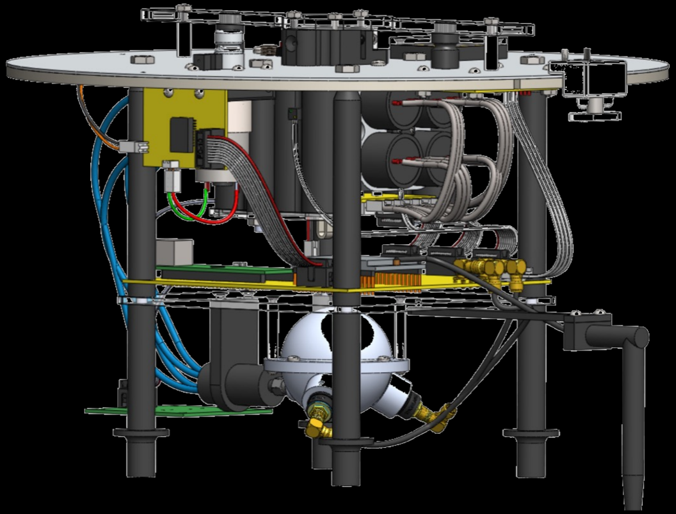
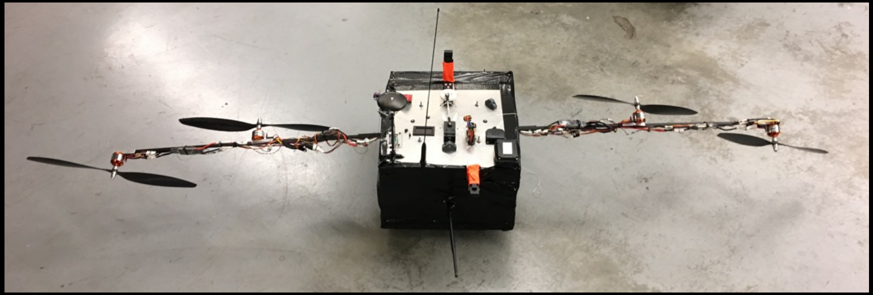
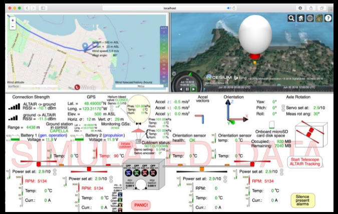
Dark Energy … and a New Miniature Stratospheric Platform for Ultra-Low-Cost Communication, Precision Calibration, & Earth Observation







Engineering Physics Seminar

4 Dec. 2025

Canadian Space Agency / Agence spatiale canadienne

Défense nationale / National Defence

NSERC CRSNG

Justin Albert

University of Victoria

Airborne Laser for Telescopic Atmospheric Interference Reduction

POLYTECHNIQUE MONTRÉAL UNIVERSITÉ D'INGÉNIERIE

jalbert@uvic.ca

Also! :

Neutrinos: **~0.15%**

Electromagnetic radiation: **~0.005%**

Gravitational radiation: *negligible*

Unstable SM matter & radiation: *negligible*

Antimatter: *negligible*

WHY??

How do we know this??

And what are DE & CDM???

Space Expands

Edwin Hubble
1929

<u>Henrietta Swan Leavitt</u> (1868-1921)

Discovered the "Leavitt Law" in 1912 which relates the luminosity vs. the period of Cepheid variable stars … which then allowed Hubble to determine that the Universe is expanding in 1929. (Leavitt & Pickering, HCO Circular **173**, 1 (1912))

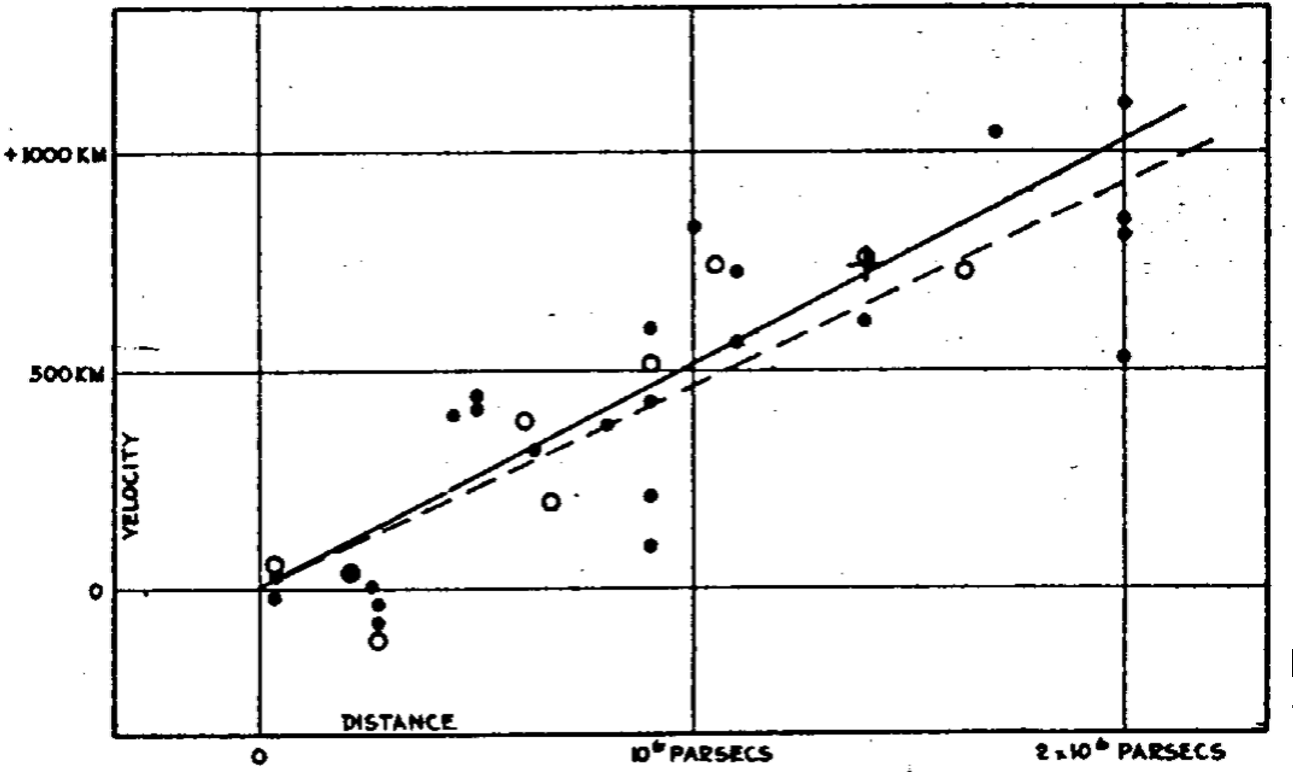
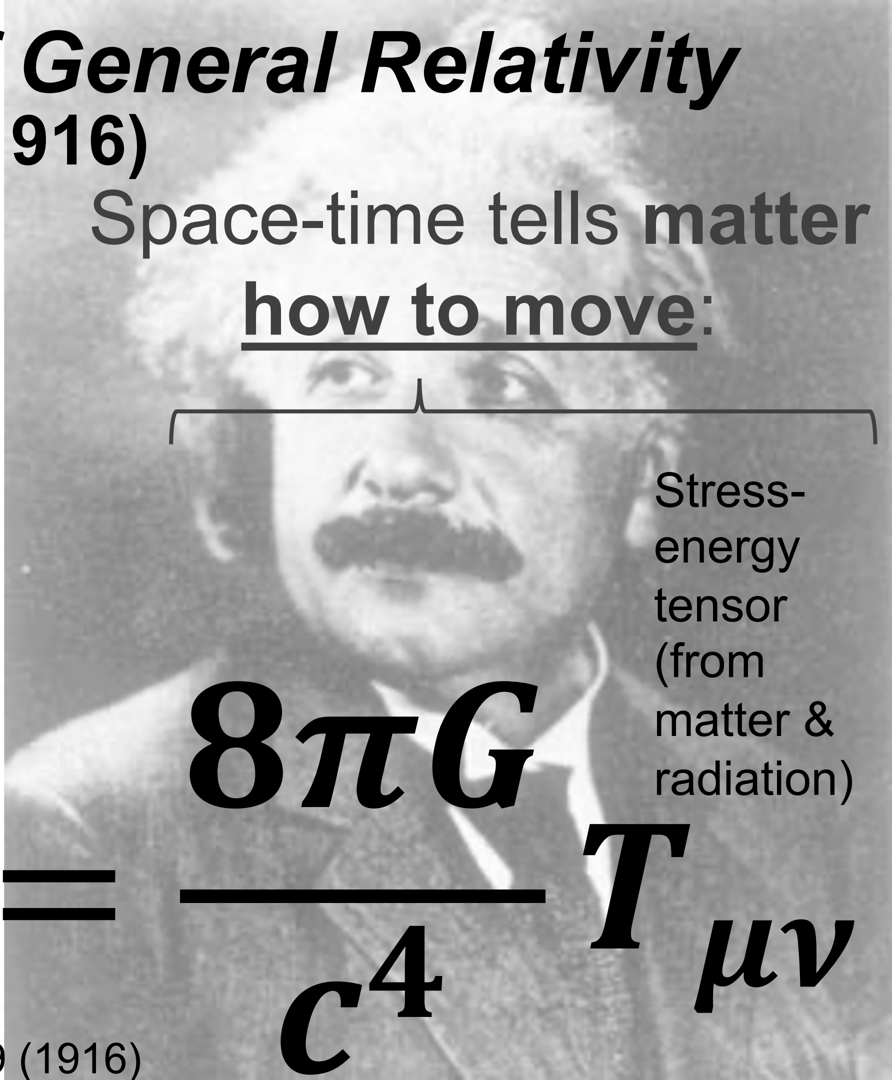


FIGURE 1

Hubble, PNAS **15**, 168 (1929)

Einstein's Equations of General Relativity (1916)



Matter tells **space-time** **<u>how to curve</u>**:

Space-time tells **matter** **<u>how to move</u>**:

Einstein tensor

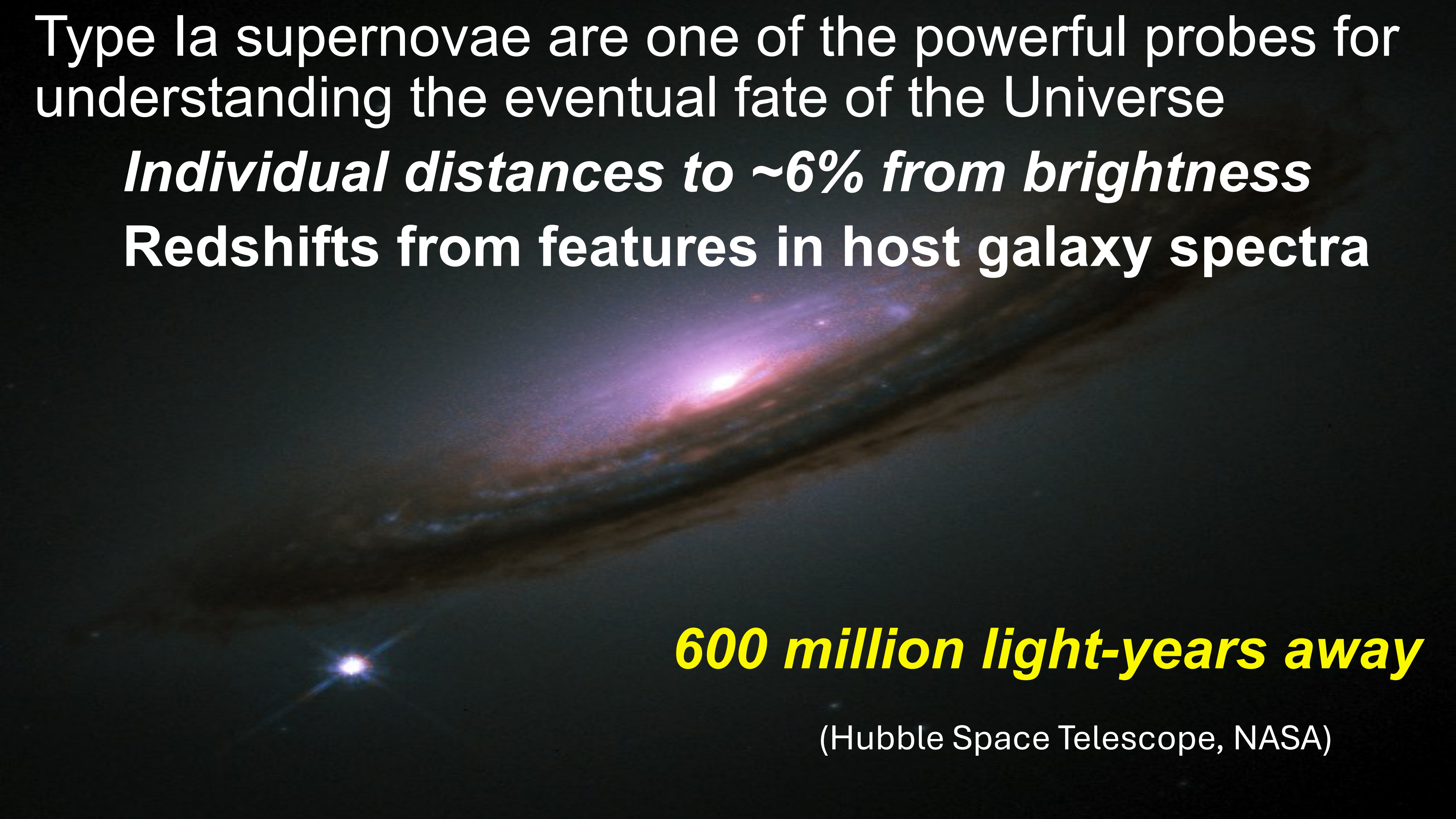
Cosmological constant (energy density of empty space)

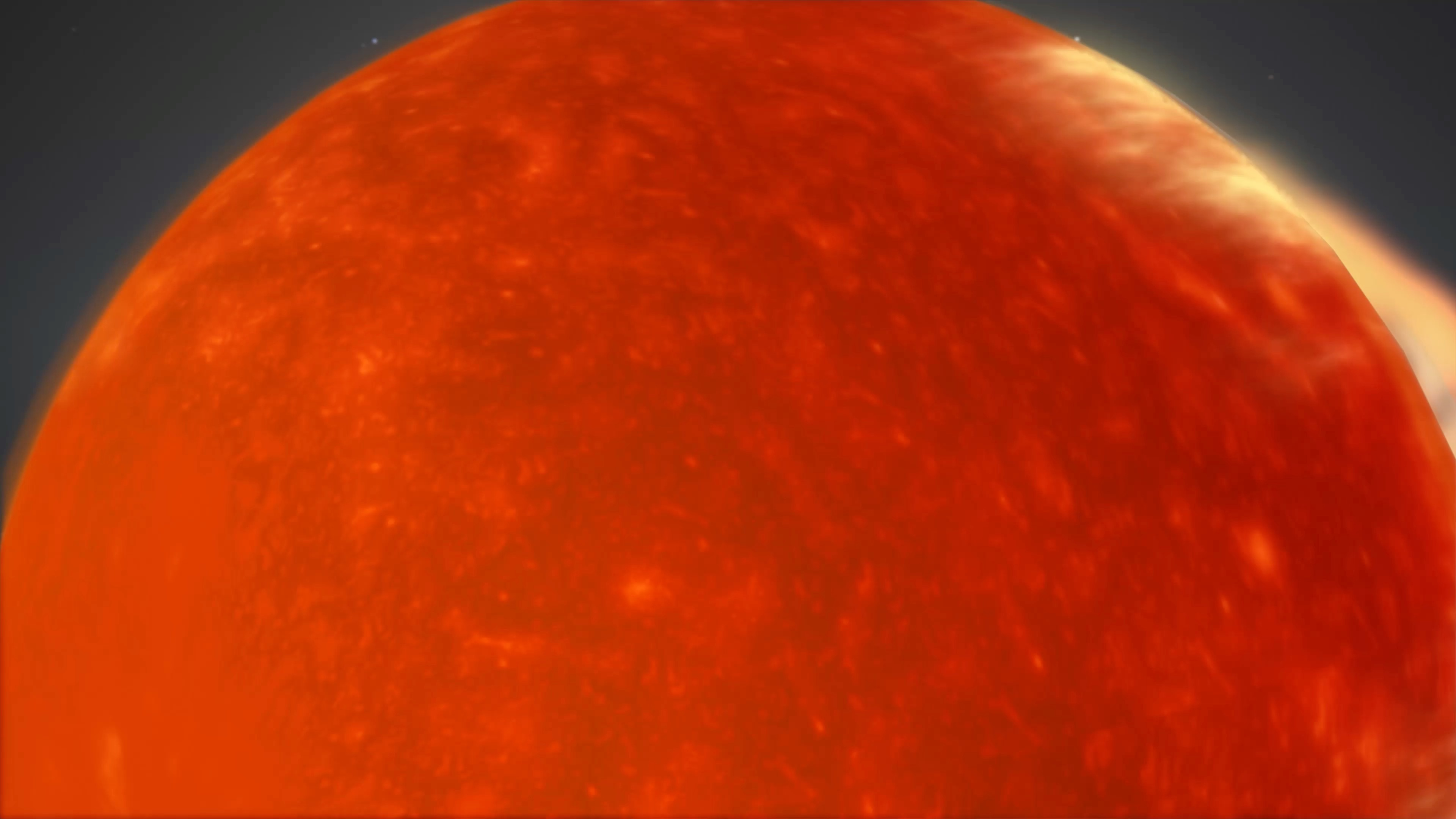
Metric tensor

Stress-energy tensor (from matter & radiation)

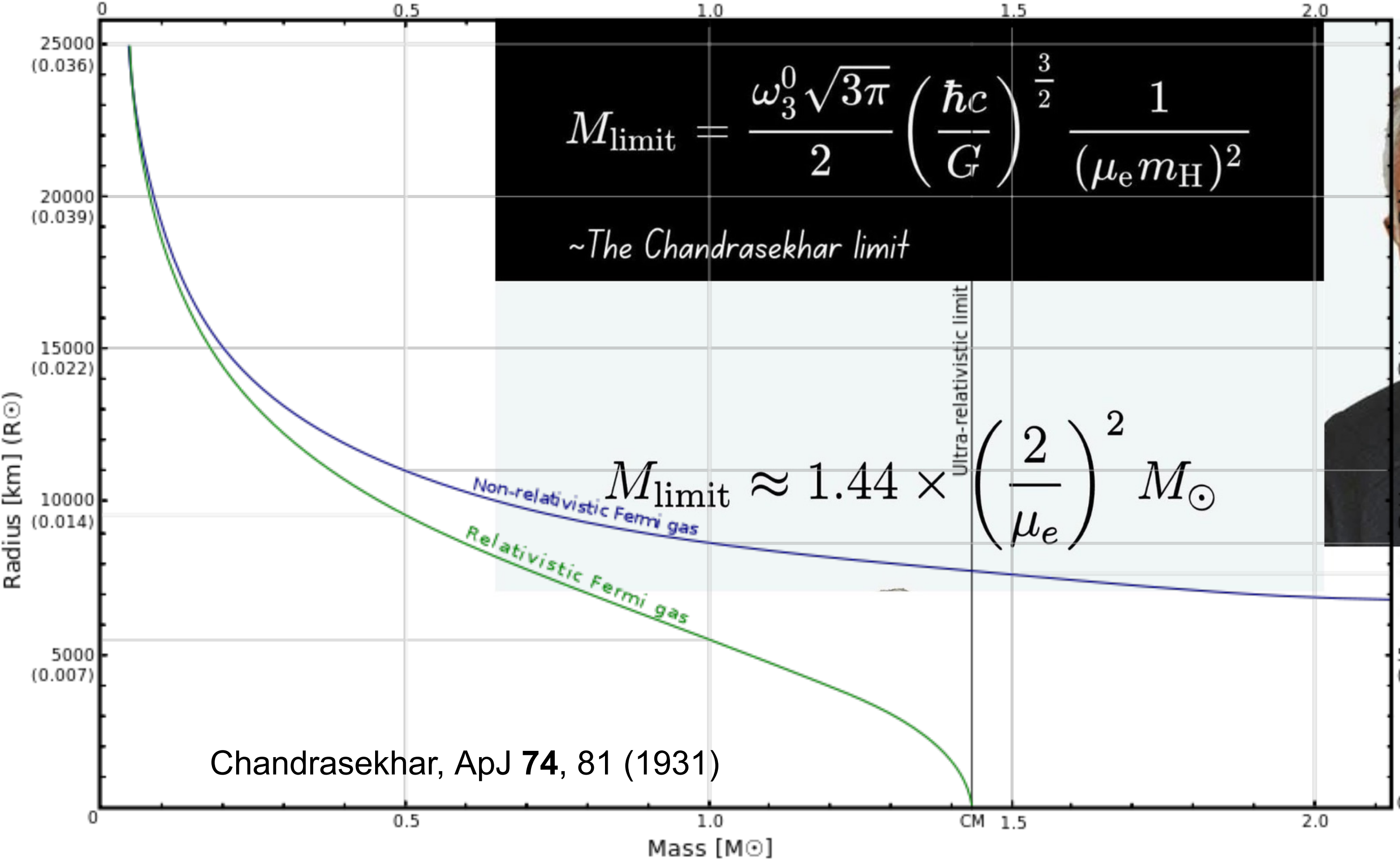
$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Einstein, Annalen der Physik **354**, 769 (1916)


Type Ia supernovae are one of the powerful probes for understanding the eventual fate of the Universe
Individual distances to ~6% from brightness
Redshifts from features in host galaxy spectra
600 million light-years away
(Hubble Space Telescope, NASA)



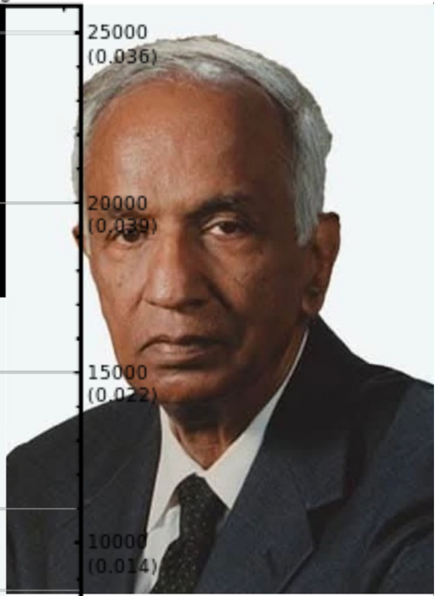
Chandrasekhar Limit on White Dwarf Mass



$$M_{\text{limit}} = \frac{\omega_3^0 \sqrt{3\pi}}{2} \left(\frac{\hbar c}{G} \right)^{\frac{3}{2}} \frac{1}{(\mu_e m_H)^2}$$

~The Chandrasekhar limit

$$M_{\text{limit}} \approx 1.44 \times \left(\frac{2}{\mu_e} \right)^2 M_\odot$$



Subrahmanyan Chandrasekhar

Hubble's Law

From redshift and distance measurements, we can express the recession speed *v* of a galaxy located at a distance *d* away from us by:

$$v = d \times H_0 \, .$$

The value of the ***Hubble Constant*** H_0 is:

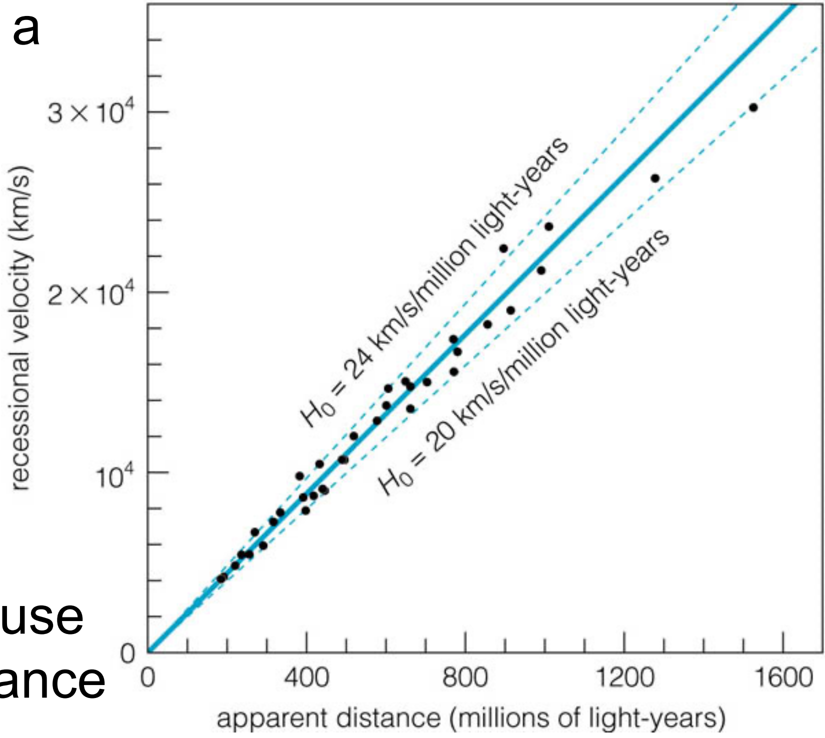
H_0 = ~21.5 [km/sec] / million light-years

or as more commonly expressed: ~70 [km/sec] / Mpc

(1 parsec (pc) = 3.2616 light-years)

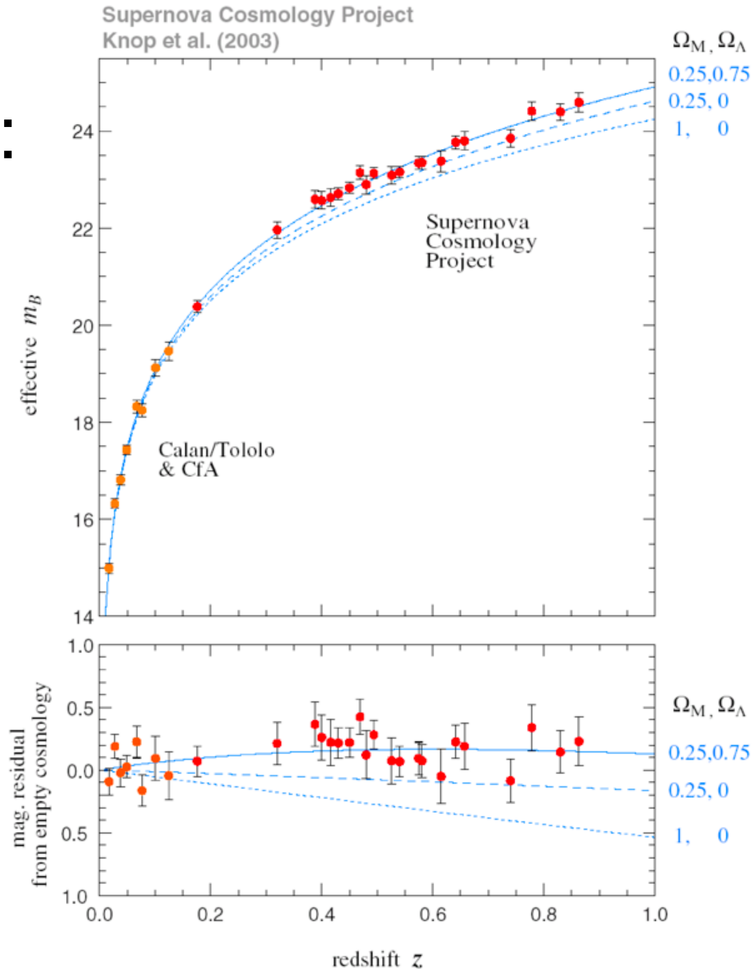
Once the value of H_0 is determined, we can use measured recession speeds to infer the distance of galaxies using the formula:

$$d = v \, / \, H_0 \, .$$

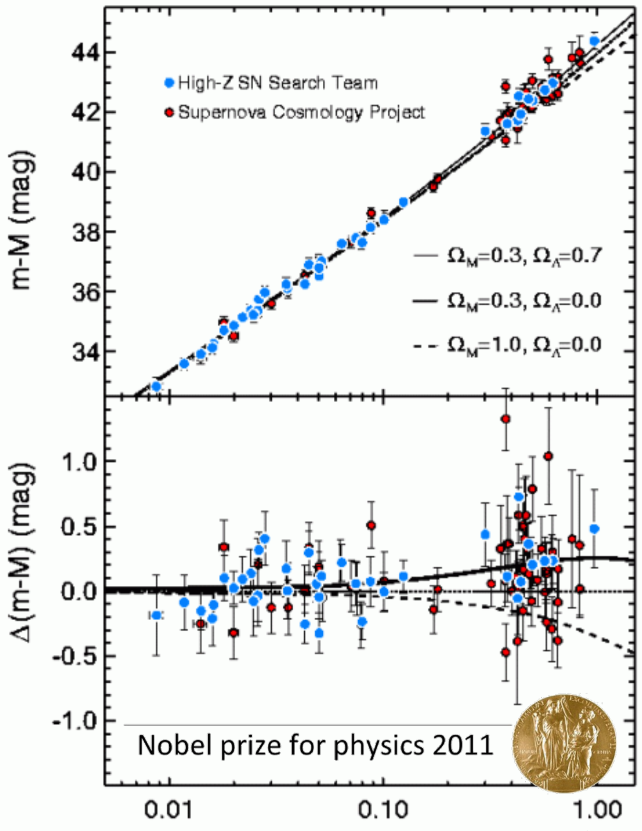


Using SNe Ia to Extend It …

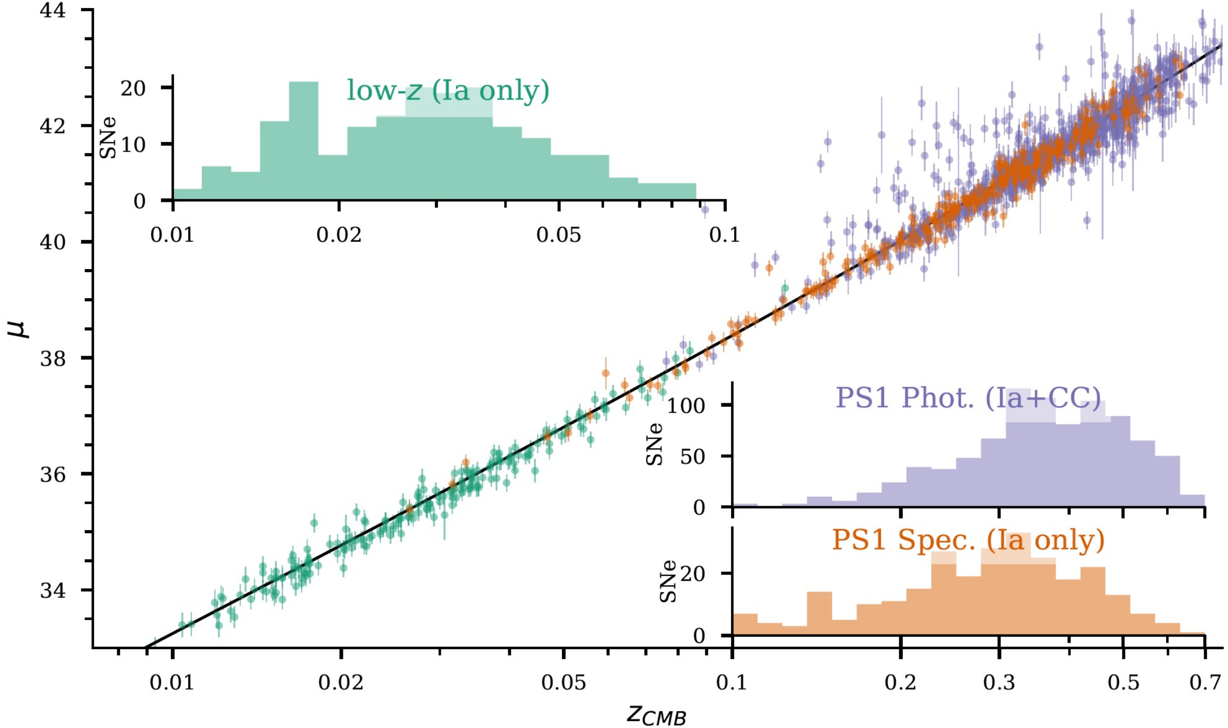
(as of 2003 …) :



(and 15 years thereafter ... :)



Jones et al. (Pan-STARRS PS1 Survey) 2018, ApJ 857, 51



Uncertainty on astronomical photometric calibration has **COMPLETELY DOMINATED** all SNe Ia dark energy measurements for well over a decade now ...

SNLS: *Conley et al (2011), ApJS* ***192****, 1*

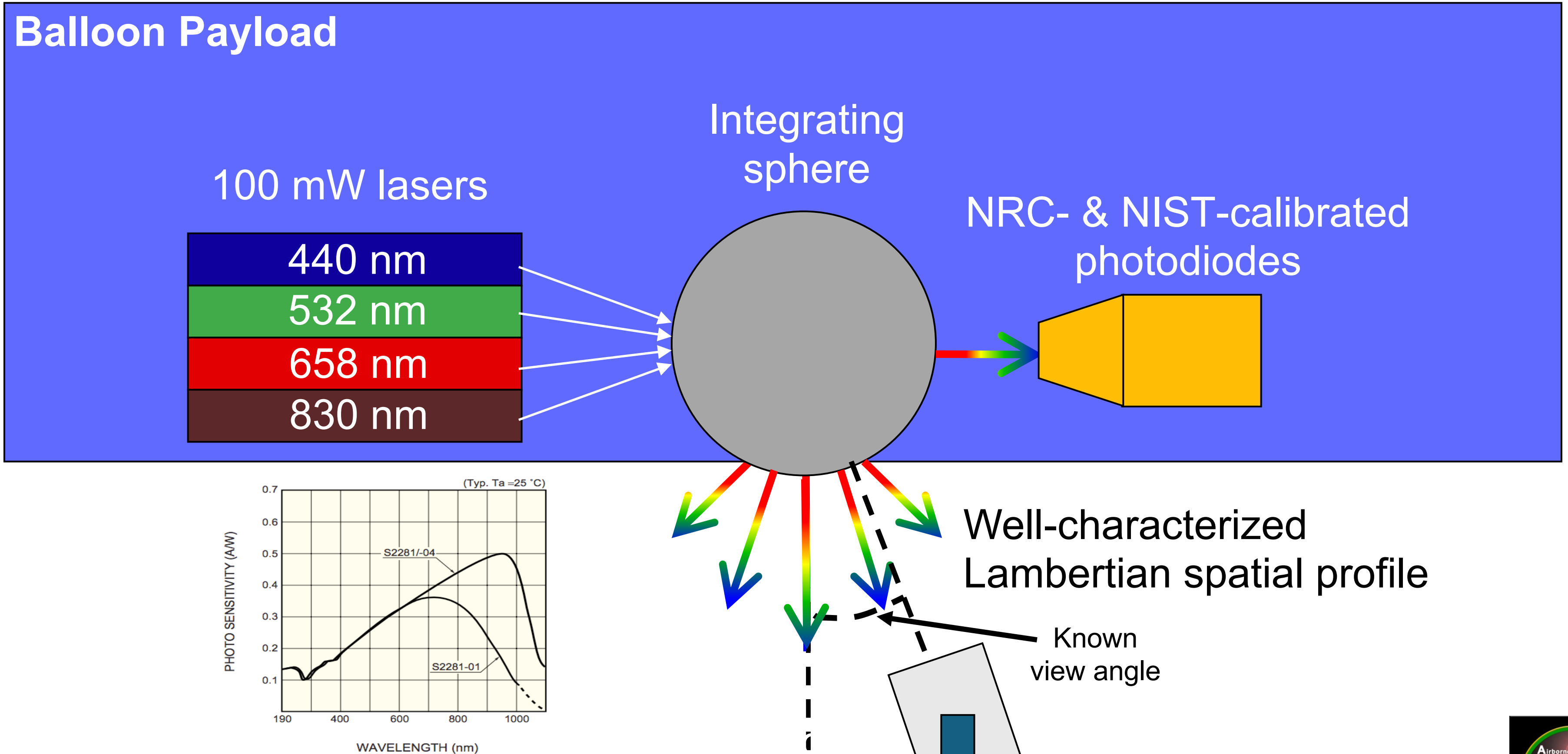
Table 7: Identified systematic uncertainties

Description	Ω_m	w	Rel. Area [a]	w for Ω_m=0.27
Stat only	$0.19^{+0.08}_{-0.10}$	$-0.90^{+0.16}_{-0.20}$	1	-1.031 ± 0.058
All systematics	0.18 ± 0.10	$-0.91^{+0.17}_{-0.24}$	1.85	$-1.08^{+0.10}_{-0.11}$
Calibration	$0.191^{+0.095}_{-0.104}$	$-0.92^{+0.17}_{-0.23}$	1.79	-1.06 ± 0.10
SN model	$0.195^{+0.086}_{-0.101}$	$-0.90^{+0.16}_{-0.20}$	1.02	-1.027 ± 0.059
Peculiar velocities	$0.197^{+0.084}_{-0.100}$	$-0.91^{+0.16}_{-0.20}$	1.03	-1.034 ± 0.059
Malmquist bias	$0.198^{+0.084}_{-0.100}$	$-0.91^{+0.16}_{-0.20}$	1.07	-1.037 ± 0.060
non-Ia contamination	$0.19^{+0.08}_{-0.10}$	$-0.90^{+0.16}_{-0.20}$	1	-1.031 ± 0.058
MW extinction correction	$0.196^{+0.084}_{-0.100}$	$-0.90^{+0.16}_{-0.20}$	1.05	-1.032 ± 0.060
SN evolution	$0.185^{+0.088}_{-0.099}$	$-0.88^{+0.15}_{-0.20}$	1.02	-1.028 ± 0.059
Host relation	$0.198^{+0.085}_{-0.102}$	$-0.91^{+0.16}_{-0.21}$	1.08	-1.034 ± 0.061

[a] Area relative to statistical only fit of the contour enclosing 68.3% of the total probability.

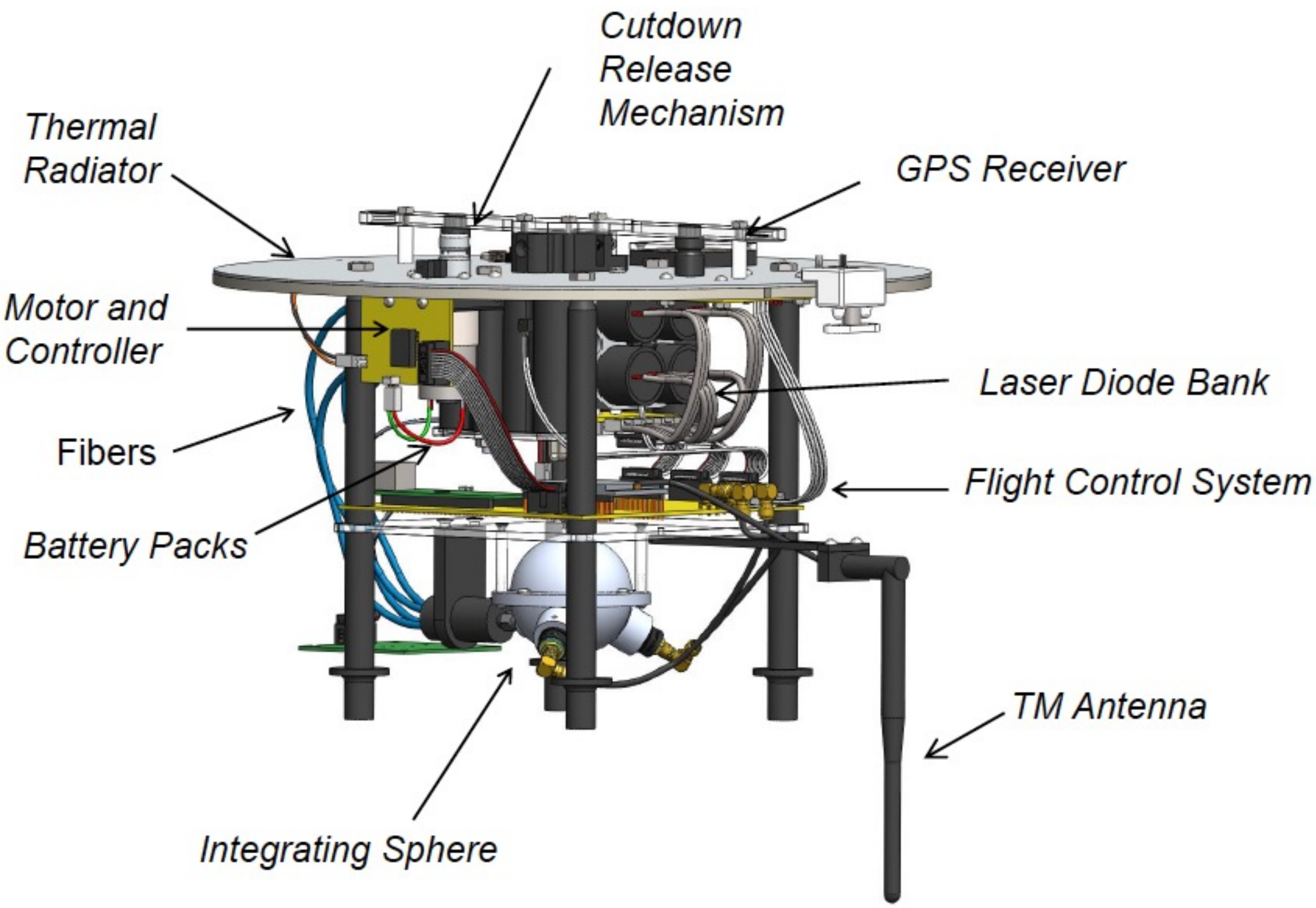
Note. — Results including statistical and identified systematic uncertainties broken down into cat
In each case the constraints are given including the statistical uncertainties and only the stated sys
contribution. The importance of each class of systematic uncertainties can be judged by the relat
compared with the statistical-only fit.

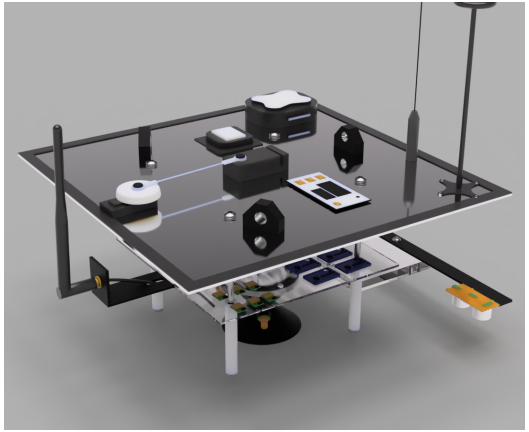
Basic Technique & Goal: *A 0.1% Calibrated, Mobile Source Above the Atmosphere*

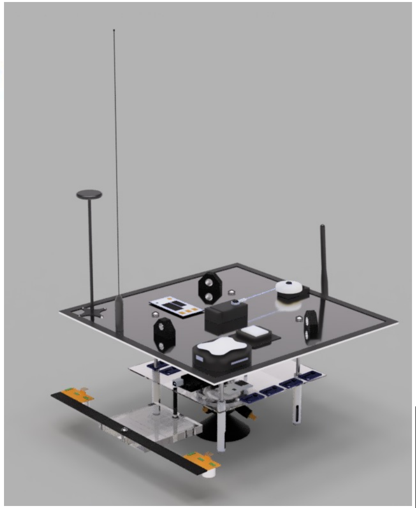


NRC- & NIST-calibrated (~ 0.1% absolute) photodiode spectral response

Basic Payload Design for Photometric Calibration





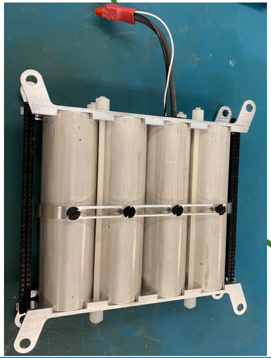


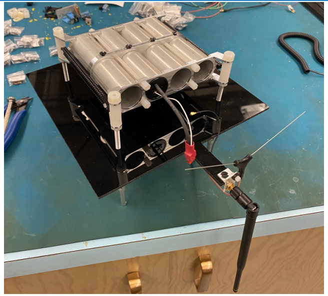
Light Sources & Calibrated Monitoring Photodiodes on 2” ID Integrating Sphere

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.

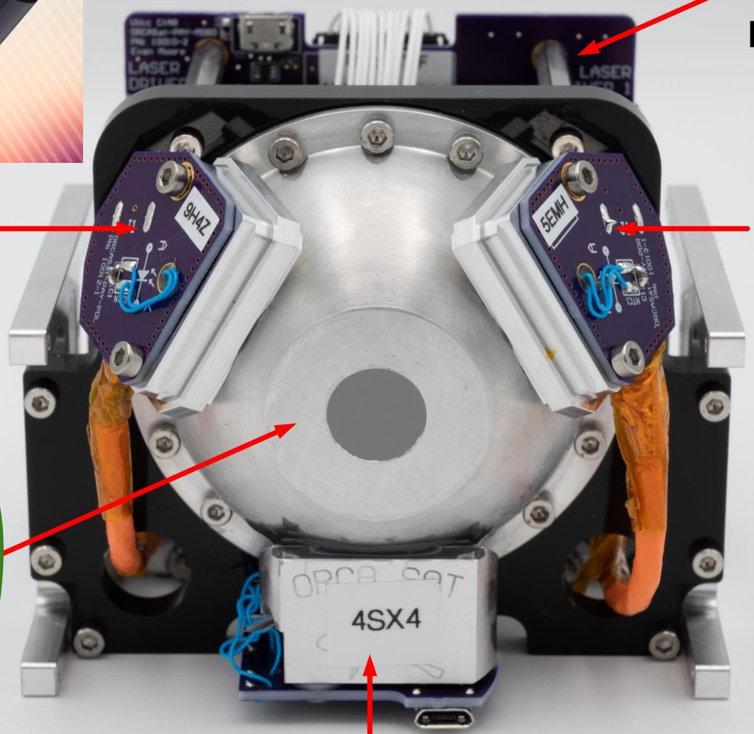




Electronics MCU, TIA, Laser drivers

Photodiode 1

Photodiode 2



Integrating Sphere (coated with Avian B)

Laser Module

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

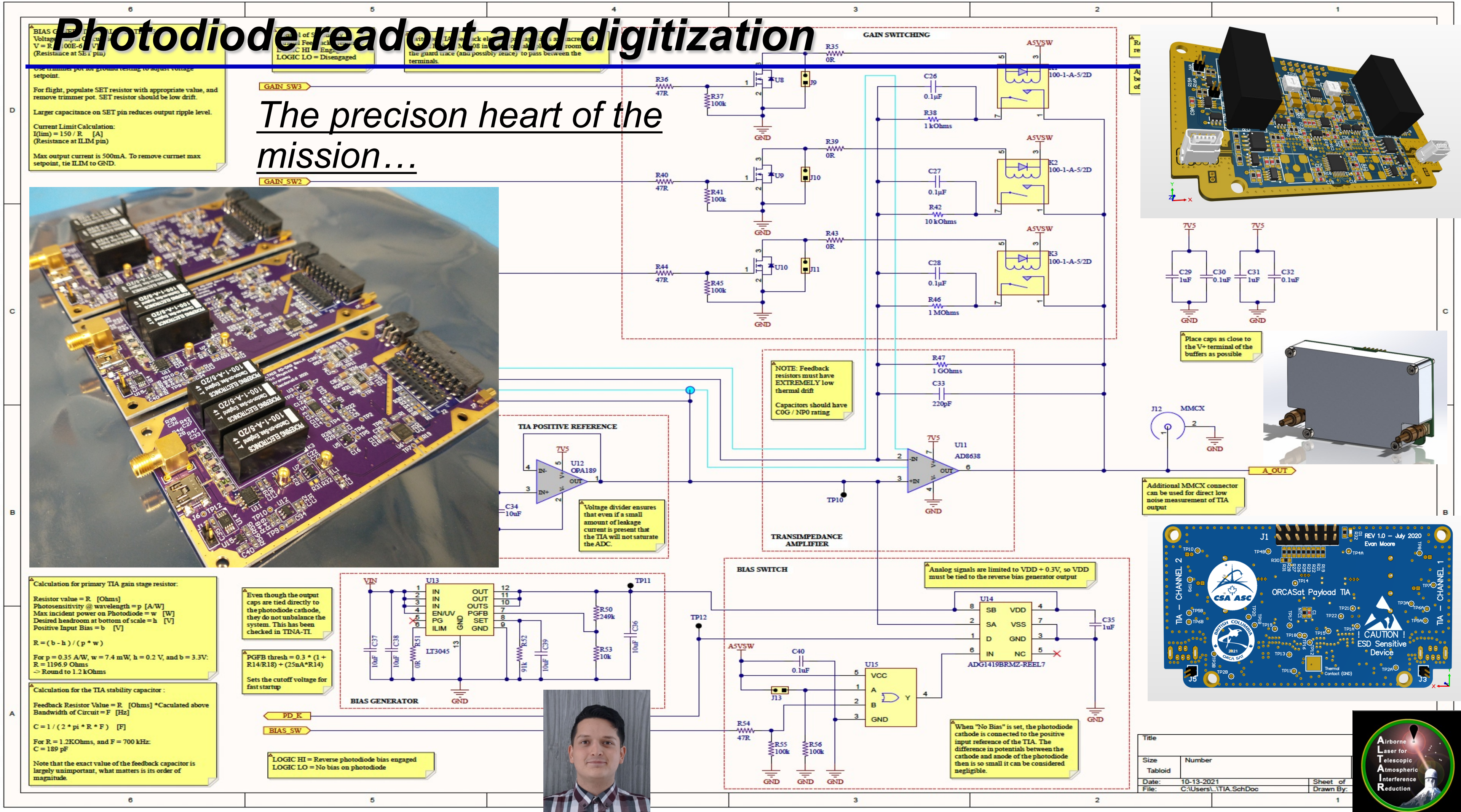
(Utilizing two different photosensor material technologies is a useful cross-check.)

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

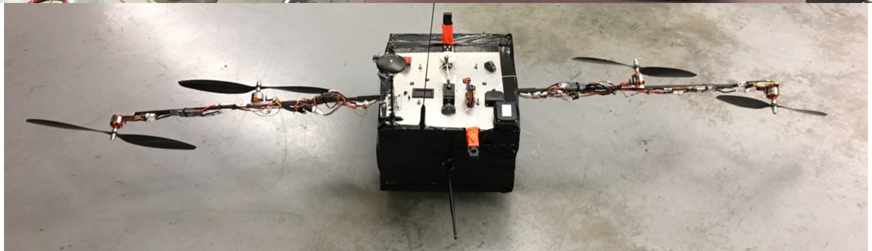
Can be swapped out for **520** nm.

Photodiode readout and digitization

The precison heart of the mission…



Payload

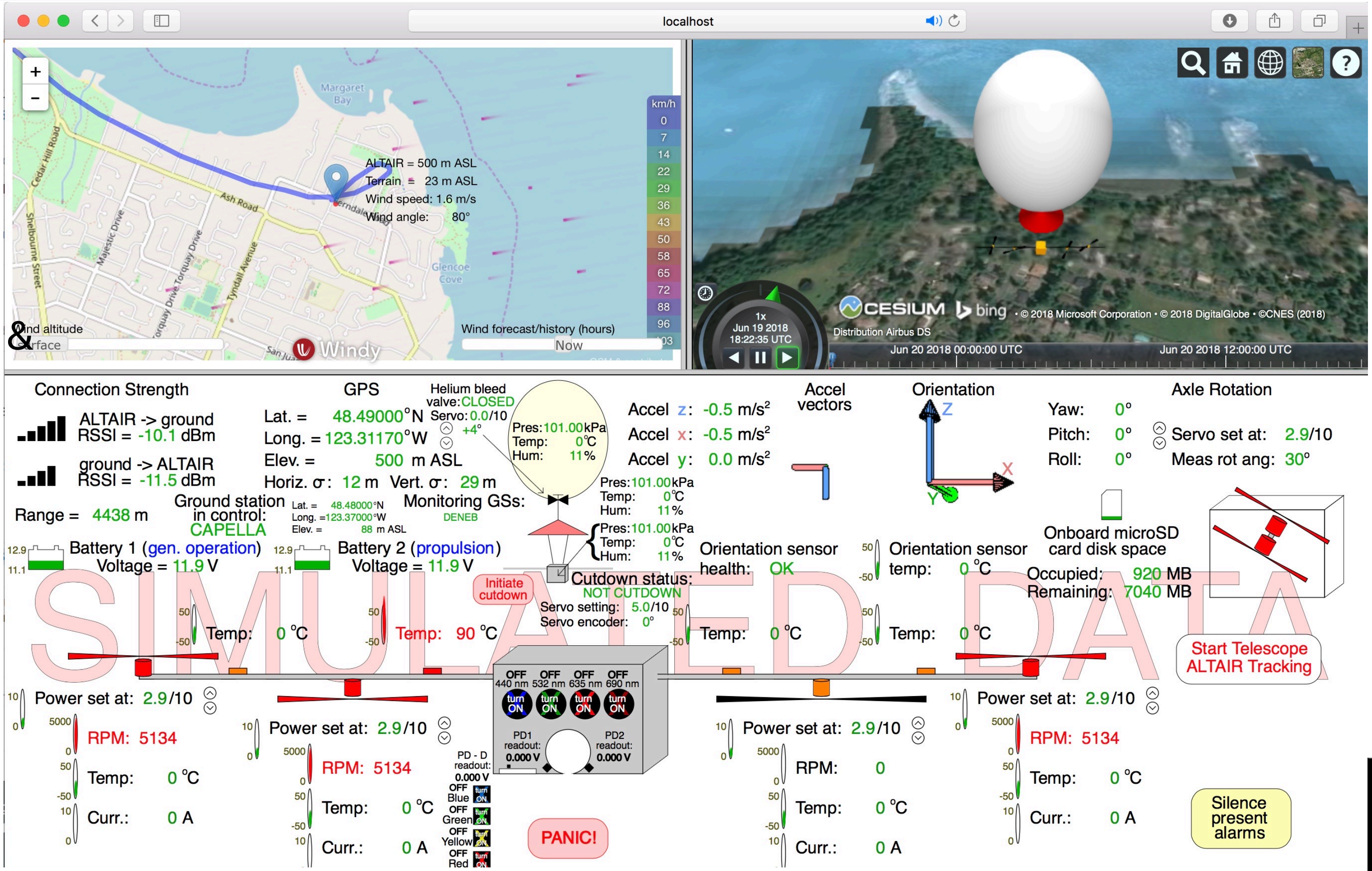


Airborne Laser for Telescopic Atmospheric Interference Reduction

Flight control – AIFCOMSS

Code actively maintained / updated at:
https://github.com/ProjectALTAIR/AIFCOMSSwithCUPredictorTest

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




ALTAIR 12
2014.05.18 05:00:24

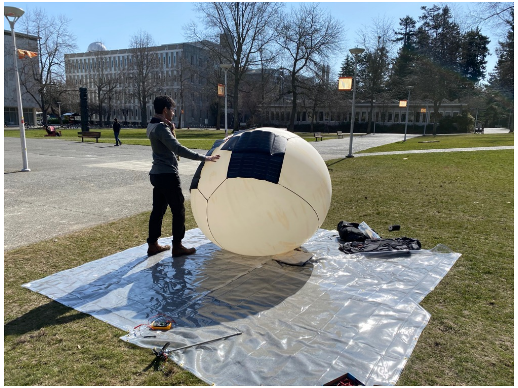
Onboard transponder (uAvionix ping900XR)

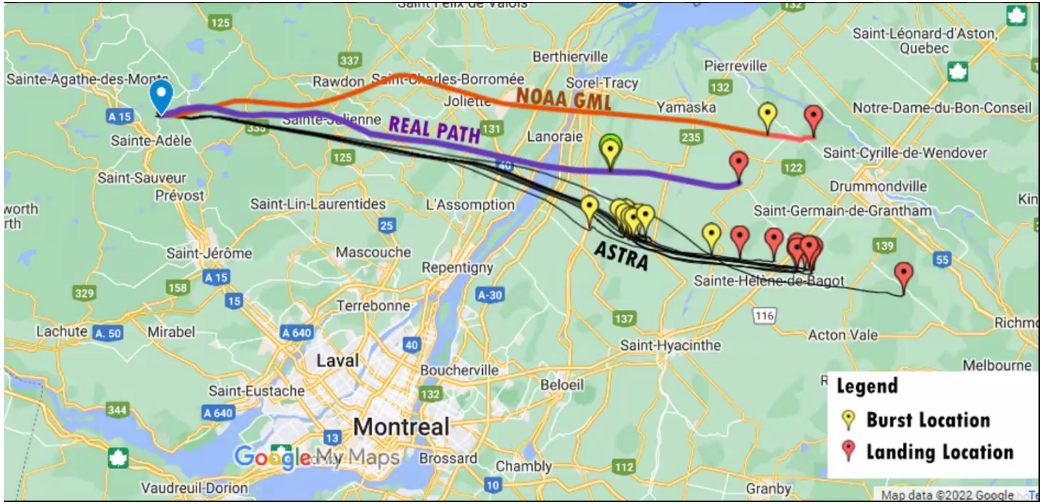
For <u>continuous real-time communication with and identification to air traffic control</u>.
(FAA & Transport Canada certified.)

So that we don't get shot down by NORAD!!! ;)
(Or by the Chilean air force!!!)

Vera Rubin Observatory
on Cerro Pachon in Chile

Operations & McGill / Montreal Test Flights





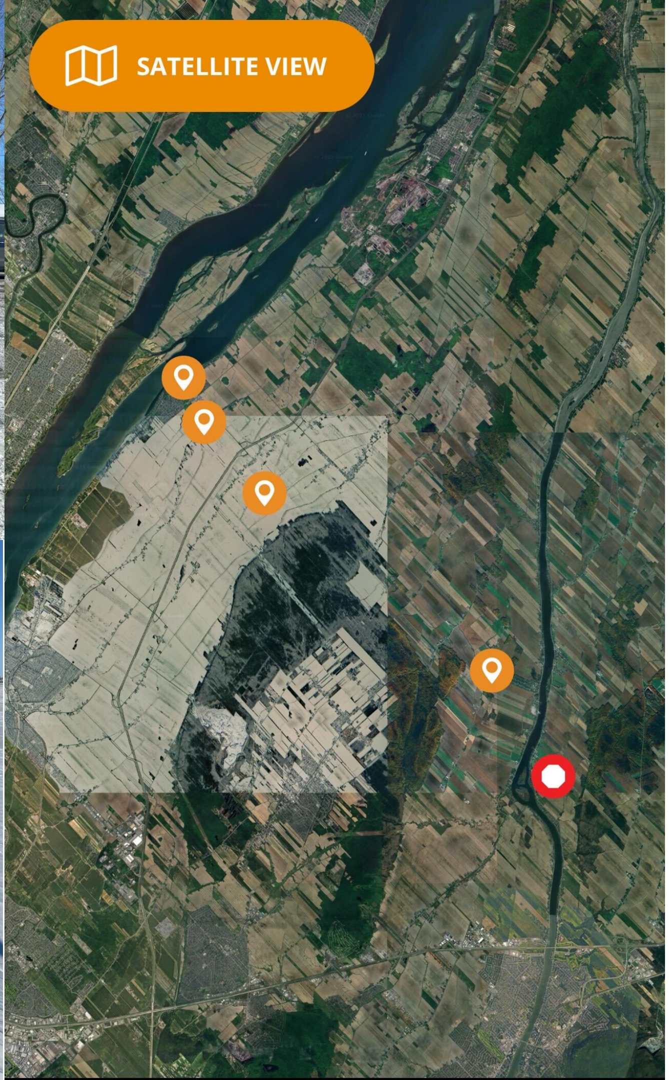
910 MHz portable directional ground antennas, range approx. 100 km.

Always ≥ 2 ground stations in contact.

Daytime Flight
Sat. Feb. 1, 2025:

Inflation (launch from Verchères, QC 11:45 am local time):

Payload recovery:

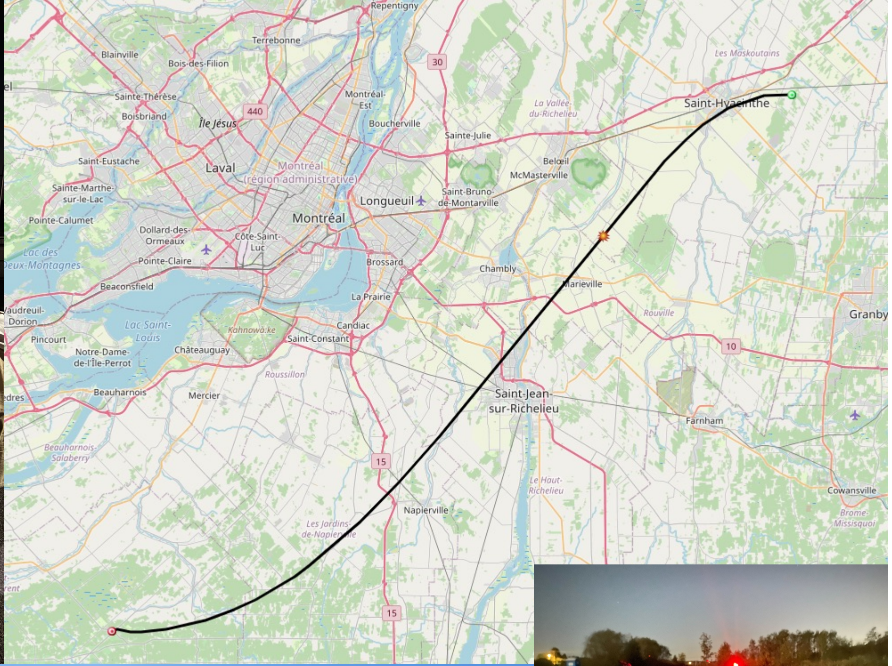


Flight path
←

Flight duration 45 mins

Nighttime Flight
Sun. Sept. 7, 2025:

Inflation (launch from Saint-Antoine-Abbe, QC 9:30 pm local time):



Flight path ←

Flight duration ~1 hr

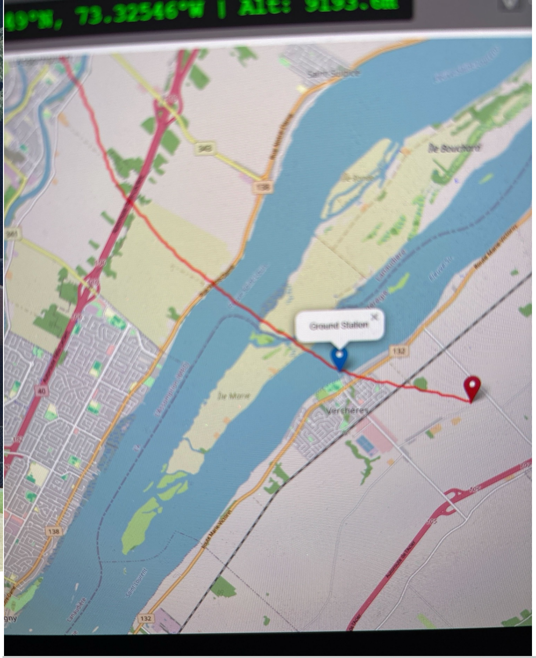
Our ground telescope observations of this particular flight were unfortunately obscured by unpredicted low clouds:

Payload recovery ~10 am the following morning:

Nighttime Ground-Observations Flight

Thu. Sept. 11, 2025:

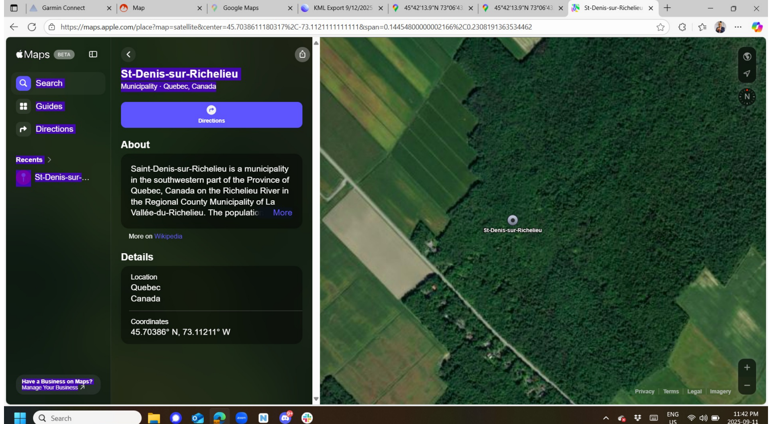
Inflation
(launch from
Parc des Moissons,
L'Assomption QC
9:50pm local time):



Flight path ←

Flight duration 45 mins

Payload landing in trees near St-Denis-sur-



Observations from Pioneer Park, Verchères:

Payload recovery mid-day on the following day,

Fri. Sept. 12, 2025:

(just after noon at ~12:10 pm local time):

... utilizing our arborist’s sling:

A couple of our payload ground-telescope observation images from this flight

⟵

Image analysis ongoing; we’re scheduled to report our observation results, with measured photometric precision from this and our other flights, at AAS in Phoenix on 6 Jan. 2026.

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.

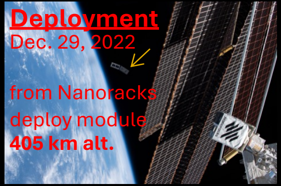
Some (very important!!!) separate & additional conclusions

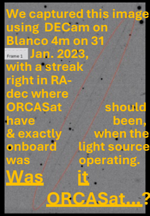
- A very interesting (& very useful) fact about Earth's atmosphere is that, at mid-latitudes, winds in the upper troposphere statistically tend to be in opposite direction to winds in the lower stratosphere.
- Thus, with just very small amounts of (weather-optimized) upward and downward propulsion (just 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 will 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 (and/or not-so-remote) areas.
    2) Earth observation (for, *e.g.*, long-term studies of Arctic ice, etc.)
    3) …… !

ORCASAT: *Lessons Learned* from the *First Optical Source Satellite Mission* for *Calibration of Ground-Based Observatories*

An initial LEO testbed for goal of precision (~0.1% level) calibration of astronomical photometry / magnitudes / flux at 660 nm and 840 nm wavelengths.

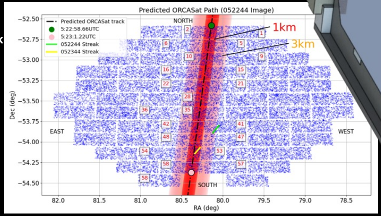
Nov. 26, 2022: Launch from KSC to ISS
Dec. 29, 2022: Deployment out of ISS → orbit
July 7, 2023: Atmospheric re-entry, burn up



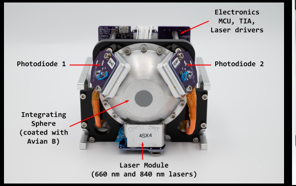


We captured this image using DECam on Blanco 4m on 31 Jan. 2023, with a streak right in RA-dec where ORCASat should have been, & exactly when the onboard light source was operating. **Was it ORCASat...?**

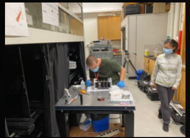
Unfortunately, it couldn't have been ORCASat: The streak trajectory was ~30° away from ORCASat's orbital trajectory, and a similar streak appeared on a DECam image we took 30 sec. later, indicating that the object also was moving across the sky ~10x slower than ORCASat... →

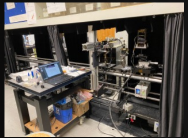


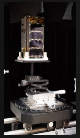
This streak (image taken with DECam on 4 Mar. 2023) really definitely was ORCASat!!! But unfortunately what it wasn't is the ORCASat onboard light source... The image was taken only 1 hour after sunset on Cerro Tololo, when ORCASat was not yet in Earth's shadow, and the streak is reflected sunlight from the spacecraft surface. →

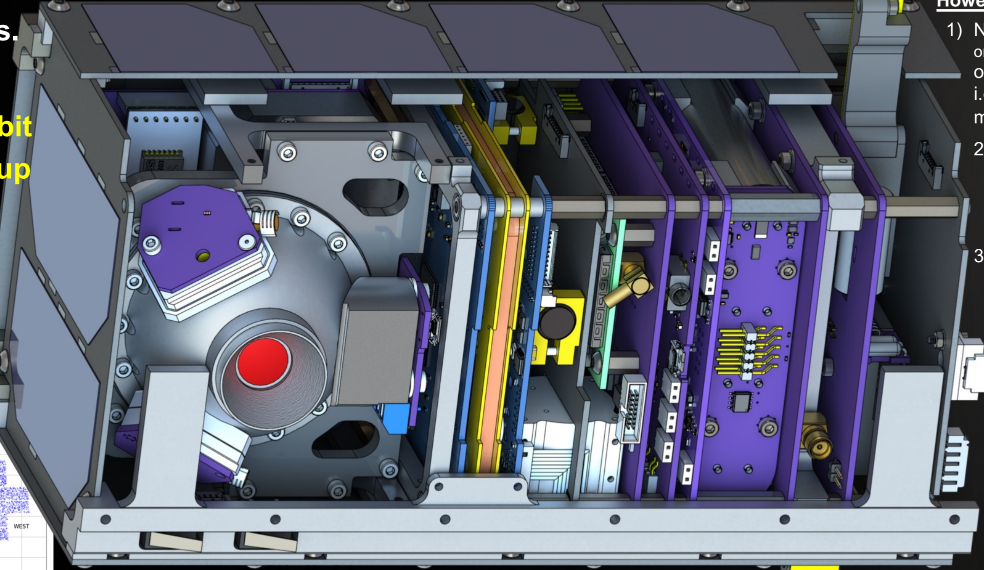


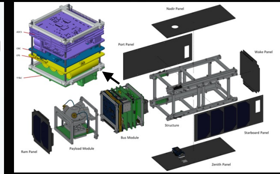
Pre-launch payload light source calibration at NRC Ottawa during summer 2022:











Main Lessons Learned:

Future small, low-cost photometric calibration satellites in LEO **can/would/will be useful!!!** Calibration with streaks (rather than or in addition to point sources) is OK!!! **However!!!:**

1) Need at least approx. **10x brighter** (& 1 or 2 more, if possible, for > wavelength range) onboard light sources!!! I.e., ≥ ~1 watt, i.e. 10x brighter than ORCASat's ~100 mW, sources would be sufficient!!!
2) Needs **well-functioning ADCS!** The attitude determination and control system (ADCS) that we had purchased from CubeSpace had fundamental flaws, e.g. an unshielded magnetometer cable.
3) Needs just **a slightly higher LEO orbit**, which won't decay in 6 months!!!! (Just 10 km higher would have meant a multi-year mission!!!...)

Poster prepared by
Diego Reyes and Justin Albert
University of Victoria
October 24, 2024

Mission was funded by: with gracious support from additional sources.

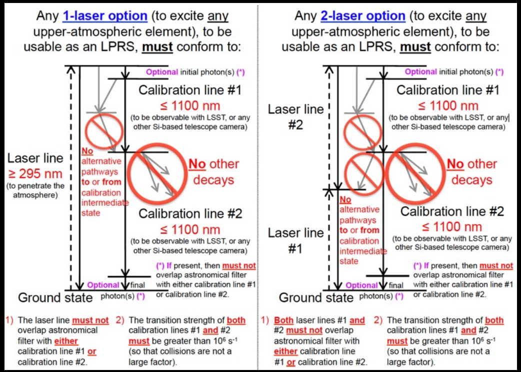
https://www.orcasat.ca

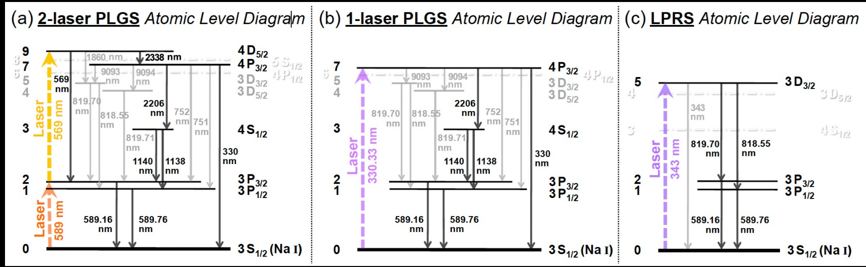
Laser Photometric Ratio Star (LPRS):

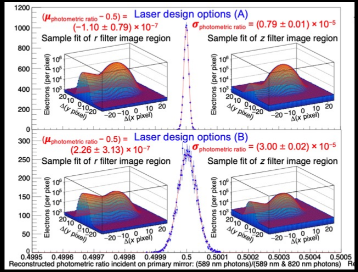
An *Ultra*-Precise (< 10^{-4}) Spectrophotometric Calibration Ratio, using a Novel Excitation of the Earth's Sodium Layer

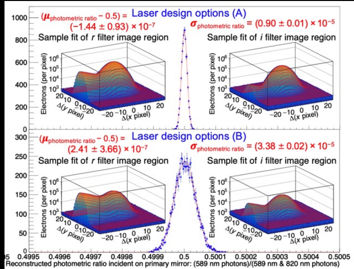
Could one create a bi-chromatic laser guide star, utilizing a cascade decay of a laser-excited component of the upper atmosphere, in which one would be assured that, to extremely high precision, the numbers of photons generated in the two colors are equal, due to the cascade nature of such a decay…?

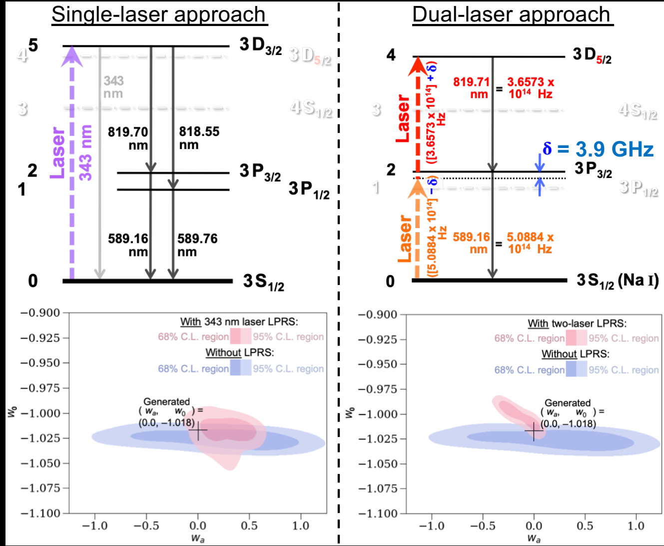
Yes! – but not in the way that polychromatic laser guide stars have ever been created or tested so far! Must use the $3D_{3/2}$ or $3D_{5/2}$ excitation of Na I ! – no other excitation would work for this in Earth's atmosphere!











Please kindly see !!! :

Albert *et al.*, MNRAS **503,** 4399 **(2021) ;**

Albert *et al.*, MNRAS **503,** 4412 **(2021) ;**

Albert, Budker, & Sadeghpour,
Nat. Sci. **2,** e20220003 **(2022).**

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

Poster prepared by
Justin Albert
University of Victoria
October 22, 2024

I acknowledge and respect the Lək̓ʷəŋən (Songhees and Xʷsepsəm/Esquimalt) Peoples on whose territory the University of Victoria stands, and the Lək̓ʷəŋən and W̱SÁNEĆ Peoples whose historical relationships with this land continue to this day.

L'Polytechnique Montréal reconnaît qu'elle est située en territoire autochtone non cédé par voie de traité, et souhaite saluer ceux et celles qui, depuis des temps immémoriaux, en ont été les gardiens traditionnels. Elle exprime son respect pour la contribution des peoples autochtones à la culture des sociétés ici et partout autour du monde.

A DUTY TO REMEMBER

36th COMMEMORATION OF THE ÉCOLE POLYTECHNIQUE MASSACRE