BLAST

Balloon-borne Large Aperture Submillimeter Telescope

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University of Pennsylvania

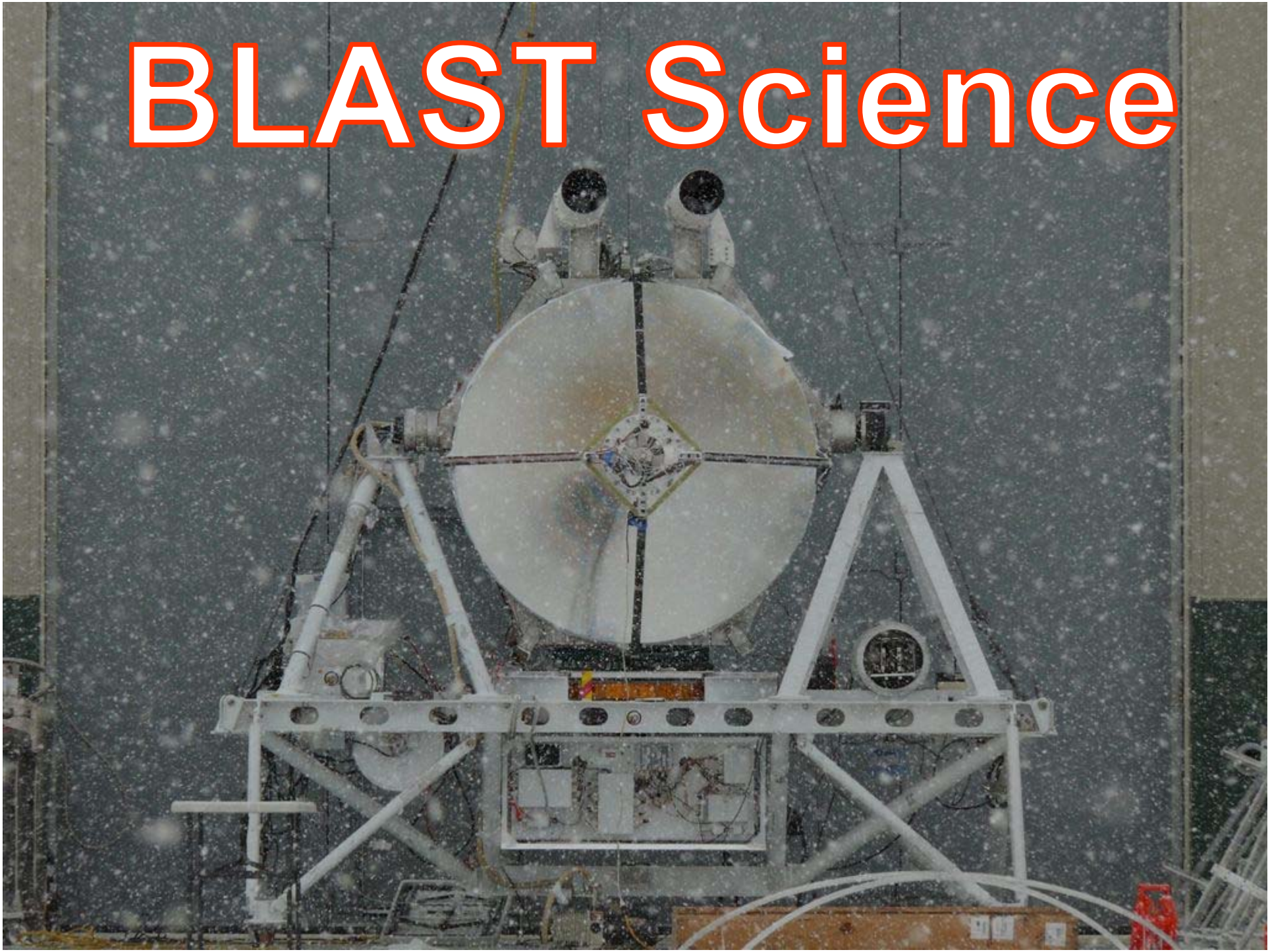
May 2015

Astronomer Cosmologist

Astrologer

Cosmetologist

BLAST Science



Cosmology: The study of the Universe as a system

Where is all the stuff?

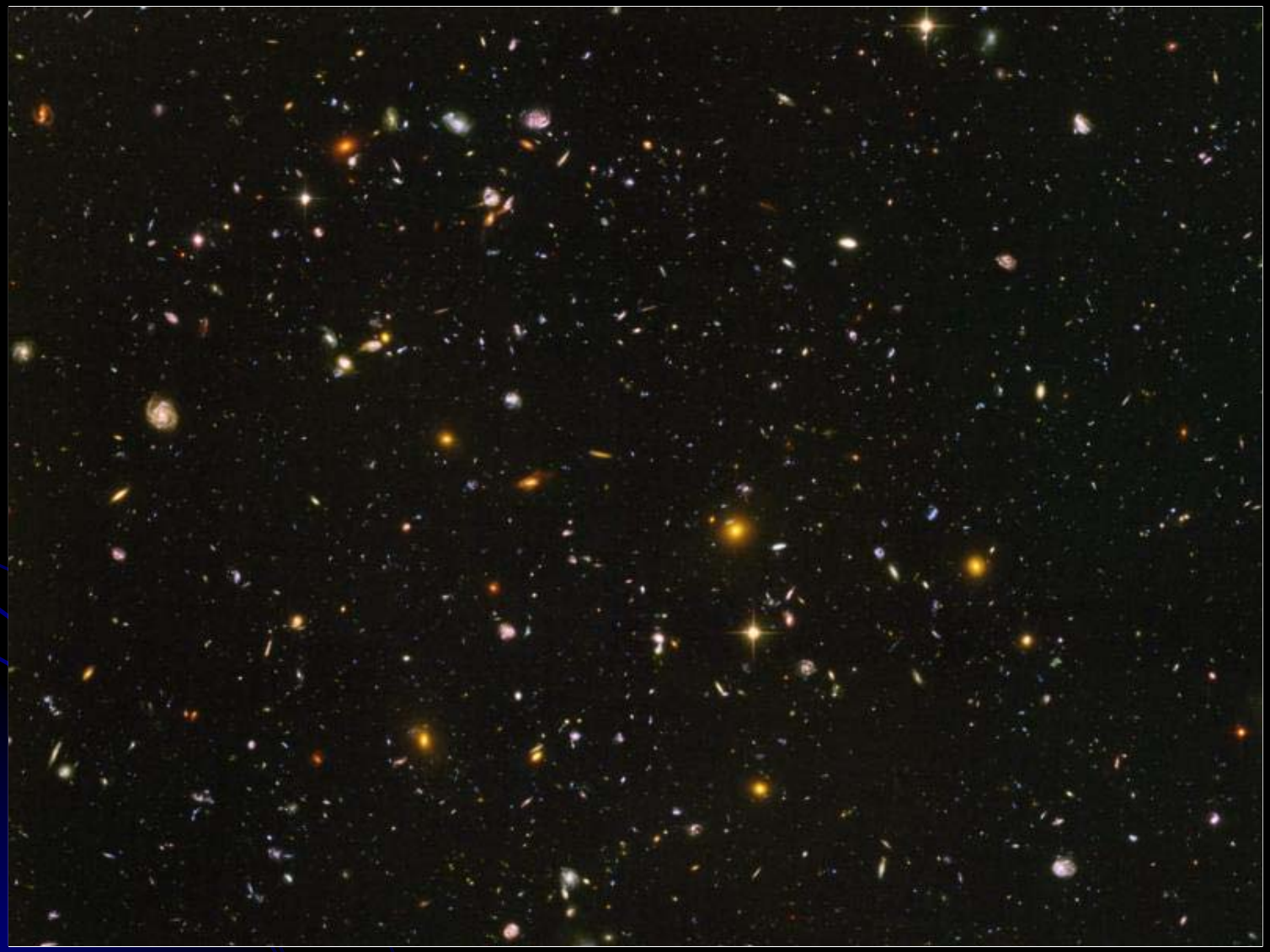
How is it organized?

How did it get that way?

But FIRST…..

How does the Universe look like?

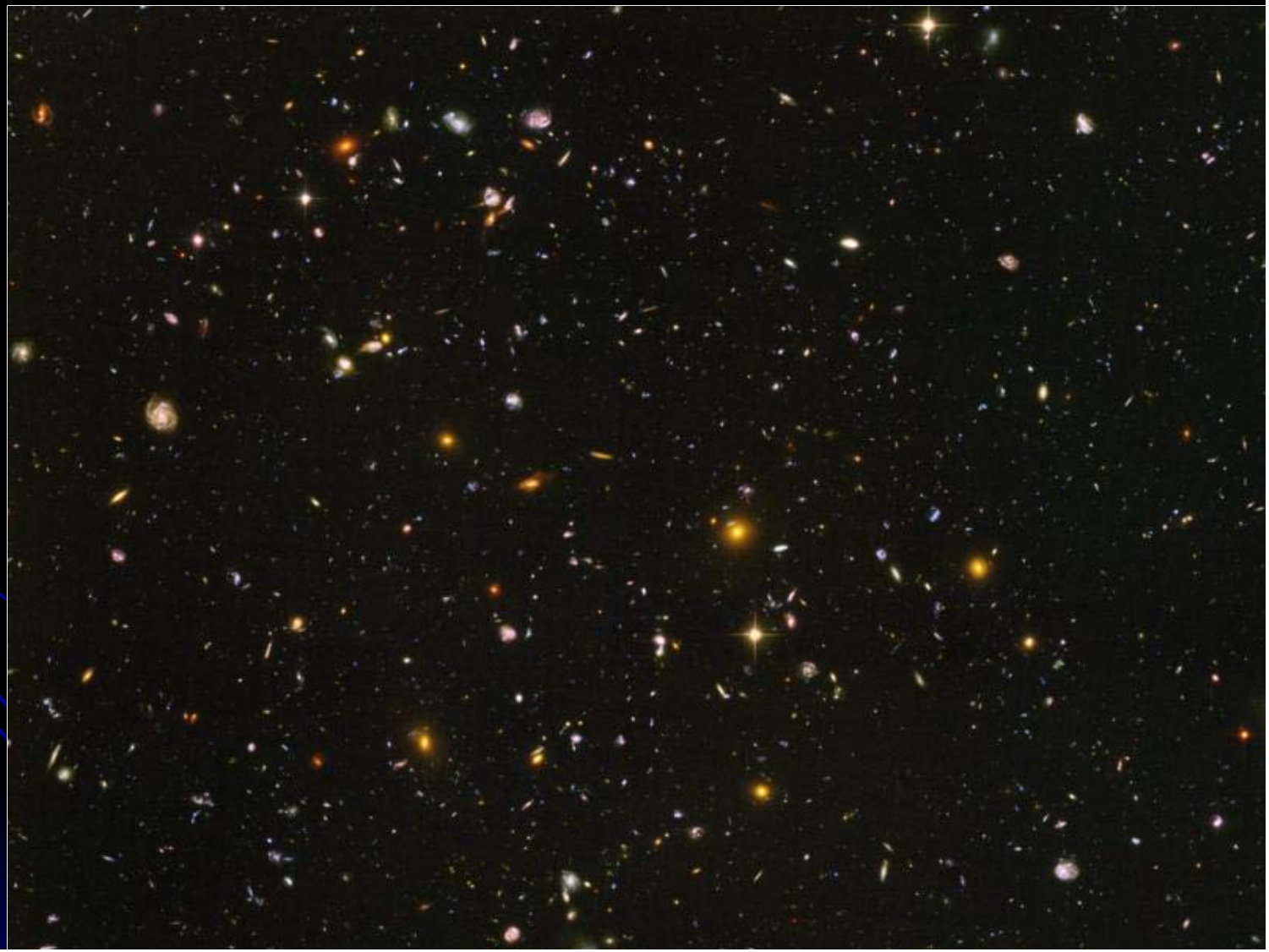
To look like this...



The Universe Evolves

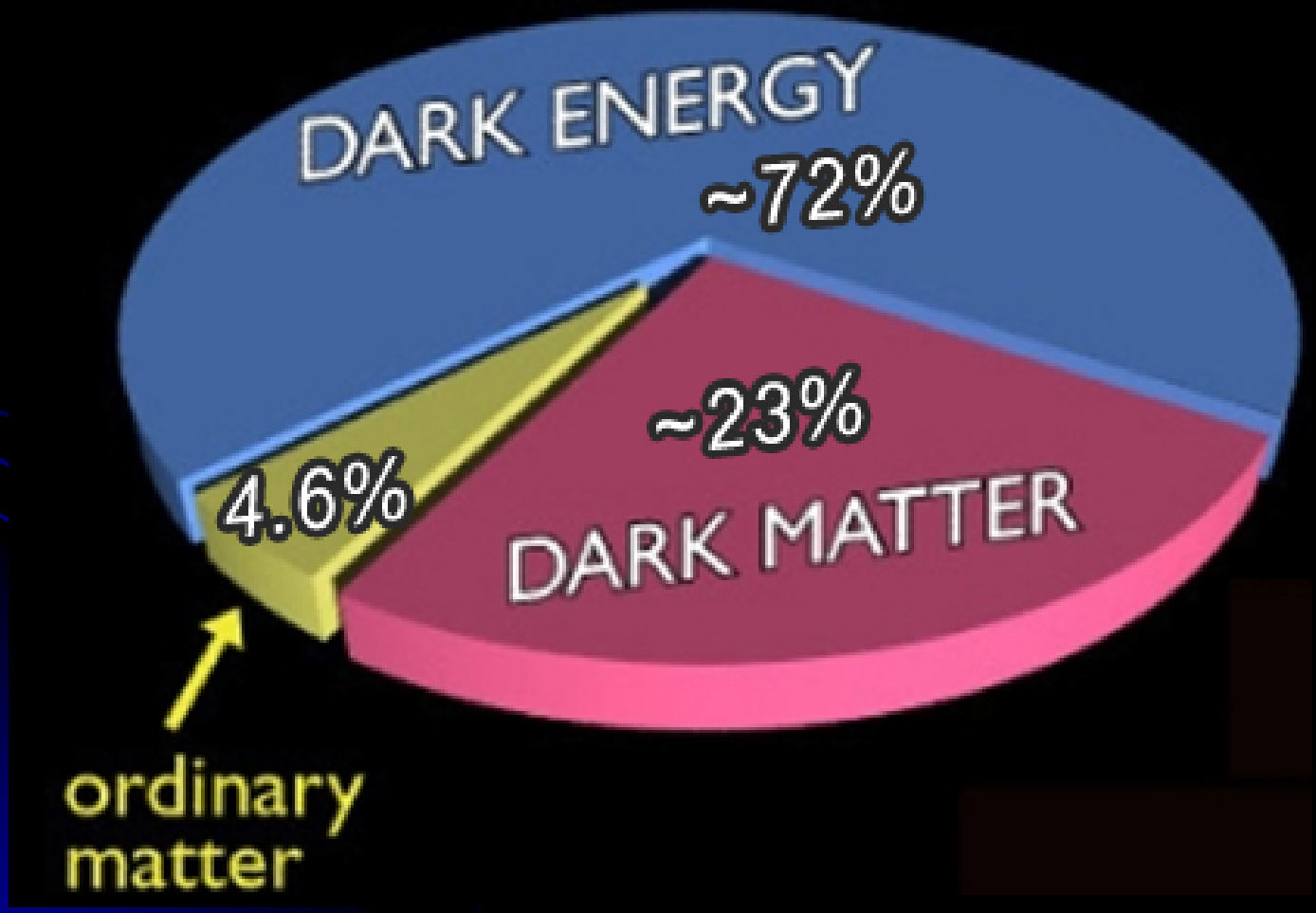
Gravity Rules

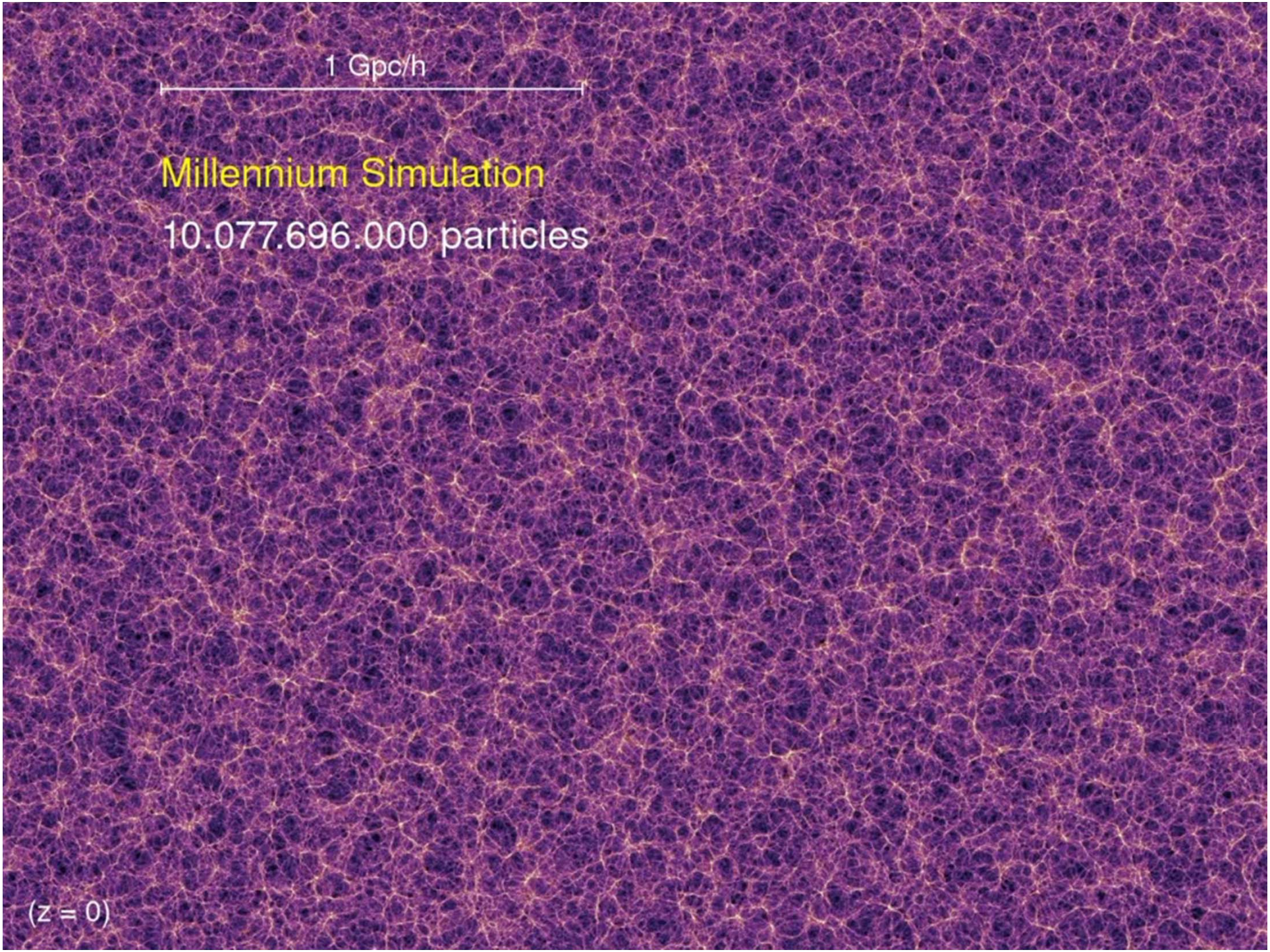
..but the details are important



From the Millennium Simulation – Volker et al. - 1997

What The Universe Is Made Of




1 Gpc/h
Millennium Simulation
10.077.696.000 particles
(z = 0)

BLAST Studies the Evolution of the Universe

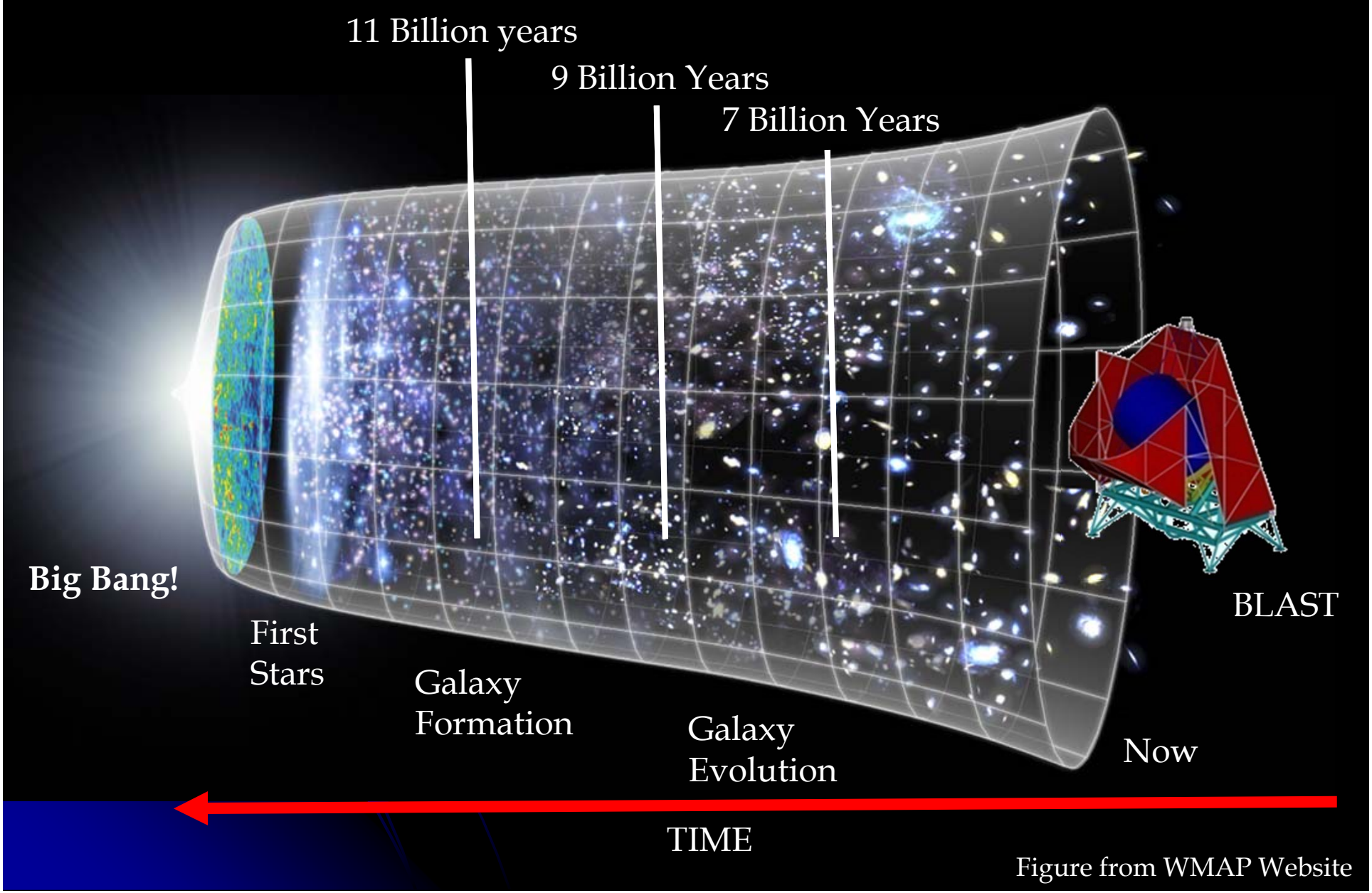
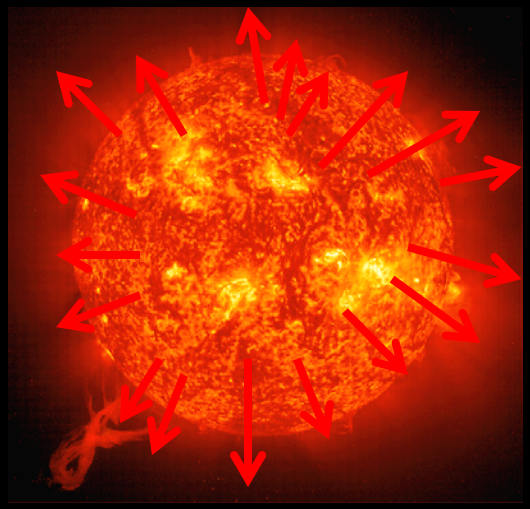


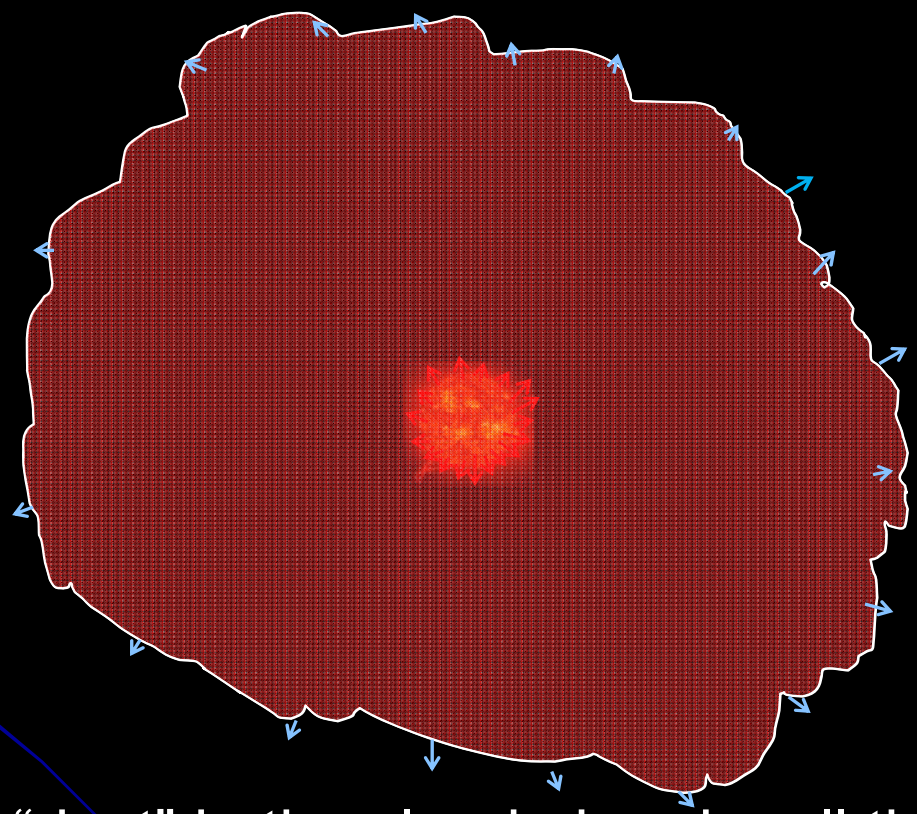
Figure from WMAP Website

Let's Talk About Stars



Stars are very HOT balls of Hydrogen gas (6000 degrees)
They emit optical photons.

Stars form in HUGE Clouds of Hydrogen



A tiny bit of “dust” in the cloud absorbs all the optical photons. The dust “warms” up 30 degrees above absolute zero.

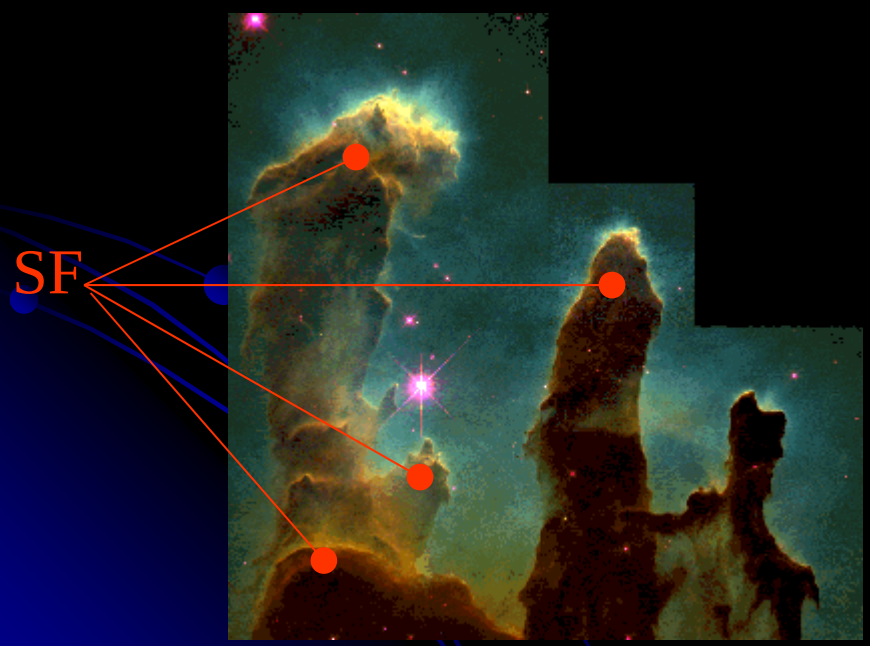
The warm cloud re-emits the energy from the stars inside in the sub-millimeter portion of the spectrum.

Understand the Connection Between Optical/IR and Sub-mm Observations

We can use (very) low-z observations to understand the effect of obscuration

Dust blocks optical and UV starlight

..and that power is re-radiated at few 100 μms



HST (optical)

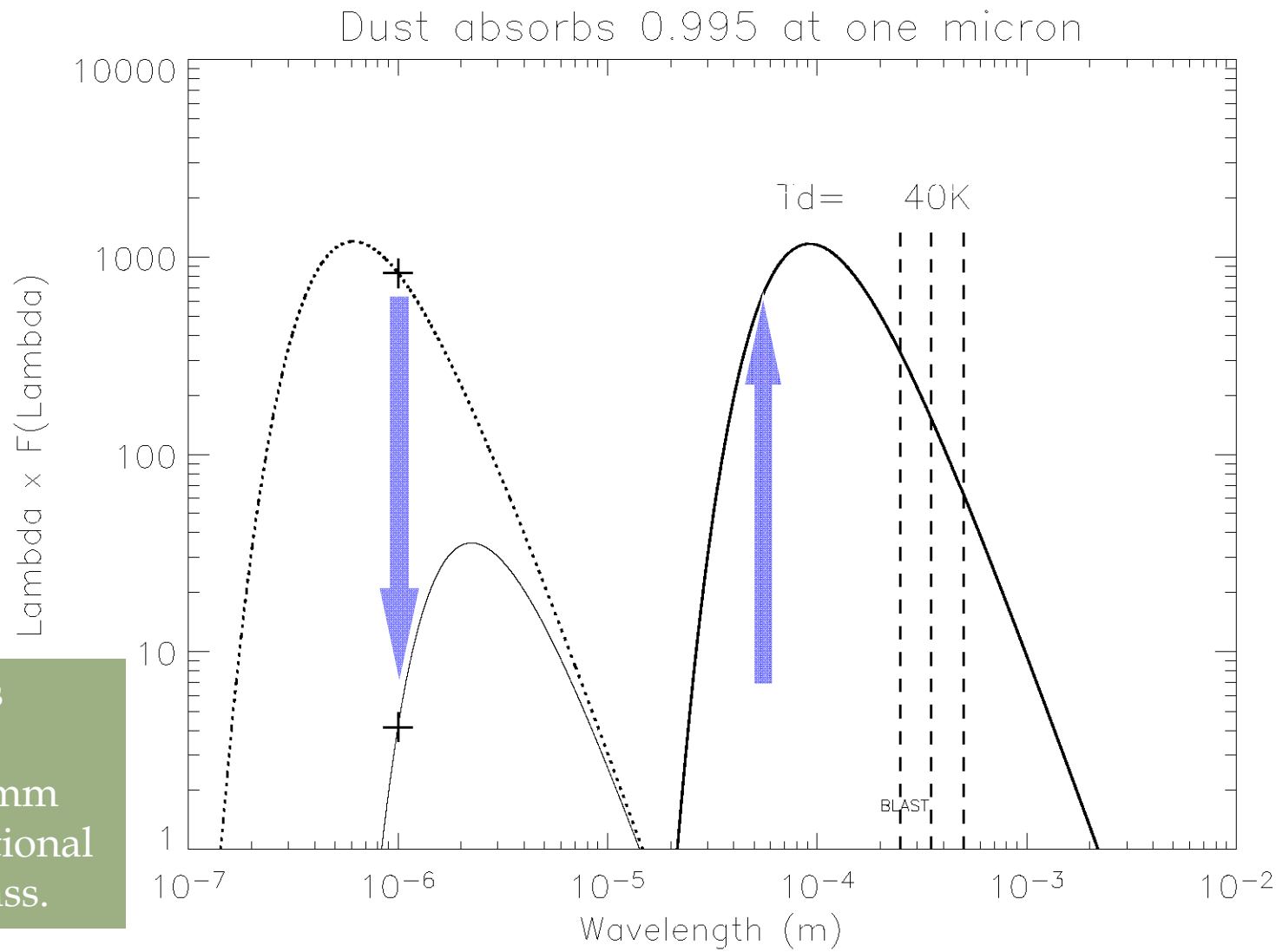
SCUBA (450 μm)

The Eagle Nebula is about 7000 l-y from Earth

Absorbed starlight is re-radiated in the sub-mm.

Reality: Stars form in clouds that are at least 50 AU in diameter which absorb nearly all of the optical starlight. These regions are bright at BLAST wavelengths.

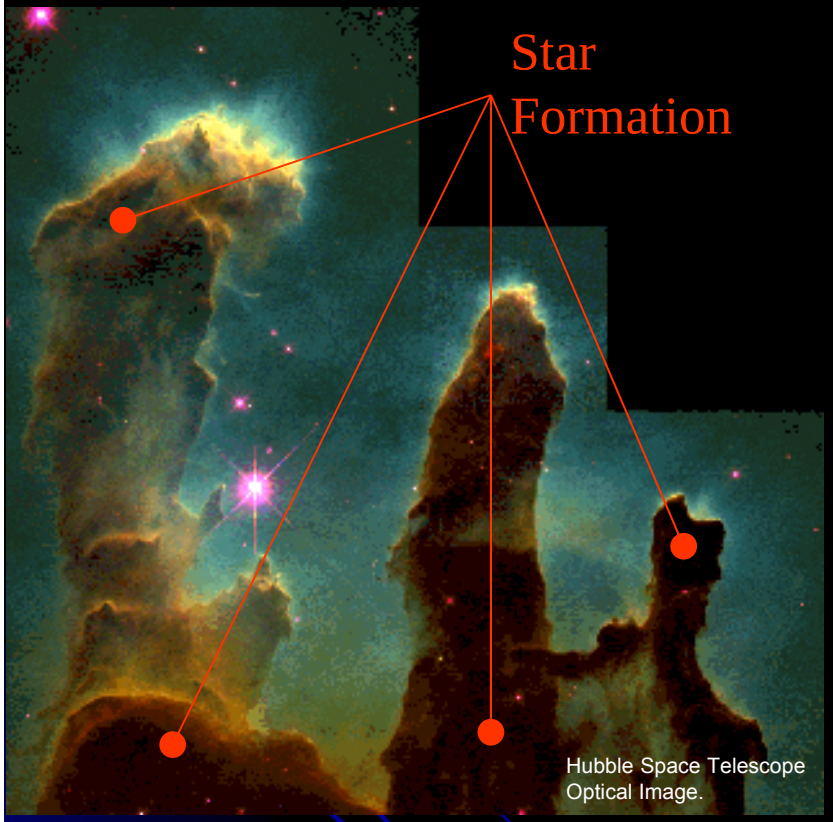
A toy model: A dust cloud 5 AU in diameter which absorbs 0.5% of the starlight would heat to 40K as it re-radiates that power.

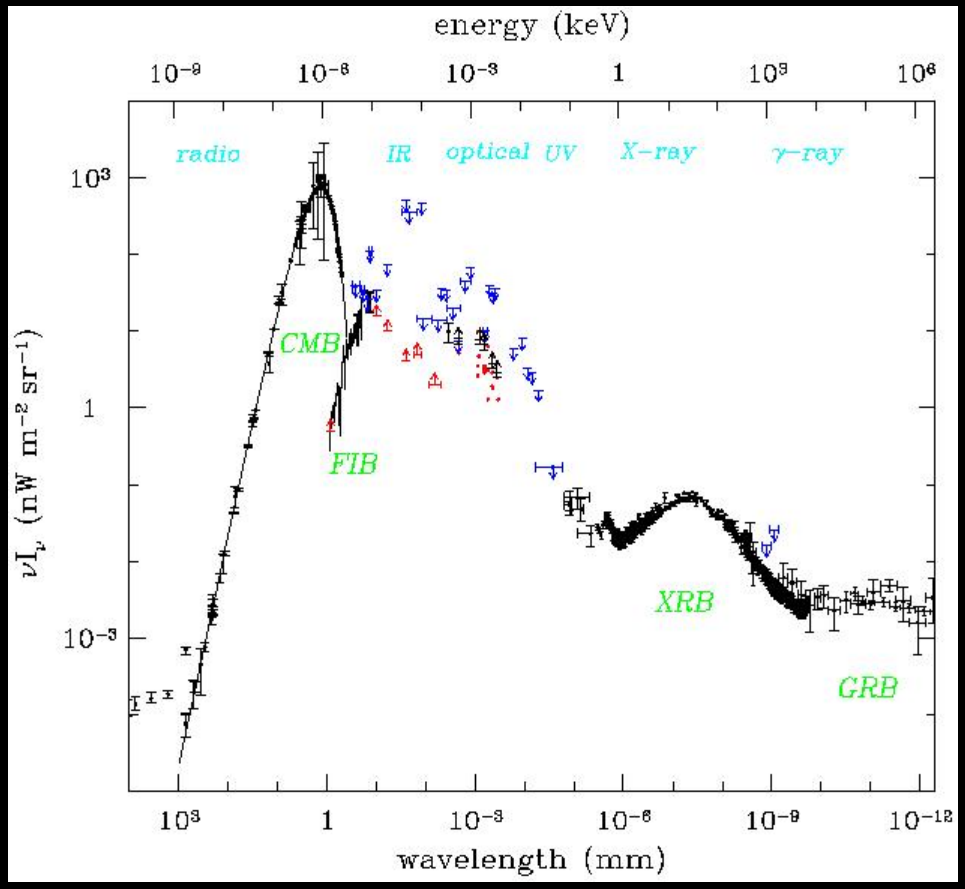


NOTE: The dust is optically thin by 10 microns. The sub-mm emission is proportional to the total dust mass.

Star Formation in Our Galaxy

The Pillars of Creation in the Eagle Nebula

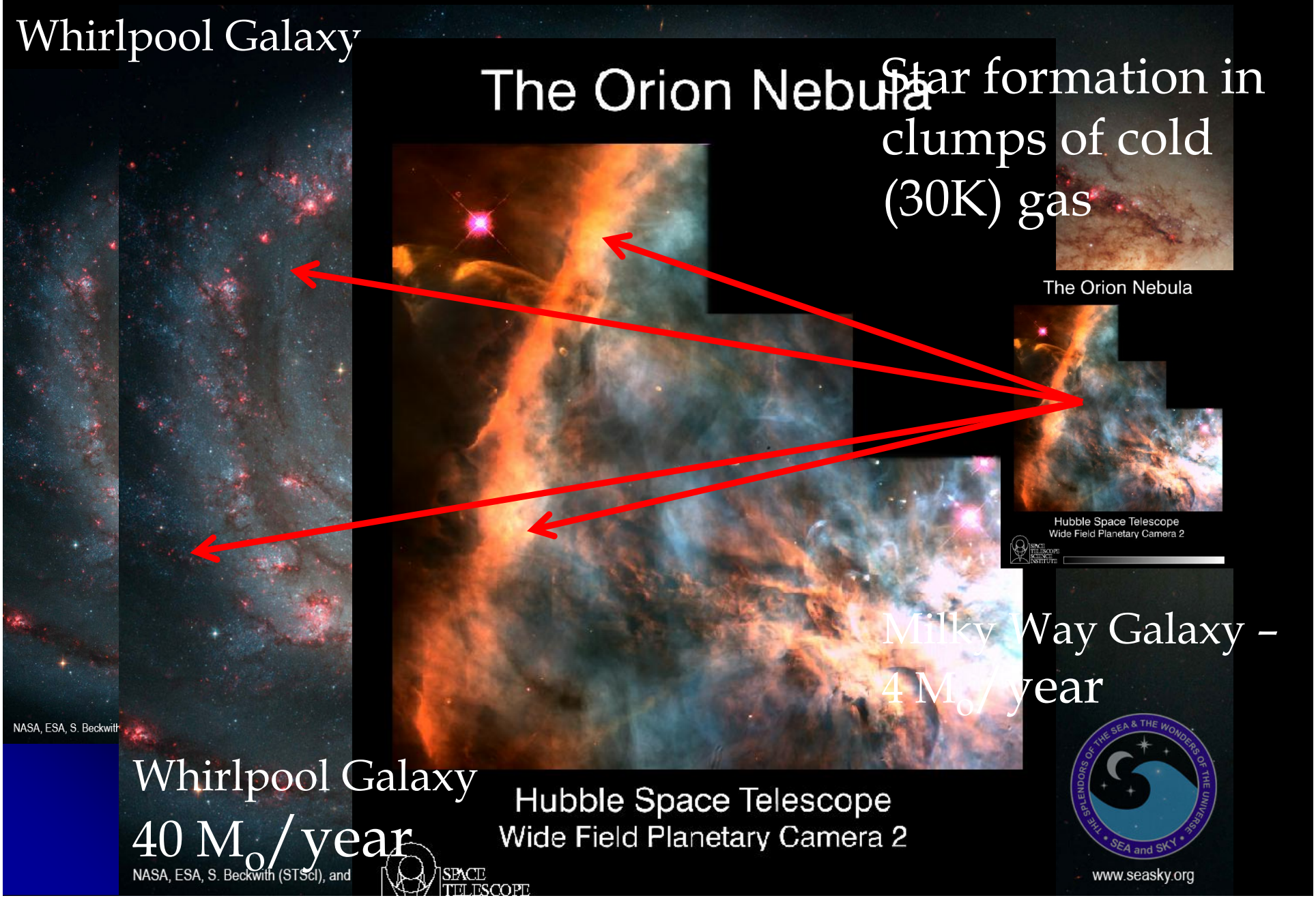




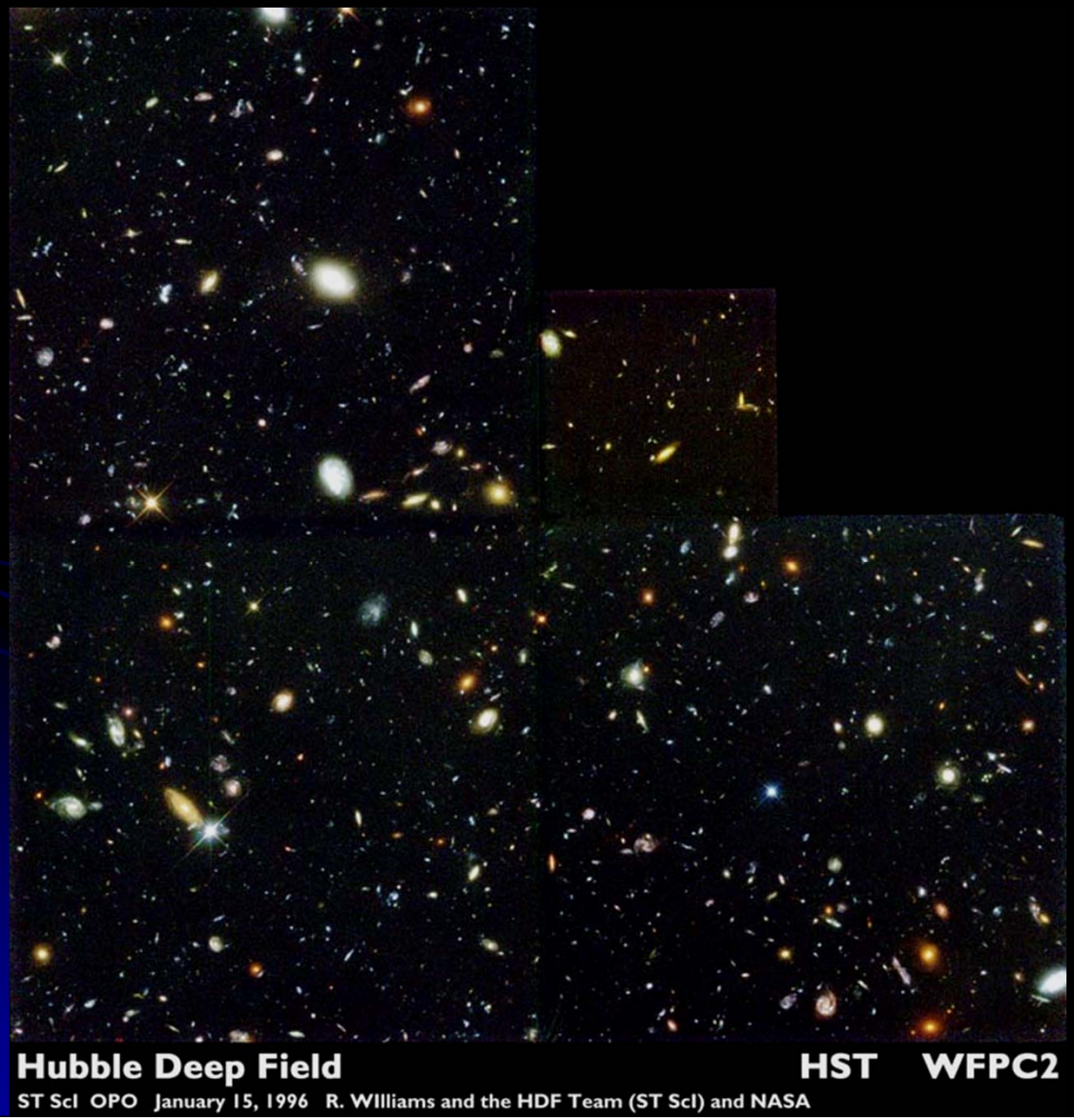
Half of all the starlight emitted since the beginning of the Universe gets absorbed by dust.

BLAST was built to observe this hidden Universe.

Galaxies and Star Formation



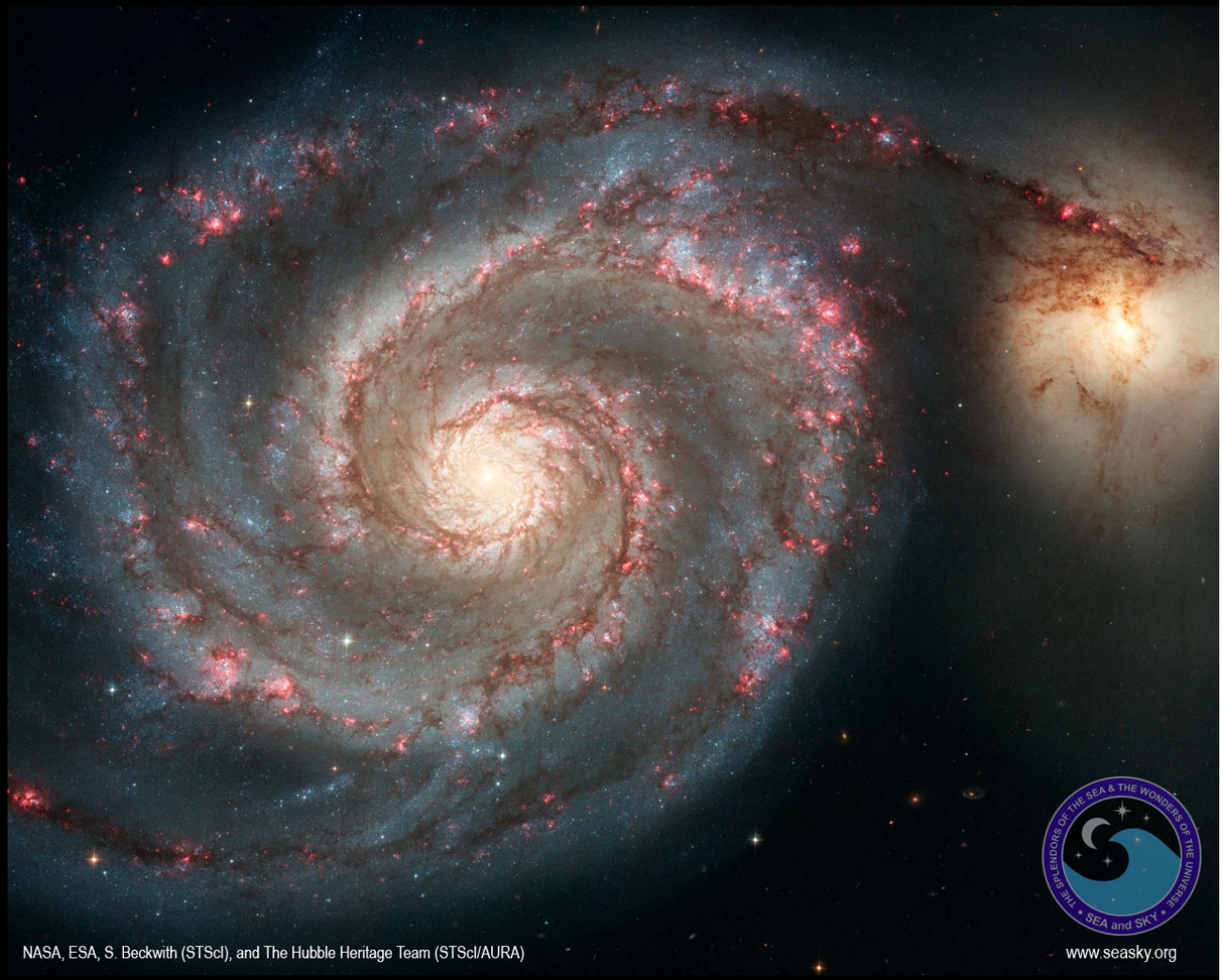
Lot's of Galaxies Out There



Where is the **ENERGY** going?

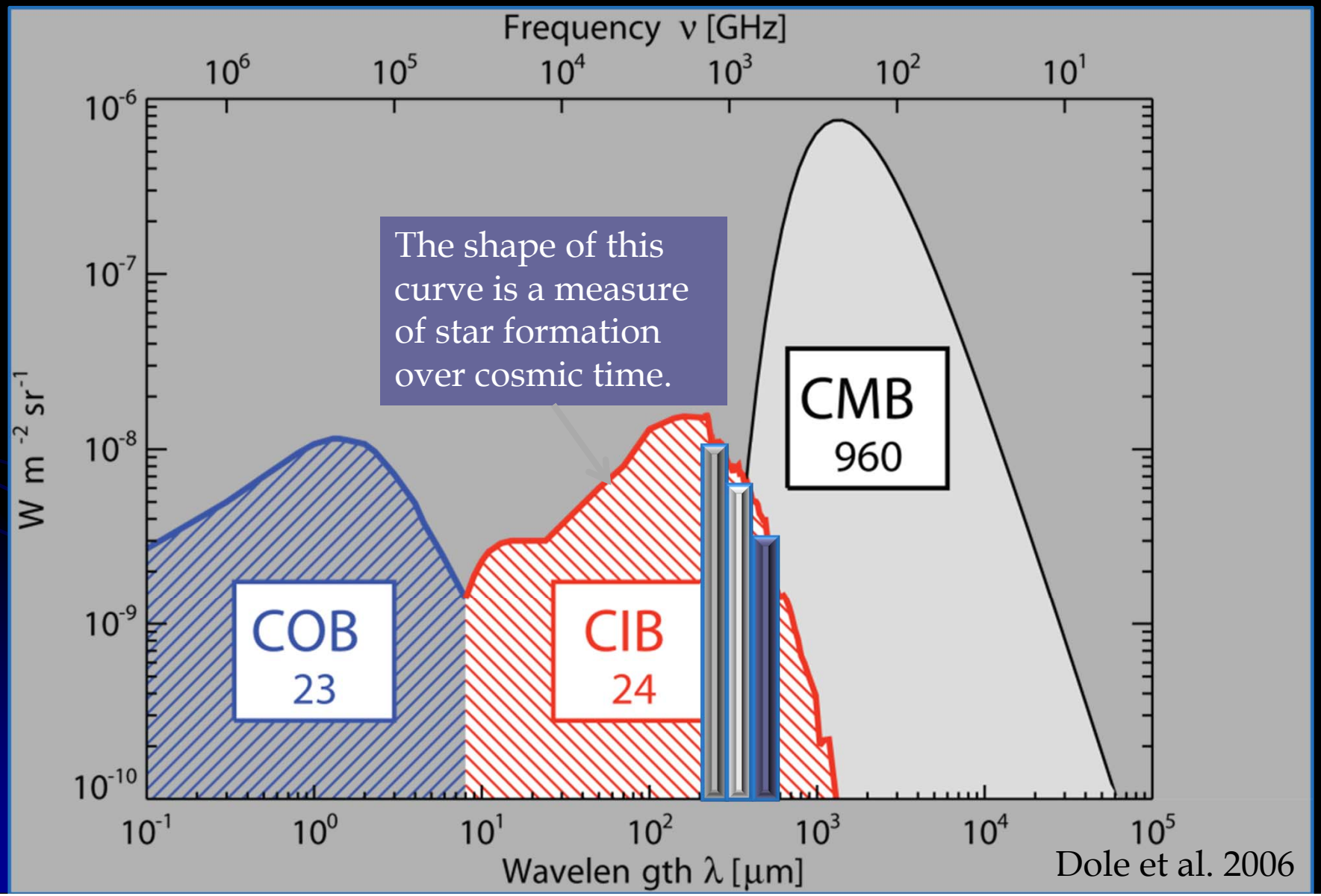
Star Formation in Distant Galaxies

Whirlpool Galaxy
25 million light years away.
Right next door!
It makes 40 stars per year.



4000 stars are made per year in this galaxy which is over 12 BILLION light years away.

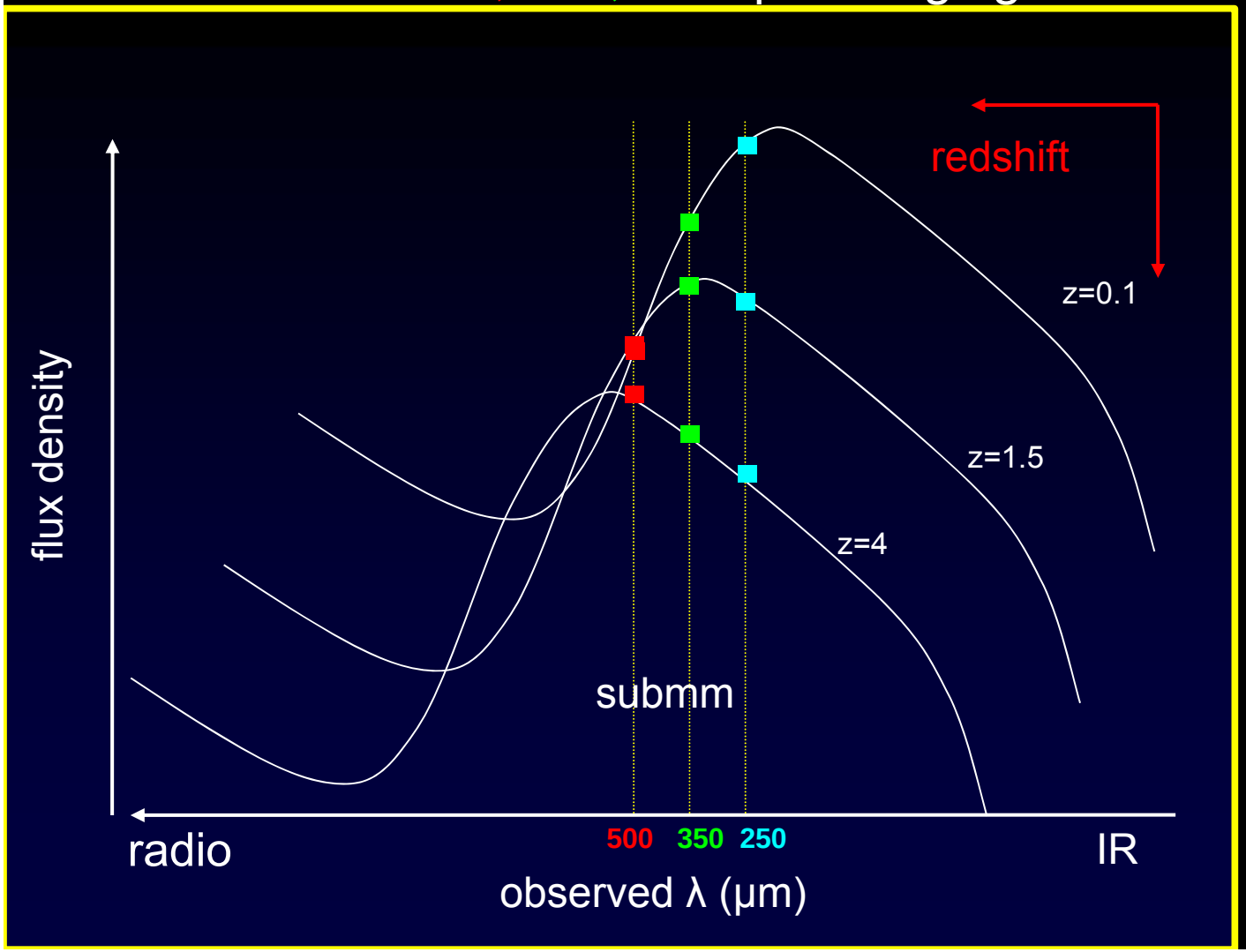
Cosmic Infrared Background



Dole et al. 2006

Submillimeter Photometry

Simultaneous 500, 350, 250 μm imaging



BLAST filters: sensitive to **bolometric flux** colours function of **redshift**

bolometric luminosity (SFR)

Study the Evolution of Structure

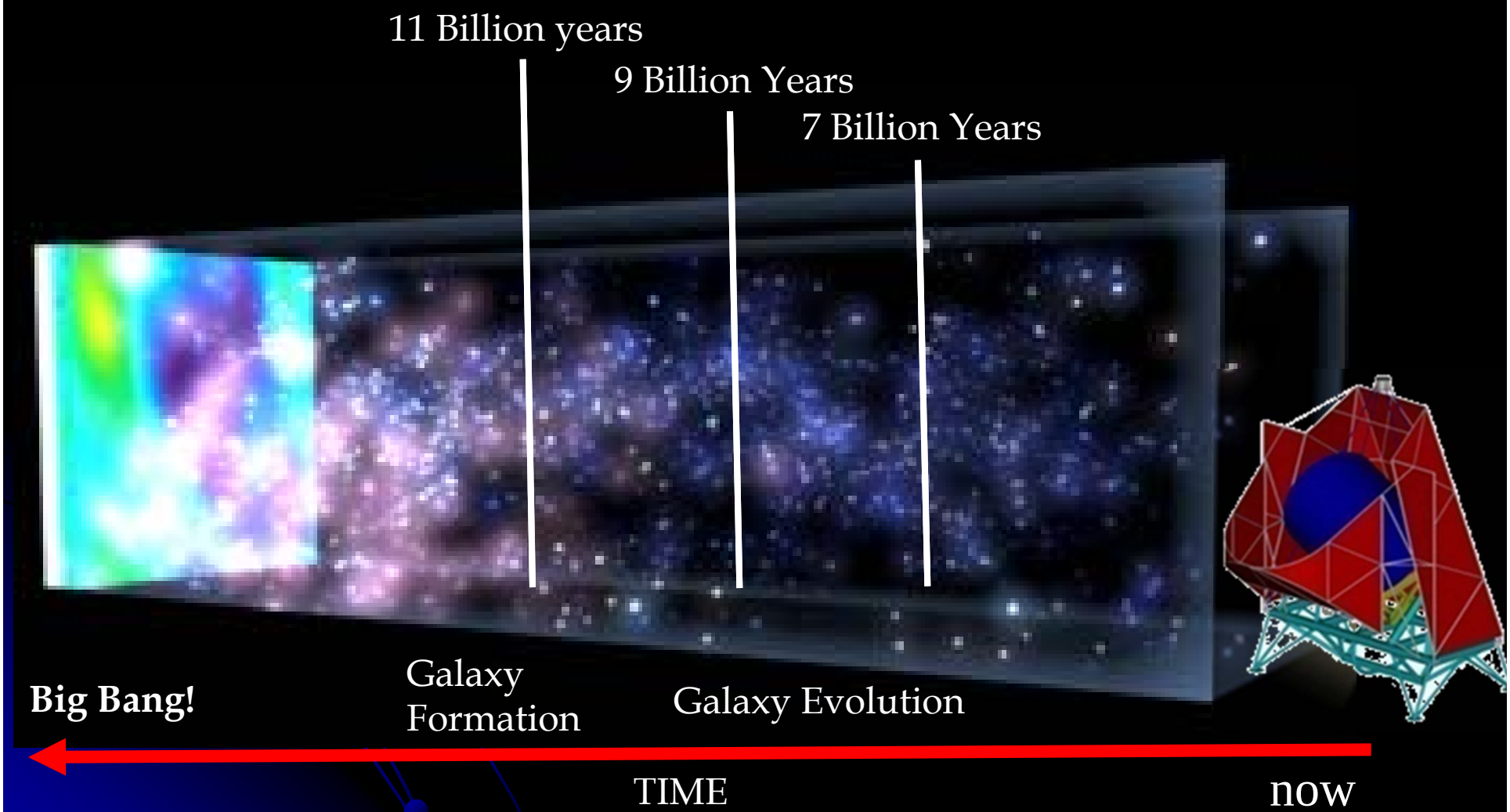
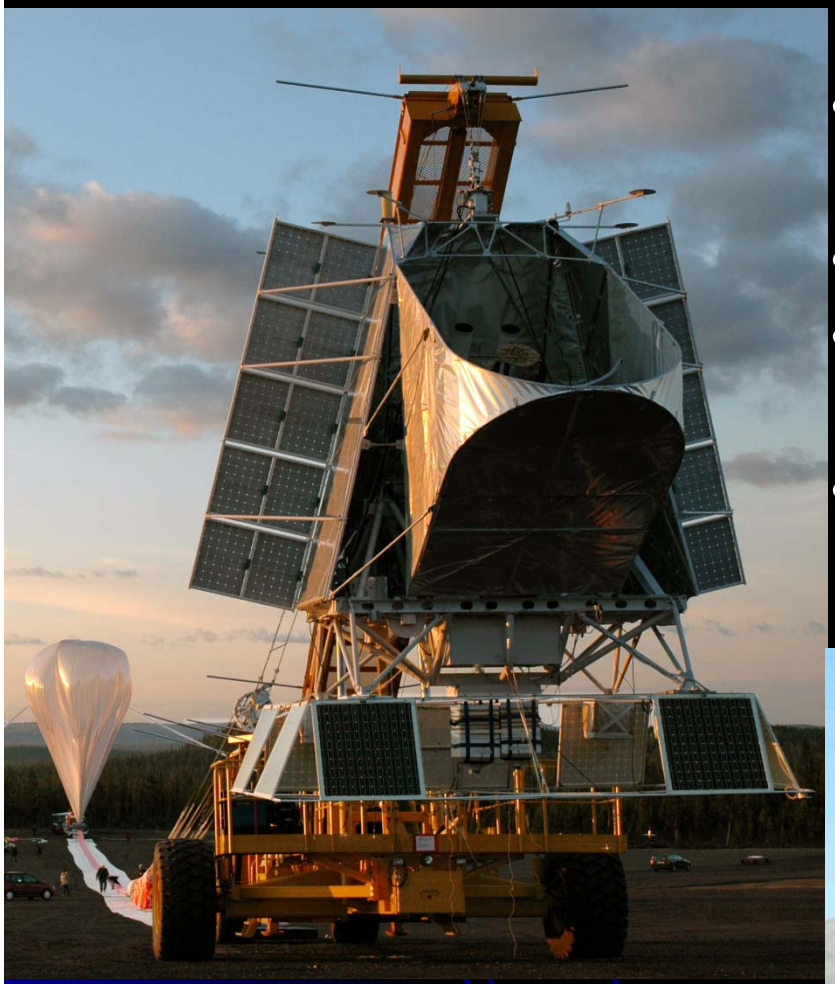


Figure from WMAP Website

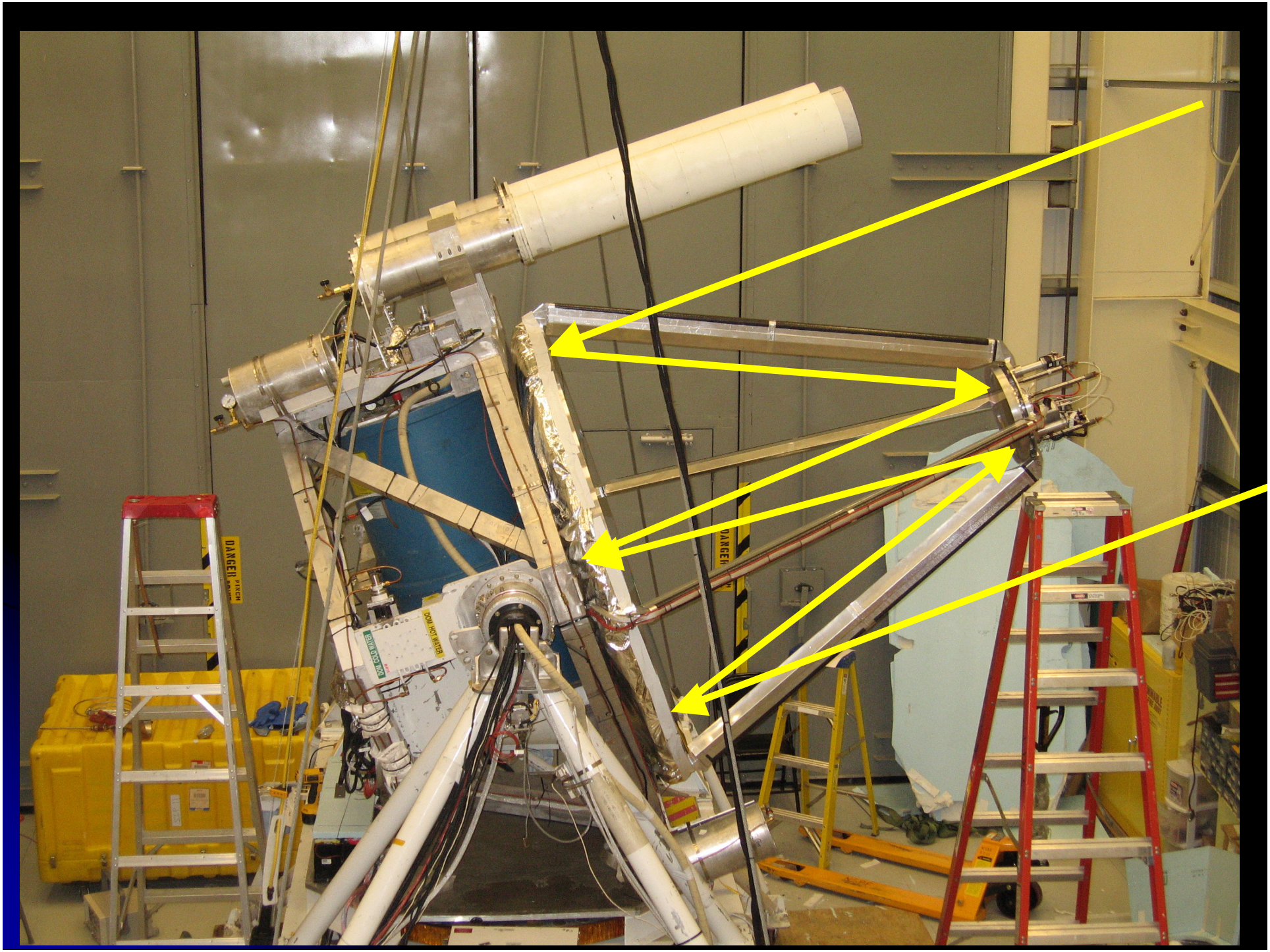
BLAST vs. HUMMER



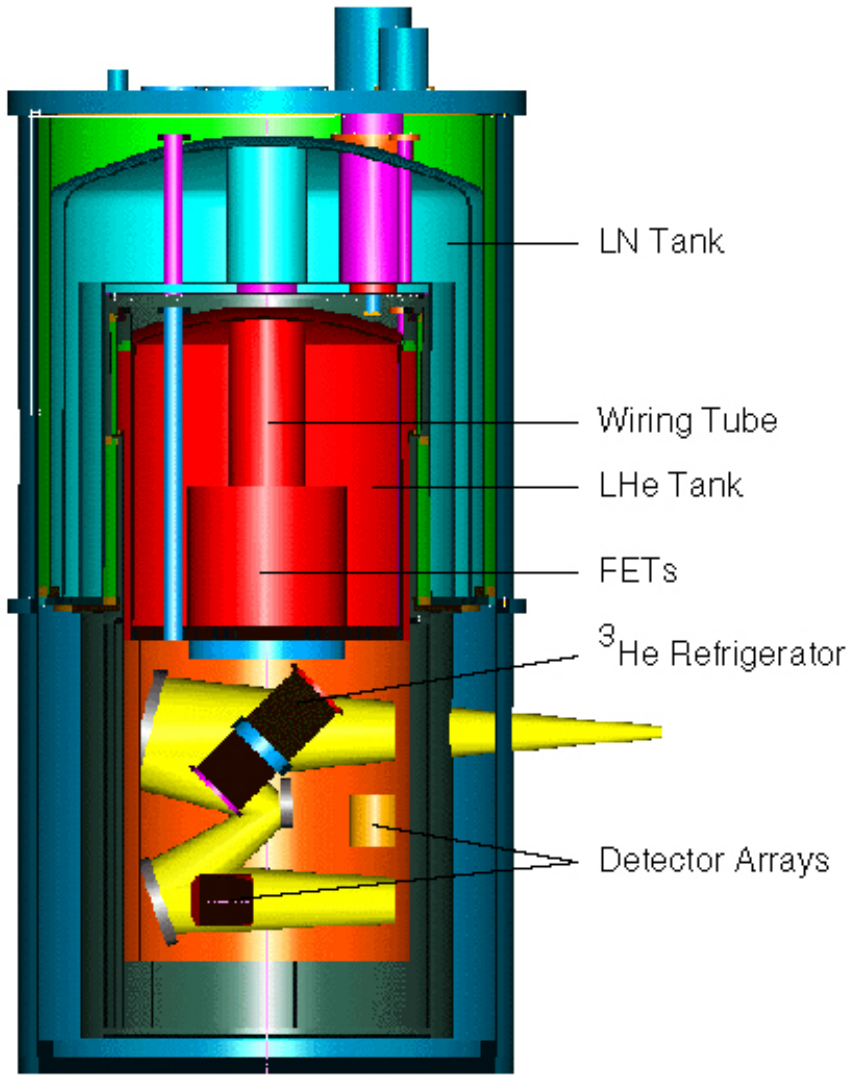
- Approximately the same size and weight

- Hummer: 0-100 km/hr in 9 seconds
- BLAST: Circumpolar in 14 days

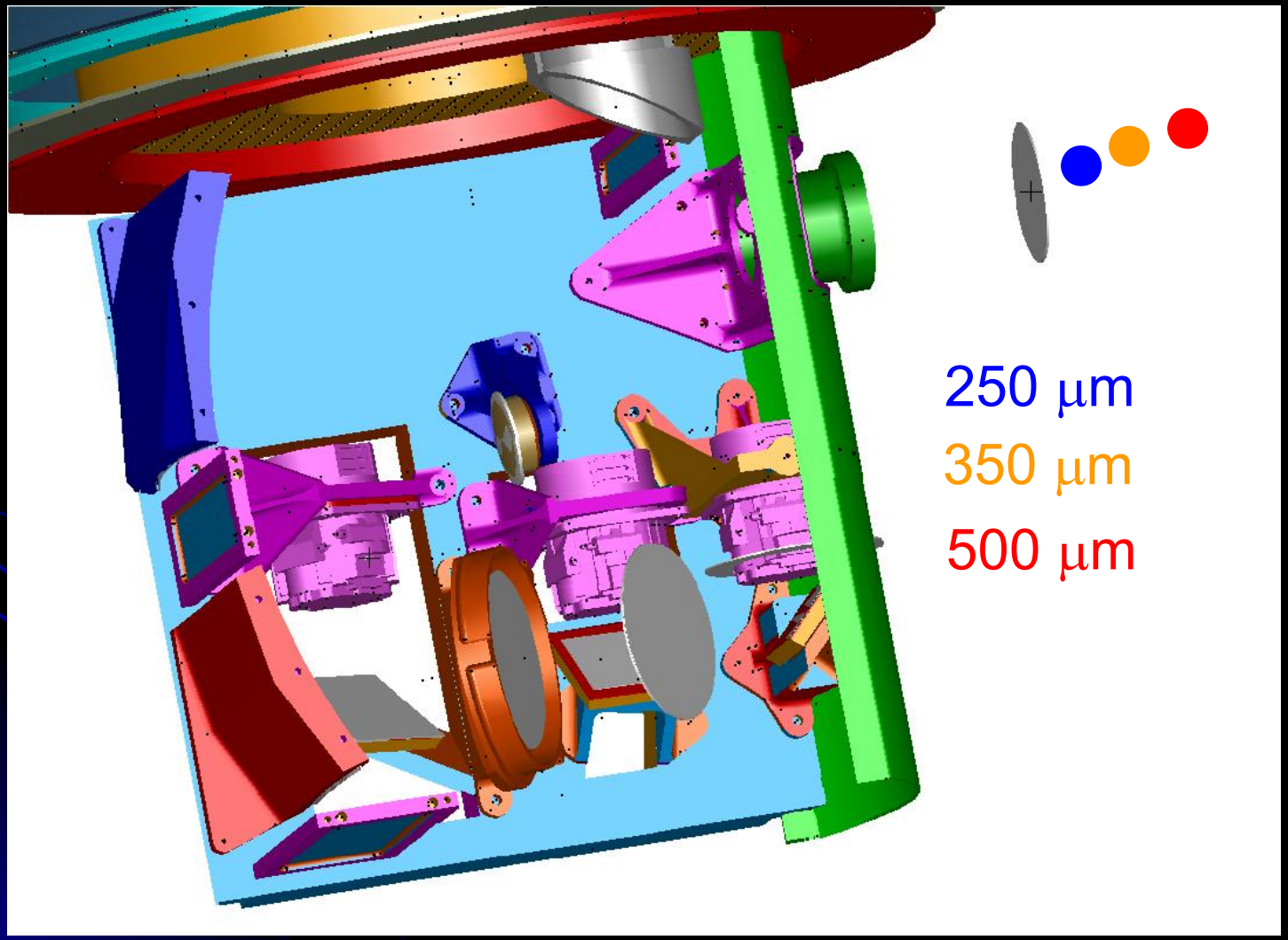
- BLAST sub-mm sensitivity exceeds that of the Hummer


DANGER
DANGER

Arrays Integrated into Cold Re-imaging Optics Box and Cryostat

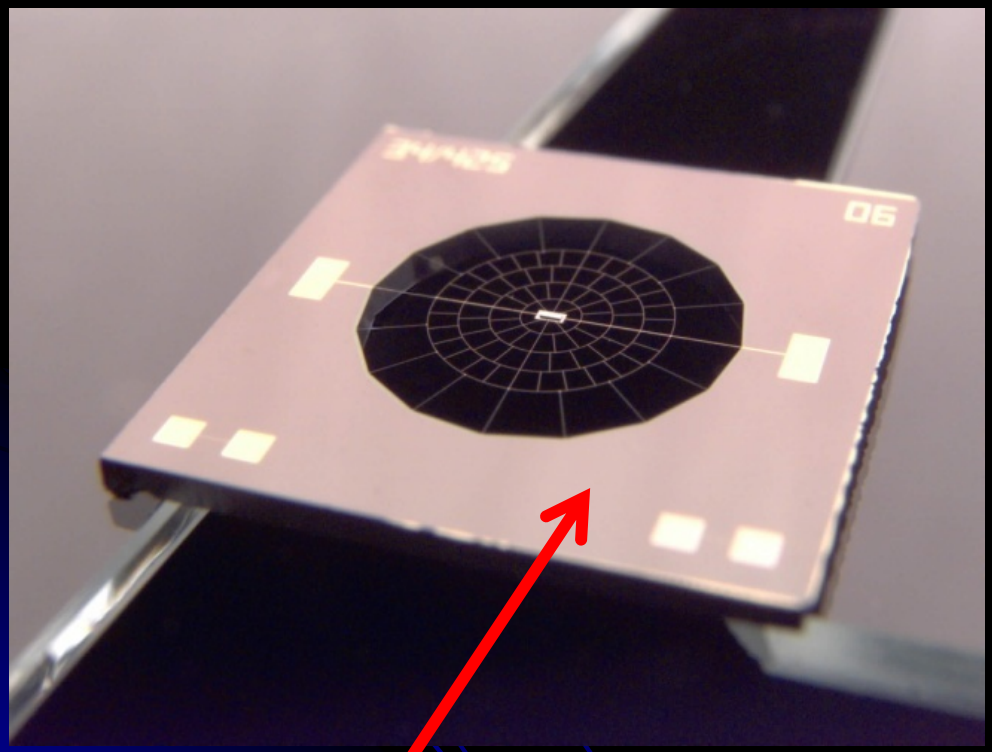


Cold Re-imaging Optics

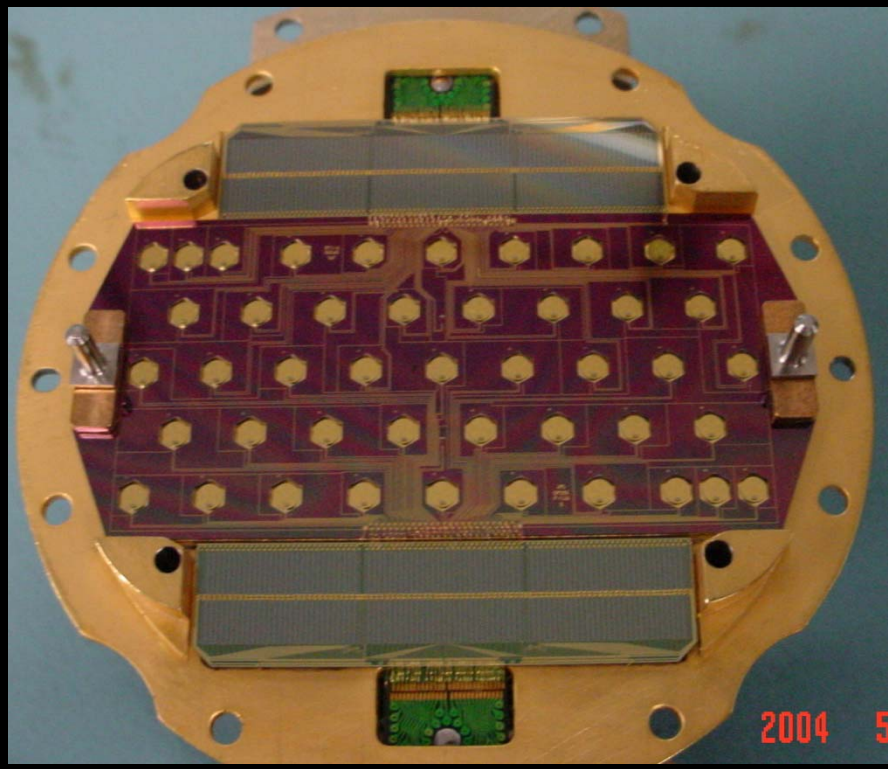


Bolometers => Heat Meters

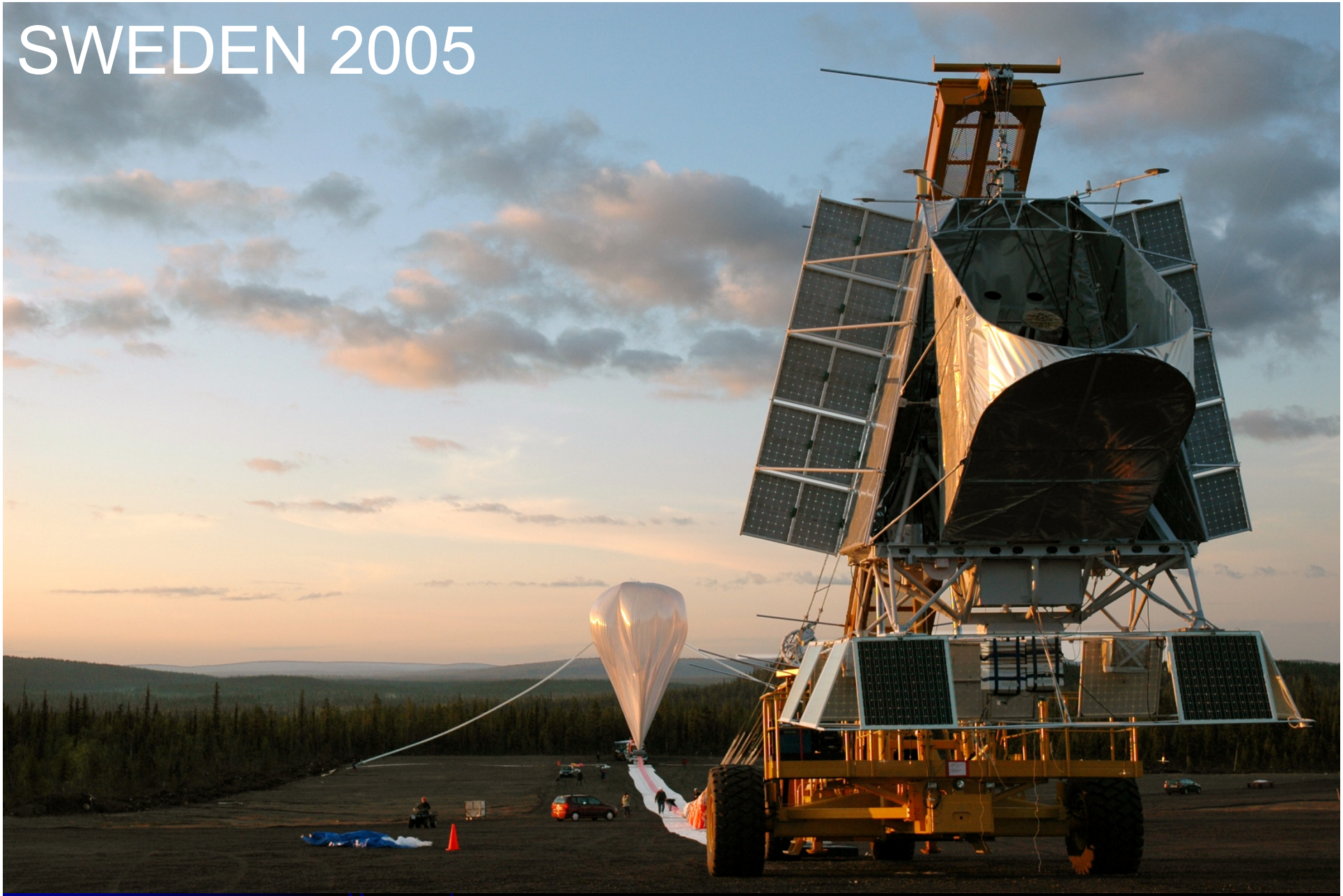
Spider Web Bolometers
Developed at JPL

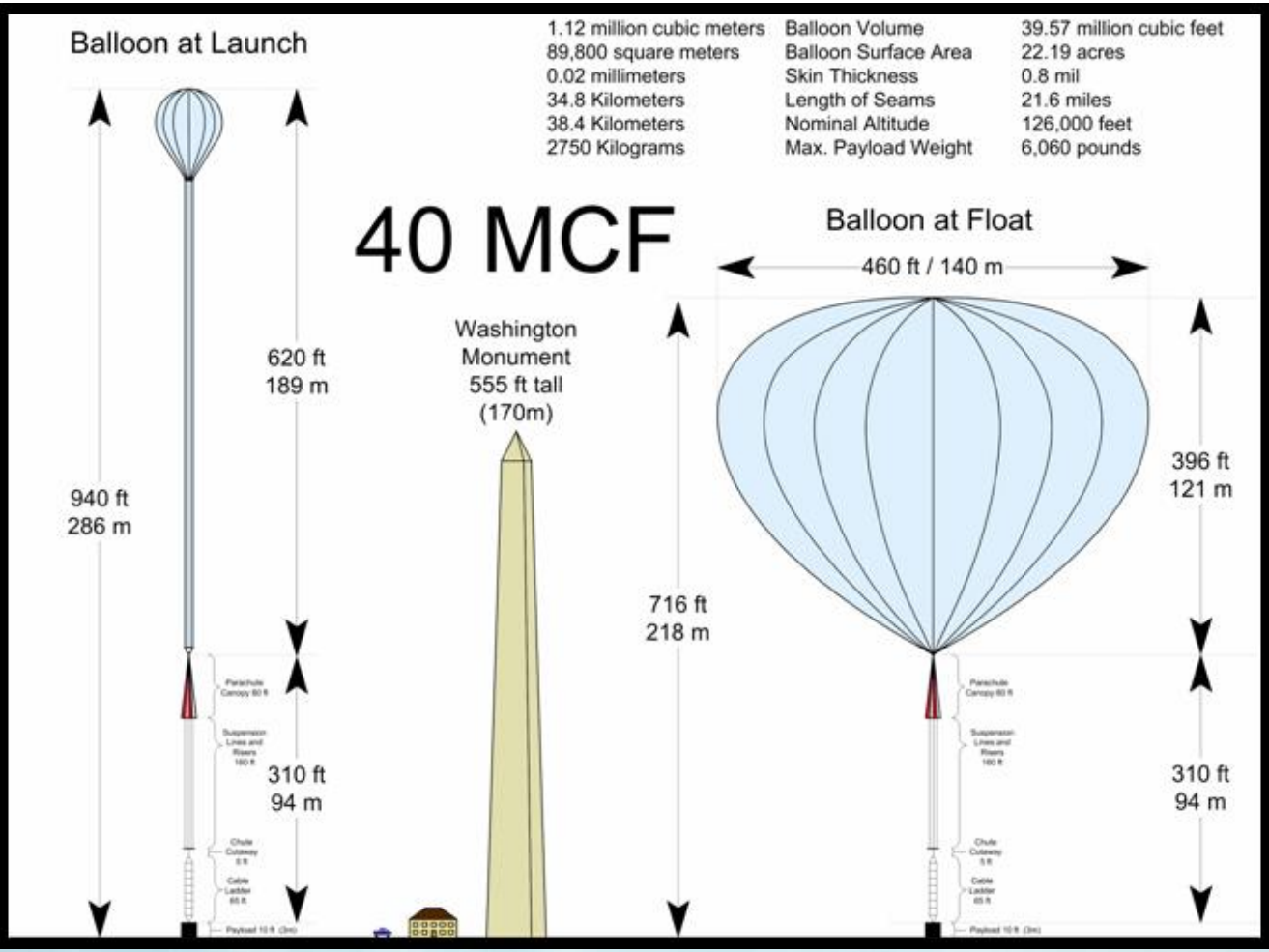


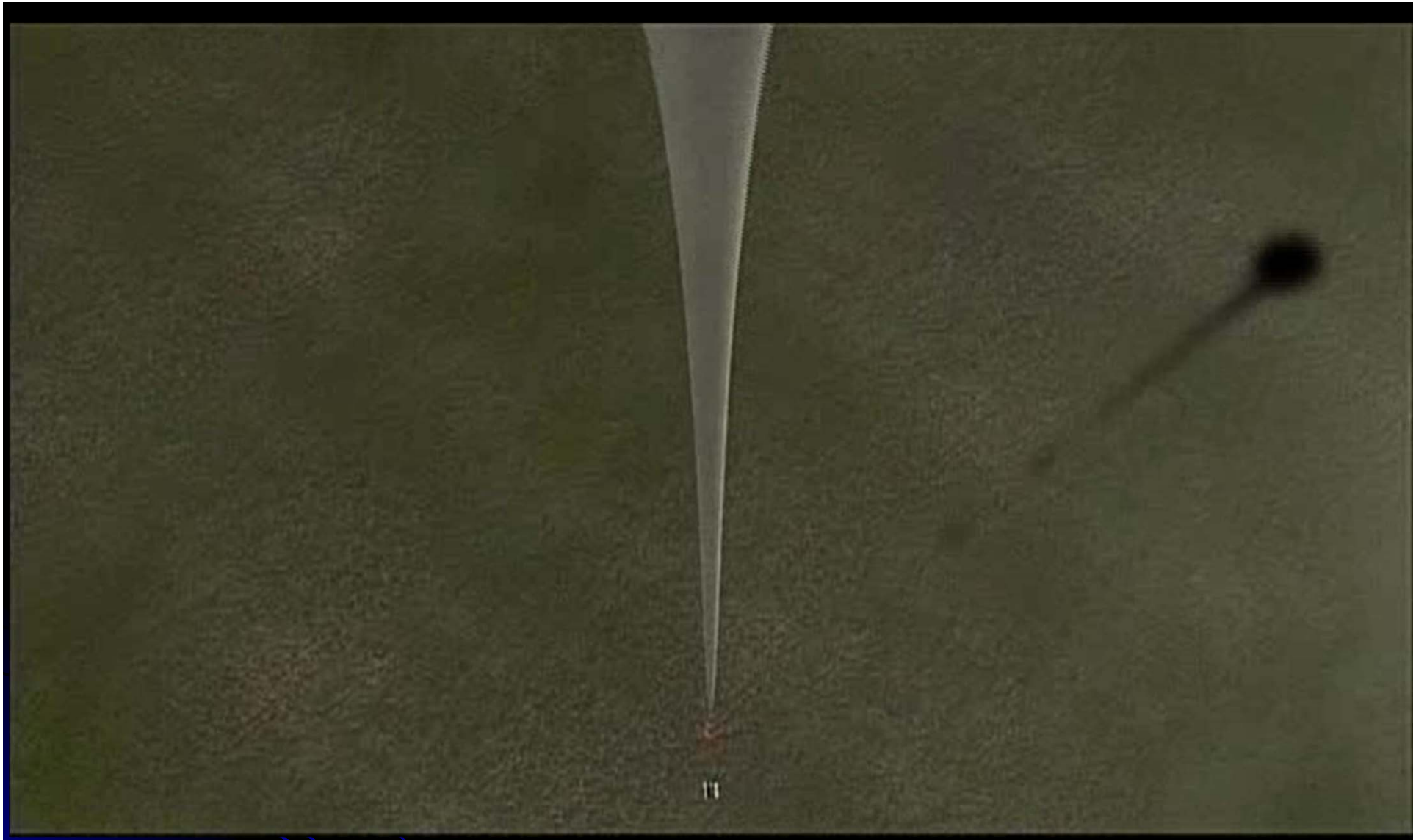
Cooled to 300 mK



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
310 ft 94 m
716 ft 218 m
396 ft 121 m
310 ft 94 m



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

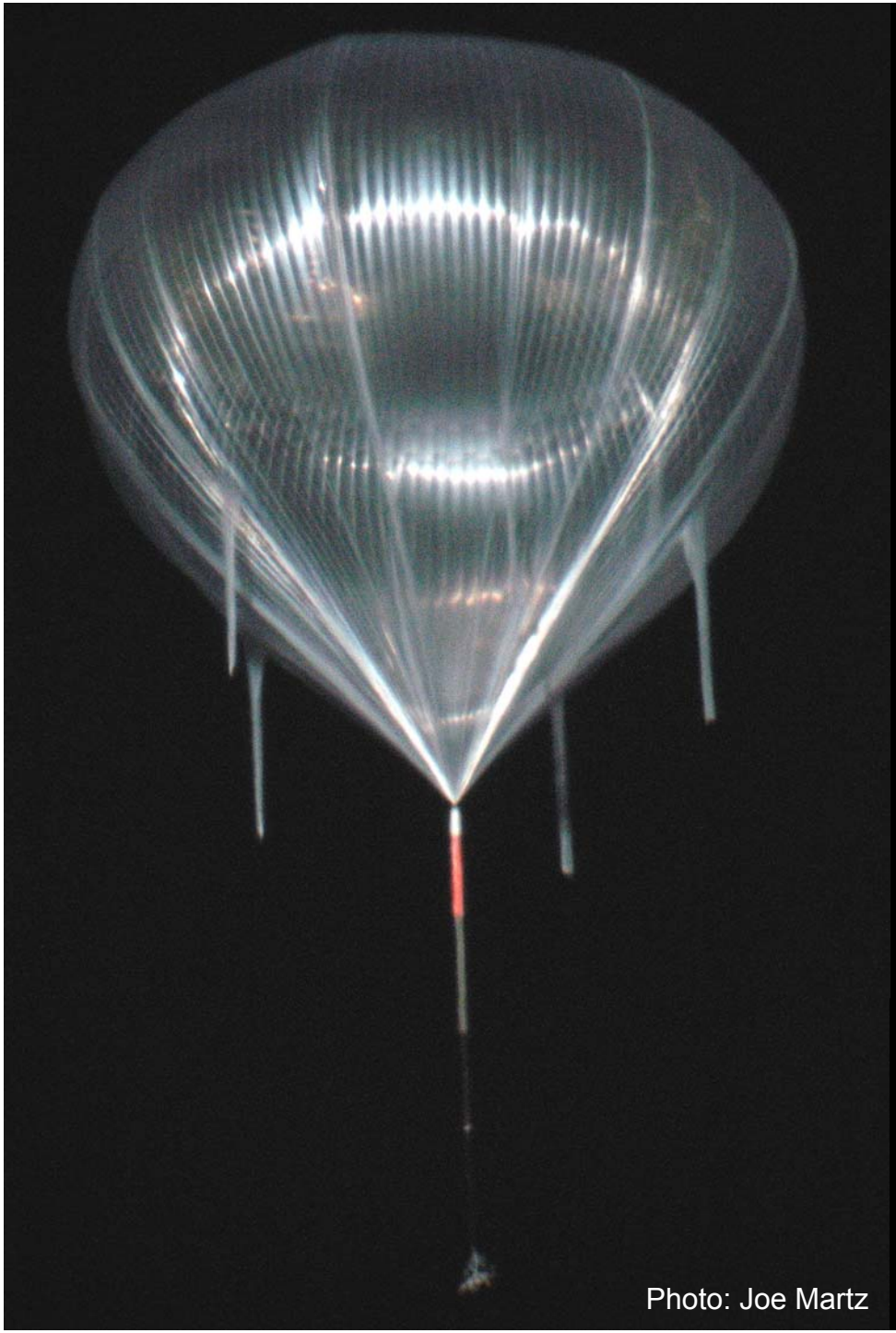
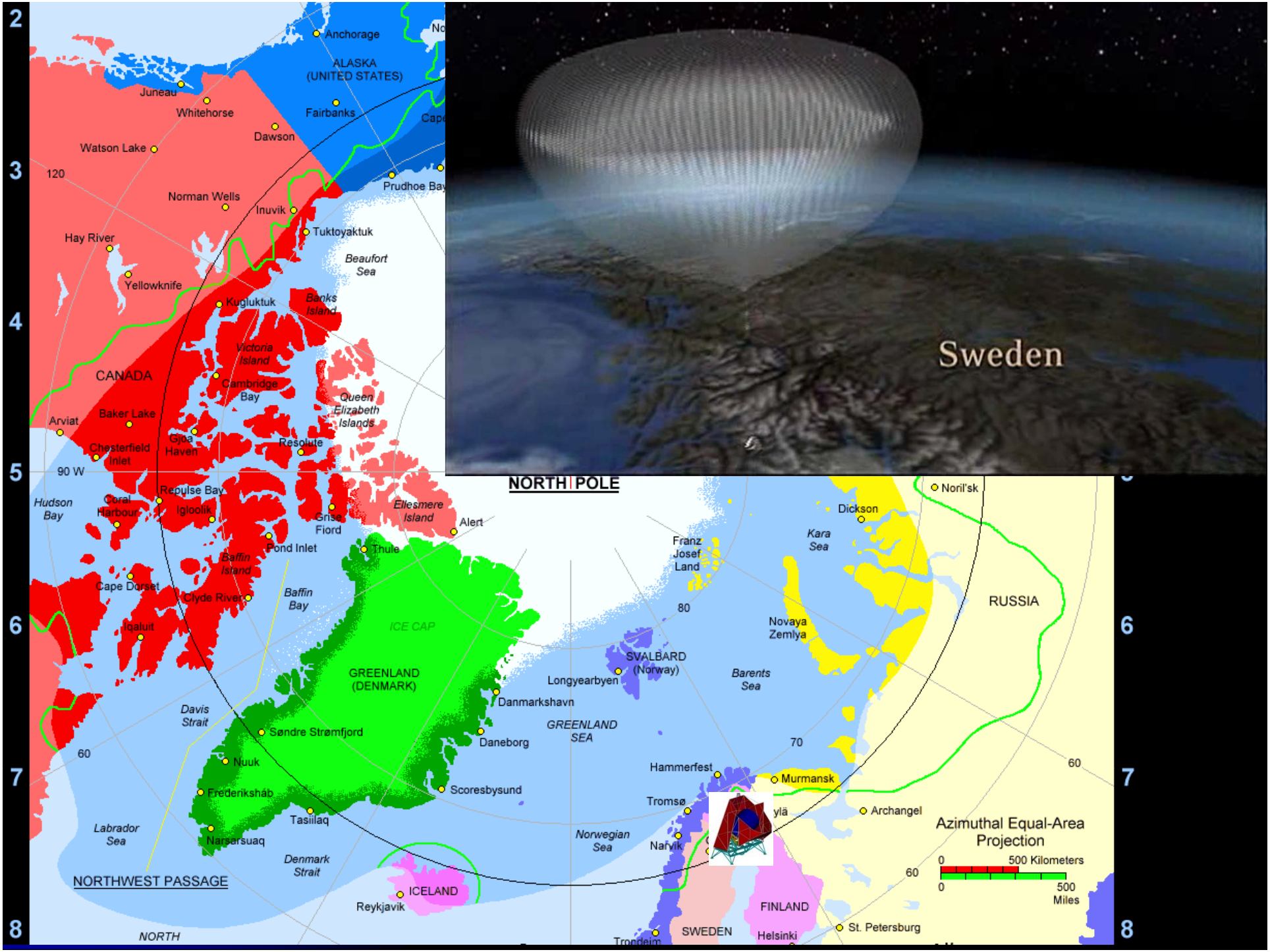


Photo: Joe Martz

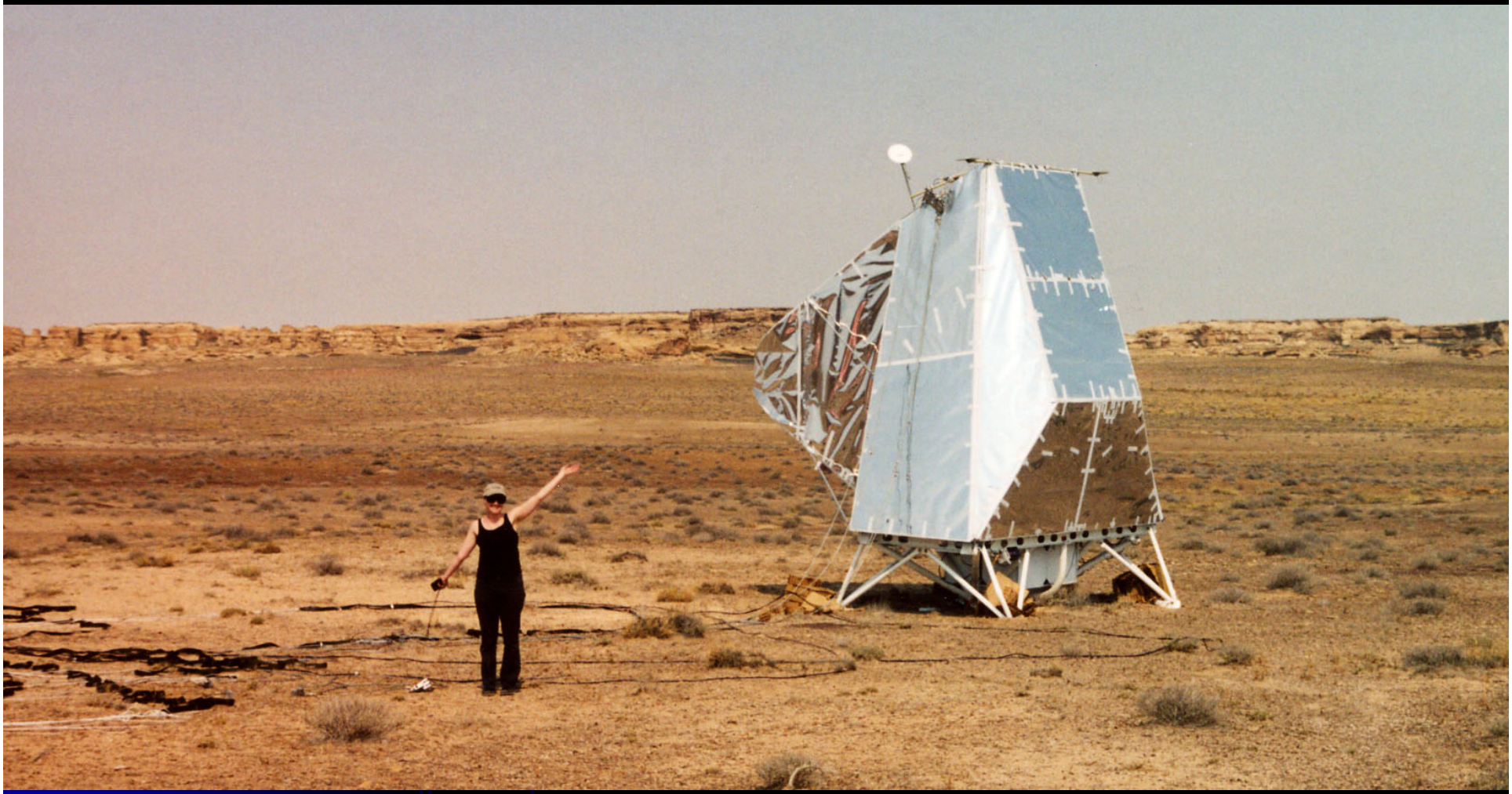
At 120,000 ft

~400 ft in Diameter
28 million cubic feet

UFO or a simple
Submillimeter Experiment?


Sweden
NORTH POLE
Anchorage
ALASKA
(UNITED STATES)
Juneau
Whitehorse
Fairbanks
Dawson
Watson Lake
Prudhoe Bay
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
Repulse Bay
Hudson
Bay
Coral
Harbour
Igloolik
Grise
Fiord
Ellesmere
Island
Alert
Pond Inlet
Thule
Baffin
Island
Cape Dorset
Clyde River
Baffin
Bay
Iqaluit
ICE CAP
GREENLAND
(DENMARK)
Davis
Strait
Søndre Strømfjord
Nuuk
Frederikshåb
Tasiilaq
Narsarsuaq
Labrador
Sea
Denmark
Strait
NORTHWEST PASSAGE
ICELAND
Reykjavik
NORTH
Danmarkshavn
Daneborg
Scoresbysund
GREENLAND
SEA
Norwegian
Sea
Franz
Josef
Land
SVALBARD
(Norway)
Longyearbyen
Barents
Sea
Novaya
Zemlya
Kara
Sea
Dickson
Noril'sk
RUSSIA
Hammerfest
Murmansk
Tromsø
Narvik
Archangel
FINLAND
Helsinki
SWEDEN
St. Petersburg
Azimuthal Equal-Area
Projection
0
500 Kilometers
0
500
Miles
120
90 W
80
70
60
60
60
2
3
4
5
6
7
8
6
7
8

Not a Scratch!



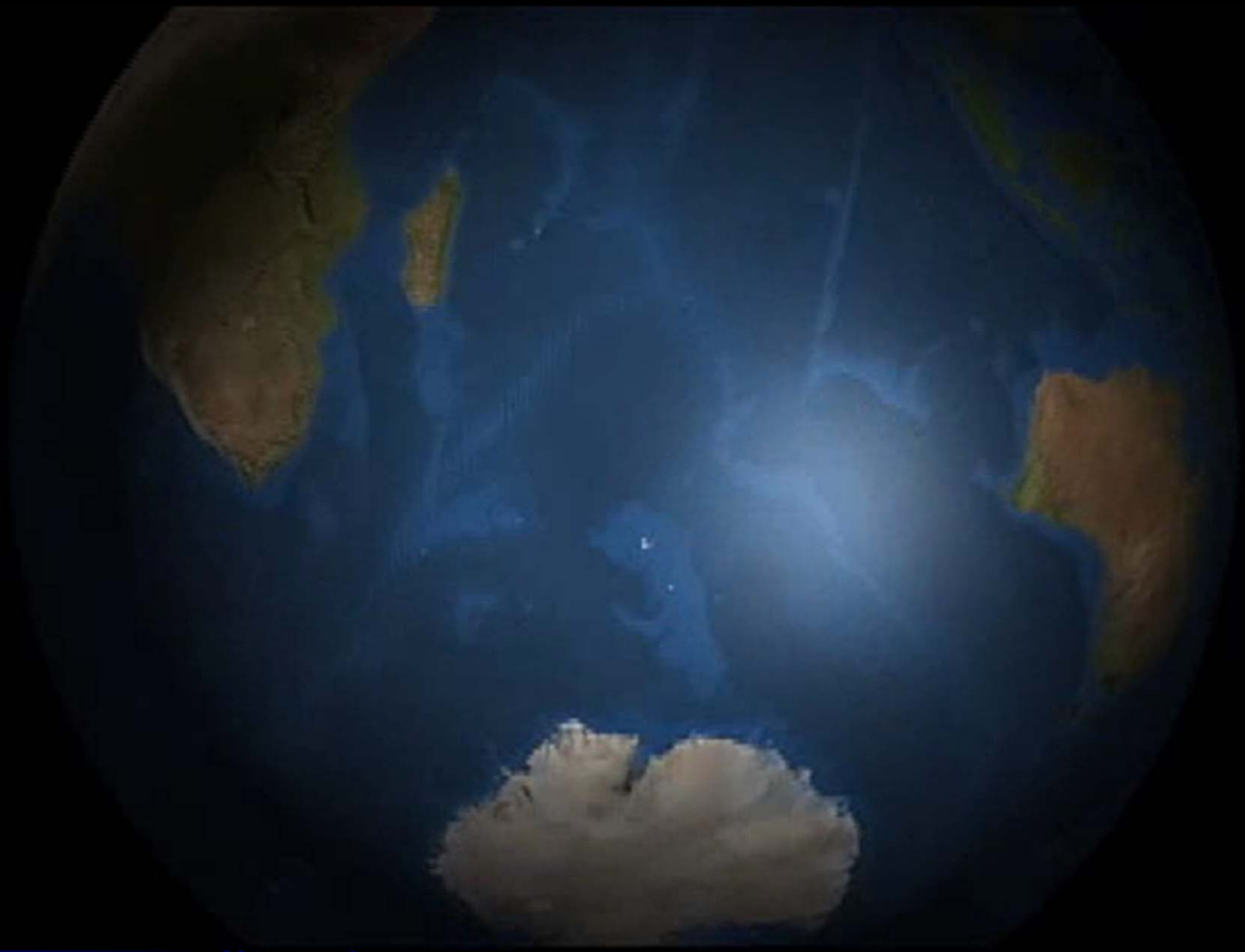
Penn Graduate Student Marie Rex

Photo: Matt Truch

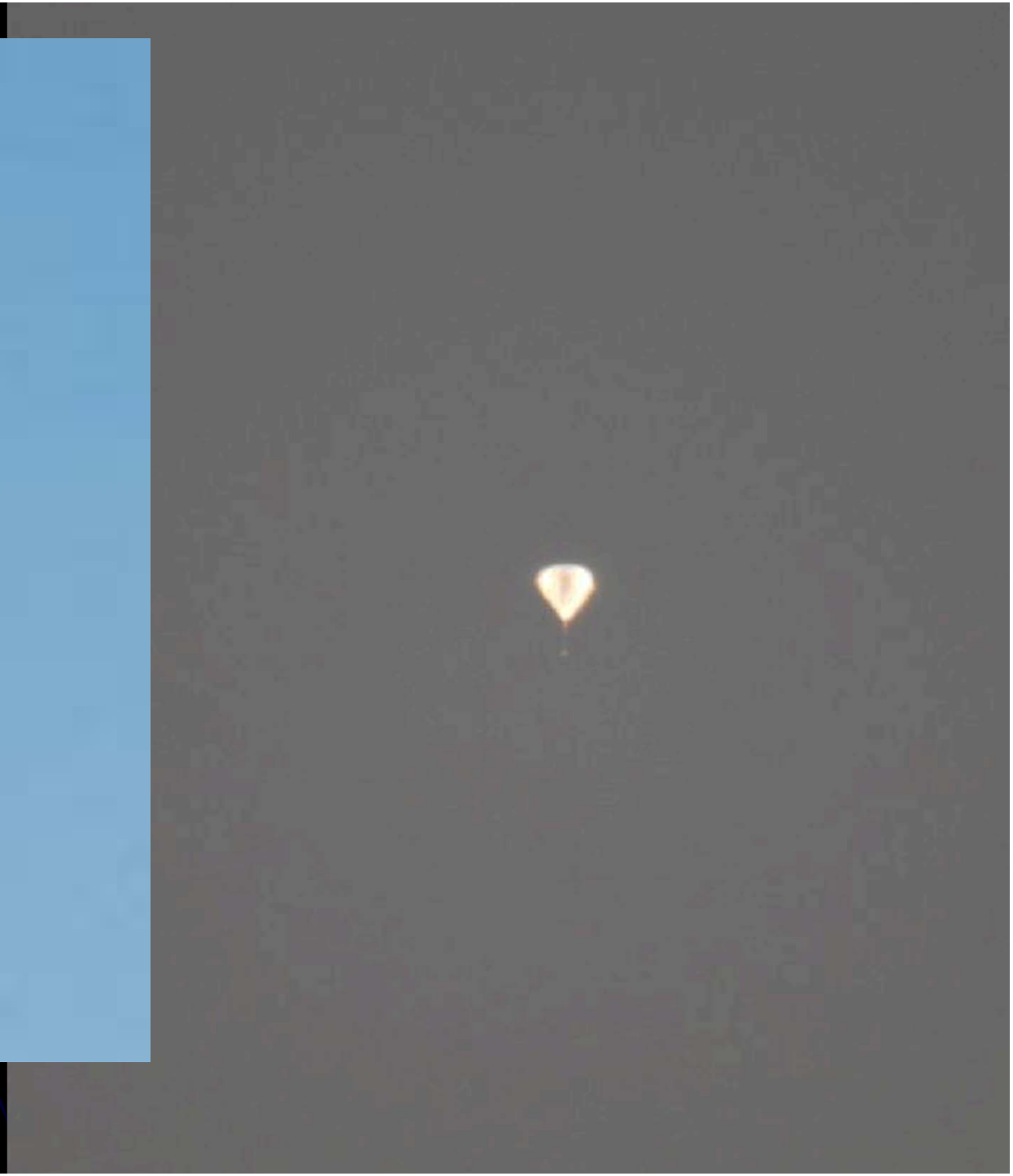
This is a GREAT Landing!!!

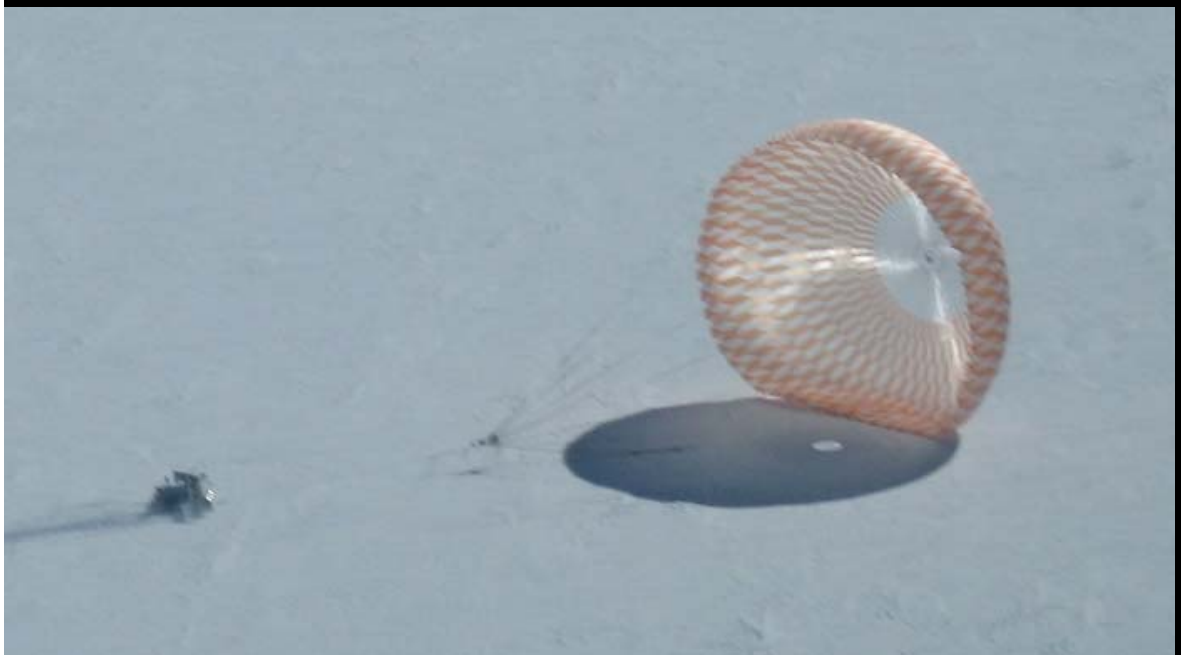
Antarctica

BLAST Flight Path Over Antarctica 2006

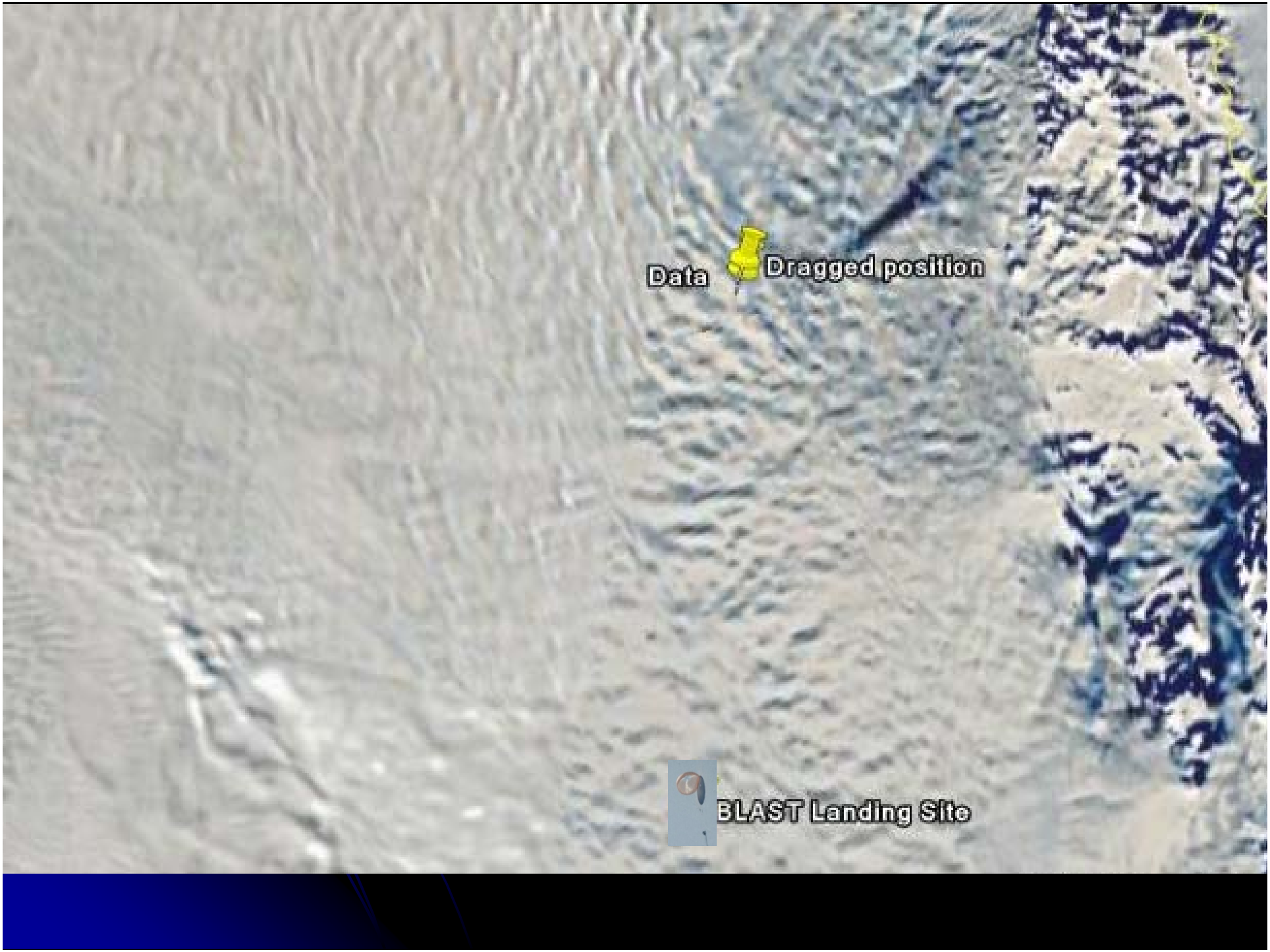


The Termination!



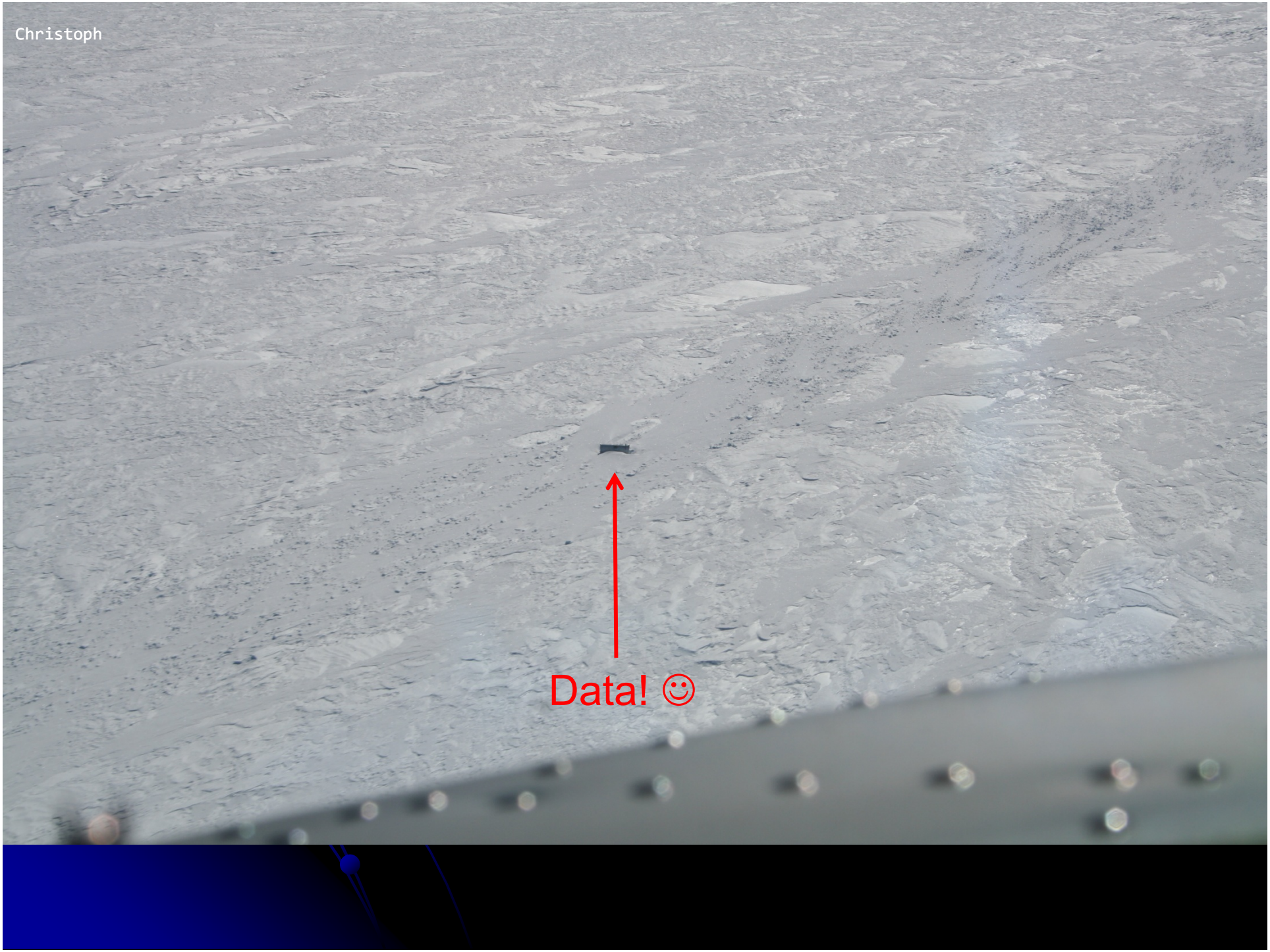


ONE DAY PASSES….


Data
Dragged position
BLAST Landing Site

No data! ☹

TWO DAYS PASS…..


Christoph
Data! ☺

TWO MORE DAYS PASS…..

RECOVERD
JANUARY 07th, 2007
@ 7600'MSL 1600 LT.
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

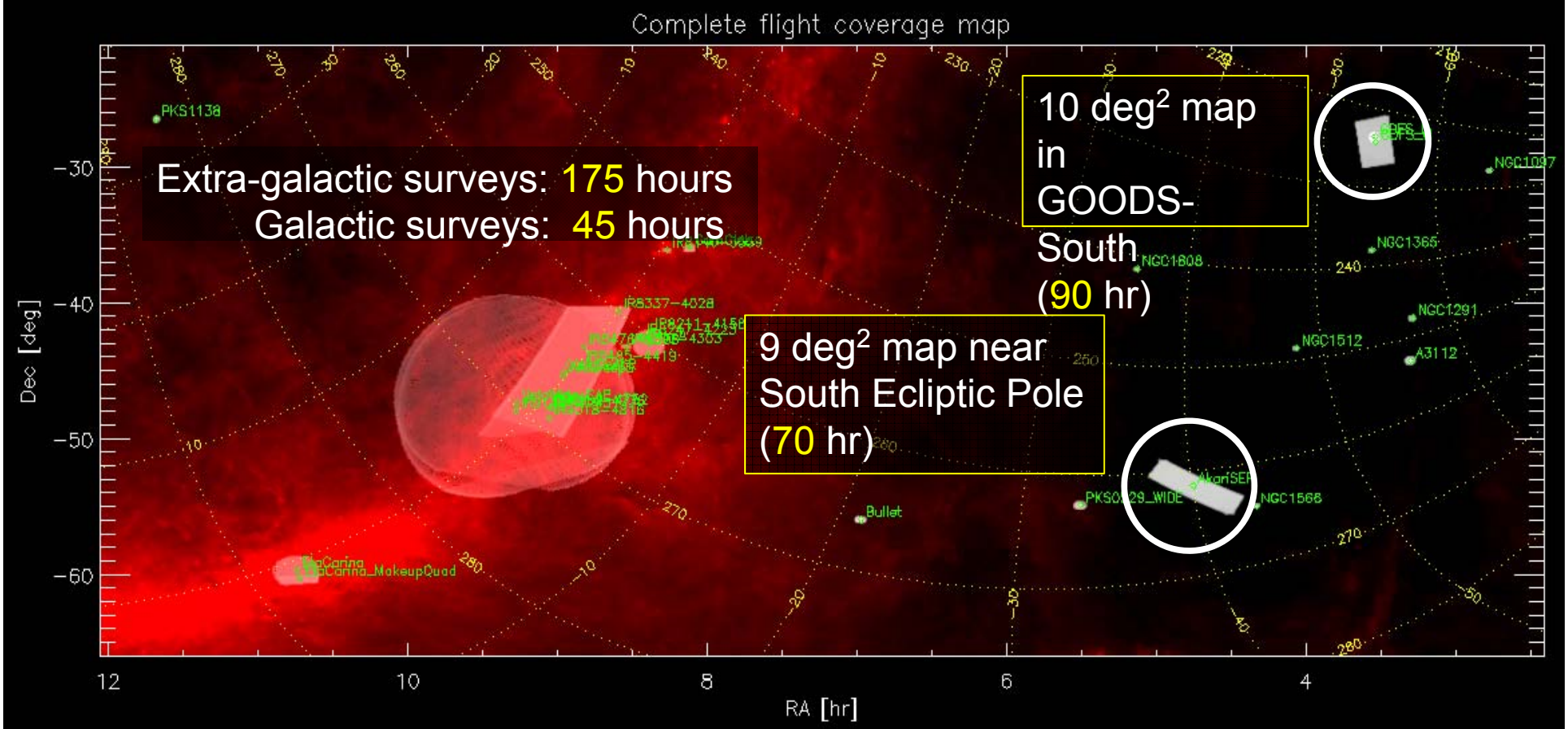
Computers: 5
Processors: 43
110,000 lines of code

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

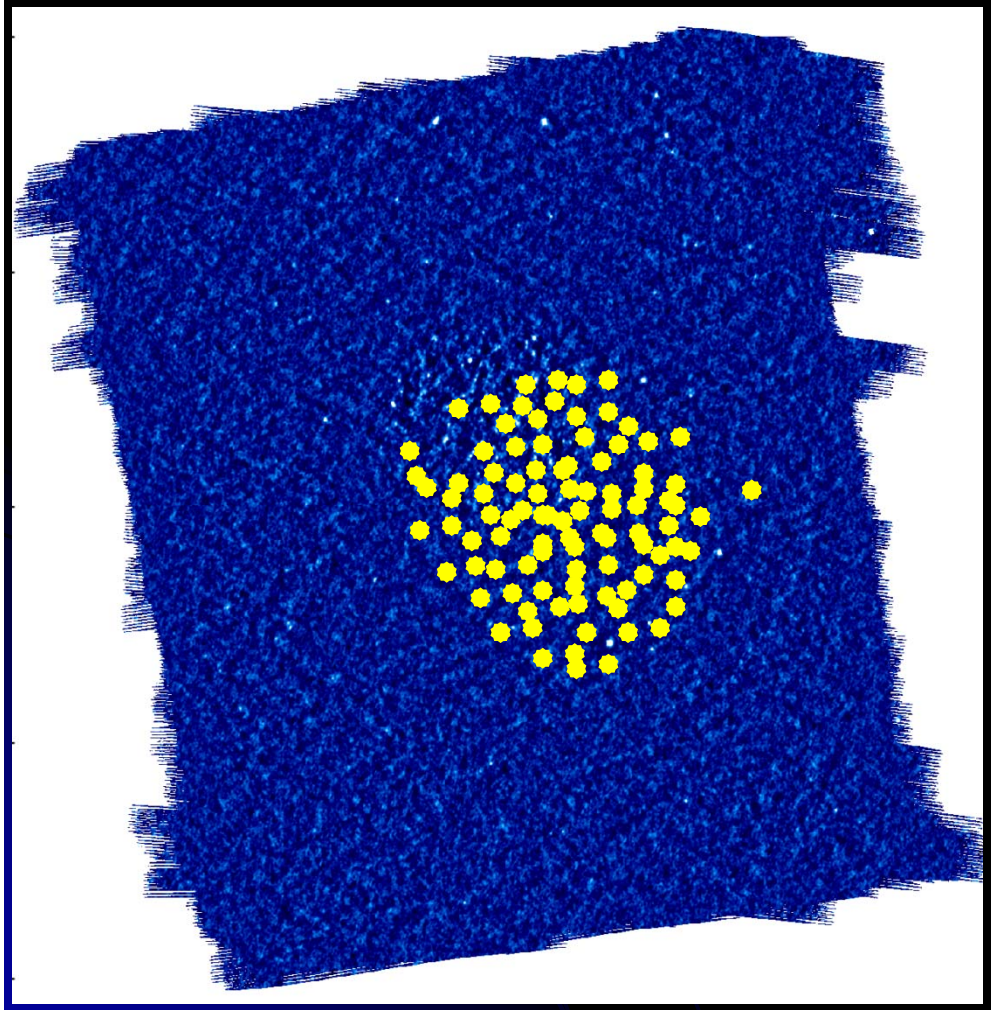
SWAG orders: 5 Mugs, mouse pads, t-shirts, stickers, tattoos

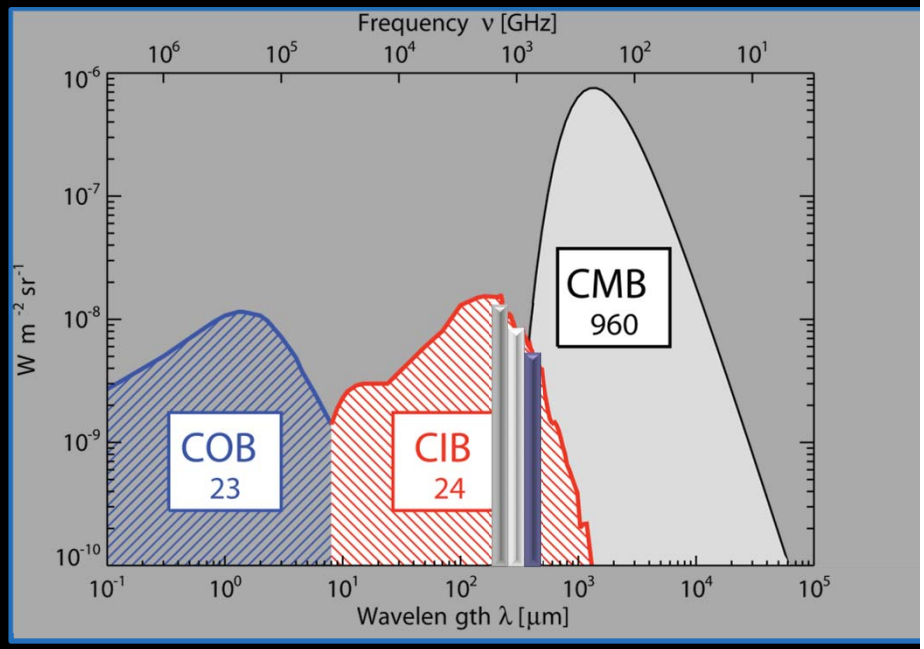
BLAST 2006: 11-day circumpolar flight from McMurdo, Antarctica



Finding all of the Starlight…

9118 galaxies over 720 arcmin^2

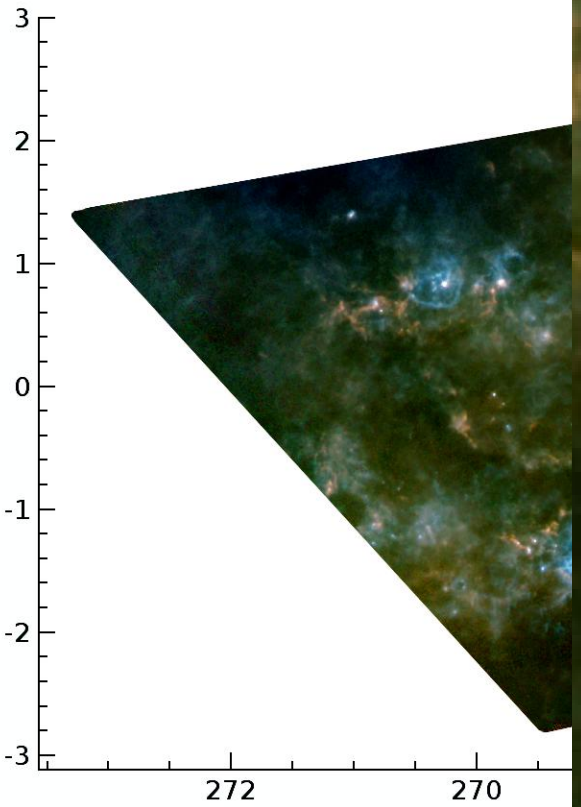


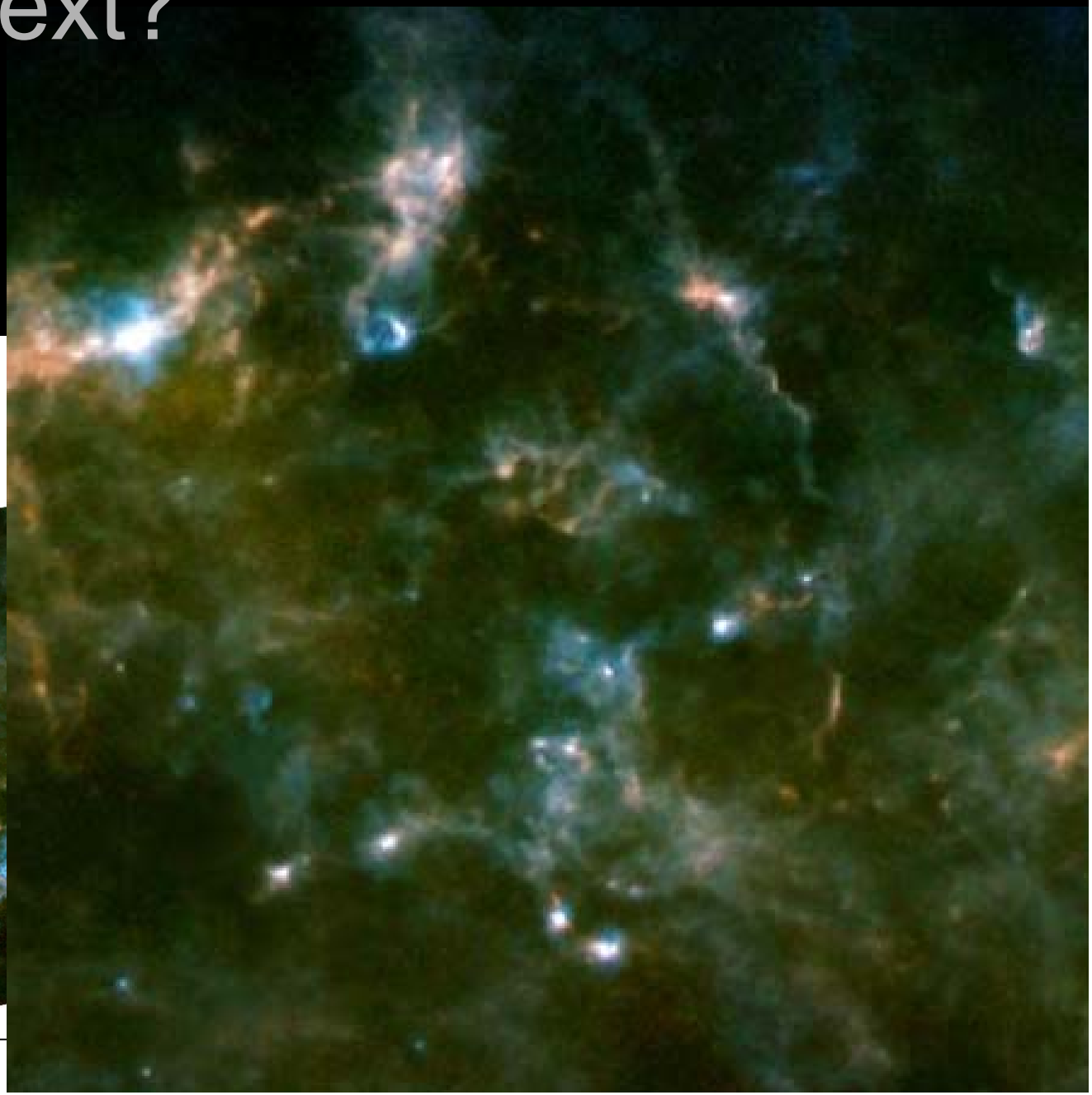


In the BLAST bands we can account for all of the CIB.

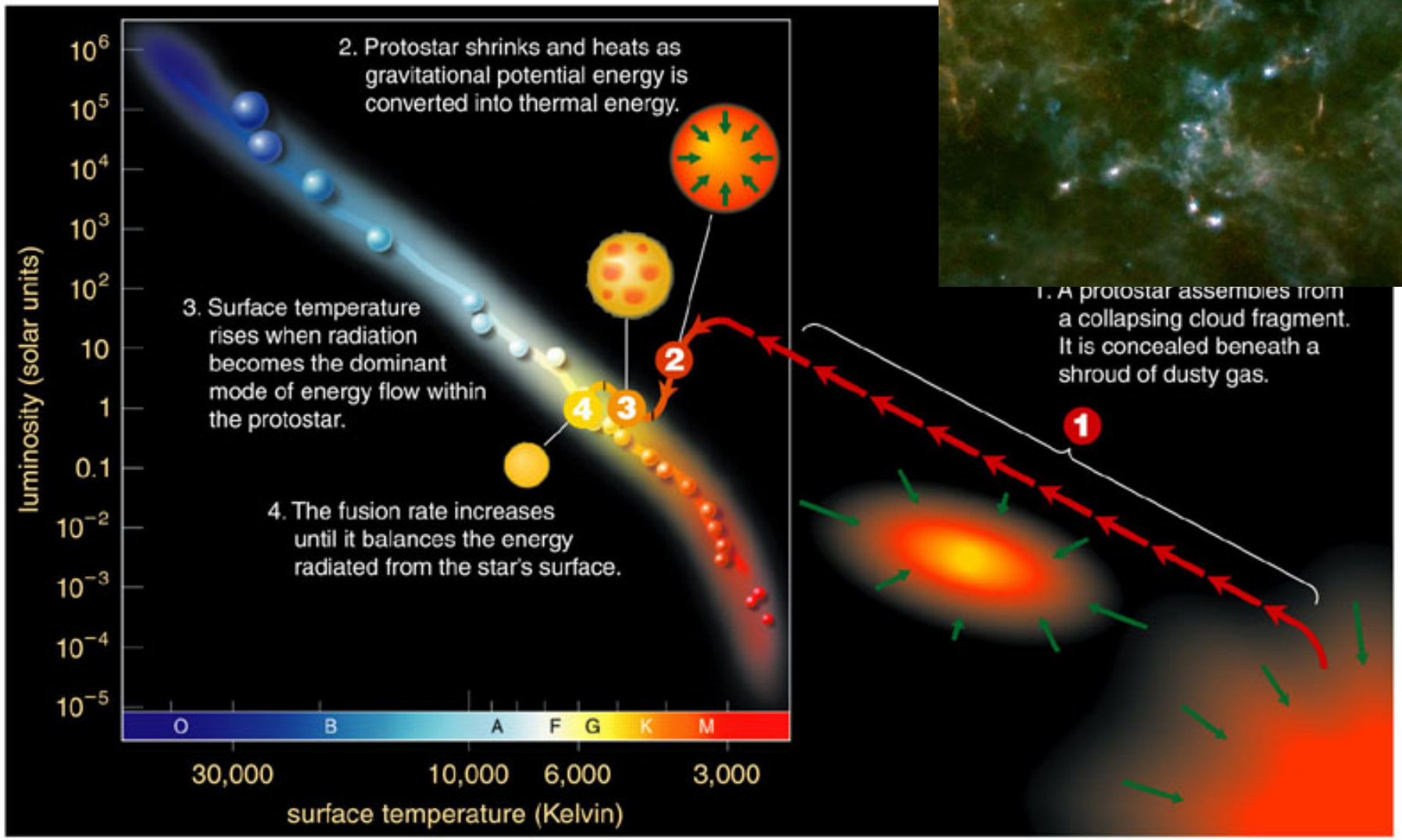
70% of the 500 micron background light comes from galaxies with z > 1.2.

So What Next?





Stages of Star Formation



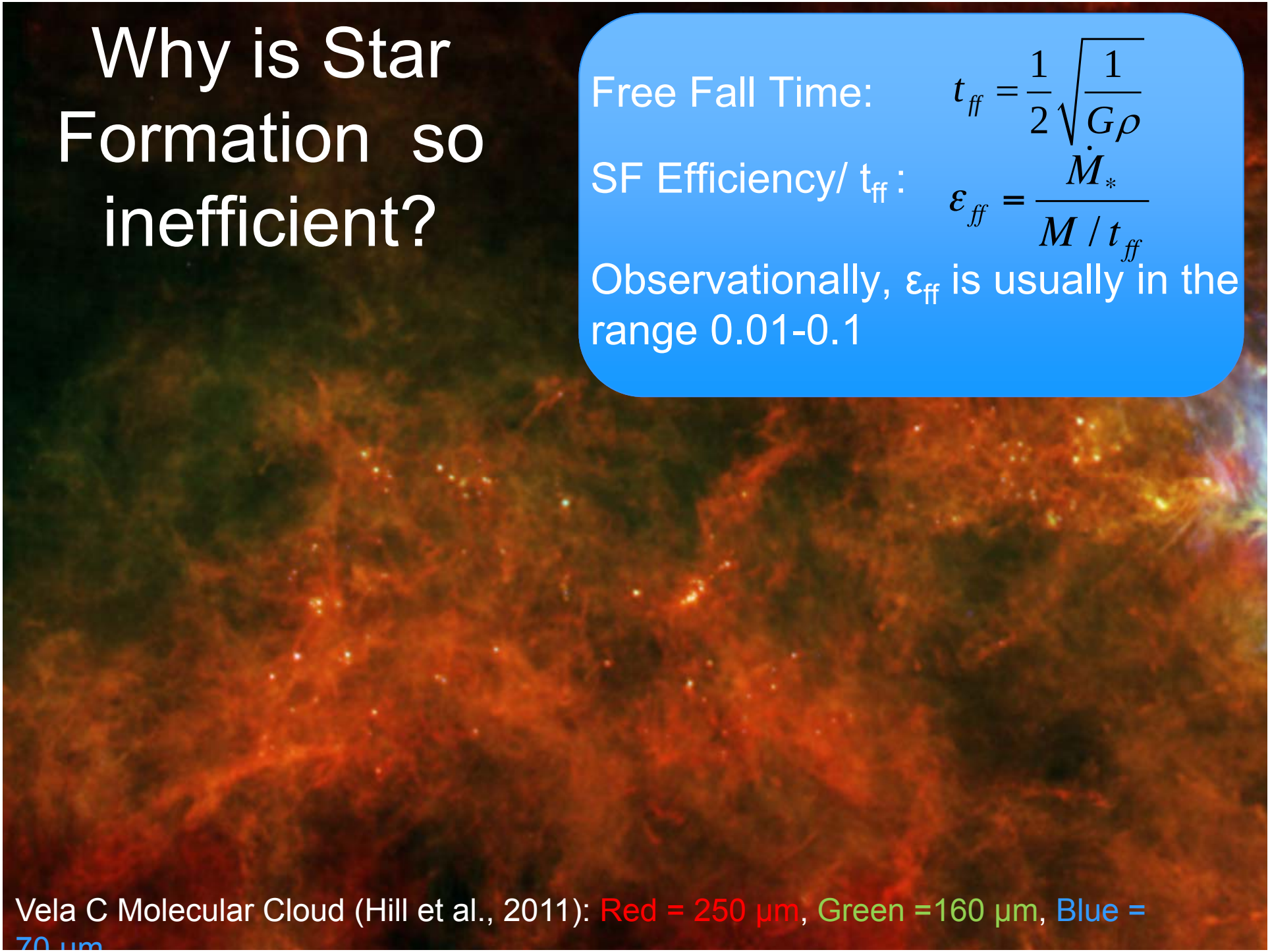
Bennett – Cosmic Perspective

Why is Star Formation so inefficient?

Free Fall Time: $t_{ff} = \frac{1}{2}\sqrt{\frac{1}{G\rho}}$

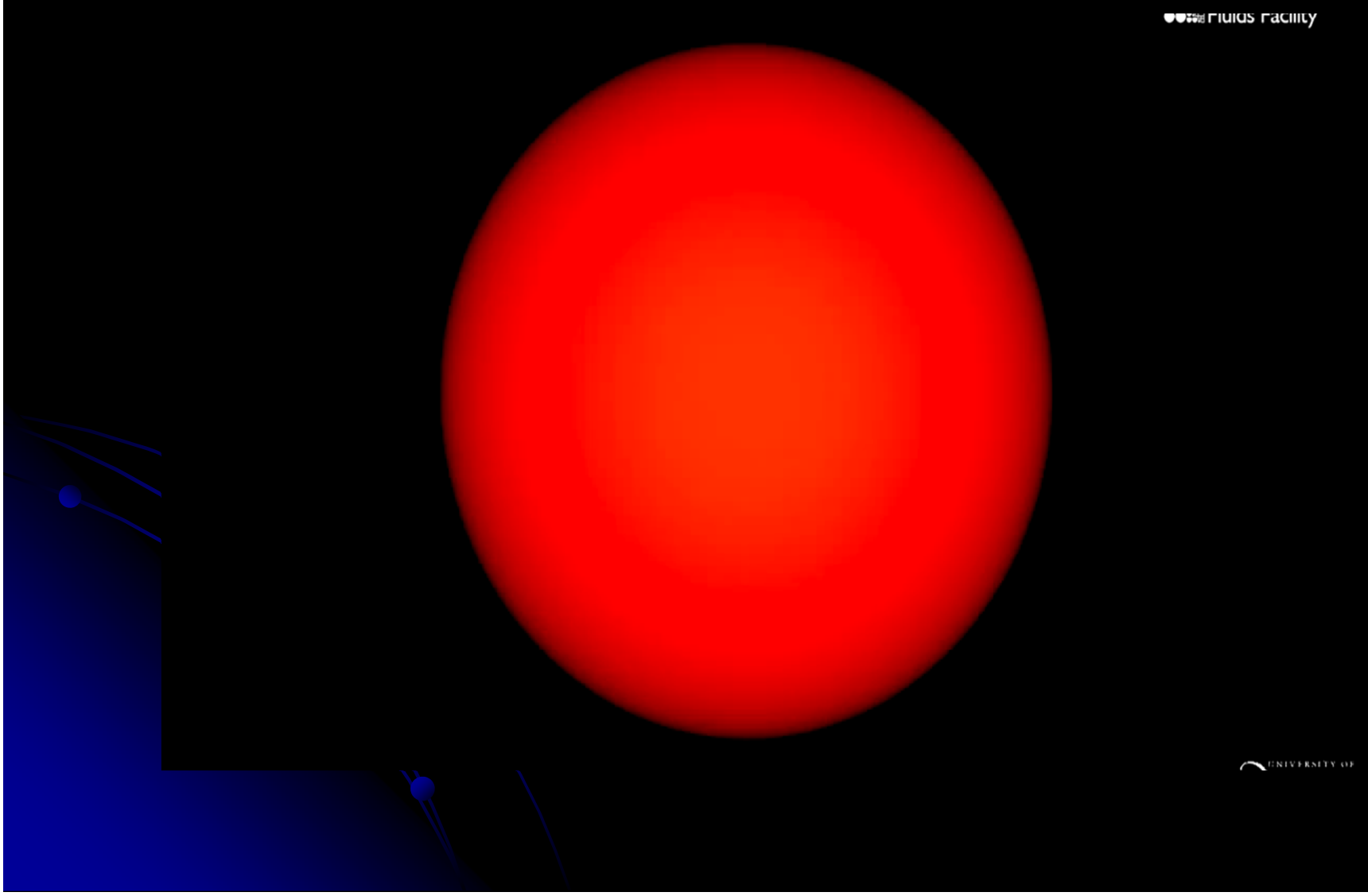
SF Efficiency/ t_{ff} : $\varepsilon_{ff} = \frac{\dot{M}_*}{M / t_{ff}}$

Observationally, ε_{ff} is usually in the range 0.01-0.1

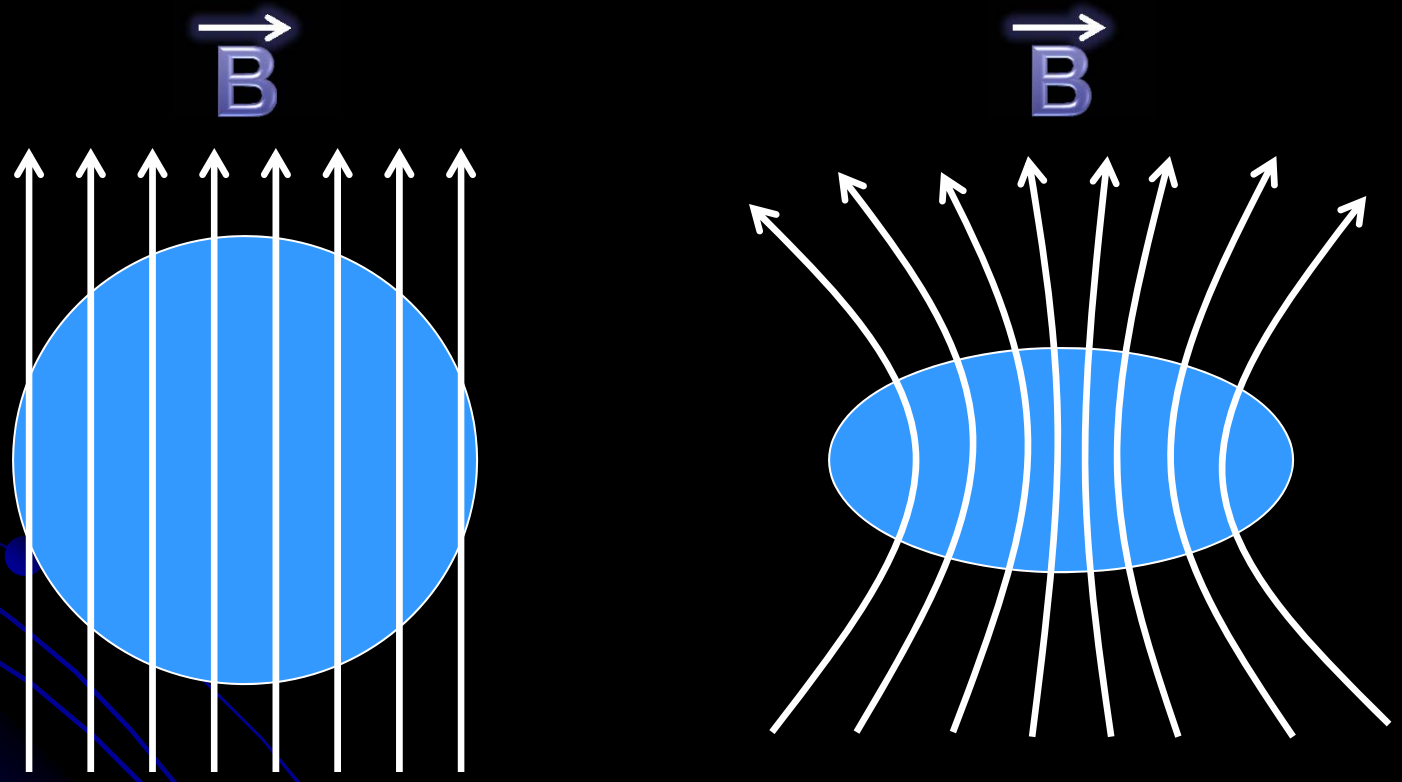


Vela C Molecular Cloud (Hill et al., 2011): Red = 250 μm, Green =160 μm, Blue = 70 μm

Turbulent Gas Motions



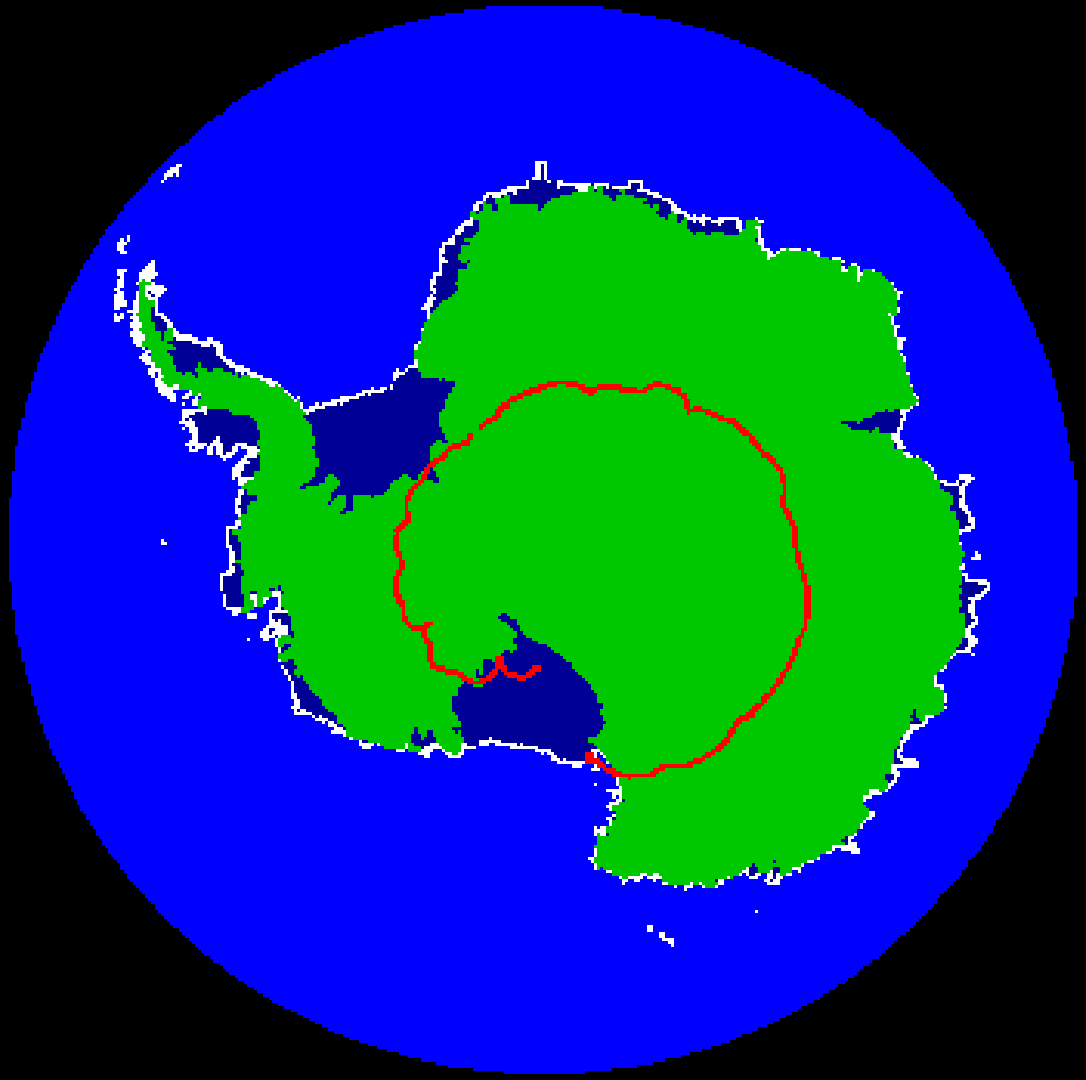
The Role of Magnetic Fields in Star Formation



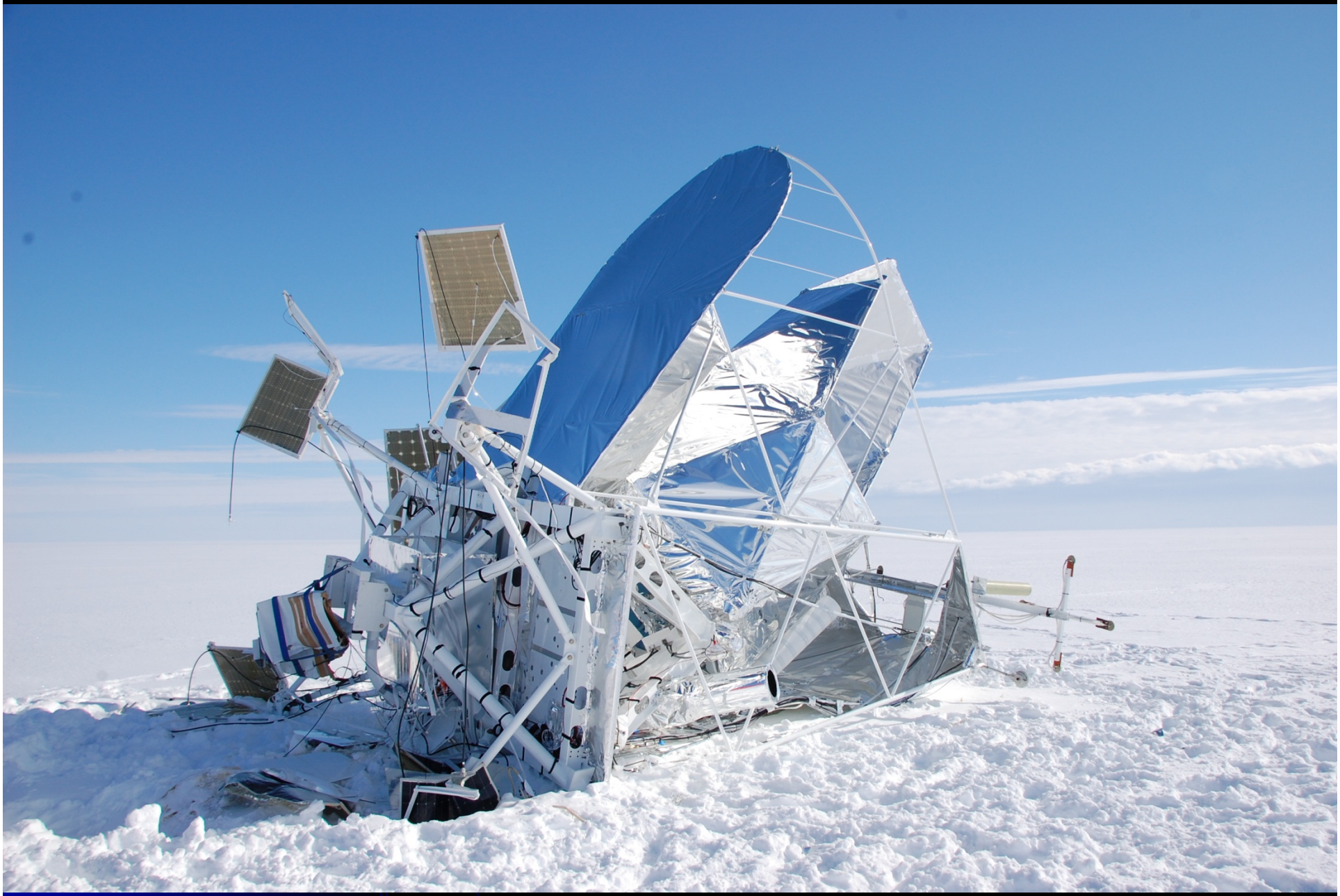
BLAST-pol

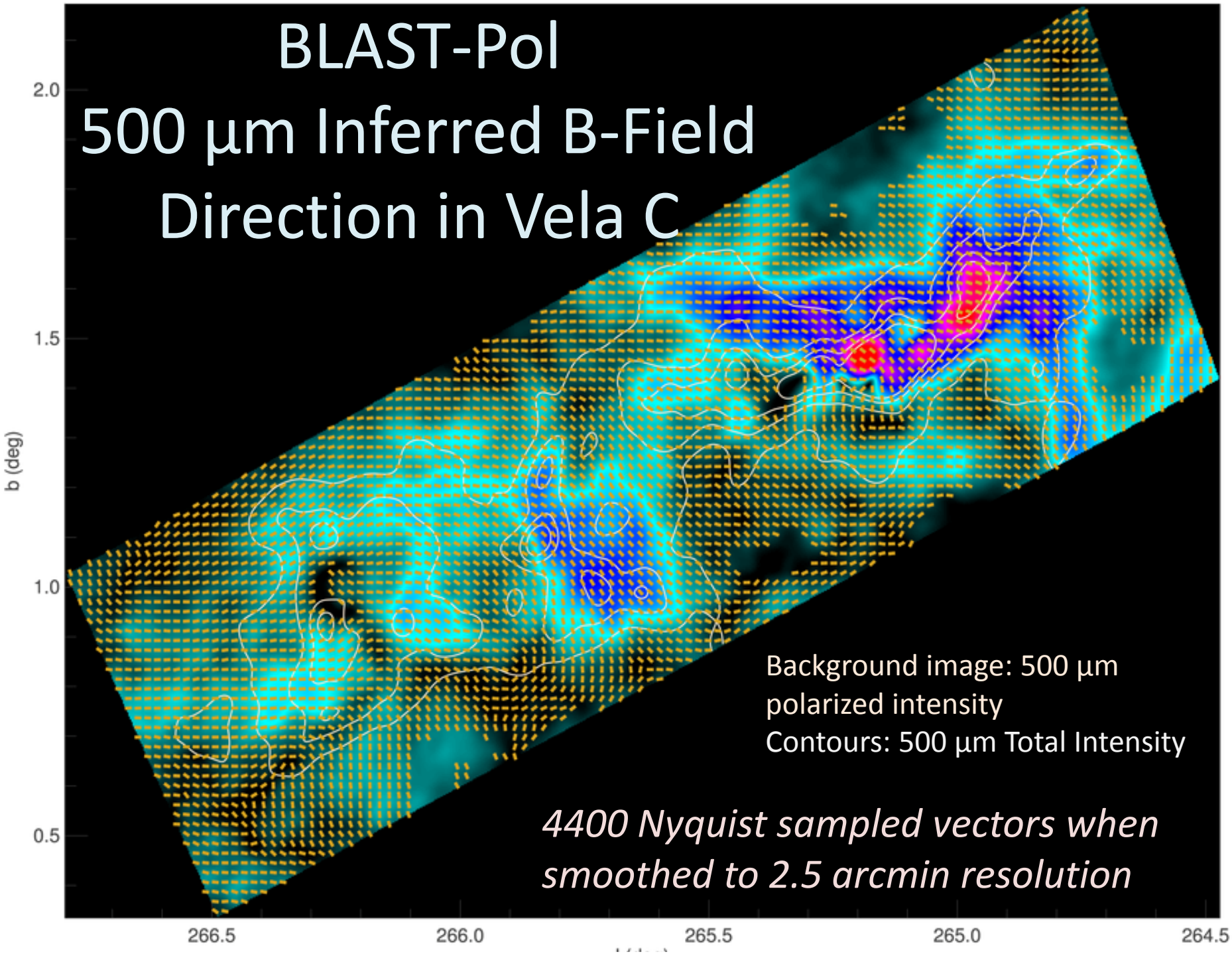
Antarctica December 2010
An again in December 2012

Payload position as of:
03:16:14Z 01/12/11
Latitude: 82° 48.67 S
Longitude: 178° 18.28 W
Altitude: 13 Feet
10.55 Knots @ 0.00°

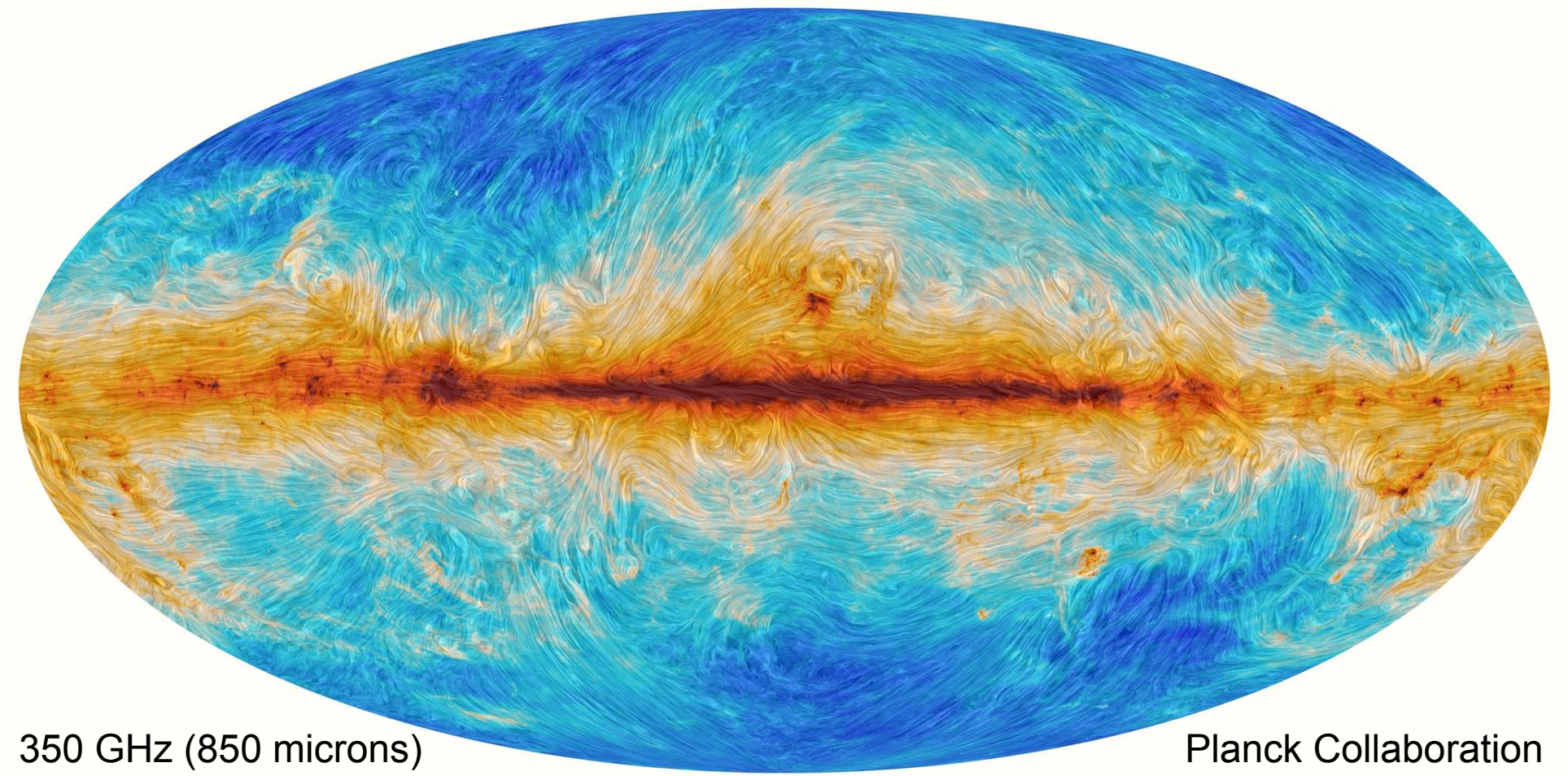


U.S. ANTARCTIC PROGRAM




BLAST-Pol
500 µm Inferred B-Field
Direction in Vela C
Background image: 500 µm
polarized intensity
Contours: 500 µm Total Intensity
4400 Nyquist sampled vectors when
smoothed to 2.5 arcmin resolution
b (deg)
2.0
1.5
1.0
0.5
266.5
266.0
265.5
265.0
264.5

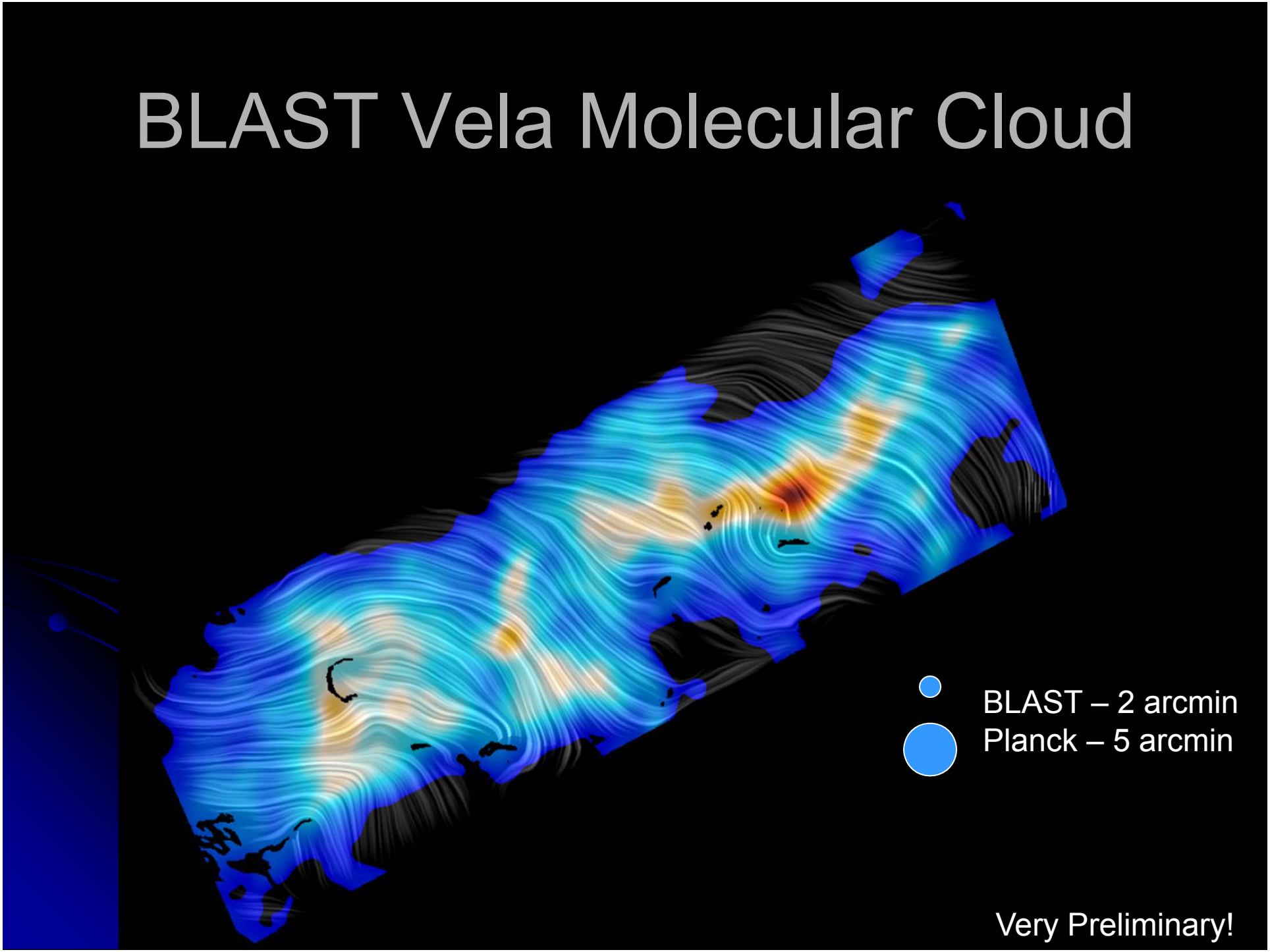
Planck Satellite View of Polarized Dust in our Galaxy



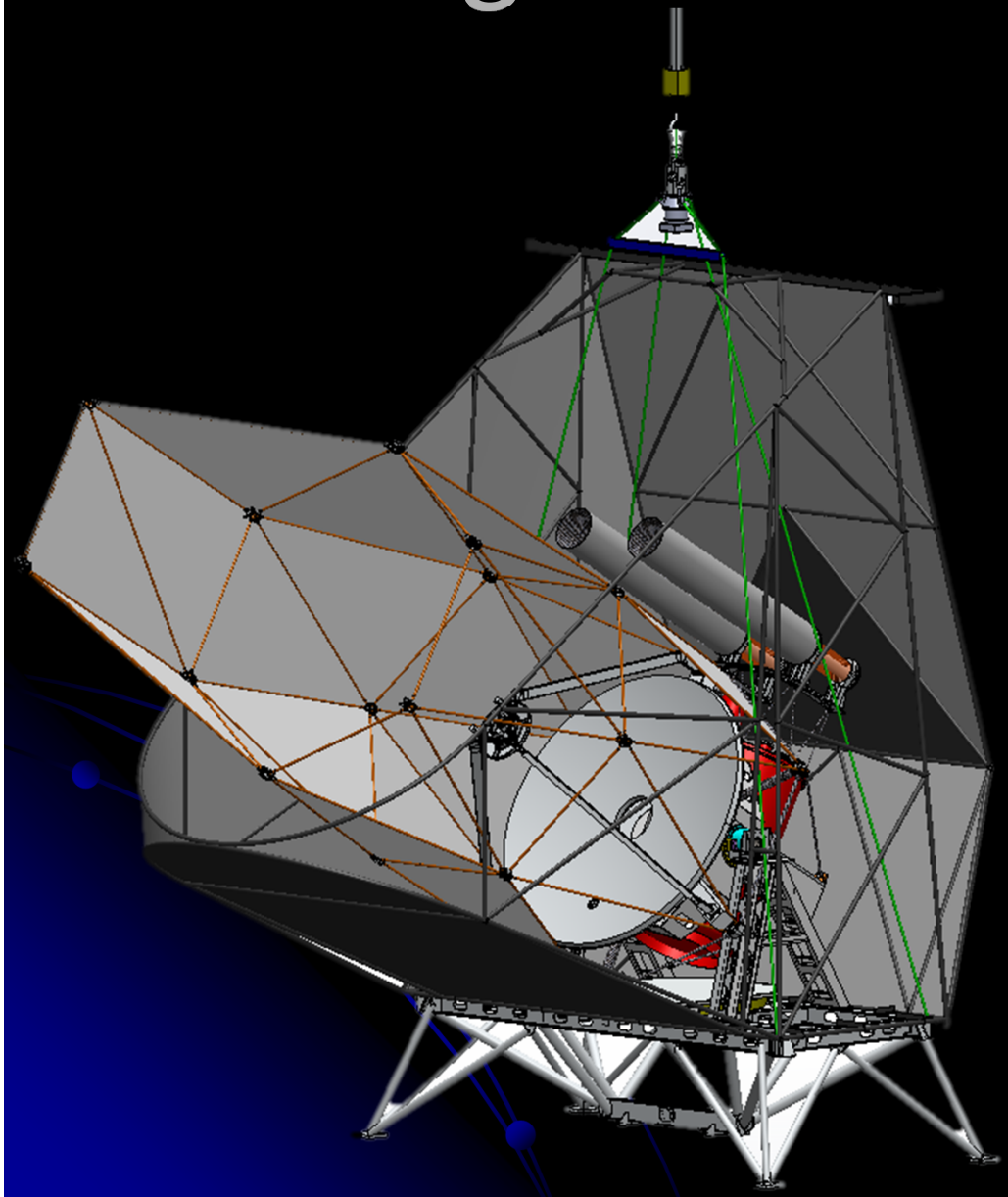
350 GHz (850 microns)

Planck Collaboration

BLAST Vela Molecular Cloud



Coming Soon – BLAST-TNG



- 2.5 meter Carbon Fiber Mirror
- 2200 KID detectors
- 22 arcsec resolution at 250 μm
- 28 day flight!
- 16 times the mapping speed

- First flight December 2016 with Shared Risk Observing

BLAST

Balloon-borne Large-Aperture Sub-millimeter Telescope

NASA

NSERC CRSNG

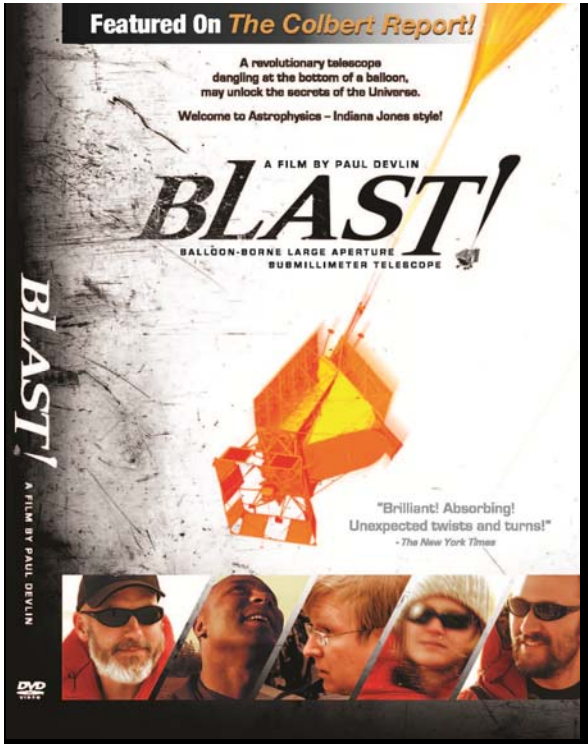
CSA ASC

National Science Foundation
WHERE DISCOVERIES BEGIN

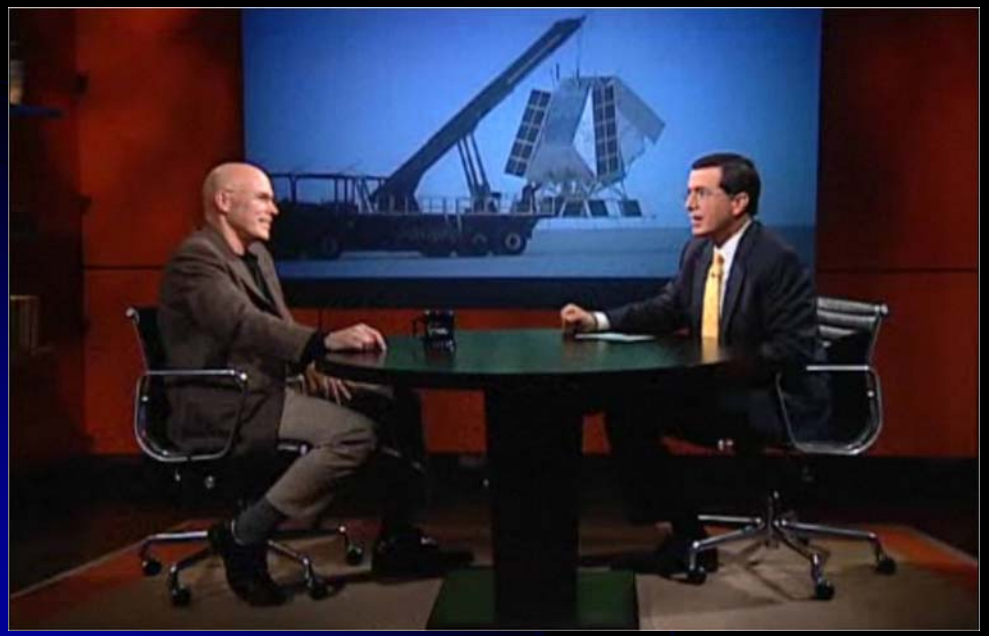
Science & Technology Facilities Council

CONACYT

COLUMBIA SCIENTIFIC BALLOON FACILITY



EVERY DAY IS SCIENCE FRIDAY



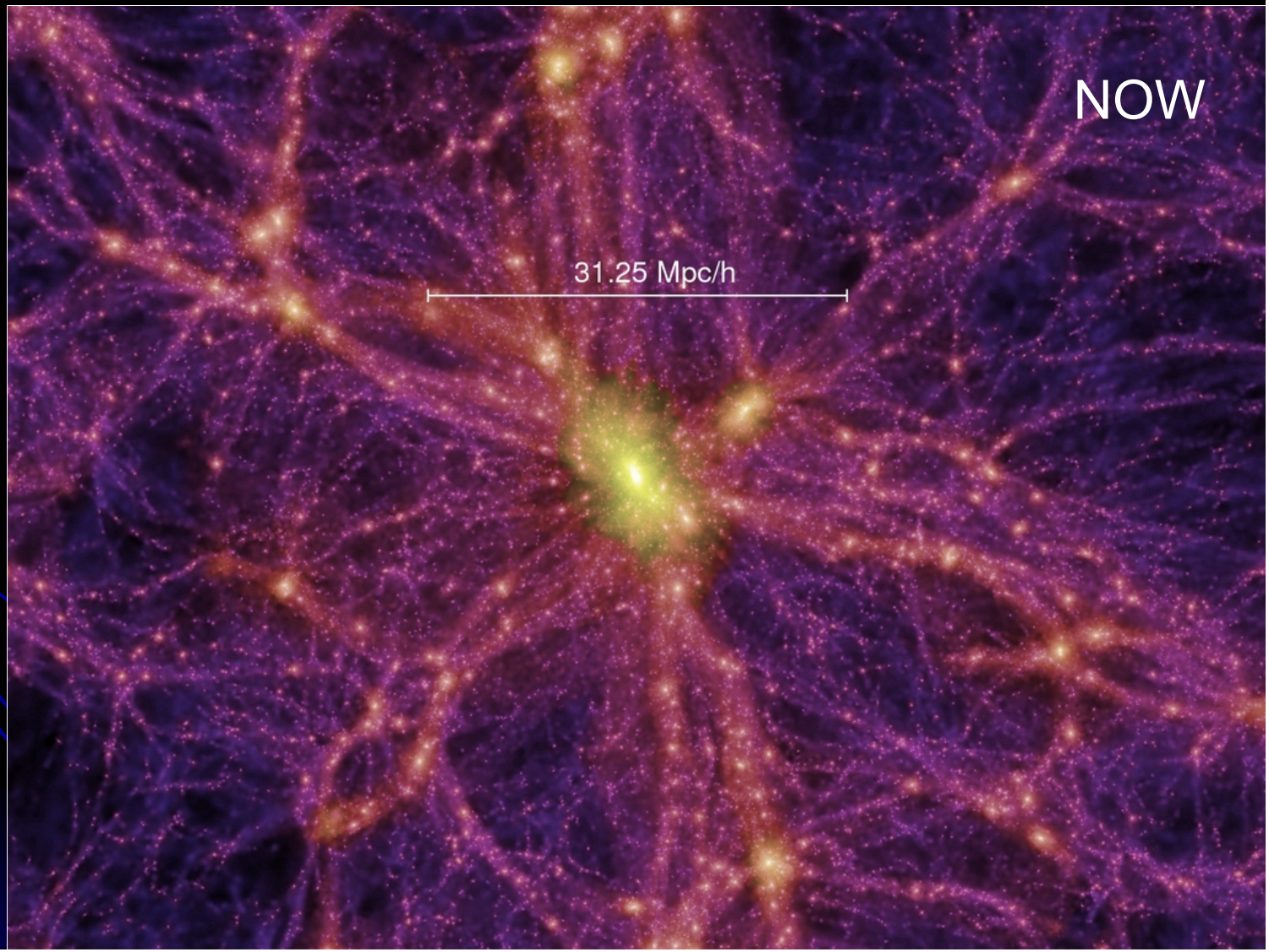
- Many undergrads!
- 16 Ph.D.s
- 5 current graduate students
- 30+ publications
- 1000+ citations

But there’s more!!!

Remember the Universe Evolving?

Gravity Rules

..but the details are important



From the Millennium Simulation – Volker et al. - 1997

Study the Evolution of Structure

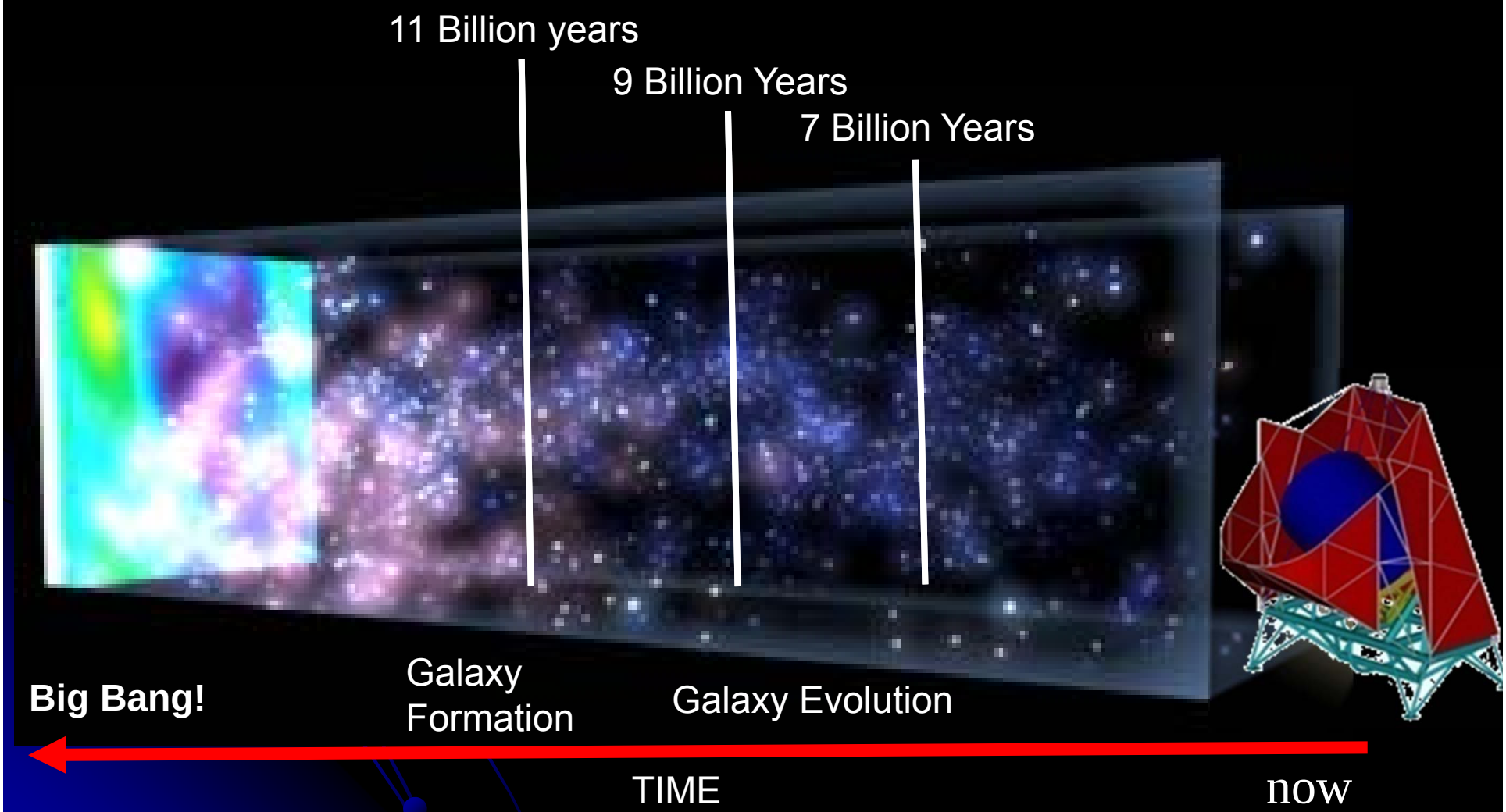
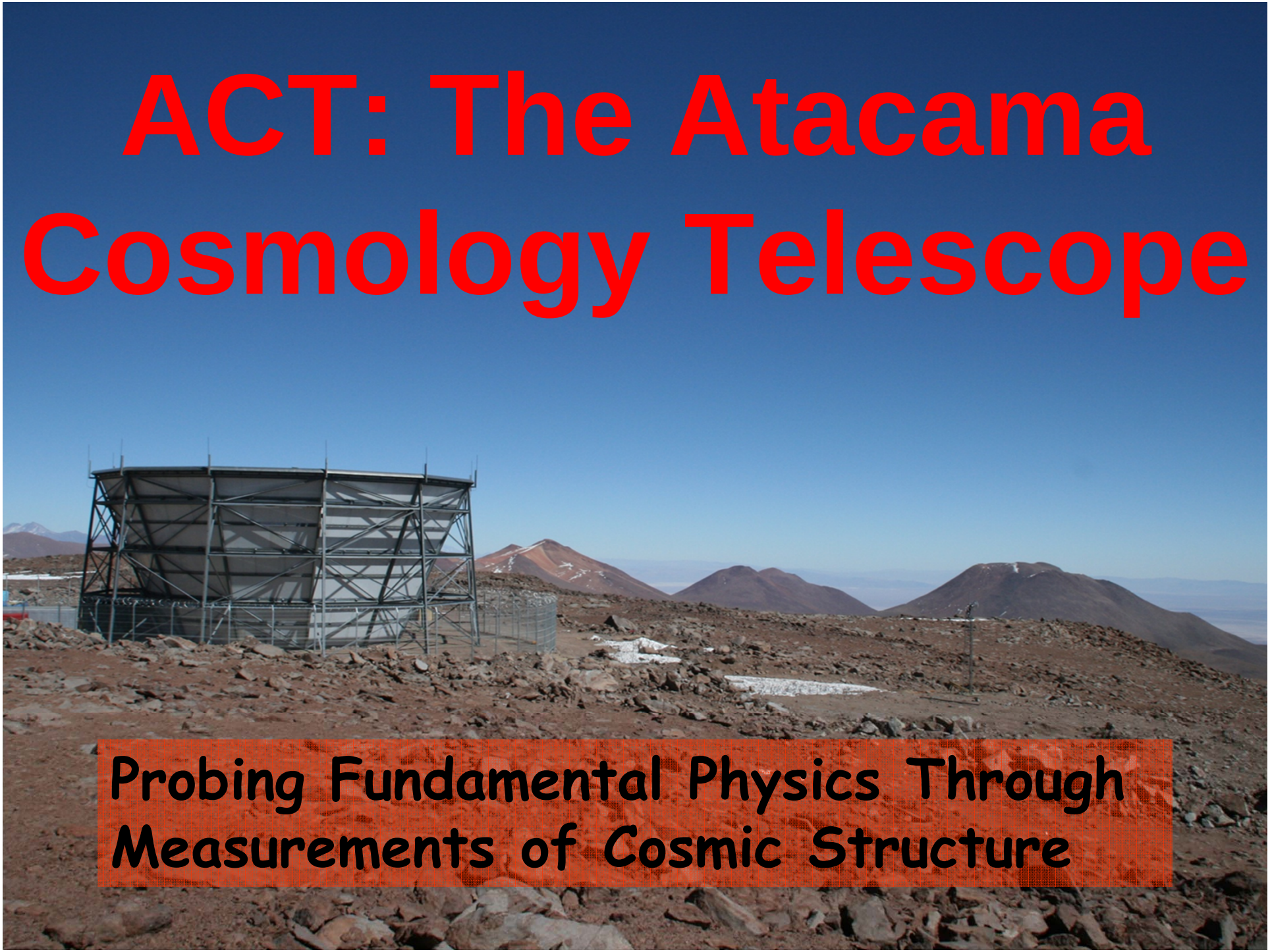


Figure from WMAP Website

ACT: The Atacama Cosmology Telescope

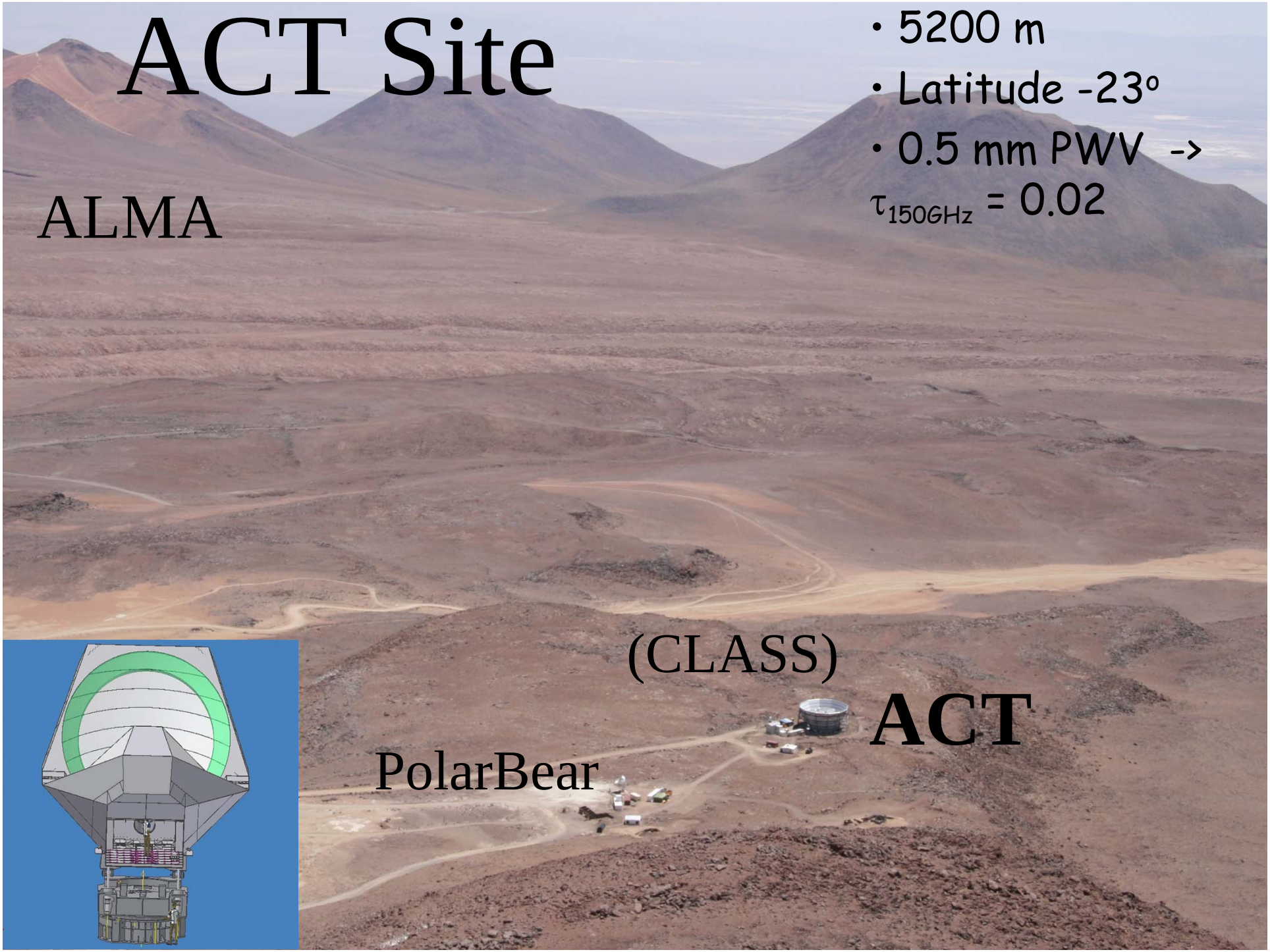


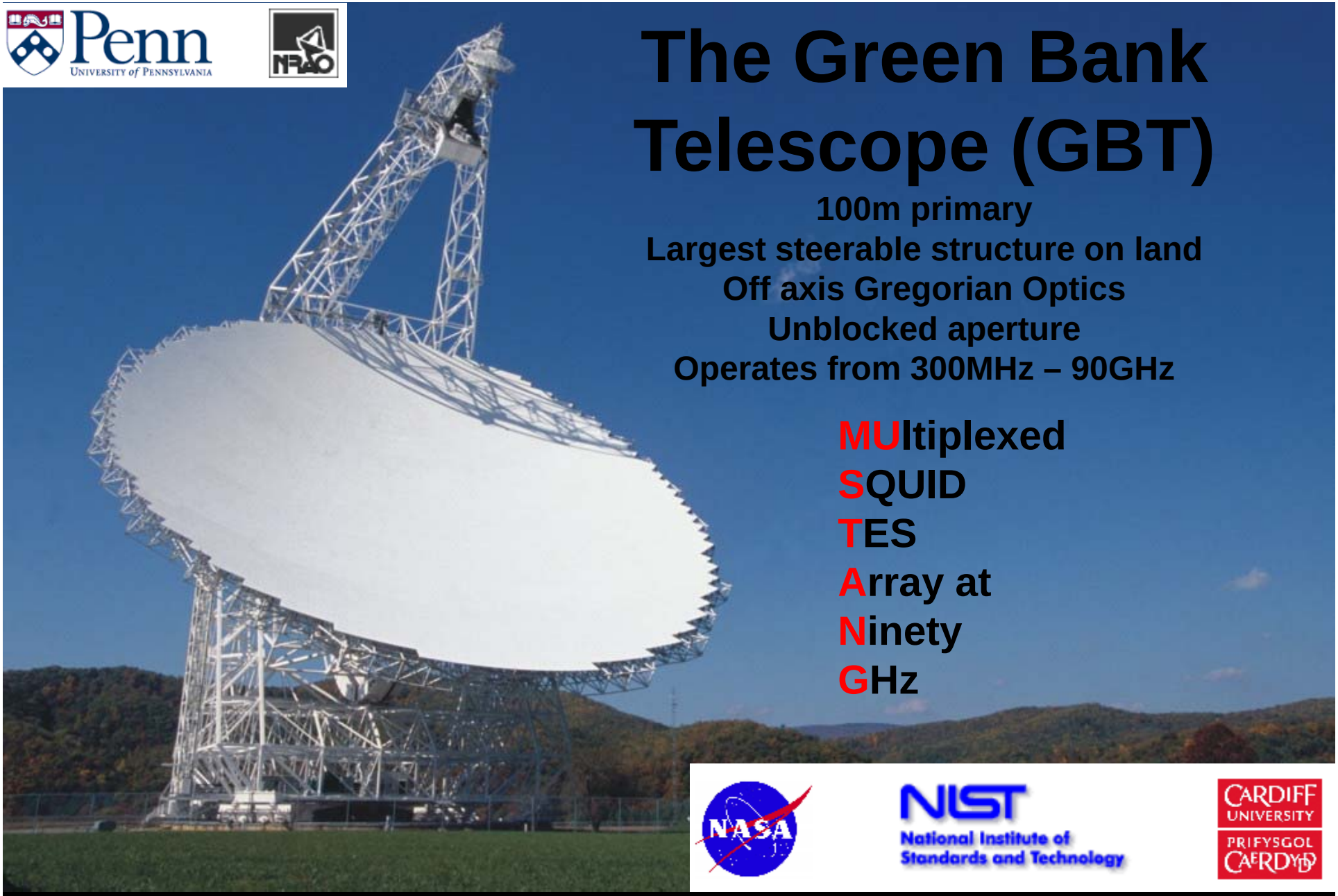
Probing Fundamental Physics Through Measurements of Cosmic Structure

ACT Site

- 5200 m
- Latitude -23°
- 0.5 mm PWV ->

$\tau_{150GHz} = 0.02$

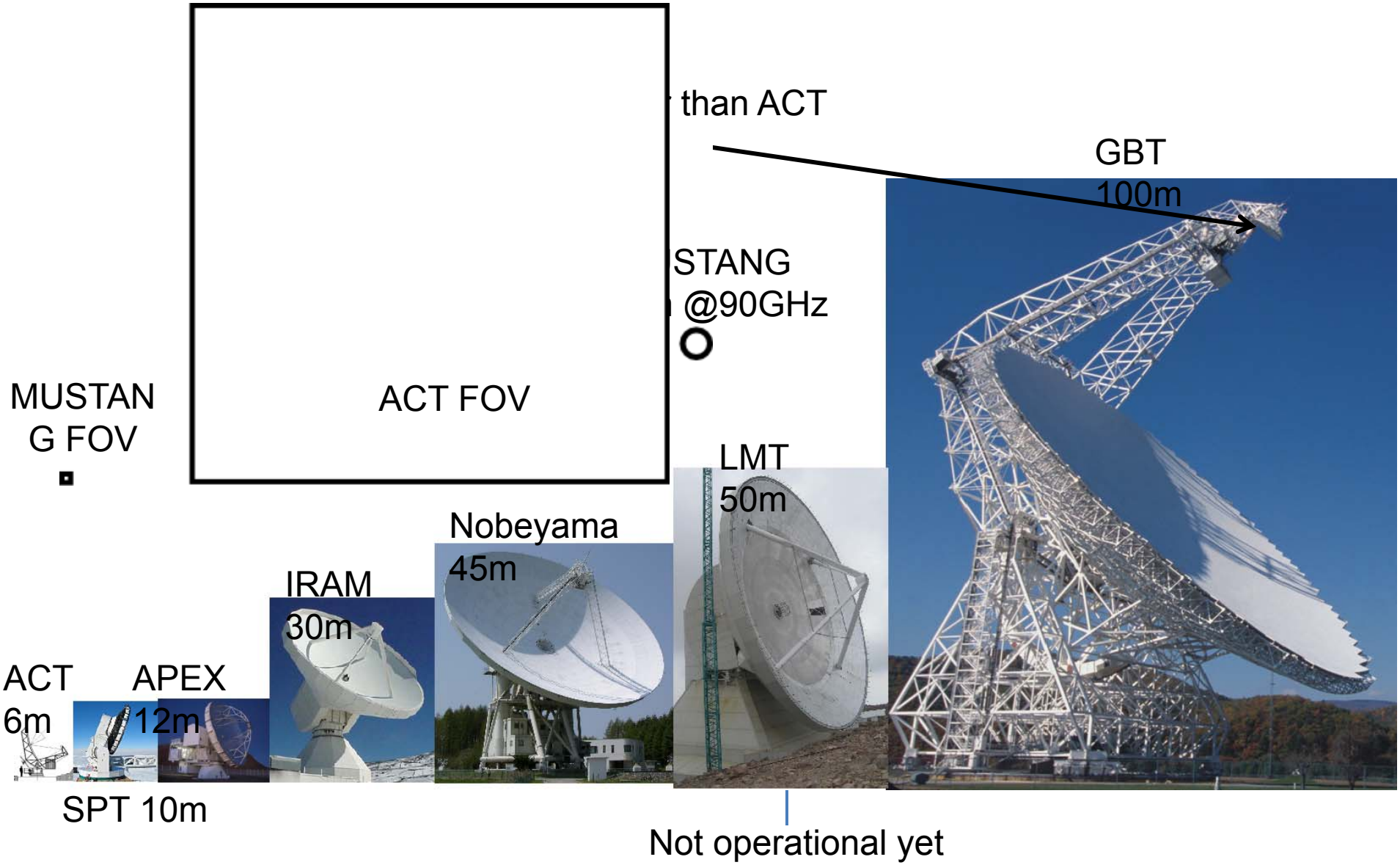




The Green Bank Telescope (GBT)

100m primary
Largest steerable structure on land
Off axis Gregorian Optics
Unblocked aperture
Operates from 300MHz – 90GHz

MUltiplexed
SQUID
TES
Array at
Ninety
GHz

Thanks!

GBT and other mm single dishes