





### Balloon-borne experiments for Cosmic Microwave Background studies

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Roma International Conference on AstroParticle Physics





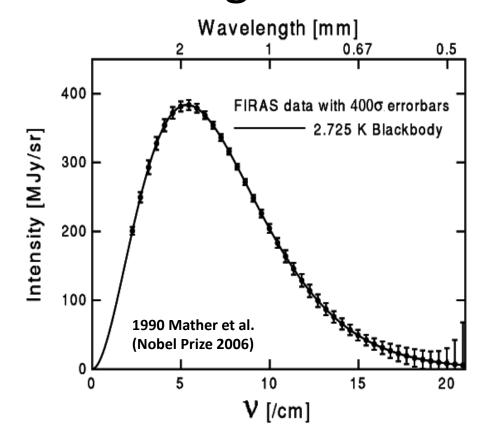




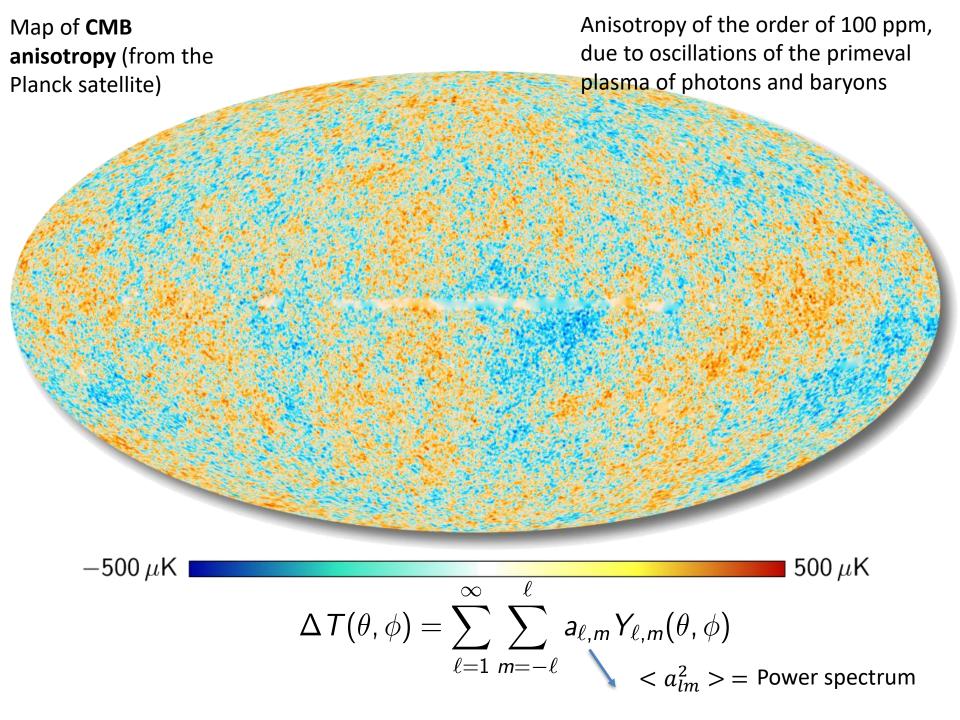


### The Cosmic Microwave Background

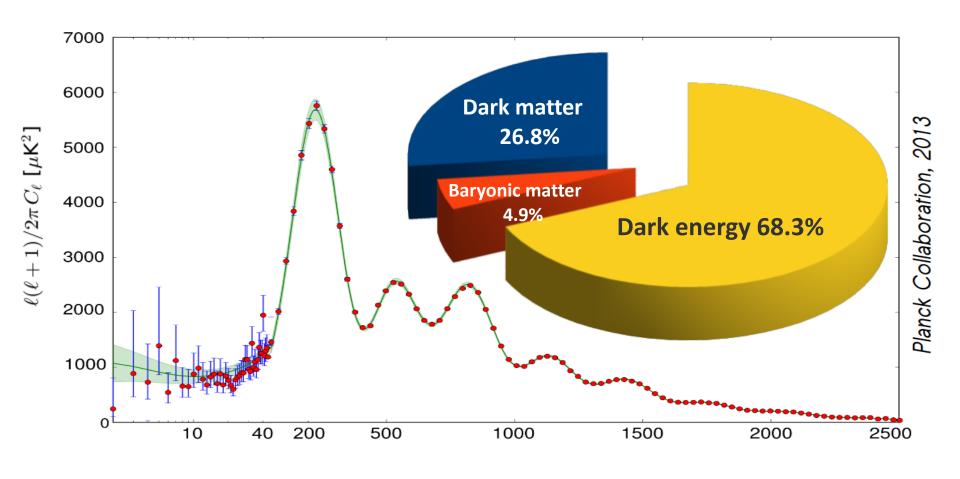
- The CMB is a faint background of thermal photons, filling the entire Universe.
- These photons where generated a few μs after the big bang, when matter and antimatter annihilated.
- They were thermalized by repeated Thomson scatterings in the primeval fireball, when the universe was ionized (first 380000 yrs)
- When the universe became neutral they formed a dazzling 3000K blackbody.
- Afterwards CMB photons did not interact with matter anymore, but were diluted and redshifted, due to the expansion of the universe, becoming today a 2.725K blackbody.



 Having travelled for most of the history of the Universe, CMB photons carry information on all phases of its evolution, with 3 main observables: spectrum, anisotropy, polarization.



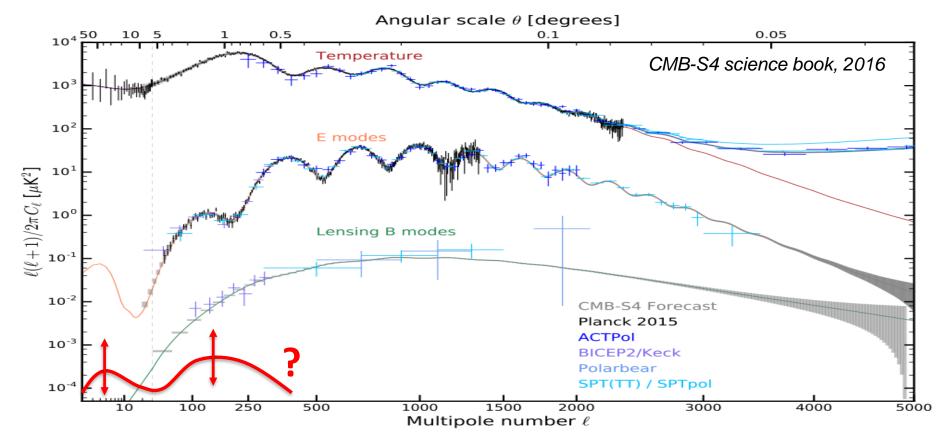
# The power spectrum of **CMB anisotropy** is perfectly well fit by an Inflationary, $\Lambda$ -CDM universe



$$C_{\ell} = \left\langle a_{\ell,m} a_{\ell,m}^* \right\rangle \qquad \Delta T(\theta,\phi) = \sum_{\ell=1}^{\infty} \sum_{m=-\ell}^{\ell} a_{\ell,m} Y_{\ell,m}(\theta,\phi)$$

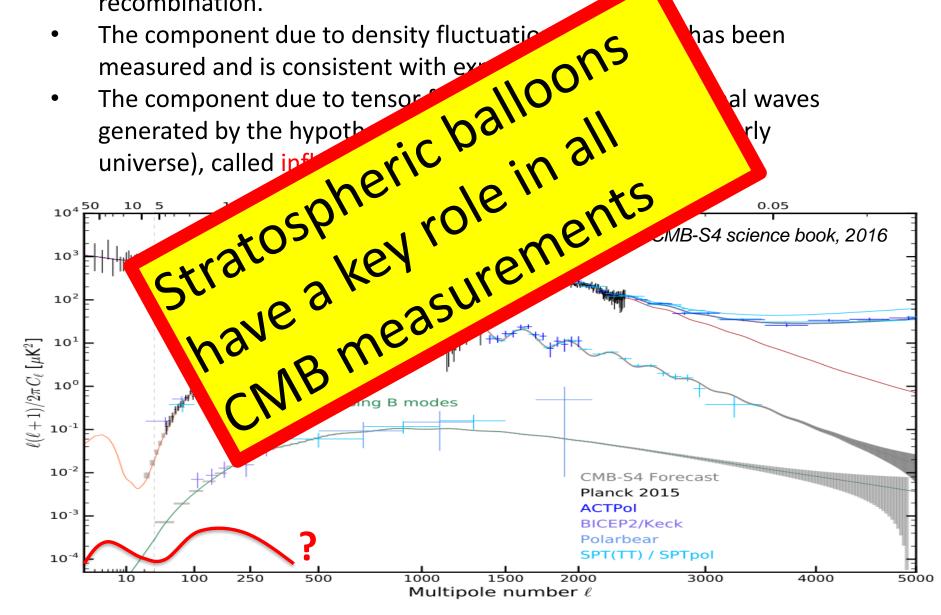
#### Polarization of the CMB

- The CMB is slightly polarized, due to anisotropic Thomson scattering at recombination.
- The component due to density fluctuations (E-modes) has been measured and is consistent with expectations.
- The component due to tensor fluctuations (the gravitational waves generated by the hypothetical inflation phase in the very early universe), called inflationary B-modes, is still to be measured.



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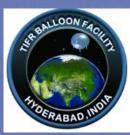
### Stratospheric Balloons:

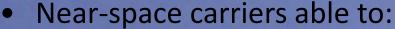










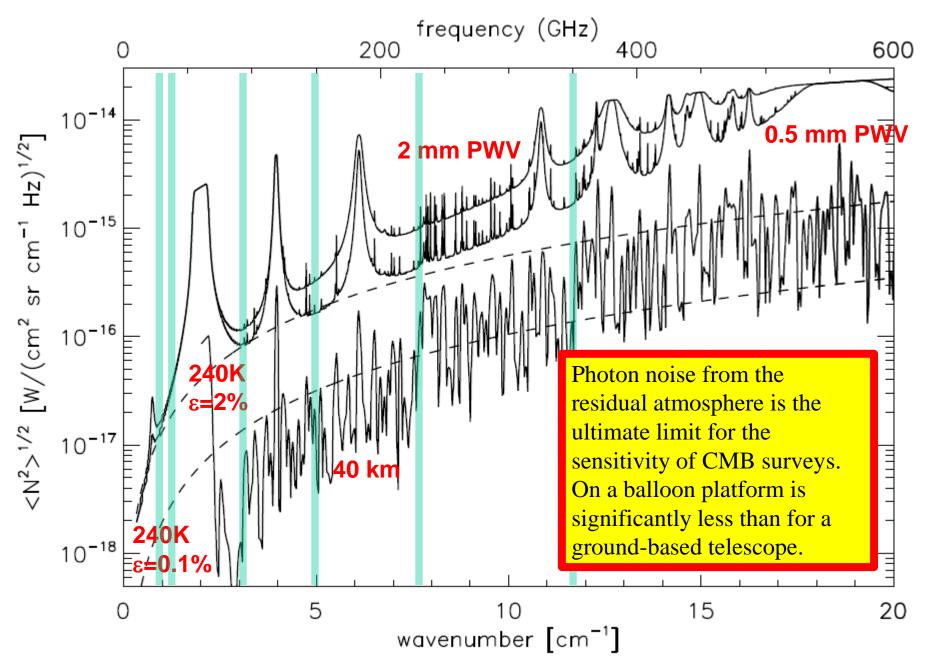


- Reach 40 km (3 mbar)
- Stay there for up to 40 days
- Lift heavy (2 tons) large payloads (larger than what we can reasonably fly on satellites)
- Cost roughly 1/100 of a satellite mission
- Allow for recovery and refly of the payloa
- Important for the CMB community:
  - To carry out sensitive observations at high frequency, high resolution, and at the largest angular scales
  - High f = the only way to monitor polarized interstellar dust. Cannot be done from the ground.
  - To qualify instrumentation in preparation satellites
  - To educate young experimentalists!





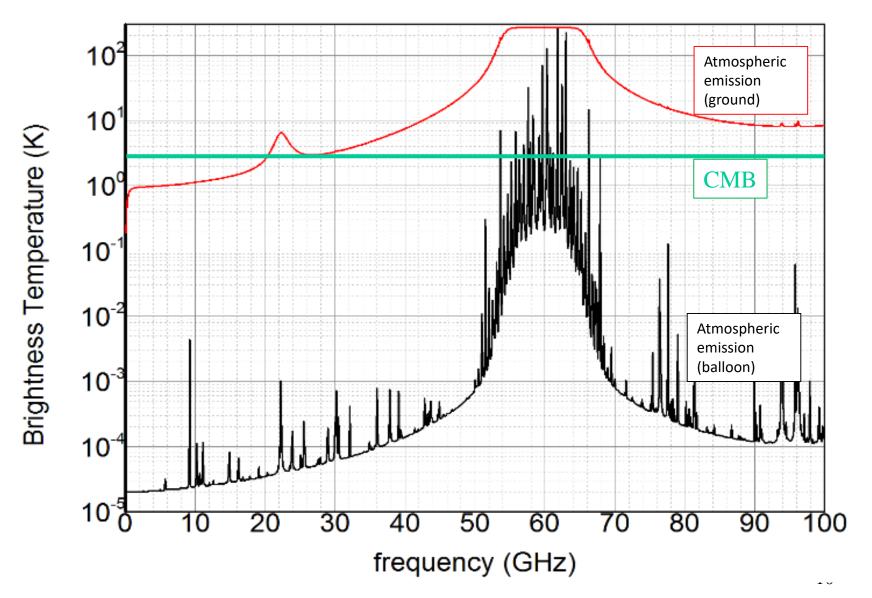
#### Photon noise from the local environment



# Advantage of CMB measurements from balloons: a) sensitivity

- In absolute terms, a large array of photon-noise limited detectors on a ultra-long-duration balloon is able to reach cosmic variance limits at all interesting angular scales.
- The comparison to the theoretical sensitivity of groundbased experiments is interesting because defines the frequency range where the balloon advantage is larger.
- In the absence of atmospheric turbulence:
  - one day of integration on a balloon equals:
    - 12 days of operation on the ground at 220 GHz
    - 34 days of operation on the ground at 270 GHz
    - 198 days of operation on the ground at 340 GHz
    - 1390 days of operation on the ground at 480 GHz
  - At these high frequencies, the advantage of a balloon mission is going to improve if atmospheric turbulence is taken into account.

# Advantage of CMB measurements from balloons: **b) Absolute brightness**



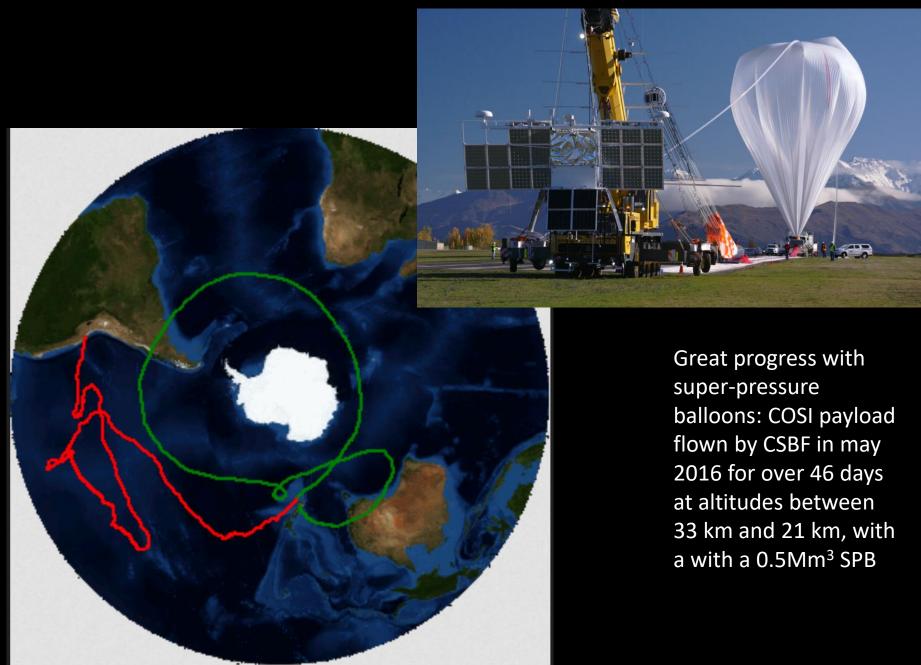
### Long Duration Ballooning

#### **Flight Options**

- Antarctic Long Duration Balloon (LDB): 10 30 days / 3 tons
- Svalbard & Kiruna Long Duration Balloon (LDB): 10 30 days / 3 tons
- Wanaka Super Pressure Balloon (SPB): 30 100 days / 1 ton
- Polar Night Flights: ~ 10 days
- Conventional Flight (Ft. Sumner, Palestine, Timmins, Kiruna): 1 day

#### **Flight Parameters**

- 33-37 km altitude
- 1 km altitude stability (200 m for SPB)
- Annual flight windows
  - January (LDB, McM,LYR), April (SPB, Wanaka), June (Palestine,LYR,Kiruna), September (Ft. Sumner)



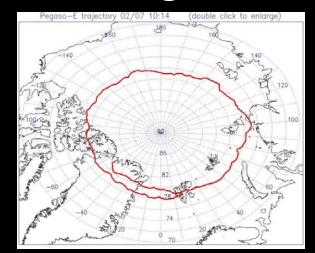
- We have flown long duration stratospheric balloons around the North Pole launching from Longyearbyen (Svalbard) both in the summer (heavy lift payloads) and in winter (pathfinders) [see Peterzen, S., Masi, S., et al., Mem. S. A. It., 79, 792-798 (2008), and PdB+SM Proc. of the I.A.U., 8, 208-213 (2013)]
- In this way CMB experiments can access most of the northern sky in a single flight,
  - within a cold and very stable environment
  - Accumulating more than 10 days of integration at float (38 km altitude).

**Top:** Ground path of a flight performed in June 2007. **Bottom right:** Launch of a heavy-lift balloon from the Longyearbyen <u>airport (Svalbard Islands, latitude 78°N)</u>.



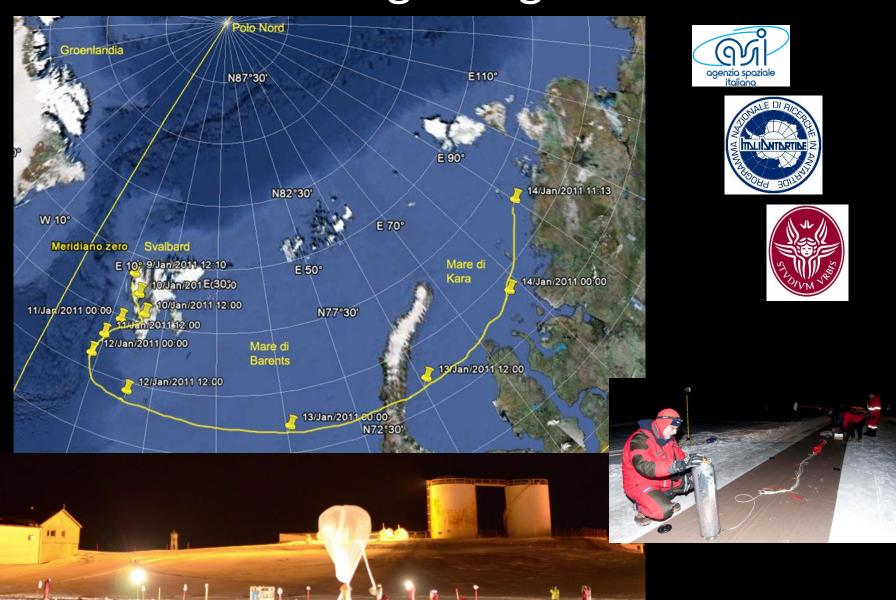
 OLIMPO has had its first flight in the Arctic (and the second one is supposed to be done from Antarctica (pending recovery and approval)

### **Polar flights**





### Polar Night Flights



### Stratospheric Balloons:













#### Disadvantages:

- Stringent limits on mass, power
- Complexity of automation
- Insane integration schedule
- Narrow, and scarce, flight windows
- Risky recovery

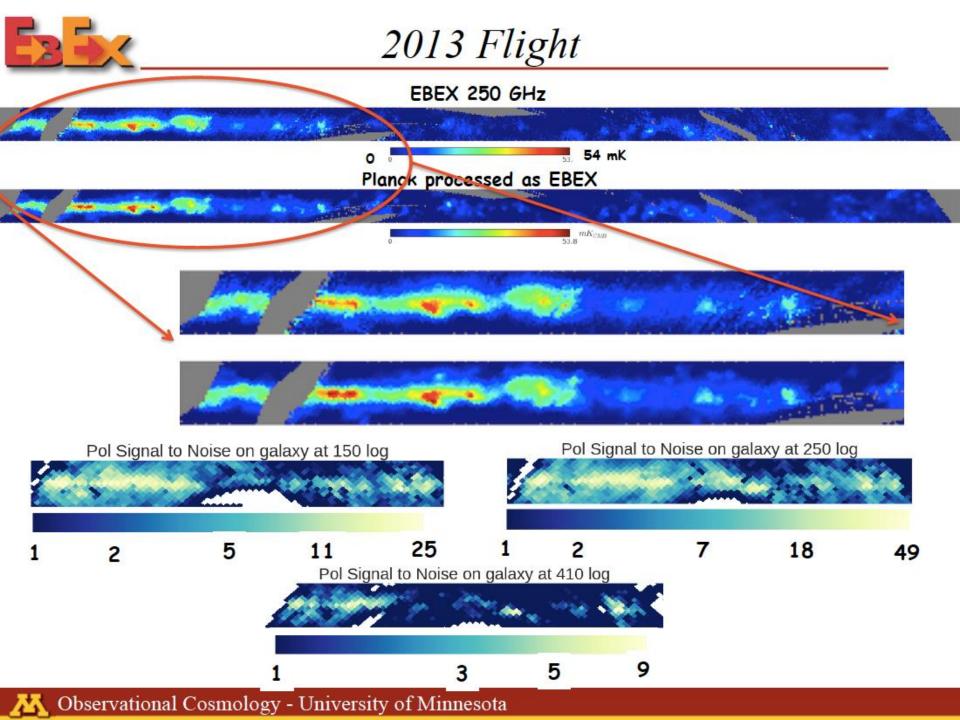
### CMB-related science from balloons

(with large advantage wrt ground-based experiments)

- Dust-cleaned polarization & Dust-cleaned inflationary and lensing B-modes
- CMB Polarization at very large angular scales
- Spectral measurements of the SZ
- Spectral measurements of CIB anisotropy
- Precision measurements of CMB spectrum (at selected frequencies)

### Current / Pending Balloons for CMB-related science

Missions Recently Flown	survey area [sky fraction]	frequencies [GHz]	resolution [arcmin]
EBEX (2012/13)	0.2	150/250/410	8/5/5
Spider (2014/15)	0.1	94/150	42/28
PILOT (2015)	< 0.01	1200/545	3
Piper (2017)	0.8	200	36
OLIMPO (N.LDB 2018)	0.01	140-220-340- 450	2/4
Missions Planned	survey area [sky fraction]	frequencies [GHz]	resolution [arcmin]
Spider (LDB 2018)	0.1	94-285 (3)	42-15
OLIMPO (S.LDB 2021)	0.01	140-220-340- 450	2/4
LSPE (N.LDB 2019)	0.25	44-240 (4)	85-20
Missions in Preparation	survey area [sky fraction]	frequencies [GHz]	resolution [arcmin]
Piper (2018-2020)	0.8	200-600 (4)	36-12
BLAST-TNG	< 0.01	1200, 860, 600	1
EBEX-IDS	0.035	150-360 (7)	8-3
BFORE	0.23	270-600 (3)	4
BSIDE	0.05	600-700	7



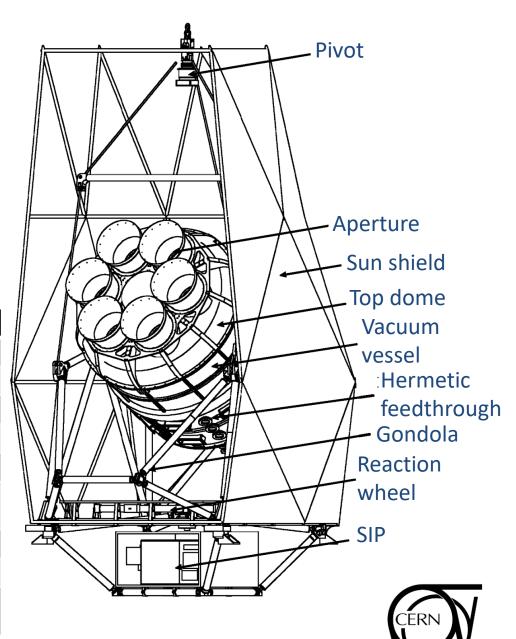
### **Spider 2015: Overview**

Sky coverage	About 10 %
Scan rate (az, sinusoid)	3.6 deg/s at peak
Polarization modulation	Stepped cryogenic HWP
Detector type	Antenna-coupled TES
Multipole range	10 < ℓ < 300
Observation time	16 days at 36 km
Limits on r <sup>†</sup>	0.03

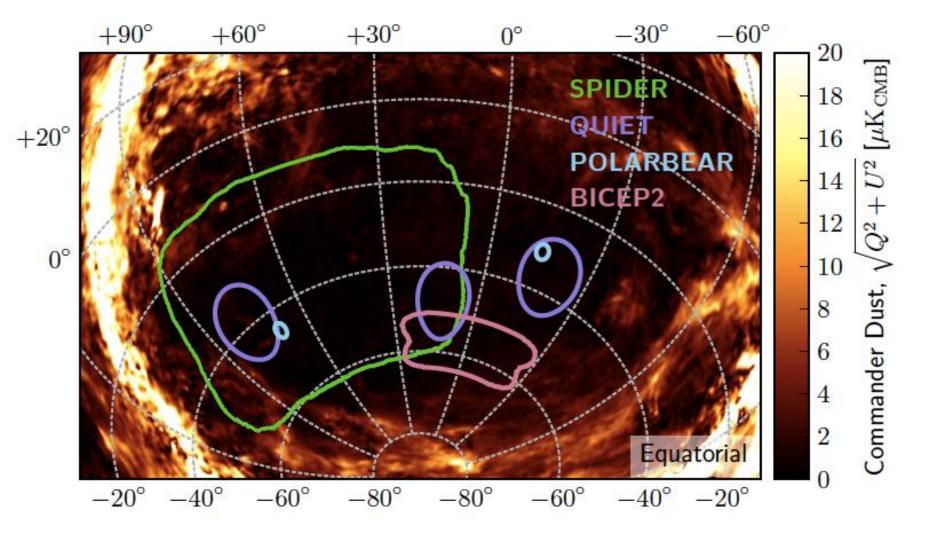
<sup>†</sup> Ignoring all foregrounds, at 99% confidence

	Frequency [GHz]	
	94	150
Telescopes	3	3
Bandwidth [GHz]	22	36
Optical efficiency	30-45%	30-50%
Angular resolution* [arcmin]	42	28
Number of detectors <sup>†</sup>	652 (816)	1030 (1488)
Optical background <sup>‡</sup> [pW]	≤ 0.25	≤ 0.35
Instrument NET <sup>†</sup> [μK·rts]	6.5	5.1
*=\		

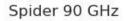
<sup>\*</sup>FWHM. †Only counting those currently used in analysis †Including sleeve, window, and baffle

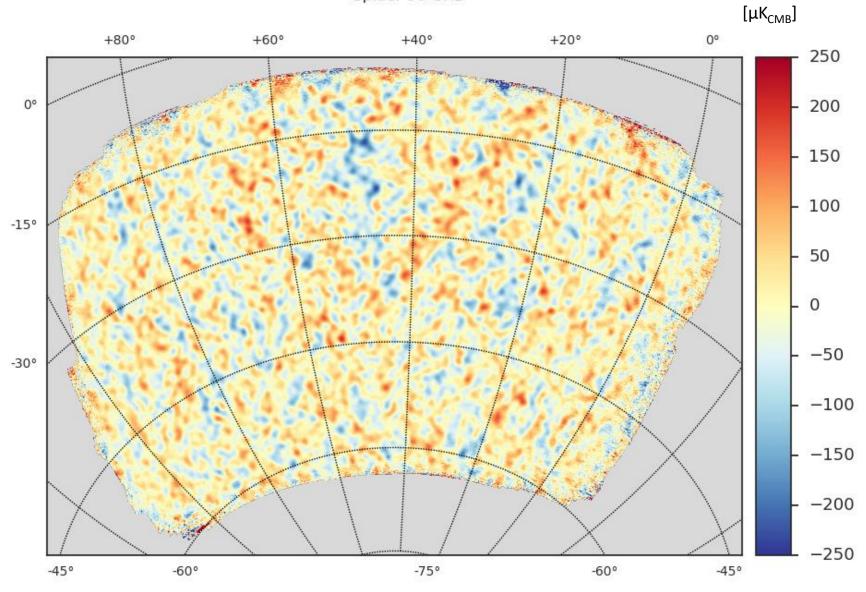


### Spider 2015: survey coverage



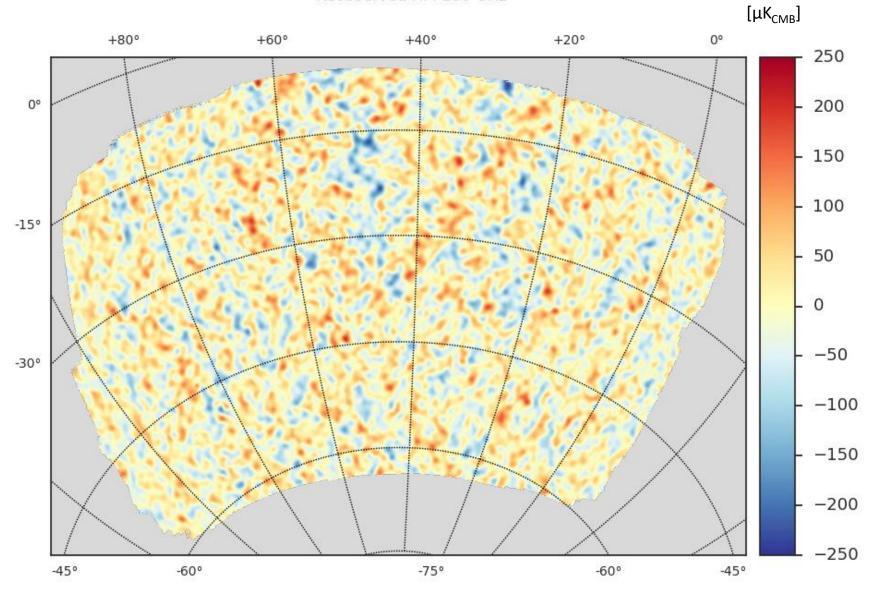




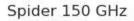


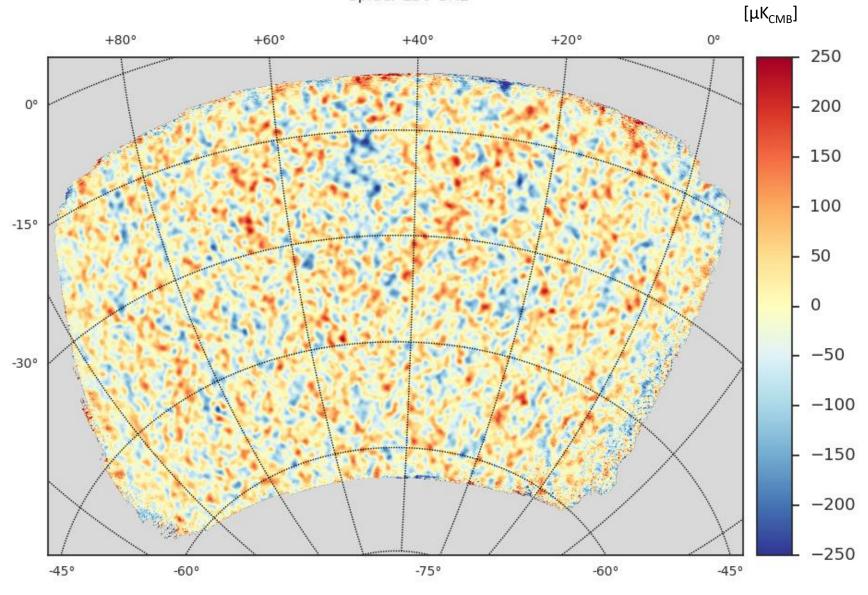


#### Reobserved HFI 100 GHz



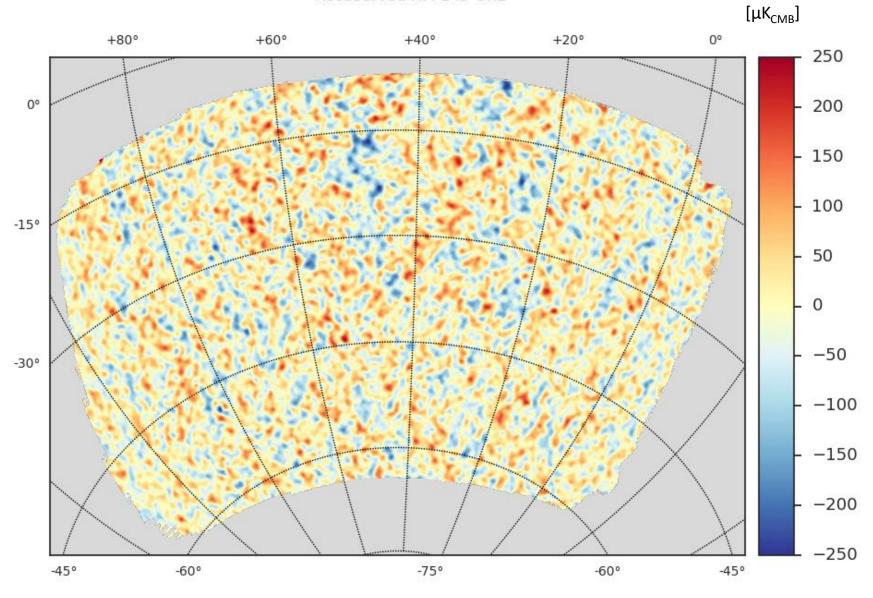






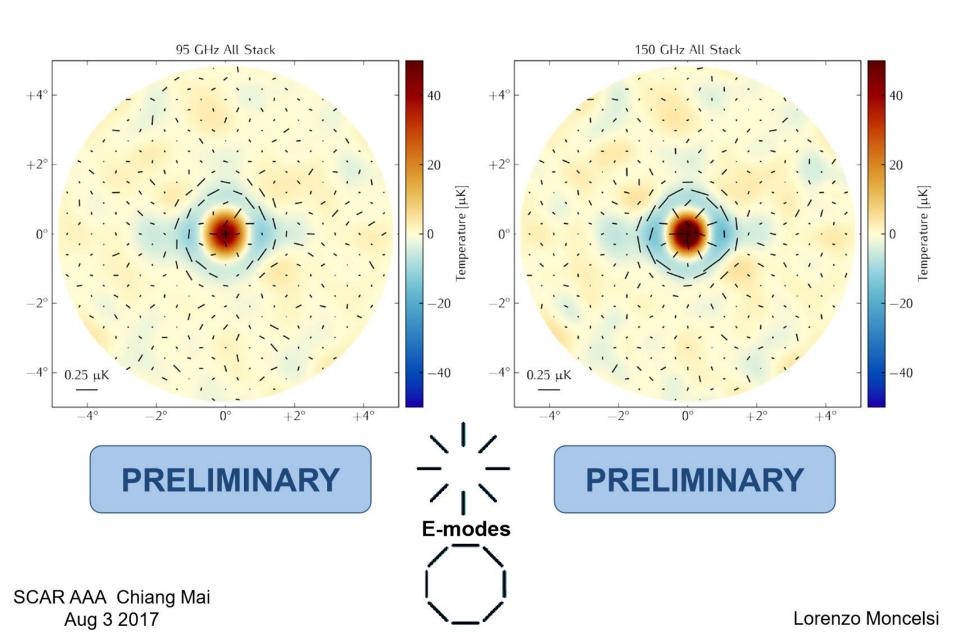


#### Reobserved HFI 143 GHz



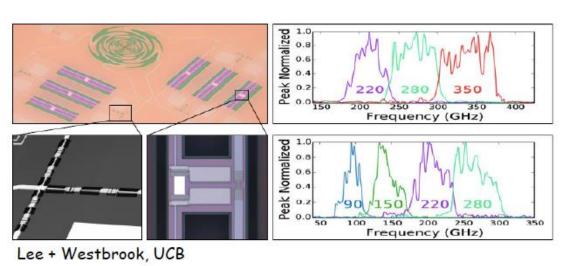


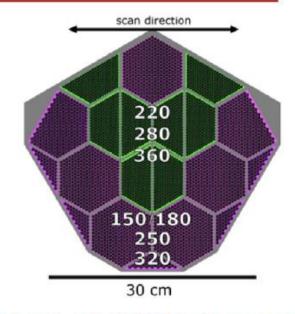
### Stacking hot spots : SPIDER



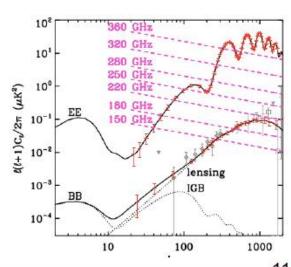
#### EBEX-IDS

- 7 bands: 150, 180, 220, 250, 280, 320, 360 GHz
- 1500 sq. deg. Co-observe with BICEP/Keck + Simmons Array
- Sinuous Antenna Trichroic Pixels (PB2, SPTPol, LiteBIRD)

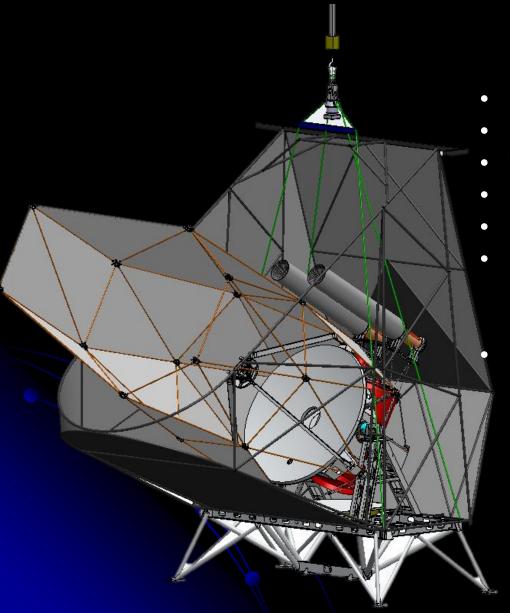




#### Total of 20562 detectors

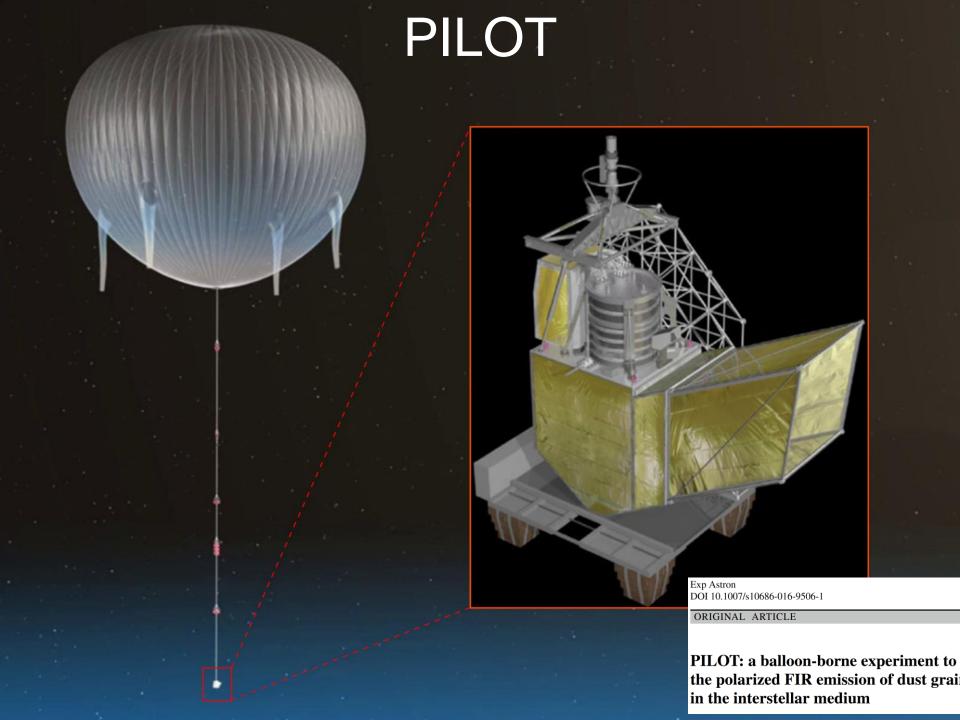


### **BLAST-TNG**



- 2.5 meter Carbon Fiber Mirror
- 2200 Polarized KID detectors
- Three bands: 250, 350, and 500 μm
- 22 arcsec resolution at 250 μm
- 28 day flight!
  - 10 times the mapping speed of BLAST-pol

First flight December 2018 (TBC) with Shared Risk Observing



**Table 1** Key characteristics and performance of the *PILOT* instrument in its nominal configuration. The last lines gives the expected  $3\sigma$  performance in the two extreme observing modes corresponding to deep (5<sup>\subseteq</sup>/hour) and large (150<sup>\subseteq</sup>/hour) surveys respectively, where the <sup>\subseteq</sup> symbol stands for square degree. Our estimated polarization sensitivity assumes a dust polarization fraction of 10 %

Primary mirror diameter [mm]	730	
Equivalent focal length [mm]	1800	
Numerical aperture	F/2.5	
Detector temperature [mK]	300	
Mapping speed [□/h]	[5-150]	
FOV [°]	$1.0 \times 0.8$	
	SW Band	LW Band
$\lambda_0 [\mu m]$	240	550
$v_0$ [GHz]	1250	545
$\Delta v/v$	0.27	0.31
Tr(dust)	0.025	0.136
beam FWHM [']	1.9	3.29
Number of Detectors	1024	1024
background [pW/pix]	5.7	4.0
$NEP_{Det} [W/\sqrt{Hz}]$	$2.010^{-16}$	$2.010^{-16}$
$NEP_{Phot} [W/\sqrt{Hz}]$	$9.810^{-17}$	$6.010^{-17}$
$NEP_{Tot} [W/\sqrt{Hz}]$	$2.210^{-16}$	$2.1  10^{-16}$
Sensitivity $(3\sigma \text{ in } 3.5')$		
Intensity [MJy/sr]	[0.98-6.28]	[0.33-2.13]
Av [mag]	[0.05-0.30]	[0.12-0.75]
Av polar [mag]	[0.47-2.99]	[1.17-7.48]









# the Large-Scale Polarization Explorer

Paolo de Bernardis, Università La Sapienza, Roma, Italy for the LSPE collaboration

















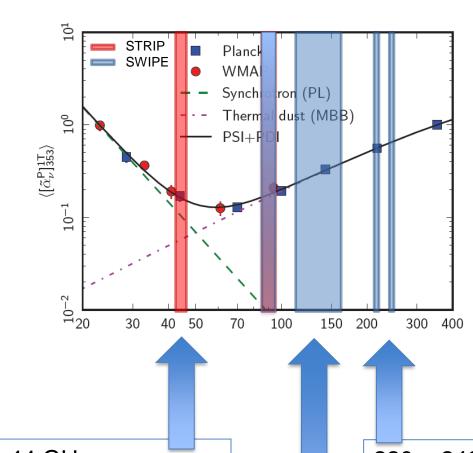


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Alexandra Capalecchie Dip. Firica Uni. Geneva & INFIN Geneva Curtain Dip. Firica Sapienza & INFIN Geneva Curtain Dip. Firica Sapienza & INFIN Geneva Div. Geneva Dip. Firica Sapienza & INFIN Geneva Div. Geneva Dip. Firica Sapienza & INFIN Geneva Dip. Firica Sapienza & INFIN Geneva Dip. Firica Università di Ruma Tur. Varqata & INFIN Geneva Dip. Firica Università di Ruma Tur. Varqata & INFIN Geneva Dip. Firica Università di Ruma Tur. Varqata & INFIN Geneva Dip. Firica Università di Ruma Tur. Varqata & INFIN Geneva Dip. Firica Università di Ruma Tur. Varqata & INFIN Geneva Dip. Firica Università di Sapienza Università di Sapienza Università di Sapienza Università di Sapienza Università di Milana Dip. Firica Università di Milana Dip. Geneva Dip. Firica Università di Milana Dip. Geneva Dip. Firica Università di Milana Dip. Geneva Dip. Firica Università di Milana Dip. Tirica U				+
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Alexrandra   DiMarca   Univerzità di Rama TarVerqata & INFN Rama2   Viviana   Fafana   Dip. Frica Tar Verqata & INFN Rama2   Dip. Inq. Ind. Uni. Firenza   Dip. Inq. Ind. Uni. Firenza   Dip. Frica Uni. Genava & INFN Genava   Dip. Frica Uni. Genava & INFN Genava   Dip. Frica Uni. Genava & INFN Genava   Dip. Frica Univerzità di Ferrara & INFN Ferrara   Dip. Frica Univerzità di Milana   Dip. Frica Univerzità di Milana Bicacca   Anna   Greqaria   Department of Physicar - Univerzity of Trierto   Danielo   Grazra   Dip. Frica Univerzità di Milana Bicacca   Anna   Greparia   Department of Physicar - Univerzity of Trierto   Danielo   Grazra   Dip. Frica Sapienza & INFN Balagna   Dip.				$^{\dagger}$
Viviana   Fafane   Dip. Furica Tur Vergata & INFN Roma2   Inronary   Finrinerchi   Dip. Furica Uni. Firenze   Finrinerchi   Dip. Furica Uni. Genova & INFN Genova   Francerca   Farartieri   Univerzità di Ferrara & INFN Ferrara   Christian   Francerchet   Environaria & INFN Forman   Francerchet   Environaria & INFN Forman   INFN Pura   Information			Università di Roma TorVergata & INFN Roma2	Ť
Flavina   Fintenechi   Dip. Ing. Ind. Uni. Firenza   Flavina   Fantanolli   Dip. Firica Uni. Genava & INFN Genava   Francerca   Farartieri   Univerzità di Ferrara & INFN Ferrara   Christian   Francerchet   Dip. Firica Univerzità di Milana   Luca   Galli   INFN Pira   Flavina   Gatti   Dip. Firica Uni. Genava & INFN Genava   Mazrima   Gervari   Dip. Firica Univerzità di Milana Bicacca   Anna   Gregaria   Department al Physicar Univerzity af Triarte   Daniele   Grazza   Dip. Firica Uni. Genava & INFN Genava   Alezrandra   Gruppura   INFN Firica Uni. Genava & INFN Genava   Riccarda   Gualticri   Dip. Firica Sapienza & INFN Roma1   Wictor   Hayner   Univerzity af Mancherter   Micalotta   Krachmalnica   Dip. Firica Sapienza & INFN Forma1   Mazrimiliana   Lattani   Univerzità di Ferrara & INFN Forma   Bruna   Maffei   Univerzità ferrara & INFN Forma   Marana   Marchetti   Dip. Firica Sapienza & INFN Roma1   Marana   Marchetti   Dip. Firica Sapienza & INFN Roma1   Manchella   Dip. Firica Sapienza & INFN Roma1   Manchella   Dip. Firica Univerzità di Milana   Diega   Malinari   Dip. Firica Univerzità di Milana   Diega   Malinari   Dip. Firica Sapienza & INFN Roma1   Marimiliana   Dip. Firica Univerzità di Milana   Diega   Malinari   Dip. Firica Univerzità di Milana   Diega   Malinari   Dip. Firica Sapienza & INFN Roma1   Aniella   Marana   Dip. Firica Sapienza & INFN Roma1   Aniella   Marana   Dip. Firica Sapienza & INFN Roma1   Aniella   Matali   Univerzità di Ferrara & INFN Ferrara   Ming Wah   Na   Univerzità di Ferrara & INFN Ferrara   Ming Wah   Na   Univerzity af Mancherter   Luca   Pagana   Dip. Firica Sapienza & INFN Roma1   Alezrandra   Paicella   Dip. Firica Sapienza & INFN Roma1   Alezrandra   Piccarilla   Dip. Firica Sapienza & INFN Roma1   Dip. Firica Sapienza & INFN Roma1   Dip. Firica Sapienza & INFN Roma1   Dip. Firica				I
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Christian   Francarchet   Dip. Firica Università di Milana   NIFN Pira				1
Luca   Galti   Dip. Firica Unit. Gonava & INFN Gonava				+
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Marrima Gervari Dip, Firica Univerzità di Milana Bicacca Anna Groquria Department of Physics - Univerzity of Triesto Daniele Grazza Dip, Firica Uni, Genova & INFN Genova Alezzandra Gruppura INAF/IASF Balagna & INFN Balagna Riccarda Gualticri Dip, Firica Sapienza & INFN Rama1 Victor Hayner Univerzity of Manchester Information of Marca Incagli INFN Pira Incagli			Dis Fisian Unit Granus & INFN Granus	+
Anna Gregoria Department of Physics - University of Tricate Daniele Graze Dip. Firica University of Tricate Daniele Graze Dip. Firica Sapienza & INFN Bologna Riccarda Gueltieri Dip. Firica Sapienza & INFN Bologna Riccarda Gueltieri Dip. Firica Sapienza & INFN Bologna Riccarda Gueltieri Dip. Firica Sapienza & INFN Bologna Riccarda Info Marca Incagli Info Micerity of Mancherter Marca Lamagna Dip. Firica Università di Milana Latanzi Università di Ferrara & INFN Ferrara Info Marimiliana Lattanzi Università di Ferrara & INFN Ferrara Davide Maina Dip. Firica Università di Milana Dip. Firica Università di Milana Dip. Firica Università di Milana Dip. Firica Sapienza & INFN Rama1 Silvia Mari Dip. Firica Università di Milana Diega Malinari Università di Ferrara & INFN Ferrara Dip. Firica Università di Milana Diega Malinari Università di Ferrara & INFN Ferrara Info Marca Info Ma				+
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Sammara   Marchotti   Dip. Firica Sapionaxa & INFN Rama1				$^{+}$
Silvia Mari Dip. Firica Sapienza & INFN Rama1 Diago Molinari Univerzità di Milano Diago Molinari Univerzità di Forrara & INFN Ferrara Gianluca Margante INAF - IASF Balagna Federica Nati Dip. Firica Sapienza & INFN Rama1 Paolo Natali Univerzità di Forrara & INFN Ferrara Ming Wah Ng Univerzità di Forrara & INFN Rama1 Luca Pagano Dip. Firica Sapienza & INFN Rama1 Alerzandra Paiella Dip. Firica Sapienza & INFN Rama1 Andrea Parzerini Dip. Firica Univerzità di Milano Bicocca Peverini Dip. Firica Sapienza & INFN Rama1 Parzerini Dip. Firica Univerzità di Milano Bicocca Drear Peverini INF. Firica Univerzità di Milano Bicocca Discontini Dip. Firica Sapienza & INFN Rama1 Lucia Piccirilla Univerzity of Mancherter Giampaoli Pirano Univerzity of Fallogra Sara Ricciardi INAF - IASF Balagna Parano Dip. Ing. Ind. Uni. Firenze Alezzia Rocchi Dip. Firica Tor Vergata & INFN Rama2 Maria Salatino Dip. Firica Sapienza & INFN Rama1 Maura Salatino Dip. Firica Sapienza & INFN Rama1 Maura Schillaci Dip. Firica Sapienza & INFN Rama1 Maria Signarelli INFN Pira Franco Spinolla INFN Pira Franco Spinolla INFN Pira INFN P				$^{\dagger}$
Anicella Mennella Dip. Firica Univerrità di Milana Diega Malinari Univerrità di Ferrara & INFN Ferrara Gianluca Marqanto INAF - IASF Balagna Paderica Nati Dip. Firica Sapienza & INFN Rama1 Paula Natali Univerrità di Ferrara & INFN Ferrara Ming Wah Ng Univerrity of Ferrara & INFN Rama1 Pagana Dip. Firica Sapienza & INFN Rama1 Alerrandra Paiella Dip. Firica Sapienza & INFN Rama1 Andrea Parzerini Dip. Firica Univerrità di Milana Bicacca Orcar Peverini DIII - CNR - Tarina Francerca Piacentini Dip. Firica Univerrità di Milana Bicacca Orcar Peverini DIII - CNR - Tarina Francerca Piacentini Dip. Firica Univerrità di Milana Bicacca Orcar Peverini DIII - CNR - Tarina Francerca Piacentini Dip. Firica Univerrità di Milana Bicacca Orcar Peverini DIII - CNR - Tarina Francerca Piacentini Dip. Firica Sapienza & INFN Rama1 Univerrity of Cardiff Sara Ricciardi INAF - IASF Balagna Paula Rivrana Dip. Inq. Ind. Uni. Firenza Alerria Racchi Dip. Firica Sapienza & INFN Rama2 Giavanni Ramea INGV-Rama Maria Salatina Dip. Firica Sapienza & INFN Rama1 Alerrandra Schillaci Dip. Firica Sapienza & INFN Rama1 INFP - IASF Balagna Alerrandra Sandri INAF - IASF Balagna Alerrandra Signarelli INFN Pira Franca Spinella INFN Pira Riccarda Tarcano IEIT - CNR - Tarina Rusiria Dip. Firica Univerrità di Milana Elirabetta Tammari Italian Space Agency Carale Tuckor Univerrity of Cardiff Fabrizia Villa INAF - IASF Balagna Giuroppe Virane IEIT - CNR - Tarina Nafera Zacchoi INAF Orervatoria Trierte Naria Zacchoi INAF Orervatoria Trierte Naria Zanchoi Dip. Firica Univerrità di Milana Bicacca				
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Paula		Morganto		+
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Luca Pagana Dip, Firica Sapionza & INFN Rama1 Alexrandra Paiolla Dip, Firica Sapionza & INFN Rama1 Andrea Parverini Dip, Firica Sapionza & INFN Rama1 Orcar Peverini IEIT - CNR - Tarina Francerca Piacentini Dip, Firica Sapionza & INFN Rama1 Lucia Piccirilla Univerzity of Mancharter Giampaalia Pirana Univerzity of Mancharter Paula Rivana Dip, Ing. Ind. Uni, Firenze Alexria Racchi Dip, Firica Fara Informac Giavanni Ramea INGY - Rama Maria Salatina Dip, Firica Sapionza & INFN Rama1 Alexrandra Schillaci Dip, Firica Sapionza & INFN Rama1 Alexrandra Schillaci Dip, Firica Sapionza & INFN Rama1 INFT - IASF Balagna Alexrandra Schillaci Dip, Firica Sapionza & INFN Rama1 INFN Pira Inca Stringhetti INFN Pira Luca Stringhetti INFN Pira Luca Stringhetti INFN Pira Luca Tarcane IEIT - CNR - Tarina Incarda Tarcane IEIT - CNR - Tarina Index Tammari Italian Space Agency Carale Tucker Univerzità di Milana Bicacca Incarda Tarcane IEIT - CNR - Tarina Index Tammari Italian Space Agency Carale Tucker Univerzità di Galiff Fabrizia Villa INAF - IASF Balagna Alexrandra Incara I			Università di Perrara & IMPM Perrara	+
Alexandra Paiella Dip. Firica Sapienza & INFN Rama1 Andrea Parrerini Dip. Firica Univerzità di Milana Bicacca Orcar Poverini IEIIT - CNR - Tarina Francezca Piacentini Dip. Firica Sapienza & INFN Rama1 Lucia Piccirilla Univerzity af Mancherter Giampaola Pirana Univerzity af Cardiff Sara Ricciardi INAF - IASF Balagna Paola Rizzane Dip. Inq. Ind. Uni. Firenze Alexria Racchi Dip. Firica Tar Vergata & INFN Rama2 Giavanni Ramea INGV - Rama Maria Salatina Dip. Firica Sapienza & INFN Rama1 Maria Salatina Dip. Firica Sapienza & INFN Rama1 Alexrandra Schillaci Dip. Firica Sapienza & INFN Rama1 Giavanni Signarolli INFN Pira Franca Spinolla INFN Pira Franca Spinolla INFN Pira Luca Stringhetti INAF - IASF Balagna Alexrandra Tartari Dip. Firica Univerzità di Milana Bicacca Riccarda Tarcane IEIIT - CNR - Tarina Luca Toronxi INAF - IASF Balagna Giavanzia Tamari Dip. Firica Univerzità di Milana Elirabetta Tammari Italian Space Agency Carale Tuckor Univerzità di Galiff Fabrixia Villa INAF - IASF Balagna Giuroppe Virane IEIIT - CNR - Tarina NaF - IASF Balagna Giuroppe Virane IEIIT - CNR - Tarina NaF - IASF Balagna Vittaria Univerzità di Rama TarVergata & INFN Rama2 Andrea Zacchei INAF Orerevatoria Trierte Naria Zanneni Dip. Firica Univerzità di Milana Bicacca				+
Andrea Parserini Dip. Firica Università di Milana Bicacca Orcar Peverini EIIT CNR - Tarina Prancerca Piccentini Dip. Firica Sapienza & INFN Rama1 Picarilla University af Mancherter Giampaola Pirana University af Mancherter Prancerca Ricciardi INAF - IASF Balagna Pirana Dip. Ing. Ind. Uni. Firenze Racchi Dip. Firica Tar Vergata & INFN Rama2 Ricciardi Racchi Dip. Firica Tar Vergata & INFN Rama2 Ricciardi Rama Dip. Firica Sapienza & INFN Rama2 Ricciardi Rama Dip. Firica Sapienza & INFN Rama1 Rama Sandri INAF - IASF Balagna Schillaci Dip. Firica Sapienza & INFN Rama1 Ricciardi Rama INFN Pira Informati Dip. Firica Università di Milana Bicacca Riccarda Tarcane IEIT - CNR - Tarina INAF - IASF Balagna Tarcane INAF - IASF Balagna Informati Tamari Dip. Firica Università di Milana Bicacca Informati Tamari Italian Space Agency Carale Tuckor Università di Milana III Informati Vittaria Università di Rama TarVergata & INFN Rama2 Andrea Zacchei INAF - IASF Balagna Informati Tricette Maria Zanchoi Dip. Firica Università di Rama TarVergata & INFN Rama2 Andrea Zacchei INAF - Inviversità di Milana Bicacca			Dip. Firica Sapienza & INFN Roma1	$^{\dagger}$
Orcar Peverini IEIT - CNR - Tarine Francerca Piacentini Dip. Firica Sapienza & INFN Rama1 Lucia Piccirilla University of Mancherter Giampaala Pirana University of Cardiff Sara Ricciardi INAF - IASF Balagna Paala Rizrane Dip. Inc. Ind. Univ. Firenze Alexzia Racchi Dip. Firica Tar Vergata & INFN Rama2 Giavanni Ramea INGV - Rama Maria Salatina Dip. Firica Sapienza & INFN Rama1 Maria Sandri INAF - IASF Balagna Alexzandra Schillaci Dip. Firica Sapienza & INFN Rama1 Franca Spinola INFN Pira Franca Spinola INFN Pira Luca Stringhetti INAF - IASF Balagna Alexandra Tartari Dip. Firica Univerzità di Milana Bicacca Riccarda Tarcane IEIT - CNR - Tarina Luca Terenzi INAF - IASF Balagna Maurizia Tammari Dip. Firica Univerzità di Milana Elirabetta Tammari Italian Space Agency Carale Tuckor Univerzità di Gardiff Fabrizia Villa INAF - IASF Balagna Giureppe Virane IEIT - CNR - Tarina Nicala Vittaria Univerzità di Rama TarVergata & INFN Rama2 Andrea Zacchei INAF Orcervatoria Trierte Maria Zannoni Dip. Firica Univerzita Trierte		Parrorini	Dip. Firica Università di Milana Bicacca	Ť
Francezon Lucia Piccirilla Univerzity af Manchester Giampaula Pirana Picciardi MAF-IASF Balagna Picciardi Dip, Firica Sapienza & INFN Rama1 Univerzity af Cardiff Paula Rizzene Dip, Ing, Ind, Unit, Firenze Riscene R	Orcar	Peverini	IEIIT - CNR - Tarina	I
Giampaele Pirane Univerzity of Cardiff Sara Ricciardi INAF - IASF Belagna Paele Rivrane Dip. Inq. Ind. Uni. Firenze Alexria Reachi Dip. Firica Tar Vergata & INFN Rema2 Giavanni Romee INGV-Rome Maria Salatine Dip. Firica Sapienza & INFN Rema1 Maria Salatine Dip. Firica Sapienza & INFN Rema1 Alexrandra Schillaci Dip. Firica Sapienza & INFN Rema1 Alexrandra Schillaci Dip. Firica Sapienza & INFN Rema1 Franca Spinelli INFN Pira Franca Spinella INFN Pira Franca Spinella INFN Pira Luca Stringhetti INAF - IASF Belagna Andrea Tartari Dip. Firica Univerzità di Milane Bicacca Riccarda Tarcone IEIIT - CNR - Tarrina Luca Tarenzi InAF - IASF Belagna Maurizia Tomari Italian Space Agency Carale Tucker Univerzità di Milane Elirabetta Tommari Italian Space Agency Carale Tucker Univerzità di Gardiff Fabrizia Villa INAF - IASF Belagna Giuroppe Virone IEIIT - CNR - Tarrina Nicela Vittoria Univerzità di Roma TarVergata & INFN Rema2 Andrea Zacchei INAF Orerevatoria Trierte Maria Zannoni Dip. Firica Univerzità di Milane Bicacca		Piacontini	Dip. Firica Sapionza & INFN Roma1	I
Sara Ricciardi INAF-IASF Balagna Paola Rivrano Dip. Inq. Ind. Uni. Firenzo Alezzia Racchi Dip. Firica Tar Vergata & INFN Roma2 Giovanni Romeo INGV-Roma Maria Salatina Dip. Firica Sapienza & INFN Roma1 Maura Sandri INAF-IASF Balagna Alezzandra Schillaci Dip. Firica Sapienza & INFN Roma1 INAF-IASF Balagna Alezzandra Schillaci INFN Pira INFN Pira INFN Pira Luca Stringhotti INAF-IASF Balagna Andrea Tartori Dip. Firica Univerzità di Milana Bicacca Riccarda Tarcone IEIT-CNR-Tarina Luca Terenzi INAF-IASF Balagna Maurizia Tomari Dip. Firica Univerzità di Milana Elirabetta Tomari Italian Space Agency Carale Tuckor Univerzity af Cardiff Fabrizia Willa INAF-IASF Balagna Giureppe Virano IEIT-CNR-Tarina Nicala Vittoria Univerzità di Roma TarVorgata & INFN Roma2 Andrea Zacchei INAF Orservatoria Trierte Maria Zannoni Dip. Firica Univerzità di Milana Bicacca				+
Paula Rizrane Dip. Inq. Ind. Uni. Firenze Alezzia Racchi Dip. Fürica Tar Verqata & INFN Rama2 Giavanni Ramea INGV - Rama Maria Salatina Dip. Fürica Sapienza & INFN Rama1 Marra Sandri INAF - IASF Balaqna Alezzandra Schillaci Dip. Fürica Sapienza & INFN Rama1 Giavanni Siquarolli INFN Püra Franca Spinella INFN Püra Luca Stringhetti INAF - IASF Balaqna Andrea Tartari Dip. Fürica Univerzità di Milana Bicacca Riccarda Tarcane IEIT - CNR - Tarina Luca Terenzi INAF - IASF Balaqna Maurizia Tamari Dip. Fürica Univerzità di Milana Elirabetta Tammari Italian Space Agency Carale Tuckor Univerzità di Milana Elirabetta Tammari Italian Space Agency Carale Tuckor Univerzity di Gardiff Fabrizia Villa INAF - IASF Balaqna Giureppe Virane IEIT - CNR - Tarina Nicala Vittaria Univerzità di Rama TarVergata & INFN Rama2 Andrea Zacchei INAF Orzervatoria Trierte Maria Zannani Dip. Fürica Viniverzità di Milana Bicacca			University of Cardiff	+
Alexria Reschi Dip. Firica Tar Vergata & INFN Roma2  Giovanni Romes INGV - Roma  Maria Salatina Dip. Firica Sapienza & INFN Roma1  Maura Sandri INAF - IASF Balagna  Alexrandra Schillaci Dip. Firica Sapienza & INFN Roma1  Giovanni Signarelli INFN Pira  Franca Spinella INFN Pira  Franca Spinella INFN Pira  Luca Stringhotti INAF - IASF Balagna  Andrea Tartari Dip. Firica Univerrità di Milana Bicacca  Riccarda Tarcane IEIIT - CNR - Tarina  Luca Terenzi INAF - IASF Balagna  Maurizia Tomari Dip. Firica Univerrità di Milana  Elirabetta Tommari Italian Space Agency  Carale Tuckor Univerrità di Milana  Elirabetta Tommari Italian Space Agency  Carale Tuckor Univerrità di Milana  Giuroppe Virane IEIIT - CNR - Tarina  Nicala Vittaria Univerrità di Roma Tar Vergata & INFN Roma2  Andrea Zacchei INAF Operavatoria Trierte  Maria Zannoni Dip. Firica Univerrità di Milana Bicacca			Die lee led Uni Firenzo	+
Giovanni Romeo INGV-Roma Maria Salatino Dip. Firica Sapienza & INFN Roma1 Mara Sandri INAF-IASF Balagna Alexrandra Schillaci Dip. Firica Sapienza & INFN Roma1 Alexrandra Schillaci Dip. Firica Sapienza & INFN Roma1 INFN Pira INFN Pira INFN Pira Luca Stringhetti INAF-IASF Balagna Andrea Tartari Dip. Firica Univerzità di Milano Bicocca Biccardo Tarcone IEIT-CNR-Tarino Luca Terenzi INAF-IASF Balagna Maurizio Tomari Dip. Firica Univerzità di Milano Elirabetta Tomari Italian Space Agency Carole Tuckor Univerzity of Cardiff Fabrizio Villa INAF-IASF Balagna Giureppe Virone IEIT-CNR-Tarino Nicola Vittorio Univerzity of Cardiff Nicola Vittorio Univerzità di Roma TorVergata & INFN Roma2 Andrea Zacchei INAF Orservatorio Trierte Mario Zannoni Dip. Firica Univerzità di Milano Bicocca				+
Maria         Salatina         Dip. Firica Sapionxa ⊗ INFN Rama1           Maura         Sandri         INFF - IASF Balagna           Alorrandra         Schillaci         Dip. Firica Sapionxa ⊗ INFN Rama1           Giavanni         Signarolli         INFN Pira           Franca         Spinolla         INFN Pira           INFN Pira         INFN Pira           Luca         Stringhotti         INAF - IASF Balagna           Andrea         Tarcani         Dip. Firica Univerzità di Milana Bicacca           Riccarda         Tarcane         IEIT - CNR - Tarina           Luca         Tarcani         Dip. Firica Univerzità di Milana           Elirabetta         Tammari         Italian Space Agency           Carale         Tuckor         Univerzity al Gardiff           Fabrizia         Villa         INAF - IASF Balagna           Giuroppe         Virane         IEIT - CNR - Tarina           Micala         Vittaria         Univerzity di Rama TarVergata ⊗ INFN Rama2           Andrea         Zacchei         INAF Orzervatoria Trievte           Maria         Zannani         Dip. Firica Univerzità di Milana Bicacca			INGV - Rama	Ť
Maura Sandri INAF - IASF Balagna Alexzandra Schillaci Dip. Firica Sapienza & INFN Roma1 Giovanni Signarelli INFN Pira INFN Pira Luca Stringhetti NAF - IASF Balagna Andrea Tartari Dip. Firica Univerzità di Milano Bicocca Riccardo Tarcone IEIIT - CNR - Tarrino Luca Terenzi INAF - IASF Balagna Maurizia Tomari Dip. Firica Univerzità di Milano Elirabetta Tommari Italian Space Agency Carole Tucker Univerzity of Cardiff Fabrizia Willa INAF - IASF Balagna Giureppe Virane IEIIT - CNR - Tarrino Nicola Vittorio Univerzità di Roma TorVergata & INFN Roma2 Andrea Zacchei INAF Orservatorio Trierte			Dip. Firica Sapionza & INFN Roma1	İ
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Giovanni Siquarelli INFN Pira Franca Spinella INFN Pira Luca Stringhotti INAF - IASF Balagna Andrea Tarteri Dip. Firica Univerzità di Milana Bicacca Riccarda Tarcane IEIIT - CNR - Tarina Luca Terenzi INAF - IASF Balagna Maurizia Tammari Dip. Firica Univerzità di Milana Elirabetta Tammari Italian Space Agency Carale Tuckor Univerzità di Griff Fabrizia Villa INAF - IASF Balagna Giuroppe Virane IEIIT - CNR - Tarina Nicala Vittaria Univerzità di Rama TarVergata & INFN Rama2 Andrea Zacchei INAF Orzervatoria Trierte Maria Zannani Dip. Firica Univerzità di Milana Bicacca			Dip. Firica Sapionza & INFN Roma1	Ţ
Luca Stringhotti INAF - IASF Balagna Androa Tartari Dip. Firica Univerzità di Milana Bicacca Riccarda Tarcane IEIIT - CNR - Tarrina Luca Torenzi INAF - IASF Balagna Maurizia Tammari Dip. Firica Univerzità di Milana Elirabetta Tammari Italian Space Agency Carale Tuckor Univerzity af Cardiff Fabrizia Villa INAF - IASF Balagna Giuroppe Virane IEIIT - CNR - Tarrina Nicala Vittaria Univerzity di Roma TarVorgata & INFN Rama2 Androa Zacchoi INAF Orzervatoria Trierte Maria Zannani Dip. Firica Univerzità di Milana Bicacca			INFN Pira	1
Andrea Tartari Dip. Firica Univerzità di Milane Bicocca Riccarda Tarcene IEIT - CNR - Terine Luca Terenzi INAF - IASF Belagna Maurizia Temari Dip. Firica Univerzità di Milane Elirabetta Temmari Italian Space Agency Carele Tucker Univerzity el Cardiff Fabrizia Willa INAF - IASF Belagna Giureppe Virane IEIT - CNR - Terine Nicola Vitteria Univerzità di Roma TerVergata & INFN Roma2 Andrea Zacchei INAF Orservatoria Trierte Maria Zannoni Dip. Firica Univerzità di Milane Bicocca				+
Riccarda Tarcano IEIT - CNR - Tarina Luca Teronzi INAF - IASF Balagna Maurizia Tammari Dip. Firica Univerzità di Milana Elirabetta Tammari Italian Space Agency Caralo Tuckor Univerzity al Gardiff Fabrizia Villa INAF - IASF Balagna Giuroppo Virano IEIT - CNR - Tarina Nicala Vittaria Univerzità di Rama TarVorgata & INFN Rama2 Andrea Zacchoi INAF Orzervatoria Trierte Maria Zannoni Dip. Firica Univerzità di Milana Bicacca				+
Luca Terenzi INAF - IASF Balagna Maurizia Tamari Dip. Firica Univerzità di Milana Elirabetta Tammari Italian Space Agency Carale Tucker Univerzity of Cardiff Fabrizia Villa INAF - IASF Balagna Giuroppe Virane IEIT - CNR - Tarina Nicala Vittaria Univerzità di Rama TarVergata & INFN Rama2 Andrea Zacchei INAF Ozzervatoria Trierte Maria Zannoni Dip. Firica Univerzità di Milana Bicacca				+
Maurizia Tomari Dip. Firica Univerzità di Milana Elirabotta Tommari Italian Space Agency Carale Tuckor Univerzity af Cardiff Fabrizia Villa INAF - IASF Balagna Giuroppe Virane IEIIT - CNR - Tarrina Nicala Vittoria Univerzità di Roma TorVorgata & INFN Roma2 Andrea Zacchei INAF Ozrorvatoria Trierte Maria Zannoni Dip. Firica Univerzità di Milana Bicacca				+
Elirabetta Tommari Italian Space Agency Carale Tuckor Univerzity af Cardiff Fabrizia Villa INAF - IASF Balagna Giuroppe Virane IEIIT - CNR - Tarina Nicala Vittaria Univerzità di Rama TarVergata & INFN Rama2 Andrea Zacchei INAF Oprervatoria Trieste Maria Zannani Dip, Firica Univerzità di Milana Bicacca			Dip. Firica Università di Milana	Ť
Carole Tucker Univerzity of Cardiff Fabrizio Villa INAF-IASF Balagna Giuroppe Virane IEIIT - CNR - Tarrina Nicala Vittorio Univerzità di Roma TarVorgata & INFN Roma2 Andrea Zacchei INAF Ozzervatorio Trieste Mario Zanonoi Dip. Firica Univerzità di Milano Bicocca		Tommari	Italian Space Agency	İ
Fabrizia Villa INAF - IASF Balagna Giuroppo Virano IEIT - CNR - Tarrina Nicala Vittaria Univerzità di Roma TarVergata & INFN Roma 2 Andrea Zacchei INAF Ozrervatoria Trievte Maria Zannoni Dip, Firica Univerzità di Milana Bicacca	Carole	Tucker	University of Cardiff	I
Nicola Vittorio Università di Roma TorVorgata & INFN Roma 2 Andrea Zacchei INAF Ozzervatorio Trieste Mario Zannoni Dip. Firica Università di Milano Bicocca			INAF-IASF Balagna	1
Andrea Zacchei INAF Osservatorio Trieste  Mario Zannoni Dip. Fisica Università di Milano Bicocca				+
Maria Zannani Dip. Firica Università di Milana Bicacca			Università di Roma Torvergata & INFN RomaZ	+
			Die Finia Universitä di Miles - Pieses	+
				+
				+

### LSPE in a nutshell

- The Large-Scale Polarization Explorer is :
  - an instrument to measure the polarization of the Cosmic Microwave Background at large angular scales
  - The SWIPE instrument uses a spinning stratospheric balloon payload to avoid atmospheric noise, flying long-duration, in the polar night
  - uses a polarization modulator to achieve high stability
- Frequency coverage: 40 250 GHz (5 channels, 2 instruments: STRIP & SWIPE)
- Angular resolution: 1.3° FWHM
- Sky coverage: 20-25% of the sky per flight / year
- Combined sensitivity: 10 μK arcmin per flight
- Current collaboration: Sapienza, UNIMI, UNIMIB, IASFBO-INAF, IFAC-CNR, Uni.Cardiff, Uni.Manchester. INFN-GE, INFN-PI, INFN-RM1, INFN-RM2, INFN-FE
- See astro-ph/1208.0298, 1208.0281, 1208.0164 and forthcoming updates



LSPE:
Foreground
cleaning
strategy

44 GHz Monitor polarized synchrotron

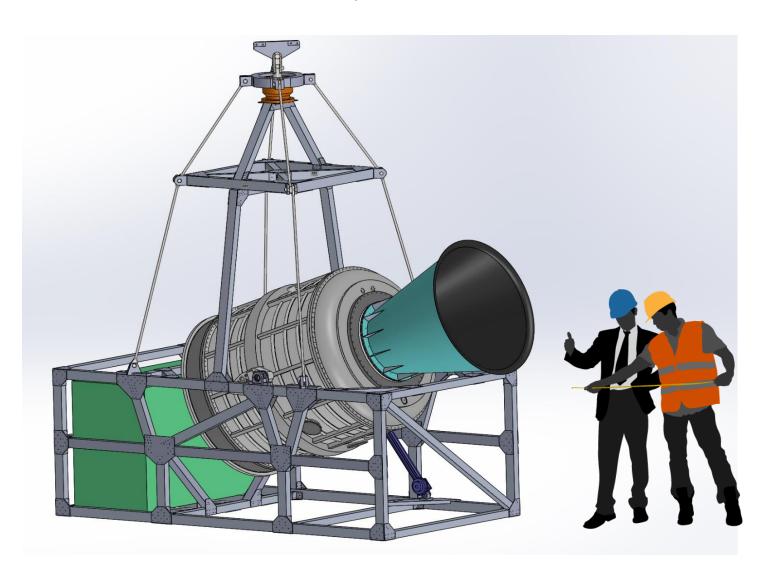
> 90 + 140 GHz Main CMB channels

220 + 240 GHz Monitor level **and slope and rotation** of polarized dust emission

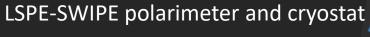
To date extrapolated from 350 GHz only



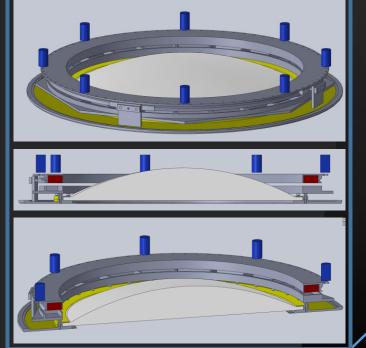
## LSPE/SWIPE



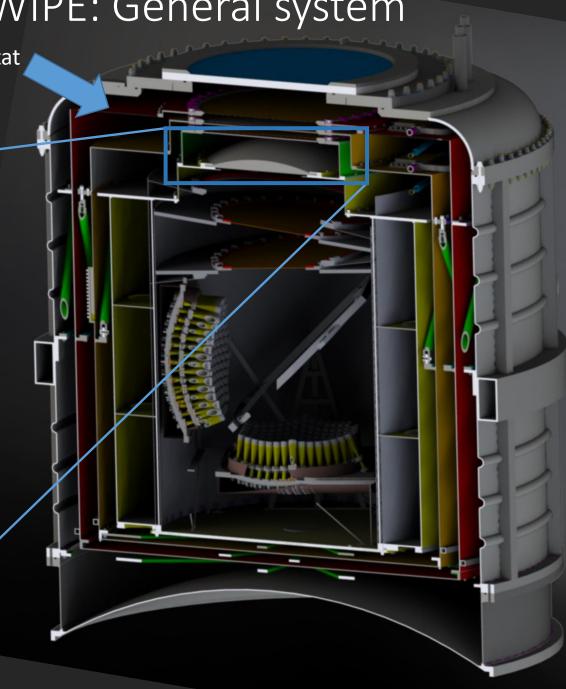


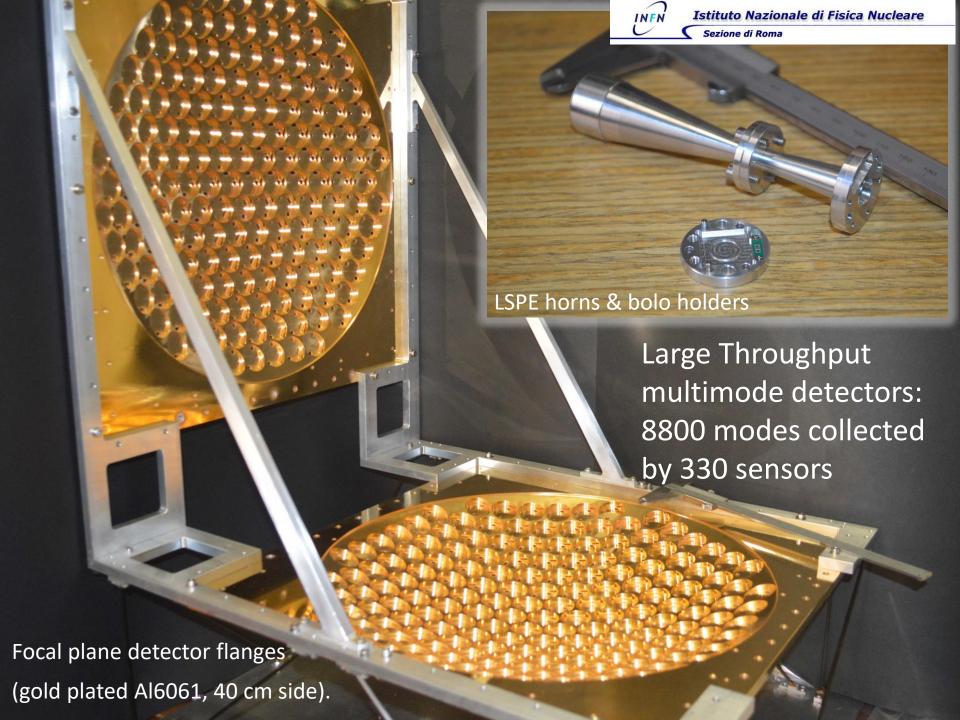


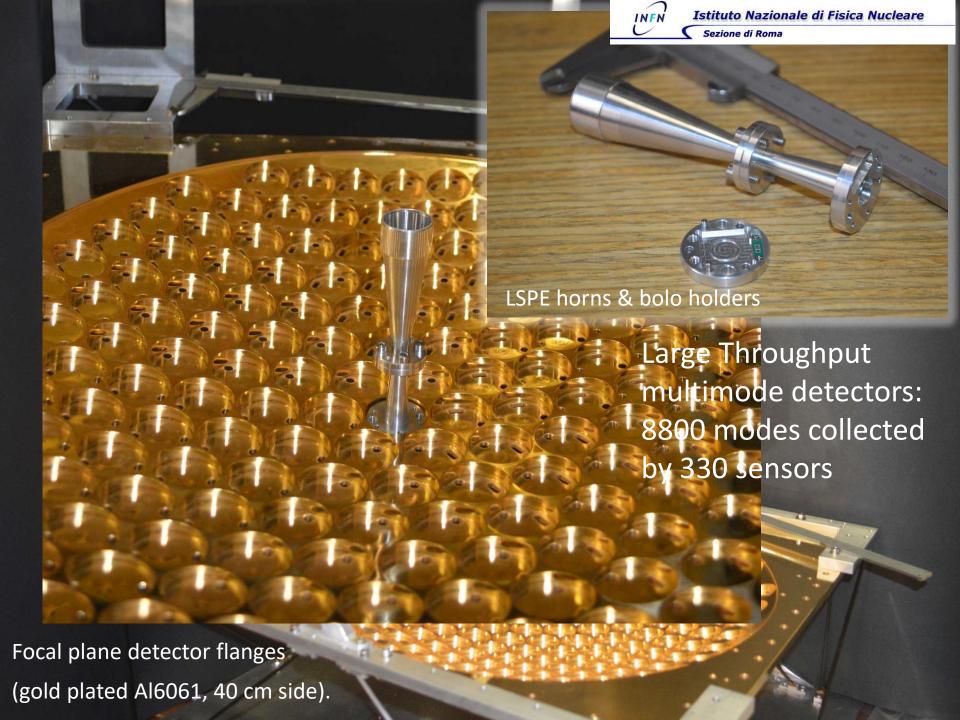
LSPE-SWIPE polarization modulator



Study of a fast (1-2 rps) levitating modulator Current baseline: stepper (See Salatino et al. 2012)

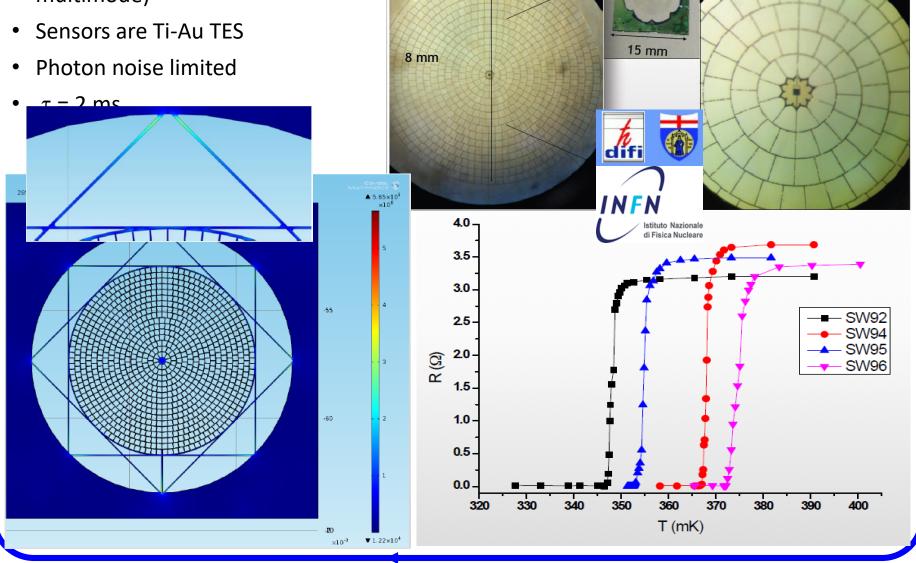




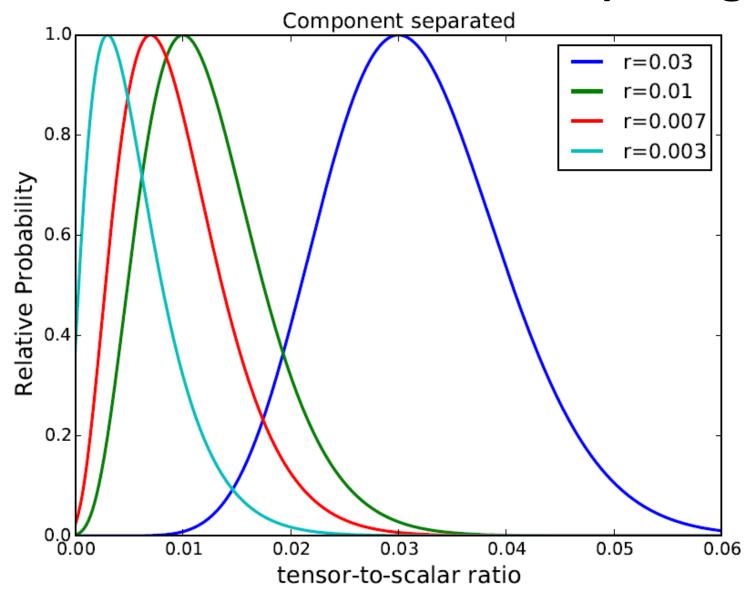


# SWIPE - multimode absorbers & TES

 The absorbers are large Si<sub>3</sub>N<sub>4</sub> spider-webs (8 mm diameter, multimode)



# **SWIPE Performance Forecast (1st flight)**



L. Pagano, F. Piacentini

### **Current Status**

- LSPE is fully funded by ASI and INFN
- STRIP will operate from the ground (Tenerife) covering the same sky as SWIPE
- STRIP and SWIPE in due course of development, consistent with a 1st launch opportunity from Svalbard (78°N) in Winter 2019/20 for SWIPE and start of data taking in 2019 for STRIP.
- Baseline science expected from (one flight + 1 year) is competitive with current gen B-mode experiments – and contributions to polarized foreground science will provide a great complement the CMB science.



# **OLIMPO**



- The OLIMPO experiment is a first attempt at spectroscopic measurements of CMB anisotropy.
- A large balloon-borne telescope with a 4-bands photometric array and a plug-in room temperature spectrometer
- see <a href="http://planck.roma1.infn.it/olimpo">http://planck.roma1.infn.it/olimpo</a> for a collaborators list and full details on the mission
- Main scientific targets:
  - SZ effect in clusters -> unbiased estimates of cluster parameters
  - Spectrum of CMB anisotropy -> anisotropic spectral distortions















# Latest $\gamma$ interaction: clusters of galaxies

- Inverse Compton Effect for CMB photons against charged particles in the hot gas of clusters (same as y-type distortion)
- Cluster optical depth:  $\tau = n\sigma$

$$I = a \text{ few Mpc} = 10^{25} \text{ cm}$$
  
 $n < 10^{-3} \text{ cm}^{-3}$   
 $\sigma = 6.65 \times 10^{-25} \text{ cm}^2$ 

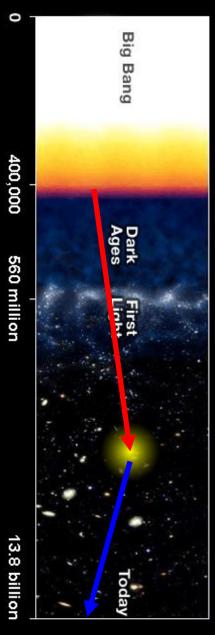
- So  $\tau = n\sigma$  < 0.01 : there is a 1% likelihood that a CMB photon crossing the cluster is scattered by an electron
- $E_{electron} >> E_{photon}$ , so the electron transfers energy to the photon. To first order, the energy gain of the photon is

$$\frac{\Delta v}{v} = \frac{kT_e}{m_e c^2} \approx \frac{5keV}{500keV} = 0.01$$

The resulting CMB temperature anisotropy is

$$\frac{\Delta T}{T} \approx \tau \frac{\Delta \nu}{\nu} \approx 0.01 \times 0.01 = 10^{-4}$$

Sunyaev R., Zeldovich Y.B., 1972, Comm. Astrophys. Space Phys., 4, 173 Birkinshaw M., 1999, Physics Reports, 310, 97-195



A&A 538, A86 (2012)

DOI: 10.1051/0004-6361/201118062

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# Low-resolution spectroscopy of the Sunyaev-Zel'dovich effect and estimates of cluster parameters

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Received 9 September 2011 / Accepted 8 November 2011

#### ABSTRACT

Context. The Sunyaev-Zel'dovich (SZ) effect is a powerful tool for studying clusters of galaxies and cosmology. Large mm-wave telescopes are now routinely detecting and mapping the SZ effect in a number of clusters, measure their comptonisation parameter and use them as probes of the large-scale structure and evolution of the universe.

Aims. We show that estimates of the physical parameters of clusters (optical depth, plasma temperature, peculiar velocity, non-thermal components etc.) obtained from ground-based multi-band SZ photometry can be significantly biased, owing to the reduced frequency coverage, to the degeneracy between the parameters and to the presence of a number of independent components larger than the number of frequencies measured. We demonstrate that low-resolution spectroscopic measurements of the SZ effect that also cover frequencies >270 GHz are effective in removing the degeneracy.

Methods. We used accurate simulations of observations with lines-of-sight through clusters of galaxies with different experimental configurations (4-band photometers, 6-band photometer, multi-range differential spectrometer, full coverage spectrometers) and dif-



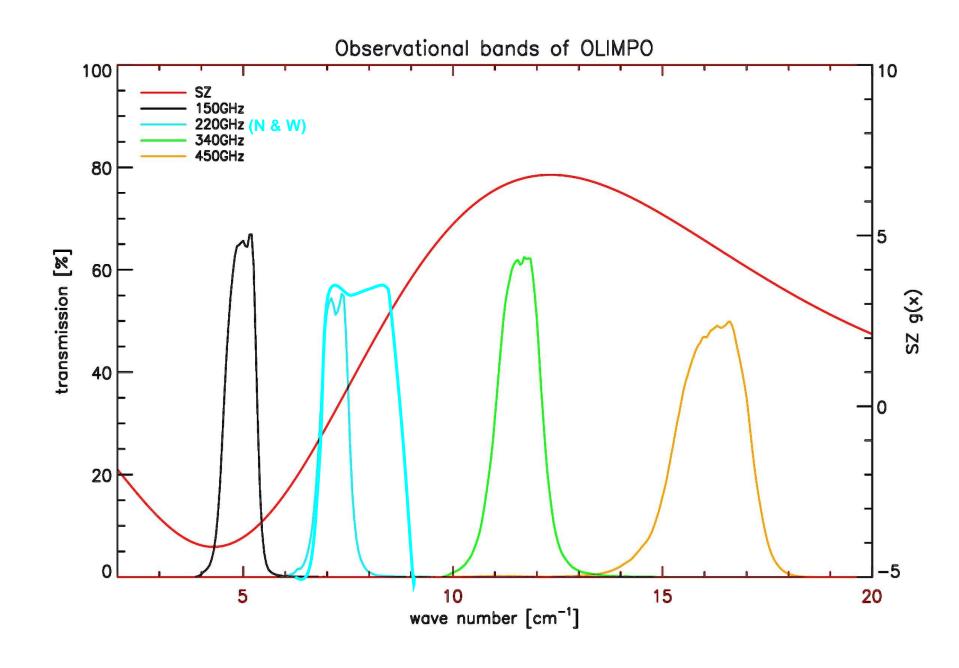
# **OLIMPO**

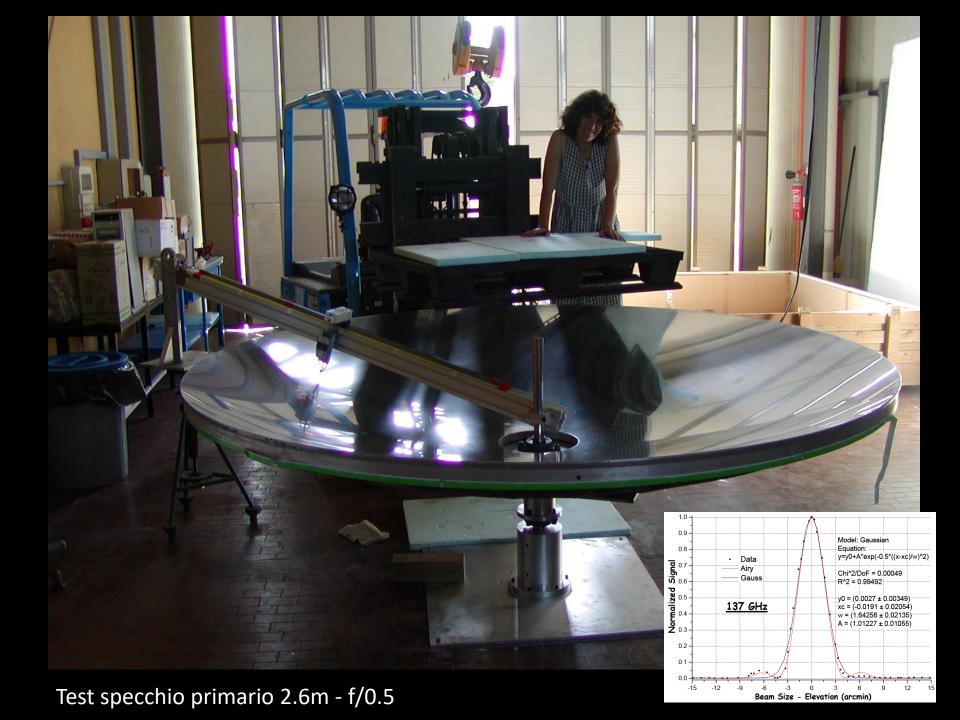


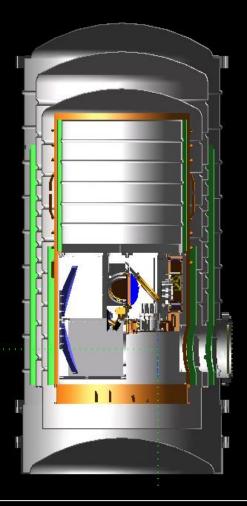
- Long Duration Balloon experiment for mm & sub-mm astronomy
- Operates from the stratosphere - launch from Svalbard
- Cassegrain telescope, 2.6m aperture
- Multifrequency arrays of bolometers
- Low resolution spectrometer

ch	v <sub>eff</sub> [GHz]	$\Delta v_{\text{FWHM}} [\text{GHz}]$	Res. [']
Ι	148.4	21.5	4.2
П	215.4	20.6	2.9
III	347.7	33.1	1.8
IV	482.9	54.2	1.8



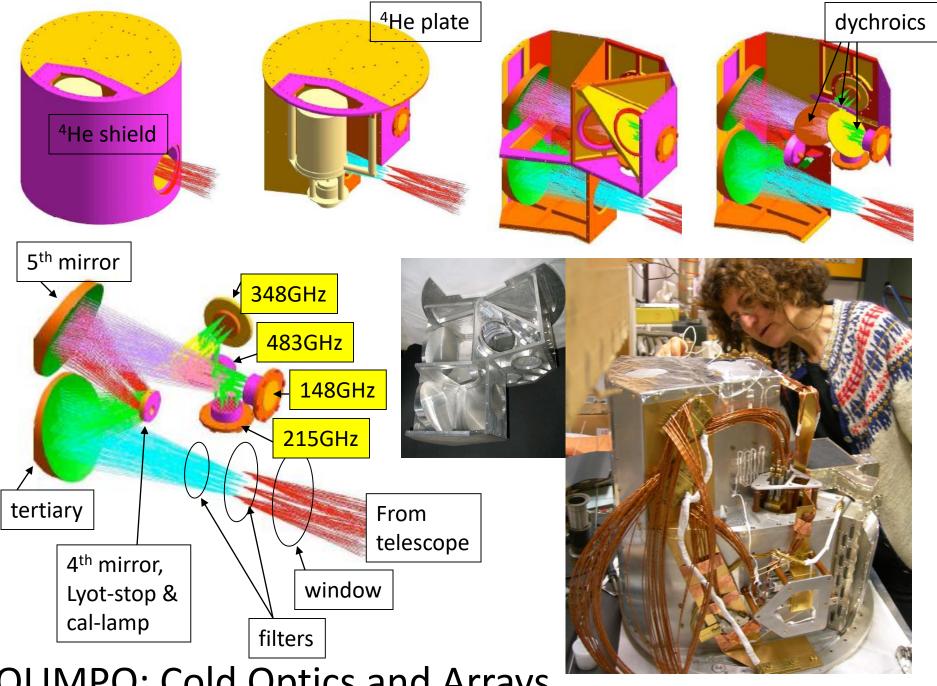




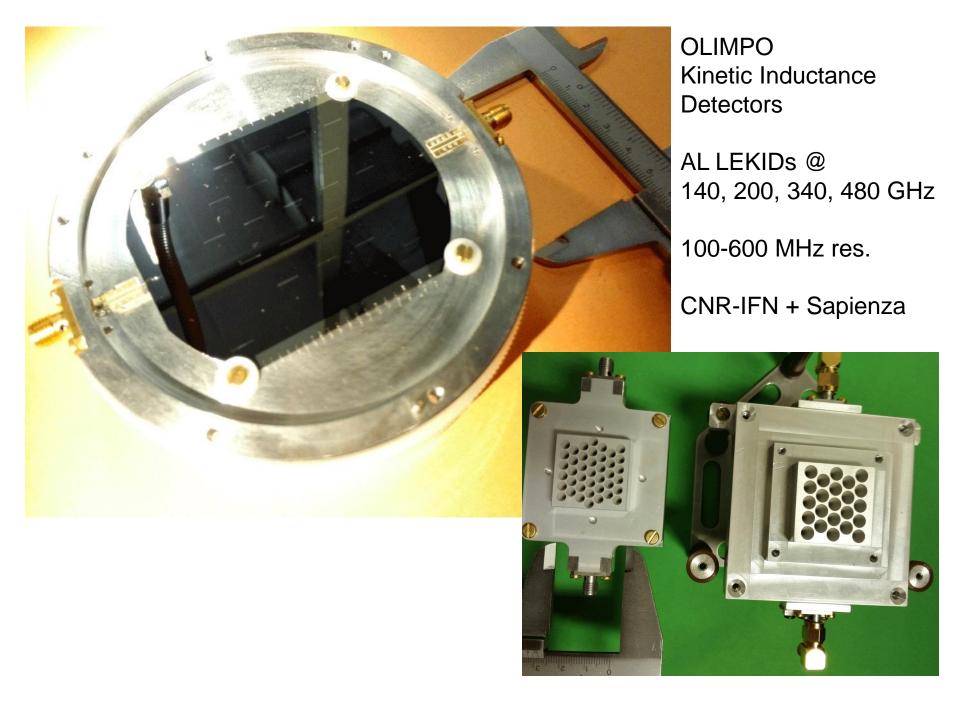


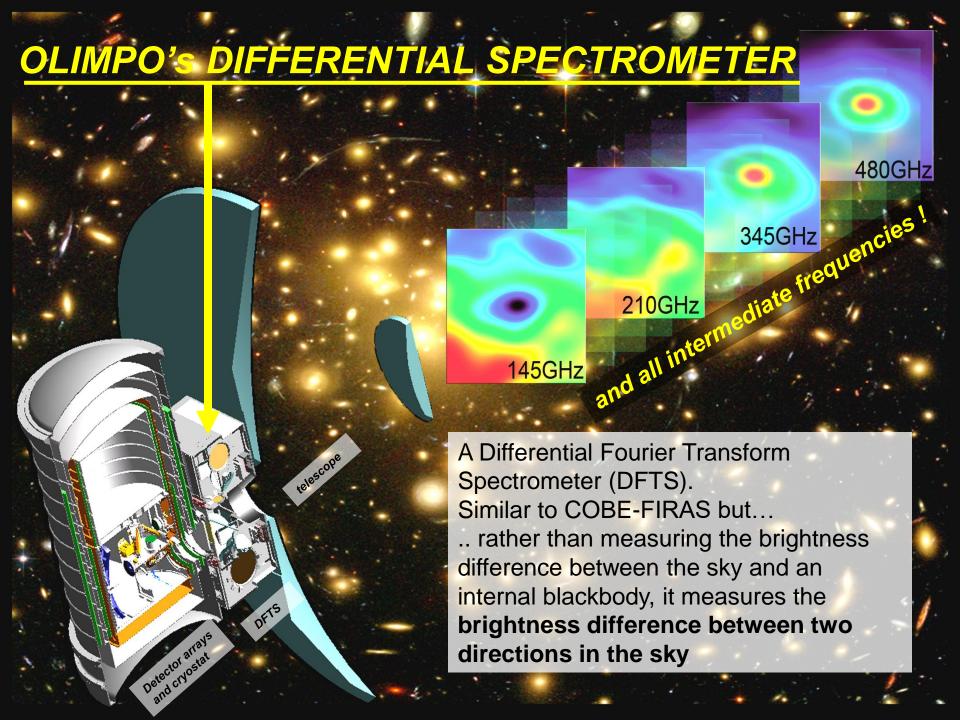
0.3K cryostat (made in Sapienza) 65L superfluid <sup>4</sup>He 70L liquid N 40LSTP <sup>3</sup>He refrigerator 50L experimental volume Hold time – 15 days @ 0.3K





**OLIMPO: Cold Optics and Arrays** 





- The instrument is based on a double Martin Puplett Interferometer configuration to avoid the loss of half of the signal.
- A wedge mirror splits the sky image in two halves  $I_a$  and  $I_b$ , used as input signals for both inputs of the two FTS's.
- In the FTSs the beam to be analyzed is split in two halves, and a variable optical path difference is introduced.

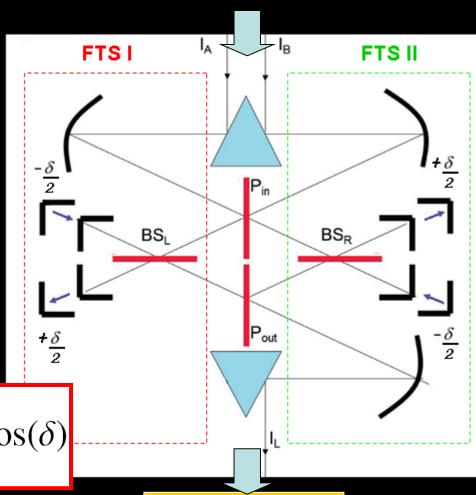
See Schillaci et al. A&A 565, A125, 2014 for a detailed description of the instrument. The output brightness is

$$I_L = \frac{1}{2}(I_a + I_b) + \frac{1}{2}(I_a - I_b)\cos(\delta)$$

 $\delta$  = variable phase shift, introduced by the variable optical path difference.

Only the *difference* between the two input brightnesses is modulated by the variable optical path difference.

### Olimpo Telescope



Olimpo Cryostat A&A 565, A125 (2014)

DOI: 10.1051/0004-6361/201423631

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# Efficient differential Fourier-transform spectrometer for precision Sunyaev-Zel'dovich effect measurements

Alessandro Schillaci<sup>1</sup>, Giuseppe D'Alessandro<sup>1</sup>, Paolo de Bernardis<sup>1</sup>, Silvia Masi<sup>1</sup>, Camila Paiva Novaes<sup>2</sup>, Massimo Gervasi<sup>3</sup>, and Mario Zannoni<sup>3</sup>

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Received 13 February 2014 / Accepted 11 April 2014

#### ABSTRACT

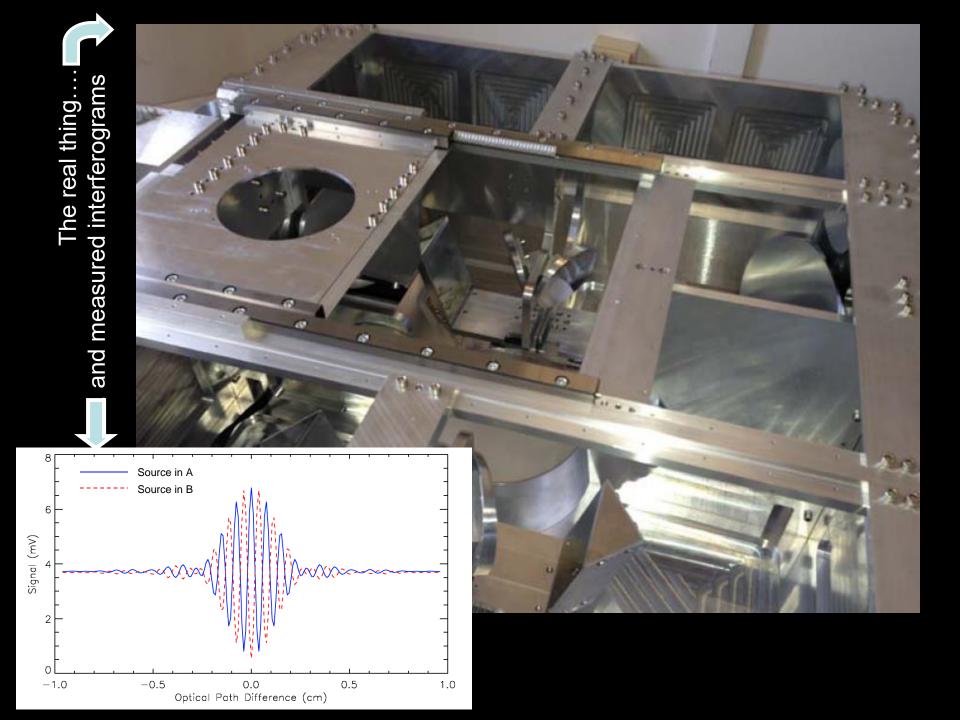
Context. Precision measurements of the Sunyaev-Zel'dovich effect in clusters of galaxies require excellent rejection of common-mode signals and wide frequency coverage.

Alms. We describe an imaging, efficient, differential Fourier transform spectrometer (FTS), optimized for measurements of faint brightness gradients at millimeter wavelengths.

Methods. Our instrument is based on a Martin-Puplett interferometer (MPI) configuration. We combined two MPIs working synchronously to use the whole input power. In our implementation the observed sky field is divided into two halves along the meridian, and each half-field corresponds to one of the two input ports of the MPI. In this way, each detector in the FTS focal planes measures the difference in brightness between two sky pixels, symmetrically located with respect to the meridian. Exploiting the high common-mode rejection of the MPI, we can measure low sky brightness gradients over a high isotropic background.

Results. The instrument works in the range  $\sim 1-20 \, \mathrm{cm^{-1}}$  (30–600 GHz), has a maximum spectral resolution  $1/(2 \, \mathrm{OPD}) = 0.063 \, \mathrm{cm^{-1}}$  (1.9 GHz), and an unvignetted throughput of 2.3 cm<sup>2</sup>sr. It occupies a volume of  $0.7 \times 0.7 \times 0.33 \, \mathrm{m^3}$  and has a weight of 70 kg. This design can be implemented as a cryogenic unit to be used in space, as well as a room-temperature unit working at the focus of suborbital and ground-based mm-wave telescopes. The first in-flight test of the instrument is with the OLIMPO experiment on a stratospheric balloon; a larger implementation is being prepared for the Sardinia radio telescope.

Key words. cosmic background radiation - instrumentation: spectrographs - techniques: spectroscopic - galaxies: clusters: general

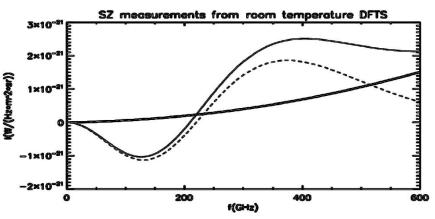


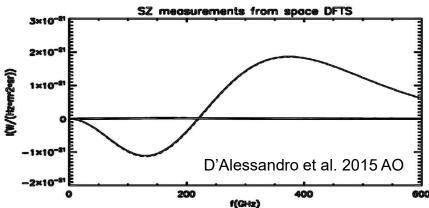
## **CMRR**

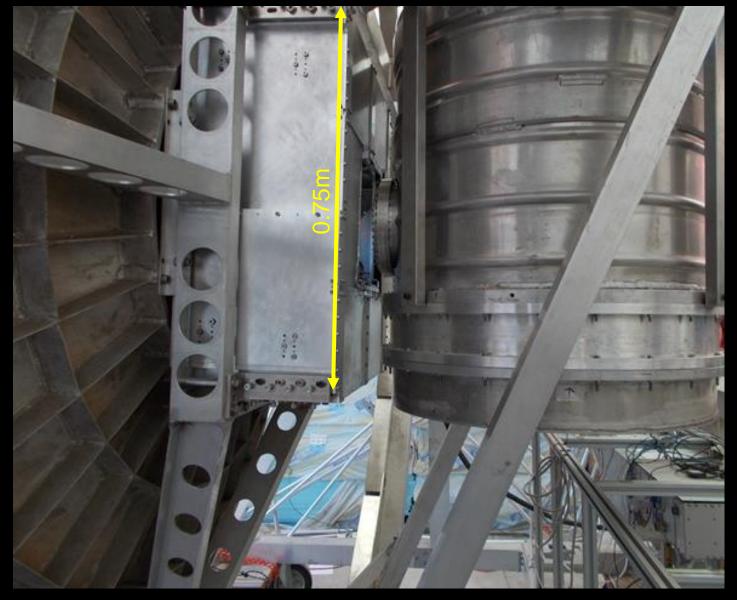
- The differential signal (SZ) is much smaller than the common mode, which is CMB + instrument emissivity (a few %) + residual atmosphere.
- We have measured the common-mode rejection ratio of the FTS using custom temperature-controlled blackbody sources at the two entrance ports of the FTS.
- It turns out that the CMRR of our DFTS is <-55dB</li>
- This means that the offset is less than the SZ signal in OLIMPO, and will be much less than the SZ signal in a cryogenic/space implementation.









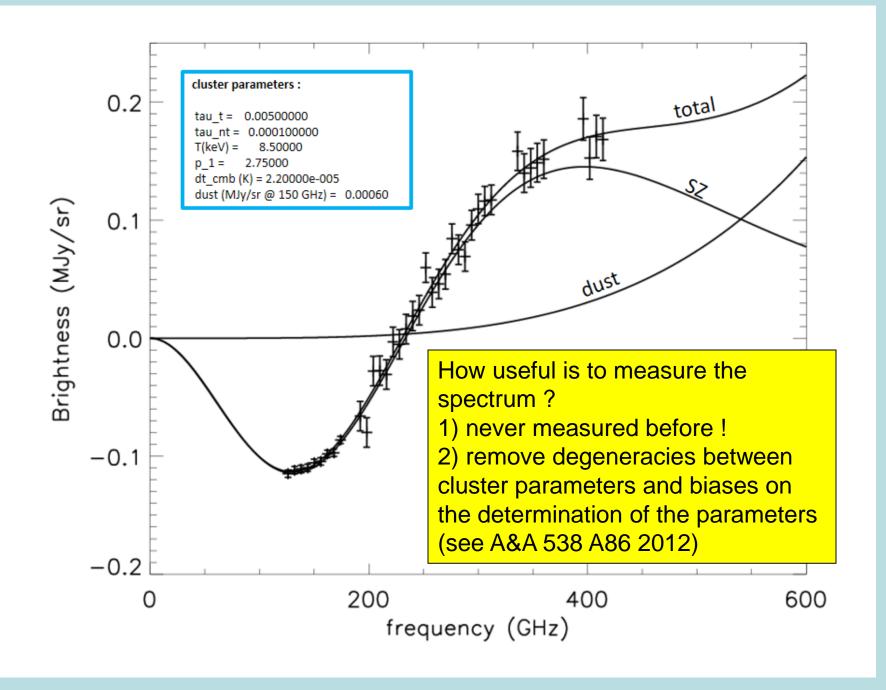


Telescope / primary mirror

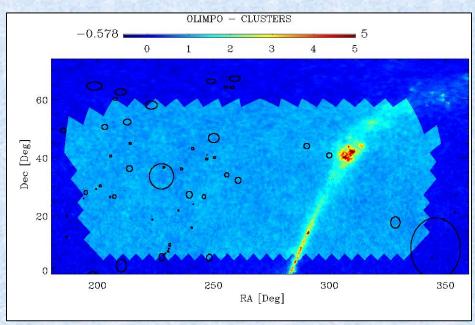
**DFTS** 

cryostat / detectors arrays

Main components of OLIMPO integrated on the payload



# **Observation Program**



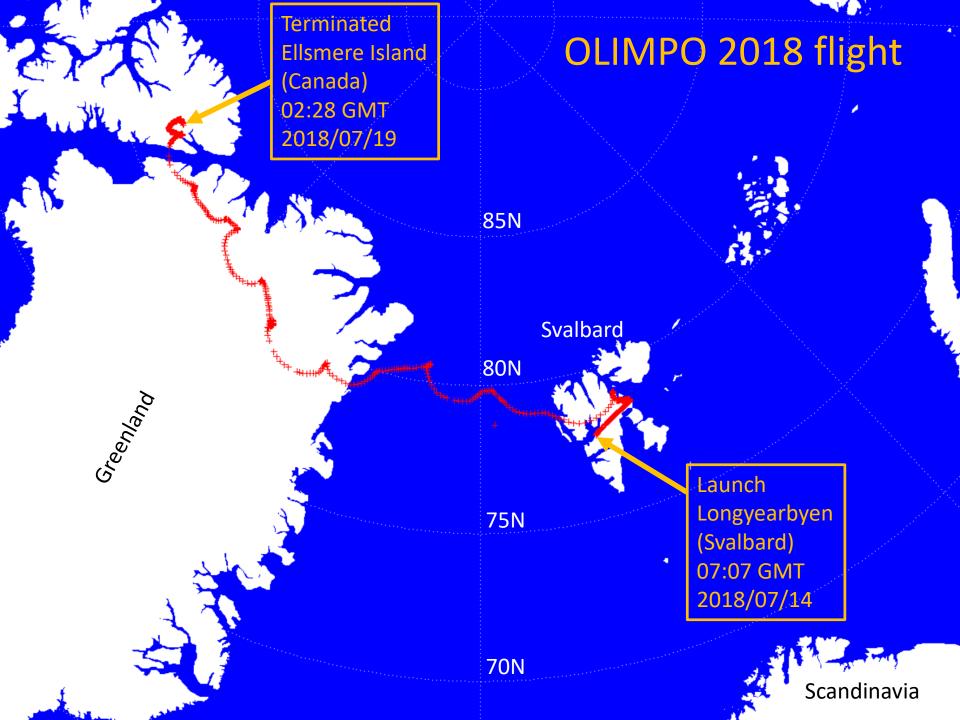
- In a circumpolar summer long duration flight (>200h) we plan to observe 40 selected clusters and to perform a blind deep integration on a clean sky region
- We have optimized the observation plan distributing the integration time among the different targets according to their brightness and diurnal elevation.

	ind	ID	RA	Dec	TIME	frac	NAME
ð	0	1	212.83	52.2	18000	1	3C295CLUSTER
ì	1	40	194.95	27.98	3600	0	ABELL1656
	2	43	203.13	50.51	3600	1	ABELL1758
	3	44	205.48	26.37	3600	1	ABELL1775
	4	45	207.25	26.59	3600	1	ABELL1795
	5	48	216.72	16.68	18000	1	ABELL1913
8	6	49	223.18	16.75	11360.88	1.27	ABELL1983
2	7	50	223.63	18.63	18000	1	ABELL1991
3	8	51	223.21	58.05	5640.53	1.28	ABELL1995
	9	53	227.56	33.53	18000	1	ABELL2034
	10	54	229.19	7	3600	1	ABELL2052
3	11	55	230.76	8.64	3600	1	ABELL2063
8	12	56	234.95	21.77	3600	1	ABELL2107
H	13	57	236.25	36.06	18000	1	ABELL2124
	14	58	239.57	27.23	3600	1	ABELL2142
	15	59	240.57	15.9	3600	1	ABELL2147
H	16	61	247.04	40.91	18000	1	ABELL2197
	17	62	247.15	39.52	3600	1	ABELL2199
9	18	63	248.19	5.58	3600	1	ABELL2204
	19	65	250.09	46.69	3600	1	ABELL2219
	20	66	255.68	34.05	7230	1.49	ABELL2244
۲	21	69	260.62	32.15	18000	1	ABELL2261
	22	70	290.19	43.96	3600	1	ABELL2319
à	23	71	328.39	17.67	3600	1	ABELL2390
9	24	98	241.24	23.92	13045.75	1.1	AWM4
ď	25	100	299.87	40.73	18000	1	CYGNUSA
r	26	101	201.2	30.19	18000	1	GHO1322+3027
	27	102	241.11	43.08	18000	1	GHO1602+4312
	28	107	230.46	7.71	3600	1	MKW03S
Ô	29	120	228.61	36.61	18000	1	MS1512.4+3647
	30	121	245.9	26.56	13147.05	1.1	MS1621.5+2640
1	31	128	201.15	13.93	18000	0	NGC5129GROUP
	32	134	199.34	29.19	18000	1	RDCSJ1317+2911
	33	143	231.17	9.96	18000	1	RXJ1524.6+0957
	34	150	211.73	28.57	18000	1	WARPJ1406.9+2834
Š	35	151	213.8	36.2	18000	1	WARPJ1415.1+3612
	36	161	194.02	25.95	18000	0	[VMF98]128
	37	162	203.74	37.84	18000	1	[VMF98]139
	38	163	205.71	40.47	18000	1	[VMF98]148
	39	164	214.12	44.78	18000	1	[VMF98]158
	40	165	250.47	40.03	18000	1	[VMF98]184



- OLIMPO launched ! 07:09 GMT, 14/Jul/2018, Longyearbyen (Svalbard)
- 5 days flight
- Great performance of Kinetic Inductance Detector Arrays, Telescope and Spectrometer.
- First Validation of KIDs in space conditions



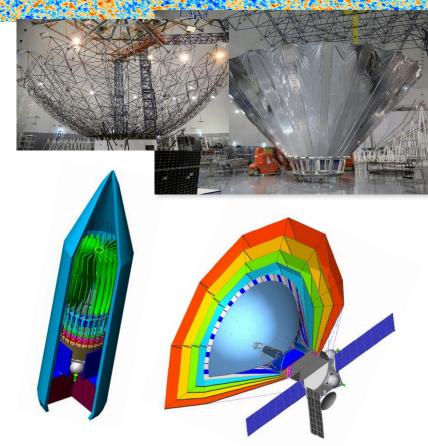


 The OLIMPO spectrometer is the prototype for a similar Differential Fourier Transform Spectrometer to be flown on the Millimetron space mission ....

 So, once again, stratospheric balloons are effectively used as pathfinders for satellite experiments.

### OLIMPO as a precursor of forthcoming space-missions

- OLIMPO is a demonstrator of new detectors, to be used in forthcoming missions (PRISM etc.)
- Will demonstrate the power of polar ballooning in the northern hemisphere for CMB missions
- The DFTS Methodology has been used in space (COBE-FIRAS, missions for remote sensing), and will be used again (PIXIE, PRISM, Millimetron)
- >20% of fhe focal plane of
   Millimetron (a ROSCOSMOS mission)
   is available for a cryogenic version of
   the OLIMPO DFTS (ASI phase-A study).



• Antenna diameter: 10 m

Range of wavelengths: 0.01 – 20 mm

• Bolometric sensitivity (λ0.3mm, 1h integration): 5x10<sup>-9</sup> Jy

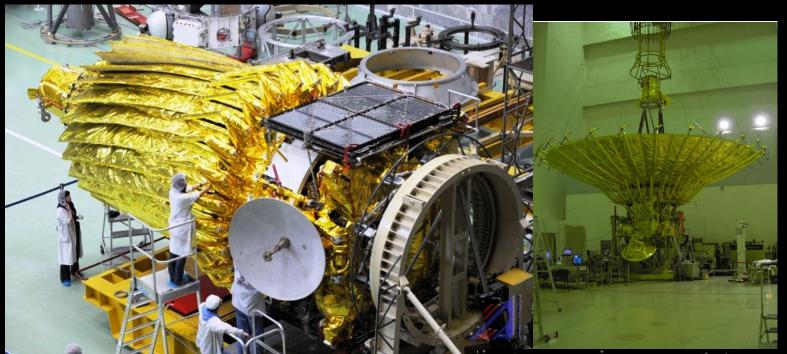
• Interferometry sensitivity ( $\lambda 0.5$ mm, 300s integration, 16

GHz bw) : 10<sup>-4</sup> Jy

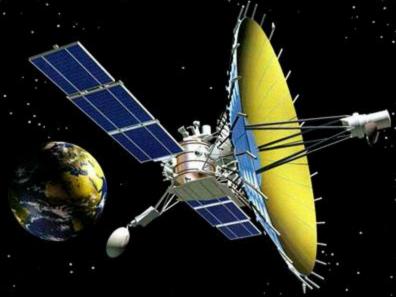
• Interferometer beam: 10-9 arcsec





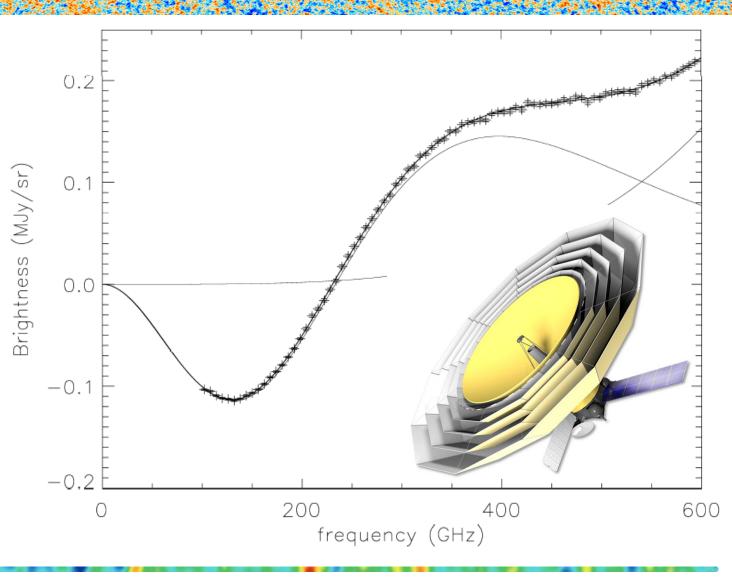


РадиоАстрон



## **Millimetron DFTS**

3 hours of observations of a rich cluster with a DFTS on **Millimetron**, using a photon-noise limited detector in the cold environment of L2, with a 10m telescope cooled to <10K. (see A&A 538 A86 2012)

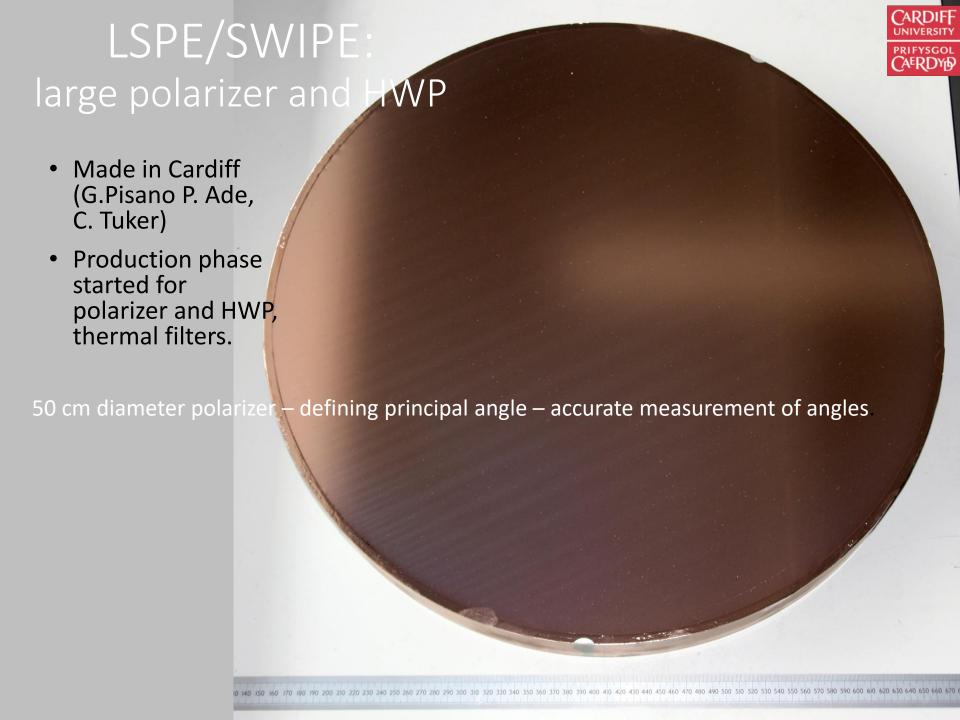






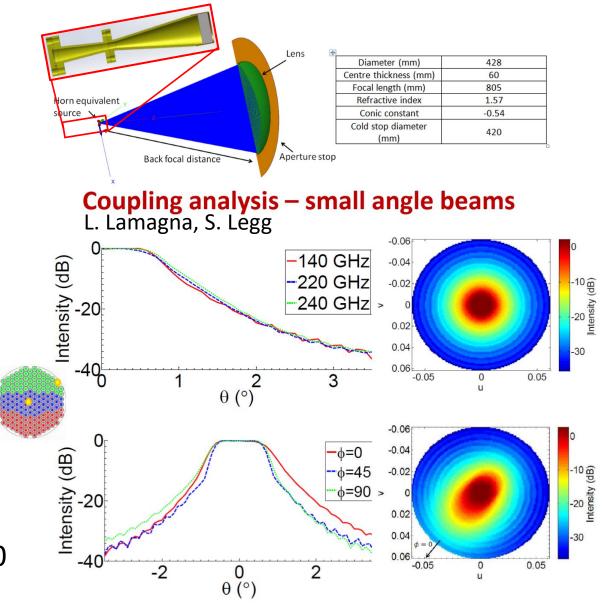
## Conclusions

- Balloons offer a great deal of opportunities for CMB research.
- They will add reliability to ground based Bmodes measurements (waiting for a final space mission, for which they should be used to qualify instruments / detectors / methods)
- Original/new satellite-based science can and should be first implemented using balloonborne experiments.



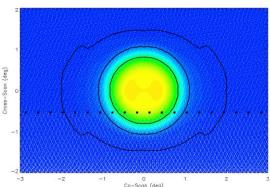
## LSPE/SWIPE: multimode optical system

 Whole system multi.mode EM simulation described in: Legg, Lamagna, Coppi, de Bernardis, Giuliani, Gualtieri, Marchetti, Masi, Pisano, Maffei, Development of the multi-mode horn-lens configuration for the LSPE-SWIPE B-mode experiment Proc. SPIE 9914, Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy VIII, 991414 doi:10.1117/12.2232400



# **Observations and Calibration Plan**

- Scanning strategy: payload spin in azimuth, at 3 rpm (18°/s)
- Coverage of the same sky area by the two instruments
- Elevation changes once a day, at the same time for both instruments
- Specific calibration observations of
  - Jupiter (to map the main beam, see figure below, samples = white dots)



- the Crab nebula and the Moon Limb (to calibrate the main axis of the polarimeters)
- the Moon can be used to map sidelobes

LSPE coverage for different sets of elevation changes. The first column reports the boresight elevation range in degrees for the two instruments. Second column, the full coverage. Third column, the coverage after masking the galaxy with the WMAP polarization mask.

Elevation	Coverage	Unmasked
SWIPE [30-40]	31%	23%
SWIPE [40-50]	27%	20%
SWIPE 35	24%	19%
SWIPE 45	22%	18%
SWIPE [30-50]	35%	26%
STRIP 45	27%	20%
STRIP 30	33%	24%

#### **STRIP**

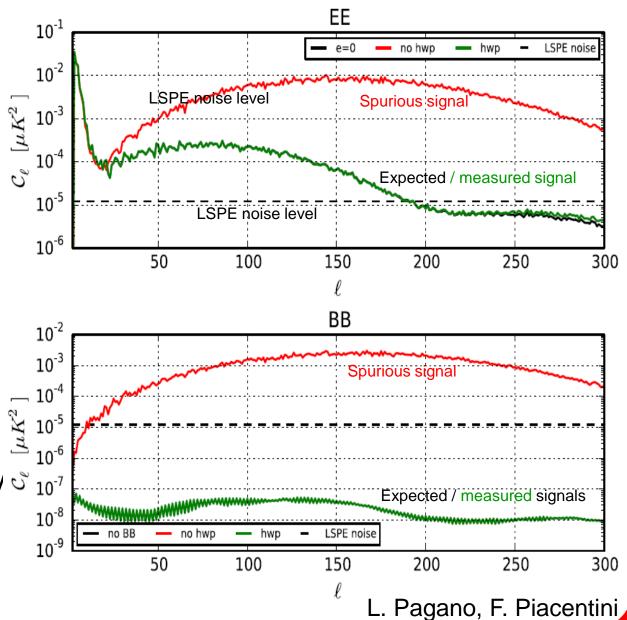
#### **SWIPE**

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

Sources culmination angle, and expected S/N per sample. Sampling rate is set at 60 Hz. We assume full Moon, as it is when it is observable by LSPE. The Crab flux is based on the free-free spectrum reported in Macías-Pérez, et al. Ap. J., 711, 417 (2010)

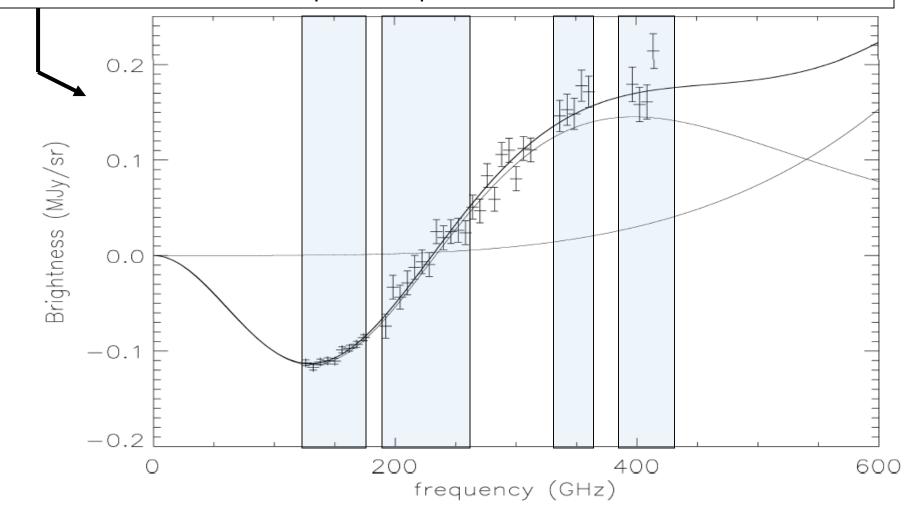
## **Performance Forecast**

- The presence of the HWP allows to fully exploit the sensitivity of LSPE-SWIPE.
- Realistic simulations to assess systematic effects (mainly beam asymmetries) which become irrelevant if the HWP is used.
- The final sensitivity ♂ target for r is <</li>
   0.01



In a FTS the spectral resolution can be changed (changing the path of the moving mirror). Mind the noise, however: it is proportional to the inverse of the spectral binwidth. In the case of OLIMPO, with a spectrometer at 250K, photon noise is important.

1.8 GHz resolution: About 110 independent spectral bins, within optimized bands. 6 GHz resolution: About 34 independent spectral bins, within the same bands.



### Expected performance for OLIMPO (photon noise limited)

### OLIMPO performance: spectrometer configurations, single detector of each array

Band (GHz)	125-175	190-315	200-225	330-365	450-500
		(wide)	(narrow)		
FWHM (arcmin)	5	3.5	3.5	2	2
Throughput (m <sup>2</sup> sr)	6.3x10 <sup>-6</sup>	3.1x10 <sup>-6</sup>	3.1x10 <sup>-6</sup>	1.0x10 <sup>-6</sup>	1.0x10 <sup>-6</sup>
Background (pW)	36	122	17	20	54
Optical NEP (aW/sqrt(Hz))	200	400	140	170	290
Number of 6 GHz bins in band	9	21	4	5	8
Error per 6 GHz bin	3	12	5	16	28
(1 sigma, 3 hours) in kJy/sr					

### OLIMPO performance: photometer configurations, single detector of each array

Band (GHz)	125-175	190-315	200-225	330-365	450-500
		(wide)	(narrow)		
FWHM (arcmin)	5	3.5	3.5	2	2
Throughput (m <sup>2</sup> sr)	6.3x10 <sup>-6</sup>	3.1x10 <sup>-6</sup>	3.1x10 <sup>-6</sup>	1.0x10 <sup>-6</sup>	1.0x10 <sup>-6</sup>
Background (pW)	11	35	5	6	15
Optical NEP (aW/sqrt(Hz))	100	200	70	85	150
NET <sub>CMB</sub> (μK/sqrt(Hz))	80	115	200	780	2500

