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

M. O. Fillingim[1], D. Chua[2], G. A. Germany[3], and J. F. Spann[4]

[1]Space Sciences Laboratory, University of California, Berkeley
[2]Space Science Division, Naval Research Laboratory
[3]Center for Space Plasma and Aeronomic Research, University of Alabama in Huntsville
[4]NASA Marshall Space Flight Center

SM21B-04 2009 Joint Assembly, Toronto, ON, CANADA 26 May 2009

Outline

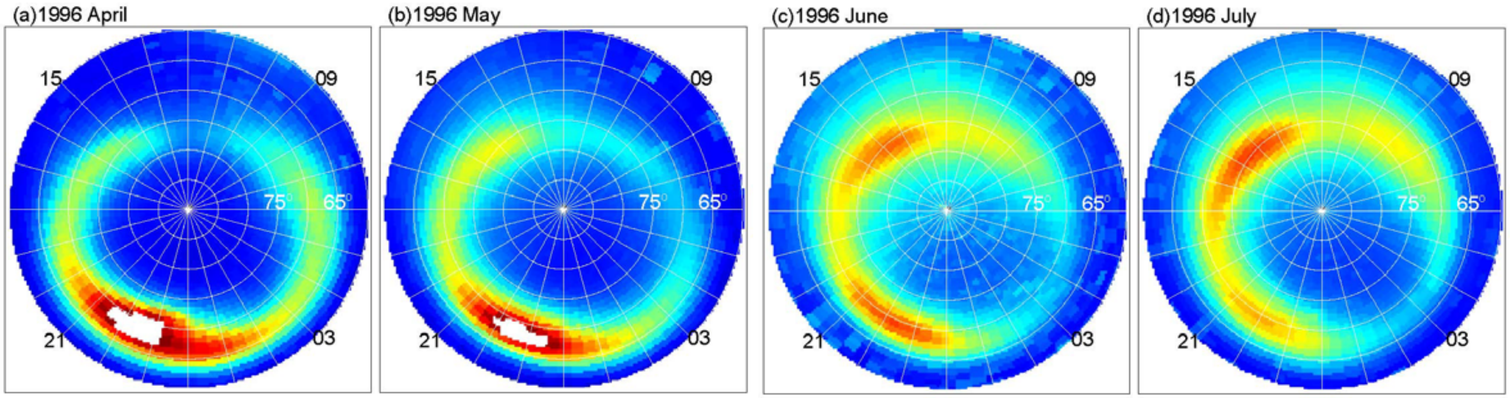
1. Motivation and Background
    - Aurora suppressed in sunlight
    - Seasonal differences in auroral energetics
    - Seasonal differences in substorm time scales

    → *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

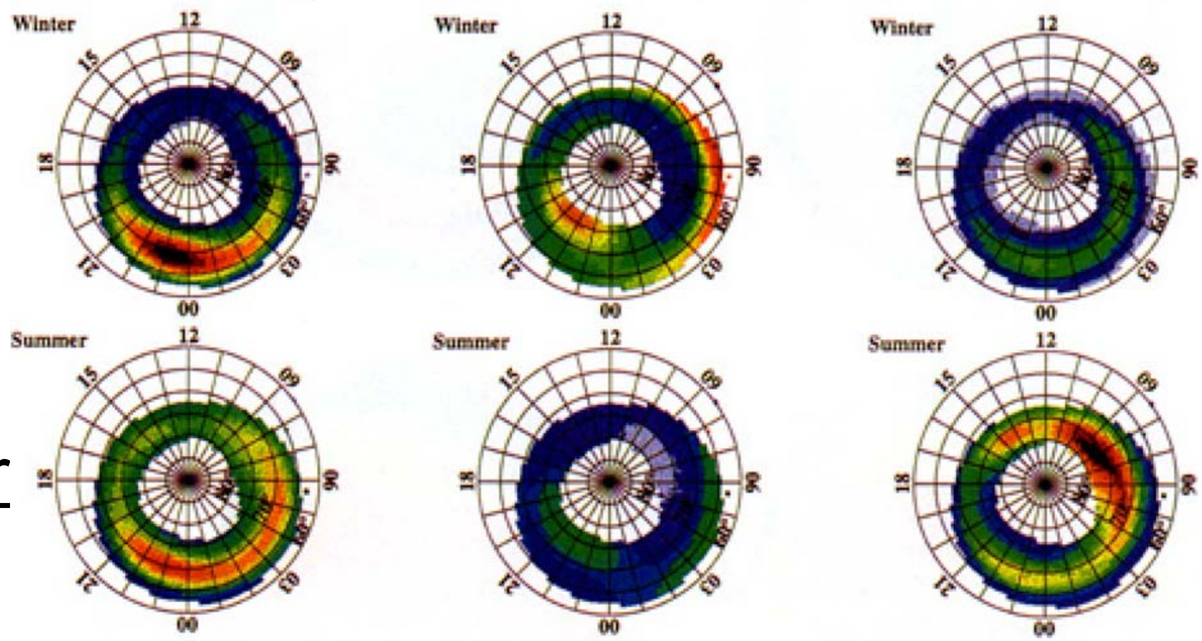
Background

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**

Energy flux | Energy | Number flux

Winter

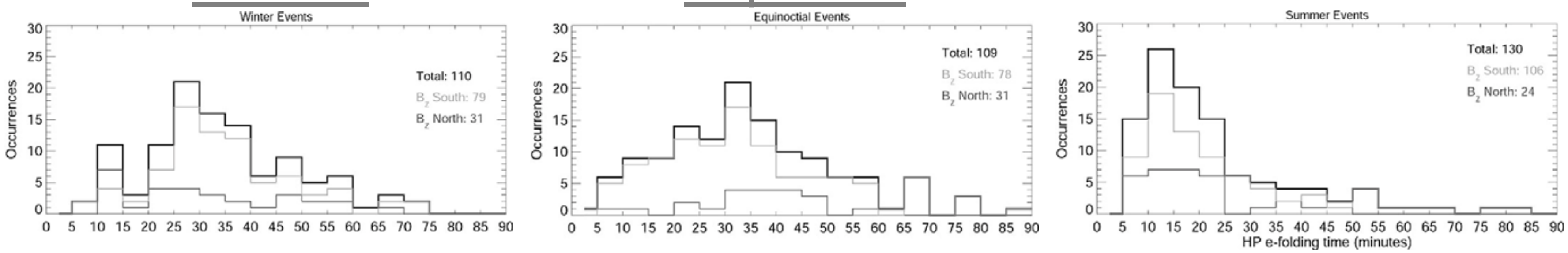
Summer



Background

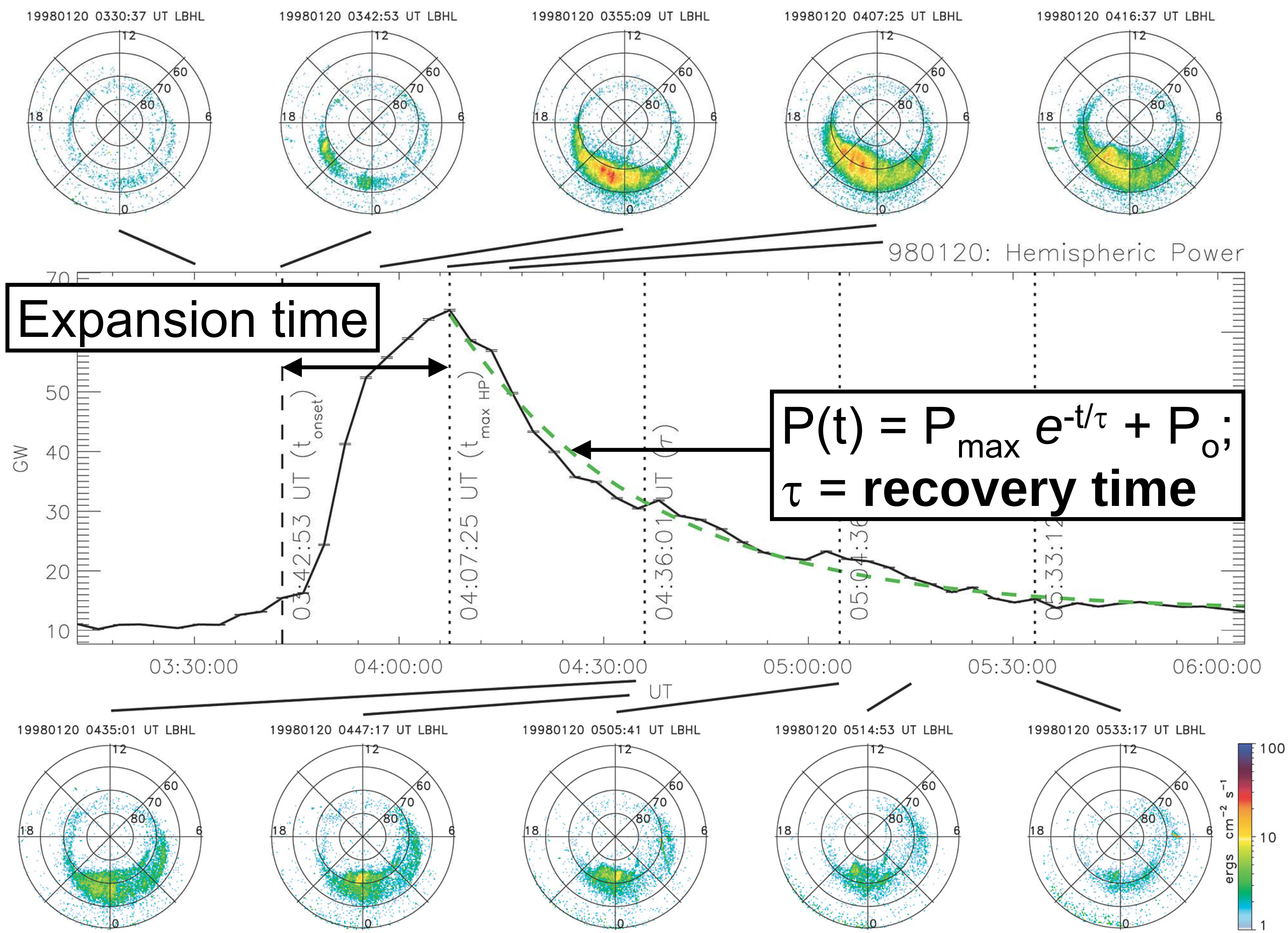
Chua et al. [2004] analyzed 350 substorms

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

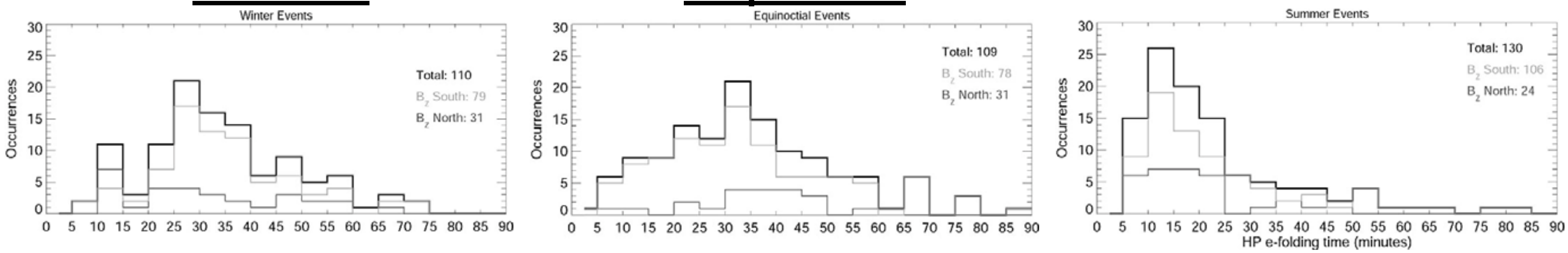


<u>SM21B-04</u> 2009 Joint Assembly, Toronto, ON, CANADA 26 May 2009

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

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**?

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

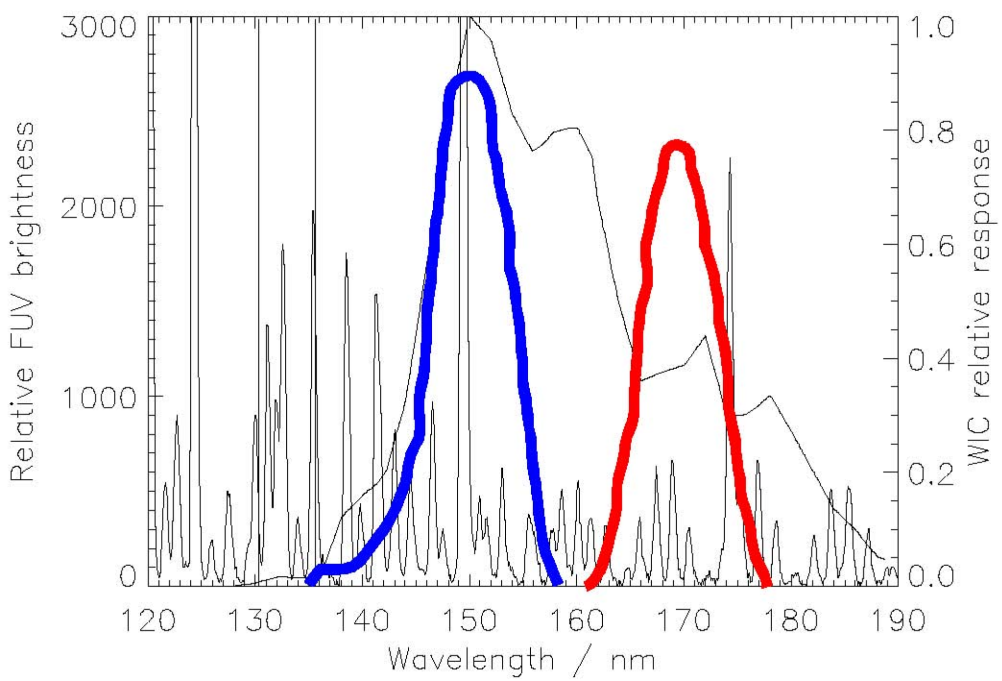
Spectral Resolution

WIC: 140 to 190 nm

LBHS: 140 to 160 nm

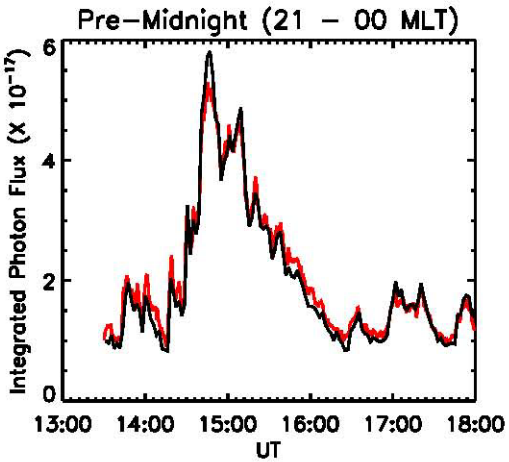
LBHL: 160 to 180 nm

Respond to different energies (due to O_2)

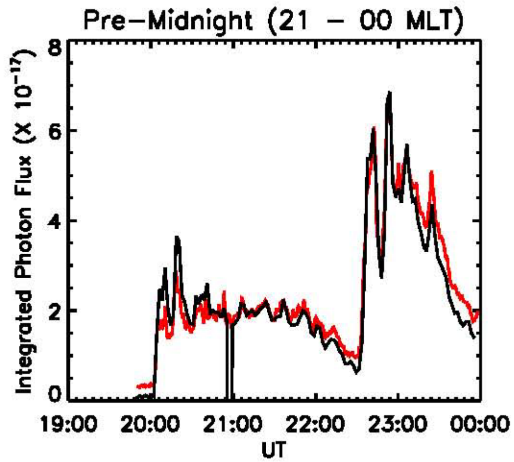


Instrumentation

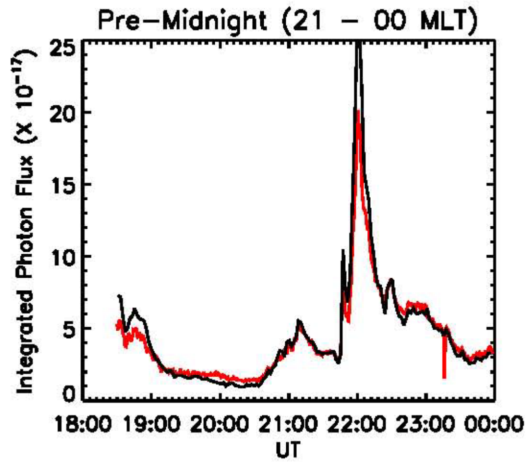
2000–12–02



2000–12–04



2000–12–07



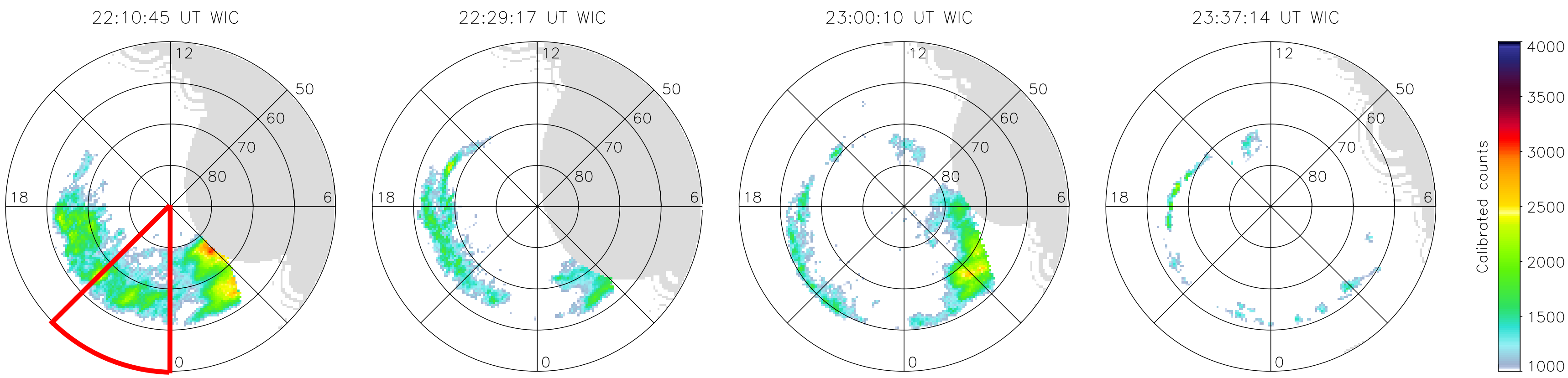
- Calibrate WIC and LBHL with "same scene" substorms
- Magnitudes and slopes of adjusted WIC and LBHL integrated photon flux (IPF) are approximately equal ✓

$$\text{Adjusted } WIC_{IPF} = (WIC_{IPF} - a)/b \approx LBHL_{IPF}$$

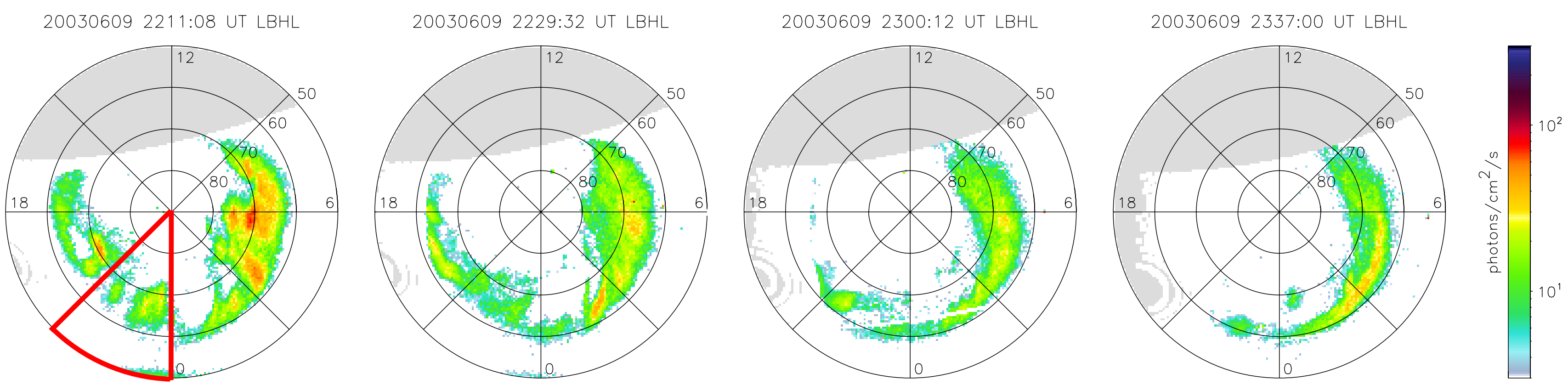
where a and b are instrument dependent constants

Results: Global Images

IMAGE WIC: Northern Hemisphere (Sunlit)

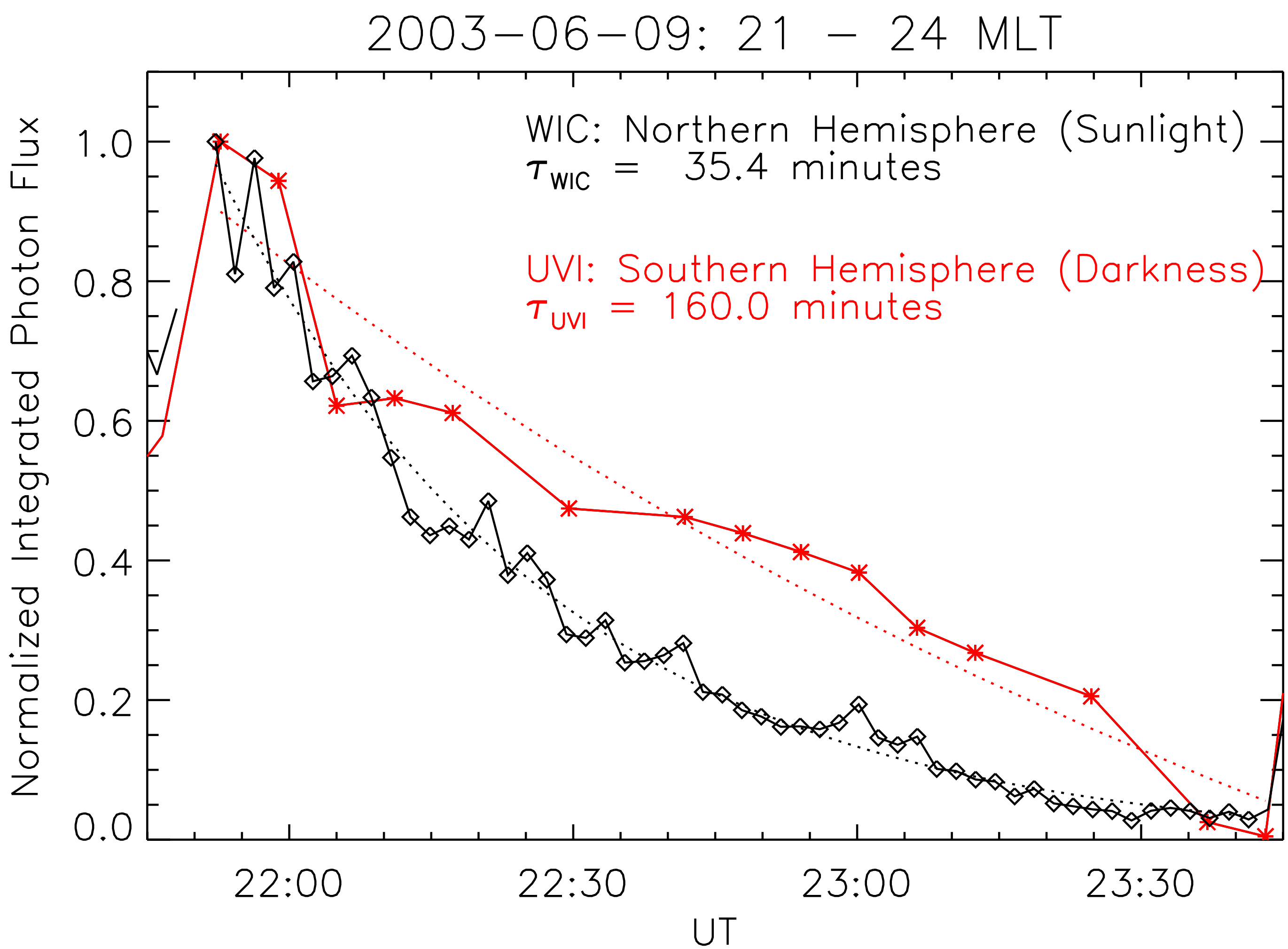


Polar UVI: Southern Hemisphere (Dark)



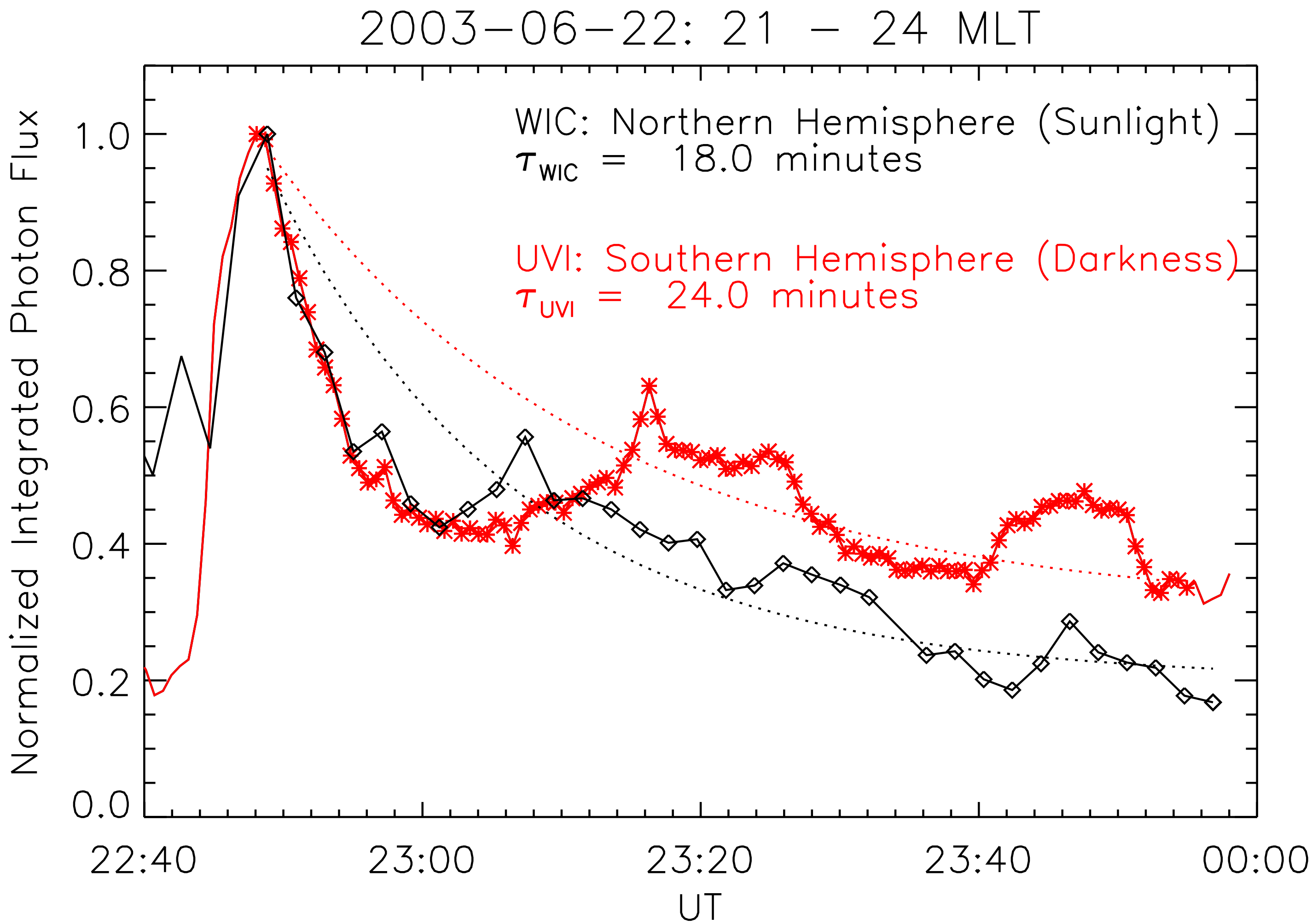
Results: Recovery Time

Northern Summer



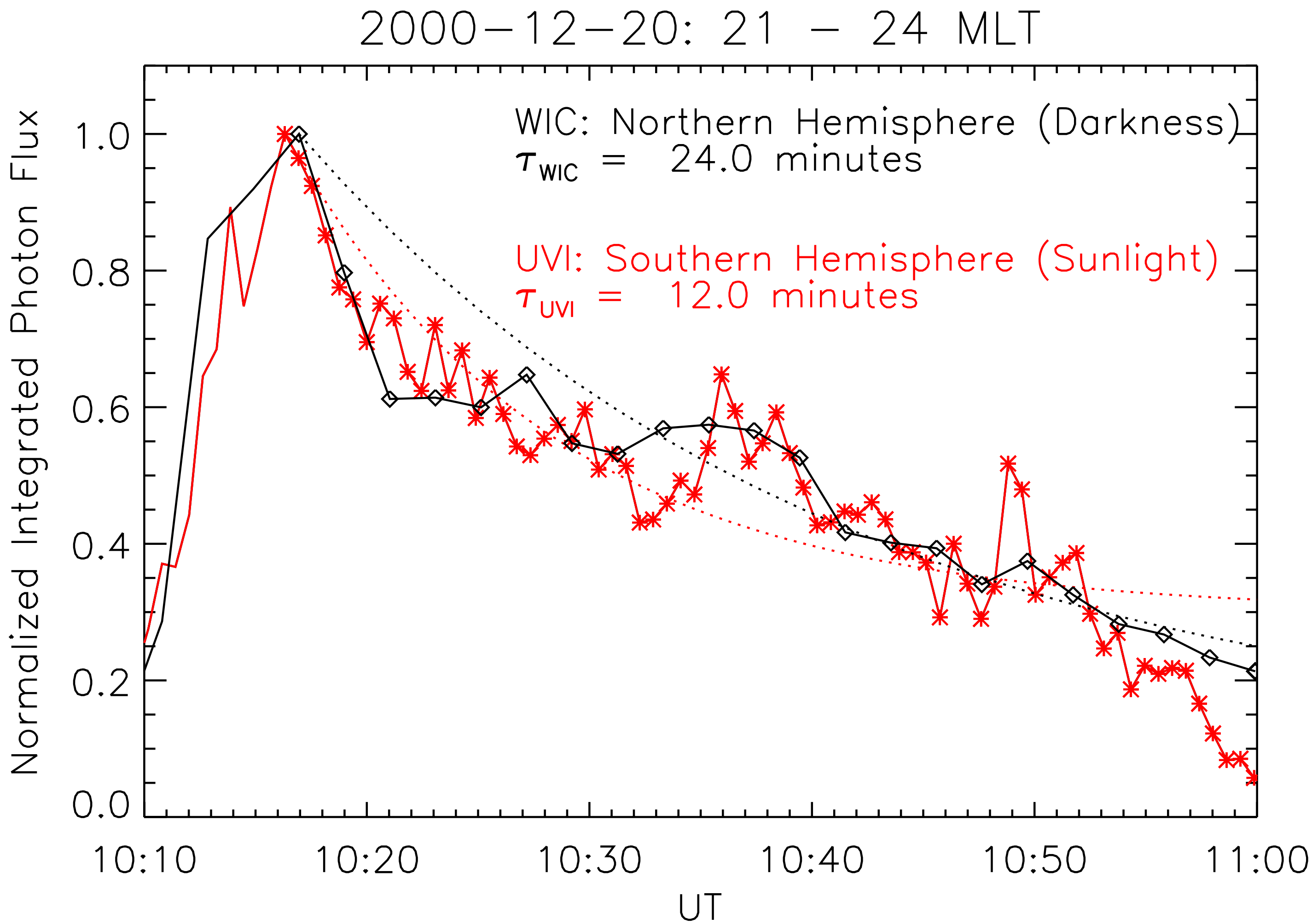
τ longer in darkness by factor of > 4; long tail in darkness

Northern Summer: 2



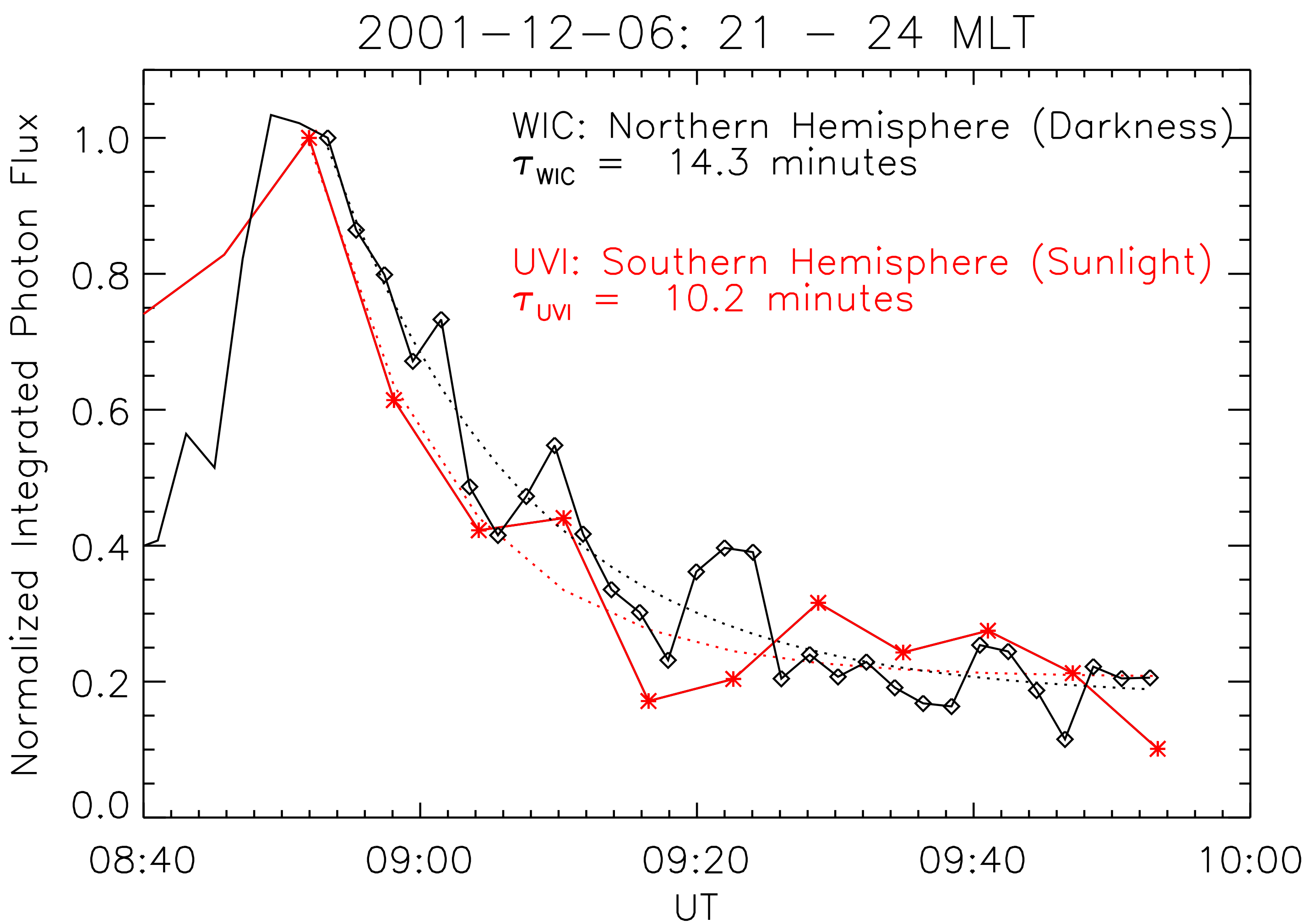
τ longer in darkness; initial **τ** ~ 5 min; weak intensifications

Northern Winter: 1



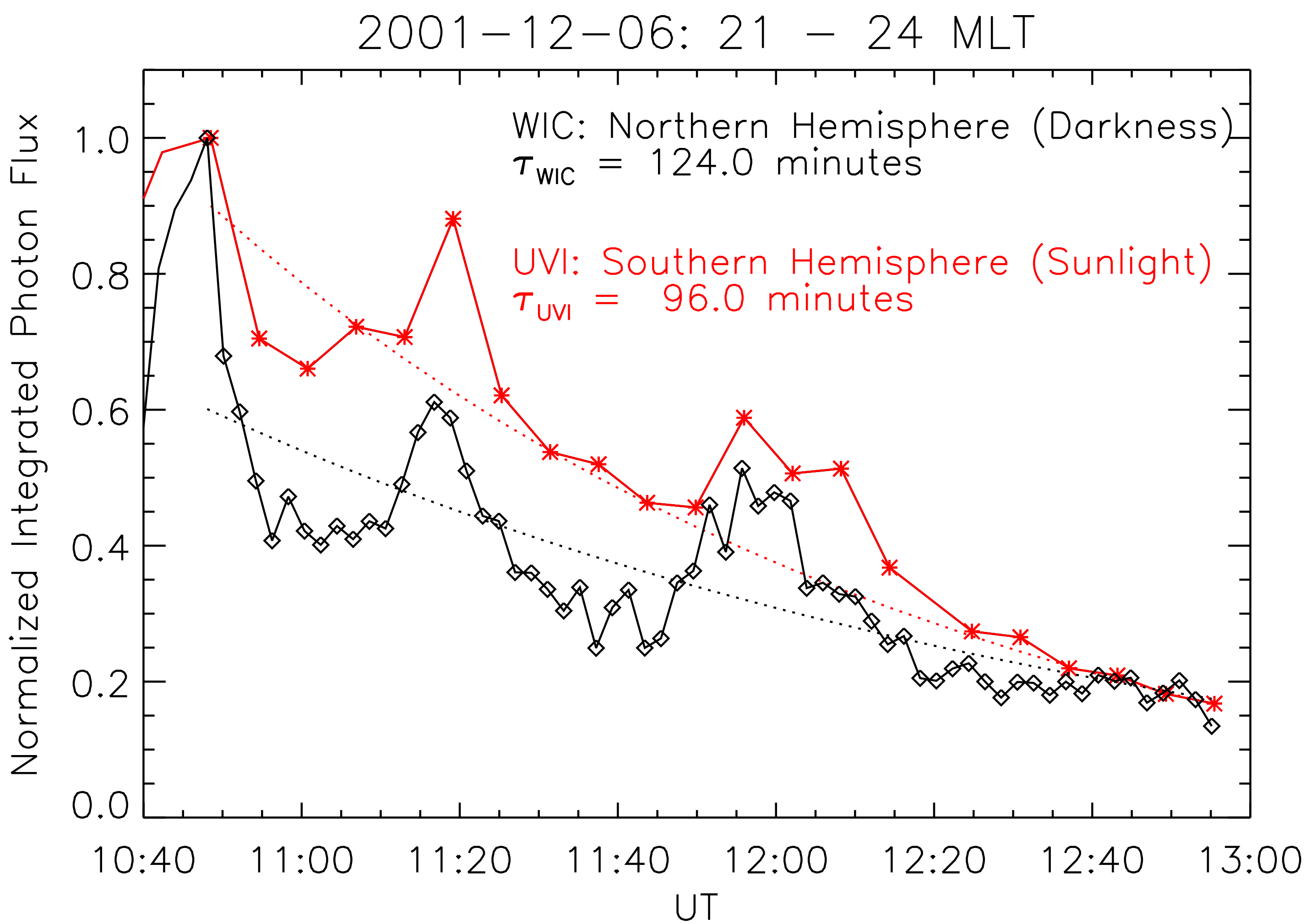
τ longer in darkness, but UVI (sunlit) is noisy – low S/N

Northern Winter: 2



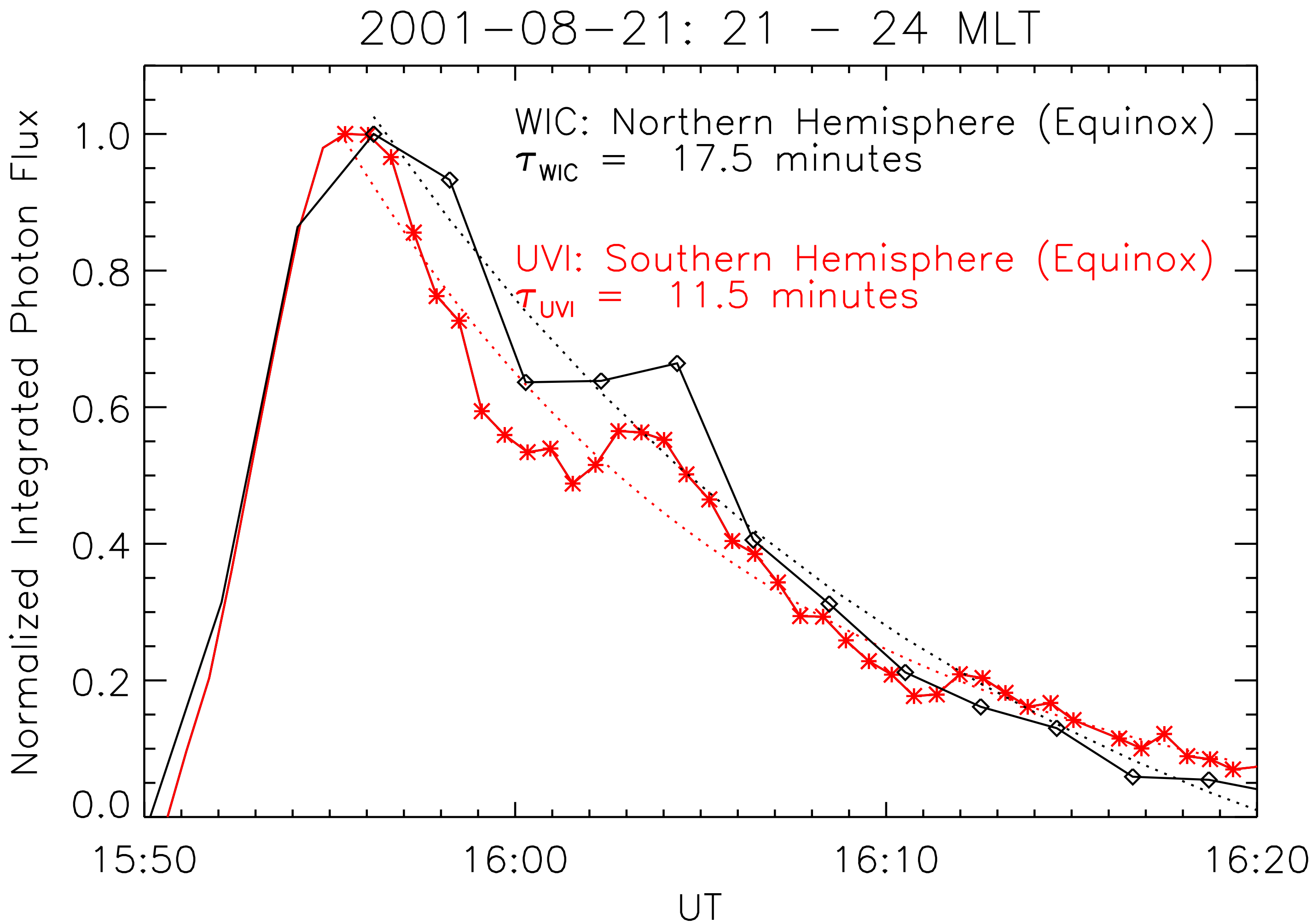
τ (slightly) longer in darkness

Northern Winter: 3



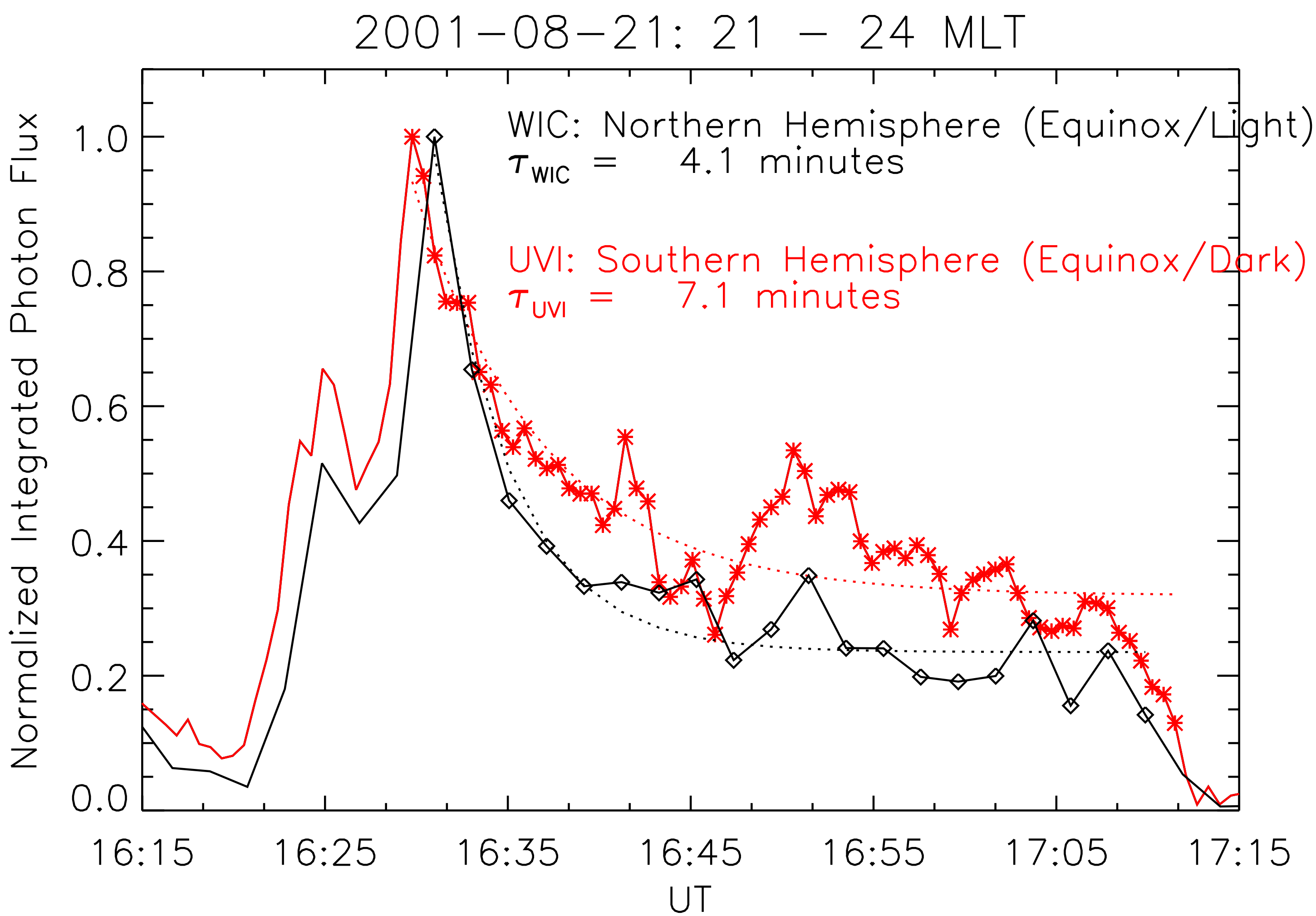
τ longer in darkness; multiple intensifications

Equinox: 1



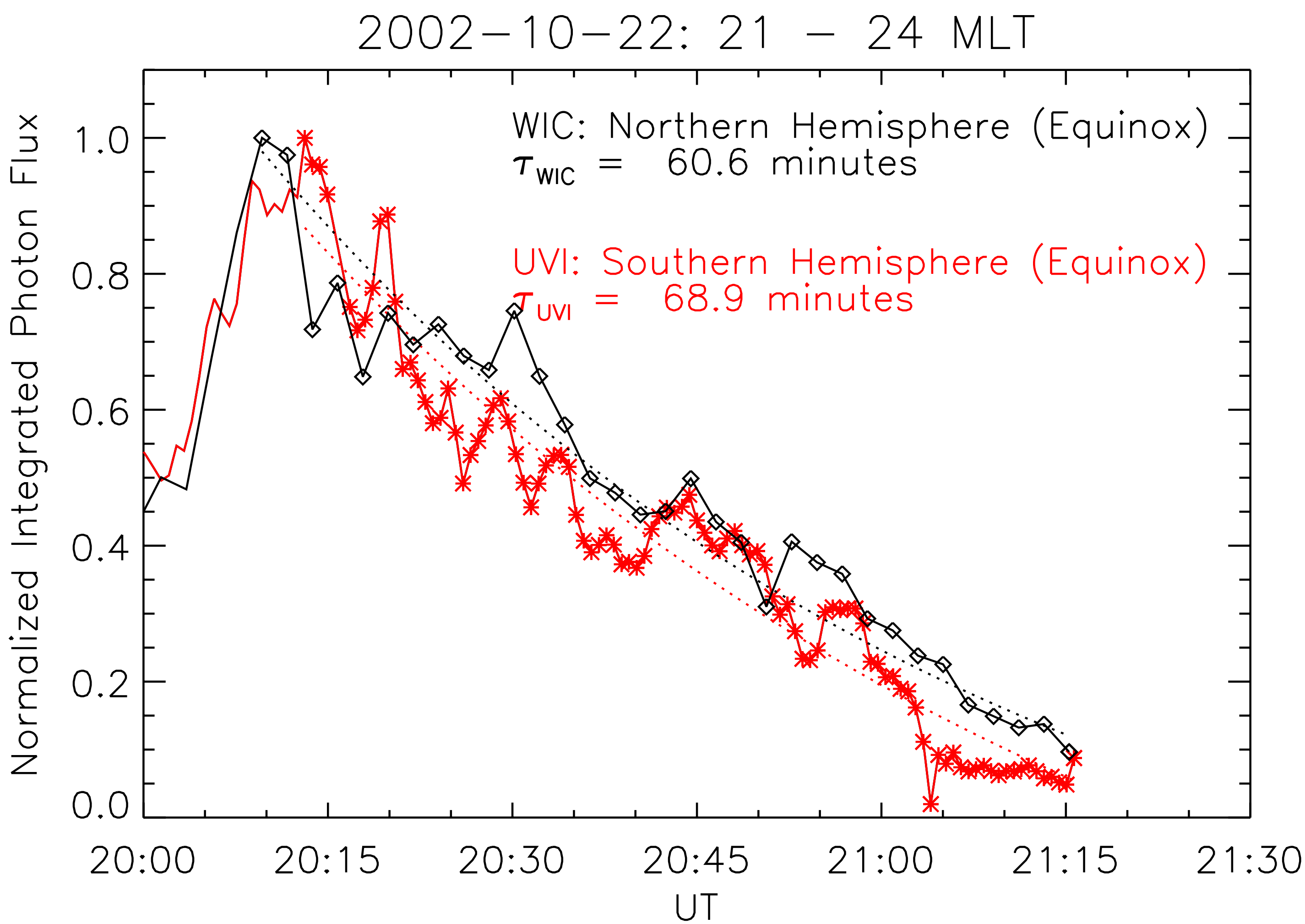
τ not the same; dipole tilt ≥ +10°; NH sunlit – longer **τ**!

Equinox: 2



τ not the same; dipole tilt ≥ +10°; NH sunlit – shorter τ!

Equinox: 3



τ nearly the same; dipole tilt ~ 0°

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
  → **Asymmetric energy input during substorms**
- Extremely large variation in substorm time scales
  → from 4 minutes to over 2 ½ hours
- Also, large variation in hemispheric differences in $\boldsymbol{\tau}$
  → $\boldsymbol{\tau}_W/\boldsymbol{\tau}_S$ from > 4.5 to < 1.3 during solstice; typically ≤ 2
- *Often* see symmetric initial rapid drop in IPF followed by asymmetric more gradual decay → 2 phase recovery(?)

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, τ 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