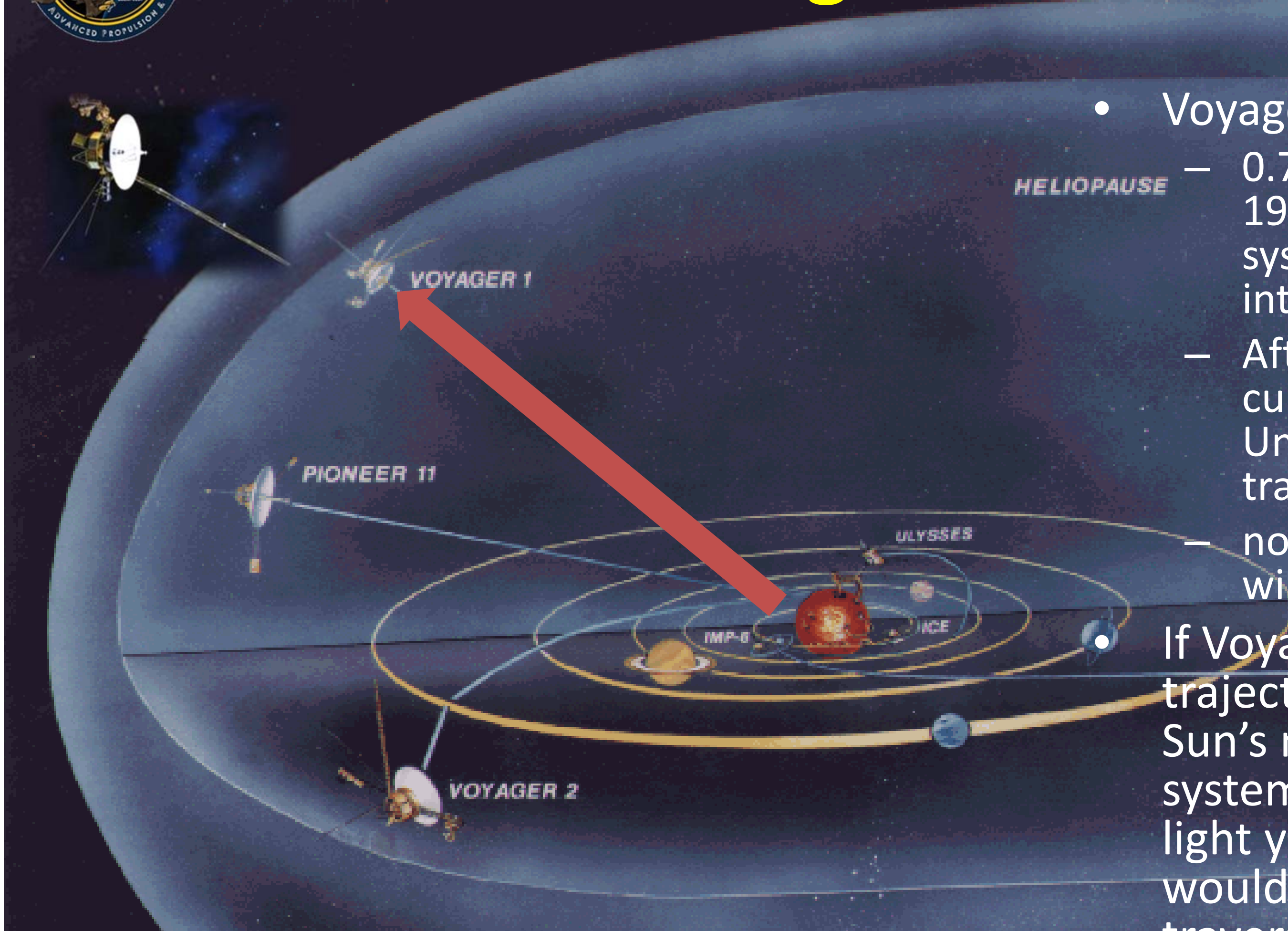
Eagleworks Laboratories

WARP FIELD MECHANICS 102: Energy Optimization

Dr. Harold "Sonny" White
NASA JSC

Picture courtesy of NASA,
http://www.nasa.gov/centers/glenn/technology/warp/warpstat.html

The Challenge of Interstellar Flight



- Voyager 1 mission:
  - 0.722 t spacecraft launched in 1977 to study outer solar system and boundary with interstellar space.
  - After 33 years, Voyager 1 is currently at 116 Astronomical Units (AU) from the sun travelling at 3.6 AU per year,
  - no spacecraft launched to date will overtake Voyager 1.
- If Voyager 1 were on a trajectory headed to one of the Sun's nearest neighboring star systems, Alpha Centauri at 4.3 light years (or 271,931 AU), it would take ~75,000 years to traverse this distance at 3.6 AU/year.

Pictures courtesy of NASA,
http://voyager.jpl.nasa.gov/imagesvideo/images/voyager2_large.jpg
http://voyager.jpl.nasa.gov/mission/interstellar.html

Putting things in PERSPECTIVE…

- Project Daedelus sponsored by British Interplanetary Society in 1970's to develop robotic interstellar probe capable of reaching Barnard's star, at ~6 light years away, in 50 years.
- The resulting spacecraft was 54,000t,
- 92% fuel for fusion propulsion system.
- ISS is ~450t

Picture courtesy of Adrian Mann, www.bisbos.com, used with permission
ISS picture courtesy of NASA (STS-135 fly-around)

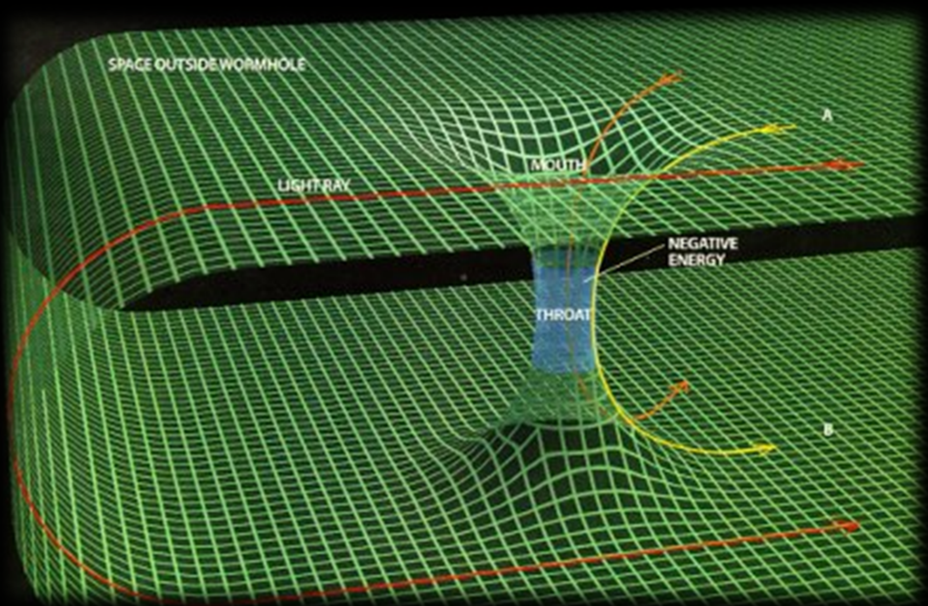
Is there another way?

"Originally an experimental craft to test the new "Diametric Induction Drive", the XCC-05 was later sold to a multi-national consortium of asteroid prospectors, and christened the "Earth Space Ship Lewis & Clark." With its new propulsion this ship was able to reach and survey the "Transition Zone" at the extreme boundaries of the Solar System. Fifteen months into its survey mission it transmitted the following message: 'Long range scans indicate an unidentified ship beyond 175 AU. Definitely a maneuvering ship. Setting course to investigate, will advise.'" It was never heard from again." -- **Fictional** vehicle, Marc Millis Design, courtesy of NASA, BACKGROUND courtesy Mike Okuda

What about hyper-fast interstellar travel?

- Is there a way within the framework of physics such that one could cross any given cosmic distance in an arbitrarily short period of time, while never locally breaking the speed of light (11th commandment)?

SPACEWARPS
(inflation)



WORMHOLES
(shortcuts)

Images courtesy NASA

Inflation: Alcubierre Metric[1]

Warp Metric:

$$ds^2 = -dt^2 + \left(dx - v_s f(r_s)dt\right)^2 + dy^2 + dz^2$$

Apparent speed

Shaping Function:

Shell thickness parameter

Shell size parameter

$$f(r_s) = \frac{\tanh\left(\sigma(r_s + R)\right) - \tanh\left(\sigma(r_s - R)\right)}{2\tanh(\sigma R)}$$

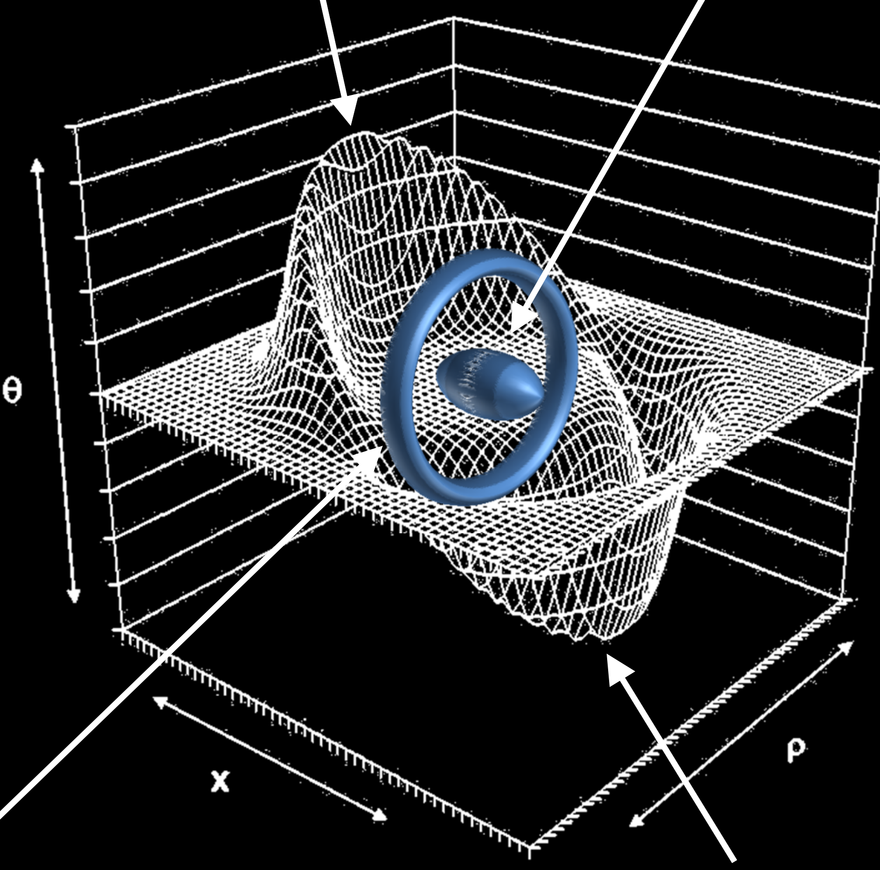
York Time:

$$\theta = v_s \frac{x_s}{r_s} \frac{df(r_s)}{dr_s}$$

York Time is measure of expansion/contraction of space

Energy Density:

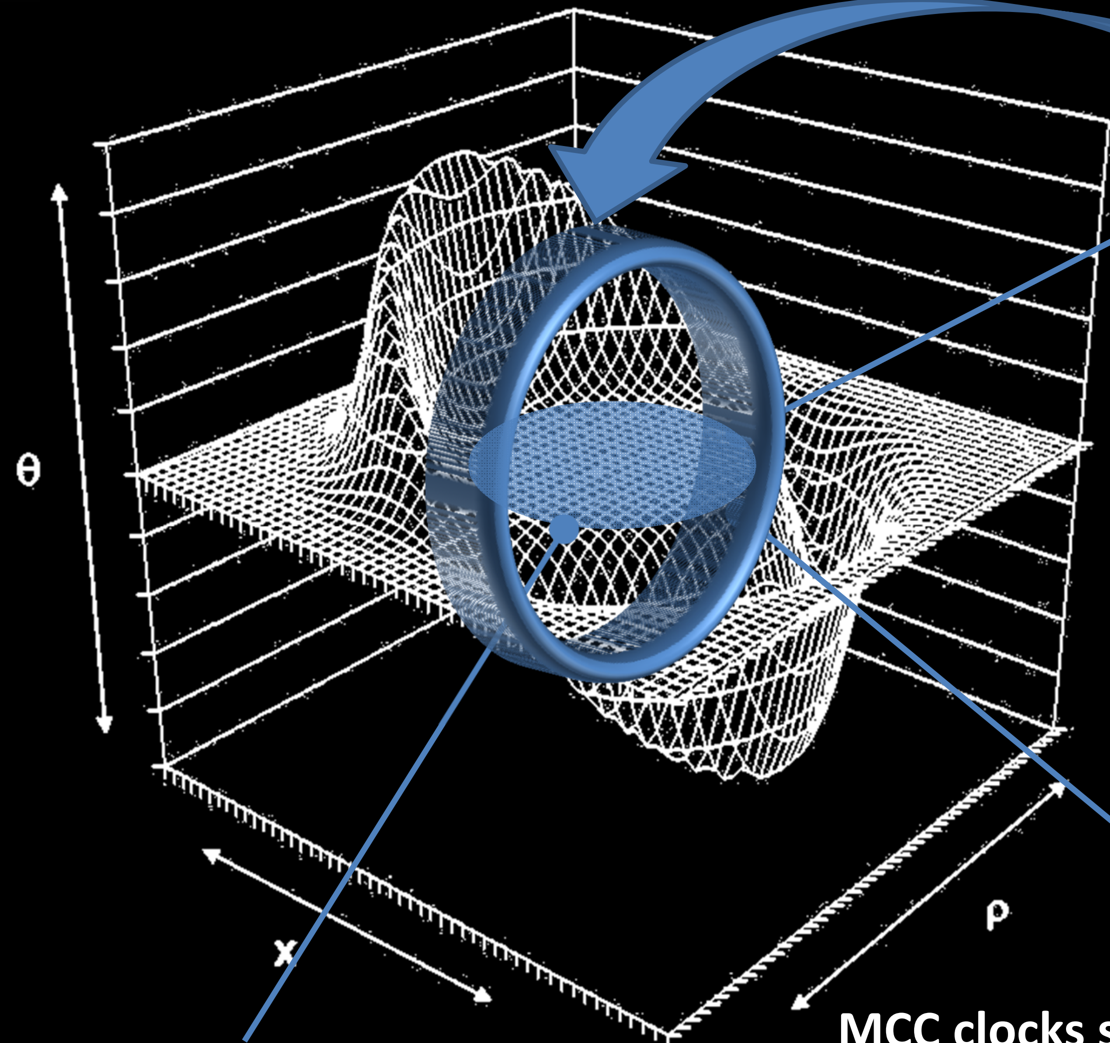
$$\frac{1}{8\pi} G^{00} = -\frac{1}{8\pi} \frac{v_s^2 \left(y^2 + z^2\right)}{4 r_s^2} \left(\frac{df(r_s)}{dr_s}\right)^2$$



1. Alcubierre, M., "The warp drive: hyper-fast travel within general relativity," Class. Quant. Grav. 11, L73-L77 (1994).

Appealing Characteristics

Proper acceleration in the bubble is formally zero



Images courtesy NASA

Unappealing characteristic

(square peg, round hole)

MCC clocks synchronized with onboard clocks

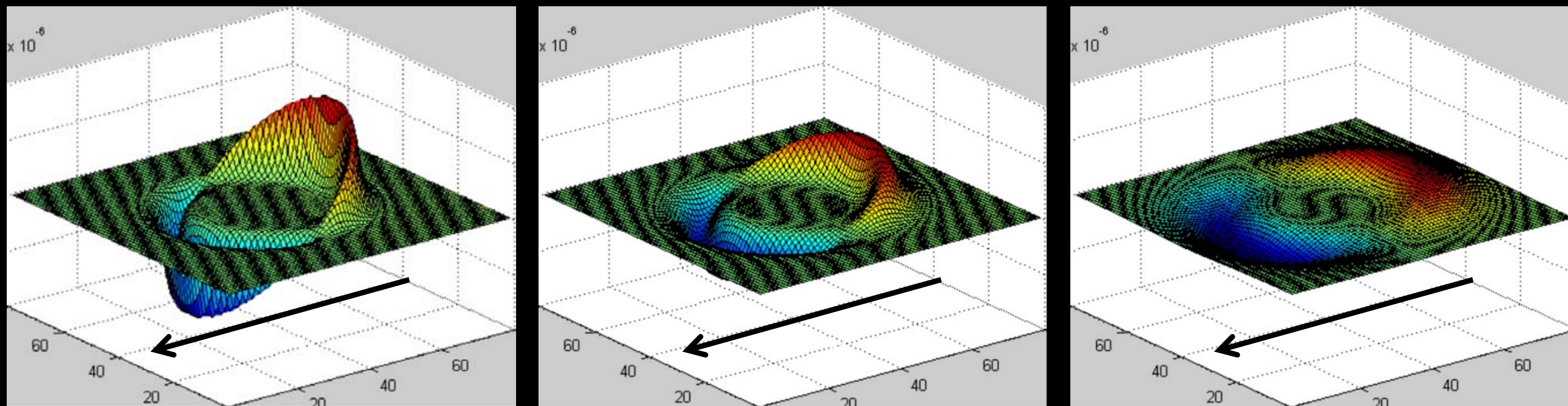
(Coordinate time = proper time)

Flat space-time inside the bubble

(divergence of phi = 0)

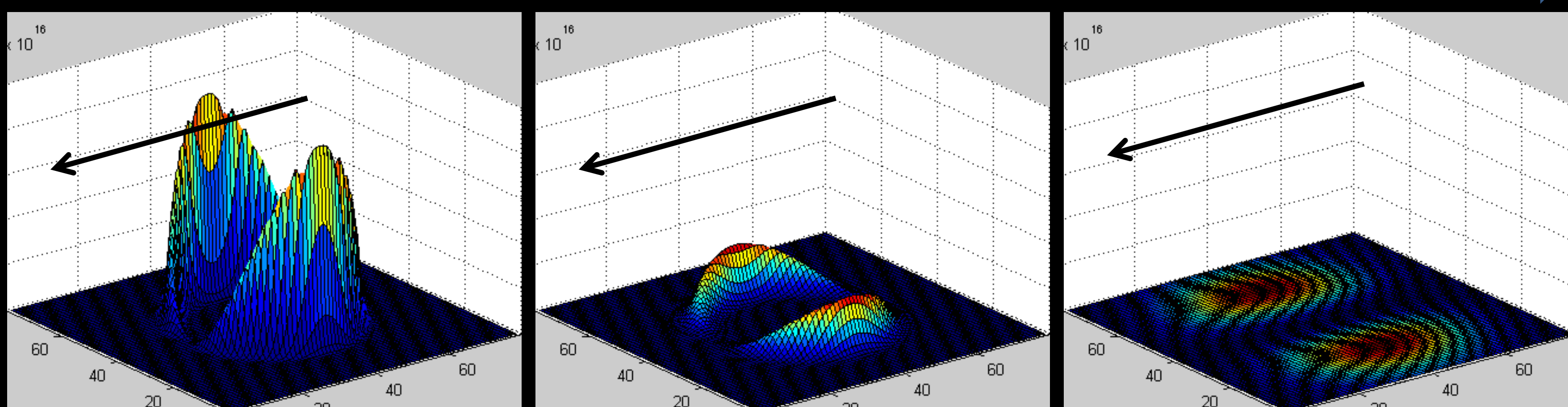
HOPE: Bubble Topology Optimization

York Time magnitude decreases →



← "bubble" thickness decreases

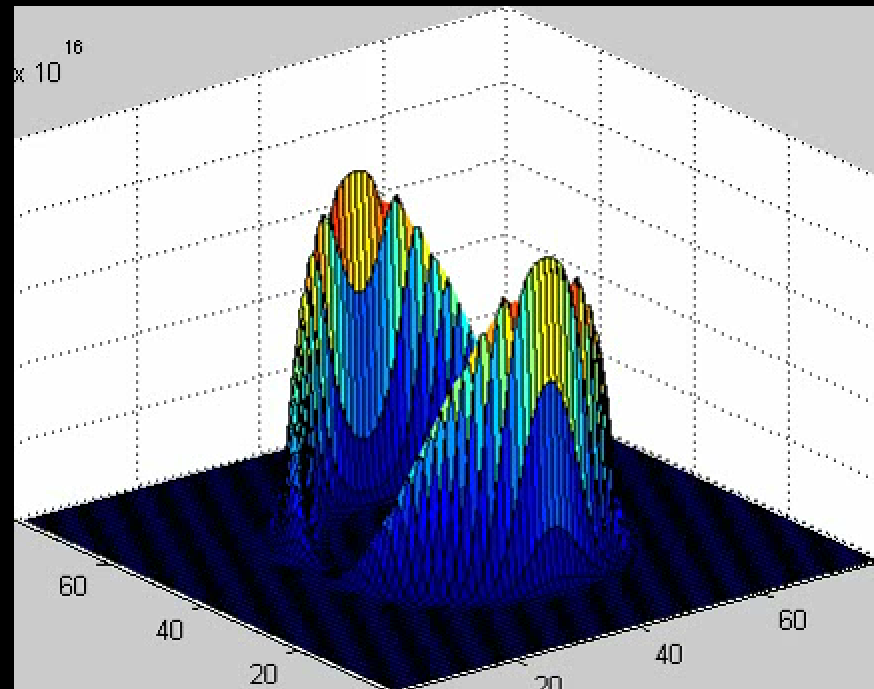
Energy density magnitude decreases →



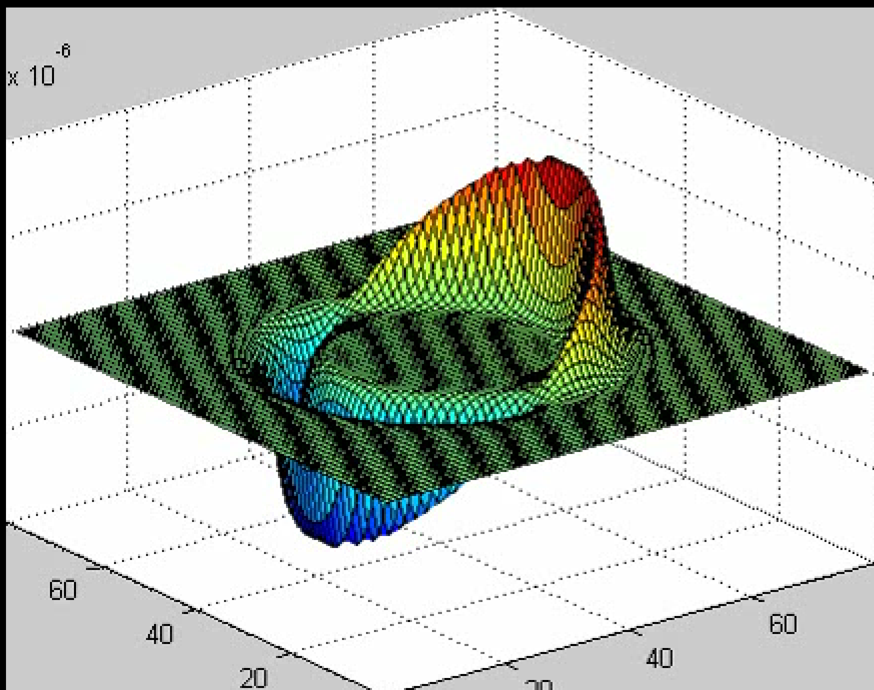
← "bubble" thickness decreases

Surface plots of York Time & T^{00}, <v>=10c, 10 meter diameter volume, variable warp "bubble" thickness

Changing topology greatly reduces the energy required



As bubble thickness increases, York Time intensity decreases



Allowing the bubble to get thicker reduces the flat space-time real-estate in the center

But space-time is really stiff: $c^4/8\pi G$

Can we further reduce the energy required by reducing the stiffness?

<u>Maybe…</u>but we need to engage higher dimensional models to do so

Higher Dimensional Models??

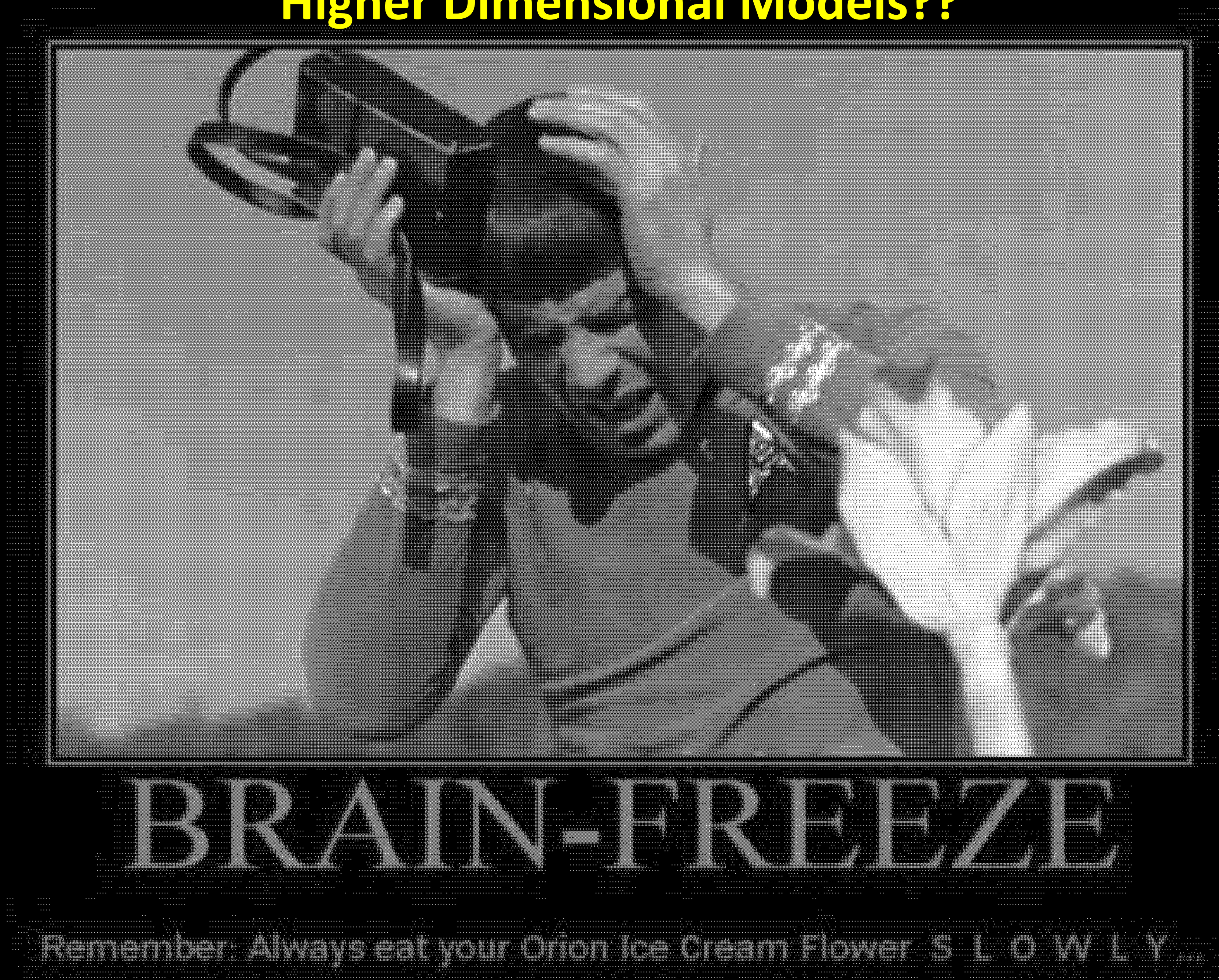


Image courtesy Paramount
Caption credit: author unknown

Brane Cosmology: Chung-Freese metric

represents the 3+1 space
(we live here or on the brane)

represents the bulk
(we live at U=0)

$$ds^2 = -c^2 dt^2 + \underbrace{\frac{a^2(t)}{e^{2kU}}}\, dX^2 + dU^2$$

a(*t*) term is the scale factor and *k* is a compactification factor for the extra space dimensions.

Null Geodesics (e.g. light rays)

If U=0, dU/dt=0, then dX/dt=1c as expected

Speed of photon in coordinate space

$$\frac{dX}{dt} = \frac{ce^{kU}}{a(t)}\sqrt{1-\frac{dU^2}{c^2 dt^2}}$$

If kU gets large, dX/dt>1 (hyperfast travel)

If dU/dt=1, dX/dt=0 (light comes to a standstill)

<u>Analogies to Alcubierre metric[1]:</u>

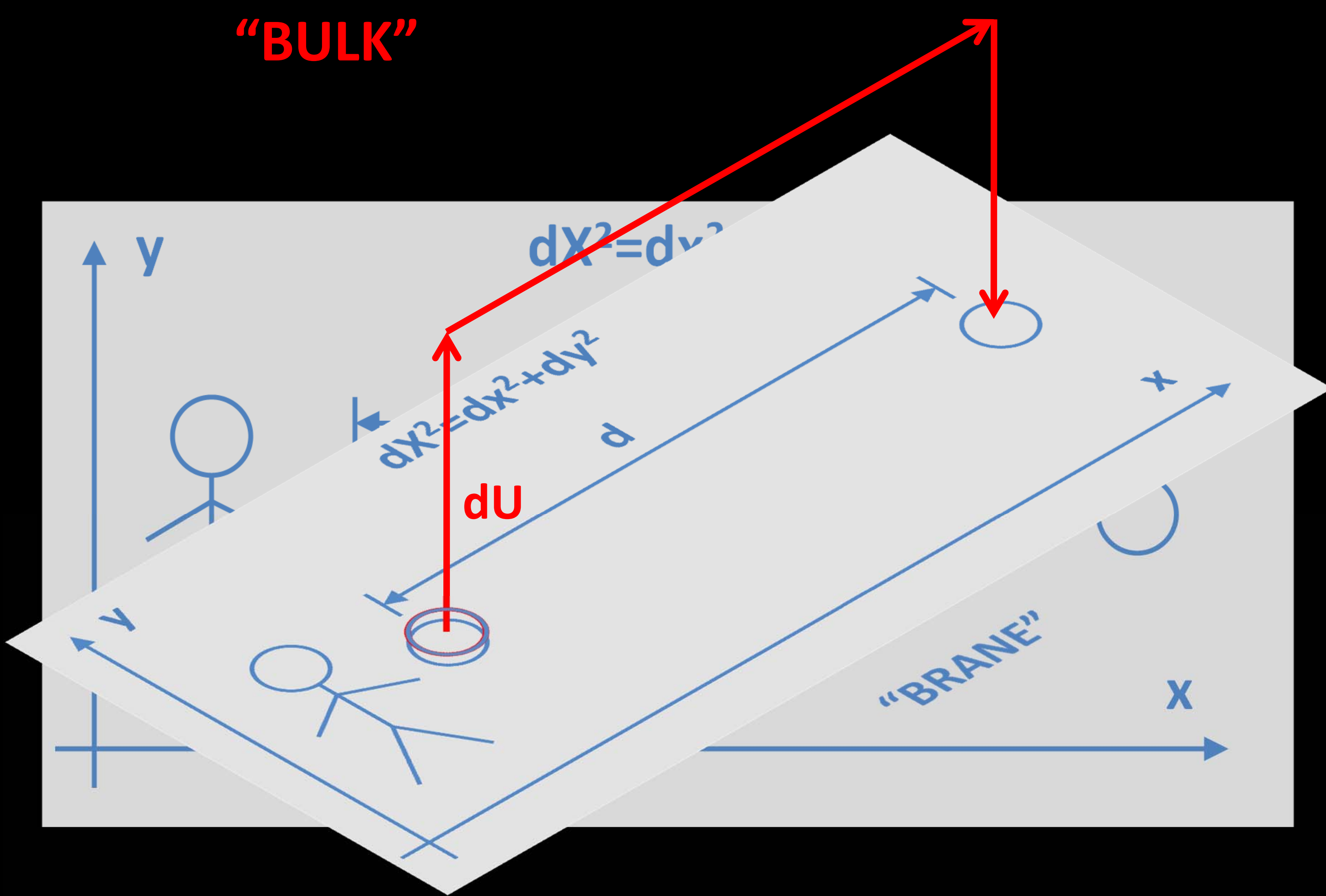
$$\gamma \approx e^{U}$$

$$\phi \approx U$$

$$\frac{d\phi}{dt} \approx \frac{dU}{dt}$$

1. White, H., Davis, E., "The Alcubierre Warp Drive in Higher Dimensional Space-time," in proceedings of Space Technology and Applications International Forum (STAIF 2006), edited by M. S. El-Genk, American Institute of Physics, Melville, New York, (2006).

2D-3D "Hyperspace" Analogy

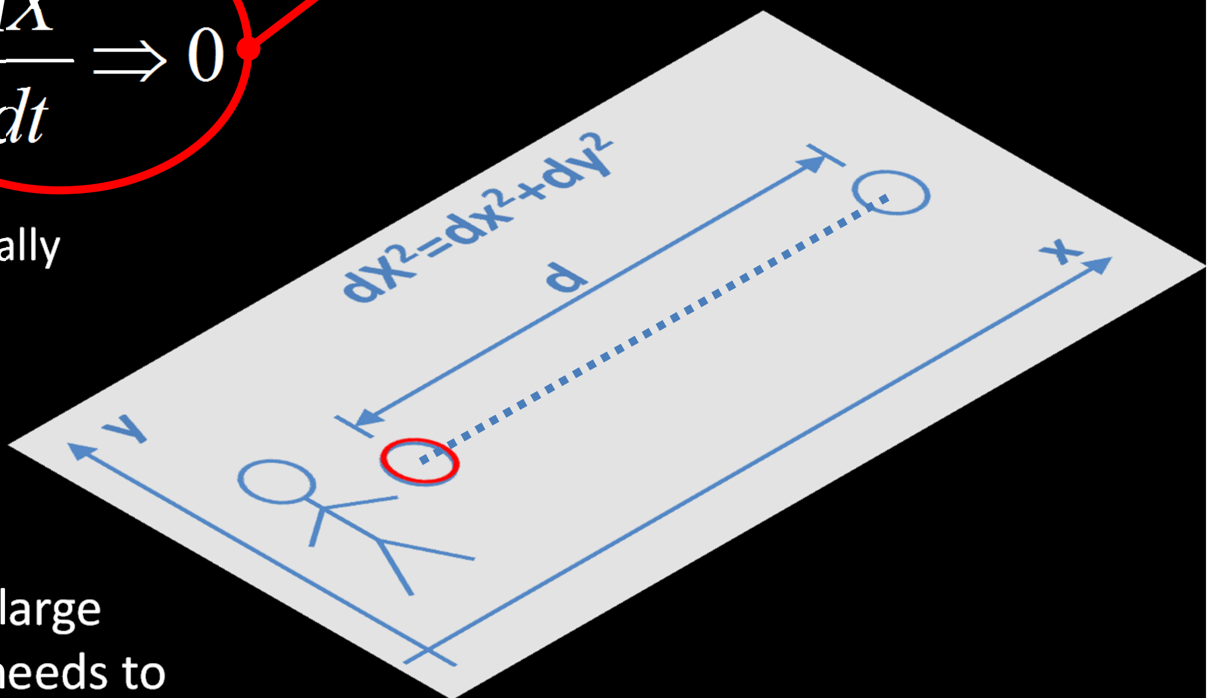


“Hyperspace” Oscillations

- Even though space-time is incredibly “stiff”, higher dimensional space-time model can be used to alleviate this using the following trick:

Reduces stiffness of spacetime!

$$\frac{dU}{dt} \Rightarrow 1, U = 0 \qquad \therefore \frac{dX}{dt} \Rightarrow 0$$

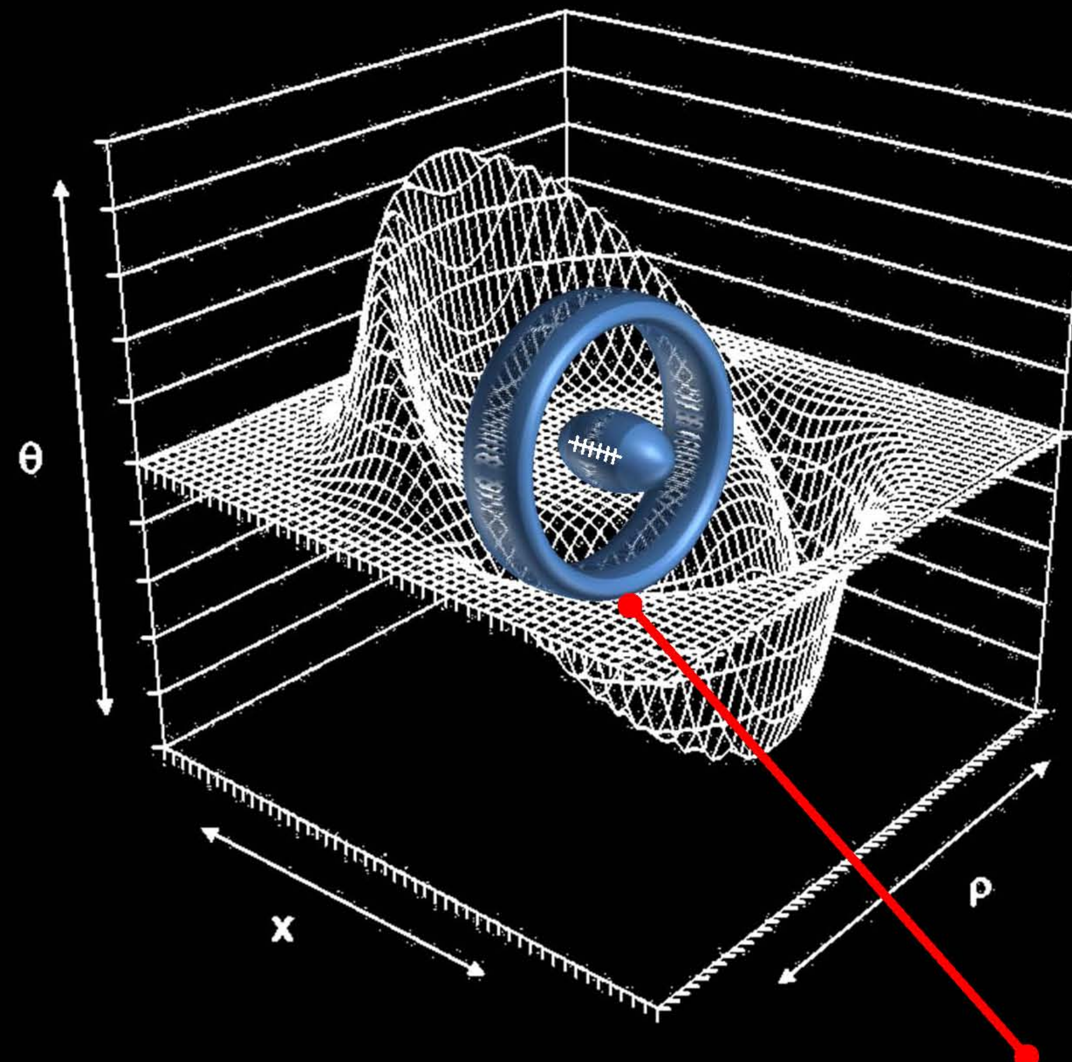


- How can this scenario be physically established?

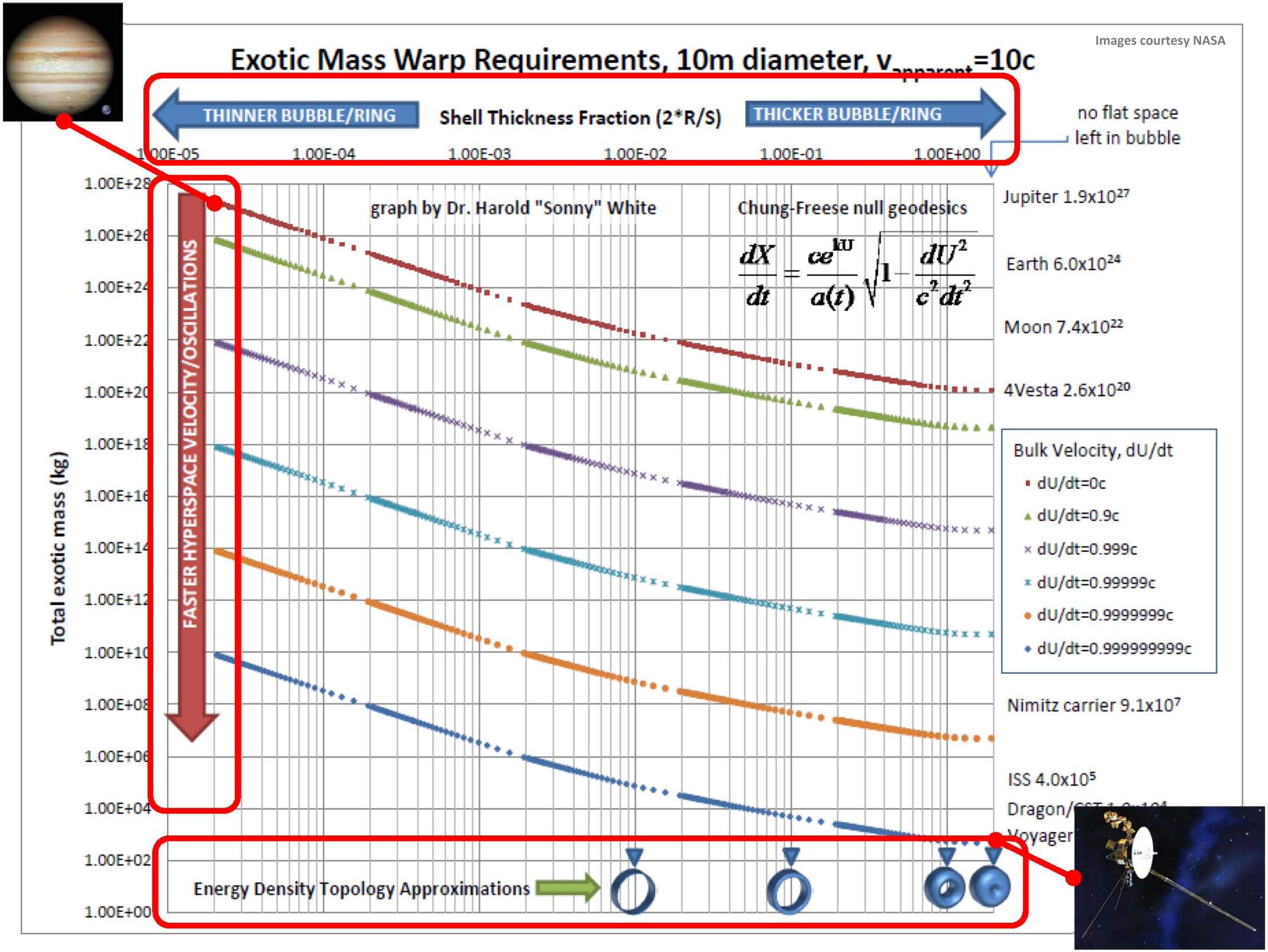
$$\frac{dU}{dt} \approx \frac{d\phi}{dt}$$

- Further, if there needs to be large *dU/dt* with *U*=0, then there needs to be **<u>oscillation</u>** in $d\phi/dt$ so this will occur repeatedly.

From Our Vantage Point…

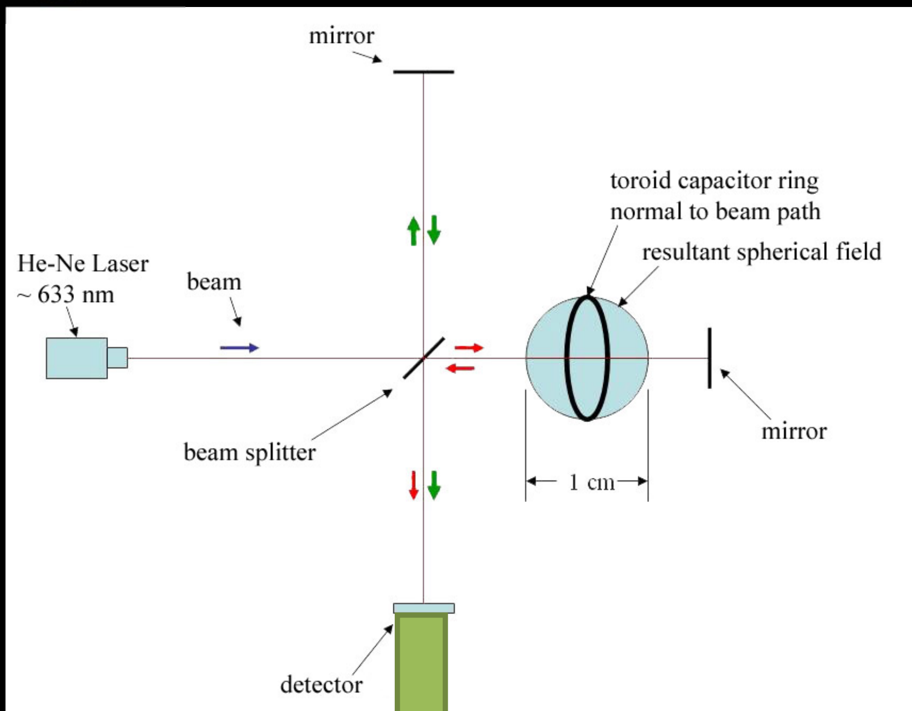


Oscillate the bubble intensity



Images courtesy NASA
Exotic Mass Warp Requirements, 10m diameter, v apparent =10c
THINNER BUBBLE/RING
Shell Thickness Fraction (2*R/S)
THICKER BUBBLE/RING
no flat space left in bubble
1.00E-05
1.00E-04
1.00E-03
1.00E-02
1.00E-01
1.00E+00
Total exotic mass (kg)
1.00E+28
1.00E+26
1.00E+24
1.00E+22
1.00E+20
1.00E+18
1.00E+16
1.00E+14
1.00E+12
1.00E+10
1.00E+08
1.00E+06
1.00E+04
1.00E+02
1.00E+00
FASTER HYPERSPACE VELOCITY/OSCILLATIONS
graph by Dr. Harold "Sonny" White
Chung-Freese null geodesics
$\frac{dX}{dt} = \frac{ce^{kU}}{a(t)}\sqrt{1-\frac{dU^2}{c^2dt^2}}$
Jupiter 1.9×10^{27}
Earth 6.0×10^{24}
Moon 7.4×10^{22}
4Vesta 2.6×10^{20}
Bulk Velocity, dU/dt
dU/dt=0c
dU/dt=0.9c
dU/dt=0.999c
dU/dt=0.99999c
dU/dt=0.9999999c
dU/dt=0.999999999c
Nimitz carrier 9.1×10^{7}
ISS 4.0×10^{5}
Dragon/
Voyager
Energy Density Topology Approximations

White-Juday Warp Field Interferometer



- White-Juday Warp Field Interferometer developed after putting metric into canonical form[1]:

$$ds^2 = \left[v_s^{\,2} f(r_s)^2 - 1\right]\left\{dt - \frac{v_s f(r_s)}{v_s^{\,2} f(r_s)^2 - 1} dx\right\}^2 - dx^2 + dy^2 + dz^2$$

- Generate microscopic warp bubble that perturbs optical index by 1 part in 10,000,000
- Induce relative phase shift between split beams that should be detectable.

$X(x,y)$

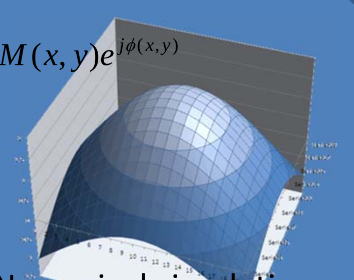
Numerical simulation of fringe at detector with device off

$X_1(x,y)$

Numerical simulation of fringe at detector with device on

2D Analytic Signal processing

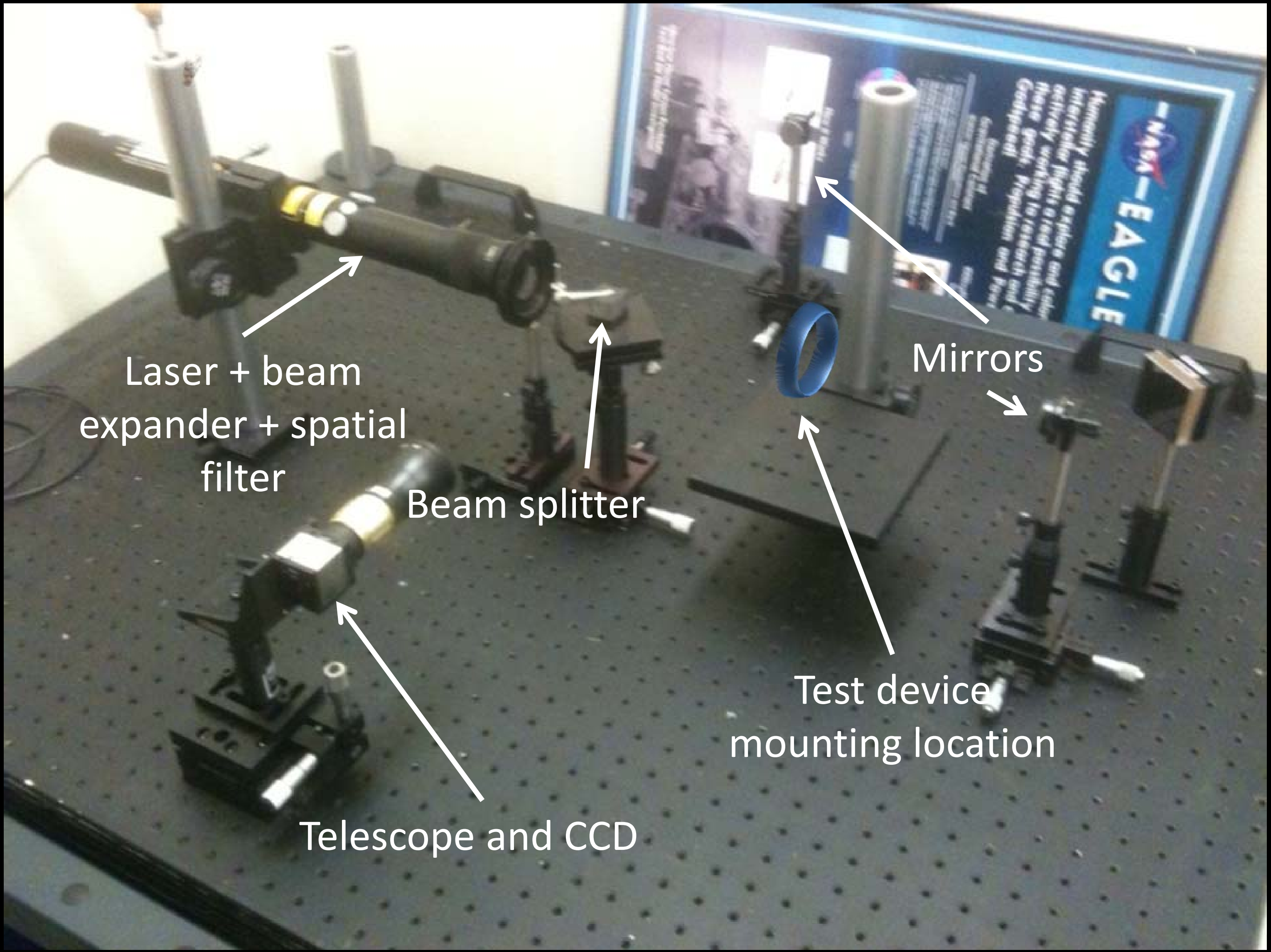
$M(x,y)e^{j\phi(x,y)}$

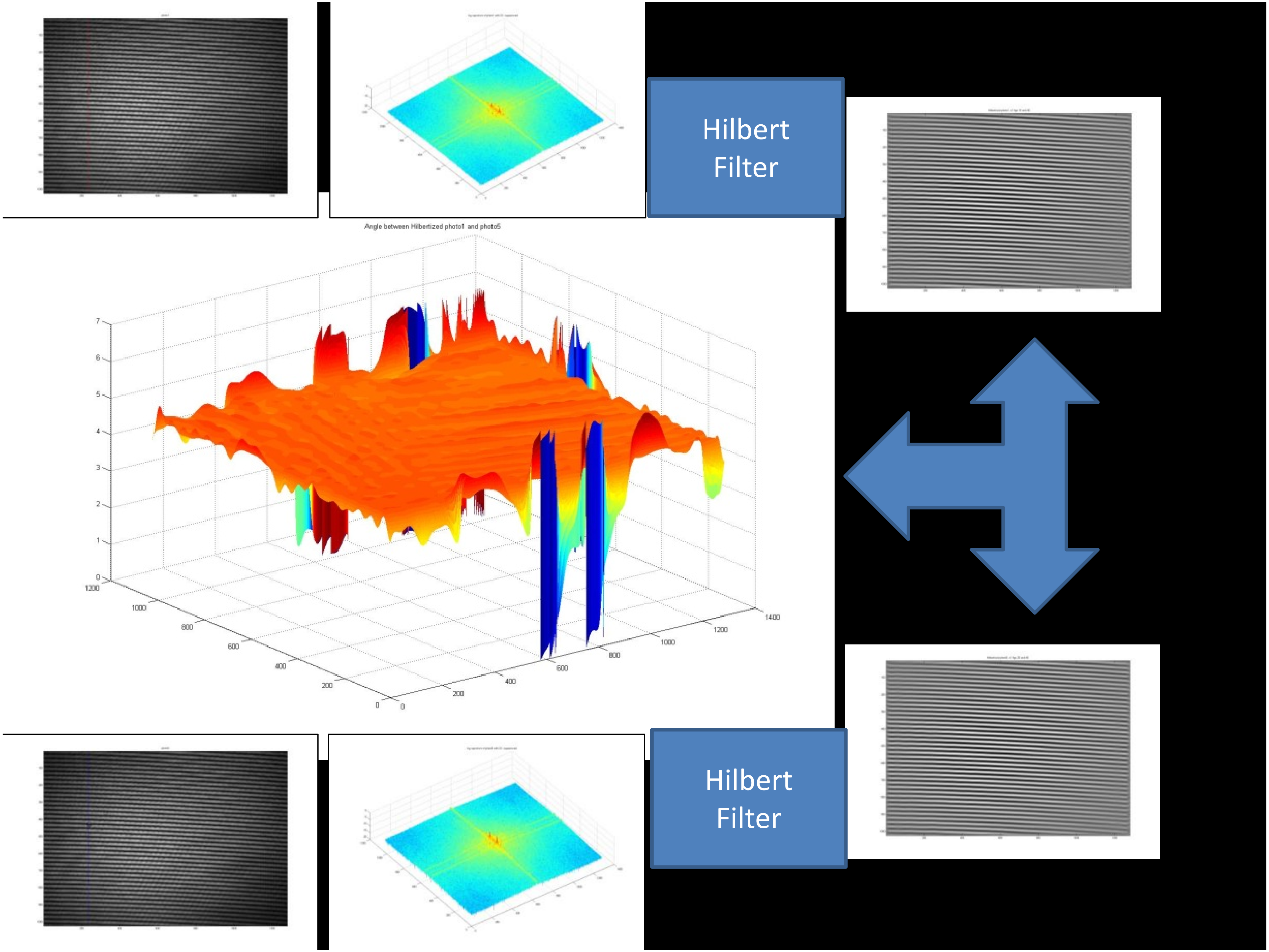


Numerical simulation of contour plot of ϕ for warp field

1. White, H., “A Discussion on space-time metric engineering,” Gen. Rel. Grav. 35, 2025-2033 (2003).

White-Juday Warp Field Interferometer



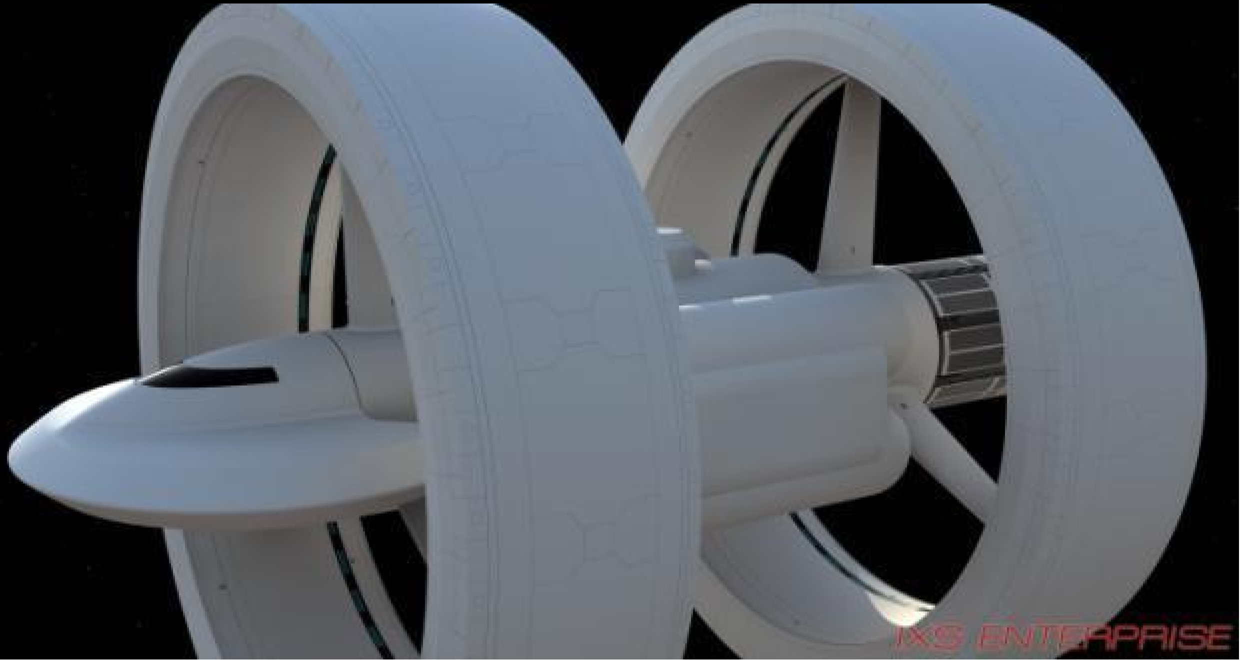

Hilbert
Filter
Angle between Hilbertized photo1 and photo5
7
6
5
4
3
2
1
0
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
1200
1400
Hilbert
Filter

Life imitating Art

Original concept design by Matthew Jeffries ~1964, modern rendering by Mark Rademaker

Draft of adapted concept using physics field equations and recent findings presented at 100YSS, also rendered by Mark Rademaker

Final version will be published along with 100YSS story in 2014 Ships Of The Line calendar




"2nd star to the right, straight on till morning…"
Godspeed!
United
Special Acknowledgements:
Amy White, Eric Davis, Richard Obousy, Paul March, David Fletcher, Richard Juday, Bill O'Neill, Ryan Valenza, Dan Nehlich, Kristen Nichols, Danny Wells, Michael Rollins, Jeff George, John Scott, Andre Sylvester, Mark McDonald, William Hoffman, Gene Grush, John Applewhite, John Brewer, Shamim Rahman, Mike Okuda, Blake Dumesnil
CD-98-76634
rendition by artist Les Bossinas found at http://www.grc.nasa.gov/WWW/bpp/BPP_Art.htm

Backups

(excerpts from Warp Field Mechanics 101)

Inflation: Alcubierre Metric

- In 1994, Alcubierre published a paper[1] exploring the consequences of inflation within the context of General Relativity.
  - Paper derived inflation-based metric allowing for rapid transit times between points without locally violating the speed of light.
  - Working mechanism was proposed to be the York Time (inflation).
  - Alcubierre metric requires a halo of negative energy density which violates several energy conditions and is considered to be classically non-physical.
- Concept of Operation
  - Spacecraft departs earth using conventional propulsion system and travels distance *d*, where spacecraft is brought to stop relative to earth.
  - Field is turned on and craft zips off to interstellar destination, never locally breaking the speed of light, but covering the distance *D* in an arbitrarily short period of time.
  - Field is turned off at standoff distance *d* from the destination, and craft finishes journey conventionally.
  - This approach would allow journey to Alpha Centauri in weeks or months, rather than decades or centuries as measured by an earth bound observer (and spacecraft clocks).

1. Alcubierre, M., "The warp drive: hyper-fast travel within general relativity," Class. Quant. Grav. 11, L73-L77 (1994).

Inflation: Alcubierre Metric

Warp Drive Metric:

$$ds^2 = -dt^2 + \left(dx - \underset{\uparrow}{v_s} f(r_s)dt\right)^2 + dy^2 + dz^2$$

Apparent speed

Shaping Function:

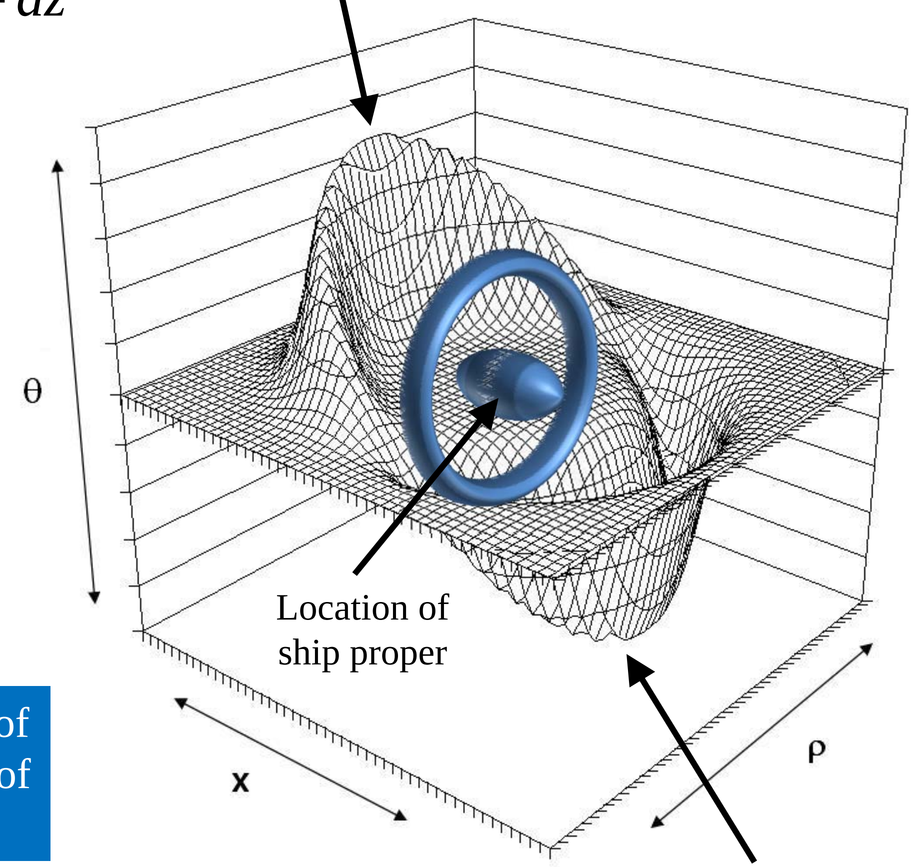
Shell thickness parameter　Shell size parameter

$$f(r_s) = \frac{\tanh\left(\sigma(r_s + R)\right) - \tanh\left(\sigma(r_s - R)\right)}{2\tanh(\sigma R)}$$

York Time:

$$\theta = v_s \frac{x_s}{r_s} \frac{df(r_s)}{dr_s}$$

York Time is measure of expansion/contraction of space



Dr. Harold “Sonny” White
09/02/2011

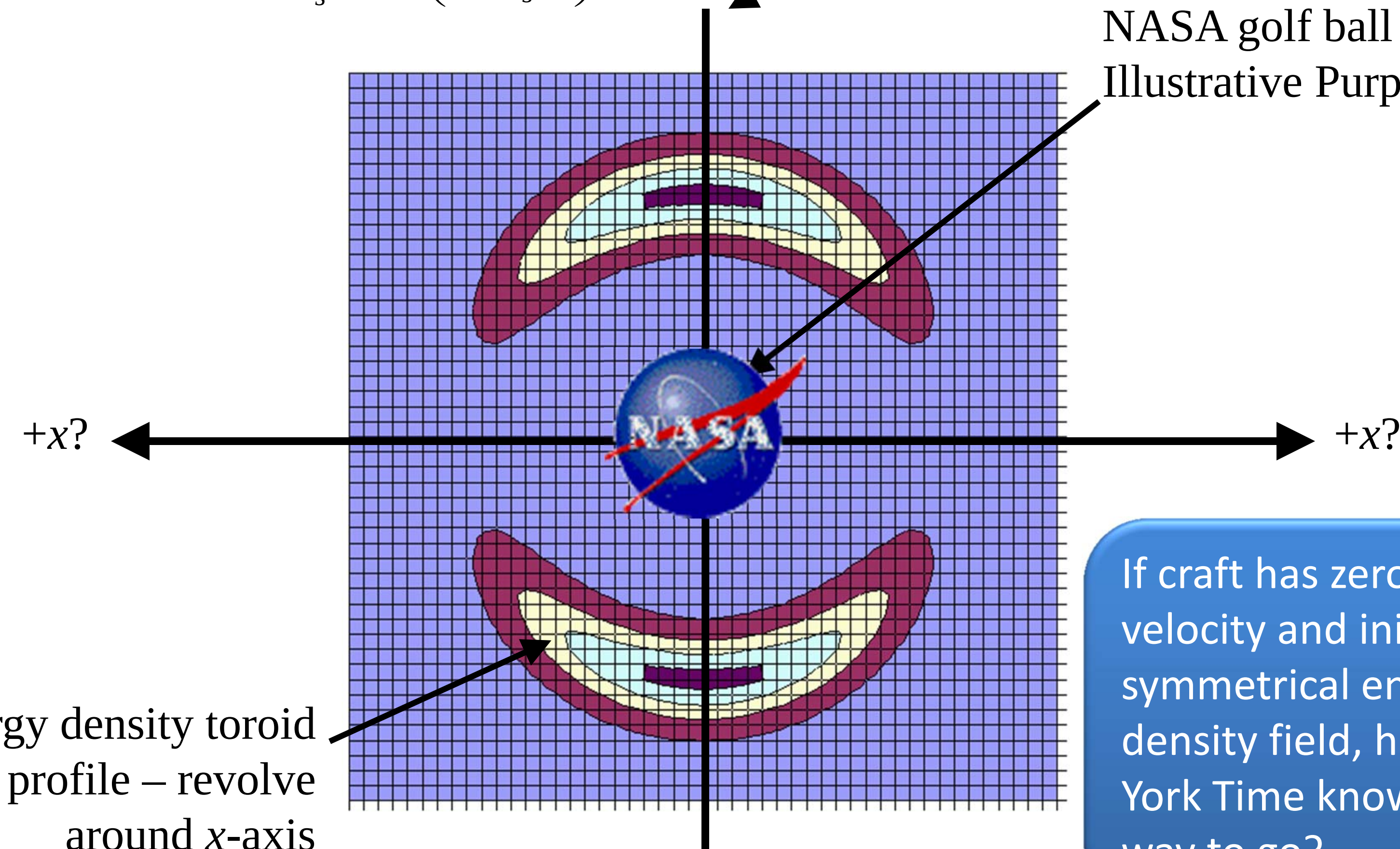
Symmetry/Asymmetry Paradox

<u>Energy Density:</u>

$$\frac{1}{8\pi}G^{00} = -\frac{1}{8\pi}\frac{v_s^2\left(y^2+z^2\right)}{4r_s^2}\left(\frac{df(r_s)}{dr_s}\right)^2$$

Symmetry Surface

Gedanken experimental NASA golf ball ship. Illustrative Purposes Only



Energy density toroid profile – revolve around *x*-axis

If craft has zero initial velocity and initiates symmetrical energy density field, how does York Time know which way to go?

Canonical Form of Alcubierre Metric

- In 2003, this author published a paper[1] that derived the canonical form of the Alcubierre metric allowing for a better understanding of the physical nature, and how it might be manifested (at least mathematically).

  – Canonical form mitigated energy density symmetry paradox and showed that working mechanism might be the boost sphere (resulting from halo) acting on initial velocity

    - e.g boost = 2, initial v = 27,500mph, apparent v = 55,000mph

  – Boost is something that can be readily engineered, while the notion of inflation is less tangible.

1. White, H., "A Discussion on space-time metric engineering," Gen. Rel. Grav. 35, 2025-2033 (2003).

Canonical Form of Alcubierre Metric

Canonical Form of Alcubierre metric:

$$ds^2 = \left[v_s^{\,2} f(r_s)^2 - 1\right]\left\{dt - \frac{v_s f(r_s)}{v_s^{\,2} f(r_s)^2 - 1} dx\right\}^2 - dx^2 + dy^2 + dz^2$$

$$ds^2 = -dt^2 + \left(dx - v_s f(r_s) dt\right)^2 + dy^2 + dz^2$$

Since the equation is now in canonical form, the boost can be derived:

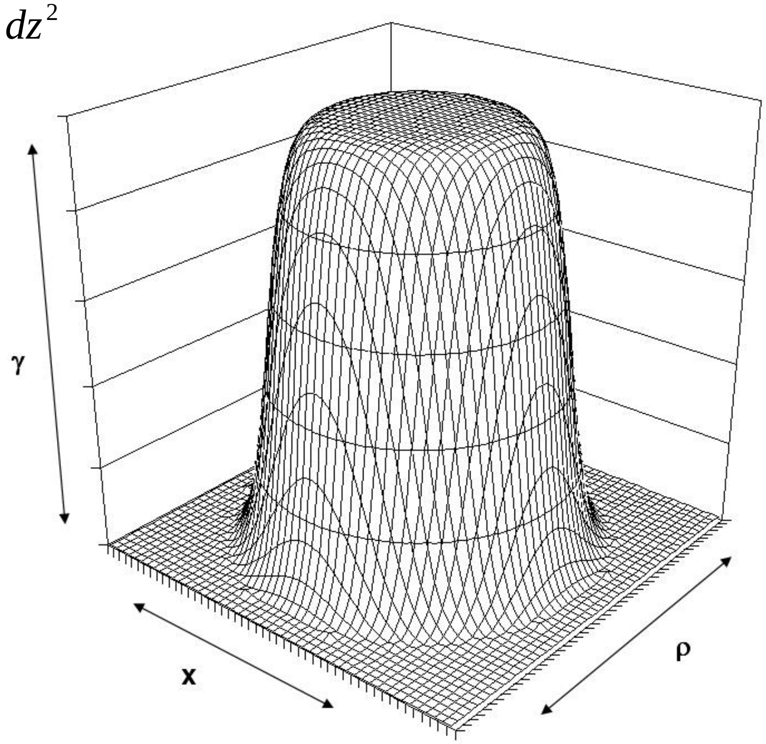
$$-e^{\frac{2\Phi}{c^2}} = \left[v_s^{\,2} f(r_s)^2 - 1\right]$$

Or taking c = 1…

$$\Phi = \frac{1}{2}\ln\left[\left|1 - v_s^{\,2} f(r_s)^2\right|\right]$$

Trivially, the Lorentz Transform or boost field is: $\gamma_\Phi = \cosh(\Phi)$

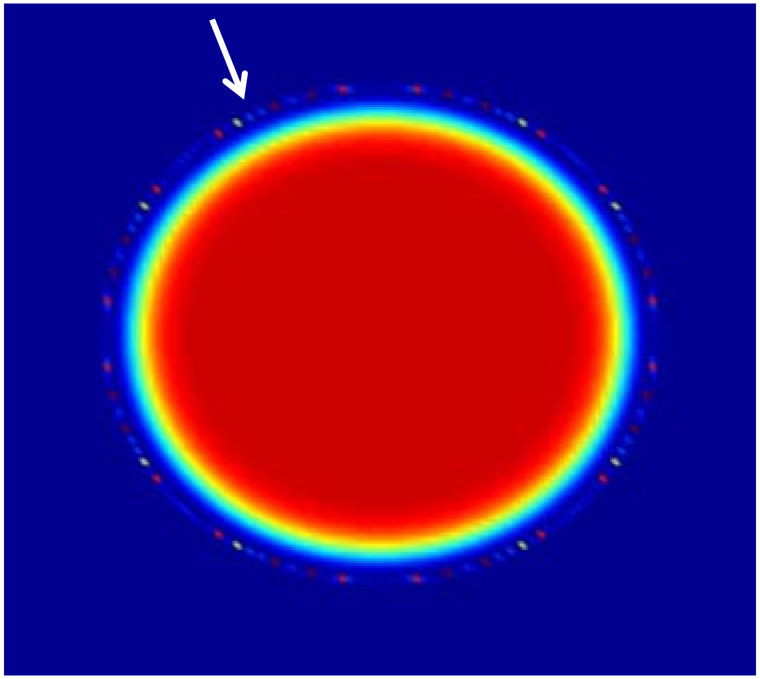
Boost Field:

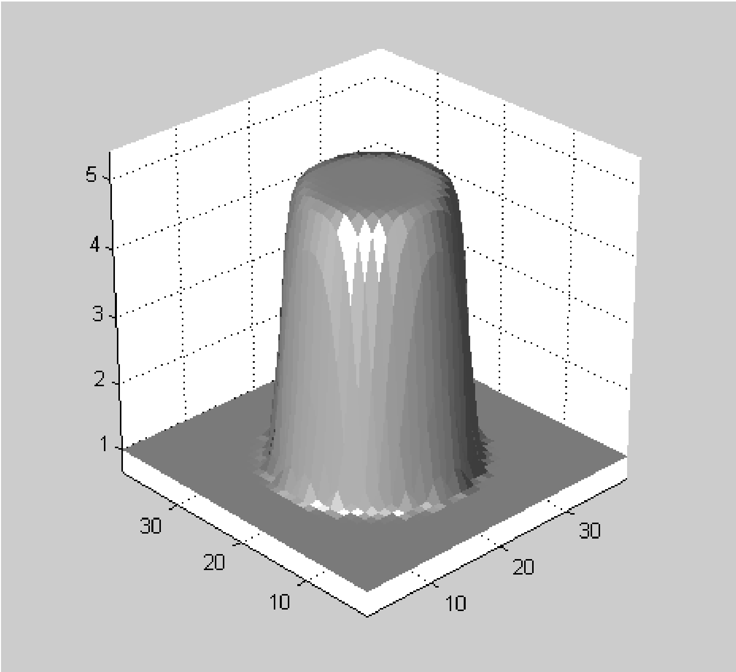


Boost Field

Surface plots of boost, <v>=10c, 10 meter diameter volume

Note pseudo-horizon surface at
$V^2 f(r_s)^2 = 1$





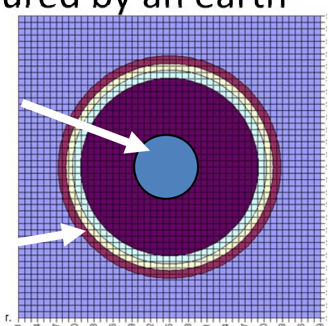
Pseudo-horizon surface not visible with larger integration step

Note pseudo-horizon at $v^2 f(r_s)^2=1$ where photons transition from null-like to space-like and back to null like upon exiting. This is not seen unless the field mesh is set fine enough. The coarse mesh on the right did not detect the horizon.

Modified Concept of Operations

- A modified concept of operations is proposed that may resolve symmetry/symmetry paradox.
- Spacecraft departs earth and establishes an initial sub-luminal velocity vi, then initiates field.
- When active, field's boost acts on initial velocity as a scalar multiplier resulting in a much higher apparent speed, $\langle v_{eff} \rangle = \gamma v_i$ as measured by either an earth bound observer or an observer in the bubble.
- Within shell thickness of the warp bubble region, the spacecraft never locally breaks the speed of light and the net effect as seen by earth/ship observers is analogous to watching a film in fast forward.
- Consider the following to help illustrate the point –
  - Assume the spacecraft heads out towards Alpha Centauri and has a conventional propulsion system capable of reaching 0.1c.
  - The spacecraft initiates a boost field with a value of 100 which acts on the initial velocity resulting in an apparent speed of 10c.
  - The spacecraft will make it to Alpha Centauri in 0.43 years as measured by an earth observer

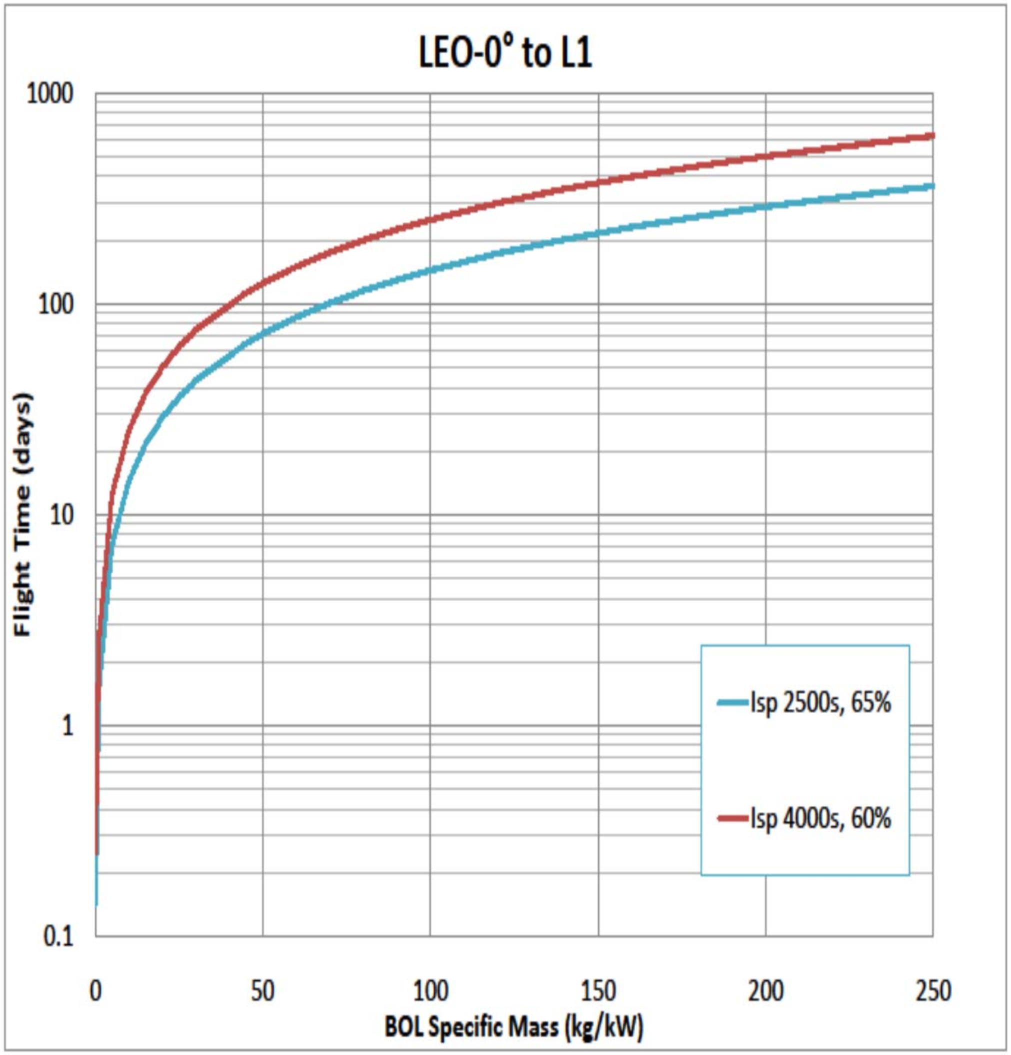
Gedanken experimental NASA golf ball ship.



Boost Shell

Cis-lunar Mission Planning

- To this point, discussion has been centered on interstellar capability , but a more “domestic” application within the earth’s gravitational well will be considered.
- Energy density for metric is negative, so process of turning on a theoretical system with ability to generate negative energy density, or a negative pressure as shown in [1], will add an effective negative mass to the spacecraft’s overall mass budget.
- In reference mission development using low-thrust electric propulsion systems for in-space propulsion, planners will cast part of trade space into domain that compares specific mass a to transit time. (see LEO to L1 inset)
- Specific mass of an architecture element can be determined by dividing spacecraft’s beginning of life wet mass by the power level.
- Transit time for a mission trajectory can be calculated and plotted on graph that compares specific mass to transit time.
- If negative mass is added to spacecraft’s mass budget, then the effective specific mass and transit time are reduced without necessarily reducing payload.
- A question to pose is what effect does this have mathematically? If energy is to be conserved, then ½ mv^2 would need to yield a higher *effective* velocity to compensate for apparent reduction in mass.



EXAMPLE:

- Assuming a point design solution of 5000kg BOL mass coupled to a 100kW Hall thruster system (lower curve), expected transit time is ~70 days for a specific mass of 50 kg/kW without the aid of a warp drive.
- If a very modest warp drive system is installed that can generate a negative energy density that integrates to ~2000kg of negative mass when active, the specific mass is dropped from 50 to 30 which yields a reduced transit time of ~40 days.
- As the amount of negative mass approaches 5000 kg, the specific mass of the spacecraft approaches zero, and the transit time becomes exceedingly small, approaching zero in the limit.
- In this simplified context, the idea of a warp drive may have some fruitful domestic applications “subliminally,” allowing it to be matured before it is engaged as a true interstellar drive system.

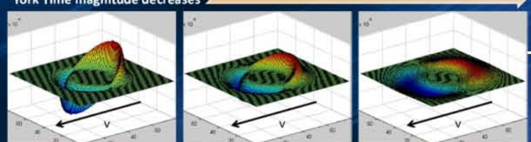
1. White, H., Davis, E., “The Alcubierre Warp Drive in Higher Dimensional Space-time,” in proceedings of Space Technology and Applications International Forum (STAIF 2006), edited by M. S. El-Genk, American Institute of Physics, Melville, New York, (2006).

EAGLEWORKS LABORATORIES

How hard is interstellar flight? Consider this: The Voyager 1 spacecraft is the highest energy spacecraft launched by humanity to date, yet it will take ~75,000 years to reach our nearest stellar neighbor, Proxima Centauri. To explore and expand, another way must be found by actively pursuing exotic propulsion research to help us reach the stars.

WARP THEORY

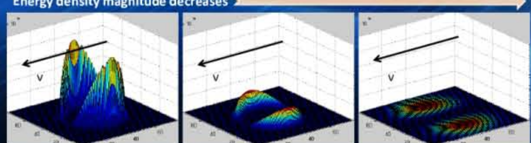
York Time magnitude decreases



"bubble" thickness decreases

Surface plots of York Time, <v>=10c, 10 meter diameter volume, variable warp "bubble" thickness

Energy density magnitude decreases

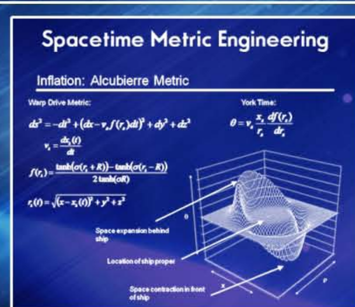


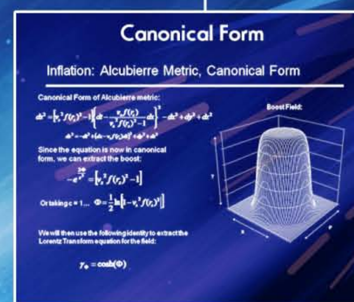
"bubble" thickness decreases

Surface plots of T^{00}, <v>=10c, 10 meter diameter volume, variable warp "bubble" thickness

Energy Density:

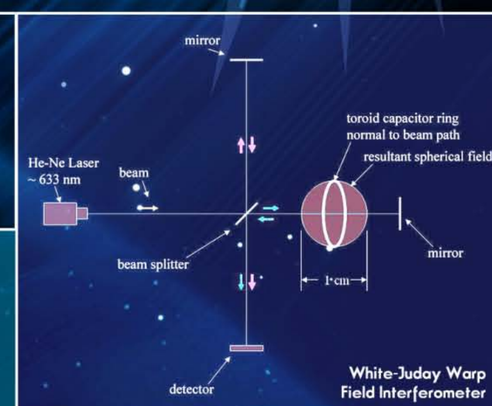
$$\frac{1}{8\pi}G^{00} = -\frac{1}{8\pi}\frac{v_s^2\left(y^2+z^2\right)}{4r_s^2}\left(\frac{df(r_s)}{dr_s}\right)^2$$





White-Juday Warp Field Interferometer

1. White, H., "A Discussion on space-time metric engineering." Gen. Rel. Grav. 35, 2025-2033 (2003).



The Warp Field Interferometer will bridge the gap between speculative and experimental by continuing open discussion and collaboration and by actively pursuing opportunities to research and test the very limit of our understanding of the universe.