The SAURON project – IV. The mass-to-light ratio,the virial mass estimator and Fundamental Plane of elliptical and lenticular galaxies

Michele Cappellari et al.(2006)

Presenter：Y.Komuro（M1）
October 24,2011

Topics

- Goal (the purpose of this study)
- Introduction(basic knowledge in this study)
- Sample & data(sample and data used in this study)
- Method(method to estimate M/L)
- Results
- Summary

･Goal

～What is the purpose of this study？～

They investigate the well-known correlations between the dynamical mass-to-light ratio and other global observables（ex . Effective radius , Velocity dispersion , Surface brightness）of E and S0 galaxies.

They want to investigate ･･･

- whether M/L is linked to the galaxy dynamics
- a second parameter in the M/L variations

･Introduction

(1) The SAURON project

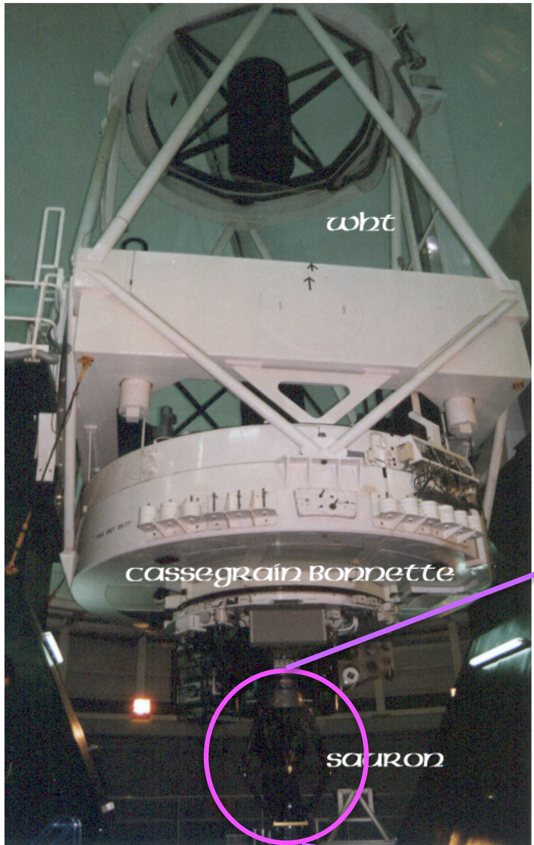
(2) Observational example

(3) Fundamental Plane (FP)

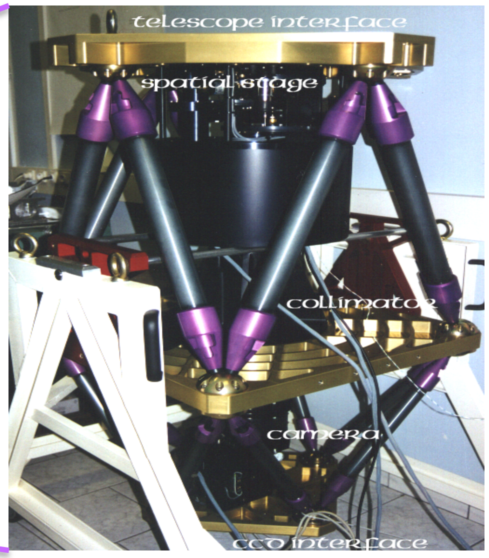
Introduction(1)

～What is the SAURON project？～

SAURON=Spectrographic Areal Unit for Research on Optical Nebulae



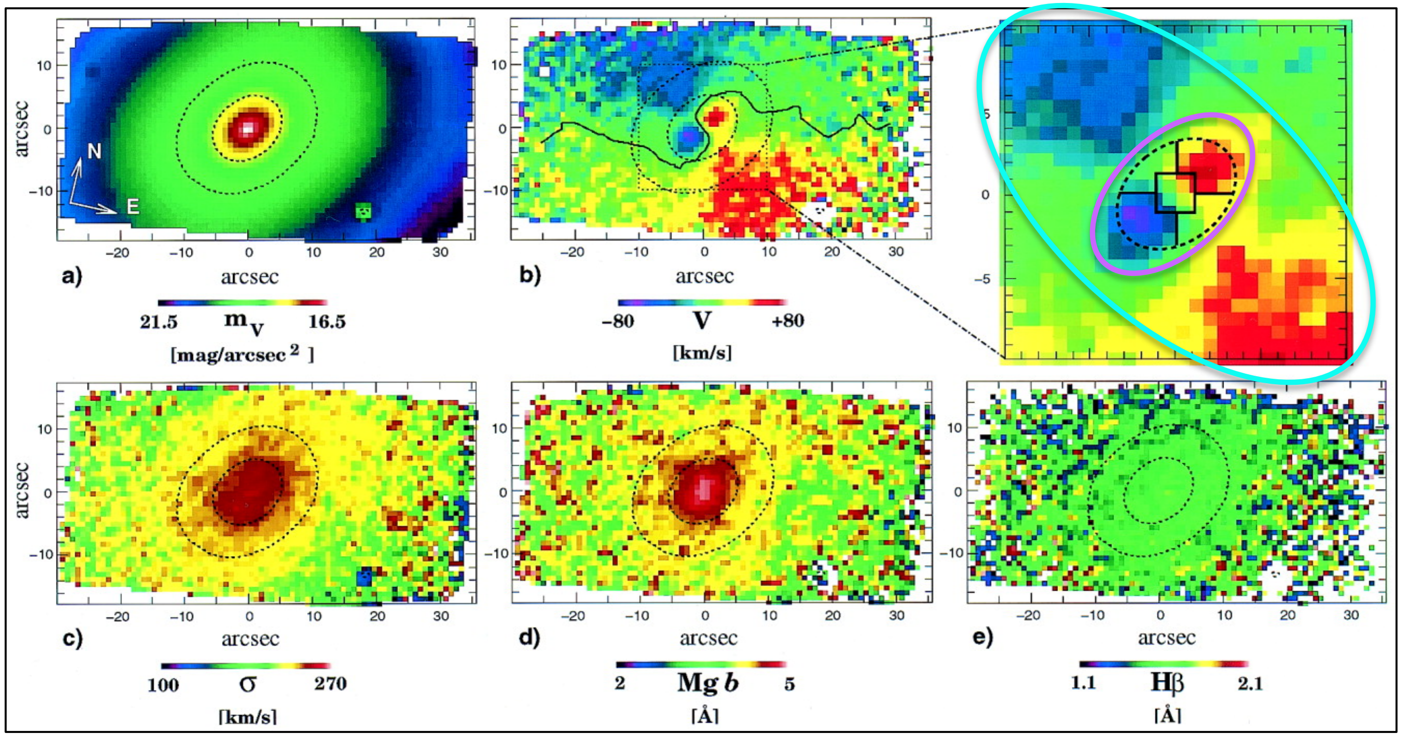
- SAURON is a dedicated instrument , mounted on the William Herschel Telescope (WHT) on La Palma.
- SAURON is designed for studies of the stellar kinematics , gas kinematics , and line-strength distribution of nearby spheroids.



http://www.strw.leidenuniv.nl/sauron/

Introduction(2)

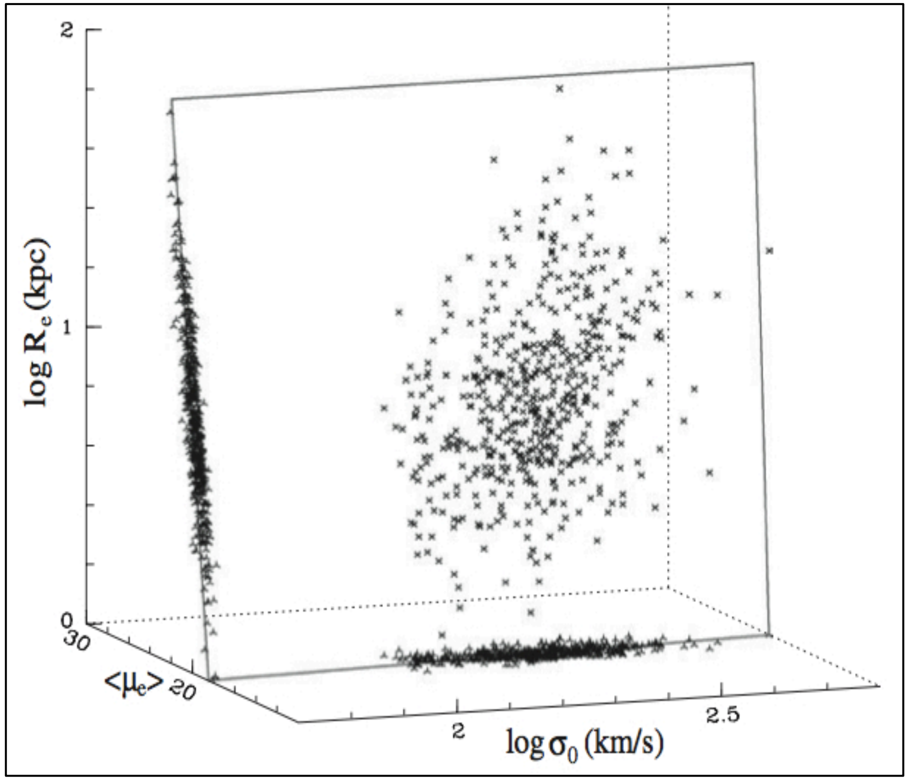
～Observational example～



- These panels are observational examples of SAURON project.
- The top right panel clearly reveal the inner (outer) kinematic component , rotating around the photometric minor axis (major axis).
- The bottom panels reveal the distribution of the velocity dispersion and the line-strengths.
- If you had known about these detailed results , you should read Davies et al.(2001).

Introduction (3)

～Fundamental Plane (FP)～



- This figure is the fundamental plane of elliptical galaxies.
- $\log(R_e) = \alpha \log(\sigma_0) + \beta \log(<\mu_e>) + C$

  ↓

  $R_e \propto \sigma_0^{\alpha} <\mu_e>^{\beta}$
- There is not correlation between the velocity dispersion and the effective radius.
- The correlation of the physical quantity of two pieces is the projection to the 2-dimensional plane of 3-dimensional distribution.

＊If the profile of surface brightness is a de Vaucouleurs profile ,

$$L_{\mathrm{tot}} = \int_0^{\infty} \mu(r) 2\pi r dr = 7.215\pi r_e^2 \mu_e$$

$$\langle \mu_e \rangle = 3.61 \mu_e$$

・Sample & data

~Selection~

The set of galaxies they use for this study was extracted from the SAURON sample of 48 E and S0 galaxies which contain 24 galaxies in each of the E and S0 subclasses.
(redshift range: $z \leq 1$, $M_B \leq -18$ [mag] , spans over a factor of 100 in mass)

selection criteria

① the distance criterion decided by SBF (Surface Brightness Fluctuation) Tonry et al. (2001)

② the availability of HST photometry obtained with the WFPC2 in the I-band (F814W)

29 galaxies meet these two criteria.

They eliminated the objects showing strong evidence of bars out of these galaxies.

The 24 galaxies remain. For exploring the low-mass range, they added M32 which is not the SAURON sample to the remaining sample of 24 galaxies.

Finally the 25 galaxies are adopted as a sample of this study.

･Method

(1) Method to estimate $(M/L)_{Jeans}$

(2) Influence of a dark matter halo

(3) Method to estimate $(M/L)_{Schw}$

(4) Method to estimate $(M/L)_{pop}$

Method(1)

~Method to estimate $(M/L)_{Jeans}$~

- For an axisymmetric Jeans model with constant M/L , and a stellar distribution function(DF) depends only on two integrals of motion $f=f(E, L_z)$.(Emsellem et al. (1994))

- The second velocity moment μ_2 is a model prediction for M/L=1 and a function of only two free parameters , i and M/L.

- They constructed axisymmetric Jeans models for the 25 galaxies in their sample and computed the model predictions for μ_2 at different inclinations .

$$d_n = \frac{\mu'_{2,n}}{\Delta\mu'_{2,n}} \quad \text{and} \quad m_n = \frac{\mu_{2,n}}{\Delta\mu'_{2,n}}$$

where $\mu'_{2,n} \equiv \sqrt{V_n^2 + \sigma_n^2}$

$$\left(\frac{M}{L}\right)_{\rm Jeans} = \left(\frac{\boldsymbol{d}\cdot\boldsymbol{d}}{\boldsymbol{d}\cdot\boldsymbol{m}}\right)^2$$

derived from the SAURON stellar kinematics

Method (2)

～Influence of a dark matter halo～

- They assume the galaxy to be spherically symmetric and the stellar density to be described by a Hernquist profile

$$\rho_\star(r) = \frac{1}{2\pi}\frac{1}{r(r+1)^3}$$

- The Dark Matter contribution is represented by a logarithmic potential

$$\Phi_{\mathrm{DM}}(r) = \frac{v_0^2}{2}\ln\left(r^2 + r_0^2\right)$$

- With these assumptions , the projected second moment μ_2 of an isotropic model , which is equal to the projected velocity dispersion σ_{p}

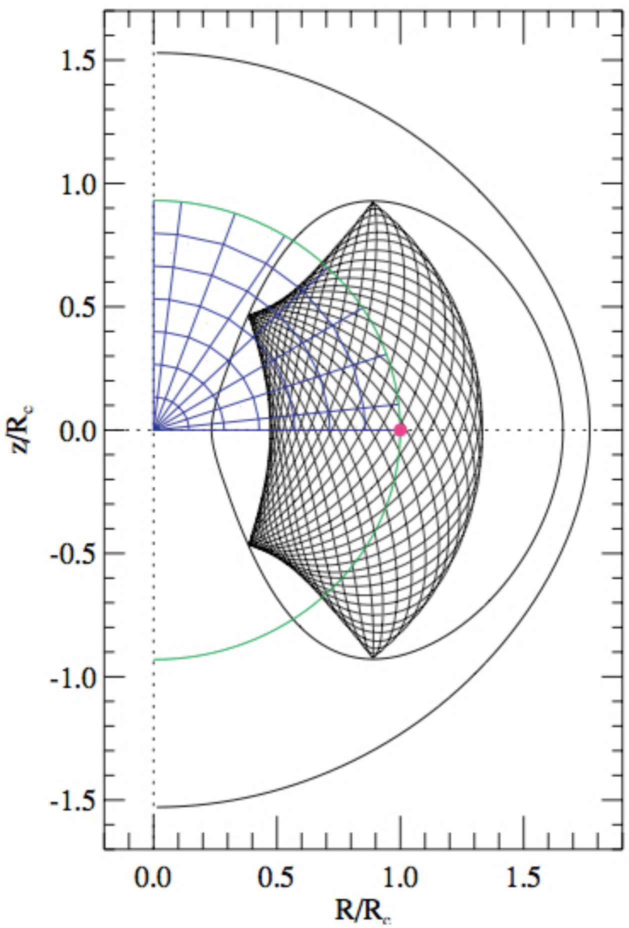
$$\sigma_{\mathrm{p}}^2(R) = \frac{1}{\pi\gamma I(R)}\int_R^\infty \left[\frac{1}{r(r+1)^2} + \frac{v_0^2}{r^2+r_0^2}\right]\frac{\sqrt{r^2-R^2}}{(r+1)^3}dr$$

$\rho_\star$ and Φ_{DM} → The projected velocity dispersion

Method(3)

~Method to estimate $(M/L)_{Schw}$~

In this method , the velocity moment is calculated by the higher order moment.(van der Marel et al.(1998))



Method(4)

～the tilt of the FP～

- The existence of the FP of the form $R_e \propto \sigma^{\alpha} I_e^{\beta}$, combined with virial equilibrium assumption $M \propto \sigma^2 R_e$ and the geometric definition $L \propto I_e R_e^2$, yields a prediction for the $(M/L)_{FP}$.

- They adopted an FP determined in the Gunn r band by Jorgensen et al.(1996) from a sample of 225 early-type galaxies in nearby clusters.

- Taking the relation by Jorgensen et al.(1996) ,

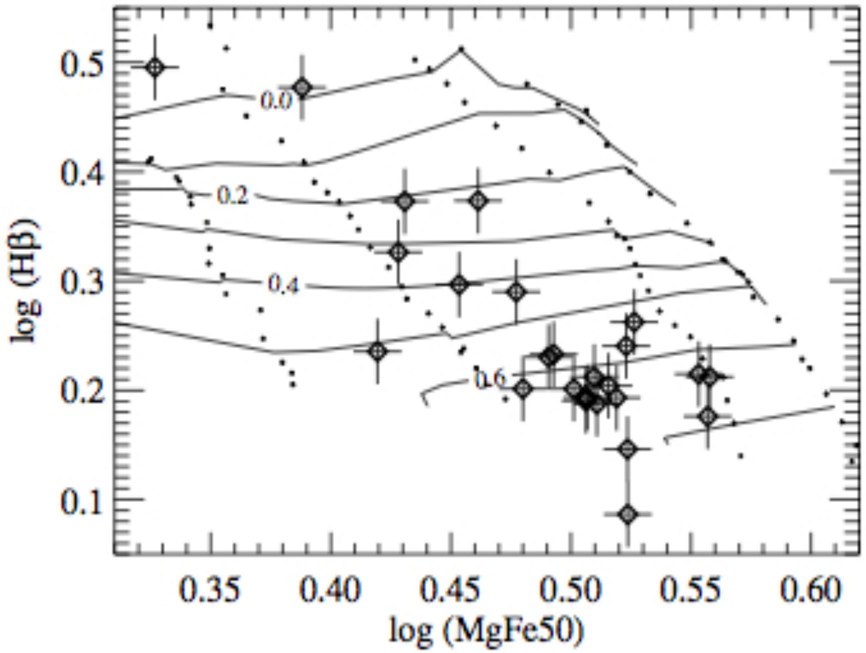
$$R_e \propto \sigma^{1.24\pm0.07} I_e^{-0.82\pm0.02}$$

$$\left(\frac{M}{L}\right)_{\rm FP} \propto R^{-0.22\pm0.03} \sigma^{0.49\pm0.09}$$

$$\left(\frac{M}{L}\right)_{\rm FP} \propto I_e^{0.02\pm0.04} L^{0.31\pm0.05}$$

Method (5)

~Method to estimate $(M/L)_{pop}$~



- This figure shows that observed values of the line strength index log[MgFe50] versus log[H β] for their sample.
- They used the SSP models VZ96 (by Vazdekis et al.(1996)) and the Salpeter IMF.
- They derived $(M/L)_{pop}$ from the SAURON Mgb , Fe5015 and H β line-strength indices.

$$[MgFe50] = 0.5 \times (0.45 \times Mgb + Fe5015)$$

They find that for SSP , the contour levels of constant $(M/L)_{pop}$ is essentially a function of H β alone. In a word a good correlation should exist between $(M/L)_{pop}$ and H β .

・Results

(1) Comparing $(M/L)_{Jeans}$ and $(M/L)_{Schw}$

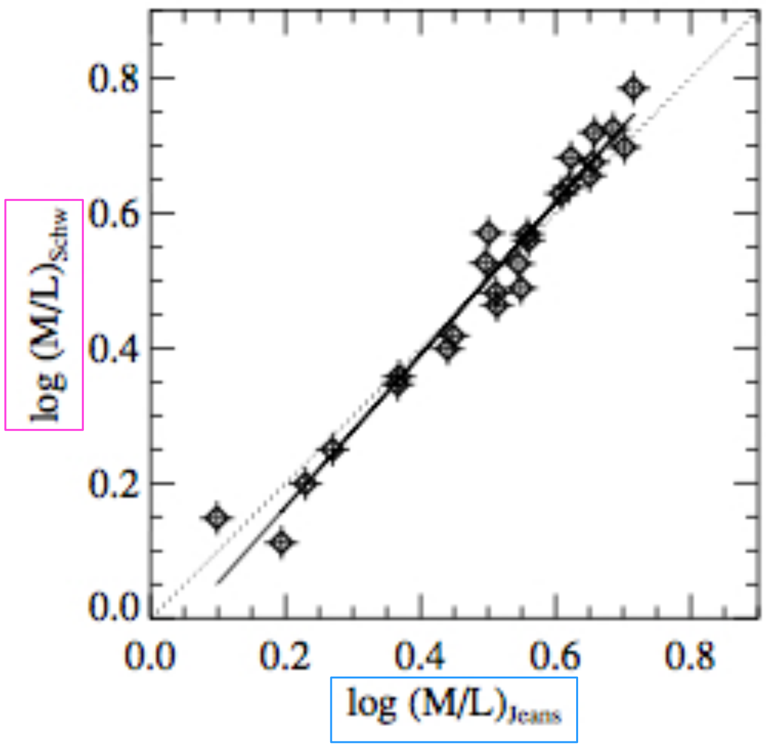
(2) Comparison with virial predictions of M/L

(3) Comparison with stellar population $(M/L)_{pop}$

(4) A second parameter in the M/L variation

Result (1)

～Comparing two- and three-integral models～



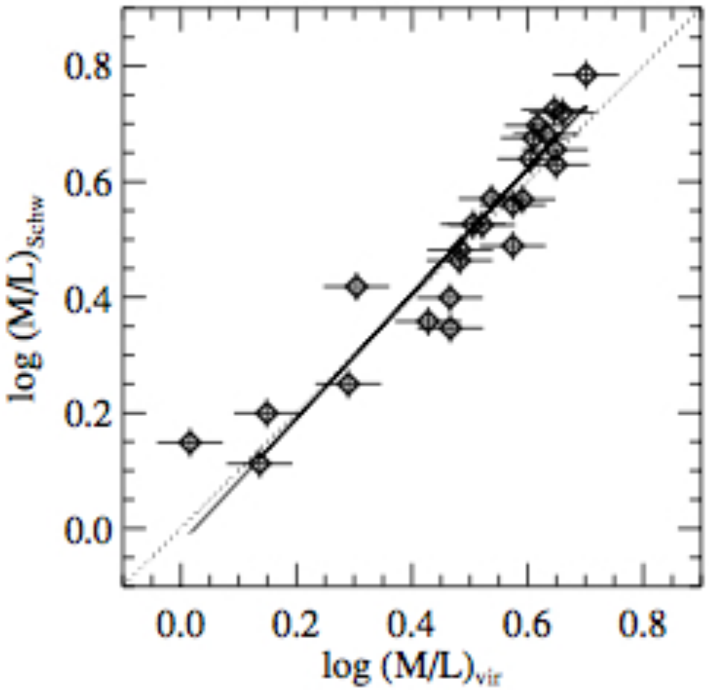
- The best-fitting correlation shows a small systematic trend $(M/L) \propto (M/L)_{\mathrm{Jeans}}^{1.13\pm0.05}$.
- An error of 6% in the model accuracy is required to explain the observed scatter along the best-fitting relation.
- The galaxy which has the highest M/L tend to show an $(M/L)_{\mathrm{Schw}}$ which is systematically higher than $(M/L)_{\mathrm{Jeans}}$.

The difference in the M/L is likely due to the fact that the Schwarzschild models use the full information on the LOSVD , while the Jeans models are restricted to the first two moments.

The Schwarzschild model is more general than the Jeans model.

Result (2)

～Comparison with virial predictions of M/L ～



- This figure shows that comparison between $(M/L)_{vir}$ and $(M/L)_{Schw}$.

$$\left(\frac{M}{L}\right)_{\rm vir} = \frac{\beta R_e \sigma_e^2}{LG}$$

$\beta(n)=8.87-0.831n+0.0241n^2$, n is Sersic index

- The best-fitting scaling factor is $\beta=5.0\pm0.1$.

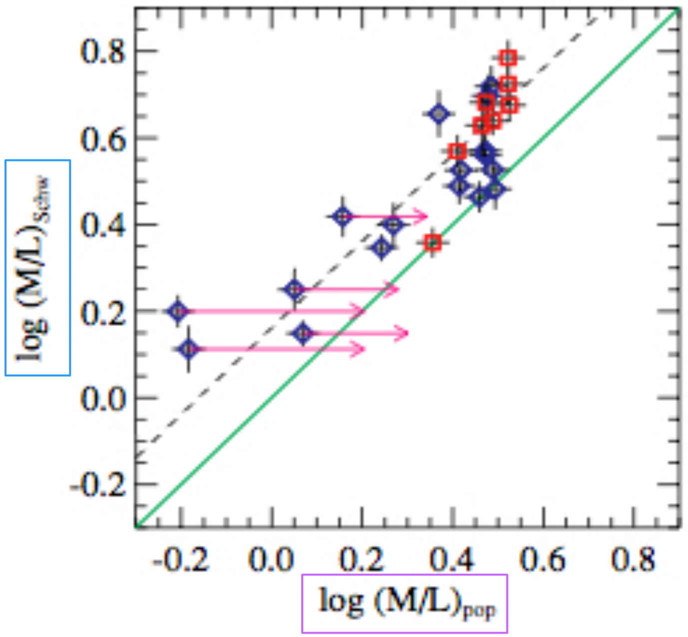
- They fitted the correlations of $(M/L)_{vir}$, in the I band , with σ and with Luminosity

$$\left(\frac{M}{L}\right)_{\rm vir} \propto \sigma^{0.82\pm0.07}$$

$$\left(\frac{M}{L}\right)_{\rm vir} \propto L^{0.27\pm0.04}$$

Result (3)

～Comparison with stellar population $(M/L)_{pop}$～

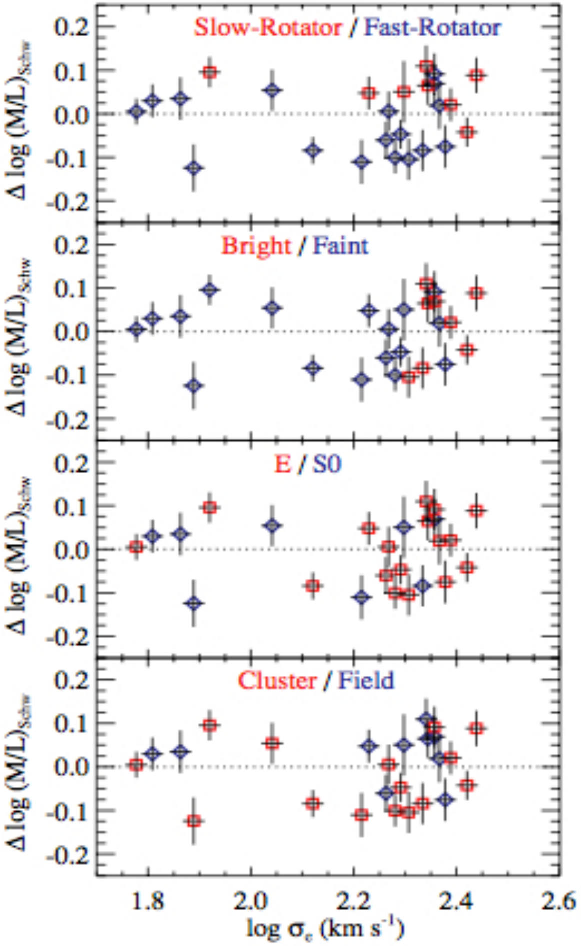


- This figure is $(M/L)_{Schw}$ versus a function of $(M/L)_{pop}$ using the SSP models of VZ96 and VZ99 , with a Kroupa (2001) IMF.
- All galaxies have $(M/L)_{pop} \leq (M/L)_{Schw}$ within the errors , but $(M/L)_{pop}$ and $(M/L)_{Schw}$ clearly do not follow a one-to-one relation.
- Adopting the Salpeter IMF all values of $(M/L)_{pop}$ would increase by $\Delta \log(M/L) \sim 0.16$.
- In this case a number of galaxies would have $(M/L)_{pop}$ $\geq (M/L)_{Schw}$.

The Kroupa IMF constrained the shape below $1 M_{\odot}$ with the result that there are fewer low-mass stars than indicated by the Salpeter IMF.

Result (4)

~A second parameter in the M/L variations~



- The first panel shows that there appears to be a tendency for the 'Slow-Rotators' to have a higher M/L than the 'Fast-Rotators' , at given σ_e .
- In the second panel , they separate the sample into the galaxies brighter and fainter than the K-band luminosity M_K=-24.
- The third panel shows that
- The fourth panel shows that the field galaxies have a marginally higher M/L than the cluster galaxies.
- The K-S probability is 2 , 32 , 74 and 10 % from the top to the bottom panel respectively.

▪Summary

- They find a relation $(M/L) \propto (M/L)_{vir}^{1.08\pm0.07}$, which confirms , with small uncertainties , the results from the FP comparisons.

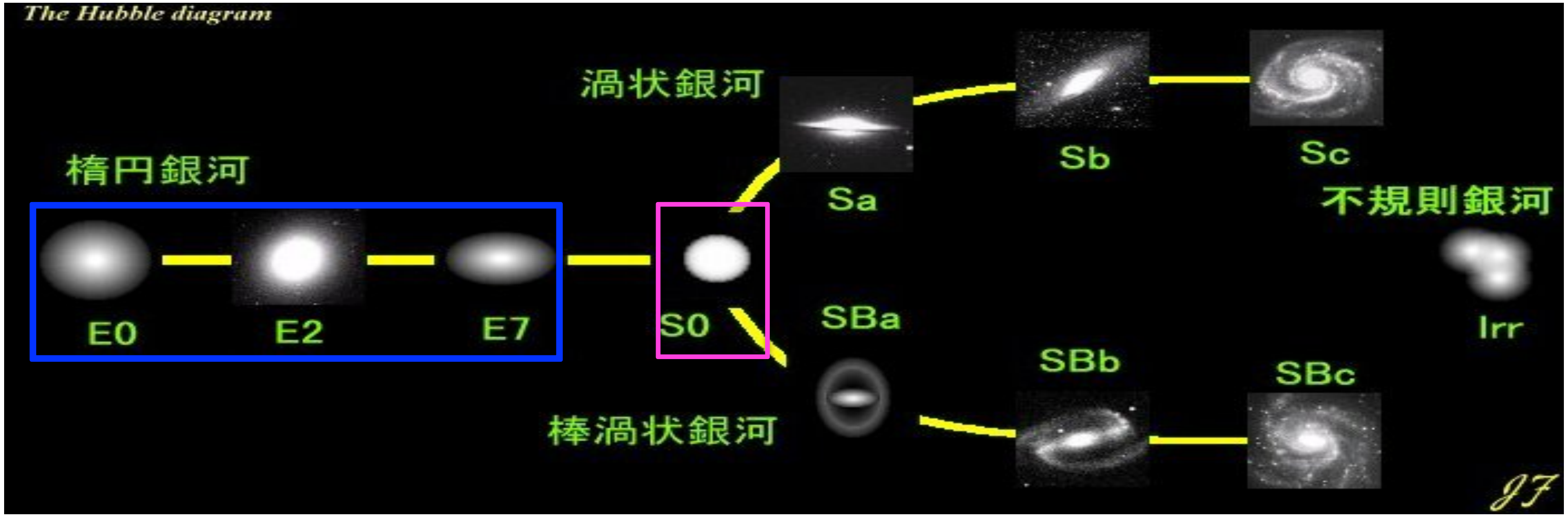
- They find that the M/L generally correlates with the $(M/L)_{pop}$.

- They find some evidence for the variation in M/L to be related to the dynamics of the galaxies .

- In particular the slow-rotating galaxies in their sample , which are more common among the most luminous objects , tend to have a higher M/L at given $(M/L)_{pop}$ than the fast-rotating and fainter galaxies.

Appendix

～Early type galaxies～



Elliptical galaxy（En）

- Star formation is comparatively inactive and the component is population of an old star.
- Elliptical galaxy is in a virial equilibrium state because a velocity dispersion and self-gravity balance.

Lenticular galaxy（S0）

- The fundamental nature is the same as the nature of an elliptical galaxy.
- However , the region where star formation is comparatively active may exist in lenticular galaxy.

Appendix

～kolmogorov-Smirnov test（K-S test）～

- K-S test is a statistical certification to investigate how extent a distribution of an observable quantity and a theoretical quantity are in agreement.

- As practical example , it is confirming the goodness of fit to a gaussian distribution or uniform distribution.

- Making Cumulative-Probability Function（CPF） F(x) and F'(x) , the difference D（D=｜F(x_{max})-F'(x'$_{max}$)｜） in the place x_{max} where the distance of CPF becomes the maximum.

- Significant probability

$$Prob(D\sqrt{N} > z) = 2\sum_{j=1}^{\infty}(-1)^{j-1}\exp\left(-2j^2z^2\right)$$

from Wikipedia