“Il mio voler cercare oltre la meta”
(“Looking beyond my goals”)

Memories of
25 years of work with Francesco

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• Francesco Melchiorri has been my mentor and I have worked with him for almost 25 years.
• It is not easy to summarize 25 years of intense activity in 20 minutes
• And even more difficult will be to give a feeling of His enthusiasm, competence, generosity … but I’ll try.
• The simplest approach for me is just to go year by year, project by project …
I met Francesco for the first time in 1979: he taught the class of Observational Astrophysics in Firenze while working at the IROE-CNR.

Francesco’s group (himself, Bianca, Enzo Natale, Roberto Fabbri) was preparing a balloon-borne experiment to measure the anisotropy of the CMB at intermediate angular scales (5°).

At that time the CMB was still an unexplored continent, offering the charm of the unknown only to a handful of brave explorers worldwide.

The spectrum of the CMB had been measured in the Raileigh-Jeans region with radiometers, and only a few years before Francesco’s group using a ground-based photometer at the Testa Grigia had shown that the spectrum was bending at high frequencies. G. Dall'Oglio, B. Olivo Melchiorri, F. Melchiorri, V. Natale, P. Lombardini, "Measurements of the Cosmic Background Radiation through the 1.0-1-4mm Atmospheric Window", Phys. Rev. D., 13, 1187 (1976)

Questions like: “The CMB: grey-body or black-body?” were quite common. The very nature of the CMB was still not well understood.

The Testa Grigia experiment to measure the temperature of the CMB in the 1.0-1.4 mm window. (1976)
The spectrum of the CMB

Woody & Richards 1981

COBE-FIRAS Mather et al. 1992
• In 1978, the CMB dipole, measured by balloon-borne and airborne radiometers, was the only known anisotropy.

• Upper limits for the anisotropy at different angular scales were already around $10^{-3} - 10^{-4}$


• had just performed a balloon-borne survey to measure the large-scale anisotropy (Dipole, Quadrupole, upper limits at 5 deg)

• And had already attempted (in 1974 !) to measure the polarization of the CMB using a balloon-borne polarimeter Caderni, Fabbri, B. Melchiorri, F. Melchiorri, V. Natale Phys. Rev. D 17, 1908, 1978.

Fig. 48. – Optical scheme of the millimetric polarimeter employed by Florence Group in searching for CBR polarization in 1974: a Cassegrain system (primary mirror (2) plus secondary mirror (3)) defined a field of view of about 0.5 degrees, while a TPX lens (4) defined a larger field of view of 5 degrees. A rotating polarizer (21) modulates the polarized component only at about 10 Hz, while a polarized source (20) may be inserted in the field via telecommand. (Adapted from [168].)
• CMB polarization is now (32 years later !) a very hot topic of our field. As usual in our field, our understanding of the subject proceeded in a non-linear way:


• However, a paper by Brans claimed that the polarization states were scrambled during the propagation of CMB photons Brans C.H., Ap.J. 147, 76 (1967)

• As a consequence CMB polarization remained for many years uninteresting.

• The Florence group of Francesco demonstrated that this was not correct in 1978 Caderni, Fabbri, B. Melchiorri, F. Melchiorri, Natale Phys. Rev. D 17, 1901, 1978.

• A paper describing a CMB polarization measurement by Nanos, which had been rejected based on Brans’ results, was accepted many years later Nanos Ap.J. 232, 241, (1979)

• And Francesco has been at the forefront of this research since 1974 !
• So, when I met Francesco for the first time, in 1979, many things were different.

• Our knowledge of the CMB and of cosmology was poor.
• Detectors were 3 orders of magnitude less sensitive than today (integration time 6 orders of magnitude longer ..)
• There was basically no digital electronics for automation of small astronomical / space instruments.

• But also the way to collaborate and to exchange results was different.
• Internet simply did not exist. e-mails neither.
• Paper preprints were circulated by surface/ship mail
• Delivery at the library of a new issue of Phys.Rev.D or Ap.J. was always an event, to study and to discuss.
• Myself and Silvia Masi were 3rd year students in the class of Electronics of prof. Ventura, in the same lab where Francesco’s group was preparing the new CMB anisotropy experiment.

• One day Francesco came in the room looking for some electronic components, and remained for a while to see what we were doing (it was an analog device to plot on paper transfer functions of electronic circuits…)

• After discussing on the stability of the instrument, he said “… by the way, we are going in Sicily to fly this instrument in two months, why don’t you come to see how it is…we need some help and, if you have never been in Sicily, it’s worth to visit !”

• We agreed enthusiastically, and our destiny was set.
• In July 1980 we arrived at the Milo base, near Trapani.
• It was an old, abandoned aviation field, where scientists and technicians of the “space service” of the CNR basically camped in the ruins of the military buildings.
• In the month we passed there Francesco taught us a lot about balloon flights, isotropometers, and detection techniques.
• The instrument was way simpler than the instruments we fly today, but still quite remarkable: it featured two independent channels (low frequency and high frequency) with He cooled bolometric detectors (1.6K), and was beam switching with an angular separation of 5 degrees.
• It simply scanned the sky at constant elevation, following the random rotation of the balloon, measured by a magnetometer.
• Data were transmitted (analogically) to ground, recorded on analog tapes, and printed on strip-chart recorders.

• Data analysis was done first by hand (using a pocket computer) Only a few years later the data were digitized and processed by a mainframe computer.

• We published the results of that flight (Ulisse) almost 12 years later …
• In 1981 Francesco got a position as Full Professor here in La Sapienza, so he moved from Firenze to Rome
• Myself and Silvia were really fascinated by this research and Francesco was able to convince us to move to Rome as well, to work at our Laurea Thesis in his group.
• He offered to host us in his home for the Laurea period – and that was really needed!
• He proposed to me a thesis on the “noise” of the CMB, and to Silvia a thesis on CMB polarization.
• Both to be measured with balloon experiments!
• These topics were extremely original for the time.
• Working day and night with Francesco, Bianca, Gianni Moreno, Giorgio Dall’Oglio, Luca Pietranera, Cecilia Ceccarelli and Armando Iacoangeli has been intense, and extremely instructive.
The “noise” of the CMB

• The idea was to measure quantum fluctuations of the microwave photons of the CMB to settle with an independent experiment the issue about its temperature and emissivity.

• Combining a measurement of the brightness with a broad-band measurement of the noise, it is possible to break the degeneracy between the two parameters, basically because the different frequencies add linearly to produce the total brightness, but add quadratically to produce the total noise.

• The noise of the detectors was still higher than the quantum fluctuations of the CMB.

• So Francesco decided to build a correlator.

• A cryogenic one! It was built in one year.
In this device the wave-interference noise of the radiation, correlated between the two detectors, produces a positive correlation, while the noise of the two detectors, uncorrelated, averages to zero correlation.
Details of the noise experiment flown from Trapani in 1982
Fig. 47. – Results of the noise experiment: the correlated output of the two bolometers is plotted vs. the square of the secant of elevation. This allows to estimate the residual atmospheric noise, while the extrapolation to zero provides the value of the CBR wave noise.

Polarization of the CMB

• The data of the 1974 flight were still very interesting.
• To give an idea of the framework, we did not have a “standard” theory of the anisotropy of the CMB.
• The basic approach was in terms of anisotropic universes (Bianchi models), producing large-scale anisotropy of the CMB.
• The polarization resulting from anisotropic scattering of CMB photons was only at large-scales, as well.
• So Francesco’s idea to extract polarization at small scales was original and new for the time. S. Masi “Search for the Cosmic Background Polarization”, Gamow Cosmology, Varenna school LXXXVI Corso, pg. 310-316, Soc. It. Fisica, Bologna, 1982
• As original and new was the idea to use Faraday rotation of the CMB polarization to constrain Cosmic Magnetic Fields. C. Ceccarelli, G. Dall' Oglio, P. de Bernardis, S. Masi, B. Melchiorri, F. Melchiorri, G. Moreno, L. Pietranera “The Polarization of the Cosmic Background Radiation and the Universal magnetic field” in THE BIRTH OF THE UNIVERSE, ed Frontieres, pg 191, (1982)
New ideas: Gamow Cosmology (Varenna School, 1982, organized by Francesco Melchiorri and Remo Ruffini)
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circa 1984

• At that time we started to understand the mechanisms producing anisotropy in the CMB at intermediate and small scales, and their relationship with the formation of structures.

• The need for high resolution observations was becoming evident.

• As usual, Francesco had already worked on the subject, collaborating with Paul Boynton at the Battelle radio telescope to measure fine-scale anisotropy of the CMB.
circa 1984

• Our balloon experiments needed to improve the angular resolution!
• Francesco started a long term activity to arrive to a balloon-borne or space-borne telescopes devoted to the CMB:
  – Space: CIRBS -> AELITA->COBRAS/SAMBA ->PLANCK
  – Balloon: ULISSE -> ARGO -> BOOMERanG ->OLIMPO
ARGO

• So Francesco’s group started to develop a medium size telescope (1.2 m) with a wobbling secondary, able to measure sub-degree anisotropy of the CMB.
• The system was flown (without much luck) in 1988 from Aire-Sur L’ Adour (France) by CNES, and with better luck in 1989 and 1993 from Trapani (ASI).
• The collaboration with Franco Scaramuzzi’s group (ENEA) for the cryogenic system was fundamental.
• Marco De Petris, Massimo Gervasi, Roberto Maoli, Pasquale Palumbo, Luca Valenziano and several others did their Thesis with Francesco, working on ARGO…
• ARGO has been an adventure, as usual, including an aborted campaign in Australia in 1992..
Fig. 3. The ARGO payload. The subsystems are labelled as follows: P: primary mirror; S: wobbling secondary mirror; SC: telescope screen; C: calibrator; D: detector; CCD: CCD star sensor; SE: signal electronics; T: telemetry electronics; PE: pointing system electronics; PS: pointing system; B: batteries
The collaboration with IKI

• The plan to fly a space mission devoted to the CMB was through a strong collaboration with IKI (Sunyaev, Galeev, Strukov, Sholomiski, Maslov, Soglasnova…)

• The AELITA program started through a lot of difficulties, and was soon abandoned by Servizio Spaziale Nazionale (pre-ASI)

• The collaboration with Sholomiski went on, and myself, Silvia Masi and Maurizio Perciballi found ourselves in Pamir in 1990, a place where the last Italian before us had been Marco Polo…. 
BOOMERanG

- In 1988 we visited the Berkeley groups of Paul Richards and George Smoot for a CMB meeting.
- We presented ARGO and heard about the activities on MAX.
- We started regular contacts and in 1992 we decided to cooperate on a new project aimed to map the CMB with unprecedented sensitivity and resolution.
- The decision was taken during a dinner at Consolato d’ Abruzzo, in Rome. Francesco decided that I should have been the coordinator of the Italian part and Paul decided that Andrew Lange should coordinate the US efforts.
- The idea was to use a long duration circumantarctic flight to increase the integration time and the opportunities to carry-out deep tests for systematic effects.
- Soon after Silvia invented the acronym BOOMERanG.
- After some initial difficulties especially with obtaining support from NSF and from ASI, Andrew stated “…. A new experiment like this is like falling in love… there is no way you can stop us…”
• Francesco has been a great supporter of BOOMERanG.

• He identified the problem of cosmic rays hits in polar regions, and proposed a “swiss cheese” bolometer absorber to reduce the cross-section.

• Andrew, Phil Mauskopf and the Berkeley group developed the so-called cat-whisker bolometer and finally the very successful spider-web bolometer.

• This has been the key technology for BOOMERanG, and will be for Planck.
OLIMPO

• The idea of the large telescope for the CMB was submitted to the Italian Space Agency by Francesco in the 90s.
• After initial support, ASI stopped to fund OLIMPO.
• Francesco devoted his efforts to a similar telescope ground-based, in the Italian alps (the Testa Grigia telescope aka MITO).
• Only in 2001 Silvia Masi submitted to ASI a proposal for OLIMPO, which was funded. For 2 years. Then ASI went silent again…
• However, OLIMPO is now in the three-years plan 2006-2008 of ASI.
• And we have the hardware mostly in place …
OLIMPO (PI Silvia Masi, Roma)

- >400 TES bolometers from Cardiff (A. Orlando, P. Mauskopf)

150 GHz 220 GHz 340 GHz 540 GHz

- 2.0 mm
- 1.4 mm
- 0.85 mm
- 0.5 mm

30’
Flights: 2007 & 2008