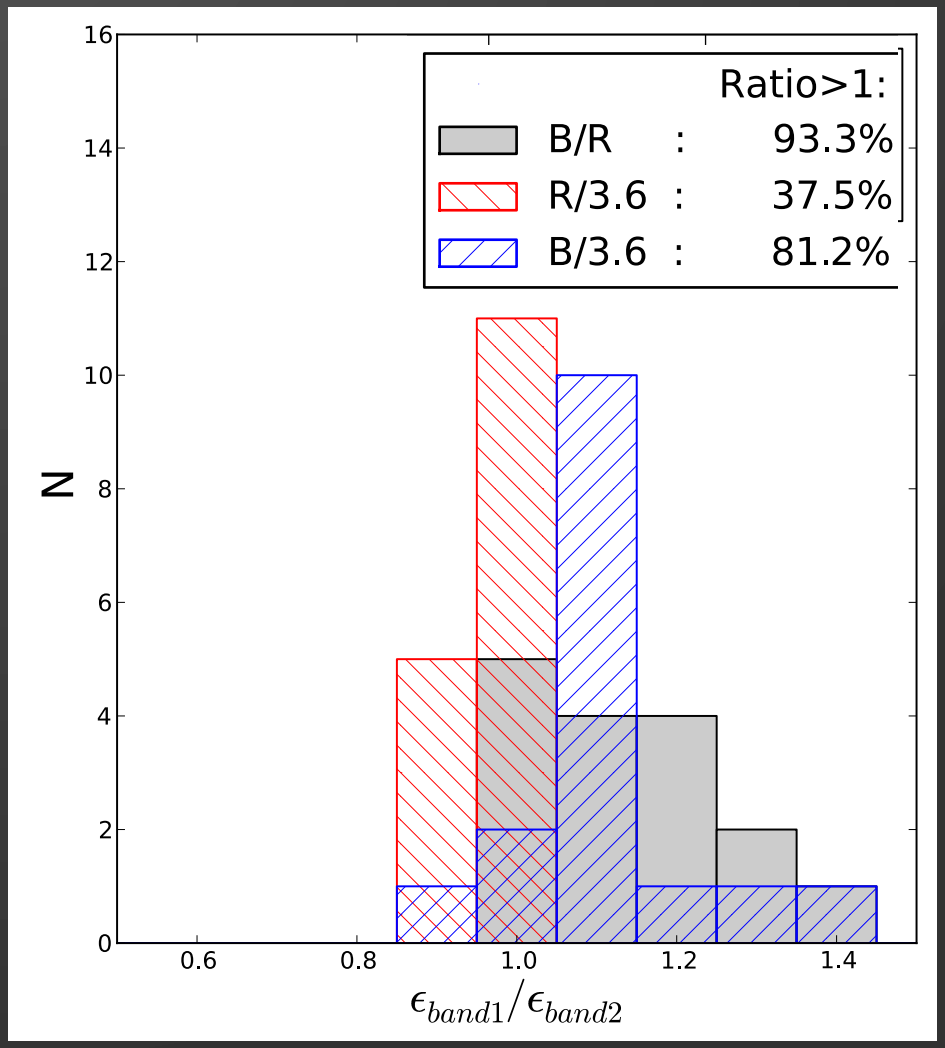


2nd result: bars look thinner in bluer bands

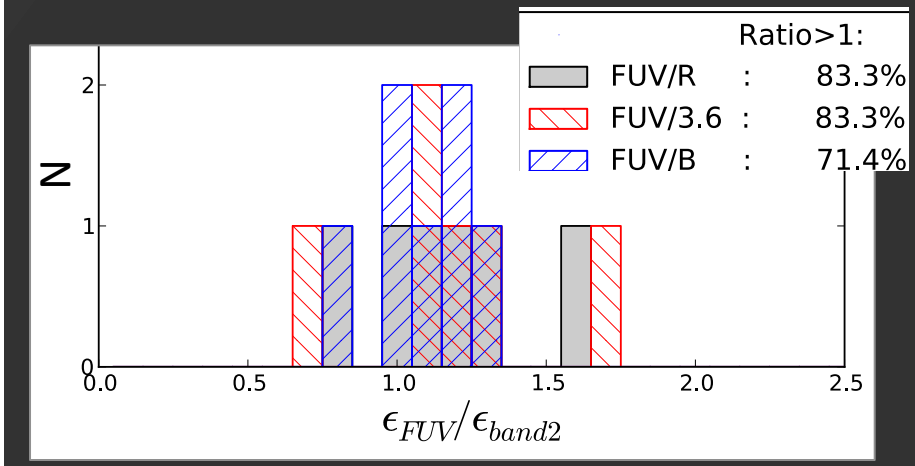


- ε_{max} is higher in the optical bands, compared to the mid-IR

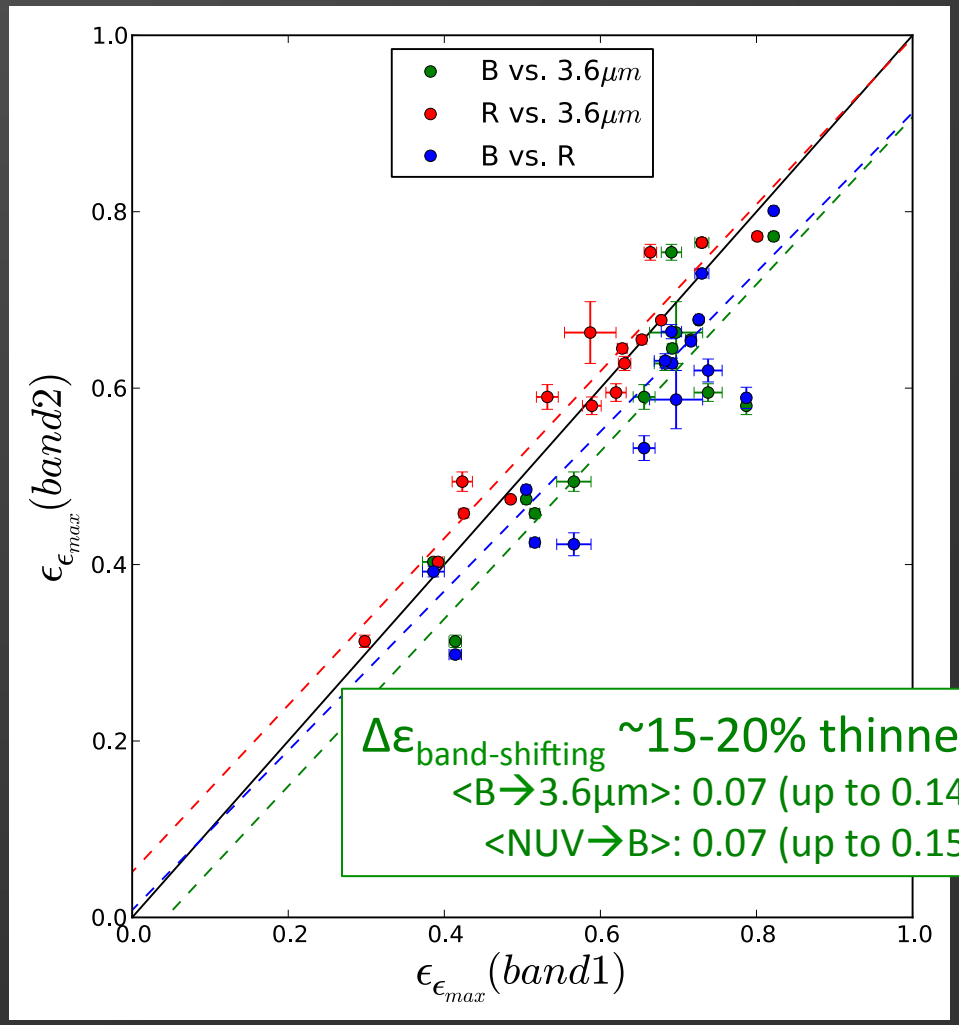
2nd result: bars look thinner in bluer bands



- ε_{max} is higher in the optical bands, compared to the mid-IR
- This result extends to the UV



2nd result: bars look thinner in bluer bands



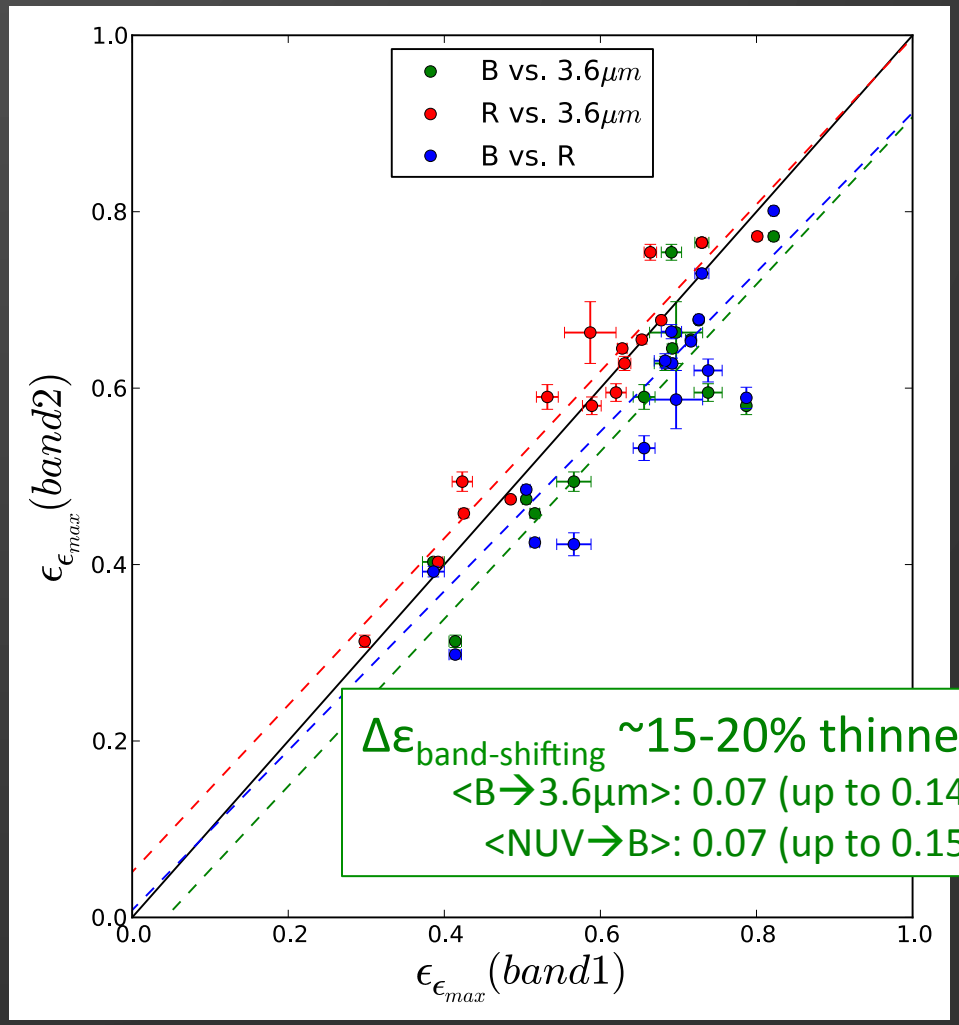
$\Delta\varepsilon_{band\text{-}shifting}$ ~15-20% thinner

<B→3.6μm>: 0.07 (up to 0.14)

<NUV→B>: 0.07 (up to 0.15)

- ε_{max} is higher in the optical bands, compared to the mid-IR
- This result extends to the UV

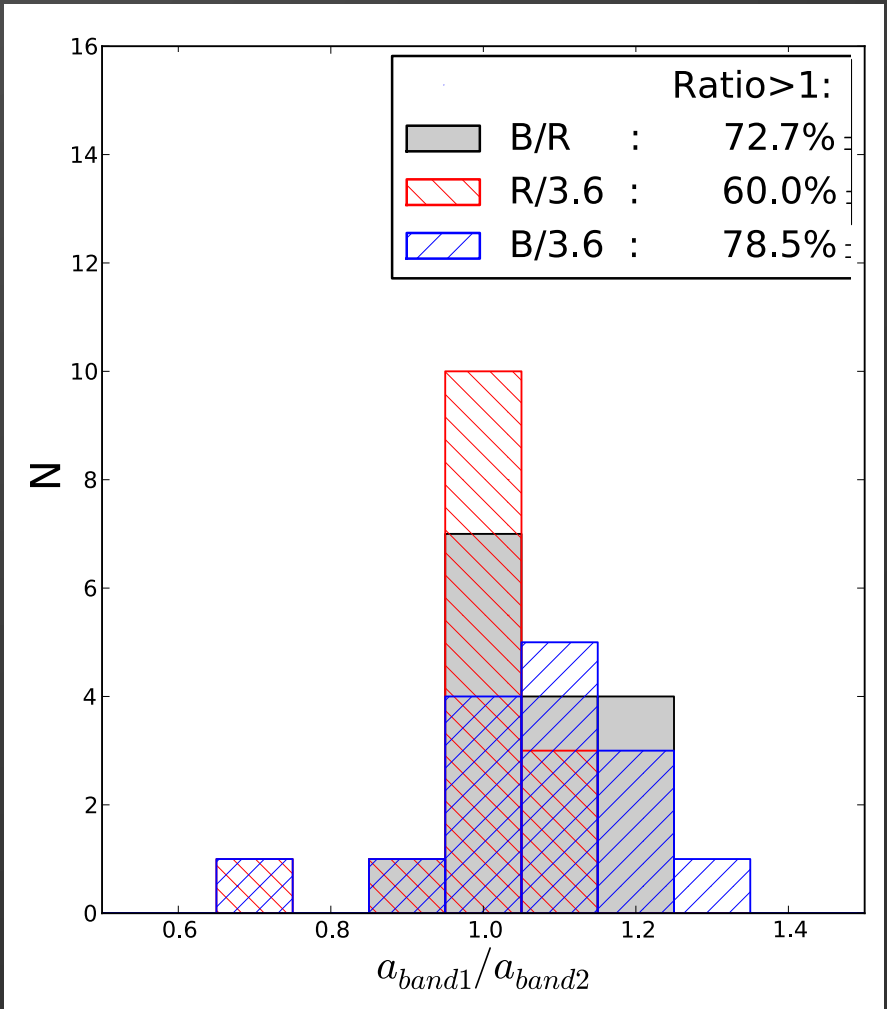
2nd result: bars look thinner in bluer bands



- ϵ_{max} is higher in the optical bands, compared to the mid-IR
- This result extends to the UV
- Driven by bulge sizes:
  - Bulge looks bigger in redder bands → smaller in the blue
    - Limits the size of the bar semi-minor axis
  - In good agreement with BUDDA results (Gadotti+08)

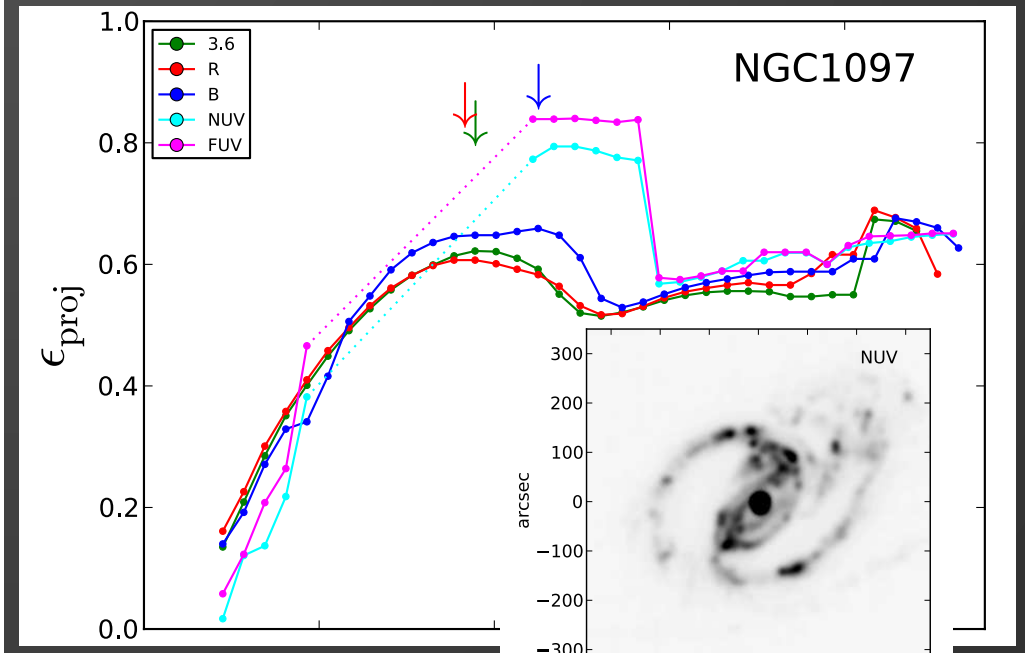
The bluer the restframe band, the thinner the bar!

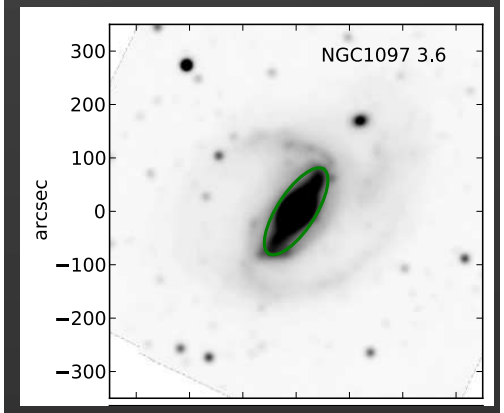
3rd result: bars look longer in bluer bands

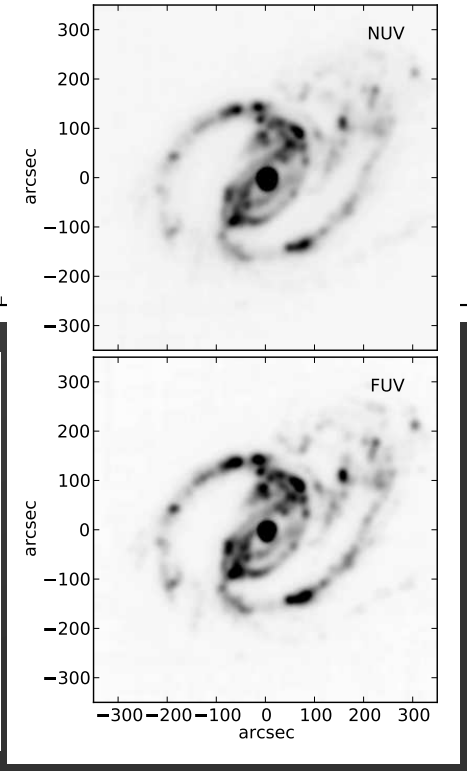


- SMA where $\varepsilon = \varepsilon_{max}$ is larger in the optical bands, compared to the mid-IR

3rd result: bars look longer in bluer bands



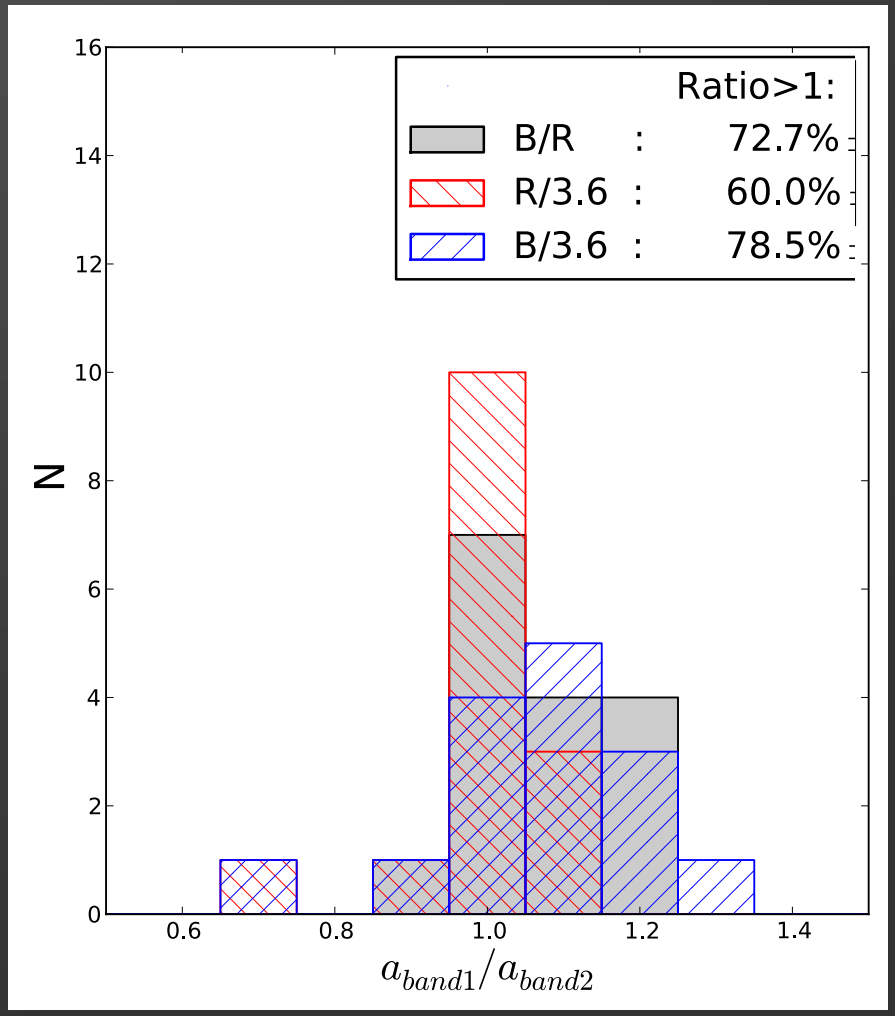




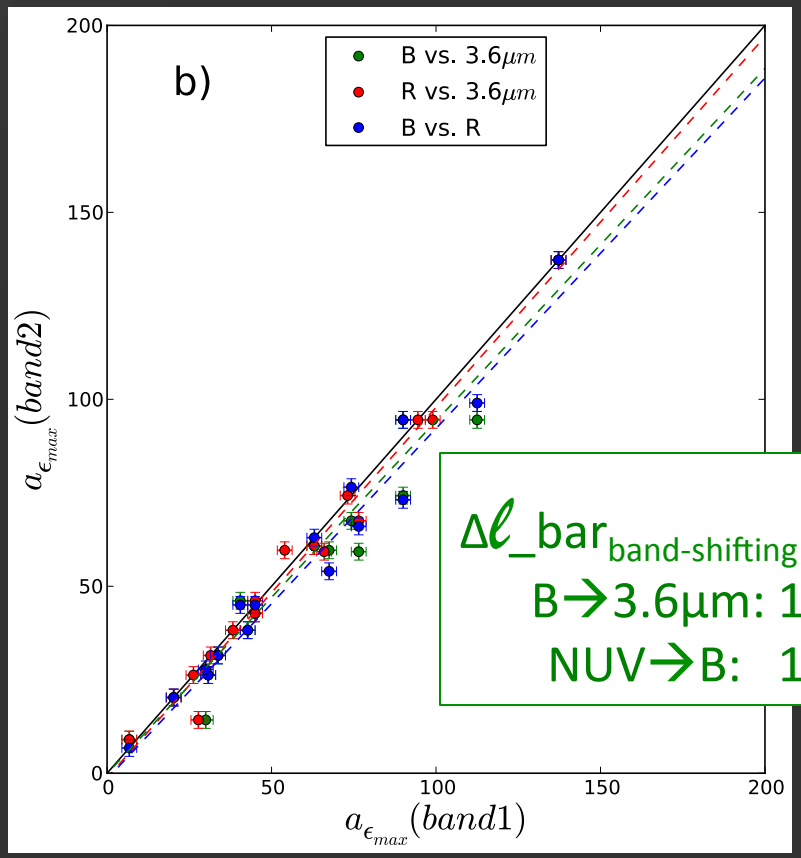
- SMA where $\varepsilon = \varepsilon_{max}$ is larger in the optical bands, compared to the mid-IR
  - Also extends to the UV
- Star-forming knots at the end of bars become more prominent and drive maximum ellipticity further out.

The bluer the restframe band, the longer the bar!

3rd result: bars look longer in bluer bands



- SMA where ε = ε_{max} is larger in the optical bands, compared to the mid-IR



$\Delta\ell$_bar$_{band\text{-}shifting}$
B→3.6μm: 10%
NUV→B: 10%

Take away points…

- As we extend bar studies out to high redshifts, our single-band studies are inevitably subject to band-shifting effects… these cannot be ignored! Why?
  - We lose 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 get thinner*, due to apparent bulge size
    - *Bars look longer*, as star-forming knots become prominent
  - How significant is this? Comparable to reported differences w.r.t. environment, AGN content, Hubble type
  - 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!

S4G: The Spitzer Survey of Stellar Structure in Galaxies

http://s4g.caltech.edu

S^{4}G in a nutshell

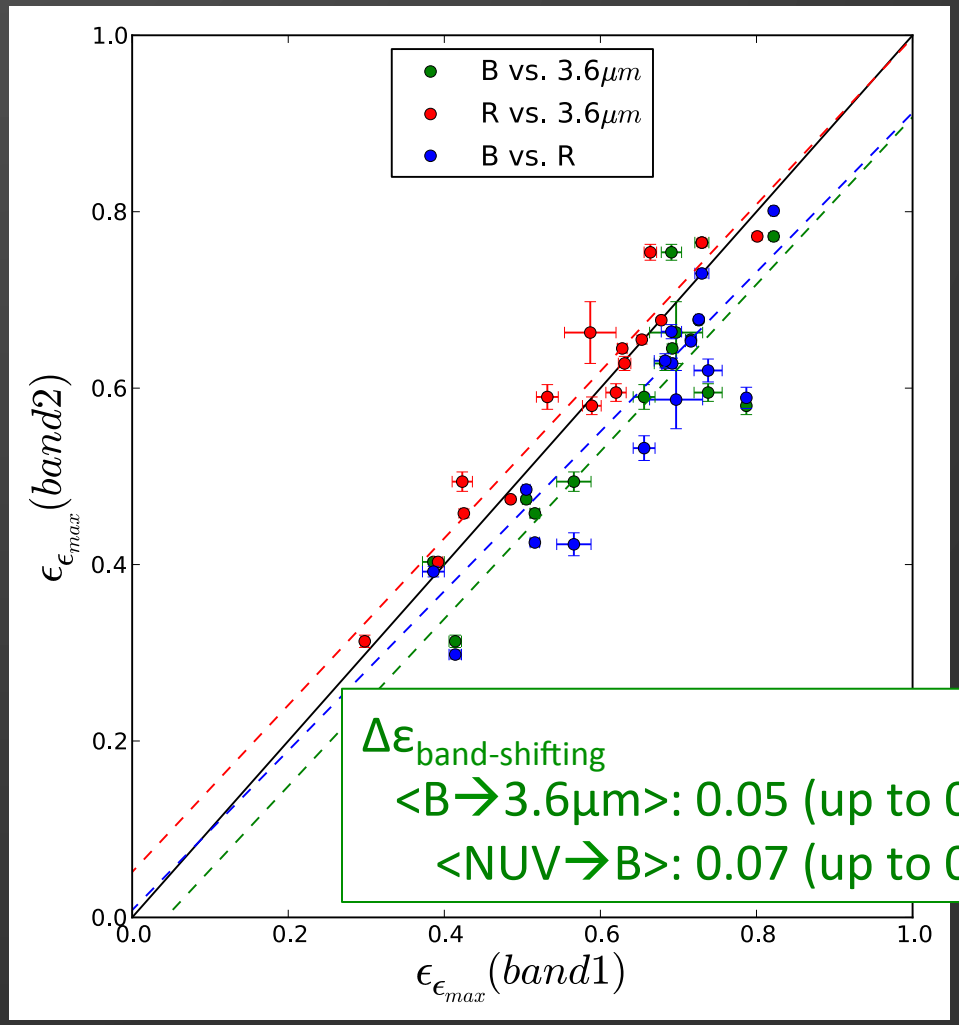
- 3.6, 4.5µm imaging with the Infrared Array Camera (IRAC) on Spitzer of all (>2000) nearby spiral, elliptical, and dwarf galaxies:
  - $v_{rad} < 3000$ km/s (d < 40 Mpc)
  - $m_B < 15.5$,
  - $D_{25} > 1.0'$
  - $|b| > 30°$
- Create the ultimate survey of the distribution of stellar structures, their masses and properties in the nearby Universe

The (growing) S^{4}G Team

- Kartik Sheth, Caltech, PI *
- Joannah Hinz, University of Arizona *
- Armando Gil de Paz, UCM, Madrid
- Michael Regan, STScI *
- Karin Menendez-Delmestre, OCIW
- Eva Schinnerer, MPIA, Heidelberg
- Bruce Elmegreen, IBM
- Debra Elmegreen, Vassar College *
- Lia Athanassoula, OAMP, France
- Ron Buta, Univesity of Alabama
- Albert Bosma, OAMP, France
- Tom Jarrett, Caltech
- Luis Ho, OCIW
- Lee Armus, Caltech
- Barry Madore, OCIW
- Dennis Zaritsky, University of Arizona
- Juan Carlos Munoz-Mateos, UCM, Madrid
- George Helou, Caltech
- Dimitri Gadotti, MPIA, Garching
- Chien Peng, NRC, Canada
- Jason Surace, Caltech
- Karen Masters, University of Portsmouth
- Patrick Ogle, Caltech
- Bahram Mobasher, UC- Riverside
- Mark Seibert, Carnegie Observatories
- Jin Koda, Caltech
- Peter Capak, Caltech
- Eija Laurikainen, University of Oulu, Finland
- Heikki Salo, University of Oulu, Finland
- Johan Knapen, IAC, Spain *

- ALICIA LANZ (CIT)
- SEBASTIEN CAMERON (IAC, SPAIN)
- SHARON MEIDT (UNM / MPIA)
- DAVID BLOCK (S. AFRICA)
- CAMERON CHARNESS (HARVEY MUDD)
- &..WE HOPE MORE WILL JOIN THE TEAM..

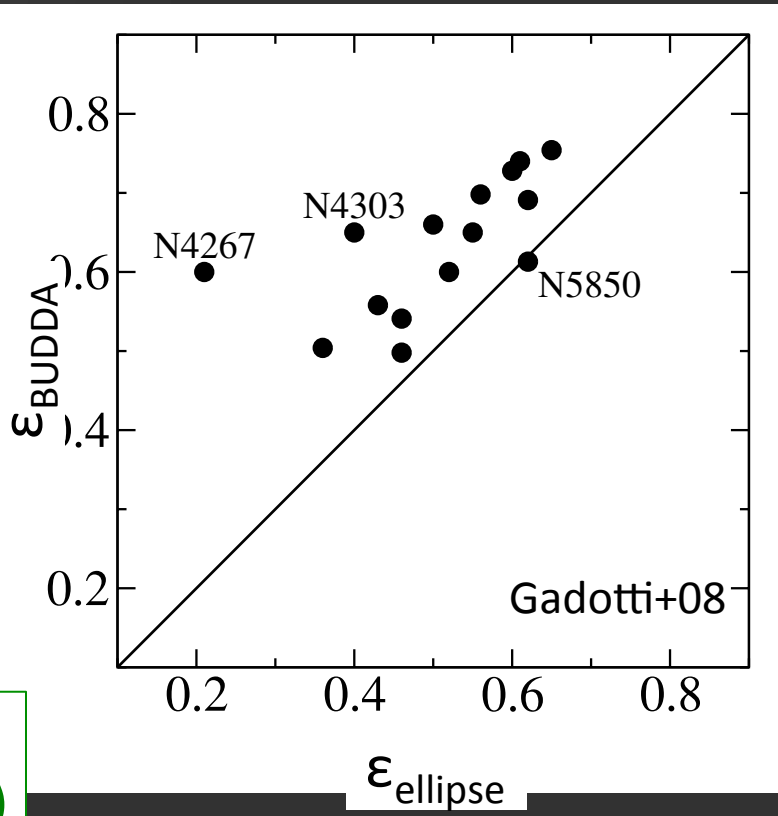
2nd result: bars look thinner in bluer bands



$\Delta\epsilon_{\text{band-shifting}}$

<B→3.6μm>: 0.05 (up to 0.2)

<NUV→B>: 0.07 (up to 0.3)

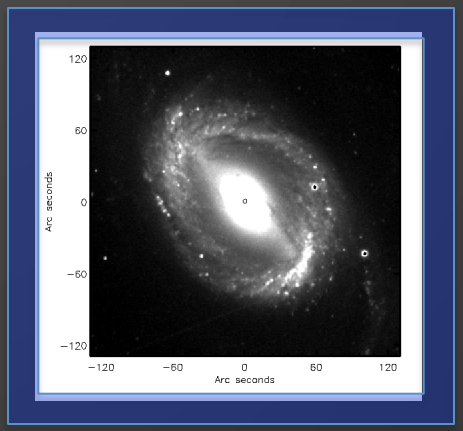


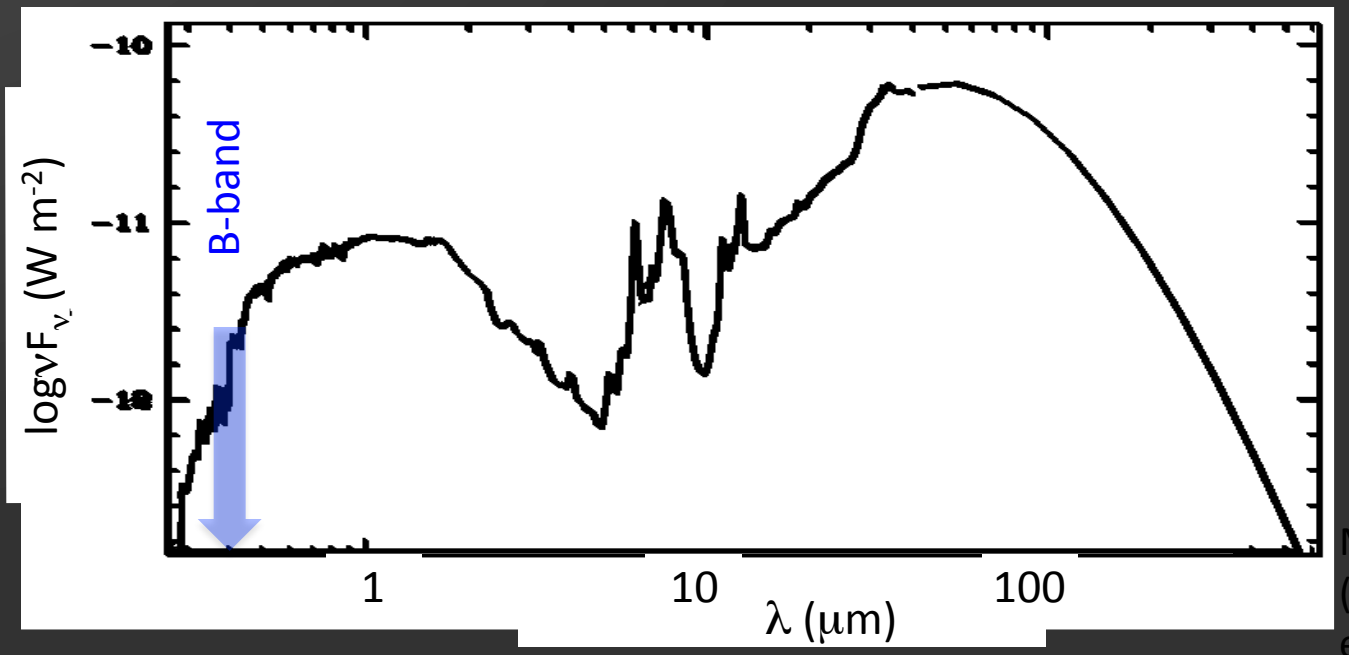
- In good agreement with BUDDA results (Gadotti+08)

The bluer the restframe band, the thinner the bar!

An example…

NGC 1512





M82 (Kennicutt et al. 2003)

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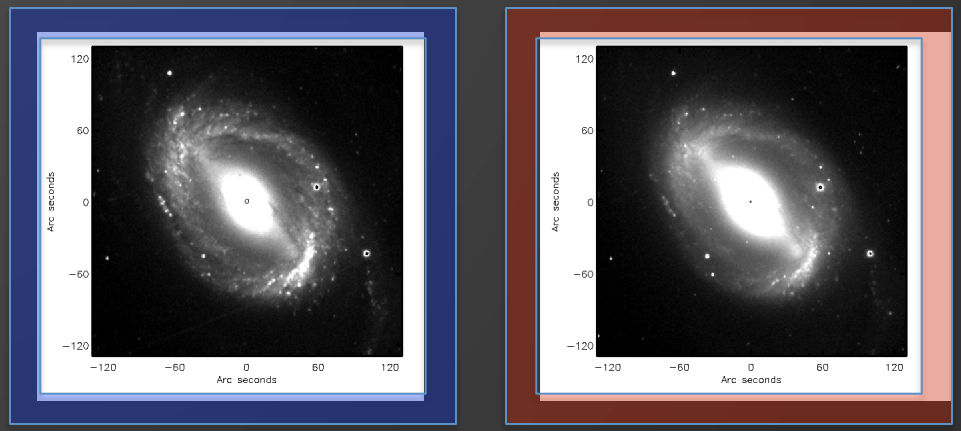

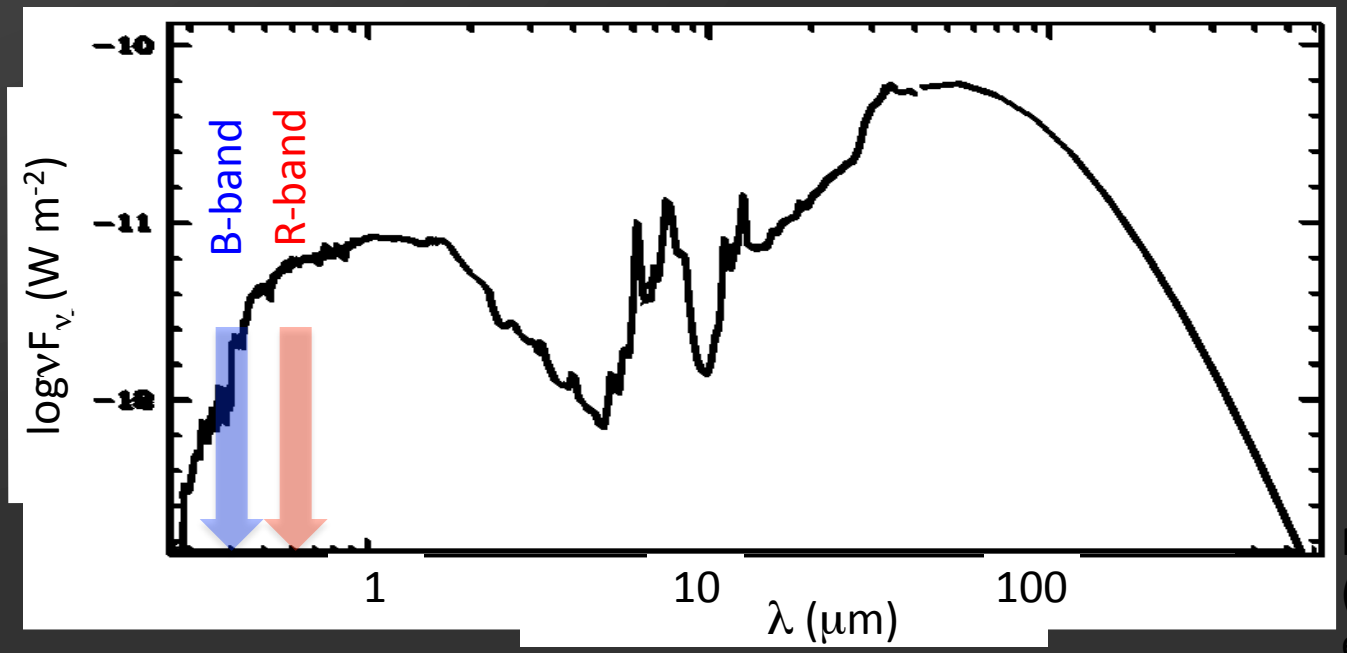

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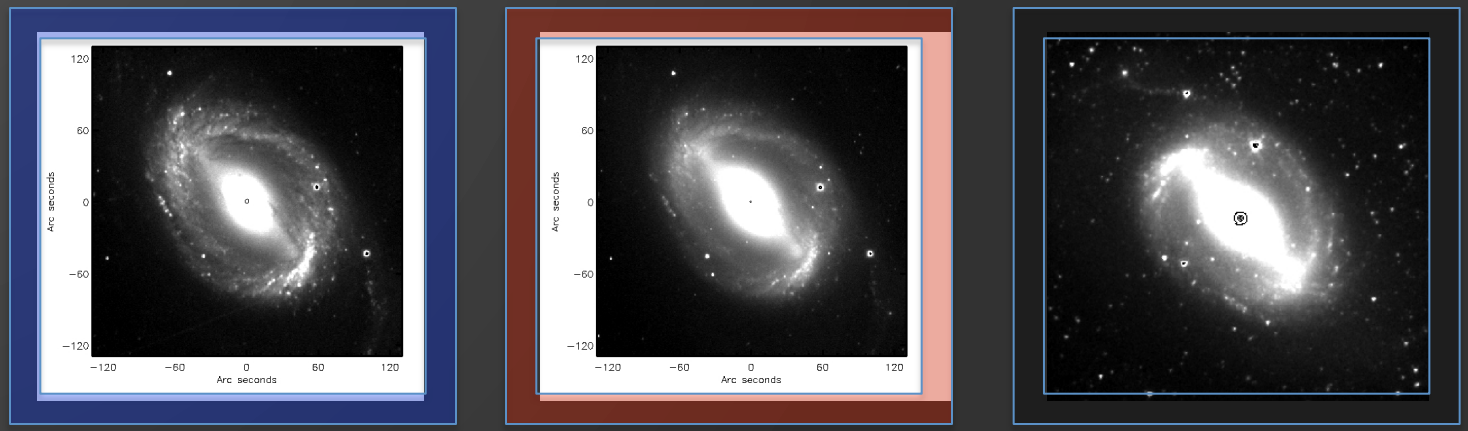
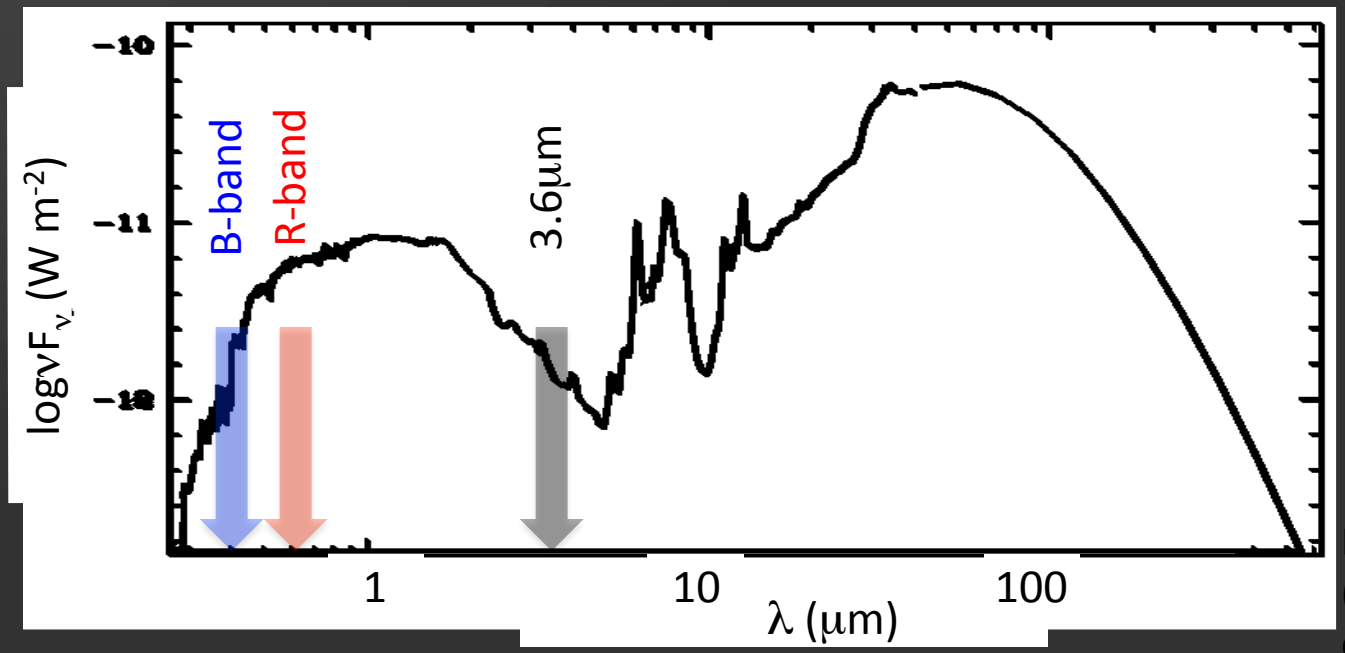
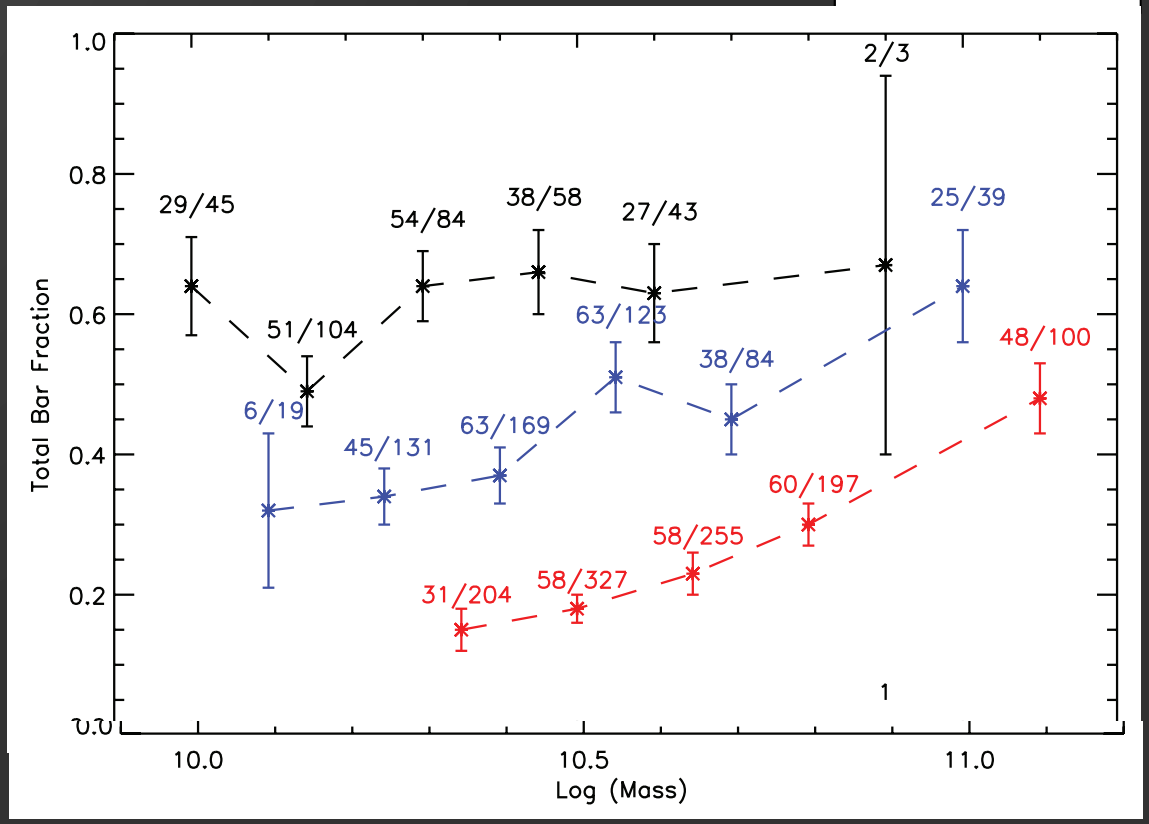




M82 (Kennicutt et al. 2003)

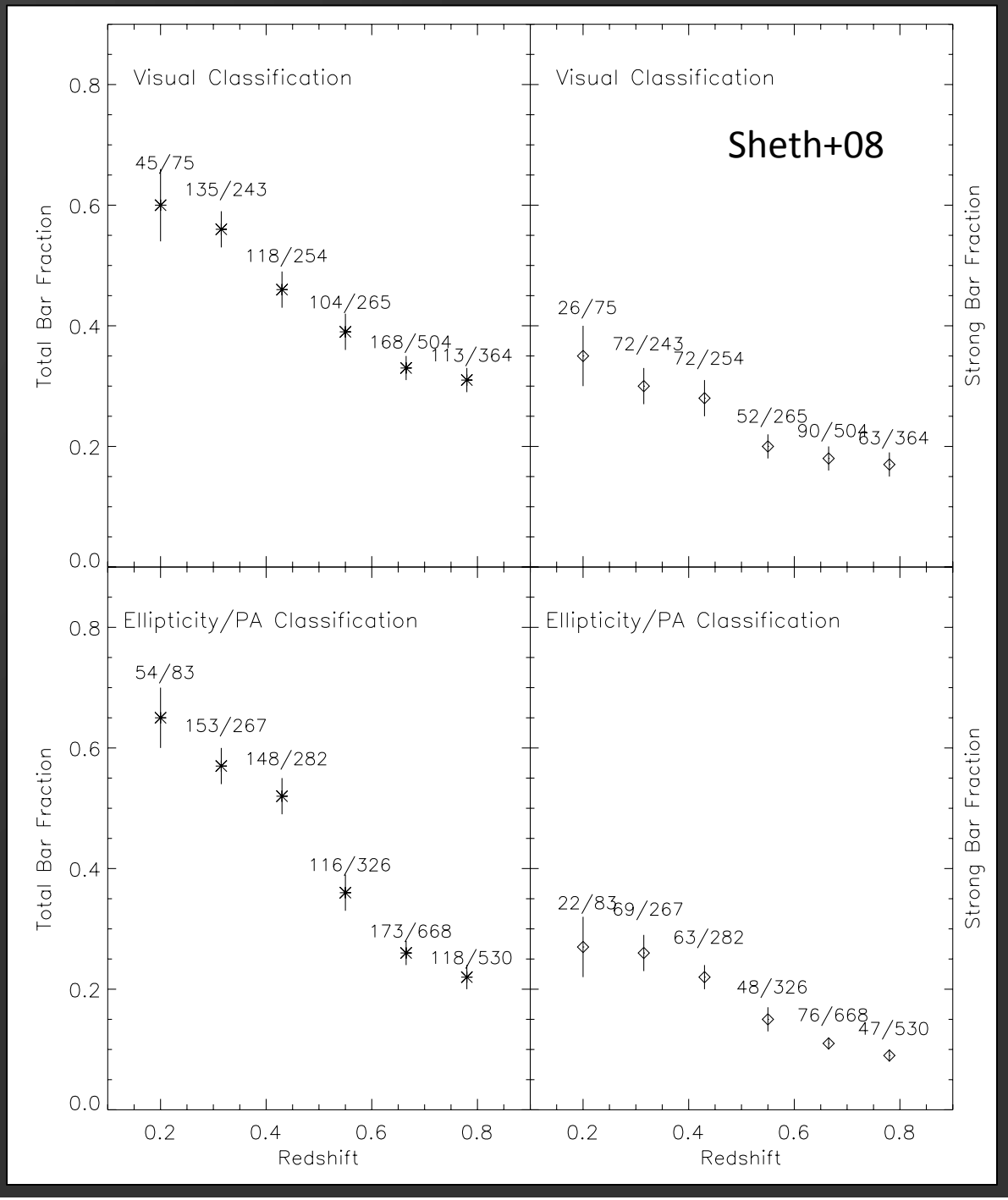
Bar studies at high-redshift

- Bar fraction declines at high redshift, but almost exclusively in the lower mass ($10 < \log M_*(M_\odot) < 11$), later-type, and bluer galaxies.



Sheth+08

Bar studies at high-redshift



Local Bars

- What we know about bars in the local universe:
  - A bar can induce large-scale streaming gas motions that can dramatically change the host galaxy.
    - Wash out metallicity gradient across galaxy (Martin & Roy 2004; but Sánchez-Blázquez+11)
    - Increase central gas concentration
      - → Trigger bursts of star formation
      - → Feed SMBH?
  - Locally, 2/3 of all disk galaxies have a bar.
  - The bar fraction stays pretty constant across wavelengths from optical to near-IR (e.g., Menéndez-Delmestre+07)

→So, band-shifting from near-IR to optical does not hamper (significantly) the ability to recognize bars, which becomes important in high-z studies

→Band shifting is ONLY an issue when going to shortwards of Balmer break (e.g., Sheth+03)