Stellar Mass-to-Light Ratios and the Tully-Fisher Relation

Bell and De Jong 2001

Why M/L?

- Relates photometry to dynamics
- Direct impact on
  - Rotation curve decomposition
  - Passband-dependent slope of Tully-Fisher relation

Why M/L?

- Rotation curve decomposition
- Can determine structure of dark matter halo if we understand contributions of
  - gas (well understood and small)
  - stars (not well understood and big)

- Tully-Fisher relation
- Relates integrated luminosity to global dynamics of galaxy + dark matter halo
- $L \sim V^3$ in optical
- $L \sim V^4$ in near-IR
- Possible to reproduce T-F in one passband without reproducing other passbands
  - Baryonic mass T-F

Galaxy Evolution Models

- Assumptions
  - Disk-dominated galaxies
  - Instantaneous recycling approximation (IRA)
  - SPS models of Bruzual & Charlot (2001)
  - Salpeter IMF (scaled down M/L by 0.7 to agree with observations)
  - Masses between 0.2 and 125 M_{sun}
  - Exponential gas disk with either Schmidt (1959) or Kennicutt (1998) star formation law

Galaxy Evolution Models

1) Closed-box, no gas infall or outflow, 12 Gyr, Schmidt law
2) + gas infall
3) + metal-enriched outflow
4) Kennicut law (no infall or outflow)
5) Mass-dependent galaxy formation epoch with no infall or outflow
6) "Burst", mass-dependent galaxy formation epoch, no infall or outflow, SFR varies on 0.5 Gyr scale with lognormal distribution of width 2 ← default model, best reproduces observations

How to construct galaxy model?

- SPS
- Convert into solar units
- Use IRA to construct stellar masses (instead of full gas mass-loss histories from SPS)
  - Error < 5%

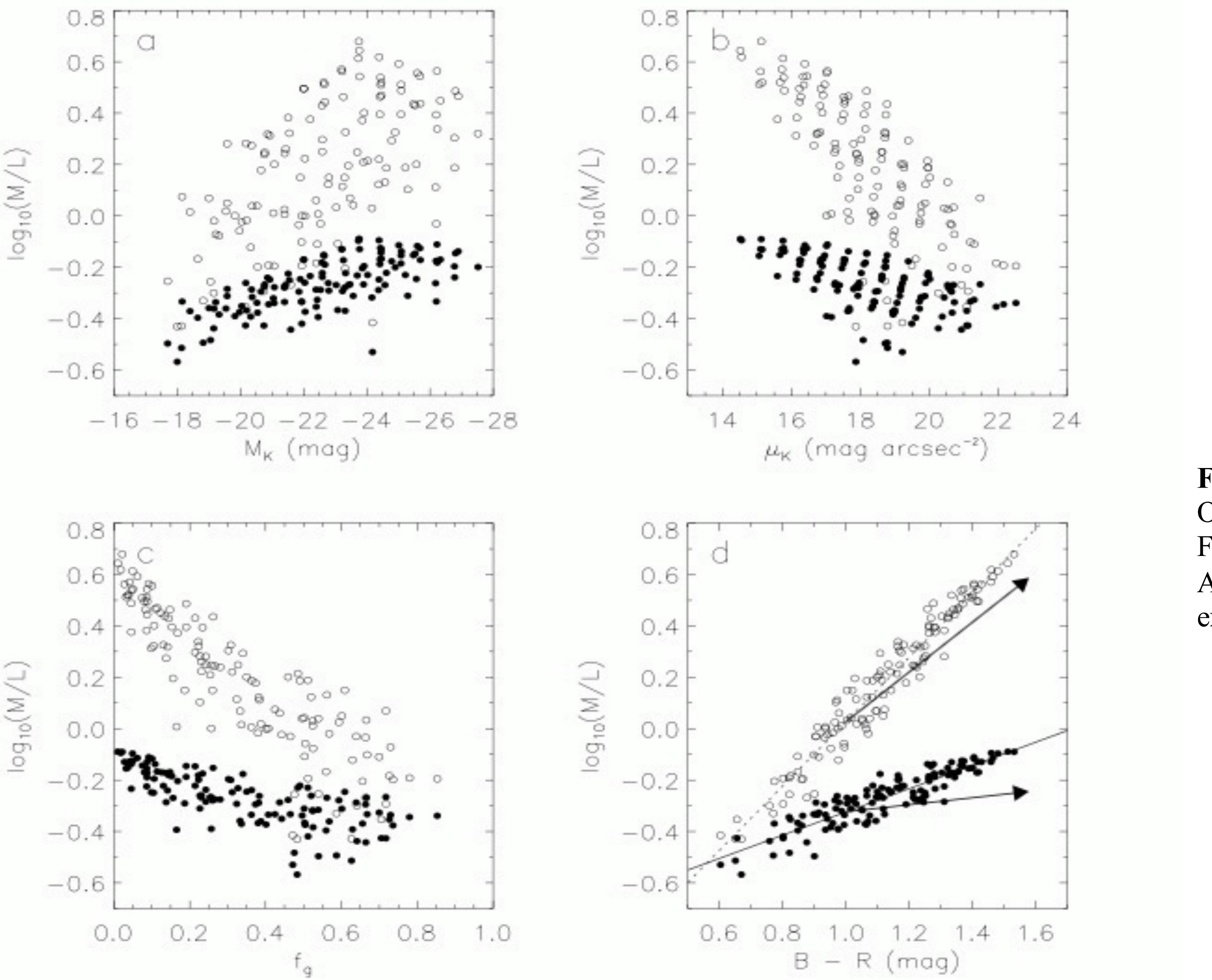


Figure 1
Open circle – B
Filled circle – K
Arrows – dust
extinction vectors

Important points

- Significant trends in all passbands
  - Factors of ~7 in B, ~3 in I, ~2 in K → K-band important for observations where you want to minimize M/L scatter
- For all models, in all optical and near-IR passbands M/L correlates strongly with galaxy color
- Assuming universal IMF, "workers determining the stellar M/L ratios of spiral galaxies will […] observe trends in stellar M/L ratio that correlate most tightly with galaxy color."
- Color gradients in spiral galaxies → significant gradients in stellar M/L (outer regions have lower M/L that inner regions)

Color-M/L Correlation

- SPS with different metallicities from Bruzual and Charlot
- Exponentially declining SFR
  - Parametrized by e-folding timescale τ
  - M/L computed after lifetime of 12 Gyr
- Strong correlation between B-R color and M/L ratio independent of metallicity or SFH

B-band

K-band

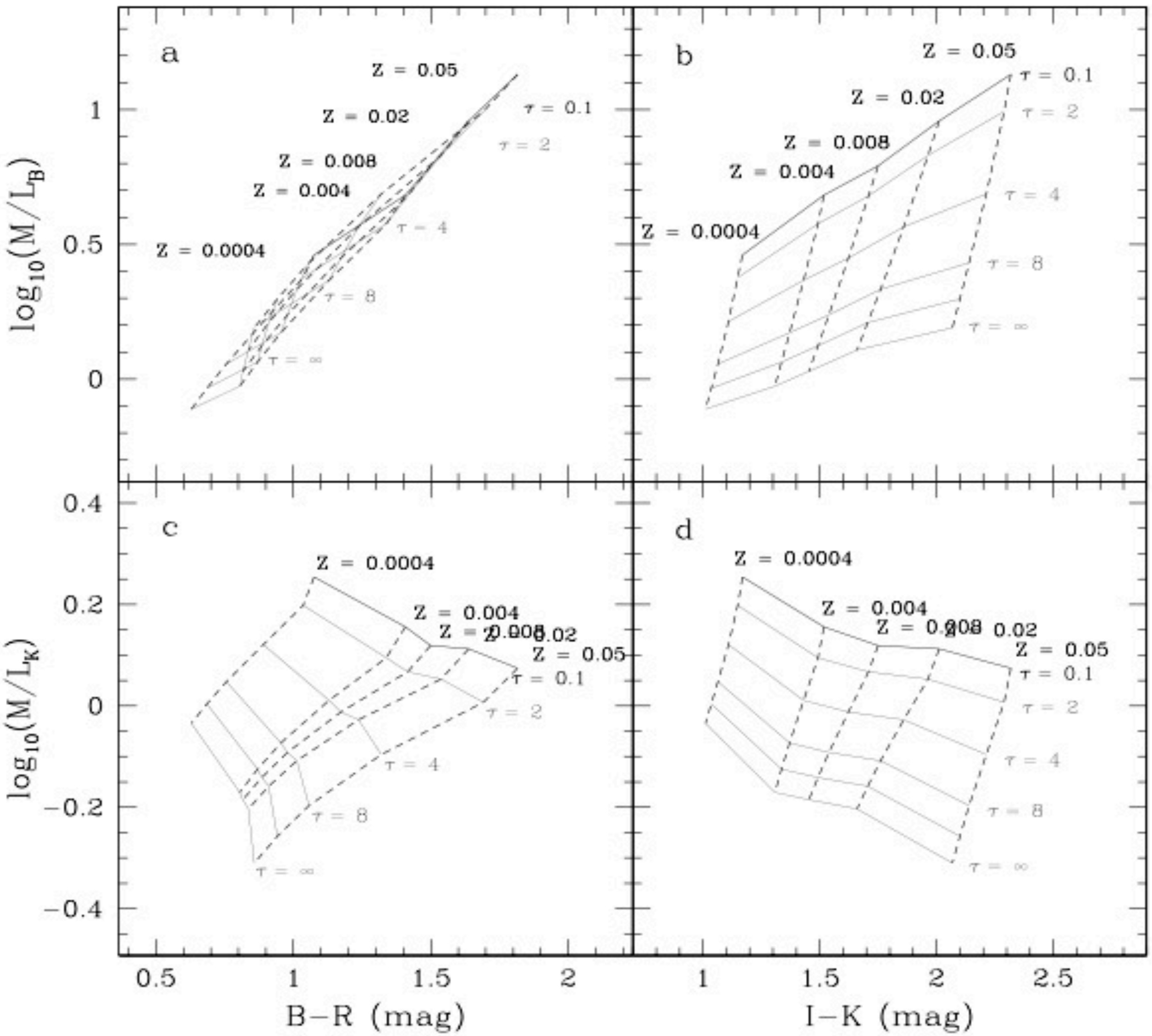
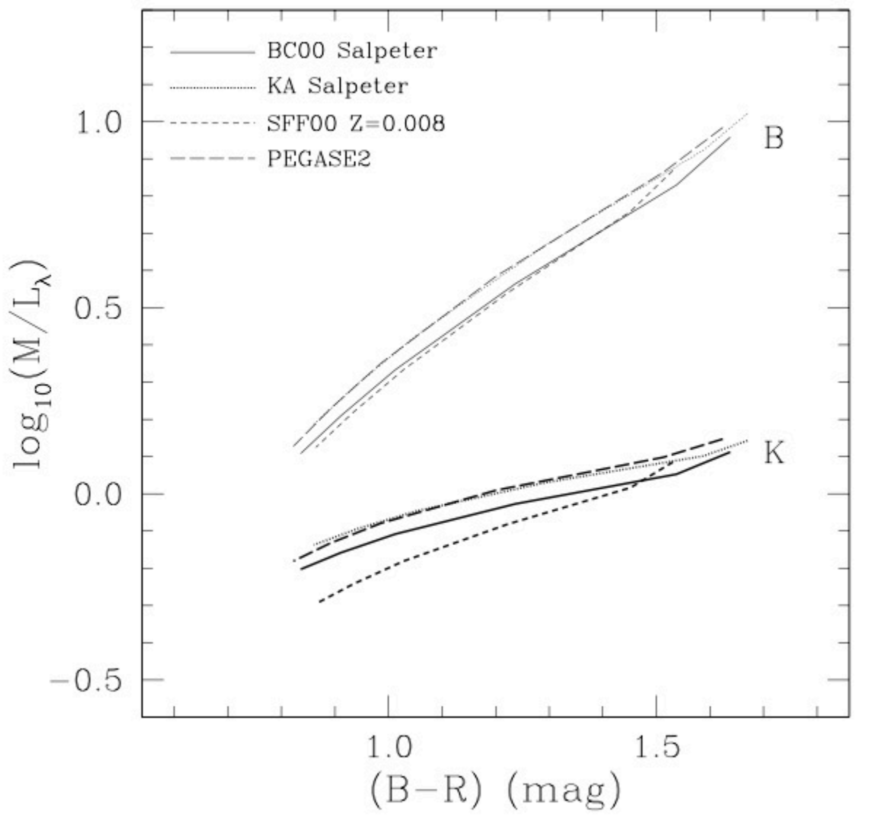


Figure 2
Solid line – different τ, same metallicity
Dashed line – same τ, different metallicity

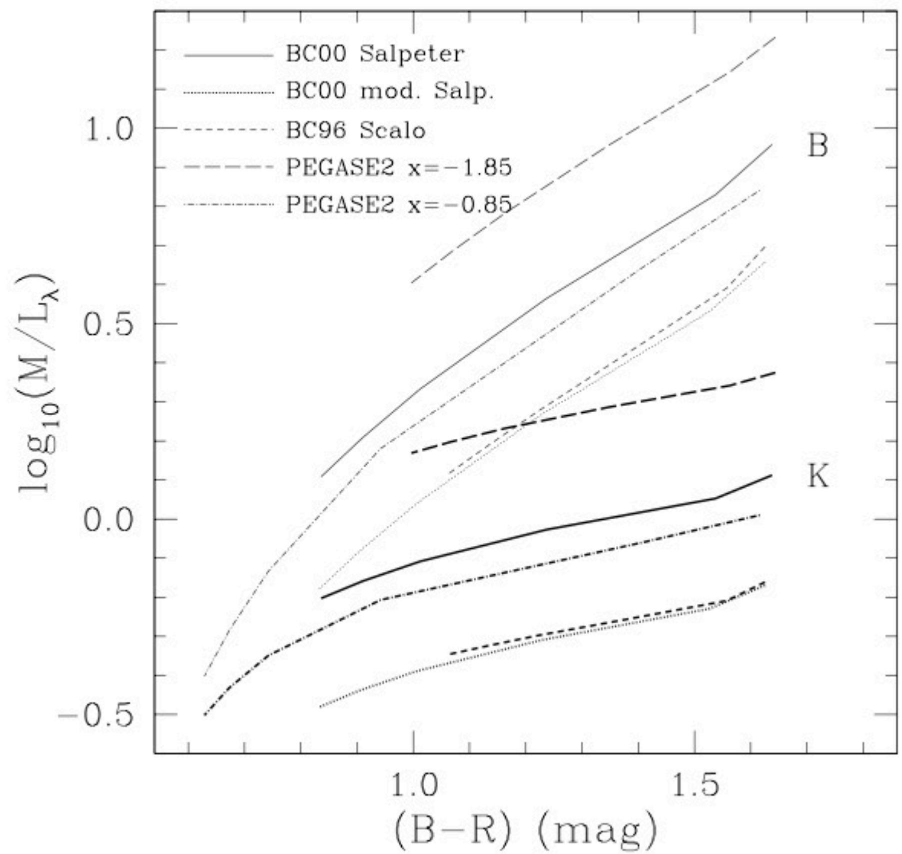
SPS uncertainties

- Salpeter IMF, solar metallicity τ models in B and K band
- Bruzual & Charlot (solid line)
- Kodama & Arimoto (dotted line)
- Schulz, Fritze-von Alvensleben, Fricke (short-dashed line)
- Fioc & Rocca-Volmerange (long-dashed line)
- Conclusion: similar slopes and zero points for M/L-color relation



IMF effect

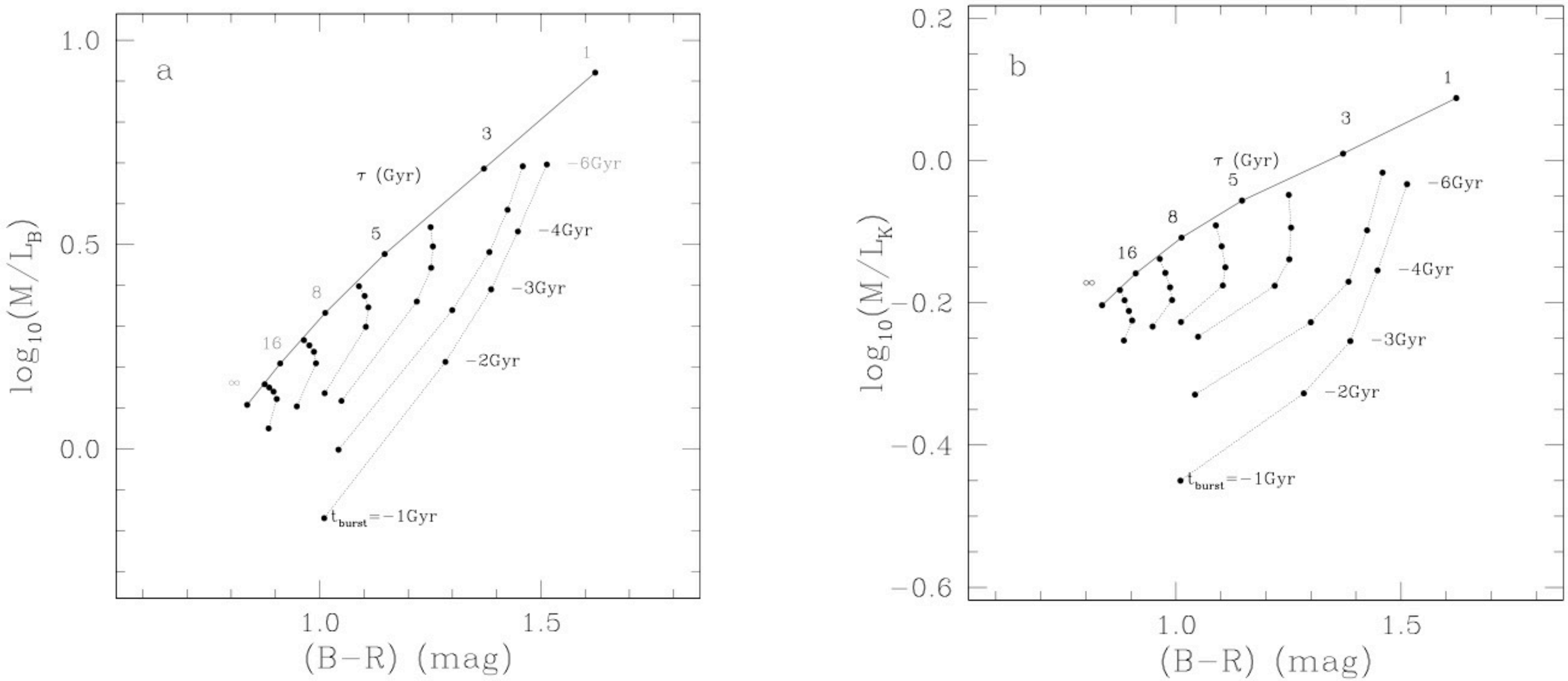
- Bruzual & Charlot
  - + Salpeter IMF (solid line)
  - + modified Salpeter IMF with x=0 below 0.6 M_{sun} (dotted line)
  - + Scalo IMF (dashed line)
- Fioc & Rocca-Volmerange
  - + x=-1.85 IMF (long-dashed line)
  - + x=-0.85 IMF (short-dashed line)
- Slopes are independent of IMF



Galaxy evolution uncertainties

- All 6 models are consistent, age change of $\pm$ 3 Gyr → M/L change of $\pm$ 0.05 dex [check Appendix]
- What about larger bursts?
  - 10% mass fraction added in 0.5 Gyr starbursts
  - Larger effect on red earlier type galaxies
  - Bias M/L ratio to lower values at a give color
  - Unlikely to occur and likely to be selected against in sample selection

Galaxy evolution uncertainties



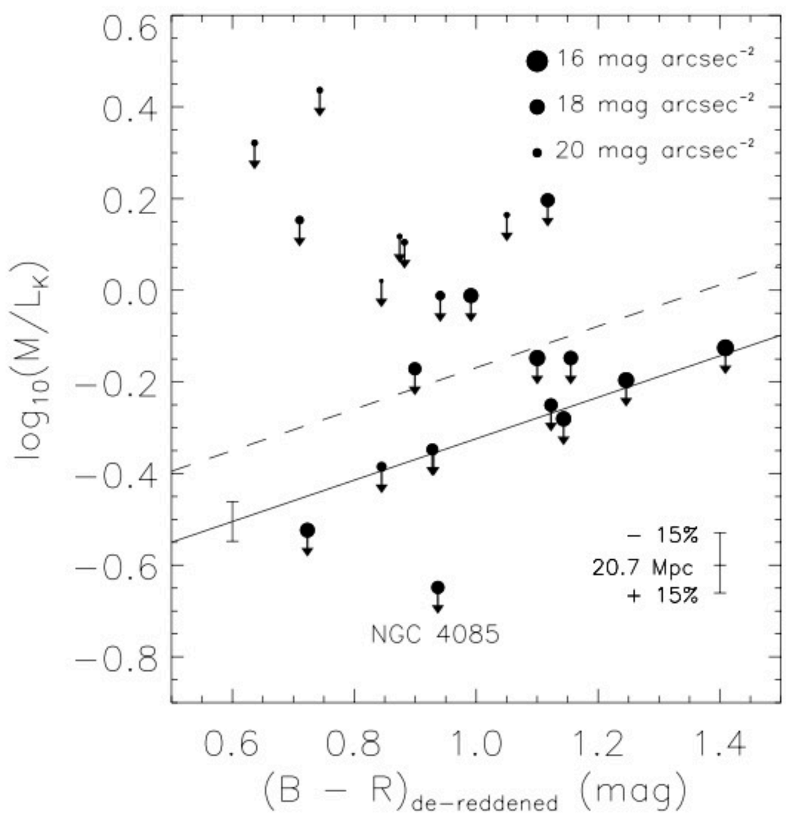
Uncertainties summary

- Color-M/L is robust in relative sense (within passband and between passbands) provided there is no change in IMF
- Model, galaxy evolution, small bursts, dust → 0.1-0.2 dex or less
- IMF gives the largest uncertainty
  - IMFs in literature give uncertainties in absolute normalization of at least a factor of 2

Rotation curves and normalization

- Constraints from maximum disk hypothesis (stellar disk makes maximum possible contribution to rotation velocity)
- Salpeter x=-1.35 IMF overpredicts (dashed line)
- Salpeter IMF x=-1.35 with x=0 below 0.35 M_{sun} (scaling by down by factor of 0.7) (solid line)

Ursa Major Cluster



Rotation curves and normalization

- Zero-point constrained to match observations, but no reason to expect slope of model to match observations
    - Galaxies with maximum disk have similar IMFs

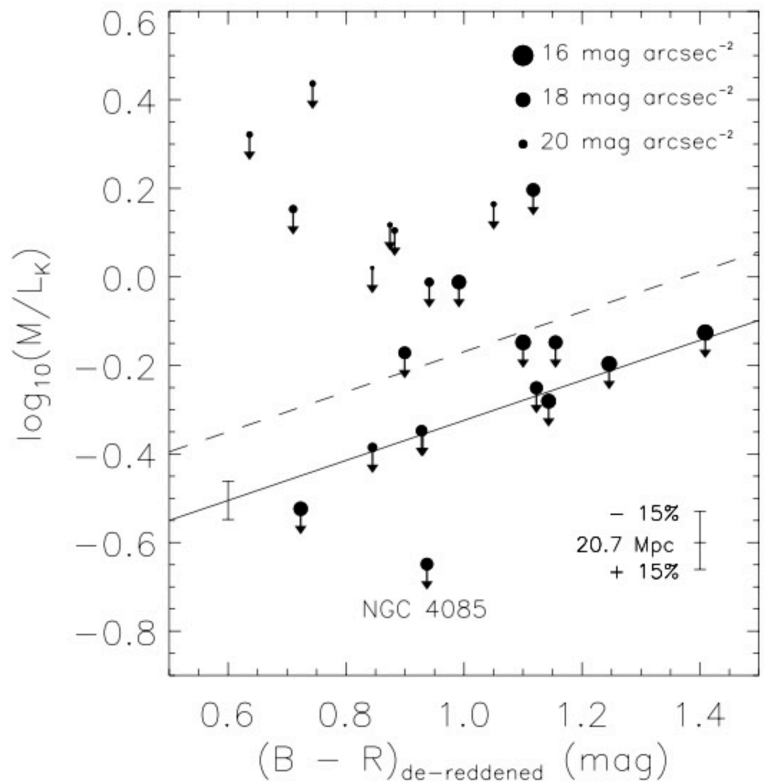


TABLE 1

STELLAR M/L RATIO AS A FUNCTION OF COLOR FOR THE FORMATION EPOCH MODEL WITH BURSTS, ADOPTING A SCALED SALPETER IMF

Color	a_B	b_B	a_V	b_V	a_R	b_R	a_I	b_I	a_J	b_J	a_H	b_H	a_K	b_K
$B-V$	−0.994	1.804	−0.734	1.404	−0.660	1.222	−0.627	1.075	−0.621	0.794	−0.663	0.704	−0.692	0.652
$B-R$	−1.224	1.251	−0.916	0.976	−0.820	0.851	−0.768	0.748	−0.724	0.552	−0.754	0.489	−0.776	0.452
$V-I$.......	−1.919	2.214	−1.476	1.747	−1.314	1.528	−1.204	1.347	−1.040	0.987	−1.030	0.870	−1.027	0.800
$V-J$	−1.903	1.138	−1.477	0.905	−1.319	0.794	−1.209	0.700	−1.029	0.505	−1.014	0.442	−1.005	0.402
$V-H$......	−2.181	0.978	−1.700	0.779	−1.515	0.684	−1.383	0.603	−1.151	0.434	−1.120	0.379	−1.100	0.345
$V-K$......	−2.156	0.895	−1.683	0.714	−1.501	0.627	−1.370	0.553	−1.139	0.396	−1.108	0.346	−1.087	0.314

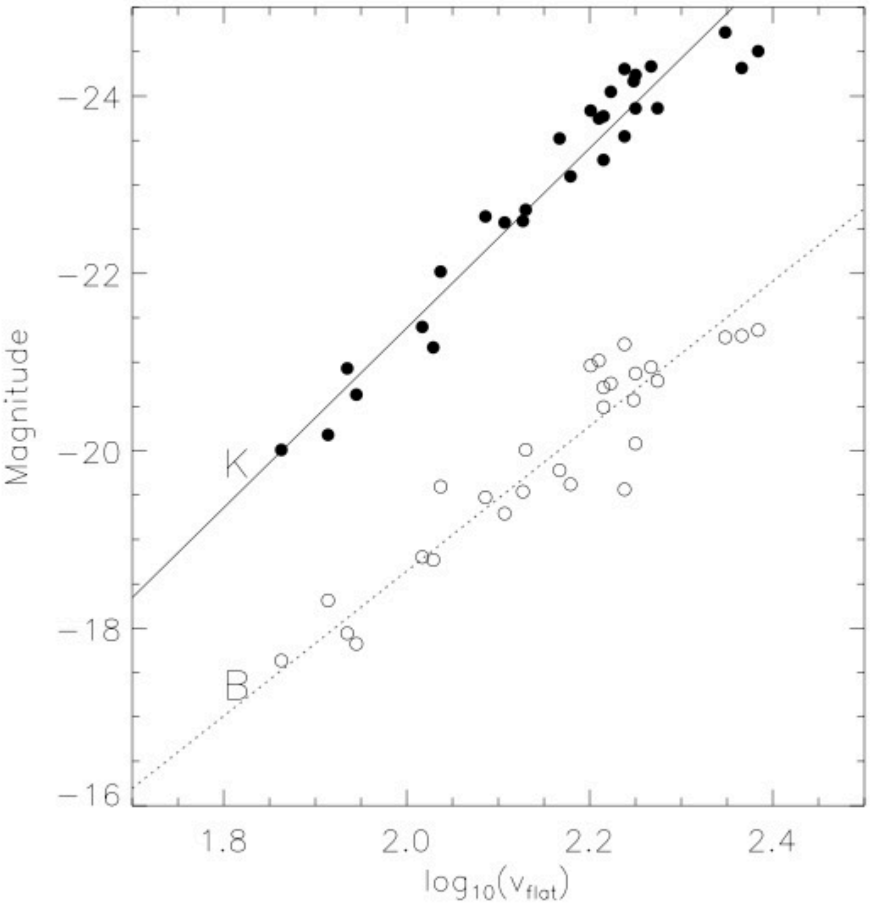
NOTE.—$\log_{10}(M/L) = a_\lambda + b_\lambda$Color. Note that the stellar M/L values can be estimated for any combination of the above colors by a simple linear combination of the above fits. Note also that if *all* (even very high surface brightness) disks are submaximal, the above zero points should be modified by subtracting a constant from the above relations.

Tully-Fisher relation

- Relates dynamical mass to luminosity
- Limited by passband-dependent slope
  - $L \sim V^3$ in blue
  - $L \sim V^4$ in near-IR
- Possible for theory to match T-F in one passband, but not in others
- Goal is to use previous results (Table 1) to find a single, passband-independent T-F relation

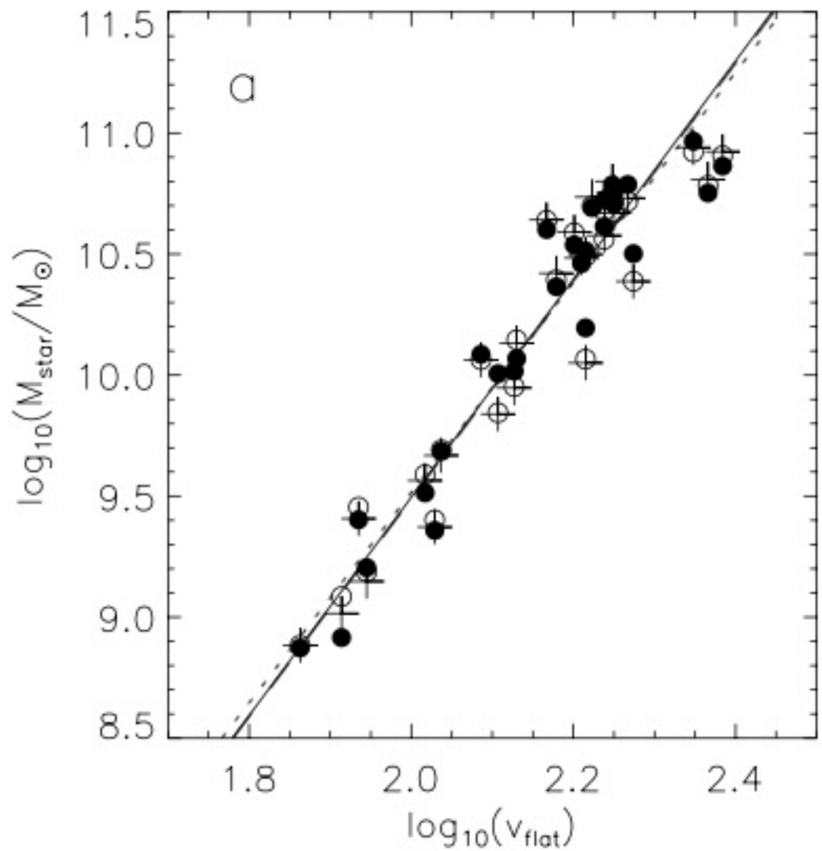
Tully-Fisher relation

- Ursa Major Cluster data
- Foreground galactic extinction
- Internal extinction
- T-F shallower in bluer passbands than in near-IR



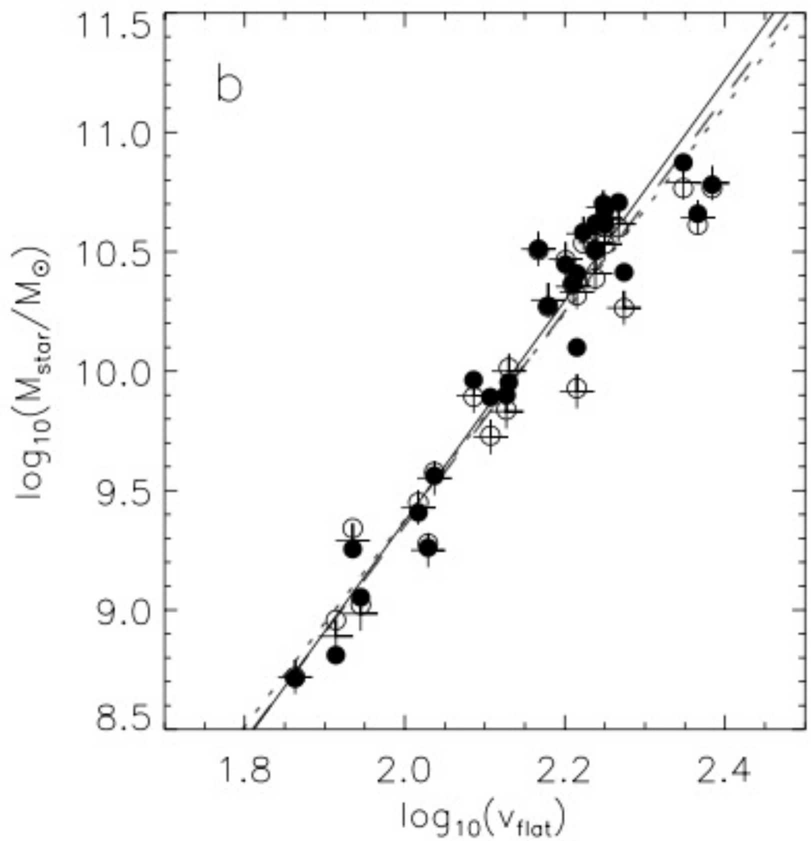
Stellar mass T-F

- Mass-dependent extinction correction
- B, R – open circles
- I – crosses
- K – filled circles
- Passband-independent relation, consistent within ~10% rms
  - L ~ $V^{4.4 \pm 0.2}$



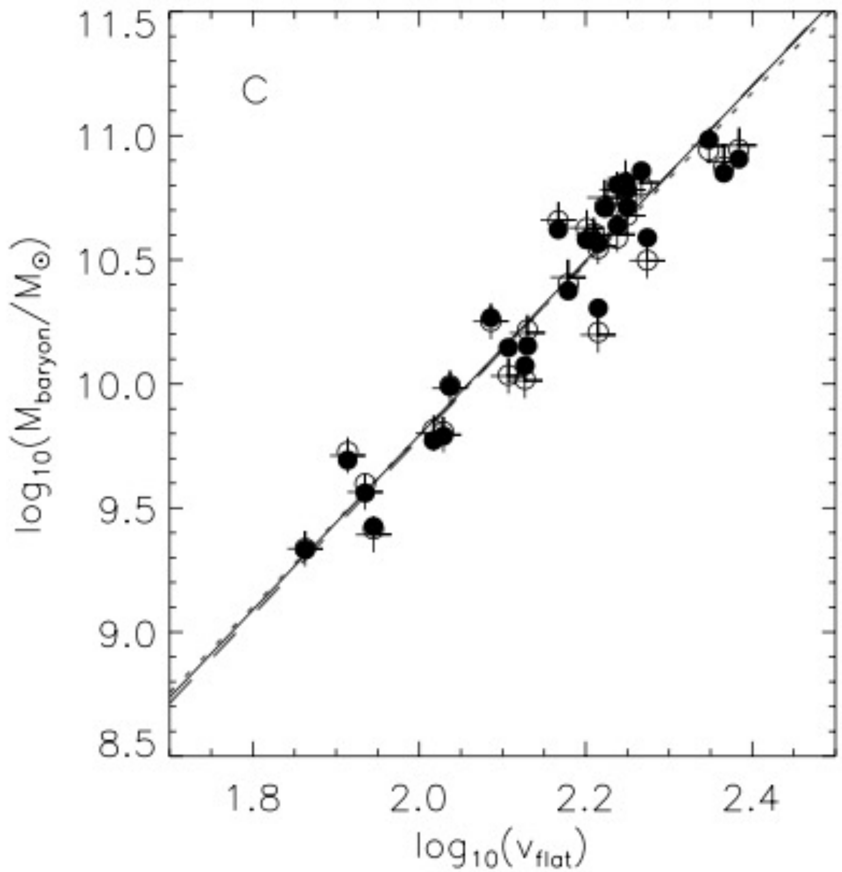
Stellar mass T-F

- Mass-independent extinction correction
- Almost the same as for mass-dependent extinction case
- B,R fits – dotted line
- I fit – dashed line
- K fit – solid line



Baryonic mass T-F

- $M_{\text{baryon}} \sim V^{3.5 \pm 0.2}$



Summary

- Under several assumptions:
  - Variations in M/L correlate strongly with color
  - Low surface brightness, high gas fraction, low-luminosity galaxies have lower M/L ratios
  - Color correlation is robust to uncertainties in SP and galaxy evolution models
  - Stellar IMF is main uncertainty
- Modified Salpeter IMF best fits the observations
- Slope of stellar T-F of Ursa Major Cluster is 4.4 ± 0.2
- Slope of baryonic T-F of Ursa Major Cluster is 3.5 ± 0.2