Interstellar Travel

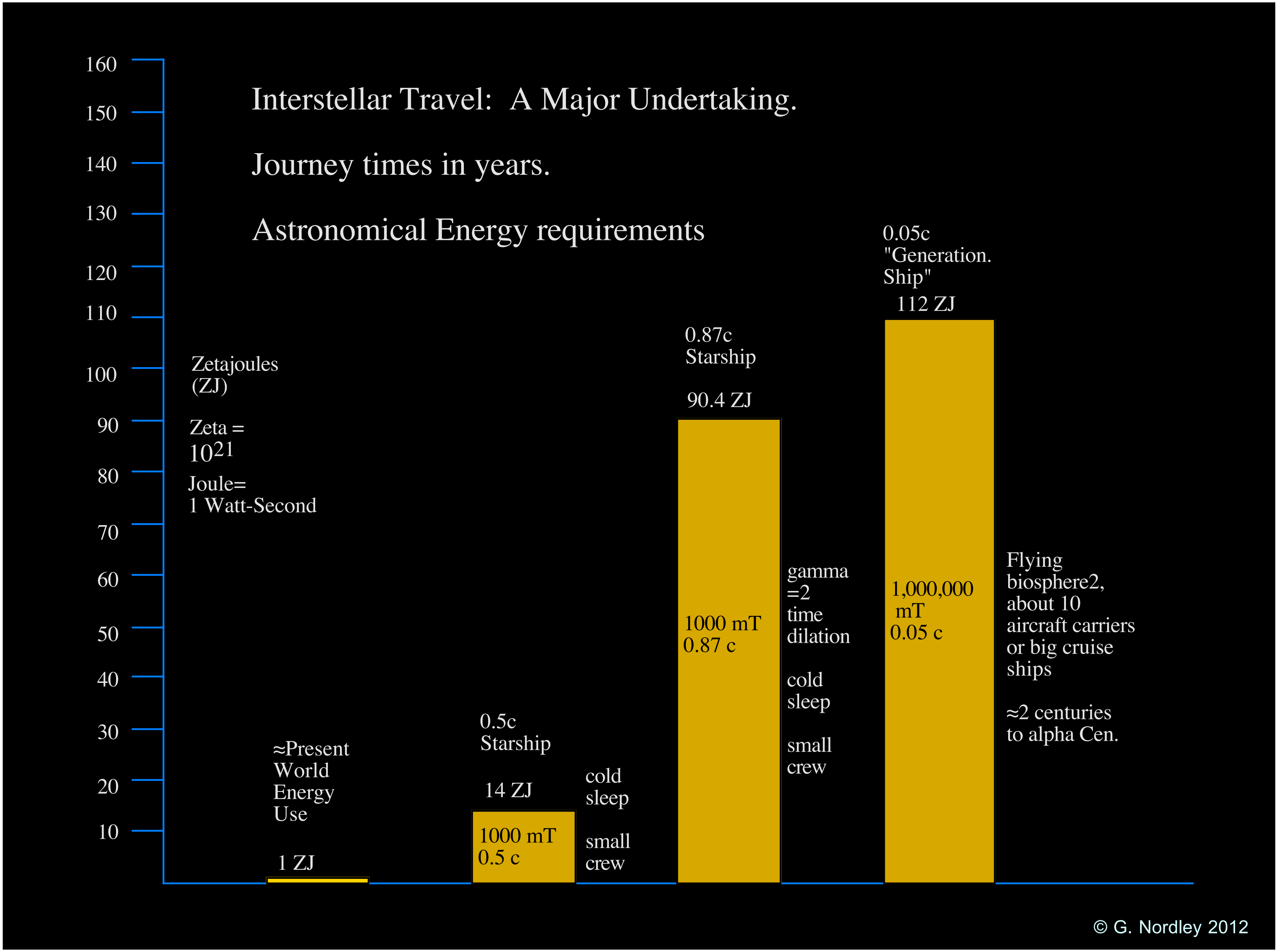
Why Interstellar Travel

Where Can We Go?

How Can We Get There

What Would an Interstellar Civilization Might Be Like

G. David Nordley
OryCon 2010


Interstellar Travel: A Major Undertaking.
Journey times in years.
Astronomical Energy requirements
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
Zetajoules (ZJ)
Zeta = 10^21
Joule= 1 Watt-Second
≈Present World Energy Use
1 ZJ
0.5c Starship
14 ZJ
1000 mT 0.5 c
cold sleep
small crew
0.87c Starship
90.4 ZJ
1000 mT 0.87 c
gamma =2 time dilation
cold sleep
small crew
0.05c "Generation. Ship"
112 ZJ
1,000,000 mT 0.05 c
Flying biosphere2, about 10 aircraft carriers or big cruise ships
≈2 centuries to alpha Cen.
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Why Interstellar Travel?

Provide realtime human guidance to exploration robots.

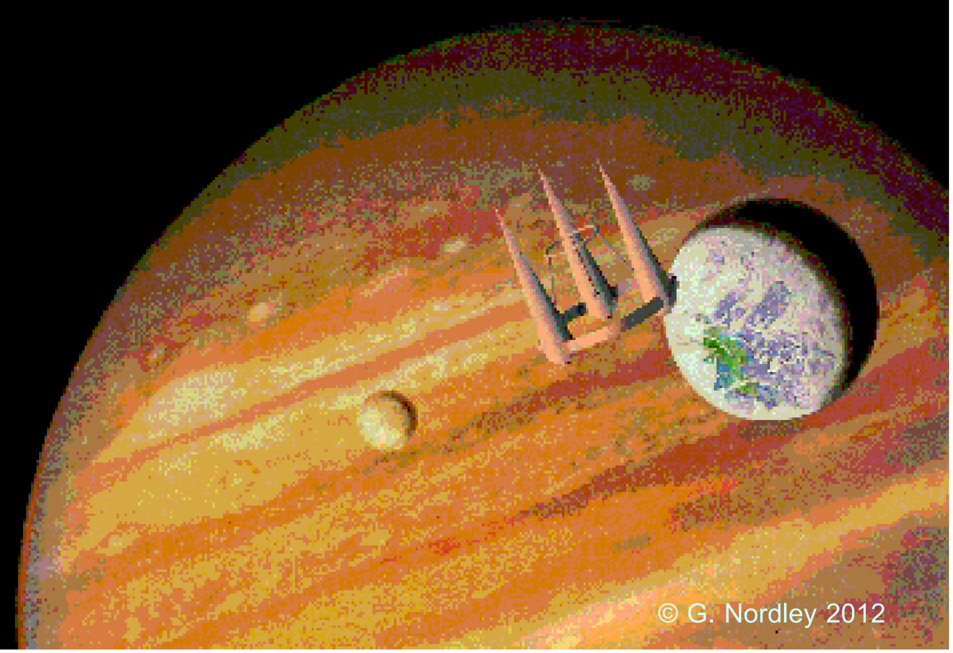
Entertainment value for actual and vicarious participants

Commerce? Unique artifacts?

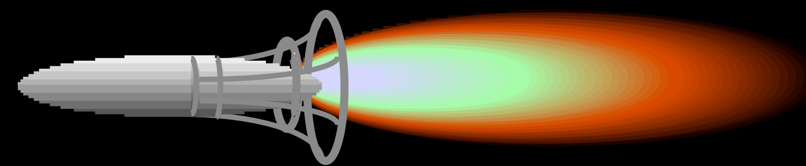
- Extrasolar artwork by aliens or human colonists?
- Archeological SETI exhibits for Earth museums

Not for...

Resources--much cheaper to
mine or make in the solar system



Extrasolar Colonies for More Living Room?



Short term:

--Isolation.

Some folks just can't get along

...or are tired of putting up with idiots.

--Empire building

No room on Earth for this antisocial occupation, but go grow your own?

Long term:

--External disasters we can't cope with otherwise? (When Worlds Collide)
we know Jupiter-sized rogue planets exist...

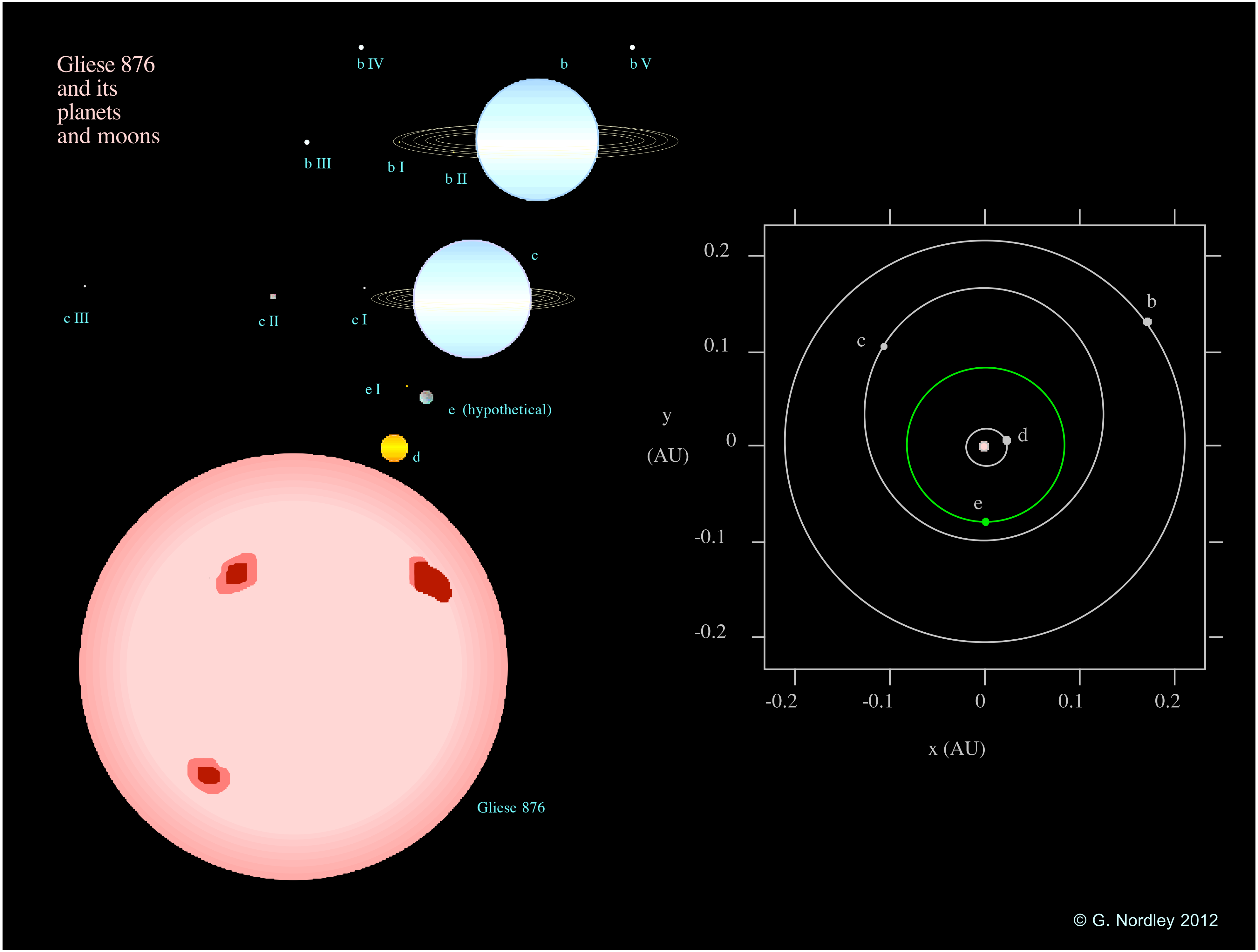
--Our habitable zone is moving out as the Sun ages and expands;

we might buy a few billion years with sunshields or moving Earth...

BUT red dwarfs last for around a trillion years.

Nearby Star Destinations

Name	Spectrum	Luminosity	Distance	"AU"	"year"	Comments
Sol	G2V	1	0	1	1	Ultraviolet an issue
Proxima Centauri	M5.5Ve	0.0007	4.223	0.026	0.014	Flares.
alpha Centuari A	G2V	1.55	4.394	1.25	1.32	Ultraviolet an issue.
alpha Centuari B	K1V	0.528	4.394	0.727	0.672	
Barnards Star	M4Ve	0.003	5.938	0.057	0.034	Flares.
Wolf 359	M5Ve	0.0002	7.674	0.014	0.007	Flares.
Lalande 21185	M2V	0.026	8.309	0.162	0.114	Flares.
UV Ceti A	M5V	0.001	8.561	0.031	0.017	Flares.
UV Ceti B &C?	M5Ve	0.0006	8.561	0.024	0.013	Flares.
Sirius A	A1V	23.5	8.601	4.84	7.2	Stable orbits difficult, deadly UV
Sirius B	B9VII	0.003	8.601	0.057	0.035	White Dwarf Deadly UV.
Ross 154	M3.5Ve	0.002	9.693	0.046	0.027	Flares.
Ross 248	M5Ve	0.001	10.35	0.033	0.018	Flares.
epsilon Eridani	K2V	0.346	10.5	0.588	0.516	Young: flares, radioactivity, eccent. Jovian
Luyten 789-6	M5.5Ve	0.002	10.87	0.04	0.023	Flares.
Ross 128	M4Vfl	0.003	10.89	0.051	0.030	Flares.
61Cygni A	K5V	0.137	11.36	0.37	0.289	
61Cygni B	K7V	0.085	11.43	0.291	0.214	
Procyon A	F5V-IV	7.17	11.41	2.68	3.43	Stable orbits difficult, deadly UV
Procyon B	A5VII	0.0007	11.41	0.026	0.014	White Dwarf. Deadly UV.
Gliese 725B	M3.5V	0.009	11.47	0.097	0.063	
Gliese 725A	M4V	0.022	11.64	0.148	0.102	
Groombridge 34A	M1V	0.024	11.64	0.154	0.107	
Groombridge 34B	M3.5Ve	0.003	11.64	0.053	0.032	Flares
Lacaille 9352	M0.5V	0.042	11.69	0.204	0.148	
epsilon Indi	K4.5V	0.221	11.83	0.47	0.390	
tau Ceti	G8V	0.466	11.9	0.682	0.621	
Luyten 725-32	M4.5Ve	0.002	12.12	0.048	0.029	Flares.
Luytens Star	M3.5V	0.009	12.39	0.095	0.062	
Kapteyns Star	M1VI	0.013	12.78	0.116	0.077	
Lacaille 8760	K7Vfl	0.059	12.87	0.243	0.175	
Kruger60A	M3V	0.012	13.07	0.109	0.073	Flares.
Kruger60B	M3V	0.006	13.07	0.079	0.050	Flares.
Gliese 876	M2V	0.012	15.33	0.109	0.064	Hot Neptune, 2 "warm" Jupiters
Groombridge 1618	K5V	0.074	15.89	0.271	0.196	
Luyten 354-89	M1.5V	0.029	16.11	0.172	0.121	
70 Ophiuchi A	K0V	0.495	16.39	0.703	0.645	
70 Ophiuchi B	K4V	0.118	16.39	0.343	0.263	
40 Eridani A	K1V	0.434	16.45	0.659	0.595	
40 Eridani B	A7VII	0.003	16.45	0.056	0.034	White Dwarf Deadly UV
40 Eridani C	M5.5V	0.006	16.45	0.08	0.051	


Gliese 876
and its
planets
and moons
b IV
b
b V
b III
b I
b II
c
c III
c II
c I
e I
e (hypothetical)
d
Gliese 876
0.2
0.1
0
-0.1
-0.2
y
(AU)
b
c
d
e
-0.2
-0.1
0
0.1
0.2
x (AU)
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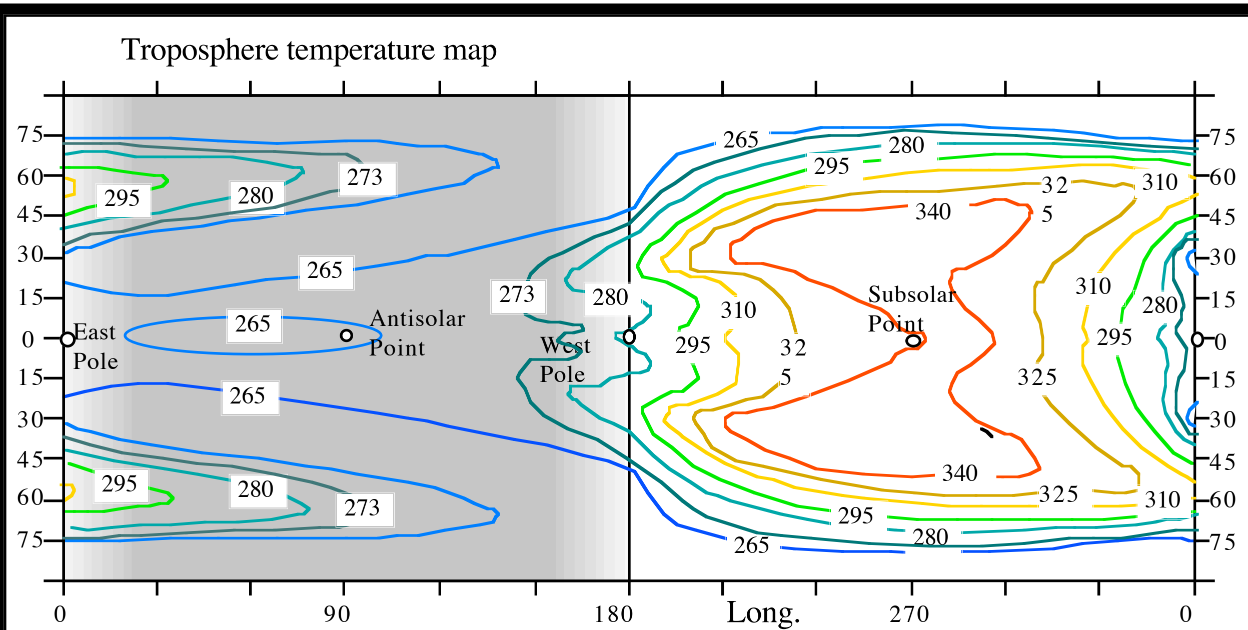
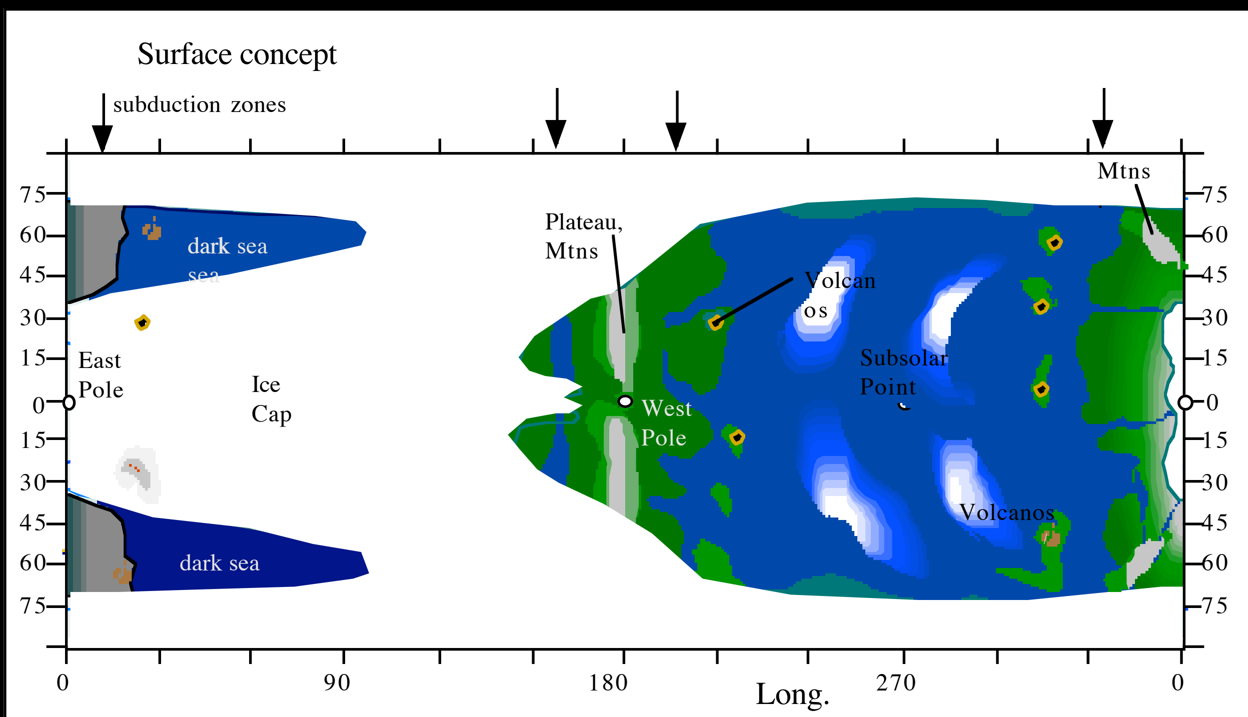
TIDE LOCKED

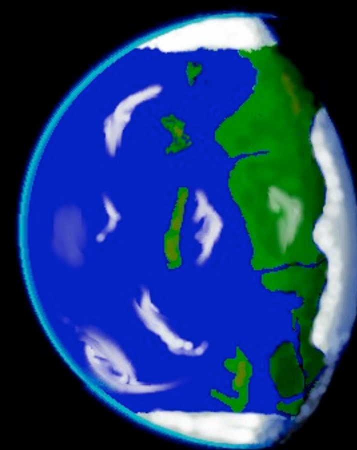
HABITABLE

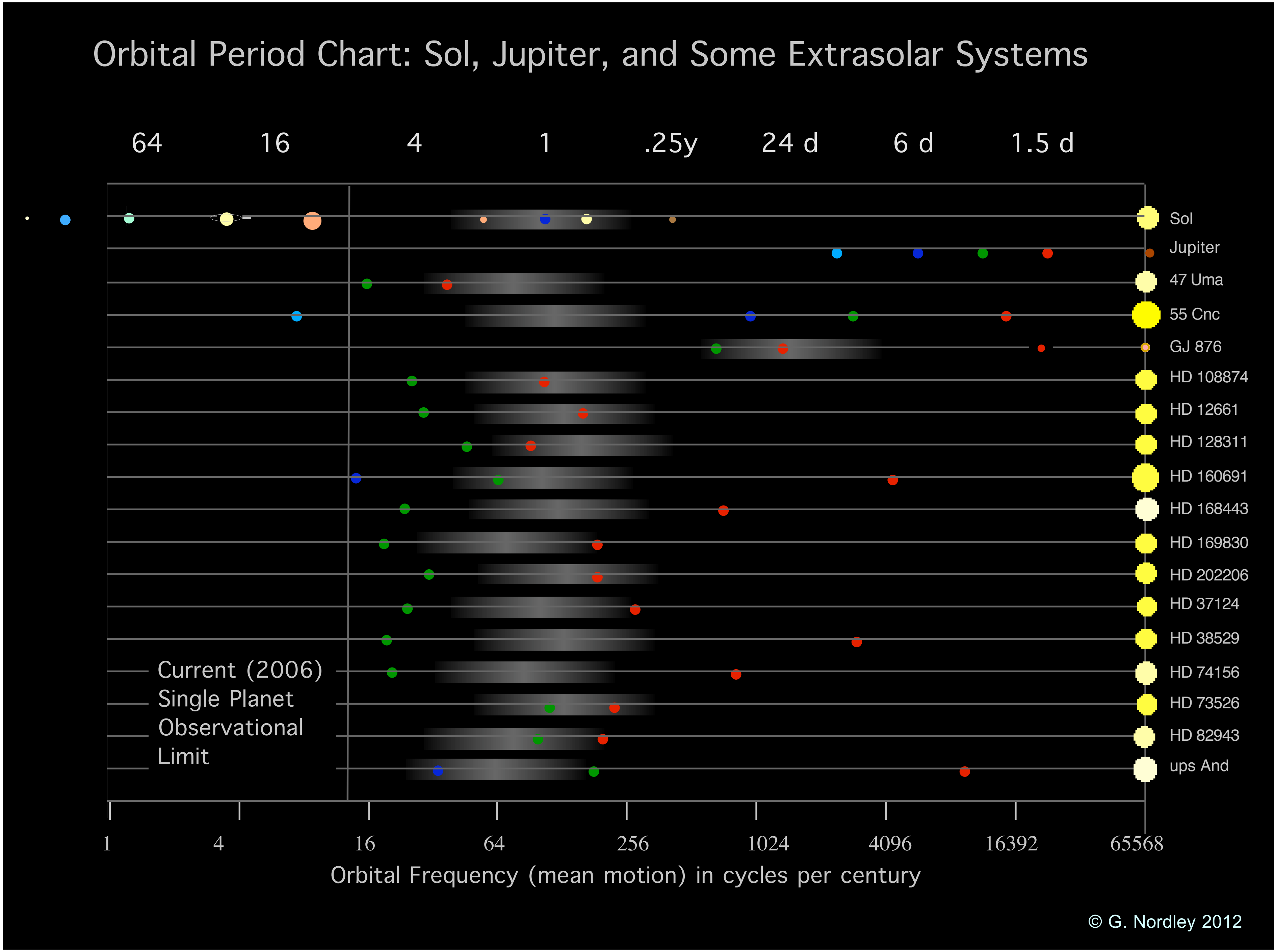
PLANETS



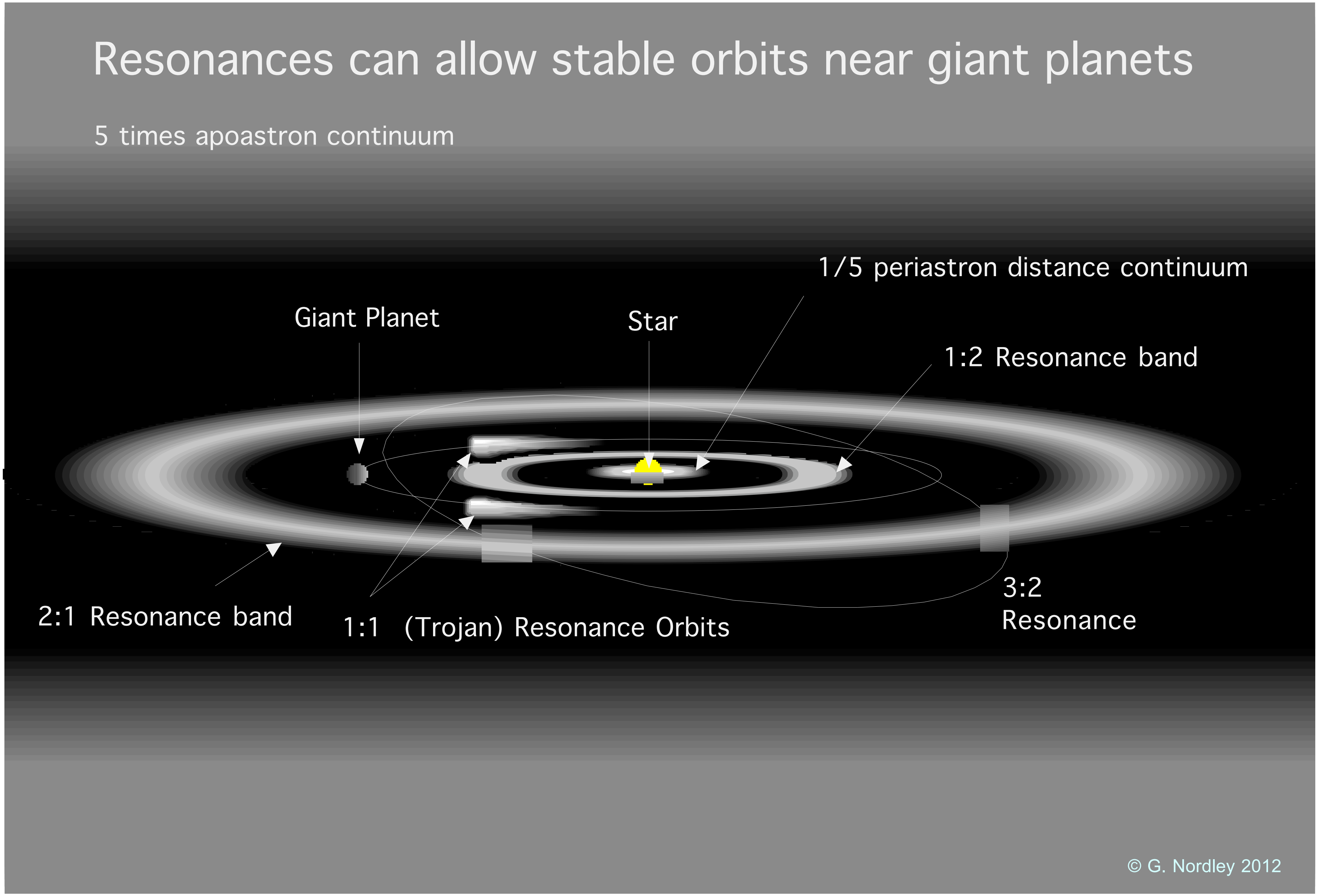
After Merlis and Schneider, 2010



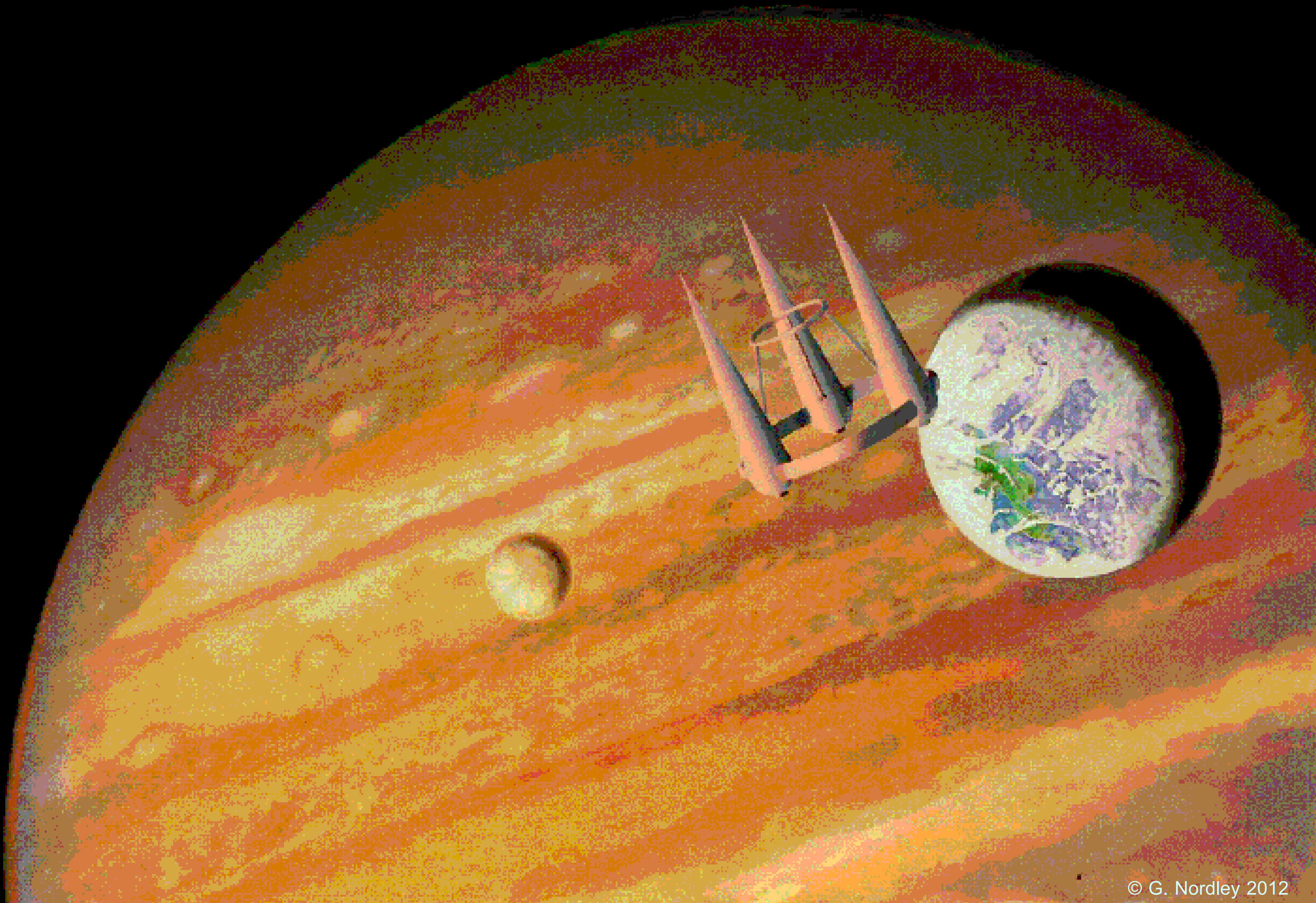




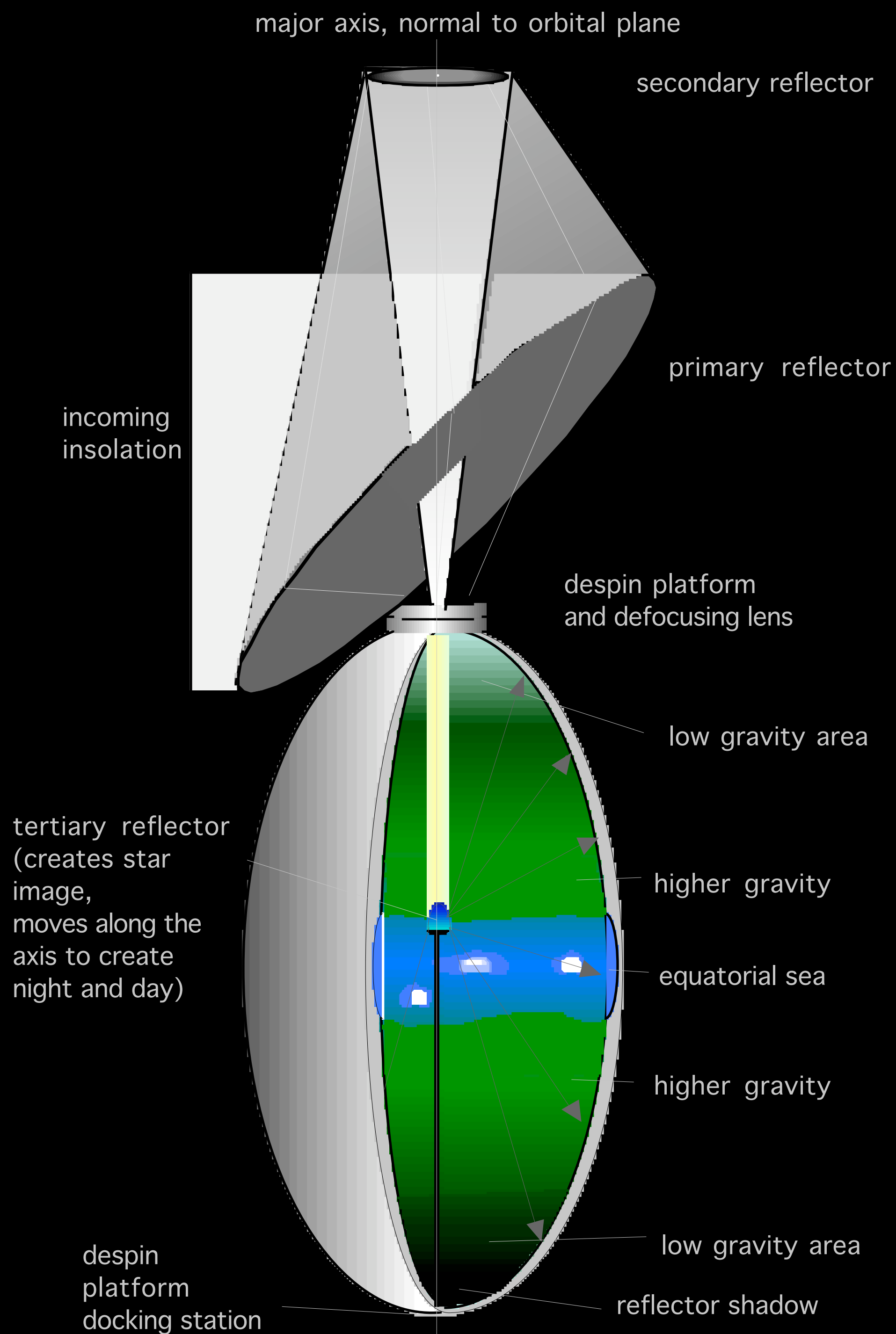
Orbital Period Chart: Sol, Jupiter, and Some Extrasolar Systems
64
16
4
1
.25y
24 d
6 d
1.5 d
Sol
Jupiter
47 Uma
55 Cnc
GJ 876
HD 108874
HD 12661
HD 128311
HD 160691
HD 168443
HD 169830
HD 202206
HD 37124
HD 38529
HD 74156
HD 73526
HD 82943
ups And
Current (2006)
Single Planet
Observational
Limit
1
4
16
64
256
1024
4096
16392
65568
Orbital Frequency (mean motion) in cycles per century
© G. Nordley 2012


Resonances can allow stable orbits near giant planets
5 times apoastron continuum
1/5 periastron distance continuum
Giant Planet
Star
1:2 Resonance band
2:1 Resonance band
1:1 (Trojan) Resonance Orbits
3:2
Resonance
© G. Nordley 2012

Habitable or Terraformable Moons?




G. Nordley 2003



Star travelers

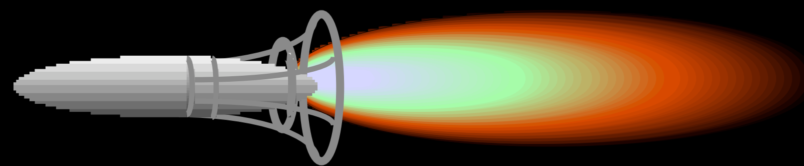
may make their

own worlds from

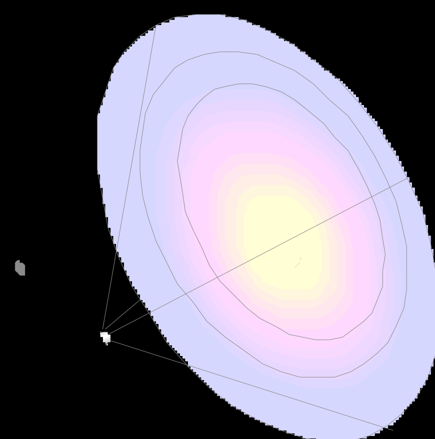
local resources.

HOW DO WE GET THERE?

--ROCKETS



--SAILS



Interstellar Flight: Energy, Velocity, Time

$$KE = m\,c^2\,(\,\gamma - 1\,) \qquad \gamma = \sqrt{(\,1/(1 - v^2/c^2)}$$

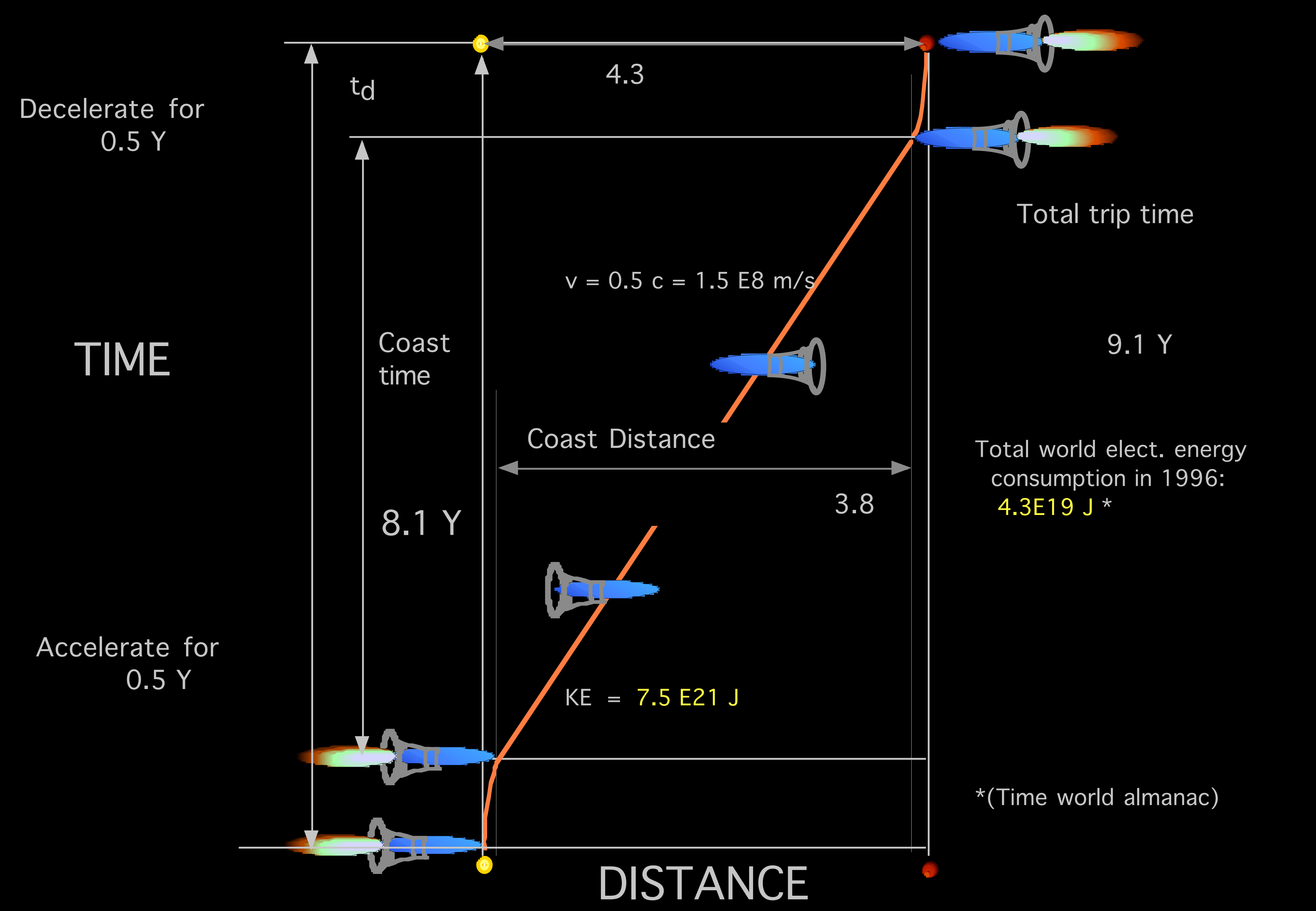
KE = Kinetic Energy γ = Lorentz factor m = mass v= velocity

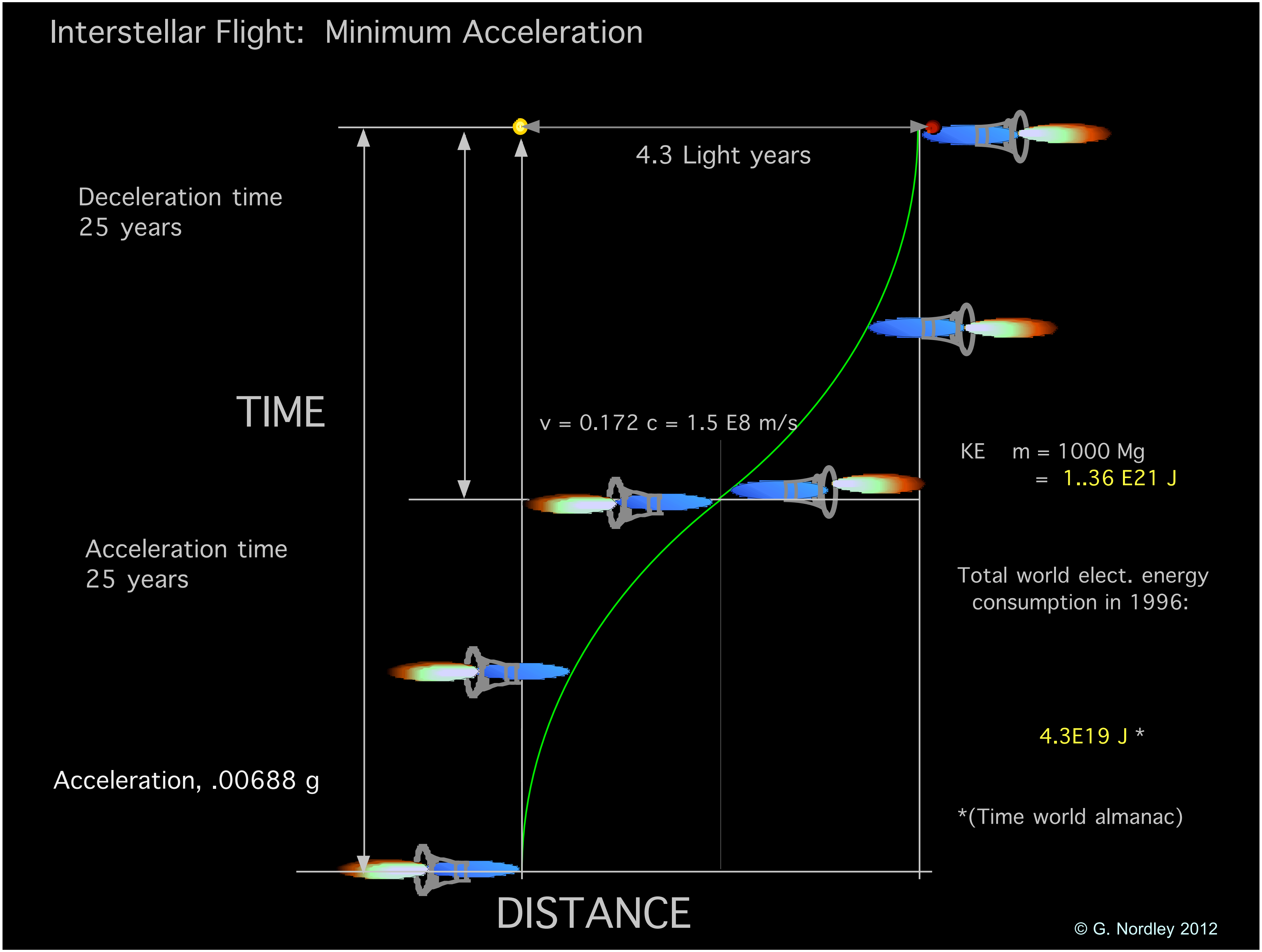
For constant acceleration a in the spaceship frame

distance $s = c^2(\gamma - 1)/a \quad = \quad KE/(m*a)$

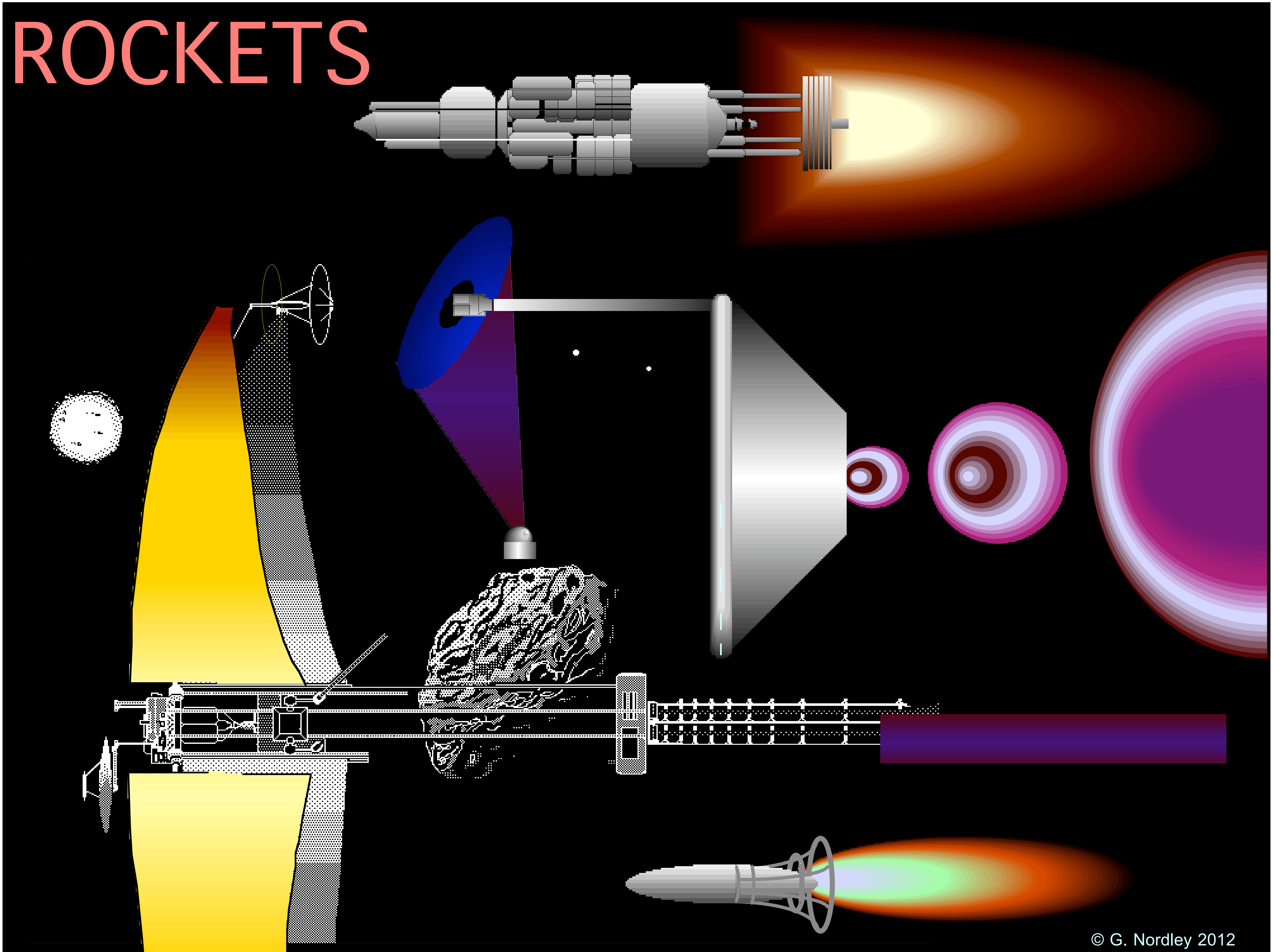
acceleration time $\Delta t = v/a + v*s/c^2$

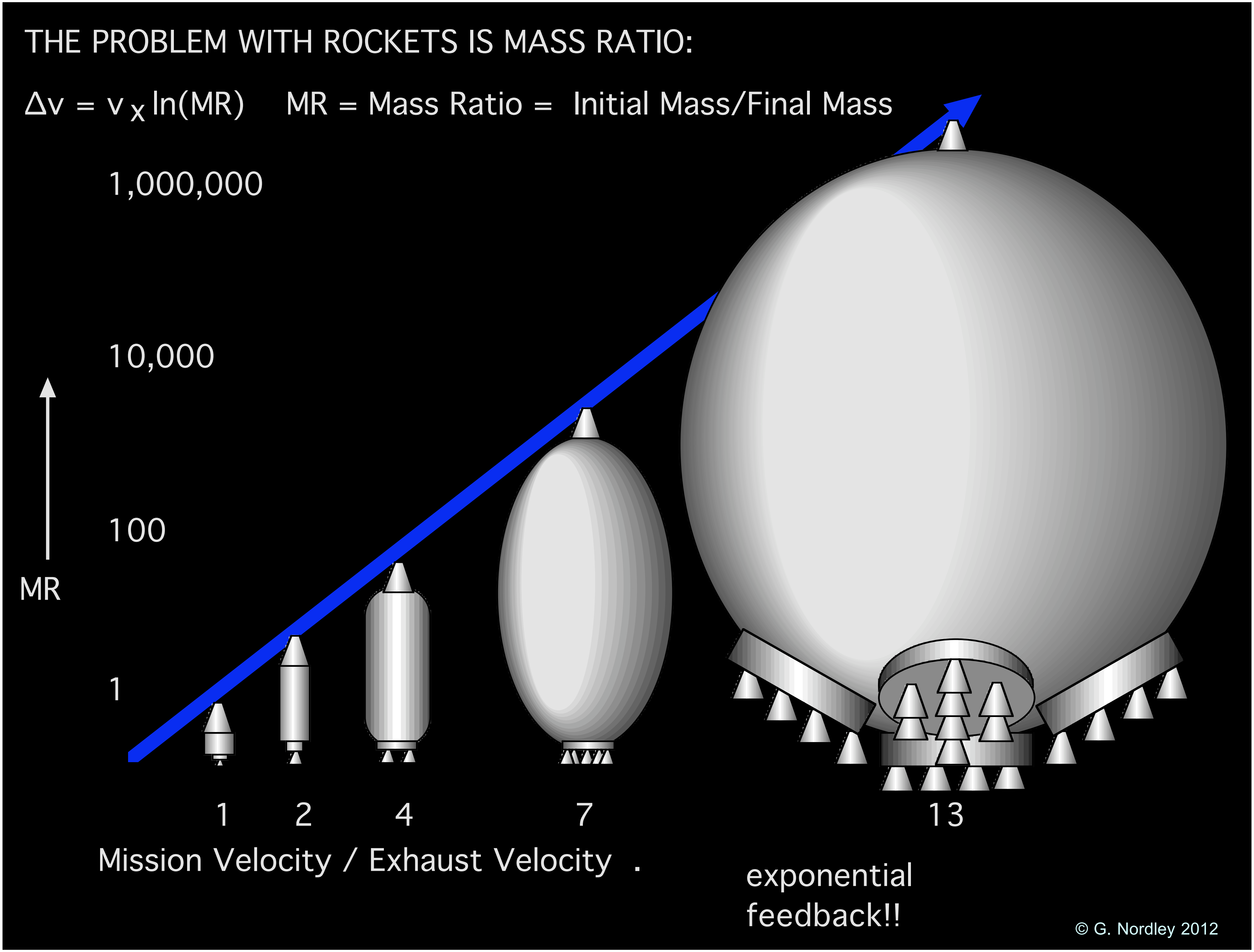
Interstellar Flight: Accelerate, Coast, Decelerate



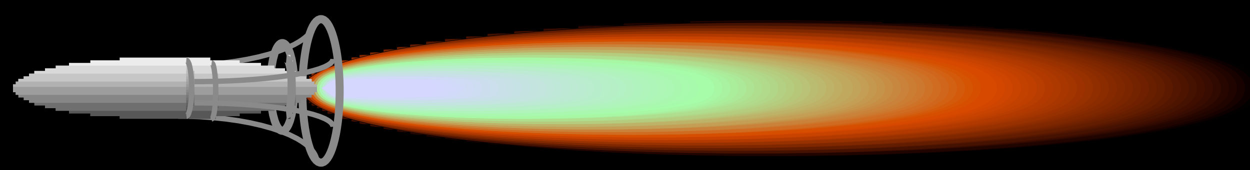

Interstellar Flight: Minimum Acceleration
4.3 Light years
Deceleration time
25 years
TIME
v = 0.172 c = 1.5 E8 m/s
KE m = 1000 Mg
= 1..36 E21 J
Acceleration time
25 years
Total world elect. energy
consumption in 1996:
4.3E19 J *
Acceleration, .00688 g
*(Time world almanac)
DISTANCE
© G. Nordley 2012

ROCKETS




THE PROBLEM WITH ROCKETS IS MASS RATIO:
$\Delta v = v_x \ln(MR)$
MR = Mass Ratio = Initial Mass/Final Mass
1,000,000
10,000
100
1
MR
1
2
4
7
13
Mission Velocity / Exhaust Velocity .
exponential feedback!!
© G. Nordley 2012

Magnetically Confined Continuous Fusion



Well Studied for power production

Potential Exhaust Velocities up to ≈ 0.1 c,

High mass ratio means ≈ 0.15 c cruise velocity

"Magnetically confined fusion is about
twenty years in the future..."
(...and always will be?)

NUCLEAR PULSE

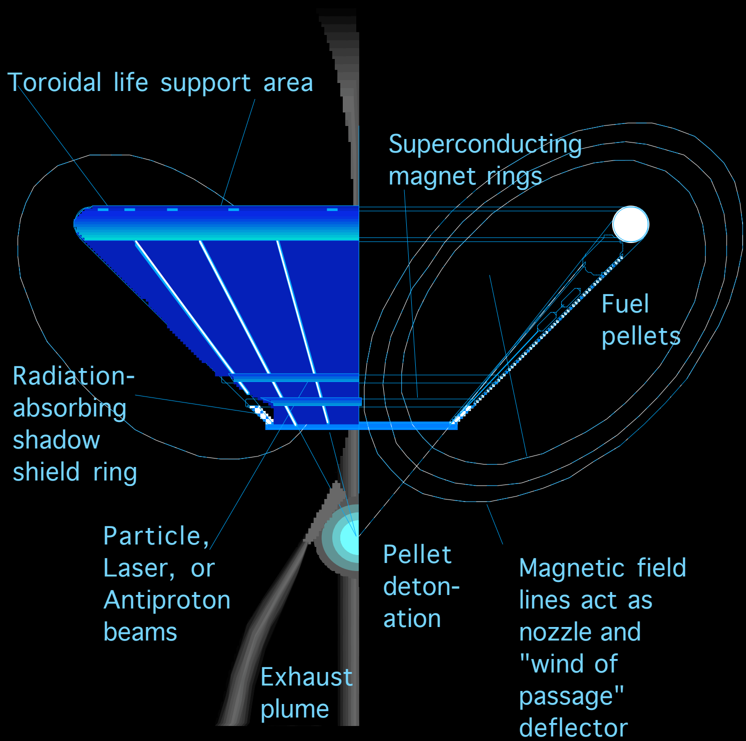
Exhaust velocities ≈ 0.01-0.1c

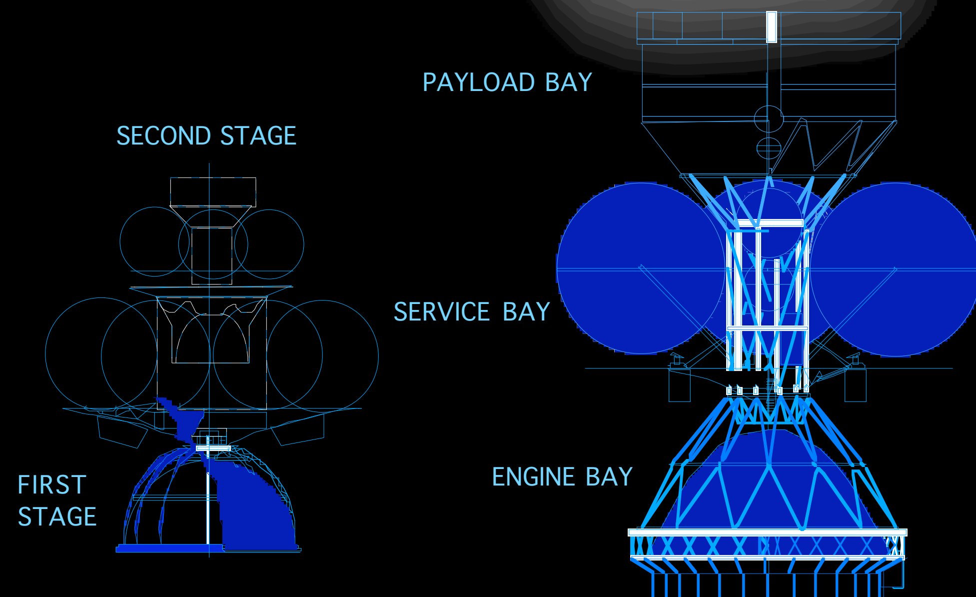
Alpha Centauri trip in decades

May use to decelerate

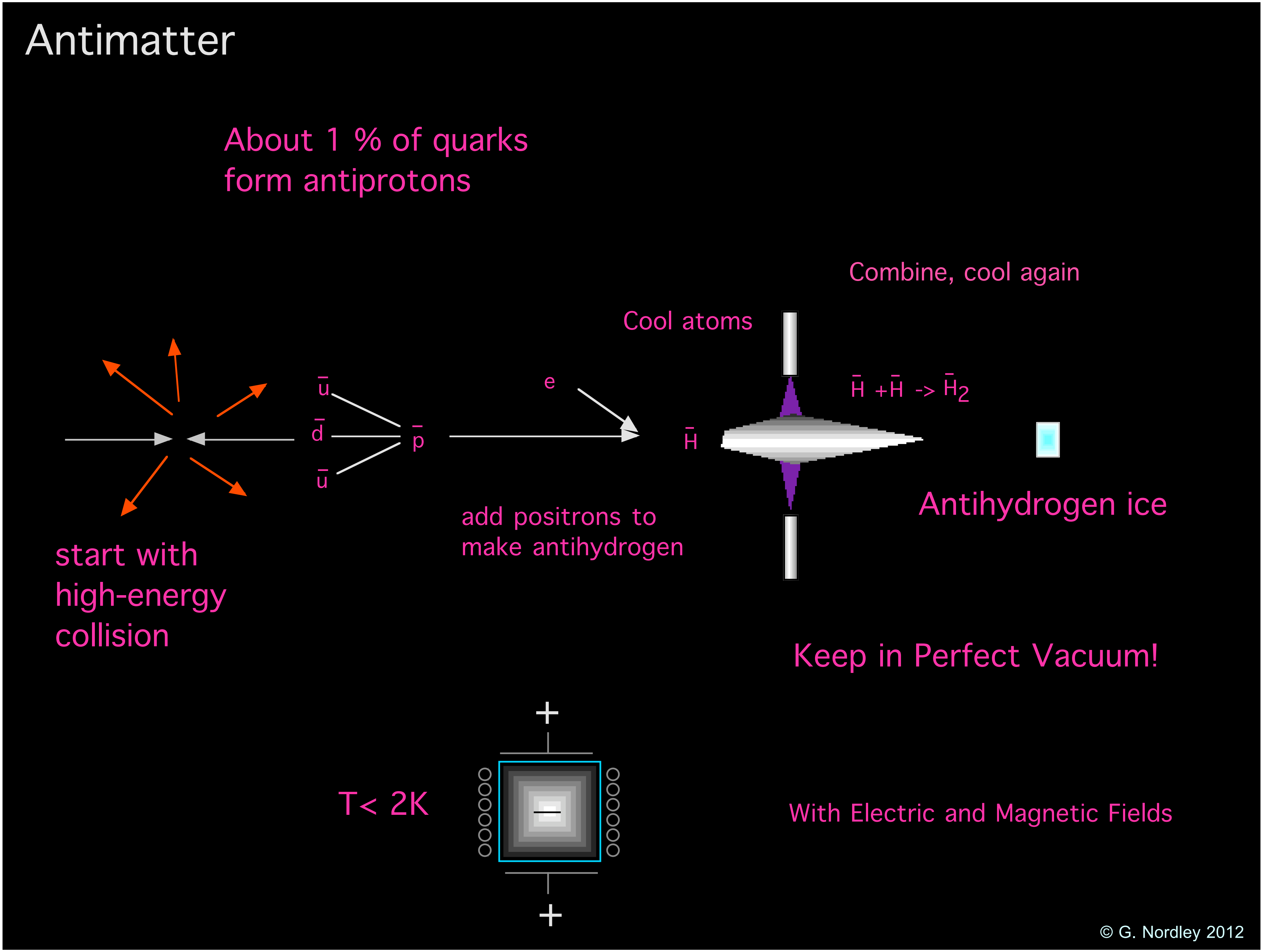
Still working on
pellet detonation....

Micropulse fusion vehicle (after Hyde)

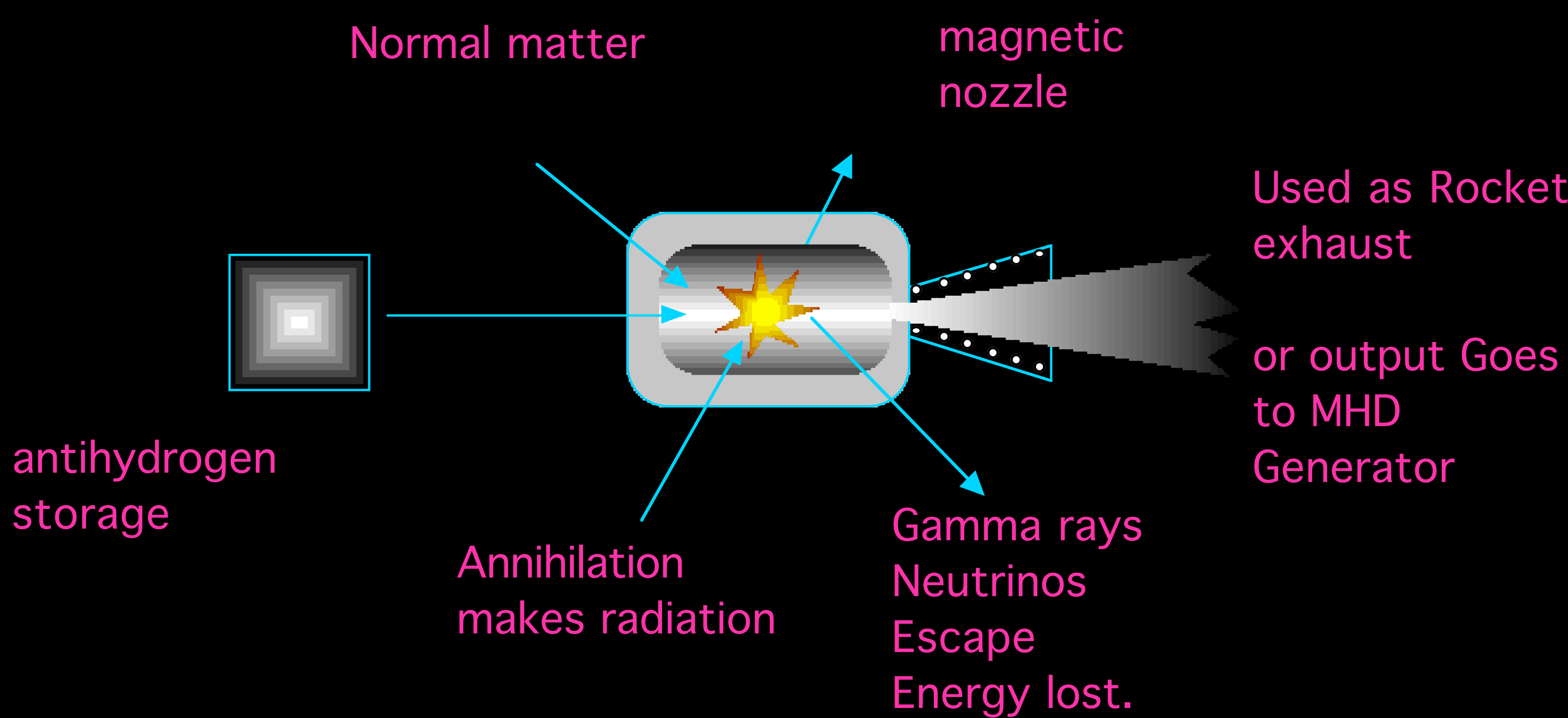


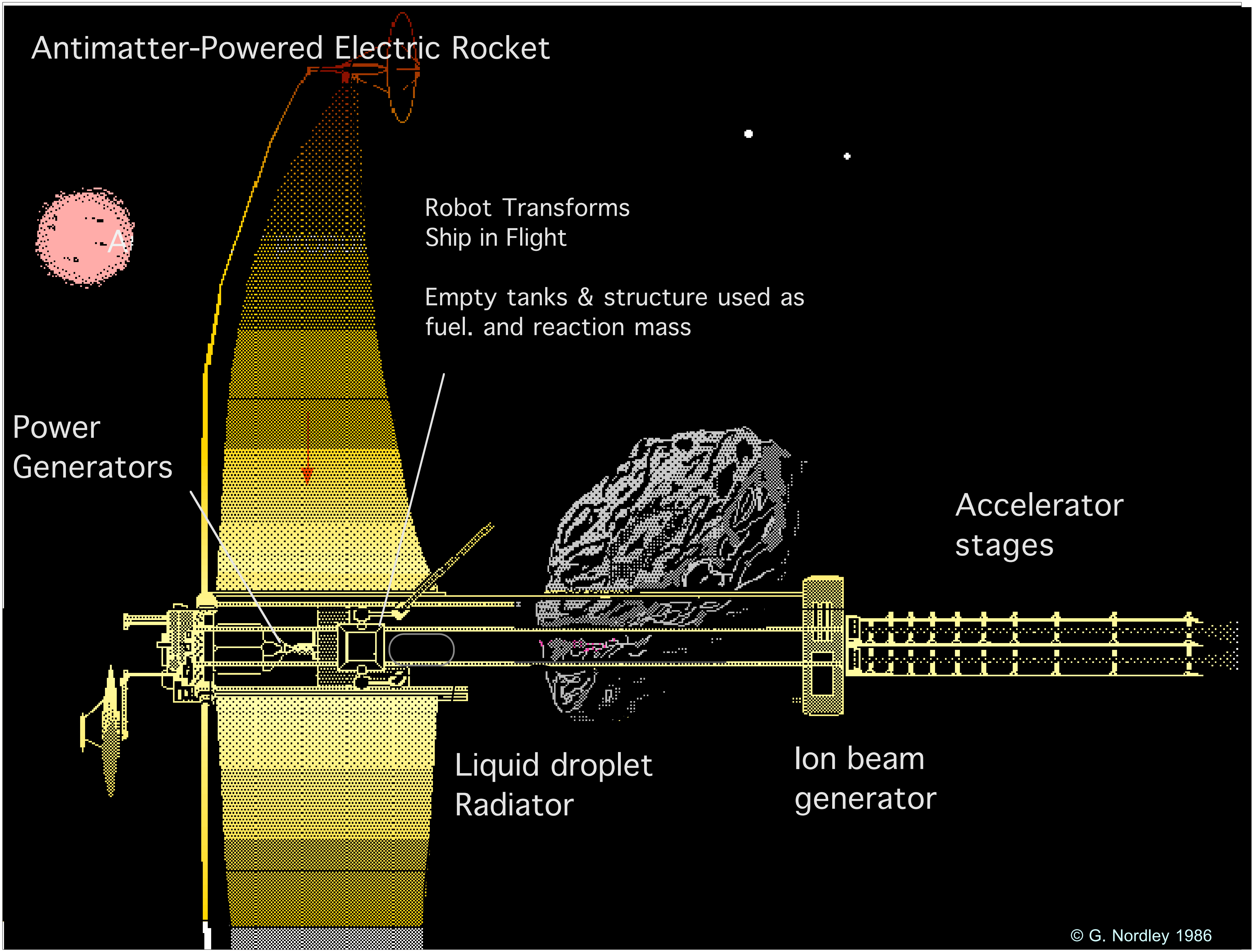


THE BRITISH INTERPLANETARY SOCIETY PROBE


Antimatter
About 1 % of quarks
form antiprotons
Combine, cool again
Cool atoms
$\bar{u}$
$\bar{d}$
$\bar{u}$
$\bar{p}$
e
$\bar{H}$
$\bar{H} + \bar{H} \rightarrow \bar{H}_2$
Antihydrogen ice
add positrons to
make antihydrogen
start with
high-energy
collision
Keep in Perfect Vacuum!
+
T< 2K
With Electric and Magnetic Fields
+
© G. Nordley 2012

Antimatter Rockets And Generators




Antimatter-Powered Electric Rocket
Robot Transforms
Ship in Flight
Empty tanks & structure used as
fuel. and reaction mass
Power
Generators
Accelerator
stages
Liquid droplet
Radiator
Ion beam
generator
© G. Nordley 1986

Interstellar Ramjets

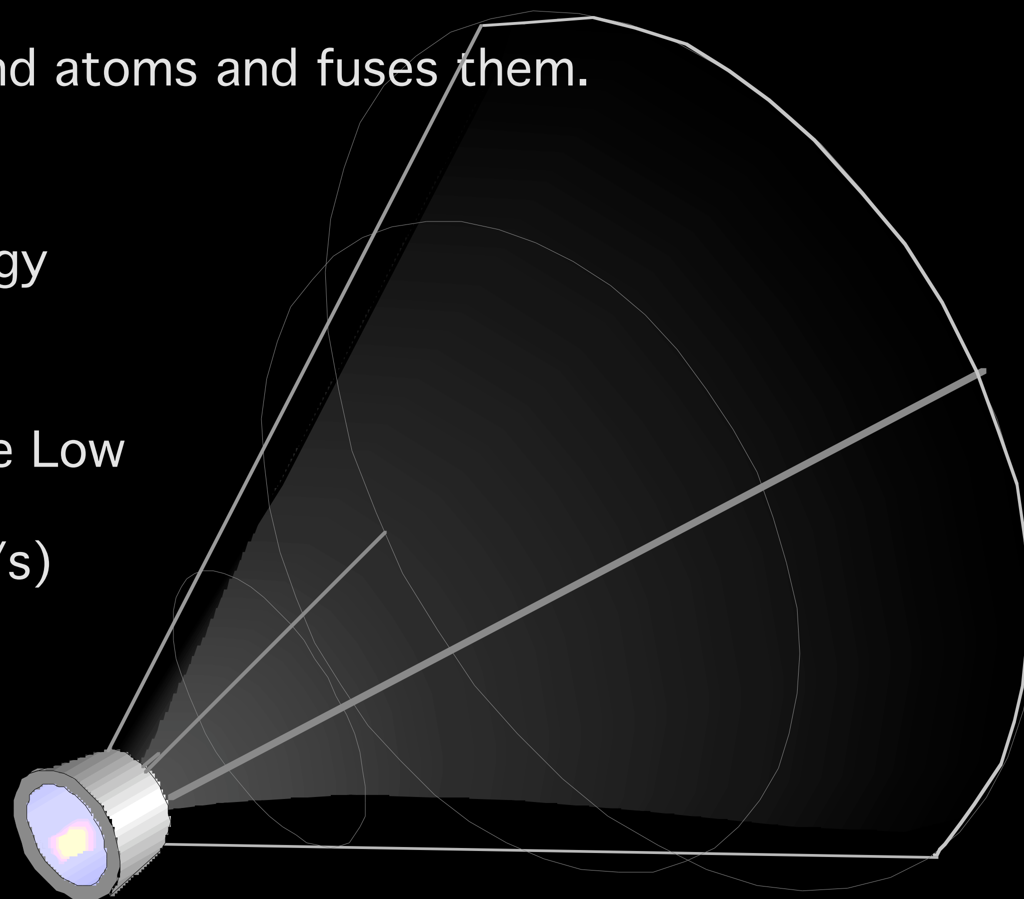
About 1 atom per cubic centimeter

Concept: Scoop up protons and atoms and fuses them.

"Free" Reaction Mass and Energy

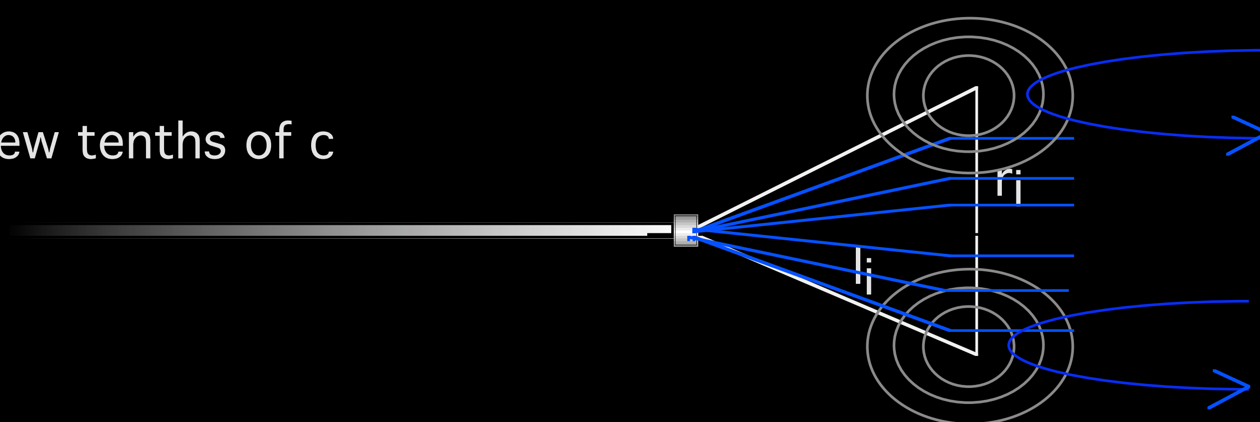
But Thrust and Acceleration are Low

To get 1 kg/s at .2c, (≈60 Mm/s)
Scoop Radius = 1,782 km



Proton fusion is difficult.

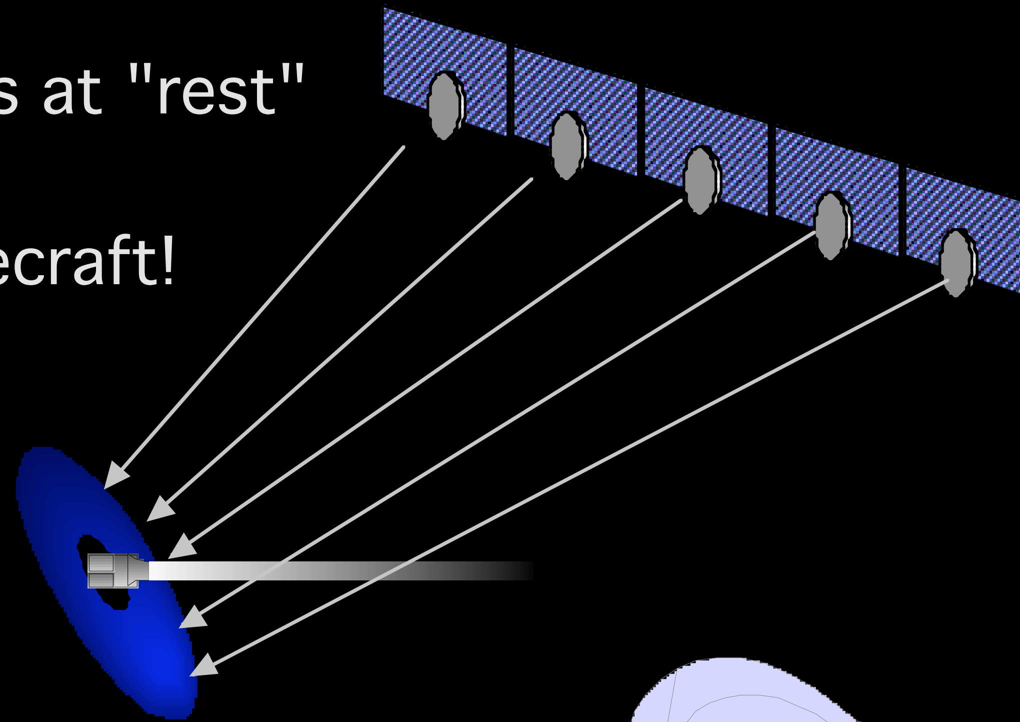
Drag may limit scoop to a few tenths of c



Beam Supported Propulsion

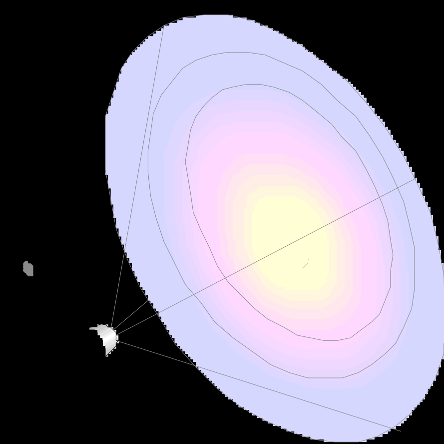
Leaves much propulsion mass at "rest"

--but beam must go to spacecraft!

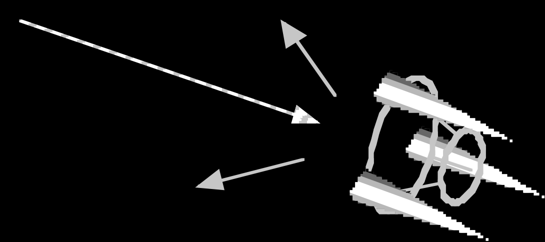


Beam Powered Rockets

Photon Sails: Sun, Lasers, Microwaves

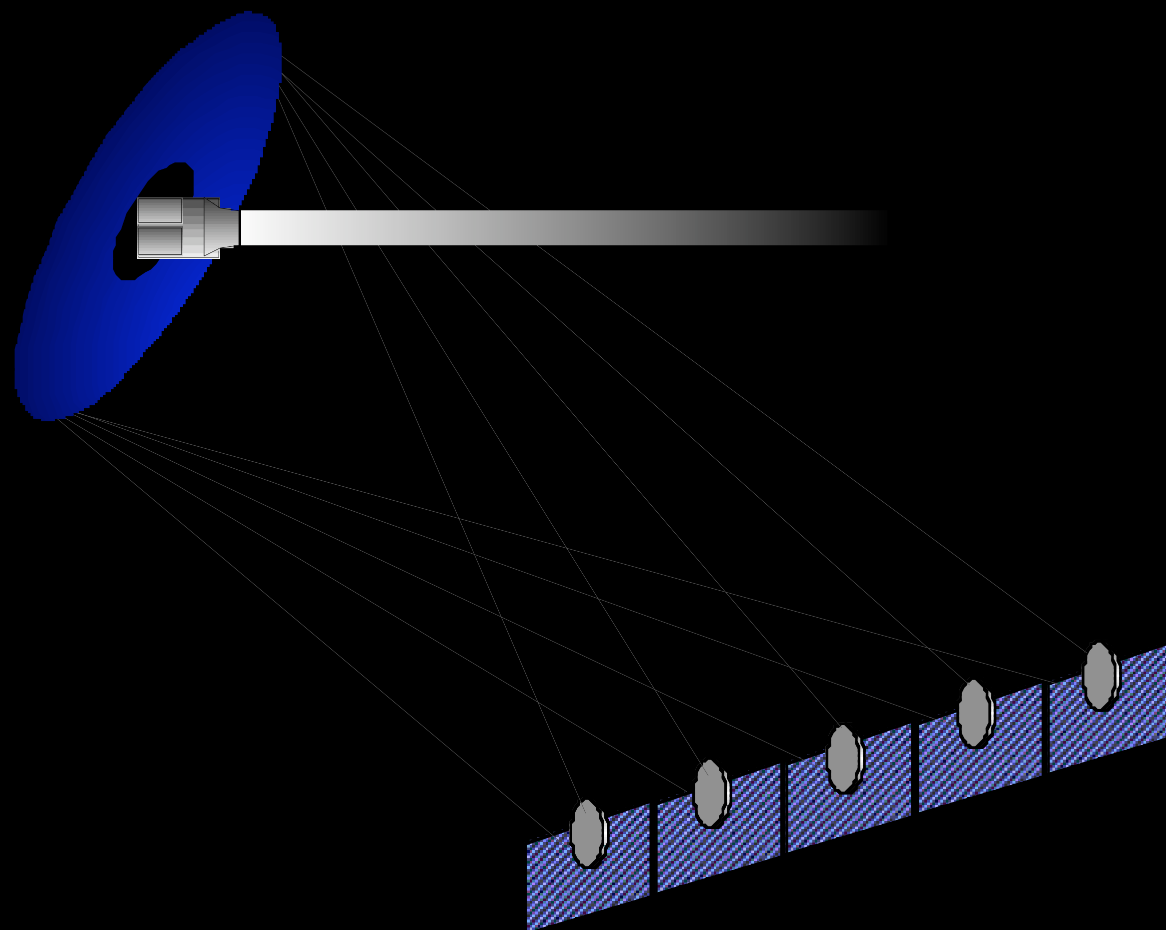


Mass Beam Riders



Beamed power rockets

The energy received is used to accelerate propellant



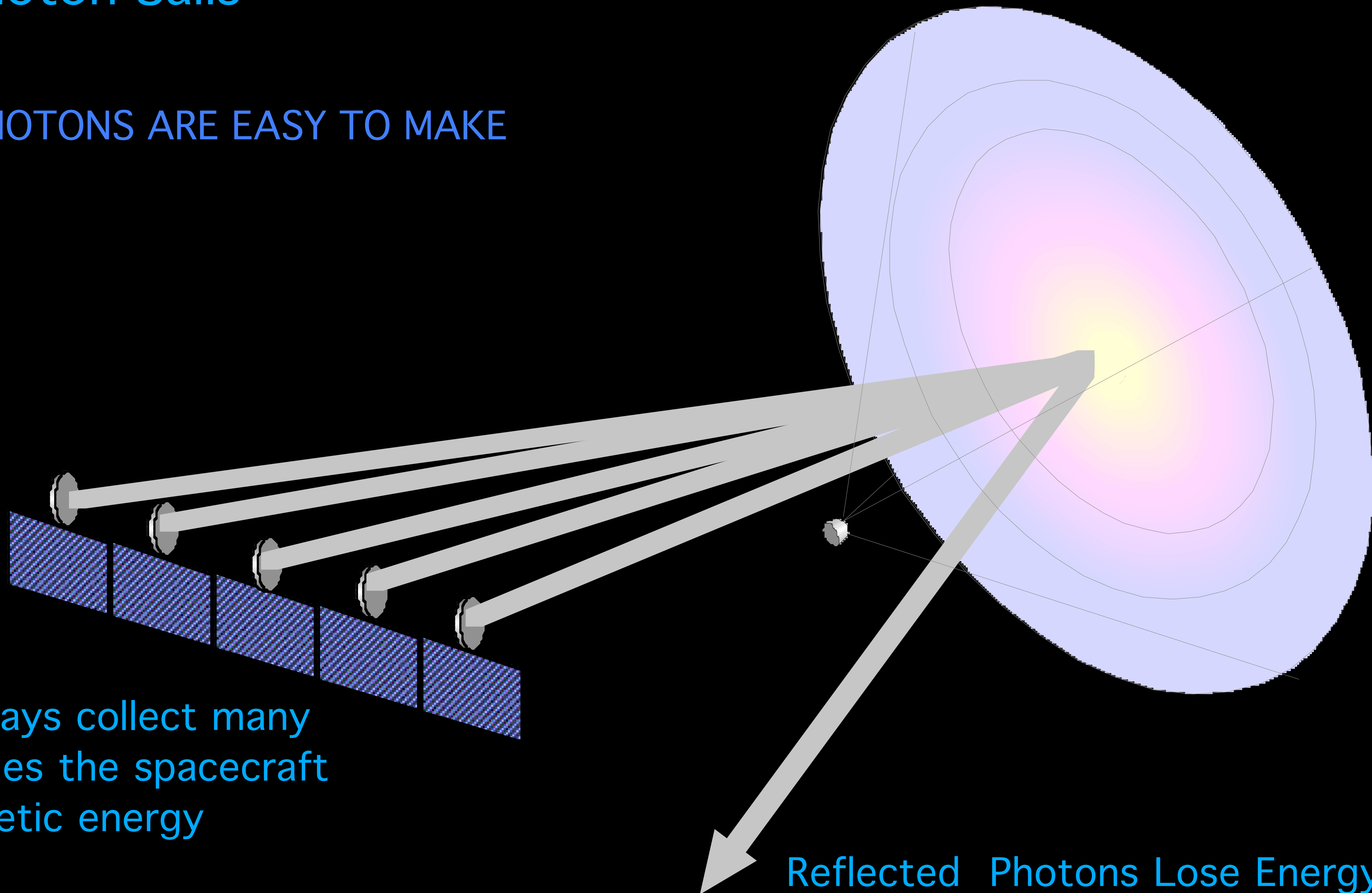
--High exhaust velocity

--Still mass ratio-limited

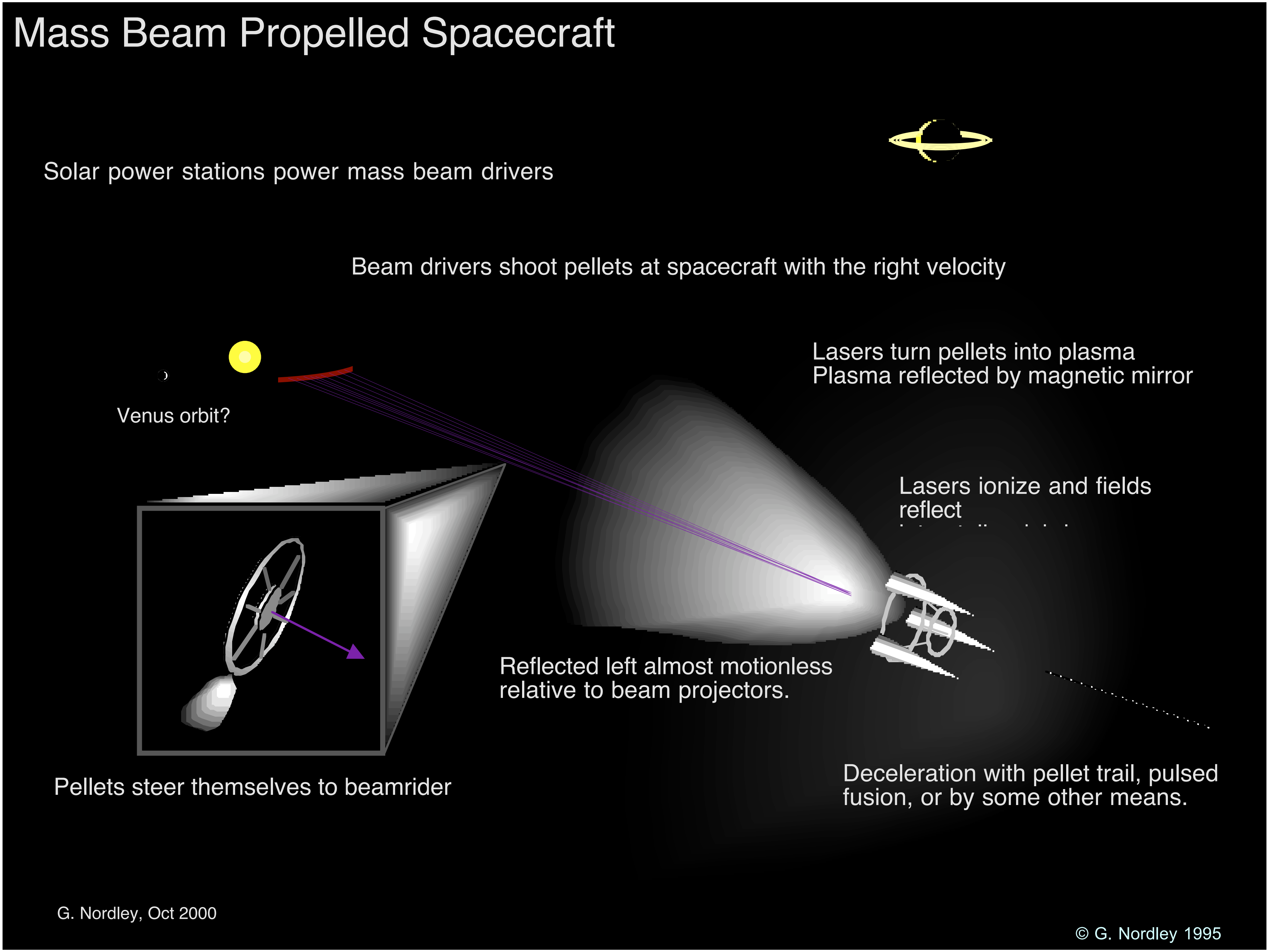
Light or Microwaves are beamed to spacecraft

Photon Sails

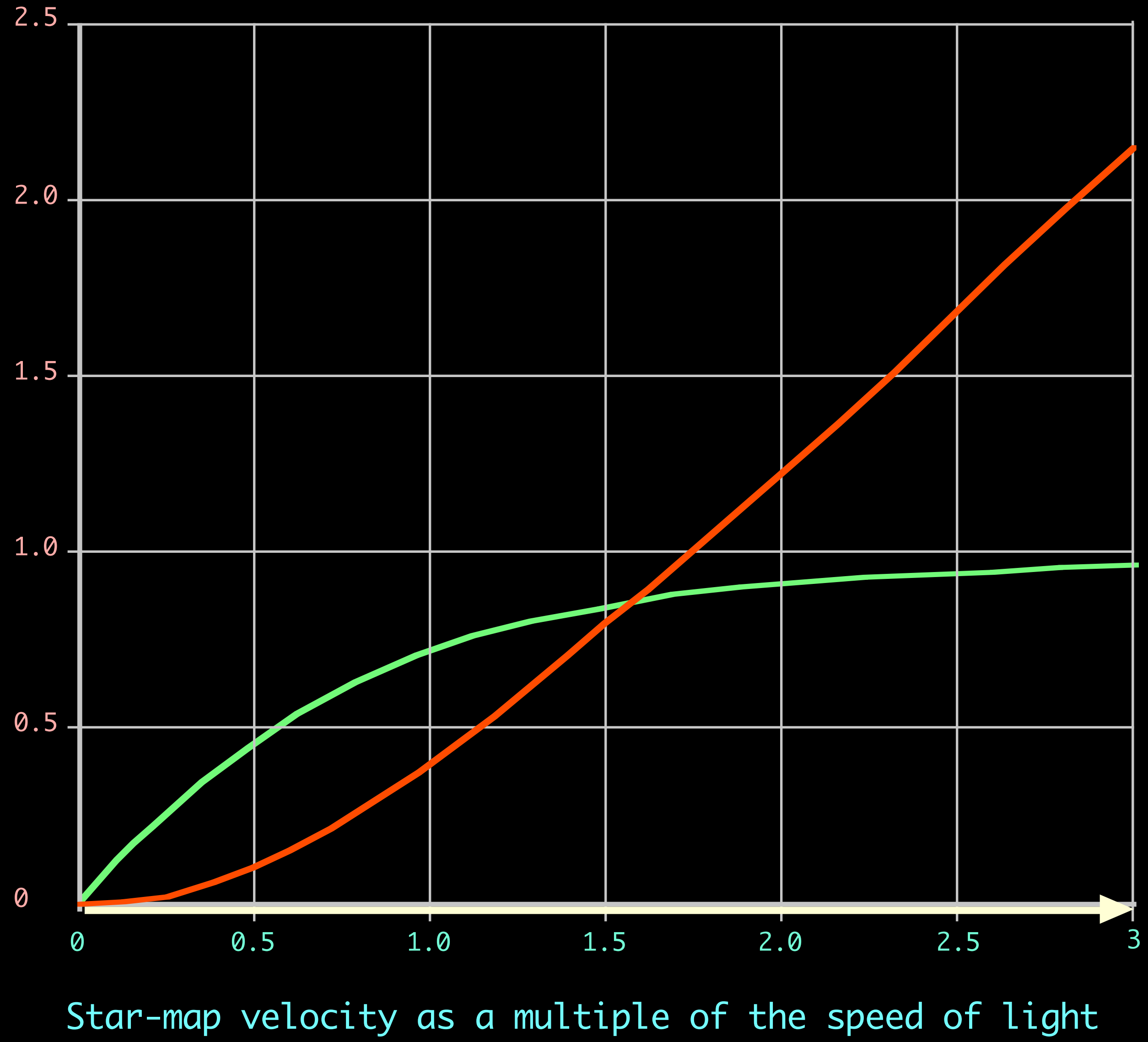
PHOTONS ARE EASY TO MAKE



Arrays collect many times the spacecraft kinetic energy


Mass Beam Propelled Spacecraft
Solar power stations power mass beam drivers
Beam drivers shoot pellets at spacecraft with the right velocity
Lasers turn pellets into plasma
Plasma reflected by magnetic mirror
Venus orbit?
Lasers ionize and fields
reflect
Reflected left almost motionless
relative to beam projectors.
Pellets steer themselves to beamrider
Deceleration with pellet trail, pulsed
fusion, or by some other means.
G. Nordley, Oct 2000
© G. Nordley 1995

RELATIVITY: NO LIGHTSPEED BARRIER FOR TRAVELERS*

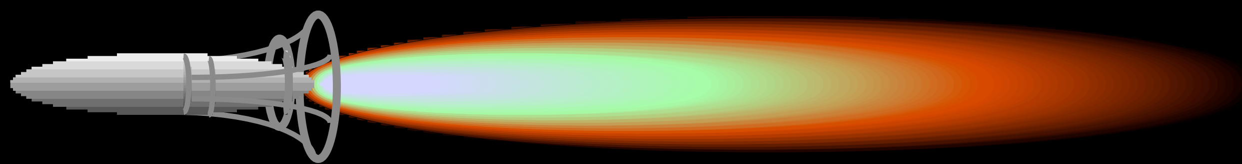


Kinetic energy in units of mc^2

Relative velocity as a multiple of the speed of light.

* But the calendars will show many years gone.

Life on a Starship



Power

Gravity?

Provisioning

Recycling

Cold Sleep?

Elbow Room

ISS NASA Image

REGENERATIVE LIFE SUPPORT - INPUTS AND OUTPUTS
From: Space Station Freedom Design Parameters -
NASA SSP 30362 (1990).

INPUTS	kg/person/day
Oxygen	0.83
Dry Food	0.62
Water in Food	1.15
Food Preparation Water	0.79
Drinking Water	1.61
Oral Hygiene Water	0.36
Hand and Face Wash Water	1.81
Shower Water	5.44
Clothes Wash Water	12.47 *
Dish Wash Water	5.44
Urinal/Commode Flush Water	0.49

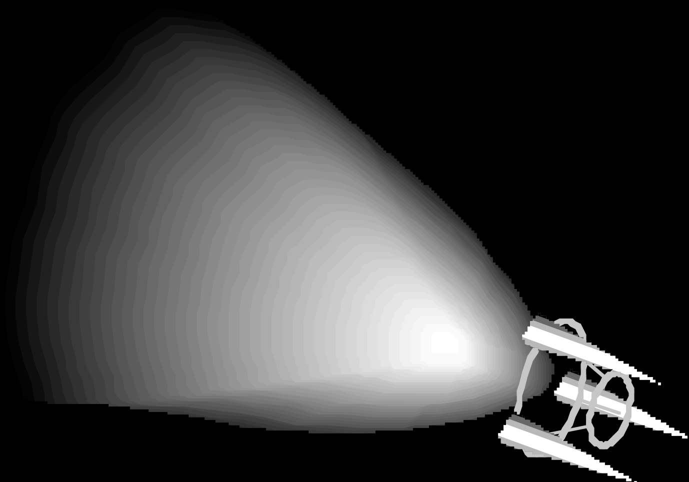
Total: 31.0 kg/person/day

OUTPUTS - kg/person/day	
Carbon Dioxide	1.34
Urine Solids	0.06
Sweat Solids	0.02
Fecal Solids	0.03
Water vapor from skin and lungs	2.28
Urine	1.50
Feces Water	0.09
Hygiene Waste Water	7.18
Hygiene Evaporated Water	0.44
Clothes Wash Water	11.87 *
Clothes Wash Water Vapor	0.60*
Food Preparation Water Vapor	0.04
Dish Wash Water	5.41
Dish Wash Evaporated Water	0.03
Urinal and Commode Flush Water	0.49

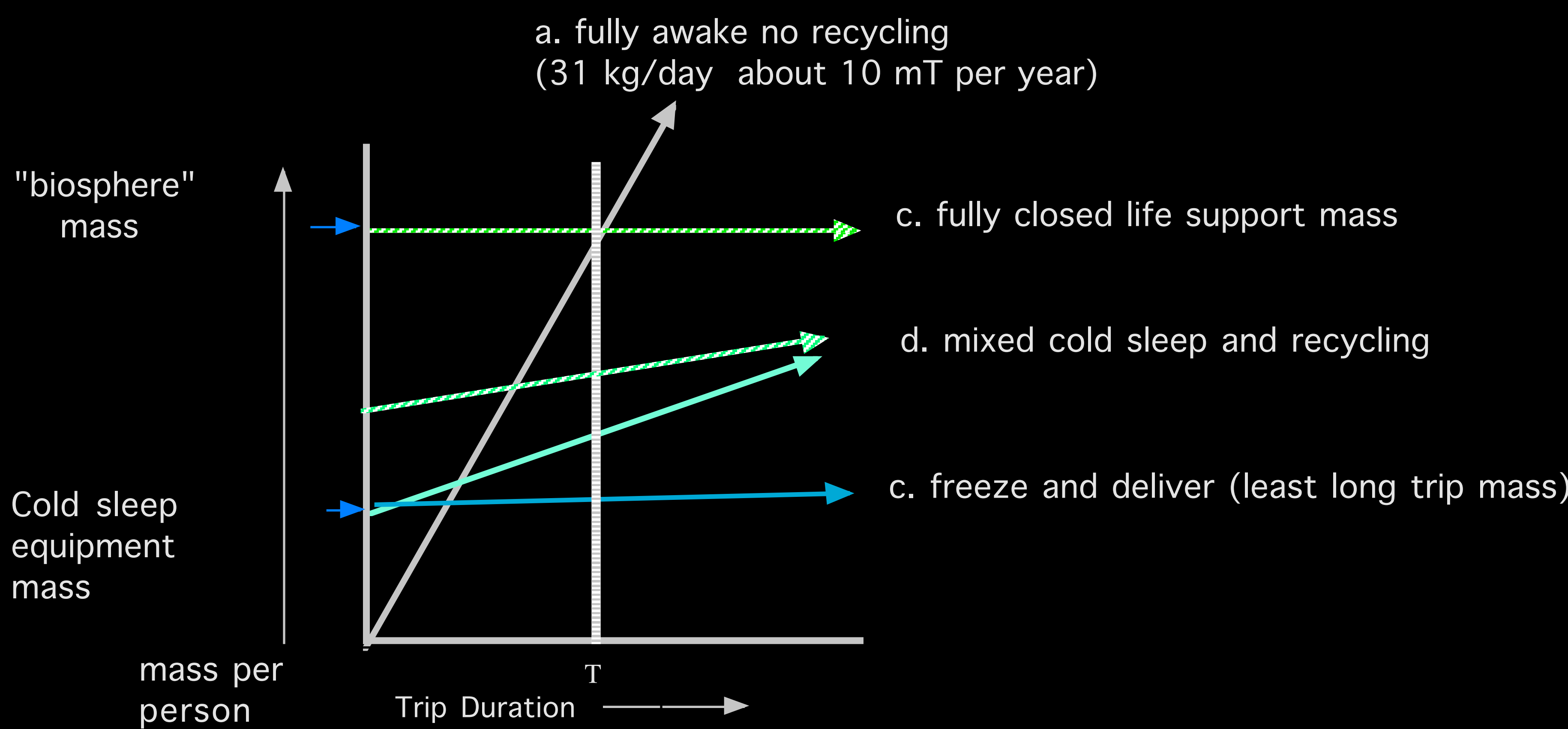
Total: 31.0 kg/person/day

If we have complete water recycling, expendable supplies per person per year of active time are about

500 kg



Life support strategy depends on technology available, and mission length



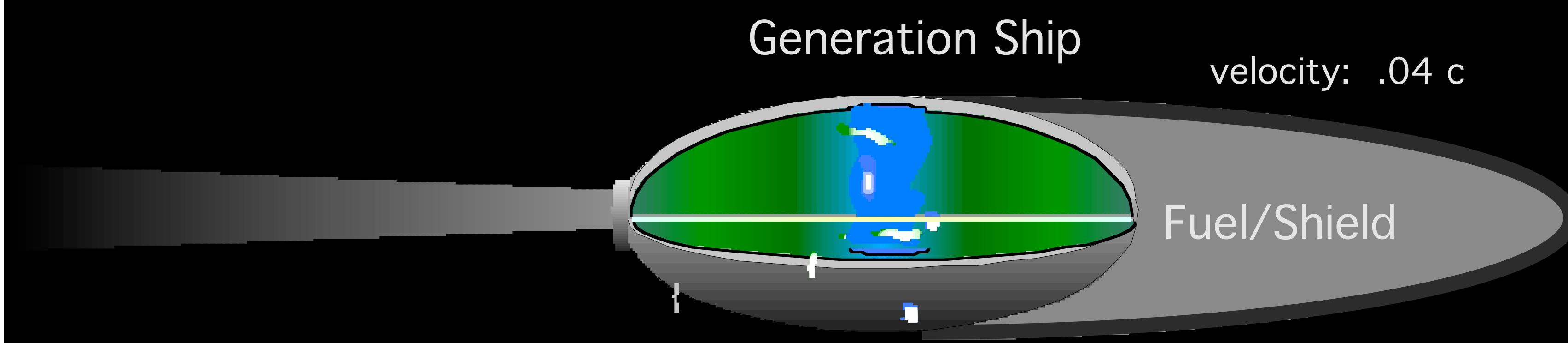
Trade between life support closure and suspended animation.

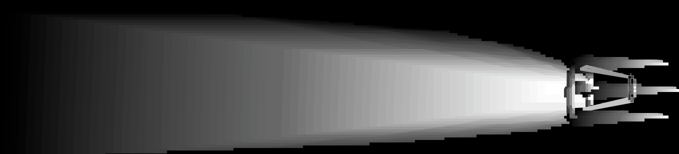
Generation ship vs smaller, faster ship.

Energy available: 100 ZJ (1E23)

Generation ship: 1,000,000 tons

velocity: .04 c

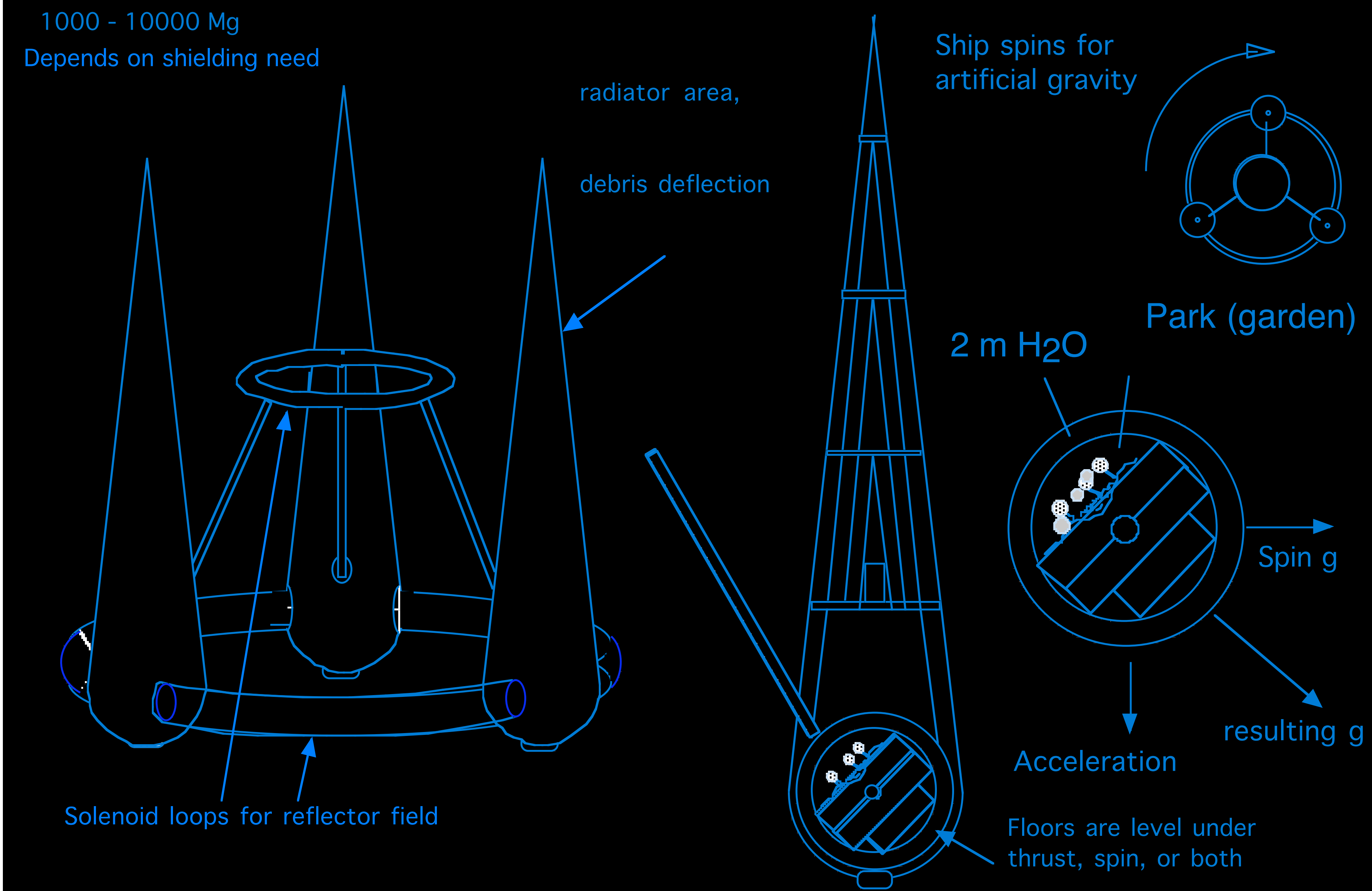




Beamrider: 1000 tons
velocity 0.84 c

Going 12 LY?
Generation Ship takes 300 years
Beamrider takes 14.3 years

STARSHIP DESIGN STUDY



Some personal conclusions:

No "generation ships." (Lifetime extension, propulsion advances)

Starships with human crews won't be launched until relative velocities of 0.3 to 0.5 c are achieved.

Interstellar Journeys will take a few years to a few decades (Solar System time)

Robotic systems will explore and prepare systems for humans.

To Proxima Centauri with a 1000 ton ship

3 g, 0.95 reflection, 0 residual velocity

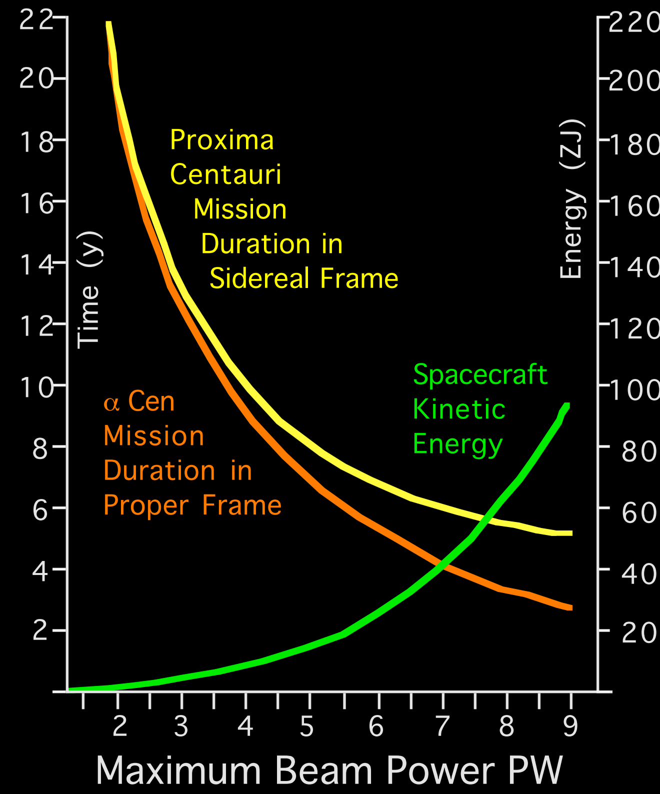
Peak power required ≈ 40,000 TW

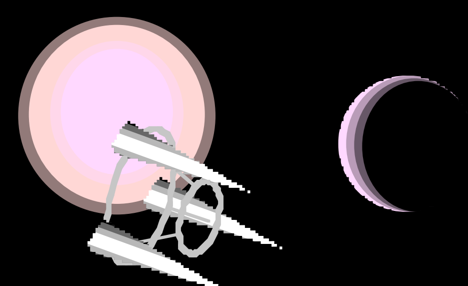
Coasting velocity = .886 C

Acceleration time:
200 d Earth-frame
152 d spaceship

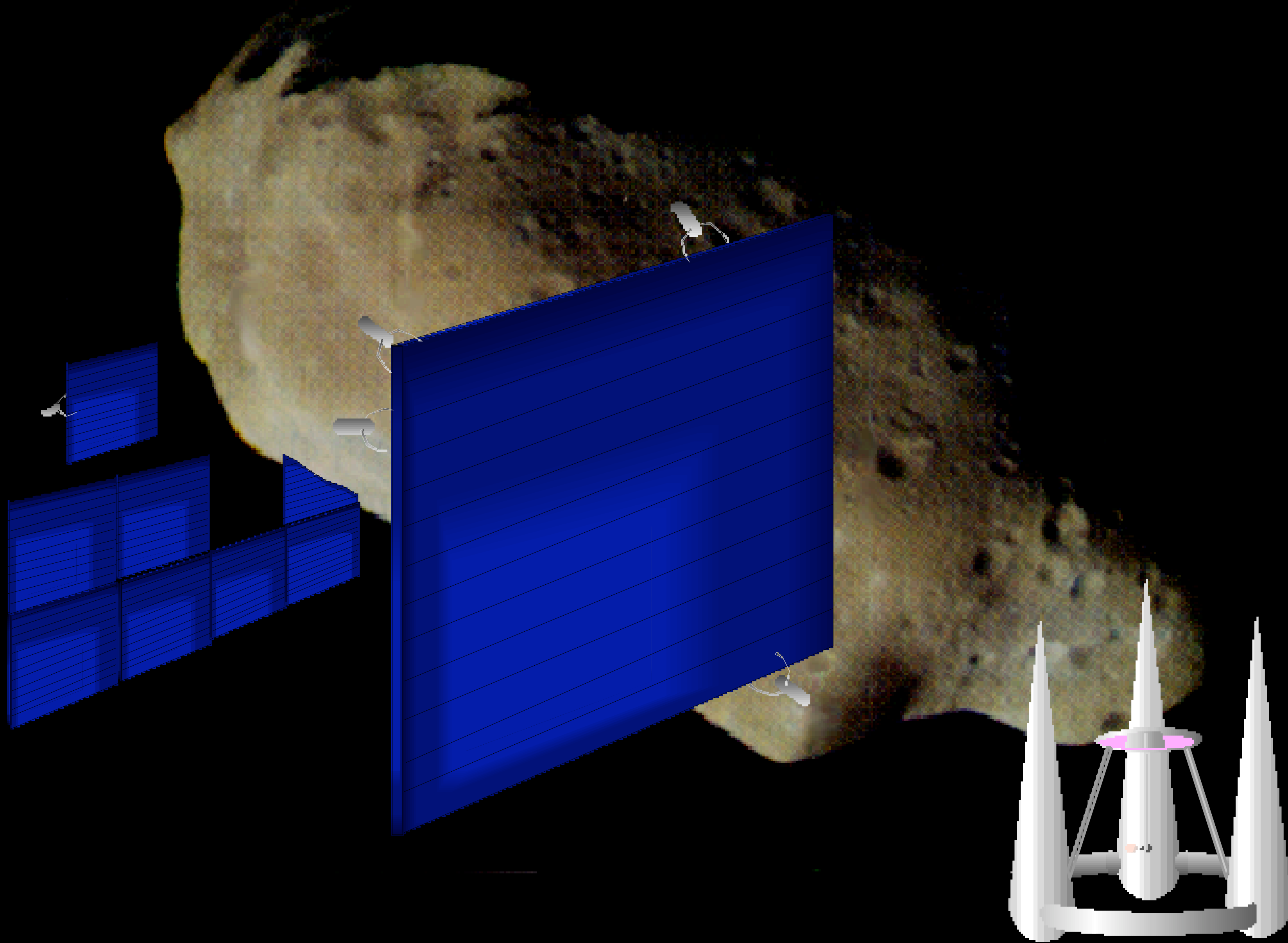
Transit time
≈ 5.33 years Earth
≈ 3 years, spaceship

20% Efficiency, Arrays to ship KE = 565 E21 J

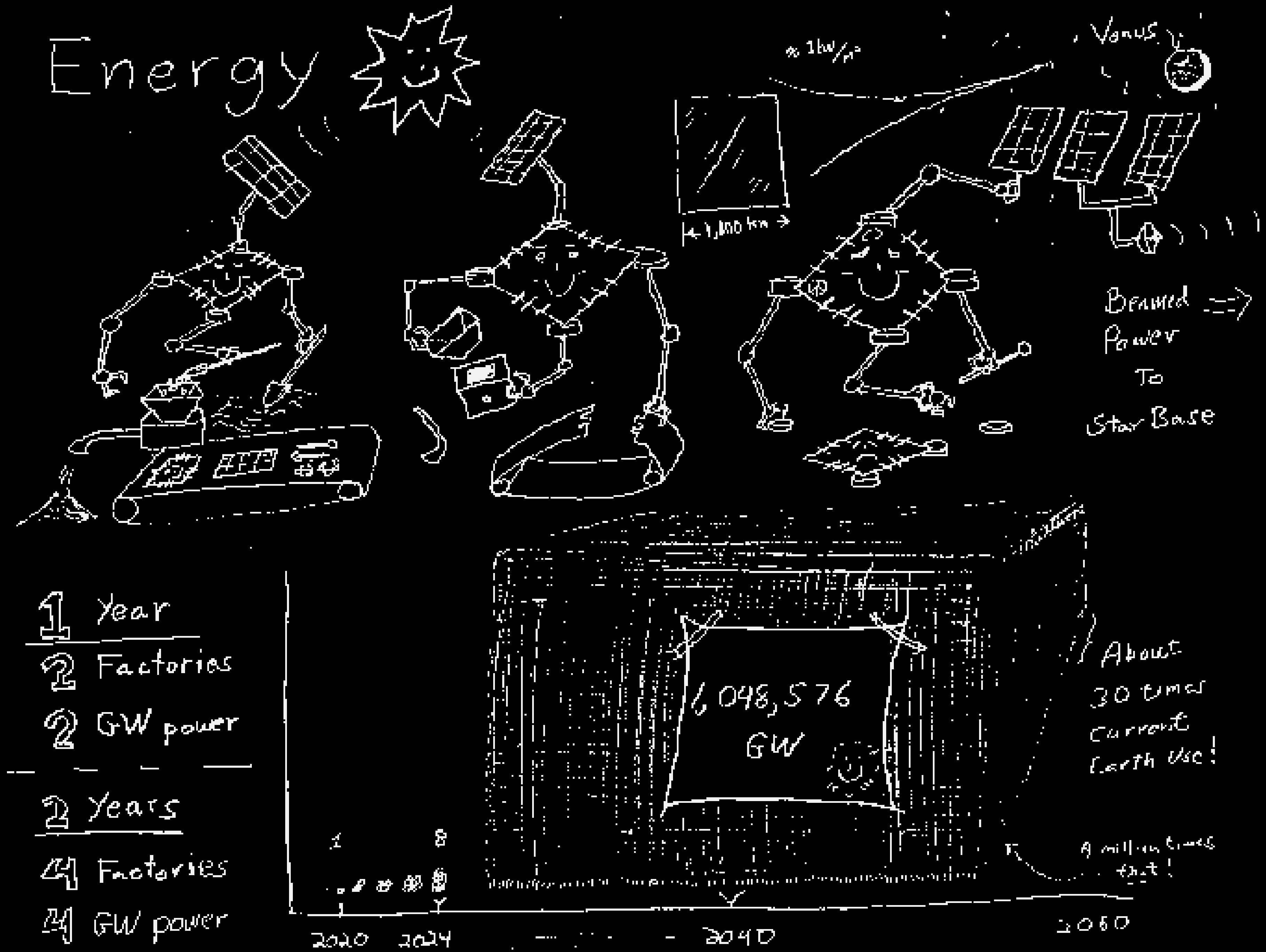


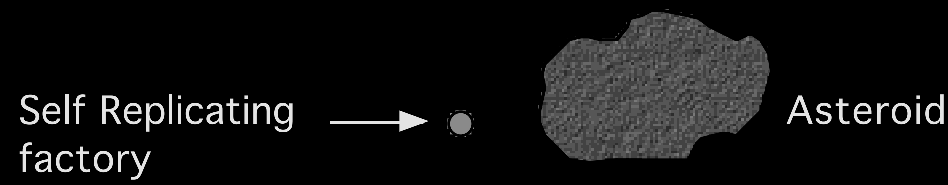


Turning Asteroids Into Solar Power Stations

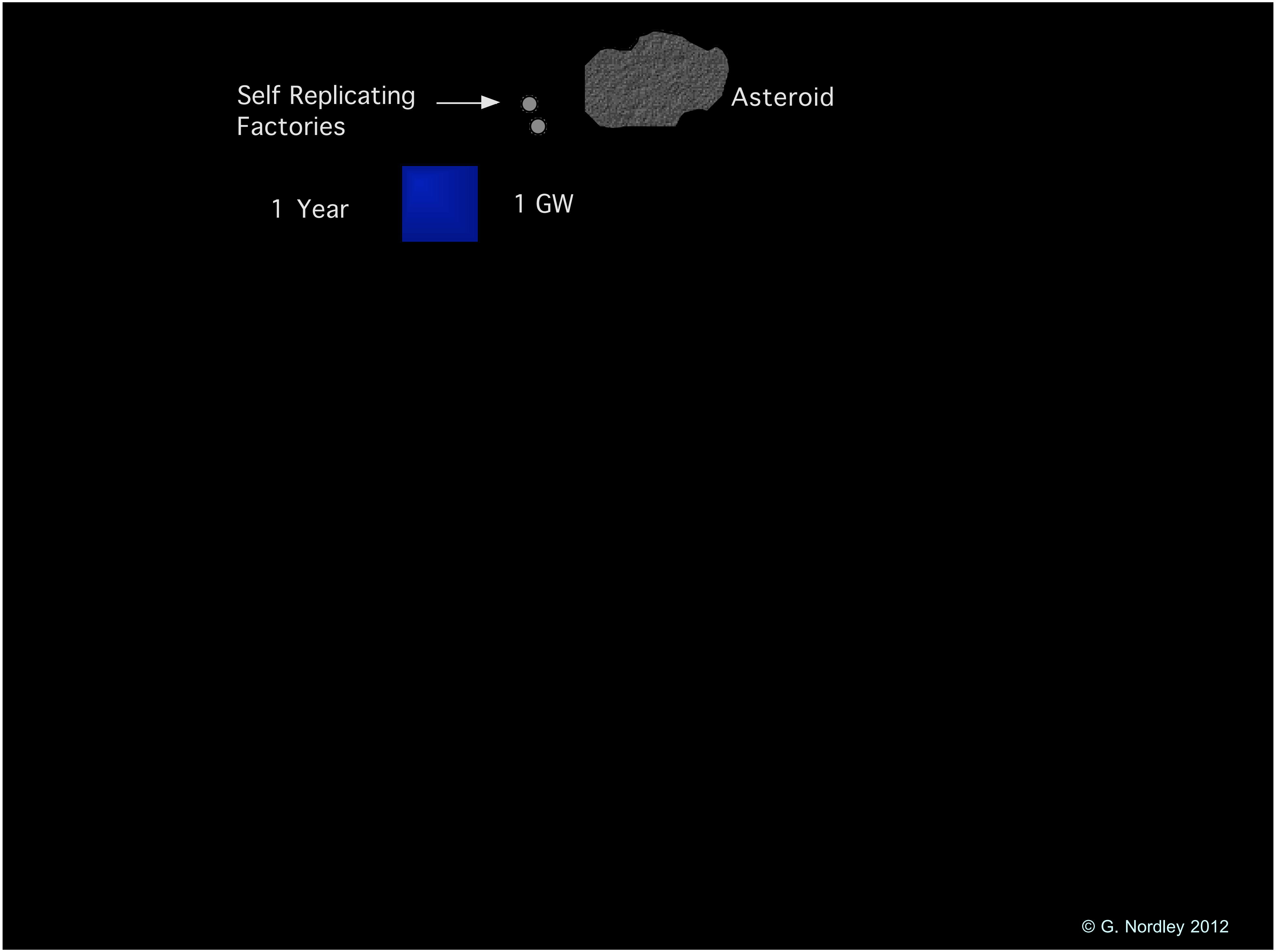


Exponential Growth





Self Replicating
factory
Asteroid


Self Replicating
Factories
Asteroid
1 Year
1 GW
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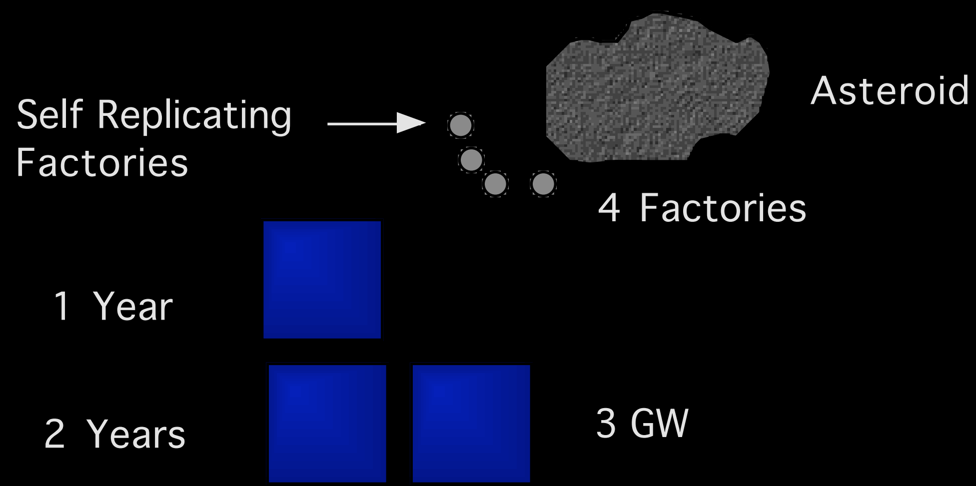
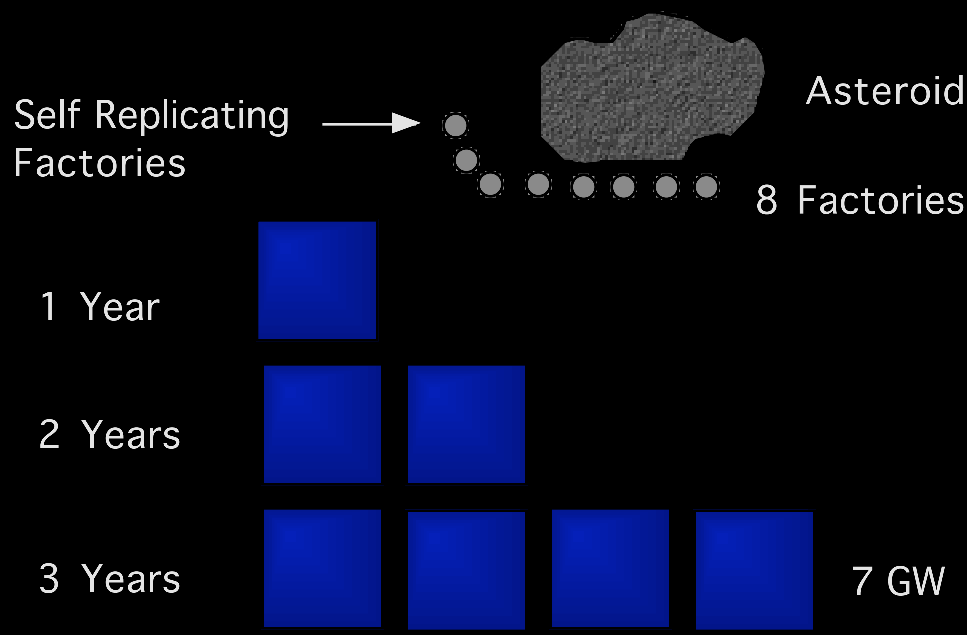
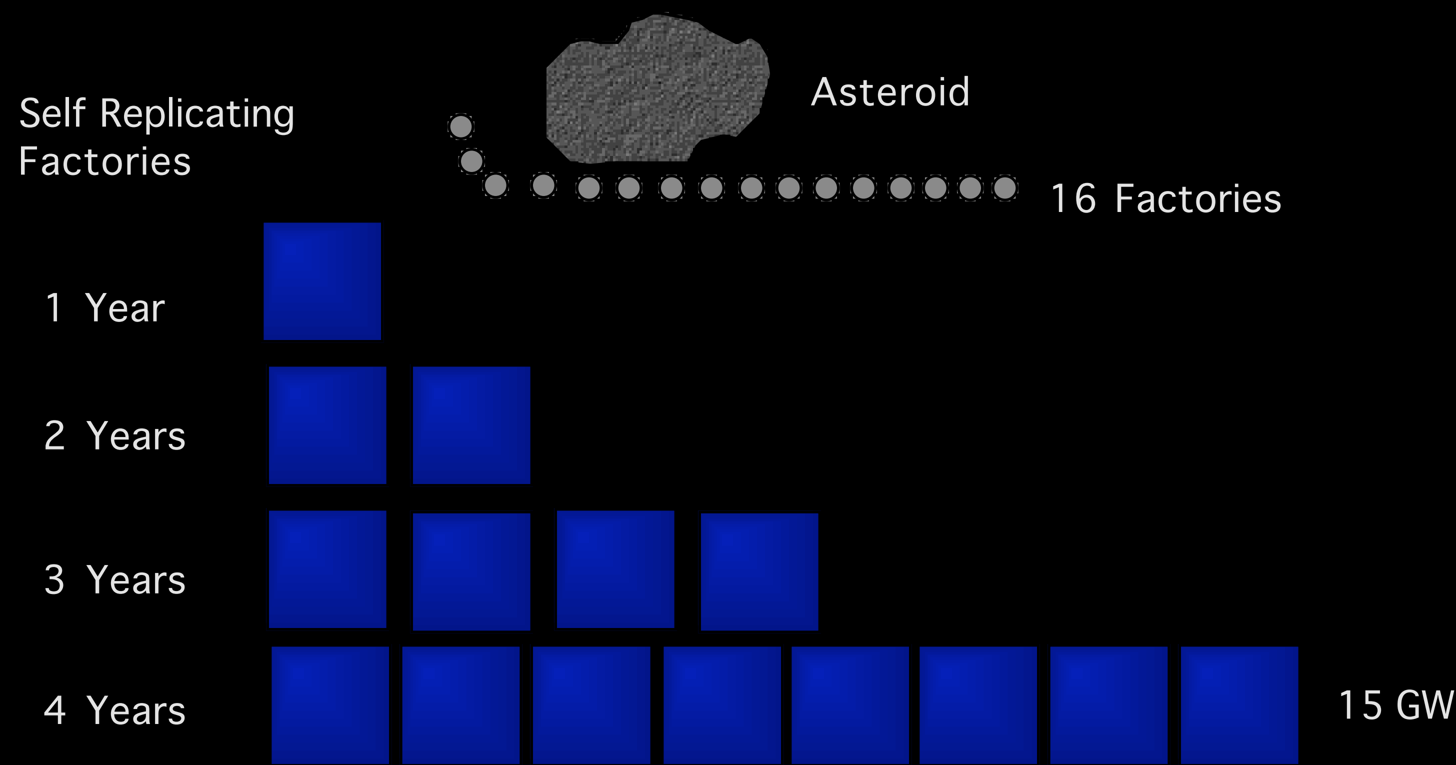
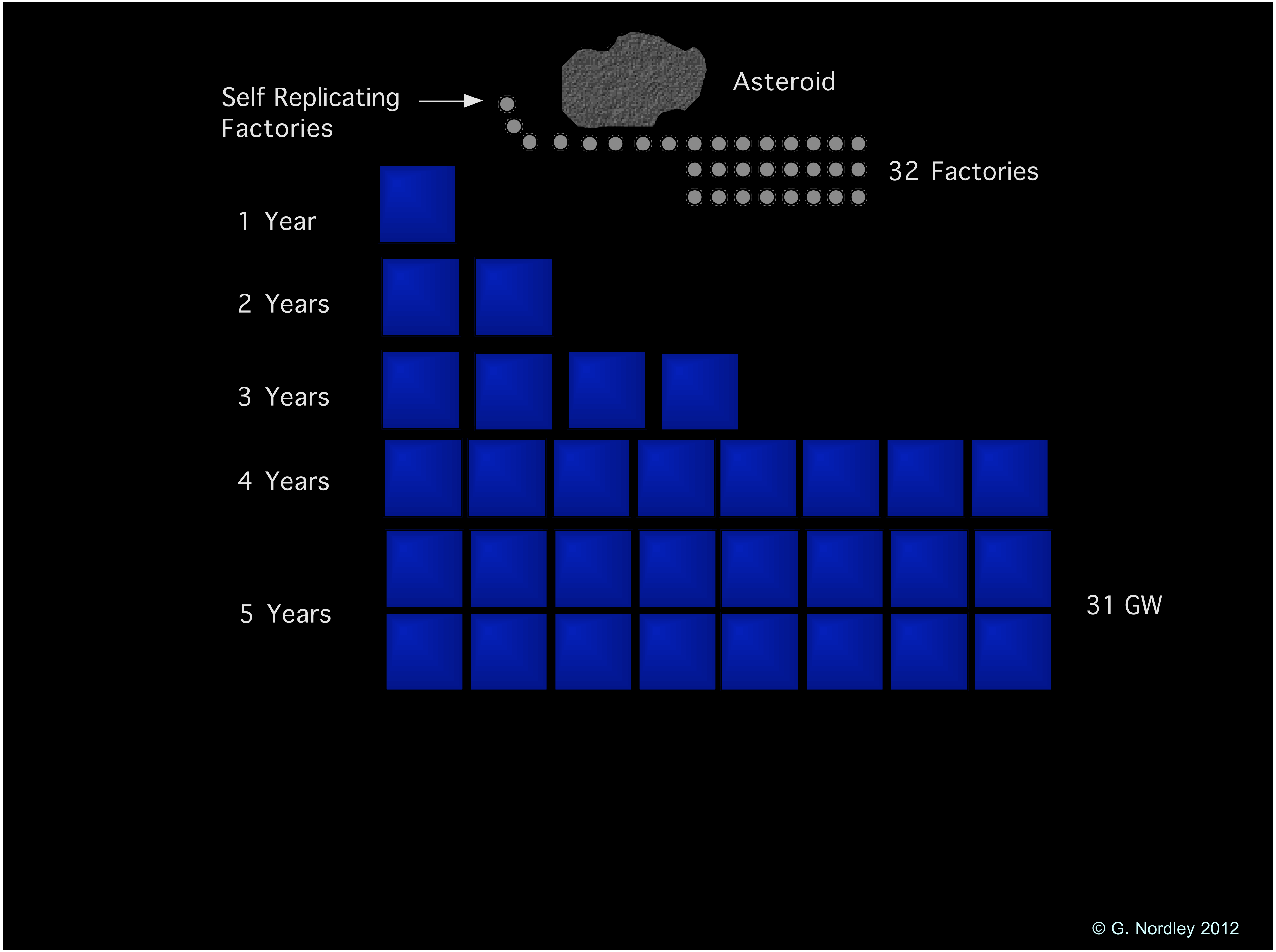

Self Replicating
Factories
Asteroid
4 Factories
1 Year
2 Years
3 GW

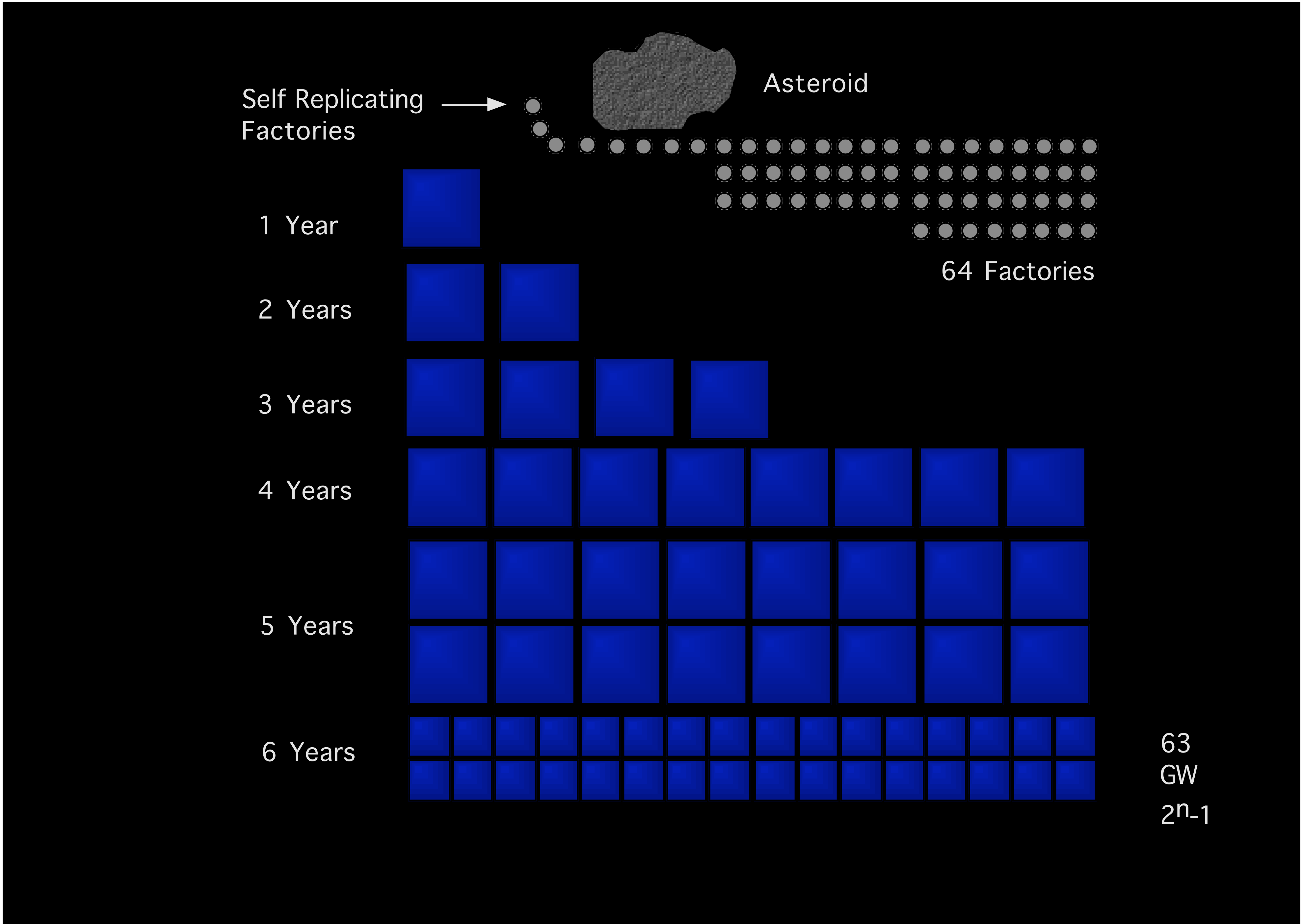


Self Replicating Factories
Asteroid
8 Factories
1 Year
2 Years
3 Years
7 GW

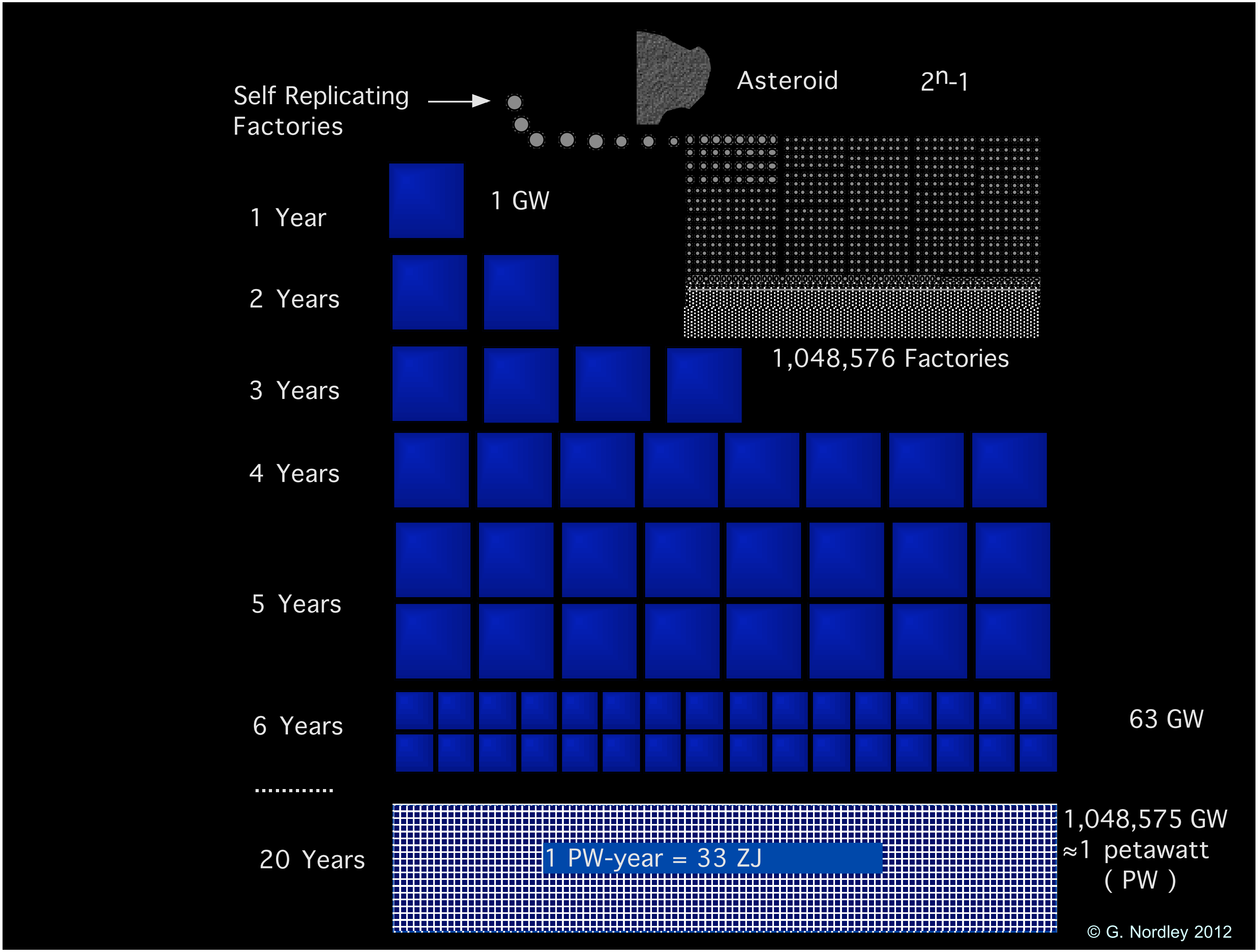


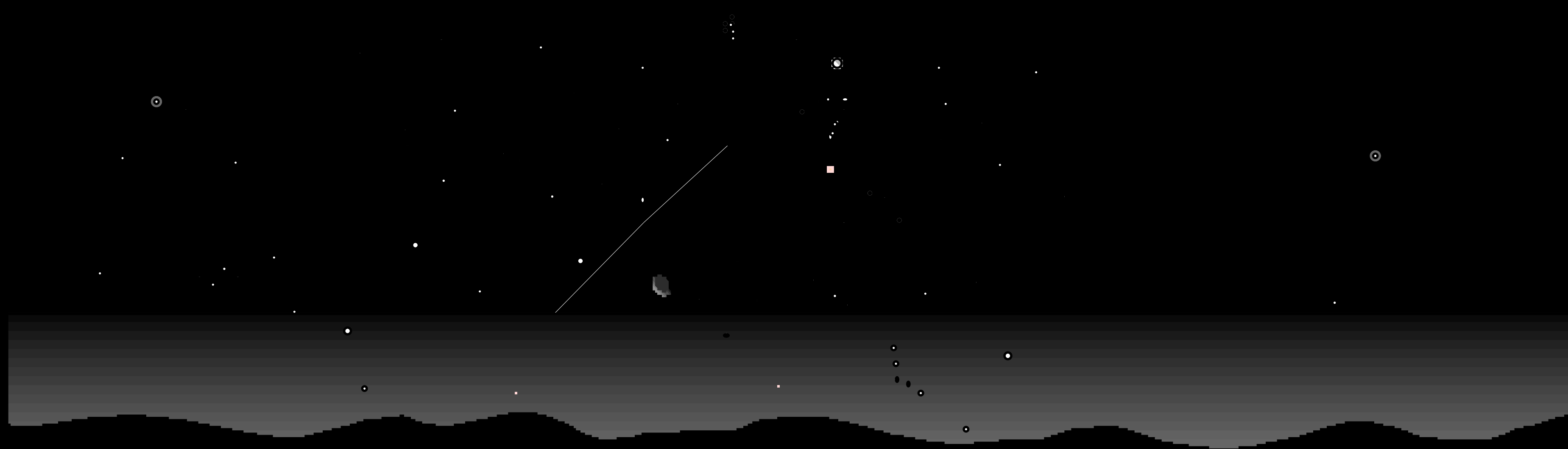
Self Replicating Factories
Asteroid
16 Factories
1 Year
2 Years
3 Years
4 Years
15 GW


Self Replicating Factories
Asteroid
32 Factories
1 Year
2 Years
3 Years
4 Years
5 Years
31 GW
© G. Nordley 2012



Self Replicating Factories
Asteroid
64 Factories
1 Year
2 Years
3 Years
4 Years
5 Years
6 Years
63
GW
2^n-1


Self Replicating Factories
Asteroid
2n-1
1 Year
1 GW
2 Years
1,048,576 Factories
3 Years
4 Years
5 Years
6 Years
63 GW
....
20 Years
1 PW-year = 33 ZJ
1,048,575 GW
≈1 petawatt
(PW)
© G. Nordley 2012



Array width: 10,000 km

Array length 55,000,000 km

Array area 55 E 15 m^2

arc length 30 deg

Fraction of a Dyson sphere: 3.75 E-6

Power collected 550 E6 TW

Starships powered to 0.86c: 36,000

Needed to build: 40 Y

Radius of raw material asteroid ≈300 km

THOUGHTS ON INTERSTELLAR CIVILIZATION

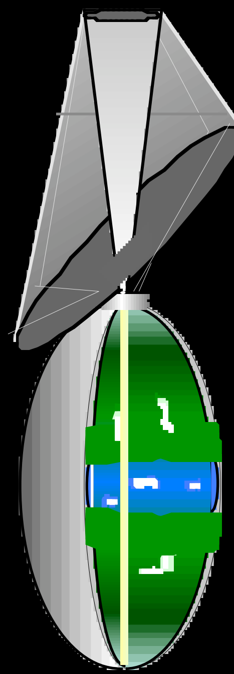
Divergent human cultures with common heritage

---Slow paced, but not totally isolated

--extended life, robot labor, large scale

Trade (if any) in unique artifacts

--robots will build what is needed from local material



Star travelers of different intelligences

--could form their own culture

--biological impulses subordinate to intelligence

--same physical laws, similar engineering achievements
cultural interchange

--so, cultural convergence among different species

This may already have happened....

Interstellar Travel Summary:

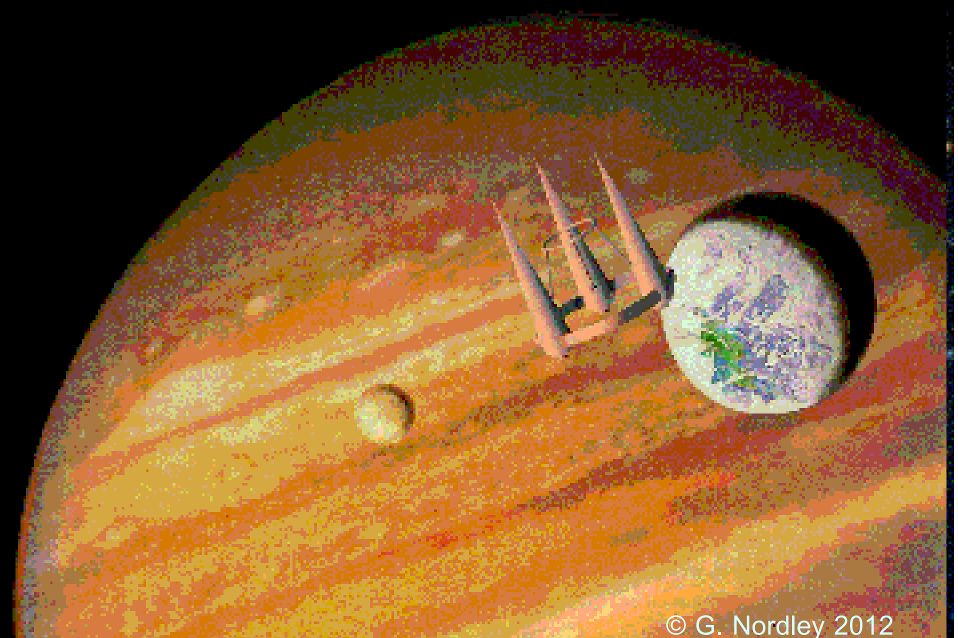
The energy requirements for human interstellar flight are huge.

Given energy, relative velocities approaching c are possible

The important technologies are robotics and space access.

Biotech advances make it easier.

Starfaring may be like
Early Seafaring; long journeys
seldom im port.




Ad Astra .
Gerald David Nordley
OryCon 2010,
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