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Review

Fast radio bursts

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ABSTRACT

More than a decade after their discovery, astronomical Fast Radio Bursts remain enigmatic. They are known to occur at "cosmological" distances, implying large energy and radiated power, extraordinarily high brightness temperature and coherent emission. Yet their source objects, the means by which energy is released and their radiation processes remain unknown. This review is organized around these unanswered questions.

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1. Introduction

The first Fast Radio Burst (FRB) was discovered in 2007 [1]. They were not universally accepted as a real astronomical phenomenon until confirmed by the identification of five more FRBs several years later [2,3]. Most of the early discoveries were made in archival data from the Parkes Multibeam Pulsar Survey, whose 13 beams survey the sky for unknown sources 13 times faster than would a single beam. Even today, 25 of the 34 FRBs in the FRB Catalogue [4] were discovered at Parkes. Slow acceptance was the result of the well known problem of electromagnetic interference, mostly anthropogenic but also including natural phenomena like lightning, in transient radio-frequency observations. In fact, the anthropogenic "perytons" [5], not understood in detail but later demonstrated to be produced by microwave ovens [6], and bearing some resemblance to the first FRB discovered, were a source of skepticism.

Since the general acceptance of FRBs, the literature, both observational and theoretical, has exploded. Searches on the SAO/NASA Astrophysics Data System [7] produce hundreds of citations, the number depending on how the search criteria are defined and whether meeting abstracts and similar unrefereed publications are included along with papers in archival journals. It would not be useful to attempt to survey this entire literature; modern bibliographic tools enable anyone to conduct such a search easily, and such a survey would become obsolete in a few months. Instead, I will try to frame the major questions, the hypotheses offered to answer them, and possible means of testing these hypotheses. This involves subjective judgment, and I apologize to those whose work I have neglected.

Astronomy is an observational science, but the ability to design an observational program introduces an experimental aspect: carrying out such a program and comparing its results to predictions is analogous to performing a laboratory experiment. The chief difference is that many astronomical theories make, at best, qualitative predictions. In astronomy initial conditions are infrequently known, their effects persist through the life of the system under study, and often essential processes are "turbulent". "Turbulence" extends far beyond the homogeneous stationary incompressible turbulence understood by Kolmogorov to include almost any complex hydrodynamic or plasma process; it often means "too complicated and uncertain to calculate".

The Solar neutrino problem is a striking exception: The Sun has lost memory of its initial conditions, except for its mass and chemical composition, and turbulence (in its convective zone) makes very little difference to its properties. No such luck applies to most astronomical phenomena, other than stellar structure and celestial mechanics. 55 years after the recognition of active galactic nuclei ("quasars") and 50 years after the discovery of radio pulsars, we have only the most qualitative understanding of how they work and no consensus as to even the basics of pulsar electrodynamics or why they emit observable pulses. Active galactic nuclei involve turbulent accretion flows and pulsars involve plasma turbulence and coherent emission; we are now warned that such processes have been particularly difficult to understand. Phenomenology may be all that we can hope for.

Recent progress in data analysis makes this an opportune time to review Fast Radio Bursts. The UTMOST [8] processor at Molonglo and the Breakthrough Listen [9] processor at Green Bank have unprecedented spectral (100–200 kHz) and temporal (10 μs) resolution that resolve the frequency and temporal structure of bursts, revealing their fine-scale dependence on both variables [10,11]. No longer are FRBs described only by a single width of $\gtrsim$ 1 ms and spectral resolution of multiple MHz, and this sharper temporal and spectral resolution has made it possible to separate the effects of scintillation from the intrinsic properties of the bursts. Spectral and temporal complexity, first found in FRB 121002 [12] and the repeating FRB 121102 [13], now appear to be universal characteristics of FRB.

The number of bits of information ideally obtainable from a burst of flux $F_\nu(t)$ and fluence $\mathcal{F}$ over a spectral width W_ν and temporal width W_t, observed with frequency resolution $\Delta\nu$ and temporal resolution Δt by an antenna of effective area A and system temperature T_{sys} (typically about 25 K), is [14]

$$N_{bits} = \frac{1}{2}\sum_{i,j} \log_2\left(1 + F_{\nu_i}(t_j)\Delta\nu\,\Delta t\frac{A}{k_B T_{sys}}\right) \sim \frac{1}{2}\frac{W_\nu W_t}{\Delta\nu\,\Delta t}\log_2\left(1 + \frac{\mathcal{F}\Delta\nu\Delta t}{W_\nu W_t}\frac{A}{k_B T_{sys}}\right). \tag{1}$$

The argument of the logarithm is 1 + the signal to noise ratio. The logarithm is summed over all independent channels, defined by widths in frequency and time. In the final approximate expression the sum is approximated by multiplication by the number of independent channels. The number of independent channels increases much more rapidly as $\Delta\nu$ and Δt decrease than the logarithm decreases, so that improving resolution increases the information content of the signal. This has revealed the spectral and temporal complexity of FRBs.

The literature survey for this review was completed April 12, 2018. I apologize for the neglect of some papers that appeared prior to that date. This review does not contain a complete bibliography, but rather a critical assessment, and judgment as to how much observational detail or theoretical speculation is appropriate is necessarily subjective. I have been willing to consider speculations about hydrodynamics and plasma physics, that often behave in unpredictable and