LOW COST ACCESS TO NEAR SPACE (LCANS09): BRIDGING THE GAP...

Eliot Young

Southwest Research Institute

Nov. 11, 2009

LOW COST ACCESS TO NEAR SPACE (LCANS09): Why Another Workshop?

- Goal: Hubble-like performance from the stratosphere. Develop the vis/UV capabilities for after HST.
- Goal: An observing facility in the stratosphere. Develop a pointed platform; let users attach their own detectors.
- Goal: Generate ideas for long duration missions (~100 days) made possible by airships or super-pressure balloons.
- Goal: Share expertise – most of the technology needed to fly diffraction-limited balloon-borne telescopes is mature.
- Workshop organizers: Eliot Young (SwRI), Robert Fesen (Dartmouth) and Qian Wu (NCAR).

The LCANS09 Program: Highlights from 14 Talks

DAY ONE: MONDAY OCTOBER 26, 2009

Session 1: Suborbital Science with High Altitude Balloons

8:40 am Welcome: Eliot Young

8:45 am Keynote Address: The Promise of LTA Science: Alan Stern (SwRI)

9:00 am The 2007 Toronto Workshop On Suborbital Science: Kimberly Strong (Univ. of Toronto)

9:30 am Capabilities of Zero-Pressure and Super-Pressure Balloons: Mike Smith (Aerostar)

10:00 am The BLAST Astrophysical Balloon Mission: Mark Devlin (Univ. of Pennsylvania)

Session 2: Existing and Proposed Long-Duration LTA Platforms

11:00 am NASA's Super Pressure Balloon Program: David Pierce (NASA, Wallops Flight Facility)

11:30 am HiSentinel: A High Altitude, LTA Airship for MDC/ARSTRAT: Steve Smith (SwRI)

12:00 pm Hale-D and ISIS - DARPA's High Altitude Airships: Scott Hovarter (Lockheed Martin)

12:30 pm: Airship, Platforms, & High Racks; A Look at JPA Vehicles: John Powell (JP Aerospace)

Session 3: Lightweight Sensors and High Altitude Imaging

2:00 pm Lightweight Optical Imaging Systems: Steve Kendrick (Ball Aerospace)

2:30 pm Lightweight Optical Elements: Charles Kirk (ITT)

3:00 pm Imaging Quality as a Function of Altitude: Wes Traub (JPL)

Session 4: Platform/Sensor Stabilization and Communication Systems

4:00 pm High-Resolution Imaging from Balloon-Borne Telescopes: Pietro Bernasconi (APL, Johns Hopkins)

4:25 pm A Low-Cost Star Tracker and Telescope Pointing System: Jeff Percival (Univ. of Wisconsin)

4:50 pm Stabilization of Balloon-Borne Telescopes: Larry Germann (Left Hand Design Corp)

5:15 pm Motion Correcting Imaging Detectors: Barry Burke (Lincoln Labs)

DAY TWO: TUESDAY OCTOBER 27, 2009

Session 5: Lightweight Instrumentation and Vehicle Communications

9:00 am Micro-Instrumentation for Lightweight Ballooning: Dwayne Orr (Columbia Science Balloon Facility)

9:25 am Lightweight Communication Systems: Kevin Shoemaker (Shoemaker Labs)

9:50 am Global Platform Communication: Tim Maclay (OrbComm)

10:15 am Small Balloon Payloads: Tim Lachenmeier (Near Space Corp.)

Session 6: Astrophysics using High Altitude Science Platforms

11:10 am An Exoplanet Coronagraph on a Stratospheric Science Platform: Wes Traub (JPL)

11:35 am Interferometry at Altitude: Galaxies, Stars, & Exoplanets: Stephen Rinehart (NASA, GSFC)

12:00 pm HALO: A High Altitude Balloon-Borne Cosmology Mission: Jason Rhodes (JPL)

12:20 pm Optical Systems Using Polymer Membranes: Dan Marker (AFRL)

Session 7: Solar and Planetary Stratospheric Telescopes

2:00 pm SUNRISE: A High Altitude Solar Telescope: Alice Lecinski (HAO, NCAR)

2:25 pm SCRIBE: A Low Cost Balloon-Borne Solar Observatory: Craig DeForest (SwRI)

2:50 pm Balloon-Borne Planetary Missions: Karl Hibbitts (JHU/APL)

Session 8: Stratospheric Science Using High Altitude Vehicles

3:45 pm High Altitude Winds & Chemistry Studies using High Altitude Platforms: William Randel (NCAR)

4:10 pm F-P Interferometer Imagery for Cloud and Trace Gas Studies: Sam Yee (APL, Johns Hopkins)

4:35 pm High Altitude Driftsonde Ballooning Operations: Terry Hock (NCAR)

4:55 pm Balloon Applications for Spaceweather and Thermosphere Dynamics: Qian Wu (NCAR)

The LCANS09 Program: Highlights from 14 Talks

DAY ONE: MONDAY OCTOBER 26, 2009

Session 1: Suborbital Science with High Altitude Balloons

8:40 am Welcome: Eliot Young

8:45 am Keynote Address: The Promise of LTA Science: Alan Stern (SwRI)

9:00 am The 2007 Toronto Workshop On Suborbital Science: Kimberly Strong (Univ. of Toronto)

9:30 am Capabilities of Zero-Pressure and Super-Pressure Balloons: Mike Smith (Aerostar)

10:00 am The BLAST Astrophysical Balloon Mission: Mark Devlin (Univ. of Pennsylvania)

Session 2: Existing and Proposed Long-Duration LTA Platforms

11:00 am NASA's Super Pressure Balloon Program: David Pierce (NASA, Wallops Flight Facility)

11:30 am HiSentinel: A High Altitude, LTA Airship for MDC/ARSTRAT: Steve Smith (SwRI)

12:00 pm Hale-D and ISIS - DARPA's High Altitude Airships: Scott Hovarter (Lockheed Martin)

12:30 pm: Airship, Platforms, & High Racks; A Look at JPA Vehicles: John Powell (JP Aerospace)

Session 3: Lightweight Sensors and High Altitude Imaging

2:00 pm Lightweight Optical Imaging Systems: Steve Kendrick (Ball Aerospace)

2:30 pm Lightweight Optical Elements: Charles Kirk (ITT)

3:00 pm Imaging Quality as a Function of Altitude: Wes Traub (JPL)

Session 4: Platform/Sensor Stabilization and Communication Systems

4:00 pm High-Resolution Imaging from Balloon-Borne Telescopes: Pietro Bernasconi (APL, Johns Hopkins)

4:25 pm A Low-Cost Star Tracker and Telescope Pointing System: Jeff Percival (Univ. of Wisconsin)

4:50 pm Stabilization of Balloon-Borne Telescopes: Larry Germann (Left Hand Design Corp)

5:15 pm Motion Correcting Imaging Detectors: Barry Burke (Lincoln Labs)

DAY TWO: TUESDAY OCTOBER 27, 2009

Session 5: Lightweight Instrumentation and Vehicle Communications

9:00 am Micro-Instrumentation for Lightweight Ballooning: Dwayne Orr (Columbia Science Balloon Facility)

9:25 am Lightweight Communication Systems: Kevin Shoemaker (Shoemaker Labs)

9:50 am Global Platform Communication: Tim Maclay (OrbComm)

10:15 am Small Balloon Payloads: Tim Lachenmeier (Near Space Corp.)

Session 6: Astrophysics using High Altitude Science Platforms

11:10 am An Exoplanet Coronagraph on a Stratospheric Science Platform: Wes Traub (JPL)

11:35 am Interferometry at Altitude: Galaxies, Stars, & Exoplanets: Stephen Rinehart (NASA, GSFC)

12:00 pm HALO: A High Altitude Balloon-Borne Cosmology Mission: Jason Rhodes (JPL)

12:20 pm Optical Systems Using Polymer Membranes: Dan Marker (AFRL)

Session 7: Solar and Planetary Stratospheric Telescopes

2:00 pm SUNRISE: A High Altitude Solar Telescope: Alice Lecinski (HAO, NCAR)

2:25 pm SCRIBE: A Low Cost Balloon-Borne Solar Observatory: Craig DeForest (SwRI)

2:50 pm Balloon-Borne Planetary Missions: Karl Hibbitts (JHU/APL)

Session 8: Stratospheric Science Using High Altitude Vehicles

3:45 pm High Altitude Winds & Chemistry Studies using High Altitude Platforms: William Randel (NCAR)

4:10 pm F-P Interferometer Imagery for Cloud and Trace Gas Studies: Sam Yee (APL, Johns Hopkins)

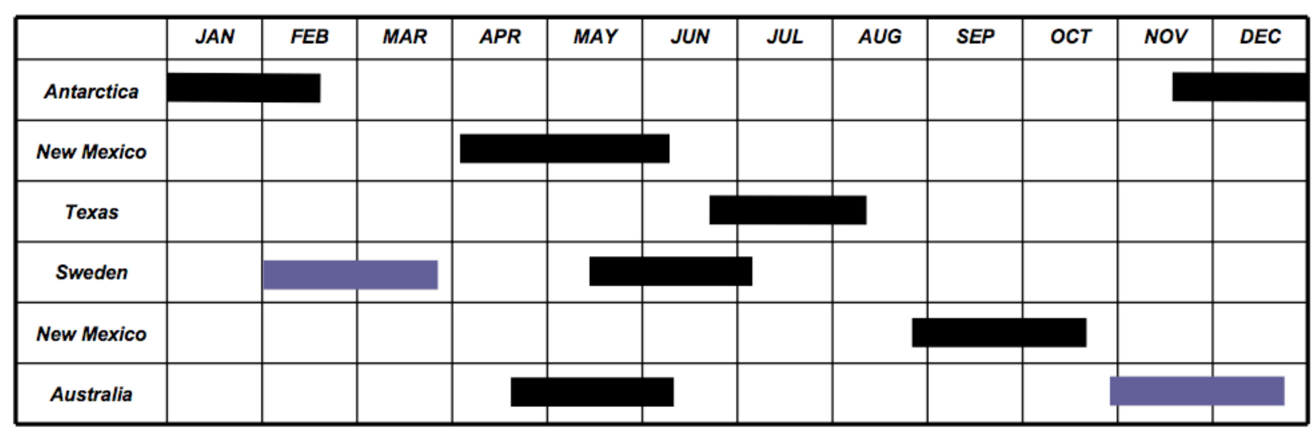
4:35 pm High Altitude Driftsonde Ballooning Operations: Terry Hock (NCAR)

4:55 pm Balloon Applications for Spaceweather and Thermosphere Dynamics: Qian Wu (NCAR)

TALK OVERVIEWS: David Pierce (CSBF)

- NASA Conducts 3 U.S. Campaigns (New Mexico, Texas) per year, plus
- Antarctica LDB Campaign, and either a Northern Hemisphere LDB (Sweden), or
- A mid-latitude LDB (Australia) campaign each year
- NASA's established Launch Sites and typical mission durations:

– Ft. Sumner, New Mexico ~2 days
– Sweden (66 degs N lat) ~5-7 days
– Australia (23 degs S lat) ~10-20 days
– Antarctica (77 degs S lat) ~40-50 days



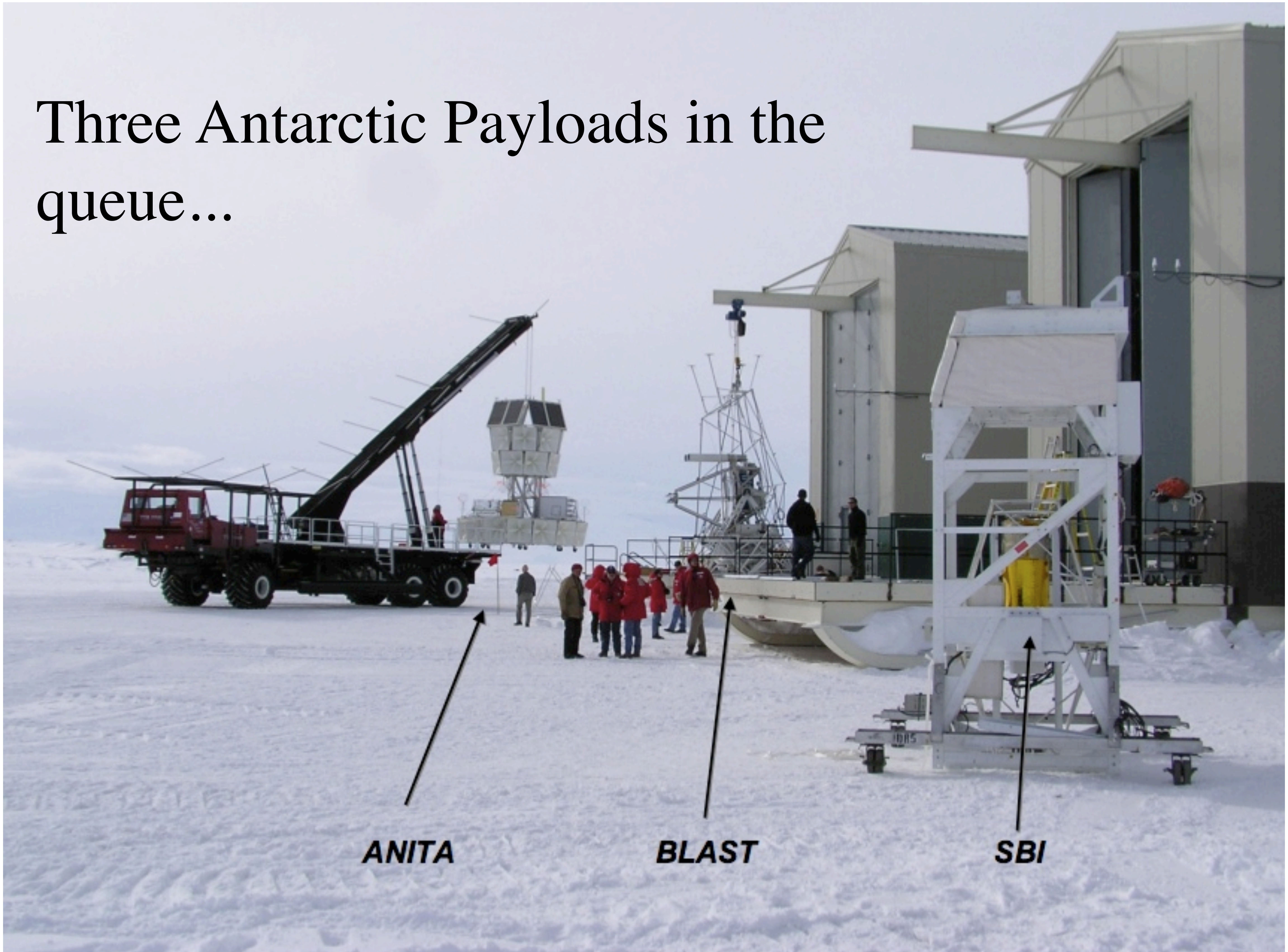
TALK OVERVIEWS: David Pierce (CSBF)

	Conventional	LDB	ULDB*
Duration	~ 2 days	40+ days	Up to 100 days
Flight Opportunities	~16 per year	3-6 per year	1 per year
Suspended Capacity	1650-8000 lbs		6000 lbs
Float Altitude	Up to 160,000 ft		Up to 110,000 ft
Flight Support Systems **All NASA Flight Support Systems are highly reliable proven systems**	CIP •Line of Sight •300 kbps direct return	SIP •Over the Horizon •100 kbps TDRSS downlink	CDM/SIP •Over the Horizon •100 kbps TDRSS downlink
Launch Locations **Operations Costs per flight, excluding Instrument**	Fort Sumner, NM; Palestine, Texas; Alice Springs, Australia **ROM $ 100-250 K**	Antarctica; Kiruna, Sweden; Alice Springs, Australia; **ROM $ 250- 500 K**	**ROM $ 500- 1000 K**

* Current development project ; 2MCF and 7MCF is considered qualified for flight

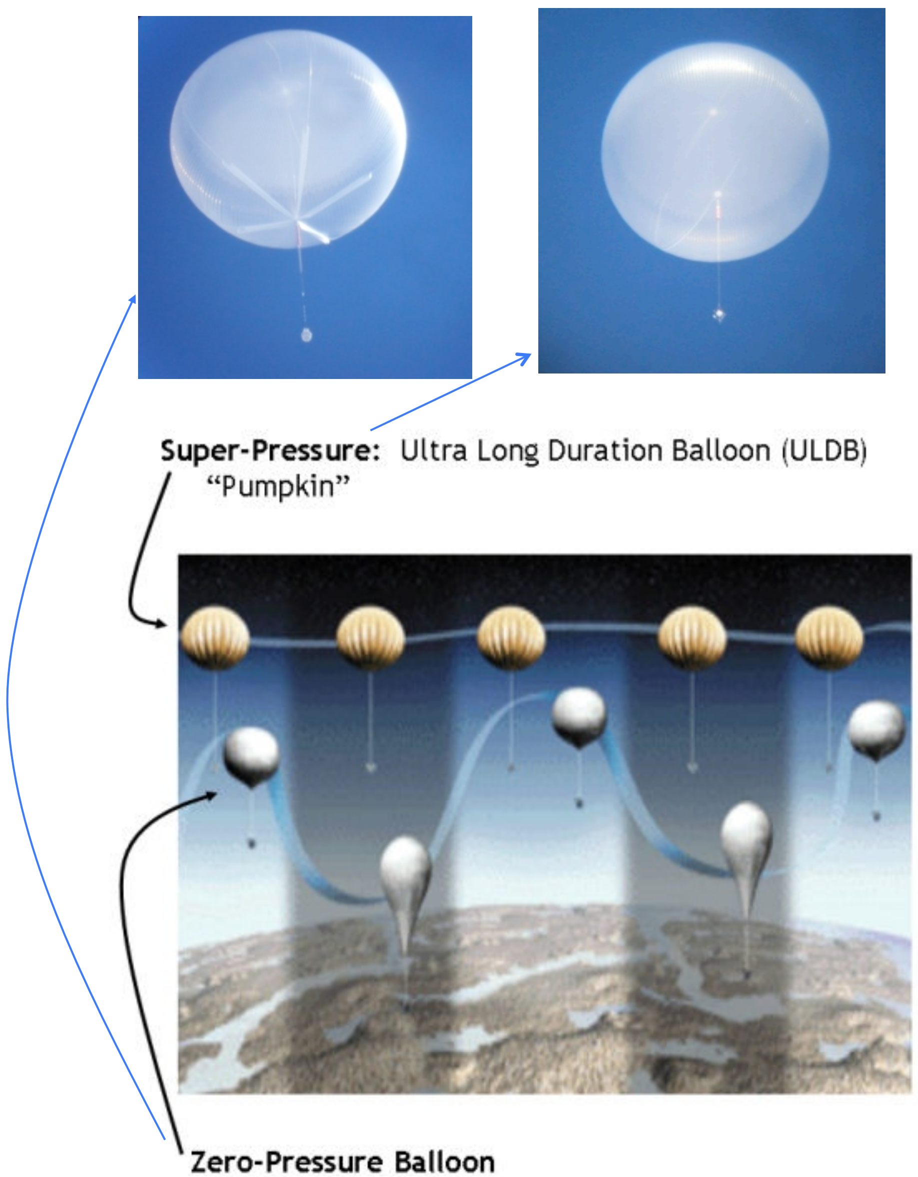
TALK OVERVIEWS: David Pierce (CSBF)

Three Antarctic Payloads in the queue...



TALK OVERVIEWS: David Pierce (CSBF)

Advantages of Super-Pressure Balloons



Zero-pressure balloons are vented at bottom, $P_{internal} = P_{external}$

Expand and contract with sunlight, gas leaks out

Must drop ballast to maintain height
➔ flight duration limited to 5-6 days in mid-latitudes

Long flights only possible in polar summers

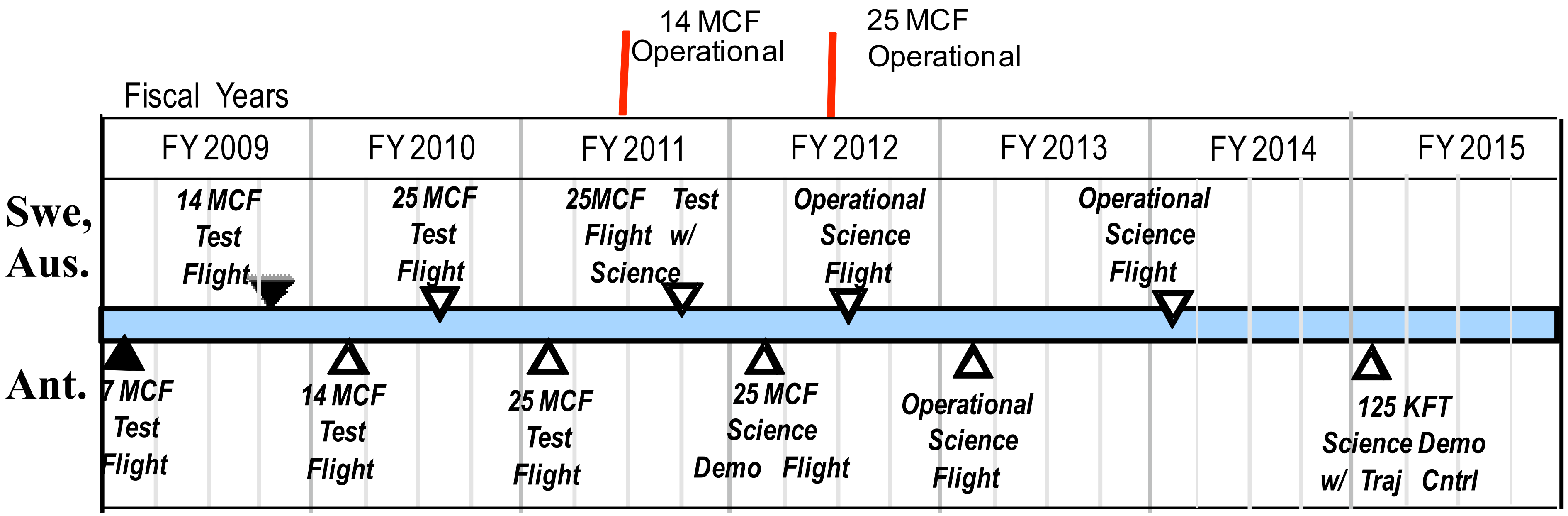
Super-pressure balloons: $P_{in} > P_{out}$
~ 150 – 200 Pa typically

Maintain nearly constant volume and height (and shape) in day/night cycle
Constant density volume is achieved allowing stable bobbing at a constant density altitude
No ballast needed, no loss of gas

Can have long flights at ANY latitude

TALK OVERVIEWS: David Pierce (CSBF)

ULDB Flight Development Schedule

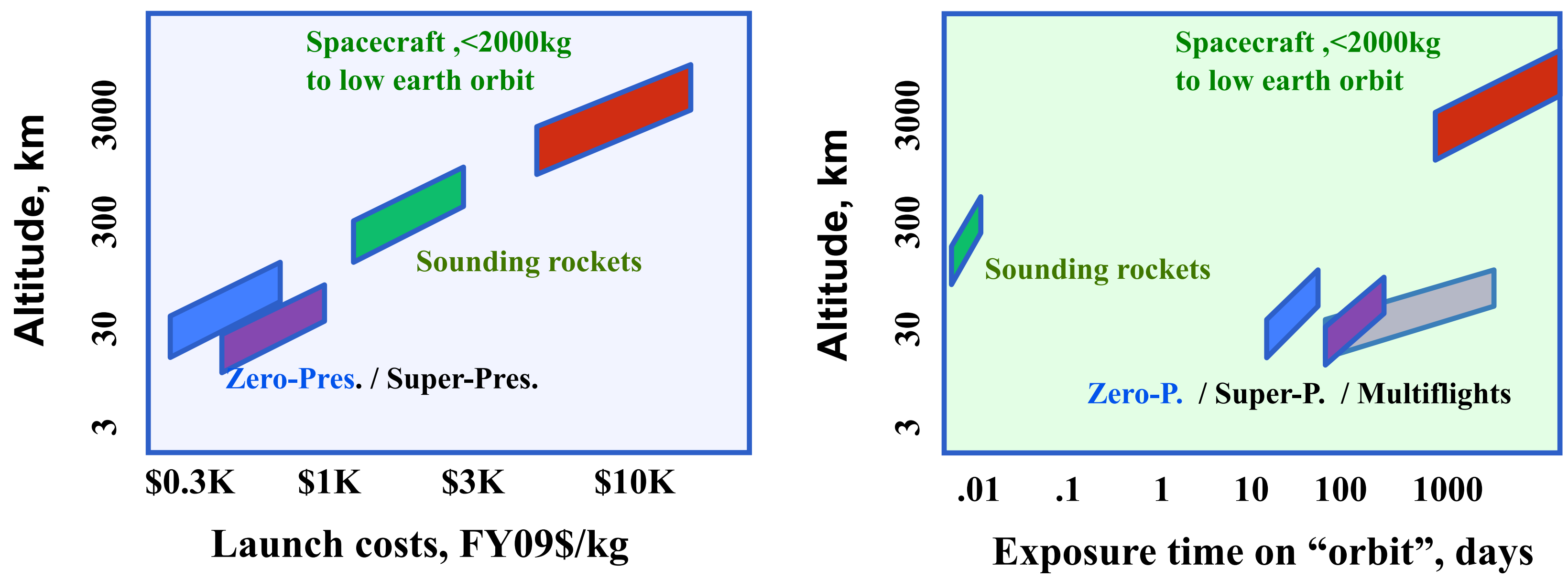


Super Pressure Balloon Capability

Volume	2 MCF	7 MCF	14 MCF	25 MCF
Altitude	100 KFT	110 KFT	110 KFT	116 KFT
Science Payload	50 Lbs	500 Lbs	1000 Lbs	2200 Lbs*

TALK OVERVIEWS: David Pierce (CSBF)

ULDB Balloons: Low Cost & Short Deployment Cycle



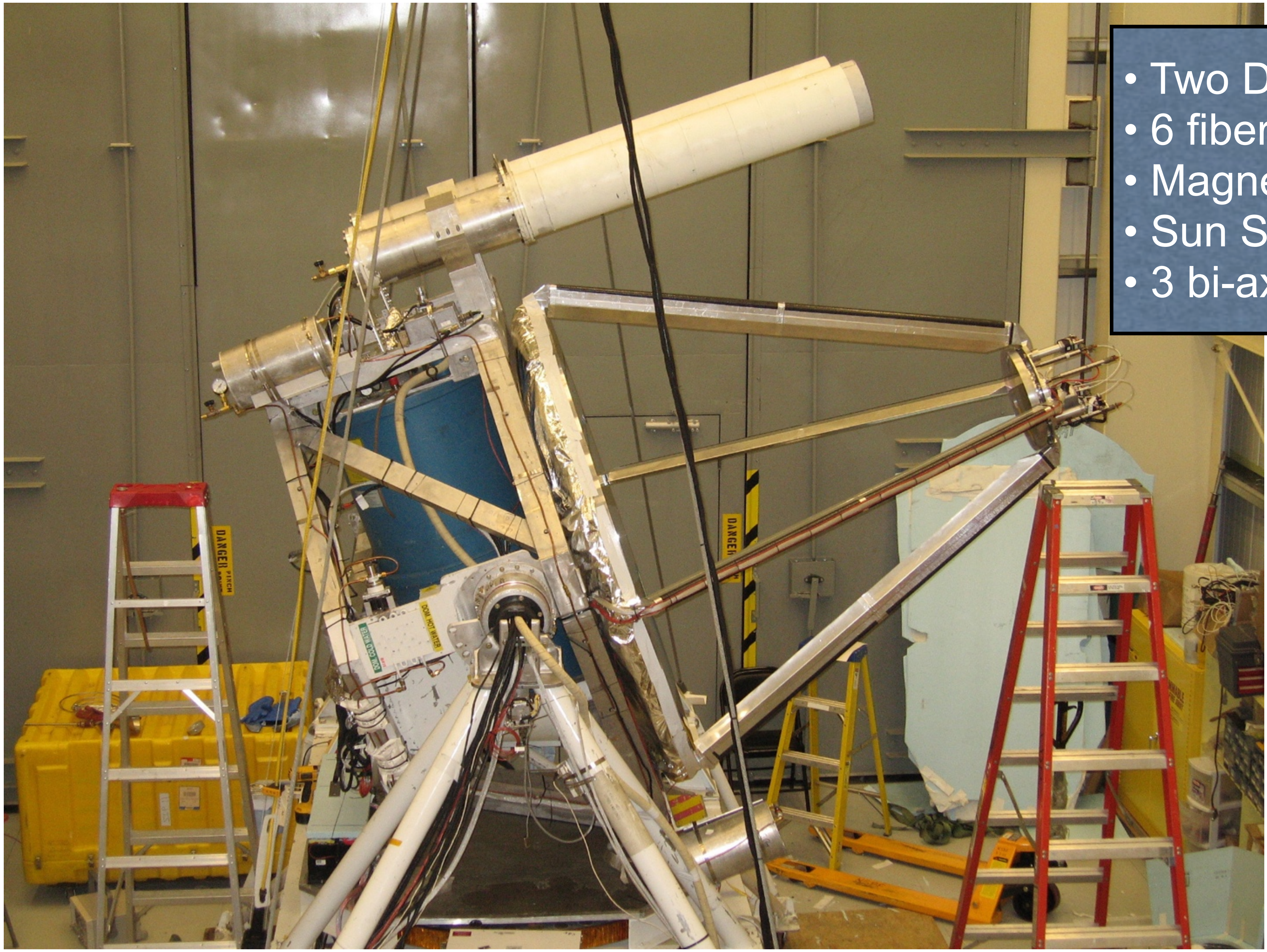
- **LDB/ULDB: NASA's lowest cost access to space (>= stratosphere)**
- Super Pressure Promises an order of magnitude increase in capability
  - -- spacecraft-scale payloads (1000-2000 kg)
  - -- exposures comparable to short-duration spacecraft
  - -- recoverable & re-usable payloads: increased exposure at low cost
- Rapid response to new phenomena

Eliot's Comments (or why Dave's talk is important)

- CSBF is *not* the bottleneck. They fly nearly every payload that NASA R&A programs recommend to them.
- Super-pressure balloons have the potential to be RADICAL GAME-CHANGERS. They enable (a) 100-day flights, (b) mid-latitude flights, and therefore (c) lots of NIGHT time at float.
- Balloon missions are cost effective even when compared to large ground-based observatories. Example: Keck time is valued \$50K per night (TSIP calculation), twice the rate of a \$5M balloon payload that flies for 100 days (day/night operation).
- Need for lighter payloads. The 25 MCF super-pressures can lift about 2200 lb, less than the 8000 lb limit raised by zero-pressure balloons. Even more critical for airships.

TALK OVERVIEWS: Mark Devlin (UPENN)

BLAST (Balloon-borne Large Aperture Sub-mm Telescope)



- Two DAYTIME Star trackers
- 6 fiber optic gyros
- Magnetometer
- Sun Sensor
- 3 bi-axial tilt meters

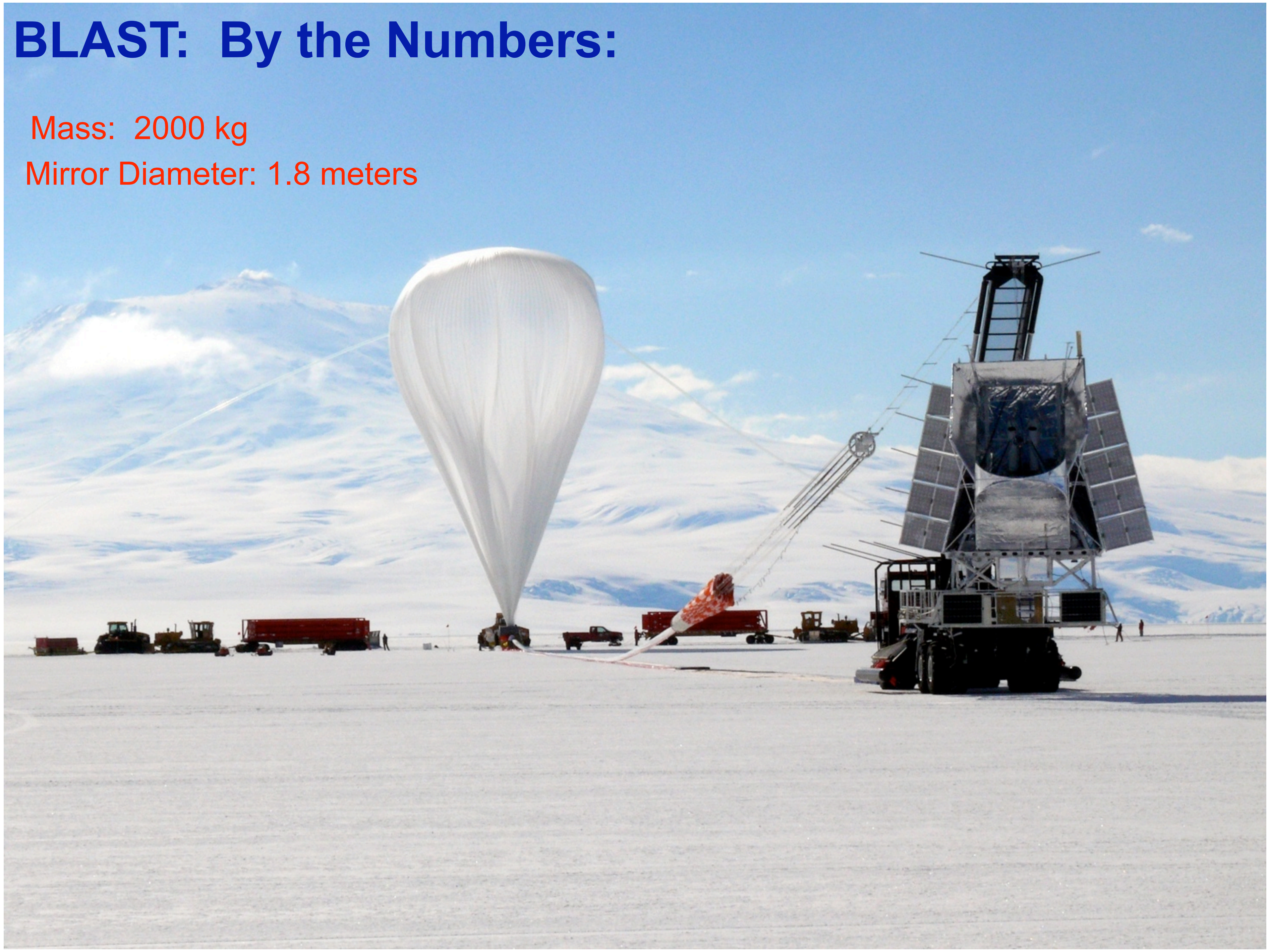
TALK OVERVIEWS: Mark Devlin (UPENN)

BLAST results: 16 papers and counting...

TALK OVERVIEWS: Mark Devlin (UPENN)

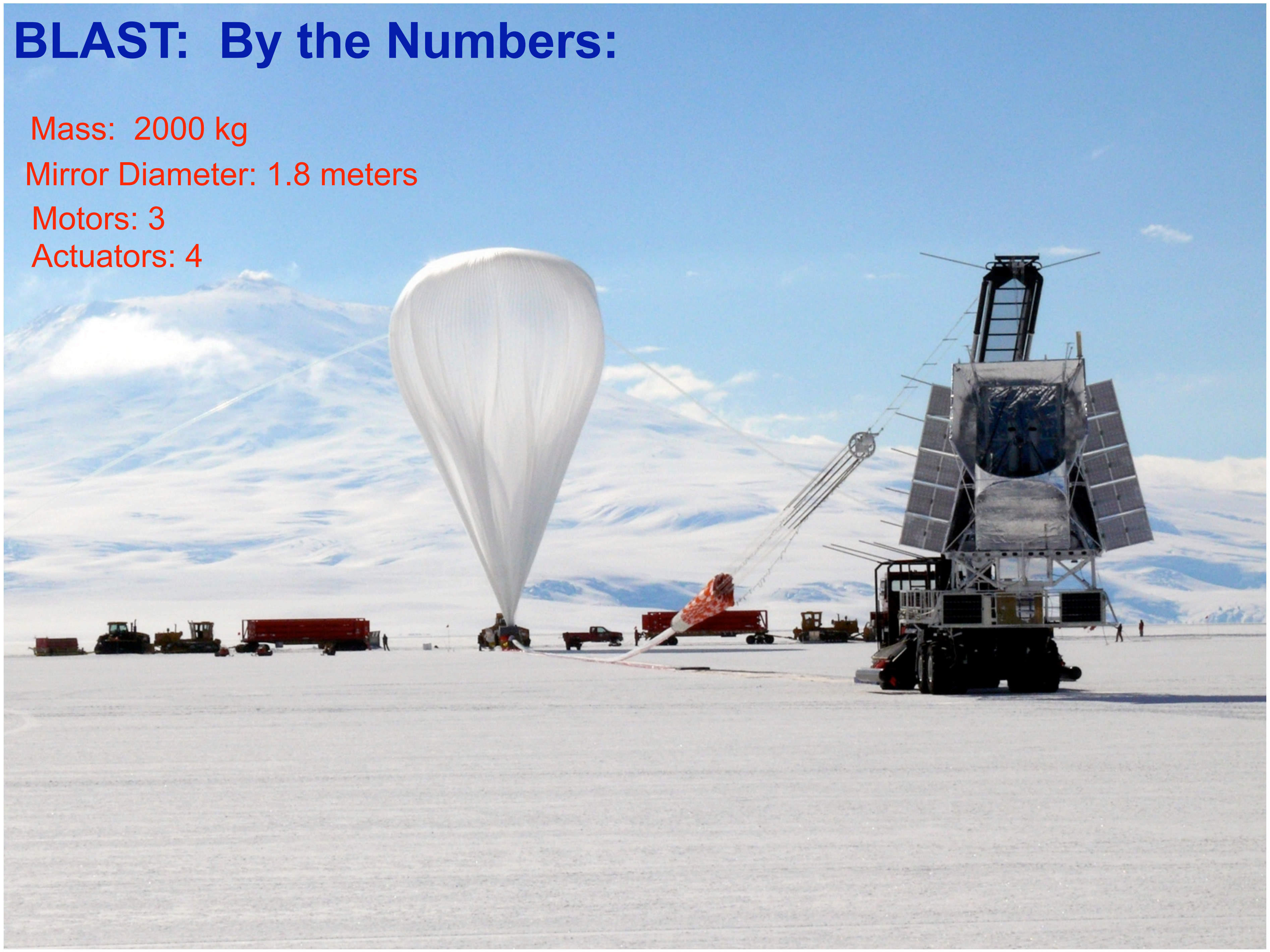
BLAST results: 16 papers and counting...

TALK OVERVIEWS: Mark Devlin (UPENN)



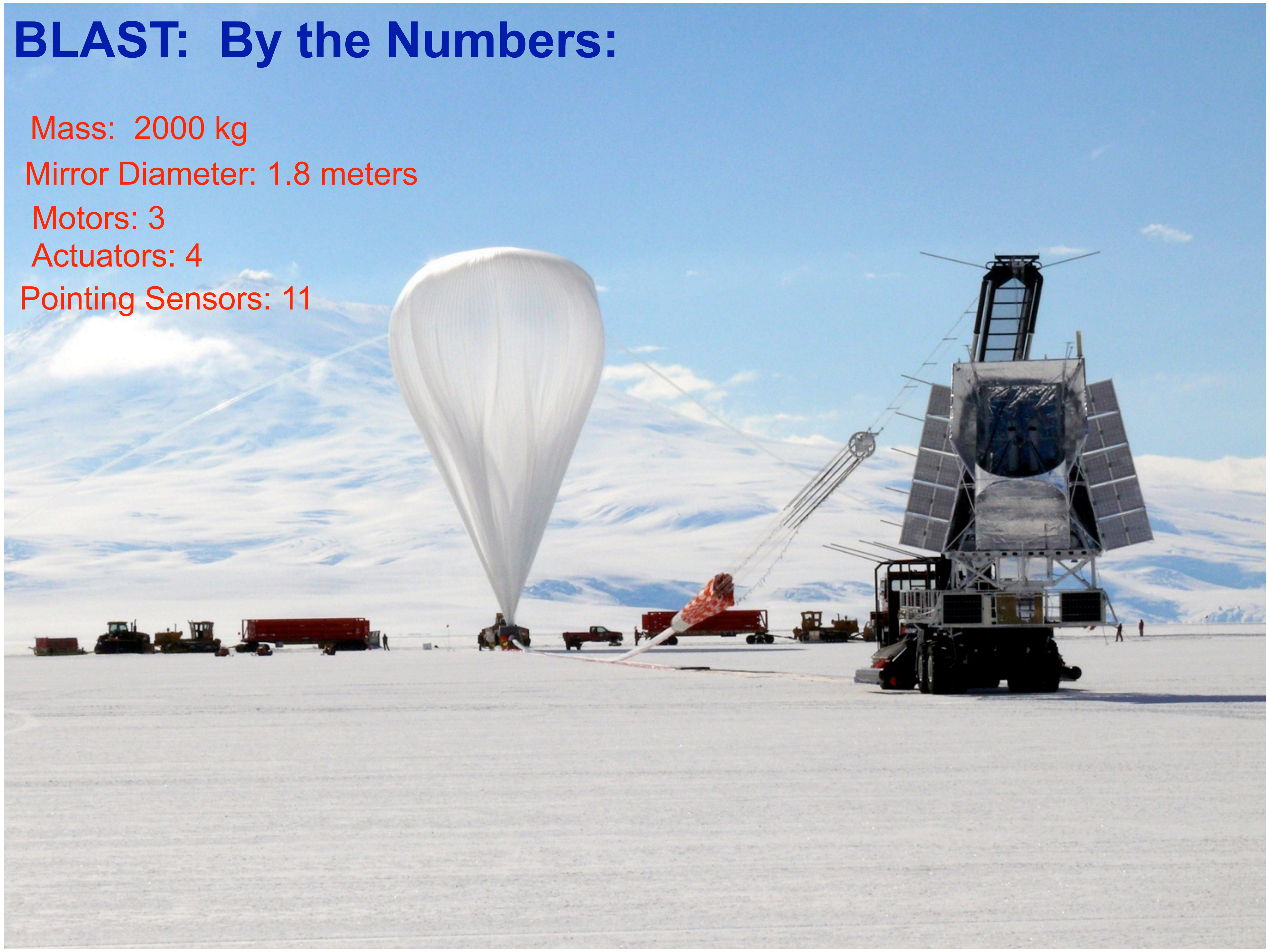
BLAST results: 16 papers and counting...

TALK OVERVIEWS: Mark Devlin (UPENN)



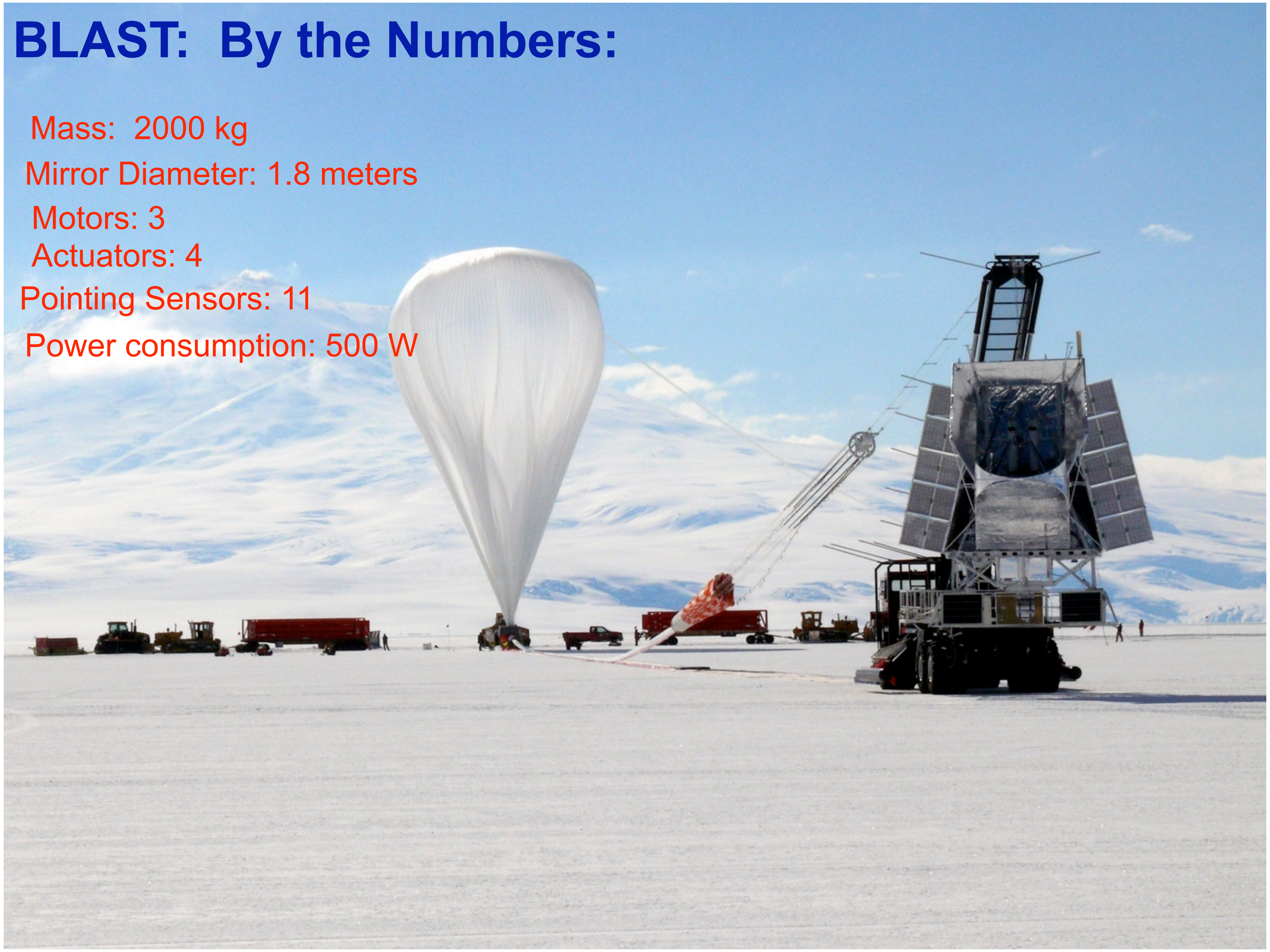
BLAST results: 16 papers and counting...

TALK OVERVIEWS: Mark Devlin (UPENN)



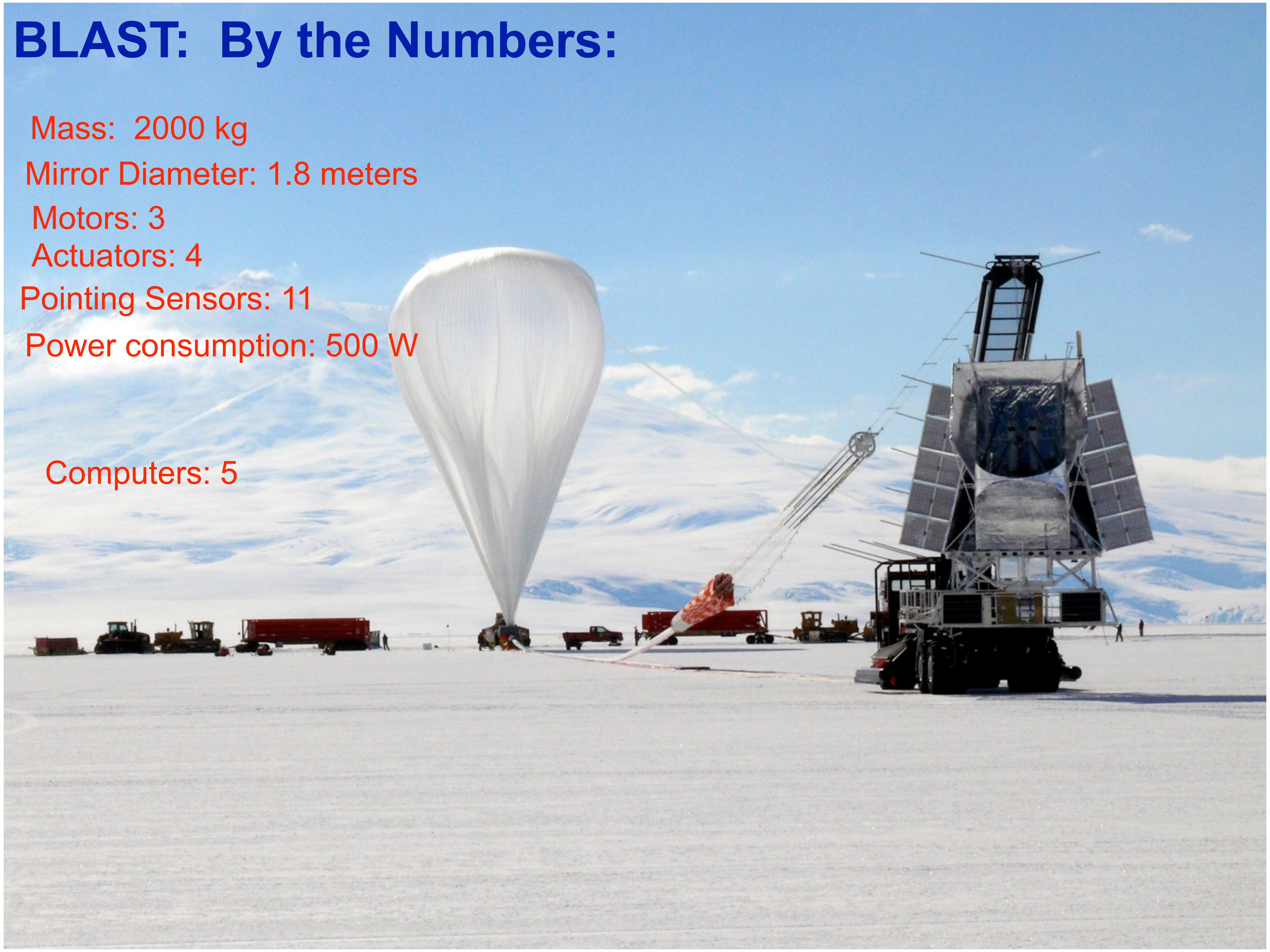
BLAST results: 16 papers and counting...

TALK OVERVIEWS: Mark Devlin (UPENN)



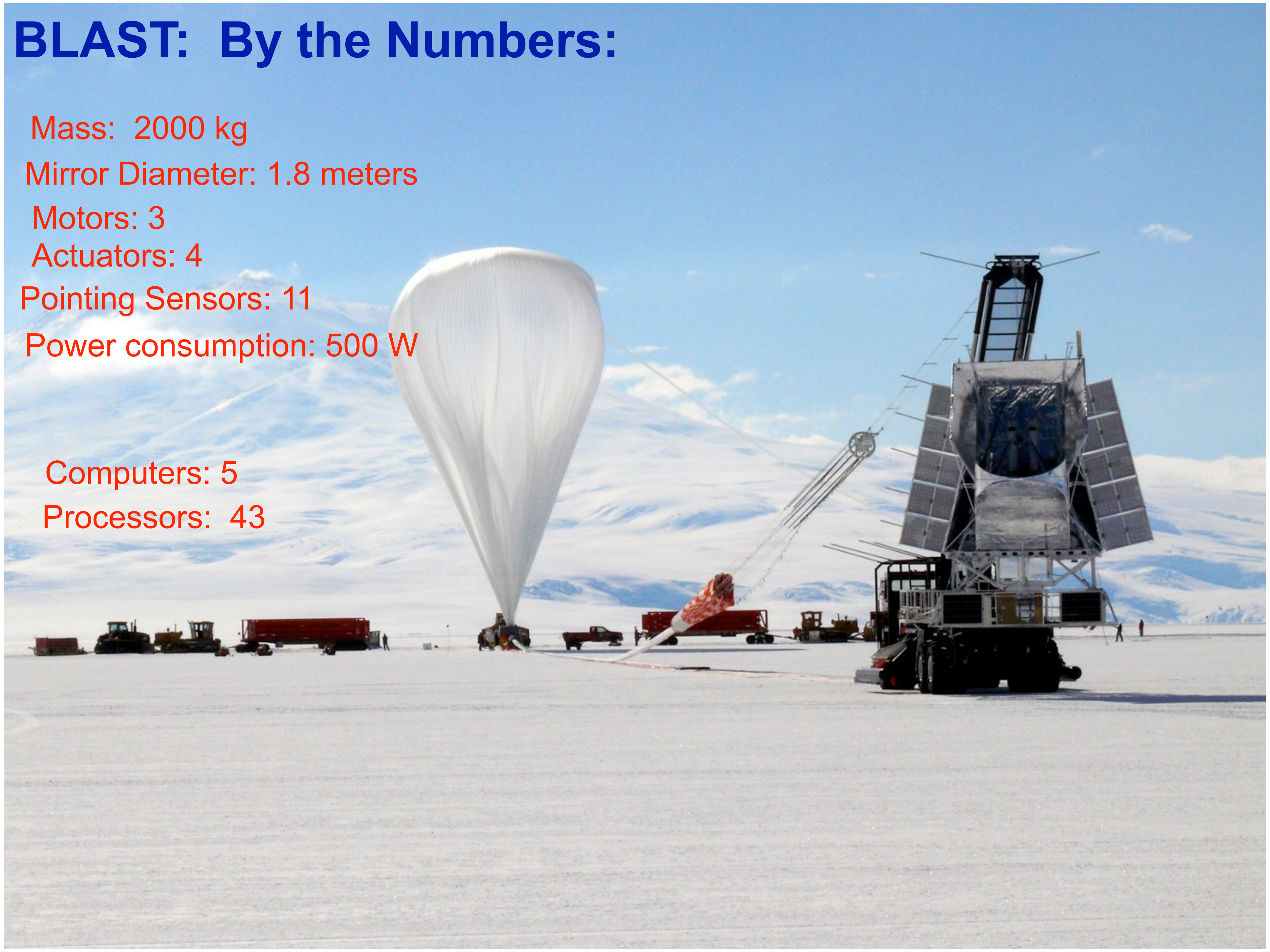
BLAST results: 16 papers and counting...

TALK OVERVIEWS: Mark Devlin (UPENN)



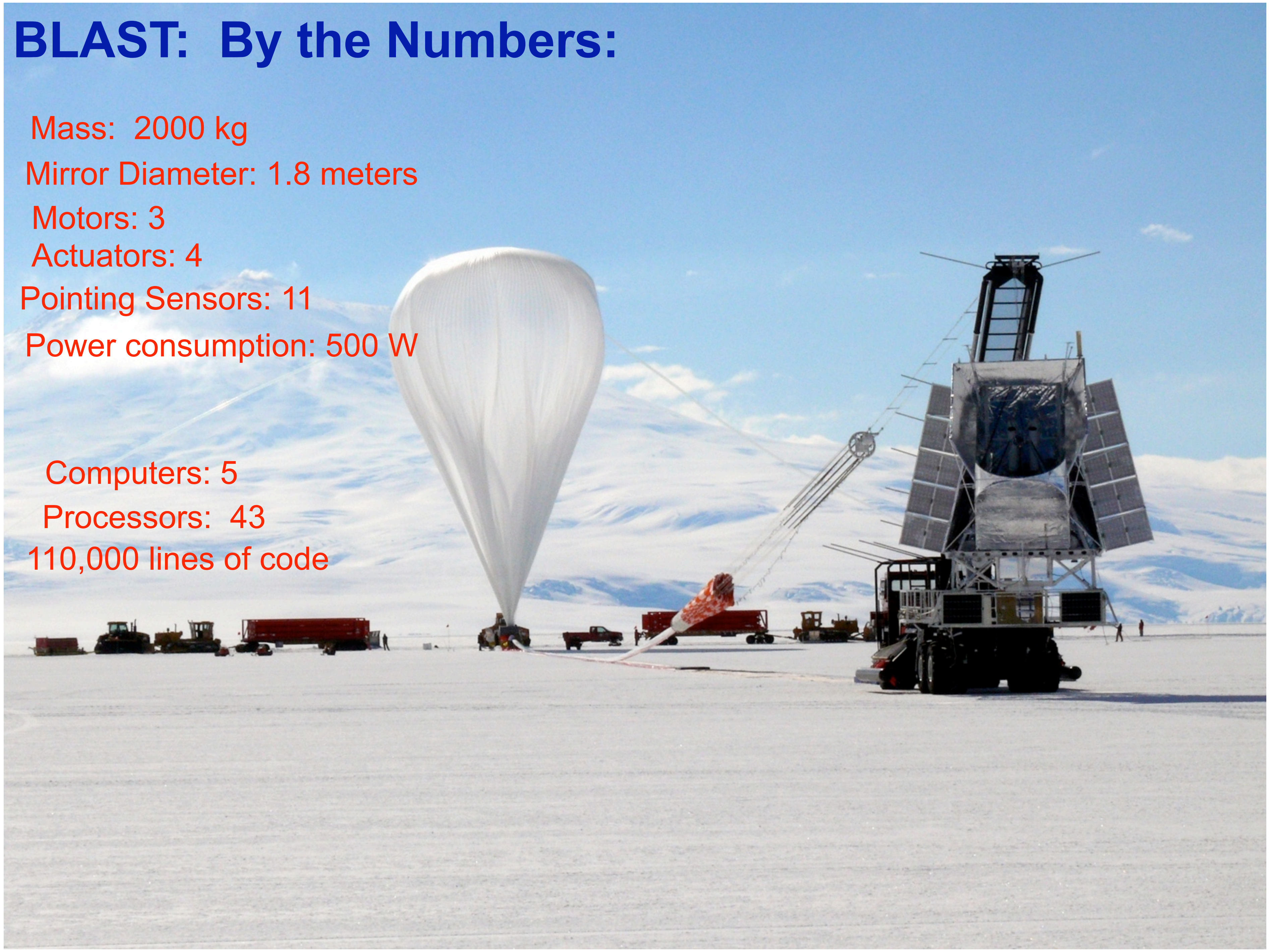
BLAST results: 16 papers and counting...

TALK OVERVIEWS: Mark Devlin (UPENN)



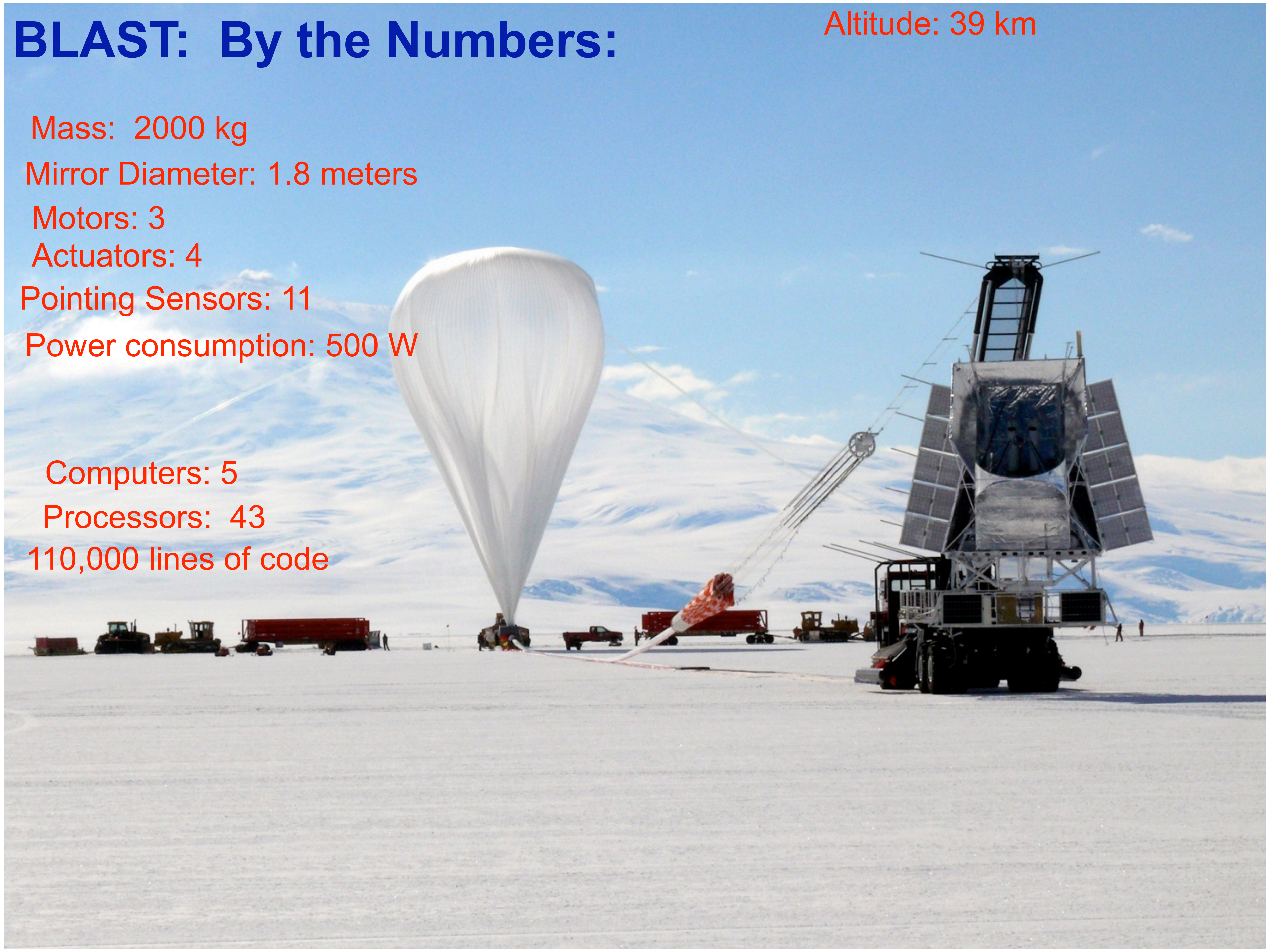
BLAST results: 16 papers and counting...

TALK OVERVIEWS: Mark Devlin (UPENN)



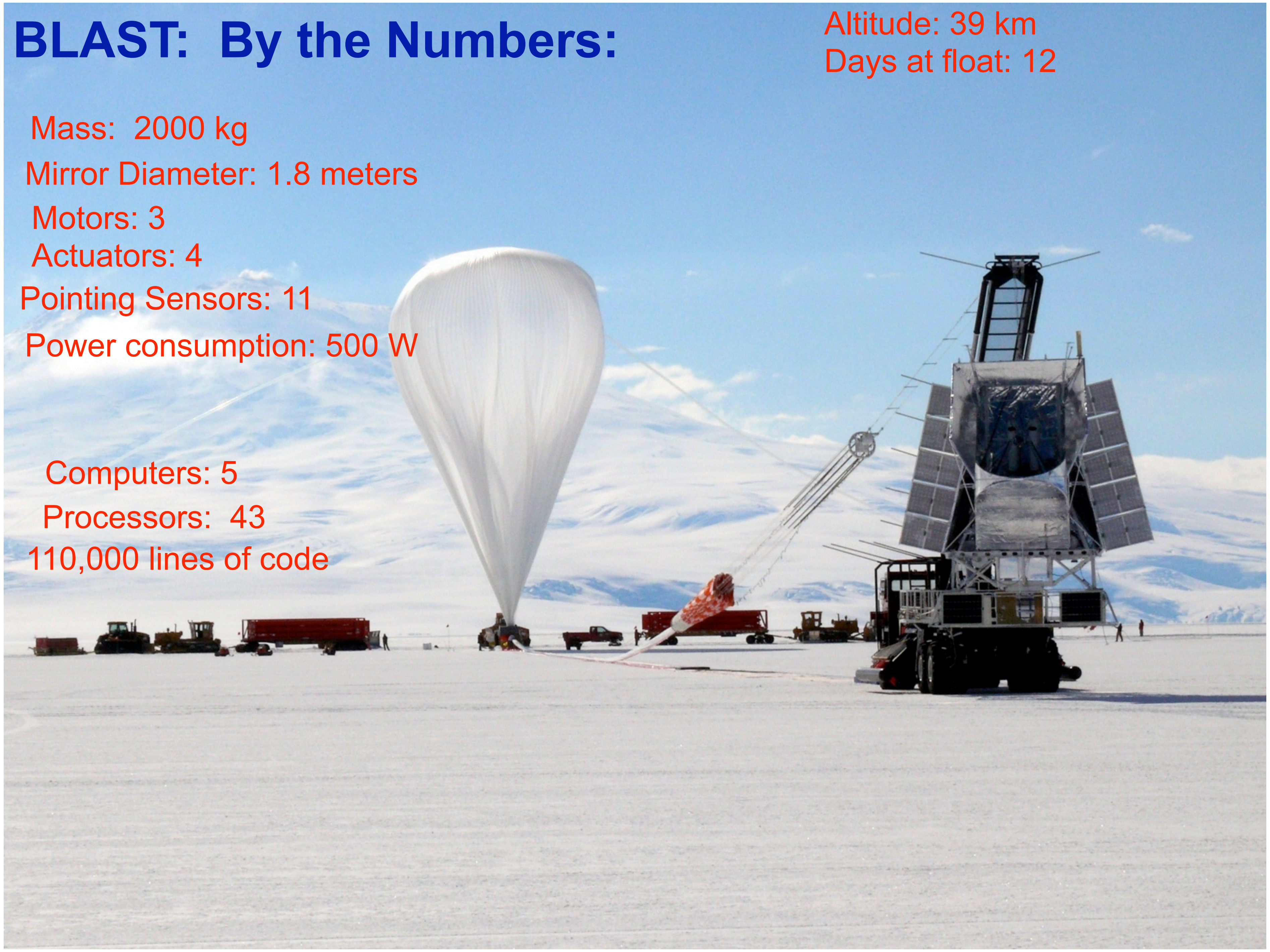
BLAST results: 16 papers and counting...

TALK OVERVIEWS: Mark Devlin (UPENN)



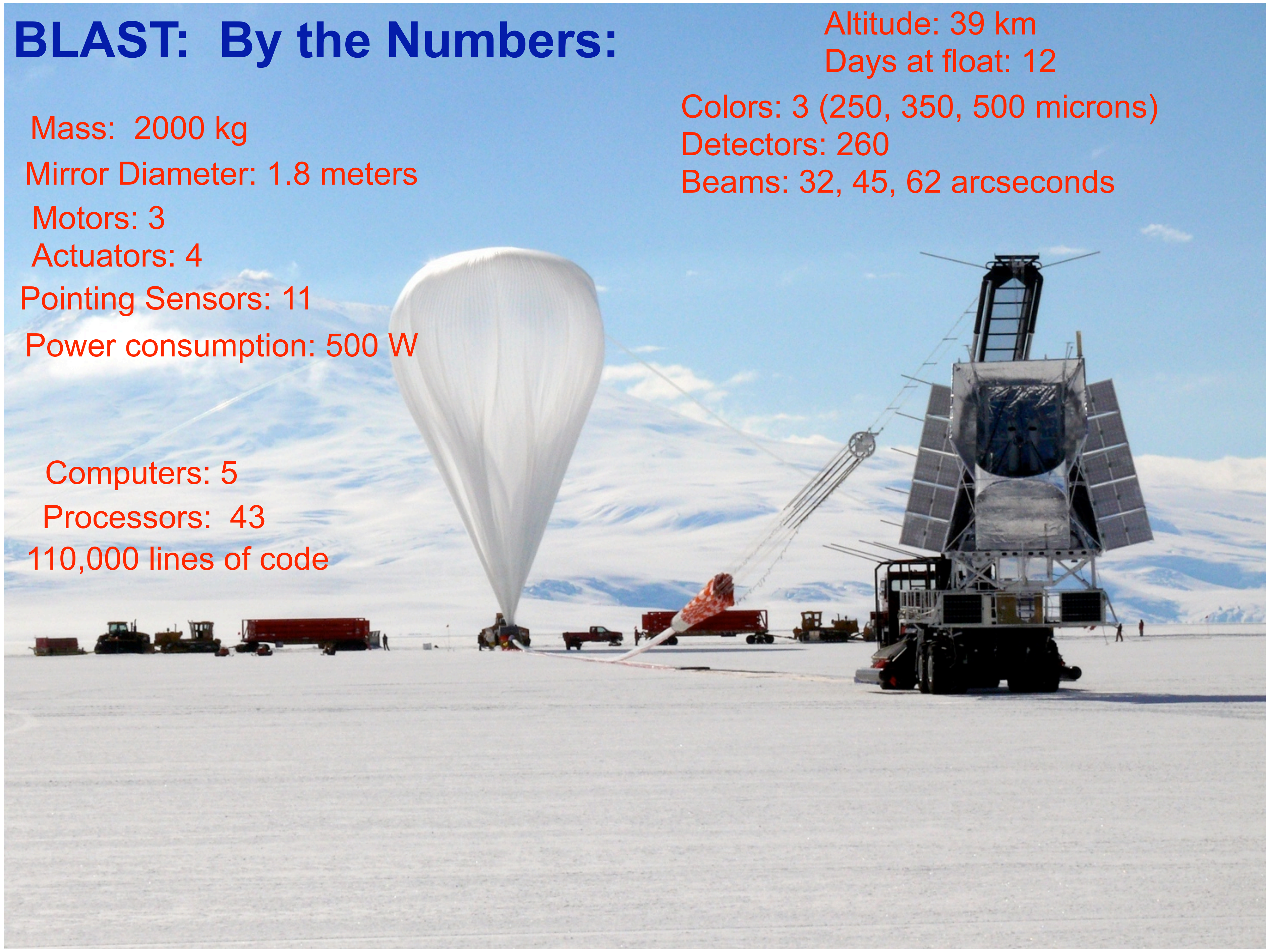
BLAST results: 16 papers and counting...

TALK OVERVIEWS: Mark Devlin (UPENN)



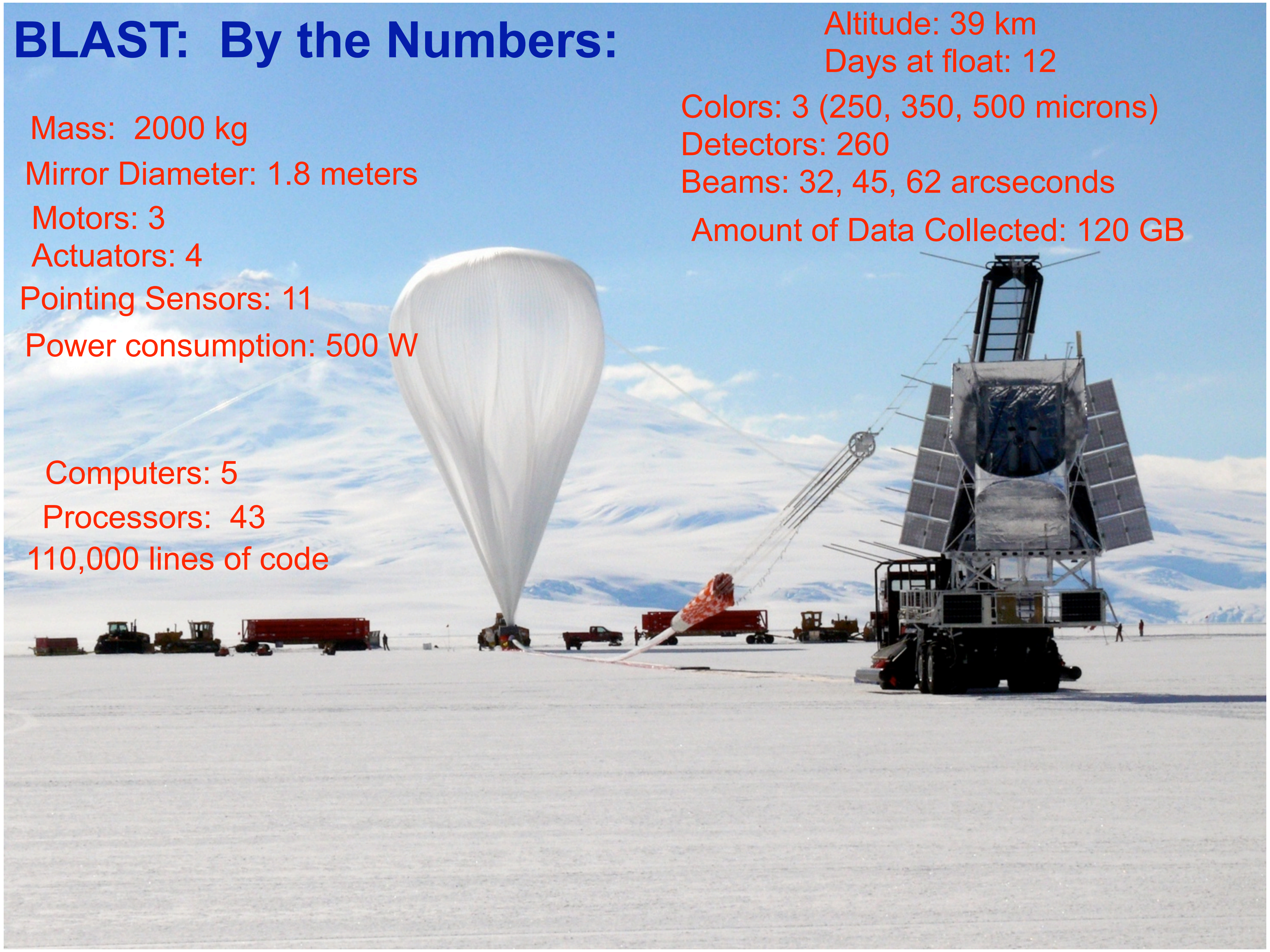
BLAST results: 16 papers and counting...

TALK OVERVIEWS: Mark Devlin (UPENN)



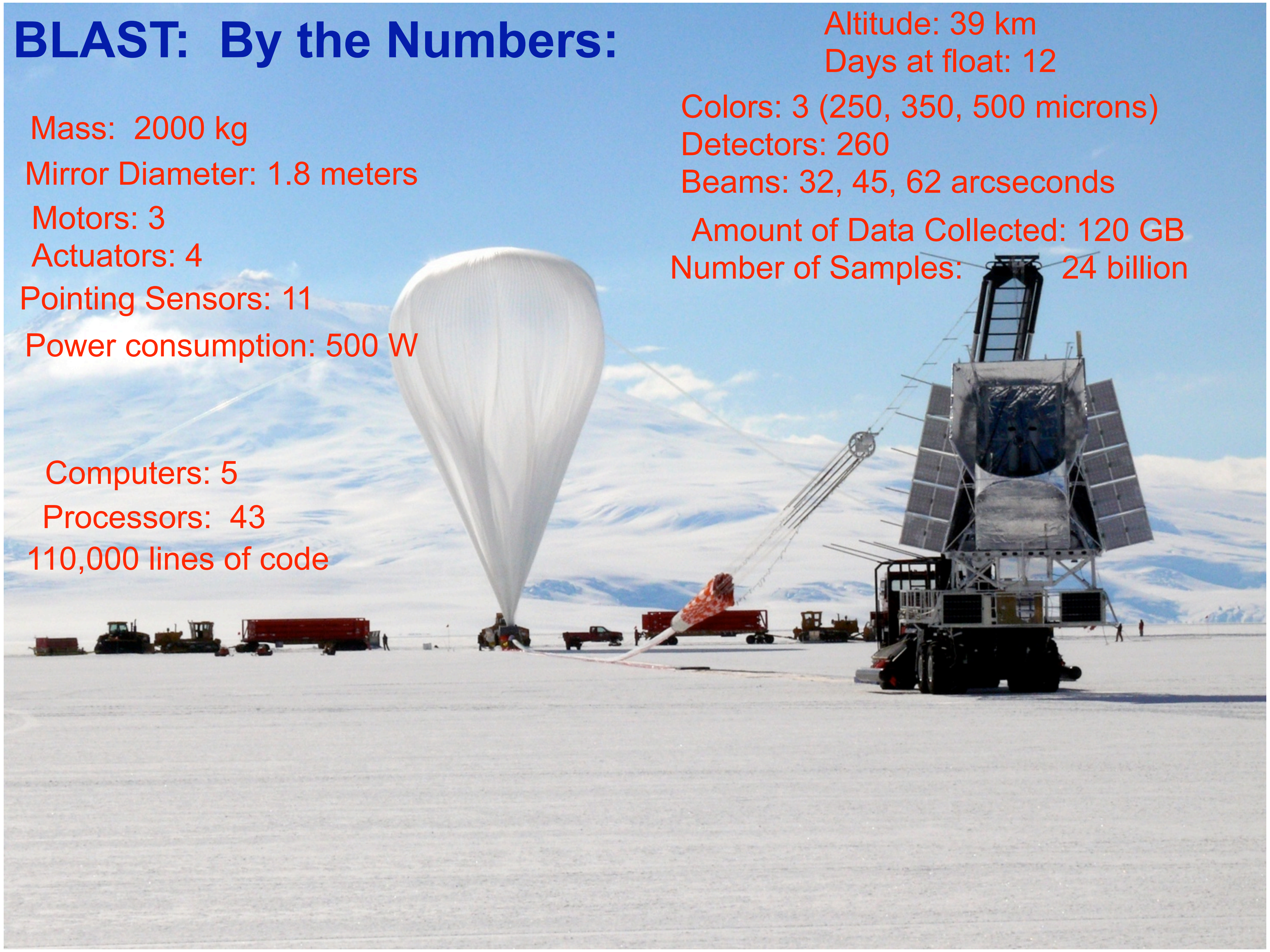
BLAST results: 16 papers and counting...

TALK OVERVIEWS: Mark Devlin (UPENN)



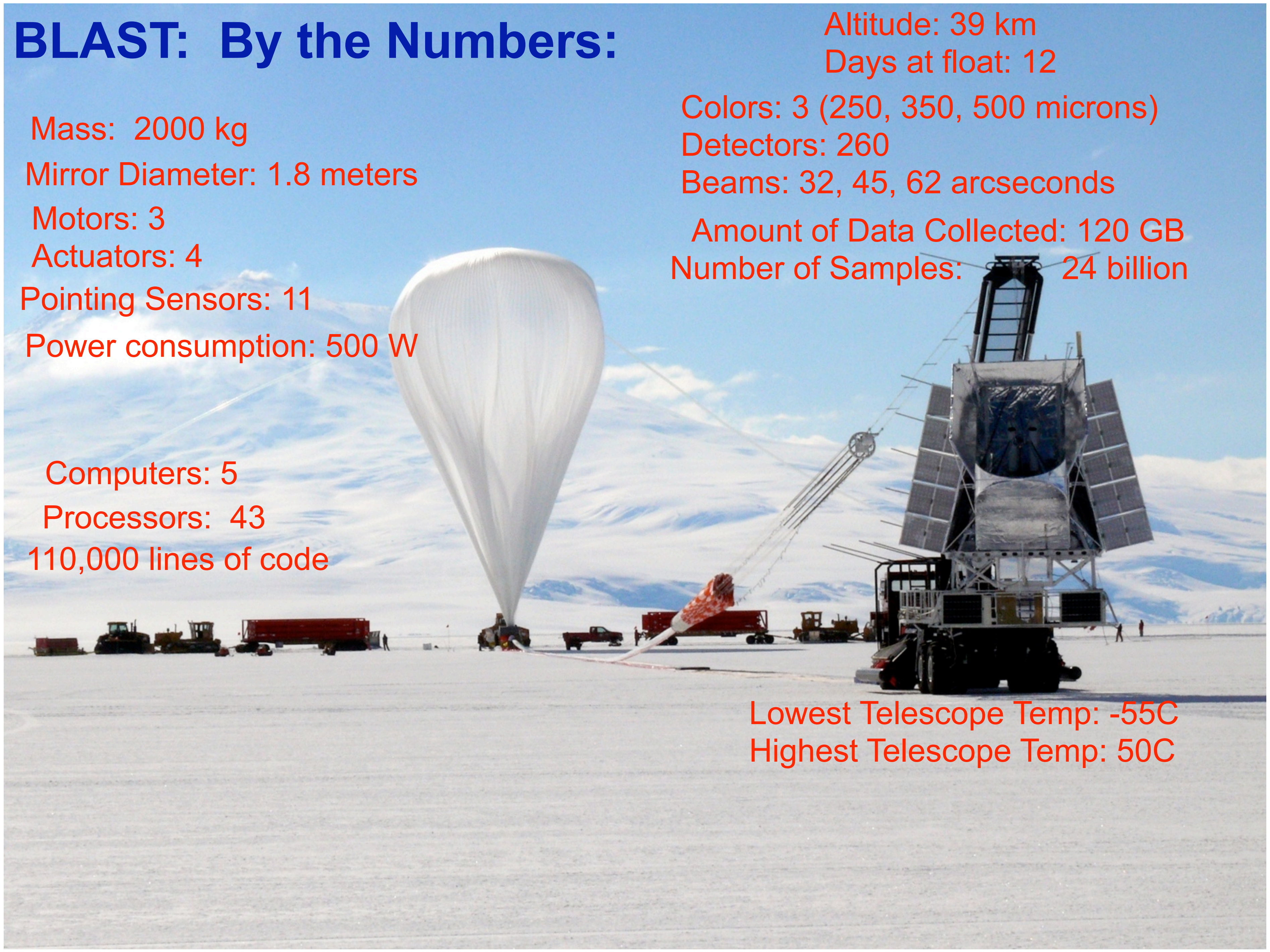
BLAST results: 16 papers and counting...

TALK OVERVIEWS: Mark Devlin (UPENN)



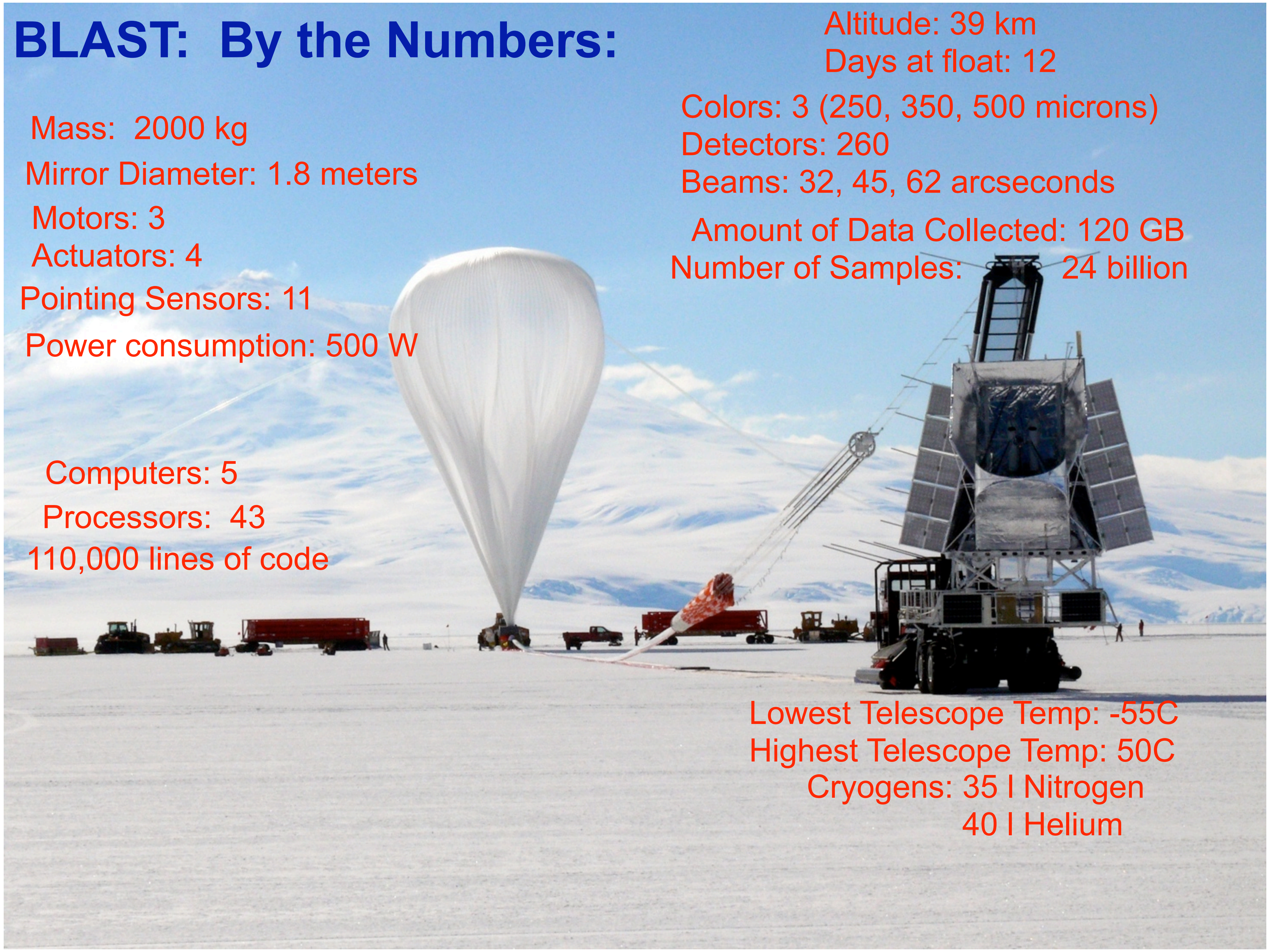
BLAST results: 16 papers and counting...

TALK OVERVIEWS: Mark Devlin (UPENN)



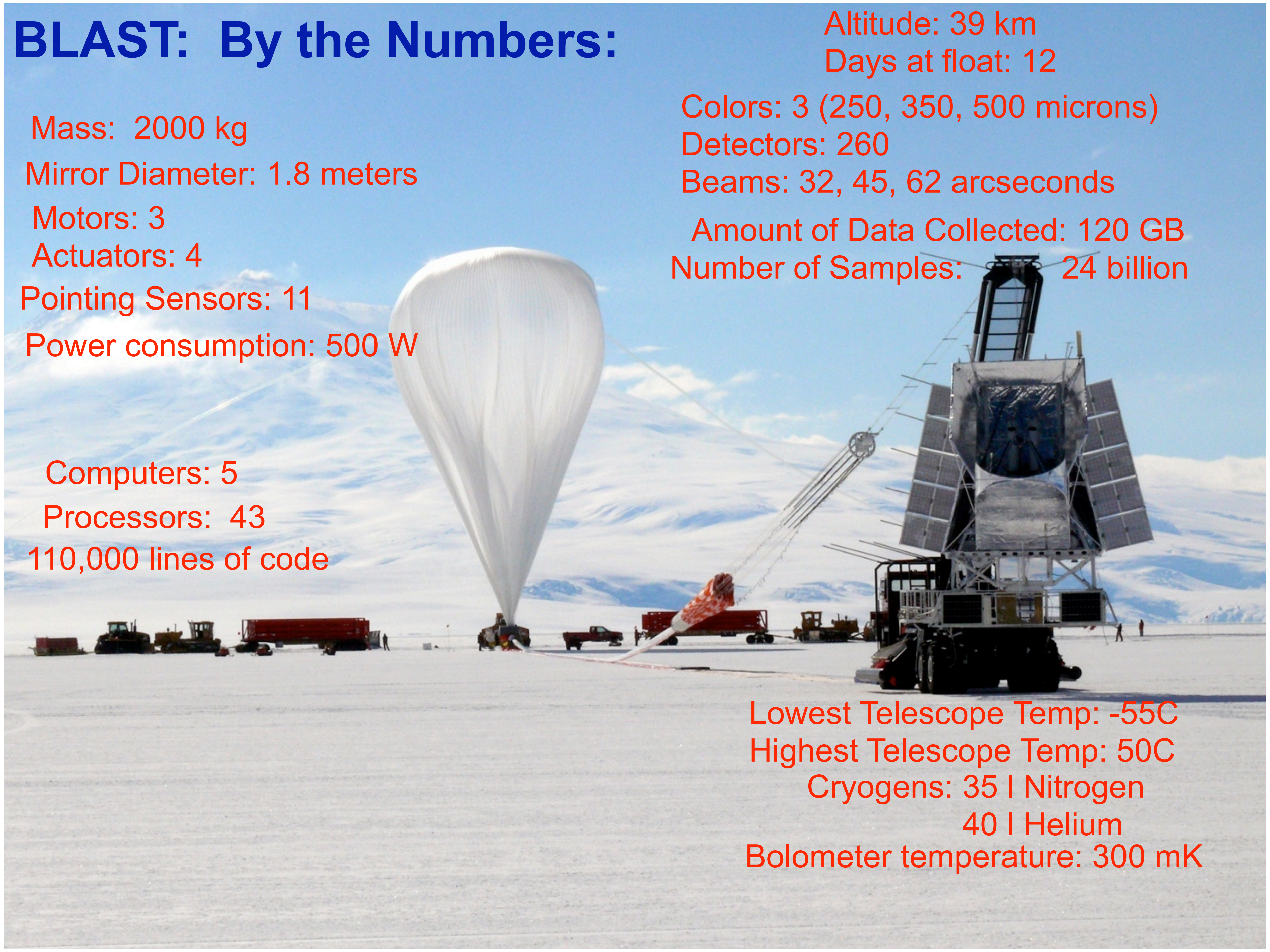
BLAST results: 16 papers and counting...

TALK OVERVIEWS: Mark Devlin (UPENN)



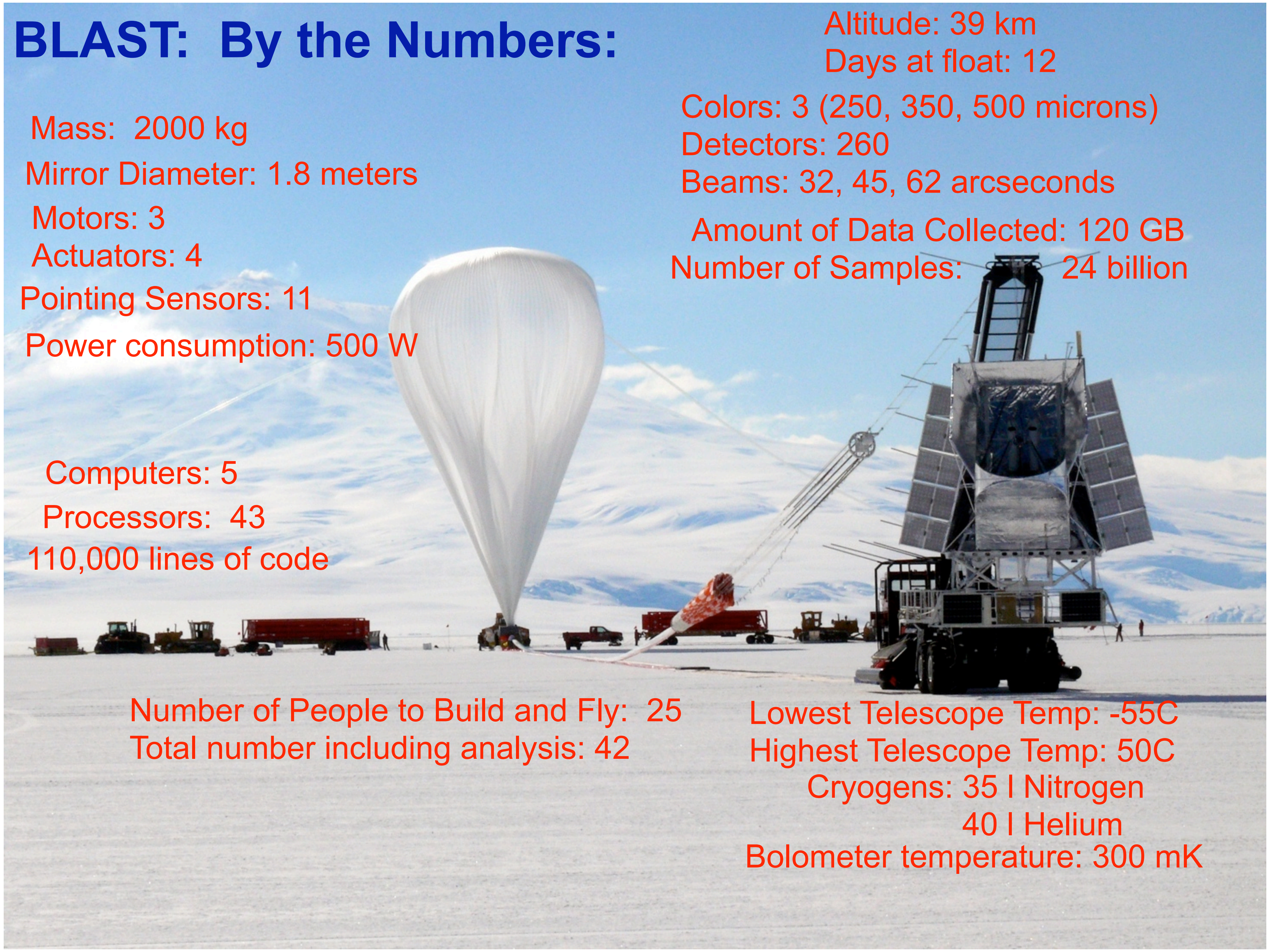
BLAST results: 16 papers and counting...

TALK OVERVIEWS: Mark Devlin (UPENN)



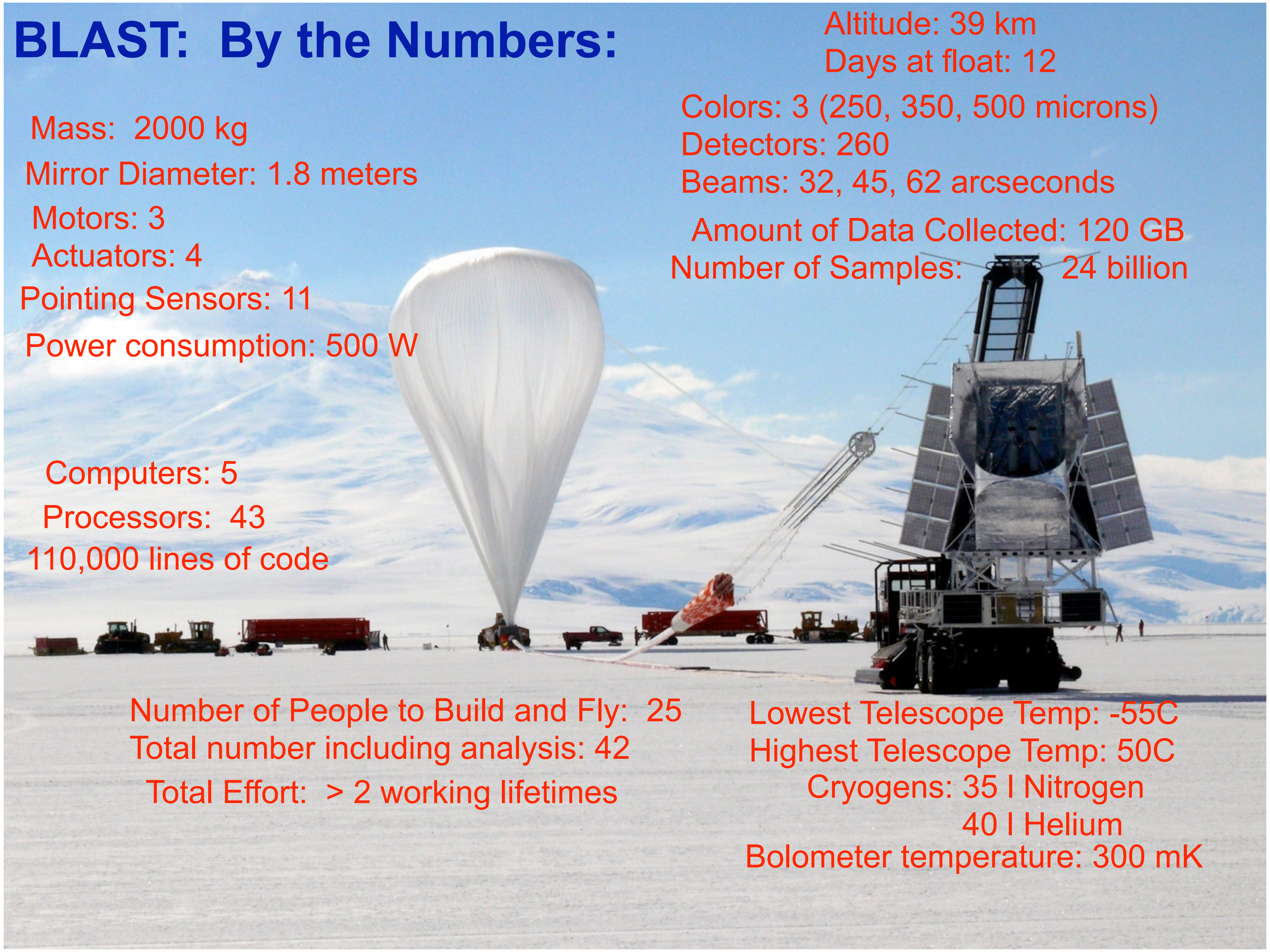
BLAST results: 16 papers and counting...

TALK OVERVIEWS: Mark Devlin (UPENN)



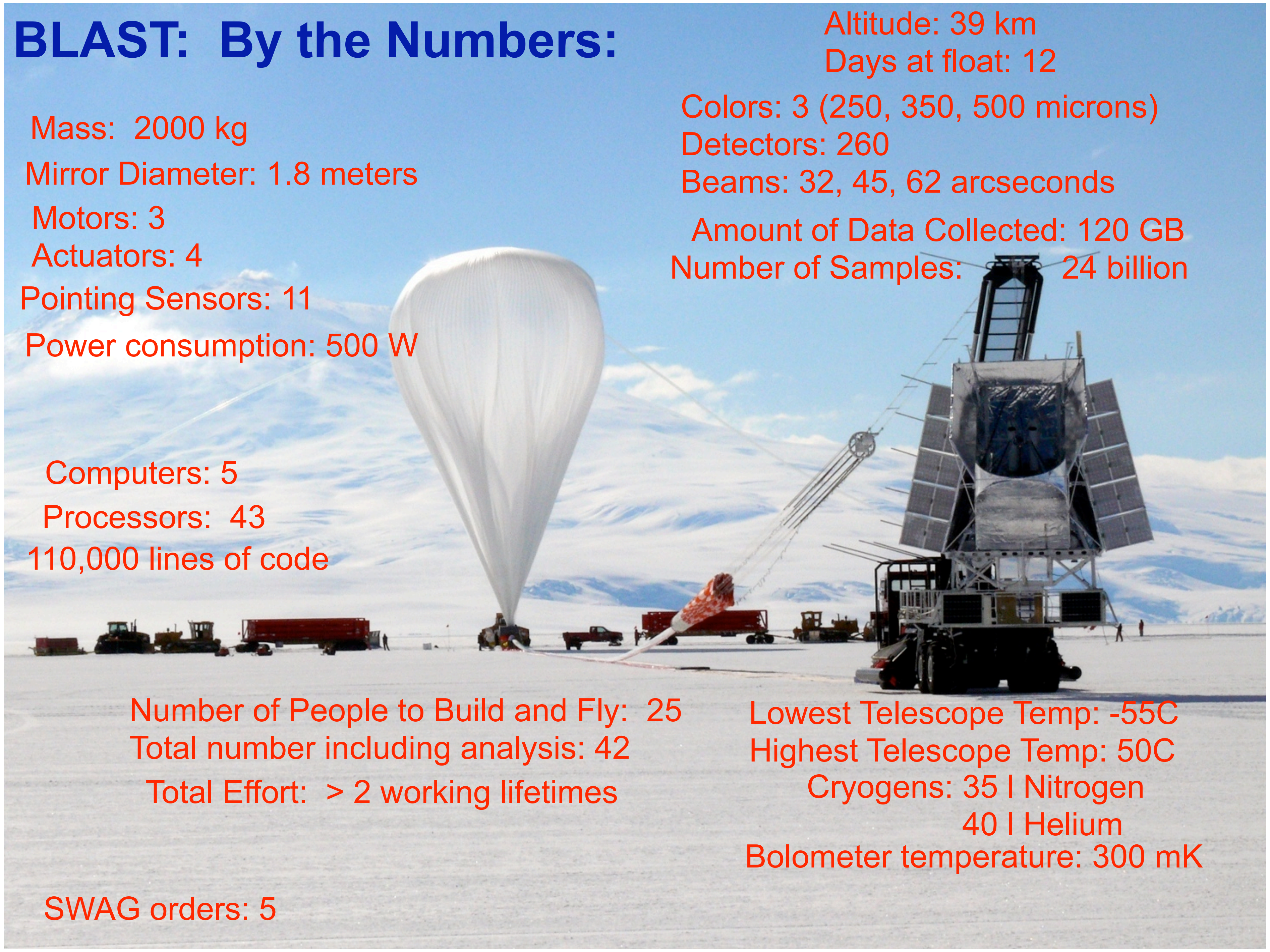
BLAST results: 16 papers and counting...

TALK OVERVIEWS: Mark Devlin (UPENN)



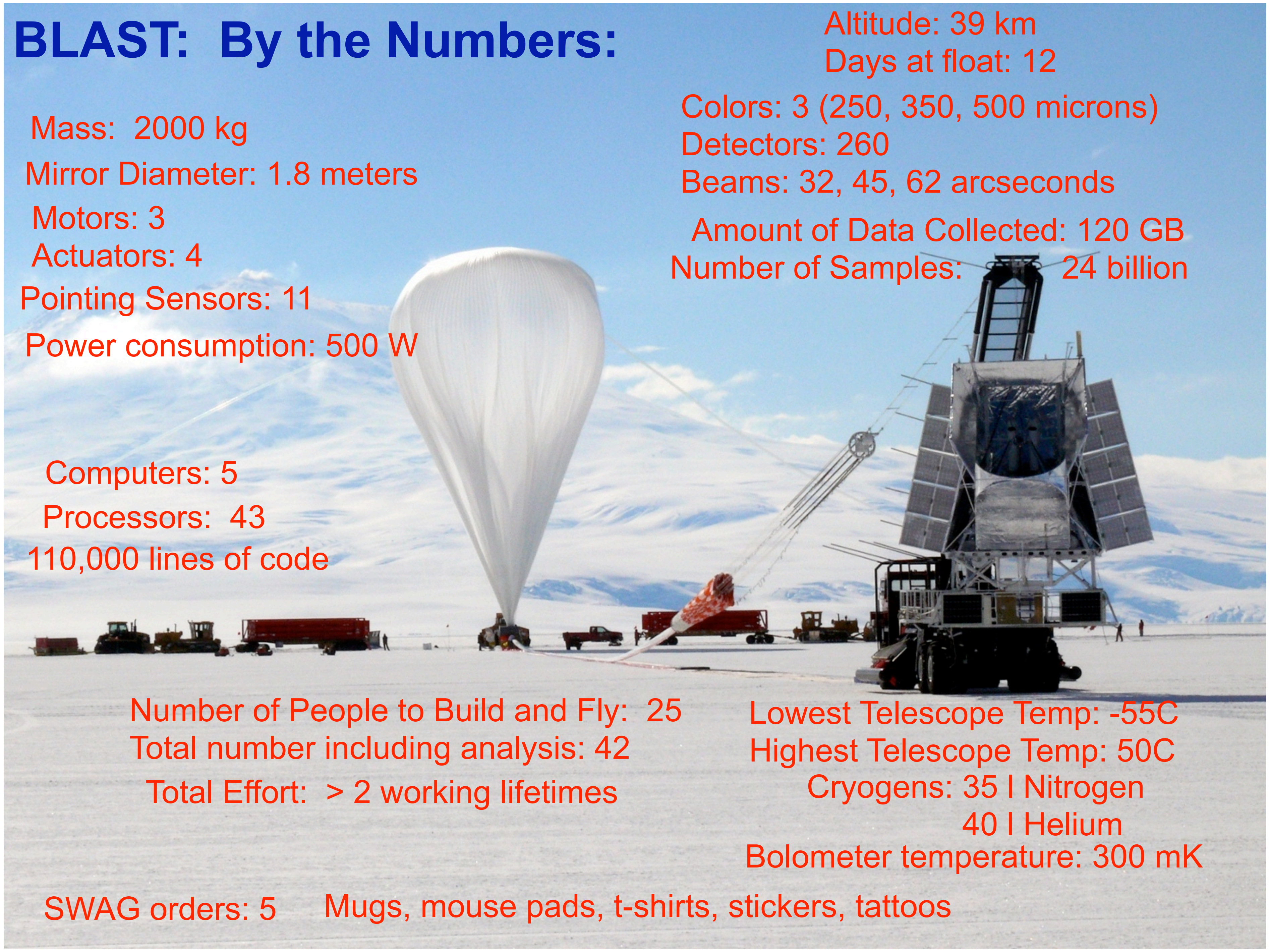
BLAST results: 16 papers and counting...

TALK OVERVIEWS: Mark Devlin (UPENN)



BLAST results: 16 papers and counting...

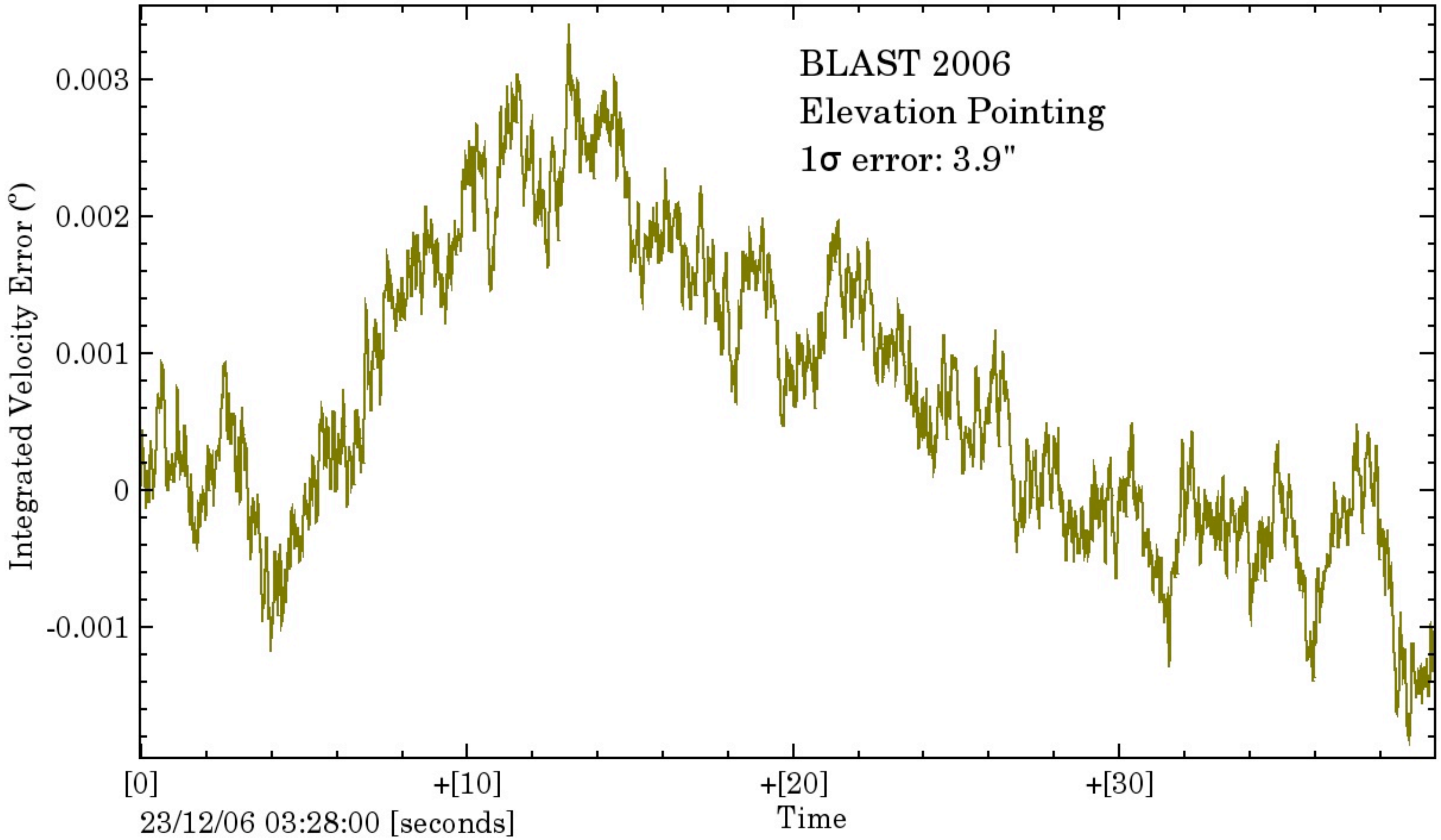
TALK OVERVIEWS: Mark Devlin (UPENN)



BLAST results: 16 papers and counting...

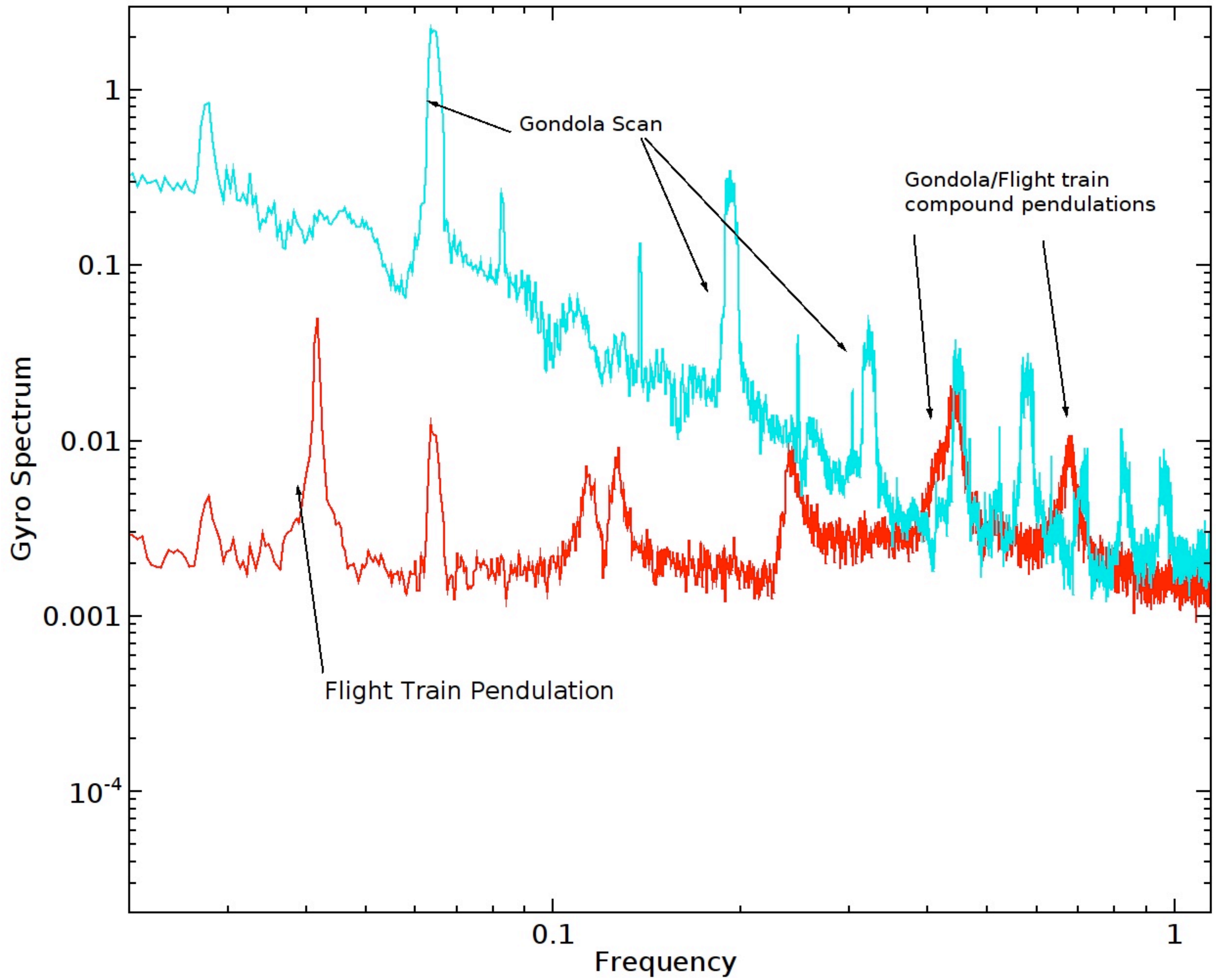
TALK OVERVIEWS: Mark Devlin (UPENN)

Pointing reconstruction: less than 5”



TALK OVERVIEWS: Mark Devlin (UPENN)

BLAST: power spectrum showing vibration modes



- For an UNPERTURBED payload, most of the power is in the pendulum fundamental (about a 20-sec period, about 14 Joules).
- The BLAST gondola scanned a patch of sky. You can see the modes driven by the scan motion.

ASIDE: The Environment at Float (CosmoCam)

CosmoCam (Scott Murphy, GSFC) is a small, pointed video camera that has taken in-flight video on recent HASP payloads. HASP = High Altitude Student Payload.

Eliot's Comments (what we should learn from BLAST)

- BLAST is a good example of a well-designed, cost-effective payload. Many redundant systems. Recommended by Danny Ball (CSBF) as a gondola to study if you're building your own.
- BLAST shows that you can get a pointing solution to a few arcseconds with roll-your-own star trackers ($25K?).
- BLAST carried cryogens, detectors at 300 mK.
- Temperature control (workshop comments made by Mark): the temperature environment is the most challenging aspect of a stratospheric payload. With many layers of MLI and other solutions (like heat pipes), it should be possible to reduce temperature gradients across your OTA to ~1 degree (?).
- Consider designs for torque-less telescopes (e.g., SUNRISE).

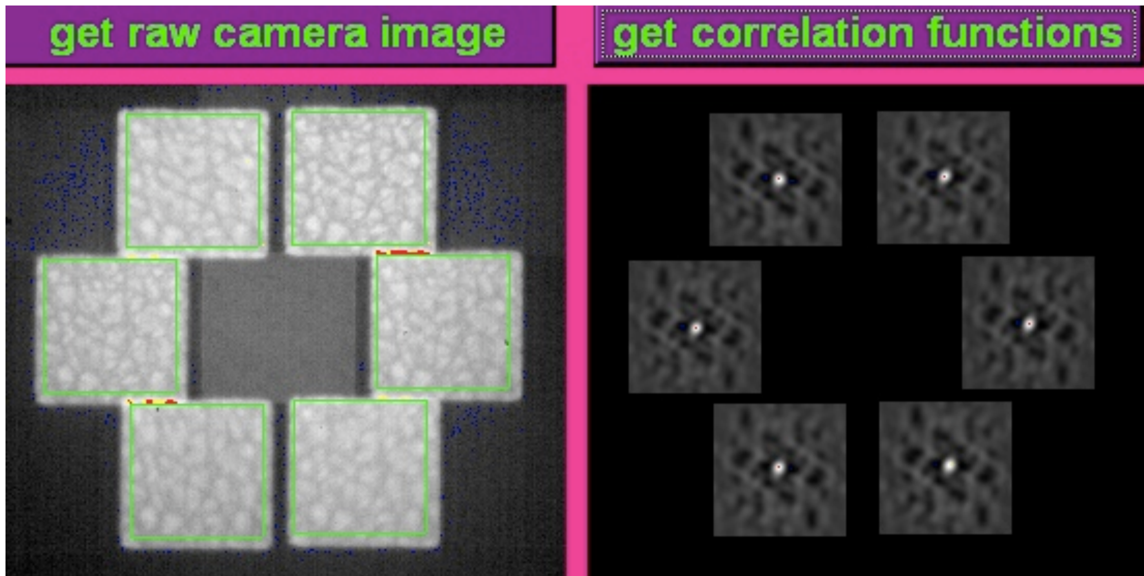
TALK OVERVIEWS: Alice Lecinski (NCAR)

TALK OVERVIEWS: Alice Lecinski (NCAR)

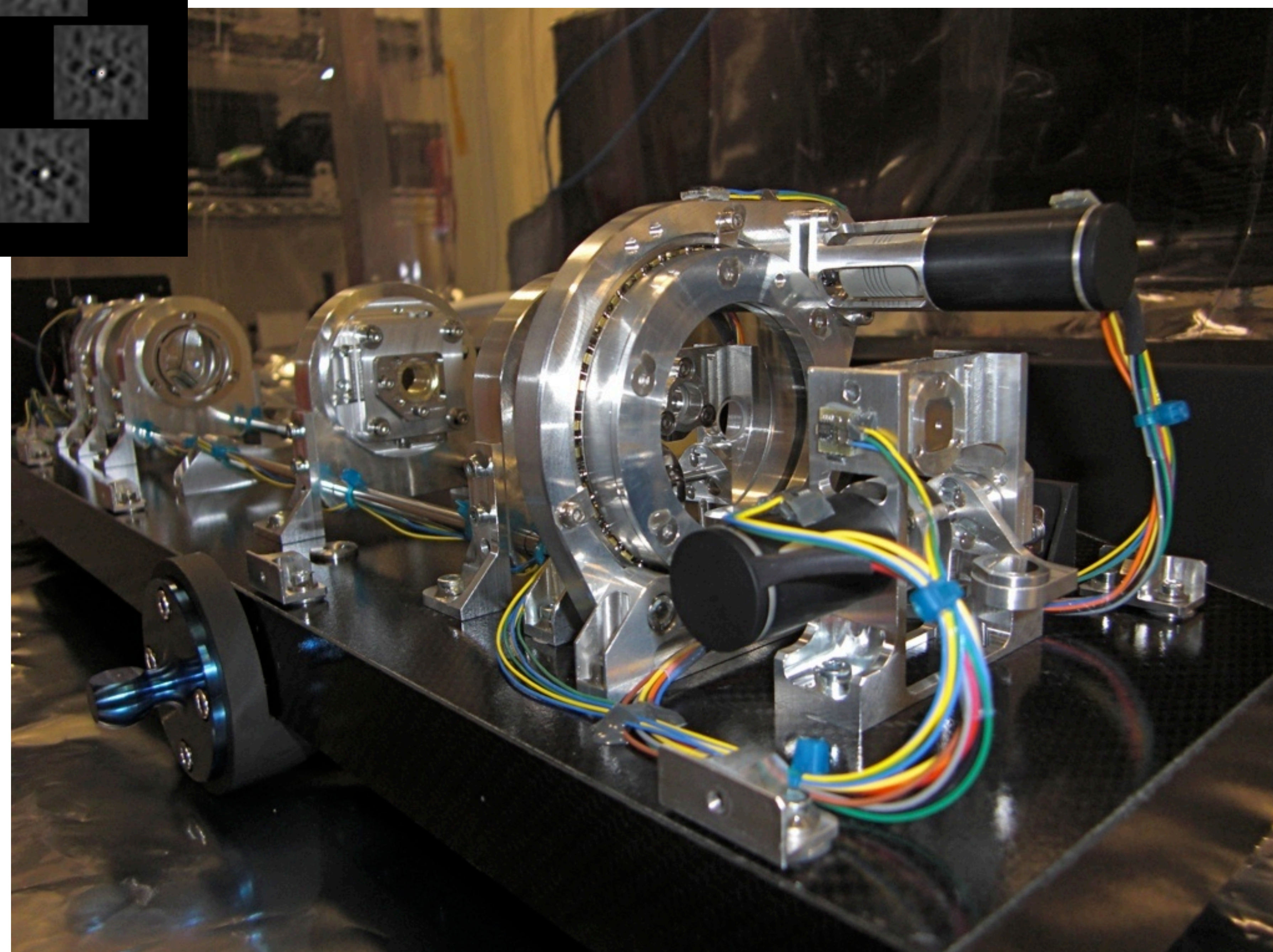
The instruments

- 1m UV/VIS Telescope
- Filtergraph (SUFI)
  - Phase-Diversity Imager
  - 5 wavelength band between 214 and 397 nm (width 1 nm)
- Magnetograph (IMAX)
  - Tunable Fabry-Perot Etalon (LiNb), used in double path
  - LCD-Modulators
  - Phase-Diversity channel
- Wavefront correction (CWS)
  - 6-element Wave-front sensor, Tip-tilt-mirror
  - Closed-loop bandwidth (0dB) 90 Hz

TALK OVERVIEWS: Alice Lecinski (NCAR)



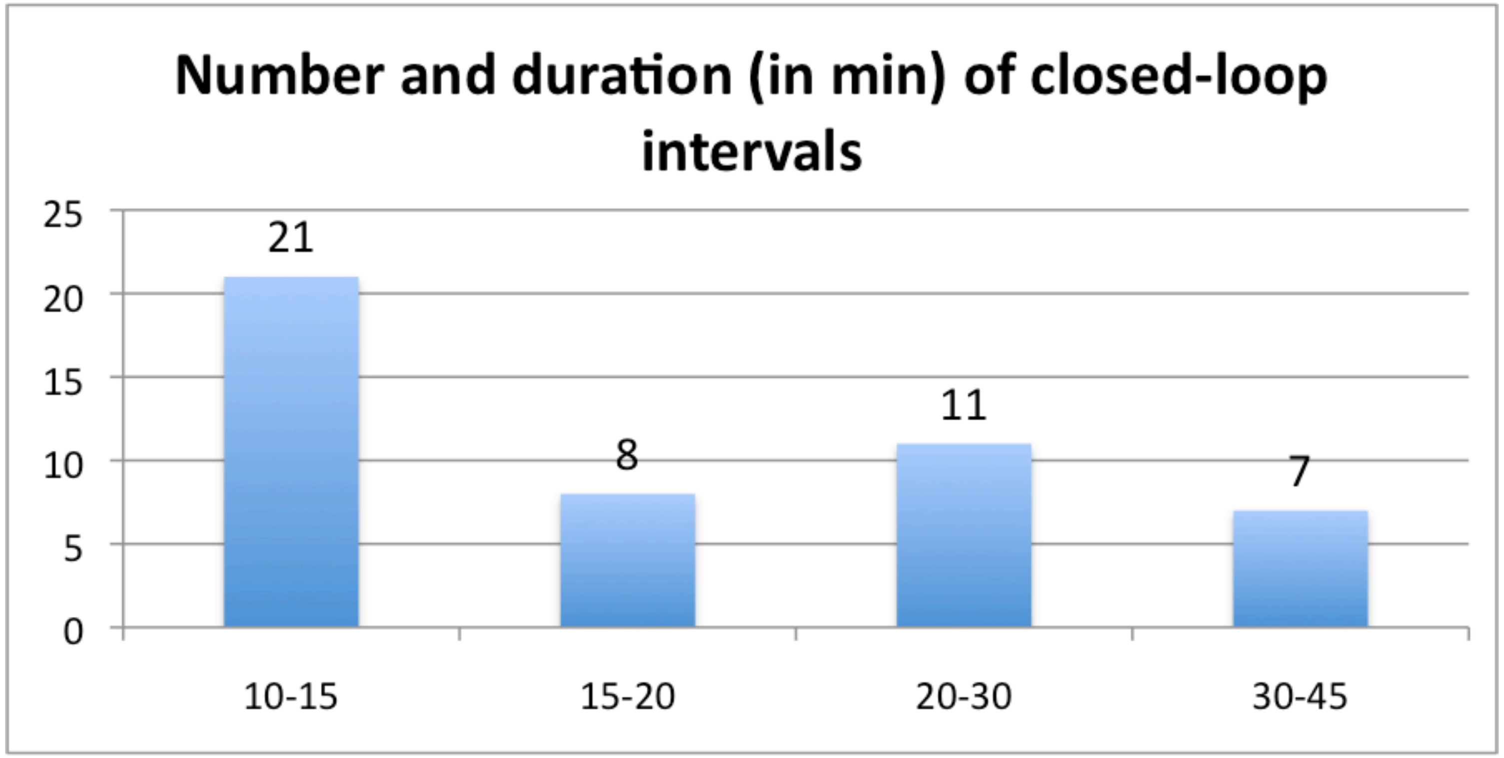
- 0.002 arcsec RMS measurement accuracy
- 90 Hz bandwidth (0 dB)



Slide courtesy W. Schmidt, KIS

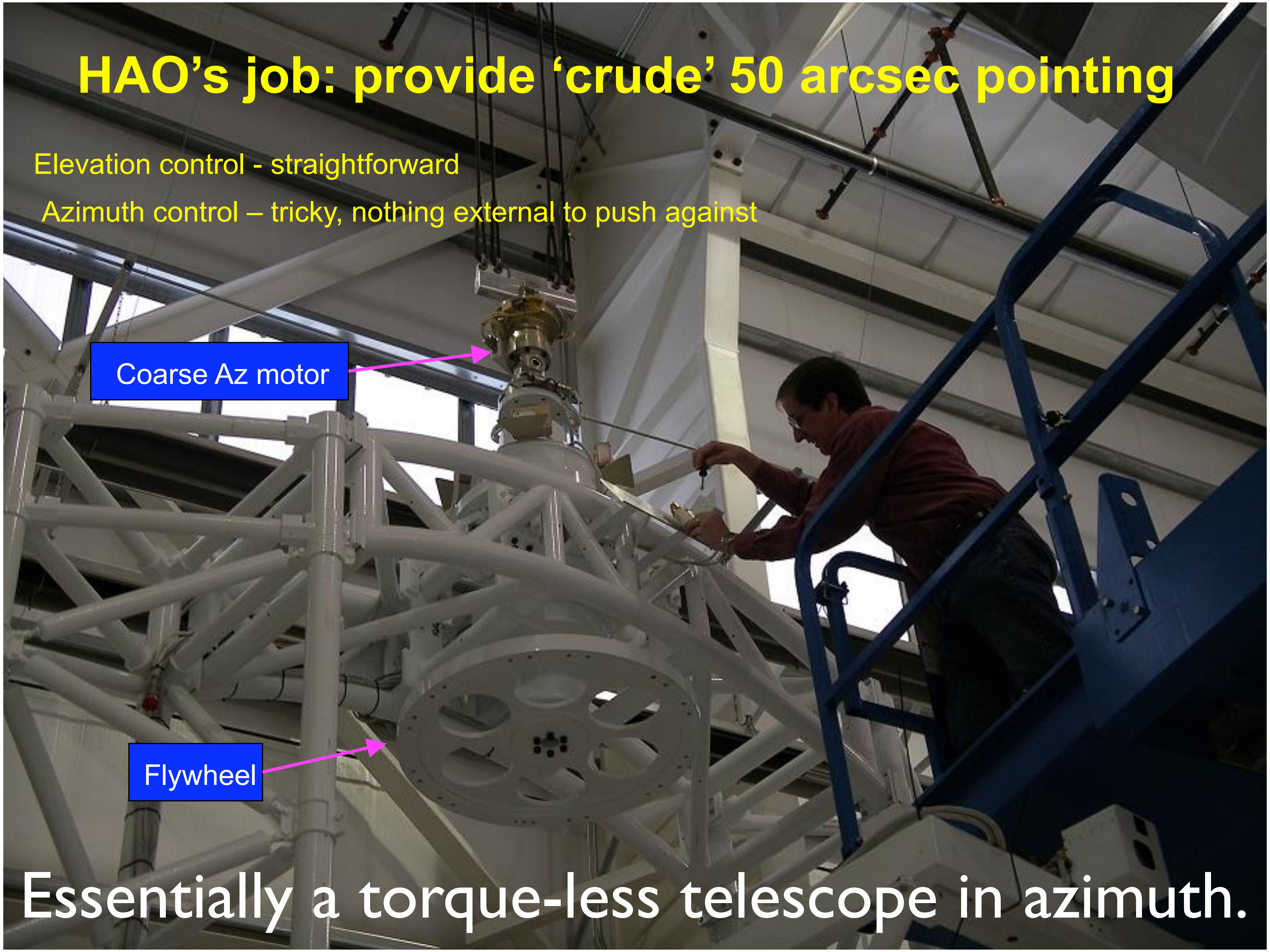
CWS: The Correlated Wavefront Sensor

TALK OVERVIEWS: Alice Lecinski (NCAR)



- Not continuous performance through the entire flight, but sequences with extraordinarily good pointing performance for 10 - 45 minutes at a stretch.
- Thirty-three hours of excellent pointing in total, producing the sharpest images of the Sun ever obtained.
- Reasons for loss of feedback loop may include vibration from the flywheel.

TALK OVERVIEWS: Alice Lecinski (NCAR)



Eliot's Comments (or why Alice's talk on SUNRISE is important)

- SUNRISE is the best demonstration to date of a pointed, stabilized balloon-borne telescope.
- The SUNRISE azimuthal flywheel/coarse pointing system should serve as (a) an example of a torque-less system and (b) a starting point. Can it be modified to make it even quieter?
- Correlated wavefront system: need to find out more. Did it only provide tip-tilt correction? Is that sufficient in the stratosphere?
- Questions that this group needs to investigate: "What is the atmospheric degradation that remains after tip-tilt correction?" and "Is a full-up AO system needed to correct for mirror distortions due to, say, transient thermal gradients?"

TALK OVERVIEWS: Steve Kendrick (Ball) and Charles Kirk (ITT) on Lightweight Mirrors

Note: we cannot archive or show slides from Charles Kirk's talk, but here are some points that he discussed.

- HST mirror: about 150 kg/m^2. ITT's lightest technology: about 10 kg/m^2.
- SiO_2 doped with TiO_2: near zero CTE near room temperature. You can adjust the CTE point by -5/+15 K.
- Borosilicate: relatively high CTE, but the CTE is near zero around -40 K. Borosilicate takes advantage of flat screen TV technology. ITT has the first ion-figured test bed (check to see if that refers to borosilicate mirrors).
- FRIT process: a toothpaste-like substance that joins faceplates to cores with well-matched CTEs.
- AMSD technology: core of segmented hex segments, pretty cheap. 18 nm (rms) segmented surface.

TALK OVERVIEWS: Steve Kendrick (Ball) and Charles Kirk (ITT) on Lightweight Mirrors

Stephen Kendrick on Mirrors

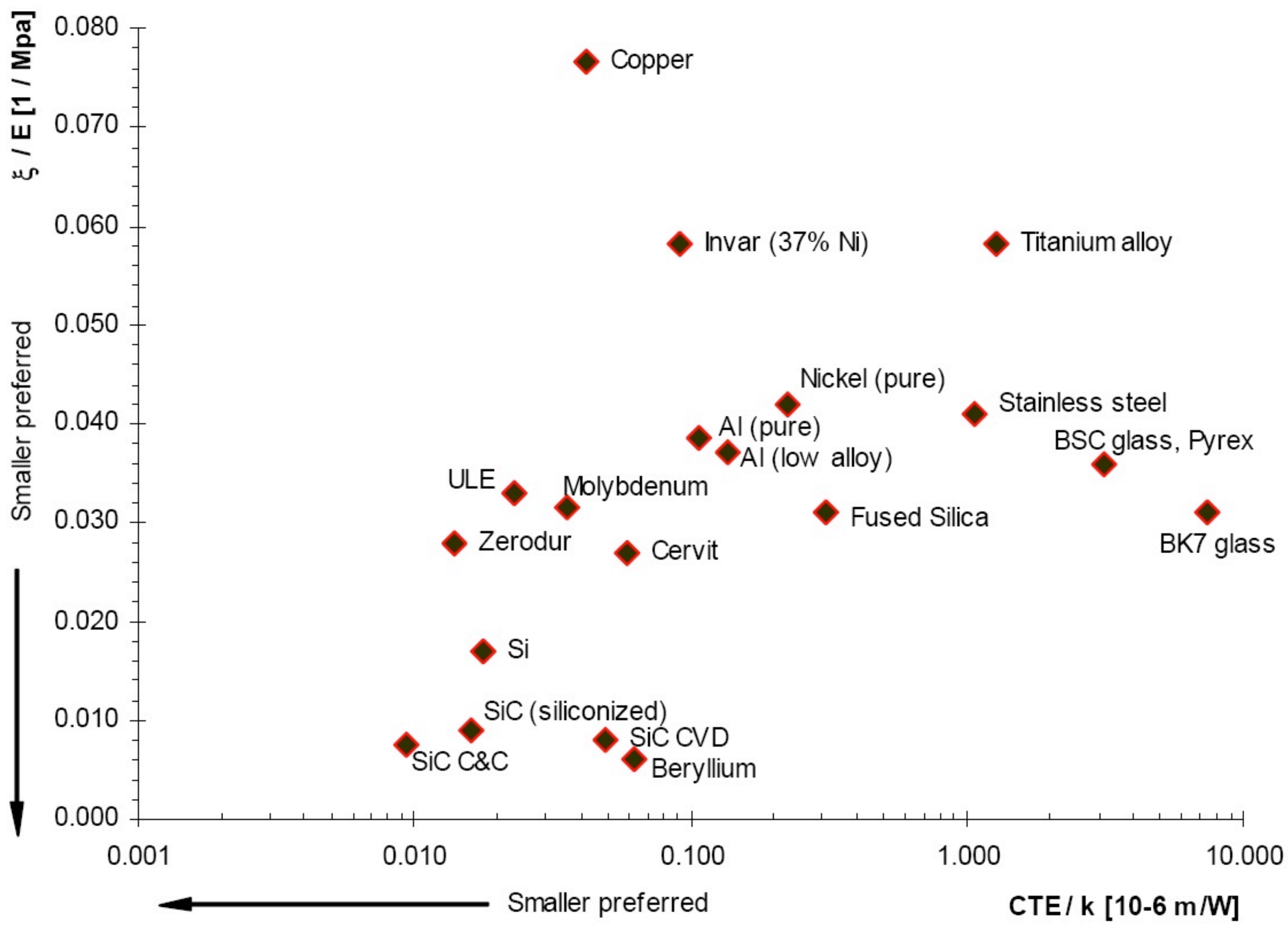
- Material properties – merit factors (density/stiffness, CTE/thermal conductivity, polishability, manufacturing and shaping processes, ability to impose integral mounting features, scatter, etc.)

- Mirror material candidates
  - Mature with high TRL
    - "Glass" (borosilicate, fused silica, Zerodur®, CLEARCERAM®–Z, ULE®)
    - SiC
    - Aluminum
  - Emerging technologies
    - Membrane
    - Composite
    - Foam (various materials)
    - Glass corrugated mirrors

TALK OVERVIEWS: Steve Kendrick (Ball) and Charles Kirk (ITT) on Lightweight Mirrors

Material selection for the mirror mounts and metering structure is critical to provide mechanical and thermal stability

- Prefer materials or constructions that offer:
  - Low mass
  - Thermal stability
  - Alignment and pointing stability
- Athermalized designs possible when structural and optical materials match:
  - Silicon Carbide with Si or SiC mirrors
  - Aluminum
  - Composites
  - Beryllium



www.eso.org/projects/owl/Blue_Book/6_Telescope_optics.pdf

CTE – coefficient of thermal expansion; k – thermal conductivity

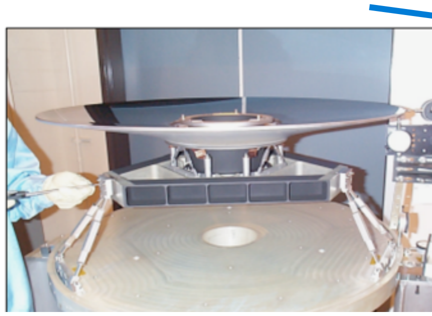
ξ- density; E – Young's Modulus

TALK OVERVIEWS: Steve Kendrick (Ball) and Charles Kirk (ITT) on Lightweight Mirrors

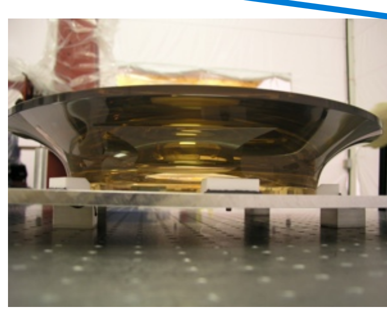
Stephen Kendrick on Mirrors

- **Mirror mass** factors include:
  - Material density and stiffness; mirror blank geometry also strongly affects stiffness
  - Manufacturing limitations on dimensions (i.e., facesheet & web thickness) as well as joining techniques
  - Testing implications (gravity deflection effects)
  - Lower mass means higher costs for the same aperture – so don't overspecify
- **Mirror construction approach (architecture solution) is usually a stronger driver of achievable lightweighting than choice of substrate material**
  - ❖ Rigid vs. semi-rigid vs flexible (meniscus or membrane) mirrors
  - ❖ Solid, open back, closed back, partially closed back, foam core, meniscus

Decreasing areal density generally means increasing costs



Spitzer Solid single arch (Be)



HiRISE Solid dual arch (Zerodur®)

QuickBird open back (Zerodur®)

Ball IR&D Partially closed back (SiC)

Kepler closed back (ULE®)

Ball has designed and implemented a range of lightweighting approaches matched to the particular system requirements

TALK OVERVIEWS: Steve Kendrick (Ball) and Charles Kirk (ITT) on Lightweight Mirrors

“Glass” and SiC are mature telescope material technologies

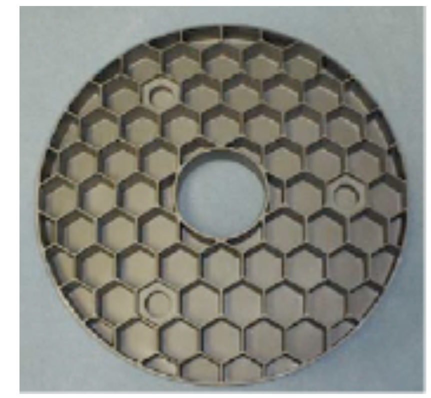

1.0 m f/2 PM with 70% lightweighting

Gas-fusion **borosilicate** by Hextek *up to 1.5m*;

15kg/m^2 demonstrated

RB **SiC** by SSG (open back example)

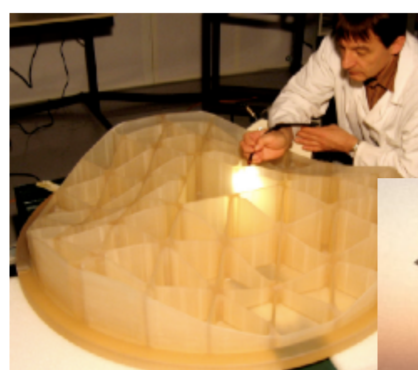
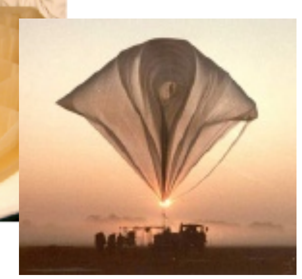
[1.8-m capability]



1.5-m CVC **SiC** plate by Trex Enterprises

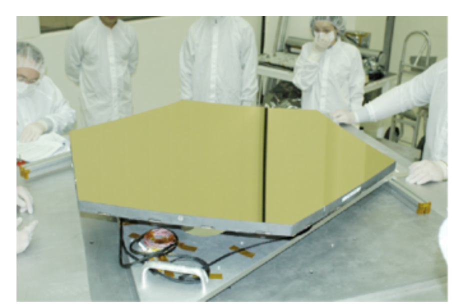
Kepler 1.45-m **ULE®** closed back; ~ 50 kg/m^2 areal density

[Corning ULE® blanks can be fabricated up to 8m]

1-m lightweighted open-back **Zerodur®** PM (<40kg) fabricated by REOSC for SUNRISE balloon-borne optical solar telescope; Gregorian

[Schott Zerodur® blanks presently available up to 4m; Ohara CLEARCERAM®-Z up to ~1.6m]

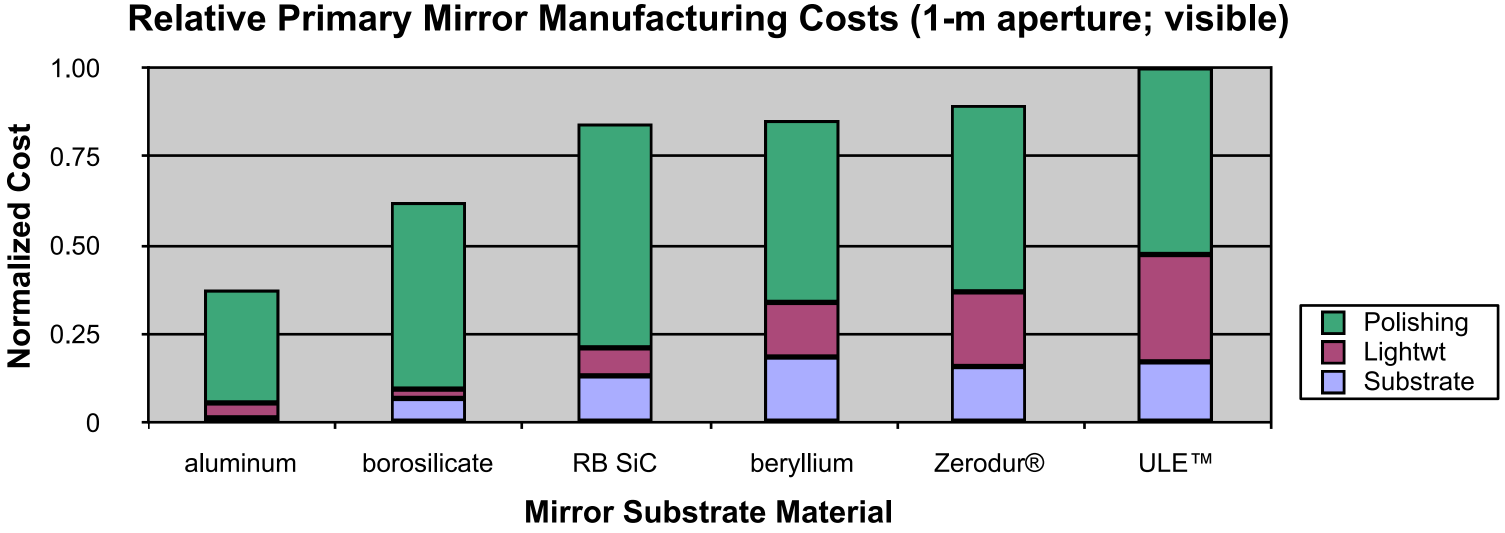


1-m RB **SiC** open back mirror by Xinetics

[2-m blank capability]

TALK OVERVIEWS: Steve Kendrick (Ball) and Charles Kirk (ITT) on Lightweight Mirrors

Polishing is often the most significant mirror fabrication cost



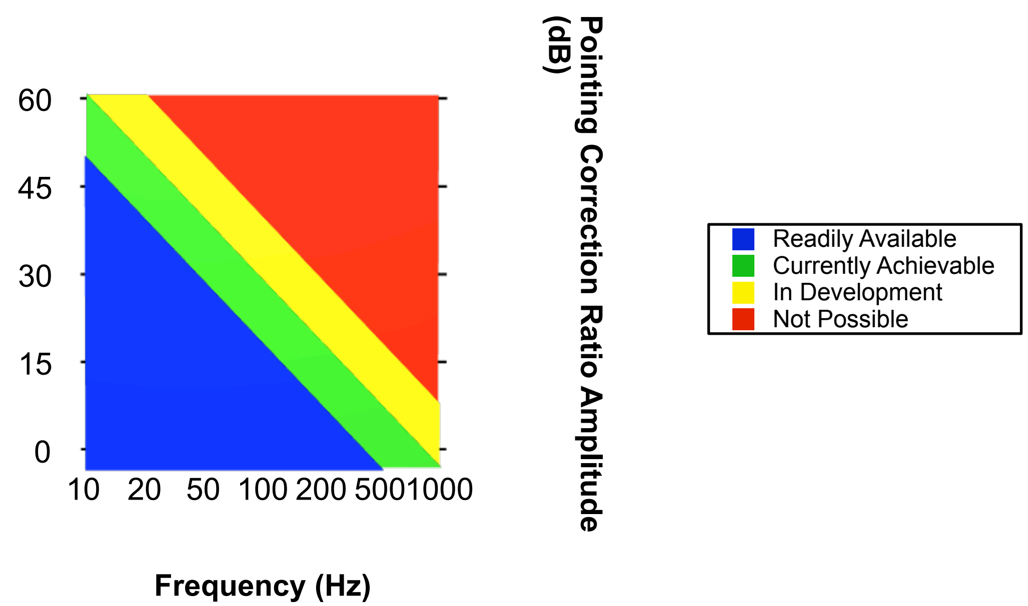
- **For the particular application look at:**
  - **substrate costs**
  - **degree of lightweighting required and subsequent lightweighting cost**
  - **polishing (WFE, smoothness) requirements**
    - **WFE drives polishing time**
    - **Some materials will require cladding to achieve microroughness**

Fabrication Trade Factors

- ULE closed back construction costs more than open-back Zerodur, but offers higher degree of lightweighting
- ULE can be slumped to shape, whereas Zerodur must be machined
- Beryllium has higher stiffness, but substrate material more expensive and would require cladding for low scatter
- SiC can have lightweight features and mounting points cast, but takes slightly longer to polish; clad to reduce porosity
- Borosilicate offers optical performance with lower material and lightweighting costs if reduced thermal stability acceptable
- Aluminum material is lowest cost and can be diamond turned, but surface scatter and smearing can yield lower quality surface; Aluminum also highest mass

TALK OVERVIEWS: Larry Germann (Left Hand Design) on Fine Pointing

Pointing System Cost is Related to the Correction Ratio Spectrum

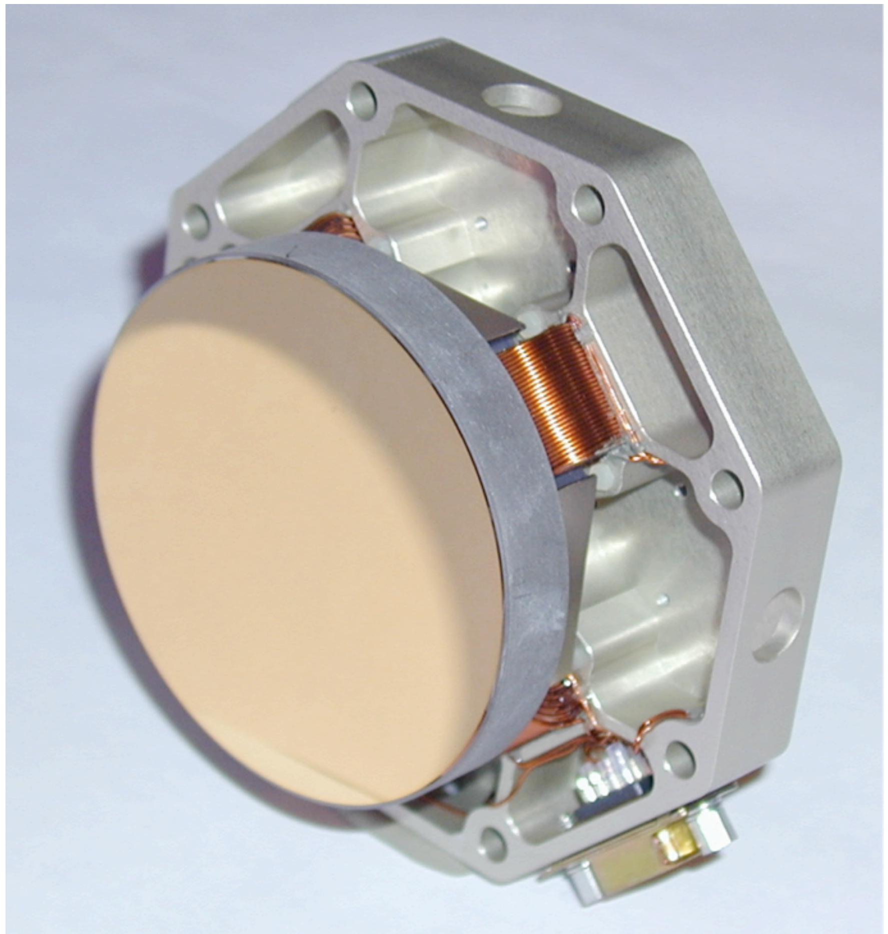


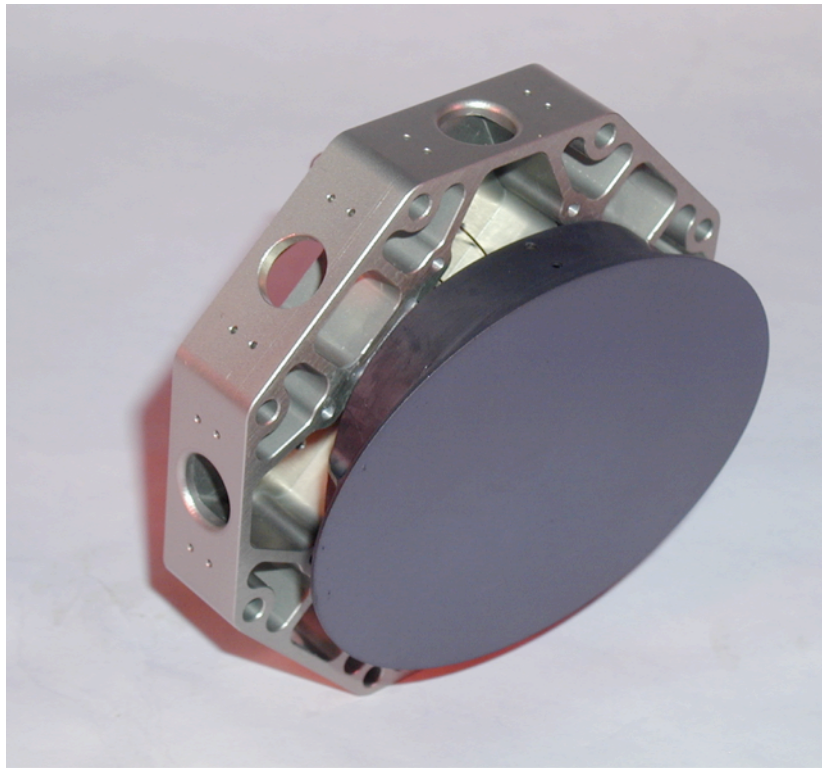
Correction Ratio Amplitude (f) = Base Motion (f) / Residual LOS Jitter Requirement (f)

TALK OVERVIEWS: Larry Germann (Left Hand Design) on Fine Pointing

CE50-35-CV-RC2 FSM Is Simple, Robust and Mature

- The CE75-35-BK SN140
- BK-7 mirror
- 76.2mm diameter aperture
- +-35mRad travel
- 120 Rad/Sec2/rootW efficiency
- 2,300 Rad/Sec2 acceleration
- wave PV @633nm surface figure error
- 450 Hz -3dB closed-loop servo control bandwidth





FO50-35-SC-RT7 Achieves Record Servo Control Bandwidth

- FO50-35-SC-RT7 SN133
- Silicon carbide mirror
- 80.7 x 60mm polished aperture
- +-5mrad travel with the reduced-travel option
- 5,000 Hz -3dB closed-loop servo control bandwidth when base-referenced
- 6,000 Hz -3dB closed-loop servo control bandwidth when optically referenced
- 3,300 Rad/Sec2 acceleration

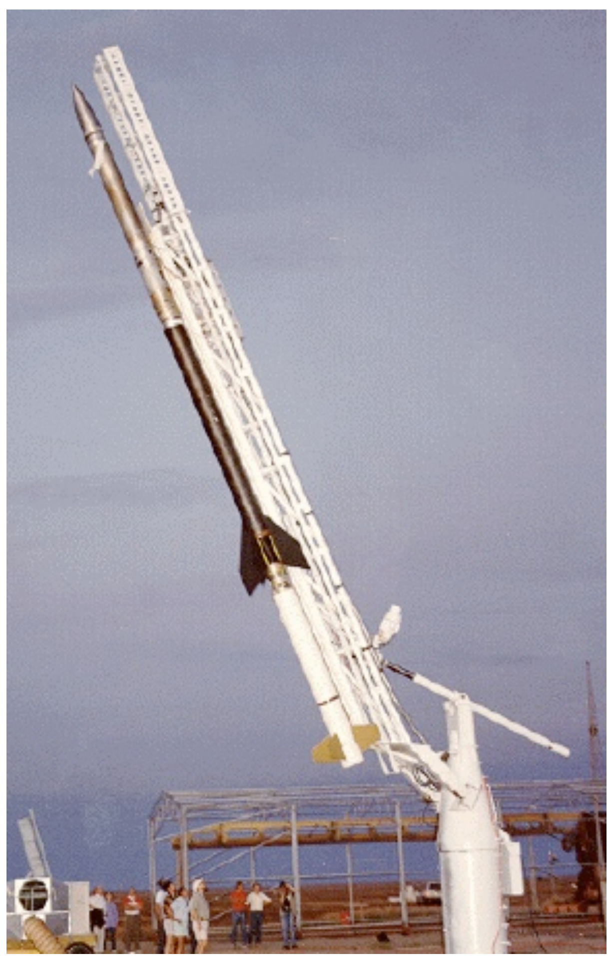
Eliot's Comments
(or why Larry's talk on FSMs is important)

- The natural perturbations on a balloon-borne telescope are EASY to correct with a Fine Steering Mirror. Even a low-cost model should do the job - frequencies are low. Self-induced perturbations may be much higher in frequency.
- An optical reference is better than a base reference. Best strategy is to have a fine motion sensor as close to the science focal plane as possible.
- Correction is only half the story. If you want to drive your FSM at 10 Hz, you probably need an optical reference signal that is sampled at 100 Hz. CONSIDER ANALOG SENSORS, like a quad cell of photodiodes.

TALK OVERVIEWS: Jeff Percival (UWisc) on the ST5000 Star Tracker

Star Tracker 5000

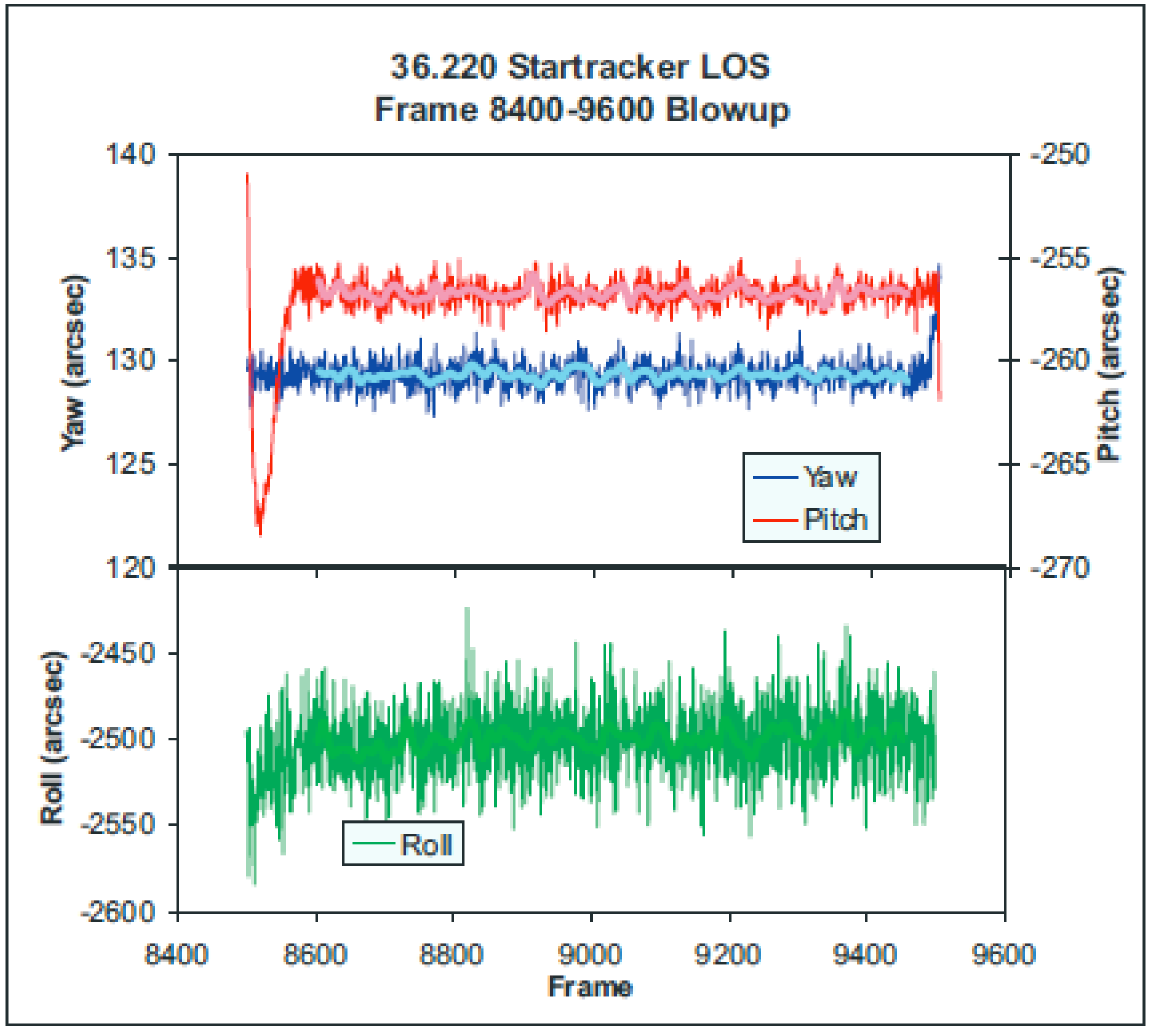
A low-cost star tracker and attitude determination system



TALK OVERVIEWS: Jeff Percival (UWisc) on the ST5000 Star Tracker

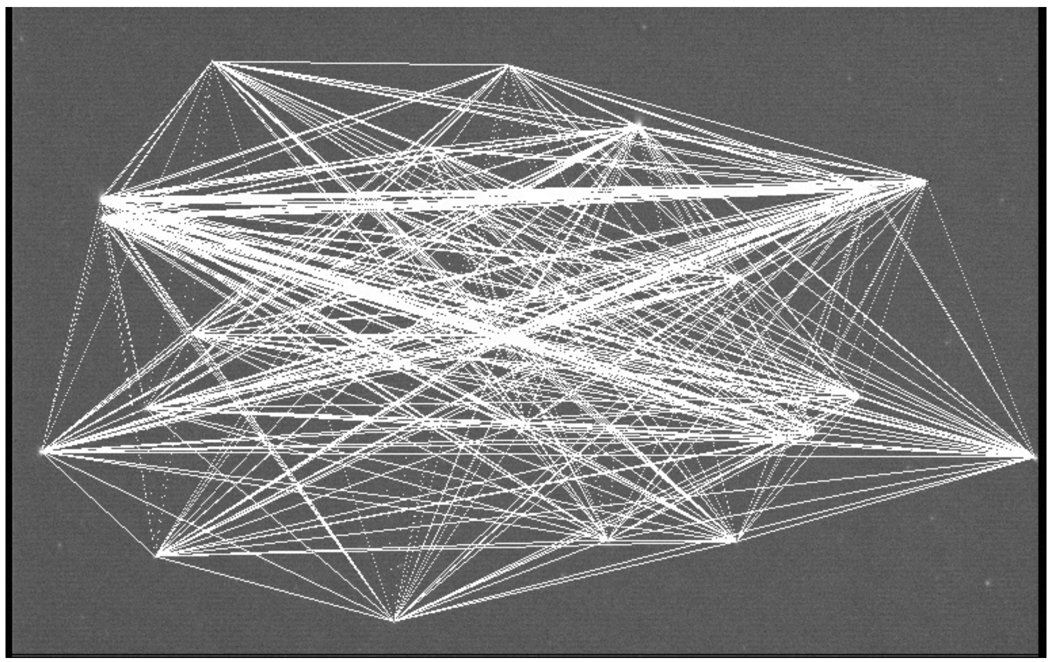
Tracking Performance

- ST5000 tracks at 10 Hz
- 3-axis tracking, Yaw, Pitch & Roll
- In-flight performance on sounding rocket flight 36.220:
- RMS tracking error in yaw and pitch: 0.54 arcseconds.
- RMS tracking error in roll: 17 arcseconds
- RMS errors depend on stars in the FOV: one flight had tracking errors > 3” for sparse, faint fields



TALK OVERVIEWS: Jeff Percival (UWisc) on the ST5000 Star Tracker

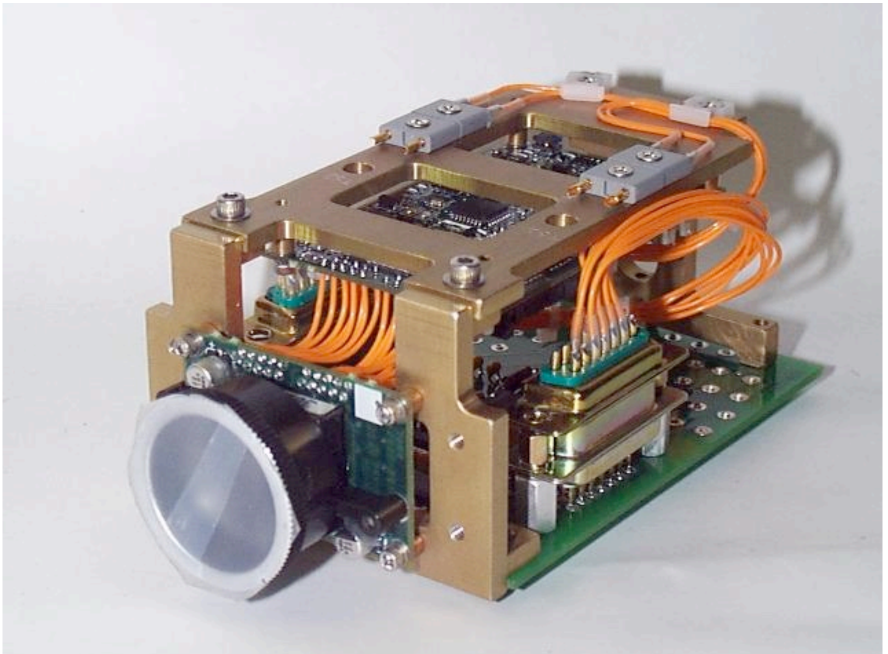
Attitude Determination



Our "lost in space" mode uses an on-board star catalog of 38400 stars with V magnitudes between 4 and 8.

- ST5000 can recognize where it's pointing by analyzing star patterns
- Some other trackers can do this, but may take long (minutes) or provide low precision (many arcminutes)
- ST5000 can solve its attitude in a few seconds, and is accurate to a few seconds of arc

TALK OVERVIEWS: Jeff Percival (UWisc) on the ST5000 Star Tracker



Sensor electronics shown above; control electronics are in a separate box that can be up to 4 meters away.

- We use commercial "off the shelf" parts where possible
- Our Electronics Technician has decades of experience building electronics for space flight
- Assemblies must withstand very-high vibration environments (20 g)
- High accelerations: the rocket can be supersonic in 1-2 seconds

ST5000 Status Summary

- Licensed to Northrop Grumman (non-exclusive)
- Working on a "Mark III" upgrade
  - Lower mass
  - Lower power
  - 35% reduction in obscuration
  - Faster, newer CPU (10x CPU speed, 32x more storage)
  - Redesigned sensor board and electronics
- Our cost is about $100,000 per unit for a "sub-orbital" level of design; commercial trackers suitable for orbital or interplanetary missions start at over $1,000,000. Our "Mark III" design will address some of these design differences.

Eliot's Comments (or why Jeff's talk on the ST5000 is important)

- Disclaimer: Jeff is a co-I with me on a NASA/APRA project to flight-qualify the ST5000 on a balloon.
- Current design should provide better than 3" pointing information AT NIGHT. Needs to be modified for daytime use.
- Current design is being superseded by the Mark III. Faster CPU, bigger CCD, smaller and lower power are the most likely changes.
- By itself, not sufficient to generate a 0.01" optical reference.
- By itself, not sufficient to generate a 1000 Hz optical reference.
- I suggest that an exoplanet telescope carries a quad cell bolted next to the science detector.

OTHER INTERESTING TALKS (ONLINE)

- Orthogonal Transfer CCDs (Barry Burke, MIT/LL). For visible imaging systems, these might bridge the gap between pointing systems that can achieve 1”-2” and the target of 0.05”, with no moving parts.
- Balloon-borne interferometers (Stephen Rinehart, GSFC). Question: is there enough signal to use with exoplanets?
- Small balloon systems (Tim Lachenmeier (NSC); Mike Smith (Aerostar); Dwayne Orr (CSBF)). The road to an exoplanet observing telescope will invariably follow demonstrations that will likely consist of small, focused payloads.

www.boulder.swri.edu/LCANS09/Talks

CONCLUSIONS

- Exoplanet observations may well be the driver that leads to an "HST in the stratosphere." That's good, because the requirements for observing exoplanets are stringent.
- I suggest we proceed in small, easily demonstrated steps. Example: measure seeing as a function of altitude to quantify whether tip-tilt corrections alone are good enough in the stratosphere. Another example: demonstrate temperature control of the OTA that is sufficient to maintain good enough image quality to provide HST-like performance. 3rd example: test quiet flywheel designs to provide torque-less pointing. 4th example: demonstrate a 2-stage optical reference system (e.g., a COTS star tracker/fast quad cell).
- NASA needs to hear the demand (paraphrasing an email from Jim Green, PSD). I suggest that we form a consortium to design and build generic stratospheric telescope "facilities" to which PIs could attach detectors. Possible members might include SwRI, JPL, NCAR, UWisc, UPenn, APL, NASA/Ames. One way to pool resources (IR&D funds), but even more significantly, it demonstrates the perceived value of developing this capability.