

ET Might Write, Not Radiate

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

—Comm. Theory Collective Subconscious

Ten Years of Wireless Research

- Spectrum Management
 - Interference hurts, so deal with it!
- Delay tolerance
 - Transmit when channel good!
- Mobility
 - Is not anathema \Rightarrow it helps!

(right?)

Completely ridiculous!!

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

GO POSTAL!

But ad hoc comparisons are unsatisfying

- Terrestrial (320km, D^4 propagation): MUCH lower efficiency
- (3.5×10^4 km uplink, D^2 propagation, $1m^2$ dish)
- Satellite: 5660 bits/joule

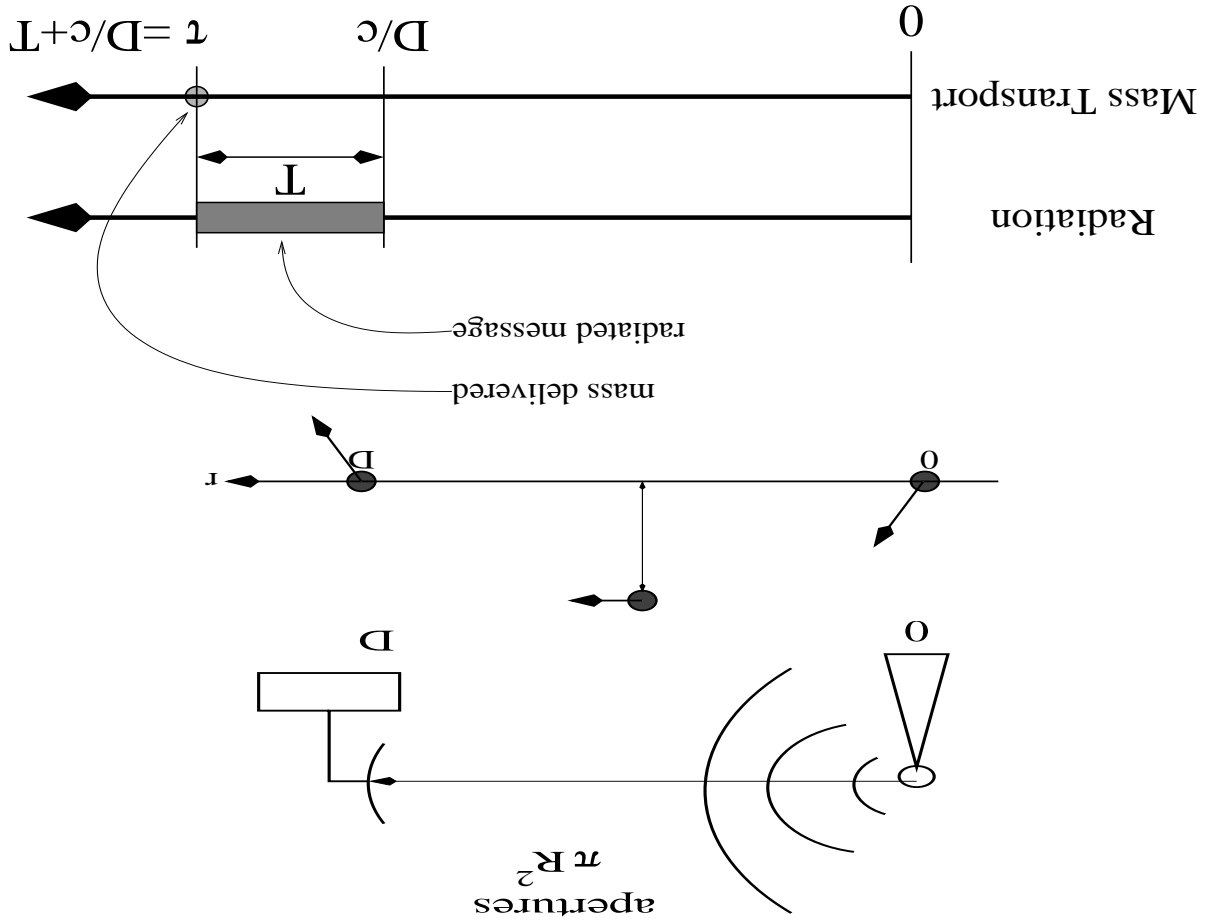
• Equivalent Radiation Energy

- 100kg DVDs: $\approx 2.5 \times 10^5$ bits/joule
- 1.2×10^8 Joules per gallon
- 200 miles at 20 miles per gallon

• NYC/Boston Matter Transport Energy

Nope, Not Ridiculous

A Little Analytic Rigor

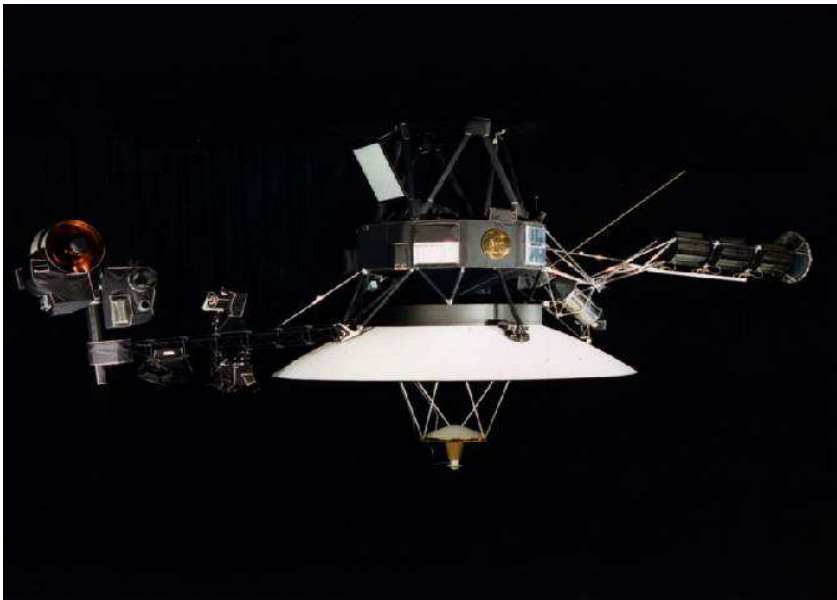


A wee bit impractical (and antisocial)

- Schwarzschild Radius: $r = 2GM/c^2 = 1.5 \times 10^{-27} M$
- Info content goes as event horizon *surface area*: $10^{72} r^2$ bits
- $\tilde{\rho} = 1.5 \times 10^{45} r$ bits/kg
- Microhole (1 μ m radius): 1.5×10^{39} bits/kg
- Donut-hole sized hole (1cm radius): 1.5×10^{43} bits/kg

How About Black Holes?

Information Density, $\tilde{\rho}$



Voyager Spacecraft: 10^6 bits/kg

Empirical Mass Information Densities I

Empirical Mass Information Densities II

- **20 lb paper @ 1000dpi:** 2×10^{10} bits/kg
- **DVD:** 3×10^{12} bits/kg
- **Magnetic Storage with FeO₂:** 2×10^{17} bits/kg
- **Optical Lithography with SiO₂:** 3.85×10^{18} bits/kg
- **E-beam Lithography with SiO₂:** 1.54×10^{21} bits/kg
- **STM with Xe on Ni:** 1.74×10^{22} bits/kg
- **RNA:** 3.6×10^{24} bits/kg
- **LiBe:** 7.5×10^{25} bits/kg

Minimum Transport Energy, E_*

Just the initial kinetic energy:

$$E_* \approx \frac{1}{2}mv^2$$



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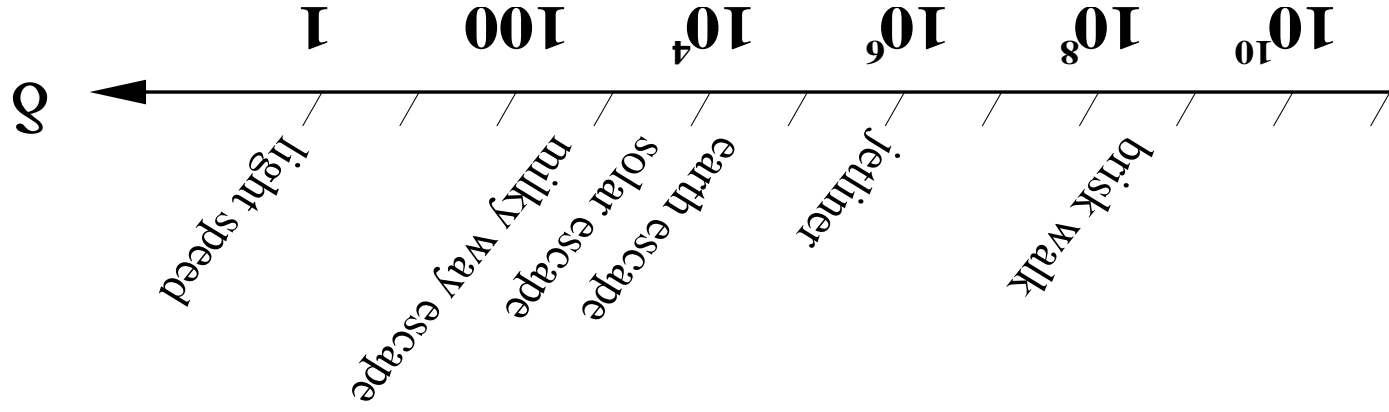
Just the initial kinetic energy:

Minimum Transport Energy, E_*

Inscribed Matter Energy Requirements

- Message size B , mass information density ρ

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



- **Artillery:** adds a factor of 2 to energy

- **Escape:** small penalty if $v > 2 \times$ escape velocity

Radiation Energy Requirements

- Energy capture

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

- Bits a la Shannon:

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

- $E_r = PT$,

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

- Large TW :

$$E_r \geq BN_0 \left(\frac{4\pi D^2}{AG} \right) \ln 2$$

Radiation to Transport Energy Ratio

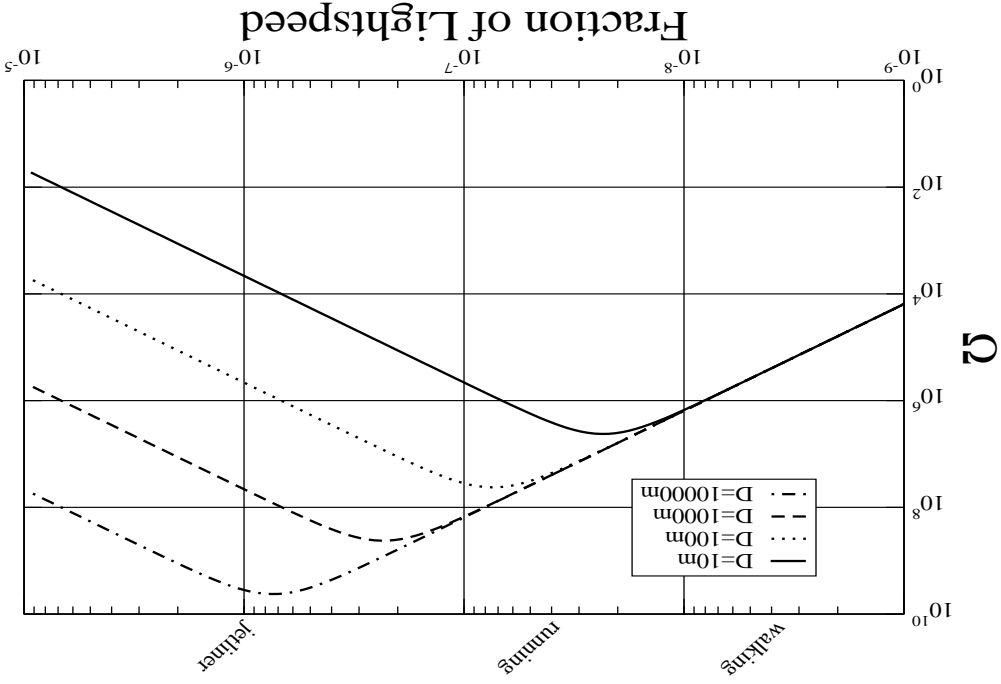
$$\Omega = \frac{E_r}{E_w}$$

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

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

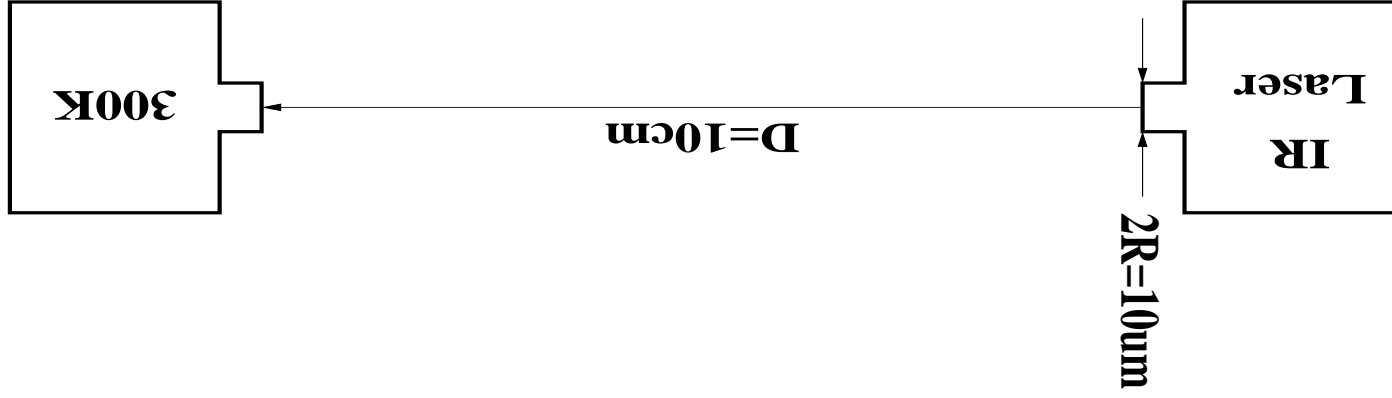
Isotropic Radiation vs. Terrestrial Artillery

$$\bar{p} = 3 \times 10^{24}, R = 5\text{cm, Temperature } 300\text{K}$$



Aside: ≈ 250 seconds between NYC and Boston ballistically

Chip to Chip Laser Links



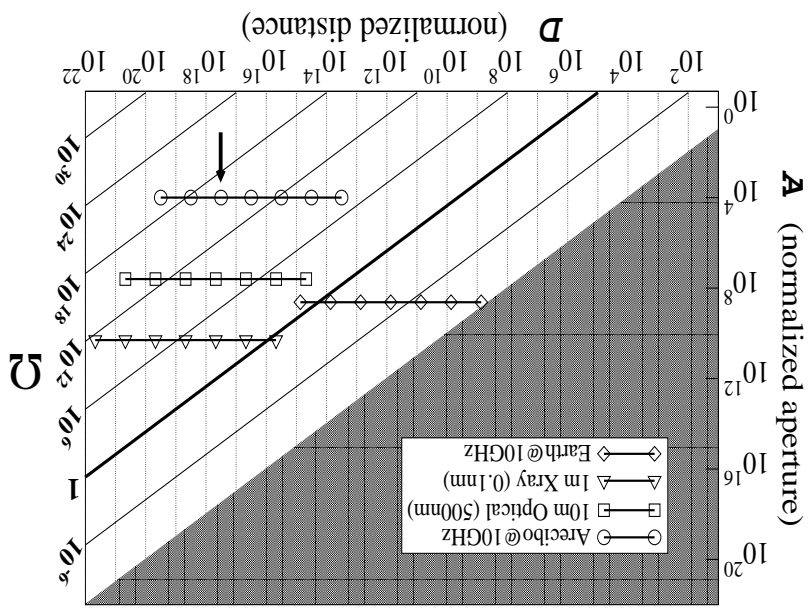
- Delay: $\delta = 10^9$

- Wavelength: $\lambda = 1\mu\text{m}$

- Magnetic storage: $\Omega \geq 10^4$

- STM inscription: $\Omega = 5 \times 10^8$

- 10k LY, Arecibo-Arecibo: $\Omega = 5 \times 10^{15}$
- Radiation/Matter: (2 megaton blast) / (Shelve 5 lb sugar bag)



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



- 10^9 bit payload
 - 900 kg mass
 - Catapult launch: about 800 joules/bit
- Breakeven Distance: 2000 light years**
- Asides:
 - Rocket Launch: distance up $\times 9$.
 - Use 3 DVDs (instead of gold disc): distance down $\times 10$



The Physics Has Spoken

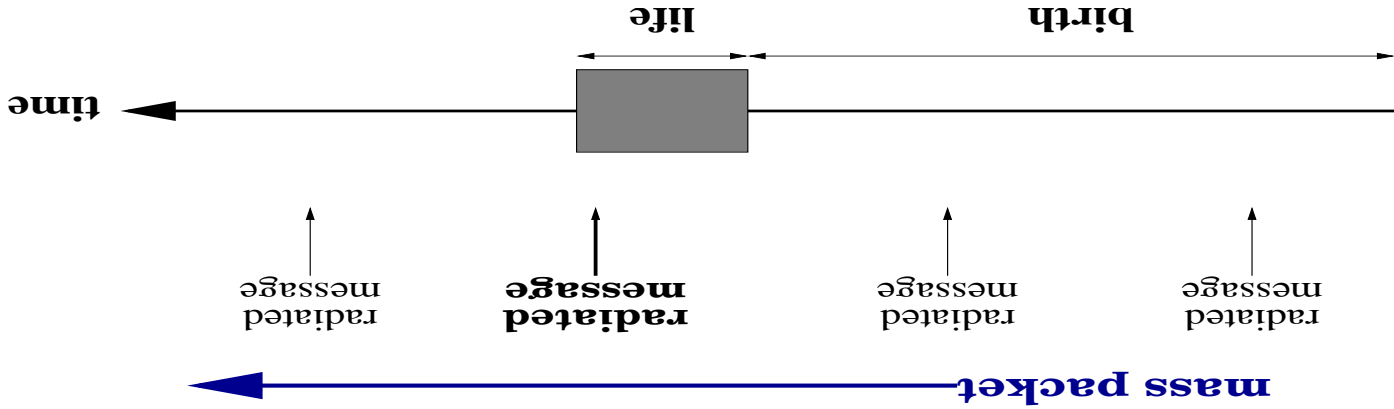
Matter is *stunningly* more efficient for a wide range of distances and methods of radiated communications.

But what about ...

Matter and Radiation Penalties

- **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?

- $\Phi = 0.99 \rightarrow 2 \times 10^5$
 - $\Phi = 0.9999 \rightarrow 2 \times 10^7$

No, inscribed matter still wins!

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

Is Radiation Better for Broadcast?

Inscription Energy/Speed

- Matter Inscription/Readout Energy and Time
 - Can be reversible and arbitrarily 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

Parking the Package

- Assume exhaust braking
- Energy penalty (excess mass): $e \frac{\delta g I_{sp}}{c}$
- $I_{sp} \equiv$ 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

Aim not a big problem

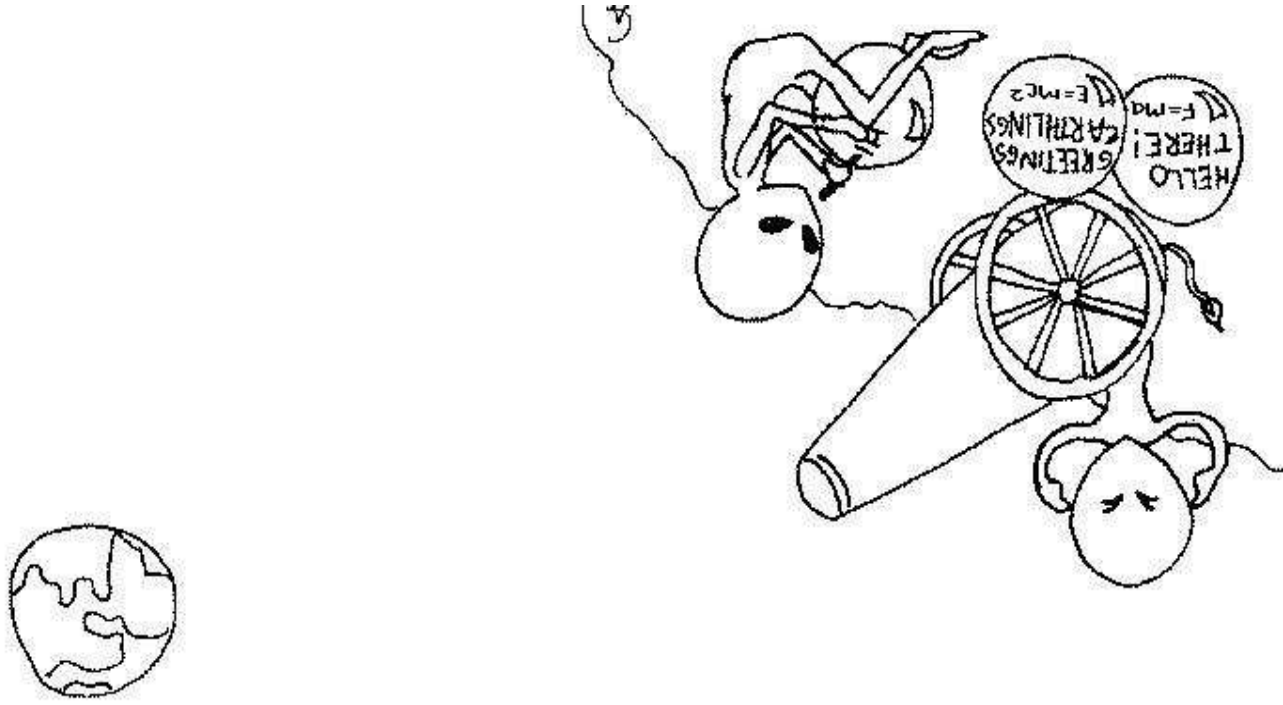
- $M = 2 \times 10^{30} \text{kg}$ (solar)
 - $v_0 = c/1000$
 - Stellar Density: 2.8×10^{-2} stars (LY) $^{-3}$
 - 10kLY trip mean miss distance: $\approx 0.14 \text{LY}$
- Angular Deflection: $\theta \approx \frac{2MG}{v_0^2 y_0}$ (radians)

Gravitational Perturbations

- **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?**

Cosmic Insults

ET might write not radiate



Overall Implication

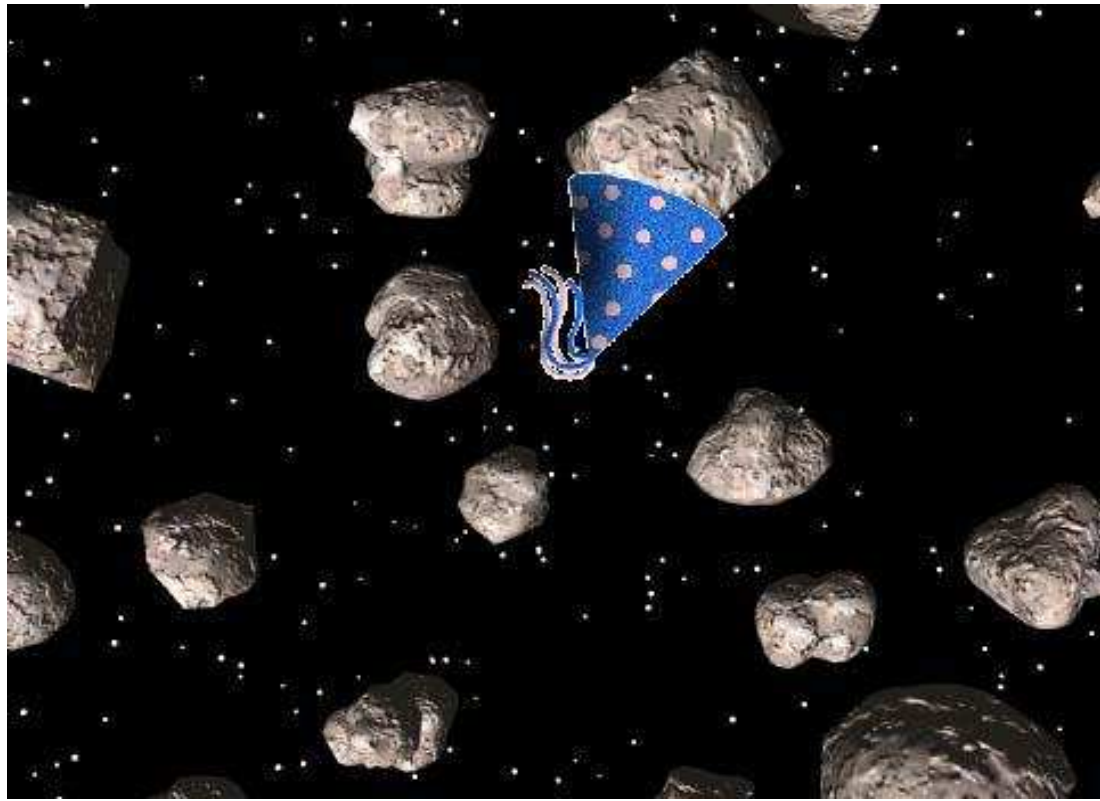
Message Advertisement?

Solar Space is BIG

Somewhat antisocial



Big Rock?

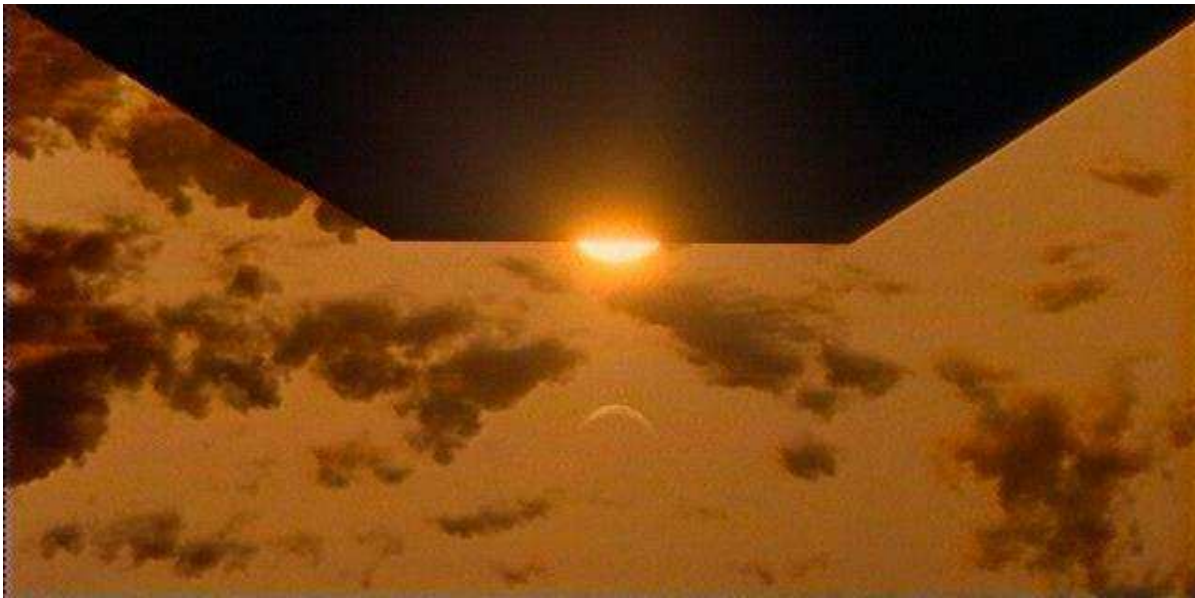


Odd Rock?

Write Not Radiate



Seeded Comet?



Active Probe?

Write Not Radiate



Life Boat?

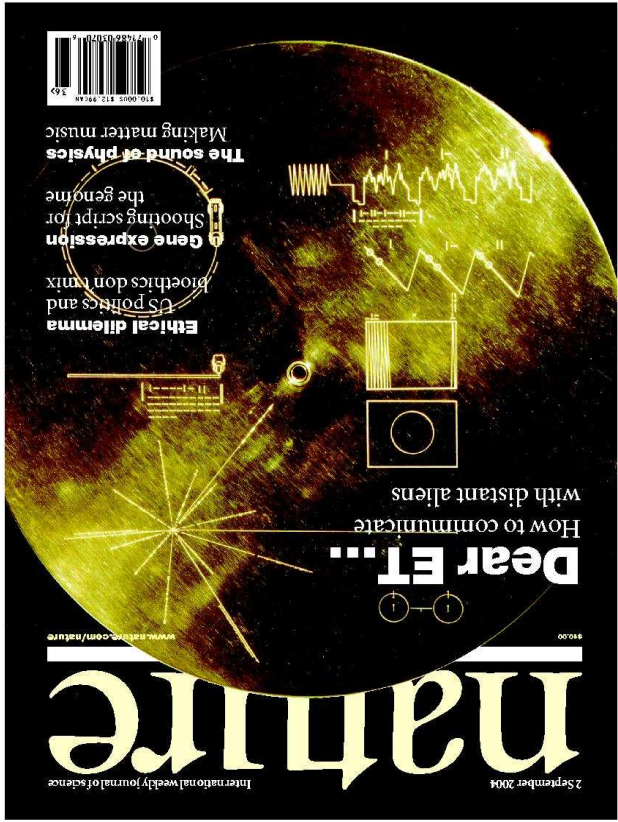
Write Not Radiate

If Delay Acceptable

CONCLUSIONS

- Inscribed matter messaging is efficient
 - FedEx and Netflix
- Might even finesse Gupta-Kumar *ad hoc* nets \sqrt{N} problem
 - little data missiles
- Chip-to-chip or mote-to-mote communication
 - smart dust tossing inscribed dust
- **Should start looking for extraterrestrial artifacts**

Nature 431, pp.47-49, September 2, 2004
Web Site: <http://www.winlab.rutgers.edu/~crose/cgi-bin/cosmic18.html>



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