

FM8
New Insights in Extragalactic Magnetic Fields

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Abstract. In this contribution we introduce the motivation and goals of IAU Focus Meeting 8, “New Insights in Extragalactic Magnetic Fields”. We provide a background for the nine contributions included in these proceedings, as well as the online contributions. A recap of the meeting is provided in the form of audience feedback that was collected during the wrap-up session at the conclusion of FM8.

1. Introduction

Magnetic fields are a key ingredient of the extragalactic Universe on many different spatial scales, from individual galaxies and active galactic nuclei (AGN) to clusters of galaxies and the cosmic web. They play an important role in the process of large-scale structure formation and enrichment of the intergalactic medium, having effects on turbulence, cloud collapse, large-scale motions, heat and momentum transport, convection, viscous dissipation, etc. They are of utmost importance in the growth of radio galaxies and AGN and are crucial for the formation of spiral arms in spiral galaxies, outflows and star formation processes.

Despite their importance and ubiquity, magnetic fields remain poorly understood components of the Universe. The origin of the fields that are currently observed remains largely uncertain. A commonly accepted hypothesis is that they result from the amplification of much weaker pre-existing “seed” fields via shock/compression and/or turbulence/dynamo amplification during merger events, and different magnetic field scales survive as the result of turbulent motions. The origin of “seed” fields is unknown. They could be either “primordial”, i.e. generated in the early Universe prior to recombination, or produced locally at later epochs of the Universe, in early stars and/or (proto)galaxies, and then injected in the interstellar and intergalactic medium. The cosmic origin of magnetic “seed fields” and the subsequent processes through which they are amplified give us critical information on the growth of structure in the universe. The history of these processes can be uncovered through accurate knowledge of the strength and structure

† This article was originally published with its supplementary material missing. This has since been updated in the online PDF and HTML versions and a correction notice has been published.

of magnetic fields in clusters, in the intergalactic medium, at the boundary of galaxy clusters, in the filamentary cosmic web, and in the relation of magnetic fields to gas flows in spiral galaxies, radio galaxies and AGN.

The coming years and decades will see a burst in our capacity to collect information and to develop our understanding of extragalactic magnetic fields. This change is due to the next generation of radio astronomy facilities, especially the SKA and its pathfinders and precursors, as well as major advances in MHD numerical simulations and algorithmic improvements to extract magnetism information from the databases. The Focus Meeting brought together the scientific community to discuss the challenges and opportunities for understanding the magnetized Universe from scales of galaxies to the cosmic web and to connect information from across the spectrum, to address the fundamental questions that remain unanswered:

- How did magnetic fields form and evolve, and how are they maintained?
- How do they control the acceleration and dynamics of relativistic particles in astrophysical plasmas?
- How do magnetic fields affect the evolution of thermal plasma in galaxies and clusters?
- How do magnetic fields illuminate otherwise invisible processes in the thermal plasma?
- How do the insights from magnetic field studies contribute to the larger questions about origins and evolution of structures in the Universe, from galactic to cosmic web scales?

Most of what is known about magnetic fields in the Universe comes from sensitive observations at radio frequencies, which directly prove the existence of relativistic electrons gyrating around magnetic field lines. In addition, measurements of the Faraday rotation effect on the polarized emission of radio galaxies provide information on both the magnetic field strength and its structure. Beside studies at cm and mm wavelengths, magnetism can be investigated at a broader range of other wavelengths. Indeed, the density of the cluster thermal gas obtained from X-ray data is a crucial parameter for the interpretation of Rotation Measure data. In addition, upper bounds to the magnetic fields in voids and large scale structure can be obtained from studies of the Cosmic Microwave Background radiation anisotropies and dust polarization, and from studies of the multi-TeV gamma-ray flux of distant blazars, whose emission is deflected by the extragalactic magnetic fields.

Given the huge shift in processing capacity that will be required by the observational facilities seeking to provide new breakthroughs, the time was ripe to take stock of the state of the field and to understand our successes and opportunities. This Focus Meeting engaged the observational and theoretical communities to consider the results already in hand, to present new algorithms and numerical techniques for the interpretation of the observations, and to address underlying theoretical issues. With this approach, we hoped to accelerate our ability to explore the massive volumes of data that will be delivered by next-generation instruments, toward our ultimate quest to obtain a deeper understanding of the magnetized Universe.

2. Selected Highlights

The aim of the Focus Meeting was to develop a diverse scientific program, covering a large range of topics related to extragalactic magnetic fields. The collection of papers presented in *Astronomy in Focus* is representative of the diversity of the contributions that animated the meeting. The meeting started with a welcome by L. Feretti and was structured around a series of invited talks, as well as a rich collection of contributed oral and poster presentations. The meeting concluded with a final discussion lead by

L. Rudnick. Readers are encouraged to peruse all the contributions, but we present here some of the highlights identified by the attendees themselves at the conclusion of the meeting. During the final discussion, audience members were invited to provide short written descriptions of what they found most interesting and exciting. They were admonished to cite work other than their own, and sometimes they even did that. Note that the citations provided here refer to these proceedings; where relevant, references to the original work are found in the individual contributions. So, with a modicum of editorializing, here's what they identified:

Early Universe, Cosmology

- Standard picture for the origin involves turbulent dynamo amplification in the interstellar or intracluster medium (*Subramanian's talk, these proceedings*).
- Primordial magnetic fields could have a measurable effect on the $B - modes$ of the CMB at low l : good news for magnetic field aficionados, but for disentangling inflation signatures, not so much! (*Yamazaki's talk, online*).
- MHD turbulence accompanying primordial fields might be capable of distorting the gravitational wave spectrum at levels accessible to LISA (*Kahniashvili's talk, these proceedings*).
- During the period of reionization, magnetic fields create Faraday rotation which can be observed in the CMB. Current estimates of $10^{-8} \text{ rad m}^{-2}$ at $z = 10$ are very encouraging for seeding the dynamos for later amplification in galaxies and clusters (*Ruiz-Granados's poster, online*).
- In the ongoing quest to identify the origins of primordial magnetic fields, a mechanism invoking photoionization in an inhomogeneous IGM around Pop III stars, primeval galaxies and quasars might do the job (*Langer's talk, online*).

Field amplification and large scale structures

Progress continues on a number of fronts to understand how the μG fields that we see today were amplified from much weaker seed fields. Recent insights include:

- It isn't clear that we can always generate the large scale coherence we need (*Sur's poster, online*), whether we can align the magnetic fields post-shock in cluster "relics" (*Ryu's talk*), and whether we can distinguish between astrophysical and primordial field origins in clusters (*Dominguez-Fernandez's poster, online*).
- Magnetic fields can suppress turbulence in the ICM, homogenize both temperature and density fluctuations (*Shukurov's poster, online*), and affect galaxy evolution and star formation (*talks by Tabatabaei, and Ramos-Martinez, online*).
- Power spectra do not sufficiently capture the structure of fields, which might form as filaments, ribbons, sheets, etc. (*Shukurov's talk, see online contribution by Seta; Jones' poster*)

Fast Radio Bursts

- The combination of Dispersion Measures and Rotation Measures for Fast Radio Bursts suggests that there are at least two different types. Contributions can be either local to the source or indicators of cosmological magnetic fields at levels $< 20 \text{ nG}$ (*Johnston's talk*).

Extragalactic radio sources

- Exquisite fine structure in Rotation Measures and magnetic fields is now being revealed by LOFAR (*talk by Hoeft, poster by Heesen*).
- ALMA is in the polarization business! including the discovery of RMs $> 10^5 \text{ rad m}^{-2}$ in 3C273's jet (*talk by Nagai*), and progress is being made in reconstruction of 3D fields in jets (*talk by Laing*).

- The first indicators of the relation between turbulence in the thermal plasma in clusters and the resulting fields are emerging (*talk by Bonafede, these proceedings*).

Normal Galaxies

- Progress continues on the challenge of dynamos on various scales (*talks by Chamandy, and Sokoloff, online*).

- On the observational side, field reversal now seen outside of Milky Way in the axisymmetric spiral NGC 4666 (*poster by Stein, online*), and even the pitch angle of the fields with respect to the spiral arms can be measured with good accuracy in M31 (*poster by Beck, online*).

- Large scale dynamos are sometimes sub-critical and will not generate strong coherent fields; causes are under investigation (*poster by Rodrigues, online*).

- Among many highlights from the CHANG-ES survey (*poster by Stil, online*), the Virgo galaxy NGC4388 has magnetized outflows extending to 5 kpc above the plane (*poster by Damas-Segovia*).

- Surprisingly, the small group of galaxies in Stephan's Quintet hosts an intergalactic field of strengths comparable to those seen in clusters (*talk by Nikiel-Wroczyński*).

Techniques and the Future

- Signatures of the primordial field can be decoded from local structure if we're clever enough to overcome a factor of 10^{24} confusion from other fields (*talk by Enßlin*).

- An incredible variety of new polarization information, including circular polarization, is coming in the next few to 10 years, new telescopes, surveys and techniques to exploit them: LoTSS, MWA, VLASS, POSSUM, MeerKAT, QUOCCA, SKA and even SOFIA in the far IR (*talks and posters by Mao, these proceedings; Loi, Ma, Rudnick, Heald, Horellou, Lopez, online; Gaensler, Hoeft, McKinven, Zinneker*).

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Supplementary materials

To view supplementary material for this article, please visit <http://dx.doi.org/10.1017/S1743921319004423>.