ET Might Write Not 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

March 24, 2004

10 Years of WINLAB Research (Infostations redux)

- Infostations:
  - Delay tolerant? ⇒ transmit when near base!
- Channel Quality
  - How good can that RF channel be? ⇒ really good!
- Interference Avoidance, Pricing & Spectrum Management
  - Interference hurts ⇒ deal with it!

An Epiphany!

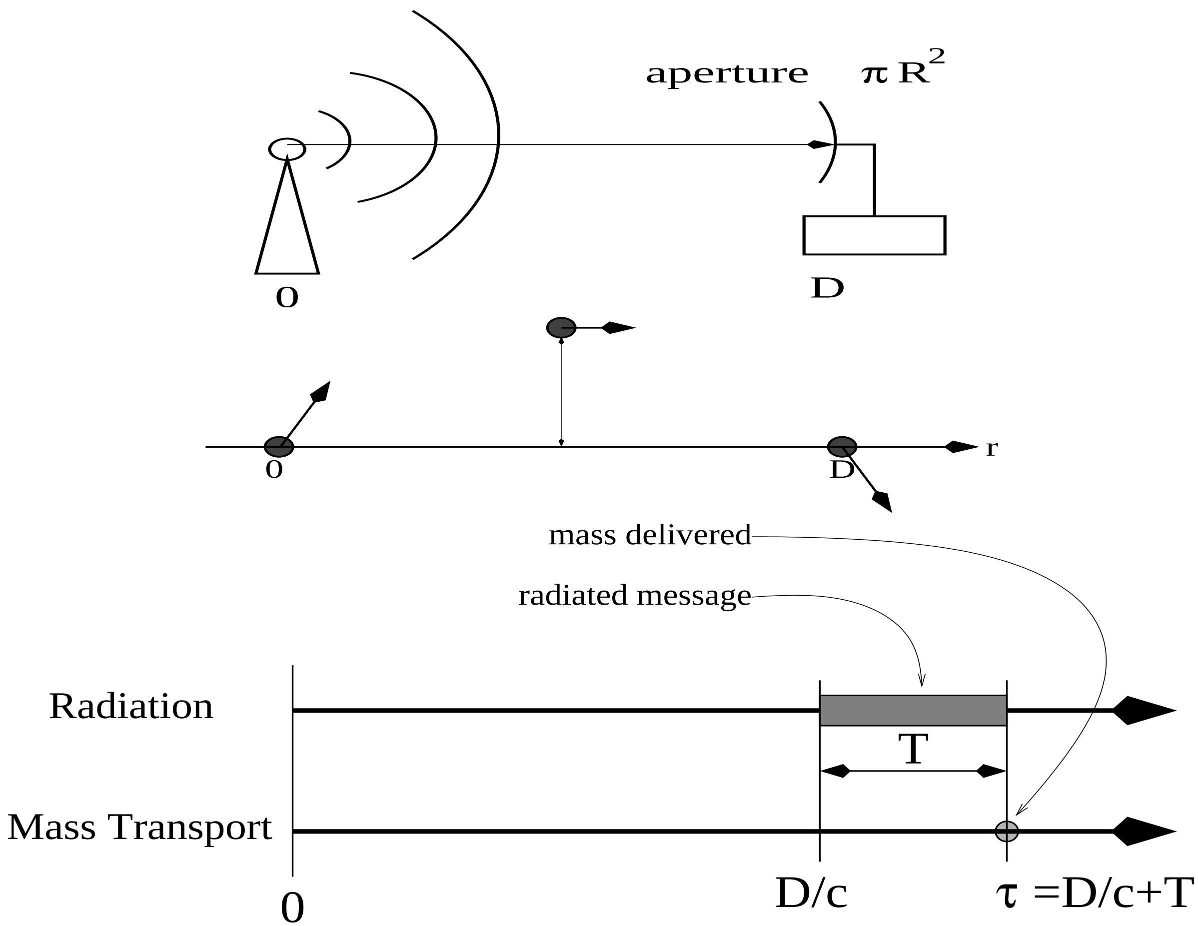
- RF Interference is bad
- Storage density is increasing
- Channel good when nearby
- Can tolerate delay
- **IMPLICATION:**
  - Forget RF! Write message down! Toss it to recipient!

Completely ridiculous .... right?

A Little Empirical Rigor

- **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
- And maybe a LOT more room at the bottom

A Little Analytic Rigor



Communications Theory IS Rocket Science

- Max bigger than mean:

$$\max_{v} h(v) \geq E[h(V)]$$

- If V deterministic:

$$\max_{v} h(v) = E[h(V)]$$

- If $h()$ convex (Jensen):

$$E[h(V)] \geq h(\overline{v})$$

Rocket Science

- Average velocity

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

- Minimum imparted energy

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

subject to $\bar{v} = \frac{D}{\tau}$.

- 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

Minimum Transport Energy

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

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

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

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

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

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

Potential Fields Setup

- $q(x)$ potential energy:

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

- Energy minimization:

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

- 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 Field Results

- Low speed:

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

- $q'(x)$ 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 ...

Artillery Problem

- Minimum energy:

$$E^* = \frac{1}{2} mgD$$

- Let $\delta = c\tau/D$
  - $\delta \approx 1 \equiv$ near light speed
  - $\delta \gg 1 \equiv$ low speed
- Delay at minimum energy

$$\delta^* = c\sqrt{2/gD}$$

- Pay a factor of 2 over free space

Escape Problem

- Needs numerical calculation
- Boils down to: need initial velocity larger than escape.
- Some energy penalty (but not a lot)
- Escape examples (rough):
  - Earth: $\delta < 2.7 \times 10^4$
  - Solar: $\delta < 7.1 \times 10^3$
  - Milky Way: $\delta < 6 \times 10^2$

Inscribed Matter Energy Requirements

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

$$E_w = \frac{B}{\tilde{\rho}} c^2 \left(\frac{\delta}{\sqrt{\delta^2 - 1}} - 1 \right)$$

- $\delta \gg 1$:

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

- Off by only $\approx 10\%$ at $0.4c$ and $\approx 50\%$ at $0.75c$
- Low speed ain't so low!
- We'll ignore relativity

Radiation Energy Requirements

- Energy capture

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

- Bits a la Shannon:

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

- $E_r = PT$,

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

- Large TW:

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

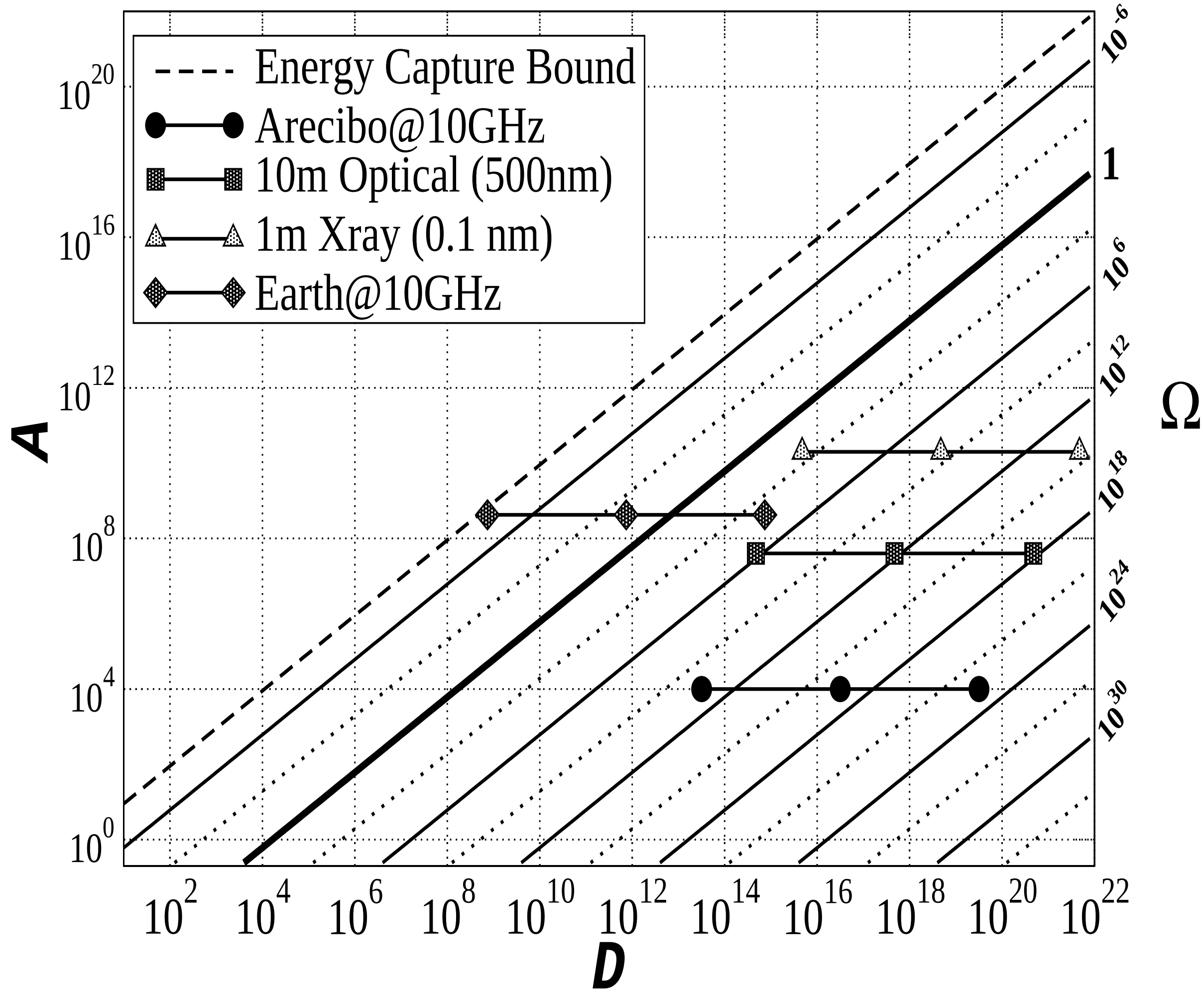
Radiation to Transport Energy Ratio

- Definition:

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

- Large TW, $\delta \gg 1$

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


Energy Capture Bound
Arecibo@10GHz
10m Optical (500nm)
1m Xray (0.1 nm)
Earth@10GHz
A
D
Ω
10^0
10^4
10^8
10^12
10^16
10^20
10^2
10^4
10^6
10^8
10^10
10^12
10^14
10^16
10^18
10^20
10^22
10^-6
1
10^6
10^12
10^18
10^24
10^30

Is Radiation Better for Broadcast?

- Radiation illuminates many $\rightarrow$ matter penalty
- Milky Way stellar density 6.4×10^{-3} stars $(\text{LY})^{-3}$
- Spherical galaxy, isotropic radiation, Arecibo-Arecibo
- $R = 10^4$ LY: 2.7×10^{10} stars (but $\Omega = 10^{28}$)
- $R = 10^6$ LY: 2.7×10^{16} stars (but $\Omega = 10^{32}$)

No, inscribed matter still wins!

Does Inscription Energy/Speed Eat Budget?

- **Matter Inscription/Readout Energy and Time**
  - Landauer said it can be reversible and abitrarily fast
- **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 not a problem**

Radiation Needs Repetition

- Civilization Birth Rate: $\alpha = 1/10^9$ per year
- Civilization Extinction Rate: $\beta = 1/10^8$ per year
- Success criterion $0 \leq \Phi \leq 1$
- Now many repetitions N (optimally placed)?
- $\Phi = 0.99 \rightarrow N = 2000$

  $\Phi = 0.9999 \rightarrow N = 200,000$,

Delivery Methods

- Big rock?
- Dust?
- Embedded dust & rock (comet)?
- Probe (Bracewell)
- Onward toward lunatic fringe

Delivery Methods (more detail)

- 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:**
  - **???????**

PUNCHLINES

- Inscribed matter messaging is NOT ridiculous
- Inscribed matter messaging might often be PREFERRED
- **Questions for storage types:**
  - General theory of inscribed matter storage?
  - Composition and Coding for survivability?
  - Ease of decoding (obviousness)?
- Learn more:

  http://www.winlab.rutgers.edu/∼crose/cgi-bin/cosmic4.html