BLAST Science

Antarctica December 2006

Cosmology: The study of the Universe as a system

Where is all the stuff?

How is it organized?

How did it get that way?

But FIRST…..

Study the Evolution of Structure

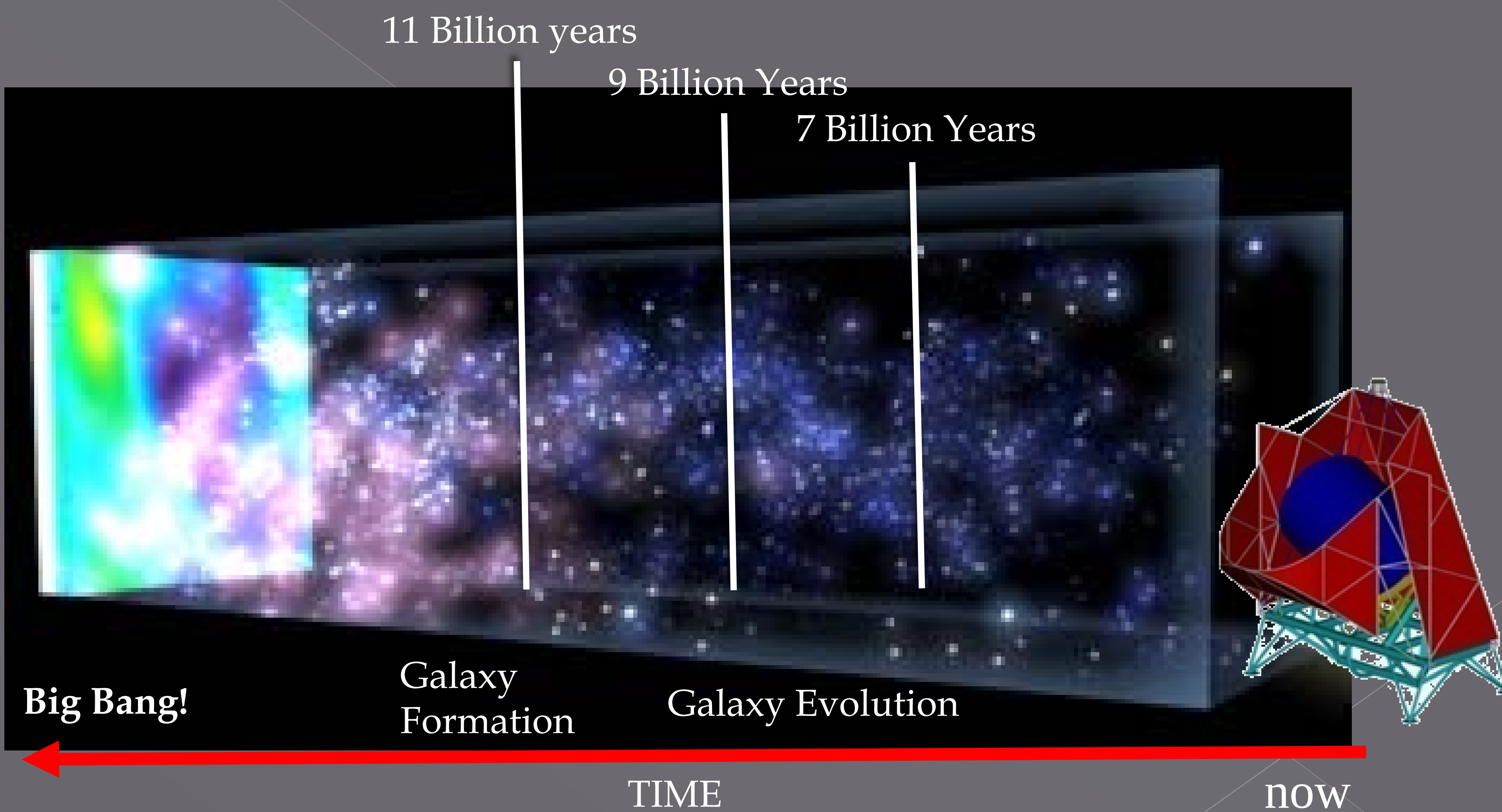
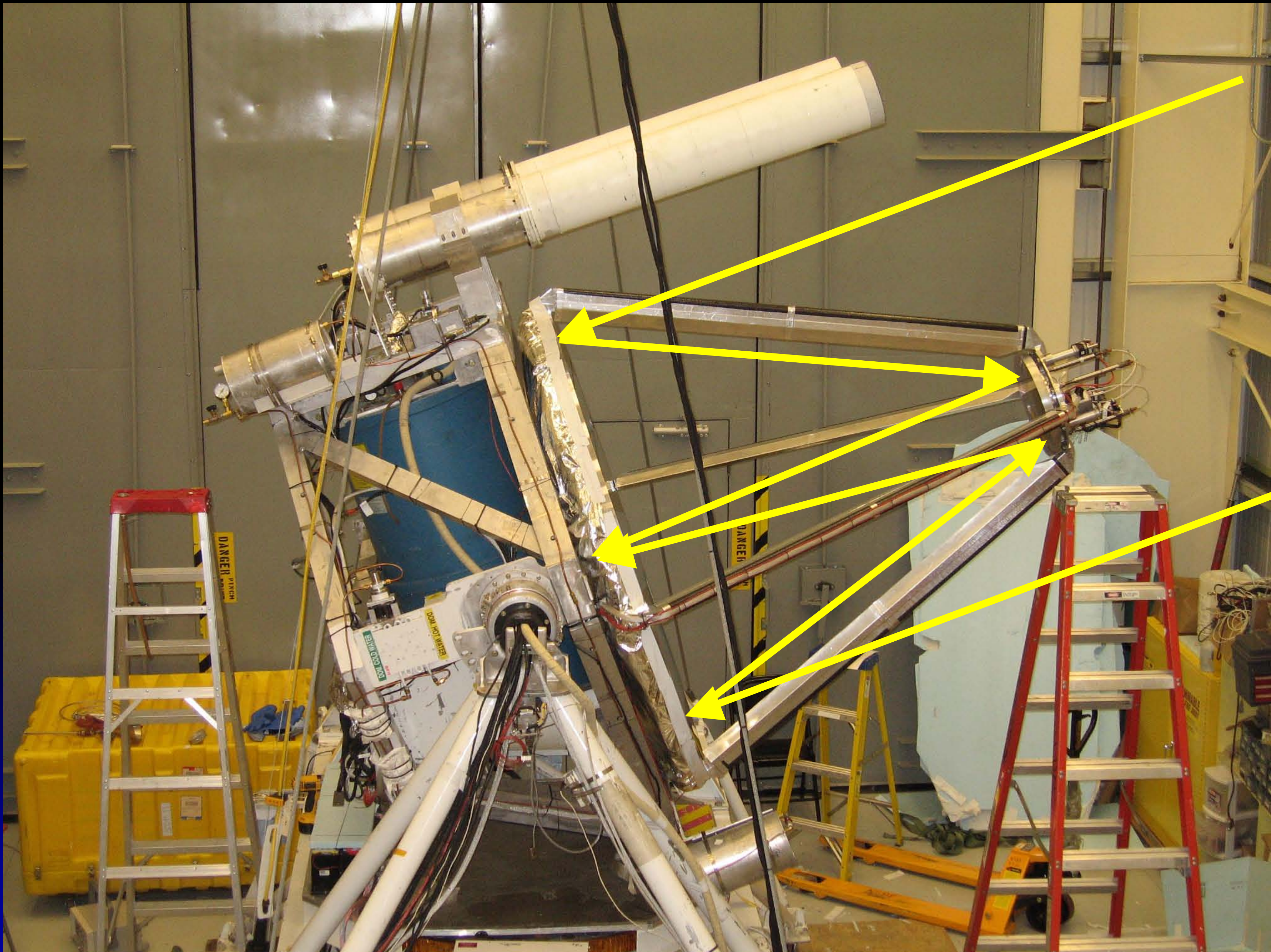


Figure from WMAP Website

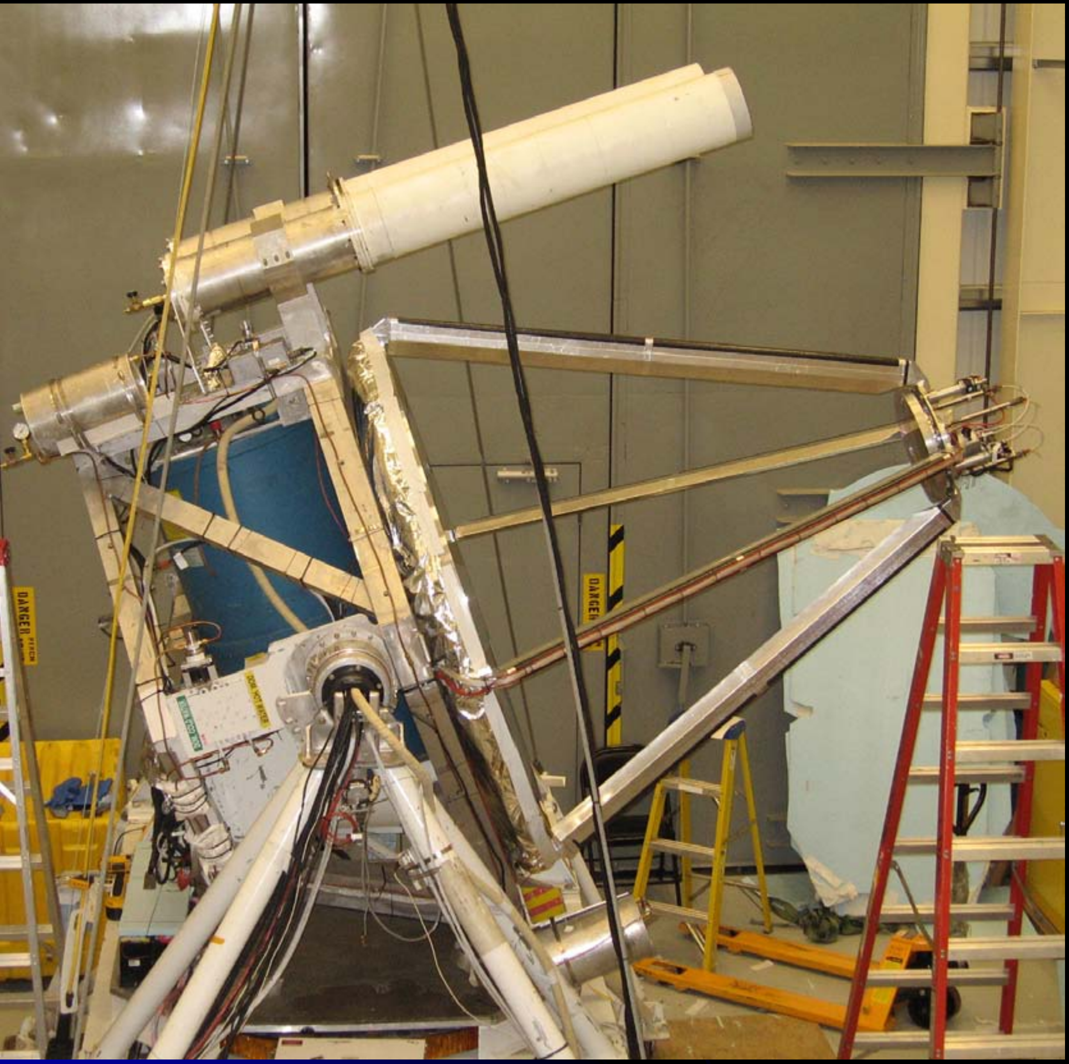
The BLAST Telescope vs. The HUMMER

- Approximately the same size and weight
- Both available in RED
- Hummer: 0-100 km/hr in 9 seconds
- BLAST: GPS *and* Star Navigation
- Circumpolar in 14 days
- BLAST sub-mm sensitivity exceeds that of the Hummer

High Altitude Balloons Take BLAST Above 99.5% of the Atmosphere for 11 Days


DANGER
DOM. COLD WATER
DOM. HOT WATER
DANGER

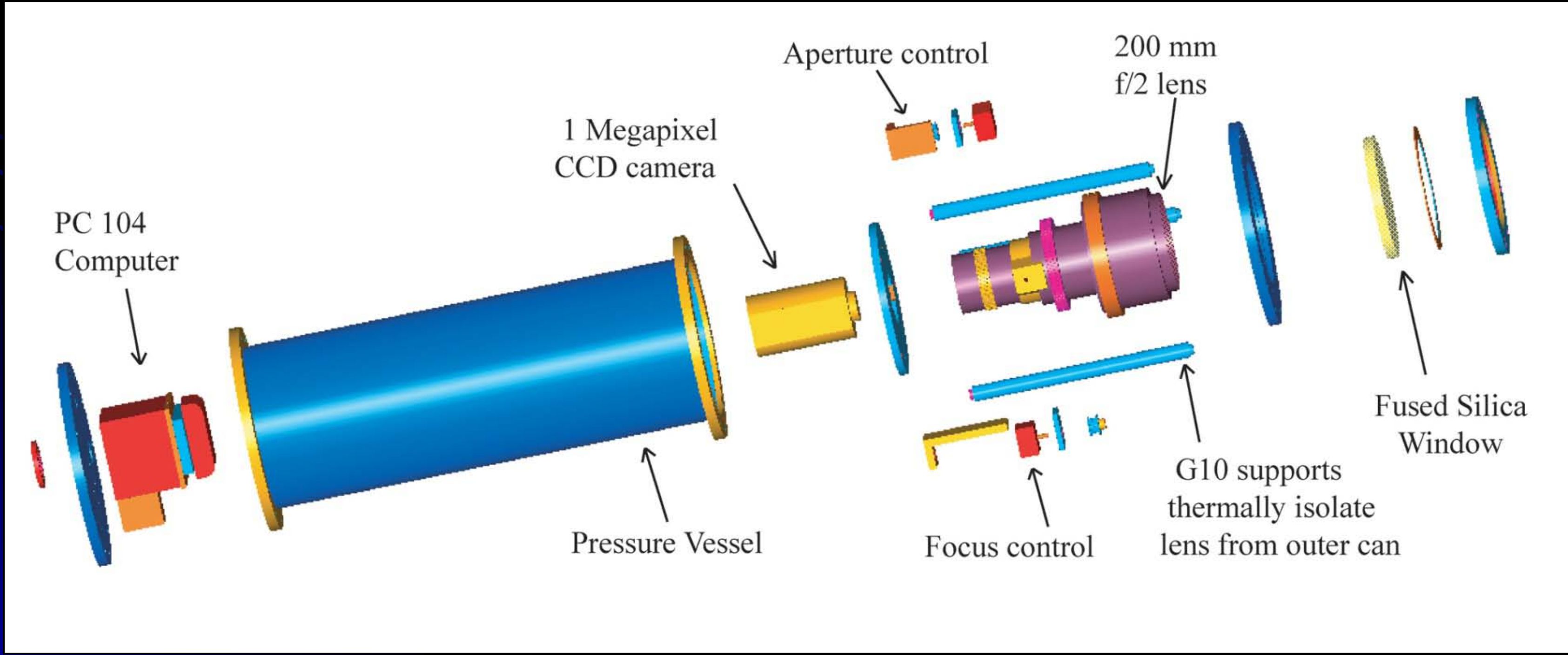
Pointing Sensors



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

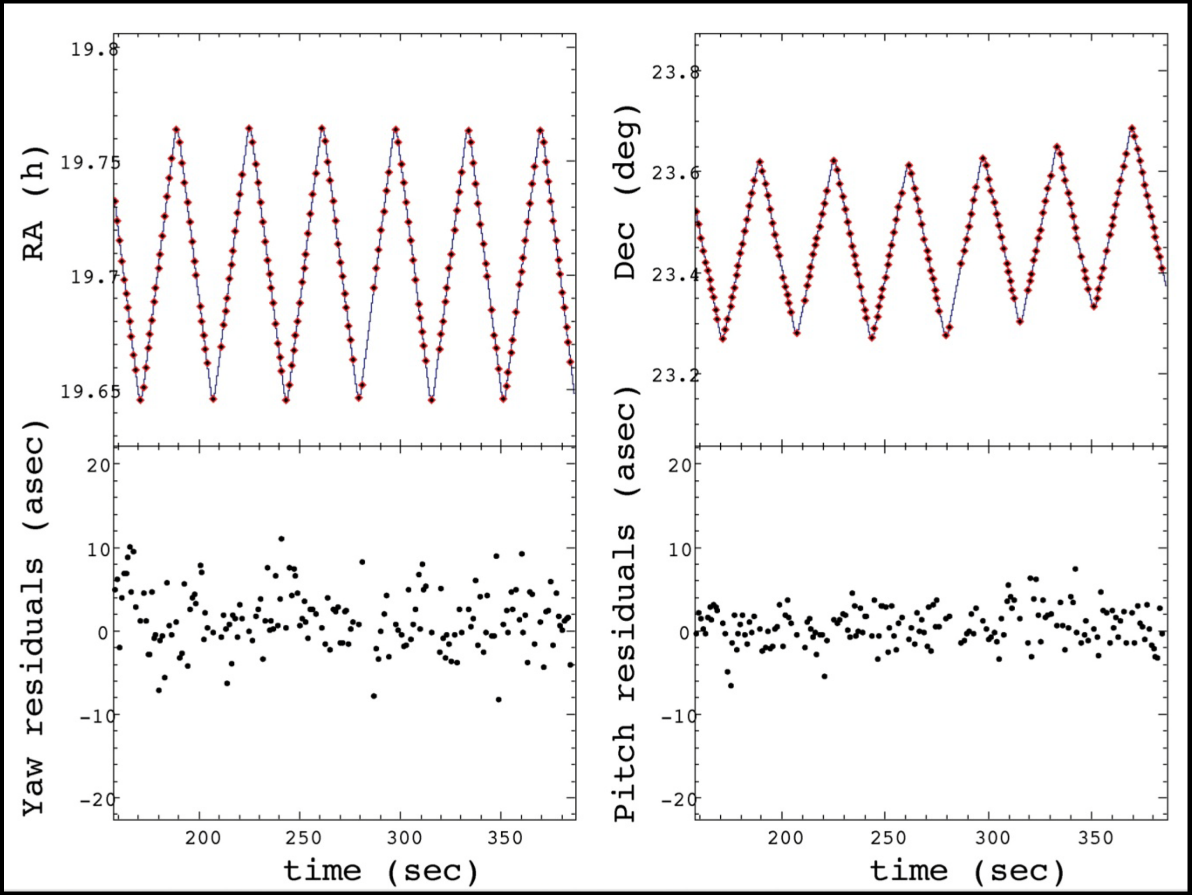
Two Daytime Star Cameras

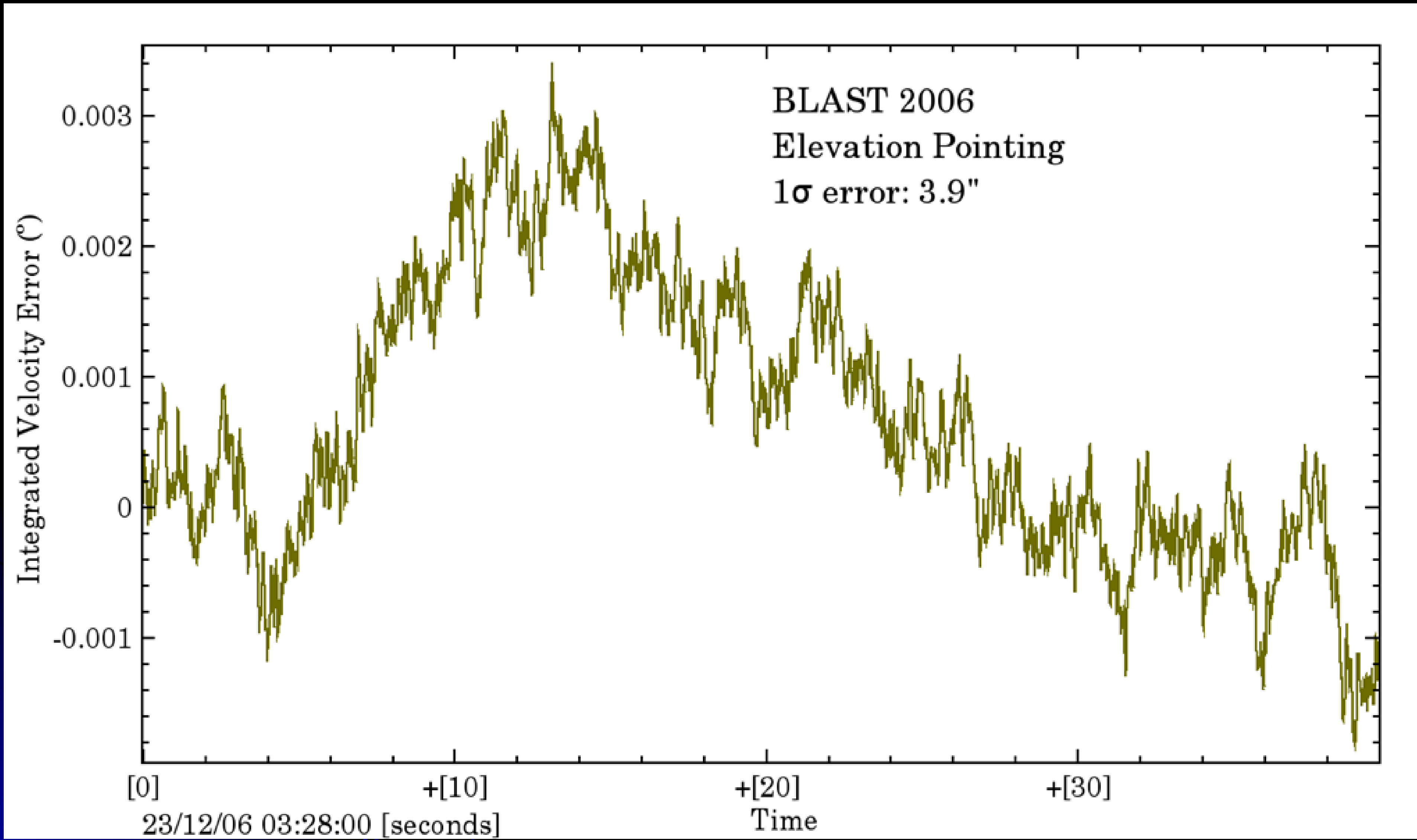
- 2 deg x 2.5 deg field of view
- Sensitive to Mag 9 stars in daytime float conditions
- 1.5 Hz pointing solutions
- Absolute accuracy < 3" rms



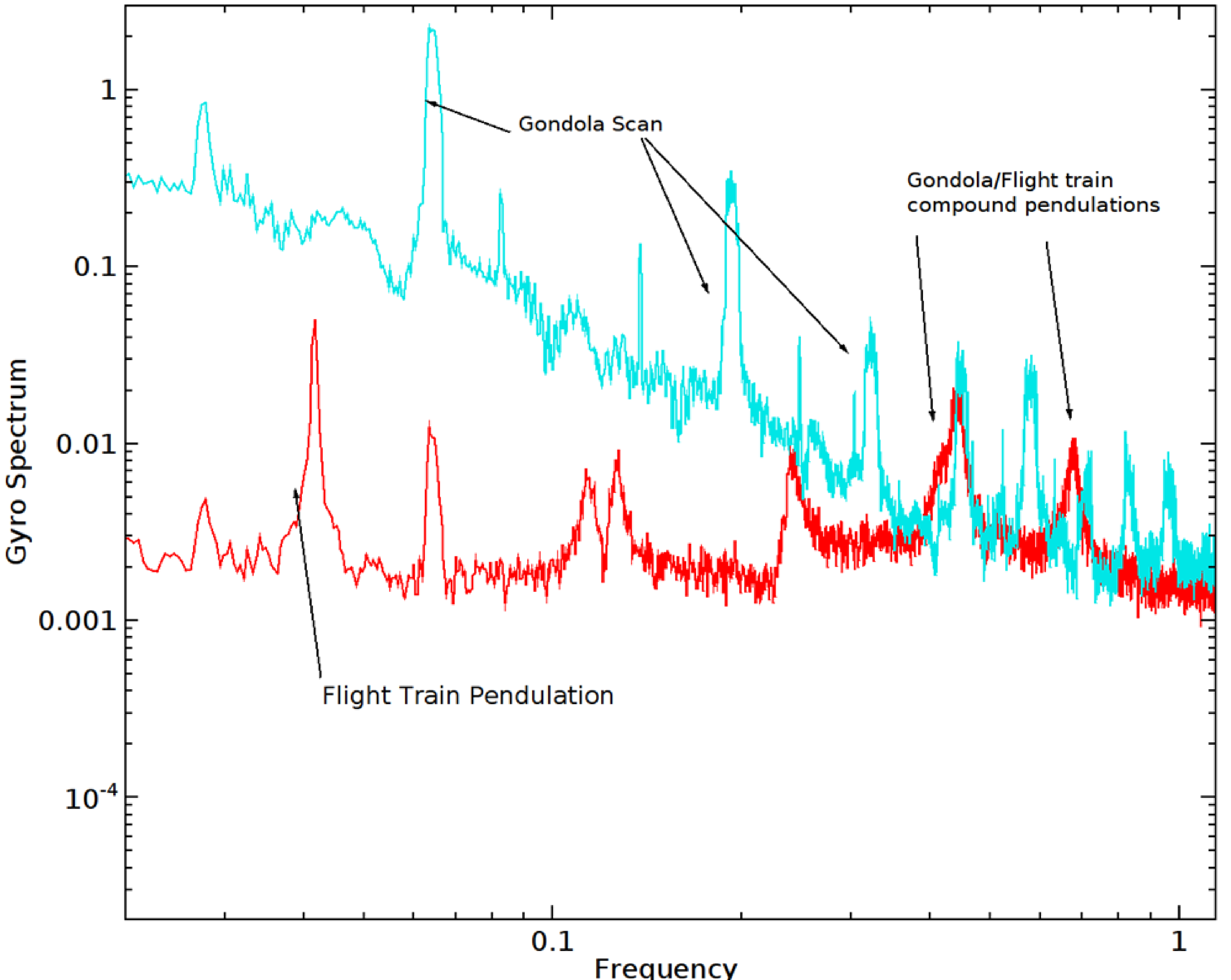
Pointing Reconstruction

- One and two star images used to find star camera solutions mid-scan
- Gyroscopes integrate between star camera solutions
- Reconstructed pointing solution accurate to < 5”





BLAST 2006
Elevation Pointing
1σ error: 3.9"
Integrated Velocity Error (°)
0.003
0.002
0.001
0
-0.001
[0]
+[10]
+[20]
+[30]
23/12/06 03:28:00 [seconds]
Time



Gondola Scan
Gondola/Flight train
compound pendulations
Flight Train Pendulation
Gyro Spectrum
Frequency
1
0.1
0.01
0.001
10^{-4}
0.1
1

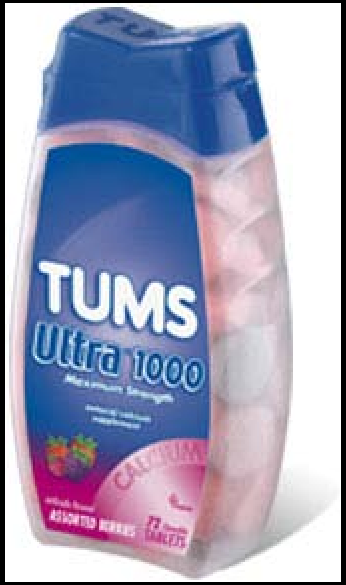

BLAST
Balloon-borne Large-Aperture Submillimeter Telescope
Antarctica

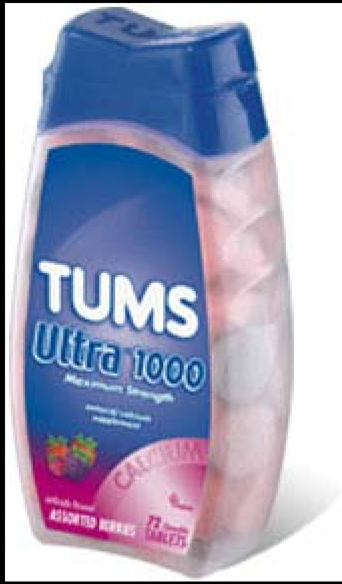

ONE DAY PASSES….

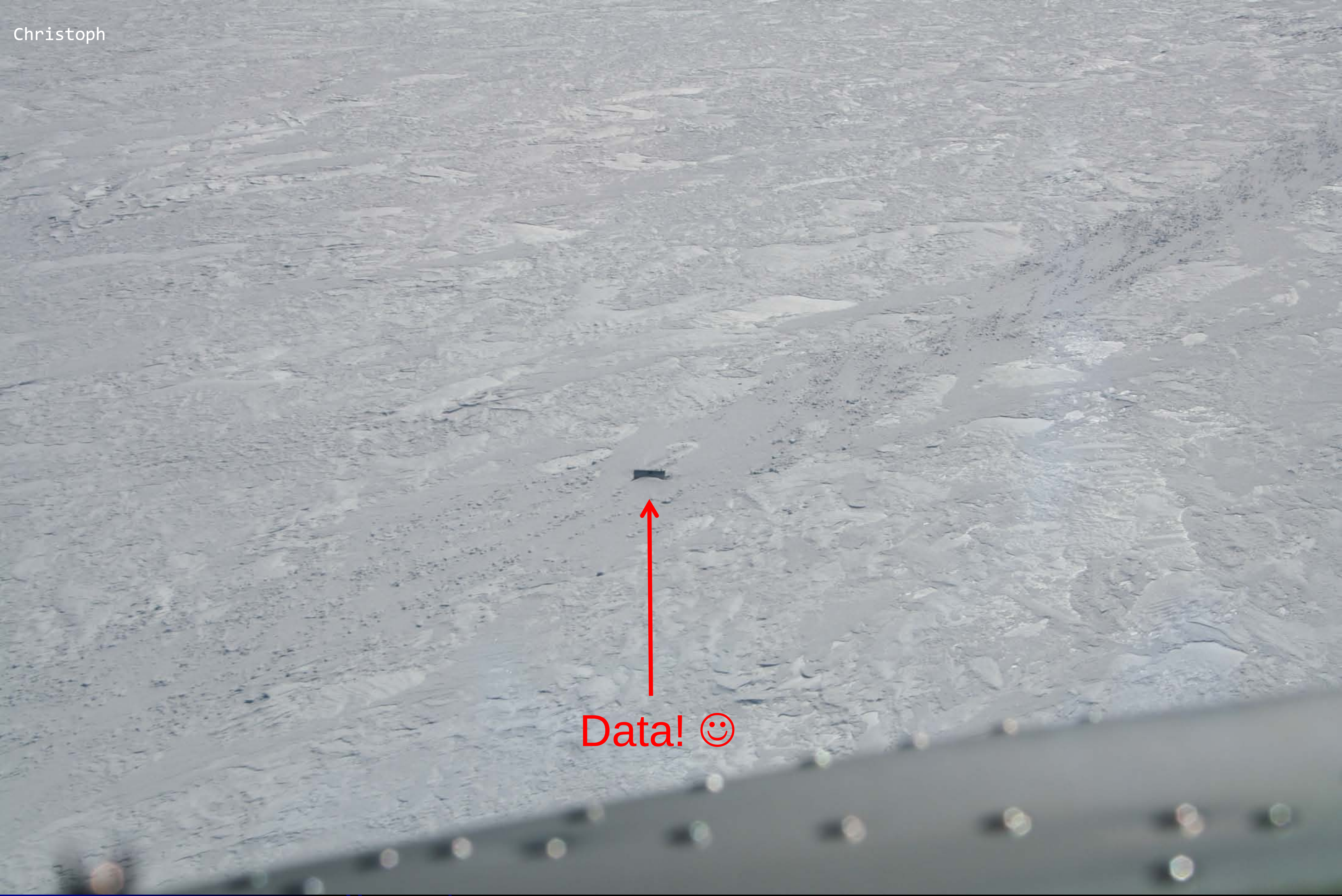

Data
Dragged position
BLAST Landing Site


No data! ☹

TWO DAYS PASS…..

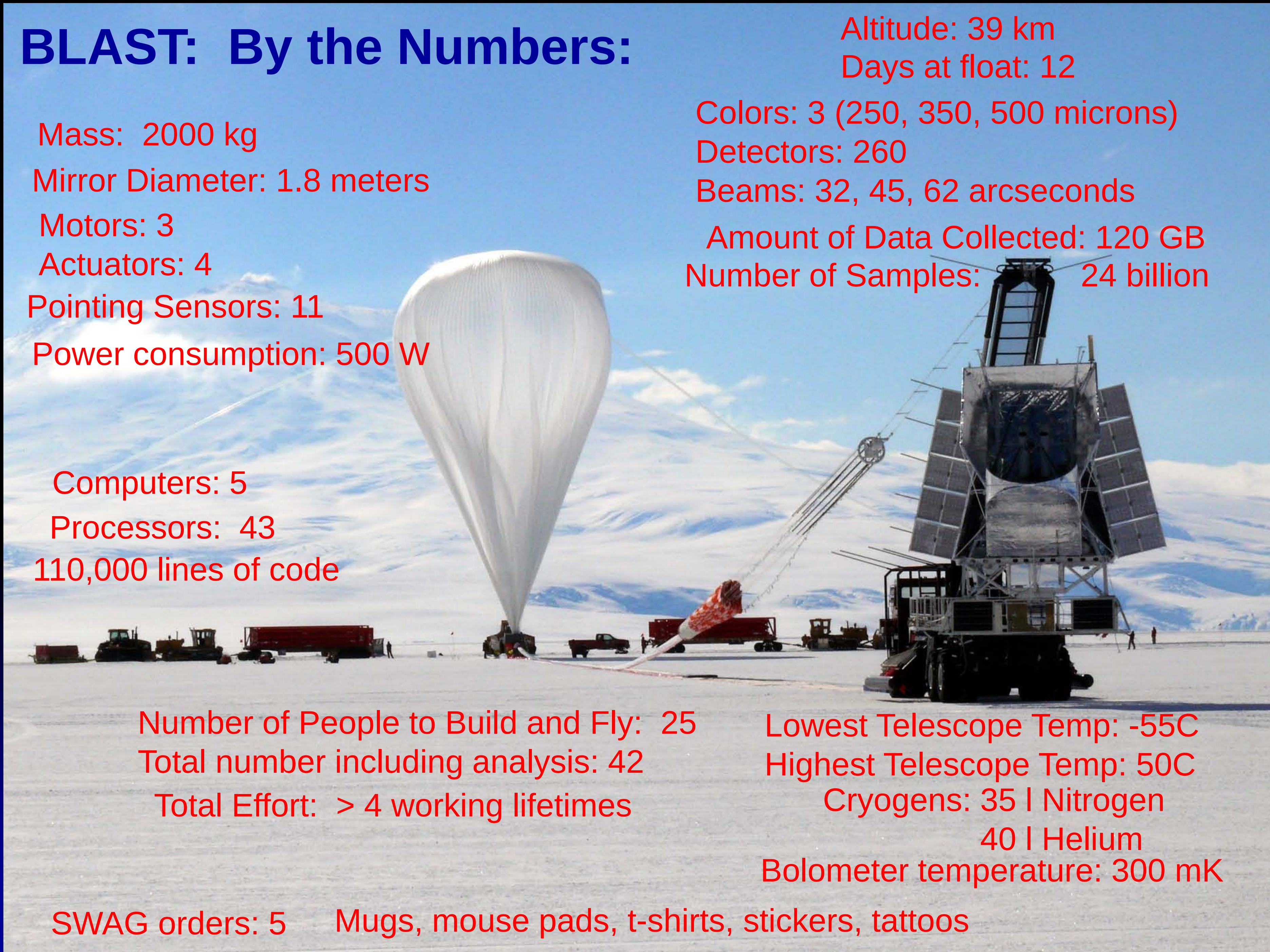





Christoph
Data! ☺

TWO DAYS PASS…..


BLAST
Data Hard Drives
Highest Recovery Priority


BLAST: By the Numbers:
Altitude: 39 km
Days at float: 12
Colors: 3 (250, 350, 500 microns)
Detectors: 260
Beams: 32, 45, 62 arcseconds
Amount of Data Collected: 120 GB
Number of Samples: 24 billion
Mass: 2000 kg
Mirror Diameter: 1.8 meters
Motors: 3
Actuators: 4
Pointing Sensors: 11
Power consumption: 500 W
Computers: 5
Processors: 43
110,000 lines of code
Number of People to Build and Fly: 25
Total number including analysis: 42
Total Effort: > 4 working lifetimes
Lowest Telescope Temp: -55C
Highest Telescope Temp: 50C
Cryogens: 35 l Nitrogen
40 l Helium
Bolometer temperature: 300 mK
SWAG orders: 5
Mugs, mouse pads, t-shirts, stickers, tattoos

So, Can I Expect to Get the Payload Back?

Flight 4 – Not so bad! Had to leave the gondola on the Ice

Flight 2 – Face plant! OUCH! Major Damage - $1M mirror lost.

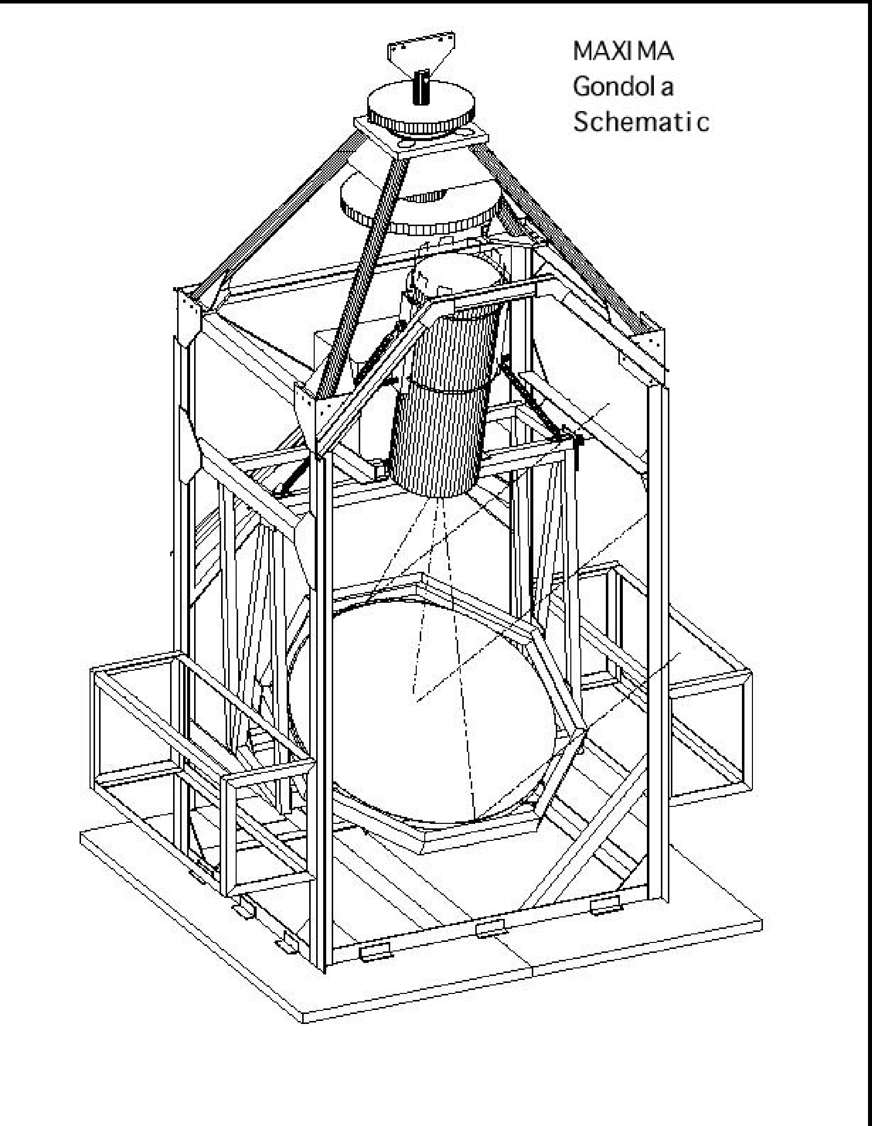
Flight 1 – NOT A SCRATCH!

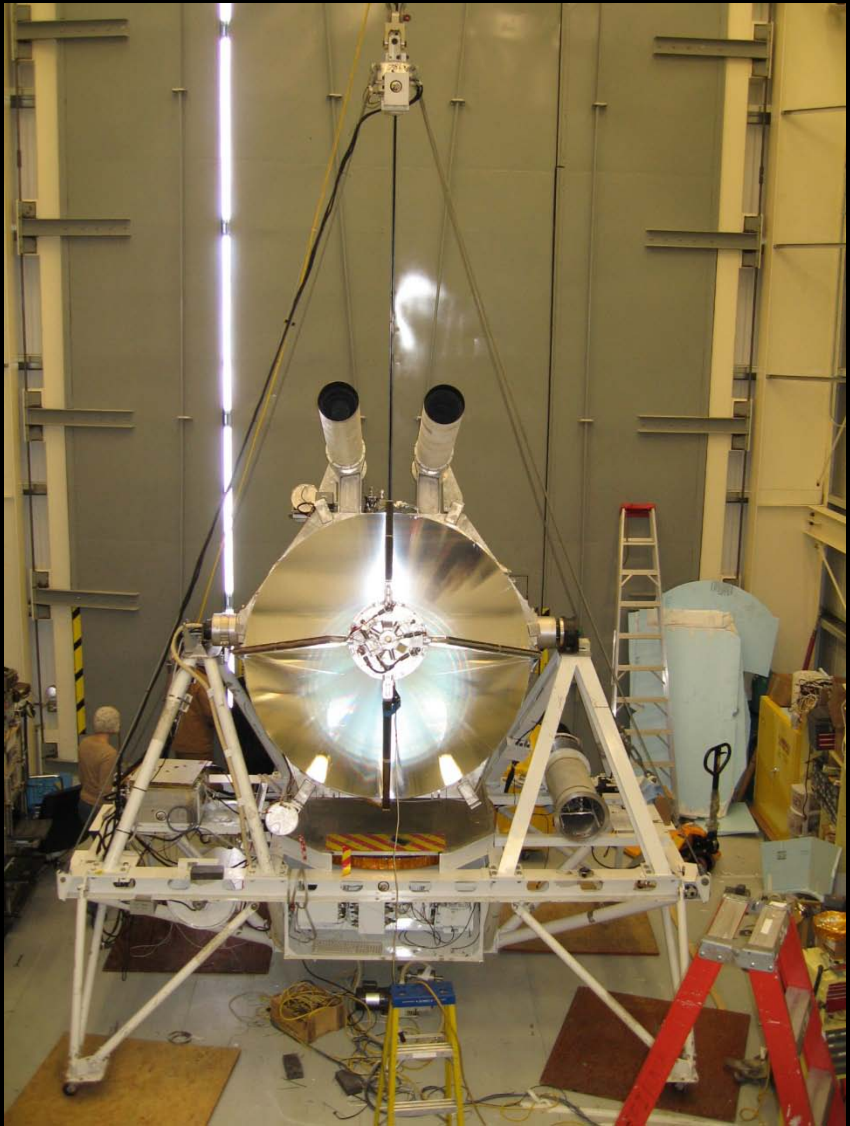
Flight 3 – Complete and Total DESTRUCTION!

What is Going to Prevent You from Getting it Back?

- The Launch or Chute Shock somehow damages your payload internally.
    - New decelerators have been implemented.
- The payload lands in water.
    - Trajectory “influence”
    - “Controlled” decent
- The payload is damaged at landing.
    - Gondola design
- The recovery somehow damages the payload.
    - Gondola design

Gondola Design Philosophy – For Telescopes



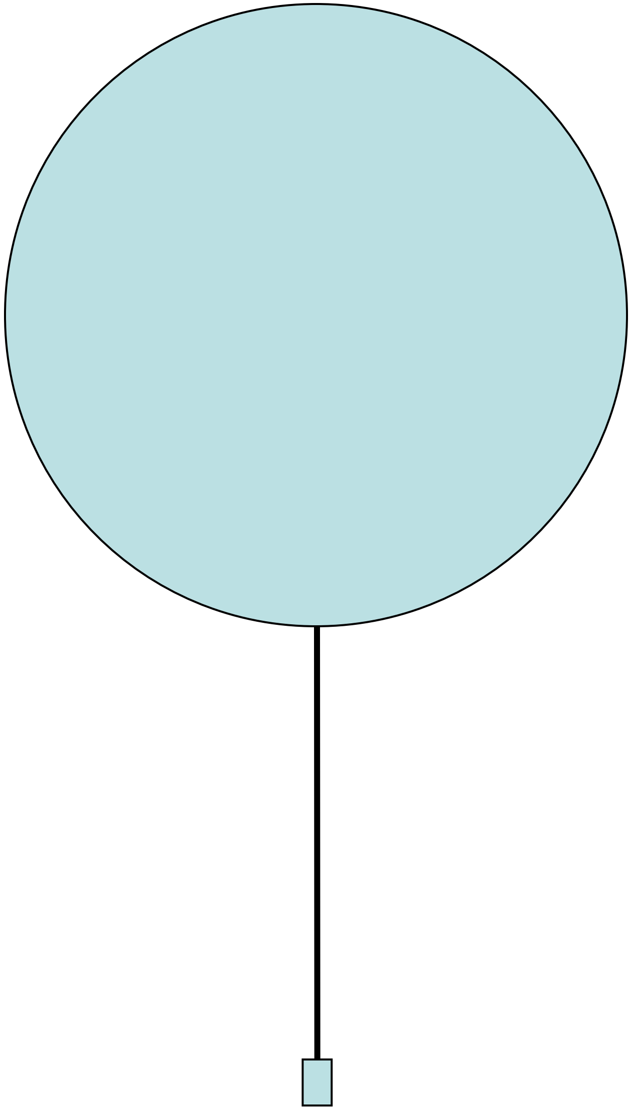


Or, You Can Build a Tank

Of Course, If You Want to Find Water, Just Land your Telescope!

Boomerang at Float!

Now That You Have a Bomb-Proof Gondola – Can you Point It?



Balloon:

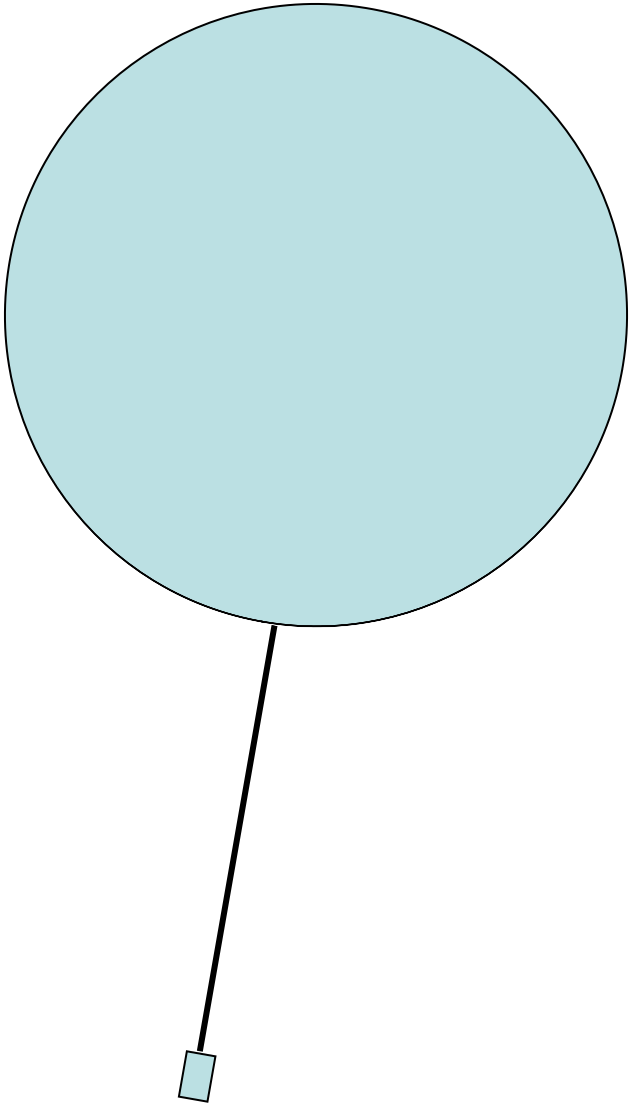
- 28.4 mcf
- Mass = 1682 kg
- Radius = 54 m
- $I_{cm} = 2 \times 10^6$ kg m^2

Flight train:

- 120 ft parachute (180 ft long)
- 60 ft ladder
- Length = 75 m
- Mass = 230 kg (!)
- Icm = 1×10^5 kg m^2

Gondola:

- Height = 8 m
- Mass = 2000 kg
- CoM = 7 m below pivot
- Icm ~ 3×10^3 kg m^2



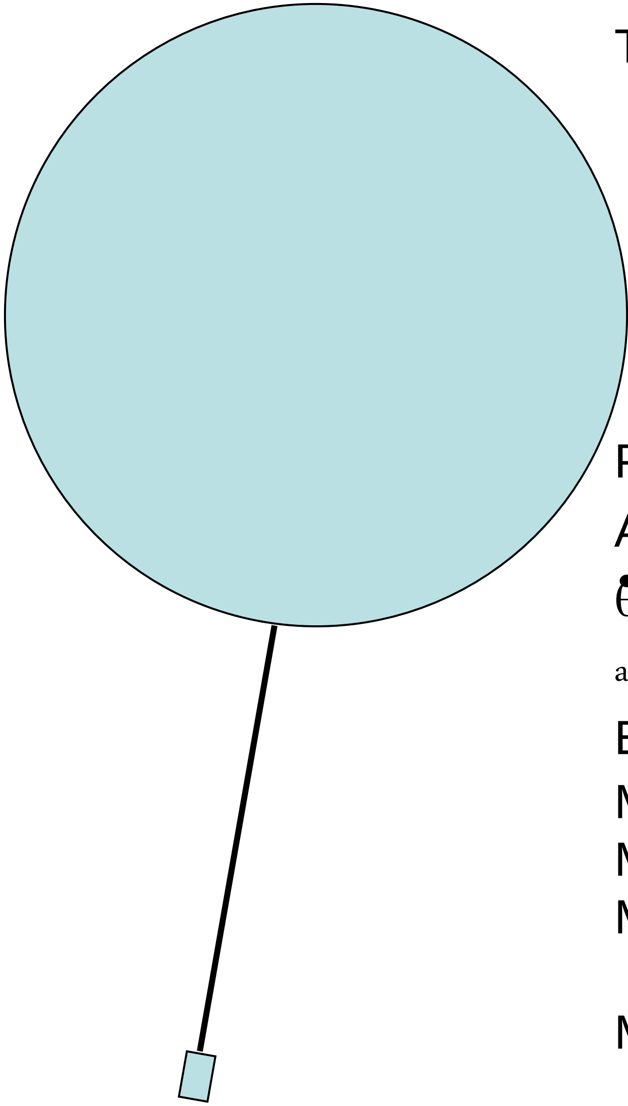
Zeroth Mode – Pendulation:

W e see “Typical” –
22 second period w/ **10 arcmin** amplitude

Pendulation with **22 second period** => 120 meters

Length of flight train (75 m) + radius of balloon(54 m)
= 129 m (22.3 second period)

TREAT this mode as a physical pendulum:



Zeroth Mode – Pendulation: A few numbers:

The moment of inertia of the pendulating system =

Balloon = 2×10^6 kg m^2

Flight train = 2×10^6 kg m^2

Gondola = 3.6×10^7 kg m^2

TOTAL = 4×10^7 kg m^2

Period of 22 seconds => $\omega = .285$ rad/sec

Amplitude of 10 arc min = $\theta_0 = 3 \times 10^{-3}$ rad

$\dot{\theta}_{max} = \theta_0 \omega$

$a = \theta_0 \omega^2$

Energy = $\frac{1}{2} I \dot{\theta}_{max}^2$ = **14 Joules !**

Maximum displacement = **0.38 meters**

Maximum velocity = **0.11 m/s**

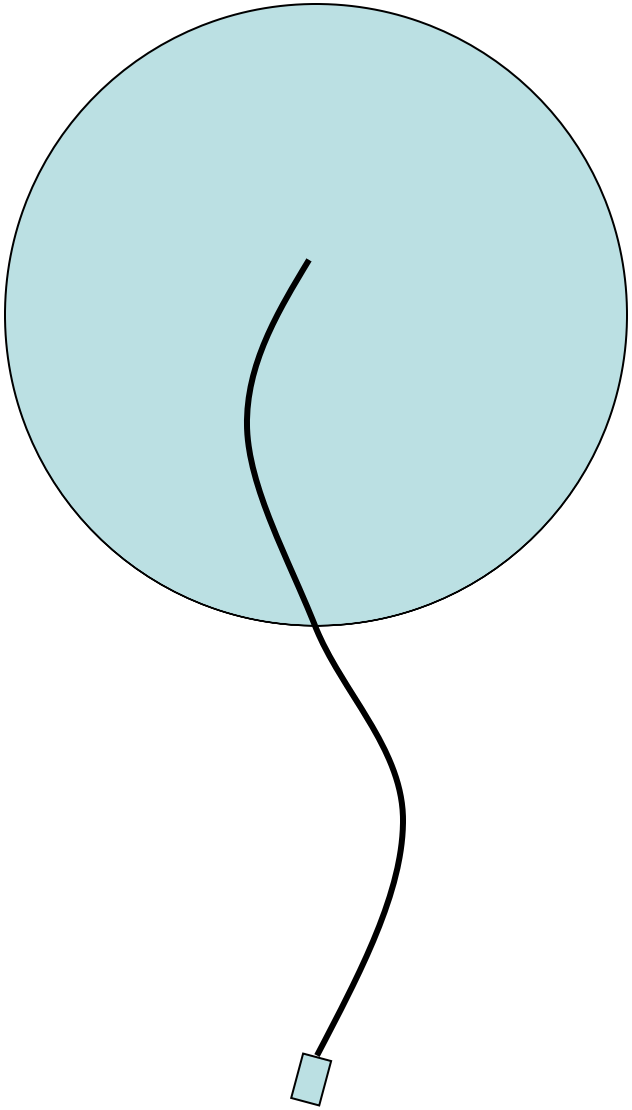
Maximum radial acceleration (at CoM of system)

= 10^{-4} m/s^2 or **1 micro g**

Maximum tangential acceleration (at CoM of system)

= 3×10^{-2} m/s^2

Differential tangential acceleration = 2.4×10^{-4} m/s^2 per m



First Mode: Vibration

Frequencies: anywhere from

0.45 to 0.65 Hz (Boom and Maxima)

Amplitude: **2 – 10 arcsec**

Tension in the flight train = 2 x 10^4 kg m/s2

Linear density of flight train = 3 kg/m

Velocity of wave on flight train = 80 m/s

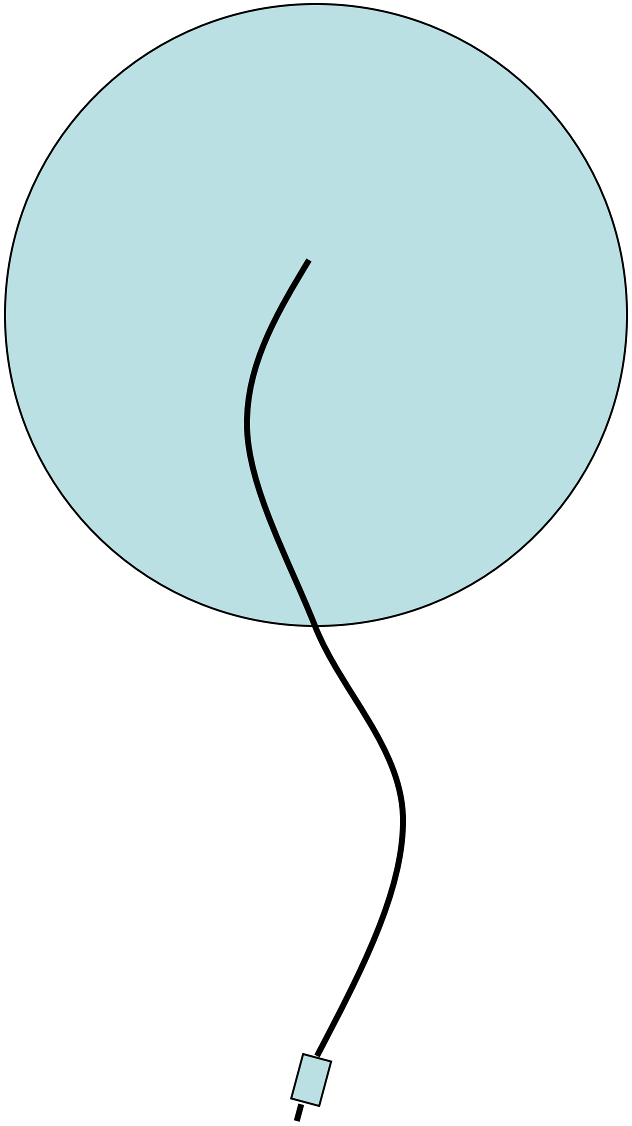
Period of first mode = $\frac{150\text{ m}}{80\text{ m/s}}$ = 1.855 sec = 0.54 Hz

"Natural" frequency of gondola about pivot is:

0.2 Hz.

If true then the gondola is acting like a driven physical pendulum rotating about its CoM

First Mode: Vibration: Some Numbers



Energy of oscillating gondola about its CoM with an amplitude of 10 arcsec and frequency of 0.5 Hz:

40 micro Joules (!!!)

POWER on gondola from wind as it is dragged though 5 mb atmosphere at 1 m/s:

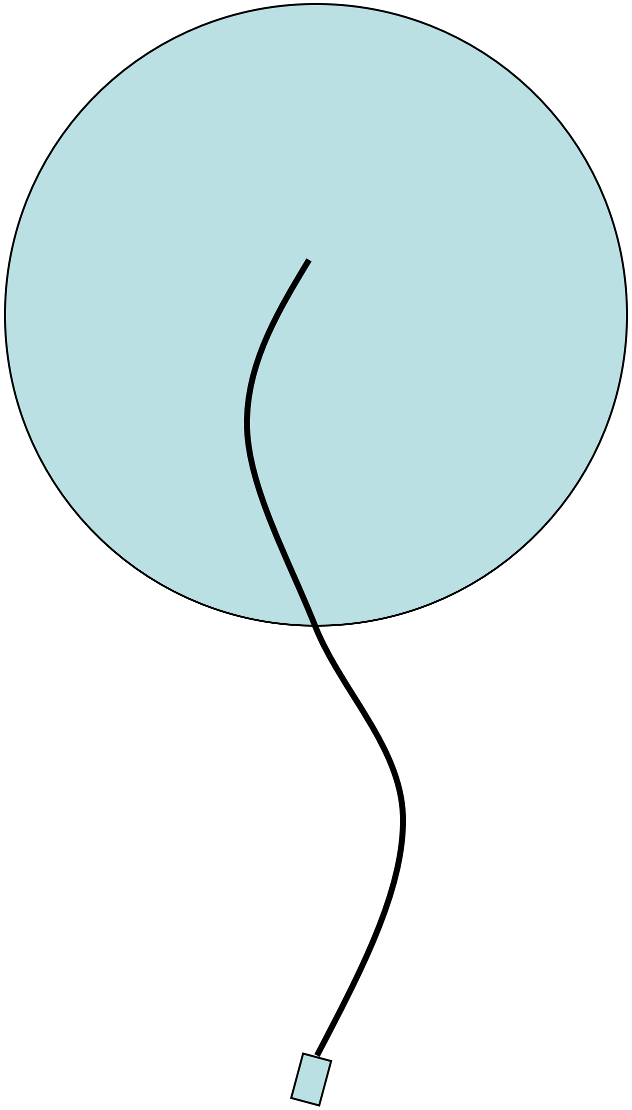
~ 70 mW

The reaction point (where the tangential acceleration cancels the CoM motion) is 3 meters BELOW the gondola.

The Pivot moves about 0.5 mm
(translation+rotation).

The maximum tangential acceleration (at the pivot) is about 0.003 m/s^2 or about 0.5 milli-g. This is the best place to put a meter to be sensitive to this motion…..and the passive damper

The best place to put the reaction wheel damper is at the CoM of the gondola. Will this do more harm than good?



Motion Conclusions:

-With a single accelerometer/tilt sensor, we don't really know what is happening because we don't know the equation of motion exactly.

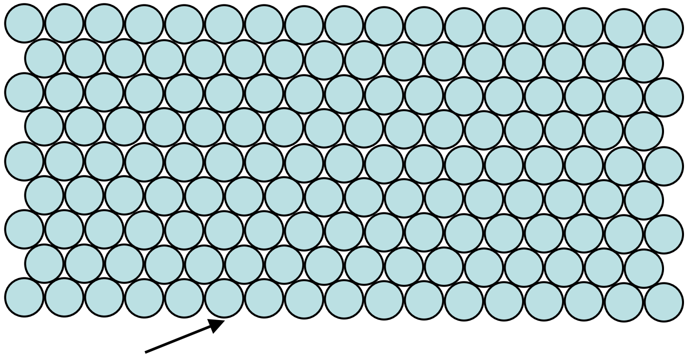
- The amount of energy associated with these motions is very small. Passive damping can't hurt. Active damping could cause problems (?).

- Multiple accelerometers and tilt sensors at several heights on the gondola could allow us to back out the actual tilt of the gondola.

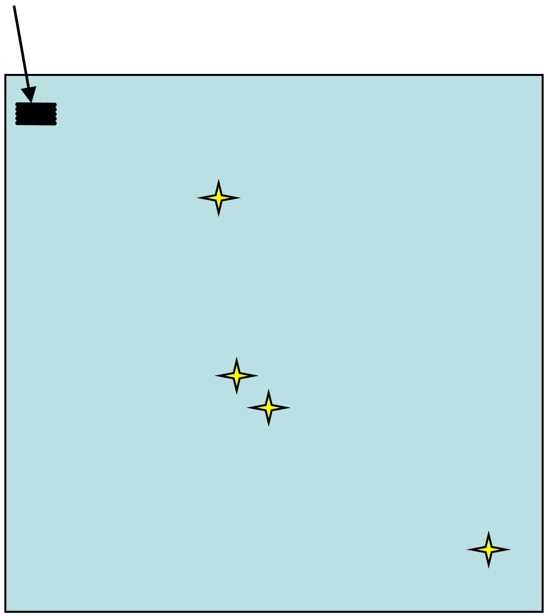
- The 0.5 Hz passive damper at the pivot could remove a MAXIMUM of 2 micro-J per cycle. Takes 20 seconds to damp out motion.

We are doomed…..Or maybe not……

What is the effect of these motions?



250 micron array 11 arcmin FOV
35 arcsec pixels.



2.8 degree CCD FOV
8 arc sec pixels

A change in roll angle of the gondola results in:

Rotation of the array (CCD) on the horizon.

$$\sim \theta_{rot} = \theta_{roll}\sin(\theta_{zenith})$$

Translation at the zenith.

$$\sim \theta_{trans} = \theta_{roll}\cos(\theta_{zenith})$$

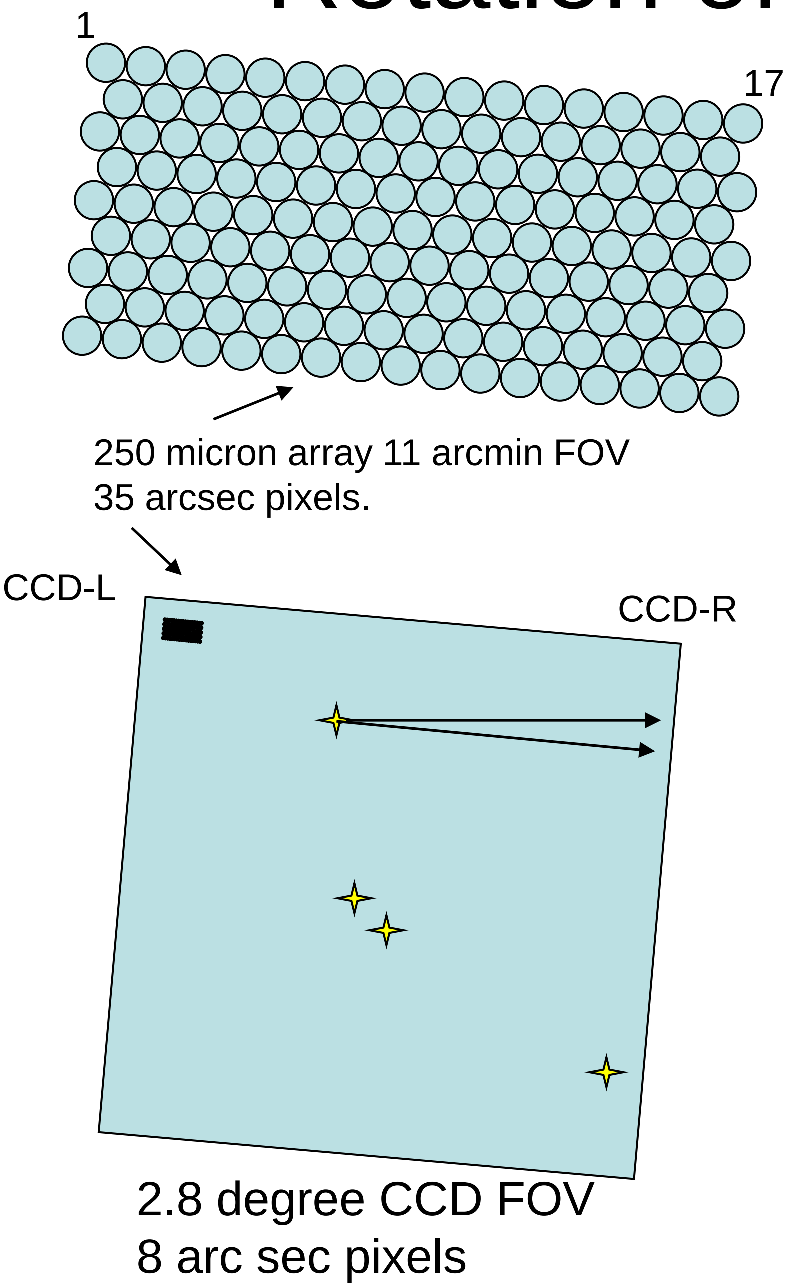
At an observing angle of 45 deg:

$$\theta_{rot/trans} = 7 \text{ arcmin (22 sec)}$$

$$\theta_{rot/trans} = 7 \text{ arcsec (2 sec)}$$

A change in PITCH changes the elevation angle of the array (CCD).

Rotation of Array and CCD



At an observing angle of 45 deg:

θ_{rot} = 7 arcmin (22 sec)

$\theta_{rot/trans}$ = 7 arcsec (2 sec)

For the 22 second pendulation:

Pixel 17 is rotated 1.4 arcsec below pixel 1
CCD-R is rotated 30 arcsec below CCD-L

We sample the CCD fast enough to resolve this motion. Tracking a single star ‘fools’ the CCD into translating the entire array up and down.

Tracking several stars gives rotation also.

For the 2 second motion:

Pixel 17 is rotated 0.02 arcsec below pixel 1
CCD-R is rotated 0.5 arcsec below CCD-L