Power and Computer Systems

Investigation into Interstellar Flight

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Wednesday, September 30th, 2009

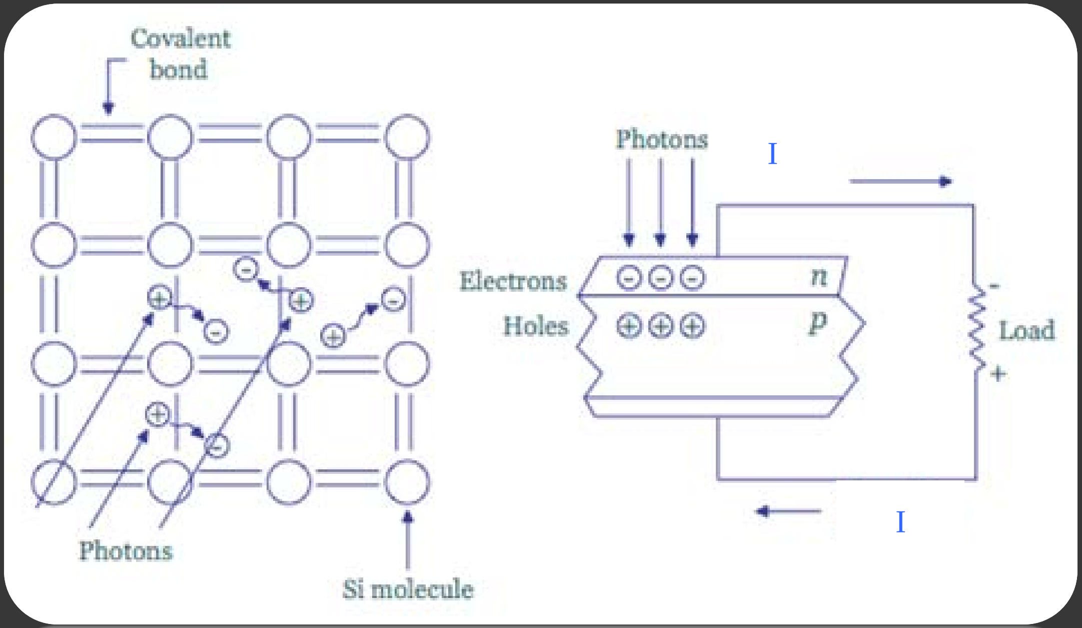
BIS Symposium | Daedalus: 30 Years Later

POWER SYSTEMS OVERVIEW

- Power Generation
- Electrical Power Conversion
- Power Storage
- Power Systems for Interstellar Missions

POWER GENERATION | SOLAR PV

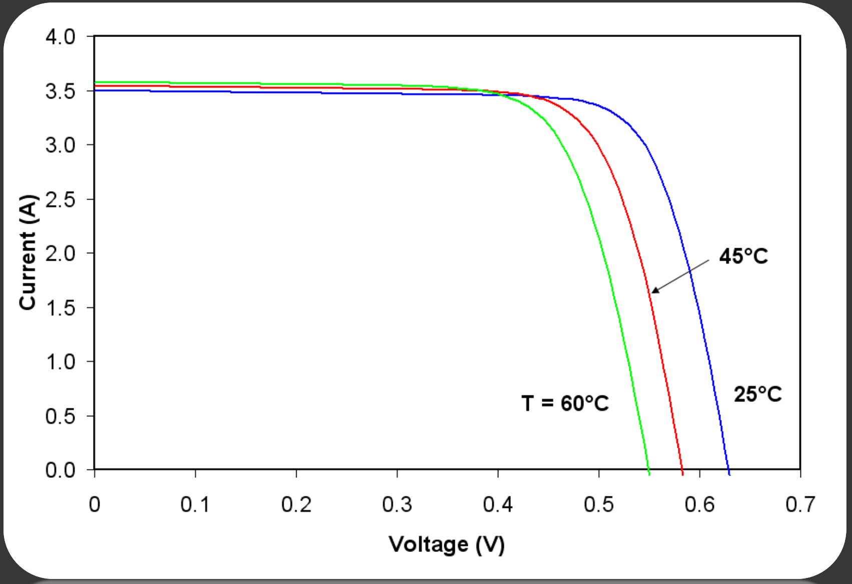
- Photovoltaics



Power Generation | Solar PV

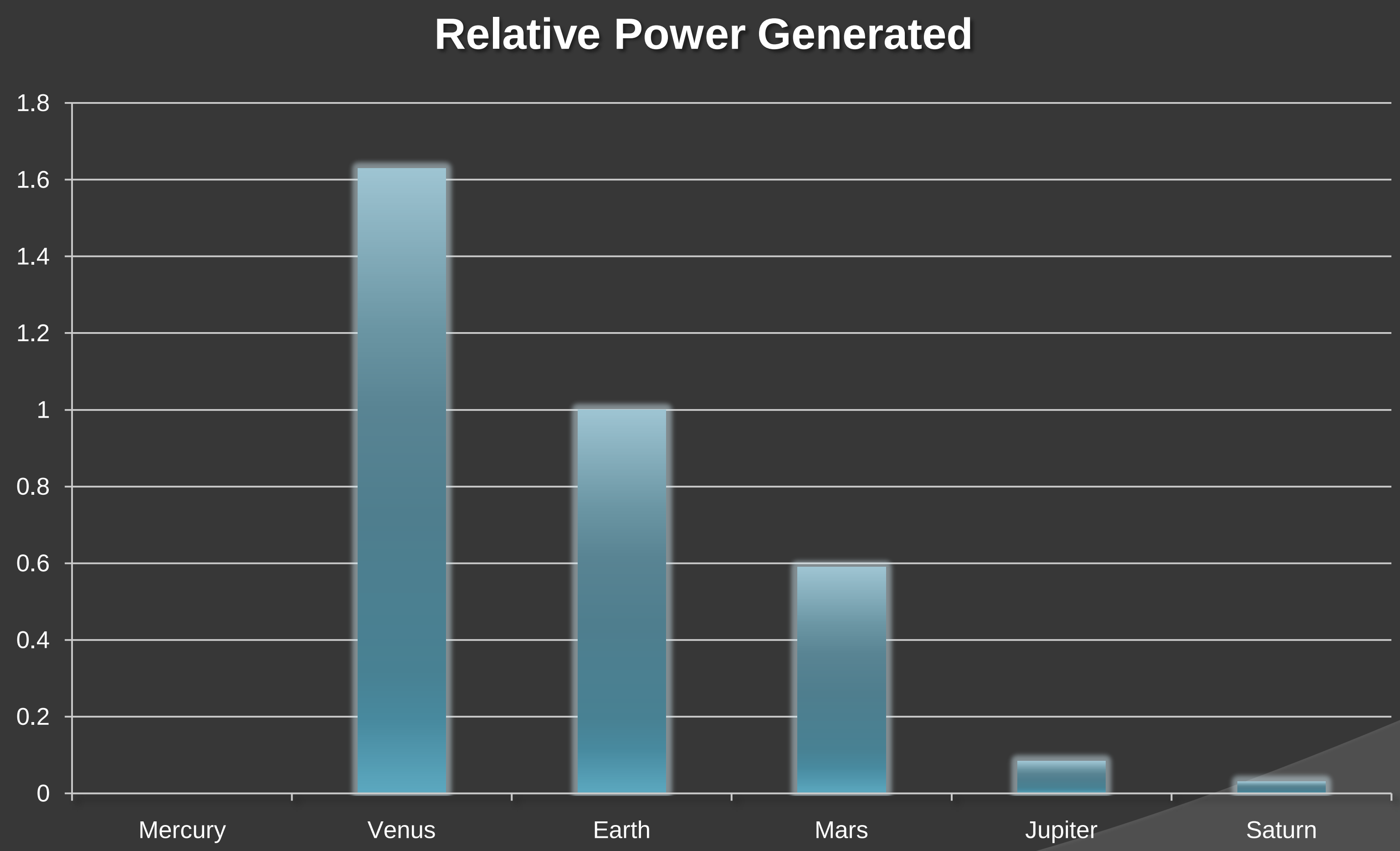
- Solar Flux

$$I = \frac{I_{Earth}}{R^{\alpha}}$$



- I_{Earth}=1358 W/m^2
- $\alpha \cong 1.5$

Power Generation | Solar PV



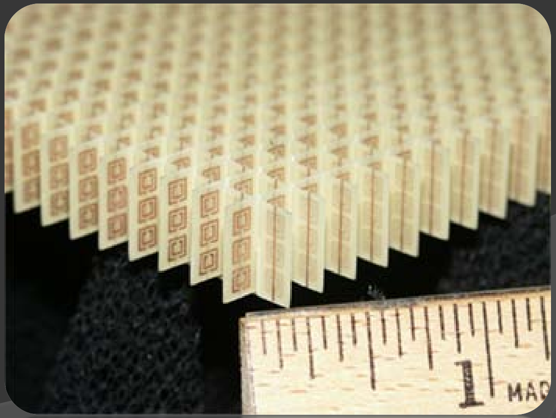
Power Generation | SemiConductor Materials

	Si	amorph Si	GaAs	InP	GaInP/GaAs
Theoretical efficiency	20.8%	12%	23.5%	22.8%	25.8%
Lab efficiency	20.8%	10%	21.8%	19.9%	25.7%
Survivability*	4 yr	4 yr	6 yr	89 yr	6 yr

* : time for 15% degradation, while in GSO (high radiation levels - 10 MeV electrons)

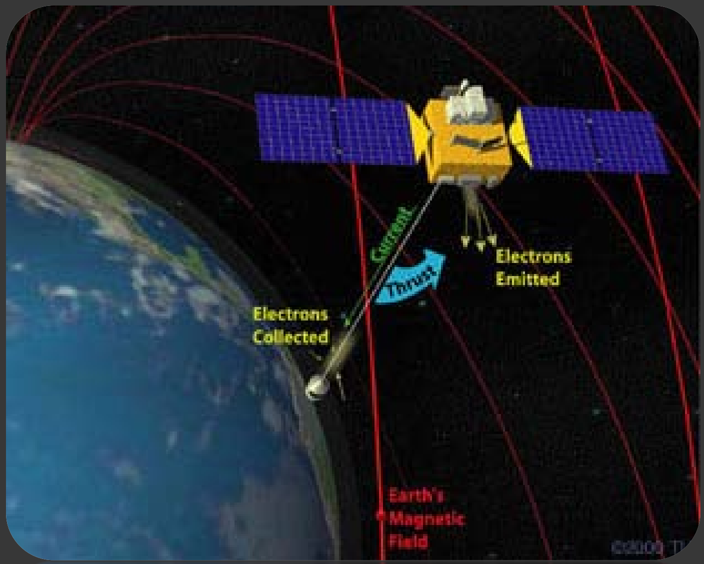
Power Generation | Solar Advances

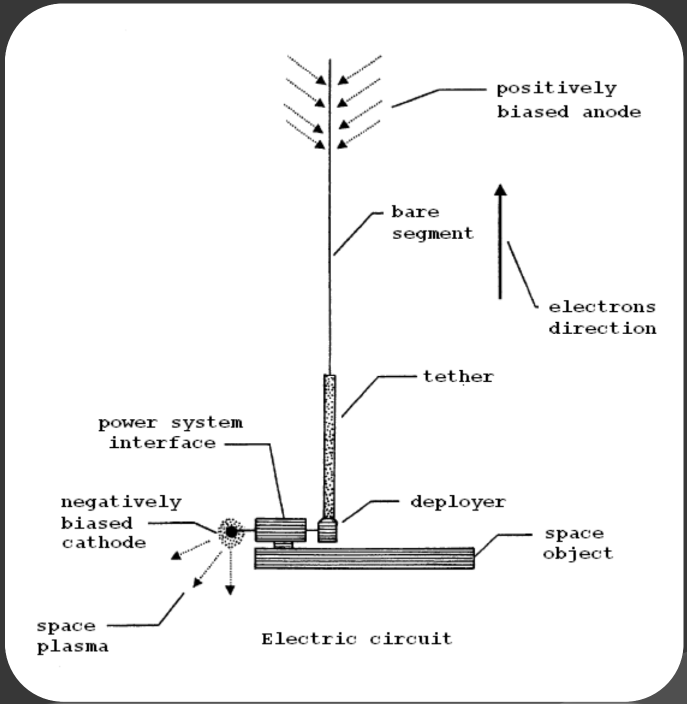
- Si processing refinement
- Thin-Film processing (flexible low cost cells)
- Metamorphic multijunction solar cells (NRAL, 40% efficiency)
- Conductive Organic Polymers
- Nanoparticle Processing (carbon nanotubes, quantum dots)
- IR Solar Cells (plastic sheets with nano-antennas)
- UV Solar Cells (permit optical wavelengths to pass)
- Antireflective, All-Angle coatings
- Metamaterials (absorb EM radiation)



Power Generation | Tethers

Tentative interest has been maintained in this technology.

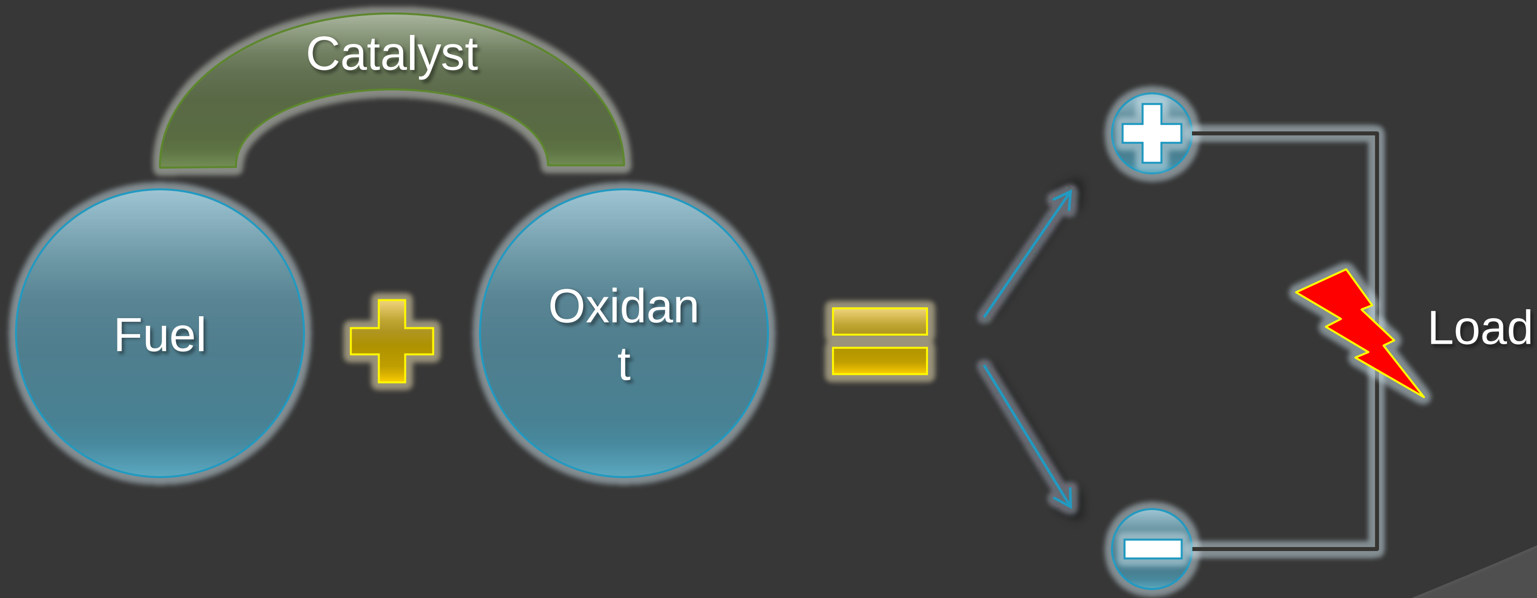




Appropriate for station keeping and supplementary power systems, for atmospheric mining platforms (Icarus).

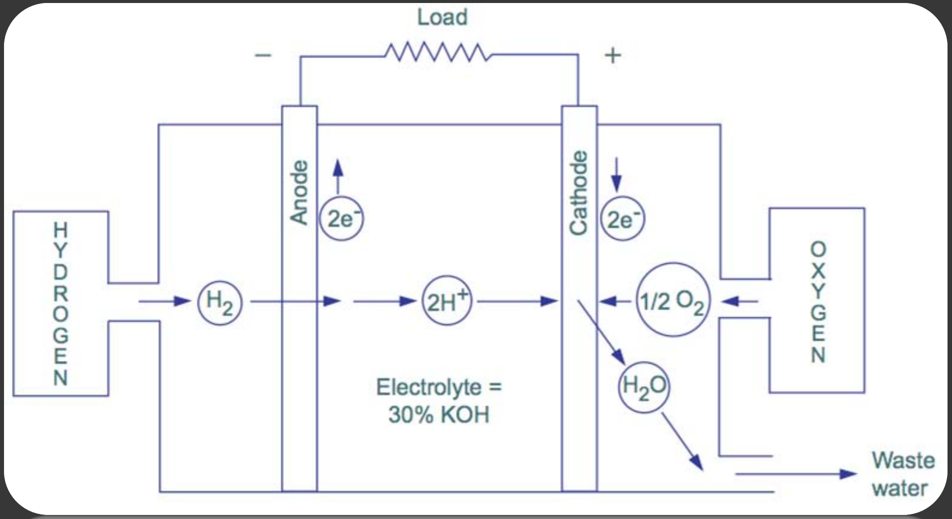
Power Generation | Fuel Cells

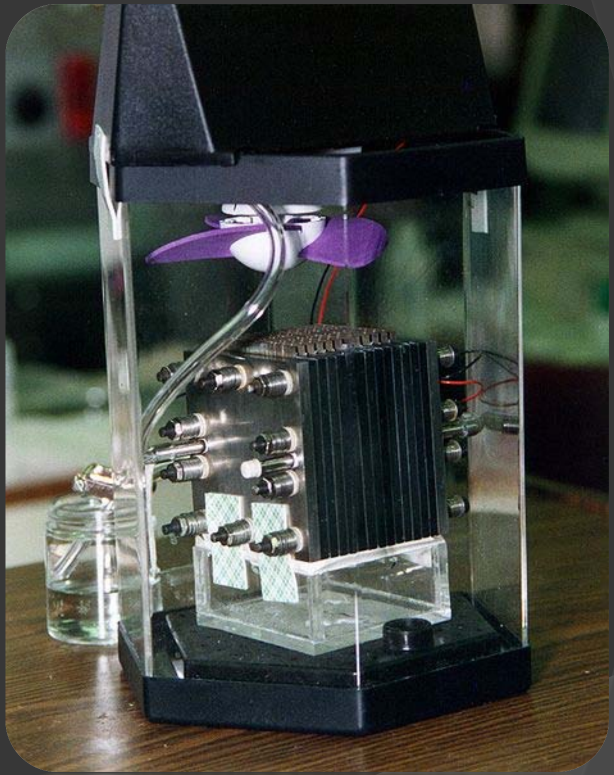
- A fuel cell is an electrochemical conversion device.



- Reaction is reversible, which allows for regenerative cells.

POWER GENERATION | FUEL CELLS

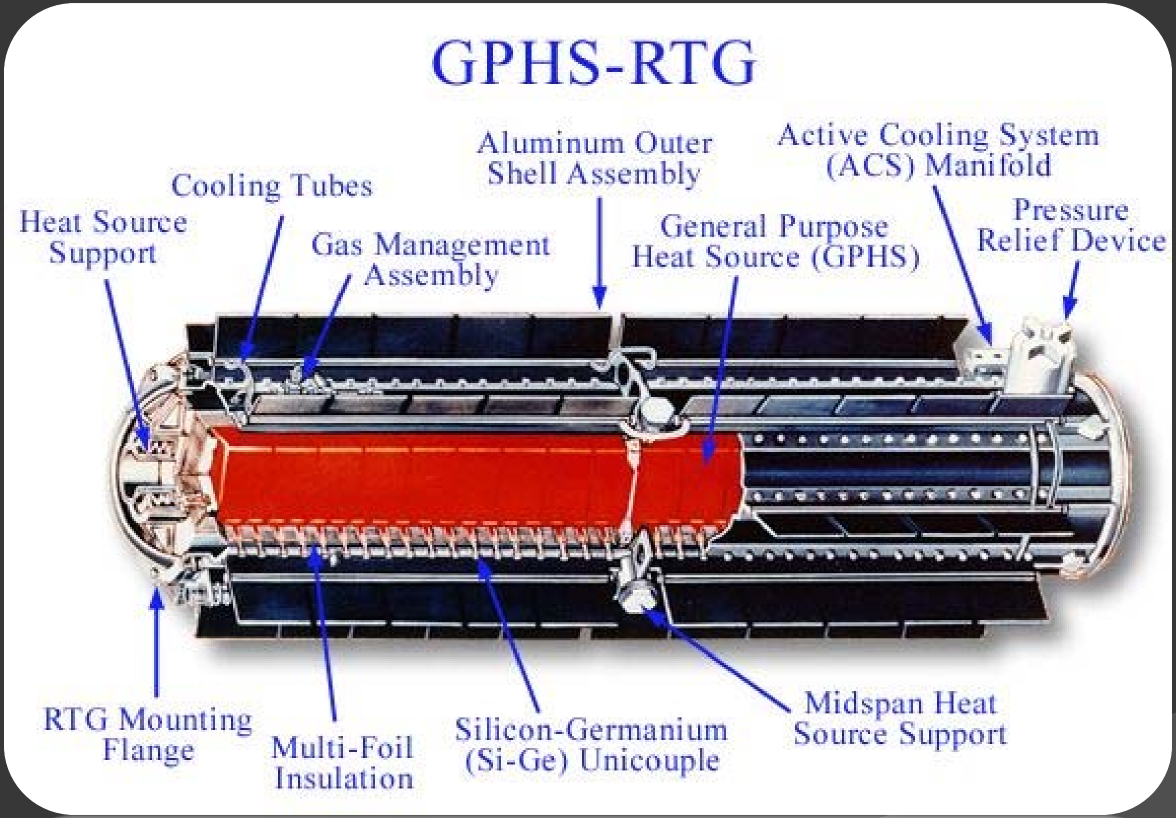




Mining gas planets gives easy access to large, renewable quantities of Hydrogen.

POWER GENERATION | RTGS

- RadioIsotope Thermoelectric Generators



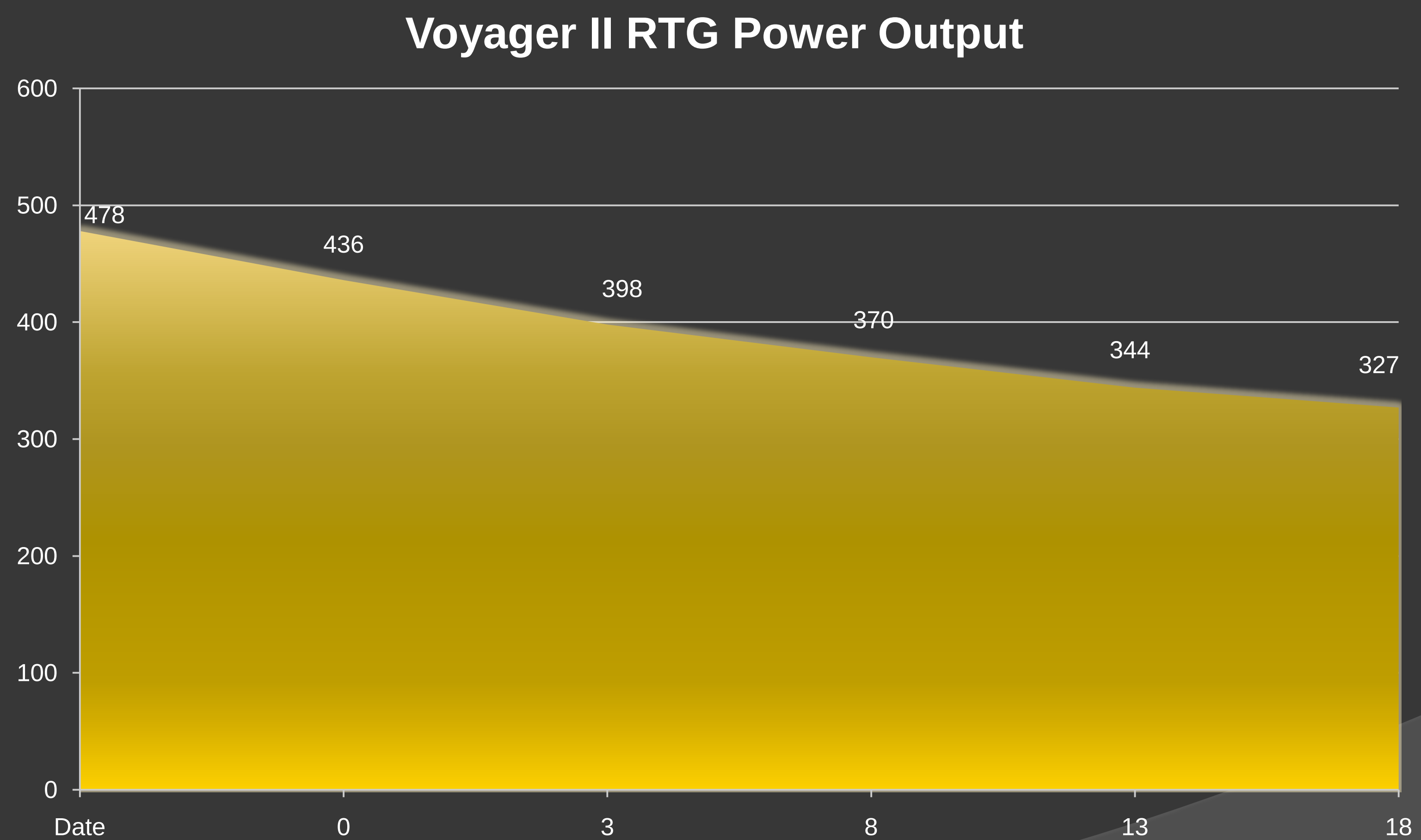
Power Generation | RTGs

- RadioIsotope/Heat Sources

Isotope	Half Life in years	Thermal Radiation per gram	Radiation level (Curie/W)
Curium-242	0.45	100	27
Strontium-90	28	0.25	153
Plutonium-238	86	0.55	30

A glowing red hot pellet of plutonium-238 dioxide.

Power Generation | Voyager II RTG

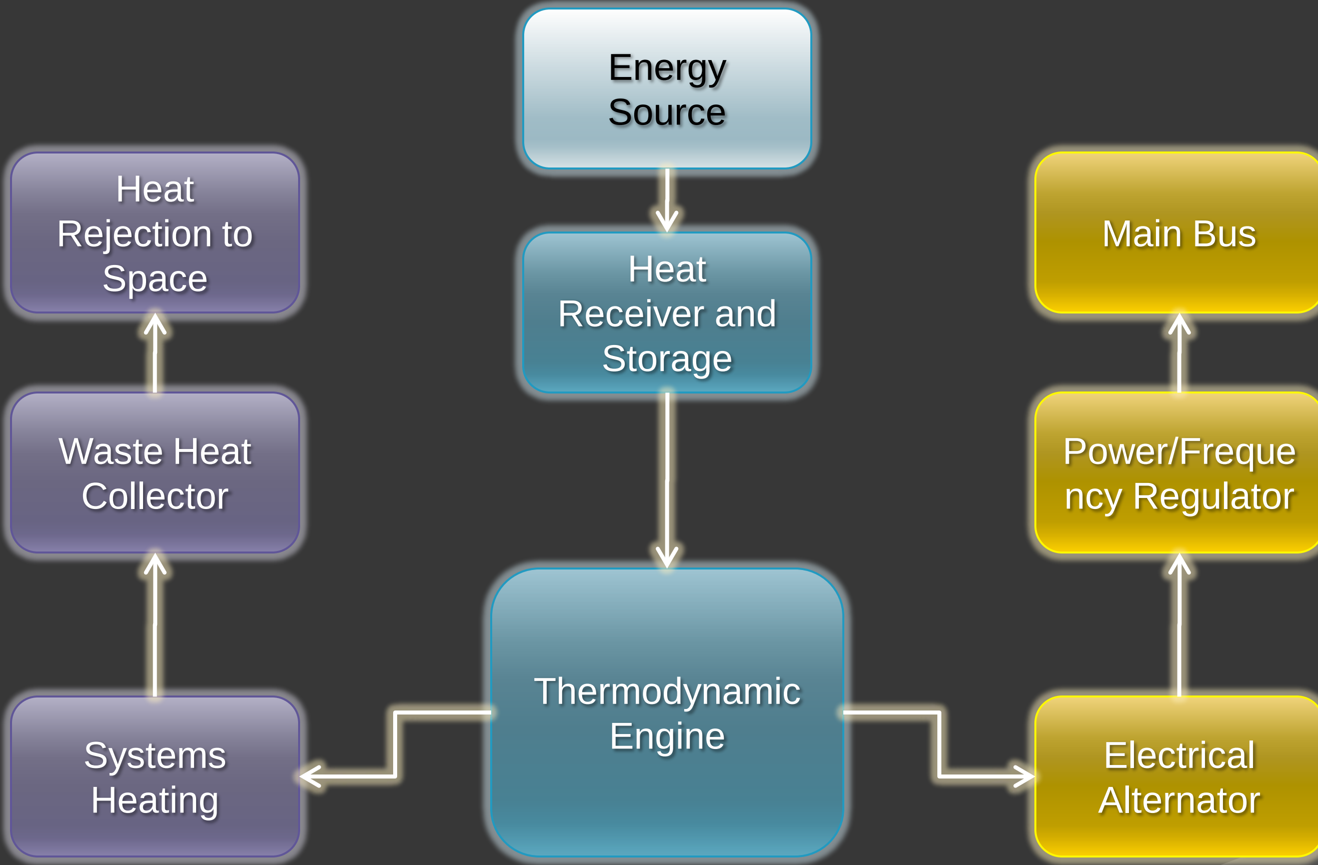


68% of initial power generation after 21 years

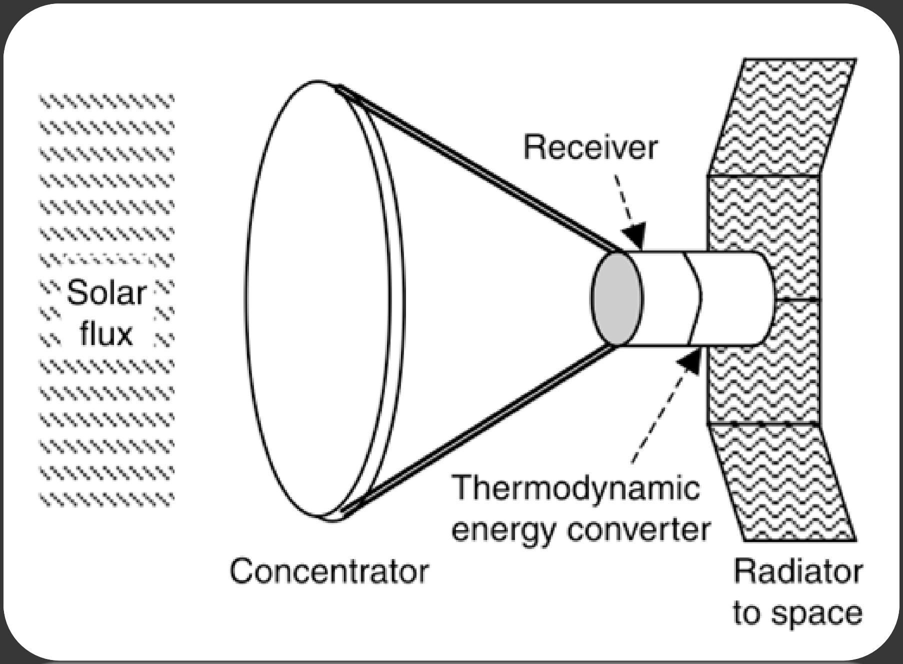
RTGs | Pros and Cons

Advantages	Disadvantages
•Long Lifetime •Invulnerable to high radiation fields •Long Mission lifetimes •Mature technology •Lightweight and Compact •High KW/Kg ratio •No moving parts •No maintenance	•Cannot be turned off •Must be continuously cooled •Spacecraft components must be shielded from radiation •Instruments must be shielded from IR interference •Low efficiency ~5% •Radioisotopes are very expensive

Dynamic Power Systems



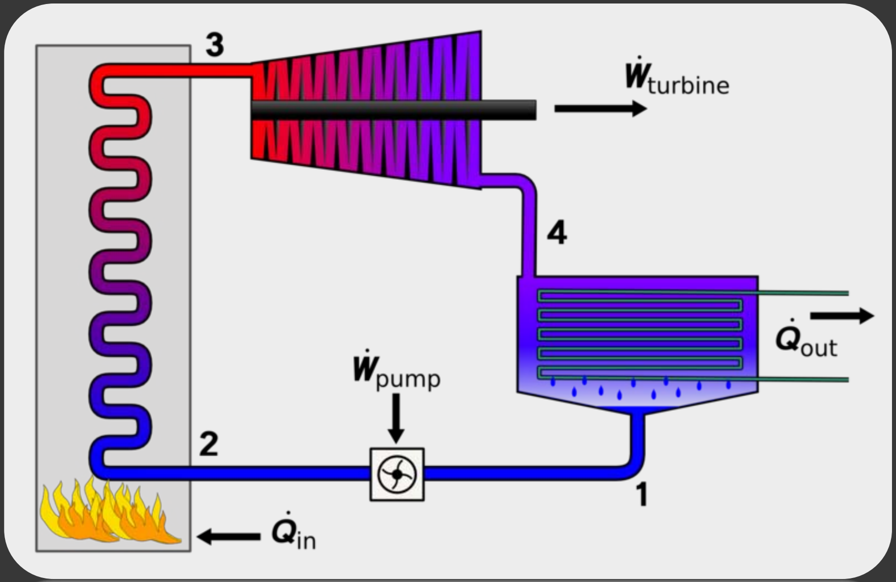
Power Generation | Solar Dynamic



The proposed ISS Solar Dynamic Power System

Power Conversion | Heat Exchange Cycles

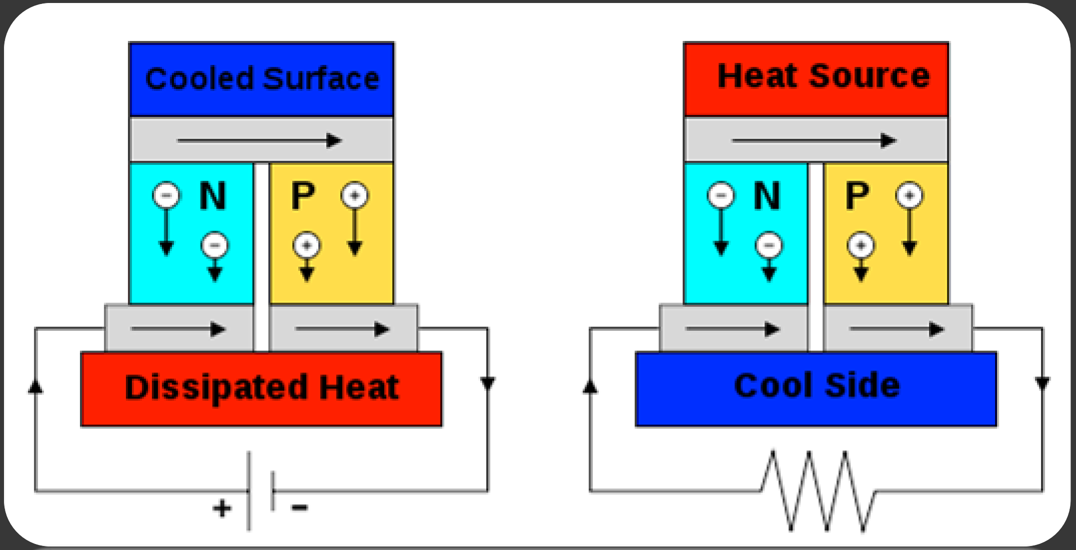
- Stirling
- Brayton
- Rankin



A liquid-metal potassium power conversion system has been outlined for use in space vehicles for human exploration of outer planets, by Adams et al, NASA (2003)

Power Conversion | Thermocouples

- Thermoelectric Effect



Add power to cool the plate (Peltier effect)

Add heat to get a voltage (Seebeck effect)

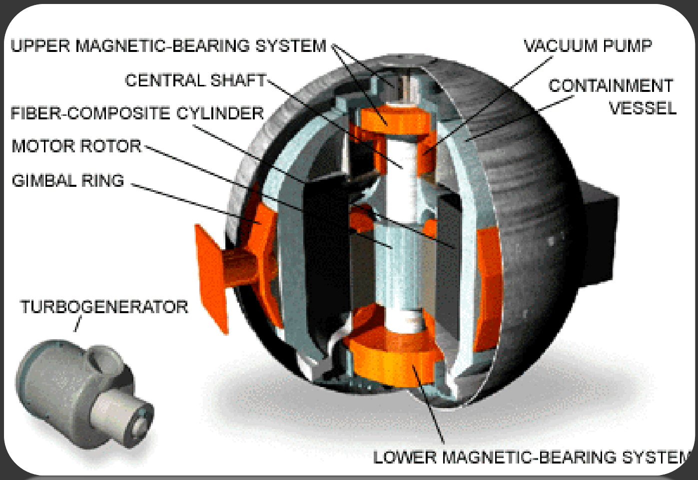
Power Storage | Batteries

	Silver zinc	Lithium sulfur dioxide	Lithium carbon monofluoride	Lithium thionyl chloride
Energy density (W h/kg)	130	220	210	275
Energy density (W h/dm^3)	360	300	320	340
Op Temp (deg C)	0-40	-50 – 75	? – 82	-40 – 70
Storage Temp (deg C)	0 – 30	0 – 50	0 – 10	0 – 30
Storage Life	30-90 days wet, 5 yr dry	10 yr	2 yr	5 yr
Open circuit voltage(V/cell)	1.6	3.0	3.0	3.6
Discharge voltage(V/cell)	1.5	2.7	2.5	3.2
Manufacturers	Eagle Pitcher, Yardley	Honeywell, Power Conver	Eagle Pitcher	Duracell, Altus, ITT

Deep cycle discharging can recondition batteries

Power Storage | Flywheels

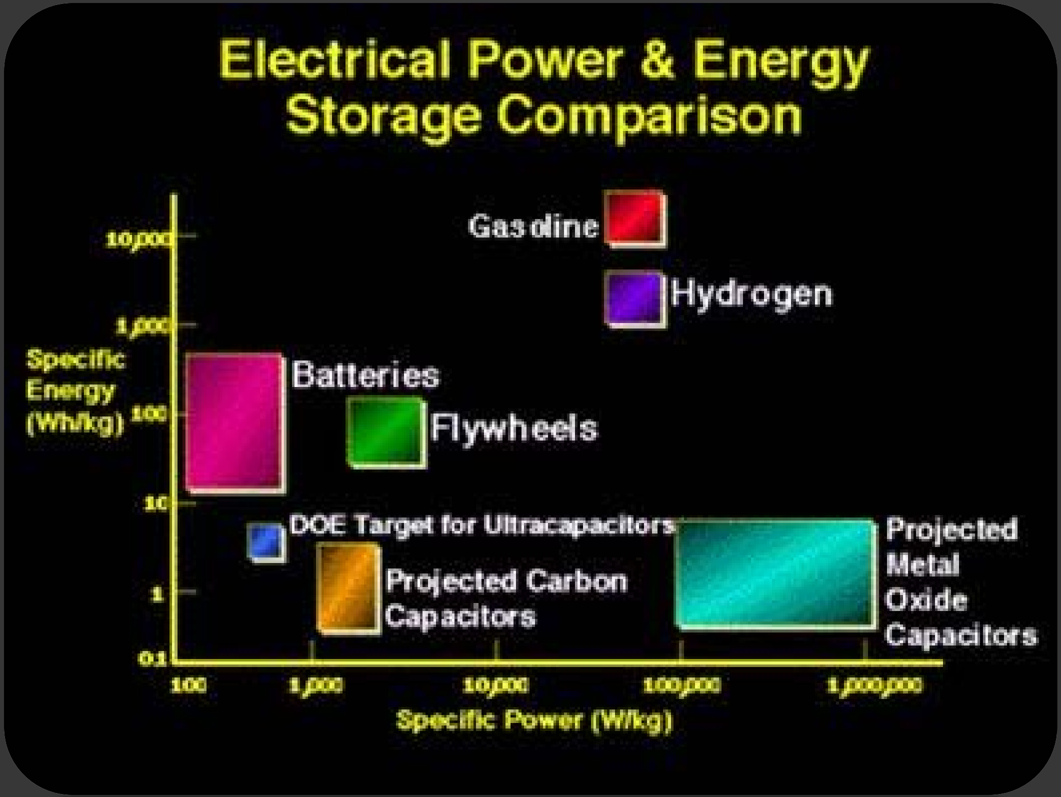
- Flywheels store KE and angular momentum.



NASA's G2 Flywheel Module

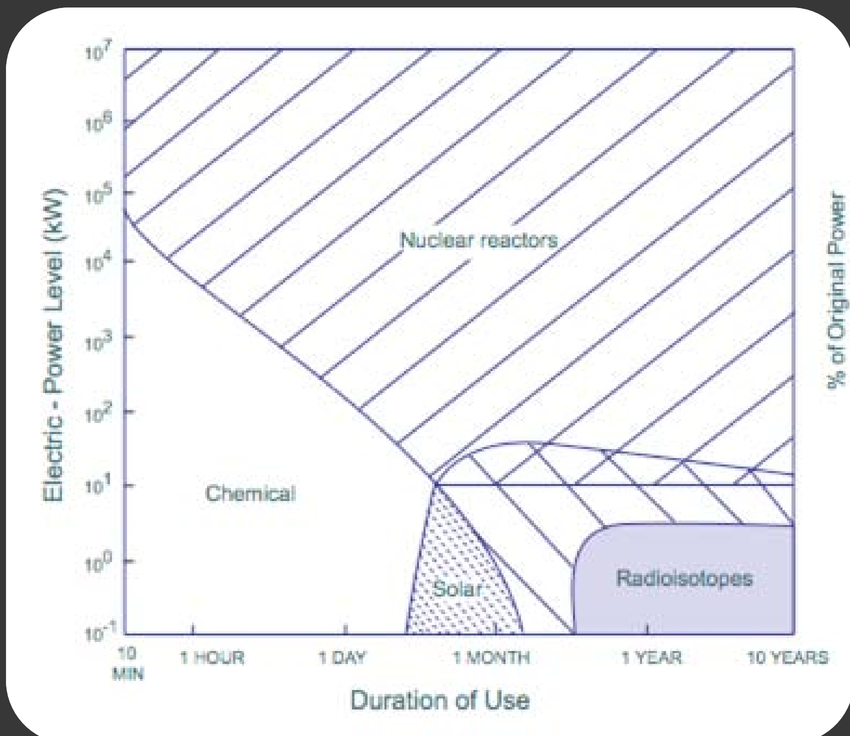
POWER STORAGE | CAPACITORS

- Supercapacitors and Ultracapacitors have capacities of 5-5000 Farad.



Maxwell Technologies new line of supercapacitors have up to 3 KF capacity and exhibit thermal stability.

Power For InterStellar Missions



Concerning Icarus

•A little bit of everything
•You don't have to take it all
•Fuel cells are great backup systems
•Flywheels keep what you would have wasted
•Wireless transmitters within S/C?
•Pulsed Fusion Microexplosion Engine with Thermocouples have the least moving parts.

Availability | Applicability | Resourcefulness | Invention | Adaptation

Computer Systems

Computer Systems | Responsibilities

- Nominal Operation
- Science
- Data Reduction/Storage
- Navigation/Attitude Control
- Communications
- Fault Control/Repair

Computer Systems | Deep Space Missions

- Very Long Flight Times
- Open Mission Profile
- Advanced Decision Tree
- Unmanned\Unserviceable

Computer Systems | Design Considerations

- No single point failure
- No single point repair
- Fault isolation/containment

Fault-Tolerance Starts With A Personality

Artificial	Biological
Self Repairing	Survival Instinct
Autonomous Design	Independence\Individuality
Vary Operational Goals	Choices\Curiosity
Online\Offline Processing	Conscious\Subconscious
Operational Overview of Subsystems\Probes	Maternal Instinct

Deep space processing only possible with rudimentary machine intelligence.

Computers | Achieving 99.99% Success Rate

- Fault Tolerance from System Integrity
- Uninterrupted Operation, even during rewrites\repairs
- Secure database of Mission profiles (constants\prime objectives)

Fault Recovery

- Double/Triple Modular Redundancy
- Rollback/Roll forward Conditioning

But how do these safety precautions affect the mission objectives?

Computers Systems | Operating Constraints

- Speed
- Memory
- Storage
- Redundancy
- Data Rate
- Failure Rate
- Power Usage

Computers Systems | Design for Reliability

- Improve programming reliability by simplifying code
- Sacrifice speed for reliability when necessary (i.e. TCP)
- Software design for asynchronous processing
  - Continuous monitoring
  - Performance evaluation
  - Seamless decision making \ protocol rewrites

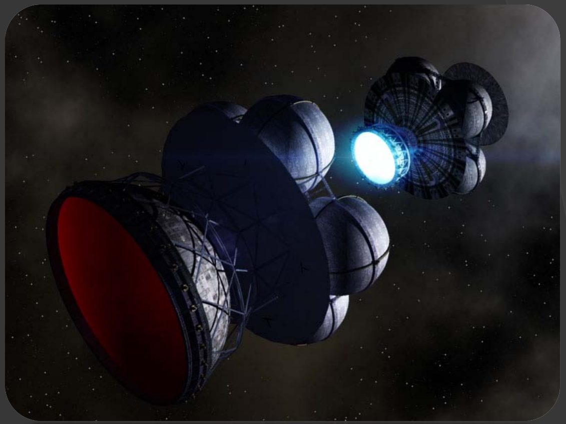
System Redundancy Testing

- N-model redundancy
- M out of N model redundancy

Model architecture performance by statistical methods.

Icarus Computer Design

- Distributive processing
- Identical computer subsystems
- All subsystems are full processing nodes
- All subsystems are interconnected
- All interconnects and switchable
- On failure, dormant systems take over
- Each system is capable of error checking, auditing and replacing each other



Simplicity above all

AD ASTRA INCREMENTIS ICARII !