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John W. Freeman
Excerpt
More information

# The Cast of Characters

The elements of storms in space are fundamental charged particles and electromagnetic (force) fields. Together these two physical quantities make up the cast of characters that are purveyors of the tempests in space. It will help our appreciation of the storms if we take a few minutes to meet these characters.

Charged particles come in two varieties, negatively charged and positively charged particles. The most stable of the negative particles is the famous electron. As the negative, orbital component of all atoms, electrons are everywhere. In another guise, electrons have become the workhorses of the human race. Coursing through electrical wires, they are the essential ingredients in practically all of our modern technology. In space, where electrons can be free from their atomic bondage and there are no wires to guide them, the motion of electrons is more complex and interesting. Uninhibited by frequent collisions with atoms, they become capable of achieving high speeds, close to the speed of light. Speed means kinetic energy. Kinetic energy is the status symbol for charged particles in space and is of great importance to storms in space. Electrons are extremely small and have very little mass. To achieve a certain kinetic energy they must make up for their low mass by high velocities.

The other main variety of charged elementary particle, of course, is the positive particles. The most famous of the positive particles is the proton. Protons make up the charged component of the nucleus of atoms and are about 2,000 times more massive than the orbiting electrons. But, like electrons, protons in space can exist as isolated, independent particles where they also are subject to complex motion produced by force fields. In addition to protons, we also have ions as positively charged particles. Ion is the generic name for an atom that has lost one or more of its orbital electrons to obtain a net positive charge. Ions may move and exist freely in space. A proton is an ion since it is the nucleus of the hydrogen atom. In our description of space storms we may use ions and protons almost interchangeably because they participate together in the complex processes of space, but in the near-Earth environment beyond the atmosphere, protons are usually the dominant ion.

The credo of charged particles might be 'May the force be with you'—it always is. Charged particles cannot escape the influence of electromagnetic force fields. Even though force fields can't actually be seen, physicists like to visualize them with imaginary lines in space and also with a direction associated with the lines. Lines closer together indicate stronger forces and the direction of the lines tells us how to compute the direction of the force.

In addition to familiar gravity, there are two force fields that may influence the motion of free charged particles in the vacuum of space. These are electric fields and magnetic fields. For our purposes, an essential distinction is that electric fields accelerate charged particles along the field. Positively charged particles are accelerated in the direction of the electric field and negatively charged particles in the opposite direction. Magnetic fields, on the other hand, can only accelerate moving charged particles in a direction perpendicular to the field (to the left for electrons and to the right for protons in an upward pointing field). In other words, electric fields can change the speed of a charged particle but magnetic fields can only change their direction. If things aren't confusing enough, put the two types of fields together and you get a different kind of motion altogether. This small poem may help clarify the matter—or it may confuse.

**Lost in Space?**

If ever you're lost
in the reaches of space,
a friendly charged particle
will find you your place.

In an upward field
of the magnetic type,
electrons turn left
and protons turn right.

In a westward field,
an electric beast,
protons head west
and electrons east.

Combine the two fields
and believe it or not,
electron or proton
toward Earth is your lot.

So follow an ion,
electron or two,
and I'm sure you'll know
just what to do.

John W. Freeman

More details about these and other exotic players in our story can be found in the Glossary and the 'Mathematical Appendix: A Closer Look', both of which can be found at the end of the book. Words explained in the Glossary are given in italic at their first occurrence in the text.

# Vignettes of the Storm

Two hundred and fifty miles above the Earth, moving 7 kilometers a second, a gangly satellite with tubular sections and glistening wings is seen moving from the darkness of night into the blinding Sun (Figure 0.1, color section). As it crosses the terminator and moves into sunlight we recognize the International Space Station (ISS) with two tiny objects floating among the superstructure — astronauts on an extravehicular construction job.

The intercom to the EVA support crew crackles: 'you okay Greg?'

'Yeah. The glare from sunrise really blinds a guy for a few moments. Got to take a break to lower my sunvisor and acclimate. I'll get back to tensioning this strut in a second.'

'No problem.'

'Jake, the Sun botherin' you?'

'Negative — I'm in the shadow of the habitat.'

'Okay guys, I'd like to start our half-hour, suit-systems check list whenever you're ready.'

'Hardly seems necessary. Why interrupt the timeline?'

' We're overdue.'

'Okay — whenever.'

'O-2 pressure, Greg?'

'21.6.'

'Roger — 21.6. Jake?'

'21.4.'

'Roger — 21.4.'

'Coolant Temp? Greg?'

'23.8.'

'23.8. Okay. Radiation dosimeter reading, Greg? … Greg, do you read me?'

'Yeah — this thing must be screwed up.'

'Why?'

'It's reading in the red zone—96 REMs and climbing!'

'Must be some mistake. Double check it when your eyes clear. Jake, how 'bout you?'

'Oh my God! Mine's in the red too!'

Suddenly the capcom from Houston Control breaks in: 'ISS—Houston, we have a report of an X class flare (Figure 0.2, color section) in the central meridian with solar energetic proton fluxes seen at L1. Terminate EVA immediately. Do you copy?'

'Roger—Houston. Terminating EVA. We've got high dosimeter readings here. Bummer! Crew, let's get these guys inside. Jake, Greg, head for the airlock. We're ready on this end.'

'On the way.'

'Oh no.'

'Jake, what's wrong?'

'I think my tether is hung up on the last strut I worked on. Can't reach the airlock with the slack I have. I have to double back and go around the other side. This will take a while. Can you see from the monitor where I'm caught?'

'No. Your tether is not in view.'

'Greg, I'm coming around to help.'

'No Jake. Get inside. I'll get this thing loose—Damnit.'

'Houston—ISS. How long do you think we have before it gets really hot out there?'

'ISS—Houston, SRAG reports a fast-rise, transient flare—about an hour 'til maximum proton flux hits Earth.'

Turning off his mike the capcom groans and curses to himself, 'How did this thing sneak up on us?'

From the Flight Controller comes the crisp message: 'All Consoles prepare for a rescue launch at mark plus three hours.'

In a room adjacent to Mission Control the Flight Director has already assembled a team of doctors with a teleconference line to radiation specialists. A routine construction EVA on the International Space Station has quickly turned into a nightmare.

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It has been an uneventful evening in the forecast room of NOAA's Space Environment Center in Boulder, Colorado. The second shift is about to end and the crew is restless, ready to head home. Unnoticed by anyone, a thin blue trace on a video monitor chart takes a sharp swing upward. A few minutes later, a red trace lower down on the same monitor shoots upward and pegs flat at the top of the graph. These traces indicate a burst of X-rays and then an increase in the flux of high-energy protons from the Sun. They are plots of data from sensors aboard the GOES-8 spacecraft in geostationary orbit.

One of the forecasters just coming on duty starts her routine scan of the complex computer displays on the room-sized console. She notices the X-ray and proton plots and turns immediately to a nearby display of the solar disk from the SOHO spacecraft. There she sees that a giant solar flare has erupted from a region on the Sun directly facing the Earth. She whistles softly and says, 'oh-oh, we're in for a whopper.' She alerts the rest of the shift, then picks up the phone to call the Air Force 55th Space Weather Squadron. The NOAA space forecast crew begins a methodical assessment of the magnitude of the coming geomagnetic storm and begins distribution of alerts and warnings for NOAA's space-weather customers.

* * *

The SOHO spacecraft stationed 1,500,000 km from the Earth at L1, that delicate point in space where the gravity field of the Earth and Sun just balance, is routinely reporting conditions on the Sun and something called the solar wind. SOHO has transmitted the solar image used by the NOAA forecasters to verify the growing storm on the Sun. In addition to the bright flare, SOHO has also caught sight of a large arching prominence in the solar atmosphere high above the flare. The prominence expands until, now larger than the Sun, it forms a giant halo around the Sun. It gains speed as it explodes outward into space. Fifty hours later, the remnants of the prominence reach L1. SOHO dutifully reports a sudden jump in the speed of the solar wind to nearly 2 million miles per hour. Accompanying this increase in solar wind speed is a change in the direction of the magnetic field being dragged along by the solar wind. In less than an hour this cloud of high-speed ionized gas with its twisted magnetic field will reach the Earth and energize the Earth's magnetosphere.

* * *

The scene is a darkened communication satellite operations control room in Arlington, Virginia. Across one wall are monitors displaying live TV pictures. The first monitor carries the Winter Olympics ski jump competition. The others across the same row display a sitcom, a weather channel, and a Spanish language commentator. Only the sound from the Olympics monitor can be heard. The panel behind a long console desk has more monitors containing charts and graphs with technical data on the status of seven communication satellites. The night shift operations crew is gathered around the Olympics monitor.

Twenty-two thousand miles above the Earth the giant Comsat orbits with its antennas pointed toward the USA and Mexico. Suddenly, a small jet of gas squirts out from a miniature rocket thruster on the side of the spacecraft. Unlike the usual satellite orientation adjustment bursts which last only a few seconds, this time the attitude control thruster does not shut off. The satellite begins to tumble, slowly at first, then more rapidly.

Back in the satellite control room, all four TV monitors go blank and a warning beep is heard from the spacecraft status monitors. An ALERT warning indicator announces that spacecraft S-5 attitude control sensors report an out-of-limits condition followed by a loss-of-signal indication from the main transmitter. 'Oh-oh! Phantom commands again!', shouts someone as the operations crew scrambles to return to their stations. They prepare to send new commands to the out-of-control spacecraft. Several control console phones begin to ring almost simultaneously. 'Prepare to re-route the four video transponders from S-5 to S-7 on my mark,' says the lead controller into his headset. 'Damn, we'll lose the extreme eastern part of our antenna footprint. We've got no other choice!' The phones are ignored. A state-of-the-art, $250 million comsat has just been reduced to orbiting junk.

* * *

Somewhere in the Bahamas, a small sailboat is plowing its way eastward in seas that have been steadily growing rougher over the last hour. It occurs to the gray-bearded skipper that they are beginning to pick up the southern edge of the hurricane Elaine. He starts to fasten the safety line to his harness as he tightens his grip on the wheel. Without warning a crack is

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heard and the mainsail mast crashes across the starboard gunwale. The sail settles into the water and the boat begins to list dangerously. The skipper screams into the cabin for his wife to activate the Emergency Position Indication Rescue Beacon (EPIRB) that will send a MAYDAY call to an orbiting satellite. Unfortunately, the computers in Florida monitoring the EPIRB system will never receive the MAYDAY call. The southbound satellite overhead is no longer listening. Moments earlier it has been knocked from its proper orientation by strong magnetic currents associated with a nearby display of northern lights. The search and rescue will never take place.

* * *

Seven miles above Nova Scotia, American Airlines Flight 80 from Chicago's O'Hare airport is heading eastward through the night bound for Stockholm's Arlanda airport with 320 persons aboard. The pilot has just interrupted the in-flight movie to announce to passengers that there is an intense display of northern lights that can be seen by looking out the right side of the aircraft. After his mike is turned off, he comments to the first officer that he has never seen the aurora this far south before. A persistent, flashing orange light on the instrument panel interrupts the quiet conversation in the cockpit. The light indicates that the automatic system has lost lock on the radio beacon from the GPS navigation system. Instead of satellite navigation, the autopilot will now be relying on the onboard inertial navigation system. The pilot mumbles something to the first officer who sets about checking the onboard system.

By now, the cabin lights have been dimmed and a few excited passengers are straining to see the aurora borealis through the windows. Not far from the plane, they can see, dancing across the sky, a series of constantly changing rays of light that appears to diverge from far overhead and end abruptly at a bright lower border. The rays are mostly pale yellow and green with hints of red closer to the ground. They seem to form a curtain with many irregular folds that wiggle, disappear and then reappear elsewhere. In the distance other curtains can be seen flashing and shifting with folds that drift slowly westward. 'Oh that's beautiful! What makes the northern lights?' a small girl whispers to her father who is trying vainly to fall asleep.

* * *

'Capt'n O'Brien, sir, there's somethin' strange here in this last printout from the NORAD mast'r satellite log. It seems shorter than it oughtta be.'

'How so?'

'Well, we got 3,246 birds on the regular roster, not count'n' the launch of that Russian SPYSAT yesterday. Now the PO shows only 3,169 known birds tracked by the radars today.'

'Any pattern to the missing birds?'

'Lemmee check a minute. Yep, Holy Smoke! They're all LEO—polar orbits.'

'How come we didn't get a warning from Space Command?'

'Dunno, unless the link is down—heard somethin' bout a space storm.'

'How the hell can 75 satellites just disappear?'

'Wait, there's a new PO comin' in now. Damn, it shows a whole bunch of new birds! ...They've got some of the transponder IDs of the old guys. Looks like somethin' took the missing birds and shoved them into different orbits! The computer couldn't make the connection. What do you make of that?'

'I'll bet its got somethin' to do with that space storm and atmospheric drag. Let's send an email to 55th and see if they know anything.'

* * *

At a television station in San Francisco, a weather presenter begins preparation for his report on the 6 PM news. He switches on the monitor that provides his link to the GOES-8 weather satellite at geostationary orbit to check the current cloud cover conditions for the Bay Area, and to prepare some colorful graphics of hurricane Elaine threatening the east coast of the US. Instead of a beautiful false color, infrared image of the cloud cover over the South Atlantic, he finds a cryptic message on the screen, 'GOES-8 WEFAX temporarily out-of-service'. It does not occur to him that another type of storm, a storm in space, has disabled the weather satellite. Nor does he realize that this same storm in space is also interfering with data transmissions from another satellite; this one keeping watch on shear along the San Andreas fault line.

* * *

In the basement of the Pentagon, the night shift at the Defense Intelligence Agency Situation Center is preparing its routine morning briefing for the Joint Chiefs on overnight troop movements in Iraq. An aid enters with a report that BIGBIRD-1, the surveillance satellite positioned over southwestern Asia, has just begun to experience phantom commands, sudden and unexpected changes in operating modes, and loss of all digital photo-channels. The mood shifts abruptly to one of heightened concern as the group begins to consider whether or not to report this satellite problem as an indication of hostile activity, possibly from a ground-based microwave beam or laser.

* * *

In Montreal, Canada, a young family has just finished a late dinner and is heading for the living room for an evening of television. 'Dishes first!' shouts mom from the kitchen. No one seems to hear her. Instead, groans of frustration are heard from the living room. The TV cable channels do not seem to be working. A message on the screen indicates 'We are Experiencing Technical Difficulty with the Relay Satellite.' Suddenly, the lights go off. The entire city and most of Quebec Province are without power. It is nine hours before electric power is restored (Figure 0.3, color section). The cable TV channels remain out.

* * *

The production manger of a microelectronics plant near Torrance, California, is just turning into his driveway after the day shift. He notices, puzzled, that his garage door has opened before he keyed the transmitter on the sun visor. As the car rolls to a stop, his beeper sounds. A cell-phone call back to the plant tells him that the automated assembly line has begun to reject large numbers of microcircuits. He is aware of a growing migraine pain near the back of his head as he calls to his wife and backs out of the garage. Frustration is evident in her voice as she calls back after him that they have tickets for a play that starts in less that two hours.

* * *

Near the Ottawa River in Quebec Province, Canada, the Deep River Neutron Monitor Facility provides hourly measurements of the flux of neutrons