------ Raf. J. Sci., Vol. 25, No.2 pp. 87-94, 2014------

Density and Mass Distribution of the Spiral Galaxy NGC 3672

Nazzeha A. Daod Mohammed K. Zeki Aziz J. Abdul-Kahader
Department of Physics
College of Science
University of Mosul

(Received 25 / 4 / 2013 ; Accepted 9 / 9 / 2013)

ABSTRACT

The density and mass of Spiral galaxy NGC 3672 has been studied as a function of the distance from the center of the galaxy. The mass of the three regions of the galaxy (nucleus, disk and halo) have been calculated and compared with other work. The total mass of NGC 3672 is found to be 1.22×10^{11} M_o at a radius of 23.7 kpc.

Keywords: Spiral galaxies, NGC 3672, galactic density, mass distribution, rotation curve.

توزيع الكثافة و الكتلة للمجرة الحلزونية NGC 3672

الملخص

تمت دراسة توزيع الكثافة و الكتلة للمجرة الحلزونية NGC 3672 كدالة للبعد عن مركز المجرة. تـم احتساب الكتلة للأجزاء الثلاثة للمجرة (النواة و القرص و الهالة) ومقارنتها مع بحوث أخرى. الكتلة الكليـة للمجرة وجدت تساوي 1.22×10^{11} M_o عند نصف قطر 3.7 kpc.

الكلمات الدالة: المجرات الحلزونية، NGC 3672، كثافة المجرة، توزيع المادة، منحني الدوران.

INTRODUCTION

The determination of galactic mass is an outstanding problem in galactic research. Different methods have been employed leading to widely different results: one method is based upon rotation curves.

Astronomers construct rotation curves for the galaxies from measurements of stars and hydrogen clouds in galactic disks. The rotation curve of a galaxy is the variation in the orbital circular velocity of stars or gas clouds at different radii r, (distances from the center of the galaxy). The manner in which the velocity varies with radius reflects the distribution of mass in the galaxy. A great deal of data for the galactic rotation curves have been obtained by various methods such as using the velocities of H_α , HI, CO, and Maser lines (Sofue, 1996; Deguchi *et al*., 2000; Maciel and Lago, 2005; Mathewson and Ford, 1996; Greisen *et al*., 2009).

The rotation of spiral galaxies was discovered in 1914, by Slipher, who detected absorption lines in the nuclear spectra of M31 and Sombrero galaxy. Thereafter, rotation

curves of galaxies have been constructed by many astronomers (Sofue, 2008; Thakre *et al.*, 2011).

Most spiral galaxies have rotation curves that show solid body rotation in the very center followed by almost a constant (flat) velocity rotation in the outer parts of the galaxy. A flat rotation curve implies that the mass continues to increase linearly with radius, i.e. spiral galaxies contain very massive halos (Sofue and Rubin, 2001). Therefore, the rotation curves of spiral galaxies present a strong evidence of dark matter. Dark matter is a material that does not produce detectable amounts of light but it does have a noticeable gravitational effects. Dark matter is possibly, made of large objects like brown dwarfs, white dwarfs, black holes or small things like neutrinos and other exotic particles that have not been seen in laboratories yet.

In this paper, we studied the galactic density and mass variation with the distance from the center of the galaxy NGC 3672 depending on its observed rotation curve (Sofue *et al.*, 1999).

NGC 3672 (Sc II) is an attractive multi-armed spiral galaxy undistinguished optically except for the small angular extent of its radius (Rubin *et al.*, 1977).

THEORY

To find the density and mass of a spiral galaxy at an enclosed radius r, we started with the following equation (Binney and Tremaine, 1987) :

$$v^2(r) = 4\pi G\sqrt{1-k^2}\int_0^r \frac{\rho(a)a^2\,da}{\sqrt{r^2-a^2k^2}} \qquad \ldots\ldots\ldots (1)$$

where ρ(a) is the galactic density, k is the eccentricity of the galaxy and v(r) is the circular velocity at a distance (r) from the center of the galaxy.

Equation (1) was solved by Daoud *et al.*, (2009) using Abel's integral technique to get a relation for the density law of the form,

$$\rho(r) = \frac{k^4}{\pi^2 Gr\sqrt{1-k^2}}\frac{d}{dr}\frac{1}{r}\int_0^r \frac{v^2(a)a\,da}{\sqrt{r^2-a^2k^2}} \qquad \ldots\ldots\ldots (2)$$

Again, equation (2) was used by Daod, (2012) to study the density and mass as a function of r for spiral galaxies which show the general form of rotation curve (steep nuclear rise and high central rotation. followed by a broad maximum in the disk and then a flat rotation due to massive halo), and three different orientations of the flat part were considered (rising up slightly, almost flat and going down slightly).

Daod, (2012) derived the density and the mass of spiral galaxies as a function of the distance from the center of the galaxy. Two sets of equations were derived for the density and the mass, one for the inner parts of the galaxy ($r < r_t$), where r_t is the turn off radius, and the other set of equations are for the outer regions of the galaxy ($r > r_t$), so

$$\rho_1(r) = \frac{2\alpha^2\{2-\sqrt{1-k^2}(k^2+2)\}}{3\pi^2 G\sqrt{1-k^2}} \qquad \ldots\ldots\ldots (3)$$

and

$$M_1(r) = \frac{8\alpha^2\{2-\sqrt{1-k^2}\,(k^2+2)\}}{9\pi G}\, r^3 \qquad \ldots\ldots\ldots(4)$$

$\rho_1(r)$ and $M_1(r)$ are the inner density and mass of the galaxy respectively at a given radius ($r<r_t$).

The density for the outer regions of the galaxy is given by:

$$\rho_2(r) = \frac{2\beta^2\{2-\sqrt{1-k^2}\,(k^2+2)\}}{3\pi^2 G\sqrt{1-k^2}} + \frac{\beta\gamma k\{\sin^{-1}k - k\sqrt{1-k^2}\}}{G\pi^2\sqrt{1-k^2}\,r} \qquad \ldots\ldots(5)$$

where α, β, and γ are quantities taken from the rotation curve of the given galaxy. Using the following equation:

$$dM = 4\pi a^2\sqrt{1-k^2}\,\rho(a)da \qquad \ldots\ldots\ldots(6)$$

Then,

$$M(r) = 4\pi\sqrt{1-k^2}\int_0^r \rho_2(a)a^2 da \qquad \ldots\ldots(7)$$

or

$$M(r) = \frac{8\beta^2\{2-\sqrt{1-k^2}(k^2+2)\}}{9\pi G} r^3 + \frac{2\beta\gamma k\{sin^{-1}k - k\sqrt{1-k^2}\}}{G\pi} r^2 \qquad \ldots\ldots(8)$$

Since the outer mass should be the mass of the outer regions only i.e. the mass within the distance between r_t and r ($r > r_t$). Then

$$M_2(r) = M(r) - M(r_t) \qquad \ldots\ldots\ldots(9)$$

or

$$M_2(r) = \frac{8\beta^2\{2-\sqrt{1-k^2}\,(k^2+2)\}}{9\pi G}(r^3 - r_t{}^3) + \frac{2\beta\gamma k\{sin^{-1}k - k\sqrt{1-k^2}\}}{G\pi}(r^2 - r_t{}^2) \qquad \ldots\ldots(10)$$

Again $M_2(r)$ is the mass of the outer regions (shell mass) at a distance where $r > r_t$. The total mass of the galaxy at any radius $r > r_t$ should be

$$M(r) = M_1(r_t) + M_2(r) \qquad \ldots\ldots\ldots(11)$$

And the total mass of the galaxy at r_g (the total radius of the galaxy) should be,

$$M_{tot}(r) = M_1(r_t) + M_2(r_g) \qquad \ldots\ldots\ldots(12)$$

CALCULATIONS AND RESULTS

Observational data given in Table (1) of the rotation curve of the galaxy NGC 3672 and its plot (Fig. 1) were adopted from Sofue *et al.*,(1999) to calculate the density and the mass of the galaxy as a function of the distance from its center.

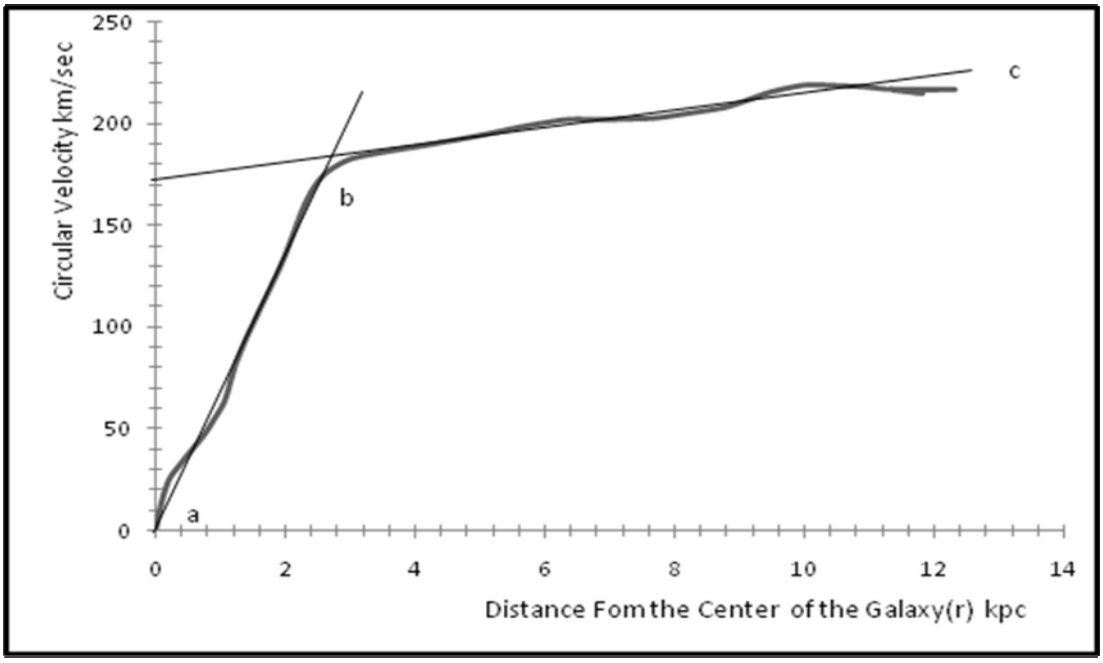

Fig. 1 : Rotation Curve of NGC 3672

Fig. (1) shows the observed rotation curve of NGC 3672 with two fitting lines: the line ab for the radius $r<r_t$ and the line bc for the radius $r > r_t$. The quantities, α (the slop of the line ab), β (the slop of the line bc), r_t (the turn off radius) and γ (the intersection point between the line bc and the vertical axis) were taken from (Fig. 1) and their values tend to be,

α = 66.67 km/sec/kpc, β = 4.35 km/sec/ kpc, γ = 172 km/sec and r_t = 2.7 kpc.

The value of the eccentricity (k) is calculated from $(\sqrt{1-k^2}=0.1)$, the flatness characteristic of spiral galaxies (Binney and Tremaine, 1987).

A computer program in Quick-Basic language was constructed to calculate the density and the mass of NGC 3672 at different distances from the galactic center using the above observational quantities and the equations (3), (4), (5), (10) and (12).

Calculations show that the central (inner) density of NGC 3672 is constant and has a value of ($\rho_1(r) = 1.89\ M_o / pc^3$), where M_o denotes one solar mass. The density of the outer regions (disk and halo) of the galaxy is much less than that of the inner regions ($\rho_2(r) < 0.09\ M_o / pc^3$) and it decreases with the distance from the center of the galaxy as shown in (Fig. 2).

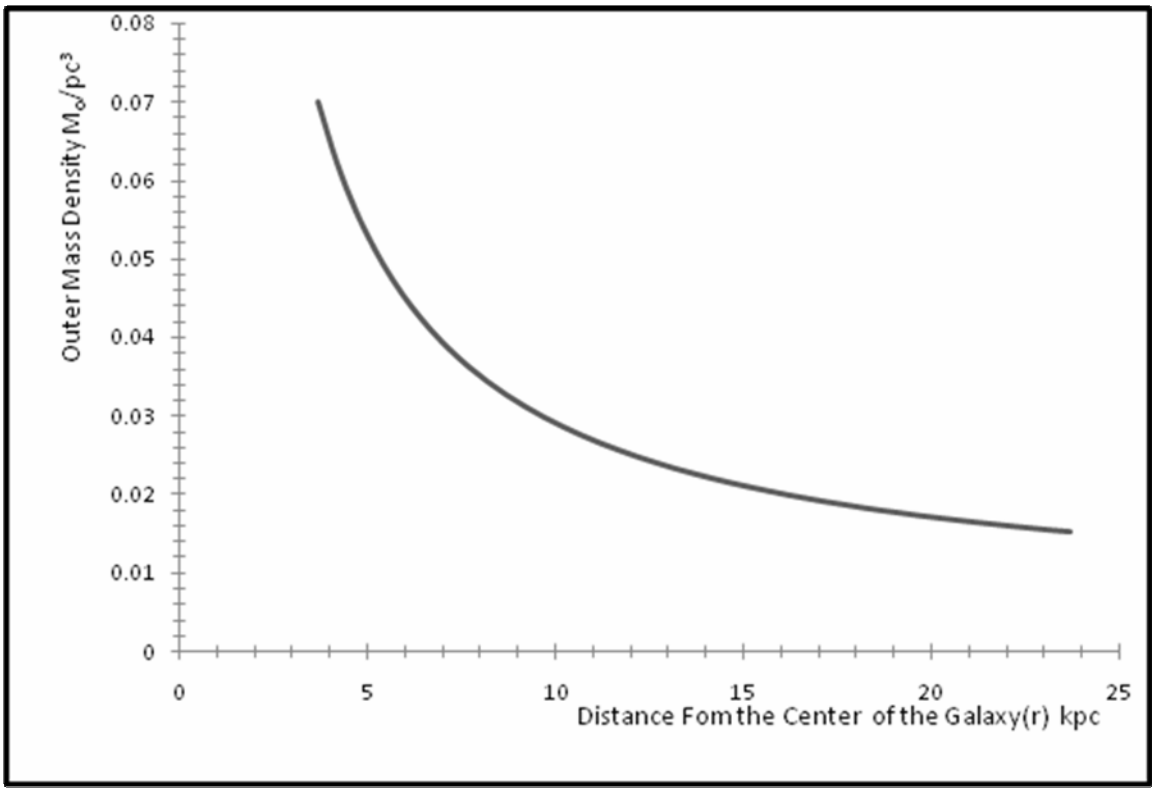

Fig. 2 : The outer Density as a Function of Radius

Our results of constant inner density and declining outer density are consistent with other works (Rubin, *et al*., 1977 ; Binney and Tremaine, 1987).

The mass of the galaxy NGC 3672 at a radius less than the turn off radius is proportional to r^3 (equation 4). Therefore the inner mass of NGC 3672 grows up quikly with distance from the galactic center (r=0) to the turn off radius ($r = r_t$) reaching a value of ($M_1(r_t) = 9.78\times10^9\ M_o$).

The outer mass of the galaxy NGC 3672 at a radius $r > r_t$, is found to increase with distance Fig. (3), from the center of the galaxy, although the outer density decreases with radius Fig. (2). All rotation curves for spiral galaxies are approximately flat distances as great as r=50 kpc (Rubin *et al.,* 1977). We adopted r_g = 23.7 kpc from Rubin (1977) to calculate the Halo mass and the total mass of NGC 3672. The halo mass ($M_{halo} = 5.4\times10^{10}\ M_o$) is found to be more than the inner mass ($M(r_t) = 9.78\times10^9\ M_o$) which confirm the existence of a massive halo and also give a big evidence for the existence of dark matter. Spiral galaxies have giant halos extending to several times the radius of luminous matter (Ostriker *et al*., 1974). So if the galaxy NGC 3672 extends more than 23.7 kpc then the halo mass will be much more than that calculated above.

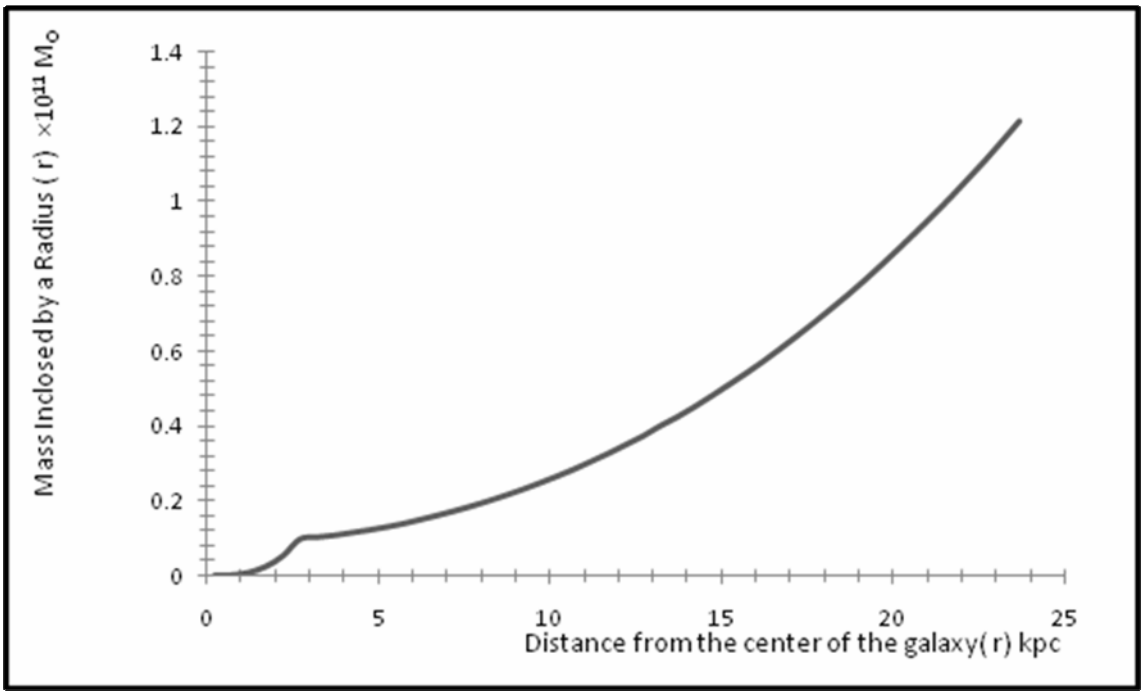

Fig. 3 : Mass Distribution of NGC 3672

Spiral galaxies are composed of four components: nucleus, bulge, disk and dark halo (Sofue, 2008). Below the calculated mass of those four components is presented.

The mass of the nucleus of the galaxy NGC 3672 is calculated at a radius of 350 pc and is found to be (2.13×10^7 M_o). The bulge mass is equal to the inner mass at $r=r_t$ and is found to be 9.78×10^9 M_o. Therefore NGC 3672 has a nucleus of a very small mass compared with the bulges mass.

Emission lines are observed over a distance of 17.6 kpc from the center of NGC 3672. The disk radius is defined as the distance at which luminous objects can be observed, i.e. the disk radius is equal to 17.6 kpc and the calculated mass from equation (10) at this radius turns to be (5.822×10^{10} M_o).

The calculated halo mass (5.4×10^{10} M_o) at a radius of 23.7 kpc is a large contribution to the total mass of the galaxy (1.22×10^{11} M_o) although luminous objects are very rare in the halo. Existence of a massive halo can be explained by the presence of the dark matter in the form of non luminous large objects like brown dwarfs, white dwarfs, neutron stars and black holes or small particles like neutrinos, baryons and unknown elementary particles which have not yet discovered in lab. experiments on earth (non baryonic dark matter).

The total mass of the galaxy NGC 3672 (1.22×10^{11} M_o) at a radius of 23.7 kpc is within the range ($1.22 \pm0.02 \times 10^{11}$ M_o) given by Rubin *et al.*,(1977). Calculations also show that NGC 3672 has a nucleus of small mass and a massive halo which is consisted with that found by Rubin too.

CONCLUSION

In this work we calculated the density and mass of the spiral galaxy NGC 3672 at different distances from the center of the galaxy using equations derived by Daod, (2012) and the observed rotation curve from Sofue *et al.*,(1999). Calculations confirm that the galaxy NGC 3672 has a small nuclear mass and a massive halo. The total mass of the NGC

3672 at an outer radius of 23.7 kpc is (1.22×10^{11} M_o) and this value might grow up if the galaxy extends farther than 23.7 kpc.

REFERENCES

Binney, J.; Tremaine, S. (1987). "Galactic Dynamics ". Princeton University press, USA.

Daod, N.A. (2012). The distribution of the density and mass for spiral galaxies. *J. Raf. Sei*. **23**(2), 131-173.

Daoud, N.A.; Abdul-Kahader, A.J.; Zeki, M.K. (2009). Density law of spiral galaxy relative to rotation curves. *J. Raf. Sci*., **20**(3), 90-96.

Deguchi, S.; Fujii, T.; Izumiura, H.; Kameya, O.; Nakada, Y.l. (2000). SIO maser survey of the galactic disk IRAS sources. *Ap. J. Suppl.*, **128**, 571.

Greisen, E.W.; Spekkens, K.; Van Moorel, G.A. (2009). Aperture synthesis observations of the nearby spiral NGC 6503: modeling the thin and thick HI disks. *Astronomical J*. **13**, 4718 – 4733.

Maciel, W.J.; Logo, L.G. (2005). A new determination of the rotation curve from galactic disk planetary nebulae. *Revista Mexicana de Astronomiay Astrofisica,* **41**, 383 - 388.

Mathewson, D.S.; Ford, V.L. (1996). Parameters of 2447 southern Spiral galaxies for use in Tully-Fisher relation. *Ap. J. Suppl*. **107**, 197.

Ostriker, J.P.; Peebles, P.J.; Yahil, A. (1974). The size and mass of galaxies and the mass of the universe . *Astrophysical J. Lett*. **193**, (L 1 - L4).

Rubin, V.C.; Thonnard, N.; Foed, W.K. (1977). Extended rotation curves of high-luminosity spiral galaxies. I the angle between the rotation axis of the nucleus and the outer disk. *Ap. J*., **217**, (L1 – L4).

Sofue, Y. (1996). The most completely sampled rotation curves for galaxies. *Ap. J*. **458**, 120 - 131.

Sofue, Y. (2008). Pseudo rotation curve connecting the galaxy, dark halo and local group. *Astron. Soc. Japan*, **1**, 77.

Sofue, Y.; Rubin, V. (2001). Rotation curves of spiral galaxies. *Annu. Rev. Astron. Astro. Phys*., **39**, 137 – 174.

Sofue, Y.; Tutui, Y.; Honma, M.; Tomita, A.; Takamiya, T.; Koda, J.; Takeda Y. (1999). Rotation curves of spiral galaxies. *Astrophysical J*., **523**, 136 – 146.

Thakre, M.; Upadhyaya, G. K.; Thakre, N.; Sharma, R. K.; Vyas, A. (2011). Nuclear steep point amplitude and mass distribution. *International J. Physics and Applications,* ISSN 0974 – 3103. **3**(1), 97 – 103.

Table 1: Rotation curve of the galaxy NGC 3672

R(kpc)	V(km/s)	Rkpc)	V(km/s)	R(kpc)	V(km/s)	R(kpc)	V(km/s)	R(kpc)	V(km/s)
0.000	0.00000	2.050	140.04424	4.100	189.00208	6.150	201.15388	8.200	204.99055
0.050	8.17544	2.100	144.33340	4.150	189.27492	6.200	201.39310	8.250	205.23523
0.100	15.13671	2.150	148.70644	4.200	189.55257	6.250	201.61047	8.300	205.47990
0.150	20.56873	2.200	152.99306	4.250	189.83353	6.300	201.79230	8.350	205.72458
0.200	24.70579	2.250	157.02589	4.300	190.11633	6.350	201.92653	8.400	205.96925
0.250	27.46013	2.300	160.69182	4.350	190.40004	6.400	202.00821	8.450	206.21397
0.300	29.48961	2.350	163.95436	4.400	190.68407	6.450	202.04192	8.500	206.45905
0.350	31.49676	2.400	166.83565	4.450	190.96817	6.500	202.03947	8.550	206.70548
0.400	33.50391	2.450	169.37354	4.500	191.25230	6.550	202.01483	8.600	206.95642
0.450	35.49586	2.500	171.58896	4.550	191.53644	6.600	201.97968	8.650	207.21886
0.500	37.45622	2.550	173.48656	4.600	191.82059	6.650	201.94208	8.700	207.50446
0.550	39.39904	2.600	175.08005	4.650	192.10477	6.700	201.90767	8.750	207.82874
0.600	41.34069	2.650	176.91264	4.700	192.38916	6.750	201.88106	8.800	208.20566
0.650	43.28233	2.700	177.55305	4.750	192.67419	6.800	201.86626	8.850	208.64209
0.700	45.22398	2.750	178.57098	4.800	192.96088	6.850	201.86575	8.900	209.13429
0.750	47.27055	2.800	179.51318	4.850	193.25090	6.900	201.87965	8.950	209.66988
0.800	49.58307	2.850	180.39392	4.900	193.56451	6.950	201.90561	9.000	210.23335
0.850	52.11268	2.900	181.20168	4.950	193.84978	7.000	201.93999	9.050	210.81155
0.900	54.69836	2.950	181.91541	5.000	194.16171	7.050	201.97919	9.100	211.39600
0.950	57.28405	3.000	182.52135	5.050	194.48186	7.100	202.02065	9.150	211.98230
1.000	59.86973	3.050	183.02319	5.100	194.80840	7.150	202.06297	9.200	212.56799
1.050	62.90426	3.100	183.44112	5.150	195.13908	7.200	202.10555	9.250	213.15005
1.100	67.30460	3.150	183.80286	5.200	195.47198	7.250	202.14818	9.300	213.72276
1.150	73.09009	3.200	184.13345	5.250	195.80585	7.300	202.19083	9.350	214.27689
1.200	78.79397	3.250	184.44948	5.300	196.14005	7.350	202.23352	9.400	214.80081
1.250	83.38112	3.300	184.75880	5.350	196.47430	7.400	202.27647	9.450	215.28461
1.300	87.38404	3.350	185.06313	5.400	196.80855	7.450	202.32050	9.500	215.72433
1.350	91.31095	3.400	18536099	4.450	197.14258	7.500	202.36777	9.550	216.12405
1.400	95.02150	3.450	185.65012	4.500	197.47588	7.550	202.42293	9.600	216.49379
1.450	98.40882	3.500	185.92891	4.550	197.80724	7.600	202.49358	9.650	216.84505
1.500	101.78680	3.550	186.19759	5.600	198.13437	7.650	202.58897	9.700	217.18665
1.550	105.14875	3.600	186.45798	5.650	198.45406	7.700	202.71693	9.750	217.52263
1.600	108.49166	3.650	186.71272	5.700	198.76292	7.750	202.88029	9.800	217.85138
1.650	111.81566	3.700	186.96431	5.750	199.05872	7.800	203.07555	9.850	218.16473
1.700	115.12383	3.750	187.21446	5.800	199.34131	7.850	203.29449	9.900	218.44795
1.750	118.42371	3.800	187.46419	5.850	199.61282	7.900	203.52797	9.950	218.68243
1.800	121.73177	3.850	187.71411	5.900	199.87662	7.950	203.76863	10.00	218.85219
1.850	125.08030	3.900	187.96494	5.950	200.13597	8.000	204.01218	10.05	218.95091
1.900	128.52258	3.950	188.21771	6.000	200.39310	8.050	208.25659	10.10	218.98521
1.950	132.12804	4.000	188.47394	6.050	200.64928	8.100	204.50122	10.15	218.97128
2.000	135.96054	4.050	188.73508	6.100	200.90376	8.150	204.74590	10.20	218.92773