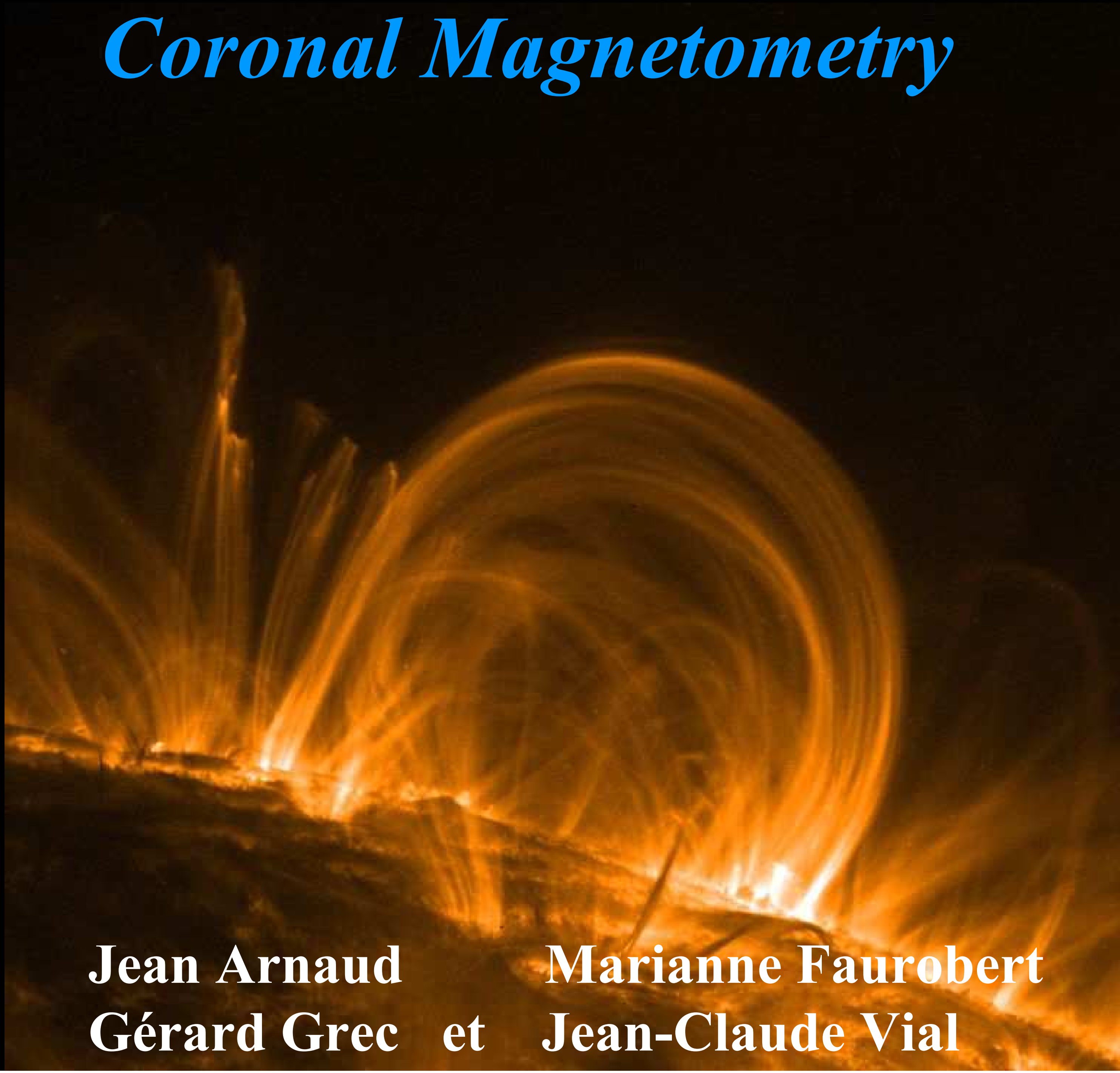
Coronal Magnetometry



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INTRODUCTION

The solar corona is a high temperature and low β plasma where the magnetic field controls or influences everything from loops heating to flares to coronal mass ejections.

It is an important component of the solar-terrestrial system, permanently observed from space missions like Yohkoh, SoHO, TRACE and, soon, STEREO and Solar B.

However no existing or planned space mission is designed to measure coronal magnetic field.

We present hereafter what is the most direct method to measure this field and explain why Antactica may be a unique place for such measurements. We conclude in bringing up our strategy towards coronal magnetometry at Dôme C.

The scientific case

The solar corona sets the inner boundary conditions which determine the state of the solar wind and magnetic fields in interplanetary space.

Measurements of the magnetic field in the low corona can yield information critical to our understanding of the structure and dynamics of the corona including important contributors to space weather (flares, CMEs, solar wind acceleration,…).

Zeeman effect observations in coronal emission lines is the only method to directly access the magnetic field magnitude in a large part of the low corona (from $1.01R_{sol}$ to $2R_{sol}$).

Some questions coronal magnetometry will adress

- Coronal loops magnetic structure: are loops flux tubes ? How much twist in the field ? Energy storage?

- Prominence cavities magnetic structure

- Dynamics of coronal magnetic field during:

Prominences eruptions, flaring active regions, CMEs

- How does the magnetic field expend from the photosphere into the corona?

- Extrapolations: need to be compared with magnetic field observations

- Intensity and magnetic field oscillations: MHD modes, energy transfert…

- Large scale magnetic fields: magnetic coupling between the corona and the solar dynamo

Very low corona observations will strongly benefit to underlined topics

Spectral lines sensitivity to the Zeeman effect

Parameter : $\gamma_Z = \Delta\lambda_B / \Delta\lambda_D$

Zeeman splitting

Doppler width

$\Delta\lambda_B / \lambda = g_{eff}\, \nu_L / \nu$ so $\Delta\lambda_B = (g_{eff}\, \nu_L / c)\lambda^2$ Vary as $g_{eff}\, B\, \lambda^2$

$\Delta\lambda_D = \lambda\, v_{th}/c$ vary as $\lambda T^{1/2}$

$$\gamma_Z = (g_{eff}\, \nu_L / v_{th})\, \lambda = \alpha\, g_{eff} B T^{-1/2} \lambda$$

In the solar corona

$$\gamma Z_{-} = (g_{eff}\, v_L / v_{th})\, \lambda = \alpha\, g_{eff} B T^{-1/2}\, \lambda$$

- High thermal velocities and weak magnetic fields (a few Gauss) → very low γZ

- Lines intensities are of the order of 10^{-5} the photospheric brigthness and Zeeman signals 3 orders of magnitude below that!

- Zeeman sensitivity increases propotionately to λ

So, the most promising lines for coronal magnetometry are IR ones:

The 1.0747 and 1.0798 μm Fe XIII lines complemented for cold material by the 1083.0 μm He I line.
Thermal IR: he 3.027 μm Mg VIII line and the 3.935 μm Si IX line

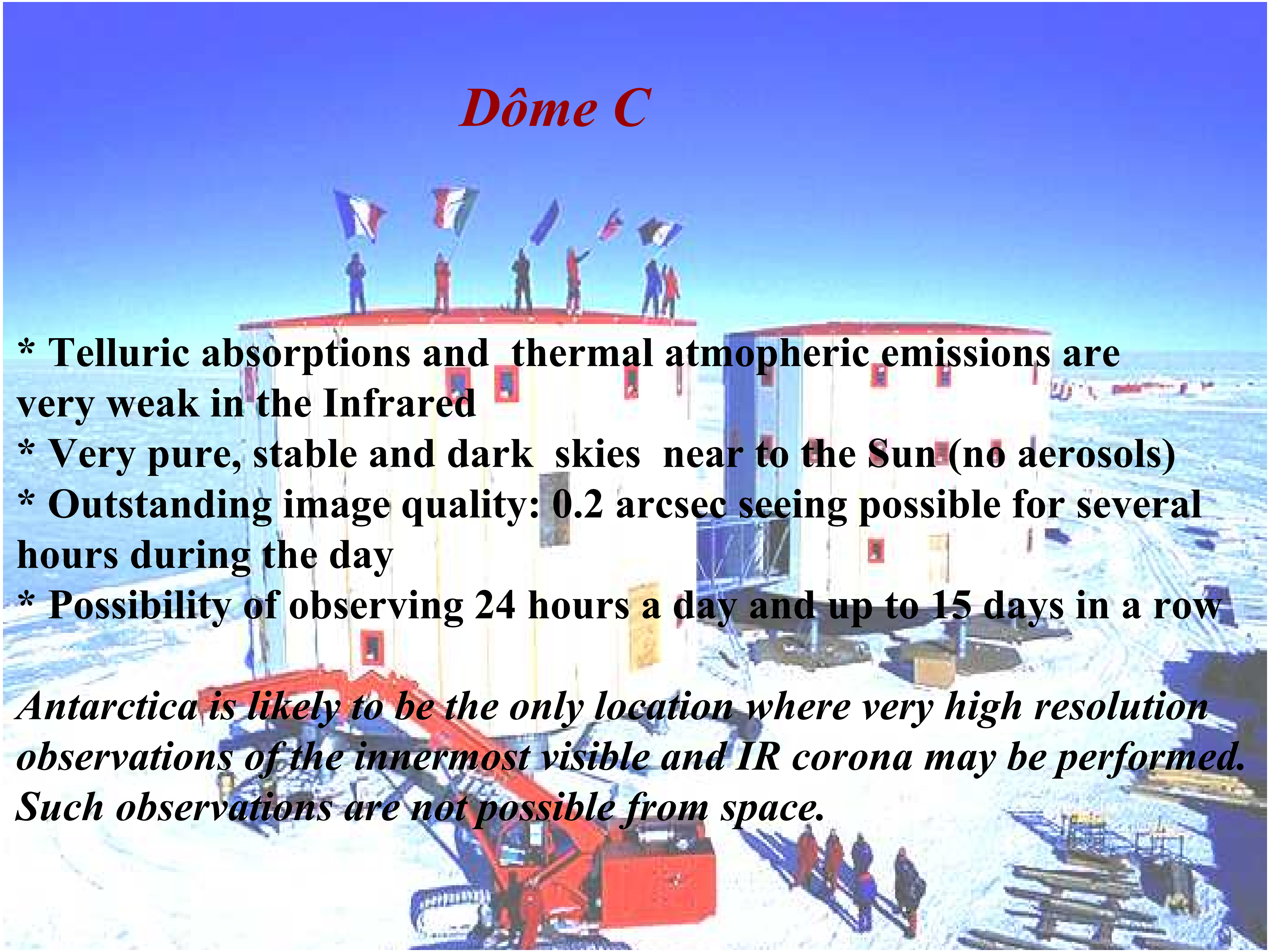
Coronal Magnetic field measurement

Stokes polarimetry of coronal emission lines:

-The observation of resonance scattering will constrain the plane-of-sky field direction

-Measurement of the longitudinal Zeeman effect provides information on the strength of the line-of-sight component of the magnetic field

- Spectropolarimetry also provides the intensity spectral profile which contains information on plasma turbulence and velocities



Dôme C

*** Telluric absorptions and thermal atmopheric emissions are very weak in the Infrared**
*** Very pure, stable and dark skies near to the Sun (no aerosols)**
*** Outstanding image quality: 0.2 arcsec seeing possible for several hours during the day**
*** Possibility of observing 24 hours a day and up to 15 days in a row**

Antarctica is likely to be the only location where very high resolution observations of the innermost visible and IR corona may be performed. Such observations are not possible from space.

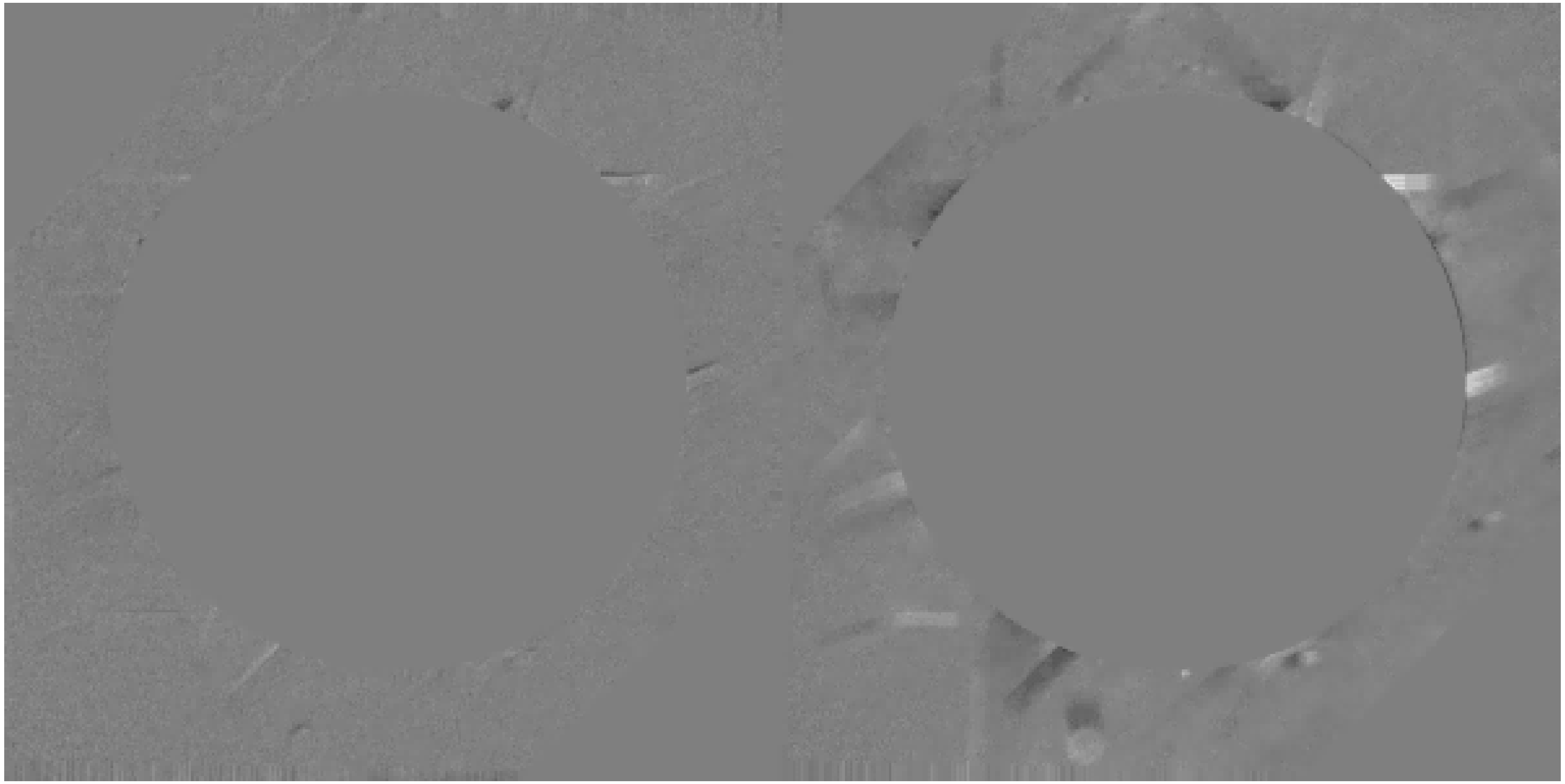
Sky Background

Visible and IR coronal emission lines observations are background limited: they are performed atop a continuum background generally dominated, for ground based instruments, by sky scattered photometric spectrum.

Sky intensity due to Rayleigh scattering (molecules) varies as λ^{-4} while Mie scattering (aerosols) is not strongly wavelength dependant.

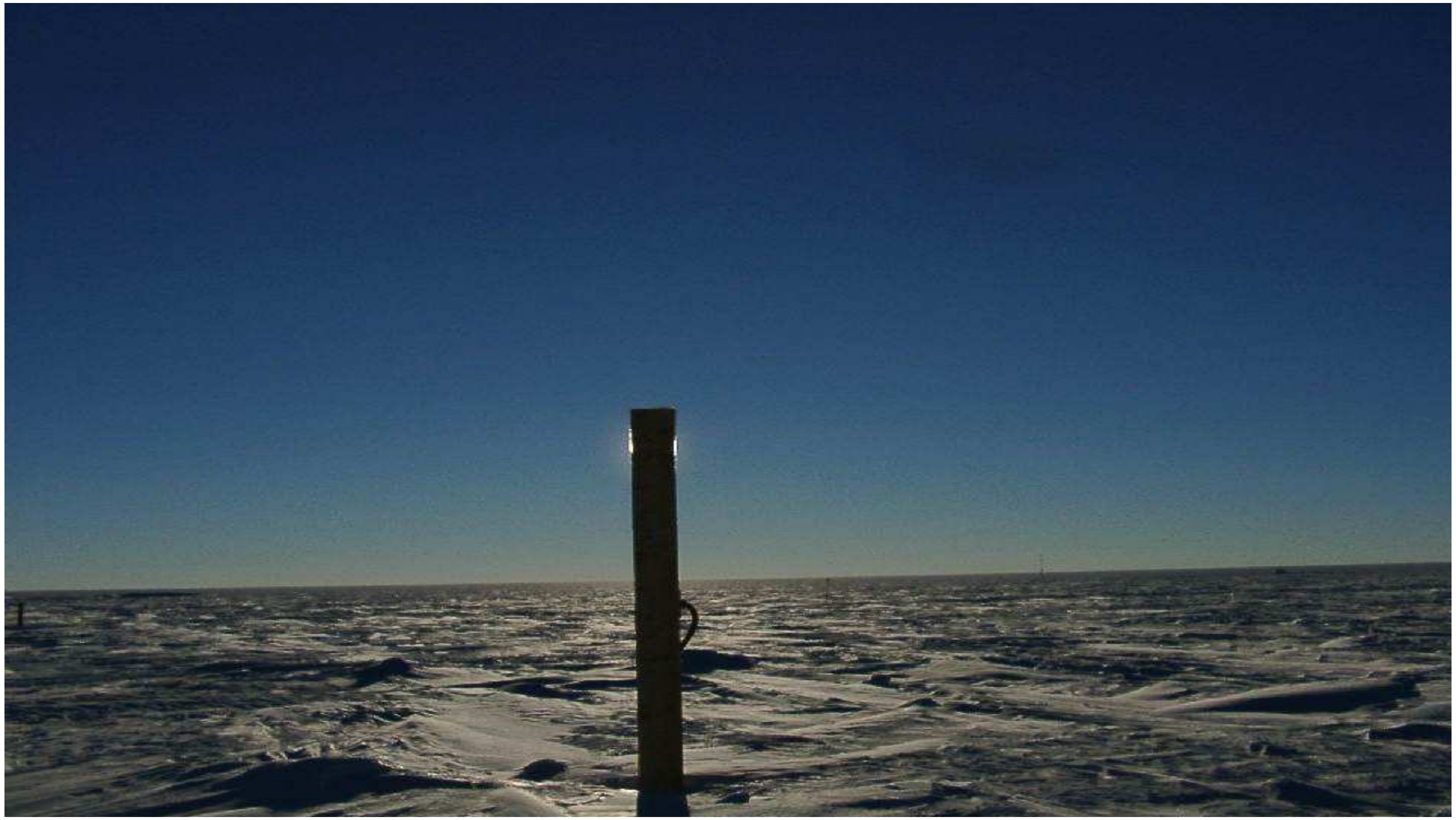
The level of aerosols (dust, bugs, …) beeing extremly low in Dôme C compared to existing coronal sites, one can expect exceptional low sky backgrounds in the infrared.

An exemple of aerosols scattering
Sac Peak coronal observations



Coronagraphic sky

Quantitative values are needed

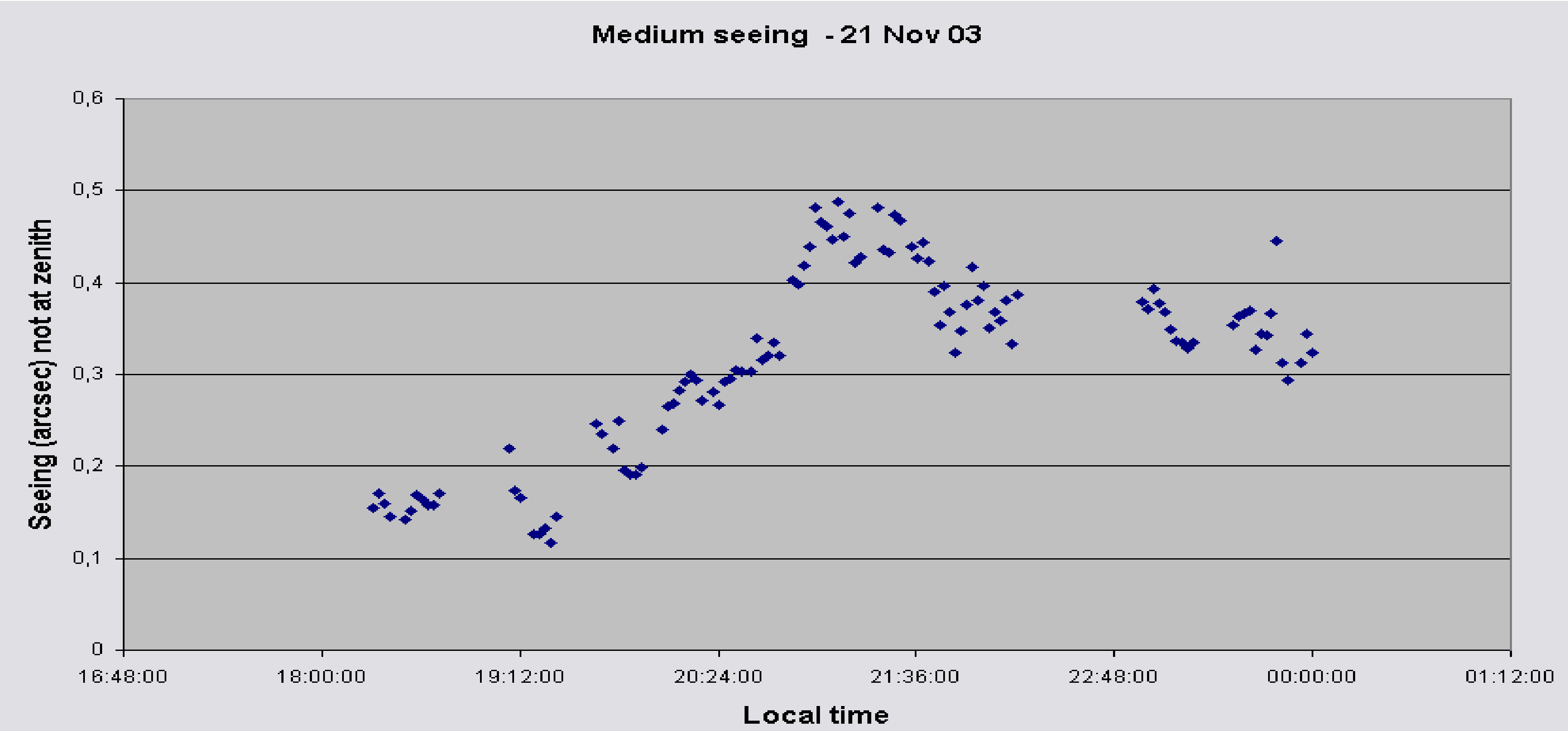


Blue sky very near to the Sun: atmospheric Rayleigh scattering . Such conditions have been observed for two weeks in a row, 24 hours a day.

Best seeing occuring at Dôme C

(Day time stellar DIMM observations)

E. Aristidi et al.



Strategy and schedule

I. **Specific site testing for coronal observations**

Observations with a 20 cm aperture coronagraph in the visible and possibly in the near IR.

Use of an NSO Sky Brightness Monitor, built for the ATST site survey and prepared for Dôme C conditions.

This first step is essential to get quantitative information on Dôme C qualities for those specific observations: statistics on sky brigthness and image quality down to very near to the solar limb , sky transparency…

II. If we get as good as expected results, it will then be possible to set up an international collaboration for **a large coronagraph (1 to 2 meters aperture).**

The 20cm Coronagraph
Observations

It will be used to perform coronal emission lines imaging to test Dôme C for coronametry and test:

image quality down to its diffraction limits in the green

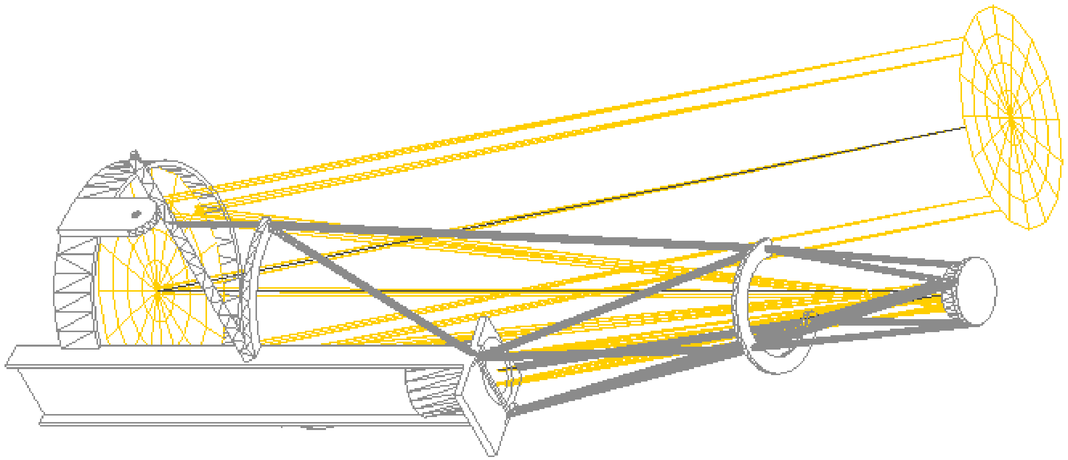
sky brigthness very near to the Sun.

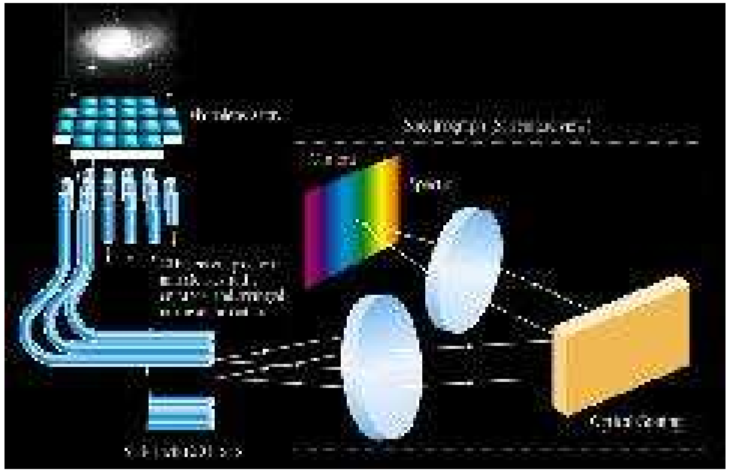
It will already allow much higher spatial resolution on visible and near IR coronal emission lines than other present time coronagraphs with subarcsecond images in the visible.

Observations continuous over up to 15 days will be possible.

Thanks to high spatial resolution and dark skies, Original scientific results on coronal structures (loops, streamers, ..) evolution, and oscillations are expected. In the near IR it will also be possible to study coronal cavities and prominences.

The large scale coronagraph





A two meters class telescope will allow a 1 Gauss sensitivity with a 1 arcsec resolution in 5 mn integration time. Better spatial resolution will be possible for high coronal magnetic fields in the very low corona above active regions.

Very high, 0.1" to 0.2" spatial resolution imaging in the near IR (corona and prominences)

Superpolished mirros with an apodized pupil (C. Aime).

Fibers feed field spectrograph (Argus mode) for field polarimetry

0.5 arcsec spatial resolution at 4 microns

Stellar IR spectro-polarimetry during winter time.

Other Instruments in the field

ATST: AURA/NSF general purpose 4 m solar telescope project to study magnetic fields and dynamics processes in the whole solar atmosphere in the 0.3 à 30 μm range. Coronal magnetometry is expected in the thermal IR.
Haleakala image quality: mean R_0 = 5 cm, at 28 m above ground,
early morning mean R_0 = 8 cm, at 28 m.

FASR: Will, using gyro-resonance emission, define surfaces of constant magnetic field in the very low corona, in the immediate vicinity of sunspots, for magnetic fields **above 200 G.** FASR will not measure the height of those fields in the solar atmosphere.

Solar C: performs 20 arcsec resolution near IR lines coronal polarimetry

Stereo: 3-D corona maps in the visible and in EUV, CMEs
Antacrtica: High spatial resolution imaging, coronal B

Scientists interested in the project

LUAN: E. Aristidi, E. Fossat, K. Agabi

LATT/OMP: F. Paletou

LESIA/Paris Observatory: J.M. Malherbe, B. Schmieder

HAO: S. Tomczyk

Napoli Observatory: G. Severino (High resolution solar disk imaging)

Turino Observatory: S. Fineschi

Université of Hawai: H. Lin

This project is part of a franco-italian PICS application

Conclusion

Our knowledge of the coronal magnetic field is still very poor.It is mandatory to considerably improve this situation for a comprehensive understanding of the coronal plasma.

Dome C is likely to be an outstanding site for high spatial resolution coronal magnetometry in the low and very low corona.

Dome C provides day time seeing much better than the best classical solar sites like Pic du Midi, La Palma or Haleakala. This is a fantastic opportunity for solar atmosphere high resolution observations (dynamics, magnetic field, …).