SOLAR FLARES: THE IMPULSIVE PHASE

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Abstract. Only during the previous solar cycle have systematic observations begun to be made with the sensitivity and time resolution, and the continuous coverage required to catch the impulsive phase and measure the rapid variations present in many wavelength ranges. Observations in X-rays, gamma-rays, UV, Hα, and radio wavelengths all reveal rapid variations during the impulsive phase and have contributed to our understanding of the different phenomena involved. Results have been obtained from several spacecraft, from rocket and balloon flights, and from ground-based observations. These are reviewed in the context of a simple single loop flare model with a view to showing what results are consistent with this model and what the major problems are in our understanding of the impulsive phase. New instrumentation planned for observations during the present Cycle 22 will provide a concerted attack on the impulsive phase as part of the Max '91 program.

1. Introduction

The terms 'impulsive' and 'gradual' were originally proposed by Covington and Harvey (1958) to describe two broad classes of microwave bursts. Kane (1969) first recognized the two components in energetic X-ray bursts. Today, the terms are used to describe the different phases of flares as observed in many wavelength ranges. Unfortunately, there is often confusion with this terminology since what appears impulsive in one wavelength range, e.g., hard X-rays, may appear gradual in another wavelength range, e.g., soft X-rays. Nevertheless, the distinction between the two phases is important since it is assumed that during the impulsive phase energy is being released 'impulsively', i.e., on time-scales of seconds or less, whereas during the gradual phase either energy is being released more gradually on time-scales of minutes to tens of minutes or no energy is being released at all.

The usual assumption is that solar flares result from the release of free energy in coronal magnetic fields either through reconnection or some other form of magnetic dissipation. The impulsive and gradual phases must then be interpreted as resulting from different energy release processes, different modes of magnetic dissipation, or different magnetic configurations. In many cases, though not all, the gradual phase is thought to result from the slow decay of the energy released during the impulsive phase with no new energy release being required. This idea that all the energy of a solar flare is released during the impulsive phase may explain why, as pointed out by Sturrock *et al.* (1984), it has often been 'implicitly assumed that to explain the impulsive phase is to explain the complete flare'. This idea may be true for many smaller flares where the impulsive phase appears as the dominant feature but for other flares, particularly the larger ones,

Solar Physics **121**: 75–94, 1989.
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gradually varying hard X-ray and microwave emissions lasting as long as an hour or more indicate clearly that energy continues to be fed into the flare long after any impulsive phase is over.

Further indications that the impulsive phase is not the complete story of flare energy release are the observations of coronal mass ejections (CMEs) lifting off *before* the impulsive phase of the presumably associated flare (Simnett and Harrison, 1985; Harrison *et al.*, 1985; Harrison, 1986). Kahler *et al.* (1988) also report that filament eruptions begin before the onset of the impulsive phase and evolve smoothly through the flare. Thus, we must conclude from these observations that in those cases, the impulsive flare was a consequence of the associated filament eruption or CME rather than that the eruption or the CME was a consequence of the flare. This places a completely new light on the significance of the impulsive phase for those events. It must be remembered that the total kinetic energy associated with the mass motion of a CME can be considerably larger than the total energy released during the associated flare.

In spite of this new understanding of the relation between the different aspects of the energy release phenomena, it is still true that 'the principal theoretical flare problem is that of sufficiently rapid primary energy release' (Brown, Smith, and Spicer, 1981). Hard X-rays are observed with such intensities that, given the standard interpretation of them as collisional bremsstrahlung from high-energy electrons in the flare plasma, energy release rates as high as 10^{30} ergs s^{-1} are required to accelerate the emitting electrons during the impulsive phase. Simpler considerations of the $\gtrsim 10^{32}$ ergs released in the biggest flares in a characteristic flare duration time of $\sim 10^3$ s show that sustained energy release rates of at least 10^{29} erg s^{-1} are required. Such energy release rates are extremely challenging theoretically given the magnetic field strengths and configurations believed to exist in the corona. It is for this reason that increasing emphasis is being placed on observations of the impulsive phase in many different wavelength ranges. This paper constitutes a review of the more recent observations of impulsive phase phenomena at all wavelengths where evidence of such phenomena is found. It is hoped that this review will be valuable to theoreticians, who will see what observations are available to compare with their model predictions, and to observers, who can use it as a basis for comparing with observations from the much improved instrumentation planned for the next maximum in solar activity during Cycle 22.

In order to provide a common basis for discussing the observations in different wavelength ranges, we present in the next section a simple flare model that is consistent with many impulsive phase observations. This model also serves to show where in the solar atmosphere the different emissions may originate and how they may be related to one another and to the various phenomena of the impulsive phase. We have broken down the paper into three sections – energy release, energy transport, and energy loss – and show how the observations in different energy ranges provide information on these processes. The following sections contain discussions of observations in hard X-rays and γ-rays, microwaves and other radio waves, soft X-rays, UV and EUV wavelengths, and Hα. Finally, a brief discussion is given of what to expect from the planned Max '91 program of new observations during the current cycle of solar activity.