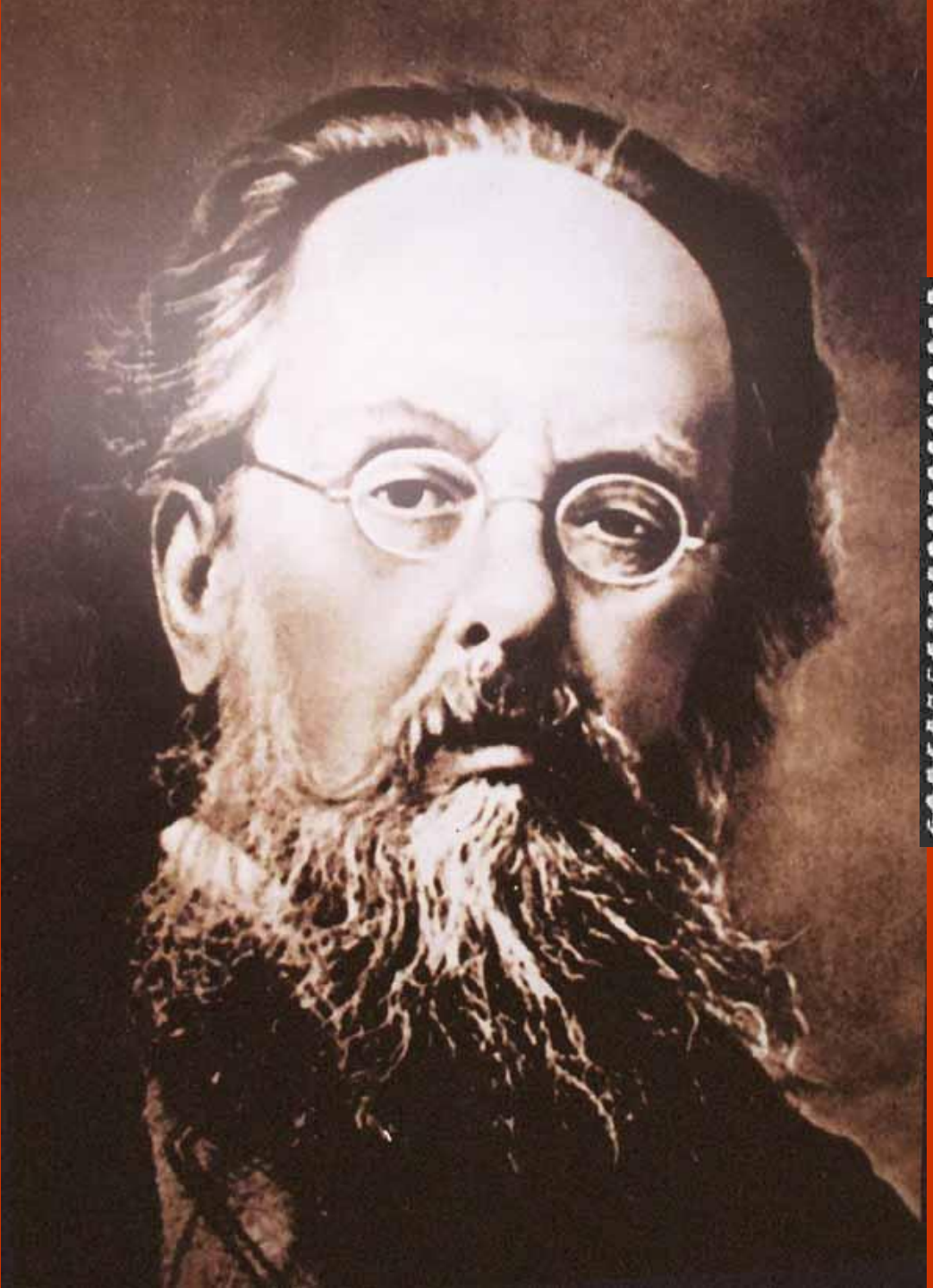
VOYAGES INTERSTELLAIRES

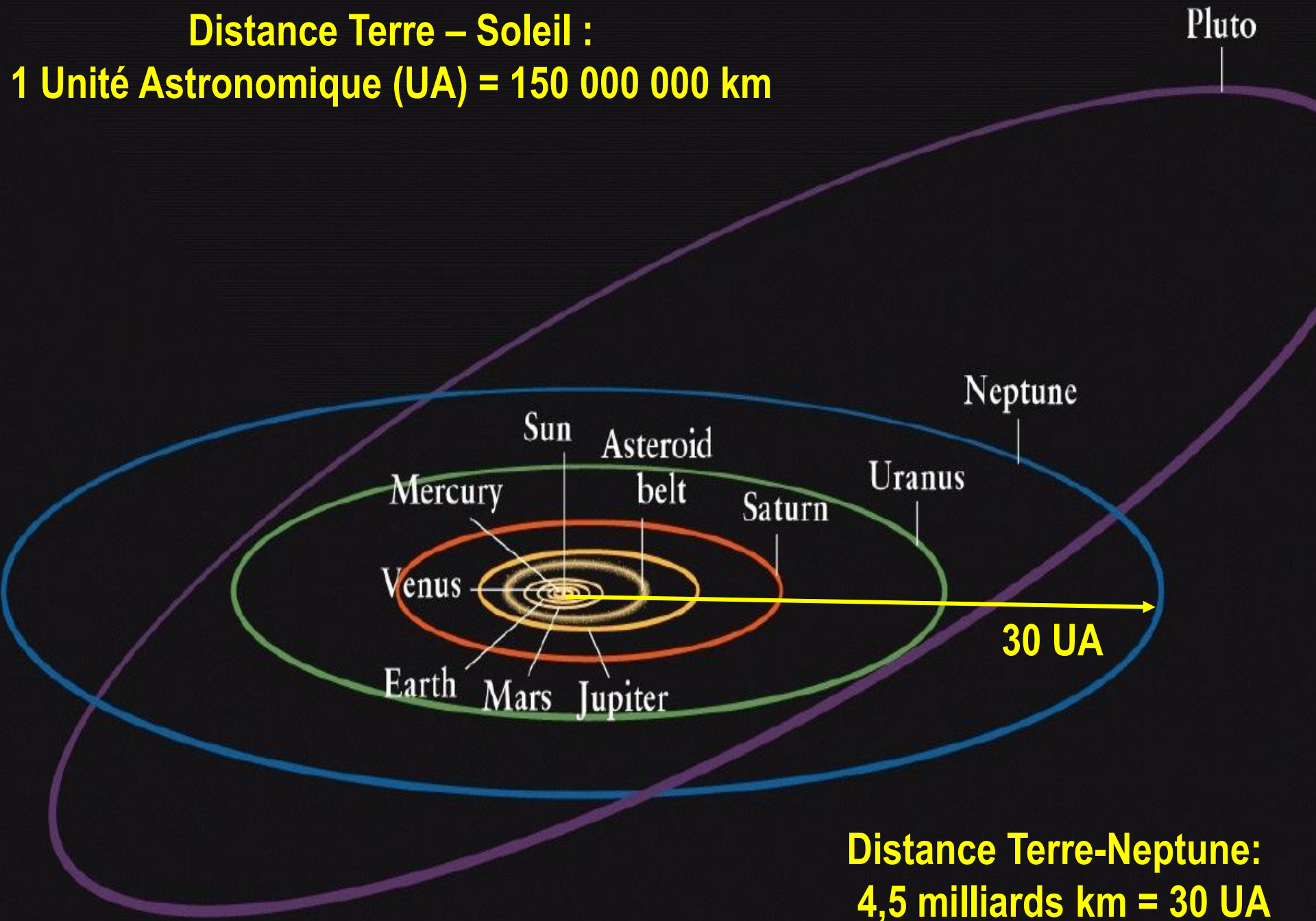
N. Prantzos (Institut d'Astrophysique de Paris)



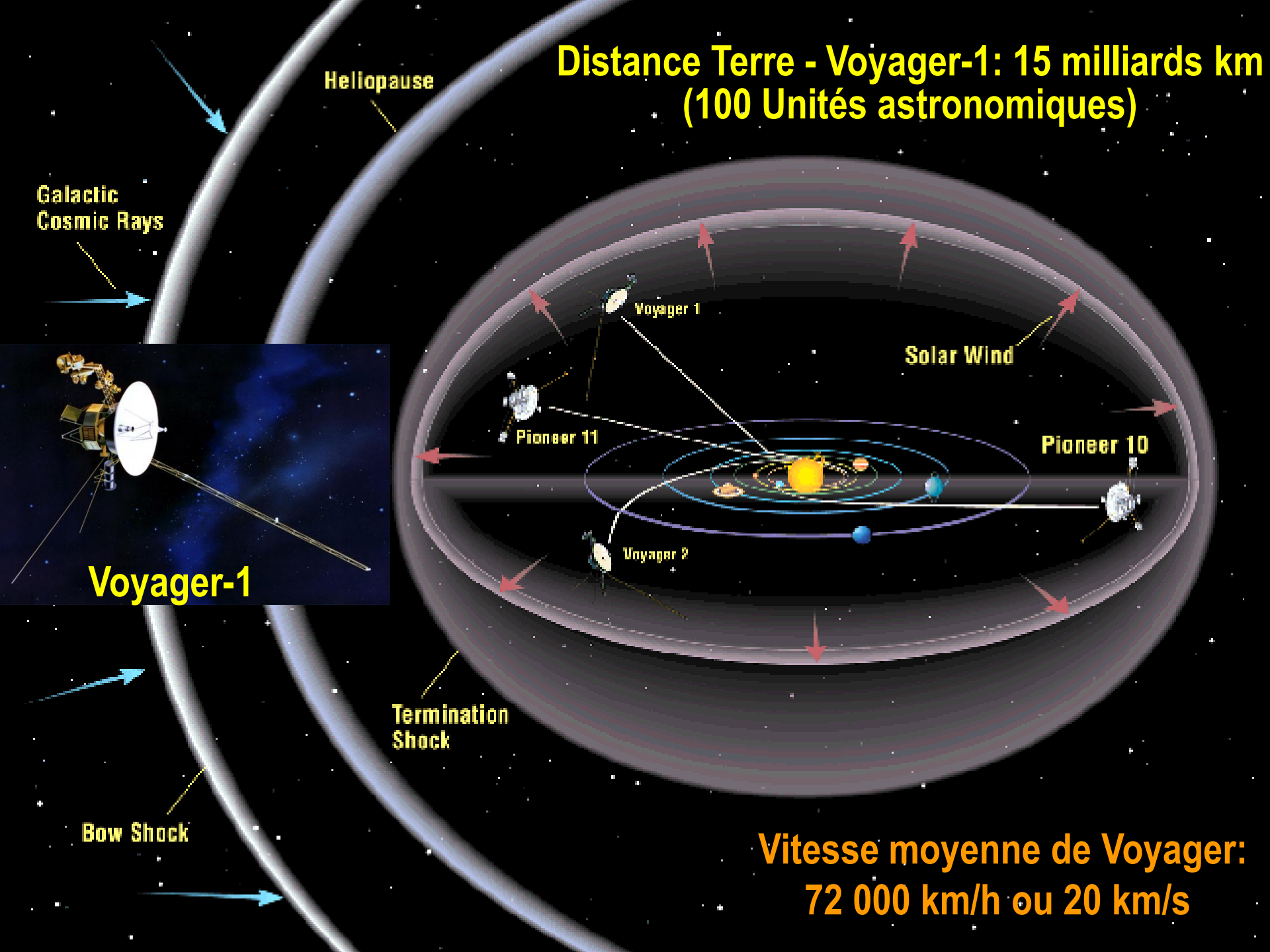
KONSTANTIN EDWARDOVICH TSIOLKOVSKI (1857 – 1935)

“La Terre est le berceau de l’humanité, mais on ne reste pas au berceau toute sa vie”

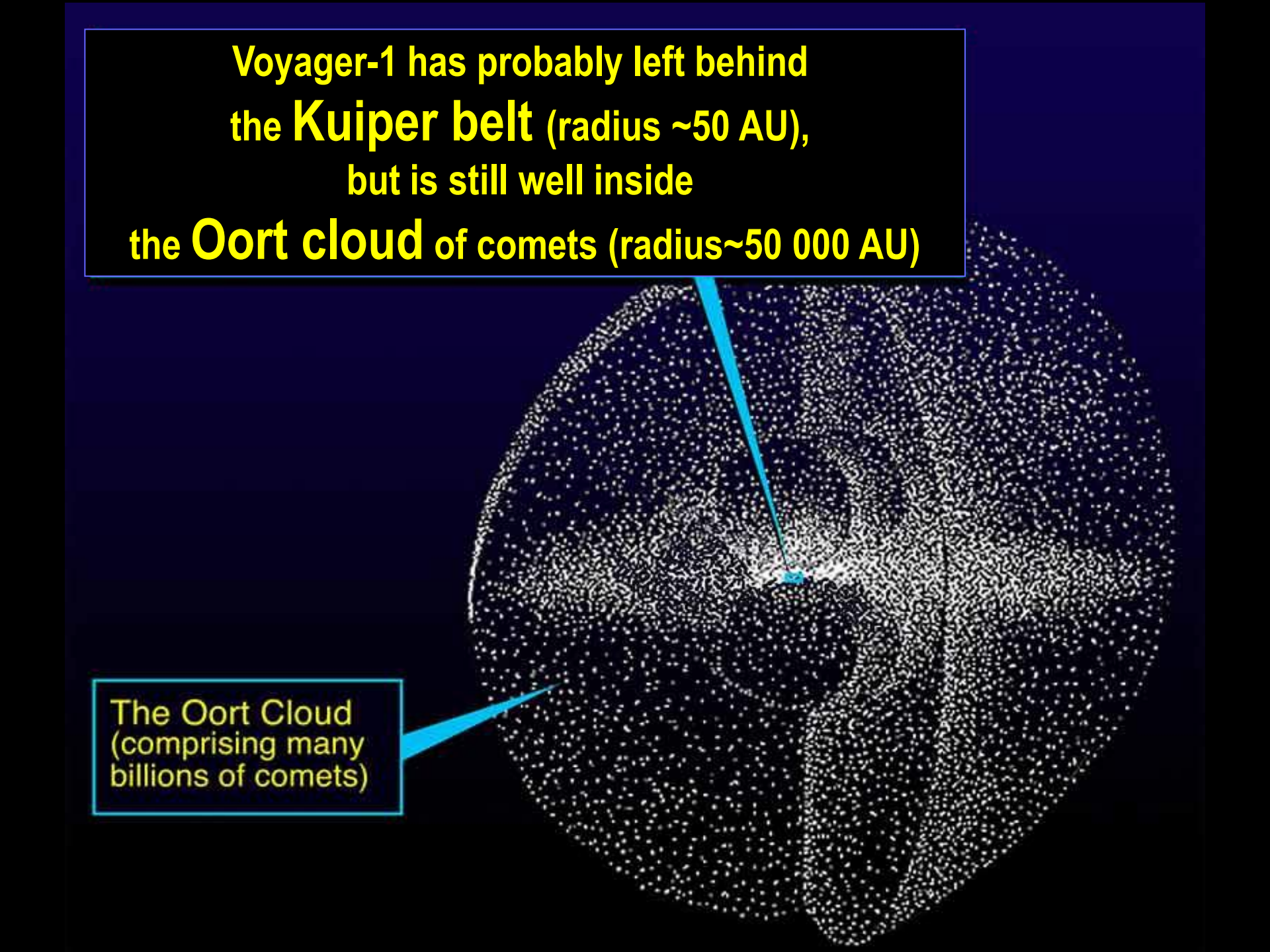
Distance Terre – Soleil :
1 Unité Astronomique (UA) = 150 000 000 km

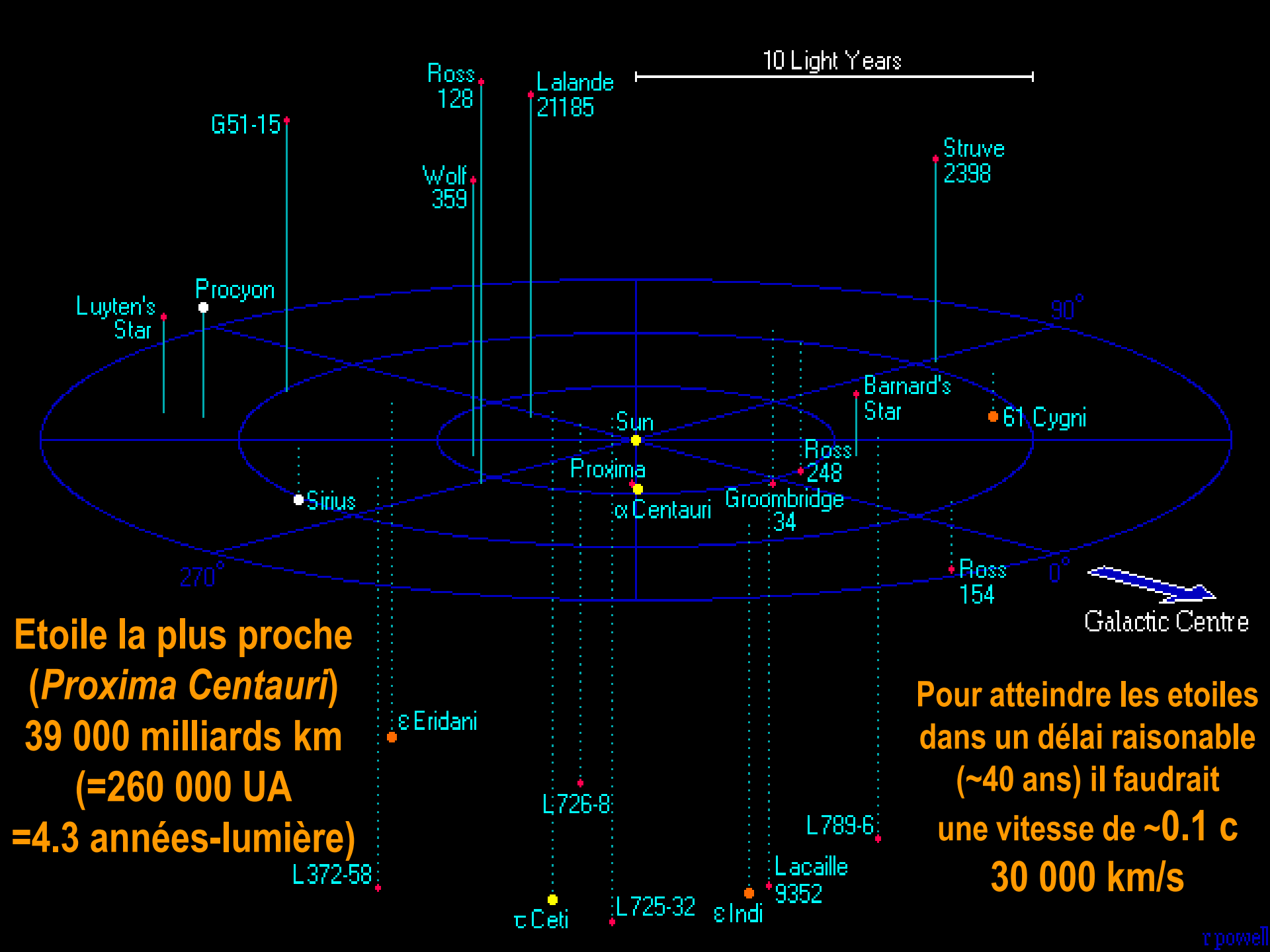


Distance Terre-Neptune:
4,5 milliards km = 30 UA


Distance Terre - Voyager-1: 15 milliards km
(100 Unités astronomiques)
Heliopause
Galactic
Cosmic Rays
Voyager 1
Solar Wind
Pioneer 11
Pioneer 10
Voyager 2
Voyager-1
Termination
Shock
Bow Shock
Vitesse moyenne de Voyager:
72 000 km/h ou 20 km/s

Voyager-1 has probably left behind
the **Kuiper belt** (radius ~50 AU),
but is still well inside
the **Oort cloud** of comets (radius~50 000 AU)





Etoile la plus proche (*Proxima Centauri*) 39 000 milliards km (=260 000 UA =4.3 années-lumière)

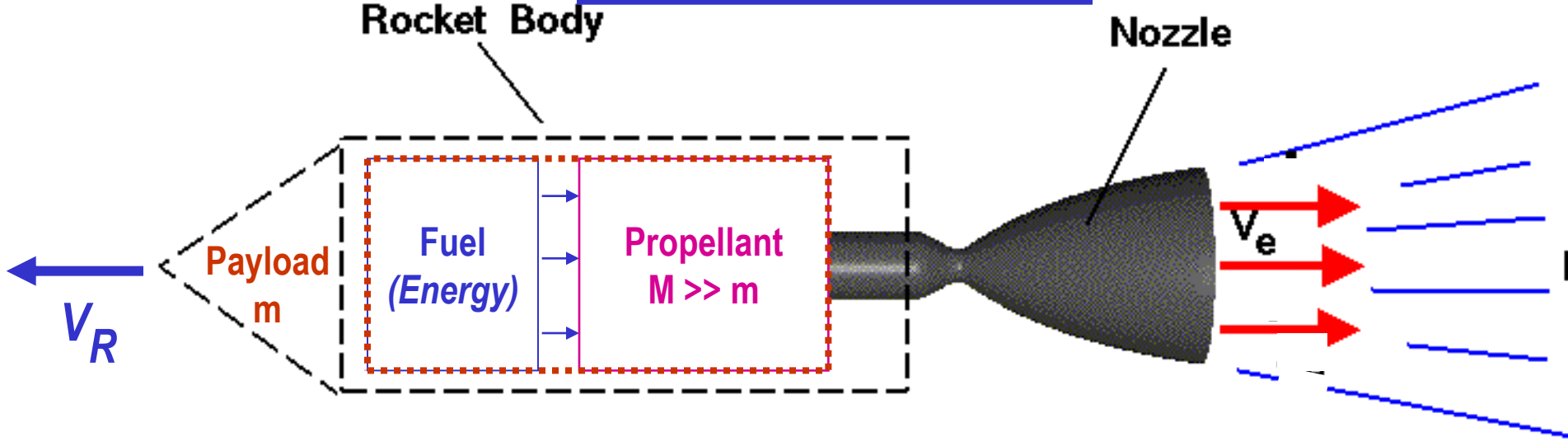
Pour atteindre les etoiles dans un délai raisonable (~40 ans) il faudrait une vitesse de ~0.1 c 30 000 km/s

rpowell

ROCKETS

The higher the exhaust velocity v_e and the mass of the propellant M
the higher will be the velocity V_R of the rocket of payload m

$$V_R = v_e \ln(M/m)$$



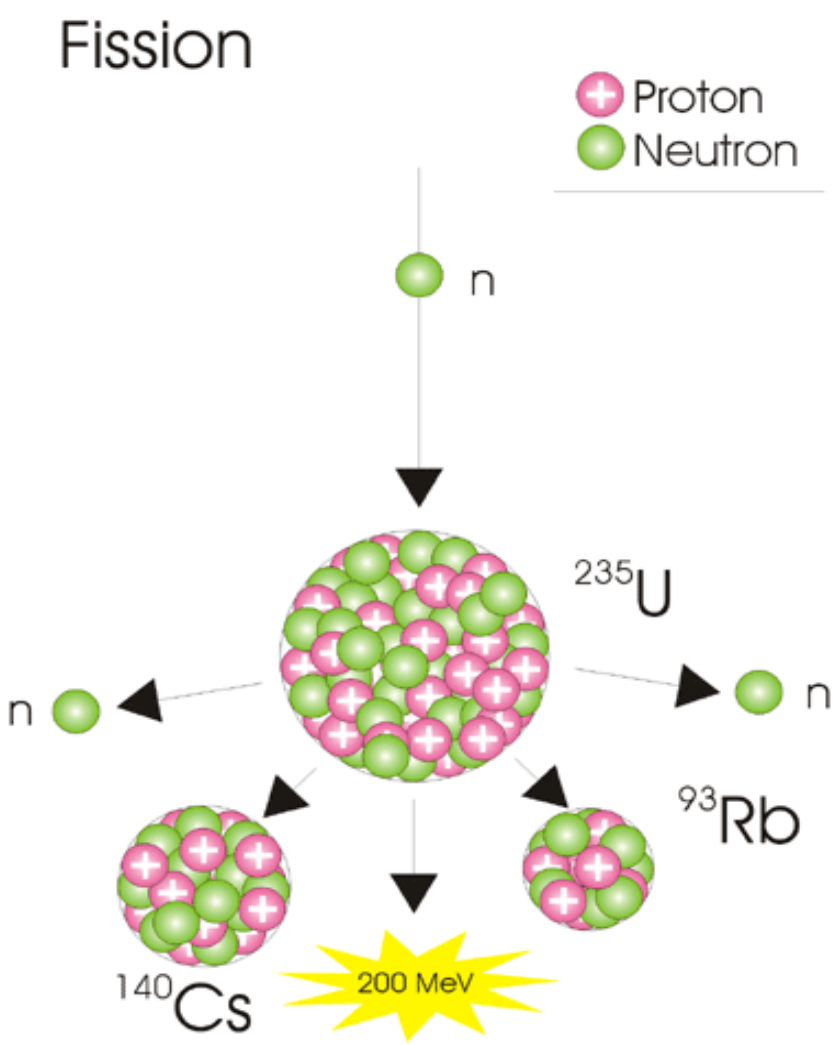
$$E = \tfrac{1}{2} M v_e^2 = a M c^2 \quad \rightarrow \quad v_e = \sqrt{2 a c^2}$$

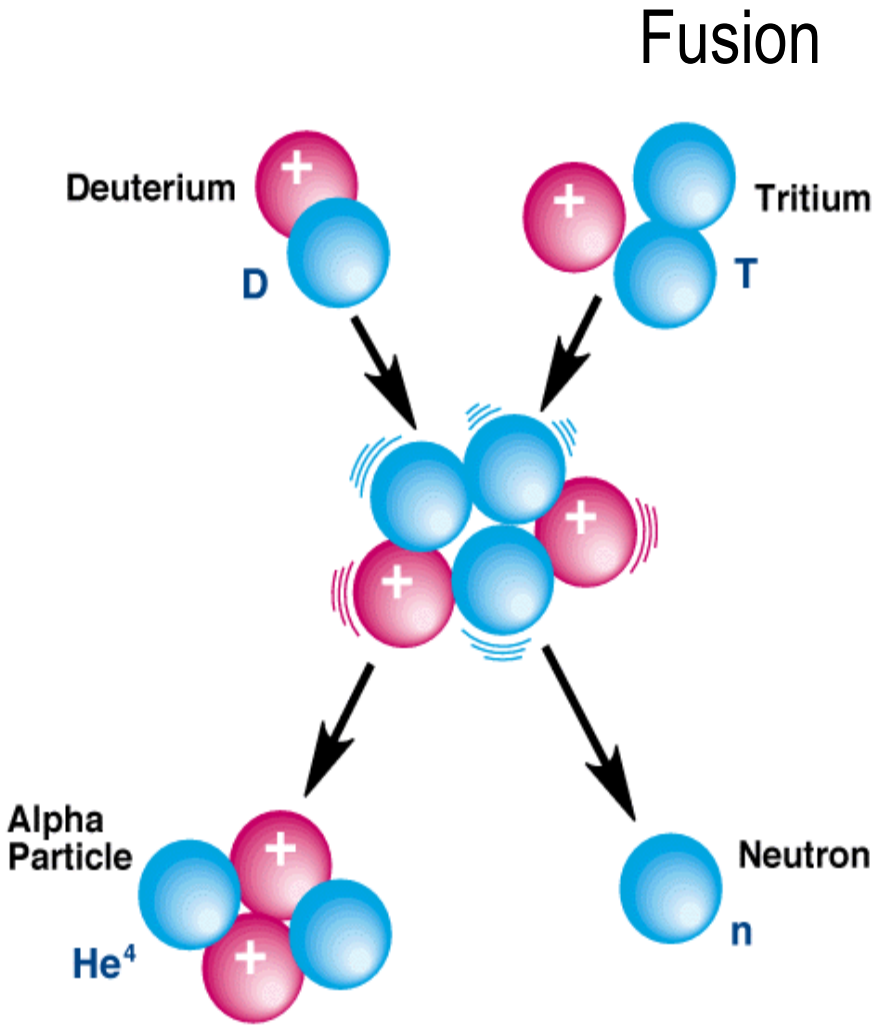
An efficient energy source is required, to convert a fraction **a** *(efficiency)*
of the mass of the propellant into kinetic energy (i.e. large exhaust velocity) of the propellant

The more efficient the energy source, the larger the exhaust velocity
and the faster the rocket will be

Propulsion Type	Specific Impulse [sec]	Thrust-to-Weight Ratio
Chemical Bipropellant	200 - 410	.1 - 10
Electromagnetic	1200 - 5000	10^{-4} - 10^{-3}
Nuclear Fission	500 - 3000	.01 - 10
Nuclear Fusion	10^{+4} - 10^{+5}	10^{-5} - 10^{-2}
Antimatter Annihilation	10^{+3} - 10^{+6}	10^{-3} - 1

Nuclear reactions

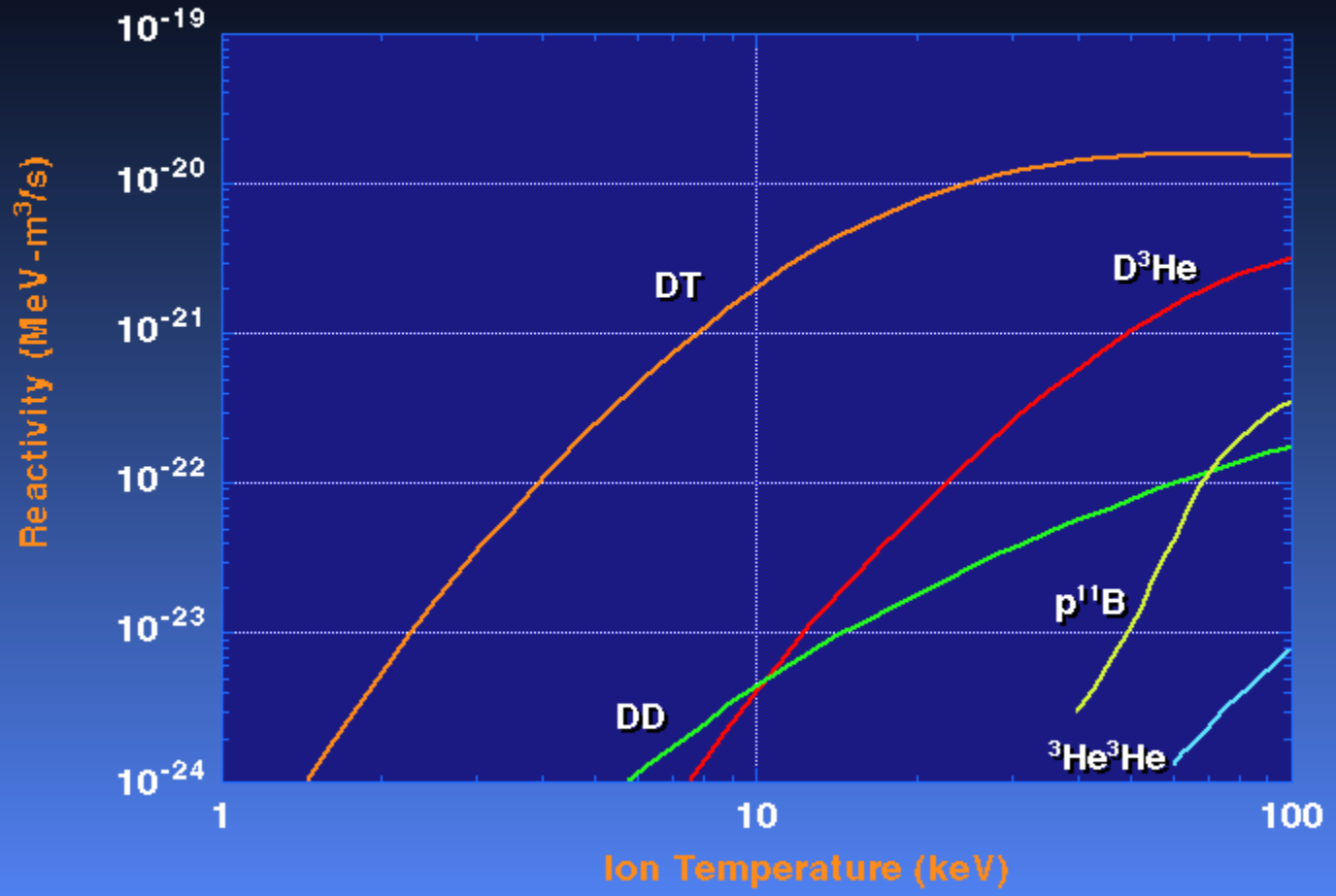




Efficiency ~a few 10^{-4}

Efficiency ~ 10^{-3}

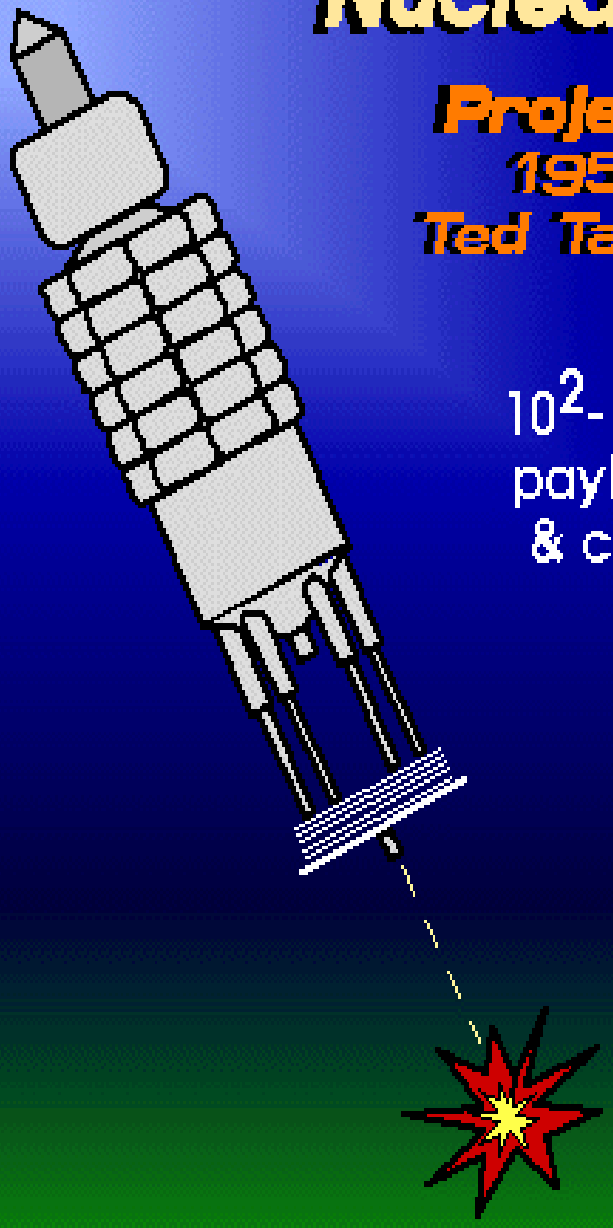
Maxwellian Fusion Reactivities ($\Sigma E_{fus}\sigma v$)



D + T	→	^{4}He (3,5 MeV)	+	n (14,1 MeV)
D + D	→	^{3}He (0,82 MeV)	+	n (2,45 MeV)
D + D	→	T (1,01 MeV)	+	H (3,02 MeV)
D + ^{3}He	→	^{4}He (3,6 MeV)	+	H (14,7 MeV)

Nuclear Concepts

Project Orion
1958-1965
Ted Taylor, et al.



10^2-10^3 T
payload
& crew

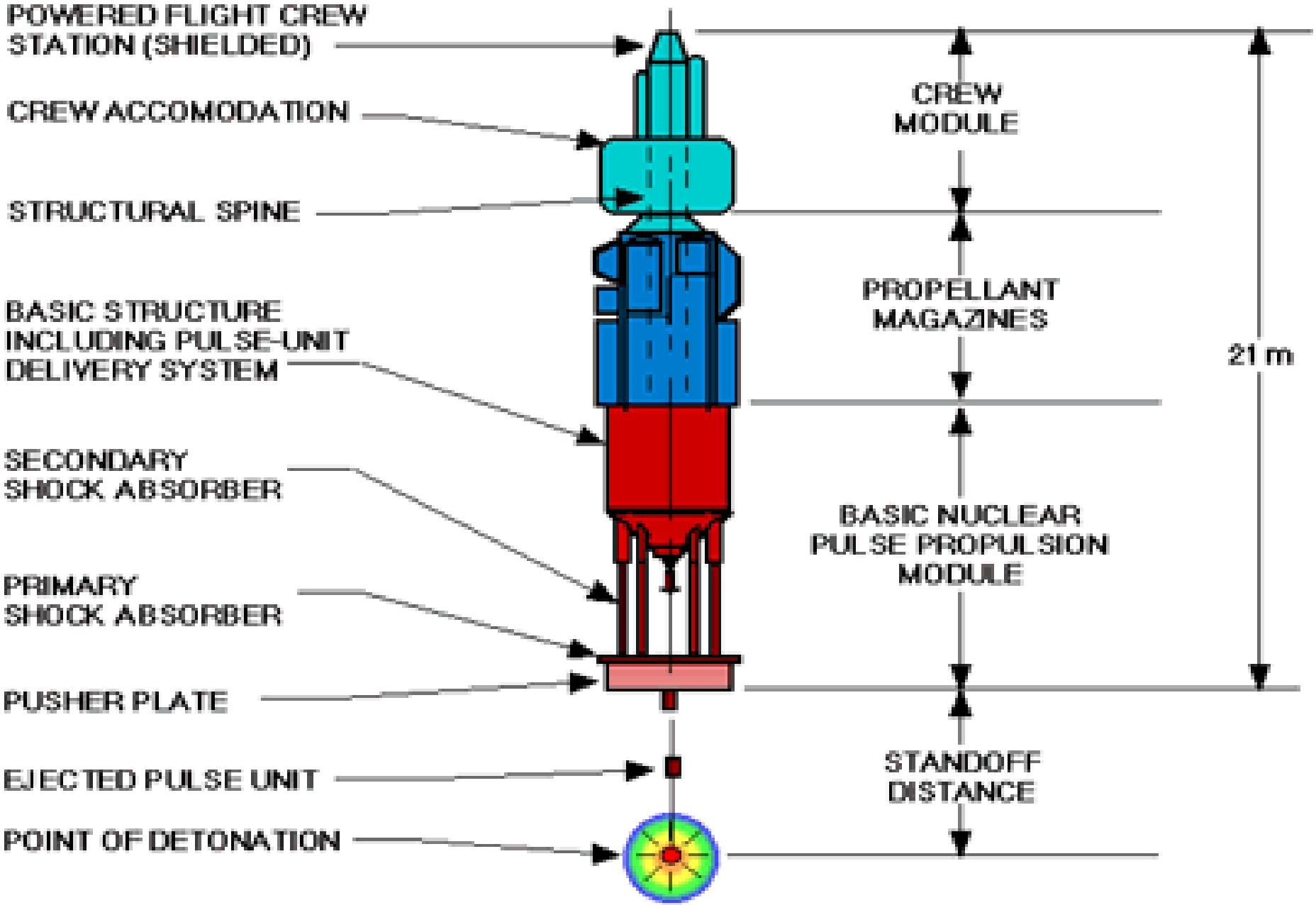
10^3-10^4 Isp
Accel ≈ 1g

10^{-2} to 10^3 T
Fission
explosions
~ 5/sec

Vols habités à l'intérieur du système solaire

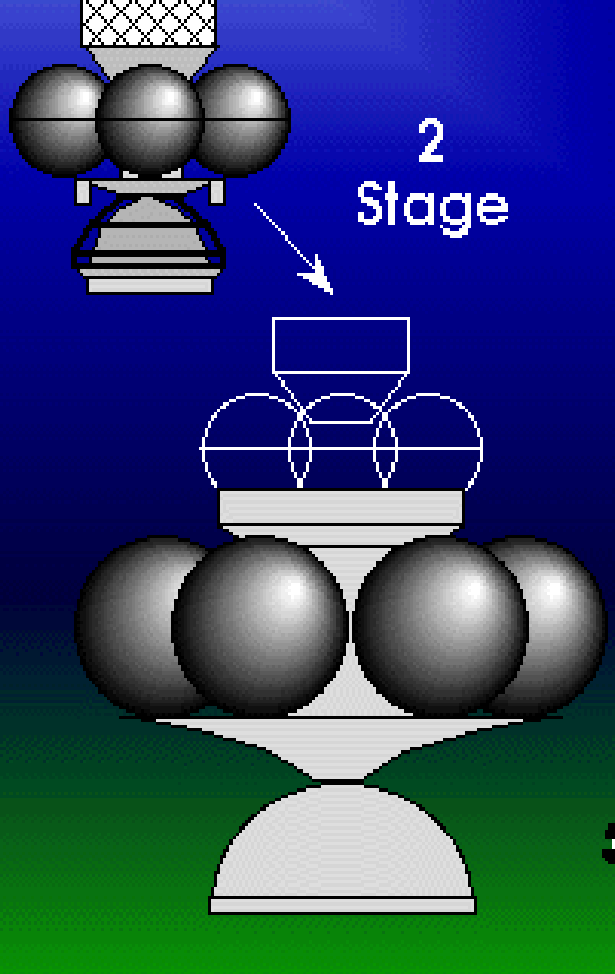
©D-94-68487

PROJECT ORION



Nuclear Concepts

Project Daedalus
1973-1978
British Interplanetary Society



2 Stage

10^2 T payload

10^6 Isp
12% Light speed

Micro-Fusion explosions
~ 250/sec

36 YEARS* Interstellar fly-by

* Was 50 years to Barnard's star ~6 pc

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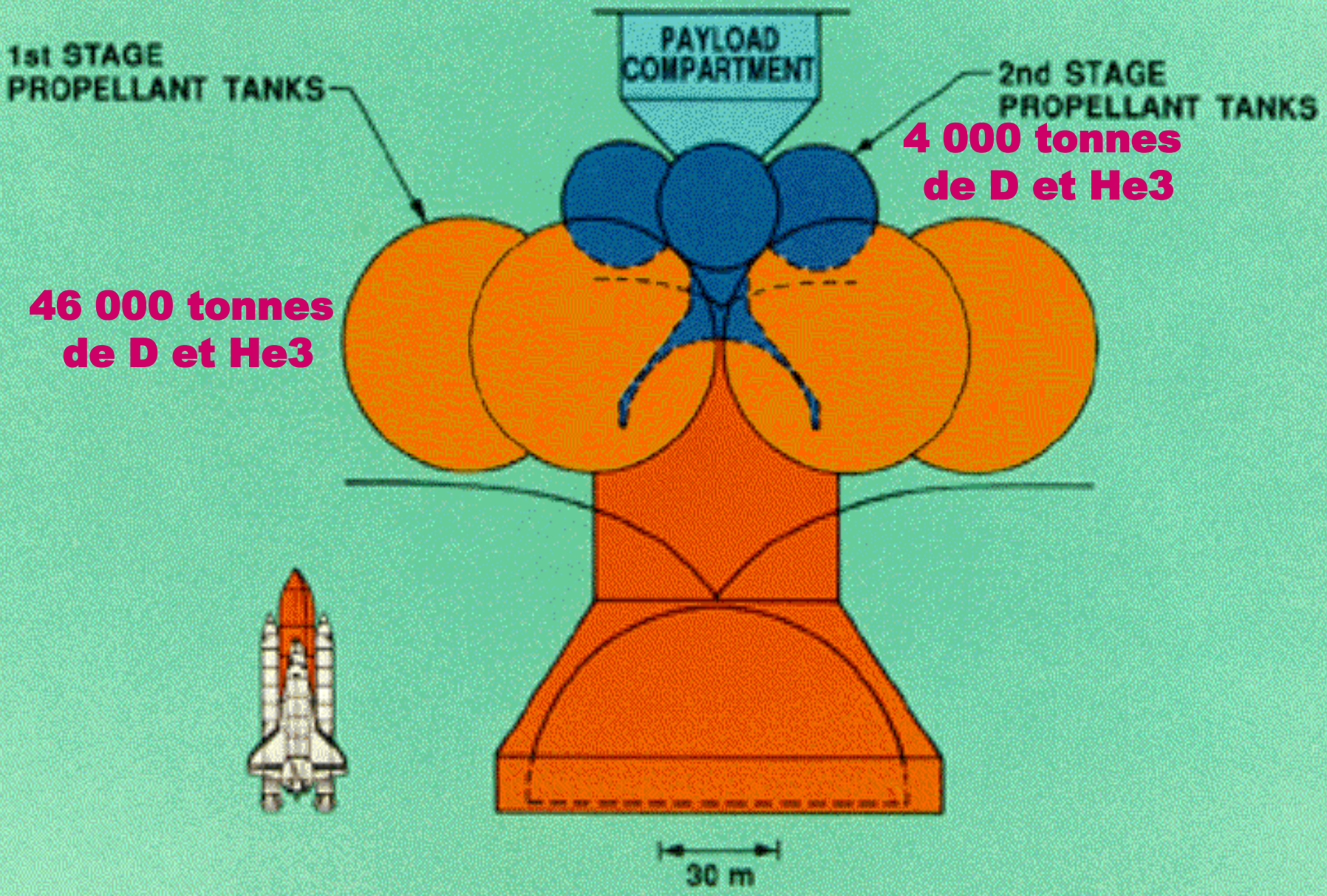
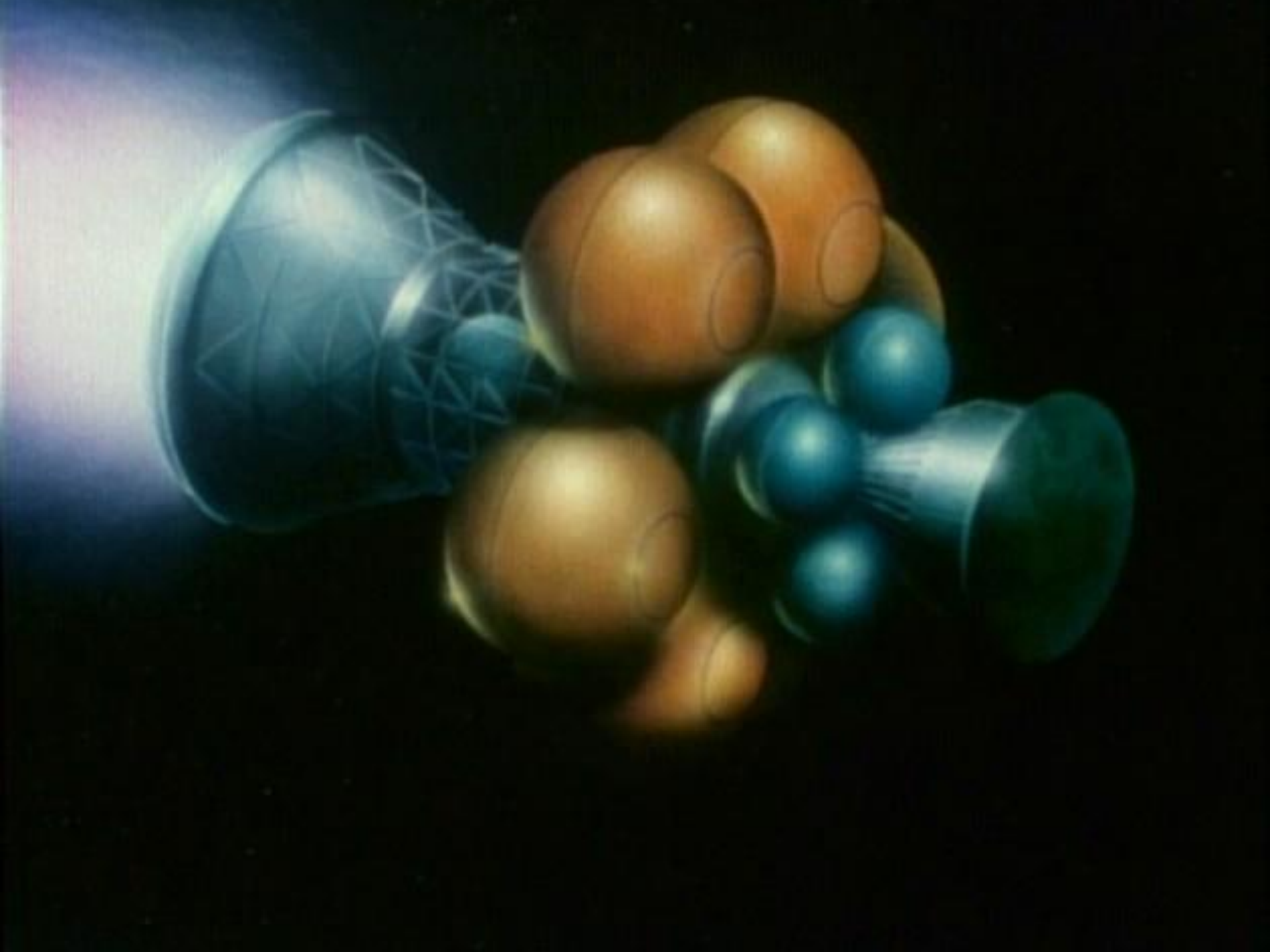
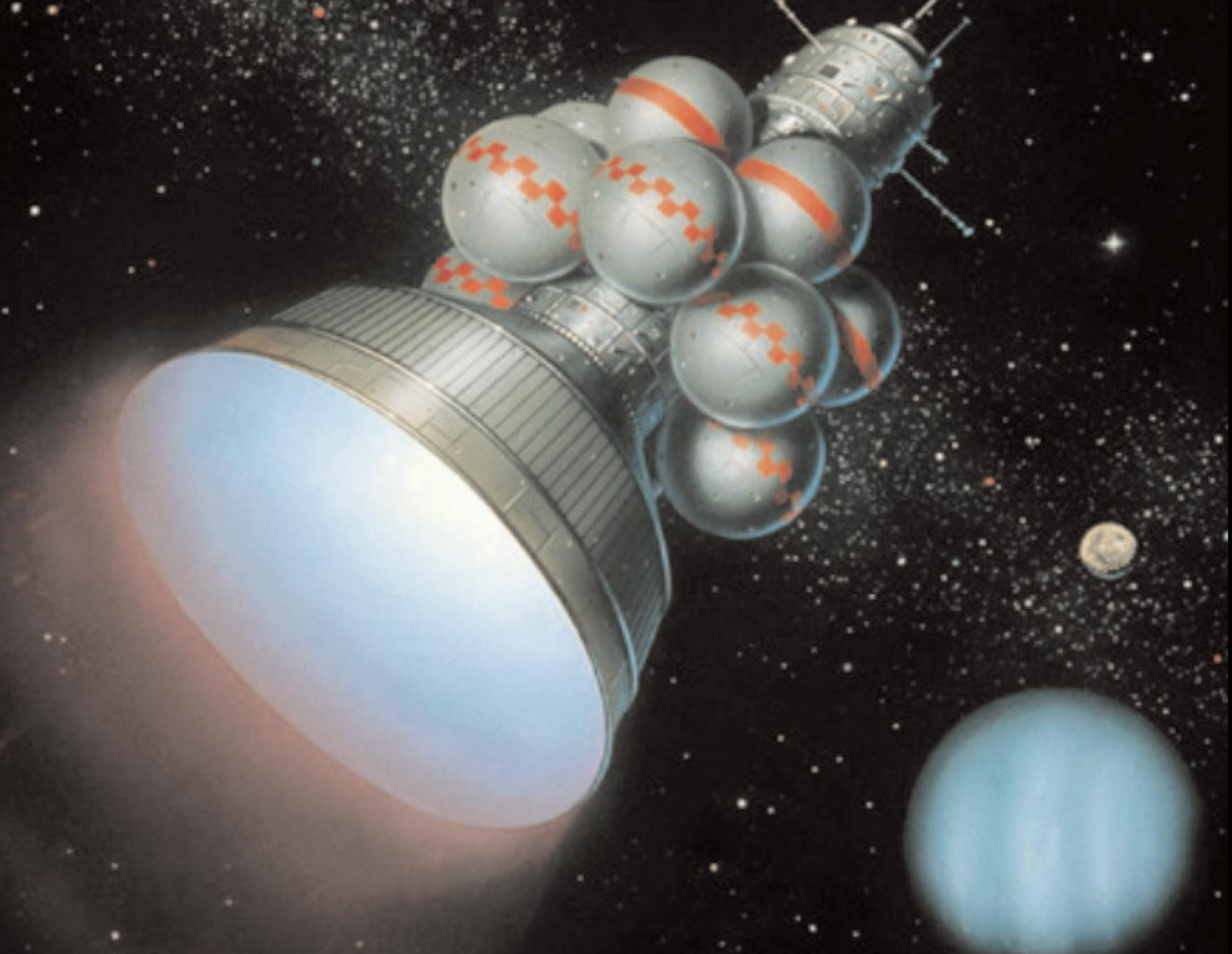
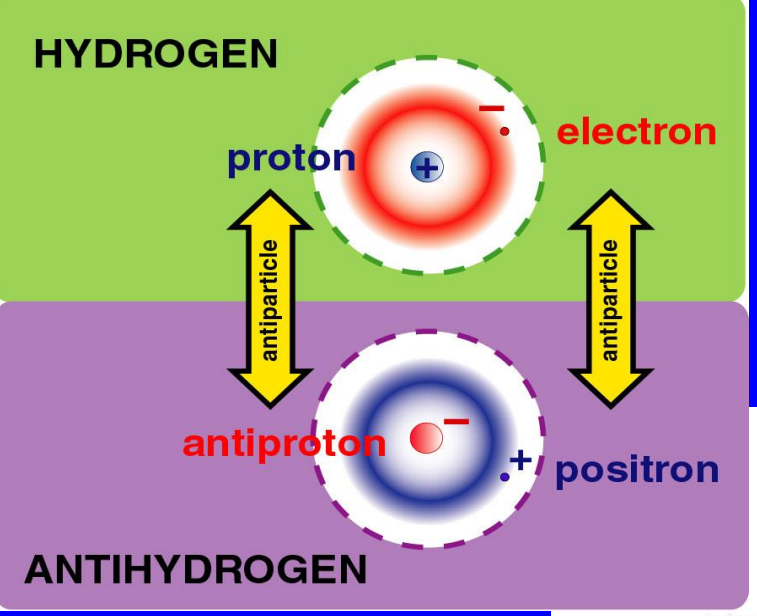
PROJECT DAEDALUS









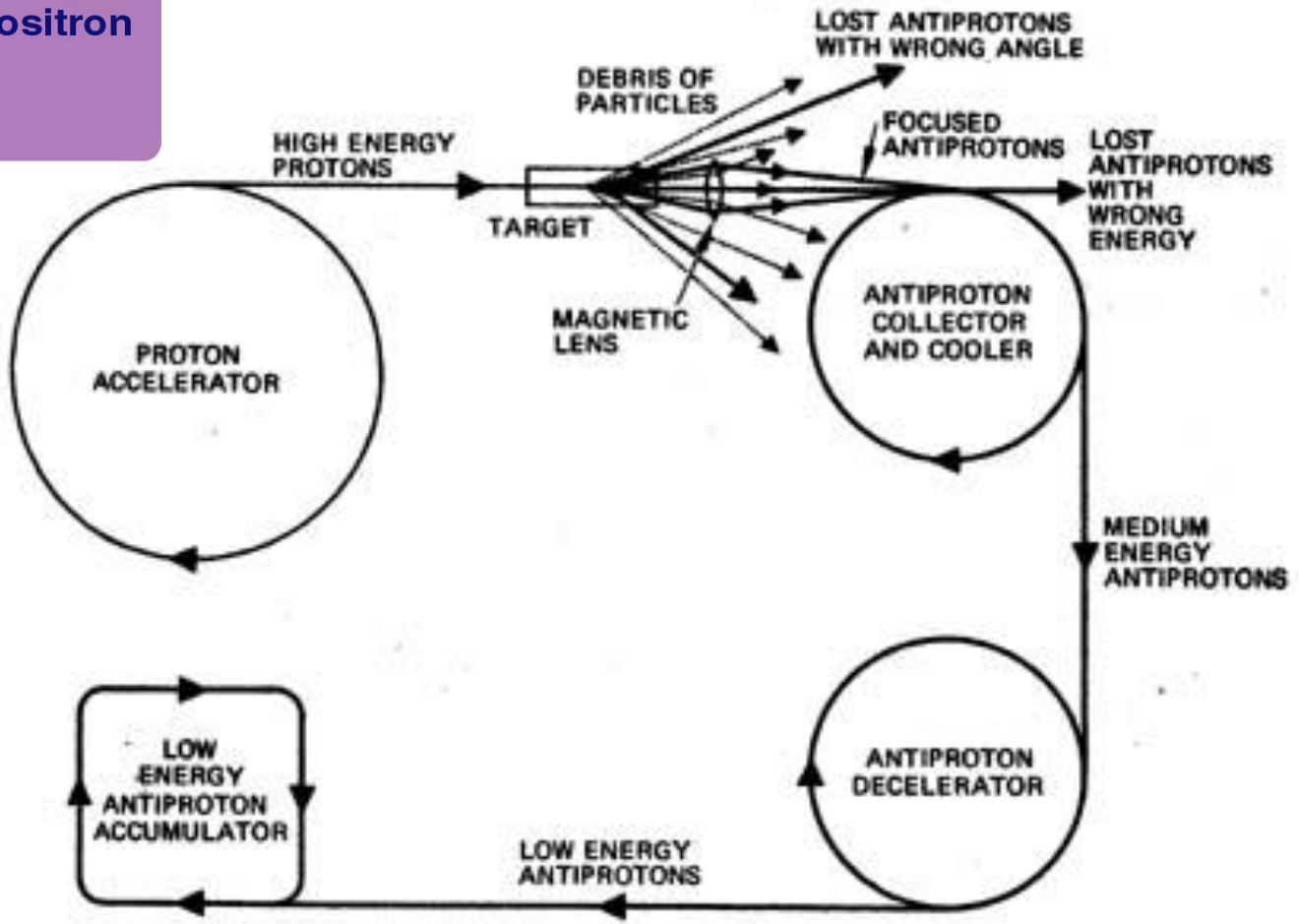
ANTIMATIERE

$$e^- + e^+ \rightarrow 2\gamma$$

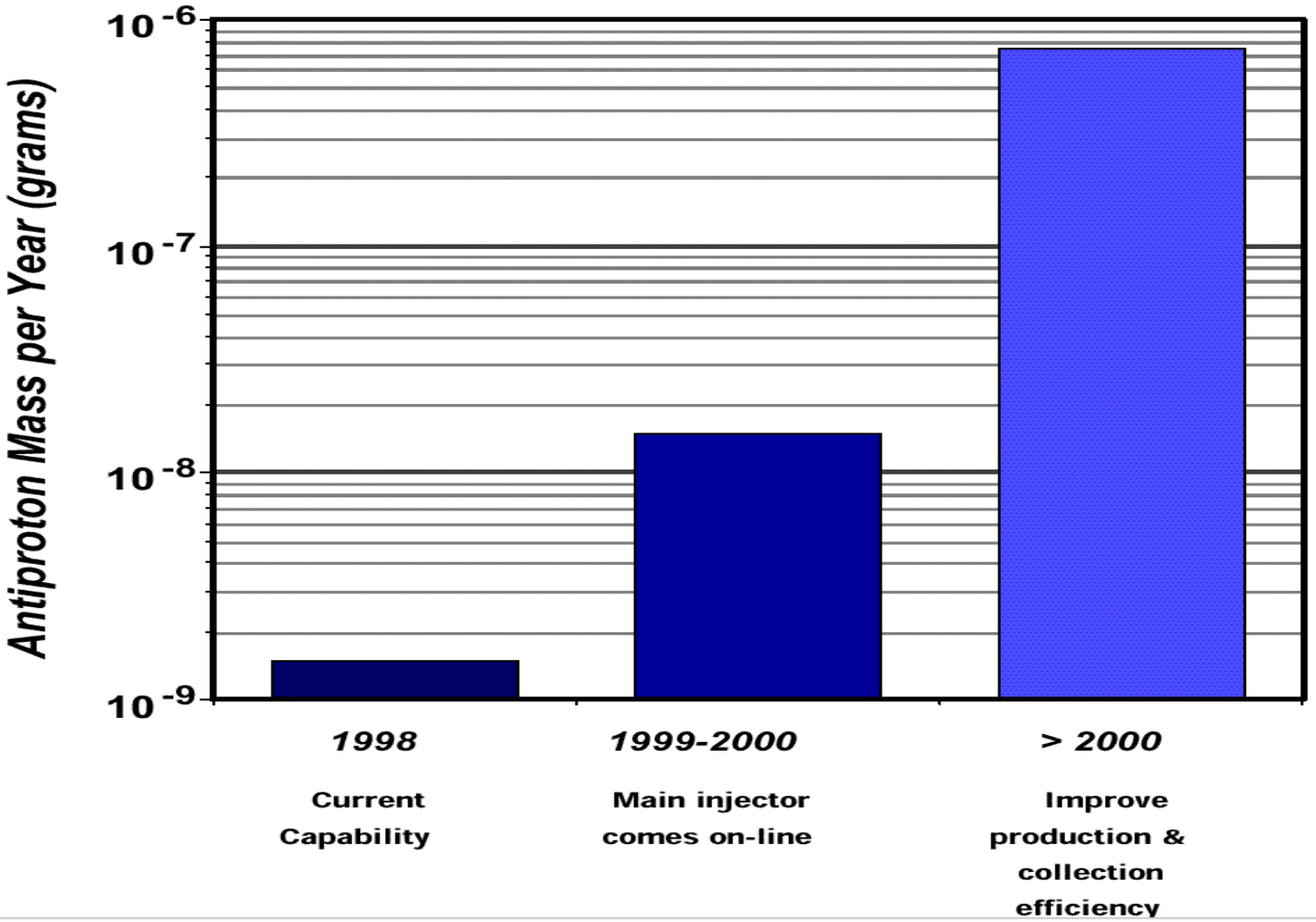
$$p + \bar{p} \rightarrow \pi^0 + \pi^- + \pi^+$$

Elle n'existe pas dans la nature

Il faut la produire au labo *en depensant (beaucoup) de l'énergie..*

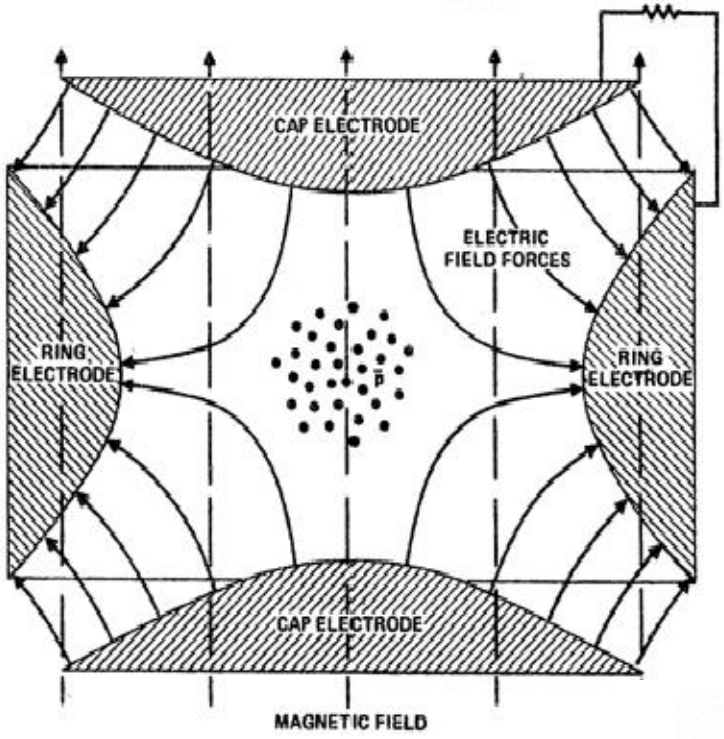


CAPACITÉ DE PRODUCTION / STOCKAGE D'ANTIMATIÈRE



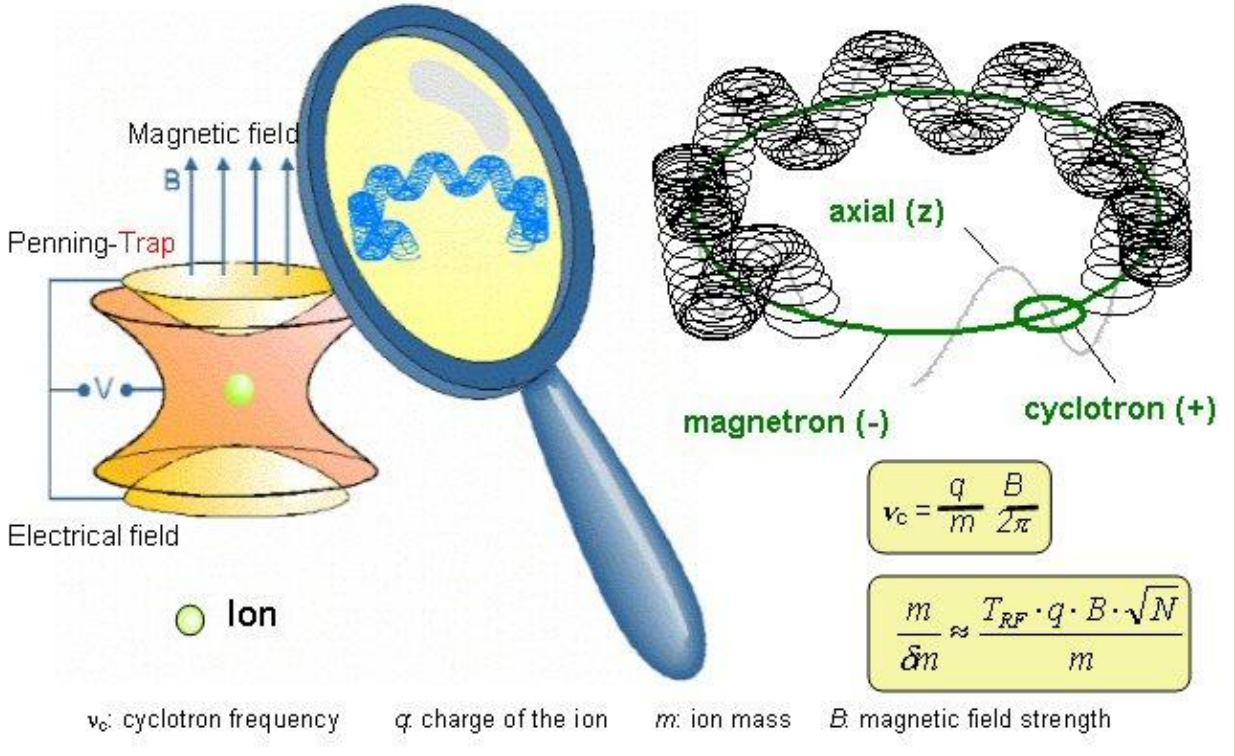
10^{-8} gr par an pour 10^{8} $

- Stockage en grandes quantités ?



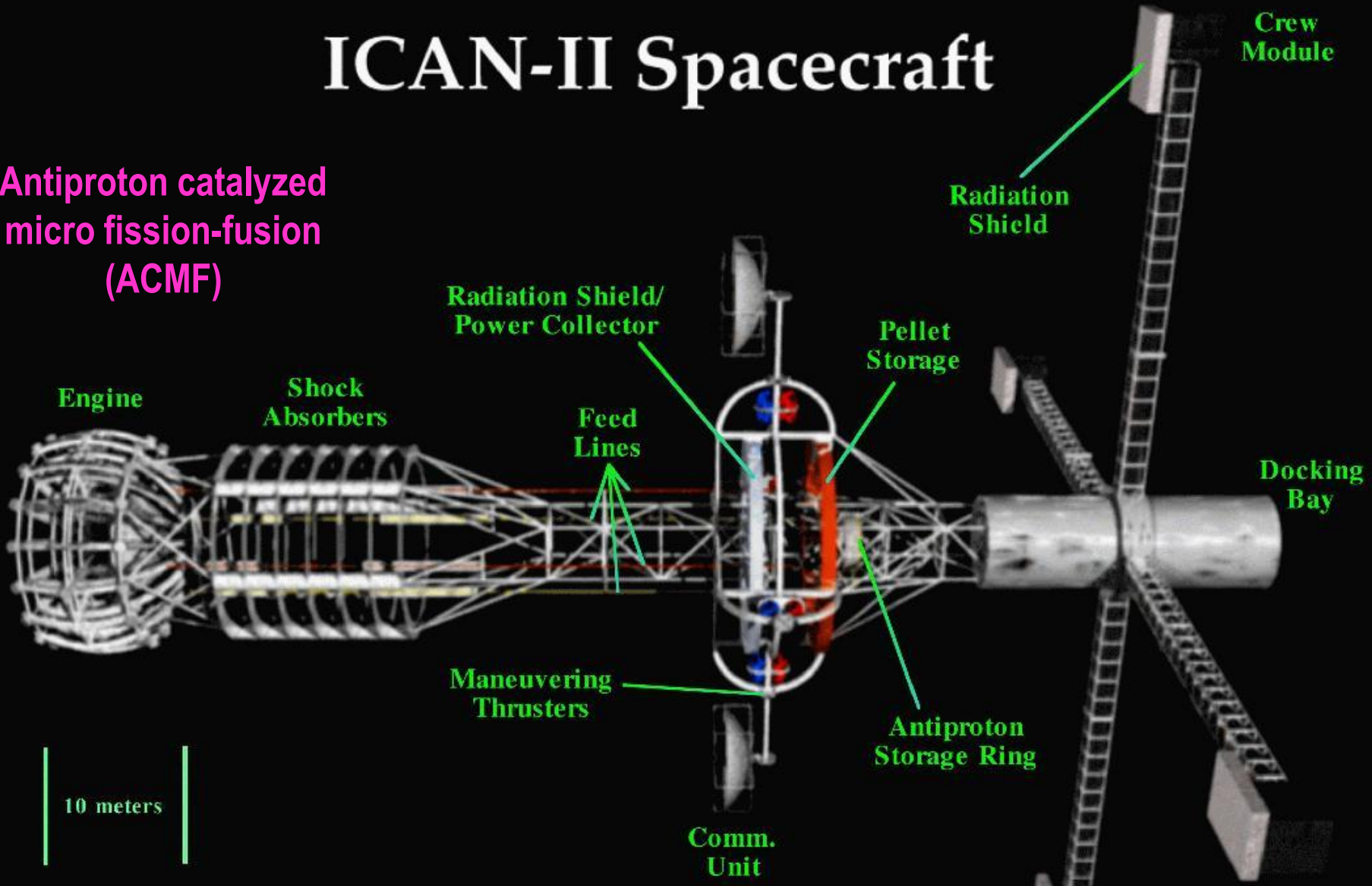
Stockage d'antimatière :

Penning trap



ICAN-II Spacecraft

Antiproton catalyzed micro fission-fusion (ACMF)



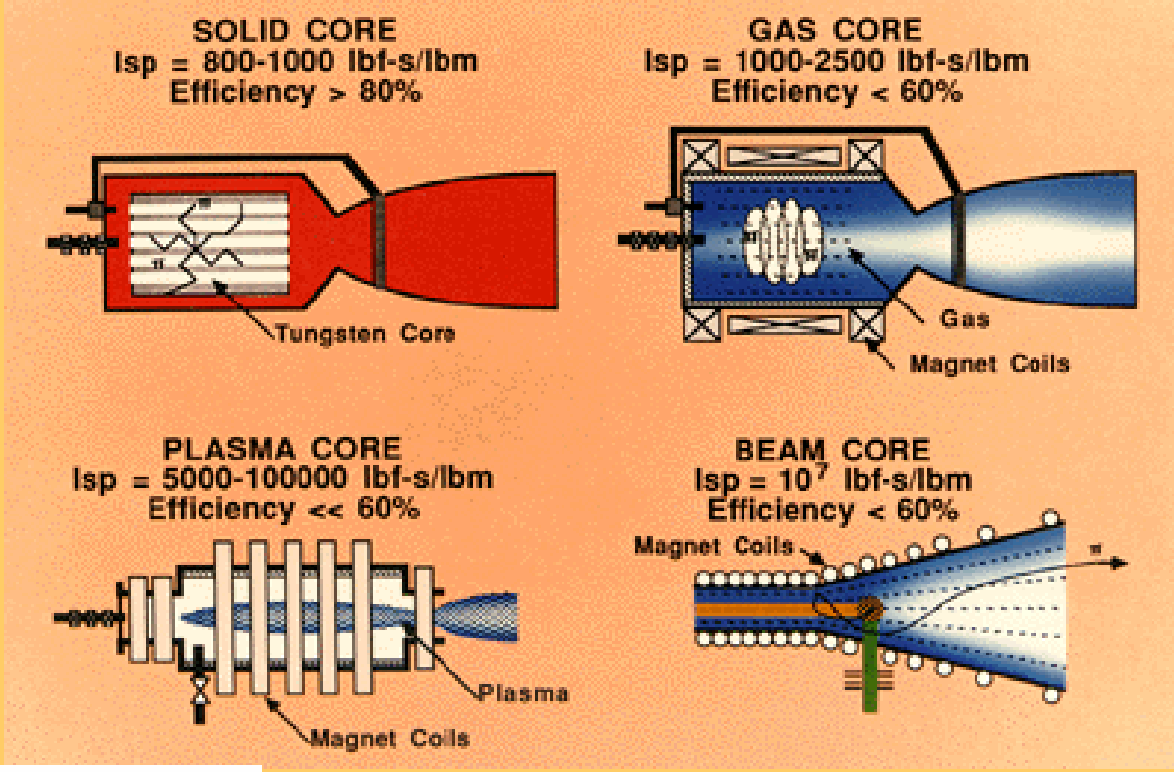
Manned mission :

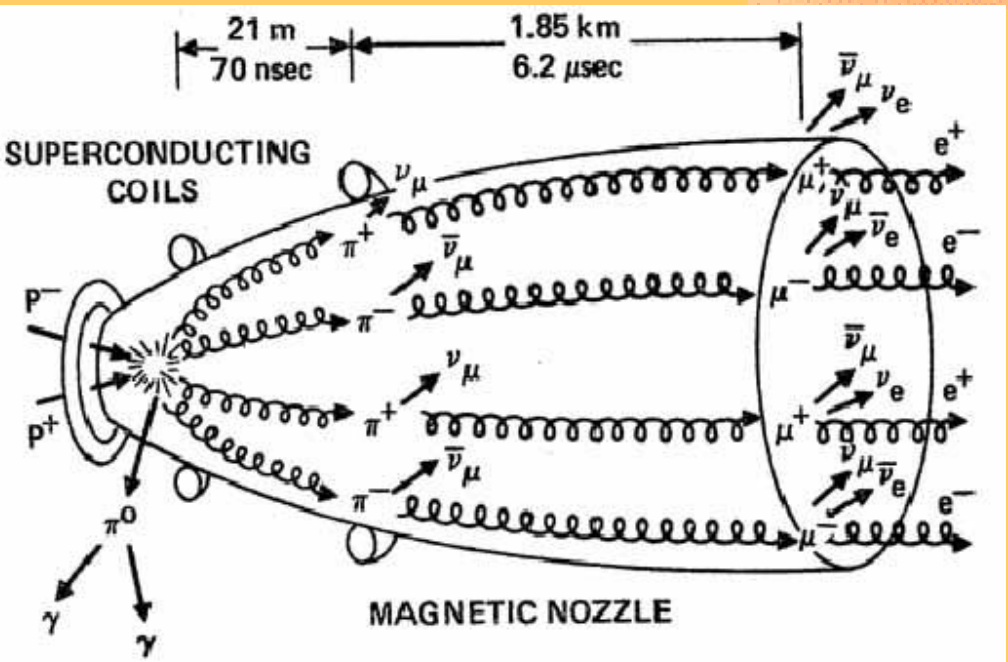
1.5 year round trip to Jupiter + 90 days stay

1 µg of antimatter required

Direct use of antimatter :

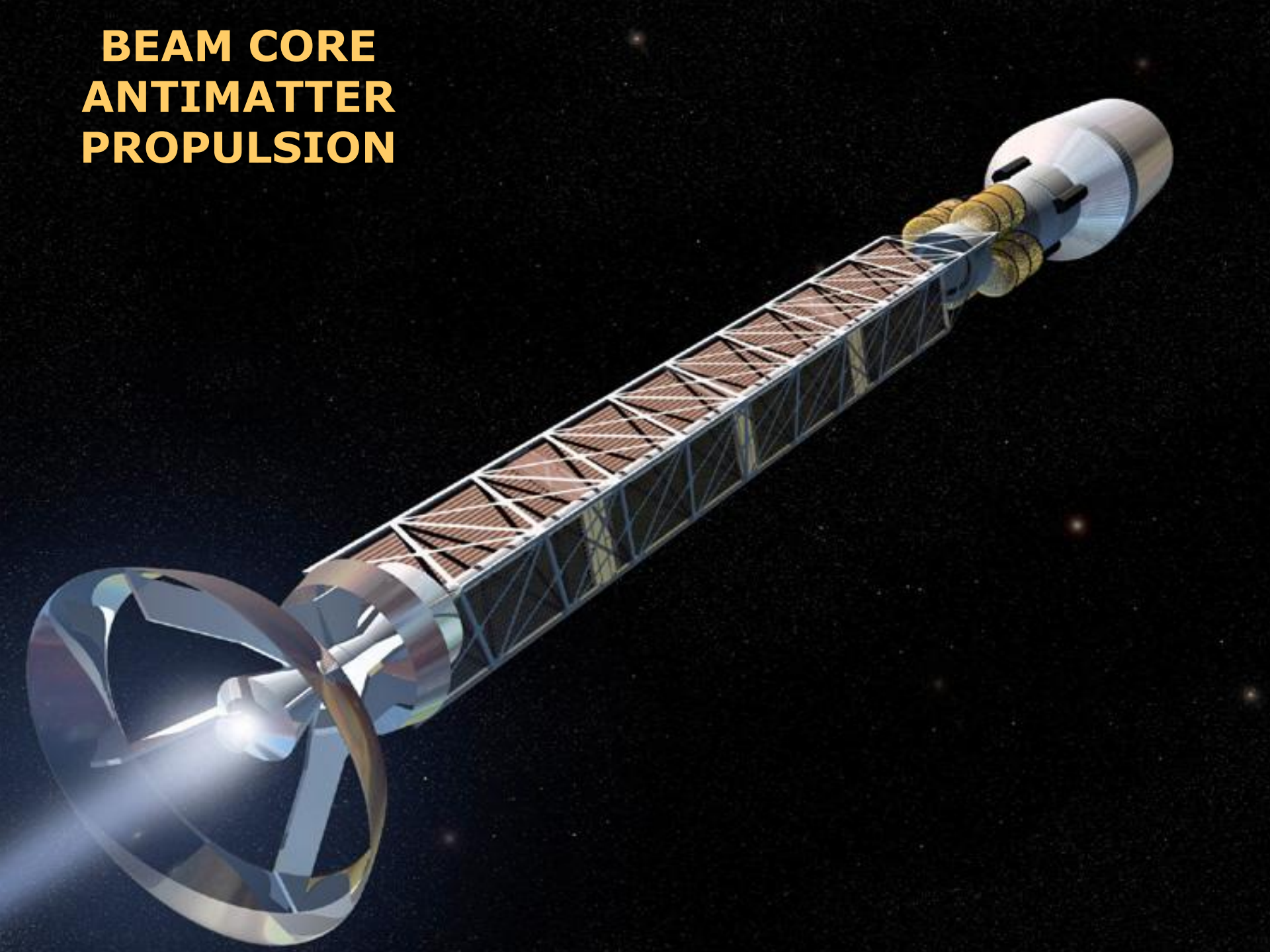
to heat a propellant



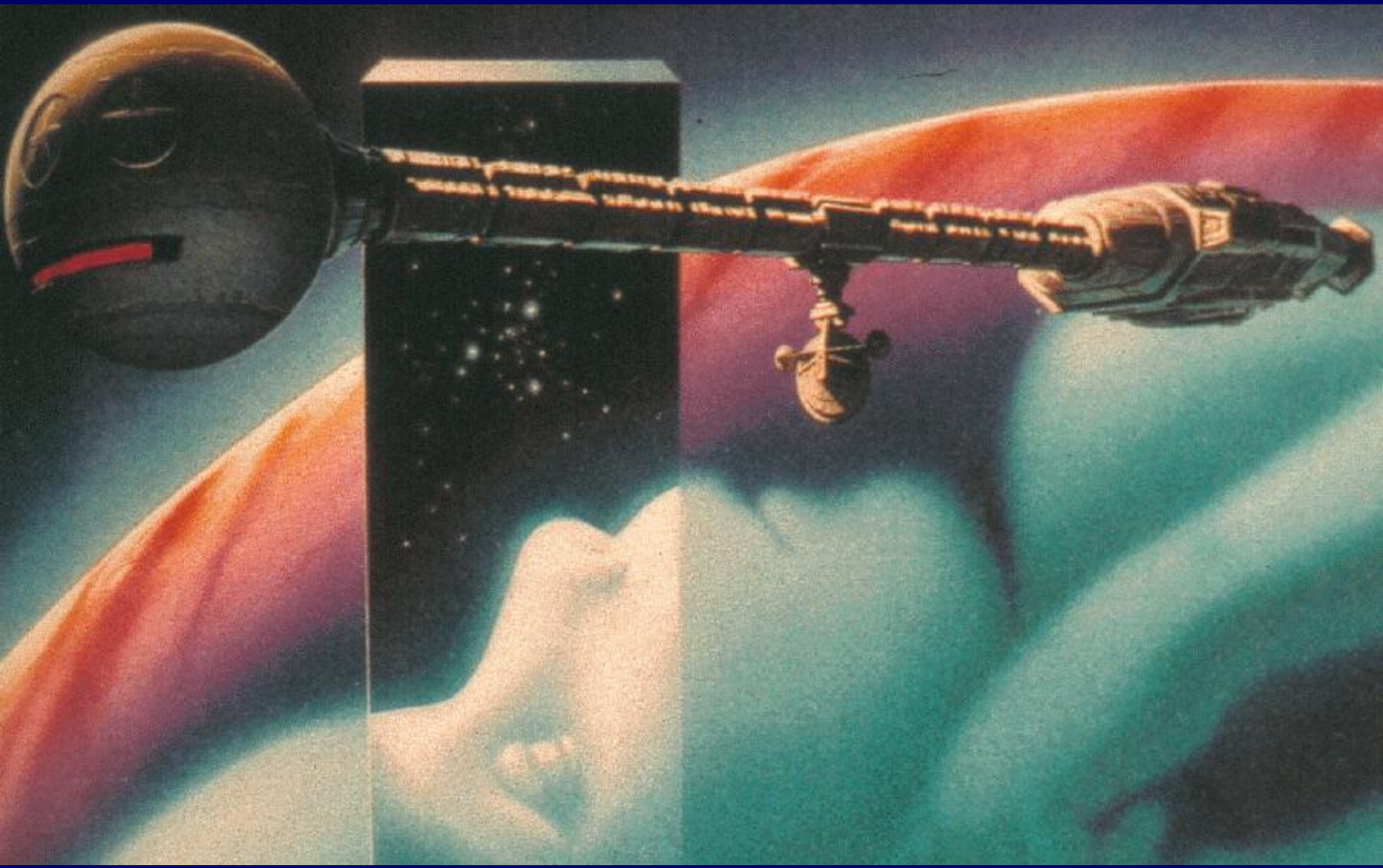


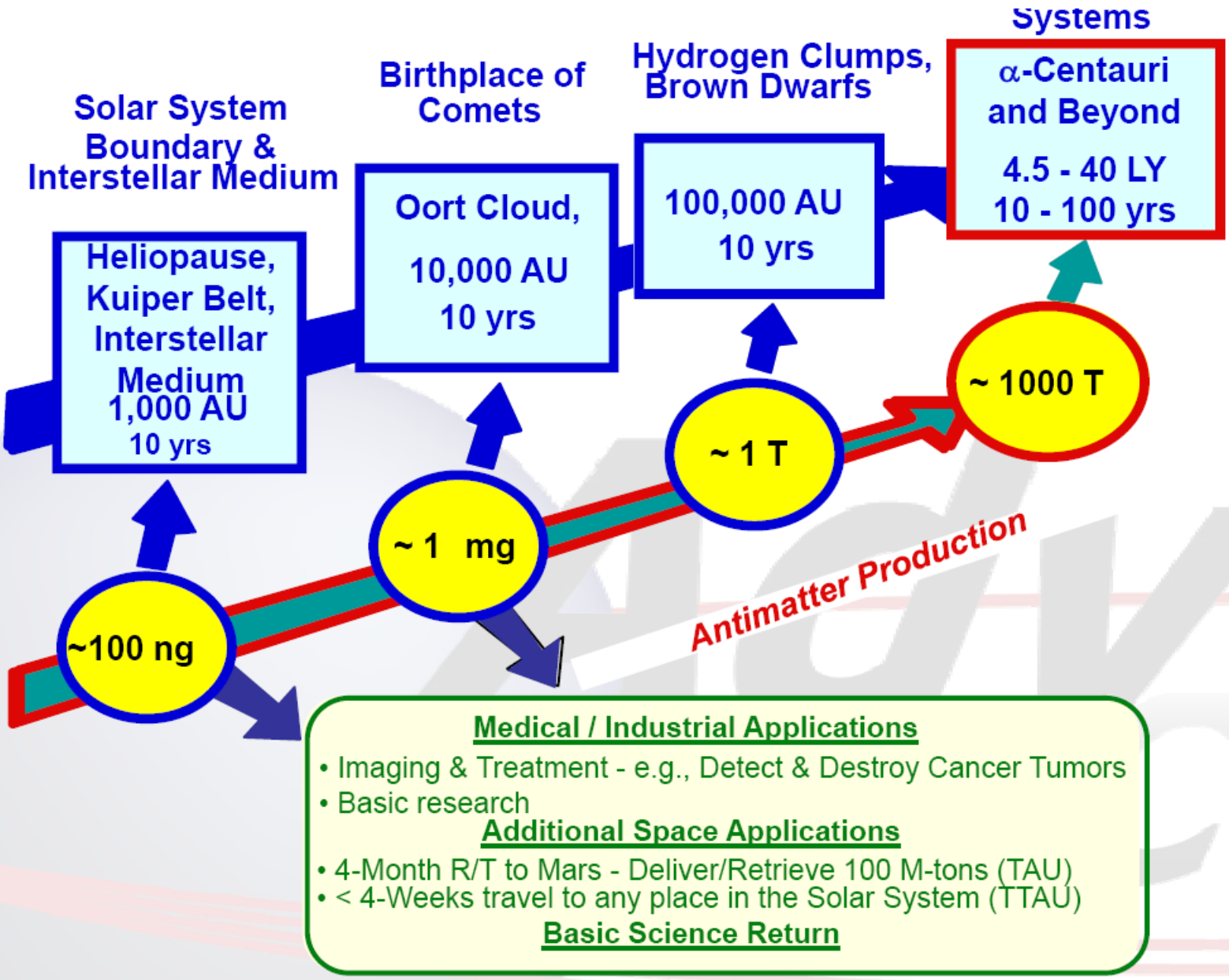
or to provide thrust
(*beam core* concept)

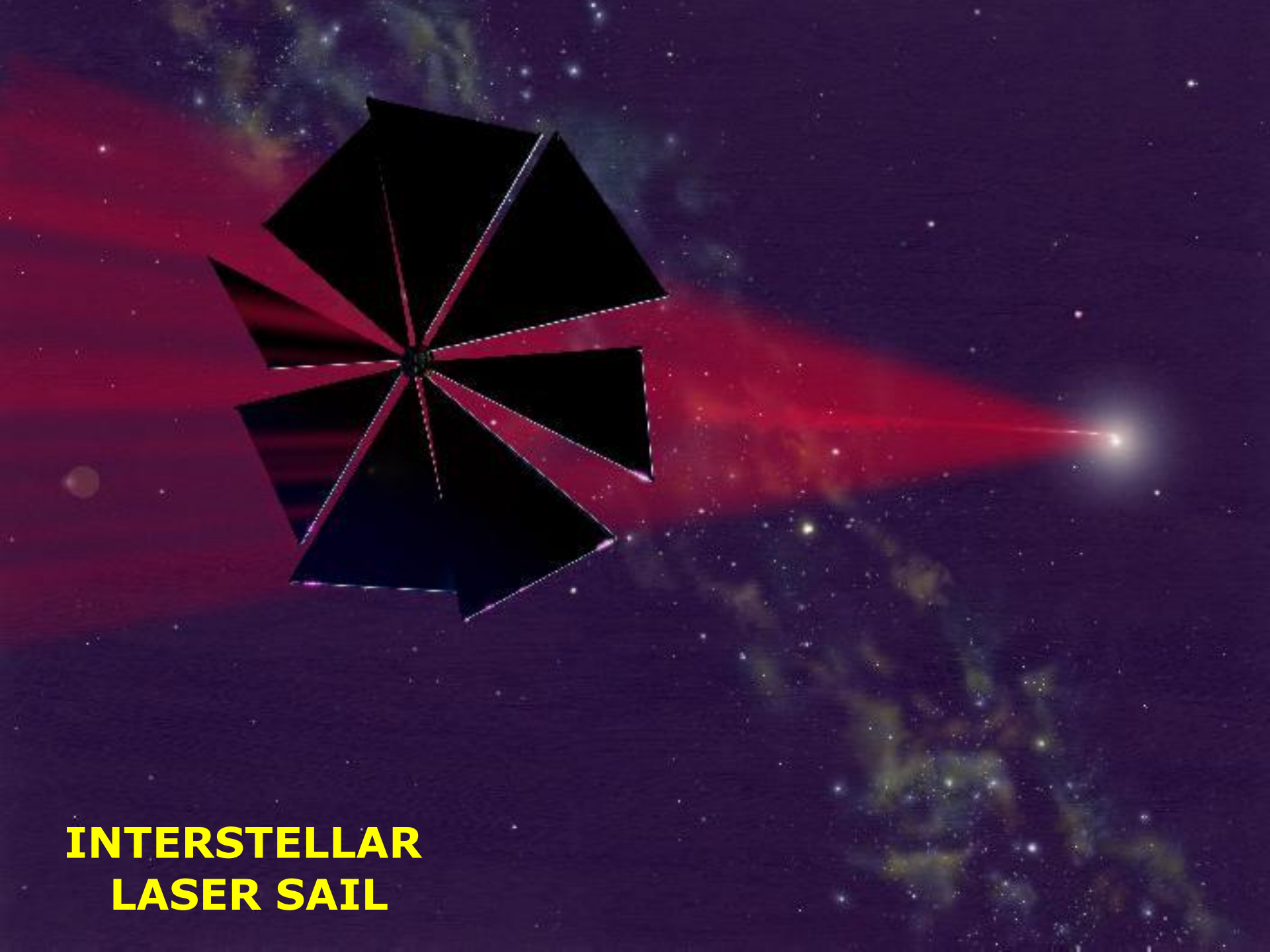
BEAM CORE ANTIMATTER PROPULSION



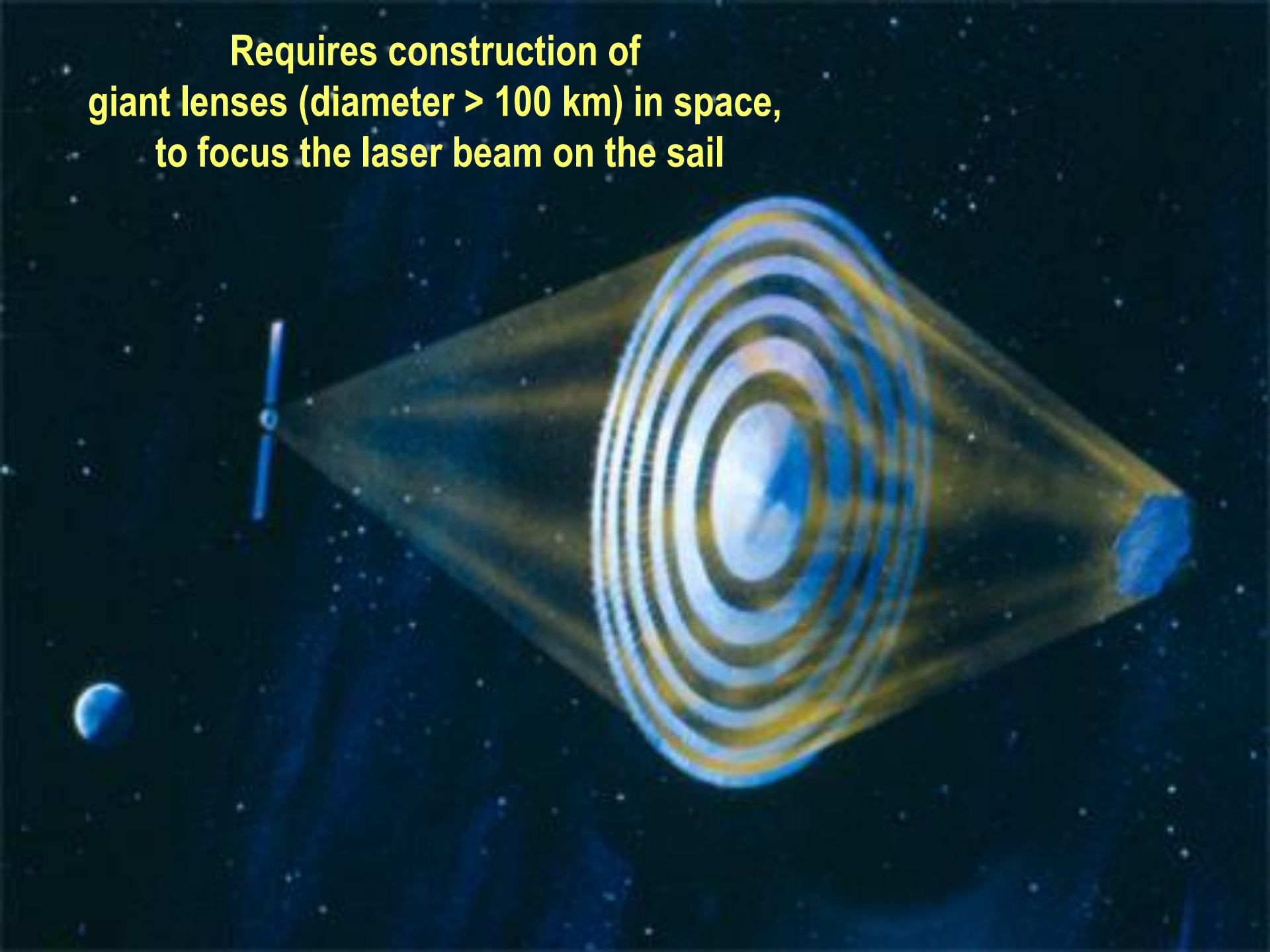
Spaceship DISCOVERY (*2001, a Space Odyssey*)




Systems
α-Centauri and Beyond
4.5 - 40 LY
10 - 100 yrs
Hydrogen Clumps, Brown Dwarfs
100,000 AU
10 yrs
Birthplace of Comets
Oort Cloud,
10,000 AU
10 yrs
Solar System Boundary & Interstellar Medium
Heliopause, Kuiper Belt, Interstellar Medium
1,000 AU
10 yrs
~ 1000 T
~ 1 T
~ 1 mg
~100 ng
Antimatter Production
Medical / Industrial Applications
• Imaging & Treatment - e.g., Detect & Destroy Cancer Tumors
• Basic research
Additional Space Applications
• 4-Month R/T to Mars - Deliver/Retrieve 100 M-tons (TAU)
• < 4-Weeks travel to any place in the Solar System (TTAU)
Basic Science Return

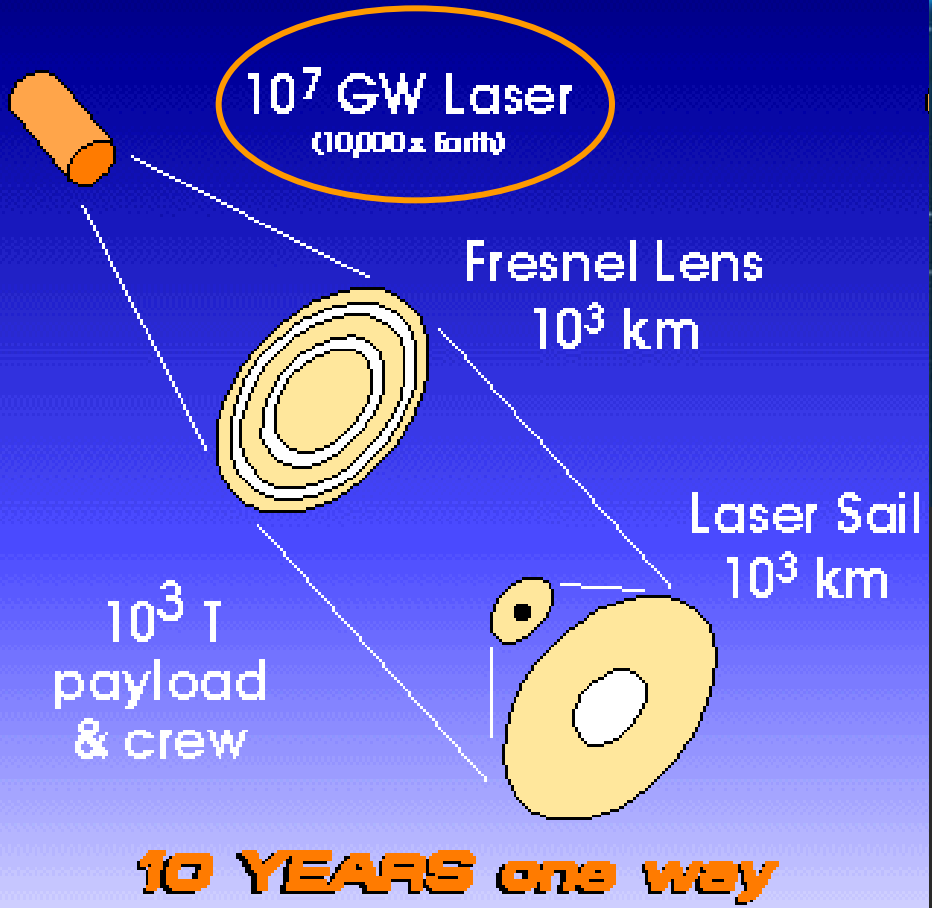

INTERSTELLAR
LASER SAIL

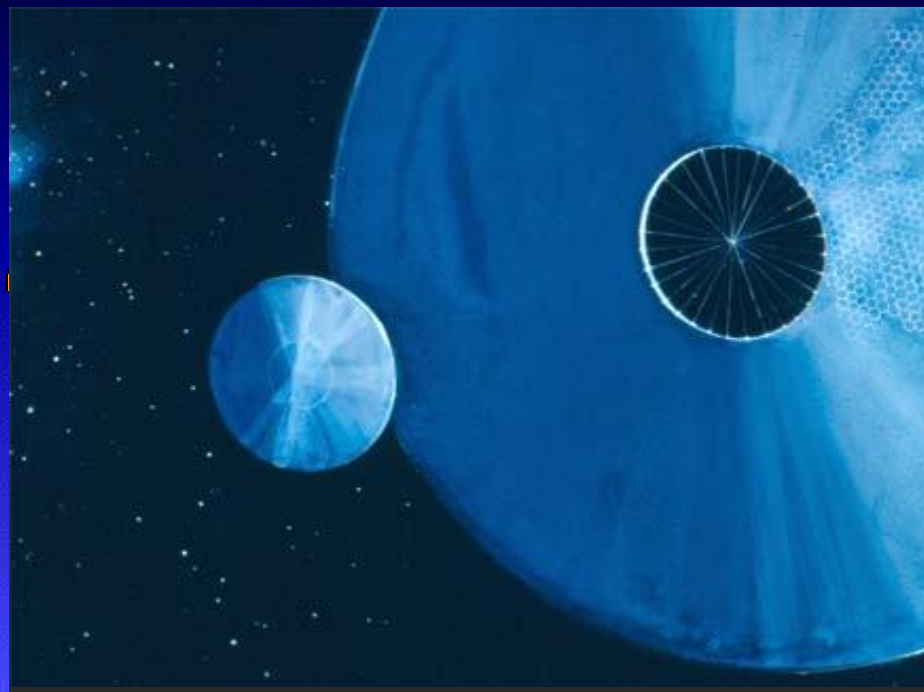
Requires construction of
giant lenses (diameter > 100 km) in space,
to focus the laser beam on the sail



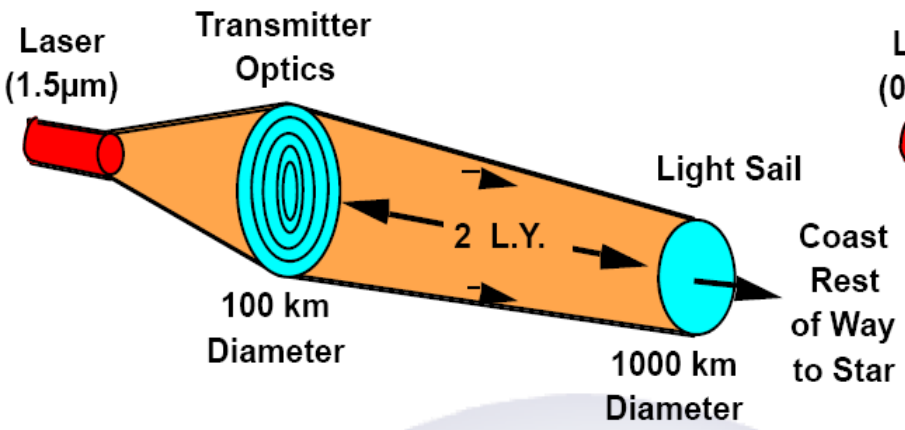
Beamed Propulsion Concepts

Laser Light Sail
1984...
R. Forward, et al

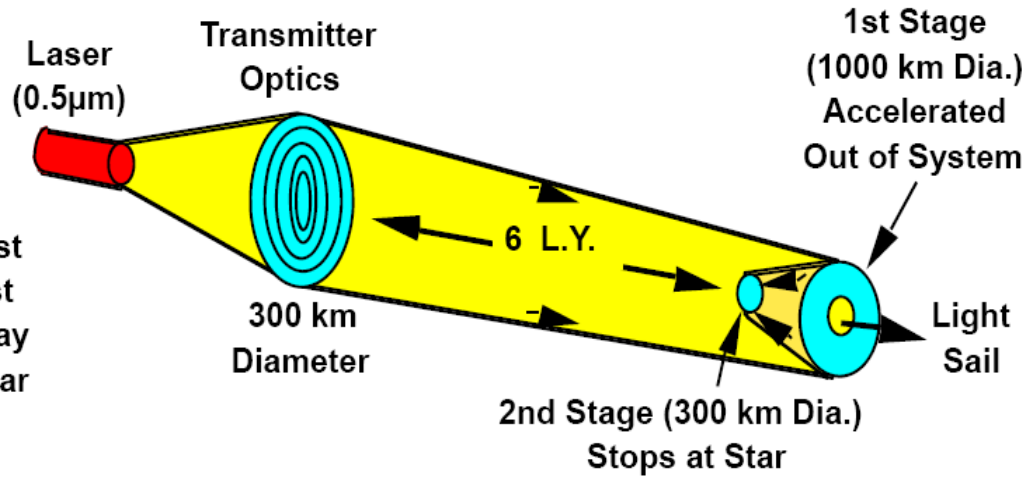




INTERSTELLAR FLYBY

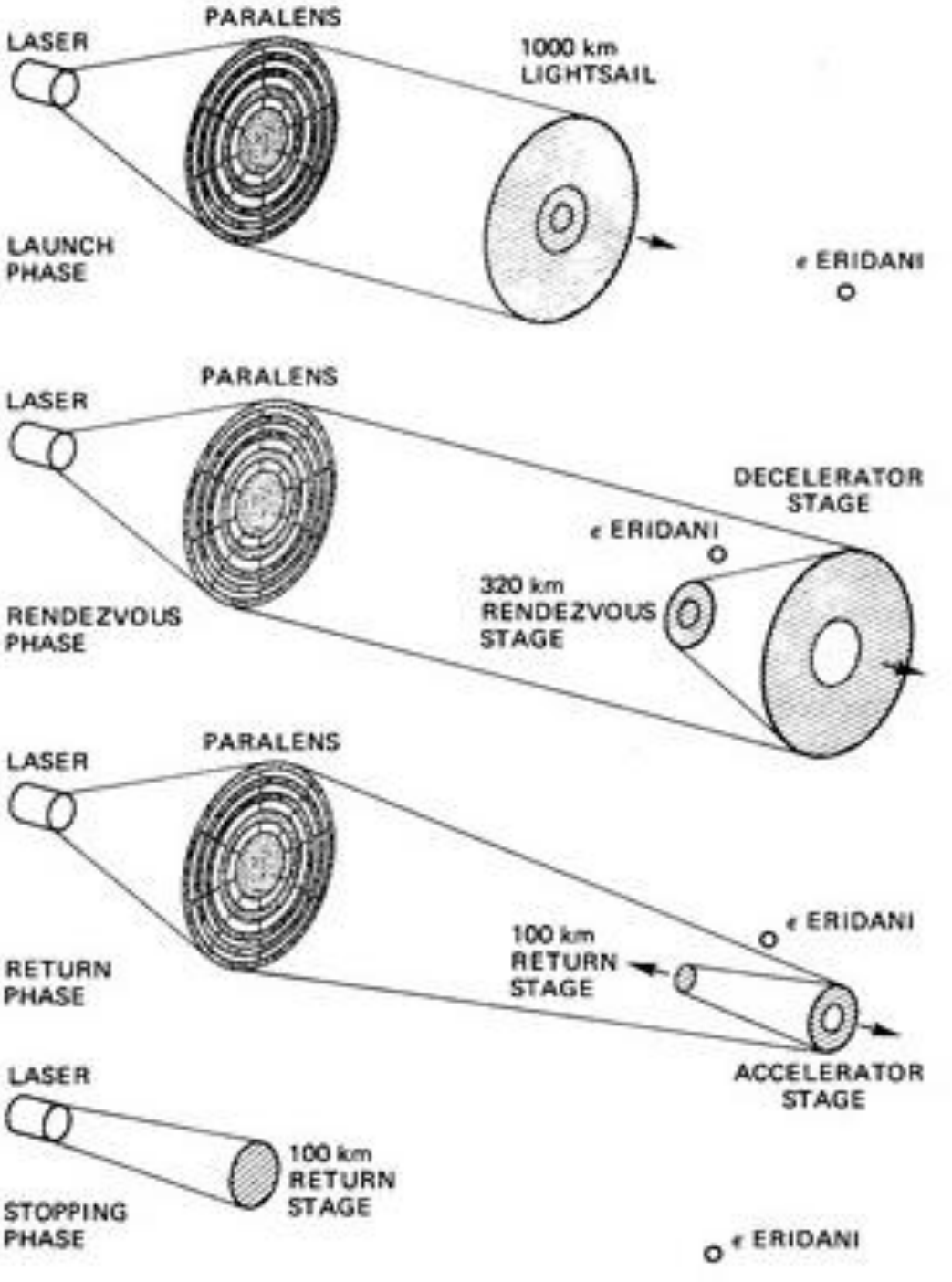


INTERSTELLAR RENDEZVOUS



- Advantages
  - Perform interstellar missions in 50 - 100 years
  - Only competitor is antimatter
  - Use as a solar sail once in orbit about target
  - Use solar power satellite as driver for robotic flybys
- Disadvantages
  - Very high laser / microwave powers (0.1-1,000 TW)
  - Very large optics (100-1,000 km)

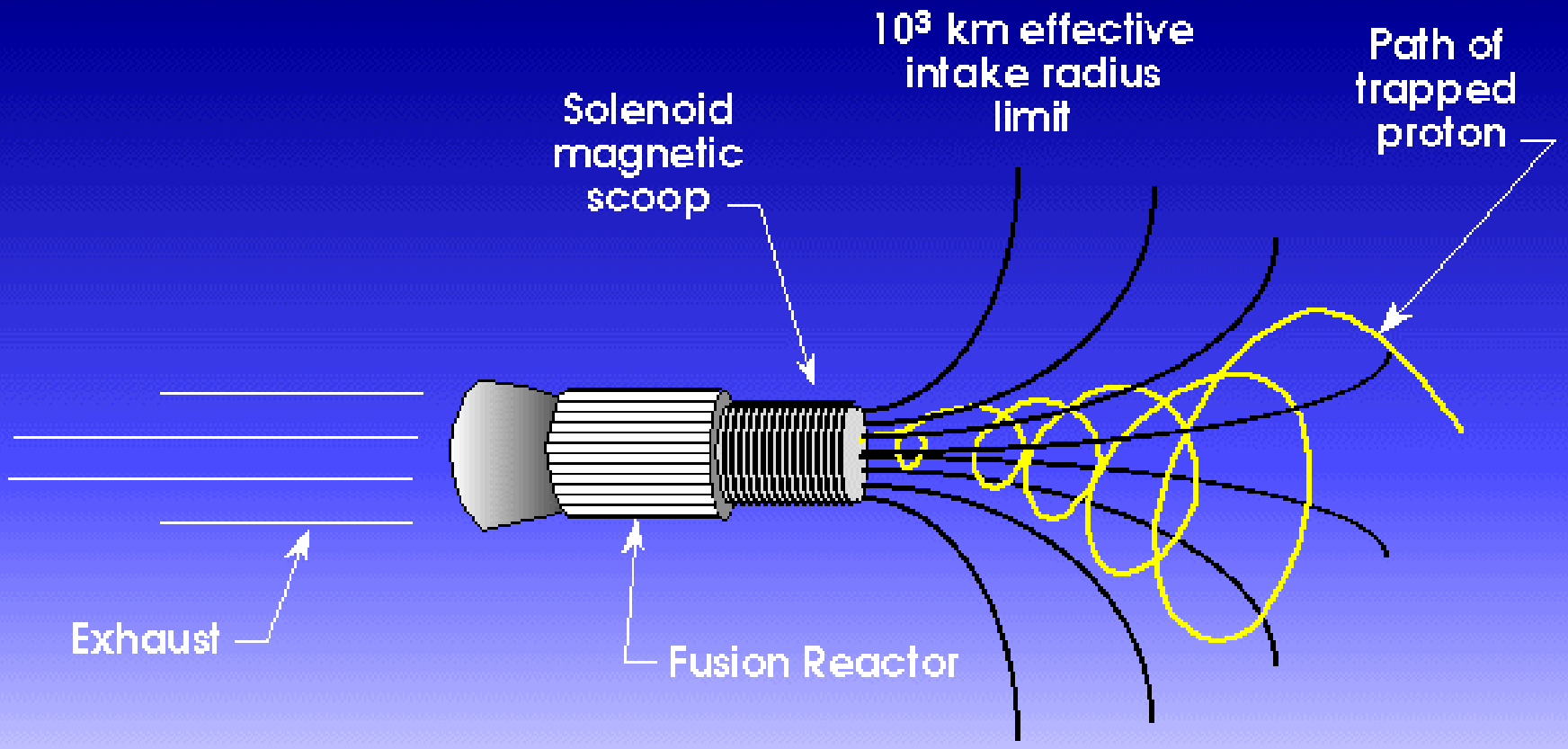
Selon R. Forward (1985) on pourrait même utiliser le faisceau laser pour décelerer le vaisseau, puis le ramener à nouveau vers le Système solaire



Fuel from Space

Interstellar Ramjet

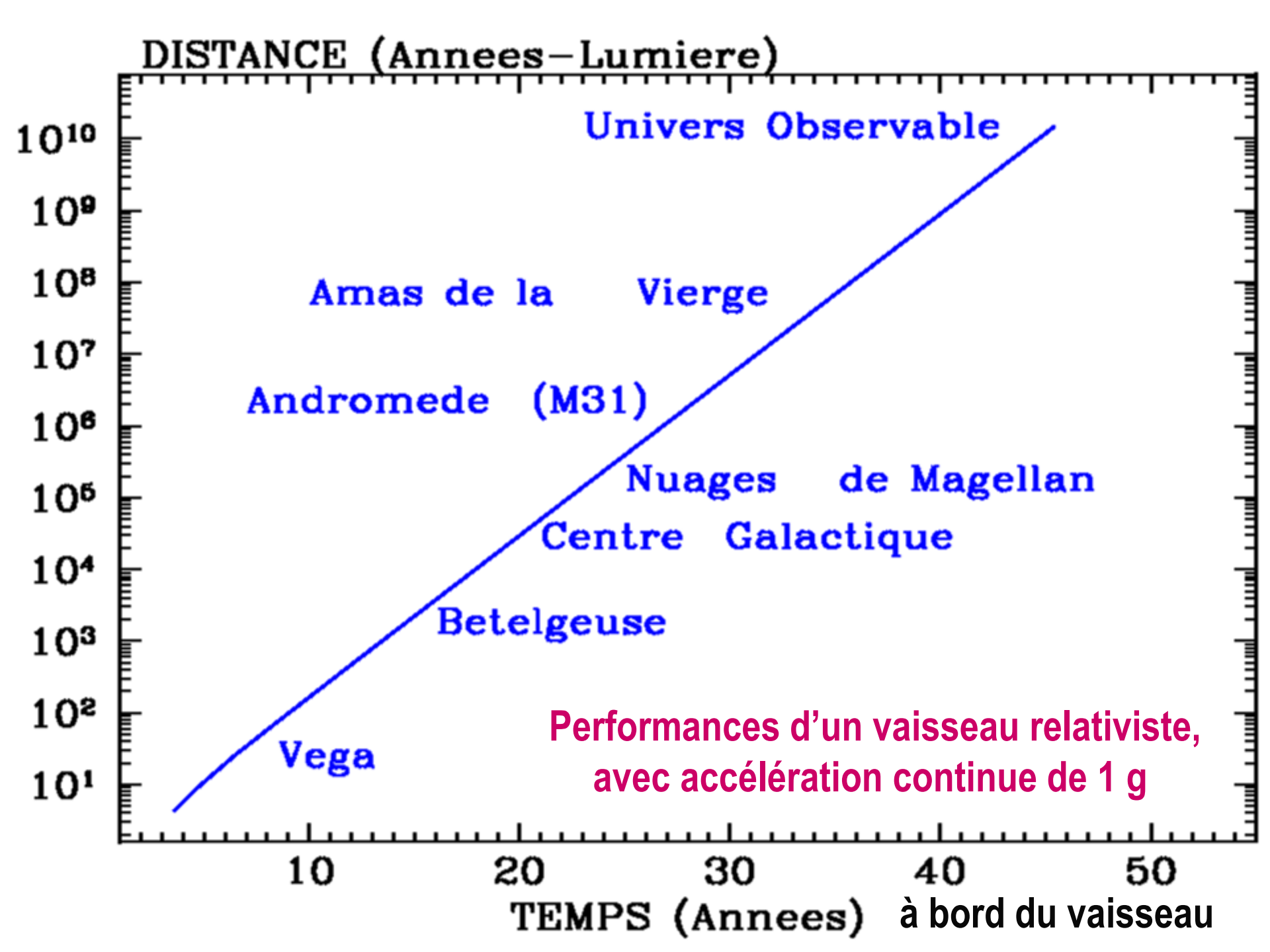
1960, R. Bussard, et al.

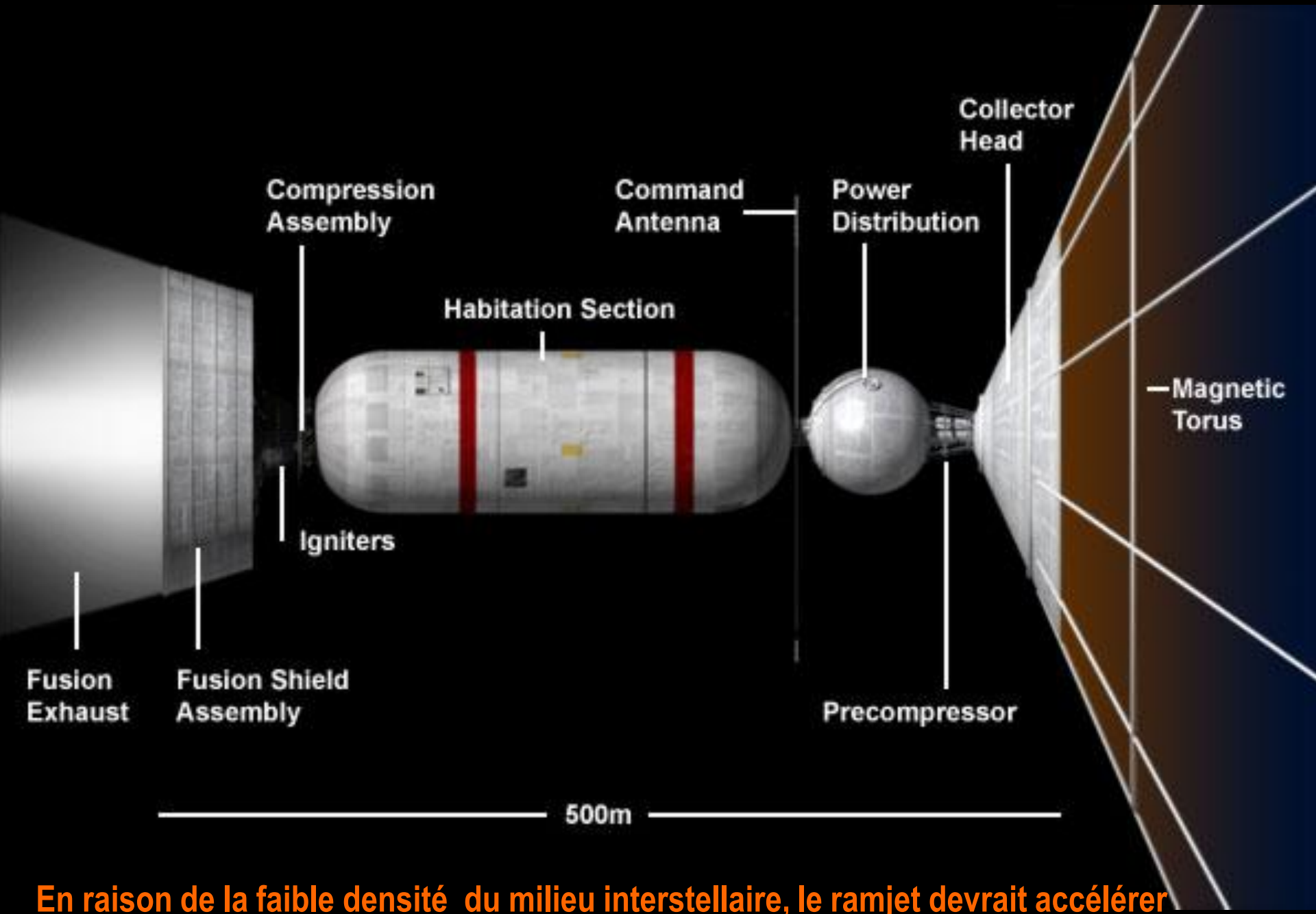


Advantage: Ramjet can accelerate as long as it finds fuel on its way

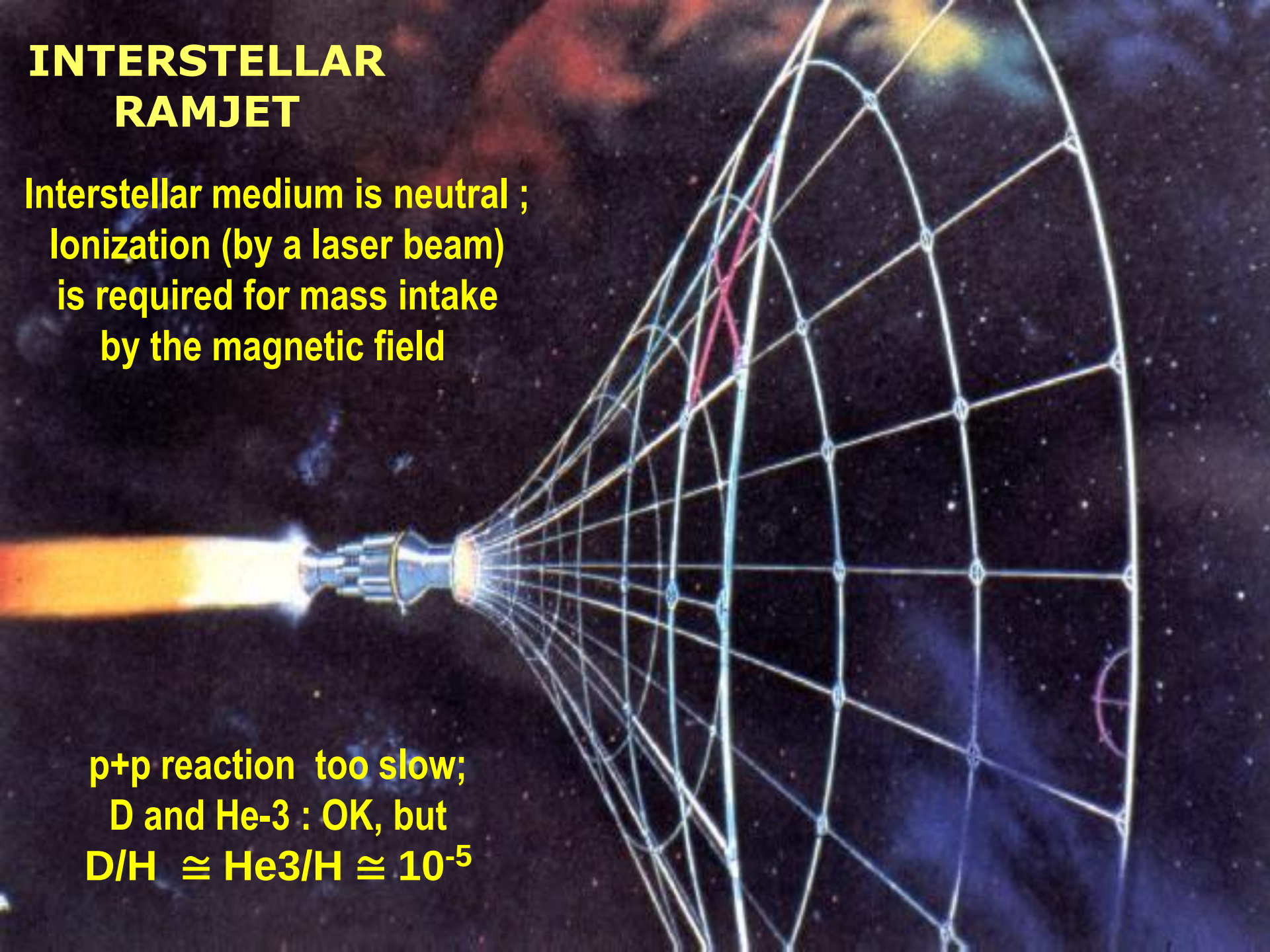
Only concept able to reach relativistic velocities

CD-94-63469


DISTANCE (Annees-Lumiere)
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
Univers Observable
Amas de la Vierge
Andromede (M31)
Nuages de Magellan
Centre Galactique
Betelgeuse
Vega
Performances d'un vaisseau relativiste,
avec accélération continue de 1 g
10
20
30
40
50
TEMPS (Annees) à bord du vaisseau



En raison de la faible densité du milieu interstellaire, le ramjet devrait accélérer à 0,06 c *par d'autres moyens* avant d'être opérationnel

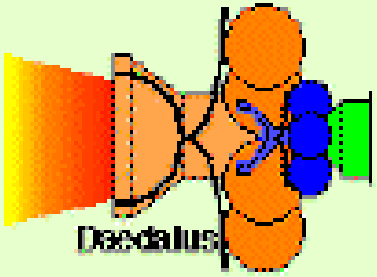

INTERSTELLAR
RAMJET
Interstellar medium is neutral ;
Ionization (by a laser beam)
is required for mass intake
by the magnetic field
p+p reaction too slow;
D and He-3 : OK, but
D/H ≅ He3/H ≅ 10-5

PROJETS DES VAISSEAUX INTERSTELLAIRES

- **Need to achieve at least 0.1c**
- **Required energies and power levels 5-100 times current world output**
  - **Saturn V at liftoff represented 0.5% of world power in 1969**

FISSION
Fission
Fragment

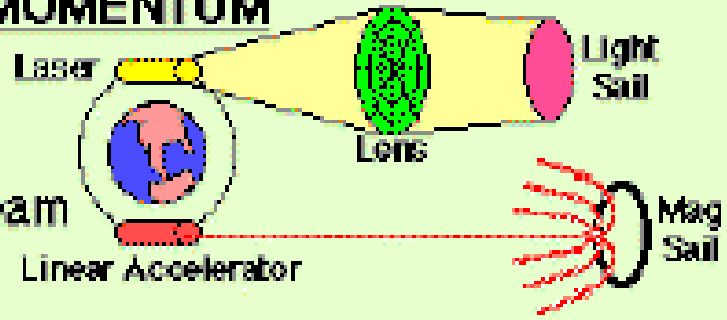
FUSION
Inertial
Confinement
Fusion (ICF)



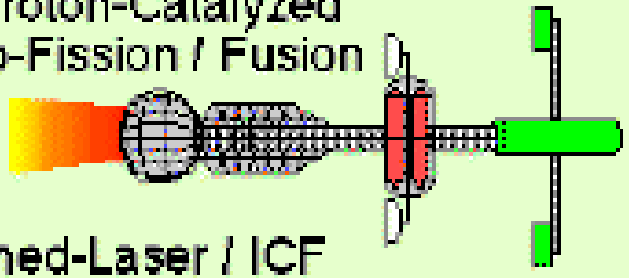
ANTIMATTER
Beam-Core
Antimatter Rocket

BEAMED ENERGY / MOMENTUM
Laser Lightsail

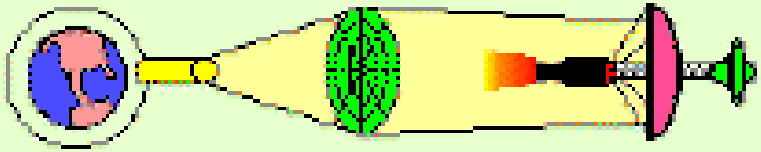
Relatavistic Particle Beam



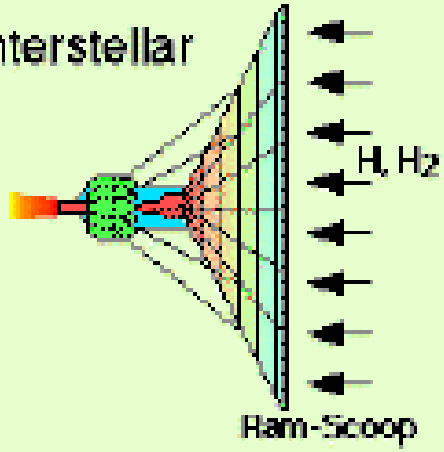
COMBINATIONS
Antiproton-Catalyzed
Micro-Fission / Fusion



Beamed-Laser / ICF

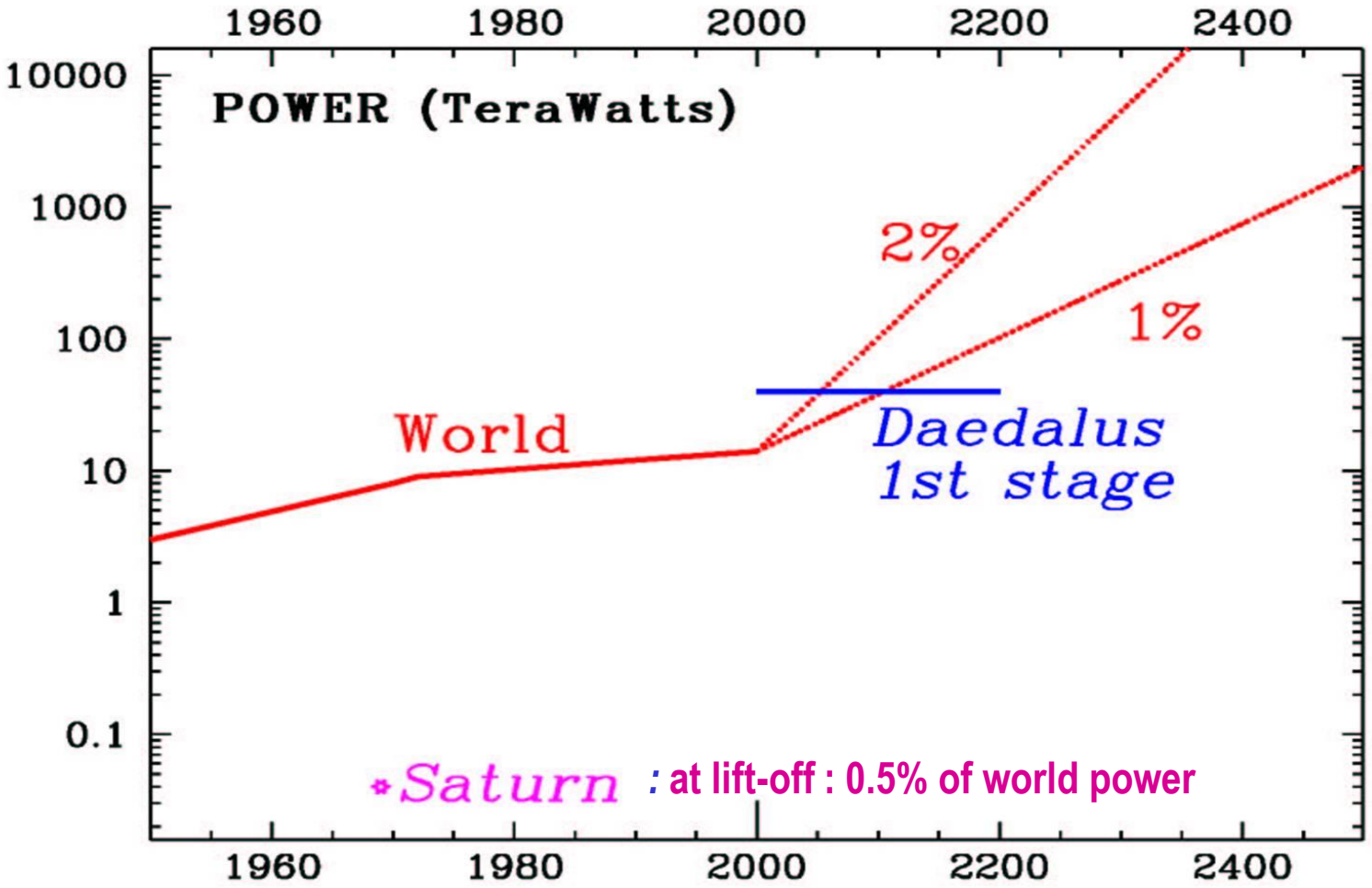


Bussard Interstellar
Ramjet



INTERSTELLAR TRAVEL IS DIFFICULT...

Total world power produced today is not sufficient to propel a 100 ton payload to the nearest stars in a few decades



…BUT NOT IMPOSSIBLE !

With a "reasonable" annual increase (1% or 2%) of our power production, we should be able to undertake it in a few centuries…

Les arches de l'espace

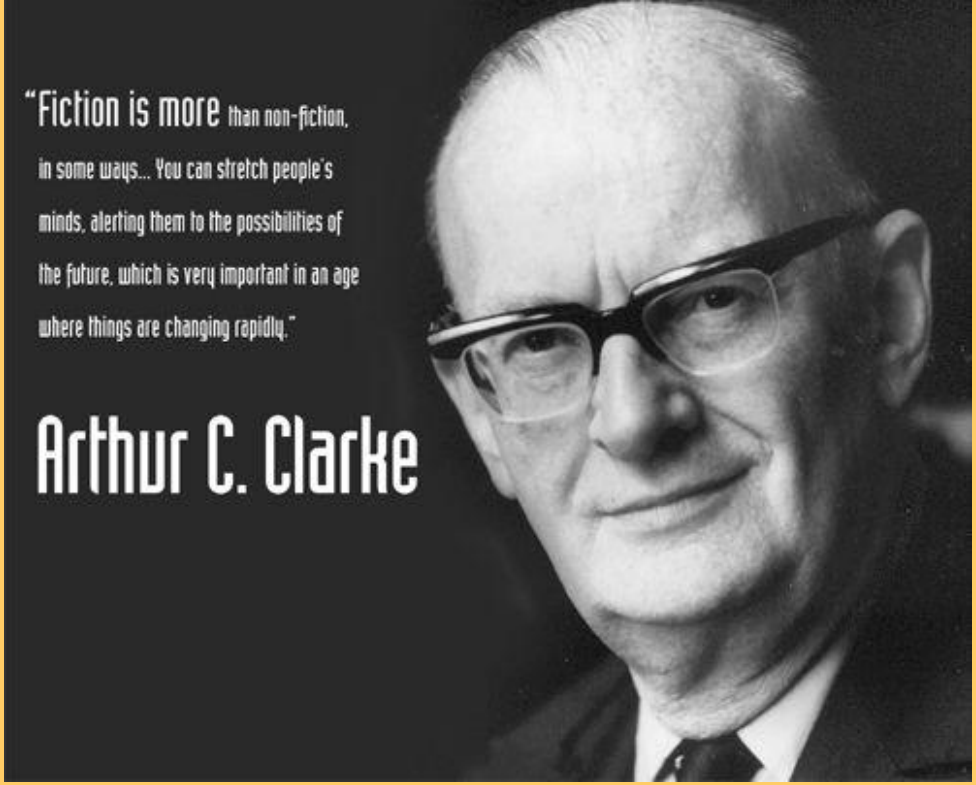
Vaisseaux - mondes

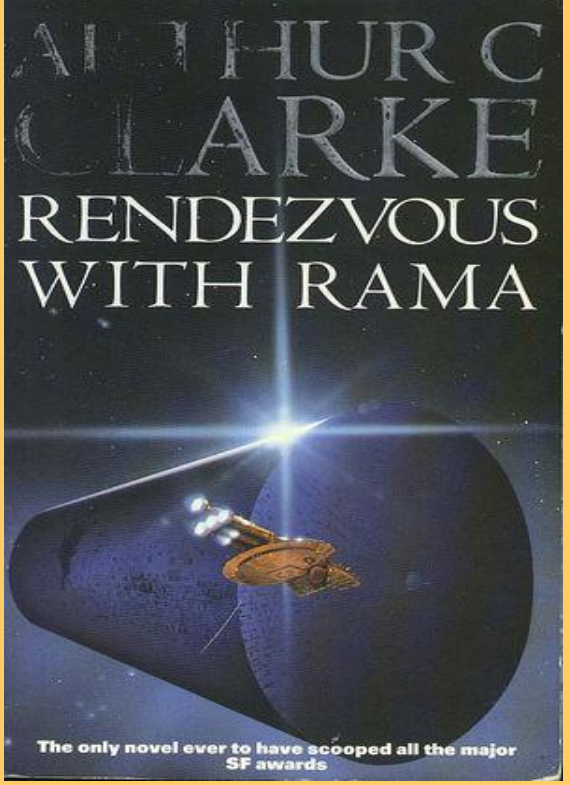
Vaisseaux de générations

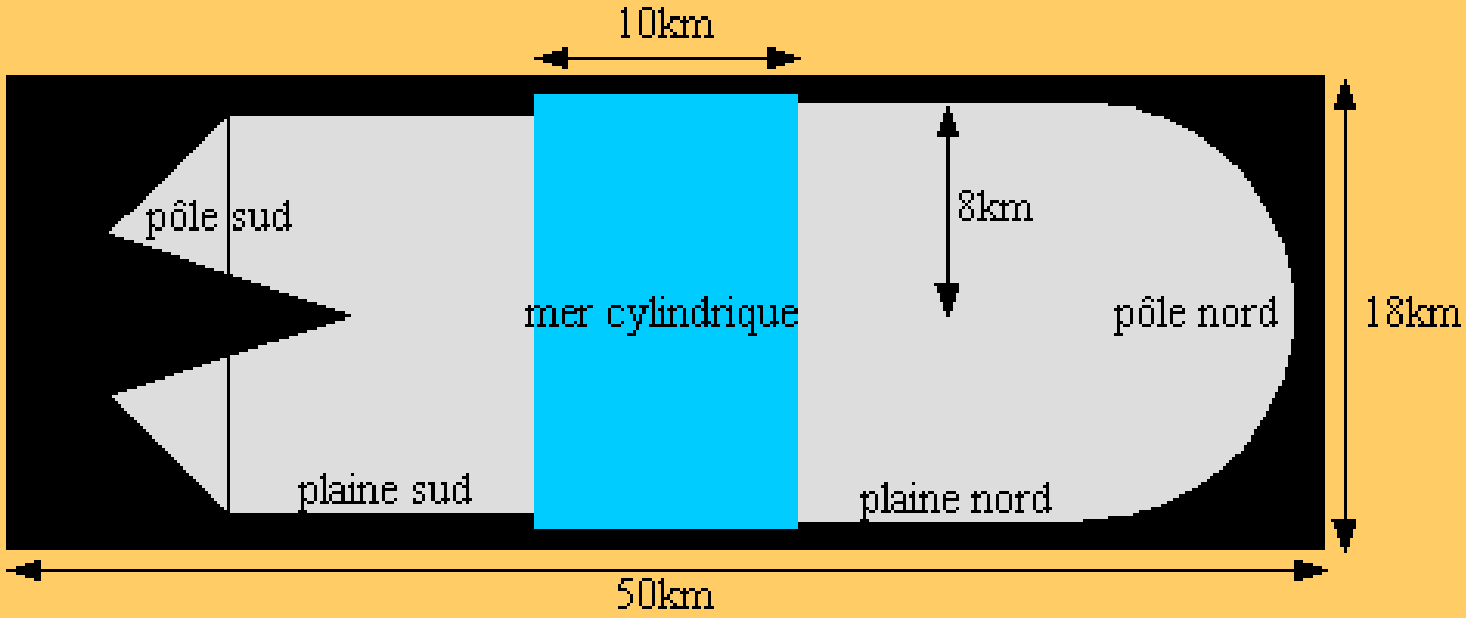
Masses :
plusieurs millions/milliards de tonnes

Energie / puissance des moteurs :
Plusieurs milliers de fois
supérieure à celle de notre civilisation
aujourd'hui


G. O'Neil (1970ies)
Space Colonies


"Fiction is more than non-fiction, in some ways... You can stretch people's minds, alerting them to the possibilities of the future, which is very important in an age where things are changing rapidly."
Arthur C. Clarke


ARTHUR C CLARKE
RENDEZVOUS WITH RAMA
The only novel ever to have scooped all the major SF awards


10km
8km
18km
pôle sud
mer cylindrique
pôle nord
plaine sud
plaine nord
50km

Comment traverser les distances interstellaires ?

(quelques années-lumière en quelques décennies…)

Le moteur “warp-drive” du vaisseau *Enterprise* pourrait être la solution…

Zero Point Energy
(Emerging science, 1948...)

What?

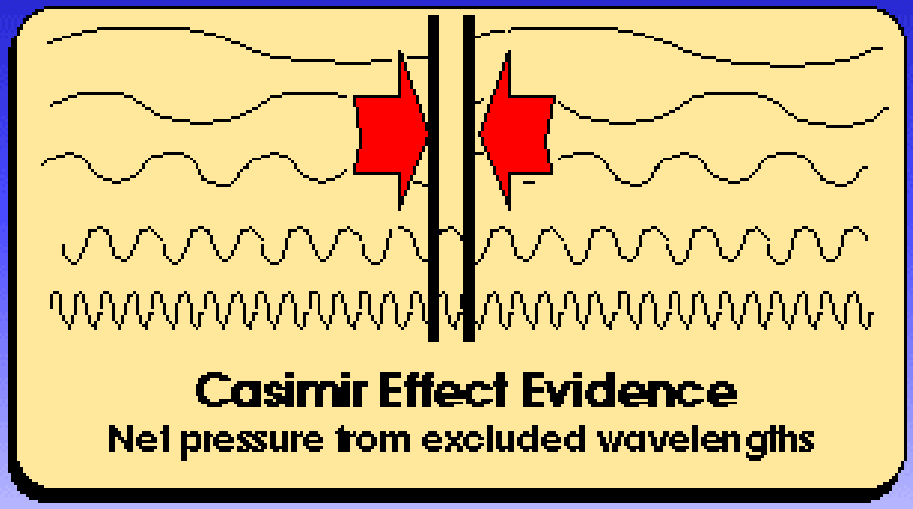
- Random Electromagnetic waves remain after all energy is removed
- Enormous energy density: 10^{24} to 10^{58} Joules/m^3
- Theorized to indirectly cause gravity and inertia

Why?

- As an energy source?
- As a reactive medium?

Evidence?

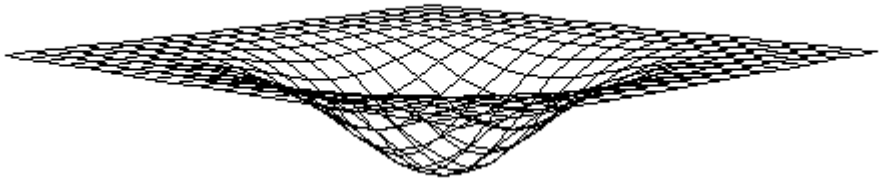
- Casimir Effect
- Plank blackbody spectrum
- quantum effects



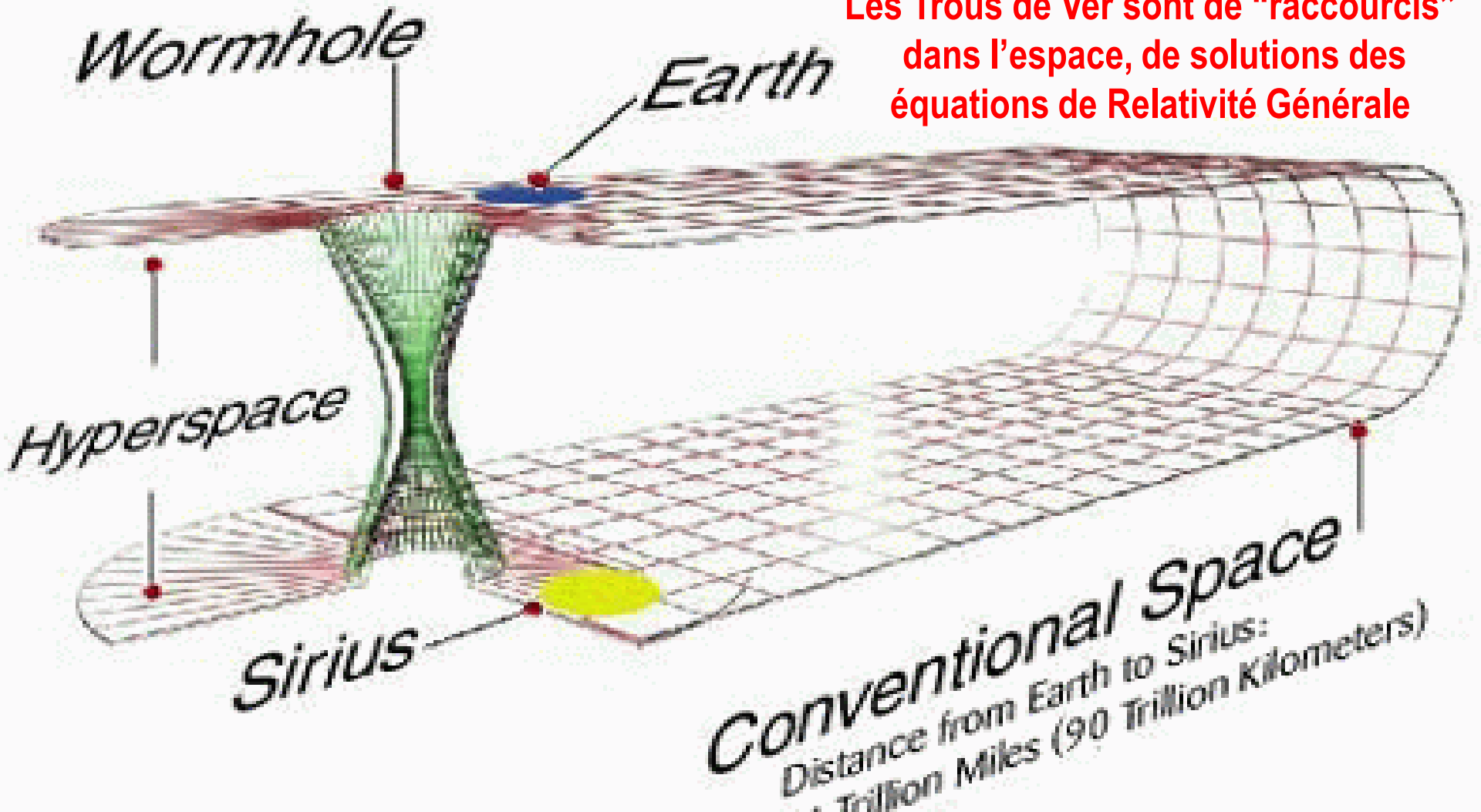
Mais on ignore combien d'énergie le vide contient ou comment on pourrait l'éxploiter

©D-94-6890

Depuis Einstein on sait que l'espace(temps) se courbe en présence d'une masse



Les Trous de Ver sont de "raccourcis" dans l'espace, de solutions des équations de Relativité Générale

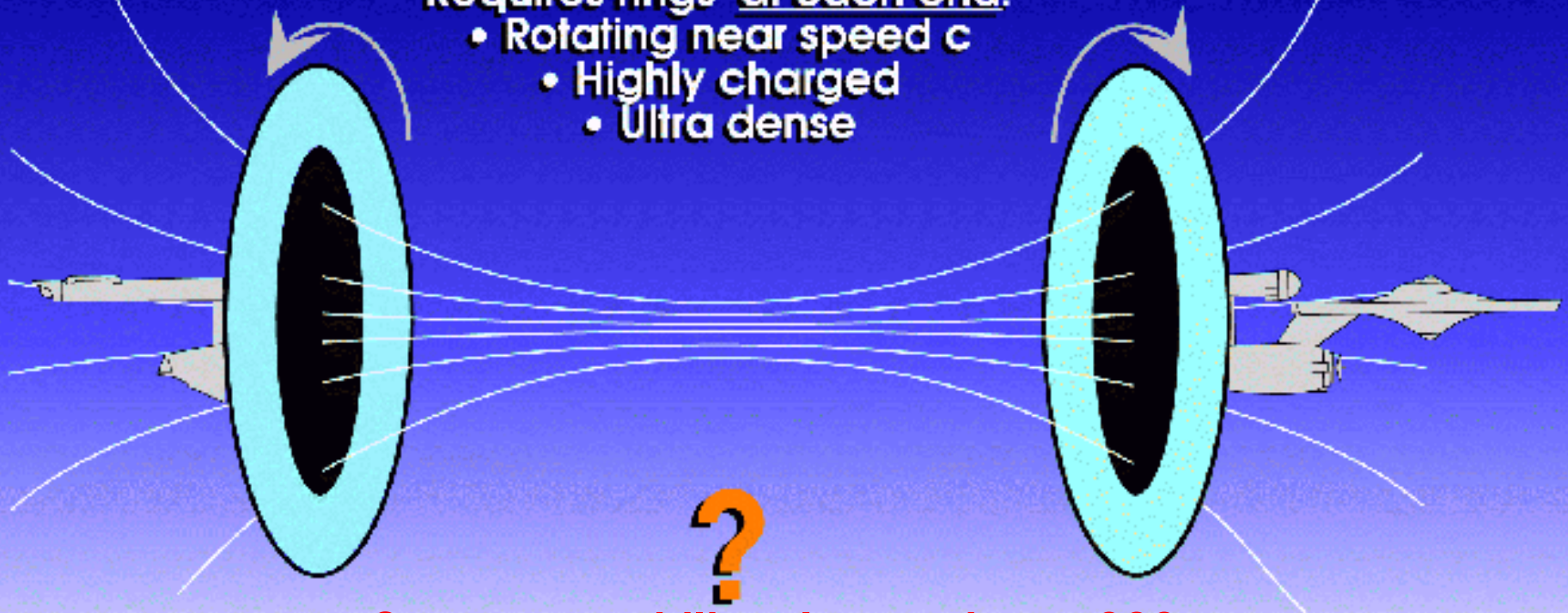


General Relativity

Worm Hole Tunnels by Inertial Drag
Morris & Thorne, 1988

A jump through "hyperspace" ??

Requires rings at each end:
- Rotating near speed c
- Highly charged
- Ultra dense

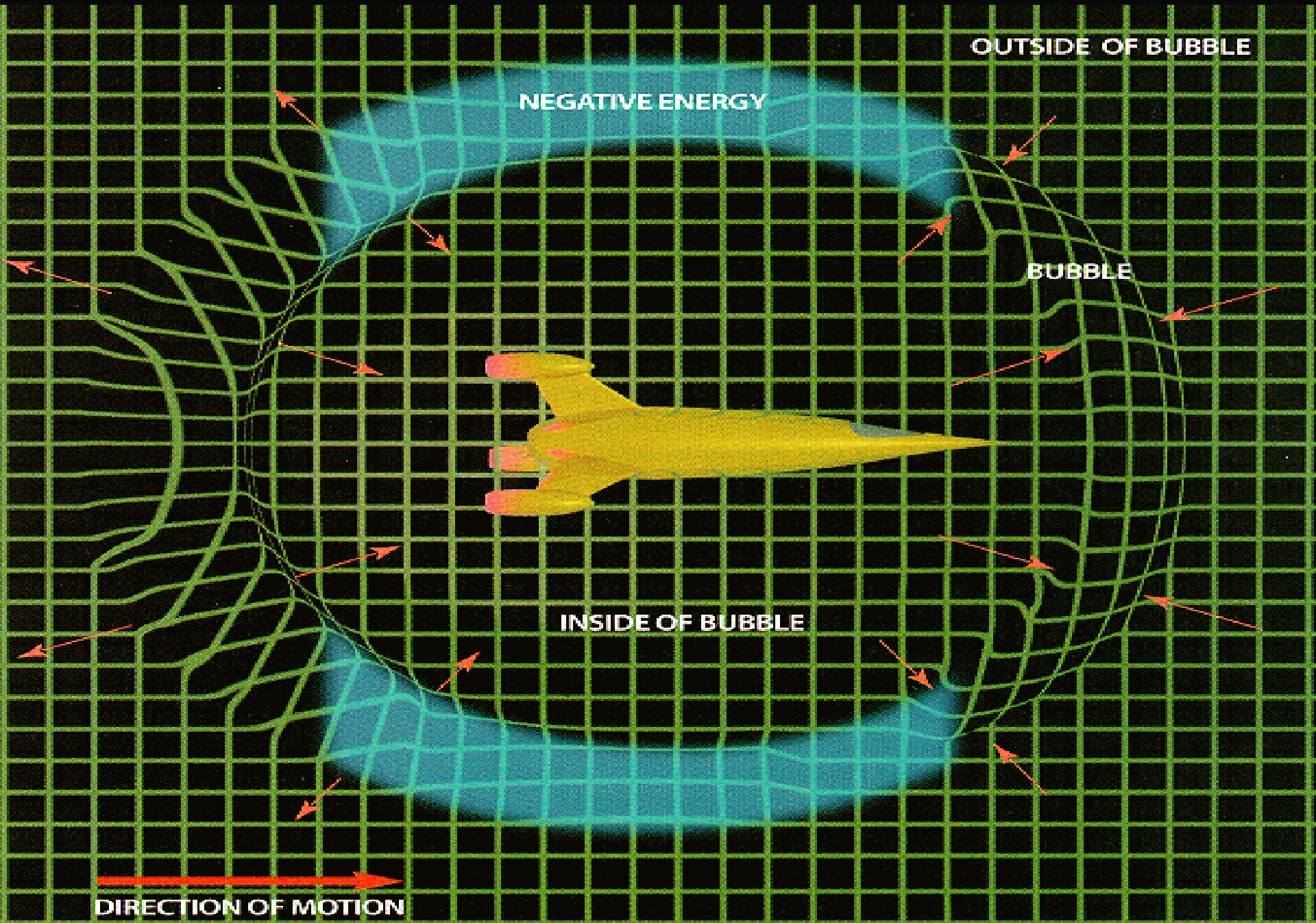


Comment stabiliser le trou de ver ???

Energie négative nécessaire (!?!?)

CD-94-68500

Faire “plier” l’espace ? (M. Alcubiere 1995)

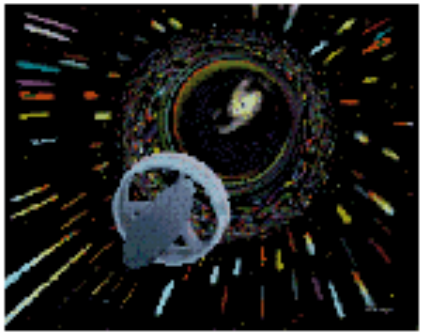


Breakthrough Propulsion Physics Project

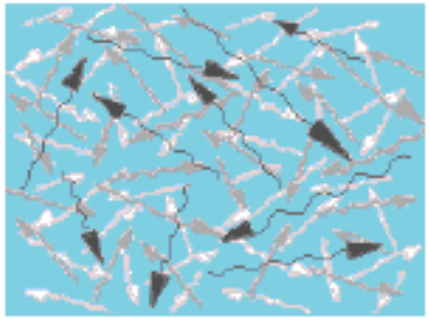
Emerging Clues

Just a *few* samples of provocative developments from recent scientific journals

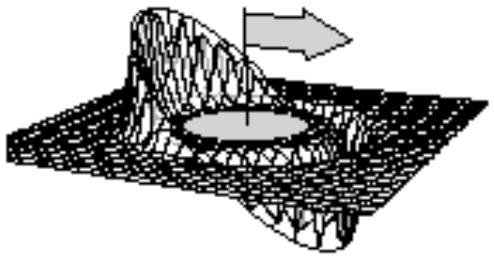
"Wormholes"



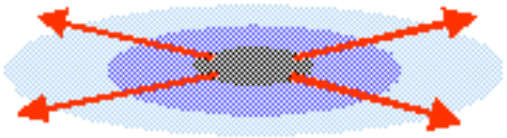
Quantum vacuum energy



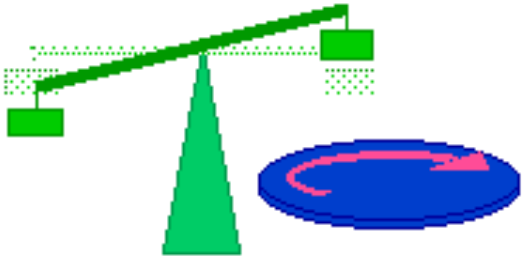
"Warp Drives"



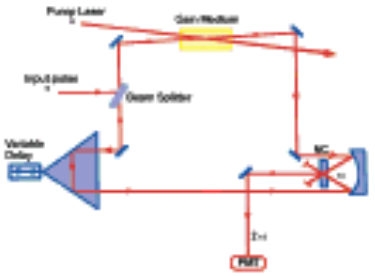
Anomalous expansion rate for the universe

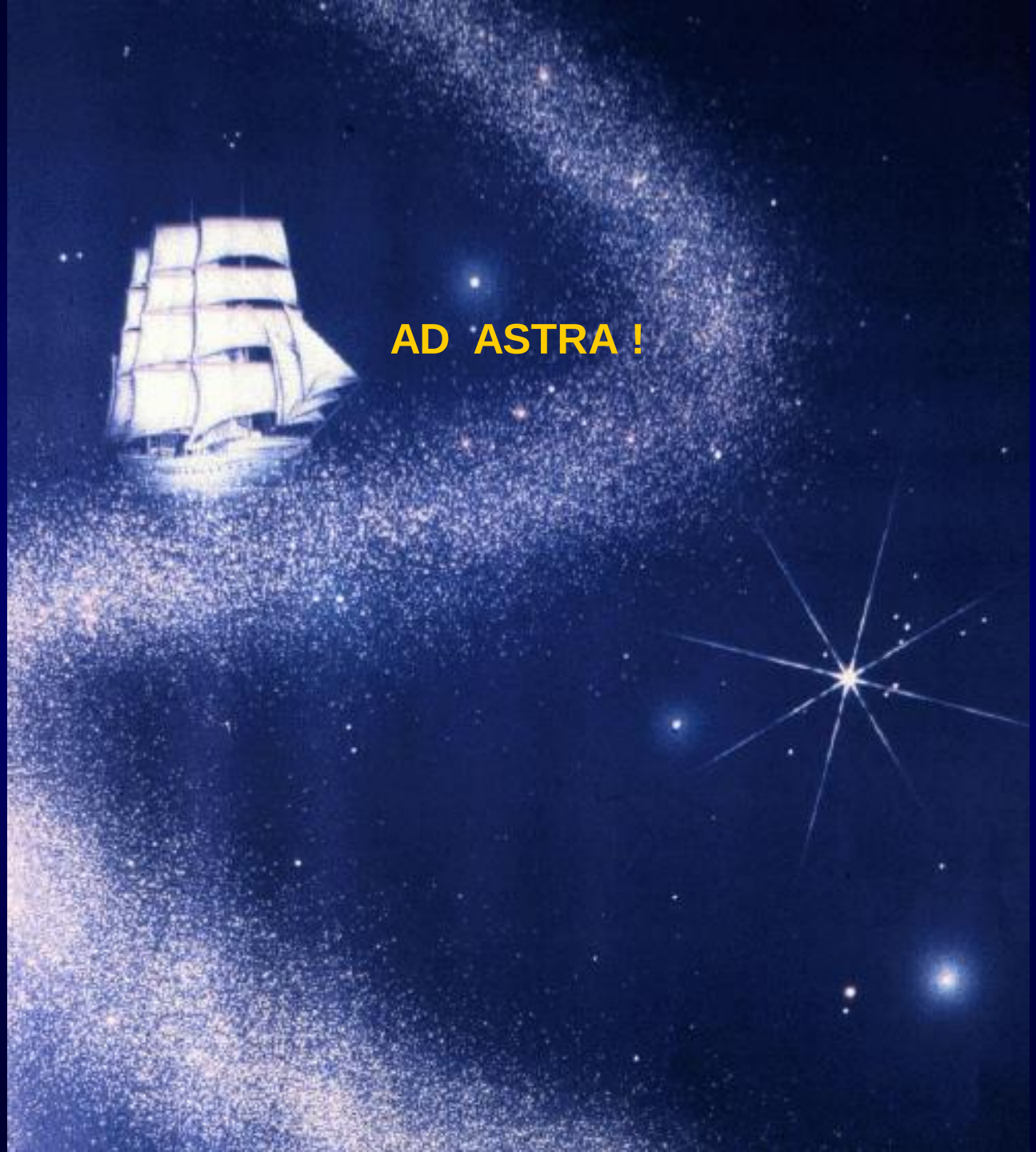


Anomalous gravity effects with superconductors



Superluminal quantum tunneling




AD ASTRA !