STARLINK'S CHILDREN:

OPPORTUNITIES FOR MASSIVE SATELLITE CONSTELLATIONS

KENT NEBERGALL

MACROINVENT.COM

THE TWEETS THAT LAUNCHED TWO DOZEN SLIDES…

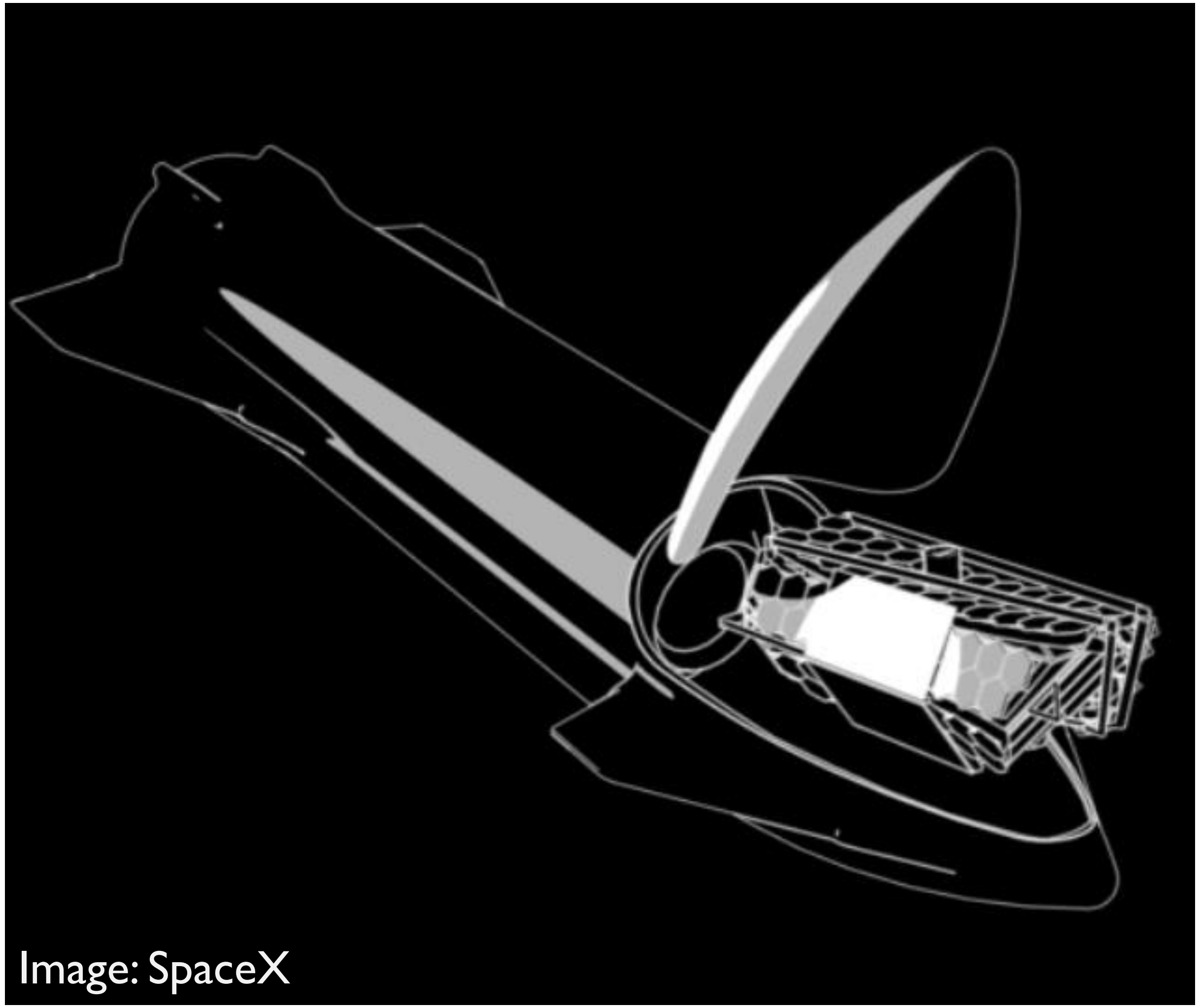


Image: SpaceX

Elon Musk @elonmusk

Replying to @DiscoverMag

We should send probes to outer solar system & get high res, true color images of these strange things. Maybe there's an alien artifact out there …

5:03 PM · Mar 29, 2019 · Twitter for iPhone

434 Retweets **5.9K** Likes

Everyday Astronaut @Erdayastronaut · Mar 29

Replying to @elonmusk and @DiscoverMag

How will Starship do interplanetary probe missions? Will it do an injection burn, release the payload then cancel out the burn and come back? Or just put up a kick stage for the interplanetary injection burn? Like Europa clipper… can StarShip do it?

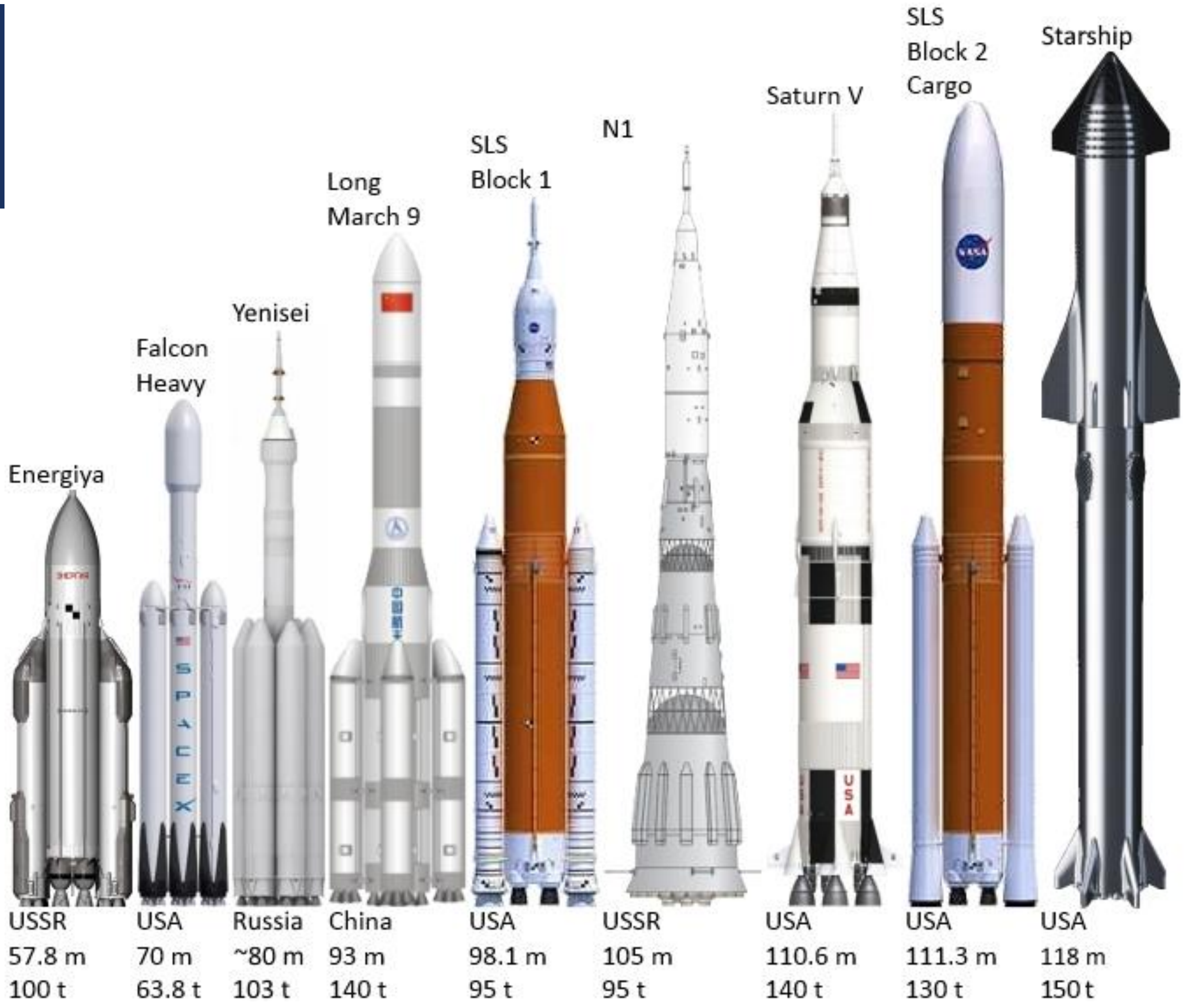
19 26 636

Elon Musk @elonmusk · Mar 29

Massive delta velocity slam from highly elliptical Earth orbit using a fully retanked, but lightened up Starship with no heat shield or fins/legs. Best choice for the impatient. Ion engines are too slow.

EXPENDABLE STARSHIP

System	Orbital	Expendable
Engines	3 Vac, 3 SL	3 Vac only
Heat Shield	Yes	No
Legs	Yes	No
Wings	Yes	No
Canards	Yes	No
RCS	Yes	Yes
Solar Power	Yes	TBD
Refueling	Yes	Yes



THE LOW-LATENCY EARTH

COMMUNICATIONS OBSERVATION INTELLIGENCE

STARLINK DEFINED

- 12,000 Satellites in three orbital shells, with 7500 of them in very low orbit
- Satellites have 5-7 year lifespan
  - 227 kg each (test fleet)
- Completion date expected – 2024 (half), 2027 (all) Estimated cost: $10 billion
- Could carry 50 percent of backhaul internet traffic and 10 percent of local traffic

LOW LATENCY COMMUNICATION: COMPETITIVE SYSTEMS

Sponsor	Name	Fleet	Mass	Altitude	Date	Nation
Google, WorldVu, Airbus, SoftBank, Virgin Group, Qualcomm	OneWeb	648	150 kg	1200 km	2021	UK+USA
Telesat	Telesat	117	?	?	2021	Canada
Amazon	Project Kuiper	3236	?	590-630	?	USA

LOW LATENCY OBSERVATION: OPTICAL SATELLITE SYSTEMS

System	CM/Pixel	Capability	Satellite Size
Planet Labs – Dove	3000 - 5000	12-24 hours per pass	3 U Cubesat, 4 kg 87 satellites
CNES - SPOT	1500	60 x 60 km per image. 26 days to repeat pass.	3.1 by 3.4 by 6 m, 3030 kg 7 satellites
Planet Labs – RapidEye	5000	Multi-spectral push-broom 77 km wide (Bought from BlackBridge, Berlin)	1 cubic meter, 150 kg 5 satellites
Planet Labs – SkySat	900	Multi-spectral, narrow field targeted images 90 second video clips	80 cm cube, 100 kg 6 satellites
Imagesat Int. - EROS B	70	Nighttime imagery available	2.3 by 1.2 m, 290 kg (wet) 1 satellite
CNES - Pleiades	50 – 70	800 km ground strip at 70 cm resolution	1000 kg 2 satellites
NRO - Keyhole	7 - 15	US NRO high end satellites ($billions)	2.4 m mirror. Hubble is 11,110 kg

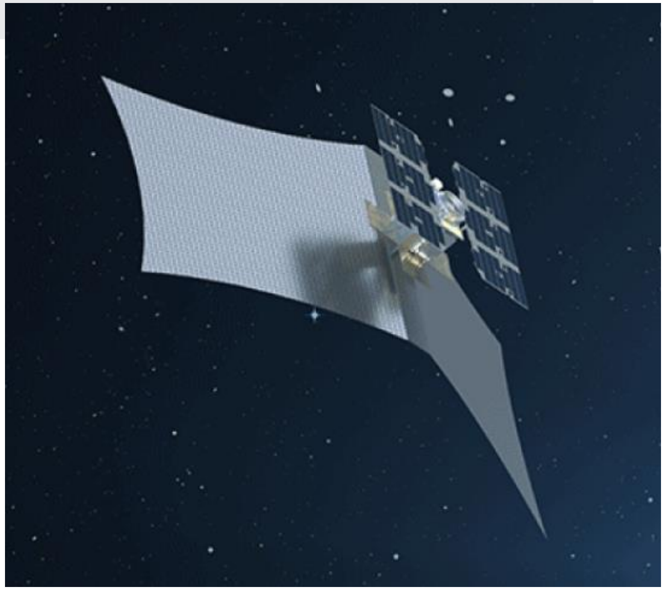
LOW LATENCY OBSERVATION: OPTICAL SATELLITE SYSTEMS – ARE INCOMPARABLE

	Satellite	KG/CM	CC/CM	KG * CM	Res CM
NewSpace	RapidEye	0.0300	200	750,000	5000
NewSpace	**Dove**	0.0013	1	12,000	3000
Commercial	SPOT	2.0200	42,160	4,545,000	1500
NewSpace	**SkySat**	0.1111	569	90,000	900
Commercial	EROS B	4.1429	47,314	20,300	70
Commercial	Pleiades	20.0000	99,000	50,000	50
Military	Keyhole	1,587.1429	33,264,000	77,770	7

RADAR SYSTEMS

Capella Space	36 sats by 2022 40 kg satellites – size of a backpack on launch	• Millimeter-scale changes in surface deformation • Can penetrate surface • Measure soil moisture, crop yields, etc. • Hourly Coverage
Xpress SAR	1-3 meter strips Sub-meter spotlights	

Deep Space Mission	**Capacity**
Radar for Icy Moons Exploration (RIME) as part of Jupiter Icy Moons Explorer (JUICE) mission (ESA-2022)	See 1-9 km through Ganymede, Europa, Callisto. Vertical Resolution 30 m to 1 percent of target depth.
Radar Ice Satellite Explorer (RISE) – Lunar cubesat proposal (NASA-2021)	6U, 10 kg cubesats in a constellation of four satellites. Look for subsurface ice and caverns with ice.



PLANETARY OBSERVATION: RADAR SATELLITE SYSTEMS

Mission	Capacity	Year
Radar for Icy Moons Exploration (RIME) as part of Jupiter Icy Moons Explorer (JUICE) mission	See 1-9 km through Ganymede, Europa, Callisto. Vertical Resolution 30 m to 1 percent of target depth.	2022 Launch, ESA
Radar Ice Satellite Explorer (RISE) – Lunar cubesat proposal	6U, 10 kg cubesats in a constellation of four satellites. Look for subsurface ice and caverns with ice.	NASA – 2021 (Proposed)

MILITARY IMPLICATIONS

Cold War	Ru/Ch Reaction	Reaction
US DEW Line in Canada, Alaska, Greenland can track land-based missile attacks from Russia, China.	Near-orbital missiles that circle over Antarctica and strike southern USA.	Need radar that can track missiles globally well enough to intercept – requires satellites in large constellations
Aircraft Carriers are basically sea bases that can go anywhere. Only US can field 12 of them.	Hypervelocity missiles for anti-ship attacks	Same. Also hypervelocity counter-weapons.
Heavy, expensive spy satellites with infrequent, predictable coverage.	ASAT systems that can target these systems for a fraction of the cost of the targeted assets.	Ability to shift satellite paths with atmospheric dips, ion drive. Mass constellations of cheaper spy sats with rapid replacement launch.

LOW LATENCY INTELLIGENCE: IMPACT ON GEOPOLITICS

Area	Positives	Negatives
ASAT Issues	Massive constellations are basically immune to the ASAT threat.	Low-cost ASAT systems could also be a greater threat. Difficult to tell an accidental versus an intentional collision.
Clearing Orbital Debris	Possible to use other satellites to detect and possibly de-orbit nearby debris.	More satellites from more providers give more risk with slimmer skill sets and quality control.
War Risks	Counter for hypervelocity and orbital ICBM warheads minimizes incentive to field such systems	Fog of war is a major deterrent to war. So what happens when AI somewhere tells a political leader that an invasion or first strike is winnable?

THE CONNECTED SOLAR SYSTEM

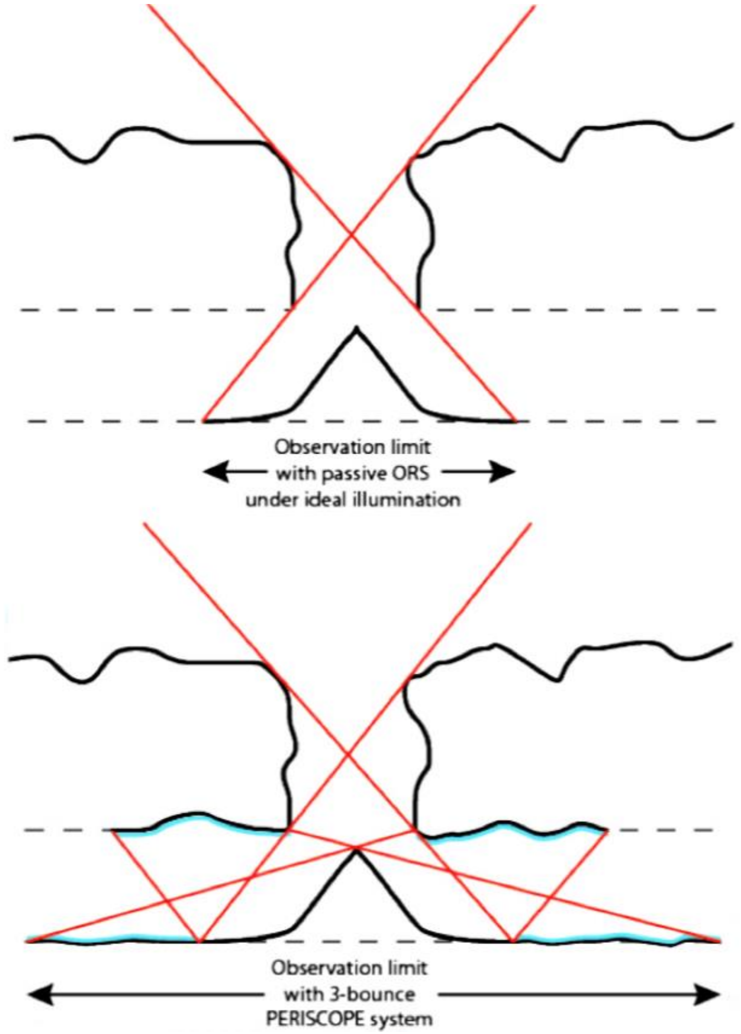
COMMUNICATIONS

OBSERVATION

INTELLIGENCE

PLANETARY OBSERVATION: PARASCOPE

- Lidar system for imaging skylight caves
- Already have a Precision Timing Laser and Telescope
- https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20190000917.pdf



STARLINK
TECHNOLOGICAL CAPABILITIES

	Possible Applications	**Analogous NASA Concepts**
Ion Drive	Asteroid Flyby Find and Deorbit Other Debris	DAWN
Laser Communications	Modify for interplanetary use Telescope for observations (modified)	Interplanetary Internet
Phase Array Communications	High speed, high resolution tracking High speed service relay	Mars Telecommunications Orbiter
Collision Detection/AI Avoidance	Very precise self-navigation in complex environments.	Deep Space 1
227 kg per satellite	Could launch many on one mission Could send with multiple instruments	Clementine (small camera/etc.) Planetary Resources

UNIFORM SYSTEMS FOR DEEP SPACE

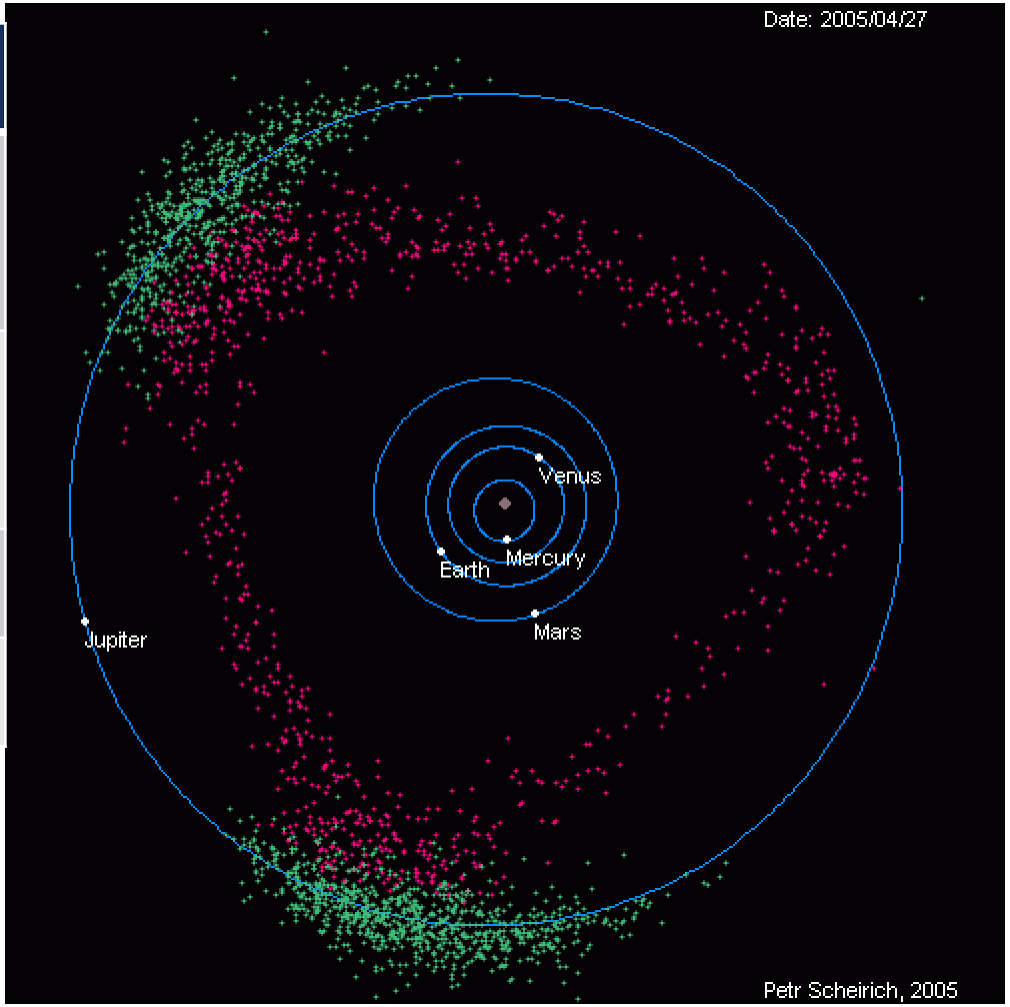
System	Mass	Applications
Starlink	227 kg	Communications, Laser comms
Starlink + Basic Res	250 kg	Basic imagery, weather 50-meter resolution from orbit
Starlink + High Res	350 kg	Planet to planet comms 5-meter resolution from orbit
StarLink + Radar	300 kg	Radar and night images

TYPICAL PLANETARY/ LUNAR CONSTELLATION

Orbit	Satellite	Role	Qty
High	High-Res Camera	Planet to Earth Comms, Deep Space Tracking Comms	6 12
Low	Low-Res Comms	Surface weather, Imagery, Local Communications	36
Low	High-Res Camera	Hourly high res coverage, Local Communications	36
Low	Radar	Exploratory Use	6
Low	Multispectral	Exploratory Use	4

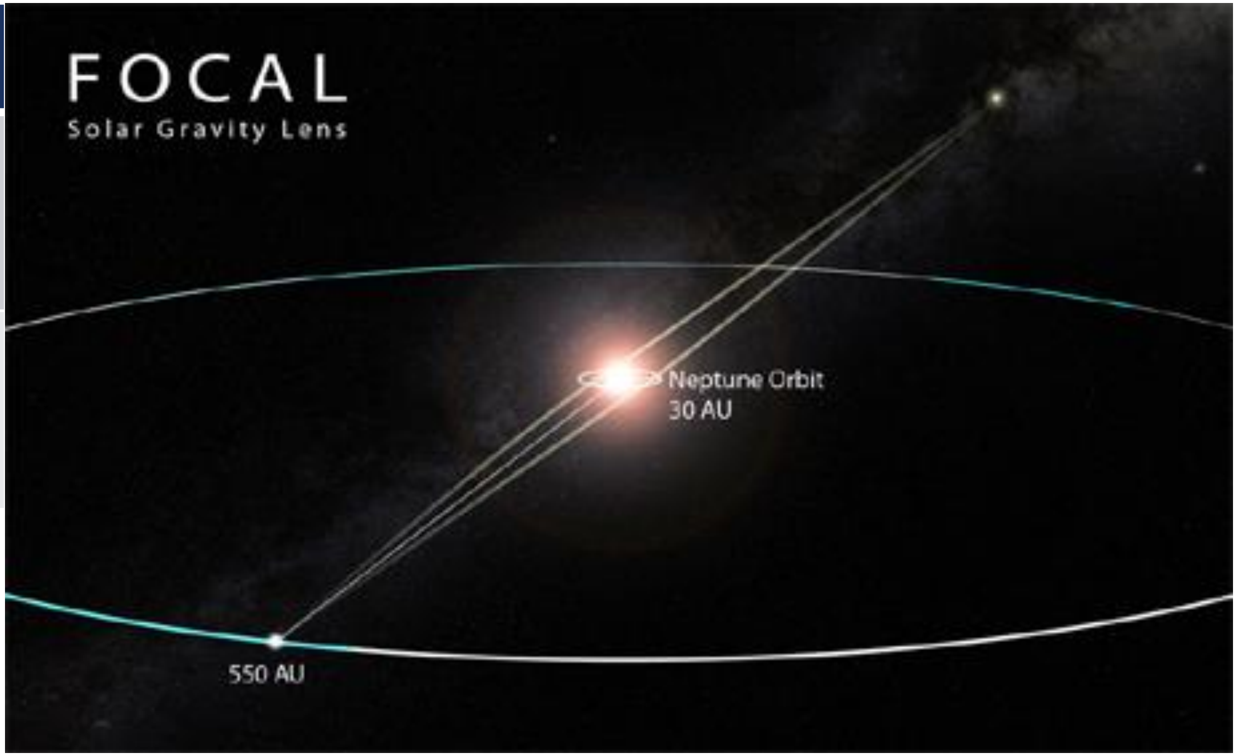
ASTEROID FLYBY FLEET MISSION

Satellite	Role	Qty
High-Res Camera	Planet to Earth Comms, Deep Space Comms	6 12
High-Res Camera	Surface Imagery In-Fleet Communications	36
Radar	Exploratory Use	18
Multi-Spect.	Exploratory Use	18



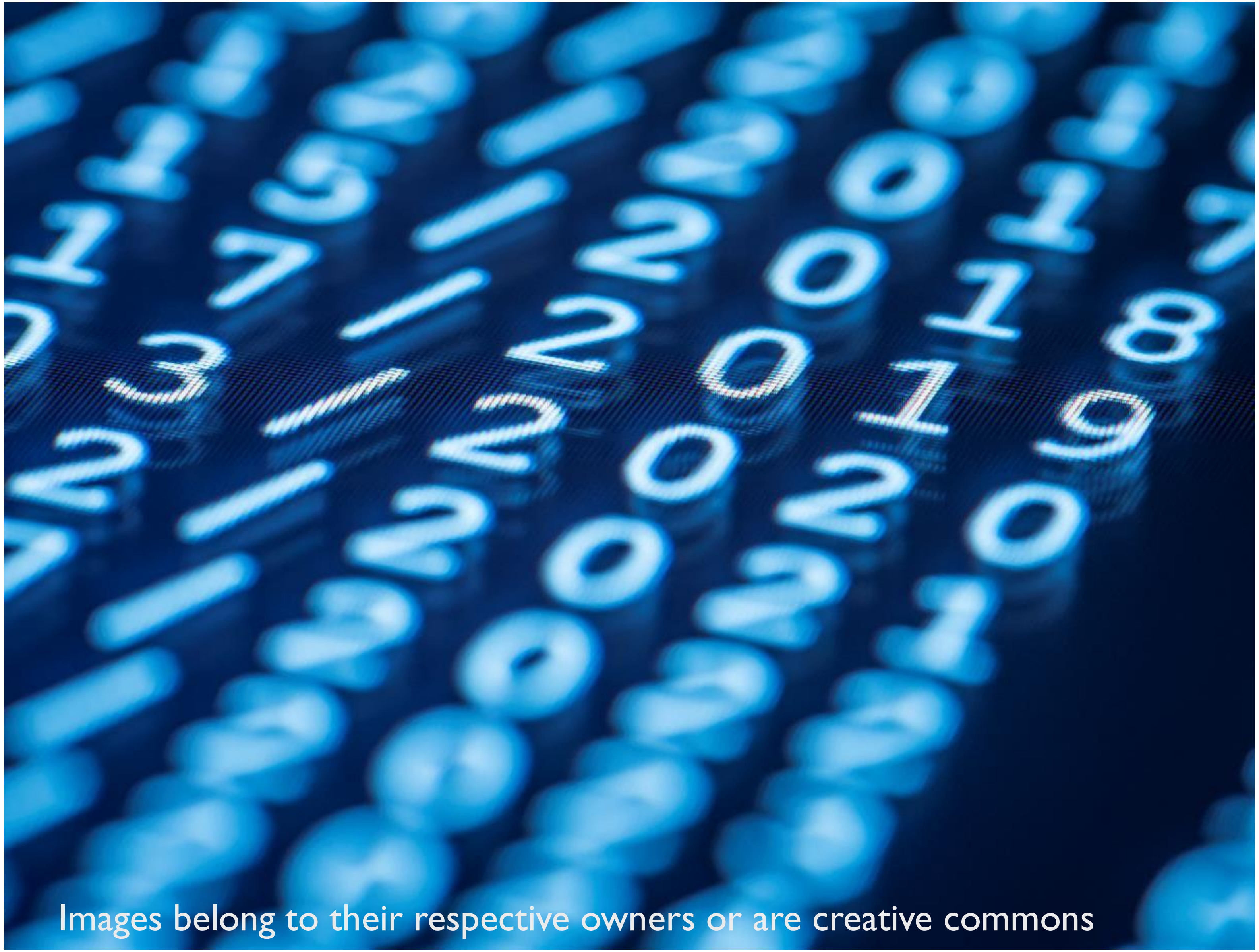
550 AU SOLAR GRAVITY TELESCOPE FLEET (FOCAL)

Satellite	Role	Min
High-Res Camera	Planet to Earth Comms	6
High-Res Camera	Telescope Use In Fleet Comms	36



BUSINESS MODELS FOR STARLINK PLUS

System	Applications
Observation Starlink	Starlink in direct competition with Planet Labs and all data sent in real time since tied directly to the backbone.
Military Starlinks (Optical/Radar)	Cost-effective secondary constellation for DOD to plug holes in defensive constellations. Also ATC.
Risk Reduction for Exploration	Risk reduction and from meteors, storms, etc. Resource location and characterization.
Asteroid Mining	Initial recon and in-situ communications grid.



QUESTIONS?

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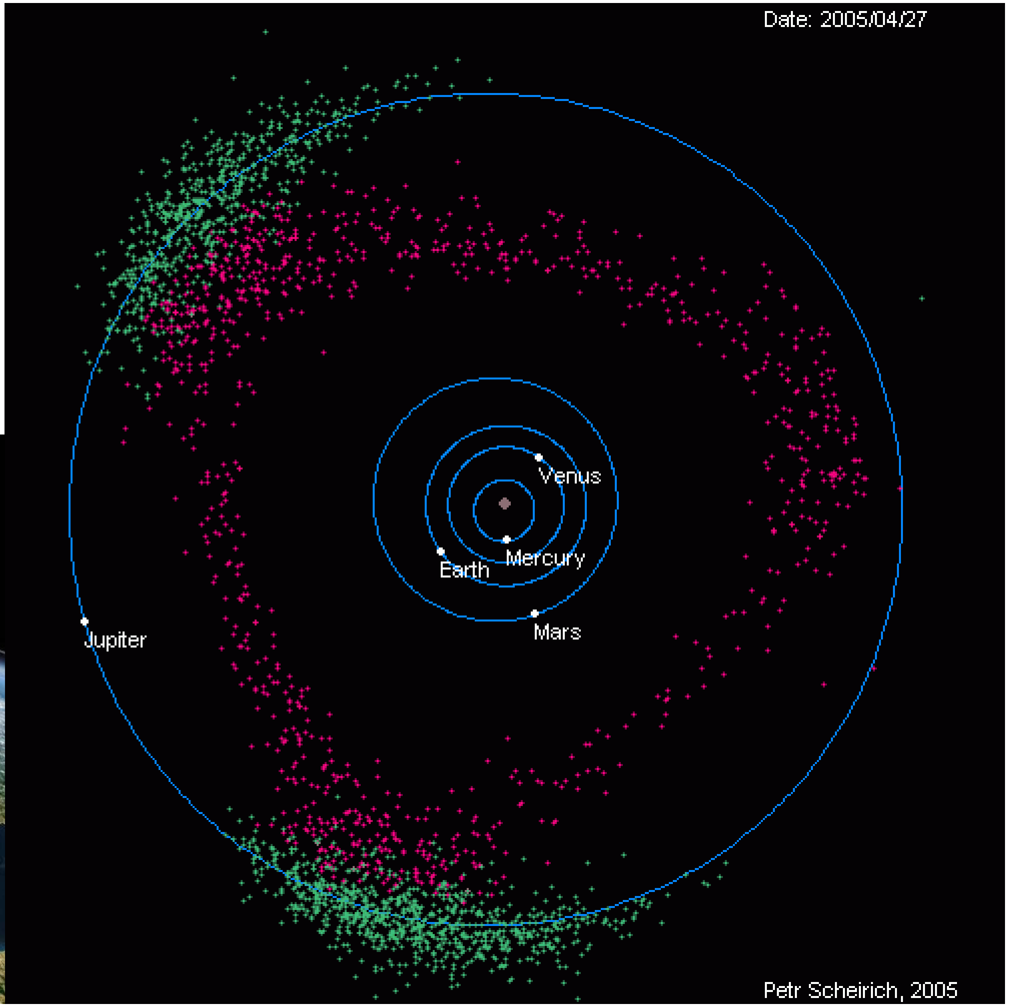
PLANETARY OBSERVATION: SPACE PROBES

Starlink Derived Option	Current Mission
100 main belt asteroids in a single launch	Lucy mission to Trojan Asteroids 6 targets from 2025 to 2028 (NASA)
Radar on multiple vehicles	Able to do sat-to-sat SAR for 3D (TanDEM-X – DLR)



PLANETARY INTELLIGENCE: WHOLISTIC POLITICAL IMPACT

- Having an ideologically-isolated dictatorship in a world with a profusion of satellite communications systems would be difficult.
  - Unfortunately, this also means that such ideologies have a global reach.
  - Having space settlements forms a political and cultural "Dead Hand" to re-introduce worldviews to Earth even if an ideological enemy is driven to terrestrial extinction.
- If political will is focused on finding resources at the lowest political cost, it makes much more sense to build a space resource program than to invade another nation.
  - This revenue source may become a form of global or local "resource curse" for nations that practice it if the economic advancement is confined to urban or politically powerful locations within a population.

IMPLICATIONS FOR MARS OR MOON CONSTELLATION

Starlink	NASA Historical
Mass of Starlink without laser system is 227 kg. Radar systems are 40 kg for the whole satellite. So a Mars-based Starlink with radar and/or optical system would be roughly 300 kg	Mars Recon Orbiter: 1031 kg dry, 2180 fueled Odyssey: 331 kg dry, 725 kg full. Mariner 69 flyby: 412 kg full. Mariner 71 orbiter: 771 kg full
Odyssey was around the same size dry, but double that with propellant. So this might be why Elon Musk discussed an expendable Starship-derived upper stage for interplanetary probes.	
100 "MarsLink" Sats - full constellation – one Starship Near constant observation and communication everywhere, 36 Radar + Comms – hourly scans (targeted). 36 Optical + Comms – hourly observation (targeted) 28 Interplanetary Comms – Relay to Earth, or Planet to Planet via larger lasers	