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ICRC 2021: Gamma-ray Direct Rapporteur

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This proceeding is an attempt to overview the space-based gamma-ray astronomy (GAD) presented at the the 37th International Cosmic Ray Conference held virtually in Berlin. There were 103 abstracts submitted that were self identified under the GAD topic. Because ICRC was held virtually this year, for the first time, the organizers had a unique opportunity to experiment with different formats than previous conferences. For each of the parallel sessions, presenters pre-recorded their talks, and under the GAD heading, there were 121 presentations recorded. This does not include the review and highlight talks which will not be covered in this document. Finally, in lieu of the parallel sessions, the conference was organized into a series of discussion sessions, twelve of which were a GAD specific topic. Each discussion session was organized independently by the convener of that session, and several of the sessions overlapped with other topics. The most overlap occurred with the ground-based gamma-ray astronomy, unsurprisingly, as gamma rays tend to not care which instrument is detecting them. There was also overlap with the new Multimessenger session, the space-based cosmic-ray astronomy session and the dark matter session. Overall space-based gamma-ray astronomy covers a wide range of scientific topics; however, four themes continued to appear: there is unprecedented coverage of the gamma-ray sky, the gamma-ray detecting missions and instruments are mature and well understood, new missions and instruments are coming online, and our current understanding of the sky is leading us to develop new experiments. A virtual conference posed a unique challenge to the organizers; however, I believe the conference organizers, discussion session conveners and the Zoom/Conference support staff did a fabulous job organizing this during these difficult times and I give my sincerest thank you to them.

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1. Introduction

It is an honor to present a rapporteur talk at the 37$^{\text{th}}$ International Cosmic Ray Conference ICRC on space-based gamma-ray astronomy (GAD). Because of the ongoing COVID pandemic ICRC was held remotely for the first time in its history. This ICRC received more contributions than ever before, which combined with the online interface made an already large and difficult task, even more challenging. There is no way that I can represent all space-based gamma-ray astronomy in a single presentation or proceeding, hence my scientific biases will come through. This proceeding will focus on the contributed work and the discussion sessions and not on the invited or review talks. I would also like to note the current scale and scope of the gamma-ray astronomy scientific community in general. There are now more flying and well characterized instruments then ever before, at every scale as illustrated in Fig. 1. This could not have been achieved if not for the work of thousands of dedicated scientists, engineers and technicians from students to senior scientists. Unprecedented developments in software have allowed deeper understanding of data that has already been taken. The premiere space-based gamma-ray observatory, the Fermi Gamma-ray Space Telescope has, been in operation for over thirteen years. Almost every contribution and discussion session referred to data from multiple telescopes with spectral energy distributions (SEDs) spanning radio to gamma rays. To fully understand the diversity of sources observed in gamma rays, we must not focus solely on one wavelength and instead observe them not only across the electromagnetic spectrum, but also with different messengers such as gravitational waves and neutrinos. With the joint detection of gamma rays with these other messengers, we have entered the multimessenger era. Gamma-ray sources are multiwavelength and multimessenger sources. This is truly a golden age for gamma-ray astronomy.

Figure 1: The space-based gamma-ray landscape

The ground-based astronomy rapporteur presenter (Alison Mitchell) and I decided to split some of the scientific results by source and science topic instead of by SED (Fig. 2). GAD will cover extragalactic sources and space-based gamma-ray instrumentation (except when uniquely GAD) and GAI will cover galactic sources and ground-based gamma-ray instrumentation (except when uniquely GAI). Included in this document are the results that were covered by the GAD rapporteur.

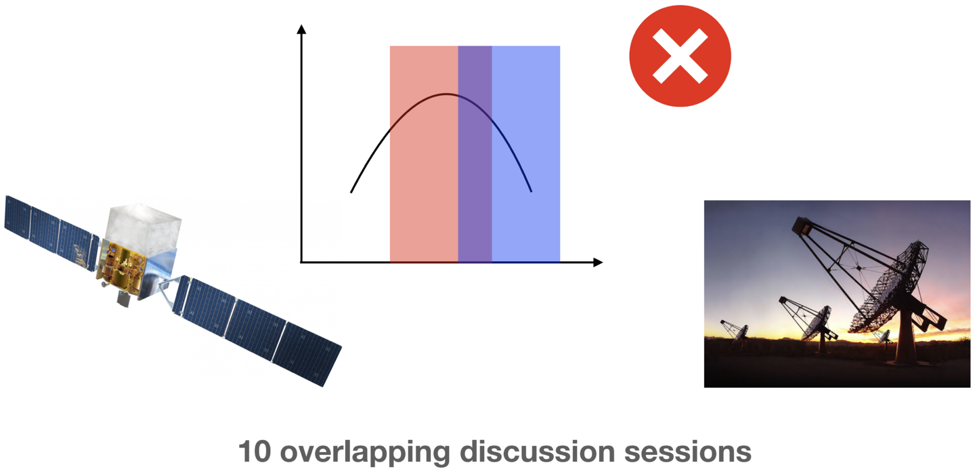

Figure 2: The space-based gamma-ray landscape

2. Extragalactic Sources

2.1 Central Engines of Fast Transients: GRBs and FRBs

The discussion session on Central engines of GRBs and FRBs covered five big questions: what is the observational frontier, what are the observational bottle necks, are planned instruments sufficient and strategies and lessons learned. The conveners provided a one slide summary and divided the session into GRBs and FRBs/Magnetars.

On the GRB side, new analyses of early GRB emission were presented [1], where almost 1% of sGRBs have precursors. There were a few discovered GRBs that looked analogous to GRB170817a [2], with short non-thermal pulses at early times and a soft thermal component at late times. There have been detailed searches for Kilonovae [3], and off-axis GRBs [4]. Finally new GRB polarization measurements with POLAR [5] show some discrepancies with ASTROSAT-I, which are being investigated. From the FRB/Magnetar perspective, observations of Giant magnetar flares could be the progenitor of a new class of GRBs [6, 7]. The search continues for high-energy counter parts to FRBs [8].

2.2 Modeling AGN's Spectral Energy Distribution

The discussion session on modeling the AGN's SED focused on the electromagnetic picture of AGN blazars: the double hump structure of the SED, EBL attenuation and of course, neutrinos. The session was run with a set of summary slides and 2 min allotted for each speaker, then a discussion.

The typical model of AGN is shown in Fig. 3 in the upper left. It is a purely leptonic model with a synchrotron self-Compton (SSC) or external Compton (EC) models. However, these models do not allow neutrino production, and do not well produce the observed SED. A high-energy hadronic bump produced through pion cascade or proton synchrotron models reproduce the observed SED, yet still more exotic models are also a possibility.

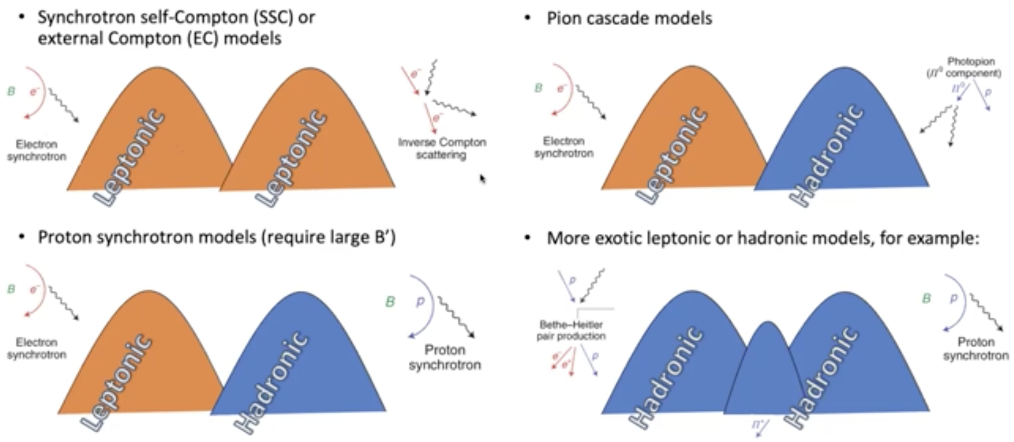

Figure 3: Models of AGN emission

Time dependent SED observations are required to distinguish models. Deeper and more continuous monitoring across wavelengths are required. Some items discussed were: Does the blazar sequence exist, and if so, what creates it?; the importance of X-rays, because they are indicative of hadronic signatures; models drawing connection between the jet and disk; and clarifying the selection of sources from a multimessenger perspective; and the multi-zone emission model [9]. Relevant works in this session include LAT variability in blazars [10]; studies of Bl Lac objects [11]; periodic emission in blazars [12]; blazar jet wobbles [13]; protons in blazar jets [14]; the rapid variability of blazars [15, 16].

2.3 Studying the variable emission from AGN in a MWL context

This discussion focused on the time variability of AGN emission including individual bright AGN flares, long-term monitoring and source surveys, and modeling in particular the SED, variability and particle acceleration. The conveners gave a brief overview and then broke the session into four parts with three minutes per speaker. The discussion addressed the following open questions: Connections between UHECRs, gamma rays, multiwavelength emission and neutrinos; the zones of emission and particle production in the jet; the particle jet and its composition; and what can polarization teach us. In particular, the importance of monitoring across wavelengths was emphasized. To fully understand AGN, observers need to look at the full light curve because snap shots do not tell the full picture. Radio emission and polarization measurements are signatures of particle acceleration mechanisms. There are also many theoretical issues to sort out, including disentangling particle acceleration mechanisms in the jet and how reconnection acceleration impacts emission.

The works presented covered several indivicual sources of interest including Mkr 421 [17, 18], OJ287 [19], CTA 102 [20], PKS B1413+135 [21], 1ES 0647+250 [22], M87 [23], 1ES 1959+650 [24], and a periodicity analysis of Mrk 501 and Mrk 421 [25].

2.4 Galaxy Clusters

The Coma Cluster morphology can be modeled with 3 point-like sources plus an extended emission disk [26]. H.E.S.S has produced new constraints on the IGMF [27]. Finally, there are new constraints on cosmological magnetic fields [28].

3. Galactic Sources

3.1 Origin of Galactic Cosmic Rays

The path of a cosmic ray is complicated: there is acceleration inside the source, an escape from the source, and propagation across the Galaxy - and none of the spectra of the same. This discussion session had a single slide overview of the talks and was broken into four different sections with discussion after. There was a blind search for low-energy cutoffs (“pion bump") in Fermi sources that shows that nearly 50 objects may be hadronic accelerators: in particular SNRs and binaries [29]. The news of the ICRC is that Superbubbles and Stellar clusters are part of this population. Fundamentally there have been many advances in the theory of particle acceleration in SFRs and modeling of gamma-ray emission. This session is covered in more detail by the GAI proceeding.

3.2 Distribution of Galactic Cosmic Rays

The distribution of Galactic Cosmic Rays discussion session started with an overview and open questions. There was a rapid 1-slide presentation with additional material from conveners with discussion following. The open questions and observations concluded that acceleration and transport shape CR spectra close to sources and asks what is the escape power of energetic leptons from sources. This is covered in more detail by the GAI and CRD proceedings.

3.3 Galactic Center and Diffuse emission

Several analyses looking at the galactic center (GC) including first results from DAMPE of the Fermi Bubbles [30] and GC lines [31], the GC as a high-energy particle accelerator [32], modeling neutral atomic Hydrogen to improve the GC fit [33], Galactic CO maps [34], Al-26 spectroscopy in the Galaxy [35], Cosmic-ray acceleration sites in the galaxy [36, 37], and adaptive template fitting to understand the Fermi GC excess [38].

There are new measurements on the isotropic diffuse [39] and the unresolved gamma-ray background [40].

4. The Solar System and New Physics

Gamma-ray observations are not solely the domain of distant objects. The moon is bright in gamma rays and we now have a measured flux over a full solar cycle [41]. Nine nearby super-luminous stars were observed in LAT data [42]. Cosmic-ray variations [43] Finally, the LAT and CTA are and will be respectively sensitive to protostellar jets [44]

In terms of new physics, searches for evidence of antimatter annihilation in gamma-ray data place constraints on anti-stars [45].

5. Catalogs, Tools and Analysis packages

5.1 The Census of Gamma-ray Sources

This discussion session highlighted new catalogs and analysis methods. There were two sets of two minute flash talks then discussion. Catalogs discussed were:

- Fermi-LAT Catalog 4FGL [46]
- Fermi-LAT 10 year monthly-transient Catalog [47]
- Fermi-LAT Low-energy Catalog [48]
- CALET Catalog [49]
- CALET Low energy gamma-ray Catalog [50]
- DAMPE gamma-ray Catalog [51]

The discussion also covered different analysis methods such as implementing neutral networks [52, 53], and deep learning [54]. The main questions are what are the upcoming missions and the prospects for population studies; what resources are needed to utilize these; identifying new source classes in catalogs; how much multiwavelength analysis is needed; how do we connect MeV to PeV gamma-ray observations; how do we share tools and cross check results.

5.2 Analysis Methods, Catalogues, Community Tools, Machine learning

This discussion session is mainly covered by the GAI proceeding, but because of its importance, it is also mentioned here. In particular, analysis tools are important and the developers should be recognized. In this session there were no flash talks, instead the conveners directed questions which prompted general discussion. There were Four different contributions grouped as follows: Open source tools, Source detection classification, Analysis techniques, Deep learning for gamma-ray shower analysis.

6. New and Upcoming Instruments for Space-Based Gamma-ray Astronomy

This discussion session included an overview from the conveners, one slide rapid talks and then a discussion. It was divided into Small(ish) missions and Large(r) missions. The current landscape of space-based gamma-ray observatories is illustrated in Fig. 4.

The discussion points included the project status of each mission, should there be several missions proposed or a single one, how do CubeSats fit into the landscape, what is next in the HE regime; and how do we consistently compare performance. The main takeaway is that there are a lot of outstanding questions in MeV gamma-ray astronomy and proposed missions reflect this interest. In particular, findings from the third release of the Fermi-LAT 4FGL make the compelling case for an MeV range mission. There are more than 1000 sources at low Galactic latitude with spectra that are not consistent with known sources as illustrated in Fig. 5 indicating a potentially new class of sources.

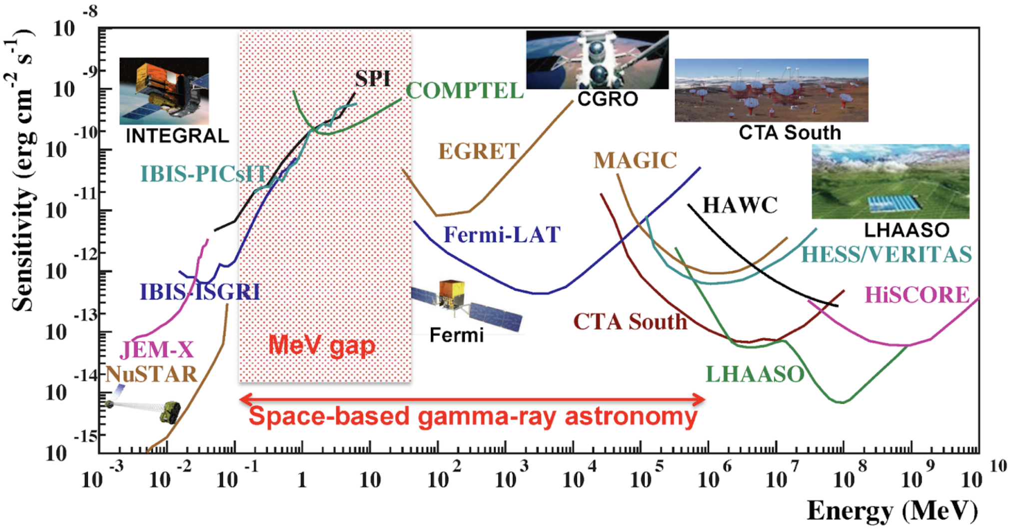

Figure 4: Gamma-ray Spectrum and Current missions

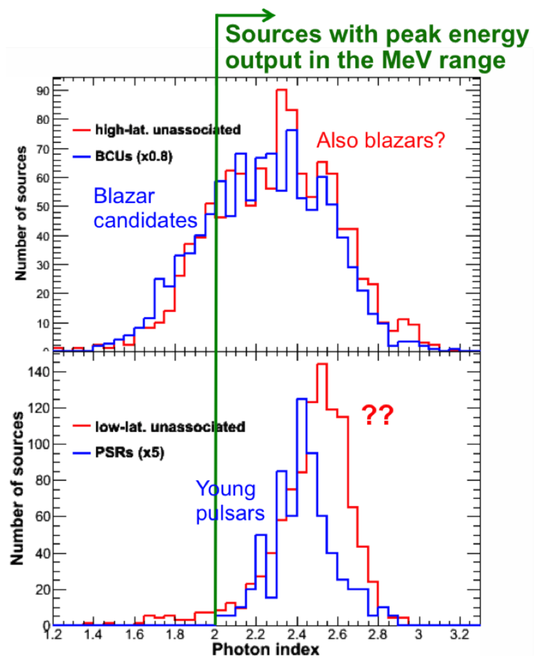

Figure 5: Sources in the 4FGL with their photon index

6.1 Small(ish) missions

Small(ish) missions include BurstCube [55], Crystal Eye and Pathfinder [56], HEPD-02 [57], POLAR-2 [58], GRAINE [59], and MeV Cube [60]

6.2 Large(r) missions

Large(r) missions include AMEGO-X [61], COSI SMEX [62] HERD [63], GRAMS [64], APT [65, 66], GECCO and Germanium Spectrometer [67]. In the time between ICRC 2021 and the proceedings, COSI SMEX was selected for implementation, so we will wait anxiously for updates from the team and wish them the best of luck going forward.

7. Summary of Summaries

In conclusion, this ICRC presented many exciting results from many space-based gamma-ray missions. It is clear that the landscape has matured over the years, as now there are many gamma-ray telescopes in space, in the pipeline and being proposed, led in no small part by the Fermi Observatory. We also see that the same questions appear across many communities: Jets are complicated! The diversity of telescopes also means that many tools available to analyze the data and there are specific challenges to combining the data among different instruments. The community is strong, and with more telescopes, we get more data and can ask more questions. There are many opportunities on the horizon for space-based gamma-ray astronomy.

8. Feedback for future conferences

I would also like to take this opportunity to provide feedback on the virtual organization and the discussion, both of which were new this year. This terrible situation provided the organizers an opportunity to change the standard format of the ICRC conference to make the sessions more accessible and promote more discussion.

Discussion Sessions

Overall the discussion sessions were well received and well attended. The conveners of the sessions had the freedom to design their session, with varying levels of success. This was a tremendous amount of work for the conveners, and their work and dedication showed through very successful sessions. Generally the conveners who compiled a single slide summary of each talk promoted the most discussion. This approach required the most effort. The conveners also wanted more time before the conference to organize the sessions - generally the few week notice was not sufficient to arrange all the talks. Finally, conveners wanted more time allocated for each session. This was particularly true if the conveners didn't ask for one slide summaries of talks.

Virtual Format

The pandemic has put into question many long held traditions of conference travel. Virtual events have some distinct advantages over in-person conferences. An online event is more accessible and pre-uploaded material made this especially true. There were two recommendations that several attendees would have benefited from:

- An online chat tool (such as slack) independent of the video conference tool (Zoom) would have enabled quick communications
- It was a challenge for attendees to watch all the videos in advance of the session (there were more than 30h of watch time per session). It would have been better to just have people upload slides and not record their talks.

I personally prefer in-person conferences but this also exposes my biases and privileges: extrovert, able bodied, sufficient travel funds, etc. It is challenging to recreate the networking and social experiences of a conference online.

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