university of groningen / Kapteyn Astronomical Institute

The Distribution of Mass within Spiral Galaxies

Unique Solutions from Gas and Stellar Kinematics

Thomas Martinsson

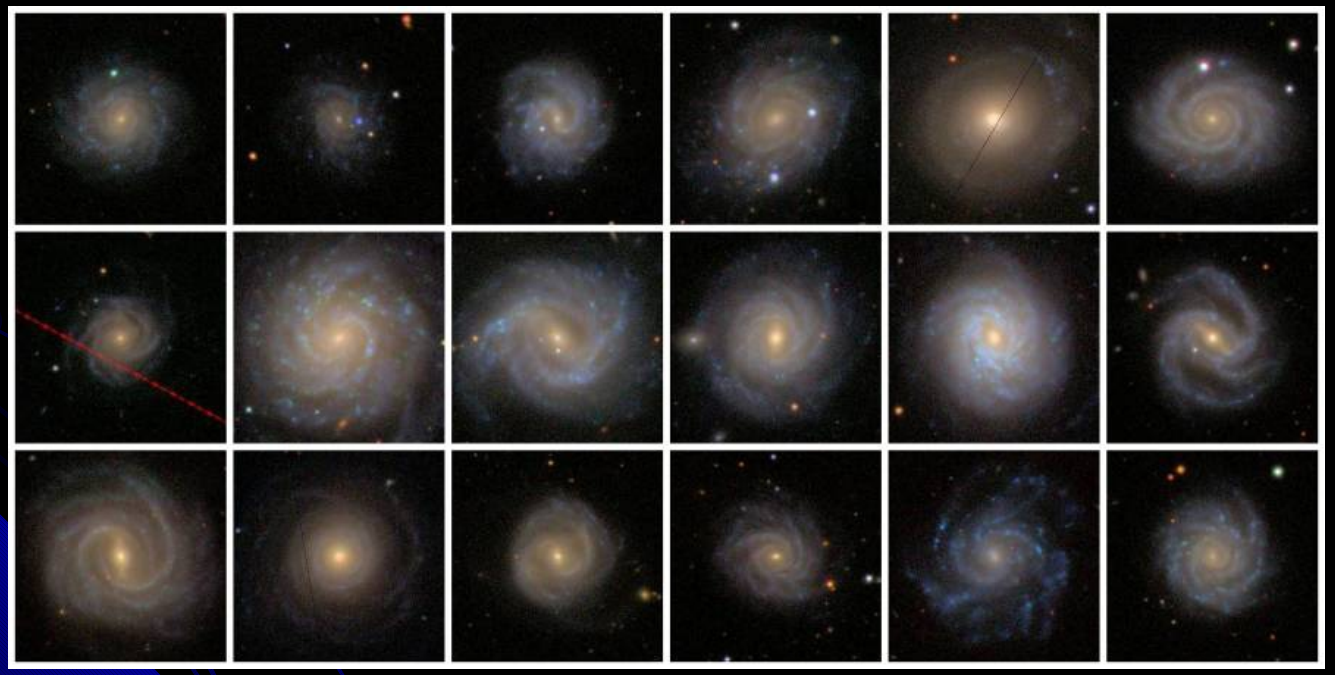
Leiden Observatory

Garching, March 2014

The DiskMass Survey

Breaking the disk-halo degeneracy

Dave Andersen, Matthew Bershady, Thomas Martinsson
Rob Swaters, Marc Verheijen, Kyle Westfall



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DMS I: Bershady et al., 2010, ApJ, 716, 198

DMS II: Bershady et al., 2010, ApJ, 716, 234

DMS III: Westfall et al., 2011, ApJS, 193, 21

DMS IV: Westfall et al., 2011, ApJ, 742, 18

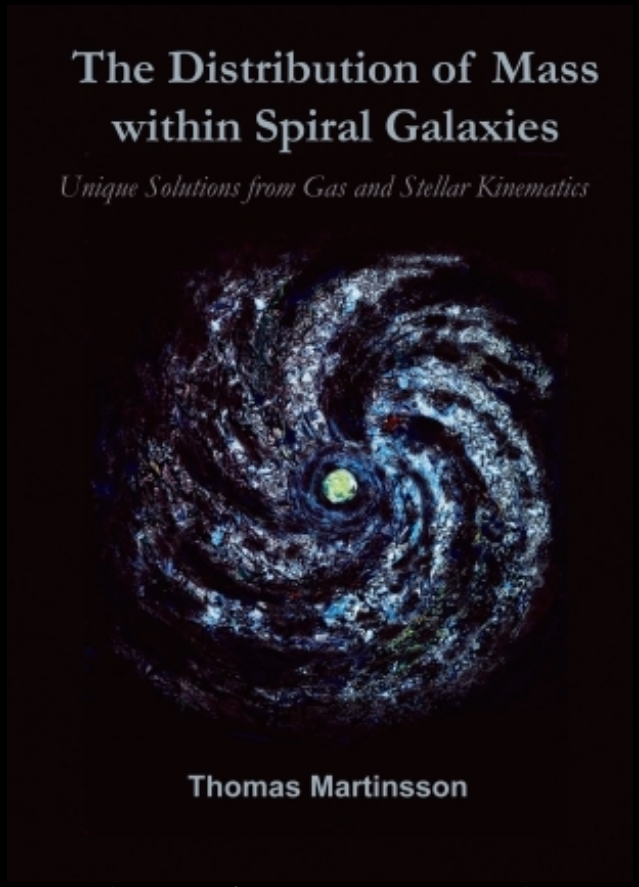
DMS V: Bershady et al., 2011, ApJ, 739L, 47

DMS VI: Martinsson et al., 2013, A&A, 557, A130

DMS VII: Martinsson et al., 2013, A&A, 557, A131

The DiskMass Survey

Breaking the disk-halo degeneracy



(Martinsson, 2011)

Outline

- Introduction
  - Rotation curve mass decompositions
  - The disk-halo degeneracy
  - The DiskMass Survey: Sample & Strategy
- Optical IFU Spectroscopy from PPak
  - Exponential decline of σ_z
  - The linear σ_z/V_{max} relation
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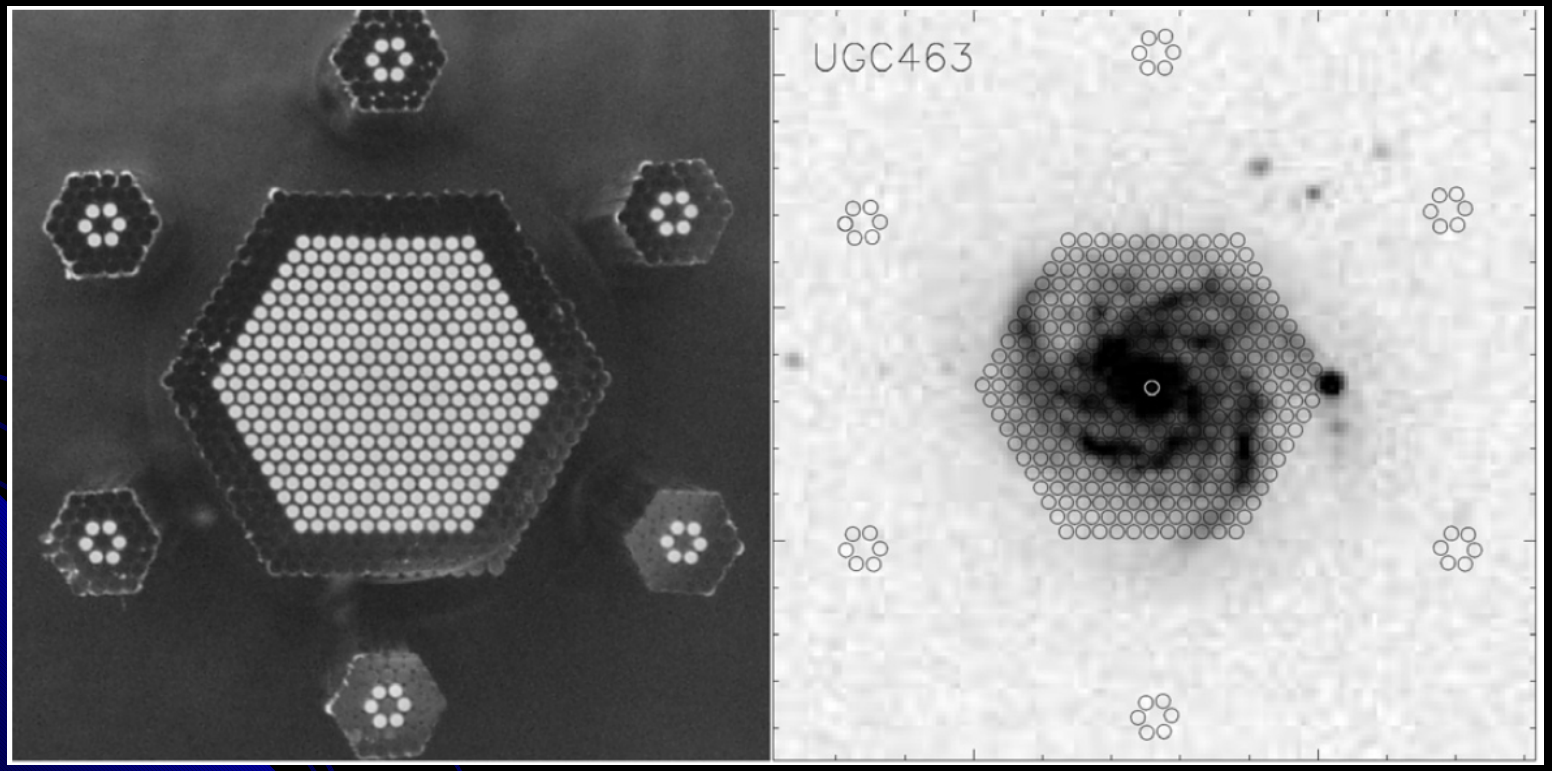
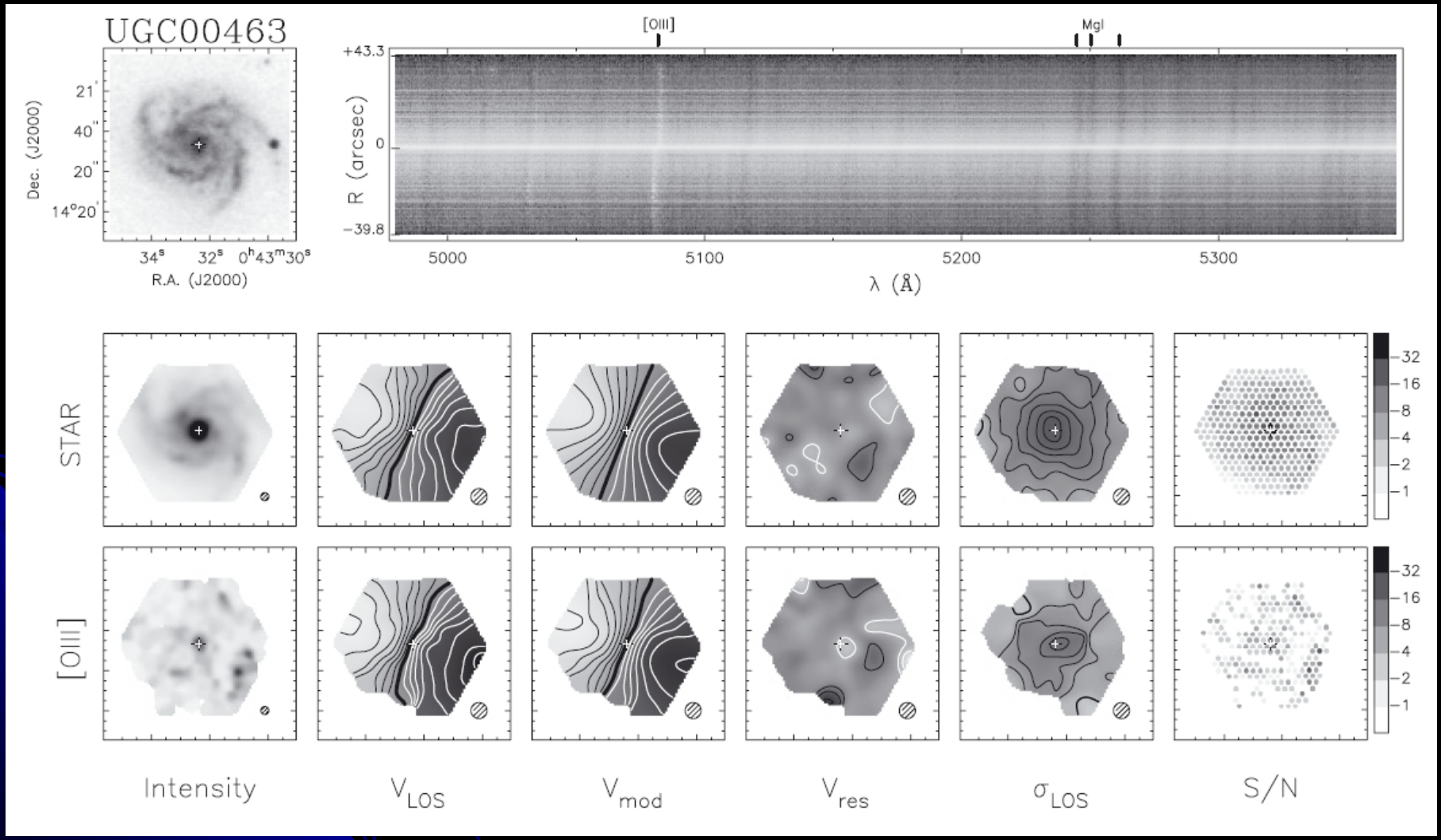
PPak Observations

30 intermediate-to-late-type spiral galaxies
Typically 5-6 hours per galaxy

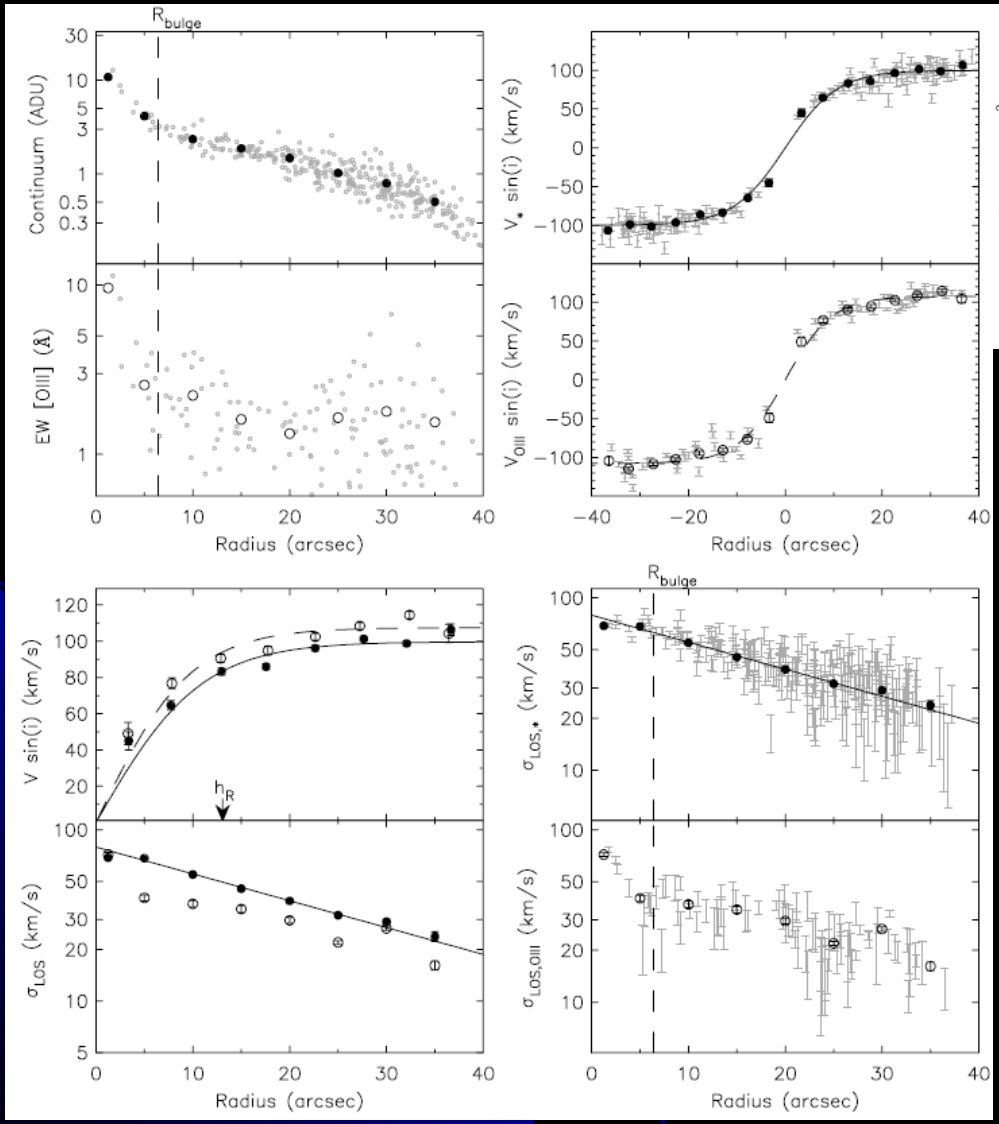


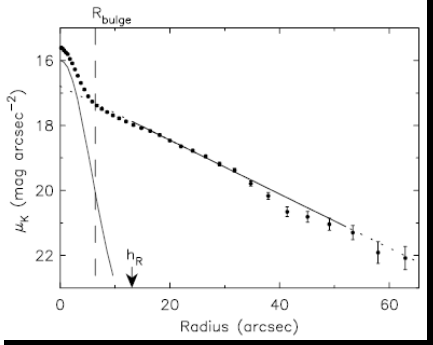
PPak Observations

MAPS..



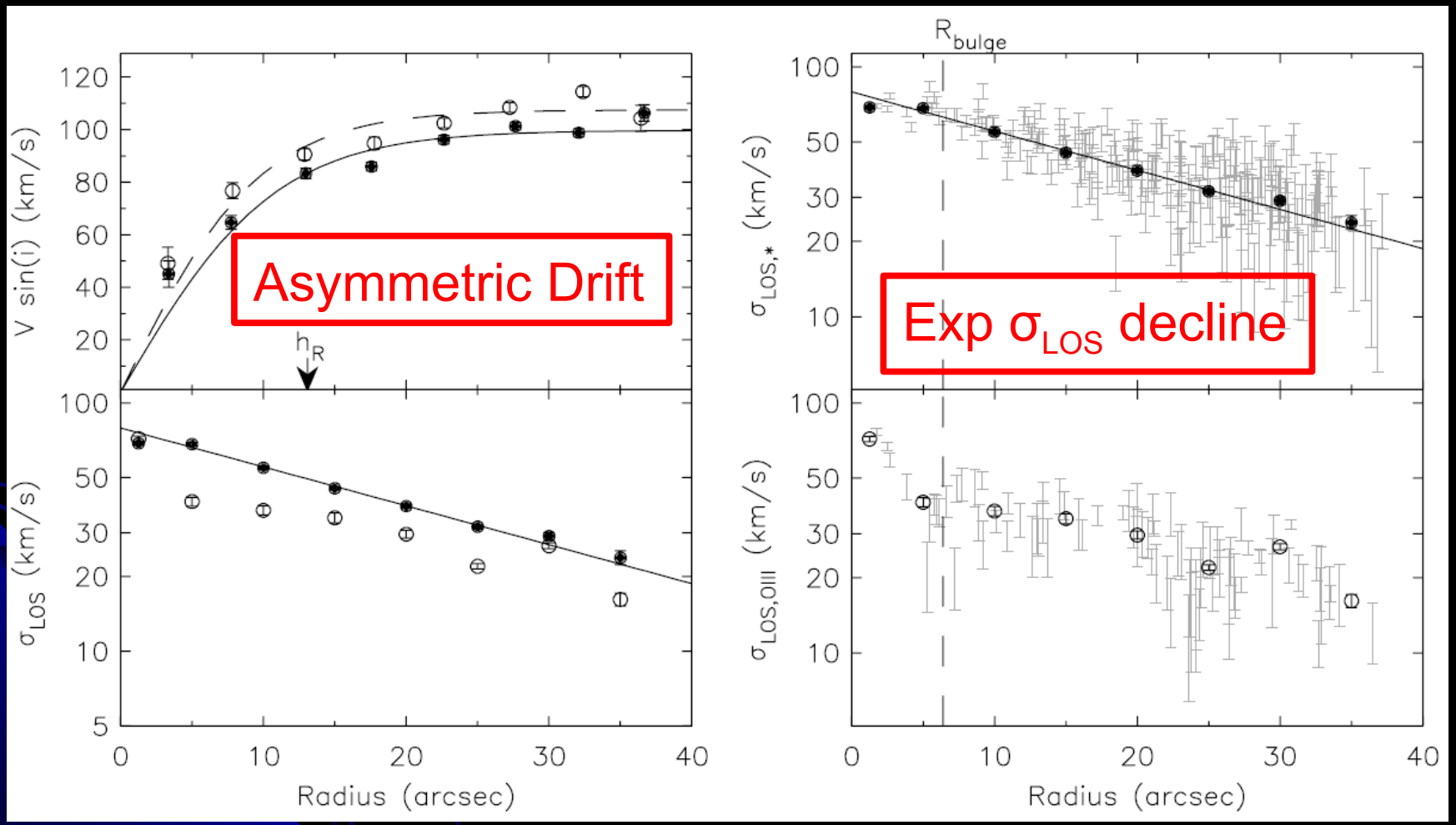
PPak Observations



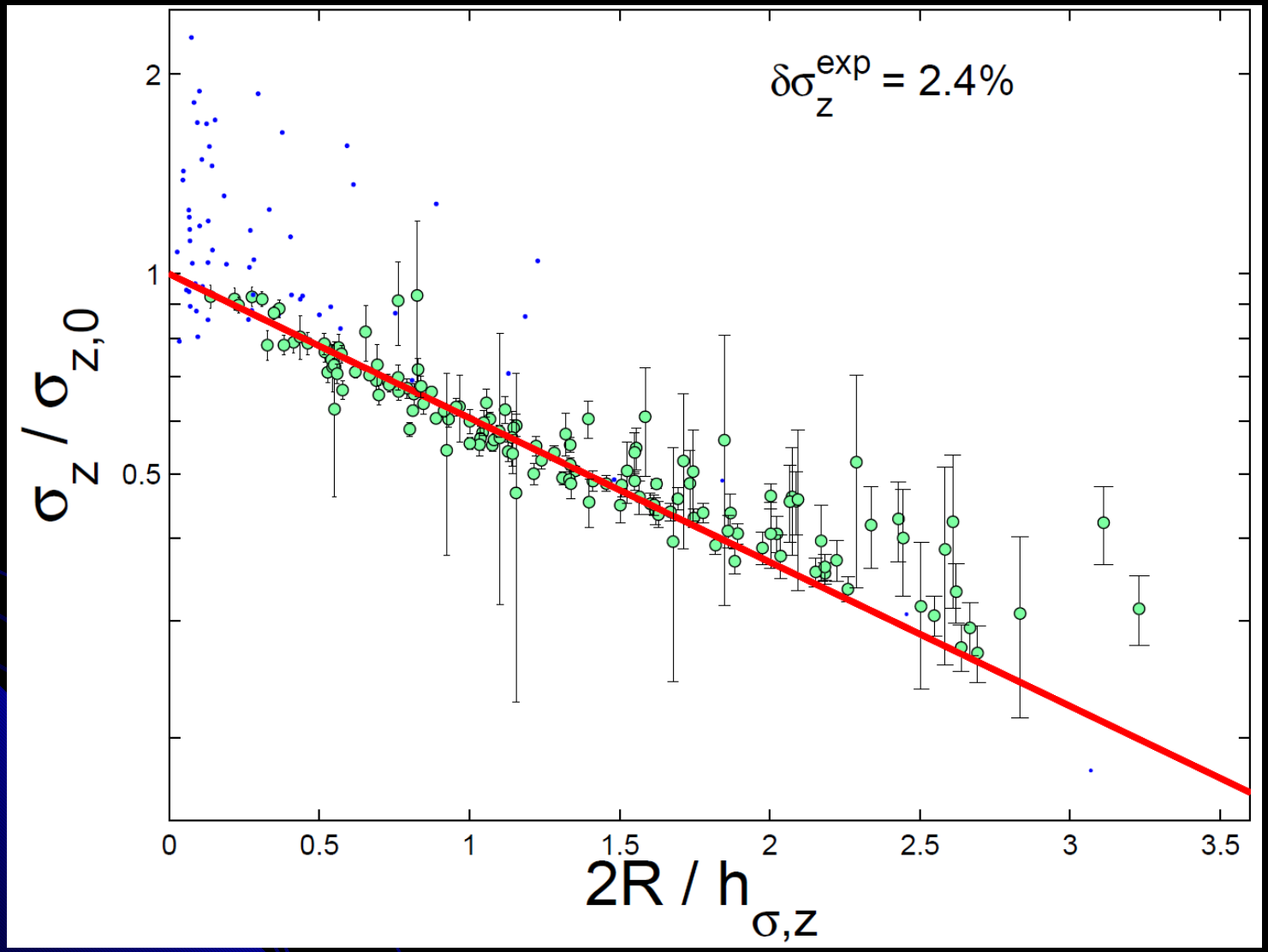


... AND RADIAL PROFILES

PPak Observations

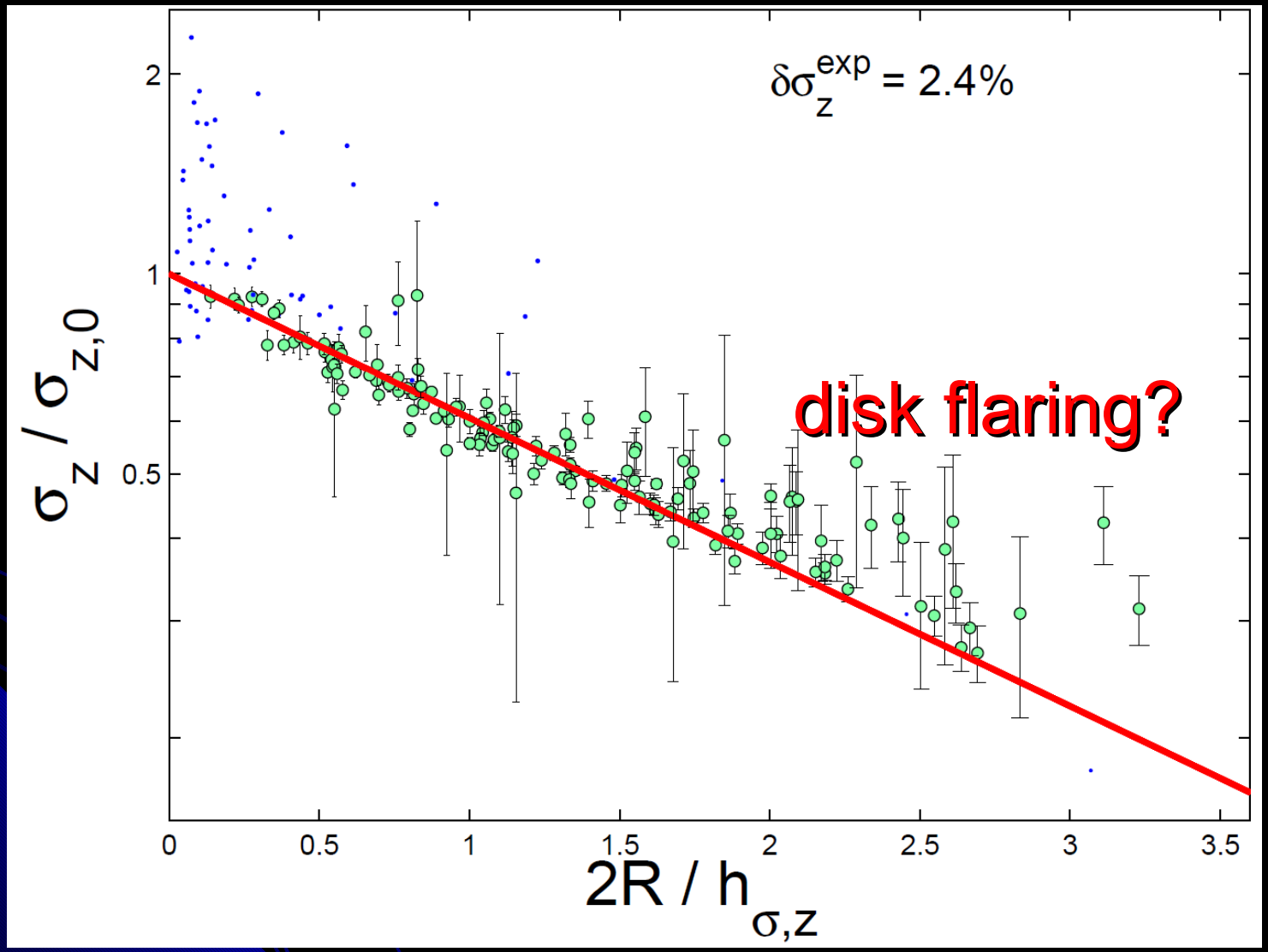


Exponential decline of σ_z



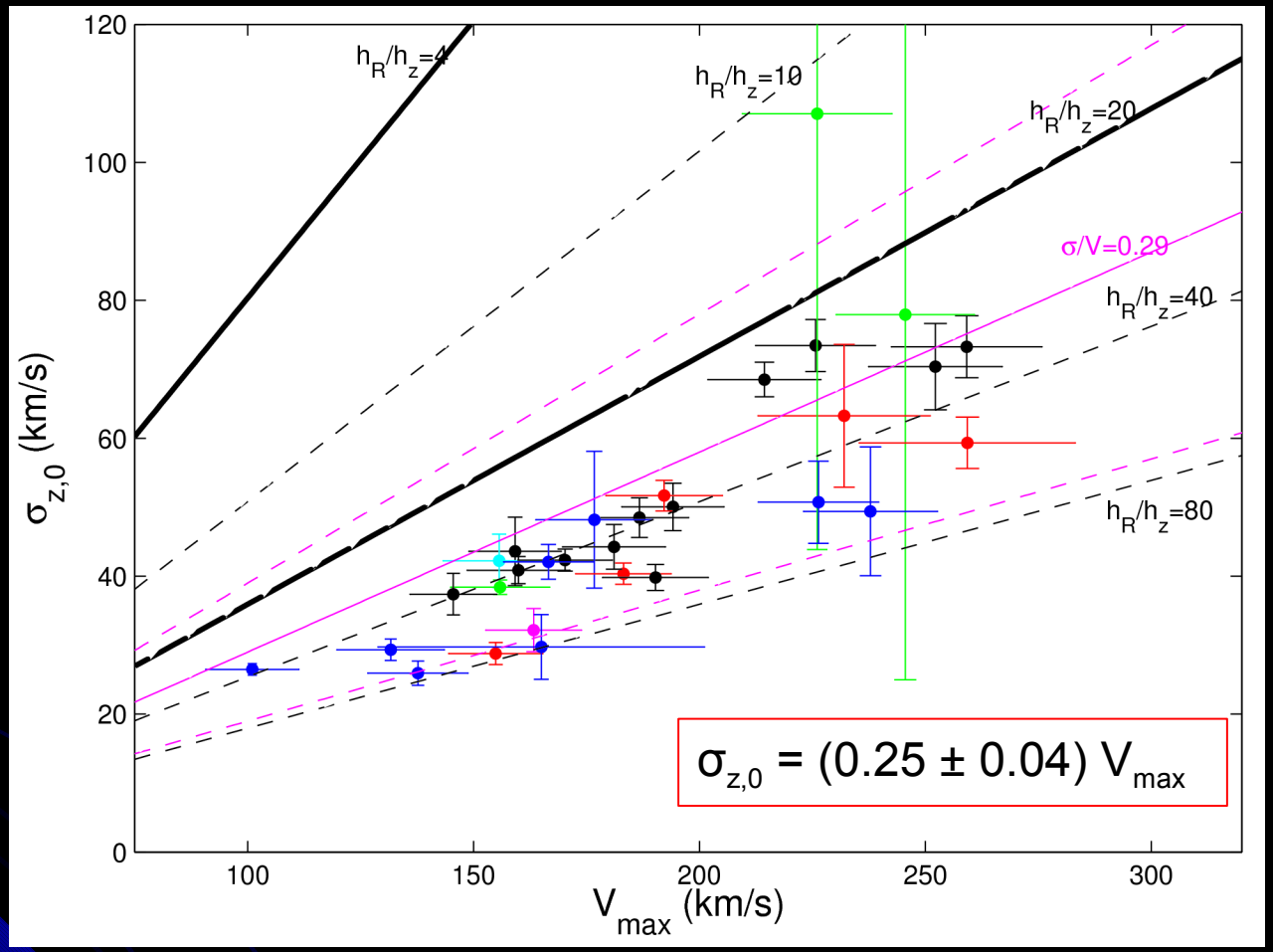
($h_\sigma \sim 2h_R$)

Exponential decline of σ_z



($h_\sigma \sim 2h_R$)

A linear σ_z / V_{max} relation

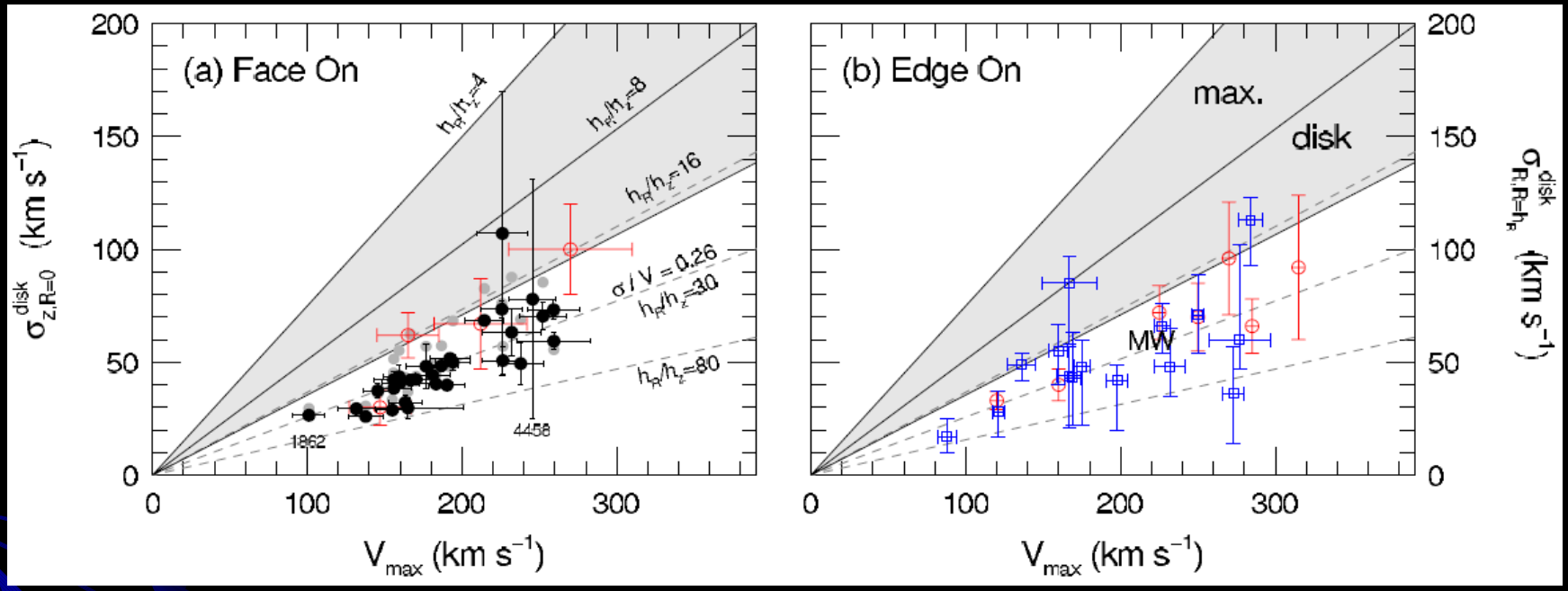


Bottema, 1993

$V_{max} \sim \sigma_{z,0}\ \mathrm{sqrt}\{h_R/h_z\}$

Disks are too thin! (when assuming maximal disks)

A linear σ_z / V_{max} relation



(Bershady et al., 2011)

Bottema (1993)

Kregel (2005)

Disks are too thin! (when assuming maximal disks)

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21-cm Radio Synthesis Observations

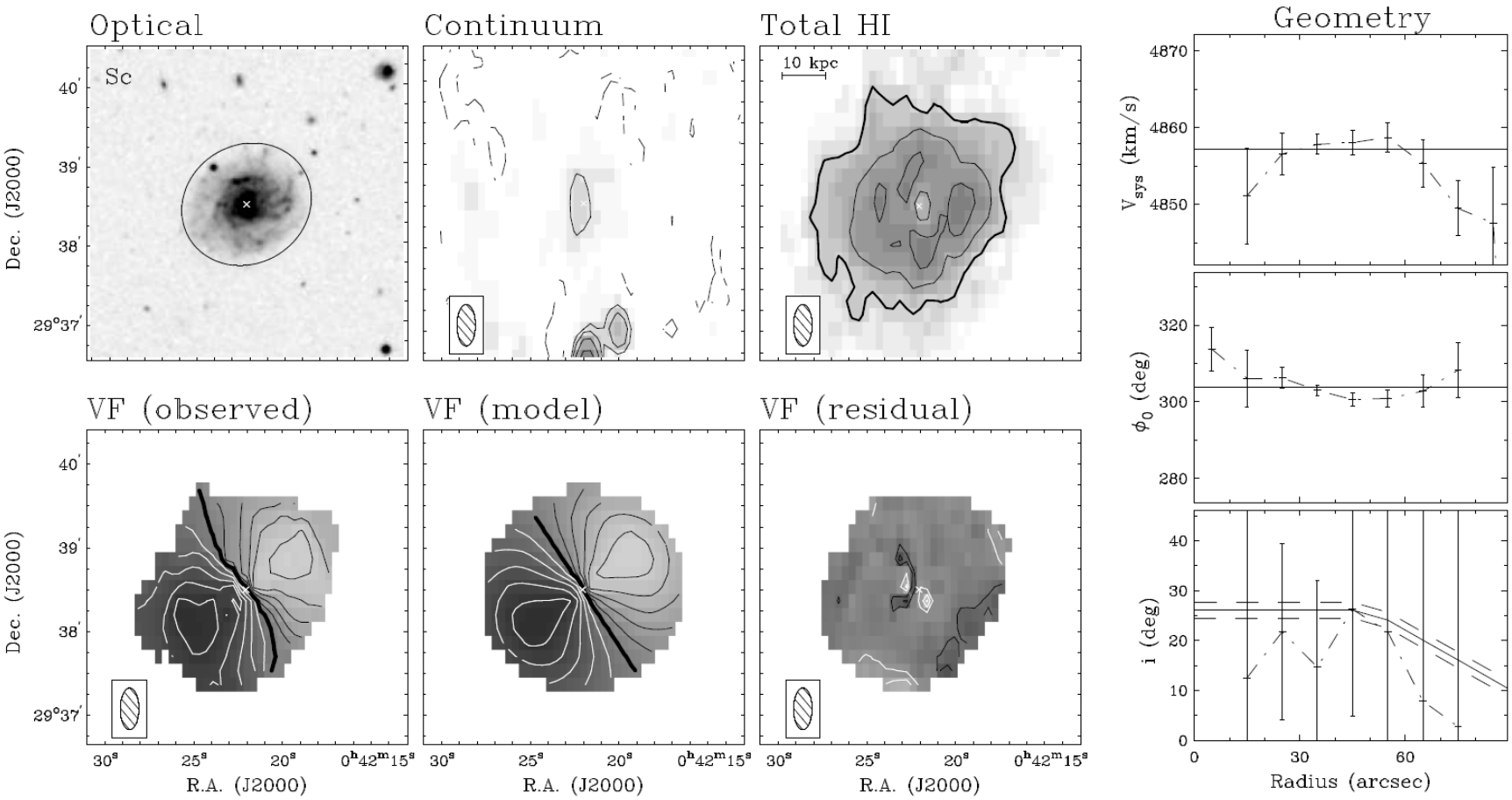
WSRT

GMRT

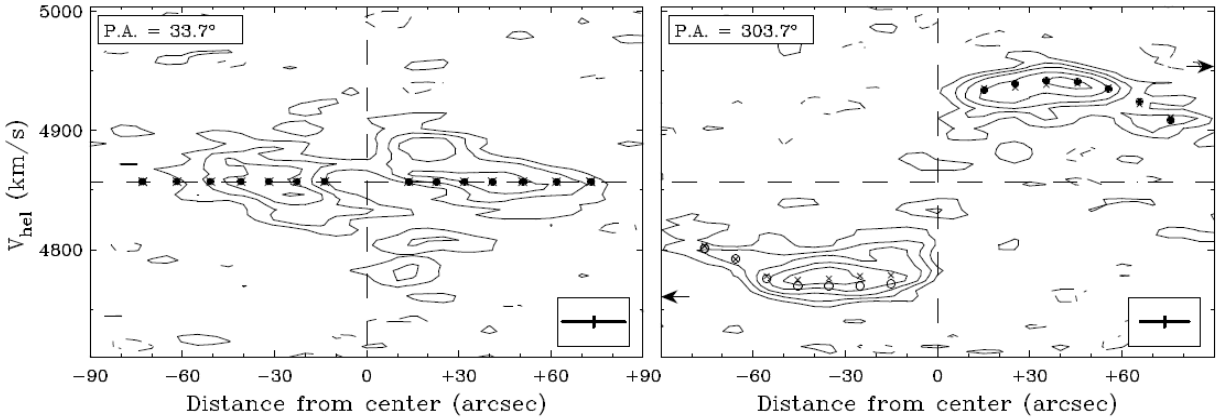
VLA

- Determine Σ_{gas}
- Extend Hα VFs to larger radii for more extended rotation curves
- Detect warps & kin. asymmetries to, e.g., reveal elongations of the potential of the DM halos
- SFR from the radio continuum

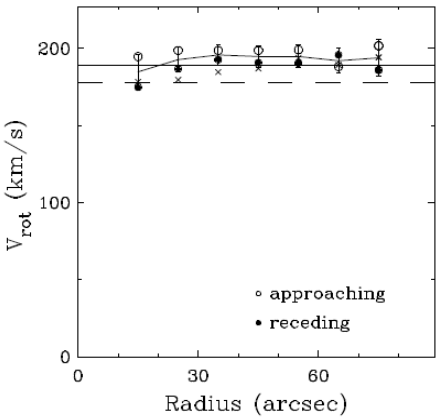
UGC00448


Optical
Continuum
Total HI
Sc
10 kpc
VF (observed)
VF (model)
VF (residual)
Dec. (J2000)
R.A. (J2000)
Geometry
V_{sys} (km/s)
ϕ_0 (deg)
i (deg)
Radius (arcsec)

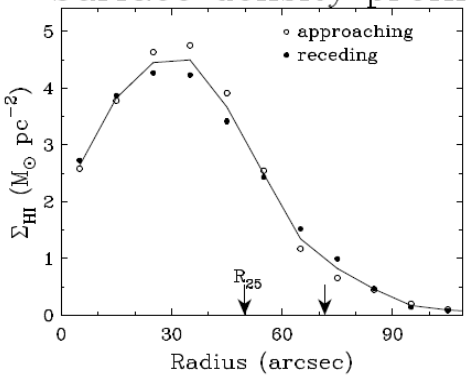
PV−diagrams



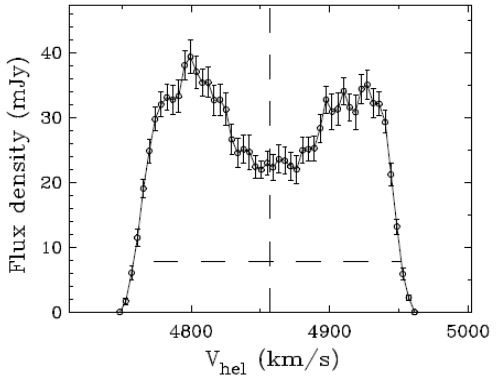
Rotation Curve



Surface density profile



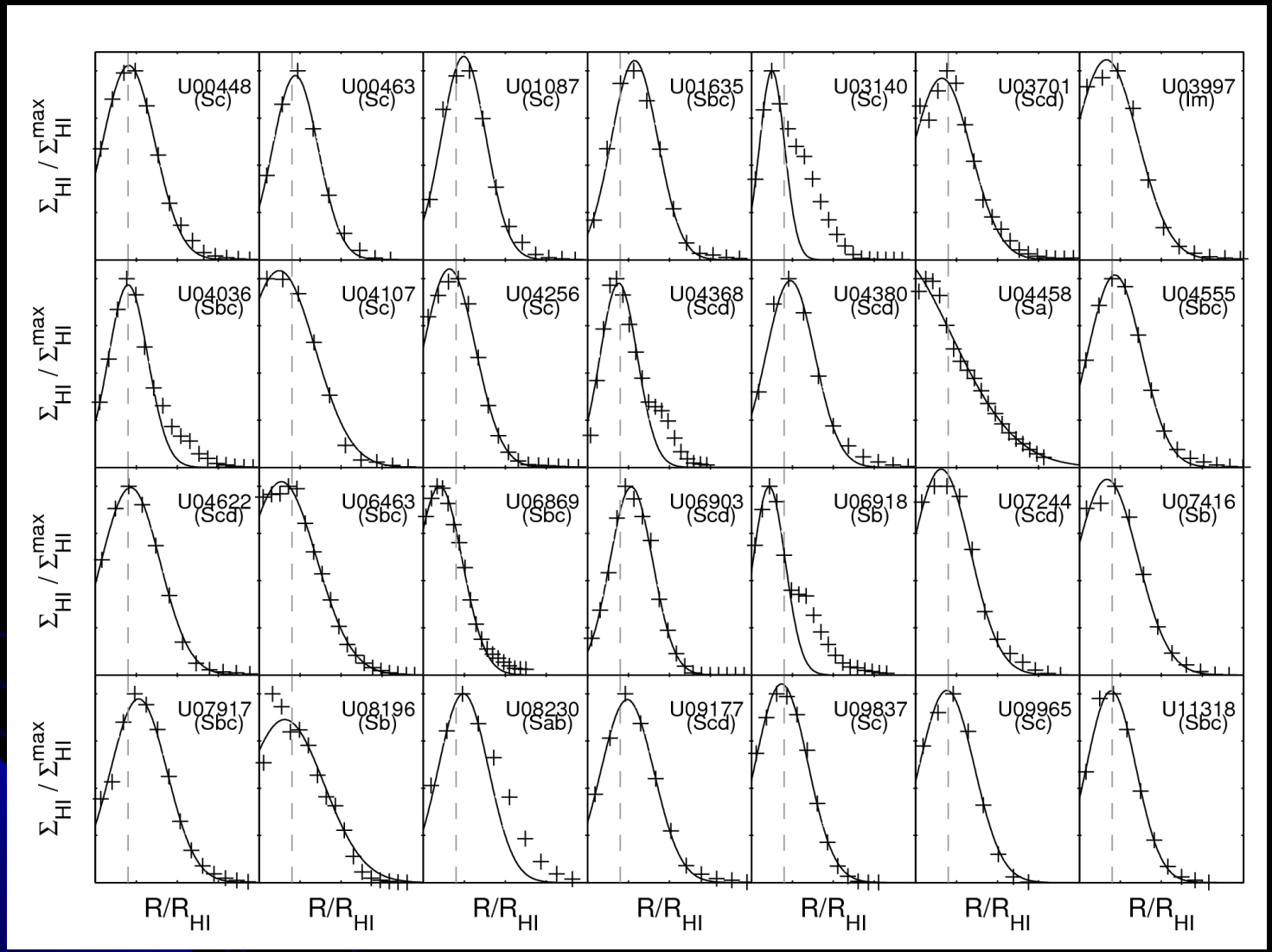
Global Profile



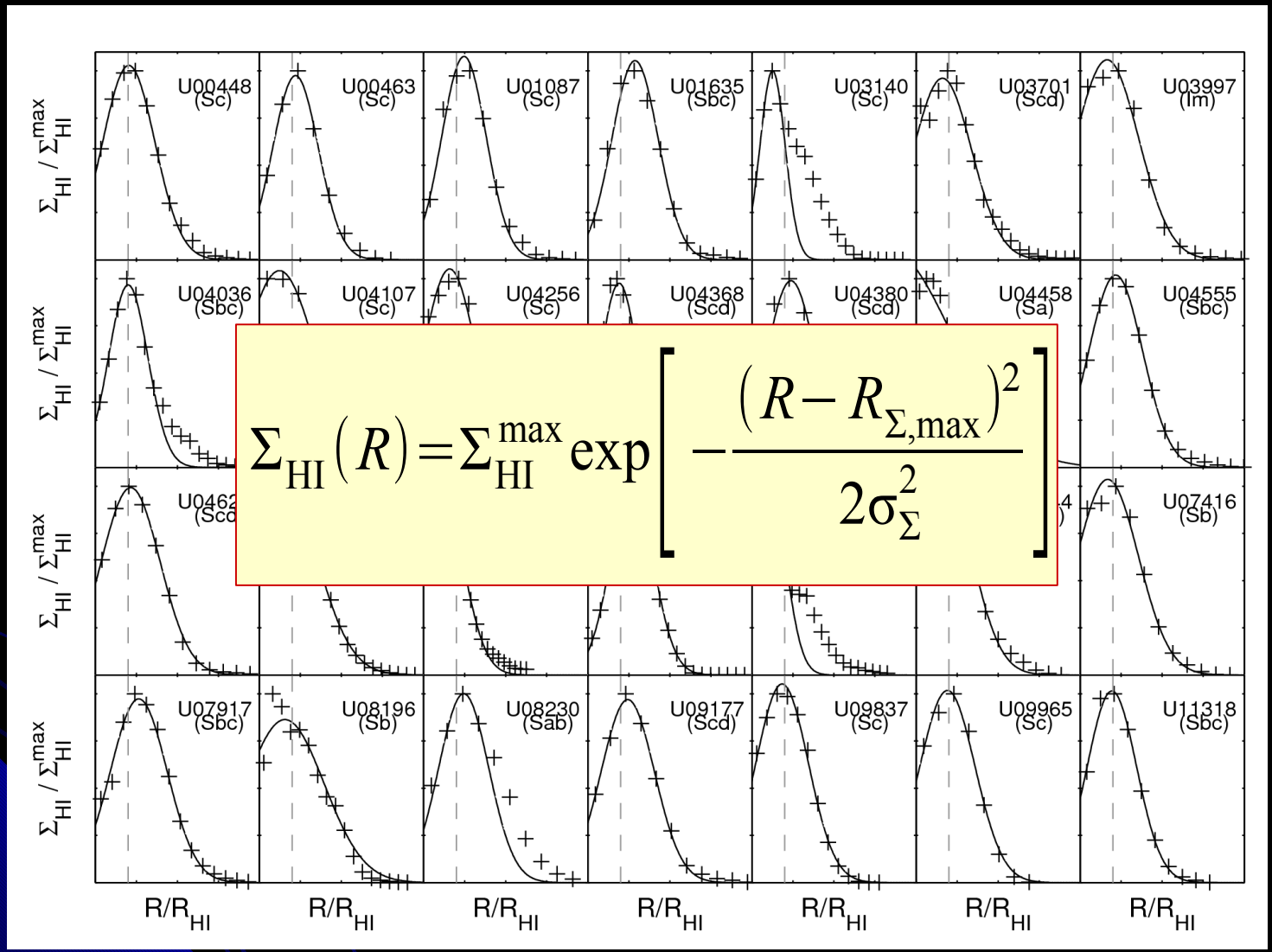
Atlas Table − UGC00448

Geometry:		**Contour levels:**	
RA	00:42:22.06 (J2000)	σ_{cont}	0.20 (mJy/beam)
Dec	29:38:30.10 (J2000)	σ_{pvd}	0.47 (mJy/beam)
V_{sys}	4857.1±0.9 (km/s)	VF (obs)	V_{sys} ± n×15 (km/s)
ϕ_0	303.7°±1.2°	VF (mod)	V_{sys} ± n×15 (km/s)
i_{TF}	26.1°±1.6°	VF (res)	±n×7.5 (km/s)
Flux & Densities:		**Velocity, Size & Resolution:**	
S_{21cm}	1.5±0.2 (mJy)	W_{20}	193.2 km/s
$S_{HI,max}$	39.3 (mJy)	R_{HI}	72 arcsec
$S_{HI}dv$	5.4±0.2 (Jy km/s)	Beam	29.9"×13.6"
$\Sigma_{HI,max}$	4.50 ($M_\odot$ pc^{-2})	Vel.Res	8.3 km/s

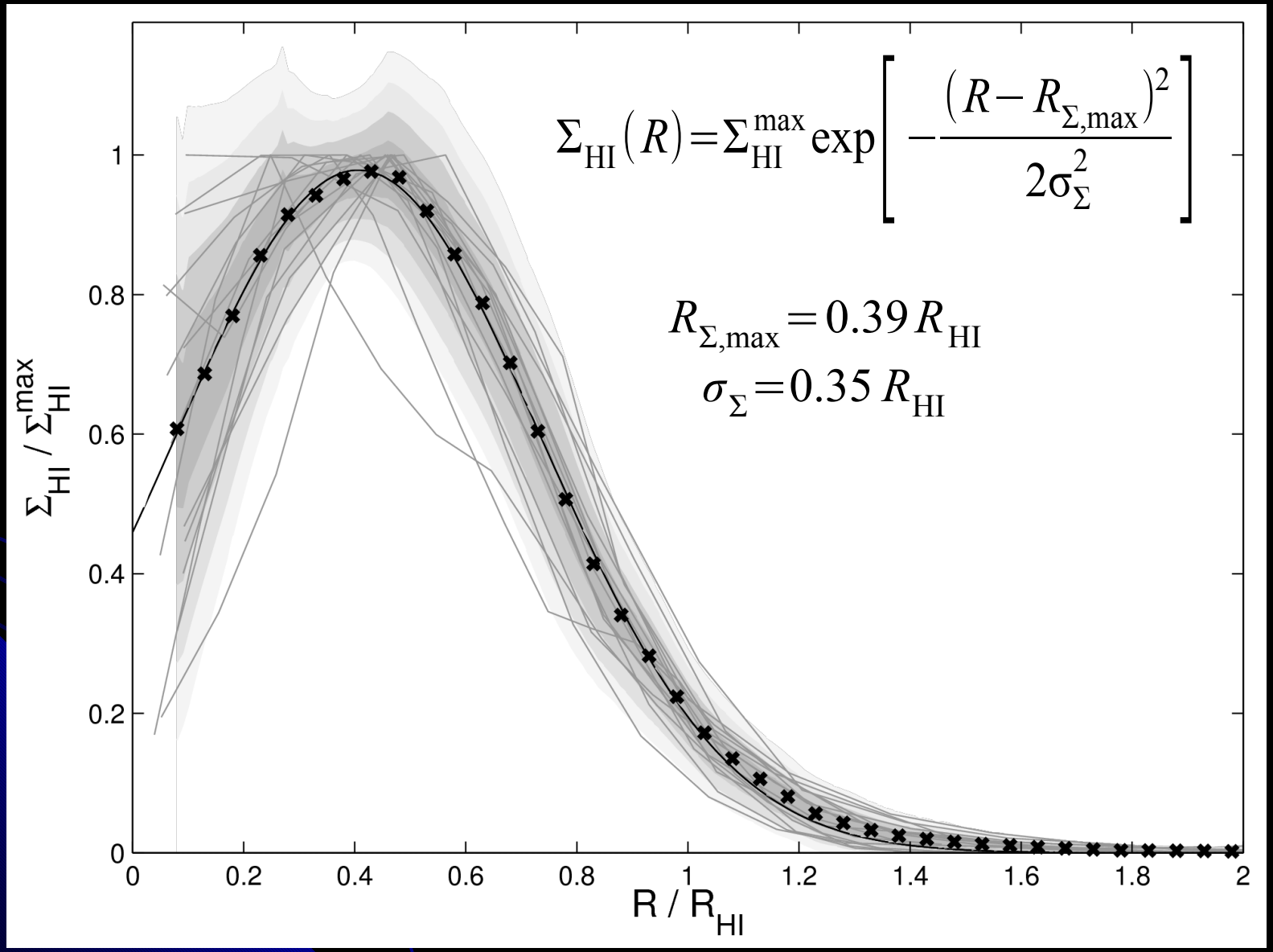
The radial Σ_{HI} profile



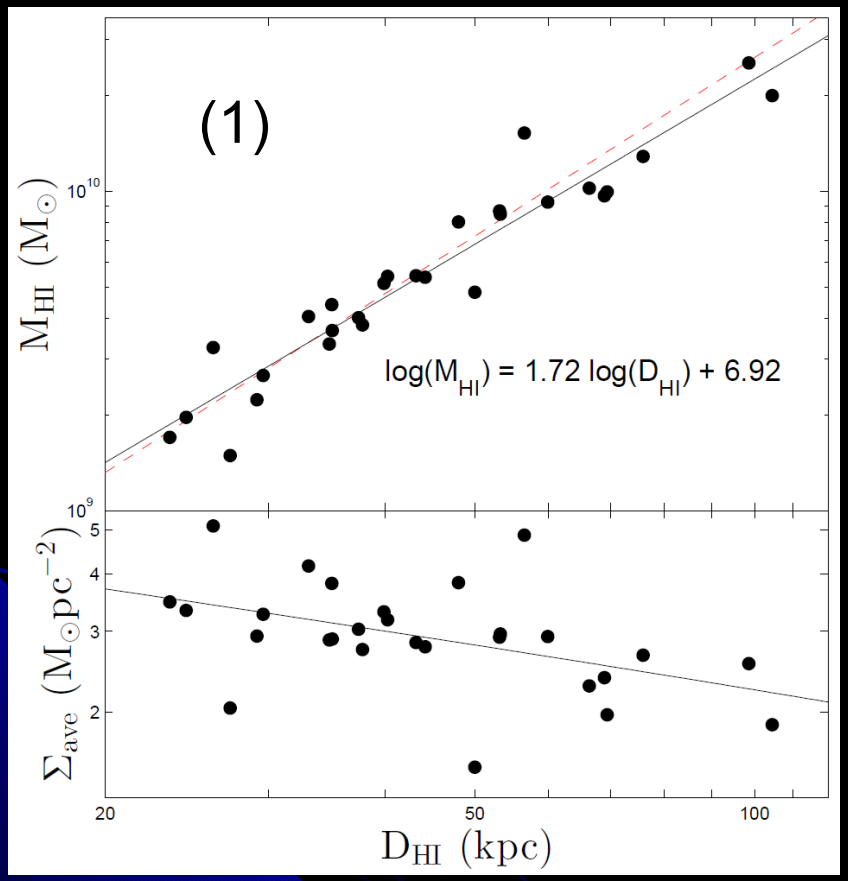
The radial Σ_{HI} profile



The average radial Σ_{HI} profile

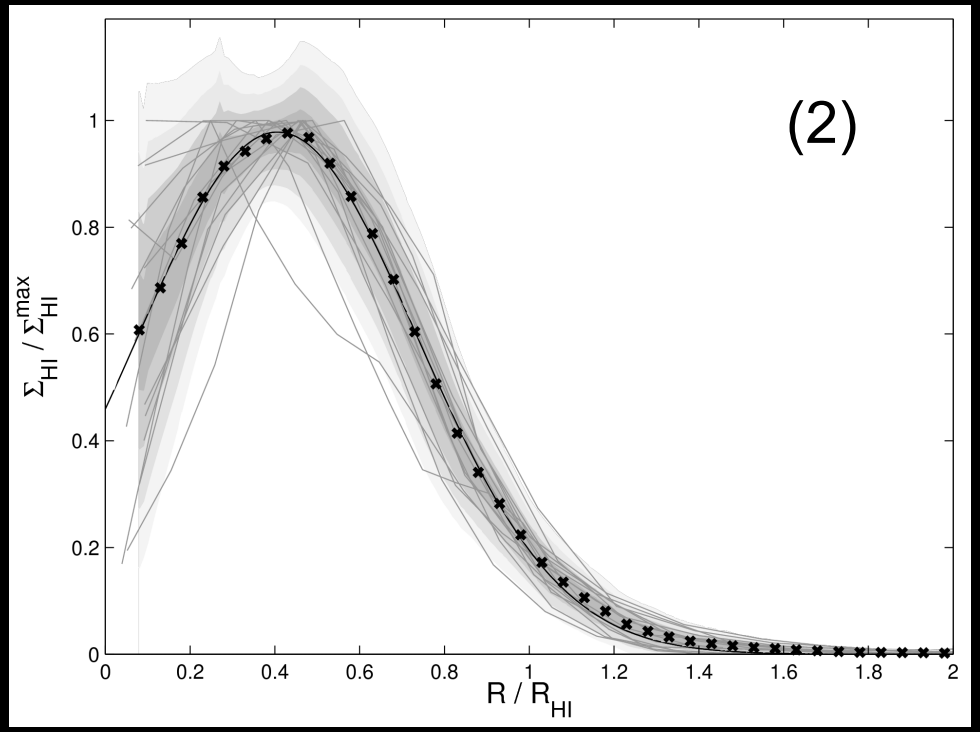


HI mass distributions from (single-dish) total-flux measurements



(Martinsson, 2011)

- M_{HI} from total flux (+ distance)
- $R_{HI}=D_{HI}/2$ from relation (1)
- Radial mass distribution from (2) (M_{HI} to normalize)



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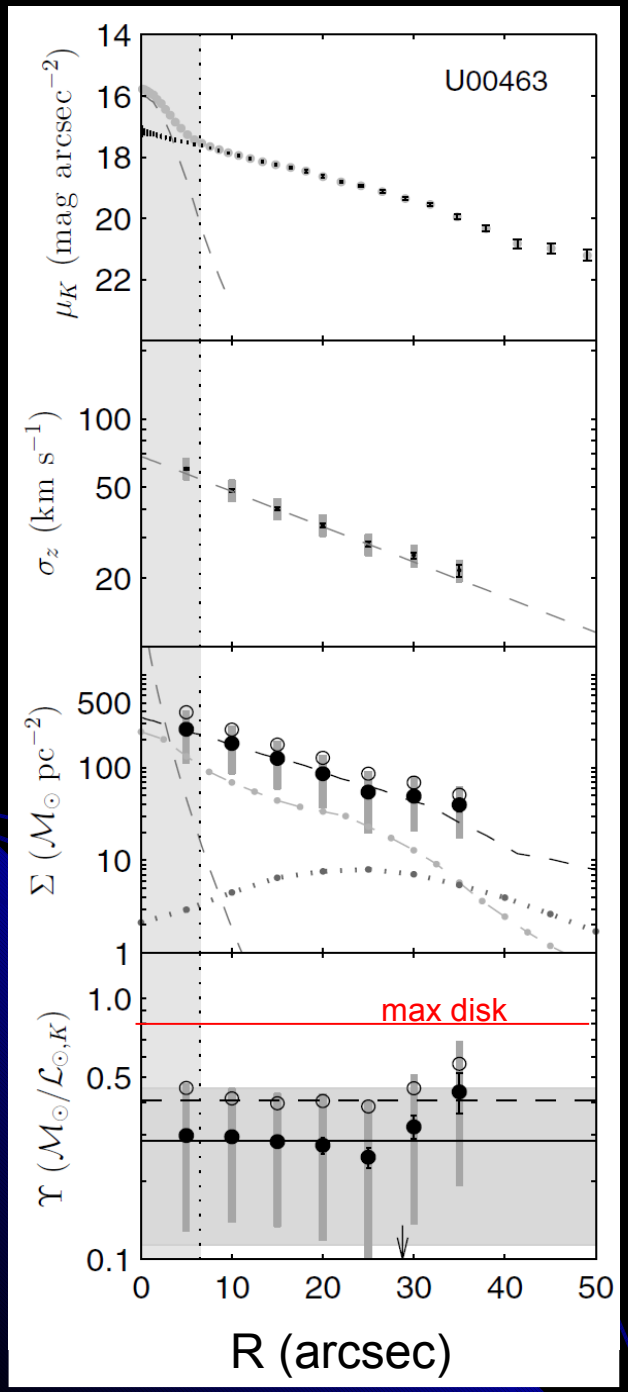
From σ_z to M/L



μ_K

σ_z

Σ

$(M/L)_K$

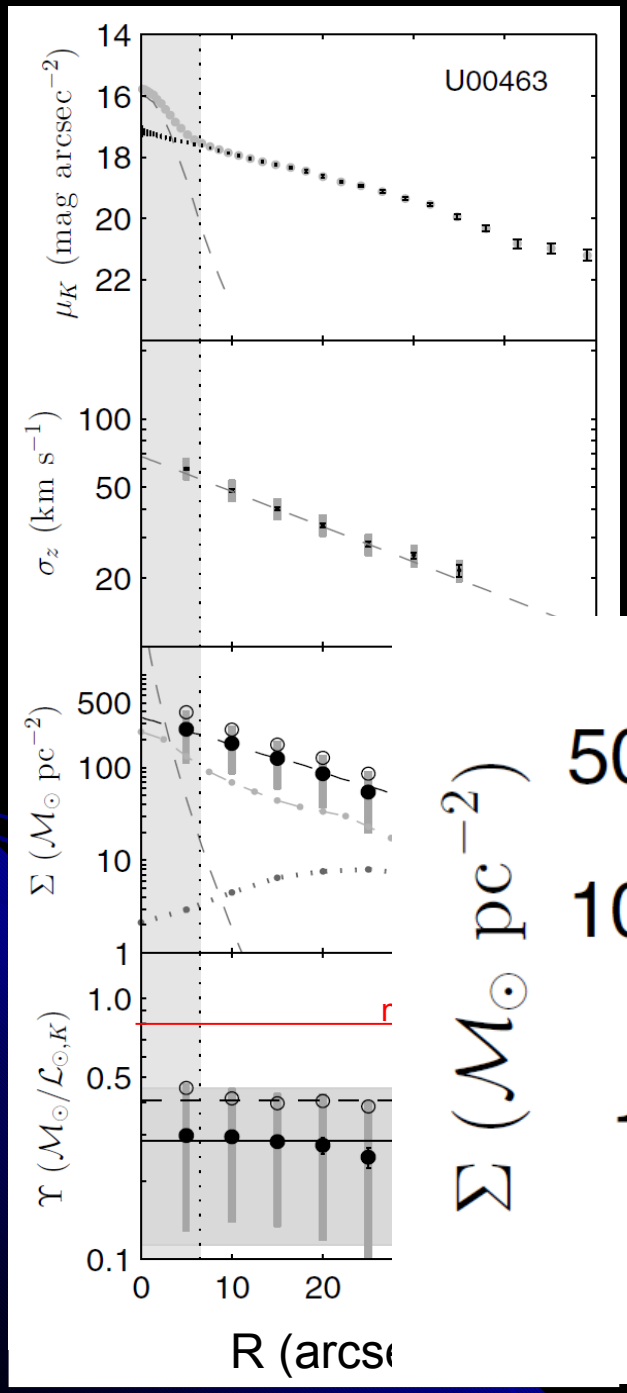
$$M/L = \frac{\Sigma_{dyn}}{\mu} = \frac{\sigma_z^2}{\mu \pi G k h_z}$$

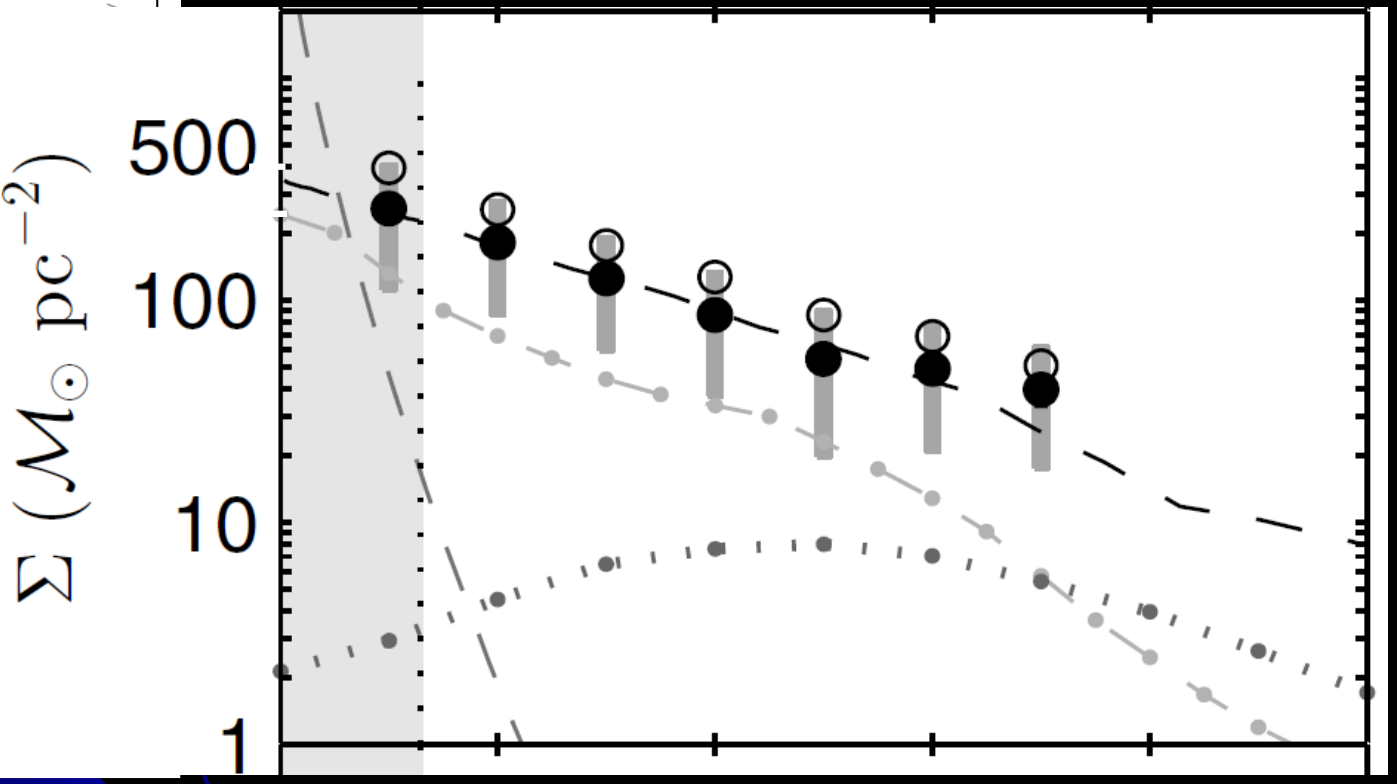
From σ_z to M/L

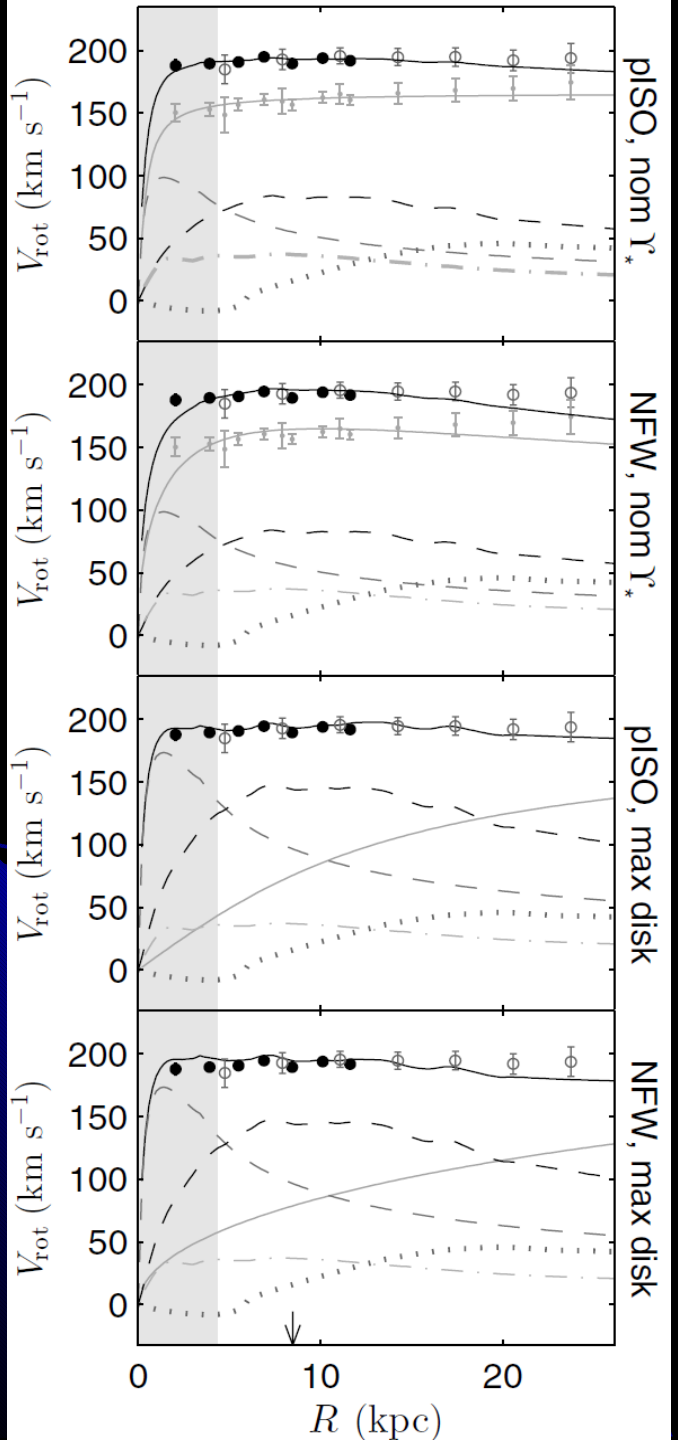
μ_K

σ_z

$$\Sigma_{\rm dyn} = \frac{\sigma_z^2}{\pi G k h_z}$$







pISO

NFW

Max. Disk

Rotation-Curve Mass Decomposition

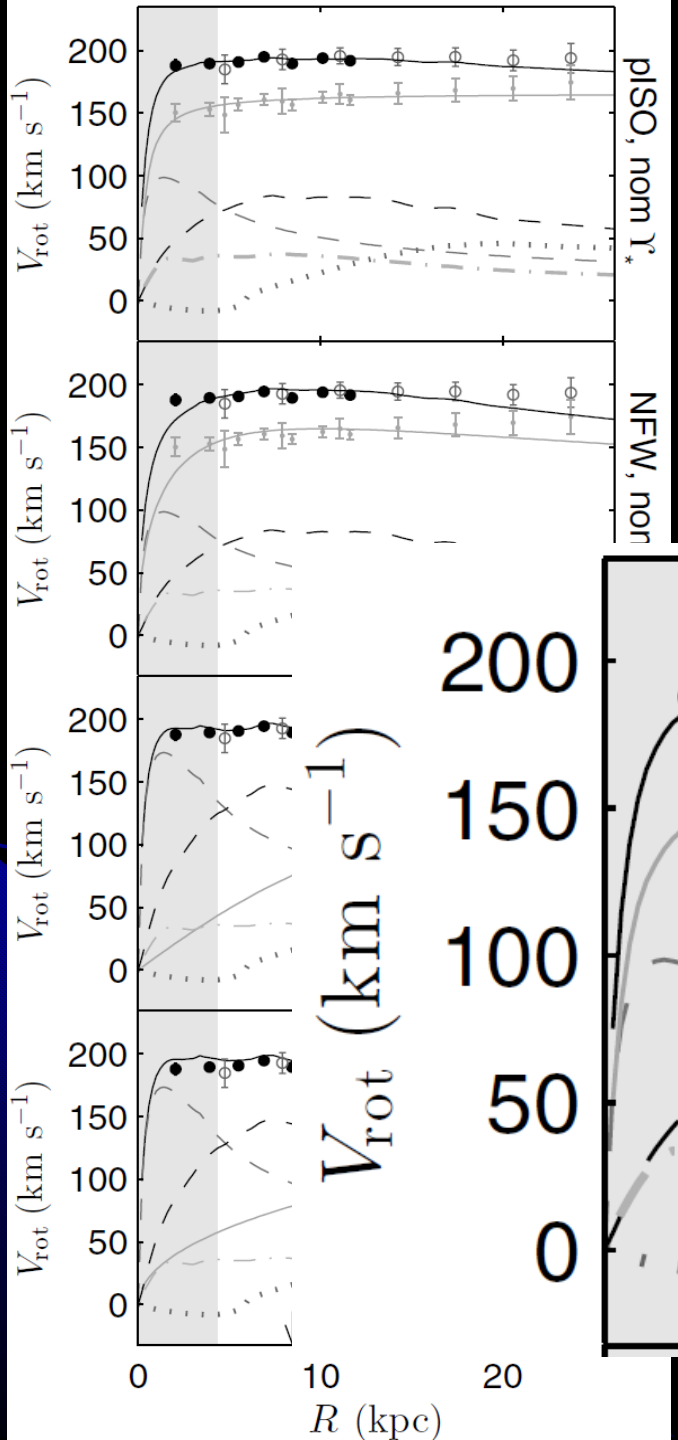
$$V_c^2 = V_{*,\rm bulge}^2 + V_{*,\rm disk}^2 + V_{\rm mol.gas}^2 + V_{\rm atom.gas}^2 + V_{\rm DM}^2$$

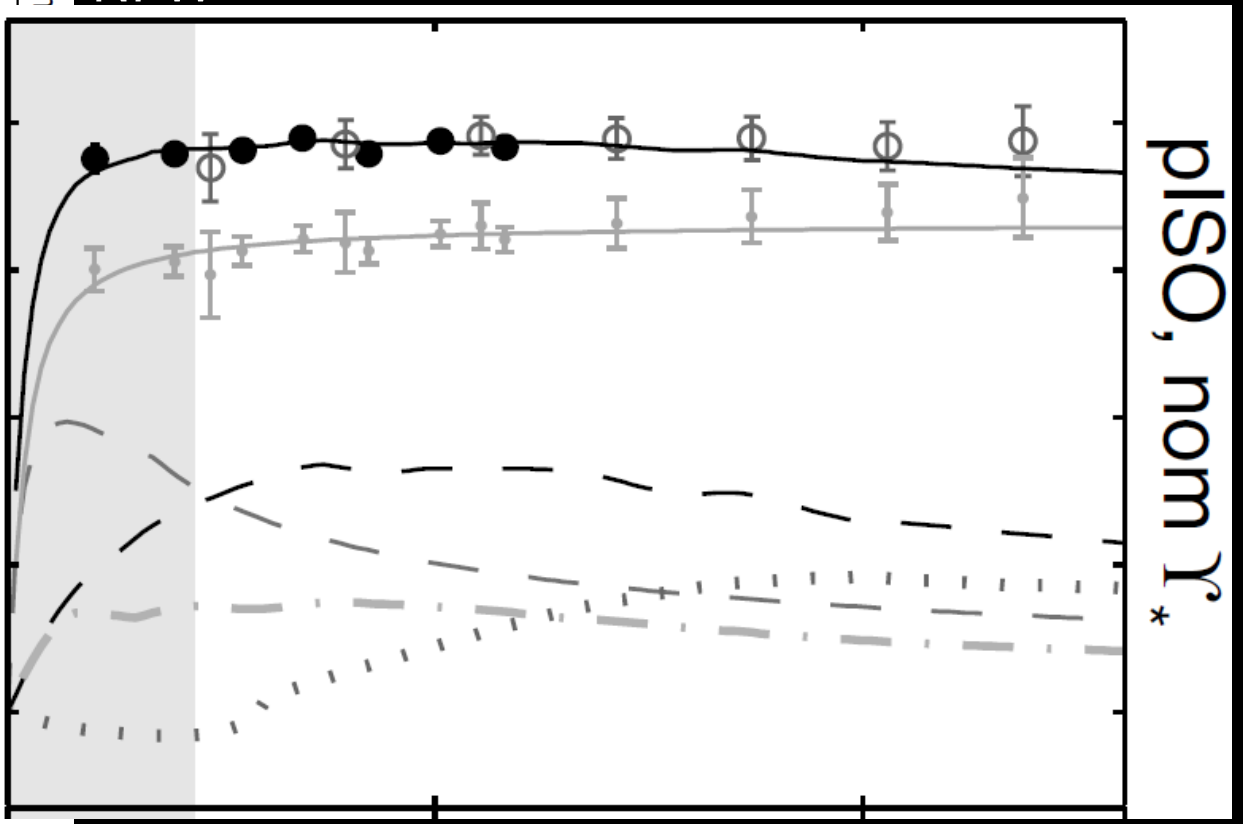
Rotation-Curve Mass Decomposition

pISO

$$V_c^2 = V_{*,\mathrm{bulge}}^2 + V_{*,\mathrm{disk}}^2 + V_{\mathrm{mol.gas}}^2 + V_{\mathrm{atom.gas}}^2 + V_{\mathrm{DM}}^2$$

NFW



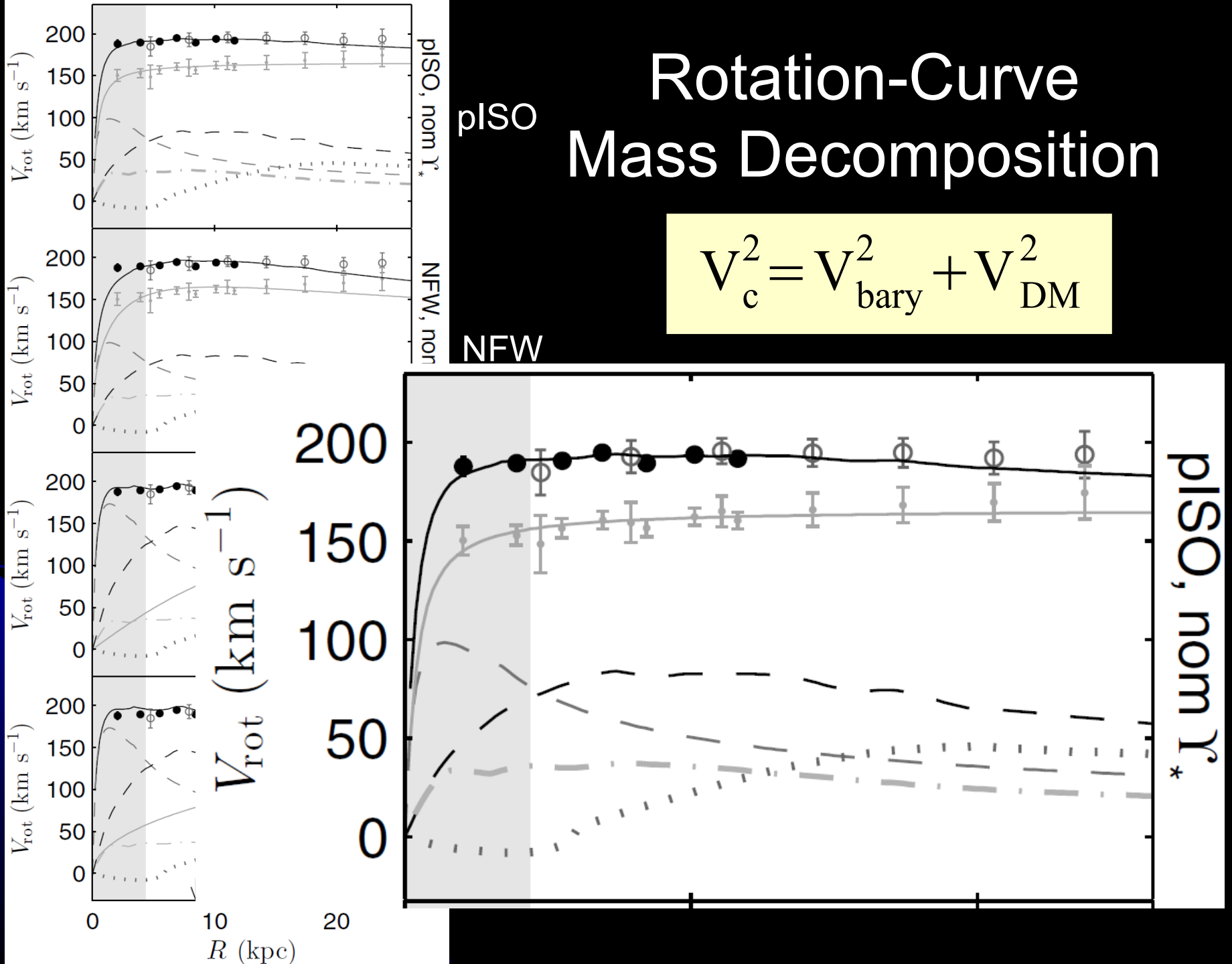


Rotation-Curve Mass Decomposition

pISO

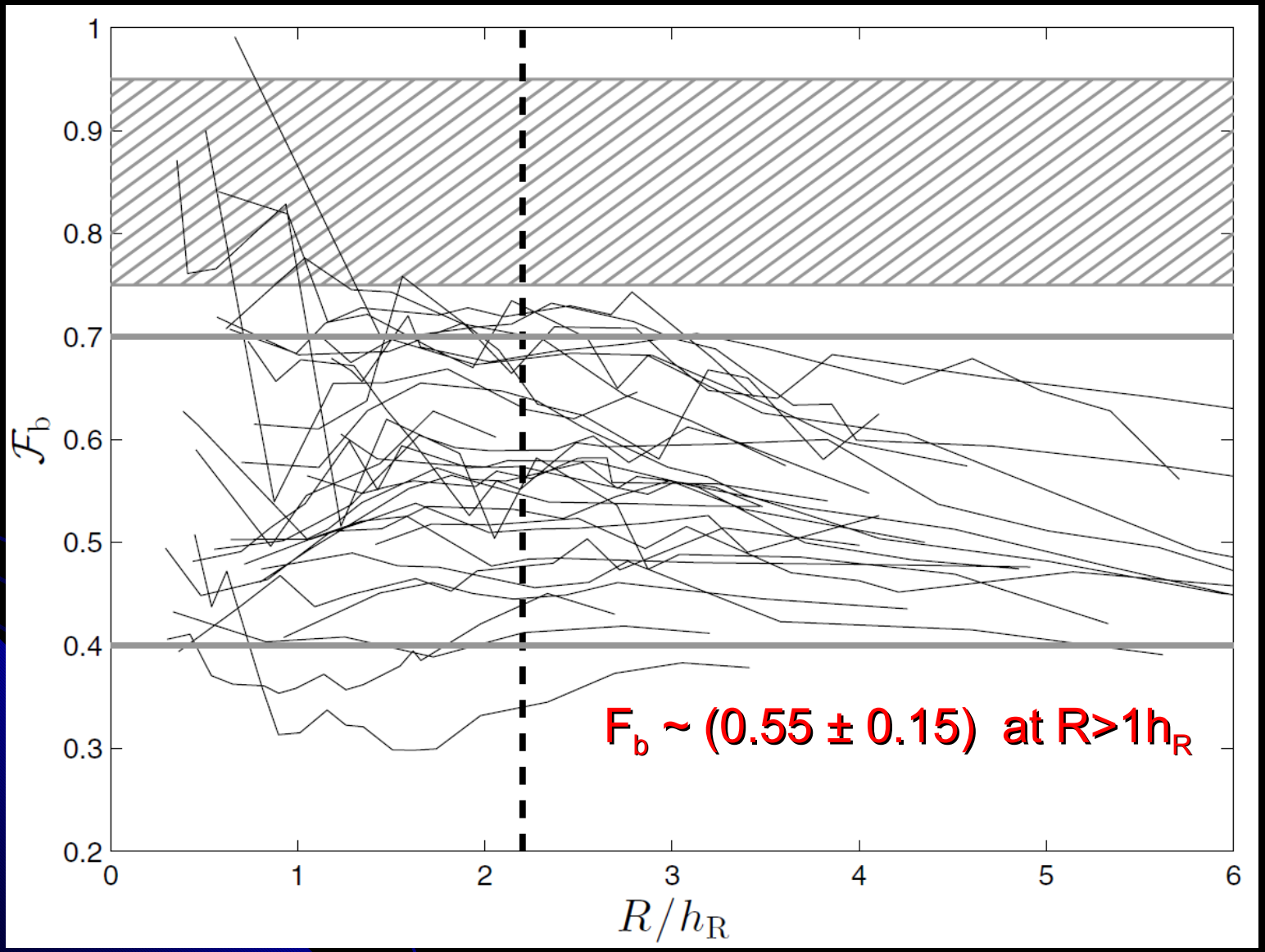
NFW

$$V_c^2 = V_{bary}^2 + V_{DM}^2$$



Baryonic Mass Fraction

$(F_b = V_b / V_c)$



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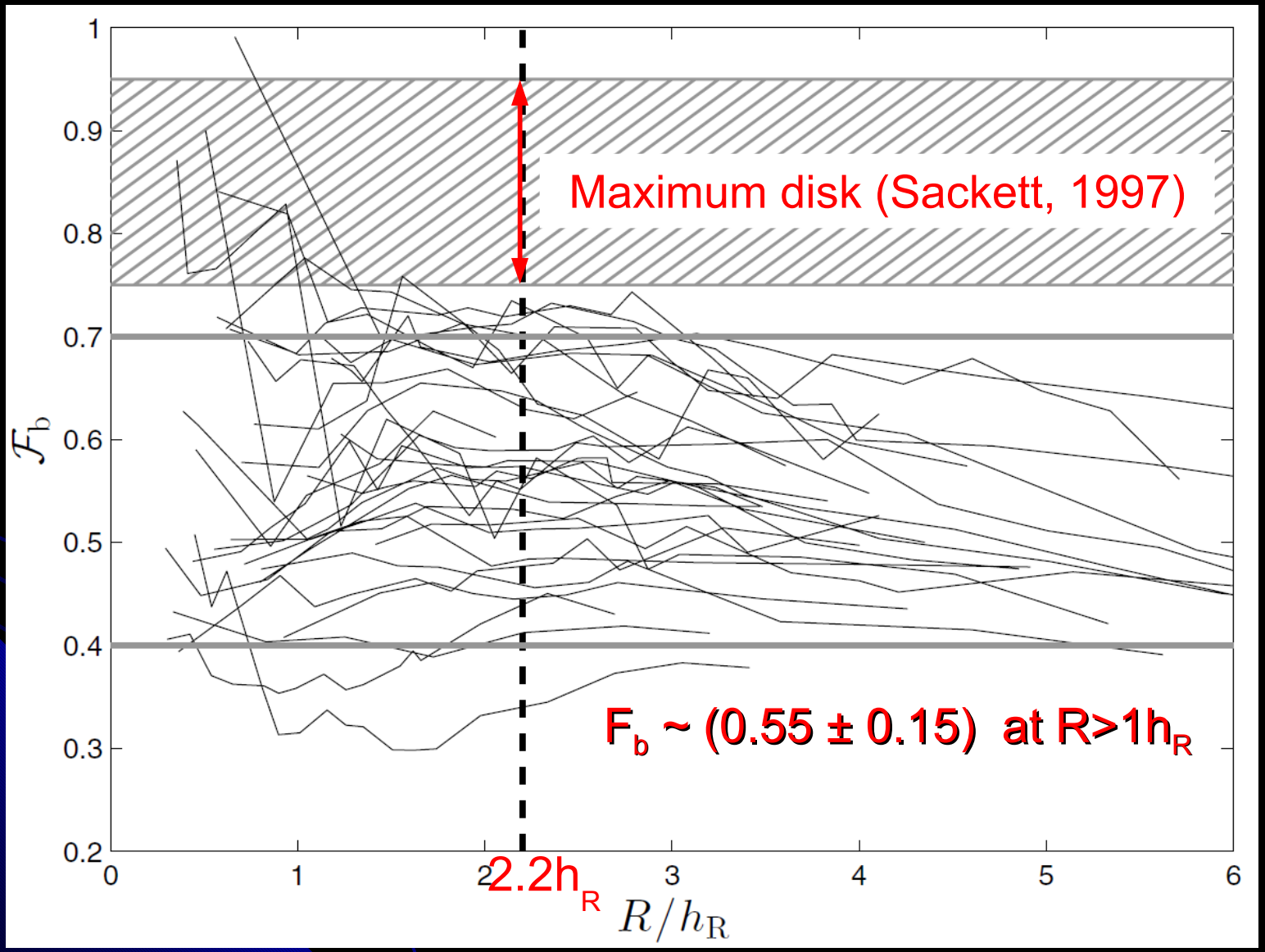
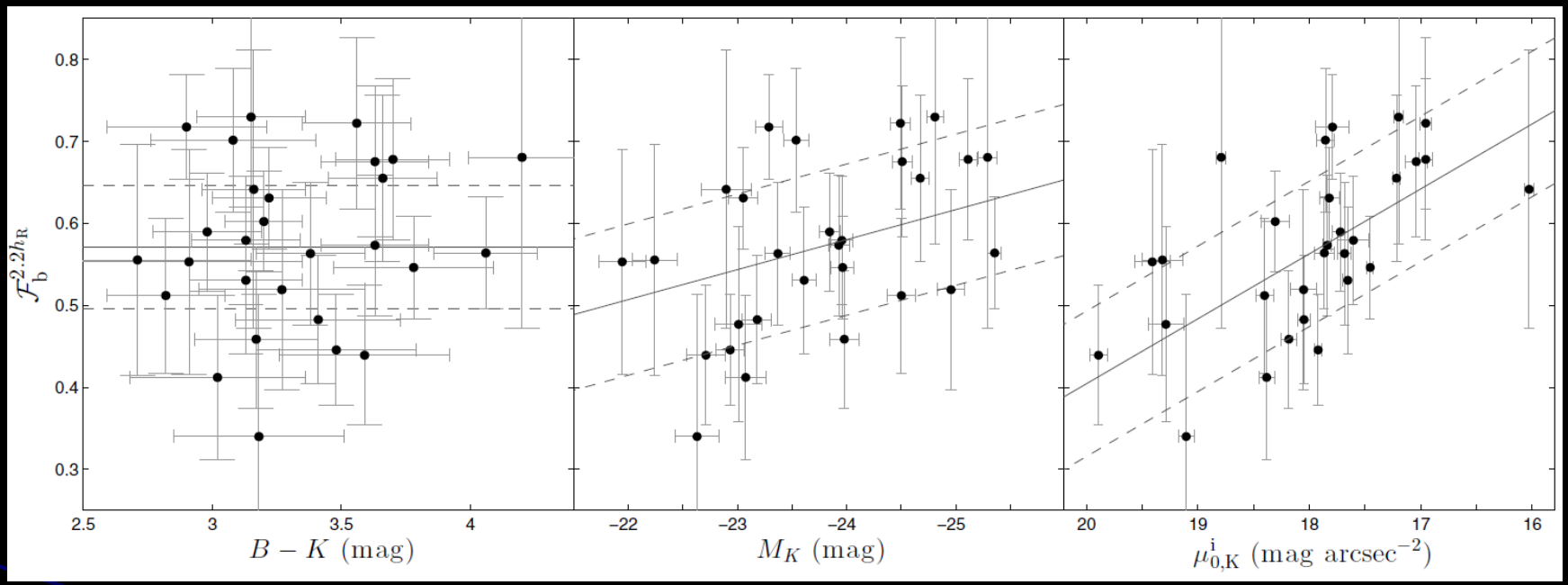


Sub-maximal disks

$F_b^{2.2h_R}$



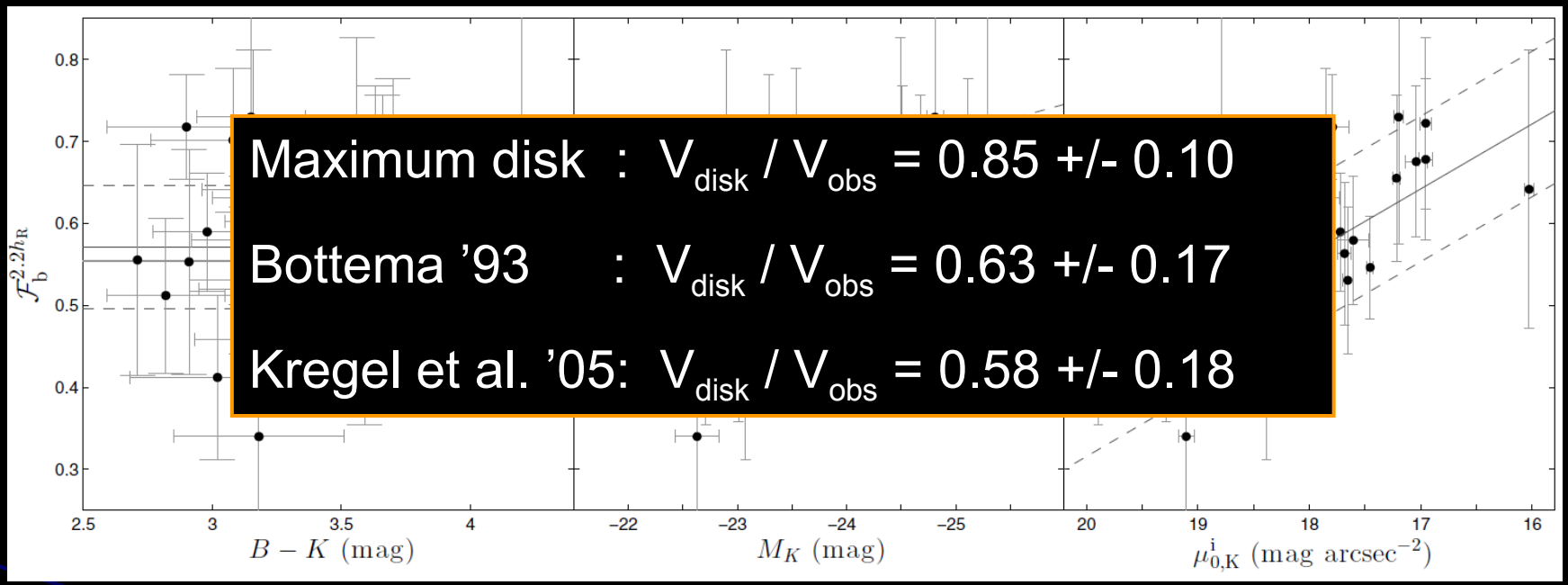
B-K M_K $\mu^i_{0,K}$

$$F_b^{2.2h_R} = 0.57 \pm 0.07$$

~30% baryons
~70% dark matter

(on average, within 2.2hR)

Sub-maximal disks



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$$F_b^{2.2h_R} = 0.57 \pm 0.07$$

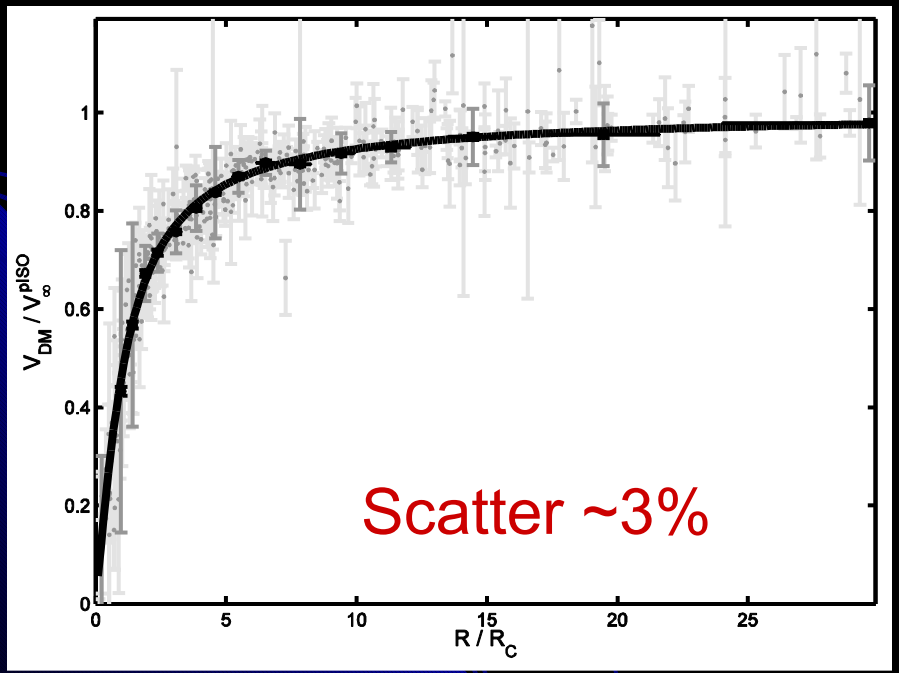
~30% baryons
~70% dark matter

(on average, within 2.2hR)

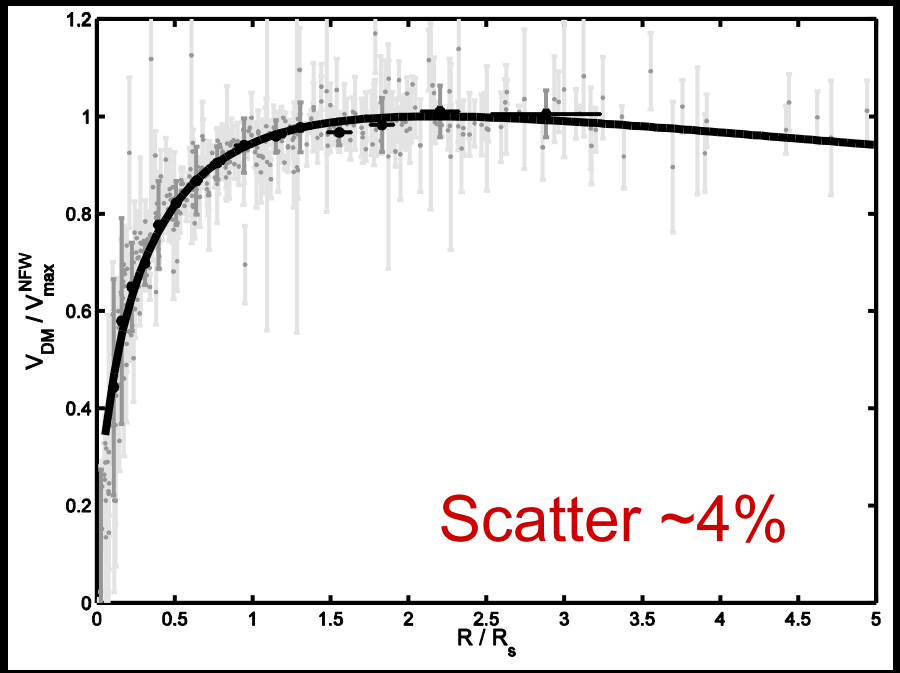
Dark Matter in Spiral Galaxies

30 uniquely determined dark-matter rotation curves normalized with fitted pISO or NFW parameters

pISO

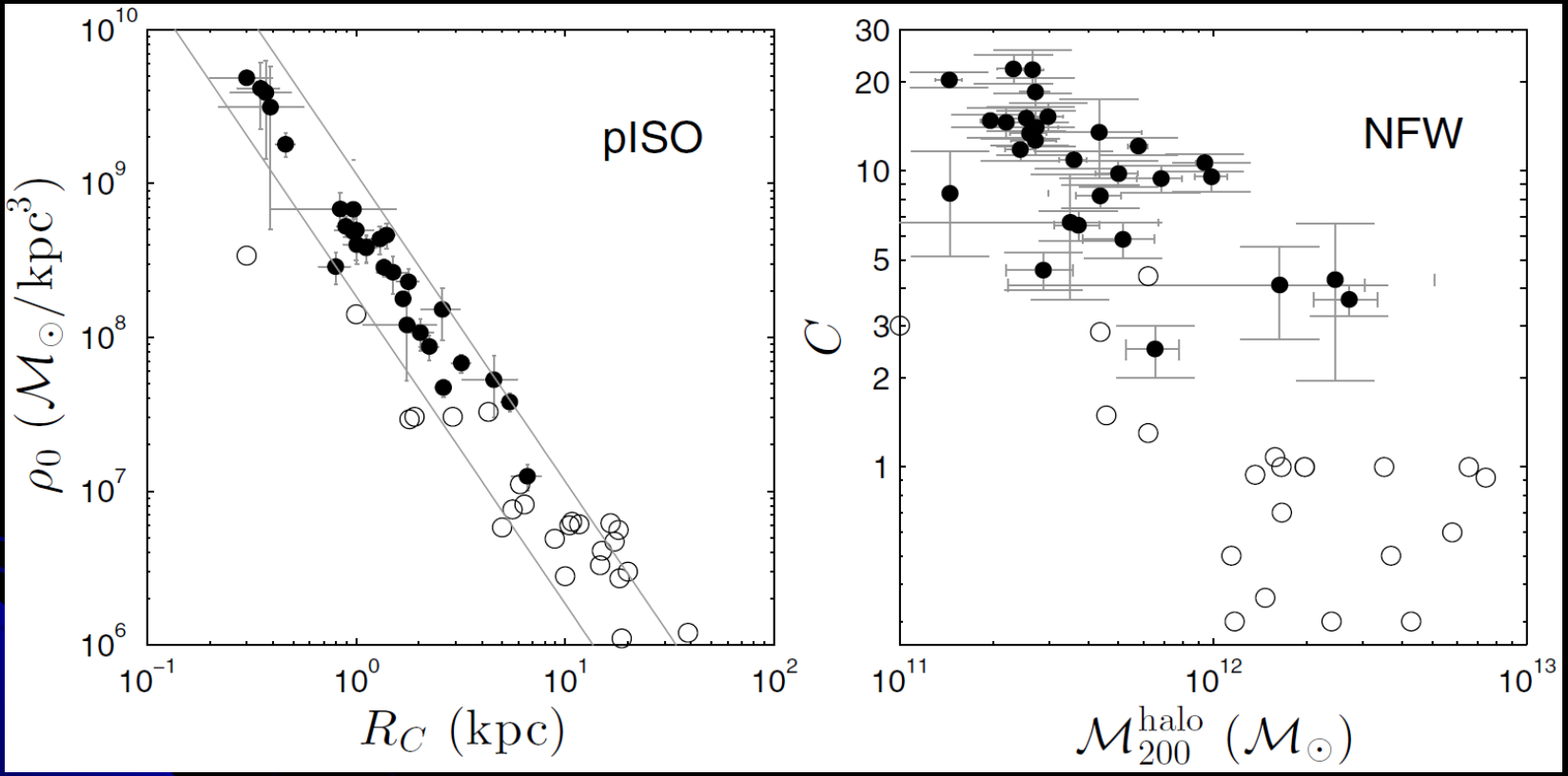


NFW

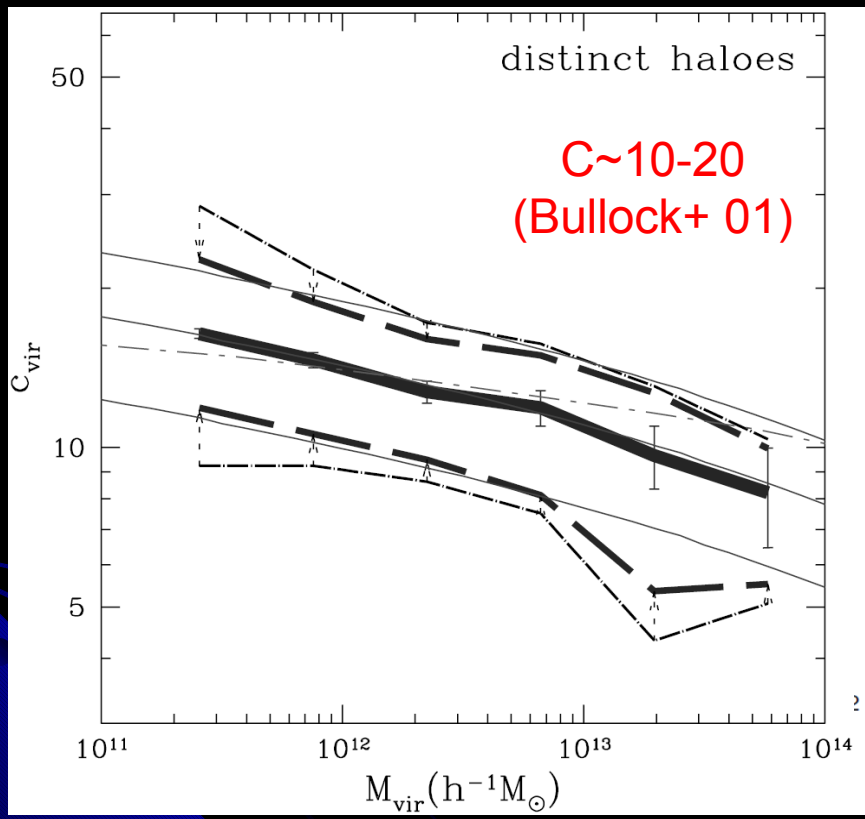


(Martinsson, 2013b)

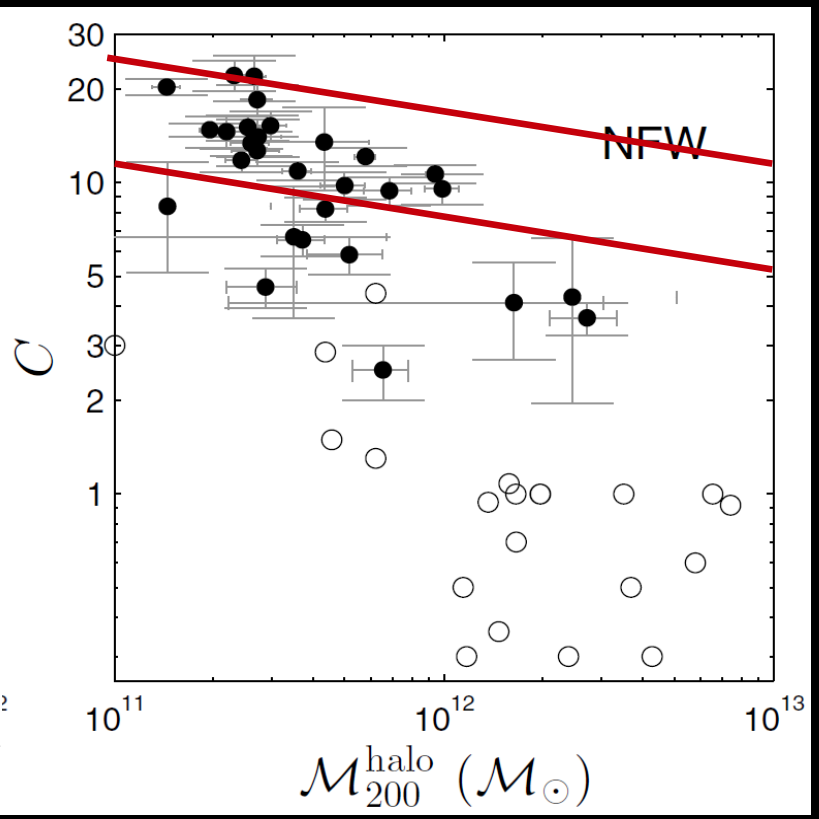
Dark Matter in Spiral Galaxies



Dark Matter in Spiral Galaxies



(Bullock et al. 2001)

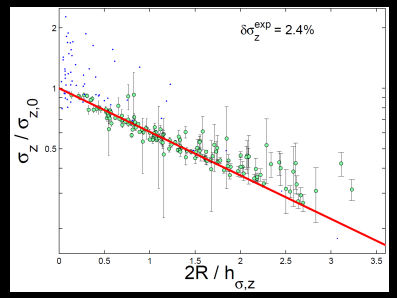


(Martinsson et al., 2013b)

Conclusions

Exponential radial decline of σ_z

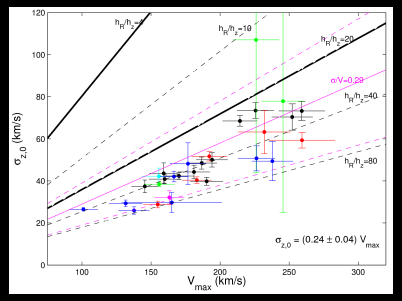
($h_\sigma \sim 2h_R$)



Tight relation between σ_z and V_{max}

$\sigma_{z,0} = (0.25 \pm 0.04)\ V_{max}$

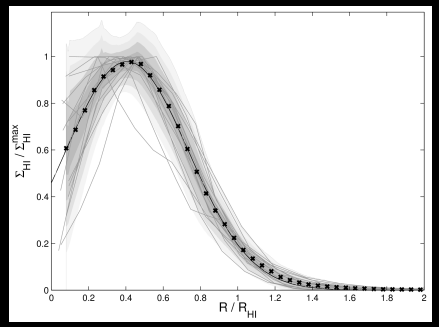
Implying that disks are sub-maximal



Gaussian Σ_{HI} profiles

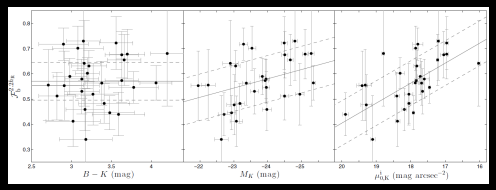
$R_{\Sigma,max} = 0.39\ R_{HI}$

$\sigma_\Sigma = 0.35\ R_{HI}$



Disks are sub-maximal

$F_{bary} = 0.57 \pm 0.07$



Dark matter distributed as in N-body simulations

C ~ 10-20