Method-dependent Bar Fraction in the Local (z~0.01) Universe

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- Algorithm for data reduction and image analysis
- Cautions for automatic bar classification
- A new method for bar classification using ellipticity augmented by bar strength ratio map
- Method-dependent bar fraction on Hubble-sequence/color
- Luminosity/mass-dependent bar fraction

1. Introduction: Observation

- ~60% of spirals (SB 30% + SAB 30%)
- Related to AGN, central SF, pseudo-bulge, ring, internal secular evolution and so on

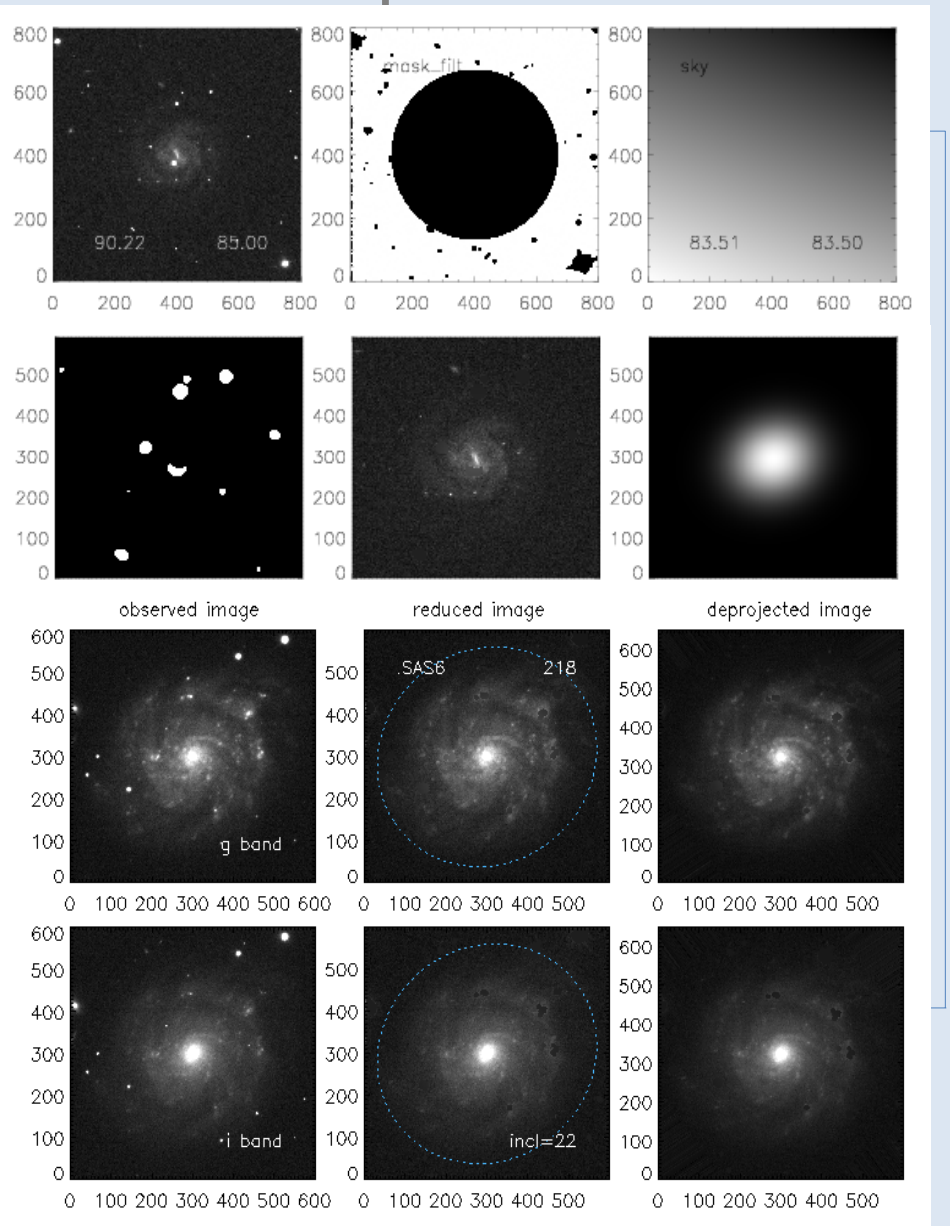
- Hubble type /Mass/Color-dependent Bar Fraction
  - Early spirals : Sheth et al. 2008, 2013,
    Lee et al. 2011,
    Galaxy zoo project
  - Late spirals : Marinova et al. 2007,
    Barazza et al. 2008, 2009,
    Aguerri et al. 2009
  - Bimodal : Nair et al. 2010

1. Introduction: Simulation

- Always formed quickly when they have a massive, dynamically cold and rotationally supported disk in isolate system (Hohl 1971; Ostriker & Peebles 1973)

- Dominant dark matter halo plays a role in delaying bar formation initially, but ultimately makes bars be stronger than in non-DM-dominated galaxies (Athanassoula 2002)

2. Sample & Reduction

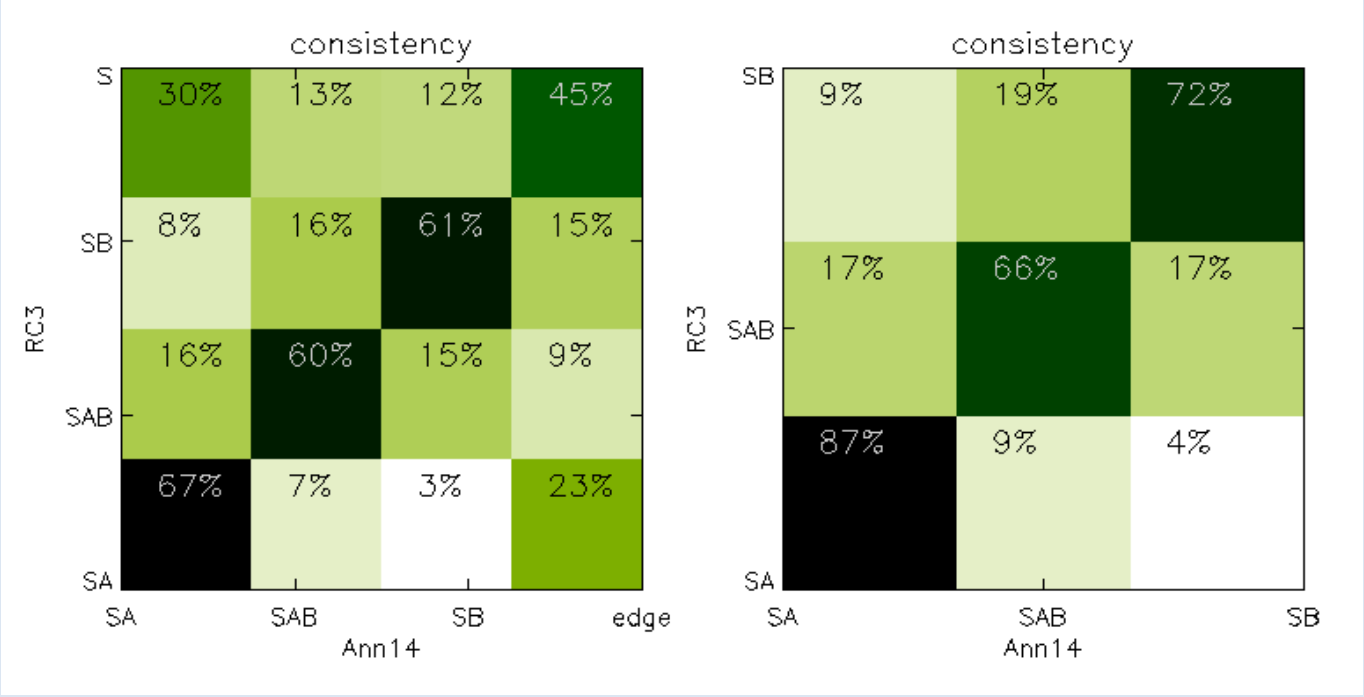


- Reduction

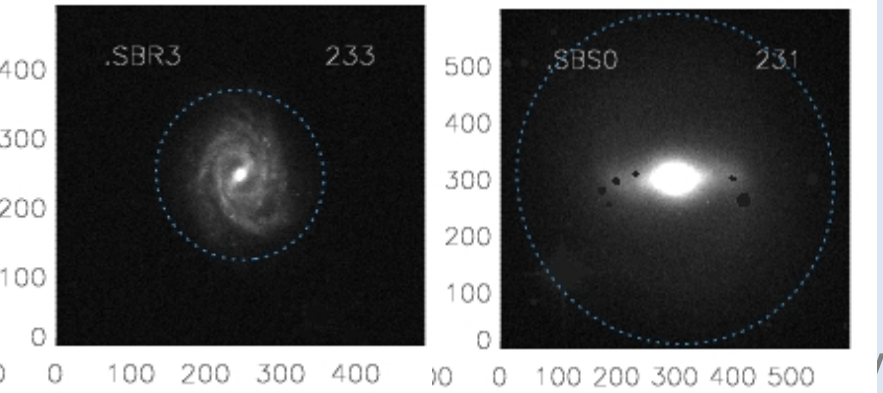
1. Subtract bias (1000DA)
2. Subtract sky background gradient – Koda's code in IDL + mask R_{25}*2
3. Mask bright stars/adjacent galaxies in IDL (visual check)
4. Deproject @R25 mag/arcsec2 by ellipse fitting with IDL
5. Discard 191 highly inclined galaxies/ 84 galaxies with smaller frame than R_{25}
   ;;#866 spirals

3. Bar Classification Methodology
(1) Visual inspection

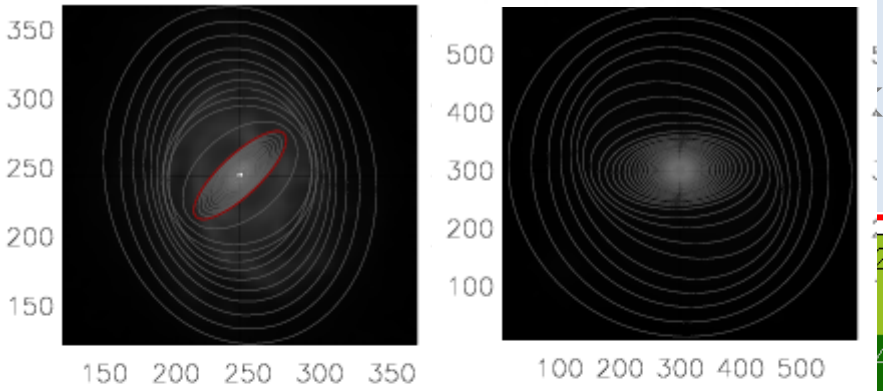
- UGC (Nilson 1973), RSA (sandage & Tammann 1987), RC3(de Vaucouleurs 1991)
- Nair & Abraham 2010; Oh et al. 210; Lee et al. 2011; Masters et al. 2010, 2011, 2012; Holye et al. 2011; Skibba et al. 2011, 2012; Simmons et al. 2014; Ann et al. 2015



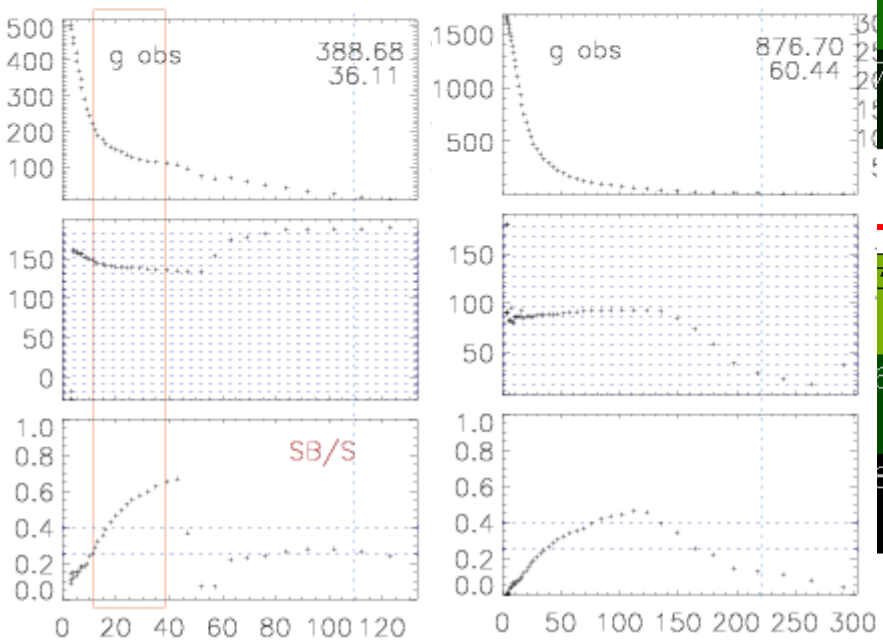
Methodology

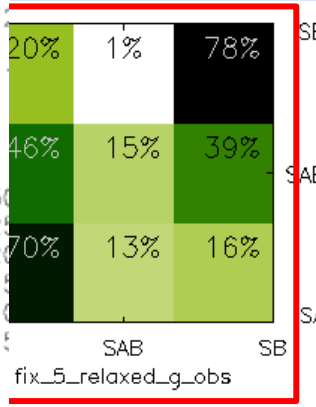


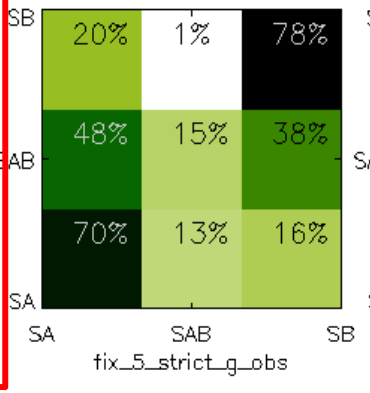
vis et al. (1985) & Anthanssoula

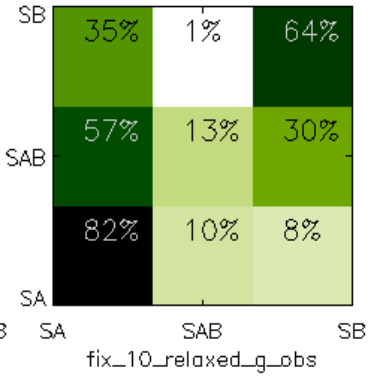


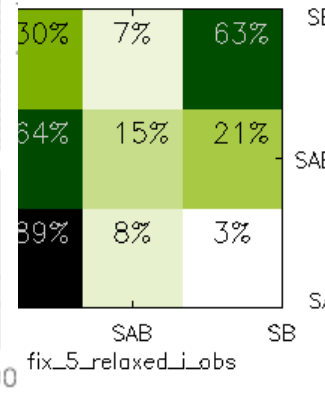
xage following Kent (1983) &

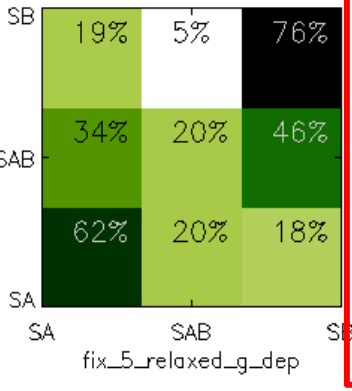


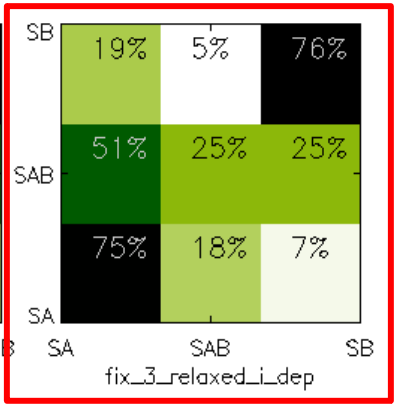








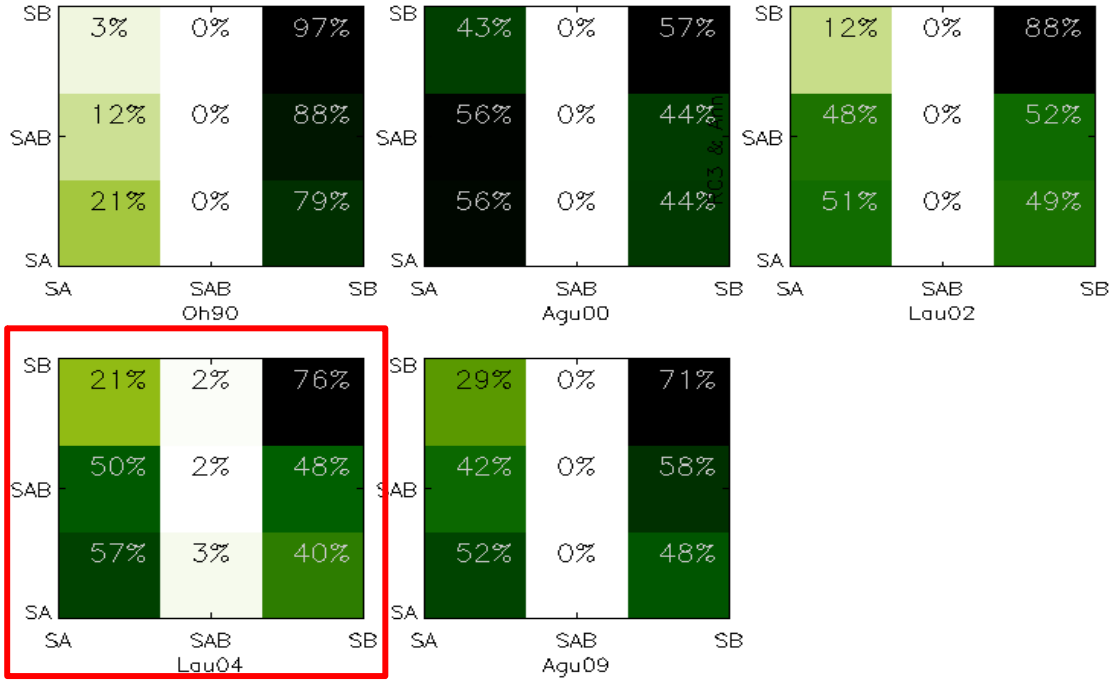


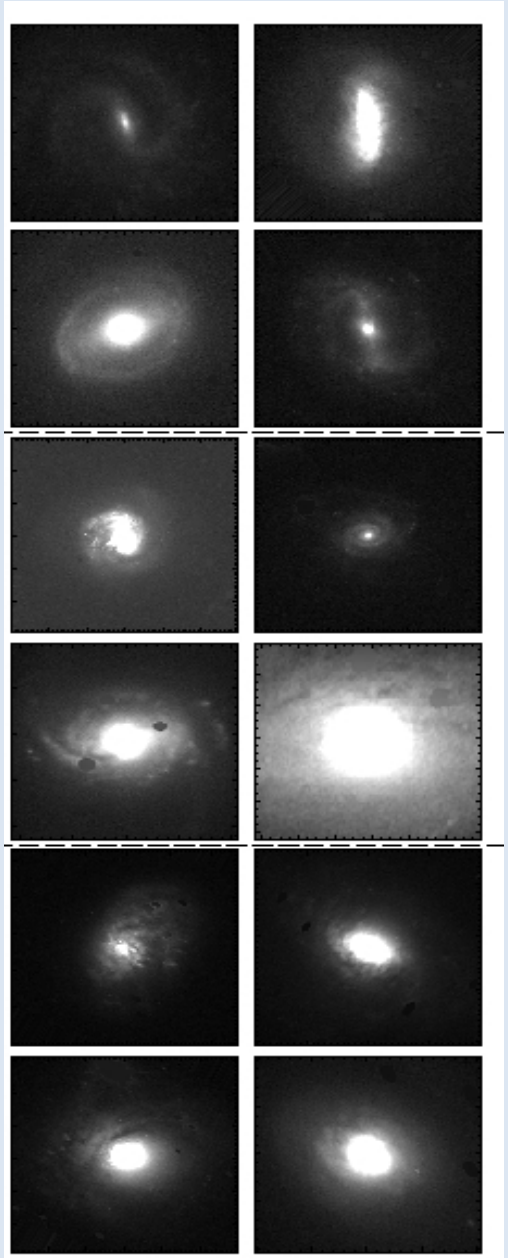


3. Bar Classification Methodology
(3) Fourier analysis

Table 2. Applying Fourier analysis

Author	I_m/I_0	Φ_m	F_{bar}	$F_{bar} < z = 0.01$
Ohta+90	$I_b/I_{ib} > 2$	-	-	78.6%
Aguerri+98				
Aguerri+00	$I_b/I_{ib} > (max - min)/2 + min$	-	-	50.3%
Laurikainen+02	$I_2/I_0 > 0.3$	const Φ_2, Φ_4	40%	54.6%
Laurikainen+04	$A_2 > 0.12(SB)$	const Φ_2, Φ_4	65%	51.6%
	$A_2 > 0.09(SAB)$			
Aguerri+09	$\Delta(I_2/I_0) \geq 0.2$	$\Delta\Phi_2 > 20$	26%	43.8%



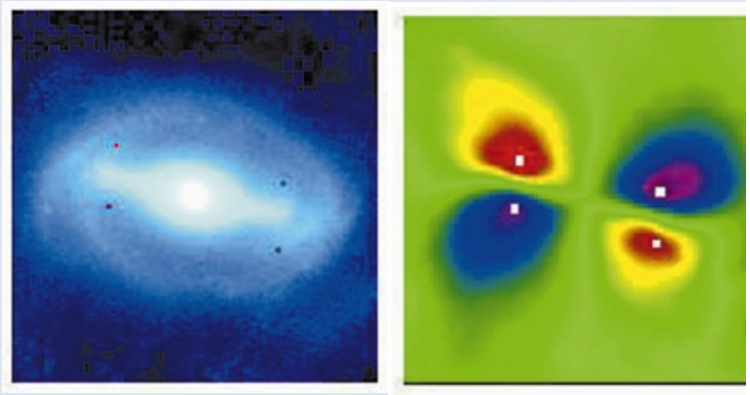


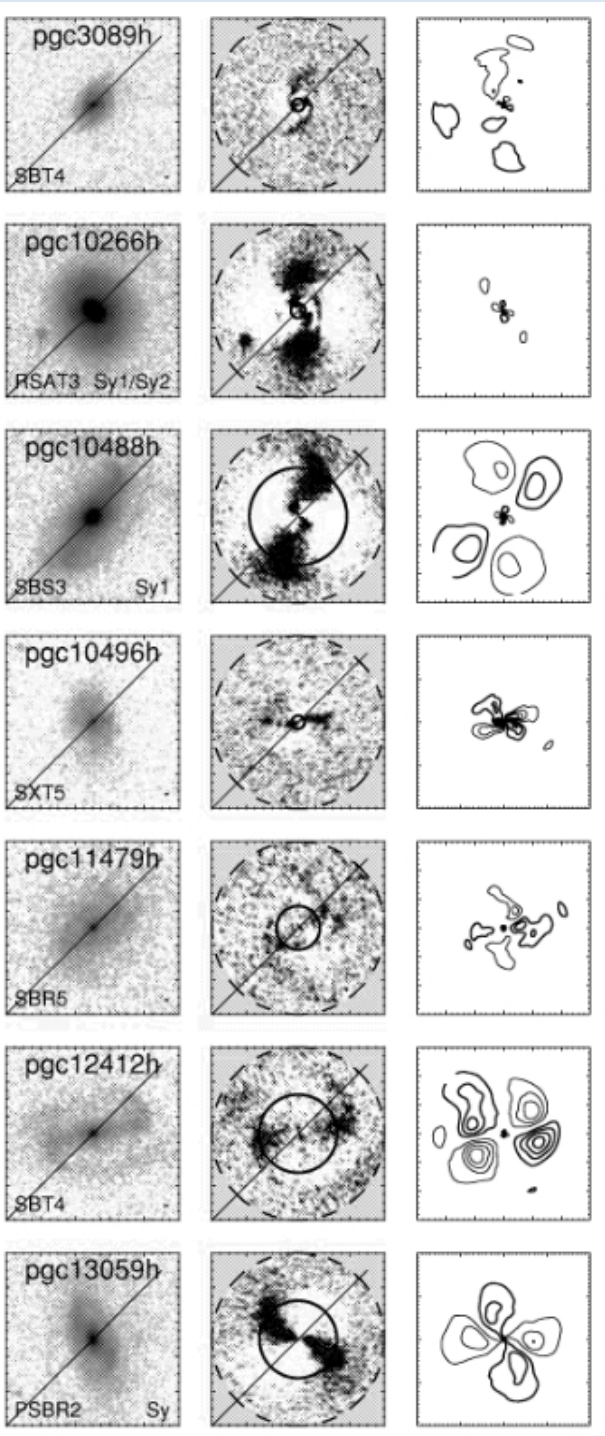
3. Bar Classification Methodolog
(4) ellipticity augmented by b

STEP1. Calculating bar strength

1. Deprojection of i band image
2. Calculation of potential by solving Poisso
   using FFT (Hohl & Hockney 1969; Quillen
   Buta & Block 2001; Laurikainen & Salo 2(
   - M/L ~ constant
   - hr/hz=2.5 in early spirals
     hr/hz=4.5 in early spirals (Grijs 1998)
   - Exponential disk & non-exponential disk
3. Bar strength (Combes & Sanders 1981)

$$Q_T(R) = \frac{F_T^{max}(R)}{\langle F_R(R) \rangle}$$

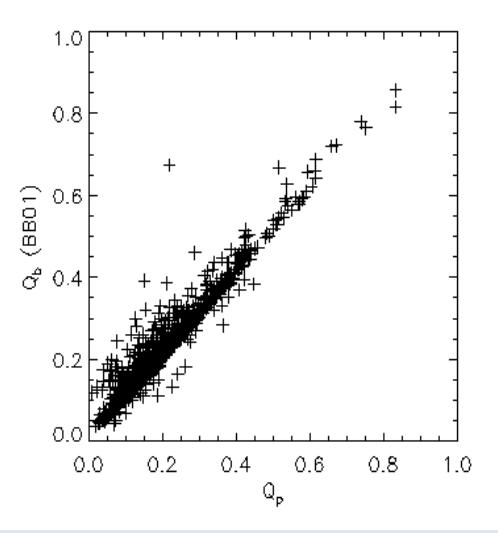


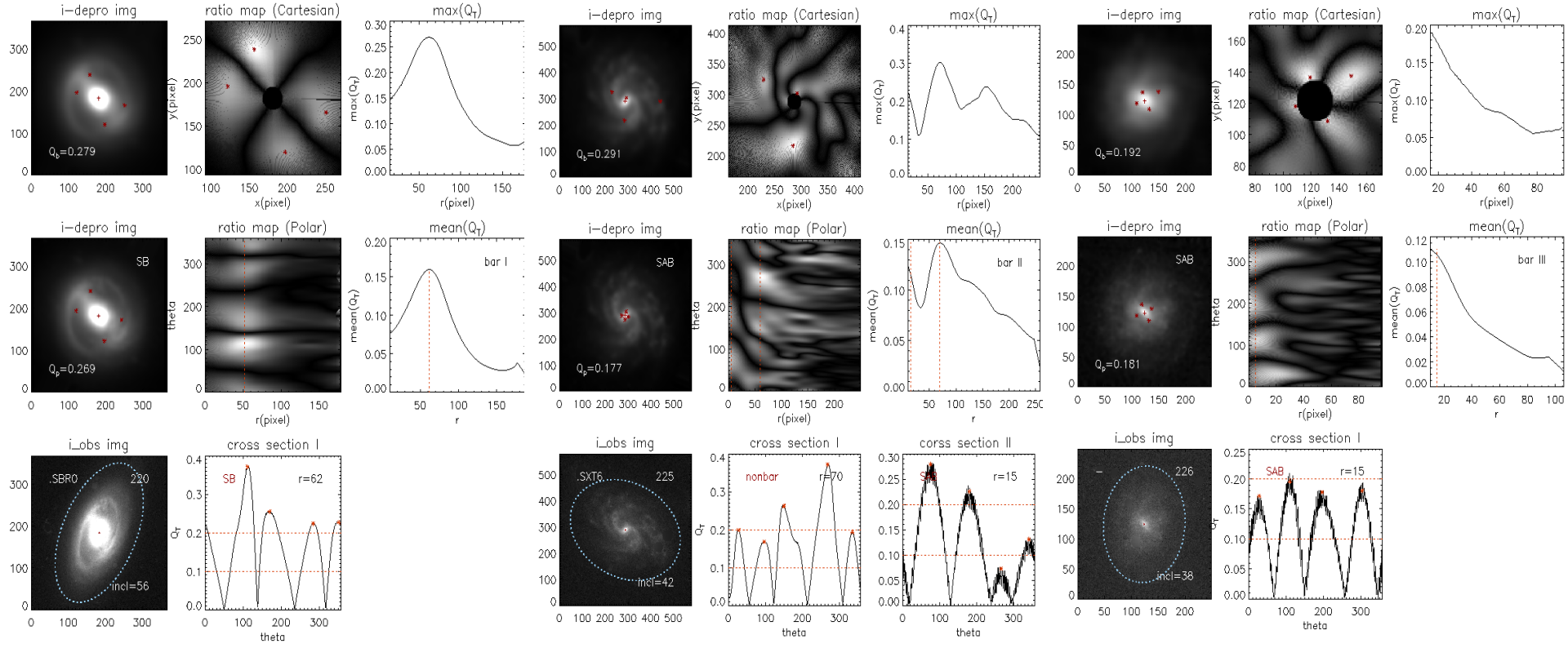


STEP2. bar Strength in polar coordinates

1. Bar strength in Polar coordinates
2. mean Q_t vs raidus
3. $Q_p \equiv$ mean Q_t of 4 peaks @ Q_{tmax} radius

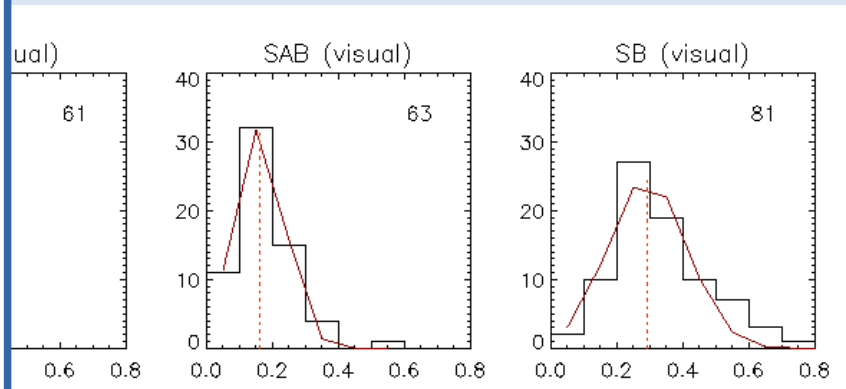
1. Bar candidates: 4 peaks!! @ Qt_{max}

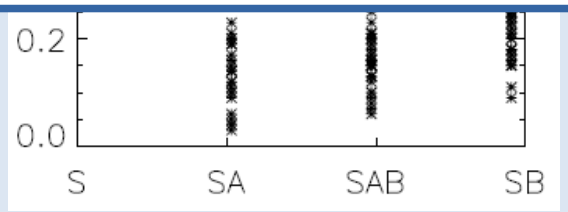


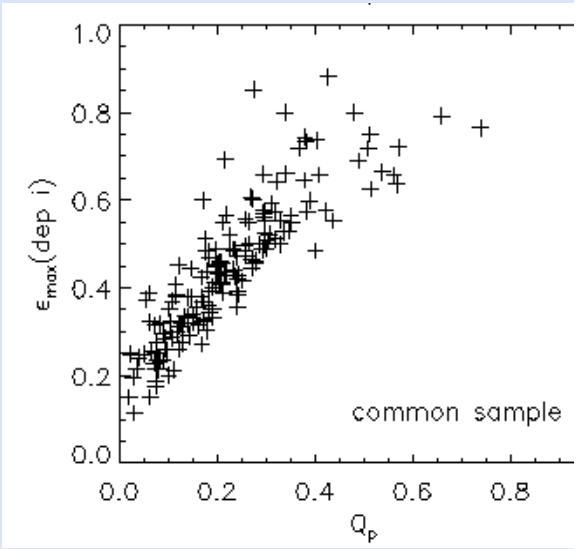


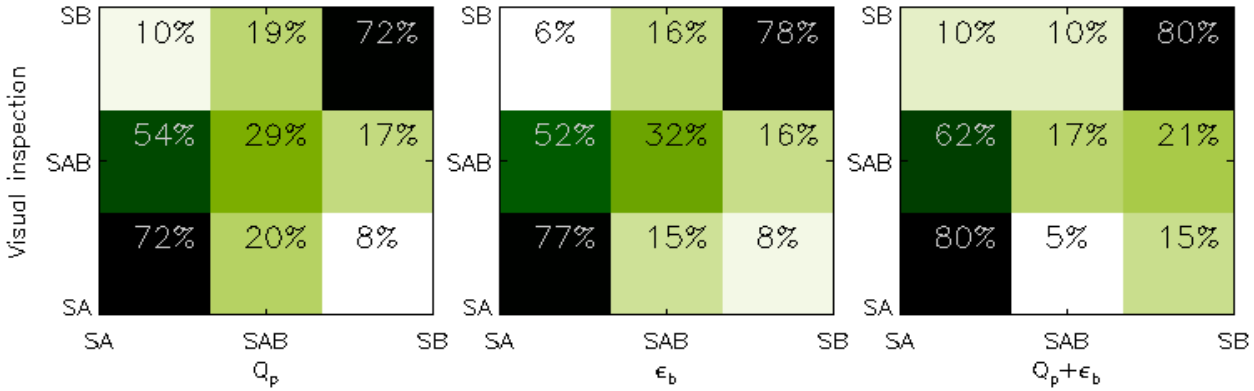
STEP3. Criterion for classification

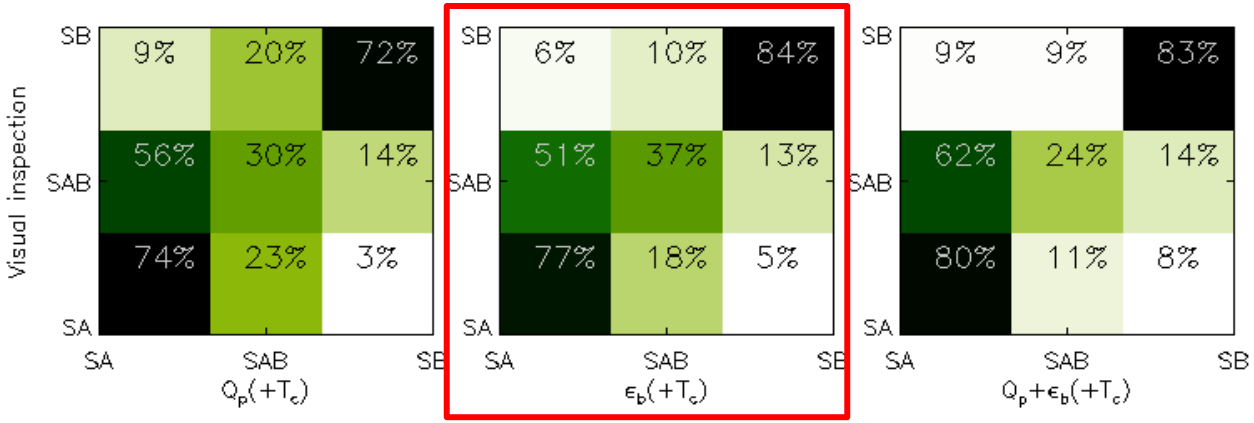
parameter	group	SA	SAB	SB
Q_p	all spirals	≤ 0.16	$0.16 < \leq 0.24$	$0.24 <$
	early spirals	≤ 0.13	$0.13 < \leq 0.21$	$0.21 <$
	late spirals	≤ 0.17	$0.17 < \leq 0.26$	$0.26 <$
ϵ_b	all spirals	≤ 0.36	$0.36 < \leq 0.47$	$0.47 <$
	early spirals	≤ 0.33	$0.33 < \leq 0.43$	$0.43 <$
	late spirals	≤ 0.37	$0.37 < \leq 0.51$	$0.51 <$



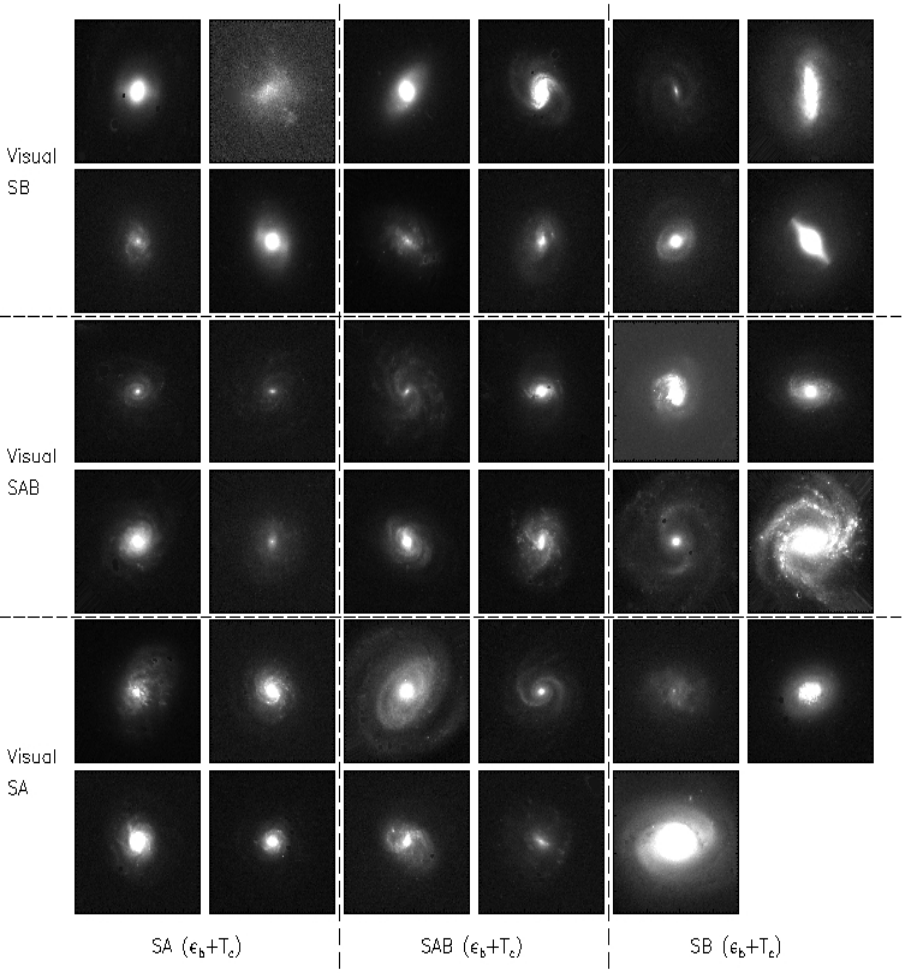


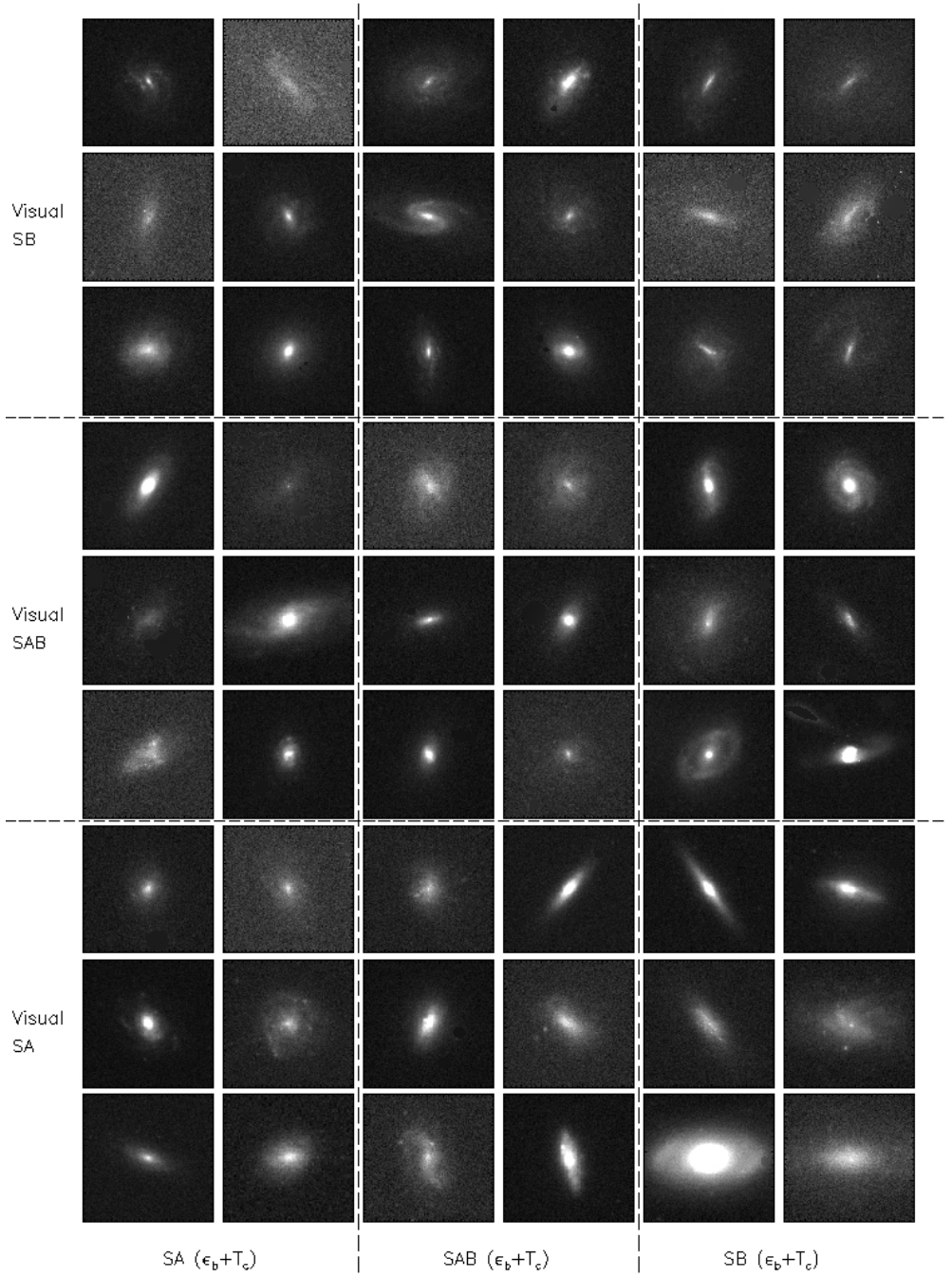




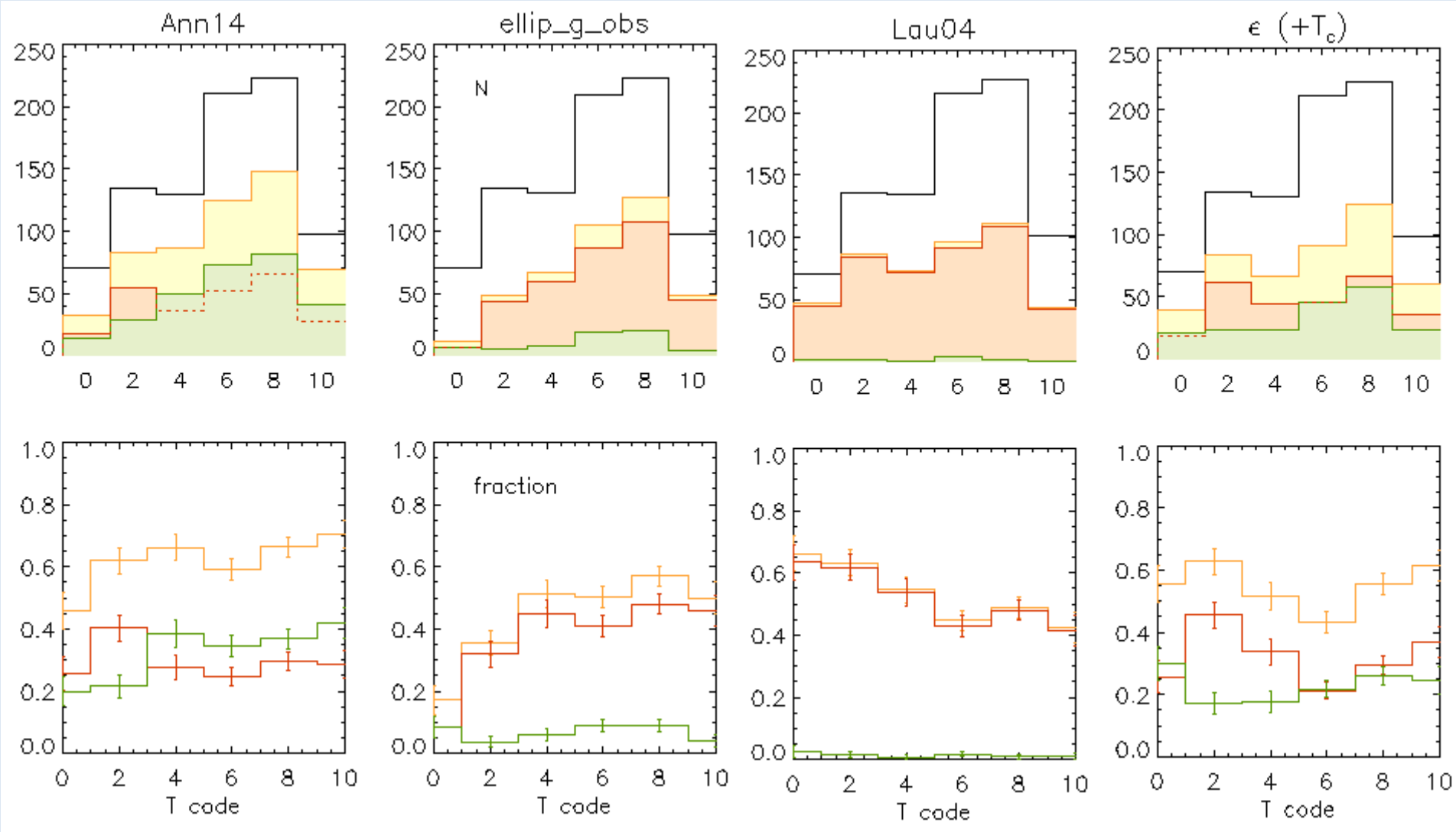


example galaxies

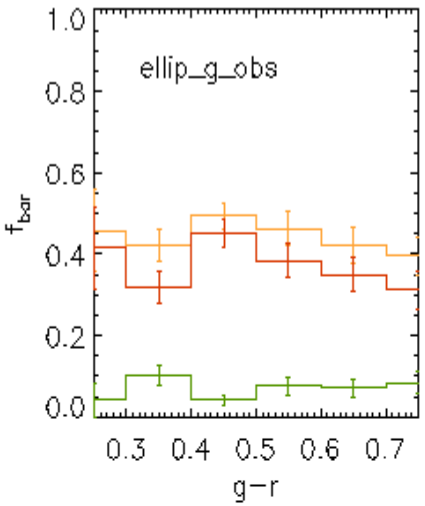


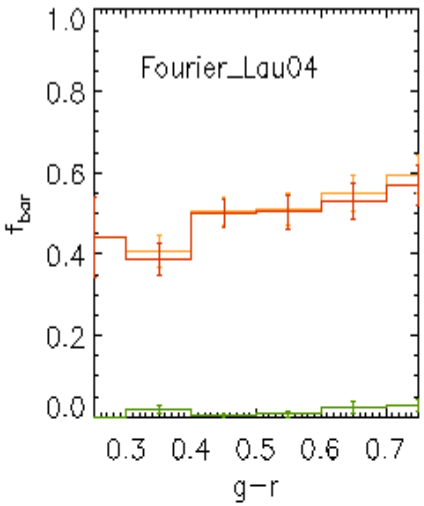


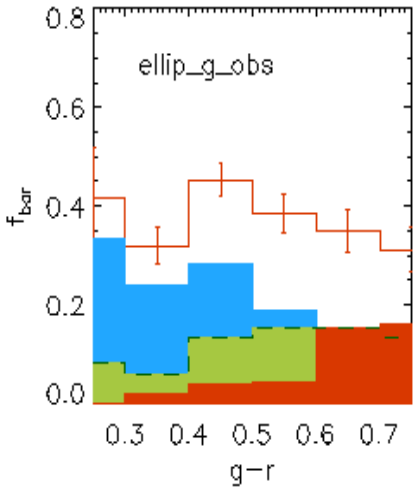
4. Hubble-dependent Bar Fraction

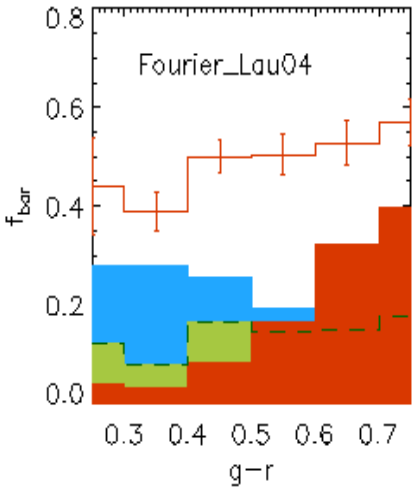


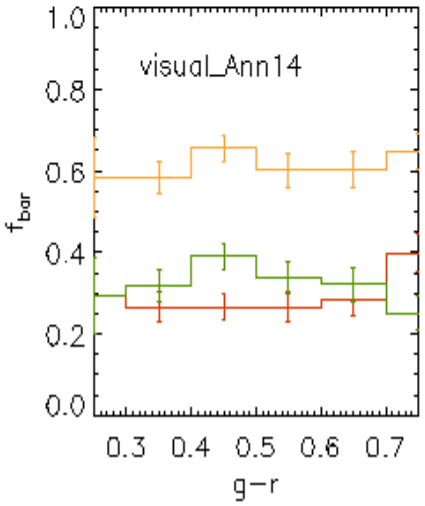
Color-dependent Bar Fraction

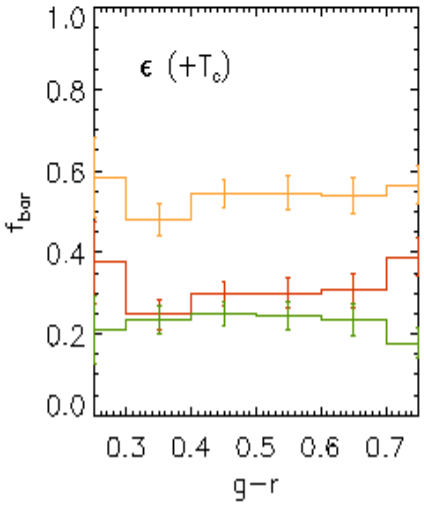


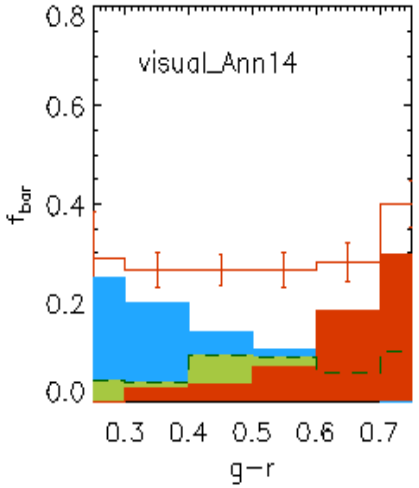


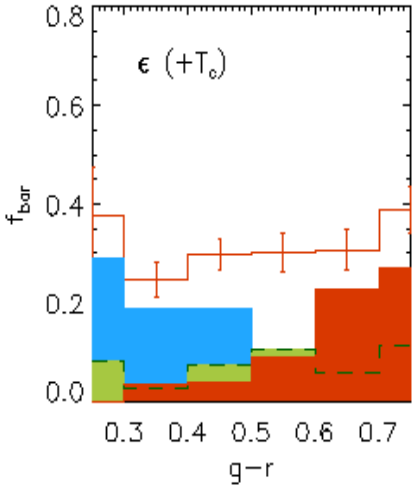




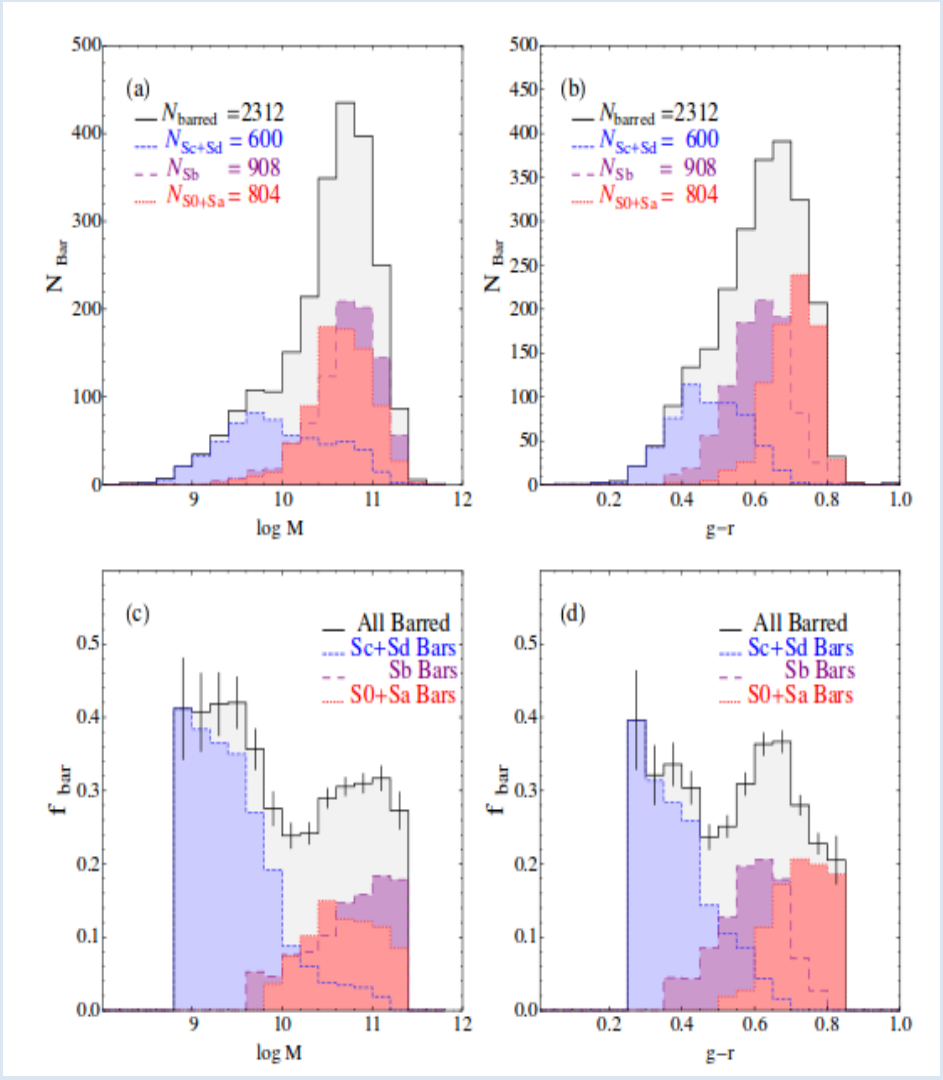


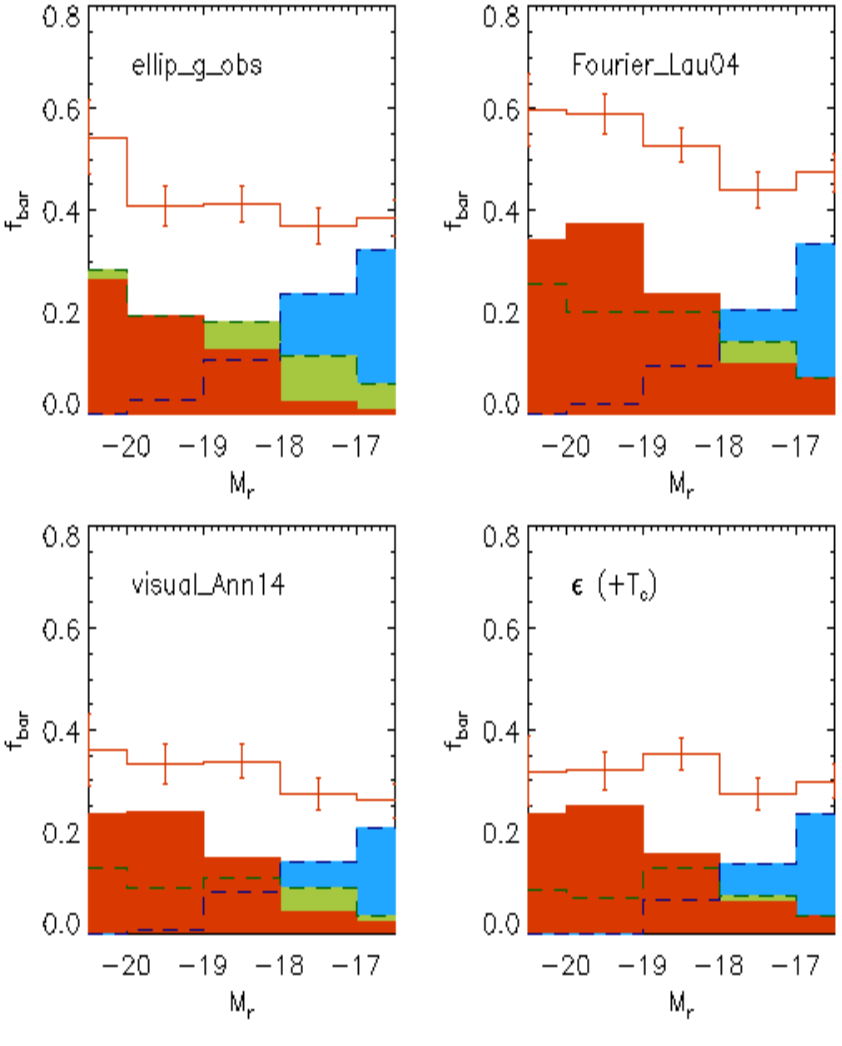






Luminosity/mass-dependent Bar Fraction





Summary

- We propose a new method to classify bar automatically using ellipticity augmented by bar strength ratio map.
- Large bulge in early spirals is the main source of confusion which makes the classification dependent on the methods.
- The controversial Hubble/color-dependent bar fractions have been induced from the systematic problems of different methods to classify bars.
- Strong bars are frequent in luminous/massive galaxies.