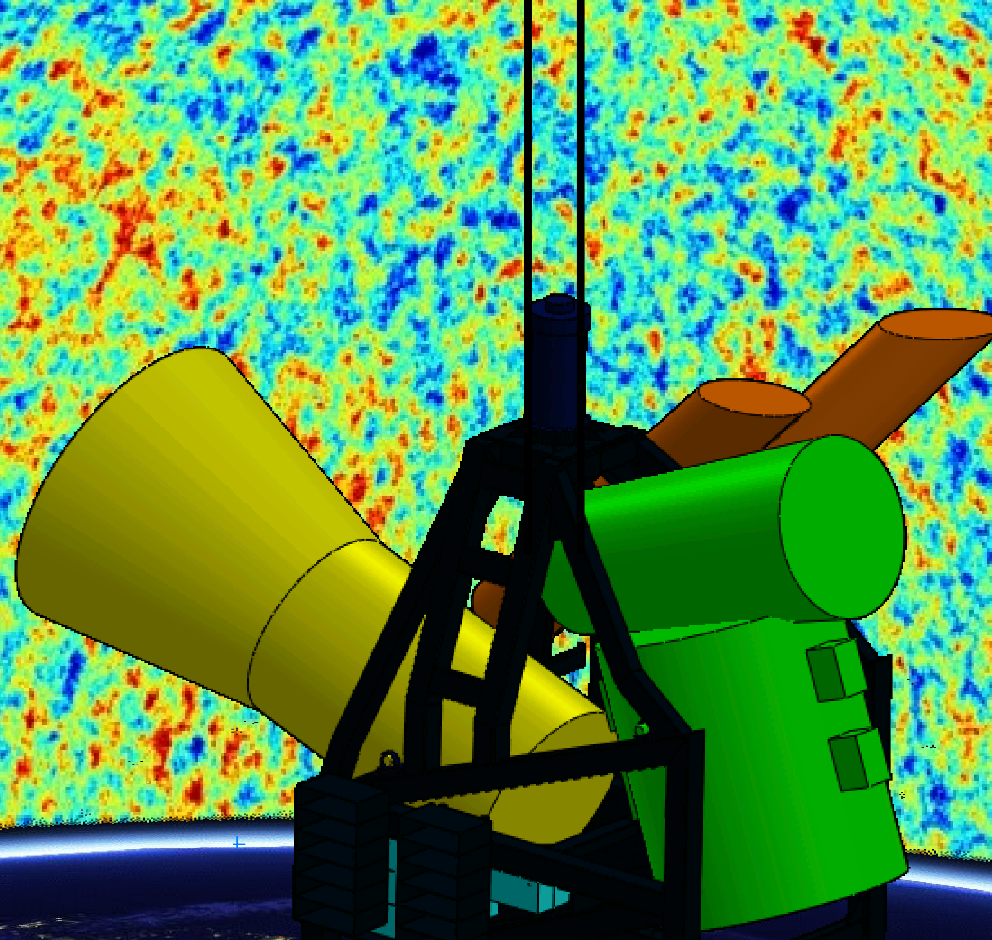


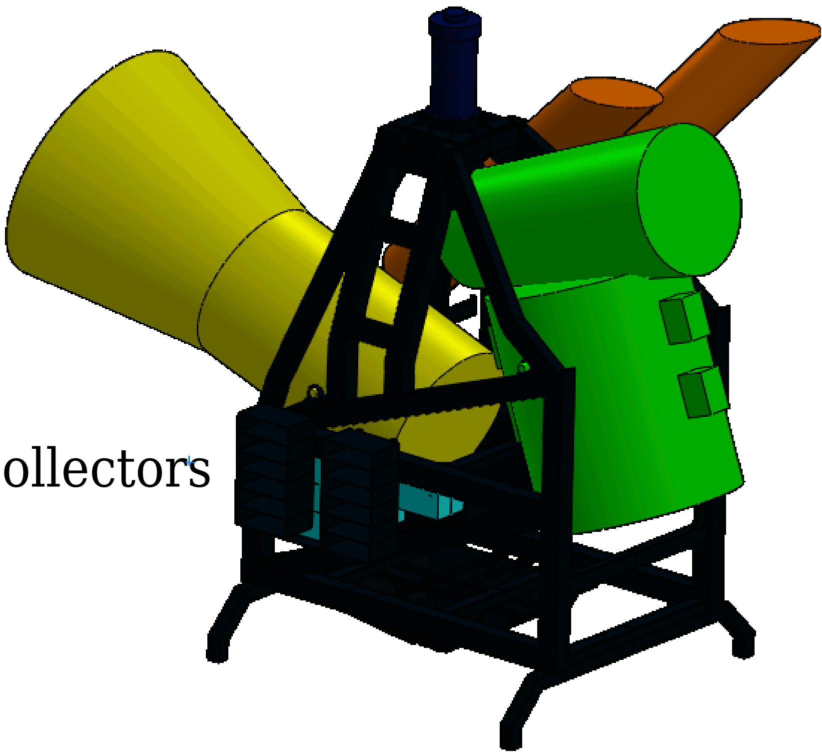
Large Scale Polarization Explorer
SWIPE instrument

Francesco Piacentini (Univ. Roma La Sapienza)
on behalf Paolo de Bernardis and the LSPE collaboration

LSPE – Main facts

- Large scale polarization **balloon** experiment
- Flying Long Duration in the **Arctic** during the night
- **2 instruments** on board (STRIP, SWIPE)
- **5 bands**, 43, 90, 95, 145, 245 GHz
- **Spinning** gondola
- Sky coverage ~30%
- Angular resolution ~1degree

- **SWIPE**, the high frequency instrument,
  - the high sensitive instrument
- Based on **large throughput multimoded** collectors
- **TES** detectors
- Stepped cold **half wave plate**



- Funded by the Italian Space Agency

Collaboration

- PIs: Paolo de Bernardis, Marco Bersanelli

The LSPE collaboration: S. Aiola[a], G. Amico[a], P. Battaglia[b], E. Battistelli[a], A. Baù[c], **P. de Bernardis**[a], **M. Bersanelli**[b], A. Boscaleri[d], F. Cavaliere[b], A. Coppolecchia[a], A. Cruciani[a], F. Cuttaia[e], A. D'Addabbo[a], G. D'Alessandro[a], S. De Gregori[a], F. Del Torto[c], M. De Petris[a], L. Fiorineschi[f], C. Franceschet[b], E. Franceschi[f], M. Gervasi[c], D. Goldie[g], A. Gregorio[h,p], V. Haynes[i], N. Krachmalnicoff[c], L. Lamagna[a], B. Maffei[i], D. Maino[c], S. Masi[a], A. Mennella[c], Ng Ming Wah[i], G. Morgante[e], F. Nati[a], L. Pagano[a], A. Passerini[c], O. Peverini[l], F. Piacentini[a], L. Piccirillo[i], G. Pisano[i], S. Ricciardi[e], P. Rissone[f], G. Romeo[m], M. Salatino[a], M. Sandri[e], A.Schillaci[a], L. Stringhetti[n], A. Tartari[c], R. Tascone[l], L. Terenzi[e], M. Tomasi[n], E. Tommasi[o], F. Villa[e], G. Virone[l], S. Withington[g], A. Zacchei[p], M. Zannoni[c]

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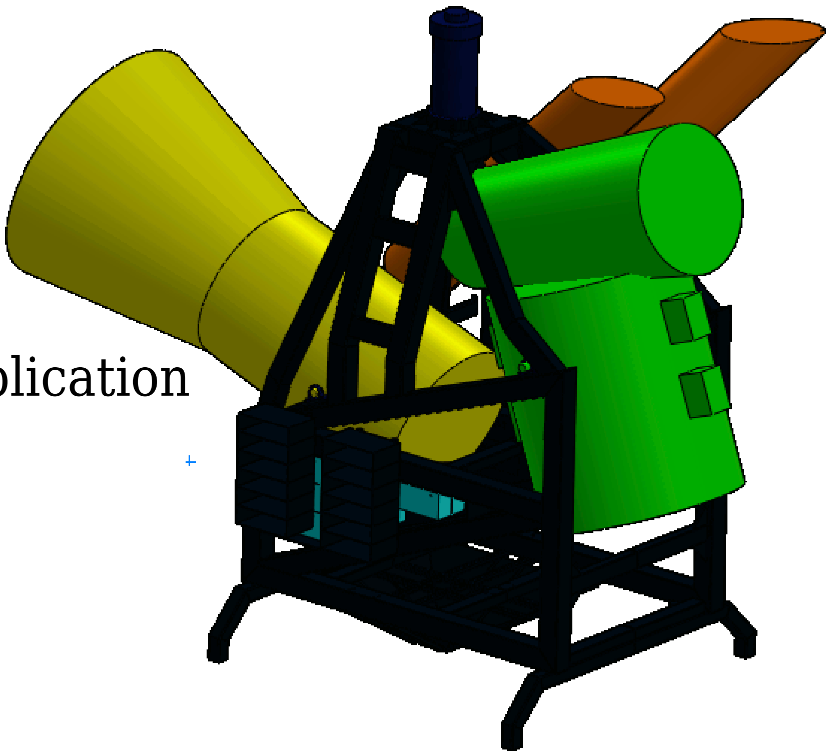
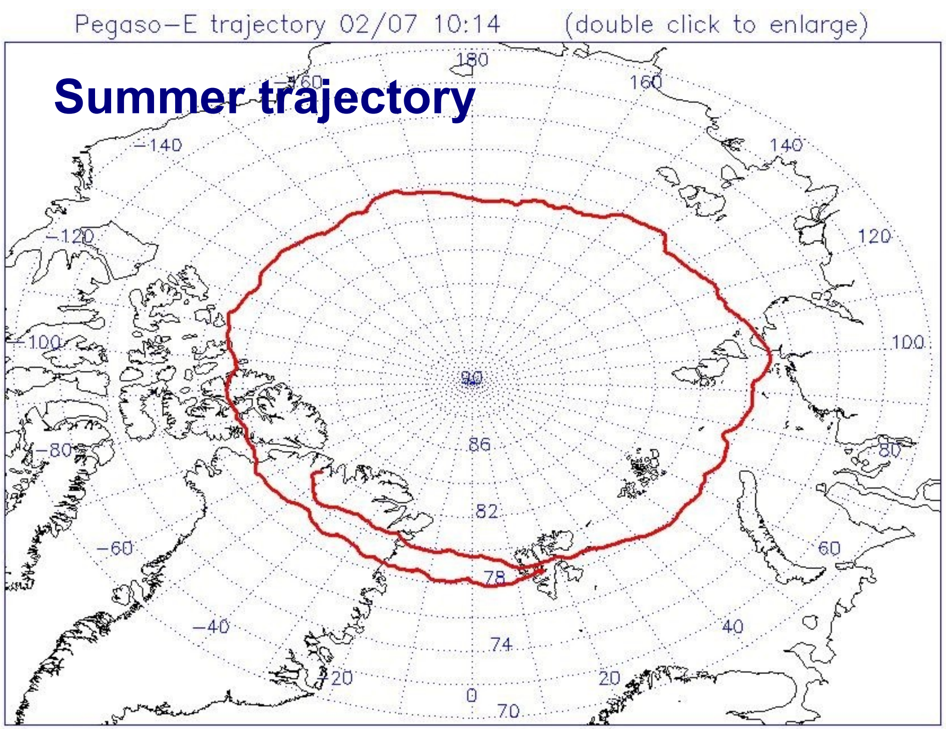
LSPE goal

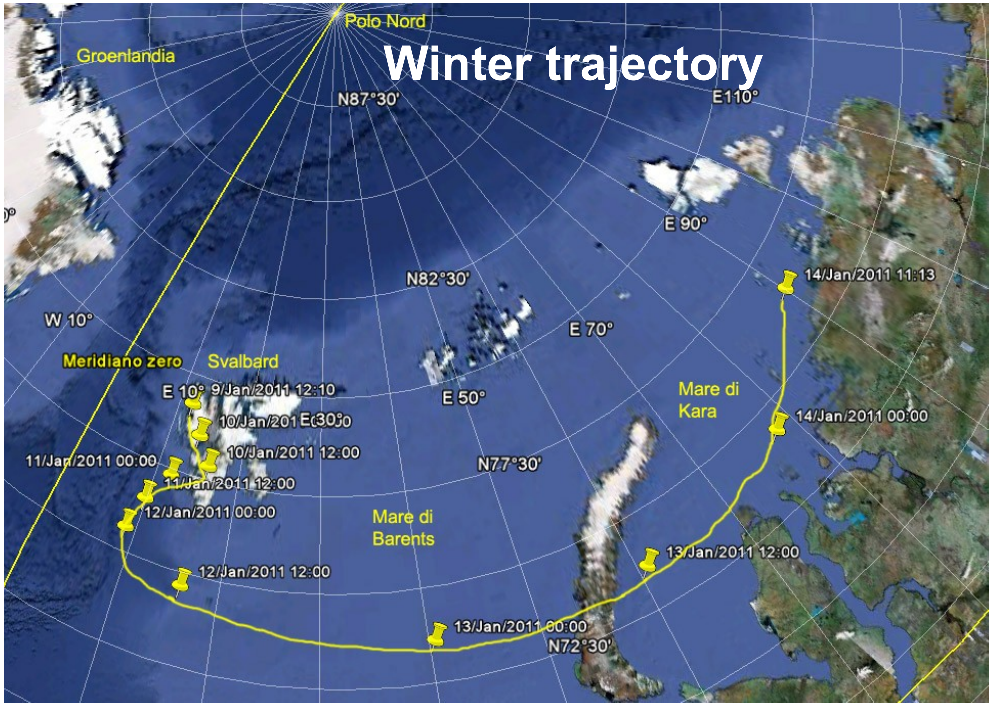
- Measure large scale CMB polarization and temperature anisotropies
- Constrain the B-modes of polarization
  - ell range [2-100]
- Improve the limit on tensor to scalar ratio **r**
  - **r** = 0.03, at 99.7% confidence
- Test and validate technologies for space application
  - LSPE was proposed after the ESA COrE proposal
  - Large Cold Achromatic Half Wave Plate (50 cm)
  - ESA ITT approved to G. Pisano (Manchester)



Winter Long Duration Arctic ballooning

- Stratospheric balloon during the polar night, in a long duration flight from Longyearbyen, Svalbard, Norway, 78°N (McMurdo is 78°S)
- Large coverage
- No Sun in sidelobes
- Accumulating more than 10 days of integration at float





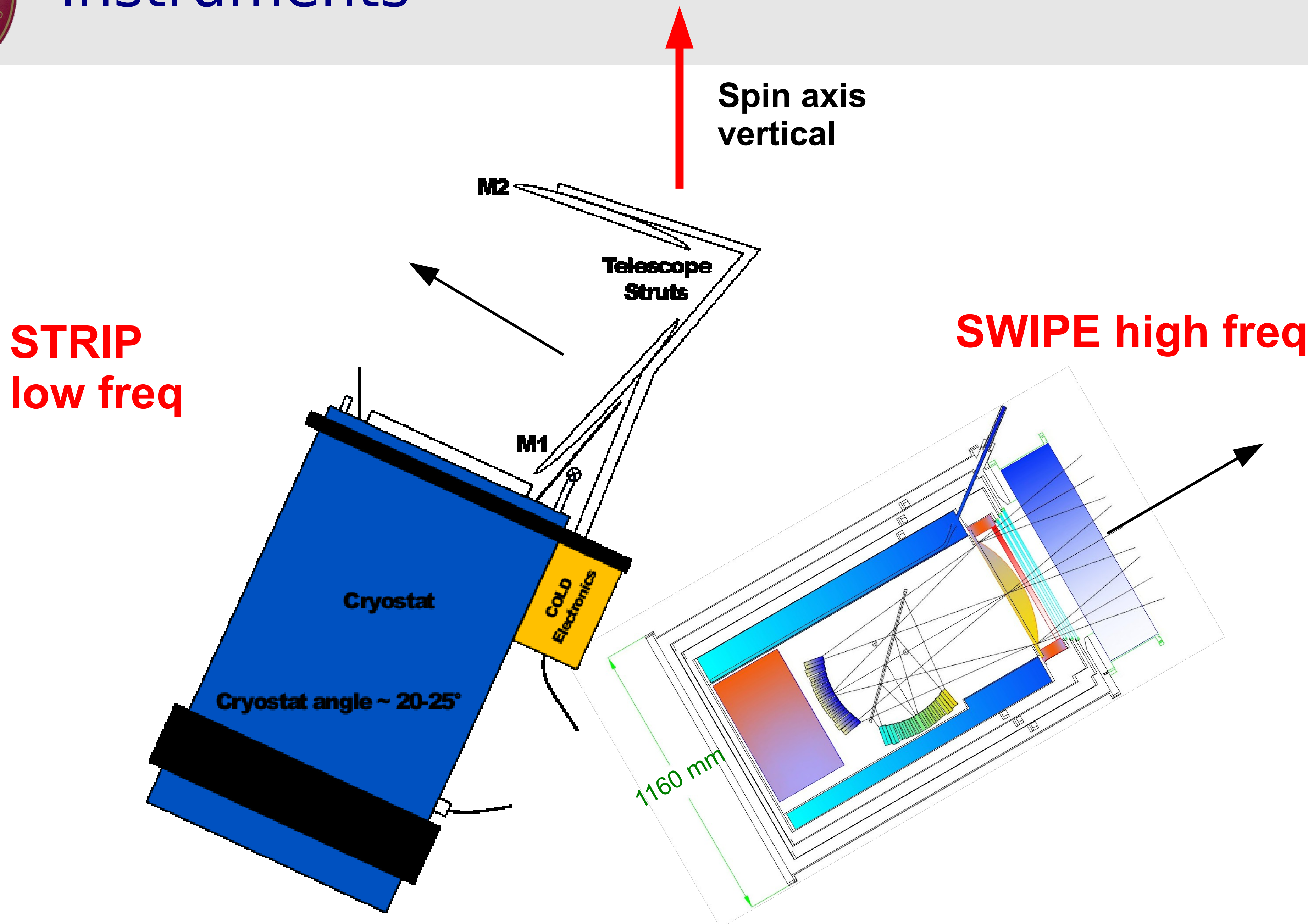
Winter Long Duration Arctic ballooning

- Thermal management.
  - The temperature of the stratosphere during the polar night is around -80°C
    - Electronic
    - Vacuum seals
    - Mechanical actuators

- Power supply: 700 W for 15 days.
  - Electrical energy storage close to 1 GJ – 450 Kg of lithium batterie

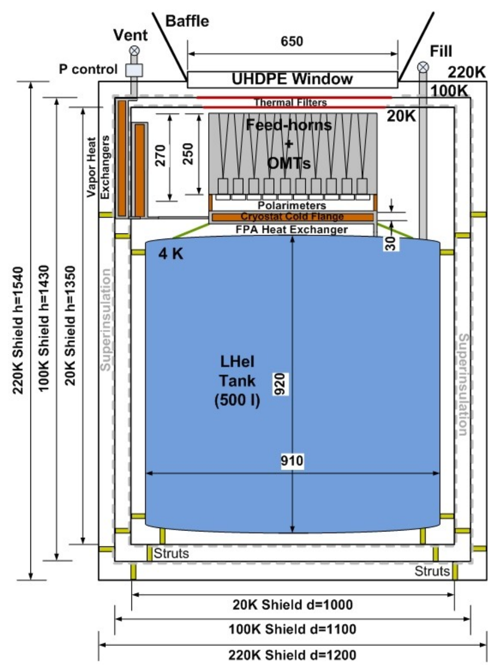
- Data management: LSPE will produce a raw data rate of about 400kbps
  - Stored on-board on solid state disks.
  - Essential housekeeping / flight info transmitted though the Iridium network
  - Line-of-sight telemetry at full rate available during the first day of the flight
  - Data-dumps when the system flies over selected locations hosting dedicated receiving stations.

Instruments



STRIP – low frequency

- An array of coherent HEMT at 20K
  - same polarimeters as in QUIET
  - 49 modules at 43 GHz, 7 modules at 95 GHz for crosscheck of systematic effects
- Measure low-frequency polarized emission

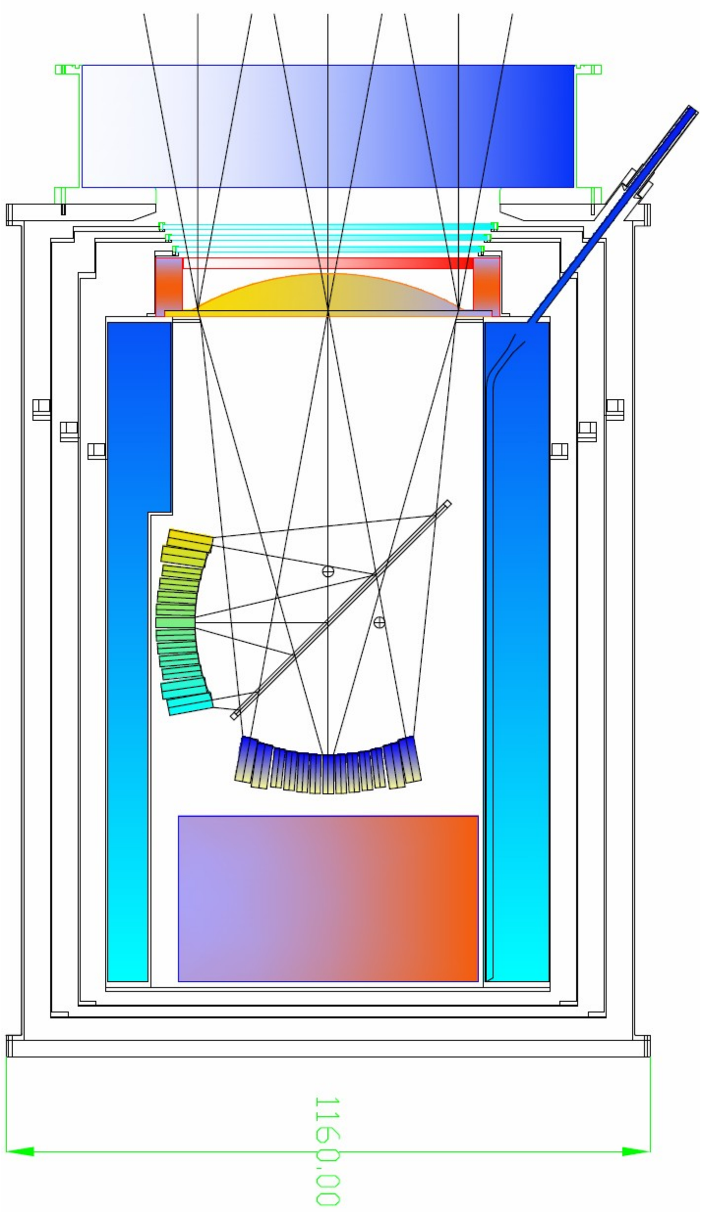


	PLANCK LFI			STRIP	
Frequency (GHz)	30	44	70	**43**	**90**
Resolution (deg)	0.55	0.47	0.22	**1.0**	**0.5**
Sky coverage (%)	100	100	100	**18**	**18**
Obs Time (months)	30	30	30	**0.467**	**0.467**
Bandwidth (GHz)	4.5	4.1	12.0	**7.7**	**16.2**
N_horn	2	3	6	**49**	**7**
Tnoise (K)	11.3	17.0	33.2	**20**	**41**
Telesc. / window (K)		< 1		**7**	**8**
Tsky (antenna) (K)	2.068	1.804	1.382	**1.822**	**1.113**
1-s sensitivity ($\mu K \times s^{1/2}$)	147	173	153	**33**	**104**
Delta Q(U) per 1.5° pixel (micro-K)	3.27	3.95	3.77	**1.78**	**6.68**
	Improvement factor wrt Planck-LFI			**2.2**	**0.6**

SWIPE – high frequency

- Window
- Filters
- 4K cooled Half Wave Plate (stepping)
  - 50 cm in diameter
- 1 lens
- Liquid Helium tank
- Wire grid polarizer / beam splitter
- 2 equivalent focal planes of TES detectors
- 3He fridge

- Separated smaller cryostat for the 245 GHz, using the same design



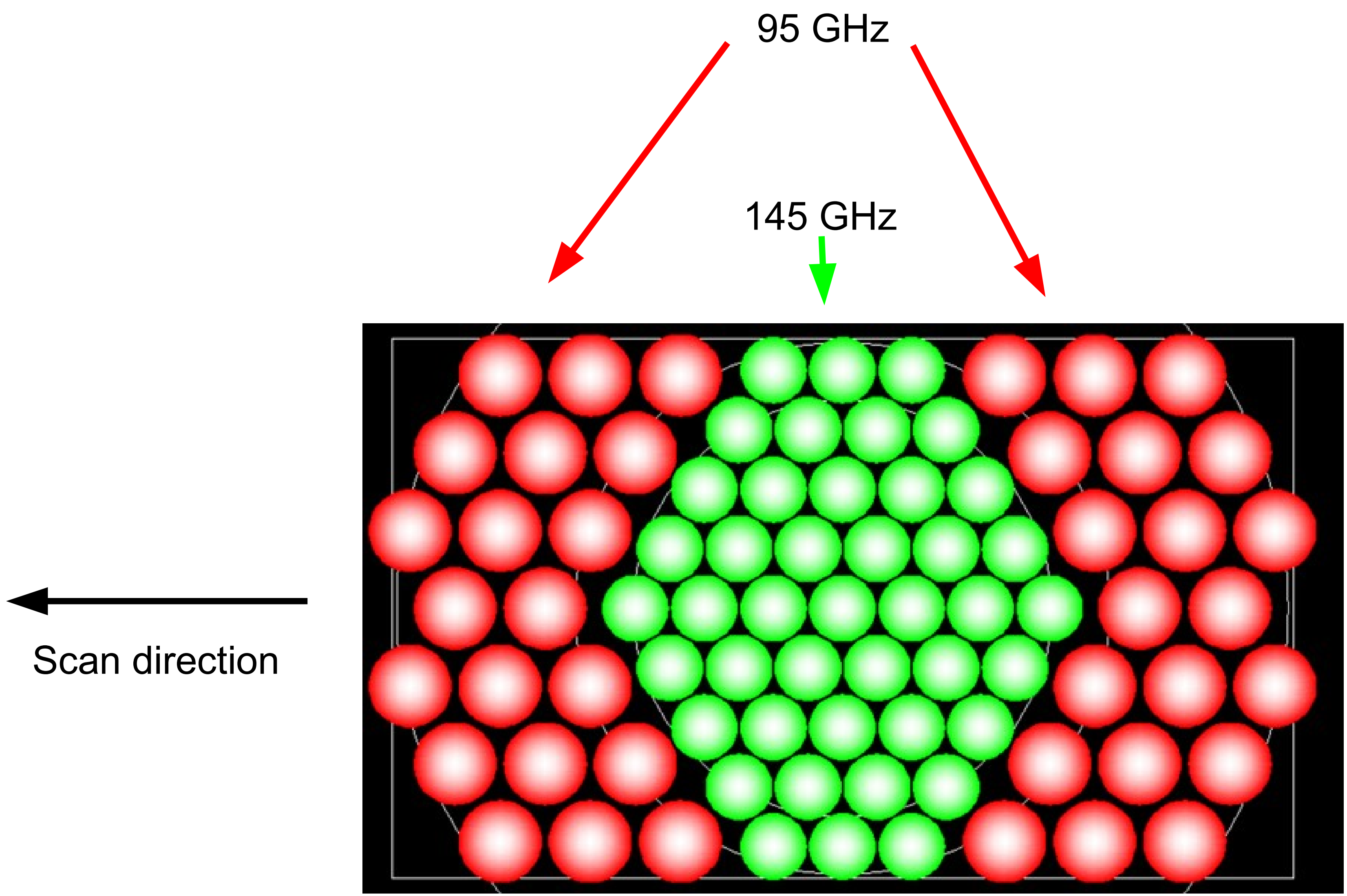
SWIPE multimoded detectors

- Power collected increases by the number of modes
- Photon noise increase as sqrt(# of modes)
  - S/N increase as sqrt(modes)
  - Just as increasing the number of detectors
  - And it's easier to be photon noise dominated
  - Angular resolution is degraded
- From electromagnetic simulations we derived the coupling modes
- Stafford Withington, TES (Cambridge)

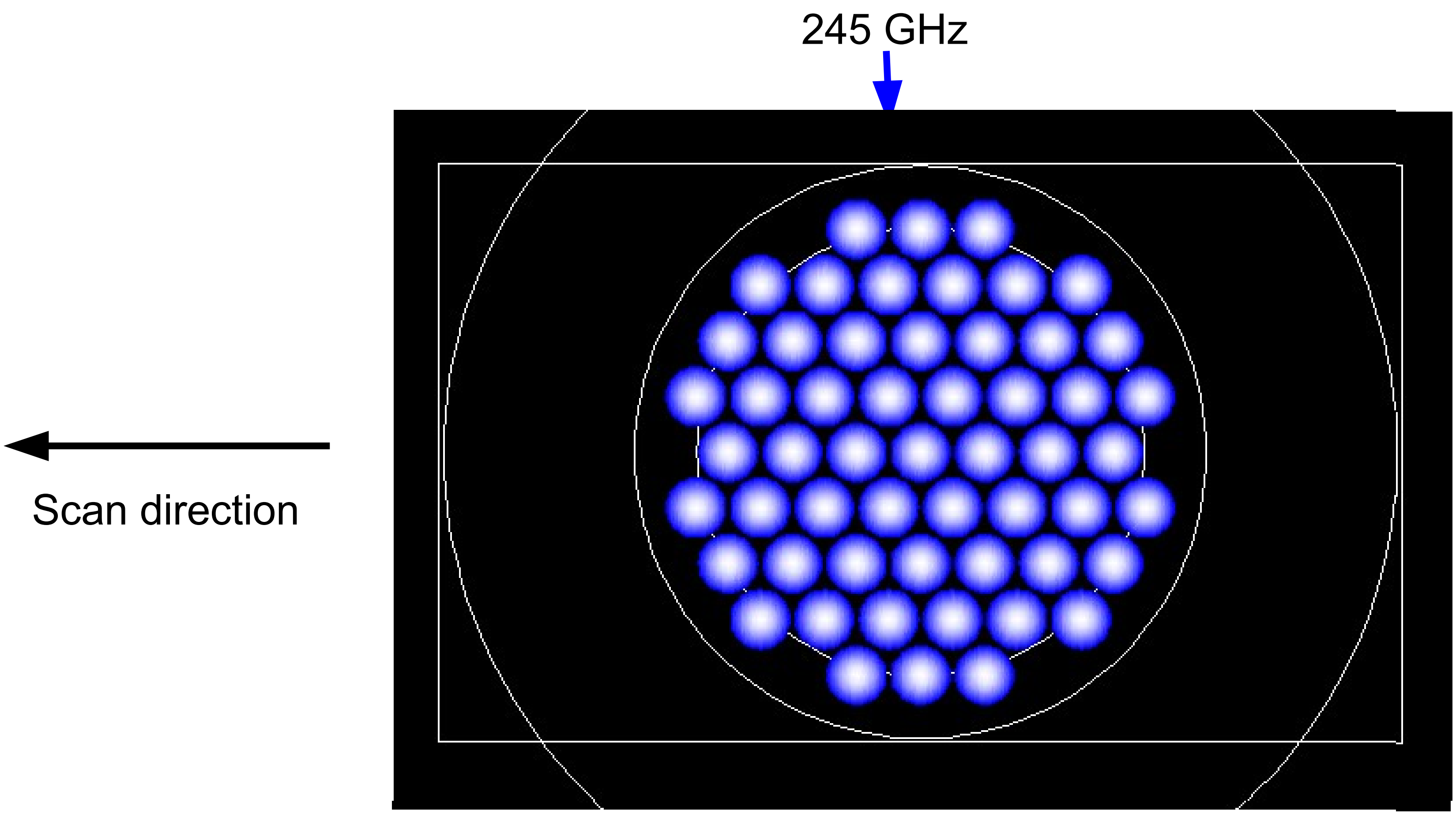
Thanks to Akito Kusaka for the nice introduction yesterday

Frequency (GHz)	95	145	245
Bandwidth (GHz)	30	45	90
Number of modes	23	35	64
FWHM (degrees)	1.84	1.48	1.23
Radiative background (pW)	23	41	102
NET photon (uK_cmb $Hz^{-0.5}$)	**17**	**17**	**20**
Number of detectors	**80**	**86**	**110**

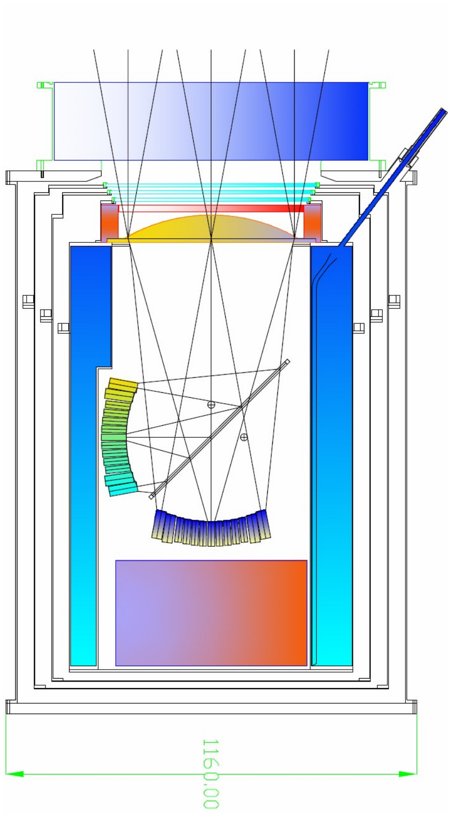
SWIPE focal plane (95 and 145 GHz)



SWIPE focal plane (245 GHz)



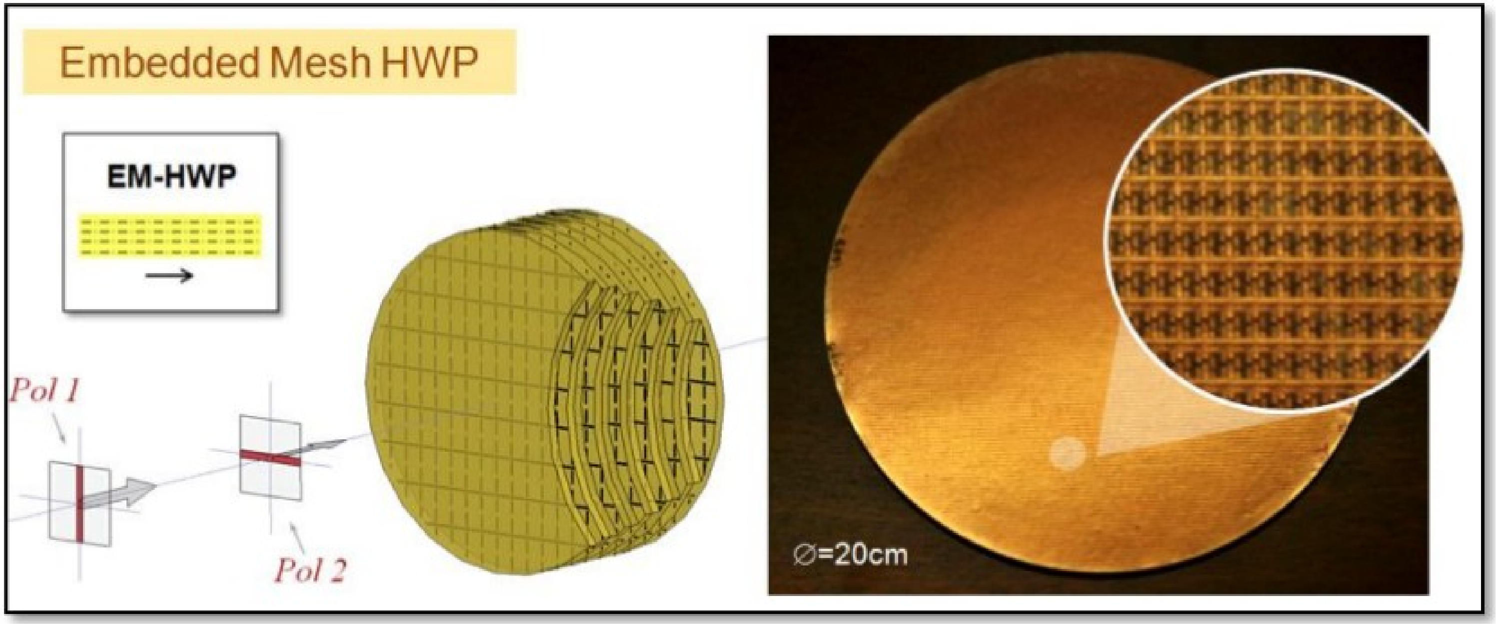
SWIPE performance



	PLANCK – HFI						SWIPE		
Frequency (GHz)	100	143	217	353	545	857	95	145	245
FWHM Resolution (arcmin)	9	7	6	5	5	5	110	89	74
Sky coverage (%)	100	100	100	100	100	100	20	20	20
Obs Time (months)	30	30	30	30	30	30	0.467	0.467	0.467
Bandwidth (%)	33	33	33	33	33	33	25	25	25
N_det (polarized)	8	8	8	8	0	0	80	86	110
Channel NET (uK s^1/2)	25	31	45	140	//	//	1.9	1.8	1.9
Integration/beam (s)	33	20	15	10	-	-	660	415	225
Delta Q(U) (uK) on SWIPE beams	0.3	0.4	0.8	2.6	-	-	**0.10**	**0.13**	**0.17**
	Improvement factor wrt Planck-HFI						**2.7**	**3.2**	**4.9**

Half Wave Plate for SWIPE – Manchester

- Dielectric embedded metal mesh
  - Metallic grids with sub-wavelength anisotropic geometries able to mimic the behavior of natural birefringent materials
  - The current mesh HWP has measured performance, in 20% bandwidth (78-100 GHz)
    - Transmission 0.9
    - differential phase-shift flatness and 180.4 ± 2.9 degrees
    - Cross-polarisation -35 dB
- ESA grant to G. Pisano (Manchester) for large prototype development



Half Wave Plate for SWIPE

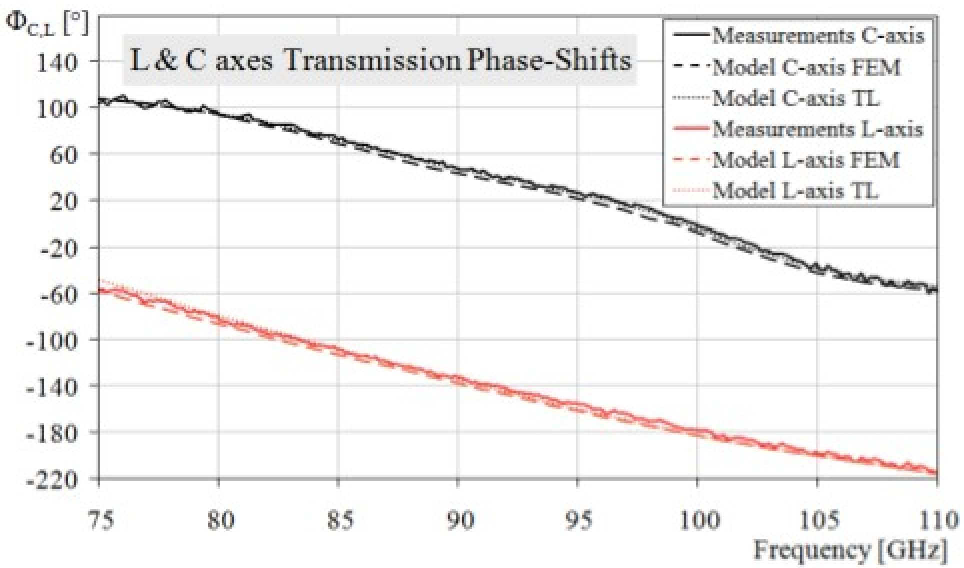


Figure 10. Mesh-HWP transmission phase-shift simulations and measurements along the *C*- and *L*-axis.

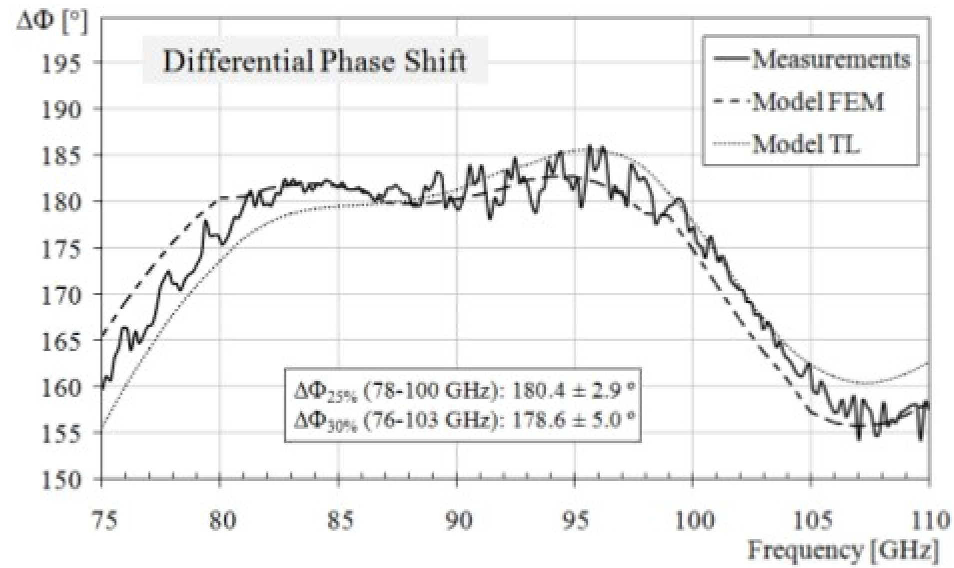


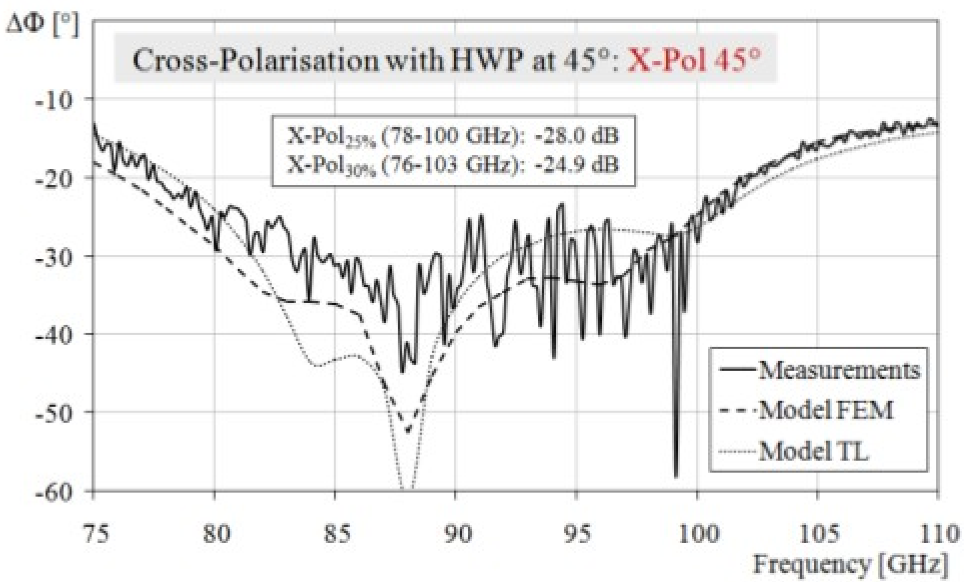
Figure 11. Mesh-HWP differential phase-shift measurements and simulations.

A BROADBAND METAL-MESH HALF-WAVE PLATE FOR MILLIMETRE WAVE LINEAR POLARISATION ROTATION

G. Pisano*, M. W. Ng, V. C. Haynes, and B. Maffei

JBCA, School of Physics and Astronomy, The University of Manchester, United Kingdom

Half Wave Plate for SWIPE



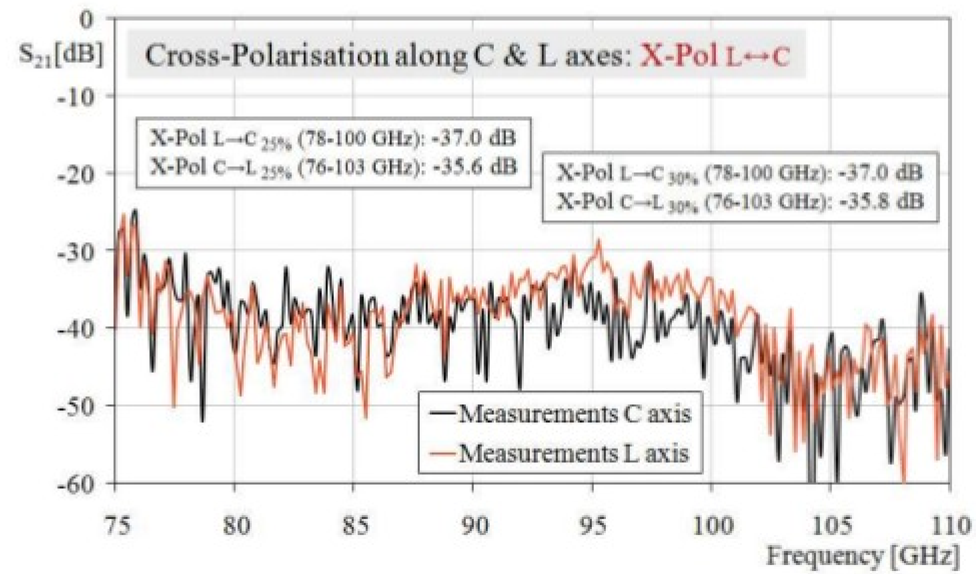


Figure 12. Mesh-HWP cross-polarisation measurements corresponding to the test set-up shown in Fig. 7(b).

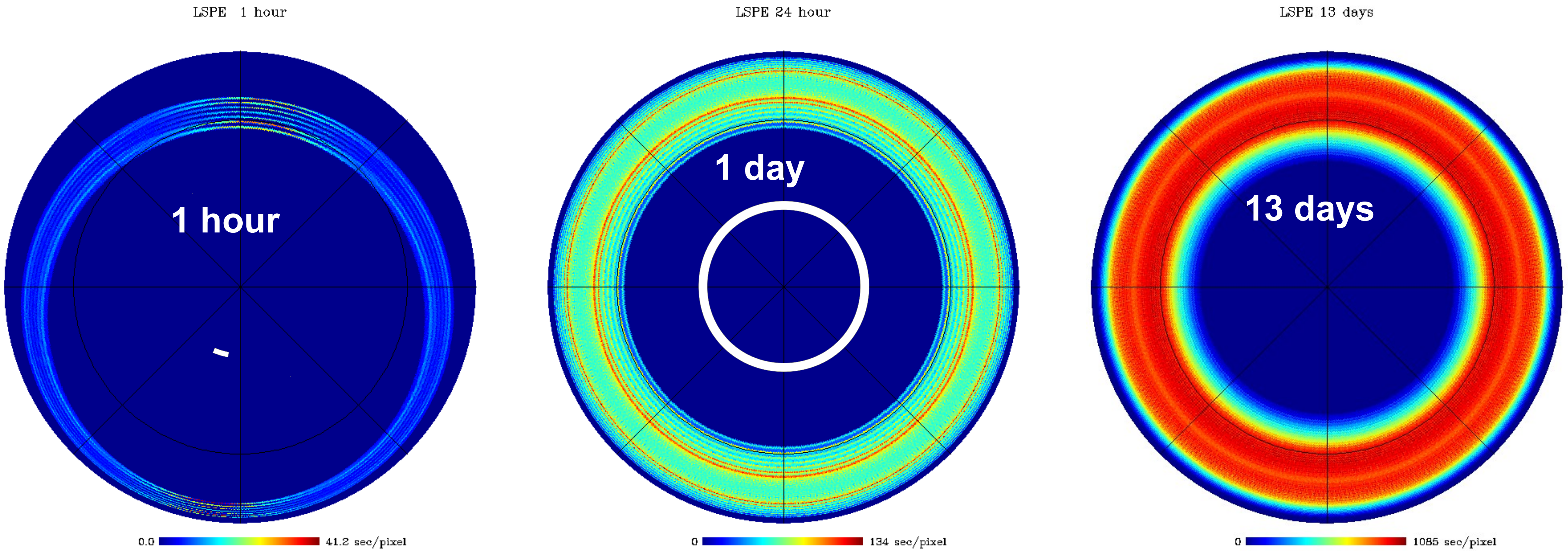
Figure 13. Mesh-HWP cross-polarisation measurements along capacitive and inductive axes corresponding to the test set-up shown in Figs. 7(a) and 7(c).

Half Wave Plate strategy: spin/step

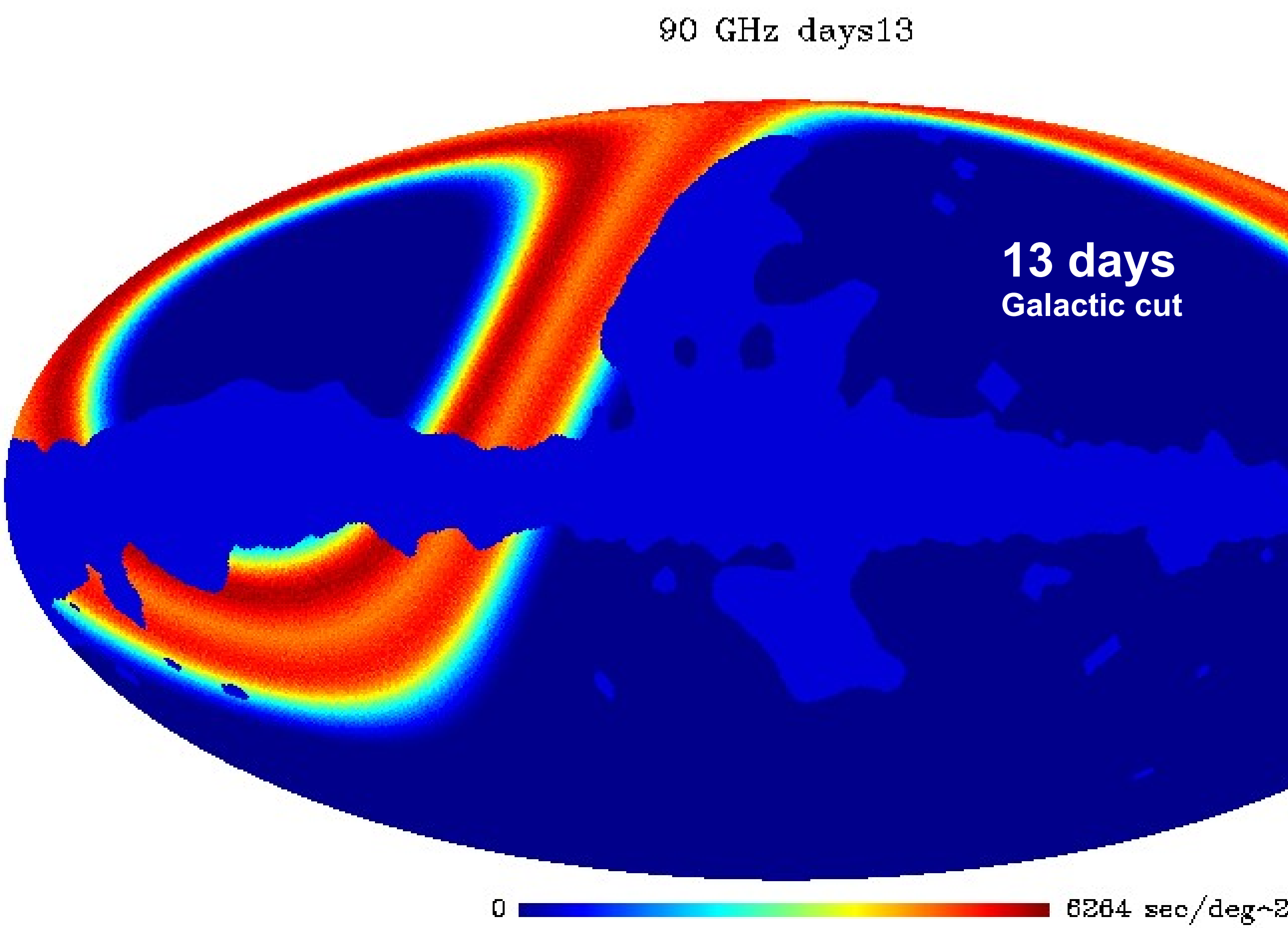
- The HWP non-idealities such as:
  - Differential emission
  - Differential reflection, multi-reflections
  - Differential phase shift
  - Thermal fluctuations of HWP
- In the spinning case, this can generate a spurious signal,
  - angular dependent
  - With components at 4 times the angle
  - Systematic effect in the recovered polarization
- In the stepping case, this generates step dependent offset
  - The offset is removed in any case
  - Signal modulation is provided by the scanning
  - Polarization is extracted by combing signals from the SAME detector at different time, with different HWP angles, same beam, same sidelobes
  - 1/f noise is treated by ML iterative mapmaking

Observation strategy

- Spin rate = 3 rpm
- Latitude = 78 N (Svalbard island)
- Longitude, variable
- Elevation range
  - independent for the two instruments
  - 30 – 40 degrees above horizon



Sky coverage



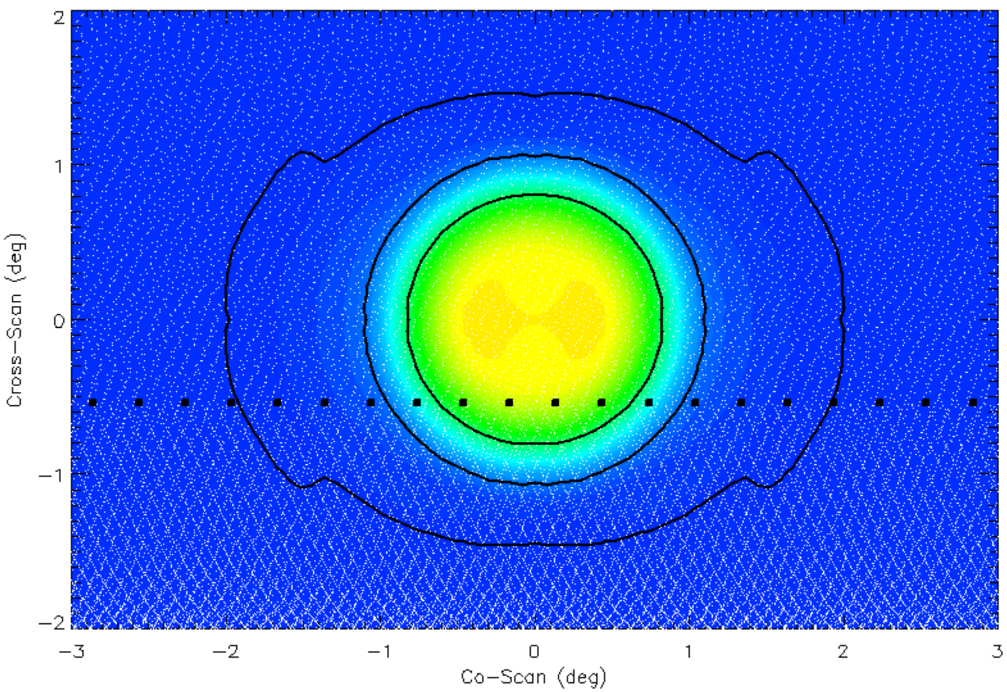
23% of the sky is observed using the WMAP polarization mask

The same sky is observed every day (depending on the elevation changes strategy)

Calibration

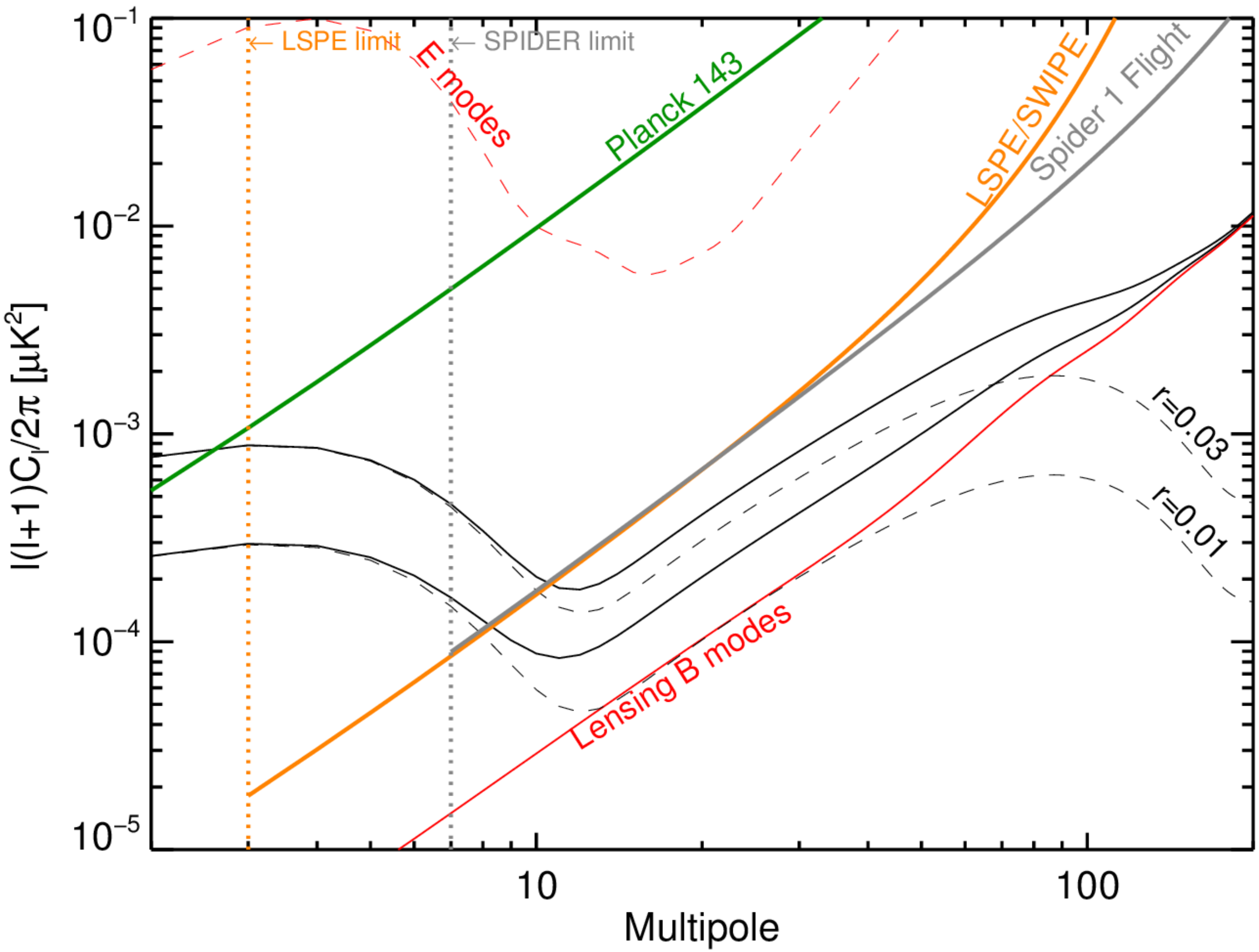
- Table
  - S/N sampling at 60 Hz
  - Signal is intensity
  - S/N for one detector
- Polarization angle and efficiency
  - Ground based
  - <ExB> power spectrum
  - Moon limb
  - Crab
- Beam mapping
  - In black: one scan
  - In white: one day
    - More than 2000 samples per day
    - Increase S/N by ~45
    - Increase S/N by ~160 in 13 days

Source	Culmination (deg)	S/N per sample at 44 GHz	S/N per sample at 90 GHz	S/N per sample at 95 GHz	S/N per sample at 145 GHz	S/N per sample at 245 GHz
Moon	30	37500	200000	2000000	700000	2000000
Crab	34	20	18	22	23	28
Mars	0	0.30	1.6	2	5.6	18
Jupiter	27	15	80	100	275	850
Saturn	-6	1.4	7	9	24	70
Uranus	16	0.05	0.24	0.3	0.8	2.5

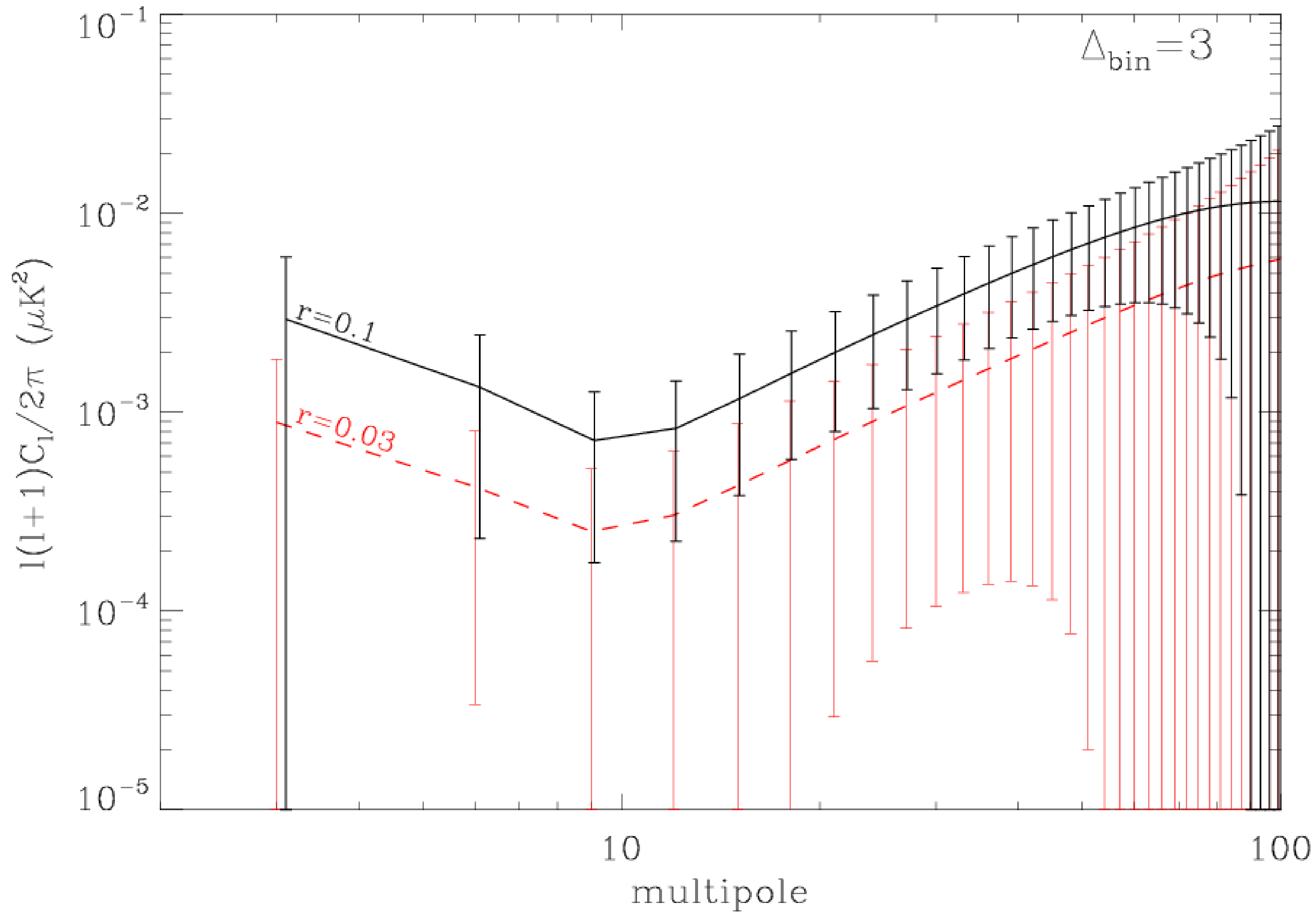


Expected performance – sensitivity

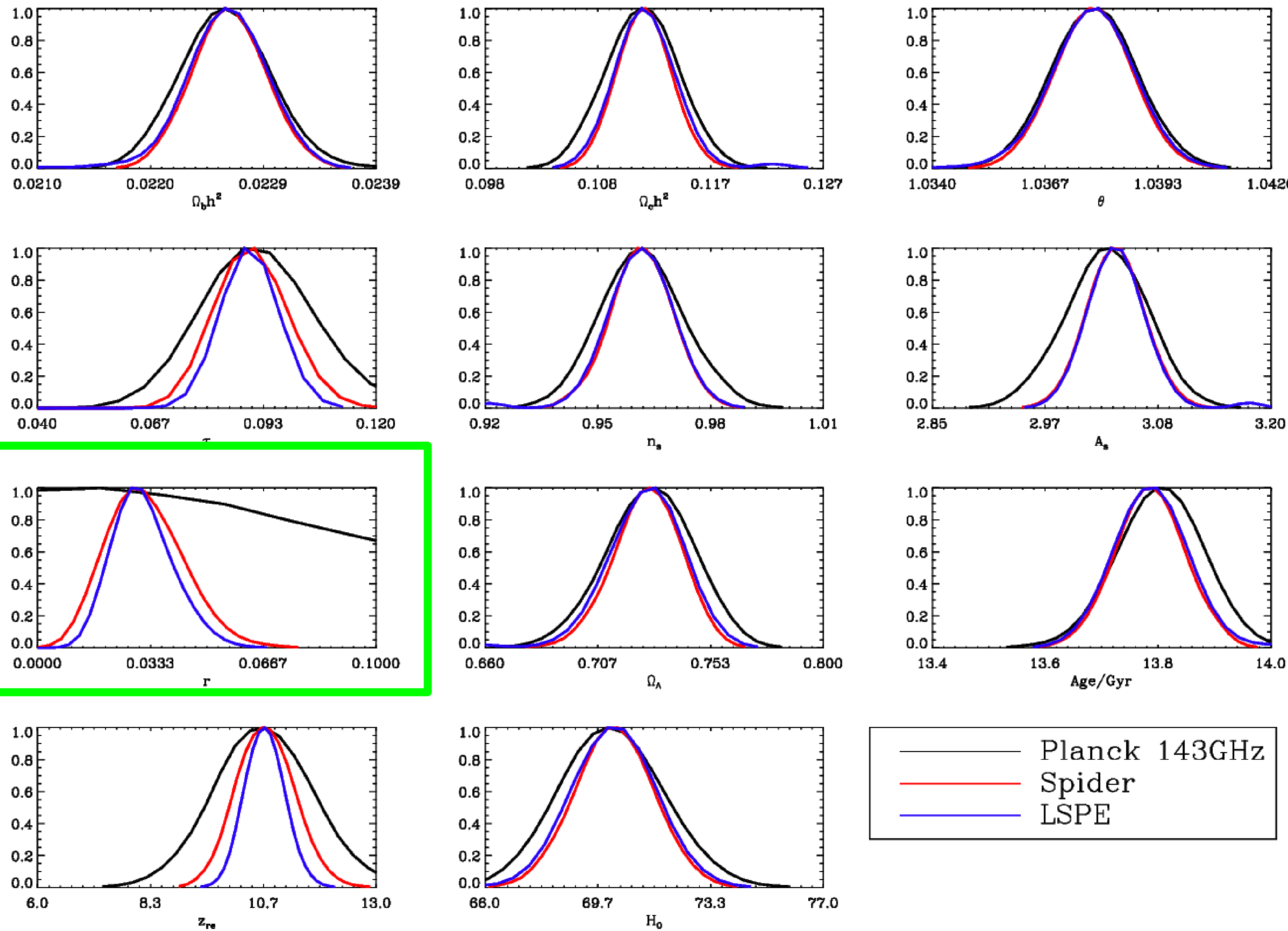
- SWIPE – high frequency → 10 μk arcmin



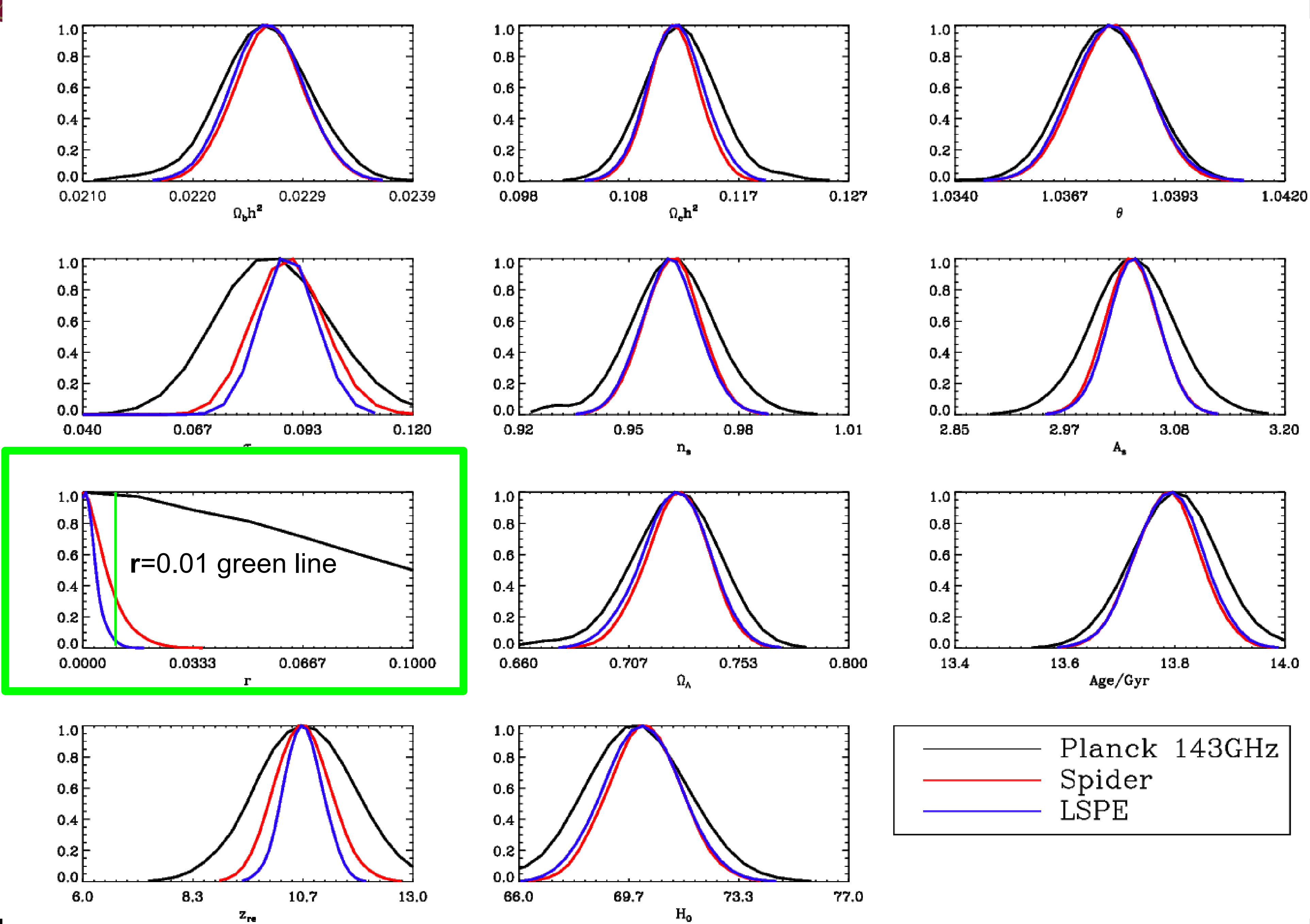
Sensitivity – BB power spectrum



Sensitivity – parameters (**r**=0.03)



Sensitivity – parameters (input **r**=0.001)



Systematic effects

	Systematic effect	Mitigation
	All listed (except pointing)	**Combination of two instruments with 90 GHz channel**
Polarization	HWP emission	Scan with HWP steady, Low temperature HWP
	Wire grid emission, reflected by HWP	Low temperature WG, antireflection coating on HWP
	Differential transmission of HWP	Scan with HWP steady
	Differential reflection of HWP	Scan with HWP steady, antireflection coating on HWP
	Differential phase shift by HWP	Scan with HWP steady, Spectral bandwidth optimization
	Slant incidence of rays on HWP	Scan with HWP steady
	Cross polar leakage	Lab Calibration / Moon / Crab
	Absolute polar angles calibration	Lab Calibration / Moon / Crab
	Thermal fluctuations of HWP	Scan with HWP steady, thermal link HWP – cryogen
Optics	Main beam uncertainty	Laboratory calibration / observation of planets
	Main beam ellipticity	Reduced in multimode system; lab. and flight calibration
	Sidelobes pickup of sky signal	Large shields, cold stop
	Sidelobes pickup of Earth and Balloon	Large shields, cold stop
Pointing	Pointing error	ACS Sensors
	Pendulation and atmospheric emission	Not polarized / orthogonal detectors
Detectors	Gain uncertainty	Calibration on anisotropy
	Gain stability	Calibration on anisotropy
	1/f noise	AC bias / T stabilization

Conclusion

- LSPE is exploring large scales, where Planck detected “anomalies”
- Night time polar balloon flight
- Designed for polarization purity
- Deep measure of polarized foreground
- Two ~90 GHz channels with different technologies (HEMT, bolometers) for crosscheck of systematic effects
- Low frequency channel for control of synchrotron polarized foregrounds
- Technology development for next generation space mission
- The **r**=0.03 at 99.7 confidence level is achievable
- Upper limit at **r**=0.01
- Nominal timescale: launch on Winter 2014/15

References

- The LSPE collaboration et al., *The Large-Scale Polarization Explorer (LSPE)*, Proc. SPIE 8446, Ground-based and Airborne Instrumentation for Astronomy IV, 84467A (September 24, 2012)
- Bersanelli, M. et al., *A coherent polarimeter array for the Large Scale Polarization Explorer (LSPE) balloon experiment*, Proc. SPIE 8446, Ground-based and Airborne Instrumentation for Astronomy IV, 84467C (September 24, 2012)
- de Bernardis P. et al, *SWIPE: a bolometric polarimeter for the Large-Scale Polarization Explorer*, Proc. SPIE 8446, Ground-based and Airborne Instrumentation for Astronomy IV, 84467C (September 24, 2012)