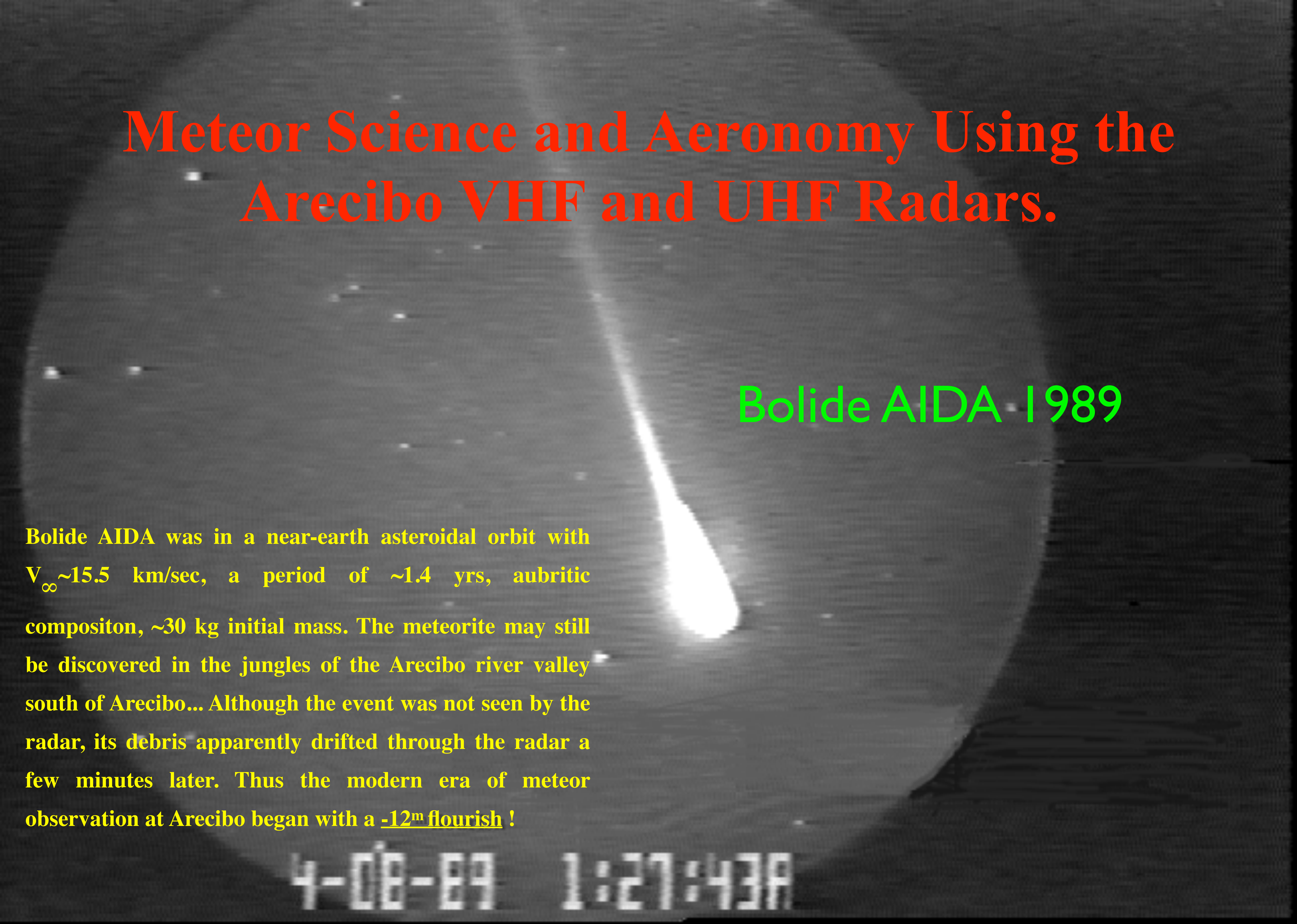
Meteor Science and Aeronomy Using the Arecibo VHF and UHF Radars.



Bolide AIDA 1989

Bolide AIDA was in a near-earth asteroidal orbit with V_∞~15.5 km/sec, a period of ~1.4 yrs, aubritic compositon, ~30 kg initial mass. The meteorite may still be discovered in the jungles of the Arecibo river valley south of Arecibo... Although the event was not seen by the radar, its debris apparently drifted through the radar a few minutes later. Thus the modern era of meteor observation at Arecibo began with a -12^m flourish !

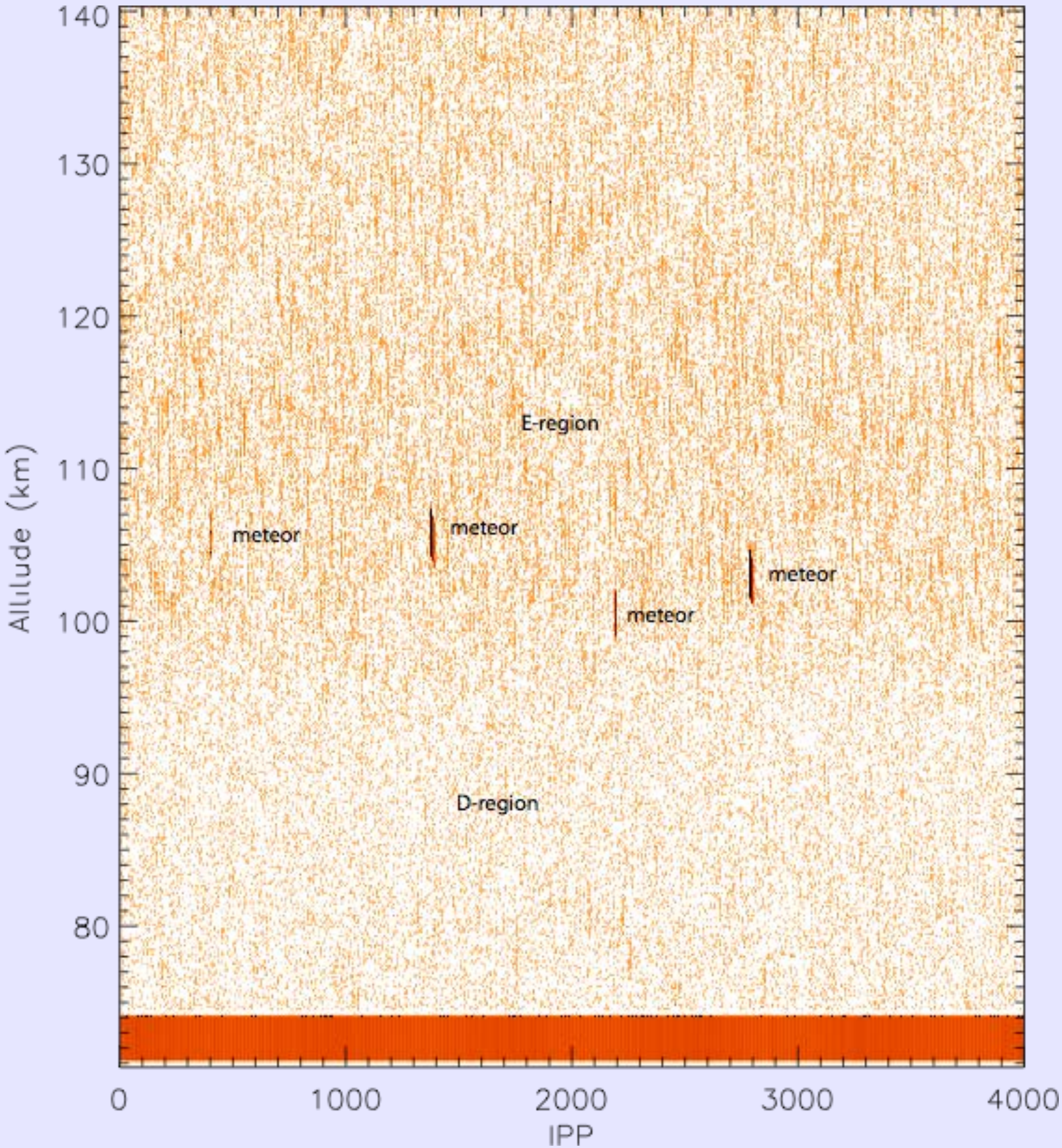
Introduction

The Arecibo Observatory (AO) 430 MHz radar system is uniquely sensitive not only as an Incoherent Scatter Radar (ISR) but also as a coherent scatter radar. The power-aperture product and cooled receivers allow this system to “see” incoherent scattering from the ionosphere with single-pulse (un-averaged) signal-to-noise ratio greater than one as shown in Figure 1—no other radar achieves this sensitivity. In addition to incoherent scattering, this radar sees coherent scattering phenomena from many sources including radar meteors that are observed at a rate of over 20,000 events per day in the very narrow (1/6th degree) 430 MHz beam.

Figure 1 shows at least four radar meteors seen with the AO 430 MHz radar. Radar meteors are similar to optical meteors except that they are seen only when illuminated by a suitable radar which then receives the radar energy scattering by the highly non-thermal (not random) plasma surrounding the meteoroid. This plasma is generated by the hypersonic impact of the meteoroid on the Earth’s upper atmosphere.

Understanding the radio science of radar scattering from the meteoroid plasma is critically important to understanding how the meteoroid interacts with the atmosphere and in determining the form—single atoms or dust/smoke—that the resultant mass flux arrives in upper atmosphere. Again the AO radar systems are unique in that in addition to the 430 MHz radar there is a VHF (46.8 MHz) radar. The VHF radar, while much less sensitive that the UHF radar, is mounted co-axially to the UHF radar and allows observations of the same meteor event at two widely separated frequencies (Figure 2) which permits details of the radio science of meteors to be better understood. In particular, it has become clear that meteoroid fragmentation occurs in the majority of meteor events.

Figure 1. Meteors observed using the Arecibo 430 MHz High-Power, Large-Aperture (HPLA) radar. This RTI (Range-Time-Intensity) plot shows at least 4 meteor events and elemental incoherent scattering (EIS). Each IPP is 1 msec in duration while each meteor has the altitude interval of the radar pulse shown at the lowest altitudes. The E-region is clearly distinguishable from the D-region even though there is no averaging other than visual integration as the SNR>1 over the entire region. The radar meteors are coherent scattering from a highly non-thermal electron enhancement as contrasted with "incoherent" scattering. As with incoherent scattering, we must understand the radio science of meteors in order to understand meteoroid physics.



Metarecord: t2290_05jun2008.066 Record: 2250
8.10445 hrs AST

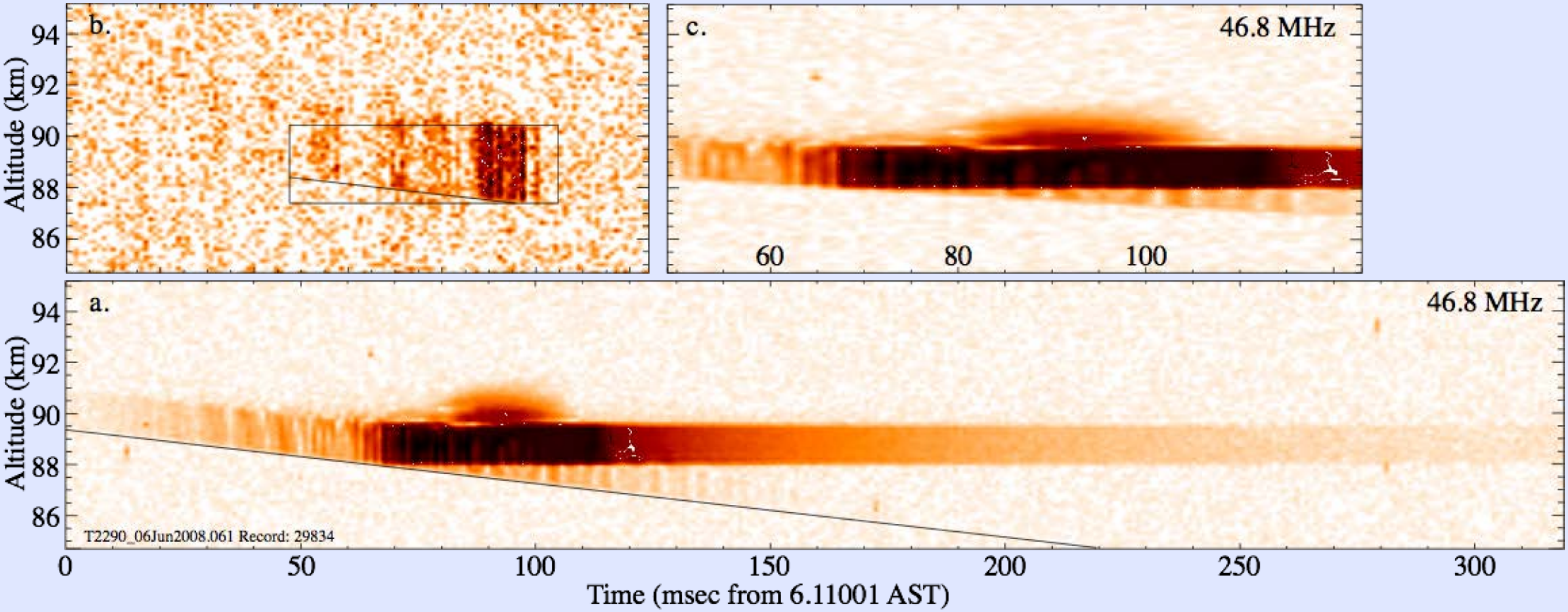
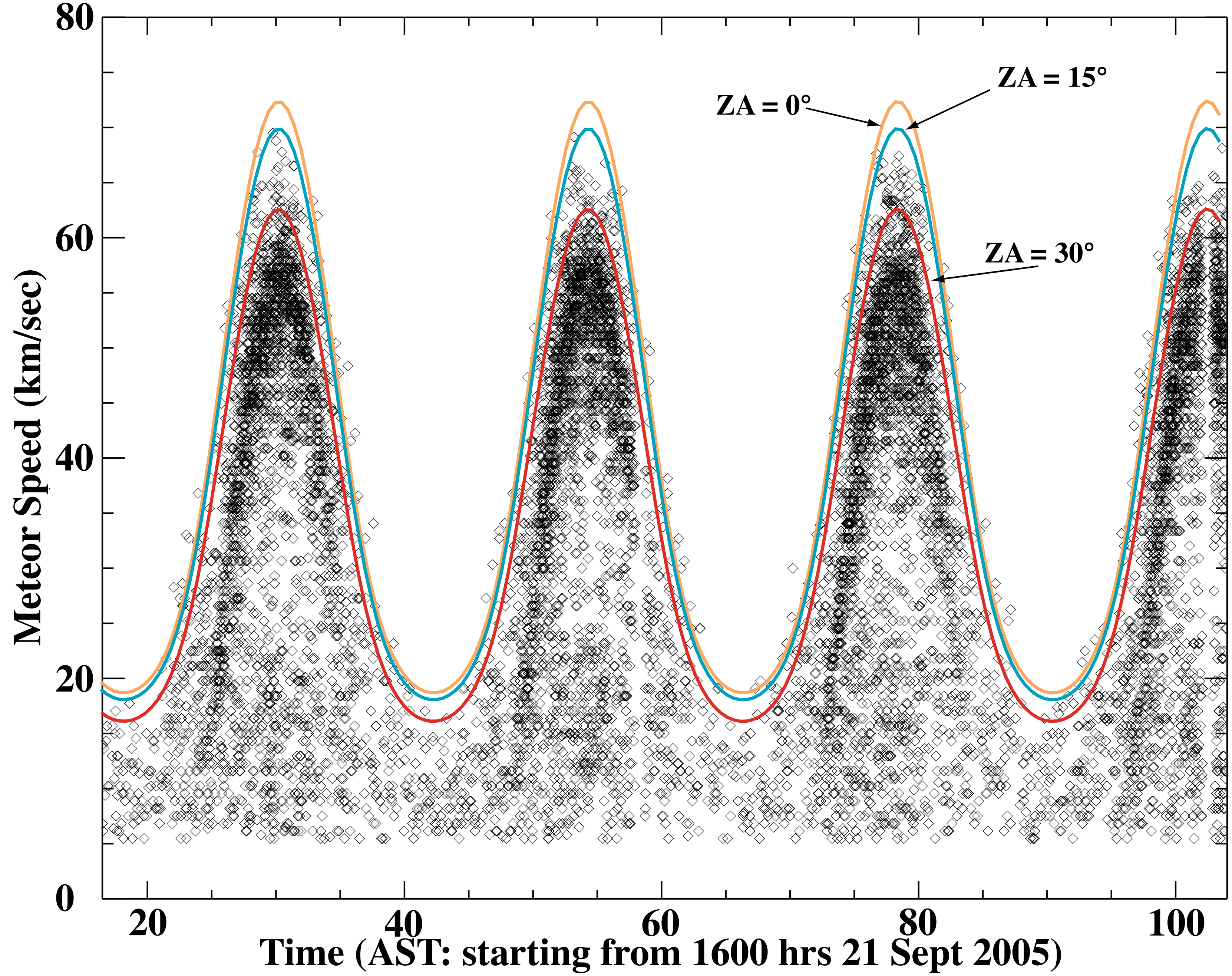


Figure 2. A V/UHF meteor with fragmentation and flaring. (a.) The VHF event shows simple fragmentation structuring with a strong flare at 67 msec and unusual additional scattering after the flare but at greater range. Simple fragmentation is indicated by the diffraction pattern—strong modulation of the intensity—indicating interference between signals scattered from two more individual radar meteors. (b.) The corresponding UHF event is much weaker with no indication of the flare trail but does indicate fragmentation. (c.) The time-expanded view of the flare clearly showing the range delayed scattering associated with the flare event. This is an interesting example of a radar scattering phenomenon that can only be observed at AO. The line-of-sight speed of this meteor event is 21.8 km/sec. The radar non-thermal scattering effects appear to indicate a “wave” and/or electrodynamic process(es) that propagate from the flare-origin at ~50-100 km/sec. Understanding the radio science aspects of this event are critical to understanding the physics associated with the strong fragmentation flare that was likely very energetic.



The AO diurnal radar meteor radial speed distribution (in atmosphere) derived from vertical-looking 430 MHz incoherent scatter measurements of the ionosphere. Each dot indicates the time and speed of an individual meteor event. Note the strong modulation of speeds and event rate from dawn—with the radar looking very close to the apex-of-Earth's-way—to dusk with the radar looking near the antapex. The curves indicate the top-of-atmosphere parabolic limit for meteoroids entering the atmosphere at the indicated zenith angles. Events above the parabolic limit come from outside the solar system and thus form a basis for exploring the local galactic environment. Approximately 5% of the events are extra-solar in origin.

Unique Arecibo meteoroid mass flux & radio science observations:

Observational Aeronomy: Uniquely able to separate meteor events from the ionospheric incoherent scatter results in order to accurately measure E-region ionization levels and thus study ionization sources including metal ions from the micrometeoroid flux. These results can can then be integrated with those of the metals lidars located at AO.

Theoretical: The radar scattering mechanism(s) for meteors must be understood in order to interpret the observational results. The 430 MHz, 46.8 MHz, and the new HF (ionospheric heater) radar will uniquely allow simultaneous observations of meteors at three vastly different frequencies enabling radio science studies.

Meteoroid Atmospheric Entry Processes: Meteoroid interaction with the atmosphere results in ablation of individual atoms along with fragmentation processes. The 3 Arecibo radars and the metals lidars offer a unique opportunity to study these processes.

Aeronomy: Radar meteoroid mass flux measurements extend to whole-earth estimates as a function of season and latitude. The form—individual ablated atoms or dust/smoke—of this flux and the net energy input to the atmosphere are critical space weather factors. Lidar observations are also critical to this study.

Electrodynamics I: Much more to be said on meteoroid dust and smoke formation and dusty plasmas physics and on the plasma physics of meteor RSTE (Range-Spread Trail-Echoes) formation.

Electrodynamics II: Is there direct meteor influence on sporadic-E and QPEs (Quasi-Periodic Echoes)?

Planetary & Local Galactic Astronomy: Addition of radar interferometry will provide highly accurate meteoroid orbit determination allowing detailed study of sources such as asteroids, comets (Kuiper & Oort Clouds), and the local galaxy (Orion arm)—about 5% of all meteors observed at Arecibo appear to be extra-solar in origin.