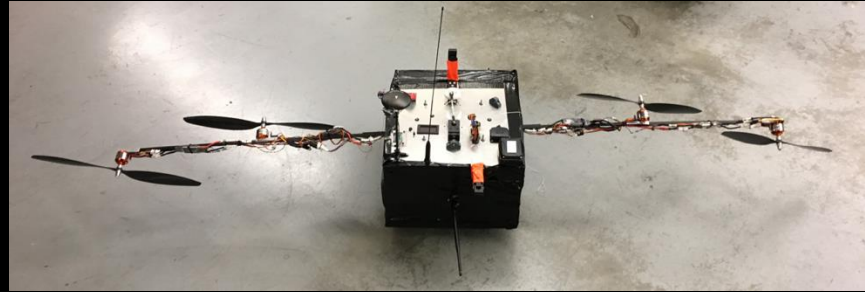
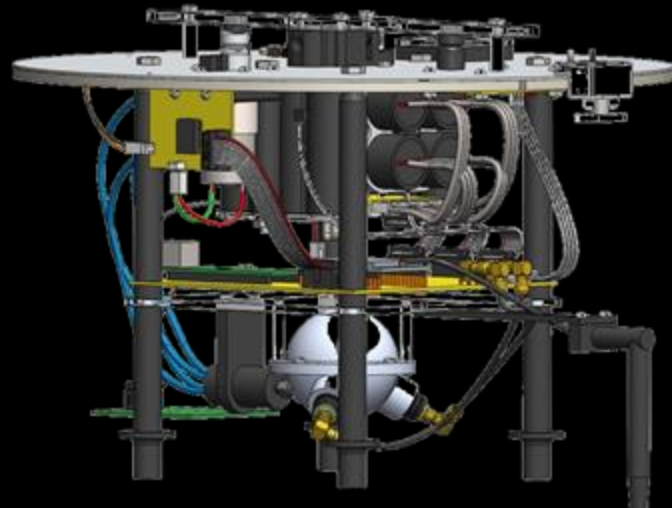


ALTAIR: High-Altitude, Low-Cost Micro-Airships for "Workhorse" Precision Rubin Observatory Calibration & Beyond



Défense nationale National Defence



Justin Albert
University of Victoria



ACCURATE FLUX CALIBRATION
in the Era of Space Astronomy and All-Sky Surveys
October 22-25, 2024

Airborne Laser
for
Telescopic Atmospheric Interference Reduction

jalbert@uvic.ca

Basic Technique & Goal: A 0.1% Calibrated, Mobile Source Above the Atmosphere

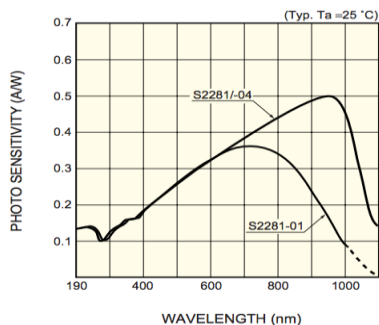
Balloon Payload

100 mW lasers

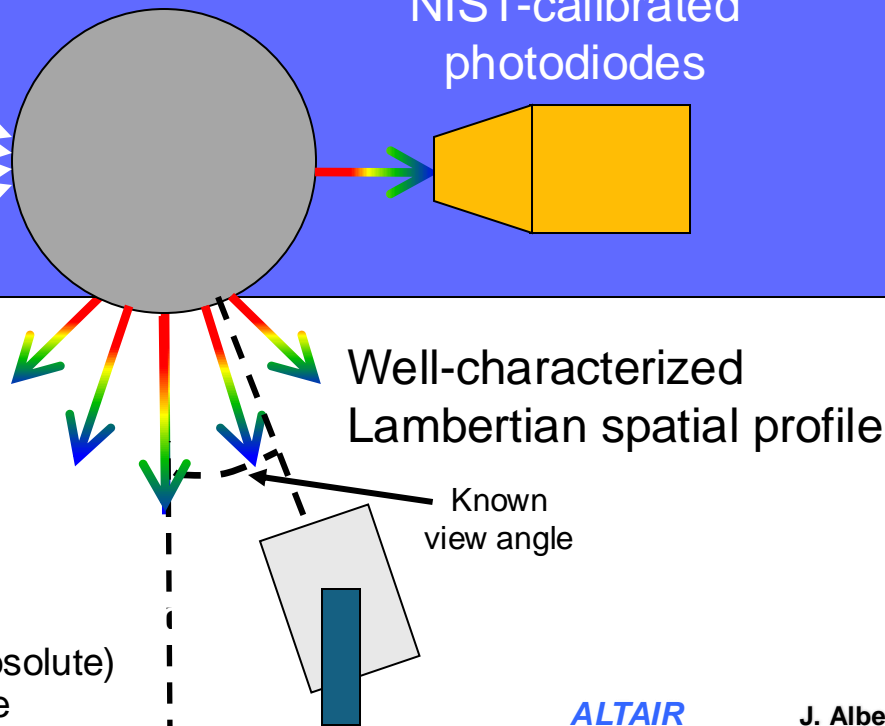


Integrating sphere

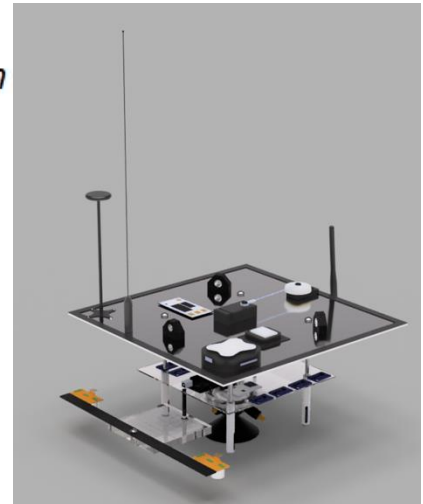
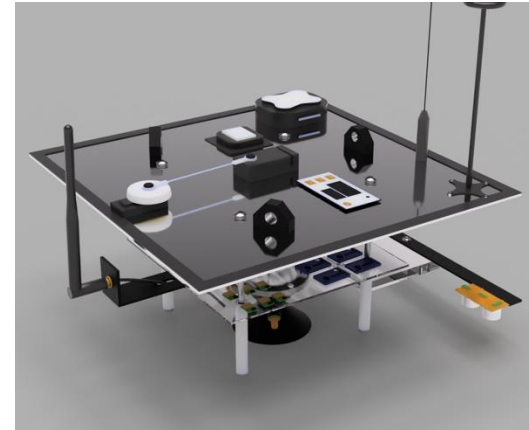
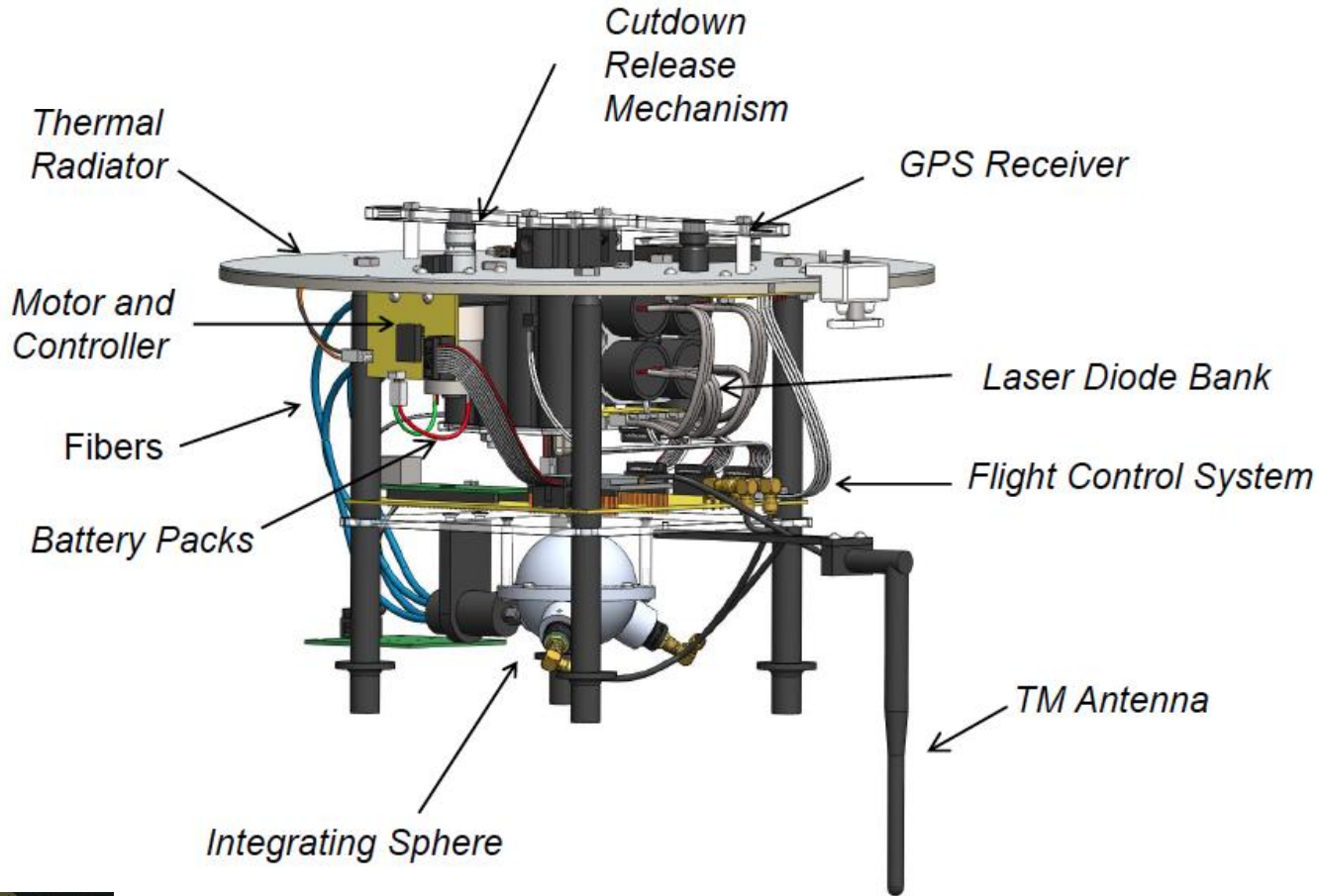
NIST-calibrated photodiodes



NIST- & NRC-calibrated (~ 0.1% absolute) photodiode spectral response



Basic Payload Design



Light Sources & Calibrated Monitoring Photodiodes on 2" ID Integrating Sphere

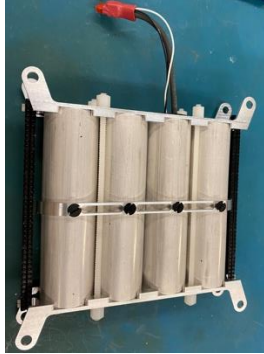
Four WorldStarTech 100 mW laser diode modules, respectively **440 nm**, **532 nm**, **658 nm**, & **830 nm**, each fiber coupled into a fused-ends, "quadfurcated" MM optical fiber (custom fab'd by Ceramoptec).



Can be swapped out for **635 nm** or **780 nm**.

Can be swapped out for **808 nm** or **850 nm**.

Electronics
MCU, TIA,
Laser drivers



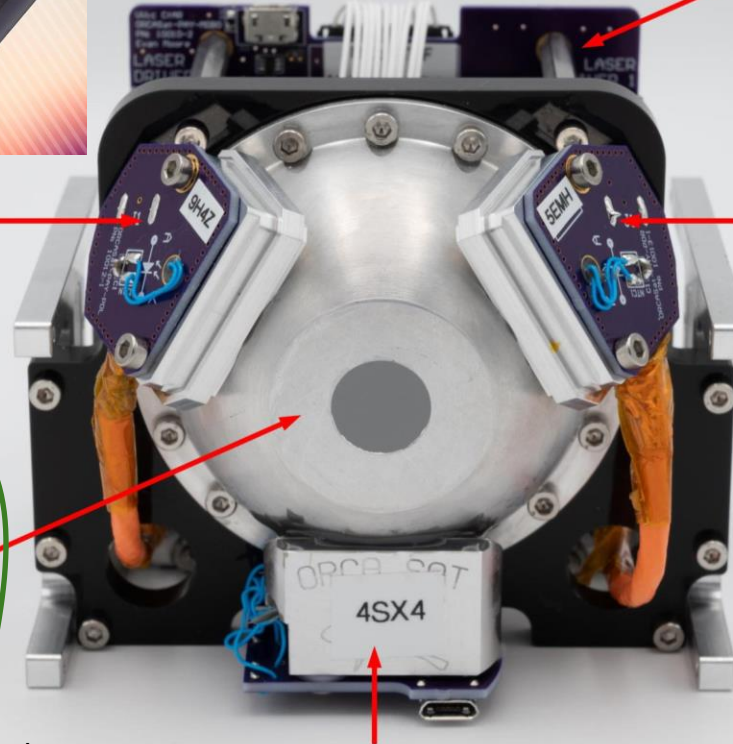
Photodiode 1

Photodiode 2

Integrating Sphere
(coated with Avian B)

Can be swapped out for **405 nm**.

Can be swapped out for **520 nm**.



One photodiode is a **Hamamatsu S12698-01 (Si)** and the other is a **Hamamatsu G10899-03K (InGaAs)**.

(Utilizing two different photosensor material technologies is a useful cross-check.)

Laser Module



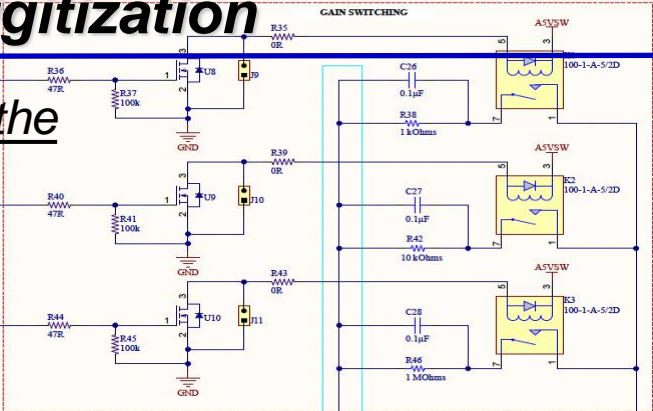
Photodiode readout and digitization

BIAS PHOTODIODE
 Voltage divider of 500k and 10k
 $V = R_2 / (R_1 + R_2) \cdot V_{in}$
 $V = 10k / (500k + 10k) \cdot V_{in}$
 (Resistance at SET pin)

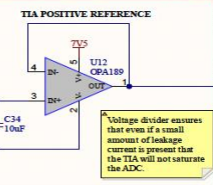
LOGIC HI = Disengaged
 the gain trace (and possibly thick) to pass between the terminals.

Report
 For flight, populate SET resistor with appropriate value, and remove trimmer pot. SET resistor should be low drift.
 Larger capacitance on SET pin reduces output ripple level.
 Current Limit Calculation:
 $I(lim) = 150 / R_{[A]}$
 (Resistance at ILDM pin)
 Max output current is 500mA. To remove current max setpoint, the ILDM to GND.

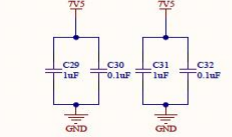
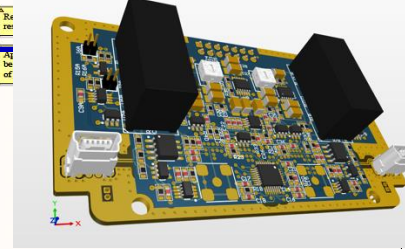
The precision heart of the mission...



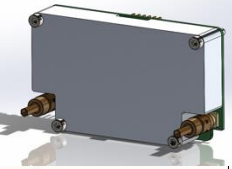
NOTE: Feedback resistors must have EXTREMELY low thermal drift
 Capacitors should have COG/NPO rating



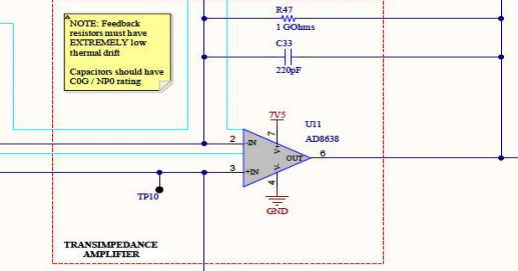
Voltage divider ensures that even if a small amount of leakage current is present that the TIA will not saturate the ADC.



Place caps as close to the V+ terminal of the buffers as possible

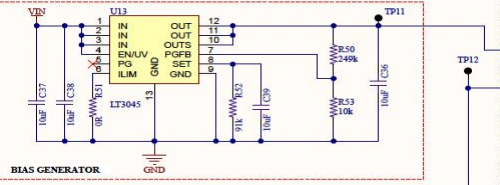


Additional MM2CX connector can be used for direct low noise measurement of TIA output



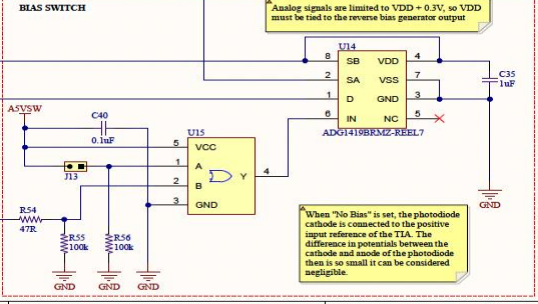
Calculation for primary TIA gain stage resistor:
 Resistor value = R [Ohms]
 Photosensitivity @ wavelength = p [A/W]
 Max incident power on Photodiode = w [W]
 Desired headroom at bottom of scale = b [V]
 Positive Input Bias = b [V]
 $R = (b - b) / (p \cdot w)$
 For $p = 0.35 \text{ A/W}$, $w = 7.4 \text{ mW}$, $b = 0.2 \text{ V}$, and $b = 3.3 \text{ V}$:
 $R = 1194.9 \text{ Ohms}$
 → Round to 1.2 kOhms

Even though the output caps are tied directly to the photodiode cathode, they do not unbalance the system. This has been checked in TINA-TI.
 PGFB threshold = $0.3 \cdot (1 + R14/R18) + (25nA \cdot R14)$
 Sets the cutoff voltage for fast startup



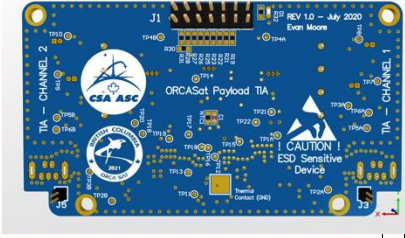
Calculation for the TIA stability capacitor:
 Feedback Resistor Value = R [Ohms] * Calculated above
 Bandwidth of Circuit = F [Hz]
 $C = 1 / (2 \cdot \pi \cdot R \cdot F)$ [F]
 For $R = 1.2 \text{ kOhms}$, and $F = 700 \text{ kHz}$:
 $C = 189 \text{ pF}$
 Note that the exact value of the feedback capacitor is largely unimportant, what matters is its order of magnitude

LOGIC HI = Reverse photodiode bias engaged
 LOGIC LO = No bias on photodiode



Analog signals are limited to VDD + 0.3V, so VDD must be tied to the reverse bias generator output

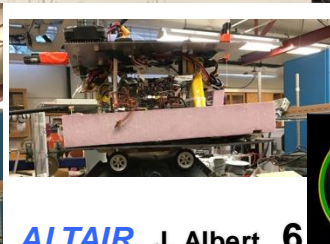
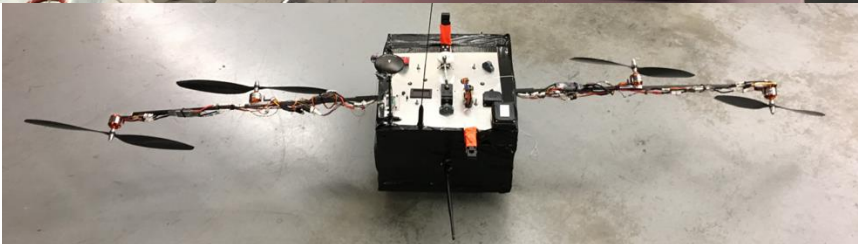
When "No Bias" is set, the photodiode cathode is connected to the positive input reference of the TIA. The difference in potentials between the cathode and anode of the photodiode that is so small it can be considered negligible.



Title	
Size	Number
Tabloid	
Date:	10-13-2021
File:	C:\Users\J. Albert\Documents\ORCASat_Payload_TIA_SchDoc
Sheet of	5



Payload

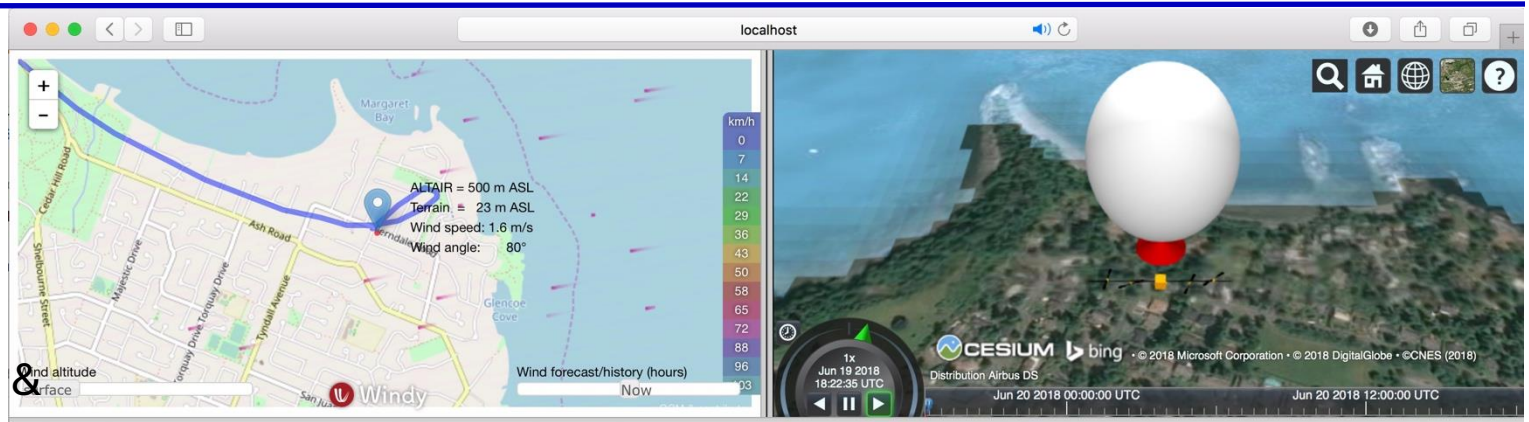


Flight control – AIFCOMSS

Code actively maintained / updated at:

<https://github.com/ProjectALTAIR/AIFCOMSSwithCUPredictorTest>

ALTAIR
Integrated
Flight
Control,
Operation,
Monitoring, &
Simulation
System



Connection Strength
ALTAIR -> ground RSSI = -10.1 dBm
ground -> ALTAIR RSSI = -11.5 dBm
Range = 4438 m

GPS
Lat. = 48.49000°N
Long. = 123.31170°W
Elev. = 500 m ASL
Horiz. σ: 12 m Vert. σ: 29 m

Helium bleed valve: CLOSED
Servo: 0.0/10
Pres: 101.00 kPa
Temp: 0°C
Hum: 11%

Accel vectors
Accel z: -0.5 m/s²
Accel x: -0.5 m/s²
Accel y: 0.0 m/s²

Orientation
Yaw: 0°
Pitch: 0°
Roll: 0°

Axle Rotation
Servo set at: 2.9/10
Meas rot ang: 30°

Ground station in control: CAPELLA
Monitoring GSs: DENEZ
Lat. = 48.48000°N
Long. = 123.37000°W
Elev. = 88 m ASL

Battery 1 (gen. operation)
Voltage = 11.9 V
Temp: 0°C

Battery 2 (propulsion)
Voltage = 11.9 V
Temp: 90°C

Orientation sensor health: OK
Orientation sensor temp: 0°C

Onboard microSD card disk space
Occupied: 920 MB
Remaining: 7040 MB

Cutdown status: NOT CUTDOWN
Servo setting: 5.0/10
Servo encoder: 0°

Power set at: 2.9/10
RPM: 5134
Temp: 0°C
Curr.: 0 A

Power set at: 2.9/10
RPM: 5134
Temp: 0°C
Curr.: 0 A

Power set at: 2.9/10
RPM: 0
Temp: 0°C
Curr.: 0 A

Power set at: 2.9/10
RPM: 5134
Temp: 0°C
Curr.: 0 A

PD - D readout: 0.000 V
PD1 readout: 0.000 V
PD2 readout: 0.000 V

PANIC!

Start Telescope ALTAIR Tracking

Silence present alarms



10/23/2024



Onboard transponder (uAvionix ping900XR)

For continuous real-time communication with and identification to air traffic control.

(FAA & Transport Canada certified.)



So that we don't get shot down by NORAD!!! ;)

(Or by the Chilean air force!!!)

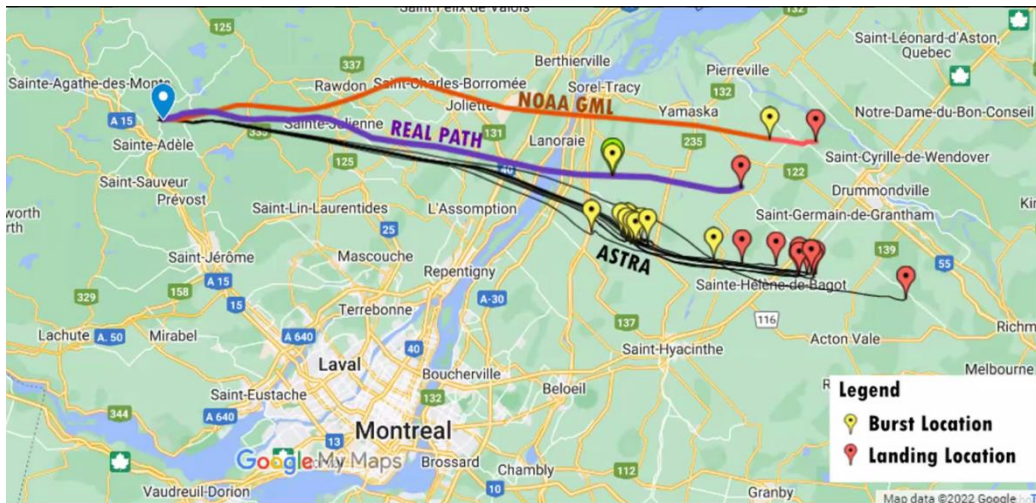


Operations & McGill / Montreal Test Flights



910 MHz
portable
directional
ground
antennas,
range approx.
100 km.

Always ≥ 2
ground
stations in
contact.



Conclusions

- Artificial sources can in principle provide up to two orders of magnitude better photometric calibration precision than any stellar, non-solar light sources can presently.
 - 1) Can ***study them right in the lab before and after use***, unlike stars.
 - 2) Can ***monitor them in-situ***, in real time.
 - 3) Can also be used to ***calibrate white dwarfs*** (and other stars, and the Moon) very precisely, and on a detector-based standards scale.
 - 4) Small balloons are ***inexpensive!!!*** *E.g.: Rubin could own 3 or so!!! – launching them at dusk each night, flying to different areas of the sky, and having them ***return home*** at dawn ***each morning!****
 - 5) ***Fully observer-controlled choice of spectrum*** & color on demand, ... and ***brightness***, ...exact ***location*** in the sky as function of time of night (or day), ...
- **Not restricted to optical/IR!**: e.g. a precisely-polarized Gunn diode-based precision microwave polarimetry calibration source could also be flown. (Radio, near-UV...)
- Balloons, of course, do not replace additionally having a satellite source to (at least occasionally!) determine effects from the very top of the atmosphere!!! But ALTAIR-style balloons can (and I posit will!) be the low-cost, ground-based-observatory-owned, workhorses.



Some separate & additional conclusions (backup slide)

- A very interesting (& very useful) fact about Earth's atmosphere is that, at mid-latitudes, winds in the upper troposphere statistically tend to be in opposite direction to winds in the lower stratosphere.
- Thus, with just very small amounts of (weather-optimized) upward and downward propulsion (just above and below the tropopause), powered using very lightweight flexible solar panels on top of the balloon (+ onboard rechargeable LiPoly batteries for nighttime power), one could utilize the winds to **circulate near the tropopause over a given region of Earth** (e.g., over a region the size of Illinois, or of Vancouver Island, etc).
- After **a few weeks**, a significant fraction of the helium would diffuse through the balloon latex, and the balloon would **descend to base** for (simple and low-cost!: latex balloons are about \$150) balloon and helium replacement. Then, balloon and payload would be sent back up again.
- This opens up many additional, very different usage possibilities:
 - 1) **Communication**: replacing the need for cell-phone towers with very wide coverage balloons in remote (or not-so-remote) areas.
 - 2) **Earth observation** (for, e.g., long-term studies of Arctic ice, etc.)
 - 3) !

