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Title: ELROI Extremely Low Resource Optical Identifier. A license plate for your satellite, and more.

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ELROI

Extremely Low Resource Optical Identifier

A license plate for your satellite, and more.

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The Space Problem

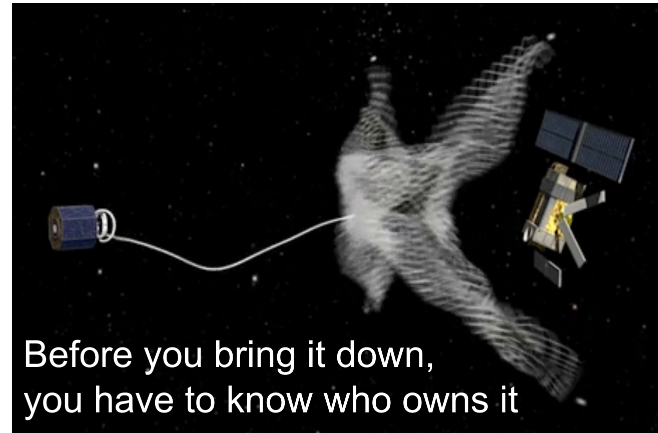
Space Policy concerns:

- Contested, Congested and Competitive
  - 24 Skybox satellites, 700 OneWeb, 4000 SpaceX, everybody's cubesats…
- Collision Avoidance and Space Traffic Control
- Anomaly resolution and recovery

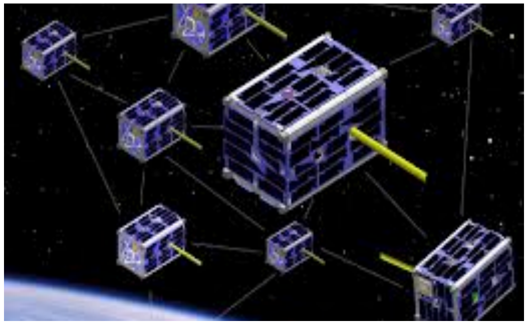
We have a solution: **an Optical Beacon to attach to everything that goes into space**

- Broadcasts satellite identity at all times
- Autonomous, safe, low SWaP
- Needs technology development for implementation
- May need policy push in addition to market pull for widespread adoption

Once you've lost track,
it's just another light in the sky
or blip on your radar

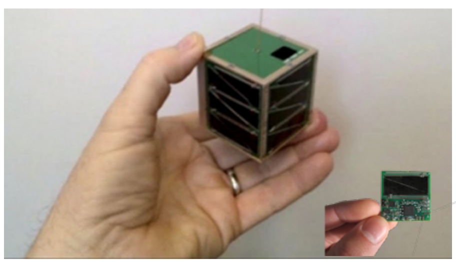


Before you bring it down,
you have to know who owns it



You just launched 23 Cubesats.
Great! Which one's which?

It's stopped talking to you.
What happened?



Satellites get smaller and
push tracking capability limits.
Can we make them 'brighter'?

If the object has an optical beacon, we can read its identification from a ground station.

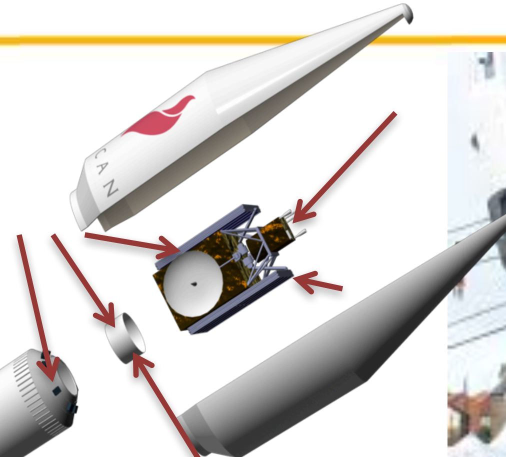
Black box?
We can read that too!

The ground station:
a small telescope and
photon counting camera

Traffic in other domains (land, sea, air) has identifiers.

Why not in space?

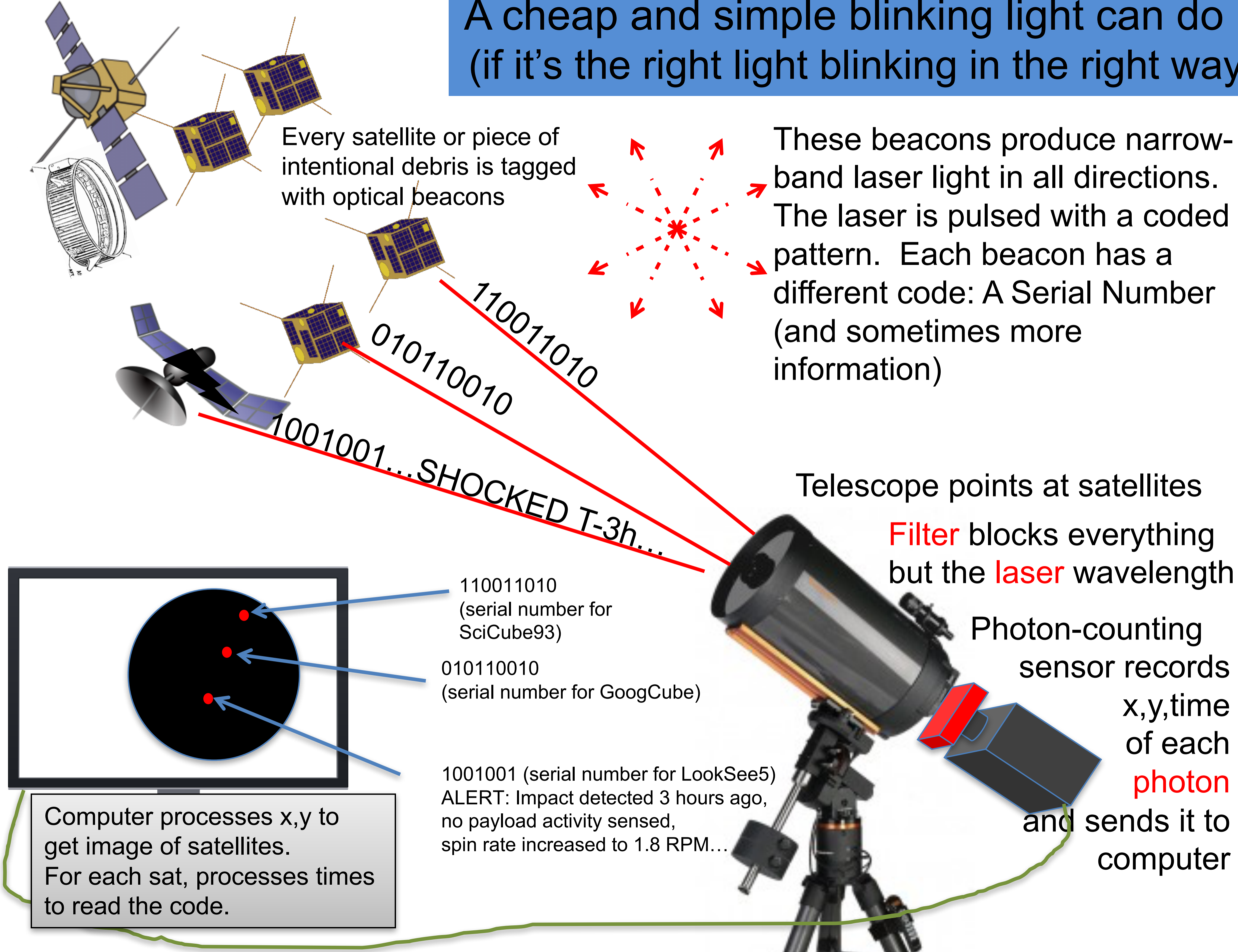
Small enough
For Cubesats



Debris objects too, if they reach orbit

"If it doesn't splash,
make it flash"

A cheap and simple blinking light can do
(if it's the right light blinking in the right way



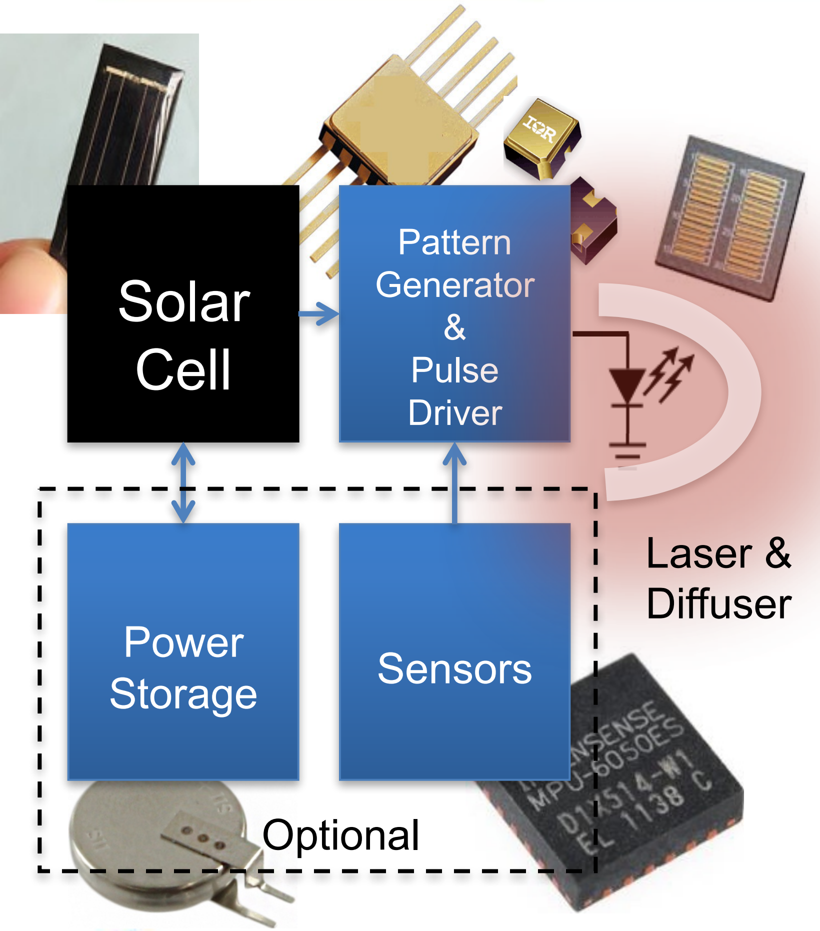
Cheap, Dependable, Useful

The identifier beacon should be

- **Scalable**
  - Start with a million serial numbers, but leave room for more
- **Reliable**
  - So it will last until the object de-orbits, long past the operational life of the payload.
- **Autonomous**
  - Attached to inert objects such as rocket bodies.
  - Doesn't require resources from a payload.
  - Keeps working even when spacecraft doesn't.
- **Readable from the ground with modest equipment**
- **Localizable**
  - Only one space object in your receiver resolution element.
- **Small, Light, Cheap and Simple to integrate**
  - So it can be used with small, light and cheap spacecraft.
  - No RFI, no signals, commands or power from payload
- **Value Added**
  - Operators will use it even if not required.

A Low Power Optical Beacon can do this!

Transmitter is simple in design, low in SWaP, cheap to produce, and easy to fly (Extremely Low Resource Optical Identifier)



SWaP and Integration

•**~1 mW** radiated optical power

•**1 cm² solar cell** provides ~2 mW total system power

•**2 cm x 2 cm x 0.5 cm, few grams**

like a thick postage stamp

Want more capability? A little bit larger is still small.

•**Autonomous and Non-interfering**

Self-powered, no data/commands, no RFI

No on/off switch or 'remove before flight'

Glue it to your spacecraft and forget it.

•**No failure cascade to/from Host**

Black Box

•IMU and other internal sensors can provide impact detection, discharge, etc. without host input (even solar cell alone gives spin rate)

•Autonomous: anomalies detected and reported back even if satellite goes silent

Ground Station is a Photon-Counting Sensor On a Small Telescope

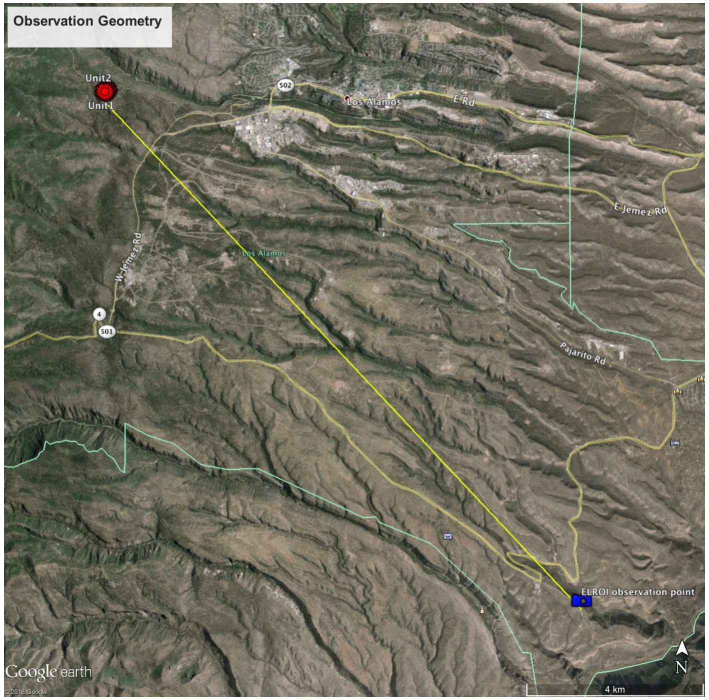
A COTS Raven Class telescope, in this case a 14" Celestron on a Paramount ME tracking mount, is combined with a photon counting sensor to act as a receiver.

Photon counting sensor from Photonis is the COTS equivalent to the LANL-developed sensor on our current ground station.

Timing: 10 GHz equiv. bandwidth allows large coding gain

Imaging: cover a ~1° field for poor TLEs,
simultaneously ID all swarm members in FOV,
get improved metric tracks for free.

Progress July 2016: Horizontal Range Test



Ground-to-ground test at 15 km range
- Equivalent atmospheric depth > sea-level to space

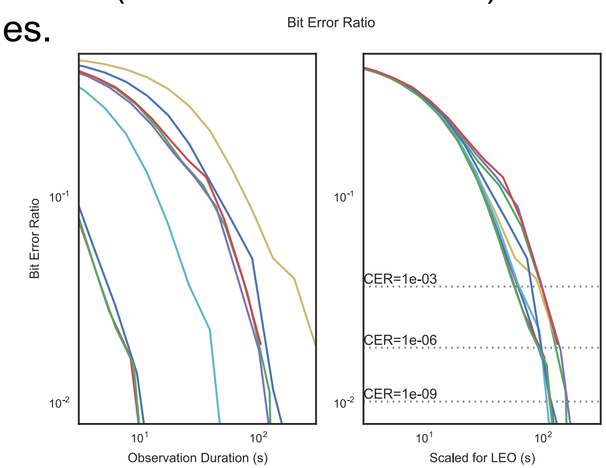
3 mW (isotropic equivalent) average optical power
- Two transmitters (one with additional attenuation)

Camera lens on photon-counting sensor

Aperture and attenuation to span range 0.1-40 counts/second
- Count rates agree with model predictions
- Same model predicts 3.3 counts/s for LEO to ground station

Satellite ID codes successfully read and distinguished

Scaling detection times to LEO count rate indicates recovery of accurate code 105-157 seconds (at 1000 km from ground station)
- Confidence level of 1 in a billion (Codeword Error Ratio) using error-correcting codes.

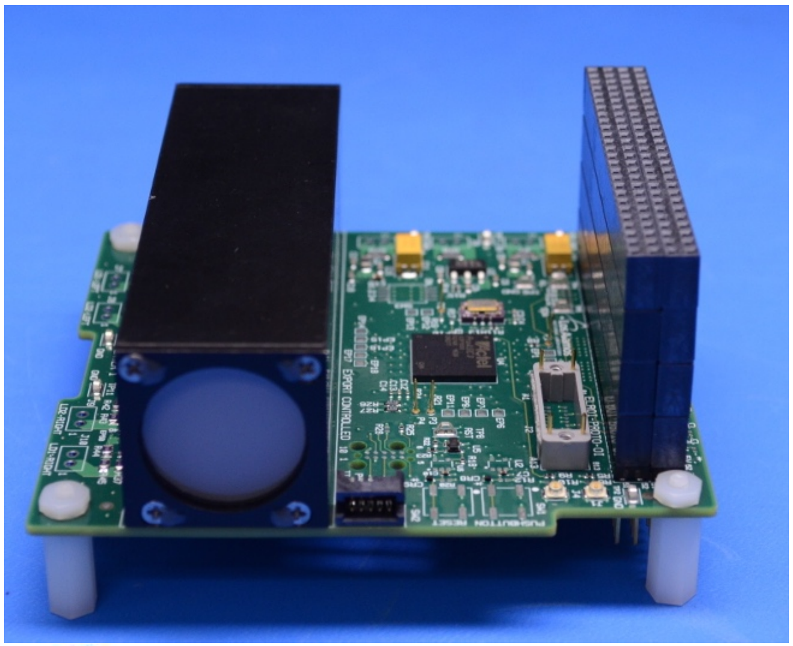


Progress April 2017: ELROI-PC104 Flight Unit Delivery to New Mexico Tech

ELROI-PC104 Flight Unit in CubeSat internal card form factor

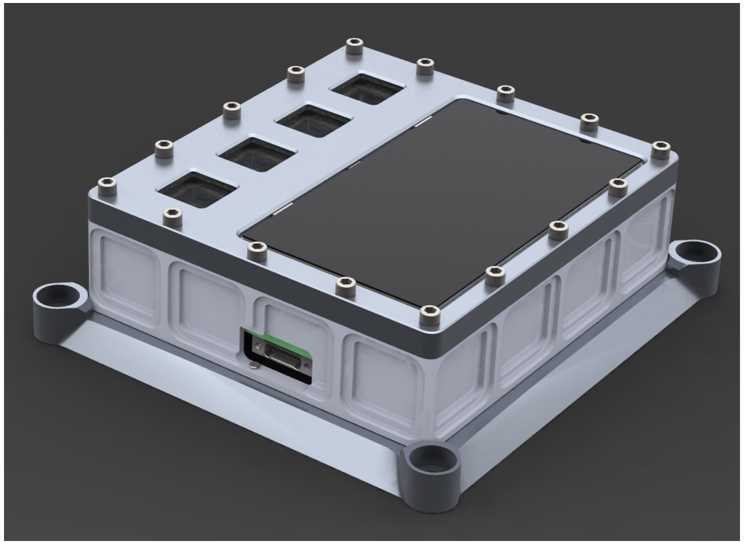
Integrated into New Mexico Institute of Technology's CubeSat (NMTSat)

Launch scheduled March 2018 (RocketLab Electron)



- 4 independently operating laser diodes
  - 638 nm red, 1W and 0.7 W peak
  - 638 nm red 1W, 450 nm blue 1.7 W
- Operates in autonomous mode on spacecraft power
  - Does not require spacecraft CPU boot
  - 45 minute delay after power-on
  - 3 red laser diodes, each with distinct code
  - 5.4 mW average optical power
  - 56 mW power consumption
- Can be commanded by spacecraft CPU
  - Codes on each diode change to transmit status
  - Blue diode can be activated (takes additional power)
  - Timing parameters variable to test link budget

Progress September 2017
ELROI Universal Prototype (ELROI-UP)



9.8 x 9.2 x 3.1 cm^3, 300 grams

Bolt to any space object
- Self powered and/or host powered
- Autonomous and/or commanded

Or attach CubeSat rails for a free-flyer

4 x 2.5 W peak power 638 nm laser diodes
- Each of 4 ID codes use any/all diodes
  - Per-code peak power 2.5 – 10 W

Currently in fabrication
- 6 units being built
- Looking for flight test opportunities

The Future: ELROI 1.0

$2 \times 2 \times 0.5\ cm^3$
"Thick Postage Stamp"

Autonomous

Cheap

Stick-anywhere (for small LEO objects)

Requires industrial design but less complicated than, *e.g.*, a wristwatch

Conclusions

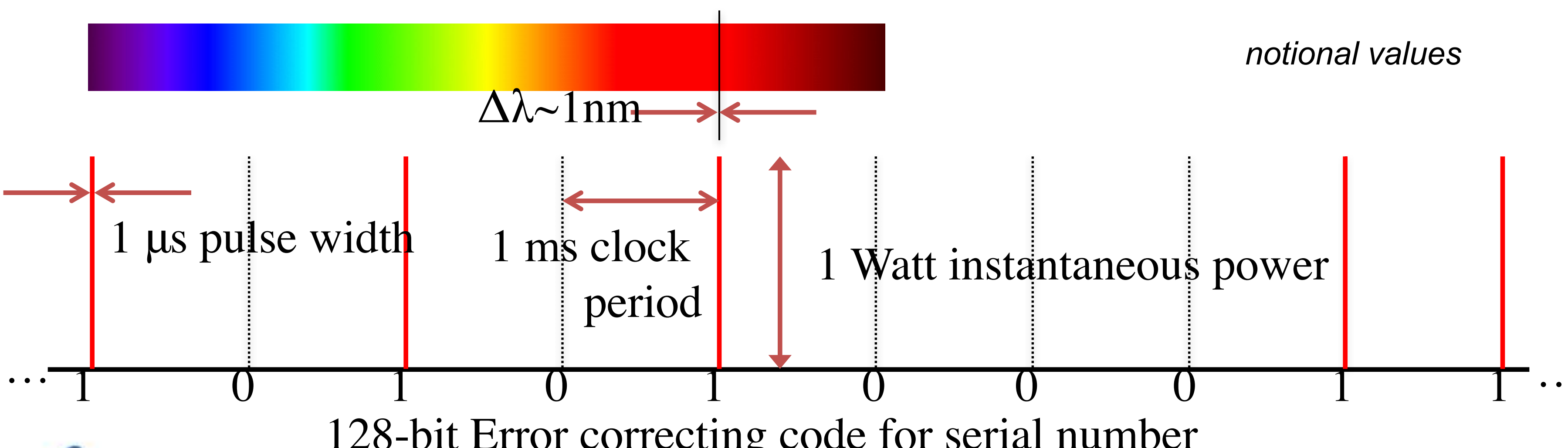
- ELROI is new CONOPS for ID, Tracking, and Diagnosis of space objects
- The technology is operating (ground receiver), flight ready (ELROI-PC104), being manufactured (ELROI-UP), or has a feasible path to production (ELROI-1.0)
- Cost / benefit ratio will make it attractive for spacecraft operators on many payloads
  - Norm setting, Policy, or international agreement may be required to get it on every new satellite or piece of space debris
  - But each object with a beacon is a step forward

Back-ups

Extremely Low Power Optical Signals Can Transmit Identification From Orbit to the Ground

Modest optics can robustly identify a specific optical signal with very little power by using narrow wavelength filter and processing gain.

1 mW (average) from LEO can be identified in a single pass, even against a background of a 1 m sunlit satellite.



Black Box and Extra Data Capability

an optional upgrade

The laser emitter can also transmit additional data in between the pulses that encode the serial number. Using Code Division Multiple Access (CDMA)-like techniques, this additional data has very little interference with the primary identification function. *E.g.*, By subdividing the nominal 1 ms clock period into ~1 microsecond intervals, each additional laser pulse can encode ~10 bits of information and each clock period can contain multiple pulses, subject to the overall power budget of the system. The CDMA codes can be tailored with different bandwidth/redundancy trade-offs, so the same observation that receives a serial number might also see a flag that says:

I have detected an anomaly: more data on Code B.

Code B would be a high-bandwidth code that requires more resources (a larger aperture receiver, longer observing time, etc.) to bring up above the noise floor. The data on this code could indicate the details of the anomaly including data from additional sensors that might be included in the transmitter package or provided from external sources. For example, mechanical shock sensors can trigger, gyros or magnetometers (or even solar cell voltage changes) could indicate a change in rotation rate. This timestamped information can allow determination of what happened (debris strike, battery explosion, system reboot, etc.) and when, without requiring radio contact with the payload.

Abstract

ELROI (Extremely Low Resource Optical Identifier) is a license plate for your satellite; a small tag that flashes an optical identification code that can be read by a small telescope on the ground.

The final version of the tag will be the size of a thick postage stamp and fully autonomous: you can attach it to everything that goes into space, including small cubesats and inert debris like rocket stages, and it will keep blinking even after the satellite is shut down, reliably identifying the object from launch until re-entry.