Bar morphology as a function of wavelength: a Local Reference For High-z Studies

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S4G

Spitzer Survey of Stellar Structure in Galaxies

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+)

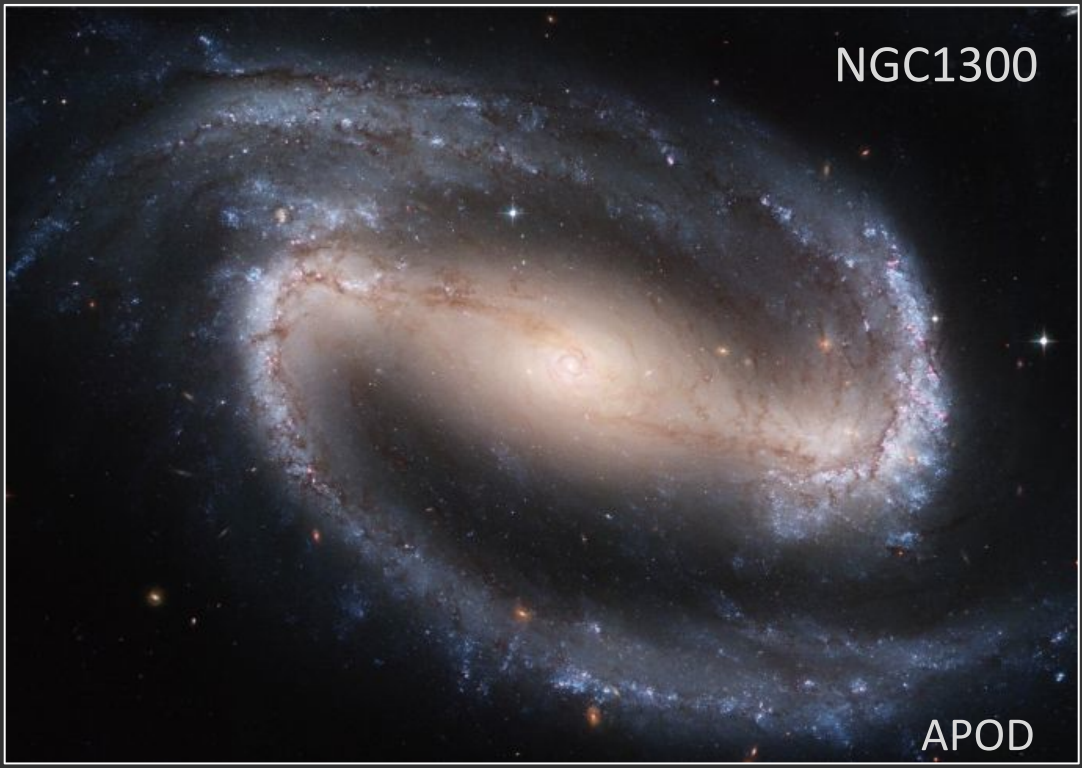
→ The presence of a bar allows us to gauge disk "maturity"

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)
  - → central accumulation of molecular gas (e.g., Sheth+05)
  - → 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 (e.g., Scoville+88)
  – Bars are dominated by old stars

NGC1068
2MASS, Large Galaxy Atlas

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

The quest for the bar fraction

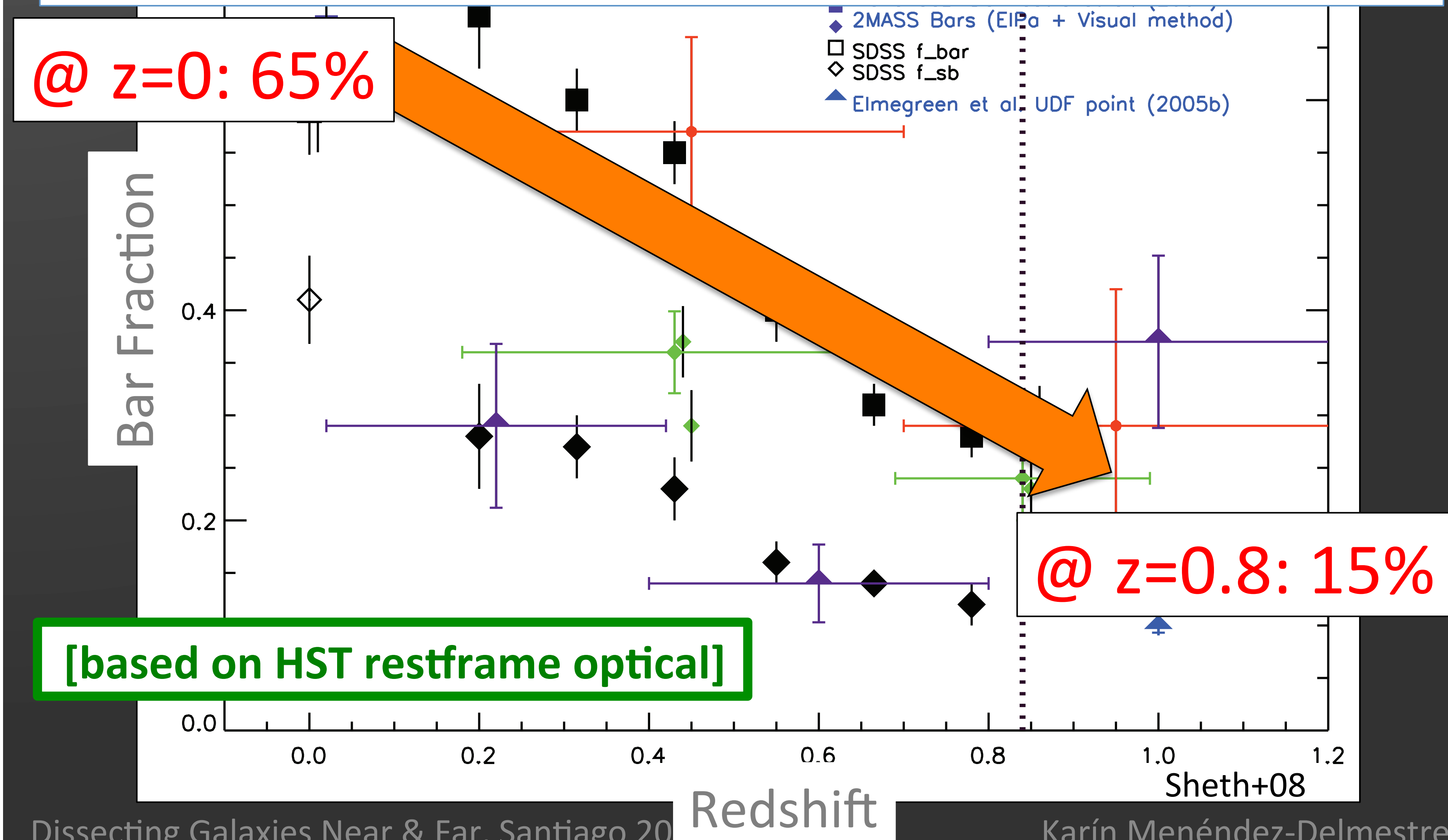
- The *Two-Micron All-Sky Survey* (2MASS; Skrutskie+05)
  - Large Galaxy Atlas (LGA; Jarrett+03)
    - > 500 large (~2' to 2°) galaxies
    - J, H, Ks

- 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: Decreases beyond z~0.4



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)

<u>How about our ability to trace bar properties?</u>

- Several studies have looked at bar properties locally

  (e.g., Erwin+05+13, Laurikainen+07, Gadotti+08, Hoyle+11)

2MASS median bar:

- a_{bar} = 4.2kpc
- ε_{bar}=0.5

Menéndez-Delmestre+07

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

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<u>How about our ability to trace bar properties?</u>

- 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)

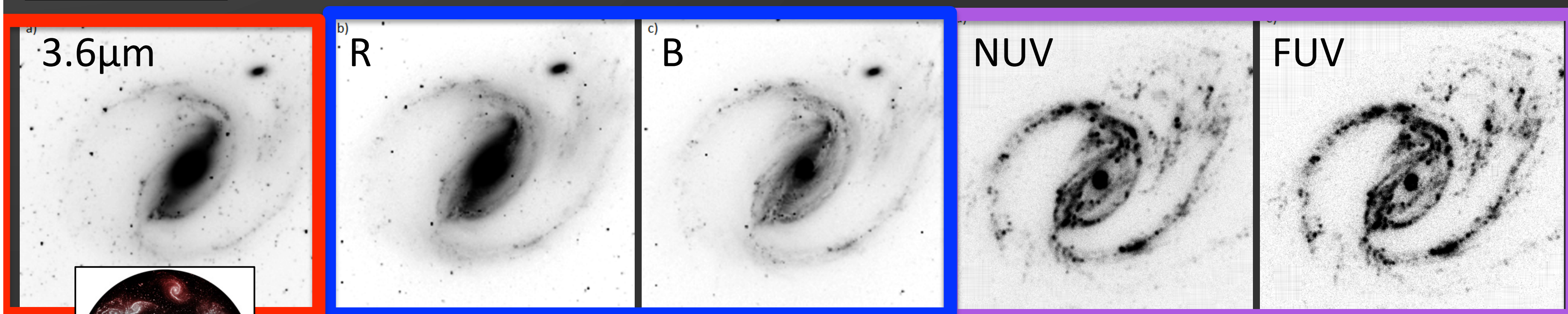
Bar Morphology at high z

need a local reference to extend studies to high redshift

- Need to know how the 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^{4}G imaging.

NGC1097



KMD+14

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

Bar Morphology at high z

need a local reference to extend studies to high redshift

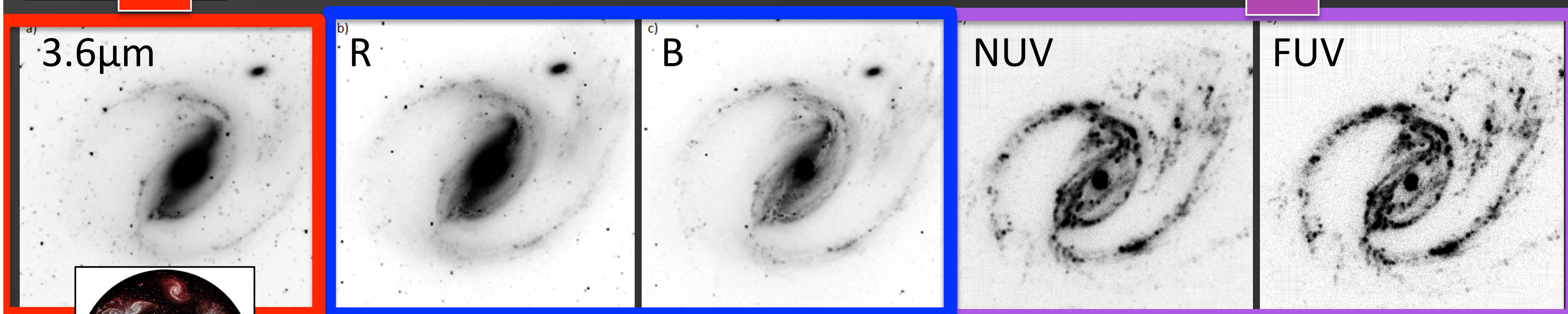
- …e bar prope… …gth!

mid-IR: optimal window for stellar structure

UV: explore band-shift out to z>0.8

…s as a functi… …f 16 … deep multi- … -IR , based on GALEX, SINGS and S^{4}G imaging.

NGC…7



KMD+14

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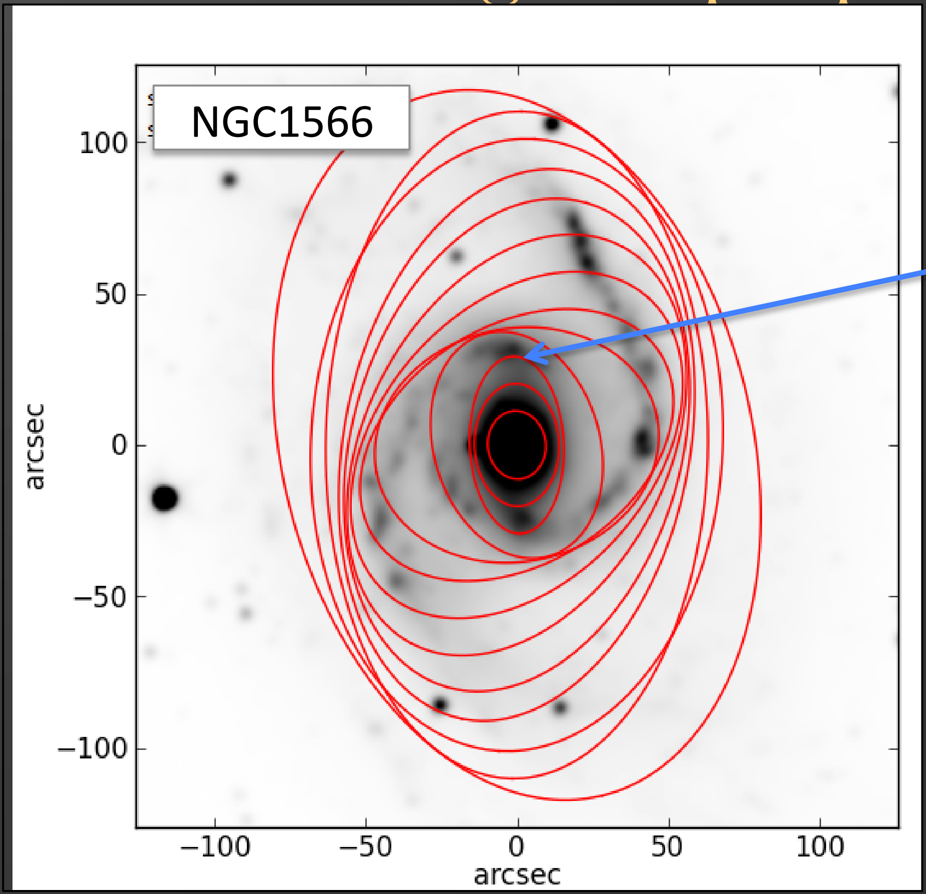
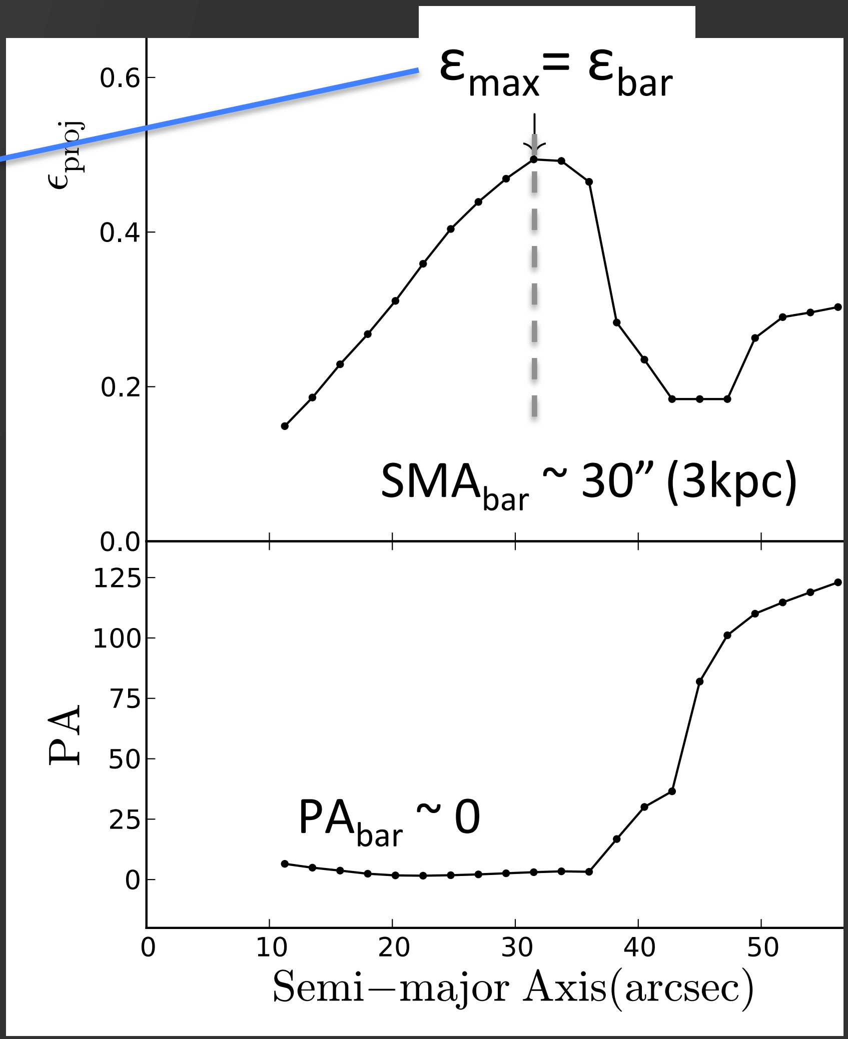
Measuring bar properties – our approach

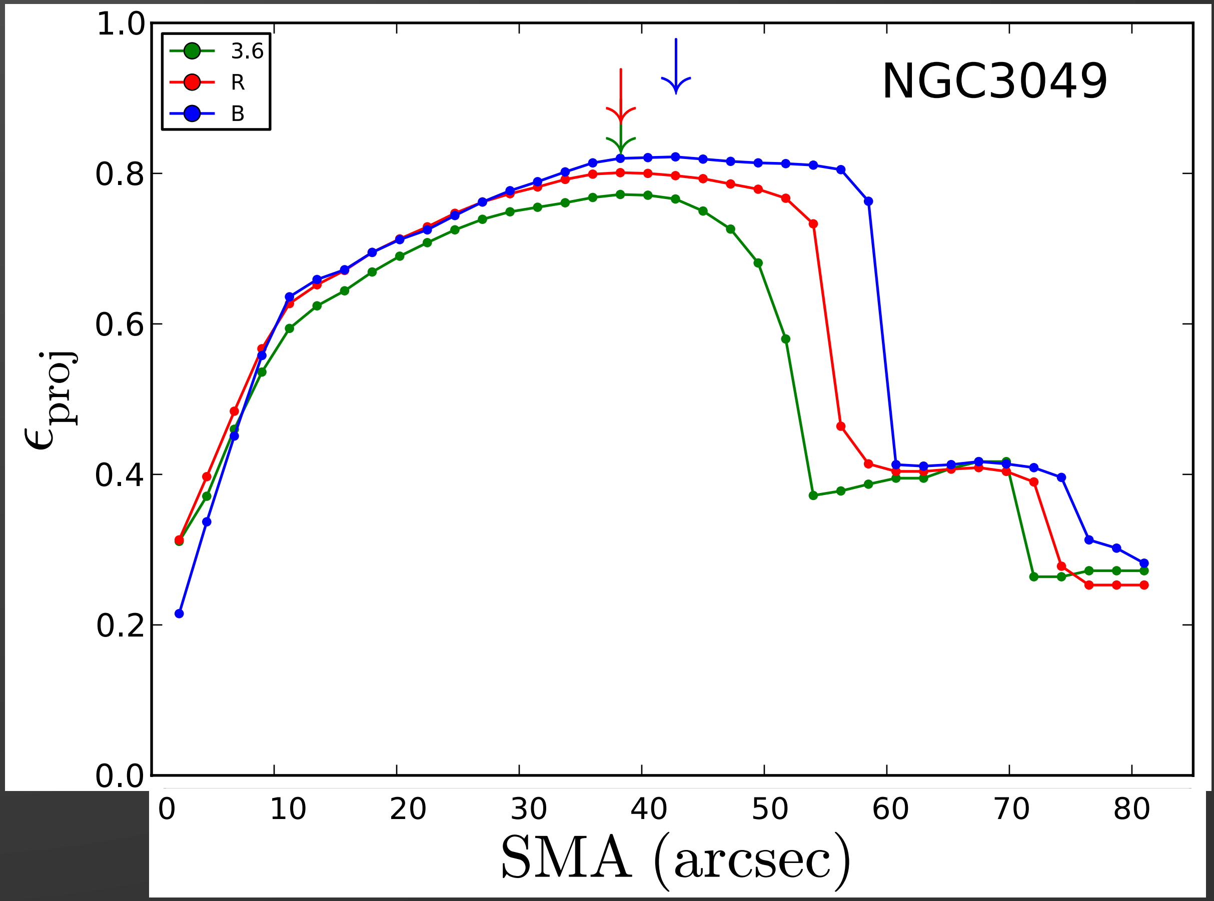


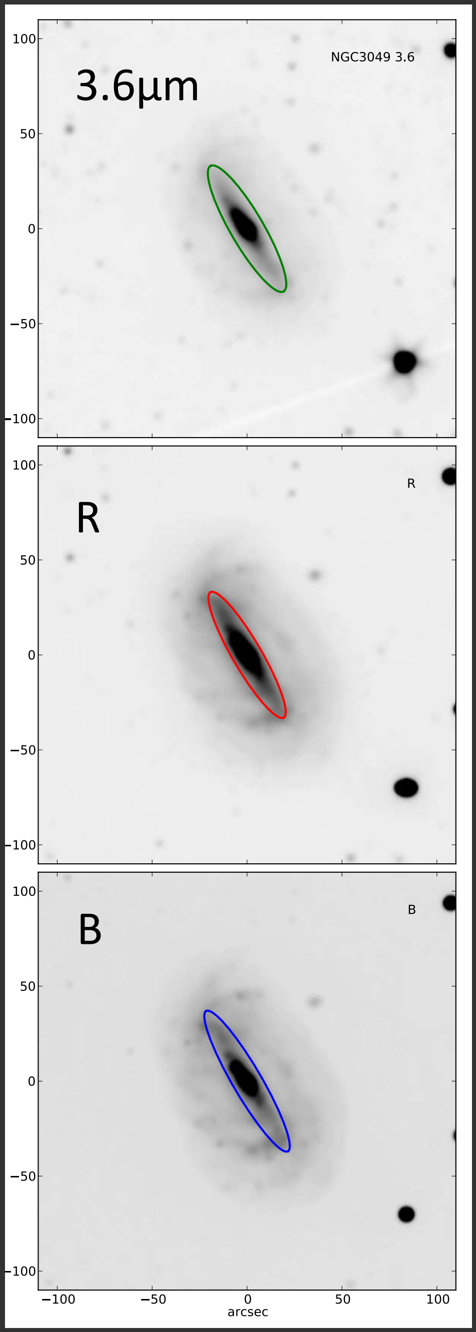


- widely-used ellipse-fit technique

KMD+14

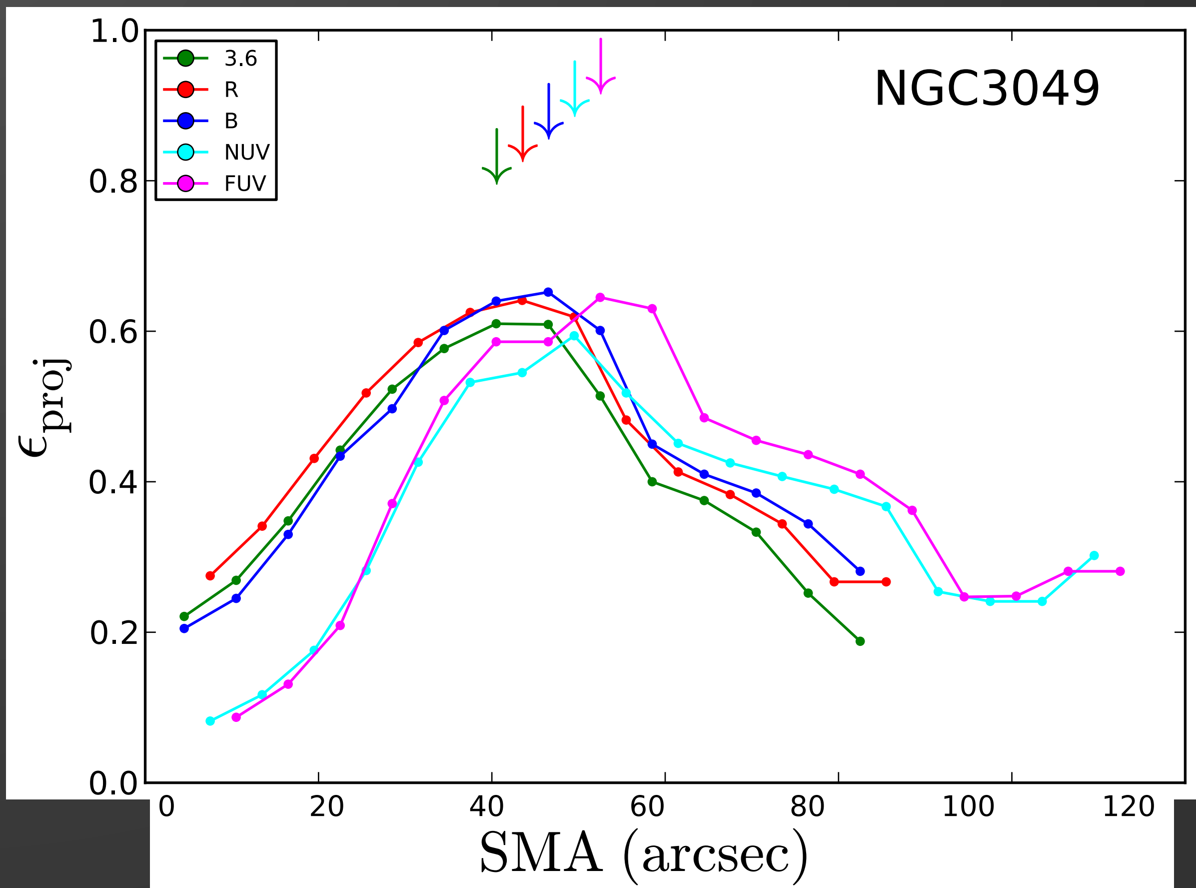
Bars properties: from optical through IR

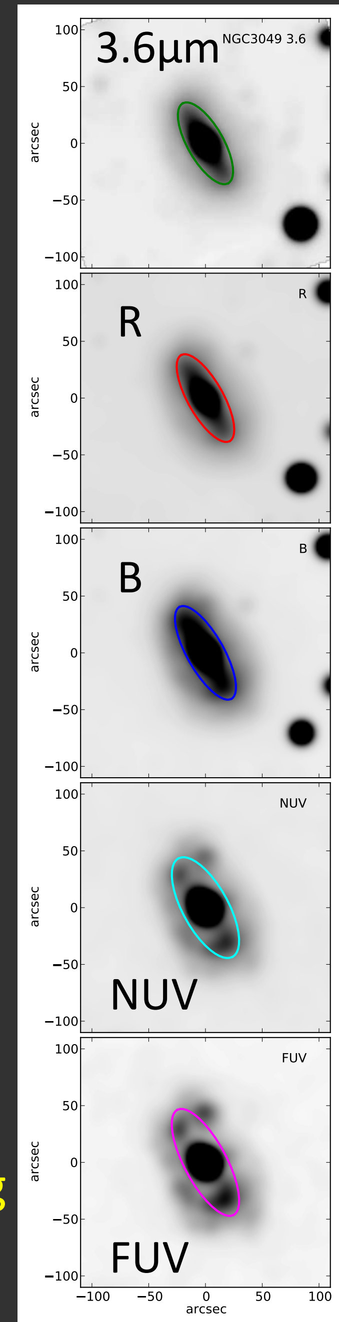




- Based on SINGs ancillary B, R and S[4]G 3.6μm IRAC/Spitzer images
- Angular resolution ~1-2"

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”

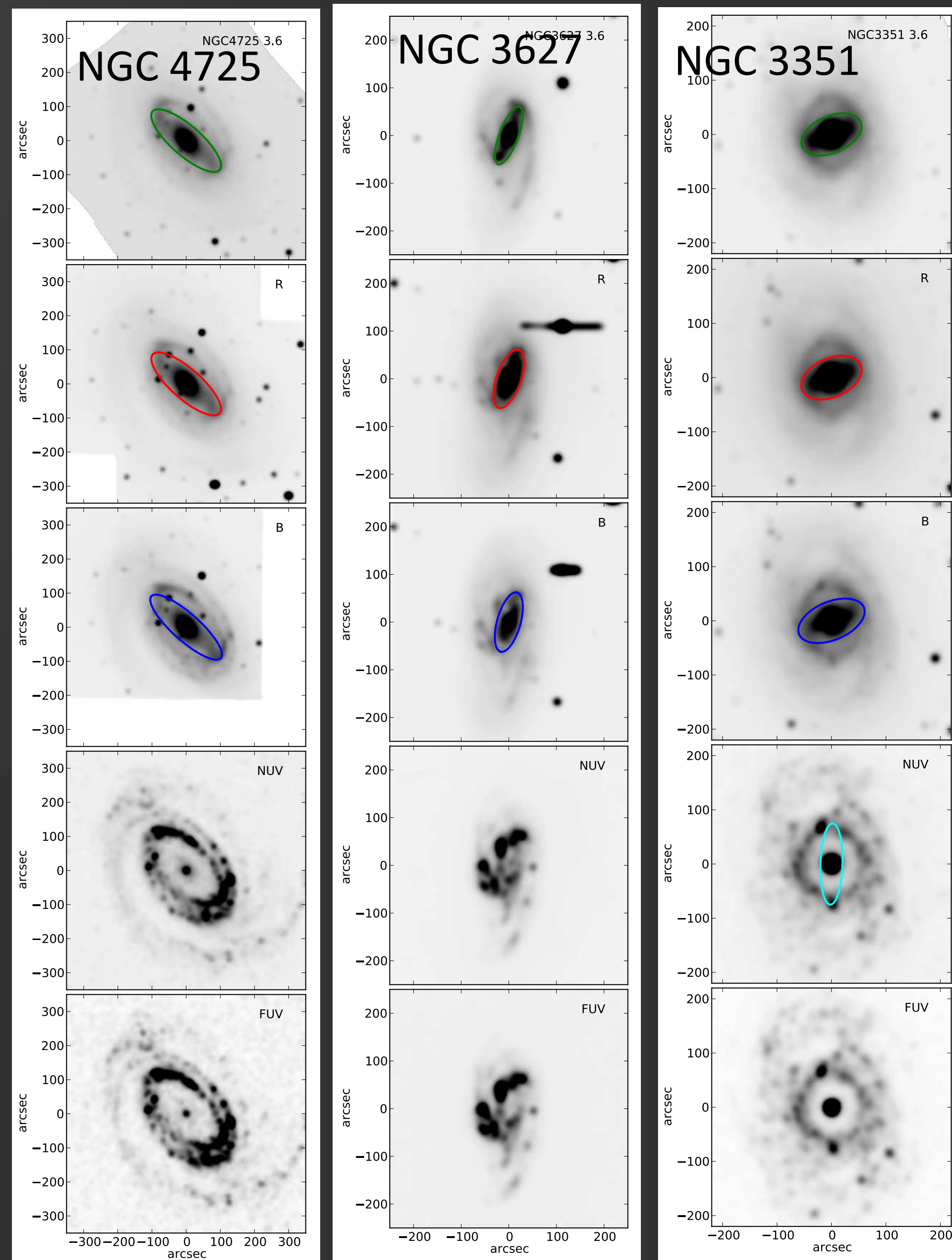
1st result:

we lose bars in the UV$_{rest}$

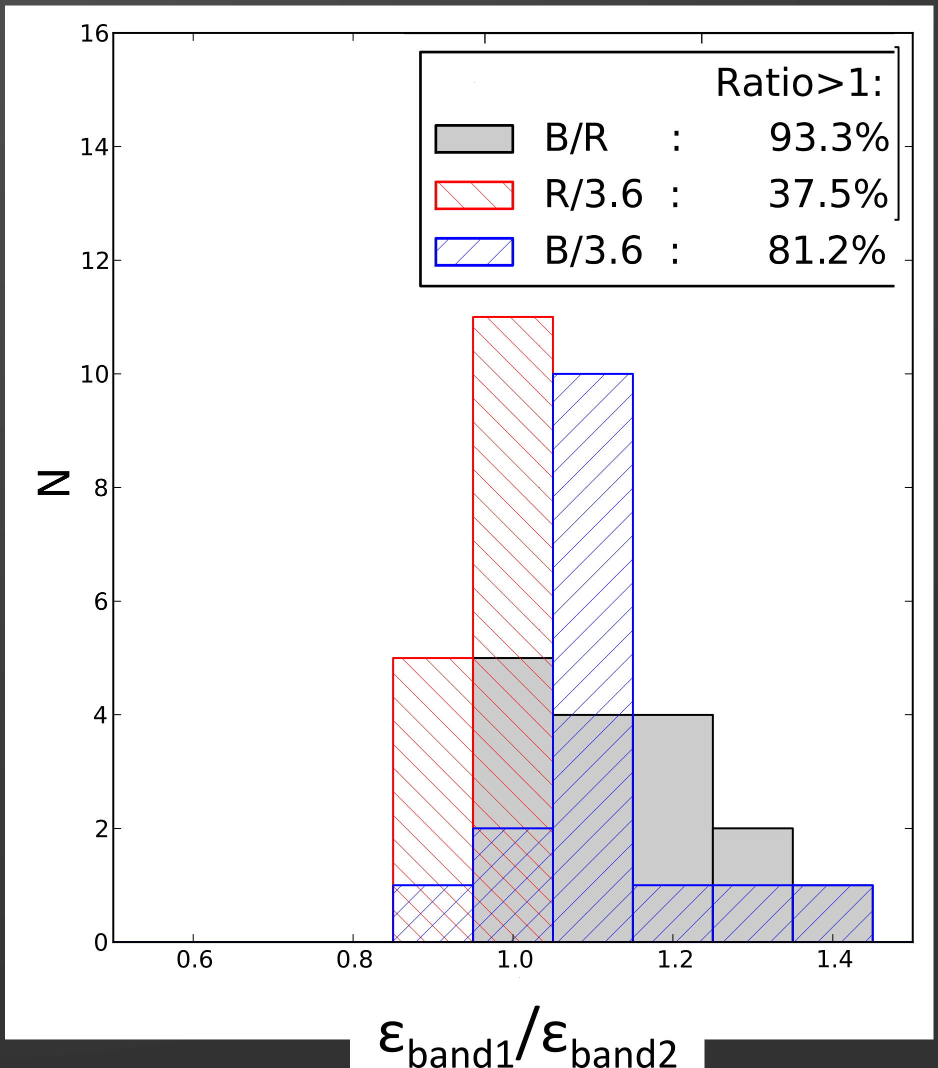
- We lose ~50% of all bars in the NUV/FUV bands
- Band shifting is an issue when going to shortwards of the Balmer break

→ Studies of bars at high redshift – beware!

→ HST data beyond z~0.8 traces emission bluewards of the Balmer break

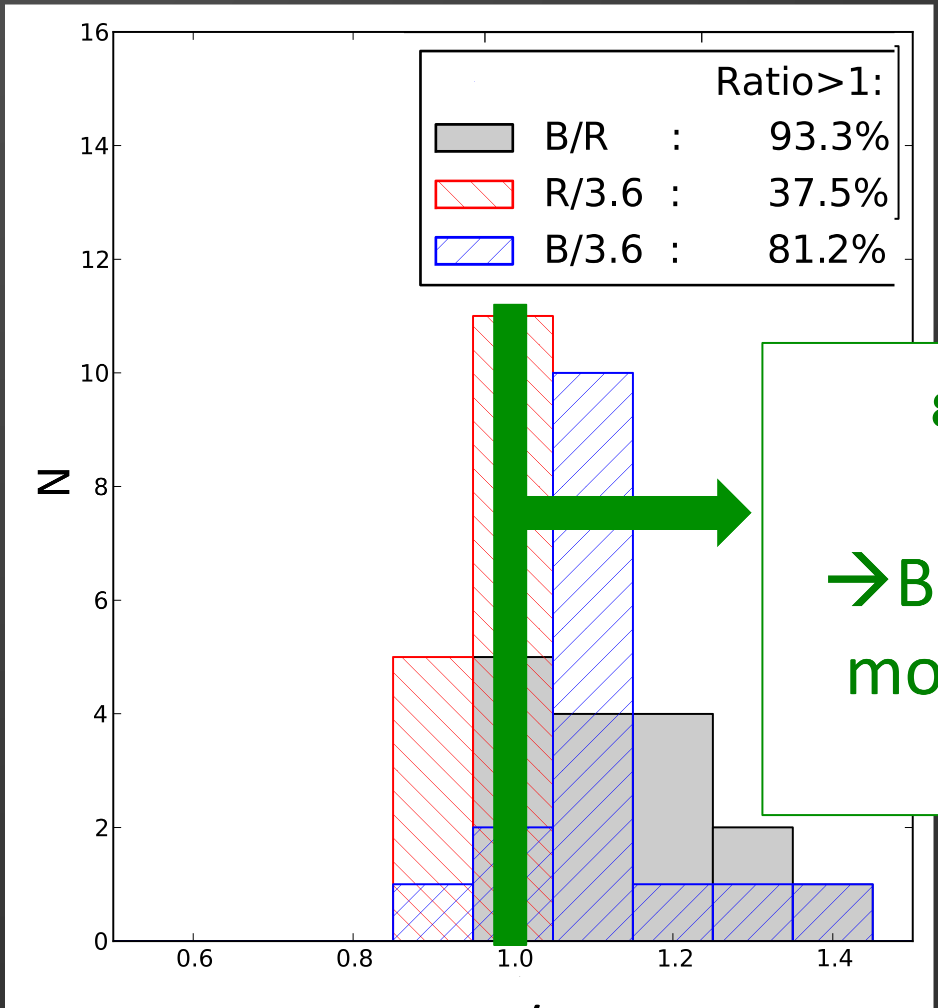


2nd result: bars look thinner in bluer bands



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

2nd result: bars look thinner in bluer bands



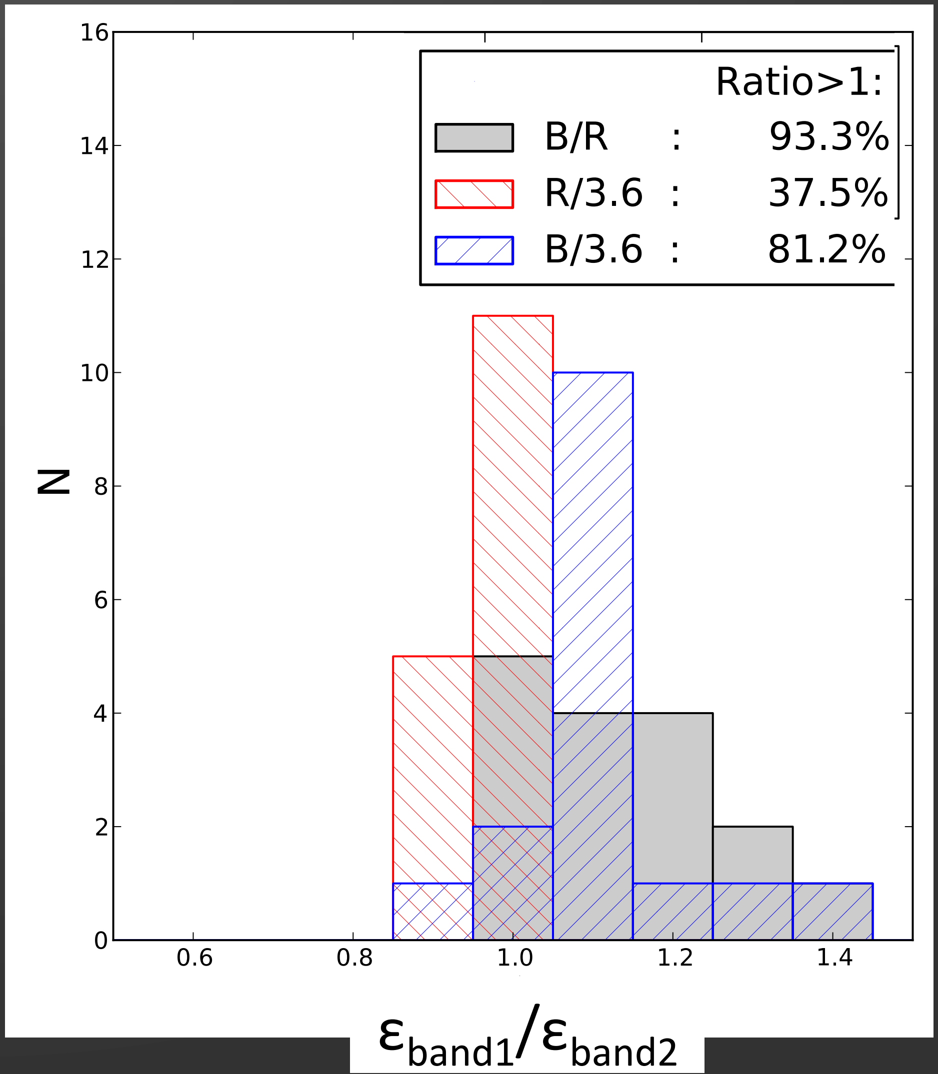
$\varepsilon_{band1}/\varepsilon_{band2}$

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

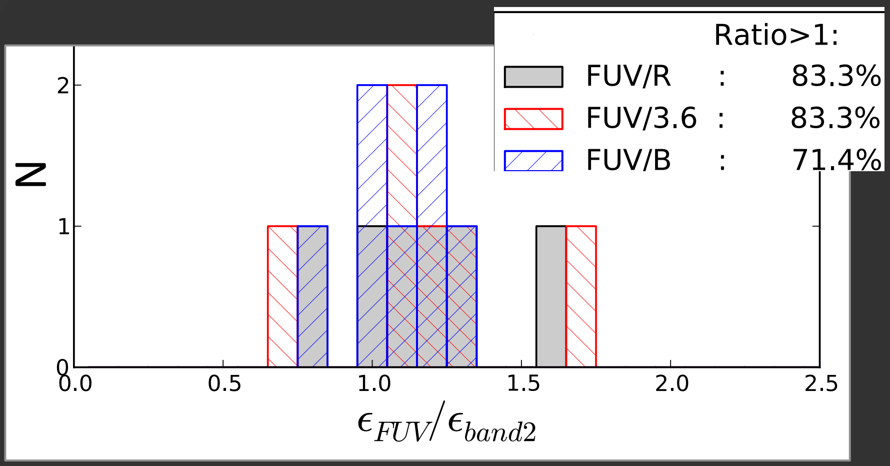
$\varepsilon_{band1}/\varepsilon_{band2} > 1$

→ Bar measured to be more elliptical in the bluer band

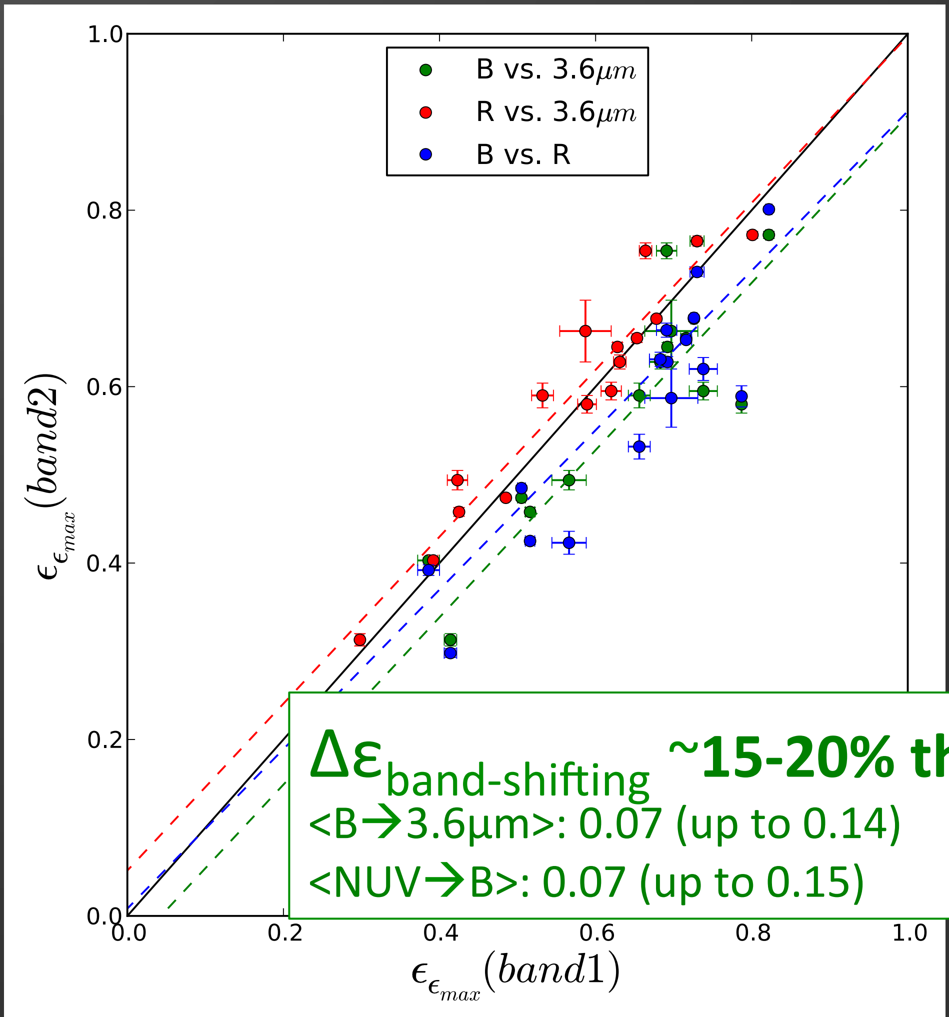
2nd result: bars look thinner in bluer bands



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



2^{nd} 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
- 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

The bluer the restframe band, the thinner the bar!

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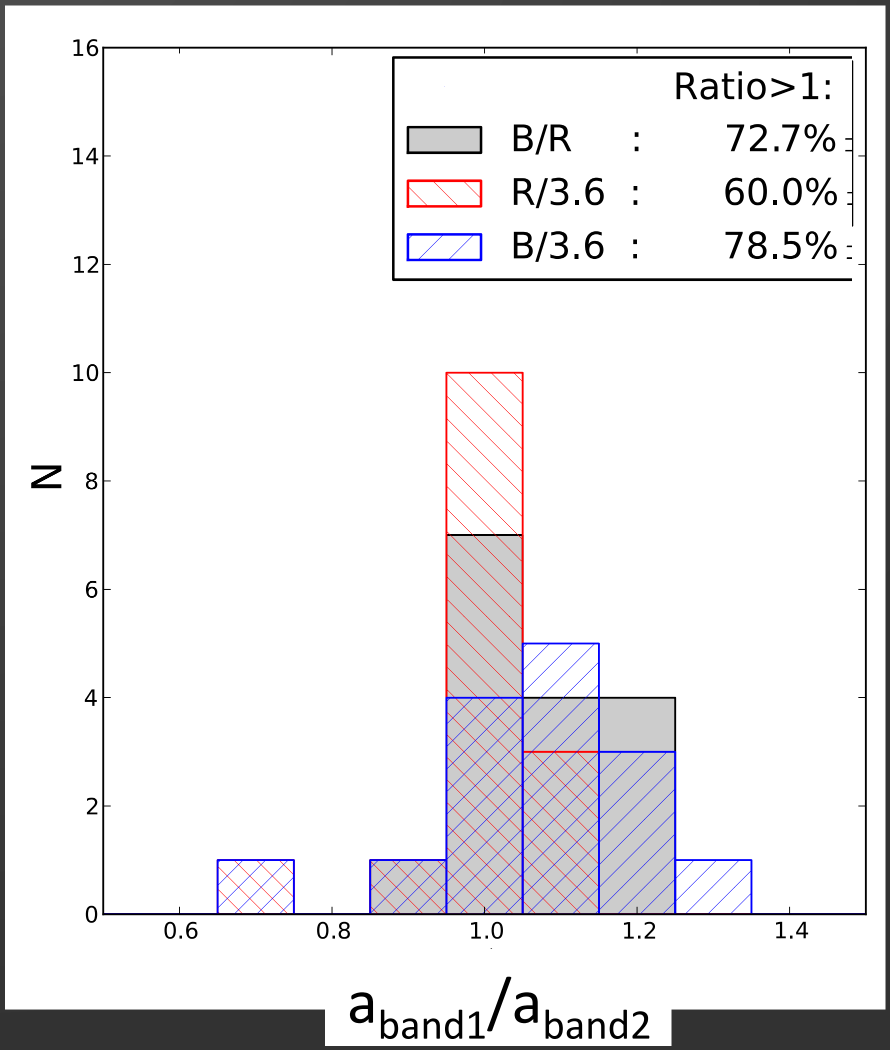
3rd result: bars look longer in bluer bands



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

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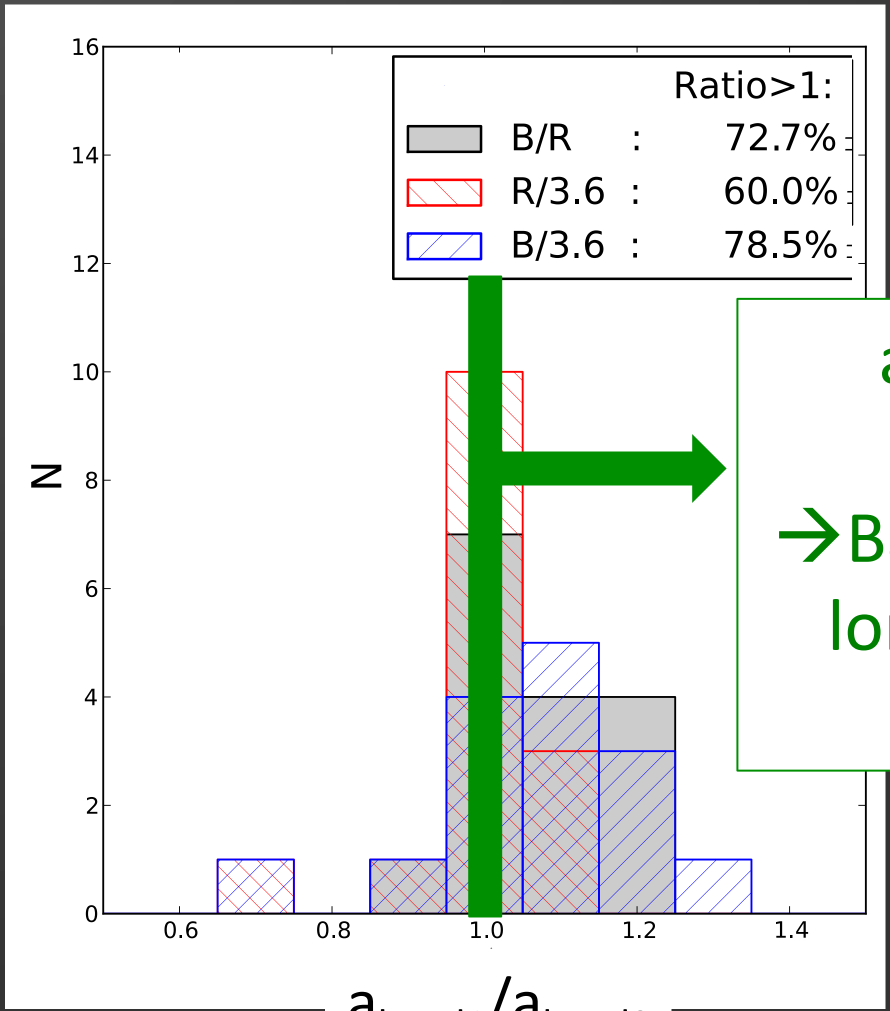


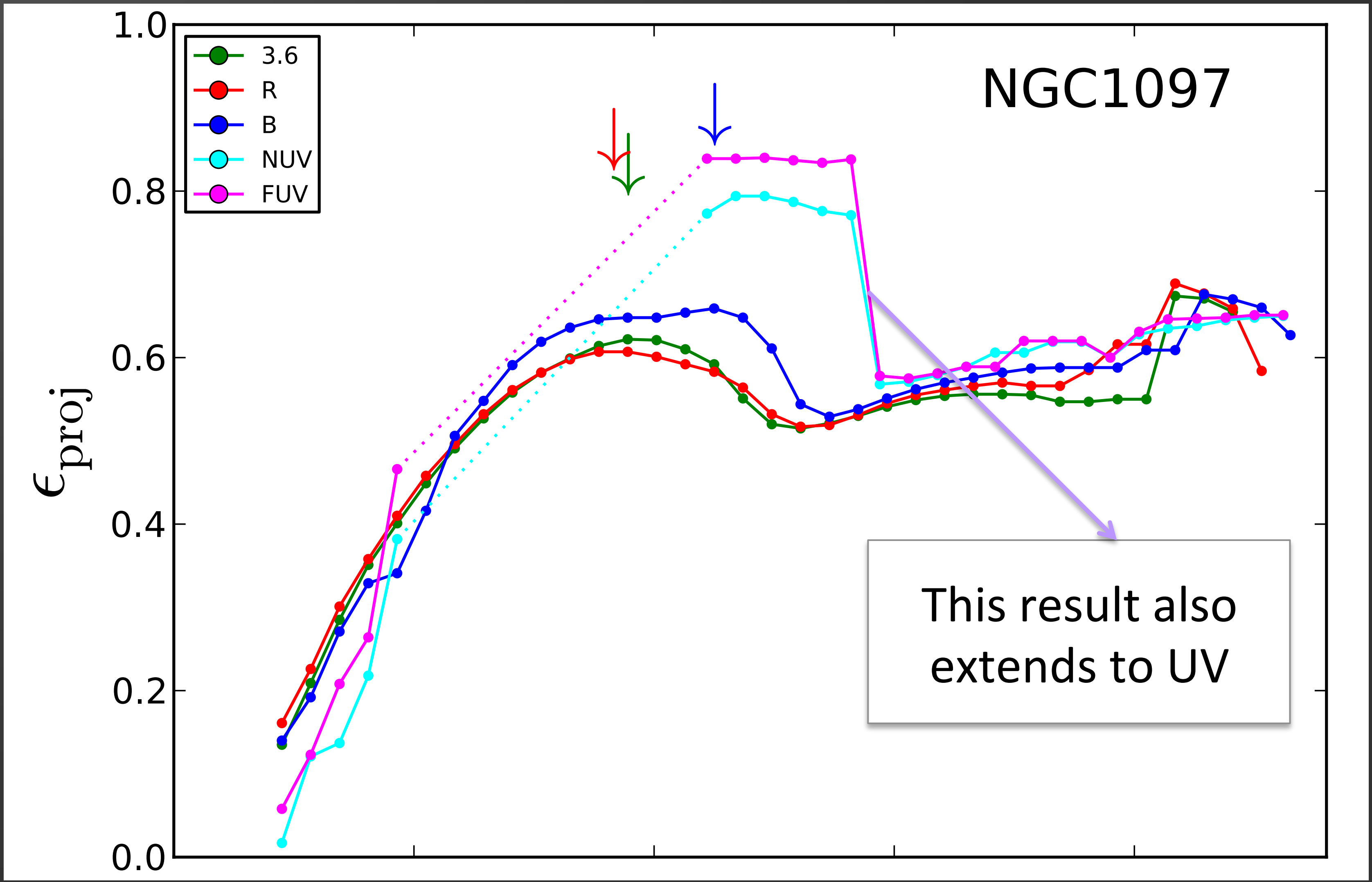
a_{band1}/a_{band2}

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

$a_{band1}/a_{band2} > 1$

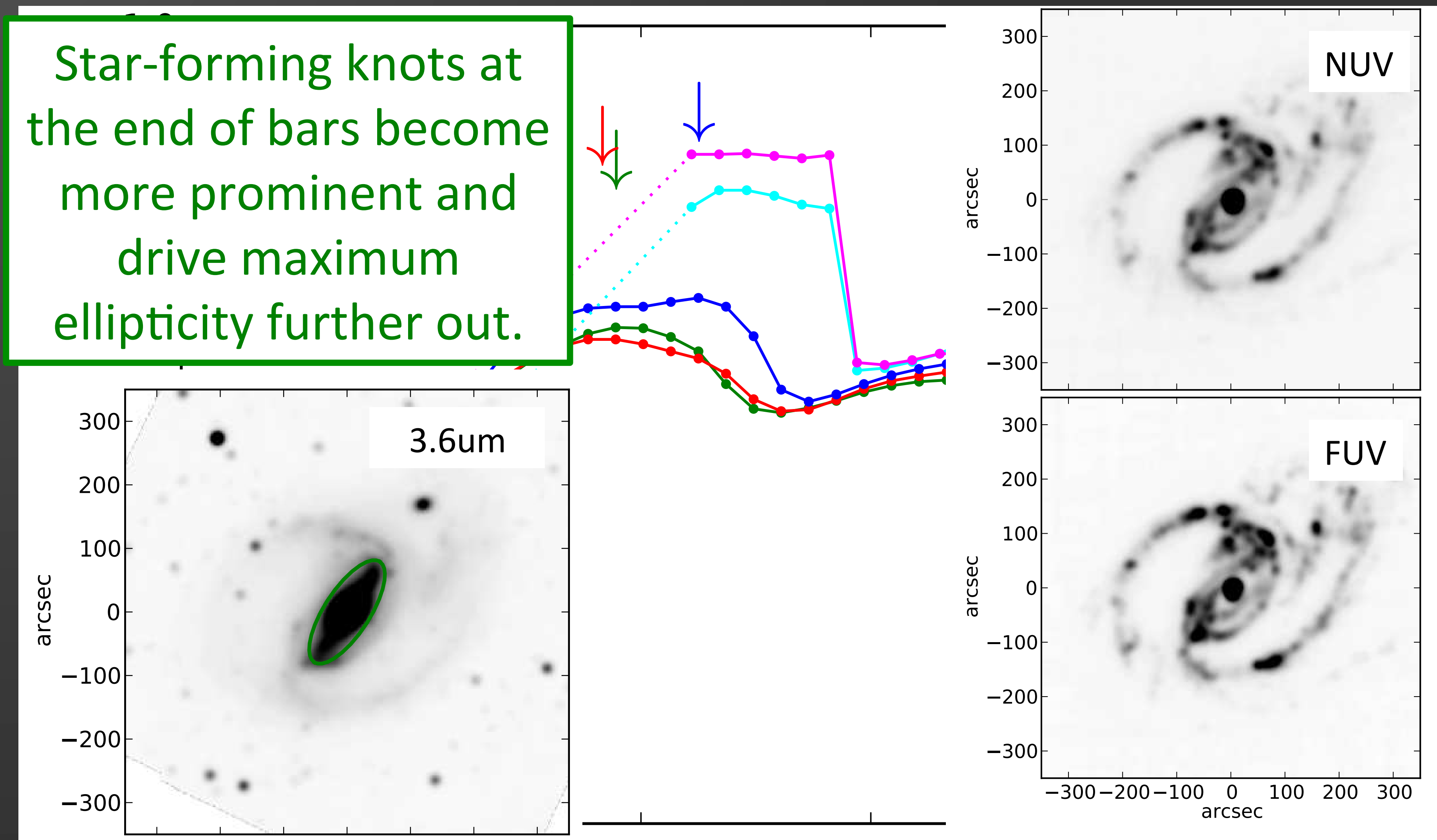
→Bar measured to be longer in the bluer band

3rd result: bars look longer in bluer bands



The bluer the restframe band, the longer the bar!

3rd result: bars look longer in bluer bands



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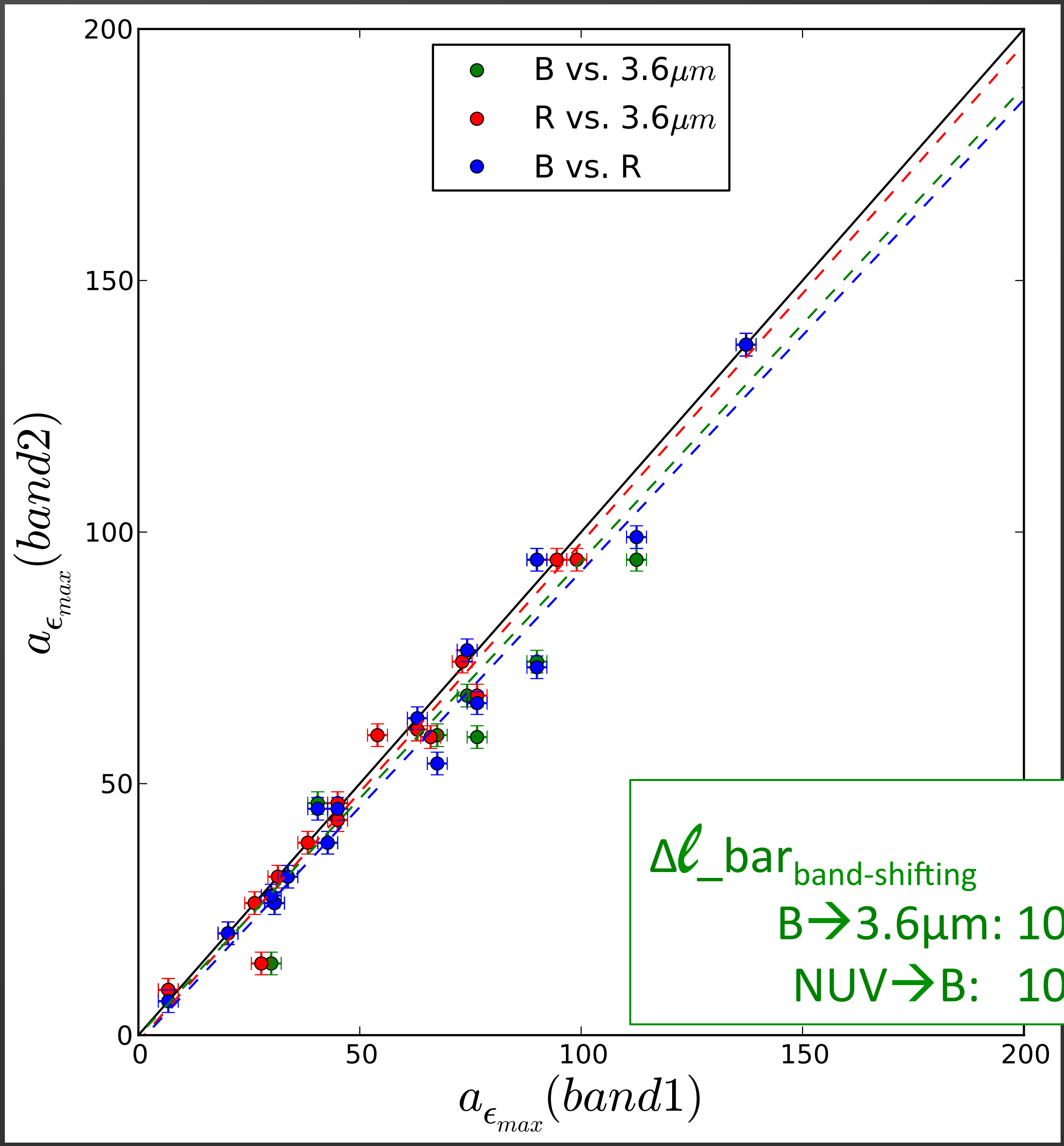
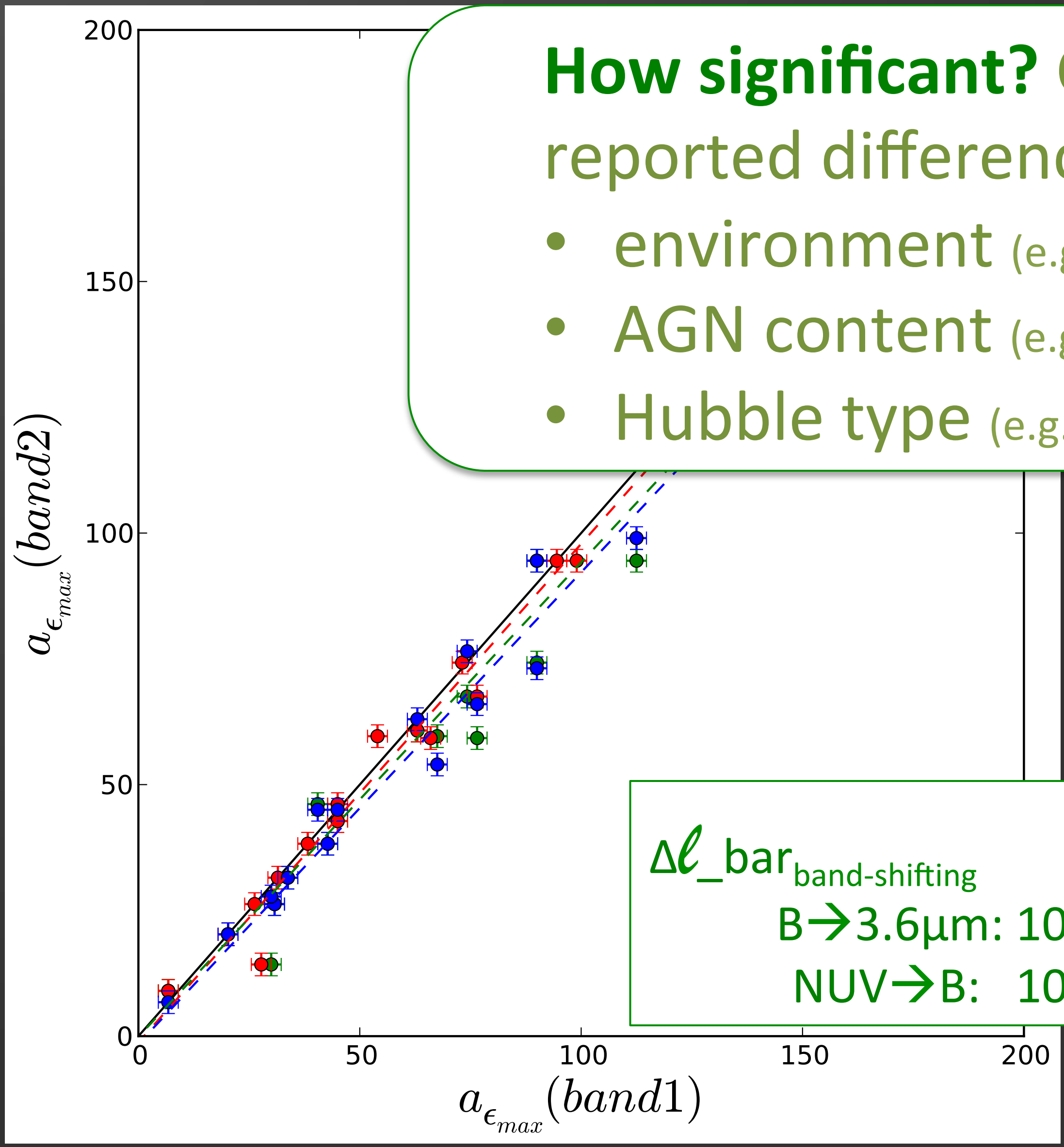


$\Delta\ell$_bar$_{\text{band-shifting}}$

B→3.6μm: 10%

NUV→B: 10%

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)

$\Delta\ell$_bar$_{\text{band-shifting}}$

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:
  - 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 get 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!

Take away points…

- As we extend bar studies out to high redshifts, our single-band studies are inevitably subject to band-shifting effects:
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    - …
    - … inent
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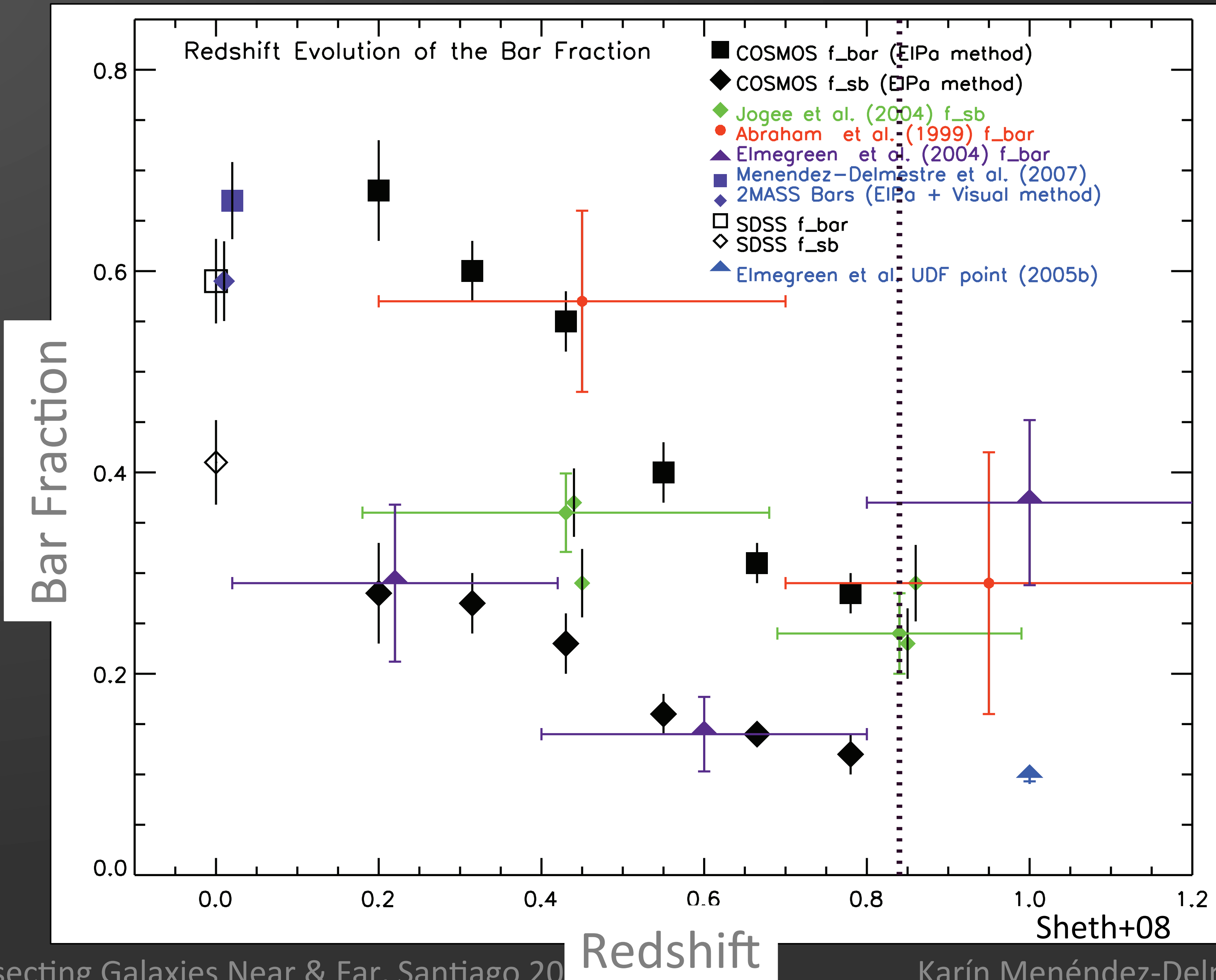
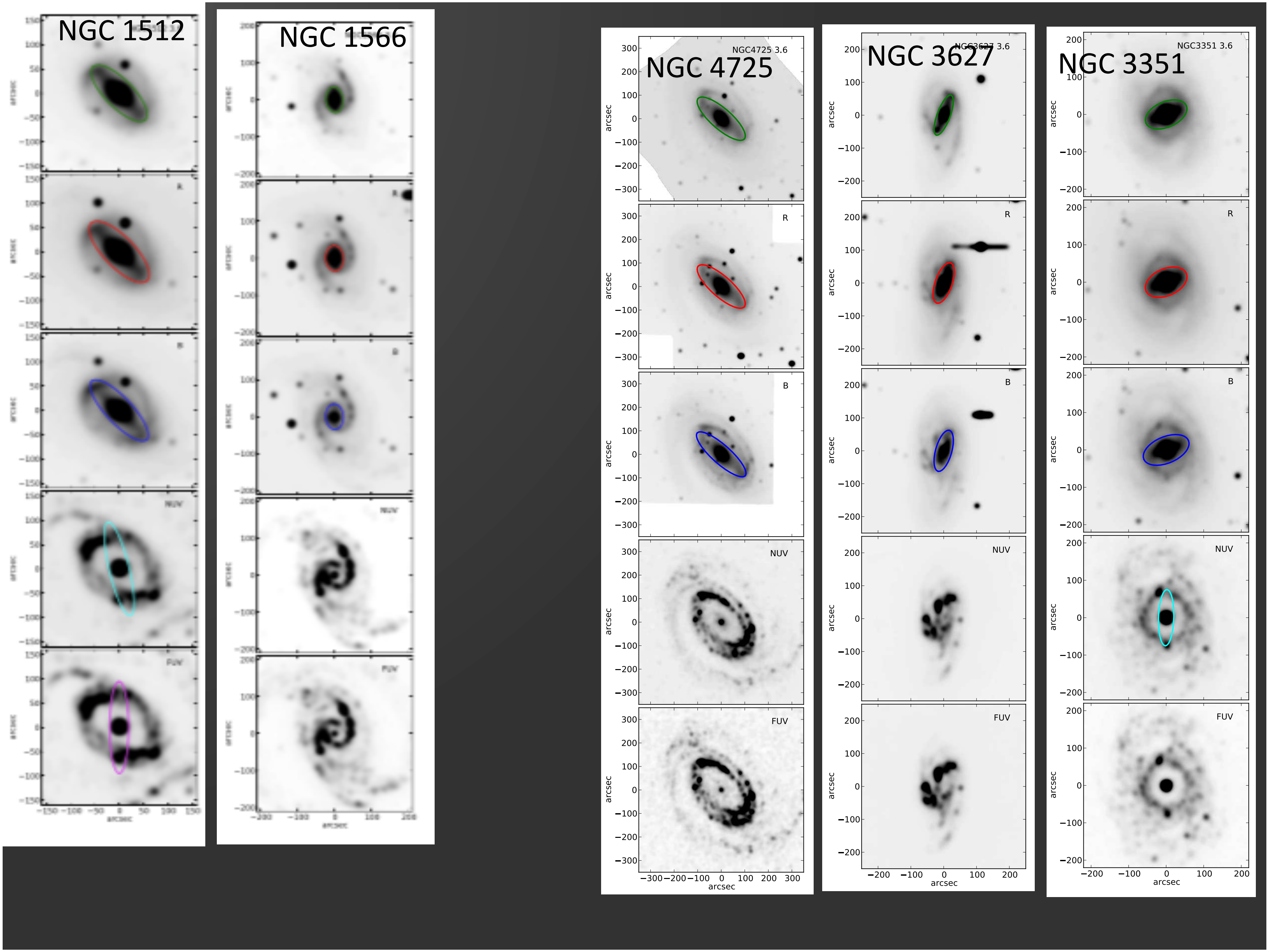
  - Need to correct for band-shifting effects even in the optical!

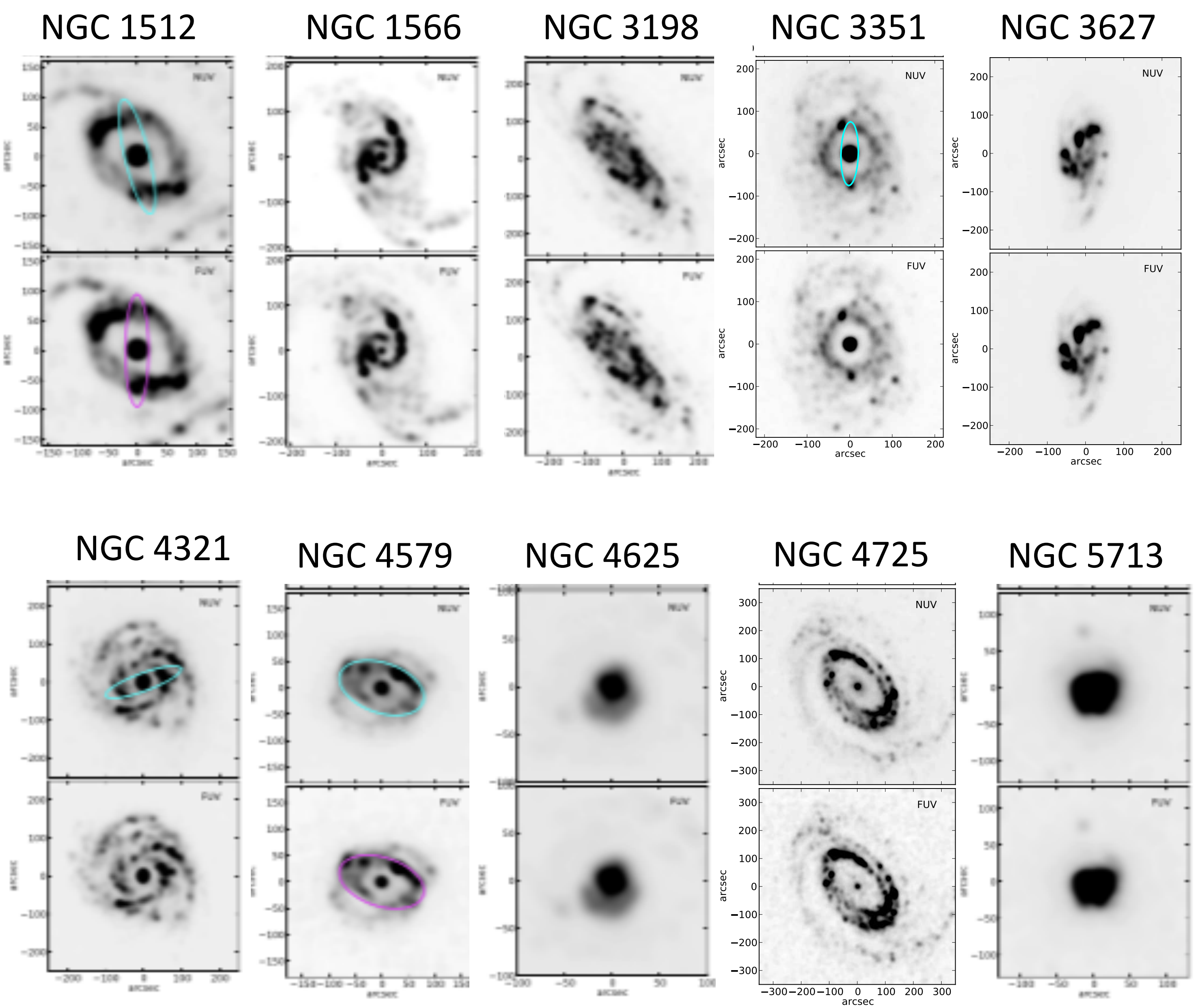
Stay tuned for

Bar properties at high-redshift!

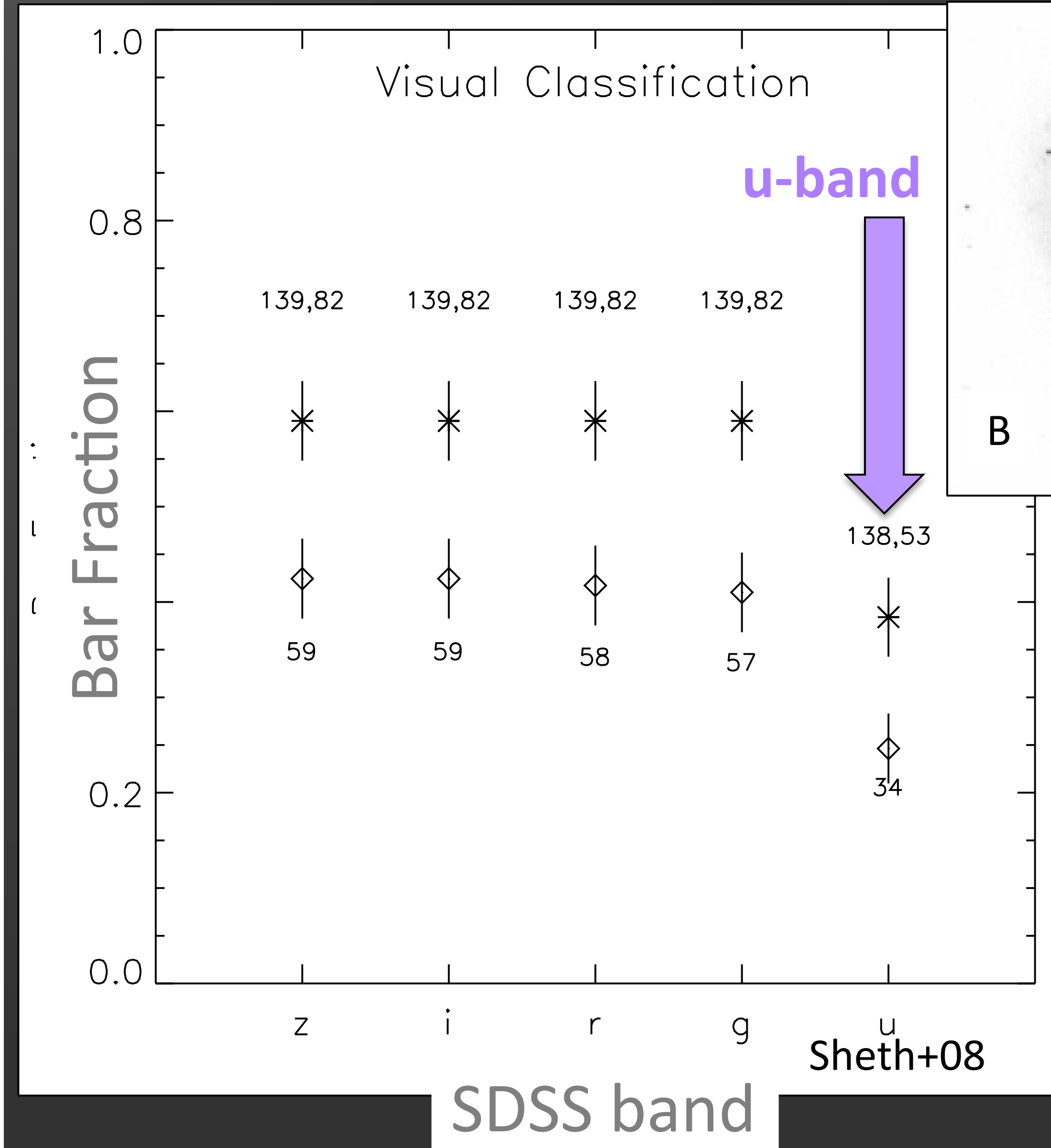

Redshift Evolution of the Bar Fraction
COSMOS f_bar (EIPa method)
COSMOS f_sb (EIPa method)
Jogee et al. (2004) f_sb
Abraham et al. (1999) f_bar
Elmegreen et al. (2004) f_bar
Menendez-Delmestre et al. (2007)
2MASS Bars (EIPa + Visual method)
SDSS f_bar
SDSS f_sb
Elmegreen et al. UDF point (2005b)
Bar Fraction
0.0
0.2
0.4
0.6
0.8
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Redshift
Sheth+08

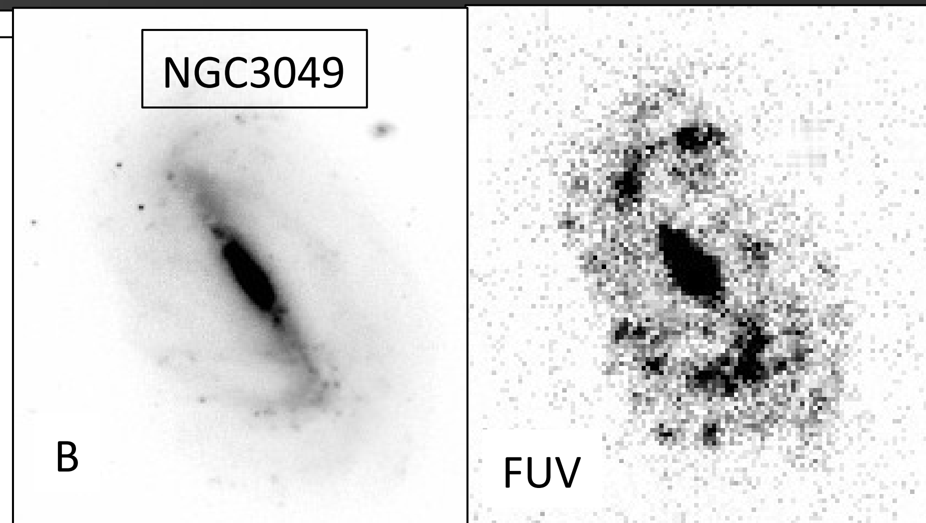


NGC 1512
NGC 1566
NGC 4725
NGC 3627
NGC 3351
NGC4725 3.6
NGC3627 3.6
NGC3351 3.6
R
B
NUV
FUV
arcsec


NGC 1512
NGC 1566
NGC 3198
NGC 3351
NGC 3627
NGC 4321
NGC 4579
NGC 4625
NGC 4725
NGC 5713
NUV
FUV
arcsec

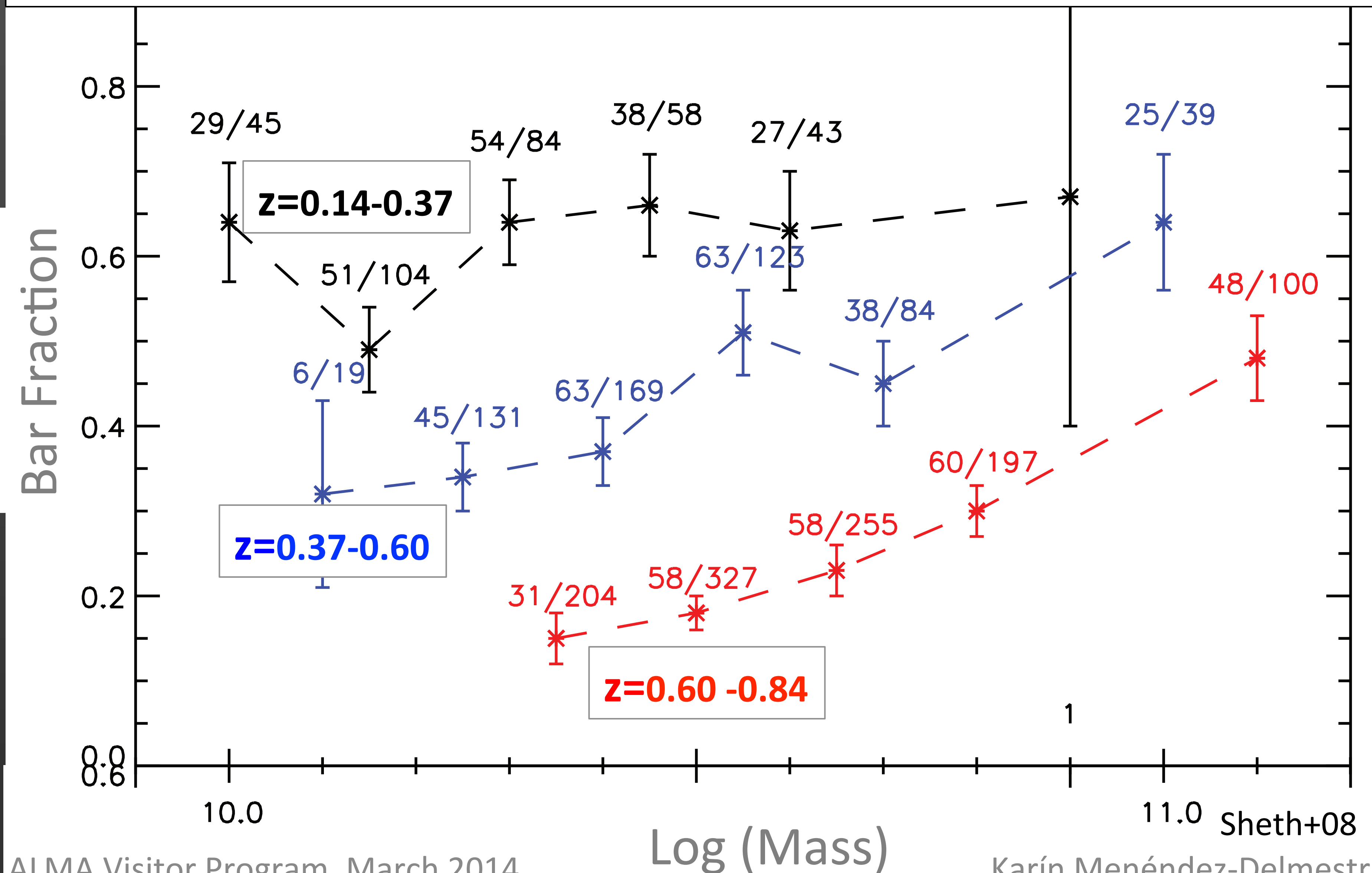
Band-shifting matters! We lose bars in the UV





- Band shifting is an issue when going to shortwards of the Balmer break
- So, restframe optical studies work out ok... but up to z~0.8!

Bar fraction declines with z, but almost exclusively in the lower mass/later-type/bluer galaxies



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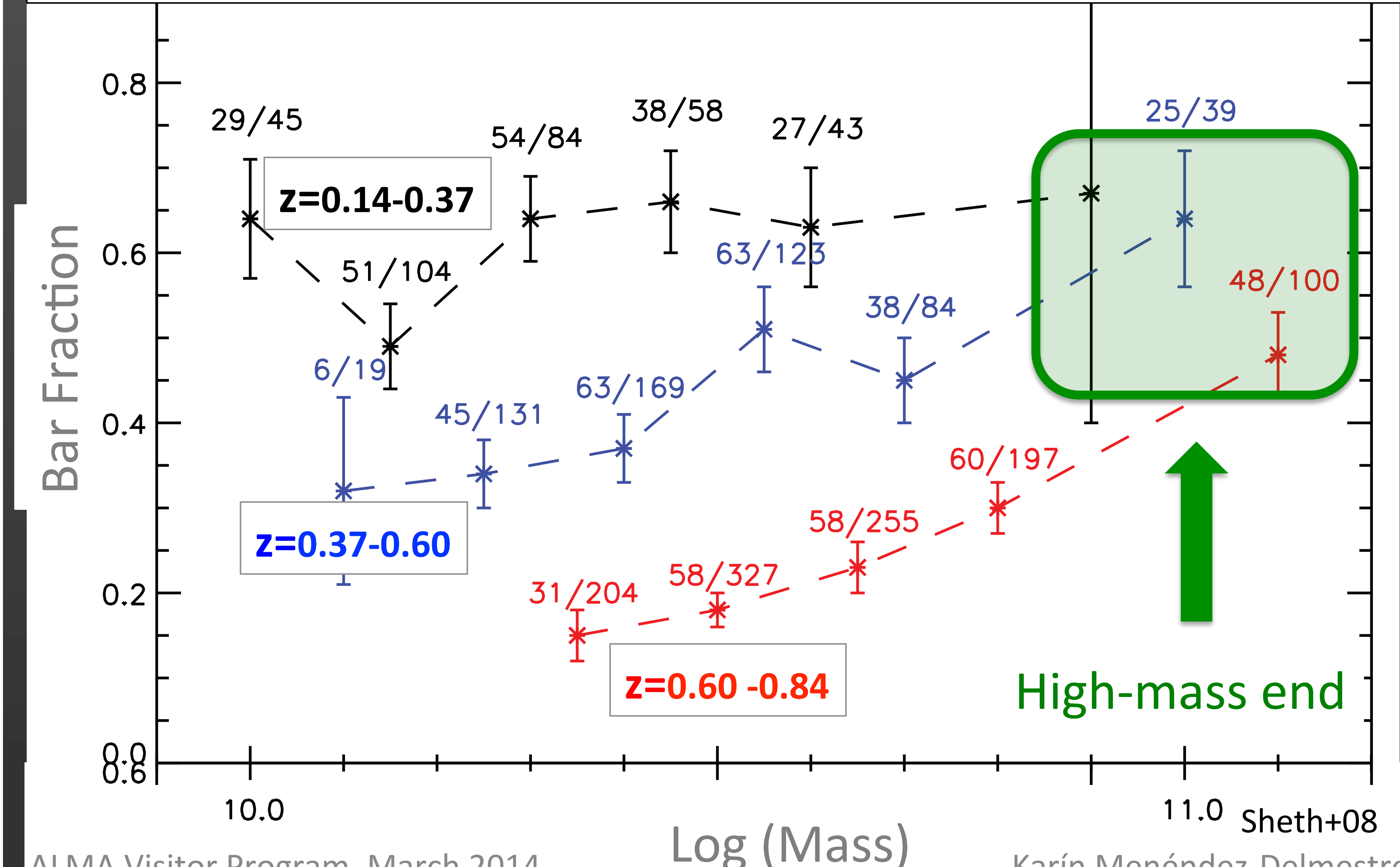

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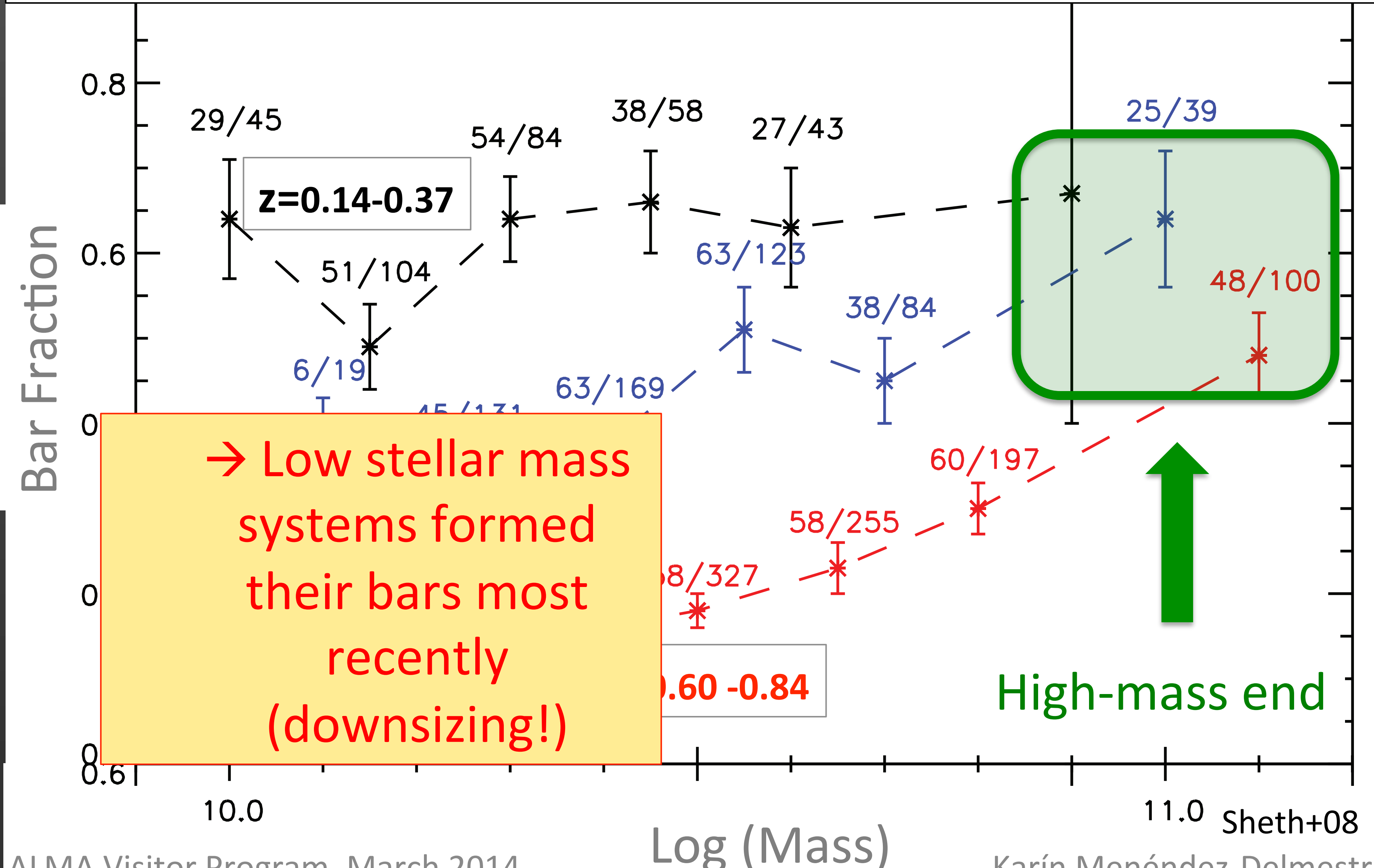

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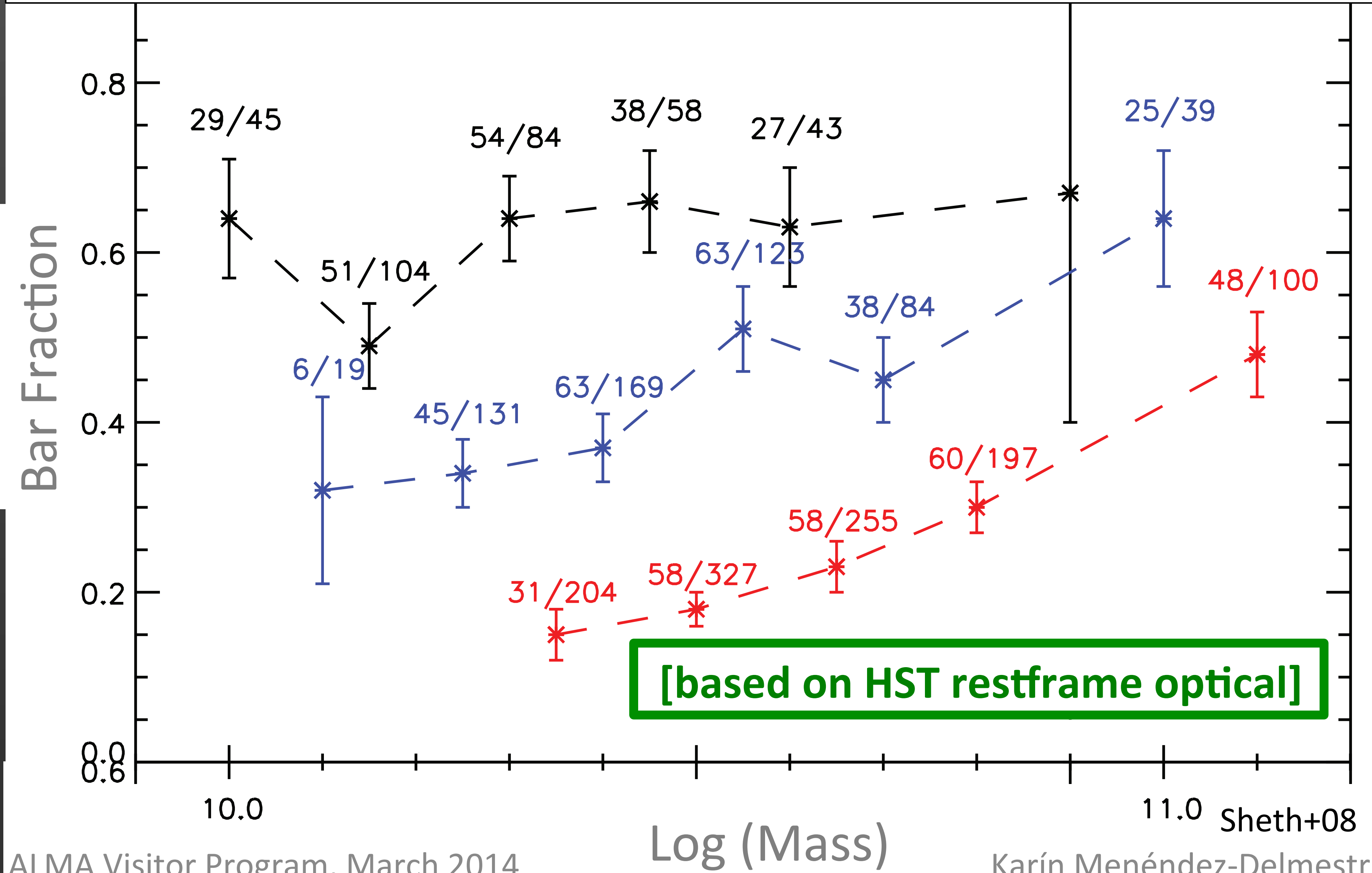

ALMA Visitor Program, March 2014

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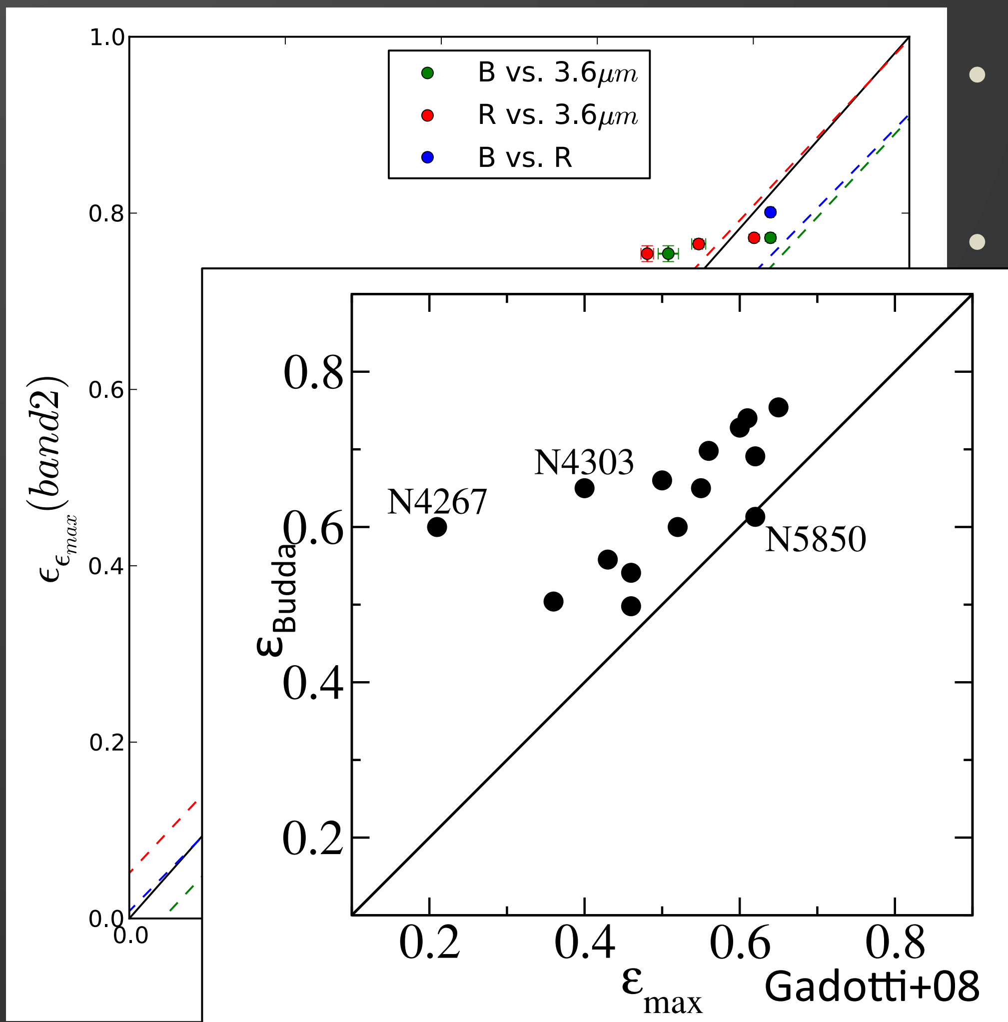
2^{nd} result: bars look thinner in bluer bands



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

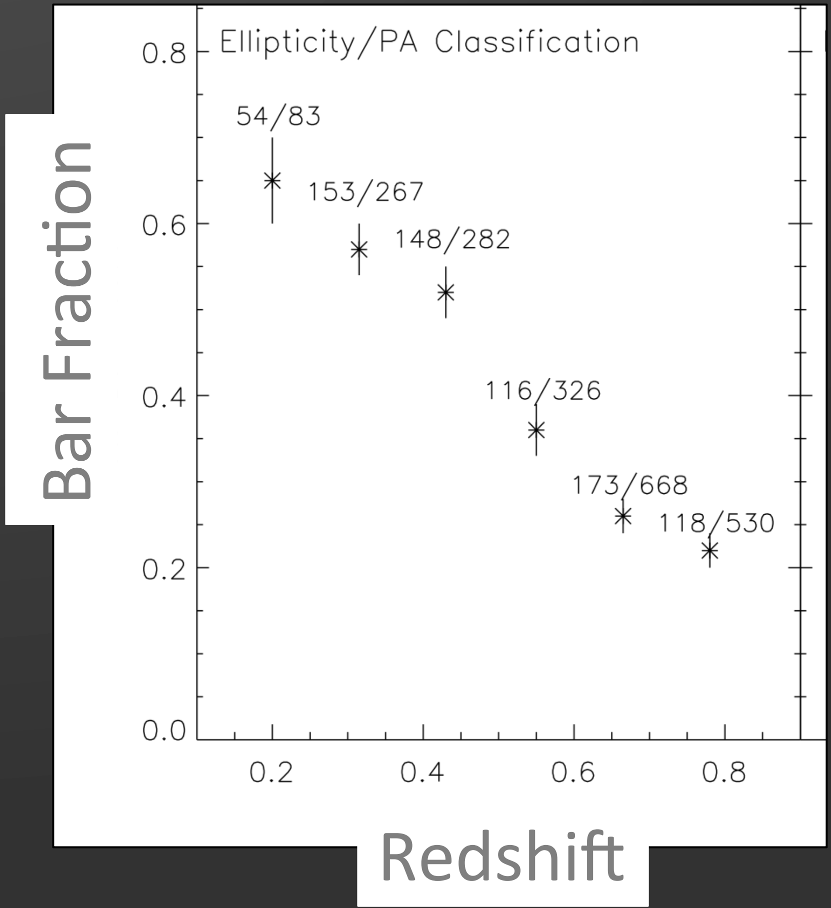
Driven by bulge sizes:

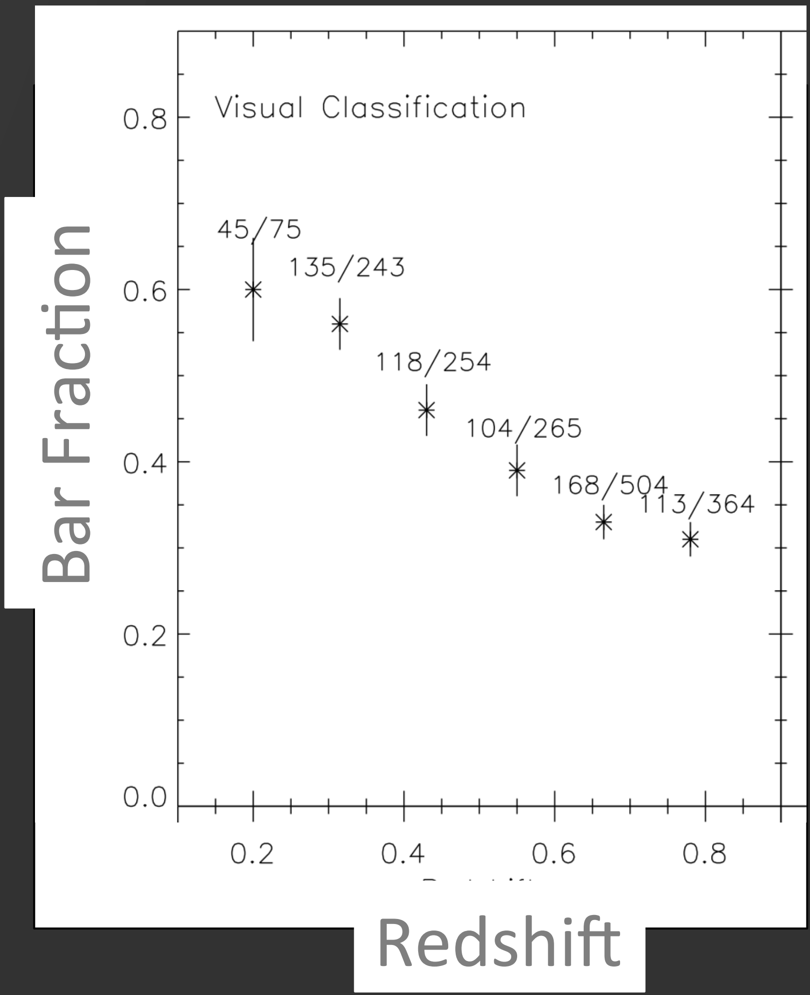
- Bulge looks bigger in redder bands → smaller in the blue
  - Limits the size of the bar semi-minor axis
- In good agreement with BUDDA results (Gadotti+08)

The bluer the restframe band, the thinner the bar!

Bar studies at high-redshift

- Bar fraction declines at high redshift
  - Based in either visual or ellip/PA classification

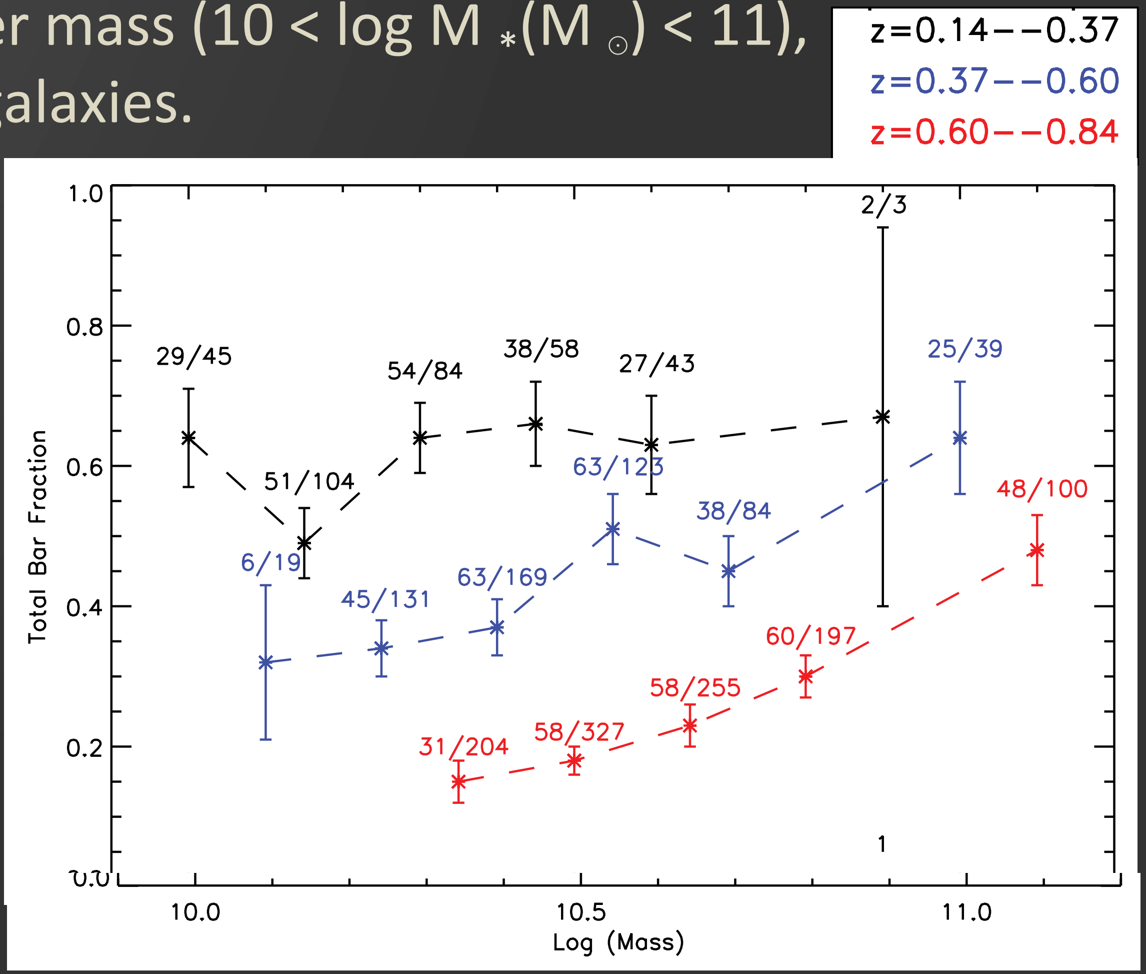




Sheth+08

Bar studies at high-redshift

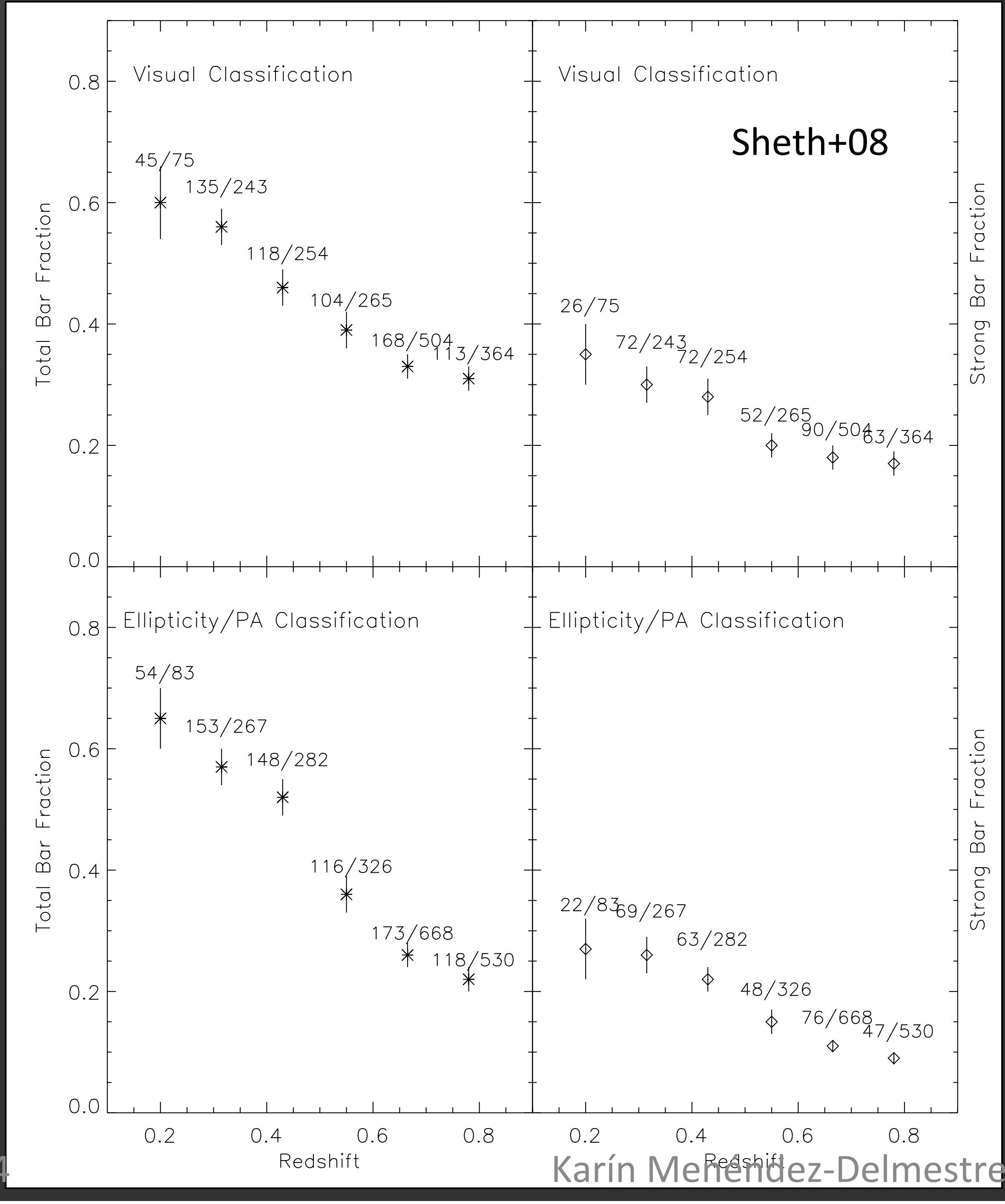
- Bar fraction declines at high redshift, but almost exclusively in the lower mass ($10 < \log M_*(M_\odot) < 11$), later-type, and bluer galaxies.



Sheth+08

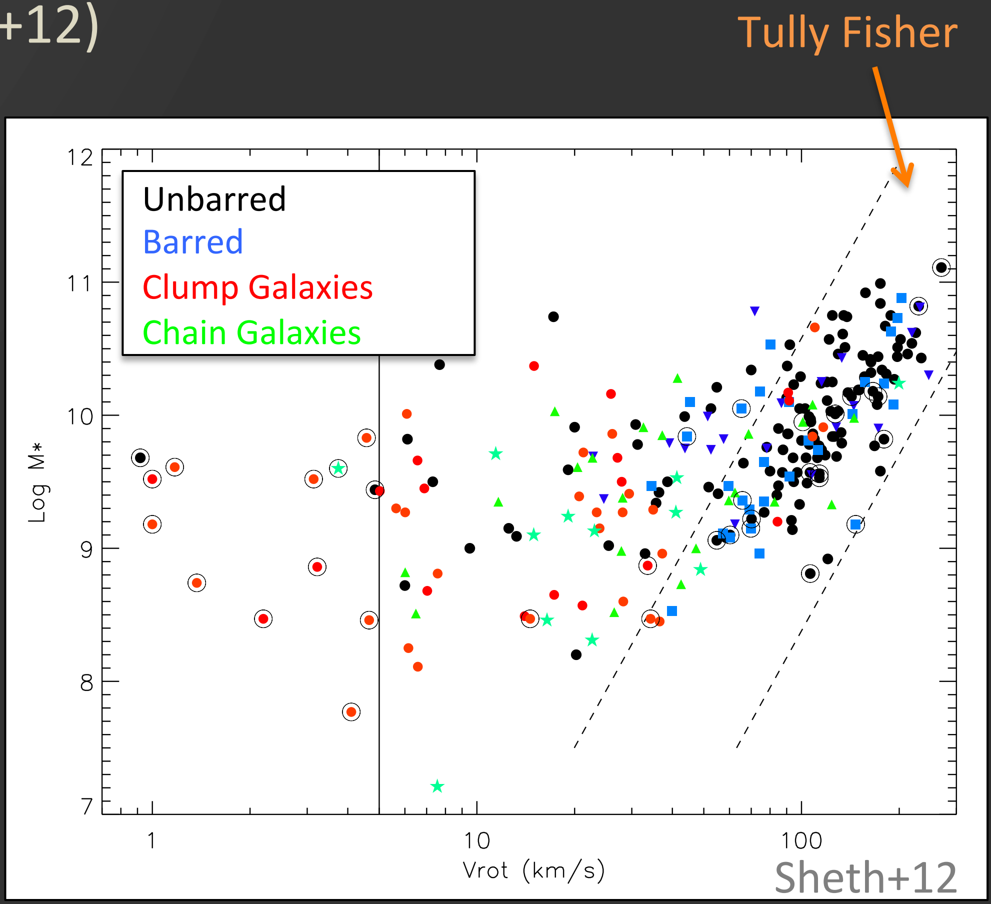
Bar studies at high-redshift

- Both the total and the strong bar fraction declines at high redshift



Bars, bars, bars

- Bars are very important cosmological signposts for inferring disk assembly
  - Disk "maturity": a galaxy disk will naturally form a bar in a couple of Gyrs unless it is dynamically hot or is dominated by dark matter.
- Local bar fraction is ~2/3 (optical: de Vaucouleurs; near-IR: KMD+07)
- Hot disks do not host bars (Sheth+12)
  - However, not every disk galaxy that is massive and cold has a stellar bar → mass and dynamic coldness of a disk are necessary but not sufficient conditions for bar formation!
  - Interaction history w/ dark matter halo is a key parameter in determining bar formation

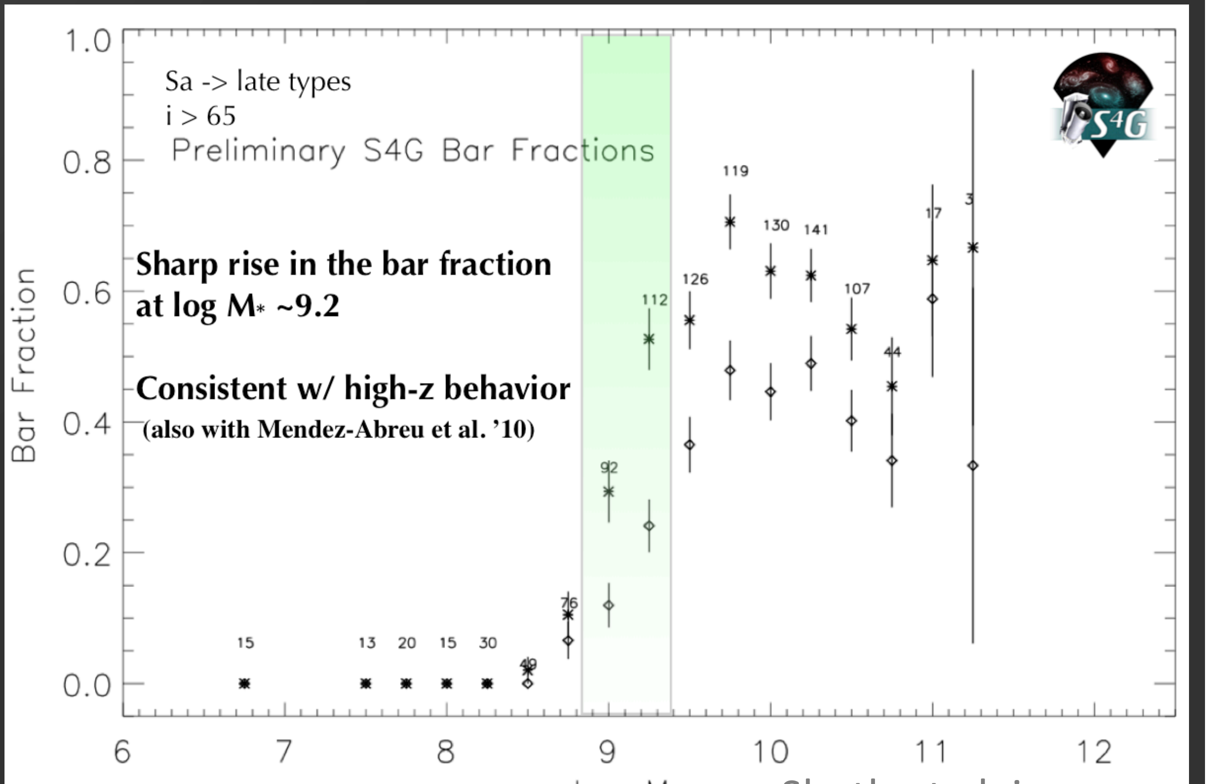


Low-mass bars… why so few?

- **Stellar mass** of the disk seems to be a key quantity with which the bar fraction evolves over time!
  - bar fraction declines at high redshift, but almost exclusively in the lower mass ($10 < \log M_*(M_\odot) < 11$), later-type, and bluer galaxies.

  → Low stellar mass systems formed their bars most recently (downsizing)

- Today log M* ~ 9.2 seems to be the turnover point for bar fraction
  - Bar fraction drops for low-mass galaxies

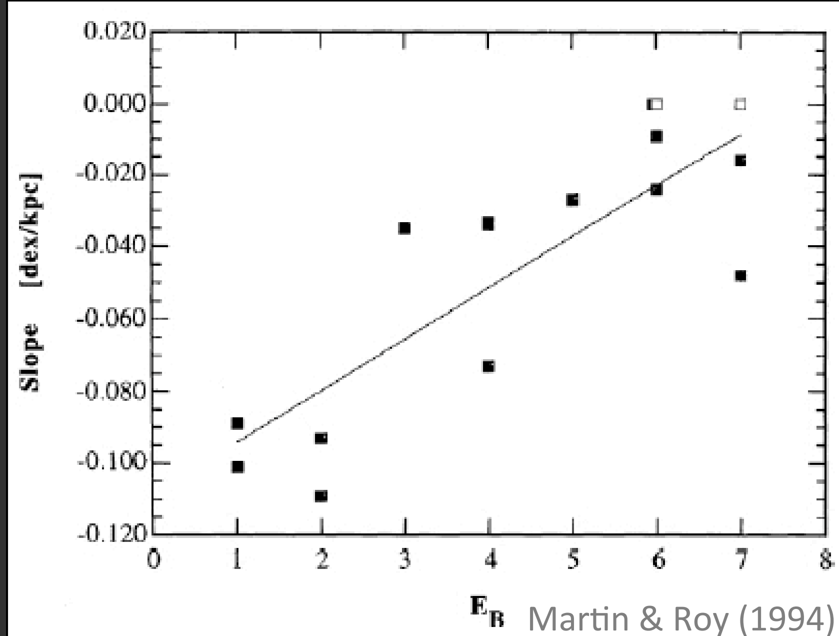


Sheth et al. in prep

Metallicity Gradients

- A bar can affect significantly its host: transporting gas inwards it can lead to a central accumulation of molecular gas (e.g., Sheth+05), triggering nuclear starbursts, leading to the formation of pseudobulges (e.g., Kormendy & Kennicutt 04) , perhaps even feeding an AGN
- Expectation that barred and unbarred galaxies should have different metallicity signatures, where barred galaxies show flat nebular emission metallicity gradients in the disk region

- slope of the O/H radial gradient as a function of bar strength → stronger bars have flatter gradients
- Furthermore, it has been suggested that bars can leave a lens behind after their dissolution → if bars indeed dissolve, one expects to find unbarred lens galaxies showing flat gradients (Gadotti et al.)



Martin & Roy (1994)

Metallicity Gradients

- A bar can affect significantly its host: transporting gas inwards it can lead to a central accumulation of molecular gas (e.g., Sheth+05), triggering nuclear starbursts, leading to the formation of pseudobulges (e.g., Kormendy & Kennicutt 04) , perhaps even feeding an AGN
- Expectation that barred and unbarred galaxies should have different metallicity signatures, where barred galaxies show flat nebular emission metallicity gradients in the disk region
- However, current CALIFA studies are coming out "empty handed" on this respect (see also Sánchez-Blázquez+11) ; Calar Alto Legacy Integral Field Area Survey (Sánchez+12) of ~600 local galaxies
- Cacho+13, Ruiz-Lara+13: find no difference in the gaseous or stellar abundances (and distribution) of barred and unbarred galaxies
  - Based on STARLIGHT, applied in a sistematic way to all CALIFA galaxies → evolutionary curves and radial profiles of physical properties
- The jury is still out!
  - Difficult to break the age-metallicity degeneracy

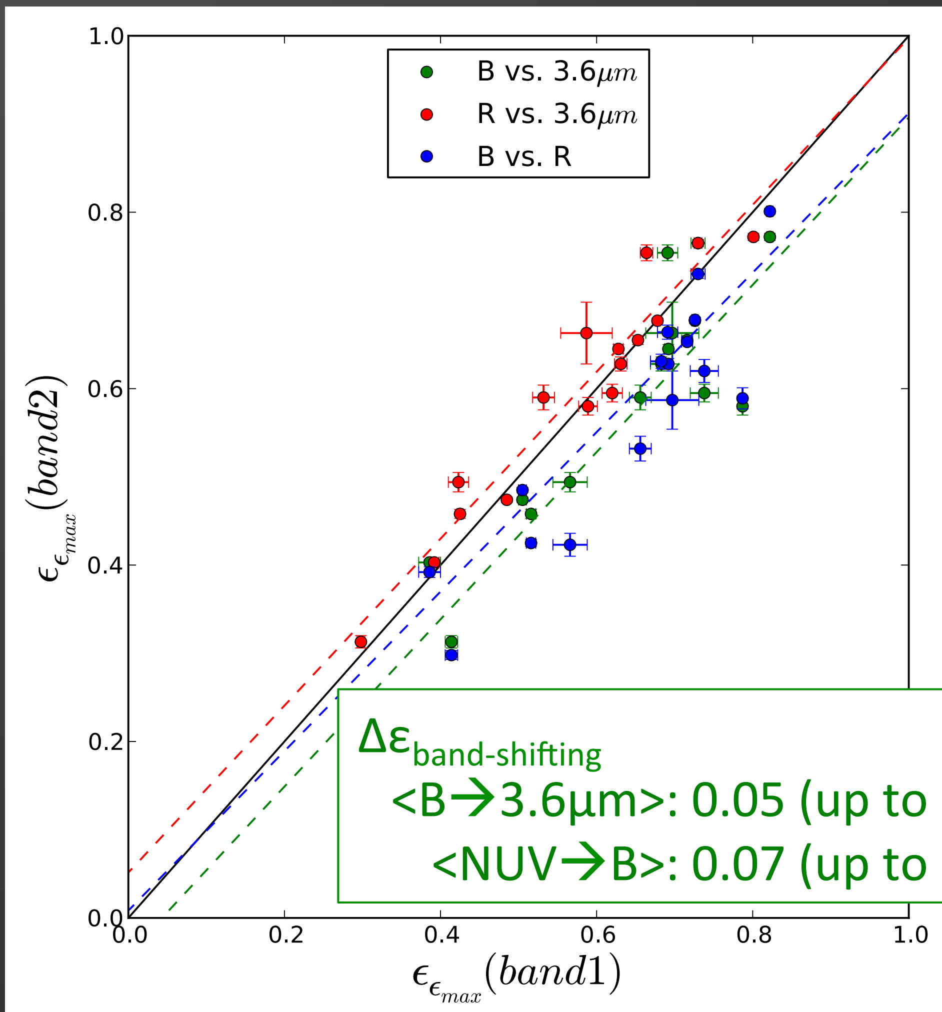
Bars in the Local Universe

- Locally, 2/3 of all disk galaxies have a bar.
- 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?
  - 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)

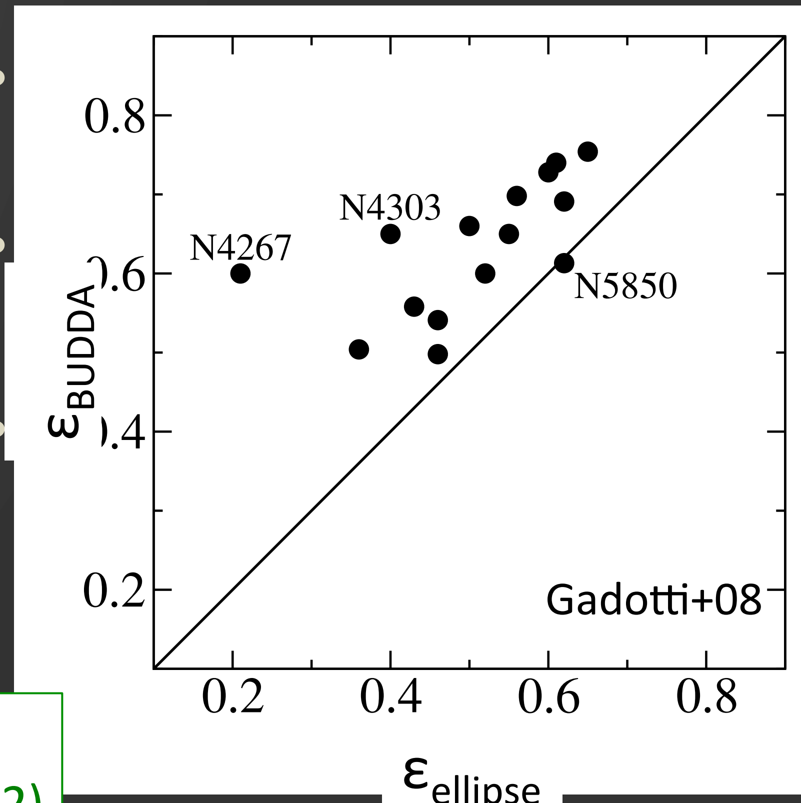
2^{nd} result: bars look thinner in bluer bands



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

<B→3.6μm>: 0.05 (up to 0.2)

<NUV→B>: 0.07 (up to 0.3)

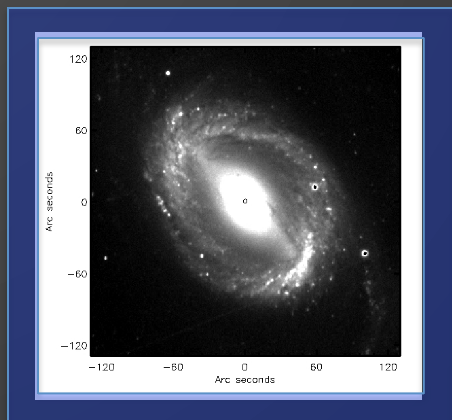


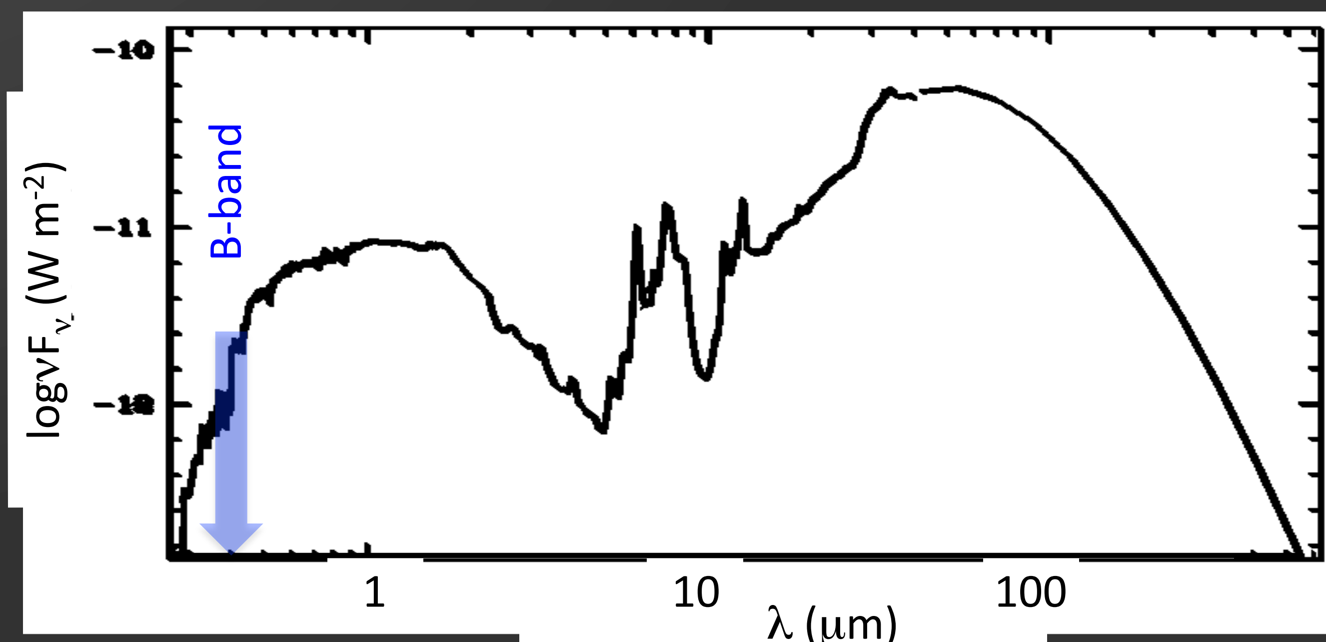
- In good agreement with BUDDA results (Gadotti+08)

The bluer the restframe band, the thinner the bar!

An example…

NGC 1512

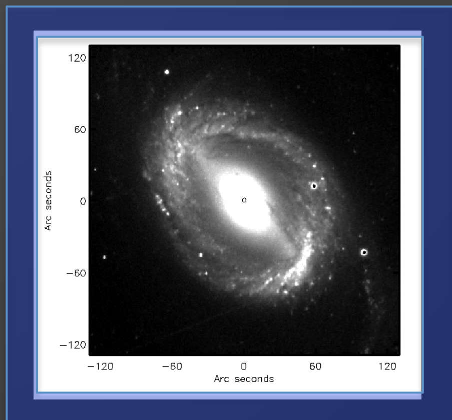


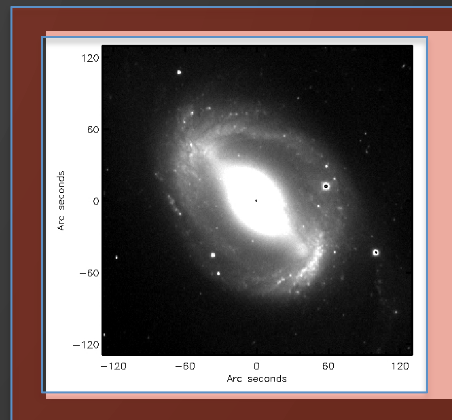


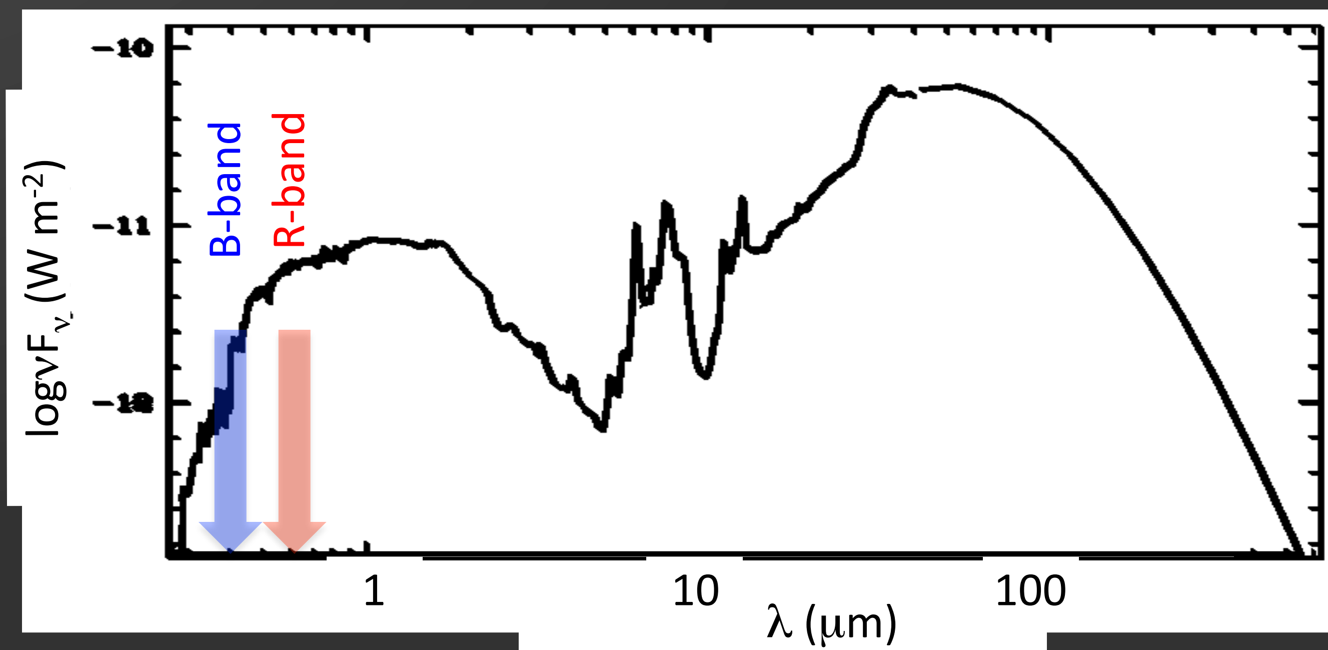
M82 (Kennicutt et al. 2003)

An example…

NGC 1512



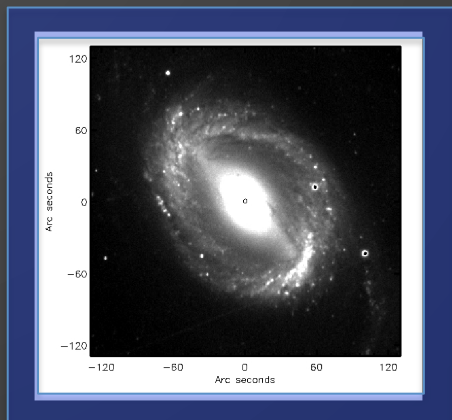


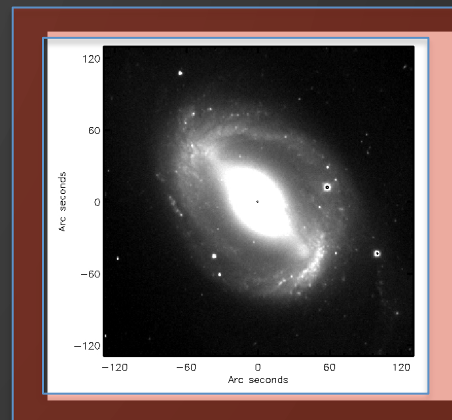


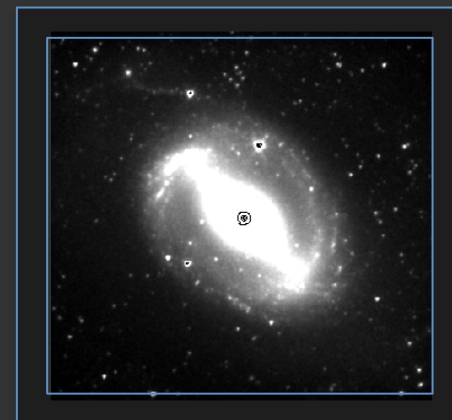
M82 (Kennicutt et al. 2003)

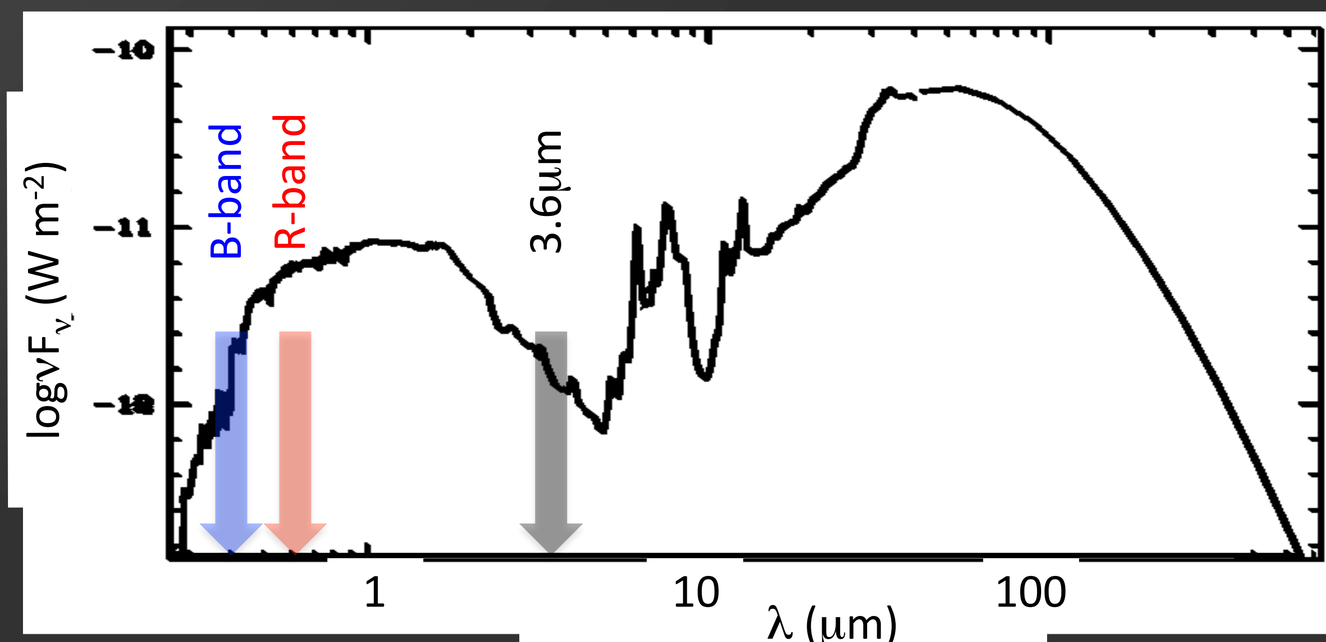
An example…

NGC 1512









M82 (Kennicutt et al. 2003)