7th IAA PDC Conference 2021 – paper 172

e-Lightning Talk April 30th 2021

"THE EFFECT OF NEAs INTERNAL STRUCTURE ON PARTICLE DYNAMICS: A WAY TO SEARCH FOR STABLE ORBITS AROUND ASTEROID DIDYMOS"

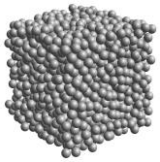
Dr S. Soldini (Presenter)
Stefania.Soldini@Liverpool.ac.uk

Dr. F. Ferrari, Dr. Y. Zhang, Dr. O. Karatekin, Dr. L. Pou, Dr. N. Rambaux, Dr. A. Campo-Bagatin, Dr H. Ikeda, K. Wada, and Y. Tsuda

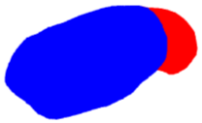
UNIVERSITY OF LIVERPOOL

Dynamics Simulation: the Role of the Internal Mass Structure

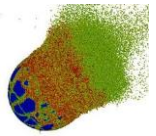
Internal Structure Model

Sphere Packing 

+

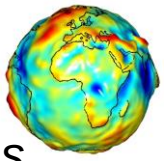
Density (ρ) Distribution 

Impact Dynamics

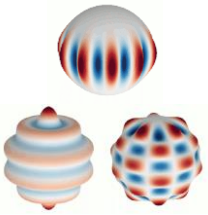
SPH Hydrocode: Hypervelocity Impact (*T.P. Remington et all*) 

Detect Orbital Motion 1 2

Orbital Dynamics

Gravity Model *Mascons* 

1

Stokes Coefficients (C_{nm}, S_{nm}) 

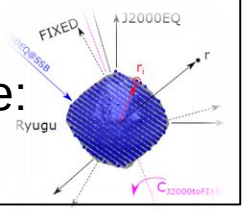
1 To compare gravity models and observations

2 To understand the nature of the motion (close prox.)

3 To find possible natural orbits around Eq.

$$\Omega = \frac{1}{2}\omega^2(x^2+y^2) + \sum_{i=1}^{N_{SPH}}\left(\frac{Gm_i}{|\vec{r}-\vec{r}_i|}\right)$$

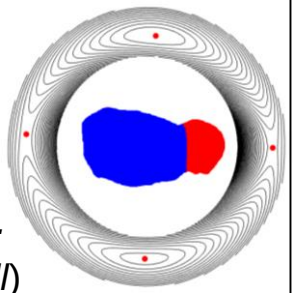
Asteroid-Fixed Rotating Ref Frame: *Effective Potential*



+

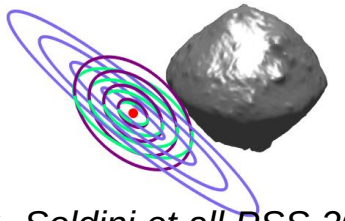
Linearised Equations: *1st Od Taylor Expansion* $\nabla\Omega = 0$

2

Equilibrium Points: *Algebraic system of Eq.* (S. *Soldini et all*) 

3

Analytical Approx. Centre Manifold: *Periodic Orbits around Equilibrium Points*

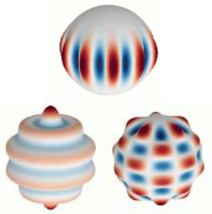


(S. *Soldini et all PSS 2019*)

Today's topic: what are we looking for?

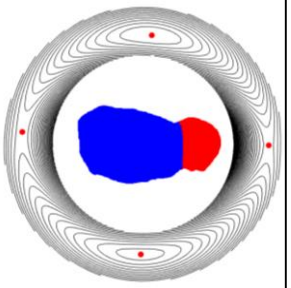
- Didymos is the main case study presented here however our approach can easily applied to any irregular object
- We are interested in comparing several internal structures by computing the following:
  - Stokes Coefficients (up to order 5)

Stokes Coefficients (C_{nm}, S_{nm})



  - Equilibrium points (stationary points of the effective potential)

Equilibrium Points: *Algebraic system of Eq.*



(S. *Soldini et all PSS 2019*)

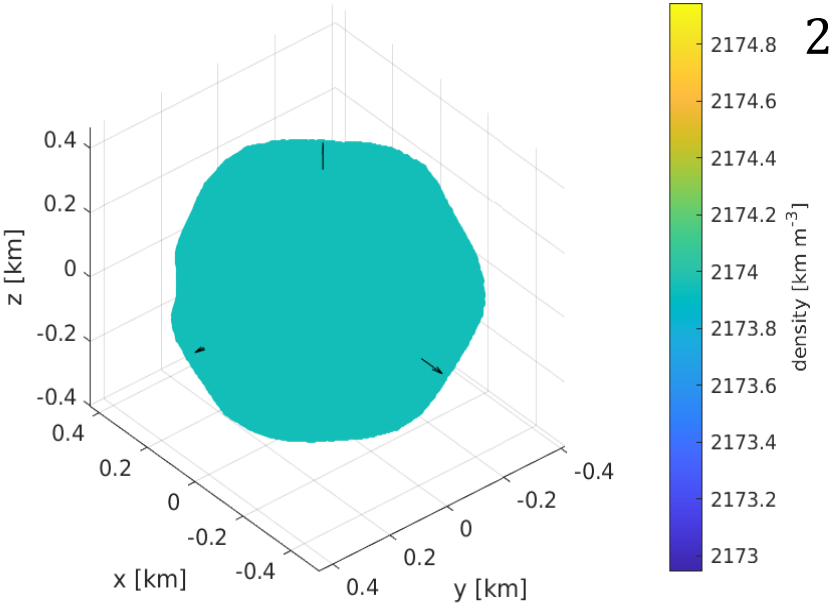
UNIVERSITY OF LIVERPOOL

Today's topic: Uniform Distribution

1. We will compare the shape model (uniform density) with Mascons model and we will change the following parameters:

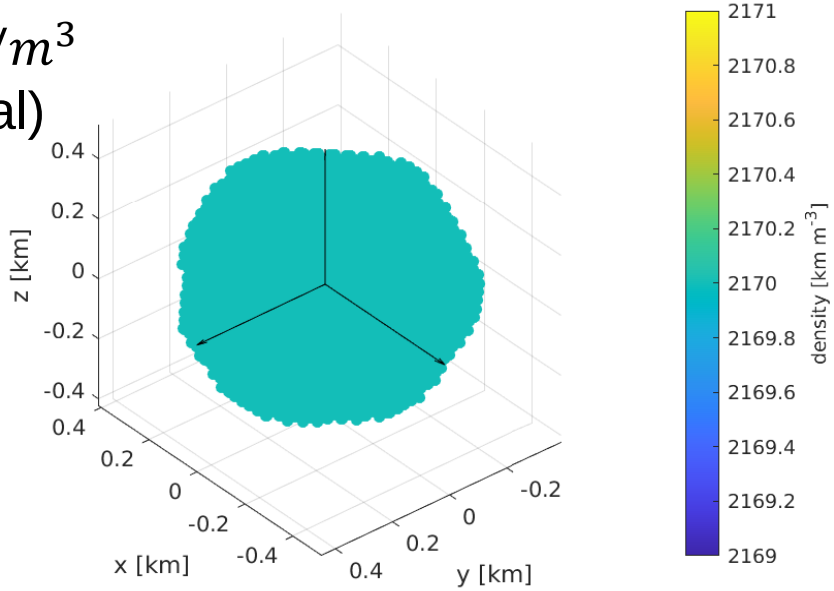
   - Bulk density (2170±350 kg/m^3)
   - Decrease in Spin axis period ($T = 2.26\ h$ (nominal) → $2.43\ h$)
   - Resolution (number of mascons considered)

6.6M Mascons



$2170\ kg/m^3$ (nominal)

10K Mascons

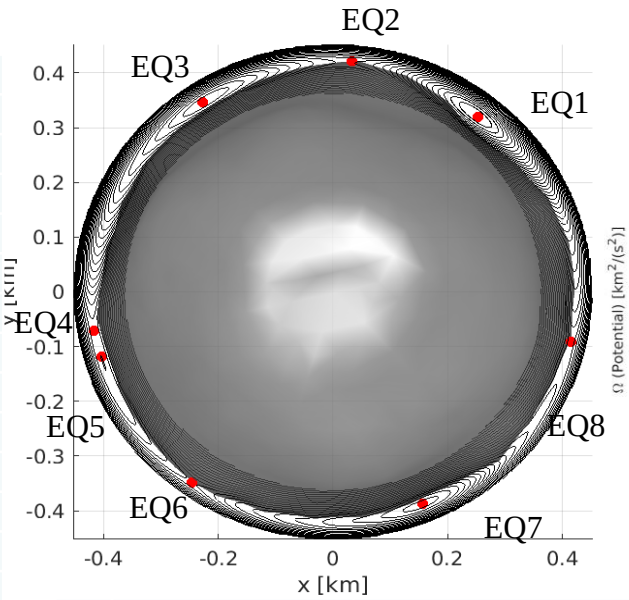


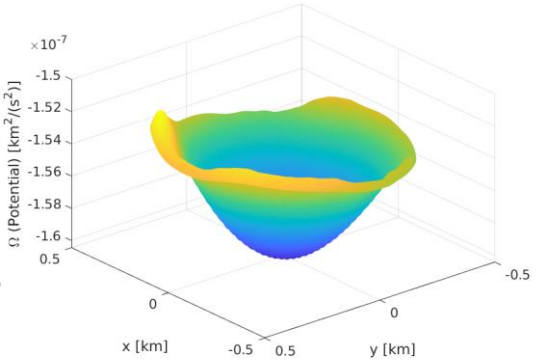
Result: Uniform Distribution

- Bulk density (2520 kg/m^3)
- Spin axis period ($T = 2.26\ h$)
- Resolution (6.6M)

Nominal Density +
Nominal Axis Period
High Resolution

n,m	Cnm	Snm
1,0	-5.2223E-06	0.0000E+00
1,1	5.3885E-06	-4.8848E-06
2,0	-6.5039E-03	0.0000E+00
2,1	-4.6831E-06	-2.1131E-06
2,2	2.7829E-03	1.1593E-06
3,0	-9.2689E-04	0.0000E+00
3,1	-1.2076E-03	6.3516E-03
3,2	1.4265E-03	-2.3941E-03
3,3	8.0600E-04	-1.0271E-03
4,0	3.9763E-03	0.0000E+00
4,1	-8.6027E-04	2.6661E-03
4,2	-5.3501E-05	1.1508E-03
4,3	2.0248E-03	3.1011E-03
4,4	1.5731E-03	-2.2534E-04
5,0	-6.2547E-04	0.0000E+00
5,1	1.2676E-04	5.5753E-04
5,2	-1.1650E-04	-7.0422E-04
5,3	-6.5566E-04	1.2492E-03
5,4	-4.7234E-04	-8.7195E-05
5,5	4.5592E-05	6.5807E-04





EQ	x [m]	y [m]	Z [m]
1	253.5492219	320.2487985	-9.02090463
2	33.63850708	421.5580061	-20.63219949
3	-227.0227286	346.1257071	-6.613293337
4	-416.181182	-71.12865533	-2.404408369
5	-404.0420744	-118.9713401	-4.786214384
6	-246.5143886	-347.9665974	-7.887229005
7	156.234735	-387.7440026	-3.579029178
8	415.0550243	-91.4585738	-3.440991479

UNIVERSITY OF LIVERPOOL

Result: Uniform Distribution

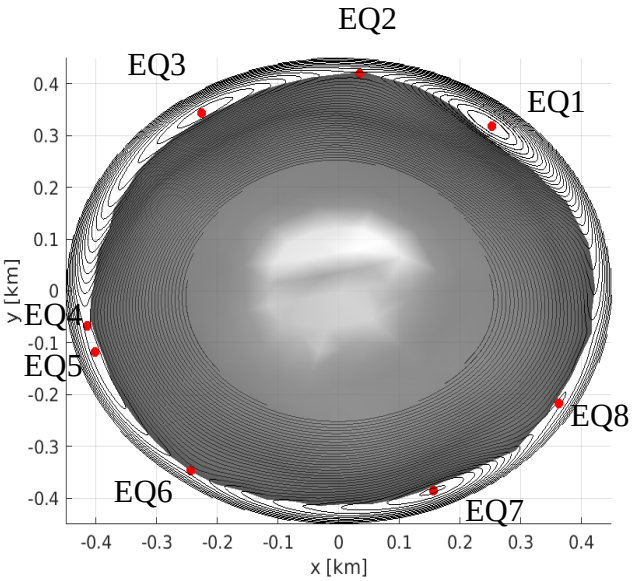
- Bulk density (2170 kg/m^3)
- Spin axis period ($T = 2.43\ h$)
- Resolution (6.6M)

Nominal Density

Nominal Axis Period +

High Resolution

n,m	Cnm	Snm
1,0	-5.2223E-06	0.0000E+00
1,1	5.3885E-06	-4.8848E-06
2,0	-6.5039E-03	0.0000E+00
2,1	-4.6831E-06	-2.1131E-06
2,2	2.7829E-03	1.1593E-06
3,0	-9.2689E-04	0.0000E+00
3,1	-1.2076E-03	6.3516E-03
3,2	1.4265E-03	-2.3941E-03
3,3	8.0600E-04	-1.0271E-03
4,0	3.9763E-03	0.0000E+00
4,1	-8.6027E-04	2.6661E-03
4,2	-5.3501E-05	1.1508E-03
4,3	2.0248E-03	3.1011E-03
4,4	1.5731E-03	-2.2534E-04
5,0	-6.2547E-04	0.0000E+00
5,1	1.2676E-04	5.5753E-04
5,2	-1.1650E-04	-7.0422E-04
5,3	-6.5566E-04	1.2492E-03
5,4	-4.7234E-04	-8.7195E-05
5,5	4.5592E-05	6.5807E-04



EQ	x [m]	y [m]	Z [m]
1	252.2470582	317.865246	-9.19306592
2	34.65584939	419.3353582	-21.35031448
3	-226.0143813	343.8408631	-6.962447077
4	-414.4233716	-68.08367074	-2.301663451
5	-401.7425944	-118.0845239	-4.89408406
6	-244.4859663	-346.8497673	-8.209863451
7	155.9460986	-385.1234847	-3.935009609
8	361.8871586	-216.9892852	3.441529613

UNIVERSITY OF LIVERPOOL

Result: Uniform Distribution

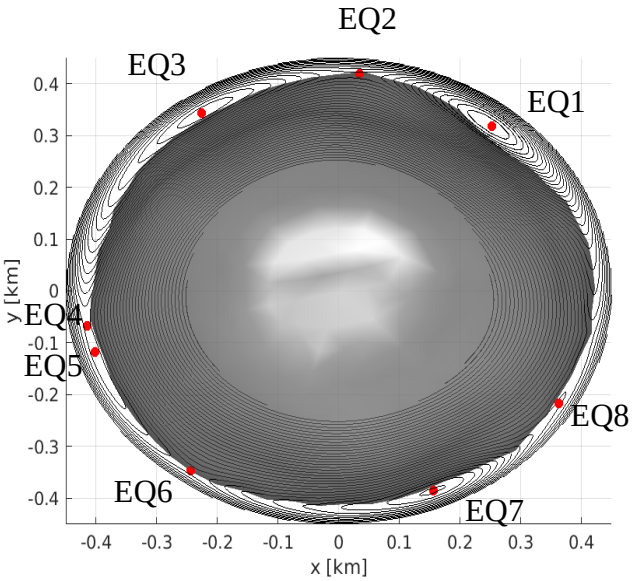
- Bulk density (2170 kg/m^3)
- Spin axis period ($T = 2.43\ h$)
- Resolution (6.6M)

Nominal Density

Nominal Axis Period +

High Resolution

n,m	Cnm	Snm
1,0	-5.2223E-06	0.0000E+00
1,1	5.3885E-06	-4.8848E-06
2,0	-6.5039E-03	0.0000E+00
2,1	-4.6831E-06	-2.1131E-06
2,2	2.7829E-03	1.1593E-06
3,0	-9.2689E-04	0.0000E+00
3,1	-1.2076E-03	6.3516E-03
3,2	1.4265E-03	-2.3941E-03
3,3	8.0600E-04	-1.0271E-03
4,0	3.9763E-03	0.0000E+00
4,1	-8.6027E-04	2.6661E-03
4,2	-5.3501E-05	1.1508E-03
4,3	2.0248E-03	3.1011E-03
4,4	1.5731E-03	-2.2534E-04
5,0	-6.2547E-04	0.0000E+00
5,1	1.2676E-04	5.5753E-04
5,2	-1.1650E-04	-7.0422E-04
5,3	-6.5566E-04	1.2492E-03
5,4	-4.7234E-04	-8.7195E-05
5,5	4.5592E-05	6.5807E-04



EQ	x (shape)-x(masc) [m]	y (shape) – y (masc) [m]	Z (shape) – z (masc) [m]
1	0.003847403	0.000210712	-0.008661242
2	-0.975622906	0.112743808	-0.158384926
3	-0.328402619	-0.219645435	0.023022111
4	-0.111927427	0.652995604	0.008059492
5	0.153686074	-0.473051144	-0.043175899
6	-0.125807044	0.253771941	-0.076221105
7	-0.2476987	-0.099202929	0.025331129
8	1.487861084	2.563104948	-0.15893172

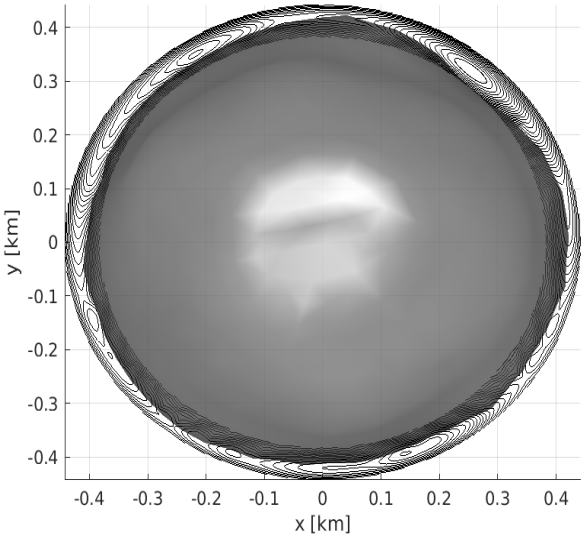
UNIVERSITY OF LIVERPOOL

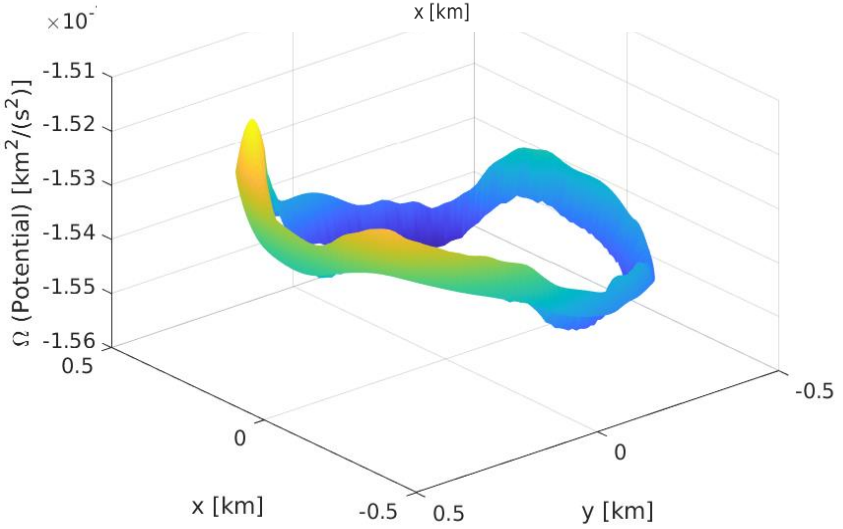
Result: Uniform Distribution

Nominal Density
Nominal Axis Period
Lower Resolution

- Bulk density (2170 kg/m^3)
- Spin axis period ($T = 2.43\ h$)
- Resolution (10K)

n,m	Cnm	Snm
1,0	-8.7059E-05	0.0000E+00
1,1	1.1193E-04	-7.4207E-04
2,0	-7.0977E-03	0.0000E+00
2,1	5.2901E-04	-3.2507E-04
2,2	2.6010E-03	-2.4390E-04
3,0	-1.0355E-03	0.0000E+00
3,1	-1.0654E-03	6.0389E-03
3,2	1.4277E-03	-2.4555E-03
3,3	9.0424E-04	-9.5631E-04
4,0	3.6600E-03	0.0000E+00
4,1	-7.0691E-04	2.5232E-03
4,2	1.4787E-05	1.3160E-03
4,3	2.1417E-03	3.0439E-03
4,4	1.3132E-03	-1.6104E-04
5,0	-4.0657E-04	0.0000E+00
5,1	6.6249E-05	2.2158E-04
5,2	-1.2408E-05	-6.1133E-04
5,3	-5.4074E-04	1.2779E-03
5,4	-4.2679E-04	-3.4040E-05
5,5	-5.5084E-05	5.7477E-04



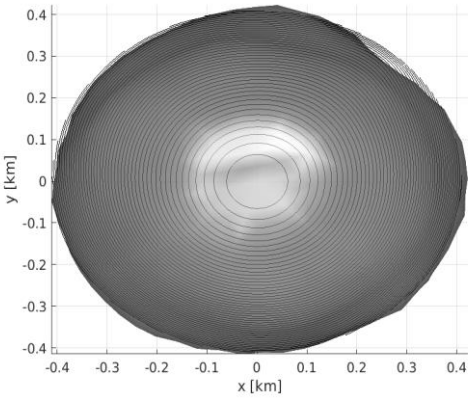


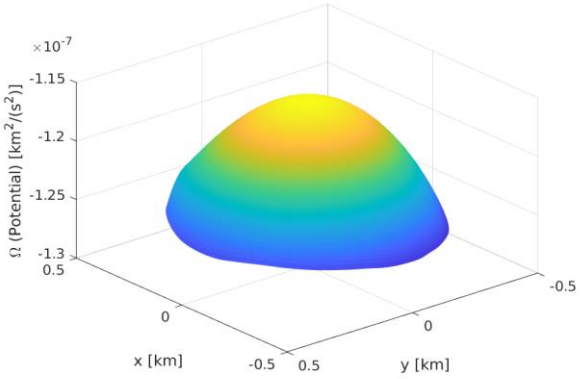
UNIVERSITY OF LIVERPOOL

Result: Uniform Distribution

- Bulk density (1820 kg/m^3)
- Spin axis period ($T = 2.26\ h$)
- Resolution (6.6M)

n,m	Cnm	Snm
1,0	-5.2223E-06	0.0000E+00
1,1	5.3885E-06	-4.8848E-06
2,0	-6.5039E-03	0.0000E+00
2,1	-4.6831E-06	-2.1131E-06
2,2	2.7829E-03	1.1593E-06
3,0	-9.2689E-04	0.0000E+00
3,1	-1.2076E-03	6.3516E-03
3,2	1.4265E-03	-2.3941E-03
3,3	8.0600E-04	-1.0271E-03
4,0	3.9763E-03	0.0000E+00
4,1	-8.6027E-04	2.6661E-03
4,2	-5.3501E-05	1.1508E-03
4,3	2.0248E-03	3.1011E-03
4,4	1.5731E-03	-2.2534E-04
5,0	-6.2547E-04	0.0000E+00
5,1	1.2676E-04	5.5753E-04
5,2	-1.1650E-04	-7.0422E-04
5,3	-6.5566E-04	1.2492E-03
5,4	-4.7234E-04	-8.7195E-05
5,5	4.5592E-05	6.5807E-04





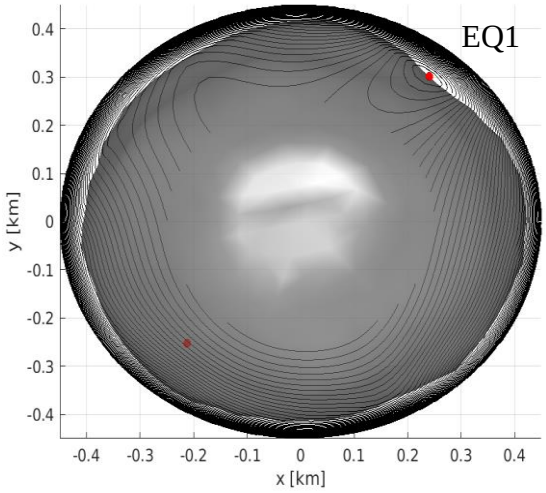
UNIVERSITY OF LIVERPOOL

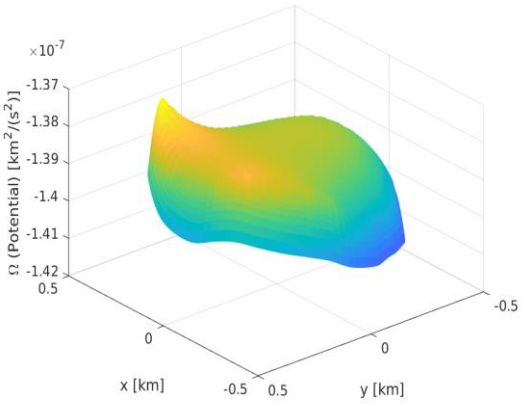
Result: Uniform Distribution

- Bulk density (2170 kg/m^3)
- Spin axis period ($T = 2.26\ h$)
- Resolution (6.6M)

Nominal Density
Nominal Axis Period
High Resolution

n,m	Cnm	Snm
1,0	-5.2223E-06	0.0000E+00
1,1	5.3885E-06	-4.8848E-06
2,0	-6.5039E-03	0.0000E+00
2,1	-4.6831E-06	-2.1131E-06
2,2	2.7829E-03	1.1593E-06
3,0	-9.2689E-04	0.0000E+00
3,1	-1.2076E-03	6.3516E-03
3,2	1.4265E-03	-2.3941E-03
3,3	8.0600E-04	-1.0271E-03
4,0	3.9763E-03	0.0000E+00
4,1	-8.6027E-04	2.6661E-03
4,2	-5.3501E-05	1.1508E-03
4,3	2.0248E-03	3.1011E-03
4,4	1.5731E-03	-2.2534E-04
5,0	-6.2547E-04	0.0000E+00
5,1	1.2676E-04	5.5753E-04
5,2	-1.1650E-04	-7.0422E-04
5,3	-6.5566E-04	1.2492E-03
5,4	-4.7234E-04	-8.7195E-05
5,5	4.5592E-05	6.5807E-04





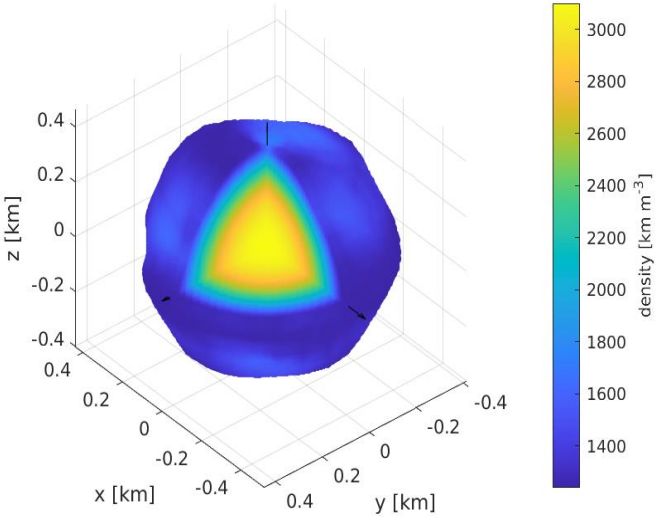
EQ	x [m]	y [m]	Z [m]
1	240.6742088	300.3057491	-11.08962009
	x (shape)-x(masc) [m]	y (shape) – y (masc) [m]	Z (shape) – z (masc) [m]
1	11.57669679	-0.146701329	0.136793007

UNIVERSITY OF LIVERPOOL

Today's topic: Radial Distribution

2. We have changed the internal density distribution by maintaining the nominal bulk density (2170 kg/m^3):

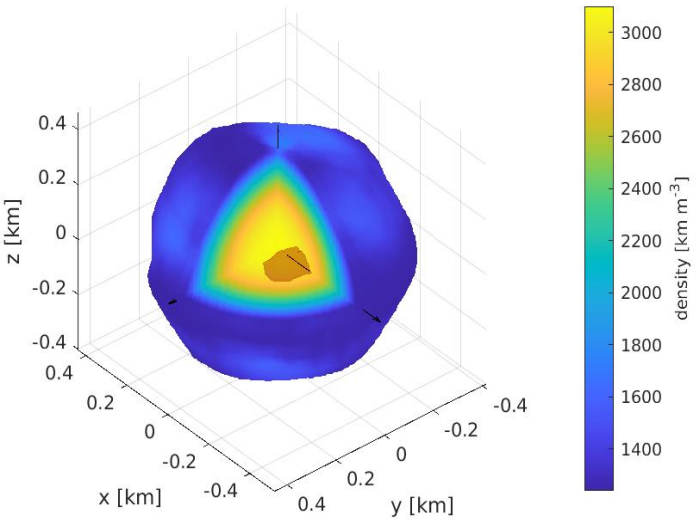
RADIAL



$$1179.65\ kg/m^3 \doteqdot 3100\ kg/m^3$$

(Yu Yang et all, CMDA 2019)

RADIAL + VOID



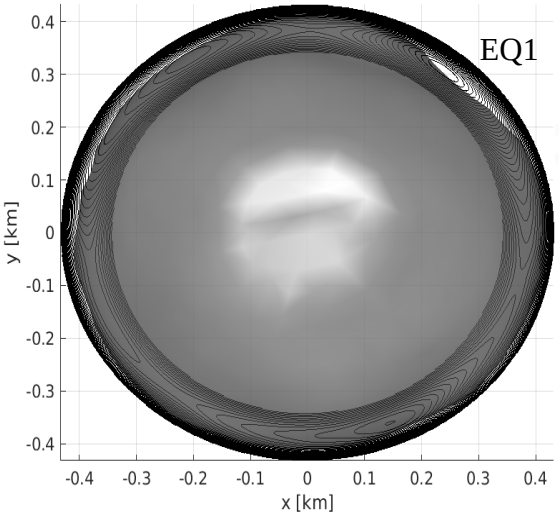
UNIVERSITY OF LIVERPOOL

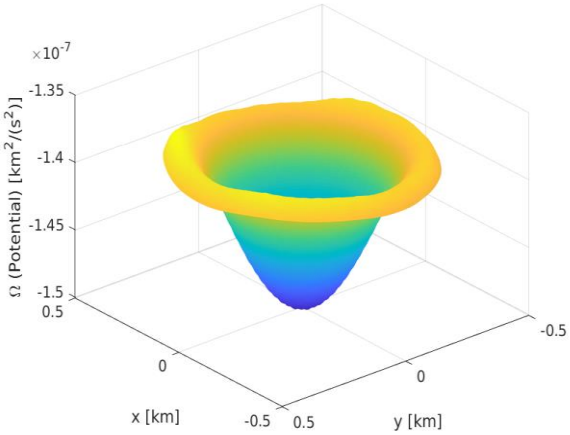
Result: Radial Distribution

Nominal Density
Nominal Axis Period
High Resolution

- Bulk density (2170 kg/m^3)
- Spin axis period ($T = 2.26\ h$)
- Resolution (6.6M)

n,m	Cnm	Snm
1,0	-1.4306E-04	0.0000E+00
1,1	-5.6774E-05	1.5530E-04
2,0	-4.0483E-03	0.0000E+00
2,1	-4.3463E-05	-1.9870E-05
2,2	1.7299E-03	-1.8330E-05
3,0	-6.5427E-04	0.0000E+00
3,1	-7.4386E-04	3.9340E-03
3,2	8.6664E-04	-1.4319E-03
3,3	4.6819E-04	-5.8745E-04
4,0	2.3901E-03	0.0000E+00
4,1	-5.2484E-04	1.6972E-03
4,2	-4.3851E-06	7.3502E-04
4,3	1.3013E-03	1.9277E-03
4,4	9.5632E-04	-1.0390E-04
5,0	-3.9148E-04	0.0000E+00
5,1	4.5656E-05	3.7608E-04
5,2	-6.0368E-05	-4.0504E-04
5,3	-3.8769E-04	7.3450E-04
5,4	-2.9427E-04	-4.9974E-05
5,5	1.8948E-05	3.9229E-04





EQ	x [m]	y [m]	Z [m]
1	240.4500522	303.6101072	-6.77322957
	x (unif)-x(radius) [m]	y (unif) – y (radius) [m]	Z (unif) – z (radius) [m]
1	0.224156587	-3.304358098	-4.316390518

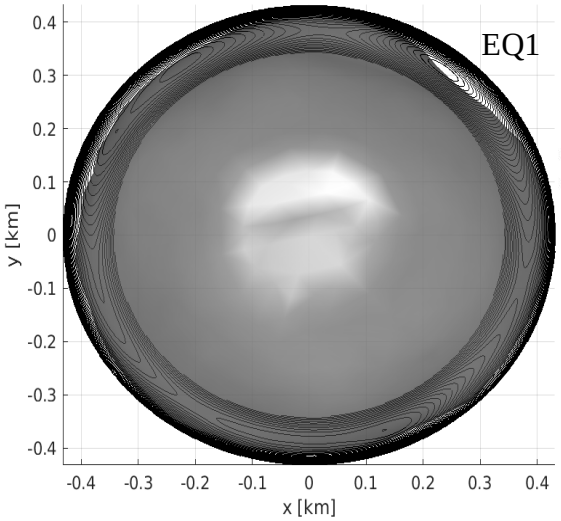
UNIVERSITY OF LIVERPOOL

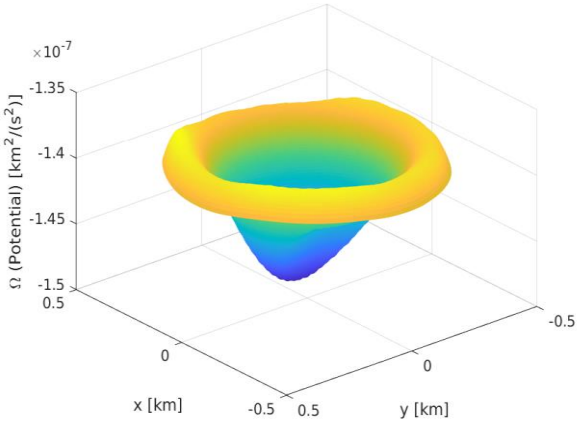
Result: Radial Distribution + Void

- Bulk density (2170 kg/m^3)
- Spin axis period ($T = 2.26\ h$)
- Resolution (6.6M)

Nominal Density
Nominal Axis Period
High Resolution

n,m	Cnm	Snm
1,0	-4.4860E-04	0.0000E+00
1,1	1.6475E-03	1.5813E-04
2,0	-3.8541E-03	0.0000E+00
2,1	6.8964E-05	-1.0053E-05
2,2	1.5006E-03	-2.0121E-05
3,0	-6.3119E-04	0.0000E+00
3,1	-8.1713E-04	3.9705E-03
3,2	8.5088E-04	-1.4490E-03
3,3	4.9509E-04	-5.8719E-04
4,0	2.3969E-03	0.0000E+00
4,1	-5.4086E-04	1.7112E-03
4,2	7.6362E-06	7.4010E-04
4,3	1.3152E-03	1.9464E-03
4,4	9.6787E-04	-1.0826E-04
5,0	-3.9786E-04	0.0000E+00
5,1	5.0259E-05	3.7903E-04
5,2	-5.8372E-05	-4.0779E-04
5,3	-3.9206E-04	7.4055E-04
5,4	-2.9614E-04	-5.1285E-05
5,5	1.5988E-05	3.9728E-04





EQ	x [m]	y [m]	Z [m]
1	238.3144292	305.8812754	-7.224162435
	x (unif)-x(radius void) [m]	y (unif) – y (radius void) [m]	Z (unif) – z (radius void) [m]
1	2.359779632	-5.575526306	-3.865457652
	x (radius)-x(radius void) [m]	y (radius) – y (radius void) [m]	Z (radius) – z (radius void) [m]
1	2.135623045	-2.271168208	0.450932865

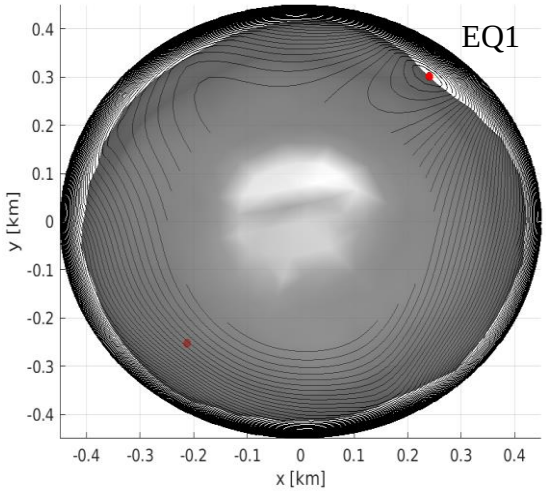
UNIVERSITY OF LIVERPOOL

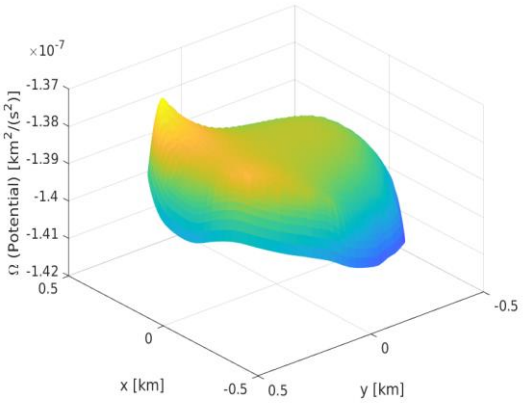
Result: Uniform Distribution

- Bulk density (2170 kg/m^3)
- Spin axis period ($T = 2.26\ h$)
- Resolution (6.6M)

Nominal Density
Nominal Axis Period
High Resolution

n,m	Cnm	Snm
1,0	-5.2223E-06	0.0000E+00
1,1	5.3885E-06	-4.8848E-06
2,0	-6.5039E-03	0.0000E+00
2,1	-4.6831E-06	-2.1131E-06
2,2	2.7829E-03	1.1593E-06
3,0	-9.2689E-04	0.0000E+00
3,1	-1.2076E-03	6.3516E-03
3,2	1.4265E-03	-2.3941E-03
3,3	8.0600E-04	-1.0271E-03
4,0	3.9763E-03	0.0000E+00
4,1	-8.6027E-04	2.6661E-03
4,2	-5.3501E-05	1.1508E-03
4,3	2.0248E-03	3.1011E-03
4,4	1.5731E-03	-2.2534E-04
5,0	-6.2547E-04	0.0000E+00
5,1	1.2676E-04	5.5753E-04
5,2	-1.1650E-04	-7.0422E-04
5,3	-6.5566E-04	1.2492E-03
5,4	-4.7234E-04	-8.7195E-05
5,5	4.5592E-05	6.5807E-04





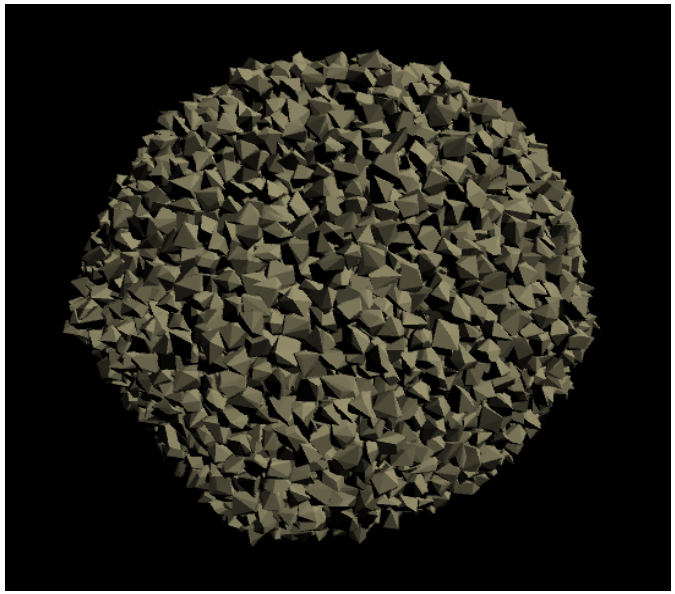
EQ	x [m]	y [m]	Z [m]
1	240.6742088	300.3057491	-11.08962009
	x (shape)-x(masc) [m]	y (shape) – y (masc) [m]	Z (shape) – z (masc) [m]
1	11.57669679	-0.146701329	0.136793007

UNIVERSITY OF LIVERPOOL

Today's topic: "M"ono/"P"oly Disperse "U"niform

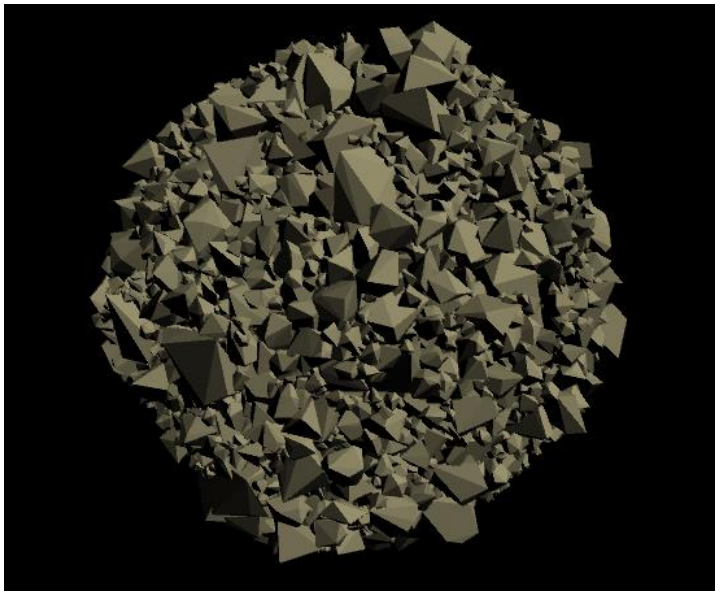
3. We have used polyhedron shaped with different sizes and considered them as point masses to find the equivalent masons model by maintaining the nominal bulk density (2170 kg/m^3):

MU



$2170\ kg/m^3$
(nominal)

PU



(Credit Fabio Ferrari)

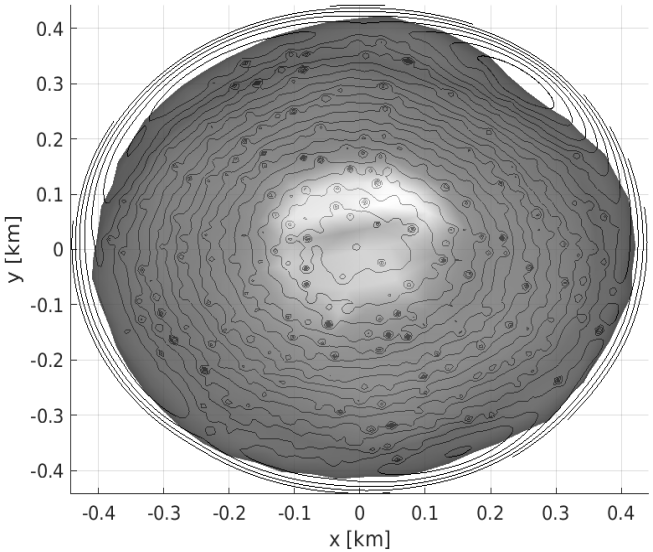
UNIVERSITY OF LIVERPOOL

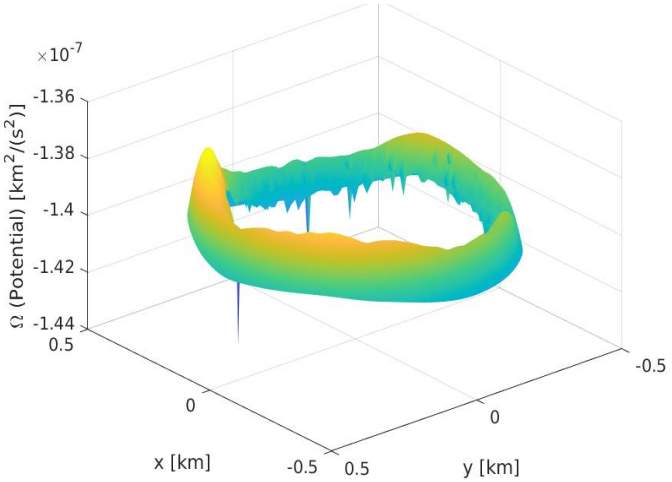
Result: MU

- Bulk density (2170 kg/m^3)
- Spin axis period ($T = 2.26\ h$)
- Resolution (9.5k)

Nominal Density
Nominal Axis Period
Low Resolution

n,m	Cnm	Snm	Cnm(10k unif)-Cnm(9.5k)	Snm(10k unif)-Snm(9.5k)
1,0	3.6721E-04	0.0000E+00	-4.5427E-04	0.0000E+00
1,1	-2.0762E-04	4.9779E-04	3.1956E-04	-1.2399E-03
2,0	-5.5453E-03	0.0000E+00	-1.5524E-03	0.0000E+00
2,1	-1.6583E-04	-1.6280E-04	6.9484E-04	-1.6227E-04
2,2	2.3856E-03	-1.8619E-04	2.1535E-04	-5.7715E-05
3,0	-9.2846E-04	0.0000E+00	-1.0701E-04	0.0000E+00
3,1	-9.1569E-04	5.3616E-03	-1.4975E-04	6.7736E-04
3,2	1.2507E-03	-2.2590E-03	1.7703E-04	-1.9654E-04
3,3	9.3459E-04	-8.8126E-04	-3.0352E-05	-7.5050E-05
4,0	3.2405E-03	0.0000E+00	4.1945E-04	0.0000E+00
4,1	-8.7001E-04	2.2062E-03	1.6310E-04	3.1697E-04
4,2	1.4450E-04	1.0102E-03	-1.2971E-04	3.0585E-04
4,3	1.6860E-03	2.7568E-03	4.5572E-04	2.8704E-04
4,4	1.3470E-03	-2.3923E-04	-3.3784E-05	7.8188E-05
5,0	-6.1733E-04	0.0000E+00	2.1075E-04	0.0000E+00
5,1	2.7473E-04	2.4288E-04	-2.0848E-04	-2.1292E-05
5,2	-2.8672E-05	-6.5279E-04	1.6264E-05	4.1469E-05
5,3	-4.9058E-04	9.3405E-04	-5.0165E-05	3.4381E-04
5,4	-4.3238E-04	-4.1981E-05	5.5864E-06	7.9412E-06
5,5	8.3436E-05	4.8030E-04	-1.3852E-04	9.4474E-05





UNIVERSITY OF LIVERPOOL

Result: PU

- Bulk density (2170 kg/m^3)
- Spin axis period ($T = 2.26\ h$)
- Resolution (8.3k)

Nominal Density
Nominal Axis Period
Low Resolution

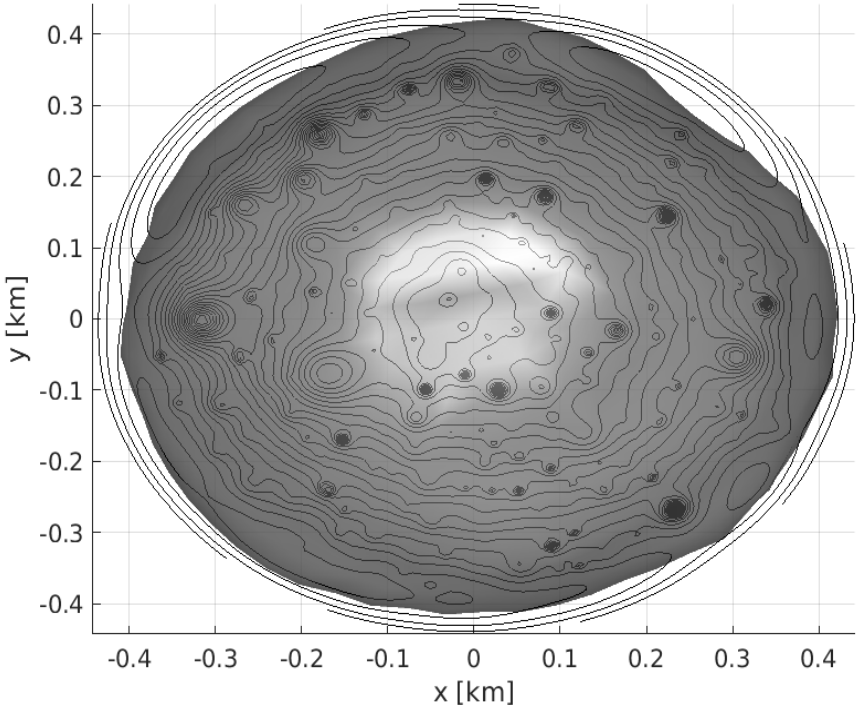
n,m	Cnm	Snm	Cnm(10k unif)-Cnm(8.3k PU)	Snm(10k unif)-Snm(8.3k PU)	Cnm(9.5K MU)-Cnm(8.3k PU)	Snm(9.5K MU)-Snm(8.3k PU)
1,0	-3.1213E-03	0.0000E+00	3.0343E-03	0.0000E+00	3.4886E-03	0.0000E+00
1,1	3.7507E-03	2.8917E-03	-3.6388E-03	-3.6338E-03	-3.9583E-03	-2.3939E-03
2,0	6.0230E-04	0.0000E+00	-7.7000E-03	0.0000E+00	-6.1476E-03	0.0000E+00
2,1	-2.1525E-03	4.7461E-04	2.6815E-03	-7.9968E-04	1.9867E-03	-6.3741E-04
2,2	1.5820E-03	-4.6686E-04	1.0189E-03	2.2296E-04	8.0358E-04	2.8067E-04
3,0	1.5292E-03	0.0000E+00	-2.5647E-03	0.0000E+00	-2.4577E-03	0.0000E+00
3,1	-1.2414E-03	5.6999E-03	1.7600E-04	3.3898E-04	3.2575E-04	-3.3838E-04
3,2	1.3284E-03	-1.7792E-03	9.9292E-05	-6.7630E-04	-7.7734E-05	-4.7976E-04
3,3	-5.8407E-04	-1.1850E-03	1.4883E-03	2.2870E-04	1.5187E-03	3.0375E-04
4,0	3.5036E-03	0.0000E+00	1.5632E-04	0.0000E+00	-2.6312E-04	0.0000E+00
4,1	-2.1462E-03	1.9163E-03	1.4393E-03	6.0688E-04	1.2762E-03	2.8992E-04
4,2	-4.9409E-04	2.7831E-04	5.0888E-04	1.0377E-03	6.3859E-04	7.3188E-04
4,3	6.9293E-04	1.9973E-03	1.4487E-03	1.0466E-03	9.9303E-04	7.5958E-04
4,4	1.5051E-03	8.2099E-05	-1.9185E-04	-2.4314E-04	-1.5806E-04	-3.2133E-04
5,0	4.5467E-04	0.0000E+00	-8.6124E-04	0.0000E+00	-1.0720E-03	0.0000E+00
5,1	-8.3000E-04	1.1568E-03	8.9625E-04	-9.3524E-04	1.1047E-03	-9.1394E-04
5,2	9.9046E-05	-8.5957E-04	-1.1145E-04	2.4824E-04	-1.2772E-04	2.0677E-04
5,3	1.1460E-04	7.1380E-04	-6.5535E-04	5.6406E-04	-6.0518E-04	2.2026E-04
5,4	2.8652E-04	8.5249E-05	-7.1331E-04	-1.1929E-04	-7.1889E-04	-1.2723E-04
5,5	-5.5496E-04	5.4920E-04	4.9988E-04	2.5574E-05	6.3840E-04	-6.8900E-05

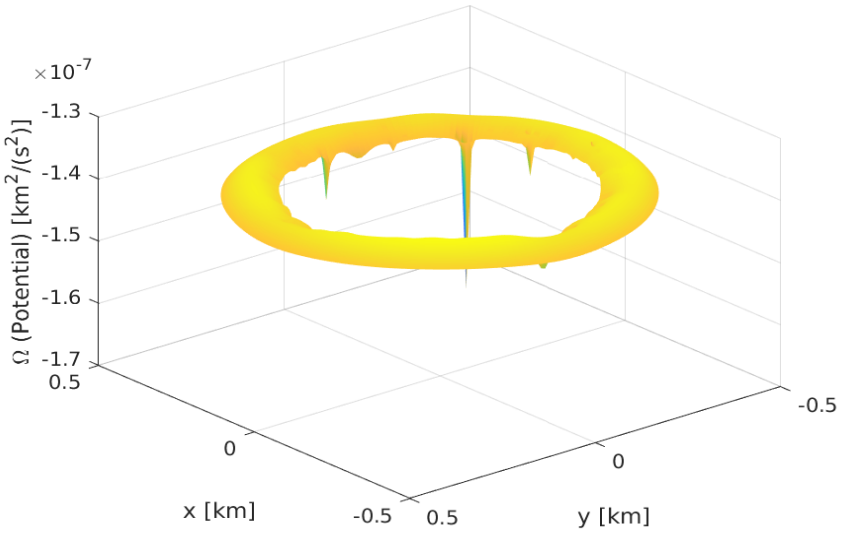
UNIVERSITY OF LIVERPOOL

Result: PU

- Bulk density (2170 kg/m^3)
- Spin axis period ($T = 2.26\ h$)
- Resolution (8.3k)

Nominal Density
Nominal Axis Period
Low Resolution





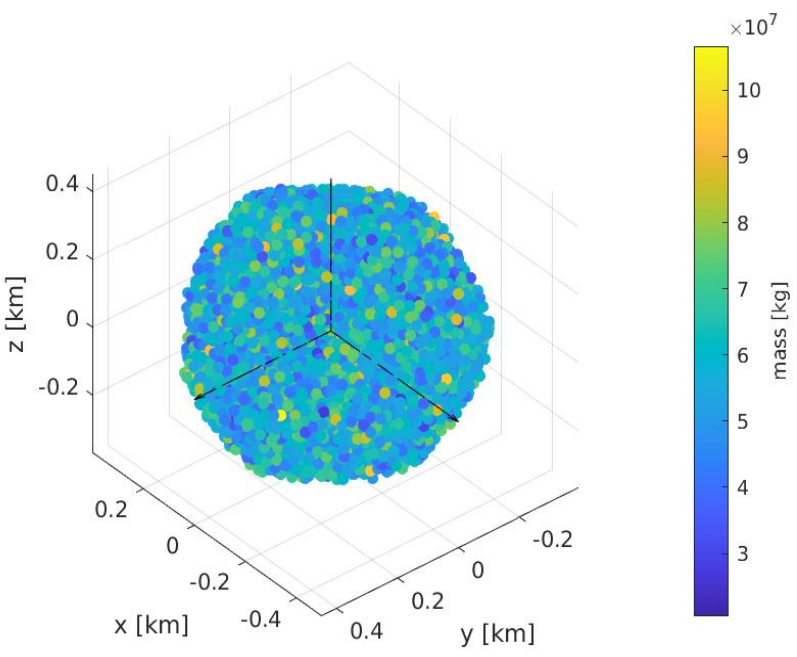
UNIVERSITY OF LIVERPOOL

Today's topic: "M"ono/"P"oly Disperse "U"niform

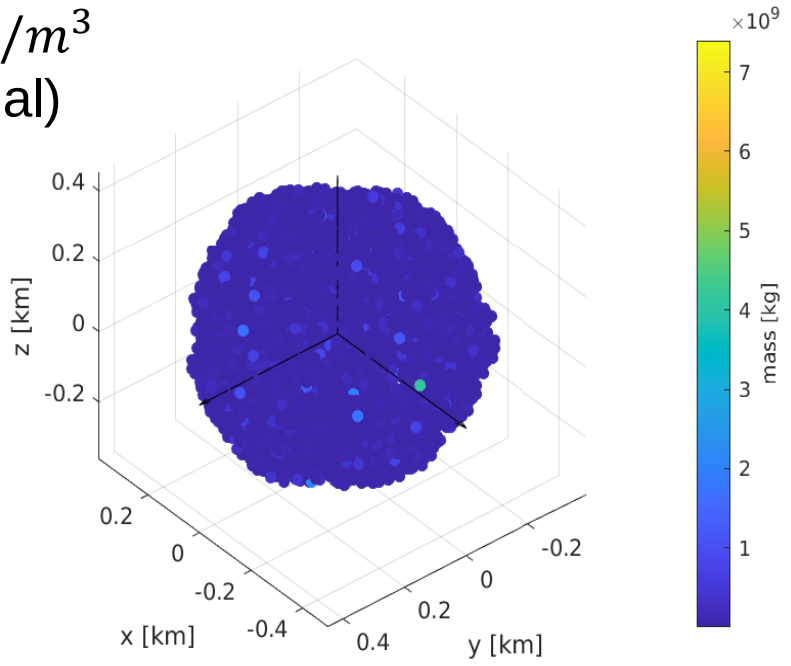
3. We have used polyhedron shaped with different sizes and considered them as point masses to find the equivalent masons model by maintaining the nominal bulk density (2170 kg/m^3):

MU

PU



$2170\ kg/m^3$
(nominal)

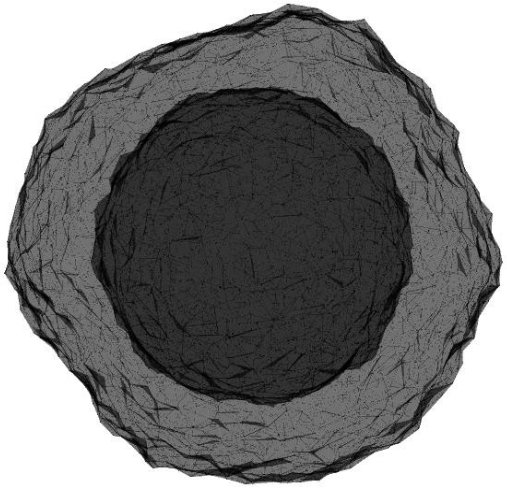


UNIVERSITY OF LIVERPOOL

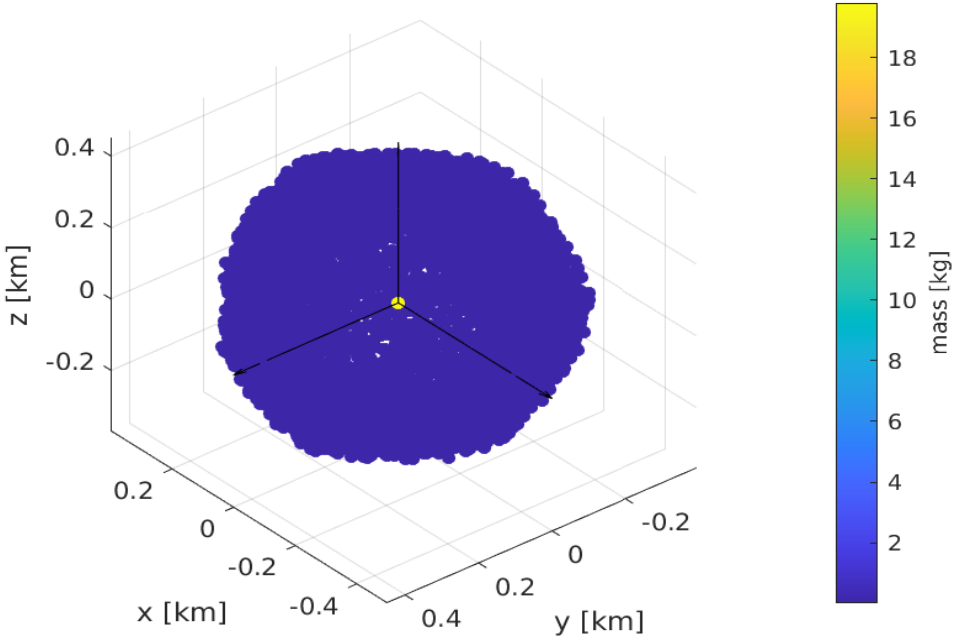
Today's topic: Mono Disperse Uniform Solid Core

4. We have used polyhedron shaped and considered them as point masses to find the equivalent mascons model by maintaining the nominal bulk density (2170 kg/m^3):

MUS



$2170\ kg/m^3$
(nominal)



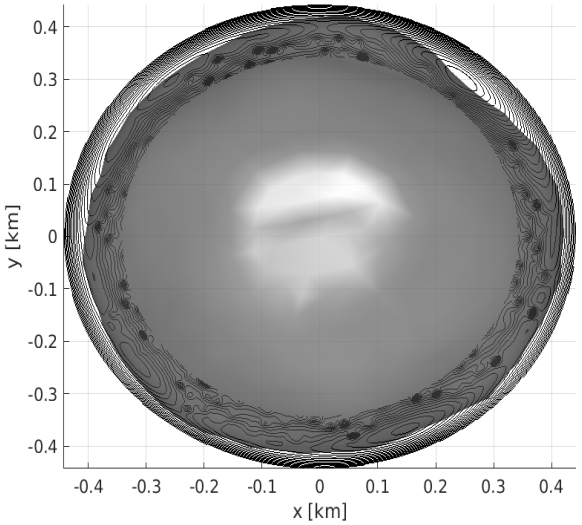
UNIVERSITY OF LIVERPOOL

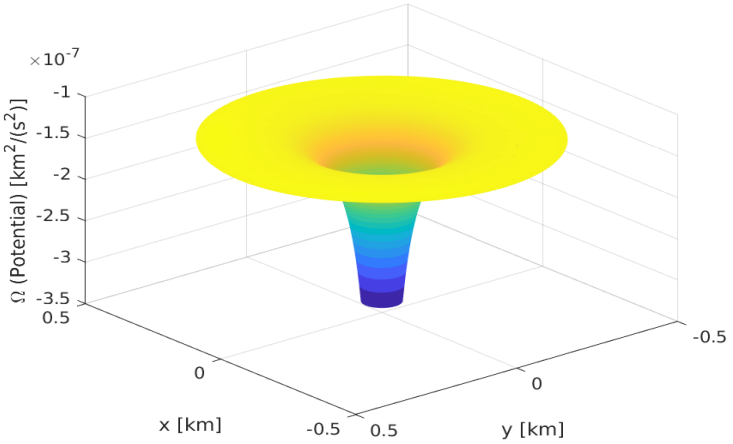
Result: MUS

- Bulk density (2170 kg/m^3)
- Spin axis period ($T = 2.26\ h$)
- Resolution (6k)

Nominal Density
Nominal Axis Period
Low Resolution

n,m	Cnm	Snm	Cnm(10k core)-Cnm(6k MUS)	Snm(10k core)-Snm(6k MUS)
1,0	4.0905E-04	0.0000E+00	-5.4445E-04	0.0000E+00
1,1	3.6767E-04	1.8251E-04	-2.6804E-04	-8.8469E-04
2,0	-5.4364E-03	0.0000E+00	-1.4682E-03	0.0000E+00
2,1	-1.7106E-04	-3.8068E-05	6.7347E-04	-2.7654E-04
2,2	2.4798E-03	-1.6856E-04	7.0161E-05	-7.2718E-05
3,0	-9.6459E-04	0.0000E+00	-3.1674E-05	0.0000E+00
3,1	-9.4927E-04	5.3589E-03	-8.9607E-05	4.5859E-04
3,2	1.2324E-03	-2.2831E-03	1.4309E-04	-8.1345E-05
3,3	9.7327E-04	-8.9284E-04	-1.0187E-04	-3.5898E-05
4,0	3.2639E-03	0.0000E+00	2.4809E-04	0.0000E+00
4,1	-8.6784E-04	2.1905E-03	1.9050E-04	2.3095E-04
4,2	1.3760E-04	1.0121E-03	-1.1855E-04	2.5078E-04
4,3	1.6847E-03	2.7424E-03	3.6904E-04	1.8088E-04
4,4	1.3218E-03	-2.0494E-04	-5.2259E-05	4.9989E-05
5,0	-5.9751E-04	0.0000E+00	2.0945E-04	0.0000E+00
5,1	2.8123E-04	2.5533E-04	-2.1641E-04	-4.3422E-05
5,2	-3.6510E-05	-6.5907E-04	2.5962E-05	7.5894E-05
5,3	-4.7534E-04	9.3464E-04	-4.3976E-05	2.8515E-04
5,4	-4.2213E-04	-4.2853E-05	1.0162E-05	7.9738E-06
5,5	8.3791E-05	4.7362E-04	-1.3425E-04	7.4265E-05



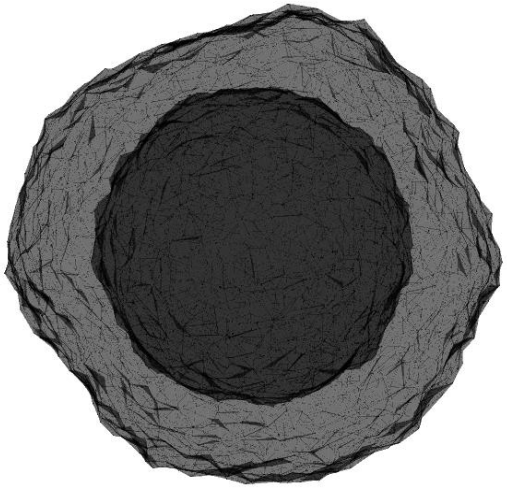


UNIVERSITY OF LIVERPOOL

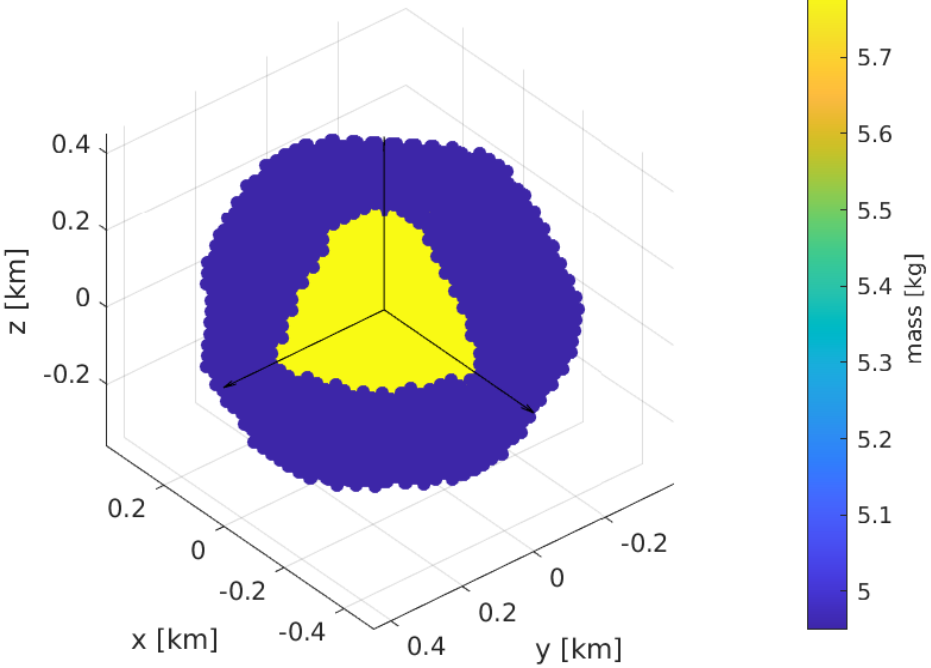
Today's topic: Mono Disperse Uniform Core

5. Fith, we have compared with a core model with multi mascons model by maintaining the nominal bulk density (2170 kg/m^3):

Uniform Core



$2170\ kg/m^3$
(nominal)



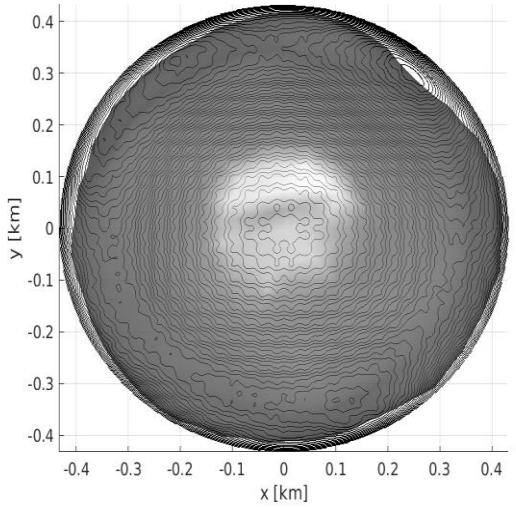
UNIVERSITY OF LIVERPOOL

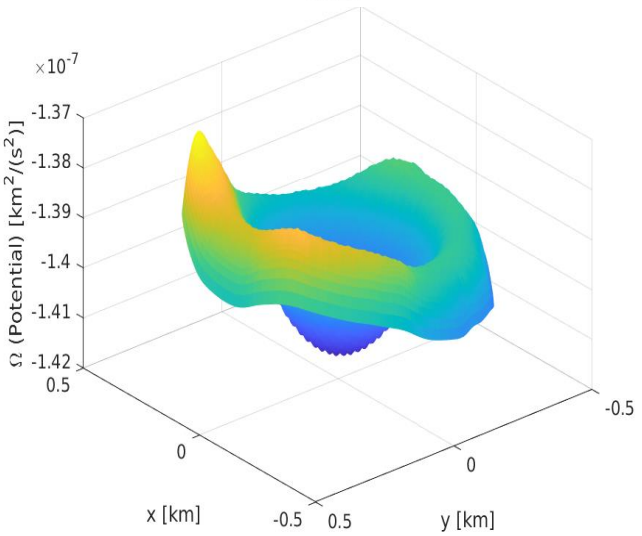
Result: uniform Core

- Bulk density (2170 kg/m^3)
- Spin axis period ($T = 2.26\ h$)
- Resolution (10k)

Nominal Density
Nominal Axis Period
Low Resolution

n,m	Cnm	Snm	Cnm(6.6m)-Cnm(10k)	Snm(6.6m)-Snm(10k)
1,0	-1.3540E-04	0.0000E+00	1.2949E-04	0.0000E+00
1,1	9.9634E-05	-7.0218E-04	-9.4244E-05	6.9727E-04
2,0	-6.9046E-03	0.0000E+00	5.7982E-04	0.0000E+00
2,1	5.0241E-04	-3.1461E-04	-5.0711E-04	3.1233E-04
2,2	2.5500E-03	-2.4128E-04	1.5620E-04	2.4199E-04
3,0	-9.9626E-04	0.0000E+00	1.0220E-04	0.0000E+00
3,1	-1.0389E-03	5.8175E-03	-1.2613E-04	3.0913E-04
3,2	1.3755E-03	-2.3645E-03	5.9830E-07	5.5189E-05
3,3	8.7140E-04	-9.2874E-04	-9.3898E-05	-6.2033E-05
4,0	3.5120E-03	0.0000E+00	3.0201E-04	0.0000E+00
4,1	-6.7734E-04	2.4215E-03	-1.4785E-04	1.3578E-04
4,2	1.9052E-05	1.2629E-03	-7.0477E-05	-1.5908E-04
4,3	2.0538E-03	2.9233E-03	-1.1169E-04	5.1222E-05
4,4	1.2696E-03	-1.5495E-04	2.3926E-04	-6.1237E-05
5,0	-3.8806E-04	0.0000E+00	-2.0958E-04	0.0000E+00
5,1	6.4820E-05	2.1191E-04	5.6248E-05	3.2072E-04
5,2	-1.0547E-05	-5.8317E-04	-1.0074E-04	-8.9715E-05
5,3	-5.1932E-04	1.2198E-03	-1.0710E-04	-2.6189E-05
5,4	-4.1197E-04	-3.4879E-05	-3.9312E-05	-4.8416E-05
5,5	-5.0455E-05	5.4788E-04	9.3953E-05	8.0847E-05





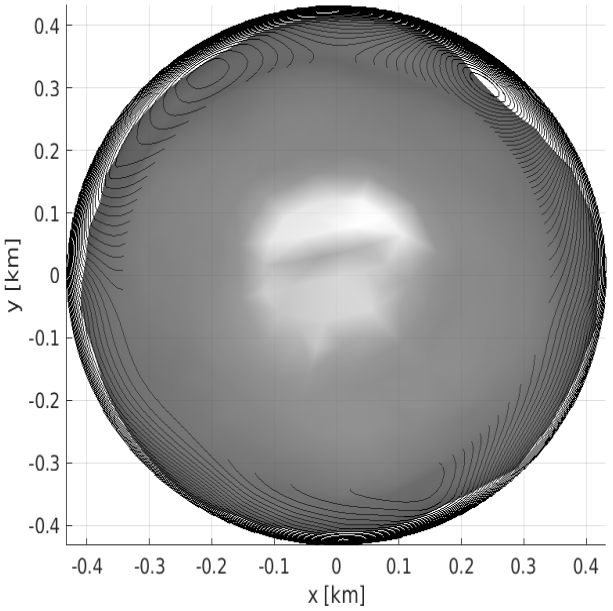
UNIVERSITY OF LIVERPOOL

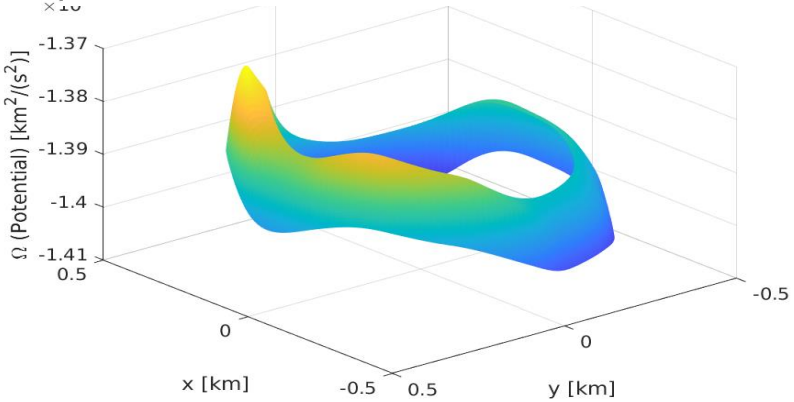
Result: uniform Core

- Bulk density (2170 kg/m^3)
- Spin axis period ($T = 2.26\ h$)
- Resolution (6.6M)

Nominal Density
Nominal Axis Period
High Resolution

n,m	Cnm	Snm
1,0	-5.9134E-06	0.0000E+00
1,1	5.3905E-06	-4.9074E-06
2,0	-6.3248E-03	0.0000E+00
2,1	-4.6999E-06	-2.2770E-06
2,2	2.7062E-03	7.0842E-07
3,0	-8.9407E-04	0.0000E+00
3,1	-1.1650E-03	6.1266E-03
3,2	1.3761E-03	-2.3093E-03
3,3	7.7751E-04	-9.9077E-04
4,0	3.8140E-03	0.0000E+00
4,1	-8.2520E-04	2.5573E-03
4,2	-5.1425E-05	1.1038E-03
4,3	1.9421E-03	2.9745E-03
4,4	1.5088E-03	-2.1619E-04
5,0	-5.9763E-04	0.0000E+00
5,1	1.2107E-04	5.3263E-04
5,2	-1.1129E-04	-6.7289E-04
5,3	-6.2642E-04	1.1936E-03
5,4	-4.5128E-04	-8.3296E-05
5,5	4.3499E-05	6.2873E-04





UNIVERSITY OF LIVERPOOL

Comparison CoM

	x [m]	y [m]	z [m]
Mesh Lab	0.00E+00	0.00E+00	0.00E+00
Radius 6.6M	-3.84E-02	1.05E-01	-9.66E-02
Radius Void 6.6M	1.11E+00	1.07E-01	-3.03E-01
Uniform 6.6M	3.64E-03	-3.30E-03	-3.53E-03
Unif Min 6.6M	3.64E-03	-3.30E-03	-3.53E-03
Unif Max 6.6M	3.64E-03	-3.30E-03	-3.53E-03
Core 6.6M	3.64E-03	-3.32E-03	-3.99E-03
MU	-1.40E-01	3.36E-01	2.48E-01
MUS	2.48E-01	1.23E-01	2.76E-01
PU	2.53E+00	1.95E+00	-2.10E+00

	x [m]	y [m]	z [m]	err x [m]	err y [m]	err z [m]
Radius 10k	-2.97E-02	-2.04E-01	-2.96E-01	-8.65E-03	3.09E-01	1.99E-01
Radius Void 10k	1.19E+00	-2.32E-01	-4.69E-01	-7.68E-02	3.38E-01	1.66E-01
Unif 10k	7.56E-02	-5.01E-01	-5.88E-02	-7.20E-02	4.98E-01	5.53E-02
Unif Min 10k	6.73E-02	-4.74E-01	-9.15E-02	-6.37E-02	4.71E-01	8.79E-02
Unif Max 10k	7.56E-02	-5.01E-01	-5.88E-02	-7.20E-02	4.98E-01	5.53E-02
Core 10K	7.56E-02	-5.01E-01	-5.88E-02	-7.20E-02	4.98E-01	5.48E-02

Key Facts

- In case of uniform body: The measurement of the Stokes Coefficient alone will not be able to uniquely determine the bulk density and rotation period
- In case of uniform body: The measurement of the EQ points alone will not be able to determine the exact density or rotation period
- Likely Didymos period is well know so having fixed this parameter means that both stocks coefficients and EQ points measurement could determine the internal structure of the object thus its mass distribution
- Mascons resolution affects our ability to compute the EQ points with semi-analytical methods
- Mascons resolution affects the value of the stock coefficients
- Voids can be easily detected by either stokes coefficient measurements or EQ points measurements (due to the shift in the CoM)
- We used the uniform case and polyhedron model/shape model to fix the resolution needed by comparing the error in the EQ points computed
- While uncertainties in mass distribution, bulk density and period affects the number of EQ points of didymos so far it seems that at least there is one equilibrium point likely to exist EQ1 of center x center x center nature (stable) and so orbits around this point can exist

Thank You!