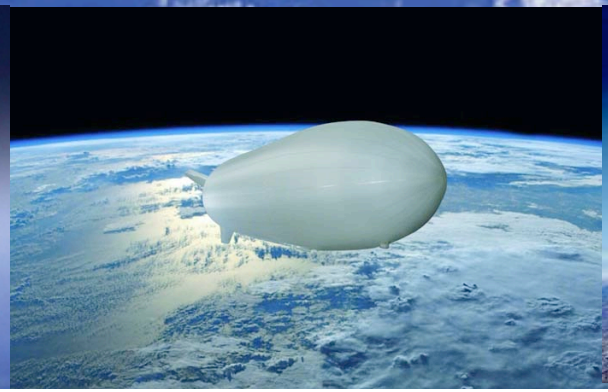
Airships:
A New Horizon for Science

Rob Fesen
Dartmouth College



HIGH ALTITUDE SCIENTIFIC BALLOONS

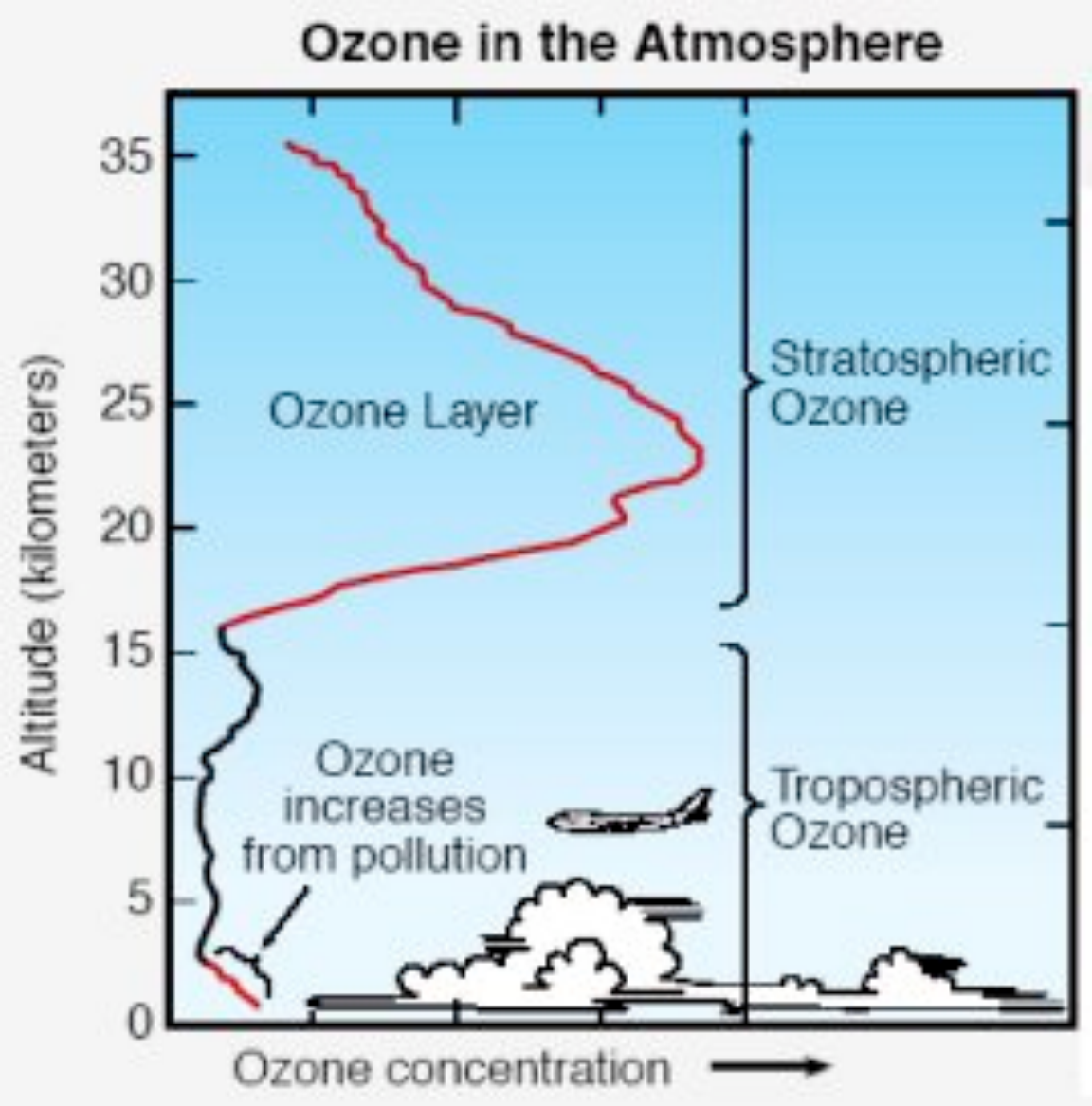
High altitude balloon have been used for over 70 year for near space exploration. Flying at altitudes in excess of 100,000 ft above the surface of the Earth for days, scientists can perform experiments and obtain data not possible below the troposphere.

One doesn't have to go up very far to get above most of Earth atmosphere.

Altitude		Pressure	Density	Temperature	
0 km	0 ft	1013 mbars	1.2 kg/m3	+15 C	+60 F
12.2 km	40,000 ft	185 mbars	0.31 kg/m3	-57 C	-71 F
15.2 km	50,000 ft	115 mbars	0.19 kg/m3	-56 C	-69 F
18.3 km	60,000 ft	70 mbars	0.12 kg/m3	-56 C	-69 F
19.8 km	**65,000 ft**	**55 mbars**	0.088 kg/m3	-56 C	-69 F
21.3 km	**70,000 ft**	**45 mbars**	0.075 kg/m3	-56 C	-69 F
24.4 km	**80,000 ft**	**28 mbars**	0.042 kg/m3	-52 C	-62 F
25.9 km	**85,000 ft**	**22 mbars**	0.034 kg/m3	-51 C	-60 F
27.4 km	90,000 ft	17 mbars	0.027 kg/m3	-49 C	-56 F

Near Space:

At 65,000 ft (20 km; 12 miles) one is 25 times closer to the ground than low earth satellites (300 miles up) and nearly 2000 times closer than geosynchronous satellites (22,500 miles up).



Stratospheric ozone contains 90% of the Earth's atmospheric ozone which acts as the planet's primary UV radiation shield.

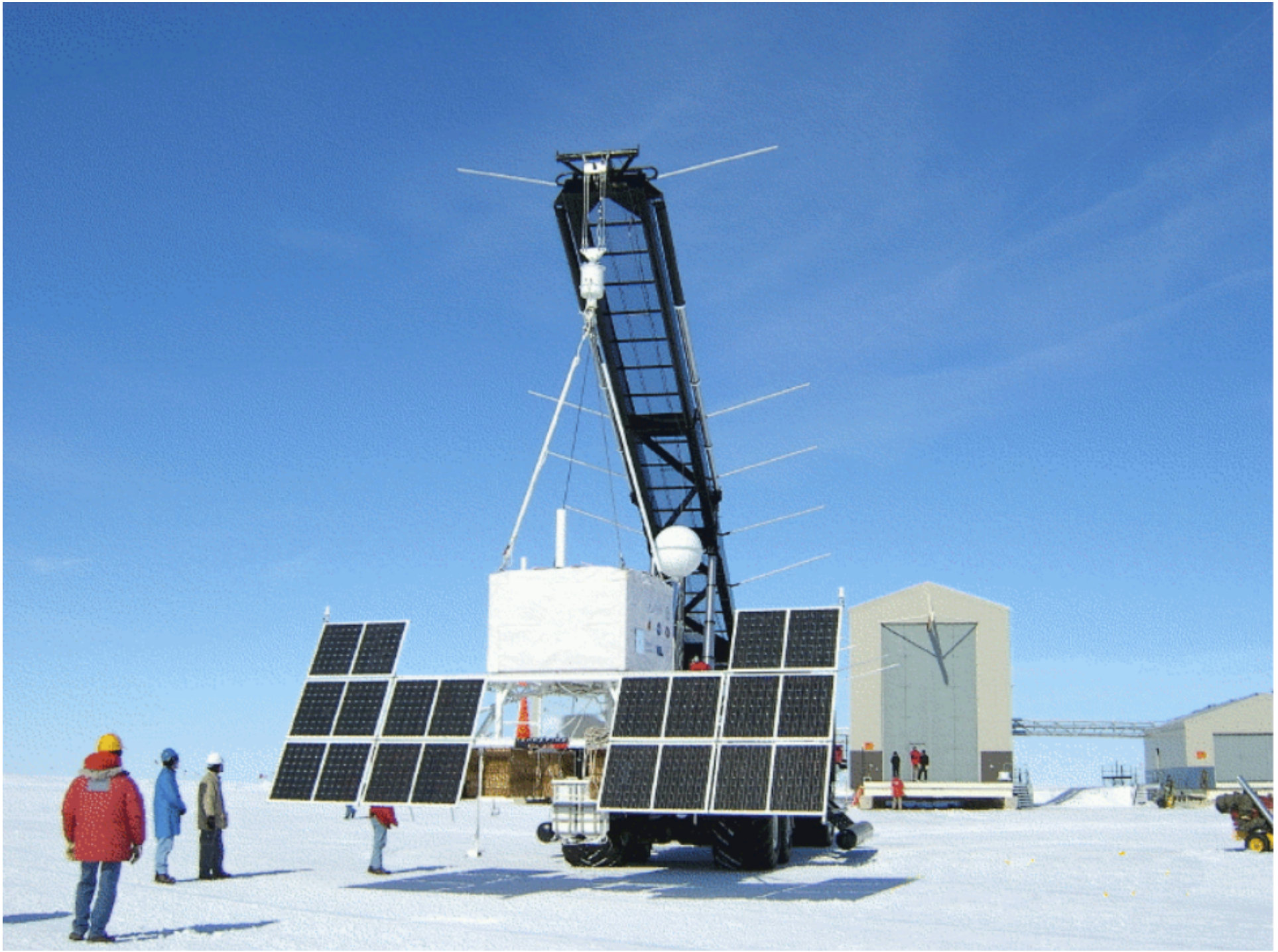
Good for us, but prevents UV and X-ray astronomical observations to be made from altitudes less than around 30 km (100,000 ft).

Standard Lighter than Air (Balloon) Science Vehicles

The science payload, commonly weighing 1-2 tons, is usually hung in a gondola at the bottom of the balloon. Balloons can reach heights of 130 kft.

The science payload is free to bob, swing, and twist -- making precise and steady pointing at targets difficult.

They also drift with the wind leading to limited flight paths (mainly polar regions) due to international overflight restrictions plus payload recovery problems.



FY-13 Antarctic Campaign: 2012-13 Season

Three balloon payloads launched in Dec. 2012 collectively flew 96 days!

Super-TIGER (PI: Binns/Washington U. St Louis): Dec 8 launch, **55-day flight**.

Studying the origin of cosmic rays via heavy elemental abundance measurements.

BLAST-pol (PI: Devlin/U. Penn): Dec 25, **16-day flight.**

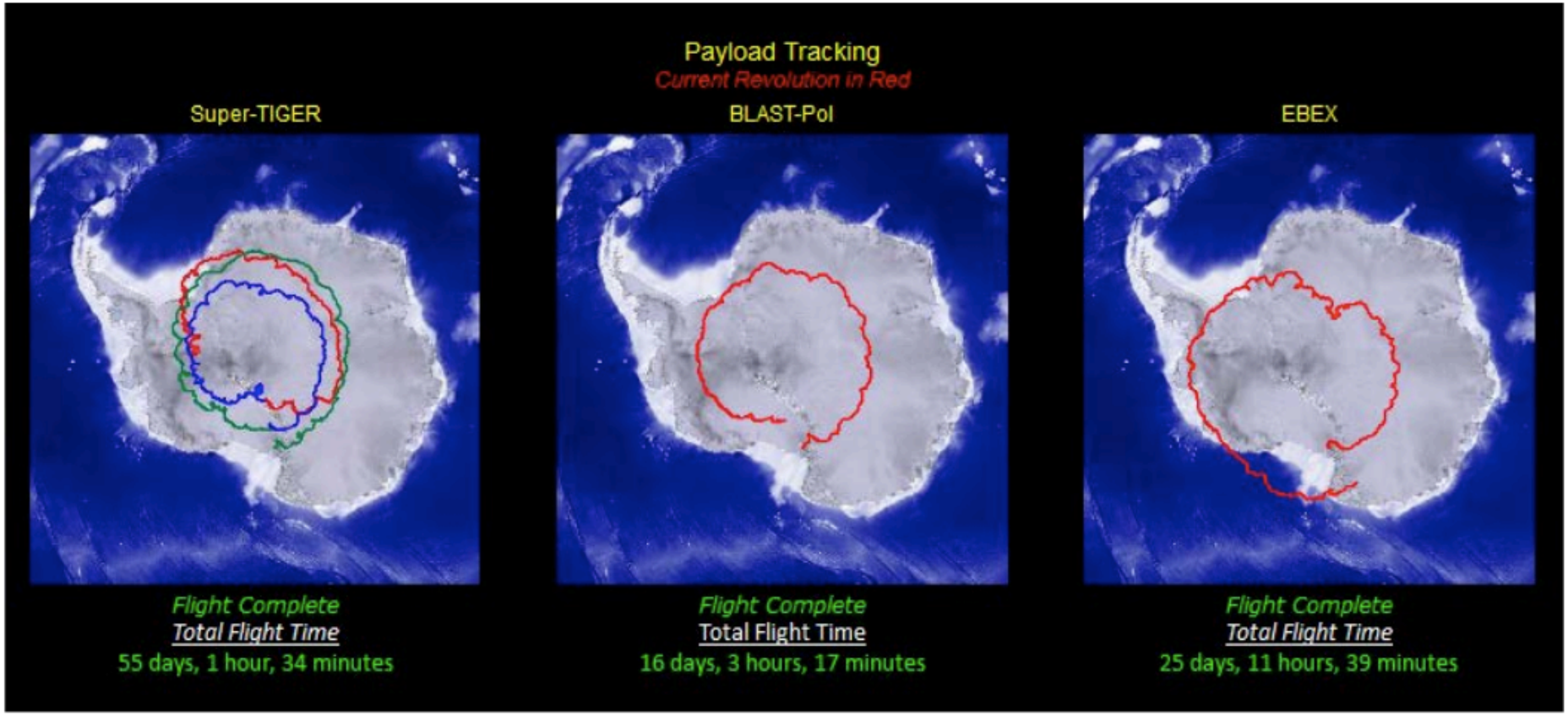
Mapping of polarized dust emission along the Galactic Plane; influence of magnetic fields on star formation.

EBEX (PI: Hanany/Minnesota): Dec 28. **25-day flight.**

E- and B-mode Explorer; CMB polarization as a probe of cosmic inflation and gravitational lensing.

April 16, 2013

"Report on the Balloon Program"



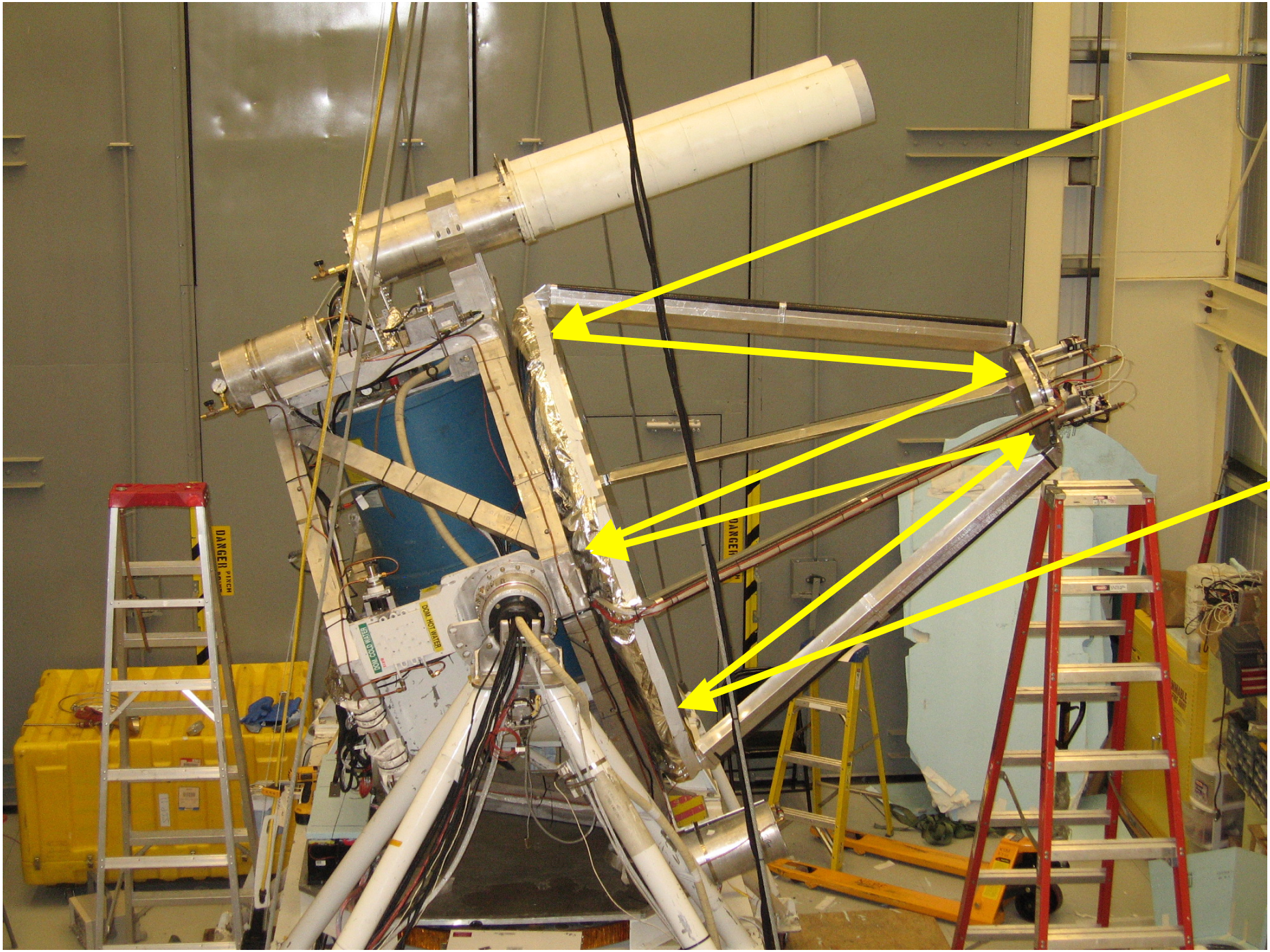
W. Vernon Jones
Senior Scientist for Suborbital Research

BLAST

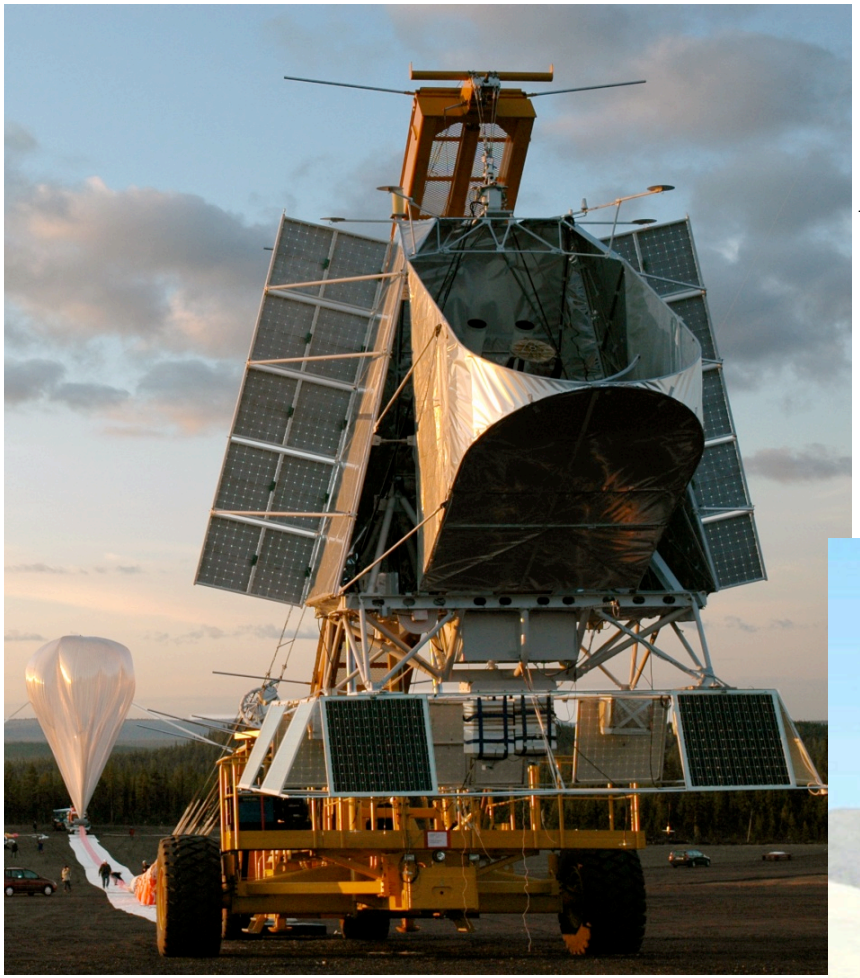
Balloon-borne **L**arge **A**perture **S**ubmillimeter **T**elescope

Mark Devlin (U. of Penn.)

Antarctica December 2006

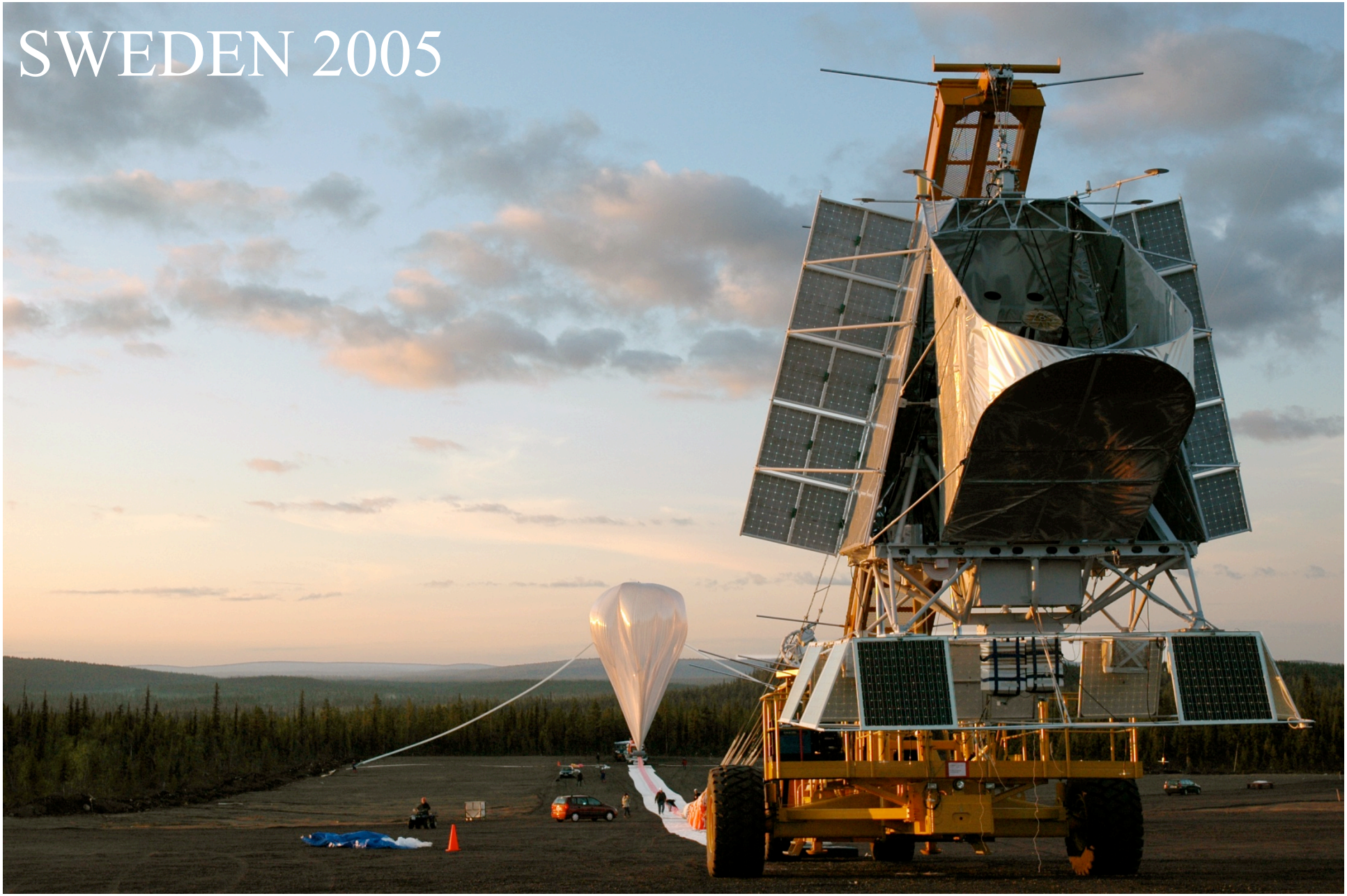

DANGER!
DANGER!
DO NOT WATER

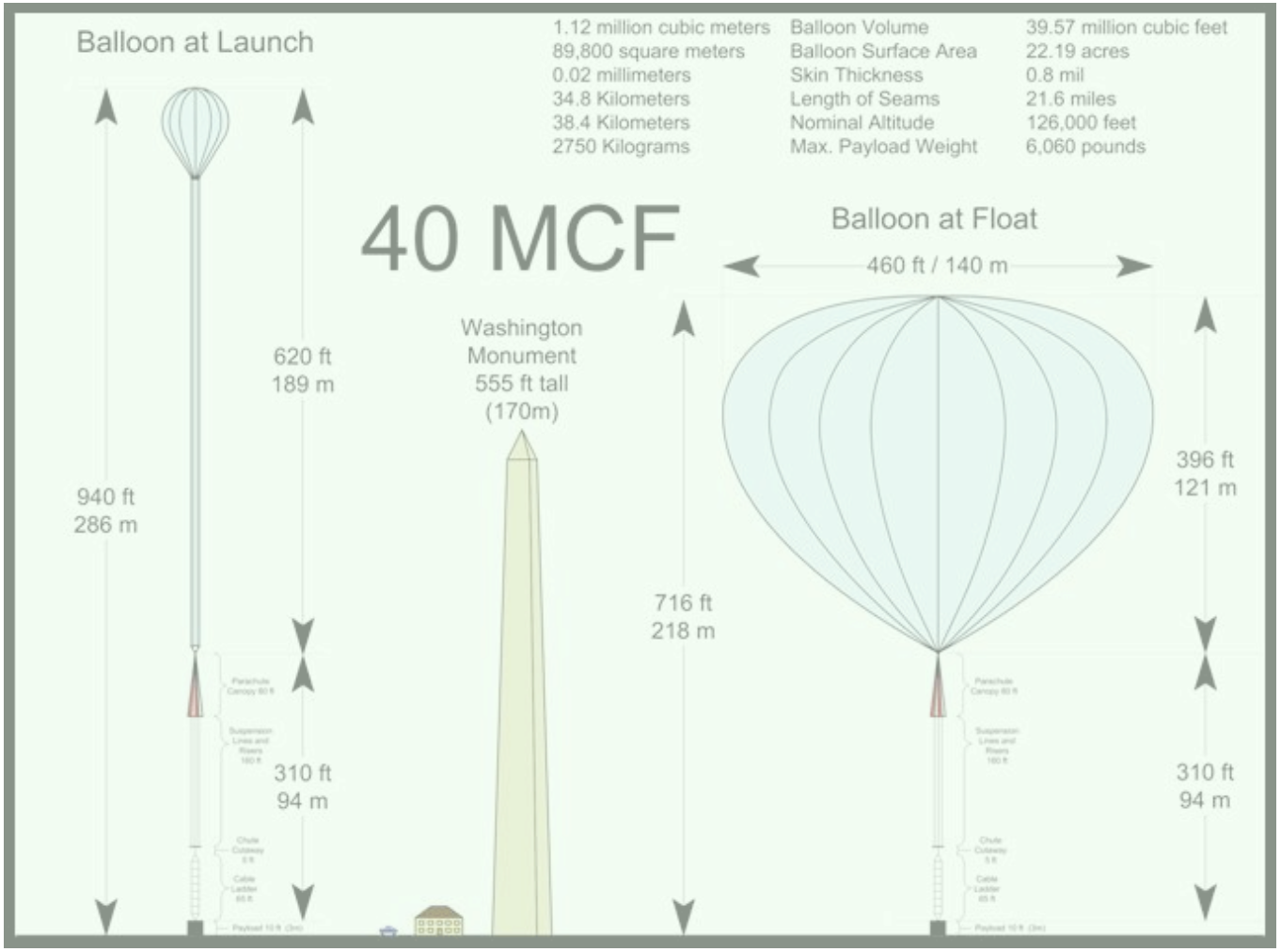
The BLAST Telescope vs. The HUMMER



Approximately the same size and weight.
Both available in RED.

SWEDEN 2005




Balloon at Launch
1.12 million cubic meters
Balloon Volume
39.57 million cubic feet
89,800 square meters
Balloon Surface Area
22.19 acres
0.02 millimeters
Skin Thickness
0.8 mil
34.8 Kilometers
Length of Seams
21.6 miles
38.4 Kilometers
Nominal Altitude
126,000 feet
2750 Kilograms
Max. Payload Weight
6,060 pounds
40 MCF
Balloon at Float
460 ft / 140 m
Washington Monument
555 ft tall
(170m)
620 ft
189 m
940 ft
286 m
716 ft
218 m
396 ft
121 m
310 ft
94 m
310 ft
94 m


Sweden
Anchorage
ALASKA
(UNITED STATES)
Juneau
Whitehorse
Fairbanks
Dawson
Watson Lake
120
Norman Wells
Inuvik
Tuktoyaktuk
Hay River
Beaufort
Sea
Yellowknife
Kugluktuk
Banks
Island
Victoria
Island
CANADA
Cambridge
Bay
Queen
Elizabeth
Islands
Arviat
Baker Lake
Gjoa
Haven
Resolute
Chesterfield
Inlet
90 W
Repulse Bay
Hudson
Bay
Coral
Harbour
Igloolik
Ellesmere
Island
Alert
Grise
Fiord
Pond Inlet
Thule
Baffin
Island
Cape Dorset
Clyde River
Baffin
Bay
Iqaluit
ICE CAP
GREENLAND
(DENMARK)
Davis
Strait
Søndre Strømfjord
Nuuk
Frederikshab
Labrador
Sea
Tasiilaq
Narsarsuaq
Denmark
Strait
NORTHWEST PASSAGE
ICEBERG
ICELAND
Reykjavik
NORTH
Dickson
Kara
Sea
Franz
Josef
Land
80
RUSSIA
Novaya
Zemlya
SVALBARD
(Norway)
Longyearbyen
Barents
Sea
Danmarkshavn
GREENLAND
SEA
Daneborg
70
Hammerfest
Murmansk
Tromsø
Archangel
Norwegian
Sea
Narvik
60
Azimuthal Equal-Area
Projection
0
500 Kilometers
0
500
Miles
FINLAND
SWEDEN
Helsinki
St. Petersburg
Trondeim
2
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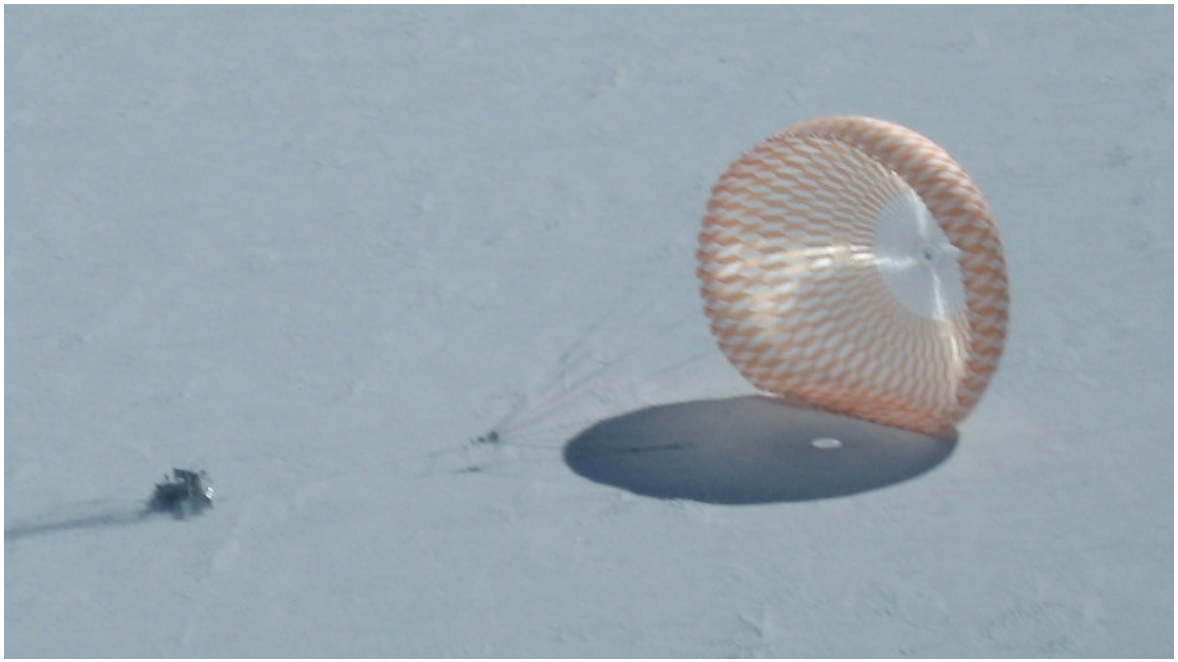
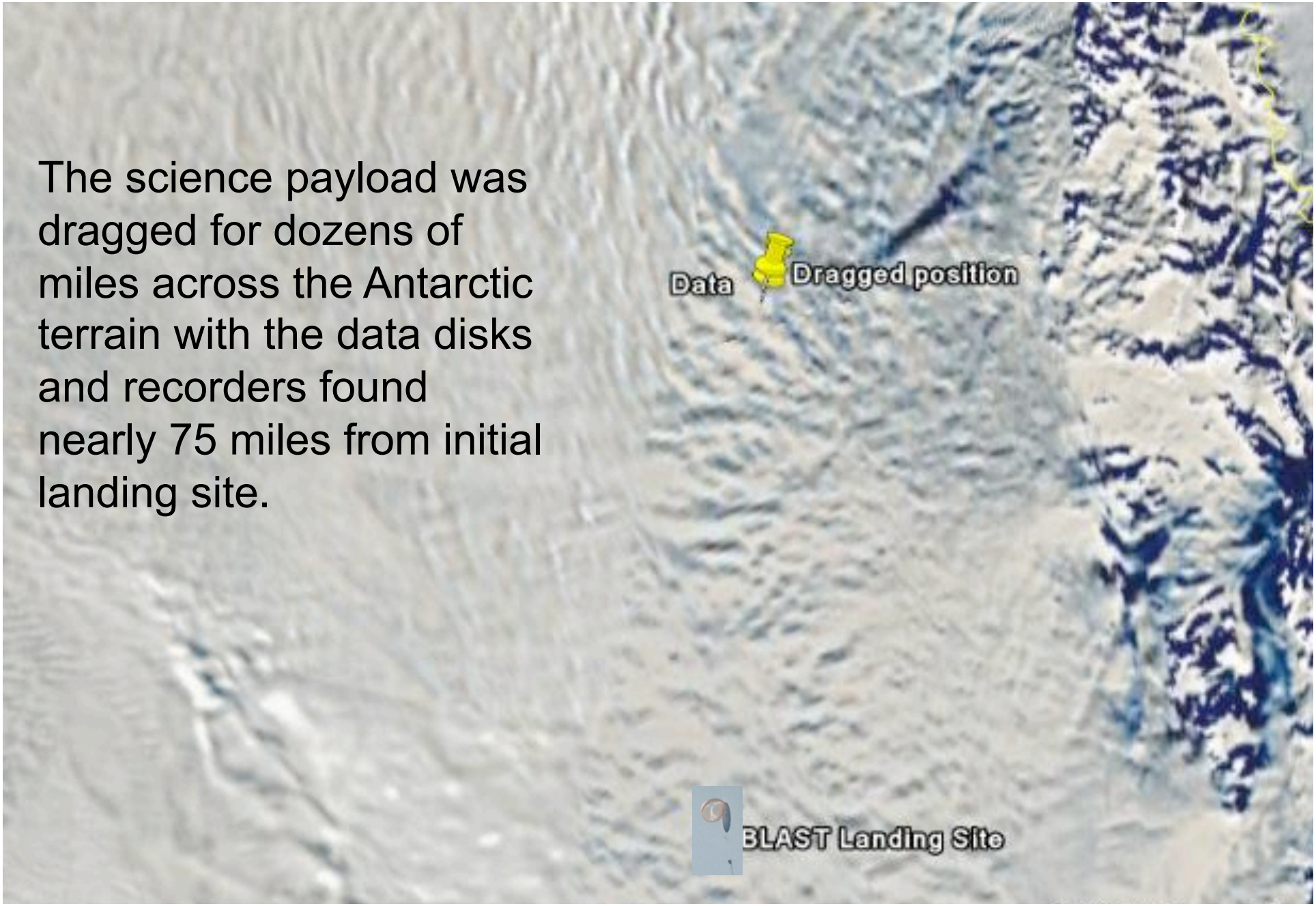
8

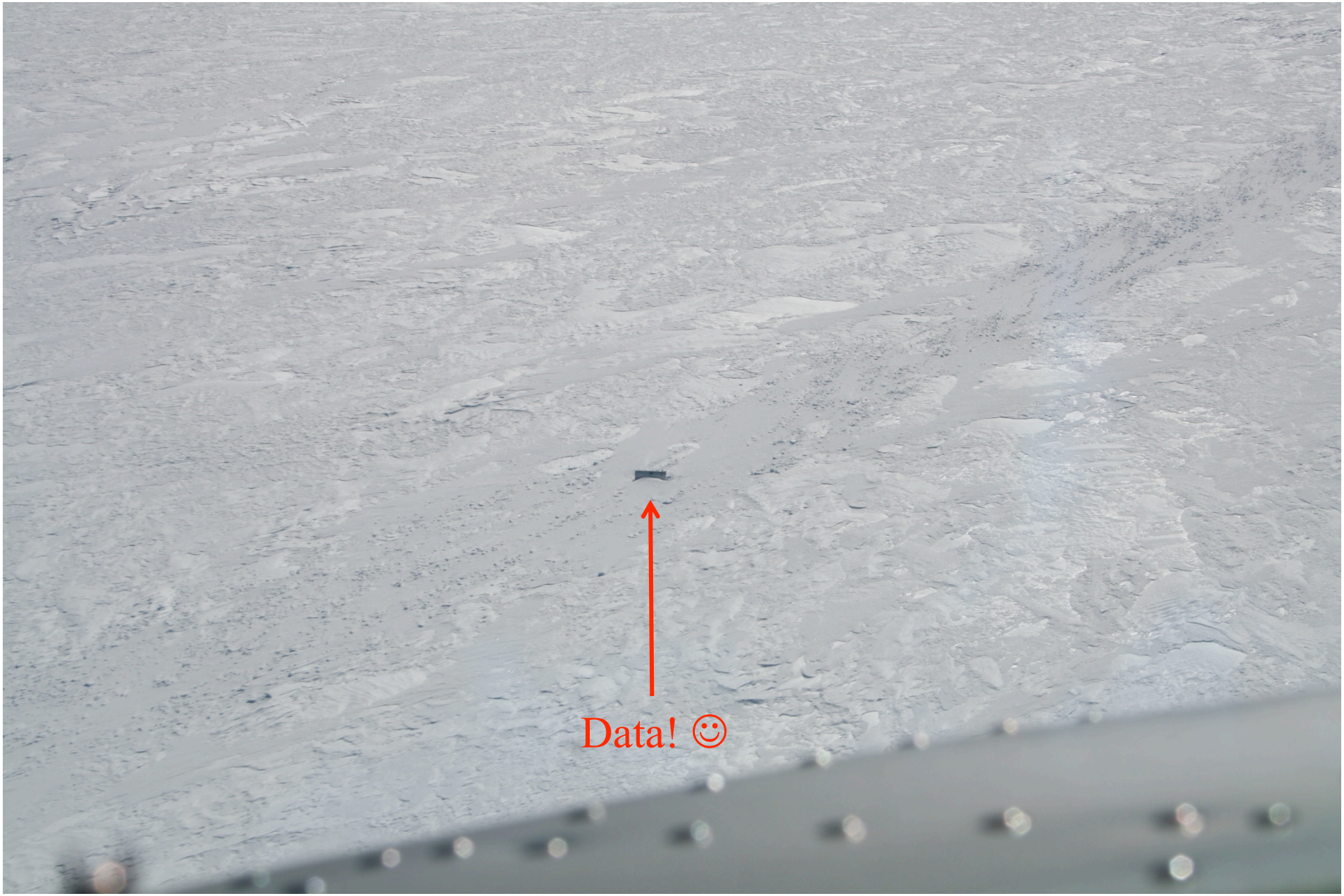
Antarctica

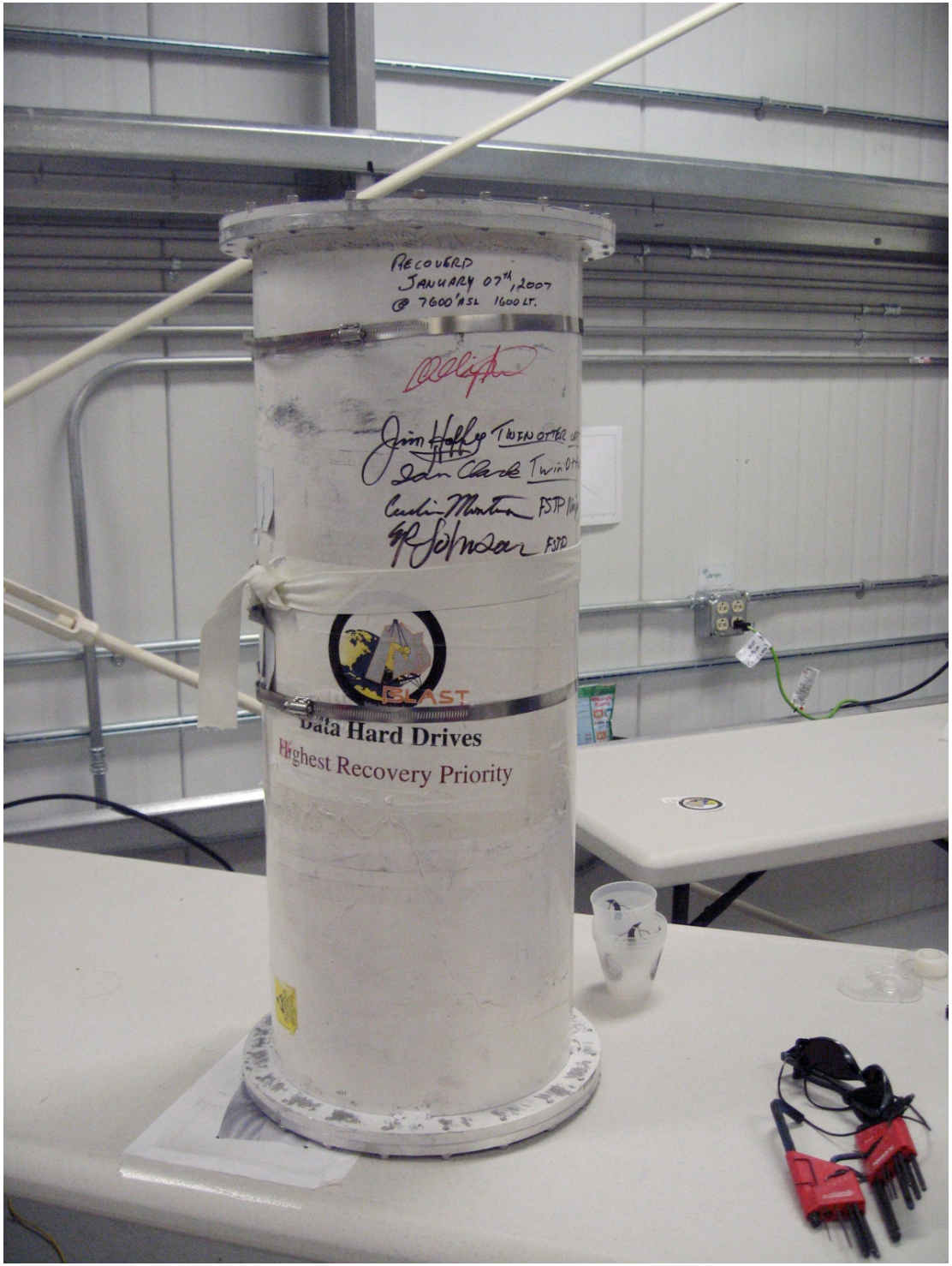



No data! ☹

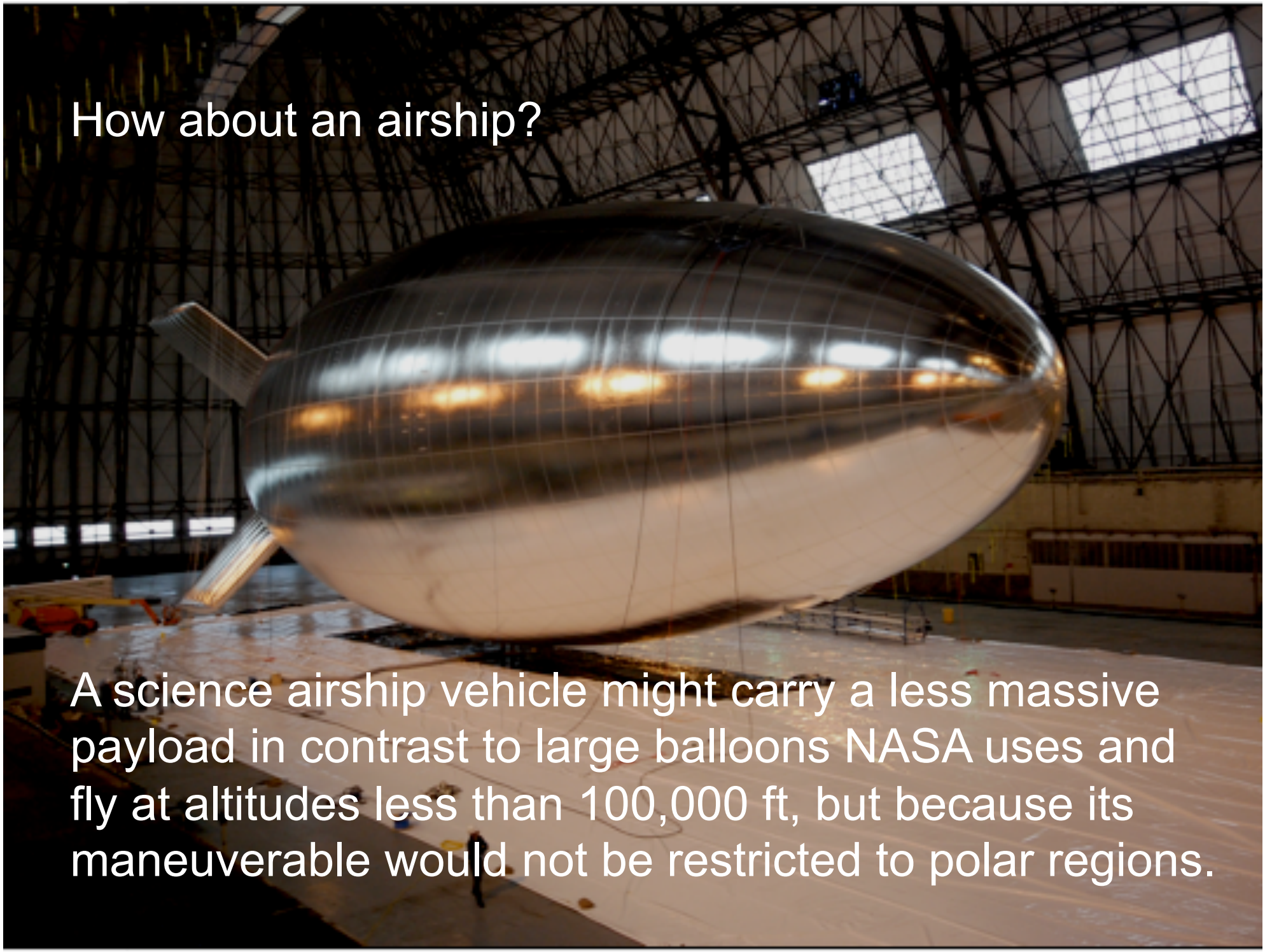
The science payload was dragged for dozens of miles across the Antarctic terrain with the data disks and recorders found nearly 75 miles from initial landing site.

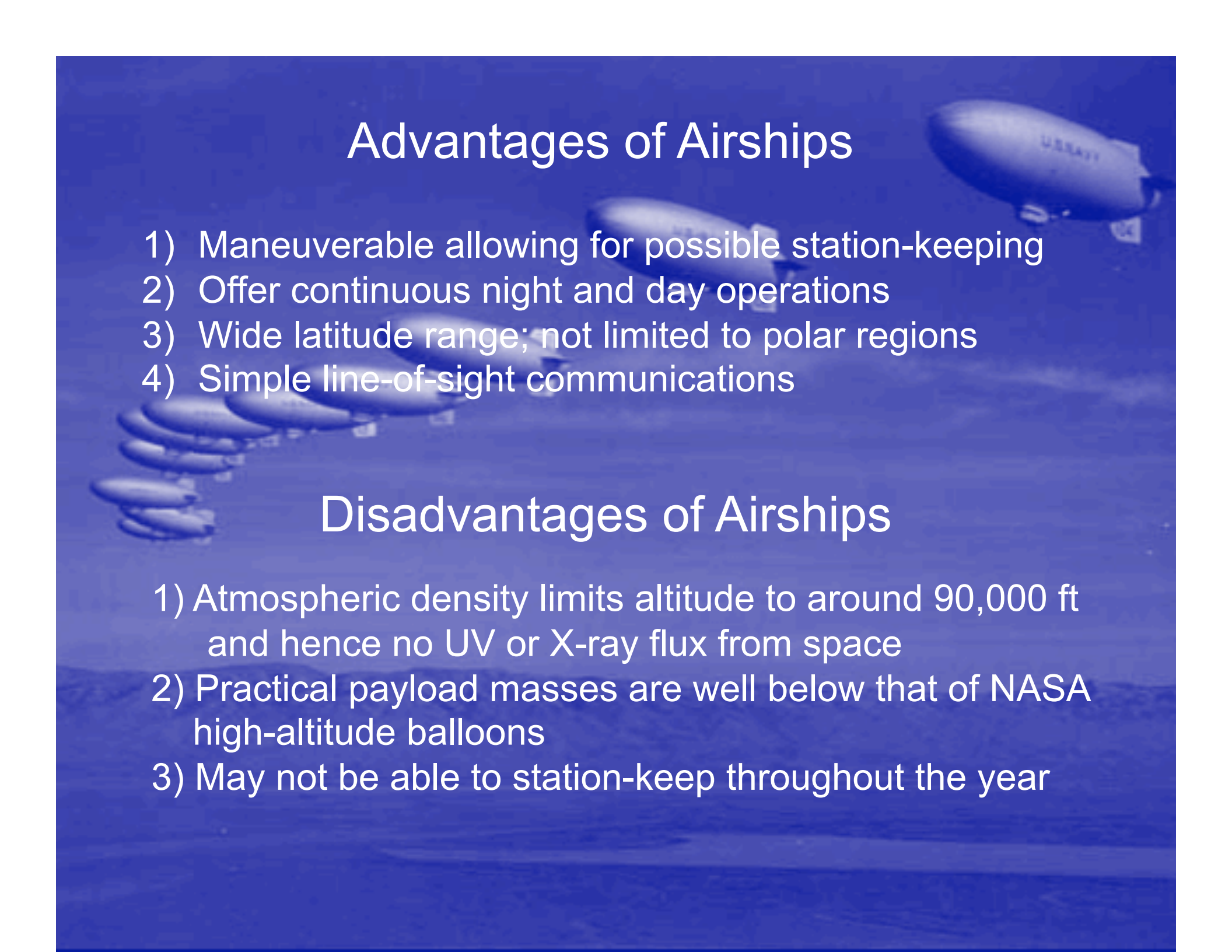



Data! ☺


RECOVERD
JANUARY 07TH, 2007
@ 7600'MSL 1600 LT.
BLAST
Data Hard Drives
Highest Recovery Priority


There must be a more elegant
way to do near space science!


How about an airship?
A science airship vehicle might carry a less massive payload in contrast to large balloons NASA uses and fly at altitudes less than 100,000 ft, but because its maneuverable would not be restricted to polar regions.



Advantages of Airships

1) Maneuverable allowing for possible station-keeping
2) Offer continuous night and day operations
3) Wide latitude range; not limited to polar regions
4) Simple line-of-sight communications

Disadvantages of Airships

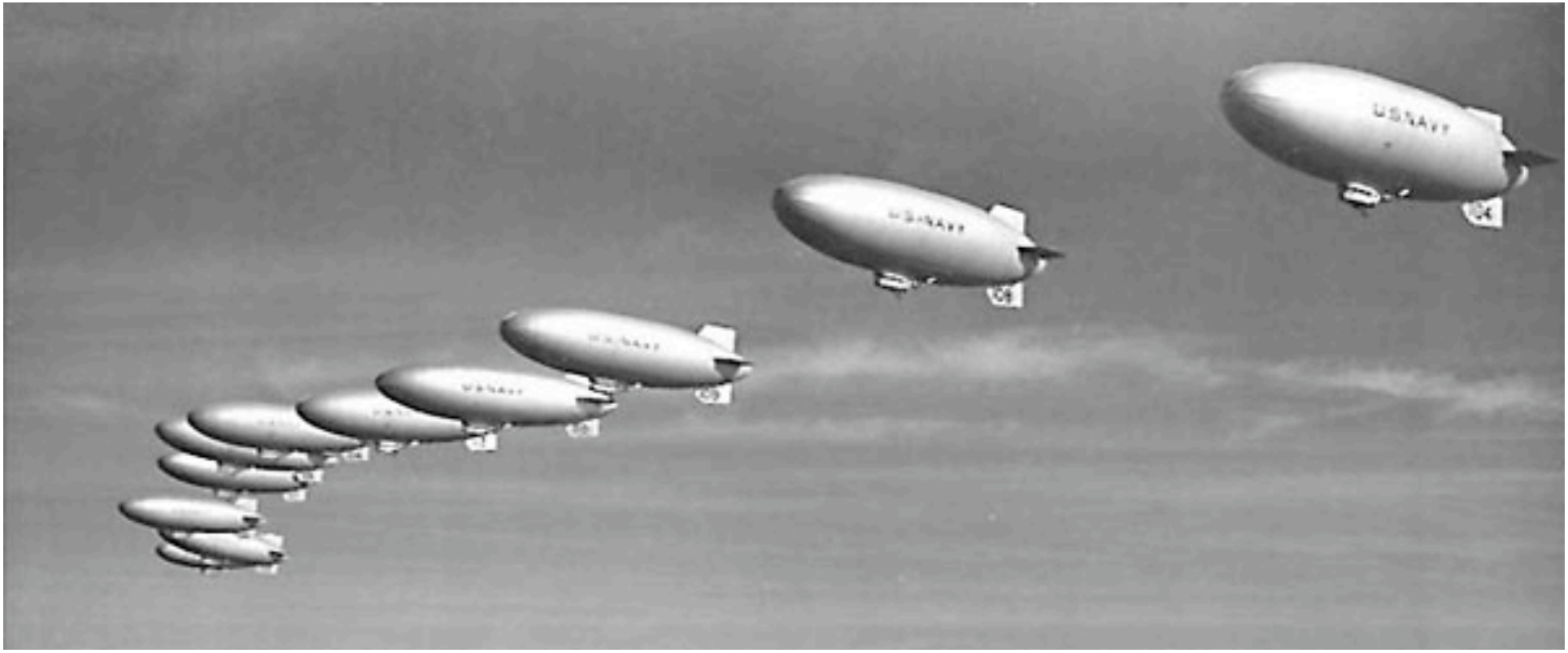
1) Atmospheric density limits altitude to around 90,000 ft and hence no UV or X-ray flux from space
2) Practical payload masses are well below that of NASA high-altitude balloons
3) May not be able to station-keep throughout the year

May 1937

EXTRA DAILY NEWS 2¢

HINDENBURG EXPLODES! 100 DEAD

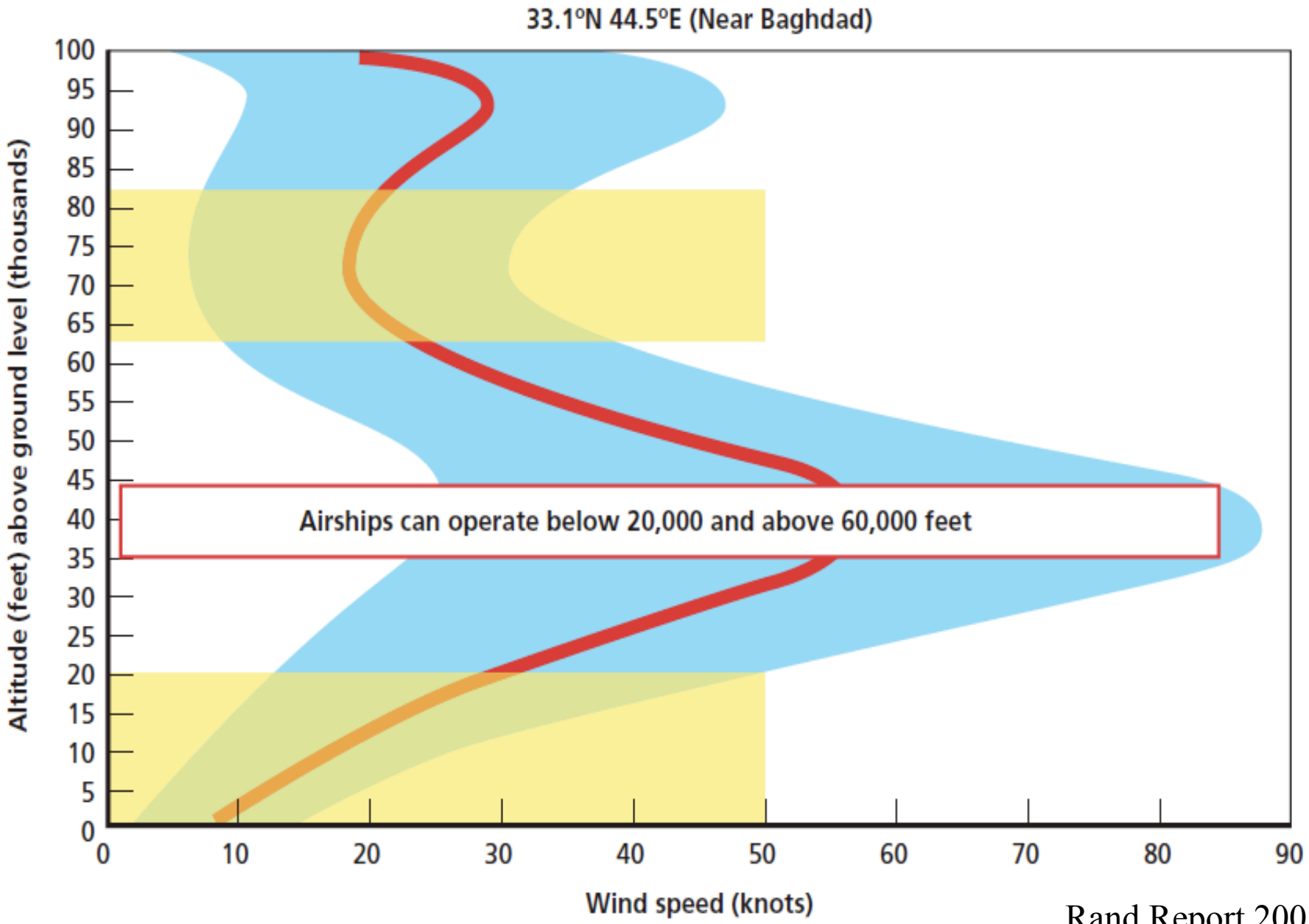
BULLETIN



Airship use continued after 1937, but for the most part only helium-filled military airships remained in use. Since helium was difficult to obtain outside of the United States, few other countries retained their airship programs.

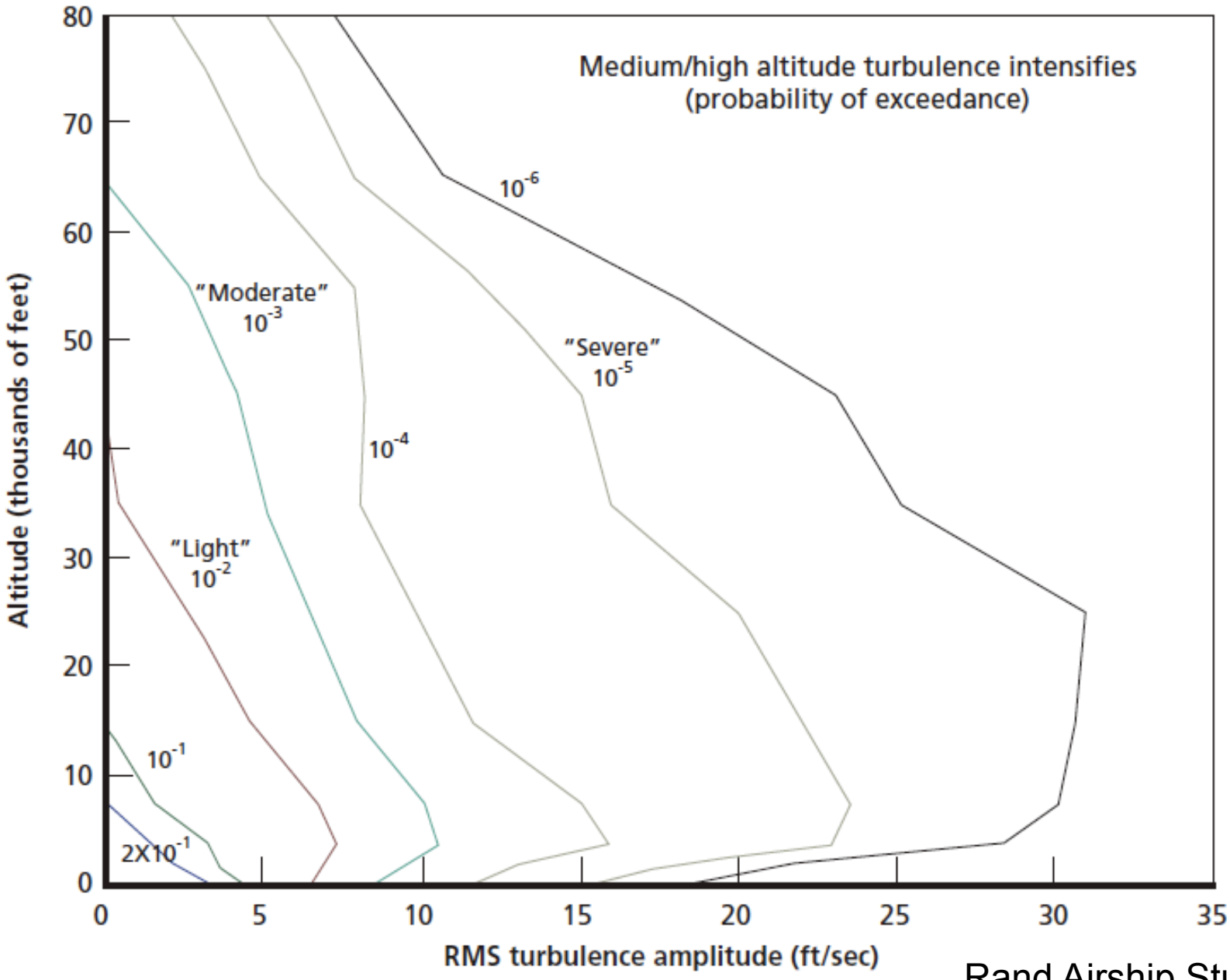
By the time that World War II began, the United States Navy was the only military force in the world that had an airship division.

Annual Winds Aloft Near Baghdad



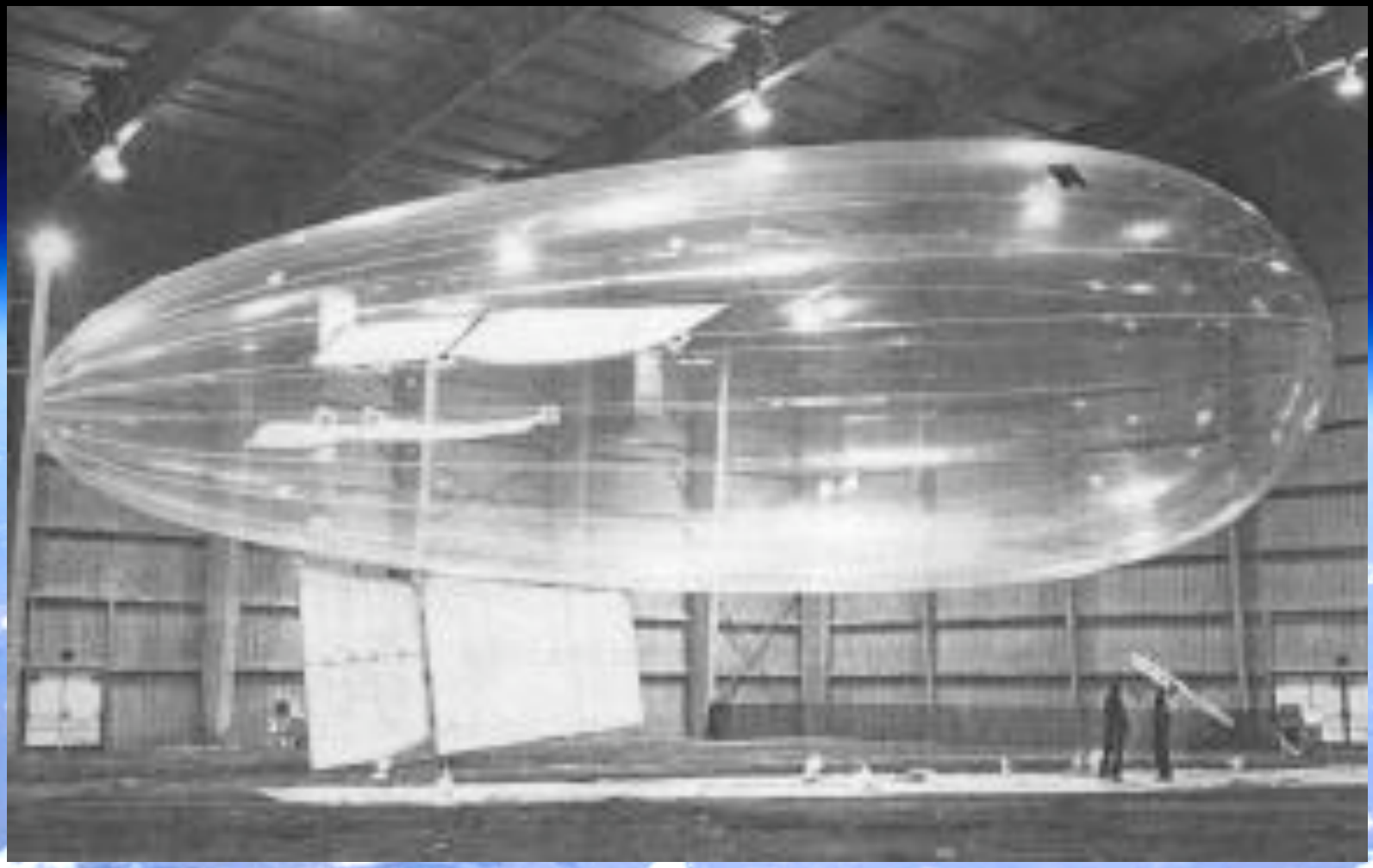
Rand Report 2005

Atmospheric Turbulence

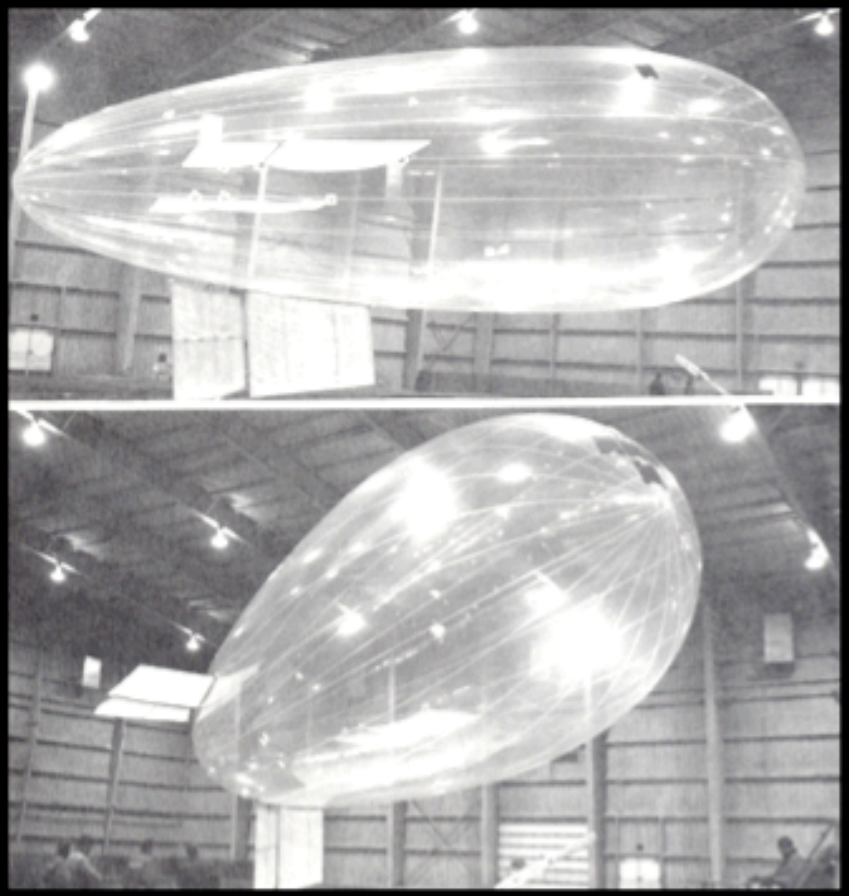


Rand Airship Study 2005

The concept of a buoyant stratospheric vehicle which can hover over any geographic location for long periods of time has been the “Holy Grail” in the LTA community for decades.



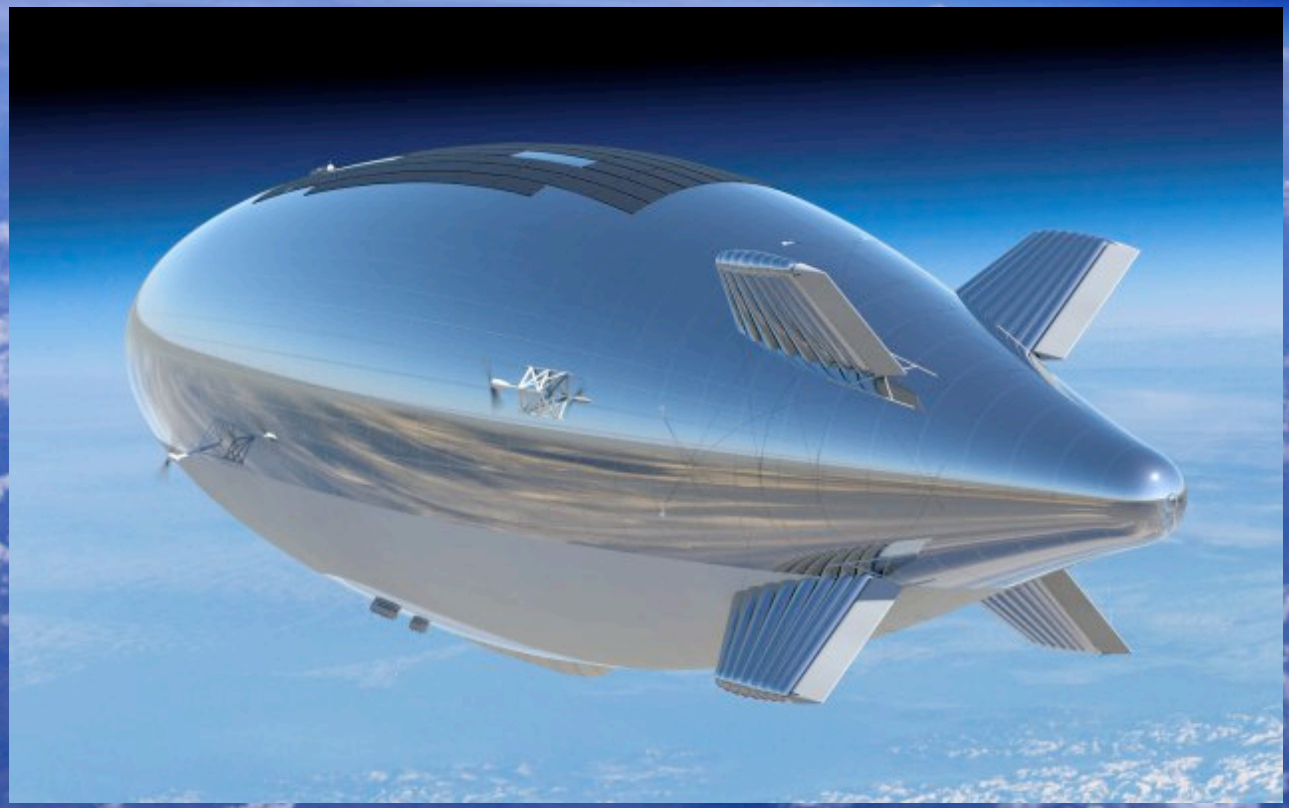
The first real attempt was made by Raven Industries in the late 60's with a project called High Platform II. This solar powered 20 knot, 136 lb aerostat had control surfaces attached to its Mylar hull and was capable of operating for more than 6 months at 70,000 ft.

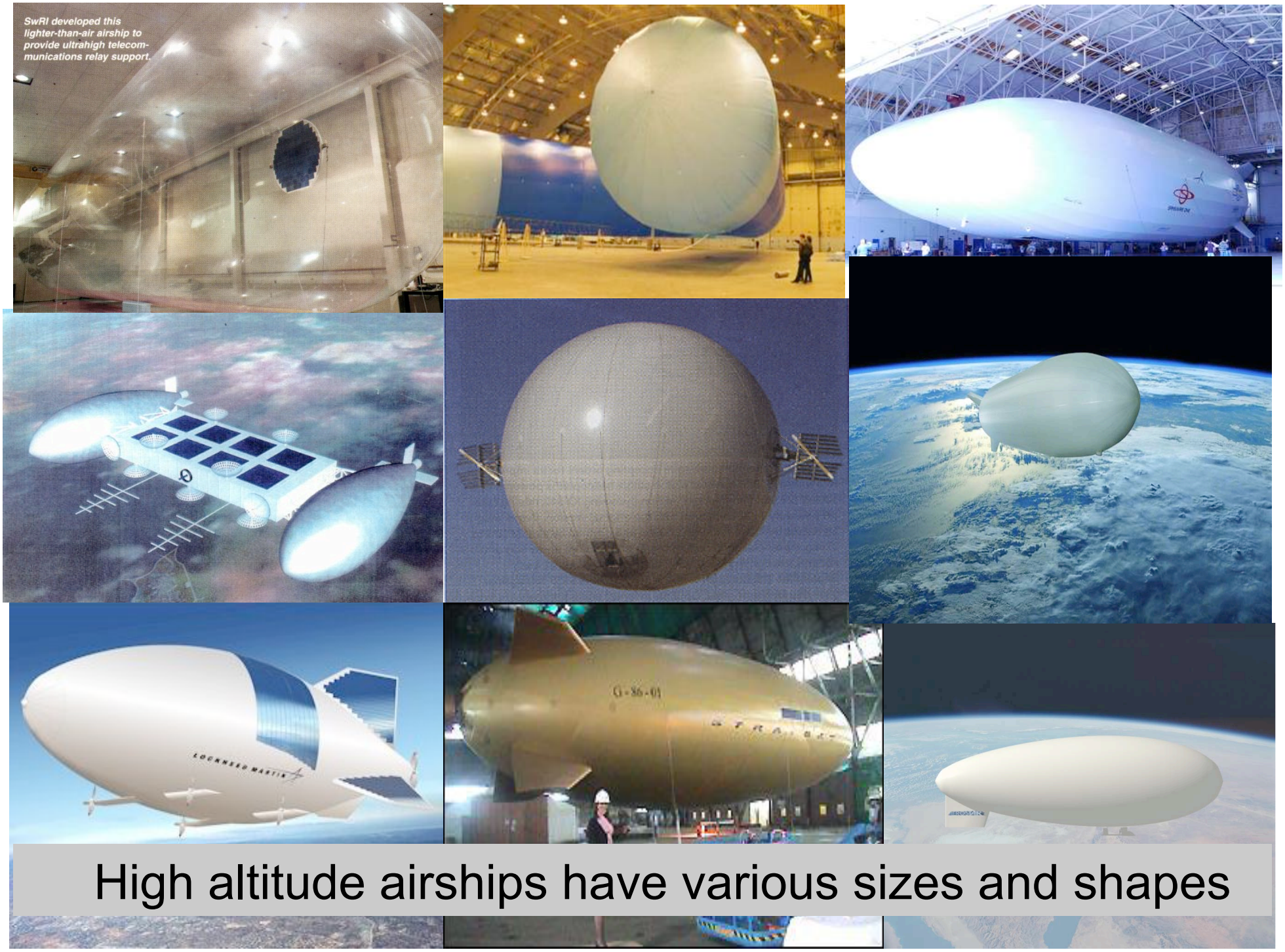


This experimental solar powered airship was flown successfully at 70,000 ft. Note the solar cell array on the nose.

The gondola provided the support for the mechanical components of the propulsion system.

There’s been a lot of excitement lately from both the military and telecommunication companies regarding the development of new, large airships positioned at high altitudes for a variety of missions.

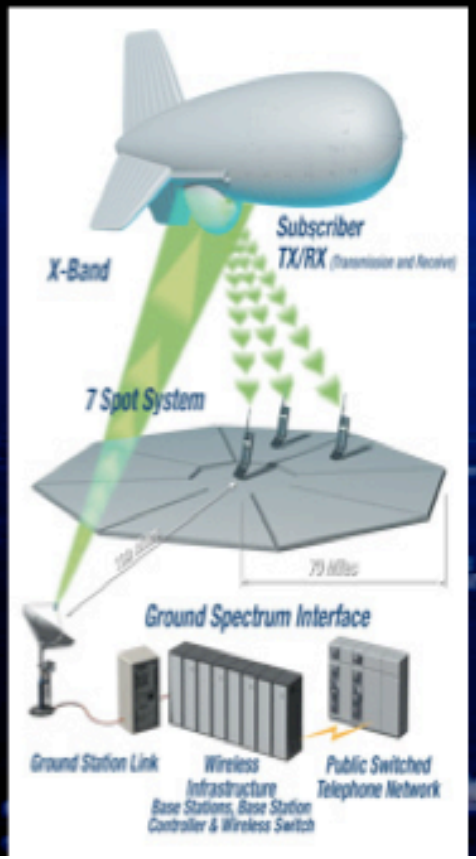


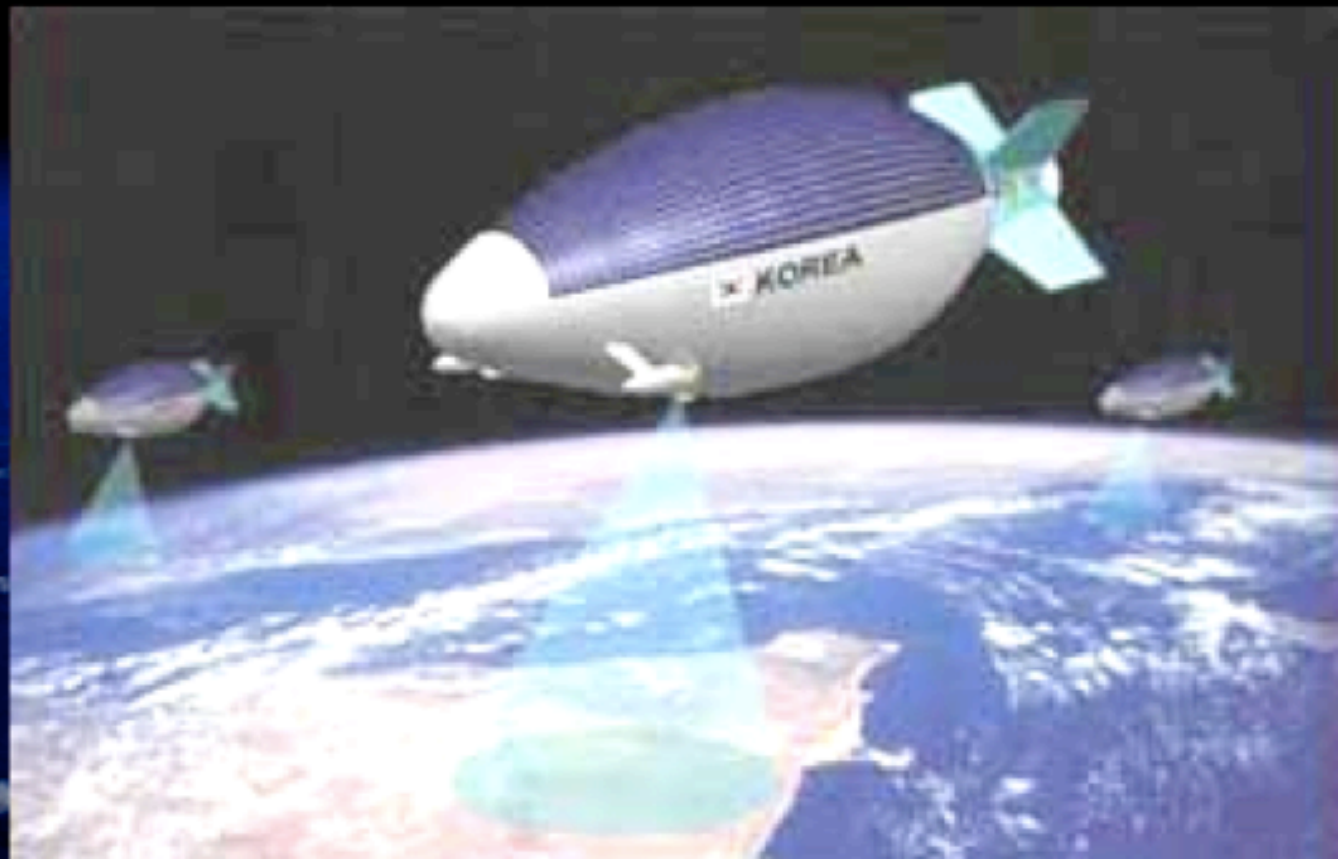


High altitude airships have various sizes and shapes

Commercial Telecommunication & Internet Platforms

Quasi-stationary, solar-powered, high-altitude platforms (HAPs) for broadcasting services have long been considered as a possible means of economically expanding commercial, high-bandwidth data services to consumers.





Commercial Telecommunication Attempted Platforms

US
- Platforms Wireless International
- Sanswire
- LTAS International LLC

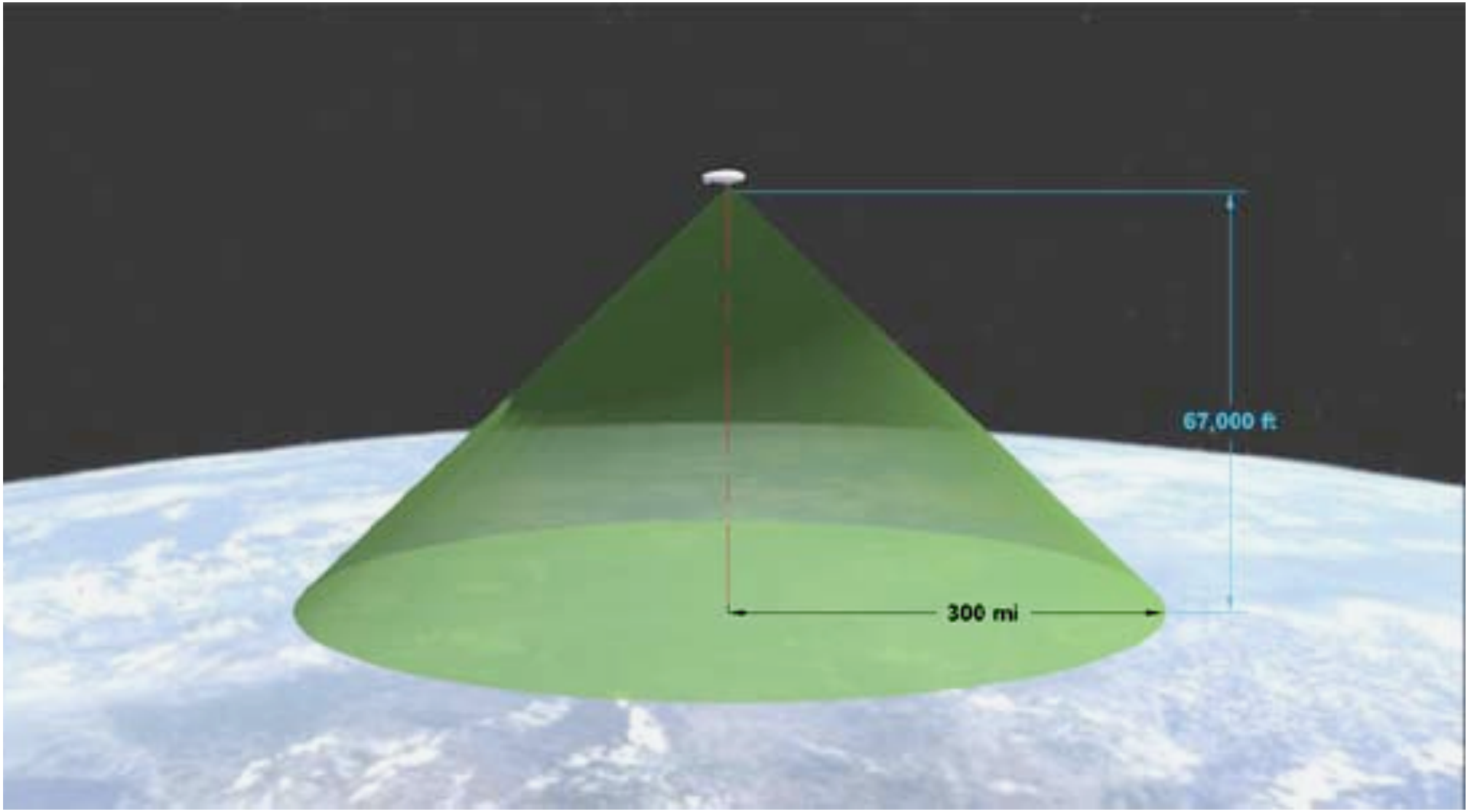
UK:
- Advanced Technology Group (ATG)

Japan:
- SkyNet
- Wireless Systems Group (Yokosuka Radio Comm.)

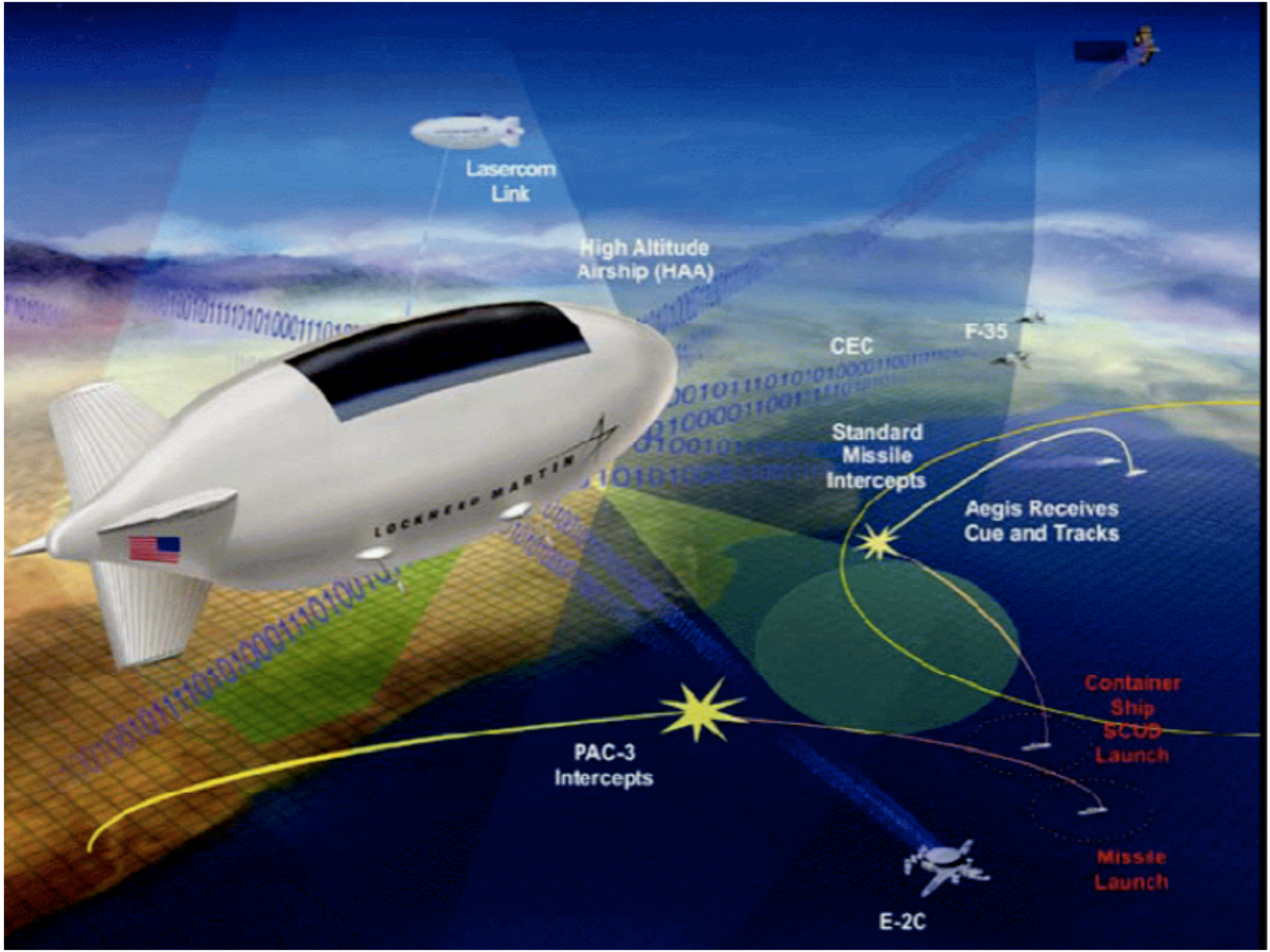
Korea:
- Ministry of Commerce, Industry and Energy

Sanswire One

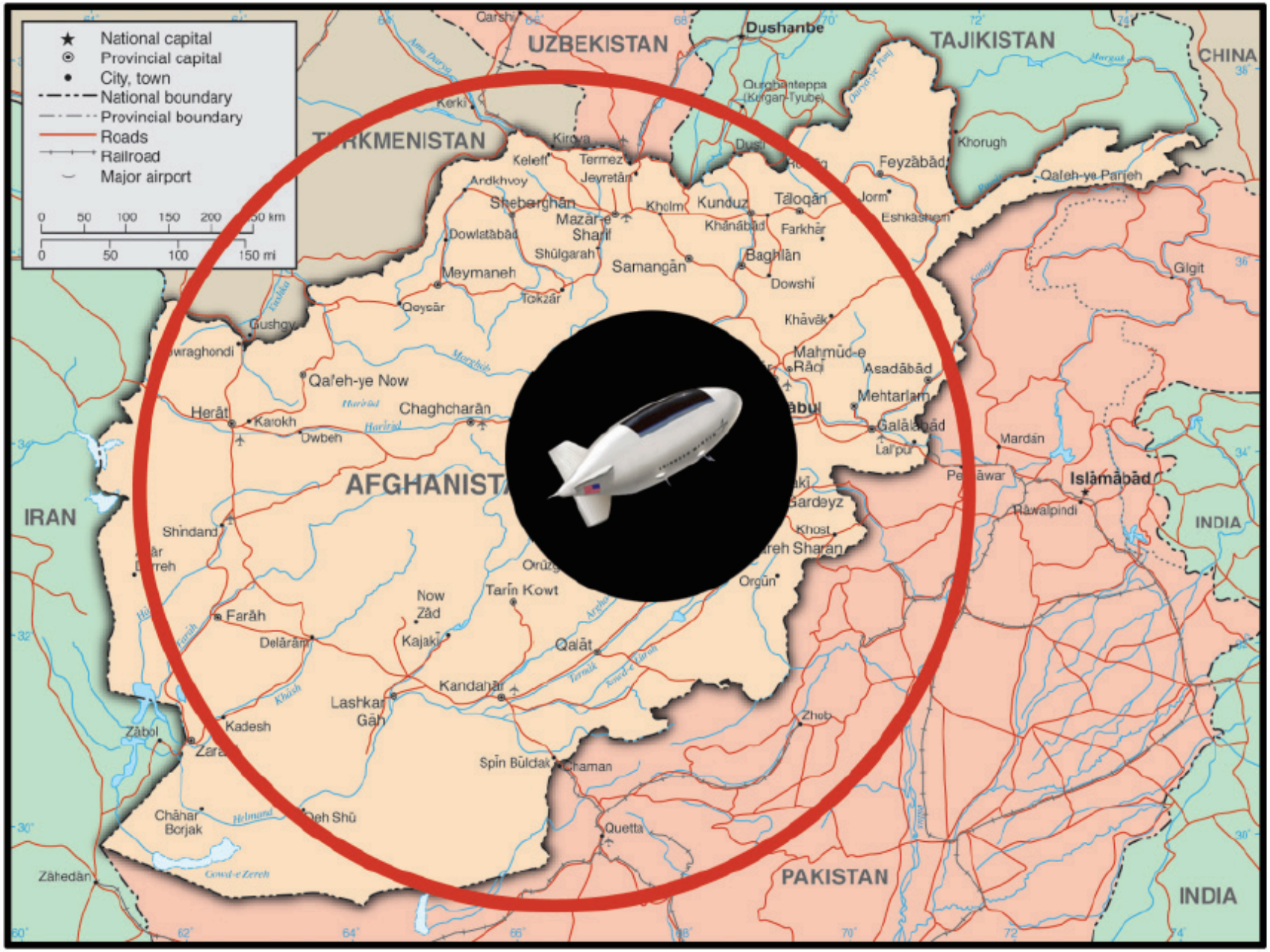
Most of the large DoD airships built to date in attempt to obtain Intelligence, Surveillance, and Reconnaissance (ISR).



An airship flying at 67,000 ft can survey an area of radius 300 miles.


Lasercom
Link
High Altitude
Airship (HAA)
CEC
F-35
Standard
Missile
Intercepts
Aegis Receives
Cue and Tracks
Container
Ship
SCUD
Launch
PAC-3
Intercepts
Missile
Launch
E-2C
LOCKHEED MARTIN

The Line of Sight Area for a Platform at 65,000 ft.



There's also been a push for much lower flying airships for multi-missions as an unmanned or manned intelligence gatherer or cargo vehicle.

Lockheed Martin's P-791:
This airship can stay aloft for up to three weeks at an altitude of 20,000 feet and carry 20 tons of payload.

Northrup Grumman's LEM-V
More than 21 days endurance with 2,750 lbs payload (in anISR configuration) and aservice ceiling of 22,000 ft.

Aeros' Aerocraft ML866/M868
With a length of 500 ft, this airship will be capable of carrying a 60 ton load at 120 kts over a distance of 3100 nm.

$7.95 JULY 5, 2010

AVIATION WEEK
& SPACE TECHNOLOGY

PERSISTENCE PAYS
What's Next in Long-Endurance UAVs

Europe's Plan for Space-Return Vehicles

COVER STORY

Rise of the Airship

The need for persistent surveillance could give airships a new lease on life

GRAHAM WARWICK/WASHINGTON

Airships are survivors—a genus of aircraft that has been around since the dawn of aviation and is now being offered another chance at lasting success. This time the mission is persistent surveillance, but can undisputed endurance carve out a role for unmanned airships that lasts beyond today's war?

As it embarks on a $517-million contract to develop the Long-Endurance Multi-intelligence Vehicle (LEMV) for deployment by the U.S. Army to Afghanistan in early 2012, Northrop Grumman believes the unmanned airship can find long-term roles in border security and disaster relief, as a communications and surveillance platform. "There is a lot of emphasis on today's war, but tomorrow the airship can provide inexpensive surveillance," says Alan Metzger, Northrop Grumman LEMV program director.

The vehicle will use 15,000-20,000 lb. of fuel to stay aloft for 3-4 weeks in the surveillance role. "That's only $20,000-25,000," he says. The Army calculates it would take 12 MQ-9 Reaper-class fixed-wing unmanned aircraft and their crews to sustain the same mission.

The LEMV's role is to maintain continuous surveillance over a wide area, providing correlated video, radar and signals intelligence data to the brigade combat team on the ground. Stripped of its sensors and long-endurance fuel tanks, the same vehicle could lift 20 tons of cargo with minimal modification, says Metzger, adding: "Airships are not for everything, but there are opportunities they are suited for. It will come down to economics."

Part of Northrop Grumman's optimism is built on the characteristics of the hybrid airship, a heavier-than-air design that combines buoyant, aerodynamic and propulsive lift to provide extended endurance in a vehicle that is easier to operate than traditional lighter-than-air craft. The efficiency of aerodynamic lift is key to LEMV being able to provide "unblinking eye" surveillance from 20,000 ft. for at least 21 days, carrying a 3,500-lb. payload of sensors.

Northrop Grumman's partner in the LEMV program is Hybrid Air Vehicles (HAV), custodian of the long legacy of Airship Industries and a pioneer in the development of hybrid airships. HAV is responsible for design of the LEMV air vehicle, and the 300-ft.-long, optionally manned platform, called the Condor 304, is scaled up from the HAV3 unmanned demonstrator the U.K. company has been flying for some time.

The endurance goal would be "difficult to do with a conventional airship," says Gordon Taylor, HAV's sales and marketing director. About 60% of the lift is aerostatic, from helium buoyancy, and the remaining 40% is aerodynamic, from the vehicle's shape. "We take advantage of aerodynamic lift in flight for the sustained capability," says Kelly Whalen, Northrop Grumman strategy development director. Additionally, powered lift is used during takeoff and landing by vectoring the thrust from four ducted propulsors.

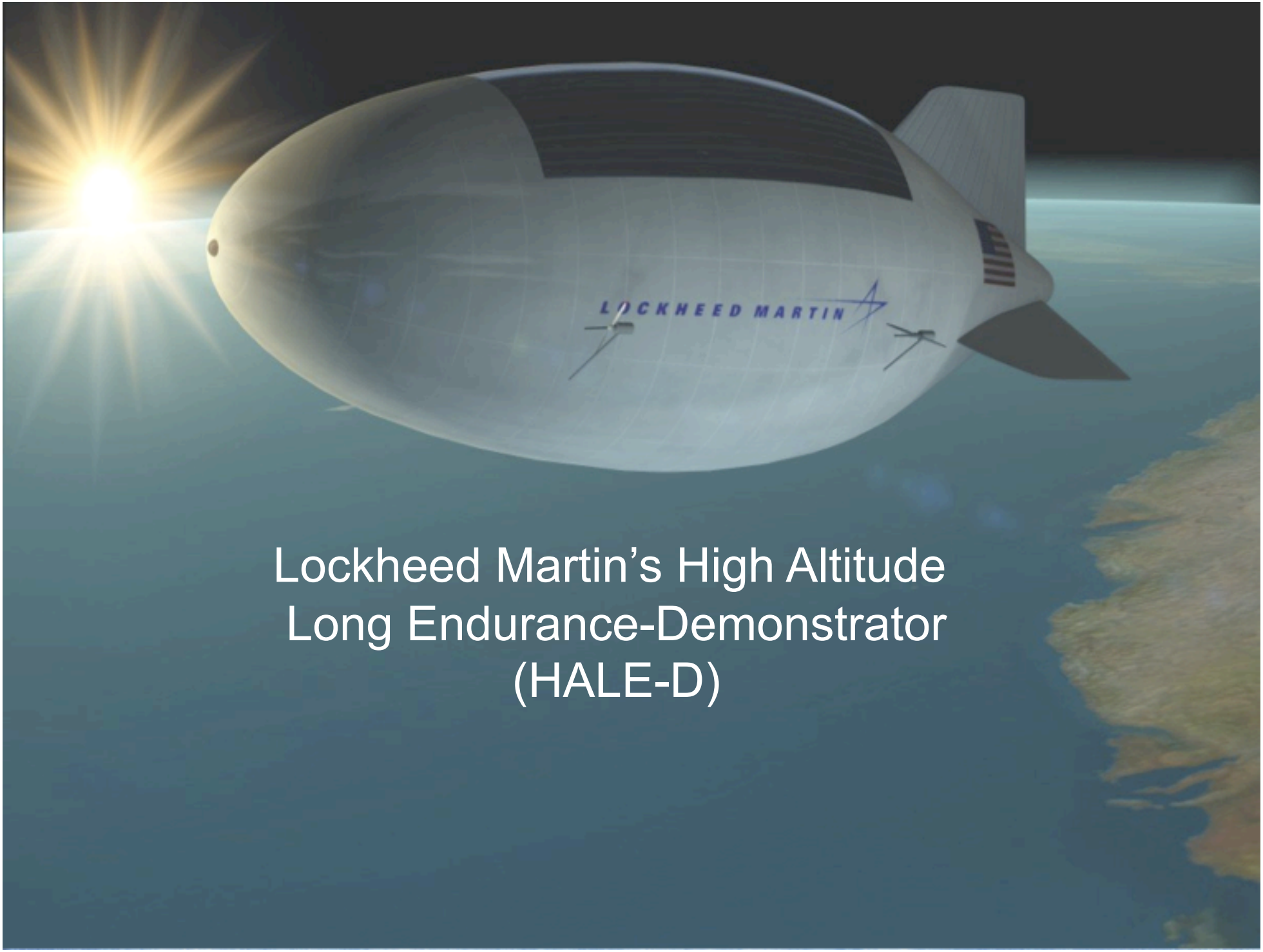
The Army wanted a vehicle that could be delivered within 18 months, so Northrop Grumman looked for a low-risk design and an experienced partner, says Metzger. The companies that preceded HAV developed the Skyship 500 and 600 commercial airships and the Sentinel 1000, a half-scale demonstrator for a U.S. Navy airborne early-warning airship that never materialized. Roger Munk, who formed what became Airship Industries and began development of the hybrid airship, was HAV's president and technical director until his death in February.

Northrop Grumman's LEMV will orbit unmanned for at least three weeks at 20,000 ft. carrying a 3,500-lb. payload of sensors.

Hybrid Air Vehicles' one-sixth linear scale HAV3 demonstrator is being used to develop control laws for the 300-ft.-long LEMV.

US Military Airship Budgets

Name	Prime Contractor	# of units	Operational altitude	FY07--FY14 .
Blue Devil	MAV6	1	20,000 ft	$243.6 million
HALE-D	Lockheed Martin	1	60,000 ft	$36.3 million
ISIS	Lockheed Martin	1	65,000 ft	$506.7 million
LEM-V	Northrup Grumman	1	20,000 ft	$356.2 million
Pelican	Aeros	1	tech demo	$42.4 million
StarLight	Global Near Space	1	65,000-85,000 ft	$2.1 million
HiSentinel	SwRI	2	66,000 ft	$11.2 million
PGSS	Aerostar & TCOM	59	6,000-9,000 ft	$2,108 million
PTDS	Lockheed Martin	66	8,000 ft	$3,170 million

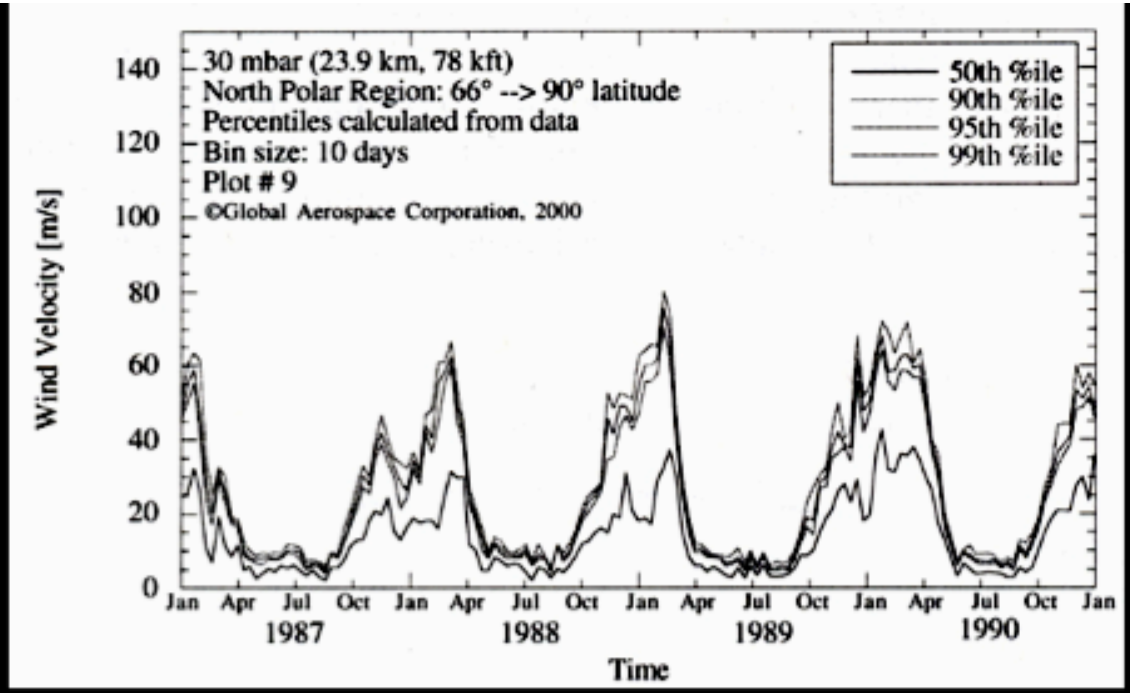


Lockheed Martin's High Altitude Long Endurance-Demonstrator (HALE-D)

Near Space starts only 12 miles away.
Why has it been so difficult to build HA airships?

- Station-keeping at night requires battery or power cells increasing weight.

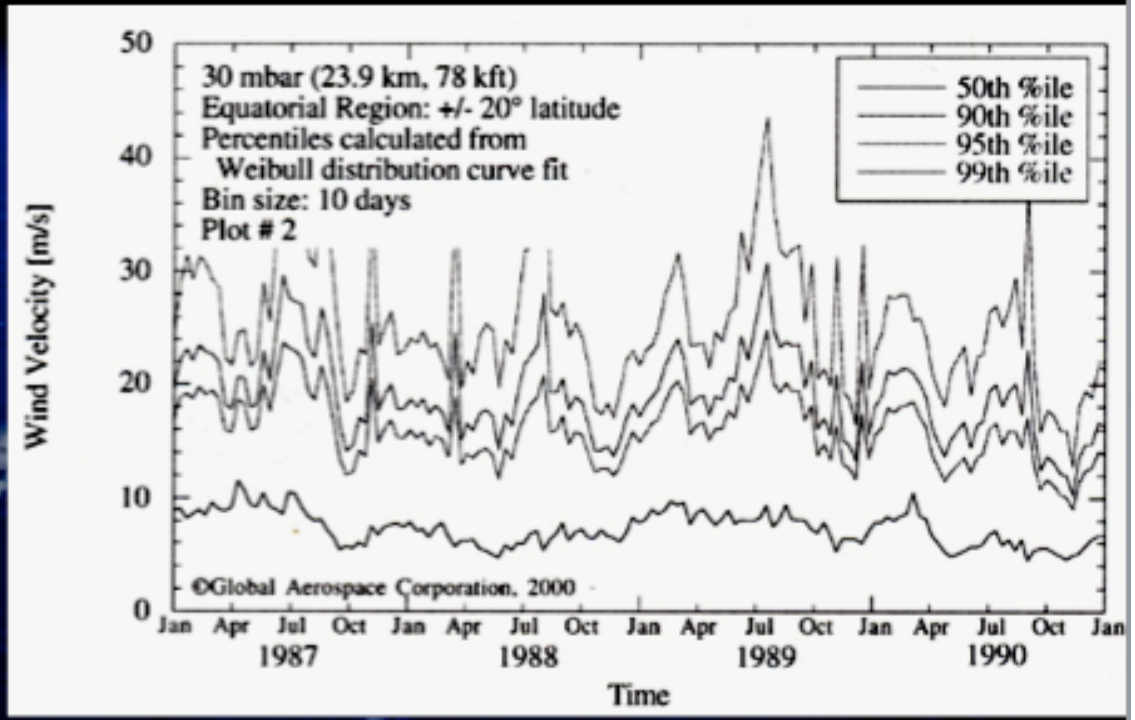
- High altitude winds can be very strong at times requiring considerable propulsion also meaning increased weight.



Typically, the highest wind speeds are seen at mid- to polar latitudes.

M. Heun (Global Aerospace Corp.)

A location near the equator offers generally slower stratospheric wind speeds over much of the year.

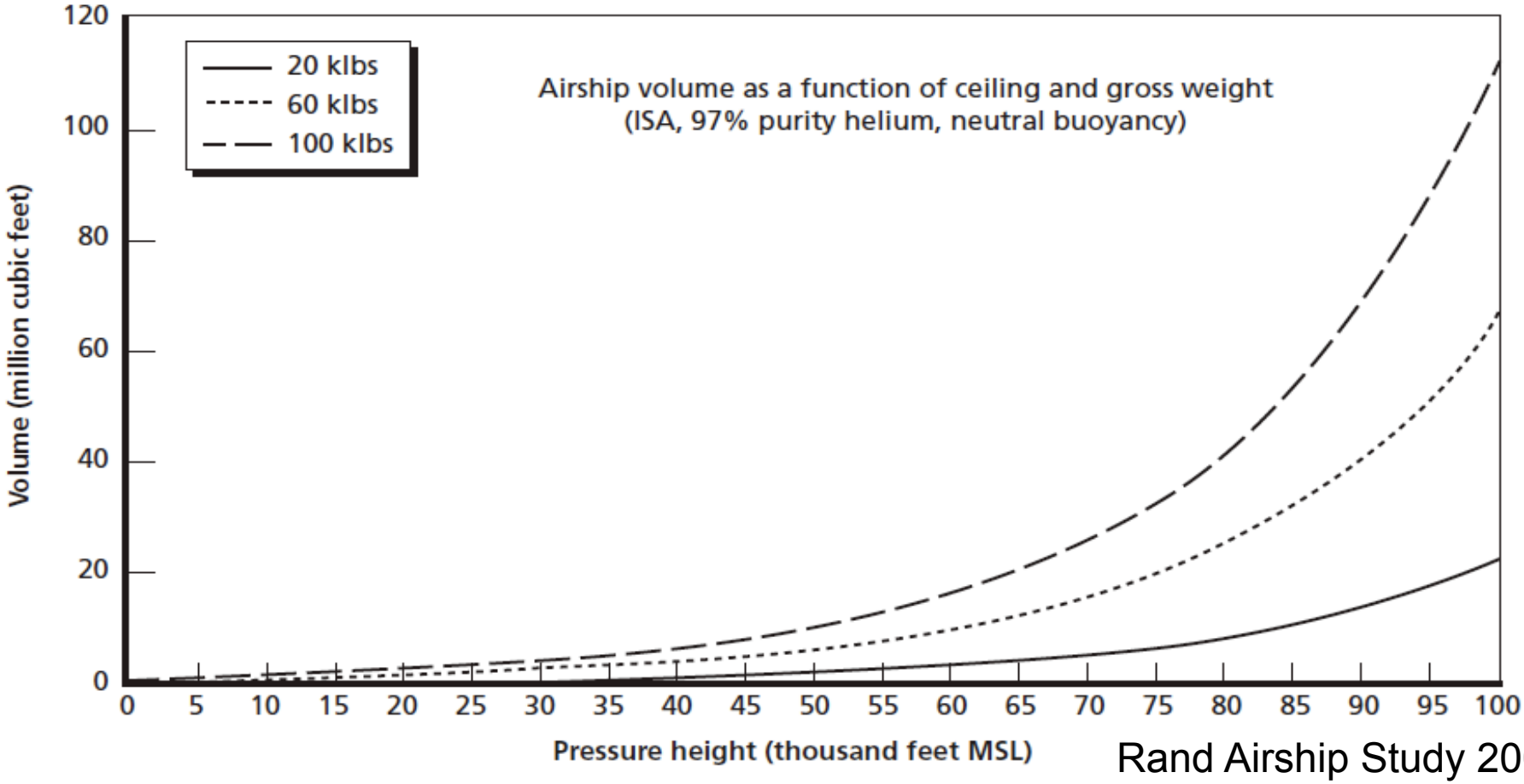


The higher up one goes, the larger the LTA vehicle needed.

The bigger the payload mass, the larger the LTA vehicle needed.

And the bigger the airship, the harder it will be to fly and push against the stratospheric winds.

This figure shows airship volume as a function of operating ceiling altitude and total system weight. Note that volume increases exponentially with ceiling altitude and linearly with weight.
For altitudes over 70,000 ft, airships become spectacularly large unless gross weight is small and thus harder to push requiring more engine power and hence more solar collectors and/or batteries meaning even greater weight and even larger envelopes.



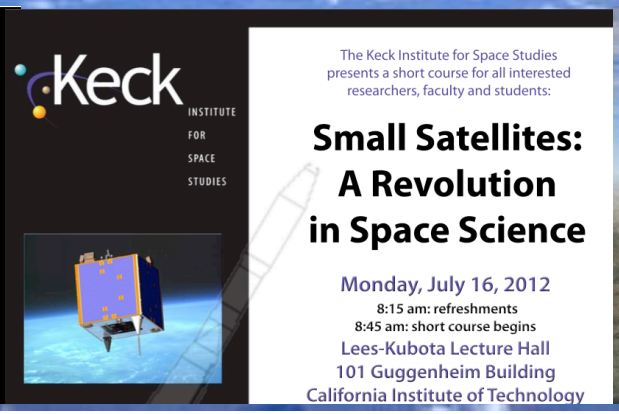
Rand Airship Study 2005

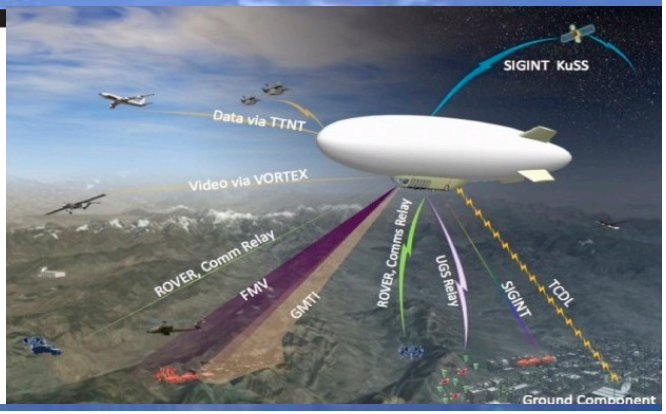
Funding from DoD has also been a problem.

-- Development of high altitude, long duration airships has suffered from a lack of strong and consistent customer support. This plus some unreasonable airship specs and ever evolving ISR requirements have made for a limited and halting progress.

Why not use the designs, experience and lessons learned from a number of these recent well-funded DoD airship programs.

The science community has realized that good (great!) balloon science can be done using instrumentation weighing less than a couple of tons.

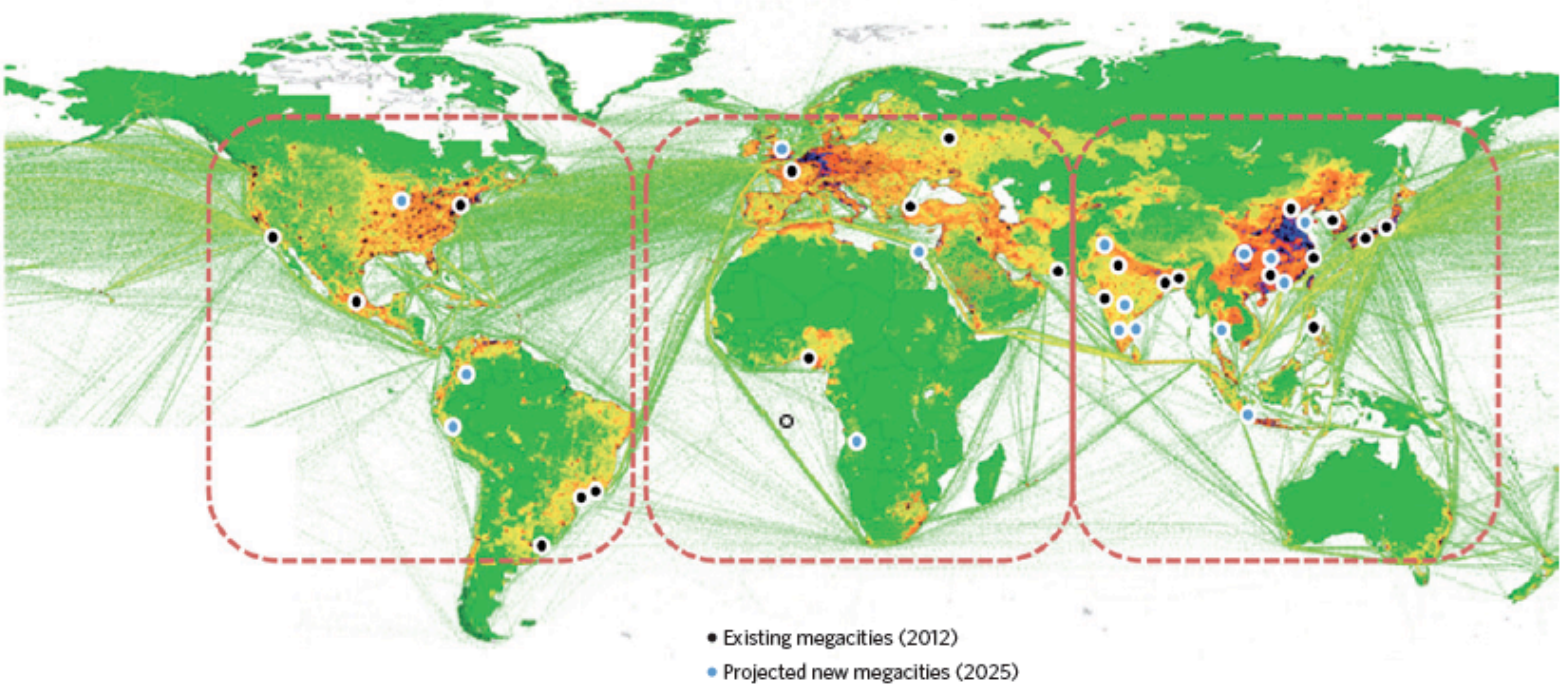




Earth and Atmospheric Science

Airships/blimps that are currently flying can obtain data not easily possible from aircraft or satellites.

Airships: Urban dome carbon monitoring

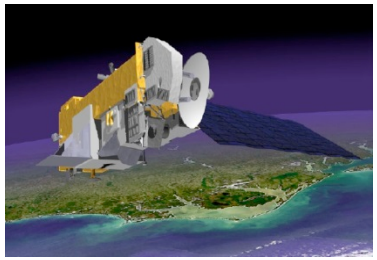


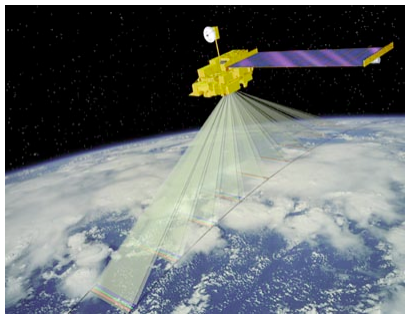
Manned airships could provide in situ data for urban areas regarding air quality, reactive chemistry, etc. not possible from conventional aircraft.

Duren, R.M and C.E.Miller (2012), Measuring the Carbon Emissions of Megacities, *Nature Climate Change* 2, 560–562 (2012) doi:10.1038/nclimate1629.

Airships: A low flying, near station-keeping airship could provide long term observational data for atmospheric studies that aircraft flights cannot easily provide.

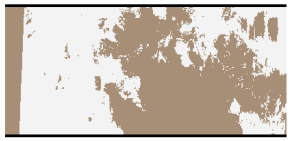
Gas and Particle Concentrations



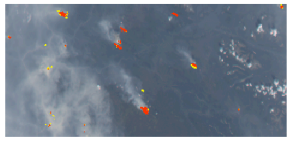


Pollutant Data

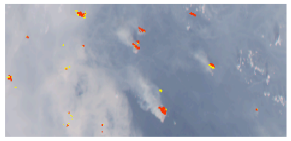
MISR's nadir (AN) camera shows three distinct smoke plumes, plus scattered smoke and clouds, over Alaska and Canada in the summer of 2004.



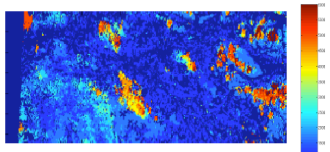
In white, smoke pixels detected by the Support Vector Machine classifier, which uses five of MISR's nine cameras to detect smoke using color, texture, and angular features.



MODIS fire detections overlaid on the MISR image in red (high confidence) and yellow (low confidence).

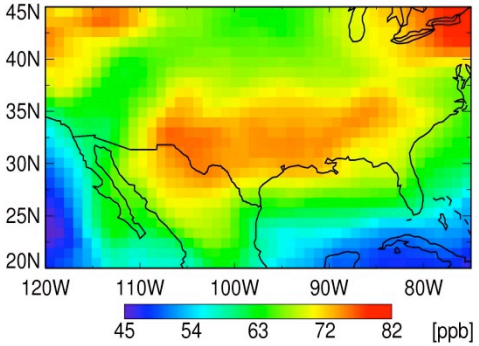


MODIS fire detections overlaid on MISR's 70.5 degree forward view. Objects above the surface shift due to parallax, but smoke is more opaque.

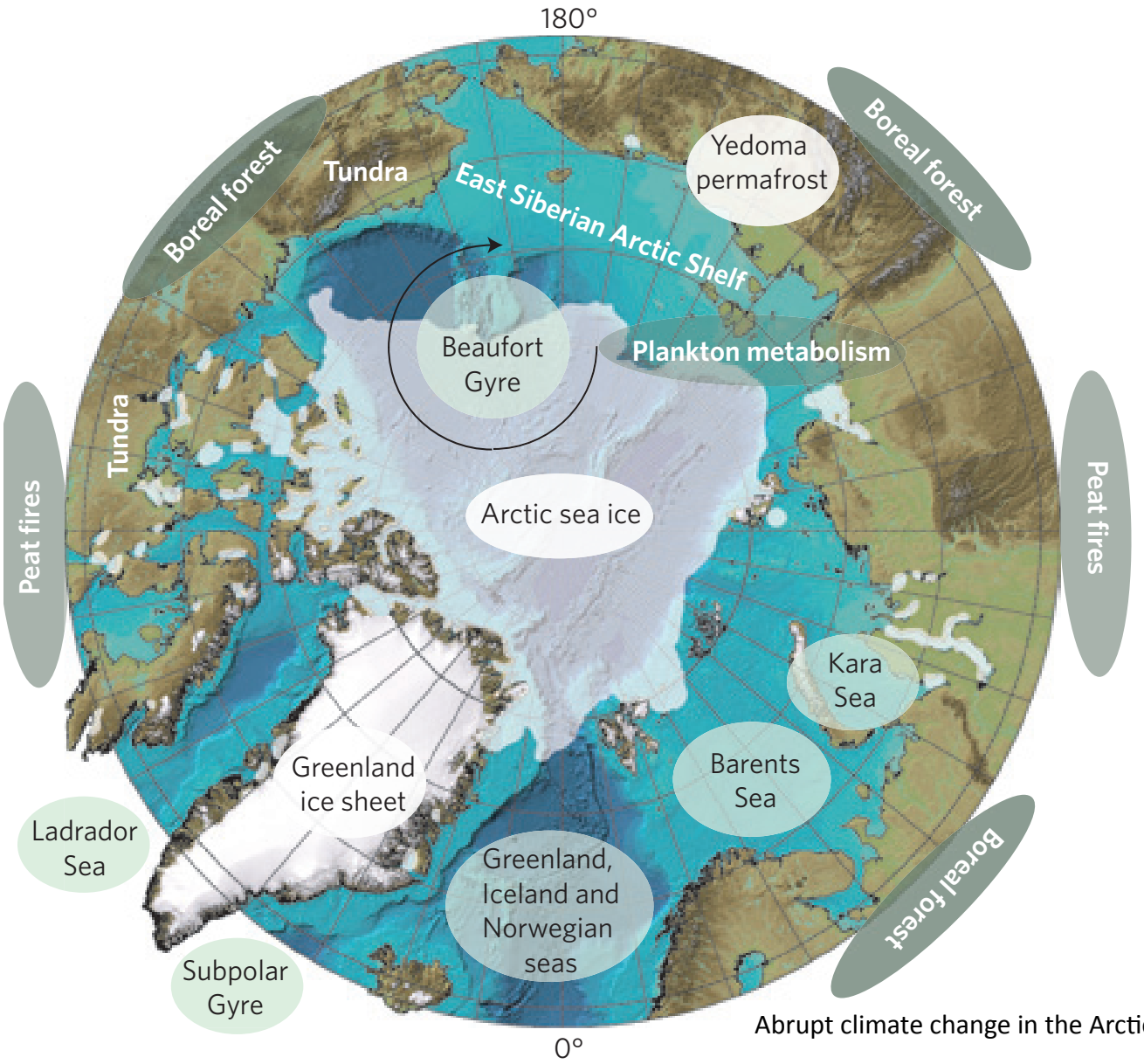


Examining the height of each MISR pixel determined by automatic stereo pattern matching allows us to estimate the injection height of the smoke plumes.

Air Quality Predictions



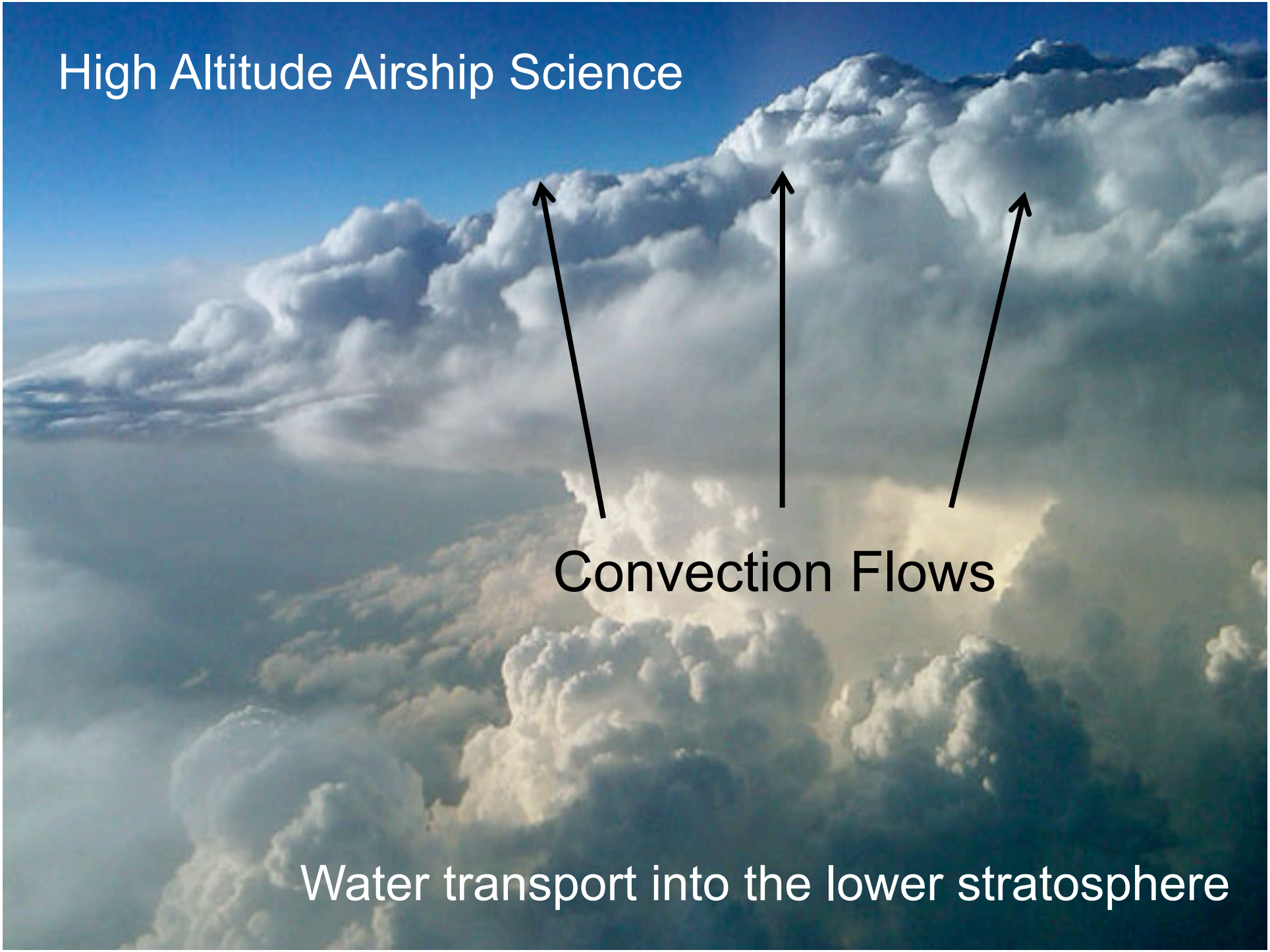
Low altitude Airships: Climate threshold elements in the arctic



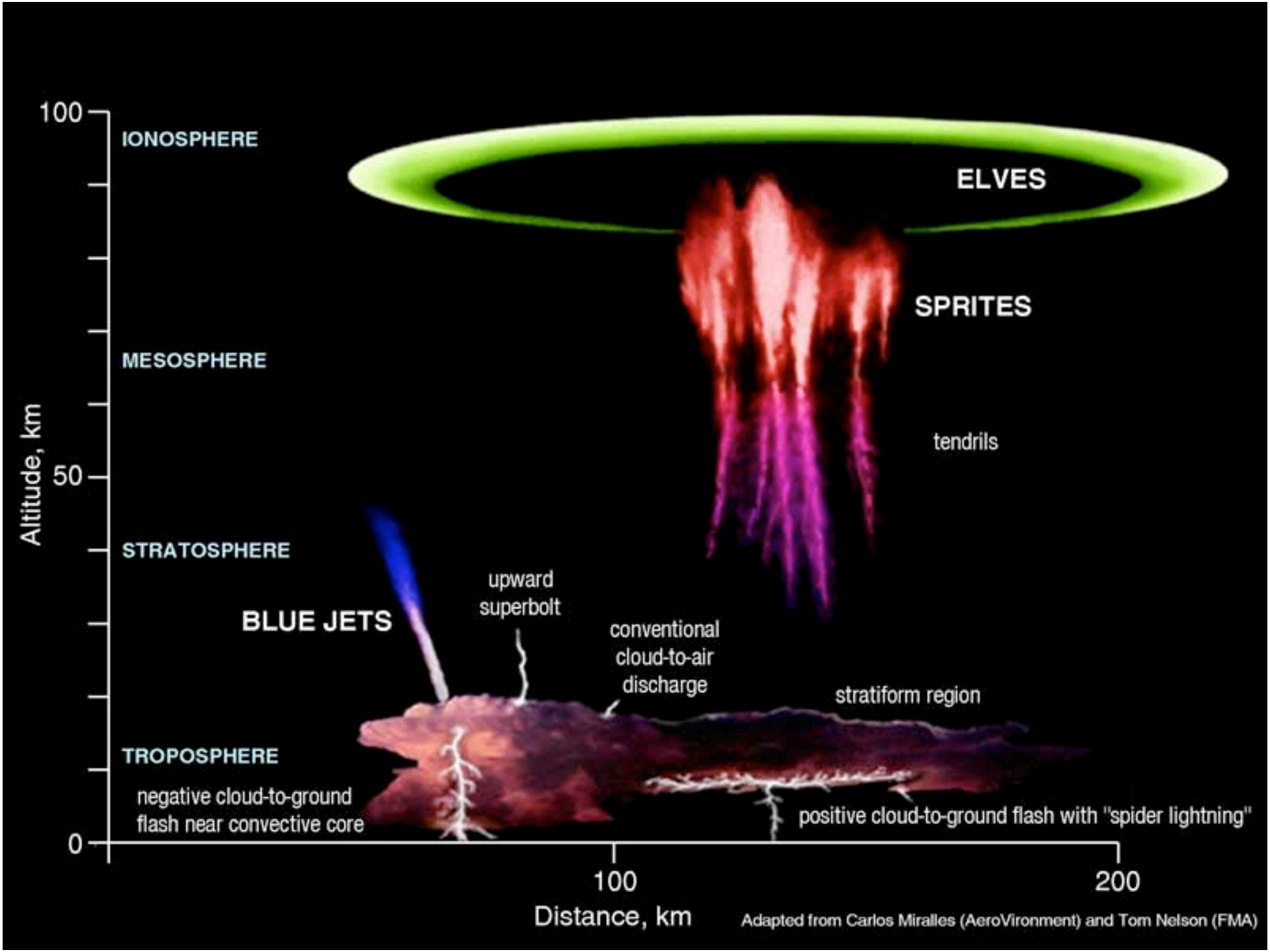
A low flying airship/blimp could provide valuable short and long term data on ice sheet melt and glacial dynamics at a spatial resolution 20 times better than a LEO satellite.

Abrupt climate change in the Arctic, Duarte et al, Nat Clim Change 2012


High Altitude Airship Science

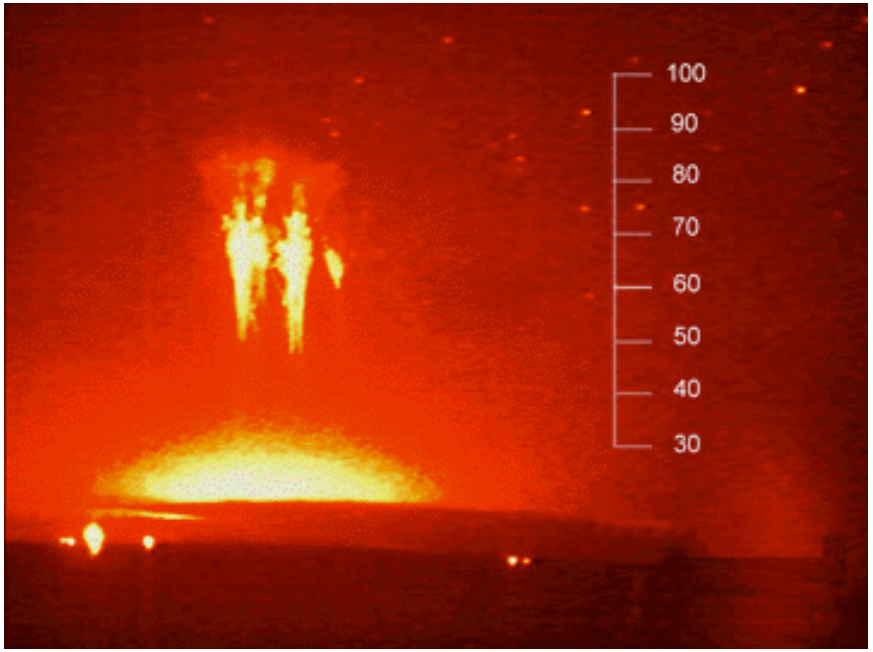

High Altitude Airship Science
Convection Flows
Water transport into the lower stratosphere


High Altitude Airship Science
Lighting from cloud tops into the ionosphere


100
IONOSPHERE
ELVES
SPRITES
MESOSPHERE
tendrils
Altitude, km
50
STRATOSPHERE
upward
superbolt
BLUE JETS
conventional
cloud-to-air
discharge
stratiform region
TROPOSPHERE
negative cloud-to-ground
flash near convective core
positive cloud-to-ground flash with "spider lightning"
0
100
200
Distance, km
Adapted from Carlos Miralles (AeroVironment) and Tom Nelson (FMA)

RED SPRITES

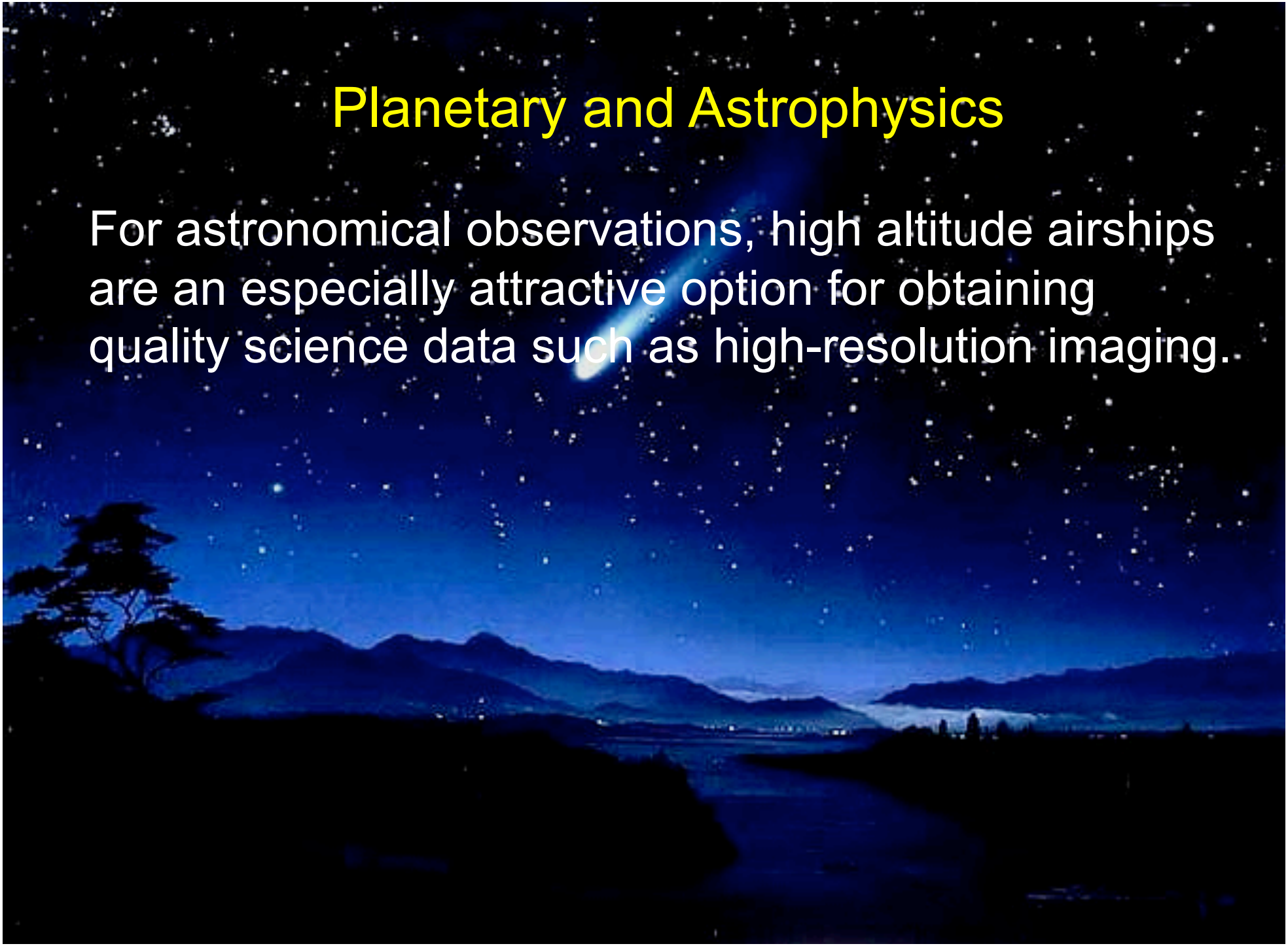
These atmospheric discharges occur very high in the Earth's atmosphere - much higher than the familiar form of lightning. Red sprites appear red in color and go from the tops of clouds to as high as the ionosphere - an ionized layer 90 kilometers above the Earth's surface. They last only a small fraction of a second.




Studies of volcano plumes

NASA High Altitude Aircraft (ER-2, WB-57F) conduct atmospheric missions

* Airborne Antarctic Ozone Experiment (AAOE)
* Airborne Arctic Stratospheric Expedition (AASE)
* Airborne Arctic Stratospheric Expedition II (AASE II)
* Stratospheric measurements of Photochemistry, Aerosols, and Dynamics Experiment (SPADE)
* Airborne Southern Hemisphere Ozone Experiment/Measurements for Assessing the Effects of Stratospheric Aircraft (ASHOE/MAESA)
* Tropical Ozone Transport Experiment/Vortex Ozone Transport Experiment (TOTE/VOTE)
* Stratospheric Tracers of Atmospheric Transport (STRAT)
* Photochemistry of Ozone Loss in the Arctic Region in Summer (POLARIS)
* SASS Ozone and Nitrogen Experiment (SONEX)
* Atmospheric Chemistry of Combustion Emissions Near the Tropopause (ACCENT)
* SAGE III Ozone Loss and Validation Experiment (SOLVE)

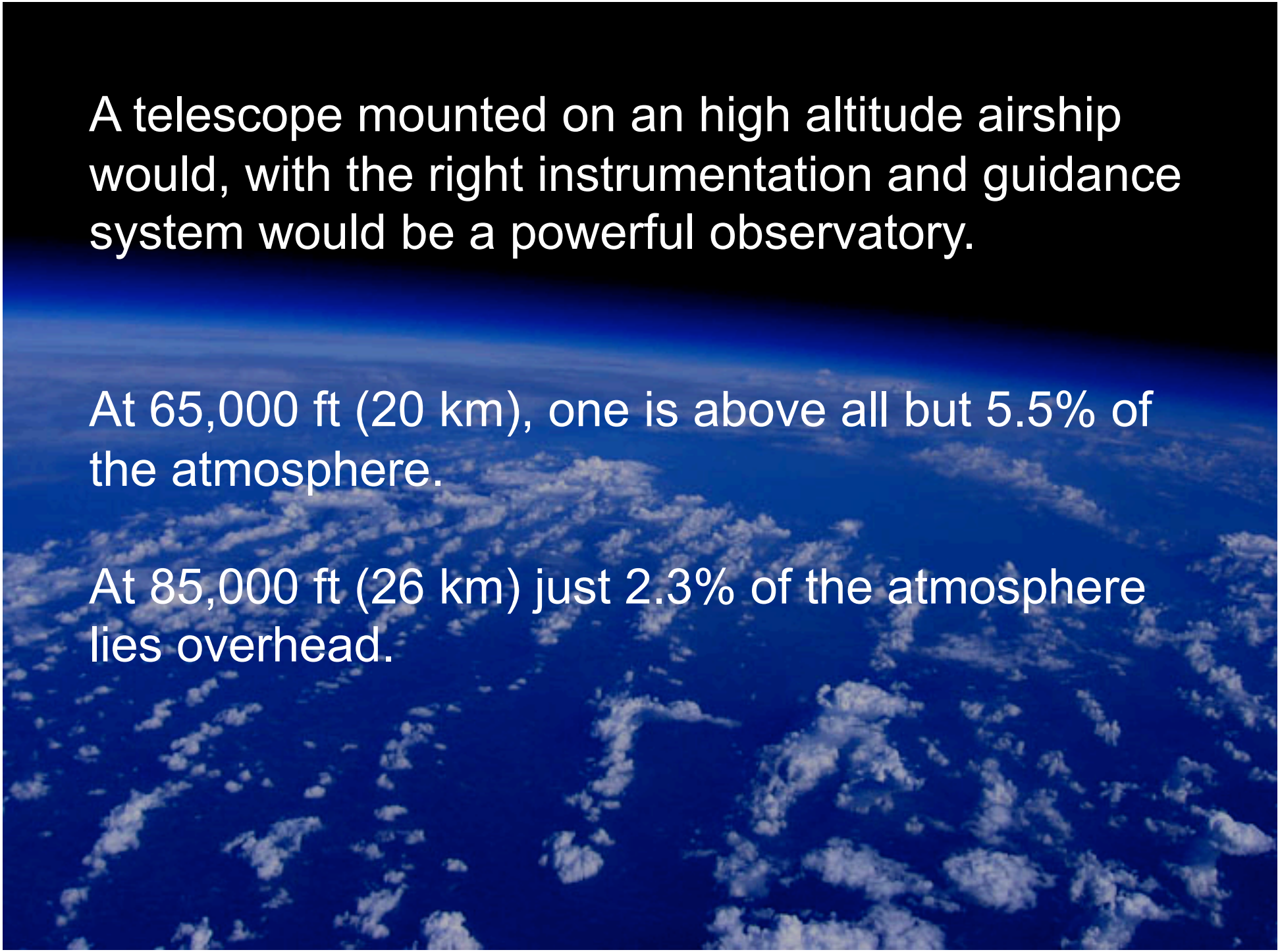


Planetary and Astrophysics

For astronomical observations, high altitude airships are an especially attractive option for obtaining quality science data such as high-resolution imaging.

Well, how high up do you have to go to avoid all clouds and stormy weather and start having space-like, high-resolution imaging conditions?

A photo taken from the window of a TR-1 (U2) aircraft from an altitude of around 70,000 ft.


A telescope mounted on an high altitude airship would, with the right instrumentation and guidance system would be a powerful observatory.
At 65,000 ft (20 km), one is above all but 5.5% of the atmosphere.
At 85,000 ft (26 km) just 2.3% of the atmosphere lies overhead.

Southwest Research Institute's HiSentinel airship can carry a 100 -200 lb payloads on it upper surfaces to altitudes of 65,000 to 70,000 ft for up to 7 days.

Lockheed Martin's HALE-D airship can fly at 65,000 ft and carry a 100 payload for 21 days, while the full scale HAA could carry 1000 lbs for week or even months.

A 65 kft High-Altitude, Station-Keeping LTA Platform

- Advantages for Astronomy:
  - Spacecraft-like near-UV/Optical resolutions and photometry.
  - No ground site to purchase or develop.
  - Station-keeping means no LDB/ULDB “no-fly” zone worries.
  - No weather interference -- thus robust target scheduling.
  - Little atmospheric extinction; superb photometric conditions.
  - Minimal scattering of moonlight. No bright time observing.
  - Horizon-to-Horizon observing capability.
  - N & S hemisphere target viewing if positioned at the Equator.
  - Simple line-of-sight communications to platform.

- Engineering Obstacles
  - Lightweight telescope + precise pointing/tracking system.
  - Ability to slew telescope without re-positioning the airship.

What a high altitude airship telescope won't do.

1. Night-sky emission lines (auroral emission) will still be present.
2. It won't be able to do UV observations – need to get above 100 kft (> 30 km) to do that.
3. Daytime optical observations are probably not possible – except maybe in the infrared (R,I, and Z bands) for brighter targets.

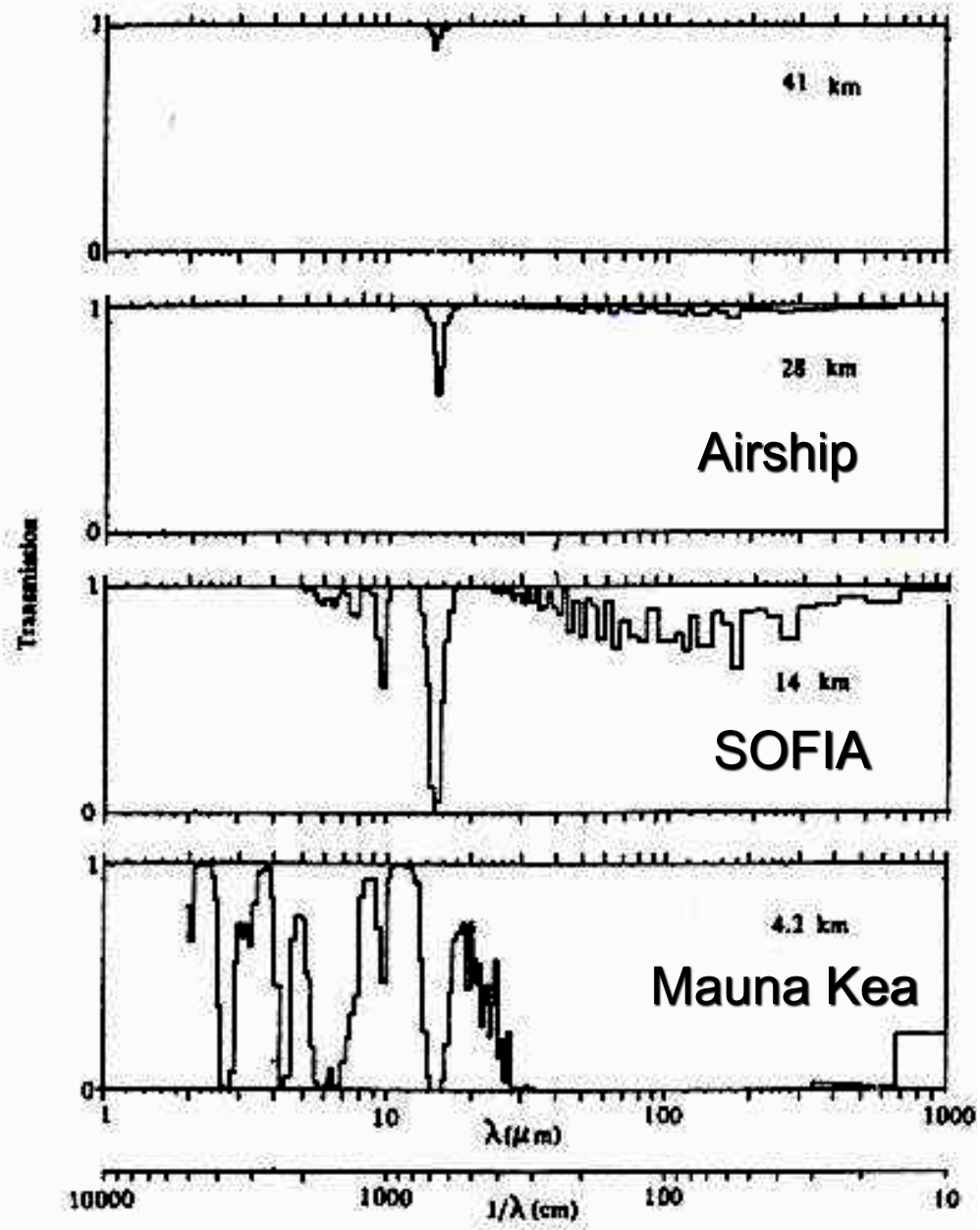
SOFIA: Stratospheric Observatory For Infrared Astronomy

Altitude:	41 kft
Primary Mirror Diameter:	2.5 m (~ HST)
Image quality:	~ 3” @ 5 microns
Diffraction image quality:	> 15 microns
Wavelength regime:	0.3 – 1600 microns
Number of observing hrs per yr:	960 hrs (~ 8 hrs per night)
Development/Construction Cost:	$482M
Est. Operations costs per year:	~$40M

Even at an altitude of 14 km (46 kft), nearly a mile above where NASA's SOFIA 747SP flies, there are still many strong atmospheric absorption features between 5 – 10 microns.

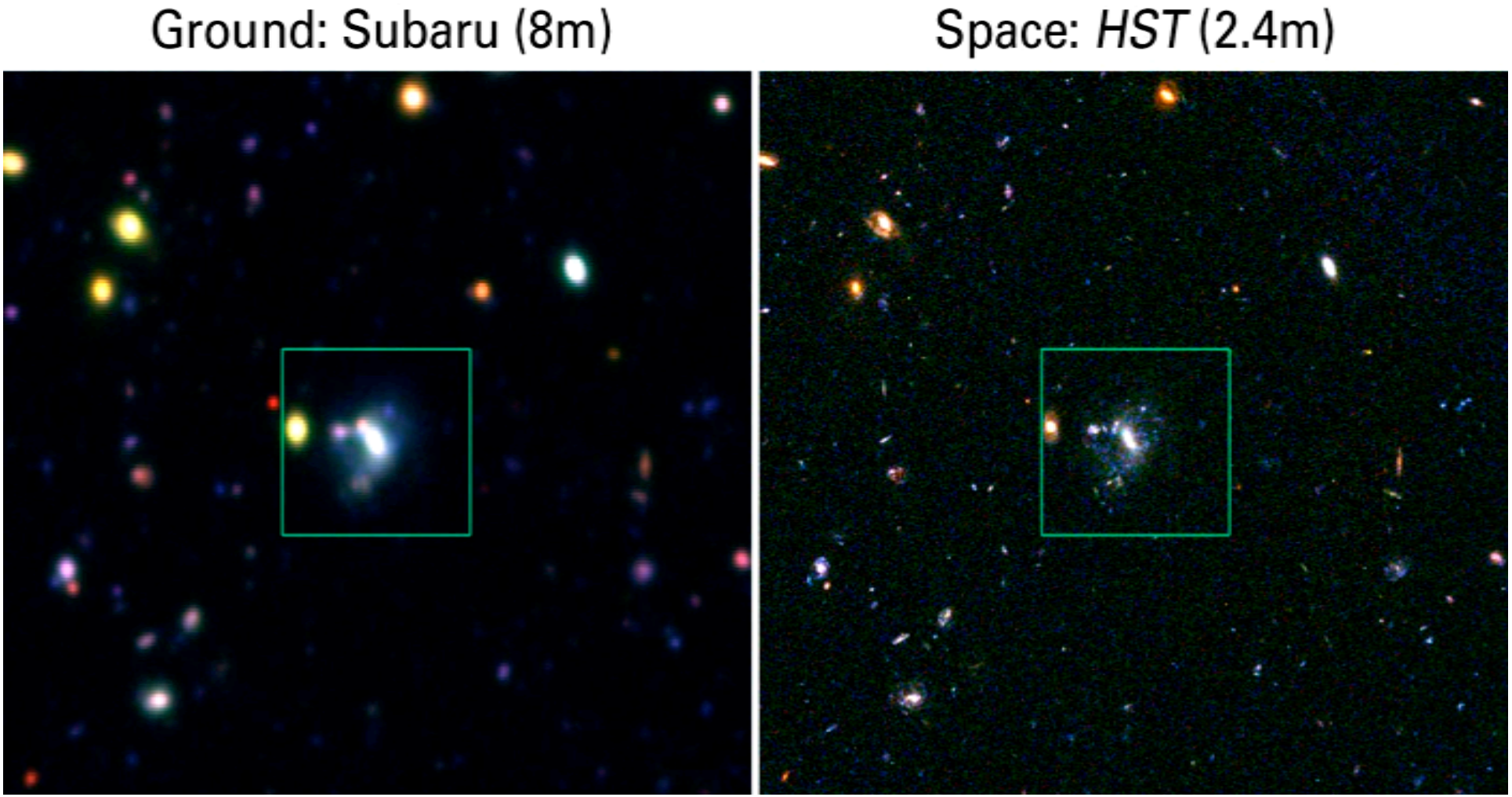
And these can vary with time.

But nearly all these features go away when flying at 28 km (90 kft), with little gained by flying higher than this.



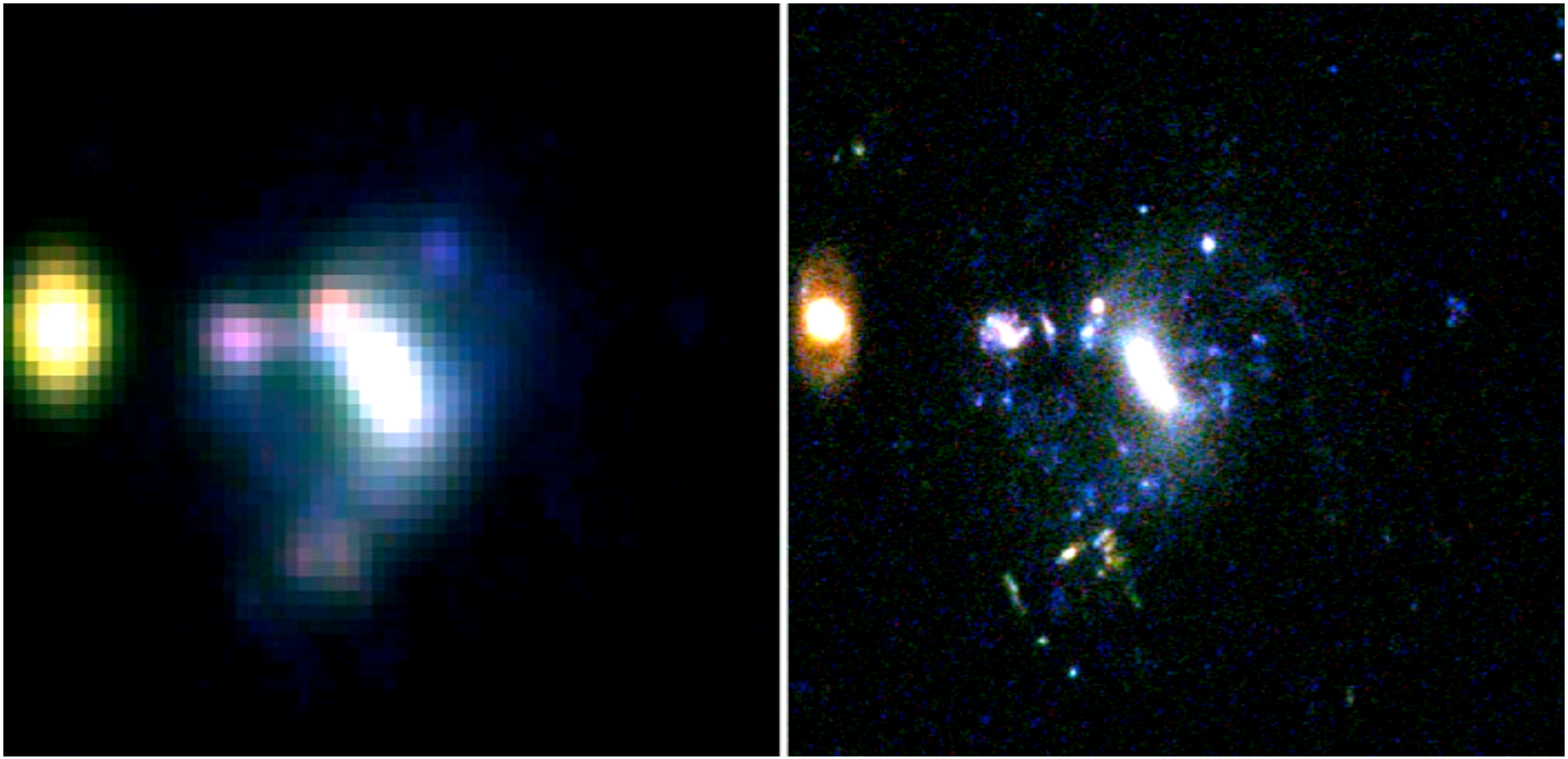
Transmission of the atmosphere at infrared wavelengths at four altitudes.
(adapted from Hanio, C.C. in "Frontiers of Astrophysics", E.H. Avrett (ed.), Harvard University Press, Cambridge, 1976)

The high value of angular resolution



8.3 m Subaru at Mauna Kea

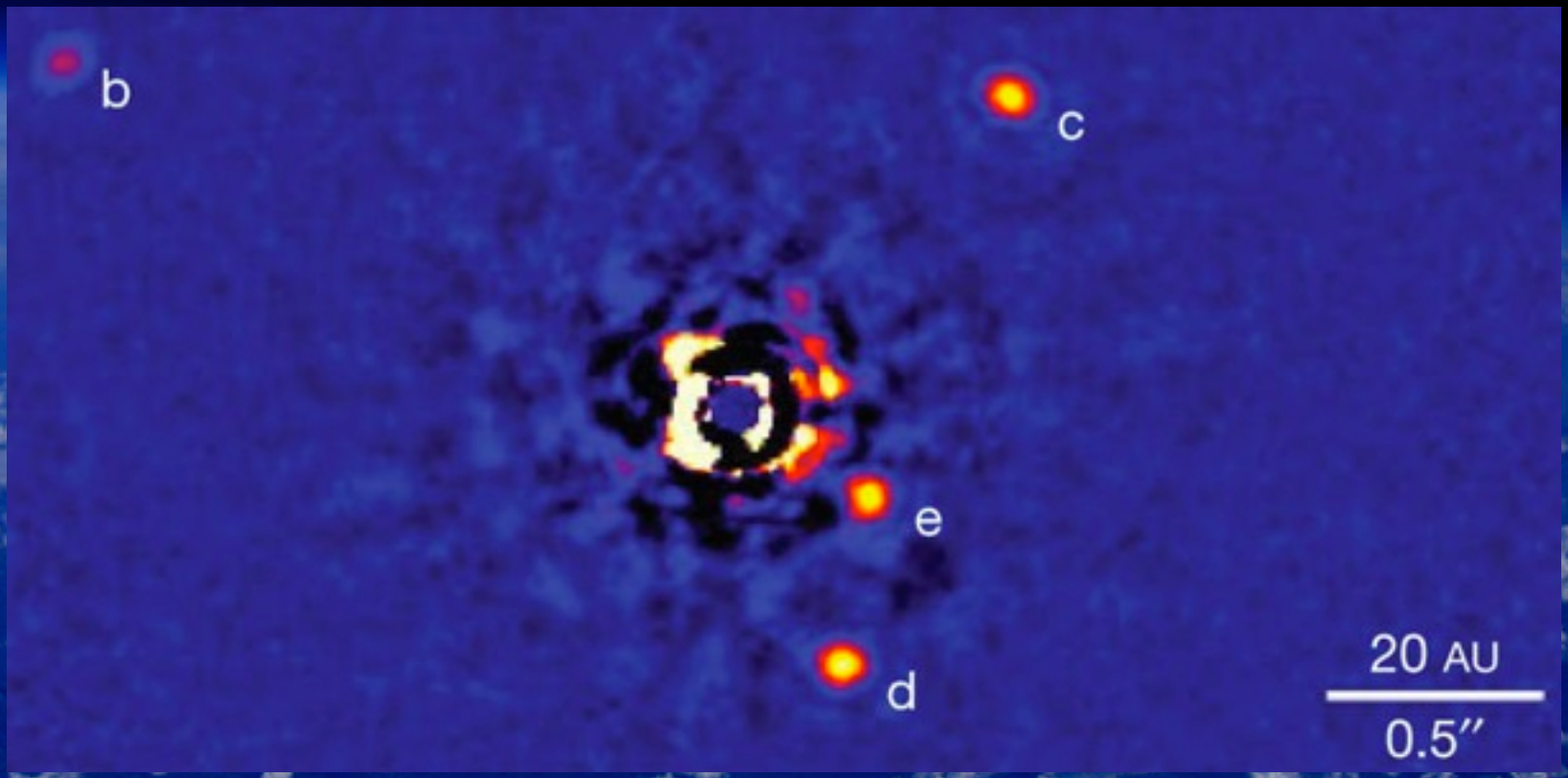
2.4 m HST/ACS Ultra Deep Field



A 2-meter airborne telescope could potentially provide 0.05” acuity in the visible – a capability that only the Hubble Space Telescope currently provides.

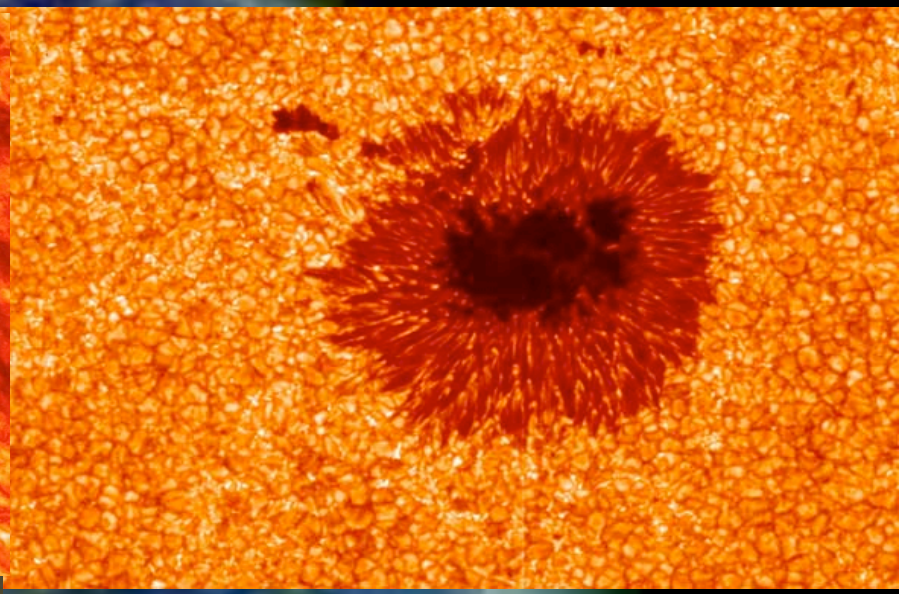
Being above the weather, an airship platform could provide such data night after night, day after day for as long as the platform remained at high altitudes.

Direct imaging of exosolar planets



HR 8799

High resolution visible and near infrared imaging of the Sun's surface features.



Conclusion

Airships offer a great new opportunity for science.

They represent a unique and versatile platform for a wide range of Earth reconnaissance, in-situ atmospheric measurements, and astronomical observations that could rival space-based missions.


HAA concept - Lockheed Martin
OPPORTUNITIES FOR AIRSHIPS
as Unique Science Platforms
LEM-V - Northrop Grumman
Sarah H. Miller
Oxford/Caltech