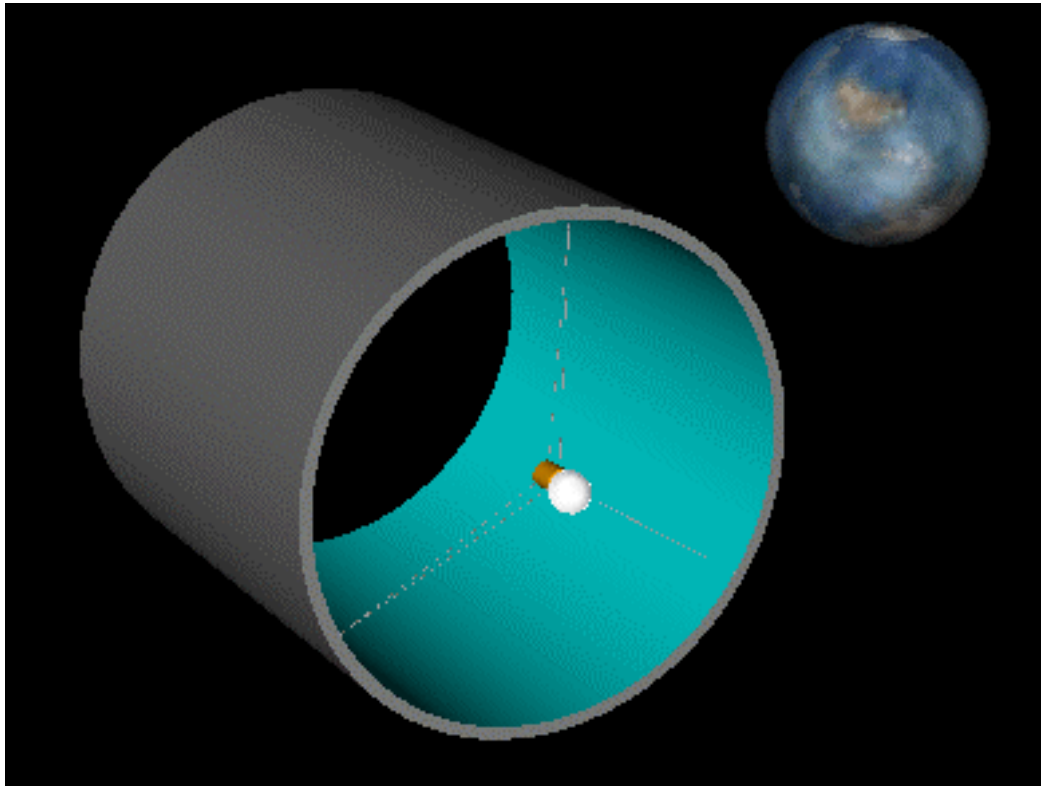
THE PROJECT:
An Observatory/Transport Spaceship for Discovering and Populating Habitable Extrasolar Terrestrial Planets

Dr. Steven Kilston
Ball Aerospace & Technologies Corp.

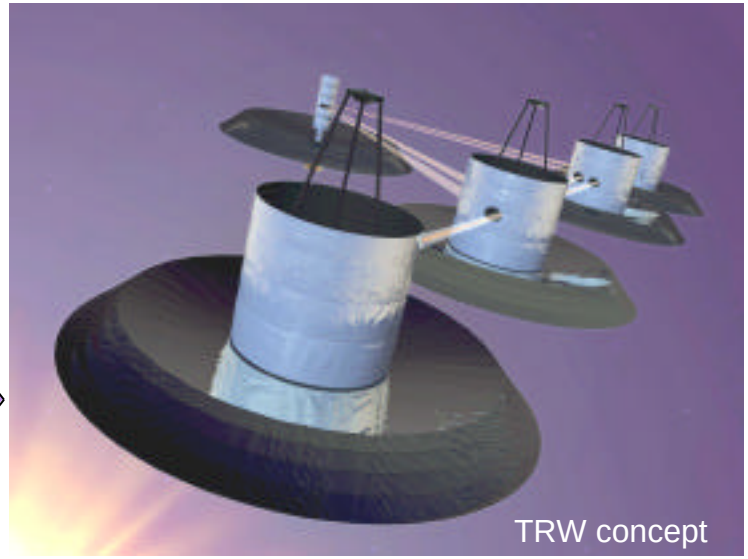


“Now that is the wisdom of a man, in every instance of his labor, to hitch his wagon to a star, and see his chore done by the gods themselves.”

Emerson, “Society and Solitude - Civilization”, 1870

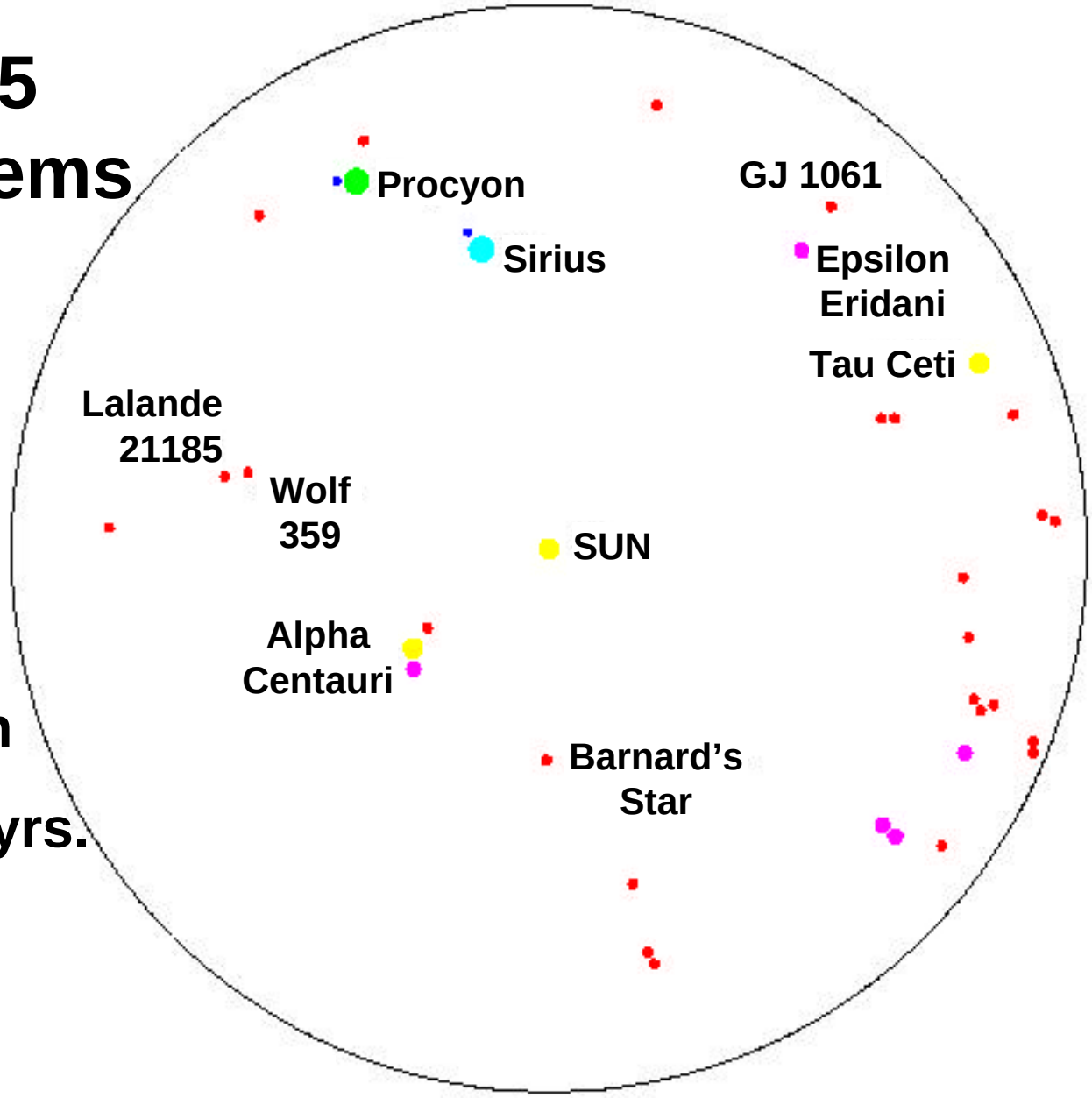
Current Circumstances Lead to THE PROJECT

- Recent extrasolar planet discoveries
  - spectroscopic identification of Jupiter-like planets affecting other stars
- Related progress in astrophysics
  - galactic chemical abundances, interstellar grains, star and planet formation theory
- New missions for planet characterization
  - Space Interferometry Mission (2005 launch)
  - **Terrestrial Planet Finder** (2011 launch)
  - Planet Imager (planned 2020 launch)
  - point out places to explore at closer range



- Fermi paradox regarding intelligent extraterrestrials -- "where are they?"
  - if an actual scarcity, we may be more advanced than most other galactic life-forms
  - so a main purpose in finding planets may be to find places for us to go
- ***Then astronomy can again play a major role in human navigation & migration***

Nearest 25 Star Systems

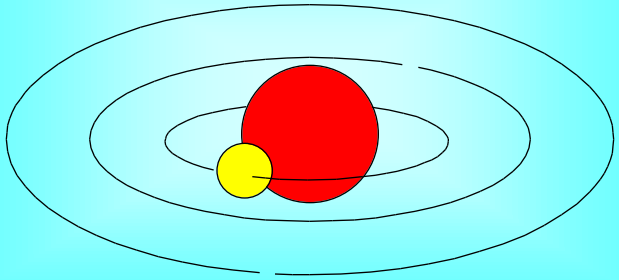


Horizon

13.1 light-yrs.

Vidi, veni

Discoveries of planets, including inward-migrating Jupiter-like ones



Suggest earth-like planets might be less common than previously thought

Drake Equation implications

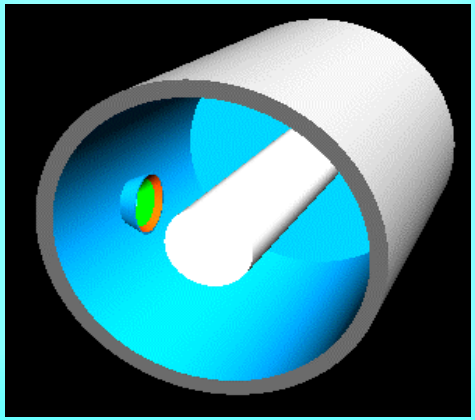
low $n_{\text{habitable planets}}$

low $n_{\text{intelligent beings}}$

We may be in highest ranks of galactic life forms

Eventually explore more closely and travel to other stars, using plausible physics, modestly advanced biology, sociology, economics, and technology (but do assume controlled nuclear fusion)

THE PROJECT

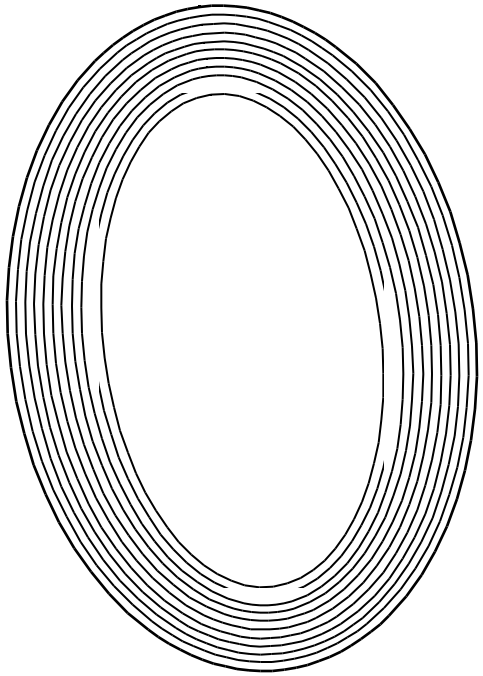


Large Interstellar Ship -- Basic Features

1 Million travelers, 100 Million ton mass, ~ $ 20 Trillion, Launch 2500 A.D.

On-board observatories

One-way voyage for thousands of years



Great Pyramid of Cheops, to scale, for comparison; has 1/16 mass of ship

Motivation

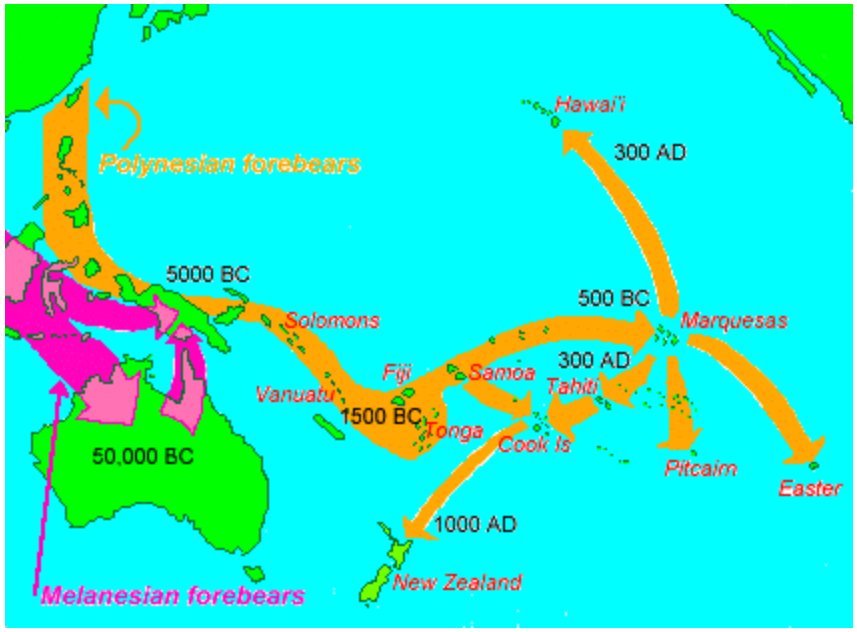
- **expanding our knowledge of the universe**
  - curiosity, exploration, and science are intrinsic to human nature
  - traveling to new places has always led to finding out new things
- **enlisting human efforts and enthusiasms toward a very grand goal**
  - will stimulate progress in all aspects of our cultures and technologies
  - human cooperation and institutions will benefit from wide participation in this complex undertaking; many present problems might be solved
  - a sense of involvement and purpose is essential to human happiness
- **participating in the process of spreading life**
  - identify a habitable extrasolar planet and establish a settlement there
  - enhance the survivability and fruition of life
  - hierarchical “Noah's Arks” spread intelligent life through galaxy in 40 Myears
    - create a rich galactic civilization in a small fraction of galaxy’s age

" . . . sometime in the next few centuries the price will be right to allow earthly communities to raft slowly out into interstellar space."

(Bracewell, 1976)

Mistakes Will Be Made, but. . .

- **THE PROJECT is a *reach* -- we realize we can't predict 500 yrs. ahead**
- Science discoveries much harder to predict than technology changes
  - Assume new technol., but no new physics: concept a ***"proof of principle"***
- No expensive decisions needed for a long time; implementation is flexible
  - Experiments/discoveries/theories in next centuries will change our plans
  - Experience beats theory; "Source of evil is inadequate ideas." (Spinoza)
  - Advances en route, and via Earth communications



History Lessons:

Exploration and adaptation on long time scales is not new: e.g.,

migrations

cathedrals,

colleges, JPL

THE PROJECT -- Proof-of-Principle Concept

Parameter	Value	Assumptions
Spaceship Mass	**100 M tons** (50% H_20)	**10^6 people** x 10^5 kg mass/person = 10^{11} kg
Cruising Speed	**600 km/s**	6 x10^5 m/s = 0.2% c
Travel Time	**10,000 years**	to 6 parsecs, (6 pc x 3.26 ly/pc) / (0.002 c)
for whole Milky Way	**40 M yr**	20,000pc/(0.0005pc/yr); 0.4% Milky Way age
Momentum	6 x10^{16} kg-m/s	10^{11} kg x 6 x10^5 m/s
Propellant to cruise	4 M tons for start	6 x10^{16} / (15,000 km/s exhaust jet velocity)
Total propellant	**8 M tons**	Decelerate accelerate; total expendables
Energy		
Propellant K.E.	9 x 10^{23} Joules	Accel./decel. 1/2 x 8 x10^9 kg x (1.5 x10^7 m/s)^2
m = E/c^2	10,000 tons	Total energy, if complete matter conversion
m(H)	1.4 M tons	H fusion power efficiency of 0.7%
m(H) "practical"	**7 M tons**	Including 20% power conversion efficiency
Sustainment power	2 x10^{10} Watts	2 x 10^4 Watts/person (gross) x 10^6 persons
Sustainment energy	6 x10^{21} J (**0.01 M ton**)	Trip total = 10^4 yr x 3 x 10^7 s/yr x 2 x10^{10} W
Ship skin temp.	370 K(less w/radiator)	[(2 x10^{10} W / 6π x10^6 m^2) / 5.67x10^{-8}]$^{1/4}$
Total fuel/propellant	**15 M tons**	m(H) and propellant for speed, sustainment

Precursors, Path, and Proposed Funding

- **Dan Goldin asked NASA Office of Space Science to investigate interstellar flight**
  - getting a boost from the recent discovery of planets around other stars
  - ultimate goal: **to reach other planets within perhaps 40 light-years of Earth**
  - NASA/JPL Workshop, ***Robotic Interstellar Exploration in the Next Century*** (July 98): uninhibited thinking on plausible ways to propel, control, & communicate with probe
- **Research path**
  - check for planets, intelligent life, interstellar meteoroid population (to choose speed)
    - **beginnings in NASA Origins program with DS-3, SIM, TPF and PI**
  - spaceships, space stations in Solar System, probes to interstellar medium and stars
  - evolve technology, toward 100-year trial of PROJECT ship within Solar System
- **Expenditures**
  - **no major costs beyond evolutionary space & other research for next 200 years**
  - PROJECT cost ~ $ 20 Trillion (1999 dollars) -- $20 Million per traveler
    - equivalent to 1 yr. of world GNP, or to 80 yrs. of U.S. Dept. of Defense budget
      - cost of U.S. nuclear weapons program thus far has been $ 5 Trillion
    - peak spending rate roughly $ 100 Billion per year, beginning around 2250
      - implies over 1 million people involved in the program, long before launch
  - this will be **a world-wide effort**, with costs and work shared among many nations
    - much wider range of disciplines involved than any aerospace program thus far

Schedule for THE PROJECT

Generate ideas; basic research; Mars settlement

2000 — **2100**

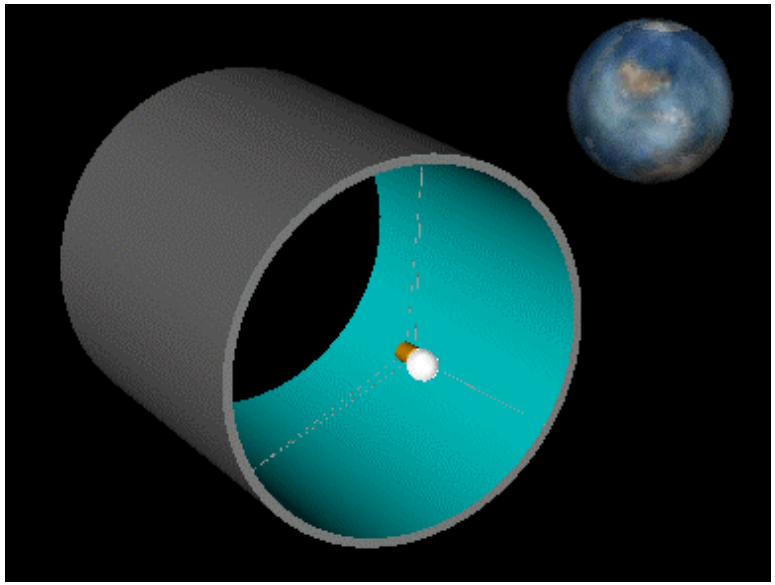
PROJECT start

Detailed design concept, built-in evol. flexibility; probes to stars?

2100 — **2200**

Prototype and demo all technologies; space colonies

2200 — **2300**



Assemble PROJECT materials; construction

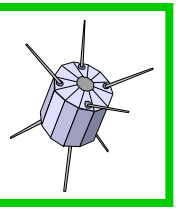
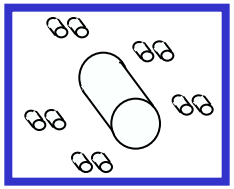
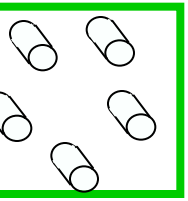
2300 — **2400**

Populate PROJECT; 100-yr. Sol. Sys. test

2400 — **2500**

Launch to Nova Terra

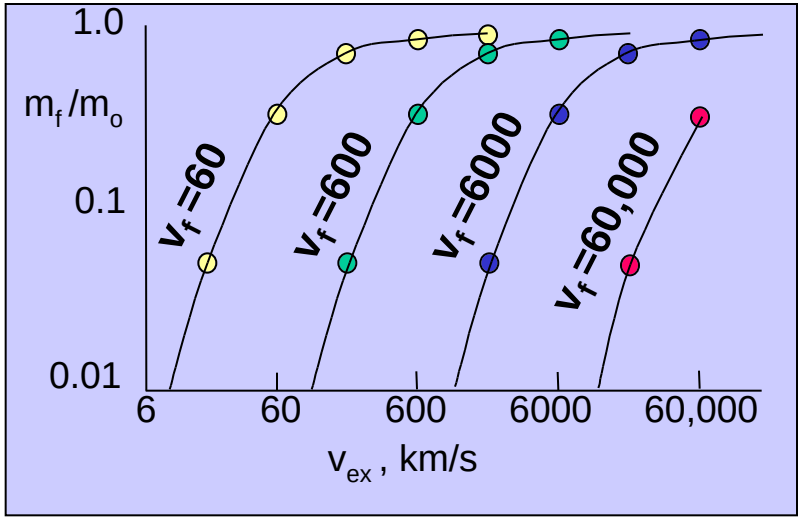
Basic Engineering Trades & Considerations

Factors	Preferred		Alternative	Considerations & Benefits
Speed	**< 0.01 c**	**vs.**	**Relativistic**	Minim. power and fuel (20 x V_{now}) Collision hazard reduction Easier astronomy
Mission Type		**vs.**		Public Interest; Adaptability Maintenance for 1000's of years Populating our galaxy
S/C Size & Number		**vs.**		Easier artificial gravity Outliers aid astronomy & defense Easier human interactions 10 x size increase each 66 years

Necessary system functions: providing food, shelter (thermal, radiation), air, cleaning, energy, communications and information transfer (and with Earth), power, propulsion, repair (mechanical, material, biomedical, environmental, plus replenishment if not a totally closed system), facilities for maintenance of societal harmony and size, scientific research, and literature/art/music/entertainment/sports

Propulsion, Power, Radioactivity, and Shielding

- **Critical weight trade**: ratio of cruising speed, $\mathbf{v_f}$, to propellant exhaust velocity, $\mathbf{v_{ex}}$
  - assume single-stage (illustrative): $\mathbf{m_o/m_f = exp\ (-v_f/v_{ex})}$; m_o initial, m_f cruising
  - current $\mathbf{v_{ex}}$ capability ~ **30-100 km/s**
  - with $\mathbf{v_{ex}}$ > **6000 - 60,000 km/s**, keep > 80% of total launch mass through to end of $\mathbf{v_f}$ = **600 km/s** journey
  - $\mathbf{v_{ex}}$=**15,000 km/s**; with enough power, expect future higher $\mathbf{v_{ex}}$ capability via accelerator technology or ??
  - 55 μm/s^2 accel. **400 yrs. to speed** (achieved at 0.8 light-year distance)



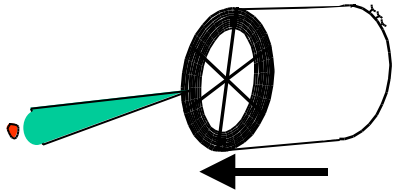
- **Power source** is controlled fusion or better, **40 TW peak**
  - Assumed **H fusion** power, efficient at 0.7% m(H), 20% power conversion efficiency
  - **m(H)**: **8 M tons** provides all needed power for 10,000 years; 99.9% for propulsion
- **Shielding & repair capabilities** must mitigate effect of cosmic rays, fusion radioactivity
  - $\mathbf{H_2O}$: **50 M tons** (5 meter thick layer) gives half an Earth atmosphere of shielding
  - assist from material, structural, and biological maintenance & repair technologies

Estimate of Potential Collision Threat

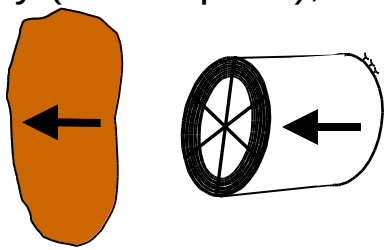
- **Relativistic ship speed could be dangerous**
  - 2 mm grain at 0.1 c --- K.E. = 1 ton of TNT)
  - suggest 600 km/s speed
    - reduces impact by factor of 2500 (to 400 grams TNT per collision)
- **Interstellar particle population, mm - km in size, presently unknown**
  - A meteorite which crashed into Greenland last December may have come from outside Solar System (Danish astronomer, Lars Lindberg Christensen -- Reuters 20-Aug.-98)
- Assume local ISM density around 0.002 M_{sun} per cubic parsec,
  - 4×10^{27}kg/$(3 \times 10^{16}$m$)^3 = 10^{-22}$ kg/m^3= 10^{-25} g/cm^3= 0.1 atom$_H$ / cm^3
- For a 6 pc voyage, 3 km^2 spaceship cross-section
  - volume is 6×10^{23} m^3 , so mass of ISM intercepted is 60 kg
  - if 1 % of that mass were in 2mm grains, yields **100,000 collisions**
    - **<u>Check:</u>** would create optical depth of 0.4 m^2 / 3 km^2 = 0.13 x 10^{-6} over 6pc
    - total optical depth looking out of galactic disk is 4 x10^{-6} (Alcock et al. 1995), 30 times greater, but over ~ 300 pc, so grains could be almost this numerous

Collision Avoidance Options

- **Detection likely to be active, as threat self-emission in cold space is very faint**
  Lidar / radar scanning options (360,000 km range at 600 km/s 10 min. warning)
- **Evasion** -- 1 km transverse motion in 10 min. needs 5.5 mm/s^2 acceleration
  F = 5.5 x10^8 N, Energy = 5.5 x10^8 x (1.5 x10^7 ÷2) x 600 = 5 x10^{18} J [m(H) = 20 tons]
  Unfortunately, is 100 times peak power output; perhaps burst power possible
- **Threat deflection or dispersion** (smaller threats) -- beam or other energy input

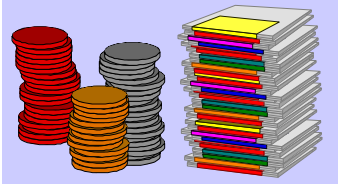
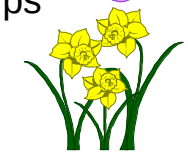


- **Shields**
  Passive
  - capture asteroid few km across, attach engine, bring to speed ahead of ship
    - won't block much view (and most impacts will not be perfectly head-on), turn off its engine most of the time, maneuver it to block threats, use raw materials for all ship needs, shuttle to it easily (same speed), use it up or let it fly past target stellar system
  - or could build a large passive shield



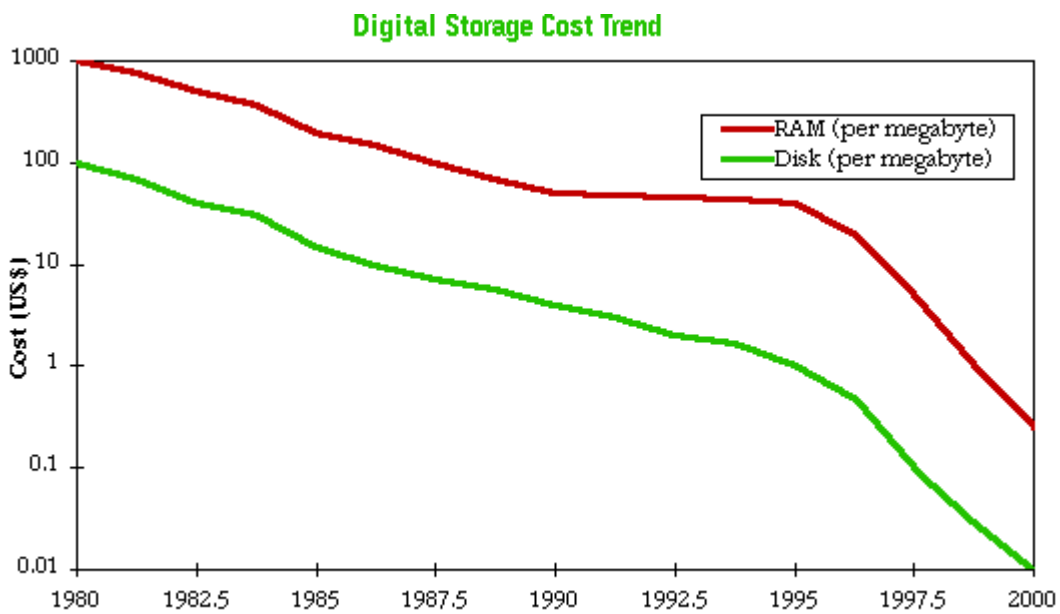
  Active or other shield designs
  - smart materials, traps, triggered responses, sentries

Materials and Resources

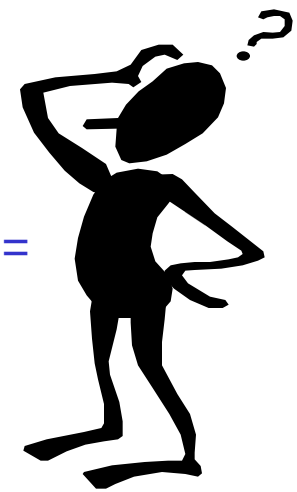
- **People** : main resource
  - to function for thousands of years, need a full, complex society
  - talents, skills, & group wisdom to maintain & repair ship and society
  - many obvious challenges, but many unforeseen and unpredictable
  - human (and robot) resources equivalent at least to a future major terrestrial urban center
- **Information**
  - in archives  , and updated from Earth communications
  - memory storage progress likely to provide essentially unlimited information
- **Materials**
  - modern technological society requires vast support systems
  - carry a pantry full of all needed chemical elements and compounds
    - for repairs, research, technology development
    - complete recycling and extraction operations, redundancies and back-ups
    - can get possible re-supply from high-speed Earth supply freighters 
  - tool and machine foundries, food and farming capabilities

Information Growth, Cost Extrapolations as Technology Change Rate Example

- Volume of published material doubled 1880 to 1930, again from 1930 to 1960, from 1960 to 1970, now doubling every 18 months (Ernst and Young)
- Manage this huge mass of data via search engines and "intelligent agents"
- Cost of data storage decreasing faster than amount of data is increasing
  - ***unrealistic*** predicted storage cost (RAM ?) in 2100: $1 per 10^{46} Bytes
  - ***extrapolated*** total data in 2100 (includes images, sounds): 10^{38} Bytes



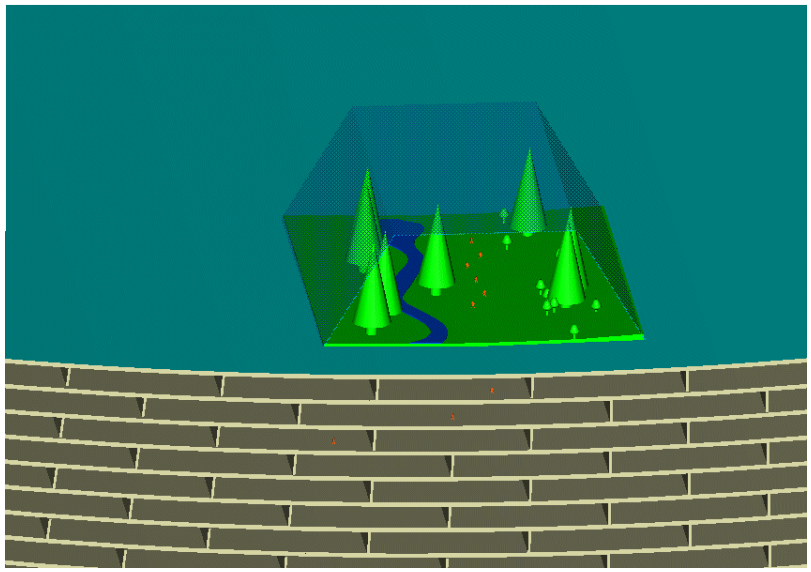
In 2500 A.D. =

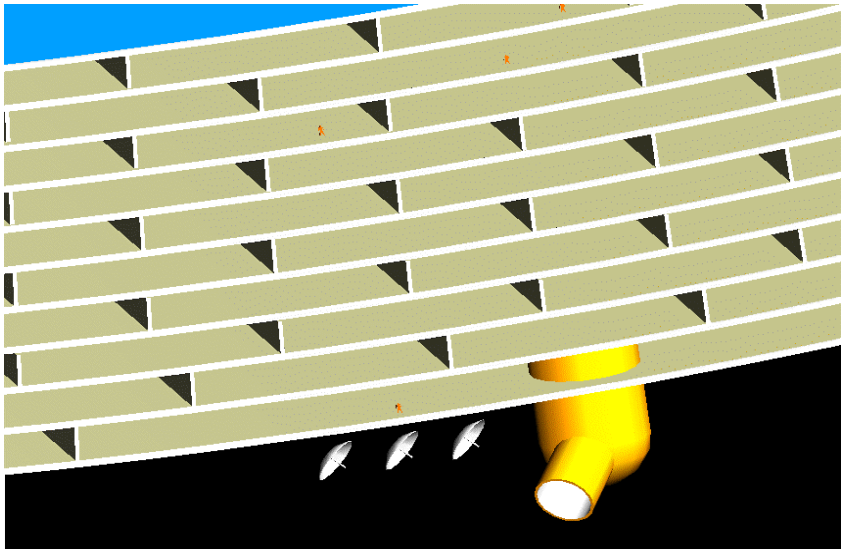


Does this mean we should wait? -- No.

On-Board Progress -- Labs and Communications

- genetic engineering laboratories to create new animals and plants and to repair any damage from new diseases or cosmic radiation
- materials research to assist in maintenance, repair, and invention
- general science labs in all fields (except Earth Sciences ??)





Cross-section: living decks (undecorated), telescopes, communications link, people

- communications with Earth: full information transfer
- social, political, psychological, and of course educational institutions to preserve, enrich, and create worthwhile lives for many generations
- cultural facilities, gathering places, recreation facilities, etc.

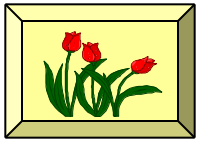
Biological Needs and Biological Changes

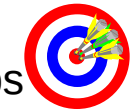
- **Life Maintenance**
  - air (1 Mton), temperature, water, food
  - light, gravity, radioactivity shielding
  - hygiene, rest, sleep, exercise, sports
  - full medical and mental health facilities
  - other species
    - symbiotic, aesthetic, emotional benefits
- **Genetic Engineering and Medical Advances**
  - lab to develop medicines, antibodies, operations
    - on-board research and innovations sent from Earth
  - lifespan extension -- potential for 100's of years ??
  - biological evolution, adaption to destination planet
- **Life Storage and Recycling**
  - cryogenic, or DNA data to reconstitute humans, animals, plants
  - many of the travelers could have clone-mates back on Earth

Social Needs, Institutions, and Evolution

- THE PROJECT first requires developing health, wealth, and peace on Earth
- Main social needs on the spaceship
  - stability, peace
    - institutions, government
    - cultural, political harmony; post-market maintenance economy
  - communication, knowledge
  - creating and enjoying beauty
- Society geared to needs of individuals, families, groups
  - meaningful involvements and opportunities for all
  - education and training, libraries, discussion circles
  - psychological and spiritual needs, births, deaths, etc.
  - group activities
    - festivals, celebrations, holidays
    - musical, dance, theater groups
    - sports and teams, games, hobbies, clubs
- Societal evolution
  - THE PROJECT involves launching not just a ship and people, but an entire civilization, a history, a series of cultures and revolutions during the voyage

Morals and ethics must not lag behind science -- Clarke





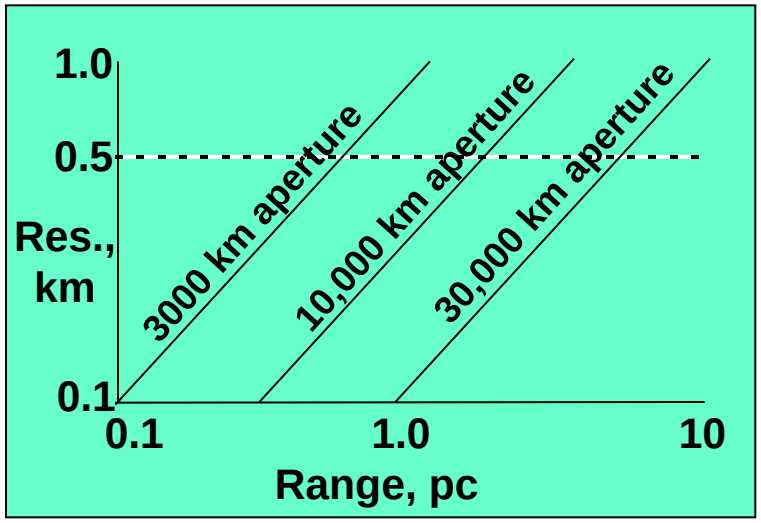
PROJECT Advantages and Disadvantages

- Disadvantages and Questions
  - Will people do and/or pay for something most of them (or their children or grandchildren) will never see completed?
  - Cost enough to cure world's diseases, plus do many other noble causes
  - To explore the universe, is this better than sending out hundreds of unmanned, camera- and sensor-laden probes moving much faster?

- Advantages
  - Provide a focus, a framework, even a purpose and a mission, to inspire and help guide us on constructive paths, taking people's minds and priorities off things like waging war
  - For many people (or their descendants) actually to have a chance at such a journey increases their interest in our space program, which now isn't easy for most to identify with directly; perhaps it might even rival football in popularity
  - Exploration, new knowledge, education, settlement, employment
  - Offers a safety-valve for humans in case of any hazardous situations developing on Earth

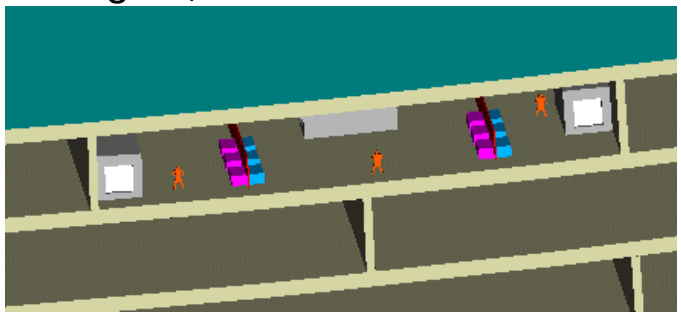
Telescope Roles and Requirements

- **Multiple observatories needed to detect**:
  - basic facts about our universe
  - favored destinations (habitable planets around young solar-type stars)
  - potential impact threats at long range (for avoidance or deflection/destruction)
- **Some basic scientific topics to explore (we'll also learn of many now unknown)**
  - distant comet belts and clouds
  - heliosphere, our bubble within the ionized gases of the interstellar medium (ISM)
  - parallaxes and high resolution images , with long-baseline separated spacecraft
  - gravity waves
- **Resolve planet life spatial patterns**
  - 0.5 km with 30,000 km baseline at 6 pc
  - exposure <10,000 s, 10^{-7} aperture filled
    - total collect area > 100 km^2
    - closer view range may be needed
- **Spectral and temporal resolutions**
  - molecular species, environm. changes
  - precision Doppler-shift: planet moons



Telescope Implementations

- **Advantages of telescopes located on or nearby an interstellar spaceship**
  - proximity to humans makes rapid interpretation, maintenance, and upgrades possible, unlike with probes (which must endure for centuries without repair)
  - high vacuum benefits observations at all wavelengths; low contamination
  - stray light sources minimized
  - closer to planet: resolution, sensitivity



- **Telescope location options**
  - platforms on main ship (despun if needed)
  - instrument platforms flying near main ship
    - long-baseline high-resolution applications, synthetic-aperture, gravity-wave
    - very useful in early detection of collisional hazards to main ship
  - small instrument platforms dropped or sent off during the voyage
    - create a very large 3-dimensional array with extremely high resolution
    - no subsequent repair capabilities
- **Telescope types and sizes**
  - at least all kinds now on Earth (might even use water to observe neutrinos, etc.)
  - in situ observations of particles, fields, many phenomena as yet unknown
  - instruments' total mass > 2 M tons; individual sizes up to ~ 100 meters

Populating our Galaxy

- **Time for spreading life**
  - Initial journey to 6 parsecs (20 sun-like stars in that range) takes ≤ 10,000 years
  - Assume < 2000 years to settle, "terra"-form, build new spaceships
  - Net rate of expansion ~ 1 parsec per 2000 years
  - Whole Milky Way (dimensions ~ 20 Kpc) in ≤ 40 M years
  - Of course, technology development during M years would increase expansion rate
- **Considerations**
  - other life forms (SETI results will be important)
  - actual occurrence frequency of habitable planets (TPF will lead the way)
  - technological, biological, societal/cultural evolution
    - on Earth and in space
  - spur to action if dangerous deteriorating conditions develop anywhere
    - for many reasons it might be safer to be on spaceship than on Earth
- **It is time to expand our notions of "*The Larger Astronomy*"**
  - includes life, people, and societies, across the universe
  - we will have to develop an ecology and sociology of the Milky Way

Summary and Conclusions

- **Astronomy has always been studied to *apply knowledge to reach goals***
    - to discover useful fundamental properties of nature, e.g., fusion energy
    - to respond to opportunities & threats, e.g., calendars, agriculture, navigation
  - THE PROJECT should give a clearer focus to much astronomical research
  - the general public will gain in enthusiasm, support, knowledge, and involvement across wide areas of scientific, technological, and societal development
- **Populating our galaxy *may be our task*, not one for other species anywhere**
  - with reasonable investment over the next 500 years, we can have a good chance (then or not too much later) of traveling to planets around other stars
  - a very large crew achieves a critical mass for survival on a long voyage
- **THE PROJECT has many *advantages right here on Earth for the near future***
  - we can enter the next Millennium with a splendid goal in front of us
  - unifying the people of Earth may require mutual participation in a major world-wide effort like this, just as past wars often served to unify national populations
  - children respond with wonder, hope, and amplified curiosity
  - we will be forced to learn and do much more about all elements of humanity and the physical world, in order to develop the understanding and the systems (on Earth and on spaceships) needed to make THE PROJECT a successful creation

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