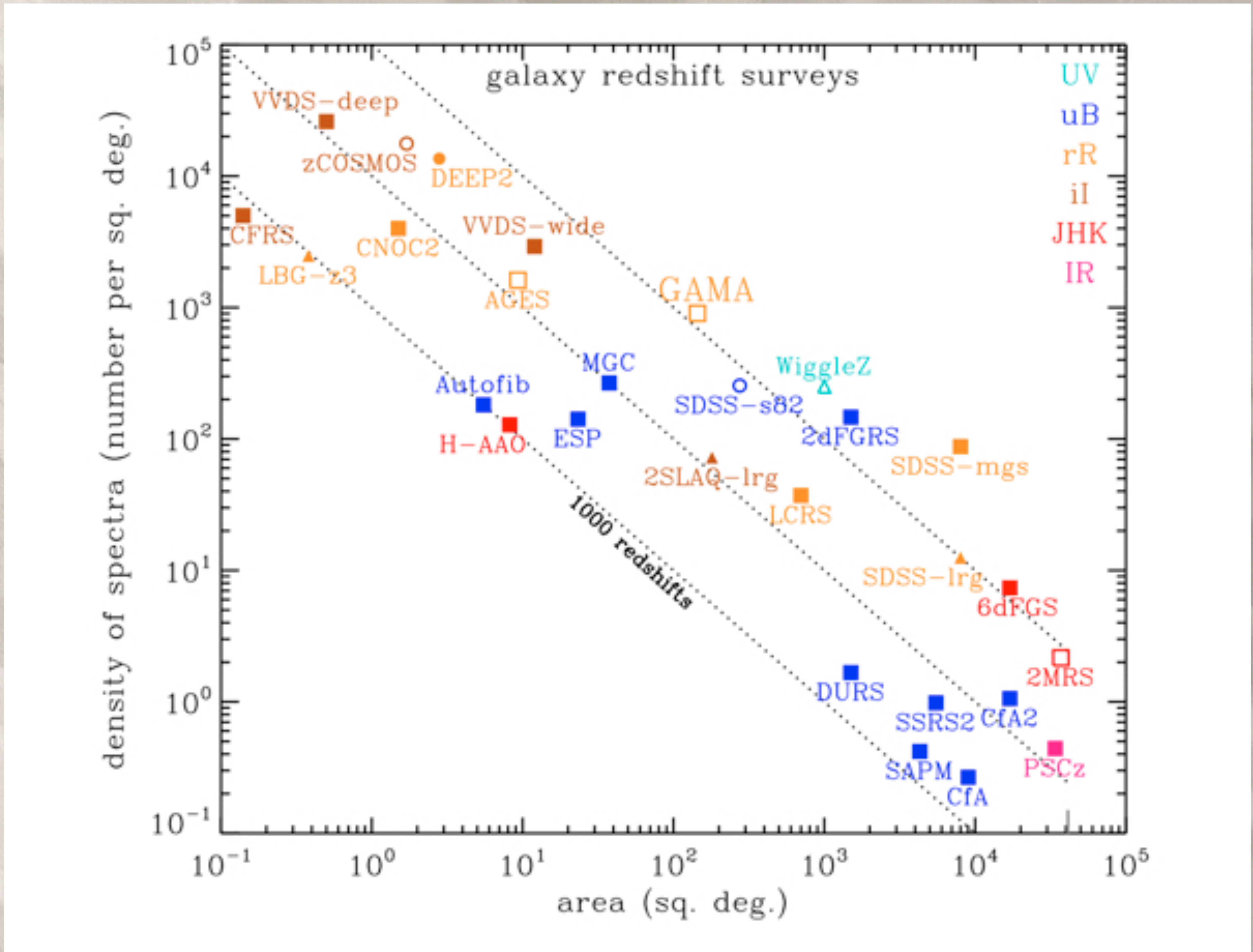
Galaxy And Mass Assembly (GAMA):
How good are stellar masses, really?

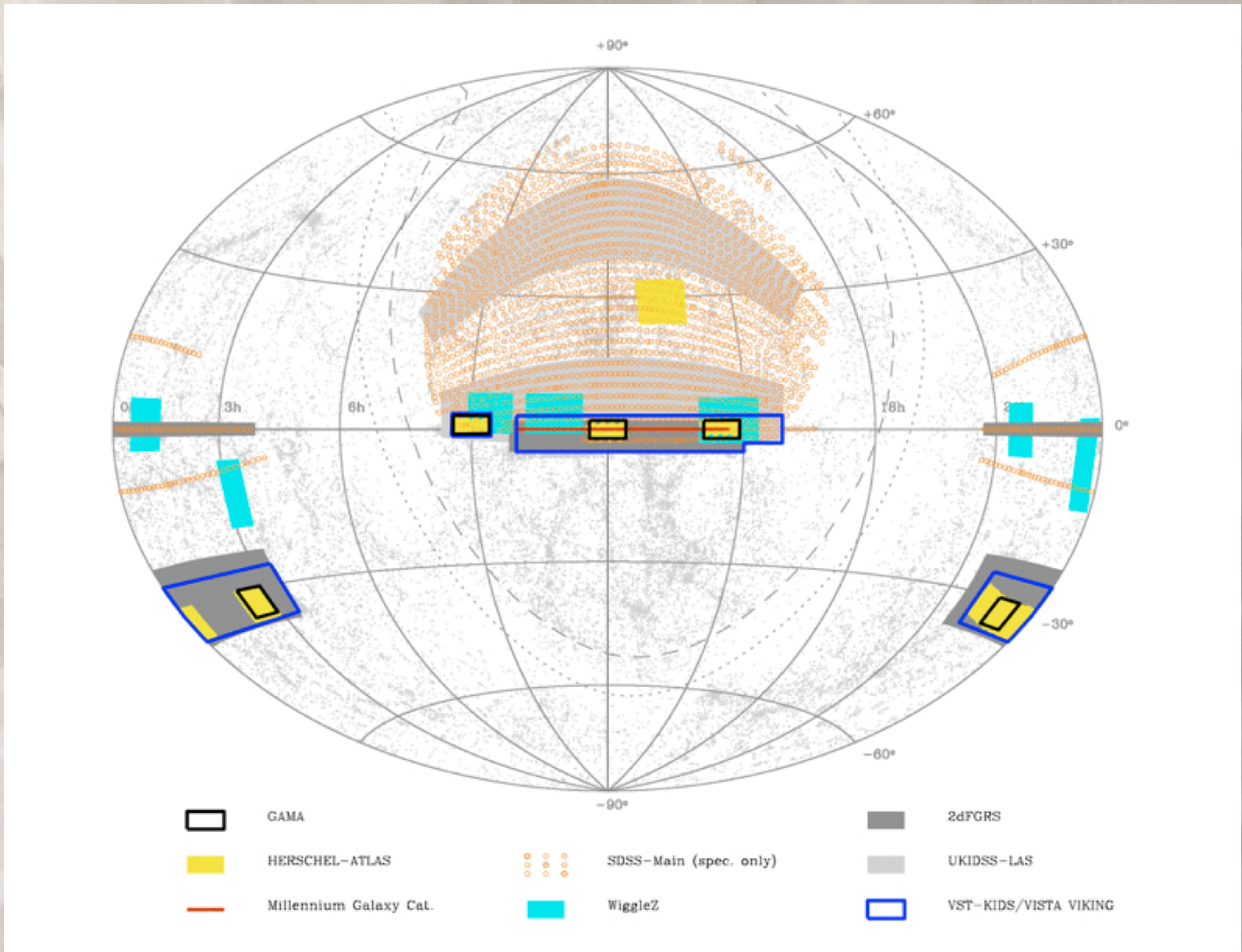
testing the consistency between stellar and dynamic mass estimates for nearby massive galaxies

Edward N Taylor – ent@ph.unimelb.edu.au
The University of Melbourne
ARC DECRA Fellow and CAASTRO Affiliate

GAMA in context



GAMA in context



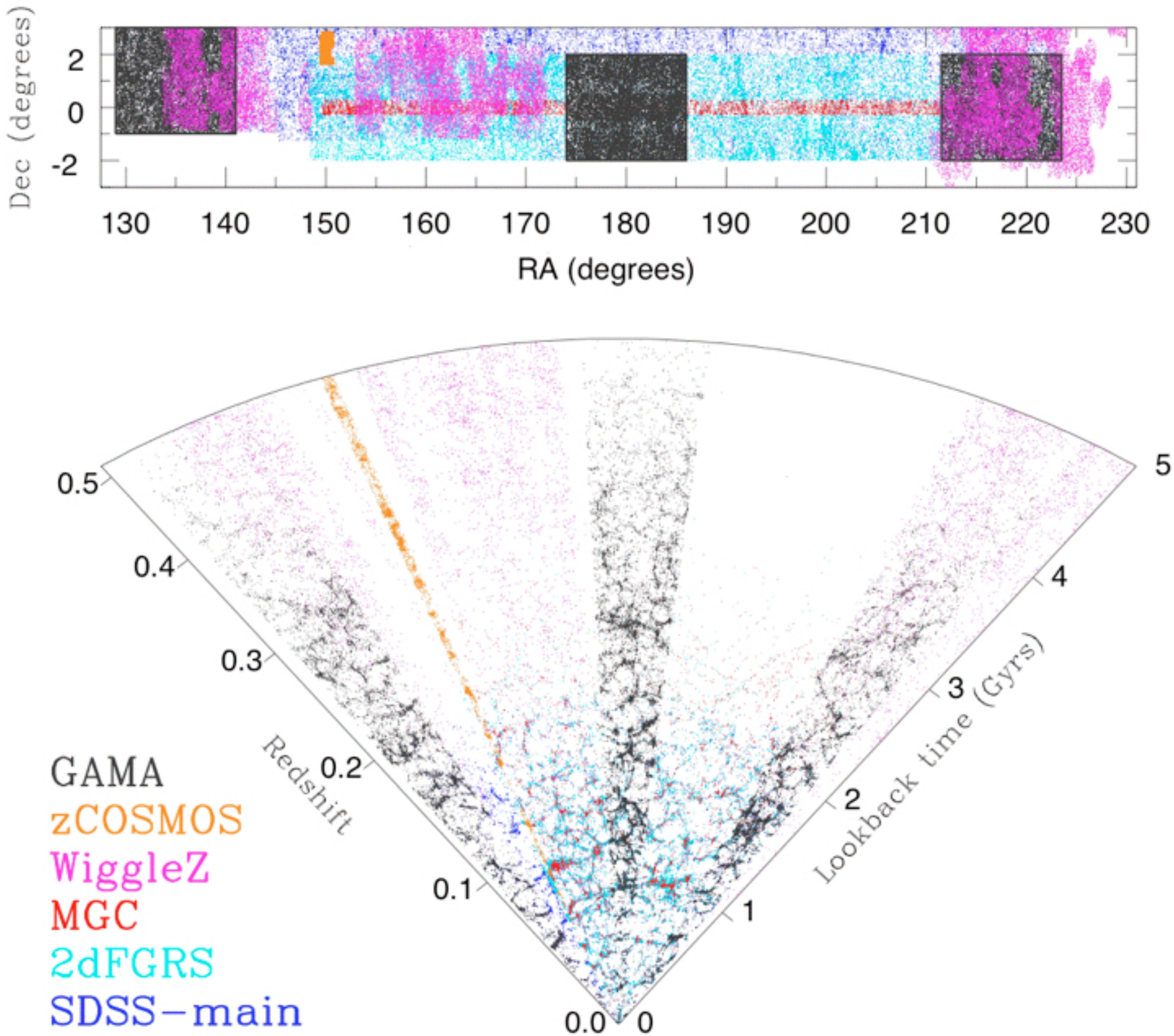

Dec (degrees)
2
0
-2
130
140
150
160
170
180
190
200
210
220
230
RA (degrees)
0.5
0.4
0.3
0.2
0.1
0.0
Redshift
0
1
2
3
4
5
Lookback time (Gyrs)
GAMA
zCOSMOS
WiggleZ
MGC
2dFGRS
SDSS-main

Table 3: GAMA and SDSS survey parameters

parameter	GAMA	SDSS
galaxy redshifts	275k	700k
sky coverage (deg.^{2})	250	~8000
spectral resolution (Å)	4.6	3.3
spectral range (Å)	3700–8800	3900–9100
spec. *r* limit (mag.)	19.8	17.77
M^* z limit	0.27	0.11
M^* volume ($h^{-3}Mpc^3$)	6.6×10^6	25.9×10^6
imaging bands	21	5
spatial resolution (″)	0.7	1.5
λ range (μm)	$0.15–10^6$	0.3–0.9
data volume	120Tb–1Pb	60Tb

GAMA | Galaxy And Mass

www.gama-survey.org/dr2/

GAMA

Galaxy And Mass Assembly

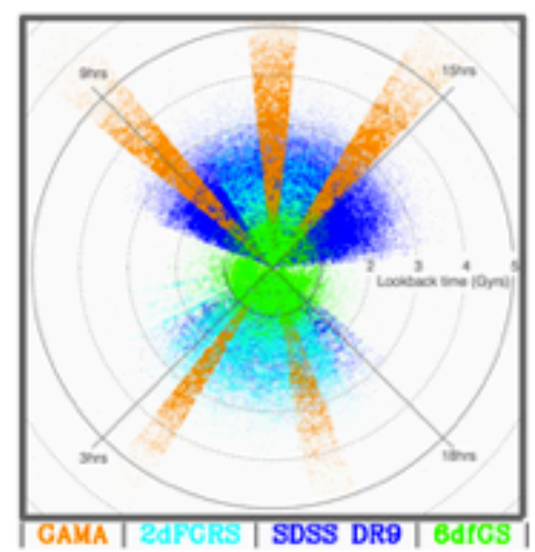
Data Release 2 | Schema Browser | Query | Data | Single Object Viewer | GAMA

▸ DR2

GAMA Data Release 2

The second GAMA data release (DR2) provides AAT/AAOmega spectra, redshifts and a wealth of ancillary information for 72,225 objects from the first phase of the GAMA survey (2008 - 2010, usually referred to as GAMA I). The DR2 web pages describe the data included in this release, and provide access to an SQL database as well as to the actual data (spectra and catalogues).

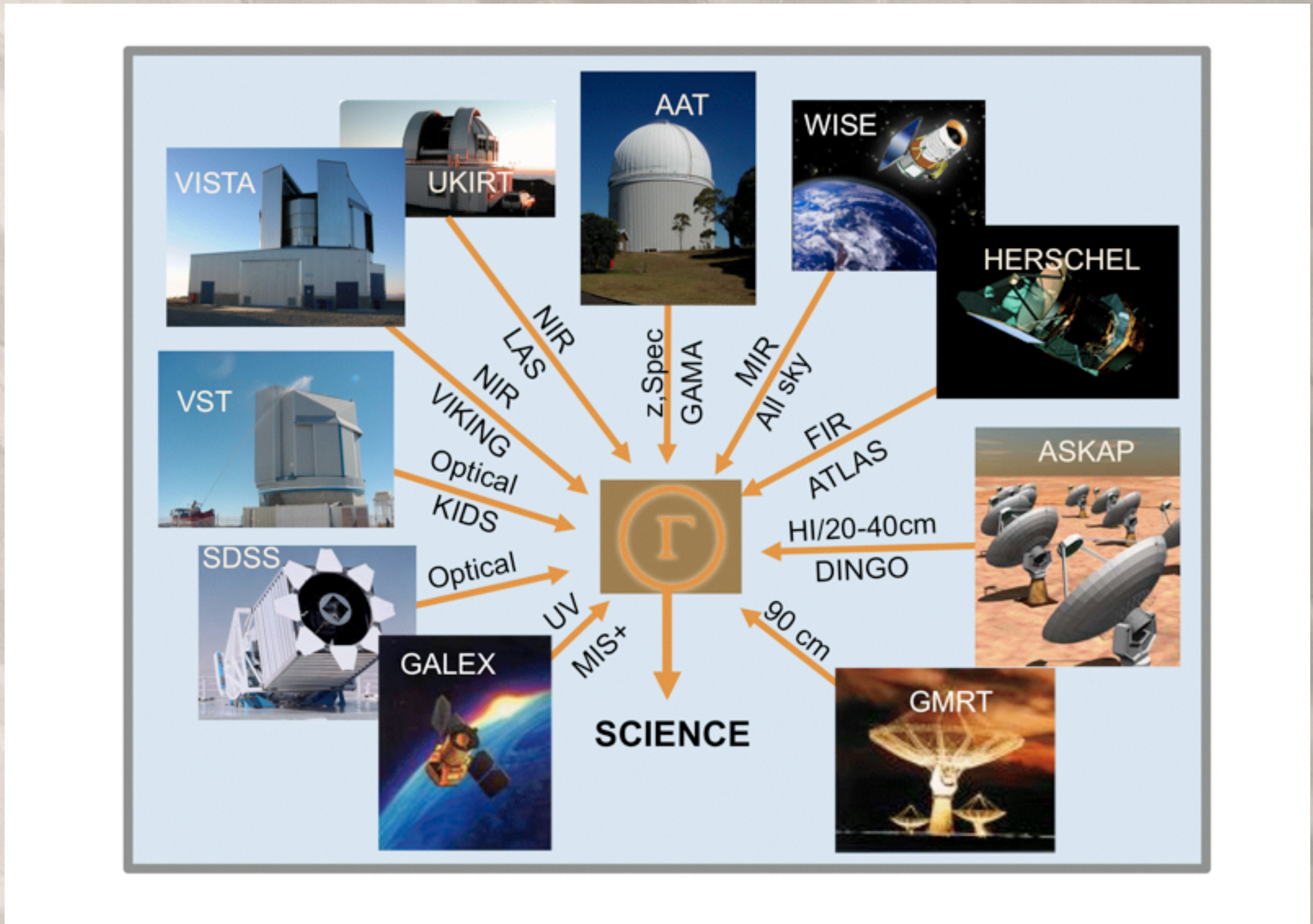
If you are using GAMA DR2 data in a publication then please cite the DR2 paper (Liske et al. 2013) and acknowledge GAMA.



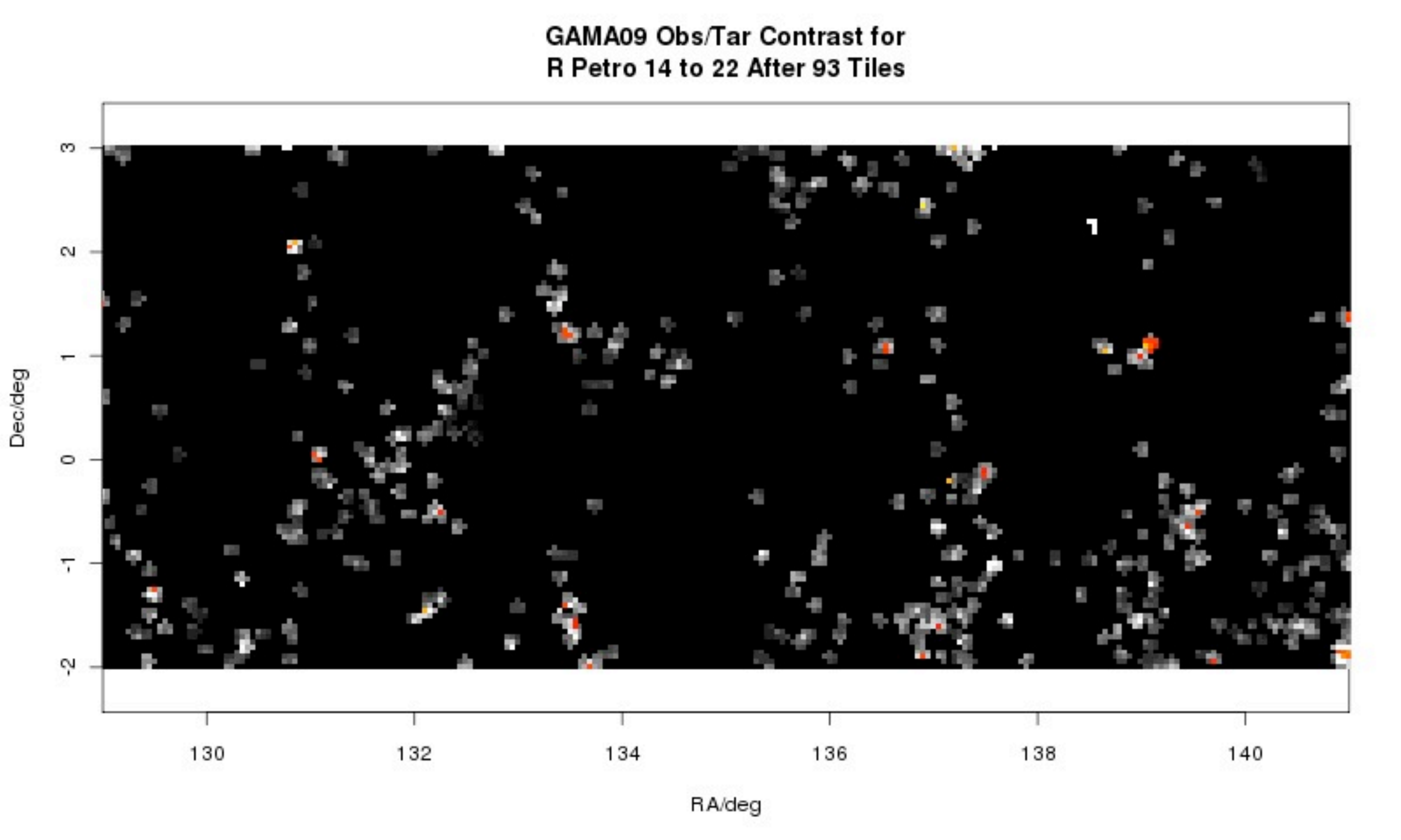
What is released?

The GAMA I survey extends over three equatorial survey regions of 48 deg^2 each (called G09, G12 and G15) and down to magnitude limits of $r < 19.4$ mag in G09 and G15, and $r < 19.8$ mag in G12. In DR2 we are releasing data for all GAMA I main survey objects with $r < 19.0$ mag (G09 and G12) or $r < 19.4$ mag (G15). Note that for G15 we are essentially releasing all GAMA I data. The total number of objects included in DR2 is 72,225. Of these, 70,726 objects (98%) have secure redshifts.

GAMA in context



GAMA: unprecedented completeness



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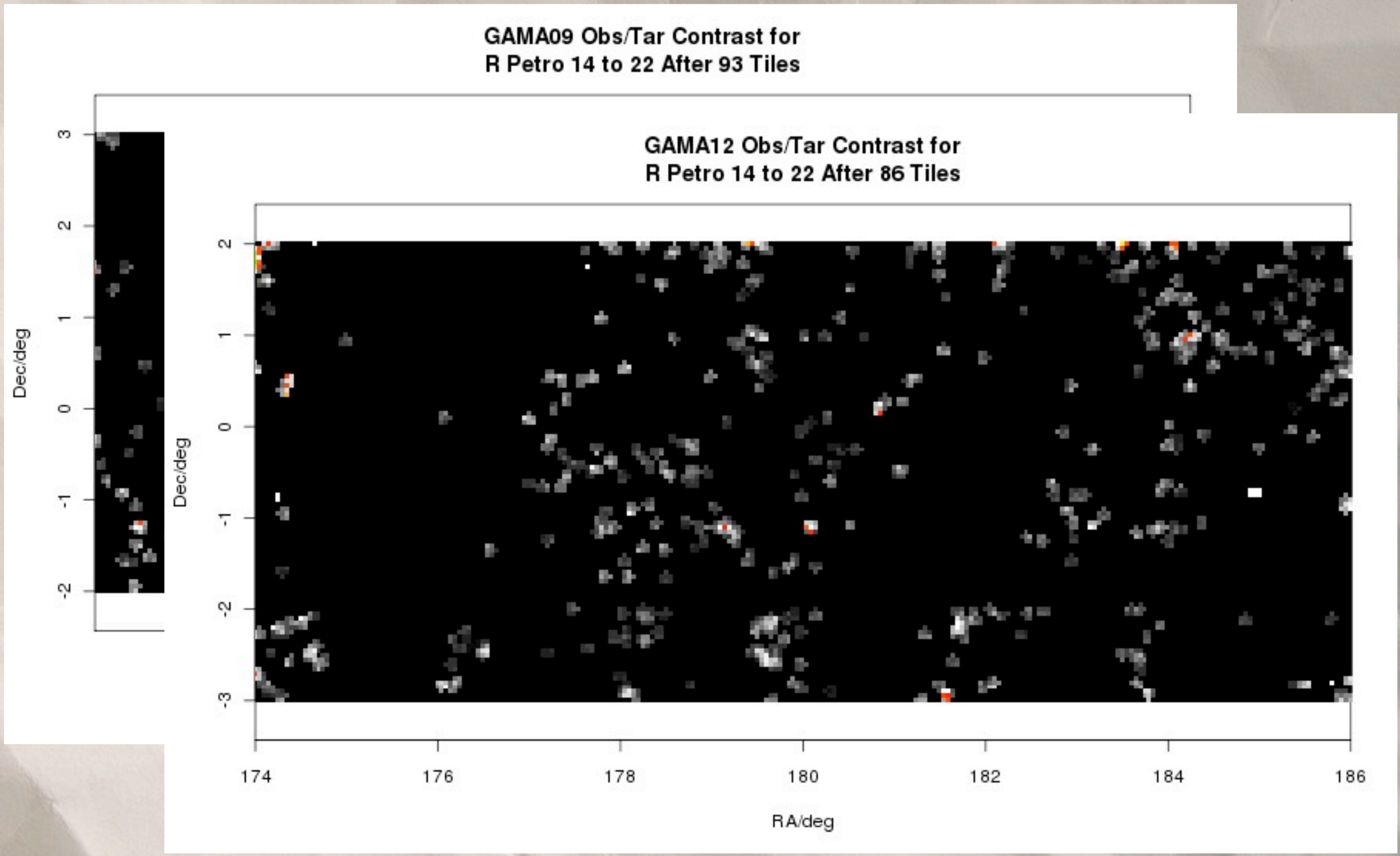

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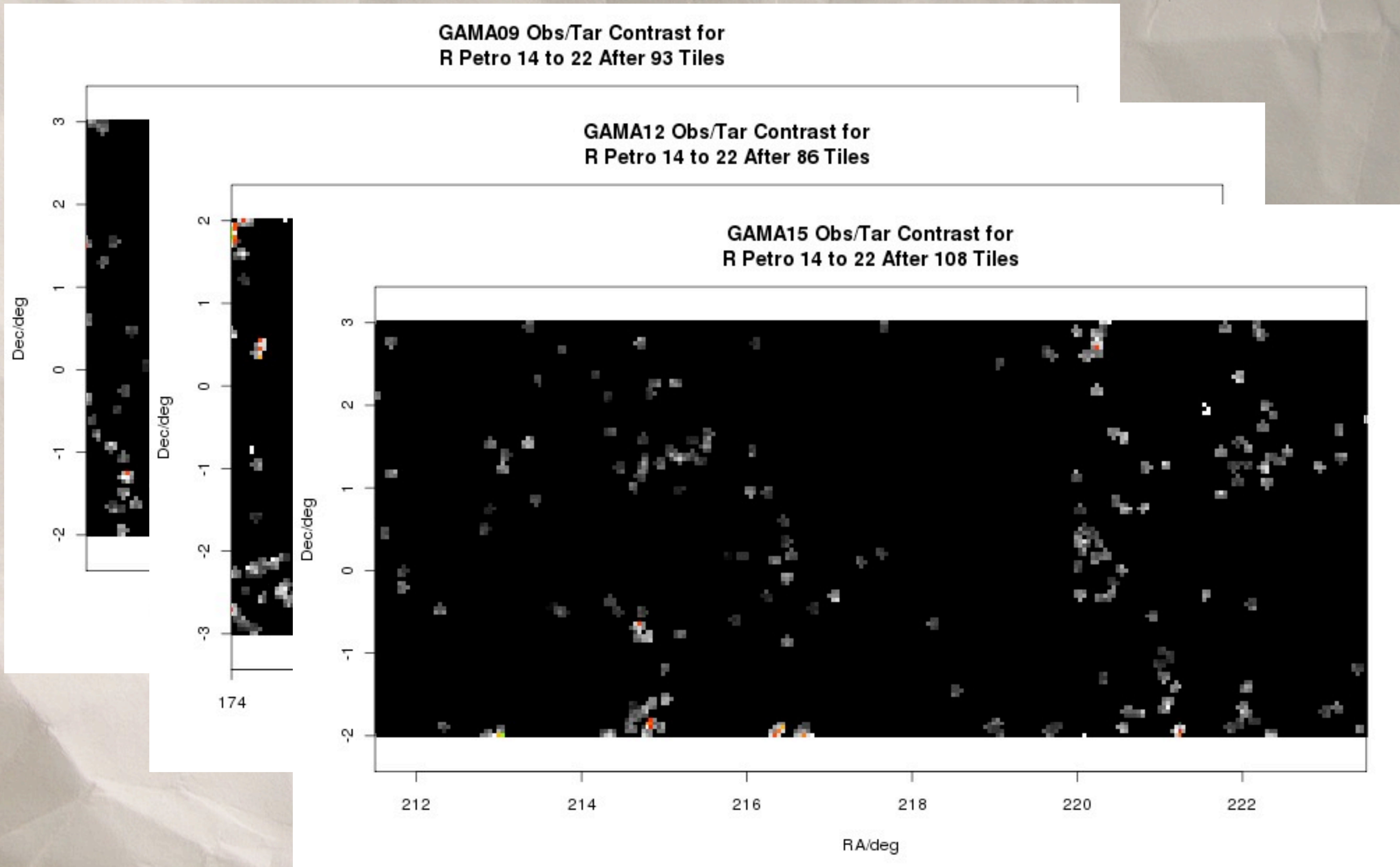

GAMA in context

GAMA in context

- ~ 300 sq. deg; $r < 19.8$ (2 mag fainter than SDSS)
- 200k redshifts; second largest redshift survey
- M_* galaxies to $z \sim 0.3$ (1/4 SDSS volume)
- full and continuous optical spectra (SDSS-like)
- **genuinely panchromatic (UV-opt-NIR-MIR-FIR)**
- **unprecedented completeness; no density bias.**
- parent sample for SAMI (2500 galaxies)

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recipe for a galaxy

recipe for a galaxy

ingredients: given (or assuming) all of the following –

Stellar spectral evolution models : $f_{star}(\lambda, M, t, Z)$

Stellar initial mass function : $p(M)\,dM$

Star formation history : $\psi_*(t'; Z)$

CSP_spectrum[wavelength, SFH, age, metal] :

$$f(\lambda, t) = {}_0\!\int^t dt' \int dZ\, \psi_*(t'; Z) \int dM\, p(M)\, f_{star}(\lambda, M, t-t', Z)$$

Dust extinction/attenuation/obscuration $E(A_V, \lambda)$

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Dust extinction/attenuation/obscuration $E(A_v, \lambda)$

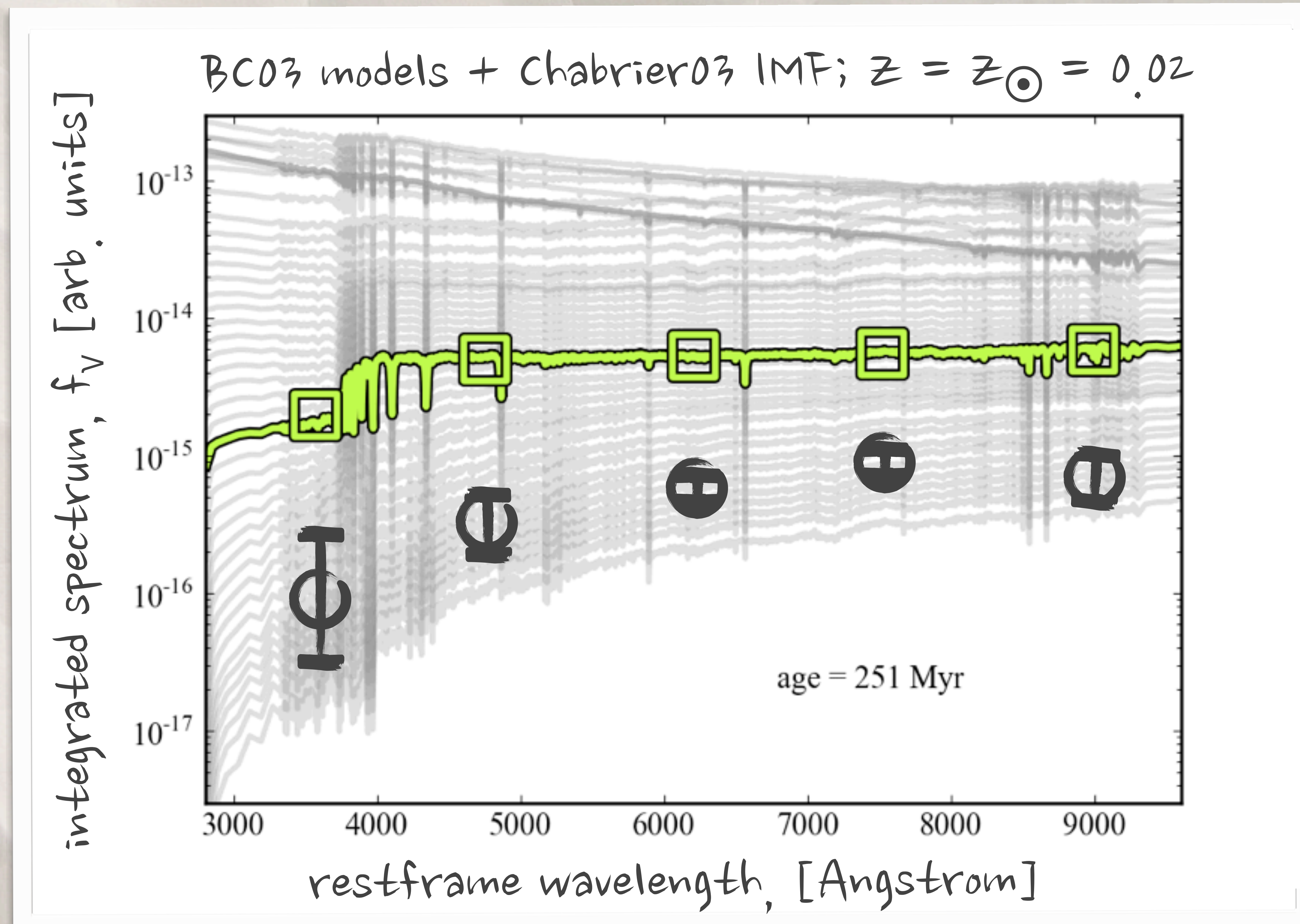
soup: the evolving spectrum for a general stellar pop'n –

model_spectrum[wavelength, age, dust, SFH, metal] :

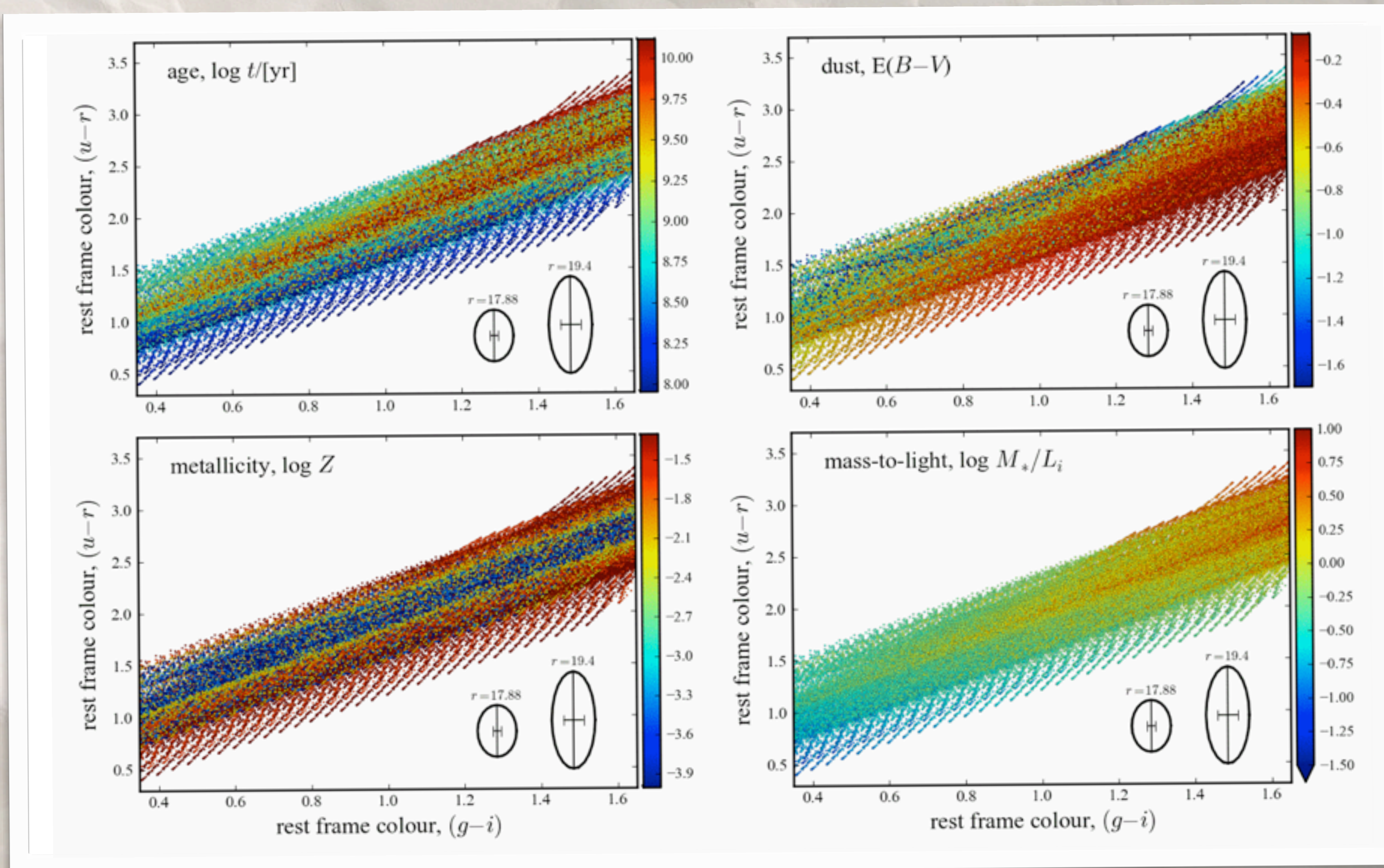
$$f_{model}(\lambda, t, A_v \mid \psi_*(t, Z))$$

$$= 10^{-0.4\, Av} E(\lambda)\, {}_0\int^t dt' \int dZ\, \psi_*(t'; Z) \int dM\, p(M)\, f_{star}(\lambda, M, t-t', Z)$$

SSP spectral evolution



estimating SP properties from broadband colours



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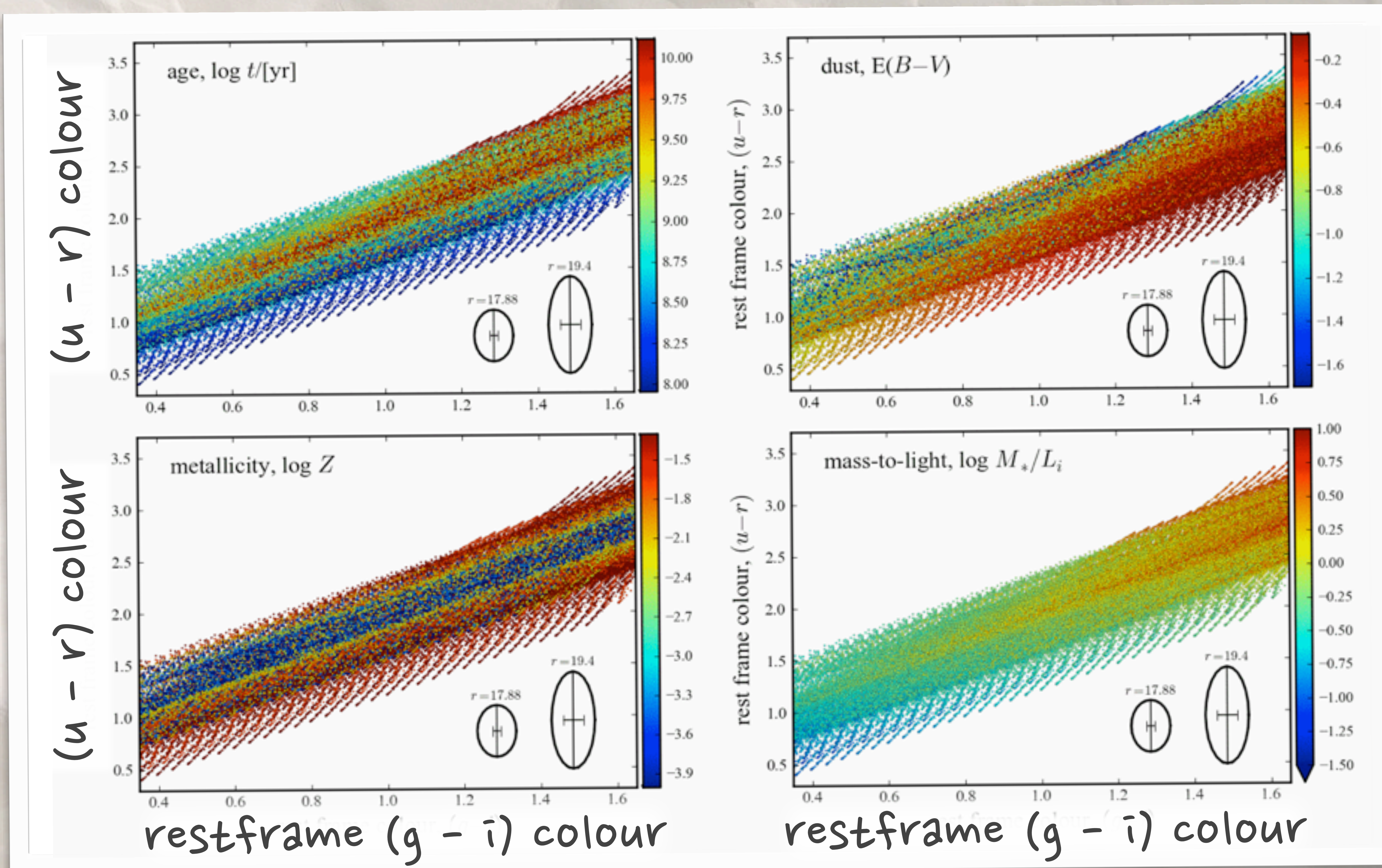
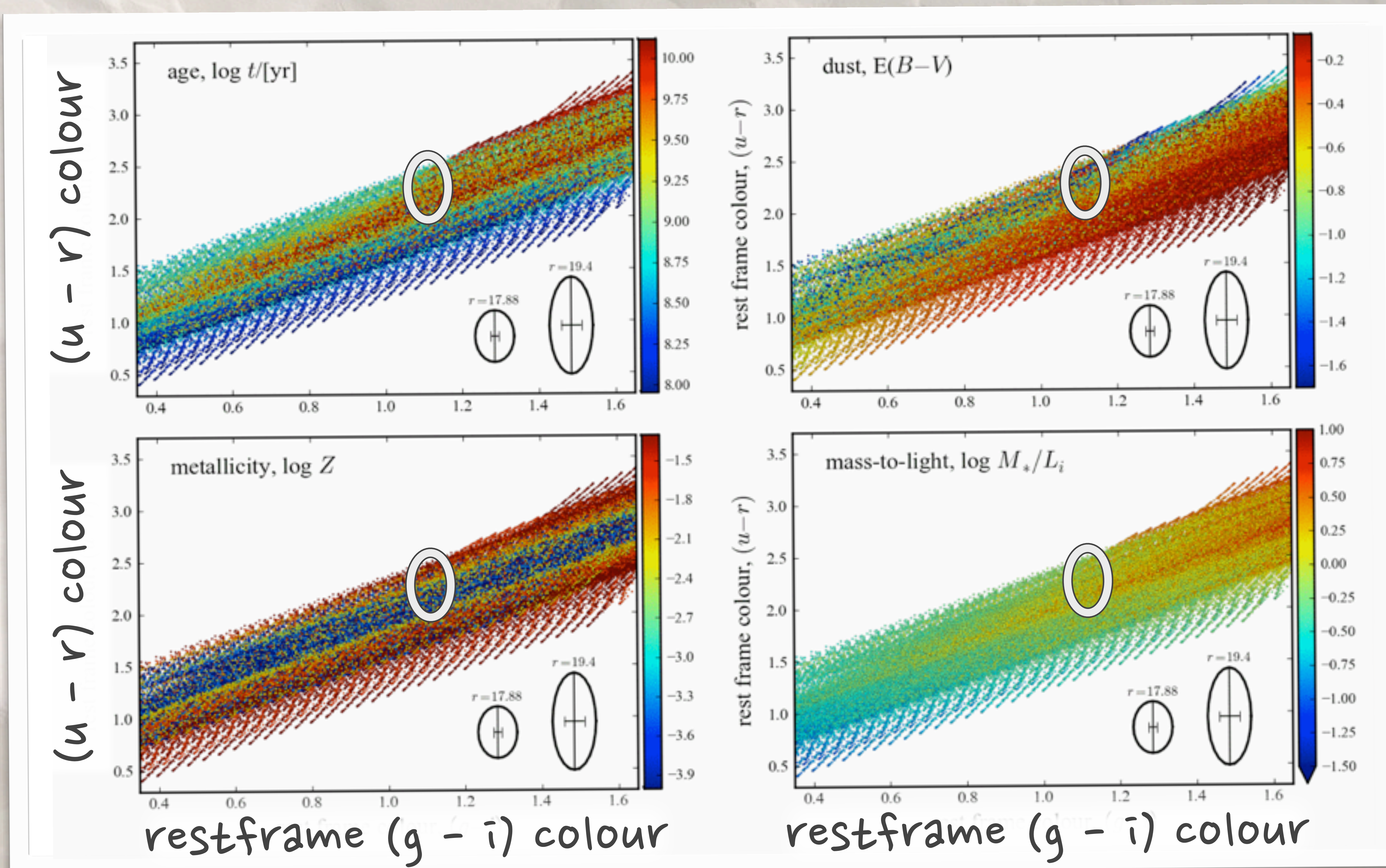
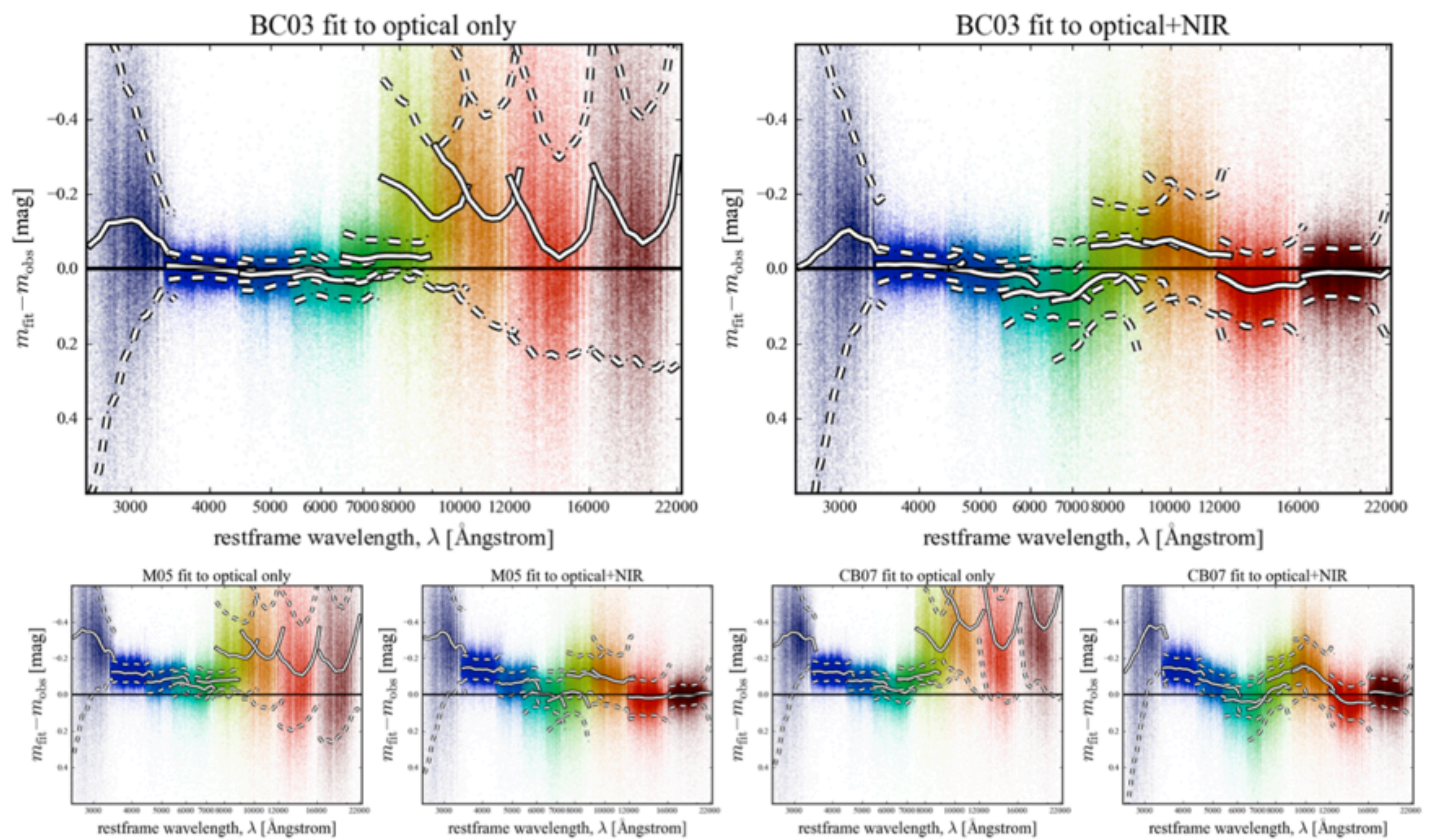


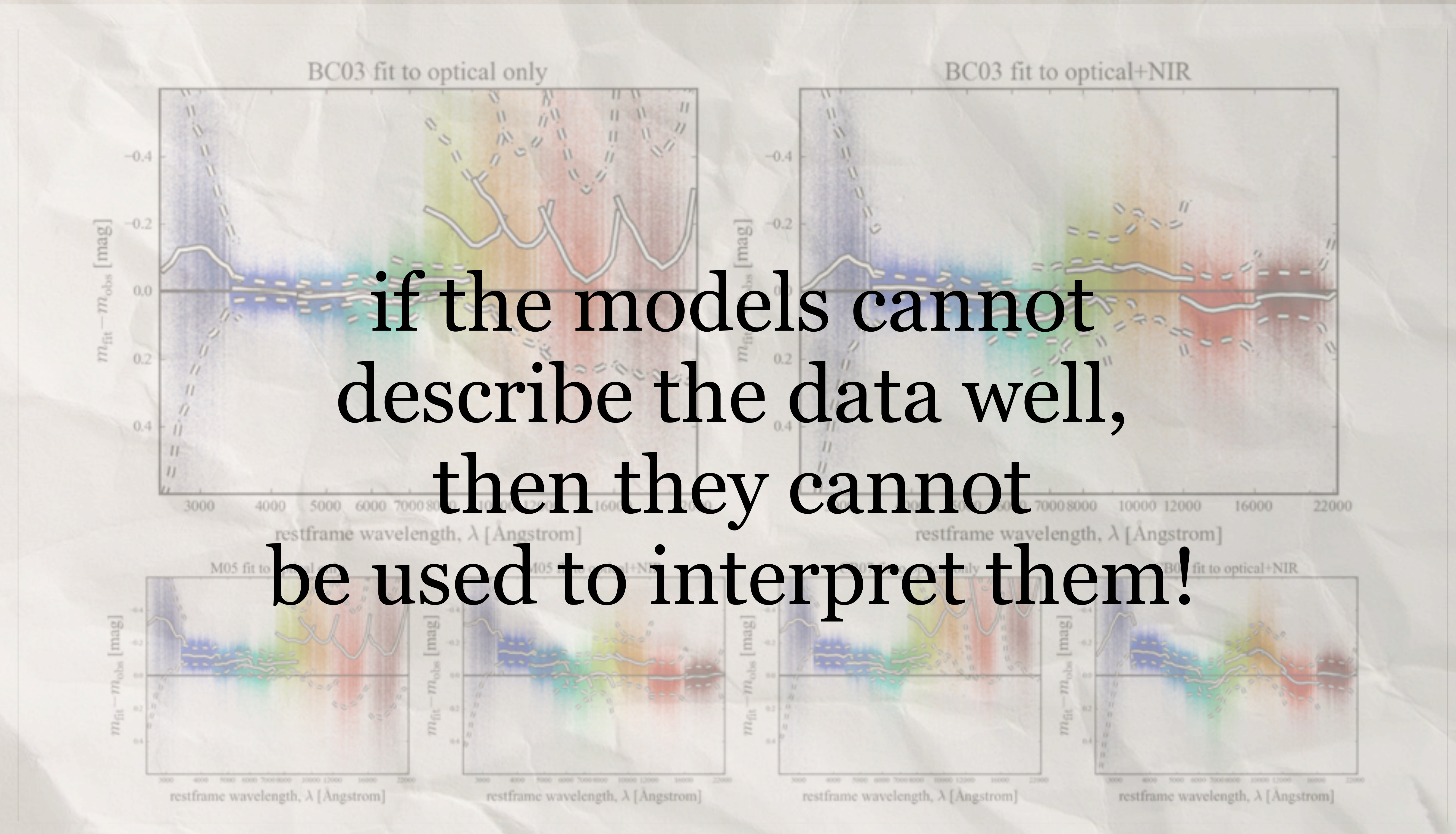
estimating SP properties from broadband colours



what, no NIR?


BC03 fit to optical only
BC03 fit to optical+NIR
M05 fit to optical only
M05 fit to optical+NIR
CB07 fit to optical only
CB07 fit to optical+NIR
$m_{fit} - m_{obs}$ [mag]
restframe wavelength, λ [Ångstrom]
−0.4
−0.2
0.0
0.2
0.4
3000
4000
5000
6000
7000
8000
10000
12000
16000
22000

what, no NIR?



if the models cannot
describe the data well,
then they cannot
be used to interpret them!

folklore: NIR data enables a better estimate of stellar mass

- M_*/L_{NIR} varies less with time
- M_*/L_{NIR} is less sensitive to the precise SFH
- L_{NIR} is substantially less affected by dust

folklore: NIR data enables a better estimate of stellar mass

NIR data breaks the
age-dust-metallicity degeneracy
and so provides a better
estimate of stellar mass

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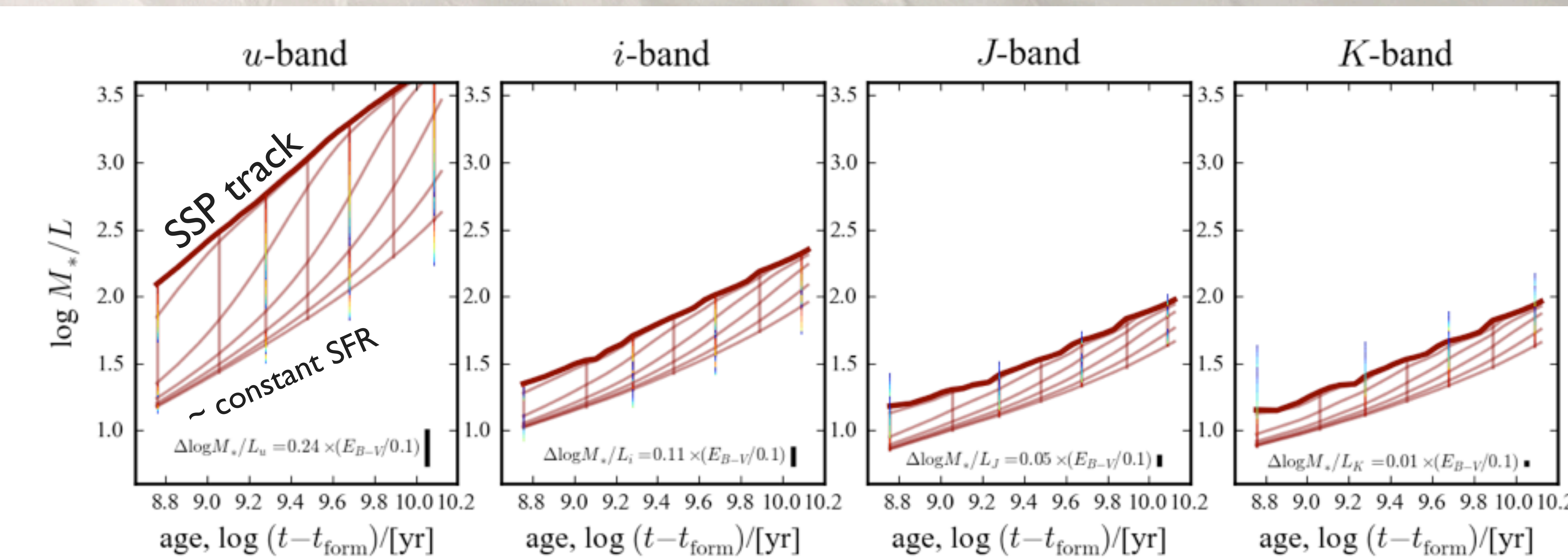
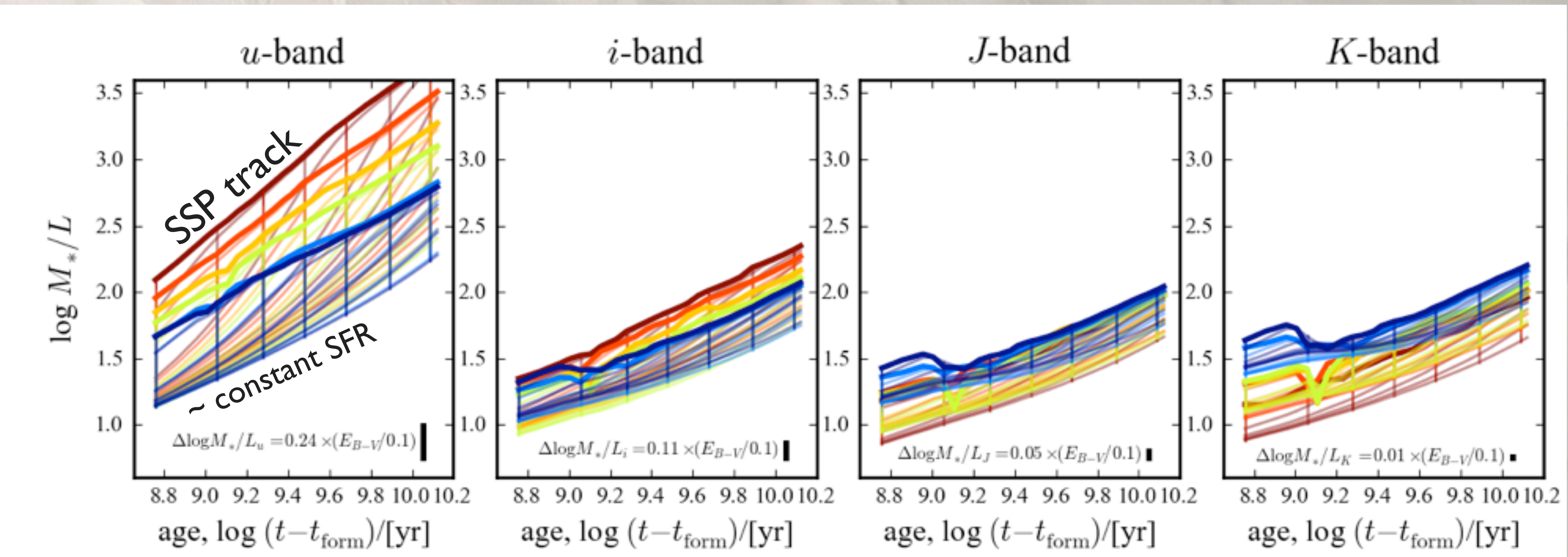
variations in M_*/L in different wavebands

variations in M_*/L in different wavebands



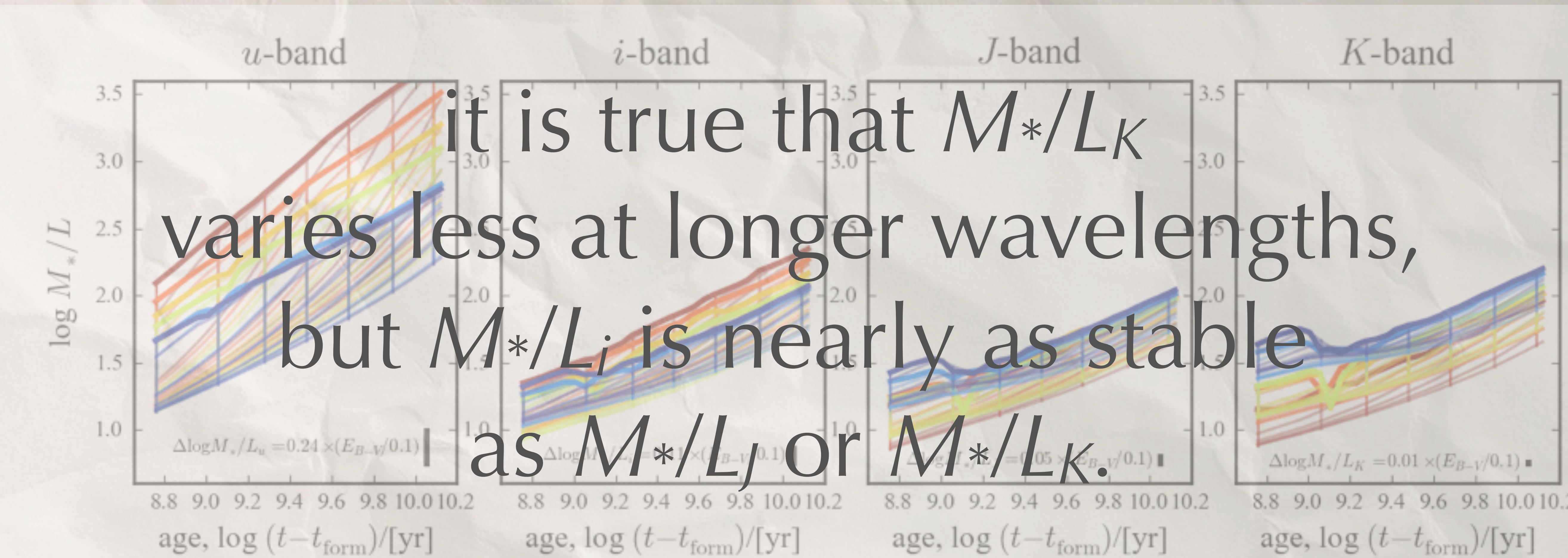
variations in M_*/L in different wavebands



implied mass accuracy:

× 22 × 5.5 × 4.0 × 4.5

variations in M_*/L in different wavebands

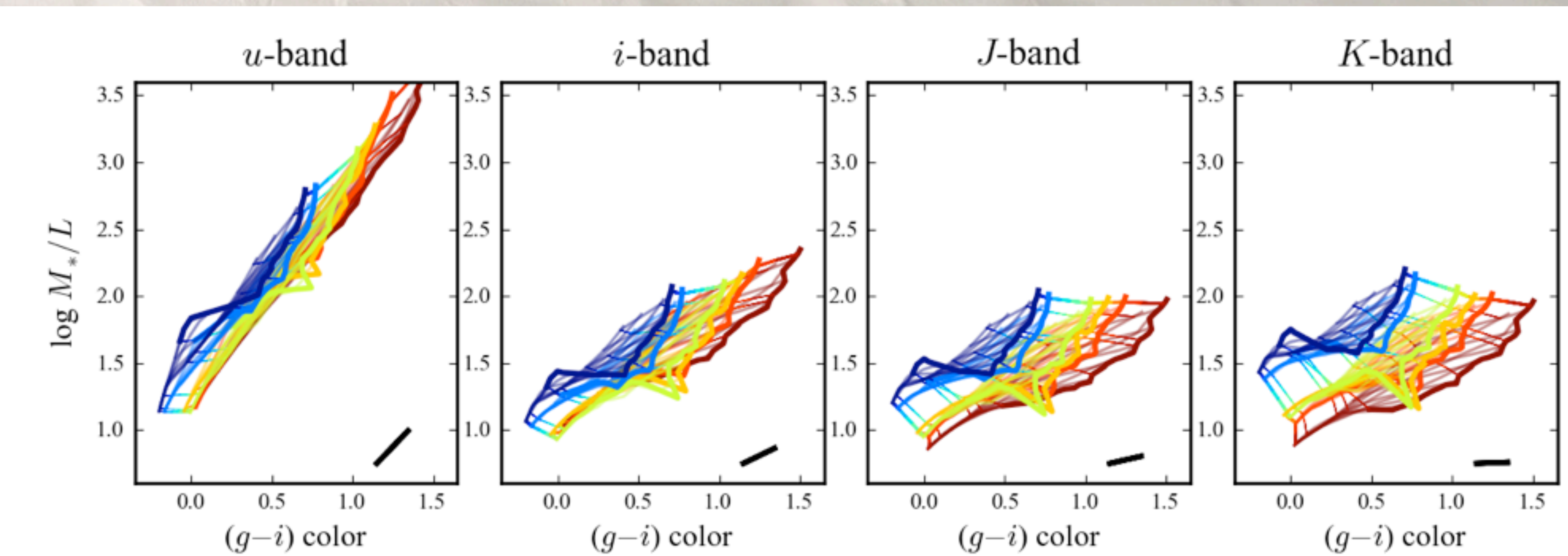


it is true that M_*/L_K varies less at longer wavelengths, but M_*/L_i is nearly as stable as M_*/L_J or M_*/L_K.

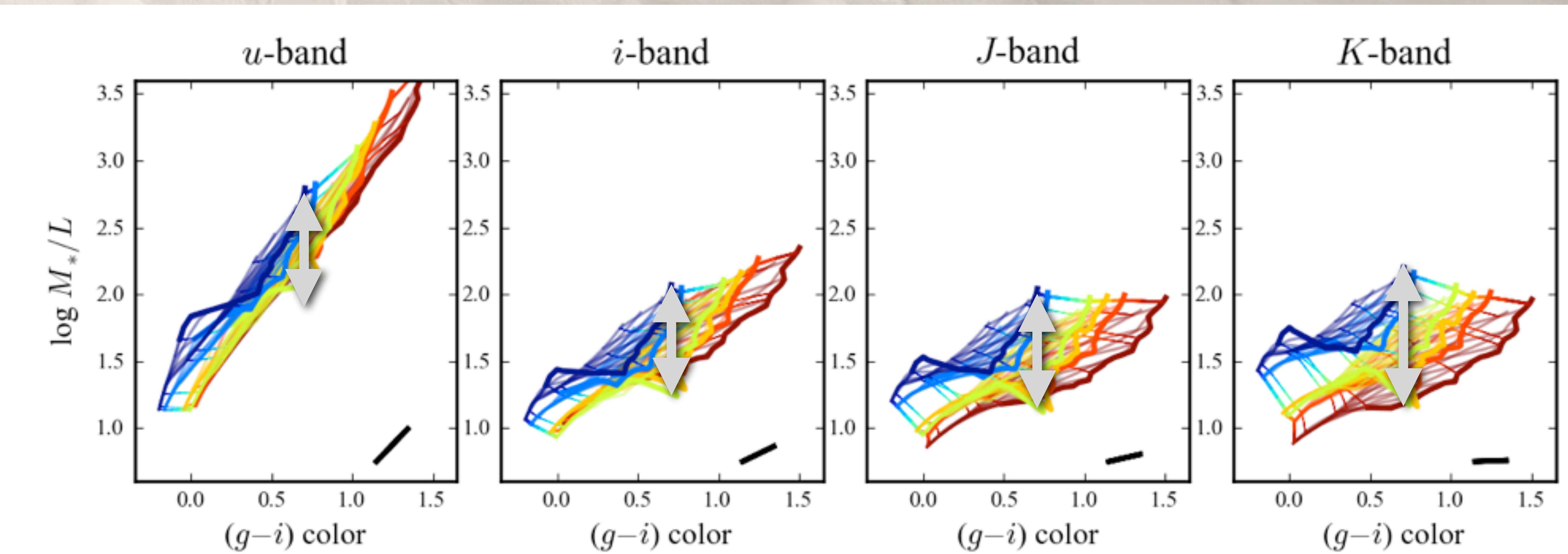
implied mass accuracy:

× 22 × 5.5 × 4.0 × 4.5

variations in M_*/L in different wavebands



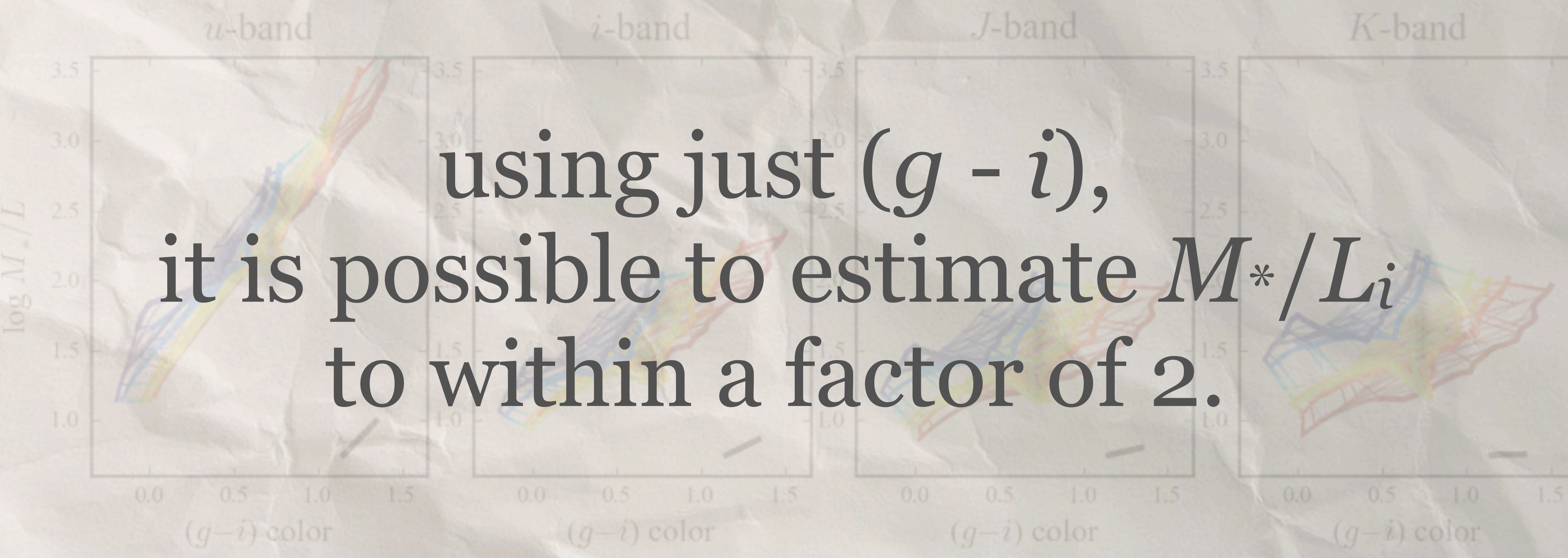
variations in M_*/L in different wavebands



implied mass accuracy:

× 3 × 2 × 3 × 4

variations in M_*/L in different wavebands

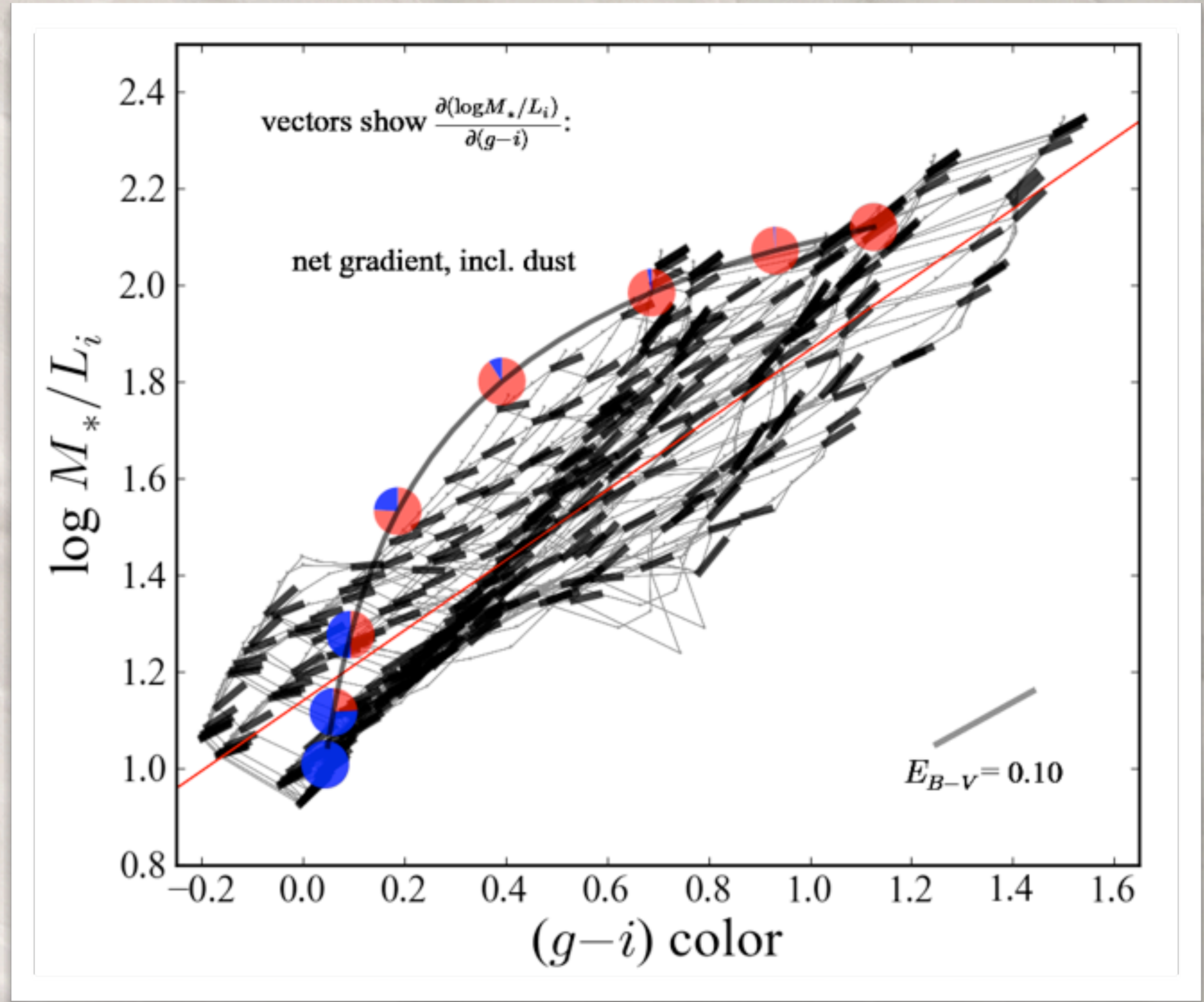


using just (g - i),
it is possible to estimate M_*/L_i
to within a factor of 2.

implied mass accuracy:

× 3 × 2 × 3 × 4

the generic relation between M_*/L_i and $(g - i)$



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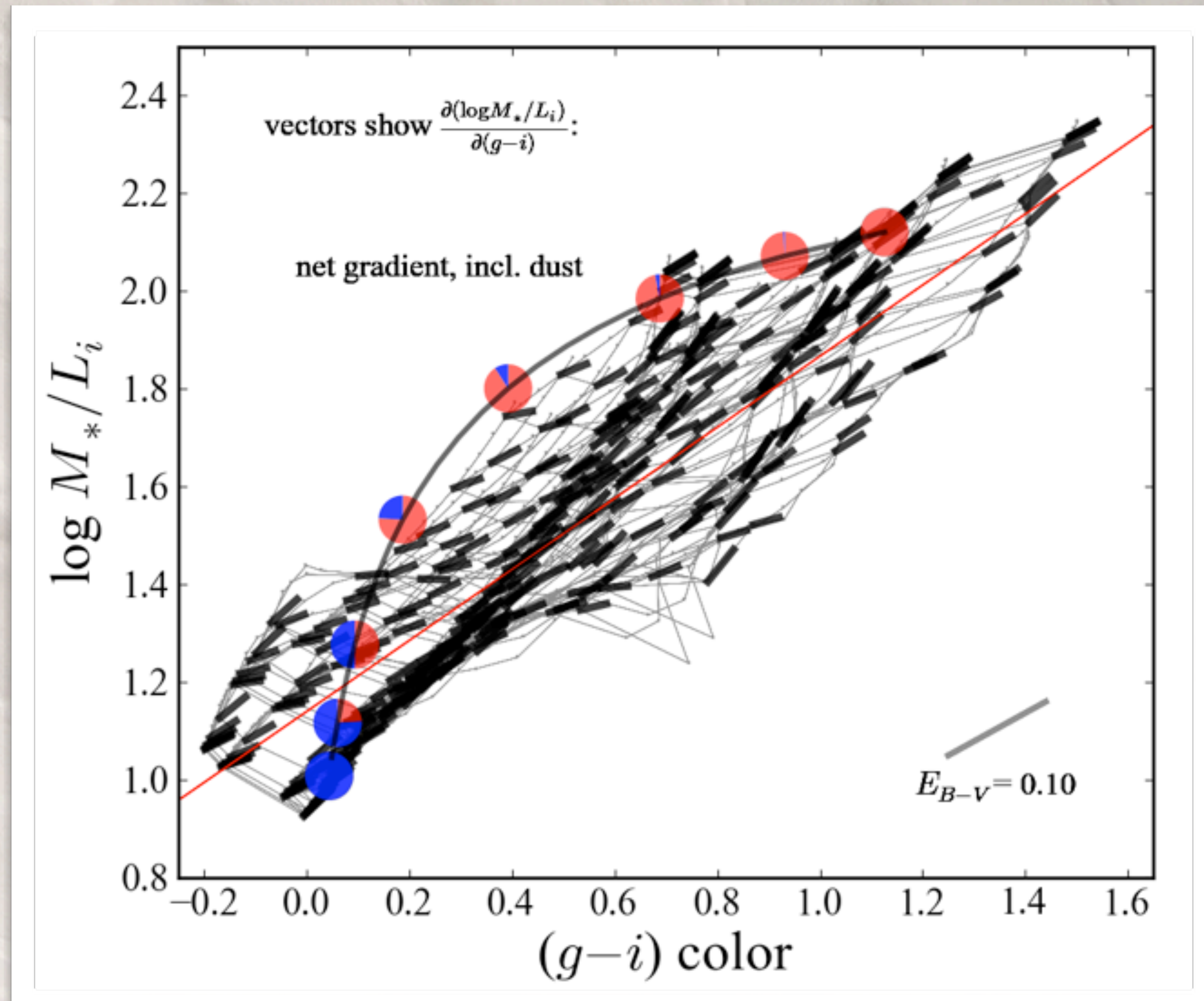

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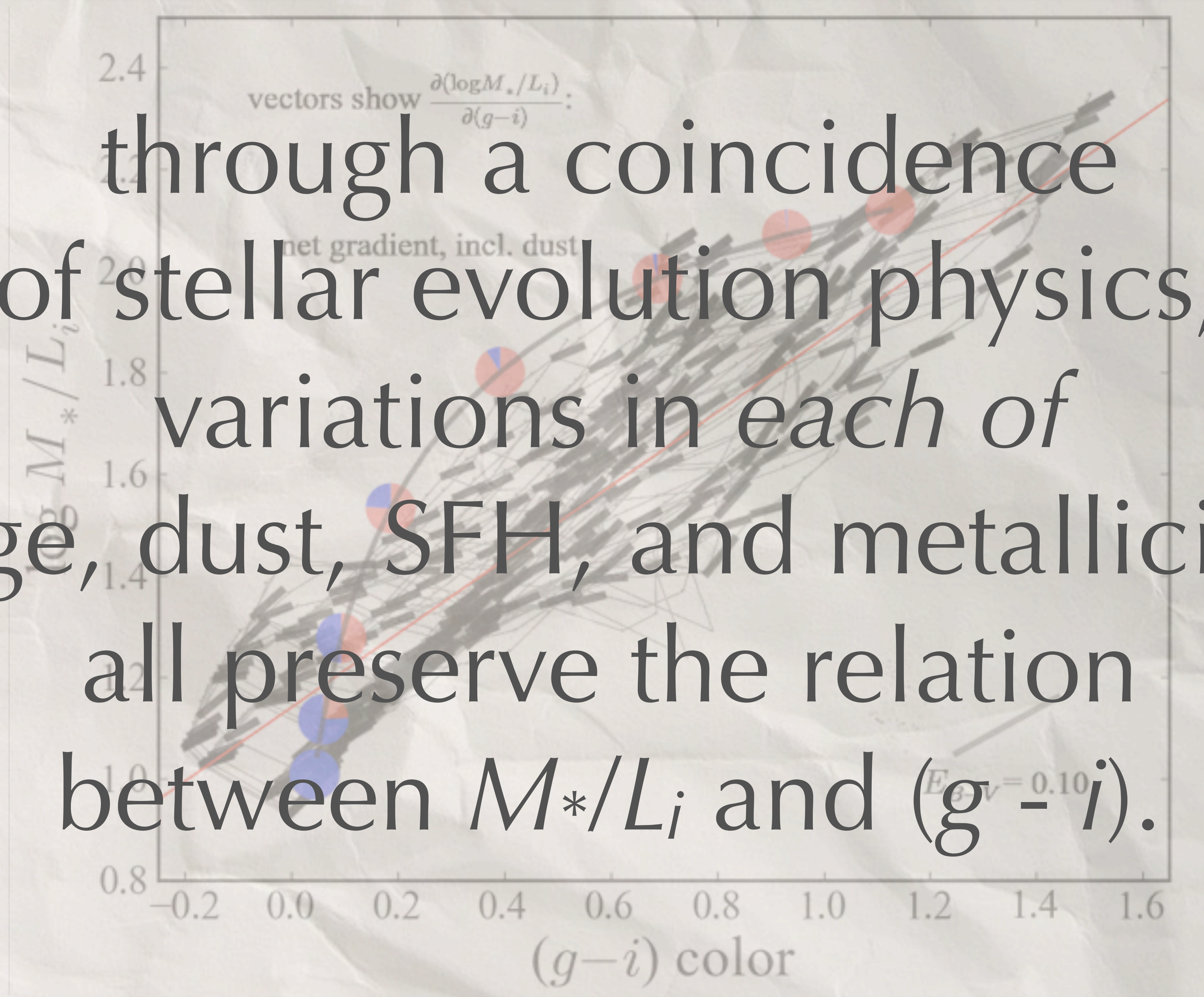
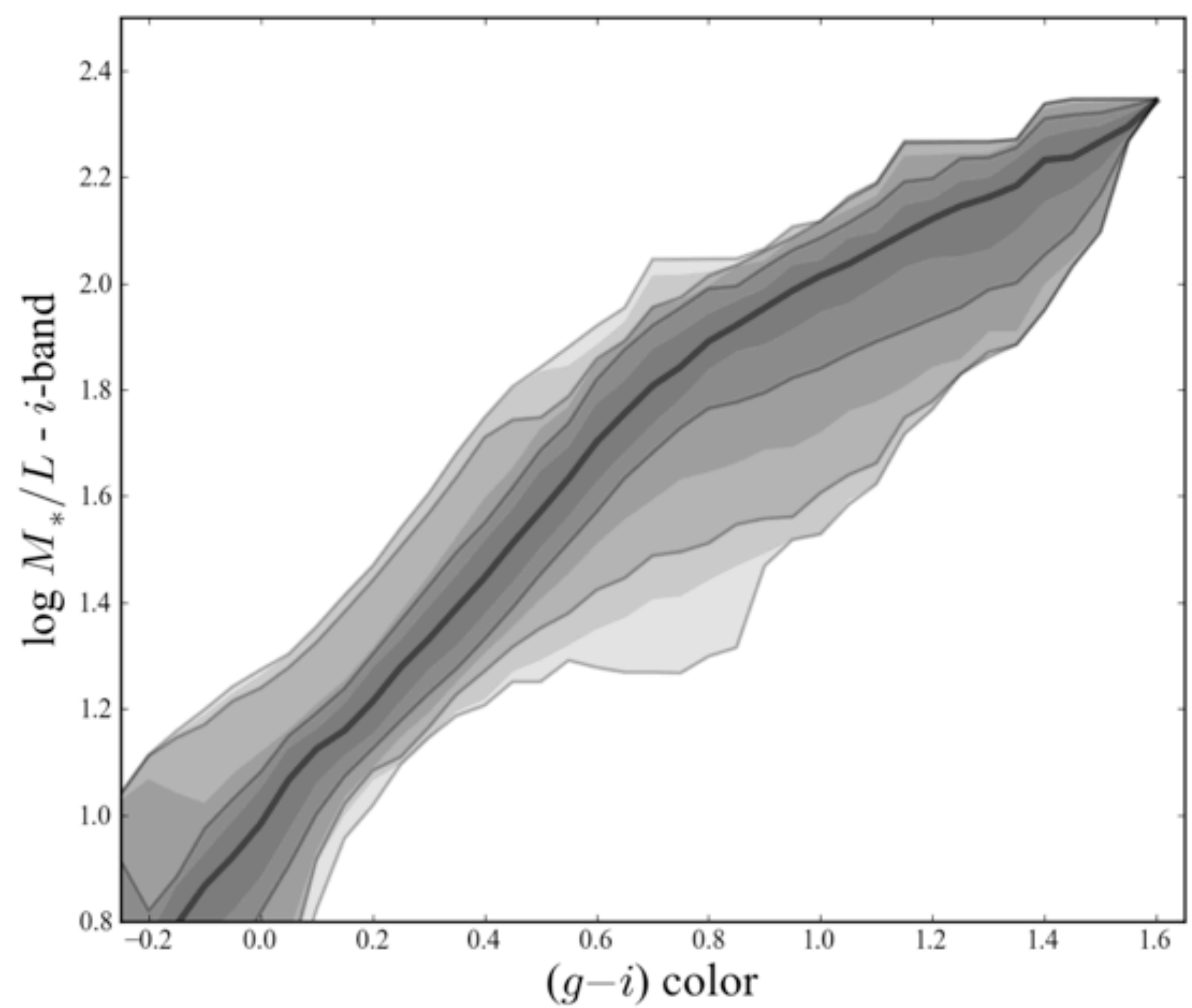


through a coincidence
of stellar evolution physics,
variations in *each of*
age, dust, SFH, and metallicity
all preserve the relation
between M_*/L_i and $(g$ - $i)$.

the generic relation between M_*/L_i and $(g - i)$



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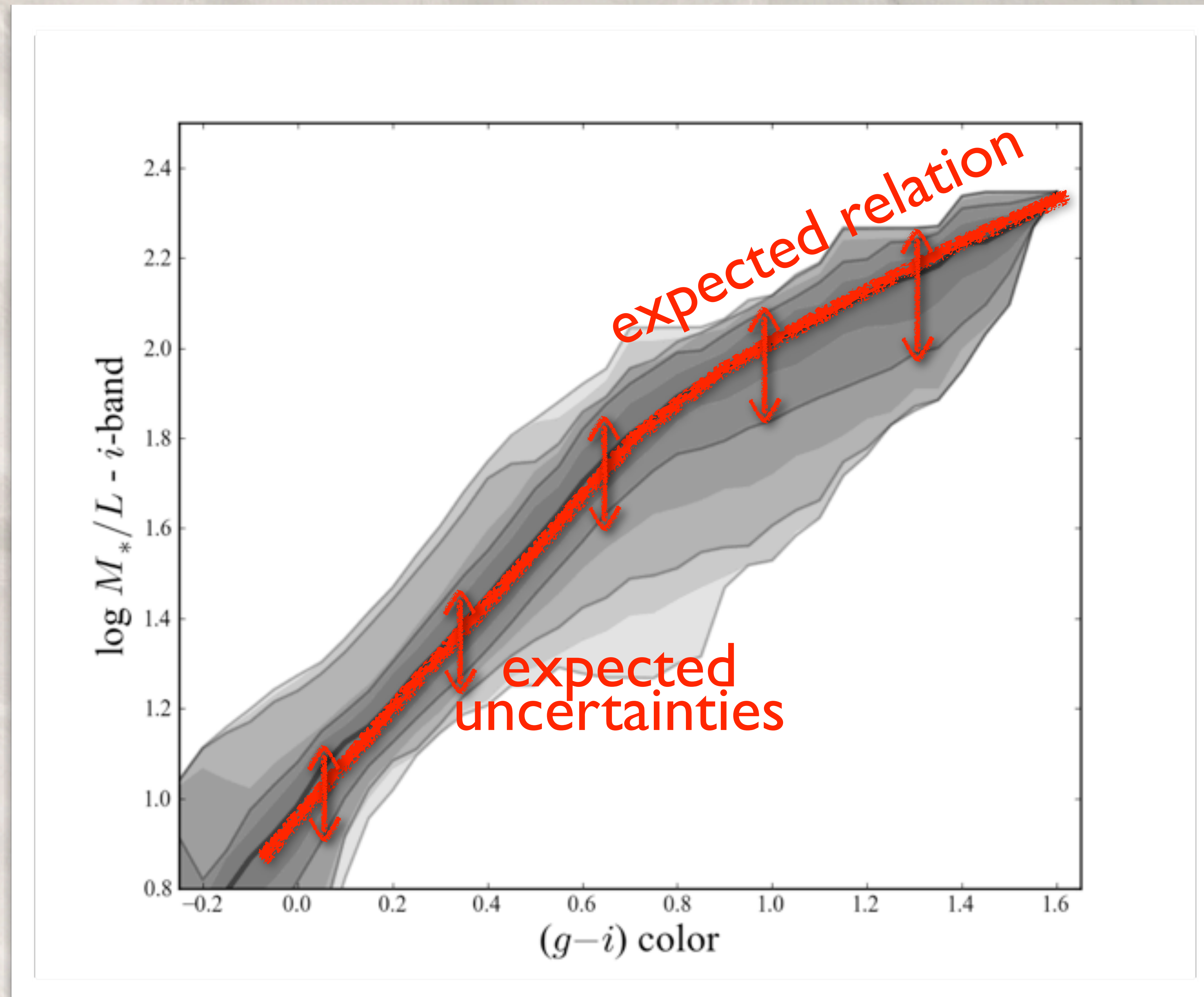
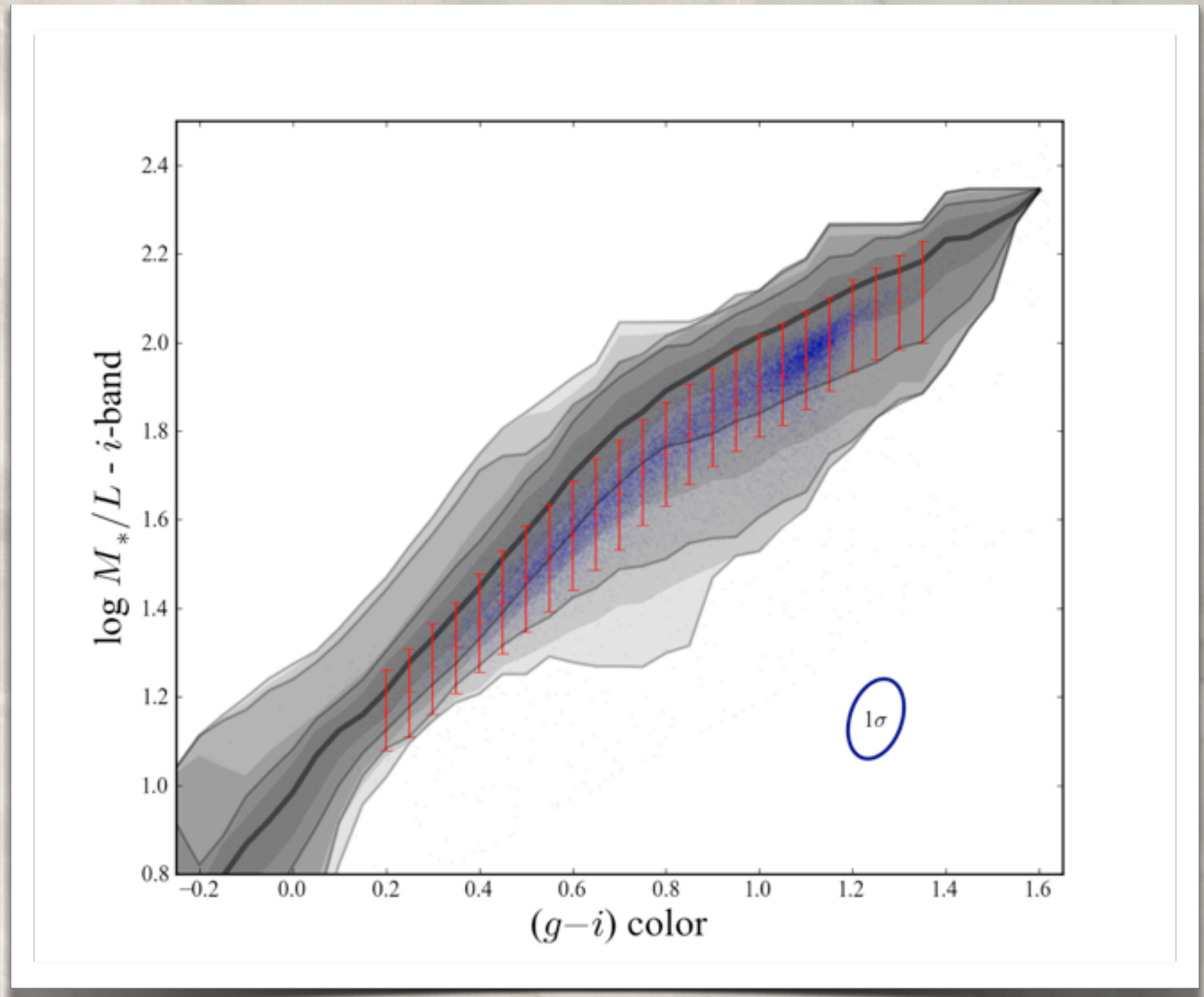
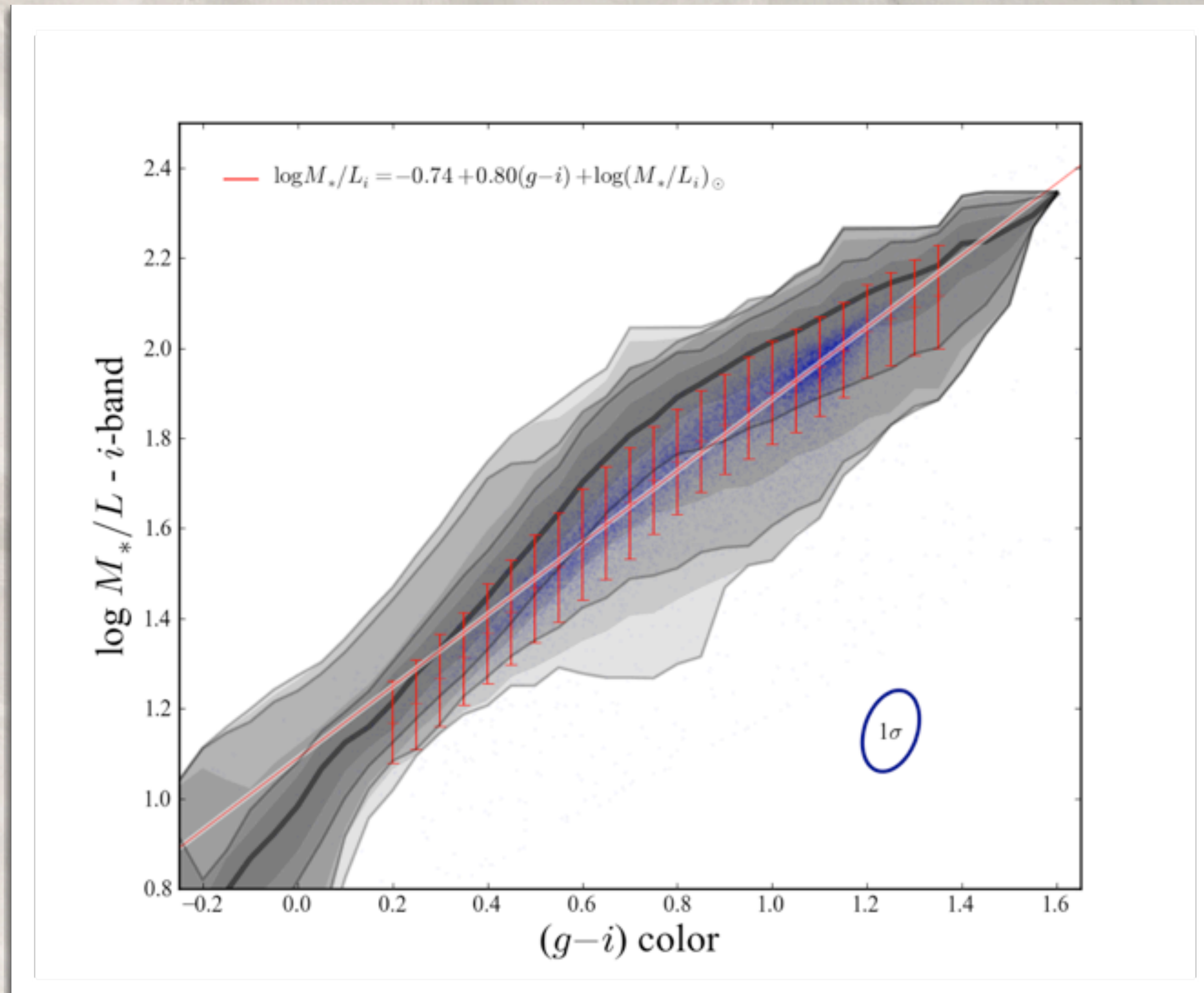


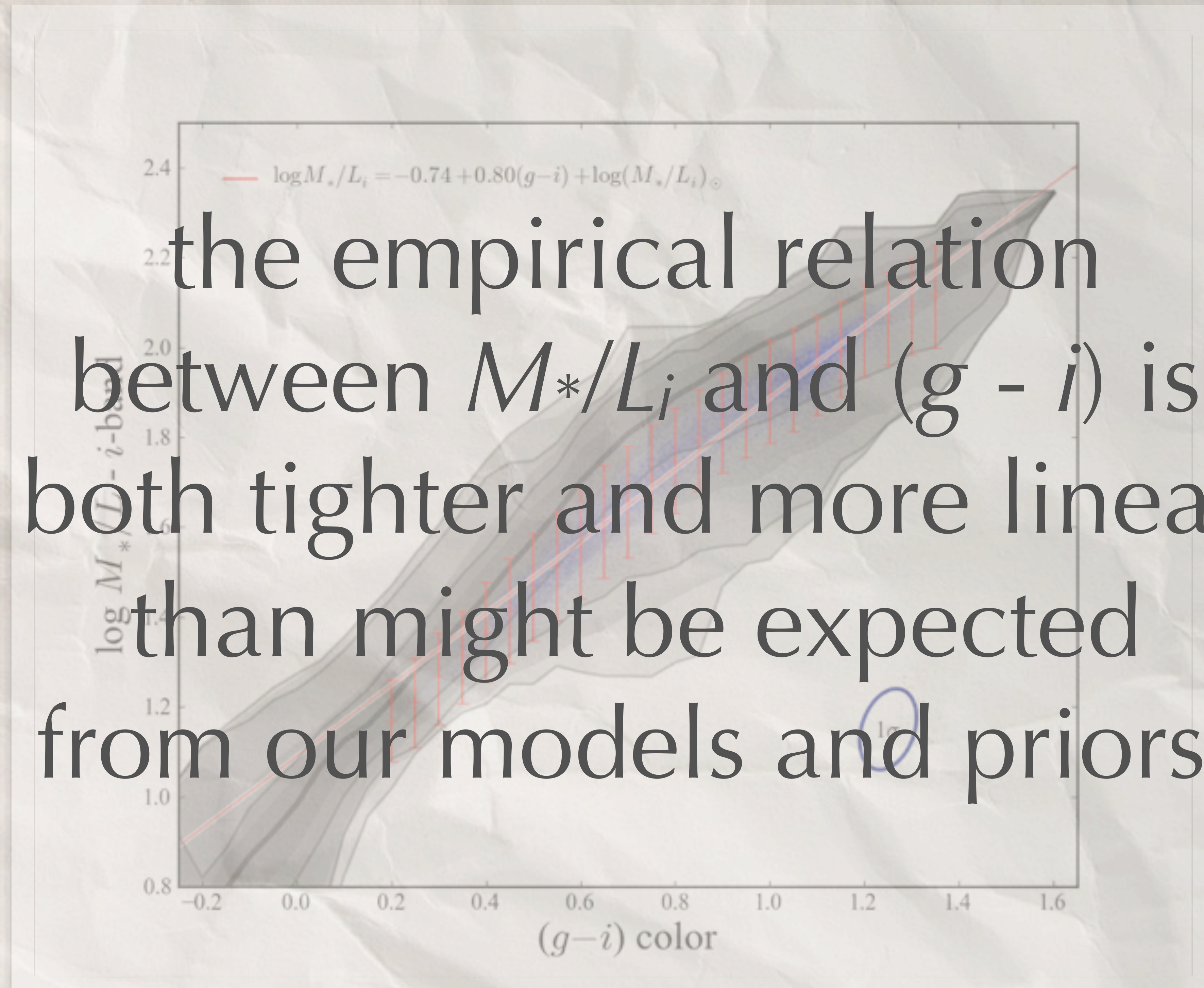
the generic relation between M_*/L_i and (g - i)



the generic relation between M_*/L_i and $(g - i)$



the generic relation between M_*/L_i and (g - i)

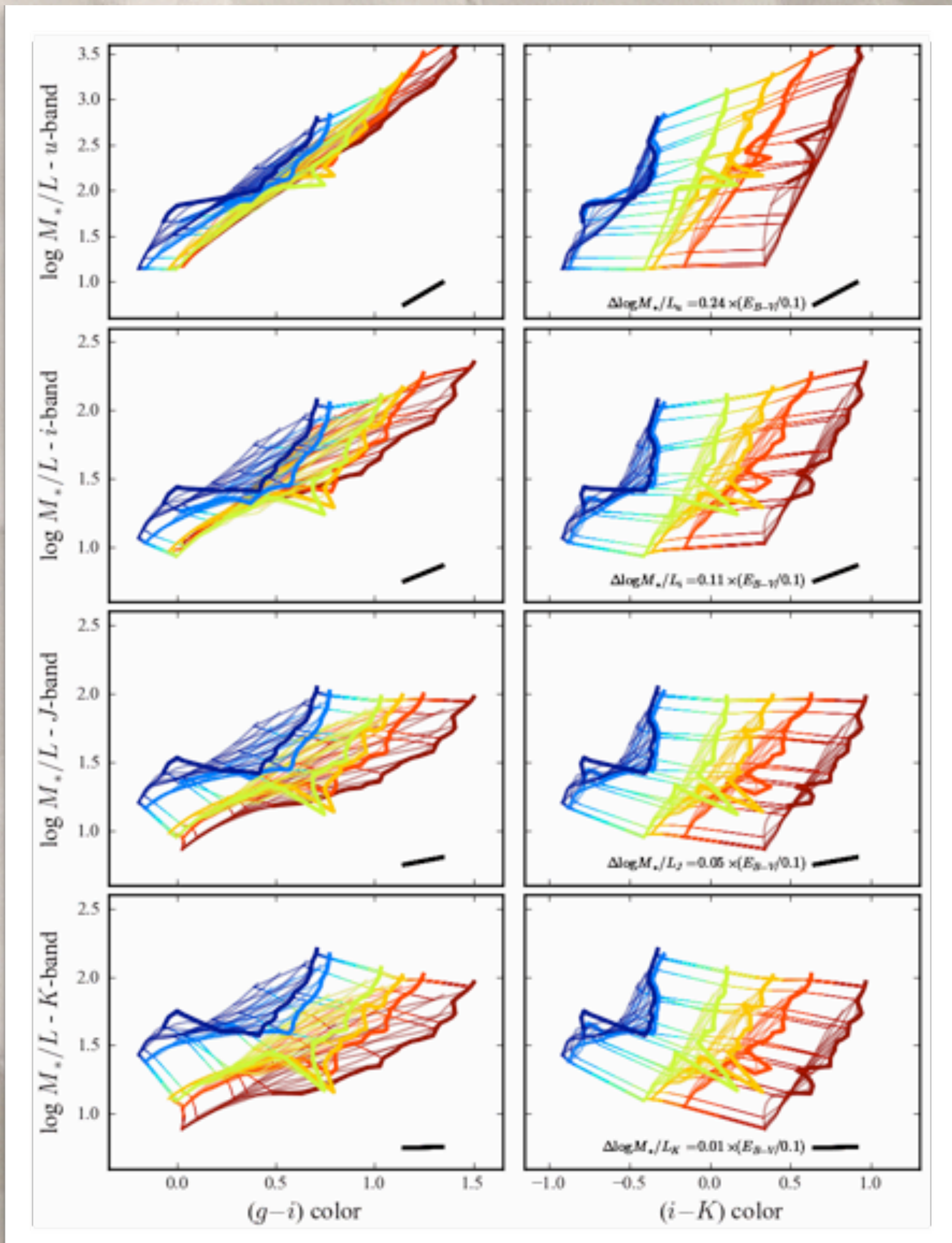


the empirical relation between M_*/L_i and (g - i) is both tighter and more linear than might be expected from our models and priors.

worth thinking about...

- in the optical there is a degeneracy between age/SFH, dust obscuration, and metallicity.
- but you **can** place strong constraints on M_*/L.
- precisely because M^*/L does not depend strongly on the values for the age, dust, or metallicity, it is not necessary to model these in great detail!
- the degeneracies between dust, age, SFH, and Z **actually help** in making (optical) M_* estimates.

what is NIR good for?



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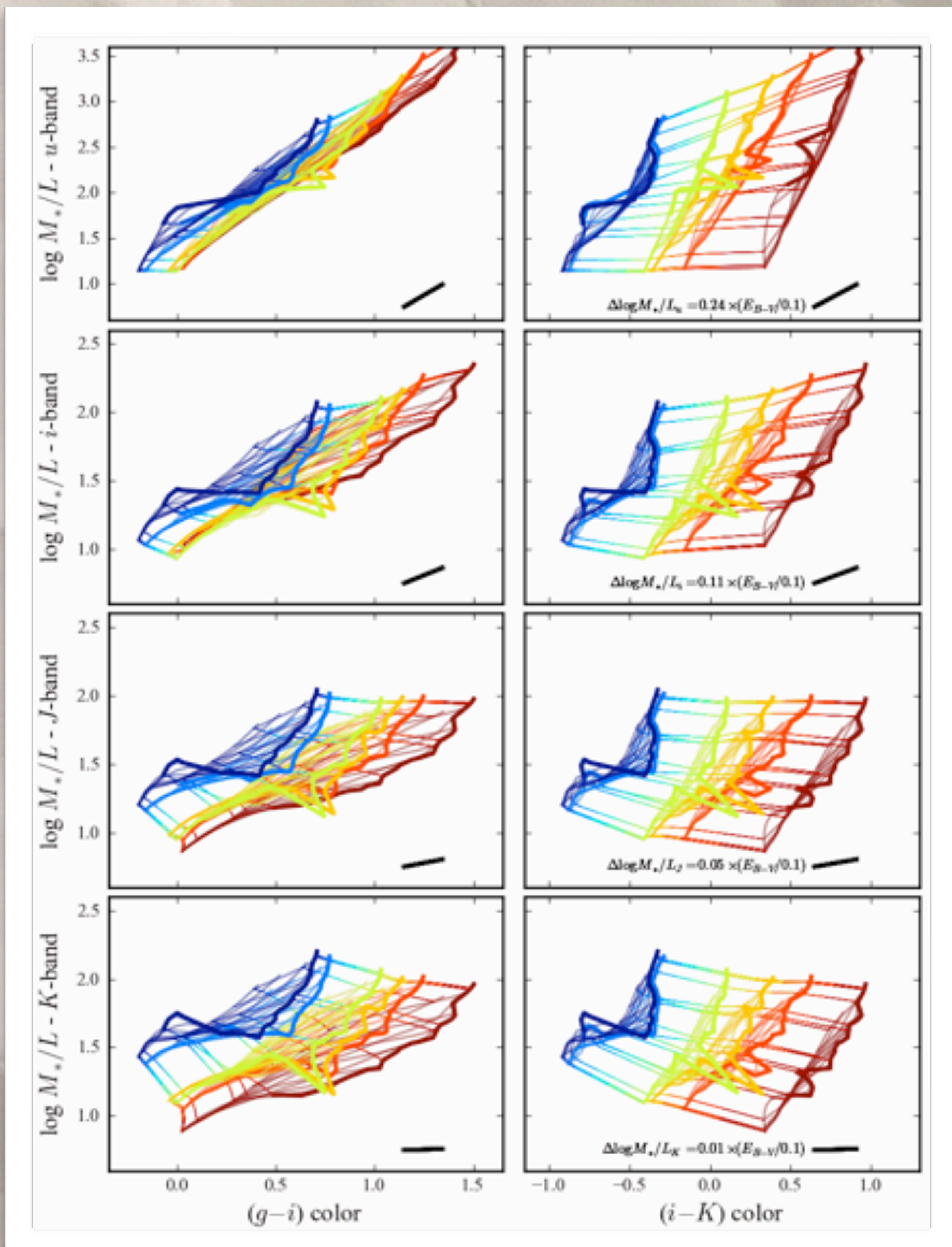
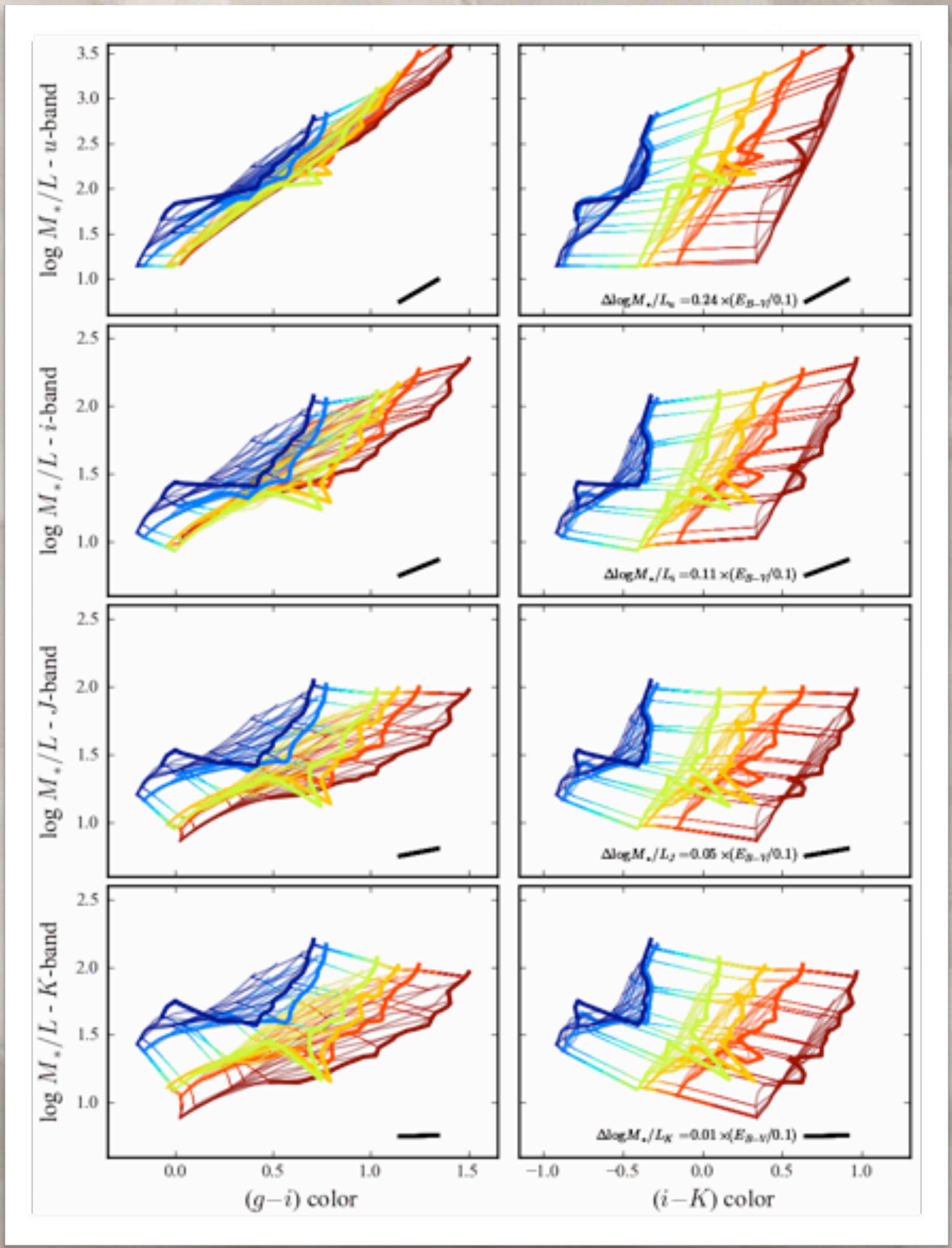


- optical colour is a good indicator of M_*/L_i.
- optical colour is a bad indicator of age, A_v, Z.

what is NIR good for?



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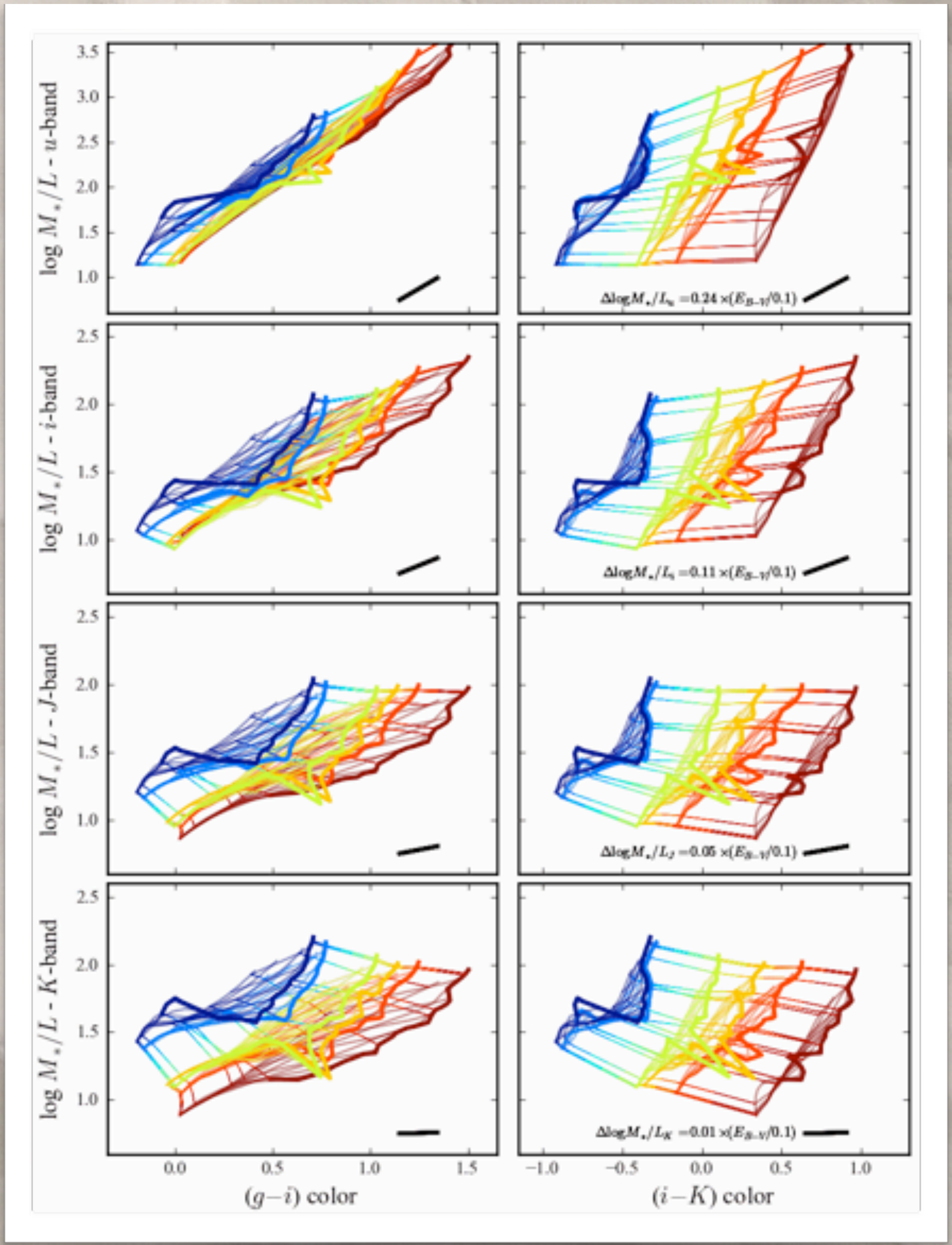
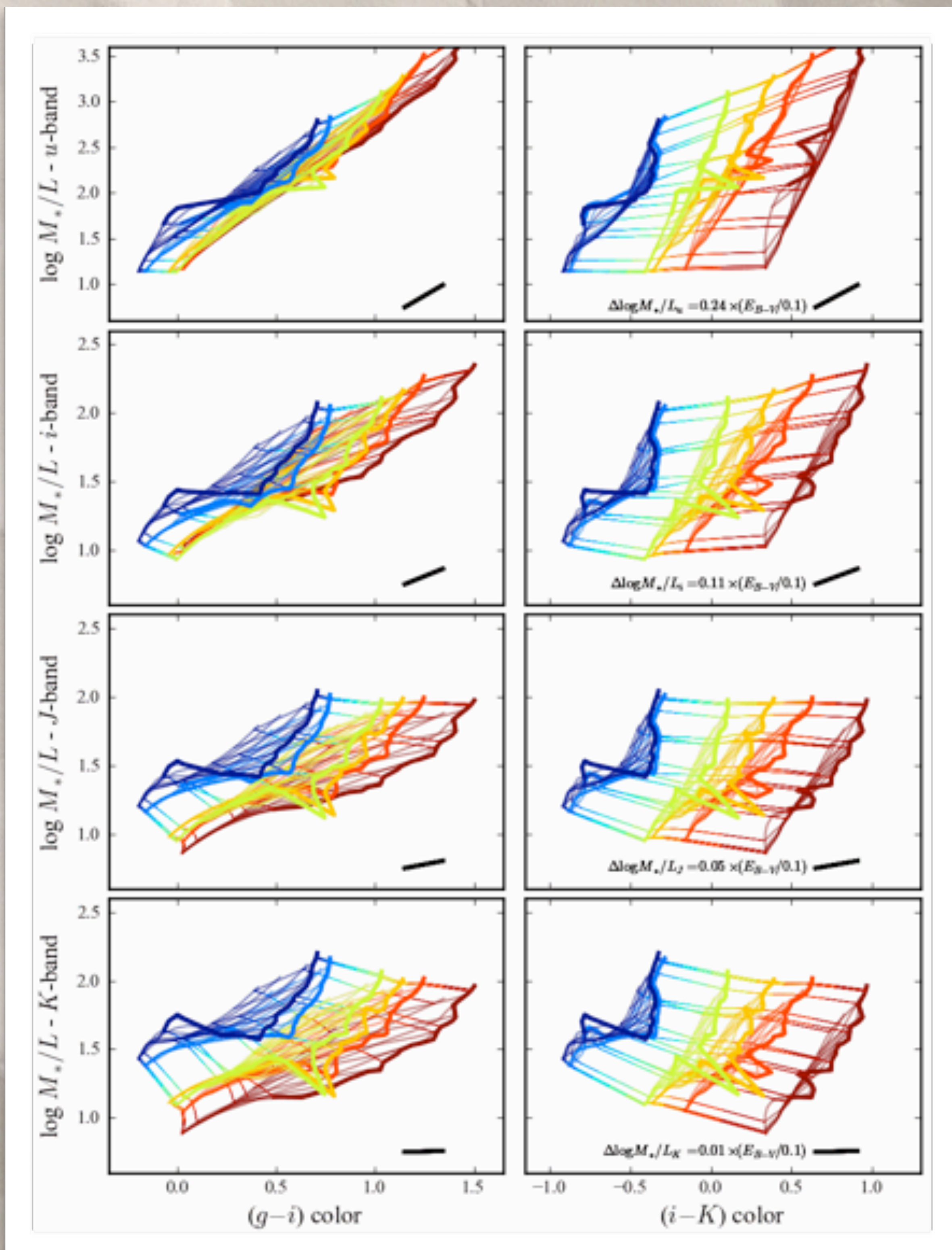


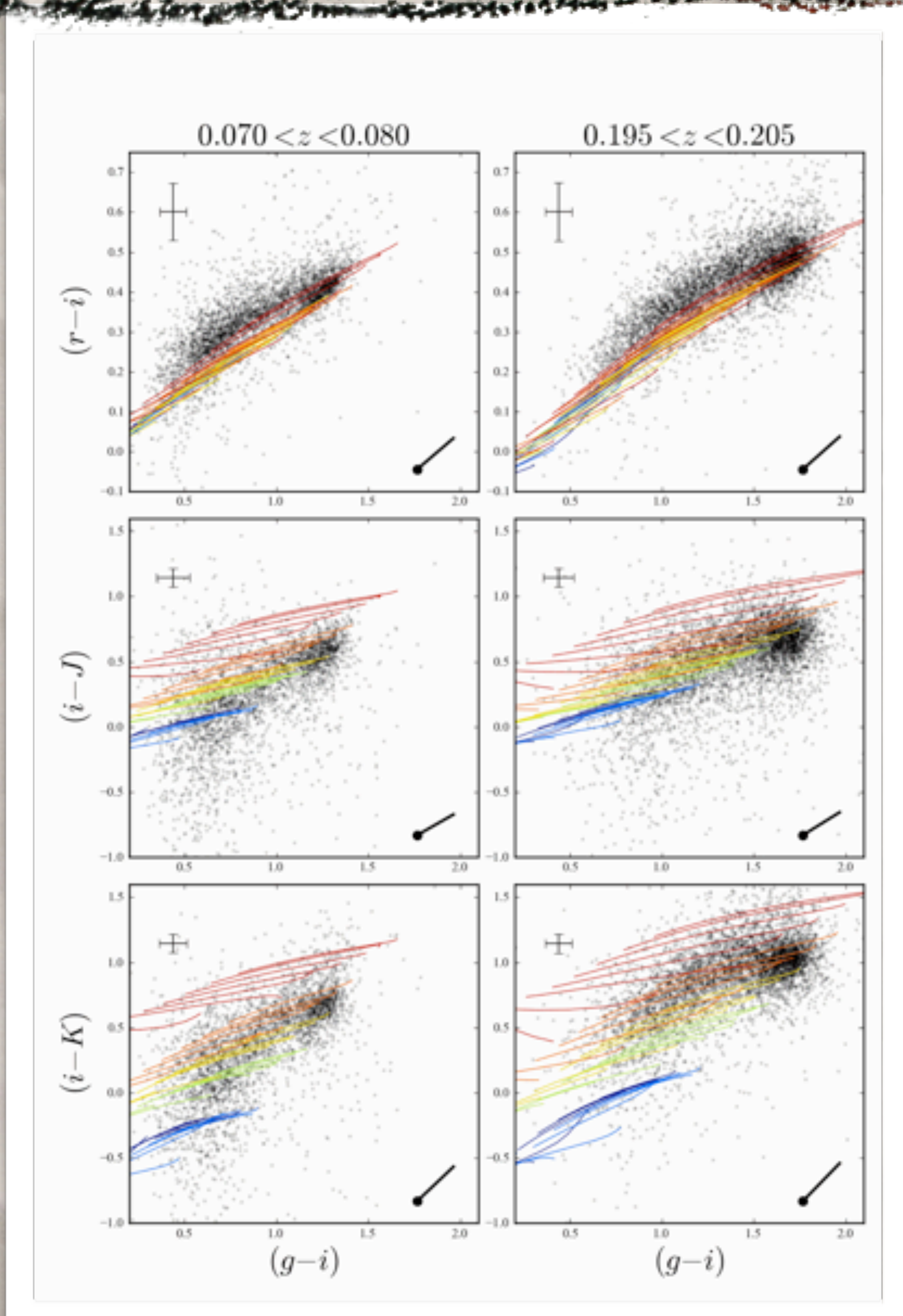
- optical colour is a good indicator of M_*/L_i.
- optical colour is a bad indicator of age, A_v, Z.
- optical–NIR colour is a bad indicator of M_*/L_i.
- optical–NIR colour is a bad indicator of age/SFH.

what is NIR good for?



- optical colour is a good indicator of M_*/L_i.
- optical colour is a bad indicator of age, A_V, Z.
- optical−NIR colour is a bad indicator of M_*/L_i.
- optical−NIR colour is a bad indicator of age/SFH.
- optical−NIR colour is a good indicator of Z/A_V.

what is NIR good for?



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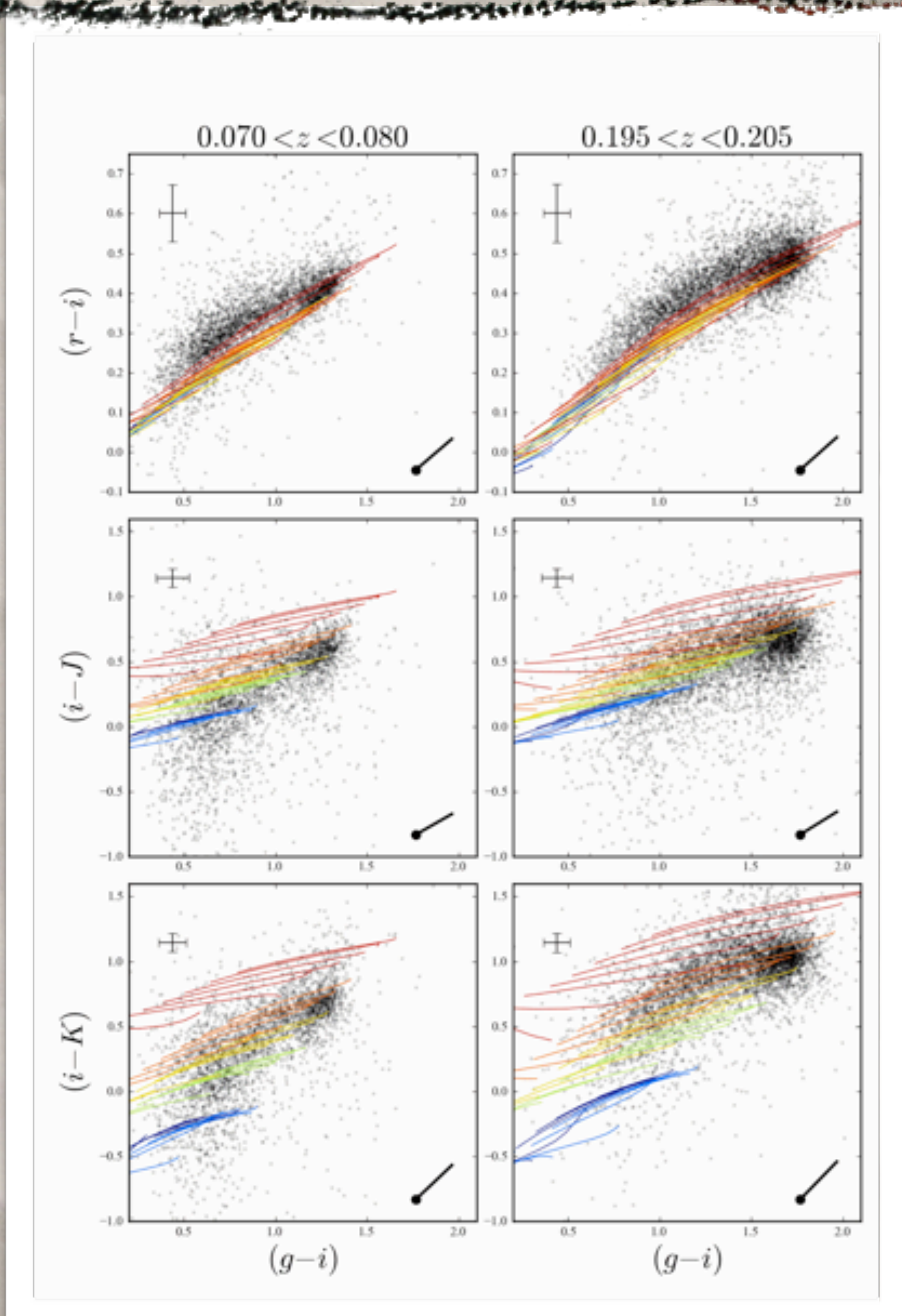
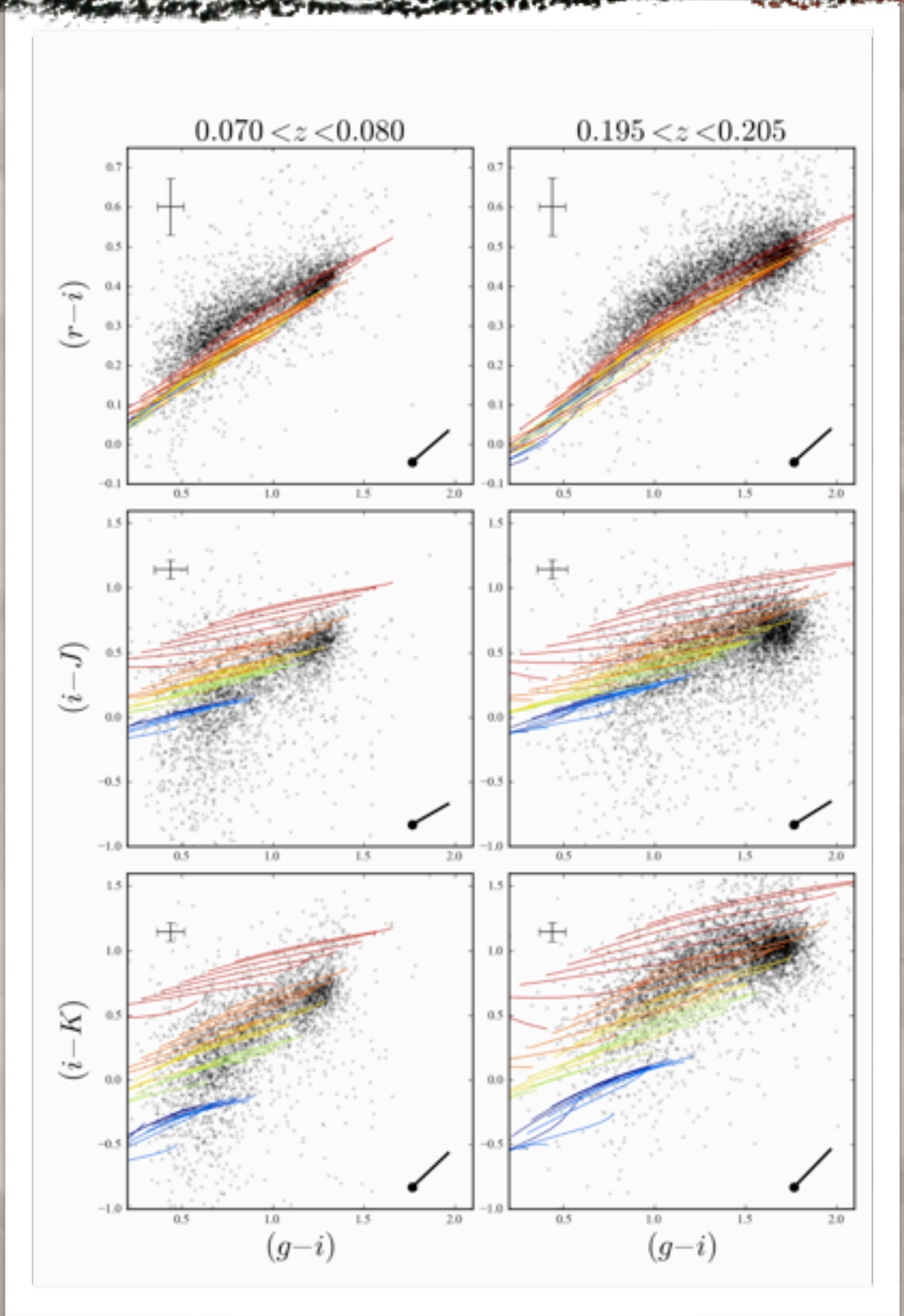


- NIR data breaks the degeneracy between age/SFH and dust/Z.
- This means you have to model these things well!

what is NIR good for?



- NIR data breaks the degeneracy between age/SFH and dust/Z.
- This means you have to model these things well!
- Popular SSP libraries do sample Z−space finely enough to be useful!

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ON THE MASSES OF GALAXIES IN THE LOCAL UNIVERSE

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ABSTRACT

We compare estimates of stellar mass, M_*, and dynamical mass, M_d, for a sample of galaxies from the Sloan Digital Sky Survey. Under the assumption of dynamical homology (i.e.,$\tilde{M}_\mathrm{d} \sim \sigma_0^2 R_\mathrm{e}$, where σ_0 is the central velocity dispersion and R_e is the effective radius), we find a tight but strongly nonlinear relation between the two mass estimates: the best-fit relation is $M_* \propto \tilde{M}_\mathrm{d}^{0.73}$, with an observed scatter of 0.15 dex. We also find that, at fixed M_*, the ratio $M_*/\tilde{M}_\mathrm{d}$ depends strongly on galaxy structure, as parameterized by the Sérsic index, n. The size of the differential effect is on the order of 0.6 dex across $2 < n < 10$. The apparent n-dependence of $M_*/\tilde{M}_\mathrm{d}$ is qualitatively and quantitatively similar to expectations from simple, spherical and isotropic dynamical models, indicating that assuming homology gives the wrong dynamical mass. To explore this possibility, we have also derived dynamical mass estimates that explicitly account for differences in galaxies' structures. Using this "structure-corrected" dynamical mass estimator, $M_{\mathrm{d},n}$, the best-fit relation is $M_* \propto M_{\mathrm{d},n}^{0.92\pm0.01(\pm0.08)}$ with an observed scatter of 0.13 dex. While the data are thus consistent with a linear relation, they do prefer a slightly shallower slope. Further, we see only a small residual trend in $M_*/M_{\mathrm{d},n}$ with n. We find no statistically significant systematic trends in $M_*/M_{\mathrm{d},n}$ as a function of observed quantities (e.g., apparent magnitude, redshift), or as a function of tracers of stellar populations (e.g., Hα equivalent width, mean stellar age), nor do we find significantly different behavior for different kinds of galaxies (i.e.,central versus satellite galaxies, emission versus non-emission galaxies). At 99% confidence, the net differential bias in $M_*/M_{\mathrm{d},n}$ across a wide range of stellar populations and star formation activities is $\lesssim$0.12 dex ($\approx$40%). The very good agreement between stellar mass and structure-corrected dynamical mass strongly suggests, but does not unambiguously prove, that (1) galaxy non-homology has a major impact on dynamical mass estimates, and (2) there are no strong systematic biases in the stellar mass-to-light ratios derived from broadband optical spectral energy distributions. Further, accepting the validity of both our stellar and dynamical mass estimates, these results suggest that the central dark-to-luminous mass ratio has a relatively weak mass dependence, but a very small scatter at fixed mass.

Key words: galaxies: fundamental parameters – galaxies: kinematics and dynamics – galaxies: stellar content – galaxies: structure

Online-only material: color figures

Friday, 19 July 13

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dynamical mass estimation
NOT THE VIRIAL THEOREM!

dynamical mass estimation
NOT THE VIRIAL THEOREM!

$$\mathrm{G}M_{\mathrm{dyn}} \sim \sigma^2 R_e$$

dynamical mass estimation
NOT THE VIRIAL THEOREM!

$$\mathrm{G}M_{\mathrm{dyn}} \sim \sigma^2 R_e$$

$$\mathrm{G}M_{\mathrm{dyn}} = K\,\sigma^2 R_e$$

dynamical mass estimation NOT THE VIRIAL THEOREM!

$$\mathrm{G}M_{\mathrm{dyn}} \sim \sigma^2 R_e$$

$$\mathrm{G}M_{\mathrm{dyn}} = K\, \sigma^2 R_e$$

This factor K encapsulates information about the structure of the galaxy.
IT IS MODEL DEPENDENT.

the relation between stellar and dynamical masses

$$\mathrm{G}M_{\mathrm{dyn}} = K\,\sigma^2\,R_e \qquad M_* = \frac{M_*}{L_i}\,L_i$$

$$\frac{M_*}{M_{\mathrm{dyn}}} = \left(\frac{M_*}{L_i}\,L_i\right) \;/\; \left(\frac{K_n\,\sigma^2\,R_e}{G}\right)$$

the relation between stellar and dynamical masses

$$\frac{M_*}{M_{\rm dyn}} = \left(\frac{M_*}{L_i}\, L_i\right) \Big/ \left(\frac{K_n\, \sigma^2\, R_e}{G}\right)$$

$$\frac{L_i}{\sigma^2 R_e} = \frac{M_*}{M_{\rm dyn}} \Big/ \frac{M_*}{L_i} \times \frac{K_n}{G}$$

the relation between stellar and dynamical masses

$$\frac{L_i}{\sigma^2 R_e} = \frac{M_*}{M_{\rm dyn}} \;/\; \frac{M_*}{L_i} \times \frac{K_n}{G}$$

the relation between stellar and dynamical masses

Direct observables

$$\boxed{\frac{L_i}{\sigma^2 R_e}} = \frac{M_*}{M_{\rm dyn}} \Big/ \frac{M_*}{L_i} \times \frac{K_n}{G}$$

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Direct observables

Genuine astrophysics: a function of mass (?)

$$\log \frac{L_i}{\sigma^2 R_e} = f(M_*) + g(g - i) + h(n)$$

Stellar populations: closely correlated with (g - i) colour

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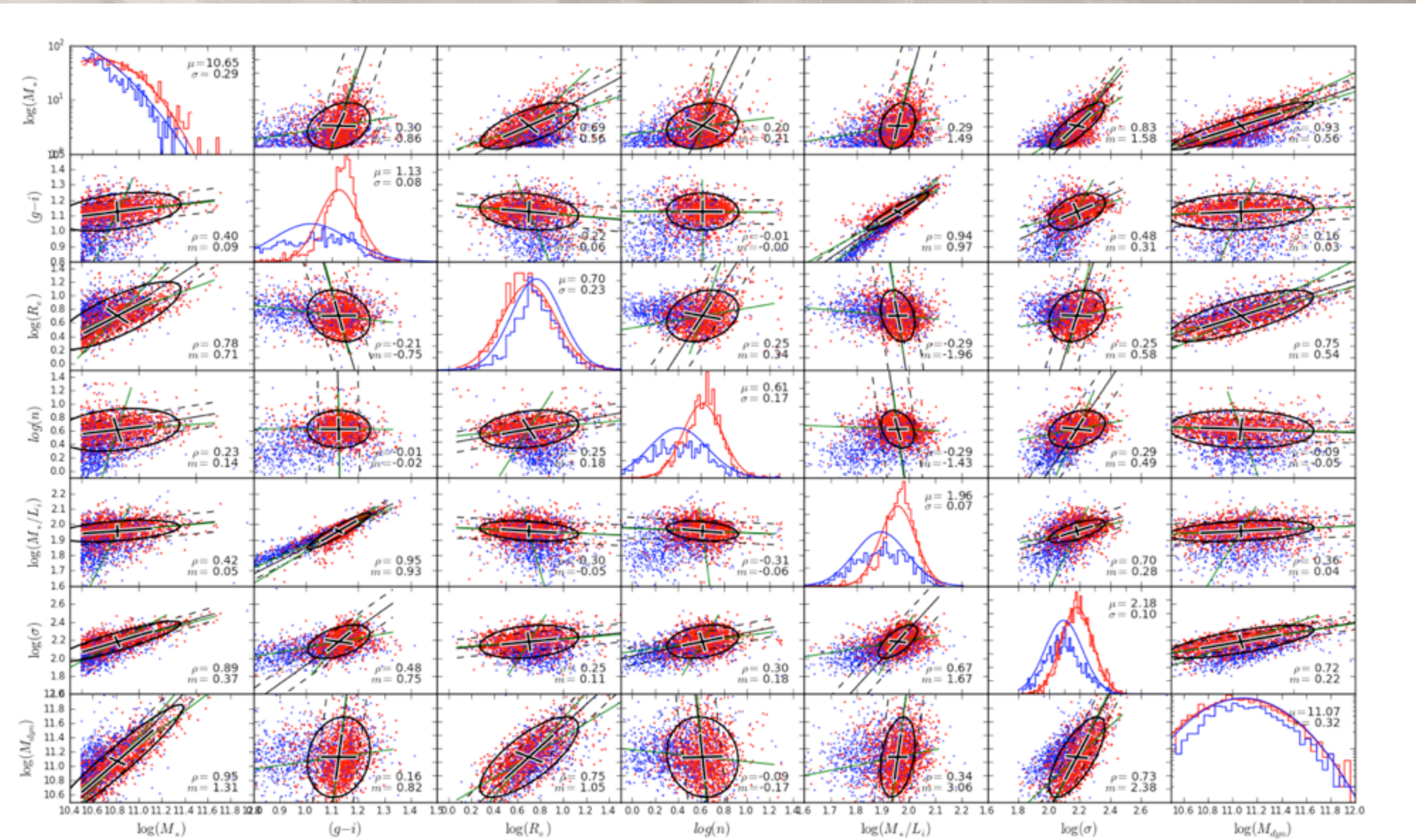
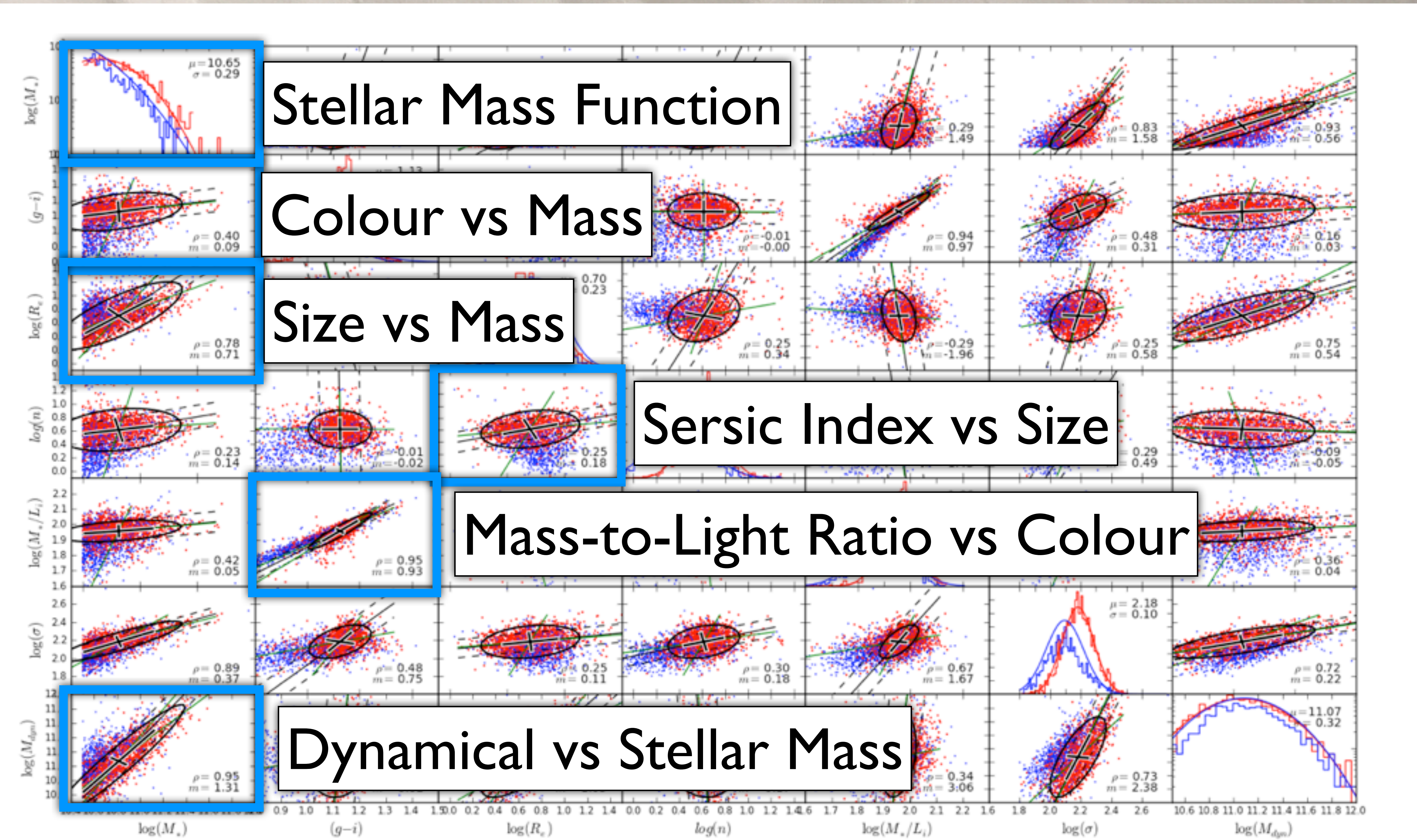
making a mock dataset

making a mock dataset



making a mock dataset



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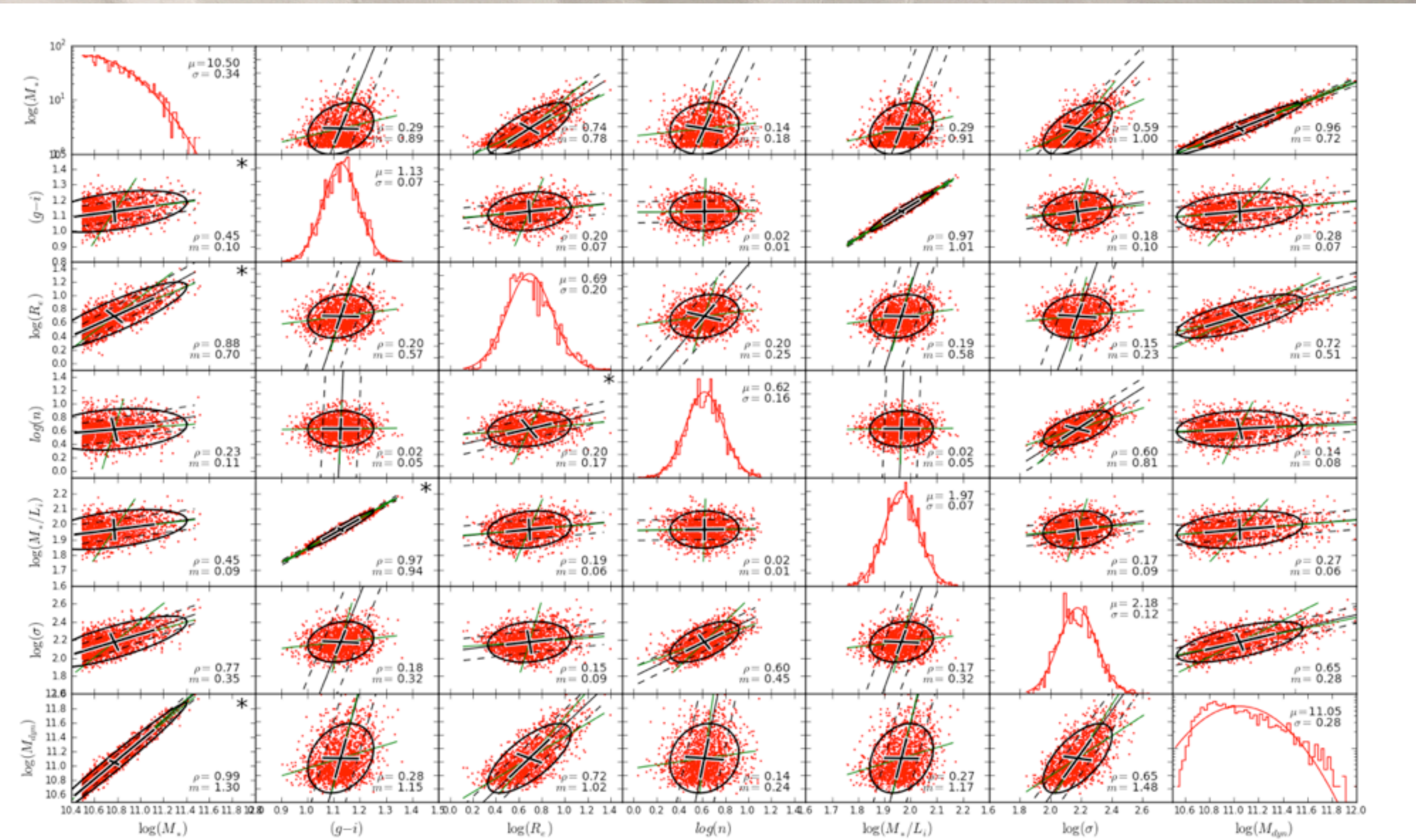

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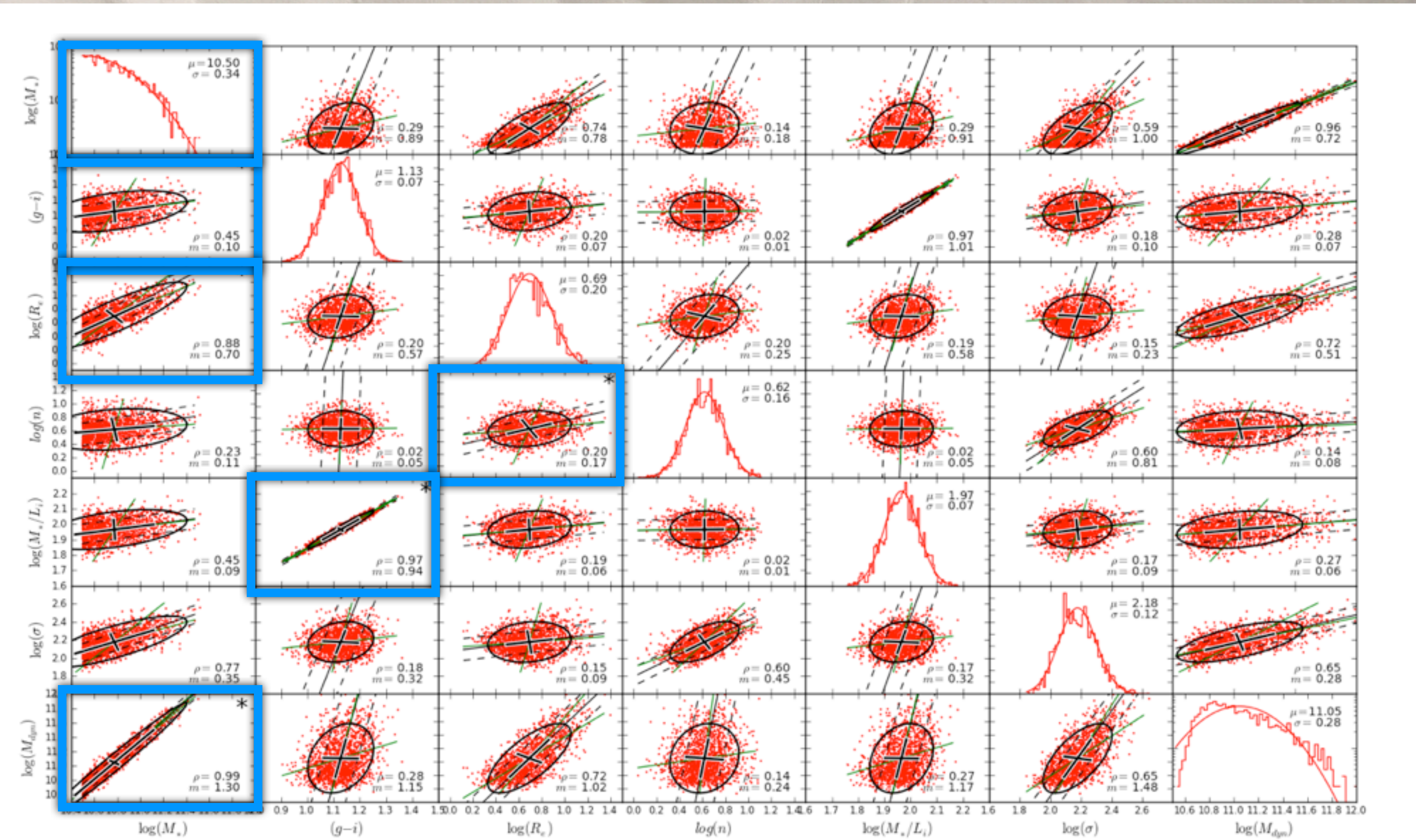

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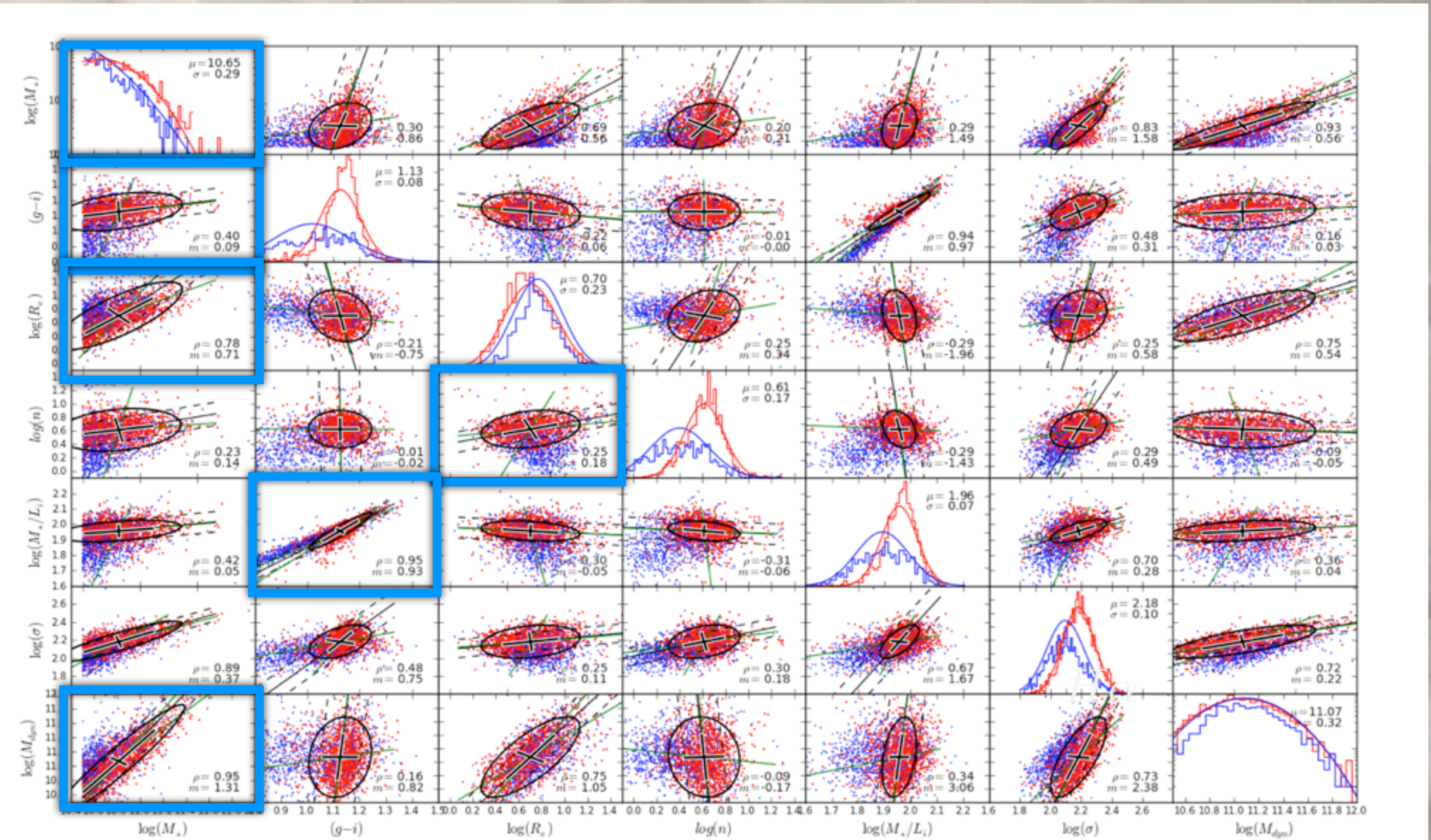

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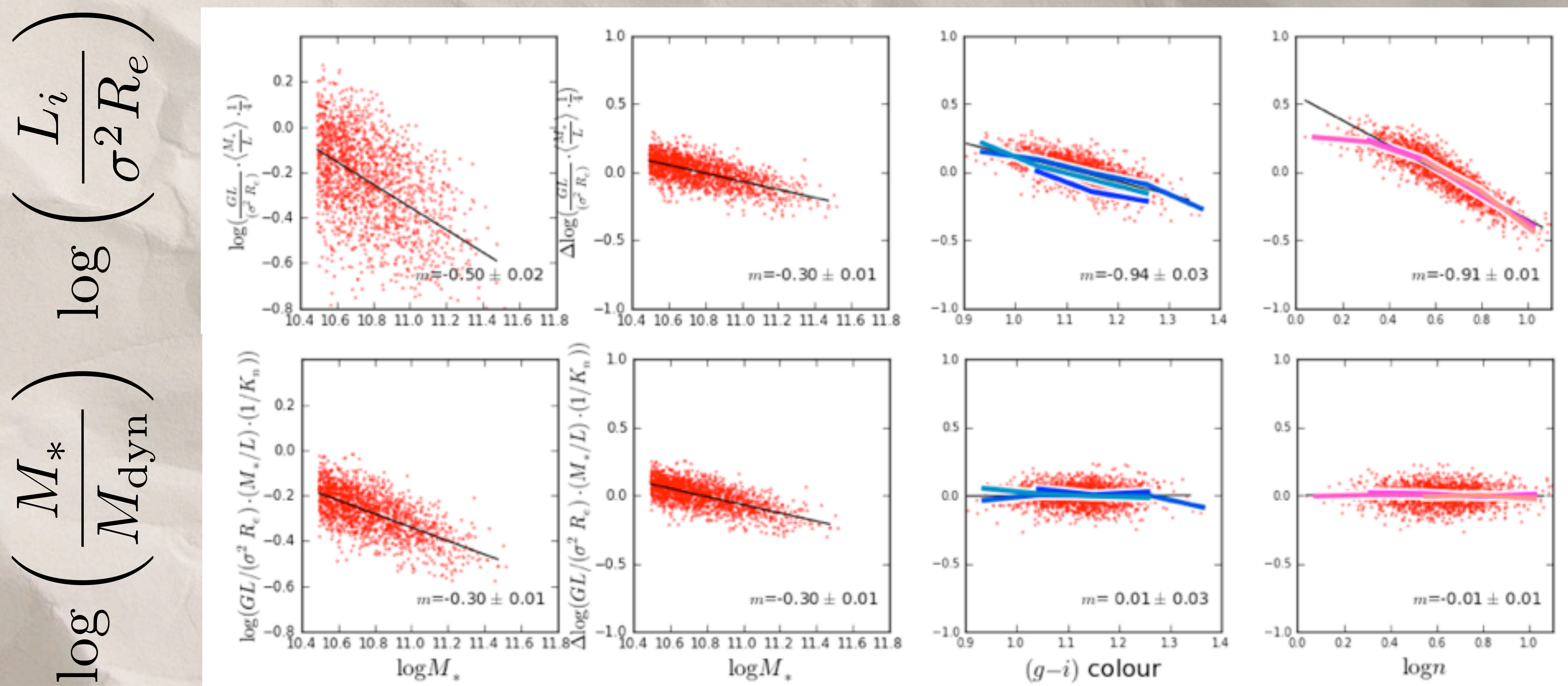
the relation between stellar and dynamical masses

simple 2D fit　　Physics　　Stellar Pop.　　Structure



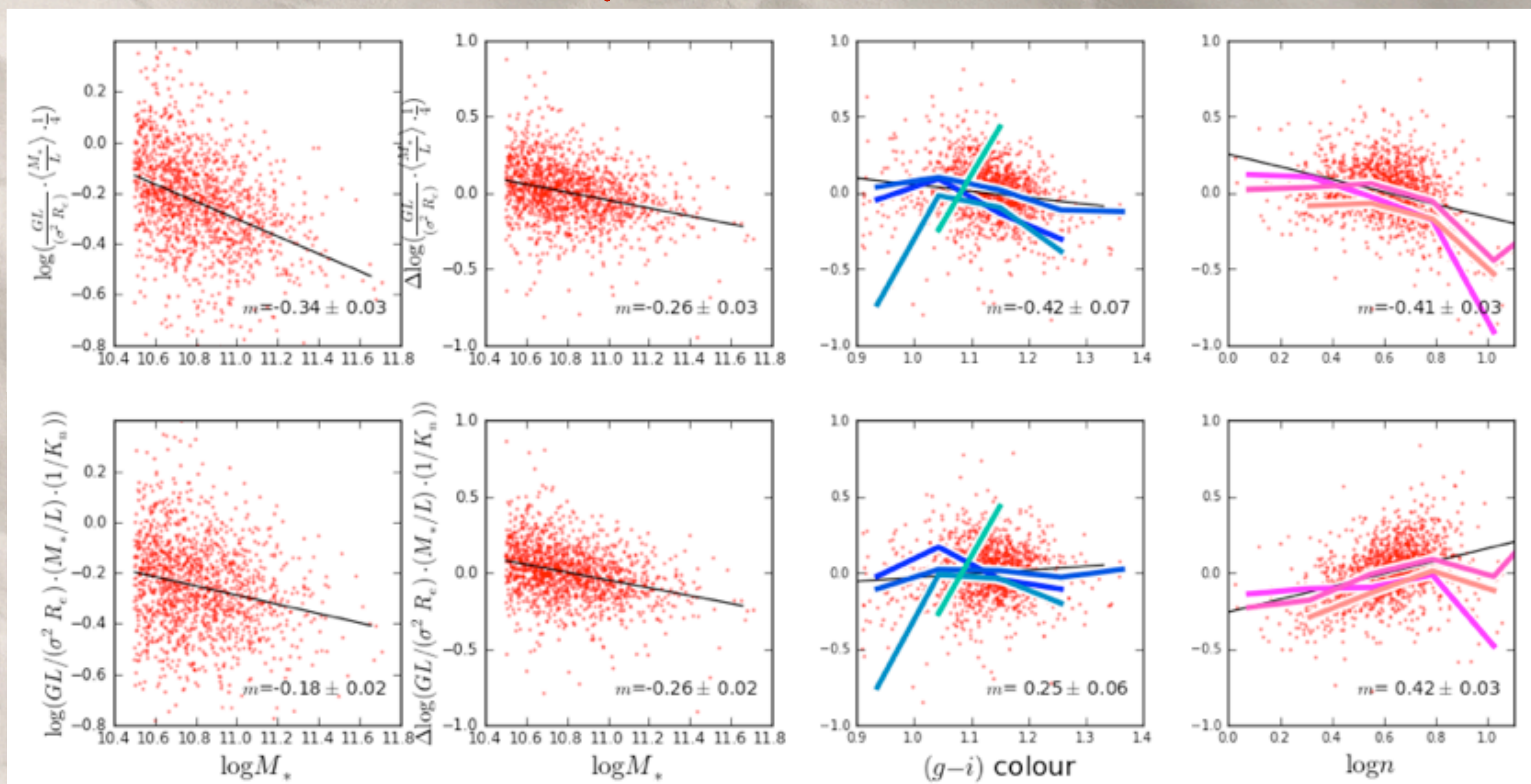
stellar mass　　stellar mass　　rf colour　　Sersic index

the relation between stellar and dynamical masses

simple 2D fit | Physics | Stellar Pop. | Structure

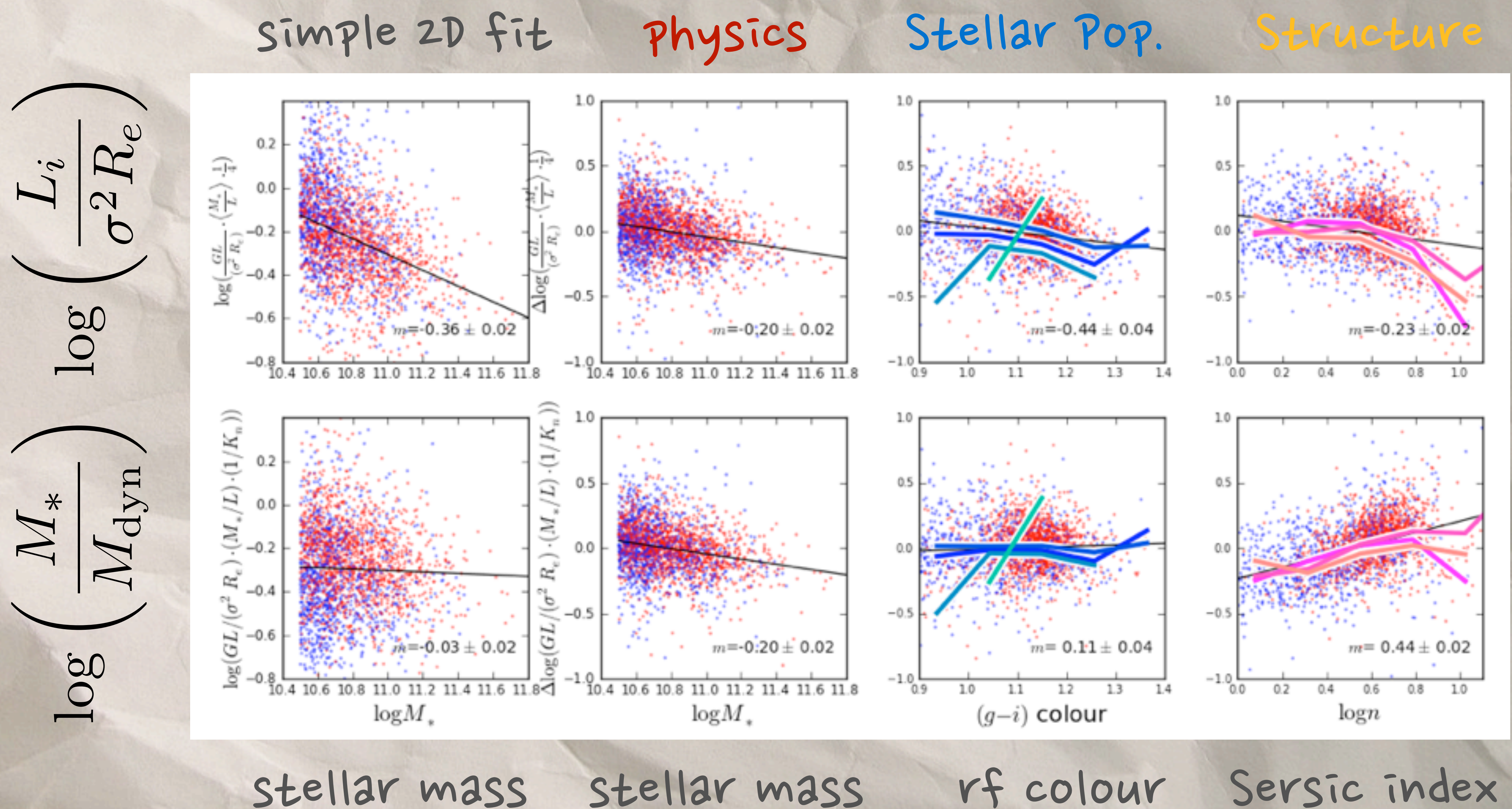
$\log\left(\frac{L_i}{\sigma^2 R_e}\right)$

$\log\left(\frac{M_*}{M_{\rm dyn}}\right)$



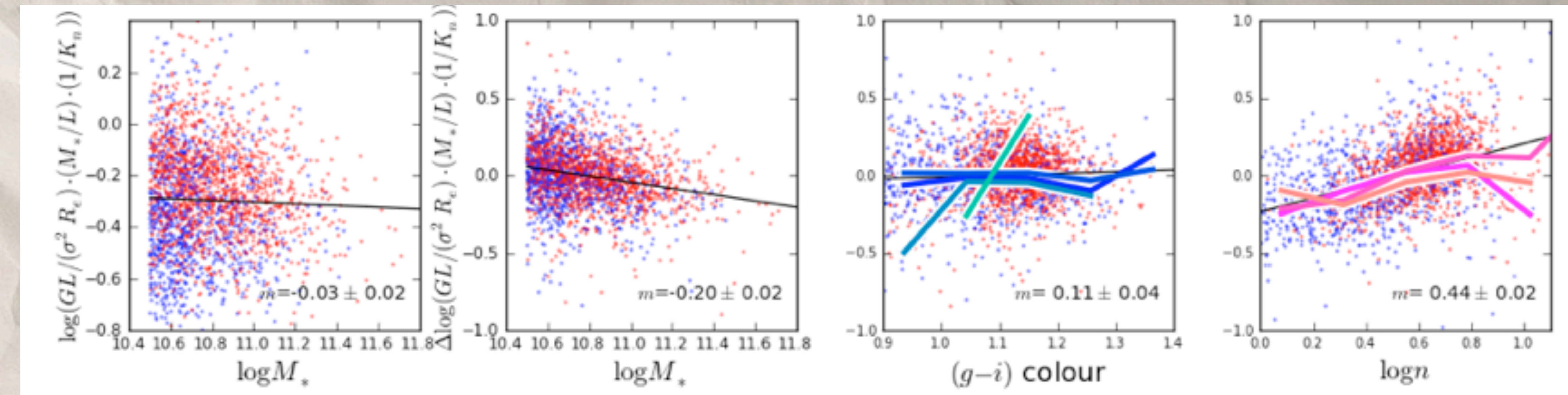
stellar mass | stellar mass | rf colour | Sersic index

the relation between stellar and dynamical masses



Simple 2D fit Physics Stellar Pop. Structure

$$\log\left(\frac{M_*}{M_{\rm dyn}}\right)$$



simple 2D fit Physics Stellar Pop. Structure

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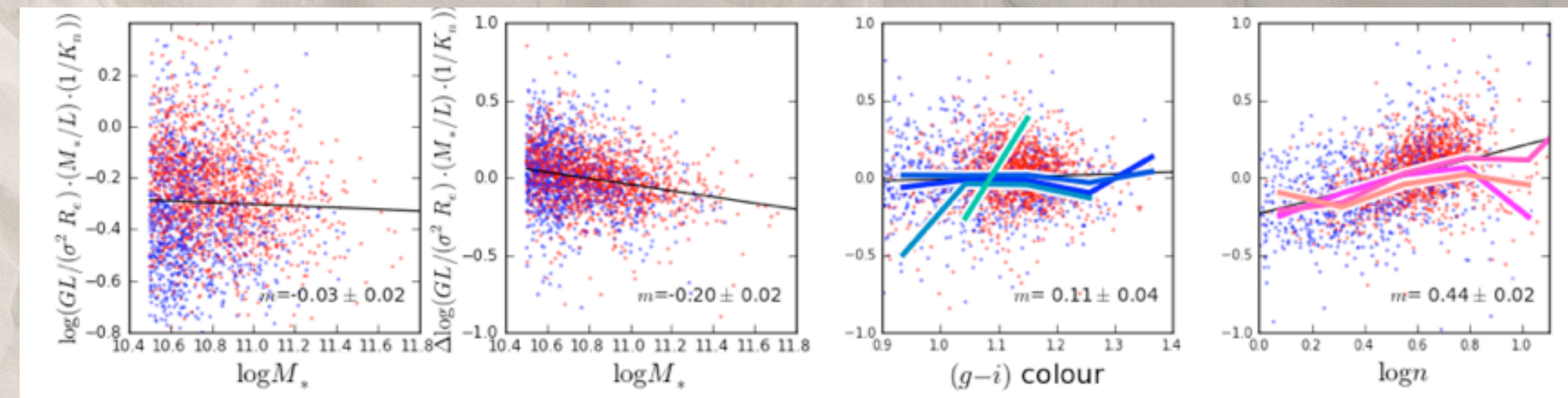
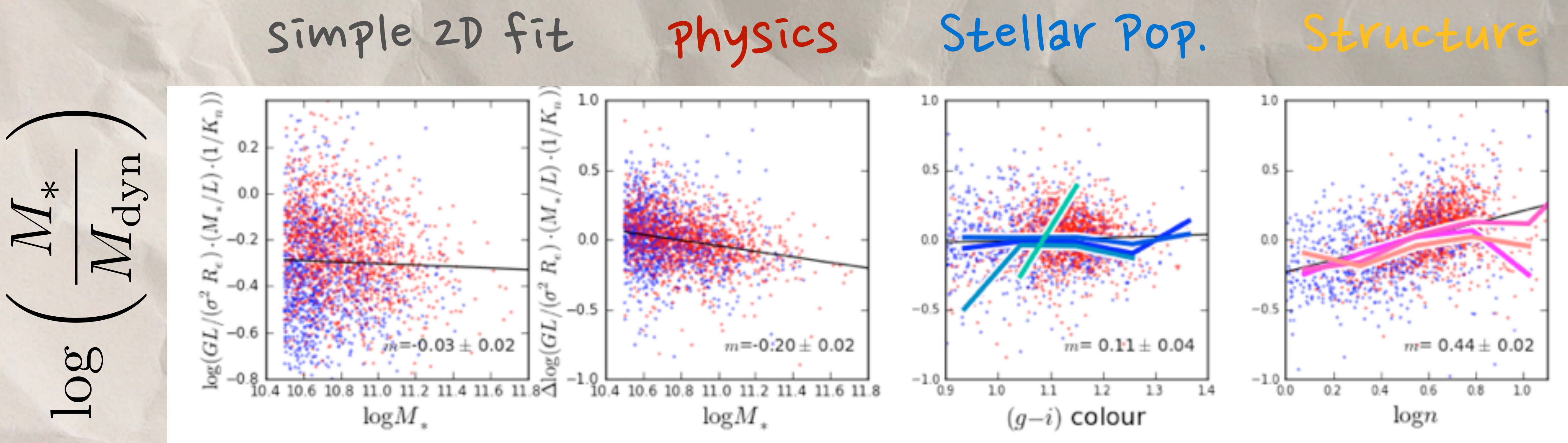


A. If we can assume that $M_*/M_{\rm dyn}$ has no astrophysical trend with *SP*, then the trend with *colour* is due to systematic errors in the values of M_* for galaxies with different stellar pops. At 99%, the bias is < ~**0.1 dex**.



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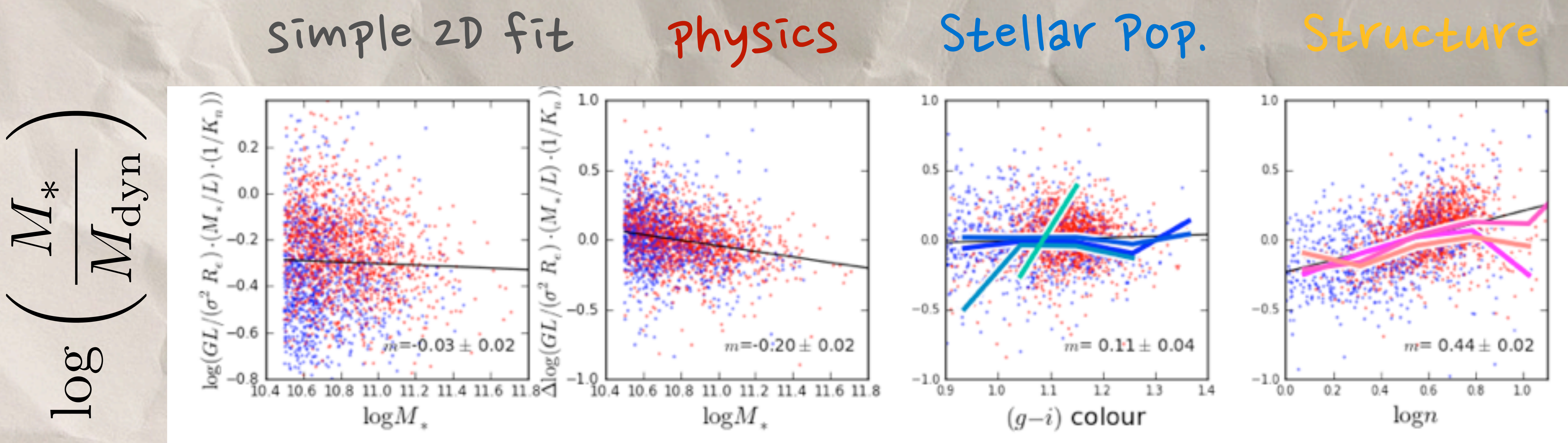
B. If we can assume that our stellar mass estimates are perfectly good, then the trend with colour is 'real', and implies that galaxies with redder stellar populations have slightly higher values of M_*/M_{dyn}.

how good are stellar masses, really?



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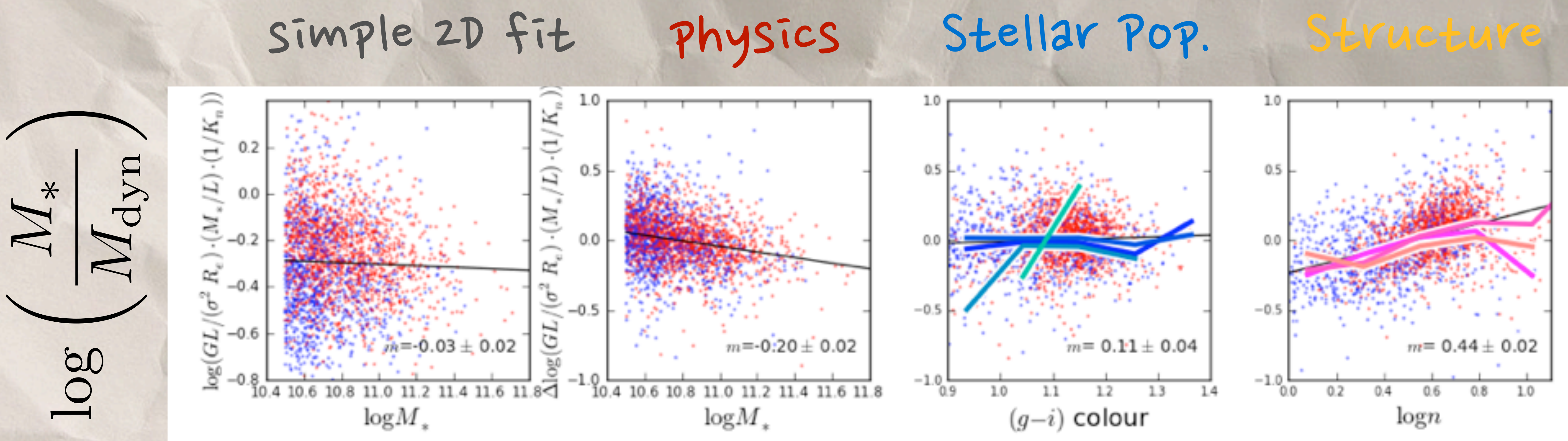
but what about dynamical masses?



A. If we can assume that $M_*/M_{\rm dyn}$ has no astrophysical trend with *structure*, then the trend with Sersic n is due to systematic errors in the values of $M_{\rm dyn}$ for galaxies with different structures. At 99%, the bias is < ~**0.35 dex**.

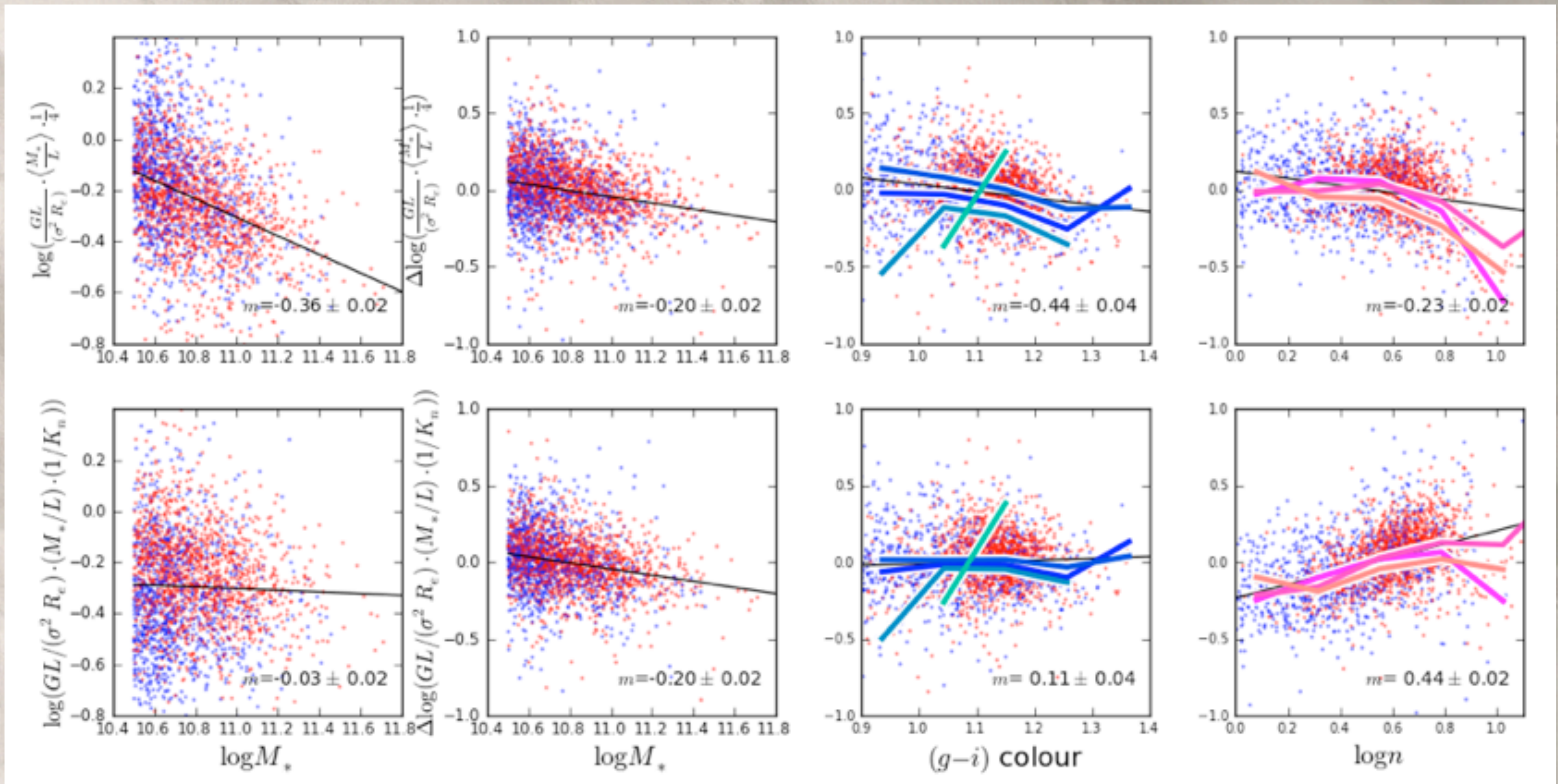
B. If we can assume that our *dynamical* mass estimates are perfectly good, then the trend with structure is 'real', and implies that galaxies with *bulgier structures* have slightly higher values of $M_*/M_{\rm dyn}$.

the fundamental plane; aka. the M_*/M_{dyn} relation

simple 2D fit | Physics | Stellar Pop. | Structure

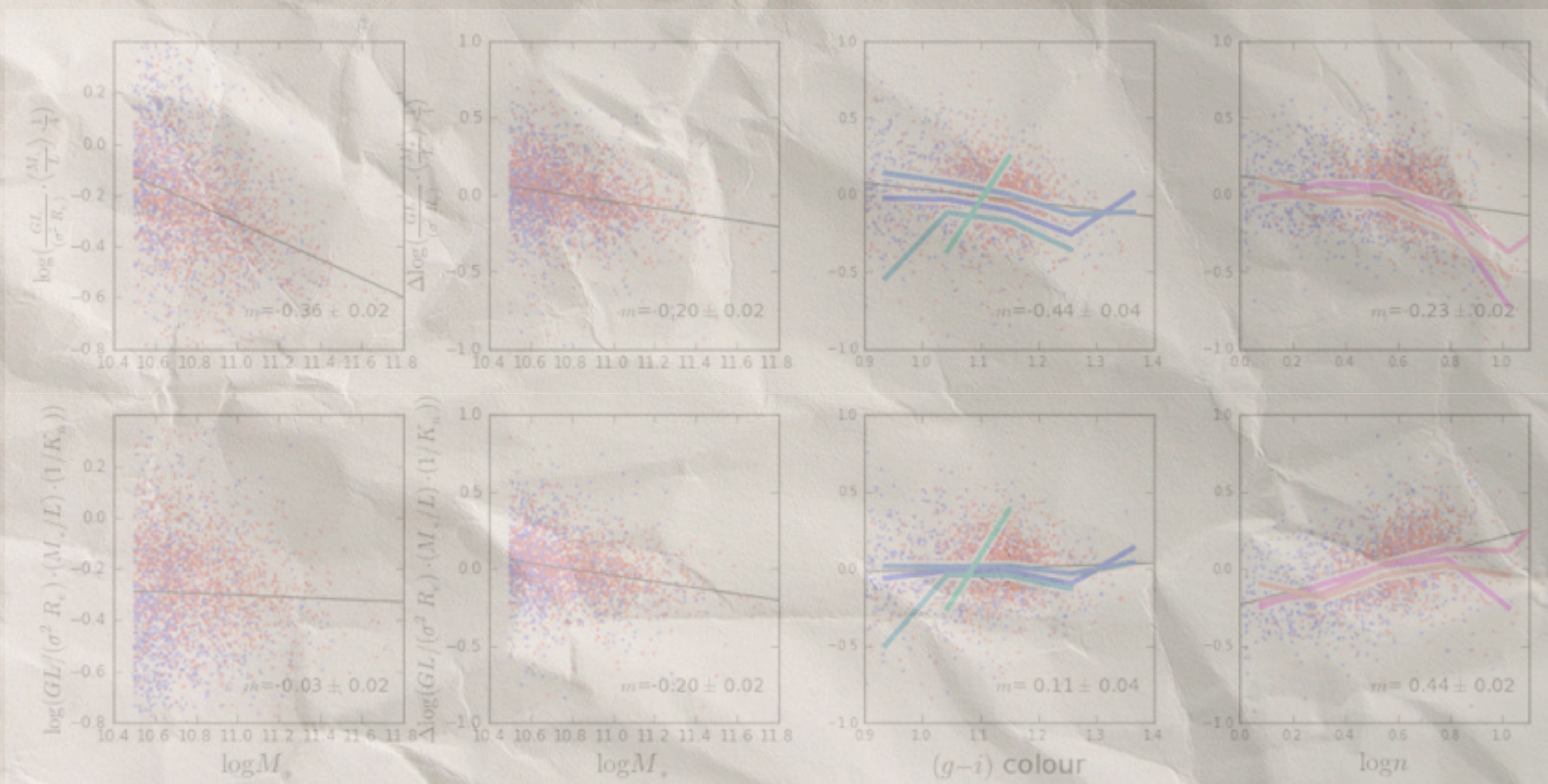
$\log\left(\frac{L_i}{\sigma^2 R_e}\right)$

$\log\left(\frac{M_*}{M_{\rm dyn}}\right)$



stellar mass | stellar mass | rf colour | Sersic index

the fundamental plane; aka. the M_*/M_{dyn} relation



the fundamental plane; aka. the M*/M$_{dyn}$ relation

simple 2D fit | Physics | Stellar Pop. | Structure

$\log\left(\frac{L_i}{\sigma^2 R_e}\right)$

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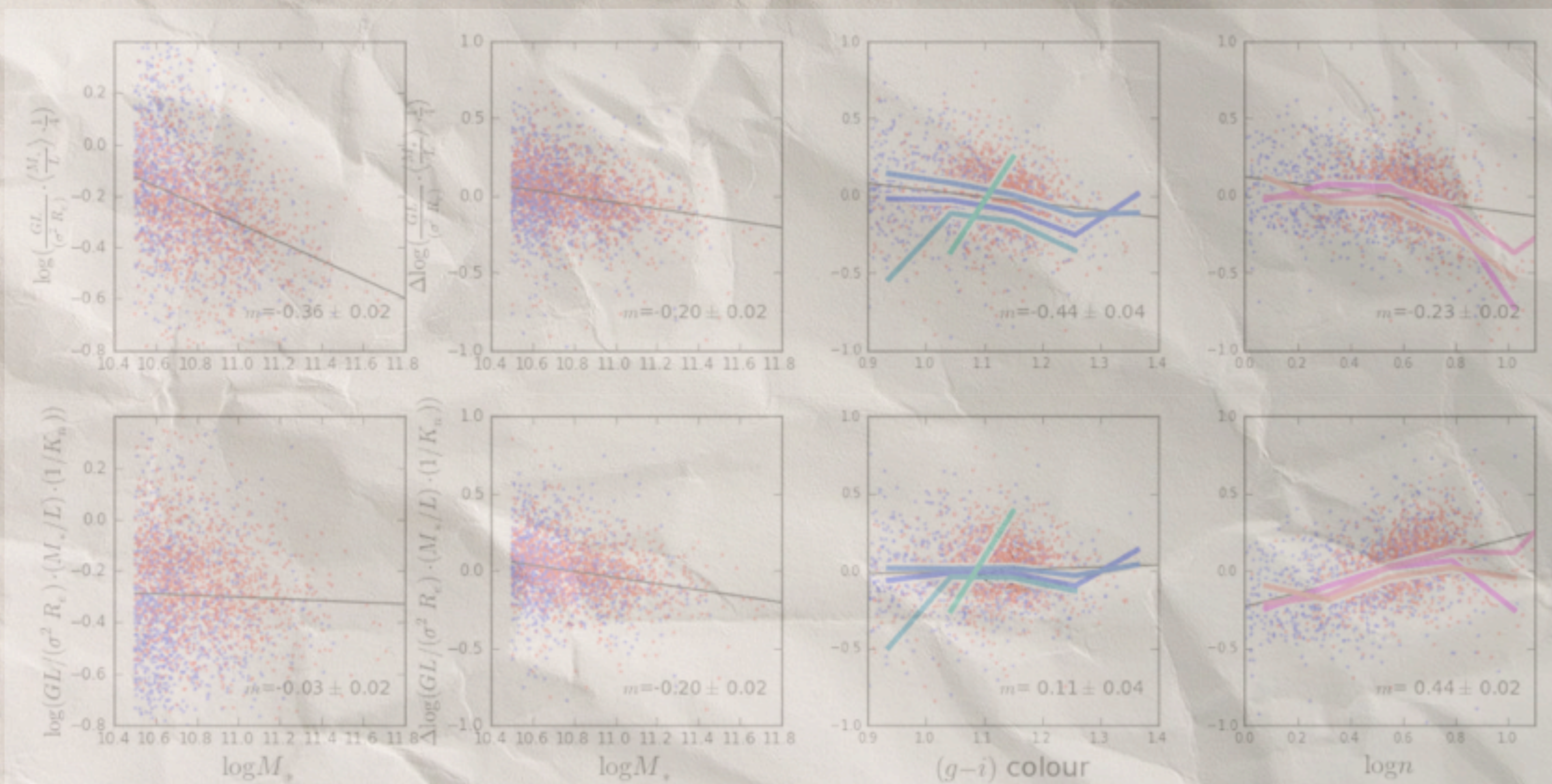
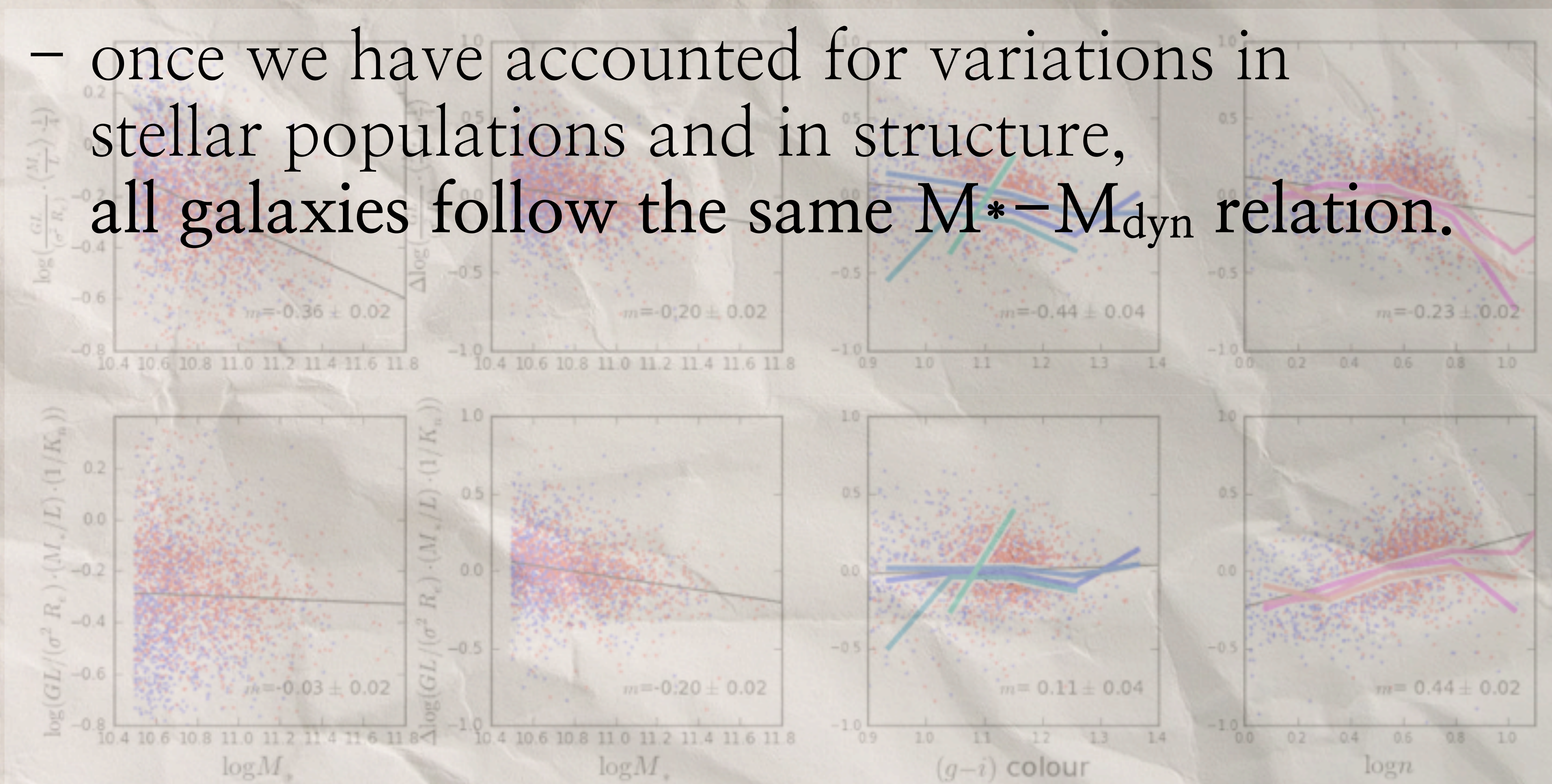


stellar mass | stellar mass | rf colour | Sersic index

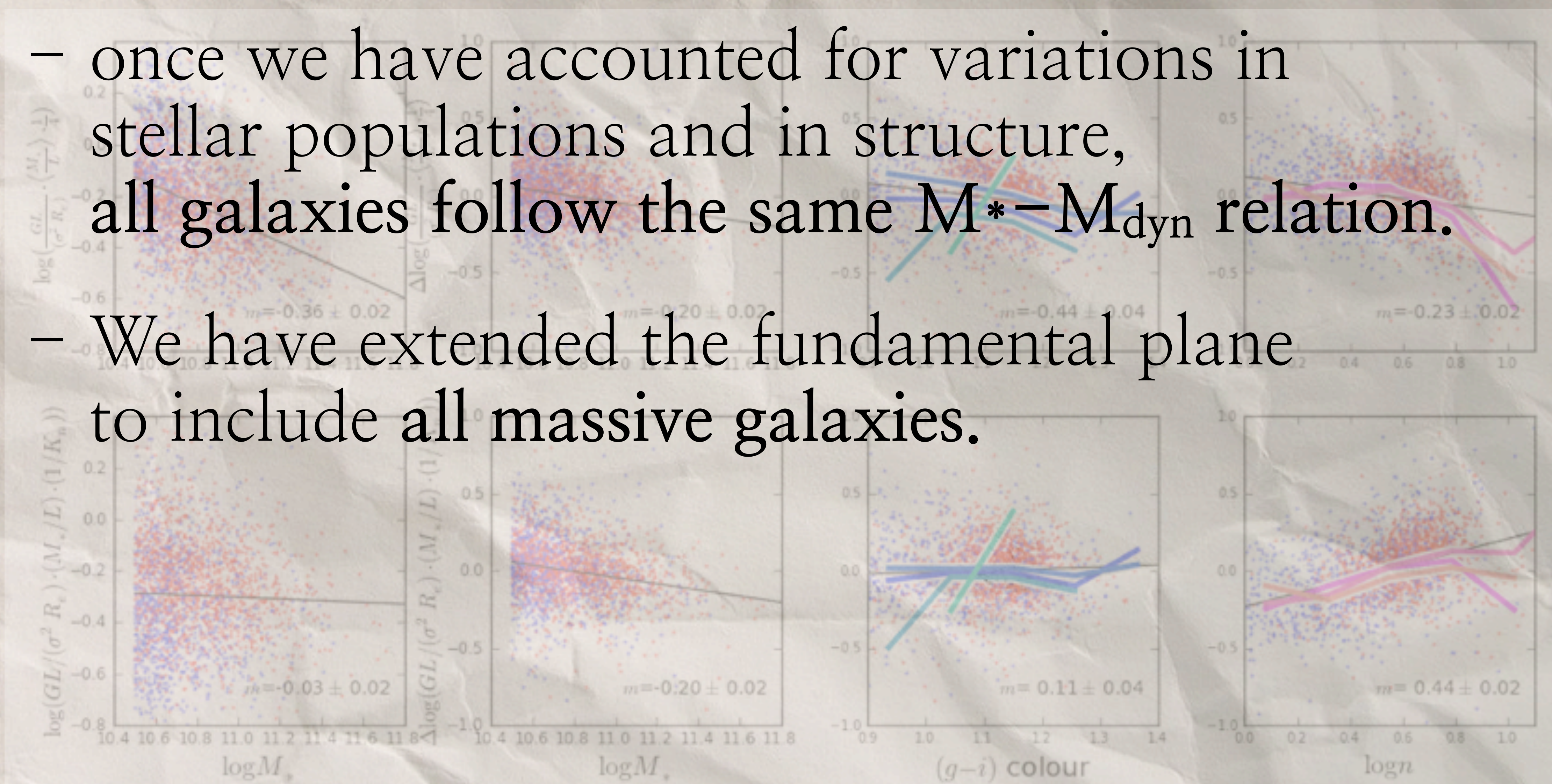
the fundamental plane; aka. the M_*/M_{dyn} relation

- once we have accounted for variations in stellar populations and in structure, all galaxies follow the same M_*-M_{dyn} relation.

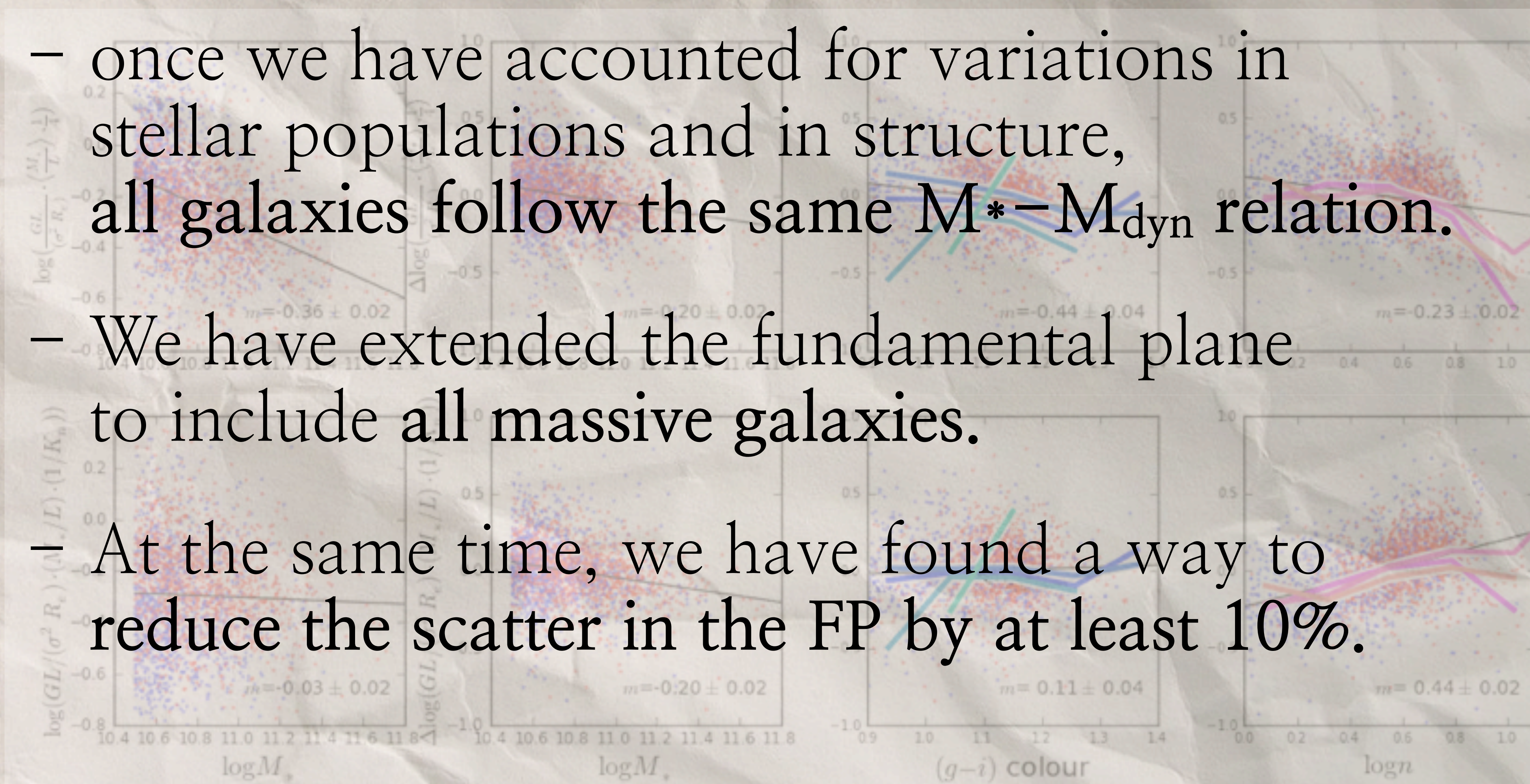


the fundamental plane; aka. the M_*/M_{dyn} relation

- once we have accounted for variations in stellar populations and in structure, **all galaxies follow the same M_*-M_{dyn} relation.**
- We have extended the fundamental plane to include **all massive galaxies.**

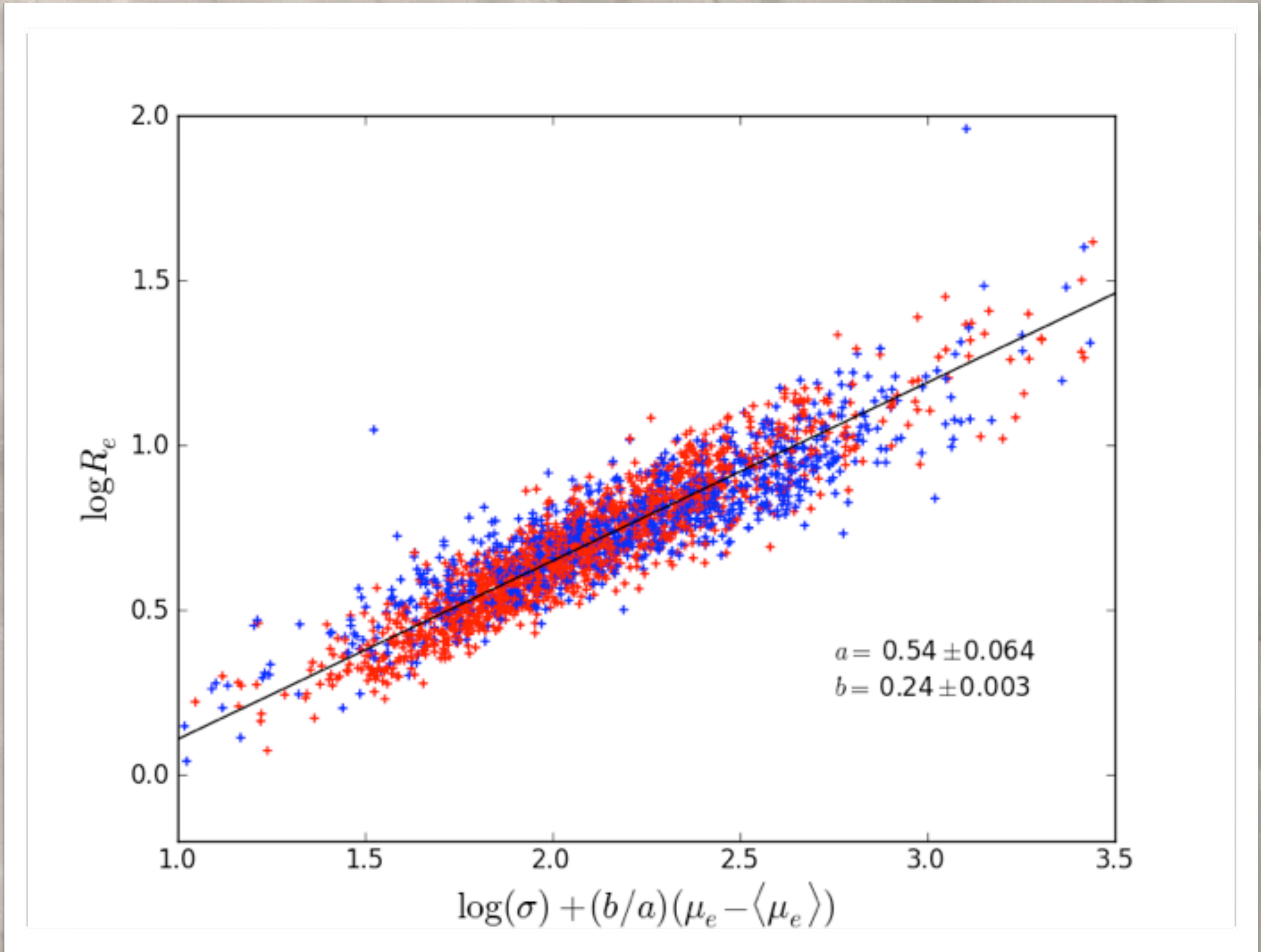


the fundamental plane; aka. the M_*/M_{dyn} relation



- once we have accounted for variations in stellar populations and in structure, **all galaxies follow the same M_*-M_{dyn} relation.**
- We have extended the fundamental plane to include **all massive galaxies.**
- At the same time, we have found a way to **reduce the scatter in the FP by at least 10%.**

the fundamental plane; aka. the M_*/M_{dyn} relation



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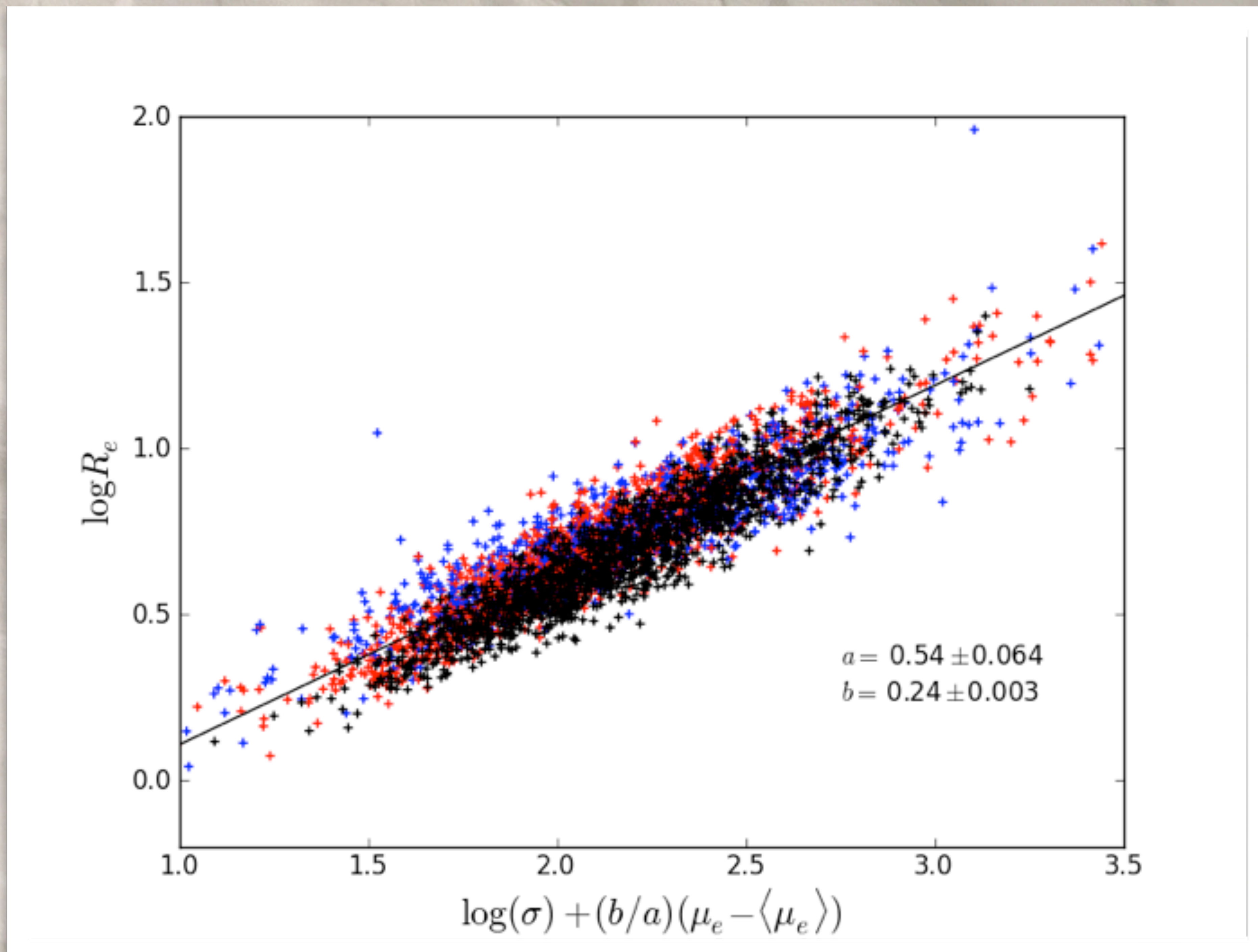

testing the consistency between stellar and dynamic mass estimates for nearby massive galaxies

testing the consistency between stellar and dynamic mass estimates for nearby massive galaxies

- stellar masses are easy.

testing the consistency between stellar and dynamic mass estimates for nearby massive galaxies

- stellar masses are easy.
- dust, metallicities and SFHs are hard.

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- stellar masses are easy.
- dust, metallicities and SFHs are hard.
- but stellar masses are still easy!

testing the consistency between stellar and dynamic mass estimates for nearby massive galaxies

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- dust, metallicities and SFHs are hard.
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- dynamical masses are hard.

testing the consistency between stellar and dynamic mass estimates for nearby massive galaxies

- stellar masses are easy.
- dust, metallicities and SFHs are hard.
- but stellar masses are still easy!
- dynamical masses are hard.
- talk to me about the fundamental plane.