Dynamical Models of Elliptical Galaxies in z=0.5 Clusters

Measuring M/L Evolution without Fundamental Plane Assumptions

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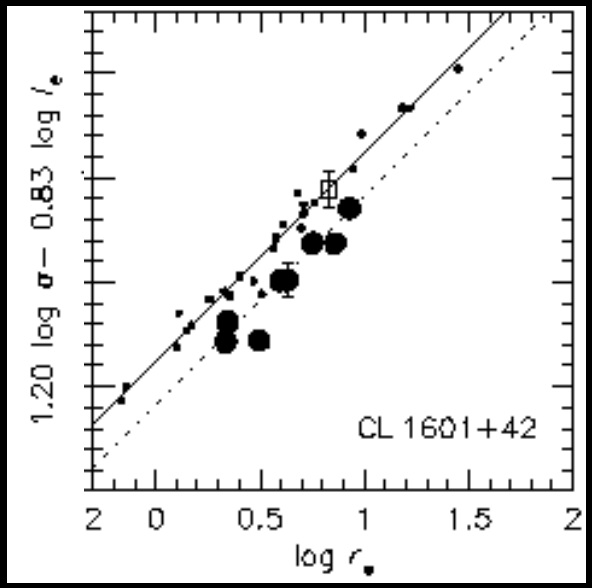
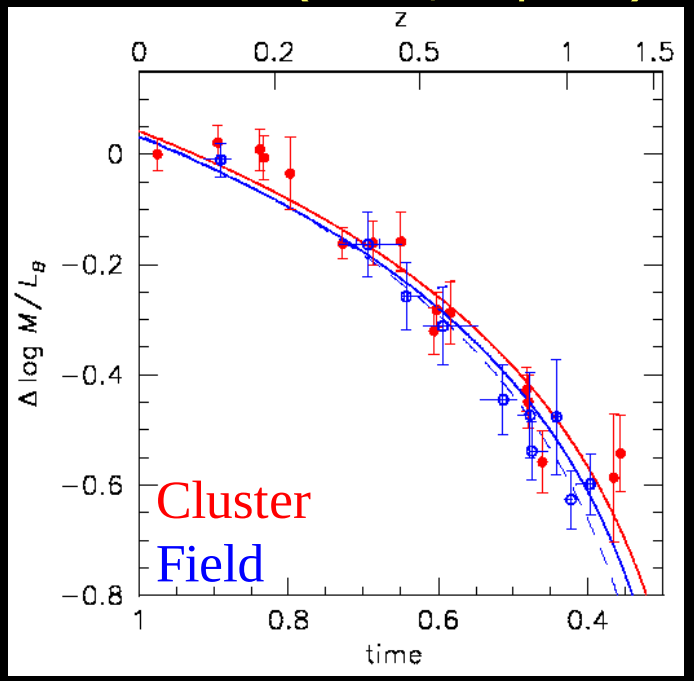
M/L Evolution using FP

- Distant galaxy observations yield effective quantities
  - High resolution imaging: R, I
  - Deep Spectroscopy: σ
- Fundamental Plane (FP)
  - $R = C\ \sigma^{\alpha} I^{\beta}$, C = FP zeropoint
- FP zeropoint evolution w.r.t. Coma
  - $\Rightarrow$ M/L evolution
  - Provided that assumptions are valid
- M/L evolution
  - $\Rightarrow$ galaxy ages
  - $\Rightarrow$ Constraint on galaxy formation theories



Results

vD & vdM (2006, Paper I)



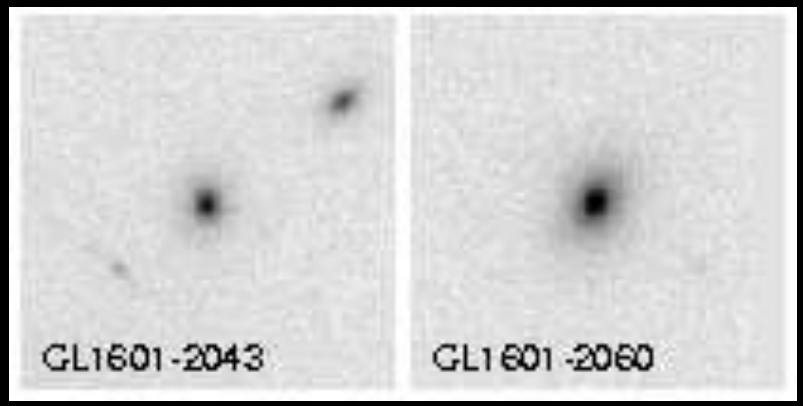
- Data
  - New: 3 clusters at z=0.5
  - Literature: 11 other clusters
  - Literature: field galaxies
- Interpretation
  - Homogeneous analysis
  - Various IMFs, progenitor bias
- Results for $M > 10^{11}\ M_{\odot}$
  - Cluster Galaxies: $d \log (M/L_B) / dz = -0.555 \pm 0.042$
    - $z(\text{formation}) = 2.0 \pm 0.2$ for "standard" IMF
    - z(formation) can be larger for top-heavy IMF
  - Field Galaxies: younger by $4.1 \pm 2.0\%$ (~0.4 Gyr)

Motivations for More Detailed Analysis

- FP to M/L conversion relies on untested assumptions
  - R, I, σ and internal structure may evolve with z; not just M/L
  - Plausible models exist in which M/L does not follow FP (e.g., Almeida, Baugh & Lacey 2006)
- FP results counter-intuitive given hierarchical formation scenarios
- Some assumptions can be avoided by using more data
  - R, I $\Rightarrow$ Surface brightness profile + axial ratio
  - $\sigma \Rightarrow$ Resolved velocity dispersion and rotation velocity profiles
- How: Modeling of Internal Dynamical Structure
  - Tools well-developed and tested in local universe
  - vdM & vD (2006, Paper II)

Sample & Data

- Three MORPHS clusters
  - CL 3C295 (z=0.456)
  - CL 0016+1609 (z=0.546)
  - CL 1601+4253 (z=0.539)
- 25 visually-classified early-type galaxies
  - 20 ellipticals, 2 E/S0, 1 S0/E, 1 SO, 1 S0/Sb
- HST/WFPC2 imaging (Archival)
- Keck/LRIS spectroscopy (New)



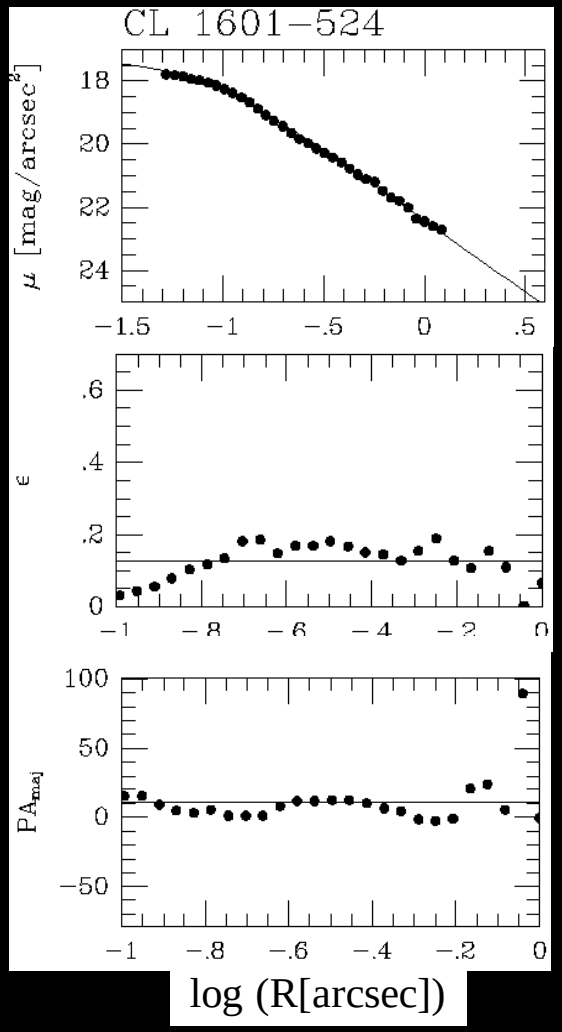
Models

- Oblate axisymmetric
- Constant ellipticity and PA
- Parameterized $\rho(R,z)$

chosen to fit photometry

- Inclination chosen statistically
- Potential from Poisson equation
- Dynamics from Jeans equations
  - DF Assumption: f(E,Lz)
- Projection along line-of-sight
- Convolution with seeing, slit width and pixel binning
- Comparison to V and σ profiles

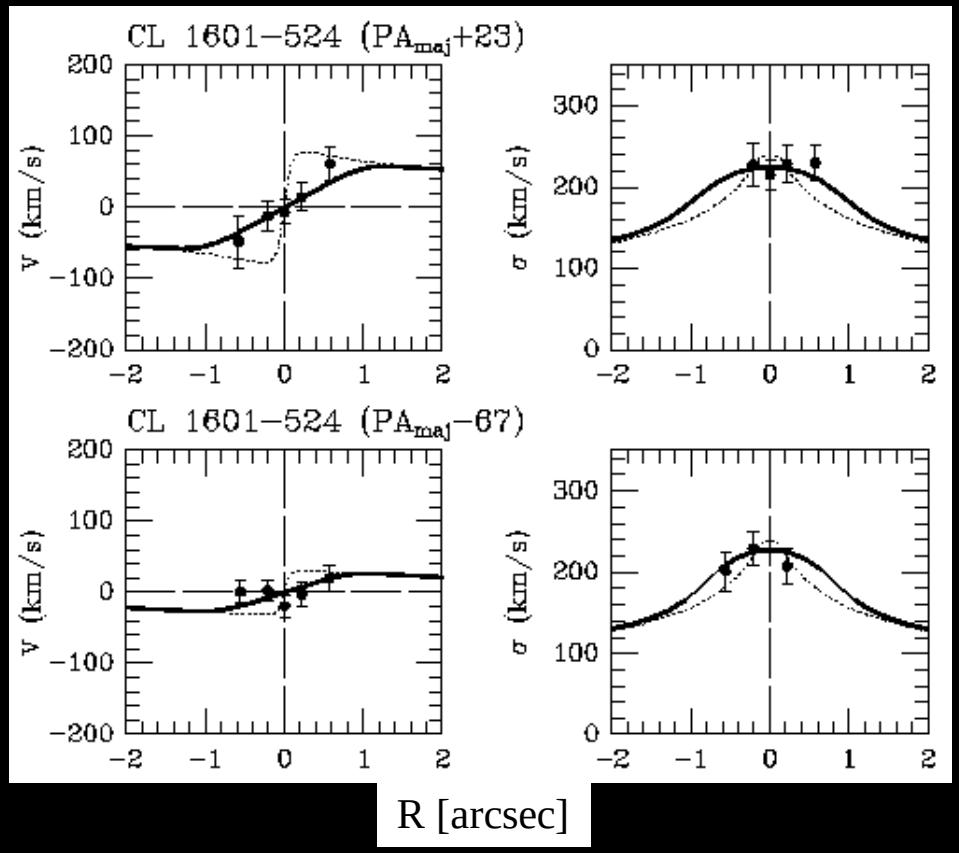
Lucy deconvolution + ellipse fitting



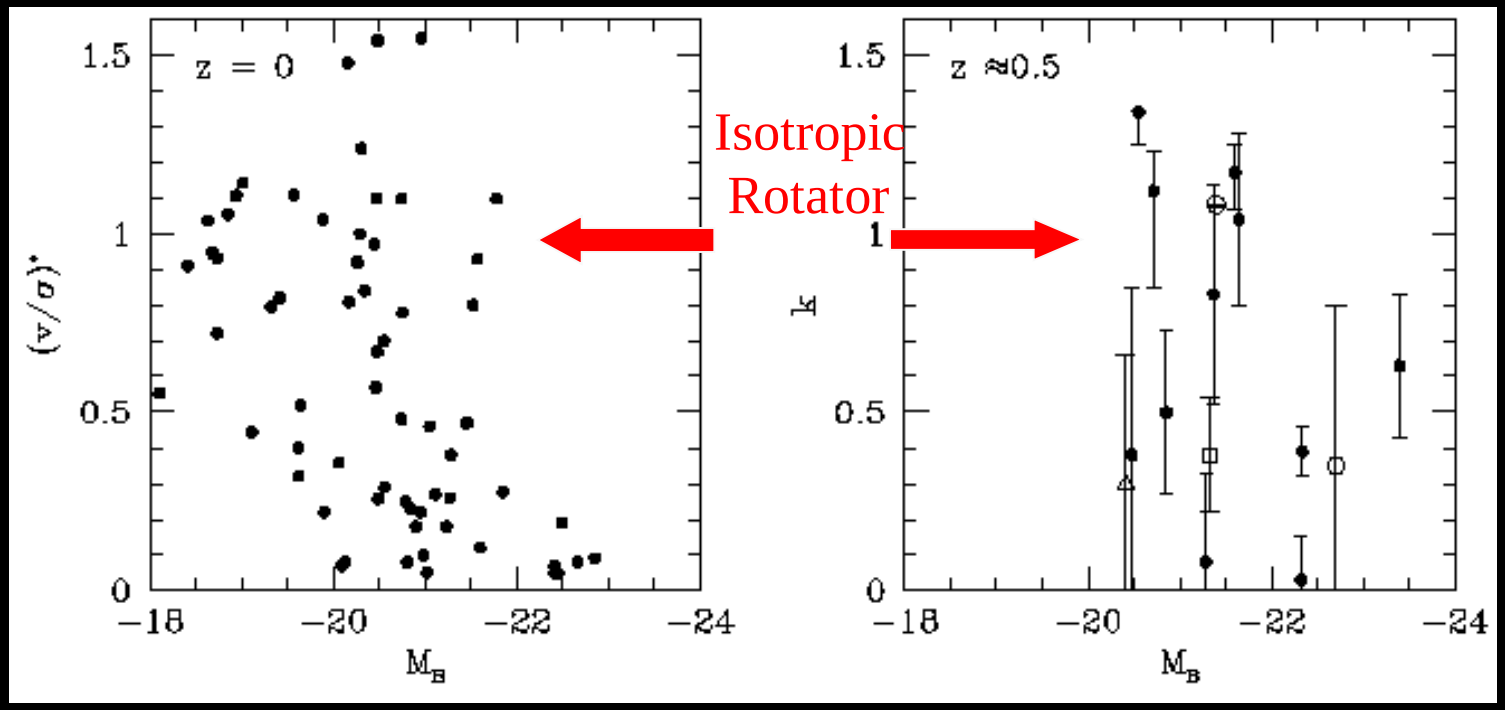
Data-Model Comparison

- Kinematical profiles
  - Pixel size 0.215″
  - Extent ~0.7″ (4.3 kpc)
- Modeling spatial resolution essential
  - Seeing 0.7″-0.9″
  - Slit width 1.1″
- Acceptable fits
- Model parameters
  - M/L_B
  - k [similar to $(V/\sigma)^*$]

Cross-correlation + Gaussian LOSVD fitting



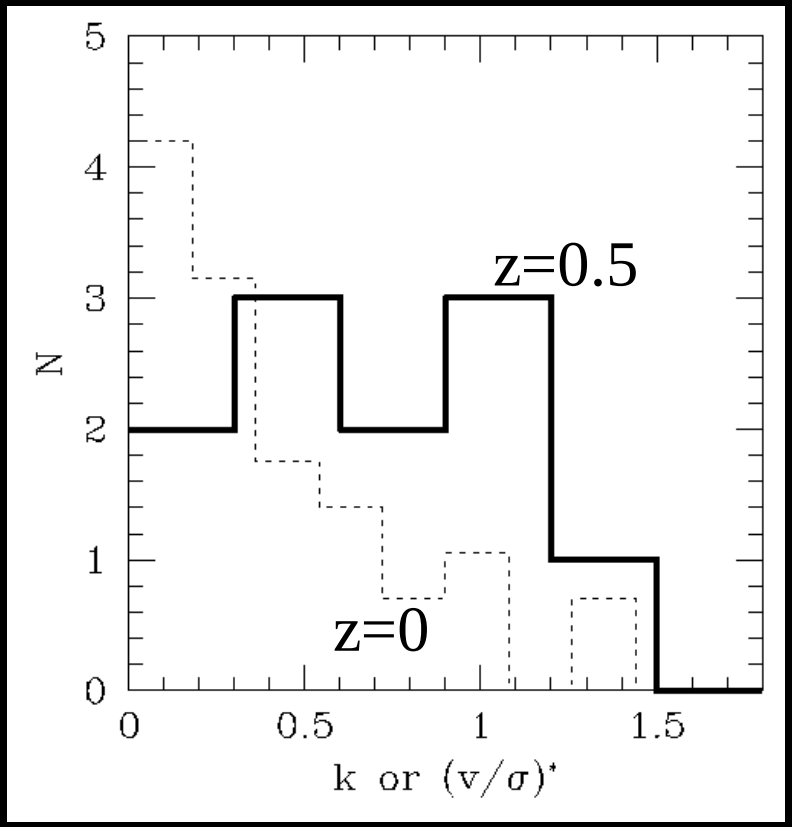
Rotation Properties



- Most luminous galaxies at z=0.5 rotate too slowly to account for their flattening
- Consistent with rotation properties of local ellipticals

Kinematical Identification S0 galaxies?

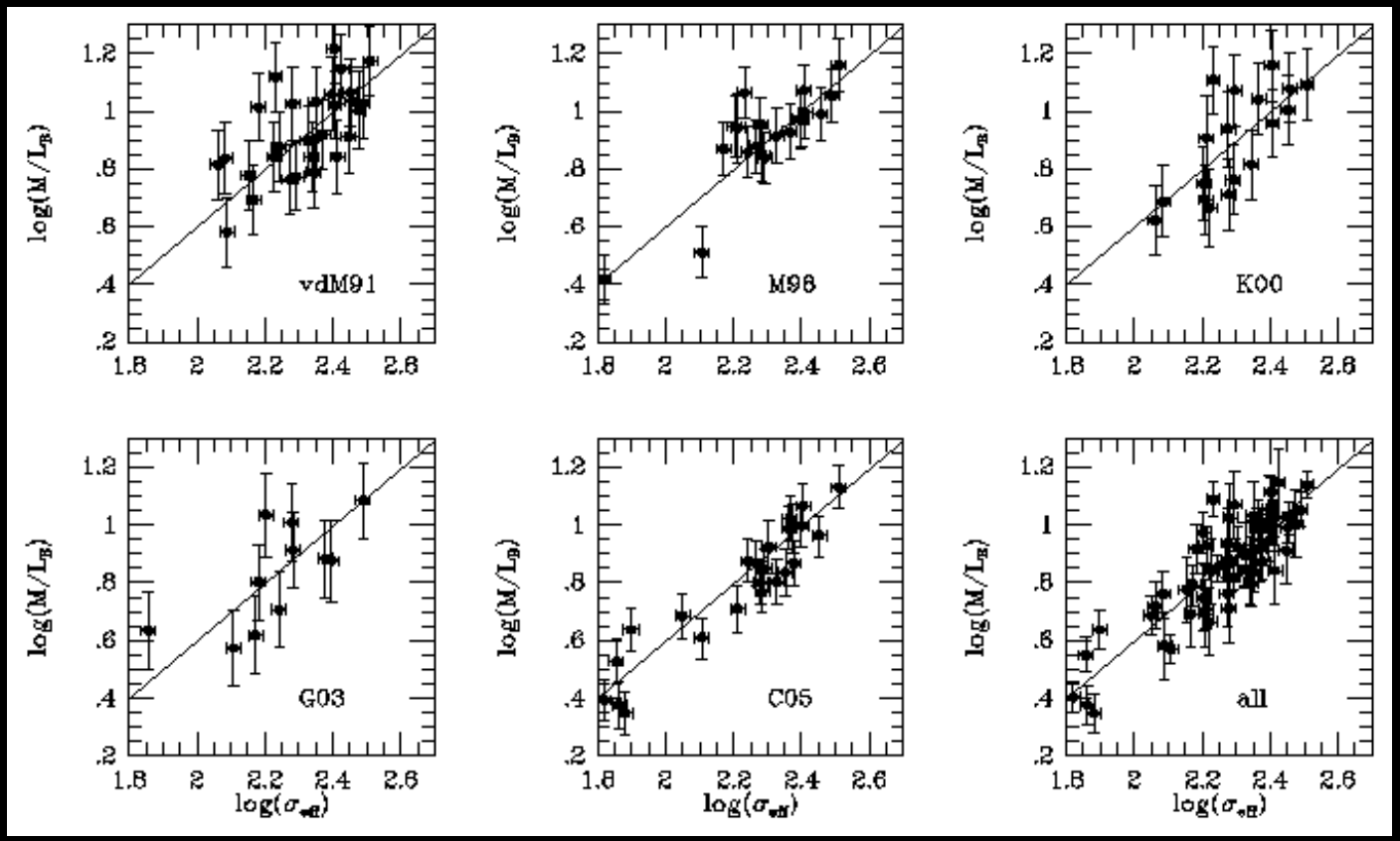
- More rapidly rotating galaxies among visually classified ellipticals at z=0.5 than z=0
- Probably more misclassified S0s at z=0.5
- Only raises the S0 fraction of the three target clusters mildly (16% ⇒ 22%)
- Insufficient to explain strong S0 evolution from z=0.5 to present



M/L in the Local Universe

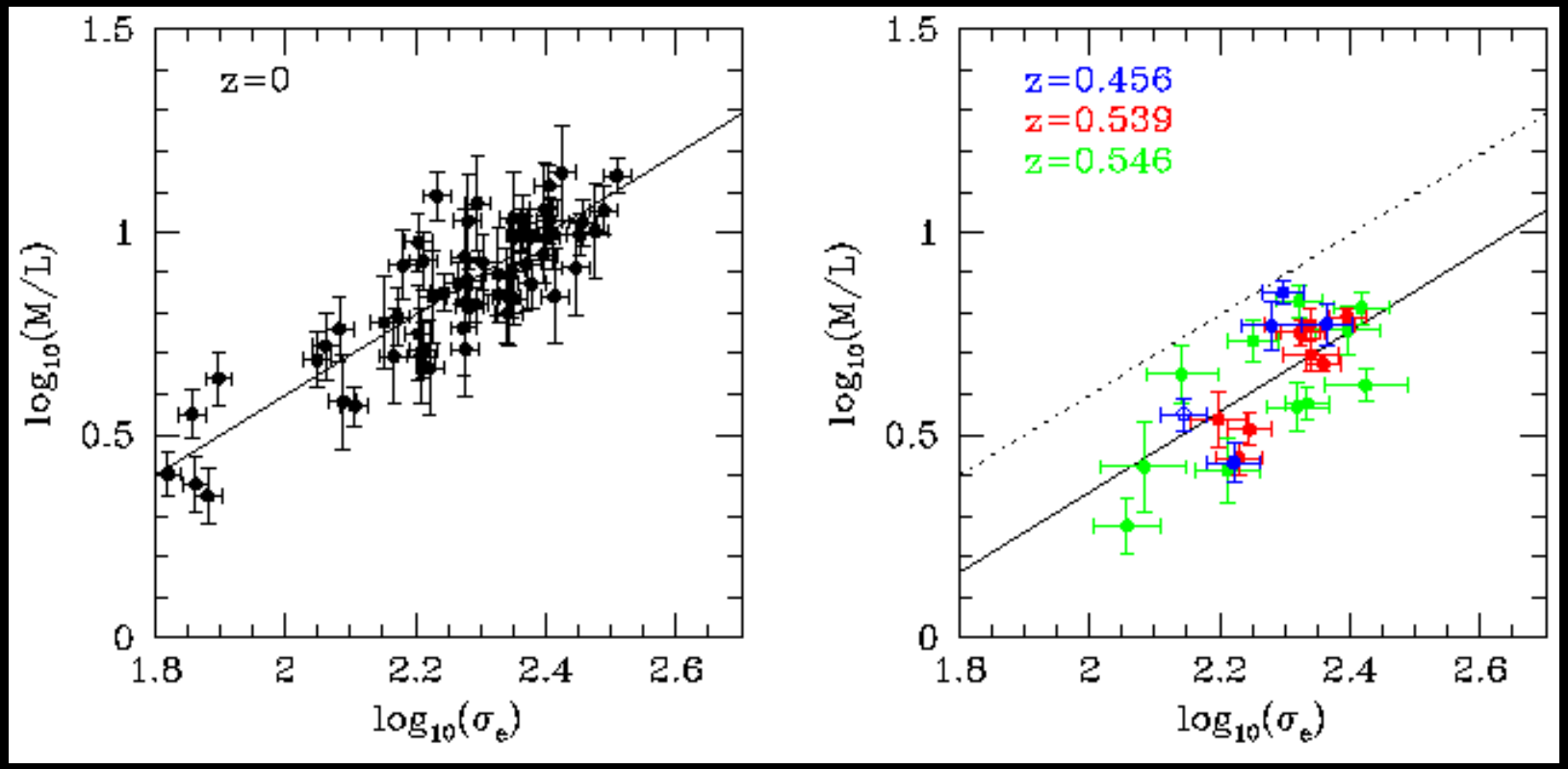
- Detailed dynamical modeling of large samples
  - vdM (1991), Magorrian et al. (1998), Kronawitter et al. (2000), Gebhardt et al. (2003)
    - Found that M/L correlates with L or M
  - Cappellari et al. (2006)
    - Found that M/L correlates even more tightly with σ
- New homogenized compilation of these model results
  - Transformed to B-band M/L
  - Individual distances from SBF method (Tonry et al. 2001)
- Result
  - $\log(M/L)_B = (0.896 \pm 0.010) + (0.992 \pm 0.054) \log(\sigma_{eff}/200\ km/s)$
  - Slope steeper than in I-band (0.82 ± 0.06, Cappellari et al.)

Local Results: Modeling Comparison



- Excellent agreement between different studies
- Systematic modeling errors small

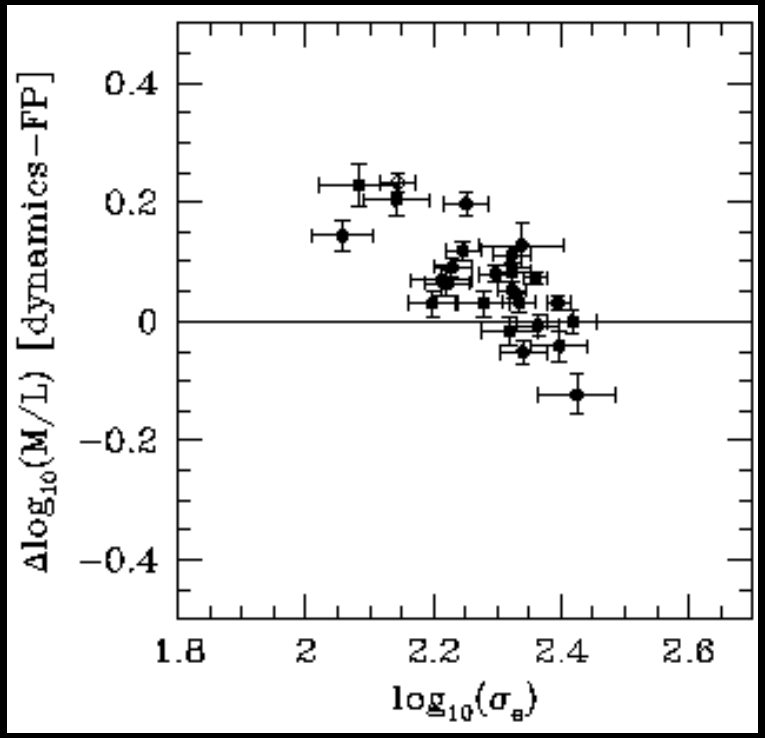
Evolution of the M/L – sigma relation



- d log (M/L_B) / dz = -0.529 ± 0.049(random) ± 0.071(sys)
- Consistent with FP zeropoint evolution (for $M > 10^{11} M_\odot$)

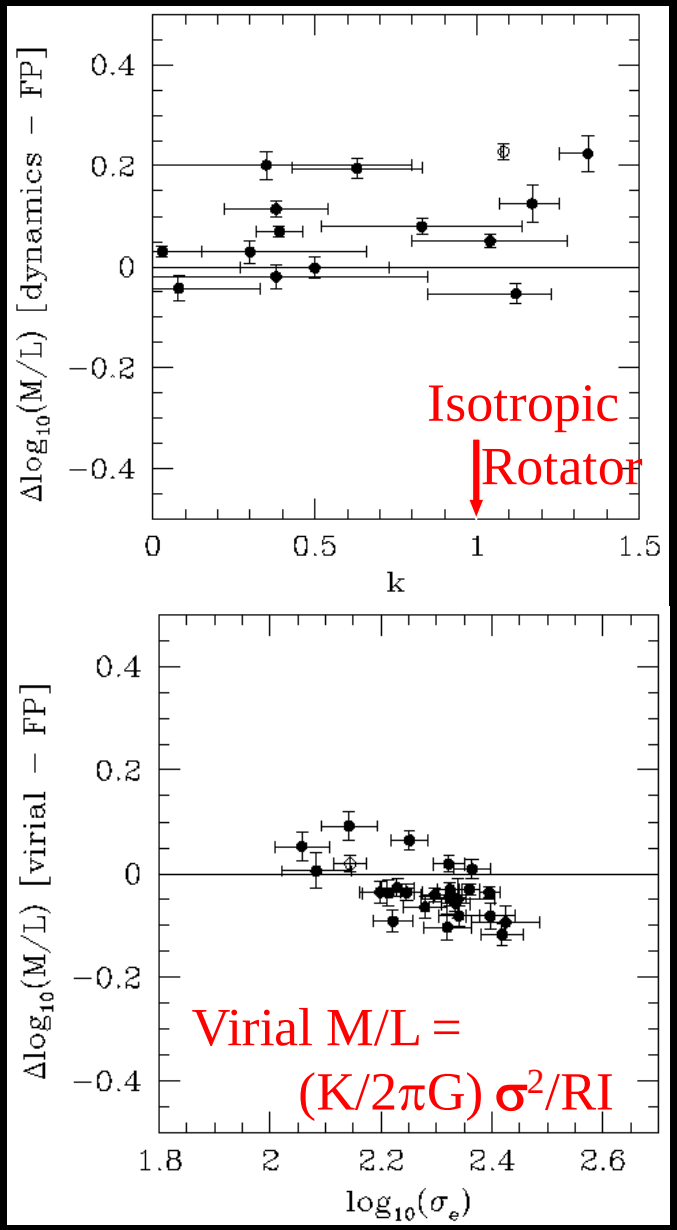
Dependence on σ (or Mass)

- FP: more evolution for galaxies of low σ
  - FP slope becomes steeper with redshift
  - Also seen in many other samples
  - Usually interpreted as difference in age
- M/L vs. σ relation: evolution independent of σ
  - Slope same at z=0.5 as z=0
  - No difference in age implied



Methodological Differences

- Why do FP evolution and M/L- σ evolution differ for low-σ galaxies?
  - Other quantities than M/L may be evolving (R, I, σ, structure, …)
    [relations not parallel!] (+)
  - Rotation may be important: affects M/L but not FP
    [aperture corrections?] (?)
  - Dynamical models may suffer from limited resolution
    [systematically errors?] (–)



Conclusions - Distant Elliptical Galaxies

- To lowest order: FP evolution = M/L evolution
  - z(form, M > 10^{11} $M_{\odot}$, cluster) = 2.0 $\pm$ 0.2 ("standard" IMF)
  - field Galaxies: younger by 4.1 $\pm$ 2.0% (~0.4 Gyr)
- When considered more carefully, many subtle effects come into play
  - Quantities other than M/L may be evolving
  - Rotation may be relevant
- Steepening of FP tilt with redshift does not necessarily imply that low-mass galaxies are younger

Conclusions – What's next

- Good reasons to move beyond global properties
- Available data and tools allow detailed modeling of internal dynamical structure
- Extend similar analyses to different samples
- Study combined M/L and color evolution
- JWST/NIRSpec will further revolutionize this field