Creating a Contact Binary via Spacecraft Impact to Near-Earth Binary Asteroid (350751) 2002 AW

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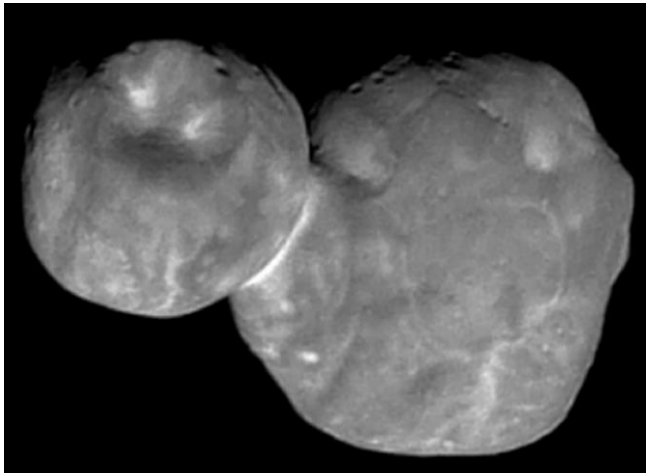
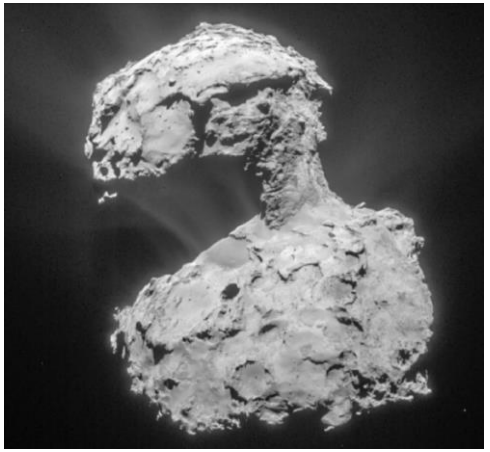
Contact Binaries (CB)

- Ubiquitous in small body population (asteroids, KBOs, …)
  - >10% of all small bodies [1,2,3]
  - 30% of NEOs [4]
- Extensive models, no observations





[1] Benner, L. A. M. et al., Icarus, 2006
[2] Sheppard, S. S. and Jewitt, D., The Astronomical Journal, 2004
[3] Mann, R. K. et al., The Astronomical Journal, 2007
[4] Virkki, et al., The Planetary Science Journal, 2022
Images courtesy of NASA, JAXA, and ESA

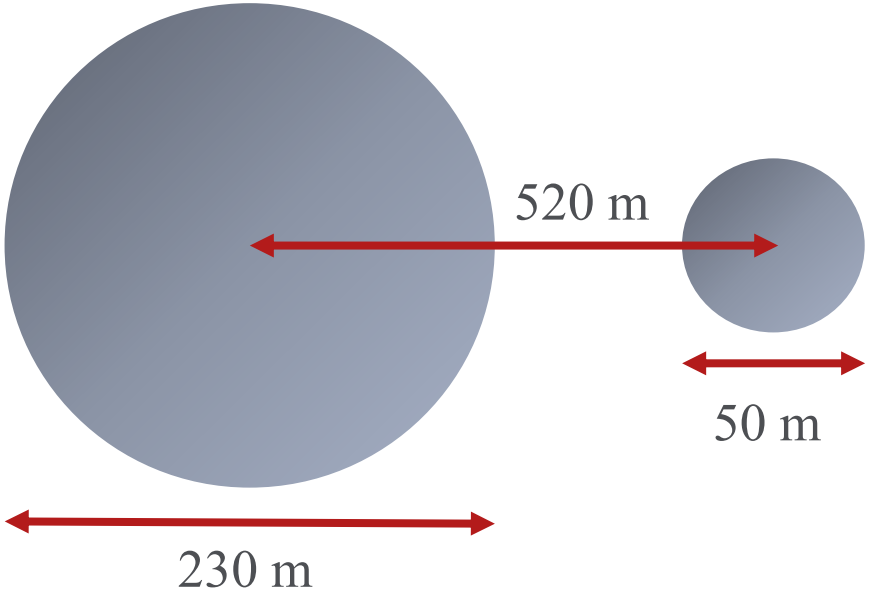
Contact Binary Formation Mission

- We will **create** a CB
  - Contact speeds $\lessapprox V_{esc}$ produces CB [5]
- Leaner DART (impactor) & Hera (observer)
- Binary system
  - Contact speed < V_{esc}

[5] Jutsi, M. and Asphaug, E., Nature, 2015

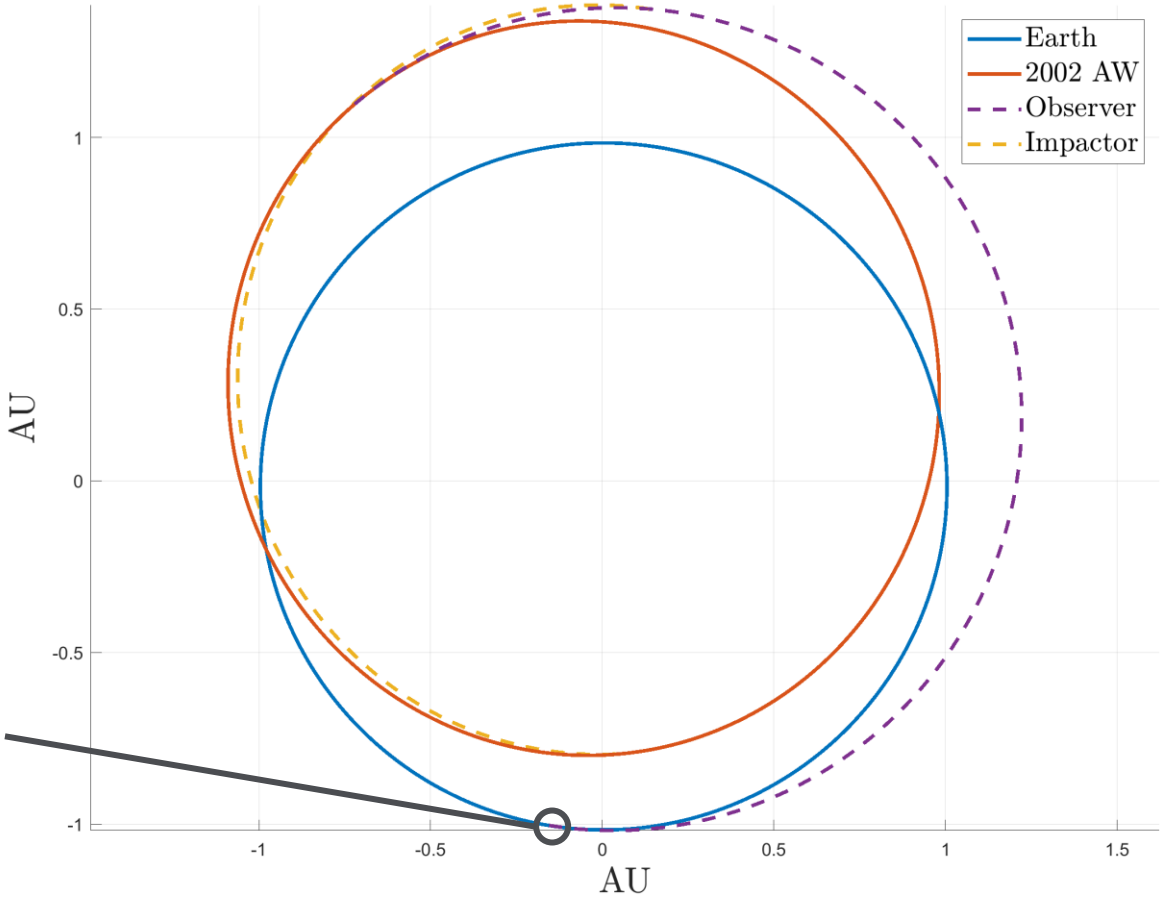
Case Study: (350761) 2002 AW

- Required impact speed of < 2.69 km/s
  - Dimorphos = 488 km/s
- 50 meter secondary [6]
  - Smallest target for PD kinetic impactor
- Rendezvous ΔV = 1.9 km/s
  - Total ΔV = 4.31 km/s



[6] Johnston, W. R., Johnston's Archive, 2022

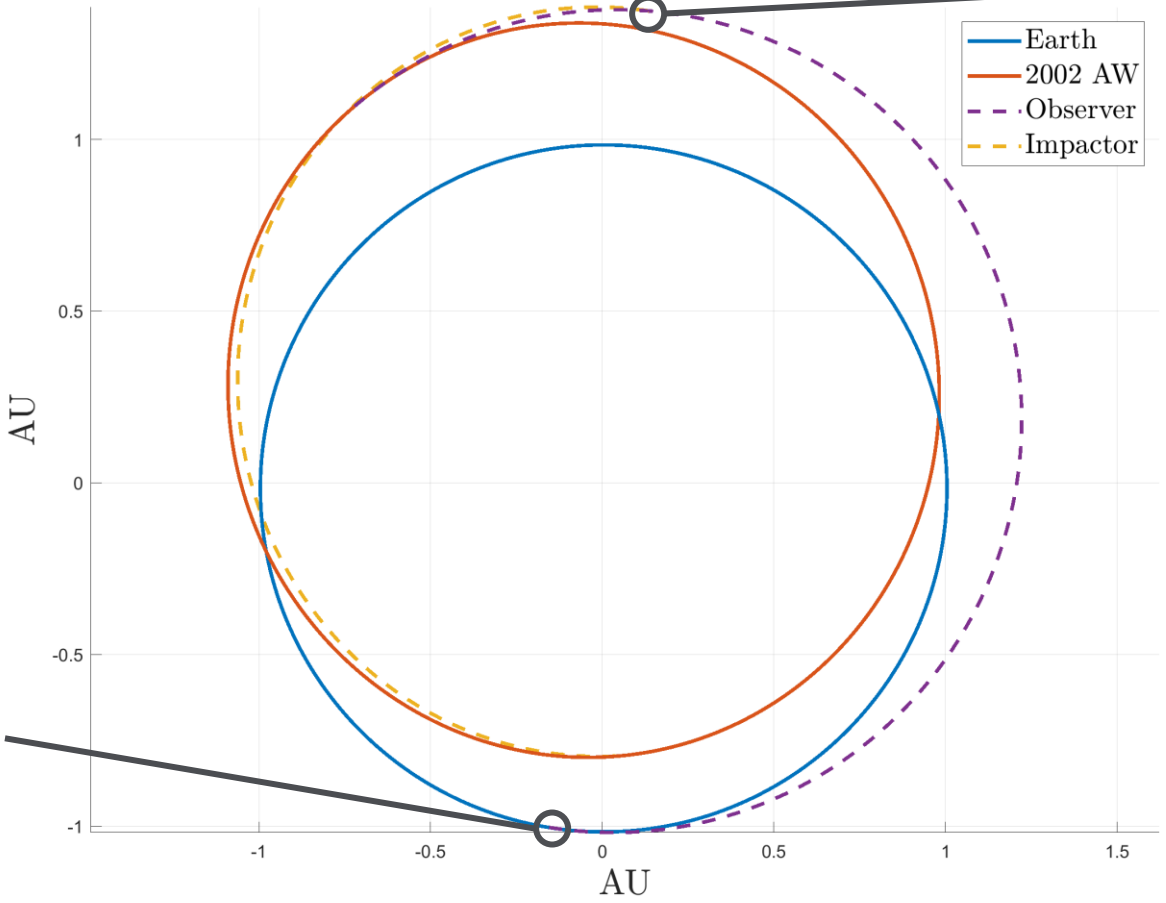
Mission Anatomy



(1) Impactor and Observer launch

Mission Anatomy

(2) Impactor maneuver

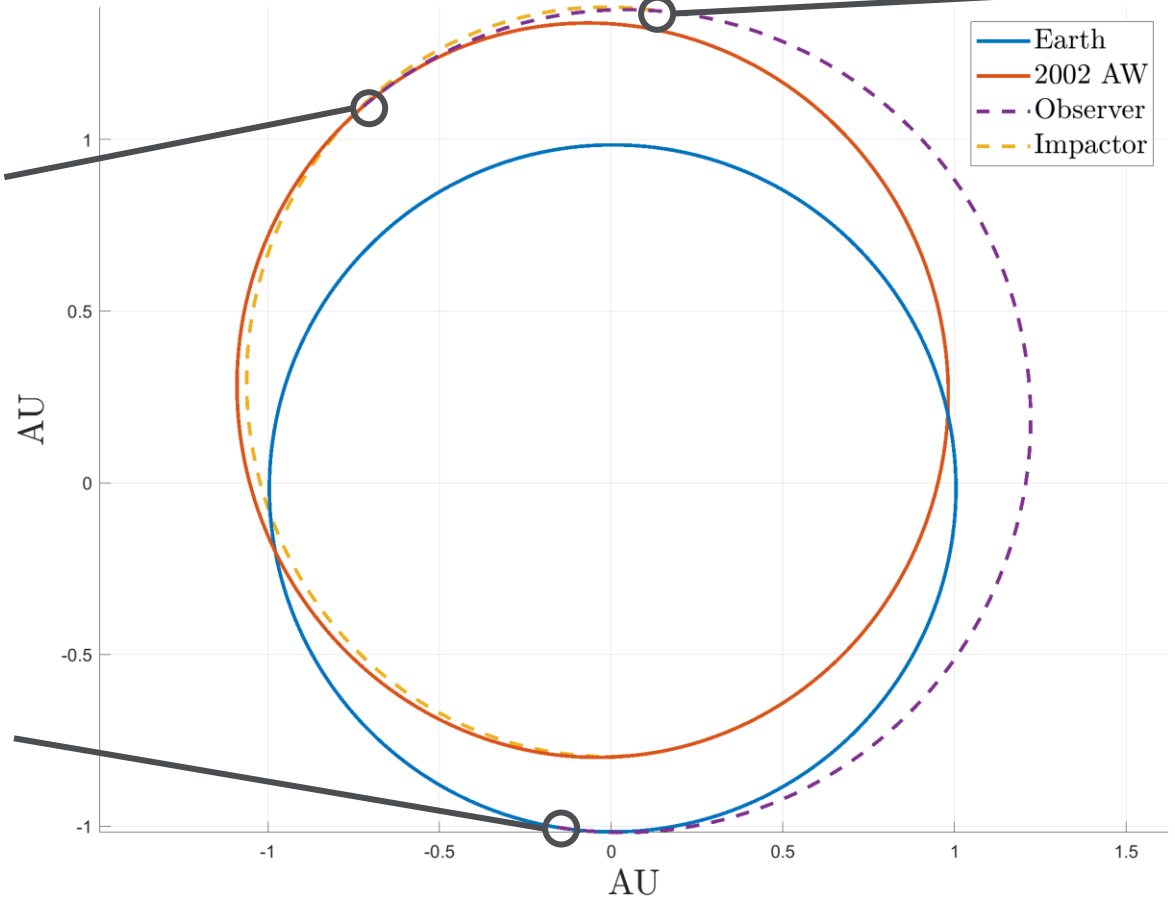


(1) Impactor and Observer launch

Mission Anatomy

(2) Impactor maneuver

(3) Observer rendezvous



(1) Impactor and Observer launch

Mission Anatomy

(2) Impactor maneuver

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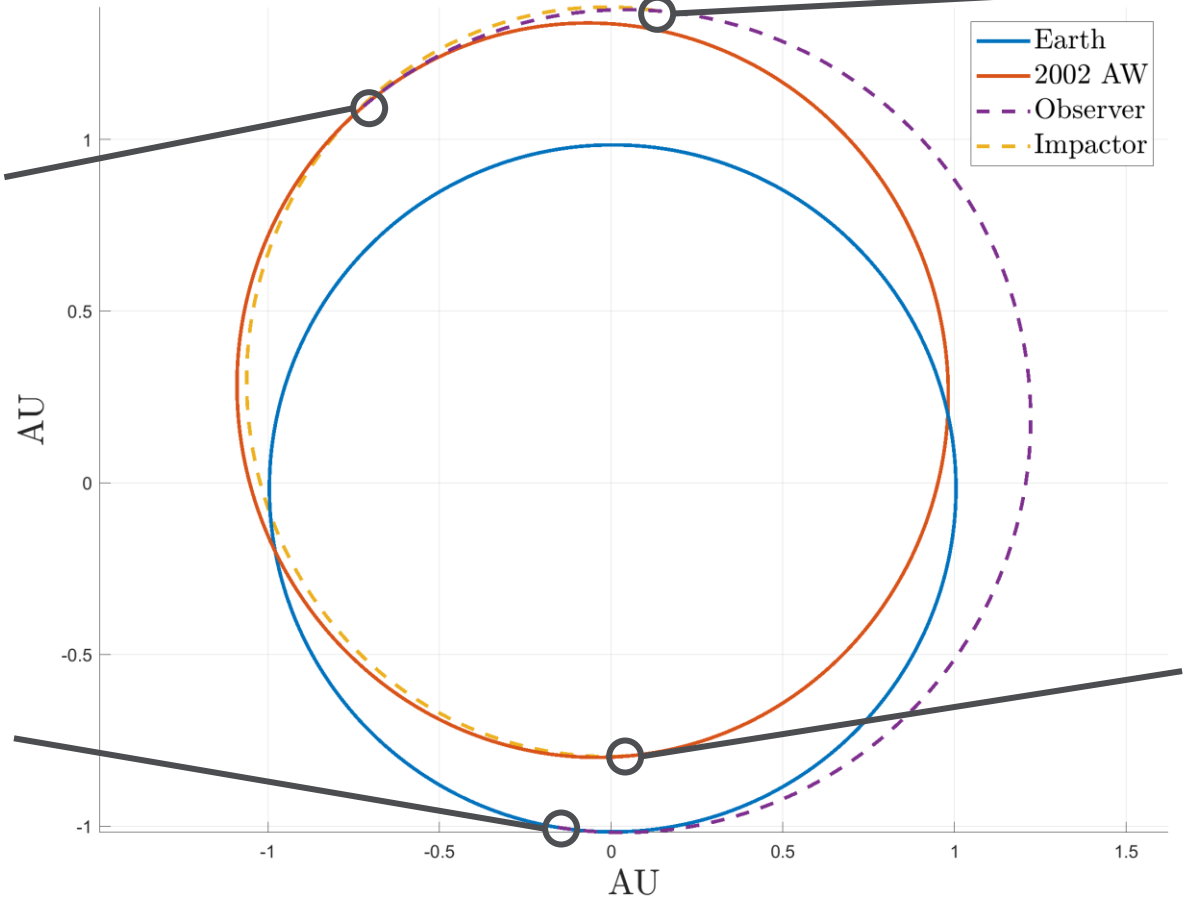
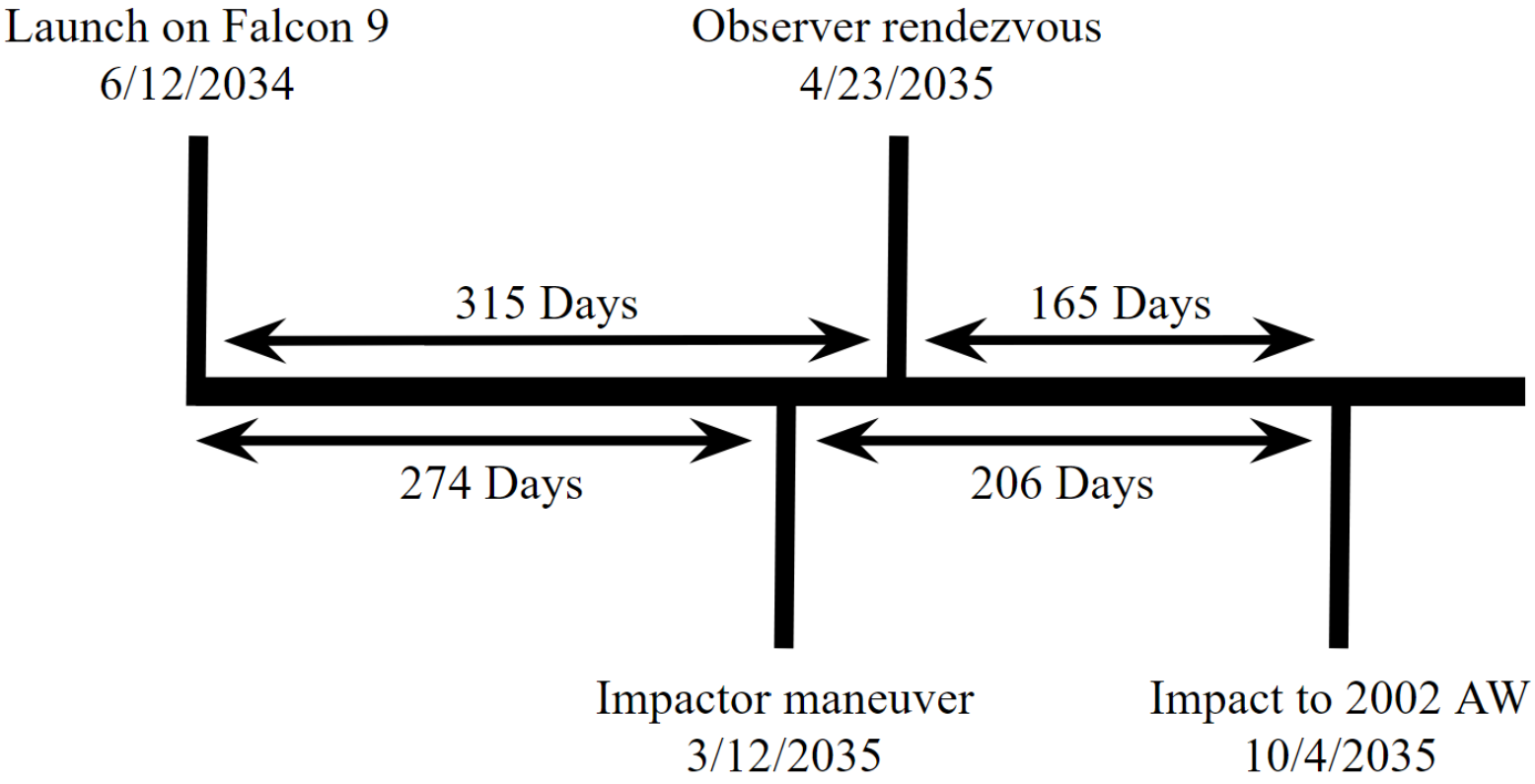


(1) Impactor and Observer launch

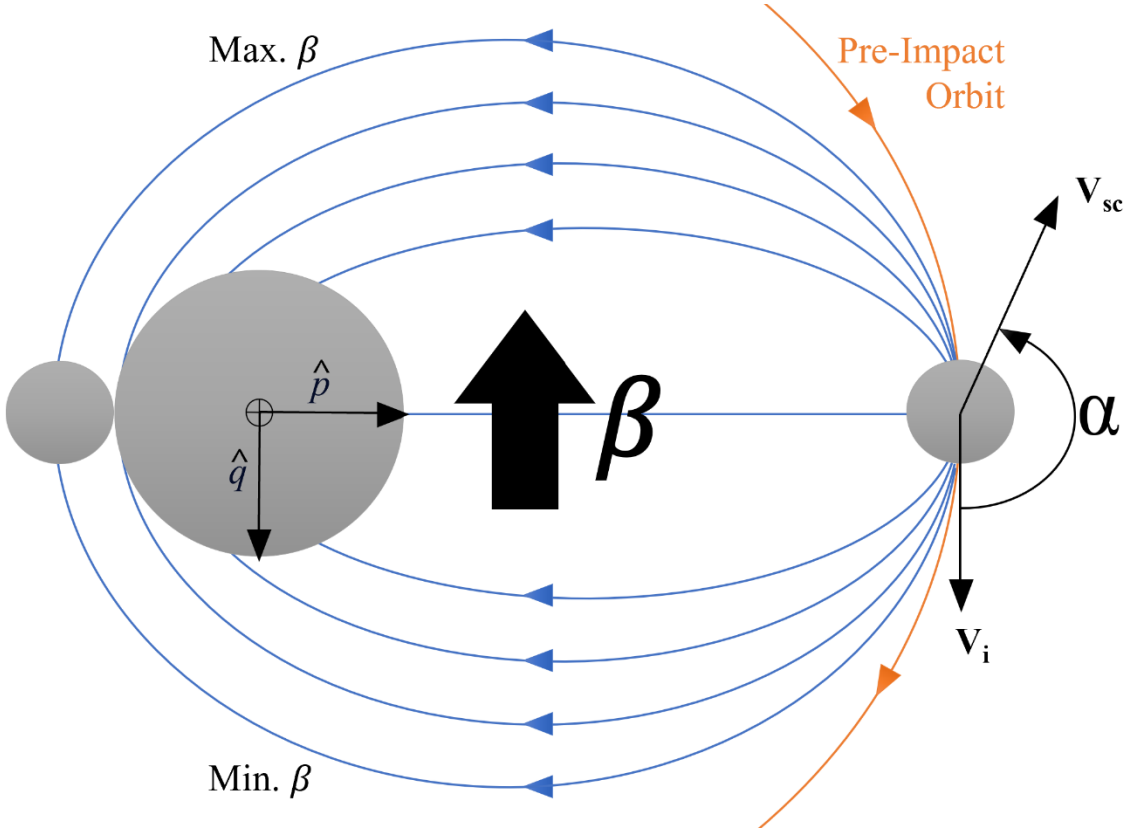
(4) Impact to secondary

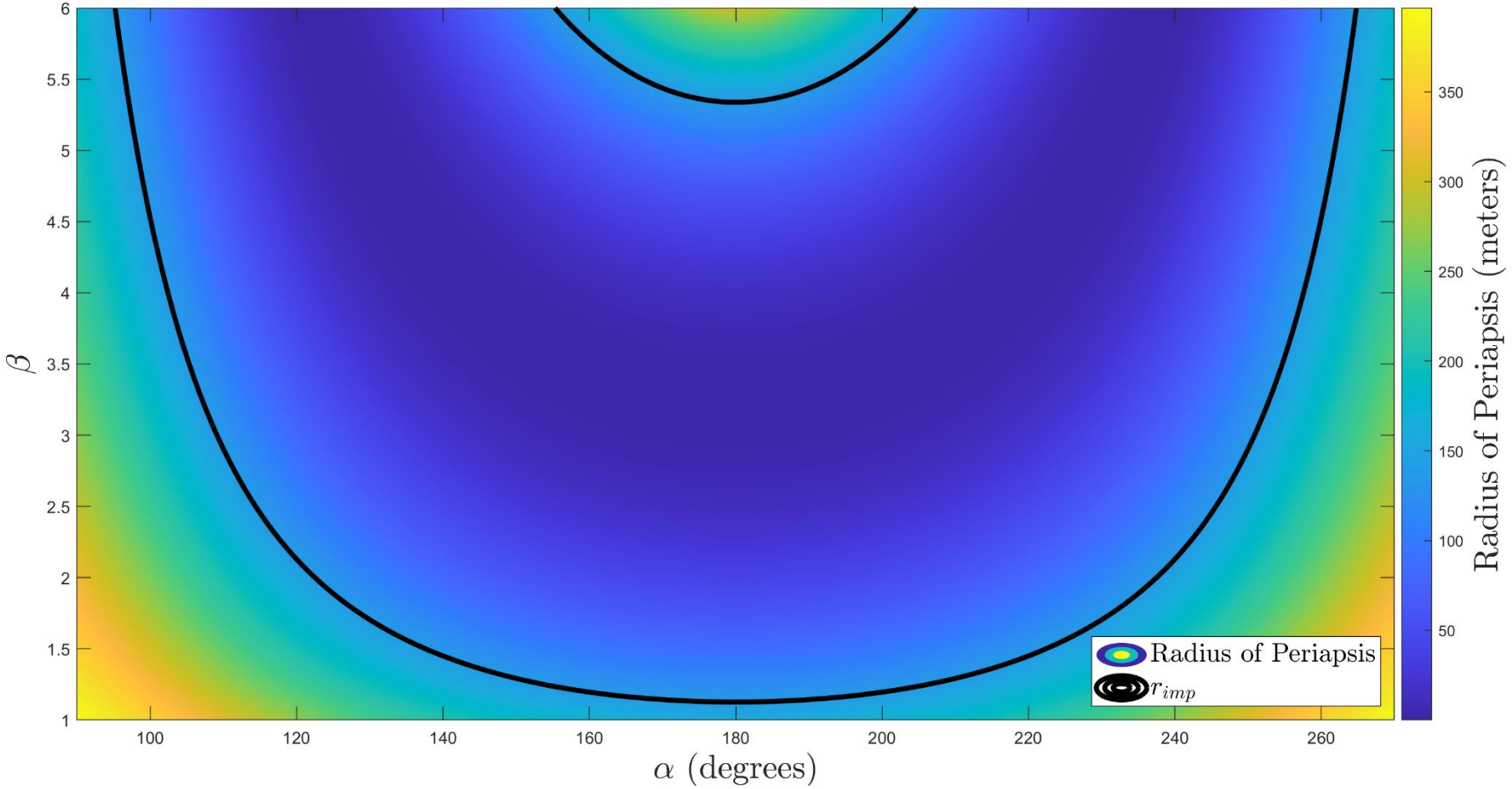
Timeline


Launch on Falcon 9
6/12/2034
Observer rendezvous
4/23/2035
315 Days
165 Days
274 Days
206 Days
Impactor maneuver
3/12/2035
Impact to 2002 AW
10/4/2035

Momentum Enhancement Factor β

- The β factor will increase the effect of momentum
- We have bounds for a min. and max. β





483 kg Impactor at 2.39 km/s rel. velocity

Conclusion

- Unique scientific impact: A contact binary's formation has **never** been observed
- This mission is **possible** and **feasible**: Existing technology spacecraft launch on a single Falcon 9

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References
[1] Benner, L. A. M., et al., Icarus, 2006
[2] Sheppard, S. S., and Jewitt, D., The Astronomical Journal, 2004
[3] Mann, R. K., et al., The Astronomical Journal, 2007
[4] Virkki, et al ., The Planetary Science Journal, 2022
[5] Jutsi, M., and Asphaug, E., Nature, 2015
[6] Johnston, W. R., Johnston's Archive, 2022

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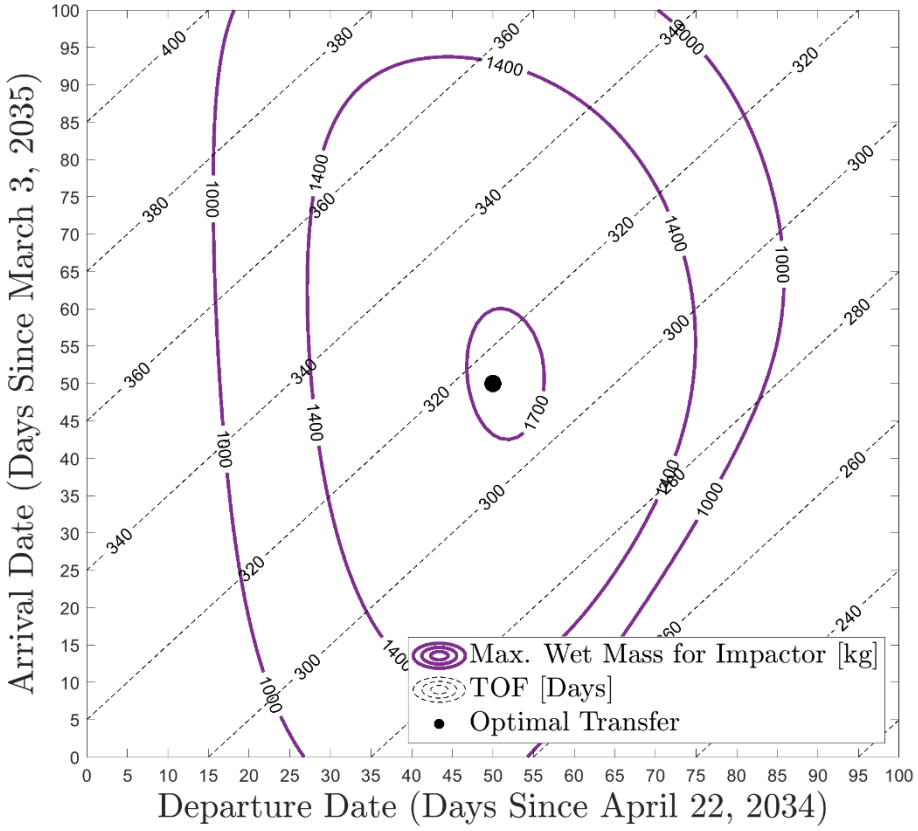
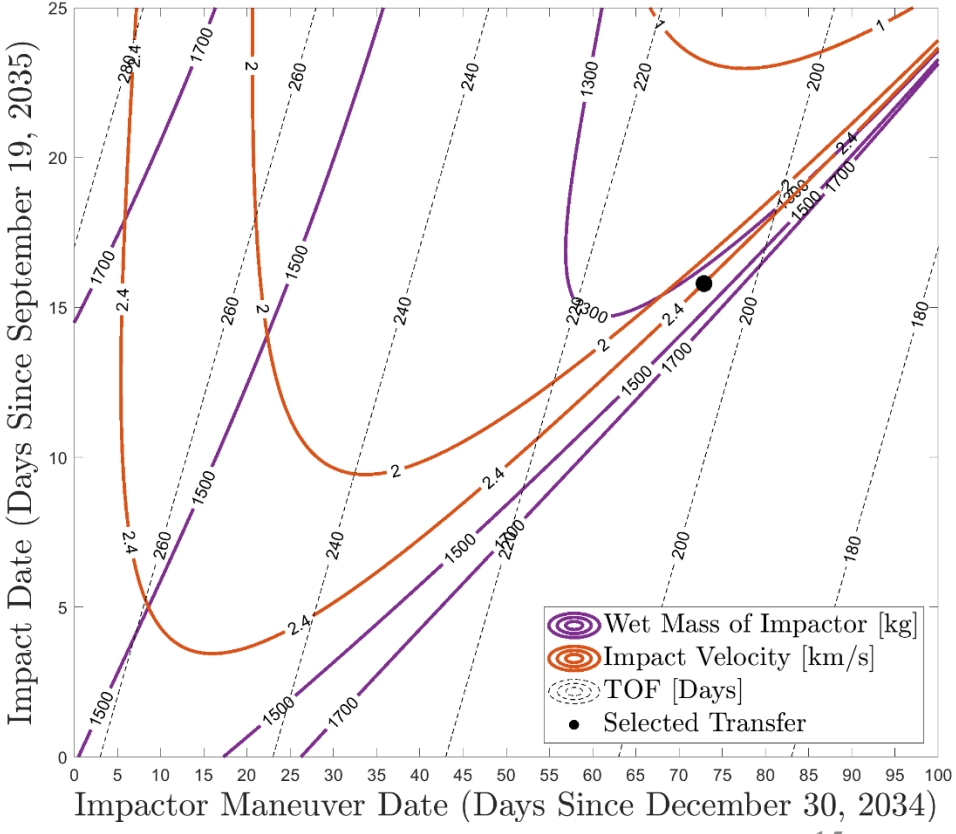
Name	Primary Diameter (m)	Secondary Diameter (m)	Semi-Major Axis (m)	Period (days)
Didymos	780	170	1190	0.4971
1990 OS	300	50	600	0.875
1999 RM45	165	74	290	0.6852
2000 UG11	260	130	426	0.7667
2002 AW	230	50	520	1.047
2002 TY57	330	60	420	0.4485
2003 SS84	120	60	270	1
2003 UX34	280	100	460	0.625
2004 BL86	320	70	500	0.6
2006 GY2	400	80	500	0.487
2009 FD	150	90	250	0.6
2014 WZ120	300	100	500	0.56938
2017 RV1	300	100	470	0.5896
2018 TF3	270	60	350	0.438

Name	Min. V_∞ Required (km/s)	Max. V_∞ Allowed (km/s)	Min. Total ΔV (km/s)
Didymos	488.2	3503	6.2
1990 OS	3.49	17.78	6.5
1999 RM45	5.12	38.28	13.5
2000 UG11	20.10	173.6	10.0
2002 AW	2.69	12.76	4.3
2002 TY57	5.01	44.16	10.3
2003 SS84	2.06	12.03	8.9
2003 UX34	22.44	168.2	11.5
2004 BL86	8.97	62.54	12.6
2006 GY2	9.97	92.50	11.1
2009 FD	7.46	69.19	8.6
2014 WZ120	35.21	253.3	14.5
2017 RV1	23.06	179.8	8.5
2018 TF3	4.61	41.64	11.9

Transfer Orbit Design





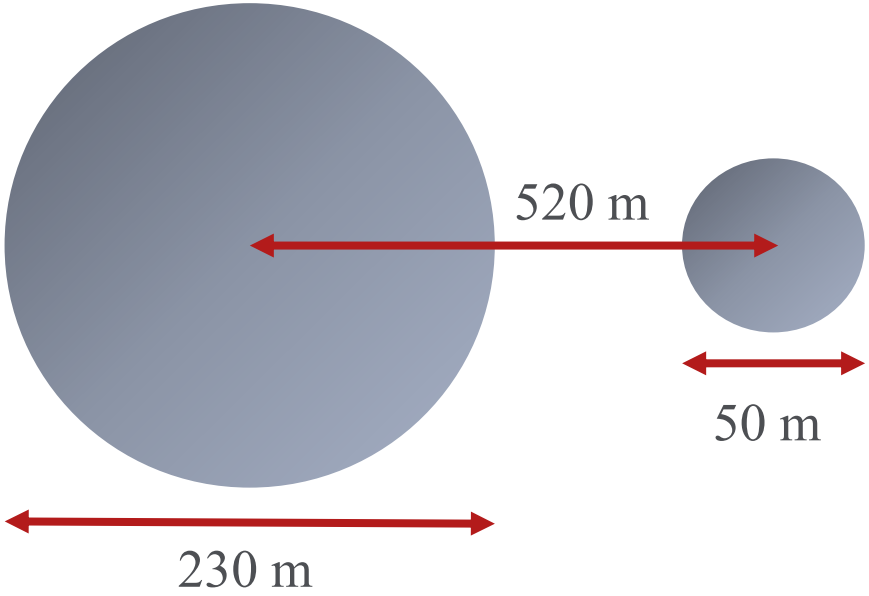
(350761) 2002 AW Characteristics

Period of Secondary = 1.05 days [5]

Density = 1580 kg/m^3 (derived)

Mass of Secondary = 1*10^8 kg (derived)

Mass of Primary = 1*10^{10} kg (derived)



Heliocentric Data:

P = 405 days	i = 0.575°
e = 0.256	Ω = 162°
ω = 119°	a = 1.07 AU

[5] Johnston, W. R., Johnston's Archive, 2022

Launch Vehicle Selection, C3 = 5.85 km^2/s^2

Vehicle	Version	Payload Mass [kg]
Falcon 9	Full Thrust, RTLS	1255
Antares	232	1455
Falcon 9	Full Thrust, ASDS	2655
Vulcan	VC2	5230
Falcon Heavy	Recovery	5735
New Glenn	New Glenn	6115
Vulcan	VC4	7700
Vulcan	VC6	9815
Falcon Heavy	Expendable	13395

Mass Budget

Impactor	CBE	402 kg
	Contingency	40 kg (10%)
	Propellant	925 kg
	Prop. Contingency	93 kg (10%)
	Total	1460 kg
Observer	CBE	316 kg
	Contingency	104 kg (33%)
	Propellant	523 kg
	Prop. Contingency	52 kg (10%)
	Total	995 kg
Total		**2455 kg**
Falcon 9 Launch		**2655 kg**
Mass Margin		**200 kg**

Using β in Momentum Balance

Full Momentum Balance

$$m_s \mathbf{V}_i + m_{sc} \mathbf{V}_{sc} = \left(m_s + m_{sc} - m_{ejecta}\right) \mathbf{V}_f + m_{ejecta} \mathbf{V}_{ejecta}$$

Introduce β

$$\beta = \frac{m_{ejecta}\left(\mathbf{V}_{ejecta} - \mathbf{V}_f\right)}{m_{sc}\mathbf{V}_{sc}} + 1$$

Take m_{ejecta} to be negligible