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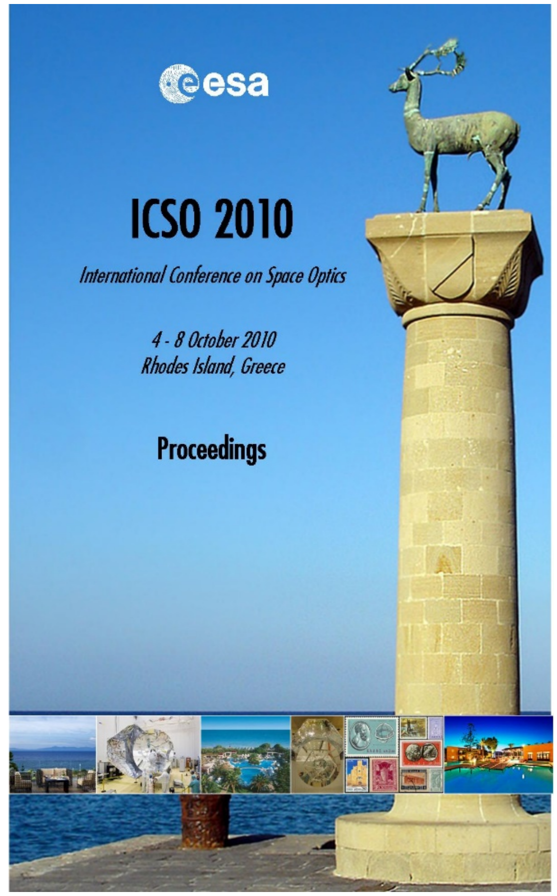

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THE SIMACC INSTRUMENT CONCEPT BASED ON TUNEABLE FABRY-PEROT MODULES

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I. INTRODUCTION

Ozone loss in the stratosphere, especially its drastic reduction in the Antarctic, has been the main driver for the middle atmosphere research during the last two decades [1]. A good understanding of the relevant processes has been obtained and the dynamical-chemical models are mature enough so that credible predictions of the future of the ozone layer can be made. However, i.e. the effect of the climate change on the pole-to-pole circulation is not clear. The proposed Spectral Imaging of Middle Atmosphere for Climate Change (SIMACC) concept aims to significantly contribute to answering the many open questions in understanding the climate change. The main objective of the proposed SIMACC mission is to investigate the changes the middle atmosphere will undergo during the ongoing rapid climate change [2].

VTT has developed novel Fabry-Perot –based hyperspectral imagers that are to be used in SIMACC [3]-[5]. In these spectral imagers the Fabry-Perot interferometer (FPI) is used at multiple orders simultaneously with each order matched to a specific pixel filter. In the visible (VIS) and very near infrared (VNIR) wavelengths (400 – 1100 nm) the standard Bayer patterned RGB color sensor was used providing the possibility for measuring three spectral bands with one exposure.

II. THE SIMACC PAYLOAD

The payload consists of a single instrument. The objectives of the SIMACC mission require measurements within two wavelength regions. The first one is the UV-VIS-NIR region 250-1270 nm. This region allows for the retrieval of O_3, NO_2, NO_3, O_2, H_2O and aerosols. The second wavelength region is located in the infrared band 1150-2350 cm^{-1} (4.3-8.7μm). This region is suitable for several atmospheric trace gases: for example H_2O, CH_4, CO_2, CO as well as temperature. The instrument will also include three fast photometers for star occultation measurements for the wavelength bands 420 – 470 nm, 580 – 630 nm and 675 – 750 nm with a 5-kHz sampling frequency.

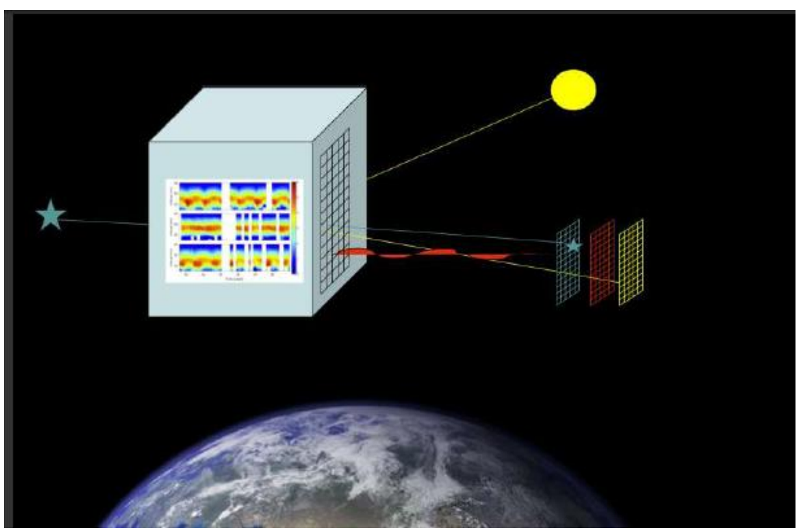

Fig. 1. Artistic view of the SIMACC Instrument Concept [2].

The UV-VIS-NIR region night side data can be collected by stellar and lunar occultations and emissions and dayside data by solar occultations and scattered solar light measurements. Heritage instruments are, for example, SAGE II, POAM, OSIRIS, GOMOS and SCIAMACHY. In the infrared the signal comes from thermal emissions and solar occultations. Heritage instruments are CRISTA, ACE-FTS, ATMOS and SABER.

SIMACC is an imaging instrument in order to achieve a truly global coverage. The viewing direction of SIMACC is limb. This makes it possible to retrieve vertical profiles with good resolution. The imaging of the limb provides also means to monitor horizontal variations of the ozone field, clouds, polar stratospheric clouds, noctilucent clouds, CO_2, CO etc. The imaging also makes it possible to record solar and stellar occultations. A complicated and vulnerable star/solar tracking mechanism can be avoided by the imaging approach.

The SIMACC instrument concept is based on an FPI used at multiple orders simultaneously with each order matched to a specific pixel filter. This principle differs from the principle used in the TESOS instrument [6] because it provides means to measure 3 – 6 spectral narrow band 2D images simultaneously.

Instrument technical summary:

- *Wavelength ranges.* UVIS: 270 - 680 nm, NIR: 740 – 780 nm & 1250 – 1350 nm, IR: 4.3 – 8.7 µm (1150 – 2350 cm-1)
- *Wavelength resolutions of spectrometers.* UVIS: 0.1-0.3 nm @ FWHM, NIR: 0.05-0.15 nm @ FWHM, IR: 8-16 nm @ FWHM (contrast 500).
- *Integration time.* The whole hyperspectral data cube is recorded in 100 s. The 2D images at selected wavelength bands are recorded in 10 s. The star spectra at selected wavelength bands (~ 12 bands per spectral channel) in occultation mode are recorded < 1 s.
- *Size.* 70-150 kg
- *Power.* 70-150 W
- *Data range.* 400-2000 kbps

The SIMACC is an imaging instrument with high spectral resolution. Push-broom types of imaging spectrometers have been used in instruments like GOMOS, OMI and GOME. In these instruments the light is dispersed by means of a prism or by a diffraction grating. These push-broom instruments form a 2D image on a detector in which one axis represents the spectral and the other the spatial dimension, making it impossible to get an image of the atmospheric limb instantaneously. In ALTIUS [7] the concept is to use the entire detector as an imager of the atmospheric limb to solve the tangent altitude registration problem. In ALTIUS acousto-optical tunable filters (AOTF) are used as the selected technology. In the SIMACC instrument the tunable filters are realized with piezo-actuated FPI technology. The advantages of the FPI technology over AOTF are higher optical throughput and better flexibility in the wavelength range selection determined only through the mirror coating materials.

III. VTT'S COMPACT HYPERSPECTRAL IMAGER

Recently VTT has presented a highly compact hyperspectral imager for UAS [1]. The spectrometer concept is described in Fig. 2. The multispectral image sensor uses a pixelized mosaic filter on a 2D detector. Barr [8] and DSI [9] have manufactured these kinds of multispectral filters for space instruments. The basic staring hyperspectral imager is based on rectangular entrance aperture which is imaged onto the detector with a lens system which has one or two FPIs inside the lens group. The FPI is placed inside the lens group in order to have minimum angular deviation for the rays going through the FPI for the same input ray angle. The advantage of a tunable filter type instrument is its flexibility to either perform recording of the whole hyperspectral data cube or record 2D images of the limb only at predefined narrow spectral bands selected for the measurement of target parameters. The spatial resolution of the image is decreased somewhat in this concept but it is tolerable because of the moderate vertical and horizontal angular resolution requirements of the SIMACC mission.

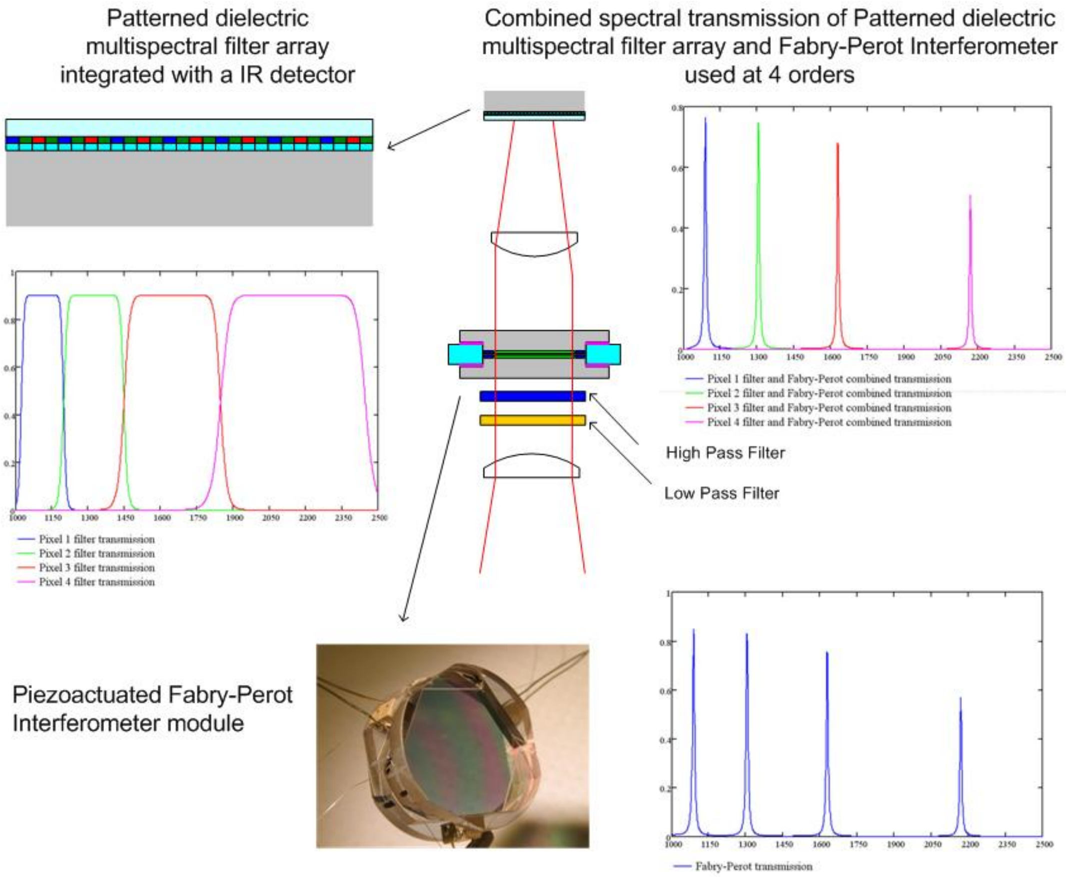

Fig. 2. Concept of the SIMACC spectrometer based on patterned multispectral pixelized filter array integrated with an IR detector. The Fabry-Perot Interferometer is used at several orders simultaneously.

IV. SIMACC OPTICS

The SIMACC optics is based on 8 spectral channels each having a dedicated staring hyperspectral imager. The instrument optics is divided into two modules: UV-VIS-NIR module and TIR module. Each module has its own telescope and spectrographs. The concept of the UV-VIS-NIR and TIR spectrometer modules are shown in Fig. 3. The basic parameters of the SIMACC spectral channels are described in Table 1.

Table 1. Major performance parameters of the SIMACC instrument optics (preliminary).

Parameter	***Range/value***	***Remarks***
UV-VIS-NIR telescope		
UV-VIS-NIR telescope aperture	200 mm	
Altitude/vertical FOV	3°	
Azimuth/horizontal FOV	20°	
Altitude IFOV	0.013°	
Azimuth IFOV	0.44°	
Solid angle of the pixel IFOV	$1.7x10^{-6}$ sterad	The patterned multipixel array has 4 to 6 pixels so the IFOV of a single pixel is in the range 2.9 - $4.3x10^{-7}$ sterad.
TIR telescope		
TIR telescope aperture	500 mm	
Altitude/vertical FOV	3°	
Azimuth/horizontal FOV	20°	
Altitude IFOV	0.013°	
Azimuth IFOV	0.44°	
Solid angle of the pixel IFOV	$1.7x10^{-6}$ sterad	

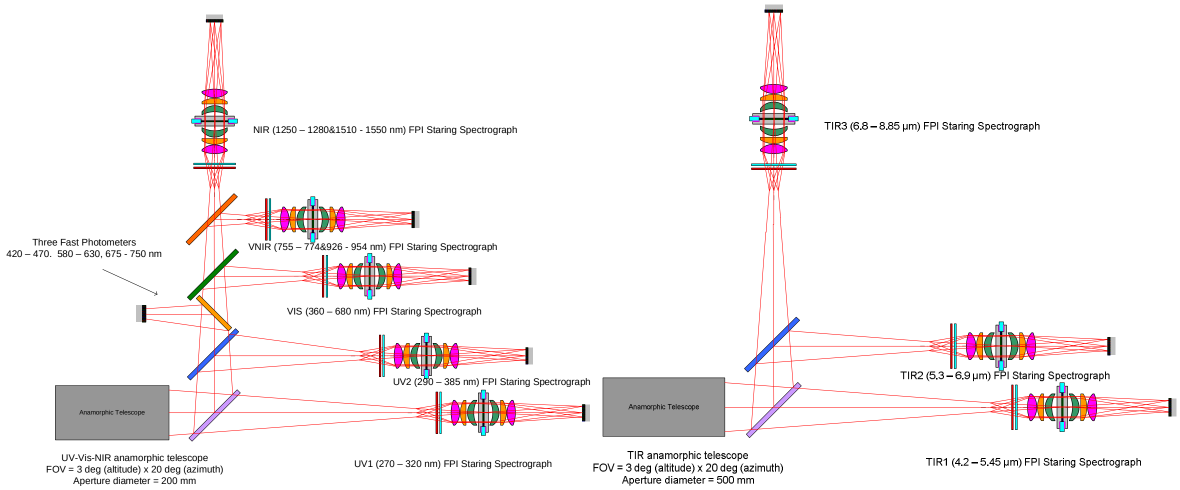

Fig. 3. Optical layouts of the SIMACC UV-VIS-NIR (left) and TIR (right) Spectrometer Modules.

The SIMACC Field Of View (FOV) is different for vertical (~3°) and horizontal (~20°) directions. Therefore special anamorphic ocular optics is required to form an intermediate image at the entrance aperture of the SIMACC staring 2D spectrograph. An anamorphic optical system will make an intermediate image of the 3° x 20° FOV whose size is similar to the entrance aperture of the spectrograph. The 2D image of the limb is generated in sequence for several narrow wavelength bands simultaneously. For example the UV1 band requires around 60 exposures for the registration of the whole spectrum in the range 270 – 320 nm with 0.275 nm sampling with an image sensor and integrated multispectral pixelized filter array with four different pixel filters.

V. CONCLUSIONS

The capability of the SIMACC instrument to perform spectral imaging of the limb provides means to monitor horizontal variations of the ozone field, clouds, polar stratospheric clouds, CO_2, CO etc. The proposed concept has high potential to create experimental data for answering many open questions in understanding the climate change. The main objective of the proposed SIMACC mission is to investigate the changes the middle atmosphere will undergo during the ongoing rapid climate change. The SIMACC instrument requires high throughput and spectral resolution combined with adequate imaging capabilities. We have described the SIMACC team's new spectral imager concept in which the Fabry-Perot interferometer is used at multiple orders simultaneously with each order matched to a specific pixel filter. This allows for significant improvements of the performance-to-volume ratio of the instrument.

REFERENCES

[1] World Meteorological Organization, "Scientific Assessment of Ozone Depletion: 2006", Global Ozone Research and Monitoring Project—Report No. 50, 2007
[2] E. Kyrölä, et.al., " Spectral Imaging of Middle Atmosphere for Climate Change (SIMACC)", Proposal in the response of Call for Proposals for ESA Earth Explorer Opportunity Missions EE-8, Finnish Meteorological Institute, 2010.
[3] H. Saari, V. V. Aallos, C. Holmlund, J. Mäkynen, and B. Delauré, "Novel Hyperspectral Imager for lightweight UAVs", Proc. SPIE, Vol. 7668, 766805 , 2010
[4] H. Saari, V. Aallos, C. Holmlund, J. Malinen and J. Mäkynen, "Hand-Held Hyperspectral Imager", Proc. SPIE 7680, 2010
[5] J. Malinen, H. Saari, G. Kemeny, Z. Shic, and C. Anderson, "Comparative performance studies between tunable filter and pushbroom chemical imaging systems", Proc. SPIE 7680, 2010
[6] T. J Kentischer, W. Schmidt, M. Sigwarth and M. V. Uexkuell, TESOS, a double Fabry-Perot instrument for solar spectroscopy, Astronomy and Astrophysics, v.340, p.569-578 (1998).
[7] http://www.altius.oma.be/, retrieved Aug 13, 2010
[8] http://barrassociates.com/, retrieved Aug 13, 2010
[9] http://www.depsci.com/, retrieved Aug 13, 2010