THE DEMOGRAPHY OF MASSIVE DARK OBJECTS IN GALAXY CENTERS

By Magorrian et al. (1998)

As presented by Mike Berry

Table of Contents

What are Massive Dark Objects? (MDOs)

- Most likely supermassive black holes
- Star clusters of the required mass and size are difficult to construct and maintain
- Fit entire LOS v-dispersion for arbitrary axisymmetric galaxy models
- Crude models predict MDO mass fairly accurately (M87)

Purpose of Paper

- Data from 36 bulges from HST photometry and decent ground based long-slit spectroscopy
- Fit two-integral axisymmetric dynamical models (not most general but computationally inexpensive)
- Find a statistical distribution of MDOs as a function of galaxy luminosity
- Not meant to unambiguously show that an MDO is present in any individual galaxy

Modeling

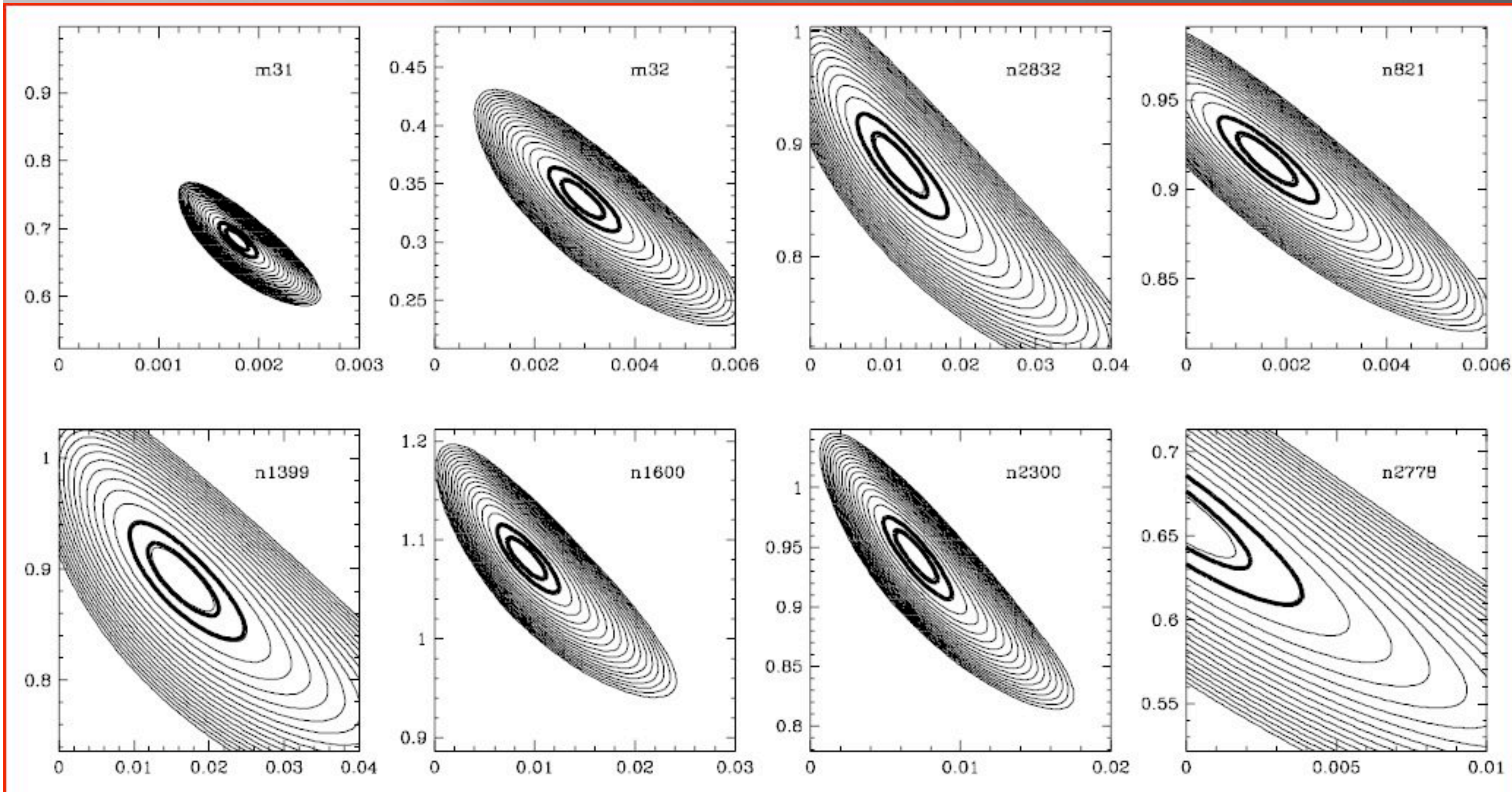
- Two-integral approach (cylindrical and axisymmetric about z-axis)
- Assume constant mass to L ratio (Υ)
- Makes them flattened spherical isotropic models
- No physics behind why galaxies must be like this

Procedure

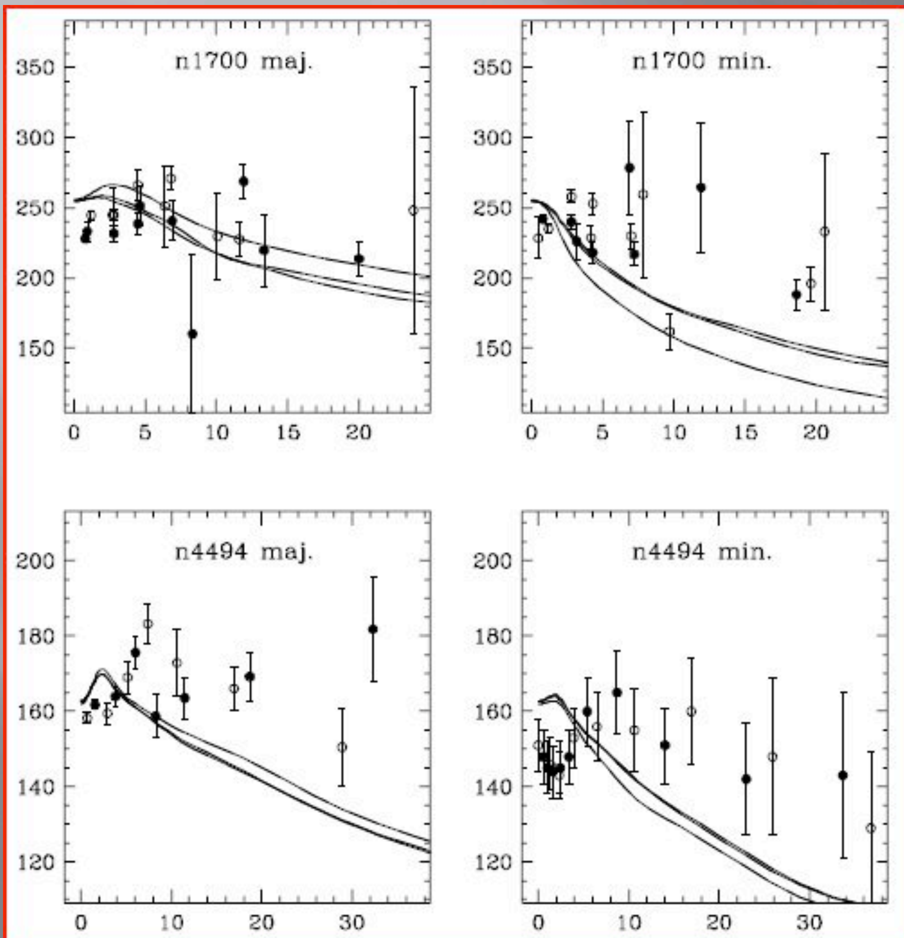
- Use maximum likelihood to find smooth L-density that fits observed surface brightness
  - Large range in density but uncertainty is less than observed error
- Calculate Φ using Υ and MDO mass M_o, then find v_r and v_z using the inclination angle (i)
- Project luminosity weighted moments to LOS velocities and convolve with observations
- Least squares fit to obtain M_o and Υ based on the likelihood that we see the observed data

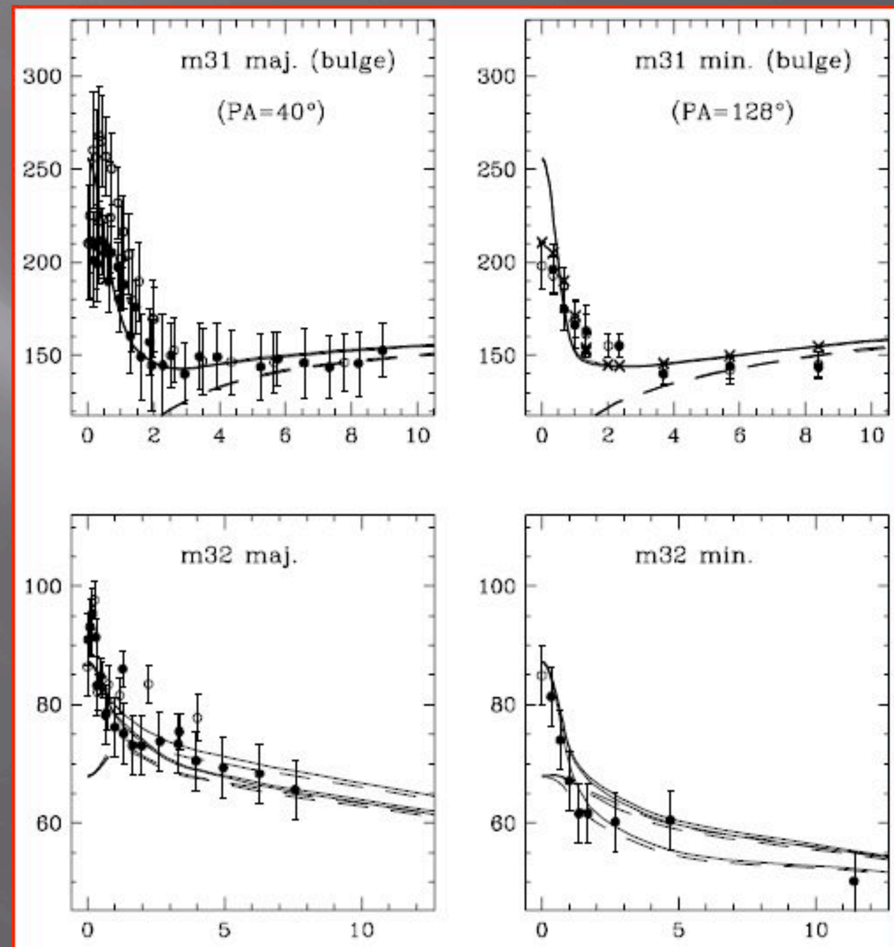
Individual Galaxy Results

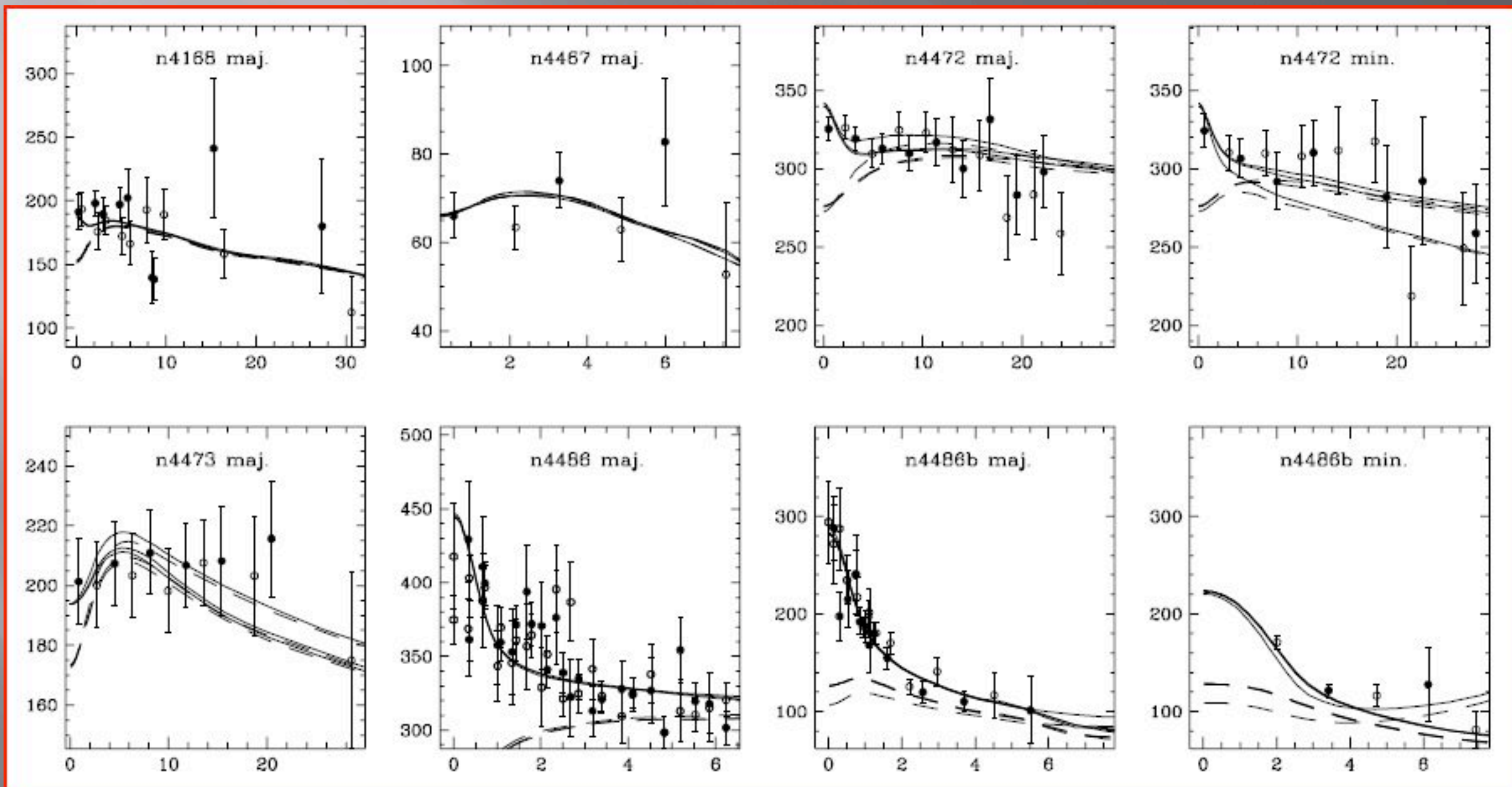
- 4 of 36 galaxies – not well fit by models
  - Known to have kinematically distinct cores
- By comparison 2 of the other 32 others are known to have kinematically distinct cores
- 3 of 32 are consistent to 1 sigma with M_o=0
- 4 of 32 are consistent to 2 sigma with M_o=0
- MDO – required to produce 2nd moment in galaxies



m31
m32
n2832
n821
n1399
n1600
n2300
n2778


n1700 maj.
n1700 min.
n4494 maj.
n4494 min.

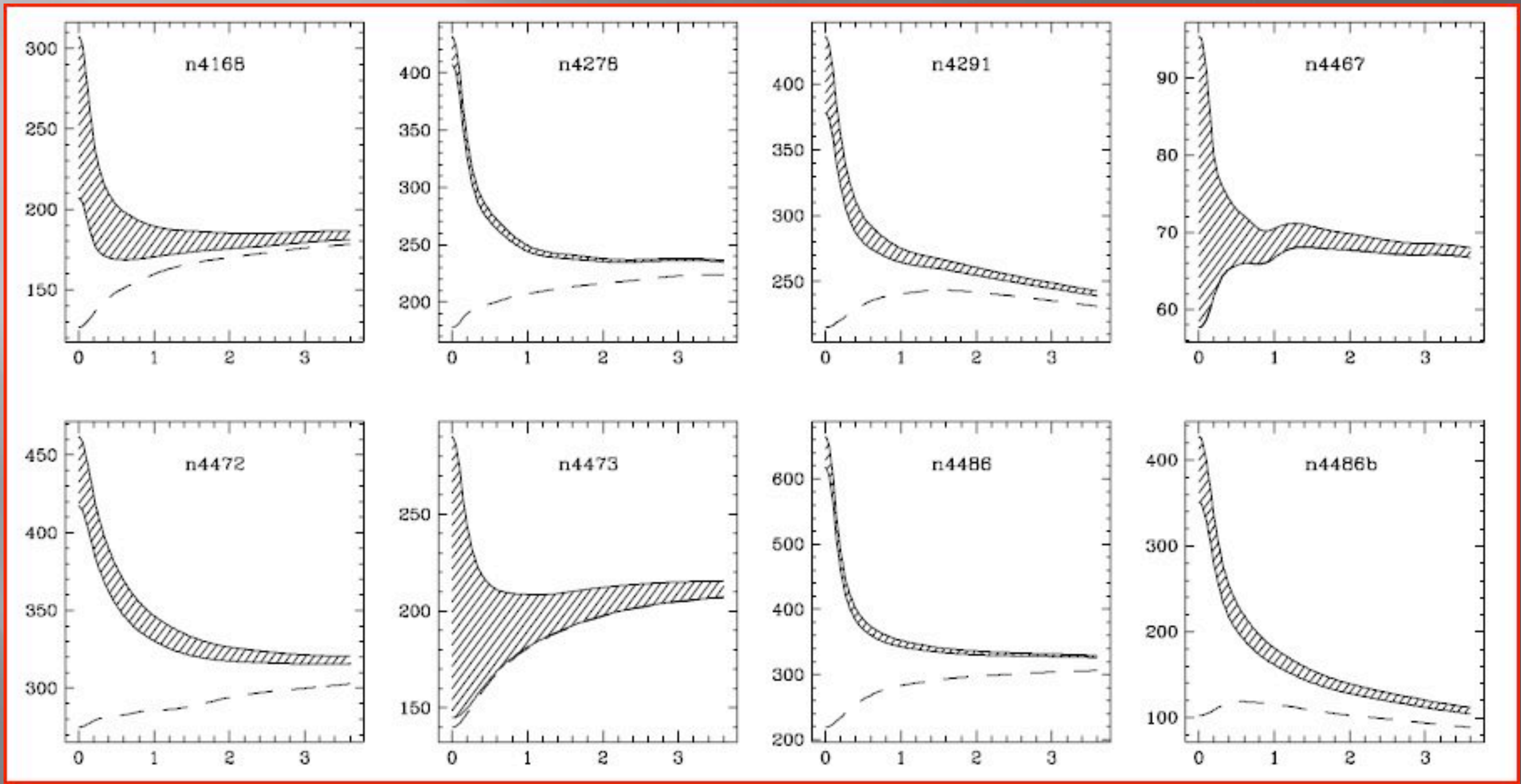

m31 maj. (bulge)
(PA=40°)
m31 min. (bulge)
(PA=128°)
m32 maj.
m32 min.



n4168 maj.
n4467 maj.
n4472 maj.
n4472 min.
n4473 maj.
n4486 maj.
n4486b maj.
n4486b min.

A few interesting galaxies

- HST data for M32, n3115, n3379, n4594
  - All are reasonably well fit
- 5 galaxies with nuclear activity or heavy dust (2 models to correct)
  - Assume all light comes from stars
  - Only use photometry >Rmin
- Galaxies with Rmin > 0 are subject to skepticism


n4168
n4278
n4291
n4467
n4472
n4473
n4486
n4486b

MDO Mass Distribution

- Assume MDO depends on x ($x = M_o/M_b$) and other parameters (w)
- Seek most likely set of parameters given data (5 models)

TABLE 4

BEST-FITTING PARAMETERIZED PROBABILITY DISTRIBUTIONS

P	f	$\log x_0$	α or $\log \Delta$	$\log \langle x \rangle$	$\langle \log x \rangle$
P_{PL1}	$1.000^{+0.000}_{-0.057}$	$-0.633^{+0.125}_{-0.100}$	$-0.784^{+0.056}_{-0.037}$	$-1.347^{+0.115}_{-0.111}$	$-3.178^{+0.893}_{-0.893}$
P_{PL2}	$0.950^{+0.032}_{-0.062}$	$-2.790^{+0.031}_{-0.063}$	$-1.725^{+0.131}_{-0.173}$		$-2.268^{+0.097}_{-0.087}$
P_S	$1.000^{+0.000}_{-0.067}$	$-1.705^{+0.204}_{-0.109}$	$-0.456^{+0.178}_{-0.122}$	$-1.880^{+0.117}_{-0.108}$	$-2.338^{+0.153}_{-0.188}$
P_G	$0.940^{+0.042}_{-0.067}$	$-2.930^{+0.325}_{-0.000}$	$-1.717^{+0.098}_{-0.082}$	$-1.808^{+0.105}_{-0.096}$	$-1.992^{+0.106}_{-0.091}$
P_{LG}	$0.970^{+0.030}_{-0.055}$	$-2.281^{+0.100}_{-0.100}$	$-0.289^{+0.060}_{-0.065}$	$-1.965^{+0.143}_{-0.119}$	$-2.282^{+0.103}_{-0.109}$

NOTES.—The best-fitting parameters ω and their 68% confidence limits for each assumed distribution $\Pr(x \mid \omega, P)$. By definition, $0 \le f \le 1$. The last two columns give the logarithm of the expectation value of $x \equiv M_\bullet/M_{\rm bulge}$ and the expectation value of $\log x$ for those galaxies with $M_\bullet \neq 0$ [both calculated from $\Pr_+(x \mid \omega, P)$]. The mean $\langle x \rangle$ does not exist for P_{PL2}.

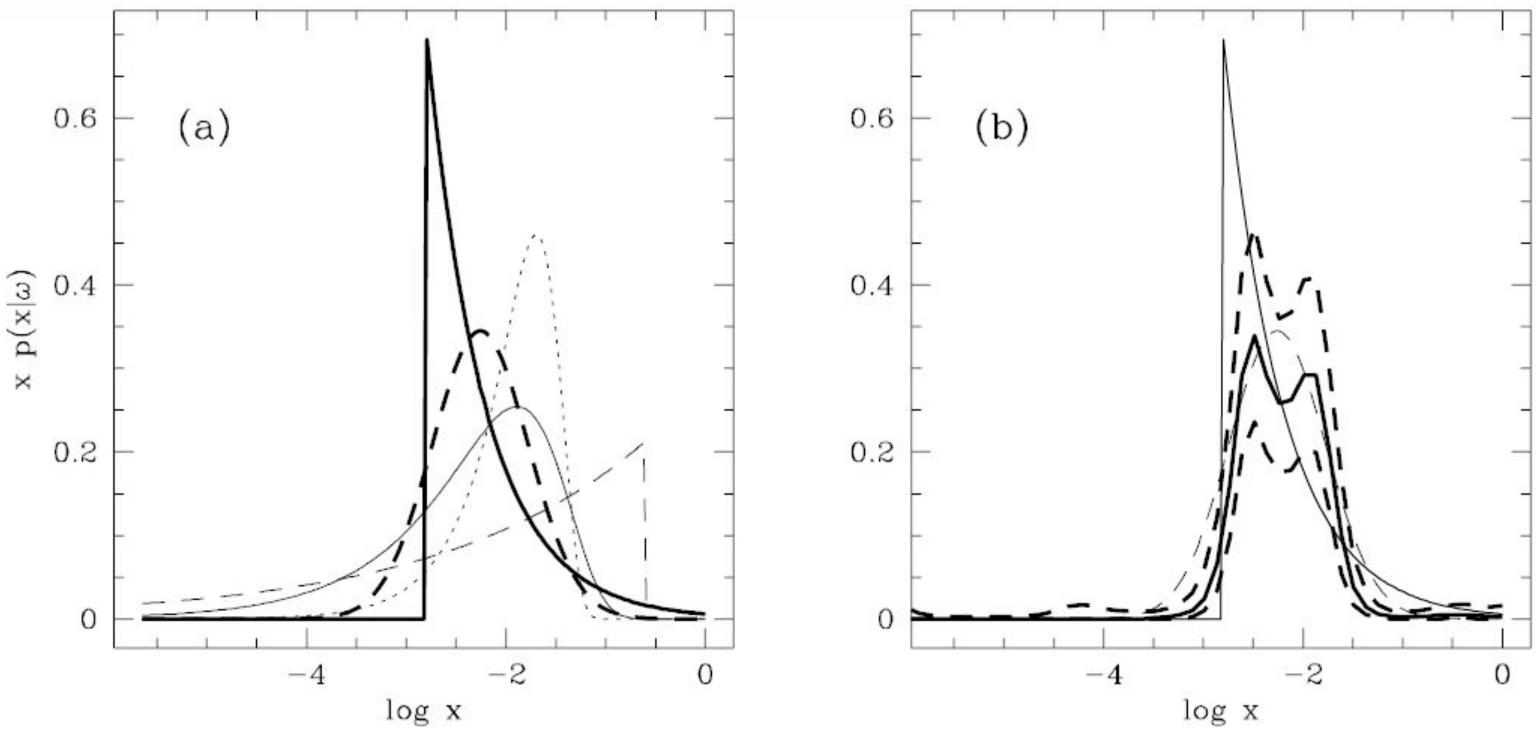


FIG. 11.—(*a*) Probability distributions Pr $(x\,|\,\omega, P)$ for the best-fitting parameters ω. The heavy solid and dashed curves show results for P_{PL2} and P_{LG}, the two best-fitting cases. The light solid, dashed, and dotted curves are for P_S, P_{PL1}, and P_G, respectively. (*b*) "Nonparametric" probability distribution Pr (x) (*heavy solid curve*) and its 68% confidence limits (*heavy dashed curves*) obtained using the Metropolis algorithm with $\lambda = 5$. The best-fitting parameterized distributions P_{PL2} and P_{LG} are overlaid as the light solid and dashed curves, respectively.

Conclusions

- 32/36 galaxies are well described by 2-integral axisymmetric models
- 28/32 require a substantial MDO
  - 97% of galaxies have $M_o/M_b \sim 0.05$
- Probably a different formation history for galaxies without a MDO
- 2-integral models are not the most generic but fits agree reasonably well with previous data