What Do Simultaneous, Conjugate Observations of Substorm Time Scales Tell Us About Magnetosphere-Ionosphere Coupling?

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Outline

1. Motivation and Background
   • Aurora suppressed in sunlight
   • Seasonal differences in auroral energetics
   • Seasonal differences in substorm time scales
     → Substorm conjugacy?

2. Methodology and Results
   • Simultaneous, conjugate substorm observations
   • Recovery time scales for different seasons

3. Summary and Conclusions
   • What have we learned?
   • Implication for magnetosphere-ionosphere coupling
   • Challenges and complications/Future direction
Background

Newell et al. [1996] showed that the occurrence rate of precipitating accelerated electrons (i.e., create aurora) is higher in darkness than in sunlight

Liou et al. [1997] found a similar result using global auroral images: discrete auroral more common in darkness than sunlight (on the nightside!)

• Ionospheric conductivity controls occurrence of aurora
Background

In addition, Liou et al. [2001] showed that the energetics of the aurora are different in darkness and sunlight: in darkness, precipitating electron energy flux is higher, electron energy is higher, and number flux is lower.
Background

Chua et al. [2004] analyzed 350 substorms

Winter  Equinox  Summer

They found that the substorm recovery time scale was about twice as long in winter/darkness (~ 32 minutes) than in summer/sunlight (~ 18 minutes)

⇒ Substorms last longer in darkness than in sunlight
Expansion time

$$P(t) = P_{\text{max}} e^{-t/\tau} + P_0;$$

$$\tau = \text{recovery time}$$
Chua et al. [2004] analyzed 350 substorms. They found that the substorm recovery time scale was about twice as long in winter/darkness (~ 32 minutes) than in summer/sunlight (~ 18 minutes).

=> Substorms last longer in darkness than in sunlight.
Background

• Aurora are more common in darkness
• Aurora are more energetic in darkness
• Substorms last longer in darkness

What’s the difference between darkness and sunlight?
→ Ionospheric conductivity! – controls occurrence and energy of aurora and length of substorms

Implications for **auroral conjugacy**
→ More energy deposited in dark hemisphere

However, previous work based on **statistical** results
→ What about for **individual events**?

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Methodology

• Identify substorms when IMAGE FUV (north) and Polar UVI (south) are viewing opposite hemispheres

• Focus on substorms near solstices and equinoxes

• Determine substorm recovery times scales for both instruments following the method of Chua et al. [2004]

• However, Chua et al. [2004] computed energy flux and hemispheric power from Polar UVI
  – IMAGE FUV doesn’t (directly) measure energy flux

• To directly compare both instruments, we compute the area-integrated photon flux (units of photons/sec)
  – analogous to auroral power from Polar UVI
Instrumentation

IMAGE Far UltraViolet (FUV)
  Wideband Imaging Camera (WIC)
Polar UltraViolet Imager (UVI)
  LBH Short (LBHS) & Long (LBHL) filters

Minor temporal and spatial differences

Spectral Resolution
WIC: 140 to 190 nm
LBHS: 140 to 160 nm
LBHL: 160 to 180 nm

Respond to different energies (due to $O_2$)
Instrumentation

- Calibrate WIC and LBHL with “same scene” substorms
- Magnitudes and slopes of adjusted WIC and LBHL integrated photon flux (IPF) are approximately equal ✓

Adjuncted $WIC_{IPF} = \frac{(WIC_{IPF} - a)}{b} \approx LBHL_{IPF}$

where $a$ and $b$ are instrument dependent constants
Results: Global Images

IMAGE WIC: Northern Hemisphere (Sunlit)

Polar UVI: Southern Hemisphere (Dark)

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Results: Recovery Time

WIC: Northern Hemisphere (Sunlight)
\( \tau_{\text{WIC}} = 35.4 \text{ minutes} \)

UVI: Southern Hemisphere (Darkness)
\( \tau_{\text{UVI}} = 160.0 \text{ minutes} \)

\( \tau \) longer in darkness by factor of > 4; long tail in darkness
Northern Summer: 2


WIC: Northern Hemisphere (Sunlight)
\( \tau_{\text{WIC}} = 18.0 \) minutes

UVI: Southern Hemisphere (Darkness)
\( \tau_{\text{UVI}} = 24.0 \) minutes

\( \tau \) longer in darkness; initial \( \tau \sim 5 \) min; weak intensifications

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Northern Winter: 1

2000–12–20: 21 - 24 MLT

\[ \tau \] longer in darkness, but UVI (sunlit) is noisy – low S/N

WIC: Northern Hemisphere (Darkness)
\[ \tau_{WIC} = 24.0 \text{ minutes} \]

UVI: Southern Hemisphere (Sunlight)
\[ \tau_{UVI} = 12.0 \text{ minutes} \]

\( \tau \) longer in darkness, but UVI (sunlit) is noisy – low S/N

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Northern Winter: 2

2001–12–06: 21 – 24 MLT

WIC: Northern Hemisphere (Darkness)
$\tau_{\text{wic}} = 14.3$ minutes

UVI: Southern Hemisphere (Sunlight)
$\tau_{\text{uvl}} = 10.2$ minutes

$\tau$ (slightly) longer in darkness

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Northern Winter: 3

\[ \tau \text{ longer in darkness; multiple intensifications} \]

\[
WIC: \text{ Northern Hemisphere (Darkness)} \\
\tau_{WIC} = 124.0 \text{ minutes}
\]

\[
UVI: \text{ Southern Hemisphere (Sunlight)} \\
\tau_{UVI} = 96.0 \text{ minutes}
\]
Equinox: 1

2001–08–21: 21 – 24 MLT

WIC: Northern Hemisphere (Equinox)
\[ \tau_{\text{wic}} = 17.5 \text{ minutes} \]

UVI: Southern Hemisphere (Equinox)
\[ \tau_{\text{uvl}} = 11.5 \text{ minutes} \]

\[ \tau \text{ not the same; dipole tilt } \geq +10^\circ; \text{ NH sunlit – longer } \tau! \]

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Equinox: 2

2001-08-21: 21 - 24 MLT

WIC: Northern Hemisphere (Equinox/Light)
$\tau_{\text{WIC}} = 4.1$ minutes

UVI: Southern Hemisphere (Equinox/Dark)
$\tau_{\text{UVI}} = 7.1$ minutes

$\tau$ not the same; dipole tilt $\geq +10^\circ$; NH sunlit – shorter $\tau$!
Equinox: 3

$\tau$ nearly the same; dipole tilt $\sim 0^\circ$

WIC: Northern Hemisphere (Equinox)
$\tau_{\text{WIC}} = 60.6$ minutes

UVI: Southern Hemisphere (Equinox)
$\tau_{\text{UVI}} = 68.9$ minutes

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What Have We Learned?

• For individual substorms, different recovery time scales in different hemispheres
• Recovery time scales longer in darkness than sunlight
• Consistent with previous statistical results ᴄ → Asymmetric energy input during substorms

• Extremely large variation in substorm time scales ᴄ → from 4 minutes to over 2 ½ hours

• Also, large variation in hemispheric differences in τ ᴄ → τ₆/τ₅ from > 4.5 to < 1.3 during solstice; typically ≤ 2

• Often see symmetric initial rapid drop in IPF followed by asymmetric more gradual decay ᴄ → 2 phase recovery(?)

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Implication for M-I Coupling

• These results suggest that the ionospheric conductivity plays an important role in substorm dynamics

• Previous interpretation [e.g., Newell et al., 2001]: In sunlit (higher conductivity) hemisphere, ambient plasma density is sufficient to carry imposed current → no or weak potential/particle acceleration

• What about recovery time scales…
  Treat each hemisphere as a circuit; each circuit has a different resistance, hence a different time constant → \( \tau \sim R \sim 1/\Sigma \) → as conductivity increases, \( \tau \) decreases

• 2 phase recovery: strong driving → symmetric response → Threshold below which conductivity dominates(?)
Challenges/Complications

• Elusive “isolated” substorm – multiple intensifications
  → Fit parameters sensitive to endpoints

• Differences in spatial/temporal/spectral responses
  → Complicates quantitative comparisons
  → Integrated photon flux rather than hemispheric power

• Differences in spatial coverage/orbits/field of view
  → Complicates conjugate studies
  → Confined to local, not global, comparisons

How to address these (instrumental) challenges?

→ Two (or more) identical instruments in conjugate orbits