Humans to the Moon & Mars: Private Industry

Neesha R. Schnepf
Parker Hinton
Brian Claytor
Kya Sorli

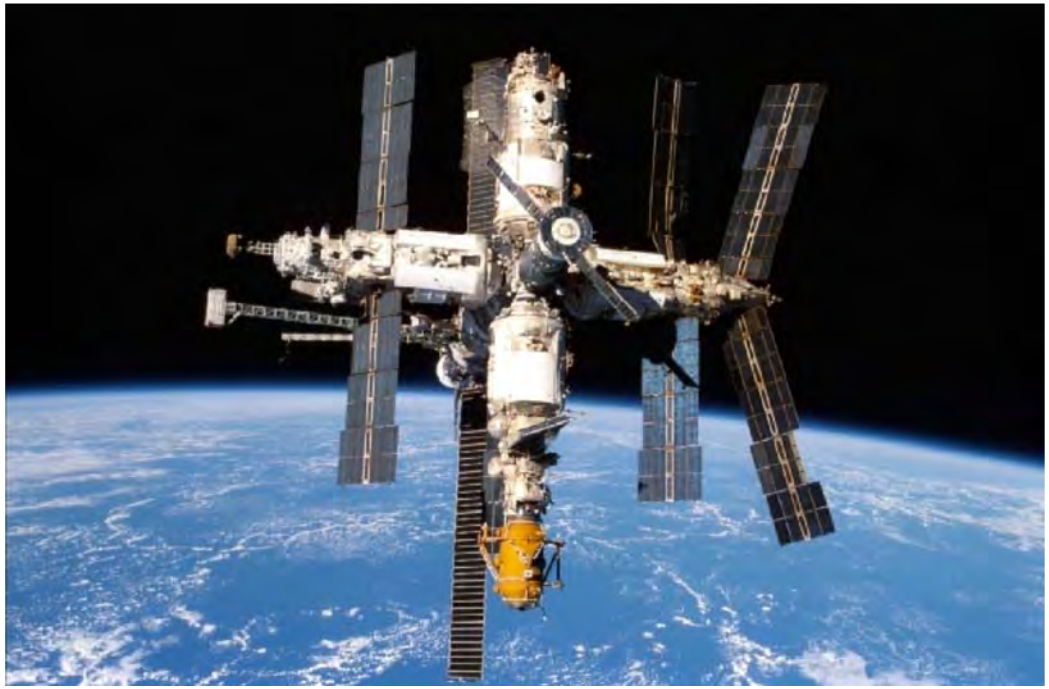
Historical context

Humans in space starts with USA vs USSR

- Soviet Space Agency (now Roscosmos) founded on July 22, 1951
- National Aeronautics and Space Administration (NASA) founded on October 1, 1958
- Yuri Gagarin (USSR)-- 1st man to enter space on April 12, 1961
    - Alan Shepard (NASA) becomes 2nd on May 5, 1961
- Valentina Tereshkova (USSR)-- 1st woman to enter space on June 16, 1963
    - Svetlana Savitskaya (USSR)-- 2nd woman to enter space in 1982. On July 25, 1984 became 1st woman to go to space 2x and the 1st woman to do an EVA
    - Sally Ride (USA)-- 3rd woman to enter space in 1983. 1st known LGBTQ person in space (BUT: she was closeted her entire career. Came out in 2012, when her obituary acknowledged her partner of 27 years).

Humans in space starts with USA vs USSR

- USSR did the first spacewalks, first photos of Moon's surface, first space station
- Apollo program ended in 1975, US focus shifted to primarily robotic exploration
- Russia continued focusing on human spaceflight: Mir space station (1986-2001)



Space agencies with human spaceflight capability

Agency	Acronym	Founding date	Accomplishments
Russian Federal Space Agency	Roscosmos	July 22, 1951	• Human space launch • Human spaceflight • Spacewalk • Rendezvous & docking • Operates a space station
National Aeronautics and Space Administration	NASA	October 1, 1958	
China National Space Administration	CNSA	April 22, 1993	

https://en.wikipedia.org/wiki/List_of_government_space_agencies

Space agencies with lunar landing capability

Agency	Founding date	Accomplishments
Roscosmos	July 22, 1951	• Controlled impact w/ Lunar surface • Uncrewed soft landing • Uncrewed lunar rover • Automated lunar sample return mission
NASA	October 1, 1958	• Crewed circumlunar spaceflight • Controlled impact w/ Lunar surface • Uncrewed soft landing • Crewed Moon landing and sample return
CNSA	April 22, 1993	• Controlled impact w/ Lunar surface • Uncrewed soft landing • Uncrewed lunar rover
Indian Space Research Org.	August 15, 1969	• Controlled impact w/ Lunar surface

https://en.wikipedia.org/wiki/List_of_government_space_agencies

Companies contracted by NASA for historical missions

Mission	Start	End	Private Companies
Mercury (1st crewed mission)	1959	1963	North American Aviation; Western Electric Company; Chrysler Corp.; Convair; McDonnell Aircraft Corp.
Gemini (1st rendezvous & EVA)	1963	1966	
Apollo (1st men on Moon)	1961	1972	General Dynamics/Convair; Boeing; Rocketdyne Div. of North Americ. Aviation; Douglas Aircraft Corp; IBM; General Electric; Glenn L. Martin Company (now Lockheed Martin Corp.); Grumman Aerospace Corp. (now Northrop Grumman Corp.)
Skylab (1st USA space station)	1973	1974	Douglas Aircraft Corp; Grumman Aerospace Corp. (now Northrop Grumman Corp.); McDonnell Aircraft Corp.; Martin Marietta Corp. (now Lockheed Martin Corp.)
Space Shuttle	1981	2011	Boeing; Northrop Grumman Corp.; Lockheed Martin; Rocketdyne

3 main companies for humans in space

Blue Origin [since 2000]

- Jeff Bezos (Founder; net worth of $108 billion)
- Steve Squyres (chief scientist)
- More than 2k employees
- Funded by $1 billion/year in Bezos' Amazon equity sales
- Profit plan
  - Launches
  - Space tourism

SpaceX [since 2002]

- Elon Musk (CEO & Founder; net worth of $20 billion)
- 2012: became 1st commercial company to dock a spacecraft at the ISS
- More than 6k employees
- Profit plan
  - Launches
  - Space tourism

Virgin Galactic [since 2004]

- Richard Branson (Chair & Founder; net worth of $3.8 billion)
- Profit plan
  - Space tourism
  - Space travel for expedited Earth travel

"The Apollo program costs $20 billion in 1970s dollars—the equivalent of $100 billion in today's money. " -- Lafleur, 2010 (http://www.thespacereview.com/article/1579/1)

There are many other private companies tackling challenges to get humans in space...

...now for what these companies are working on.

Company Projects

Launch Vehicles

	Stages	Purpose	Thrust (kN)	Height (m)	First Launch	Progress
Blue Origin New Shepard	1	Payloads + Crew (suborbital)	489	18	29 Apr 2015	10/11 full mission success
Blue Origin New Glenn	2	Payloads + Crew (orbital & beyond)	18,200	89	Projected 2021	In Development
SpaceX Falcon 9	2	Payloads (orbital)	8541	70	4 Jun 2010	75/77 full mission success
SpaceX Falcon Heavy	2 + 2 boosters	Payloads (orbital & beyond)	23,753	70	6 Feb 2018	3 successful flights (3 booster landings, 1 core landing)
SpaceX Super Heavy	2	Payloads + Crew (orbital & beyond)	72,000	118	Projected 2020	In Development

LV Size Comparison

Saturn V

- 34,000 kN thrust
- 111m tall

SpaceX Falcon Heavy can produce ~70% thrust of Saturn V

Blue Origin New Glenn will produce ~54% thrust of Saturn V

Crew Modules/Spacecraft - SpaceX

Dragon

- Cargo to ISS (and eventually humans)
- ISS payload capacity: 6000kg
- Payload volume: 10m^3 pressurized, 37m^3 unpressurized
- **1st flight:** 8 Dec 2010; docked with ISS
- **1st cargo delivery:** 25 May 2012
- 17/18 successful missions
- Reusable! One capsule has flown 3 times, and 6 others have flown twice

Crew Modules/Spacecraft - SpaceX

Starship

- Payloads & crew for orbital and lunar/planetary missions
- Will launch on the Super Heavy rocket
- 50m tall
- 1100 m^3 payload volume
- Designed to carry 100,000kg to Earth orbit, or
  100 people to Mars

Crew Modules/Spacecraft - Blue Origin

New Shepard Capsule

- Suborbital payloads (and eventually humans)
- Suborbital payload capacity: ~a few hundreds of kg's
- Payload volume: 15m^3 pressurized
- Designed to carry crew + microgravity, atmospheric, and space research payloads
- Can achieve ~3 minutes of microgravity conditions

Crew Modules/Spacecraft - Boeing

CST-100 Starliner

- Cargo and crew to LEO
- LEO payload capacity: 13,000kg
- Payload volume: 11m^3 pressurized
- **Projected tests:**
  - Pad abort test on 4 Nov
  - If successful, uncrewed to ISS on 17 Dec
  - Planned crewed test in 2020

Crew Modules/Spacecraft - Sierra Nevada

Dream Chaser

- Reusable spaceplane, like a smaller version of Space Shuttle
- 2 versions: crewed and cargo
- Up to 7 crew
- ISS payload capacity: 5500kg
- Will provide at least 6 ISS cargo missions starting in 2021

Crew Modules/Spacecraft - Virgin Galactic

SpaceShipTwo

- Suborbital spaceplane for space tourism and microgravity research
- Lifted to altitude by cargo plane, then released and powered by rocket engine
- Will carry up to 6 passengers and 2 pilots
- Payload volume: 14m^3 pressurized
- **1st flight to space:** 13 Dec 2018
- **Since then:** 1 other successful flight

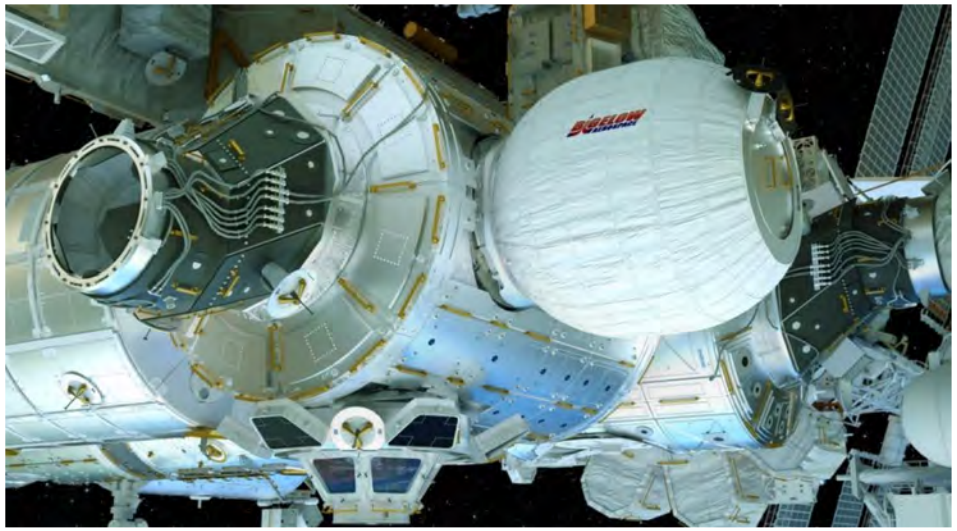
Crew Modules/Spacecraft Overview

	Type	Purpose	Volume (m^3)	# of Crew	First Spaceflight	Progress
SpaceX Dragon	Capsule	Cargo for ISS (eventually crew)	47	7	8 Dec 2010	17/18 full mission success
SpaceX Starship	Spacecraft	Payloads + crew for orbital & planetary missions	1100	100	Projected 2021	In Development
Blue Origin New Shepard	Capsule	Suborbital payloads, space tourism	15	6	29 Apr 2015	10/11 full mission success
Boeing CST-100 Starliner	Capsule	Payloads + crew to LEO	11	7	Projected 4 Nov 2019	In Development
Sierra Nevada Dream Chaser	Spaceplane	Payloads + Crew to ISS	??	7	Projected 2021	In Development
Virgin Galactic SpaceShipTwo	Spaceplane	Space tourism	14	8	13 Dec 2018	2 successful flights...1 person killed in test flight

Space Habitats - Bigelow Aerospace

Bigelow Expandable Activity Module (BEAM)

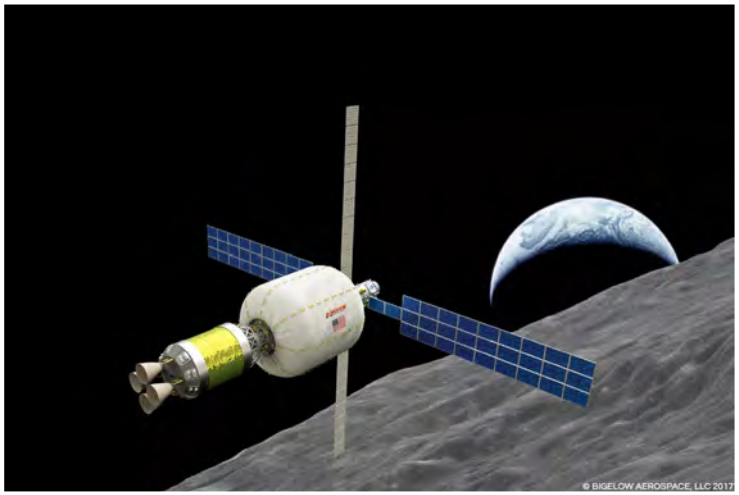
- Inflatable habitat module built for ISS
- Expands from 1.4 to 16m^3
- **Launched:** 8 Apr 2016
- **Successfully expanded:** 28 May 2016
- Currently used as cargo storage



Space Habitats - Bigelow Aerospace

B330

- Fully autonomous space station for research and space tourism
- Currently being developed
- Designed to house 6 crew
- Internal volume: 330m^3



Tourism

Tourism

- Sci-fi favorite, but minimal development at this point
- 3 broad categories:
  - Orbital, suborbital and lunar
- To date, only space tourism via Russian Space Agency and Russian Company Space Adventures
  - 2001-2009: 7 high profile tourists sent to ISS for 10 days
    - 20+ million per trip
- None since 2010
- Waking back up….
  - FAA forecasts space tourism could be billion Dollar market within 20 years (2010)

Dennis Tito, first Space Tourist and American Multimillionaire

Power Players and Setbacks

- **NASA:**
  - 2022: Starting to allow private astronauts to ISS (~$59 million)
- **Virgin Galactic**
  - Expected to start doing suborbital flights in 2019
  - Reusable spaceplane, 3-6 minutes weightlessness (~$200,000)
  - Destruction of "Galactic" spaceplane → major setback
- **Blue Origin**
  - Working on reusable, suborbital tourism flight vehicles
- **SpaceX**
  - Plans to send two space tourists around the moon

Power Players and Setbacks

- Orion Span
  - Aurora Station “luxury hotel”
  - Scheduled in 2021
  - January 2019:
    - ~$217,000 raised so expect delays
- Unforgiving industry
  - Corporate graveyard
  - Riddled with canceled projected, sold off ideas

Legal Issues

Legal Concerns

What are the big questions for space law?

- Who owns space?
  - Moon, natural resources
- Who is liable for damages incurred from launches, industry, etc?
- Who oversees environmental and human rights restrictions in space?
- Who resolves disputes?

Legal Precedent: Two Keystone Treaties

1) UN Outer Space Treaty of 1967
    a) Article I: Guarantees freedom of space exploration for all mankind
    b) Article II: "Outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means"
        i) Countries can freely explore the Moon
        ii) Resources collected are property of that country when they return
    c) Article III: Space activities must be performed in accordance with international law
    d) Launch operator's nationality and location of launch site determines who's responsible for damages

Notice no mention of corporations!

1) Moon Treaty (1984)
    a) Countries must create international laws to regulate space activities
    b) Outer space is the "common heritage of mankind"
    c) NOT SIGNED by the space faring countries

What About the USA?

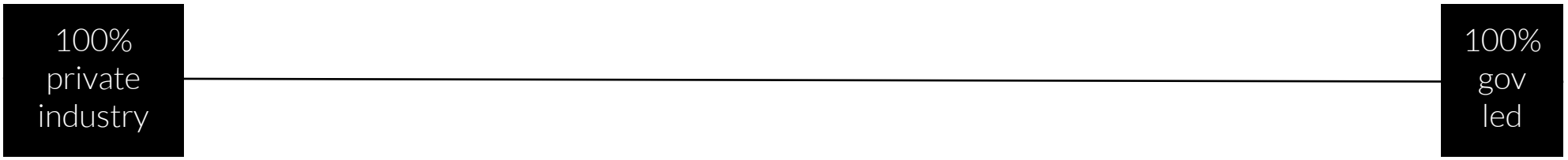
- 2015 **Commercial Space Launch Competitiveness Act**
  - Big Takeaways
    - US citizens may "engage in the commercial exploration and exploitation of 'space resources' [including ... water and minerals]."
      - Biological life may not be exploited commercially
    - Commercial enterprises are subject to authorization and continuing supervision by US government
    - Reiterates that USA does not own any celestial body
      - Some experts disagree

- 2018 House passed the **American Space Commerce Free Enterprise Act**
  - Non-government US enterprises do not have the same obligations as the United States under the Outer Space Treaty

Resource Mining

Discussion

PROS



CONS

Backups!

Launch Vehicles - Blue Origin

New Shepard

- Suborbital payload & crew launches
- Reusable capsule and booster
- 489 kN (110,000 lbf) thrust
  - 1 BE-3 engine
- 18 meters tall
- **1st flight:** 29 Apr 2015
  - Successful launch and capsule recovery
  - Booster crashed
- **Since then**: 10 successful launches & landings
- Has delivered 46 payloads

Launch Vehicles - Blue Origin

New Glenn

- Payloads & crew to Earth orbit and beyond
- Reusable 1st stage, minimum of 25 missions
- 18,200 kN (4,090,000 lbf) total thrust
  - 1st stage: 7 BE-4 engines
  - 2nd stage: 2 BE-3U engines
- 82m tall with 7m payload fairing
- **Projected flight in 2021**

Launch Vehicles - SpaceX

Falcon 9

- Payloads to Earth orbit
- 2 stages, reusable 1st stage
- 8541 kN (1,920,000 lbf) total thrust
  - 1st stage: 9 Merlin engines
  - 2nd stage: 1 Merlin engine
- 70m tall (including payload fairing)
- **1st flight:** 4 June 2010
- **1st successful 1st-stage ground landing:** 22 Dec 2015
- Regularly launches payloads into orbit and supplies cargo to ISS
- 75/77 full mission successes

Launch Vehicles - SpaceX

Falcon Heavy

- (A Falcon 9 rocket with 2 additional 1st stage boosters)
  - Most powerful active LV, 3rd-most powerful ever
- Payloads to Earth orbit and beyond
- 23,753 kN (5,340,000 lbf) total thrust
- **1st flight:** 6 Feb 2018
  - Successful launch and booster landing
  - Unsuccessful core landing
- **Since then:** 2 successful flights (1 successful core landing)

Private Industry

Mining Resources

This is the topic of next weeks presentation, so I'll focus on the private industry aspects.

Quick Theory

- During gravitational formation, Earth's metals sink towards the core
- The result is a near depletion of metals in the crust
- Much of what we have in the crust today may have been delivered by asteroids.
- "most of the precious metals on which our economies and many key industrial processes are based have been added to our planet by … about 20 billion billion tonnes of asteroidal material." [1]

So there's money to be made…

Ranked according to "cost-effective":

Name	Type	a (AU)	e	Value ($)
Ryugu	Cg	1.190	0.190	82.76 billion
1989 ML	X	1.272	0.137	13.94 billion
Nereus	Xe	1.489	0.360	4.71 billion
Bennu	B	1.126	0.204	669.96 million
Didymos	Xk	1.644	0.384	62.25 billion
2011 UW158	Xc	1.621	0.376	6.69 billion
Anteros	L	1.430	0.256	5.57 trillion

Source Asterank.com

Profit??

No existing infrastructure or technically feasible plan for harvesting these resources.

Several organizations have said they are working on asteroid mining, including:

Organisation	Type
Planetoid Mines Company	Pri…pany
NEO Resource Atlas (NEORA)	…ny
Deep Space Industries	
Planetary Resources	
Moon Express	
Kleos Space	…ompany
TransAstra	Private company
Aten Engineering	Pri
Air Space and Beyond (ASB)	Pri
OffWorld	Pri
Asteroid Mining Corporation Ltd. UK[56]	Pri

Vaguer y

Fluffery

My **subjective** picture after visiting websites…

Lab & Earth testing tech (tur…ing sea water to rocket fuel)

Unclear what product / goa… …nposition techniques.

Recently acquired by Bra… …er

Potentially gone under? Dated inside… …e

No news for over a year, website vague goals of lu… …sample return by 2(

No news for over a year, website vague goals of lunar sample return by 2(

Seems to have good tech ideas – unclear if any progress has or will ever …theme), no clear plans..

…osition

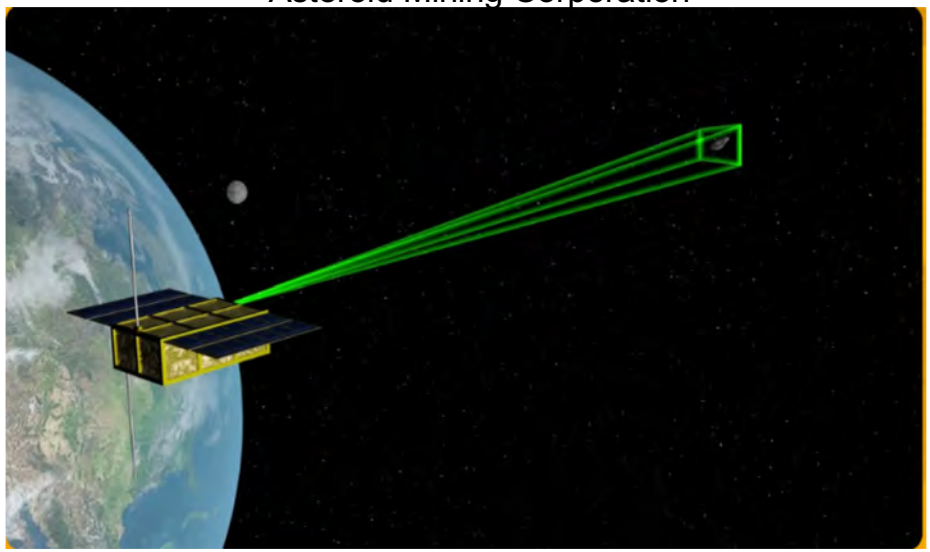
Bologna

Current Status (Planetary Resources & Asteroid Mining Corporation)

- Building / launching cubesats with spectrometers to determine asteroid composition

- Profit potential ? (Make this data proprietary)

Asteroid Prospecting Satellite One (APS-1)
Asteroid Mining Corporation



"APS-1 will conduct a spectral survey of 5000 NEAs in order to identify which are the most viable candidates for mining"

Conclusion

There's not a whole lot going on as far as private industry and extra-terrestrial resource mining. There are tech and knowledge gaps, and of the companies doing something useful, they're trying to fill those gaps.

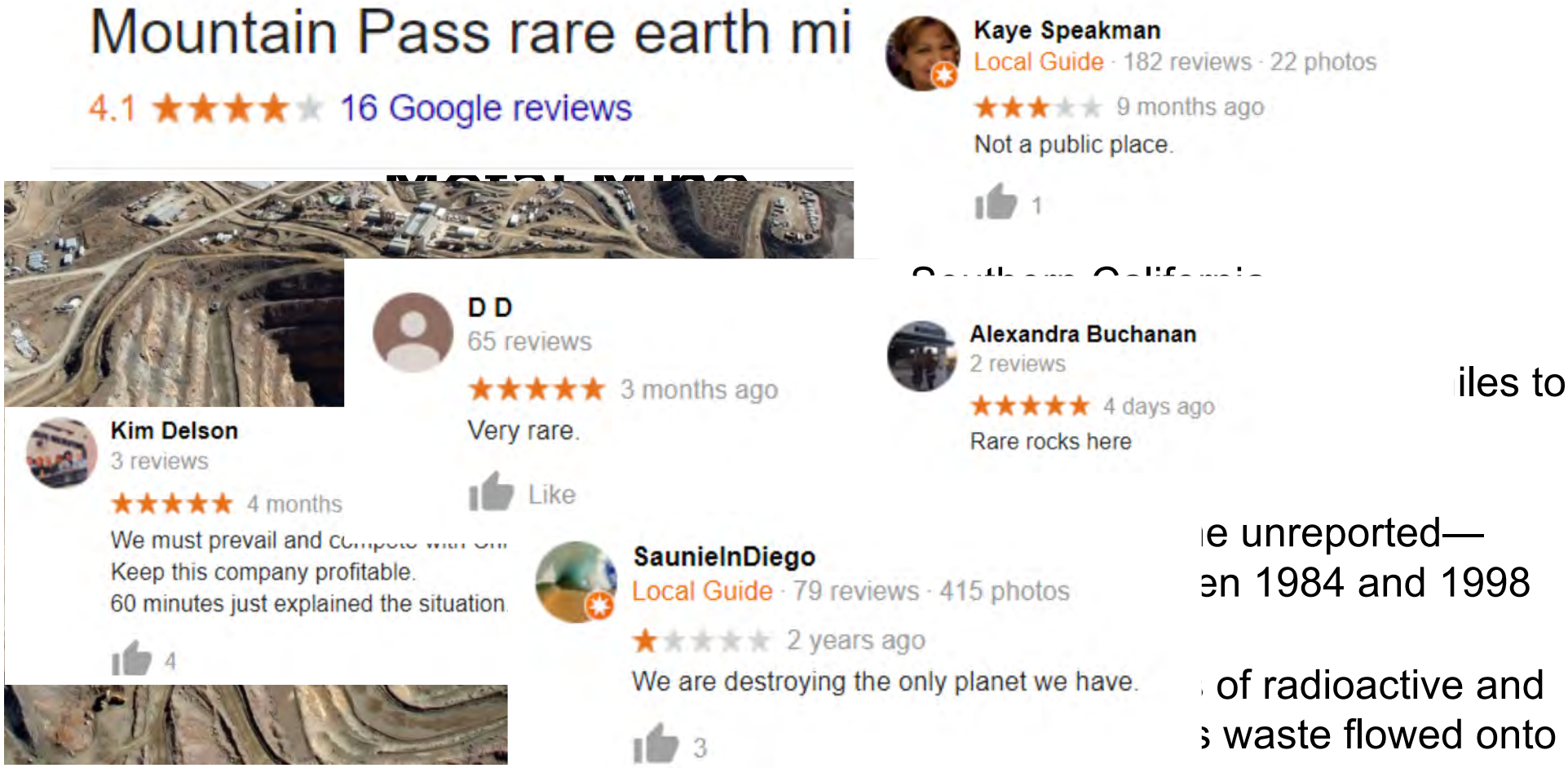
POPPYCOCK! for now

So there's not much of a real extra-terrestrial mining industry, should there be?

"**Humanity has been mining Earth deposits for decades in order to extract tiny amounts of economically valuable metals and thereby, producing huge natural devastations of our planet. Recently, asteroids have grabbed our attention since they** are fascinating objects carrying the hints of Solar System origin and, at the same time, **containing large amounts of valuable resources**"

So perhaps asteroid mining is an ethical goal to work towar

from book Assessment and Mitigation of Asteroid Impact Hazards (pp.73-101)



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Mining Ethical Questions

- If we can mine from asteroids instead of the earth, should we?

- Should the asteroids, moon, and mars be free game, or belong to anyone in particular?

- Should government or private industry lead these mining efforts were they to happen?

Government enabling private industry seems to be a new theme…

NASA Strategic Plan 2018

- Strategic Objective 2.1: Lay the Foundation for America to Maintain a Constant Human Presence in Low Earth Orbit Enabled by a Commercial Market.

- “Enable space-based low Earth orbit economy by transitioning ISS operations and maintenance to commercial and international partners”

- Should the government pay private industry to do government work?

NASA 2020 Budget Request

Budget Authority ($ in Millions)	Fiscal Year 2018	2019	2020	2021	2022	2023	2024
Deep Space Exploration Systems	$4,790.0	$5,050.8	$5,021.7	$5,295.5	$5,481.4	$6,639.0	$7,042.3
Exploration Systems Development	$4,395.0	$4,092.8	$3,441.7	$3,441.0	$3,468.4	$3,788.5	$3,654.7
Exploration Research & Development	$395.0	$958.0	$1,580.0	$1,854.5	$2,013.0	$2,850.4	$3,387.6
Exploration Technology	$760.0	$926.9	$1,014.3	$976.1	$995.4	$964.4	$943.1
LEO and Spaceflight Operations	$4,749.2	$4,639.1	$4,285.7	$4,369.5	$4,369.5	$4,235.5	$4,182.3
International Space Station	$1,493.0		$1,458.2	$1,448.5	$1,449.4	$1,352.6	$1,315.7
Space Transportation	$2,345.8		$1,828.6	$1,854.1	$1,814.5	$1,746.2	$1,727.2
Space and Flight Support (SFS)	$910.3		$848.9	$891.9	$905.7	$911.8	$914.5
Commercial LEO Development	$0.0	$40.0	$150.0	$175.0	$200.0	$225.0	$225.0
Science	$6,211.5	$6,905.7	$6,303.7	$6,319.0	$6,319.0	$5,846.5	$5,815.0
Earth Science	$1,921.0	$1,931.0	$1,779.8	$1,785.6	$1,779.7	$1,666.5	$1,674.6
Planetary Science	$2,217.9	$2,758.5	$2,622.1	$2,577.3	$2,629.4	$2,402.4	$2,350.9
Astrophysics	$850.4	$1,191.6	$844.8	$902.4	$965.2	$913.5	$907.7
Heliophysics	$688.5	$720.0	$704.5	$638.6	$769.3	$692.0	$709.8
James Webb Space Telescope (JWST)	$533.7	$304.6	$352.6	$415.1	$175.4	$172.0	$172.0
Aeronautics	$690.0	$725.0	$666.9	$673.6	$680.3	$587.1	$587.0
STEM Engagement	$100.0	$110.0	$0.0	$0.0	$0.0	$0.0	$0.0
Safety, Security, and Mission Services	$2,826.9	$2,755.0	$3,084.6	$3,084.6	$3,084.6	$2,871.6	$2,871.6
Center Management and Operations	$1,983.4		$2,065.0	$2,058.4	$2,052.9	$1,906.0	$1,905.8
Agency Management and Operations	$843.5		$1,019.6	$1,026.2	$1,031.7	$965.6	$965.8
Construction & Envrmtl Compl Restoration	$569.5	$348.2	$600.4	$468.8	$468.8	$468.8	$387.8
Construction of Facilities	$483.1		$517.5	$385.9	$385.9	$385.9	$304.9
Environmental Compliance and Restoration	$86.4		$82.9	$82.9	$82.9	$82.9	$82.9
Inspector General	$39.0	$39.3	$41.7	$42.1	$42.5	$43.0	$43.4
NASA Total	$20,736.1	$21,500.0	$21,019.0	$21,229.2	$21,441.5	$21,655.9	$21,872.5

NASA and Commercial

- NASA has nine companies competing for up to $2.6 billion in lunar transportation contracts. Known as the Commercial Lunar Payload Services program (CLPS), the effort would send small payloads and robots to the moon's surface as early as 2021. [4]

- CLPS contracts are indefinite delivery, indefinite quantity contracts with a cumulative maximum contract value of $2.6 billion during the next 10 years. [Nasa.gov]

- NASA's budget sets aside $363 million specifically to help companies develop "a large lunar lander" to take cargo and astronauts to the moon's surface.

Additional Questions

- Should we maintain a constant human presence in LEO?
- Should the taxpayer be subsidizing this presence?
- Is there something called the NSSP doing everything worth doing already?

References

[1] ‘The tungsten isotopic composition of the Earth’s mantle before the terminal bombardment’ Matthias Willbold, Tim Elliott and Stephen Moorbath *Nature*

[2] The Chemical Sciences and Society Summit (CS3)

[3] NASA strategic plan 2018