Instrumentation development for spectroscopic observations of the Cosmic Microwave Background

Giuseppe D’Alessandro
Rencontres de Moriond

20 March 2016

All activities shown on this talk are supported by the OLIMPO collaboration
Thermal Sunyaev Zel’dovich

The effect occurs when the photons of the cosmic microwave background radiation crosses a cluster of galaxies.

In the process, the CMB spectrum is distorted, in a way depending on the physical conditions of the hot intra-cluster gas.

The photons of the CMB carry primordial information, but also information on clusters of galaxies!
Thermal Sunyaev Zel’dovich

The effect occurs when the photons of the cosmic microwave background radiation crosses a cluster of galaxies.

In the process, the CMB spectrum is distorted, in a way depending on the physical conditions of the hot intra-cluster gas.

The photons of the CMB carry primordial information, but also information on clusters of galaxies!
OLIMPO experiment

The OLIMPO experiment consists of a mm-wave telescope, with 2.6m diameter aperture, designed to operate aboard of a stratospheric balloon. The first target for OLIMPO is the CMB, in particular its anisotropy, and in particular the S-Z effect.

The experiment is equipped with 4 arrays of detectors optimized to measure S-Z signals.
The plugin improvements


The DFTS plug-in permits to switch from photometry mode to spectroscopy mode by moving a folding mirror.

Within the OLIMPO bands the mean resolution is 1,8GHz. This means we can have up to 70 independent data points.

- Scientific goal
- Olimpo experiment
- A DFTS plug-in
- Optic assembly
- Flight electronic
- First test and measure
- Common mode rejection
- Conclusion
The plugin improvements

Photometer in L2 with 6 bands
Parameters: optical depth, plasma temperature, peculiar velocity, non-thermal components, dust

Scientific goal
Olimpo experiment
A DFTS plug-in
Optic assembly
Flight electronic
First test and measure
Common mode rejection
Conclusion
The plugin improvements

Spectrometer in L2 at 5GHz

Parameters: optical depth, plasma temperature, peculiar velocity, non-thermal components, dust

• Scientific goal
• Olimpo experiment
• A DFTS plug-in
• Optic assembly
• Flight electronic
• First test and measure
• Common mode rejection
• Conclusion
The design of a Fourier transform spectrometer for the OLIMPO experiment started on 2012 thanks to Dr. Alessandro Schillaci. The main purpose was to transform the experiment from a standard 4-band photometer into something no one had ever done: a differential spectrometer on a stratospheric balloon.

$$I_L = \frac{1}{2}(I_a + I_b) + \frac{1}{2}(I_a - I_b) \cos(\delta)$$
In 2013 the optical design finished and the mechanical project started. The mechanical project ended in end of 2013.

The main purpose was to transform the experiment from a standard 4-band photometer into something no one had ever done: a differential spectrometer on a stratospheric balloon.

\[ I_L = \frac{1}{2}(I_a + I_b) + \frac{1}{2}(I_a - I_b) \cos(\delta) \]
In January 2014 all parts of the Spectrometer were finished and tested; and the DFTS was ready for first laboratory tests. The main purpose was to transform the experiment from a standard 4-band photometer into something no one had ever done: a differential spectrometer on a stratospheric balloon.

\[ I_L = \frac{1}{2}(I_a + I_b) + \frac{1}{2}(I_a - I_b) \cos(\delta) \]
Flight electronic

A control electronics is needed to drive and coordinate all the movements to activate the instrument, calibrate and tune it, and perform measurements with the optimal instrument parameters (scan speed, scan amplitude, scan extension etc.). This complex electronic system has to be commanded remotely during the flight using simple serial commands.
Flight electronic

A control electronics is needed to drive and coordinate all the movements to activate the instrument, calibrate and tune it, and perform measurements with the optimal instrument parameters (scan speed, scan amplitude, scan extension etc.). This complex electronic system has to be commanded remotely during the flight using simple serial commands.
Flight electronic

A control electronics is needed to drive and coordinate all the movements to activate the instrument, calibrate and tune it, and perform measurements with the optimal instrument parameters (scan speed, scan amplitude, scan extension etc.). This complex electronic system has to be commanded remotely during the flight using simple serial commands.

- Scientific goal
- Olimpo experiment
- A DFTS plug-in
- Optic assembly
- Flight electronic
- First test and measure
- Common mode rejection
- Conclusion
Flight electronic

- 3 DC-DC converter
- Frontal connectors
- Delay line motors driver
- H bridge for actuator
- Electronic boards

• Scientific goal
• Olimpo experiment
• A DFTS plug-in
• Optic assembly
• Flight electronic
• First test and measure
• Common mode rejection
• Conclusion
Gunn 150GHz

This source was used because it has two major advantages: it is very powerful and it emits virtually a single frequency. So it is a good source to make measurements of resolution of the spectrometer.

At the longest possible optical path difference introduced by our DFTS (8 cm), the width of the 140 GHz line is 1.87 GHz.

\[ \Delta \sigma \sim \frac{1}{2OPD_{max}} \]
Hg Lamp: input comparison

In order to test the performance at higher frequency, we coupled the DFTS to a thermal source, an Hg lamp (Philips 125W) producing a 5000K grey body.

In the continuous interferogram, the Hg lamp is placed in the center of port A, while the center of port B is filled with the room-temperature blackbody. In the dashed interferogram the positions of the two sources are switched.
Interferograms measured with an Hg discharge lamp, band-pass filtered at 600 GHz, for operation of the left FTS alone, of the right FTS alone, and of the complete DFTS. The two FTSs contribute almost equally to the total signal, and the DFTS is still modulating efficiently at this high frequency.
During the measurements, the spectrometer does not observes just the CMB (black). As a first approximation for the astrophysical foregrounds, one has to consider also the brightness of interstellar dust (green). The largest emission is due to the instrument itself (blu). The sum (red) of all foregrounds is much larger then the SZ signal (violet).
We built Black Body calibrators, optimizing the geometry and the quality of the internal absorbing material. The optimized PID algorithm which control the temperature of sources permits to regulate the temperature with a standard error of 3mK on one hour of measurement.
Measurements were taken for different temperature differences, between -30K and +30K. The measurements were carried out during the calibration campaign in preparation of the launch of OLIMPO, and then served as a test and simulation of the real measurement in flight. For this reason they were used only and exclusively in flight configuration.
Measurements were taken for different temperature differences, between -30K and +30K. The measurements were carried out during the calibration campaign in preparation of the launch of OLIMPO, and then served as a test and simulation of the real measurement in flight. For this reason they were used only and exclusively in flight configuration.

-30σ error bars
Measurements were taken for different temperature differences, between -30K and +30K. The measurements were carried out during the calibration campaign in preparation of the launch of OLIMPO, and then served as a test and simulation of the real measurement in flight. For this reason they were used only and exclusively in flight configuration.

\[ \Delta T = 7 \pm 1 \, mK \]
These measurements have led to significant improvement and it is shown that in the OLIMPO flight it will be possible to detect the SZ spectrum with a common mode contamination smaller than the signal to be measured.

The temperature offset is: 7 +/- 1 mK. That gives an lower limit for CMRR of: 303030
Conclusion

The spectral study of CMB distortions, is a still relatively unexplored, and should be carried out using efficient spectrometers; A differential spectrometer like the one studied in these works has many benefits:

• it can measures directly difference the brightness of two separate fields of view, with high rejection of the common mode

• it can separate better the CMB from foreground emissions than a simple photometer;

• the systematics are easily under control and measurable before on laboratory and during instrument

During last years work the spectrometer for OLIMPO experiment was fully assembled and tested and a repeatable method was developed in order to maximize the efficiency, arriving very close to 100% [A&A 565, A125 Schillaci et al. (2014)]; and other spectrometers were designed for several experiments: MILLIMETRON, SRT and PRISM [JCAP 006, Prism collaboration, (2014)]
Conclusion

- Scientific goal
- Olimpo experiment
- A DFTS plug-in
- Optic assembly
- Flight electronic
- First test and measure
- Common mode rejection
- Conclusion

References:
Backup slide
These measurements have led to significant improvement and it is shown that in the OLIMPO flight it will be possible to detect the SZ spectrum with a common mode contamination smaller than the signal to be measured.

Simulated measurement of the SZ spectrum obtained from the OLIMPO DFTS. In black the common mode residual, the SZ signal in blue, and in red the sum of them.
**Set-up #2: Results**

These measurements have led to significant improvement and it is shown that in the OLIMPO flight it will be possible to detect the SZ spectrum with a common mode contamination smaller than the signal to be measured.

---

**Simulated measurement of the SZ spectrum obtained from the MILLIMETRON, PRISM DFTS. In black the common mode residual, the SZ signal in blue, and in red the sum of them.**
We have measured, using a custom setup, the emissivity of metallic wire-grids, suitable for polarimeters and interferometers at mm and far infrared wavelengths. We find that the effective emissivity of these devices is of the order of a few %, depending on fabrication technology and aging.
The DFTS of OLIMPO is built like a plugin, and for many reasons we cannot cool it. For this reason the detectors, in FTS mode, will receive an additional background signal from the mirrors and the other optical elements, which will emit like a grey body with fluctuation given by: