

The Rotation of Bulges



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Outline

- Introduction
 - Previous works and expectations
- Kinematical Measurements
 - Careful rotation curves of bulges and disks
- Structural Analysis
 - 2D bulge/disk/bar decompositions with BUDDA
- ~~Results and Conclusions~~
Some

Introduction

ROTATION OF THE BULGE COMPONENTS OF DISK GALAXIES

JOHN KORMENDY

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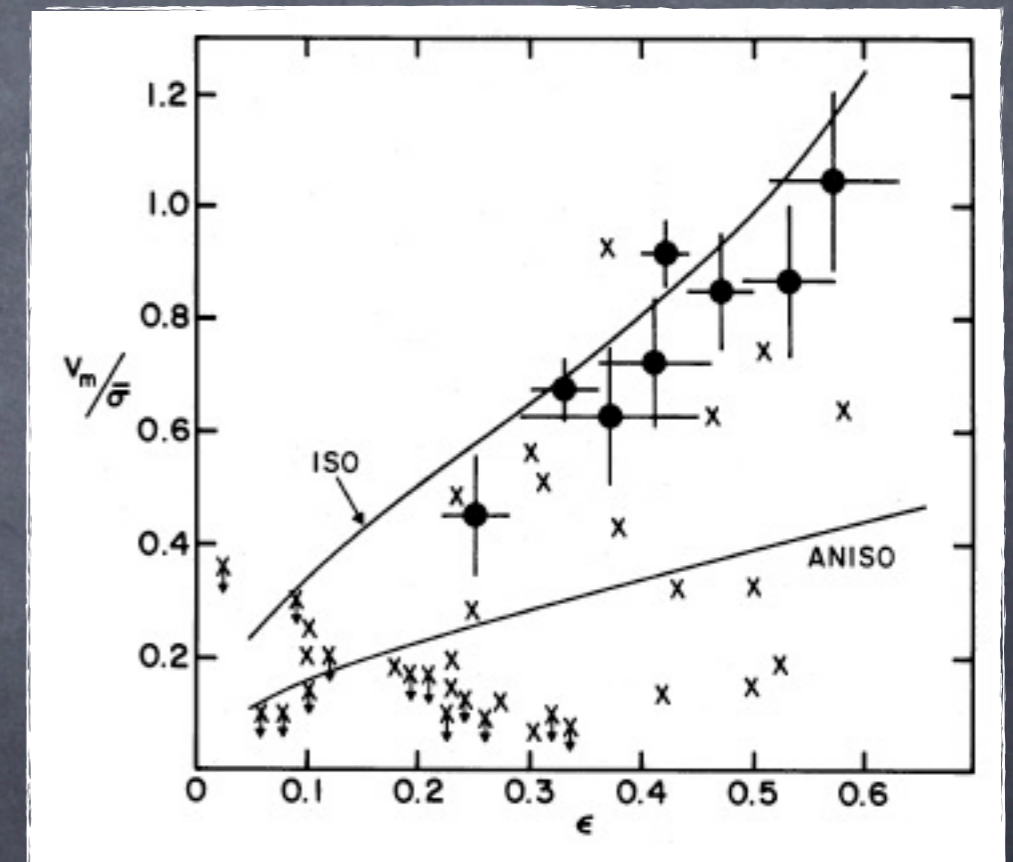
AND

GARTH ILLINGWORTH

Kitt Peak National Observatory¹

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- Kormendy & Illingworth '82
- Bulges are isotropic oblate rotators, unlike ellipticals



Introduction

KINEMATICS OF EXTRAGALACTIC BULGES: EVIDENCE THAT SOME BULGES ARE REALLY DISKS

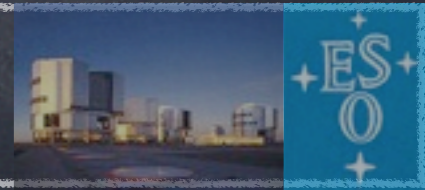
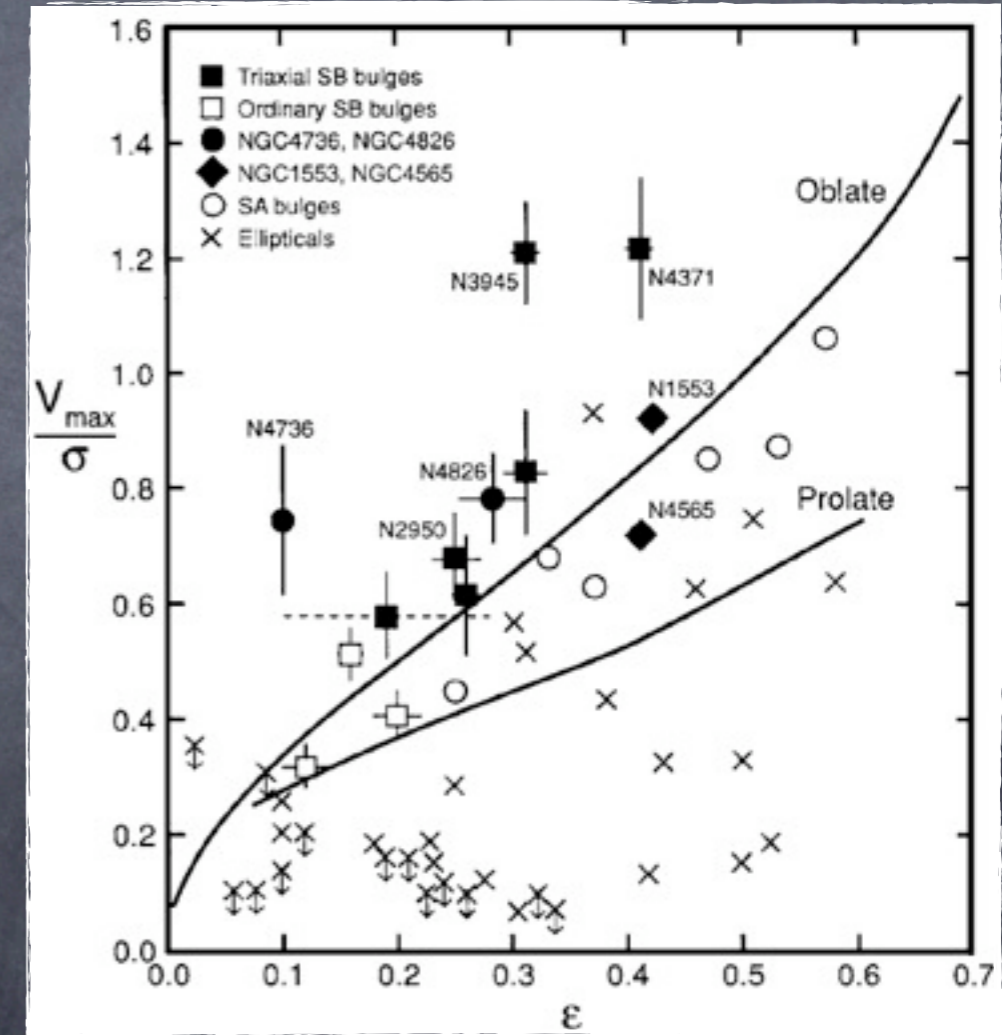
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→ bars

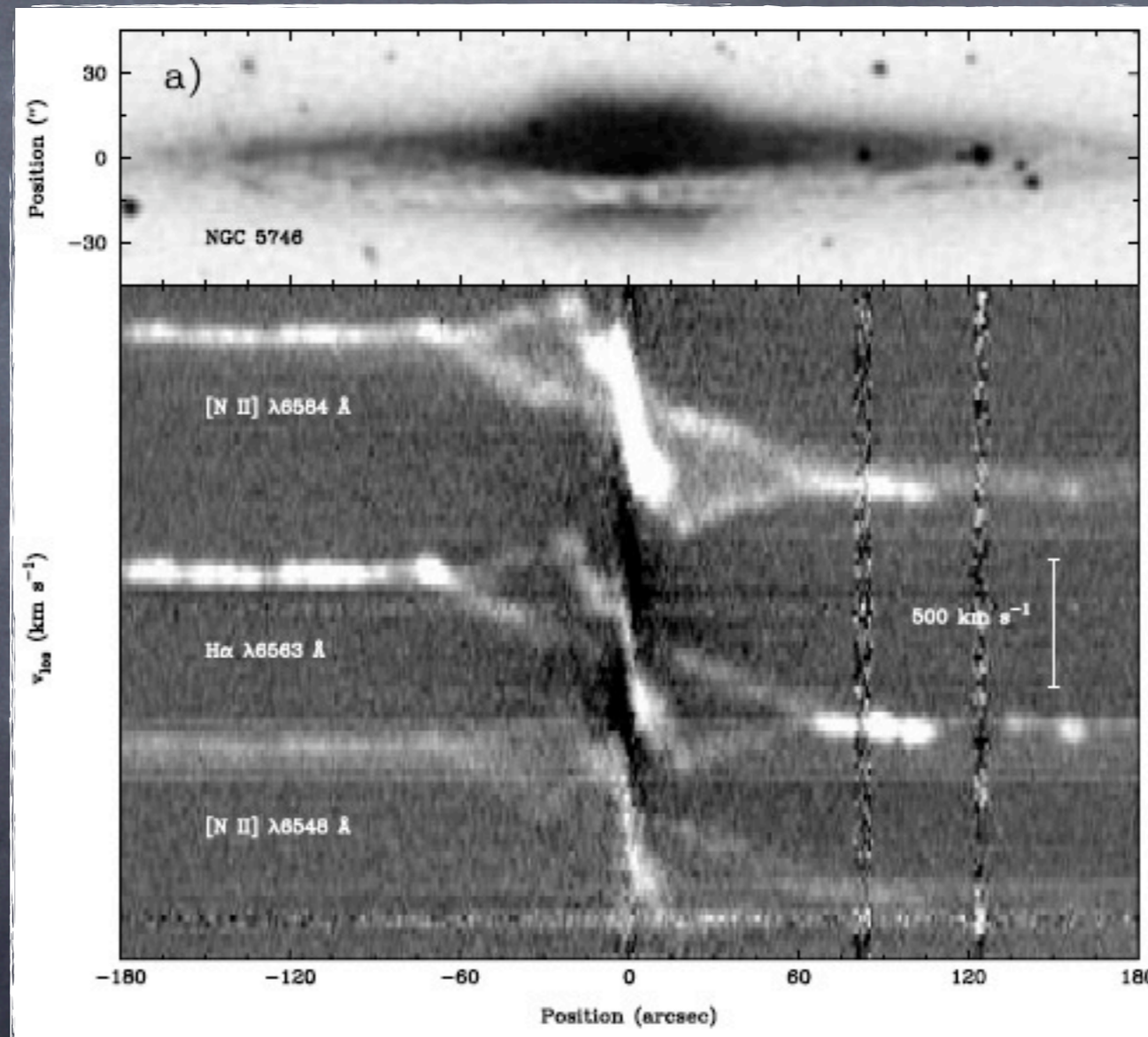
• Kormendy '93

• Box/Peanut bulges have more rotational support



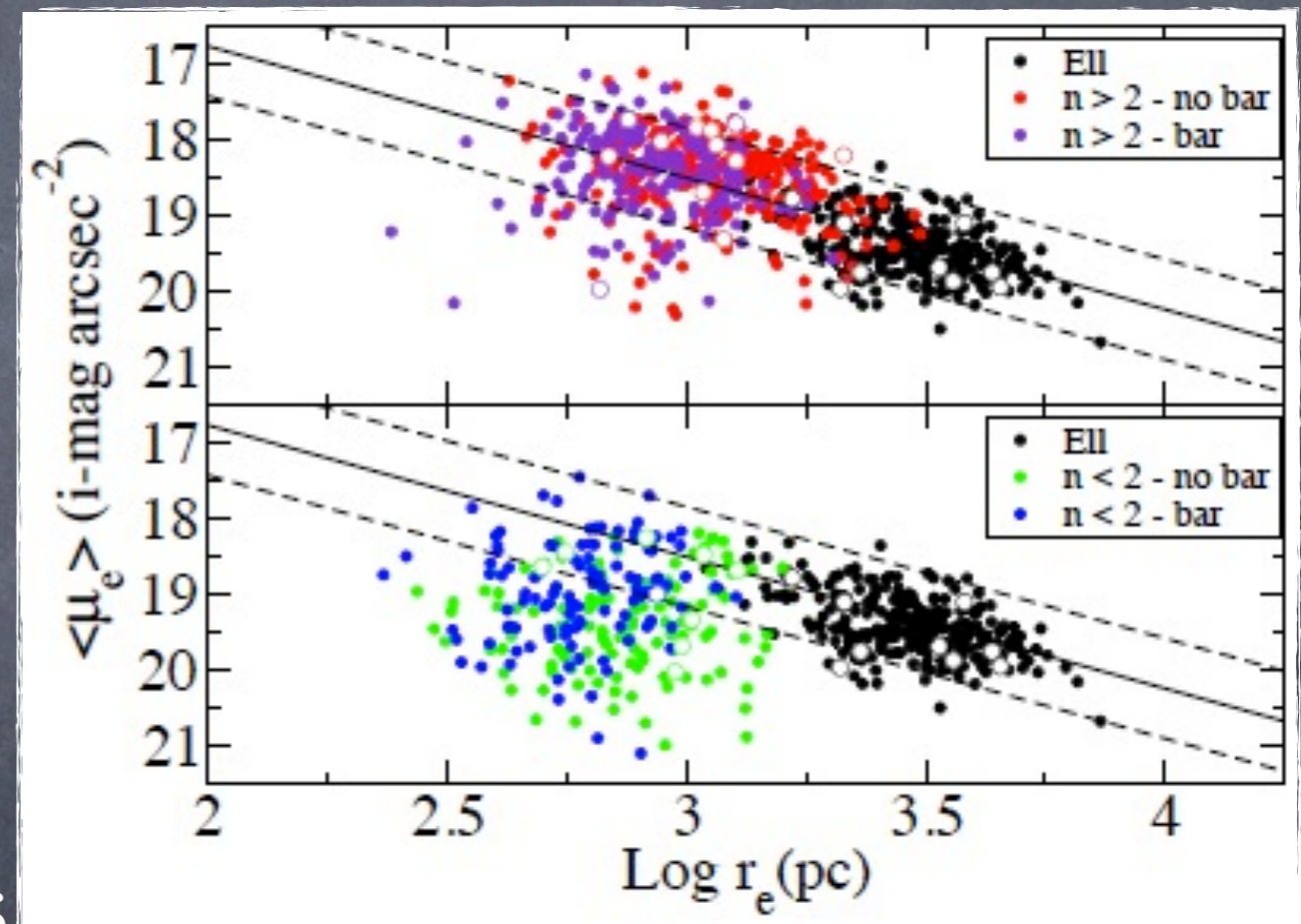
Introduction

- Box/Peanut bulges are the central parts of bars (Kuijken, Merrifield, Bureau, Freeman, Athanassoula)



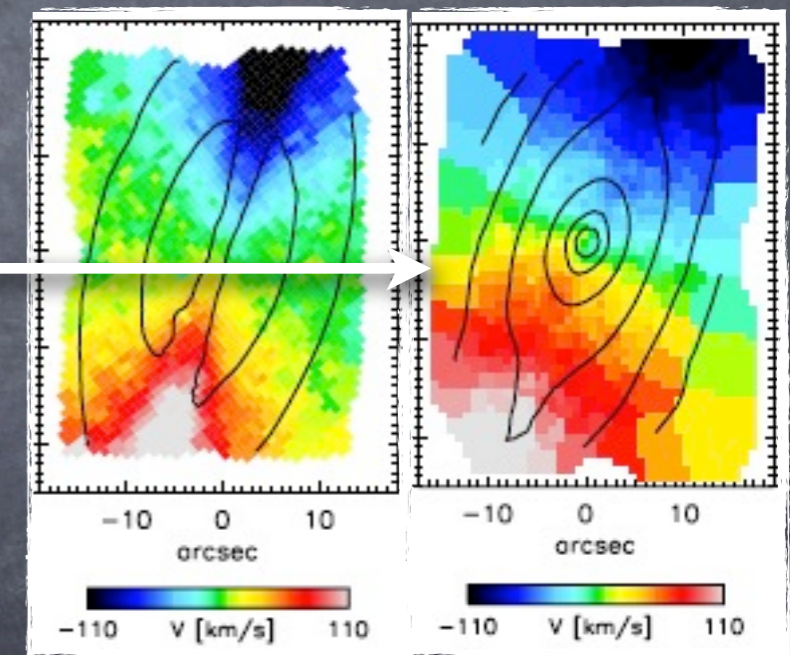
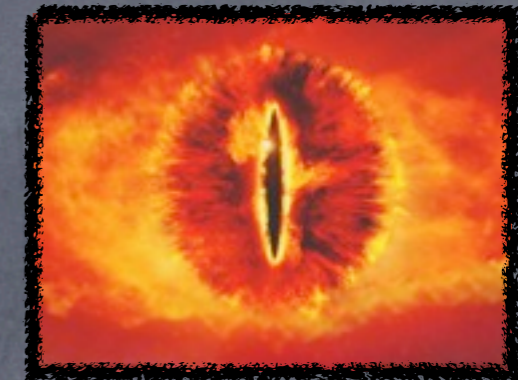
Introduction

- Disc-like pseudo-bulges: formed from disk (e.g. Athanassoula '05, Gadotti '09)
 - low Sersic index
 - low B/T
 - disc-like structure
- Galaxies can have 3 bulges



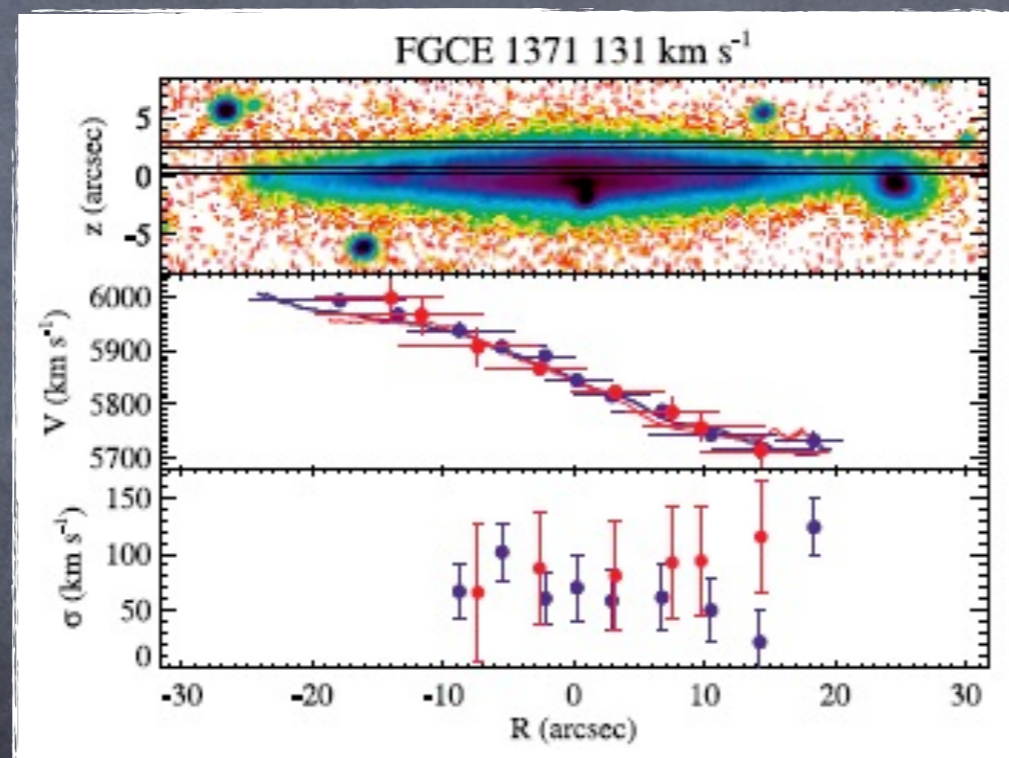
Introduction

- SAURON (Emsellem+ '04, Falcon-Barroso+ '06, Ganda+ '06)
- 2D kinematics (IFU)
- classical bulge rotation
- cylindrical rotation in bars
- kinematically decoupled cores
- velocity dispersion drops



Introduction

- Yoachim & Dalcanton '08
 - in massive galaxies, thick disks rotate as thin disks



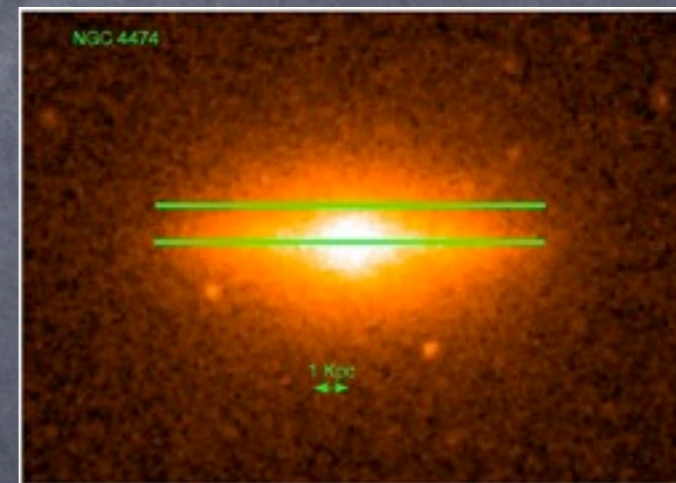
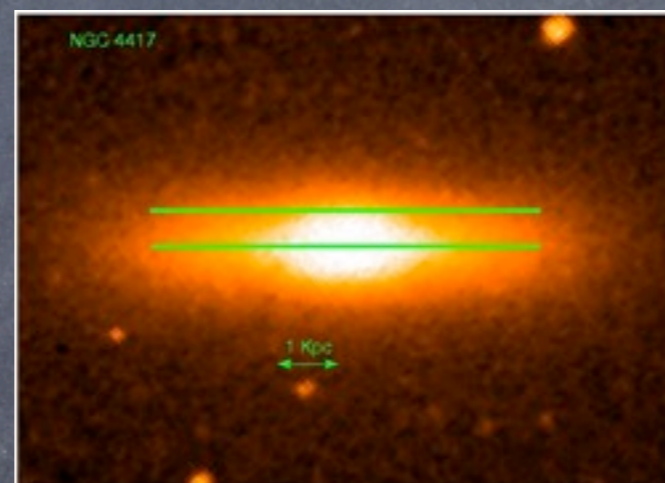
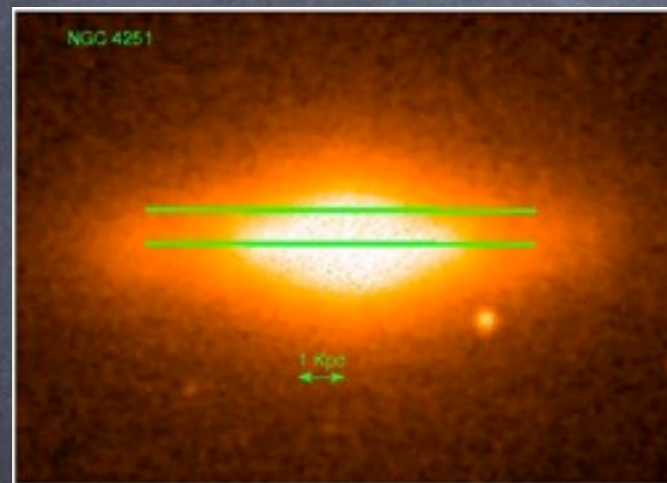
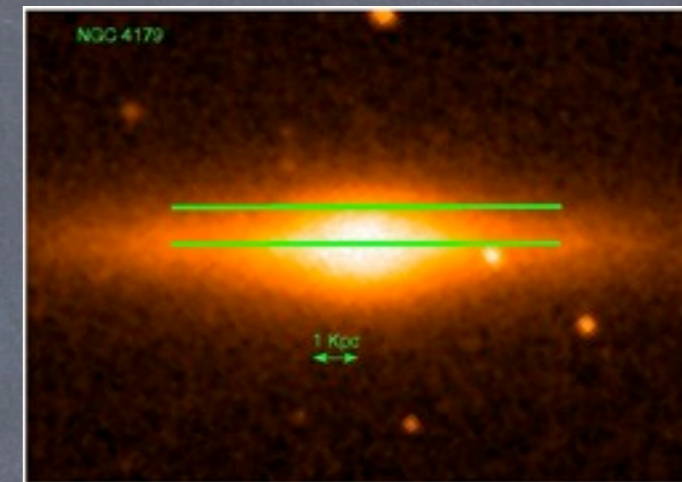
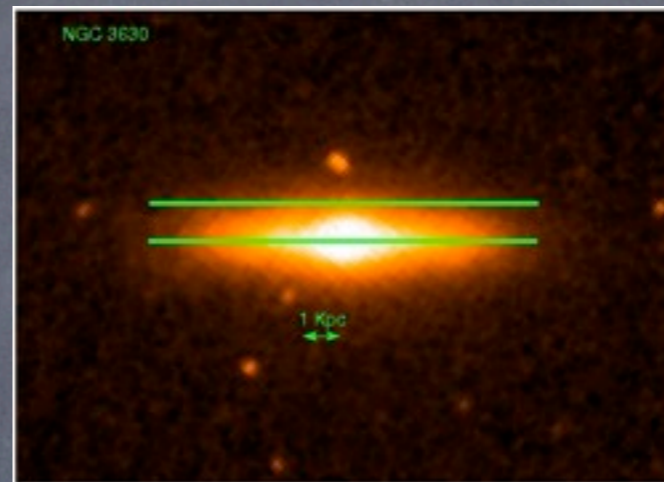
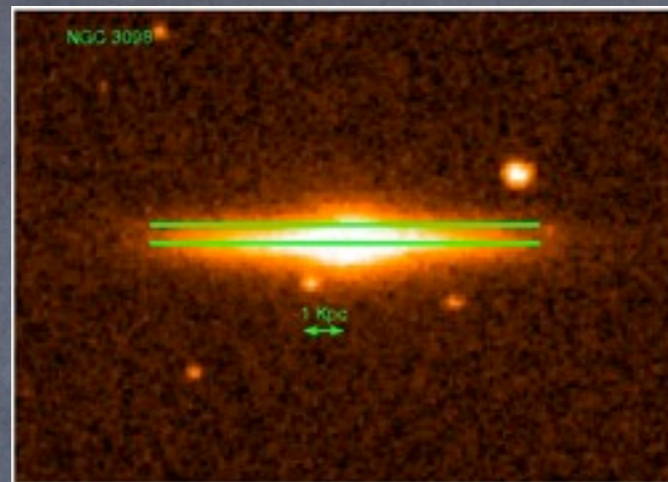
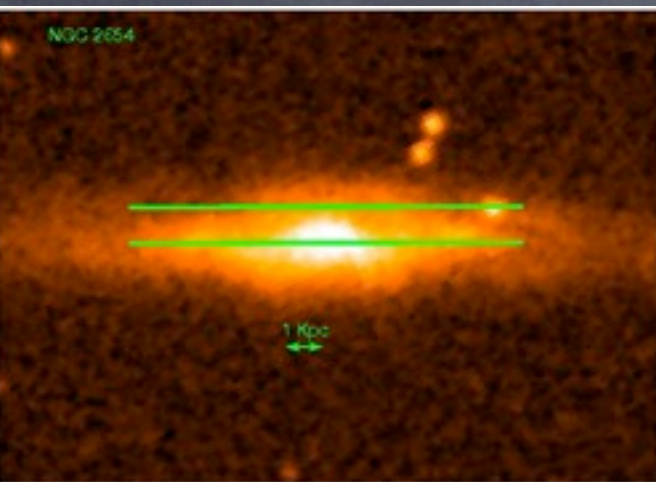
Introduction

- Which kinematics are we measuring?
 - classical bulge, disc-like bulge, bar, thick disk?
 - importance of structural analysis
- Naive expectations:
 - systems formed through mergers shouldn't rotate much
 - disc-like bulges have strong rotational support

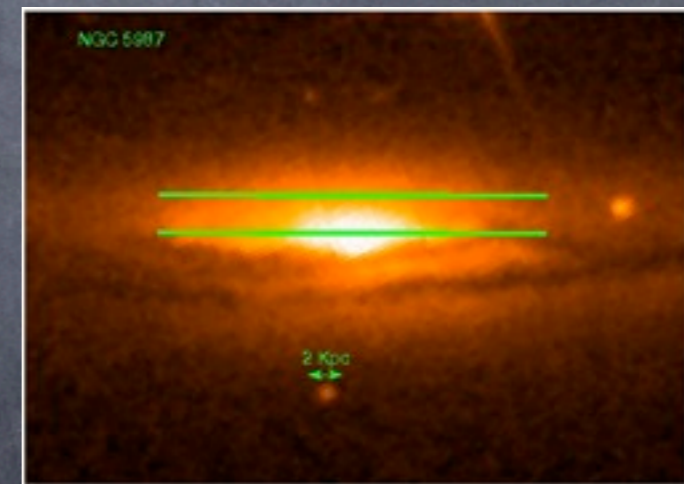
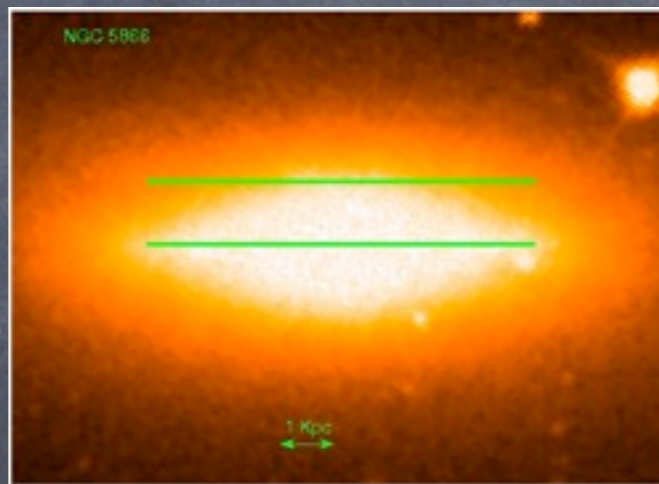
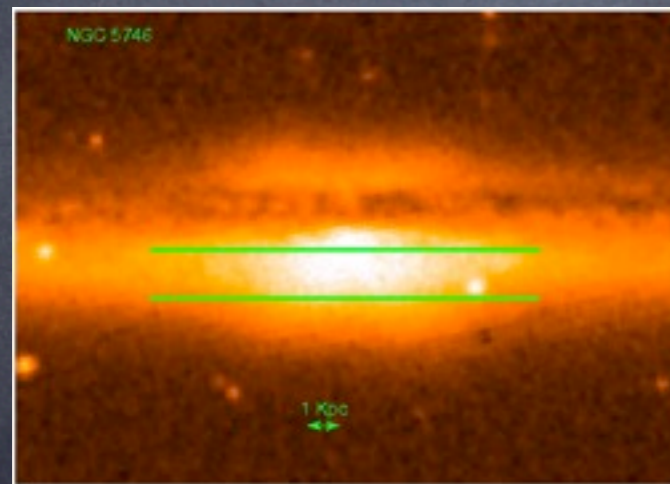
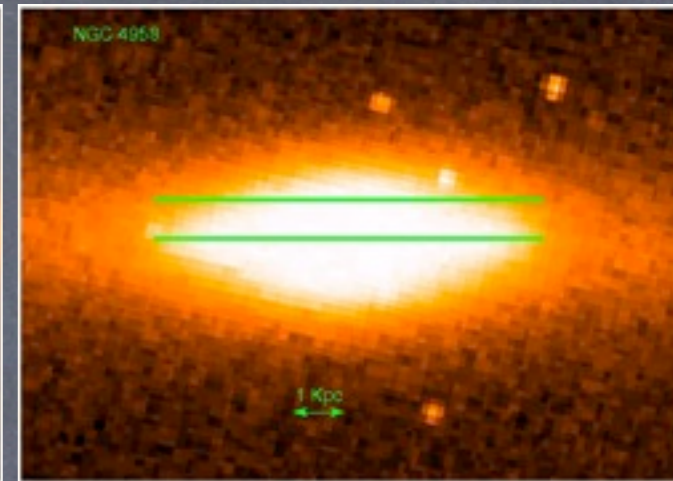
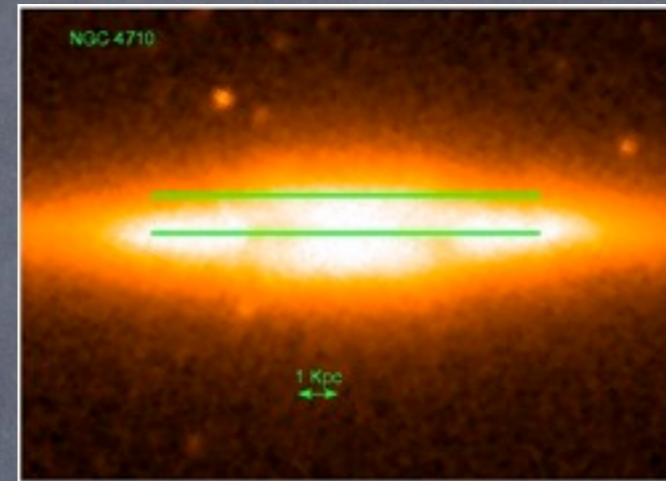
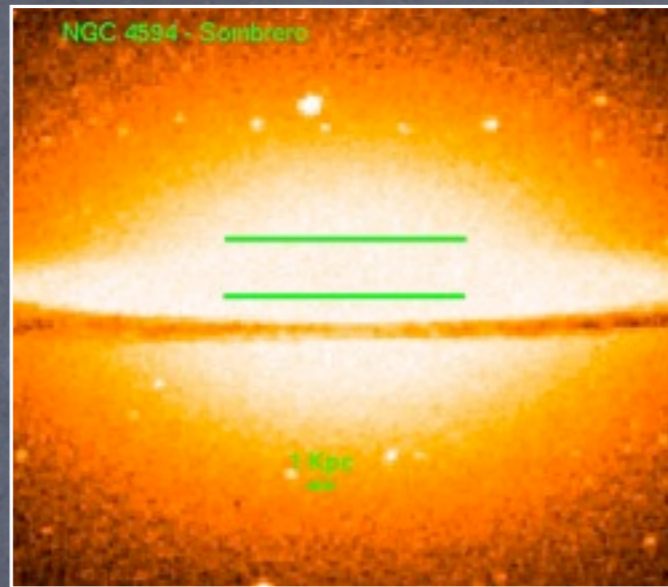
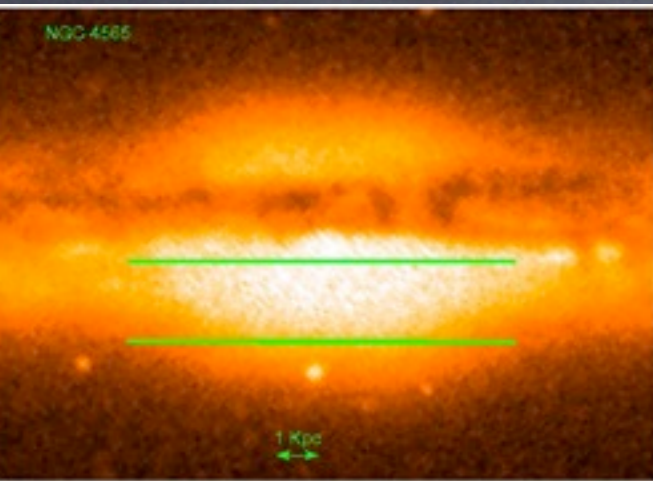
Sample & Observations

- all (14) galaxies very close to edge-on, visually inspected
- span a range in bulge shape and luminosity:
 - peanut, box, elliptical
- 2.5m Bok telescope (Steward Observatory)
- Mg I triplet + Na I
- S/N around 10–20 @ 1' from center (1 object/night)

Sample & Observations



Sample & Observations



Kinematical Measurements

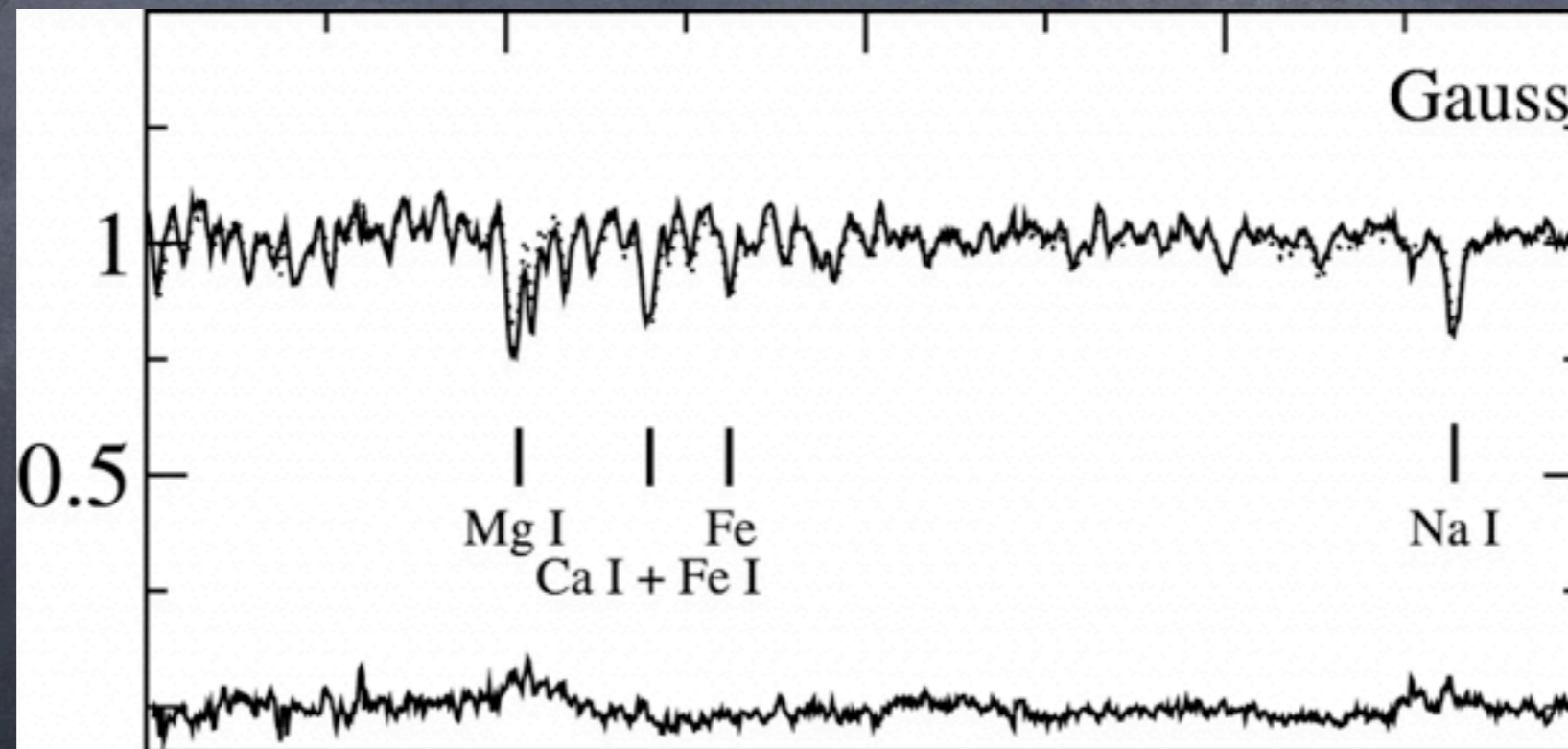
- line profile fitting in pixel space (van der Marel & Franx '93; Gadotti & de Souza '05)

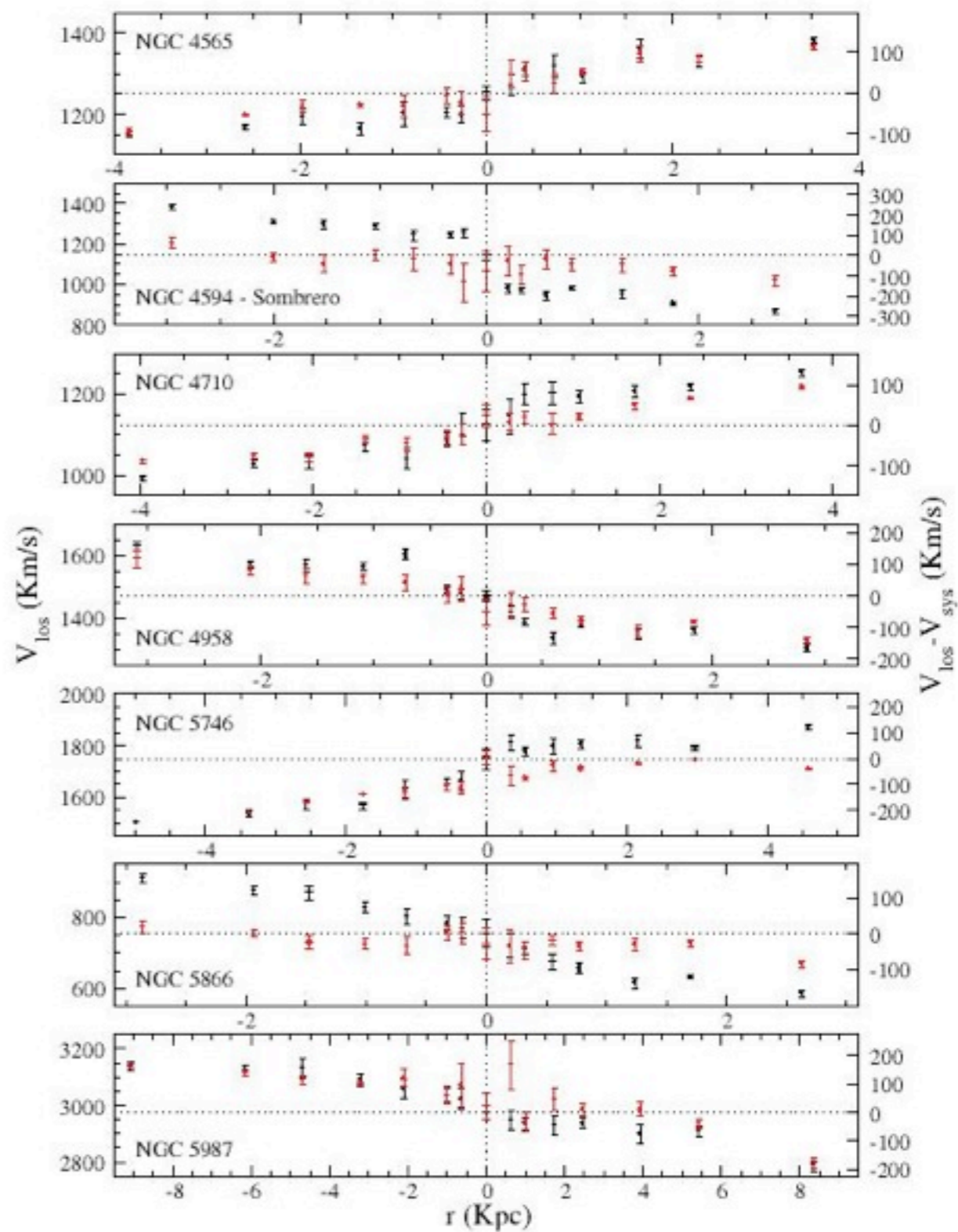
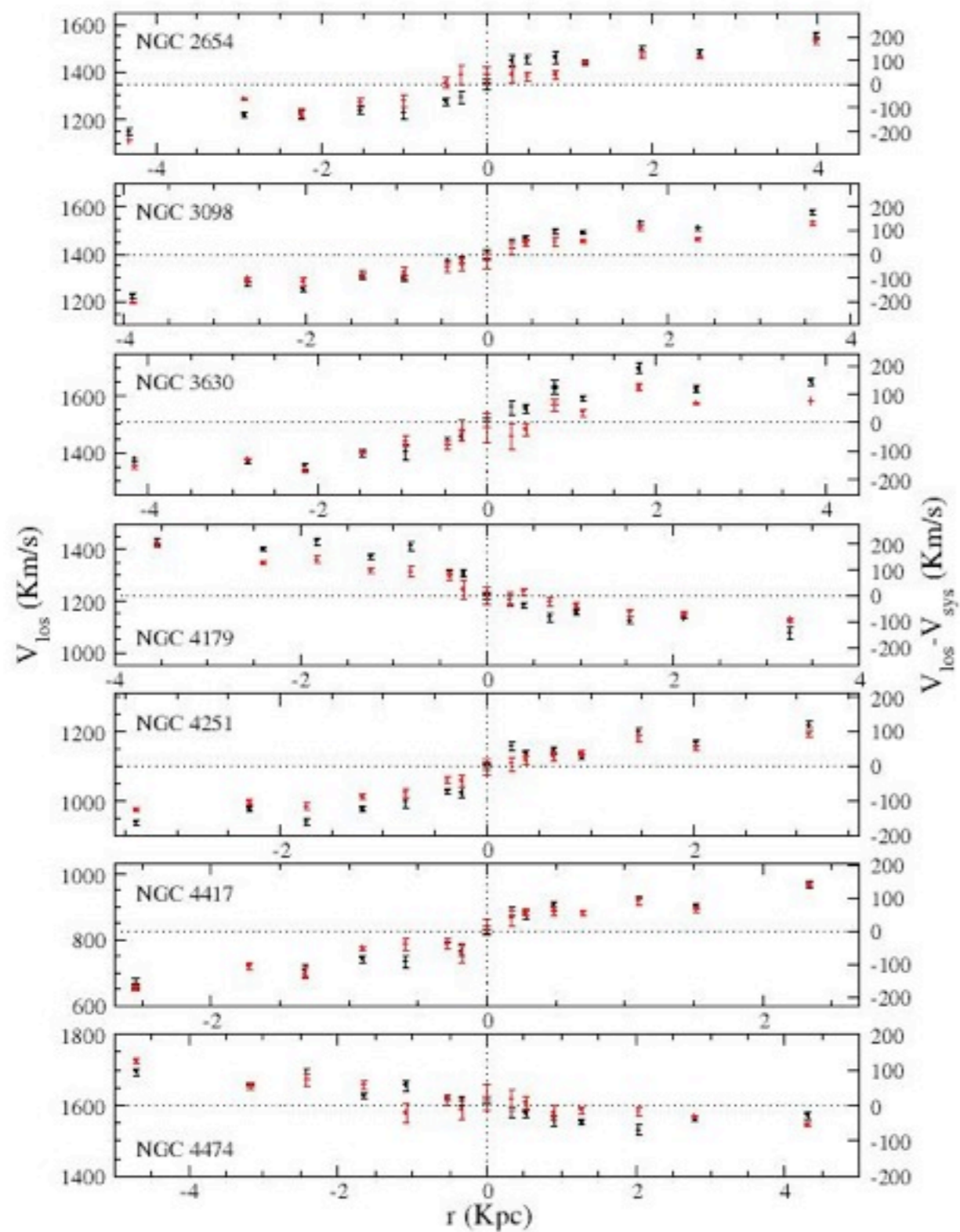
$$L(v) = \frac{\gamma\alpha(w)}{\sigma} [1 + h_3H_3(w) + h_4H_4(w)],$$

- LOSVD assumed to be Gaussian

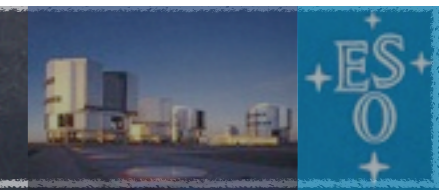
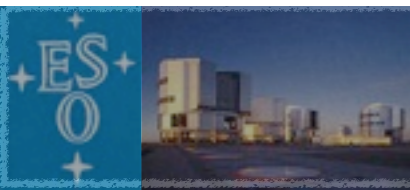
$$\alpha(w) = \frac{1}{\sqrt{2\pi}} e^{-w^2/2} \quad w \equiv \frac{v - v_0}{\sigma}.$$

- up to 5 template stars - minimizes template mismatch





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Structural Analysis

- BUDDA (de Souza, Gadotti & dos Anjos '04, Gadotti '08) mostly on SDSS i-band images:
 - 2D fitting using generalized ellipses (Athanasoula et al. '90)
$$\left(\frac{|x|}{a}\right)^c + \left(\frac{|y|}{b}\right)^c = 1$$
 - (double) exponential edge-on disk (van der Kruit & Searle '81)
$$L(R, z) = L_0 e^{-R/h} \operatorname{sech}^2(z/z_0)$$
 - Sersic bulge (Sersic '68)
 - Sersic bar
$$\mu_b(r) = \mu_e + c_n \left[\left(\frac{r}{r_e}\right)^{1/n} - 1 \right]$$

Structural Analysis

- Parameters:

- disk: $\mu_0, h, \mu_0', h', z_0$

- bulge: μ_e, r_e, n

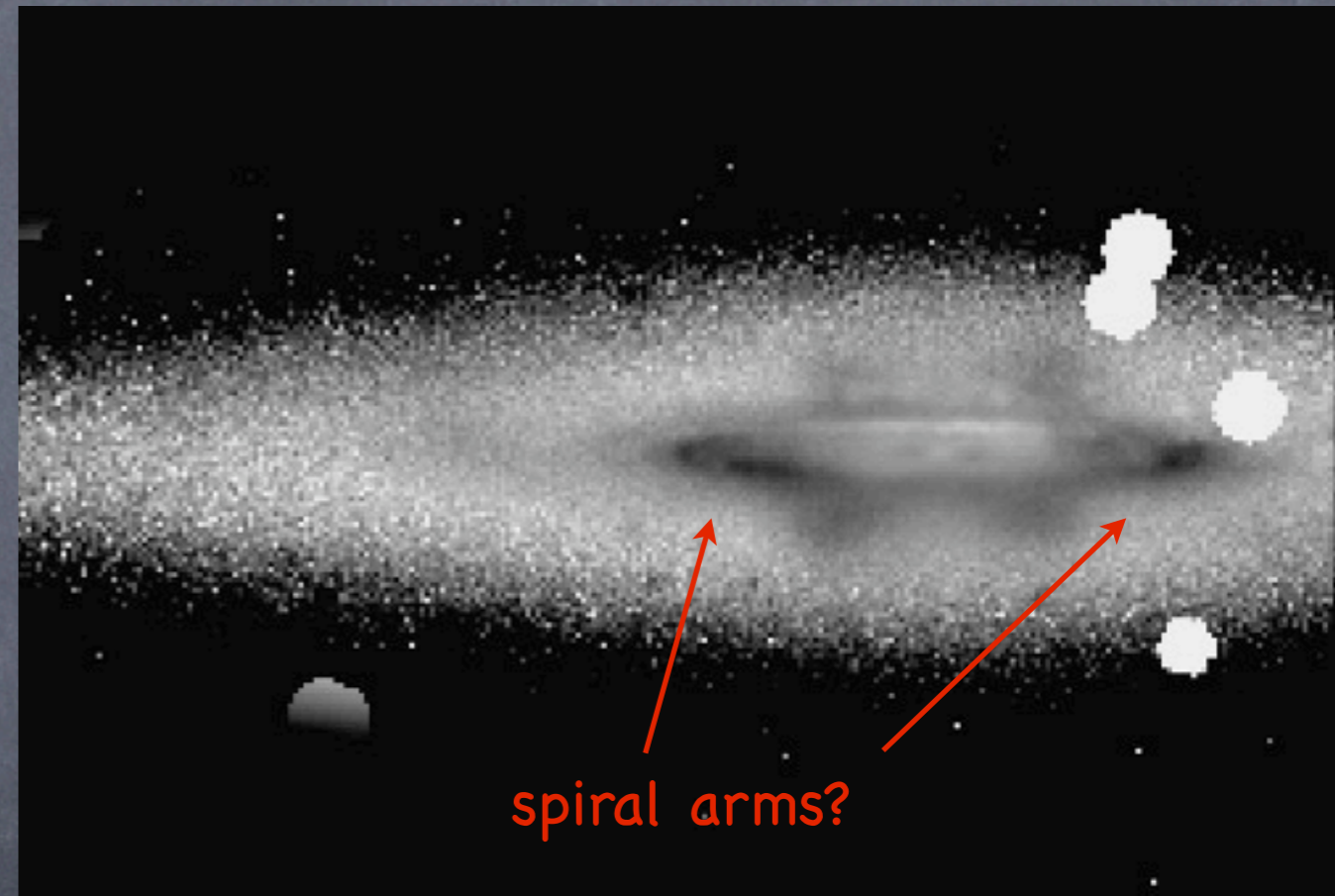
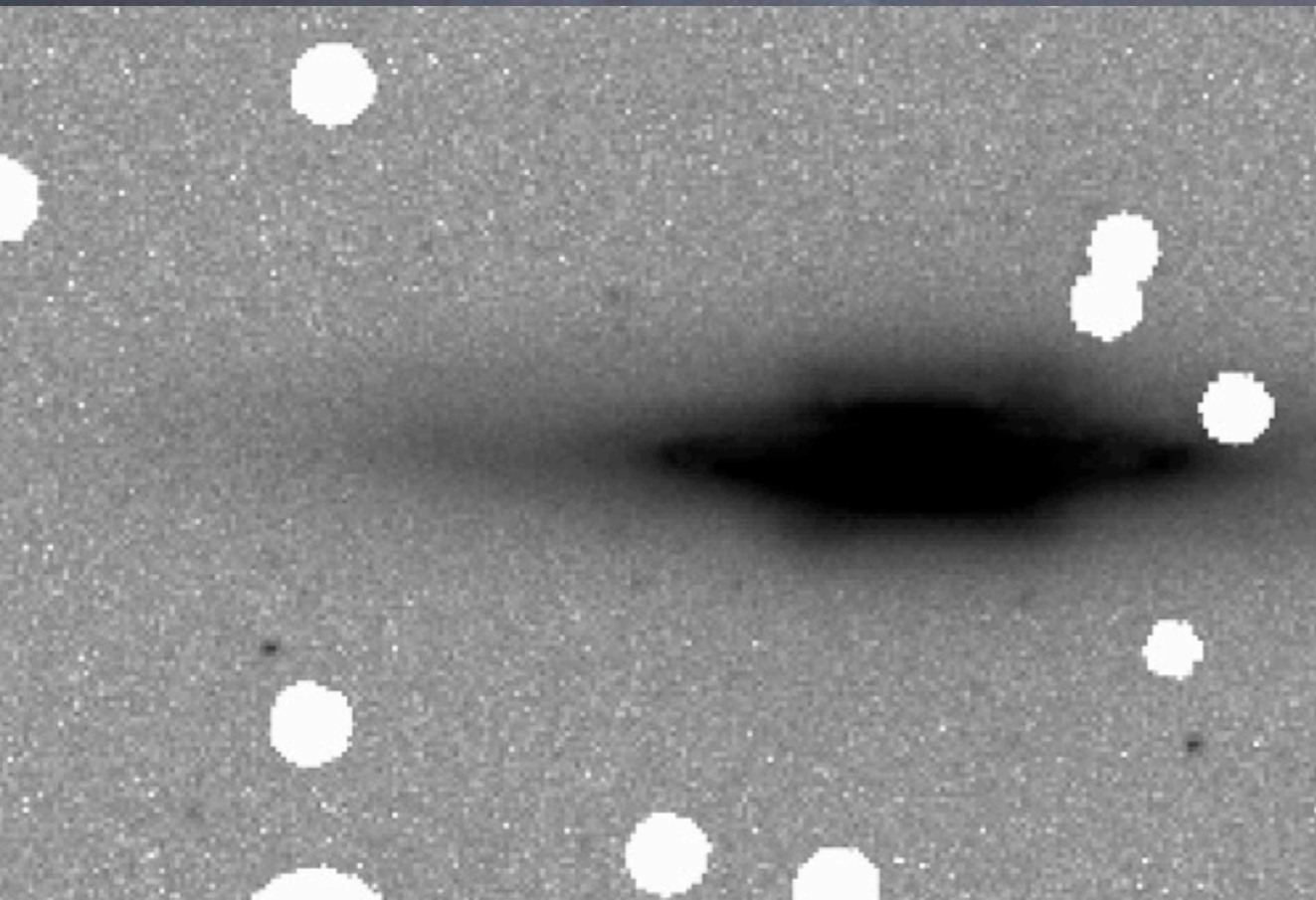
- bar: $\mu_{e,Bar}, r_{e,Bar}, n_{Bar}, L_B, c, \epsilon$

- B/T, D/T, Bar/T

Structural Analysis

- Peanuts (NGC 2654)

Enhanced Residual

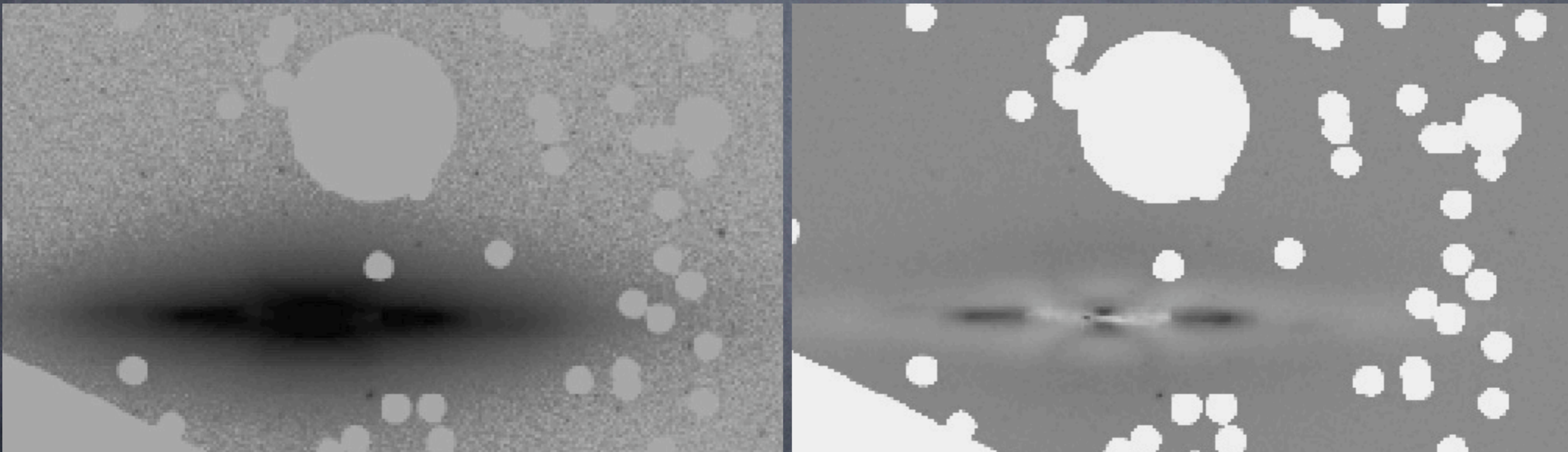


- Important to model bars (Gadotti '08)!

Structural Analysis

- Not so clear bar cases (NGC 4710 - Ks)
- Can check Luetticke, Bureau, Kuijken

Enhanced Residual

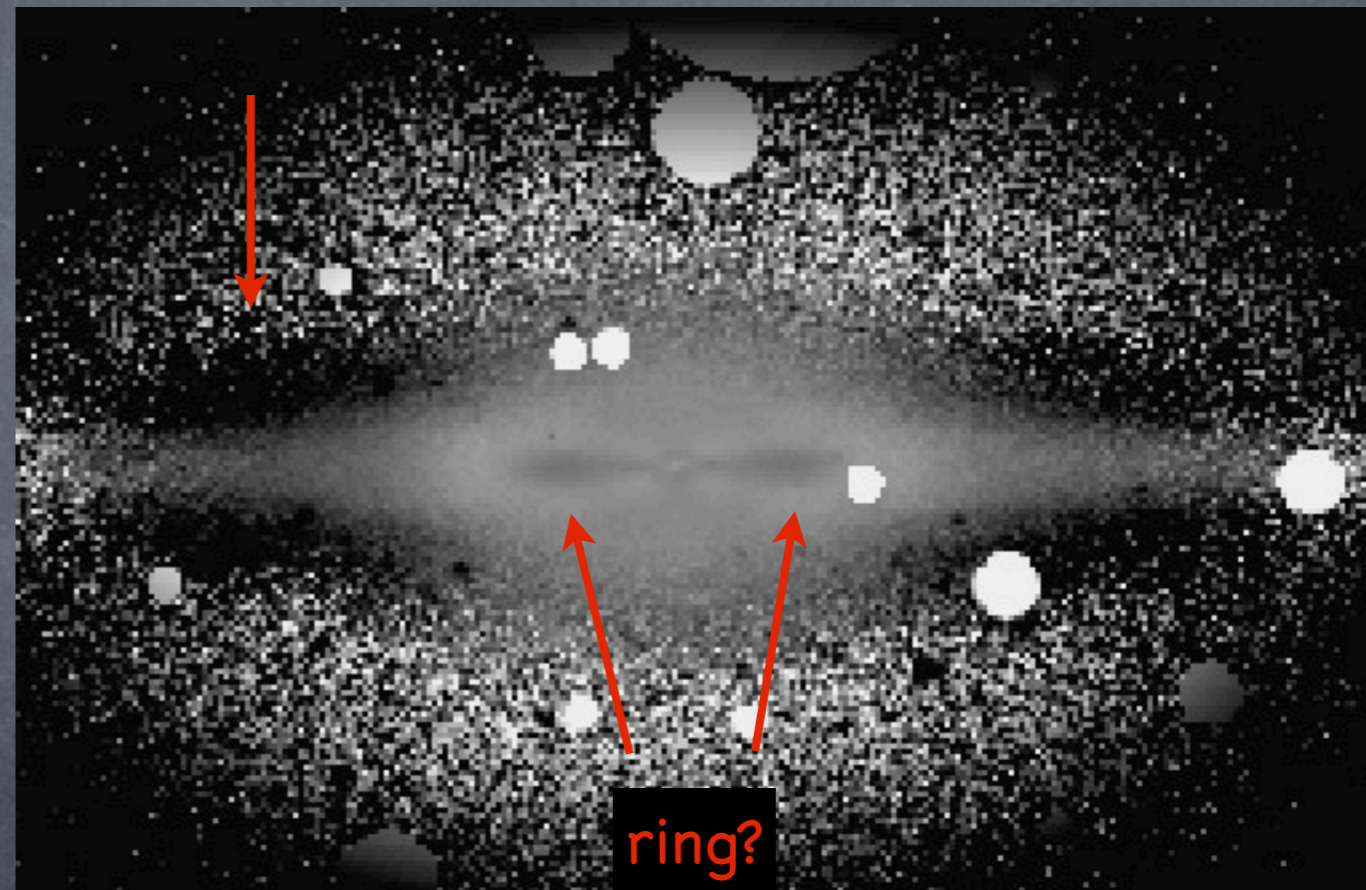
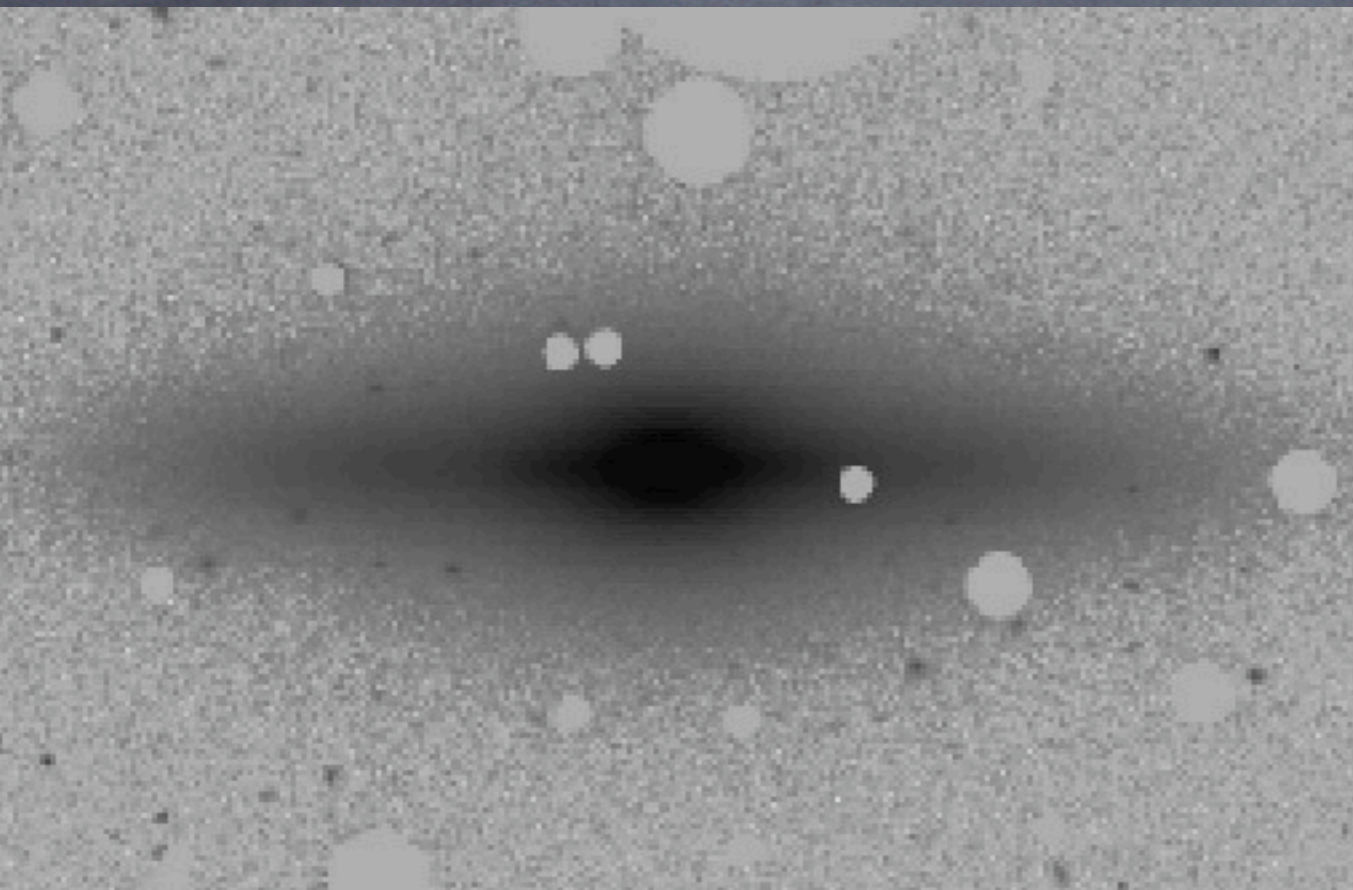


- bulgeless ($B/T=0.001$) - classified as S0!

Structural Analysis

- Thick disk, no bar (NGC 4179)

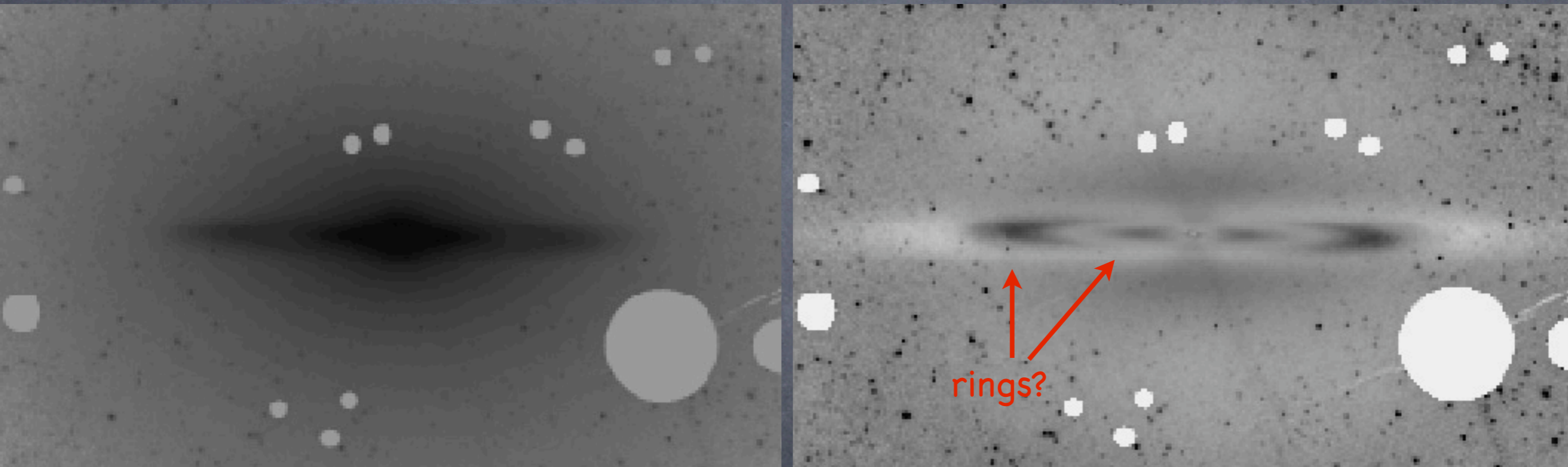
Enhanced Residual



Structural Analysis

- A remarkable case (NGC 4594 - Spitzer, IRAC 1)

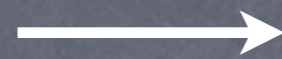
Enhanced Residual



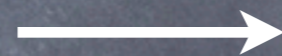
- Model includes halo ($n=1.9$, $B/T=0.13$)

Bulge Rotation vs. n

n	$V_{rot}(km/s)$
1.2	111
1.4	52
1.8	0
1.9	0
2.0	0
2.1	0
2.3	15
2.6	18
4.3	33



disc-like bulges with rotational support



classical bulges with pressure support