The Stability of Galaxy Disks

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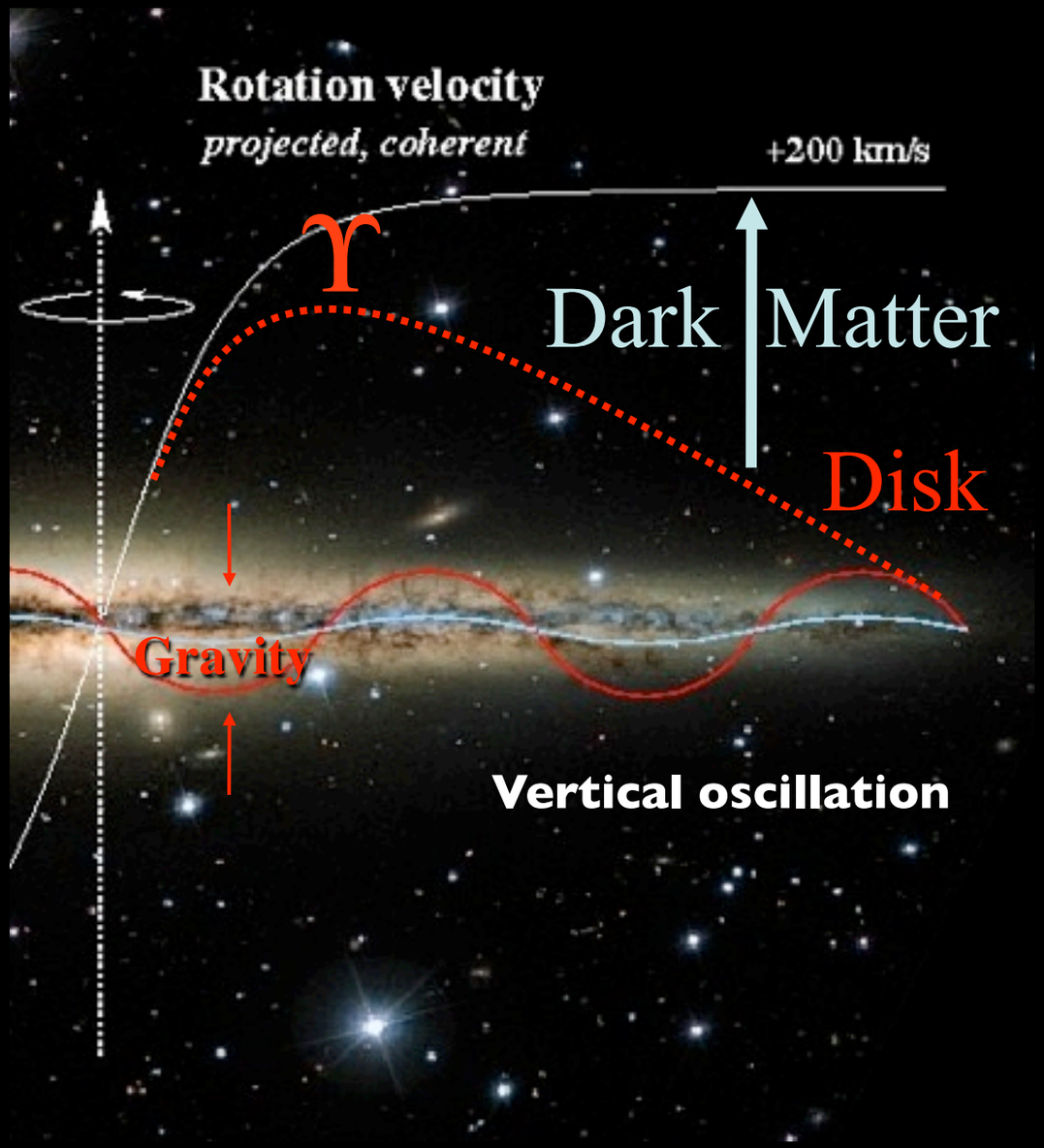
The DiskMass Survey In Brief



The DiskMass Survey is a focused study of face-on galaxies with the primary aim of understanding the dark and luminous mass distribution in disk-dominated systems.

- Vertical oscillations dynamically isolate the disk contribution via:

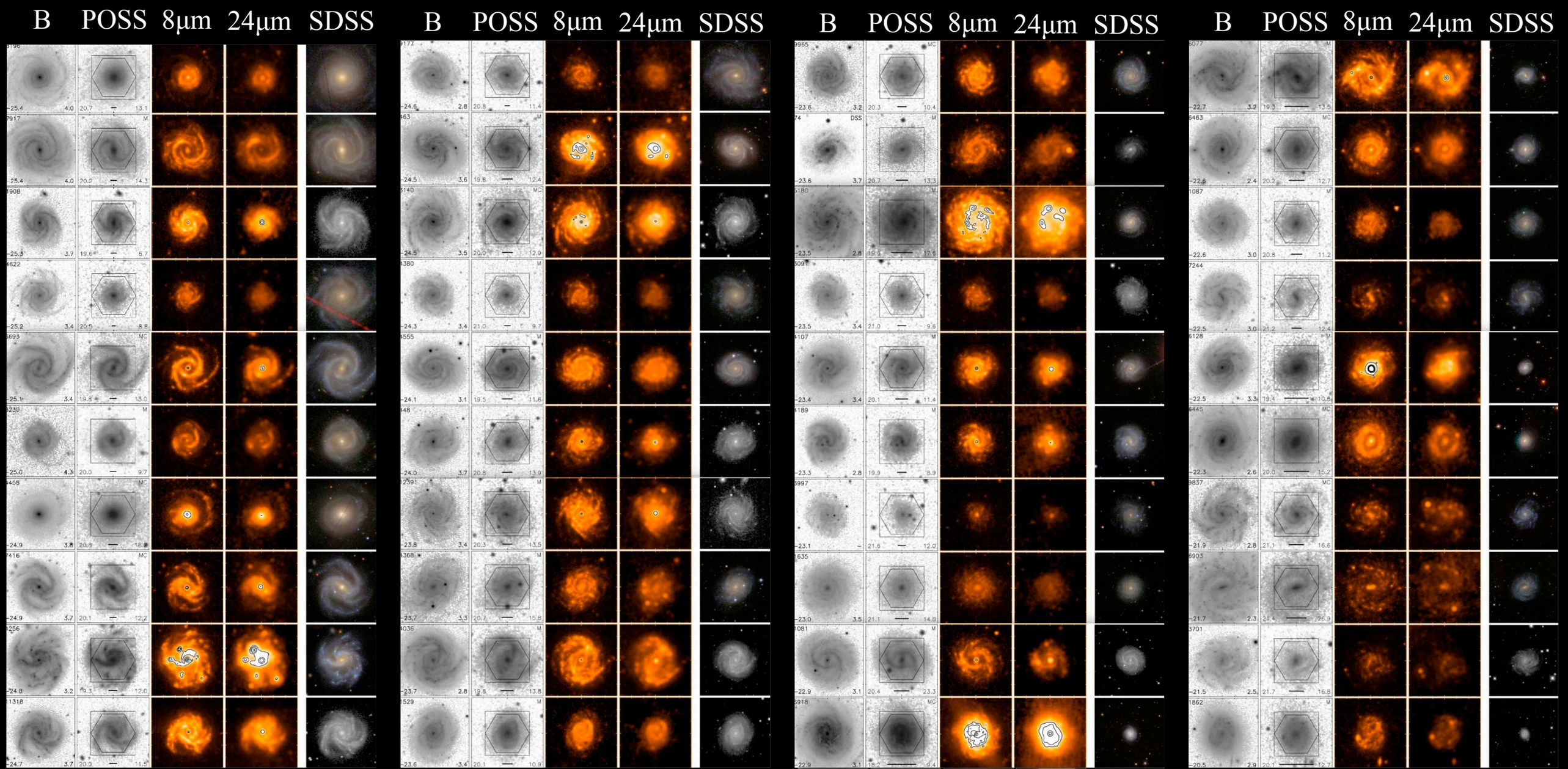
$$\Sigma_{dyn} = \sigma_z^2 / \pi\, G\, k\, h_z$$

$$\Upsilon_{dyn} = \Sigma_{dyn} / \mu$$

- σ_z is the vertical velocity dispersion
- k is a constant describing the vertical density distribution (exp, sech, $sech^2$)
- h_z is the scale height

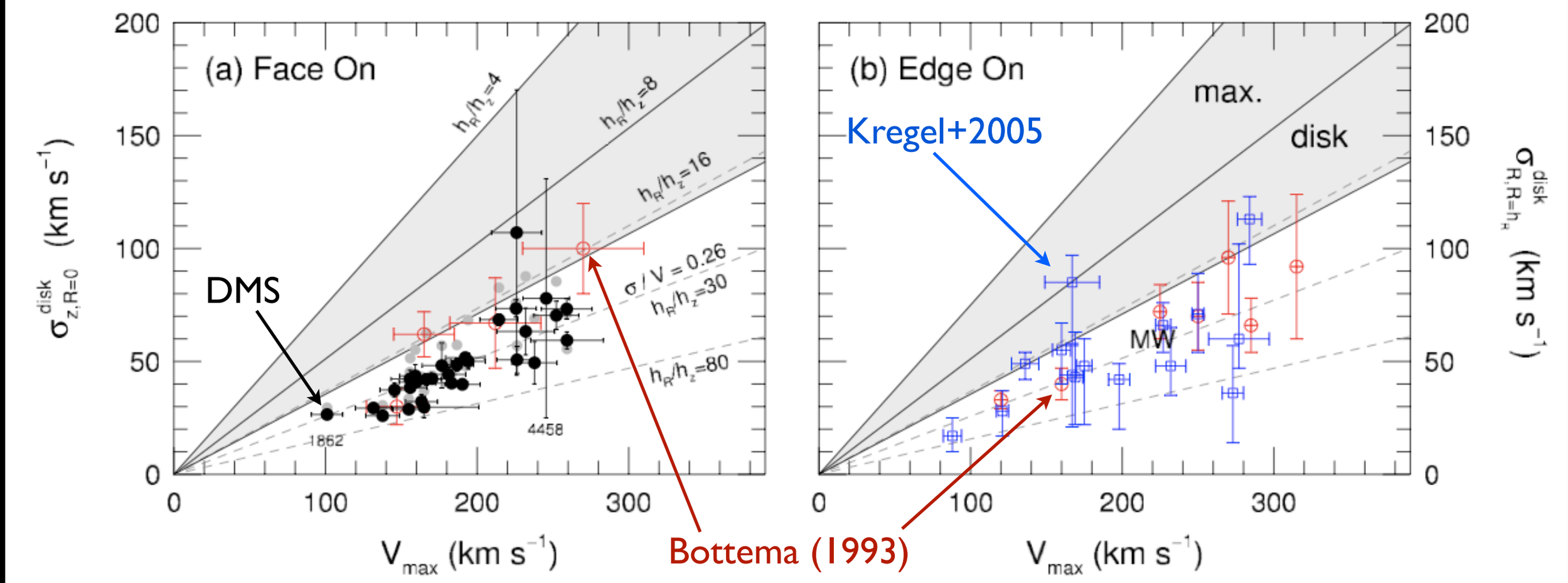
The DiskMass Survey In Brief

- 40 late-type spirals
  - primarily Sb-Sc type
  - $-21.5 > M_K > -26.0$
  - $2.0 < B-K < 4.2$
  - $21.8 > \mu_{R,0} > 18.6$ (Freeman ~ 20.7)
- Extensive Data Set
  - SPK+PPK IFU Spectroscopy
    - Stellar (MgI, CaII) + Ionized Gas (OIII, Hα) kinematics
  - HI Radio synthesis imaging
  - UBVRIJHK + Spitzer (I2, I4, M1, M2) photometry



DiskMass Survey Results

- Galaxy disks are submaximal (Bershady+ 2011)



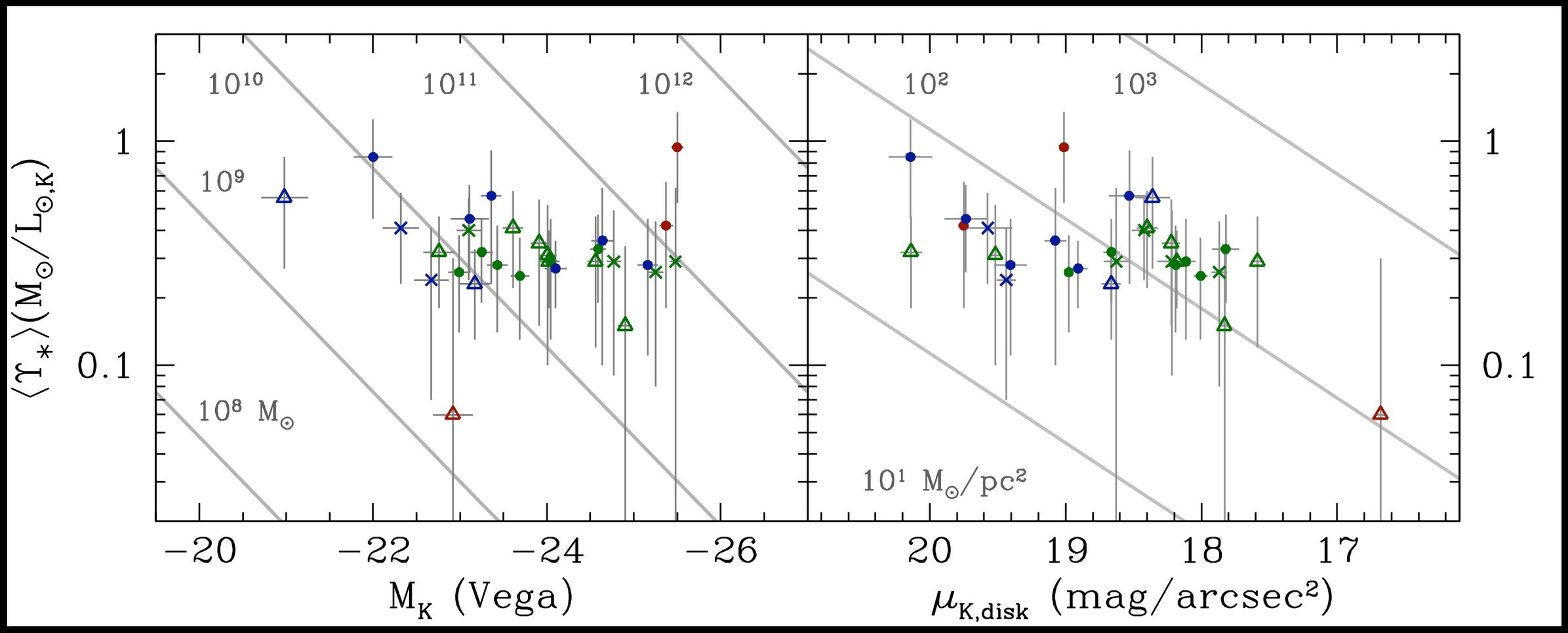
Bershady+ 2011

DiskMass Survey Results

- Galaxy disks are submaximal (Bershady+ 2011)
- $\Upsilon_K \sim 0.3$ (Martinsson+ 2013, in press)

Sb or earlier
Sbc or Sc
later than Sc

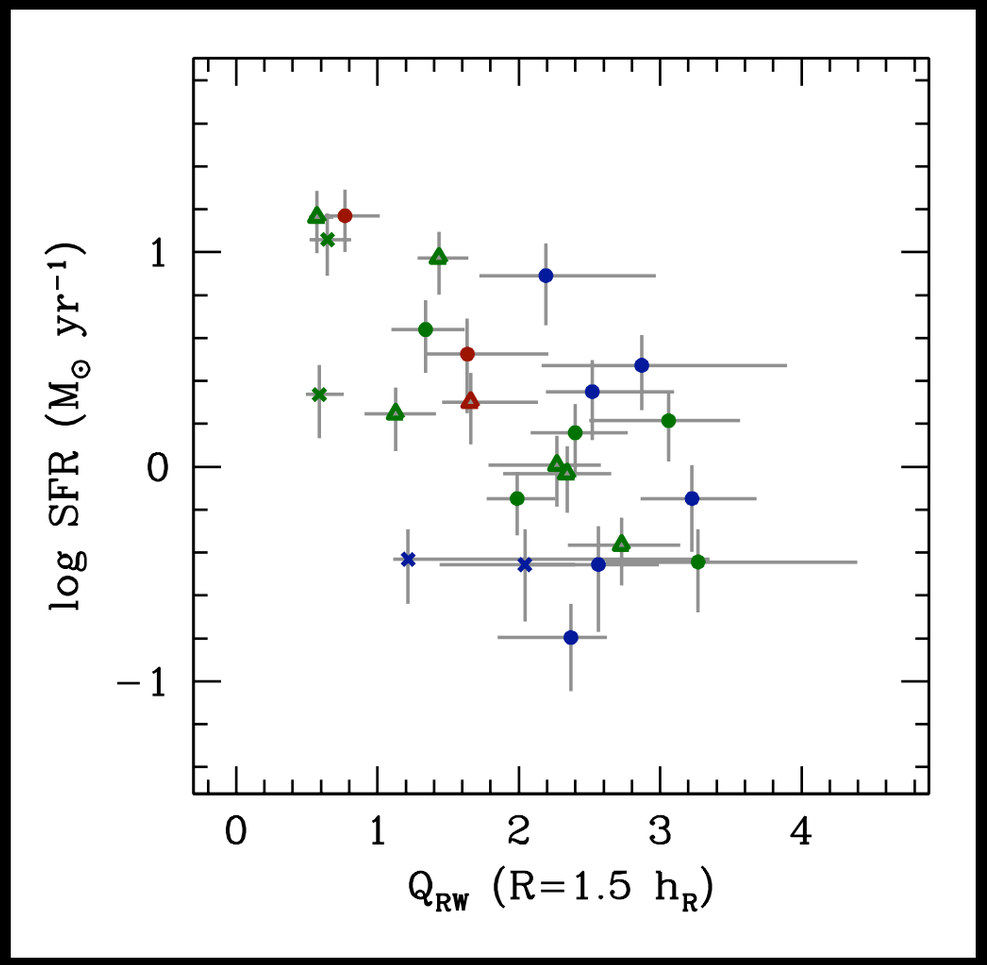
No Bar (S)
Weak Bar (SAB)
Strong Bar (SB)



Data from Martinsson+ (2013)

DiskMass Survey Results

- Galaxy disks are submaximal (Bershady+ 2011)
- $\Upsilon_K \sim 0.3$ (Martinsson+ 2013, in press)
- Disk stability correlates with SFR (Westfall+ in prep)



Sb or earlier
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Preliminary

Why stability matters

- How susceptible are galaxy disks to perturbations?
  - Density wave theory suggests they should be given morphological features like bars and spiral arms
- How do these perturbations affect/regulate their secular evolution?
  - For example, perturbations could
    - produce gravitational effects that might facilitate star formation
    - scatter stars thereby increasing their velocity dispersion and making the stellar disk more stable

The Stability Criterion

- Single component fluid disk

$$Q_i = \frac{\kappa\, \sigma_{R,i}}{\pi\, G\, \Sigma_i}$$

$$\kappa^2 = 2\frac{V_{\rm circ}}{R}\left(\frac{V_{\rm circ}}{R} + \frac{dV_{\rm circ}}{dR}\right)$$

(Toomre 1964)

- Correction for a collisionless fluid

$$Q_{i,*} = \frac{\pi}{3.36} Q_i$$

1. Kinematics
2. Axial Ratios
3. Stability

- Disk thickness corrections

(Romeo & Wiegert 2011)

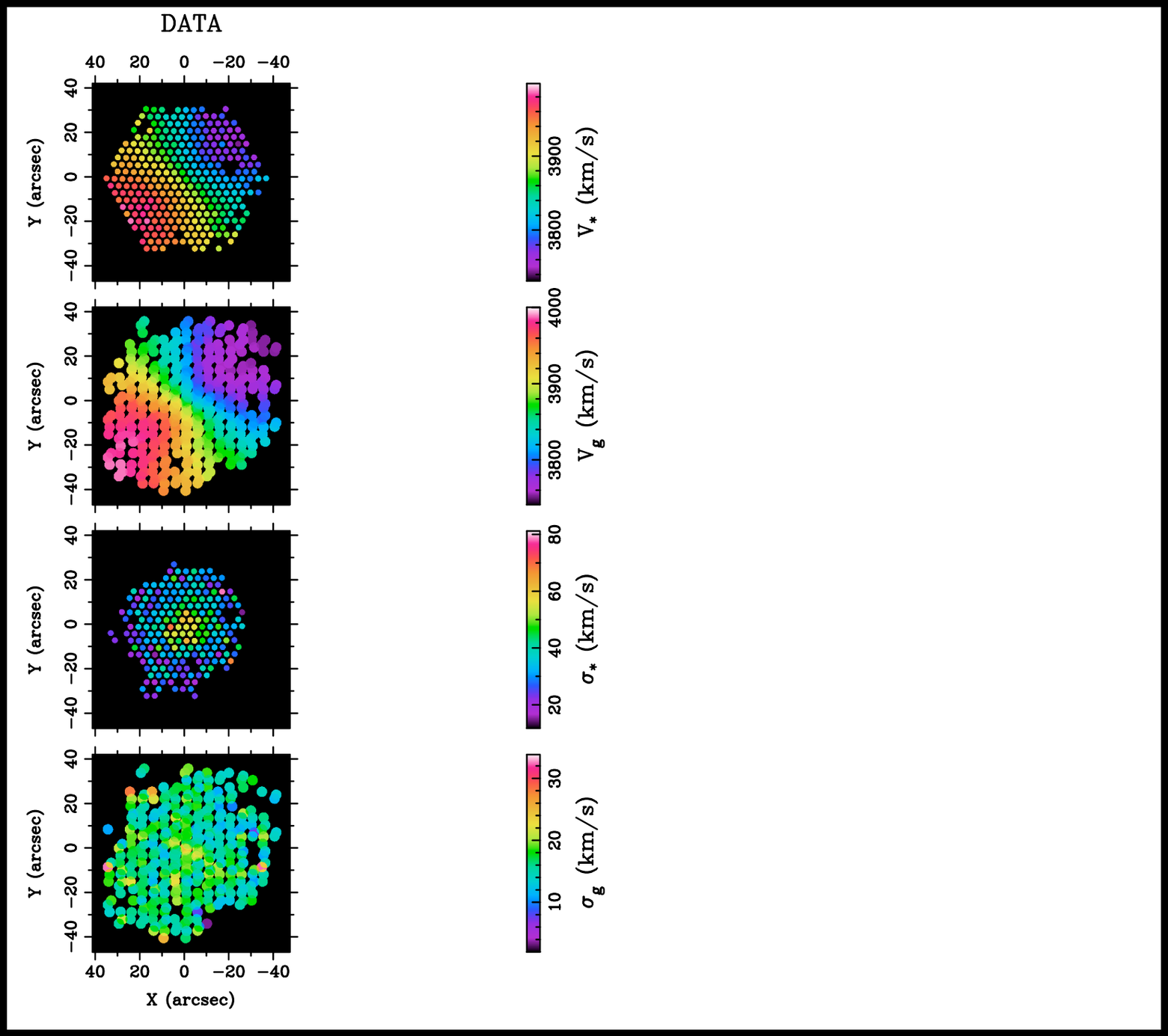
$$Q_{i,h} = \left(0.8 + 0.7\frac{\sigma_z}{\sigma_R}\right) Q_i$$

- Two-component disk solution

$$\begin{aligned} Q_{\rm RW}^{-1} &= W Q_{*,h}^{-1} + Q_{{\rm gas},h}^{-1}, Q_{*,h} > Q_{{\rm gas},h} \\ &= Q_{*,h}^{-1} + W Q_{{\rm gas},h}^{-1}, Q_{*,h} < Q_{{\rm gas},h} \end{aligned}$$

$$W = \frac{2\sigma_R \sigma_{\rm gas}}{\sigma_R^2 + \sigma_{\rm gas}^2}$$

Kinematic Maps



UGC 4368

We construct a generative model based on analytic dynamical theory.

The best-fitting parameters of the model and their errors are determined by sampling from the Bayesian posterior.

Bayesian Inference

Hypothesis

Data

Parameters

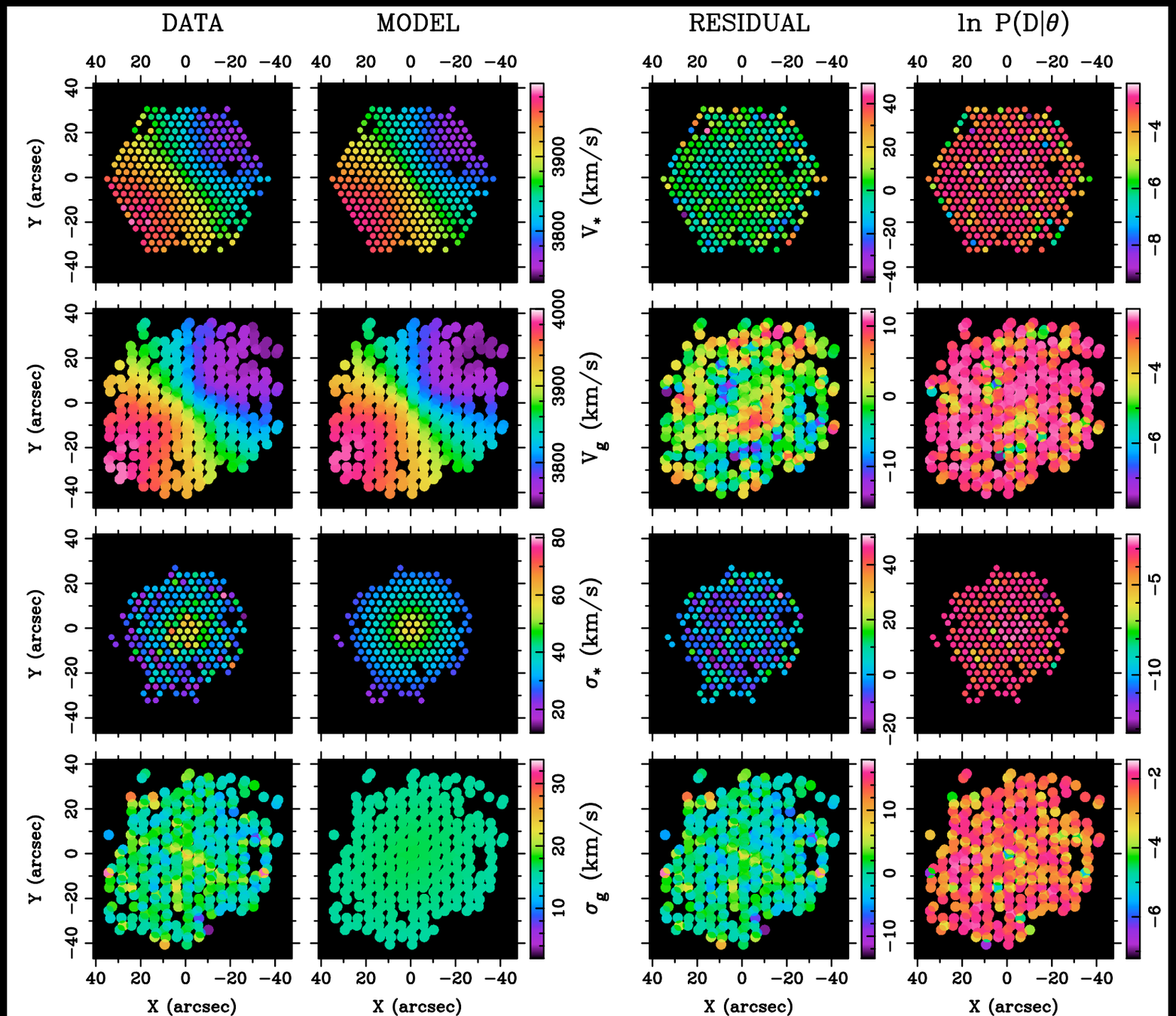
Likelihood

Prior Probability

$$P(\boldsymbol{\theta}|\mathcal{D},\mathcal{H}) = \frac{P(\mathcal{D}|\boldsymbol{\theta},\mathcal{H})P(\boldsymbol{\theta}|\mathcal{H})}{\int P(\mathcal{D}|\boldsymbol{\theta},\mathcal{H})P(\boldsymbol{\theta}|\mathcal{H})d\boldsymbol{\theta}}$$

"Evidence"

Generative Modeling



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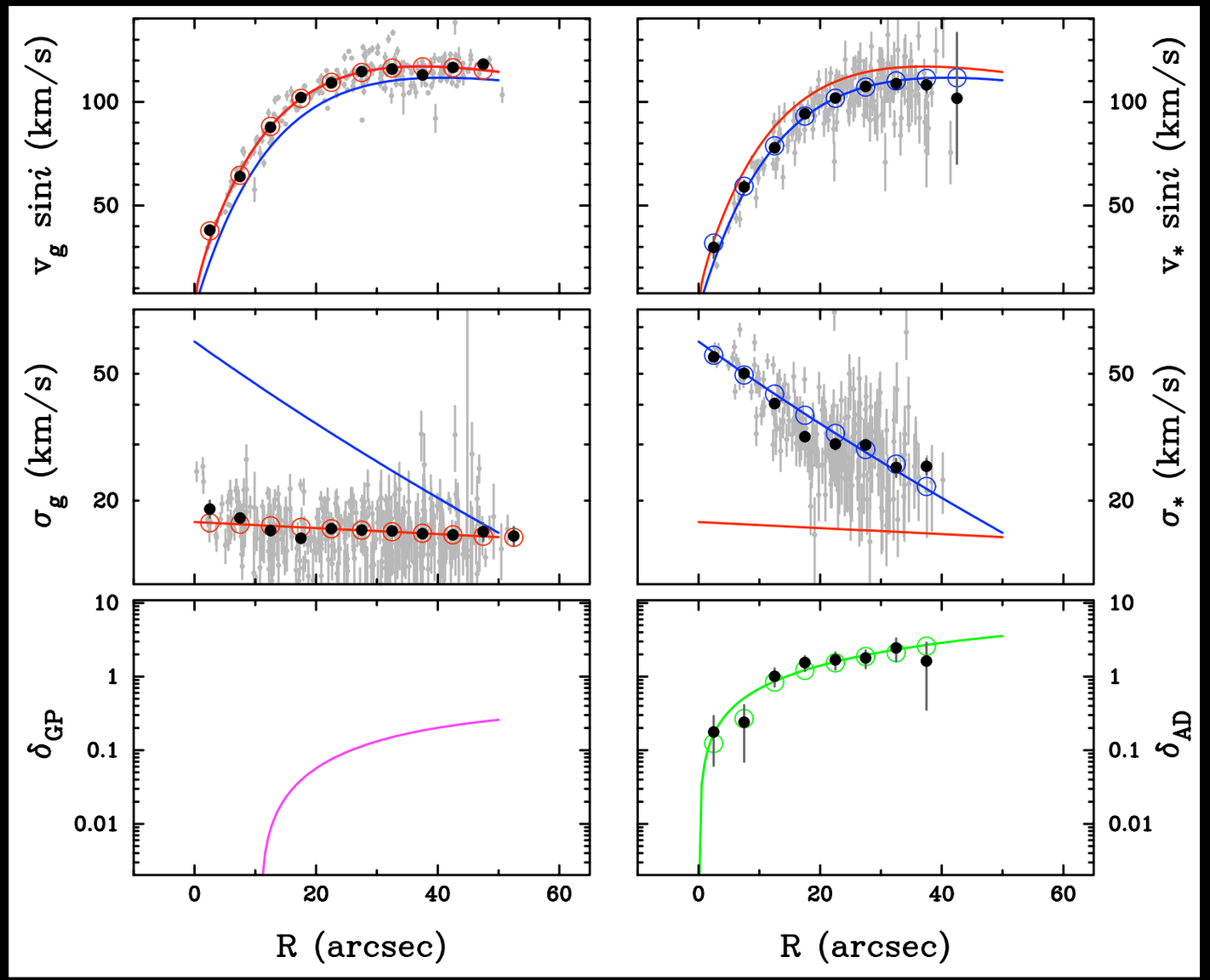
Preliminary

Generative Modeling

- Model elements:
  - Geometry (i, PA, etc.)
  - Stellar rotation curve
  - Stellar velocity ellipsoid
    - σ_R, $\alpha=\sigma_z/\sigma_R$, $\beta=\sigma_\theta/\sigma_R$
  - Corrects V_g to V_c:
    - $V_c^2 = V_g^2 + \sigma_g^2\,\delta_{GP}$
- Asymmetric drift:
  - $V_g^2 = V_*^2 + \sigma_*^2\,\delta_{AD}$
  - $\delta_{AD} > 0$ for nearly all galaxies



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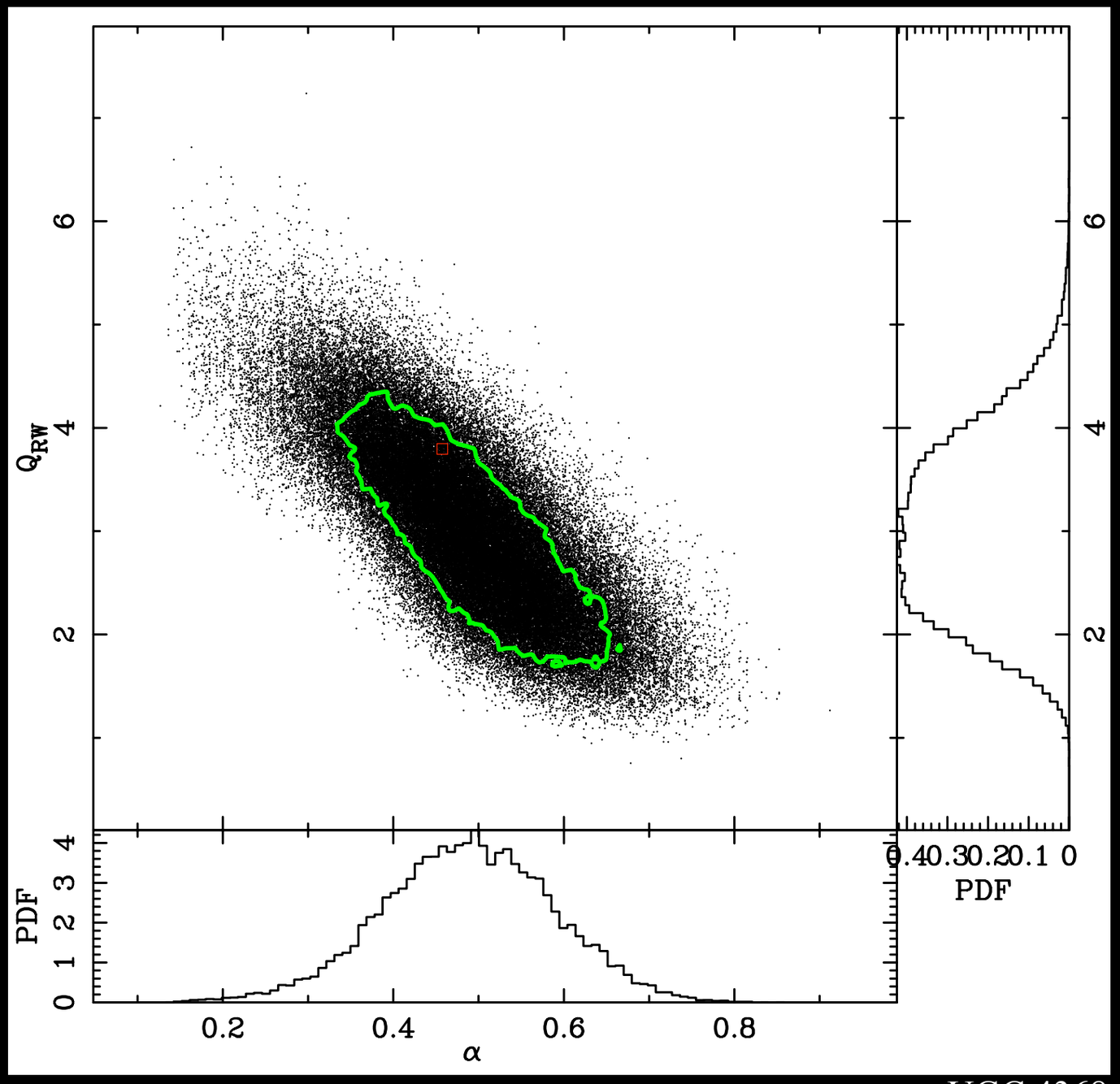
Preliminary

Generative Modeling

Preliminary

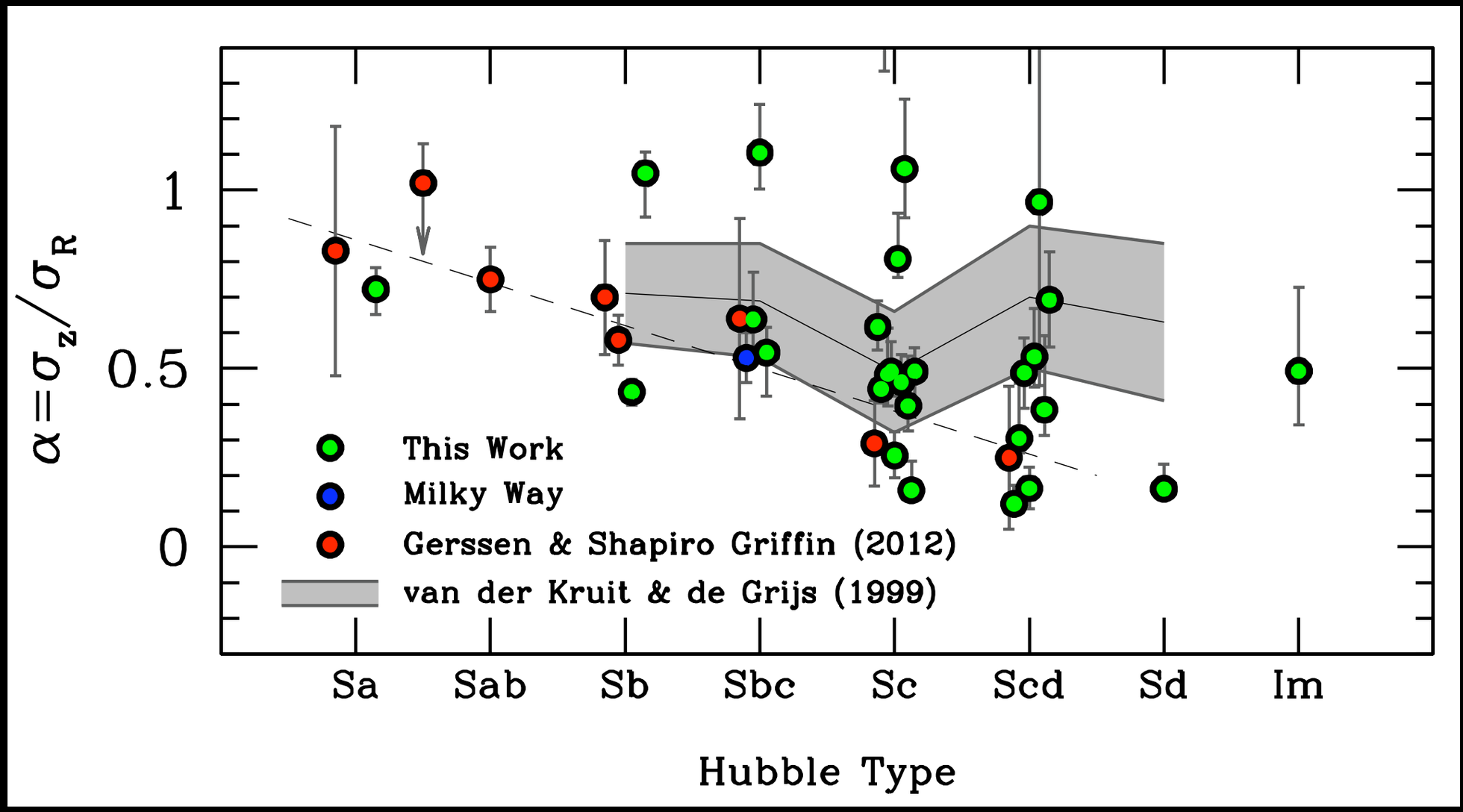
The MCMC sampling provides a set of parameters drawn in proportion to their probability.

From these, we can derive other properties of the galaxy, such as disk stability.



$\alpha = \sigma_z/\sigma_R$

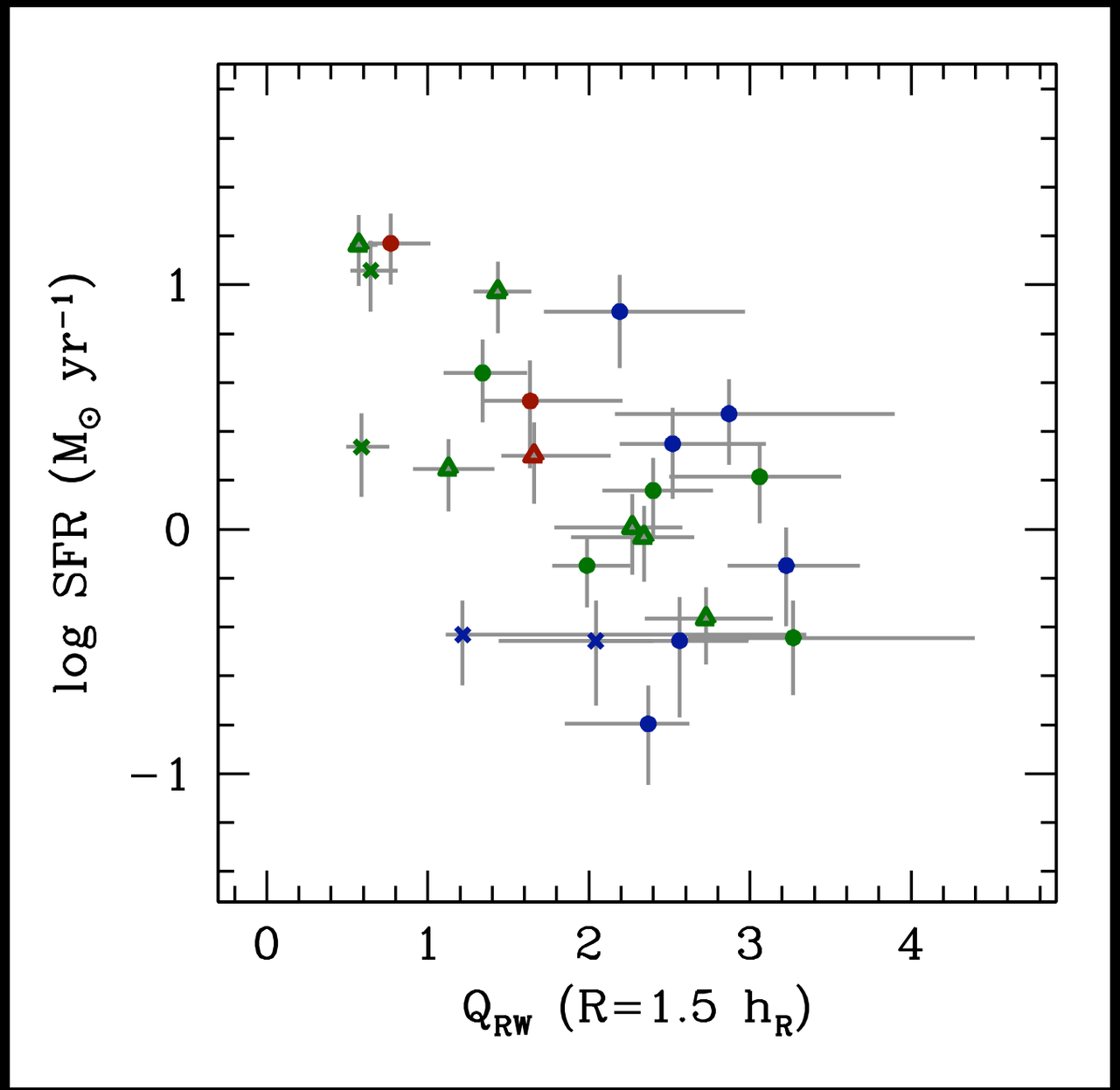
Axial Ratios



- α may change with Hubble type due to relative influence of scattering processes (Gerssen & Shapiro Griffin 2012)

Preliminary

Star formation vs. Stability

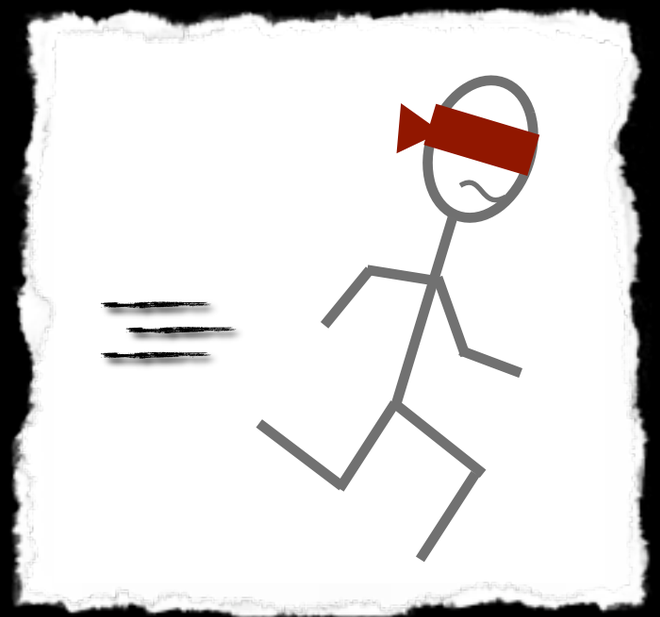


- Although the correlation is rough, galaxies with a higher SFR are generally less gravitationally stable.
  - Star-formation rates are based on the 21-cm radio continuum.
- Does this make sense?

Preliminary

What do scaling relations suggest?

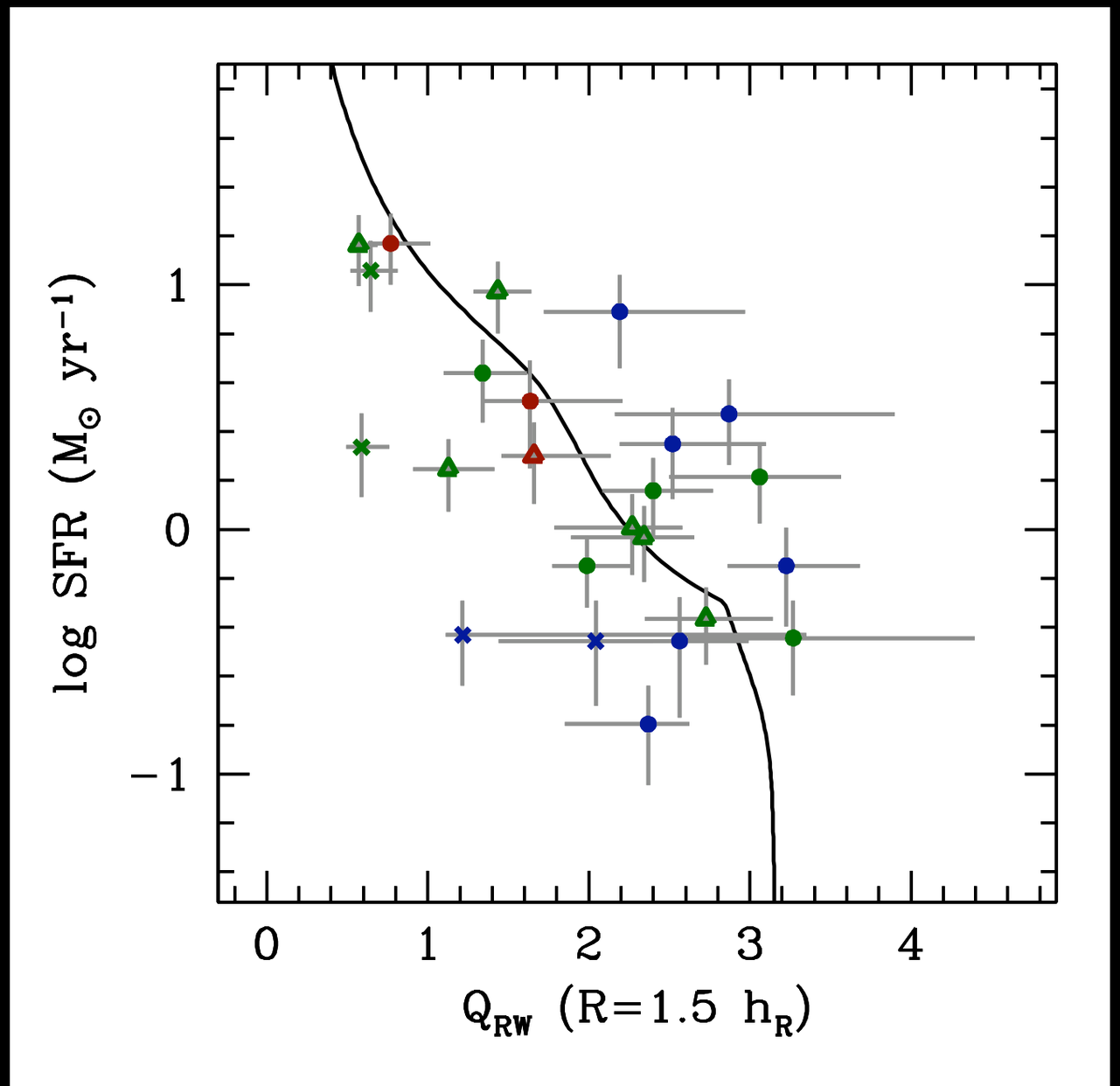
SFR, $\mu_{0,K}$, h_R, Υ_K, α, σ_g, k, X_{CO}



Kennicutt (1998)
Verheijen & Sancisi (2001)
Regan+ (2006)
Bershady+ (2010)
Saintonge+ (2011)
Martinsson (2011)
Andersen & Bershady (2013)
Martinsson+ (2013)

Q_{RW}

Star formation vs. Stability

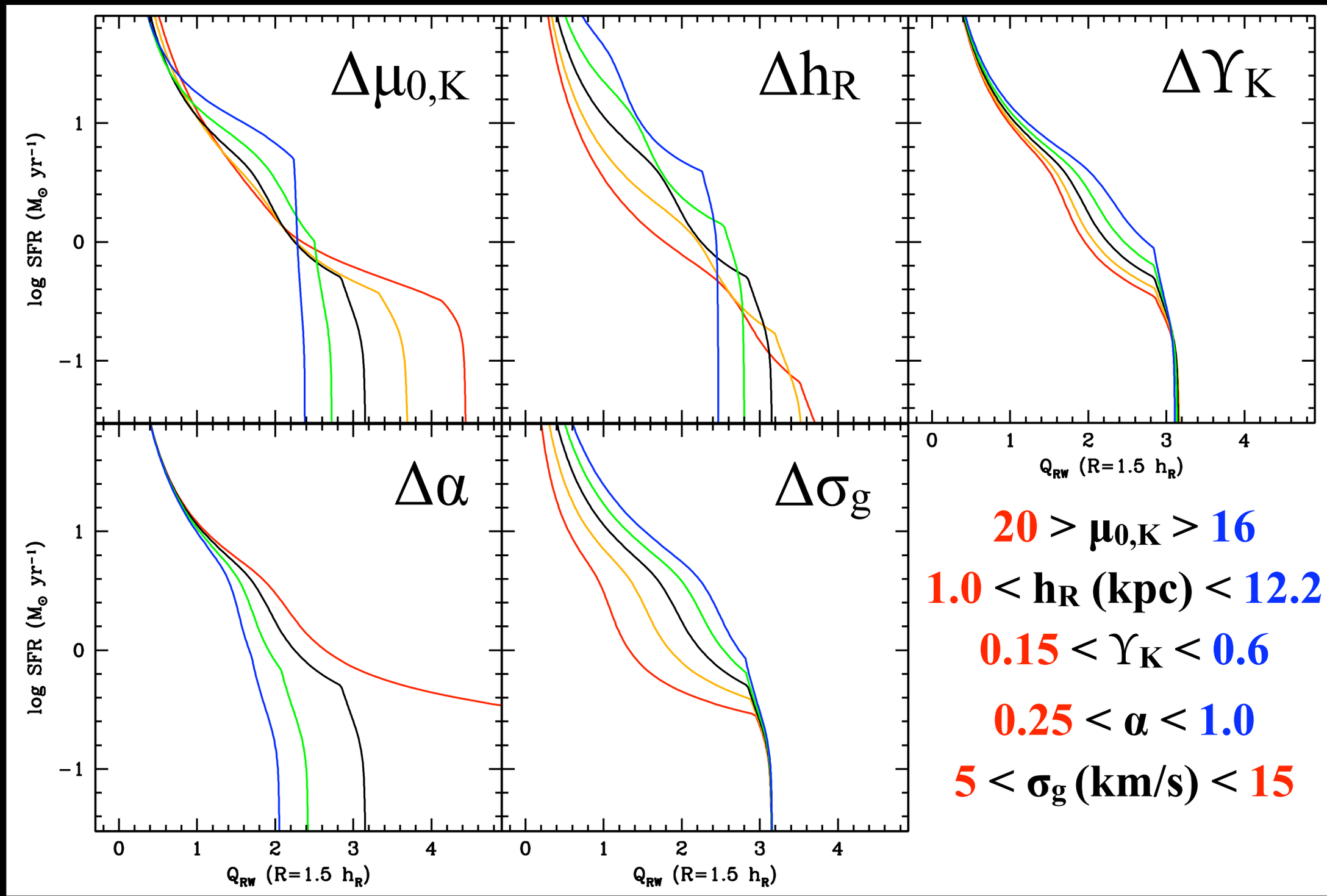


- Although the correlation is rough, galaxies with a higher SFR are generally less gravitationally stable.
  - Star-formation rates are based on the 21-cm radio continuum.
- Does this make sense?

Yes.

Preliminary

Star formation vs. Stability



Summary

- The DiskMass Survey is a focused study of face-on galaxies with the primary aim of understanding the dark and luminous mass distribution in disk-dominated galaxies.
  - A primary driver for building PPak, the CALIFA workhorse. (Verheijen+ 2004)

- Galaxy disks are submaximal (Bershady+ 2011)
- $\Upsilon_K \sim 0.3$ (Martinsson+ 2013, in press)
- Disk stability correlates with SFR, as we expect it should. (Westfall+ in prep)