Eagleworks Laboratories
WARP FIELD PHYSICS

Dr. Harold “Sonny” White
NASA JSC
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)?

WORMHOLES
(shortcuts)

SPACEWARPS
(inflation)

Images courtesy NASA
**Inflation: Alcubierre Metric**

**Warp Metric:**

\[ ds^2 = -dt^2 + (dx - v_s f(r_s) dt)^2 + dy^2 + dz^2 \]

**Shaping Function:**

\[ f(r_s) = \frac{\tanh(\sigma(r_s + R)) - \tanh(\sigma(r_s - R))}{2 \tanh(\sigma R)} \]

**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:**

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

York Time magnitude 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
Bubble Oscillation Optimization

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

\[ \frac{dX}{dt} = \frac{ce^{kU}}{a(t)} \left(1 - \frac{dU^2}{c^2 dt^2}\right)^{1/2} \]

\[ \frac{dU}{dt} \Rightarrow 1, U = 0 \quad \therefore \quad \frac{dX}{dt} \Rightarrow 0 \]

\[ \gamma \approx e^U \quad \phi \approx U \quad \frac{d\phi}{dt} \approx \frac{dU}{dt} \]

Oscillate the bubble intensity
Exotic Mass Warp Requirements, 10m diameter, $v_{\text{apparent}}=10c$

Shell Thickness Fraction ($2R/S$)

Chung-Freese null geodesics

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

Images courtesy NASA

Jupiter $1.9 \times 10^{27}$

Earth $6.0 \times 10^{24}$

Moon $7.4 \times 10^{22}$

4Vesta $2.6 \times 10^{20}$

Nimitz carrier $9.1 \times 10^{7}$

ISS $4.0 \times 10^{5}$

Dragon/Voyager
Warp Field Interferometer

- 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.

Warp Bubble Detection Attempts Using Interferometry

• Goal is to use interferometer to detect and measure effect of warp bubble on optical path length through the measurement of associated interference fringe shifts.

• The EWL has attempted to mitigate the effect of vibrations & air currents
  – Using a vibration-isolated optical table
  – Using a vibration-isolated room
  – Using an optical hood
  – Using signal processing to increase signal to noise ratio
  – Collecting statistical data to increase signal to noise ratio
Interferometer and Test-article Setup

- High-voltage power supply
- Low-voltage power supply
- Test article
- Along-axis mirror
- Off-axis mirror
- Beam splitter
- Imager
- 2 Polarizers (jointly used for intensity control)
- Laser
- Iris
- Computer for interference image capture and test article power cycling
SINGLE PATCH

INTERFEROMETER MODAL ANALYSIS, ANALYTIC SIGNAL VARIATION
Interferometer Modal Analysis: Synthetic Data

- A set of 1000 synthetic interferogram fringe patterns were generated as JPEG image frames
  - Set contained repeating sequence of 10 frames with sinusoidal shifting in time with a shifting amplitude of $1/10$ of a spatial radian.
  - No noise added to the shifting (i.e. unwanted vibrations not included)
  - Gray scale intensity sampled at upper left pixel and a Discrete Fourier Transform (DFT) calculated for the sample train.
  - Very strong peak observed at $1/5$ Nyquist frequency as expected, and of course, no noise spectrum.

2 fringe patterns out of set of 1000, showing maximum shift amplitude (In this case, the fringe pattern on the right is shifted about 1 radian up and to the left compared to the fringe pattern on the left.)

Conclusion: Small, repetitive shifts in fringe lines can be easily detected with a temporal DFT approach.
Modal Analysis: Analytic Signal Variation, Single Patch

Calculate DFT of this 128x128 region centered at arrow tip.

The result is an array of complex values, called the analytic signal. Use the complex value at the center and calculate the “phase”. Repeat for all of the captured frames and store the representative phase values as a 1D series.

Now, set all DFT coefficients to zero except for this small region around this peak corresponding to the fringe lines, and inverse transform.

2D DFT of the dashed region
Single Patch Modal Analysis, always off

Test Article Off

Magnitude Spectrum of Phase Series
Single Patch Modal Analysis, cycled on/off

- Test article cycled on and off at .25 Hz, and associated fringe images frame sampled at 2.5 Hz for 3149 samples.
- Any effect should show up at frequency 315.
- Nothing around that frequency stands out above the noise for this run.
- No evidence that the test article caused fringes to shift at this measurement precision.
- Concern that single patch may not sample enough of image, so subsequent effort done to sample across image.

Magnitude Spectrum of Phase Series
MULTIPLE SAMPLE POSITIONS

INTERFEROMETER MODAL ANALYSIS, ANALYTIC SIGNAL VARIATION
Description of Work

- Room and table were floating
- Optical hood covering table
- Test article cycled on every 4 seconds
- Frames captured every 0.4 seconds
- 3149 frames processed
- Sampling occurred at 88 positions in image plane
- At each pixel sampled (through 3149 frames), the sample train was Fourier transformed, and the magnitude spectrum reviewed (see next slides)
Test Article Off

Magnitude Spectrum of Phase Series

![Magnitude Spectrum of Phase Series](image)

- **X-axis**: Frequency
- **Y-axis**: Magnitude

The graph shows a sharp drop in magnitude at a specific frequency, indicating a significant change in the phase series.
Test Article Cycled every 4 Sec (2 sec @ 20KV, 2 sec off)

Are these bumps actual differences w.r.t. test article “off”?  
- Or are they always present, but affected differently by noise between runs?
Close up (cycled)
Air Dielectric in Beam Path

- Cap ring replaced with high-voltage device "Ozona" such that the charge collection sphere partially blocked the interferometer beam in the leg along the laser axis.
- High voltage source was cycled on and off in 2 second intervals.
- The screen capture was operating at a rate of 0.4 sec per frame.
- The optics table was floating but not the room.
- The optics table was not covered.
- HV source power strip was on the micro flat table next to the interferometer table.
HV Power Supply Off
HV Power Supply Cycled @ 2 second Intervals

Nyquist Frequency/5:
73.9 - Where we might expect to observe the effect.

This peak is at 74.4 if we use the 0-100 rulings as a scale bar. May just be noise.  
Nyquist Frequency: 369.5
DAN NEHLICH, SOUTH DAKOTA STATE UNIVERSITY

INTERFEROMETRY MEASUREMENTS OF A DC TOROIDAL CAPACITOR
SDSU Interferometer Setup

Warp Field Interferometer

DC Toroidal Capacitor Test Article

Interference Pattern
Image Subtraction Approach

• Positing that aberrations may include fringe pattern shifting in addition to or instead of induced curvature in the patterns, image subtraction was used to determine possible correlations to the voltage differential.
  – This method treats each image as an array and subtracts that array from the preceding, resulting in an image representative of the shift that occurred.
  – Average intensity of each subtracted image is calculated and statistical comparison is performed.
  – Statistical analysis of mean intensity values of each subtracted image, showed the observed shifts tended to increase during charge/discharge cycles, and remain constant in the control runs.

• The data presented in these scatter plots represents 2200 unique data points for charge/discharge cycles at 19 kV.
• Each point plotted represents approximately 20 images taken at the same point of the cycle, yielding an average intensity for each point in time along the graph.
Control, Charge, Discharge Scatter Plots

Figure 6: Image Subtraction during Test Article Charge Cycle from 0 V to 19 kV

Figure 7: Image Subtraction with no charge/dischare present

Figure 8: Image Subtraction during Test Article Discharge Cycle from 19 kV to 0 V
Hough Transform Approach

- In order to establish a direction of fringe pattern shifting, edge detection algorithms were necessary to determine individual line locations.

- The Hough Transform, along with the associated houghpeaks and houghlines functions in Matlab, was utilized to this end.

- An algorithm was written to utilize the edge mapping function of the transform, determine the distance of each line to the origin (normal to the fringe orientation) and then sort and weight the data to provide the relevant fringe locations for analysis.

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Average Shift (pixels/frame)</th>
<th>St. Dev.</th>
<th>Average Shift -limited (pixels/frame)</th>
<th>St. Dev.</th>
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Average Shifts of Interference Pattern
ENHANCED WARP FIELD PHYSICS EXPERIMENTS

IMAGE AVERAGING, FABRY-PEROT INTERFEROMETER, & TIME OF FLIGHT
Fabry-Perot Warp Field Interferometer

- Consists of two reflecting, highly parallel surfaces, called an Etalon
- The interference pattern is created within the Etalon
- Multiple reflections in the Etalon reinforce the areas where constructive and destructive interference occurs
- Allows for much higher-precision measurements of fringes (image averaging without software)

Example: Michelson-Morley Interferometer image for Sodium source

Example: Fabry-Perot Interferometer image for Sodium source (note doublet)
Fabry-Perot Experiment

He-Ne Laser

SA-210 Scanning Fabry-Perot Interferometer
Time of Flight Schematic

Newport Broadband Amplitude Modulator
- Model: 4102NF
- Type: Broadband Amplitude Modulator
- Operating Frequency: DC-200 MHz
- Wavelength Range: 500-900 nm
- Material: MgO:LiNbO$_3$
- Maximum $V_\pi$: 195 V @ 633 nm
- Maximum Input Power: 2 W/mm$^2$ @ 532 nm
- Aperture Diameter: 2 mm
- RF Bandwidth: 200 MHz
- RF Connector: SMA
- Input Impedance: 10 pF
- Maximum RF Power: 10 W
- Connector: SMA

Thorlabs High-Speed Avalanche Detector
- Model: APD210
- Rise Time: 0.5 ns
- Supply Voltage: +12 to +15 V
- Current Consumption: 200 mA
- Max. Incident Power: 10 mW
- Spectral Range: 400 – 1000 nm
- Frequency Range: 1-1600 MHz
- Maximum Gain: 2.5x10$^5$ V/W

Agilent Technologies Infiniium DSO9254A 2.5 GHz Oscilloscope
- 2.5 GHz bandwidth across all 4 analog channels
- 20 GSa/s max. sample rate
- Standard 20 Mpts memory per channel, upgradeable to 1 Gpts
Time of Flight Experiment
Forward Plan

• DC Toroidal Capacitor Approach:
  – Work with larger sample sets to decrease effects of vibrational “noise”, and develop test articles with longer regions of optical influence to increase the signal.
  – Utilize image averaging algorithms to increase fidelity of interference information.
  – Utilize the Fabry-Perot Interferometer to increase the sensitivity of the experimental apparatus to below 1/100 of a wavelength.

• Explore the $d\phi/dt$ dependency in future test devices
  – The idea of an optimized space warp needs negative vacuum energy, and large $d\phi/dt$ - both of these conditions are present in the q-thruster technology also being explored in the lab.
  – Use the q-thruster physics models to guide design of RF frequency test devices to be evaluated in the warp field interferometer, the Fabry-Perot Interferometer, and the time of flight experiment.
Q-Thruster

- **Q-thrusters** are a low-TRL form of electric propulsion that operates on the principle of pushing off of the quantum vacuum.

- A terrestrial analog to this is to consider how a submarine uses its propeller to push a column of water in one direction, while the sub recoils in the other to conserve momentum – the submarine does not carry a “tank” of sea water to be used as propellant.

- In our case, we use the tools of Magnetohydrodynamics (MHD) to show how the thruster pushes off of the quantum vacuum which can be thought of as a sea of virtual particles - principally electrons and positrons that pop into and out of existence, and where fields are stronger, there are more virtual particles.

- The idea of pushing off the quantum vacuum has been in the technical literature for a few decades, but to date, the obstacle has been the magnitude of the predicted thrust which has been derived analytically to be very small, and therefore not likely to be useful for human spaceflight.

- Our recent theoretical model development and test data suggests that we can greatly increase the magnitude of the negative pressure of the quantum vacuum and generate a specific force such that technology based on this approach can be competitive for in-space propulsion (~0.1N/kW), and possibly for terrestrial applications (~10N/kW).

- As an additional validation of the approach, the theory allows calculation of physics constants from first principles: Gravitational constant, Planck constant, Bohr radius, dark energy fraction, electron mass.
Q-thruster Physics Data

What we suspect:

- A variety of industry experiments, for which theory is lacking, may be Q-thrusters including Boeing, Lockheed-Martin, EM Drive, Cannae, etc.
- Low measured thrust but specific power ranges from 0.3 to 10+ N/KW
Q-thruster Roadmap

~10N/kW
High altitude, high speed aircraft
Lox, LCH4 fed turbines power banks of q-thrusters
High thrust, high Isp spacelift (2000s effective specific impulse)

~0.1N/kW
In-space Space-lift Aero
Blimp Test
Orbit transfer
Deep Space Exploration

In-space
ISS Free Flyer COTS Free Flyer Class D Mission
Space Tugs
Outer solar system exploration & beyond

Fast Mars missions
POSSIBLE MISSIONS TO MARS, THE OUTER SOLAR SYSTEM, AND BEYOND WITH Q-THRUSTERS
Mars

- 90t spacecraft
- 2MW power
- 0.4N/kW (800N)
- 246 day mission with 70 day stay at Mars

- 90t spacecraft
- 2MW power
- 4N/kW (8000N)
- 140 day mission with 90 day stay at Mars
Jupiter

0.4 N/kW
194 days

4 N/kW
61 days

- 90t spacecraft
  - 50t cargo, 20t power, 20t propulsion
- 2MW power
Saturn

0.4 N/kW
263 days

4 N/kW
86 days

- 90t spacecraft
  - 50t cargo, 20t power, 20t propulsion
- 2MW power
Uranus

0.4 N/kW
399 days

4 N/kW
129 days

- 90t spacecraft
  - 50t cargo, 20t power, 20t propulsion
- 2MW power
Neptune

- 0.4 N/kW
- 492 days

- 4 N/kW
- 160 days

- 90t spacecraft
  - 50t cargo, 20t power, 20t propulsion
- 2MW power
Pluto

0.4 N/kW
518 days

4 N/kW
167 days

- 90t spacecraft
  - 50t cargo, 20t power, 20t propulsion
- 2MW power
$0.4 \text{ N/kW}$

$5.6 \text{ years}$

$4 \text{ N/kW}$

$1.8 \text{ years}$

- $90t$ spacecraft
- 50t cargo, 20t power, 20t propulsion
- $2\text{MW}$ power
PROXIMA CENTAURI

0.4 N/kW
122.5 years

4 N/kW
29.9 years

- 90t spacecraft
  - 50t cargo, 20t power, 20t propulsion
- 2MW power
Matthew Jeffries is the artist that created the familiar Star Trek enterprise look.
Updated concept based on Dr. White’s theoretical findings, rendered by Mark Rademaker with artwork and inputs from Mike Okuda
Updated concept based on Dr. White’s theoretical findings, rendered by Mark Rademaker with artwork and inputs from Mike Okuda
**Warp Field Physics Vision**

- **Reduced transit times for impulsive trajectories** (Velocity boost)
- **Fast Mars**
- **Fast Outer Solar System**
- **1,000 - 100,000 AU**
  - Interstellar Precursors
- **> 270,000 AU**
  - Rapid Interstellar

**TERRESTRIAL PHASE**

- **0.1 AU**

**AU**

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<th>AU</th>
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<th>#NPGs</th>
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<tr>
<td>0.1</td>
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**Interferometer**

(Altered optics properties of space-time)
GODSPEED!
Principles of Q-thruster Operation

- Local mass concentrations, say in the form of a conventional capacitor with a ceramic dielectric, affect vacuum fluctuation density according to equation 1

\[
\rho_{v\_local} = \rho_v \sqrt{\frac{\rho_{m\_local}}{\rho_v}} = \sqrt{\rho_{m\_local} \rho_v}
\]  
(1)

- Just as relativistic acceleration (Unruh radiation) can change the apparent relative density of the vacuum, so too can higher order derivatives according to equation 2.

\[
\delta \rho = \frac{1}{4\pi G} \left[ -\frac{1}{a^2} \left( \frac{da}{dt} \right)^2 + \frac{1}{a} \frac{d^2 a}{dt^2} \right]
\]

\[
\delta \rho = \frac{1}{4\pi G} \left( \frac{1}{\phi^2} \left( \frac{d\phi}{dt} \right)^2 - \frac{1}{\phi} \frac{d^2 \phi}{dt^2} \right)
\]

(2)

- The tools of MagnetoHydroDynamics (MHD) can be used to model this modified vacuum fluctuation density analogous to how conventional forms of electric propulsion model propellant behavior.
• Consider the following thought experiment: what would an inertial observer in deep space find if the dark energy density were to be integrated over the light horizon of the observable universe, \(~13.7\) billion light years?

• Starting with the Friedman Equation (and after some manipulation), the following equation can be derived that formally captures the results of this thought experiment:

\[
\frac{2}{3} \rho_0 c^2 4\pi c^2 t_H^2 = \frac{c^4}{G}
\]

- Using \(9.9 \times 10^{-27}\) kg/m\(^3\) [2] with \(t_H\) of 13.7 billion years yields a predicted value for the gravitational constant of \(6.45 \times 10^{-11}\) m\(^3\)/kg\(\cdot\)s\(^2\).

- A possible physical meaning to this rearranged equation solved for \(G\) is that gravitation is an emergent phenomenon rather than a fundamental force.

- To be specific, the claim could be made that the gravitational coupling constant may be a long wavelength consequence \((\lambda = c t_H)\) of dark energy.
Bohr Radius

- The vacuum perturbation equation just derived can be used to evaluate the state of the quantum vacuum in close proximity of the proton at the center of the Hydrogen atom.

- The first step is to calculate a quasi-classical density for the hydrogen nucleus. The radius of the hydrogen atom nucleus is given as \( R_0 = 1.2 \times 10^{-15} \text{m} \) (\( R = R_0 \cdot A^{1/3} \) where \( R_0 = 1.2 \times 10^{-15} \text{m} \) and \( A \) is the atomic number - these are experimentally determined by electron scattering).

- The radius can be used with the mass of a proton to calculate a quasi-classical density of the hydrogen nucleus:

\[
\rho_m = \frac{m_p}{\frac{4}{3} \pi R_0^3} = 2.31 \times 10^{17} \frac{\text{kg}}{\text{m}^3}
\]

- Using \( \rho_v = 2/3 \times 9.9 \times 10^{-27} \text{kg/m}^3 \), along with this quasi-classical density \( \rho_m \), the perturbed negative pressure state of the quantum vacuum around the hydrogen nucleus is calculated to be:

\[
\rho_{v\_local} = \sqrt{\rho_m \rho_v} = 3.90 \times 10^{-5} \frac{\text{kg}}{\text{m}^3}
\]

- The question can be asked how much volume of this perturbed state of the quantum vacuum is needed to have the equivalent energy value as the ground state of Hydrogen (13.6eV or 2.18x10^{-18} Nm)

\[
r = \left( \frac{E}{\rho_{v\_local} c^2 \frac{4}{3} \pi} \right)^{\frac{1}{3}} = a_0
\]

- The calculated radius is \( r = 5.29 \times 10^{-11} \text{ m} \), which is an exact match to the given value for the Bohr Radius, \( a_0 = 5.29 \times 10^{-11} \text{ m} \).
• Frank Wilczek, Nobel laureate: “We have achieved a beautiful and profound understanding of the origin of most of the mass of ordinary matter, but not of all of it. The value of the electron mass, in particular, remains deeply mysterious…”

• Consider the energy state of the perturbed quantum vacuum field around the proton, and set this equal to the kinetic energy of the orbiting electron at the ground state.

\[
\frac{4}{3} \pi a_0^3 \rho_{v_local} c^2 = \frac{1}{2} m_e v^2
\]

• We know the speed of the orbiting electron:

\[
v = \alpha c = c / 137
\]

• We can solve for the electron mass, and using the predicted value for \( \rho_{v_local} \) of \( 3.9 \times 10^{-5} \text{ kg/m}^3 \), we get a predicted electron mass of \( 9.1 \times 10^{-31} \text{ kg} \).
Magnetic Pressure

• The first step now is to calculate the magnetic pressure around the Hydrogen nucleus.

  The magnetic field as perceived by the electron is given by the following relationship. The speed of the orbiting electron is \( \alpha c \).
  \[
  B = \frac{\mu_0 q v}{4 \pi a_0^2}
  \]

  The magnetic pressure is a simple calculation:
  \[
  \frac{B^2}{2 \mu_0} = 6.25 \times 10^7 \text{ N/m}^2
  \]

• The quasi-classical plasma pressure of the perturbed quantum vacuum state around the Hydrogen nucleus can be calculated by converting the electron velocity to temperature using \( \frac{1}{2} m_e v^2 = kT \), and making the assumption that the virtual electron-positron plasma has the same effective temperature as the orbiting electron.

• When the plasma pressure calculation makes use of a 2/3 factor, analogous to the predicted dark energy fraction of 2/3 picked up during integration to calculate the Gravitational constant, the values are nearly identical:
  \[
  P = n_e kT = \frac{2}{3} \frac{\rho_{v_{local}}}{m_e} kT = 6.24 \times 10^7 \text{ N/m}^2
  \]