Astronomy
VLA, HEIDI & YOKOH

Narration
If we could see the Sun with magnetically sensitive eyes it would look like a constantly changing bundle of twisted fields, curling between sunspots, stretching and reconnecting as magnetic energy is released in flare explosions. To see what happens to all this energy we need to tune into the radio emissions produced by the accelerated electrons spiralling rapidly high up the magnetic loops. The most sensitive radio telescope on Earth at centimetre wavelengths is the VLA, the Very Large Array, near Socorro in New Mexico. It has twenty-seven dishes, each 25 metres in diameter, arranged along three arms up to 21 kilometres long. When all the dishes are close together it is ideally suited to imaging rapid events over the entire Sun. As the dishes are moved wider apart, they effectively zoom in to see smaller regions in finer detail.

Mukul Kundu
The VLA has taught us a lot about the solar flare process which we could not have done otherwise. For example, by observing at different wavelengths you can actually observe several different layers of the Sun's atmosphere and their effects in the Sun's corona. The difference in altitudes between them may be of the order of several tens of thousands kilometres. The picture at 20 centimetre wavelength lies way above the picture that you saw at six centimetre wavelength. And this is primarily because the radio emission is generated by energetic electrons which spiral around the lines of force in the Sun's corona. In other words it actually maps the strength of the magnetic field in the flaring region. The magnetogram is at the photospheric level, whereas the computed field lines are in the corona and the blob that you see actually is at an altitude of 130,000 kilometres and the separation between the two foot points is something like 200,000 kilometres. And this particular burst lasted only about three seconds because the beaming electrons actually took that much time to move from one foot point to the other foot point. You also notice that the same thing is happening over and over again. It is due to a succession of radio-emitting electrons propagating from one foot point to another foot point at very high speeds of the order of one-third the velocity of light. And that explains why these bursts are so rapid and last only a short time.

Narration
Such flares also emit x-rays and gamma rays which, unlike radio waves, do no penetrate the Earth's atmosphere. The hard x-ray imaging telescope called HEIDI will be carried by a high altitude balloon over 40 kilometres high to record solar flares. It is designed to stay up there for eight hours or more. Why does it have to be so long?

Carol Jo Crannell
The reason is that hard x-rays and gamma rays can't be focused by lenses or mirrors. We need to use another trick and the trick we use is analogous to that of a pinhole camera. We use grids. This is a sample, about a centimetre thick, made out of tungsten, a very dense material. The grids, about this diameter, have slits and slats in them. The slits let hard x-rays and gamma rays pass. The slats are thick enough to actually stop the energetic radiation that we're trying to image. Now what we have done in the actual balloon payload is use pairs of these. The pair works together something like this. What I have here is a film. That's actually a contact print of the grid that I just showed you. If I have them so that the slits on one piece of film cover the slats on another, you can't see through it, but if I move them, keep them straight, you see the opening and now the light, analogous to the hard x-rays and gamma rays, can pass. Move it again and I can close them up again. So that's how it really works, except that we separate it by large distances to get to very fine angular resolution out of the system. When the telescope is actually operating the grids rotate synchronously to give us the opportunity to reconstruct images of the Sun and its solar flares in two dimensions.

Ken Phillips
To understand the complete picture of the Sun's atmosphere we have to open up regions of the electromagnetic spectrum that are accessible only from rockets and satellites – namely the x-rays and ultraviolet regions. For example, this ultraviolet image here shows the network structure. This is much coarser than granulation, like a hairnet stretching across the Sun. In close-up we can see the hairnet structure in more detail and a thin, very hot transition layer at temperatures of one hundred thousand degrees, just above the much cooler photosphere. We can also see a faint loop stretching high into the even hotter corona. The temperatures in the corona can be as high as two million degrees and computer modelling has shown that plasma waves, driven by magnetic forces, can provide much of the heating. When particles are moving this rapidly they emit x-rays by collision with one another. This picture of the Sun was taken with a rocket-borne x-ray camera. It shows plenty of flare activity, especially above sunspots. The temperatures here can reach twenty million degrees or higher, enough to trigger short bursts of nuclear fusion. And in 1991 the Japanese YOHKOH satellite provided this spectacular series of images, revealing a wealth of detail never seen before.

Narration
We see phenomena on both local and global scales – from tiny transient brightenings in dark coronal holes to vast interacting loops and flares. At the edge of the Sun these loops may be seen as great arches of matter, lifting free of the Sun's gravitational pull, driven by flare energy. Sometimes a cloud of this matter escapes and starts a long journey across the solar system – a coronal mass ejection event. The clouds grow too big for direct imaging but they can still be followed.

Richard Harrison
We can track these clouds by looking at the scintillation or twinkling of radio sources around the entire sky. Just as a star twinkles when you look at it through the Earth's atmosphere, a radio star twinkles when you look at it through these coronal mass-ejected clouds. In this full sky scintillation map the Sun is just north of centre and the red regions are regions where the radio stars are scintillating very significantly. So this enormous red region to the upper left shows a large mass ejection cloud passing just left of the Earth as you look towards the Sun. To the right of the image we see a quiet sky where we simply see the mottled effect because of the radio sources themselves, there is no event in the solar system in that location. Clearly some of these clouds can collide with the Earth and have dramatic effects and that can cause significant navigational problems; it can cause significant pulses in power-generating circuits and a host of other effects. Fortunately most of the mass-ejected clouds will miss the Earth and just travel out through the solar system, but how far do they go? What do they do beyond the Earth's orbit? Well the Voyager spacecraft have now passed beyond Pluto and Neptune, the two outermost planets, as they pass through the solar system. Recently they have detected radio emission, apparently coming into the solar system, of frequency about one kilohertz. This radio emission seems to coincide with the time that coronal mass ejections reach the outer reaches of the solar system. And it seems that the mass-ejected events, in fact, are interacting with the very edge of the solar system, the heliopause, which is where the magnetic fields of the solar system literally merge into the magnetic fields of interstellar space. So, after their phenomenally successful planetary mission, it seems that the Voyager spacecraft are now giving us information on the very edge of the solar system.