Will ET Write or Radiate

Christopher Rose[1] and Gregory Wright[2]

[1]WINLAB
Rutgers University
Piscataway, New Jersey 08854 USA

[2]Antiope Associates
18 Clay Street
Fair Haven, New Jersey 07704 USA

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10 Years of Wireless Research

- Mobility
  - Not anathema $\Rightarrow$ it helps!
  - Delay tolerant? $\Rightarrow$ transmit when near base!
- Interference Avoidance, Pricing & Spectrum Management
  - Interference hurts $\Rightarrow$ deal with it!

A Hoary Old Epiphany

- RF interference is bad
- Mobility is good
  - Channel really good when nearby
  - Can often tolerate delay
- Storage density is increasing (faster than Moore)
- **Go Postal!**
  - Forget RF! Write message down! Toss it to recipient!
  - Netflix! FedEx!

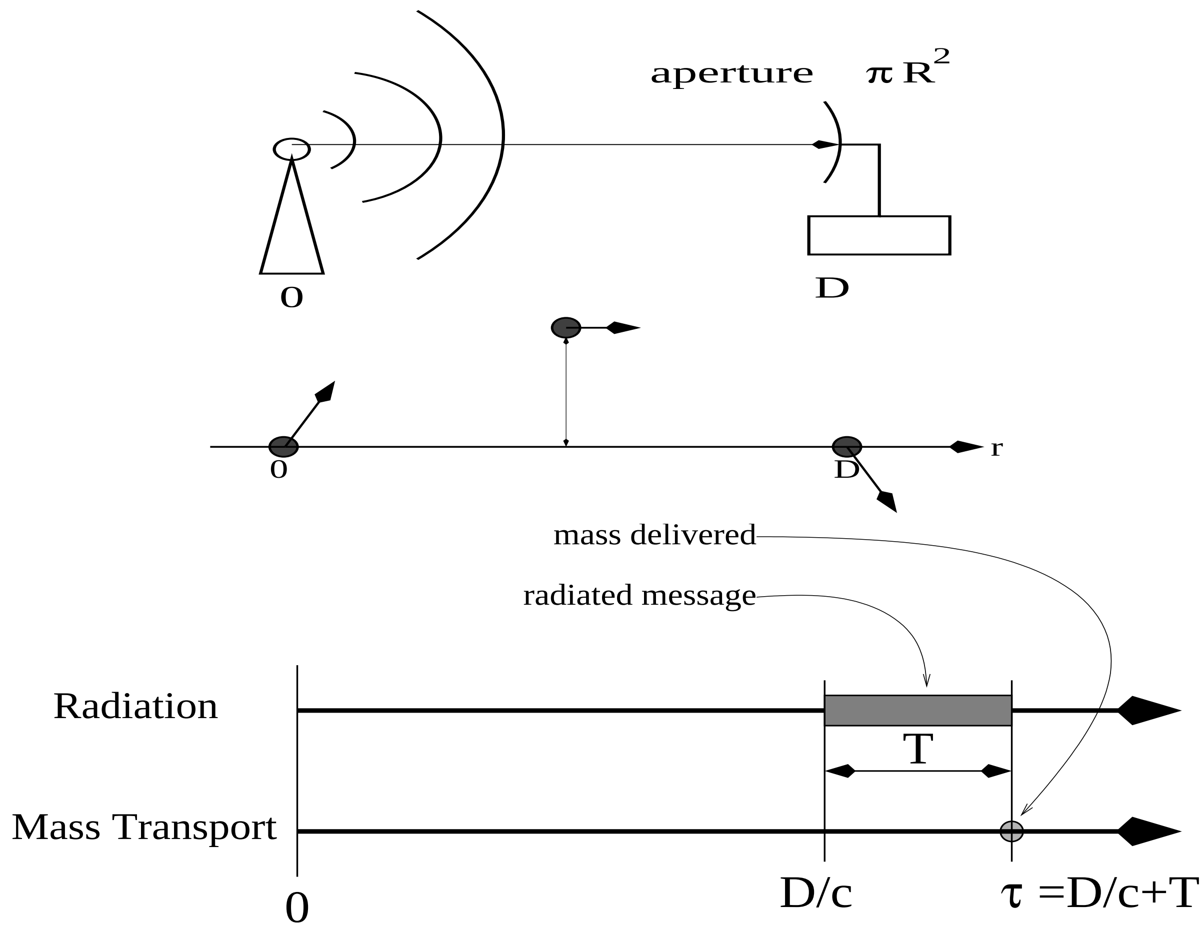
Completely ridiculous!!

(right????)

A Little Empirical Rigor

- **Magnetic Storage** with FeO_2: 2×10^{17} bits/kg
- **Optical Lithography** with SiO_2: 3.85×10^{18} bits/kg
- **E-beam Lithography** with SiO_2: 1.54×10^{21} bits/kg
- **STM** with Xe on Ni: 1.74×10^{22} bits/kg
- **RNA**: 3.6×10^{24} bits/kg

A Little Analytic Rigor



Radiation Energy Requirements

- Energy capture

$$\nu(D) = \frac{AG}{4\pi D^2}$$

- Bits a la Shannon:

$$B = TC = TW \log_2\left(\frac{P\frac{GA}{4\pi D^2}}{N_0 W} + 1\right)$$

- $E_r = PT$,

$$E_r = BN_0 \frac{4\pi D^2}{AG}\frac{TW}{B}\left[2^{\frac{B}{TW}} - 1\right]$$

- Large TW:

$$E_r \geq BN_0 \frac{4\pi D^2}{AG}\ln 2$$

Some (freespace) Rocket Science

- Average velocity

$$\frac{1}{\tau}\int_0^{\tau} v(t)dt = \frac{D}{\tau} = \bar{v} = E[v(t)]$$

- Minimum imparted energy subject to $\bar{v} = \frac{D}{\tau}$:

$$E^* = \min_{v()} \max_t h(v(t))$$

- Jensen says

$$E^* = \min_{v()} \max_t h(v(t)) \geq \min_{v()} E[h(v(t))] \geq h(\bar{v})$$

with equality iff $v(t)$ is constant $= \bar{v}$

(Jensen's Inequality Rock(et)s!)

Minimum Transport Energy

- GIVEN: $h()$ and $\overline{v}$

$$E^* = h(\overline{v})$$

- $h(v) = mc^2\left(\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} - 1\right)$:

$$E^* = mc^2\left(\frac{1}{\sqrt{1-\left(\frac{\overline{v}}{c}\right)^2}} - 1\right)$$

- $h(v) \approx \frac{1}{2}mv^2$:

$$E^* \approx \frac{1}{2}m\overline{v}^2$$

But What About Gravity?

- $q(x)$ potential energy:

$$\mathcal{E}(t) = h(v(t)) + q(x(t))$$

- Energy minimization:

$$E^* = \min_{x()} \max_{t} \mathcal{E}(t, x(t), v(t)) \geq \min_{x()} \frac{1}{\tau} \int_0^\tau \mathcal{E}(t, x(t), v(t)) dt$$

- Calculus of variations:

$$\frac{d}{dt}\left(\frac{\partial \mathcal{E}}{\partial v}\right) - \frac{\partial \mathcal{E}}{\partial x} = 0$$

$$\ddot{x} h''(\dot{x}) - q'(x) = 0$$

Potential Field Results

- Non-relativistic:

$$m\ddot{x} = q'(x)$$

- $q'(x)$ is force at position x: $\rightarrow$ "free fall"
- Freefall? $\rightarrow$ $\mathcal{E}(t) = \text{constant}$
- $\mathcal{E}(t)$ constant $\rightarrow$ minimization satisfied with equality, so ...

Potential Fields Results

- Low speed:

$$m\ddot{x} = q'(x)$$

- $q'(x)$ is force at position x: $\rightarrow$ "free fall"
- Freefall? $\rightarrow \mathcal{E}(t) =$ constant
- $\mathcal{E}(t)$ constant $\rightarrow$ minimization satisfied with equality, so ...

Gravity Summary

Artillery: adds a factor of 2 to energy

Escape: small penalty if $\bar{v} > 2 \times$ escape velocity

Inscribed Matter Energy Requirements

- Message size B, mass information density $\tilde{\rho}$

$$E_w \approx \frac{1}{2}\frac{B}{\tilde{\rho}}\bar{v}^2 = \frac{1}{2}\frac{B}{\tilde{\rho}}\left(\frac{c}{\delta}\right)^2$$

  - Brisk Walk: $\delta = 3 \times 10^8$
  - Jetliner: $\delta = 10^6$
  - Earth Escape: $\delta < 2.7 \times 10^4$
  - Solar Escape: $\delta < 7.1 \times 10^3$
  - Milky Way Escape: $\delta < 6 \times 10^2$

Radiation to Transport Energy Ratio

- Definition:

$$\Omega = \frac{E_r}{E_w}$$

- Large TW, $\delta \gg 1$

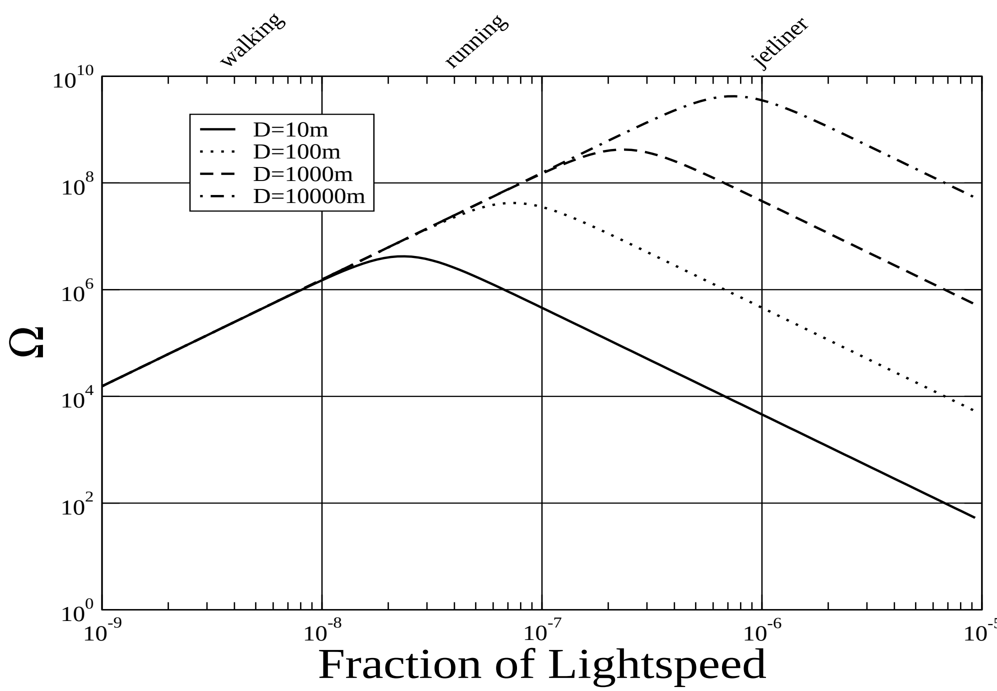
$$\Omega \geq \left[\frac{\tilde{\rho} N_0}{c^2}\right] \left[\frac{4\pi D^2}{AG}\right] (2 \ln 2)\, \delta^2$$

Normalized Aperture $\equiv \mathcal{A} = \frac{2R}{\lambda}$
Normalized Distance $\equiv \mathcal{D} = \frac{D}{2R}$

$$\Omega \geq \left[\frac{\tilde{\rho} N_0}{c^2}\right] \left[\frac{8}{\pi^2} \left(\frac{\mathcal{D}}{\mathcal{A}}\right)^2\right] (2 \ln 2) \delta^2$$

Isotropic Radiation vs. Terrestrial Artillery

$\rho = 3 \times 10^{24}$, $R = 5$**cm, Temperature** $300K$



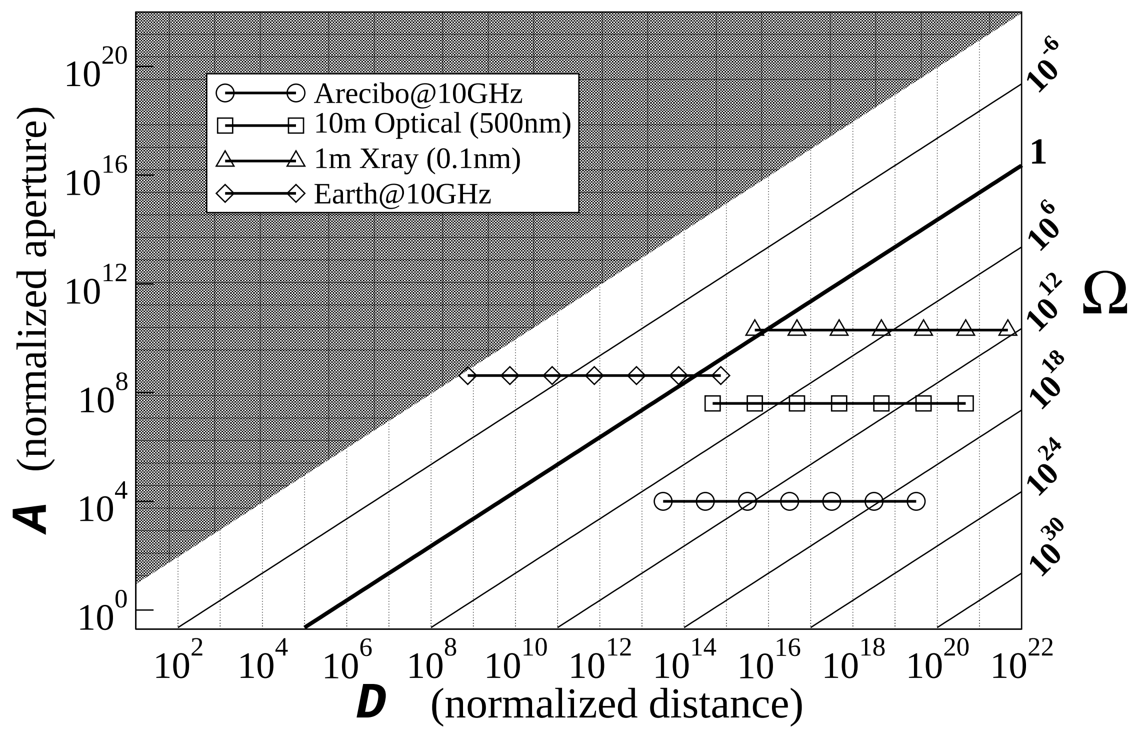
Chip to Chip Laser Links

- Temperature: $300K$
- Delay: $\delta = 10^9$
- Aperture: $R = 5\mu$m
- Wavelength: $\lambda = 1\mu$m
- Distance: $D = 10$cm
- $\Omega = 5.17 \times 10^{-14}\tilde{\rho}$

MUCH better to toss magnetic chits!

Interstellar

$\rho = 10^{22}$, $\delta = 10^{3}$, **Temperature** $3K$



(from Nature 431, pp.47–49, September 2, 2004)

Other Issues

General

- Radiation is broadcast – IM still wins (at reasonable receiver densities)
- Inscription energy budget – generally small

Interstellar

- Radiation needs repetition – penalty can be very large
- Matter deceleration at target – not terrible for $\delta \geq 10^3$
- Cosmic ray bombardment – even with shielding IM wins
- Advertisement at target – still studying

Is Radiation Better for Broadcast?

- Radiation illuminates many $\rightarrow$ matter penalty
- Milky Way stellar density 2.8×10^{-2} stars $(LY)^{-3}$
- Spherical galaxy, isotropic radiation, Arecibo-Arecibo
- $R = 10^4$ LY: 1.13×10^{11} stars (but $\Omega = 10^{28}$)
- $R = 10^6$ LY: 1.13×10^{17} stars (but $\Omega = 10^{32}$)

No, inscribed matter still wins!

Does Inscription Energy/Speed Eat Budget?

- **Matter Inscription/Readout Energy and Time**
  - Can be reversible and abitrarily fast (R. Landauer)
- **Empirical energy calc:**
  - 60000 ATP/second for 20 minutes: 4639 Kbase of E-coli
  - 8×10^{-20}J per ATP molecule
  - 6.2×10^{-19}J bit^{-1}.
  - E^* at earth escape: 1.68×10^{-17} J bit^{-1}.
- **Construction energy probably not a problem**

Radiation Needs Repetition

- Civilization Birth Rate: $\alpha = 1/10^9$ per year
- Civilization Extinction Rate: $\beta = 1/10^6$ per year
- Success criterion $0 \leq \Phi \leq 1$
- Now many repetitions N (optimally placed)?
- $\Phi = 0.99 \rightarrow N = 2 \times 10^5$

  $\Phi = 0.9999 \rightarrow N = 2 \times 10^7$,

Package Deceleration Penalties

- Need exhaust braking
- Energy penalty (excess mass): $e^{\frac{c}{\delta g I_{sp}}}$
- $I_{sp} \equiv$ Specific Impulse
  - Chemical: 10^2
  - Nuclear Electric: 10^4
  - Fusion: 10^6
- $I_{sp} = 20,000$, $\delta = 1000 \rightarrow$ penalty 4.6
- $\delta = 100$ or $I_{sp} = 2000 \rightarrow$ penalty 4.4×10^6

Cosmic Insults

- **Insults:**
  - High energy particle bombardment
  - Heating (diffusion)
  - Ion tracks, dislocations, subatomic cascades
- **Shielding:**
  - 10 million years at 10% bacteria viability: 3 m radius rock (3g cm^{-3} density)
  - 3.4×10^6 penalty
- **Clever Composition, Coding and Correction:**
  - **???????**

Advertisement Methods

- Big rock?
- Dust?
- Embedded dust & rock (comet)?
- Active Probe (Bracewell)?
- Colonization via panspermia (Crick)?

Paradigm-Piercing Punchlines

- Inscribed matter messaging is **NOT** ridiculous
  - FedEx and Netflix are on to something
- Finesses Gupta-Kumar *ad hoc* nets $\sqrt{N}$ problem?
  - little data missiles
- Chip-to-chip or mote-to-mote (high latency) communication?
  - smart dust tossing inscribed dust
- **ET might write not radiate**
  - look for artifacts not radio

Learn more:

Nature cover story (431, pp.47–49, September 2, 2004)

http://www.winlab.rutgers.edu/∼crose/cgi-bin/cosmic19.html