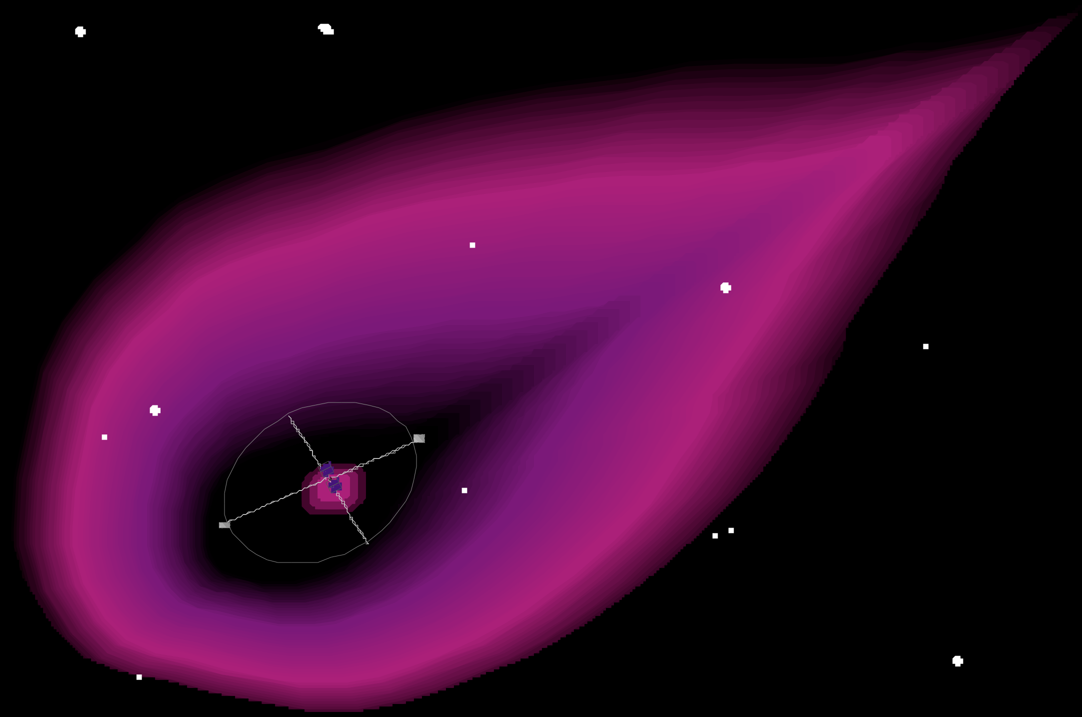
ARTIFICIAL MAGNETOSPHERES

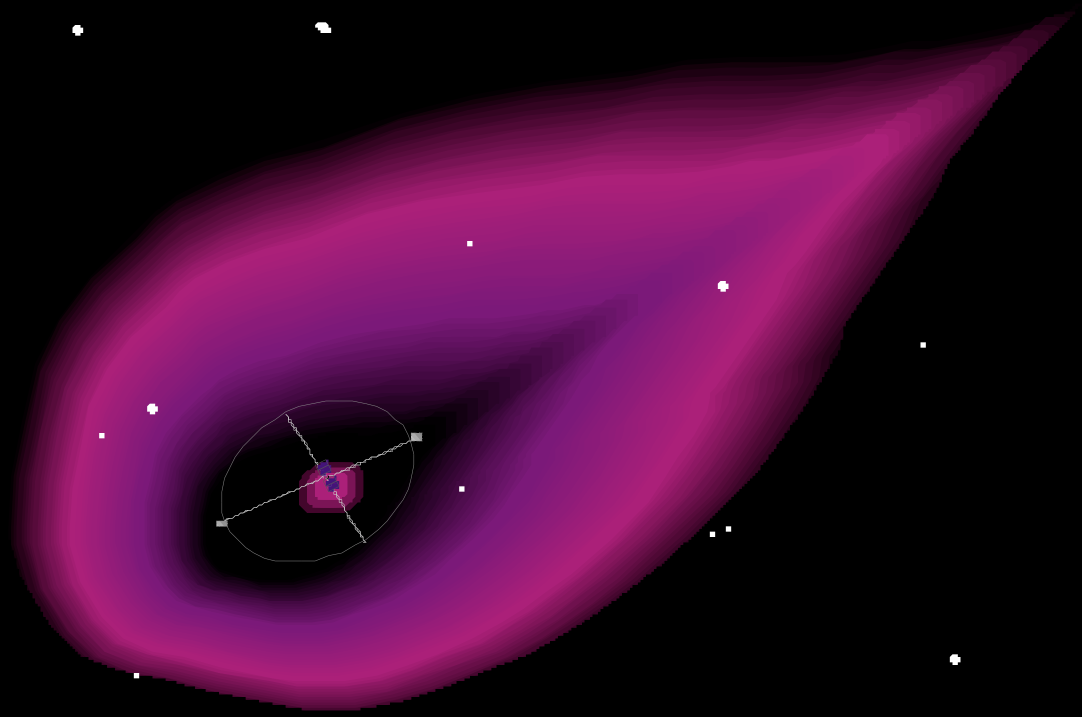


GERALD NORDLEY
SPACE ACCESS 07 MAR 22

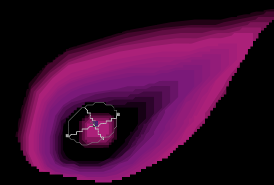
ARTIFICIAL MAGNETOSPHERES

- Radiation Protection
- Propulsion
- Terraforming

- Current loop basics
- Some technologies
- Some applications



GERALD NORDLEY
SPACE ACCESS 07 MAR 22



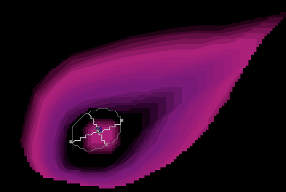
Huge literature available

Calculations here based on classic '64 Prescott paper
(available free on internet!)

More recent work by Cocks also instructive.

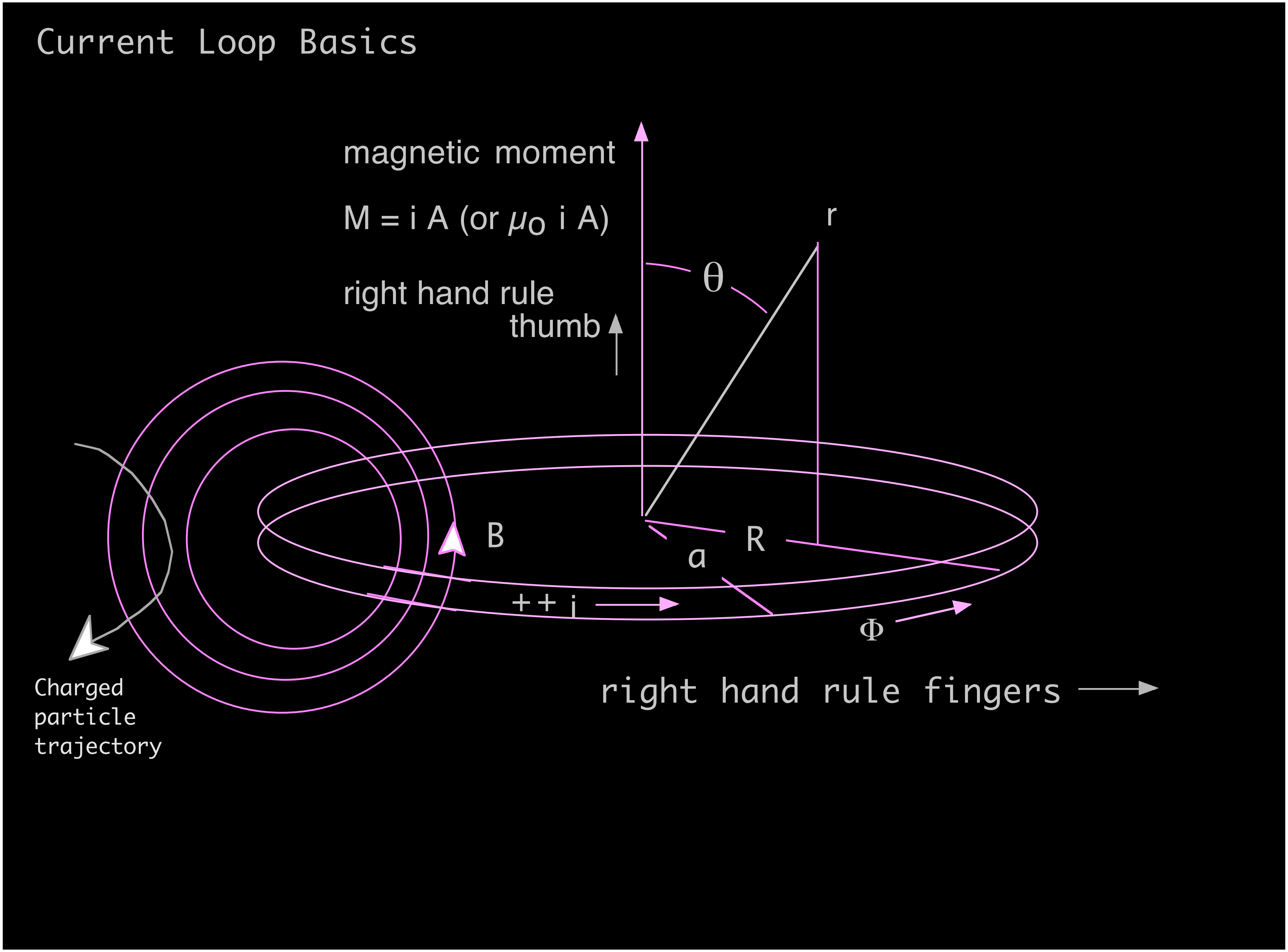
The intent here is to introduce/review -- serious contemporary work is done with numerical analysis...

Interest and awareness in this tends to wax and wane...people forget it's an option. (See Landis, '91)



Shielding Variations

- pure magnetic loop (the main focus here)
- pure electrostatic (not considered here)
- combined magnetic and electrostatic
  - requires power source
  - generally least massive alternative
- some mass shielding combined with any or all above


Current Loop Basics
magnetic moment
M = i A (or μo i A)
right hand rule
thumb
r
θ
B
R
a
+ + i
Φ
right hand rule fingers
Charged
particle
trajectory

Störmer Radius and the Shielded Area around a Single Loop.

GEORGE C. MARSHALL SPACE FLIGHT CENTER

MTP-RP-64-1

DISTRIBUTION OF UNBOUND CHARGED PARTICLES IN THE STATIC MAGNETIC FIELD OF A DIPOLE

By Arthur D. Prescott

Störmer radius

The "Störmer radius" is the product of the charge-to-momentum ratio (q/p) of the incident particles and the Magnetic moment **M** divided by 4 π.

$c_{st}^2 = (q/p)\ \mathbf{M} / 4\pi$

$c_{st}^2 = (q/p)\ i\,A / 4\pi$ (for a circular current loop area A)

$c_{st}^2 = (q/p)\ i\,a^2/4$ (for a circular current loop radius a)

$\lambda = a/c_{st} = 2/\mathrm{sqrt}(i\ q/p)$ low λ, good, high λ bad

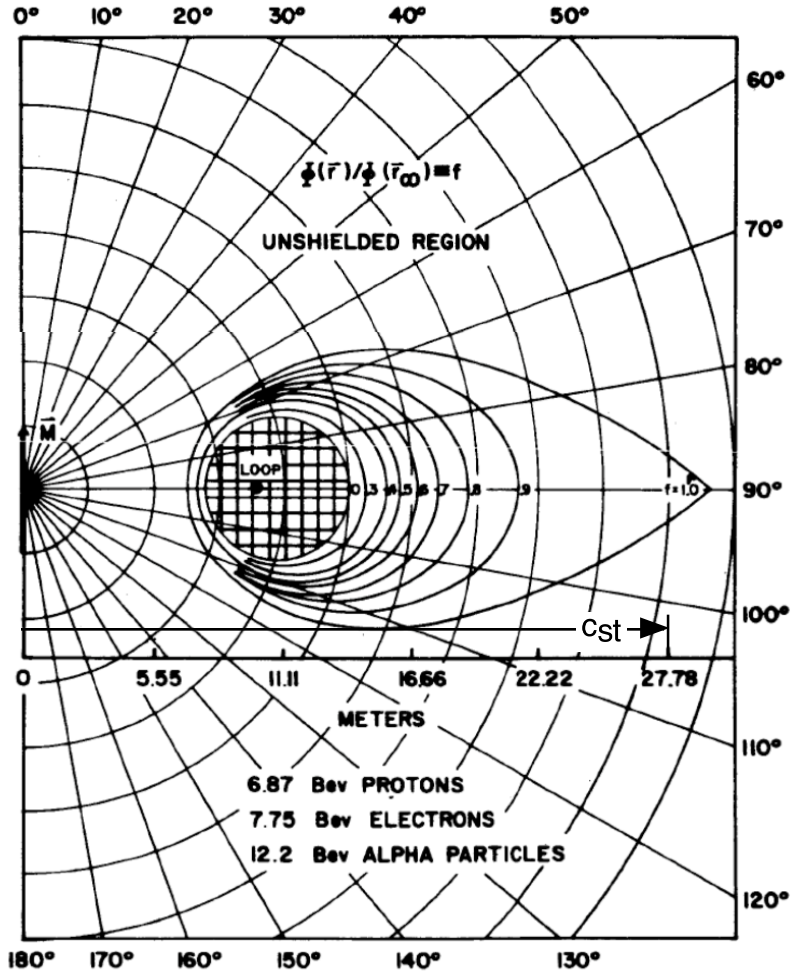
Note that:

The fully shielded area is not centered on the loop cross-section.

c_{st} is NOT the dimension of the fully shielded area.

c_{st} IS representative of the extent of the area that is at least partially shielded.

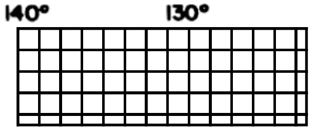
IV. PARTICLE DISTRIBUTION IN THE MAGNETIC FIELD OF A FINITE CURRENT LOOP



a = 10 m c_{st} = 27.8 m

$\lambda = a/c_{st} = 0.36$

$\overline{\gamma}_c = -1.023656$



Totally Shielded Area

M = 2.51 E5 Wb-m (T-m^3) = 800 amp x 100π m^2

Constant particle flux contours in the (r,θ) plane for unbound charged particles around a 10-m current loop with a dipole moment M = 2.51E5 Wb-m

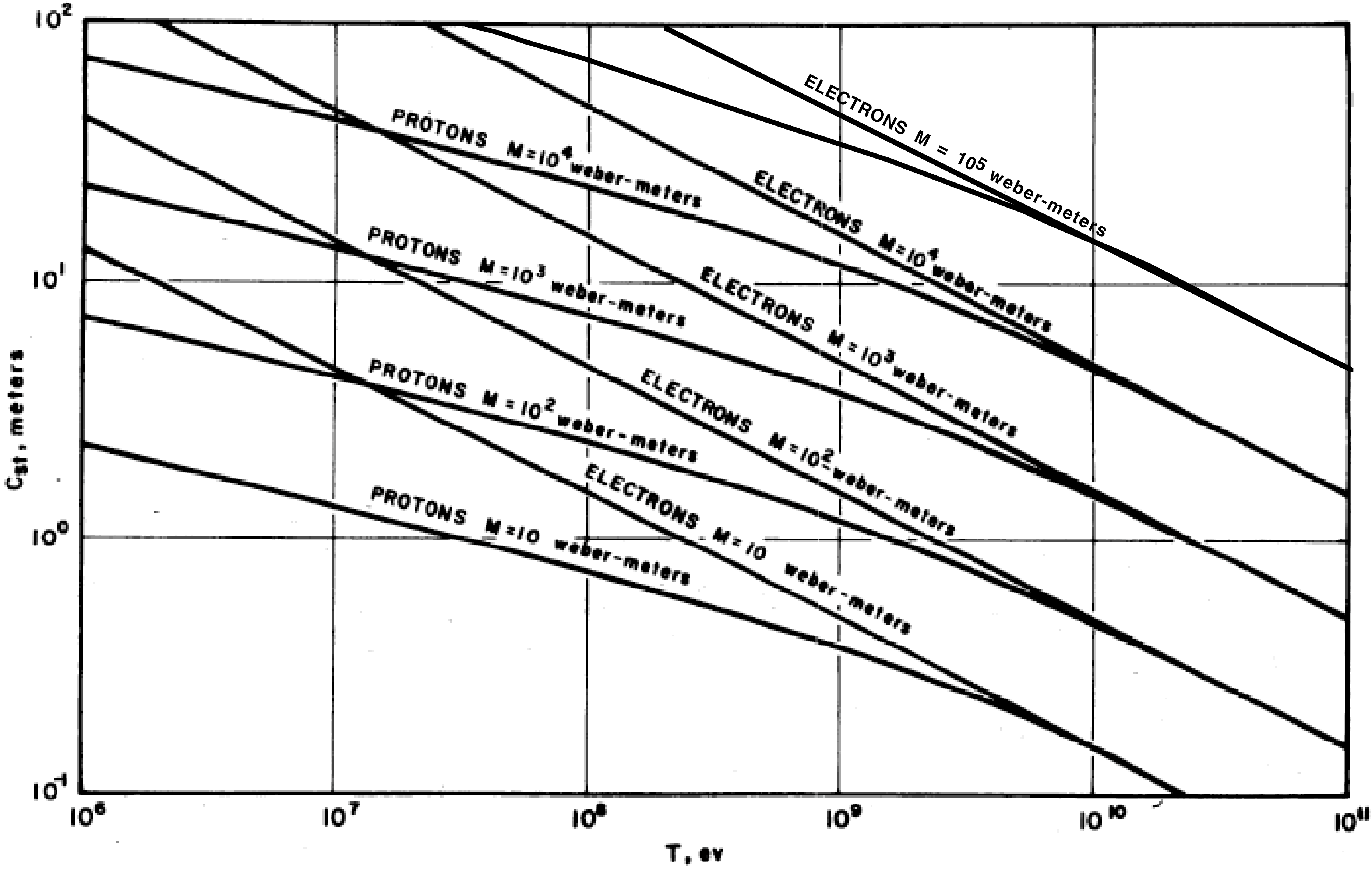
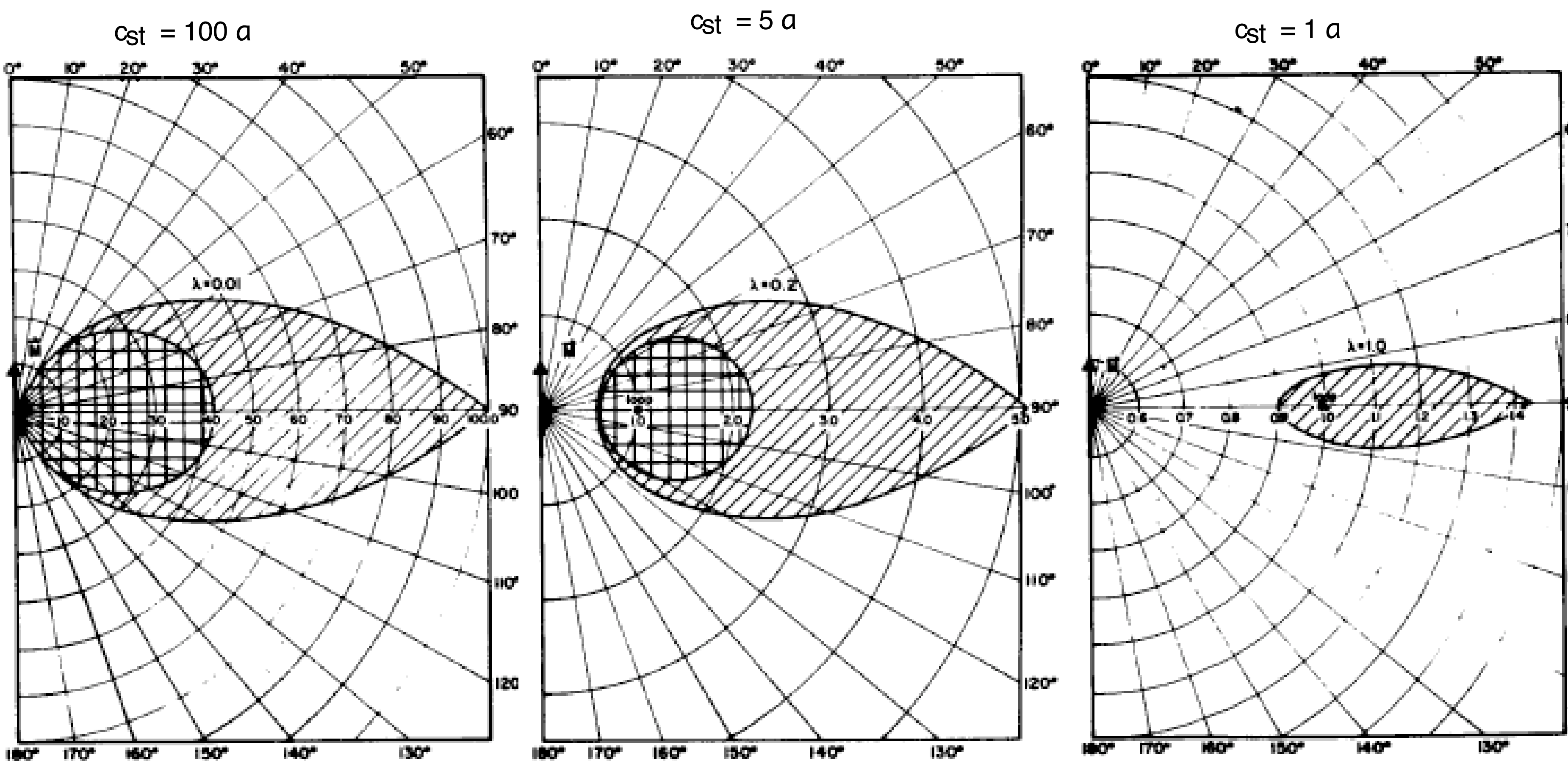
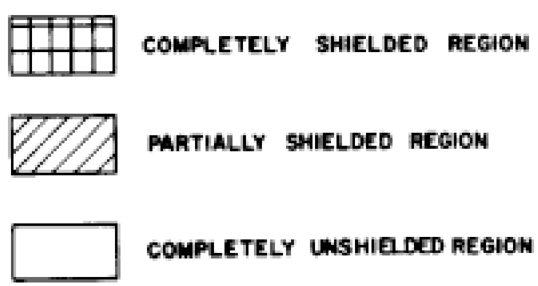


Fig. 4-PARTICLE STÖRMER RADIUS FOR PROTONS AND ELECTRONS vs. KINETIC ENERGY, WITH MAGNETIC DIPOLE MOMENT AS A PARAMETER.





$\lambda = a/c_{st}$	Radial Width of Completely Shielded Region	
0.01	41.40 a	0.41 cst
0.20	1.60 a	0.32 cst
0.36	0.62 a	0.22 cst
1.00	no completely shielded region	

Superconductor Status

American Superconductor

American Superconductor has now been able to make ribbon-shaped YBCO wires that are 100 metres long and just 4-mm wide. It made them by depositing YBCO onto a substrate of nickel alloy, which has highly aligned grains that the YBCO grains can in turn follow. The firms says its wires can carry a current of up to 140 Amperes when cooled with liquid nitrogen -- about 150 times as much as a standard copper wire of the same dimension. "Just one of these wires would be able to carry enough power to serve the needs of approximately 1000 homes," says Alex Malozemoff, the firm's chief technical officer.

The new wires could be used for power transmission and distribution cables, propulsion motors, power regulators and fault current limiters as well as in prototype power cables, maglev trains and MRI. The company says it has already shipped nearly 3000 metres of the new wire to its customers this year and expects to scale up production to 10,000 metres by the end of 2007.

http://physicsweb.org/articles/news/10/7/11/1

Numbers for mass and current density of HTS cable vary...

http://casa.colorado.edu/~danforth/science/magsail/magsail.html
The density of our superconductor is presumably something on the order **of 5grams/cm3**.
If we give it a **diameter of 12mm**--about the diameter of a good mountaineering rope--
it could carry a **megampere of current** and still maintain superconductivity.
The insulation can be assumed to be fairly light (~0.5 grams/cm3) and fairly thin (~3mm).

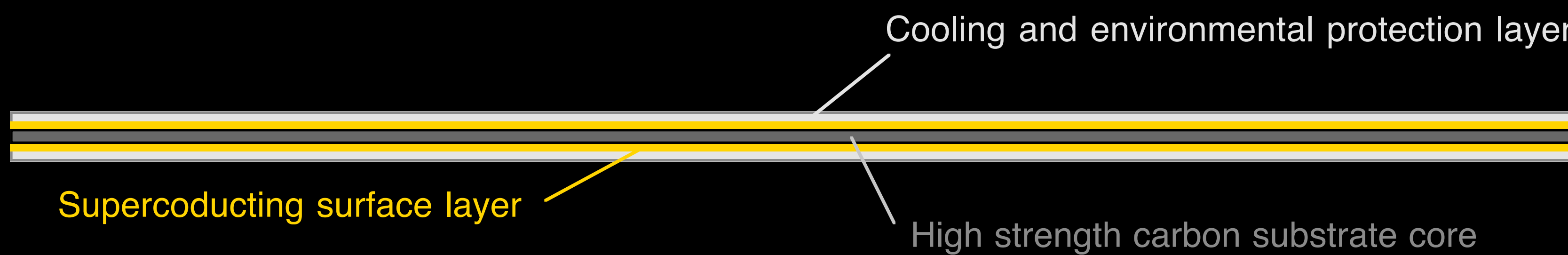
Superconductor science & technology (Supercond. sci. technol.) **ISSN** 0953-2048
The mass density of superconducting (bismuth, lead)-strontium-calcium-copper-oxide (PBSCCO) cores of silver-sheathed tapes, subject to different states of cold working and thermal treatment, has been determined taking advantage of a modified hydrostatic weighing. It turned out that the densification was more effective the smaller the initial density of the parent material. A core density of about **5 g cm[-3]** was attained,

http://www.magnet.fsu.edu/scientificdivisions/asc/research/bscco.html
19-filament Bi-2223 tape with the Jc (77K, self-field) of 60 kA/cm2.

Recent development of niobium-tin superconducting wire at OST
Zhang, Y.; McKinnell, J.C.; Hentges, R.W.; Hong, S.
Applied Superconductivity, IEEE Transactions on
Volume 9, Issue 2, **Jun 1999** Page(s):1444 - 1446
Digital Object Identifier 10.1109/77.784660

Summary: Oxford Superconducting Technology (OST) produces Nb3Sn superconductive composites via several different fabrication methods. We report here some aspect of improvements made in these products. Enhancement in very high field properties have been introduced for bronze processed composite using Nb filaments with Ta addition and bronze matrix with Ti addition. In modified jelly roll (MJR) composite non-copper critical current density has been improved to over **3000 A/mm^2 (3E5 A/cm^2) at 10T** by modifying design. This performance is reproduced routinely in production

Future Superconductors



A research team has created a new type of superconducting wire that not only carries a high electric current without resistance but also is remarkably strong, light, thin, and long. As the team reports in the August *Physical Review B*, the wires are made from an unusual magnesium-carbon-nickel compound layered around a carbon fiber.

Adams and his colleagues were surprised by the size of the critical current:extrapolated to an absolute zero value of 40 million amperes per square centimeter, 10 times higher than predicted from previous experiments with packed powders and almost as high as the theoretical maximum for non-high-temperature superconductors. Such a current would produce a magnetic field of up to 15 tesla in these wires--powerful enough to use in several futuristic spacecraft propulsion systems

$I_c(0) \approx 40$ M amp/cm^2

$I_c(77) \approx 10$ M amp/cm^2

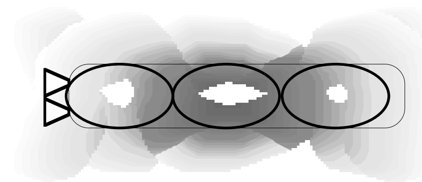
@$B \approx 15$ T

$\sigma \approx 2{,}000 - 3{,}000$ kg/m^3
(mainly carbon substrate)

Magnetic Shield Design Philosophies

1. Design field to fit ship

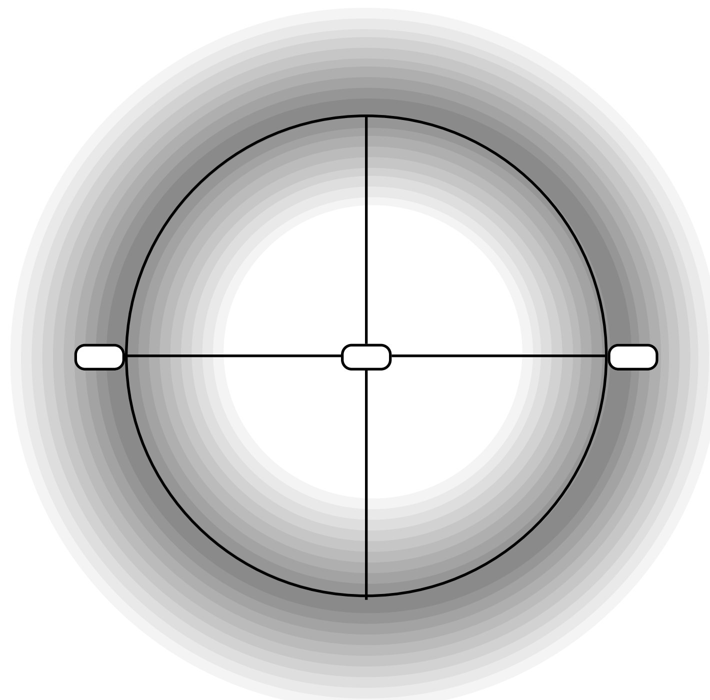
- Least impact on other design considerations
- Trade between weight and unprotected volume
- Easier human maintenance
- High field strength issues



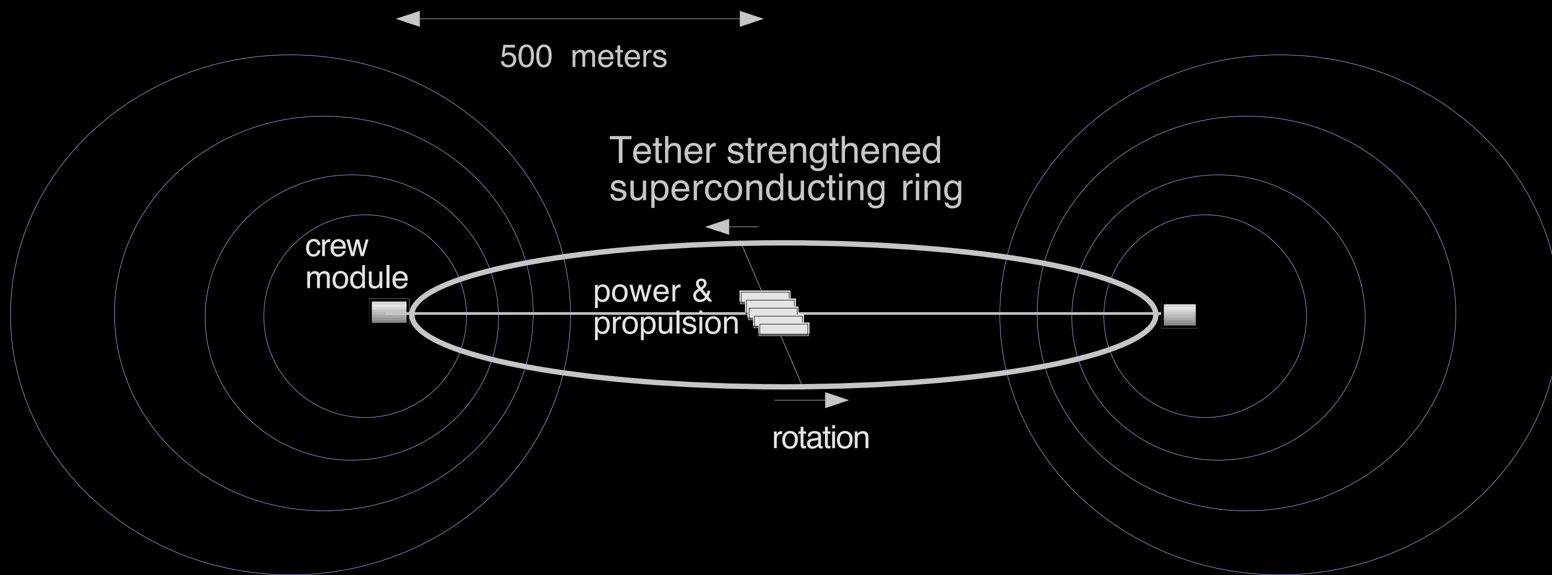
(analog simulators built in the 60's!)

2. Design ship to fit field

- Simpler shield design
- Deployment & redeployment issues
- Less shield mass and field strength
- Extended structure control issues
- Synergy with rotating g designs



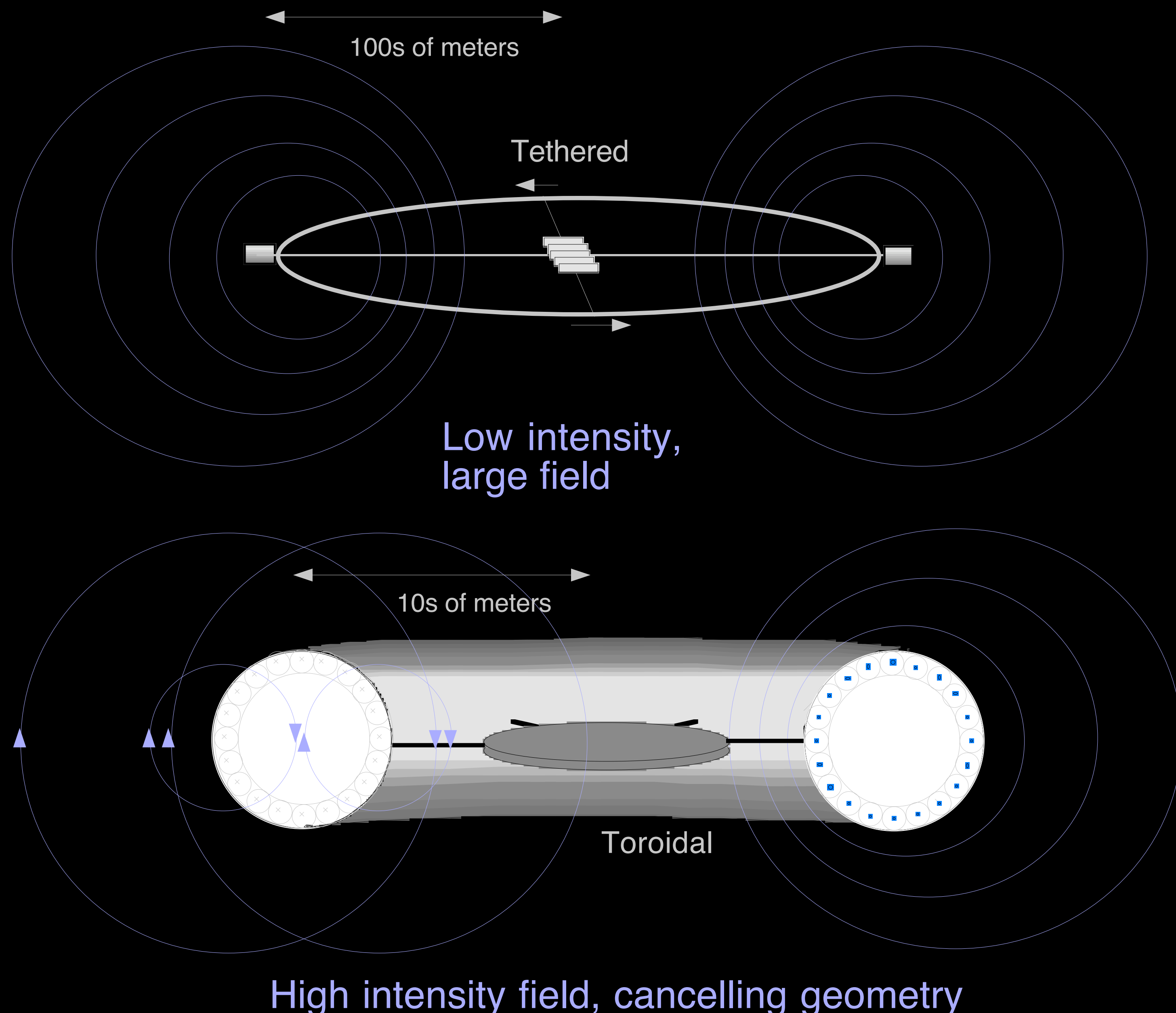
"Tether magshield" Design



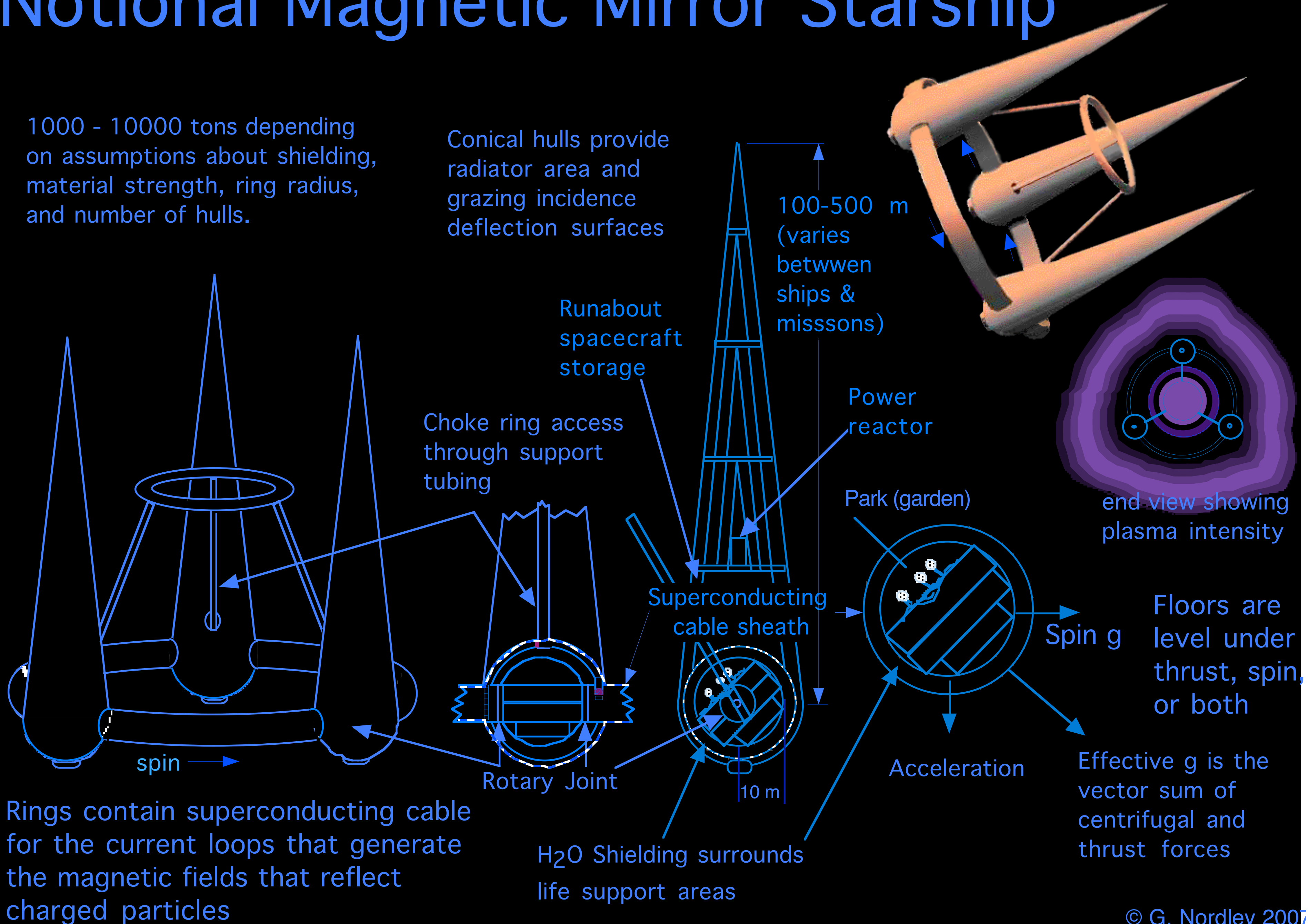
"Conservative" 1Mamp/cm^2 5 tons/m^3
Fully protected volume scaled
for 0.5 GeV protons
$\Delta r \approx 20$ m
Higher energy fluxes reduced but not eliminated
Current: 22 Mamps
Central field ≈ 300 Gauss
Loop Stress = 127 MNt
(vs tether fiber strengths ≈2 GPa)
Loop mass circa 70 tons including cooling & support

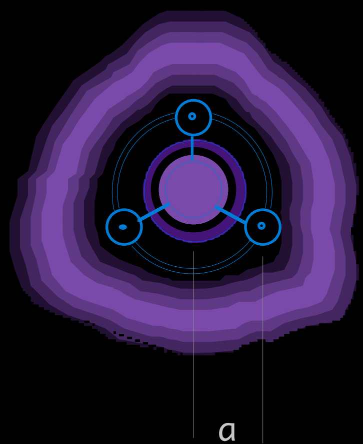
"Enhanced" 10 Mamp/cm^2, 4 tons/m^3
Fully protected volume scaled
for 1 GeV protons
$\Delta r \approx 20$ m
Higher energy fluxes reduced but not eliminated
Current: 34 Mamps
Central field ≈ 360 Gauss
Loop Stress = 290 MNt
(vs tether fiber strengths ≈2 GPa)
Loop mass circa 10 tons including cooling & support

Alternative Geometries for Shielded Spacecraft



Notional Magnetic Mirror Starship



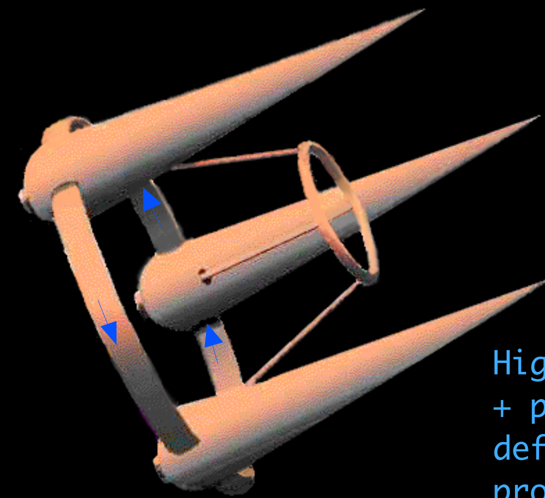


Shield/Reflector

for 12 GeV

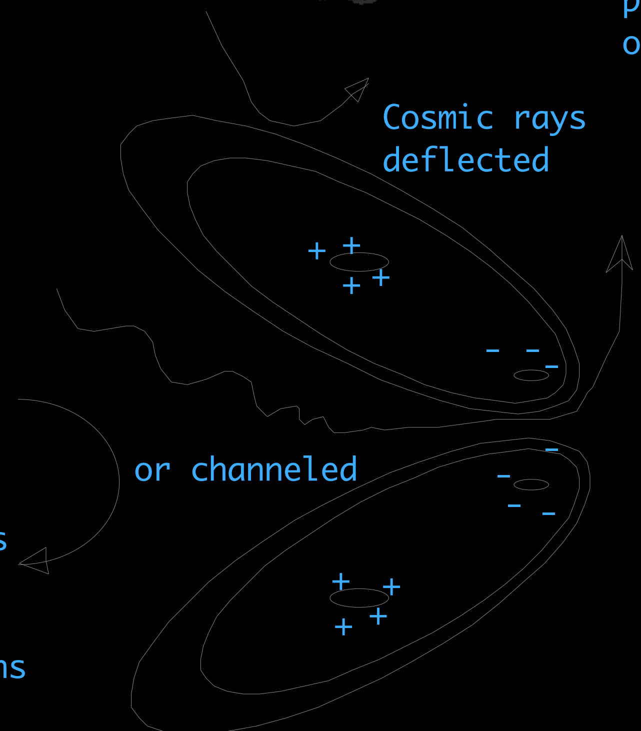
alpha particles

(.97c)

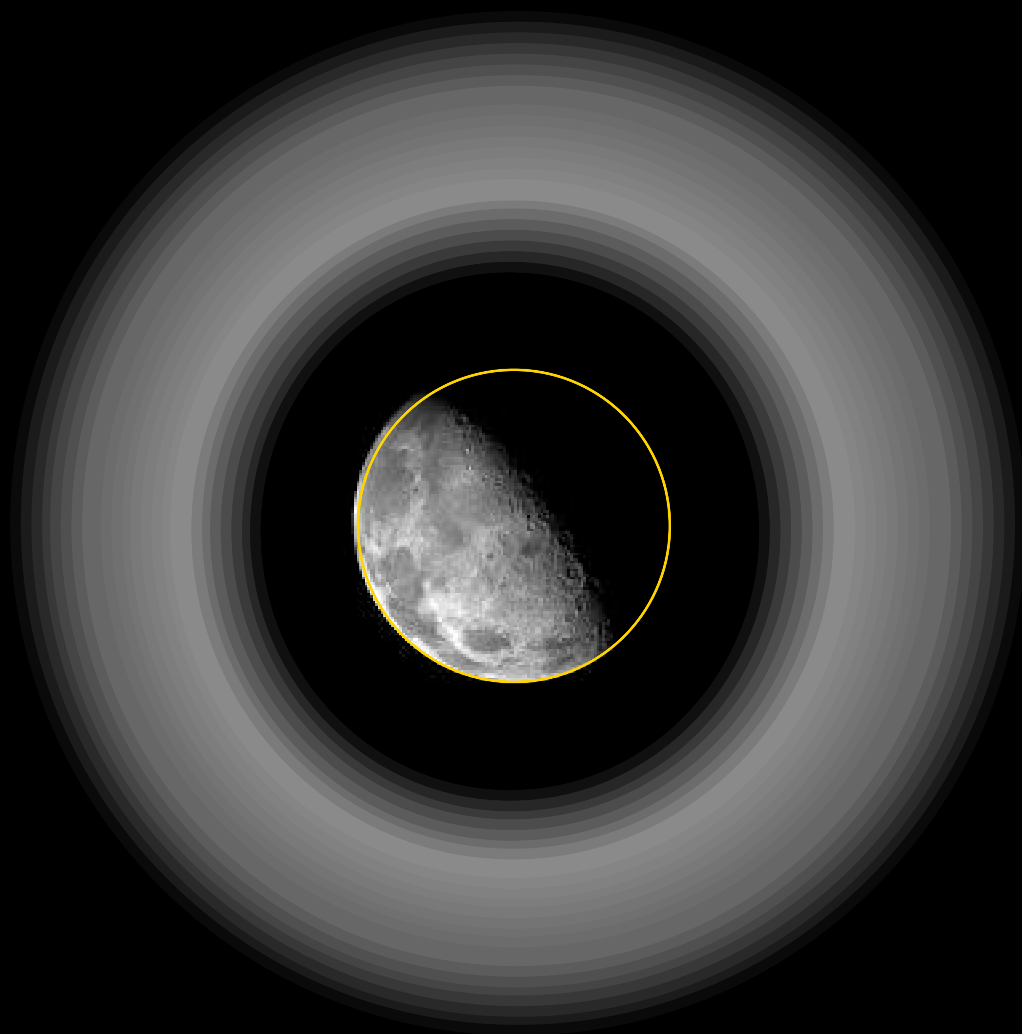


Starship reflector configuration combines

- two current loops
- electrostatic charge difference
- passive water layer around habitats



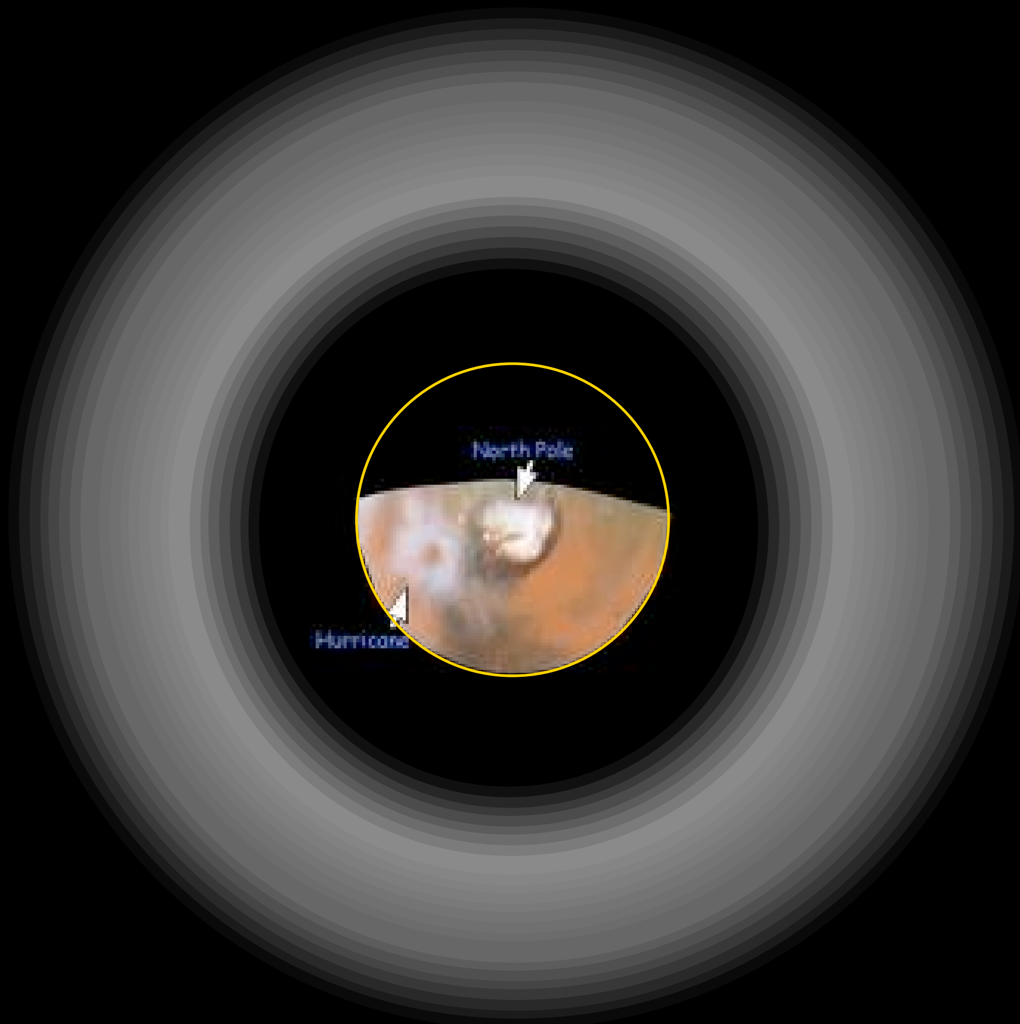
Artificial Lunar Magnetosphere



scaled for:
KE = 1Gev protons
q/p ≈ .108
a = 1,738 km
i = 100 Mamp
c_{st} = 4,187 k m
λ = 0.435
ΔR (protected)
= 1758 km

Supercond. Cable:
J_c = 100 kamp/cm^2
σ = 8 g/cc
cx area: .100 cm^2
mass = 873,614 tons
+ support, shade, and security

Artificial Martian Magnetosphere



scaled for:
KE = 1Gev protons

$q/p \approx .108$

$a = 3,397,000$ m

$i = 140$ Mamp

$c_{st} = 8,183$ km

$\lambda = 0.35$

ΔR (protected)
= 2210 km

Superconducting Cable:

$J_c = 100$ kamp/cm^2

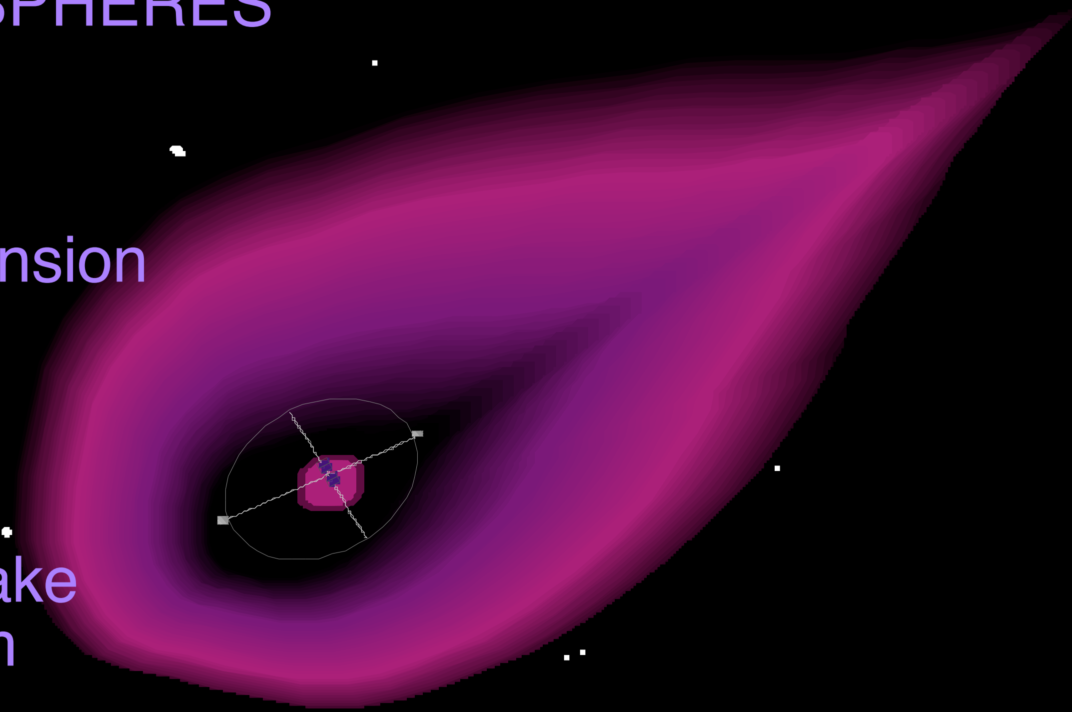
$\sigma = 8$ g/cc

cross sectional area:
= 140 cm^2

mass = 1.2 million tons
+ maintenance & security

ARTIFICIAL MAGNETOSPHERES

Some comments....



- Superconductor, high tension materials may be ready by the time we are.

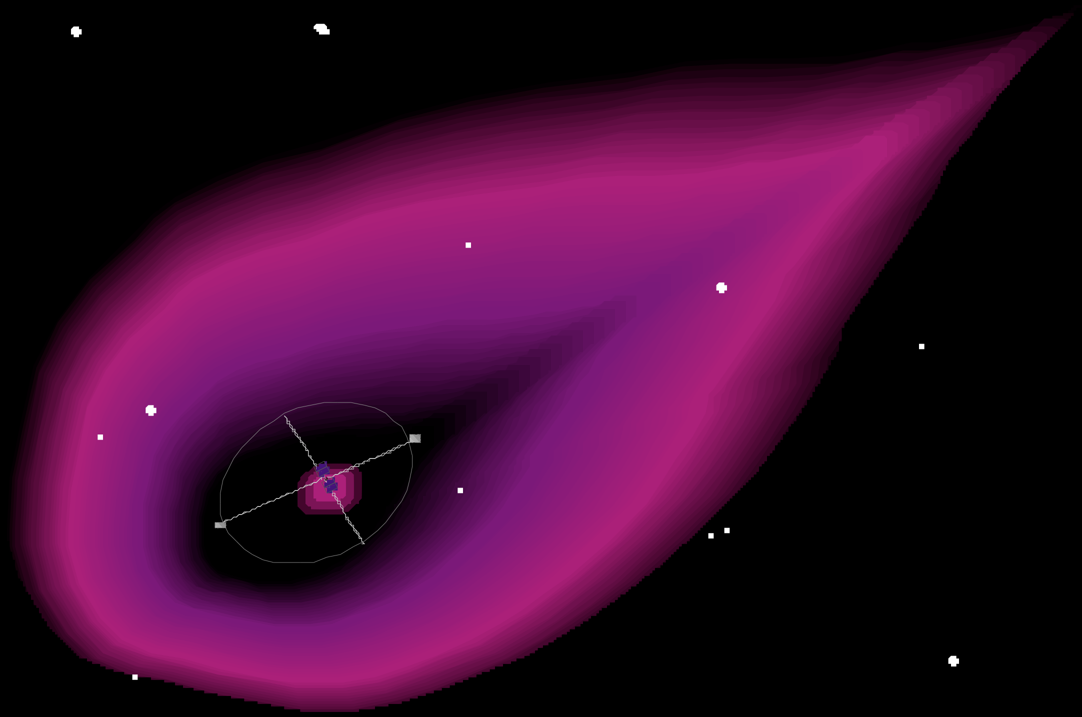
- Look for synergisms, "Motie engineering" i.e. make one piece of mass perform several functions.

- Synergism with tethers looks particularly promising.

- Field strength environment issues need research--may be a greater issue than conductor stress and weight.

GERALD NORDLEY
SPACE ACCESS 07 MAR 22

ARTIFICIAL MAGNETOSPHERES



GERALD NORDLEY
SPACE ACCESS 07 MAR 22