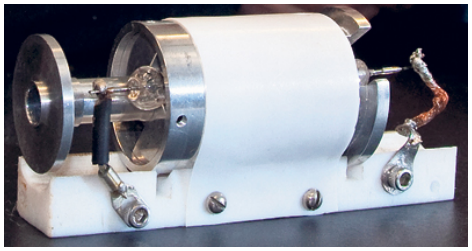
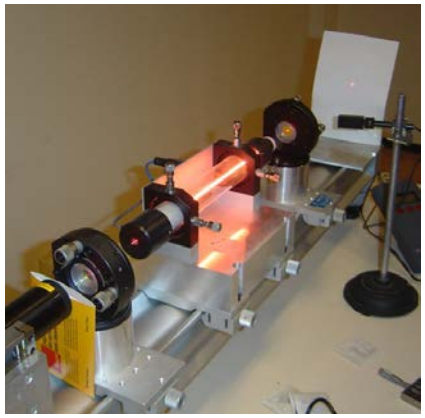
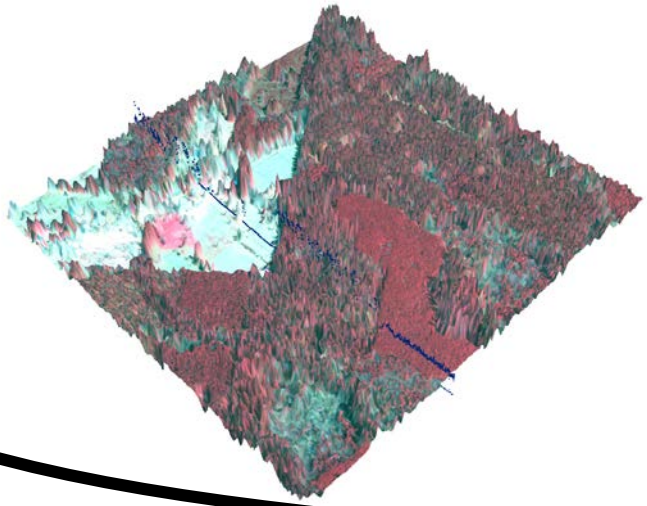
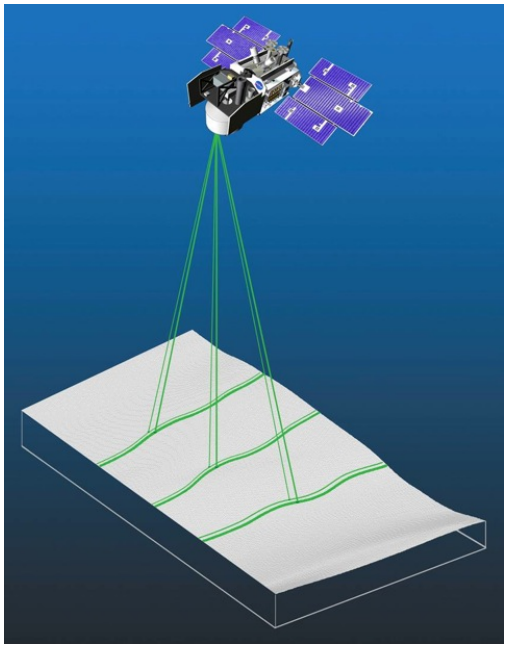


Lasers & Forestry -

The 1st 20 years; and the next 10 years

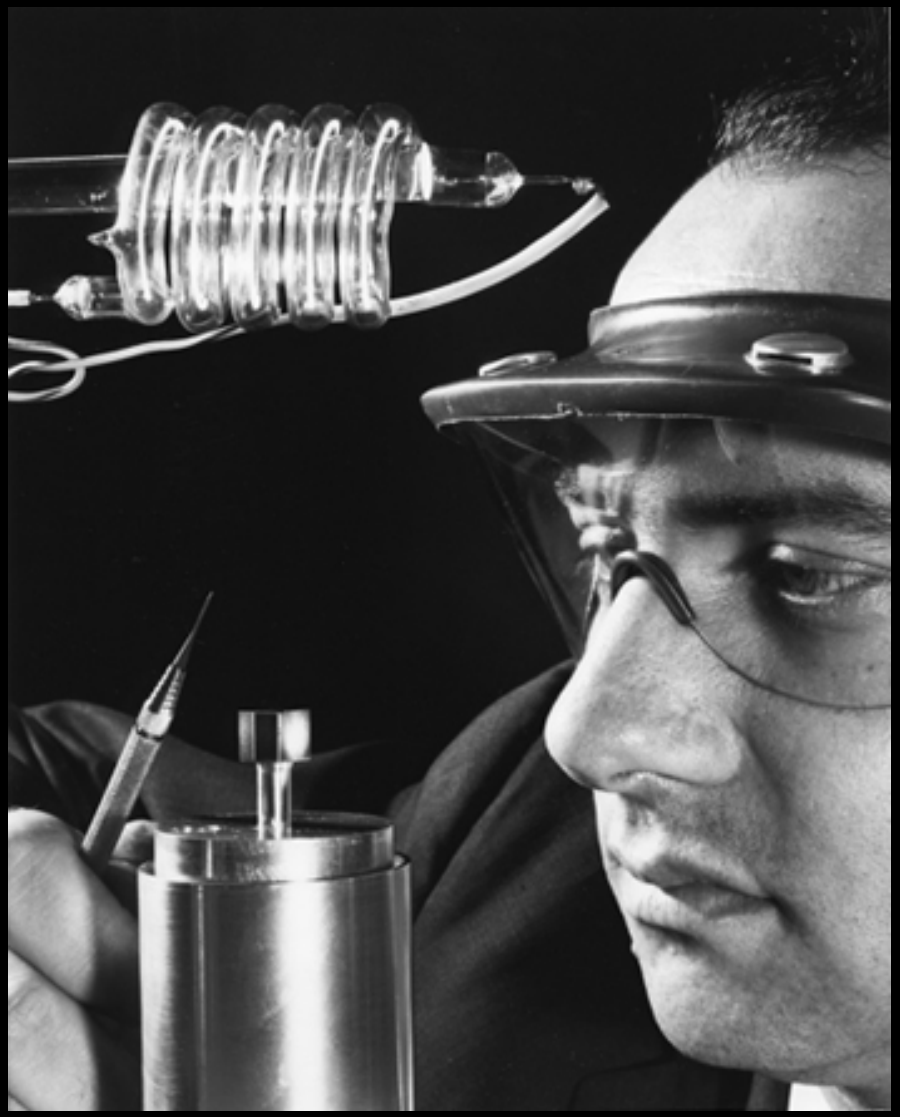


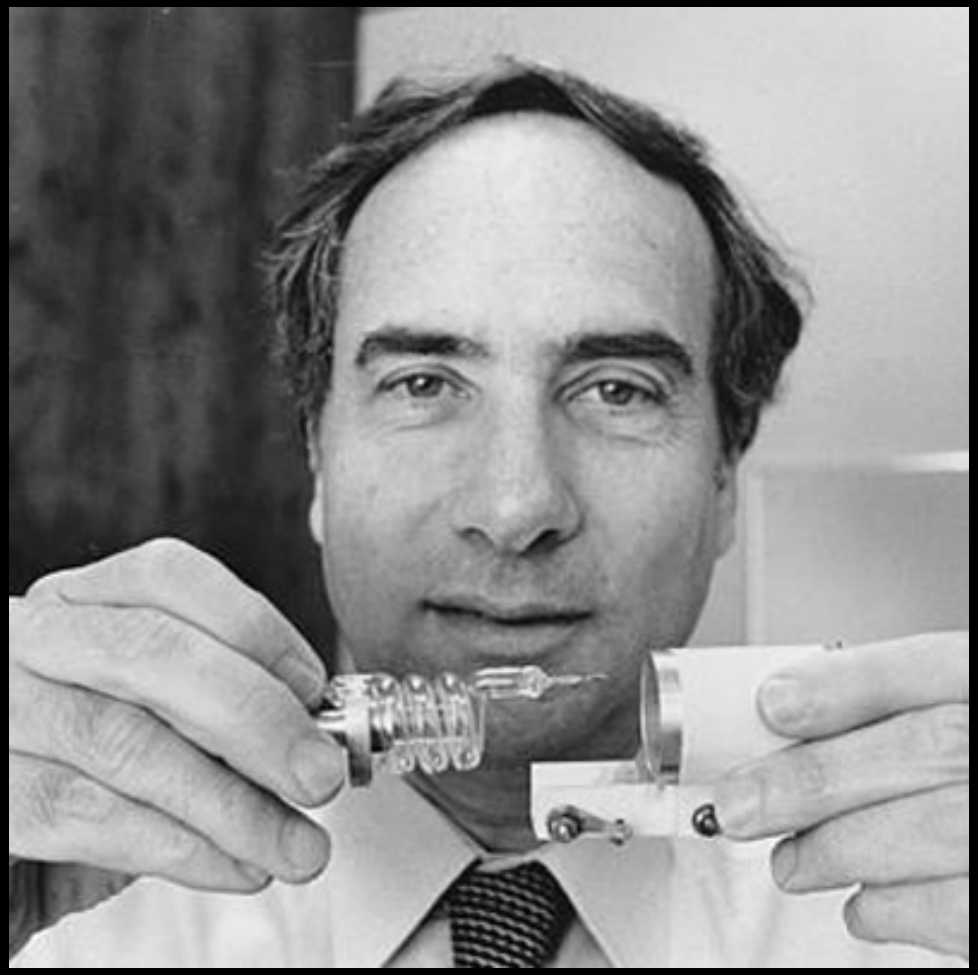


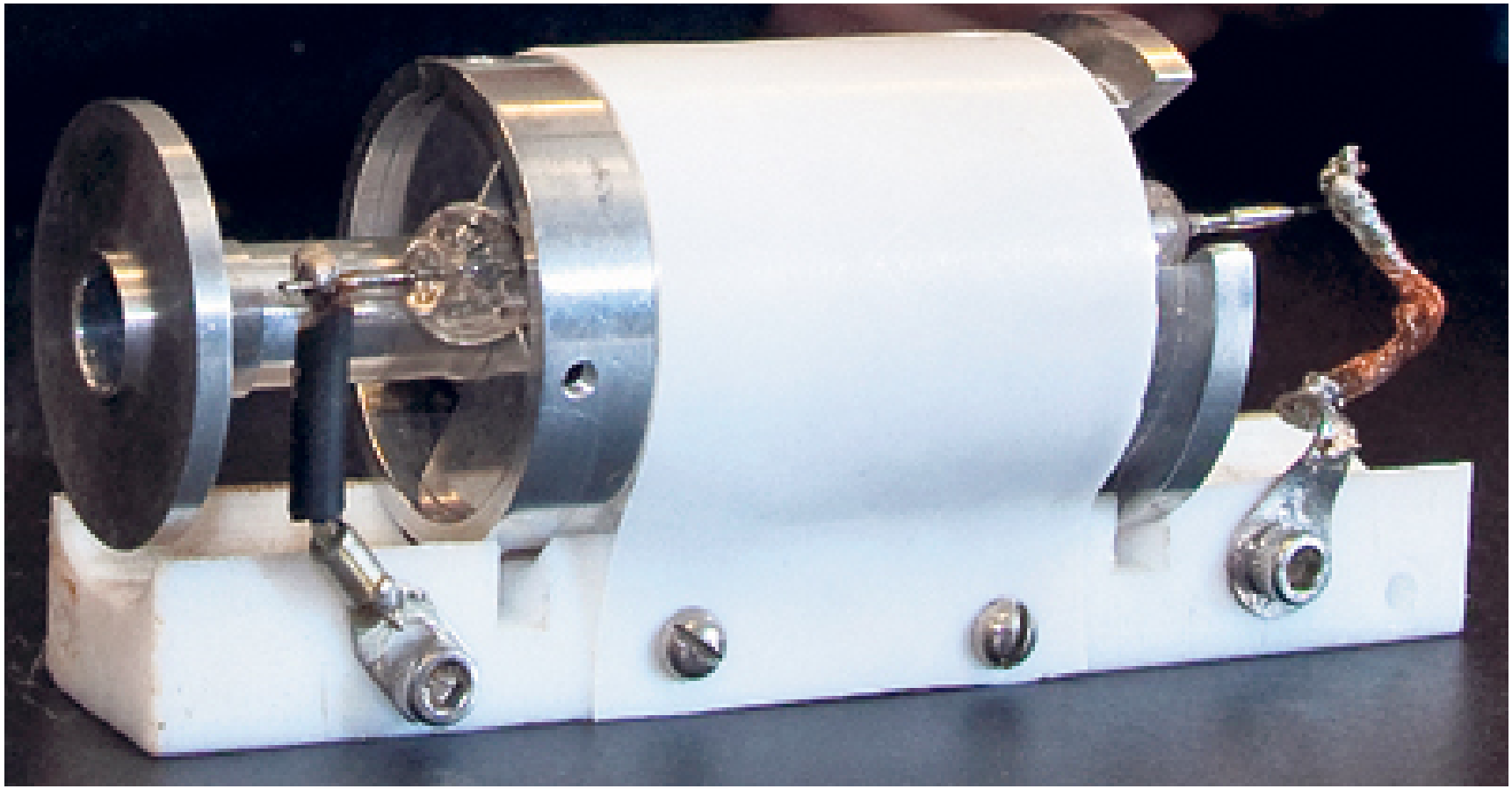


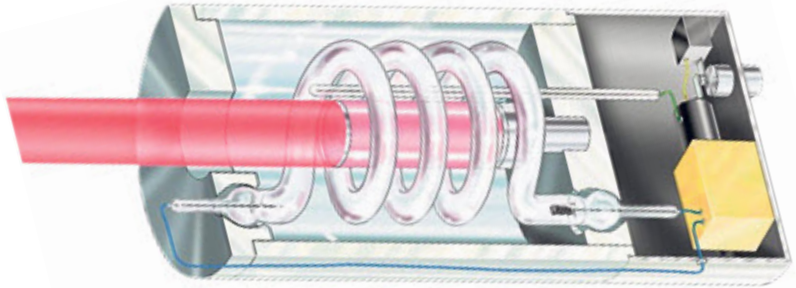
Ross Nelson, NASA-Goddard Space Flight Center

AWARE – Corner Brook, NL, May 25-26, 2016

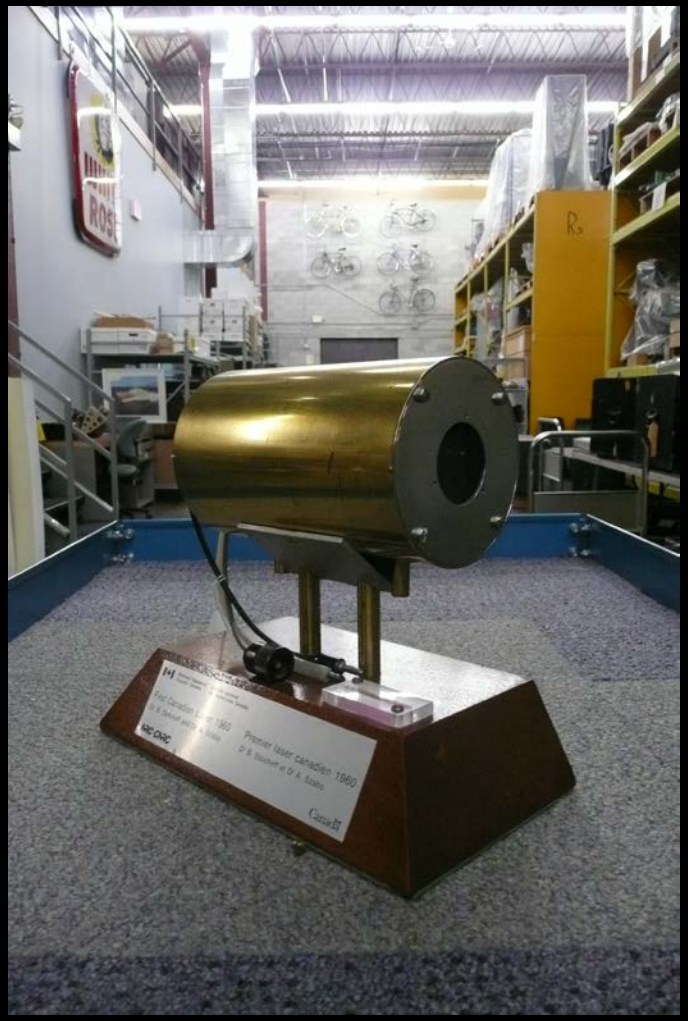


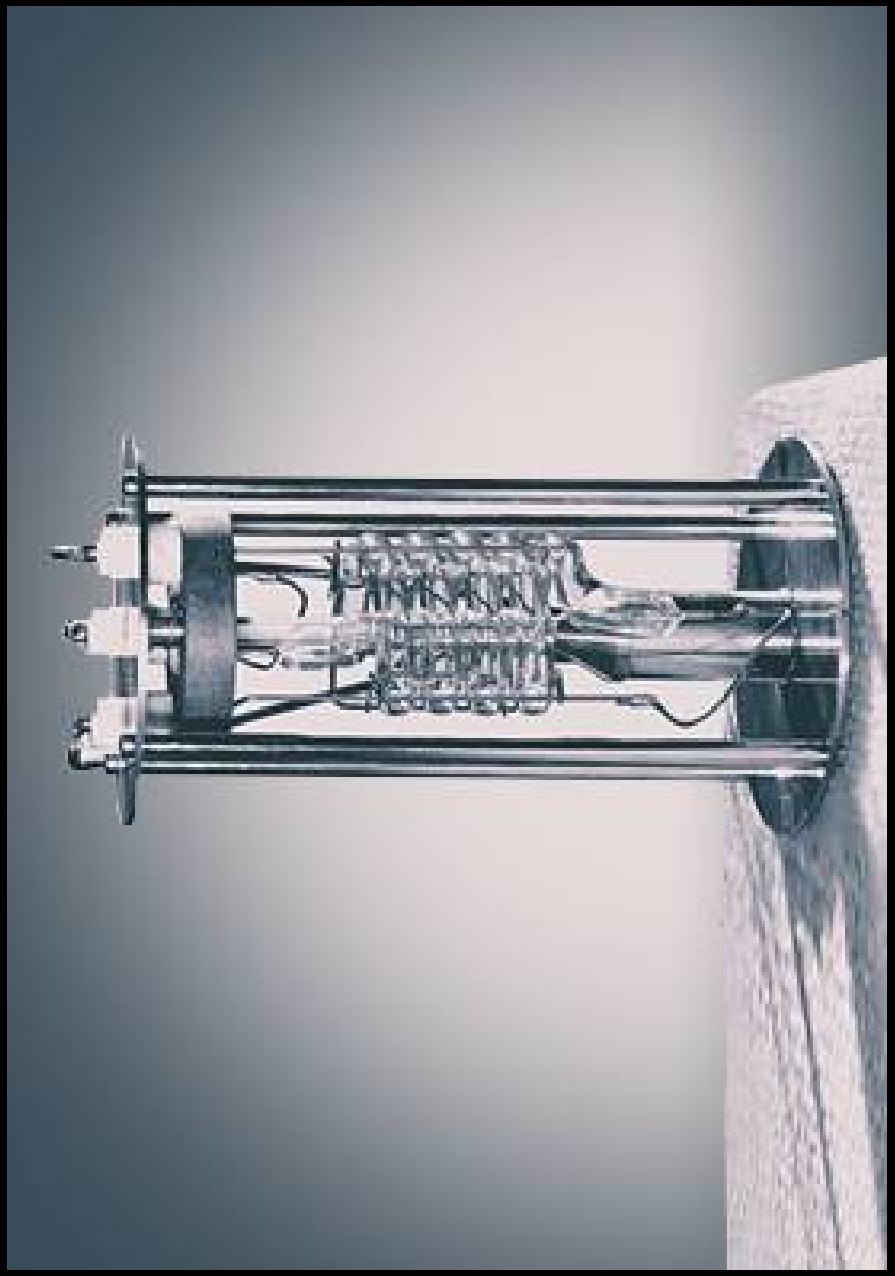


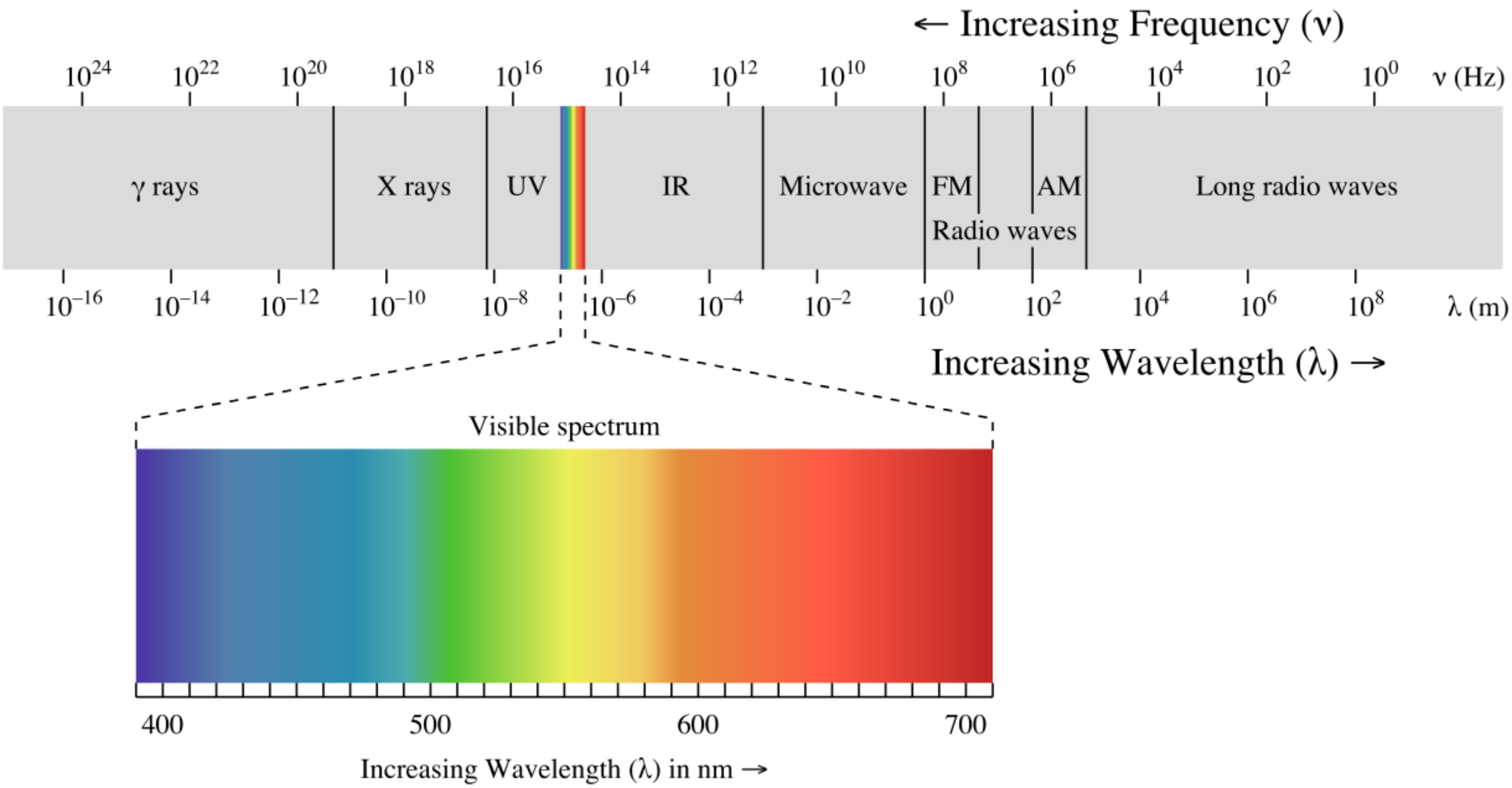


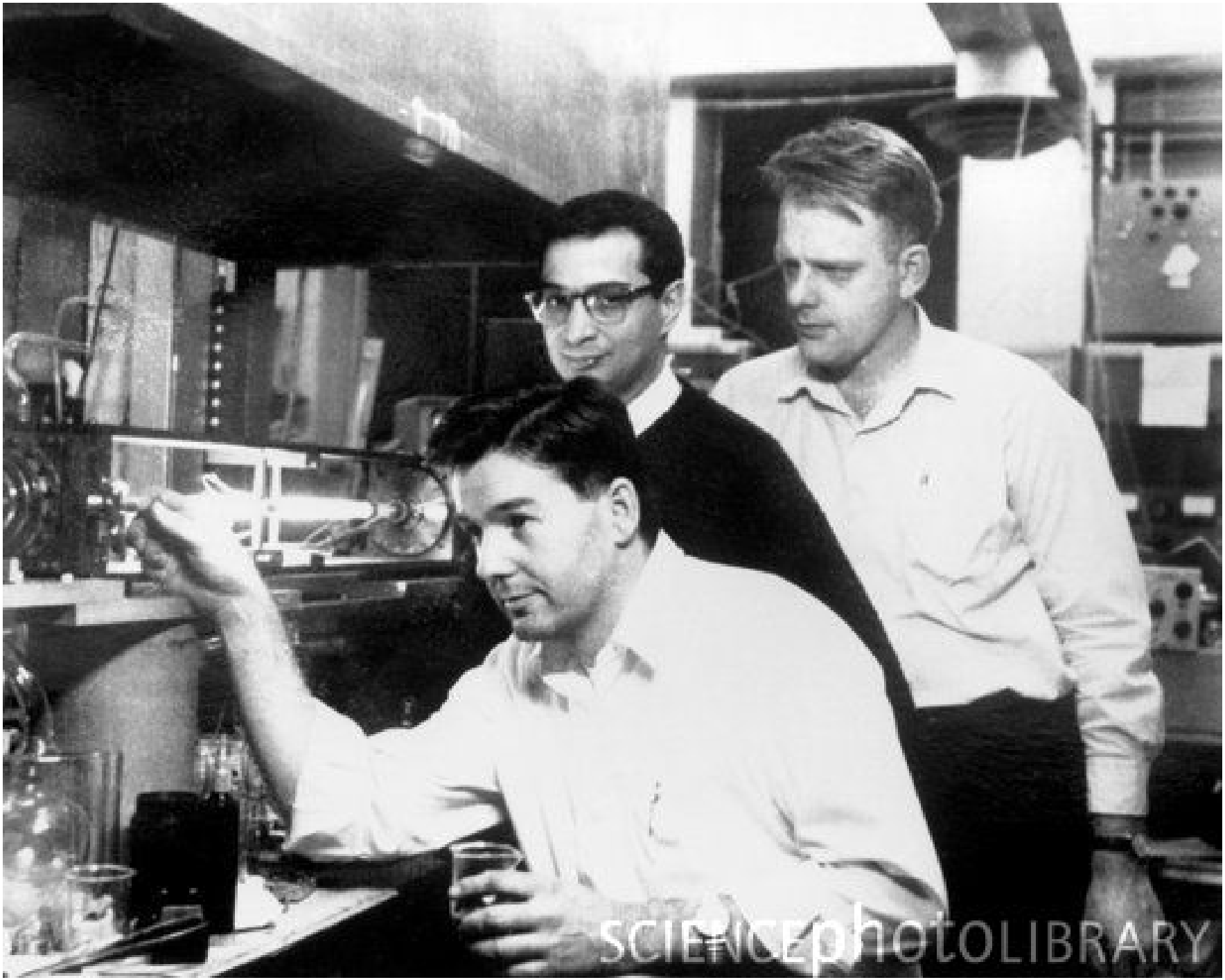


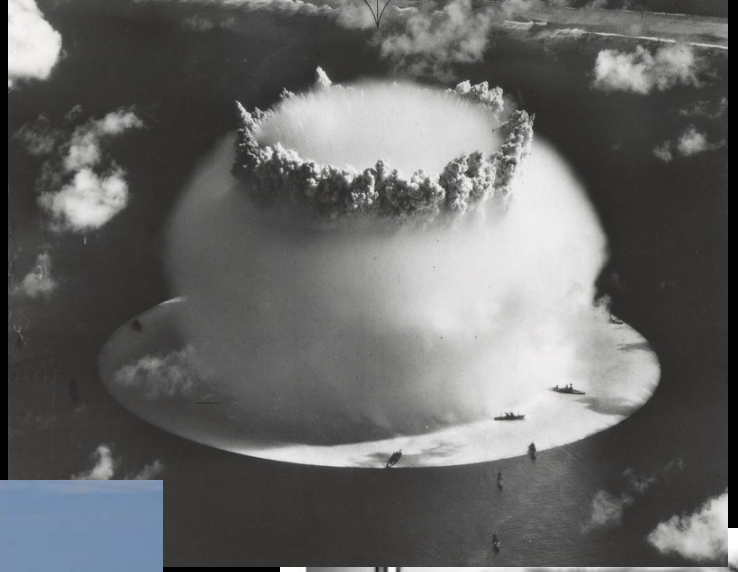
Theodore Maiman
May 16, 1960
Hughes Research Lab, Malibu CA
Ruby laser – 0.694 um


Premier laser canadien 1960




← Increasing Frequency (ν)
10^24 10^22 10^20 10^18 10^16 10^14 10^12 10^10 10^8 10^6 10^4 10^2 10^0 ν (Hz)
γ rays
X rays
UV
IR
Microwave
FM
AM
Radio waves
Long radio waves
10^−16 10^−14 10^−12 10^−10 10^−8 10^−6 10^−4 10^−2 10^0 10^2 10^4 10^6 10^8 λ (m)
Increasing Wavelength (λ) →
Visible spectrum
400
500
600
700
Increasing Wavelength (λ) in nm →


SCIENCE photoLIBRARY



If you see the flash, duck and cover!

In the US, much of the early laser research was driven by national security and the US Department of Defense.

Laser research projects characterizing:

1. sea ice thickness, extent, location of leads, location/height of pressure ridges – subs near Russian Arctic coast (Nautilus, Skate, Seadragon, 1958-1962).

2. ocean circulation patterns, wave height – naval exercises.

3. oil spills, on water and land via Raman backscatter and fluorescence, perhaps driven by Alaska Pipeline (1974-1977).

4. shallow water bathymetry, impetus Vietnam war (1963-1975).

5. terrain (not vegetation) mapping – battlefield recon.

Laser Altimetry – does it even work?

Rempel and Parker (1964): CW He-Ne gas laser. Sort of….

Jensen and Ruddock (1965): abstract, getting better….

Jensen (1967): It works! We can see things besides noise.

Rempel and Parker 1964: 0.633 um CW He-Ne gas laser

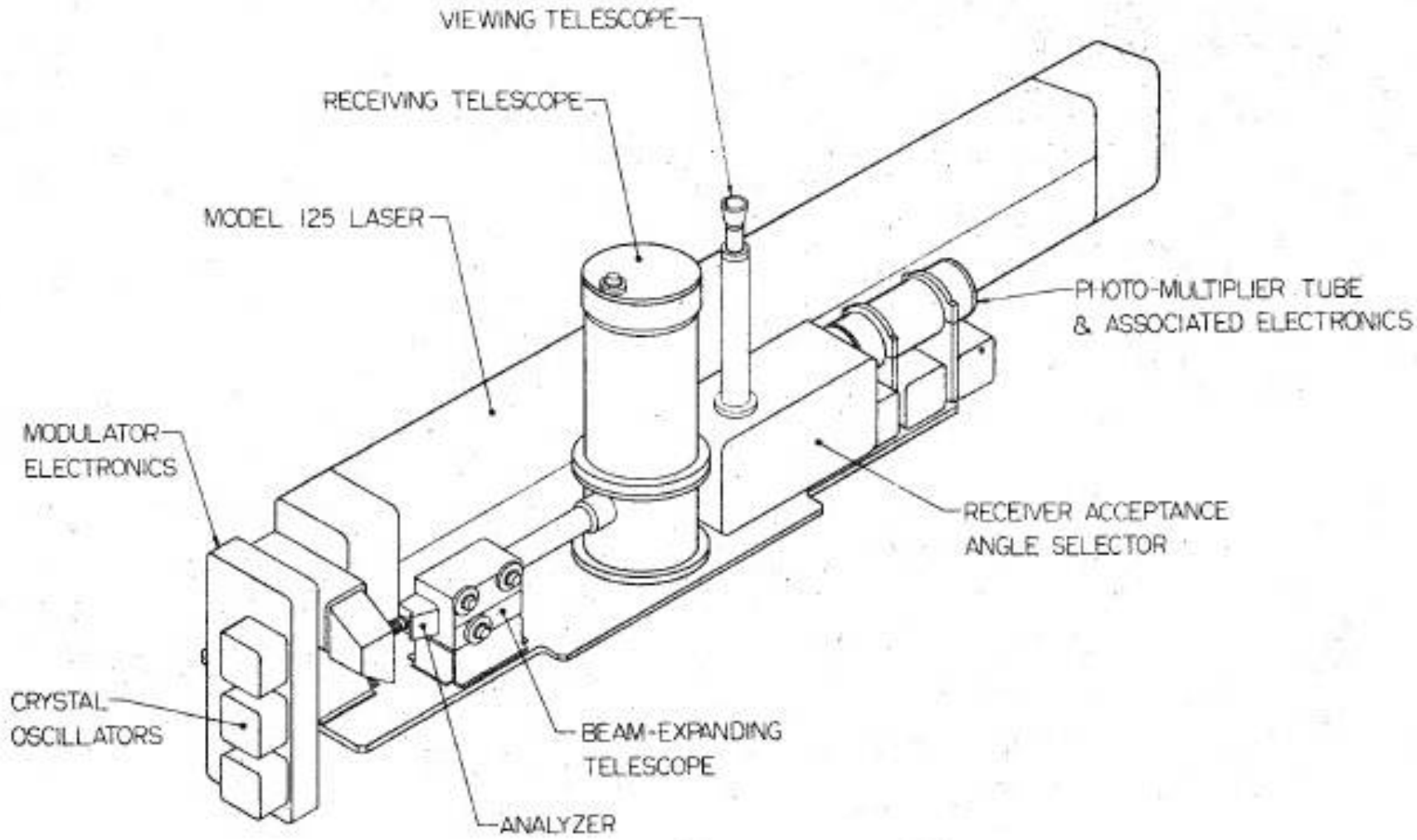
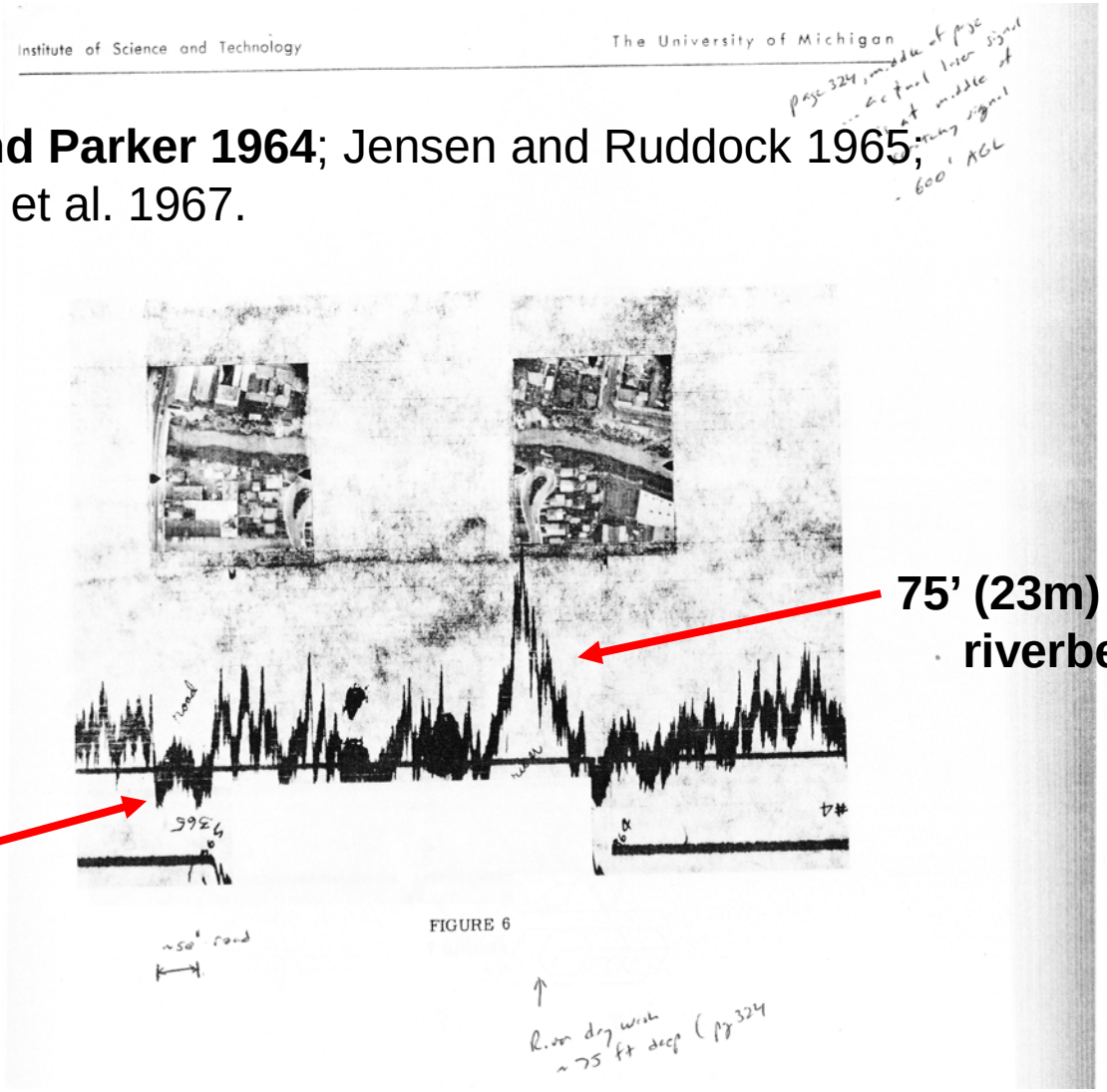


FIGURE 8

Rempel and Parker 1964

Rempel and Parker 1964; Jensen and Ruddock 1965; Jensen et al. 1967.



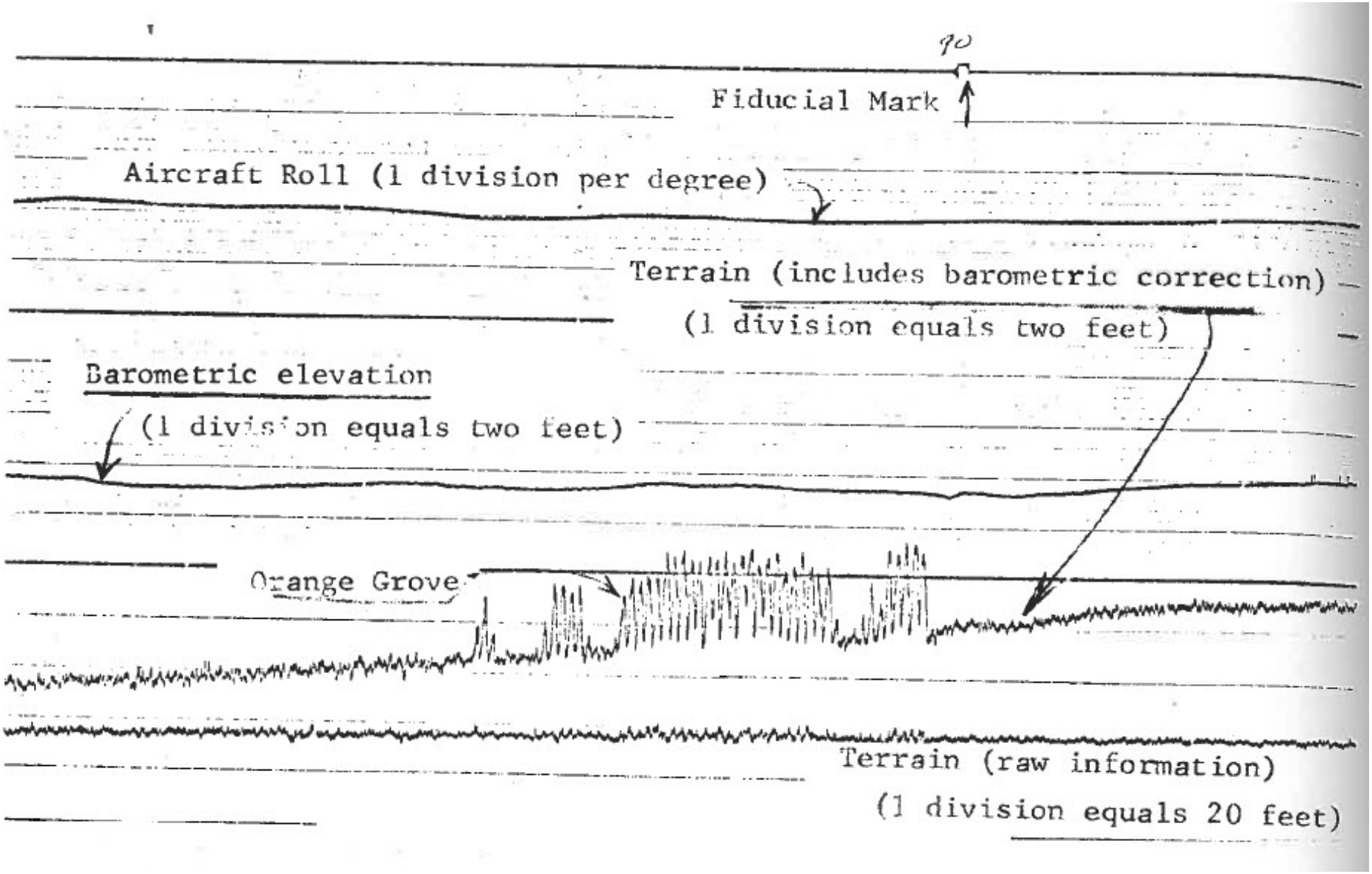
75’ (23m) deep riverbed

50’(15 m) wide road

He-Ne 0.633 um CW laser, strip recorder (oscillograph) w/0.6” noise, flight altitude ~600’ (182m). San Jose, CA, November 1963

Rempel and Parker (1964) – first mention of measuring vegetation, pg 327.

“The laser altimeter will be able to show ground elevations, as well as tree heights, if as little as 5 percent of the forest cover permits an optical path to the ground.”

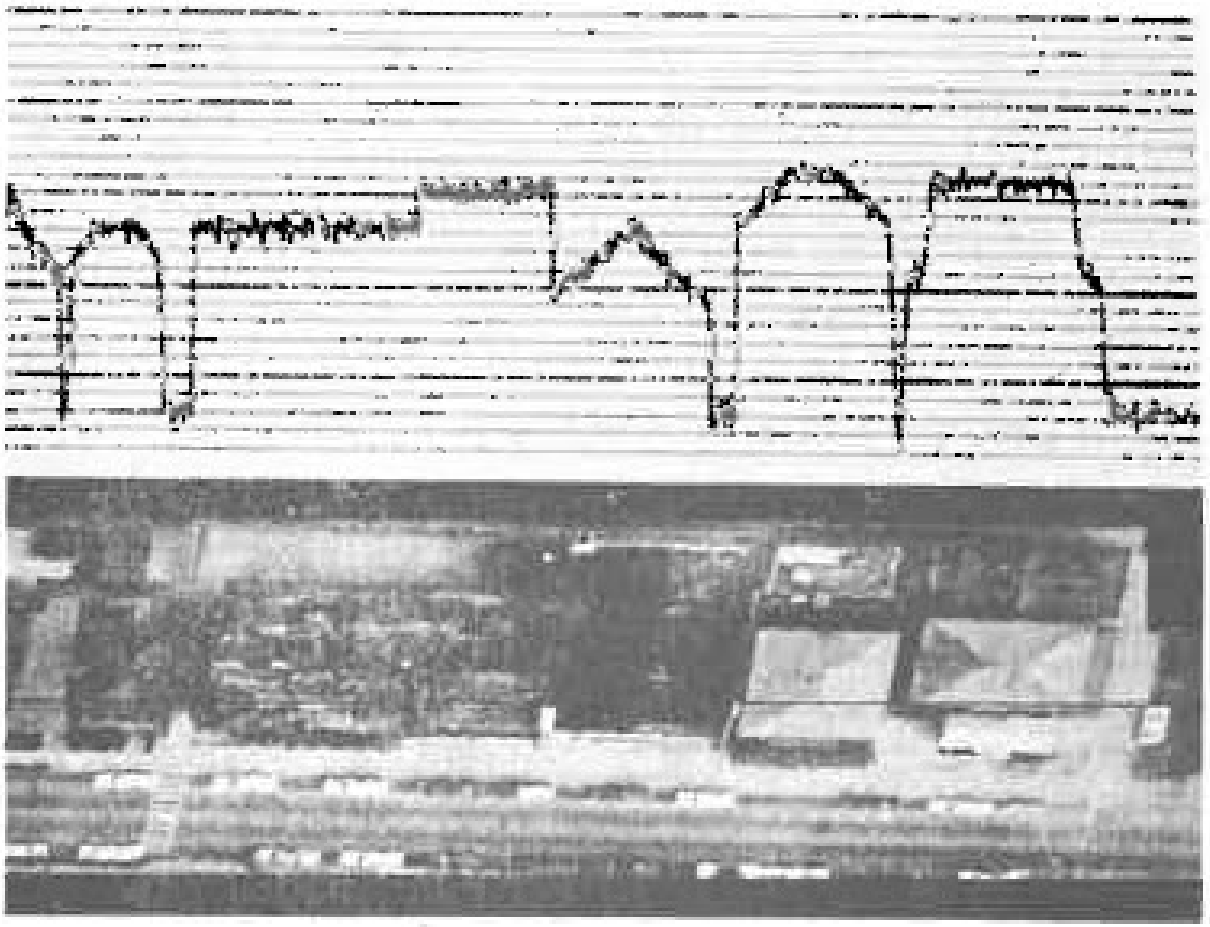


Jensen 1967, same system as Rempel and Parker 1964.

Buildings at Atlantic City are shown along with the accompanying strip photograph of path.

Jensen 1967

1.5 m elevation accuracy
@ 300 m AGL



Terrain Mapping: Link 1969 - 1965 flights

1. Study Site: Fort Stewart, Georgia.
12 sites with various obstacles to military maneuvers –
1600 ft x 100 ft (487 m x 30 m).

2. Marking the sites:
- orange cloth strips, 6” x 100’ ⊥ to flight line every 300’

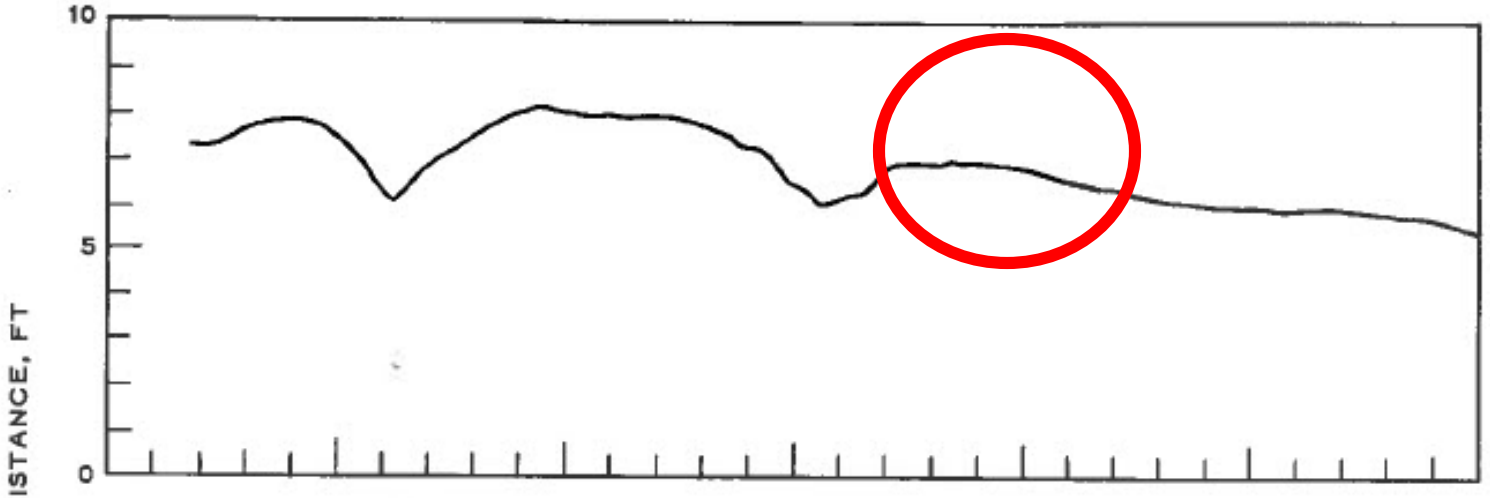
3. Aircraft Instrumentation:

Laser: CW He-Ne gas, 0.633 um

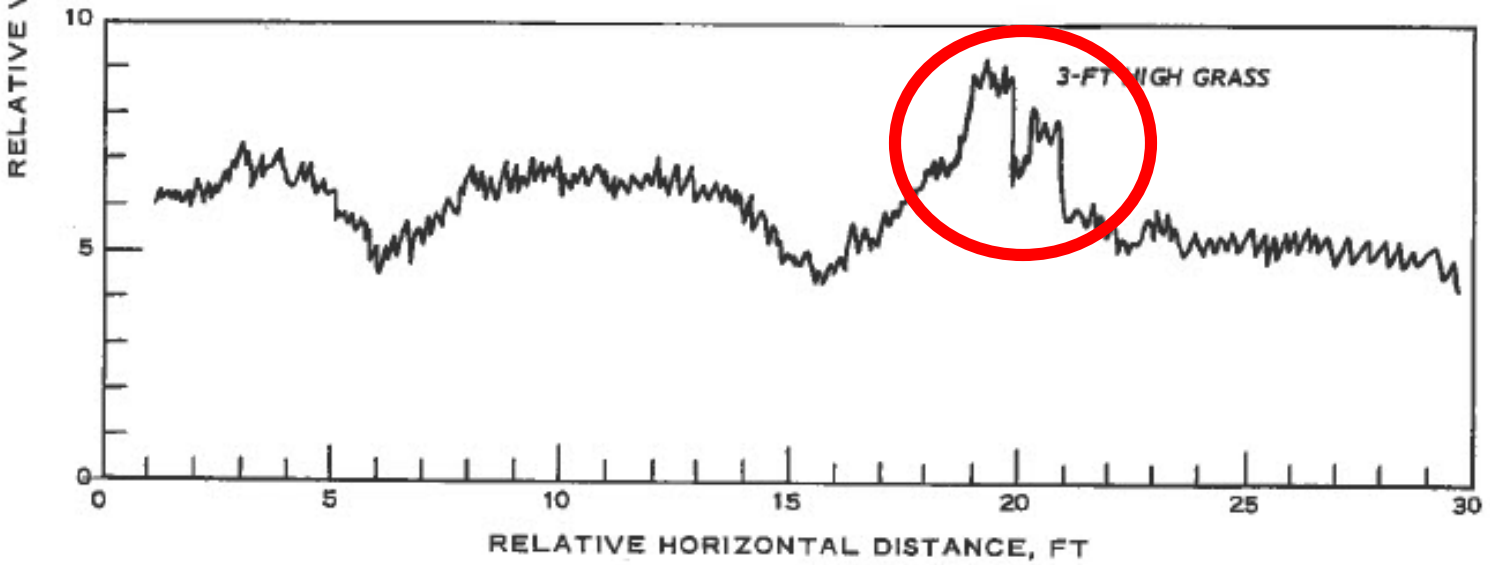
Altitude, Z: temp. stabilized barometric pressure w/ drogue chute.

X,Y position: none
Aircraft Attitude, roll/pitch: none
} **Coincident 9”x9” stereophotos**

Data recorder: oscillograph



GROUND SURVEY REFERENCE PROFILE



LASER ALTIMETER REFERENCE PROFILE

Timeline of early natural resources work:

UK: 1965 demonstrated a topographic profiler accurate to <1.5 m.

Hickman and Hogg (1969) – top/bottom bathymetry to 26', Lake Ontario using a 20 kW Ne gas laser.

Australia: 1972, terrain profiler, CW argon gas laser, 0.488 um, to collect topography between geodetic stations (Penny 1970; 1972).

Canada: 1974, CCRS has

- 0.337 um N lidar for fluorscensing & Raman scattering for oil, [algae],
- 0.540 um Ne lidar for bathymetry,
- Litton LTN-51 INS,
- 14 track magnetic tape drives,
- doppler radar,
- cameras and IR scanners.

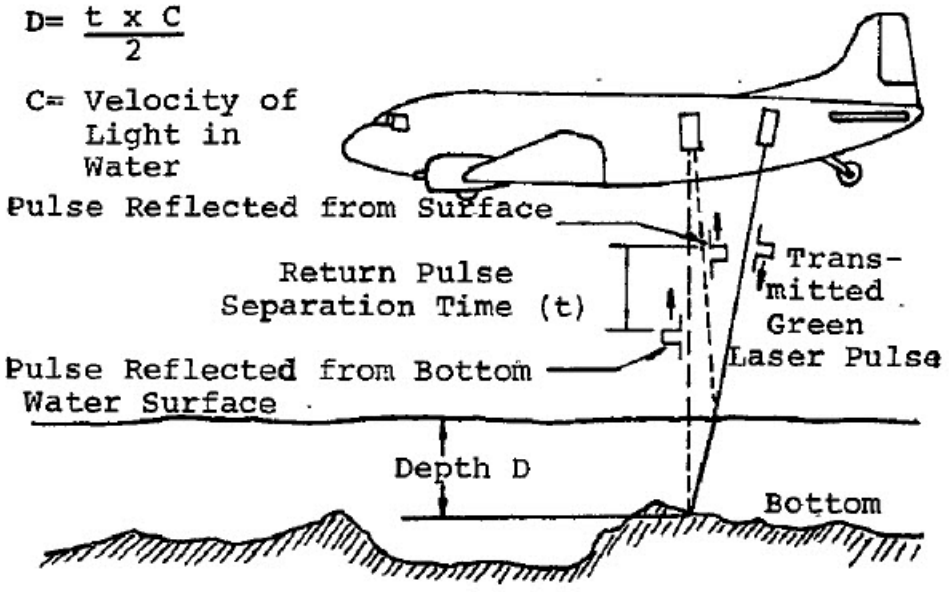


Figure 4. CCRS Airborne Laser Bathymetry Mode

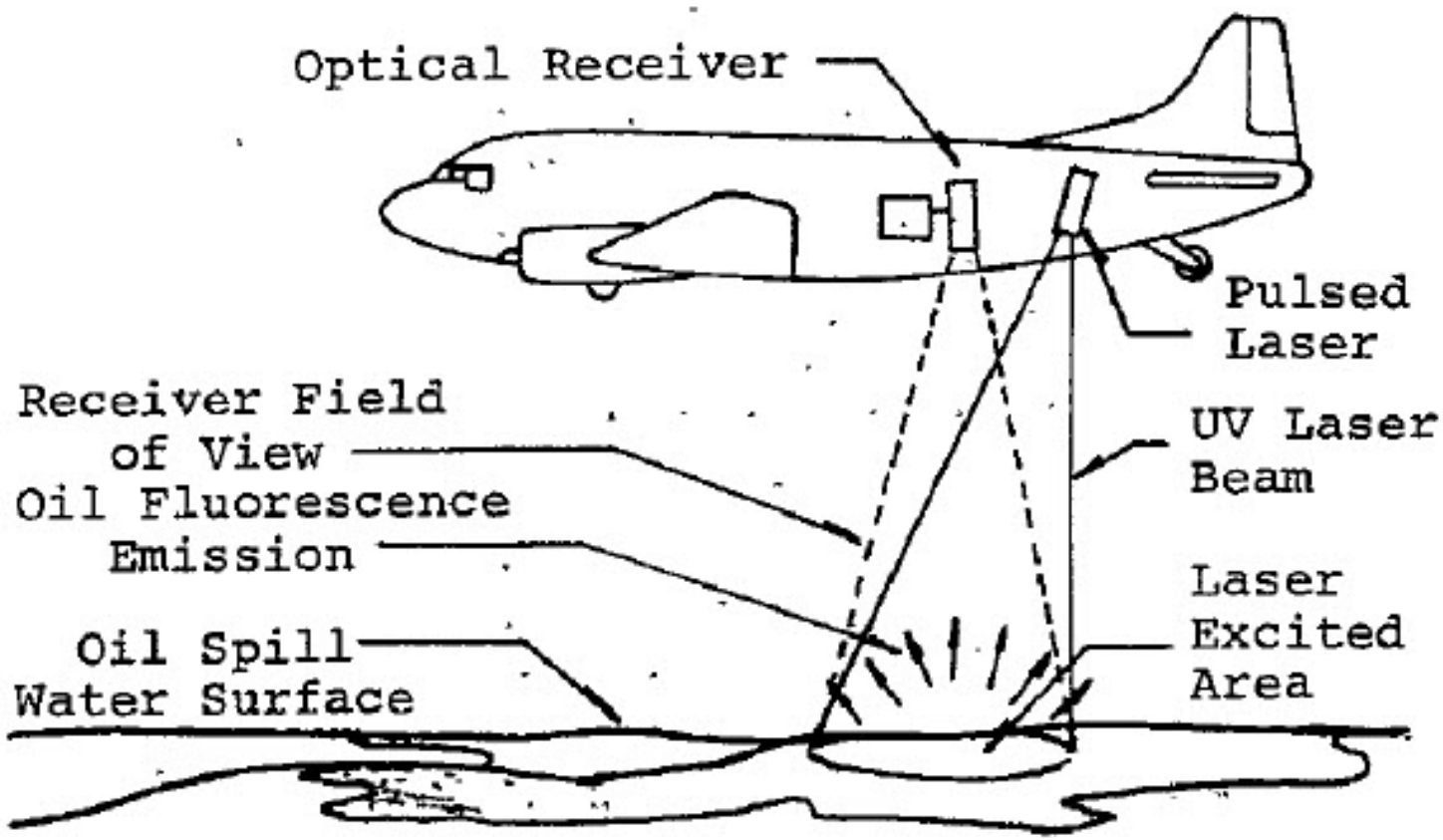
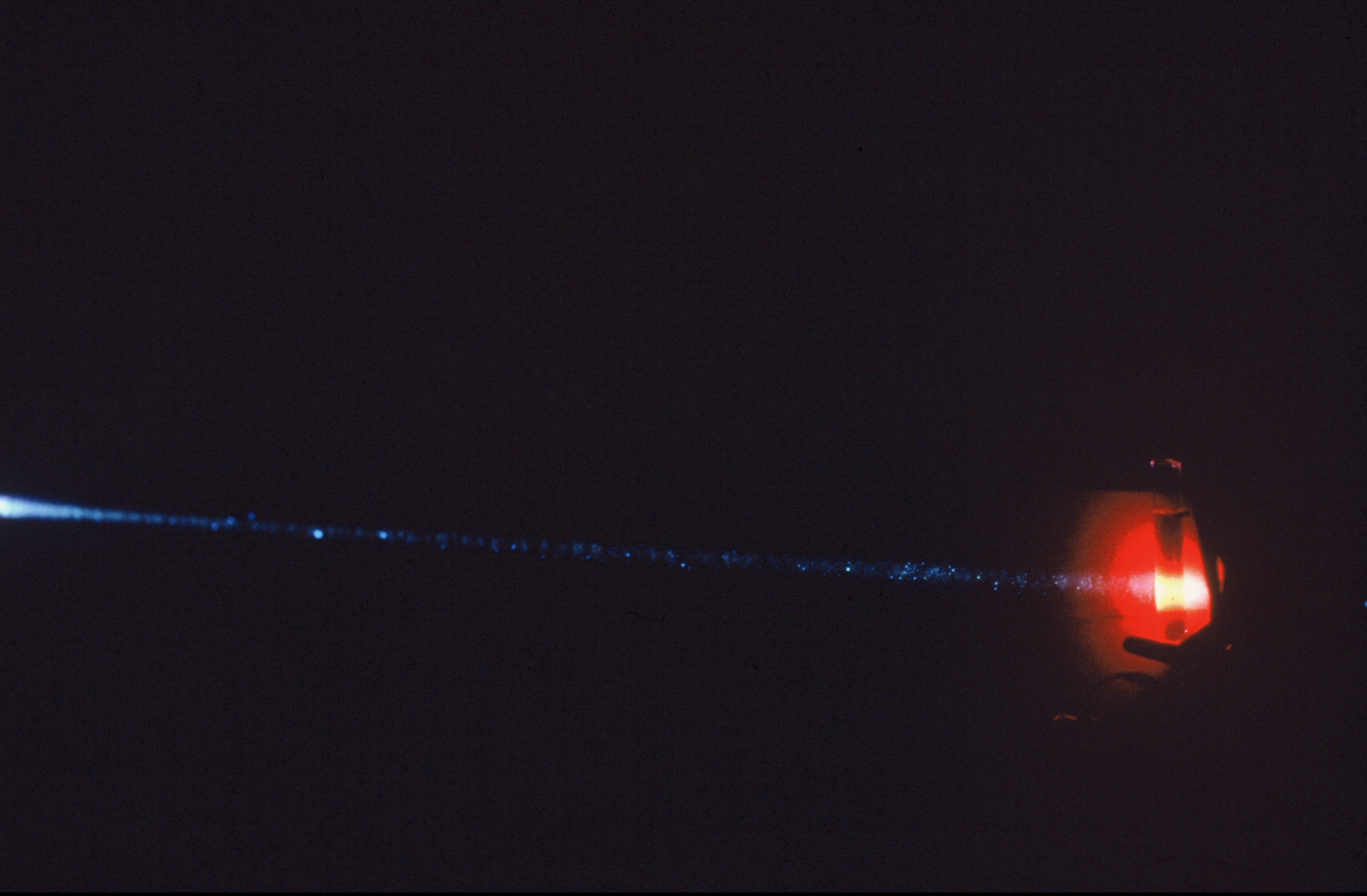


Figure 3. CCRS Airborne Laser Fluoro-sensor Mode



So who's looking at trees as a signal?

СЪЕМКА ПРОФИЛЯ КРОНЫ ДЕРЕВА С ПОМОЩЬЮ ЛАЗЕРНОГО ДАЛЬНОМЕРА

Drawing the crown profile of a tree with the aid of a laser

В. И. СОЛОДУХИН, А. Г. КУЛЯСОВ, Б. И. УТЕНКОВ,
А. Я. ЖУКОВ, И. Н. МАЖУГИН,
В. П. ЕМЕЛЬЯНОВ, И. А. КОРОЛЕВ

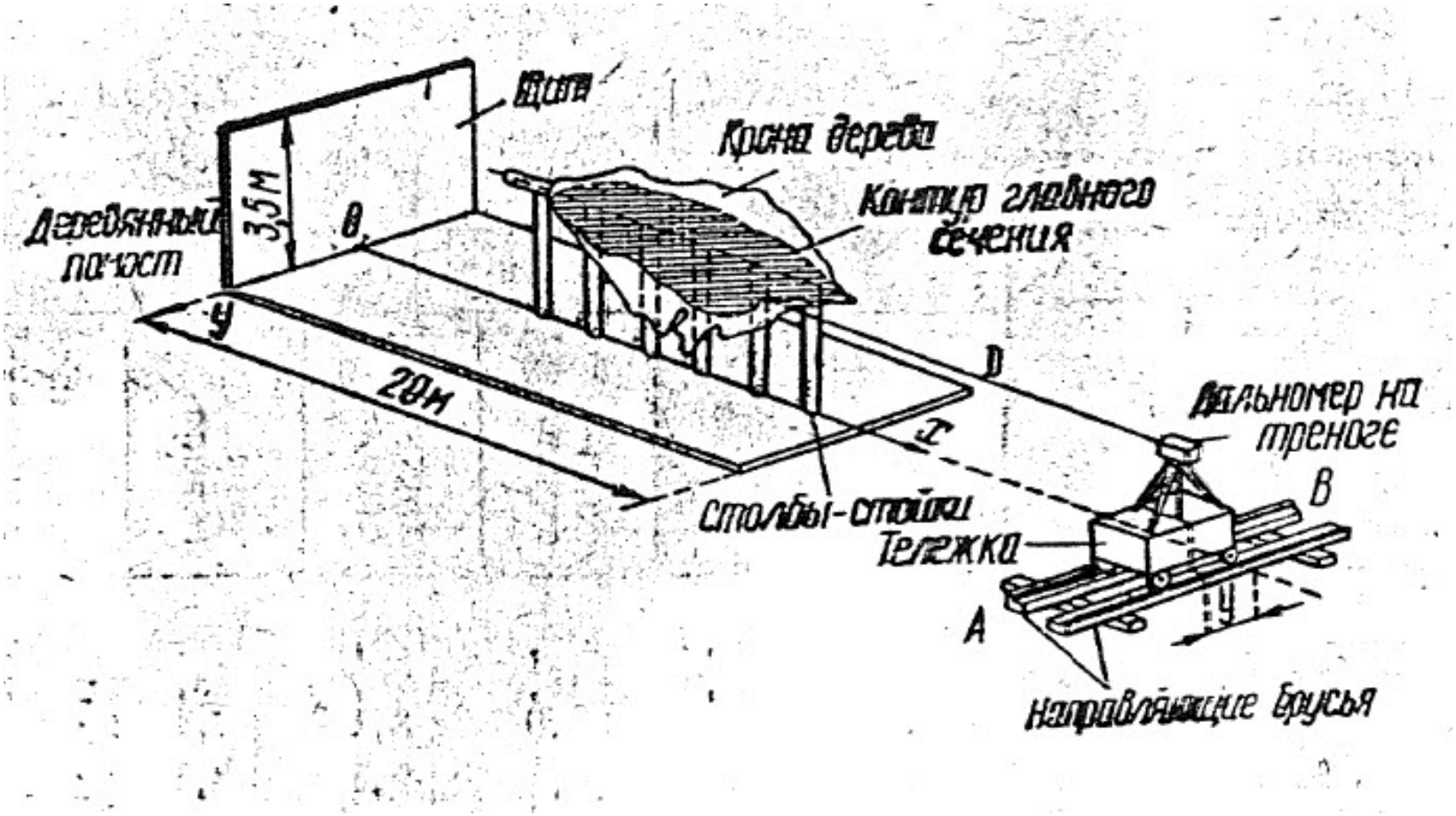
Solodukhin, V.I.

Светодальномерный метод измерения расстояний находит все более широкое применение в различных областях народного хозяйства. Его можно успешно использовать и при оценке лесных ресурсов. Таксация огромных лесных массивов существующими методами не всегда отличается достаточной достоверностью и является одной из самых трудоемких работ в лесном хозяйстве.

В 1974 г. на специально оборудованной площадке (рис. 1) нами была выполнена съемка профилей крон четырех срубленных деревьев, расположенных горизонтально. Она осуществлялась путем измерения расстоя-

71

Solodukhin, V.I., A.G. Kulyasov, B.I. Utenkov, A.Ya. Zhukov, I.N. Mazhugin, V.P. Emel'yanov, and I.A. Korolev. 1977a

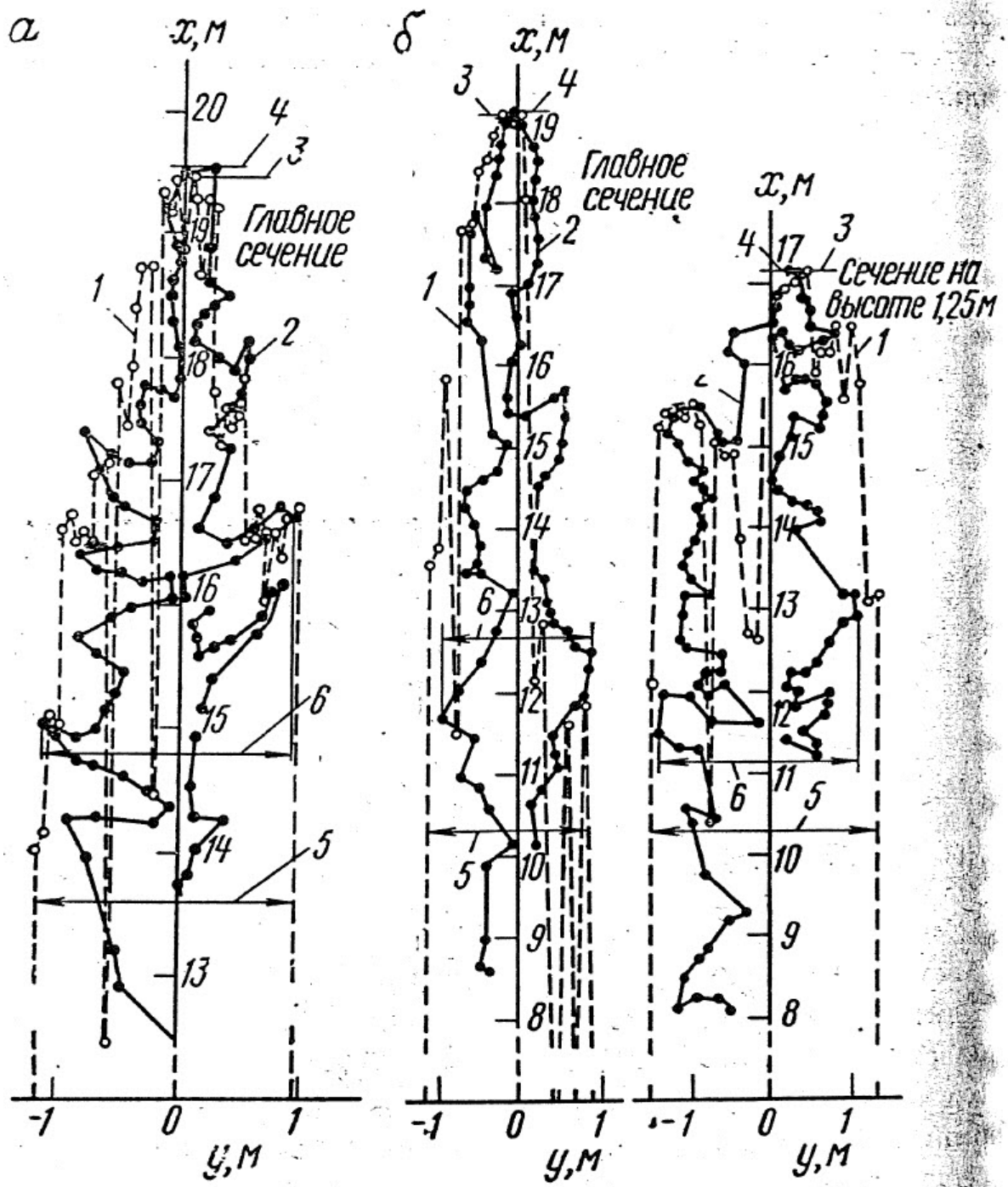


27 yo spruce or 61 yo birch

+

0.633 um laser rangefinder, 25mm spot

=



Conclusions:

-Tape to laser, good agreement.

-Increase power from 1.5 to 15-20 mW then can go airborne@ 300 m AGL.

Solodukhin et al. 1979:

Solodukhin et al. 1979: flights,

Max. elevation Δ, ground vs laser under forest = 40 cm, RMSE = 14 cm

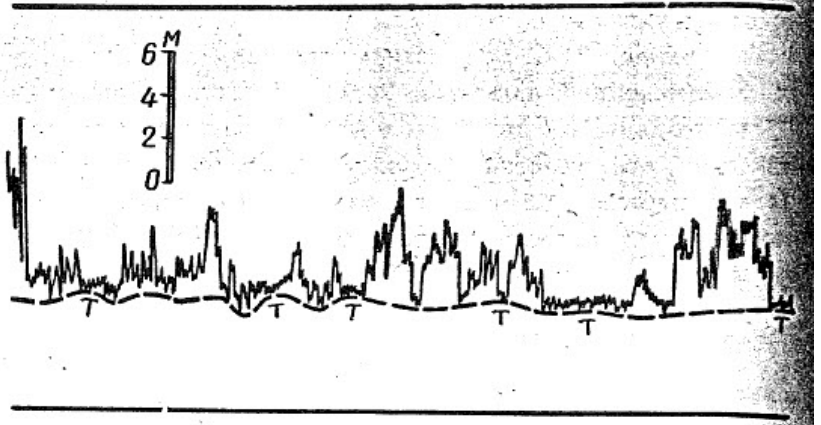


Рис. 2. Смешанные хвойно-лиственные молодняки

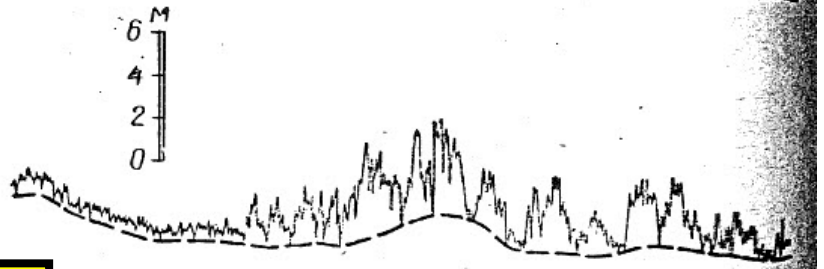


Рис. 3. Заросли ольхи

Building height Δ, laser vs ground, 2 – 7 cm

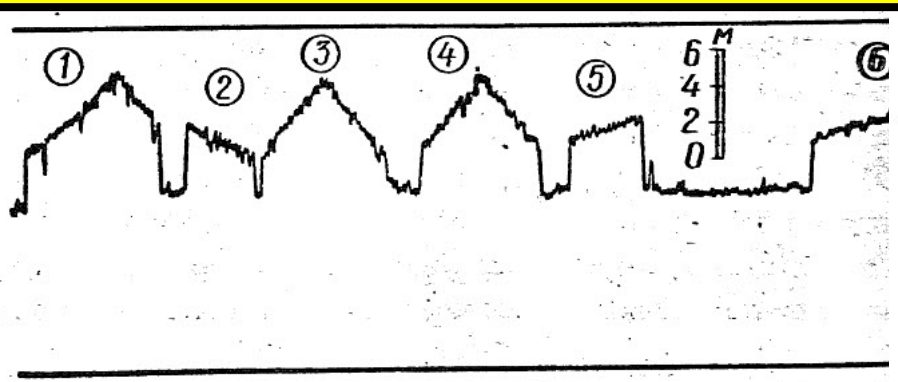
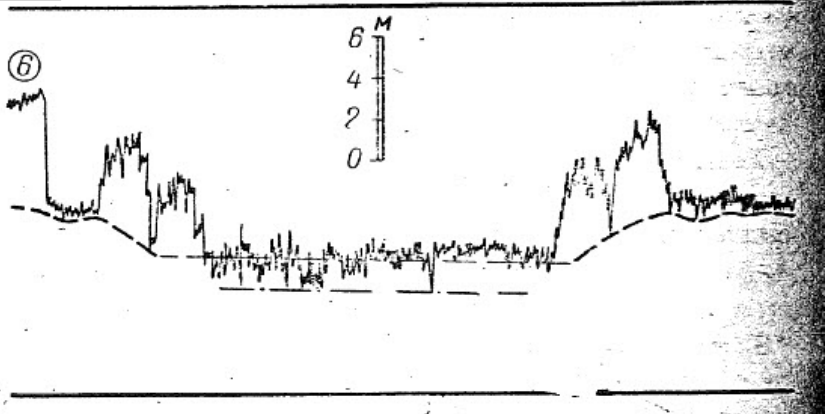
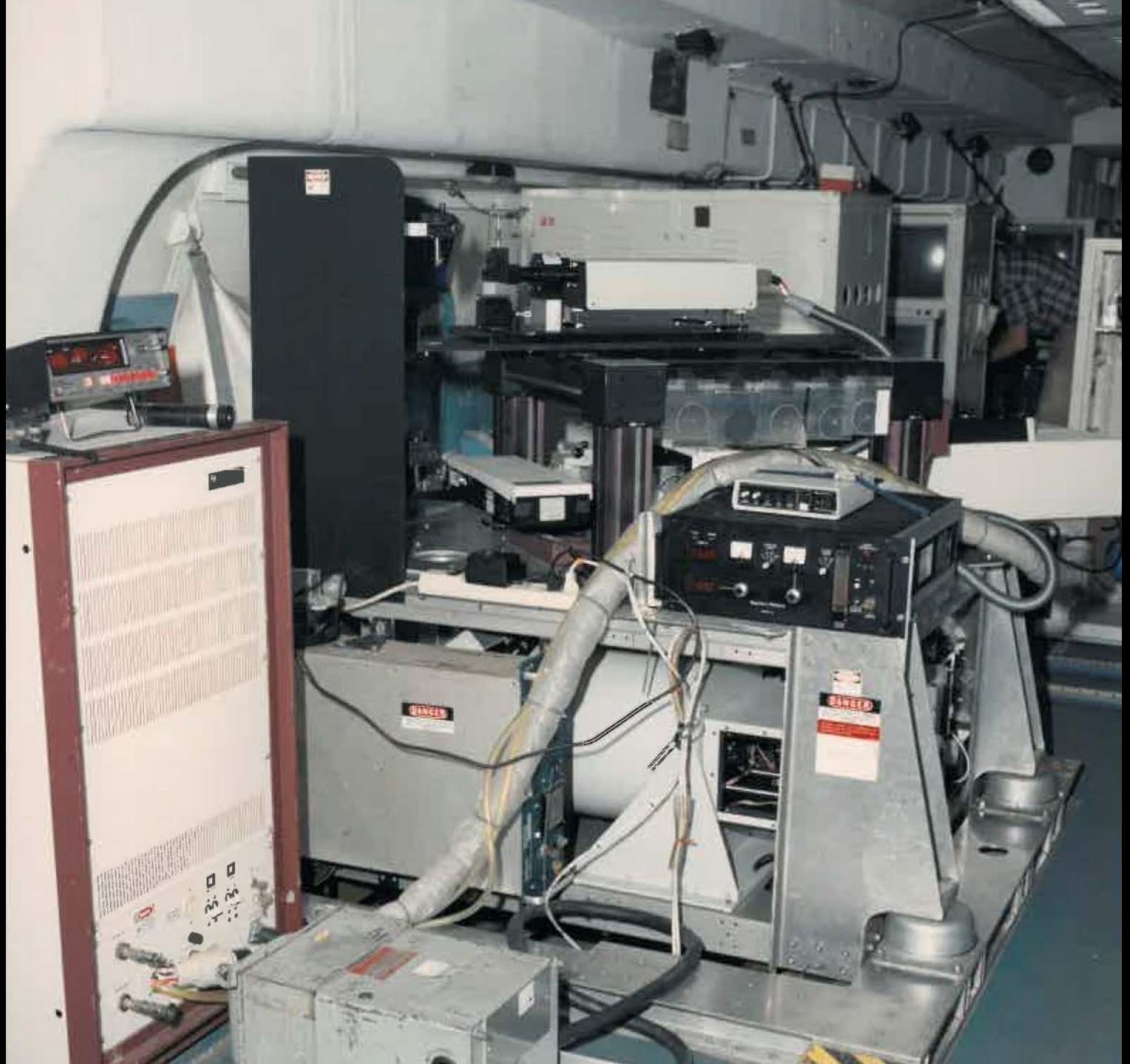
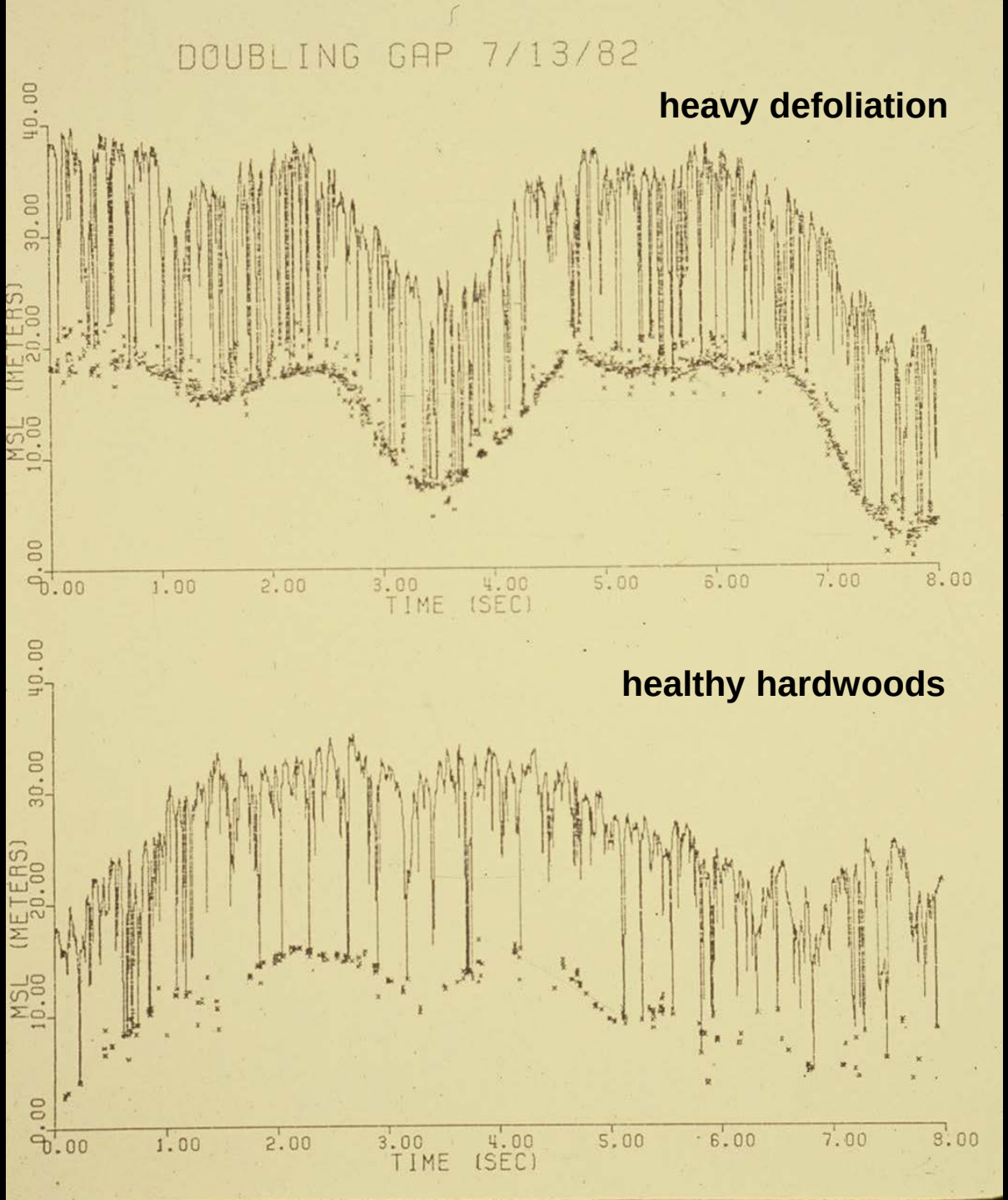


Рис. 6. Строения кирпичного завода



NASA
428
N428NA




DOUBLING GAP 7/13/82
heavy defoliation
MSL (METERS)
40.00
30.00
20.00
10.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
TIME (SEC)
healthy hardwoods
MSL (METERS)
40.00
30.00
20.00
10.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
TIME (SEC)

So that's our heritage.

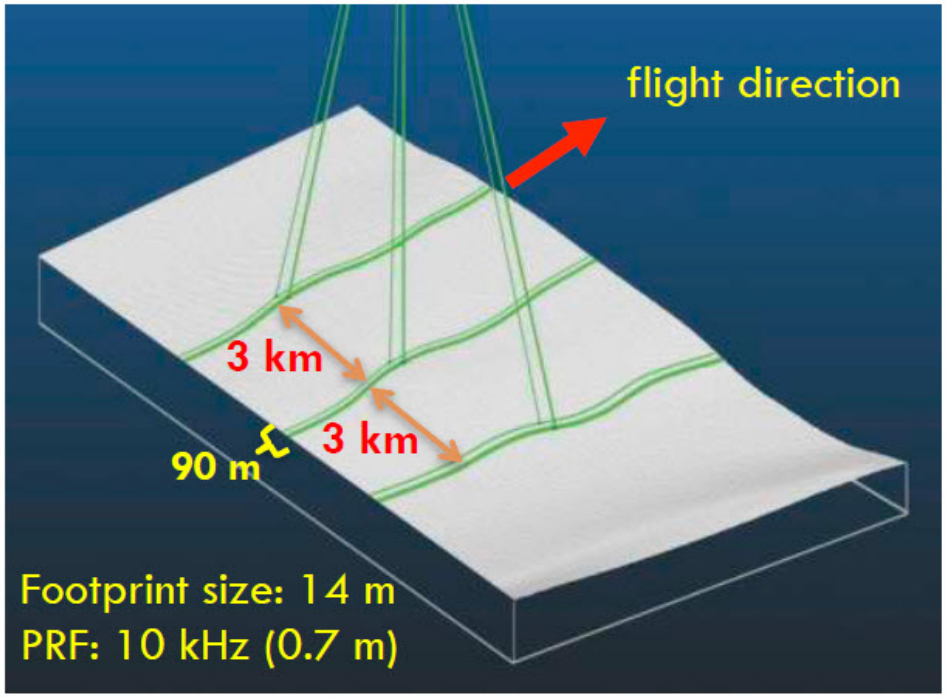
1960 – 1980: DOD research, big systems, no GPS, no INS, paper traces, multi-track tapes later, primarily CW lasers.

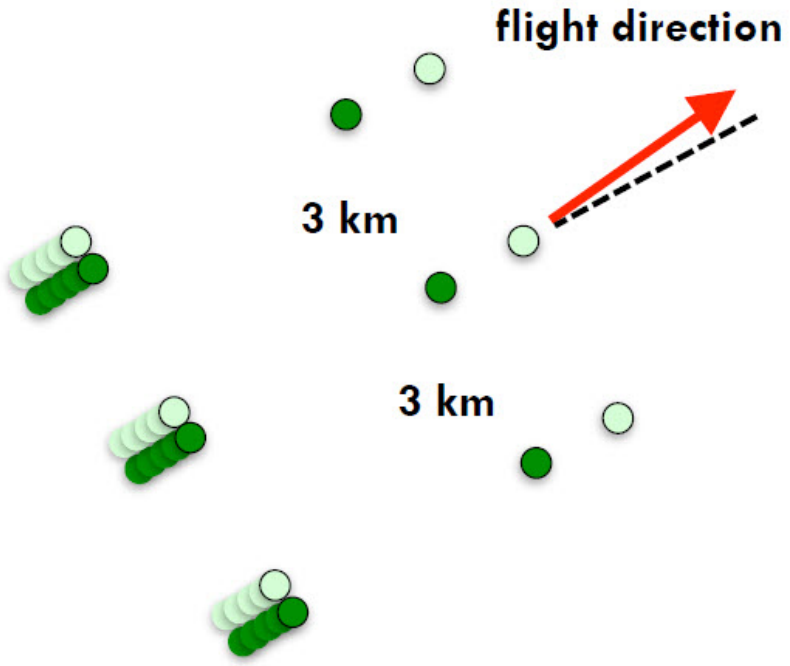
1980 – 2015: 100s of multinational researchers, 1000s of papers, profilers → scanners, 100 Hz → 350 kHz, ocillographs → ss hard-drives, INS, GPS, 1 t → 30 kg single return or CW → multistop or waveforms, airborne → TLS – ALS – spacecraft (GLAS, 2003-7)

2016+ ?? As a forestry lidar community, where are we going, and what do we have available to us?

ICESat-2 **2017(8?) launch, 3-5 year mission**

Single laser pulse at 532nm, split into 6 beams. Single-photon sensitive detection.





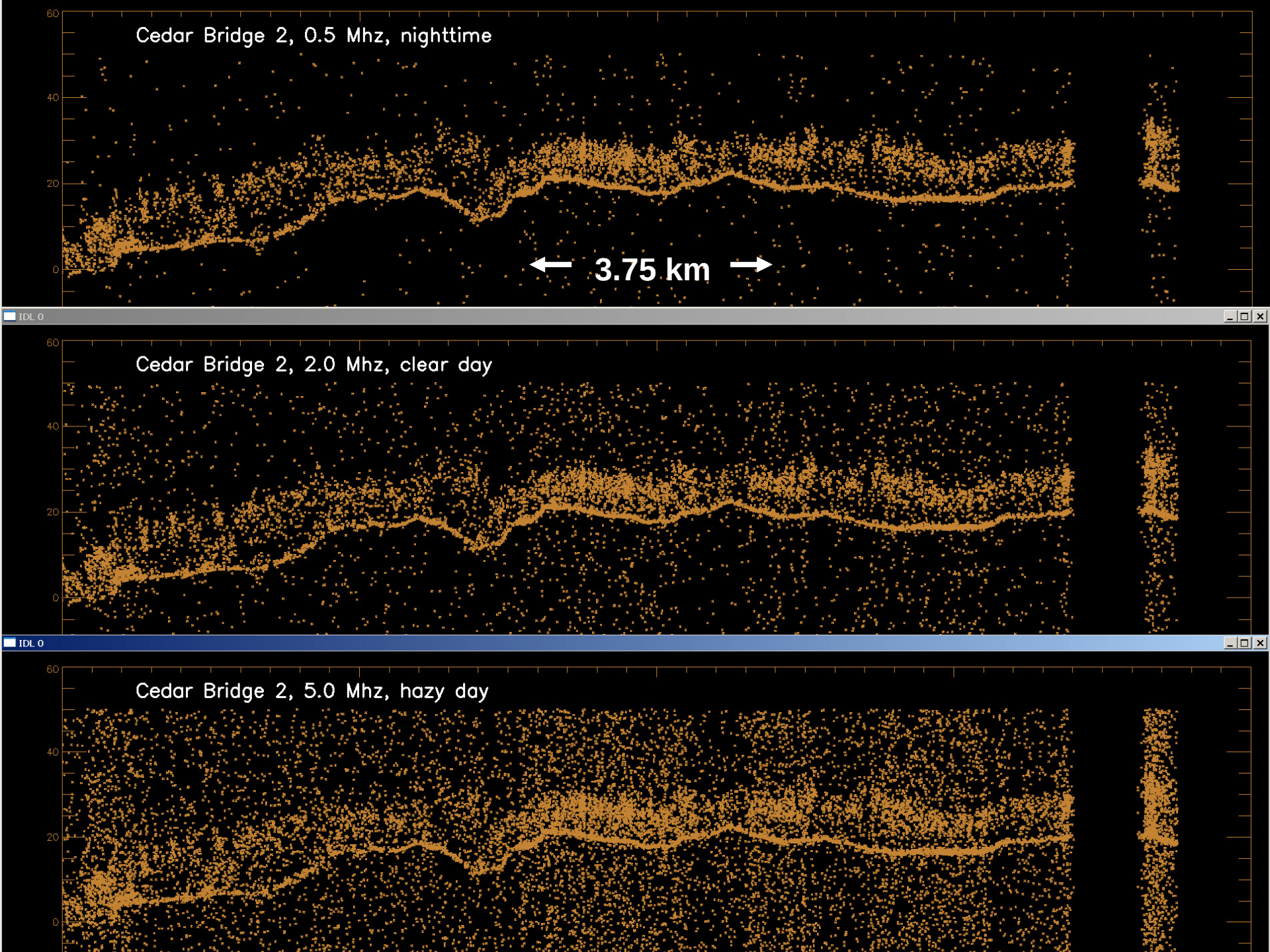
3 km spacing between pairs provides spatial coverage

90 m pair spacing for ***slope determination*** (2° yaw)

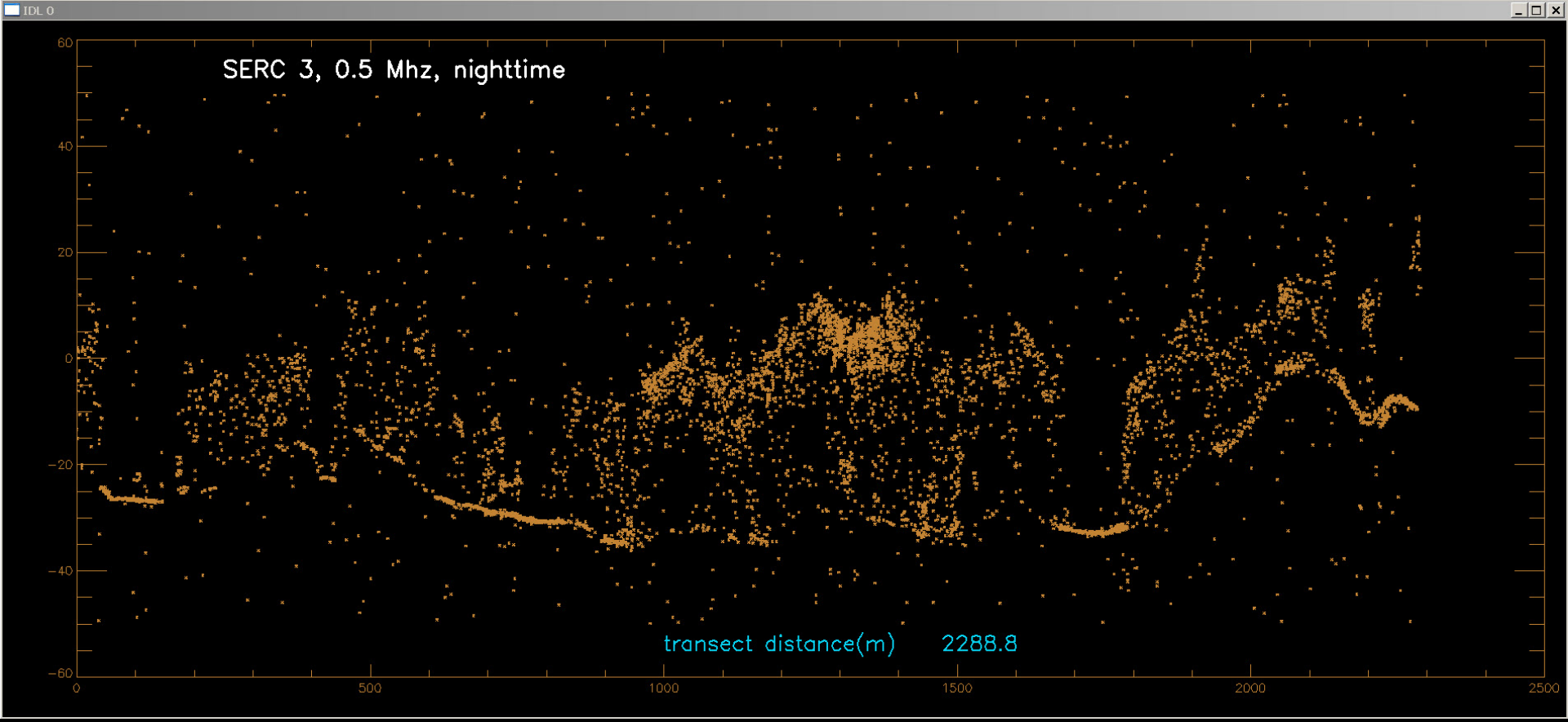
high-energy beams (4x) for better performance over low-reflectivity targets

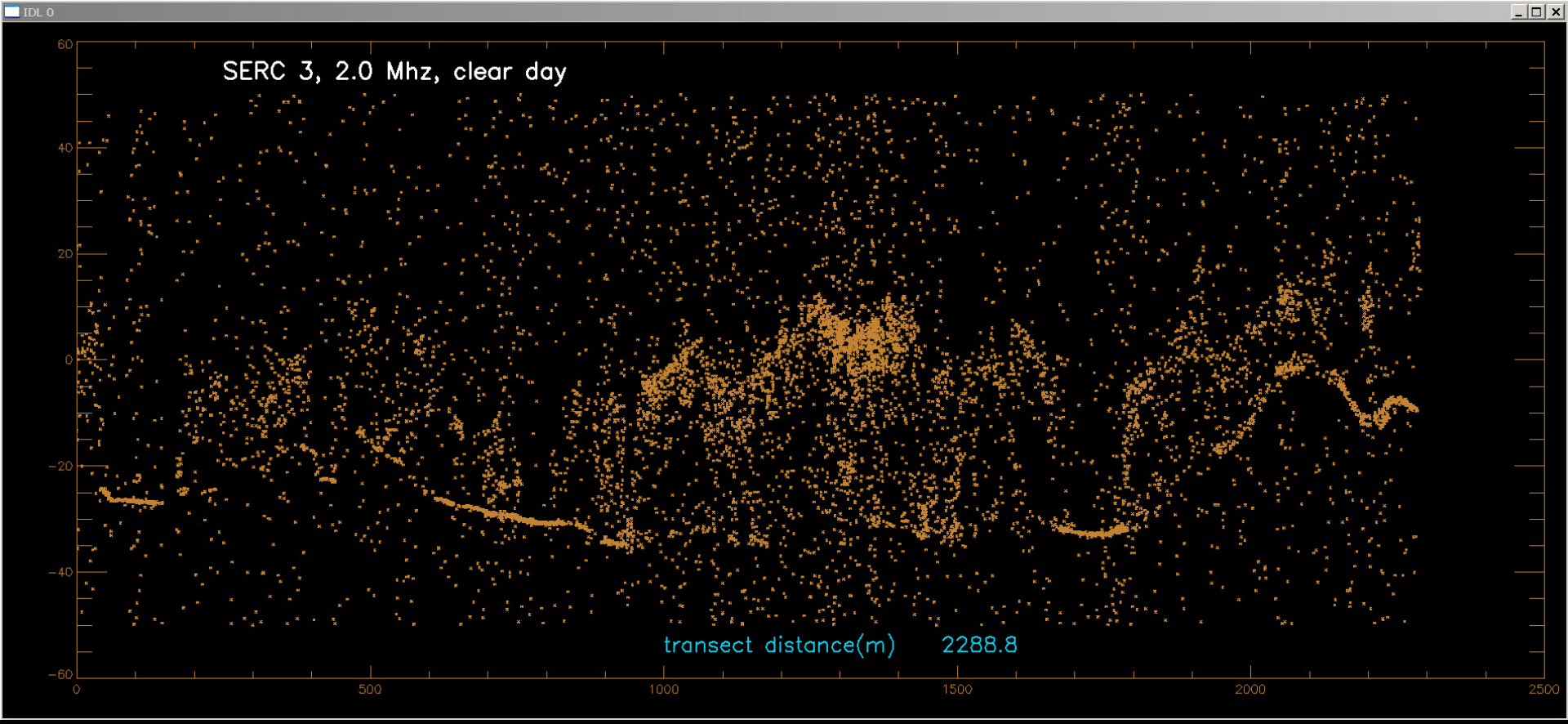
92° inclination; 91-day repeat orbit, 1387 revs.

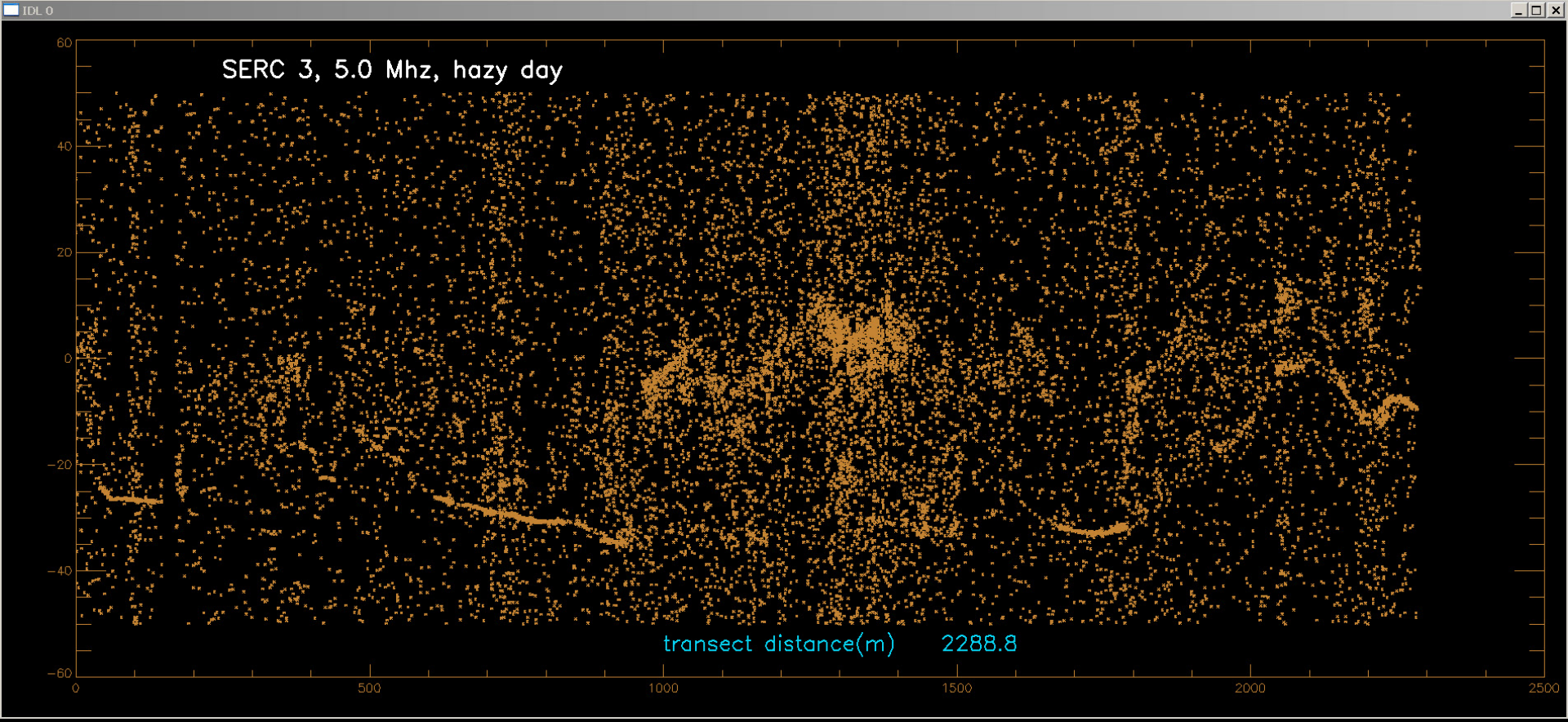
Pine Barrens – southern NJ


Cedar Bridge 2, 0.5 Mhz, nighttime
60
40
20
0
3.75 km
IDL 0
Cedar Bridge 2, 2.0 Mhz, clear day
60
40
20
0
IDL 0
Cedar Bridge 2, 5.0 Mhz, hazy day
60
40
20
0

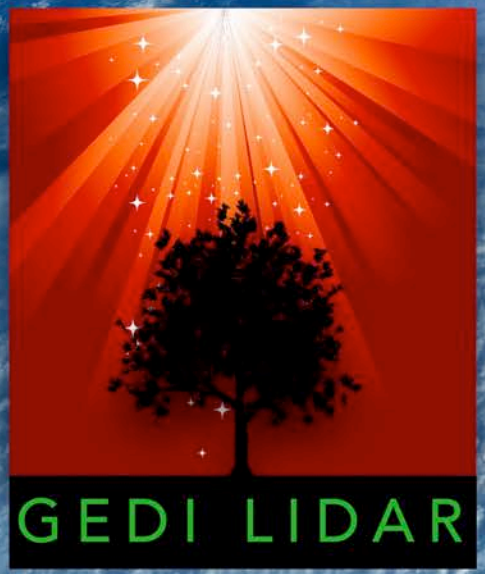
SERC – mid-Atlantic
deciduous trees


IDL 0
SERC 3, 0.5 Mhz, nighttime
60
40
20
0
−20
−40
−60
0
500
1000
1500
2000
2500
transect distance(m) 2288.8


IDL 0
SERC 3, 2.0 Mhz, clear day
60
40
20
0
−20
−40
−60
0
500
1000
1500
2000
2500
transect distance(m) 2288.8


IDL 0
SERC 3, 5.0 Mhz, hazy day
60
40
20
0
−20
−40
−60
0
500
1000
1500
2000
2500
transect distance(m) 2288.8

GLOBAL ECOSYSTEM DYNAMICS INVESTIGATION

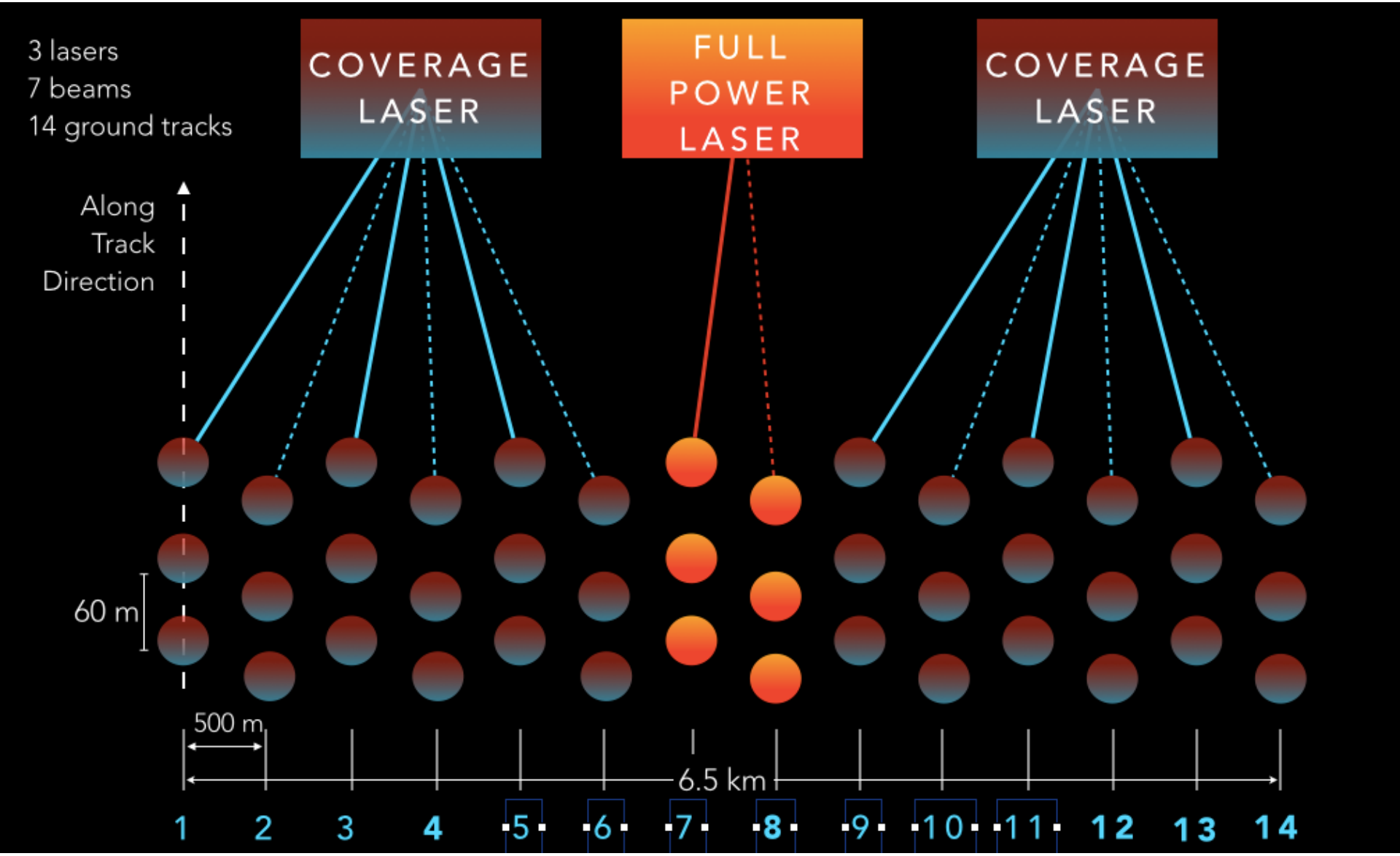


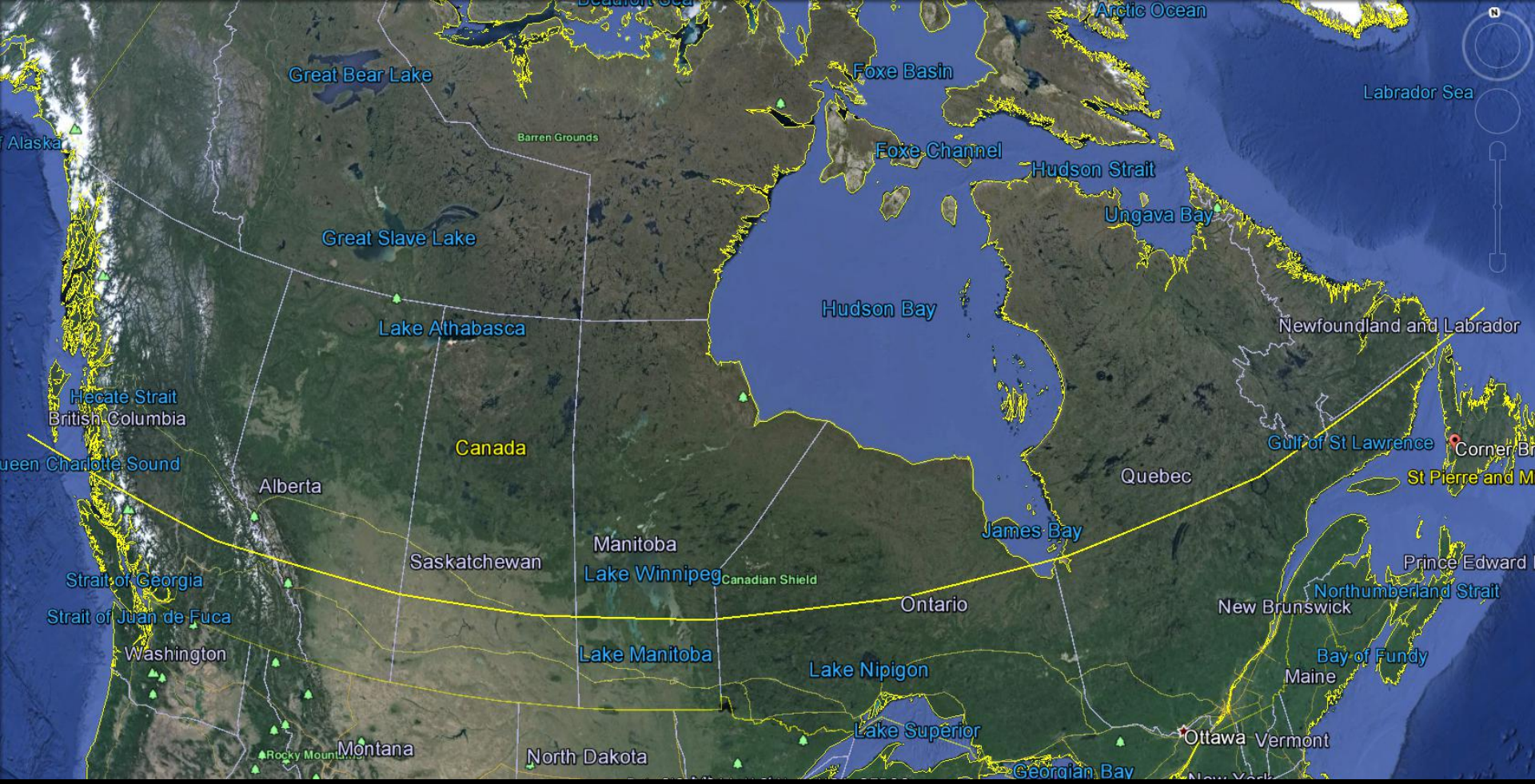
- Earth's first comprehensive, high-resolution data set of ecosystem structure
- Selected by NASA Earth Ventures Instrument Competition
- Led by UMD in collaboration with NASA GSFC
- Major Science Questions

What is the carbon balance of the Earth's forests?

How does forest structure affect habitat quality and biodiversity?

How will the land surface mitigate atmospheric CO_2 in the future?


3 lasers
7 beams
14 ground tracks
COVERAGE LASER
FULL POWER LASER
COVERAGE LASER
Along Track Direction
60 m
500 m
6.5 km
1
2
3
4
5
6
7
8
9
10
11
12
13
14



GEDI coverage: south of the 51.65° N line.
One orbit every 92.7 minutes, precessing.

What does AWARE have available to it for provincial/national forest assessment?

1. **Access to dependable,turn-key ALS systems and data.**

2. **Future access to ICESat-2 photon-counting data (~2018 – 2022, no currently planned follow-on).**

3. **Model-based, 2-phase (ground-air) and 3-phase (ground--air-space) sampling frameworks and estimators.**

4. **Access to provincial and industrial field-based forest inventory data (ON, AB, NL, & NB).**

5. **Canadian universities and companies well-versed in ALS remote sensing.**

What does AWARE need to conduct repeatable commercial forest inventories?

In my opinion, the most important characteristic of a laser-based commercial forest inventory is consistency of measurement.

- **same ALS system,**
- **same time of year,**
- **same flight lines,**
- **same allometric equations,**
- **same ground-ALS equations,**
- **same stratification***.**

- **This doesn't mean that you can't change these items.**
- **It does mean that you should archive your data at t0, t1, t2… so that old data can be reworked given a Δ.**

What would I do if my goal was to develop a ground plot – airborne lidar – space lidar 3-level sampling framework to estimate AG carbon for all of Canada?

1. **forget about satellites – I2 will be gone by 2022.**

2. **Buy 3 or 5 turnkey airborne laser scanning systems, Cross-calibrated. Put 2 (4) on the shelf.**

3. **Run N-S ALS transects every 50 km over forested areas, including 250 km out onto the tundra.**

4. **Collect/invest in shrub allometry, by WWF ecozone & establish network of shrub and forest plots across Canada. Fly them with your ALS.**

5. **Develop ground biomass = f(ALS).**