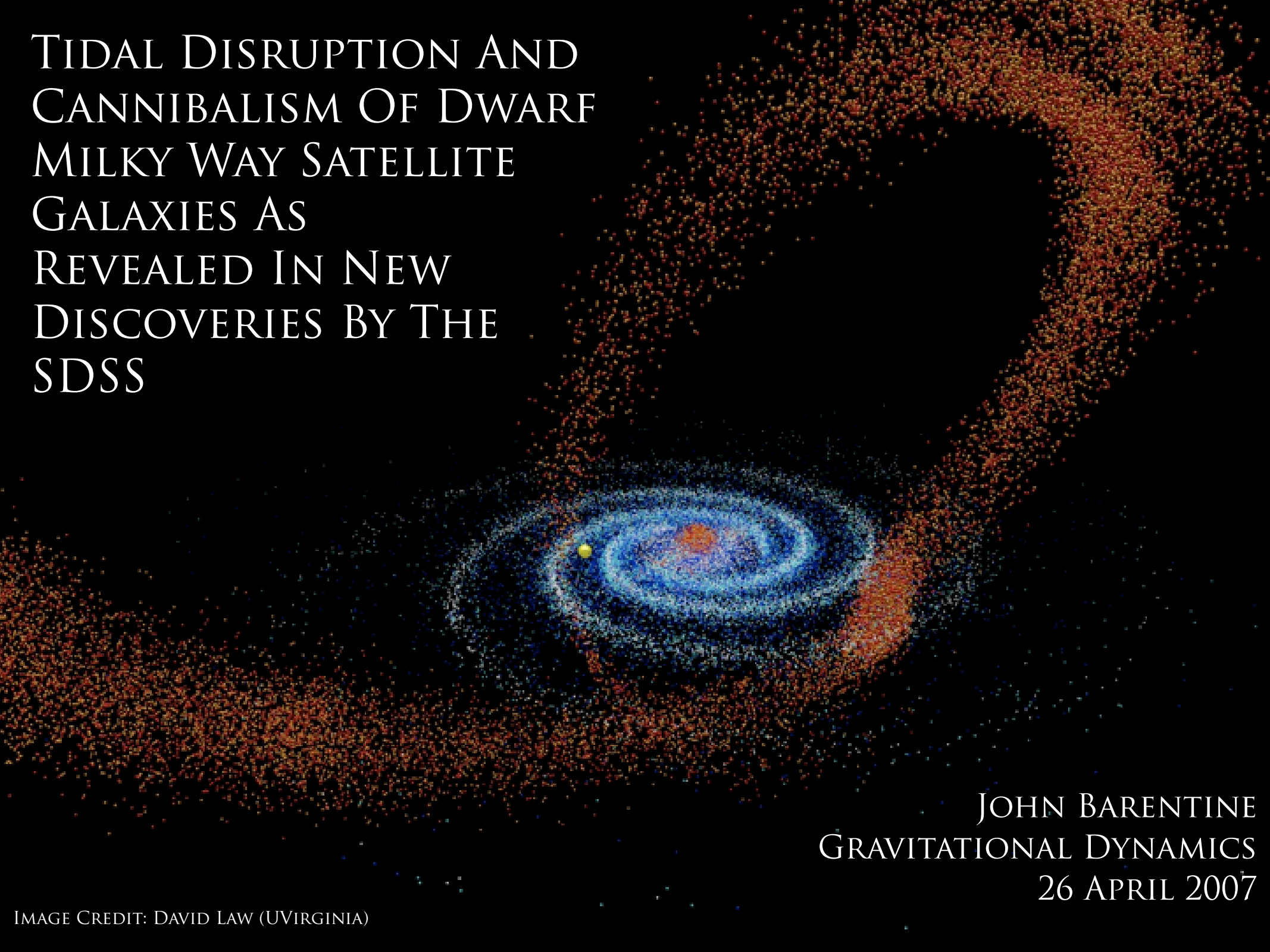
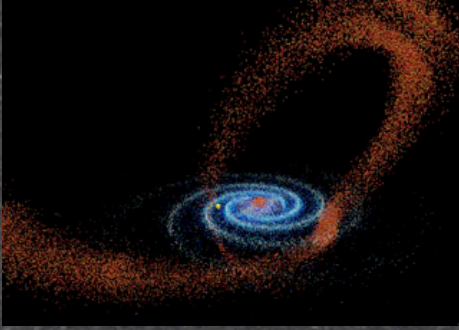


TIDAL DISRUPTION AND  
CANNIBALISM OF DWARF  
MILKY WAY SATELLITE  
GALAXIES AS  
REVEALED IN NEW  
DISCOVERIES BY THE  
SDSS



JOHN BARENTINE  
GRAVITATIONAL DYNAMICS  
26 APRIL 2007



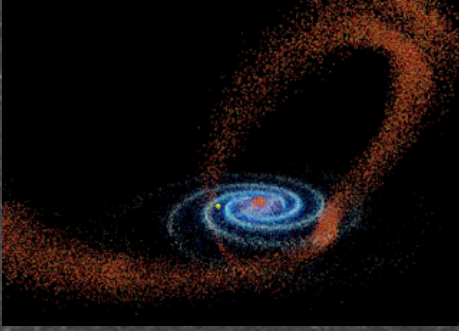
# ROADMAP

1. BACKGROUND

2. DYNAMICS OF MINOR MERGERS AND  
GALACTIC CANNIBALISM

3. THE SDSS CONTRIBUTION

4. GLOBAL PROPERTIES OF DWARF  
INTERACTIONS



# MECHANICS OF DYNAMICAL FRICTION

DECELERATION DUE TO  
GRAVITY

$$\frac{d\vec{v}_M}{dt} = D[\Delta\vec{v}] = -4\pi G^2 M m_a \ln \Lambda \int d^3\vec{v}_a f(\vec{v}_a) \frac{\vec{v}_M - \vec{v}_a}{|\vec{v}_M - \vec{v}_a|^3}$$

CHANDRASEKHAR'S FORMULA

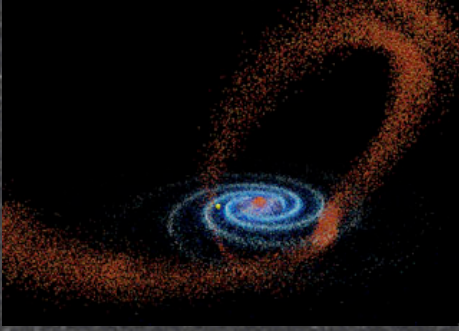
$$\frac{d\vec{v}_M}{dt} = -16\pi^2 G^2 M m_a \ln \Lambda \left[ \int_0^{v_M} dv_a v_a^2 f(v_a) \right] \frac{\vec{v}_M}{v_M^3}$$

LOW-VELOCITY LIMIT

$$\frac{d\vec{v}_M}{dt} \simeq -\frac{16\pi^2}{3} G^2 M m_a \ln \Lambda f(0) \vec{v}_M$$

HIGH-VELOCITY LIMIT

$$\frac{d\vec{v}_M}{dt} \simeq -4\pi G^2 M m_a n \ln \Lambda \frac{\vec{v}_M}{v_M^3}$$



# USEFUL DYNAMICAL PARAMETERS

$$\frac{dr}{dt} = -0.428 \ln \Lambda \frac{\sigma_s^3}{\sigma_{MW}^2}$$

RATE OF ORBIT DECAY

$$t_{fric} = \frac{2.34}{\ln \Lambda} \frac{\sigma_s^3}{\sigma_{MW}^2} r = \frac{2.7 \times 10^9 \text{ yr}}{\ln \Lambda} \frac{r}{30 \text{ kpc}} \left( \frac{\sigma_{MW}}{200 \text{ km s}^{-1}} \right)^2 \left( \frac{100 \text{ km s}^{-1}}{\sigma_s} \right)^3$$

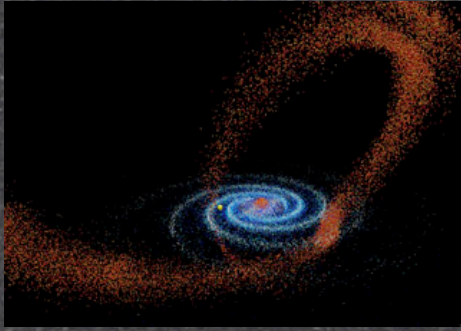
INSPIRAL TIME

$$r_J = r \left( \frac{M}{2M_{MW}(r)} \right)^{1/3} = \left( \frac{GM r^2}{4\sigma_{MW}^2} \right)^{1/3}$$

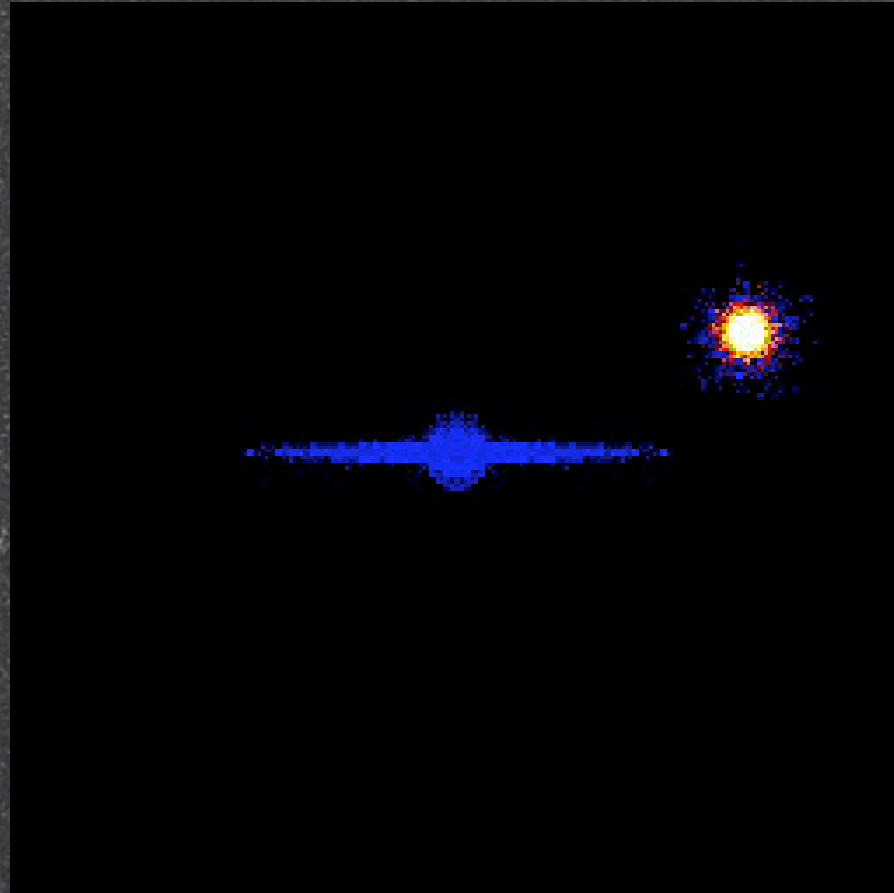
JACOBI RADIUS

$$r_h = r \frac{\sigma_s}{2^{3/2} \sigma_{MW}}$$

HALF-MASS  
RADIUS



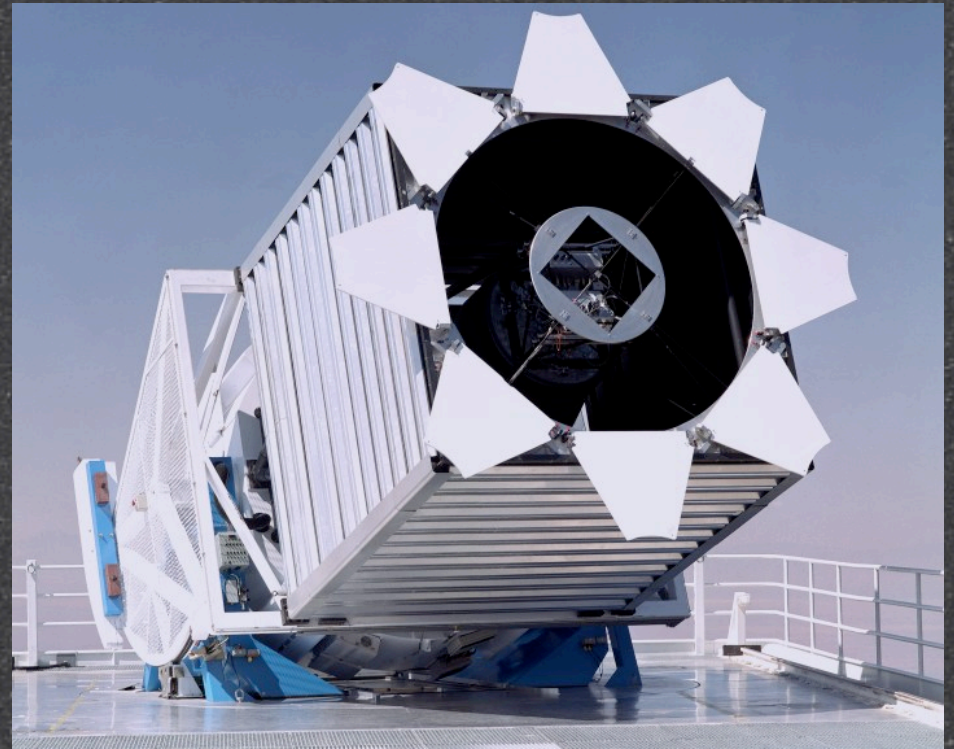
# A TIDAL SIMULATION



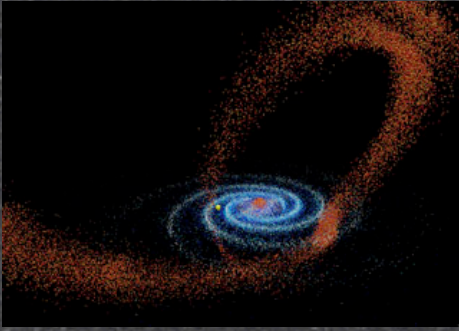
ANIMATION CREDIT: KATHRYN JOHNSTON (WESLEYAN U.)

# THE SDSS (I)

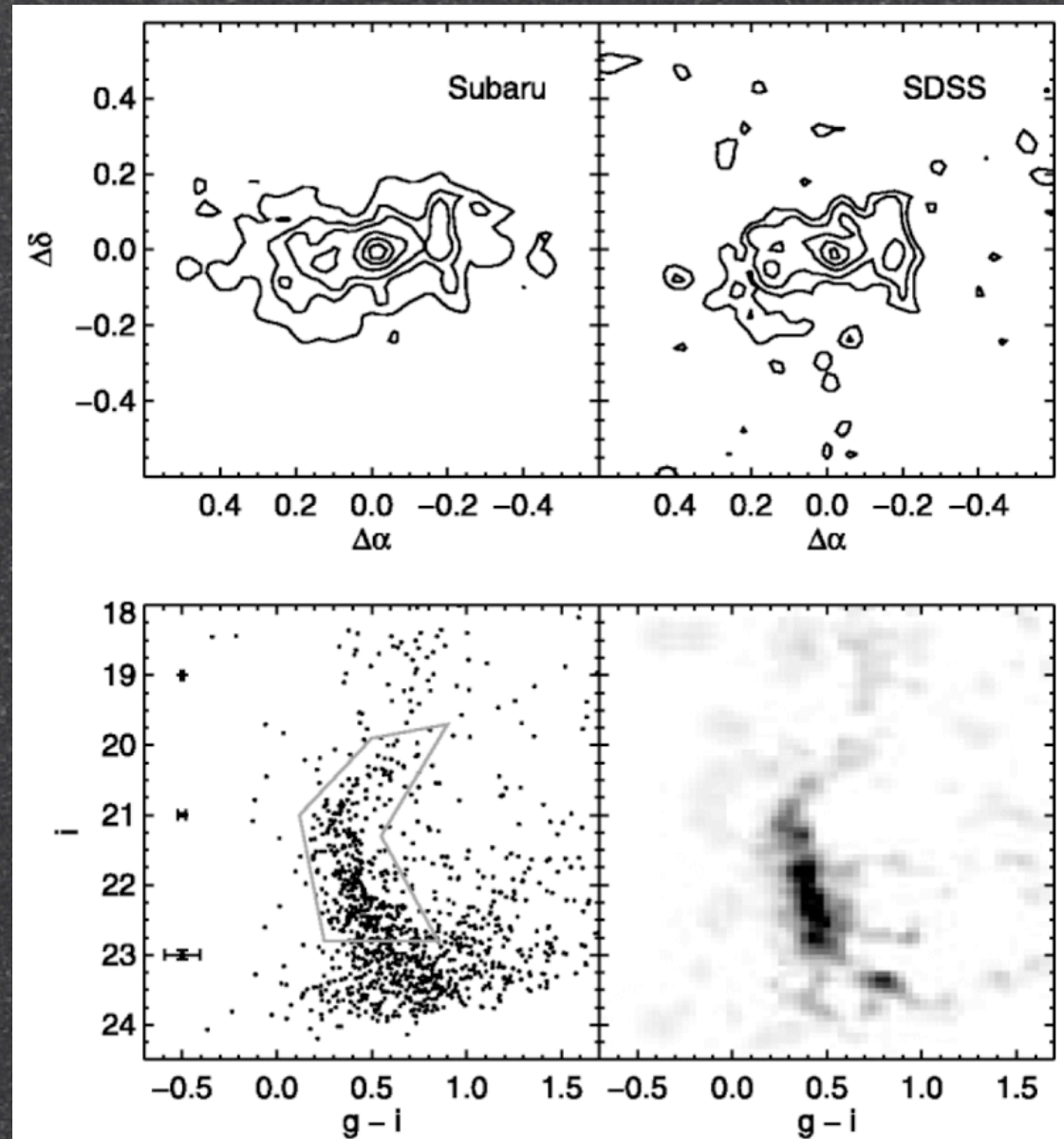
Surveyed  $\sim 9000$  square  
degrees to  $g = 22$

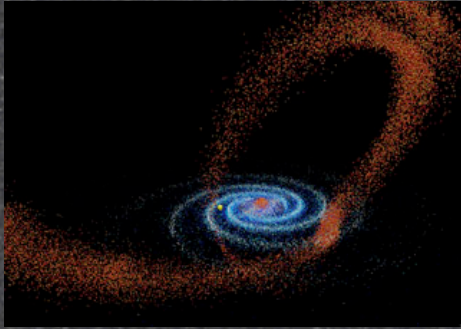


1-2% relative photometry  
of 100 million objects,  
spectroscopy of 1 million



# SAMPLE DETECTION: UMA II





# DYNAMICAL PARAMETERS OF SDSS DISCOVERIES

Name	$r$ (kpc)	$\sigma_{MW}(r)$ (km s <sup>-1</sup> ) <sup>1</sup>	$\ln \Lambda$	$r_h$ (kpc)	$t_{fric}$ (Gyr)	$r_J$ (kpc)	$M$ ( $M_\odot$ )	$\frac{dr}{dt}$ (km s <sup>-1</sup> )
Uma I	100	90	3.2	3.9	563	7.9	$2 \times 10^{13}$	-0.2
Willman I	50	110	3.4	1.6	396	3.2	$1 \times 10^{13}$	-0.1
CVn I	220	5	0.3	155.6	35	311.1	$9 \times 10^{14}$	-5.9
Boo	60	110	3.4	1.9	475	3.9	$1 \times 10^{13}$	-0.1
Uma II	30	120	3.5	0.9	276	1.8	$5 \times 10^{12}$	-0.1
Coma	44	120	3.5	1.3	405	2.6	$8 \times 10^{12}$	-0.1
CVn II	150	60	2.8	8.8	429	17.7	$5 \times 10^{13}$	-0.3
SEGUE I	23	125	3.6	0.7	227	1.3	$4 \times 10^{12}$	-0.1
Hercules	140	65	2.9	7.6	457	15.2	$5 \times 10^{13}$	-0.3
Leo IV	160	50	2.6	11.3	340	22.6	$7 \times 10^{13}$	-0.5

<sup>1</sup>Obtained from the model of Dehnen et al. (2006).

# DSPH PROFILE COMPARISON

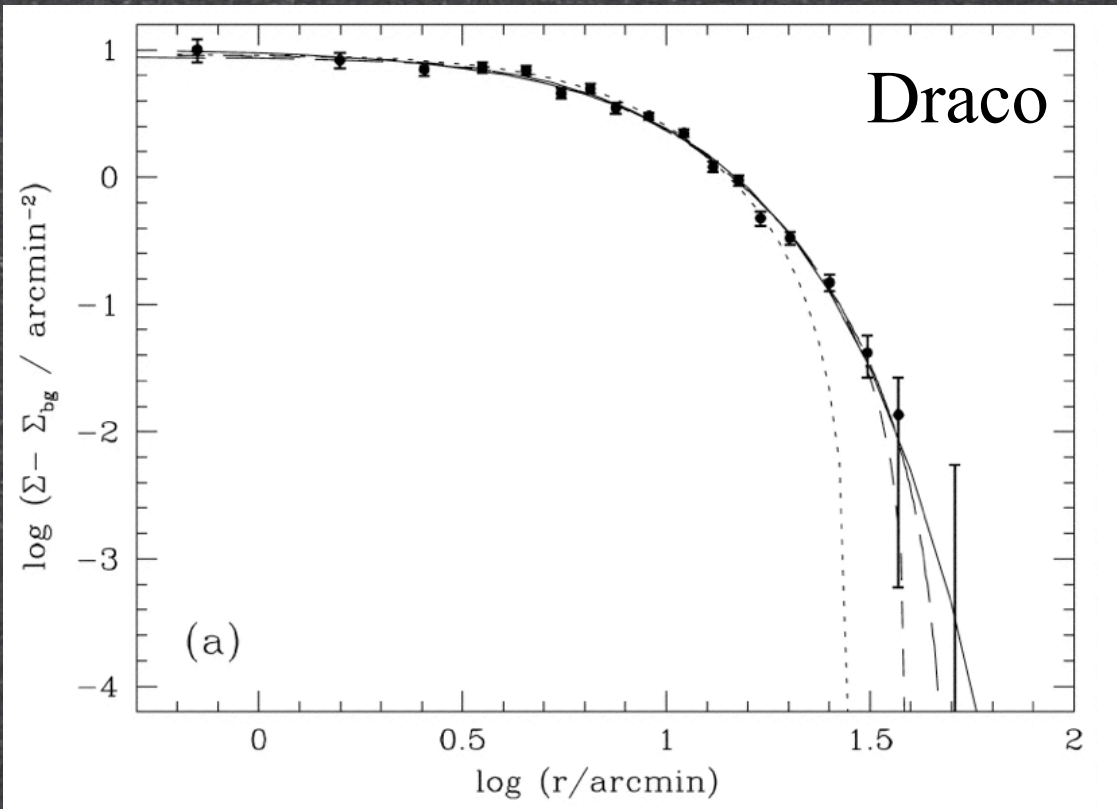
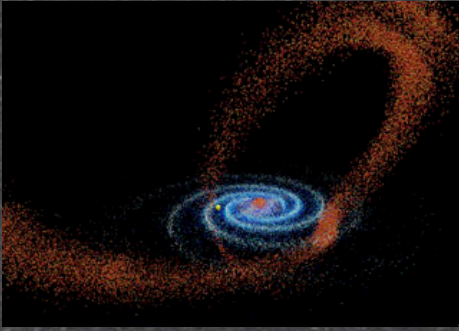


FIGURE 9 OF ODENKIRCHEN ET AL. (2001)

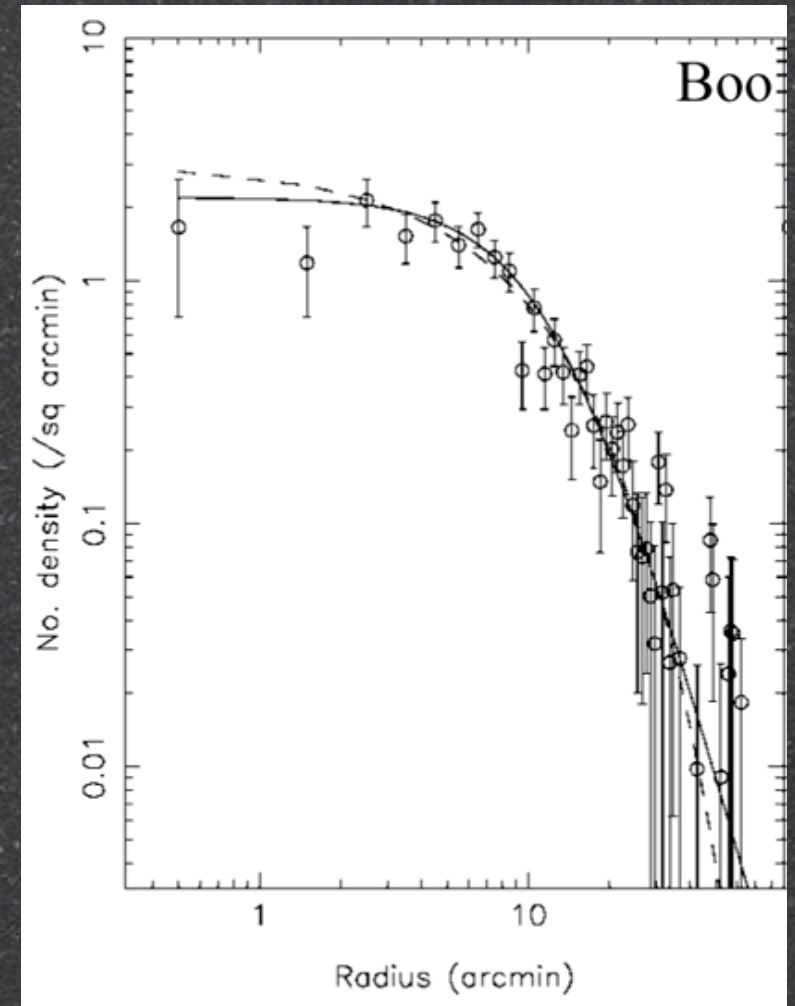
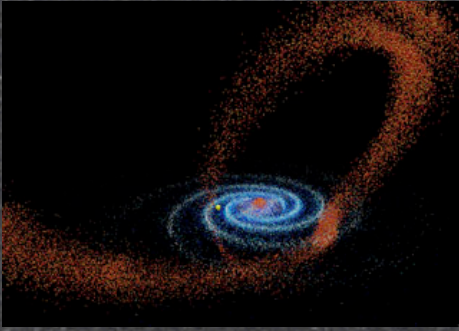


FIGURE 4 OF BELOKUROV ET AL. (2006)



# DISRUPTED DSPH/GC COMPARISON

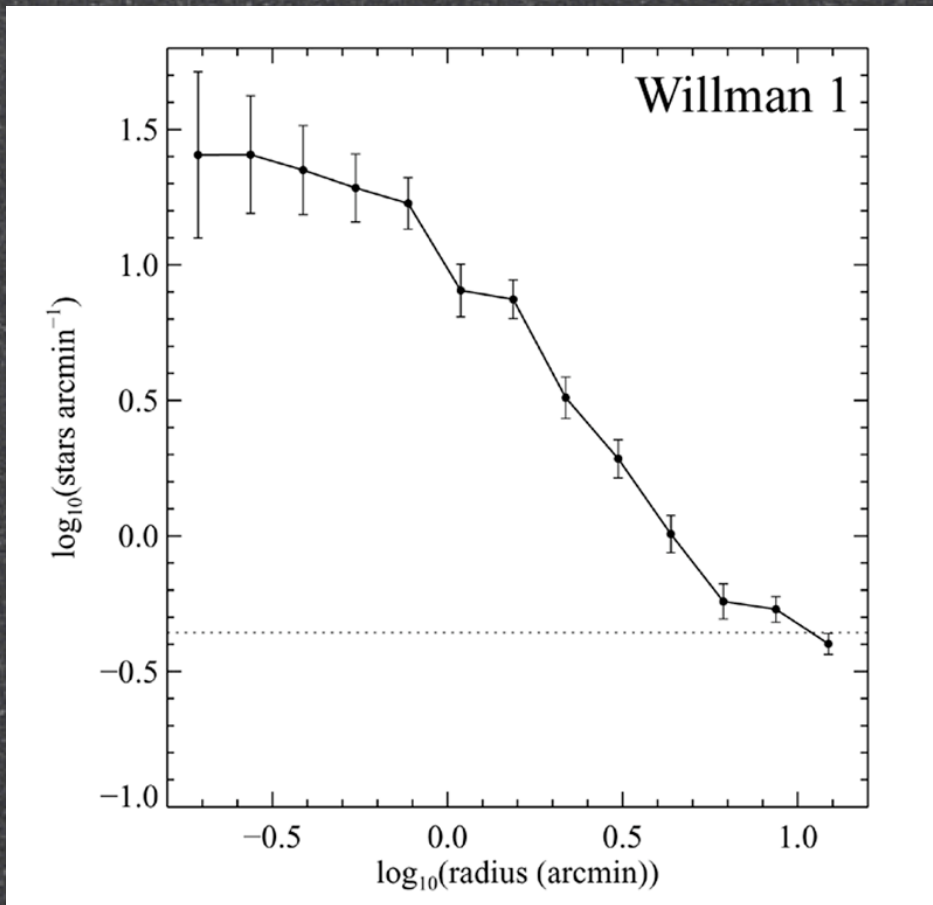


FIGURE 2 OF WILLMAN ET AL. (2005B)

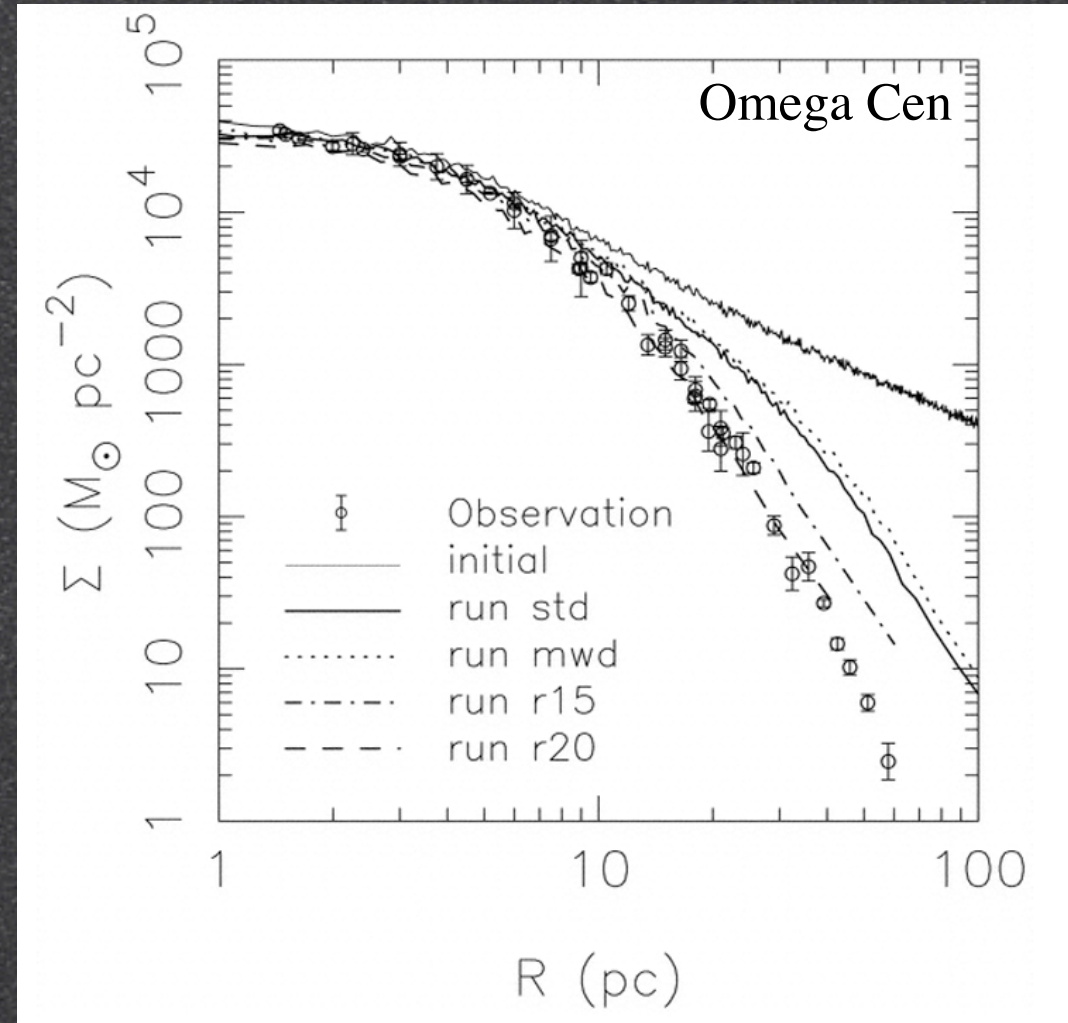
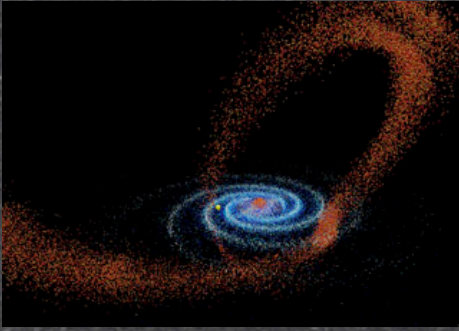
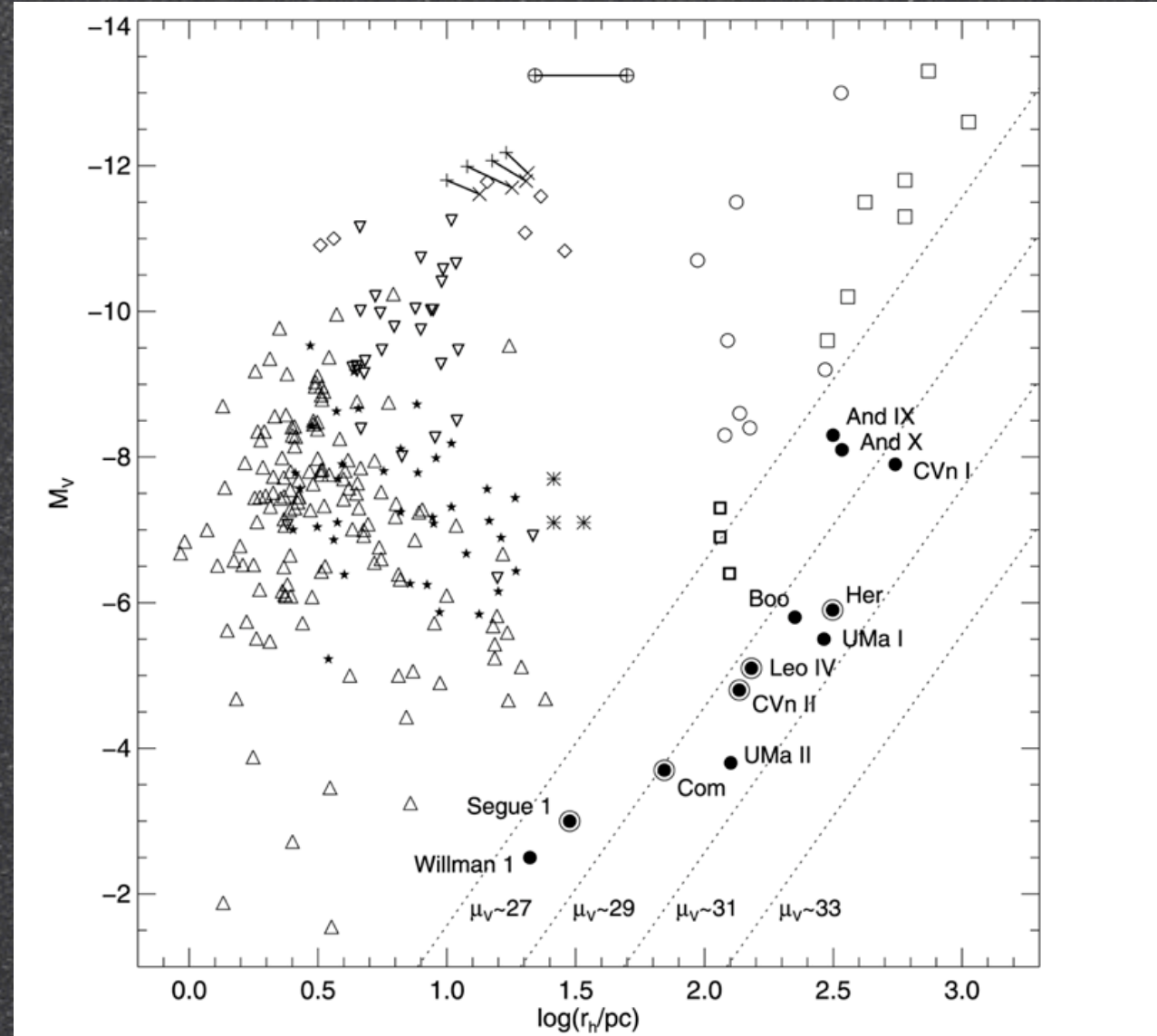
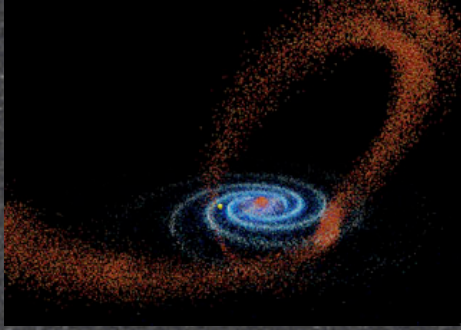


FIGURE 4 OF IDETA & MAKINO (2004)



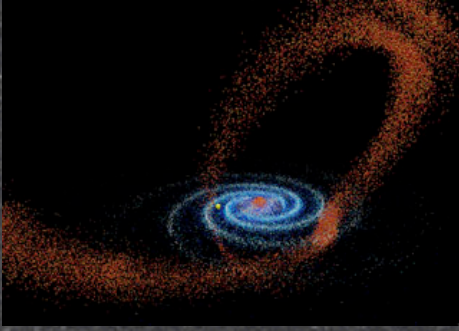
# TWO DYNAMICAL FAMILIES?





# CONCLUSIONS

1. THE ASSEMBLY OF THE MILKY WAY CONTINUES TO THE PRESENT
2. GLOBULAR CLUSTER AND DWARF SPHEROIDAL POPULATIONS APPEAR TO MERGE AT LOW MASS
3. THE CENSUS OF MILKY WAY DWARF COMPANION OBJECTS IS INCOMPLETE



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