# Global dark energy and local gravity-antigravity interplay

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Dark energy was discovered
in observations
of the Hubble expansion flow
at the horizon-scale distances ~10 Gpc

Riess et al. (1998)
Perlmutter et al. (1999)

**2011**

DE produces antigravity which is stronger at present than matter gravity in the Universe as a whole

The simplest straightforward assumption ($\Lambda$CDM model):

Dark energy is described by the Einstein cosmological constant $\Lambda$

It has long been taken for granted that

$\Lambda$ (=DE) is significant only

for the Universe as a whole

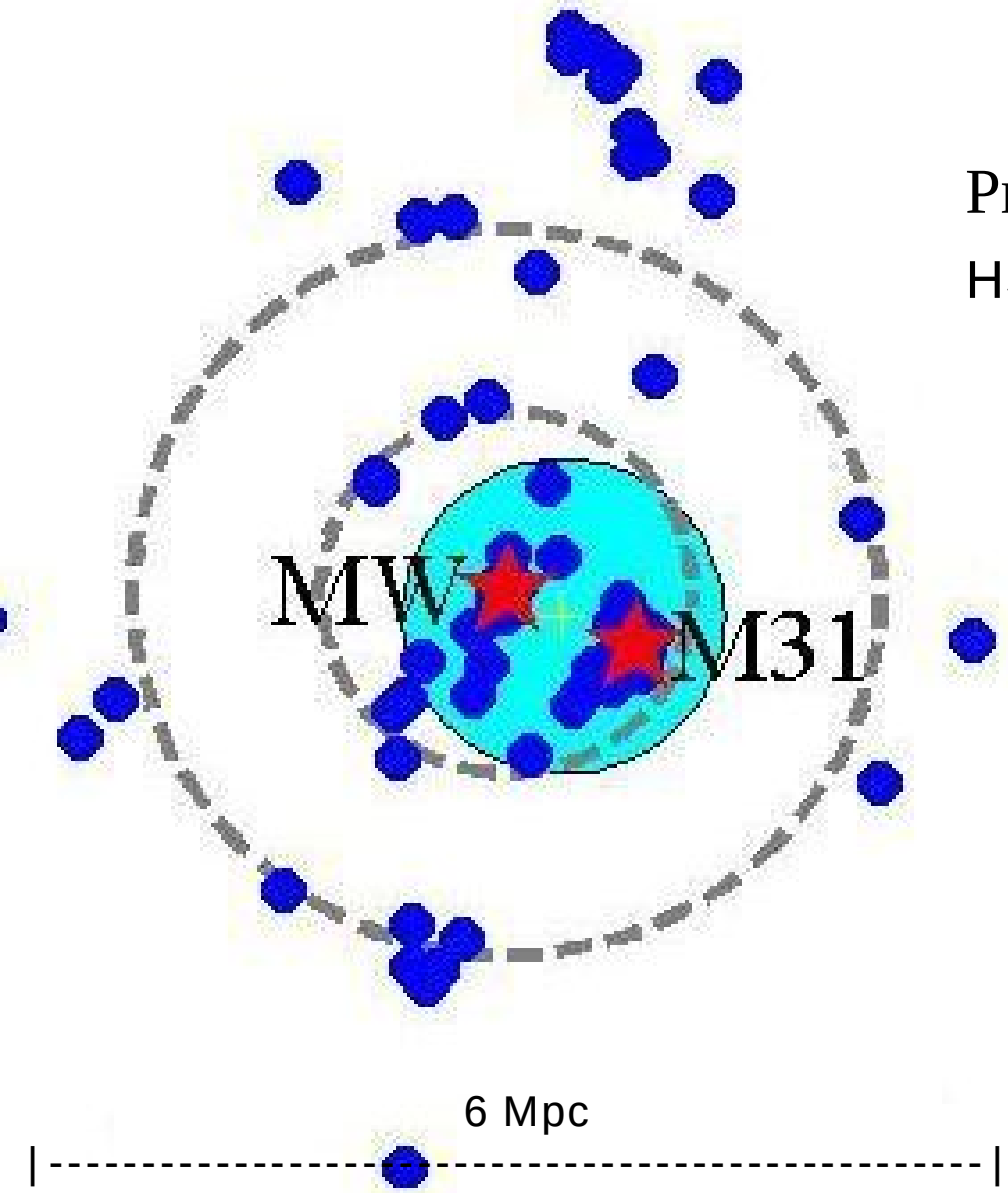
Chernin, Teerikorpi, & Baryshev (2000):

In fact, DE antigravity acts everywhere in space;

it is stronger than matter gravity

at distance of ~ 1 Mpc from us

# LOCAL GROUP & OUTFLOW: MAP




Projection on Supergalactic Plane

HST data: Karachentsev et al. 2006

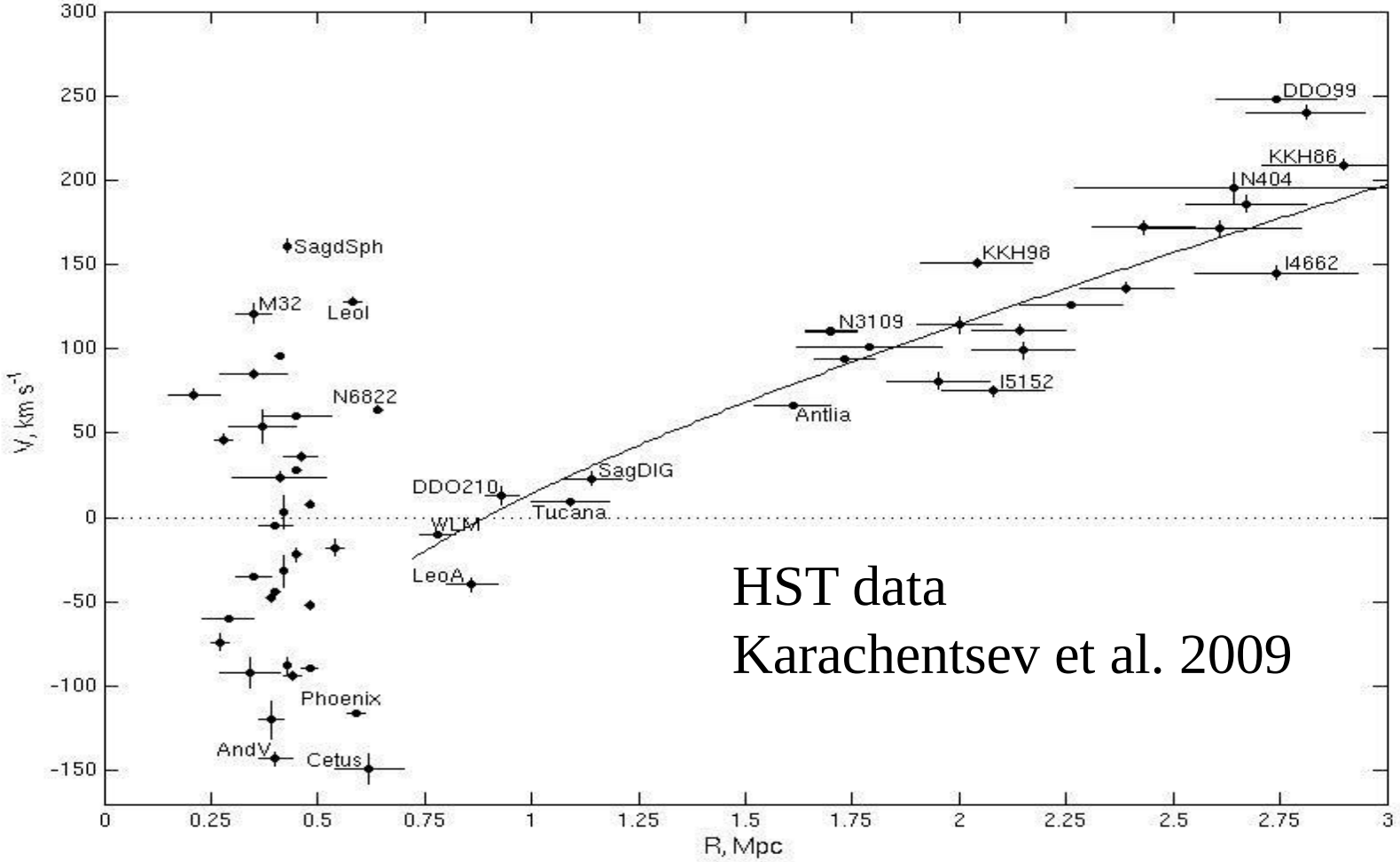
Group matter mass

$M \approx (2\text{-}4)\ 10^{12}\ M_{sun}$

Group radial size

$R \approx$ **1-1.3 Mpc**

# LOCAL GROUP & OUTFLOW: V vs. R



# LOCAL GROUP & OUTFLOW: MODEL

# group & outflow are imbedded in the DE background of constant uniform density (the same in any reference frame)

# group: a bound MW-M31 binary

# outflow of dwarf galaxies: moving test particles

# Einstein antigravity law

Two bodies undergo mutual repulsion force $F_E$ which is proportional to the distance R between them:

$$F_E = - G M_{eff}/R^2 = + (8\pi/3)G \rho_\Lambda R$$

$$M_{eff} = (4\pi/3) \rho_{eff} R^3; \qquad \rho_\Lambda = - \mathbf{p}_\Lambda;$$

$$\rho_{eff} = \rho_\Lambda + 3 p_\Lambda = - 2\rho_\Lambda < 0$$

# LOCAL GRAVITY vs. ANTIGRAVITY

Kottler (1918): point-like mass on $\Lambda$-background

$$ds^2 = A(R)\, dt^2 - R^2\, d\boldsymbol{\Omega}^2 - A^{-1}\, dR^2$$

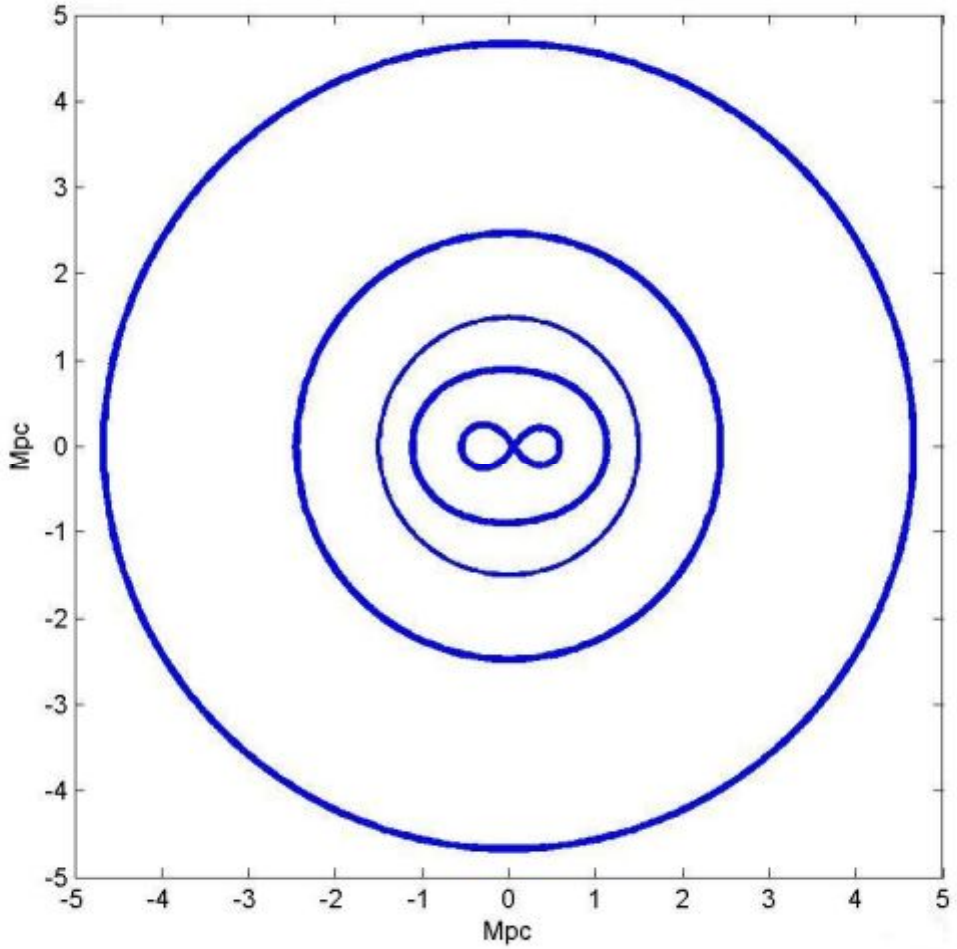
$$A(R) = 1 - 2GM/R - (8\pi G/3)\, \boldsymbol{\rho_\Lambda}\, R^2$$

Newton limit:

$$1 + \varphi \approx A^{1/2} \approx 1 - GM/R - (4\pi G/3)\, \boldsymbol{\rho_\Lambda}\, R^2$$

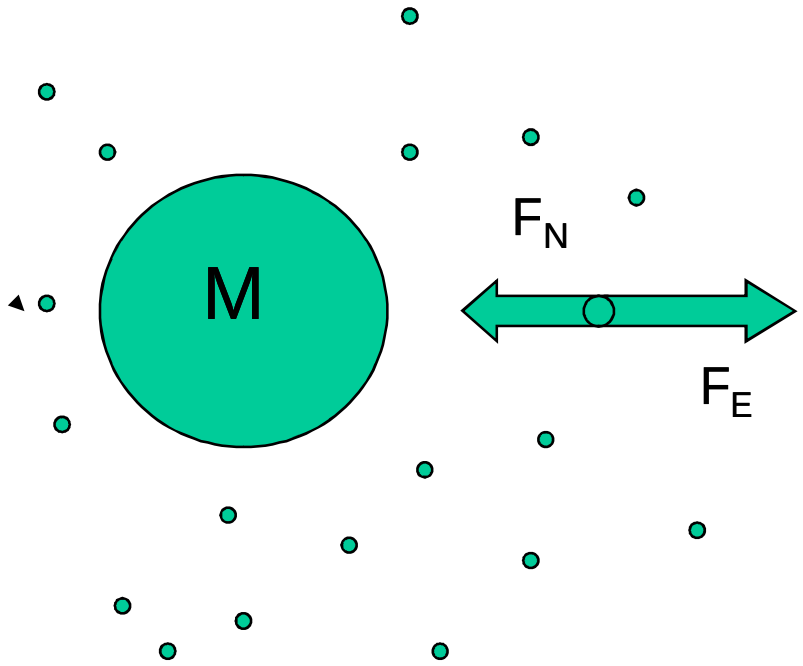
$$F(R) = -\operatorname{grad} \varphi = -GM/R^2 + (8\pi G/3)\, \boldsymbol{\rho_\Lambda}\, R \quad \bullet$$

# LOCAL GRAVITY-ANTIGRAVITY POTENTIAL




**POTENTIAL IS SPERICAL IN OUTFLOW AREA**

# OUTFLOW in LOCAL FORCE FIELD



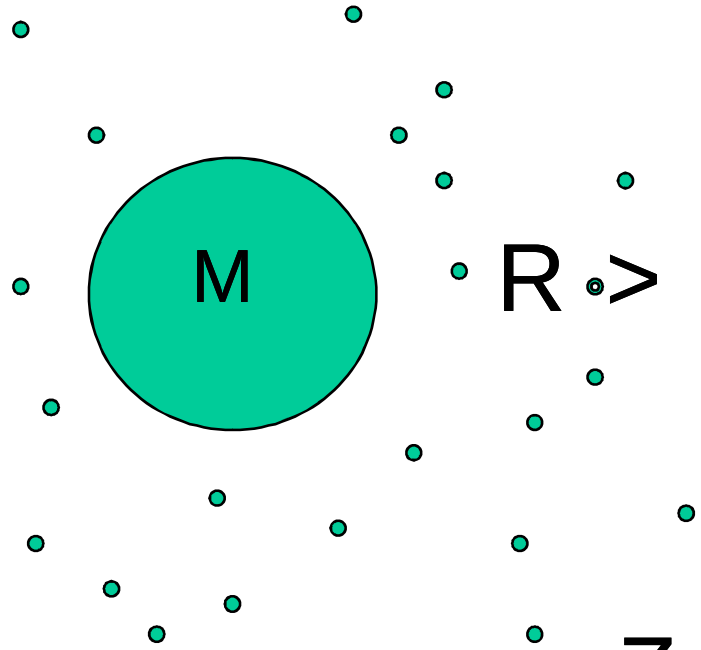

spherical mass
&
test particles around

Newton gravity: $F_N = - G M R^{-2}$

Einstein antigravity: $F_E = + (8\pi/3) G \rho_\Lambda R$

**(Center of mass frame, force per unit mass)**

# Antigravity is stronger than gravity, if



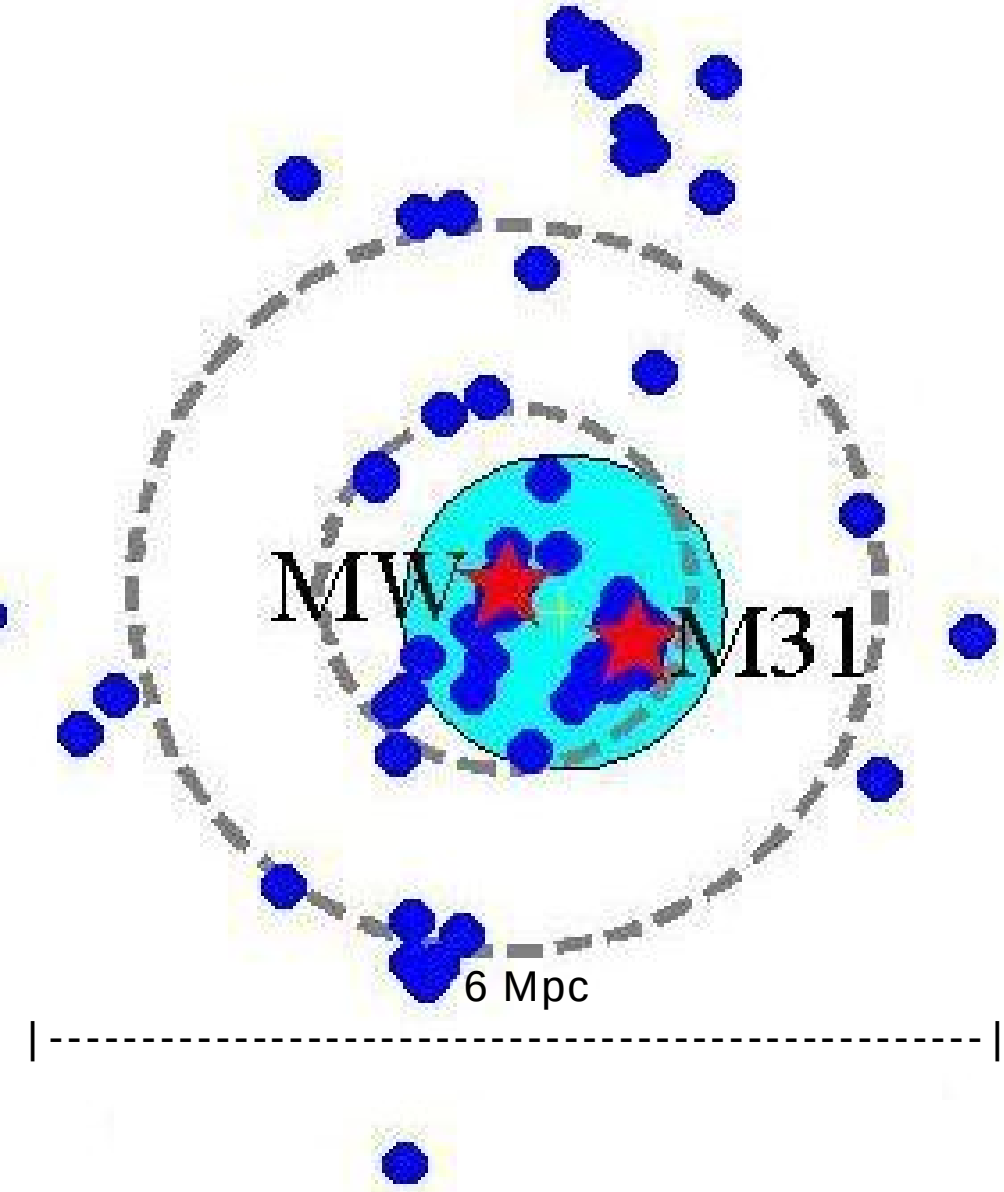

$$R > R_{ZG} = [\, 3\,M/(8\pi\,\rho_{\Lambda})\,]^{1/3}$$

Zero-gravity radius

$$R_{ZG} = 1.1 \cdot (M/10^{12}\,M_{sun})^{1/3} \quad \mathrm{Mpc}$$

**(Chernin et al. 2000)**

# LOCAL GROUP: $R \approx \mathbf{R_{ZG}}$




Group matter mass

$M \approx (2\text{-}4)\ 10^{12}\ M_{sun}$

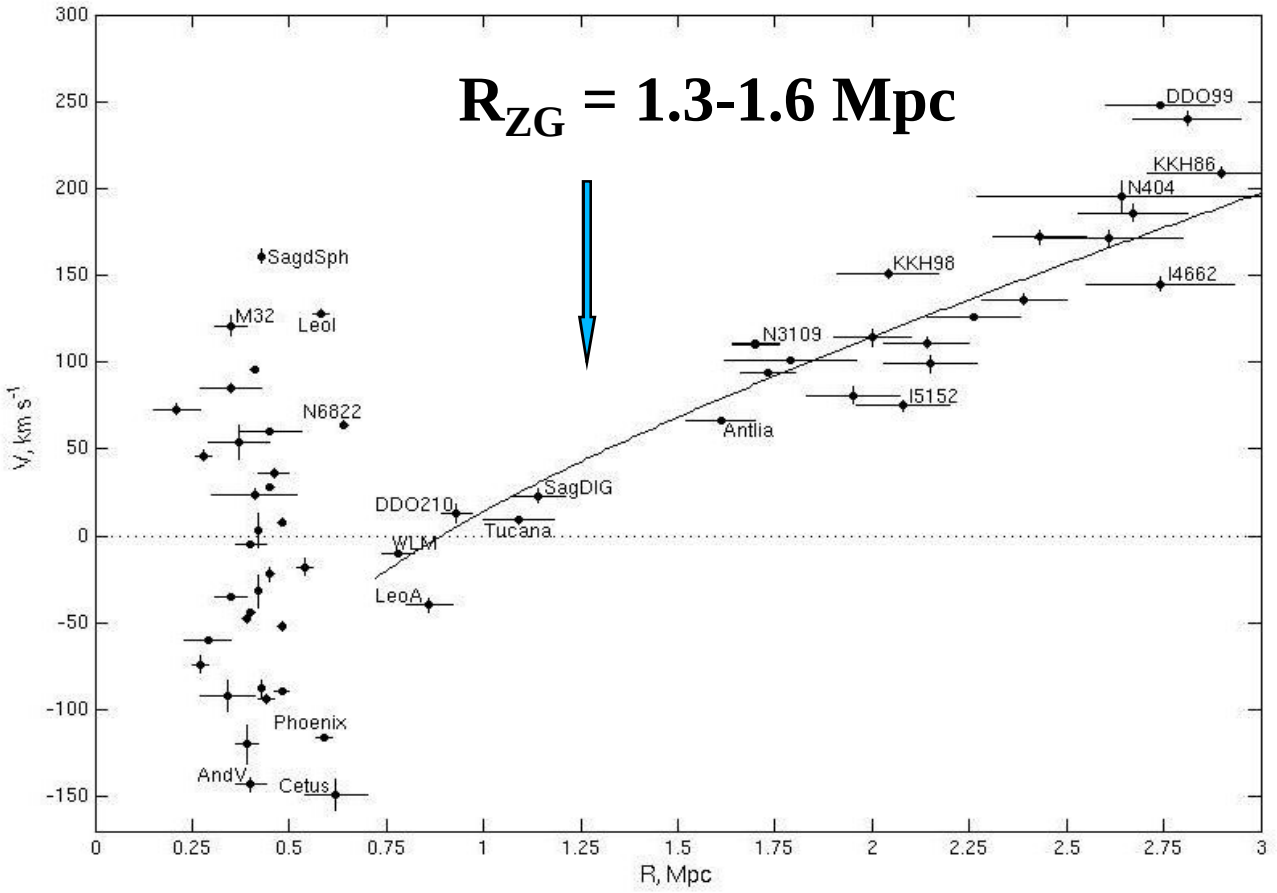
Group zero-gravity radius

$\mathbf{R_{ZG} \approx 1.3\text{-}1.6\ Mpc}$

Group radial size

$R \approx$ **1-1.3 Mpc**

# OUTFLOW: ANTIGRAVITY DOMINATES




group:

$R < R_{ZG}$

gravity dominates

outflow:

$R > R_{ZG}$

antigravity dominates

# OUTFLOW ACCELERATION: $R > R_{ZG}$

$$d^2R/dt^2 = - GM/R^2 + G(8\pi/3)\rho_\Lambda \; R > 0$$

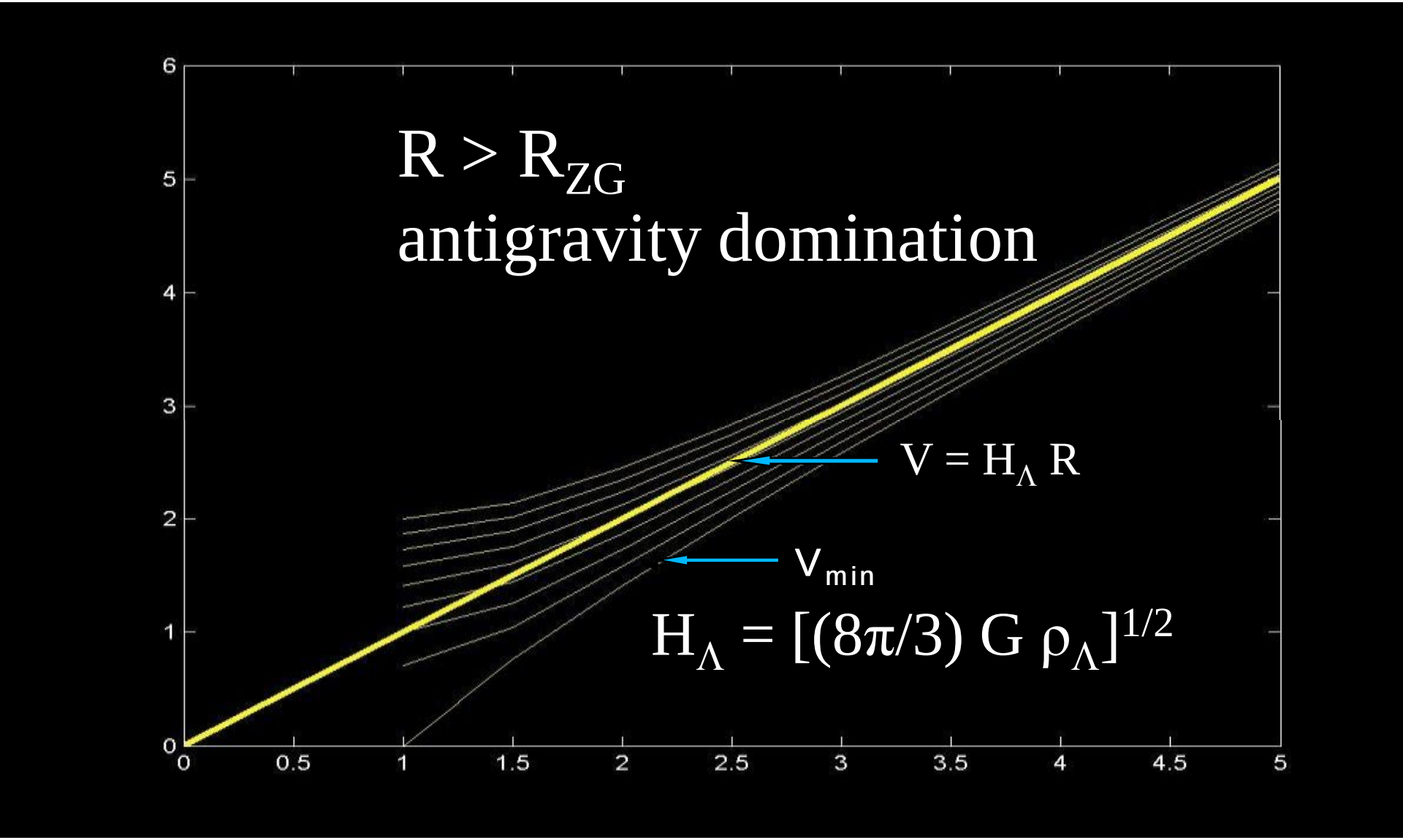
$$(1/2)\, V^2 = GM/R + G\,(4\pi/3)\; \rho_\Lambda\, R^2 + E,$$

**(E =Const)**

**Evolution trend: Hubble Law** $V \rightarrow H_\Lambda R$

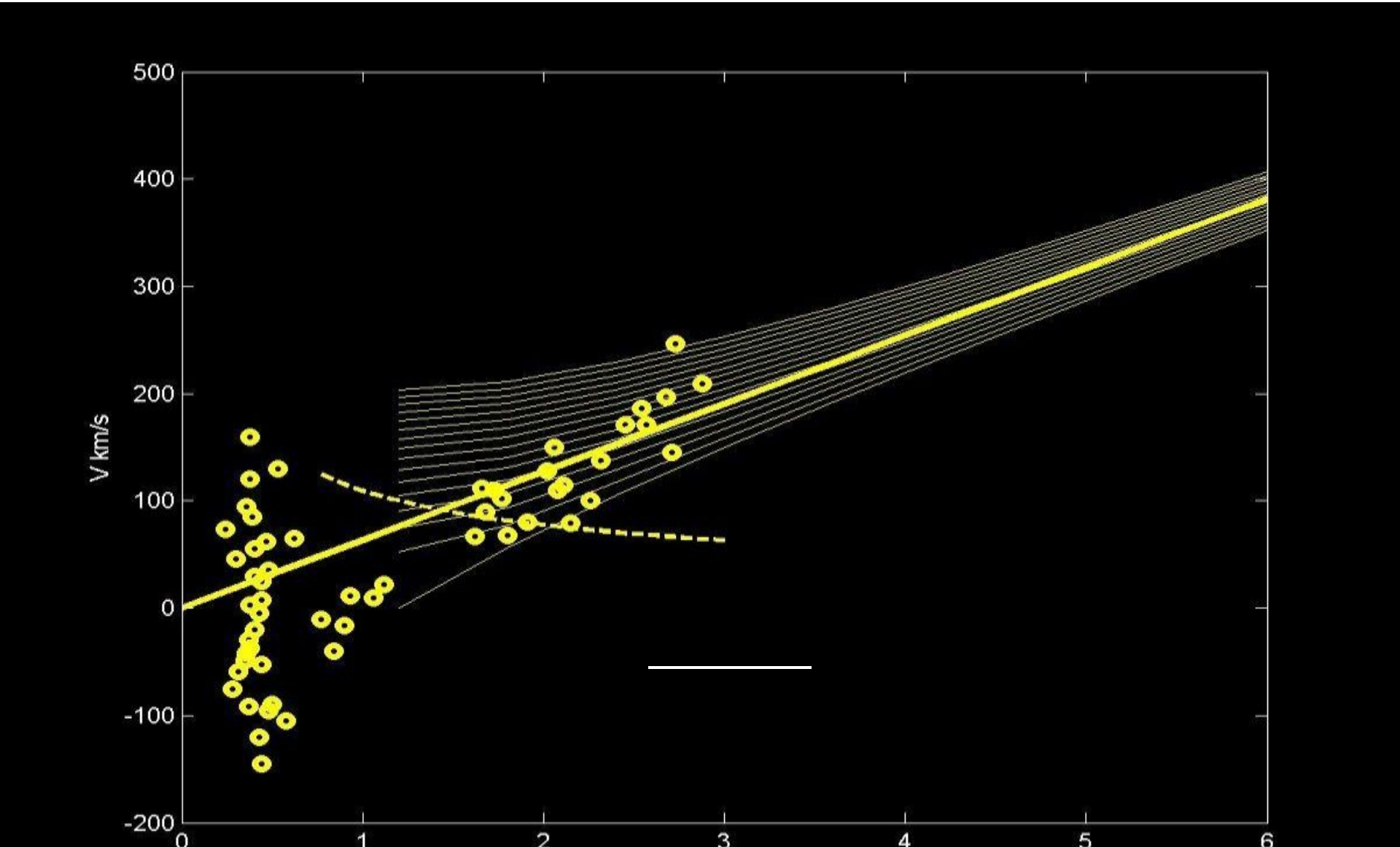
$$H_\Lambda = [(8\pi/3)\, G\, \rho_\Lambda]^{1/2} \approx 60 \quad \text{km/s/Mpc}$$

# MODEL: PHASE TRAJECTORIES

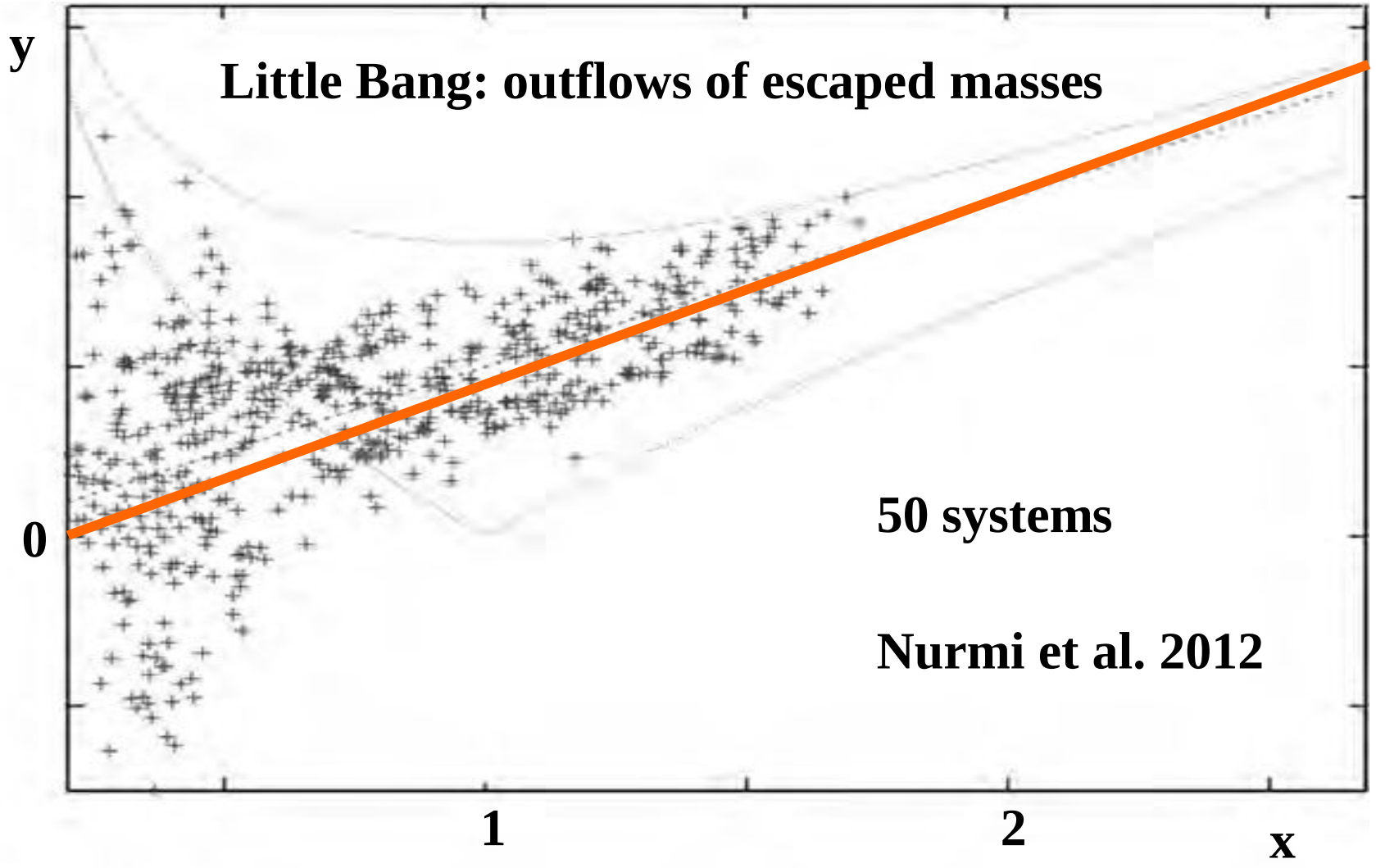



$x = R/R_{ZG}, \quad y = V/(H_\Lambda R_{ZG})$

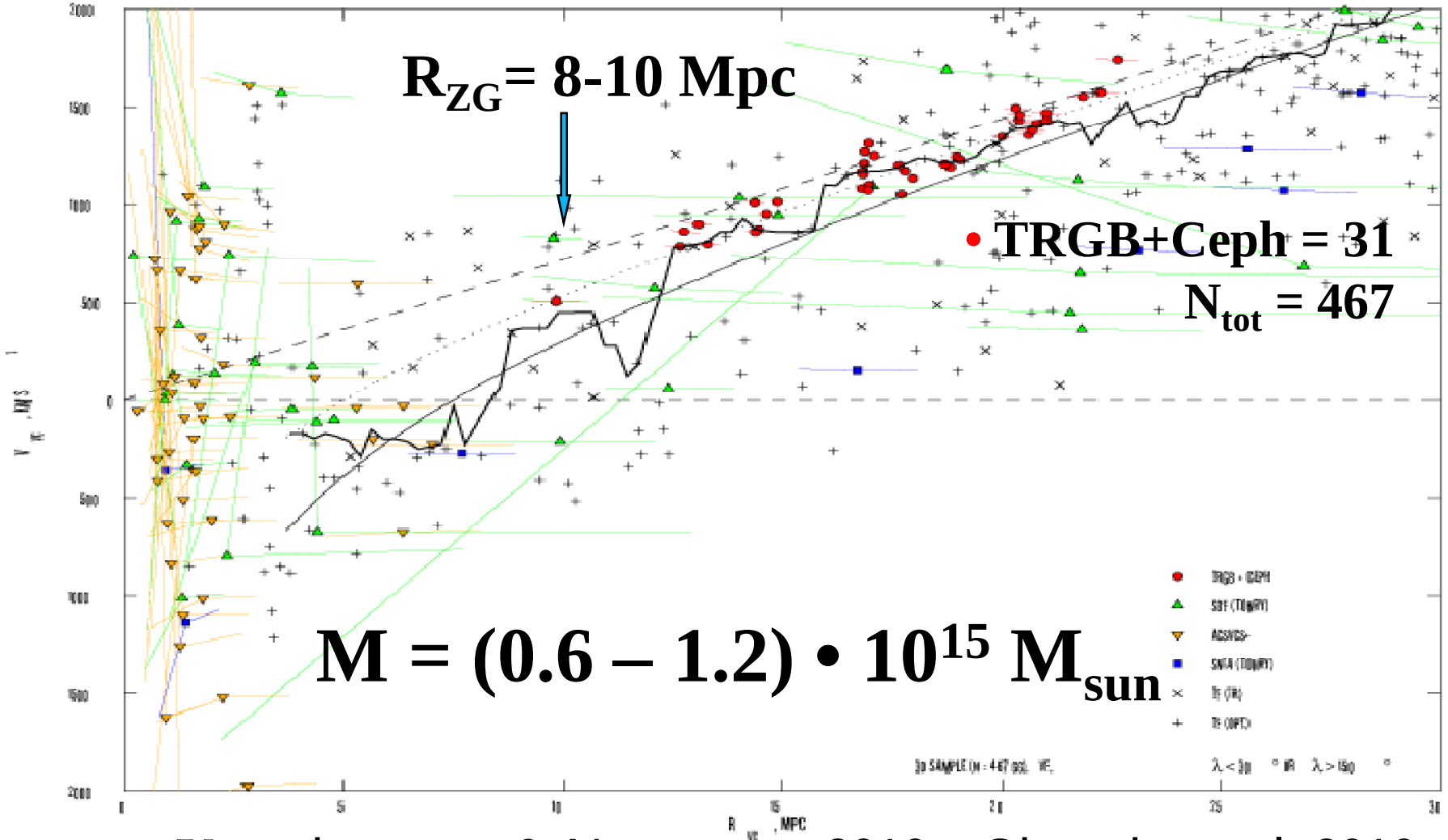
# MODEL & HST DATA



# N-BODY SIMULATIONS: COMBINED DIAGRAM



# VIRGO CLUSTER & OUTFLOW




Karachentsev & Nasonova 2010, Chernin et al. 2010

# 6 LOCAL OUTFLOWS: HST DATA

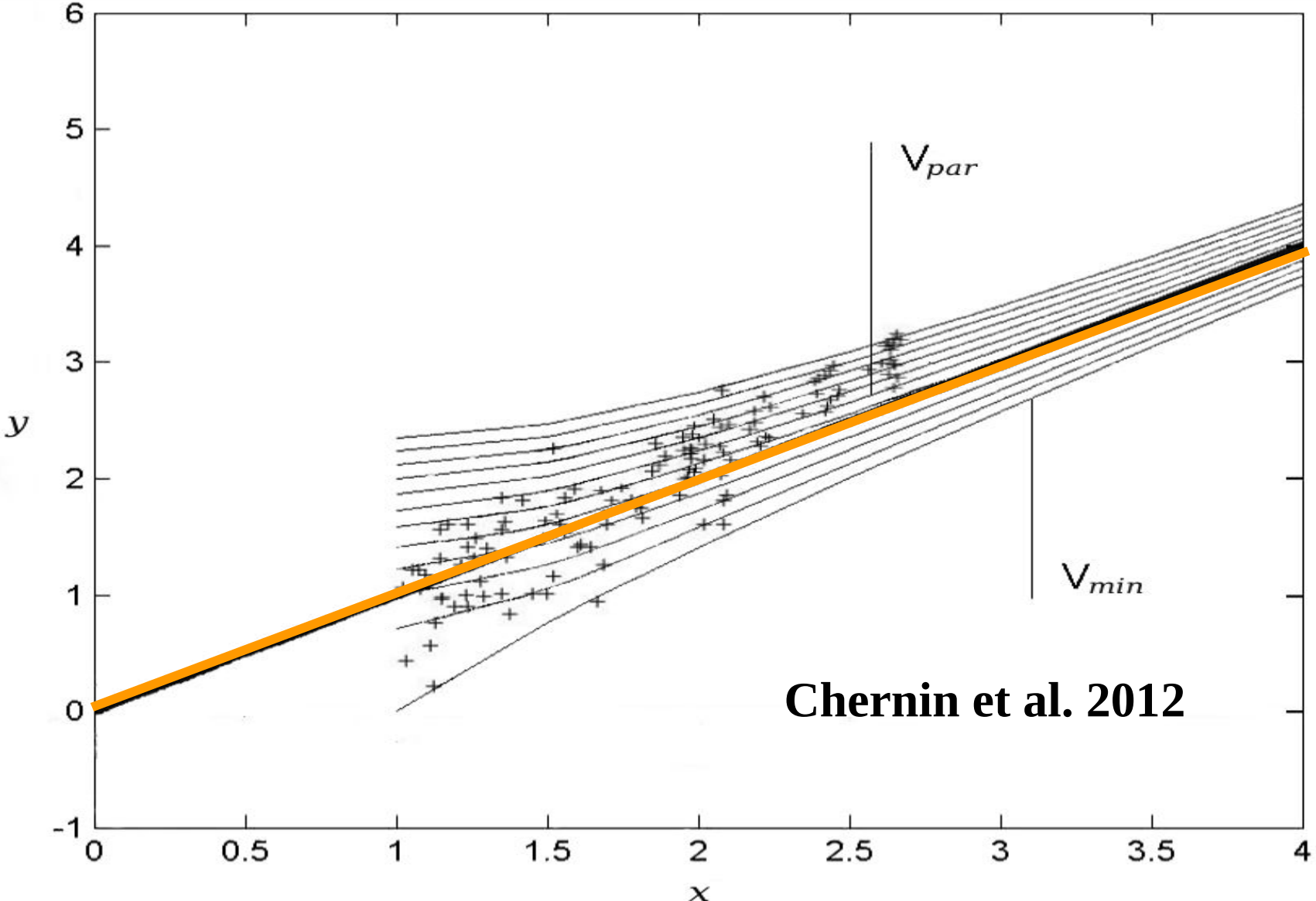
Karachentsev et al. 2006-2010

Around groups: LG, M81, Cen A, CV-I
Around clusters: Virgo and Fornax

Masses of 6 groups and clusters

Distances and Velocities of 200 galaxies,
60 of them in outflows

# 6 NEARBY OUTFLOWS: COMBINED DIAGRAM



# R- ESTIMATOR OF DE

M & $R_{ZG}$ ARE KNOWN

FROM OBSERVATIONS OF 6 SYSTEMS

$$\rho_X/\rho_{DE} = 3\,M[8\pi\,\rho_{DE}\,R_{ZG}^{3}]^{-1} = 0.3\text{-}7$$

# H-ESTIMATOR OF DE

**TIME RATES $H = V/R$ OF 6 OUTFLOWS**

**ARE KNOWN FROM OBSERVATIONS**

$$\rho_x / \rho_{DE} = \langle H \rangle^2 / H_\Lambda^2 = 0.4 - 1.2$$

CONCLUSIONS: WE HAVE DISCOVERED THAT

# DE exists on local scales of ~ 1-10 Mpc

# DE antigravity is stronger than matter gravity in expansion outflows around nearby groups and clusters of galaxies

# DE local density on scales of ~ 1-10 Mpc is nearly, if not exactly, equal to global DE density