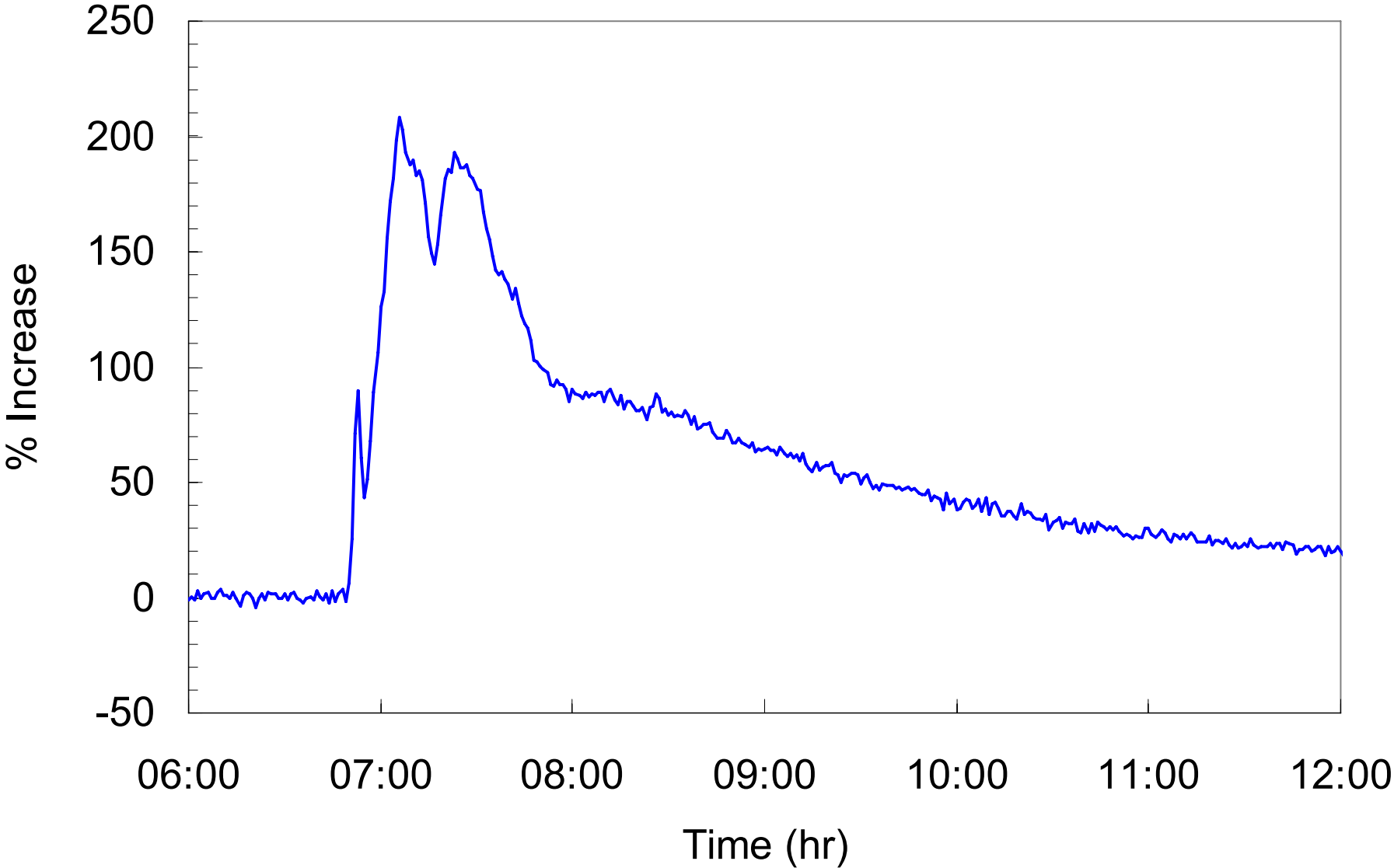


The 20 January 2005 GLE - two acceleration mechanisms

K.G. McCracken, H. Moraal, P.H. Stoker

SEE2007, Athens, 24 September 2007
(Submitted to J. Geophys. Res.)

Sanae Neutron Monitor
20 January 2005



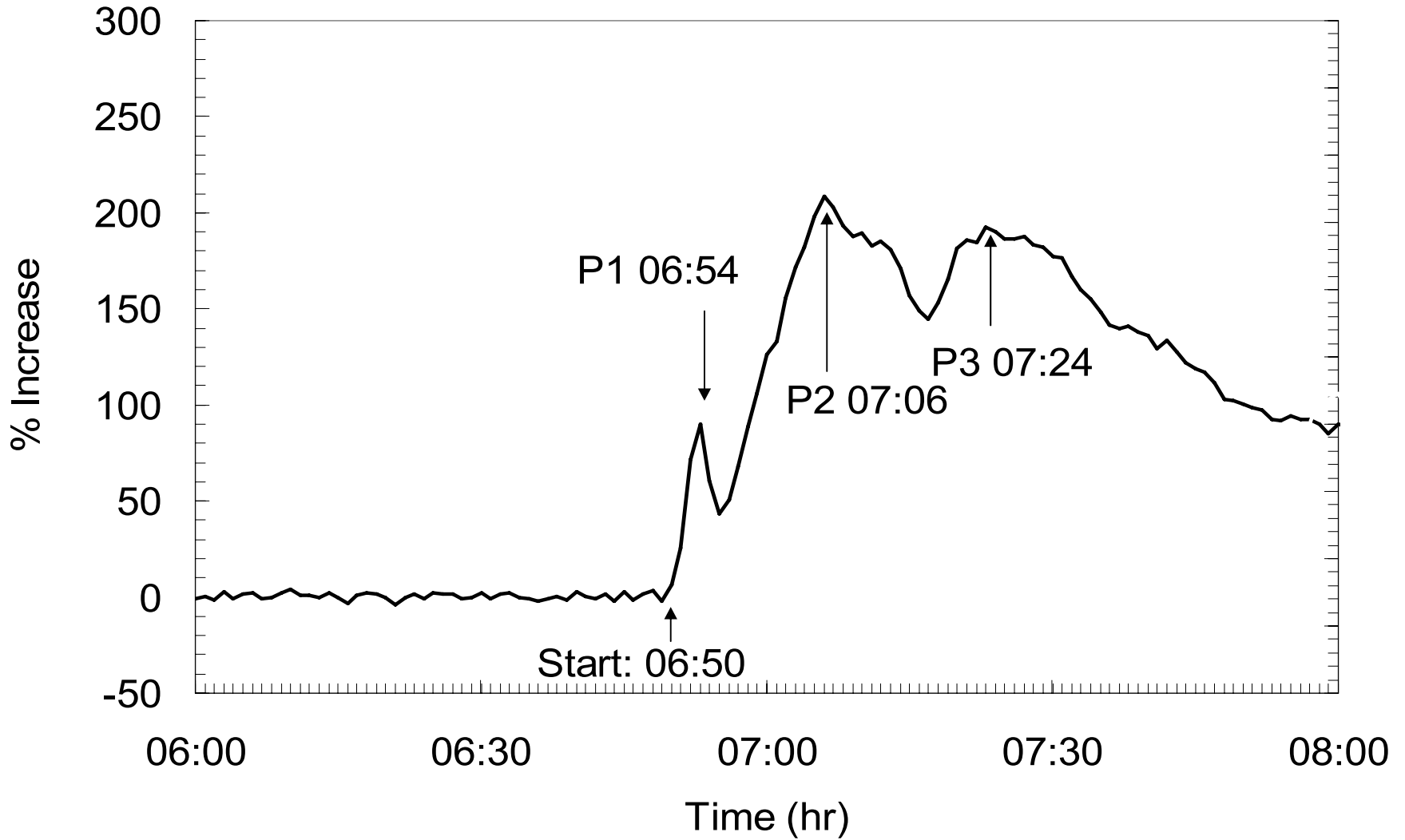
Summary

- Sanae NM saw three distinct pulses; others mostly one
- First pulse prompt; highly anisotropic
- Second pulse gradual; much less anisotropic
- Third pulse due to HMF shift – not significant
- Relate 1st pulse to RHESSI X-ray observations
- Origin of 2nd pulse
- Model for the 20 January 2005 GLE
- First pulse is a common feature of GLEs
- 1-to-1 correspondence with “impulsive” and “gradual” SEPs
- The generic solar energetic particle event

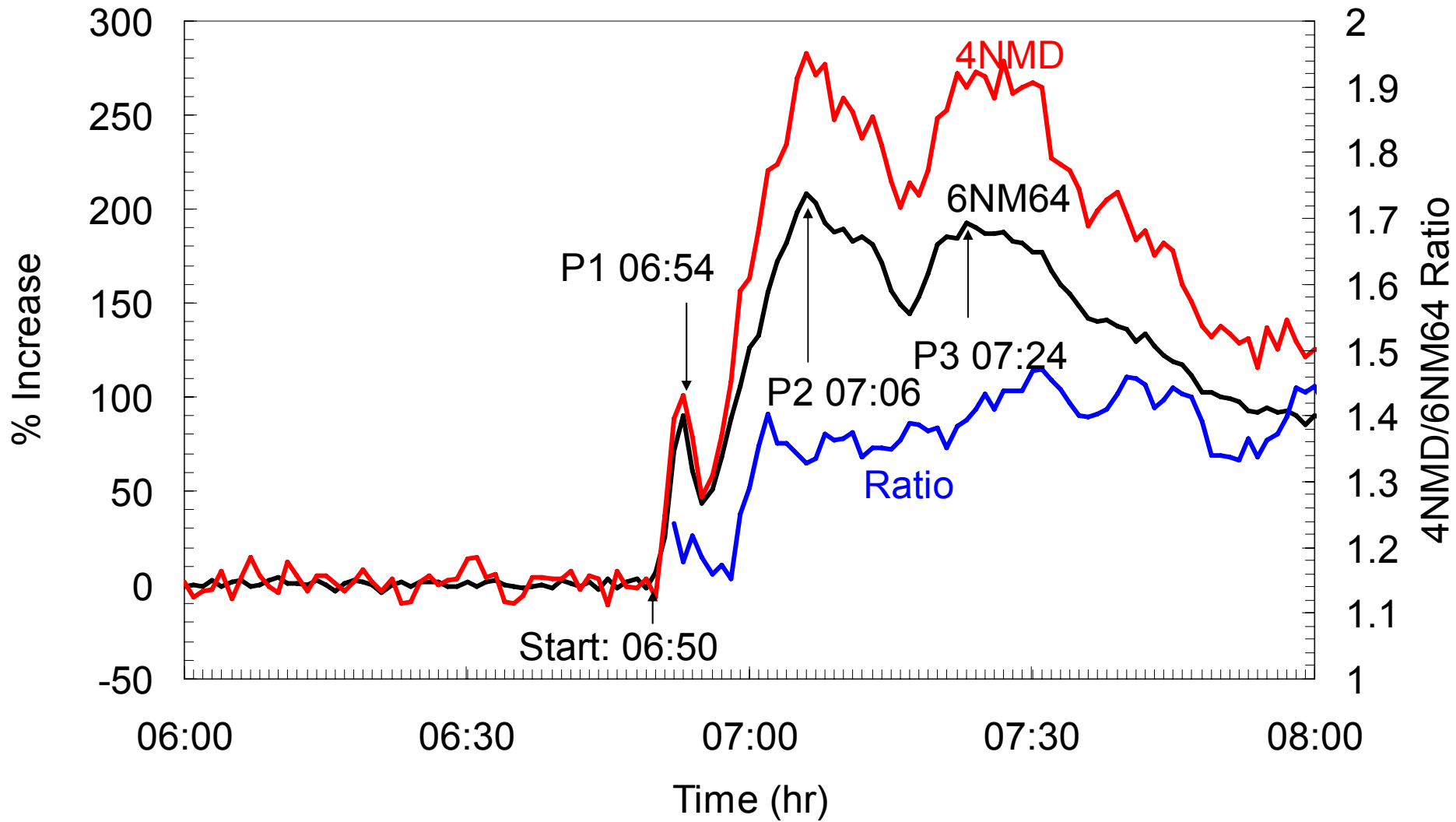
“Efforts to study the relative contributions from acceleration mechanisms in flares and CME-driven shocks appear to be more fruitful.”

Grechnev et al., preprint, 28 June 2007

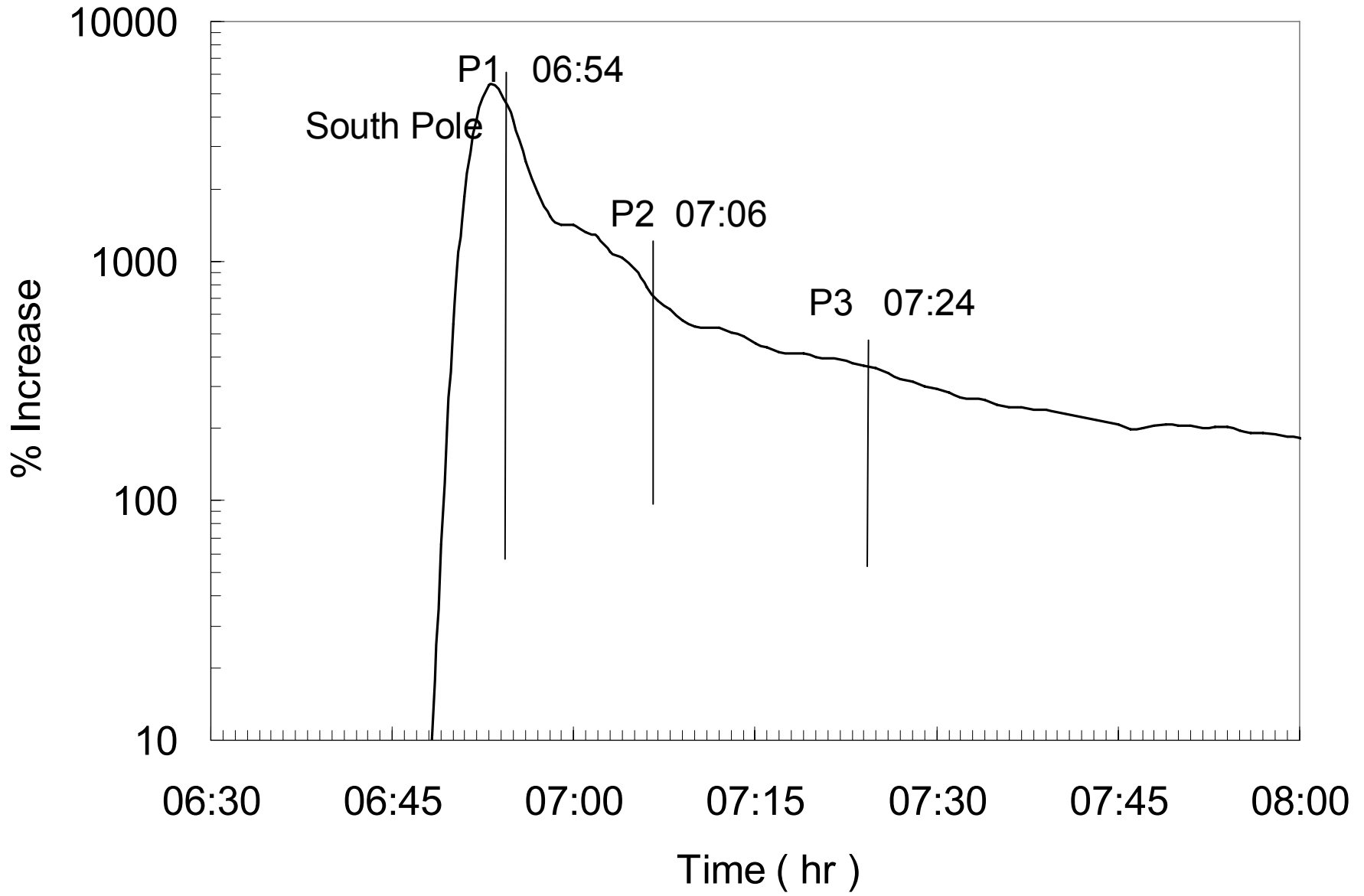
Sanae Neutron Monitor 20 January 2005

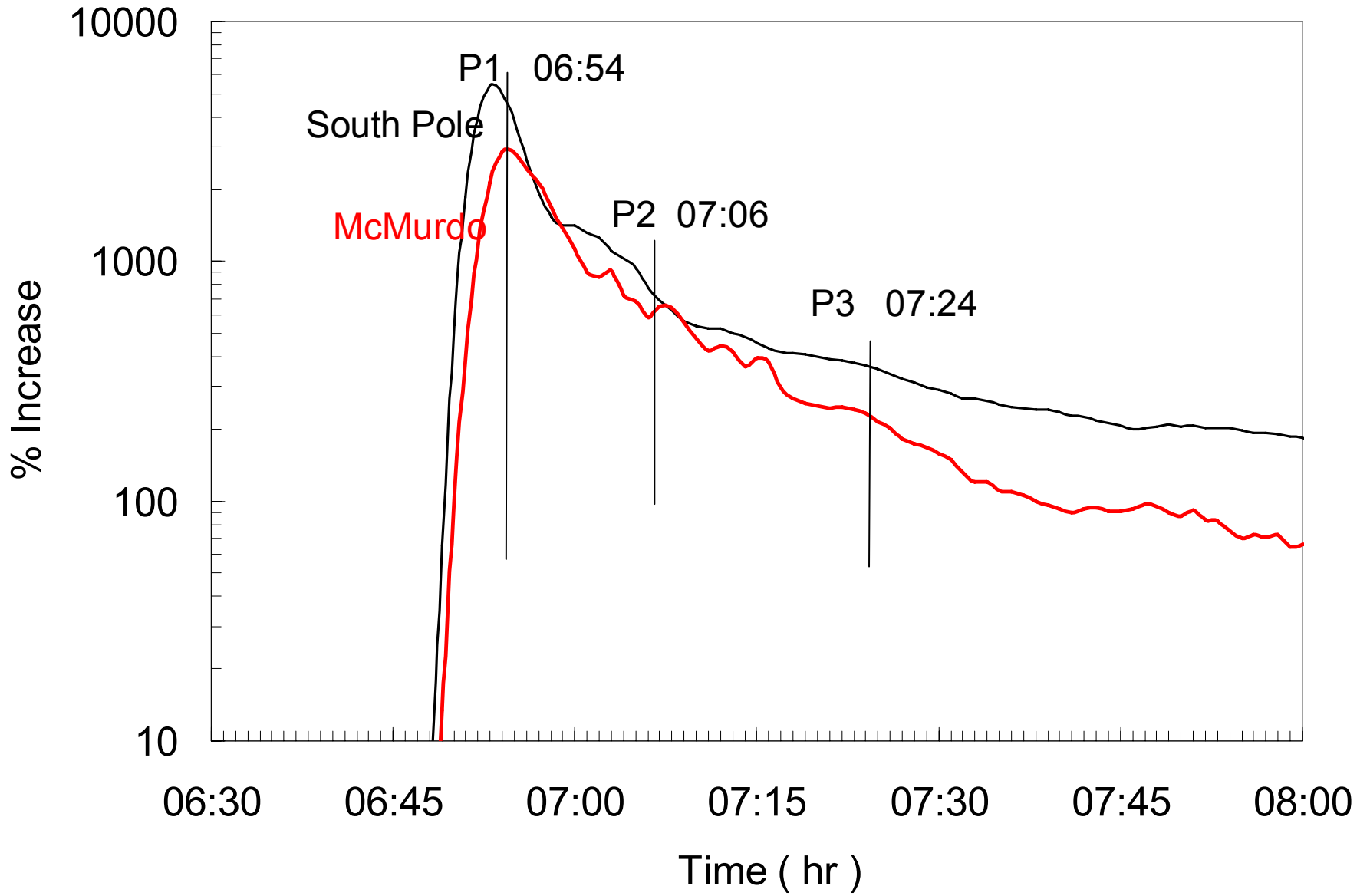


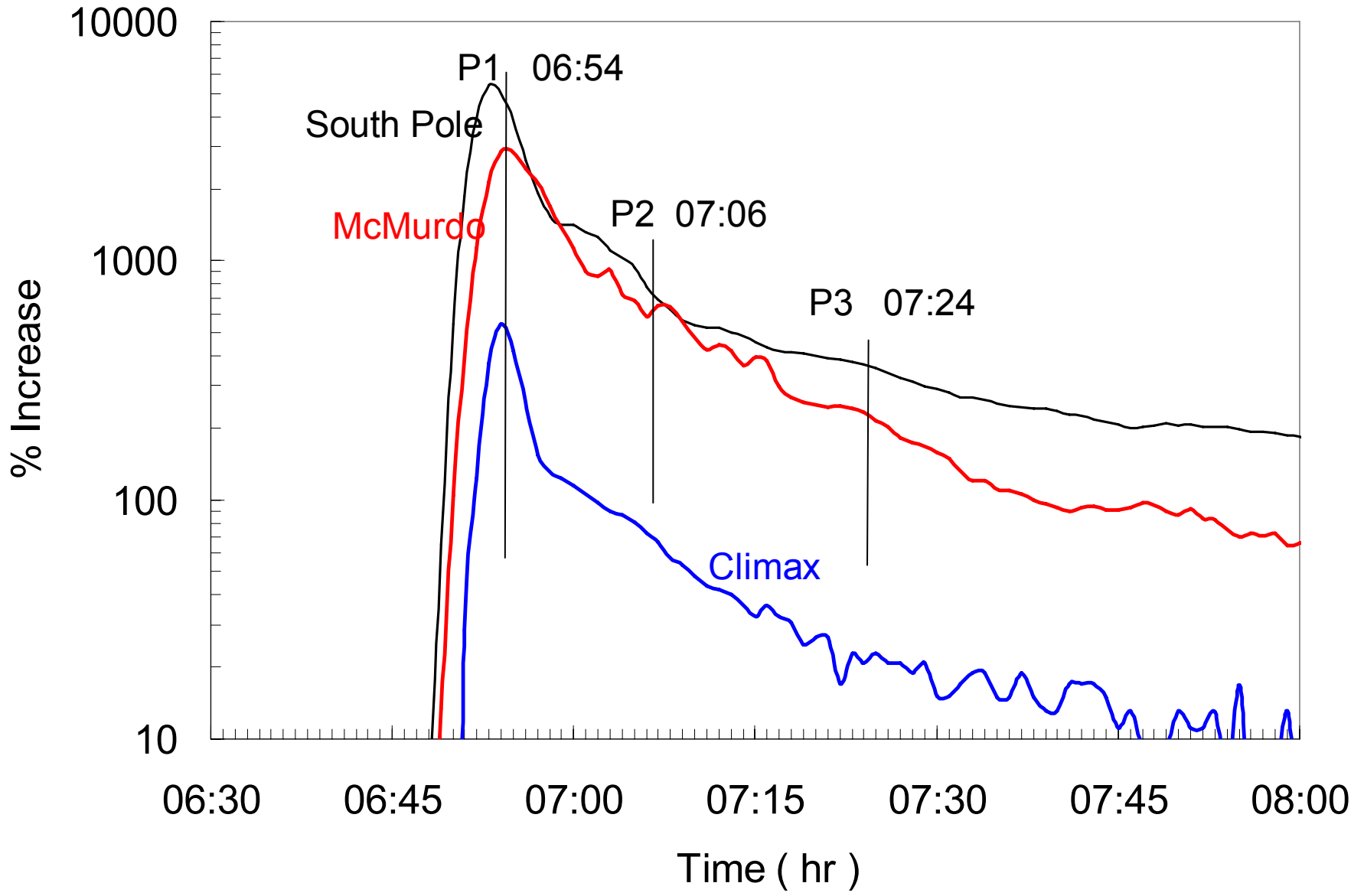
Sanae Neutron Monitor 20 January 2005

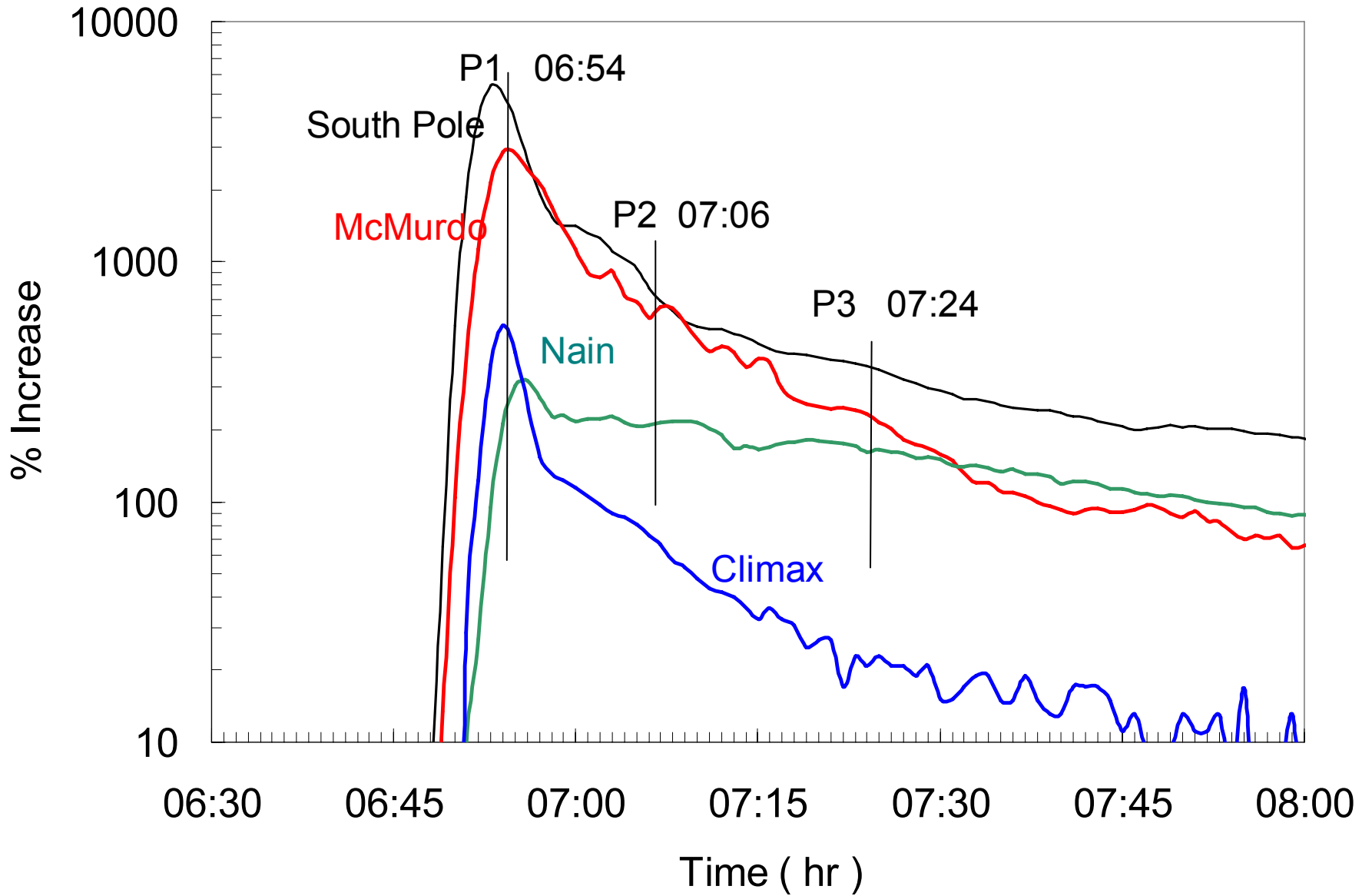


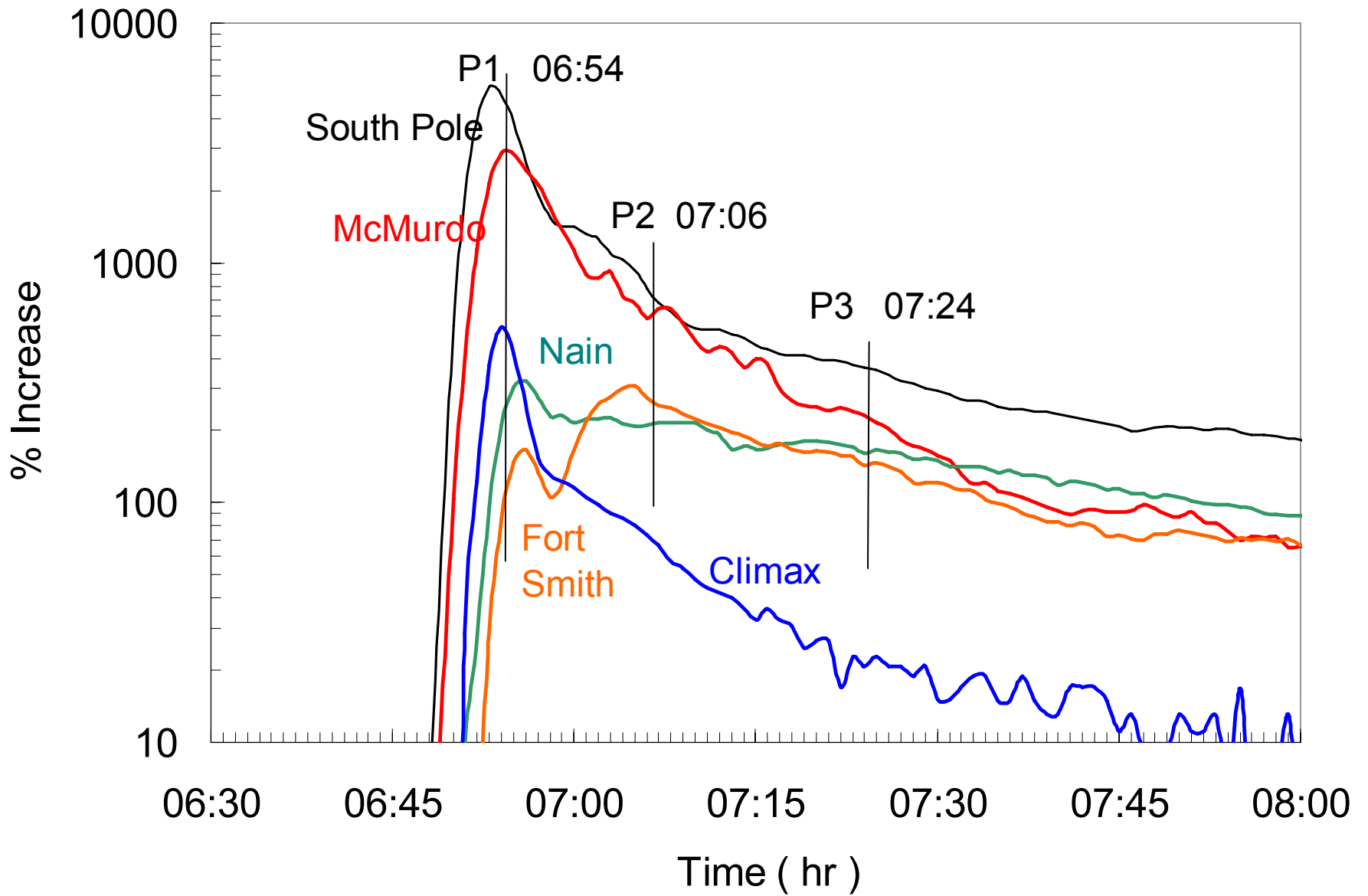
NMs that saw pulse 1



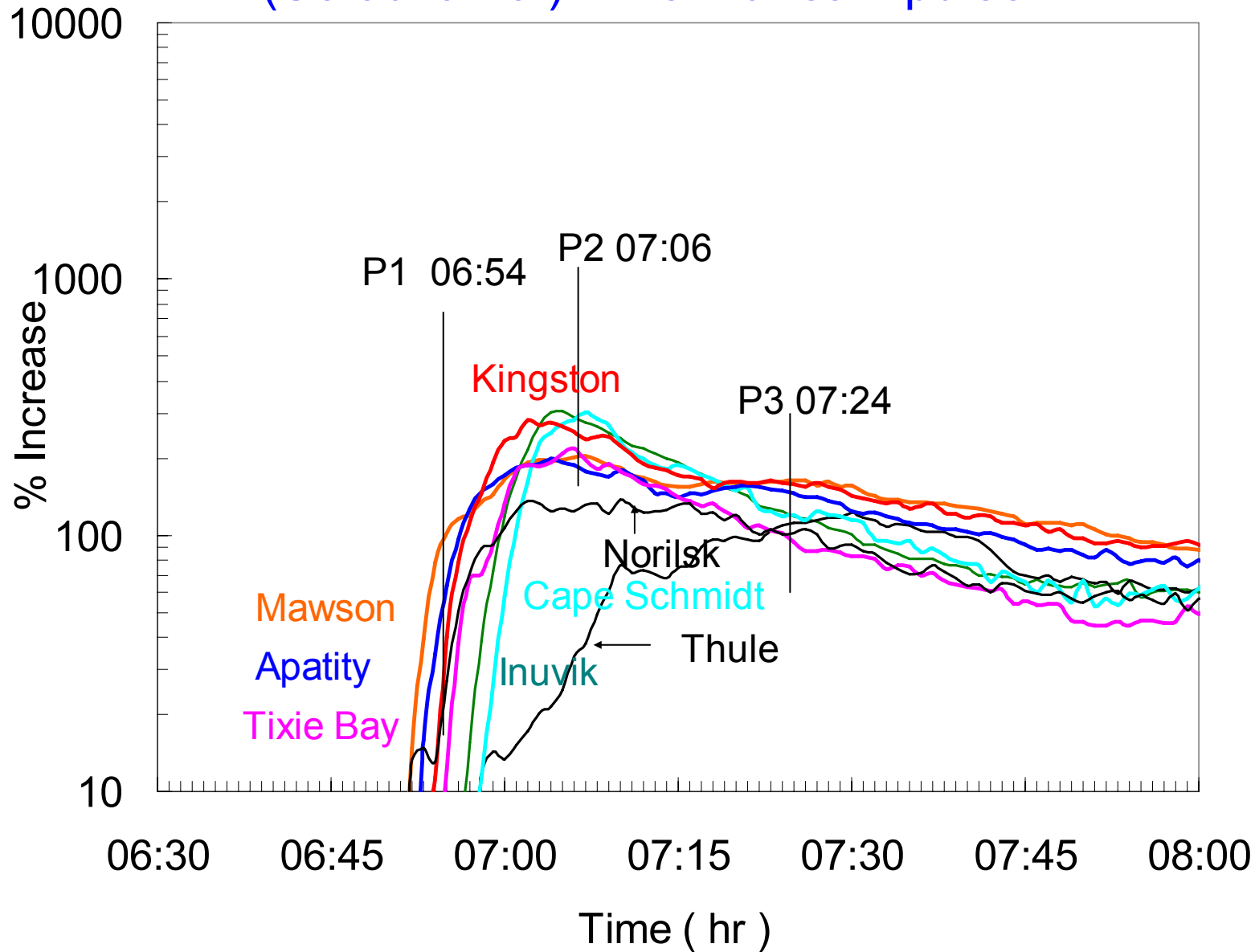




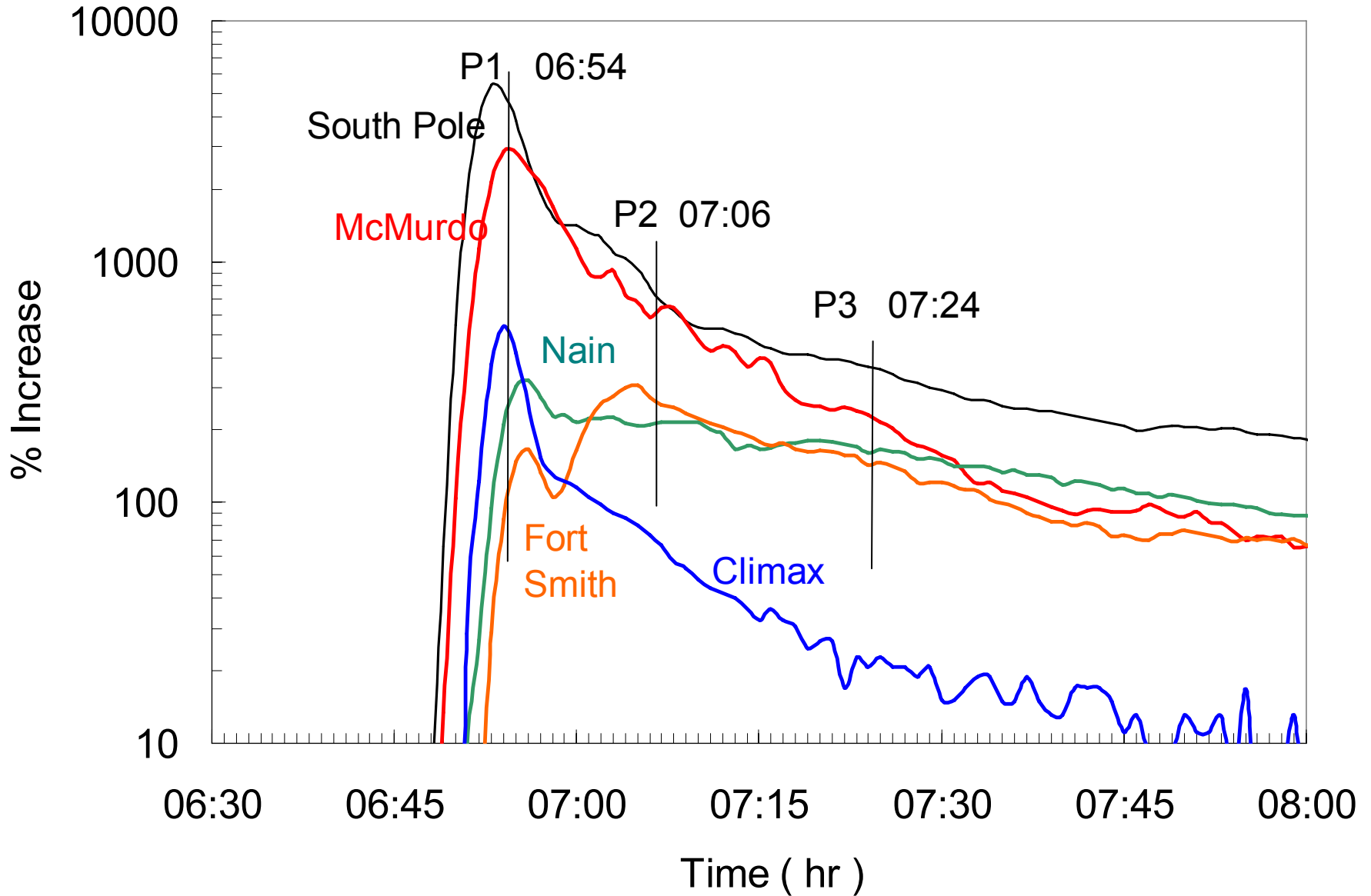




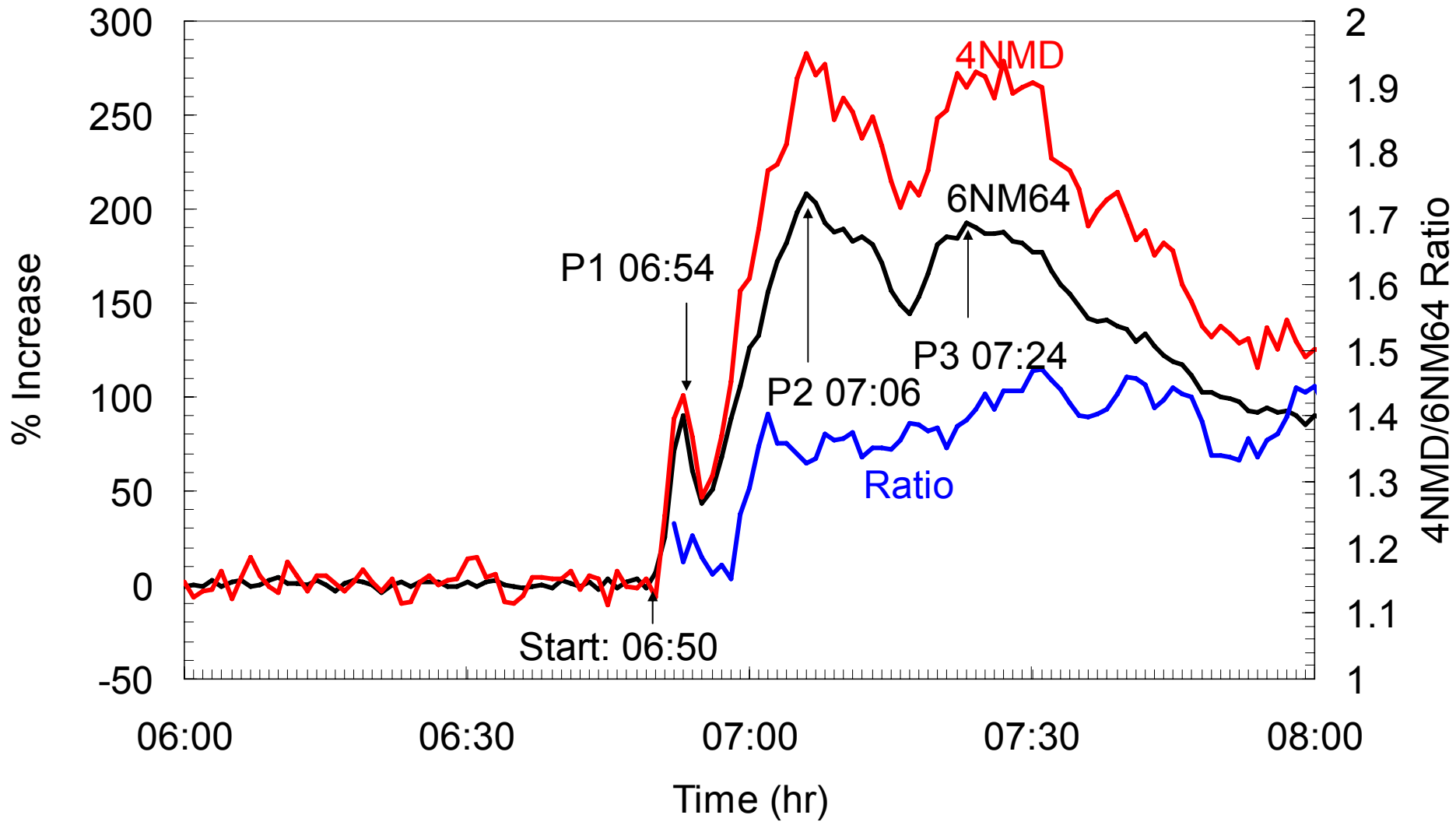
(Selection of) NMs that saw pulse 2



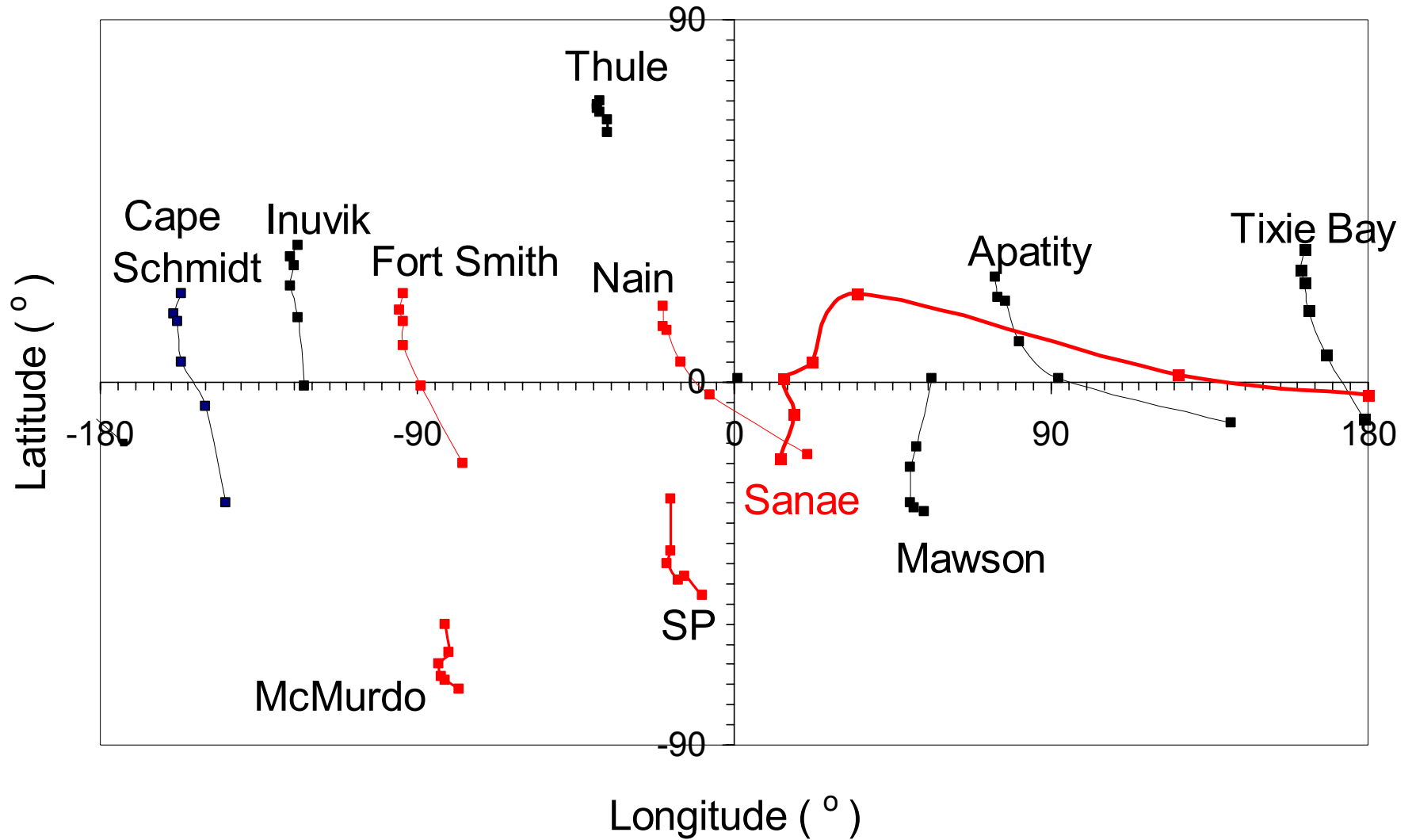
Properties of P1



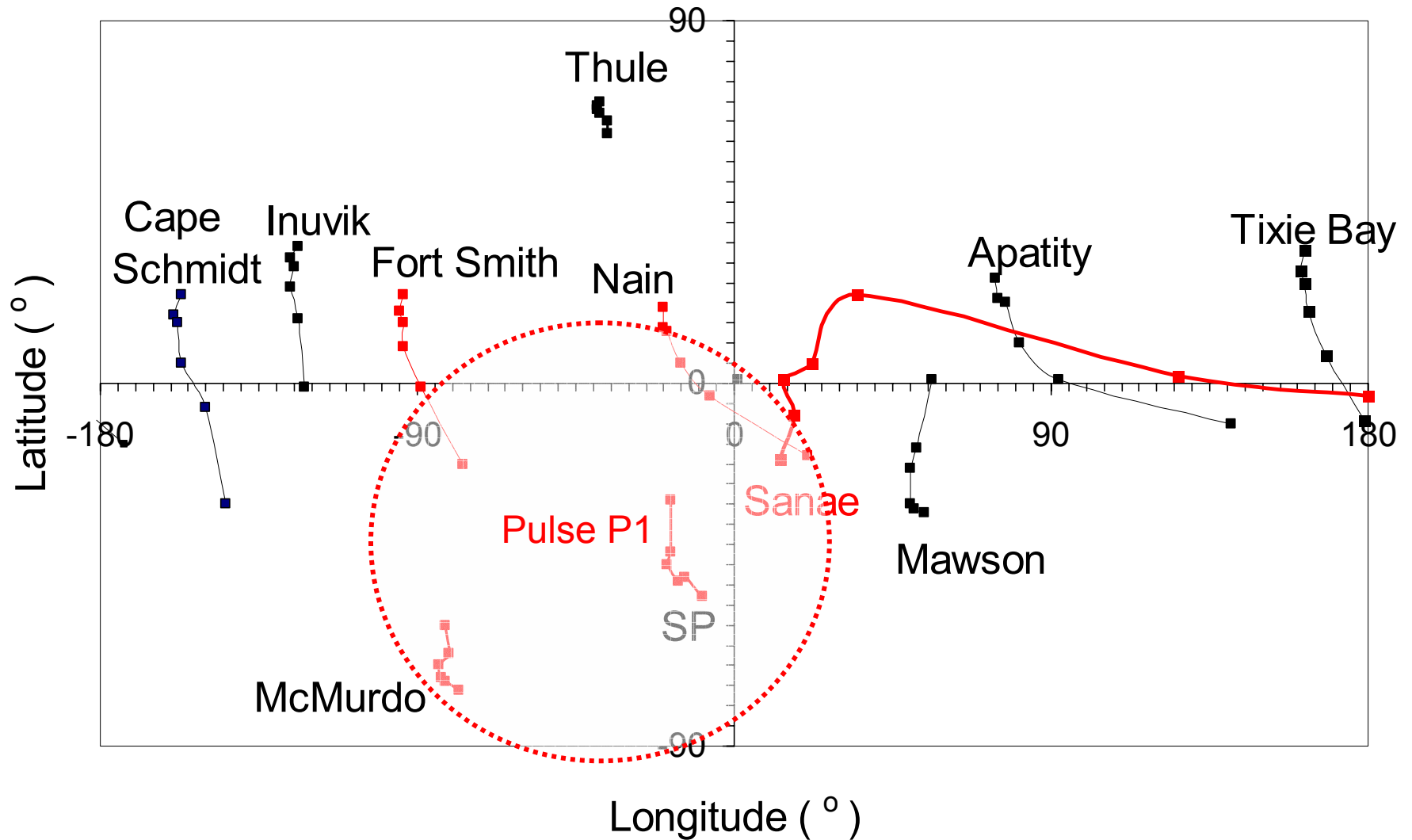
P1 significantly harder than P2 and P3



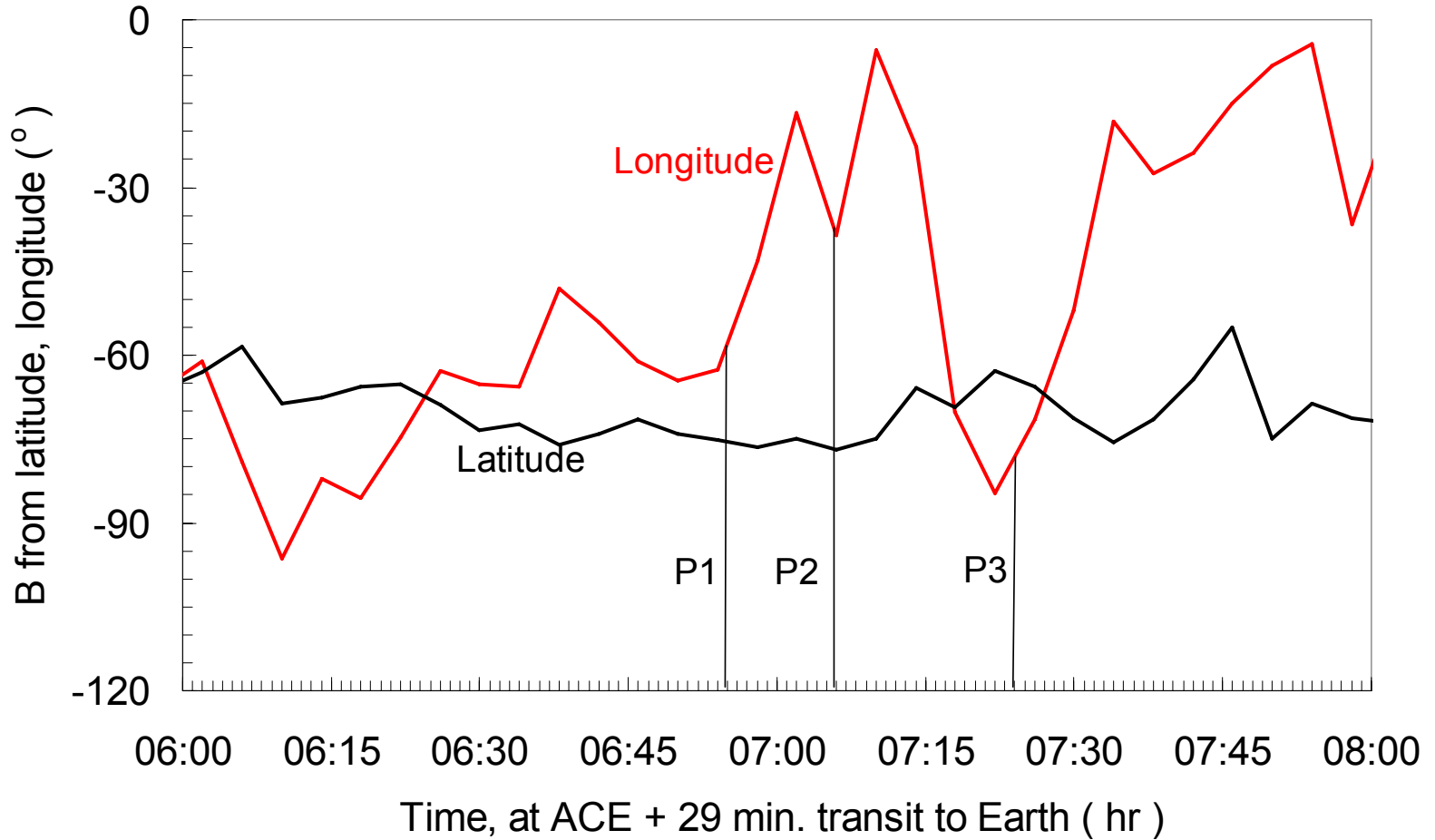
Asymptotic Directions

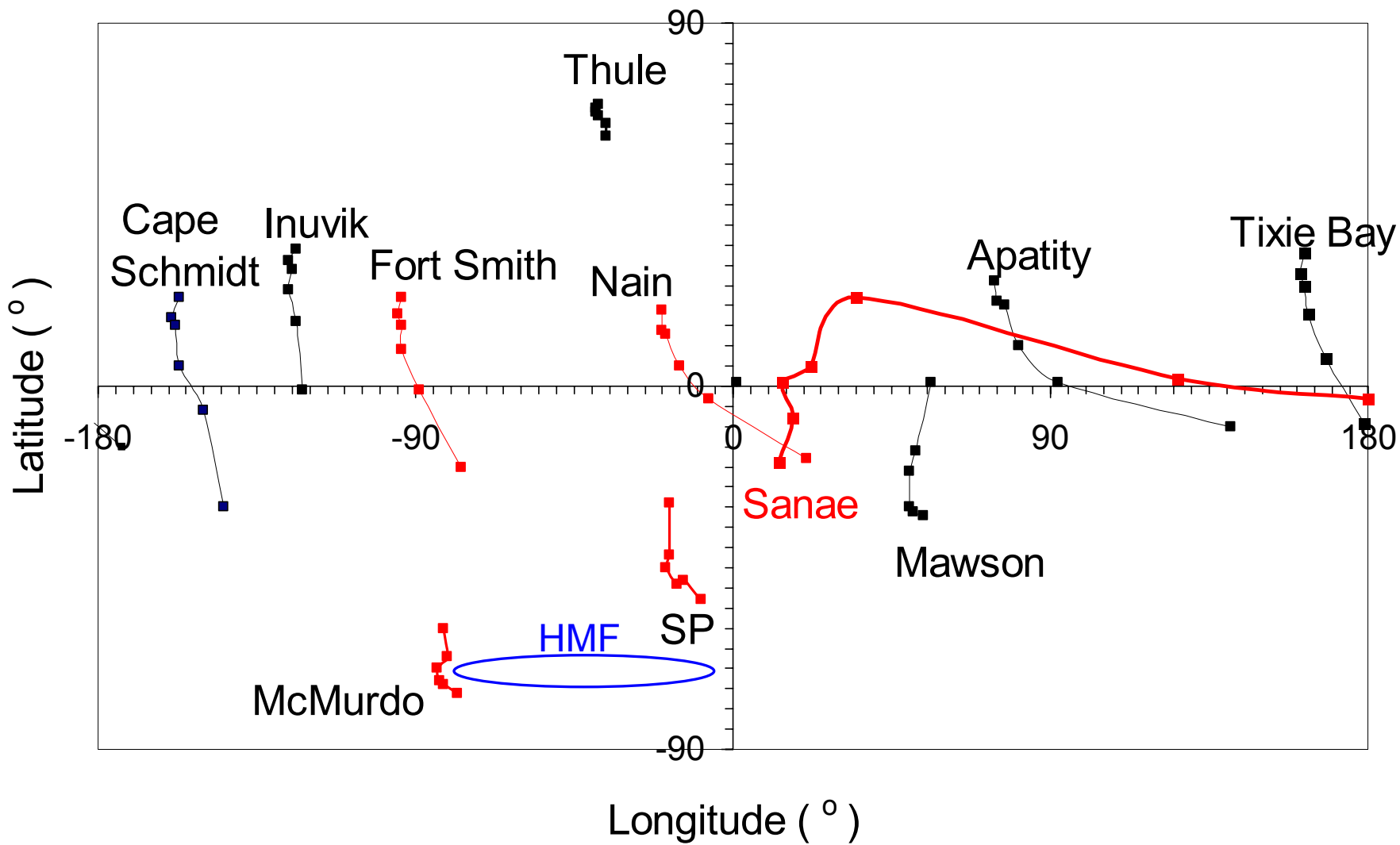


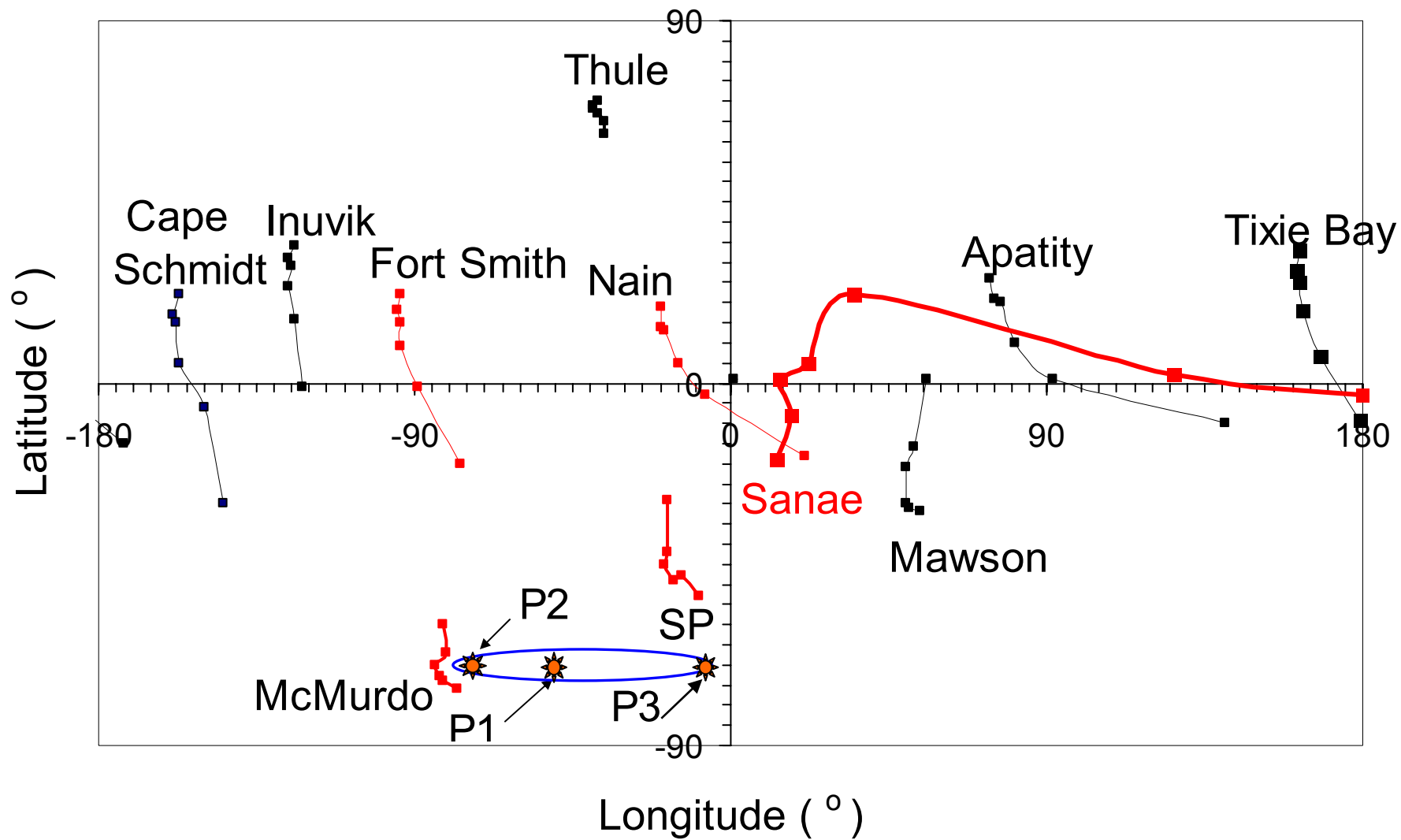
Asymptotic Directions



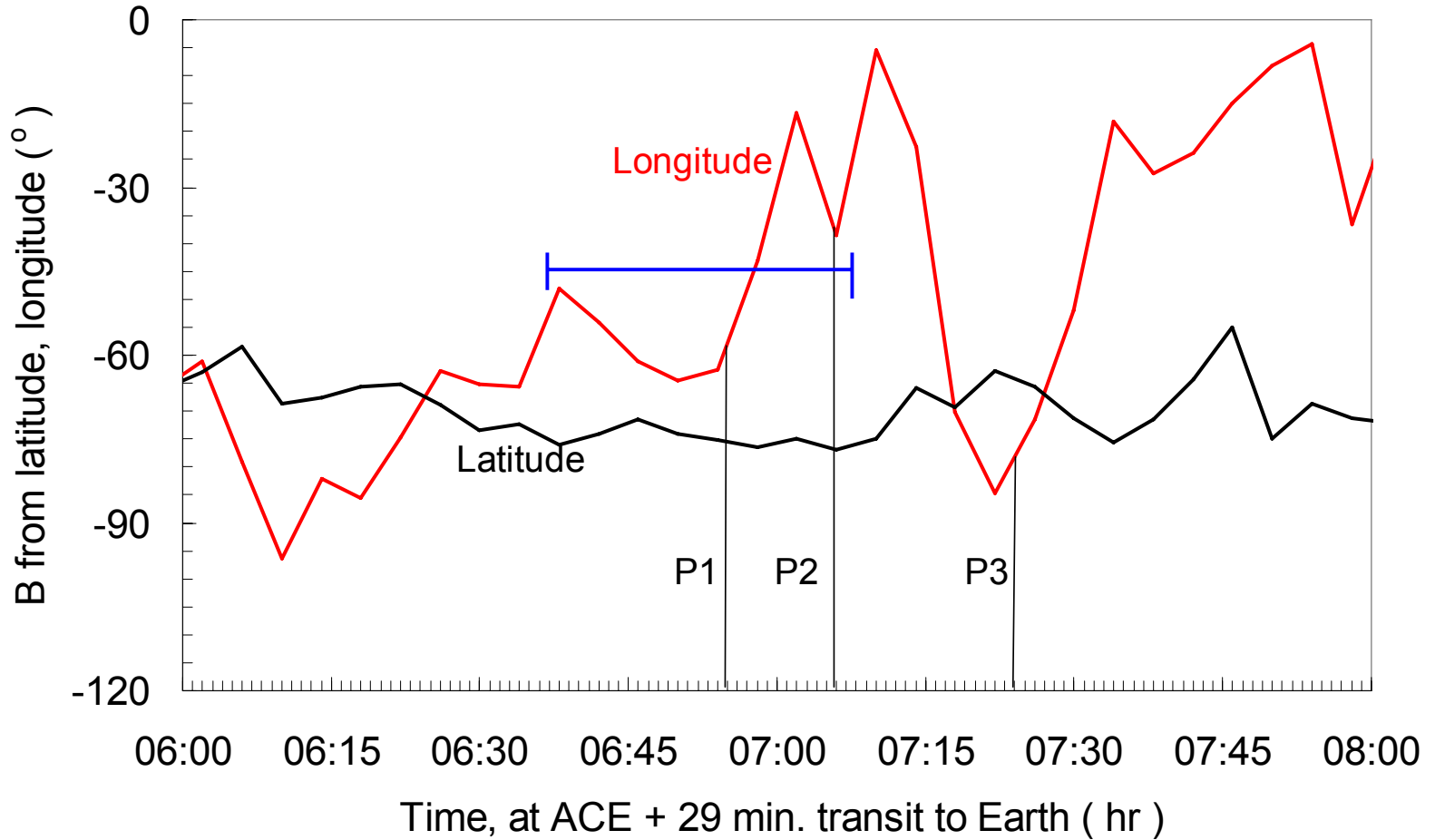
ACE Magnetic Field



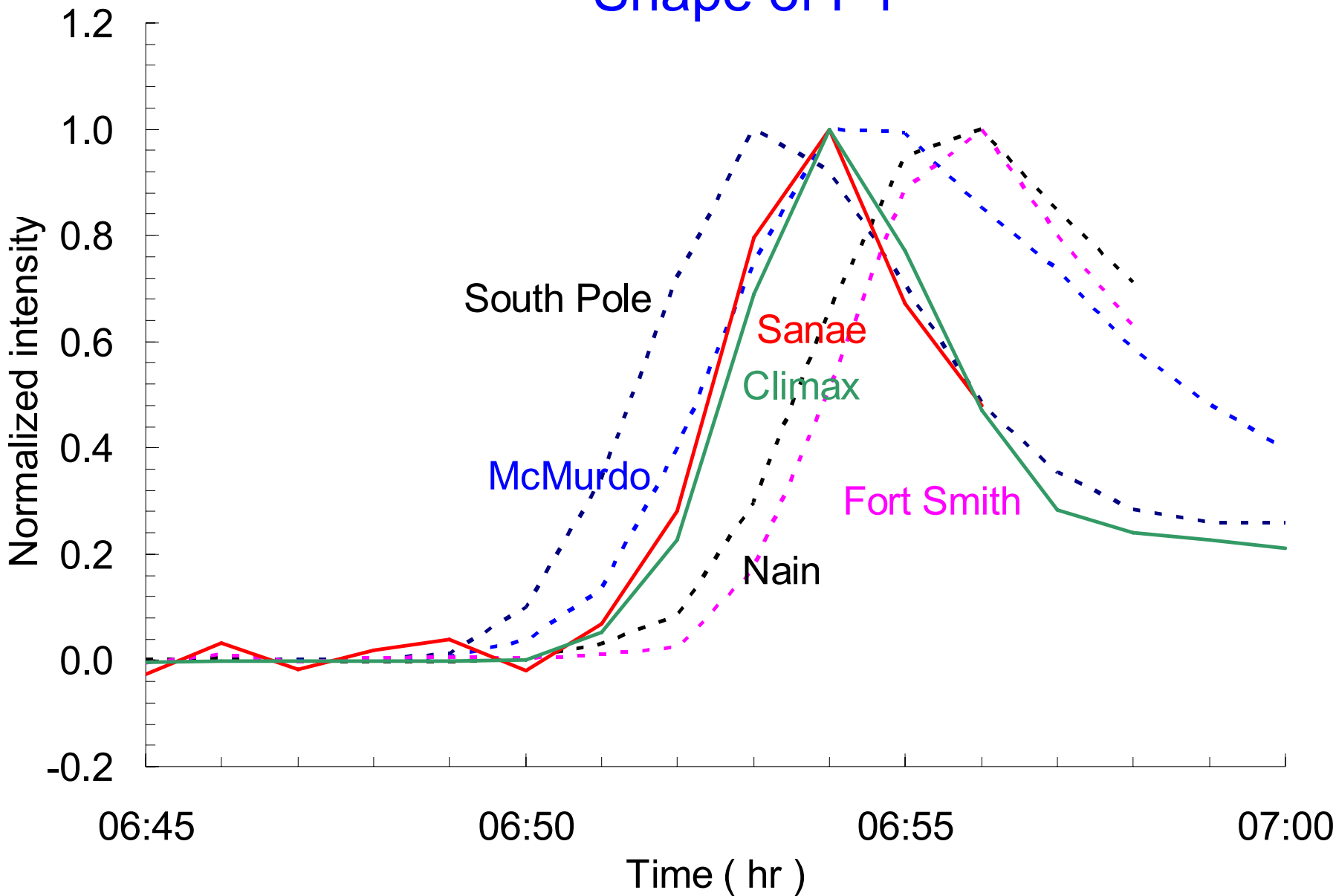




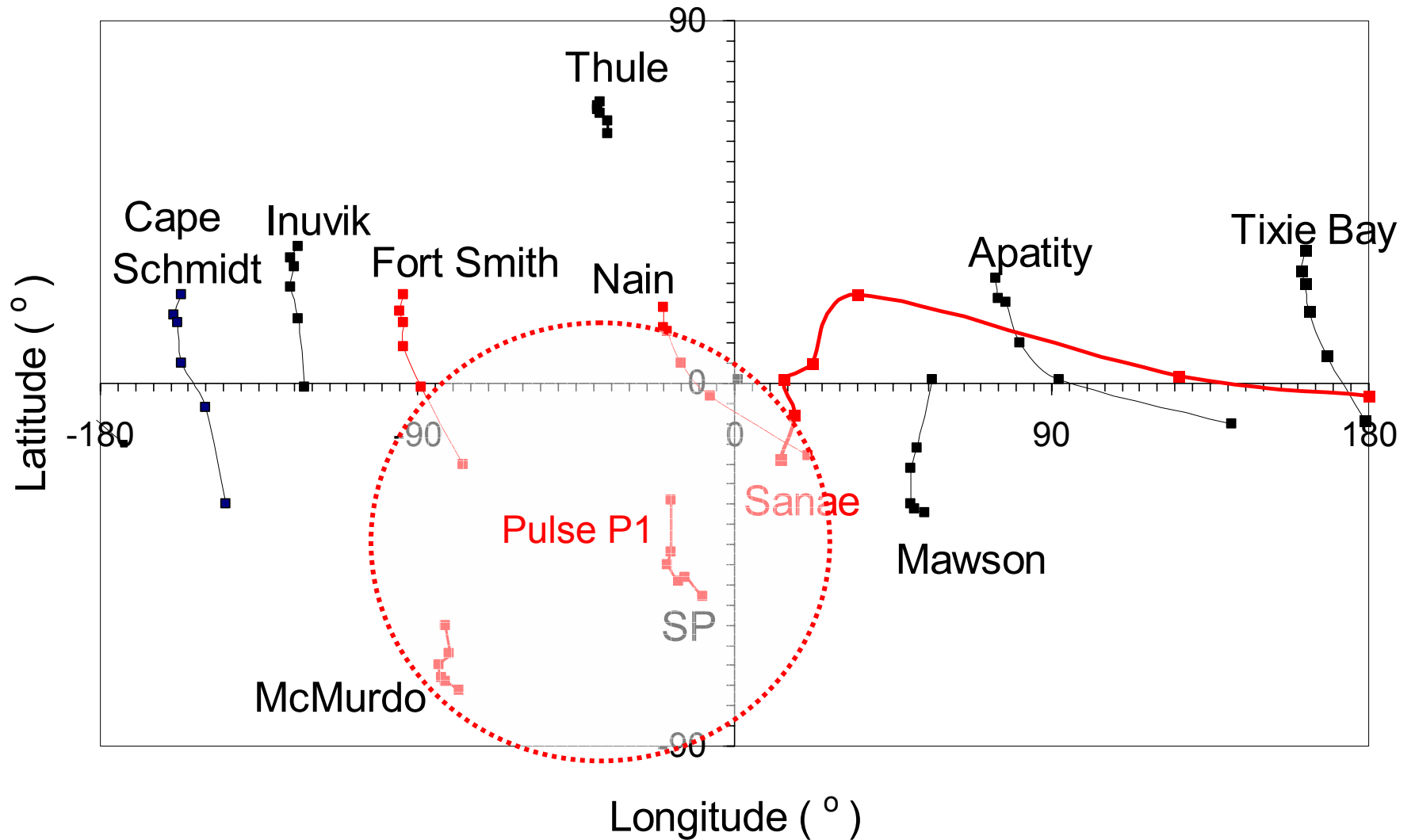
ACE Magnetic Field



Shape of P1

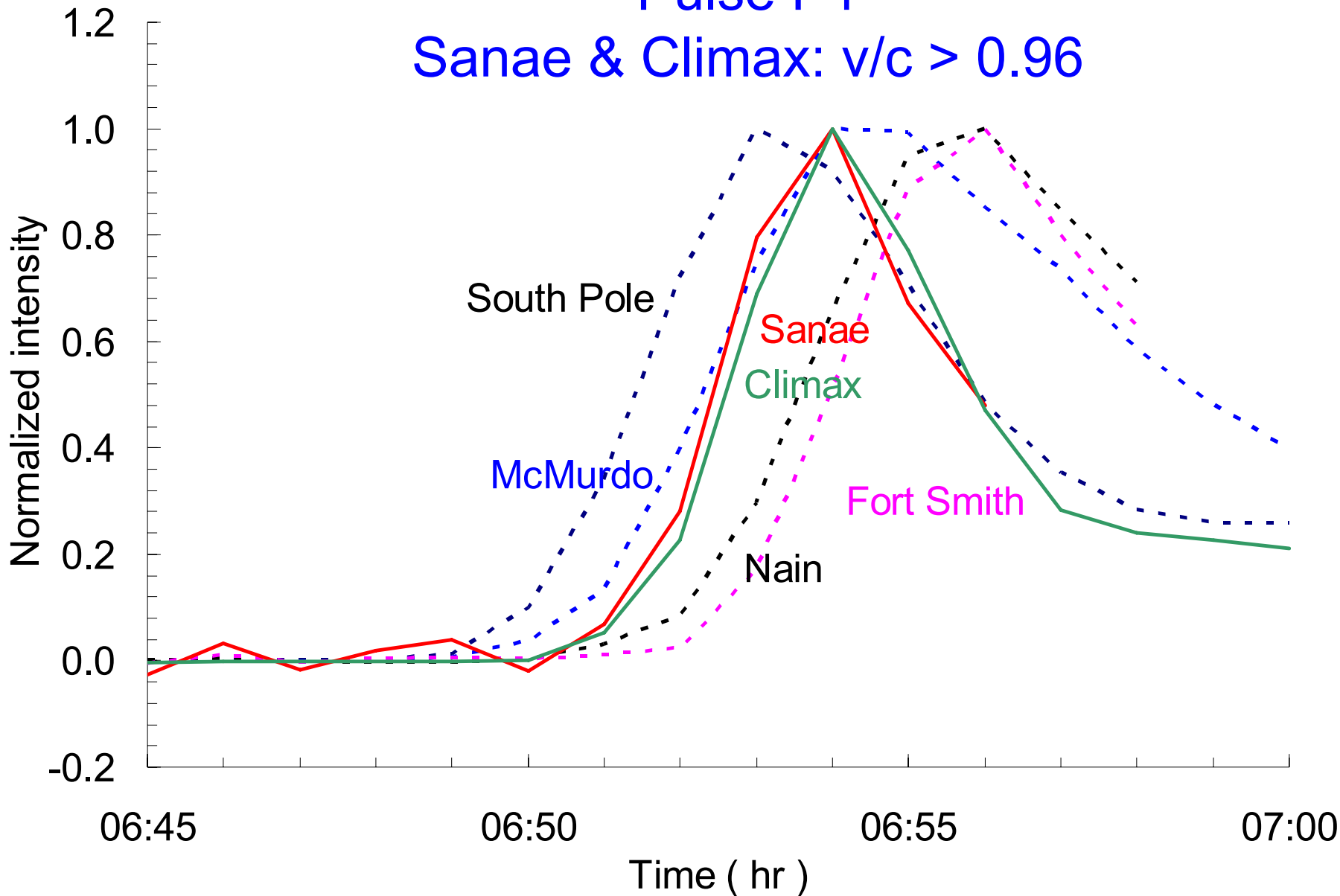


Asymptotic Directions

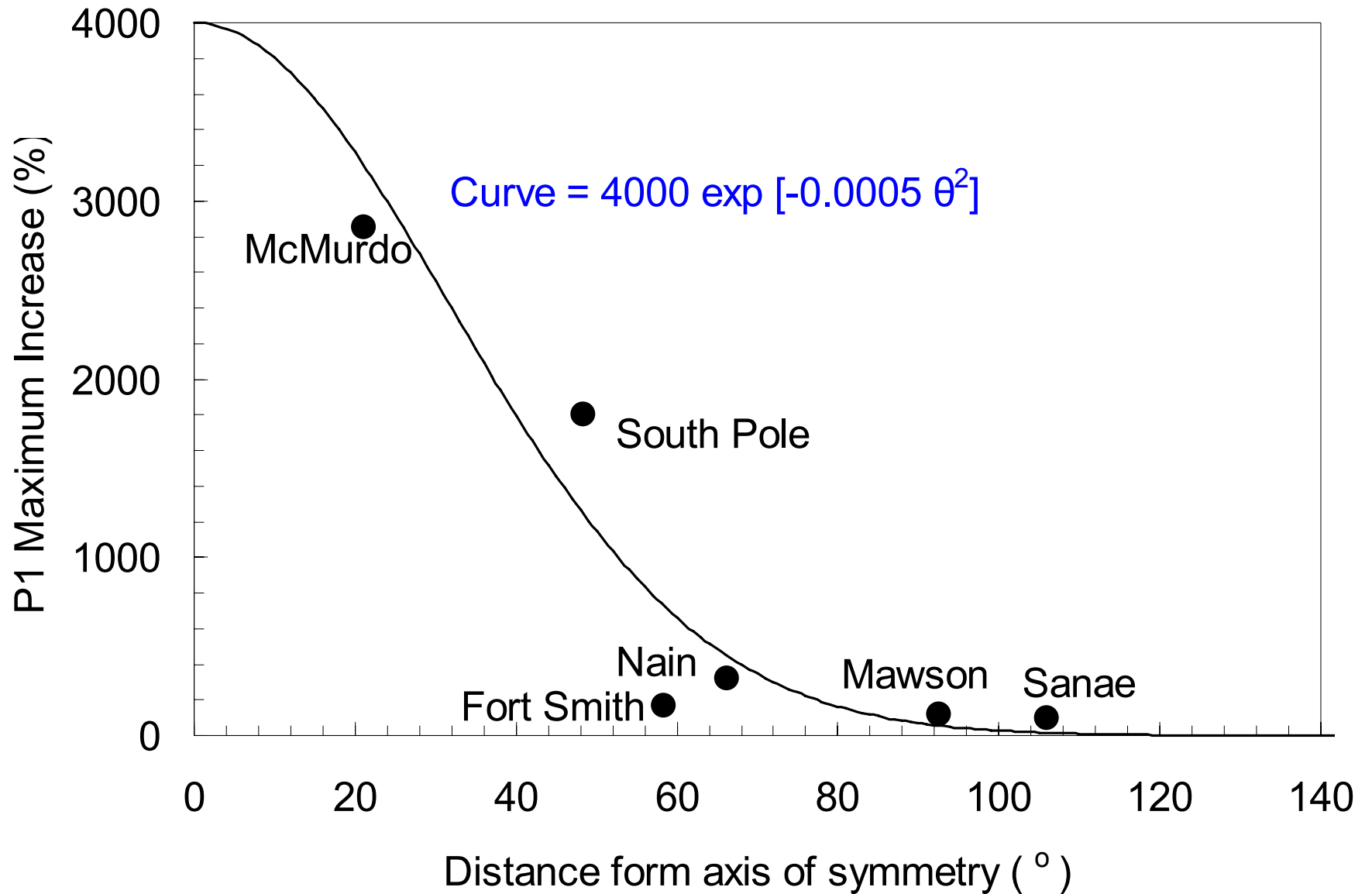


Pulse P1

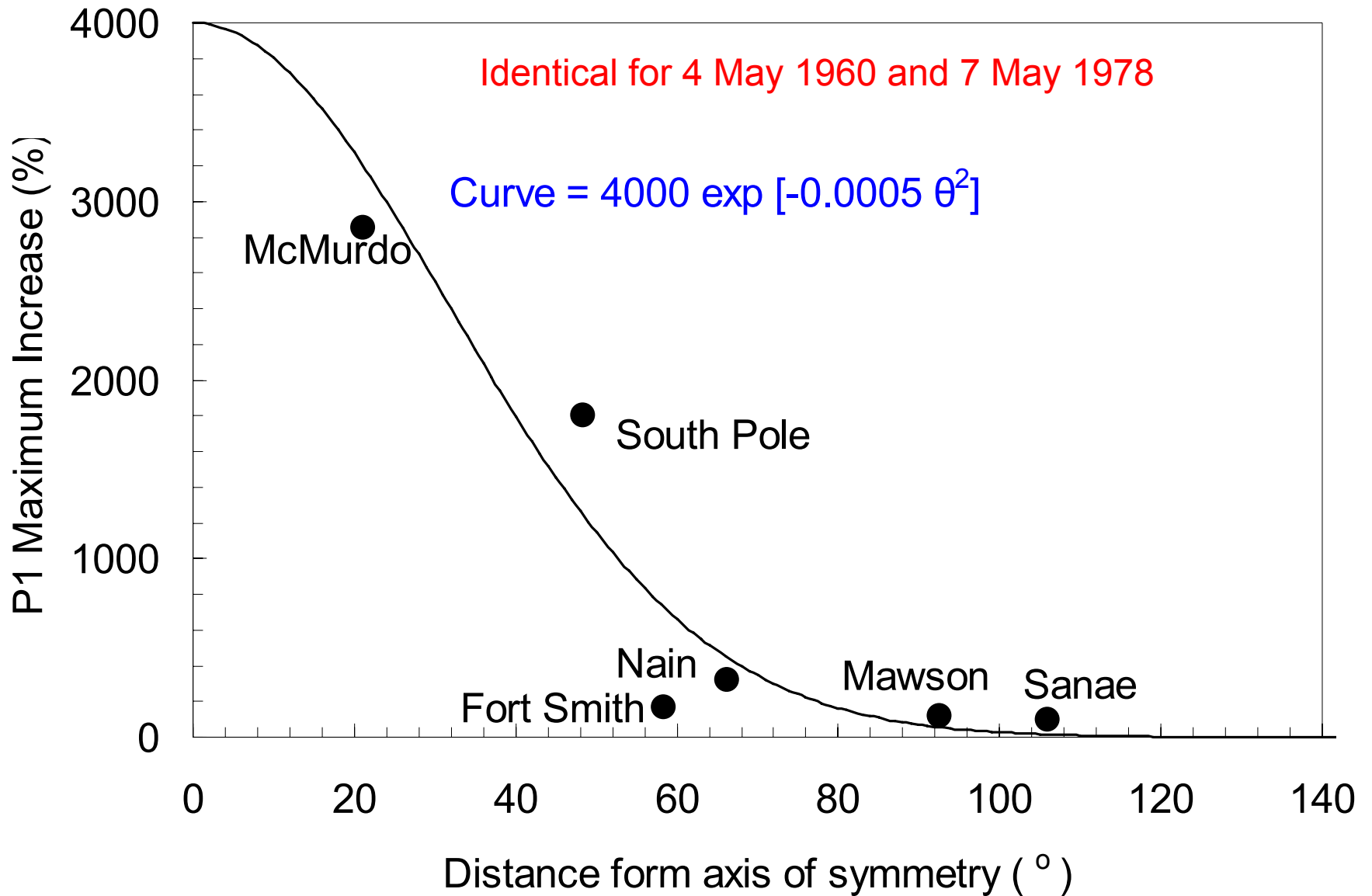
Sanae & Climax: $v/c > 0.96$



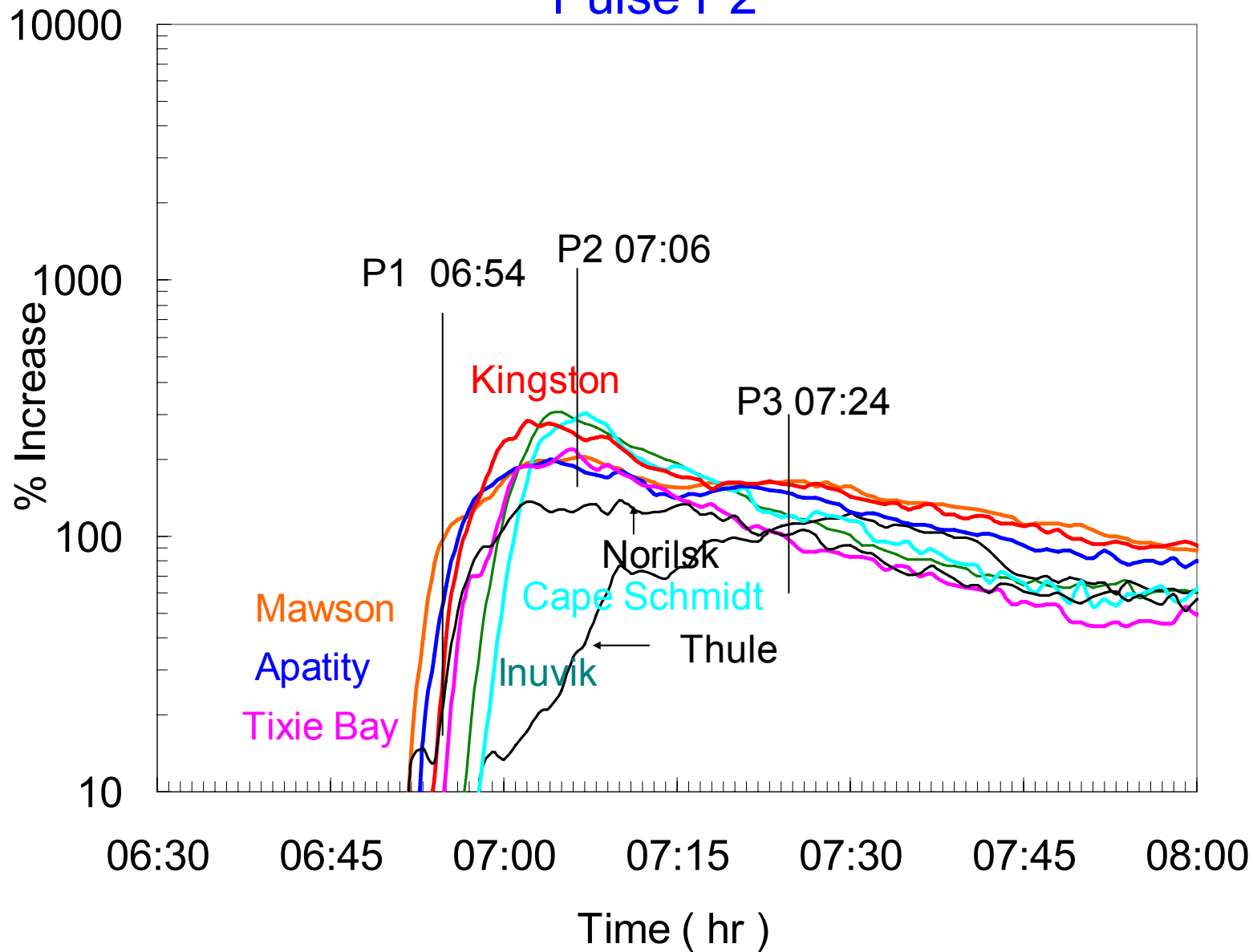
Anisotropy of P1



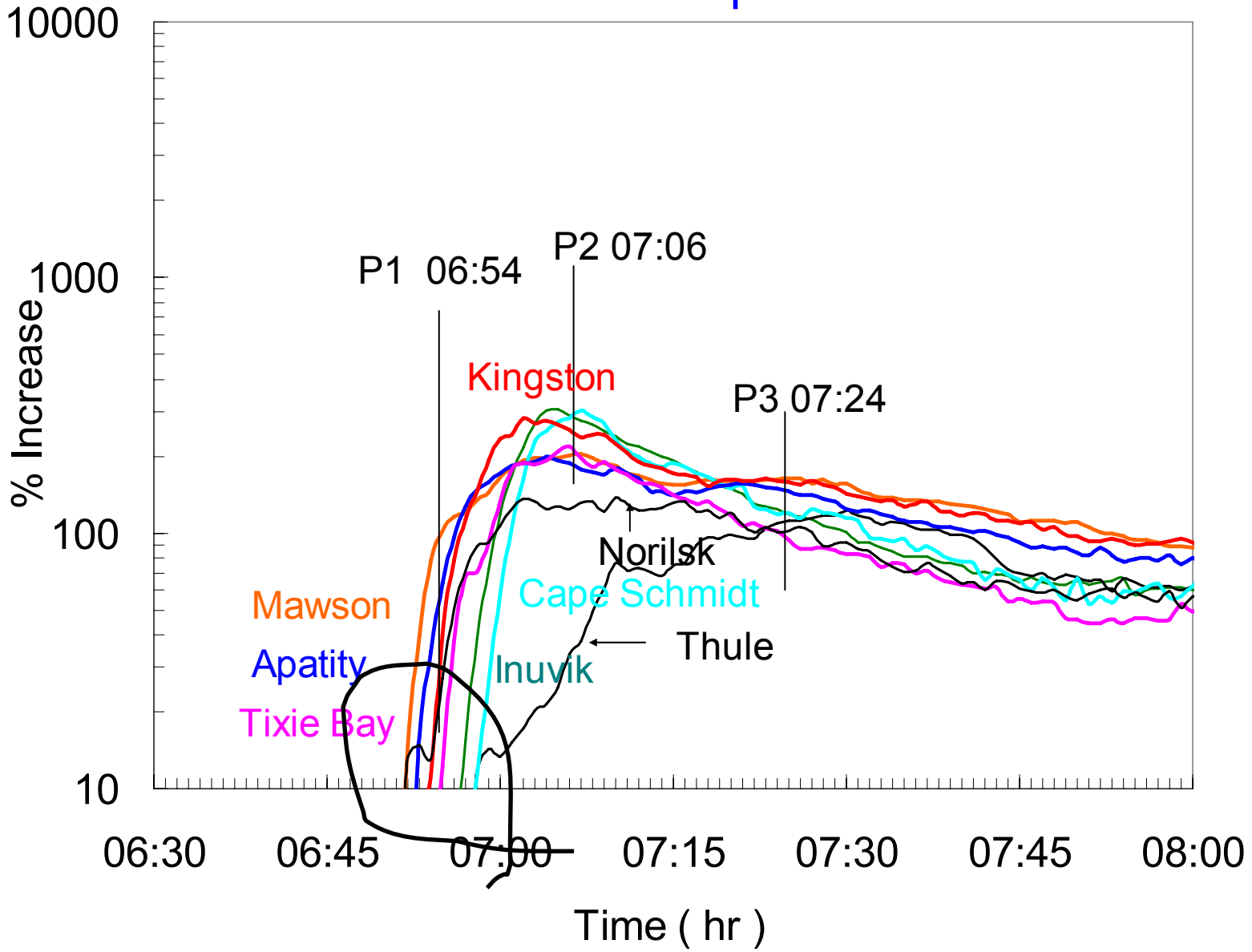
Anisotropy of P1

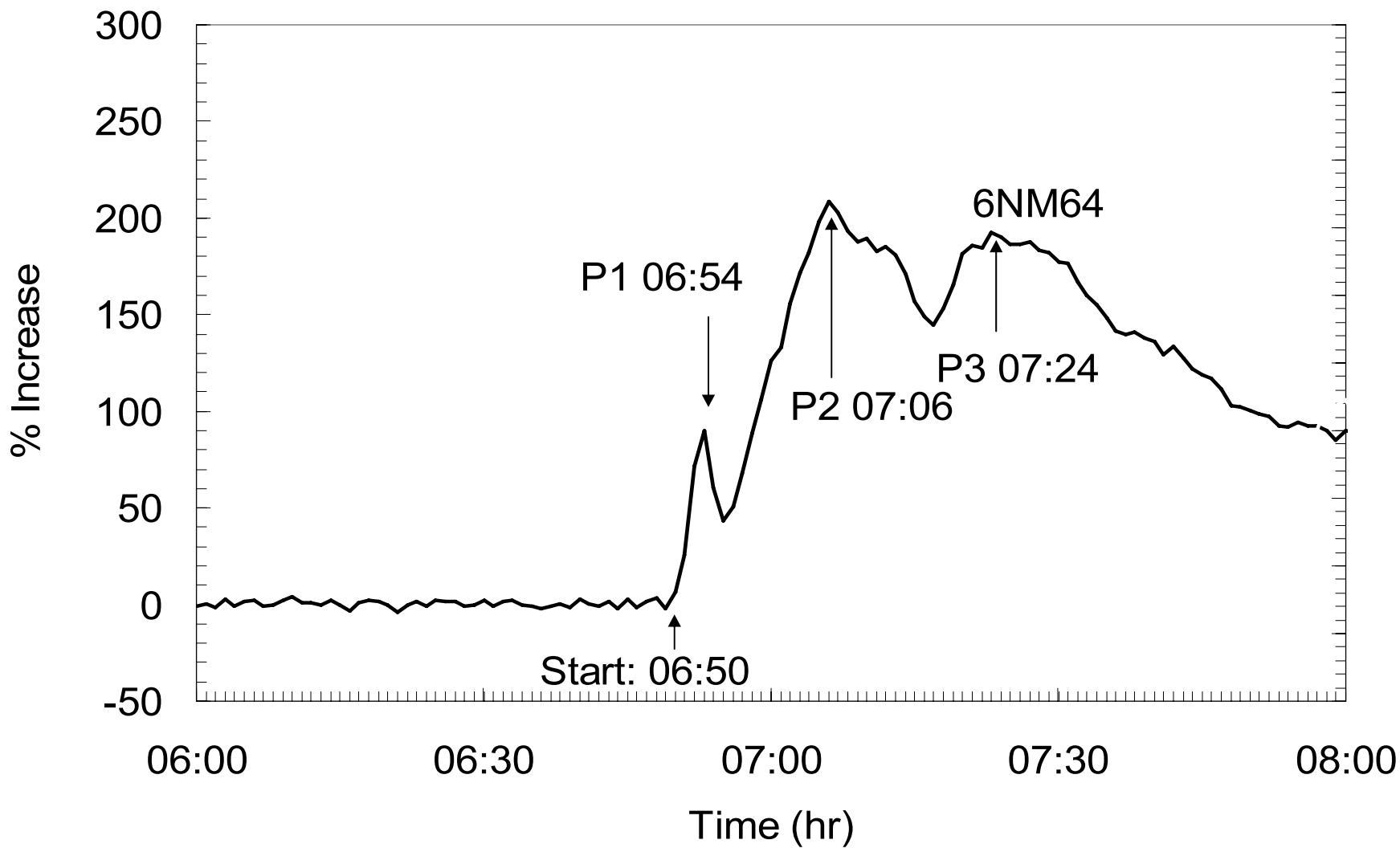


Pulse P2

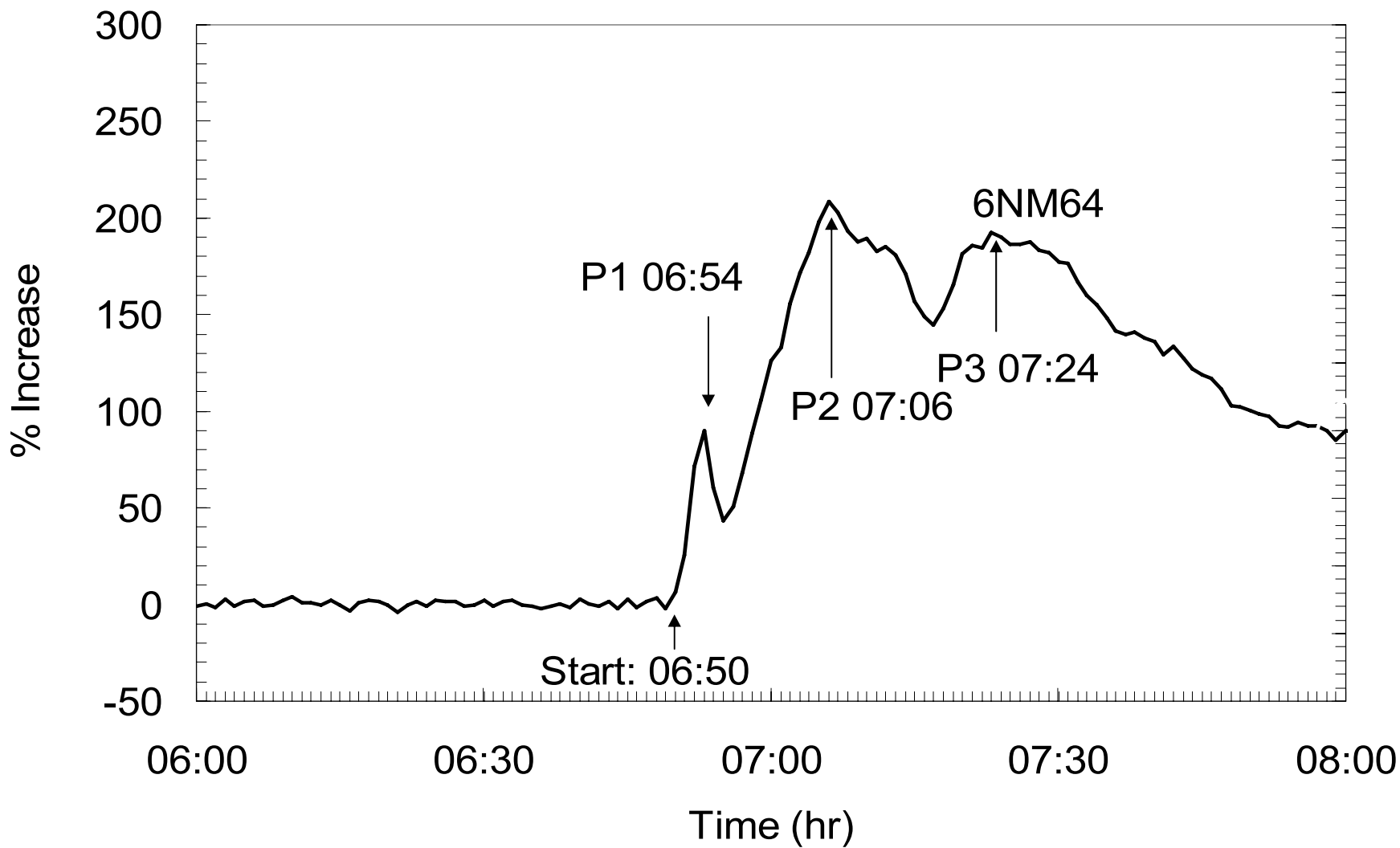


Start time of pulse P2

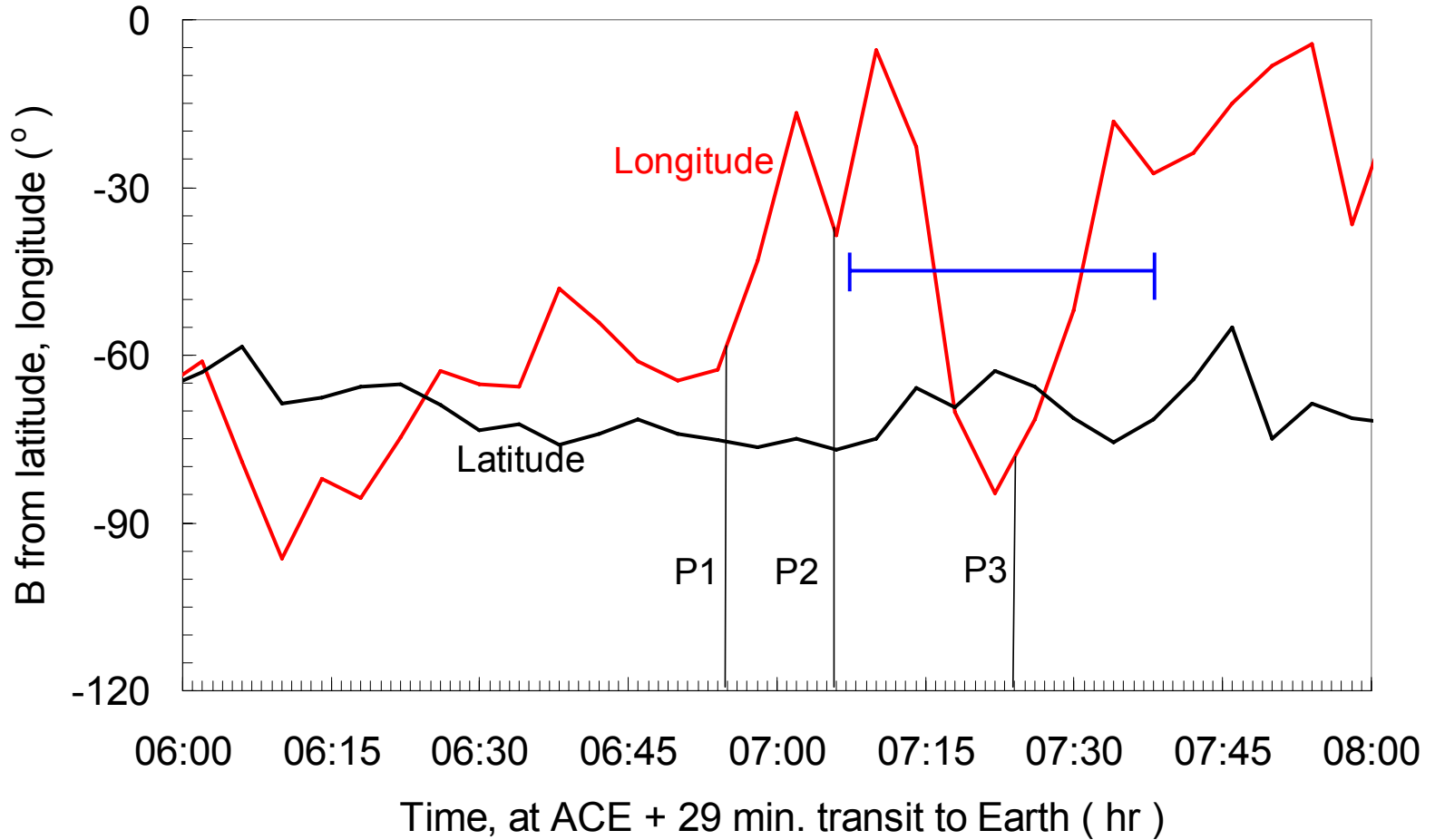




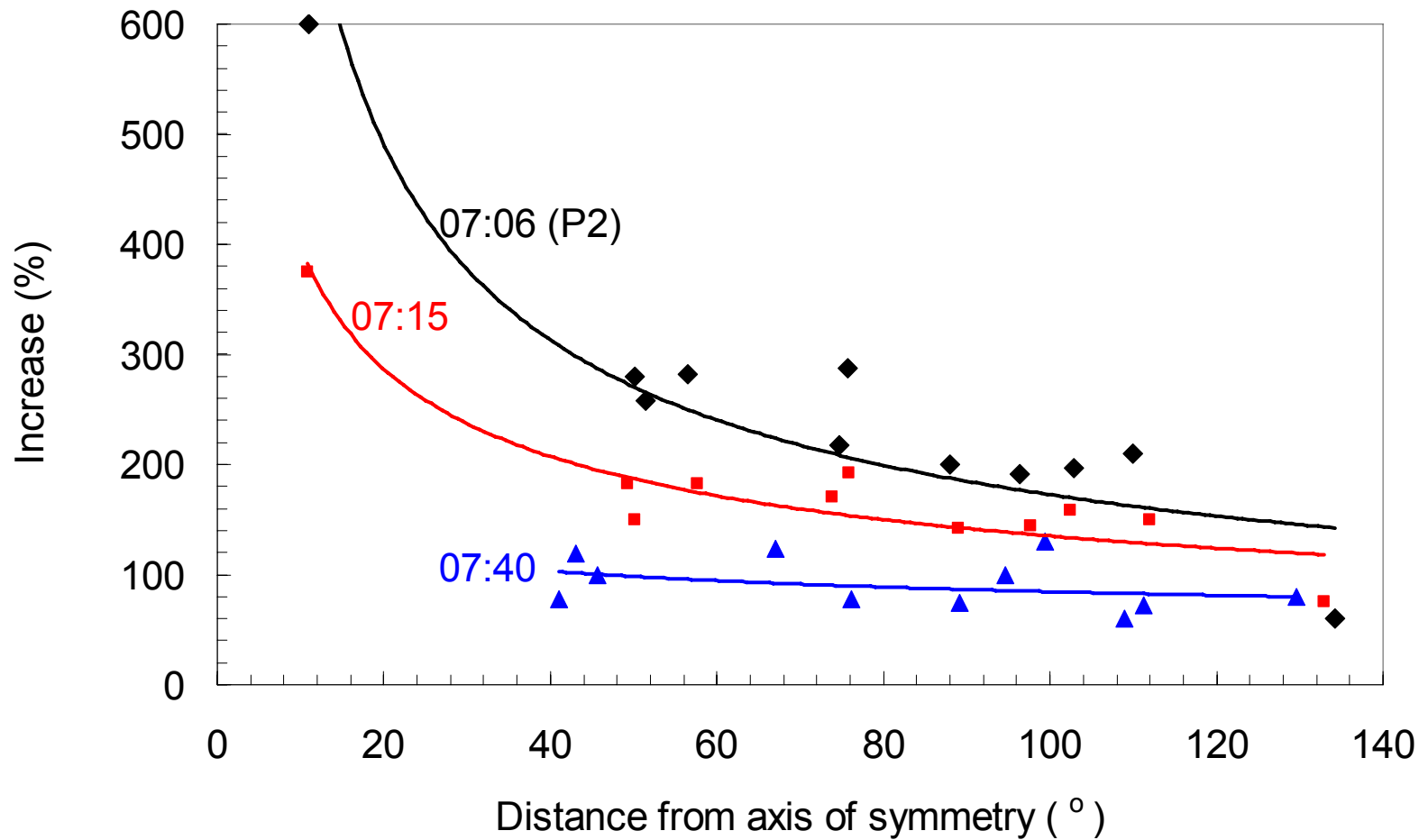
Origin of P3



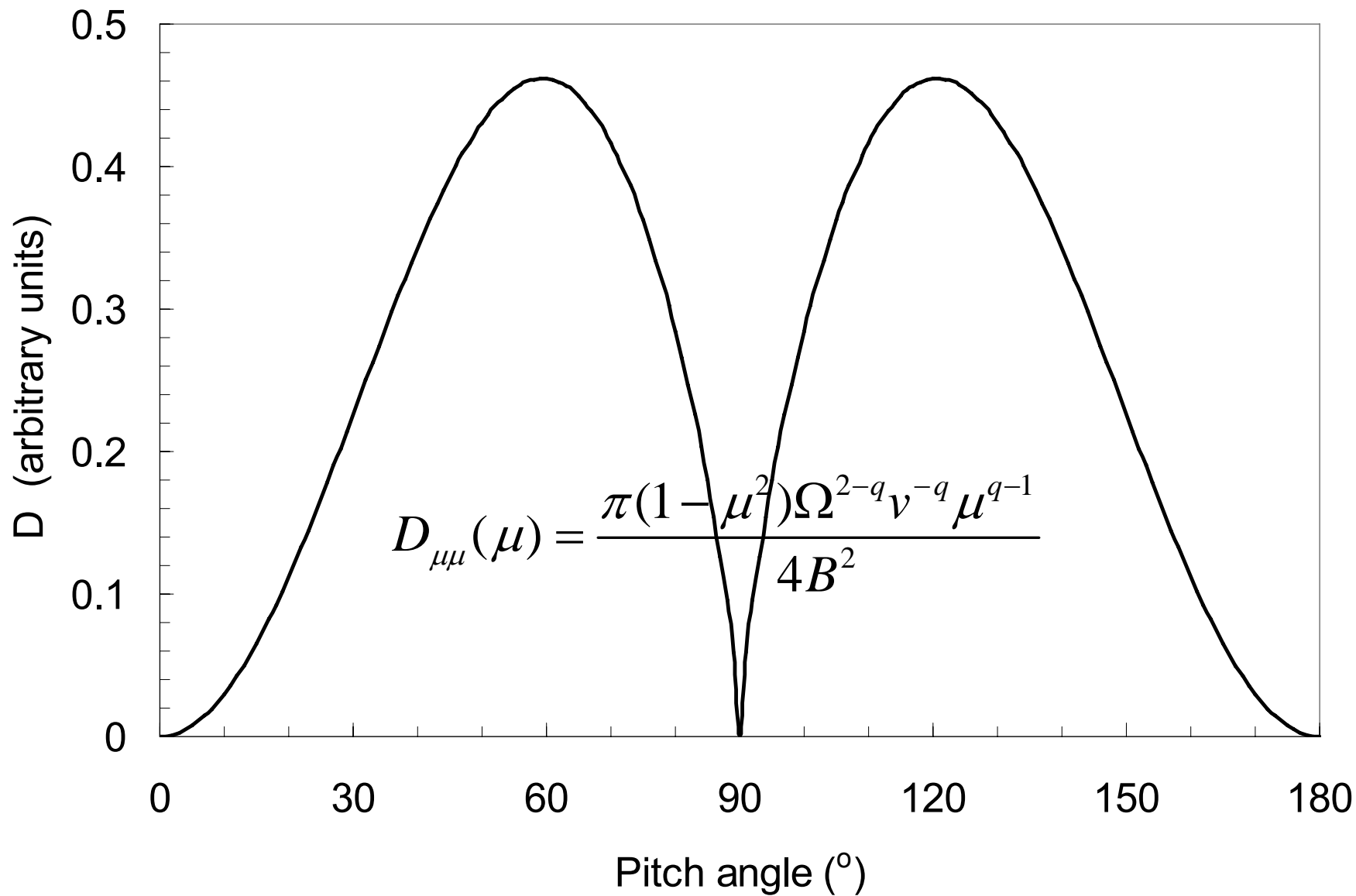
ACE Magnetic Field



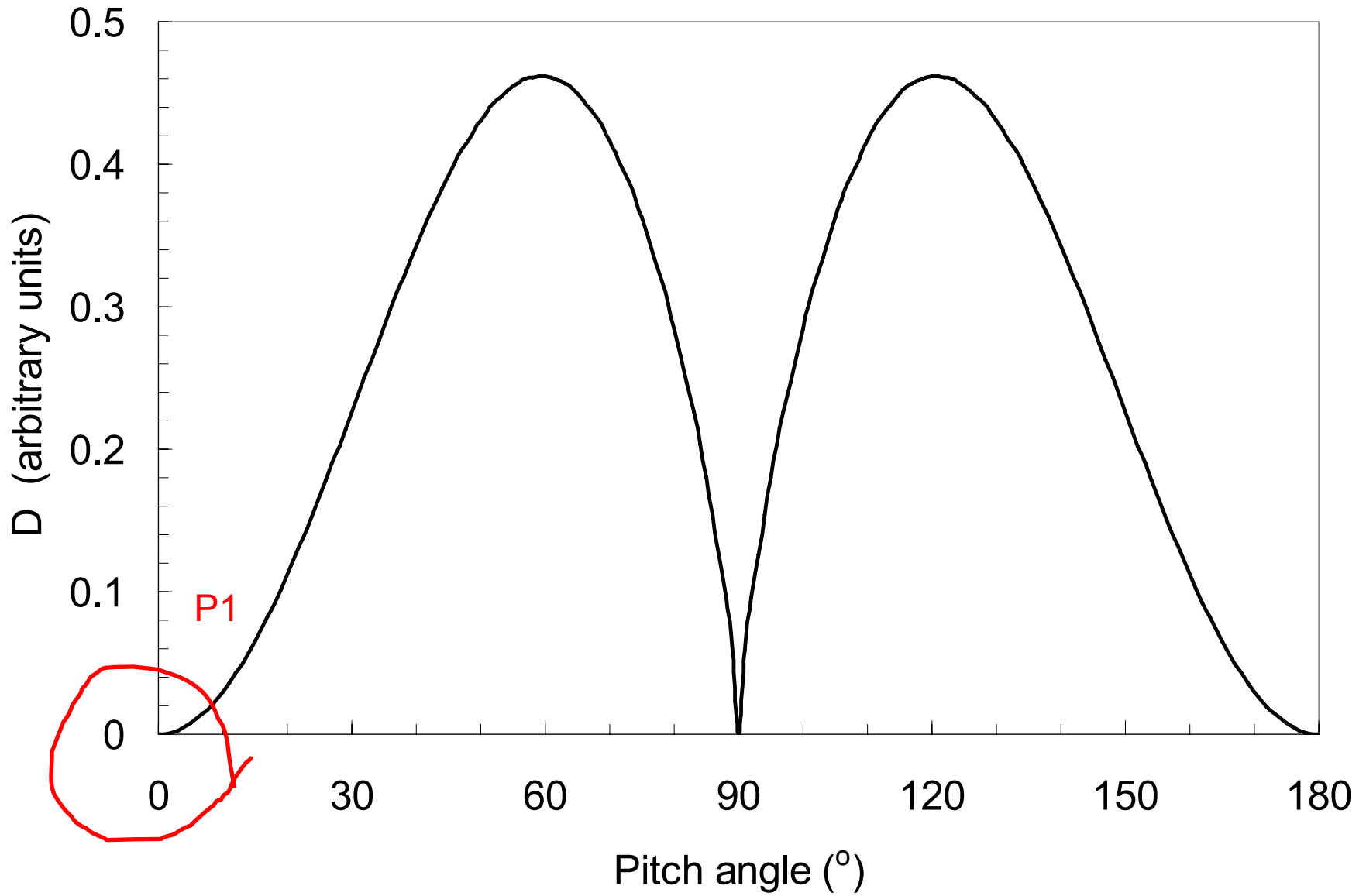
Anisotropy of P2 (and P3)



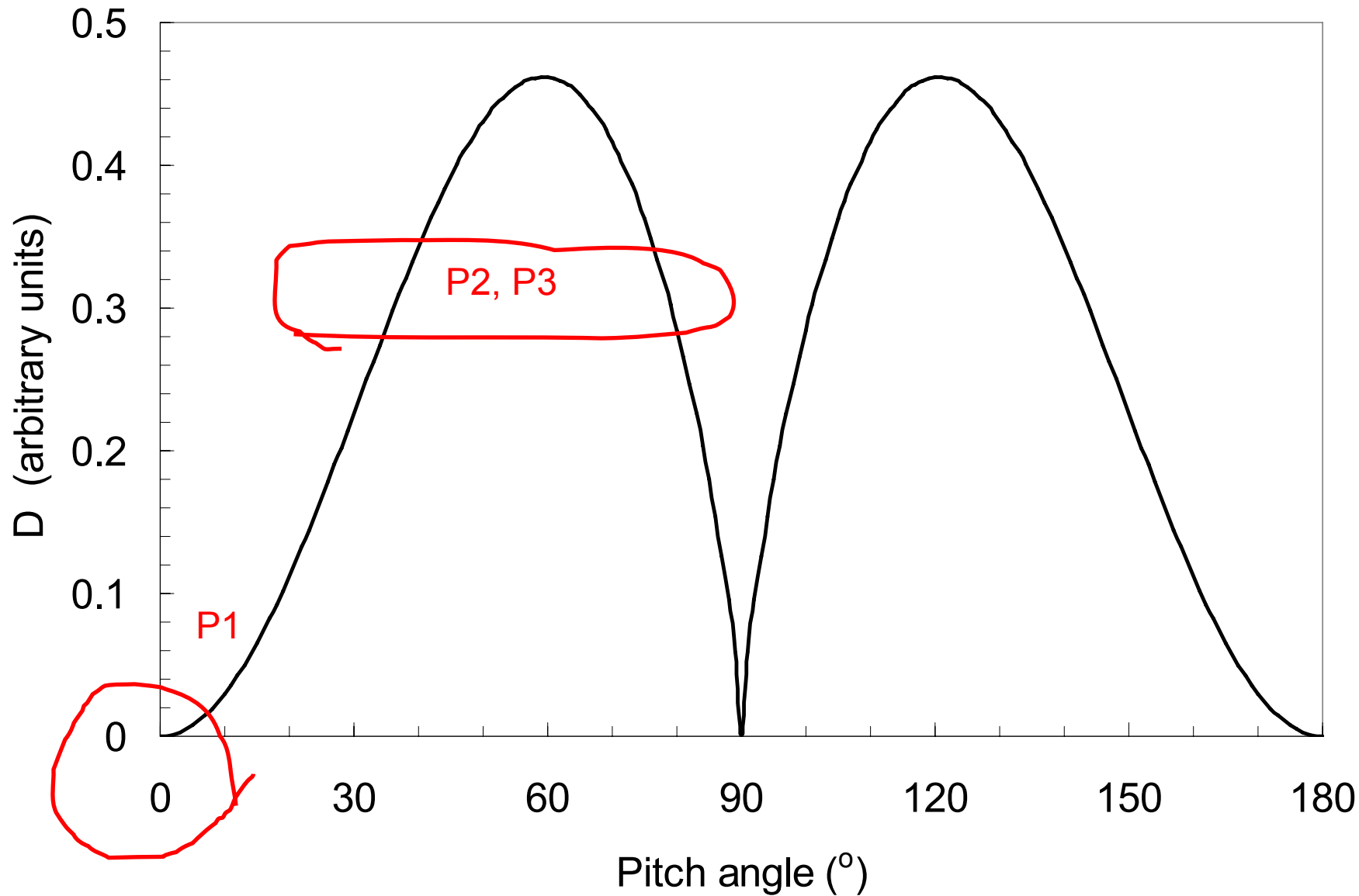
Two mean free paths?
No - quasi-linear scattering theory



Two mean free paths?
No - quasi-linear scattering theory



Two mean free paths?
Quasi-linear scattering theory

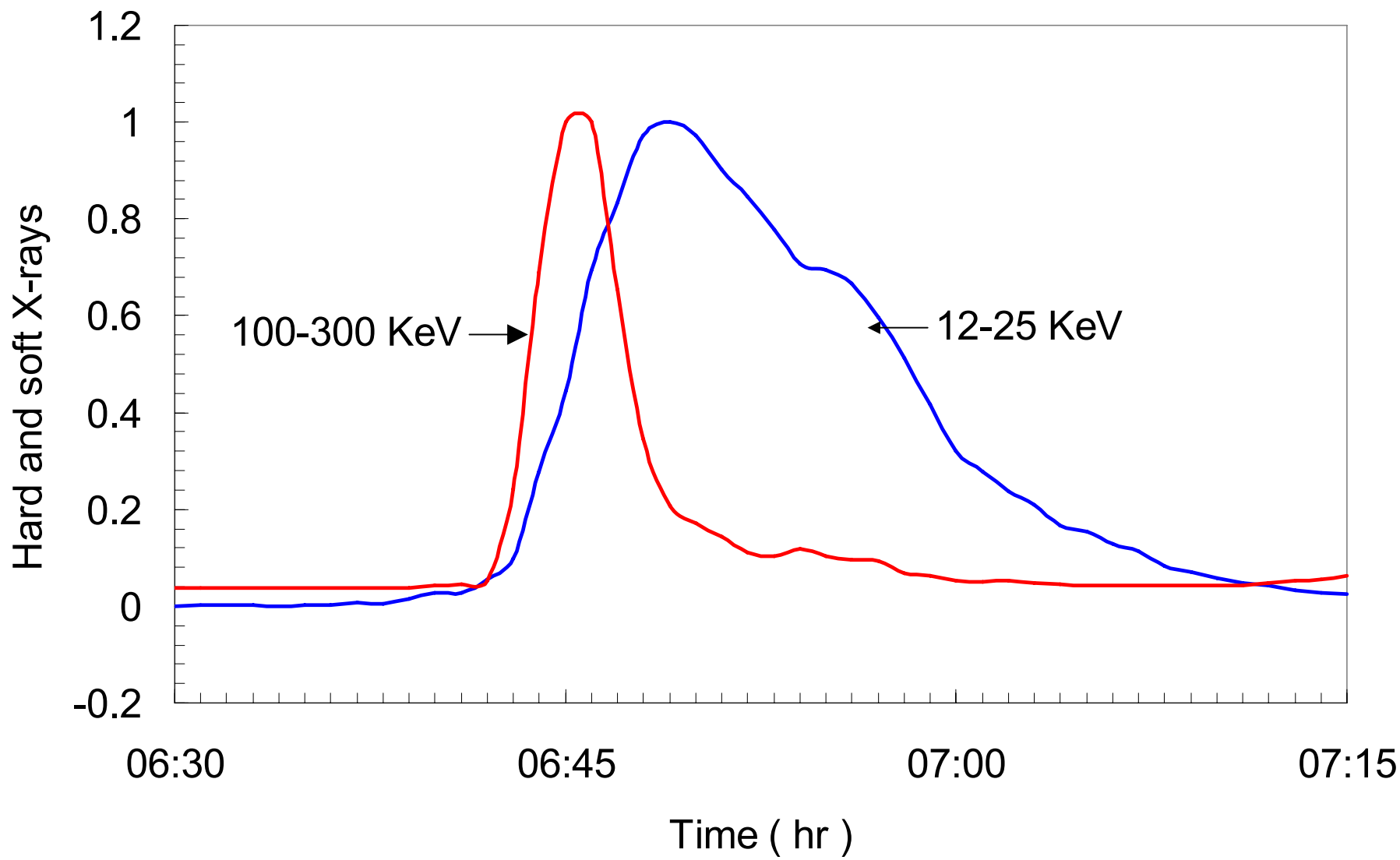


Adiabatic Focusing

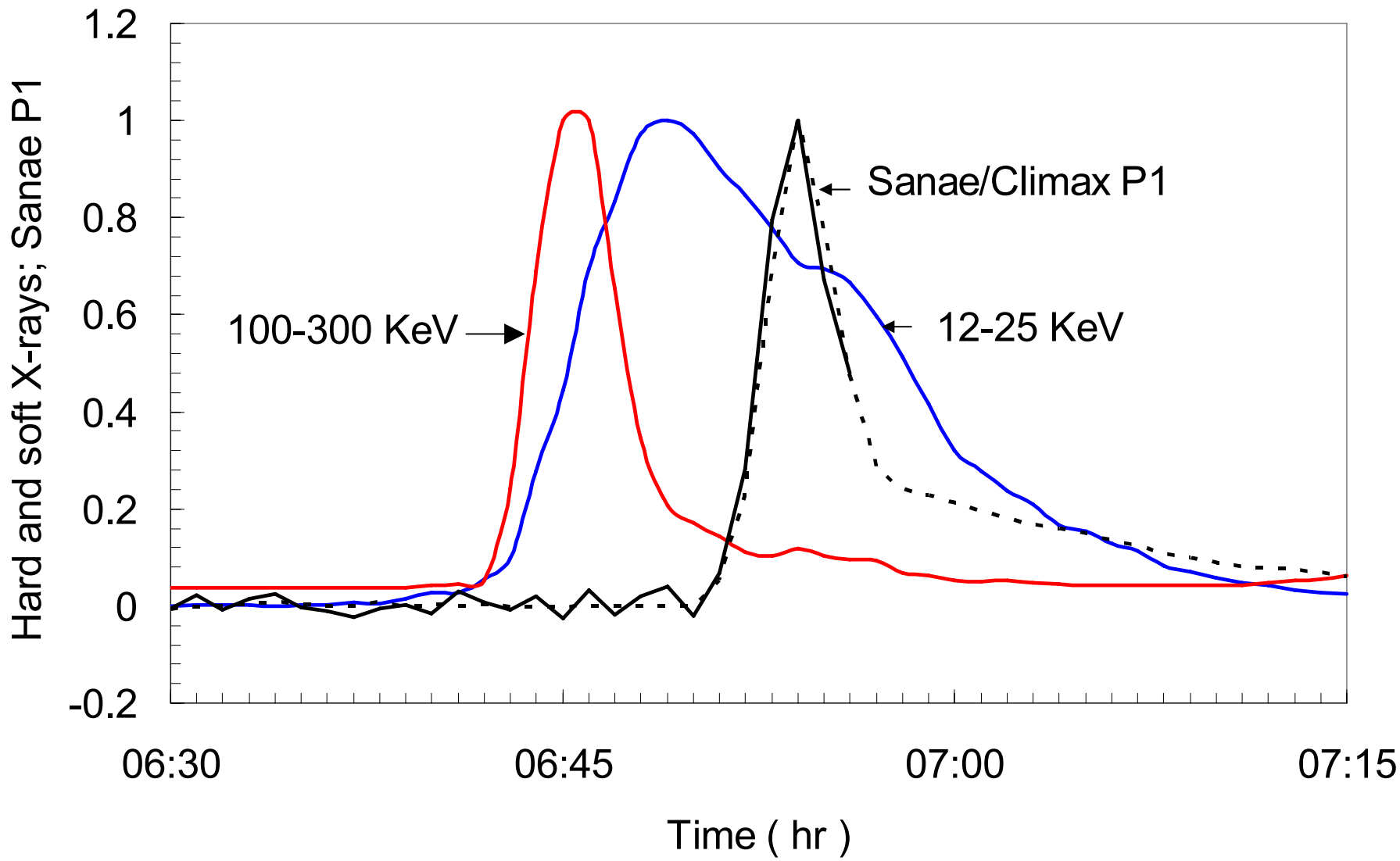
$$\sin^2\theta/B = \text{constant}$$

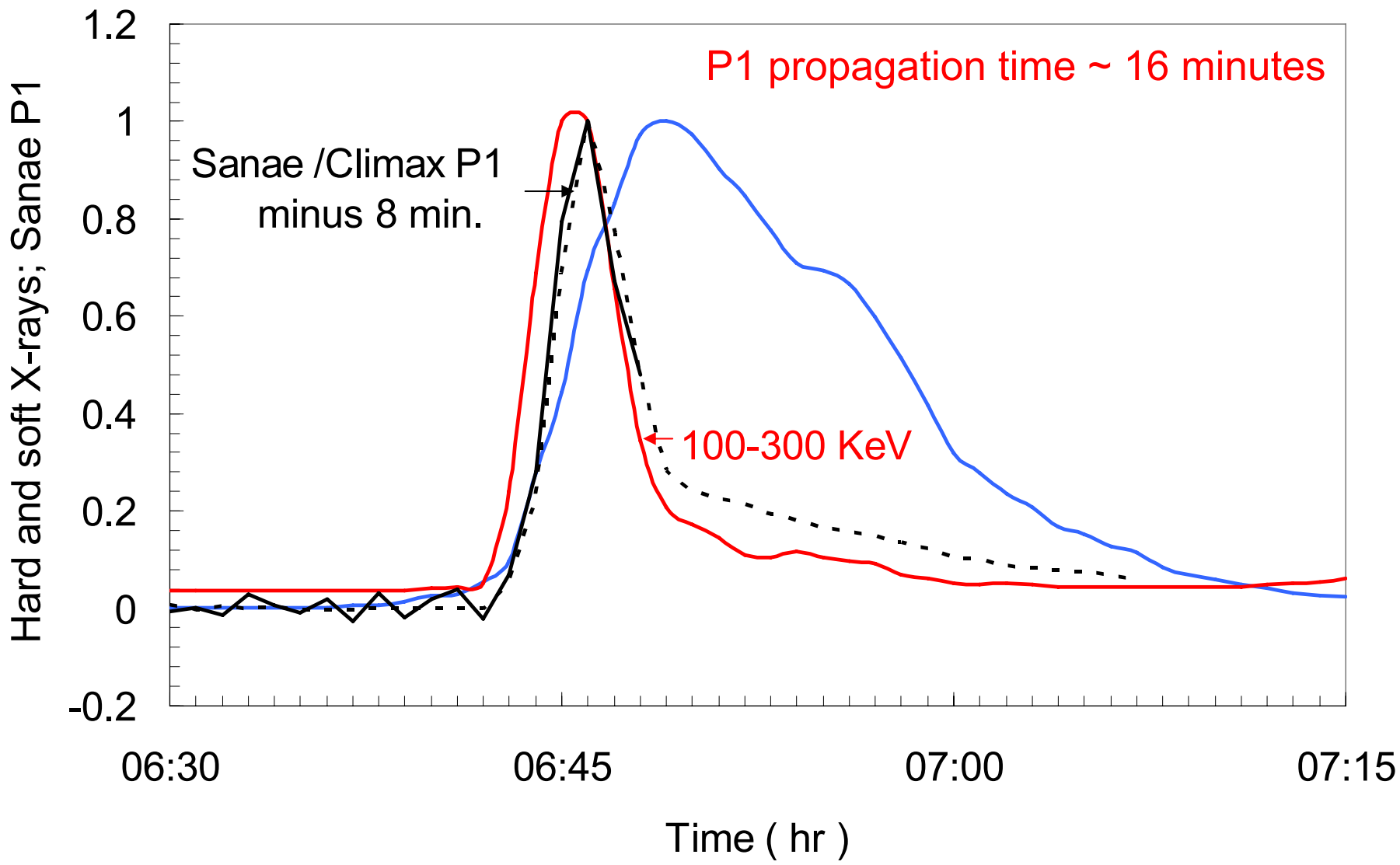
- P1 – accelerated at $\sim 1 r_s$ – strongly focused
- P2 (and P3) - accelerated at $> r_s$ – less focused

RHESSI X-rays

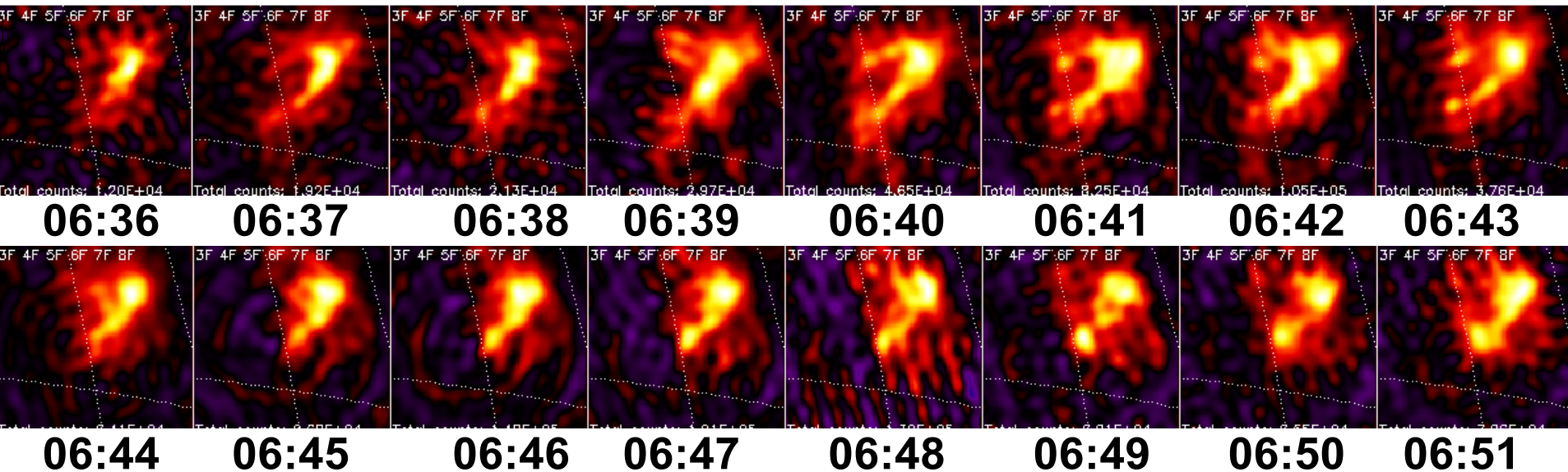


RHESSI X-rays

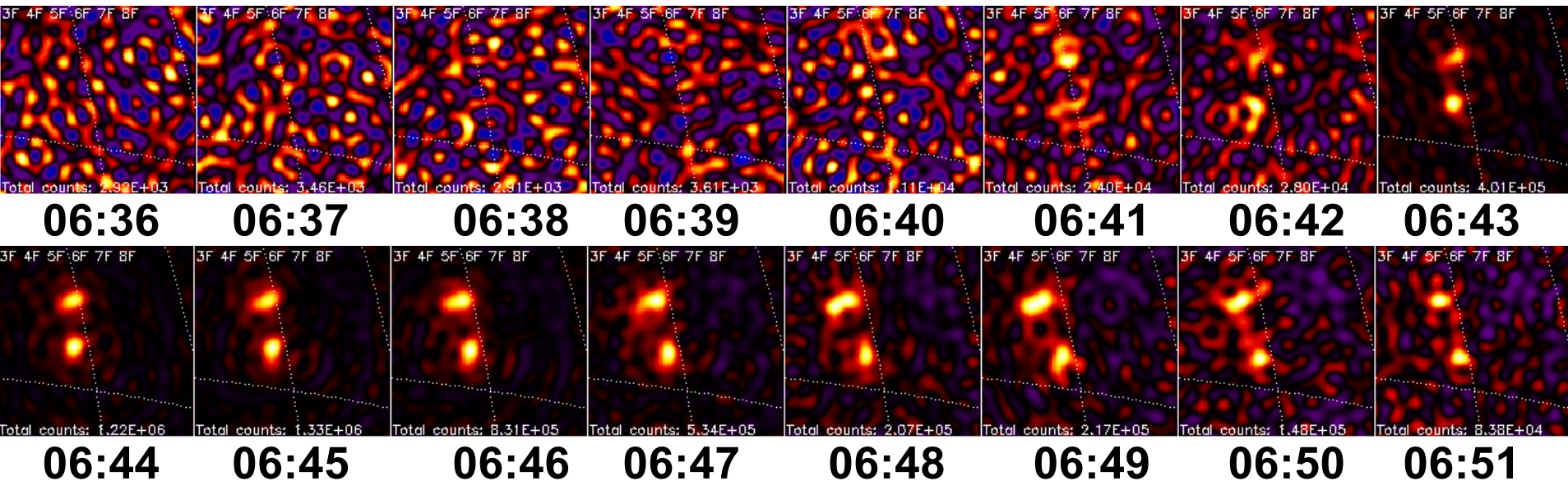




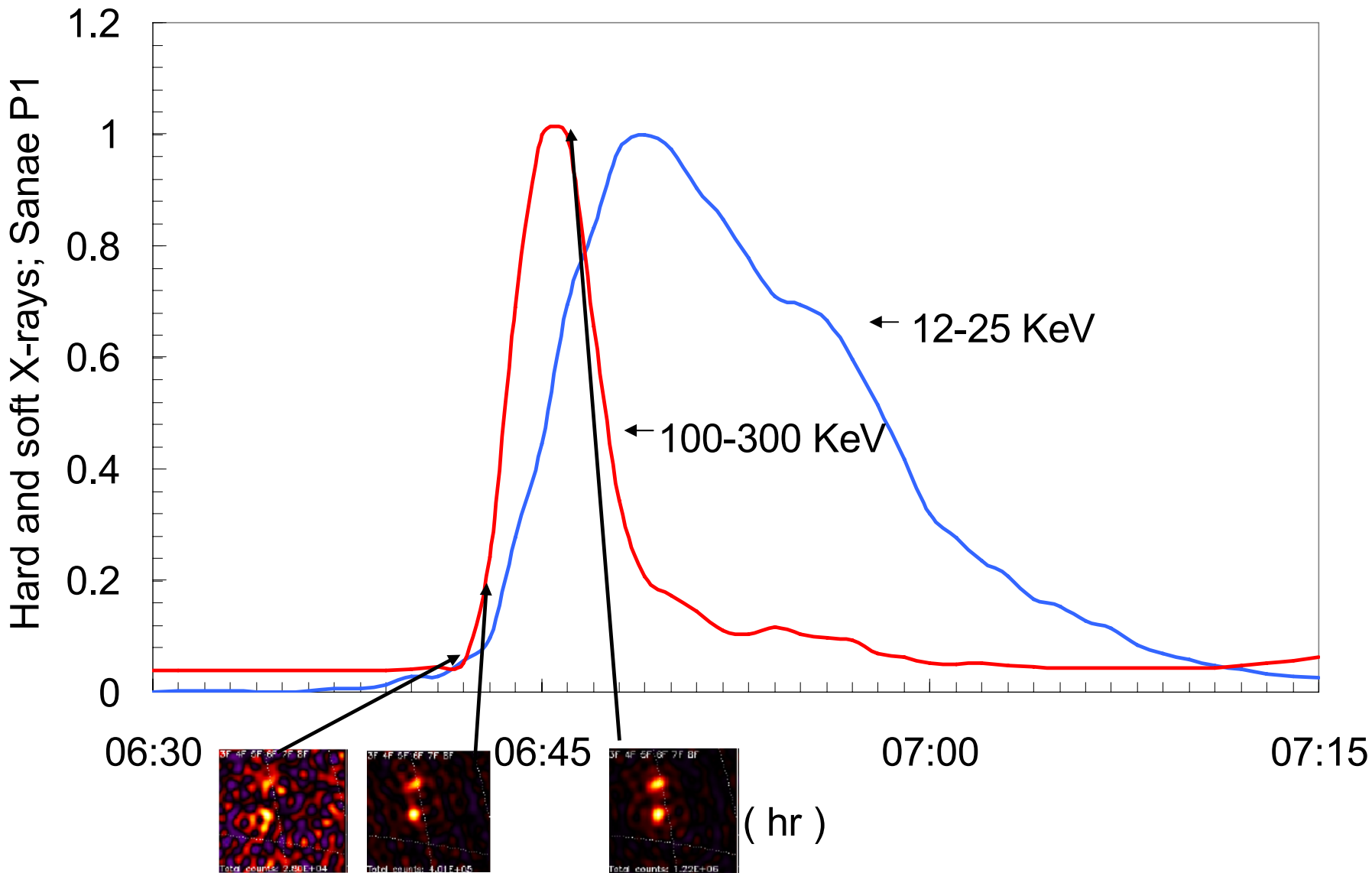
12 – 25 KeV



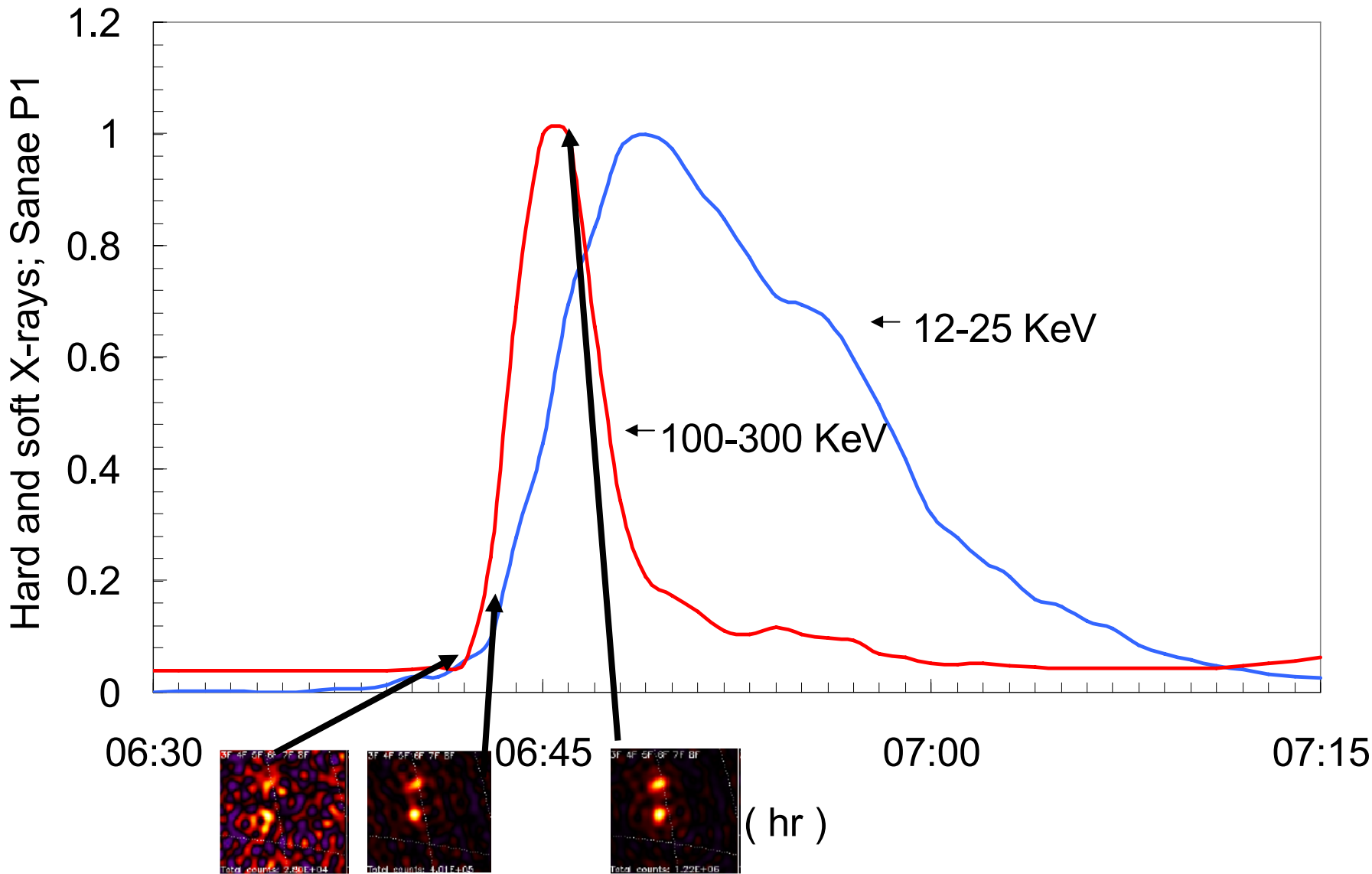
100 – 300 KeV



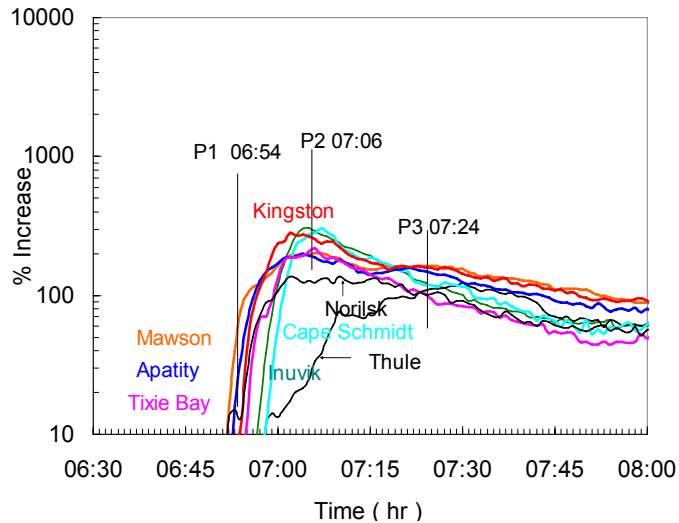
Origin of pulse P1



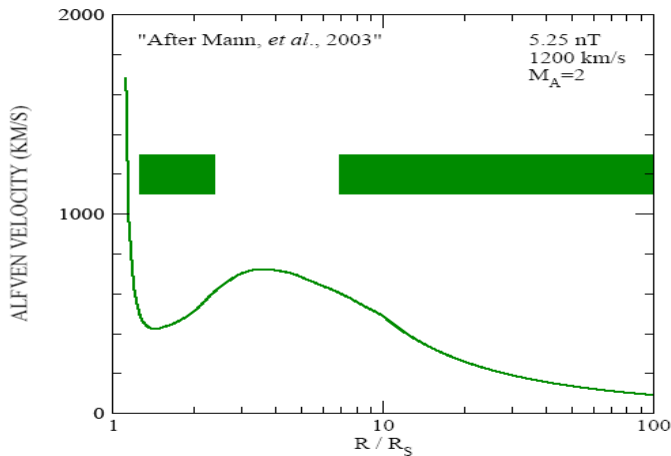
Strongly confirmed by Grechnev et al. (2007) in > 300 MeV gamma rays



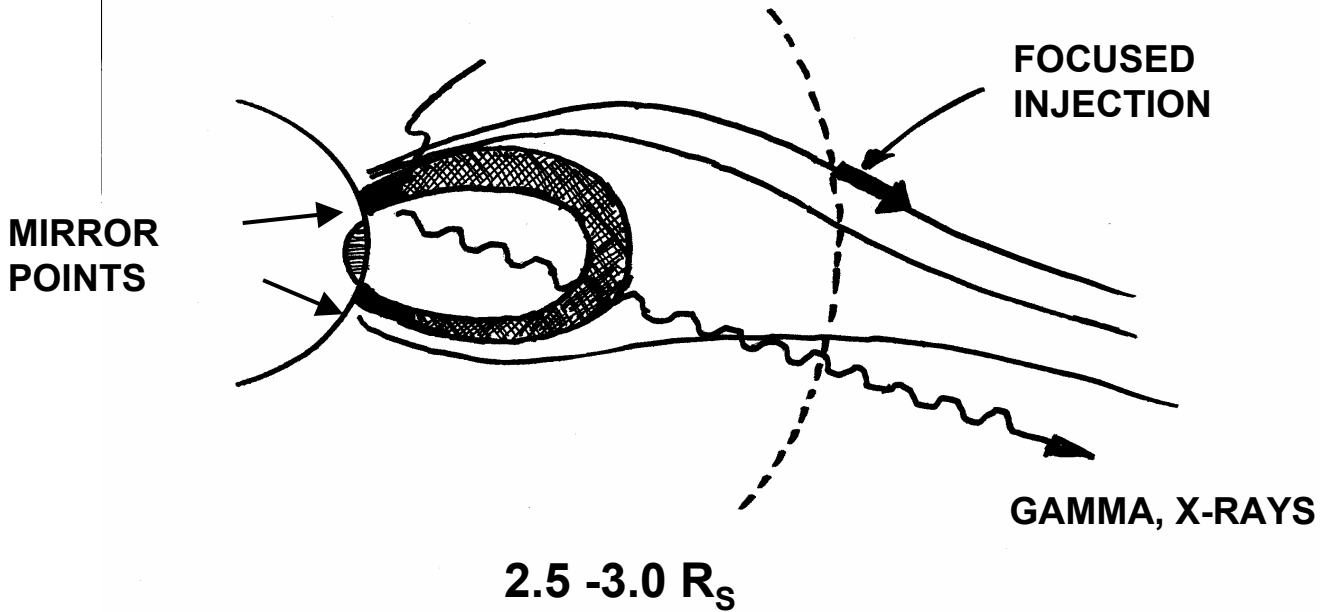
Origin of pulse P2



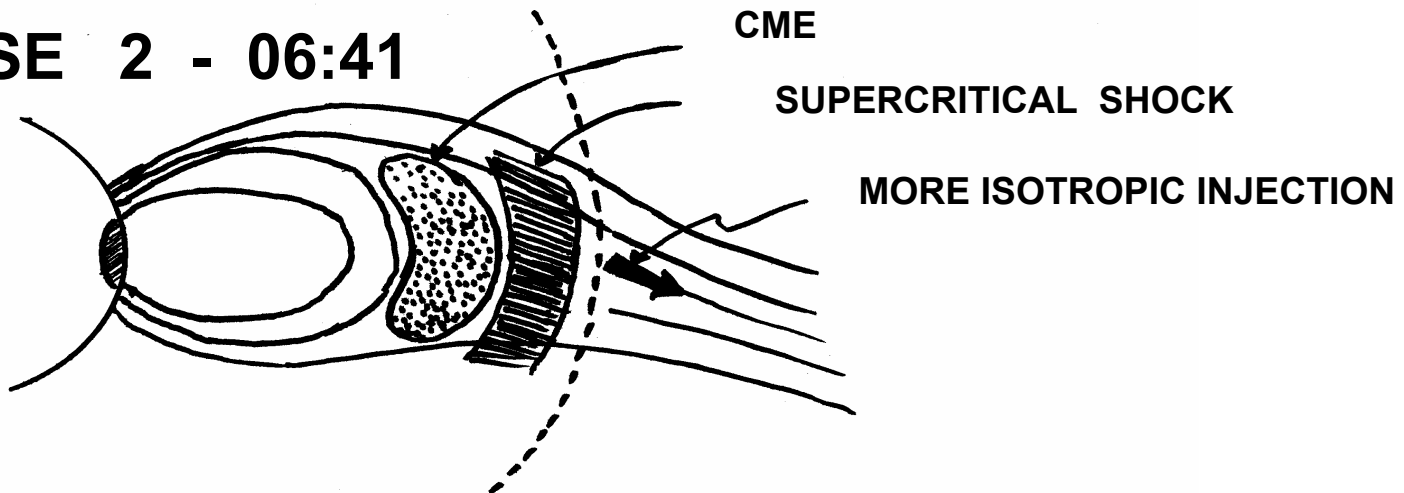
- P2 reached Earth at ~ 06:57 UT
- P2 left sun at ~ 06:41 UT
- CME lifted off at 06:32 UT at ~ 2500 km/s
- CME was at ~ 2.5 solar radii at 06:41 UT
- High Alfvén Mach number (~5.0)
- Acceleration in CME shock
- More isotropic release; less focused
- Significant scattering en route to Earth



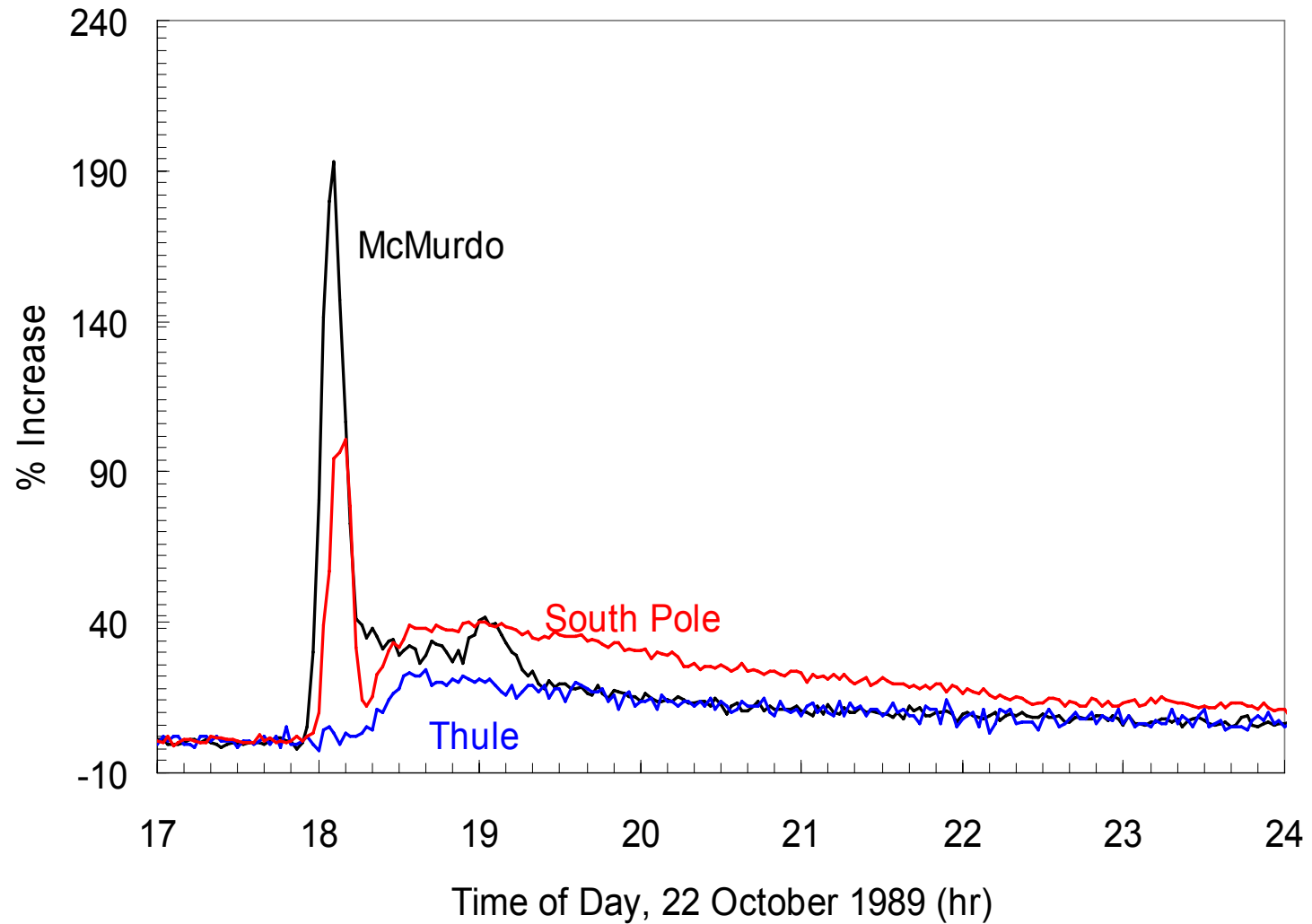
PULSE 1 - 06:35



PULSE 2 - 06:41



P1- A common occurrence (After Shea and Smart, 1996)

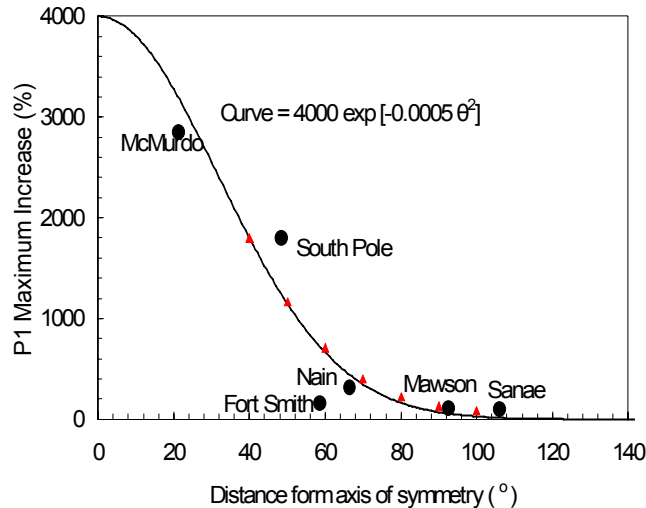


P1- A common occurrence

Event	Date	Onset difference (min)	Impulsive event (P1)	Stations with P1	Position on Sun	Amplitude (P1/P2) (%)
1	7 Mar 42	8	yes	1	west limb	4000/1500
2	23 Feb 56	9	no	-	N25, W85	-/>3000
3	4 May 60	3	yes	7	N10, W90	300/-
4	15 Nov 60	30	yes	2	N25, W35	160/80
5	7 May 78	<5	yes	10	N24, W68	215/-
6	22 Oct 89	15	yes	3	S27, W32	200/20
7	24 Oct 89	14	no	-	S29, W57	-/110
8	15 Nov 89	10	yes	1	N11, W28	12/3
9	21 May 90	10	yes	2	N34, W37	20/5
10	24 May 90	30?	yes	2	N36, W76	50/7.5
11	20 Jan 05	8	yes	6	N12, W58	2900/300

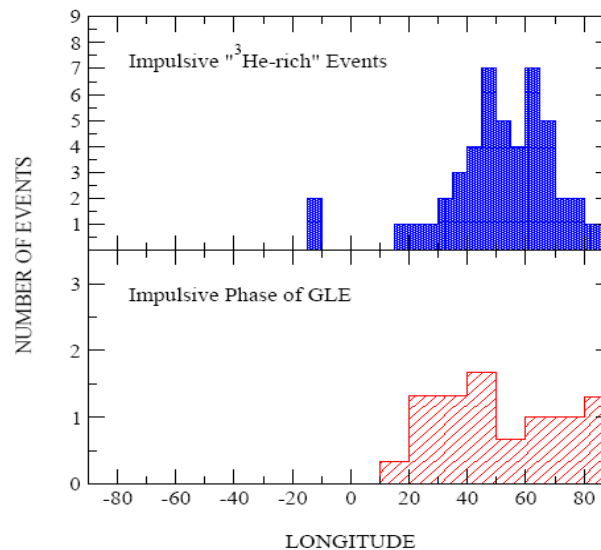
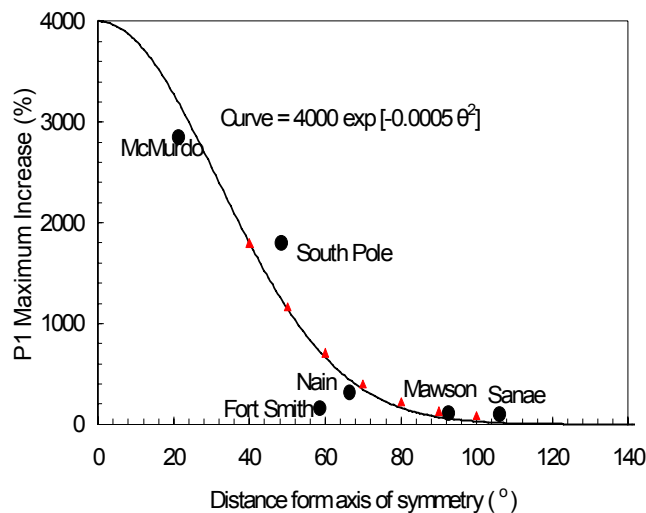
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GLE Compared to low-energy SEP events

	GLE	SEP
Impulsive event	<ul style="list-style-type: none">BriefLow in coronaCoincident with flareWest of 28° WMimics HXR and gammaStrong anisotropyHard spectrum	<ul style="list-style-type: none">BriefLow in coronaCoincident with flareWest of 30° W$^3\text{He}/^4\text{He}$ high
Gradual event	<ul style="list-style-type: none">Longer durationOriginates $\sim 2.5\text{-}3.0 r_s$Solar longitudes from 15° EMild anisotropySofter spectrum	<ul style="list-style-type: none">Longer durationOriginates $\sim 4\text{-}6 r_s$All solar longitudes$^3\text{He}/^4\text{He}$ normal

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The Generic Solar Energetic Particle Event (both GLE and low energies)

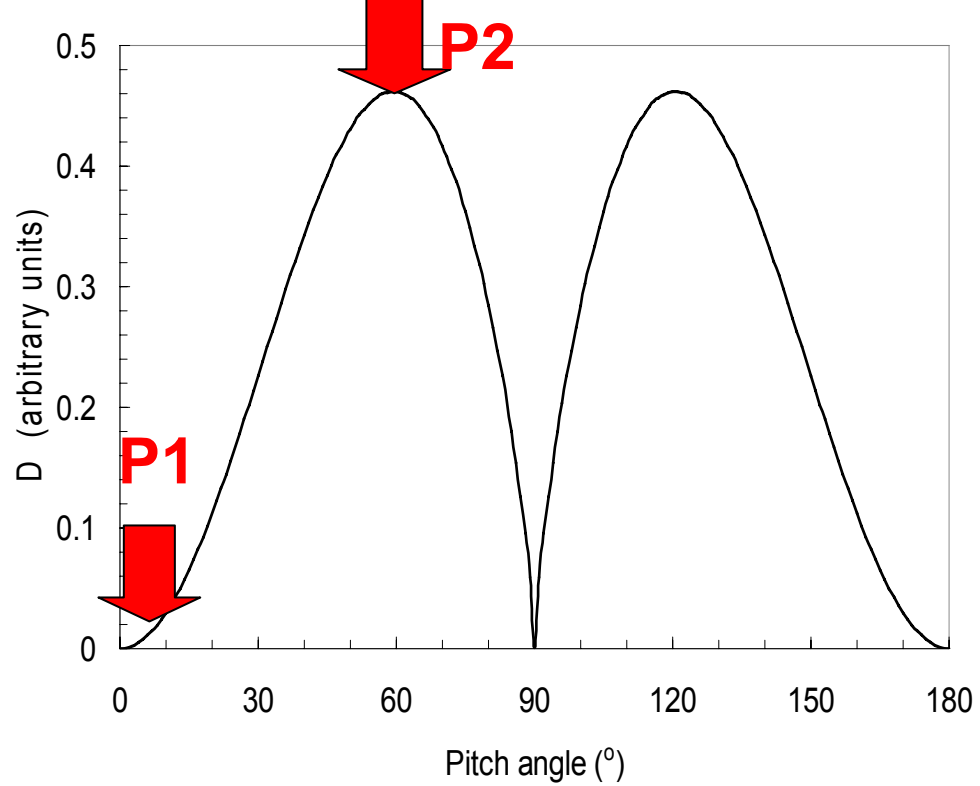
The Generic Solar Energetic Particle Event (GLE and Lower Energies)

Impulsive Phase

- A highly anisotropic pulse of cosmic rays at Earth
- Coincident release of high-energy gamma and neutron pulses
- Hard cosmic ray spectrum
- Acceleration low in corona
- Scatter-free propagation due to focusing close to the Sun
- High $^3\text{He}/^4\text{He}$ ratio; high ionisation state
- From western third of solar disk

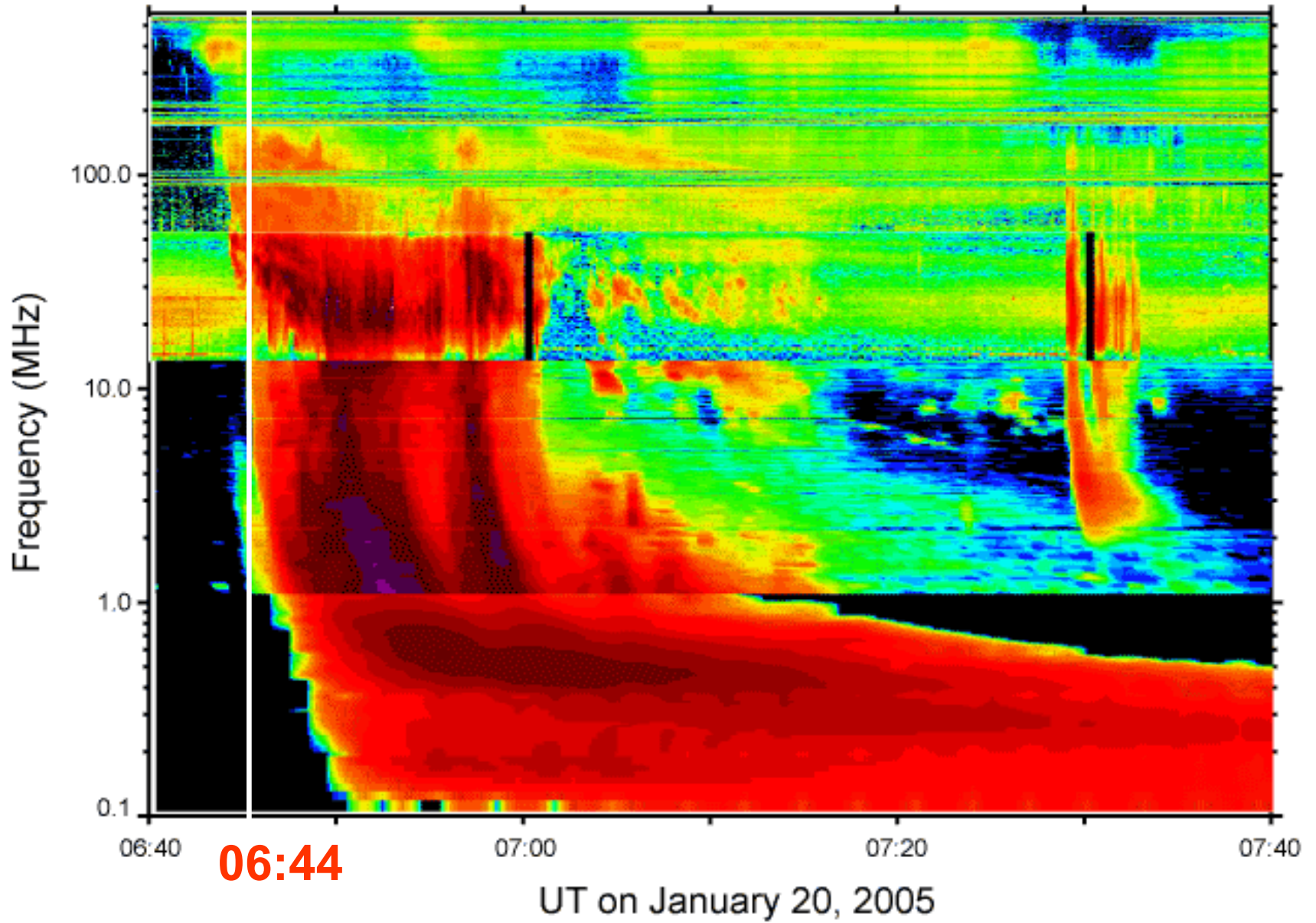
Gradual Phase

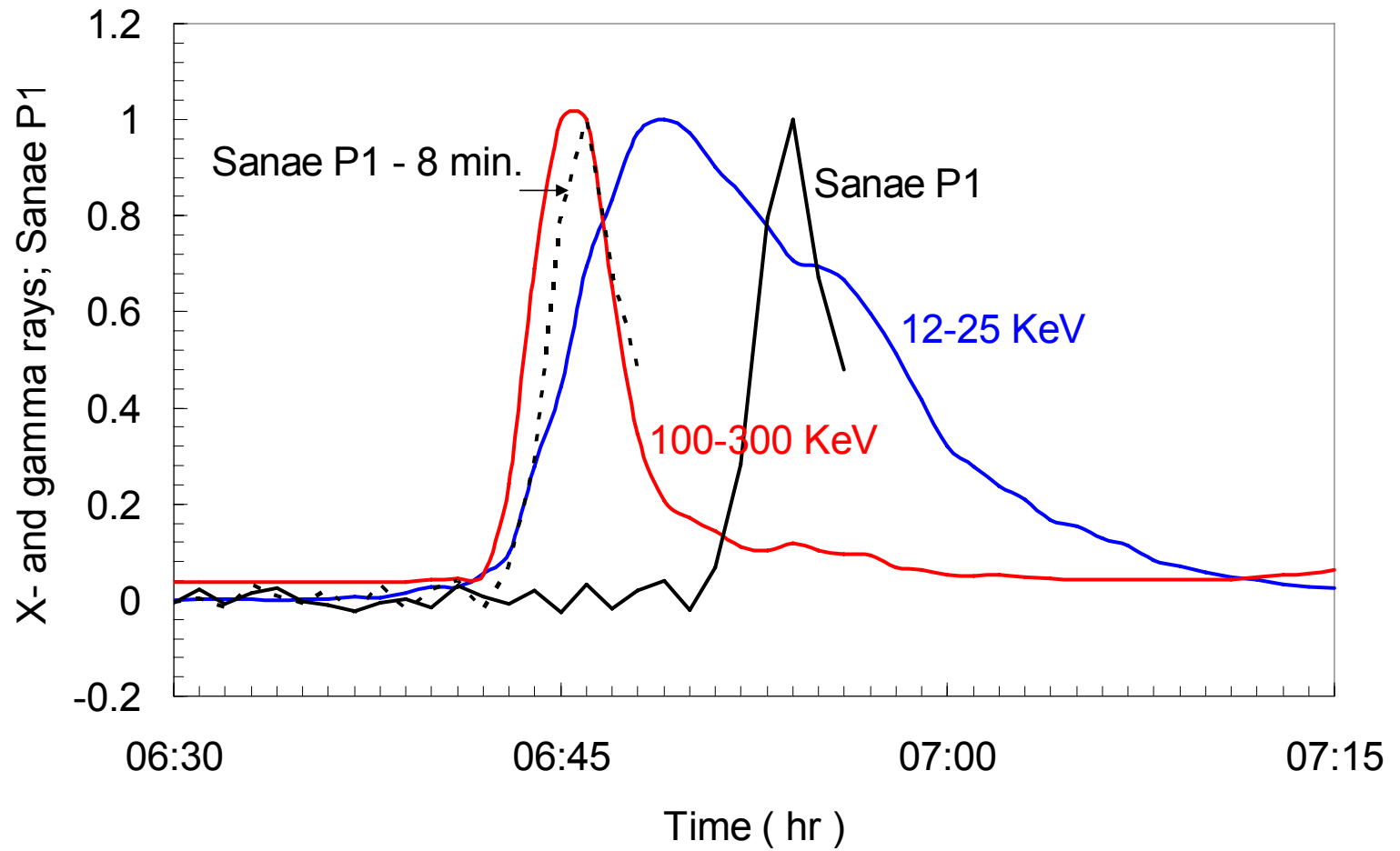
- Mildly anisotropic cosmic-ray pulse at Earth
- Soft cosmic-ray spectrum
- Acceleration high in the corona, $>2.5 - 3.0 R_s$
- Diffusive propagation to Earth
- From central regions of solar disk



THE BIG M EFFECT

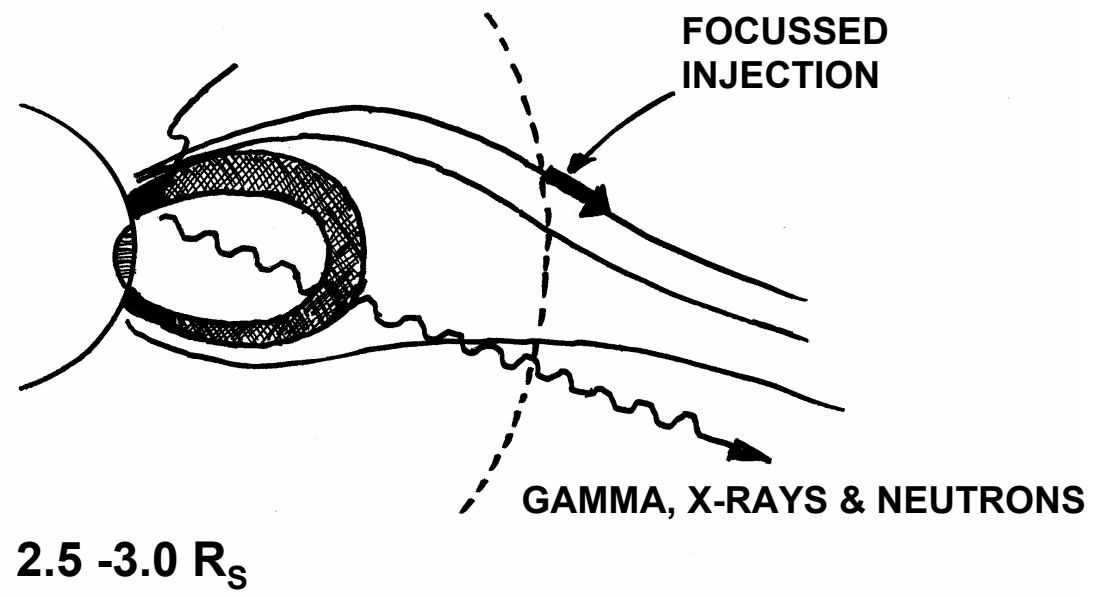
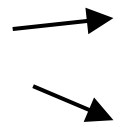
Culgoora/BIRS/Wind-WAVES



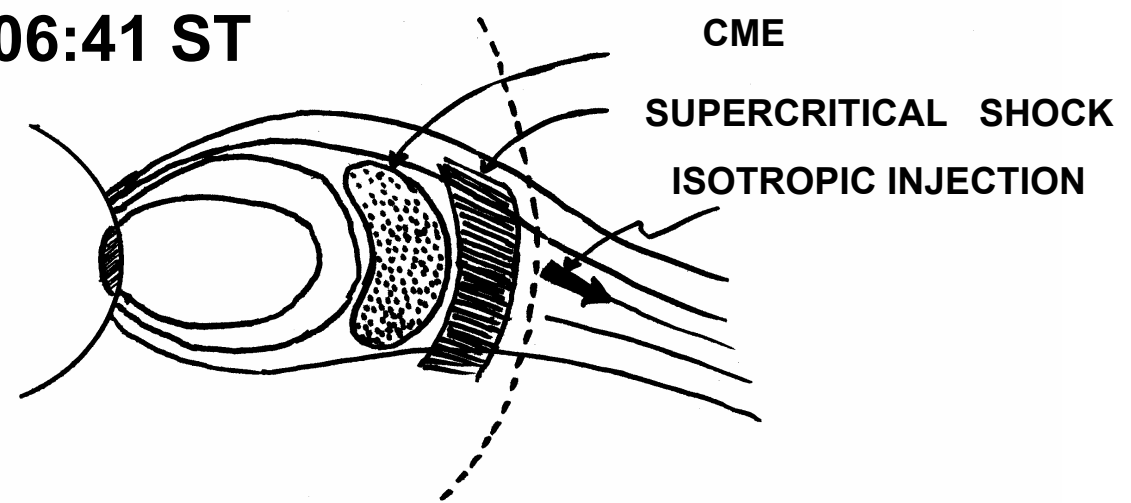


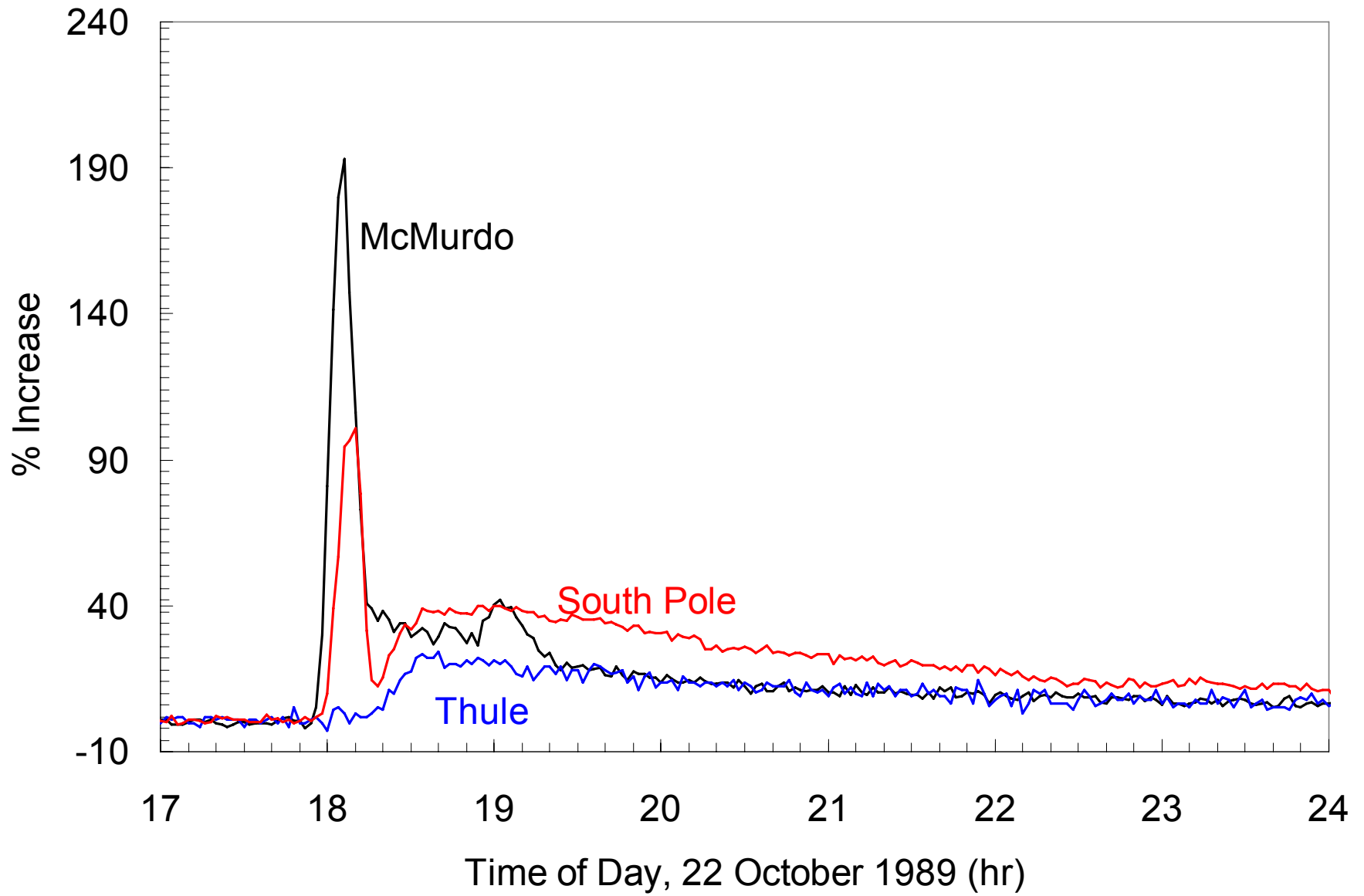
PULSE 1 - 06:38 ST

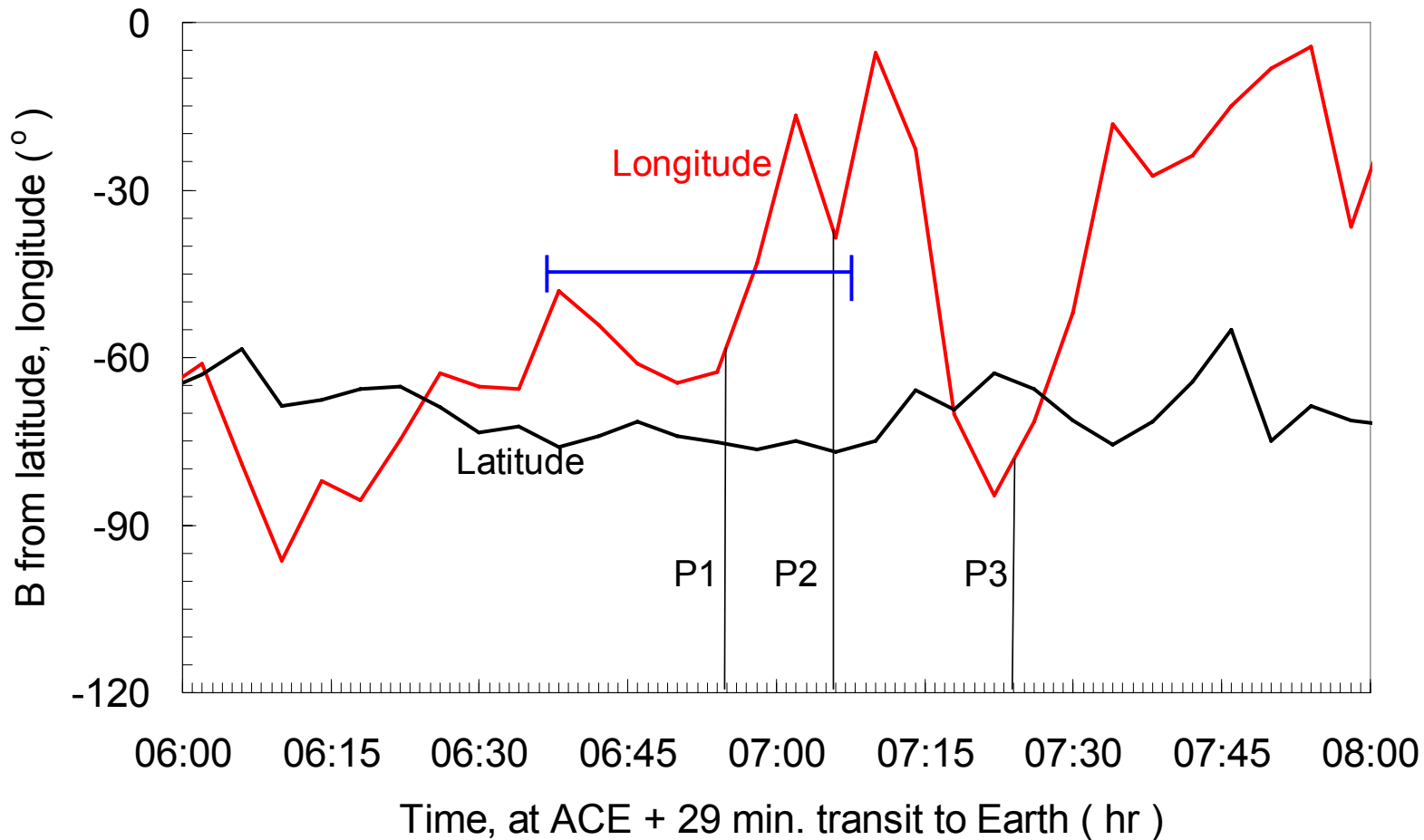
MIRROR POINTS

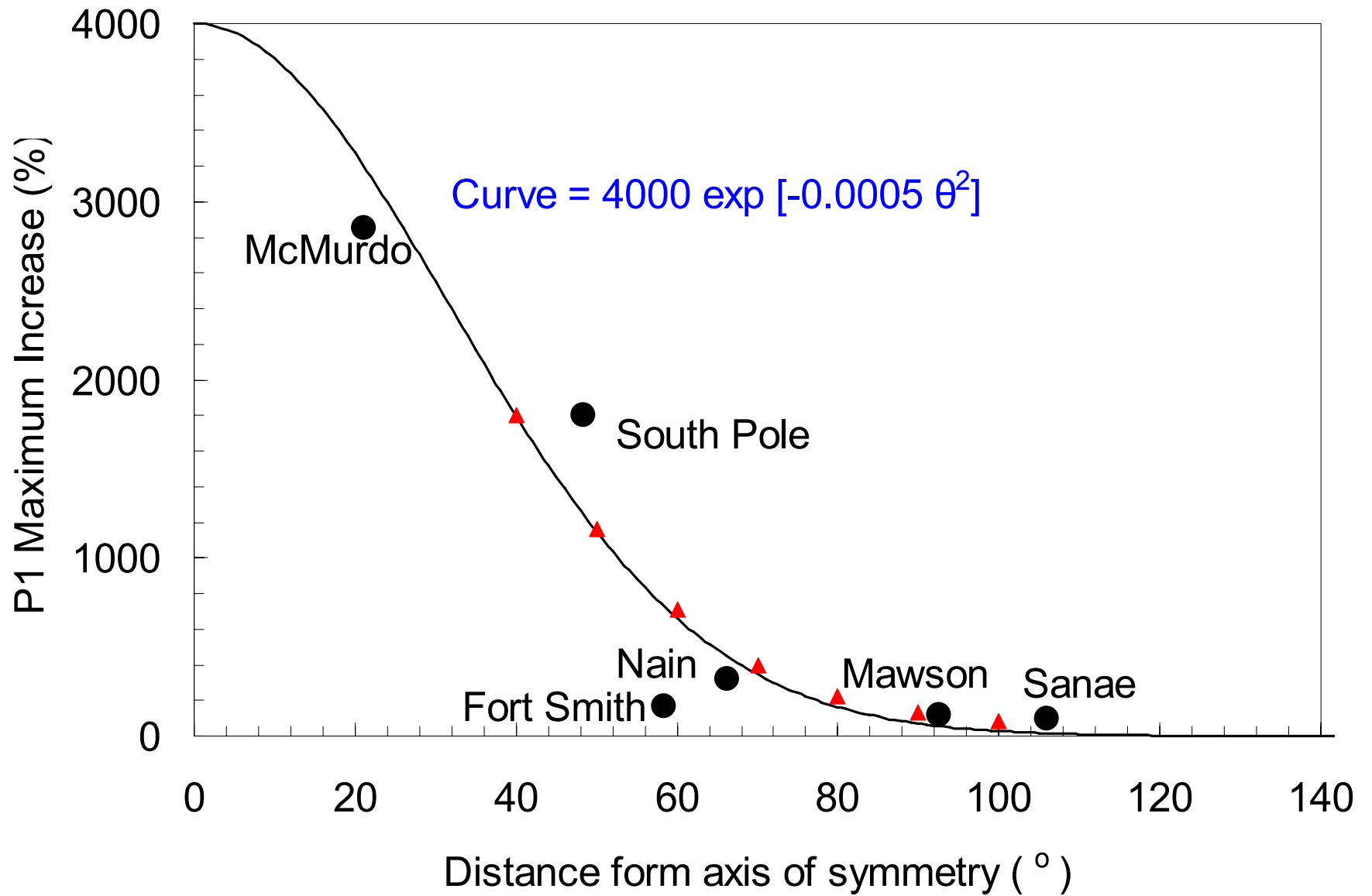


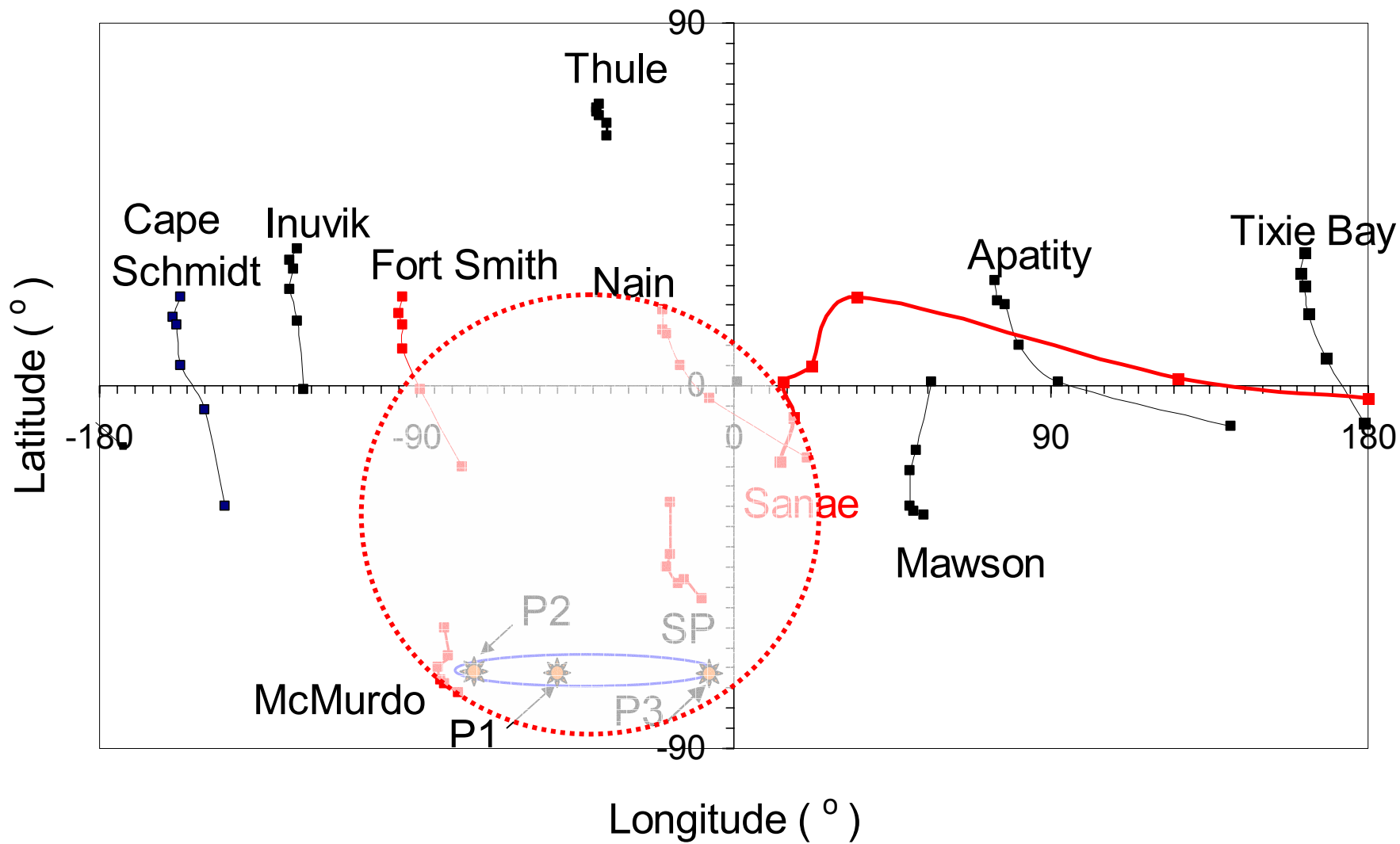
PULSE 2 - 06:41 ST











Hypothesis:

Prompt pulse 1 accelerated in solar flare near surface
at $>\sim 1 r_{\text{sun}}$.

Strongly adiabatically focused

Hypothesis:

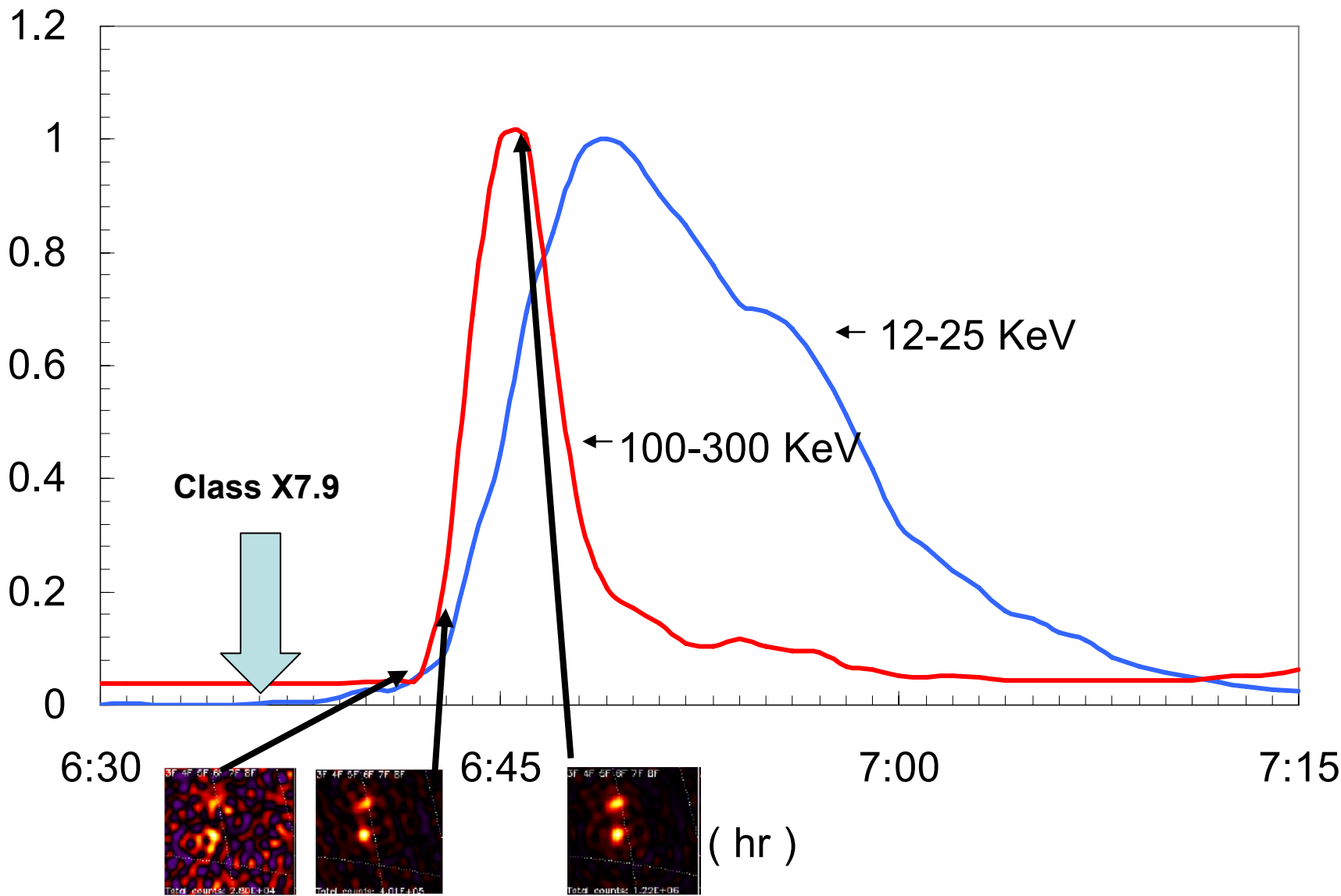
Pulse 1 accelerated in solar flare near surface
at $\sim 1 r_{\text{sun}}$.

Strongly adiabatically focused

Pulse 2 accelerated/released in CME at $2 - 3 r_{\text{sun}}$

Much less focused

X- and gamma rays; Sanae P1



THE P1 PULSE- 20 January 2005

