ET Might Write, Not Radiate

Christopher Rose[1] and Gregory Wright[2]

[1]WINLAB, Rutgers University

[2]Antiope Associates, Fair Haven, NJ

iCORE Summit 2006

May 24, 2006

PHYSICIST

Communications Theorist

The Usual Response

Wireless Research As Usual, then an EPIPHANY!

- **Interference is bad**
  - Mutual interference is a network killer (Bob's topic tonight)
- **Mobility is good**
  - Can often tolerate delay
  - Channel especially good when nearby
- **Storage density is increasing**
  - Faster than Moore!

Wireless Research As Usual, then an EPIPHANY!

- **Interference is bad**
  - Mutual interference is a network killer
- **Mobility is good**
  - Can often tolerate delay
  - Channel especially good when nearby
- **Storage density is increasing**
  - Faster than Moore!

GO POSTAL

Forget Radio! **Write** message down! **Toss** it to recipient!

Completely ridiculous!!

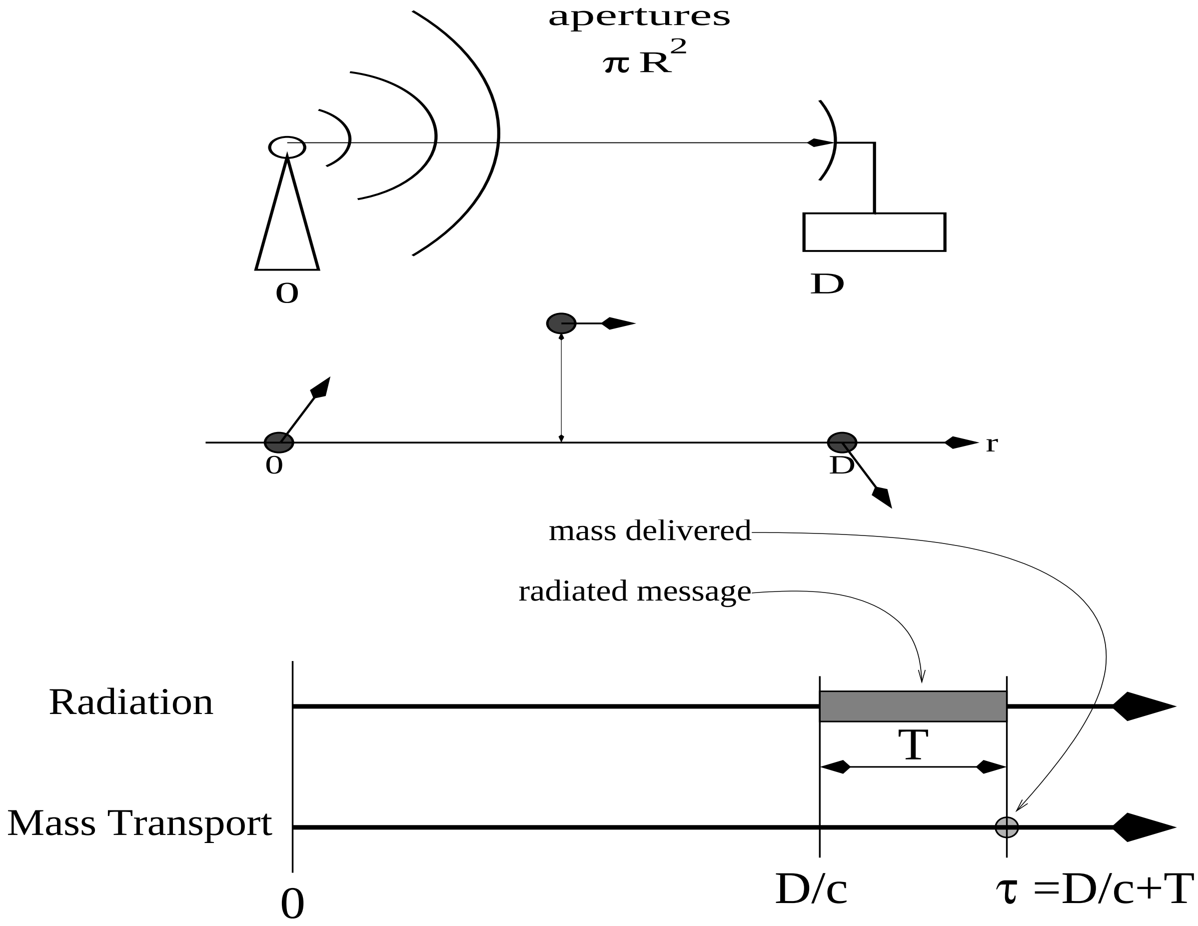
(right?)

Look More Closely At What We Think We Know

A truck filled with storage media, driven across town, is a very reliable high bit rate channel.

–Comm. Theory Collective Subconscious

A Little Analytic Rigor



Radiation Energy Requirements

- **Shannon Capacity:**

$$C = B/T = W \log_2 \left(\frac{P}{N_0 W} + 1 \right)$$

- Power capture fraction:

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

- $\mathcal{E}_r = PT$:

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

- Large TW:

$$\boxed{\mathcal{E}_r \geq BN_0 \left(\frac{4\pi D^2}{AG} \right) \ln 2}$$

Writing Energy Requirements (ROCKET SCIENCE!)

$$\mathcal{E}^* = \min_{x(t)} \max_{t} \mathcal{E}(t)$$

Writing Energy Requirements (ROCKET SCIENCE!)

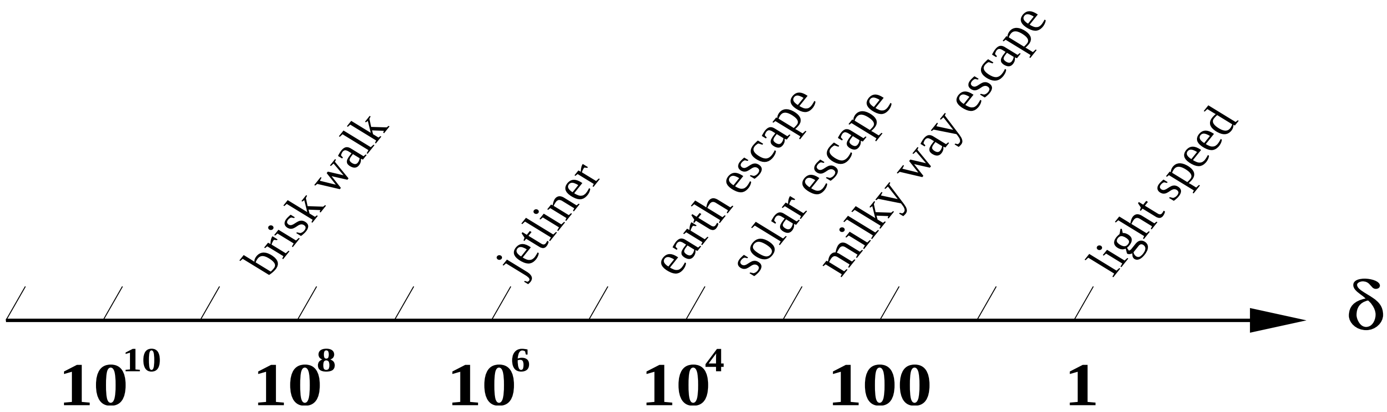
$$\mathcal{E}^* = \min_{x(t)} \max_{t} \mathcal{E}(t) = \frac{1}{2} m \bar{v}^2$$

Via Jensen's inequality → communications theory **IS** Rocket Science!

Inscribed Matter Energy Requirements

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

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



- **Artillery:** adds a factor of 2 to energy
- **Escape:** small penalty if $\bar{v} > 2 \times$ escape velocity

Radiation to Transport Energy Ratio

$$\Rightarrow \boxed{\Omega \equiv \frac{\mathcal{E}_r}{\mathcal{E}_w}} \Leftarrow$$

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

$$\text{Normalized Distance} \equiv \mathcal{D} = \frac{D}{2R}$$

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

Equal Receiver/Transmitter Apertures

Information Density, $\tilde{\rho}$

How About Black Holes?

- Schwarzschild Radius: $r = 2GM/c^2 = 1.5X10^{-27}M$
- Info content goes as event horizon *surface area*: $10^{72}r^2$ bits

$$\tilde{\rho} = 1.5 \times 10^{45} r \text{ bits/kg}$$

- Microhole (1μm radius): 1.5×10^{39} bits/kg
- Donut-hole sized hole (1cm radius): 1.5×10^{43} bits/kg

A wee bit impractical?

Information Density, $\tilde{\rho}$

How About Black Holes?

- Schwarzschild Radius: $r = 2GM/c^2 = 1.5X10^{-27}M$
- Info content goes as event horizon *surface area*: $10^{72}r^2$ bits

$$\tilde{\rho} = 1.5 \times 10^{45} r \text{ bits/kg}$$

- Microhole (1μm radius): 1.5×10^{39} bits/kg
- Donut-hole sized hole (1cm radius): 1.5×10^{43} bits/kg

VERY antisocial!

Empirical Mass Information Densities I

Voyager Spacecraft: 10^6 bits/kg

Empirical Mass Information Densities II

- **20 lb paper** @ 1000dpi: 2×10^{10} bits/kg
- **DVD**: 3×10^{12} bits/kg
- **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
- **Li + Be**: 7.5×10^{25} bits/kg

Radiation

vs.

Inscribed Matter

Terrestrial Artillery vs. Radiation

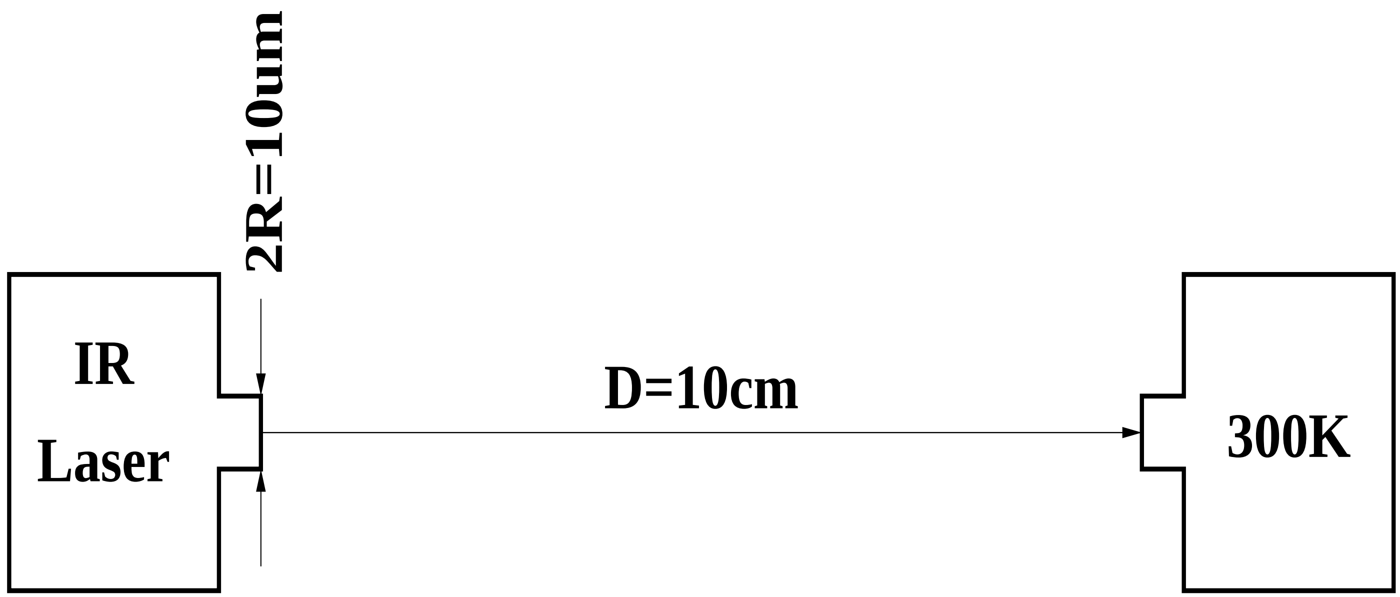
$\tilde{\rho} = 3 \times 10^{24}$, 1 GHz Carrier, $R = 5$cm, Temperature $300K$

Range (meters)	Transit Time	Ω
10	1.43 sec	1.3×10^7
100	4.5 sec	1.3×10^8
10^3	14.3 sec	1.3×10^9
10^4	45 sec	1.3×10^{10}

Aside: ≈ 4 minutes between NYC and Boston ballistically (320km).

Chip to Chip Laser Links

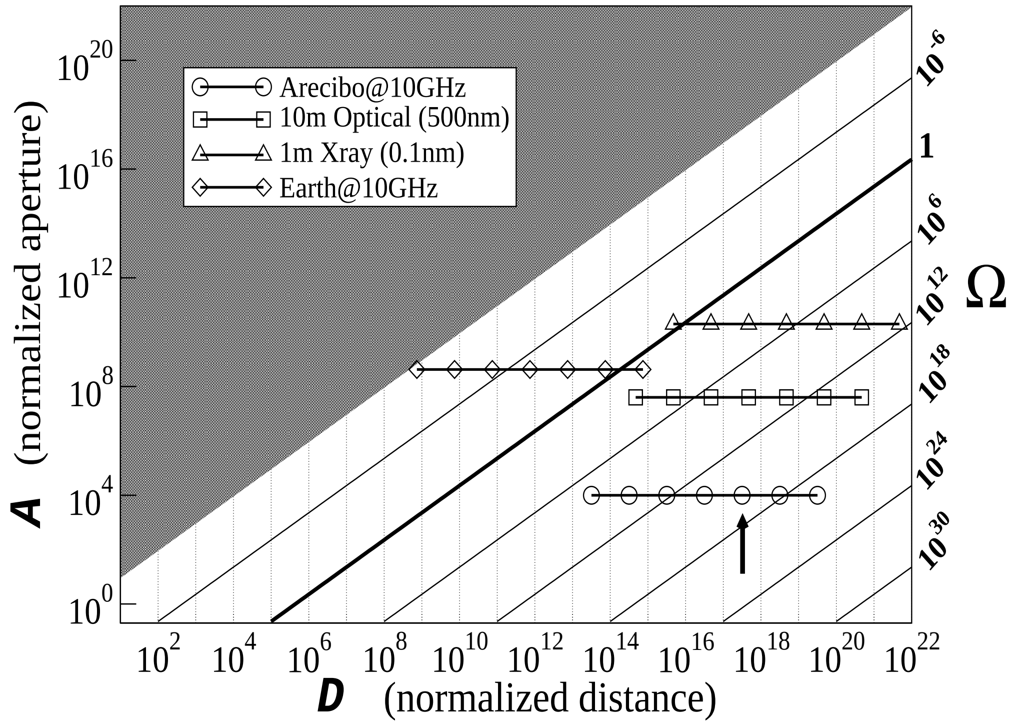
$\delta = 10^9, \lambda = 1\mu\text{m}$



Magnetic chits: $\Omega \geq 10^4$

STM inscribed chits: $\Omega \geq 5 \times 10^8$

Interstellar



($\tilde{\rho} = 10^{22}$, $\delta = 10^3$, Temperature $3K$)

$\longrightarrow$ 10k LY, Arecibo-Arecibo: $\Omega \geq 5 \times 10^{15}$

– Radiation/Matter: (2 megaton blast) / (Shelve 5 lb sugar bag)

Voyager

- 10^9 bit payload
- 900 kg mass
- Catapult launch: about 800 joules/bit

Breakeven Distance: ≈ 2000 light years

- Asides:
  - ETA nearest star: ≈ 100 kilo-years
  - Rocket Launch: distance up $\times 9$.
  - Use 3 DVDs (instead of gold disc): distance down $\times 10$
  - Use 1 gram of “RNA”: distance down $\times 10^6$
    ($\approx 1/4000$ distance to nearest star)

Communications Theory Has Spoken

Theoretically, matter is *stunningly* more energy-efficient than radiation

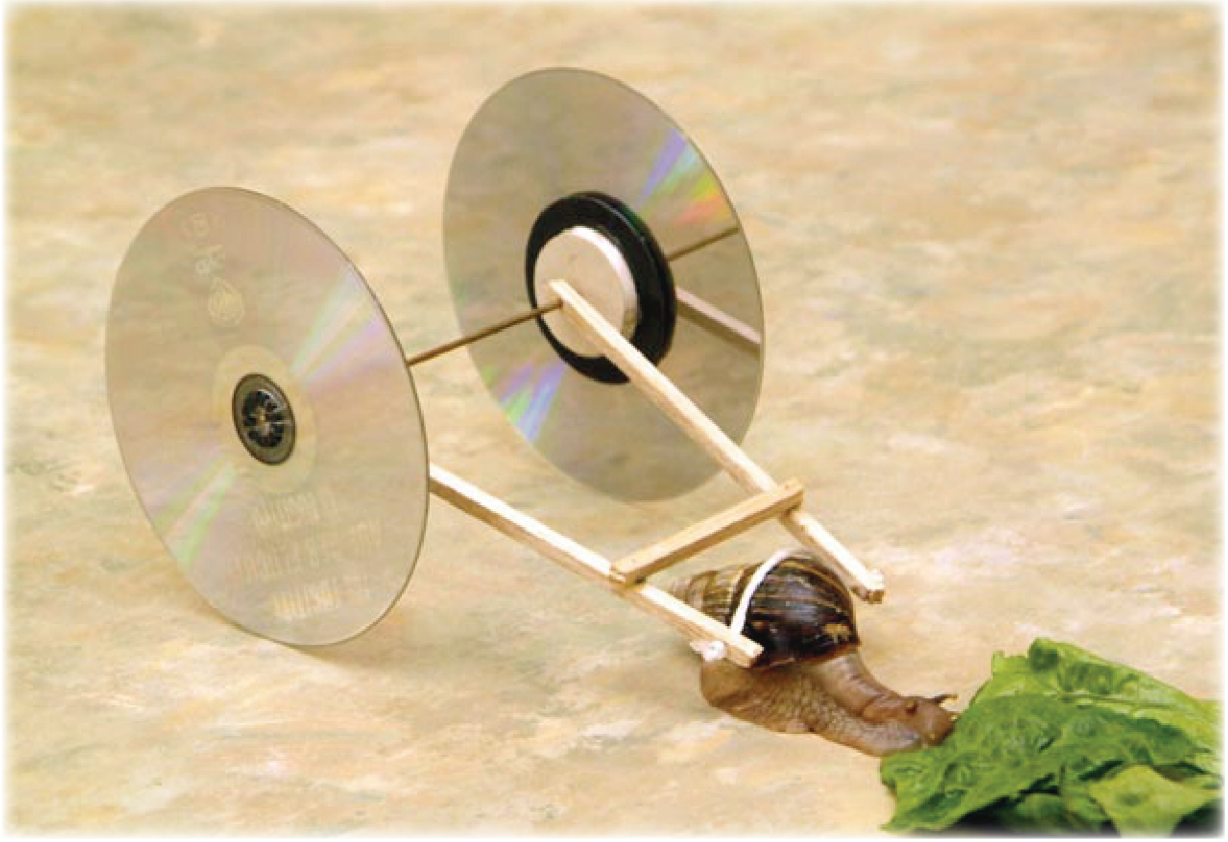


Figure 1. The SNAP system in a feed-forward action. In keeping with the systems engineering principle that interfaces between modules should be transparent, the backend's yoke is connected to the frontend's shell with a piece of transparent scotch tape, not visible in the image. (Photograph by Herbert Bishko.)

Sluggish Data Transport Is Faster Than ADSL

by Ami Ben-Bassat, Israel
Revital Ben-David-Zaslow, Department of Zoology, Tel Aviv University
Shimon Schocken, Efi Arazi School of Computer Science, IDC Herzliya, Israel
Yossi Vardi, Israel

"If everything seems under control, you're just not going fast enough." (Mario Andretti)

We describe an experiment in which a Giant African Snail, acting as a data transfer agent, exceeded all known "last-mile" communications technologies in terms of bit-per-second performance, adding to the many paradoxes of broadband communications.[1] We discuss the unique motivational and guidance systems necessary to facilitate snail-based data transport, and observe with satisfaction that in a society that worships the fittest, fastest, and furtherest, the meek and the slow can sometimes outperform all known competitors, giving rise to the new and exciting field of sluggish data networks.

The History of Snails as Communications Agents

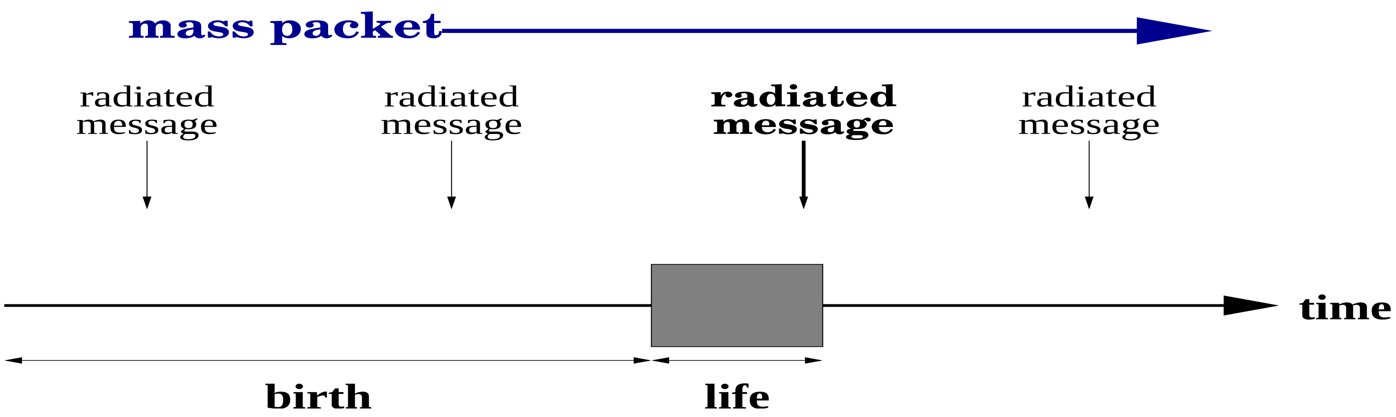
The use of snails as data communications agents was not considered before now. As we show in this paper, the negative attitude towards using snails in communications networks is an example of bounded rationality[2] impeding bold and creative engineering.

Snails are widely assumed to be slow animals. Yet the literature on sluggish speed is surprisingly limited, and few have actually bothered to measure and record it formally. Further, reported gastropod speeds vary widely with species and circumstance, ranging from 0.000023[3] to 0.0028[4] meters per second.

HEY! What About ... ?

- **Radiation**
  - Impermanence and Repetition
- **Matter**
  - Broadcast
  - Inscription Energy
  - Deceleration At Target
  - Navigation
  - Preservation
  - Advertisement

Matter Persists – Radiation Vanishes



- Civilization Birth Rate: $\alpha = 1/10^9$ per year
- Civilization Extinction Rate: $\beta = 1/10^6$ per year
- Success criterion $0 \leq \Phi \leq 1$
- **How many radiated repetitions?**
  - $\Phi = 0.99 \rightarrow 2 \times 10^5$
  - $\Phi = 0.9999 \rightarrow 2 \times 10^7$

Is Radiation Better for Broadcast?

Radiation illuminates many → matter penalty

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

No, inscribed matter still wins!

Inscription Energy/Speed

- **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} (≈ 4 eV bit^{-1}).
  - E^* at earth escape: 1.68×10^{-17} J bit^{-1}.

Construction energy probably not a problem

Parking the Package

- Assume 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

Gravitational Perturbations

Angular Deflection: $\theta \approx \frac{2MG}{v_0^2 y_0}$ (radians)

- $M = 2 \times 10^{30}$kg (solar)
- $v_0 = c/1000$
- Stellar Density: 2.8×10^{-2} stars (LY)$^{-3}$
- 10kLY trip mean miss distance: ≈ 0.14LY

Aim not a big problem

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)
  - **penalty:** 3.4×10^6
- **Clever Composition, Coding and Correction?**
  - need better channel characterization

Message Advertisement?

Solar Space is BIG

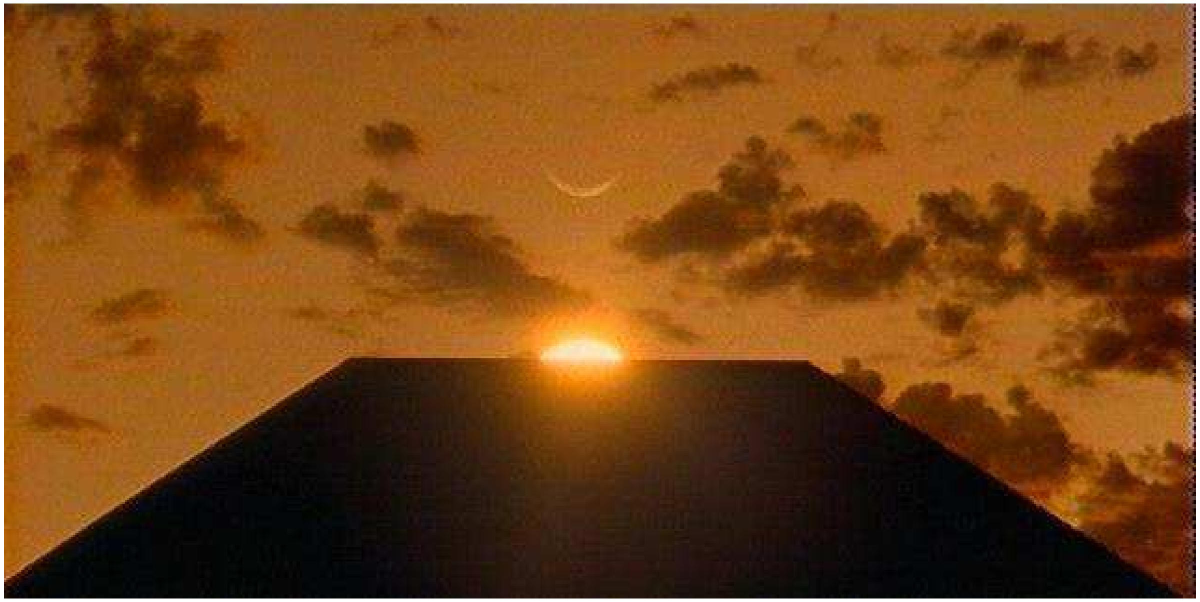
Big Rock?

Somewhat antisocial

Odd Rock?

Seeded Comet?

Active Probe?



Life Boat?

Noah's micro-ark?

CONCLUSION

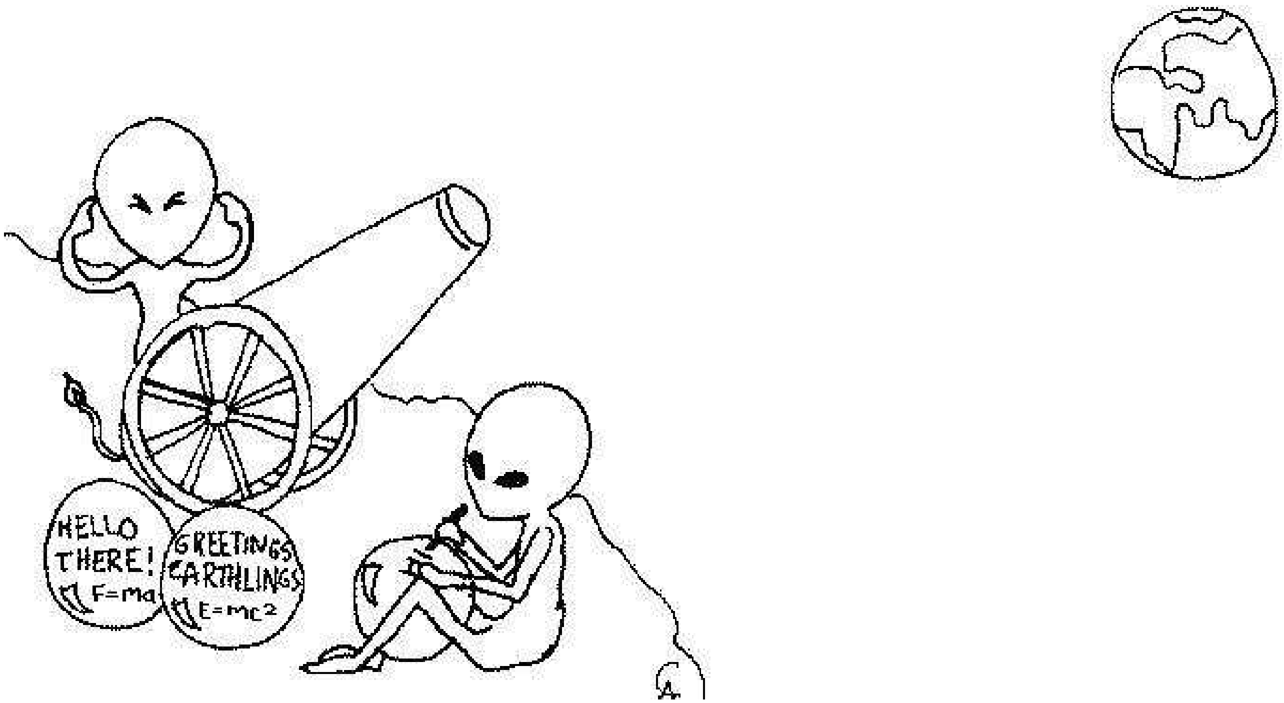
IF: energy important & delay acceptable

THEN: inscribed matter messaging is efficient

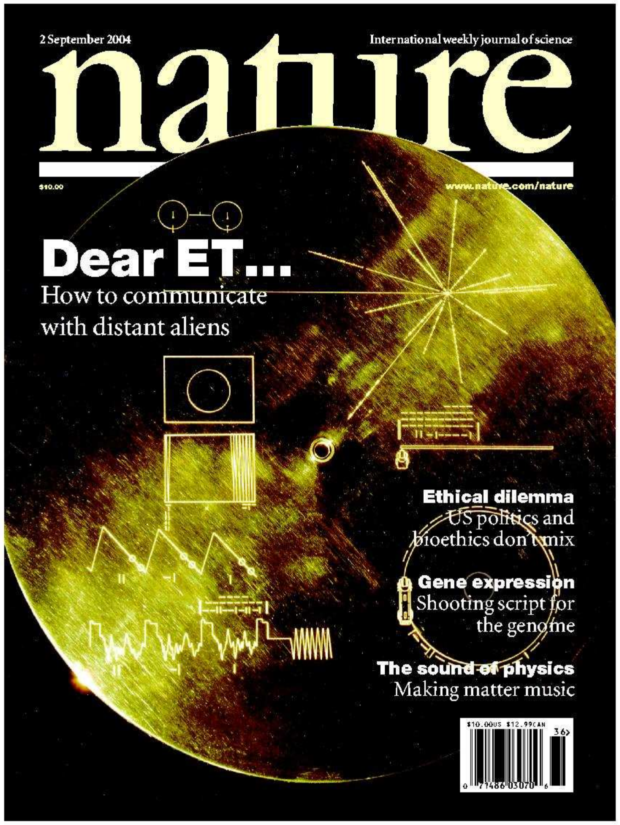
- Terrestrial
  - FedEx, Netflix, Snail Mail (literally!)
- Chip-to-chip or mote-to-mote
  - smart dust tossing inscribed dust
- Biological systems
  - construction/dispersal cost for messenger molecules

But perhaps most important ...

Good Comm. Theory Party Banter



Learn More



Nature 431, pp.47–49, September 2, 2004

Web Site: http://www.winlab.rutgers.edu/∼crose/cgi-bin/cosmic17.html

Special Thanks To

Norman Beaulieu

who steered this work toward **Nature**