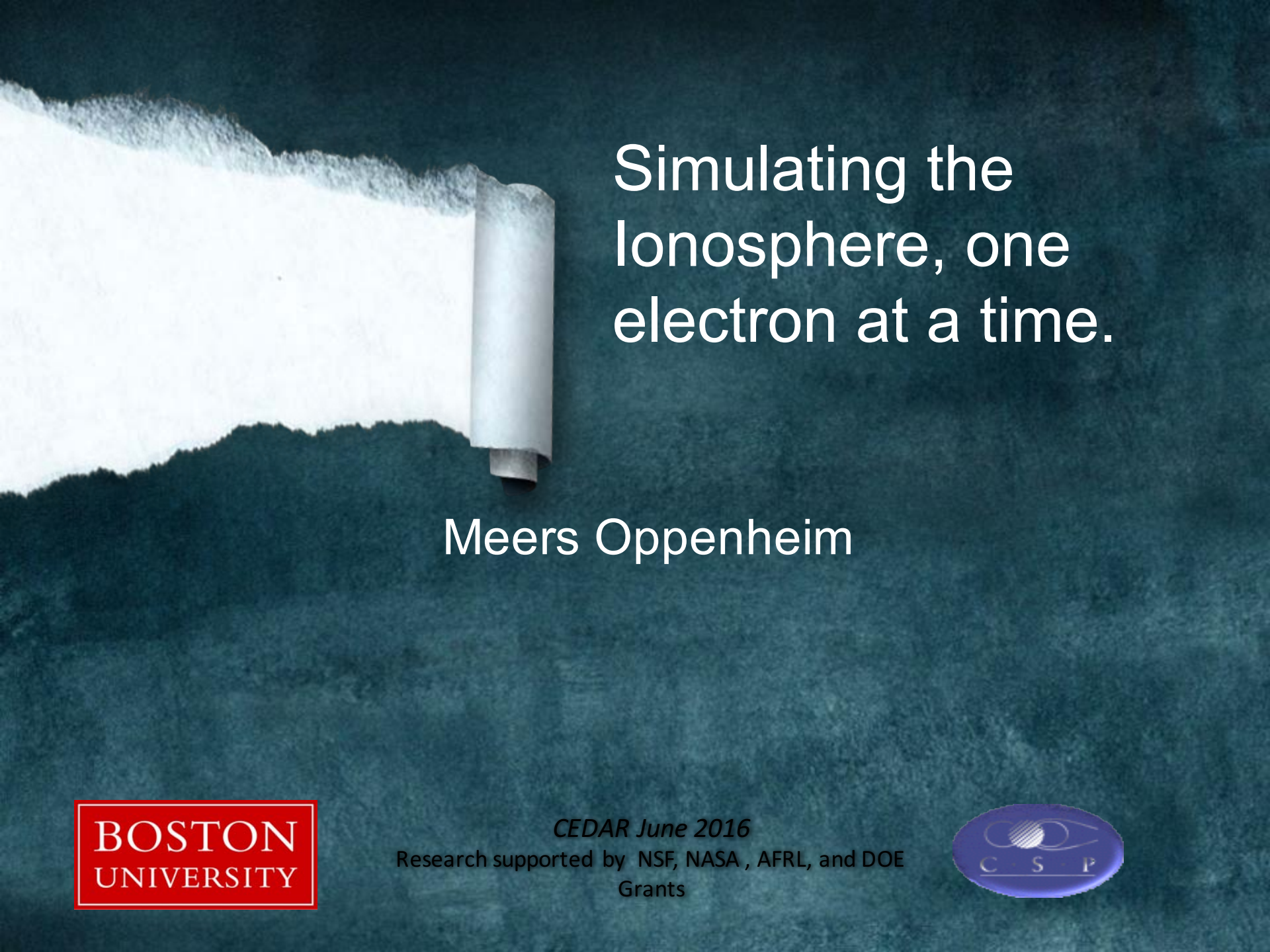


Simulating the Ionosphere, one electron at a time.

Meers Oppenheim

BOSTON UNIVERSITY

CEDAR June 2016

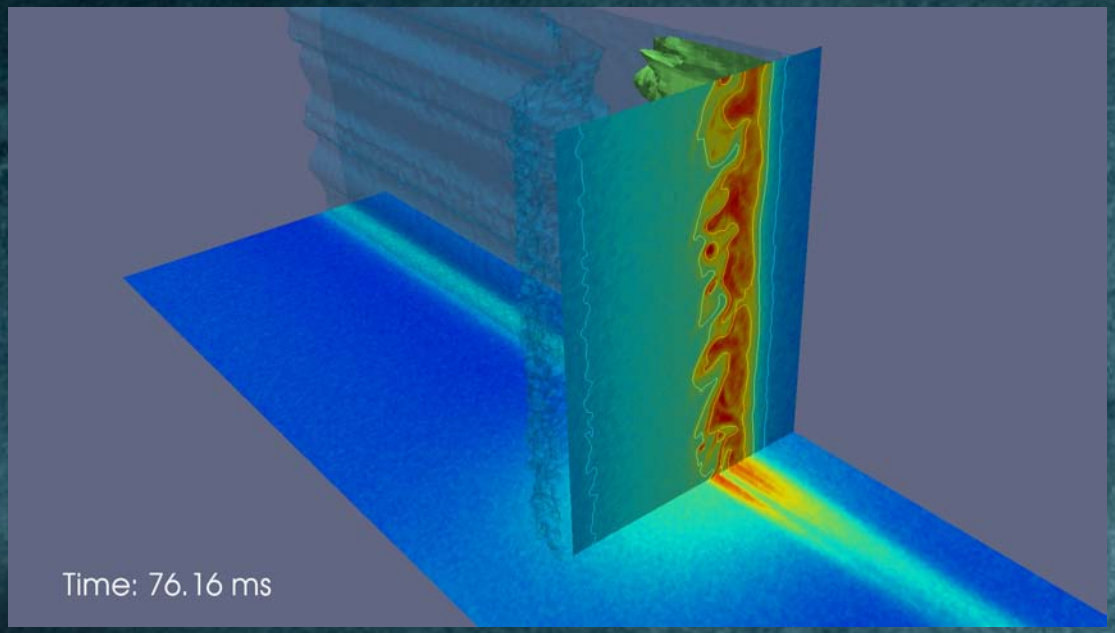
Research supported by NSF, NASA , AFRL, and DOE Grants

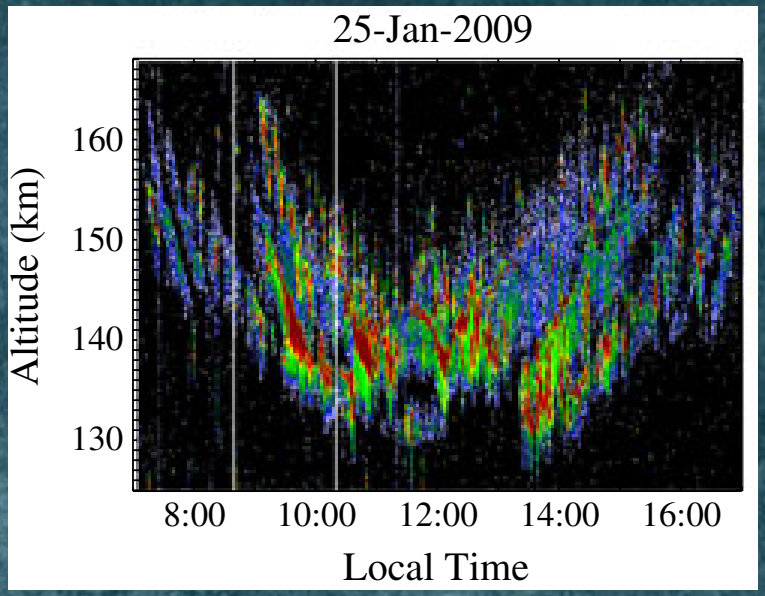
C · S · P

What?

- Plasma Physics
- Particle-in-Cell Simulations
- Two Examples:
  - Meteor Simulations
  - 150 km Echo Simulations

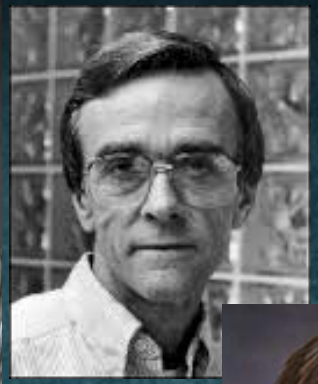

Stampede Supercomputer at TACC





Who!





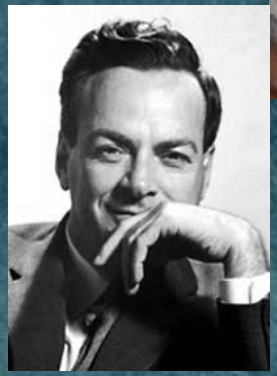

Past, Present and Future Graduate Students





BU Colleagues





Plasma Theory in 5 Minutes

1. Charged particles create fields: *Maxwell's Equations*

$$\vec{\nabla} \cdot \vec{E} = \frac{e}{\epsilon_0}(n_i - n_e) \qquad \vec{\nabla} \times \vec{E} = -\frac{\vec{\partial} B}{\partial t}$$

$$\vec{\nabla} \cdot \vec{B} = 0 \qquad \vec{\nabla} \times \vec{B} = \mu_0 \vec{J} + \mu_0 \epsilon_0 \frac{\vec{\partial} E}{\partial t}$$

2. Lorentz Force Accelerates Particles:

$$\frac{\vec{d} p_i}{dt} = q_i [\vec{E} + v_i \times \vec{B}]$$

3. Equations of Motion
4. Collisions deflect particles (important in the lower ionosphere and other regimes)

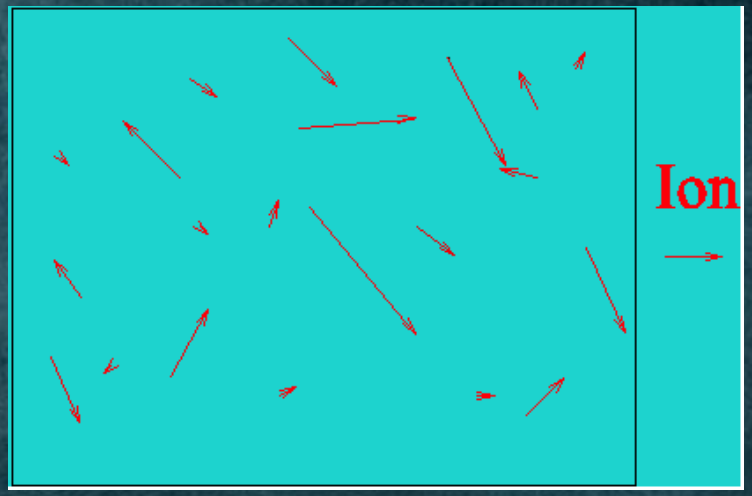
Too many particles – Need simplifications!

Plasma Simplifications

1. Fundamental Laws
2. Kinetic Theory ⟷ PIC Simulations
3. Multi-Fluid Theory
4. Magnetohydrodynamics (MHD) Theory

Particle Simulations

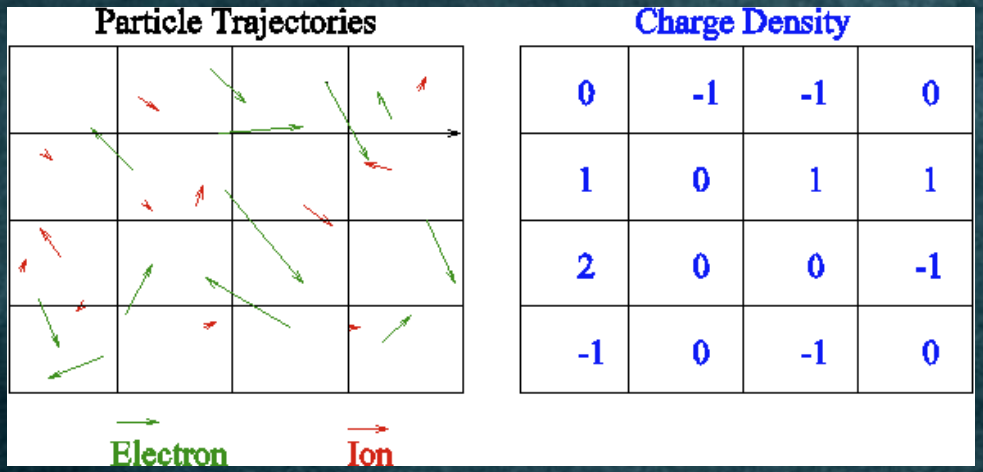
- Particles move within a box:
  - Position: $\boldsymbol{x}_i$
  - Velocity: $\boldsymbol{v}_i$
- Particles interact through fields
- Fields accelerate particles
- Too Slow!



$$\overrightarrow{F_{ij}} = \frac{q_i q_j}{4\pi\epsilon_0 |\overrightarrow{x_i} - \overrightarrow{x_j}|^2}$$

Electrostatic Particle-In-Cell

1. Gather to determine charge density, ρ



$$\rho(x) = \sum_{particles} q_i \delta(x - x_i)$$

2. Calculate Electric field:

$$\vec{\nabla} \cdot \vec{E} = \rho / \epsilon_0$$

3. Update velocities:

$$\frac{d\vec{v}_i}{dt} = \frac{q_i}{m_i}\left[E(\vec{x}_i, t) + \vec{v}_i \times B(\vec{x}_i, t)\right]$$

4. Collide particles with neutrals
5. Update Positions:

$$\frac{d\vec{x}_i}{dt} = \vec{v}_i$$

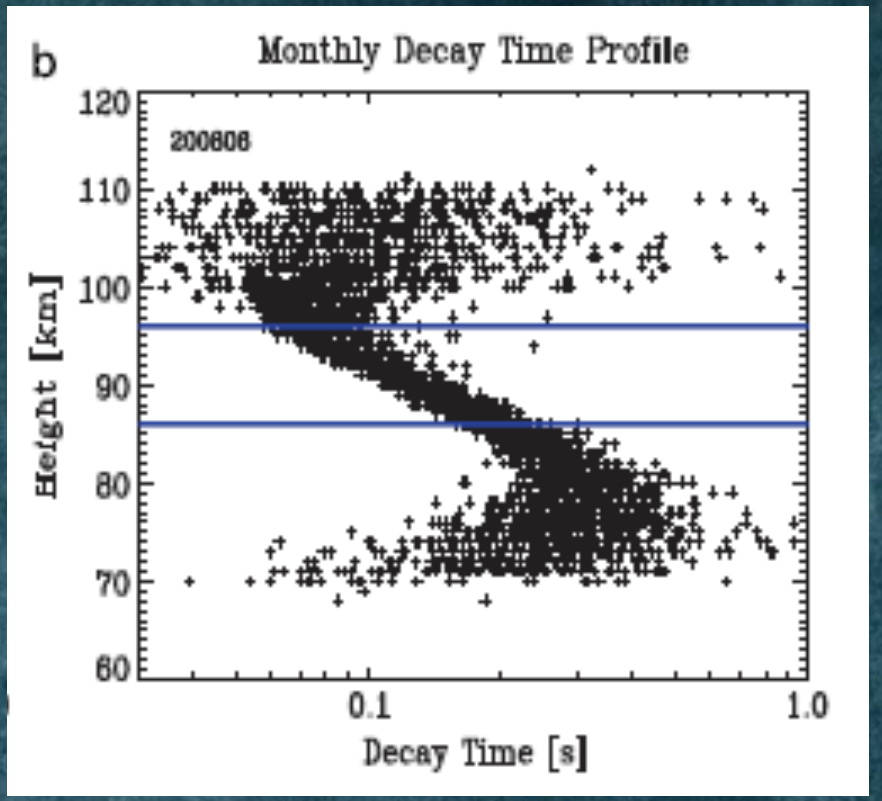
6. Go to Step 1

Modern PIC Simulations Require Supercomputers

- Up to 8,000 processors simultaneously
- 2048x1024x1024 grid
- 8×10^9 PIC particles

Stampede Supercomputer at TACC

Specular Meteor Radar Raises a Question



Kim, J.-H., Y. H. Kim, G. Jee, and C. Lee (2012),

First Meteor Paper:

GEOPHYSICAL RESEARCH LETTERS, VOL. 27, NO. 19, PAGES 3173-3176, OCTOBER 1, 2000

Electrodynamics of meteor trail evolution in the equatorial E–region ionosphere

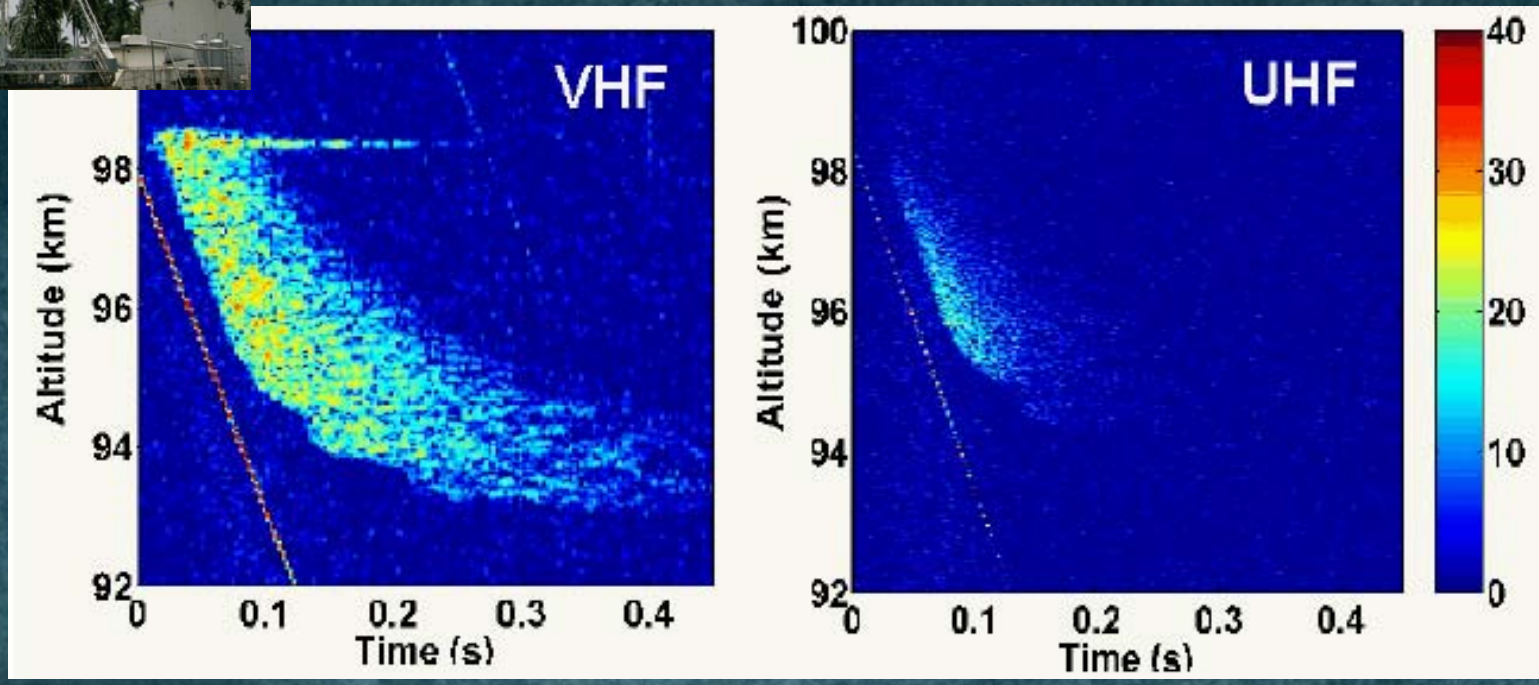
Meers M. Oppenheim, Axel F. vom Endt and Lars P. Dyrud

Center for Space Physics, Boston University

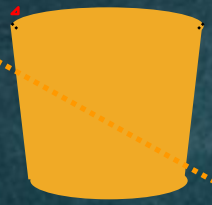
Abstract. Using analytical models and kinetic simulations, this paper shows that weakly ionized meteor trails near the geomagnetic equator evolve through three distinct stages. First, a large electric field is generated perpendicular to both the geomagnetic field and the trail. Second, plasma density waves grow asymmetrically across the trail. Third, turbulence develops in the trails. Throughout this process, the electron $\mathbf{E} \times \mathbf{B}$–drift velocity plays an essential role in controlling the motion of the trail. These plasma dynamics have important implications for the interpretation of meteor radar echoes.

Long–duration, non–specular radar echoes of meteor trails observed at the geomagnetic equator have been attributed to the GDFB instability mechanism [*Chapin and Kudeki*, 1994a; *Chang et al.*, 1999]. In this study, we investigate the small-scale electrodynamics of meteor trails using a hybrid kinetic–fluid simulator. Further, we restrict ourselves to the equatorial case, where more detailed observational data has been published [*Chapin and Kudeki*, 1994b]. While this paper presents the most detailed simulations of meteor trail electrodynamics to date, a number of other researchers have investigated the similar electrodynamics generated by barium cloud releases [*Blaunstein et al.*, 1993].

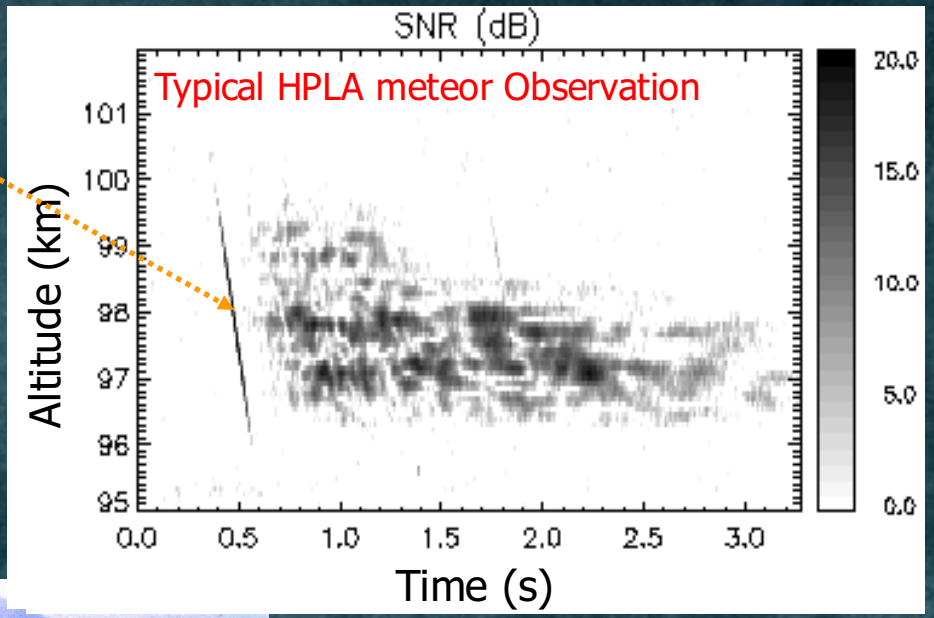
Modern HPLA Observations



Jicamarca Meteor Measurements



- Antenna:
  - 300m x 300m
  - 18,432 dipoles
- *A High-Power Large-Aperture Radar (HPLA)*

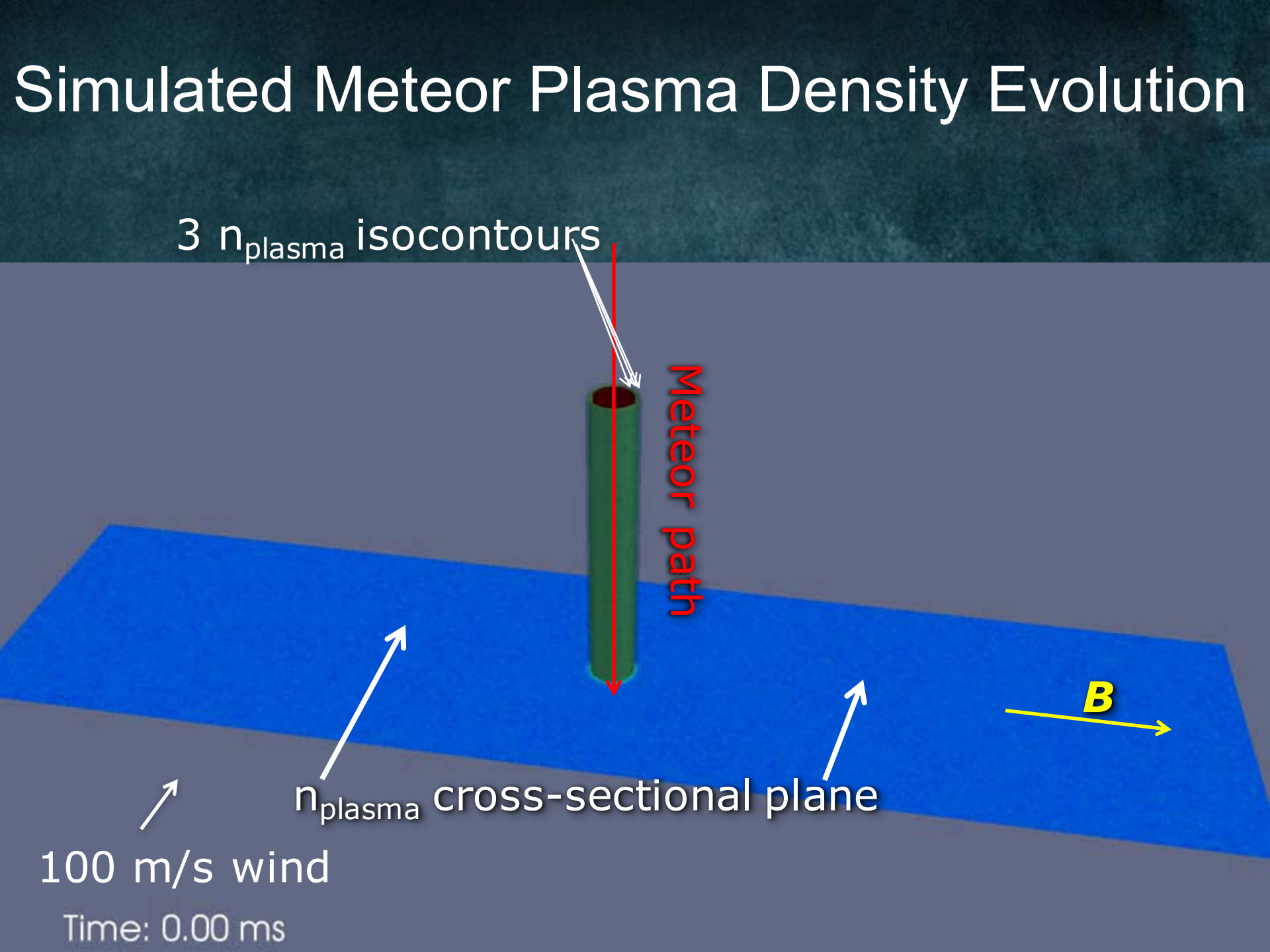


Importance of Small Meteors

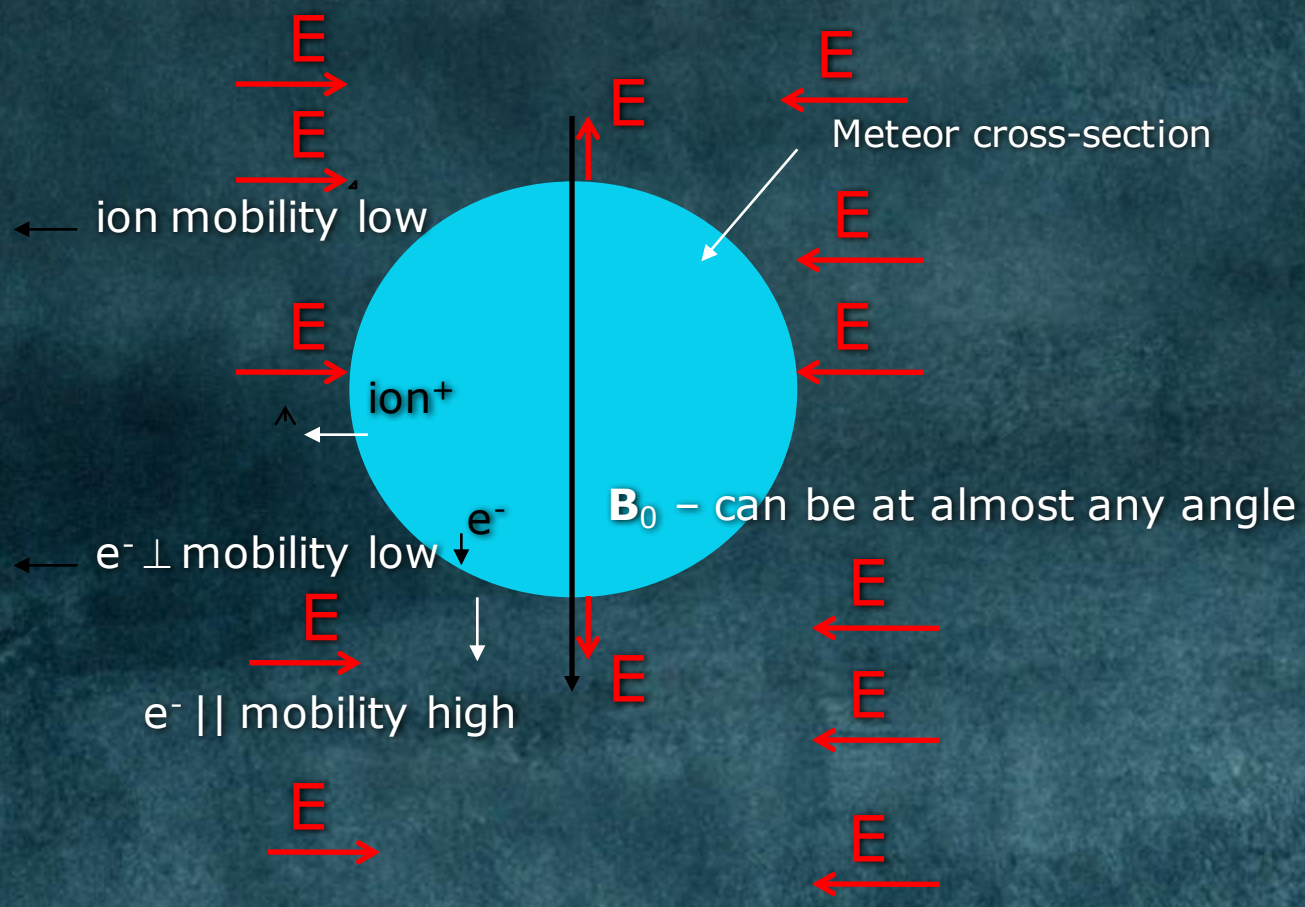
- Upper Atmospheric Science:
  - Source of metals in the upper atmosphere
    - Modifies chemistry
    - Dust source (Noctilucent clouds & PMSEs++)
    - Long lived E-region ions - affects nighttime conductivity
    - Metal layers responsible for Sporadic E
  - Radars measure atmospheric winds (and winds)
- Solar System studies:
  - The Earth is a giant debris detector
  - How much is out there?
  - Where is it coming from?
  - What is it made from?
- Communication: Meteor burst communication
- Spacecraft Threats:

Leonids 1966

Simulated Meteor Plasma Density Evolution



Meteor Fields: Theory



In Background Plasma

$$\nabla^2\phi = 0$$

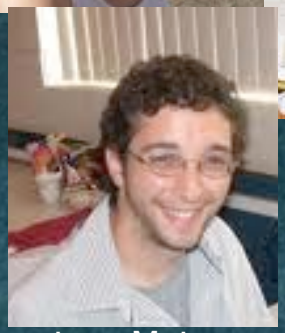
Dimant & Oppenheim (AG,2006)

Meteor Research at BU

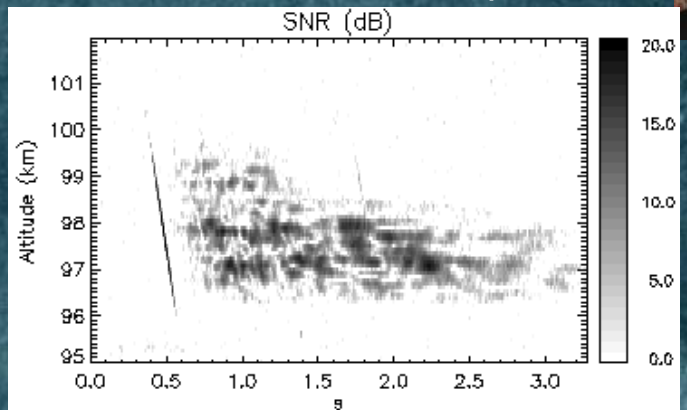
- Meteor Papers + Abstracts:
  - 2000-2015
  - 52 total from NASA ADS
  - 28 Refereed papers
  - 2.5 Theses



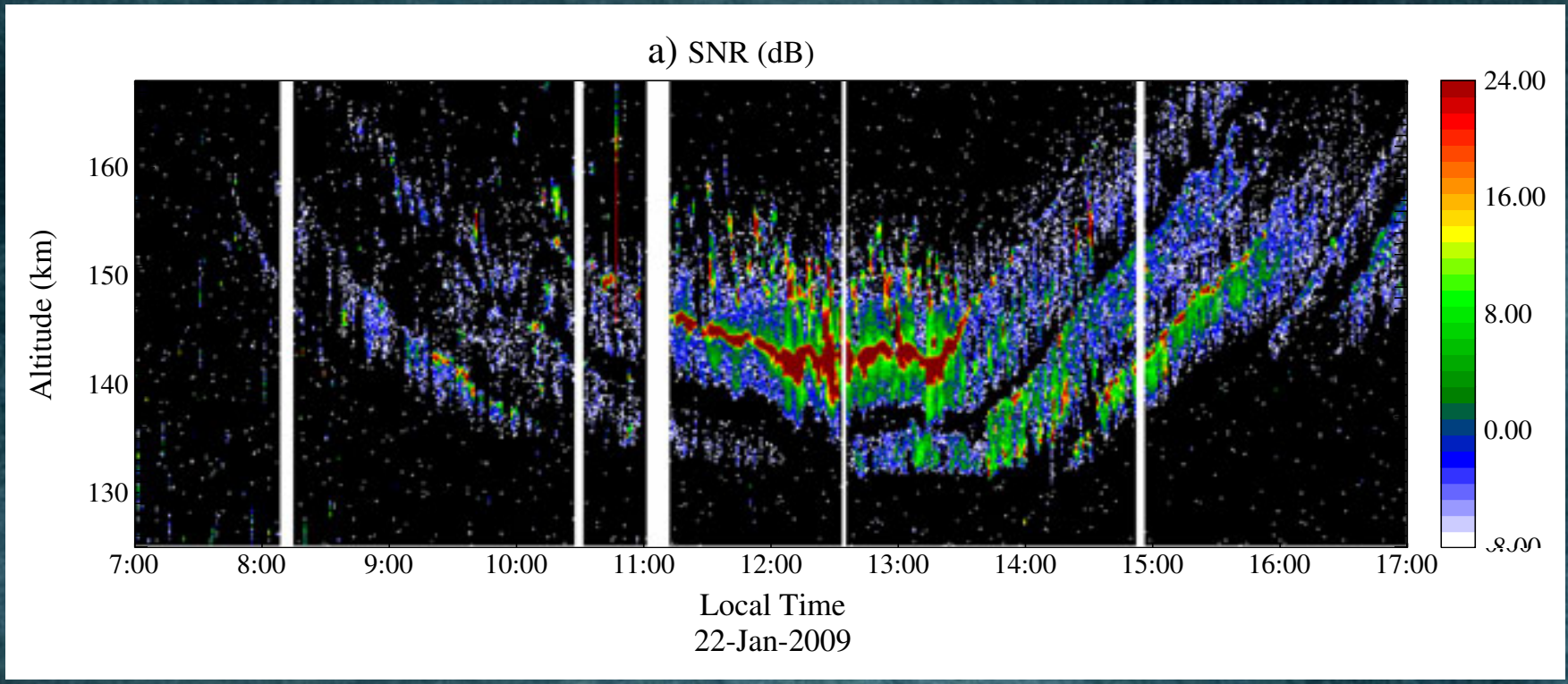




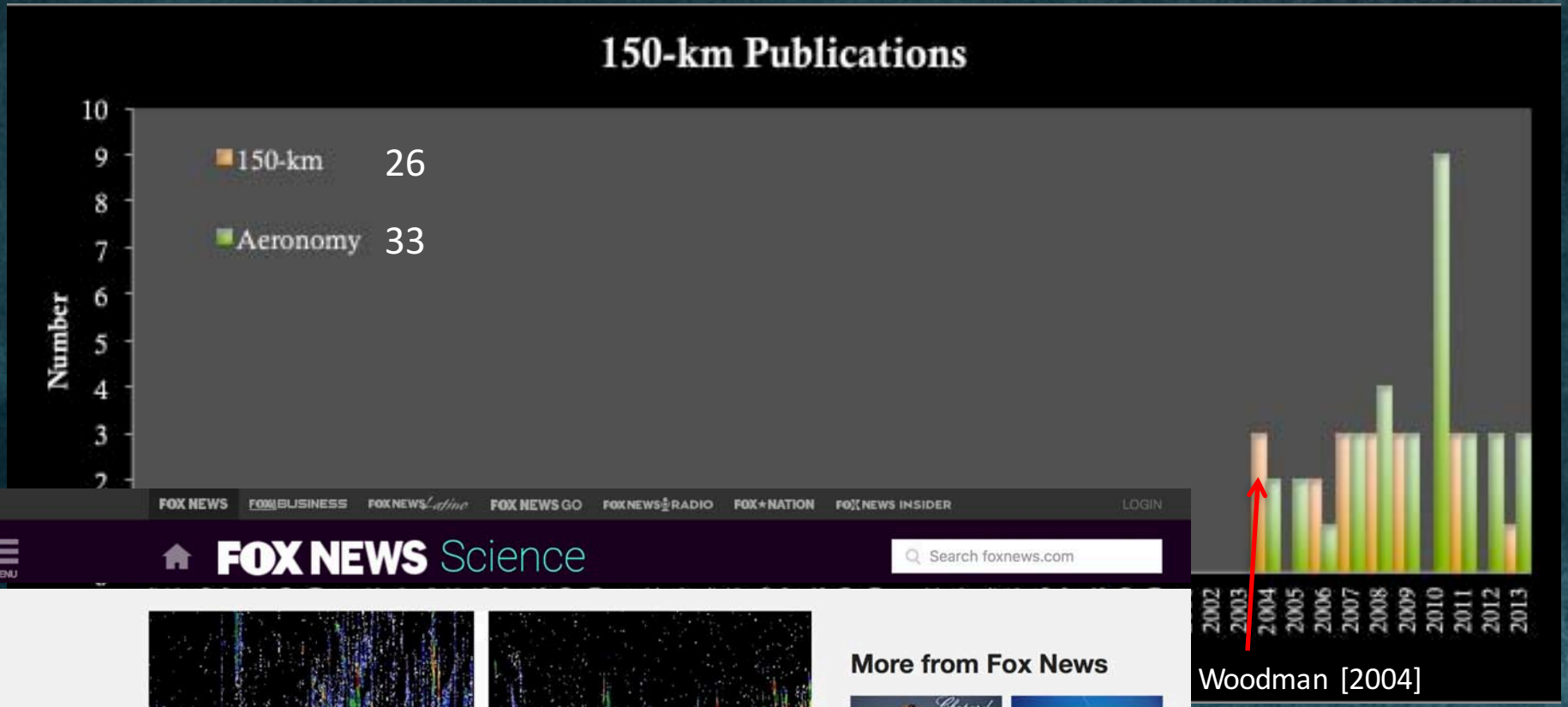

Jicamarca Radio Observatory Meteor

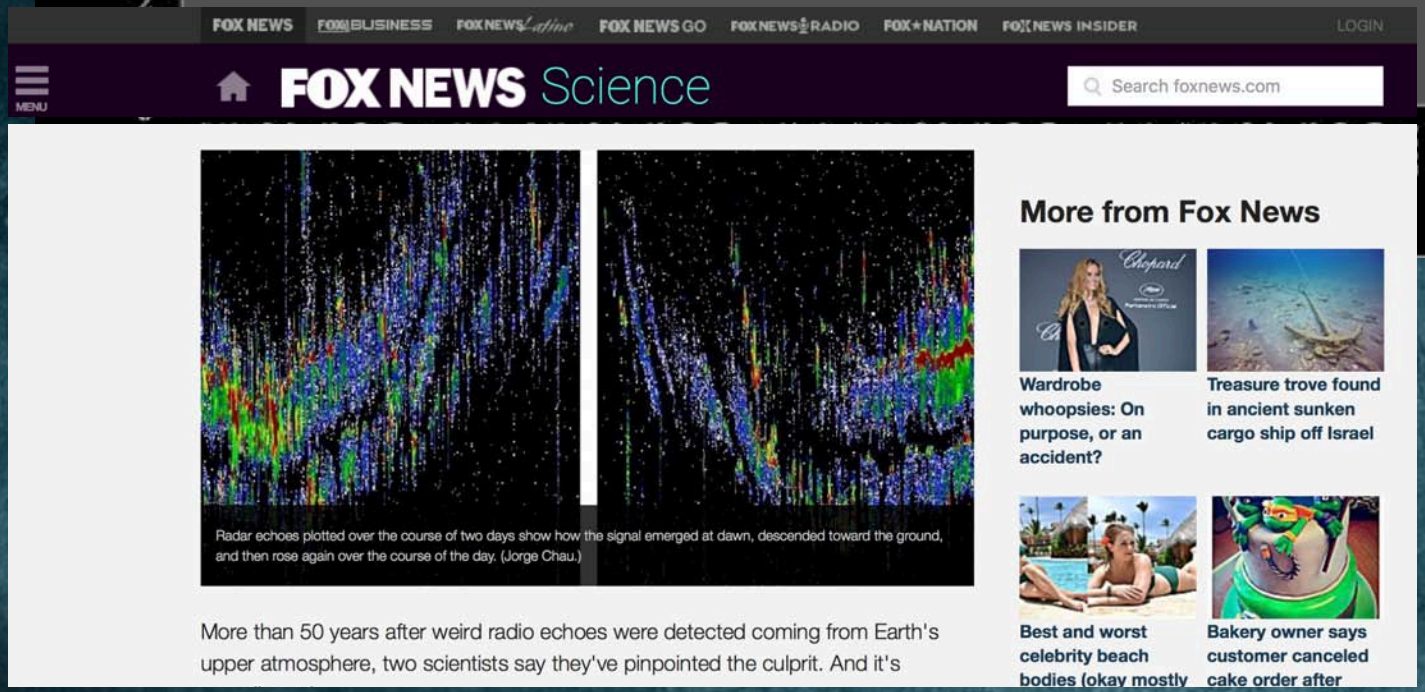


150-km Echoes



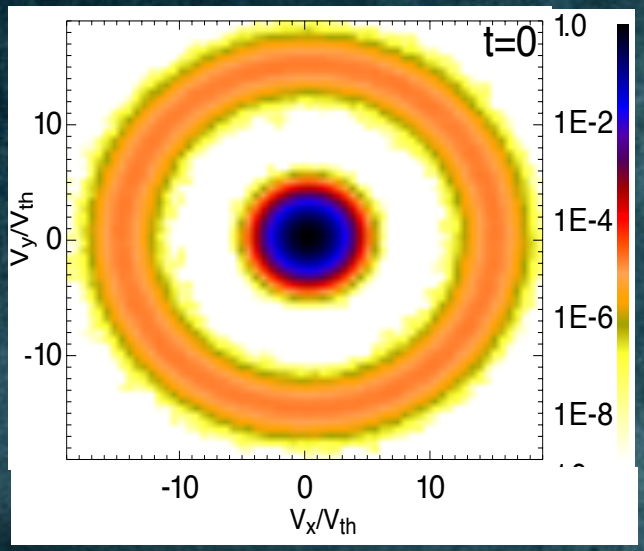
Who cares about 150 km echoes?

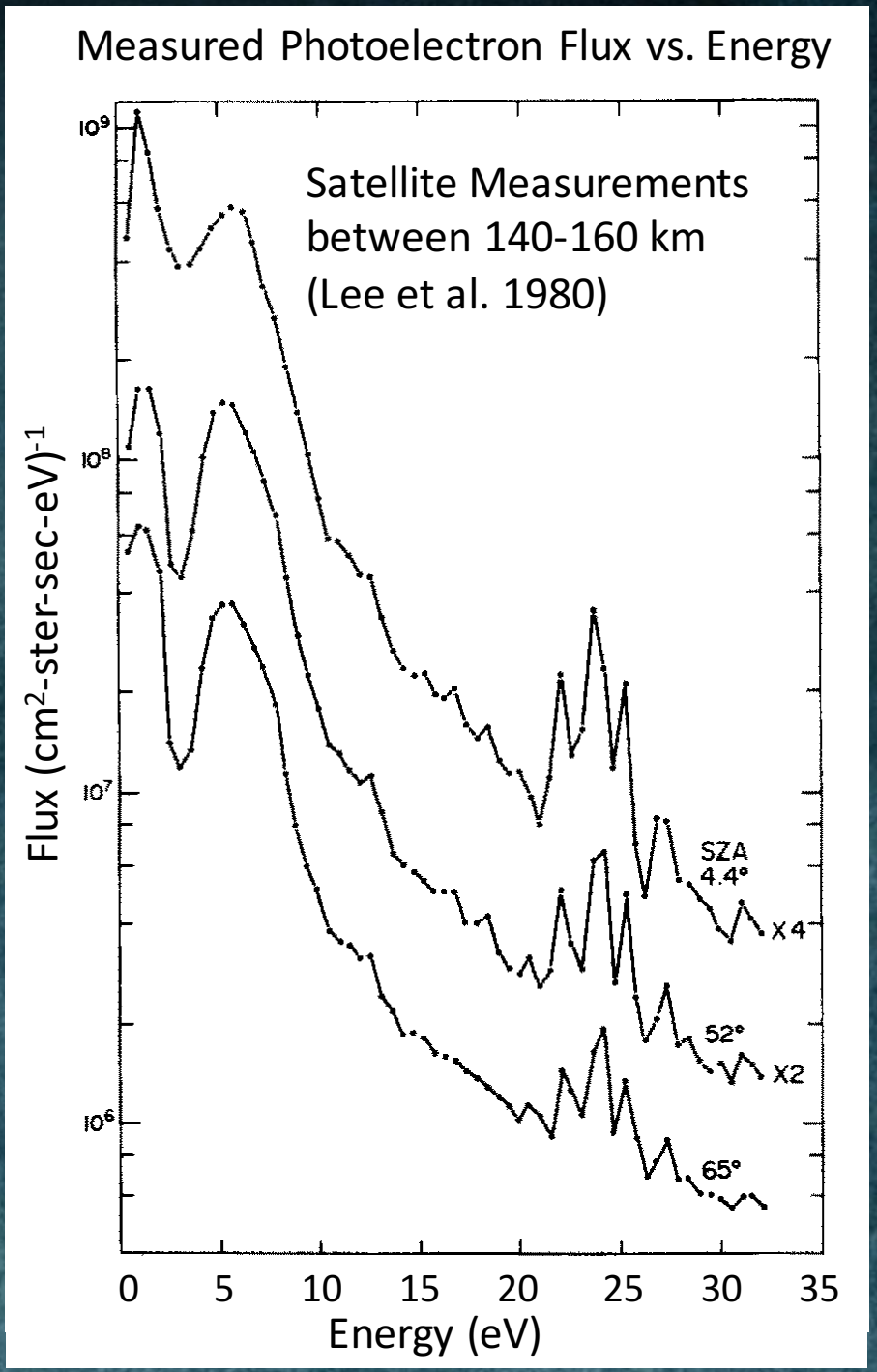




Our Hypothesis…

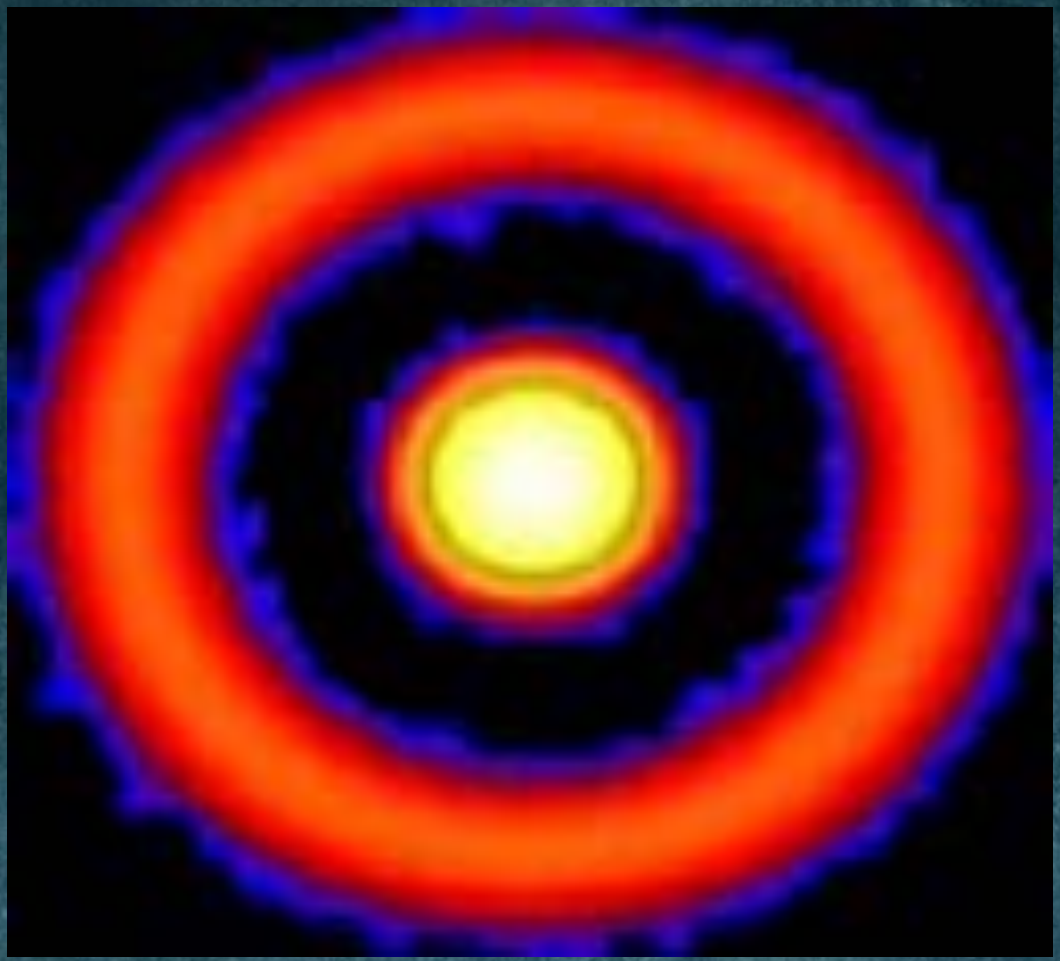
- Photoelectrons
- Create a shell of energetic electrons in velocity space.
- Energetic Electrons Create Electron Waves
- Electron Waves Create Ion Waves





Model: Photoelectrons Create Energetic Shell of Electrons

3D shell of electrons around a cold core



Vperp

Vparallel

- Includes photoelectron regeneration
- collisions

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2016GL068179

Key Points:
- Origin of 150 km echoes
- Simulations of photoelectron-induced irregularities in the ionosphere
- Answers a long-standing mystery about a geophysical observation

Supporting Information:
- Supporting Information S1
- Movie S1

Correspondence to:
M. M. Oppenheim,
meerso@bu.edu

Citation:
Oppenheim, M. M., and Y. S. Dimant (2016), Photoelectron-induced waves: A likely source of 150 km radar echoes and enhanced electron modes, *Geophys. Res. Lett.*, *43*, doi:10.1002/2016GL068179.

Received 8 FEB 2016
Accepted 29 MAR 2016

Photoelectron-induced waves: A likely source of 150 km radar echoes and enhanced electron modes

Meers M. Oppenheim[1] and Yakov S. Dimant[1]

[1]Center for Space Physics, Boston University, Boston, Massachusetts, USA

Abstract VHF radars near the geomagnetic equator receive coherent reflections from plasma density irregularities between 130 and 160 km in altitude during the daytime. Though researchers first discovered these 150 km echoes over 50 years ago and use them to monitor vertical plasma drifts, the underlying mechanism that creates them remains a mystery. This paper uses large-scale kinetic simulations to show that photoelectrons can drive electron waves, which then enhance ion density irregularities that radars could observe as 150 km echoes. This model explains why 150 km echoes exist only during the day and why they appear at their lowest altitudes near noon. It predicts the spectral structure observed by Chau (2004) and suggests observations that can further evaluate this mechanism. It also shows the types and strength of electron modes that photoelectron-wave interactions generate in a magnetized plasma.

1. Introduction

Shortly after the large VHF radar at the Jicamarca Radio Observatory (JRO) was deployed in 1962, it detected unexpected echoes at around 150 km altitude [*Balsley*, 1964]. Figure 1 shows two modern examples of these "150 km echoes." Despite decades of investigation, the origin of these reflections remains a mystery. This paper introduces a novel model to explain many aspects of these echoes and presents a series of simulations to show its plausibility.

28 APRIL 2016

New study explains source of mysterious radar echoes

Posted by edeatrick

By Elizabeth Deatrick

After 50 years, scientists think they may have cracked one of atmospheric science's most persistent mysteries.

For decades, scientists sending radar signals into space have noticed there is some phenomenon reflecting these waves back to the ground at around 150 kilometers (90 miles) above the ground.

Jicamarca Radio Observatory, where the 150-kilometer radar echoes were first discovered. *Image credit: JRO (public domain via Wikimedia Commons)*

Every day at dawn, the unknown phenomenon appears. Radar waves bounce off of it and return to radar receivers like an echo. Whatever is generating the "150-kilometer echoes" grows stronger and descends 20 to 30 kilometers (12 to 19 miles) toward the ground until the sun is directly overhead. The source of the echoes then rises again until sunset, when the echoes disappear. The echoes fade during solar eclipses, and grow more powerful during solar flares. Radar operators have detected these echoes since the 1960s, but rockets, satellites, and other instruments probing the upper atmosphere see nothing.

This bizarre behavior has stumped scientists for years. Now, a pair of researchers at Boston University

GEOSPACE

GeoSpace is a blog on Earth and space science, managed by AGU's Public Information staff. The blog features posts by AGU writers and guest contributors on all sorts of relevant science topics, but with a focus on new research and geo and space sciences-related stories that are currently in the news.

SUBSCRIBE VIA EMAIL

Enter your email address to subscribe to this blog and receive notifications of new posts by email.

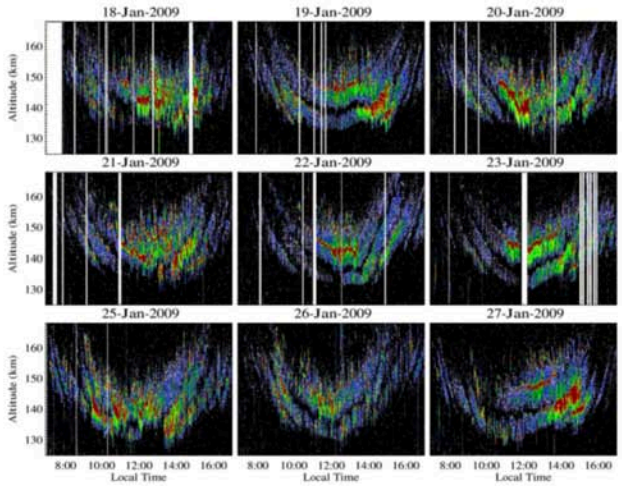
Email Address

Subscribe

OTHER AGU BLOGS

FROM A GLACIER'S PERSPECTIVE >>

THE LANDSLIDE BLOG >>



Mysterious high-altitude radar echoes (examples shown above; red portions are stronger than blue and green zones), appear at dawn and disappear at dusk.

Jorge Chau

Mysterious radar echoes in the sky explained?

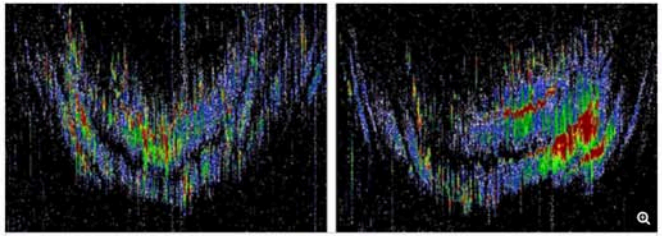
By Sid Perkins | May. 5, 2016 , 12:15 PM

They appear at dawn at an altitude of about 150 kilometers: odd radar blips that descend from the sky over the course of the morning, growing stronger as they drop 20 km as the day progresses. Then they rise back to 150 km during the afternoon, before disappearing at sunset. These radar echoes have puzzled researchers for decades. And now a new study may finally have an explanation for what causes them.

At first glance on a radar screen, the echoes don't look much different than the zones of light and heavy precipitation that show up on weather radars, which operate at much shorter

Mystery of Bizarre Radar Echoes Solved, 50 Years Later

By Jeanna Bryner, Live Science Managing Editor | May 12, 2016 08:51am ET



Radar echoes plotted over the course of two days show how the signal emerged at dawn, descended toward the ground, and then rose again over the course of the day.

Credit: Jorge Chau.

More than 50 years after weird radio echoes were detected coming from Earth's upper atmosphere, two scientists say they've pinpointed the culprit. And it's complicated.

In 1962, after the Jicamarca Radio Observatory was built near Lima, Peru, some unexplainable phenomenon was reflecting the radio waves broadcast by the observatory back to the ground to be picked up by its detectors. The mysterious cause of these echoes was sitting at an altitude of between 80 and 100 miles (130 and 160 kilometers) above sea level.

"As soon as they turned this radar on, they saw this thing," study researcher Meers Oppenheim, of the Center for Space Physics at Boston University, said, referring to the anomalous echo. "They saw all sorts of interesting phenomena that had never been seen before. Almost all of it was explained within a few years." [In Photos: Mysterious Radar Blob Puzzles Meteorologists]

Peculiar radar echoes

Though the other phenomena detected by the observatory got explanations, these radar echoes continued to baffle scientists.

To see what was happening at that altitude, researchers at the time sent rockets, equipped with antennas and particle detectors, through the region. The instruments, which were designed to detect radar waves, "saw almost nothing," Oppenheim said.

Mysterious 'alien' radar signals received on Earth at dawn every day could be echoes caused by the SUN

- Radar waves sent into space return to scientists' receivers like an echo
- It begins at dawn, and grows stronger until the sun is directly overhead
- Researchers have long sought the origin, but it has so far gone undetected
- Study suggests energized electrons create 'waves' which reflect signals

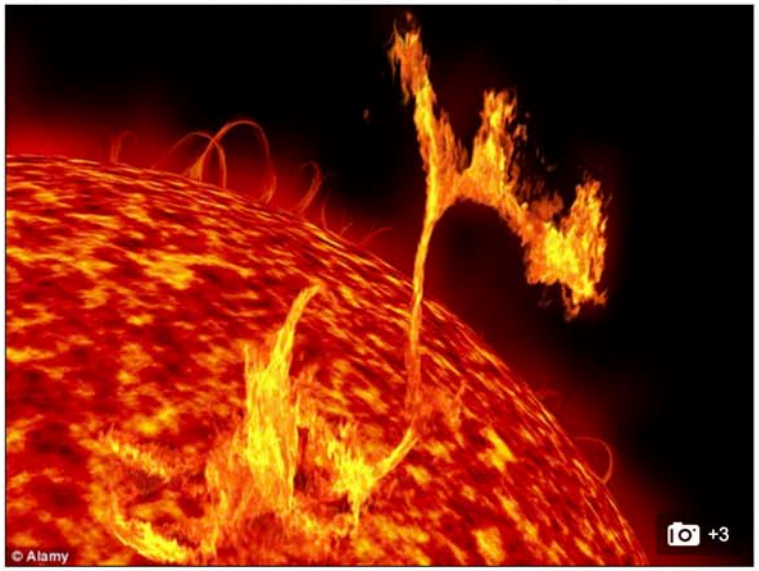
By CHEYENNE MACDONALD FOR DAILYMAIL.COM

PUBLISHED: 13:52 EST, 9 May 2016 | **UPDATED:** 15:12 EST, 9 May 2016

For more than 50 years, scientists have remained perplexed by a strange phenomenon known as the '150-kilometer echoes.'

It happens every day at dawn – radar waves sent into space by researchers are reflected by an unknown entity 150 km above the ground, returning to the receivers like an echo.

Now, a team of researchers at Boston University says the sun's radiation may be to blame.



For decades, scientists have been perplexed by a strange phenomenon. It happens at dawn – radar waves sent into space by researchers are reflected by an unknown entity 150 km above the ground, returning like an echo. During a solar eclipse, the echoes fade. But during solar flares, they grow more powerful

The mysterious 'echoes' were first detected in the 1960s.

WHAT THE STUDY FOUND

Today's headlines | Most Read


The first art gallery? Archaeologists discover large collection of 14,500-year-old animal paintings in...


Neanderthals were BORN wide and stocky: Fossils reveal vast differences between modern babies and their...


The transforming 'hypercopter' that can hit 293mph: Airbus awarded patent for record breaking helicopter...


Saab's Gripen E fighter to take on the F-35: Jet travels at 1,522 mph with improved sensors, weaponry and...


Last of a dynasty: 3,800-year-old mummy of ancient Egyptian woman described as 'one of the most important...


Could you tell the difference? Meatless plantburger that 'tastes, feels and even bleeds' like meat goes on...


Forget the giant squid: Scientists say there could be school bus-sized MEGASQUID lurking in our oceans


Was MS804 struck by a METEOR? Russian space officials had warned that rock which entered Earth's atmosphere...


Grief in the wild: Heartbreaking study finds male snub-nosed monkey spent an hour with his dying mate - and...


FBI unveils sniffer dog for the digital age: Iris the Labrador can smell hard drives and tiny USB sticks...


Wound-plugging XStat syringe saves its first life on the battlefield: Device uses SPONGES to stop bleeding...


Bet the Wifi was a bit ropey! Apple bossTim Cook jokes thinks he's spotted an iPhone in a 1670 Dutch...


Meet Pizza Hut's latest employee: Pepper the robot to take orders and give recommendations in Asian trial


The 'red geysers' that turn galaxies into cosmic graveyards: Supermassive black holes drive intense...


Survival of the FATTEST: Female meerkats gain weight if their sisters do in an attempt to move further up...

MORE HEADLINES

FEMAIL TODAY

Atmosphärenforschung: Forscher erklären mysteriöse Himmelechos

Von Axel Bojanowski

imago

Radarforschung

Seit 54 Jahren rätseln Forscher über einen unsichtbaren Spiegel: Hoch am Himmel reflektiert er Radarwellen. Jetzt gibt es eine Erklärung für das Mysterium.

Dienstag, 17.05.2016 – 11:46 Uhr

Drucken

Nutzungsrechte | Feedback

THEMA Meteorologie

Geologie

Alle Themenseiten

Mehr auf SPIEGEL ONLINE

Neue Satellitendaten: Extremer Sonnensturm verfehlte die Erde (24.07.2014)

Graf-Seismo-Kolumne: Rätsel der Erde

Mehr im Internet

Buchtipp "Nach zwei Tagen Regen folgt Montag": 33 erstaunliche Rätsel der Erde, von Axel Bojanowski

"GRL": "Photoelectron-induced waves"

Teilen Twittern E-Mail +

Täglich zur Dämmerung geschieht es. Radarwellen, die Wissenschaftler gen Himmel schicken, kommen zurück zur Erde. 150 Kilometer über der Erde werden sie reflektiert wie an einem unsichtbaren Spiegel.

Während des Tages verstärken sich die Echos, und sie kommen immer schneller zurück. Denn zur Mittagszeit sinkt der mysteriöse Horizont, der die Radarwellen reflektiert, auf 25 Kilometer. Abends steigt der Spiegel der Echos wieder auf 150 Kilometer Höhe. In der Nacht verschwindet er.

1962 waren die Reflektionen entdeckt worden. "Seither haben wir versucht herauszufinden, was vor sich geht", sagt Jorge Chau vom Leibniz-Institut für Atmosphärenphysik (IAP).

Doch weder Satelliten, Raketen, Laser, noch andere Instrumente wurden fündig. Sie entdeckten keine verdächtigen Substanzen in der Luft. So kamen unvermeidlicherweise Signale Außerirdischer als Ursache der Echos ins Gespräch.

Doch Wissenschaftler hatten schnell die Sonne in Verdacht - schließlich entscheidet offenbar ihr Stand über die Stärke der Echos. Und bei Sonnenfinsternis versiegen sie, bei Eruptionen von Sonnenteilchen erstarken die Reflektionen.

Undurchdringliche Partikelwelle

Jetzt meinen Forscher der Boston University, das Rätsel gelöst zu haben. Am Computer simulierten sie, wie Sonnenstrahlung auf Partikel in der Atmosphäre wirkt.

DAILY NEWS 10 May 2016

Invisible radar wall in the atmosphere caused by UV from the sun

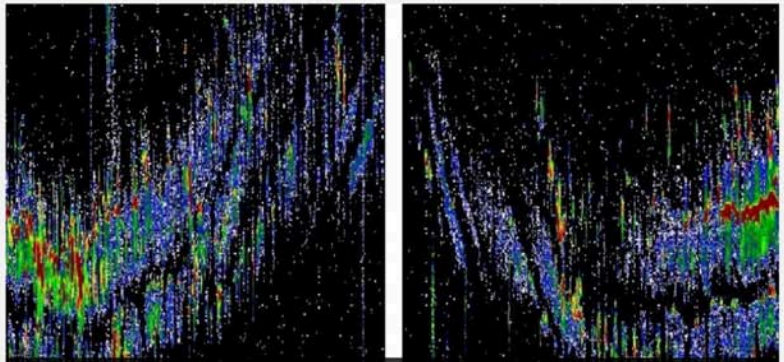
The Jicamarca Radio Observatory in Peru, where radar echoes in the upper atmosphere were first detected
View Pictures/REX/Shutterstock

By Shannon Hall

NATURAL SCIENCE

Mystery of bizarre radar echoes solved, 50 years later

LIVE SCIENCE. By Jeanna Bryner, Live Science Managing Editor · Published May 16, 2016



Radar echoes plotted over the course of two days show how the signal emerged at dawn, descended toward the ground, and then rose again over the course of the day. (Jorge Chau.)

More than 50 years after weird radio echoes were detected coming from Earth's upper atmosphere, two scientists say they've pinpointed the culprit. And it's complicated.

In 1962, after the Jicamarca Radio Observatory was built near Lima, Peru, some unexplainable phenomenon was reflecting the radio waves broadcast by the observatory back to the ground to be picked up by its detectors. The mysterious cause of these echoes was sitting at an altitude of between 80 and 100 miles (130 and 160 kilometers) above sea level.

"As soon as they turned this radar on, they saw this thing," study researcher Meers Oppenheim, of the Center for Space Physics at Boston University, said, referring to the anomalous echo. "They saw all sorts of interesting phenomena that had never been seen before. Almost all of it was explained within a few years."

More from Fox News

Wardrobe whoopsies: On purpose, or an accident?

Treasure trove found in ancient sunken cargo ship off Israel

Best and worst celebrity beach bodies (okay mostly best)

Bakery owner says customer canceled cake order after finding out she was

Items found in Florida sinkhole challenge story of the Americas

Bill Cosby ordered to stand trial for sexual assault

Trending in Science

ByteMeCommies 10 days ago

Like climate science, their models reflect their bias, not reality.

2 Like Reply

MeRex 10 days ago

Maybe they will find Obama's real birth certificate.

2 Like Reply

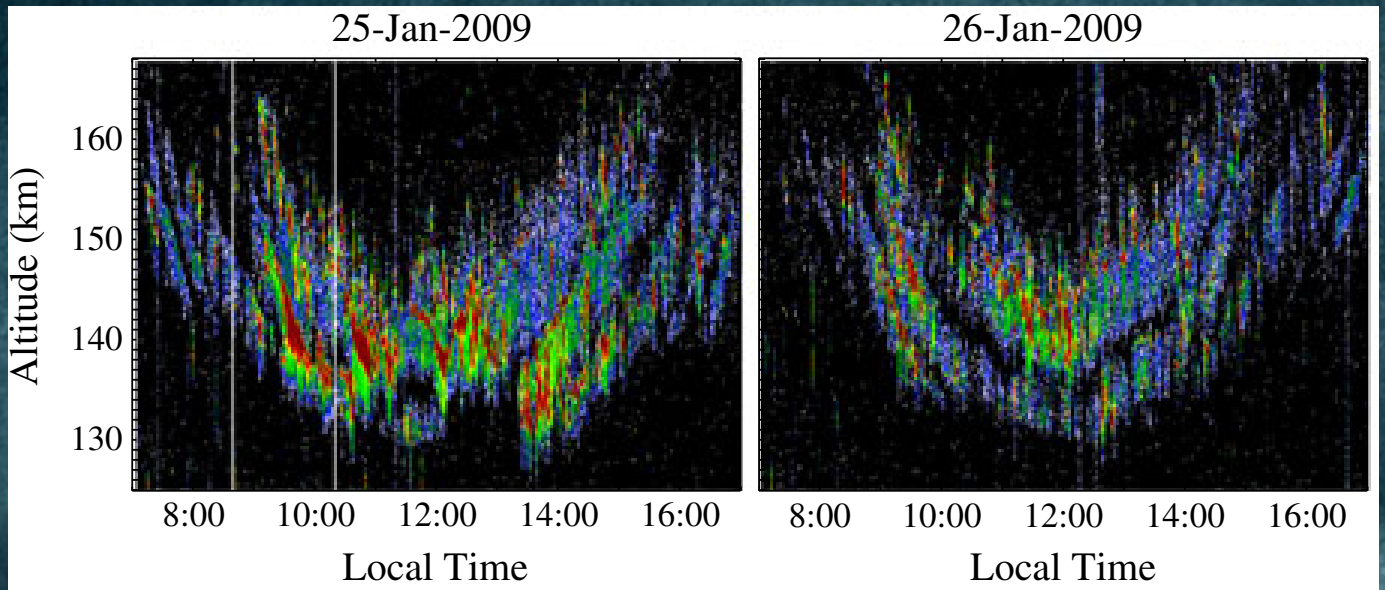
dlethe 9 days ago

@MeRex It is in Kenya.

1 Like Reply

150 km Conclusions

- Simulations show that photoelectrons may create 150-km echoes:
  - exist only in daylight;
  - Show the necklace shape because EUV photons penetrate most deeply at noon;
  - disappeared during a partial solar eclipse;
  - Narrow spectral width
  - Most energy perpendicular to B
  - Some energy off-B; and
  - appear at a range of latitudes [Chau and Kudeki, 2013].
- It does not explain
  - why the waves do not appear at higher latitudes.
  - Explain structuring;



Lessons Learned

- PIC simulations allow numerical experiments to test ideas
- Scientific Breadth is Essential
  - E-region Turbulence
  - Bow Shock Turbulence
  - Auroral Acceleration Region Physics
  - Meteor Theory, Simulations, and Observations
  - Spread-F Simulations
  - Global Ionosphere-Magnetosphere-SW Simulations
  - Solar Chromosphere Physics
- Embrace the Minutia and the People!