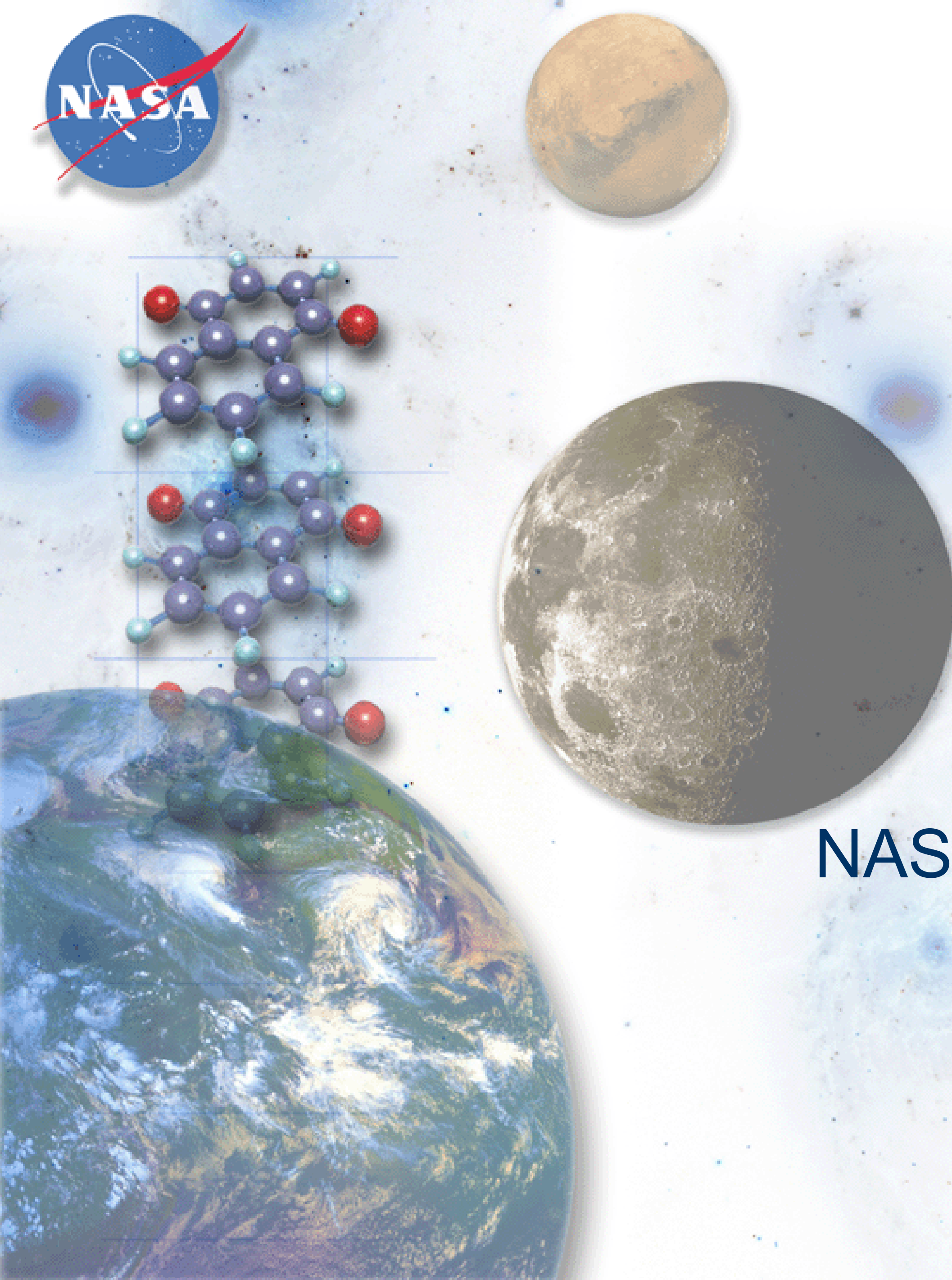


NASA Exploration Team

NASA's Exploration Team:

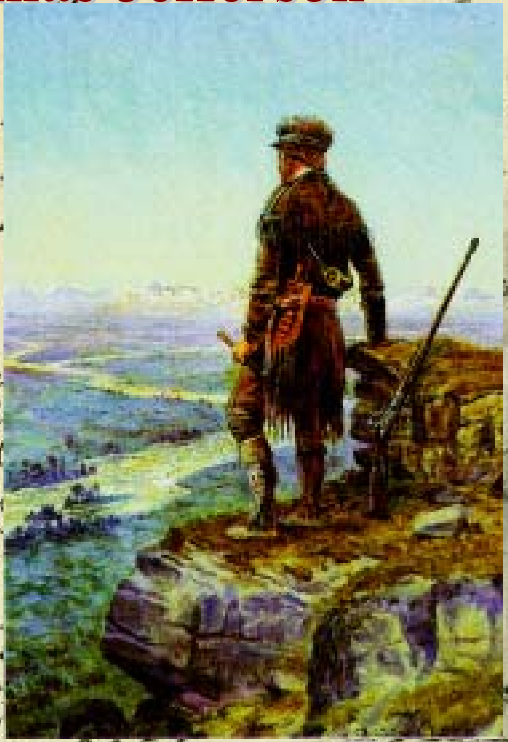
Vision and Priorities

National Aeronautics and
Space Administration

June 12, 2002

"However our present interests may restrain us with our own limits, it is impossible not to look forward to distant times"

-- Thomas Jefferson



The Corps of Discovery and America's Future

“The object of your mission is to explore…”

From Thomas Jefferson’s ‘Letter of Instruction’ to the Corps of Discovery [June 20, 1803]

<u>Jefferson’s pillars for the country’s great enterprise of exploration:</u>

“Instruments for ascertaining, by celestial observations, the geography of the country…”

=> Scientific exploration, enabled by technology.

“…[and to ascertain the suitability of the frontier] for the purposes of commerce.”

=> Economic opportunity, enabled by government investment.

“Your observations are to be taken with great pains and accuracy, to be entered distinctly and intelligibly for others as well as yourself….”

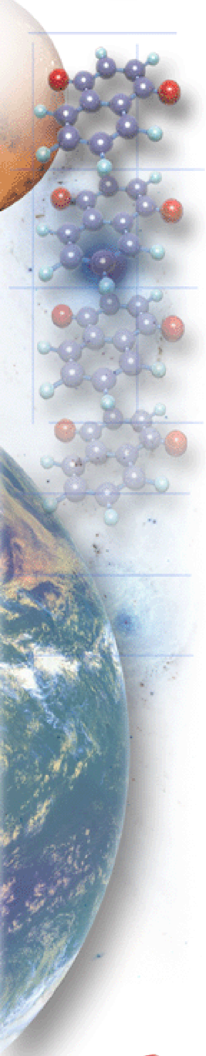
=> Public engagement, enabled by effective communication.

“You will therefore endeavor to make yourself acquainted, as far as diligent pursuit of your journey shall admit, of… the extent of…[life beyond the frontier].”

=> The adventure of new discoveries…the <u>unanticipated.</u>


NEXT's Grand Vision
Exploration of life in the Universe
. . . enabled by technology
first with robotic trailblazers,
and eventually humans,
going anywhere, anytime

Exploration of Life in the Universe



To *discover* scientific evidence and processes that *reveal* our place in the Universe, by *exploring* new places and phenomena, *leading* outward beyond the vicinity of the Earth, *enhancing* the quality of life and *sharing* the adventure of discovery with all humanity.

The imperative for space exploration can be articulated by three *Grand Challenges*:

How did we get here?

How did life arise on Earth?
How did intelligence evolve on Earth?
How did the Earth and Solar System form and evolve? . . .

Where are we going?

What is the fate of life on Earth?
What is the interaction between life and the Earth's environment?
How do we optimize the role of humans in space? . . .

Are we alone?

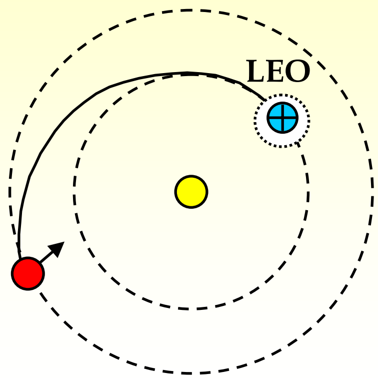
Are there other abodes for life in the Solar System?
Are there other abodes for life in the Universe? . . .

More on What the Vision is

- Exploration of Life in the Universe
- Changing the pace of discoveries and enabling new ones
- Bringing new machines on site to facilitate faster and better science activities with higher and faster yields
- Ultimately bringing humans on site to radically alter the pace of discoveries
- All of this is catalyzed by cycles of innovation-driven investment

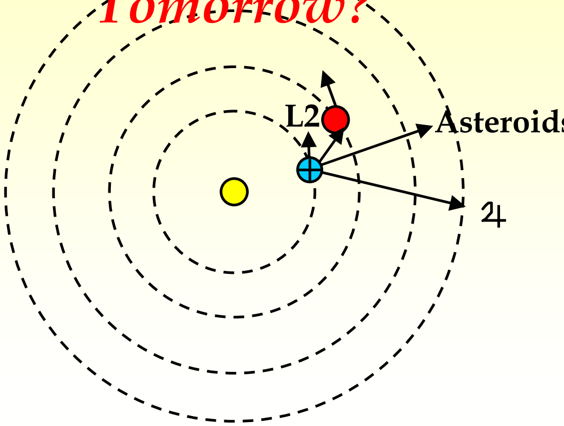
What is the NEXT Vision Difference?

Where Are We Today?



- Minimum Energy Transfers
- Launch cost indiscriminant of payload value
- Destination-Dependent (in series)
- Humans Only to LEO
- Low-Bandwidth Telecomm
- Infrequent Visits: *Hostage to Time*

Where Do We Want to Go Tomorrow?



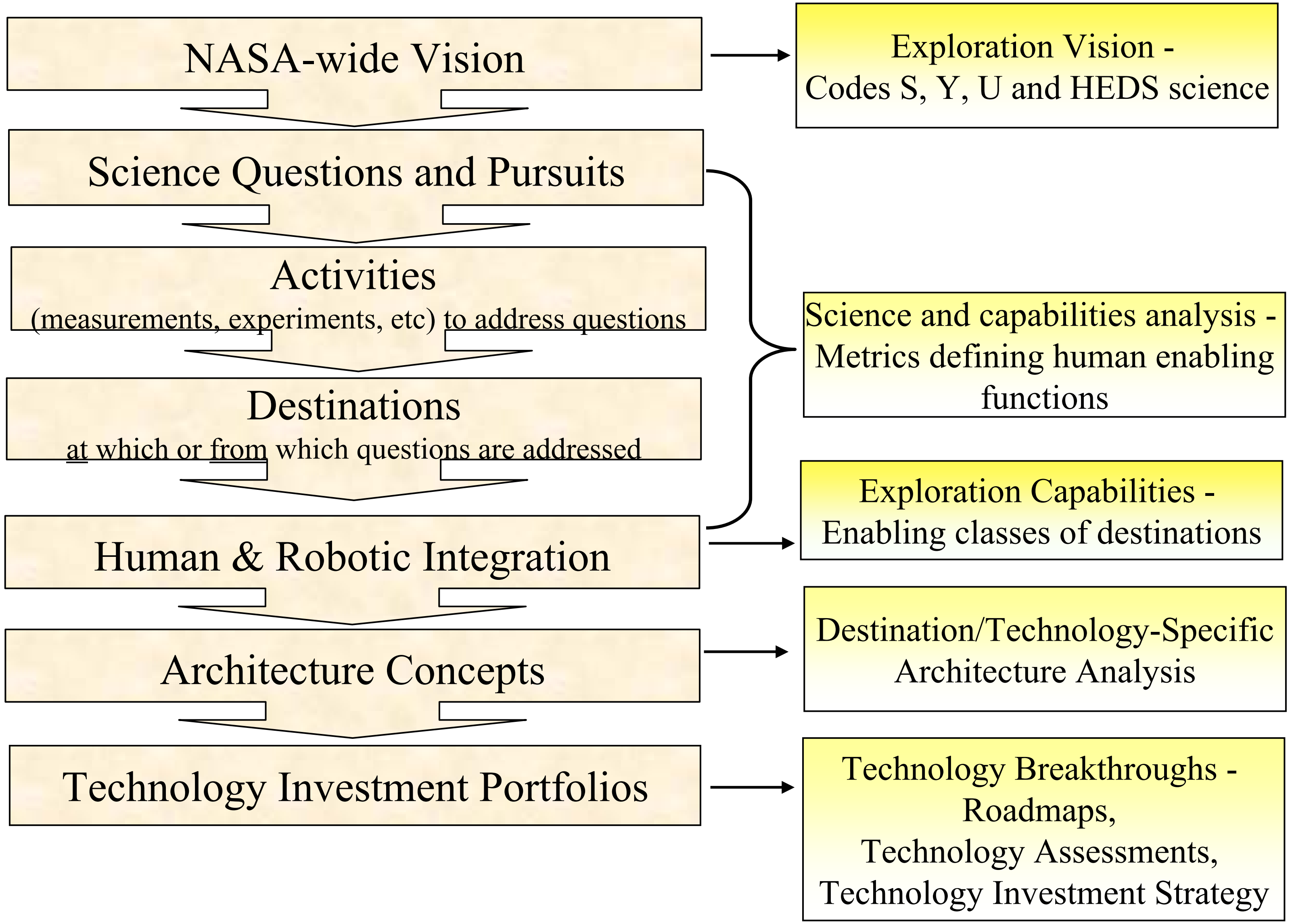
- Non-minimum Energy transfers
- Launch cost determined by payload value
- Destination-Open (in parallel)
- Humans to L2, Mars …. Wherever
- Video Bandwidth Telecomm
- Frequent visits: *Sustained Operations*

Investing in technology makes the difference:

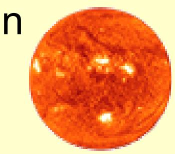
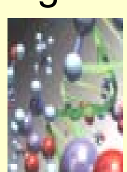
Increase value/lb - while decreasing cost/lb

NASA Exploration Team

Traceable Thought Process and Current Progress



Example Science Traceability

Vision	Science Questions	Pursuits	Activities	Destinations
How Did We Get Here?	•Solar System evolution 	• History of major Solar System events	• Planetary sample analysis: absolute age determination “calibrating the clocks”	• Moon • Mars • Asteroids
Where Are We Going?	• Humans adaptability to space 	• Effects of deep space on cells	• Measurement of genomic responses to radiation	• Beyond Van-Allen belts
	•Earth’s sustainability and habitability 	• Impact of human and natural events upon Earth	• Measurement of Earth’s vital signs “taking the pulse”	• Earth orbits • Libration points
Are We Alone?	• Life beyond the planet of origin 	• Origin of life in the Solar System • Origin of life in the Universe	• Detection of bio-markers and hospitable environments	• Mars • Europa • Titan • Cometary nuclei • Libration points

Why Use Humans?

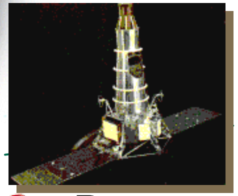
To Accelerate Discovery & Innovation

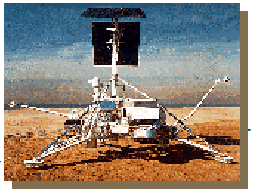
Discoveries

Leadership:
Emerged as
Cold War victor

Prosperity:
Catalyst for
"information age"

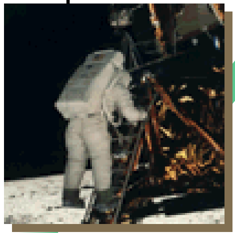
Motivation:
Surge in
education of
scientists and
engineers


Ranger


Surveyor


Lunar orbiter

Apollo 11

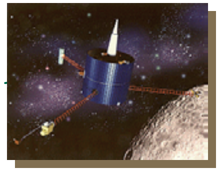


Apollo 12 @
Surveyor 3 site

Apollo 17 Rover

Discovery:
Origin of the Earth - Moon system

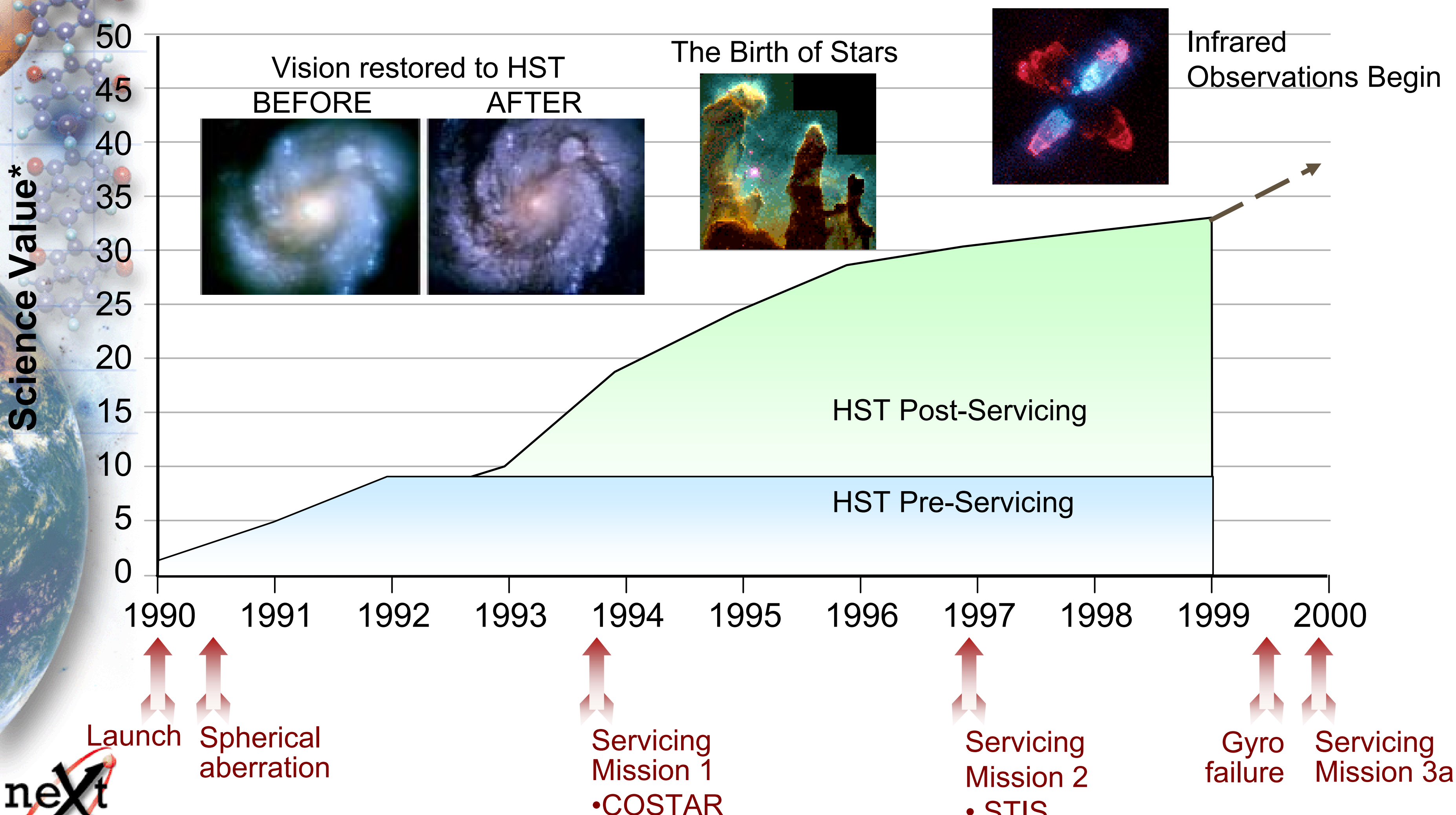

Clementin
e


Lunar
Prospector

Time

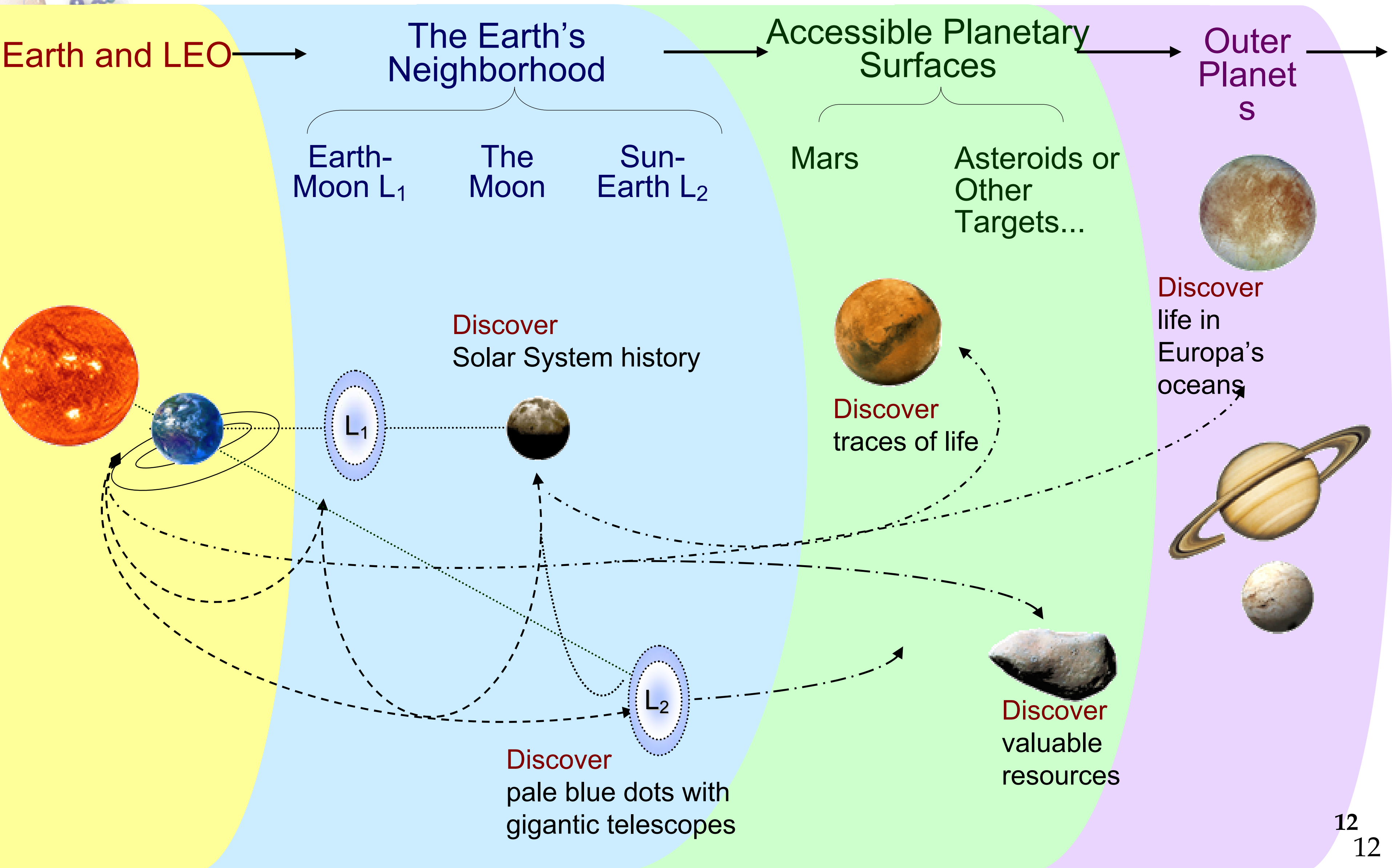
10

Why Use Humans?
Astronauts Enable Discoveries: HST



*1990-1999 data - most important stories per year
Source: *Science News*

The Places We Could Go



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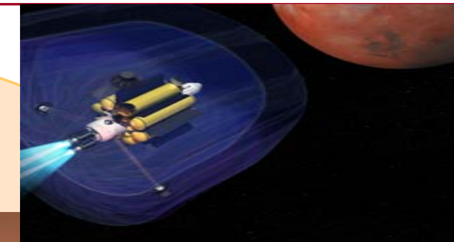
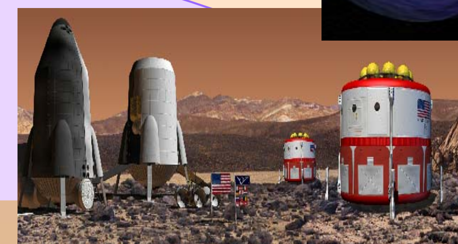
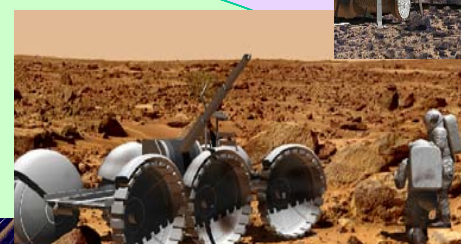
Stepping Stones



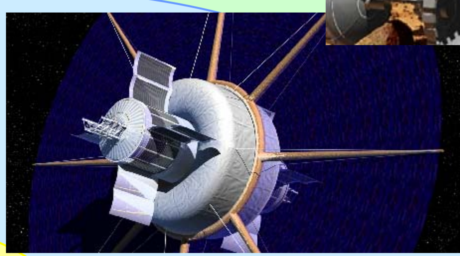
Go anywhere, anytime



Sustainable Planetary Presence

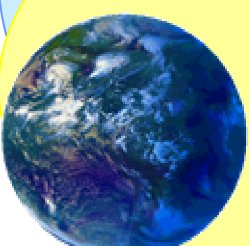


Accessible Planetary Surface



Earth's Neighborhood

Earth and LEO



- Space Station experience
- Solar System learning
- Technology advancements

Earth's Neighborhood

- Traveling up to 1.5 million km
- Enabling huge optical systems
- Operating in deep space
- Staying for 50-

Accessible Planetary Surface

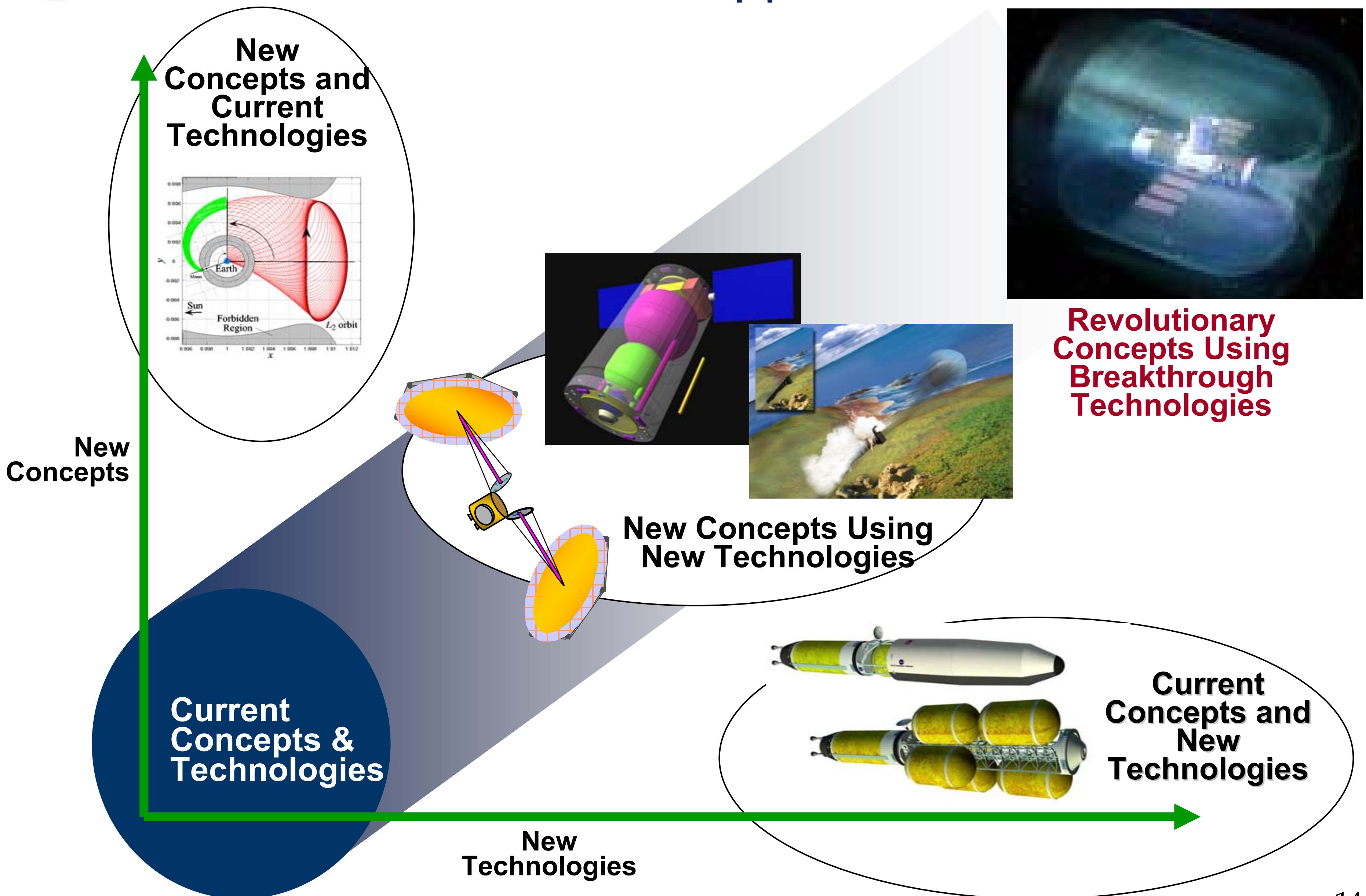
- Traveling out to 1.5 AU
- Enabling tactical investigations
- Visiting and operating on another planet
- Staying for 1-3 years

Sustainable Planetary Presence

- Traveling out to ~1.5 AU, and beyond
- Enabling sustainable scientific research
- Sustaining operations on another planet
- Staying for indefinite periods

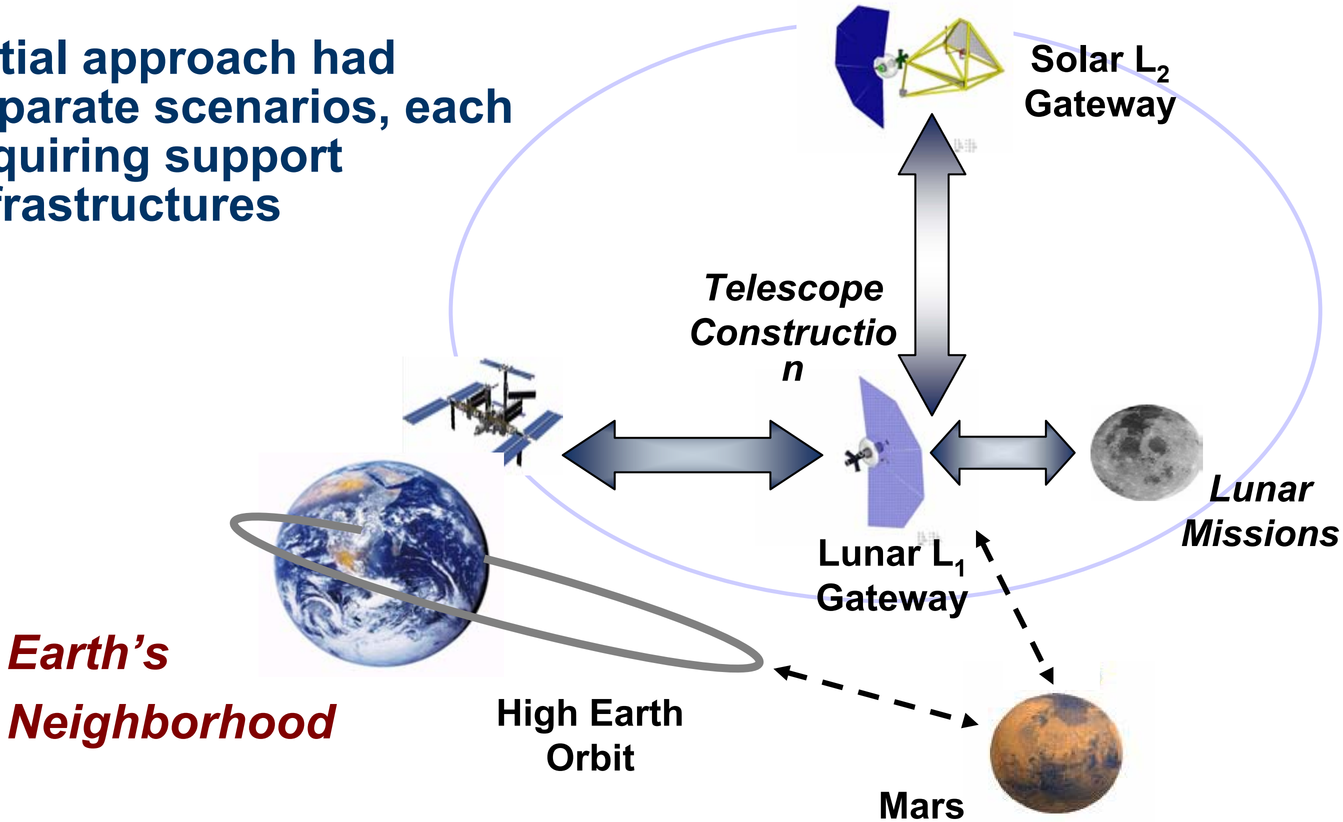
Overview

NEXT Approach



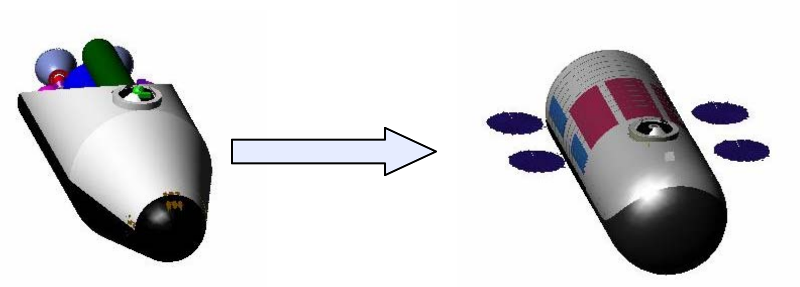
New Approach to Exploration Concepts

- **Initial approach had separate scenarios, each requiring support infrastructures**

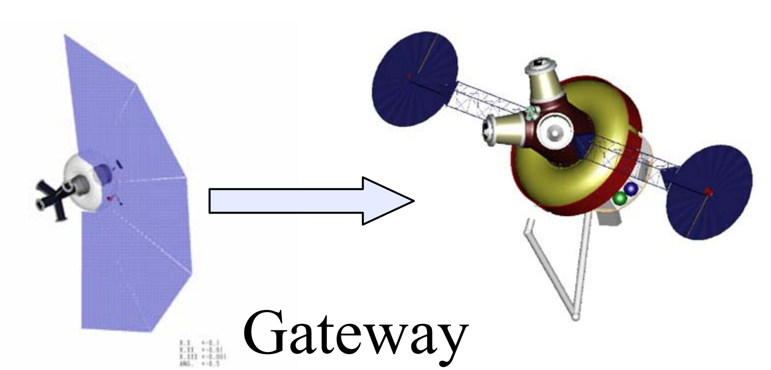


- **Discovered new approach for meeting trajectory requirements for vehicles in Earth's Neighborhood with new benefits;**
  - **Low energy transfers between Lunar L1 and solar L2**
  - **Created efficient Gateway Concept**

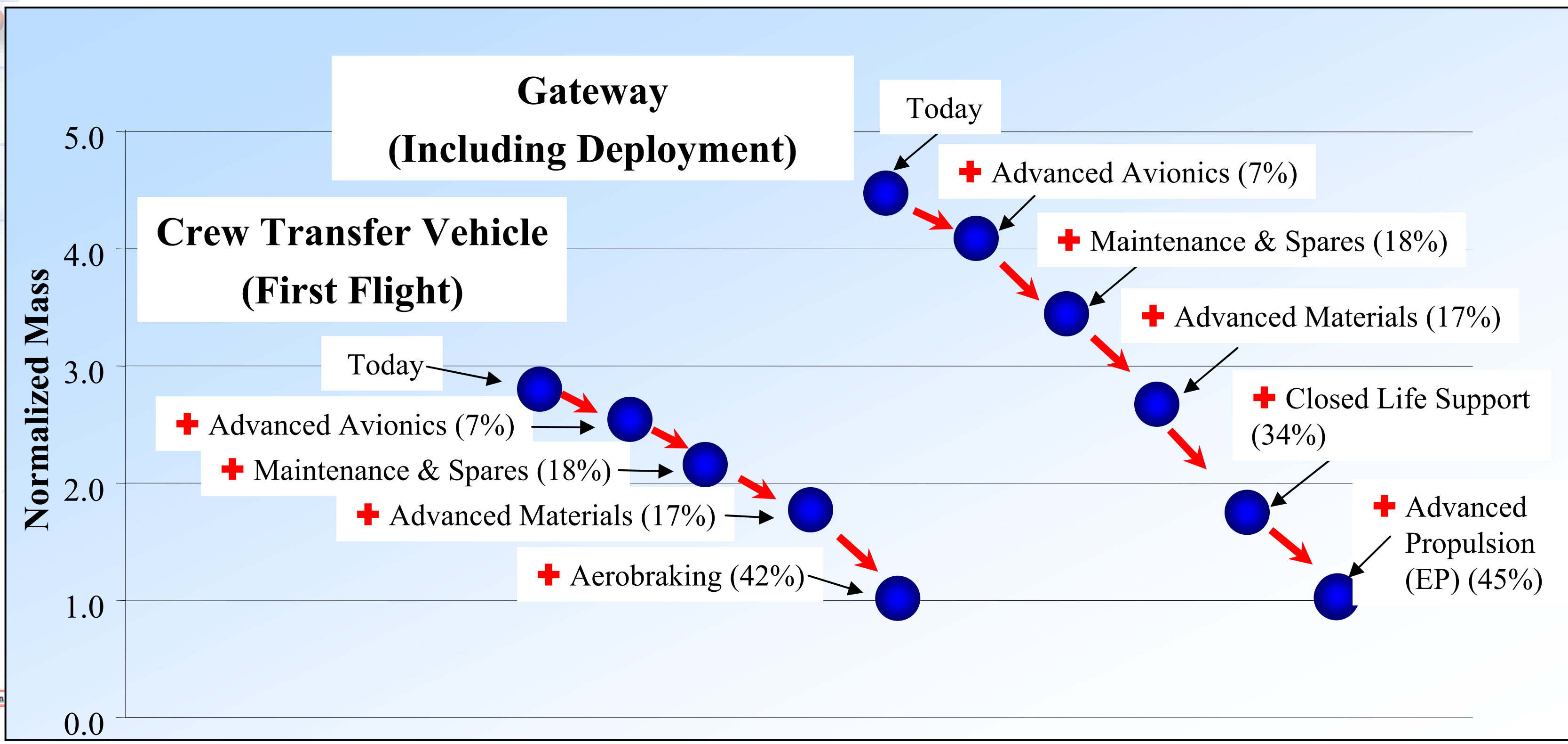
Evaluating Technology Investments
Example: Exploration in the Earth's Neighborhood



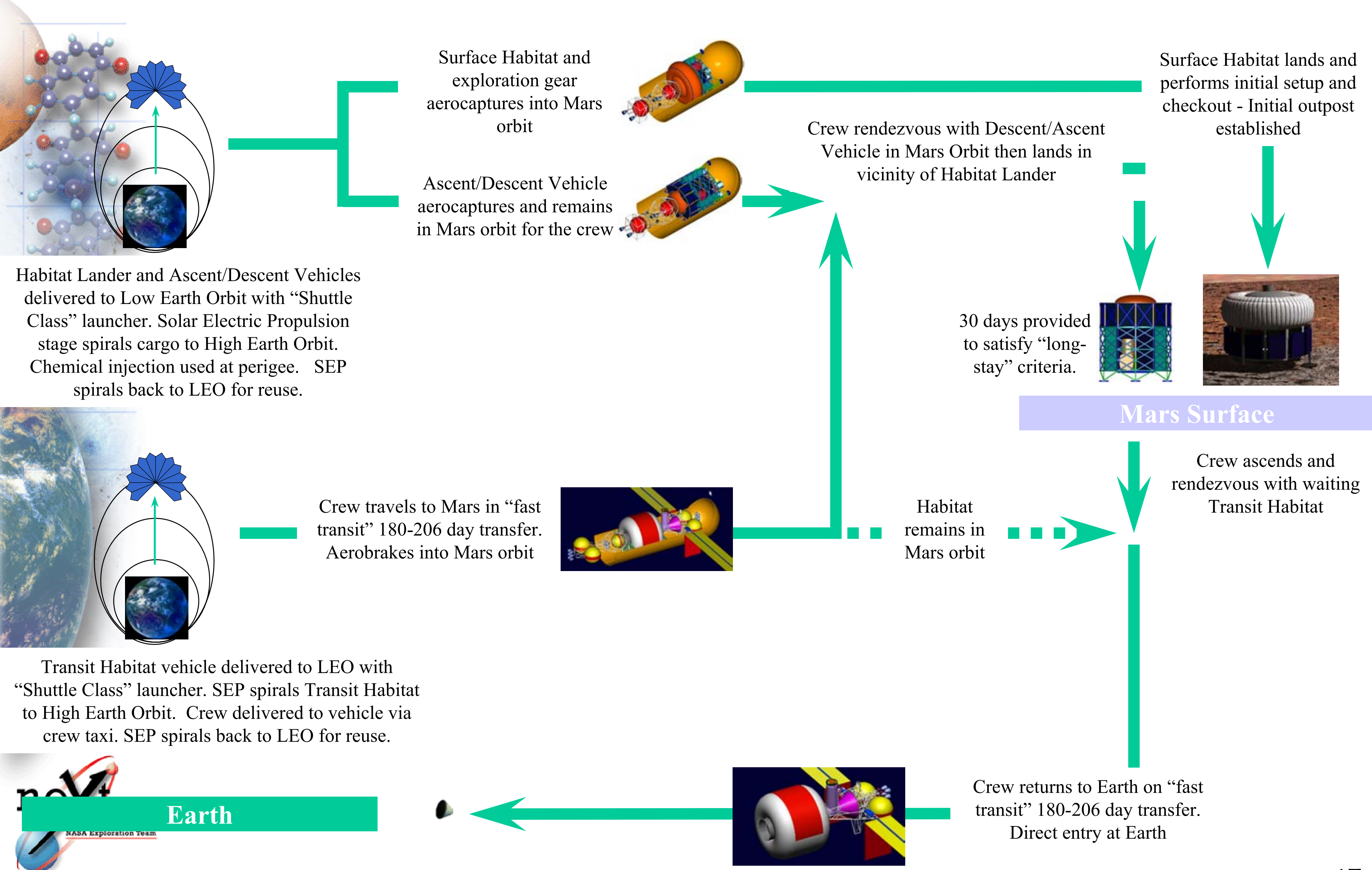
Crew Transfer Vehicle



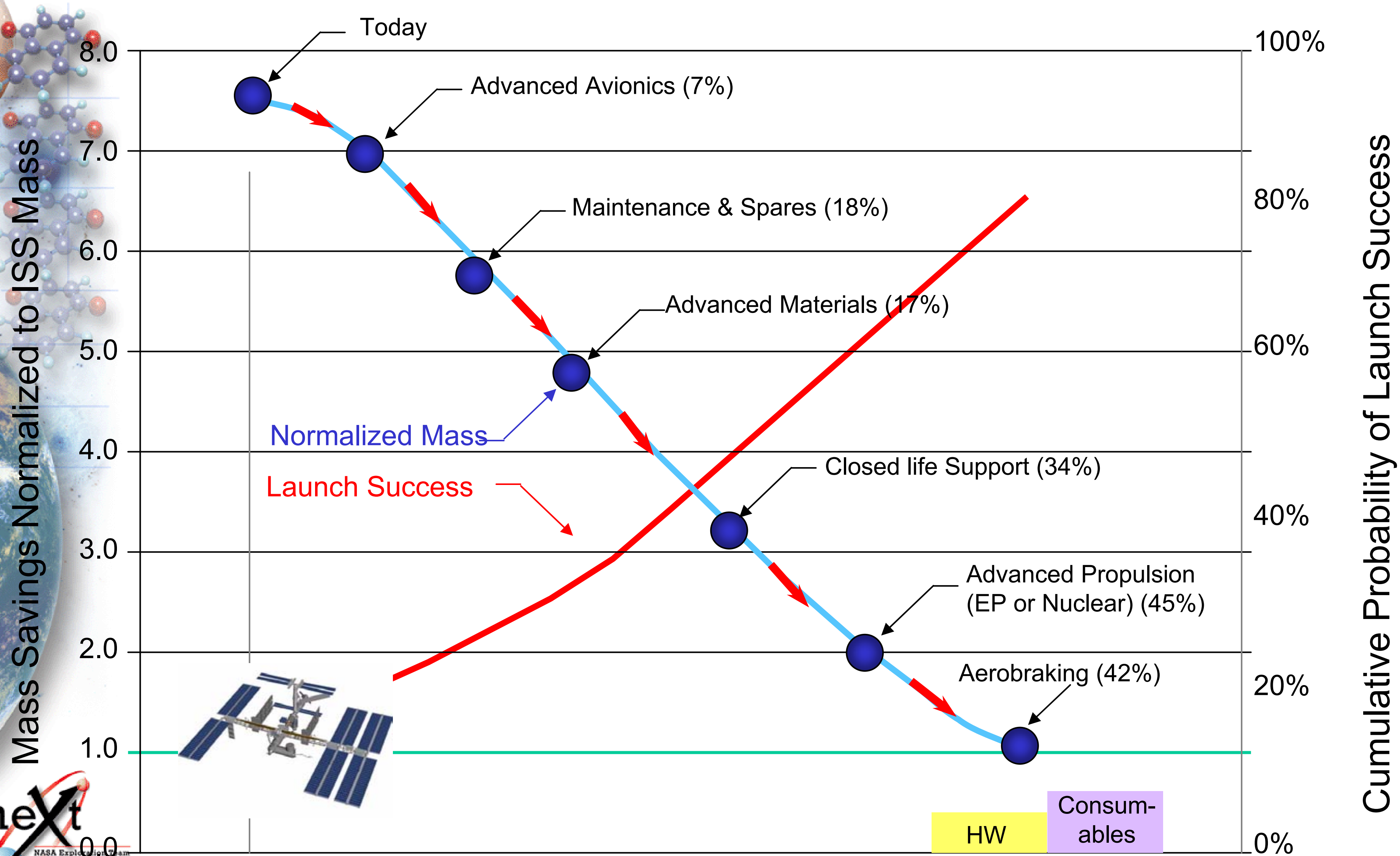
Gateway



Example Architecture: Mars Mission
(SEP Option)



Evaluating Technology Investments
Example: Mars Human Mission



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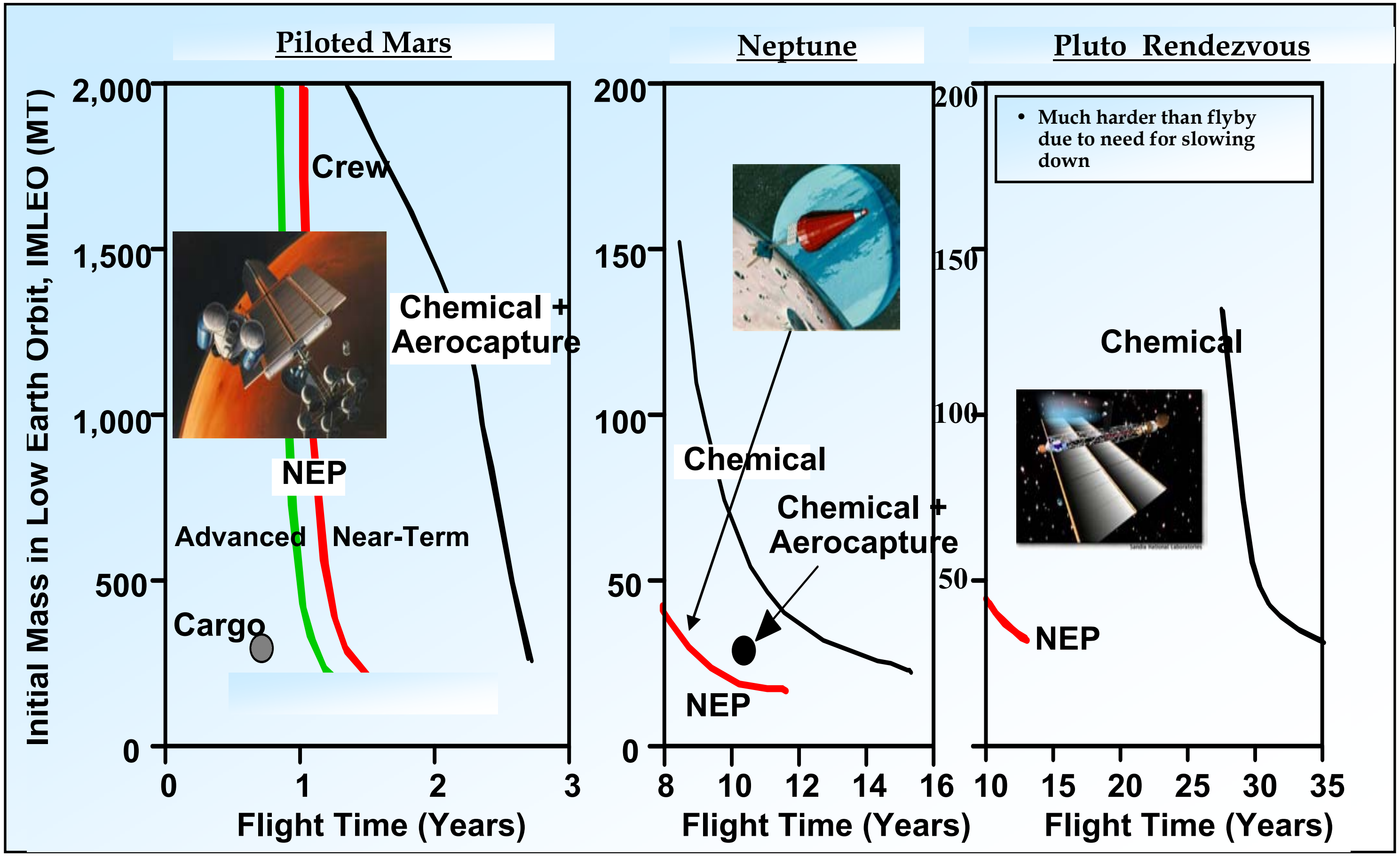
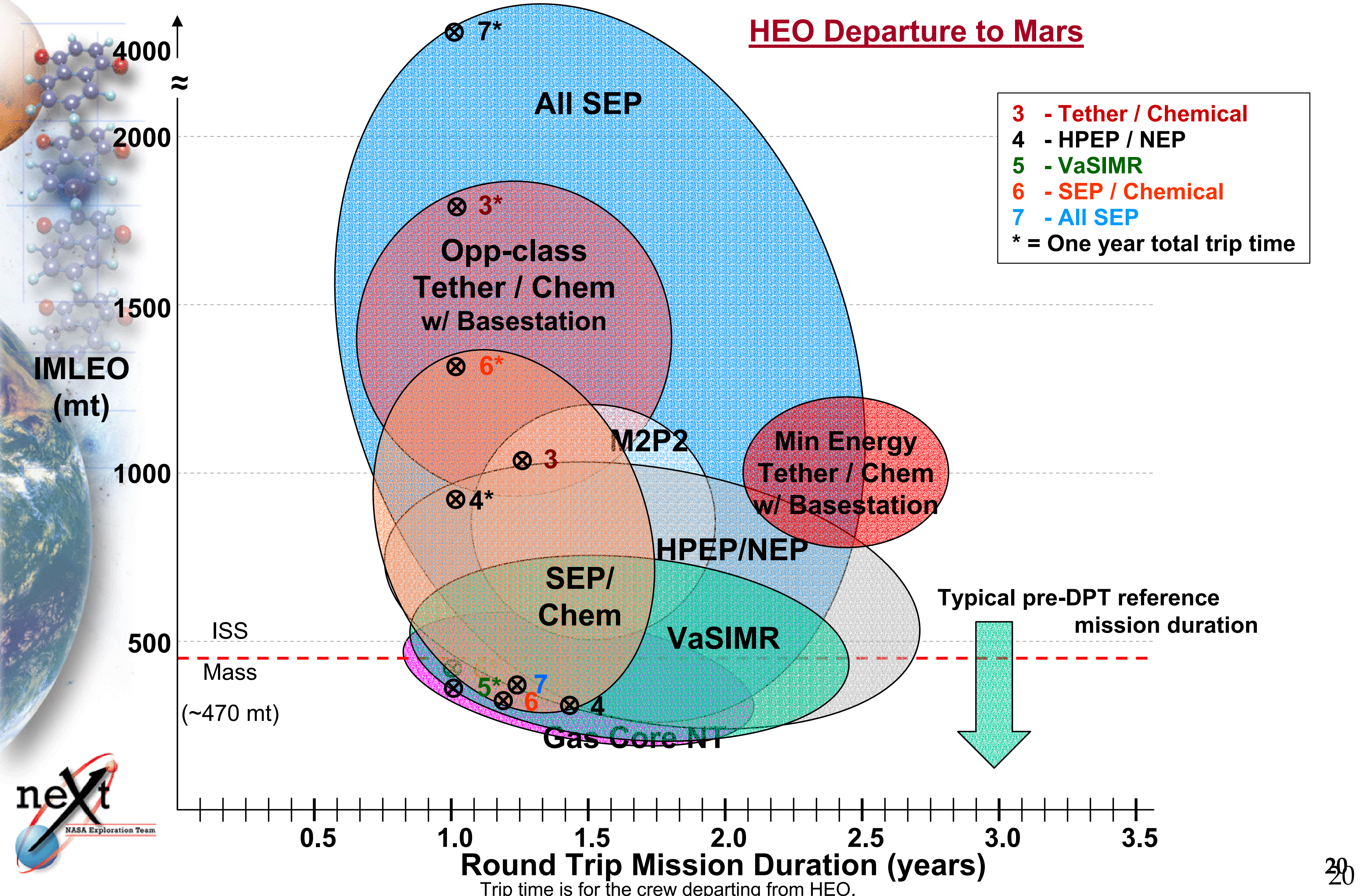
Evaluating Technology Investments
Example: Nuclear Electric Propulsion

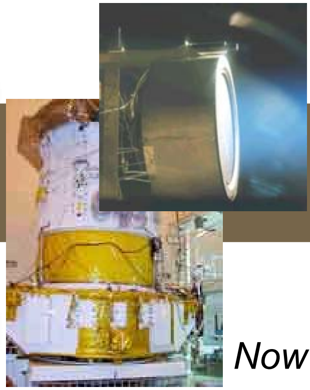
- Nuclear Electric Propulsion can provide both IMLEO and trip time benefits for piloted and robotic missions
- Significant enhancements from advanced power and thruster technologies
- Lack of sunlight prevents use of SEP or Solar Sails for orbit rendezvous missions significantly beyond Mars

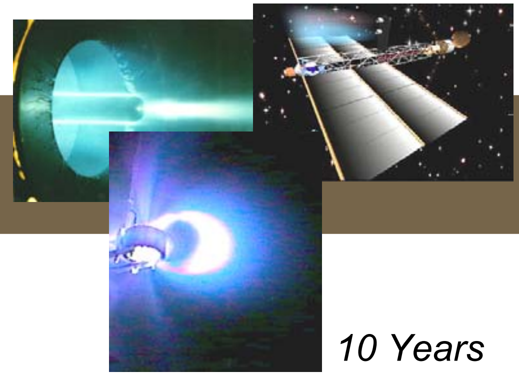


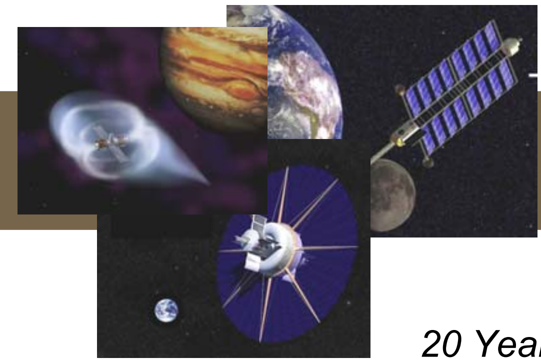
Evaluating Technology Investments
Example: Interplanetary Transportation Options



In-Space Transportation Technologies







	Now	10 Years	20 Years
Application Missions	Humans to LEO. Upper Stages for LEO-to-GEO and robotic missions	Human mission capability for near-Earth space. Robotic missions anywhere in the solar system	Safe, low-cost human and robotic exploration of the solar system
Safety & Reliability	~1/200 failure probability	100X safer	10,000X safer
Mass	Chemical state-of-the-art	3X - 5X reduction	10X reduction
Cost	$3000/kg LEO-to-GEO	$1000/kg - $300/kg	$300 - $100/kg

Leading Candidate Technologies:

- High power electric propulsion (Isp: 3500 - 10,000 sec; power: 100 kW - 1 MW)
- Aeroassist and aerocapture (mid L/D aeroshells; ballutes)
- Plasma sails for efficient interplanetary transfer and inherent radiation protection
- Fission propulsion for reduced IMLEO and enhanced crew safety
- Momentum Transfer Tethers as a reusable in-space infrastructure for robotic and human exploration
- High energy density materials and advanced chemical fuels to increase Isp and reduce propulsion system mass

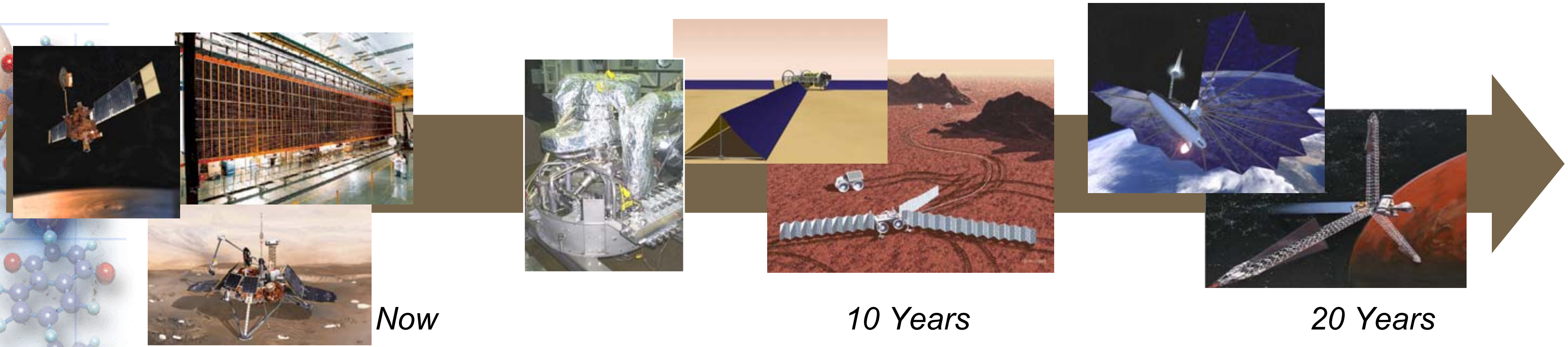
National Benefits:

Lower cost and more reliable space transportation for commercial enterprises (e.g., communications, resource monitoring, tourism) and defense needs

Evaluating Technology Investments
Example: ETO Cargo Trade Space

Candidates	Launch Frequency @ 400 mt/yr	Scale @ 8 km/s Shot	ROM Cost	Strength/Weakness
Slingatron	800 Launches @1-25/day	Gyration = 9 Hz D = 300 m	Non-recurring: $2.2B Recurring: $650 - $2,540/kg payload	Strength - High Frequency launch Weakness - Engineering complexity
Blast Wave Accelerator	800 Launches @ 1 - 2/ day	Number of explosive rings = 2,800 L = 860 m	Non-recurring: $1+B Recurring: $1,238 - $3,122/kg payload	Strength - High energy density explosive Weakness -Controlled detonation
Electromagnetic Coil Gun Rail Gun	800 Launches @ 1-3/day	L = Several hundred meters	Non-recurring: $2.7B Recurring: $3,000-$5000/kg	Strength - Higher technical maturity Weakness - Massive electric energy storage
ELVs Delta 7920	78 Launches	Payload mass to LEO: 5000 kg	$9,700 - $11,100/kg payload	
Pegasus	888 Launches	Payload mass to LEO: 450 kg	$26,700 - $33,300/kg payload	

Power System Technologies



	Now	10 Years	20 Years
Application Missions	LEO/GEO satellites Earth & planetary science missions International Space Station	Mars long-stay robotic labs Libration point observatories Electric propulsion	Human missions far from Earth High power electric propulsion
Power level & Robustness	Short duration/low power Mars surface PV	kW class Mars surface PV	Multi-MW PV and nuclear dynamic systems for in-space
	100w class RTGs	10+kW surface nuclear	100+kW surface nuclear
	10-100kW near-Earth PV	Higher efficiency/low mass PV for in-space	Robust, high power surface systems

Leading Candidate Technologies:

- Thin-film and high-efficiency photovoltaic cells to reduce the array area and stowed volume
- Advanced dynamic and static conversion to reduce both thermal input and radiator size
- High density energy storage to increase the duration of mobile systems
- High efficiency power management and distribution to reduce losses and save system mass

National Benefits:

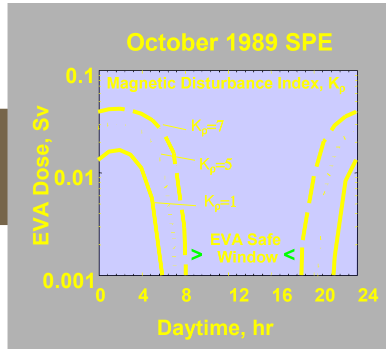
Increased reliability and reduced cost of NASA, military and commercial satellites and spacecraft.
More compact power systems for remote terrestrial applications, hybrid/electric vehicles and hand-held devices.

Evaluating Technology Investments
Example: Power Trade Space

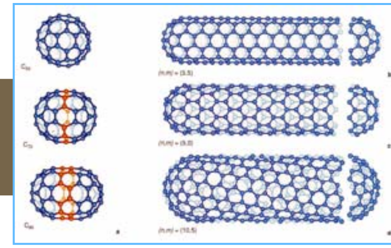
Applications	Nuclear	Isotope	PV only	PV/ RFC	PV/ Batt	FC/ RFC	Batt.	Beam	Power Level
LEO Fuel Depot	X		**X**					X	~3 MW
BNTR	**X**					X			30-50kW
NEP	**X**								30-50kW/ 100kW-MMW
SEP/ Chem				**X**	X				20-30kW/ 1-2MW
Ascent/ Descent/ Re		X				**X**	X		3-5kW
30 day Mars	**X**	X		X	X	X			10-20kW
500 day Mars	**X**								60-100kW
10 hour rover		X				**X**	X		crewed, 1-3 kW
Multi-day rover	X	**X**		X		X			crewed, 5-10 kW
Mars mobile drill	X	**X**		X		X		X	1-5 kW
14 day lunar	X	X	**X**						2-100kW
45 day Lunar	**X**	X						X	10-100kW
Lunar S. pole	**X**	X	**X**			X	X	X	2-100kW
L2	X		**X**	X				X	2-10kW

(shaded cell, shown as **X**) = Preferred concept

Crew Health & Safety: Radiation Protection



Flight rules



Optimal shielding materials

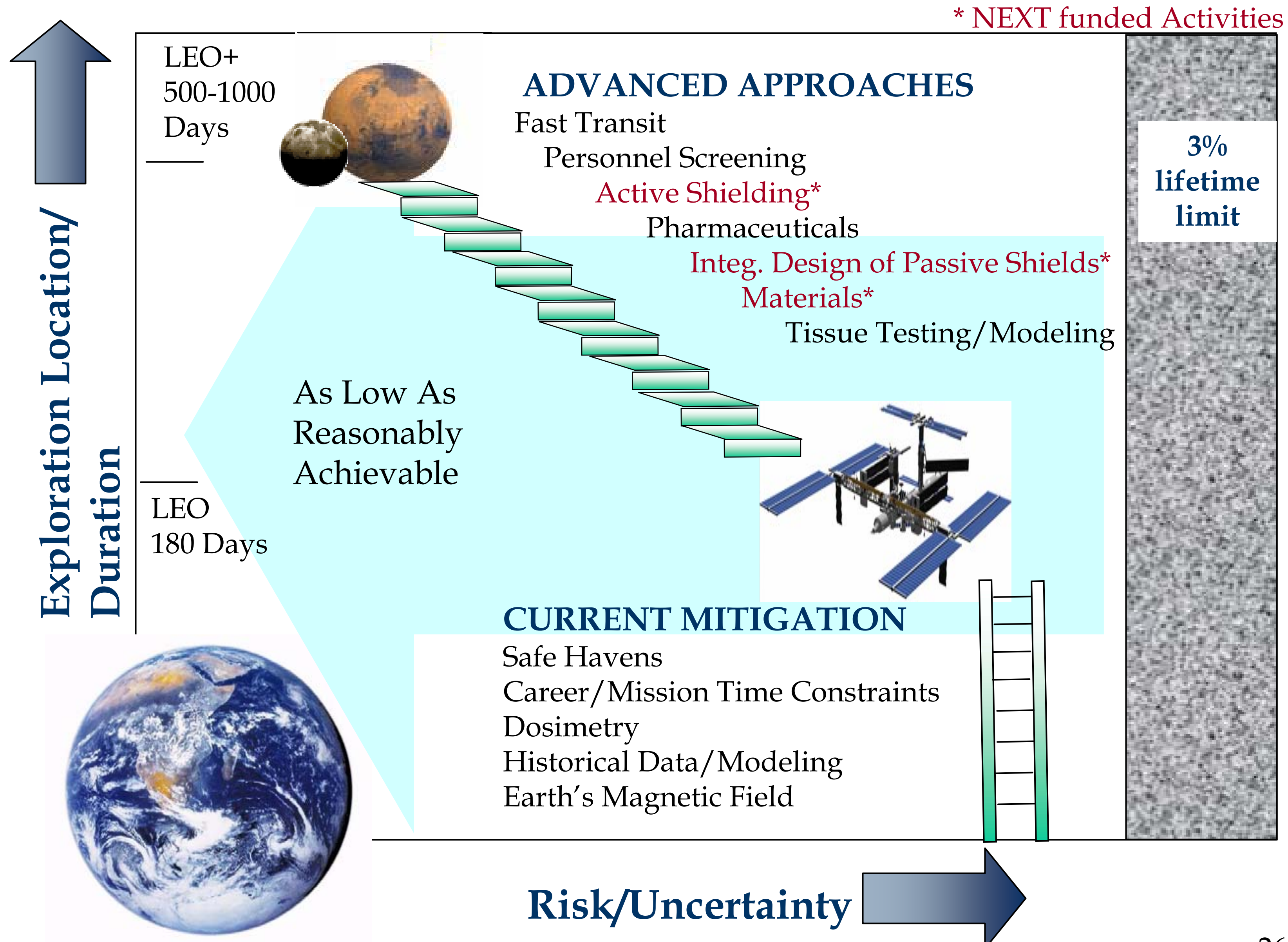
Biomolecular Intervention

	Now	*10 years*	*20 years*
Application Missions	**Short duration missions in low Earth orbit**	**Extended missions in Earth's Neighborhood**	**Long-duration missions to more distant destinations**
Uncertainty in cancer risk	**600%**	**120%**	**50%**
Radiobiological database	**10% complete**	**50% complete**	**100% complete**
Solar flare strategies	**40% complete**	**75% complete**	**100% complete**
Model Validation	**Ground facilities**	**ISS; free flyers; balloons**	**Beyond Van Allen Belts**

Leading Candidates Technologies:

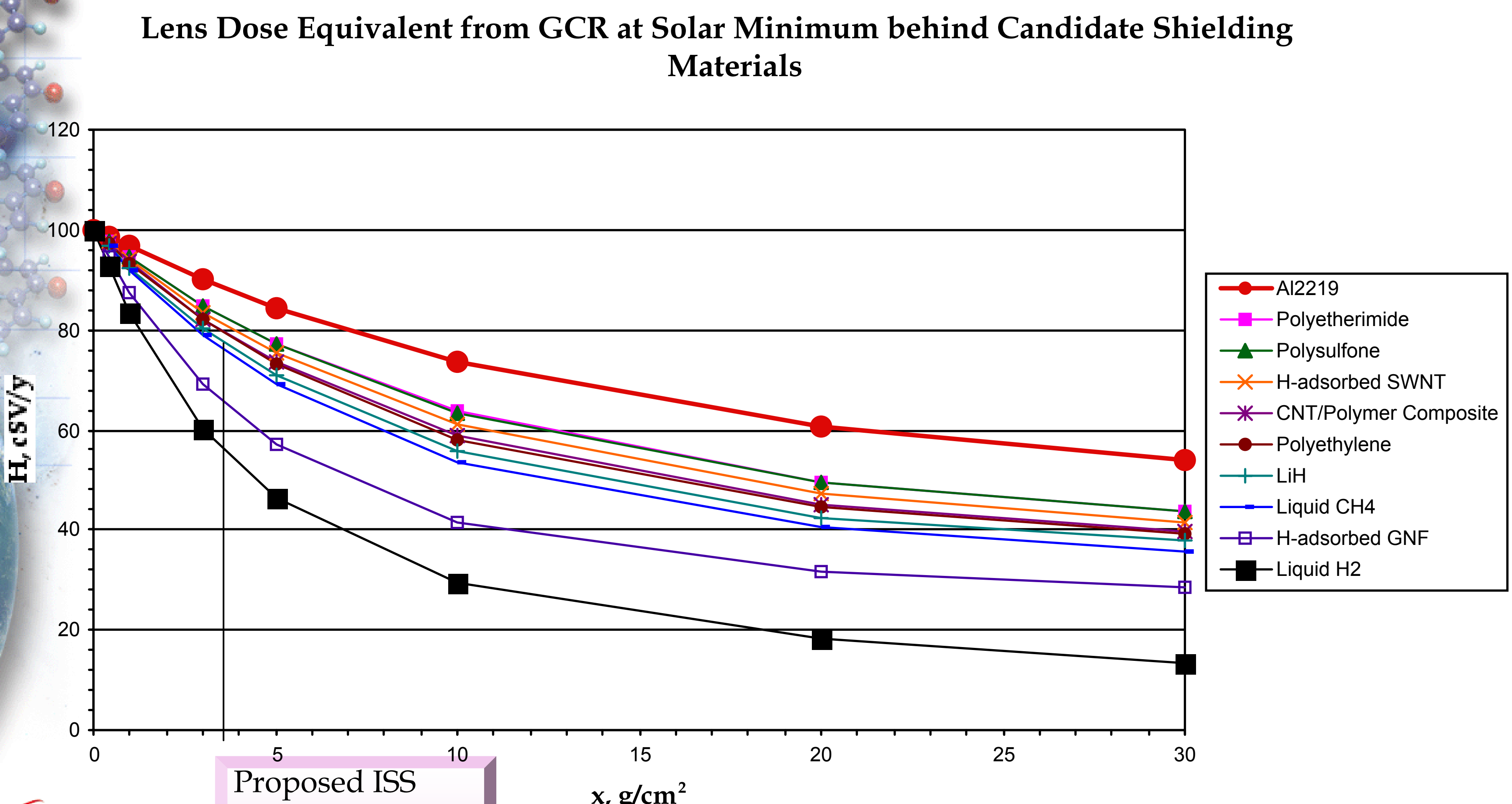
- Biomolecular risk prediction; molecular surveillance; genetic screening
- New structural materials with optimal shielding properties with significant improvement over aluminum
- Electromagnetic shields, including electrostatic, magnetic, and plasma shields from innovative propulsive techniques
- Pharmacology: antioxidants, antisense drug discovery, ribozymes; cell cycle modifiers
- Biomolecular intervention, such as stem cell replacement and gene therapy

Attacking the Radiation Challenge



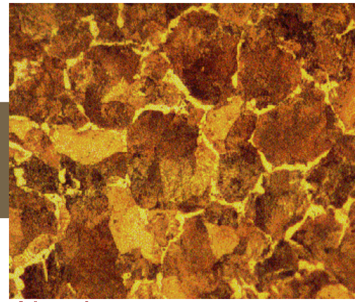
Evaluating Technology Investments

Example: Shielding Effects on Radiation



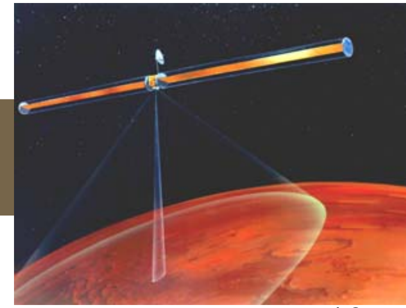
Proposed ISS sleeping quarters shield for 35% reduction

Materials Technologies

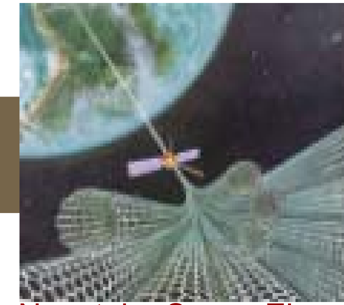


Aluminum

Now



Thin-film radar antenna *10 years*



Nanotube Space Elevator *20 years*

	Now	*10 years*	*20 years*
Application Missions	Small robotic missions International Space Station	Large-aperture robotic missions Light-weight launch vehicles	Low-mass, smart structures for human & robotic exploration
Strength-to-Mass Ratio	Aluminum - 1x	10x	1000x
Deployment.	Very low precision	Low precision	High precision structures
Embedded Elements	Antennas, some sensors	Add: Receivers, transmitters, interconnects	Add: Propulsion, processors, actuators, etc.

Leading Candidate Technologies:

- Carbon Nanotubes with up to 1000 times greater strength/mass
- Carbon nanotube microfibers with 40x stiffness/mass
- Thin-film materials with 1% nanotube whisker reinforced polymers results in dramatic improvement in thin film properties
- Wide bandgap semiconductors for high temperature environments, high-power circuitry, and high-strength MEMS devices
- Silicon carbide & elastomeric foams for self deploying & complex space structures
- Zeolites, carbon molecular sieves, etc. for in situ propellant production and air/water revitalization

Natural Benefits:

Benefits all facets of standard of living and national defense, such as medical, all forms of transportation, computing, energygenration and distribution, military vehicles, etc.

NEXT / THREADS R&T Approach: Progressive Exploration Capabilities

Downselect points for multiple technology development

Earth's Neighborhood Capability

- In-space propulsion, Isp>1000 sec
- Power systems, >200 w/kg
- Integrated Human/ robotic capabilities
- Crew countermeasures for 100 days
- Closed water/air systems
- Materials, factor of 9
- IVHM - Integrated vehicle health monitoring
- Current launch systems

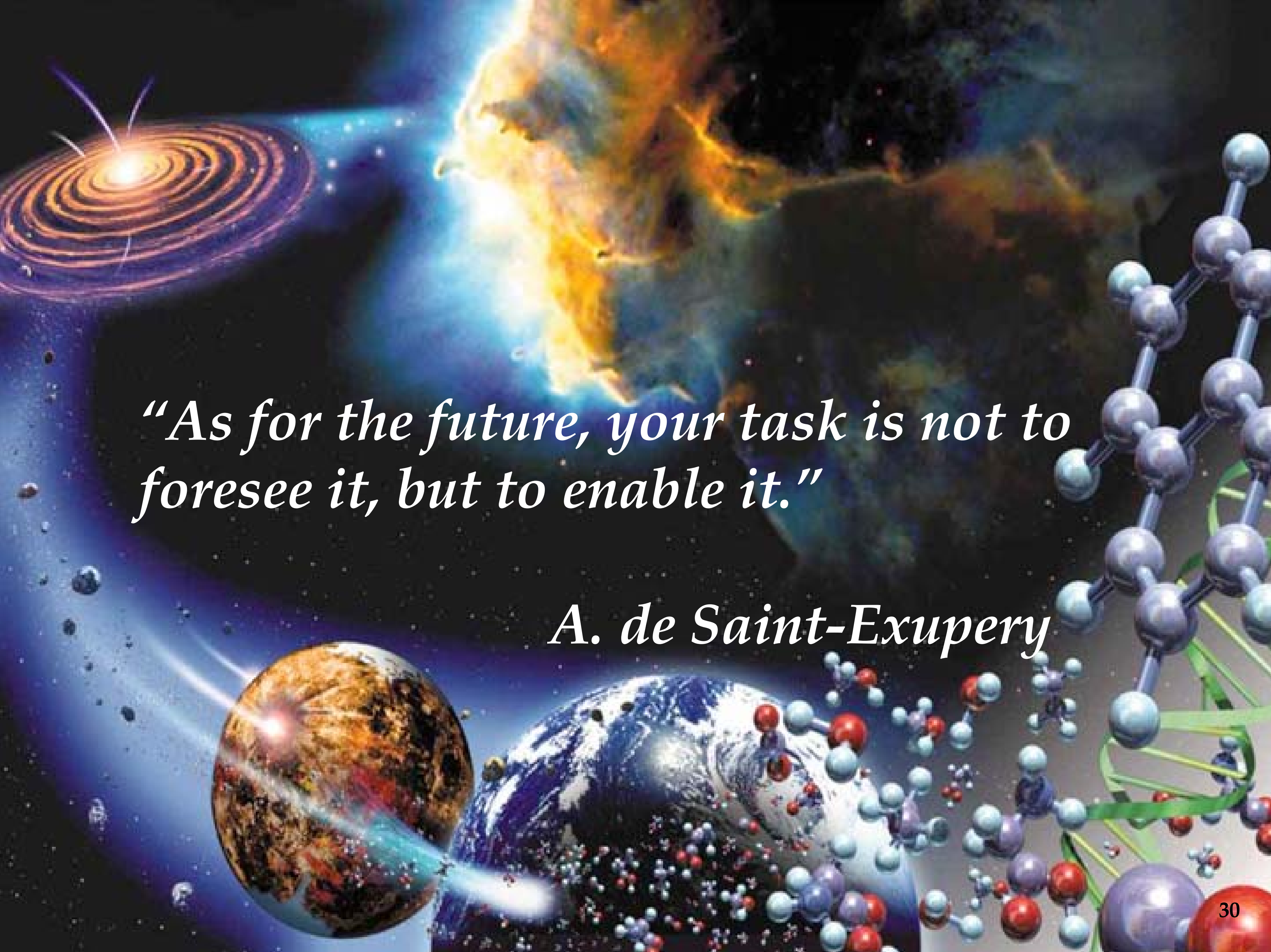
Accessible Planetary Surface Capability

- In-space propulsion, Isp>3000 sec
- Power systems, >500 w/kg
- Robotic aggregation/assembly
- Crew countermeasures for 1-3 years
- Closed life support
- Materials, factor of 20
- Micro-/Nano- avionics
- ETO @ ~$2000/kg

Sustainable Planetary Surface Capability

- In-space propulsion, Isp>3000 sec
- Sustainable power systems
- Intelligent systems, orbital and planetary
- Crew countermeasures for indefinite duration
- ISRU for consumables & spares
- Materials, factor of 40
- Automated reasoning and smart sensing
- ETO @ <$2000/kg

Now | 2010+ | 2020+ | 2030+


"As for the future, your task is not to foresee it, but to enable it."
A. de Saint-Exupery