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😄Our three commandments ⛪

0. **NEVER NASTY, NEVER SARCASTIC.** Maybe the question is stupid but the person is not and they are just reading from external reports!

1. **We, the PIs, have all needed expertise for all proposed tasks**. Our in-kind collaborators or visiting professors can help us speed-up our results, best scrutiny our procedure and assist in the formation of students. -> not sure this is still true

2. We believe that our proposed procedure/interpretation is the most reasonable. However, in COSMOMAG we have all the tools to test and even adapt to different procedures, if the evidence changes. We have included many comparison tests in all WPs exactly for this. **We can produce breakthrough results even if Nature will surprise us.**

3. **Every task is synergetically designed to work with the others.** Even when only 2 PIs are involved for their technical expertise, the aims, the methods and the results are shared with all other PIs and are necessary to all other WPs. Thus we cannot remove task X from the project.

General Questions

BIG VISION OF THE PROJECT

1. **What are the main weakness of your project?**
   We consider potential problematic points of the projects as “risks” and we have tried to go through all those risks and find mitigation strategies. This means that from our perspectives, there should be no weaknesses (if they are defined as “risks that are not properly considered and addressed”.

2. **Which two sentences do you think will be added to every textbook thanks to your project**

“The earliest information on our universe comes from the Cosmological magnetic fields probe. It refers to the state of the primordial plasma just some microseconds (picoseconds?) after the Big Bang.”

We hope it will be “Cosmological magnetic fields exist, are nowadays observable in voids. They have a primordial origin, which can be traced back to the epoch of …” [depends on outcome]

3. **Where do you want to be in six years?**

We will be standing in front of this panel presenting new development of our project and the presentation will be starting “Just FOUR cosmological probes constitute the basis of ALL our knowledge of the Universe” (:–)).

We wish we will have a new mainstream branch of research, focused on the exploitation of our new cosmological probe, followed by the international community. We will have formed and strong international network of experts and scientists trained by the project.

4. **How is your “new” probe better/different than the other probes, is it complementary?**
   As we explained in the presentation: there is currently no observational data coming from the time before 3 minutes after the Big Bang. Our probe will be the first.

   There is no other such probe, the complementarity is crucial and our project fully wants to exploit it, by combining observations at very different epochs. Only through the full complementarity we can remove all degeneracies between different models (in the best case).

5. **What exactly do you mean by “holistic”?**

   By holistic, we mean that our research will combine, all together, several information, methods and observations, which are usually disconnected and treated separately in the community.

6. **What you exactly mean by “new probe”? What’s the quantity you are going to probe?**

   Our new probe is the present day characteristics of strength and scales of magnetic fields, and a quantitative methodology to trace them back to their origin in the early Universe.

7. **Are there major international initiatives that will make your project of less interest?**

   We are well integrated in nearly all known major international observatories related to cosmological magnetic fields, such as the CTA and SKA, PTAs, LISA,... Methodology wise, we are not aware of any other collaboration that combines such a complementary expertise and therefore is able to provide the same output as COSMOMAG. Since our project is about synthesis of all complementary data on cosmological magnetic fields, any new development in any research directions of our workpackages will only help our goal, by providing additional information to incorporate in the holistic picture.

8. **So, why will your approach work while others have failed?**

   Data for this only recently have become available. Single WP will be in the condition to go beyond the state of the art in specific lines of research (thanks to our expertise and new methods) but no single researcher can do it, we need a large synergetic collaboration, and it will be the first time such a team is created for this formidable task .

9. You are applying to the most expensive program of the Horizon Europe Framework. What are the pillar and the mission area of Horizon Europe in which your project best fits in?

   We are proposing Frontier Science and therefore we fall in Pillar 1 : Excellence Science. We want to create “high-quality new knowledge”, “strengthen human capital” and we commit to “open Science practices. “

10. **Who are your major competitors?**

    For each individual piece of expertise relevant to the project, we have colleagues, who are sometimes our competitors, that work on topics that are part of the project. For example, Montpellier group of Jedamzik that works on magnetic field evolution, Helsinki group of Hindmarsh that works on modeling of gravitational waves from phase transitions. But, to the best of our knowledge, there is no group similar to what will be COSMOMAG, which would combine all the expertise together to work on establishing an overall self-consistent picture of cosmological magnetogenesis.

11. **Are there any weak points in the research proposal that you need to clarify?**
    We might have better explained our strategy to bridge the large scale separation from primordial universe simulations with Pencil and late cosmological simulations with Enzo. Our strategy here will be to produce a suite of patched simulations, of increased size, so that there will be a continuity of spatial coverage. Pencil is needed in the early universe because it allows a more robust representation of MHD turbulence and radiative transport there, while Enzo is necessary to simulate large-scale structures because it has gravity, and galaxy formation physics implemented.

12. **What do you need all this money for? Why do you need this big budget?**
    Without the Grant, it would be impossible for each one of us, independently, to reach the scientific objective of our project, because it requires complementary and vast expertise and significant workforce working together at the same time and towards the same objective. Individually, it would be impossible for each one of us to recruit all the necessary highly qualified personnel, or train new researchers for this task, and we will miss the resources to implement the synergy. They need to meet and exchange visits very frequently all through the project, because we expect the main advancements to be possible only through focused teamwork.
    No individual group could so far achieve the same goal with propose in COSMOMAG.

13. **If the approach fails what will be the alternative way forward? The panel does not want to fund a six-year project if the success is entirely dependent on one method/approach that may fail.**
    Our project combines so many observables and methods that a single point of failure will not compromise our project. The project is designed to cope with many unexpected findings, and to produce breakthru results in anycase, as evidenced by the track record of the four PIs (i.e. many publications and results over the year using different methods/approach)

14. **You already had several works together, why cannot you perform your science regardless of the Synergy grant?**

    MISSING

15. **If the project is not funded, will you keep working together?**

16. **If the project is funded, what will precisely do in the first months? Do you already have a concrete plan? (look at recruiting plan of the first 6 months)**

17. **What is unique about your project?**
    It has never been proposed before, it is based on observational data and theoretical ideas which were not present until a couple of years ago, and it will use telescopes which are under construction which will be completed during the project. And therefore what we will do has never been possible before.

18. **What is the main outcome of your project?**
    We think we will plausibly show that cosmological magnetic fields exist, that they are nowadays observable in voids. If so, they must have a primordial origin, and thanks to COSMAG we will be also able to constrain their generation mechamisms (depending on GW data). In all cases, COSMOMAG's legacy will be the development of a new cosmological probe of epochs never probed so far, to explore strong links between nowadays and the very early universe.

19. **Can you clarify the innovative aspects of the technique you are going to use compare to what others are doing?**

20. **Why is your project timely?**

21. **What are the long standing questions of the community that you are going to answer? (also in the case of non-detections)**

22. **What will be your guaranteed/minimal result?**
    (just refer to last slide?)

23. **In what sense do you have "expected outcomes" in your project proposal?**

24. **Does it promise to go substantially beyond the state of the art?**
    Obvious ?

25. **Has it the chance to cross-fertilize disciplines? / What will be your impact on society? / What is the place of Europe in your project?/ What is the scientific transformative potential? / Does it have a grand challenge that can boost European research? Will your project open new research directions, what are they?**
    If we succeed in producing strong evidence for beyond the standard model phenomena in the early universe, linked to magnetic fields, this will have a transformative impact on high energy particle physics, which will for sure influence future experiments at particle colliders (LHC, and the future possible larger circular collider).
    Understanding the origin of cosmic magnetism is one of the key themes for the construction of the Square Kilometer Array (which has large european participation), and

thus an answer to this will impact the entire astrophysical community. If we "solve" the H0 tension with magnetic fields, this will have a strong impact on modern cosmology.

26. In what field of application would your project be useful?
    Cosmology, astronomy, fluid dynamics and magneto-hydrodynamics, particle physics

27. What is each one of the PIs actually going to do?
    We all have hands on experience in data analysis and/or numerics and we will initiate the project and train students and post-docs. We will be involved in first person in all critical technical tasks (e.g. code implementation, observing proposals, data analysis) and assist the work of post-docs. During the project, we will focus on the synergy aspects by identifying new links between our members.

28. I noticed that the bulk of the work will be carried by Post-Doc and PhDs, what are you going to do beyond supervising them?
    Beyond the crucial task of supervising, our technical work will be crucial in initiating all tasks. At every step in the project, we are going to use our technical expertise to solve problems, validate simulations and code produced by members. A significant fraction of our activity will also be to ensure communications and to gather continuous feedback from junior members, through regular meetings.

29. What is the role of PI Neronov?

30. What is the role of PI Caprini?

31. What is the role of PI Vazza?
    He will do code implementations in ENZO to simulate magnetism in the present-day universe, and he will interpet radio observations based on this. He will mostly be working at code implementations, and will train Post-Docs and PhDs and help them with the production of full simulations.

32. What is the role of PI Brandenburg?
    He will produce simulation of the early universe with Pencil, predicting magnetic field evolutions and gravitational wave productions, and radiative transport during recombination. He will do mostly code implementations, and train Post-Docs and PhDs and help them with the production of full simulations.

33. We have one more minute, do you want to make a final statement?

34. I**n which order did you write your proposal? First B1 or B2?**
We started from a draft of B1 to define the basic questions and methods, then we converged on details working on B2 and then we finally revised B1 accordingly.

35. Which important research gap/currently intractable problem do you aim to tackle?
Coupling of very different cosmological epochs? The modification of bayron an DM density perturbations (and recombination) due to magnetic field effects. ?

ORGANISATION / TEAM ASPECTS

36. What is the exact role, contribution of expertise of "in kind members / visiting professors / advisors in the board"?
– In-kind contributors are colleagues at our home institutions and we obviously want to leverage our long-lasting and fruitful collaboration with them. They will provide complementary insights into certain tasks in some WPs. We have experience in co-supervision of PhD students with them, we will extend this practice also in the course of the project.
– Visiting professors will provide us with "reality checks" and "complementary insights" into our work progress on specific tasks in some work-packages. Visiting professors will also contribute to dissemination of results generated by our project to the larger scientific community.
– Advisors (members of the Advisory Board) will supervise the overall progress of the project, both from the scientific and management point of view.

37. Why are the people in the team the best? Why have you chosen this team in particular? Why is this particular combination of the PIs the best for the project?
We made sure to select key people who were arguably the first to produce pivotal results in the most important aspects of COSMOMAG (examples: first paper for the generation of gravitational waves from primordial magnetic fields; first link between blazar observations and magnetic fields in voids). Some of these topics were disconnected until recently, so this justifies why this team has never fully worked together before, but is planning to do now.

38. **This project is slightly outside your 'comfort zone', how are you going to cope with this?**
Only with such ambitious project, and thanks to the strength of the synergy, each of us can invest substantial time and energies by expanding our own expertise in different territories, and gain new powerful ideas and connections from the international community.

39. **Organisation of internal meetings?**
This is a highly collaborative project so we meet (remotely or in person or remotely) very often. At the start of the project the executive board made of the 4 PIs will meet weekly to best initiate the project and coordinate on the advertisements of all positions. Later on in the project, we will have weekly meeting for all tasks involving at least two PIs, to ensure the co-design of simulations or observations. Furthermore we plan to have yearly workshops involving the entire collaboration, for the synthesis work. We will meet yearly also with the advisory board. We will also frequently meet at other international meetings.

40. **Collaborators seem to have a too key role in your project, can you comment about that?**
The four PIs have the full scientific responsibility and expertise needed for the project. However, whenever possible we will use our in-kind members (or visiting professors) to speed-up some of the corresponding developments and to better validate our findings.

41. **How are you going to ensure a fair gender representation in your project?**
All our Host Institutions have strict protocols and code of conducts to ensure a fair gender representation and selection process. On top of that, all PIs will be proactive in advertising all job opportunities to the largest as possible number of female applicants. In the project, we will continuously review our task assignments, with periodic meetings, to be ensure a fair gender distribution of key tasks and visibility at meetings.

We will make provisions favouring gender equality. In the hiring process, we will consider career breaks, we will accommodate where necessary parental leave and remote working. Of course, our host intsitutions have equal salary levels independent on the gender.

42. **How are you going to ensure an inclusive selection process and diversity in your team?**
All our Host Institutions have strict protocols and code of conducts to ensure a fair representation of minorities and selection process. On top of that, all PIs will be proactive in advertising all job opportunities to the largest as possible international pool of applicants. In the project, we will continuously review our task assignments, with periodic meetings, to be ensure a fair minority distributions of key tasks and visibility at meetings. In the case of impossibilities in travelling due to VISA issues, we will ensure always a remote connection possibility for our members.

43. What is the carbon footprint of your project? What about the usage of big infrastructures, or the organisation of large meetings?

We rely on the usage of large computers facilities who are already taking action for "green computing". Most of our observations will come form survey produced by large observing facilities (e.g. CTAO, SKA), and are going to be produced regardless of COSMOMAG. In the organisation of meetings, we will make sure all meetings locations in the EU can be reached also via train, and that the possibility of a remote connection is always present.

44. How are you going to select a Ombudsperson?

The PIs will nominate one person from the people in the advisory board as project ombudsperson (which can also be changed every two year).

45. Independence – (from e.g. platforms, collaborators, former supervisor etc)

COSMOMAG is data driven, hence we need continuous access to observations. Our PIs are part of all key ones, although several data will also be publicly available with time. All PIs are group leaders and are fully independent from other senior colleagues. All key expertises required to bring COSMOMAG to success are in the group already, and the important contributions by our in-kind collaborations will allow us to faster reach our goals, and involve a larger network of researchers.

46. Budget – extra equipment? Feasibility – is the work promised in line with the funding requested/available?

The budget in COSMOMAG is mostly driven by personnel, collaboration meeting, workshops and computing equipment. The costs have been validated with our host institutions, and the experience of PIs in dealing with significant grants ensures their estimates are reasonable. No realistic reasons for exceeding the requested budget are foreseen.

47. Why is this work best carried out at your Host Institution, and not e.g. in the USA,...?

All key observatories or telescopes listed in our proposal are either fully international collaborations (CTAO, LISA, SKAO) or European collaborations (LOFAR) [else?] , and we have access to them through our host institutions. The computing needs of the project are well covered by supercomputers available in the host institution, or larger European consortia (e.g. PRACE)

48. What is your strategy for selection of collaboration partners, e.g. with competitors?

49. Expertise in area X/method Y seems to be missing in your project...?

50. Your interaction with other ERC grant holders at the institution?

51. The synergy aspect of your entire project does not stand out. Can you say more about it?

52. How will your PhD and Post-Doc profit for being in a synergy project?

53. What are the PIs main achievements so far?

We have never contributed so far all to the same paper or research.
Each of us has profoundly changed the state of the art of our line of research, and obtained results which changed the way in which people do research in our fields.
Each PI: Brandenburg: seminal results in turbulence and magnetic fields in several plasma environments (from galaxies to stars to the early Universe) with the PENCIL code he created, now used in hundreds of papers. Neronov: pioneered the use to gamma-ray observations of blazars to probe the magnetisation of voids. Caprini: she pioneered the study of the gravitational waves production by primordial magnetic fields, and she obtained fundamental relations between primordial generation mechanisms and magnetic field properties in the early universe. Vazza: fundamental characterisation of non-thermal phenomena (cosmic rays, turbulence, magnetic fields) in galaxy clusters and cosmic structures using innovative numerical simulations.

54. Why will the ERC Grant be crucial for you at this stage?

55. What impact of the ERC project on your field (and possibly beyond) do you envisage beyond the project duration?

56. What is your more long-term research vision? (5-10 years)

57. What could be possible themes of the PhD topics?

58. Is there any problem if PI Brandenburg is close to retirement by the middle of the project?

No, he will be able to employ himself on the grant. The supervision of PhD students will not be a problem because they will start when Brandenburg is still employed, both of the PhD is even co-supervised by Caprini.

RISKS, TIMING OR RESULTS ISSUE ALONG THE PROJECT

59. **What would you do if equipment X/PostDoc Nr. 2 were not funded by the ERC?** (It should be clear from your answer that this would limit the impact of your project as you have carefully planned your budget; you would apply for alternative funding sources,...)
    The budget and the project design were done carefully, so removing either a piece of equipment (e.g. local computing nodes) or elements of personnel will cause a significant delay or loss of results. In this case, all PIs are going to look for additional funding sources.

60. Validation of project results: How will you know that you have succeeded? How will you interpret results? E.g. statistical power analysis,...?
    Some ideas to work one: a) predictions to be tested with future particle colliders b) predictions for LISA or SKA for the scenario in which PTA signal is from cosmic magnetic fields;

61. **What is the key risk of the project? How do you deal with it, what is your plan B?**
    What if during the project we will have to revise the magnetic field strength and scales to the left?

62. **What if your phd/team member does not reach the goal you assigned to him/her? What will you do?**
    We absolutely want our junior recruits to enjoy this endeavour with us, so their performance is equally important to us than their well-being. This is key for the synergy to work. COSMOMAG is structured so that through frequent collaboration meetings, networking, bi-weekly status meeting between the PIs groups, and Advisory Boards (including our ombudsperson) we will timely identify and react to any "performance" issue. We collectively supervised more than 60 between master and PhD students [FV counted this based on our CV, not accounting for bachelor or post-docs] so far, and thanks to our experience with international students with many possible different background and attitudes, we have ample ways of solving this issues, i.e. by collectively redistributing tasks, reshaping time schedules, or increasing the help by senior colleagues in the collaboration.

63. **What if the ERC decides to fund your project with a X% less of budget? Which objectives you will be able to achieve?**
    We will look for additional funding sources, trying to keep the project as is [something about the fact that our synergy won't work if we start removing pieces and WPs]

64. **We have the budget to fund just X projects over more than 800. Why yours should be among the funded projects?**
    In terms of ambition in physics, it is almost by definition impossible to find a project more ambitious than COSMOMAG, which aims at connecting the two largest imaginable extremes in the history of the Universe. We have the potential to deliver fundamental new inputs to the development of standard model of particles , going beyond it.

65. **What is your dissemination/outreach strategy with the general public?**
    We will take advantage of the many public outreach events that our HI are routinely organising (EU night of researchers, public openings, public lectures etc), and obtain spaces dedicated to our project. We will make sure that each big result of the project is advertised via press release and via social media. In parallel with the regular program of our conferences, we will make sure to organise public seminars on our important themes.

66. **I think that your project is too ambitious, can you comment about that?**
    It absolutely is very ambitious, but the results we collectively produced so far, the data and methods we will have access to, and the synergy approach we designed together makes us

67. **You never worked together before: how can we be sure you will work well together?**
    We know each other since several years, and we published in pairs half a dozen papers, related COSMOMAG topics, only since recently new instruments and observations have allowed us to concretely think about joint works. This has already resulted into the publication of a new joint publication (Brandernburg, Neronov Vazza 2023) , and over the last year we have already met several times to discuss future works and meetings.

68. Why are we the best/only persons to carry it out?

69. Is the other person(s) really needed as a PI or only as a team member?

70. Is it timely? (Why wasn't it done in the past? Is it feasible now?)

71. What's the risk? Is it justified by a substantial potential gain? Do we have a plan to manage the risk?
72. If you get results with one specific collaboration, can all PIs be added to it?
    The norm in our field, and in all collaborations we will use in COSMOMAG, is that additional collaborators outside of the collaboration can always be invited in papers.

73. **How do you recruit/select people?**

The new positions will be publicly advertised and the selection will follow the local rules for each institution, paying particular attention to diversity aspects. We will make sure that all advertisements mention the highly collaborative and international environment in which each post-doc or PhD is meant to work.

74. **How will the postdocs and the PhD students collaborate?**
    For tasks involving PhD and Post-Docs together, they will meet together with PIs (also from other WP) to define all to-dos in time. We will encourage relations between post-docs and PhDs because they are vital for the informal exchange of information, for example promoting more informal meetings not involving the PIs.

75. **What if a PhD or Post-Doc is underperforming or struggling?**
    First, we all have long experiences (depending on seniority of course) in supervising students at any level. In anycase, we will make sure to frequently and timely have exchange with students, and we will also make sure they often interact with other members (senior/junior) of the project. There also is a ombudsperson in COSMOMAG, to best address more personal issues with local PIs. This will ensure that any potential issue is recognised in time, and that people can even be reassigned to different tasks in the project, or that a particular duty is redesigned/reshuffled.

76. Baryogenesis bounds: if you generate these B-fields before EW do you have troubles with those? (smtgh about helical fields and isocurvatures perturbations). This is a recent concern about Kamada et al.
    The answer to this is not fully clear …

WP1

77. The synergy aspect of this project is not very evident, can you explain in this sense this will be a synergetic WP? It seems you can do all activities in parallel and without collaboration.

78. **Is your project destroyed if you find that the voids are completely polluted by the outflows from galaxies?**
    All groups who simulated this agree that outflows cannot possibly contaminate <100GeV blazar observations, while in the case of RM there are some disagreement. In COSMOMAG we will produce the best possible suite of simulations to produce joint predictions for radio and gamma observations, continuing a line of research already in

place. If for unexpected reasons the pollution by outflow is shown to dominate voids, this will be anyway a breakthrough in galaxy evolution and it will represent an exciting challenge for our understanding of galaxy formation, with profound implication for the study of feedback, AGN and particle acceleration in the universe.

79. Can you explain in a few words how the constraints from voids work?

80. What if less extreme blazars are observed?

The more the better, but also with less blazars it is possible to do the proposed science.

81. Non-detection of GeV background (argument for plasma instabilities?)

82. Interpretation of your radio synchrotron and Faraday rotation data depends on assumptions on electron density and cosmic rays in the LSS, which are uncertain. How would you deal with that uncertainty?

During his ERC StG project, Vazza has jointly modelled synchrotron and RM data (as well as X-ray, SZ, HI and other data) in his simulations, in order to break or minimise all these degeneracies.

83. How will you treat Galactic foreground for the RM study? How can you model Galactic Foreground if there are no radio astronomers in this Task?

84. You mention two gamma-ray propagation codes (CRbeam, CRpropa) . What's the best?

85. Can you comment about detectability of helicity? Will you look for it?

86. Any issue with timing of CTAO?

87. WIll you have dedicated or sure access to CTAO and LHAASO observations?

88. Is the timing of the SKA critical? What if it is late?

A delay of SKAO will be unlucky, but not critical. While the SKAO will boost the number of observable RM sources, we will anyway be able (and already are) to use SKAO's precursors, like LOFAR, MEERKAT, EMU, which will be steadily increasing their amount of sources and will keep go deeper in sensitivity.

89. Are you expert in Radio observations? Who is going to reduce the observations?

FV did his PhD in a Radio Astronomy Institute, is part of LOFAR, is the PI of 4 successful radio observing proposal (LOFAR, JVLA and GMRT) and has been a key collaborator of all most important radio detections attempts of the cosmic web in these latest years. He has supervised PhDs and Post-docs on cutting edge radio observing projects and his Host Institution routinely provides top quality training for radio astronomers. He is a

strong contributor to the SKA science case (leading chapters in SKAO White Books) and is involved in the preparation of synthetic data for the next SKAO data challenge.

90. Do you have dedicated access to LOFAR/EMU observations?
FV is member of LOFAR and part of EMU working groups. LOFAR data in polarisation will be accessible within the collaboration, while for EMU polarisation (POSSUM) data it will be easy to enter that part of the collaboration. FV is already involved in the workflow of RM data from these surveys and the planned tasks in WP1 do not conflict with other planned activities of working groups, also because some of the key personnel is our inkind collaborators (Carretti, O'Sullivan, Bonafede).

91. Do you have dedicated access to future UHECR data in PAO?

92. What if the LUDO-LOFAR proposal is not accepted?
If this particular proposal for Lofar 2.0 will not be accepted, we will still be able to apply through different consortia (e.g. through italian guaranteed time or LOFAR working groups) to a similar proposal, which is a key priority in LOFAR.

93. Now we have Lower bounds on IGM from Fermi, when we will observe it with CTA, how sure will be that this will be not an astrophysical signal of B-fields?

94. If we have a CTA detection, can we exclude it is going to be a plasma instability?
95. Why did you choose this specific method to model the galactic foreground?

WP2

96. The synergy aspect of this project is not very evident, can you explain in this sense this will be a synergetic WP? It seems you can do all activities in parallel and without collaboration.

97. “Innovative” cosmological simulations: in what sense are they innovative?
It is the first time ever in which direct numerical simulations of magnetic field generation in the primordial universe are injected into a fully cosmological simulation -also including galaxy formation physics and the feedback of magnetic fields onto galaxy formation. This will arguably represent the widest (and boldest) coupling of cosmological epochs and scales ever attempted in cosmological simulations (?)

98. How much does you project depends on the LCDM model assumption?
Our project does very little depend on cosmological detail. In the primordial universe, we are radiation dominated, hence dark matter is either irrelevant or just not created yet, and dark energy is totally irrelevant. In the late universe, the evolution of linear structures

like voids and filaments is weakly affected by dark energy (or details of dark matter, e.g. cold vs warm dark matter) but these differences introduce very little effects on our observables (RM or blazar observations).

99. How critical is the modelling of turbulence in simulations? Do you have analytical models to back it up?

We know what the equations of magneto-hydro dynamics are, we focus on direct numerical simulations, meaning we are solving the equations as stated.
Especially in the early universe simulations, no model assumptions are used. An important part of our work is to understand the key laws analytically, and our numerical work will underpin these theories.
In late-universe cosmological simulations, the larger range of scales requires the use of sub-grid modelling. We will investigate to which extent changes in the sub-grid models can affect the magnetisation of galaxies and their outflows. However, to be best of our present knowledge, even if the ejected fields might result stronger, their filling factor will always remain small.

100. Where and when exactly will Pencil and ENZO simulations going to overlap?

They will overlap across recombination epoch, which is 400,000 yrs after the Big Bang. Pencil will pass magnetic field spectral properties and amplitude to ENZO simulations. We will do a patched design of runs, so that the two codes will be able to overlap in scales (at least partially).

101. Does MHD approximation always work?

We are fully aware that kinetic plasma effects are fundamental on many aspects of astrophysics. However, for all the scales and epochs we are concerned with in this project, a fluid MHD description is perfectly valid because at all epochs (both radiation dominated in early universe or late large-scale structure and galaxy simulations) we are in a collisional regime and the fluid is highly conductive. In Pencil anyway there already are capabilities for Particle In Cell Physics and extending MHD.

102. Why do you care about magnetic helicity?

Magnetic helicity is an extremely well conserved quantity. It plays an important role even when it is vanishing on average. A detection of magnetic helicity would directly point towards parity violation and possibly to an explanation of the matter-antimatter asymmetry.

103. Are you going to detect it in COSMOMAG?

The detection of polarisation from GW will imply helicity of primordial magnetic fields. In CMB there are hints of detections (correlation between E and B polarisation called cosmological birefringence) which does point to parity violation. However this can also be produced by contamination by the galactic or systematics in the telescope.If this is

not detected, this will point to an interesting physical tension. There have been only a few proposal to detect it through fully-sky analysis of photon arrival directions, however the uncertainties appear to be larger than anticipated.

104. How will you treat subgrid models in cosmological simulations? How do you deal with uncertainties and limitations of these models?

Based on all the results so far, also by Vazza, the expected amount of dynamo amplification on sub-grid scales is little or negligible in filaments or voids, which are the targets of our simulations. Unresolved dynamo might affect the amplitude of B-fields in outflows from galaxies, but will not change the filling factors of bubbles. In the ENZO code, there already is the capability for sub-grid models of turbulence, which we can test if for whatever reason it will appear to be important.
(see next answer for feedback subgrid models)

105. For constrained simulations how do you decide which is the best feedback model?

We have devoted an entire task in WP2 to the accurate testing of the range of possible feedback model implementations within the same code, in order to bracket the possible uncertainties. The goal is to anchor our predictions of magnetic fields to feedback models which can well reproduce both low AND high-z (including available JWST results avaialbe at the time) galaxy data. This extends a line of research conducted by Vazza in the latest few years in his ERC Starting Grant, and it will also involve a couple of in-kind members (Bondarenko & Revaz) for independent assessment and stressting of our results.

106. How will be your dedicated AMR strategy to increase spatial resolution?

Vazza has experience in designing new mesh refinement strategies in ENZO to selectively increase the resolution to focus on specific processes (e.g. shocks, turbulence). The design of the perfect ad-hoc strategies will require some testing but it is a standard procedure and it can also use what has been implemented in other codes.

107. Why are ENZO simulations better than Illustris (or else)?

Vazza has devoted the last 5 years to the development of a numerical framework in the ENZO code exactly to develop simulations of different models of magnetism (astrophysical vs primordial) in his ERC StG MAGCOW, and has at the moment the only set of simulations of magnetic fields which can well reproduce all known observational constraints (gamma/RM/synchrotron). However, in this project we will probe scales and epochs never fully explored so far, and in COSMOMAG we have the expertise and the methods to adapt to new numerical approaches and readily test with other simulations (also by inkind collaborators), if needed.

108. There is a lot of computing time asked (40+ 45 million CPU hours over 6 years). How realistic is it to get all that computing time within the project?

Our track record shows that we can routinely access very large amount of computing times on a yearly basis. We have dedicated computing time in our host institutions, and we have also reserved a budget at two Host Institutions (Nordita & UniBO) to additionally buy computing nodes (5 and 5) to have further continuous reserved access. Also, for such an ambitious process we can routinely apply to EU Prace calls for larger computing projects - which we have routinely been doing with success in the past.

109. Would your cosmological evolution code cover all possible regimes of magnetic field evolution (say, transition from hypermagnetic to magnetic field at electroweak phase transition)?

Although this was not explicitly anticipated in the project, the exploration of this transition has already be started with the PENCIL and exploration in this respect have already begun in collaboration with one of our in-kind member, Oksana Iarygina.

WP3

110. The synergy aspect of this project is not very evident, can you explain in this sense this will be a synergetic WP? It seems you can do all activities in parallel and without collaboration

111. The strategy to combine Pencil and ENZO is not clear

112. Can you give us an example or clarify how magnetic fields can be created in the primordial universe?

Quantum fluctuations will provide very small fluctuations of EM fields, which will be rapidly amplified during the Inflation

For several mechanisms, the key mechanism is the formation of an instability (like Weibel instabilities) requiring anisotropy of the velocity field.

113. **How will you do better than Jedamzik's approach? How sure it is that your results will be better?**

WIth Pencil we will use much larger (4096^3, and possibly up 8192^3) direct numerical simulation, allowing us to probe a much larger dynamical range, and we will have full radiative transport (photon-Boltzmann hierarchy), unlike previous work, allowing us to model the transition from viscously damped regime to the photon-drag regime. The synergy of COSMOMAG will allow us to restrict the possible initial conditions (B, lb) to

run the simulations, We are inviting as visiting professor K.Jedamzik in this work package.

114. Who will run Boltzmann code simulations? Who is going to produce CMB analysis?

We are going to do post-analysis of publicly available CMB data, using the Boltzmann code of our in-kind collaborators, supervising a PhD student who will produce …

115. Are you a member of PTA? Of LISA?

Yes.

116. How do you exclude the contamination by SMBH?

Both explanations are presently possible. We have included in the project (T3.1.3) ways in the project to use PTA data in combination with other future probes (LISA, SKA) to measure the spectral shapes and detection of anisotropies, to distinguish the signals.

117. What it will be proven, during the project, that the SGWB is caused by BH?

118. Which catalog of local SMBH is going to be used?

119. Can you explain how are GW connected to magnetic fields? (in a plot?)

120. Is CMB not providing information of the universe before 3 minutes? (B-modes)

121. Will you address B-fields influence on the 21 cm data?

122. What's FV role in WP4?

FV has already worked at papers with Paoletti and Finelli on the combination of their CMB modelling with cosmological simulations. He will supervise a PhD student working in close collaboration with them and Caprini on producing new CMB forecasts for LiteBird.

123. What if LITEBIRD will detect B-fields on the CMB?

The shape of the spectrum will inform us on the source of the polarisation. B-fields generated by phase transitions may produce signals distinguishable from inflation, while the inflationary magnetic field could produce a fully degenerate signal with inflation. Thanks to the results of our project by 2030, we will characterize the effect on the CMB of an inflationary B-field to provide insight to distinguish the infl. B-signal in a possible lightbird detection .

WP4

124. The synergy aspect of this project is not very evident, can you explain in this sense this will be a synergetic WP? It seems you can do all activities in parallel and without collaboration

125. If you see inconsistent evidences for magnetic field in different detection techniques, what will be your conclusion?

126. What do you mean exactly with "Beyond the Standard Model"?

127. Does a magnetic field general in the early Universe uniquely imply BSM physics or can you produce B-fields in voids with processes within the SM?

128. What will you learn about dark energy?

We will provide information about the fundamental laws of physics at high energy scales, much higher than in colliders. If the explanation of dark energy resides in Beyond SM physics, there is some possibility that our final results can influence and improve the knowledge at this epoch.

129. What will you learn about dark matter?

130. The frequency ranges of PTAs is too limited (by observation time) to discriminate models through their shapes.

We will combine three aspects: fitting spectral shape, detecting anisotropy, detecting a continuous wave

131. What will you learn about matter-antimatter asymmetry?

132. Understanding of GW mostly depending on the assumption that QCD it is a first-order transition, while probably it's a cross-over.

The order of the phase transition is an information we can infer from the presence of a SGWB. So if we can prove the PTA signal is a SGWB of primordial origin, we will constrain the physical conditions of the QCD transition to be first-order, which would be a Beyond SM phenomenon.

133. Contamination by all sources of GW?

In COSMOMAG we participate in LISA and PTA to the effort of modelling the instrumental noise to minimise the systematic and have the best possible characterising the expected primordial bg, which is fundamental to search for the signal in the data. ***?***

134. What if there is generation of B-fields by two different epochs? (EW and QCD)?

We will exploit the great advantage of the use of GW, which are very sensitive to the initial generation and not to the later processing of magnetic fields by turbulence. ***?***

135. **How can you break the degeneracy between different models of primordial magnetism, producing the same endpoint but starting from a different initial magnetic field? (i.e. different paths depending on helicity)**
If gamma and radio observations pinpoint a definitive answer on the amplitude of B, COSMOMAG will allow us to trace it back to possible initial conditions; combining it with Gravitational waves we will be able to constrain the Initial conditions to a narrow subset and connect this to the BSM scenario compatible with this.

Discussion with Georges Meynet:

4 PIs presented 2.5 min (not linked to expertise of PIs)

Criticism was that one part of the project (construction of an analogue model of supernova explosion) is not giving relevant insight into science of explosions and not just an analogy, not giving new insight.

They had very positive opinion at the exit from the interview, were surprised to see this criticism.

>All following questions were incorporated in the long list above!

136. How do you see your synergy and what will be your organisation during the project?

137. What do you think is the most important point?

138. What will be your impact on society?

139. What is the place of Europe in your project?

140. Will your project open new research directions, what are they? (we need to talk about LISA, Einstein Telescope)?

141. How will you project develop on longer perspective?

142. Co-supervision of PhD is good, we should know how to stress this if asked about “new generation of scientists”.

143. Can you describe the risks related to the project and our mitigation strategy. (finding a good PhD is btw. A major risk).

@Recurrent questions “liked” by the evaluation panels (according to https://www.youtube.com/watch?v=F4qXVGcdH5w):
F