Evidence for Secular Evolution in (non-barred) Spiral Galaxies

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Organisation of Talk

- Structural Correlations of Bulges and Disks:
  - Motivation / Historical Perspective
  - Observations
  - Simulations
  - Decompositions and Constraints:
    Correlated Exponential Bulges and Disks
  - Type I vs II, Transition, Bulgeless, Truncated …
- Colour / Population Continuity
- Spectroscopic Evidence for Secular Evolution

Structure of Bulges and Disks

Motivation:

- Need a prescription to characterize structural evolution of galaxies
  ⇒ stability, versatility (e.g. are scale lengths stable?)

- Understand bulge/disk formation process(es):
  do bulges form before/after/simultaneously with the initial disk?
  ⇒ if sec. evolution, expect $n<2$ central profiles
  ⇒ if accretion/merger, expect $n>2$ central profiles
  ⇒ best discriminant: population/kinematical data

- Understand differences between Type I/II spirals:
  Bars, dust, young stellar population (inner disk truncation)?

- Locally, study population/dust effects on structural parameters
  (e.g. Sercic n, scale lengths, B/T ratios) and colour/pop. gradients

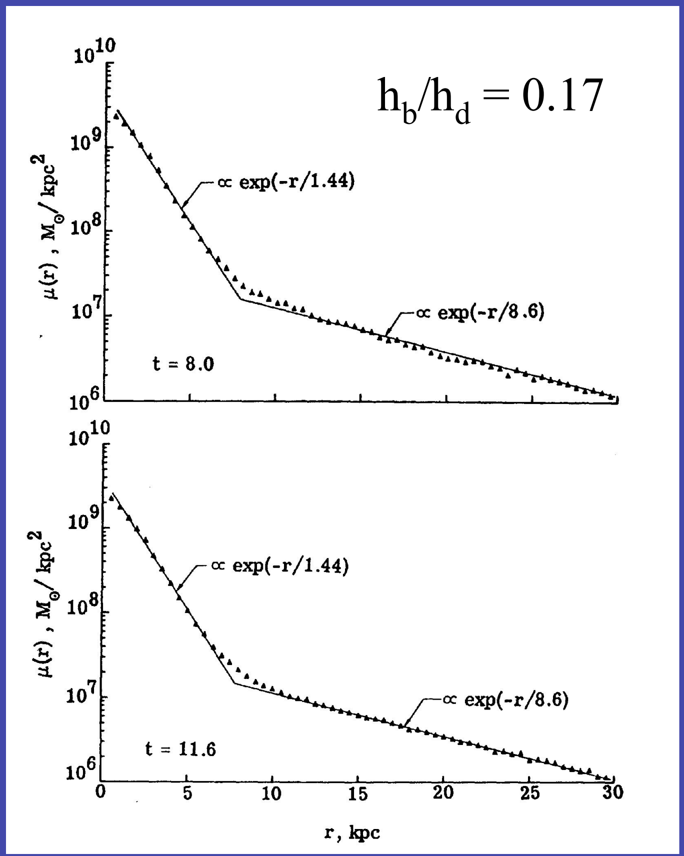
Structure of Bulges and Disks

- Spiral bulges are nearly exponential:

Hohl 1971 (ApJ, 168, 343)

"*Numerical Experiments with a Disk of Stars*"

⇒ "The final distribution gives a high-density central core and a disk population of stars that are closely approximated by an exponential variation"



Modern reference (observations):

Andredakis et al 1995

(MNRAS, 275, 874)

[already addressed by van Houten 1961, Burstein 1979, Elmegreen^2 1985, Kent 1986 …]

Structure of Bulges and Disks

- Bulges and disks have *correlated* exponential scale lengths:

Courteau, de Jong & Broeils (1996, ApJL, 457, 73)

“Evidence for Secular Evolution in Spiral Galaxies”

326 nearby bright UGC spiral galaxies (<i> = 60°)

⇒ scale length ratio uncorrelated with Hubble type, with $h_b/h_d \approx 0.1 \pm 0.04$ (~ consistent with Hohl)

⇒ “*This suggests a scale-free Hubble sequence of spiral galaxies*”

caveat: used fixed Sersic n, single r-band (some K-band), mostly late-types

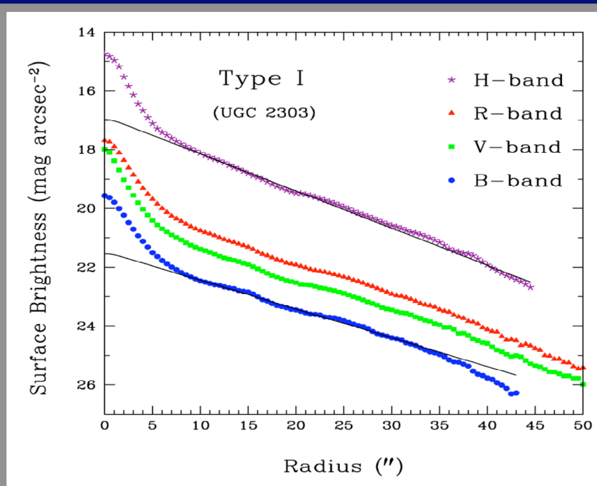
Structure of Bulges and Disks

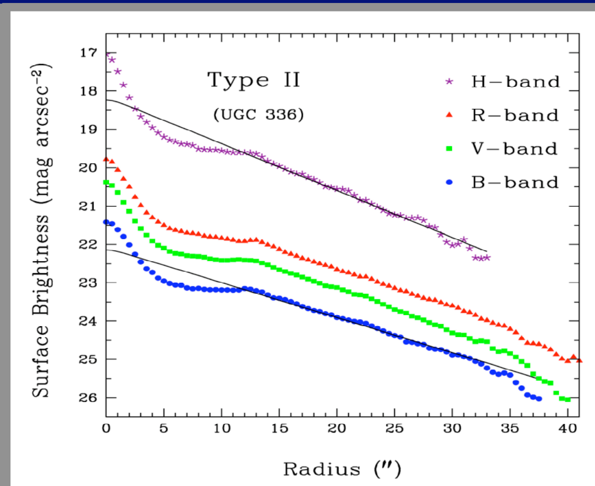
- Need for multi-wavelength analysis with full range of n:
  MacArthur, Courteau, & Holtzman (2003, ApJ, 582, 689)

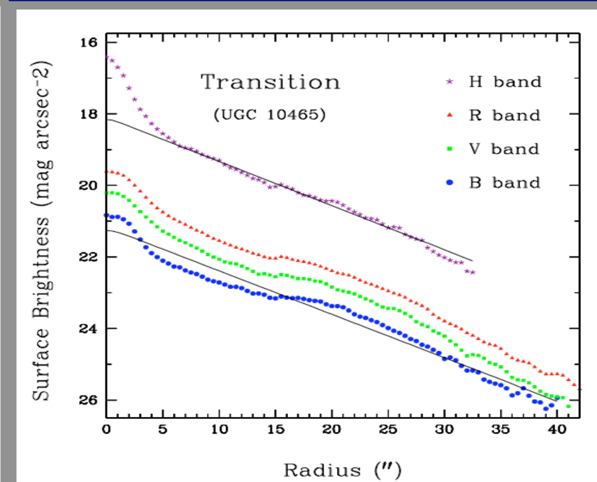
  " Structure of Disk-Dominated Galaxies. I. Bulge/Disk Parameters, Simulations, and Secular Evolution"

– Model B/D parameters in BVRH for 121 face-on & moderately tilted late-type bright spirals
  > only include those that can be fit properly.

– Type I (43%), Type II (44%), Transition (13%)

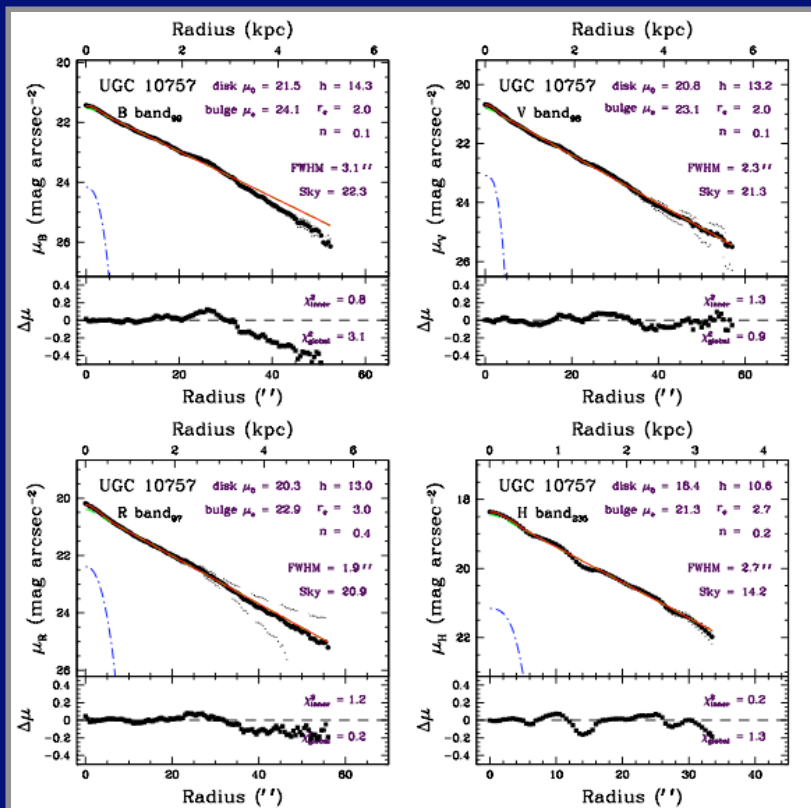


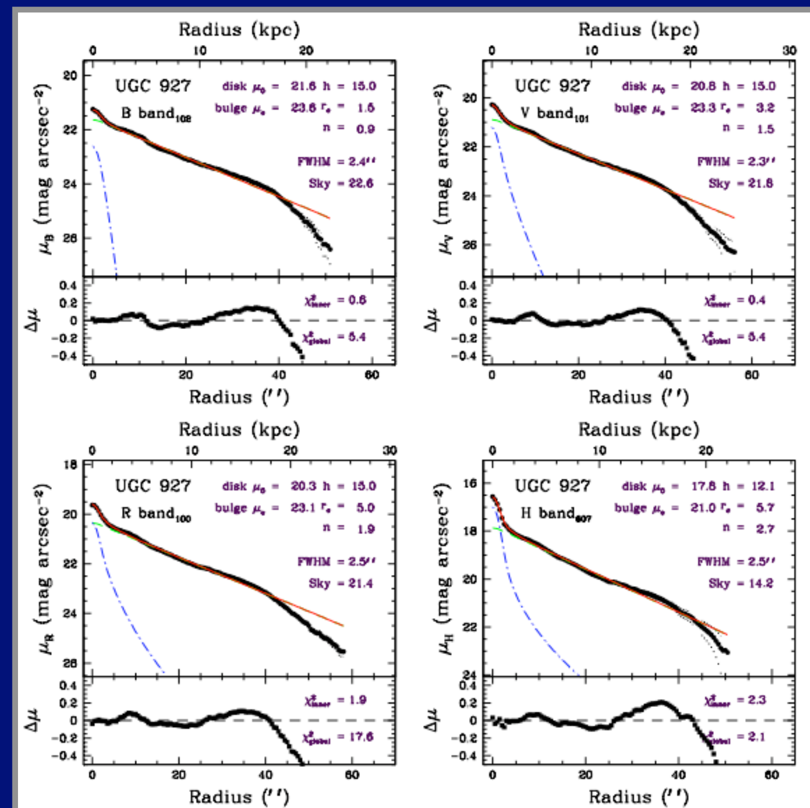




Structure of Bulges and Disks

- All types of profiles: Type I, II, Transition
  also subclasses: bulgeless, truncated, Type III (Irwin)





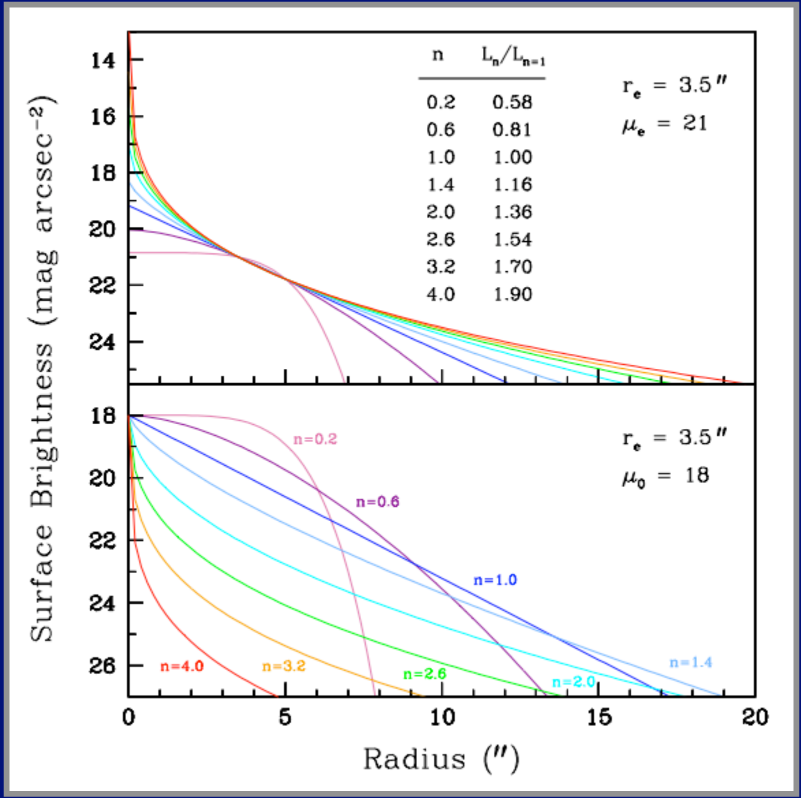
bulgeless

truncated

Bulge/Disk Decompositions

- Fit a generalized Gaussian $r^{1/n}$ profiles (Sercic 1968):

$$I(r) = I_o \exp\{-(\tfrac{r}{h})^{1/n}\}$$



- 1D vs 2D:

1D	Pros	speed, robust to initial estimates
	Cons	restricted to axi-symmetric models
2D	Pros	can model non-axisymmetric, non-spherical structures: (bars, rings, arms)
	Cons	computer intensive, very sensitive to init. estimates

Bulge/Disk Decompositions

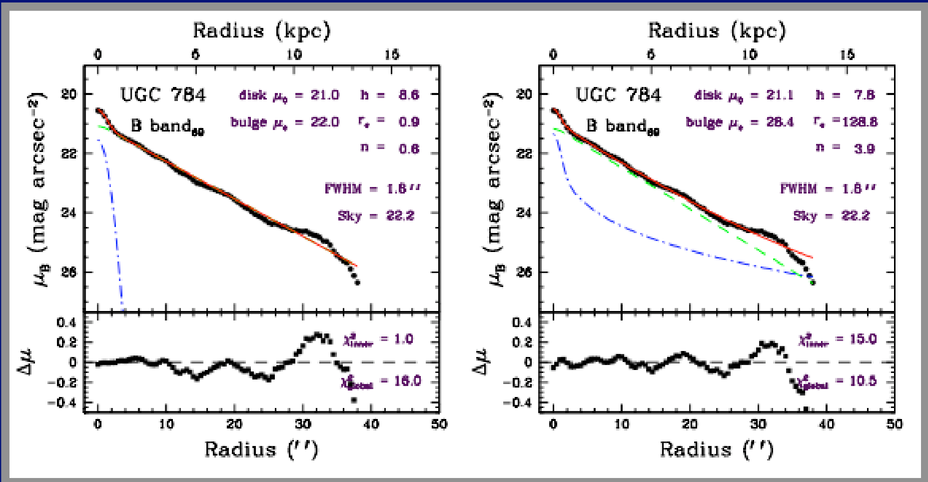
MacArthur etal (2003) … Simulations :

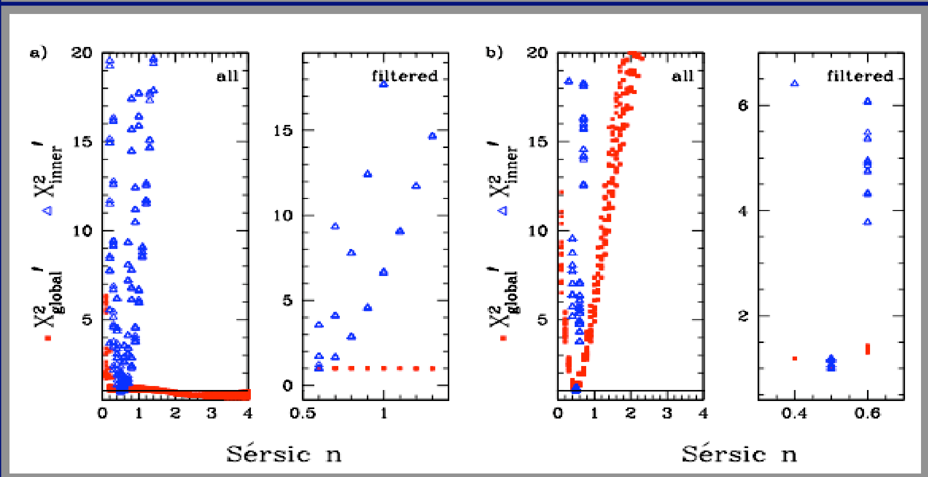
- created artificial surface brightness profiles and galaxy images with combinations of μ_e, r_e, n, μ_d, $r_{d,}$ seeing FWHM, sky levels.
  Range of bulge n: [0.2, 4.2; 0.2]
- convolved theoretical profiles with Gaussian PSF to simulate seeing + Gaussian noise + repeats (40/100 noise runs averaged per combination)
  Seeing values [1.0”, 3.0”; 0.5”]

⇒ Total of 750,000 mock profiles / images

Bulge-Disk Decompositions

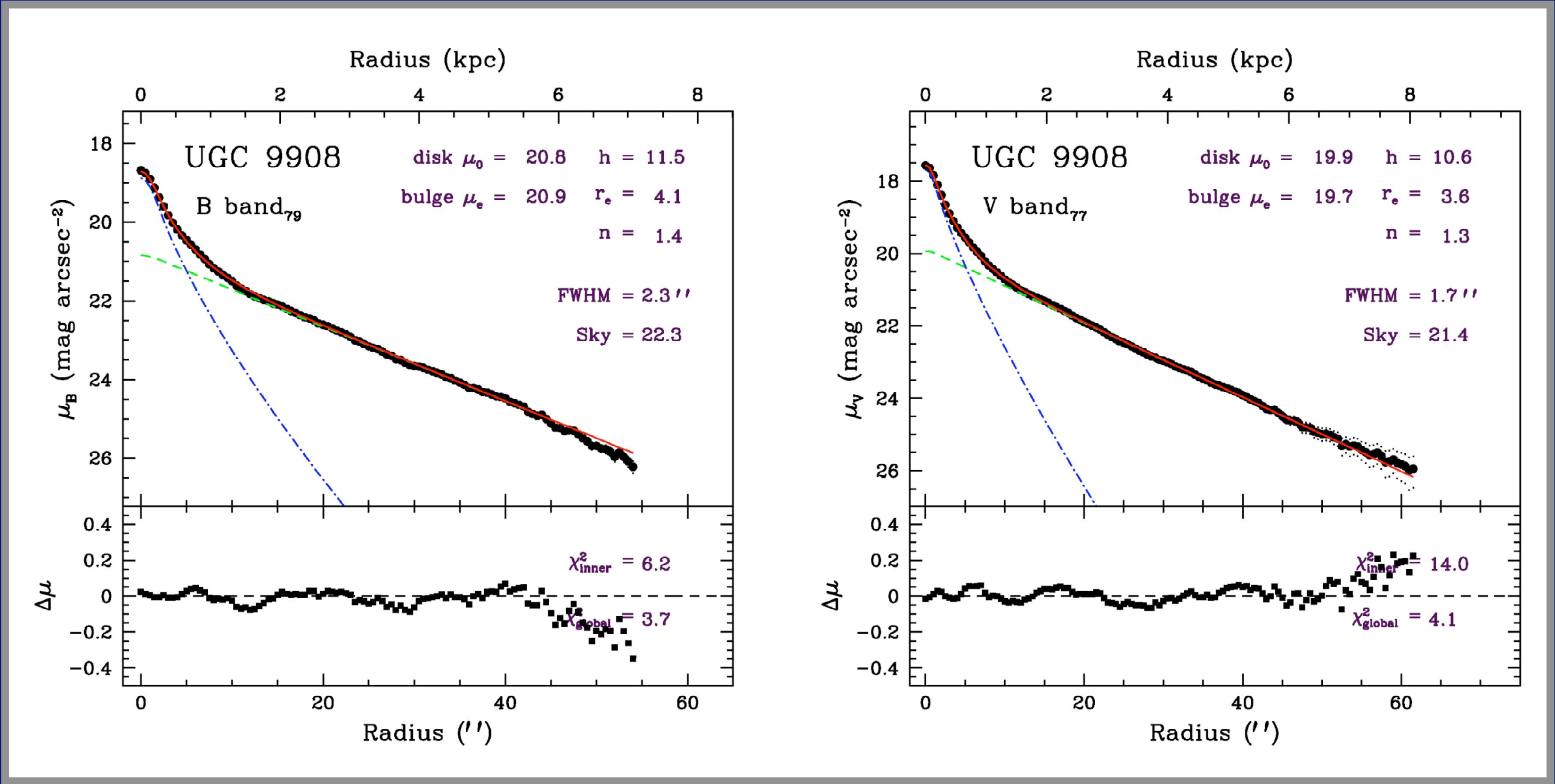
Use of Constraints:





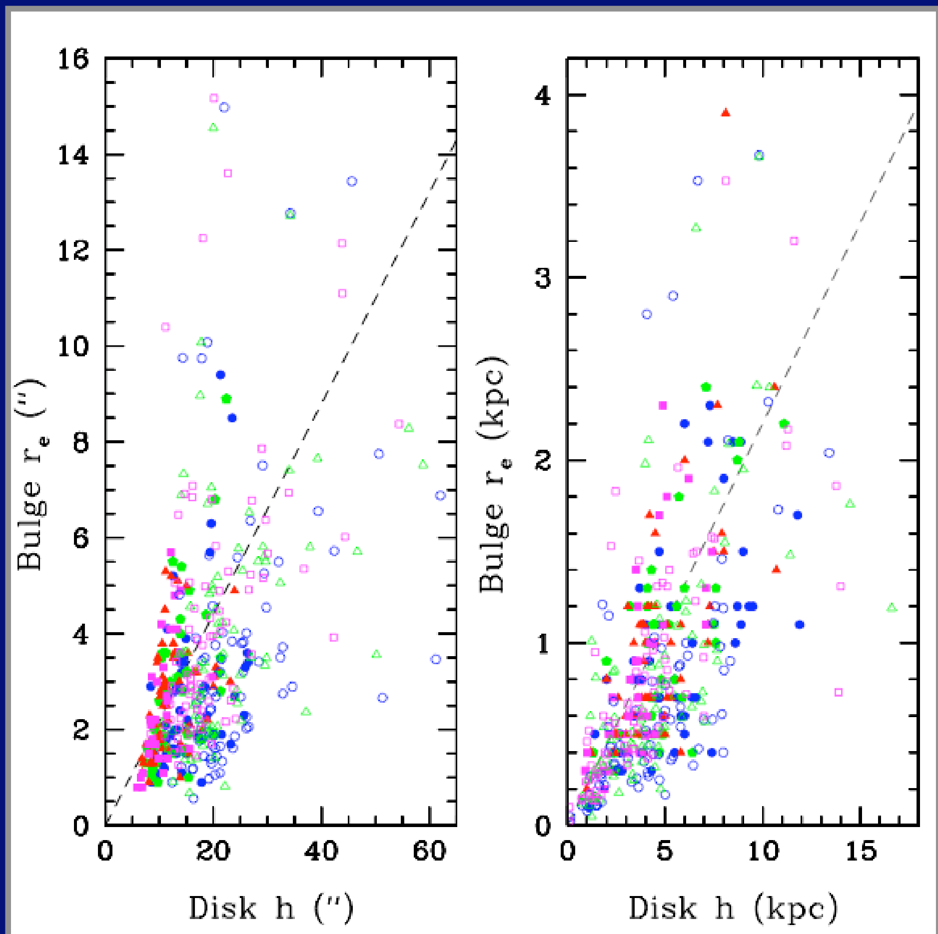
Without constraints and use of inner χ^2, a Sercic value of n~4 would be favored over n=0.6.

Bulge-Disk Decompositions



Fit for Sersic bulge and exponential disk only: a nuclear component, if any (faint/small cores), is washed out by seeing. ⇒ get upper limit to Sersic *n*

Bulge/Disk Scale Ratios



Structural coupling between the bulge and disk

$\langle r_e/r_d \rangle = 0.22 \pm 0.09$

[for Type I only]

- Independent of λ and Hubble type
- Consistent with N-body models of secular evolution *(next slide)*

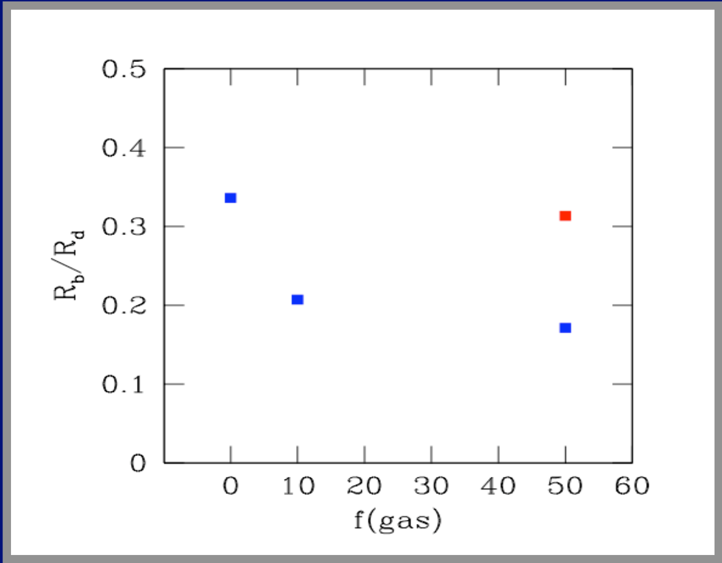
solid points: our data; open points: Graham (2002)

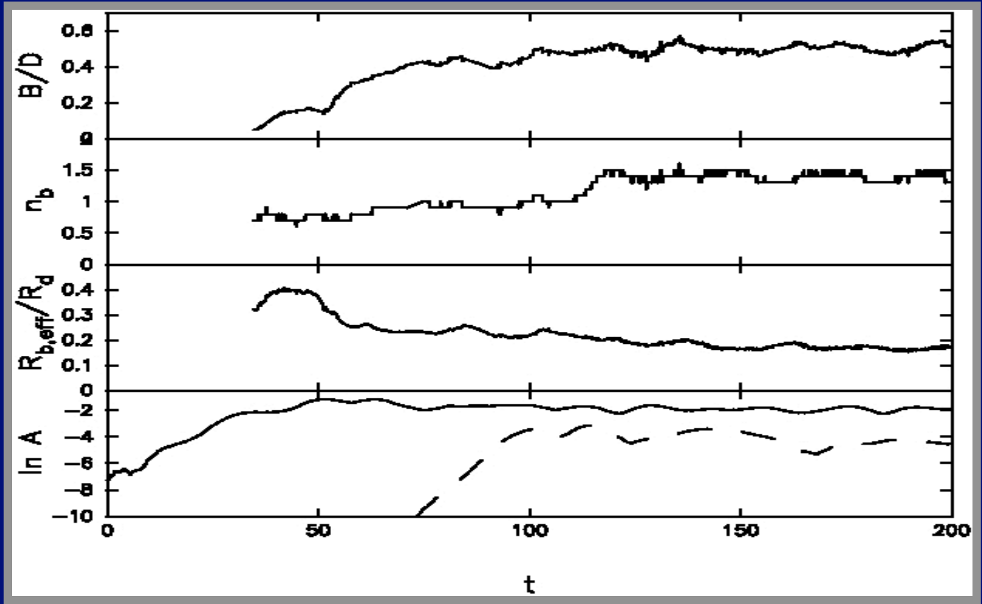
MacArthur, Courteau, & Holtzman (2003)

Bulge/Disk Scale Ratios

$\langle r_e/r_d \rangle = 0.22 \pm 0.09$ [for Type I only]

- Consistent with N-body models of secular evol. (Friedli, Pfenniger, Debattista, Mayer, Tissera, …)

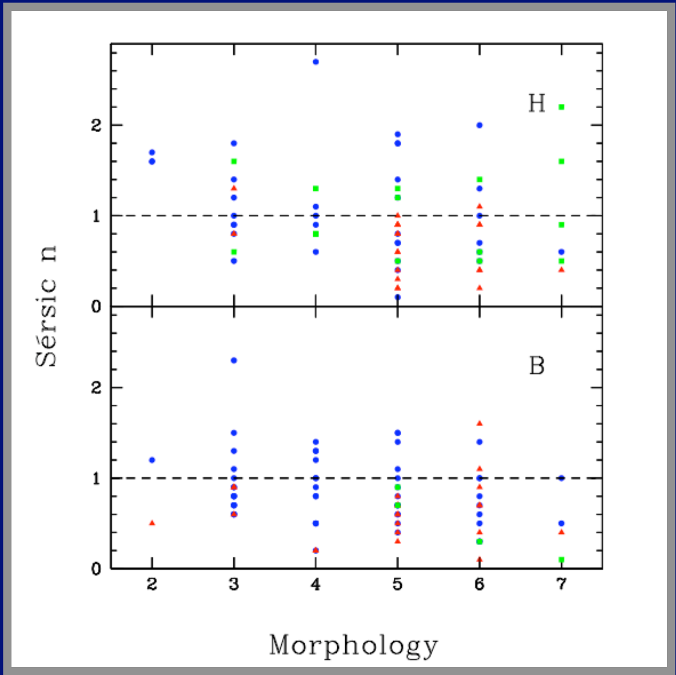


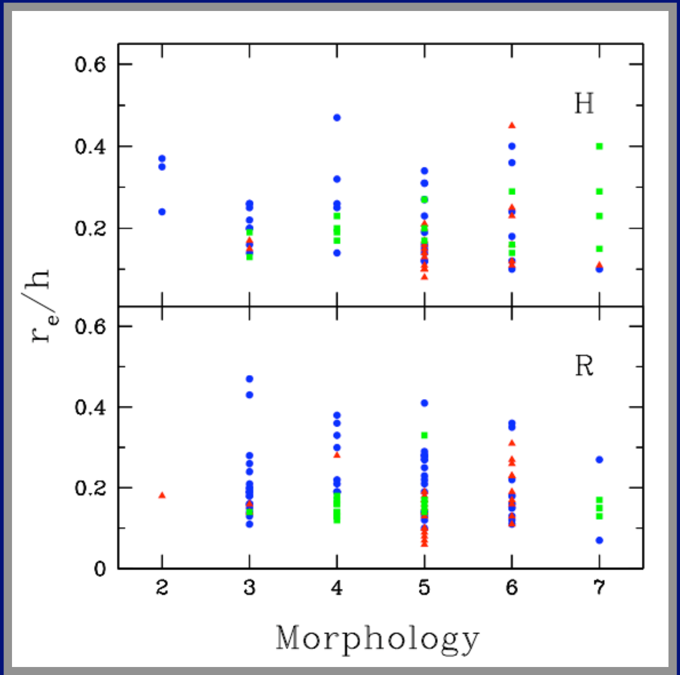


Mayer, Carollo, Moore, & Debattista 2004; Debattista (2004; private communication)

Structure of Bulges and Disks

- Bulge Sersic n < 2 (see also *Balcells et al 2004*)
- <r_e/h> = 0.22 +/- 0.09 (0.20 to 0.24 from late to early type, ~indep. of wavelength; Hubble sequence nearly scale free)





MacArthur etal (2003) also include data from Graham (2001)

Colours of Bulges and Disks

- Blueness of central regions and small colour difference with the inner disk

  (Balcells & Peletier 1994; Balcells/Peletier/Thomas, this workshop)

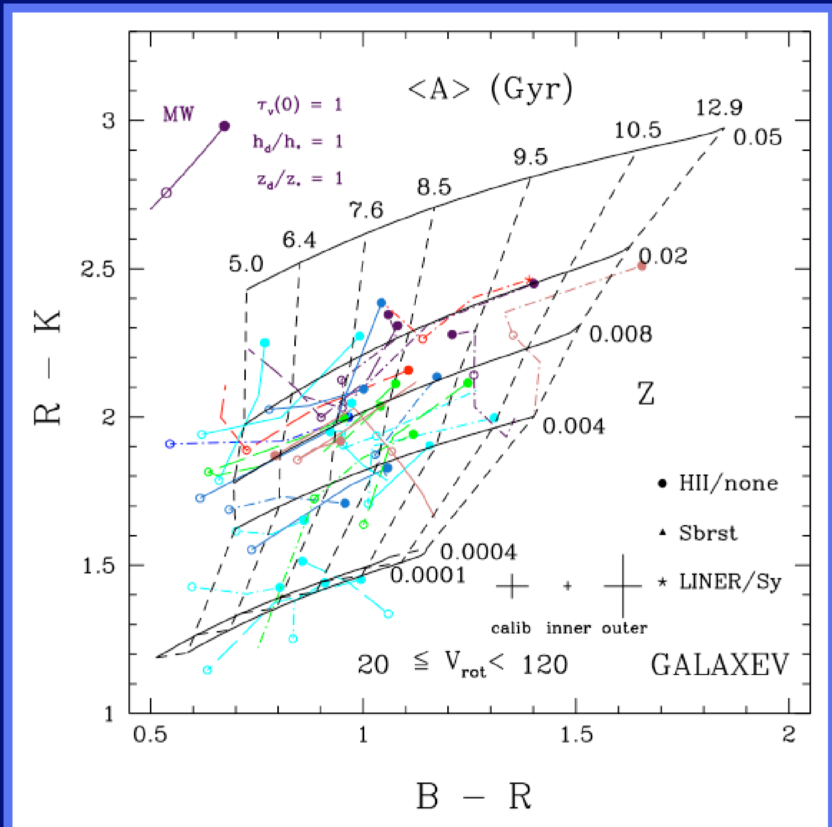
- MacArthur, Courteau, Bell, & Holtzman 2004 (ApJ, 152, 175)

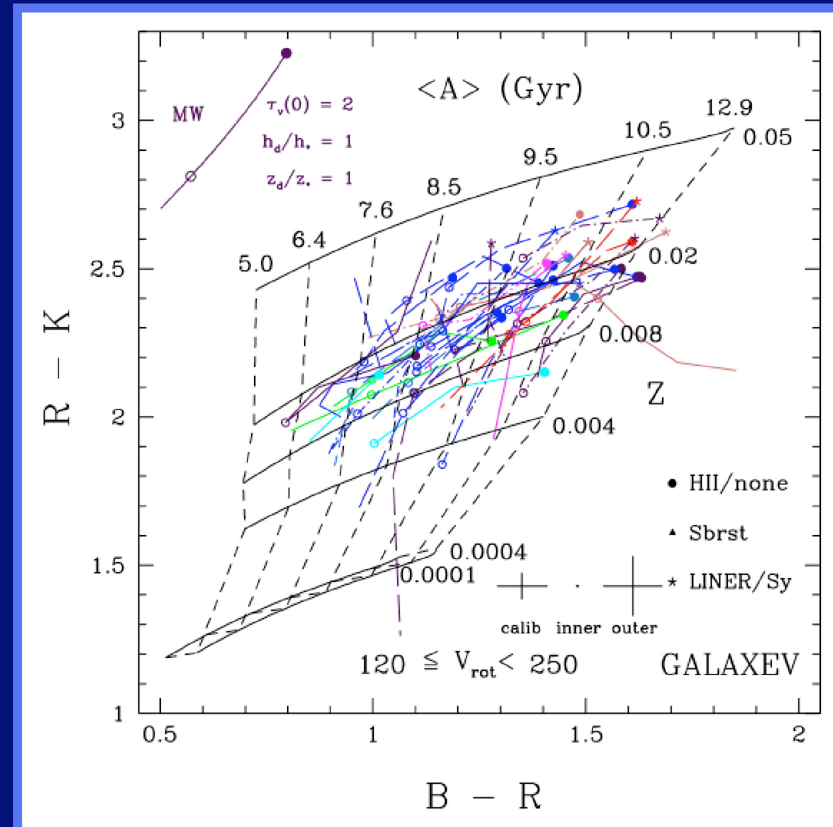
  " Structure of Disk-Dominated Galaxies. II. Color Gradients and Stellar Populations "

  – Use Bruzual & Charlot (2003) SSPs with standard ingredients convolved with an exponential SFH to compare with color-color diagram

Colour Gradients

- Compare colour gradients with stellar population models
- Determine main drivers of SFH as a function of galaxy structural parameters (e.g. surface density, total mass)





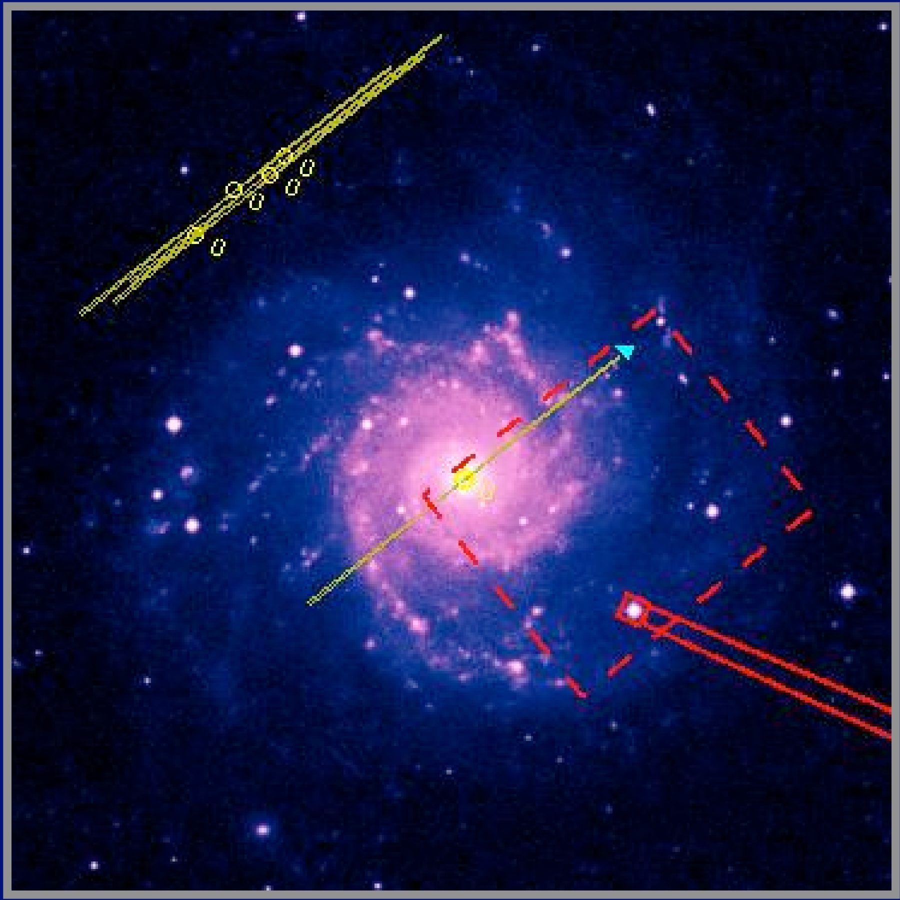
MacArthur, Courteau, Bell, & Holtzman (2004, ApJ, 152, 175)

Gemini Project 2002-2004

- GMOS long-slit spectroscopy of 12 nearby **face-on** barred/unbarred galaxies (high spatial and spectral resolution: 0.072” pix^{-1}; 0.45 Å pix^{-1} [~10 Å])
- Spectral coverage (4000 - 6700Å): absorption line indices (e.g. Lick) to disentangle age, metallicity, *and* dust. t_{exp} ~ 1.5h on 8-m
- High-order Balmer lines to correct for diffuse nebular emission
- Line indices out to >1.5 disk scale lengths to separate bulge and disk arm/inter-arm populations

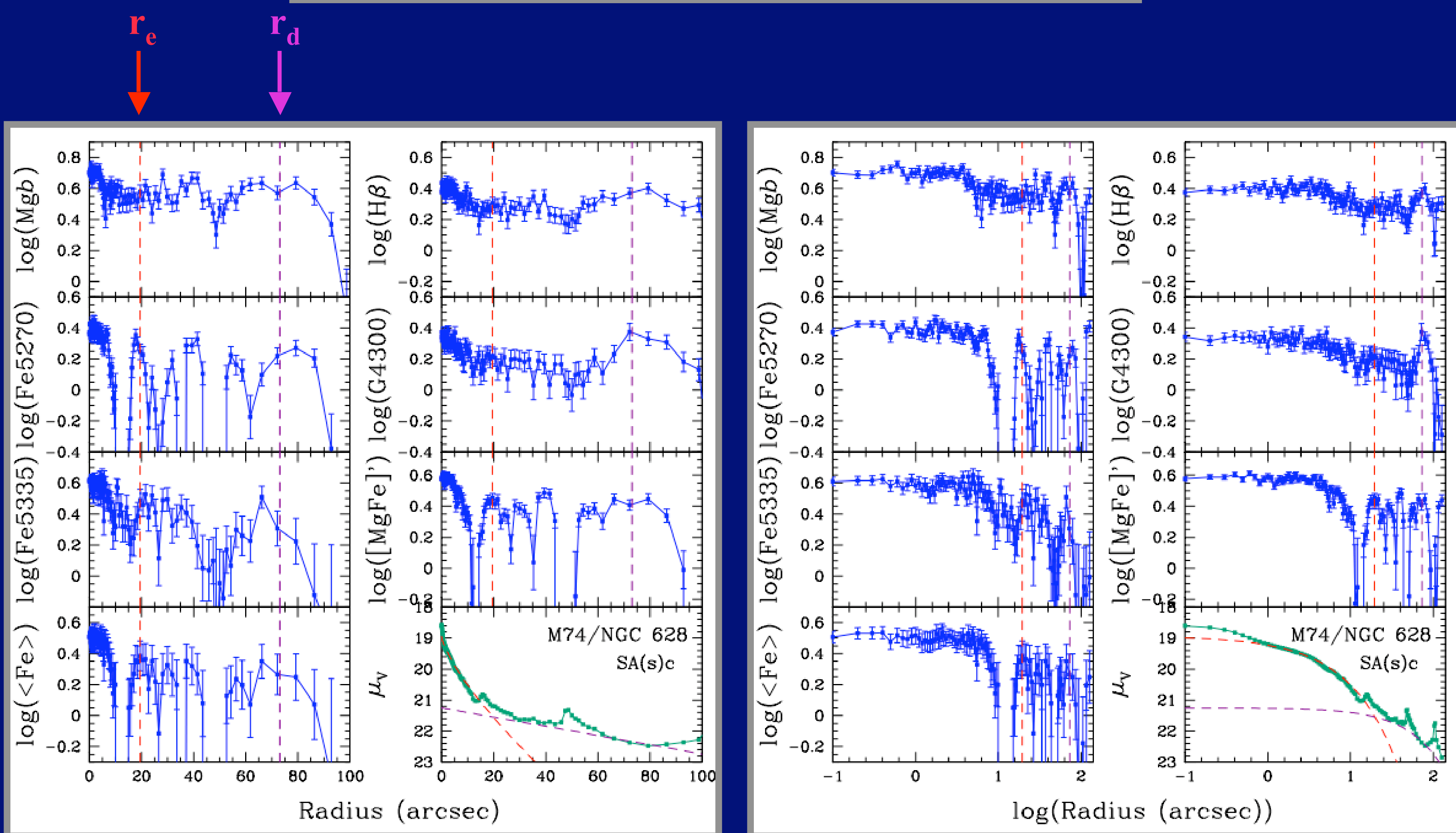
GMOS/N Data

NGC 628 / M74 (Sc)



MacArthur, Courteau, and Gonzalez (in progress)

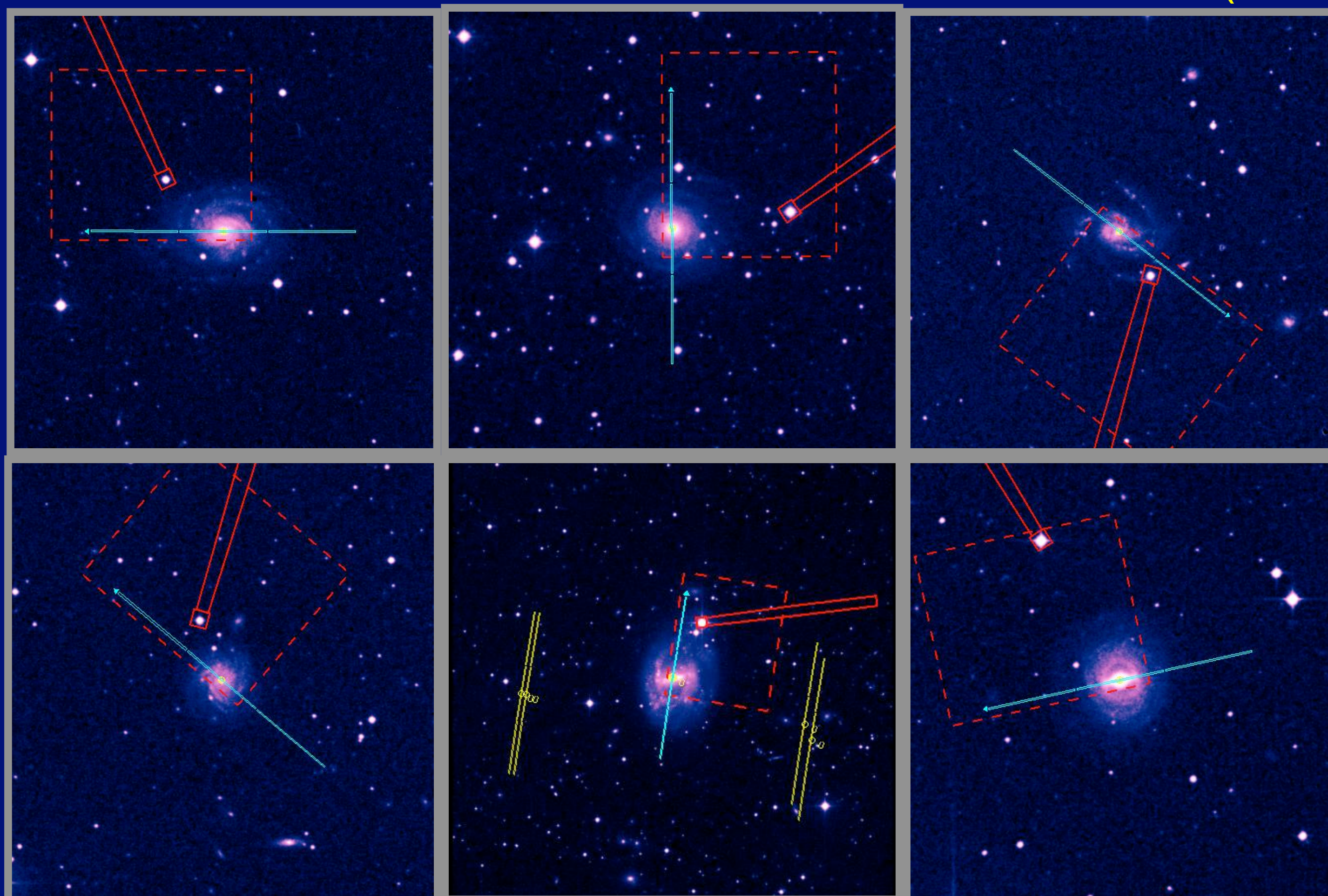
GMOS/N Data



MacArthur, Courteau, and Gonzalez (in progress)

GMOS/N Data

NGC 173 (SAc) NGC 7490 (Sbc) NGC 7610 (Scd)



NGC 7495 (SABc) NGC 7741 (SBcd) UGC 2124 (SBa)

Advantages of our study

- High spectral resolution allow for accurate correction for nebular emission with higher order Balmer indices ($H\gamma$ & $H\delta$)
- High enough S/N (≥ 15) for indices measure beyond 1.5 disk scale lengths (5' long slit)
- Remove HII regions/spiral arms
- Extract/calibrate indices: look at radial trends
- Compare indices with SPS models

☑ Compare inner indices with ***Sauron*** collaboration (late-type sample; e.g. M74)

Summary

- Bulges and disks have correlated scale-lengths with $r_e/r_d = 0.22 \pm 0.09$;
- Bulge n < 2; typically ~1 for late-types;
- Explain structural correlations, Type II's, transition, bulgeless, truncation types, ... in terms of bar mixing (populations, dust), fragmentation, and CDM-motivated structure formation scenarios. Constraints for hydro/N-body simulations;
- Colours reveal age and metallicity differences;
- Need high-resolution (spatial & spectral), wide-field spectroscopy (1D or 2D) to unravel old and intermediate-age populations in barred and unbarred spiral galaxy bulges and inner disks
  $\Rightarrow$ Lauren MacArthur PhD 2005