2019 IAU Planetary Defense Conference

Association of Space Explorers (sponsor)

Summary

Monday April 29, 2019

1. **Opening Session**
   - **Welcome from Jason Kalirai, APL civil space lead, opening remarks on the DART deflection demo set for interception of Didymoon in 2022.**
   - **Jim Garvin, chief scientist at Goddard SFC/NASA.**
     - **Zhamanshin: an impact crater 870,000 years ago in Kazakhstan**
     - **OSIRIS-REx now conducting NEO exploration at Bennu**
     - **Importance of collisional events and phenomena across solar system**
   - **The conference presentations and video are online at:**
     - **http://pdc.iaaweb.org/**
   - **NASA administrator Jim Bridenstine gave a detailed keynote address.**
     - **A Chelyabinsk occurs on average every 60 years.**
     - **Importance of NEO tracking and deflection capability to NASA and US government.**
     - **Need to use space program to assure defense from NEO impacts**
     - **25,000 NEOs > 140 m in diam; some 8300 found. (the law requires NASA to find 90% of these)**
     - **18 space faring nations now in the ASE-suggested SMPAG….we need more.**
     - **IAWN (asteroid warning network) is going strong**
     - **DART is funded and will launch in 2021.**
     - **The SLS heavy lift booster will aid Planetary Defense, given its immense throw-weight to orbit and deep space. SLS will also help us explore Europa, and the moon. Makes possible a 3.5 year transit to Europa.**
     - **First time a NASA administrator has committed to flying a planetary defense demo mission (DART), and expressed support for a space-based NEO detection telescope (NEOCam).**

2. **Session 1: Key Developments in Planetary Defense**
   - **UN Office of Outer Space Affairs, Romana Koffler**
     - **Shows flow of decision-making on NEOs to the UN's COPUOS, using IAWN and SMPAG to the body.**
     - **Romana summarized the latest activities of IAWN and SMPAG**
     - **Reference here: http://www.unoosa.org/documents/pdf/smpag/st_space_073E.pdf**
   - **ESA Planetary Defense Activities, Rudi Jehn.**
     - **Observations, information, and mitigation**
     - **Showed map of telescopes collaborating on detection**
     - **Building the FlyEye telescope…1 meter mirror under construction.**

        - **Sited on Sicily at 1800 m. Second to go to Chile, in La Silla.**
            - **Southern hemisphere coverage**
        - **48-hour whole sky scan. Fast detection and warning.**
        - **But Earth's night side only.**
    - **PD warning function: calculation of impact probability at SpaceDyS in Pisa**
    - **Mitigation:**
        - **fireball camera network**
        - **Would like to base these in space as hosted payload**
        - **Impact effects engineering tool**
        - **HERA spacecraft will inspect the DART impact. Space safety cornerstone. Launch so at to arrive at Didymos in 2026.**
        - **Support development of international deflection/mitigation protocols.**
        - **AIDA (DART/HERA) collaboration with NASA**
    - **Let's make our planet a safer place.**
- **NASA Planetary Defense Coordination Office, Lindley Johnson.**
    - **PDCO is in its 4th year of operations….**
    - **Observations Program**
        - **Objective – find 90% of 140 m and larger**
        - **Find and observe**
        - **Predict the orbit**
        - **Characterize the risk**
    - **PDCO Missions:**
        - **Find NEOs**
        - **Warn government, media, public**
        - **Mitigate: technologies and techniques**
        - **Coordinate within US government**
            - **…and other space agencies under endorsement of UN COPUOS**
    - **Appraise range of effects**
    - **Develop strategies to mitigate the impact effects on human welfare**
    - **Showed the PDCO high level functions chart**
    - **JPL's CNEOS website shows discovery stats….by project.**
        - **Discovering about 1800 NEOs per year.**
    - **Surveys have detected 20001 NEOs as of today.**
    - **NEOs 140 m and larger number about 25000; only 1/3 found.**
        - **Will take 30 more years at current rate to find 90%.**
    - **Shows international decision making process: cooperation is key.**
    - **US government Action Plan published in 20 June 2018.**
        - **NEO preparedness plan**
    - **DART—new flight mission initiated to test kinetic impact in 2022.**
    - **NEOWISE still operating and discovering new NEOs**
    - **DART funded for its deflection demo mission**
    - **NEOCam awaiting funding, but its instruments are in development**
        - **An IR, space-based instrument to detect NEOs from the Sun-Earth L1 pt.**

- **Israel Space Agency planetary defense interest, Harel Ben-Ami,**
    - **Describes their PD activities**
    - **NEO impact is a global hazard, we should work as one to prevent.**
    - **WISE observatory, in Israel, soon to begin operating to detect NEOs**

Session 2 Advancements in NEO Discovery and Characterization

- **J. Cano—Recent Evolutions in ESA's NEO Coordination Center System:**
    - **ESA's NEO coordination center system**
- **Tim Spahr, NEOCam—Building the Reference small body population model**
    - **RSBPM**
    - **Non-biased set of orbital elements for objects in each class**
    - **340,000 Main Belt Asteroids in complete population down to Visible magnitude ~20.**
    - **Filling out the NEO population by plotting orbital elements**
    - **Jupiter is pushing asteroids around and that affects the longitude of perihelion; not uniform—have to do it right.**
- **NEMO: A global near-real-time fireball monitoring system -- Drolshagen & Ott**
    - **Fireball detection improvements**
- **Micheli, Italy: Observational activities at ESA NEO Coord. Ctr.**
    - **Still organizing a discovery telescope. But their assets do follow up observations**
- **Vasilov, Russia: Impact Monitoring System of Institute for Applied Astronomy, Russian Academy of Sciences**
    - **Dealing with uncertainty of orbit of NEO, ellipsoidal "uncertainty region"**
    - **Using a line of variation approach**
    - **Defining the uncertainty region for each "virtual" asteroid and then predicting any possible collisions.**
    - **Goal is to provide a cross-check of NEODyS and CNEOS impact prediction work**
- **Harris, Al: Update of NEO Population and current survey status.**
    - **The 2017 numbers are still good; only marginal errors in 2019.**
    - **942 > 1 km; survey 94.5% complete**
        - **Still 52 big ones undiscovered.**
    - **D > 140 m is 37.6% discovered,**
    - **Use his presented diagram.**
    - **Most of the risk remains from the small number of yet undiscovered large NEAs.**
        - **Most are hiding behind the sun…or at perihelion behind the sun, in resonant orbits.**
        - **Big ones aren't coming out of the blue, but loop around from behind the sun and that will give us time to find them.**
    - **PHAs are about 20% of total NEA population**

- **Erik Christensen: The Catalina Sky Survey and its increased discovery and follow up capability**
  - **4 instruments on Mt. Lemmon and Mt Bigelow**
  - **New cameras in both survey telescopes**
  - **Image the whole sky in 3-4 nights.**
  - **2018…got more than 1000 NEOs in a single year**
    - **Found one impactor**
  - **I52 is a follow up telescope, as is V06 -- They get astrometry of new objects**
  - **NEOFixer – software to improve quality of NEO catalog, so as to set priorities to follow up site observations**
    - **Importance, size, cost, benefit, etc. to rank NEO observations**
- **Larry Denneau, UH: Detections of Small Impacting Asteroids with the ATLAS telescope system**
  - **ATLAS sited at Haleakala, Maui and Mauna Loa, Hawaii**
  - **Covers entire Hawaii night sky every 48 hours**
  - **Growing to 4 telescopes soon, early 2020s. Chile and South Africa.**
  - **Tunguska frequency is about 1 in 766 years**
  - **10 million NEOs of H < 27**
- **Wainscoat: The Pan STARRS Data Archive – An invaluable resource of faint NEO detections**
  - **Cameras: 60-64 CCDs in 1 and 2; 2 inches square;**
  - **but higher noise, a challenge for fast moving objects**
- **Tancredi—Uruguay: Is there a preferred date for a possible impact?**
  - **Faculty of Ciencias, Dept. Astronomy, Uruguay**
  - **Out of 1174 falls til present, only 105 were damaging.**
  - **About ¼ of reported falls are damaging ones.**
  - **Urban land is .44% of land, and 0.13% of Earth area**
  - **About 25% of urban land has buildings on it.**
  - **Concludes that there are 6100 falls per year over Earth, and about 1800 over land.**
  - **Analysis shows there is no preferred date for doomsday.**
- **Steele, New Zealand: The contribution of intermediate and long period asteroids to the overall large body impact hazard.**
- **Farnocchia—Impact of small NEO 2018 LA:**
  - **Detected just 8.5 hours before impact. Only 2 meters across.**
  - **We will see a Chelyabinsk-sized impactor about a week out, if in night sky.**
  - **BUT -- About half of these come from the daytime sky—not detectable.**
- **Naidu: Identifying Short-term impactors with LSST**
  - **Examined how effective LSST will be**
- **Masiero: Recent results in characterization of NEOs by the NEOWISE mision.**
  - **About a third of NEOs are low albedo, and are best seen in IR**
  - **Over 1500 NEOs have now been characterized by NEOWISE.**
- **Taylor: Arecibo radar observations of potentially hazardous asteroids**

- **Can view any PHA within 20 lunar distances, or 0.05 AU**
- **Can obtain very fine orbital determination**
- **Also Sizes and shapes.**
- **3100 Phaethon was about 40% larger/volume/impact energy than expected.**
- **3122 Florence – triple asteroid system with 2 moonlets.**
- **2017 YE5 – definitely a binary, two-component asteroid**
- **2003 SD220 – torpedo shaped, very slow 12-day rotator, tumbling.**

- **Lister: The LCO follow-up network for NEOs**
- **Exercise inject #1:**
  - **Paul Chodas: director of CNEOS**
  - **Threat exercise materials are all posted here:**

    https://cneos.jpl.nasa.gov/pd/cs/pdc19/

  - **To summarize, mythical asteroid PDC 2019, some 100-300 m in diameter, poses an impact threat in April 2027, eight years from now. The object has a 1 in 100 chance of striking Earth over North America. It is making a close approach to Earth in May 2019, but will not return until the impact encounter (again, 1% probability) in 2027. The IAWN is conducting an observations campaign to improve knowledge of the NEO's orbit.**

Tuesday, April 30, 2019: Session 2 and Session 3:

- **Jones was unable to attend these sessions due to his attendance at the burial at Arlington Cemetery of Capt. John W. Young. Please see the video stream of these two sessions on Tuesday at: http://pdc.iaaweb.org/**
- **The papers presented at the Tuesday sessions were:**

0820		**INTRODUCTORY REMARKS**
		Session 2: Continued
0830	IAA-PDC-19-02-23	The boulders on asteroid Ryugu: clues to the formation history of the to morphology
0842	IAA-PDC-19-02-24	Faint NEO Observations Using The UH-2.2m Telescope
0854	IAA-PDC-19-02-25	Discovering and Studying Near Earth Objects with The Large Synoptic S (LSST)

0906	IAA-PDC-19-02-26	The Near-Earth Object Camera: Overview
0918	IAA-PDC-19-02-27	NEOCam Survey Cadence and Simulation
0930	IAA-PDC-19-02-28	The NEOCam Science Data System
0942	IAA-PDC-19-02-29	Near-Earth Asteroids Monitoring for Hazard Assessments
0954	IAA-PDC-19-02-30	Find_Orb: Orbit Determination and Analysis Software
1006		**BREAK**
		SESSION 3: APOPHIS
		SESSION ORGANIZERS: Marina Brozovic, Davide Farnocchia
1036	IAA-PDC-19-03-01	Apophis 2029: Planetary Defense Opportunity Of The Decade
1048	IAA-PDC-19-03-02	Yarkovsky Acceleration Of (99942) Apophis
1100	IAA-PDC-19-03-03	Abrupt Alteration of Apophis' Spin State Redux
1112	IAA-PDC-19-03-04	Using a Discrete Element Method to Investigate Seismic Response and S 99942 Apophis During its 2029 Tidal Encounter with Earth
1124	IAA-PDC-19-03-05	Trajectory Concepts For An Apophis Rendezvous Mission
1136	IAA-PDC-19-03-06	Asteroid Probe Experiment: Mission To Apophis
1148	IAA-PDC-19-03-07	AI3: The Asteroid In-Situ Investigation – 3 Ways to measure the interio
1200	IAA-PDC-19-03-08	A Cubesat Mission to Asteroid Apophis Based on M-ARGO?
1212	IAA-PDC-19-03-09	Science and Planetary Defense Priorities for Spacecraft Encounter Miss (99942) Apophis During its 2029 Close Encounter with Earth

1224 IAA-PDC-19-03-10 Six Very Close Potentially Hazardous Asteroid Flybys in the Late 2020s

1400 Lessons From The 2012 TC4 Campaign: First Global Planetary Defense

- **Tuesday, impact exercise inject #2: Paul Chodas briefs the Day 2 scenario:**

  https://cneos.jpl.nasa.gov/pd/cs/pdc19/

  - **Latest observations through July '19 now show the impact probability is 10%.**
  - **Latest diameter estimate for 2019 PDC to roughly 140 to 260 meters (460 to 850 feet).**
  - **Impact would release in the range of 100 to 800 megatons of equivalent energy, possible producing serious devastation over a large region**
  - **The international forum for space agencies called the Space Mission Planning Advisory Group (SMPAG) is meeting to consider a coordinated international response to the impact risk posed by 2019 PDC. The group recommends development of a suite of possible deflection missions.**
  - **There is value in a recon mission to determine orbit, mass, rotation, structure, shape, material, etc.**
  - **Can use kinetic impact or nuclear explosives (NE) for deflection**
  - **KI could disrupt the NEO**
    - **Might require many launches to achieve delta V and not disrupt the NEO**
  - **NE can use 1-size spacecraft that rendezvous and then detonates**
    - **Requires only 1 launch, one 100 kT device.**
  - **There is a US task force working on this, which will recommend course of action to US president**
  - **The above is part of an exercise; not real.**

Wednesday, May 1, Session 4, Deflection and Disruption Models and Tests

(co-chairs, Tom Jones/ASE and Andy Cheng/APL)

- **Megan Bruck Syal: LLNL – Simulation of DART (Double Asteroid Redirection Test) impact: Effects of impact conditions and target properties**
  - **DART will hit at 6.65 km/sec with 555 kg spacecraft**
  - **Rubble pile structure assumed**
  - **How does impact angle affect result?**
  - **Rock composition doesn't change Beta (the momentum multiplier coefficient) much – 1.3 to 1.4**
  - **Porosity eats up energy, less ejecta. For a given size, resulting delta v is higher due to lower density asteroid (less mass)**

- **Material strength: chondrites have less strength than terrestrial rocks, Beta not affected much**
    - **Didymos B shape still uncertain; shape affects beta**
    - **Model study examines impact angle effects; off the axis of symmetry, more oblique impact**
    - **An oblique impact causes ejecta to go in "wrong" direction reducing efficiency of KI.**
    - **Impact angle is an important factor, like material, strength, composition, and porosity. Values of Beta are around 1.3 or 1.4**
- **Cathy Plesko: Progress at Los Alamos on planetary defense, inter-agency with NASA**
    - **Using Los Alamos assets to model impacts on target asteroids**
    - **Model used a Didymos B–like target, 100 m across, basalt, pear shaped.**
    - **Model result betas are > 7 – 17**
        - **Lots of spall coming off from the adjacent hemisphere which increases the beta for an impact event**
        - **Another model beta = 4 - 8 because of spall in models**
    - **Case study 3 model: a lobate, low density, dry object, not a comet but a contact binary**
        - **Get some spall outside crater;**
        - **Beta >8 -11**
    - **Summary—need to constrain binding energy, and examine importance of shear strength and tensile strength**
- **Mike Owen, LLNO, modeling DART impactor and crater formation using realistic spacecraft shapes.**
    - **Models cubes, sphere, and DAWN model**
    - **Modeling a crater shape and use that to help model ejecta material and shorten the simulation.**
    - **Uses 3D rubble pile model.**
    - **Not much difference between sphere and cube spacecraft in ejecta pattern**
    - **Spacecraft model: rubble pile doesn't show influence of spacecraft shape.**
    - **In the monolith case – circular crater with small footprint of solar arrays**
    - **6-7 meter deep craters, roughly 12 m wide**
    - **More compact spacecraft liberates more mass and momentum in ejecta**
    - **Beta is 2-3 in the rubble pile, dominated by ejecta from the target matrix material.**
    - **Lower beta with more realistic spacecraft and object shapes/boulders**
    - **Need spacecraft internal structure, and model the damaged target material as more granular rather than fluid.**
- **Angela Stickle – APL: Spacecraft geometry & target structure on DART impact model**
    - **APL team modeling**
    - **Joins LCROSS and Deep Impact as cratering experiments**
    - **Beta = 1 means no ejecta, just adding momentum**
    - **Beta > 1 due to ejecta plume acting like a thruster**

- **Estimation of Beta important because DART will not measure beta. We just get the momentum change.**
- **Porosity and material strength greatly affected impact crater size and depth, and thus ejecta and beta**
- **Solid vs hollow projectiles create different ejecta curtain shapes**
- **Asteroids are nature's way of asking "How's that space program coming along?"**
- **DART will get us a shape of Didymoon, but not mass. Will have to estimate it.**

- **Dawn Graninger, Livermore: understanding effect of rubble pile structures on asteroid deflection**
  - **KIs affect orbit timing, not shoving body out of the way**
  - **Monolithic structures are not realistic asteroid models**
  - **Many are rubble piles, with different regions of dust vs rubble vs rocks**
  - **Used Spheral++ code, can use a rubble pile generator. A good model for this case**
  - **Generates boulders throughout the target. A lumpy object.**
  - **Assumed reasonable shape, strength, porosity, and boulder properties**
  - **Impactor shape was a flat plate of aluminum hitting at 6.25 km/sec**
  - **Full 3D model of Didymos used in simulation, with varying impact points around equator**
  - **Beta = 1.8 to 2.1 as outputs ….boulders on crater edges can reduce beta slightly**
  - **Impacts into regolith absorb shock and reduce ejecta recoil**
  - **Beta varies over 15% due to boulders vs regolith impacts**
  - **Just ran 4 cases. Need to vary porosity more, strength of boulders may be lower.**
- **Emma Rainey, APL: DART Impact working group**
  - **Applications of DART impact simulation results – 2D to save expense of 3D models**
  - **Beta estimation is critical to assess deflection performance**
  - **Rubble pile 2D modeling: rubble piles of boulders, small rocks, and fine particles**
  - **About 62% boulder fill fraction, with rest filled by matrix, boulders 1-10 meters**
  - **The matrix was modeled as porous, 20 or 60% porosity**
  - **Have run 57 models…beta results range from 1.5 to 3.7, this is a slice of results and don't span all conditions and assumptions**
  - **Smaller beta into porous regolith; solid rock boulder yields higher beta**
  - **Ejecting small rocks on surface increases beta due to mass of ejecta**
  - **Post impact: we don't measure beta. We get the change in orbital period**
  - **If we get mass, then we can estimate beta. HERA probe required to get mass.**
  - **Can use the models to estimate beta based on the delta v measured.**
  - **Using imagery, we can further match the models.**
- **Raducan, Sabina: Imp. College London: Numerical modeling of DART impact and importance of HERA mission.**
  - **Need crater size to nail down Beta from DART**
- **Robert Luther: HERA impact simulation group, MFN, Berlin:**

- **Model results for beta from ISale simulation code**
- **Must assess crater shape and size to get target properties from Beta**
- **Layering can play a role for Beta, too, as well as target properties**

- **Remington, Tone, LLNL: Deflection of a Small Object Using a Kinetic Impactor**
  - **Beta influenced by angle, composition, and porosity. Need to know target properties.**
  - **SPHERAL modeling code used.**
  - **Used a shape model of 67/P to evaluate**
  - **Use nuclear standoff device and x-rays to ablate surface: use this slide**
  - **Did a simulation of the nuclear detonation on the y axis, an irregular surface**
    - **Easy to push too hard, and get disruption**
    - **Even a 5 kT device can disrupt the surface rather than deliver a gentle push**
  - **DART may be hitting Didymoon as an irregular object. Hard to model, might have extreme slopes.**
- **James Walker, SWRI: Size scaling of Beta during hypervelocity impact into porous and consolidated rock**
  - **Firing aluminum projectiles into Al targets**
  - **Measuring the swing of a pendulum target to get beta**
  - **Projectile size increases the ejecta released much more effectively**
  - **Damage saturation occurs at higher speeds**
  - **The average ejecta velocity goes up as size of impactor increases**
  - **Rock tests – nice impact test video…into granite showing ejecta**
    - **2 impactor sizes, 2.5 and 4.5 cm**
    - **Into concrete and sandstone—the sandstone target fractured**
    - **Into pumice, too. Fluffy rock, porous**
  - **You want to impact with the biggest impactor you have**

Session 5 on Mitigation Campaign Design

- **Cheryl Reid, APL: DART**
  - **14 month flight time to impact**
  - **HERA essential to get follow up measurements**
  - **May fly by another object enroute**
  - **Launch 2021 from Vandenberg**
  - **By next PDC, we will be just a few months from launch**
- **Cristina Thomas, observations of Didymos…**
  - **Need to know exactly where Didymos B will be**
  - **The orbital period will change by 73 sec or so, need to measure the change within 7.3 sec. → leading to Beta**
- **Carolyn Ernst – APL – DART , proximity observations by DRACO camera**
  - **See slide of size comparisons from DART website**

- **Launch 7/22/21—Navigation to hit Didymos, plus imaging the target Didymoon, constrain impact site, shape and characterization of target.**
- **200K images, the last within 20 sec of impact. 9/27/22**

- **Elena Adams, APL: DART technology and engineering challenges**
    - **DART overview slide**
    - **What new tech will DART demonstrate?**
    - **Smart nav autonomous nav technology**
    - **NEXT C ion propulsion engine**
    - **Roll out solar arrays**
    - **Transformational solar array concentrators**
    - **Radial line slot array--flat**
- **Mehta: APL: Renderer and Camera Emulator (RCE) for DART**
- **Patrick Michel: Cote D'Azure Observatory, Nice: HERA: ESA component of AIDA with DART**
    - **Launch in Nov 2023, HERA to arrive Didymos in 2027**
    - **HERA gets mass, shape, volume, densities, spin/pole, libration.**
    - **Gets crater properties: diameter, depth, volume, shape**
    - **Science: small asteroid below the spin disruption size limit;**
        - **Binary asteroid investigation**
        - **Rotational breakup process**
        - **Top-shape asteroids, unlike Itokawa**
        - **Will Didymos be top-shaped or irregular?**
- **Keratekin: HERA planned mission and payload operations at close proximity to Didymoon after impact**
    - **Asteroid framing cameras, lidar, thermal infrared, radio science, 2 cube sats,**
    - **1 day on surface of Didymoon with cubesat, with radar sounder**
- **Mariella Graziano, ESA: HERA GNC and data fusion**
    - **Feature identification and tracking.**
- **Tomas Kohout, Czech Academy of Sciences: APEX cubesat for HERA mission:**
    - **Asteroid Protection Explorer**
    - **Science goals of APEX are many: Planetary defense, science, ISRU, and asteroid mining**
- **Dave Dunham, consultant: How to use NEOs to deflect a long period comet…**
    - **Redirect a comet using a NEO Earth swingby to smack a rogue object.**
    - **Necessary due to speed and size of comets**
    - **Asteroid projectile…navigated to strike the target**
    - **About a dozen NEOs can be parked near Earth in a 1-year orbit that's available for future redirection to a target**
    - **Four resonance asteroids could be used to protect against comets …giving you four chances to intercept and deflect.**
- **Paul Abell, NASA JSC: About Hayabusa 2:**
    - **Small carry-on impactor (SCI) strike on Ryugu**
    - **Image of the ejecta plume and crater produced**

- **Brent Barbee – GSFC: Mission design for PDC 2019 asteroid**
  - **Mitigation gateway website at NASA…**
  - **Nuclear explosive rendezvous mission is very flexible**
- **MASCOT lander on Ryugu—**
  - **Bouncing off the NEA.**
  - **Good images at MASCOT site.**
- **Trangsrud: NEOCam instrument design**
  - **Get 80% of 140 m objects in 5 years**
  - **Waiting on spacecraft funding, but instrument design well under way.**
- **Dunham, Dave, and Kovalenko, Russia. System to observe daytime asteroids: trajectory and orbit design**
  - **From ground, will always miss 1/3 of NEOs due to sun side of Earth**
  - **Almost all 10m and > diameter NEOs will be discovered up to 1 day before possible collision**
  - **2 spacecraft in SE L1 orbit halos. 30 cm aperture with 3 telescopes aboard each spacecraft**
  - **1 spacecraft per Soyuz booster launch**
  - **SODA – system of observation of daytime asteroids**
- **Hestroffer, France: BIRDY—a smallsat for NEO recon and exploration**
- **Exercise Inject 3 – Day 3 press release at: https://cneos.jpl.nasa.gov/pd/cs/pdc19/**
- **Latest exercise results:**
  - **As of Dec. 30,. 2021: ASTEROID PREDICTED TO IMPACT NEAR DENVER, COLORADO**
  - **140-220 m diameter**
  - **Stony object**
  - **Will airburst 6-9 km up -- West of Denver**
  - **510 Mt, about 34K times Hiroshima**
  - **Asteroid is skyscraper-sized, a contact binary**
  - **4 times bigger across than Tunguska, which was 5 Mt energy release.**
  - **Tunguska-style explosion at 5-15 Mt would sweep across Denver**
  - **2019 PDC impact scours Denver from the Earth. Large unsurvivable area covering all of downtown Denver.**
    - **Must evacuate entire Denver area**
  - **Like prehistoric events that formed Libyan desert glass, Chilean impact glass**
  - **We can use space skills to prevent this**
    - **Deflection campaign done internationally**
    - **Flew a recon flyby, successful**
    - **6 KI missions planned.**
    - **Rendezvous recon spacecraft—with nuke option**
    - **Retasked interplanetary spacecraft to provide second rendezvous**
    - **Successful kinetic impacts will move impact point eastward; westward is not feasible**
  - **Uncertainties:**

        - **Have to move NEO 12000 km east, but uncertain how much each KI will move it, due to mass and beta uncertainty**
        - **Will get mass with rendezvous mission, but KIs will already be on the way**
    - **Nuke deflection feasible—a 100 kt nuclear explosive is feasible**
    - **Design KIs so they can jettison mass and reduce delta v delivered, avoiding disruption**