Submission regarding review of Field of Research classifications

National Committee for Space and Radio Science

Submitted: 7 June 2019

The existing Field of Research (FoR) classifications are based on the *Revised Field of Science and Technology Classification in the Frascati Manual* (2007), and the *Frascati Manual* (2015), published by the OECD. The *Manual* is the internationally recognised methodology for collecting and using R&D statistics. It sub-divides the 6 main fields of science using 2-digit codes and states that '*new and emerging multi- or inter-disciplinary areas will need to be classified in the future in order to measure R&D inputs and performances*.'

The OECD classification defines research and experimental development (i.e. R&D) activity to comprise basic research, applied research, and experimental development aimed to generate new knowledge products. The National Committee for Space and Radio Science (NCSRS) believes that the current ABS definitions of research and socioeconomic objectives could be better aligned with these OECD recommendations. Reasons for this are discussed below.

The FoR classifications are used to facilitate monitoring and evaluation of research activity (e.g. through data reporting), to facilitate resource allocation (e.g. by funding agencies), and indirectly to support the conduct and growth of R&D disciplines. Research funding agencies categorise funding applications and allocate reviewers of those applications by FoR. The outcomes of these processes determine the success of funding applications and in turn influence the allocation of resources to research areas by research organisations. Furthermore, the existence and classification of specific FoR codes sends a message to R&D organisations of official recognition of these fields and thus may direct thinking along such lines.

The NCSRS argues that the current FoR codes for the disciplines of space science and radio science are inappropriate, have hindered the development of these disciplines, and if not changed will continue to hinder their development contrary to the national interest. This argument is based upon the following factors.

1. The current codes are inconsistent with the classification of space and radio science fields of research by the world's international scientific unions and publishers.
2. The current codes are incoherent and fragment these disciplines across a confusing variety of fields.
3. The current codes do not account for substantial changes in science, and activities undertaken and likely to be undertaken, in these disciplines.
4. The current codes thus hinder the appropriate allocation of reviewers for funding proposals.
5. The current codes do not permit accurate reporting on research activity in these discipline areas.
6. The current codes do not support acknowledged national priorities in space and radio science.

Evidence supporting these arguments is also presented below.

The National Committee for Space and Radio Science therefore recommends:

(i). That, in line with OECD practice, the definition of research be broadened to include research and experimental development, where R&D activity comprises basic research, applied research, and experimental development. The current Field of Research (FoR) codes should thus be relabelled Field of Research and Experimental Development (FoRD) codes.

(ii). That consideration be given to realigning the Socioeconomic Objective (SEO) divisions in line with OECD recommendations, and a new Division entitled *Exploration and exploitation of space,* introduced.

(iii). That the 4-digit FoR Group *Astronomical and Space Sciences* be separated into two, 4-digit Groups: *Astronomical Sciences*; and *Space Sciences*.

(iv). Precise subdivisions of the 4-digit FoR codes should be decided in consultation with the astronomy and space sciences communities. However, the NCSRS suggests the new 4-digit Group *Space Sciences* include the following subdivisions: solar physics and the interplanetary medium; magnetospheric, ionospheric and mesospheric physics; astrodynamics, space situational awareness and space weather; solar system planetary science; satellite and satellite-based positioning; Earth observation and remote sensing; space medicine and space life sciences; instrumentation and sensors for space science; space sciences not elsewhere classified.

(v). That consideration be given to a 4-digit FoR code *Radio Science* with subdivisions to be decided in consultation with the appropriate communities. The NCSRS suggests as a starting point the following subdivisions, based on the areas of focus of the International Union on Radio Science (URSI): electromagnetic metrology; EM fields and waves; radio communication systems, radar and signal processing; electronics, photonics and hybrid systems; electromagnetic environment, noise and interference; wave propagation in non-ionised media and remote sensing; wave propagation and remote sensing of ionised media; waves in plasmas; electromagnetics in biology and medicine.

Alignment of FoR and SEO classifications with OECD recommendations

The OECD Frascati Manual (2015) provides the internationally recognised methodology for collecting and using R&D statistics. The Manual considers research and experiment development (i.e. R&D) to be joint allied activities and thus specifies its classifications in terms of fields of research and experimental development (FORD) codes rather than FoR codes as used by the ABS. Further, the Manual defines R&D in terms of three types of activity: basic research, applied research, and experimental development. Here experimental development means producing new products or processes or improving existing products or processes. By definition, R&D is carried out in order to generate new knowledge products as its output, irrespective of its purpose.

The Frascati Manual specifies a different and much simpler classification for R&D than used in Australia, based on 6 major fields of R&D rather than 22 divisions of research. The Manual states that these 6 major fields are clearly defined but the level of disaggregation within each component is left to each country.

The NCSRS believes that the OECD description of research and experimental development, i.e. activity to generate new knowledge products, is more applicable to modern research activity than the ABS label 'research.' Thus the NCSRS would prefer to see FoR codes replaced with FoRD codes.

The Frascati Manual points out that the purpose of R&D may be very difficult to establish since an R&D product can be used for a variety of purposes. It outlines in Table 12.1 a socioeconomic objective classification comprising 14 major fields. This includes the category *Exploration and exploitation of space*. This is a growing area of international and national socioeconomic activity and the NCSRS believes there should be a SEO Division with this focus.

International definitions of space science and radio science

Very broadly, space science refers to scientific research carried out from space, and of the space environment. The principal international body representing space science is the Committee on Space Research (COSPAR), a member organisation of the International Council for Science. Its Commissions are listed in Appendix A. Following COSPAR, the NCSRS defines space science to include the following areas:

- the Sun and interplanetary environment
- Earth observation and climate
- studies of the Earth-Moon system, planets and small bodies of the solar system
- satellite and satellite-based positioning (i.e. satellite orbit determination and GNSS)
- aeronomy
- Earth's near-space environment, including the upper atmosphere and ionosphere
- space weather and impacts
- medical and life sciences related to space
- related space missions, ground instruments and data analysis techniques.

Applications of space science include:

- Space vehicle design and development
- propulsion technologies (e.g. hypersonics, ion thrusters)
- weather prediction and climate modelling as supported by space science
- space-based Earth observations
- precision navigation and timing services
- satellite enabled communication and data services
- over-the-horizon radar and surveillance
- space situational awareness and space surveillance
- effects of Earth's space environment on radio astronomy
- aerospace bioscience and medicine, human factors.

The COSPAR definition includes space-based studies of astrophysics, materials science and fundamental physics. These are excluded by the NCSRS to avoid overlap with research activities in astronomy and physics (for example, as represented by the National Committee for Astronomy, and the National Committee for Physics).

The International Astronomical Union (IAU) comprises nine Divisions, two of which encompass the Sun and heliosphere, and planetary systems and astrobiology (Appendix A). These overlap some areas of space science, although COSPAR is clearly the principal body representing space science. Further consultation between the astronomy and space science communities on proposed subdivisions is recommended.

The COSPAR definition of space science is largely followed by the editorial practices of major international space science journals, including: *Journal of Geophysical Research: Space Physics* (American Geophysical Union); *Geophysical Research Letters* (AGU); *Space Weather* (AGU); *Journal of Space Weather and Space Climate* (EDP Sciences); *Planetary and Space Science* (Elsevier); Advances in Space Research (Elsevier). More specialised journals include: *Journal of Applied Geodesy* (De Gruyter); *International Journal of Geoinformatics* (Assoc. Geoinf. Tech); various IEEE journals, etc.

Very broadly, radio science encompasses the study of the properties and applications of electromagnetic fields and waves. The International Union of Radio Science (URSI), also a member of the International Council for Science, is the principal scientific body representing studies of radio science. The associated areas of study are listed in Appendix A. Following URSI, the NCSRS defines radio science to include the following:

- Electromagnetic fields and waves
- electronics and photonics
- radio communication and signal processing systems
- EM wave propagation, including in the ionosphere and in plasmas
- remote sensing
- metrology and environmental effects of EM wave propagation
- electromagnetics in biology and medicine
- radio astronomy technology.

The URSI definition of radio science is largely followed by the editorial practices of major international journals, including: *Radio Science* (AGU); *Optics Letters* (OSA); *Applied Optics* (OSA); *IEEE Antennas and Wireless Propagation Letters*; *IEEE Transactions on Antennas and Propagation; IEEE Geoscience and Remote Sensing Letters*.

Both the COSPAR and URSI definitions include radio astronomy. This area is usually regarded as part of astronomy, but the ionosphere may affect the propagation of EM signals used in astronomy, and radio science R&D is essential in developing techniques used in radio astronomy. These aspects are therefore included by the NCSRS, while the broader areas of science associated with radio astronomy are excluded.

As outlined below, the current FoR codes are inconsistent with the classification of space and radio science fields of research by the world's international scientific unions and publishers.

Incoherence of the current codes

The present FoR codes most applicable to space science and radio science projects, following the international and NCSRS definitions above, are listed in Appendix B.

Clearly space and radio science projects can fall under a plethora of 4- and 6-digit FoR codes. Partly this is because of the range of topics (especially new ones) spanning these disciplines, but also because the classifications never properly represented space and radio sciences as coherent disciplines.

This is source of potential confusion when researchers choose FoR codes to best represent their work, and hence can lead to inappropriate selection of reviewers. This also impacts on R&D activity and future growth of these disciplines.

This confusion also leads to misclassification of non-space and radio science projects. For example, inspection of data on ARC funded projects completed over the years 2010-2018 shows that some projects which are clearly concerned with astronomy appeared under the FoR codes 020101

(astrobiology), 020108 (planetary science), and 020109 (space and solar physics). On the other hand, some space and radio science projects appeared under the FoR codes 020103 (cosmology and extragalactic astronomy), and 020105 (general relativity and gravitational waves).

Field 020102 (astronomical and space instrumentation) includes projects from astronomy, space science and radio science discipline areas.

Note that ARC grant applications usually identify more than one FoR code, perhaps because of a perception this may increase the likelihood of success. This provides more room for confusion when reporting activity.

Similar confusion between different disciplines occurs for other FoRs, e.g. 040302 (extraterrestial geology).

Clearly, reporting of R&D trends, expenditure and performance across the space and radio science disciplines will be incorrect with the current classifications. Further, the large amount of research activity in astronomy means that misclassification, or misunderstanding of the classification of projects, can adversely affect smaller but nationally important related disciplines such as space science. For these reasons space science research activities need to be separated from astronomy into a new 4-digit FoR Group encompassing relevant areas of space science research.

Changes in activities in space and radio science

The scope of the space and radio science disciplines has grown substantially in recent years. New areas of R&D activity have developed, due to advances in science and technology and the growing national and international urge to develop capacity in these disciplines. These growth areas include:

- Earth observations (e.g. using satellite-based gravity measurements, new opportunities for hyperspectral imaging with cubesats; data analysis techniques)
- Weather prediction and climate modelling (e.g. using satellite-based radio occultation to improve weather forecasting; improved understanding of coupling between the magnetosphere and radiation belts and the underlying neutral atmosphere)
- Precision navigation and timing services, including the science needed to improve these
- Space situational awareness, including development of sensors, active experiments, advanced risk assessments, and astrodynamics and advanced orbital simulations
- Space weather impacts on technology
- Development of small satellites and sensors
- Satellite data processing technologies, including artificial intelligence and on-board processing
- Advanced manufacturing systems, including in situ processes
- New launch and rocket and thruster technology
- Space medicine, remote healthcare, and space life sciences
- Environmental effects of EM wave propagation
- Electromagnetics in biology and medicine

- Space-related hybrid radio and optical communications
- Space-related quantum technologies for secure communication.

Some of these areas do not appear to be represented by current FoR codes (e.g. space medicine and space life sciences; electromagnetics in biology and medicine; astrodynamics). Conversely, data on ARC funded projects shows that the growing body of research on the detection and properties of exoplanets falls into a number of FoR classifications: 020101 (astrobiology), 020102 (astronomy and space science instrumentation), 020103 (cosmology and extragalactic astronomy), 020104 (galactic astronomy), 020108 (planetary science), and 020110 (stellar astronomy and planetary systems). This is confusing.

A new 4-digit FoR Group dealing solely with space science will allow inclusion of current and developing areas of relevant R&D activity with minimal confusion.

The current codes do not support national priorities in space and radio science

In the past decade several national agencies have made recommendations on national priorities in space science and related areas of radio science. These include:

- Australian Academy of Science, *Decadal Plan for Australian Space Science 2010 – 2019*
- Defence White paper 2016
- Defence Industry Policy Statement 2016
- Defence Integrated Investment Program 2016
- Space Industry Association of Australia White Paper: *Advancing Australia in Space*, 2017
- Australian Strategic Policy Institute, *Australia's future in space*, February 2018
- Department of Industry, Innovation and Science*, Review of Australia's space industry capability*, March 2018
- CSIRO, *Space, A roadmap for unlocking future growth opportunities for Australia*, September 2018
- Australian Space Agency, *Advancing space, Australian Civil Space Strategy 2019 – 2028*, April 2019.

In essence these all recommend development of Australian space-related capability, in particular in areas related to position, navigation and timing, Earth observation, communication technologies and services, space situational awareness, robotics and automation on Earth and in space, access to space, and 'leapfrog R&D'. In response the Federal Government has provided significant funding through a range of programs including

- $300 million to Geoscience Australia for the National Positioning Infrastructure Capability, the Satellite-Based Augmentation System, and Digital Earth Australia
- $19.6 million Space Infrastructure Fund
- $6 – 9 billion for space-related projects in the Defence Integrated Investment Program
- $110 million in government and matching funding plus $130 million in-kind for the SmartSat Cooperative Research Centre.

Clearly R&D in space and related radio sciences is an important national priority, with substantial investment which will span more than a decade. These discipline areas and the related industries should experience significant growth and will require accurate assessment and reporting of this activity. In order for the FoR classification to accommodate and accurately represent this expansion in activity a 4-digit FoR Field for space science, independent of that for astronomy, is required.

References

Revised field of science and technology (FOS) classification in the Frascati Manual, Working Party of National Experts on Science and Technology Indicators, OECD, Feb. 2007, https://www.oecd.org/sti/inno/38235147.pdf

Frascati Manual 2015: Guidelines for collecting and reporting data on research an experimental development, The measurement of scientific, technological and innovation activities, OECD publishing, Paris, doi:10.1787/9789264239012-en.

Appendix A. International Council for Science Definitions of Space and Radio Science

Committee on Space Research (COSPAR) https://cosparhq.cnes.fr/

Commission A: Space studies of Earth's surface, meteorology and climate
Commission B: Space studies of the Earth-Moon system, planets, and small bodies of the solar system
Commission C: Space studies of the upper atmospheres of Earth and planets including reference atmospheres
Commission D: Space plasmas in the solar system, including planetary magnetospheres
Commission E: Research in astrophysics from space
Commission F: Life sciences as related to space
Commission G: Materials sciences in space
Commission H: Fundamental physics in space

International Astronomical Union (IAU) https://www.iau.org/science/scientific_bodies/divisions/

Division A: Fundamental astronomy.
Division B: Facilities, technologies and data science
Division C: Education, outreach and heritage
Division D: High energy phenomena and fundamental physics
Division E: Sun and heliosphere
Division F: Planetary systems and astrobiology
Division G: Stars and stellar physics
Division H: Interstellar matter and local universe
Division J: Galaxies and cosmology

International Union of Radio Science (URSI) https://www.ursi.org/homepage.php

Commission A: Electromagnetic metrology
Commission B: Fields and waves
Commission C: Radiocommunication systems and signal processing
Commission D: Electronics and photonics
Commission E: Electromagnetic environment and interference
Commission F: Wave propagation and remote sensing
Commission G: Ionospheric radio and propagation
Commission H: Waves in plasmas
Commission J: Radio astronomy
Commission K: Electromagnetics in biology and medicine

Appendix B

Field of Research codes currently applicable to space science.

0201 Astronomical and space sciences
020101 Astrobiology; 020102 Astronomical and space instrumentation; 020107 Mesospheric, ionospheric and magnetospheric physics; 020108 Planetary science; 020109 Space and solar physics; 020110 Astronomical and space sciences not elsewhere classified

0202 Atomic, molecular, nuclear, particle and plasma physics
020204 Plasma physics, fusion plasmas, electrical discharges.

0401 Atmospheric sciences
040105 Climatology

0403 Geology
040302 Extraterrestrial geology

0901 Aerospace engineering
090108 Satellite, space vehicle and missile design and testing

0909 Geomatic engineering
090902 Geodesy; 090904 Navigation and position fixing

1005 Communications technologies
100508 Satellite communications

Field of Research codes currently applicable to radio science.

0201 Astronomical and space sciences
020102 Astronomical and space instrumentation; 020107 Mesospheric, ionospheric and magnetospheric physics; 020110 Astronomical and space sciences not elsewhere classified

0202 Atomic, molecular, nuclear, particle and plasma physics
020204 Plasma physics, fusion plasmas, electrical discharges; 020299 Atomic, molecular, particle and plasma physics not elsewhere classified.

0203 Classical physics
020302 Electrostatics and electrodynamics

0205 Optical physics: all fields.

0404 Geophysics
040401 Electrical and electromagnetic methods in geophysics

0906 Electrical and electronic engineering
090601 Circuits and systems
090609 Signal processing

0909 Geomatic engineering
090904 Navigation and position fixing

1004 Medical biotechnology
100402 Medical biotechnology diagnostics; 100499 Medical biotechnology not elsewhere classified.

1005 Communications technologies: all fields