THE INFLUENCE OF DARK MATTER HALOES ON OORT CLOUD COMETS

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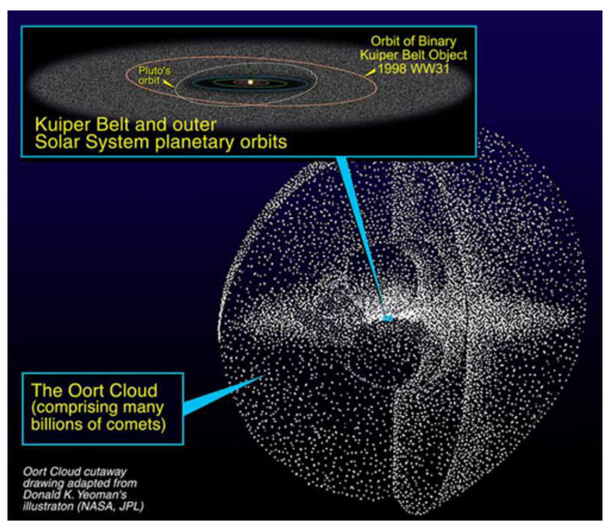
We have investigated the effect of gravitational perturbations from dark matter haloes on Oort cloud comets, which are the most loosely bounded bodies in the solar system. Oort cloud comets receive perturbations form external bodies: the galactic disk, nearby stars, and giant molecular clouds (GMC). Many authors have studied the effects of these external perturbations. Recent *N*-body simulations have revealed that dark matter particles form spherical-shape substructure called "dark matter halo" (DMH). They predict that DMH have a broad size distribution ranging from galactic size down to Earth-size and its distribution is steeper than that of GMC. We evaluate the strength of the perturbation by DMH using the impulse approximation and compare it with those by GMC and stars.

Oort cloud

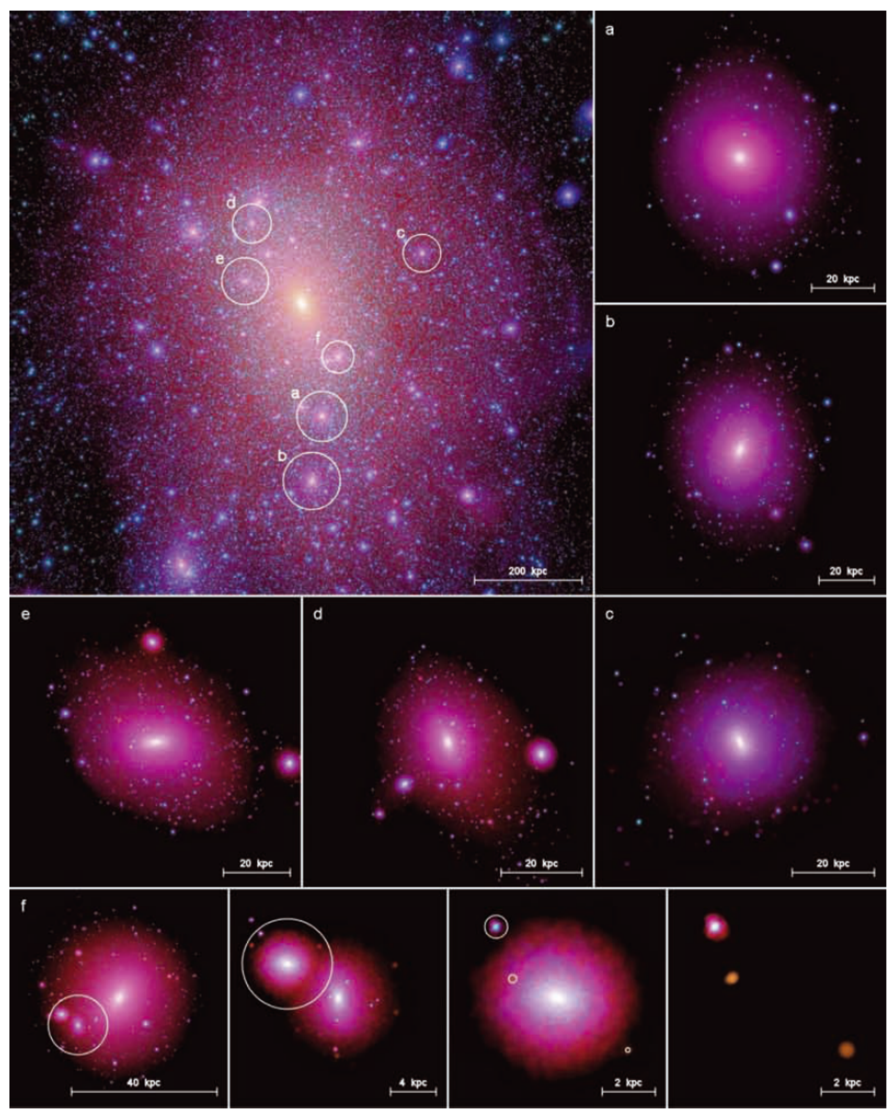
- a reservoir of long-period comets
- a spherical structure
- stretching to ~10^5 AU

◆Images of the Oort cloud (*predicted from observations of long-period comets*)



◆Images of substructure of substructure of DMH (*N*-body simulation)

Springel et.al. (2008)



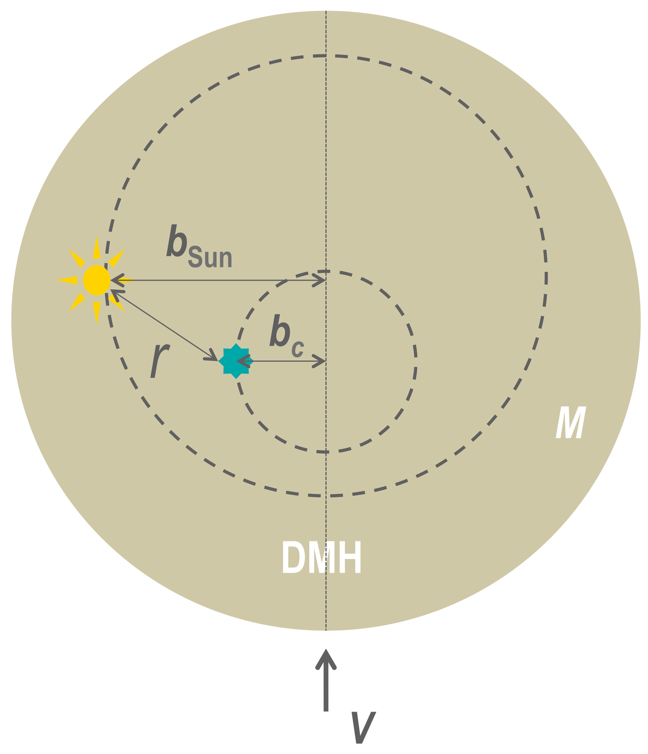
MODELS & CALCULATIONS

velocity change by an encounter with a DMH

Impulse approximation

$$\Delta v = \frac{2G}{V}\left\{\frac{M(b_c)\mathbf{b}_c}{b_c^2} - \frac{M(b_{\rm Sun})\mathbf{b}_{\rm Sun}}{b_{\rm Sun}^2}\right\}$$

- V :velocity of the DMH
- M :total mass of the DMH
- $M(R)$:mass of the DMH within R from its center
- b_c :impact parameter against the comet
- $b_{\rm Sun}$:impact parameter against the Sun



Definition of Increase Rate of Velocity Dispersion (IRVD)

$$\mathrm{IRVD} = \frac{\langle \Delta v^2 \rangle}{\Delta t} = \int_{b_{\min}}^{b_{\max}}\int_{M_{\min}}^{M_{\max}} \left\{ \langle |\Delta v|^2 \rangle \frac{dn}{dM} 2\pi b V \right\} db\, dM$$

$$\langle |\Delta v|^2 \rangle = \frac{1}{4\pi}\int_{4\pi} |\Delta v(b, M(R))|^2 d\Omega$$

Structure Model of DMH/GMC

$$M(R) = M\frac{(R/r_c)^2}{(1-R/r_c)^2} \qquad r_c = AM^{\alpha}$$

M: total mass of a DMH

Mass Functions

$$\frac{dn}{dM} = BM^{\gamma}$$

The values predicted by numerical simulations/ obtained by observations:

Springel et.al. (2008) Solomon et.al. (1987) Garcia-Sanchez et al.(2001), Rickman et al.(2008)

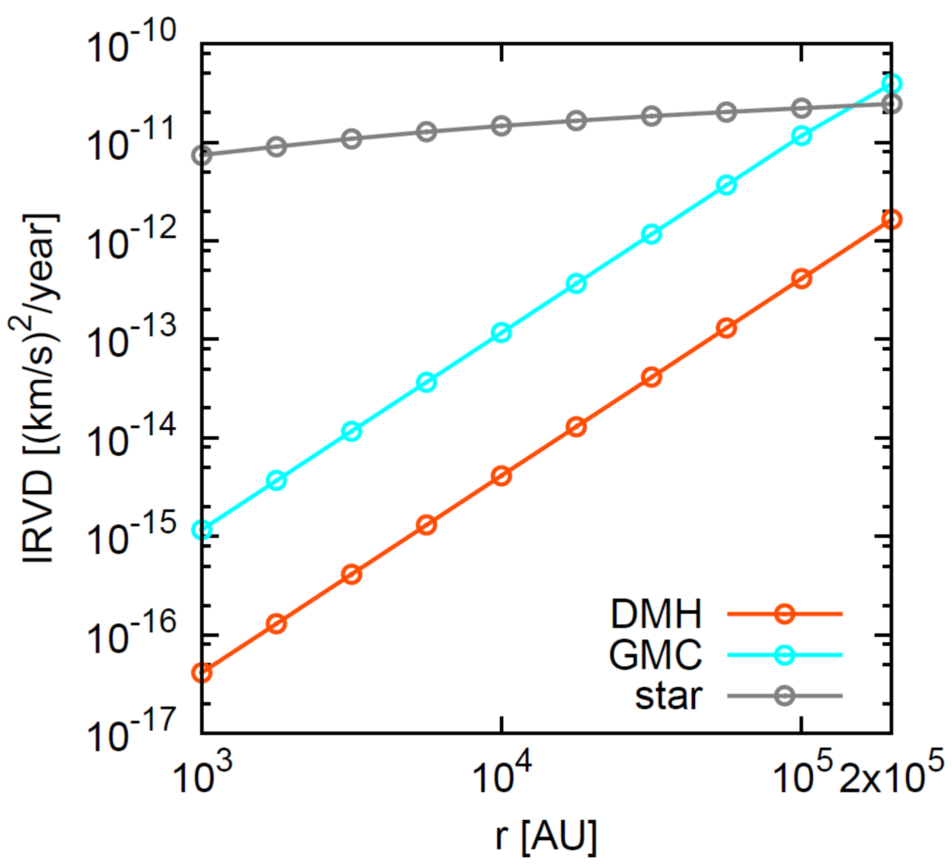
	v [km/s]	A [AU]	α	γ	$\rho_{\rm local}$ [$M_{\rm Sun}$/pc^3]	$M_{\min}$ [$M_{\rm Sun}$]	$M_{\max}$ [$M_{\rm Sun}$]	$b_{\min}$ [AU]	$b_{\max}$ [AU]
DMH	200	72000	0.38	-1.9	0.035	10^{-6}	10^{10}	1	10^{10}
GMC	20	8600	0.5	-1.5	0.096	10^2	2×10^6	1	10^{10}
stars	20	-	-	-1.9	0.1	0.21	9	1	10^{10}

※ The factor *B* is calculated using $\rho_{\rm local}$, γ and *M*-range so that the total mass is conserved.
※ Stars are treated as point masses.

RESULTS

Comparison of IRVD of DMH, GMC, and stars

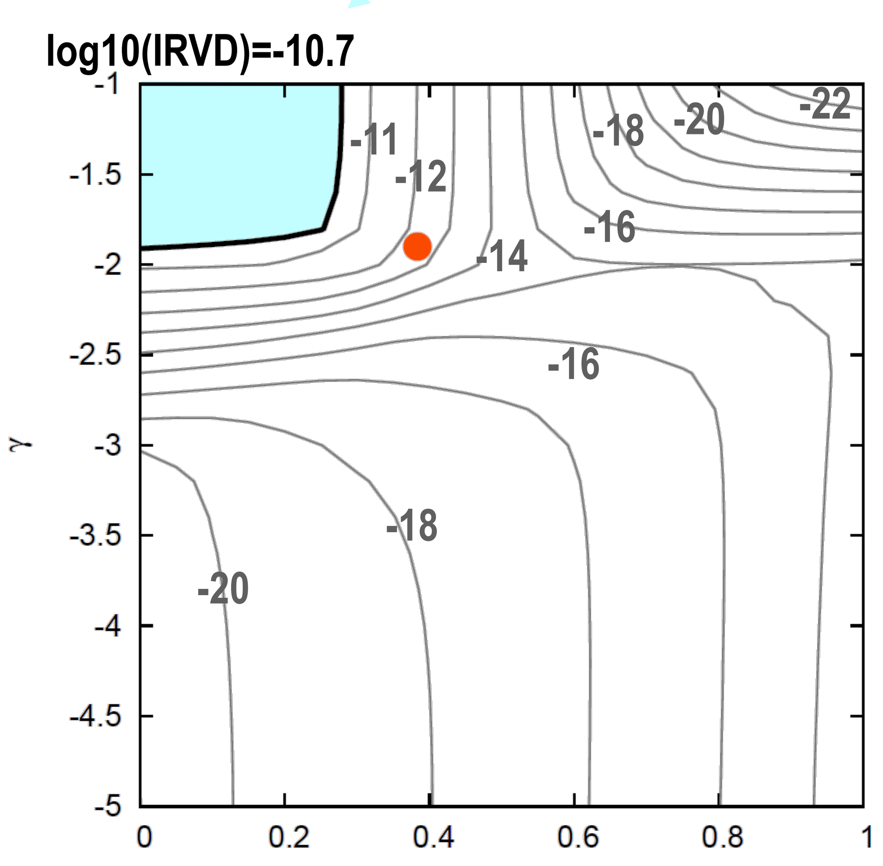
◆ IRVD as functions of *r*



- IRVD of DMH is always the smallest.
- IRVD of DMH & GMC are almost proportional to r^2.
- IRVD of stars is almost proportional to log(*r*) .
- IRVD of GMC exceeds that of stars where r>~2x10^5AU.

Dependence of IRVD on α & γ

◆ contours of IRVD of DMH for r=10^5AU on the α-γ plane



region where IRVD>stars

● values of α & γ for DMH predicted by simulations

- There is a region where IRVD of DMH be larger than that of stars.
- Since α & γ are not well known, the influence of DMH on comets in the outer region of the Solar system might not be discarded.

Indexes of Mass Functions (γ)

GMC (observations)

Solomon et.al. (1987)

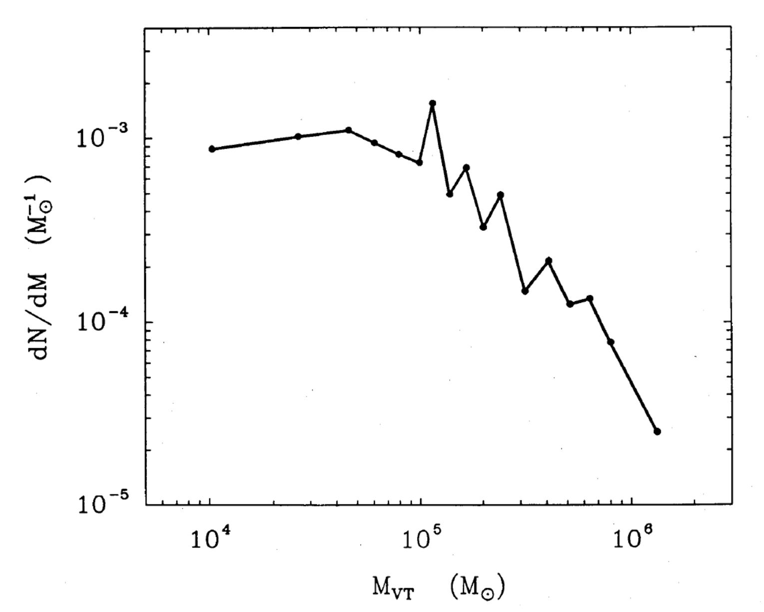


FIG. 3.—The molecular cloud mass spectrum dN/dM. A fit to the data above $M = 7\times10^4\ M_\odot$ gives $dN/dM \propto M^{-3/2}$. There are 15 clouds in each bin and the standard deviation is $\pm24\%$. The turnover at low mass is due to undercounting of smaller clouds in the more distant parts of the galactic disk.

DMH (simulations)

Springel et.al. (2008)

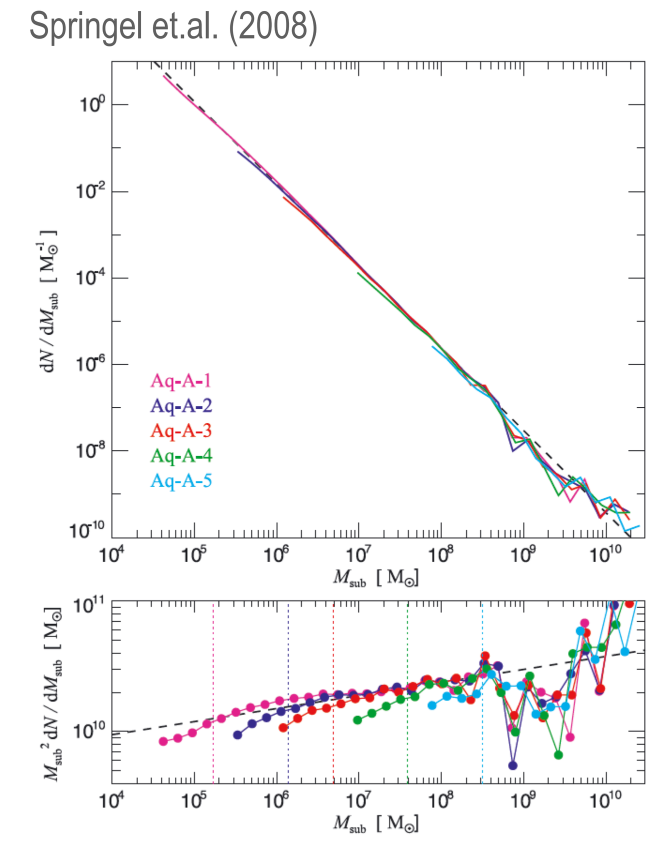


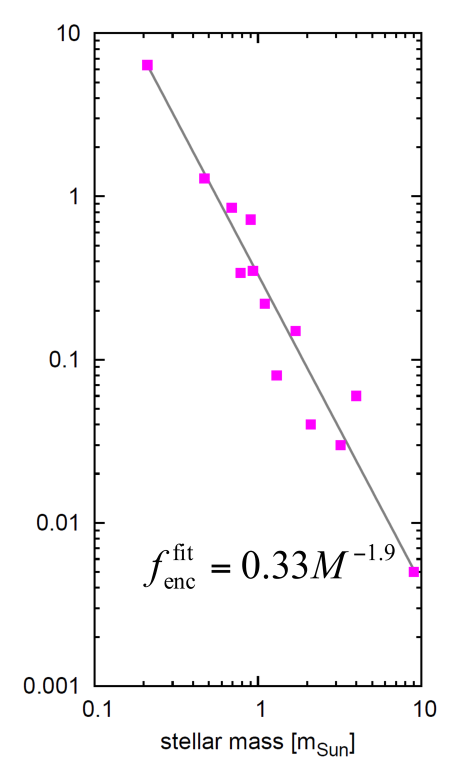
Figure 6. Differential subhalo abundance by mass in the 'A' halo within the radius r_{50}. We show the count of subhaloes per logarithmic mass interval for different resolution simulations of the same halo. The bottom panel shows the same data but multiplied by a factor $M_{\rm sub}^2$ to compress the vertical dynamic range. The dashed lines in both panels show a power law $dN/dM \propto M^{-1.9}$. For each of the resolutions, the vertical dotted lines in the lower panel mark the masses of subhaloes that contain 100 particles.

Stars (observations)

Garcia-Sanchez et al.(2001), Rickman et al.(2008)

Current environment of the Sun

stellar type	solar apex v [km/s]	encounter frequency <1pc /1Myr	velocity deviation [km/s]	mass [$M_{\rm Sun}$]
B0	18.6	0.005	8.5	9
A0	17.1	0.03	11.4	3.2
A5	13.7	0.04	13.7	2.1
F0	17.1	0.15	16.8	1.7
F5	17.1	0.08	20.9	1.3
G0	26.4	0.22	21.6	1.1
G5	23.9	0.35	22.6	0.93
K0	19.8	0.34	19.7	0.78
K5	25.0	0.85	25.1	0.69
M0	17.3	1.29	24.7	0.47
M5	23.3	6.39	24.1	0.21
w d	38.3	0.72	36.6	0.9
giant	21.0	0.06	23.7	4



Mass of DMH/GMC within radius *R* for total mass *M*