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Using Information From Rendezvous Missions for Best-Case Appraisals of Impact Damage To Planet Earth Caused by Natural Objects

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J. O. Arnold*, P. W. Chodas**, S. Ulamec***, D. L. Mathias*, and C. D. Burkhard*

*NASA Ames Research Center, Moffett Field, CA 94035, USA

** NASA Jet Propulsion Laboratory , 4800 Oak Grove Dr. Pasadena CA 91011, USA

***DLR RB-MUSC, German Aerospace Center, Linder Höhe, 51147 Cologne, Germany

OBJECTIVE & APPROACH

OBJECTIVE:

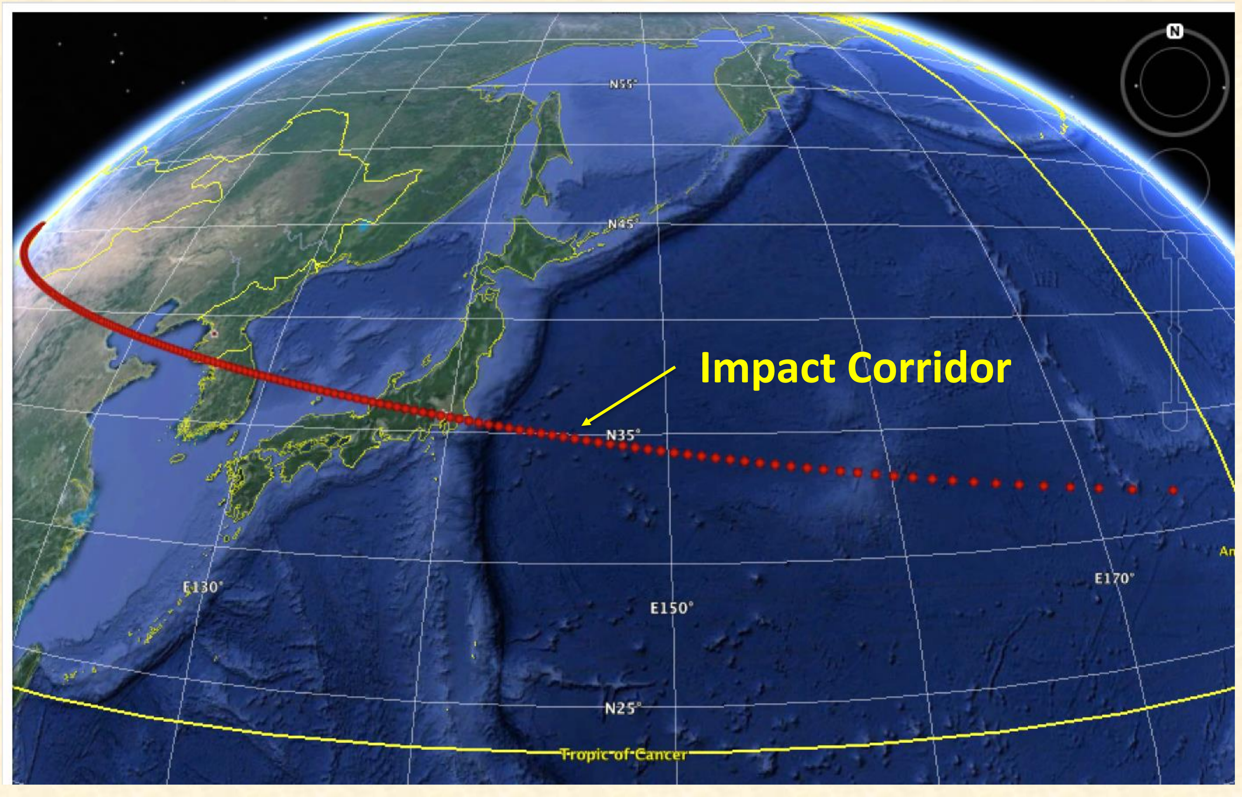
Specify uncertainty reductions in Probabilistic Asteroid Impact Risk (PAIR) assessments enabled by data obtained from rendezvous missions: Why, How, and What value is added to information to be provided to decision makers?

APPROACH:

Discuss PAIR Assessments of the Hypothetical Asteroid 2017 PDC based on the initial observation and why lack of data leads to uncertainty in the results.

Describe how data from a rendezvous mission can be used to pin-point 2017 PDC's impact location, improve quantification of devastation levels and show how the resulting information would be better suited for officials empowered to take action to mitigate threat from the asteroid.

IMPACT CORRIDOR AS OF MAY 15, 2017



2017 PDC INITIAL OBSERVATION

- Probable impact corridor spans from the Atlantic far into the Pacific Ocean.
- Probability of impact is 1 in 100 as of May 15, 2017.
- Absolute Magnitude: 21.9 +/-0.4, corresponding to a range from 160 to 290 m.
- NASA JPL CNEOS provided ATAP the entry speed and angles at 100 km altitude along the entire impact corridor. Speed varies from 17.58 to 16.92 km/s. Max entry angle at mid corridor is 47.7^0

PAIR RESULTS – Based on MAY 15 , 2017 OBSERVATION

- Mean Affected Population plotted at mean burst latitude and longitude.
- Uncertainty in orbit leads to uncertainty in blast location. Uncertainty in properties of 2017 PDC leads to uncertainty in levels of Affected Population - approximately two orders of magnitude.
- Not shown, maximum level of Affected Population in Japan slightly $>10^7$. and minimum levels of ~ 10^3 in the Gobi desert and Kazakhstan.

PAIR ASSESSMENT – AT INITIAL OBSERVATION

- Risk assessment based on same PAIR approach as used for recent Science Definition Study [1] and Monte Carlo sampling of characteristics from ensemble (Stony and Carbonaceous).
- Plot shows "Affected Population" versus distance along impact corridor.

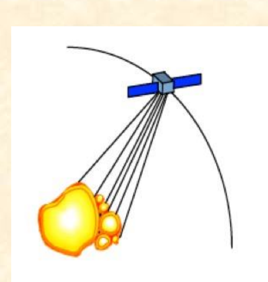
Overpressure Range	Affected Population, %	Expected Damage
68 - 136 mbar 1 - 2 psi	10	Window breakage
136 - 272 mbar 2 - 4 psi	30	Partial collapse of roofs/walls
272 – 680 mbar 4 – 10 psi	60	Partial building destruction
680+ mbar 10+ psi	100	Total building destruction and fatalities

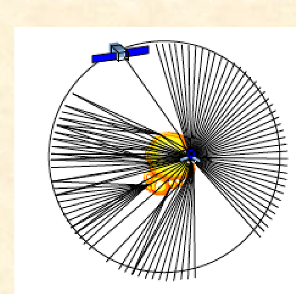
COMMENTS ON INITIAL PAIR ASSESSMENT

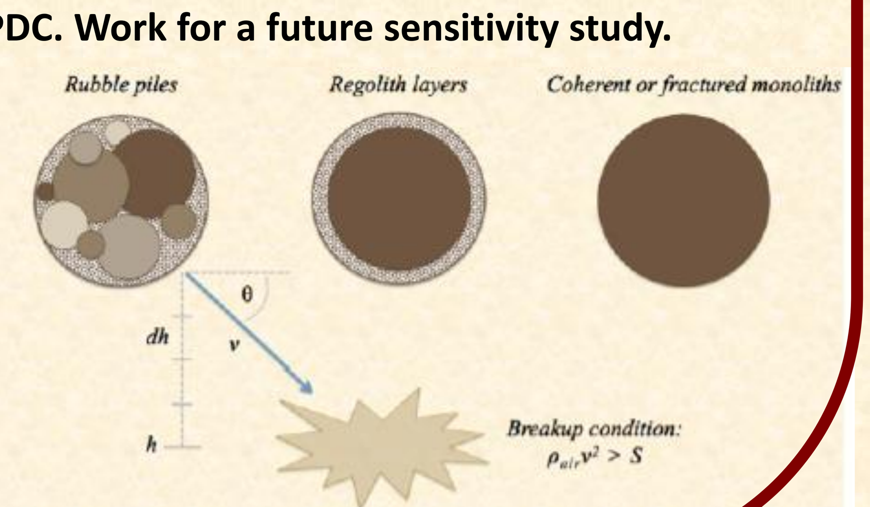
- Corridor is <u>very</u> long and will continue for years even with ground observations. Values for Affected Population vary widely, 10^3 to 10^7 depending on mass and other characteristics of 2017 PDC.
- Results for low values of Affected Population suggest that land areas exist where "Taking the Hit" might be a possibility for consideration by decision makers, or in the Pacific, far from shore based on the 2016 Asteroid Generated Workshop [2].
- The data with high values of Affected Population suggests that if the strike occurs there, clearly, mitigation action is required.

HOW A RENDEZVOUS MISSION MINIMIZES UNCERTAINTY AND ADDS VALUE TO INFORMATION

- Optical navigation, combined with ground observations, dramatically improves definition of the asteroid's orbit and predictions of the atmospheric pierce point, probably to less than 100 km for asteroid 2017 PDC.
- In-situ measurements provide detailed information about the asteroids shape, size, mass, spin rate, spin orientation, regolith, sub/interior structure and distribution of the constituent fragments (both location and inhomogeneity).
- The orbit of rendezvous spacecraft provides the effective mass of the asteroid while radar mapping provides detail of mass distribution. The spacecraft also acts as a "shepherd" over long periods, enabling precise definition of 2017 PDC's orbit.
- Regolith and subsurface definition to tens of meters comes from monostatic radar while definition of the deep interior structure to 10 – 15 m comes from bistatic tomography [3]
- Knowledge from the rendezvous mission provides entry conditions for a new ATAP model [4] that can treat entry and breakup of rubble pile and monolithic asteroids that could be representative of 2017 PDC. Work for a future sensitivity study.







- Monostatic Bistatic

HOW BEST TO MINIMIZE UNCERTAINTY?

- The answer is to obtain comprehensive data about 2017 PDC with priority on that which best minimizes overall uncertainty in the risk assessment.
- The data need to be available in timely manner, so that risk assessments can be updated, and information can be provided to decision makers empowered to implement mitigation, or "Take the Hit"
- The <u>BEST</u> way to obtain data about the asteroid is by in-situ observations enabled by a rendezvous mission, complimented with that from an intense, coordinated ground observation campaign.

Bottom Line

- ATAP's Probabilistic Asteroid Impact Risk (PAIR) assessment capability can provide information (WHERE and HOW DEVASTATING STRIKES CAN BE] to decision makers for their deliberations regarding mitigation actions.
- As exemplified by the study of the hypothetical threat from 2017 PDC, it is clear that a rendezvous mission, in combination with ground observations enables the <u>best-case</u> risk assessments.
- Data from a rendezvous mission enables pin-pointing the strike location to within 100 km or less along the very long impact corridor initially available - via the improved orbit.
- In-situ characterization enables refinement of the levels of Affected Population, important for determining whether the looming threat requires deflection, or not.

REFERENCES

[1] Mathias, D. L., Wheeler, and L., Dotson, "A Probabilistic Asteroid Impact Risk Model: Assessment of Sub-300 m Impacts" Icarus 289 C (2017) pp 106-119, doi:10.1016/j.jicarus.2017.02.009.

[2] Morrison, D. D, Venkatapathy, E., "Asteroid Generated Tsunami: "Summary of NASA/NOAA Workshop NASA/Technical Memorandum (NASA/TM-219463) January 2017".

[3] Heriqe, A. et.al, "A Direct Observation of an Asteroid Structure from Deep Interior to Regolith: Why and How? 4th IAA Planetary Defense Conference 13-17 April, Frascati, Rome Italy

[4] Wheeler, L. F. and Mathias, D. L., 2017 "Modeling the atmospheric breakup of varied asteroid structures: inference for the Chelyabinsk meteor and risk assessment application: 5th IAA Planetary Defense Conference, 2017 Tokyo, Japan