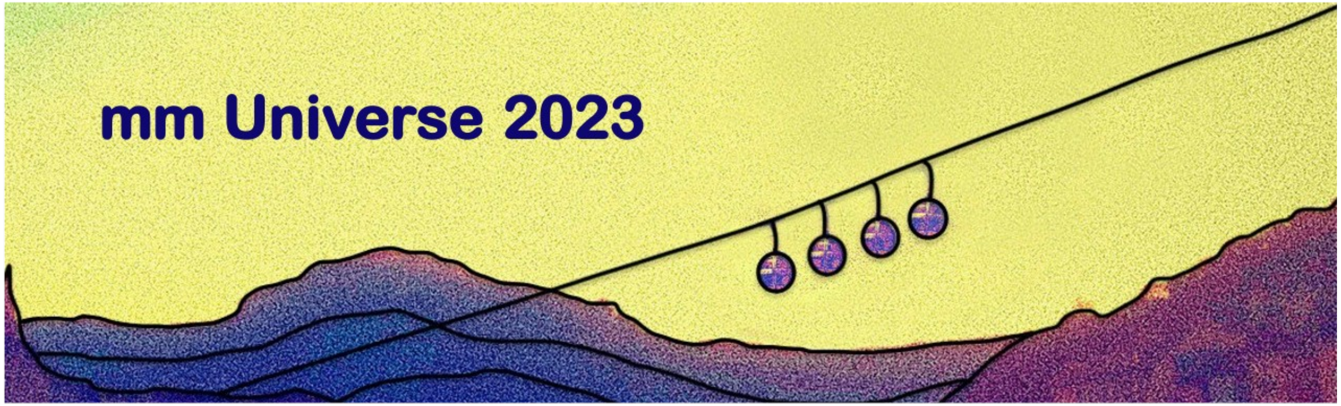
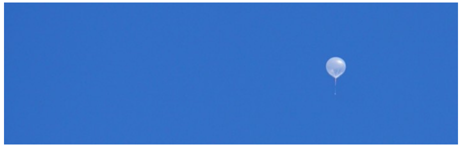


Observing the Universe at millimetre wavelengths
Jun 26 – 30, 2023
LPSC Grenoble, France

The BLAST Observatory

Speaker: Federico Nati, Uni. of Milano-Bicocca, Italy
for the BLAST Observatory Collaboration



The BLAST Observatory

UPenn, USA
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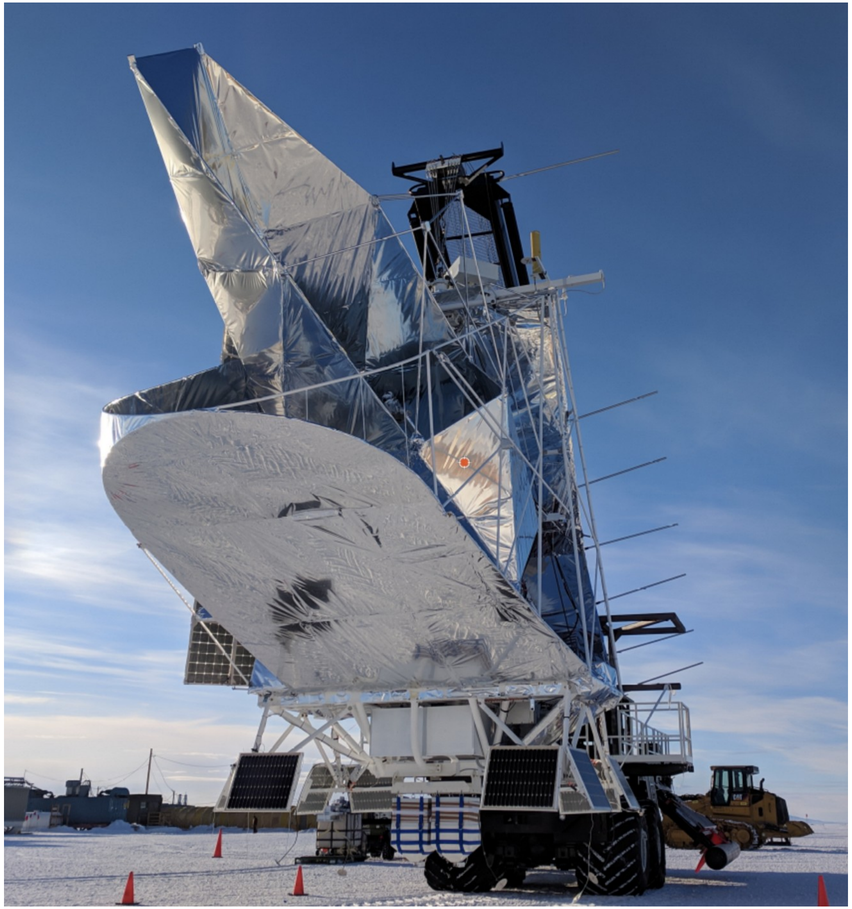
Zhi-Yun Li

Cardiff Uni., UK
Carole Tucker

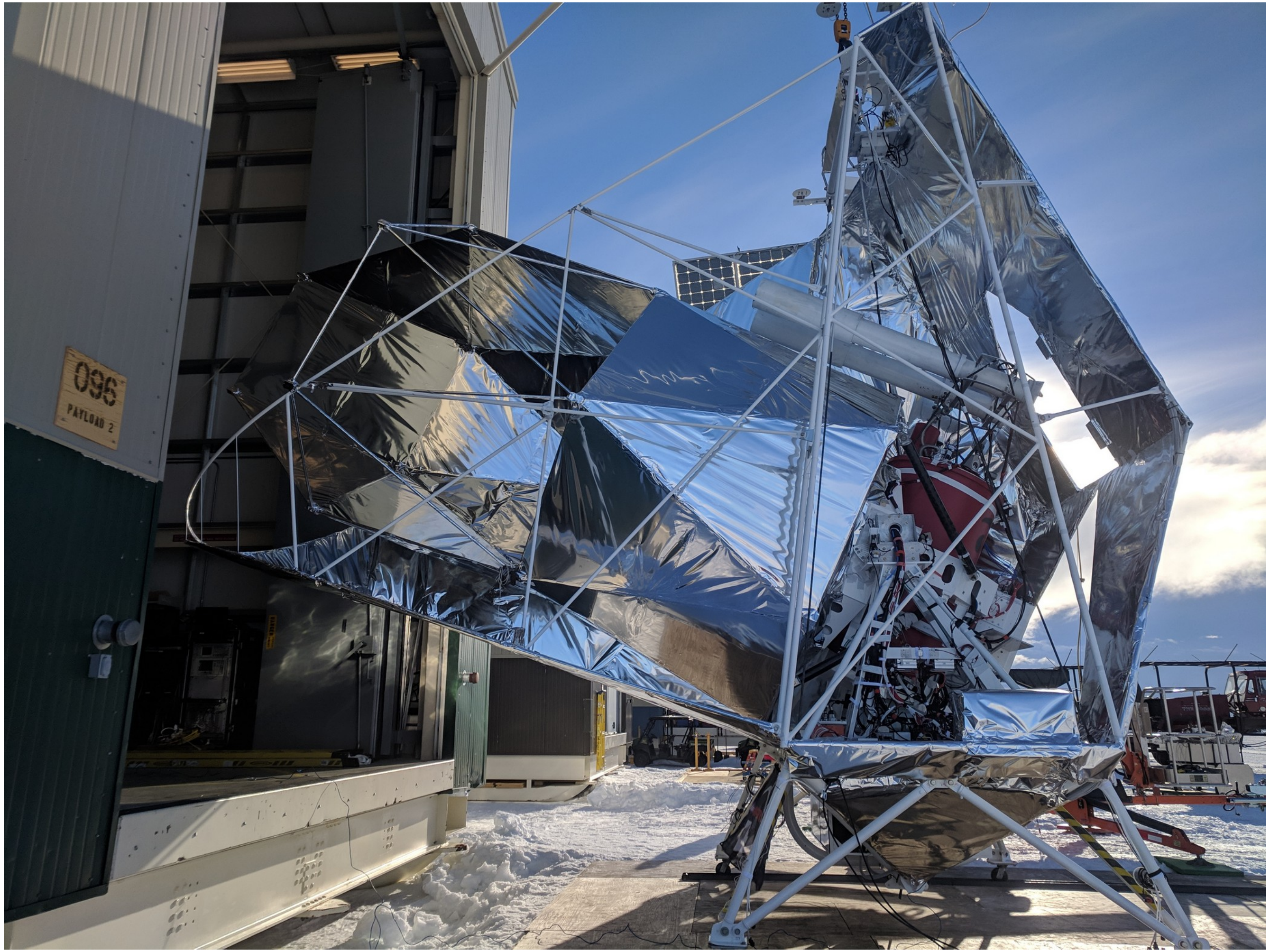
The BLAST Observatory

Last BLAST version, BLAST-TNG, right before launch in 2020, McMurdo, Antarctica

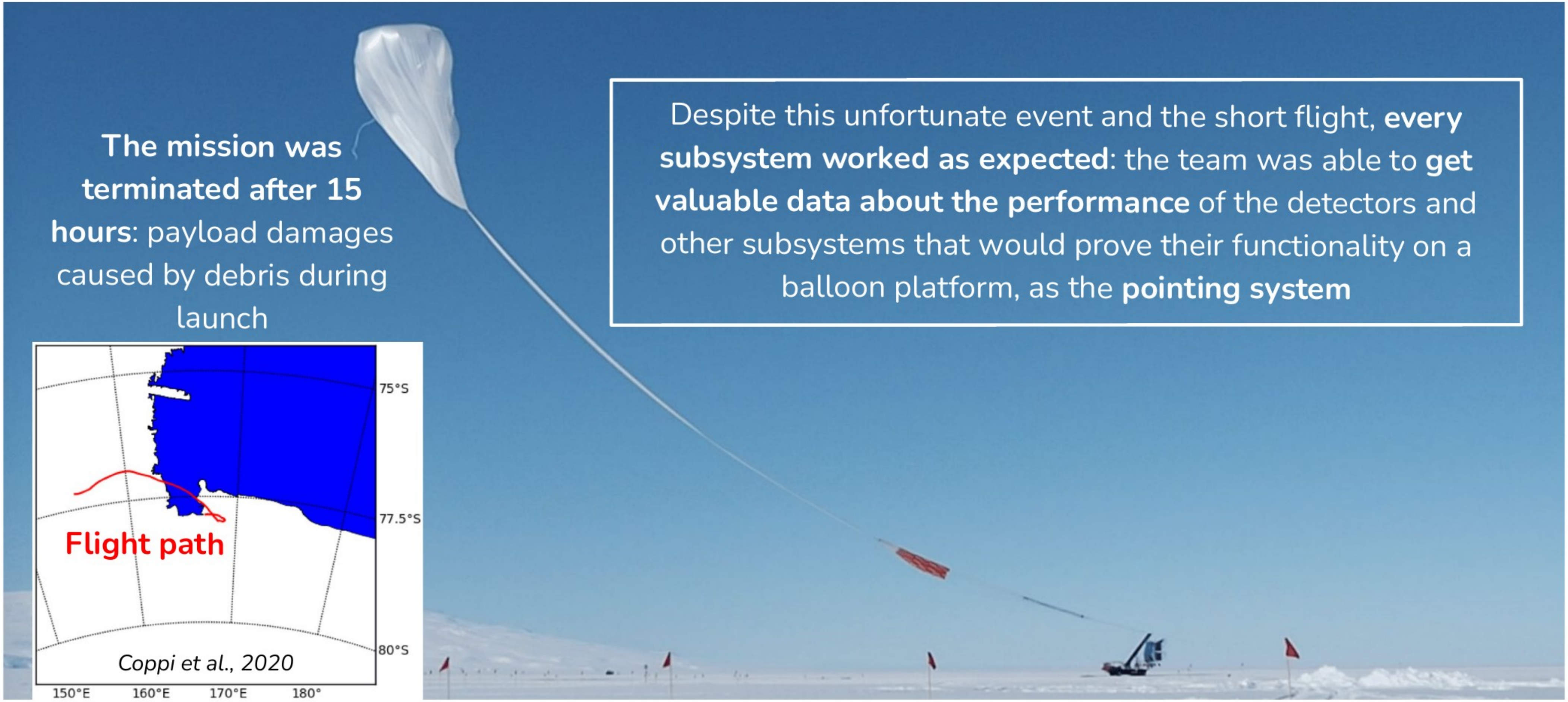
BLAST-TNG in Antarctica (Jan 2020)




BLAST-TNG


096
PAYLOAD 2

Blast-TNG launch from McMurdo, Antarctica, 6 Jan 2020

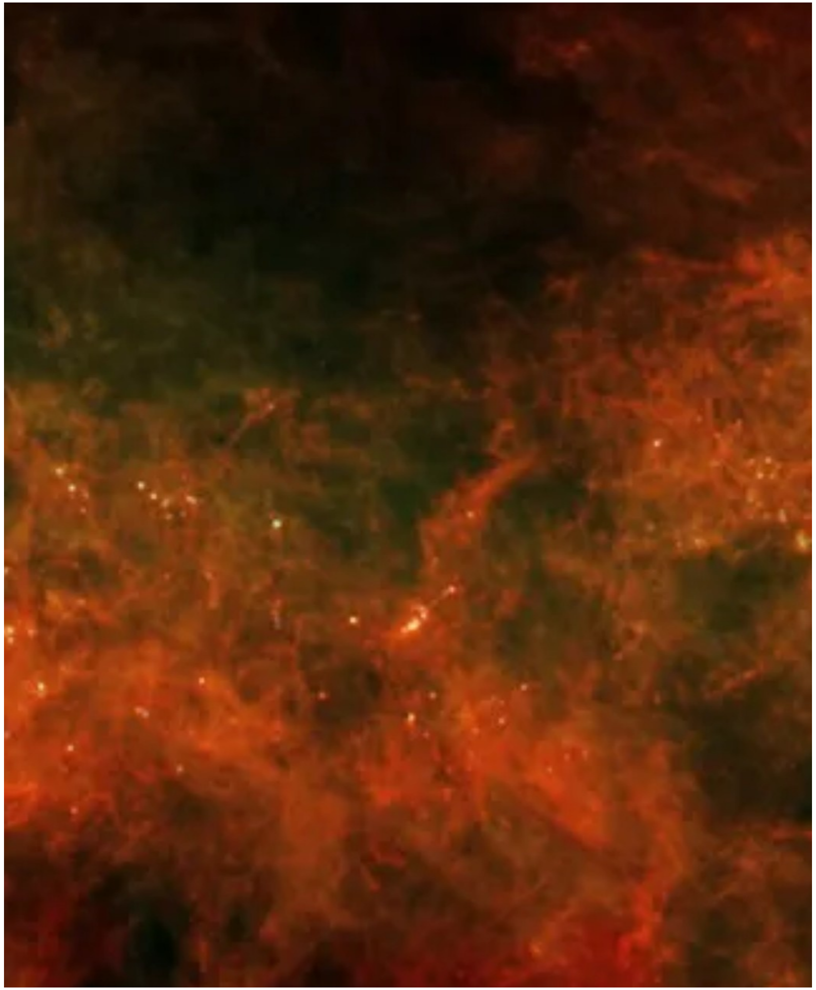



C-GKBG

InterStellar Medium (ISM)

Key questions:

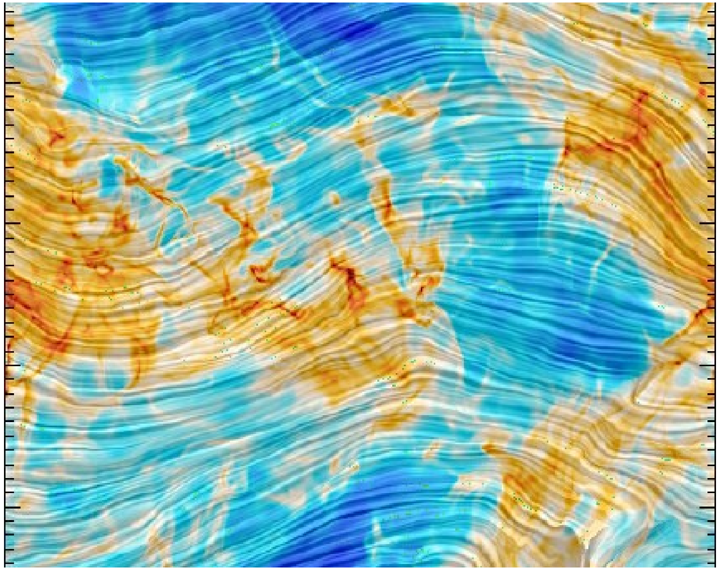
- Does interstellar dust come in distinct compositions, and what are their physical properties?
- What are the physical properties of magnetohydrodynamic (MHD) turbulence in the ISM, and what is the dominant mechanism of energy dissipation?
- What role do magnetic fields play in regulating star formation?



Magnetic field effects at different physical scales in our galaxy

Clouds
Scale: 1 - 100 pc

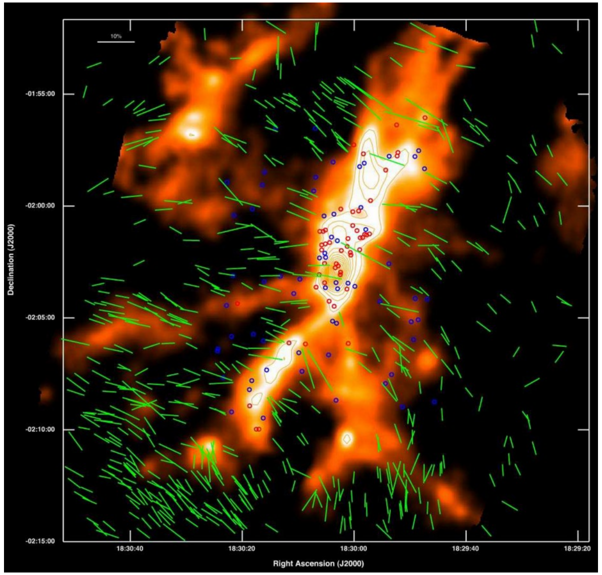
Effect: Influence where dense molecular clouds form



Shu et al., 1984
Nakamura and Li, 2008

Filaments and cores
Scale: 0.01 - 1 pc

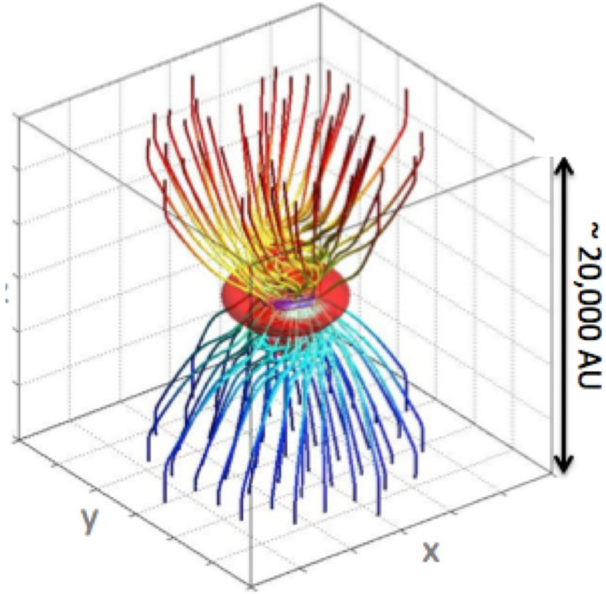
Effect: Direct accretion of gas, possibly slow down of collapse, fragmentation?



Sugitani et al. 2011
Li et al. 2014

Protostellar Disks
Scale: < 0.01 pc

Effect: Inhibit formation of large disks



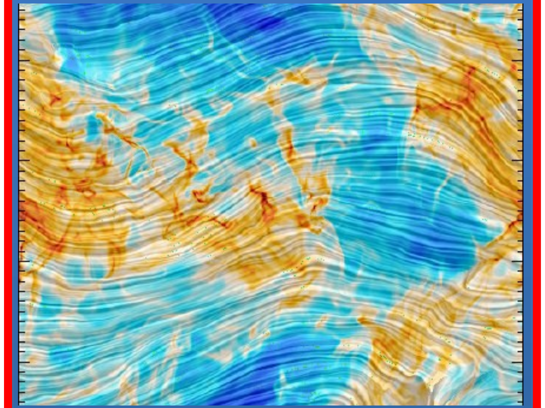
J. Davidson+ '14
Galli & Shu '93

Star Formation Mechanisms (in addition to gravity)

Supersonic Turbulence

E.g. MacLow and Klessen, 2004

Magnetic Fields



Shu et al., 1984
Nakamura and Li, 2008

Feedback

E.g. Krumholtz, Matzner and McKee, 2006

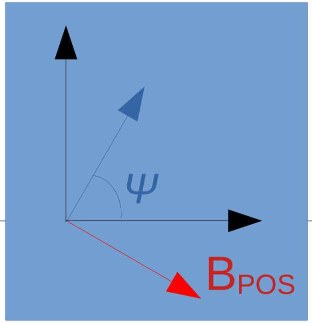
All contribute and are important on different size and density scales.
But the (by far) least understood/hardest to observe is the magnetic field.

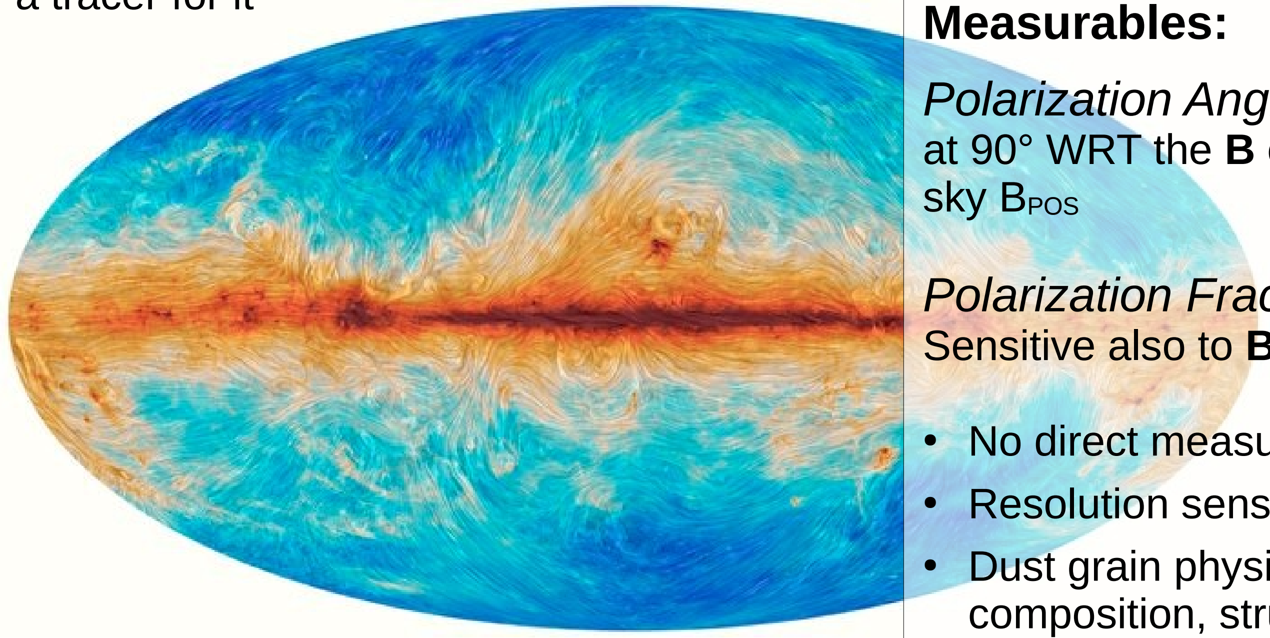
We want to measure **galactic magnetic fields in clouds**

We would like to know intensity and direction of **B**

We could do this in principle through Zeeman effect, but this is not possible for most clouds

So we use and **indirect method**: we measure the linearly polarized light emitted by galactic **dust grains**, since they interact with the magnetic field and therefore provide a tracer for it





Planck Intermediate XIX, 2015

Measurables:

Polarization Angle Ψ

at 90° WRT the **B** component project to the plane of the sky B_{POS}

Polarization Fraction

Sensitive also to **B** component along the line of sight, B_{LOS}

- No direct measurement of field strenght
- Resolution sensitive
- Dust grain physics effects (alignment, temperature, composition, structure)

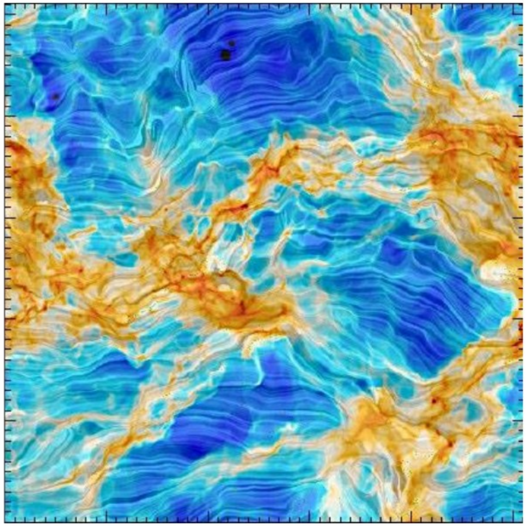
Magnetic fields have a lot of **measurable** effects

- We can study magnetic fields with polarized light emitted by **galactic dust**
- Perform statistical comparisons with numerical simulations to constrain the involved physical mechanisms
- Observe the effect of magnetic fields on filament collapse (weak vs strong)

“Matter shapes field”

Weak magnetic field

($|B_0|$=0.35μG)



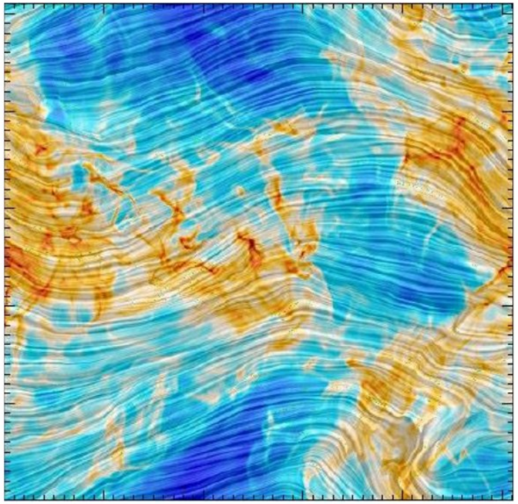
disordered B-field

low N_H ➔ B-field || to N contours

high N_H ➔B-field || to N contours

Strong magnetic field

($|B_0|$=10.97μm)



ordered B-field

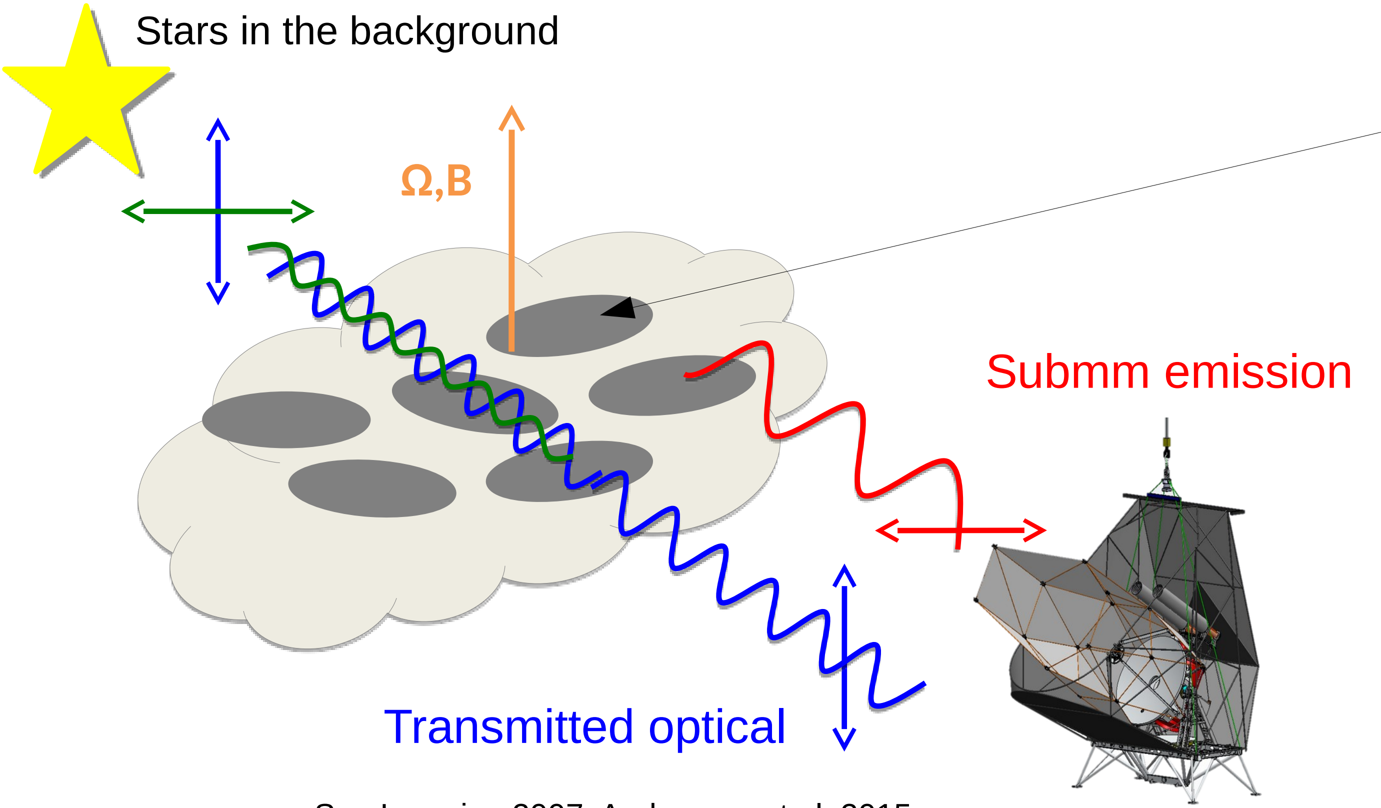
low N_H ➔ B-field || to N contours

high N_H ➔B-field perp to N contours

“Field shapes matter”

RAMSES MHD Simulations from Soler et al. 2013

The BLAST Obs. will be sensitive to the polarized IR emission from dust grains



Asymmetric grains with dimensions from ~1μm to ~10s of μm

Strong absorption in UV and Optical region

Emission in the infrared and sub-mm

T ~20K

See Lazarian 2007, Andersson et al. 2015

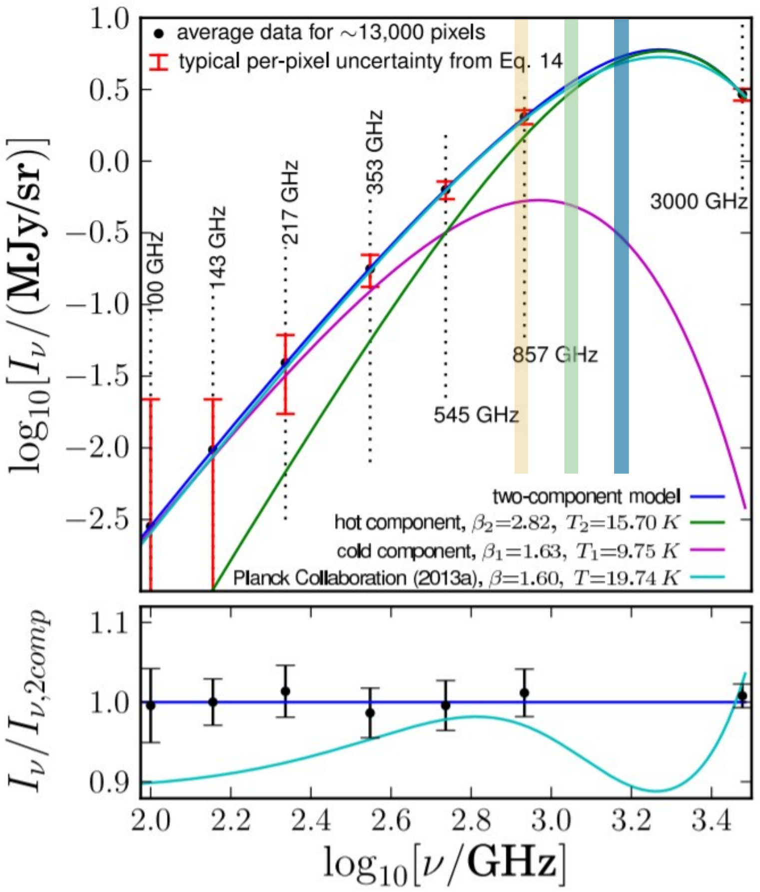
SO1. Distinguish between two-component and single-component models for the composition of dust grains as a function of environment.	Linear polarization spectrum from 175 to 350 μm for: Diffuse ISM regions ($N_H < 4\times10^{20}$ cm^{-2}), a translucent cloud ($N_H \approx 1\times10^{21}$ cm^{-2}), and molecular clouds ($N_H > 2\times10^{21}$ cm^{-2}).

SO2. Measure physical properties of magnetohydrodynamic (MHD) turbulent gas motions and energy dissipation in regions of diffuse Galactic gas.	Measure the *EE*, *BB* power spectra over $200 < \ell < 20{,}000$, for both diffuse ISM regions ($N_H < 4\times10^{20}$ cm^{-2}) and a translucent cloud ($N_H \approx 1\times10^{21}$ cm^{-2}). Determine whether there are any breaks in the power-law index α of $\Delta\alpha \geq 1$.

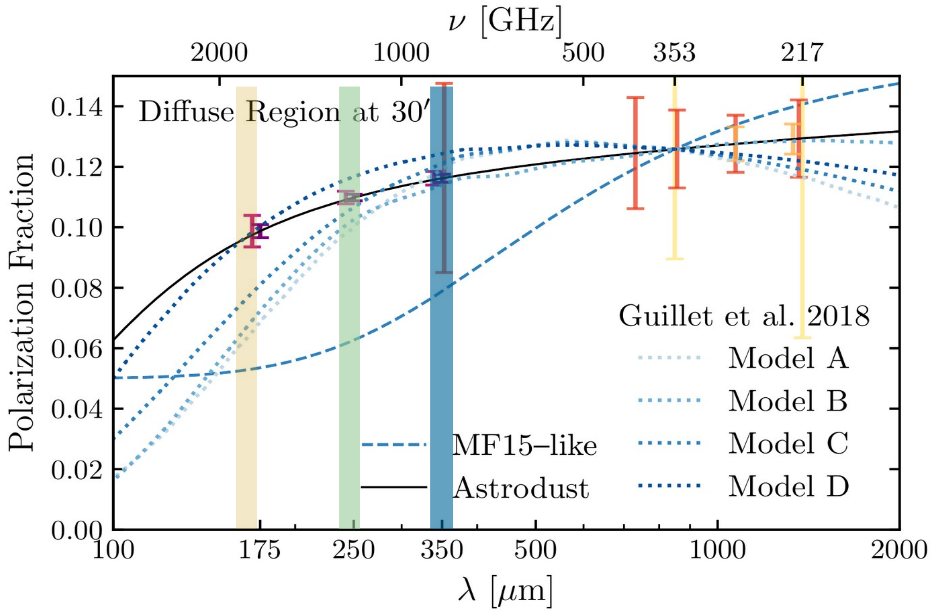
SO3. Determine the ratio of energy density of magnetic fields, turbulence, and gravity in molecular clouds and filaments, and test for correlations with local star formation efficiency.	Linear polarization maps (θ, p) of nearby molecular clouds and surrounding dust with $\leq$ 0.1 pc resolution. Polarization maps with $\leq$1 pc resolution of a large sample of molecular clouds with masses ranging from 10^3 to 10^6 $M_\odot$.

BLAST Observatory frequencies ⇨

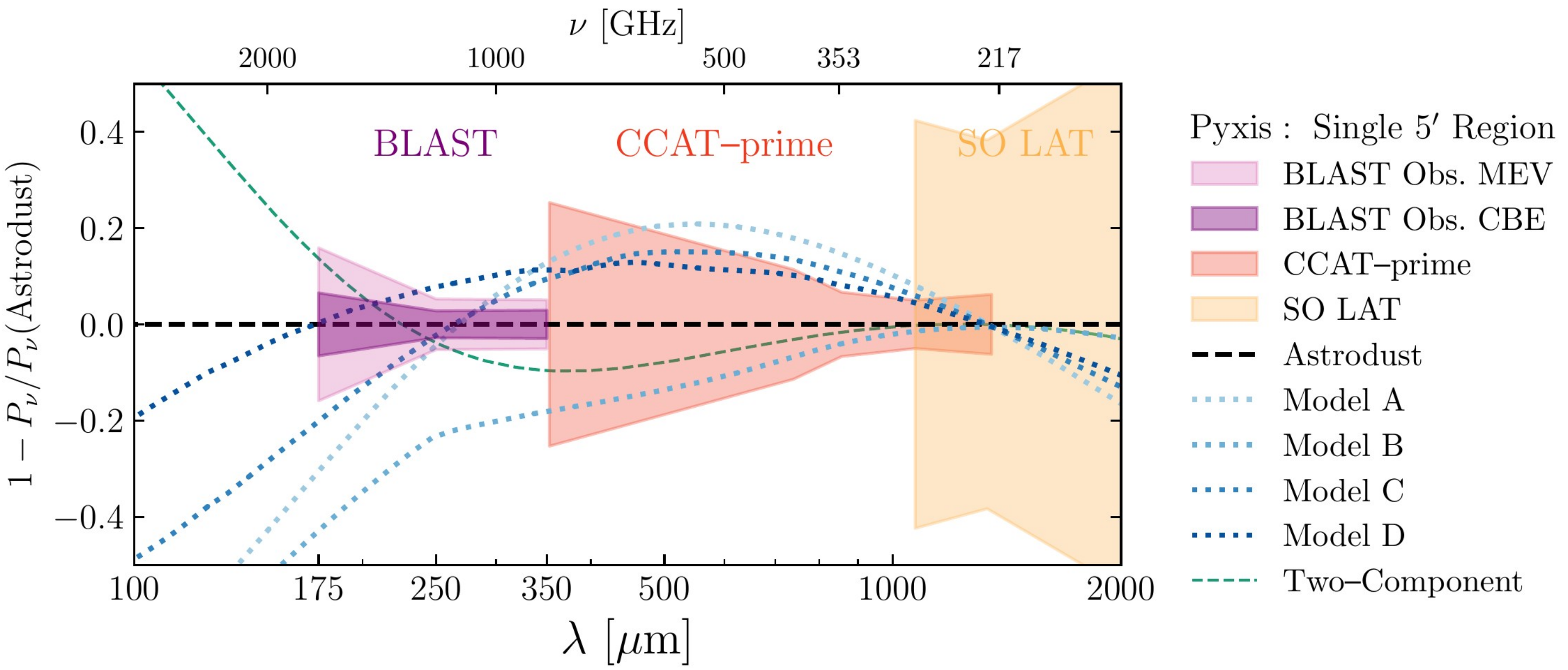
857 GHz (350 micron)
1200 GHz (250 micron)
1713 GHz (174 micron)



- Bands chosen where dust SED peaks
- And where dust models predict more deviation from each other in polarization fraction



Interstellar dust composition



Polarized dust emission from the translucent cloud Pyxis (model from 850 μm measurements by Planck)

The BLAST Observatory will provide thousands of independent polarization measurements in the Pyxis cloud alone

Purple errorbars show the forecasted performance for the BLAST Obs. on the fiducial dust SED.

BLAST Obs. complements the lower-frequency measurements of FYST/CCAT-p and the Simons Observatory (SO LAT)

The predicted level of correlation between polarized dust emission at different frequencies varies sharply among models, and it is quantified with cross-correlation angular power spectrum:

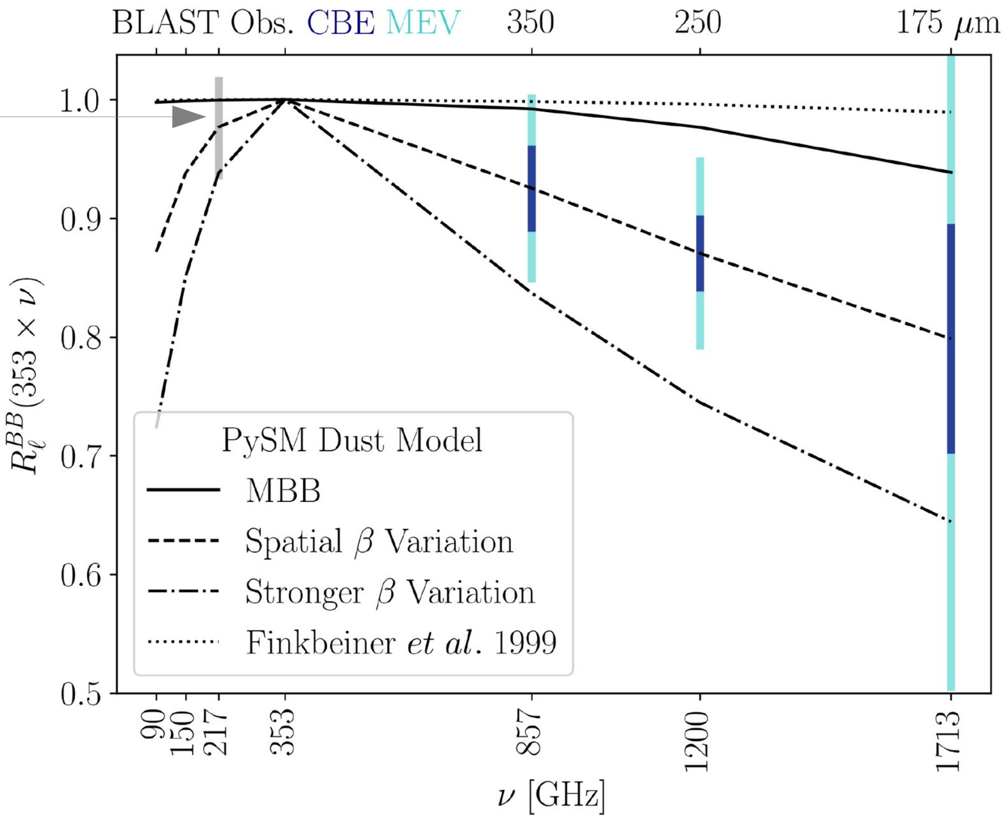
$$R_\ell^{BB}(\nu_1 \times \nu_2) \equiv C_\ell^{BB}(\nu_1 \times \nu_2)/\sqrt{C_\ell^{BB}(\nu_1 \times \nu_1)C_\ell^{BB}(\nu_2 \times \nu_2)}$$

Planck measurement at 353 x 217 GHz consistent with no de-correlation (grey bar)

BLAST Obs. can discriminate among the suite of dust models implemented in the PySM sky simulation

The image shows the forecasted BLAST Observatory measurements of the BB correlation ratio between 353 GHz and BLAST frequencies, for a 100 deg2 diffuse ISM observing region.

Blue/cyan Error bars show sample variance uncertainties for forecasted BLAST Obs, correlation with 353 GHz (120 ≲ l ≲ 2300).

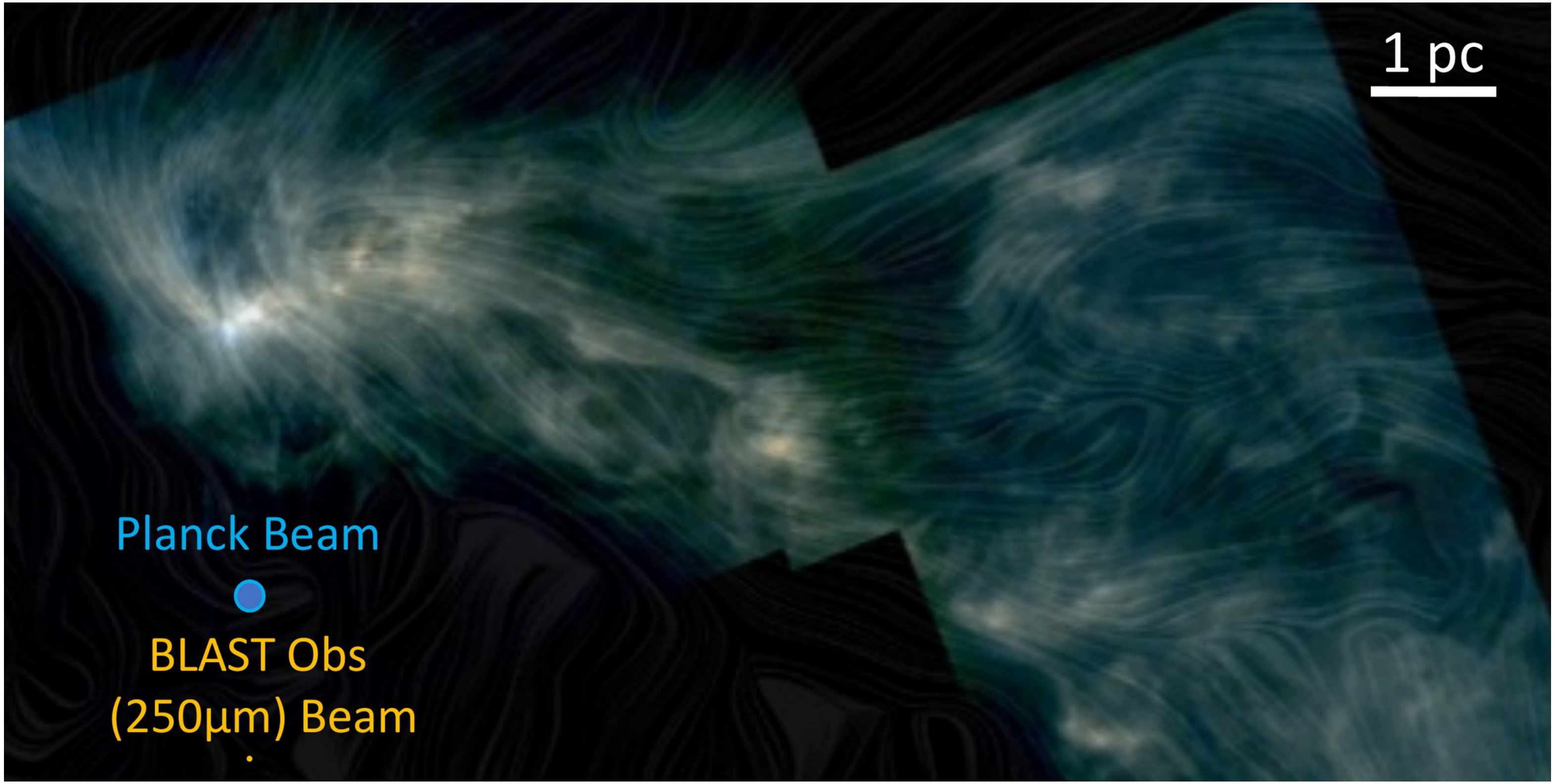


Magnetic fields and star formation

Star formation typically only produces stars at about 1% the rate expected from a free-fall collapse

The respective roles of magnetic fields, turbulent gas motions, and feedback from young stars in setting this low efficiency are still under debate

BLAST Observatory will survey the polarized dust emission of at least a thousand filamentary clouds, encompassing a wide range of masses, star formation activity levels, and turbulence properties



BLAST Observatory will map magnetic fields over the entire molecular clouds (Corona Australis shown), with at least 16× better resolution (0.03 pc) compared to Planck.

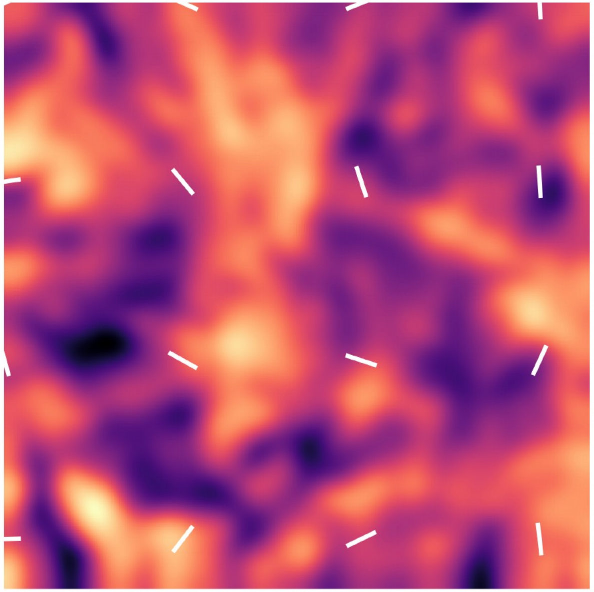
These maps will be used to study the change in magnetic field properties from the diffuse gas envelope surrounding the core, all the way down to the magnetic fields of individual ∼0.1 pc sized dense cores.

Comparison in **angular resolution and polarization sensitivity** between Planck at 353 GHz and the BLAST Obs.

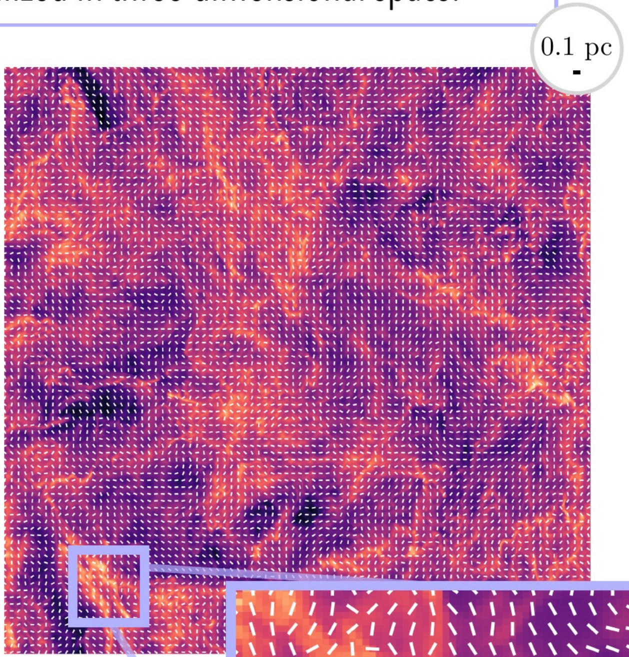
Where Planck had only a handful of independent polarization measurements at 80′, the BLAST Obs. will measure tens of thousands of independent measurements at 3′ resolution in diffuse fields, and even better in Pyxis.

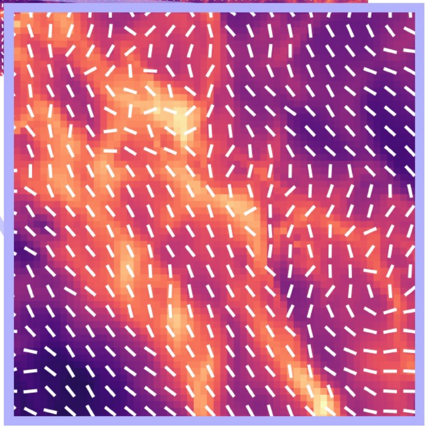
This will enable measurements of small-scale non-Gaussianity in polarization.

The BLAST Observatory measures magnetic field structure in the diffuse ISM where the polarized emission is localized in three-dimensional space.



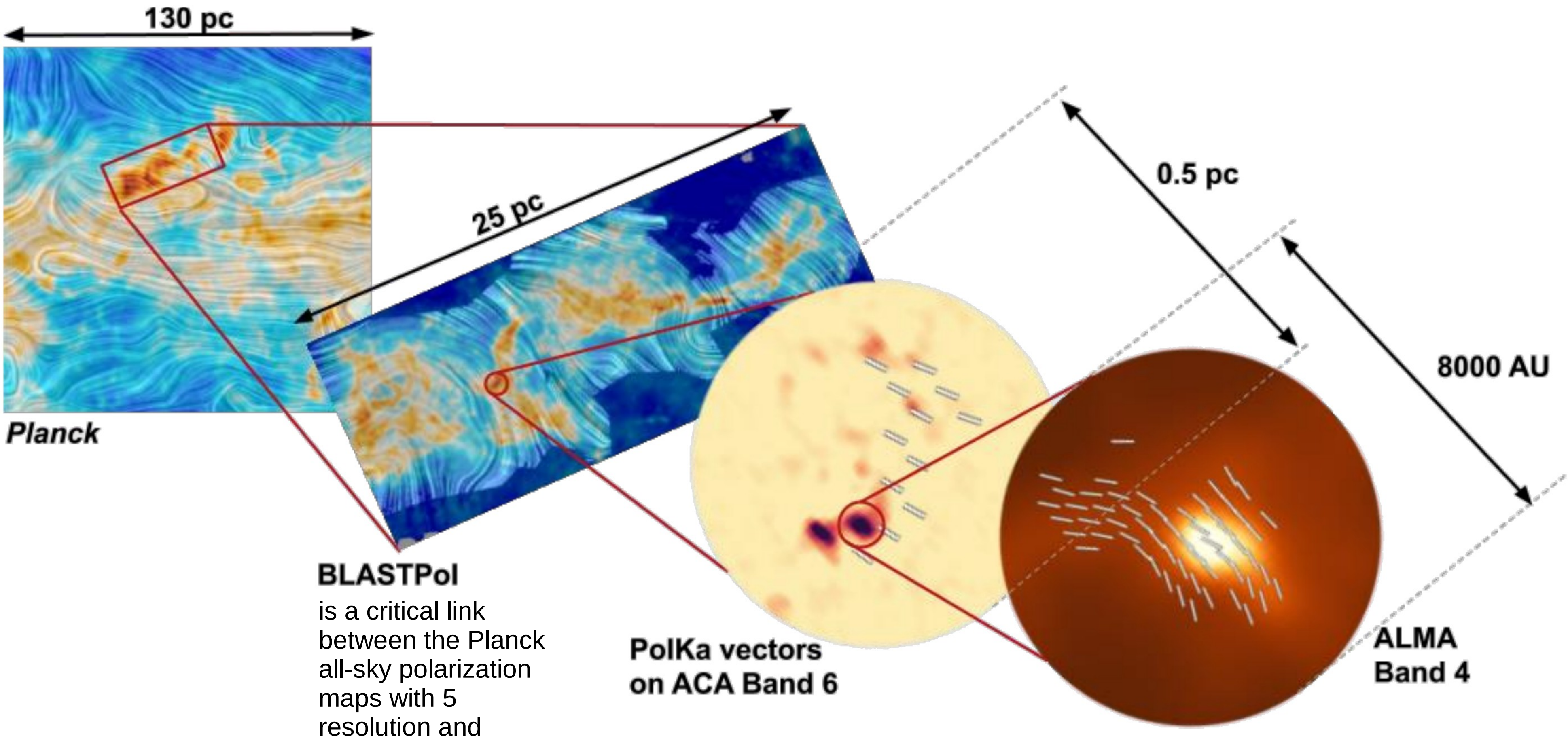
Planck data must be smoothed to 80′ resolution to achieve 3σ polarization maps in the diffuse ISM.





BLAST Obs. will enable detailed studies of turbulence and small-scale non-Gaussianity.

Scale and resolution gap in IR polarimetry of the ISM



BLASTPol

is a critical link between the Planck all-sky polarization maps with 5 resolution and ALMA's ultra-high resolution, but with only ~ 20 field of view.

Observing Program for 31 day flight

Survey[a]	*Science Objective(s)* [STM]	*Distance [pc]*	*Best resn.*[b] *[pc]*	*Area*[c] *[deg^2]*	*Obs. time*[d] *[hrs]*	*Approx. no. B-vectors*[e]
Diffuse ISM Field 1 ($N_H < 4 \times 10^{20}$)	Dust properties **[SO1]** MHD turbulence **[SO2]**	100–500	0.15	100 (100)	48 (40)	25,000
Diffuse ISM Field 2[f] ($N_H < 4 \times 10^{20}$)	Dust properties **[SO1]** MHD turbulence **[SO2]**	100–500	0.15	100 (0)	48 (0)	25,000
Pyxis ($N_H \sim 1 \times 10^{21}$) translucent cloud	Dust properties **[SO1]** MHD turbulence **[SO2]**	175	0.03	60 (60)	30 (16)	100,000
>10 Nearby molecular clouds (*MEV: 6 clouds*)	B-Fields in SF **[SO3]** Dust properties **[SO1]**	140–800	0.027 – 0.1	240 (72)	96 (24)	1,600,000
Galactic plane survey of filamentary clouds	B-Fields in SF **[SO3]** Dust properties **[SO1]**	150–15,000	0.03 – 2.0	200 (90)	40 (20)	1,400,000
Large Magellanic Cloud[f]	Dust properties **[SO1]**	50,000	7	64 (0)	30 (0)	320,000
Small Magellanic Cloud[f]	Dust properties **[SO1]**	61,000	8	64 (0)	30 (0)	280,000
Shared risk observations	*Proposed by the astronomy community*				124 (42)	

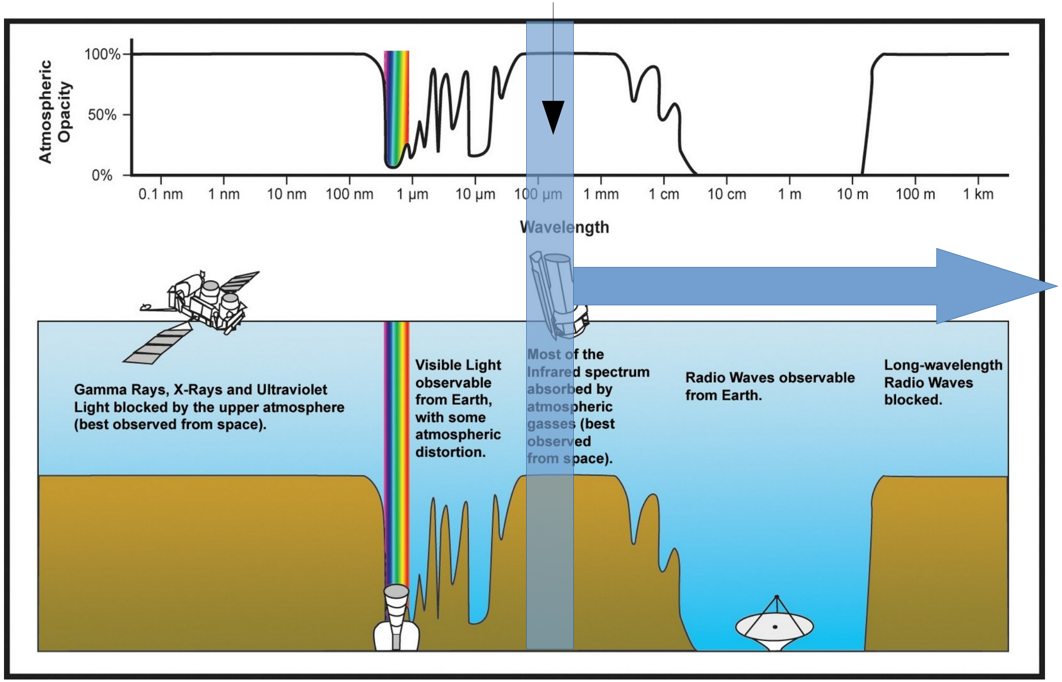
Why a balloon?

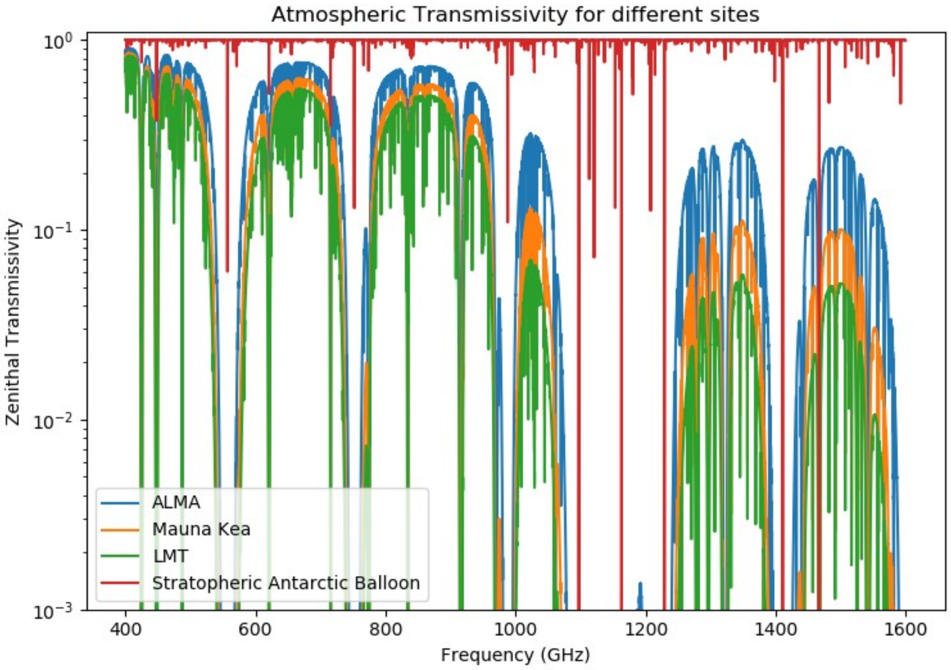
Strong and wide H2O lines for all the sites on the ground

Lower transmissivity throughout all the spectra

Additional optical loading on the detectors

BLAST sensitivity region



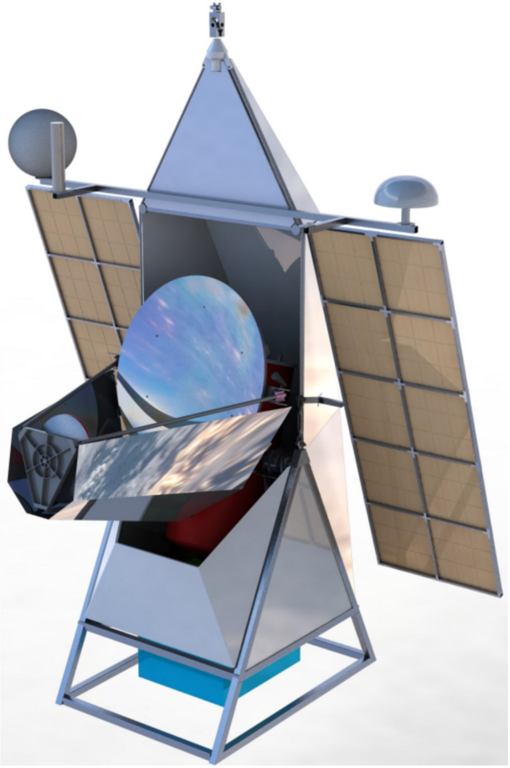


Key requirements

- High angular resolution → large mirror, diffraction-limited optics,
- Short wavelengths to observe at the peak of the dust SED
- Large angular scales → state of the art detectors with low 1/f
- High sensitivity and mapping speed → large field-of-view, sensitive detectors, plus low loading from off-axis optics
- Long duration flight and sky access → super pressure balloons from mid-latitudes

	Flight Days
CBE (Current Best Estimate) Performance expected based on current telescope design	31
MEV (Minimum Expected Value) Instrument performance required to meet the science objectives	14

Wavelength (μm)	Frequency (GHz)	Beam FWHM (``)
175	1700	28/35
250	1200	39
350	857	55

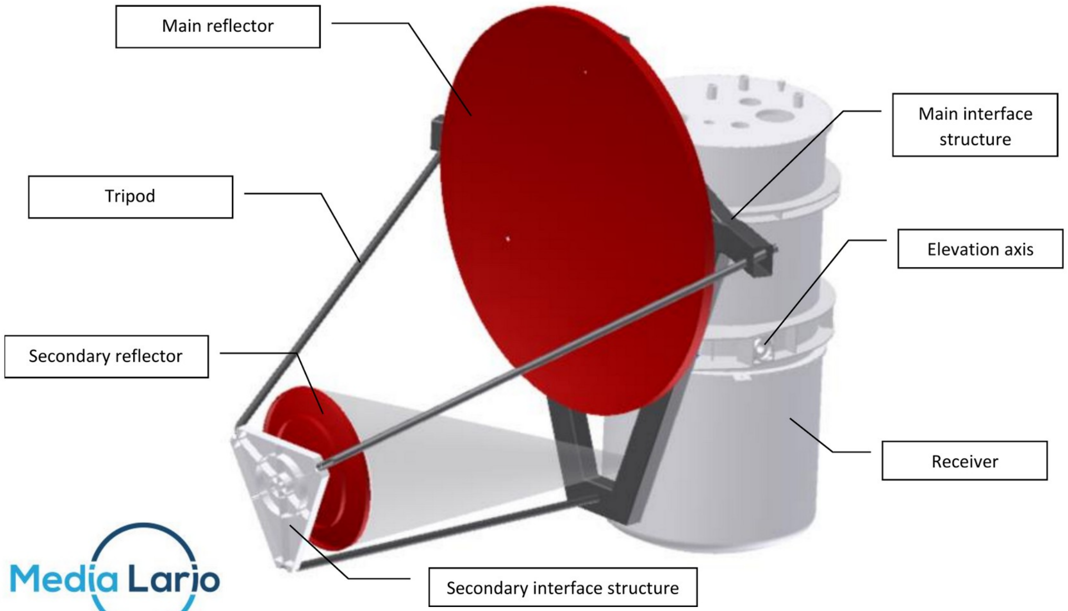


Gondola	Dimensions	5.6 m x 4.4 m x 7.0 m, Aluminum Construction		
Telescope	Temperature	**day**: 260 K **night**: 240 K		
	Primary Diameter	1.8 m, 1.6 m illuminated		
	Primary RMS	5 μm (10 μm)		
	F-number	f/3.5		
	Optical Design	Off-axis Gregorian		
Cryostat	L^4He Reservoir (L)	300		
	Cryogenics Stages	6: 140K, 40K, 4K, 2K, 0.270K, 0.1K		
	Cryostat Hold Time (days)	31 (36 Projected)		
	Sub-K Technology	Sorption Cooler + ADR		
Detectors	MKID Quantum Efficiency	0.8 (0.7)		
	Feed-horn Efficiency	0.9 (0.7)		
	F-number at the Detectors	f/5		
	Throughput	$A\Omega = \lambda^2$		
	Central Wavelength (μm)	**175**	**250**	**350**
	Number of MKIDs	3296	3296	1682
	Detector Yield (included in MEV and CBE)	>80%	>80%	>80%
	Pixel Size	$3f\lambda$	$2f\lambda$	$2f\lambda$
	Background Power per Detector (pW)	9.2 (6.6)	6.6 (4.9)	4.8 (3.7)
	Background NEP per Detector ($\times 10^{-16}\mathrm{W}/\sqrt{\mathrm{Hz}}$)	1.80 (1.75)	1.30 (1.26)	0.93 (0.93)
System	Beam FWHM (arcsec)	28	39	55
	Lyot Stop Fractional Transmission	0.6	0.6	0.6
	Total Instrument Transmissivity	28% (13%)	35% (21%)	42% (27%)
	FoV per Array (deg)	0.75		
	Filter Widths ($\Delta\lambda/\lambda$)	0.3		
	Nominal Scanning Speed	0.1°/s		

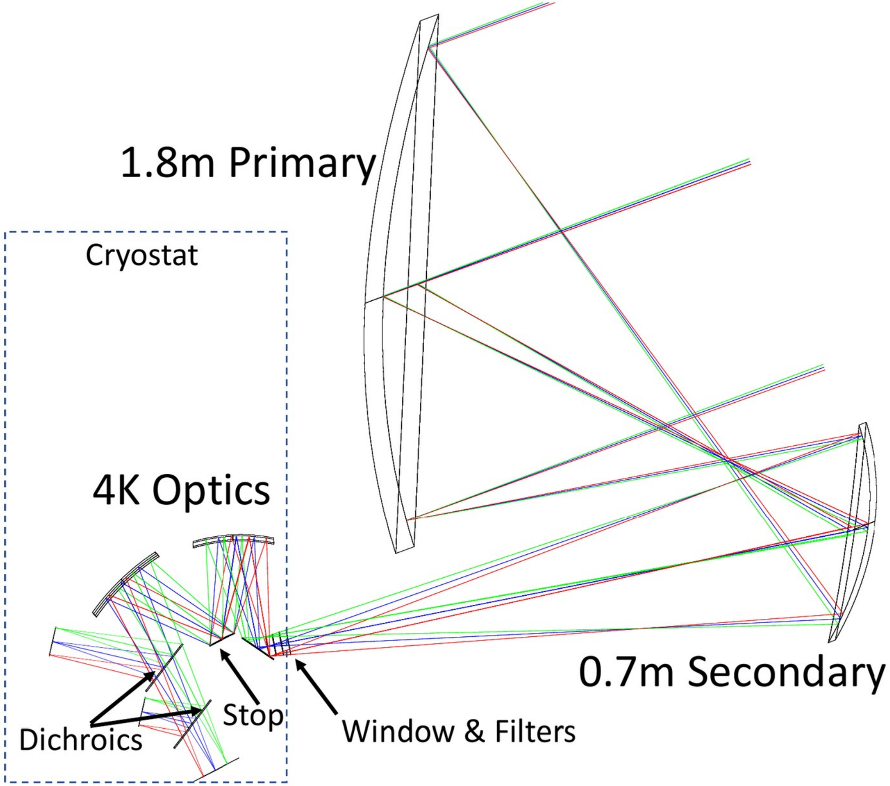
Telescope

Built by Media Lario (Italy), manufacturer of sub-millimetre reflectors for ALMA and LMT, and of the 2.5 meter TeraHertz telescope for the ASTHROS balloon mission of NASA/JPL, which is representative of the technology proposed for the BLAST Obs.

Cold optics follows closely the one already tested for the previous BLAST-TNG system



Media Lario



Telescope

Built by Media Lario (Italy), manufacturer of sub-millimetre reflectors for ALMA and LMT, and of the 2.5 meter TeraHertz telescope for the ASTHROS balloon mission of NASA/JPL, which is representative of the technology proposed for the BLAST Obs.

The final design will have mirrors with large scale surface errors better than 5 μm RMS, small-scale surface roughness surface roughness better than 0.5 μm RMS, positional tolerances of 50 μm, and focusing precision of 10 μm. They have metrology systems with accuracy down to 5 nm RMS to validate performance.

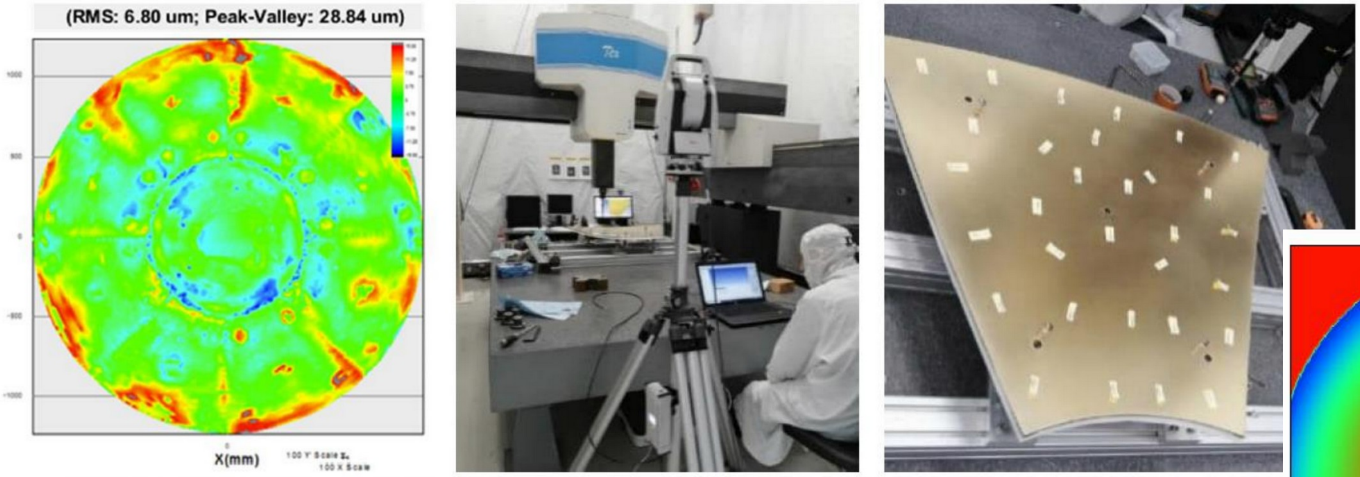
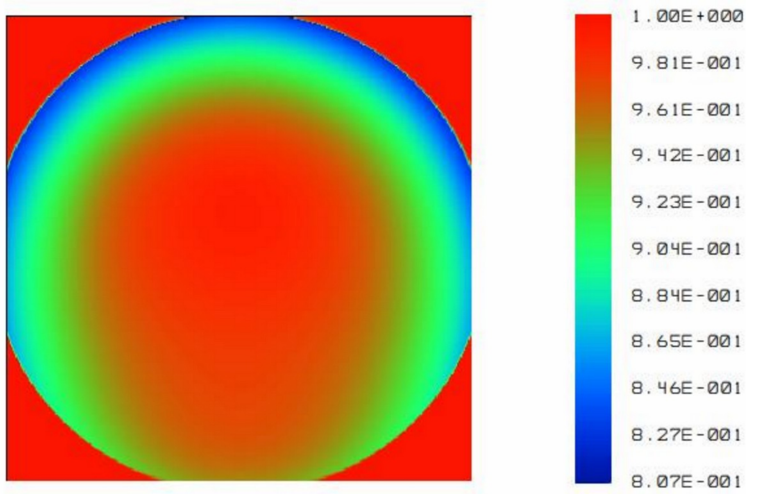
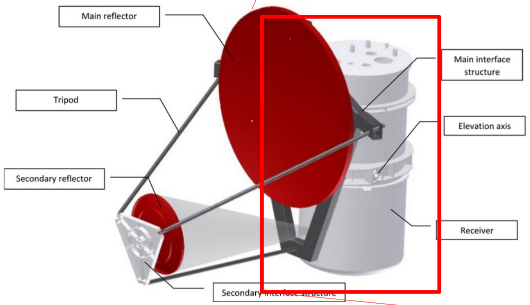


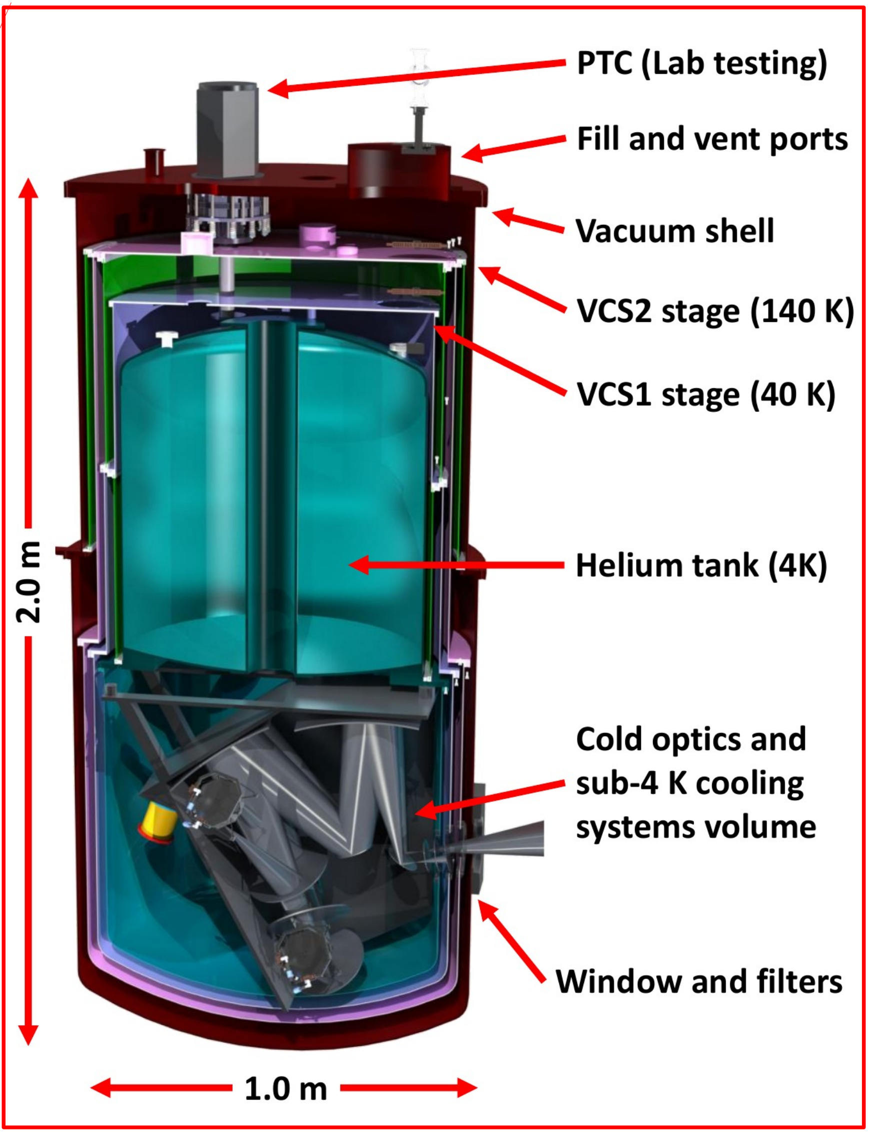
Figure 2. ASTHROS M1 surface accuracy (left) and CMM vs. Laser Tracker measurements (centre, right)



Cryostat

- LHe the only cryogen
- 300 L capacity, 36 days hold time
- Vapor cooled shields
- Based off BLAST-TNG design
- Capacity for operation using a pulse tube cooler instead of LHe on the ground to reduce costs and risks associated with the LHe supply chain
- Sub-4K cooling provided by pumped pot, He3 sorption, and ADR to 100 mK

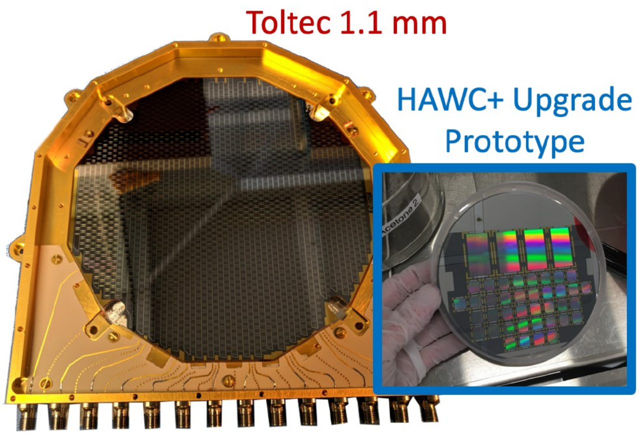




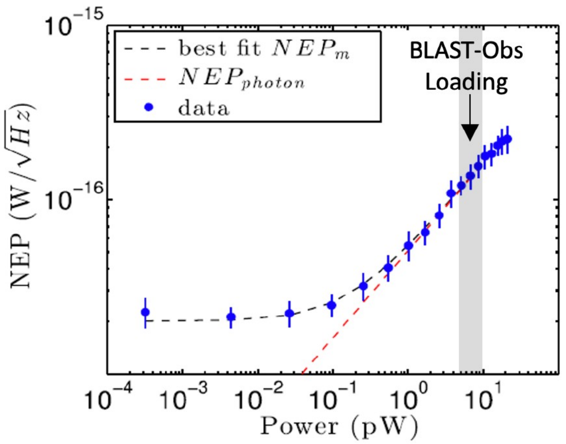
Detector arrays

- TiN dual-polarization KIDs operated at 100 mK for improved 1/f performance
- Coupled to lithographically-defined silicon-platelet feedhorns
- Same general design and architecture as demostrated in-flight with BLAST-TNG
- Minor low-risk changes to array fabrication will result in significant improvements in detector performance (150 mm silicon wafers, technologies produced for Toltec, CCAT-prime)
- Background-limited performance demonstrated for BLAST-TNG
- The low-Tc TiN films to be used in BLAST Observatory exhibit significantly lower 1/f noise than previous generation TiN-based KID devices.
- Readout based on Xilinx RFSoC ZCU111 is able to frequency-multiplex 8274 detectors using only 8 lines, 112 W

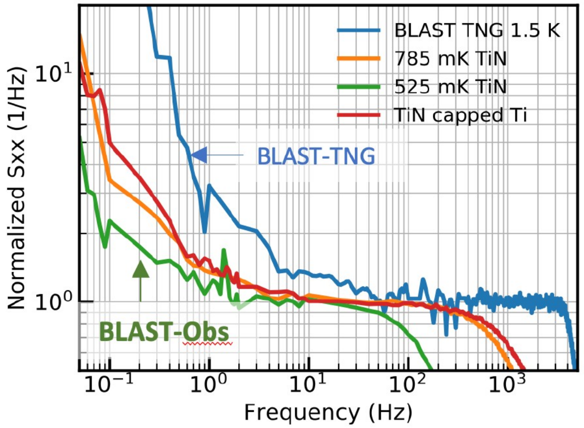
150 mm Fabrication



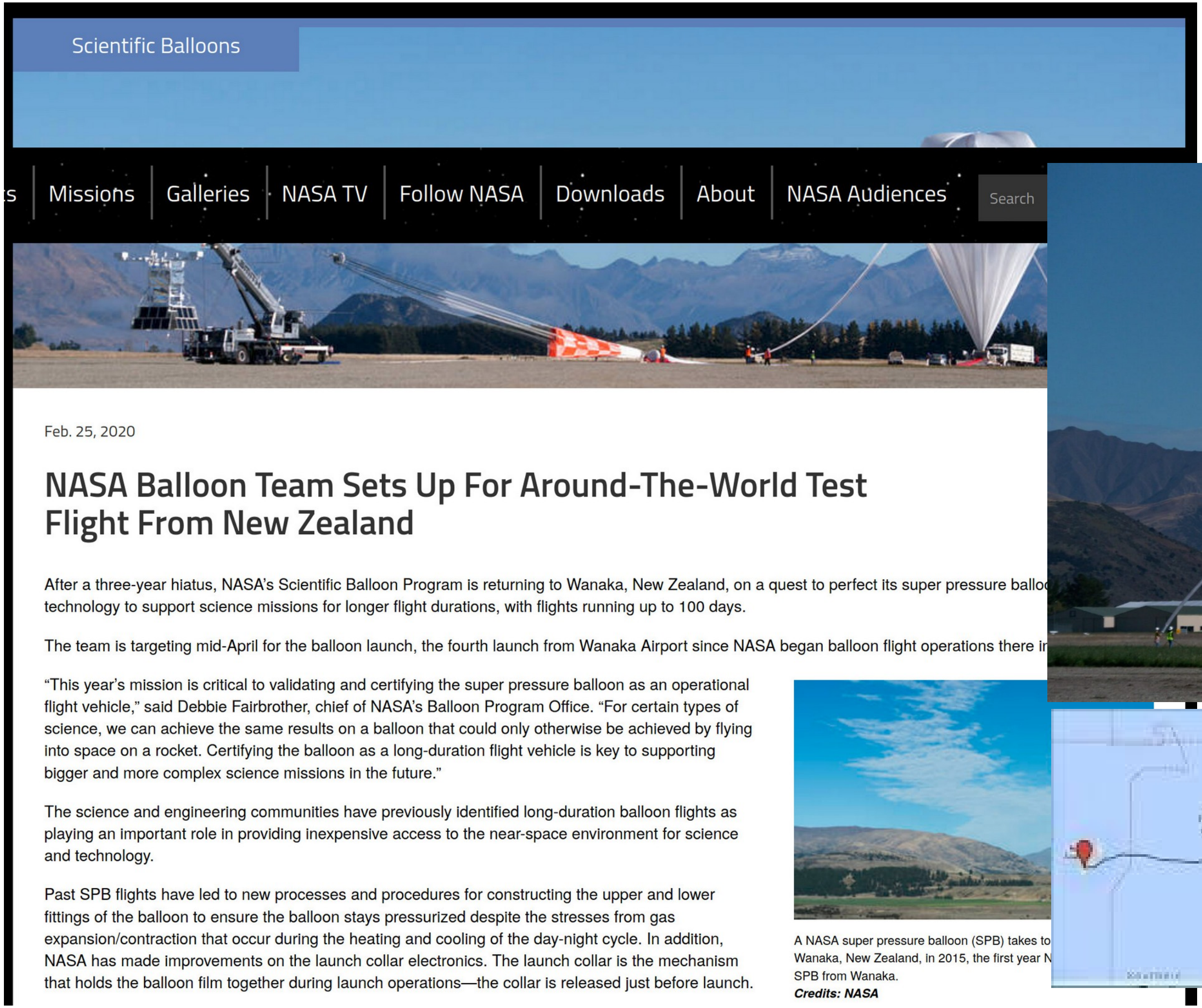
Background Limited



Improved 1/f Noise



NASA Ultra Long Balloon flight from Wanaka, New Zealand



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Feb. 25, 2020

NASA Balloon Team Sets Up For Around-The-World Test Flight From New Zealand

After a three-year hiatus, NASA's Scientific Balloon Program is returning to Wanaka, New Zealand, on a quest to perfect its super pressure ballo technology to support science missions for longer flight durations, with flights running up to 100 days.

The team is targeting mid-April for the balloon launch, the fourth launch from Wanaka Airport since NASA began balloon flight operations there i

"This year's mission is critical to validating and certifying the super pressure balloon as an operational flight vehicle," said Debbie Fairbrother, chief of NASA's Balloon Program Office. "For certain types of science, we can achieve the same results on a balloon that could only otherwise be achieved by flying into space on a rocket. Certifying the balloon as a long-duration flight vehicle is key to supporting bigger and more complex science missions in the future."

The science and engineering communities have previously identified long-duration balloon flights as playing an important role in providing inexpensive access to the near-space environment for science and technology.

Past SPB flights have led to new processes and procedures for constructing the upper and lower fittings of the balloon to ensure the balloon stays pressurized despite the stresses from gas expansion/contraction that occur during the heating and cooling of the day-night cycle. In addition, NASA has made improvements on the launch collar electronics. The launch collar is the mechanism that holds the balloon film together during launch operations—the collar is released just before launch.

A NASA super pressure balloon (SPB) takes to Wanaka, New Zealand, in 2015, the first year N SPB from Wanaka.
Credits: NASA

Light-weight gondola

Must be lightweight to meet SPB requirements

Designed by StarSpec, based on extensive experience with SuperBIT

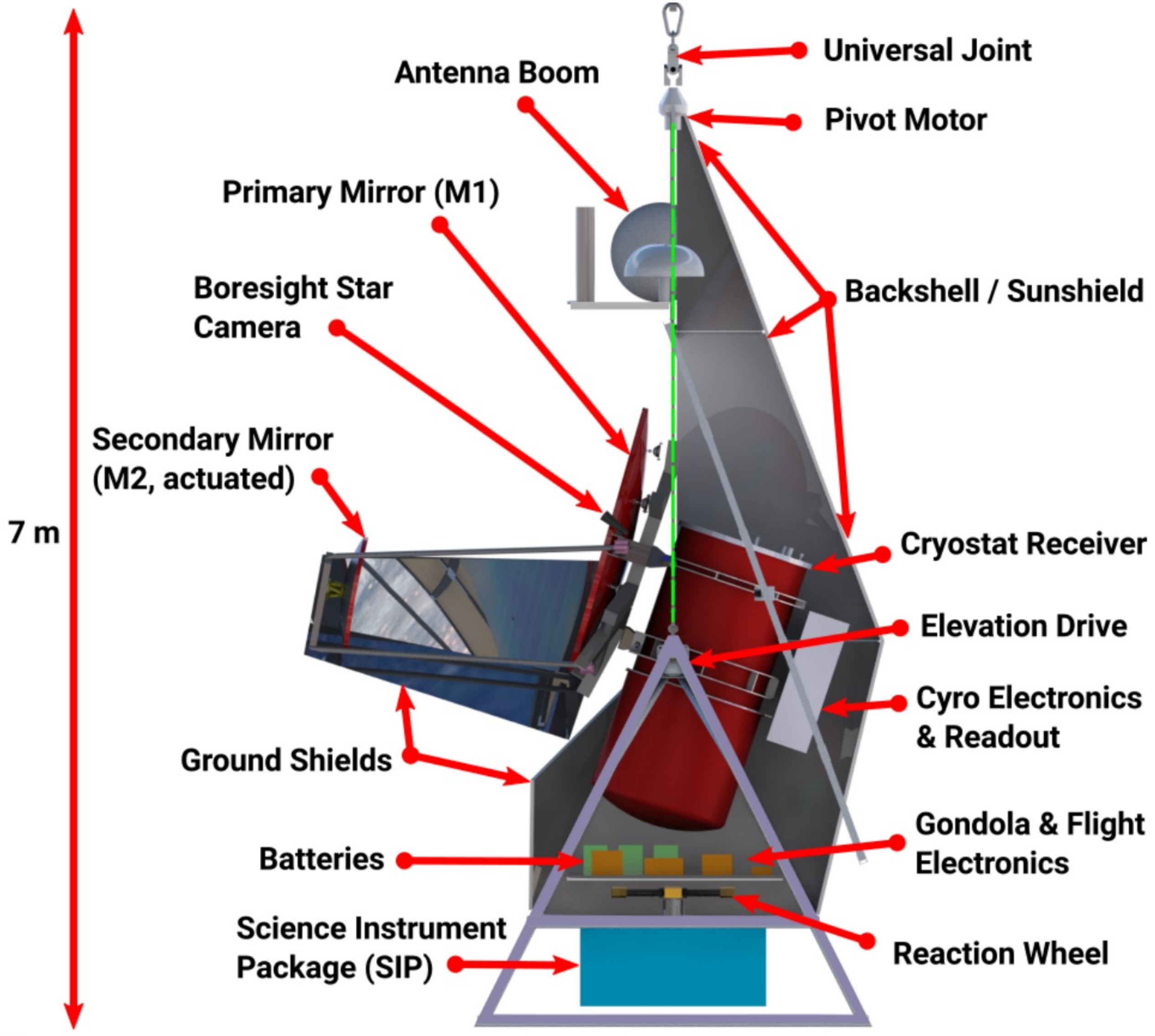
Lightweight; strength based on aluminum honeycomb panels over aluminum frame

No carbon fiber structural elements to ensure robustness

Total payload mass: 1242 kg

Total power consumption between 500 and 600 W

Power supply ~2000 W



Telemetry and Downlink

Without compression, data rate ~ 53 Mbps, which is > the current bandwidth provided by CSBF.

Combination of

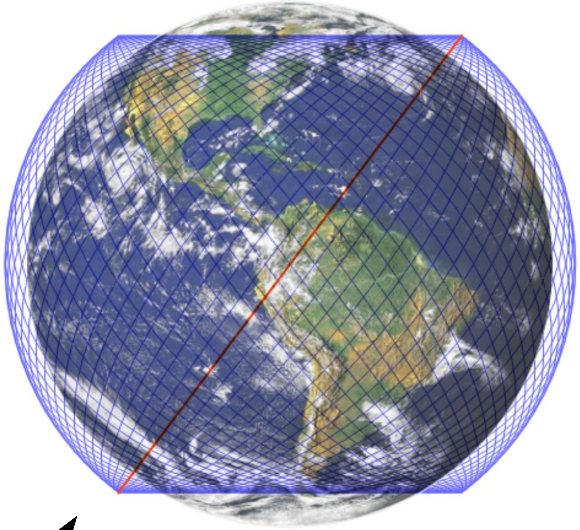
- compression
- improved 1/f (which allows slower sampling rates)
- night-only observations

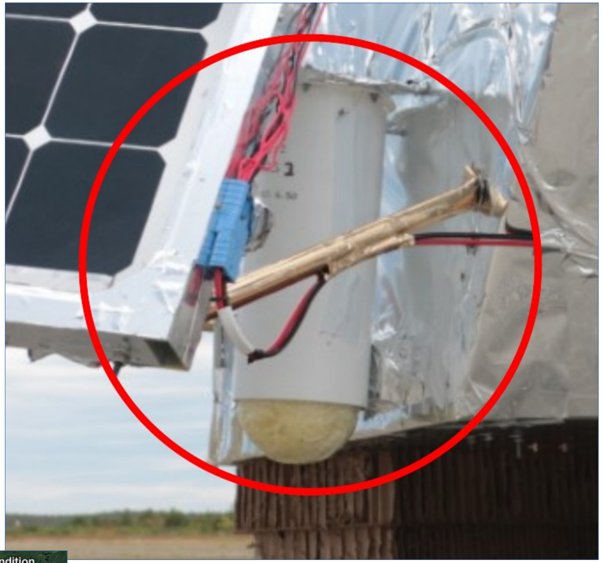
reduces the averaged data rate to 1.76 Mbps.

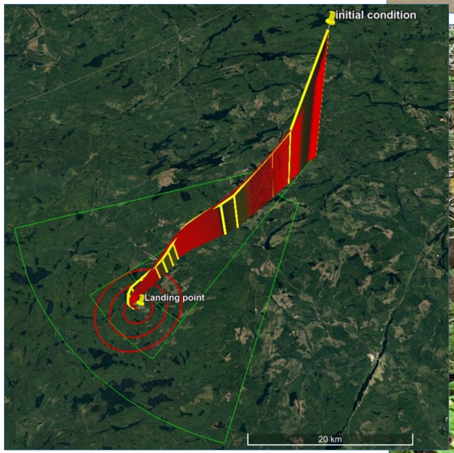
Science data stored so that they can be transmitted when telemetry is available

Commercial options becoming available, including Starlink (to 52° S), Amazon Kuiper (to 56° S) and OneWeb (polar), all of which would exceed 5 Mbps (we will only need to operate them for a fraction of the day)

Possibility of using *download by parachute* (Sirks et al. 2020), successfully tested on SuperBIT flights

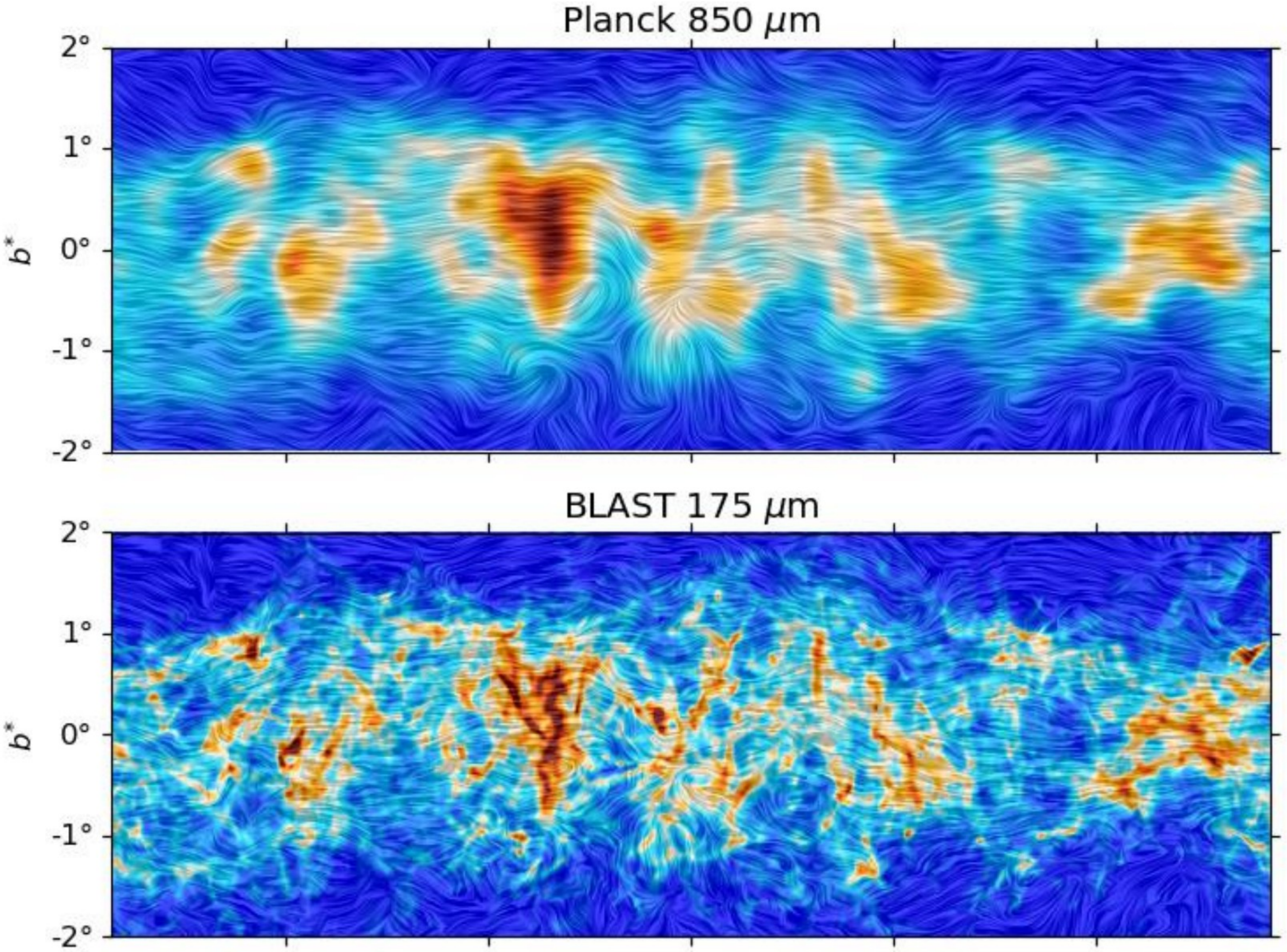






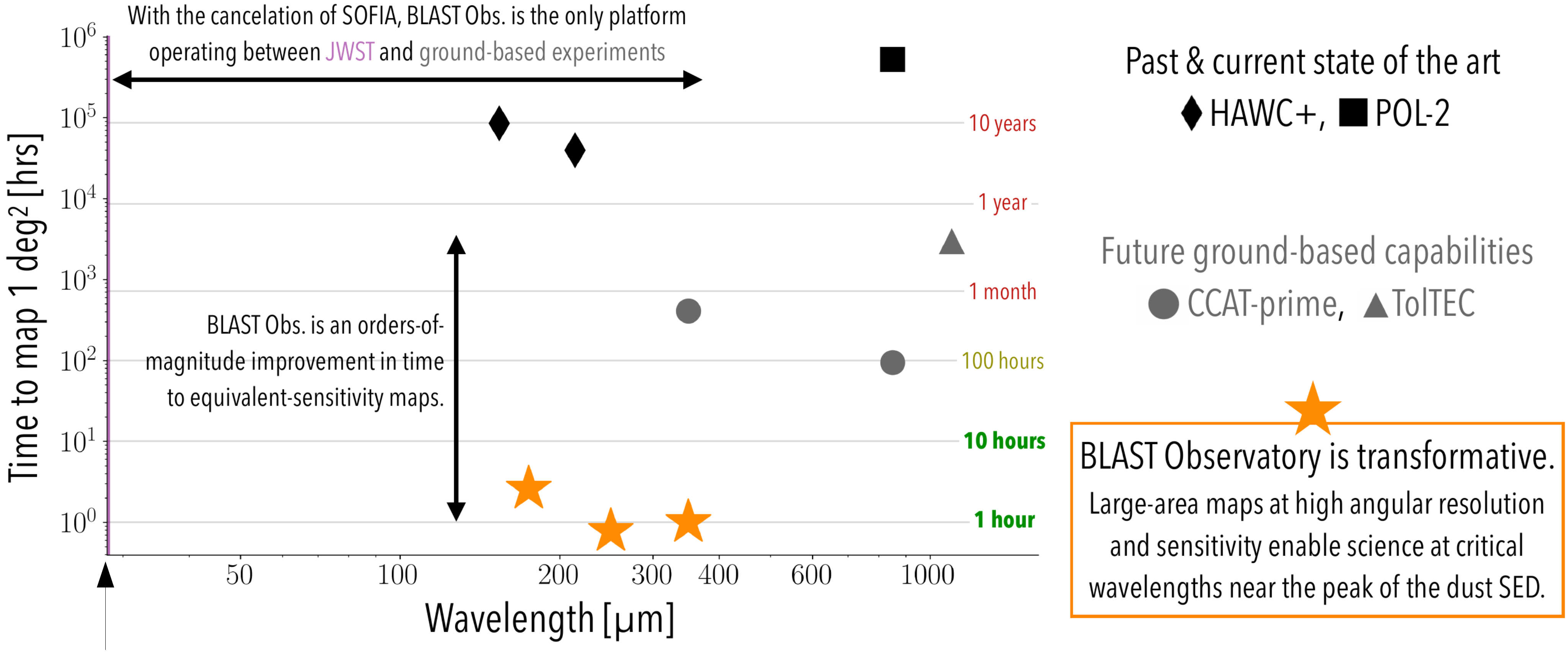
The interpretation of the results of all of BLAST Observatory measurements requires the development of simulations (see example at right of a simulation of cloud which might be found in the Galactic Plane).

Further, the processing of raw timestream data into science-ready maps requires extensive development. We are planning to use many of the tools developed for Simons Observatory and many of our members are part of SO.



Final remarks

BLAST Obs. provides a vast improvement in mapping speed over current and planned facilities



Vertical axis shows estimated time to detect dust polarization at 3σ for a 1 deg2 region of diffuse ISM (All estimates assume smoothing to the BLAST Obs. 350 μm resolution of 55″)