Paper No: 09	Agenda item: 2.3
SCAR PPG	AGATA
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SCAR Executive Committee Meeting 2023

Trieste, Italy, 15-16 September 2023

Antarctic Geospace and ATmosphere reseArch (AGATA)

2022-23 Report

Lead Proponents

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On behalf of the core members.

Sponsoring SSG(s): **Physical Sciences, Geosciences**

Summary of the duration and budget request
Duration: 8 years
Budget: 30,000 US$ per year

Abstract

The AGATA Scientific Research Programme (SRP) aims to significantly advance the current knowledge of the Antarctic atmosphere and geospace, in the bipolar, interhemispheric context. AGATA SRP will contribute to answering the outstanding scientific questions related to the whole-atmosphere coupling, space weather influences and whole atmosphere response to climate change. These questions will be addressed with a multi-disciplinary and multi-instruments approach, and by bringing together communities which investigate and study the polar atmosphere and geospace. Scientists who need atmospheric corrections for their measurements will also be involved. AGATA will take advantage of existing and planned instrumentation in Antarctica, and it will aim for coordinated research efforts and data exchange, also considering recent advances in the Arctic. While the understanding of physics of the neutral and ionized atmosphere has been significantly improved using both ground-based and space-based radio soundings, the questions that remain open need to be addressed with a synergistic approach. This requires active involvement of various research groups in the field.

a) Introduction - scientific objectives and statement of work (including contributions to SCAR's Strategic Plan)

The Antarctic Geospace and ATmosphere reseArch (AGATA) Scientific Research Programme (SRP) will contribute to answering the outstanding scientific questions within atmospheric and space physics, namely:

1. How are different atmospheric layers coupled in the polar regions?
2. How does the upper polar atmosphere respond to increased geomagnetic activity, including energy transfer from space?
3. How does the whole polar atmosphere impact short- and long-term climate variations?

Answering these questions will not only have implications on the understanding of processes in the polar atmosphere, but it will also greatly improve our understanding of the global atmospheric dynamics, thus contributing to the development of large-scale whole atmosphere and climate models. The AGATA SRP will take actions according to scientific and technological themes (described in the next section) that focus on revealing the role of processes in the in the Antarctic atmosphere (and apply knowledge to the Arctic region too) in the coupling between (1) different atmospheric layers (i.e., different spheres, such as troposphere, stratosphere, ionosphere), (2) the neutral and ionized atmospheric components within the spheres. Additionally, the impact of space weather and space climate conditions on the whole atmosphere-system (i.e., also including processes in the magnetosphere), both in the polar regions and globally, is one of the objectives of our group. AGATA builds upon open questions that have already been identified by the 1st SCAR Antarctic and Southern Ocean Science Horizon Scan (Kennicutt et al., 2015):

- *Open Question # 71 "What are the differences in the inter-hemispheric conjugacy between the ionosphere and that in the lower, middle and upper atmospheres, and what causes those differences?"*
- *Open Question # 72 "How does space weather influence the polar ionosphere and what are the wider implications for the global atmosphere?".*
- *Open Question # 73 "How do the generation, propagation, variability and climatology of atmospheric waves affect atmospheric processes over Antarctica and the Southern Ocean?".*

AGATA welcomes the recommendation expressed in the vision within the SCAR Strategic Plan 2023-2028: *"Atmospheric, astronomical, and astrophysical scientists can also use the Antarctic to understand fundamental questions about the universe and the physical phenomena occurring in the Earth's upper atmosphere"*.

b) Scientific approach and rationale (including synergies with other SCAR programmes and products)

Antarctica and the Southern Ocean encompass a wide range of magnetic latitudes (from the polar cap to middle latitudes) and geographic latitudes, enabling a unique multi-disciplinary investigation of the neutral and ionized atmosphere and their coupling both vertically, horizontally, and within each of the atmospheric layers. Beside the ground-based instruments traditionally used to monitor the polar atmosphere (ionosondes, radiosondes, riometers, magnetometers, backscattering and incoherent scattering radars, GNSS receivers, etc.), a number of instruments (e.g., geodetic networks, radio telescopes) have been demonstrated to be very useful to get better coverage and to provide complementary measurements. Different scientific communities and national programs often have common objectives. However, the cooperation between them is not yet fully achieved. The ambition of AGATA is to provide a framework to facilitate this coordination. AGATA will facilitate the sharing of data, infrastructure and expertise, bringing also the experience matured in the Antarctic/Arctic from several institutions that are already present in the AGATA Programme Planning Group (PPG) Core Membership. The (Ant)Arctic counterpart has an essential role in AGATA because the comprehension of the climate/weather and the space climate/weather changes derives from a global picture composed by regional assessments. This cannot be done without a bipolar perspective (see, e.g., Alfonsi et al., 2022). Recently the connections between the poles have been receiving increasing attention (see, e.g. Jin and Xiong 2020; Kim 2021; Reidy et al. 2018; Smith et al. 2020; Swarnalingam et al. 2022).

The investigation of processes in the polar atmosphere associated with the solar–terrestrial interactions is of great importance to improve our understanding of their impact on the global atmosphere, as well as their role in the current and future climate changes. Polar investigations have significantly improved due to the legacy of the four International Polar Year (IPY) programs, which involved participation of thousands of scientists. It also facilitated data and infrastructures sharing, favoring in particular the establishment of common platforms that, in recent years, developed into e-platforms (such as databases, repositories, and access portals). Under the IPY programmes, the physics of the upper atmosphere and the solar–terrestrial interactions were among the high priority fields of study. During the last IPY (2007–2009), ICESTAR (Interhemispheric Conjugacy Effects in Solar-Terrestrial and Aeronomy Research), a SCAR Scientific Research Program, highlighted the advantages of the interhemispheric approach for a better understanding of the polar atmosphere. Since the conclusion of ICESTAR (in 2012) these investigations have been continued within the SCAR Expert Group GRAPE (GNSS Research and Application for Polar Environment, http://grape.scar.org/). Within GRAPE the idea to propose a new SRP was born and inevitably AGATA drew the attention of several communities. In that context, the AGATA leading team is already in contact with the US National Science Foundation and other national science agencies, to contribute to the identification of priorities in polar space weather research that should be achieved during the 5th IPY (2032-2033). AGATA topics are also of interest for ANtarctic Gravity Wave Instrument Network (ANGWIN), an ongoing Action Group approved by SCAR in 2018. Thanks to the collaborations matured within GRAPE, AGATA will be able to gather contributions and expertise from a significant part of the scientific community dealing with the physics from lower to upper atmosphere. In synergy with ANGWIN, AGATA aims to investigate the vertical coupling between the neutral and ionized atmosphere. These outcomes will be of interest also for the SRPs AntClimNow and INSTANT. AGATA also aims to bring the AAA EG (past SCAR SRP) close to the Physical Science Group to facilitate the interaction between researchers in the fields of Astronomy, Astrophysics, Atmosphere and Ionosphere/upper polar atmosphere.

In this framework, the scientific approach of AGATA SRP will have a strong interdisciplinary connotation investigating several topics, which are preliminarily listed (but not limited to) in the following.

- **Water Vapour:** the AGATA Team will investigate the water vapour (WV, also called Precipitable Water - PW), one of the most important natural greenhouse gases. The water vapour radiation feedback is recognized as one of the most important contributors for the Arctic temperature amplification, among other factors (Rinke et al. 2019). However, it is one of the most difficult parameters to measure and quantify. Different techniques (satellite sounders, GNSS and radiosondes) allow the estimation of WV. These different techniques have permitted a better understanding of patterns and trends in PW. Long term WV from GNSS time series in the Arctic revealed that the stations in between Greenland and continental North America have negative trends in the WV content, while those located in regions bordering the Atlantic Ocean showed a positive trend. Regarding Antarctica, the stations in the West Antarctic sector showed a positive trend while those on the coastal zone of East Antarctica exhibited small negative trends. By observing the interannual variability and its dependence on meteorological variables, polar regions showed a general moistening: Antarctic moistening seems to be driven by the surface warming, while the Arctic PW variability can be explained by a combination of surface temperature, tropopause temperature, precipitation, and the North Atlantic atmospheric circulations. In the frame of AGATA, we will support an increased use of ground and satellite data to improve the spatial and temporal resolution of PW maps. These maps will be used to improve polar weather prediction (e.g. European Centre for Medium-Range Weather Forecasts (ECMWF) Era-Interim model, Dee et al. 2011,) and climate studies.

- **Sudden Stratospheric Warming (SSW)**: these large atmospheric disturbances observed as a reversal in the wind and the temperature gradients in the polar stratosphere occur during the winter season. They are due to the influence of planetary waves and the mean flow interaction (Matsuno, 1971). The study of SSWs is a challenge because continuous ground-based observations of mesospheric wind and temperature in the vicinity of the stratospheric polar vortex edge are still rare. As a consequence, the interhemispheric differences of the SSW manifestations are not yet understood (Kruger et al. 2005; Yamazaki et al. 2020). It is known that energetic particle precipitation (EPP) from the magnetosphere could also affect the stratospheric polar vortex dynamics (Verronen et al., 2021; Szeląg et al., 2022; Edvartsen et al., 2023). EPP can lead to the depletion of ozone in the polar mesosphere (up to 8%) and thus is an important variable in atmospheric and climate modeling. The long-term effects and magnitude of the impact of EPP on the regional climate variability in both southern and northern polar regions are open questions that can only be addressed with a multi-disciplinary and multi instrument approach. AGATA will coordinate and facilitate joint research efforts and provide such measurements.

- **Atmospheric gravity waves, acoustic–gravity waves, traveling ionospheric disturbances and planetary waves**: the upper mesosphere and lower thermosphere, are dominated by the effects of atmospheric waves. Atmospheric gravity waves (AGWs) have been intensively investigated in the last decades due their recognized importance in the general circulation, structure and variability. They are an essential component in the Earth climate system (Fritts and Alexander, 2003; Alexander et al., 2010). AGW observations in Antarctica have been improved due to the formation of the SCAR Action Group ANGWIN (Moffat-Griffin, 2019). AGATA will further consolidate these efforts also in the global context of vertical coupling in the atmosphere.

- **Ionospheric irregularities**: the ionosphere can be characterized by uneven and highly structured electron density distributions especially at high latitudes (Alfonsi et al., 2022 and references therein). In particular in the southern hemisphere, the ionospheric structuring in the polar regions can be significantly larger than in the Arctic. This is an important space weather phenomenon which is related to instabilities and turbulence in the polar ionosphere as well as geomagnetic forcing. Comprehension of the physical processes behind the formation and evolution of ionospheric plasma irregularities at high latitudes is still far from being complete, since comprehension implies understanding. A long-term monitoring in combination with multi-instrument case studies is needed. AGATA will facilitate these, and will contribute to answering this outstanding question of ionospheric structuring.

- **Upper atmosphere prediction under space weather adverse conditions**: adverse space weather conditions can lead to enhancement of thermospheric drag and uneven distribution and strong gradients in the electron density. Such conditions can significantly impact the services based on vulnerable technologies (GNSS PNT, HF communication) and also the satellite orbits, communication links. The capability to predict upper atmosphere conditions is still poor due to their high variability in time (covering minutes, days, seasons and even the solar cycle) even during quiet geomagnetic periods. To complicate it further, they also have significant variations as a function of magnetic local time and geographic location. At high latitudes, the upper atmosphere is open to the entry of solar particles which means that these regions are particularly vulnerable. Due to their sensitivity, they can be also seen as global space weather sentinels. AGATA will directly contribute to such future models and forecasts by facilitating data sharing and coordinating research activities within this scope.

- **Other scientific aspects of interest for AGATA:**

    - **Electrical activity (including lightning activity)**: there is an increasing attention in the research community to this problem, as electrical activity has been shown to exhibit a dramatic increase in relation to global warming (Holzworth et al., 2021). This observation has been shown to have important consequences in the Arctic for the ignition of forest fires (Kharuk et al., 2023) and the chemistry of the upper troposphere (Zhang et al., 2023), but may have many additional implications at both poles through the coupling mechanisms of the troposphere and upper atmosphere that are linked to lightning (e.g., see Siingh et al., 2005). AGATA will investigate the impact of increased lightning activity on the different layers of the atmosphere.

- **Long and short term variations in the geomagnetic field:** ground-based vector magnetometers in both polar regions have provided essential data and observational context for many studies (e.g., the interactions of the solar wind and interplanetary magnetic field with the outer magnetosphere, travelling convection vortices, and ground signatures of dayside magnetic reconnection). AGATA will help to facilitate the collaborations that will be even more essential as the number of magnetometers at high conjugate latitudes increases.

Additionally, AGATA aims to encompass the societal impact to support space weather services: AGATA will catalyze fundamental research on phenomena whose enhanced understanding open pathways for improved space weather services. Antarctic measurement campaigns, advanced modeling, and agile data dissemination arrangements by AGATA will be a crucial contribution in the global efforts for enhanced resilience against space weather storms. Societal needs for reliable space weather forecasts with long lead times are continuously increasing with our growing dependency on systems that are operated in space or impacted by rapid variations in space and upper atmospheric conditions. Power transmission networks, satellite traffic management, space-based navigation and communication are examples of systems and operations whose failures can impact our everyday life in several non-direct ways. One of the achievements in the last years, is the PECASUS consortium, which is one of the four global centers providing space weather advisories according to ICAO (International Civil Aviation Organization) regulations. PECASUS sends advisories to airliners using the existing aeronautical fixed network for international aviation (AFS). Due to the topology of the geomagnetic field, polar areas, both Antarctic and Arctic on equal weight, have special relevance in space weather activities. One of AGATA's main objectives is to enhance visibility of Antarctica as an important sentinel of geospace processes whose research today is mostly conducted with Northern hemispheric observations. This objective can be reached by coordination with international organizations (e.g., COSPAR PSW, ISES and WMO ET-SWX) which have representation by AGATA consortium members. Furthermore, yet another societal impact of AGATA is its contribution to global and local models and forecasts of neutral atmosphere dynamics at different altitudes, as explained above.

These overarching questions include a wealth of specific scientific problems, some of which are listed in the following:

1. What is the role of coupling between the neutral and the ionized layers in the atmosphere at the poles for the global atmospheric circulation and energy transfer through different atmospheric layers?
2. How can we improve the modeling of the coupling of the neutral atmosphere to the ionized atmosphere at high latitudes?
3. Due to the nearly vertical geometry of the geomagnetic field lines, the magnetic reconnection between the Earth's magnetic field and the IMF results in a prompt response of the high latitude ionosphere to fluctuations in the solar wind. How does it influence lower latitudes and the global atmosphere?
4. The effects of solar perturbations on the upper atmosphere over the poles are often asymmetric. The circulation in the neutral atmosphere is also asymmetric. Do we fully understand the reasons for such asymmetries?
5. Can we understand the formation and evolution of ionospheric plasma irregularities, as well as their impacts on infrastructure in the southern hemisphere? What are the processes that make the Antarctic irregularities so different from the Arctic?
6. Can we understand the origin of the long-term behavior of the polar (whole) atmosphere including climatology, and discriminate between natural and anthropogenic contributions to such changes?

To make progress on these and many other questions (Bergeot et al., 2020), increasing monitoring by improving the current coverage and extending the number of multi-instruments sites, is needed. Thus, the following actions are proposed:

- Strengthen the collaboration between atmospheric scientists and heliophysicists to improve our knowledge about solar wind forecasting (including CME/CIR propagation) and space weather impacts;
- Foster the collaboration among experts of different disciplines, such as astrophysics, planetary science, neutral atmosphere physics and chemistry, and heliophysics to share the competencies necessary to understand the role of different drivers of atmospheric and ionospheric dynamics from above and below;
- Facilitate the sharing of data, algorithms and models to harmonize the exploitation of the information (adoption of standards, agreement on metrics, use of shared communication tools, use of interoperable tools, etc.);
- Keep and strengthen the collaboration between the research communities that manage and exploit ground-based and in-situ observations to optimize and maximize their efforts given an increasing number of multi-instrument sites on the ground and multi-sensor payloads in space.

c) Experimental section and methodologies

AGATA aims to improve observational coverage of the polar regions by leveraging existing and new instrumentation and also to improve knowledge transfer between experimentalists and modellers. This will be facilitated by cross-disciplinary collaboration in a manner inspired by other successful initiatives. An important role model is the US NSF-funded CEDAR programme. Other models include, for example, the EISCAT Peer-Review Trans-National Access (TNA) programme (opening infrastructure access to all scientists and students regardless of membership), and the International Space Science Institute (ISSI, link accessed 1 Aug 2023), which organizes dedicated workshops for both experts in the field and early career researchers. One key aspect of coupling between the neutral and ionized layers of the atmosphere and near-Earth space is that significant processes take place over spatial and temporal scales (from sub-seasonal to decadal) of many orders of magnitude. Specifically, the coupling of layers in the polar atmosphere is characterized by:

- Dynamics on length scales from infrasonic and acoustic-gravity waves up to planetary waves and the polar vortices, and time scales at least from the semi-diurnal tides up to quasi-biennial oscillation. Another aspect is solar activity induced atmospheric expansion on scales from storms up to solar cycles. The latter connection is only partially accounted for by including solar activity indices in empirical models (e.g. NRLMSISE-00, Picone et al., 2002 which has been specifically improved to reproduce thermospheric drag) as was dramatically demonstrated by the failing of Starlink launch on Feb 4, 2022, where both thermospheric density and magnetic field at orbital altitudes were disturbed (e.g. Laskar et al., 2023 and Tsyganenko et al., 2022).

- Ion and neutral chemistry, production and transport of O_x, NO_x and HO_x species in the polar vortices, and their effect on trace gasses absorbing UV, visible and infrared radiation. In fact, the importance of the polar regions in neutral atmospheric coupling comes to a large extent from phenomena in the polar vortices, including subsidence of thermospheric air and its effects of ozone chemistry. Energetic particle precipitation including the aurora is a significant source of nitrogen oxides and hydrogen oxides, with effects on middle atmospheric dynamics and composition (see Meraner and Schmidt, 2018, and the references in its introduction).
- Aerosol processes in the troposphere, stratosphere and polar mesopause region. Here, the polar regions are of importance due to the presence of polar stratospheric clouds in the winter, and polar mesospheric clouds/noctilucent clouds during summer.
- Magnetospheric electron precipitation on scales including flickering aurora (sub-second variations) and whistler wave acceleration, up to diffuse aurora.

Multi instrument approach and data sharing

Satellites in low orbits, such as typical polar orbiting satellites, are not able to distinguish spatial from temporal variation. The same is true for ground-based single-point measurements such as older radars and ionosondes. The way around this is to observe a whole region simultaneously from space and ground. This can involve satellite clusters and constellations, and ground-based instrument networks.

AGATA will work to improve multi-instrument coverage of both the Arctic and Antarctic polar regions, in order to resolve spatial from temporal variations and cover all important scales of interaction. The long time scales involved also point at the importance of statistical studies of large (solar cycle length) datasets, in contrast to case studies of limited datasets from the more conspicuous geomagnetic storm events.

Specific Instruments utilized in the Antarctic and Arctic and the information they can provide are:

- **Magnetometer networks** ⇒ electric currents in the upper atmosphere
- **GNSS occultation receivers** ⇒ ionospheric irregularities and vertical structuring
- **Ionosonde networks** ⇒ ionospheric structure and dynamics
- **Optical instruments**
    - Narrow-band **auroral imagers** ⇒ energy of electron precipitation
    - Wide-band colour or monochromatic auroral imagers ⇒ large scale structure of aurora
    - **OH imagers** ⇒ atmospheric gravity waves
    - **Fabry-Perot interferometers** ⇒ thermospheric winds and dynamics
- **Imaging radars** including
    - **PANSY in Antarctica** ⇒ atmospheric winds and dynamics; ionospheric structuring and dynamics
    - **EISCAT 3D**, **MAARSY** and other systems in the Arctic ⇒ ionospheric structure, mesosphere/stratosphere/troposphere dynamics
- **SuperDARN** ⇒ large scale ionospheric convection and waves
- **ANGWIN** network ⇒ atmospheric gravity waves
- **Riometer networks** ⇒ ionisation in the lower ionosphere/mesosphere region
- **GNSS networks** (i.e. POLENET, ANET, IGS, national stations) ⇒ tropospheric water vapour retrieval, variability and evolution; Total Electron Content, ionospheric scintillation indices computation
- **Microwave radiometers, infrared sounders** (i.e. AIRS, AMSU-B,,MHS, GOCE-2) ⇒ Integrated Water Vapour retrieval
- **Satellites**
    - Existing satellites (CLUSTER, MMS, A-Train, ARASE, POES, Swarm, CSES) for Earth-space interactions, atmospheric composition and surface remote sensing;
    - Cubesat and other small satellite projects are abundant and can aid coverage, provided launch opportunities.

Advantages of AGATA

The key experimental and methodological issues can be summarized in the following items.

- Make the existing instruments in the polar regions (as listed above) known, by allowing interaction with students and young scientists from diverse disciplines.
- Make polar atmospheric and solar-terrestrial data sources known and improve their utilization according to FAIR (Findable, Accessible, Interoperable, Reusable) principles.
- Identify gaps in coverage, in both temporal and spatial scale. This is of special importance in Antarctica.
- Emphasize collaboration between experimentalists and modelers, and assimilate multi-instrument data in atmospheric models.
- Archive the data in standard formats and utilize high performance computing facilities to analyze large datasets.

Recent technical developments to exploit

- Software defined radio (SDR) receivers have given rise to a new generation of radars, ionosondes, riometers, satellite receivers, etc, more affordable and possible to deploy at any site where power is available;
- Fast EMCCD and CMOS cameras for auroral studies produce large data volumes, thus data compression and AI methods for data selection have to be developed;
- Micro- and nanosatellites for scientific use.

Coordination of instrument development

An issue where collaboration between institutes and not least between established and early career scientists has the potential to lead to big improvements is the coordination of instrument development and deployment. As model examples, we consider the ground-based observatory networks mentioned above (ANGWIN, SuperDARN, ionosonde and optical networks and several others), as well as collaborations such as the regular Nordic Observatory Meetings (NOM). Such collaboration allows scientists to provide updates on their instrumentation, and carry out joint planning and calibration campaigns. Also the collaboration with networks not specifically set up for atmospheric studies, like POLENET, will be actively pursued.

d) Management and reporting (including a Scientific Steering Committee)

AGATA adopted a governance still from its PPG status, having a Leader, a Co-Leader and a Secretary, organizing its activities according to 4 Working Groups (WGs) led by a Leader and a Deputy per WG and having an Advisory Board of 5 members. Here follow the details:

PPG Leader Lucilla Alfonsi
PPG Co-Leader Nicolas Bergeot
Secretary Wojciech Miloch

WG1 Science Leader: Emilia Correia, Deputy: Shreedevi PR
WG2 Technology Leader: Carl-Fredrik Enell, Deputy: Monia Negusini
WG3 Dissemination, Outreach, Capacity building Leader: Liliana Macotela, Deputy: Adriana Maria Gulisano
WG4 International coordination and anchoring Leader: PT Jayachandran, Deputy Kirsti Kauristie

Advisory Board

- Mark Engebretson
  Professor Emeritus of Physics
  Augsburg University (USA)
  Expertise: Geomagnetism and Space Weather

- Johnathan Kool
  Manager, Australian Antarctic Data Centre
  Australian Antarctic Division
  SCAR SCADM Chief Officer

- Sergio Dasso
  Head of the Laboratorio Argentino de Meteorologia del esPacio (LAMP)
  Researcher (IAFE, UBA-CONICET) & Professor (DCAO, FCEN, UBA), Argentina
  WMO Member of panel of Space Weather and Space Physics

- Jim Madsen
  Executive Director, Director (Interim), Wisconsin IceCube Particle Astrophysics Center (WIPAC)

University of Wisconsin-Madison
Astronomy and Astrophysics from Antarctica (AAA) SCAR EG

- Tracy Moffat-Griffin
  British Antarctic Survey
  Co-PI of ANGWIN SCAR AG

The PPG governance was functional to the preparation of the SRP proposal and to the dissemination of the AGATA initiative. The SRP governance is foreseen more articulated for what concerns WP1 and WP2, but keeping the other WPs with the same objectives. The AGATA Leaders and co-Leaders (including those of the WGs) will be elected on the basis of the nominations made by the AGATA community that, at the time of writing, counts more than 70 people. The Steering Committee will be formed by the AGATA Leaders and the WGs' Leaders. We also want to keep the Advisory Board to assist our action during the SRP lifetime.

e) Milestones, outcomes, outputs, and benefits (including metrics of performance)

We foresee a milestone at the SRP kickoff and at the reporting time, on a 6 months-basis, when we plan to organize a Round Table with experts with whom the audience can interact to gather scientific ideas and to start new collaborations.
Since its PPG status, AGATA is measuring its degree of interest and its capacity to attract and (possibly) to sustain students and Early Career Researchers (up to 5 years from PhD). At the time of writing we can report that the AGATA kickoff meeting (KOM) held in Berlin during the IUGG General Assembly on 12 July 2023 and online was attended by about 80 people. The financial support was provided to 6 students and ECRs to attend the AGATA KOM (thanks to the support by SCAR and SCOSTEP/PRESTO). The AGATA KOM, foreseen to last one hour and half, saw an active participation that extended further discussion beyond the official close. The main inputs to AGATA come from: the SCAR AAA community that welcomes the AGATA initiative as a very promising opportunity for collaboration; the students and ECRs asking for dedicated schools and training initiatives and for participation to polar expeditions; ANGWIN members to strengthen the collaboration in view of being part of AGATA; scientific community working on neutral atmosphere and on neutral-ionized atmospheric coupling to reinforce their contribution to AGATA; upper atmosphere community that welcomed the sharing of data and coordination of activities; students and ECRs ask to facilitate the data access and information.
We plan to continue to measure our performance in terms of meeting attendees, students and ECRs support, capacity to attract funds (applications to funding agency versus rate of success), Master and PhD thesis, joint scientific papers, etc.

f) Data management plan

As per the definition from the Research Data Alliance workgroup on data management plans (Miksa et al., 2019), a common practice is that "Data Management Plans are free-form text documents describing the data that is used and produced during the course of research activities. They specify where the data will be archived, which licenses and constraints apply, and to whom credit should be given, etc." This is in fact a best case scenario; often this information is spread across Rules-of-the-Road documents, data README files, and other documentation.

A best practice is therefore to implement a machine-actionable DMP (maDMP) for every dataset, i.e. a set of keyword-value pairs providing the required information, including:

- Contact details of related parties (OrcID, institute ID, etc)
- Sources of funding used to produce the dataset
- Dataset details including DOI or other PID of dataset
- Data license
- Quality assurance and preservation statements

- Other information.

Currently the data are managed by different groups and institutions. AGATA will encourage the data owners involved in AGATA to provide all necessary information on their data access and database. For several of the partners this will extend upon and continue their previous participation in data search projects including:

- ESPAS FP7 and PITHIA-NRF
- The EOSC-Hub

All this information will be available on the AGATA webpages. This will facilitate data access and information according to FAIR principles. The project will also handle project information such as contact details of applicants. GDPR and other rules apply to such information, so in addition to scientific data management plans AGATA will also implement at least one DMP for project documents.

g) Capacity building, education and training plan

AGATA also targets in building capacity and training activities directed towards the Antarctic-Arctic, atmospheric-ionospheric, and SCAR community. AGATA also intends to raise public awareness internationally by education/outreach to the general public, high school students, and university students. For that, AGATA will liaise with National Antarctic (and Arctic/polar) Programmes. AGATA will put special emphasis to SCAR member countries with less developed Antarctic programs and will try to attract countries that are not SCAR members, highlighting inclusion and diversity, also collaborating with SCAR EDI AG. Specifically, AGATA envisages the following fields of action:

1. Capacity building
   - Internship and secondments will be encouraged and facilitated. For that, an elaboration of a list of hosts willing to supervise and advise early career scientists will be made. At the same time, a list of agencies and fellowship schemes where to apply for travel grants will accompany the list of hosts (e.g., the SCAR Fellowship Scheme, SCOSTEP).
   - Participation of early career scientists in AGATA meetings and workshops will be supported by offering, within the constraints of budget limitations, bursaries for travel and subsistence. The condition of each bursary will be a report by the bursary holder about their research and workshop experiences, which will be posted on the AGATA webpages.
   - Special AGATA sessions during scientific meetings (e.g., the International Union of Radio Science URSI, American Geophysical Union AGU, European Geosciences Union EGU, European Space Weather Week ESWW, etc.).

2. Education and training plan
   - Providing coordinated outreach using programs such as the European Research Night, International Day of Women and Girls in Science, and Open Day at any of the SCAR research organizations. When necessary, outreach materials will be created.
   - Use the SCAR social media (Twitter, Facebook, LinkedIn) to provide updates, news, and alerts about field work activities and to disseminate key scientific results. The latter will be also considered to be published in the SCAR Newsletter.

Capacity building and outreach activities are essential for the continuous development of any program. Thus, AGATA puts a special emphasis on these. Furthermore, through an internal organization survey 60% of our community will focus on capacity building while the 40% remaining part will focus on outreach activities. At the same time, the activities listed above have the potential to raise the profile of both SCAR and Antarctic research within the broader atmospheric community.

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Supporting information

i. Short biosketch and homepage URL for proposed Chief Officer(s) and lead investigator(s)

Lucilla Alfonsi is a senior researcher at Istituto Nazionale di Geofisica e Vulcanologia (INGV). Her main interests concern the study of the upper atmosphere related to space weather applications, particularly about the investigation of ionospheric irregularities from ground based, as well as from the in situ measurements. She is also expert on the investigation of the long-term changes of the upper atmosphere on a planetary scale in the frame of Global Change studies and on the design and development of ionospheric scintillations models. Her research focuses on polar regions. She participated in Arctic and Antarctic expeditions to install and maintain the INGV upper atmosphere observatories.
https://www.ingv.it/en/organizzazione/chi-siamo/personale/#326

Nicolas Bergeot is a senior researcher in Geophysics at the Royal Observatory of Belgium. His major areas of interest are geophysics and geodesy. He has a specific expertise in GNSS (e.g. GPS, Galileo) data processing for geophysical interpretations and data acquisition on the field (Europe, Pacific, Antarctica). His recent research focuses on space weather, ionospheric meteorology and climatology, ionosphere of Mars, near-real time monitoring, ionospheric modelling, polar research, high precision positioning for geodynamic/glaciological applications.
http://gnss.be/member.php?id=nicolas_bergeot

Wojciech J. Miloch is professor in physics at the University of Oslo. His research focuses on ionospheric plasma processes at high latitudes, ionospheric plasma turbulence, and space weather phenomena related to ionospheric irregularities. He is responsible for multi-instrument sites on Svalbard, northern Norway, and in Antarctica. In addition to the ground-based, satellite and rocket instrumentations, he is responsible for developing data products and a forecast service characterizing ionospheric irregularities and structuring based on satellite and ground based observations. He has participated in several polar expeditions and has established and is in charge of the Ionospheric Observatory at the Norwegian Antarctic Station Troll in Dronning Maud Land.
https://www.mn.uio.no/fysikk/english/people/aca/wojciecm/

The AGATA governance is described in *Section d.*
The list of the AGATA core members is available at:
https://www.scar.org/science/agata/members/

ii. *Justification for SCAR sponsorship (why does SCAR support add value?)*

Currently SCAR is running 3 SRPs but none of them deal with the role of the solar-terrestrial interactions for the conditions in the atmosphere (both lower and upper atmosphere). Such interactions and impact are also important drivers in climate control. Thus, AGATA aims to gather the communities that investigate the polar weather, atmosphere, and geospace. By bringing this expertise together, AGATA will be able to address the coupling between different atmospheric layers, set the physical processes into a bi-polar perspective, and investigate the impact of geomagnetic activity on the whole-atmosphere system, including the energy transfer. It will make use of the actual ground-based instrumentation and satellite measurements. Synergistic effects are essentials to reveal new ways of atmospheric research with the use of radio-sounding, and to identify open problems and a roadmap of how to address them. Such an approach will significantly improve the current knowledge of the Antarctic atmosphere, its coupling to the highly dynamic geospace phenomena, and the vertical coupling and the interhemispheric interactions. It will allow for a better characterization of the atmospheric energy balance, and its role in the global climate, which affects the surface mass balance of the ice sheet, and its impact on sea level rise. The SCAR support is essential for achieving these ambitious goals and for the formation of the next generation of scientists.

iii. International involvement and partnerships

- WMO: The importance of Space Weather observations from Antarctic stations is recognized in the World Meteorological Organization (WMO). In particular, the surface section of Observing Systems Capability Analysis and Review Tool (OSCAR) of WMO, which is the official repository of the WMO Integrated Global Observing System (WIGOS) metadata for all surface-based observing stations and platforms, includes different space weather stations in Antarctic. Also different actions and discussions of the Expert-Team of Space Weather of WMO recently include Antarctic observations. AGATA will make an invaluable contribution to enrich these repositories with specific information on space weather instruments and detailed requirements on Antarctic stations.
- The SCAR Astronomy and Astrophysics from Antarctica (SCAR AAA) brings together researchers who utilize the unique Antarctic viewing conditions, sites, and infrastructure to advance our understanding of the universe. AGATA offers opportunities for exchanges to address the extreme challenges of designing, deploying and operating instruments in extreme and remote conditions. There are also science synergies as well. For example, understanding the atmosphere is vital to optimize telescope locations and to interpret event rates for cosmic ray events interactions which dominate the IceCube data stream at the South Pole.
- IPY Antarctic Geospace Observations: AGATA Team is already collaboratin with this group set up by NSF to identify priority space weather research objectives and obtain the measurements/logistical support to achieve those objectives leading up to International Polar Year 2032-2033.
- SCOSTEP: SCOSTEP, through its PRESTO program, already provided funding for the AGATA KOM and it is a crucial player in the scientific reference panorama. SCAR is sitting in SCOSTEP Bureau.
- COSPAR ISWAT (International Space Weather Action Teams) is a global hub for community coordinated collaborations addressing challenges across the field of space weather (www.iswat-cospar.org/about-us). AGATA members are already an active part of the initiative and can highlight the importance of the polar regions, being part within ISWAT of a global endeavor.

- COMNAP: As this is the body in charge to delivering and supporting national programmes side of Antarctic work, they may be able to facilitate collaborations and discovering other instruments that are of interest to AGATA but not well used by other nations
- E-SWAN (eswan.eu) is the European Space Weather and Space Climate Association: an international non-profit association established in 2022. The E-SWAN community discussed and debated the best way forward to unite and help itself to sustain and develop the successful space weather activities that have been achieved so far across Europe. AGATA members are already sitting in the E-SWAN *WG2 - Liaison office* to ensure collaboration and coordination with our SRP and with SCAR at large.

iv. *Budget justification (other potential sources of funds)*

AGATA asks to receive from SCAR 30000 US$ per year that will mainly support the participation of young students and early career researchers to AGATA related activities, such as: participation to sessions related to AGATA topics organized in the main conferences (SCAR Open Science Conference (OSC), AGU Fall Meeting, EGU General Assembly, COSPAR General Assembly, URSI General Assembly and Flagship Meetings, IUGG General Assembly, etc.); attendance to AGATA workshops and schools; scientific visits, participation to polar expeditions. A significant part of the budget will be also allocated to support outreach activities producing dissemination material for the AGATA participation to national and international festivals, exhibitions, events. A part of the budget will be used to organize the AGATA conference, foreseen not before 2026, likely exploiting the opportunity of the SCAR OSC 2026.

v. Other information (information useful to evaluators)

Expressions of interest from the International involvement and partnerships cited above will be provided with the final version of the proposal.