



The State of Play US Space Systems Competitiveness

Prices, Productivity, and Other Measures of
Launchers & Spacecraft

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*Presentation to the Future In-Space Operations (FISO) Seminar
October 11, 2017*



Updates

09/25/2017

Launches

- US Major Launches (slide 9), & US Launch Tempo (slide 24) for launch of Atlas V **September 23, 2017** ...NRO
- Global Commercial (slide 23) for launch of Proton September 11, 2017 ...Amazonas
- US Major Launches (slide 9), & US Launch Tempo (slide 24) for launch of Falcon 9 September 7, 2017 ...X-37
- US Major Launches (slide 9), Global Commercial (slide 23) & US Launch Tempo (slide 24) for launch of Falcon 9 August 24, 2017 ...Formosat
- US Major Launches (slide 9), & US Launch Tempo (slide 24) for launch of Atlas V August 18, 2017 ...TDRS
- US Major Launches (slide 9), Global Commercial (slide 23) & US Launch Tempo (slide 24) for launch of Falcon 9 August 14, 2017 ...CRS-12
- US Major Launches (slide 9), Global Commercial (slide 23) & US Launch Tempo (slide 24) for launch of Falcon 9 July 5, 2017 ...Intelsat
- Launch Systems – Multiple Measures (slide 19), “Best” Total kg in a year by any Model, for Falcon 9 ->**13 launches to date in 2017**
- Global Commercial (slide 23) for launch of Ariane 5 May 4, 2017

Other

- Commercial Crew test flight dates (slide 6)

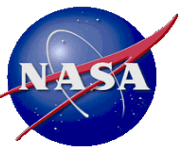
06/26/2017

Launches

- US Major Launches (slide 9), Global Commercial (slide 23) & US Launch Tempo (slide 24) for launch of Falcon 9 June 25, 2017 ...Iridium
- US Major Launches (slide 9), Global Commercial (slide 23) & US Launch Tempo (slide 24) for launch of Falcon 9 June 23, 2017 ...Bulgariasat
- Global Commercial (slide 23) for launch of Proton June 7, 2017
- US Major Launches (slide 9), Global Commercial (slide 23) & US Launch Tempo (slide 24) for launch of Falcon 9 June 3, 2017 ...CRS-11
- Global Commercial (slide 23) for launch of Ariane 5 June 1, 2017
- Global Commercial (slide 23) for launch of Soyuz (Arianespace/French Guiana) May 18, 2017
- US Major Launches (slide 9), Global Commercial (slide 23) & US Launch Tempo (slide 24) for launch of Falcon 9 May 15, 2017 ...Inmarsat
- Global Commercial (slide 23) for launch of Ariane 5 May 4, 2017
- US Major Launches (slide 9), & US Launch Tempo (slide 24) for launch of Falcon 9 May 1, 2017 ...NRO

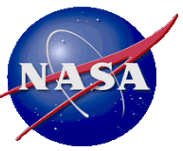
Other

- Commercial Crew: Update to dates of 1st flights (slide 9)
- Budget: Updates for 2017 budget deal May 1, 2017 (slide 8), after the 2017 Continuing Resolution
- SLS: Corrected labeling of SLS data point (slide 10); point does include a % of ground systems
- Orion: Updates to Orion data text description (slide 20)
- Commercial crew/cargo: Clarification on crew/cargo data text description (slide 21)



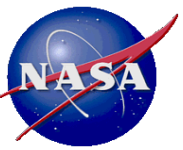
Purpose

- Collects (only) **PUBLIC** space systems cost and related data –flight rate, payload mass, etc.
 - Compile **public** data - contract announcements, budget docs, etc.
 - Separate **non-recurring and recurring**
 - **Minimal data processing**; if adjustments, only for apples to apples
 - Inflation to current year dollars, to same orbit, same mass metric, etc.
 - **Provide context**, compare across systems, graph, visualize
 - Focus on US space systems **competitiveness** (it's not all just costs)
 - **Keep fresh**
 - Update as new data is published, as launches occur, etc.
 - Focus on **recent data**, indicative of the near future



Purpose

Lets do the math




Caveats & Terminology

- The “price” to a customer is the procurement or contract “cost” to NASA, DoD, NRO, private sector, etc.
 - But total costs would include other internal program/project management costs – in a government agency, personnel and other costs
 - The data ahead are almost all flavors of this (NOT the “costs” inside a company or agency *before this or that are added, etc.*)
 - Among many other “asterisks”
- Uncertainties - inevitable; data refinement - continuous
 - Minimally processed data BUT-
 - Anecdotal evidence some launch pricing actually runs much higher in the end than publicly announced or advertised (Russia/Proton, etc.)
 - Some public data is processed more – due to different contract phases, multiple partners, not yet complete, age of the data, etc. (SLS, Orion, Commercial Crew, Apollo, etc.)

Source Data

- Source data for this report is available in the Life Cycle Cost (LCC) Model
- Data sheets are available upon request to NASA, government, government contractors or for peer/collaborative purposes
- Contact edgar.zapata-1@nasa.gov

The NASA Life Cycle Cost (LCC) Model
12/7/2016
Updates



Launch System
Life Cycle Cost Model

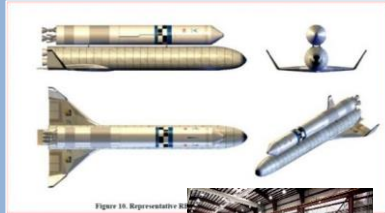




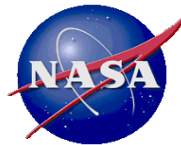
Figure 18. Representative Launch Systems



NASA Scenarios Model
for Human Exploration & Operations
Budgets vs. Life Cycle Costs



Data



Source Data

Example Data Sheet

Nominal or Inflated

Document public source, pp., doc, etc.

Document and justify adjustments (like "no EUS")

NON-RECURRING COSTS		Sources: re. Notes Below																		4,532.2		2,374.5	
Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023					
SM Real Year	\$ 839.2	\$ 479.5	\$ 889.5	\$ 1,387.2	\$ 1,640.0	\$ 1,196.0	\$ 1,200.0	\$ 1,113.8	\$ 1,197.0	\$ 1,194.0	\$ 1,270.0	\$ 1,350.0	\$ 1,119.9	\$ 1,123.9	\$ 1,135.3	\$ 1,153.3	\$ 1,175.8	\$ 1,198.7					
Inflation adjustment to 2017 per NASA Inflation Index	1.276	1.244	1.213	1.185	1.160	1.138	1.117	1.105	1.080	1.066	1.036	1.000	1.025	1.051	1.078	1.104	1.130	1.157					
SM 2017S	\$ 1,071.0	\$ 596.7	\$ 1,078.6	\$ 1,643.8	\$ 1,902.5	\$ 1,361.5	\$ 1,352.7	\$ 1,230.4	\$ 1,292.4	\$ 1,272.4	\$ 1,315.6	\$ 1,350.0	\$ 1,092.1	\$ 1,068.0	\$ 1,053.3	\$ 1,044.7	\$ 1,040.3	\$ 1,035.7					
Sum Procurement & Gov't 2006 to here in RY \$												\$ 12,466									\$ 8,257		
Sum Procurement & Gov't 2006 to here in 2017S												\$ 14,117									\$ 7,685		
Sum Procurement \$ ONLY 2006 to here in 2017S												\$ 12,605									\$ 6,862		
Sum Procurement \$ ONLY 2017 to here in 2017S												(0)									(0)		
Total Orion Development Procurement ONLY \$M in 2017S												\$ 19,666									\$ 21,802		

This data sheet gathers all the PUBLIC NASA budget data for this program and indicates all the source documents. The actual costs to date are the sum of the budgets through the date indicated, usually up to the current year, with the numbers after being the planned budgets from the same documents.

Minor adjustments include separating out Government program/project management, civil servants et al, vs. the contractor "procurement" dollars, as well as creating a new line in current year dollars using the official NASA inflation indices.

NOTE: "Actuals" PUBLIC budget data, actual costs, appear in NASA budget documents a year or more after the budget year indicated. For example, the "Actual" 2008 budget data is found in the 2010 NASA budget request.

The OFFICIAL RECORD INDICATES:

This is the data for Orion, before 2011 (aka CEV, MPCV) in Real Year \$M:

2006-\$839.2 (re. 2008 budget doc, 168652main_NASA_FY08_Budget_Request.pdf, pg. 308)
 2007-\$479.5 (re. 2009 budget doc, 210015main_NASA_FY09_Budget_Estimates.pdf, pg. 6)
 2008-\$889.5 (actual, re. 2010 budget doc, 345225main_FY_2010_UPDATED_final_5-11-09_with_cover.pdf, pg. 8)
 2009-\$1,387.2 ("enacted", not "actual" -re. 2010 budget doc, 345225main_FY_2010_UPDATED_final_5-11-09_with_cover.pdf, pg. 8)
 2010-\$1,383.5 ("request" not actual, -re. 2010 budget doc, 345225main_FY_2010_UPDATED_final_5-11-09_with_cover.pdf, pg. 8)
 2011-\$1,196.0 (re. 2013 budget doc, 622655main_FY13_NASA_Budget_Estimates.pdf, pg. 4)
 2012-\$1,200.0 (re. 2014 budget doc, 740512main_FY2014_CJ_for_Online.pdf, pg. 8)
 2013-\$1,113.8 (re. 2015 budget doc, 508_2015_Budget_Estimates.pdf, pg. 5)
 2014-\$1,197.0 ("actual" -re. NASA_FY_2016_Budget_Estimates.pdf, pg. 5 - RUD-5)
 2015-\$1,194.0 (ESTIMATED / TENTATIVE - NASA_FY_2016_Budget_Estimates.pdf)
 (\$1,190.2 "operating plan" value per "FY_2017_Budget_Estimates.pdf")

Then, inflation adjustments to 2017S, and removing 12% (government management). The model adds this back in separately, the "industry/procurement" portion of this would be approx. \$12,605M spent on Orion before 2017 in 2017S.

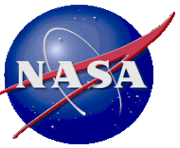
From above data
 Cx Era 2006 to 2010 and 2011 \$M nom.
 \$ 5,230
 \$ 6,431.4

Orion nom. year 2012-2021 \$M
 \$ 11,827 <- Compare -> Apx. Program LCC per GAO Mar. 2016
 See GAO-16-309SP

Orion nom. year 2011-2021
 \$ 13,053

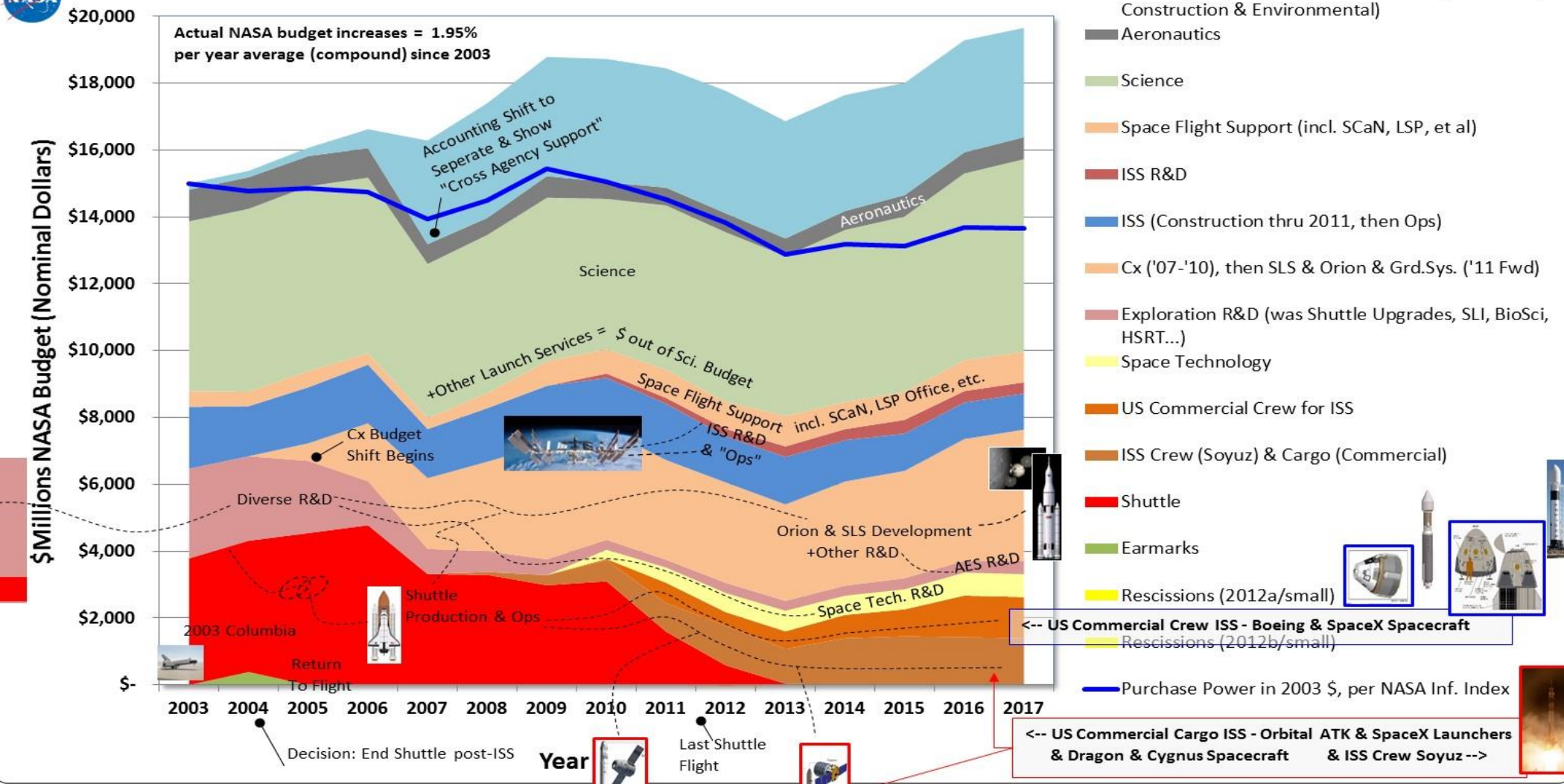
2016-2022

- Build of year by year nominal budget data:
 2016 = \$ 1,270M
 p. 182, 2016-CPRT-114-HPRT-RU00-SAHR2029-AMNT1final.pdf
 2017 - from FY 2017 budget deal - 2017 z-fy 17 wrapup budget deal - CPRT-115-HPRT-RU00-SAHR244-AMNT1.pdf
 = \$1,350M
 Also see sheet "Data-NASA Budget" for detail
- 2018 - 2021 -> p. BUD-4, fy_2017_budget_estimates.pdf
 NOTE! Senate version 2017 = \$1,300M (not \$1,270M)
 http://spacenews.com/senate-bill-cuts-other-nasa-programs-to-fund-sls-and-orion/
 http://www.spacepolicyonline.com/news/senate-appropriators-approve-19-3-billion-for-nasa-for-fy2017
- 2022 - 2023 use same as 2021, but with average 2003 to date historical budget increases of 1.95% above 2021.
 2. Removed 12% (estimated) from the above budget data for government management. (The model adds this back in separately).
 i.e., Orion Development Sum Procurement \$ ONLY remaining to completion, 2016 to 2023, in 2017 \$ as shown.



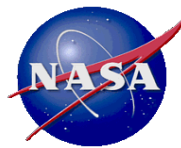
The NASA Budget – Purchase Power Drop Since 2003 = 9%

E. Zapata NASA 08/28/2017



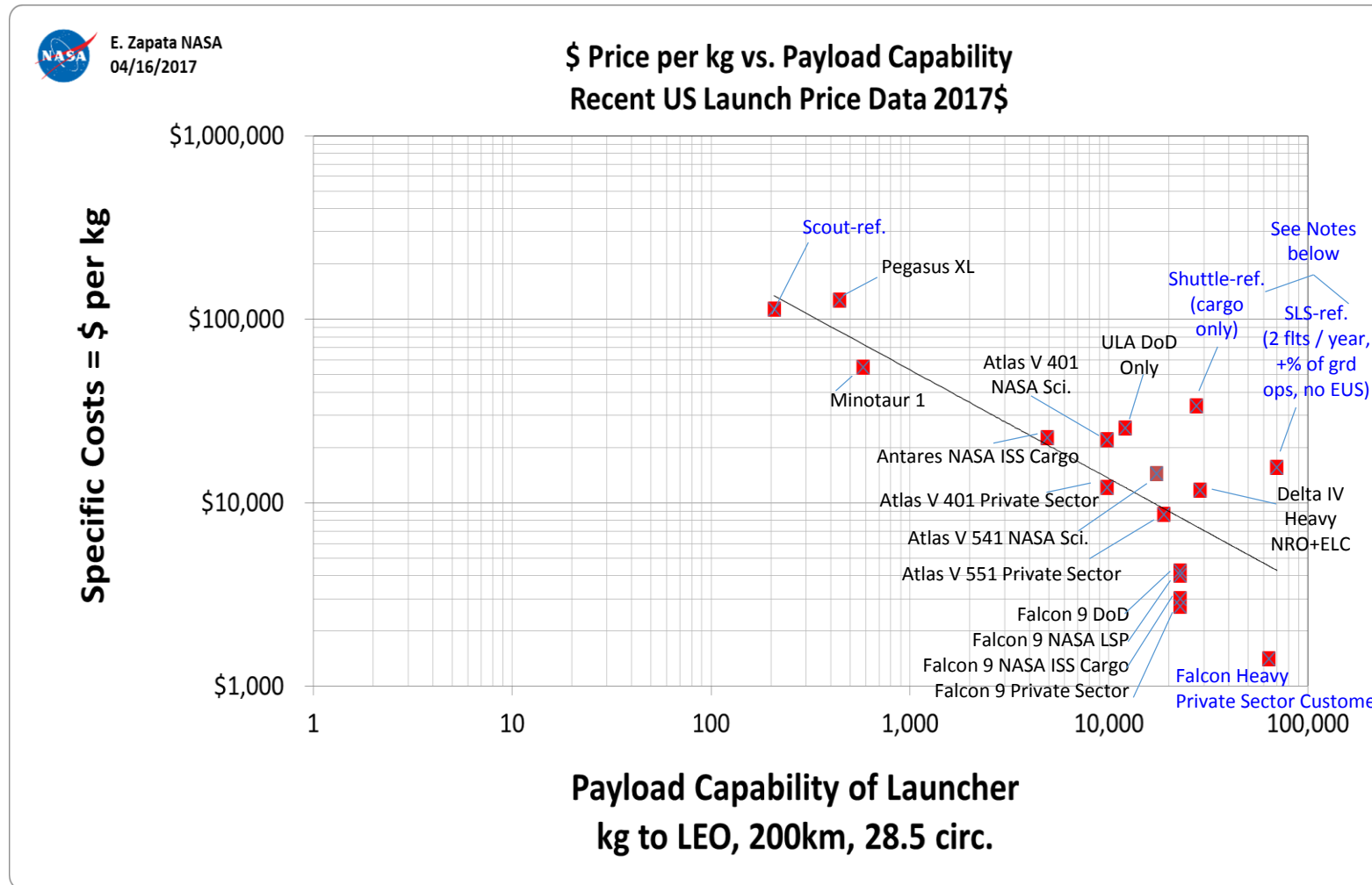
Before 2003

- > Reusable Launch
- > Hypersonics
- > SLI, NGLT, etc.
- > Technology
- > + Shuttle Upgrades

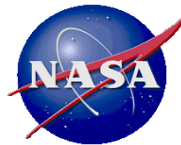


Recent Launch Prices as \$/kg of Payload (2017\$)

US Medium Launch + Scout, Shuttle, SLS, Falcon Heavy

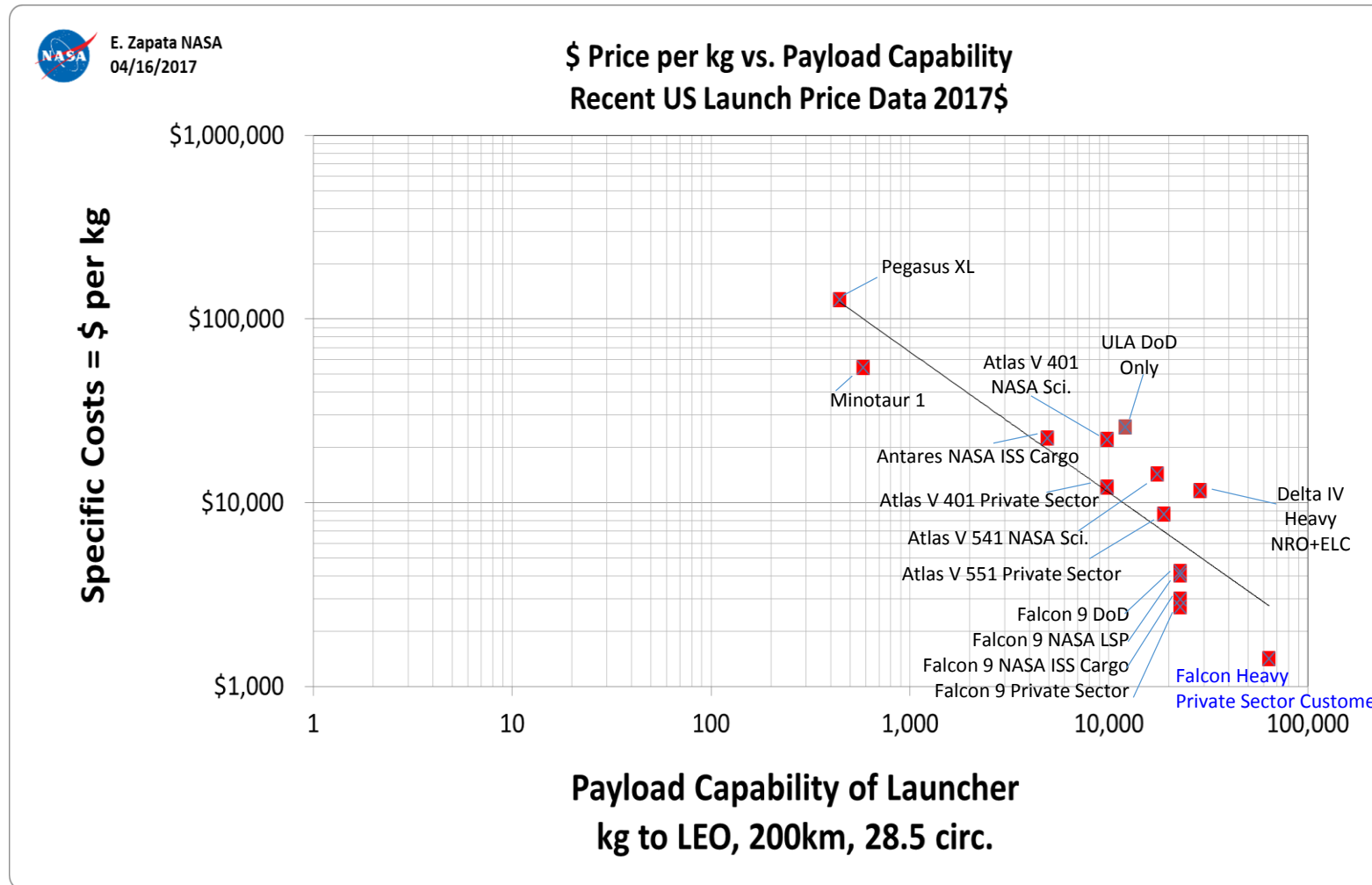


- The line is a power curve fit ONLY to the points indicated with->
- For NASA and DoD, data are prices to the government, that is procurement costs only, excluding government management, personnel and related.
- For the Space Shuttle, to give a more consistent CARGO comparison, total recurring costs from life cycle cost data (1983-2013) were adjusted to remove crew at a Soyuz price rate, NASA management (civil service) and related were removed to leave procurement dollars only, and R&D years 1981-1982 were excluded as non-operational. Similarly, for SLS the NASA management (personnel) and related costs are also excluded, but unlike Shuttle, ground ops are excluded.



Recent Launch Prices as \$/kg of Payload (2017\$)

US Medium Launch - NO Scout, Shuttle, SLS





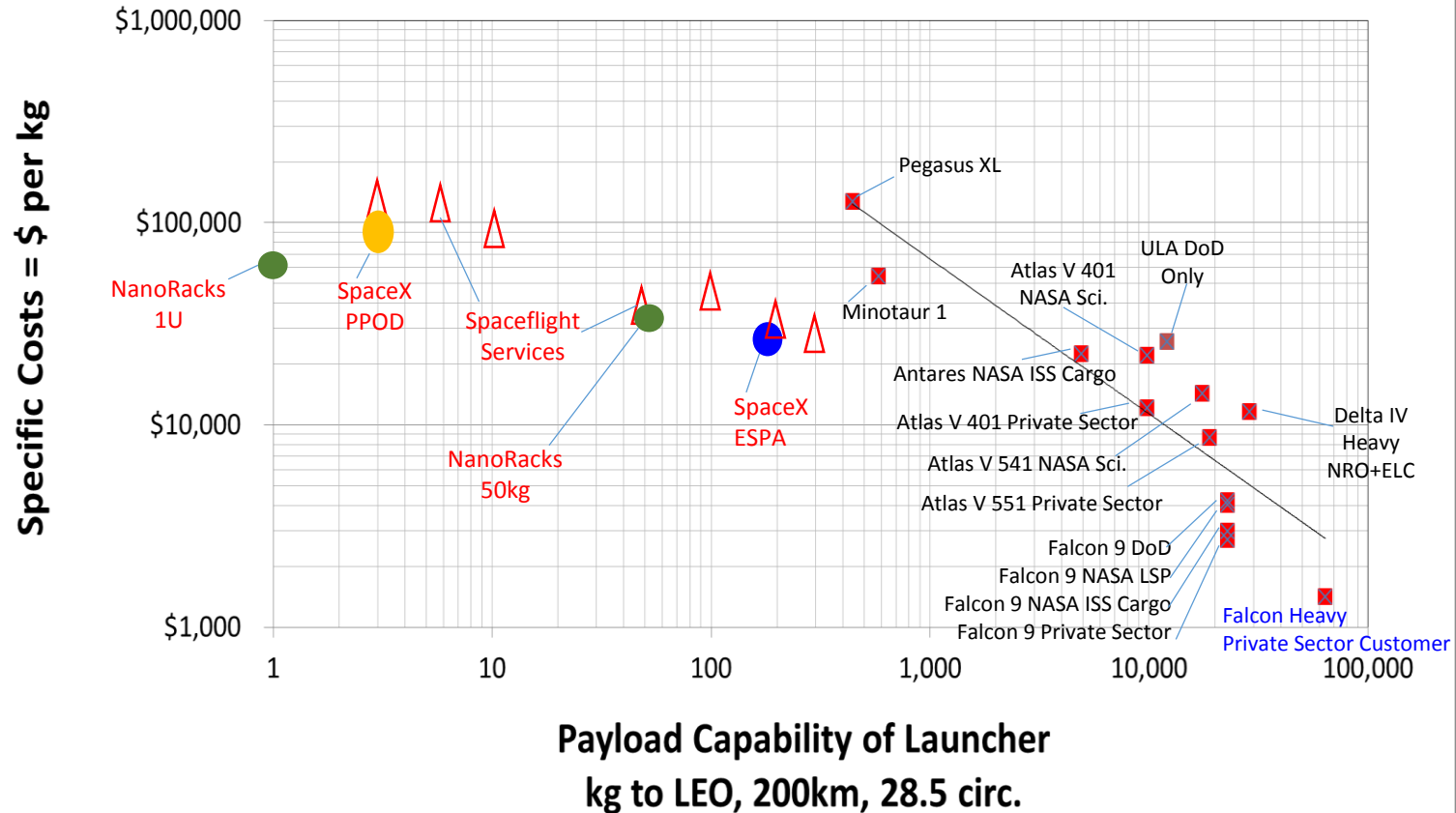
Recent Launch Prices as \$/kg of Payload (2017\$)

With Available US Small Launch / Services



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04/16/2017

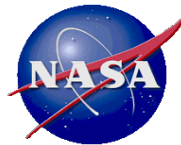
\$ Price per kg vs. Payload Capability Recent US Launch Price Data 2017\$



● NanoRacks as of 12/7/2015

△ SpaceFlight Services as of 12/7/2015

See Backup slides for data sources

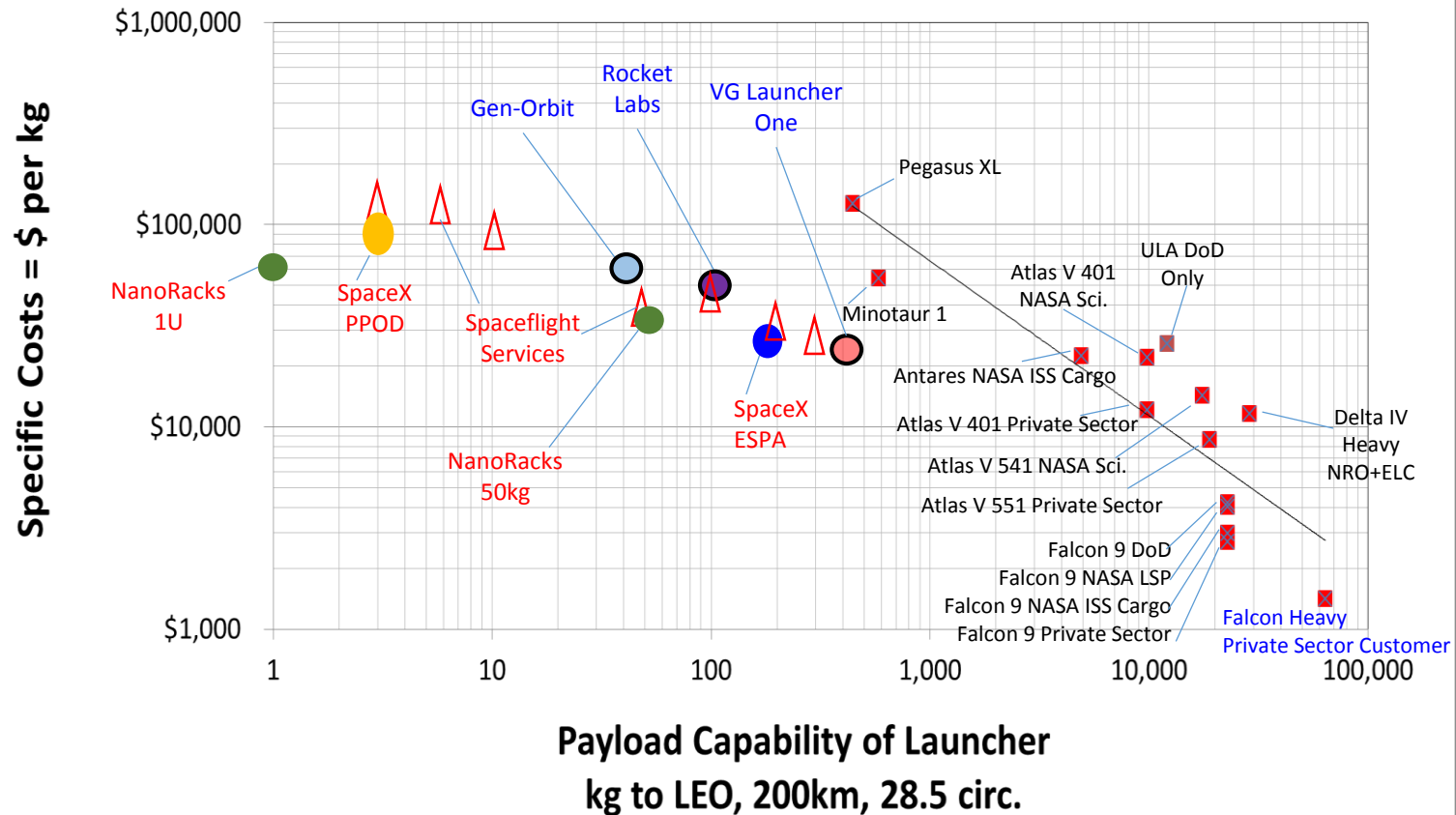


Recent Launch Prices as \$/kg of Payload (2017\$)

With Available US Small Launch / Services + Some In Development

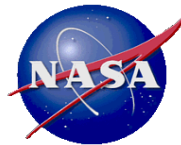
NASA
E. Zapata NASA
04/16/2017

\$ Price per kg vs. Payload Capability Recent US Launch Price Data 2017\$



- NanoRacks as of 12/7/2015
- △ SpaceFlight Services as of 12/7/2015
- Virgin Galactic Launcher One as of 9/14/2015
- Rocket Labs as of 8/10/2015
- Generation Orbit as of 6/5/2015

See Backup slides for data sources

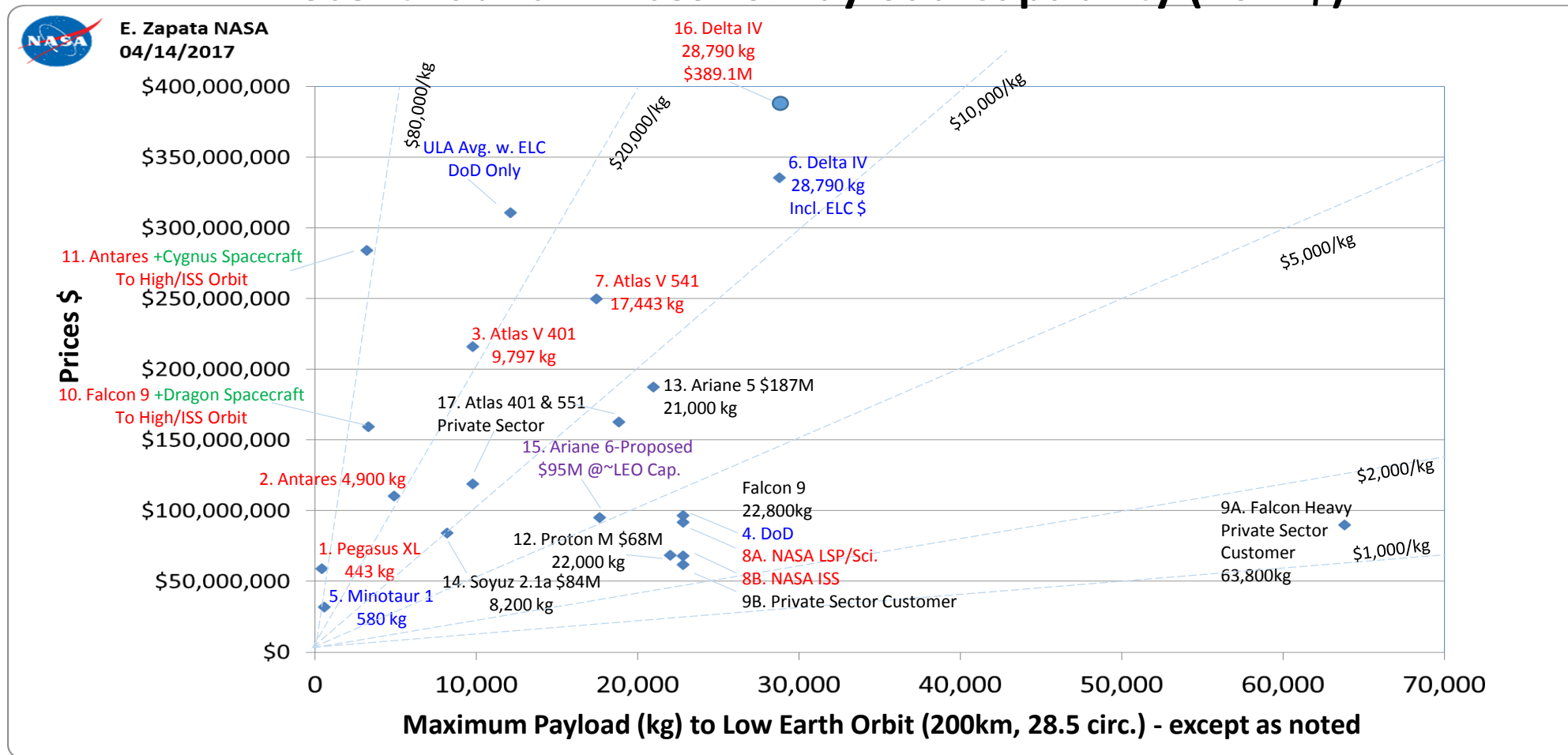


Recent Launch Prices vs. Payload Capability (2017\$)

RED = NASA

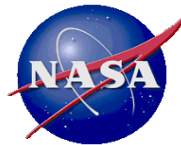
Blue = DoD

Black = Private / non Gov't



- 1. NASA price contracted for one 2017 launch (ICON)
- 2. NASA price contracted for block of launches as a service (ISS cargo, derived price, minus Cygnus Spacecraft)
- 3. NASA price contracted in 2010, launched in 2013 (MAVEN)
- 4. DoD Price contracted in 2017 for a GPS launch
- 5. DoD Price contracted, launched in 2013
- 6. Price to DoD of the launch service including the amortized EELV Launch Capabilities (ELC) contract, the yearly ELC contract amount divided evenly over the DoD only launches, for NRO
- 7. NASA Price contracted in 2012, each, with two launches procured together, launched in 2016 + TBD 2017
- 8A. and 8B. NASA Sci. price (8A) contracted in 2012, launched in 2016 (JASON), and (8B) NASA price contracted for block of launches as a service (ISS cargo, derived price, minus Dragon Spacecraft)
- 9A. and 9B. Prices for private sector customers

- 10. Price to NASA; higher orbit, plus includes providing the Dragon spacecraft for carrying / placing the customers cargo (pressurized, unpressurized, return, etc.)
- 11. Price to NASA; higher orbit, plus includes providing the Cygnus spacecraft for carrying / placing the customers cargo (pressurized, disposal, etc.)
- 12. 13. and 14. Prices to customers from 2015 launches in the 2016 FAA launch compendium
- 15. Ariane 6 –Proposed, shown w. derived equivalent LEO payload capacity. See backup slide and -> <http://www.spaceflightnow.com/news/n1406/17airbussafran/>
- 16. NASA price contracted in 2015 for one 2018 launch. See backup slide.
- 17. Per ULA -> www.RocketBuilder.com

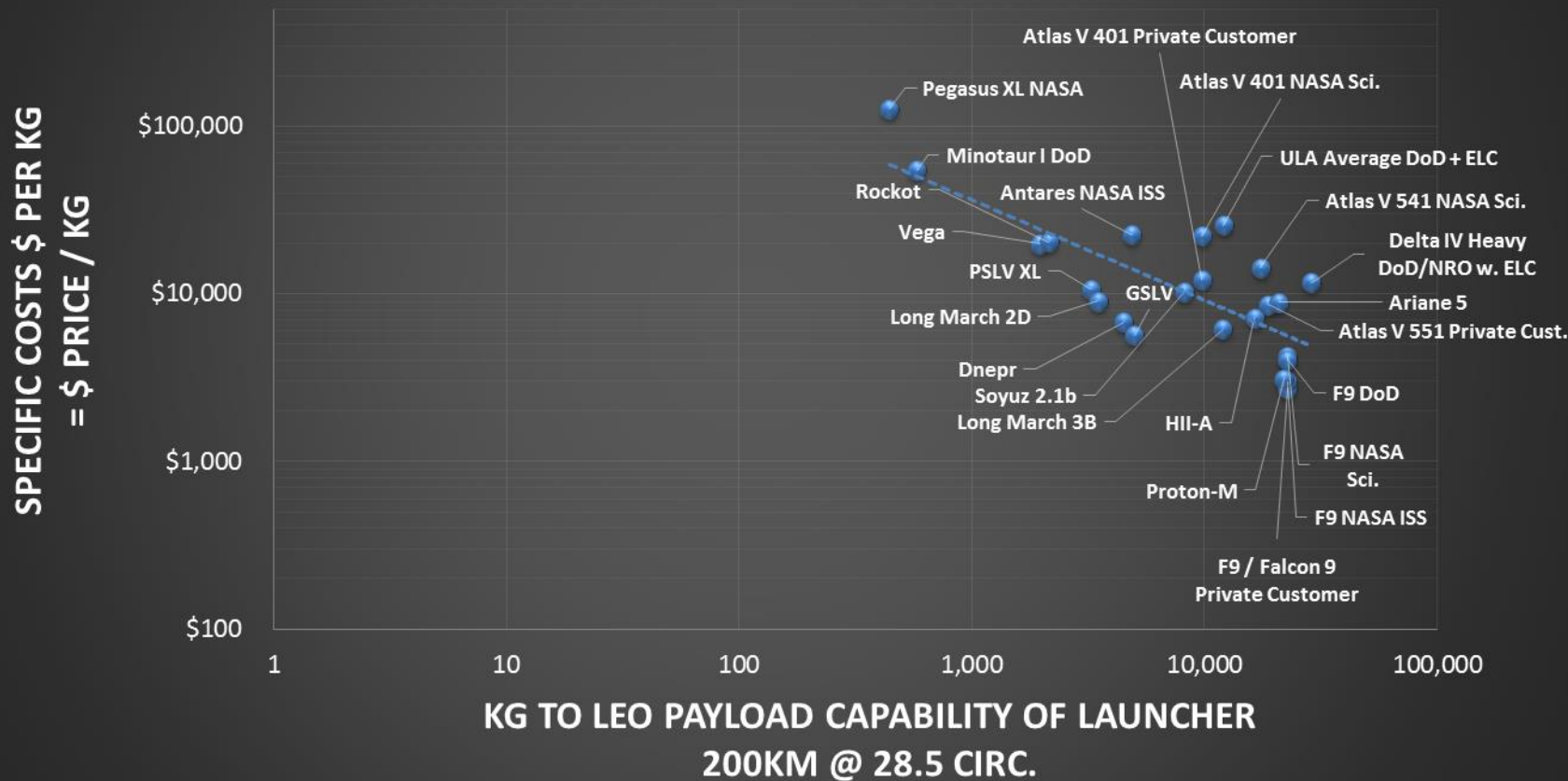


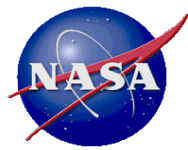
Global Views



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\$ per Kg (2017\$) Existing Capability





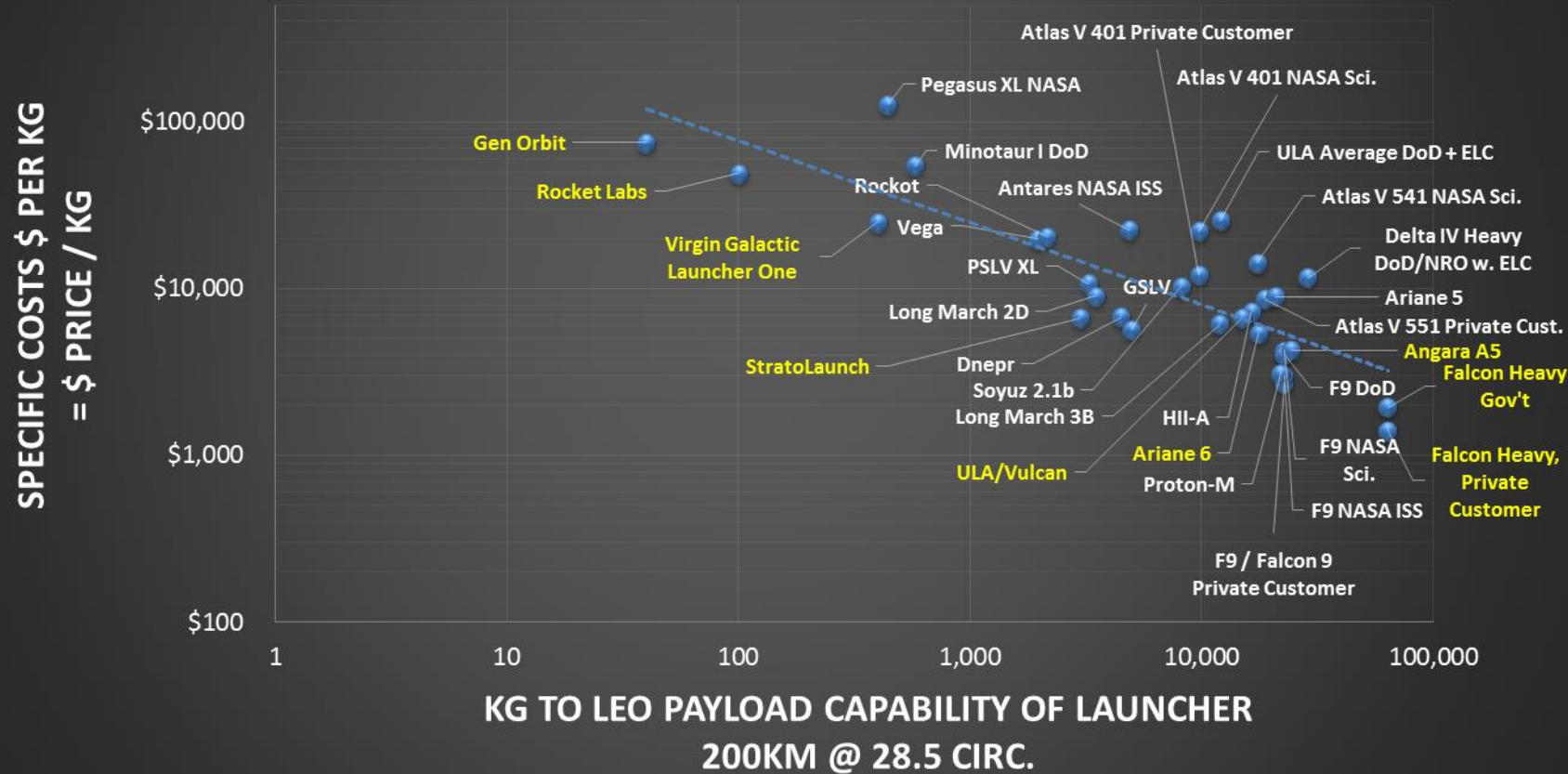
Global Views

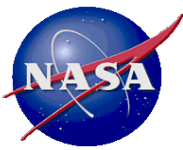


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\$ per Kg (2017\$) Existing Capability & **Planned**

Note: Proton-M and GSLV data point uncertainty high. Minotaur I data point is old, 2013. Pegasus has no announced customers after NASA in 2017. "Planned" data points are from specific company statements, but Stratolaunch, ULA/Vulcan and Angara A5 data points are derived, from less specific company statements. Falcon Heavy Gov't is estimated based on Falcon 9 Gov't price percentages above private sector price.



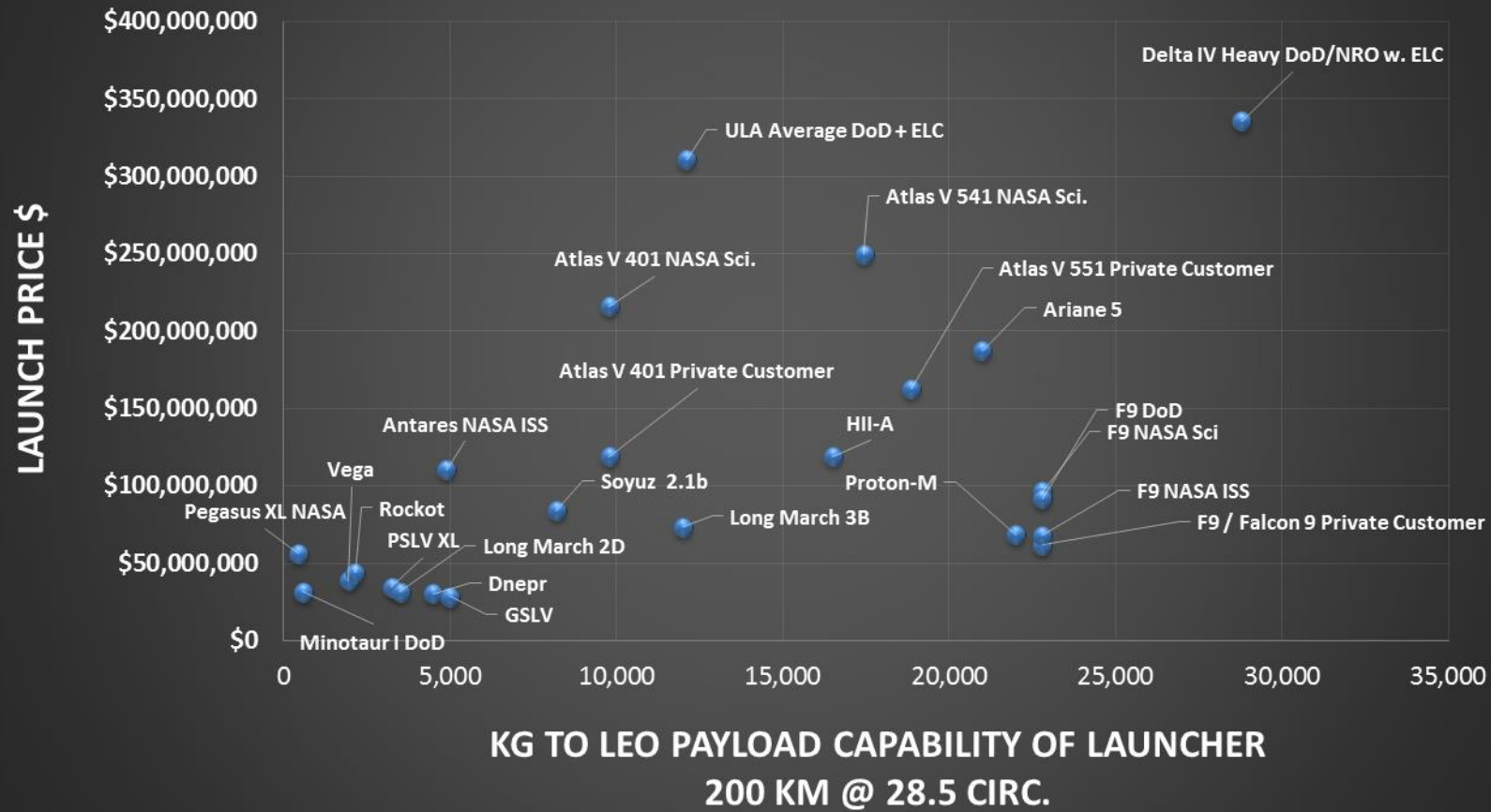


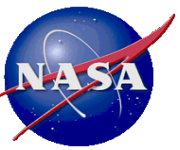
Global Views



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Launch Prices Existing Capabilities (2017 \$)

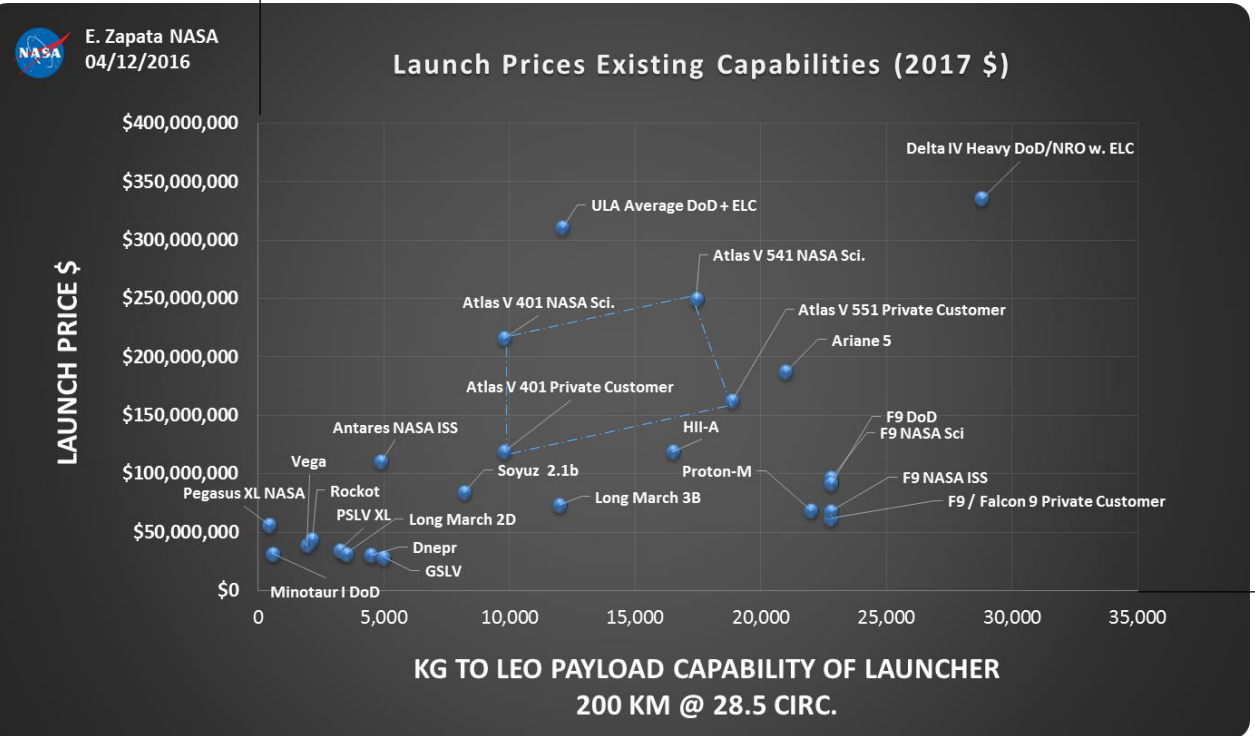




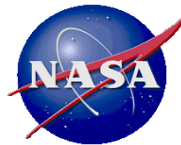
Global Views

SLS (procurement \$ only, no upper stage, + a percent of ground ops \$, no flight ops \$, IF 2 flights per year)
 70,000kg->LEO
 \$1,094,000,000 per Launch
 (Add EUS upper stage costs for more capability to ~105t)

Falcon Heavy
 63,800 kg->LEO
 \$90,000,000 Price to Private Customer



\$1,000,000,000



Note!

Launch Systems – Multiple Measures – Especially kg per Year

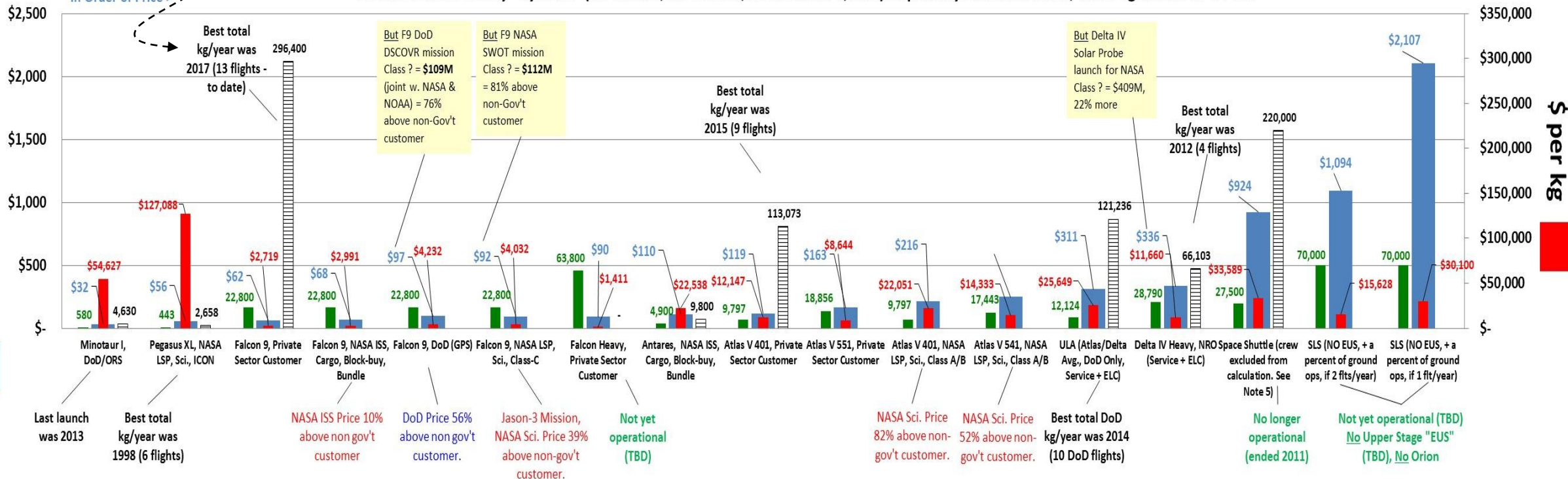


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- Cost of Entry = Price of the Specific Launcher for that Customer / Application
- Maximum Payload Capability of Launcher, kg to LEO, 200km/28.5 circ. (regardless of actual kg used by customer)
- \$ per kg
- ▤ Best Recent Yearly "System" (All Atlas's, All Delta's, All Falcon 9's, etc.) Capability Demonstrated, Total kg to LEO in a Year

Minimum Cost of Entry \$ M

RECENT DATA 2008 to date in 2017\$
In Order of Price >



Trying to estimate a launch price, the cost of a launch for NASA or DoD? Ask the following, then see which data point above is most similar.

1. Who is procuring the launch?
The NASA Launch Services Program? The NASA ISS Transportation Office (Cargo)? The NASA ISS Commercial Crew Office? The DoD / Air Force? The DoD / Air Force for the National Reconnaissance Office (NRO)? A private sector customer?
2. How is the launch procured? As a block of launches, or as a single award unrelated to others? As a service (like cargo to the ISS)?
3. With what other items is the launcher being procured alongside, such as a spacecraft (Cygnus, Dragon)?
4. What is being launched? Is the launch for simpler cargo, repetitive and similar, or more complex, irreplaceable, unique? Or is it for crew?

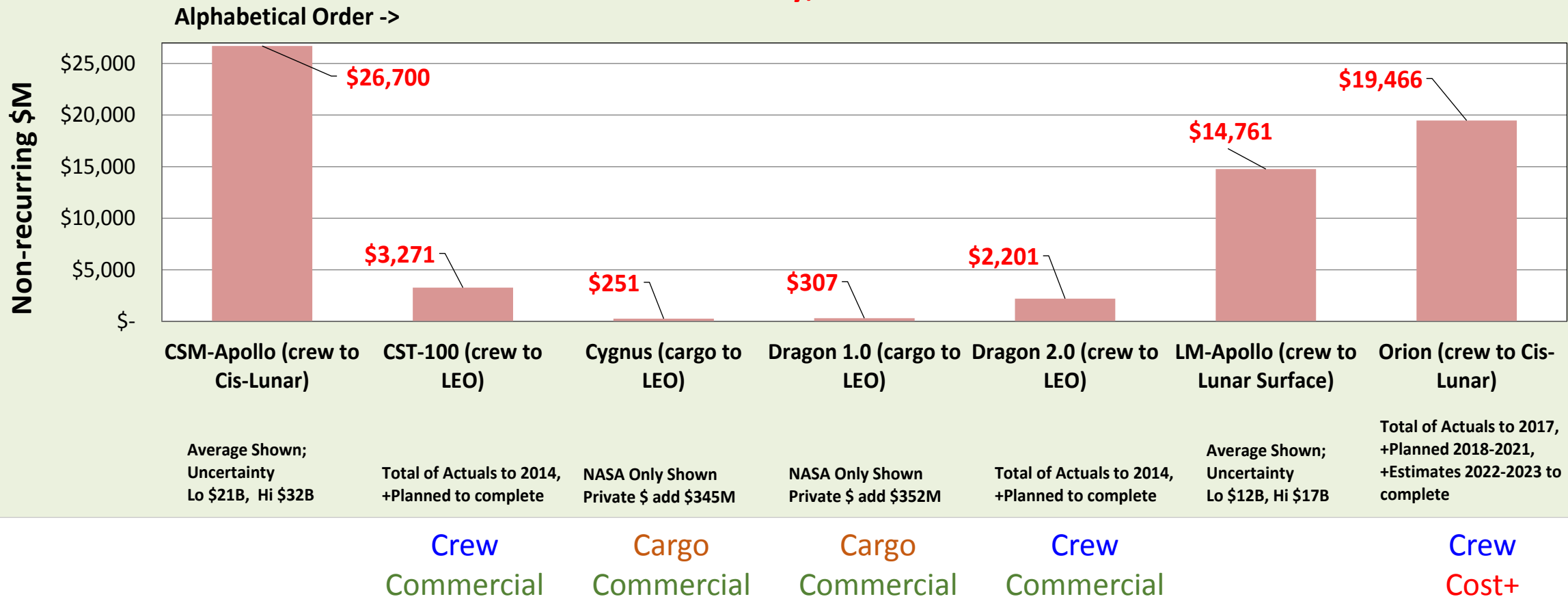


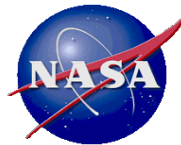
Spacecraft Costs – Development

(Costs = Price to NASA)

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6/2/2017

Spacecraft Non-recurring NASA Development,
Procurement Only, \$M 2017\$





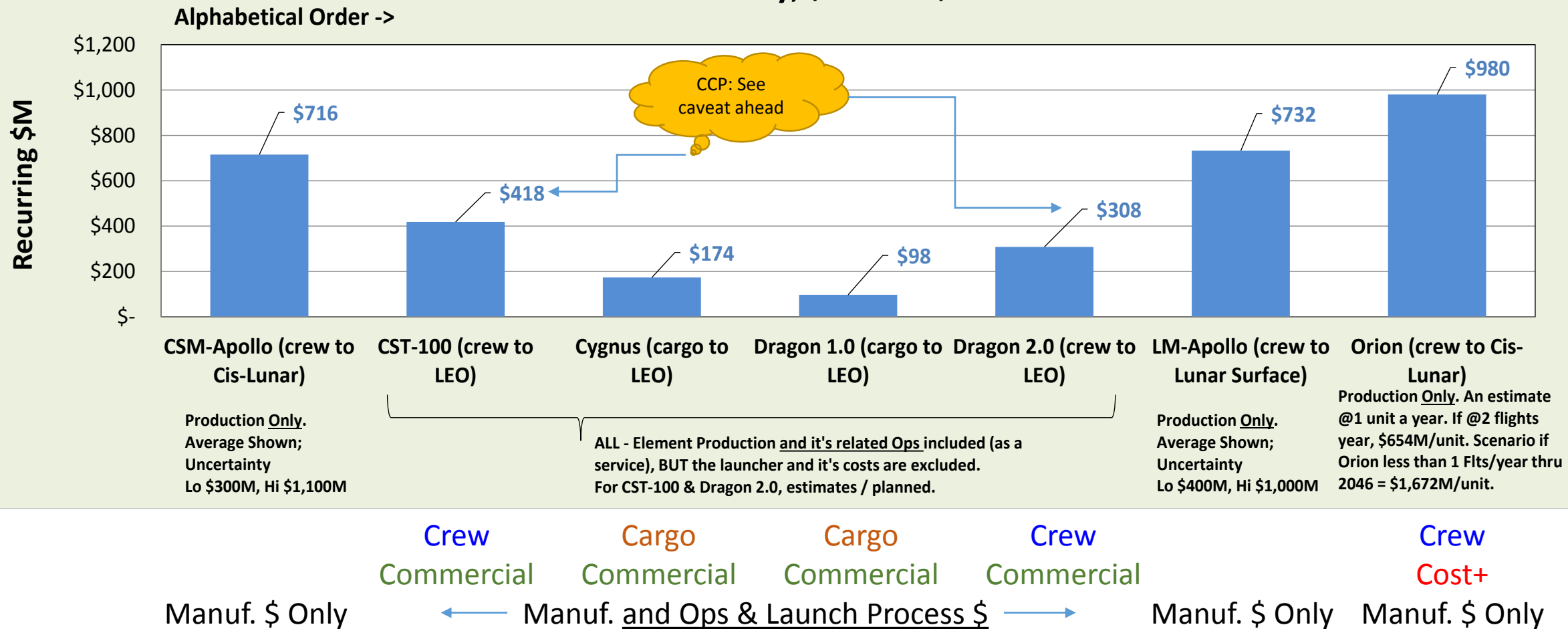
Spacecraft Costs – Per Unit – \$ Thru Delivery Point as Indicated

(Costs = Price to NASA)



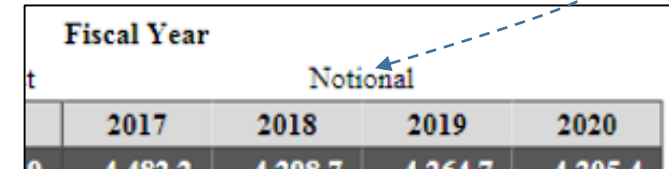
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5/8/2017

Spacecraft Recurring Price to NASA per Unit, Procurement Only, \$M 2017\$



Uncertainties, Programs Still in Development

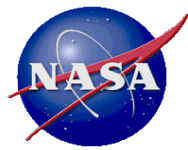
- Future budgets in public documents are often “notional”
 - They may go UP or DOWN
- Example
 - Prior Commercial Crew Recurring Price (by 2020) is based heavily (with adjustments) on FY 16 notional public budget
 - https://www.nasa.gov/sites/default/files/atoms/files/fy2016_budget_book_508_tagged_0.pdf
 - The FY 18 notional public budgets are much **LOWER** by 2020 (operational)
 - https://www.nasa.gov/sites/default/files/atoms/files/fy_2018_budget_estimates.pdf
- Other programs show **INCREASES** in 2018 notional public budget out to 2020 (development) vs. prior years



Fiscal Year	2017	2018	2019	2020
t				

Cost data updates are a continuous process

especially until programs complete development and regular operations begin

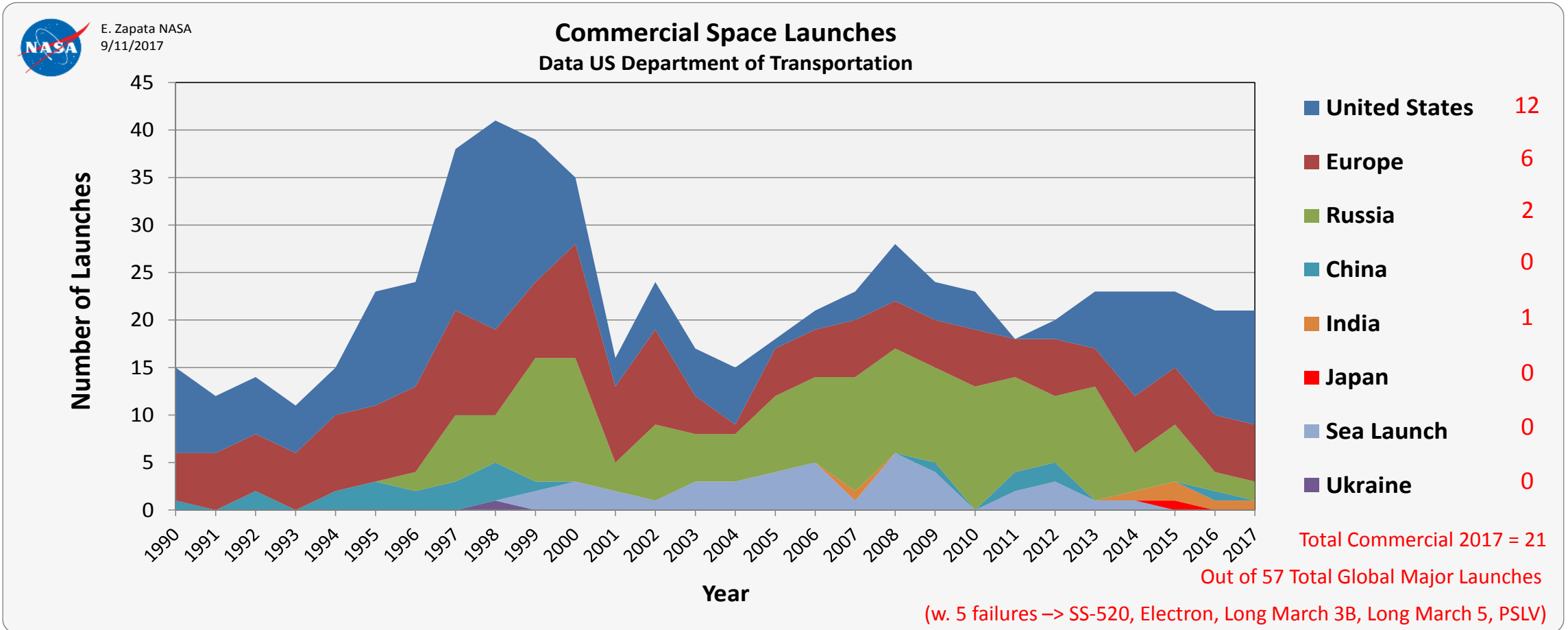


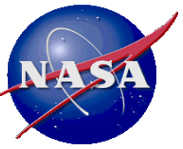
Competitiveness

Commercial launch data through 2014 from US DOT <http://www.rita.dot.gov/bts/node/490911>

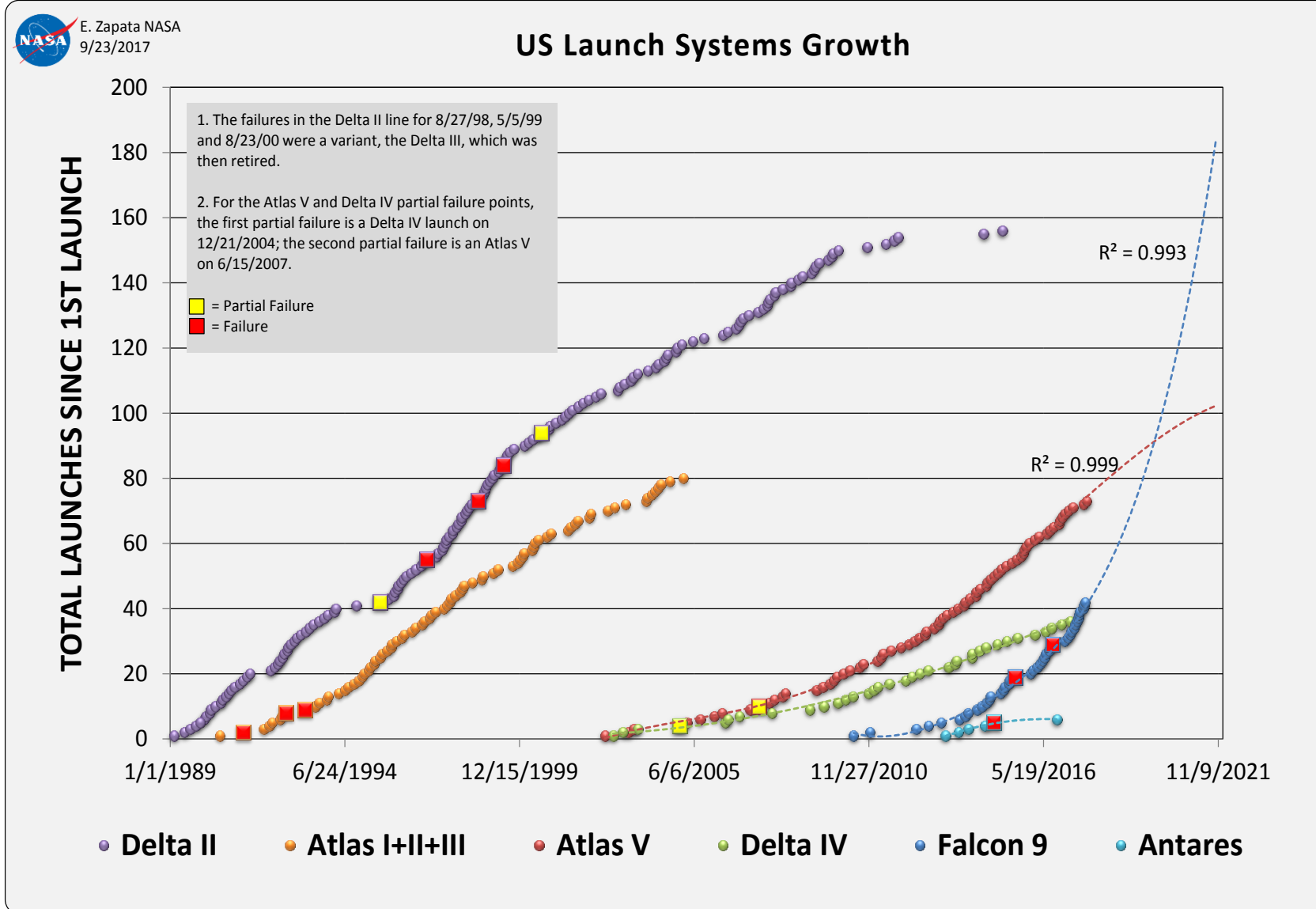
2015 -2017 data from assorted sources

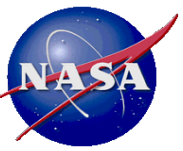
Total global major launch count and failures from <http://www.spacelaunchreport.com/log2017.html#stats>





Growth



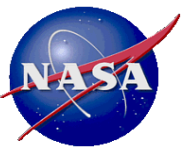


Closing

- Space is hard
- Adding up space system costs, budgets, flights, payload capabilities, etc. – not hard, just tedious
 - Define competitiveness, compare systems, understand cost vs. productivity
 - Establish facts on the ground
- **Value: situational awareness**
 - **Where are we?**
 - **Where might we go?**

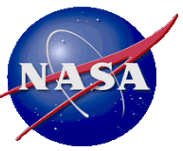
Questions?

Backup



Data Sources, Small Payload Launch Options, Small Launch in Development, Other (see slides 6-7)

- As of 12/07/2015 - NanoRacks - “Commercial payloads start at \$60,000 per 1U” + volume discounts, to 50kg as advertised @ <http://nanoracks.com/resources/faq/>
 - 3U \$295,000, 6U \$545,000, 12U \$995,000, 50kg \$1,750,000, 100kg \$3,950,000, 200kg \$5,950,000, 300kg \$7,950,000 as advertised @ <http://www.spaceflightindustries.com/schedule-pricing/>
- SpaceX - secondary payload “PPOD” to LEO \$200,000-\$325,000 (=\$67,000-\$108,000/kg; from Aug. 2012, 26th Annual AIAA USU, Conference on Small Satellites)
- SpaceX – secondary payload, ESPA-class satellite weighing up to 180 kilograms would cost \$4–5 million for LEO; from August 2012, 26th Annual AIAA USU, Conference on Small Satellites (=\$22,000 to \$28,000/kg)
- As of 09/14/2015 – Virgin / Launcher One - **In development** - 400kg to LEO for \$10M (=\$25,000/kg) per <http://www.parabolicarc.com/2015/09/14/virgin-galactic-announces-capable-launcherone/>
- As of 08/10/2015 - Rocket Lab - **In development** - 100kg to LEO for \$4.9M (=\$49,000/kg) per <http://www.geekwire.com/2015/reserve-a-launch-for-your-satellite-online-rocket-lab-can-make-it-so/> albeit to a 310 mile high orbit, implying performance to LEO 200nm is more, so the “ ”
- As of 06/05/2015 - Generation Orbit - **In development** – 40kg to LEO for \$2.5M (=\$62,500/kg) per <http://www.satellitetoday.com/launch/2015/06/05/generation-orbit-gains-golauncher2-commitments-plans-golauncher-3/>
- As of 07/08/2016 – Stratolaunch / Vulcan Aerospace – **In development** – No public price statements by the company. Some early payload performance statements (6,100kg to LEO) that have since been overtaken by events. https://en.wikipedia.org/wiki/Stratolaunch_Systems



Misc.

Ariane 6 in the news:

July 2, 2014

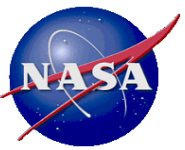
Airbus Defends Springing Last-minute Ariane 6 Design on ESA

“PARIS — The head of Airbus’ space division on July 1 said his company was forced to come up with an Ariane 6 rocket design that competed with the version approved by the European and French space agencies **because the agency version ultimately would have decimated Europe’s rocket industry.**

Testifying before the French Senate Committee on Foreign Affairs, Defense and Armed Forces, Francois Auque said the solid-fuel-dominated Ariane 6 design that the European Space Agency and the French space agency, CNES, approved in July 2013 would have attracted mainly European government customers — a market whose size would mean reducing Europe’s rocket design and production industry by two-thirds.

To avoid being decimated, he said, European rocket builders needed to be sure that the commercial market, which accounts for 90 percent of the launches of Europe’s current heavy-lift Ariane 5 vehicle, would support the new vehicle.”

<http://www.spacenews.com/article/launch-report/41117airbus-defends-springing-last-minute-ariane-6-design-on-esa>



Misc.

Delta IV Cost (Price) to NASA:

March 18, 2015

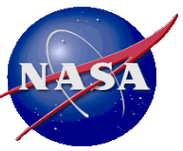
Delta 4-Heavy Selected for Launch of Solar Probe

“As expected, NASA announced its selection of the United Launch Alliance Delta 4-Heavy rocket to dispatch the Solar Probe Plus mission from Earth. Liftoff from Cape Canaveral is set for July 31, 2018, at the opening of a 20-day launch window, NASA said in a press release.

...

The launch contract’s value is \$389.1 million, according to NASA.”

<http://spaceflightnow.com/2015/03/18/delta-4-heavy-selected-for-launch-of-solar-probe/>



Misc.

Falcon 9 Cost (Price) to NASA:

November 22, 2016

NASA Selects Launch Services for Global Surface Water Survey Mission

“NASA has selected Space Exploration Technologies (SpaceX) of Hawthorne, California, to provide launch services for the agency’s Surface Water and Ocean Topography ([SWOT](#)) mission. Launch is targeted for April 2021 on a SpaceX Falcon 9 rocket from Space Launch Complex 4E at Vandenberg Air Force Base in California.

The total cost for NASA to launch SWOT is approximately \$112 million.”

<https://www.nasa.gov/press-release/nasa-selects-launch-services-for-global-surface-water-survey-mission>