FLARE ONSET AT SITES OF MAXIMUM MAGNETIC SHEAR

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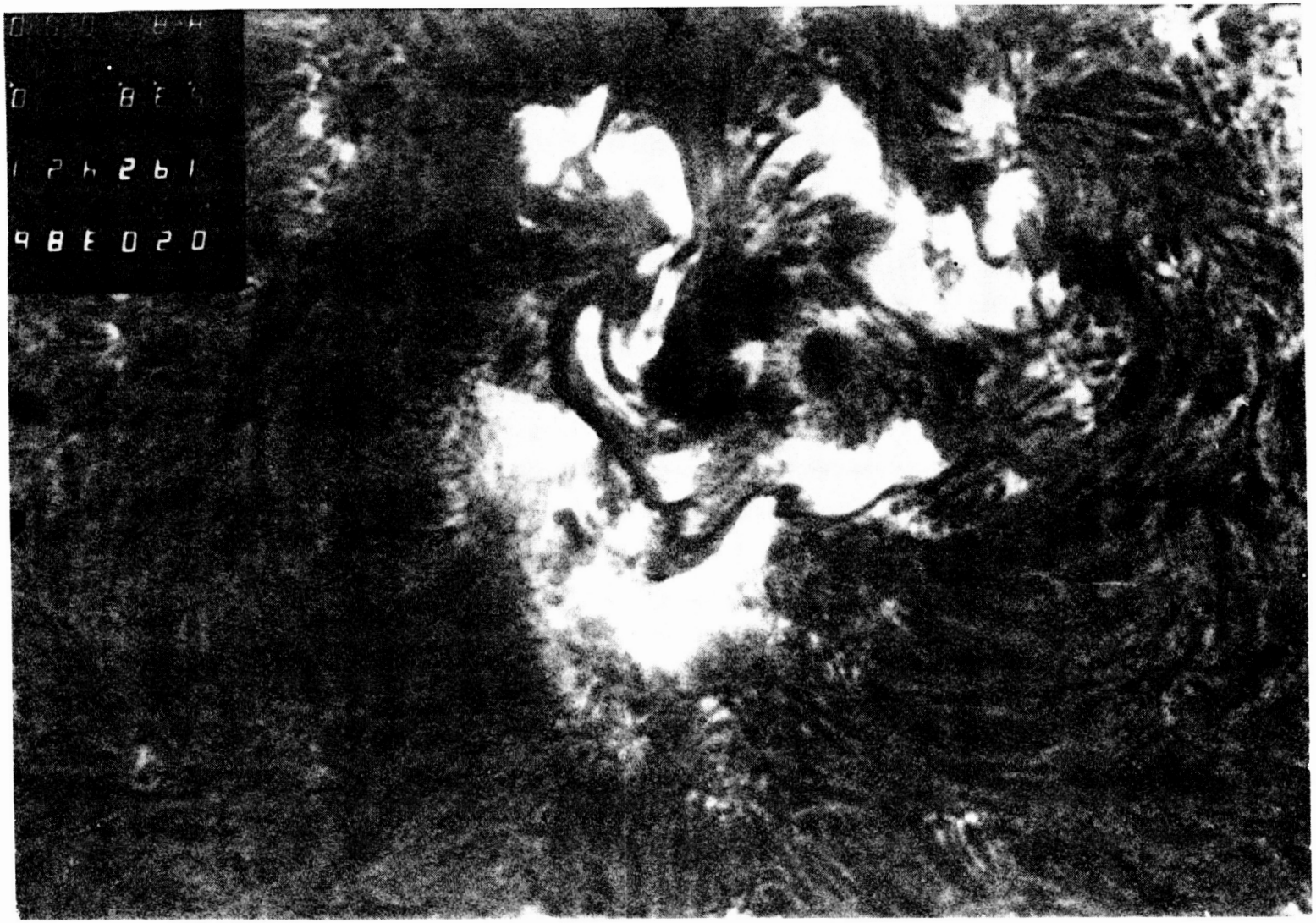
Observations of the transverse component of the Sun's photospheric magnetic field obtained with the MSFC vector magnetograph show us where the fields are nonpotential. We have studied the correlation between locations of nonpotential fields and sites of flare onset for four different active regions. On the top panels (3-12) of this poster display we outline the details of this study for active region AR 4711 (February 1986). On the lower panels (13-20) we present results of similar studies for three other regions: AR 2372 (April 1980), AR 2776 (November 1980), and AR 4474 (April 1984). For all four regions we show that flares initiate at sites on the magnetic neutral line where the local field deviates the most from a potential field. ⇒

This result is consistent with the concept that the source of the flare energy is the free energy stored in nonpotential fields. However, it has been the advent of measurements of the transverse field that has allowed a quantitative evaluation of nonpotential fields. The line-of-sight component of the photospheric field determines the potential field structure but it gives no indication where the field has been stressed into nonpotential configurations. By comparing the observed and potential fields' transverse components, the nonpotential characteristics of the field can be determined. To obtain a quantitative measure of nonpotentiality, we use the parameter angular shear, $\Delta\Phi$, the difference between the directions of the observed and potential transverse fields. In this study we evaluate $\Delta\Phi$ and the transverse field strength B_T along the neutral line, starting with AR 4711 in panels 3 & 4. $\Rightarrow$

AR 4711 (PREFLARE), FEB. 3, 1986



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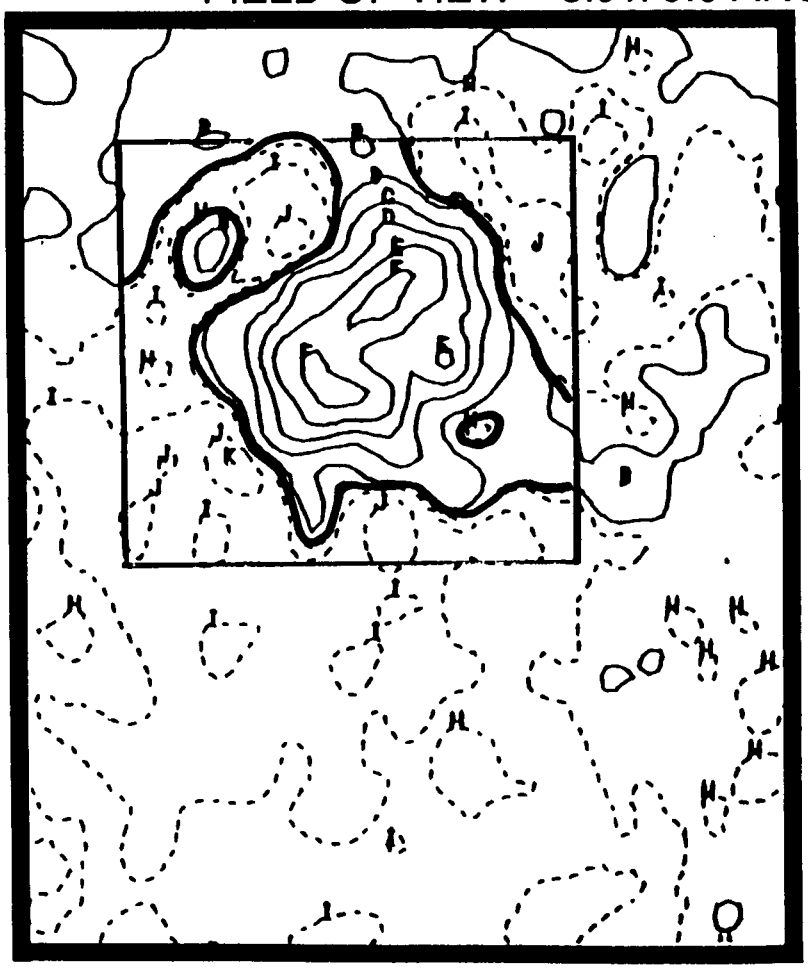
AR 4711, (PREFLARE) H-α, FEBRUARY 03/1924 U.T. STRUCTURE AND CONFIGURATION SHOULD BE COMPARED WITH THE LONGITUDINAL (BL) MAGNETOGRAM IN FIGURE 4, WHERE THE AREA OF ENLARGEMENT FOR ANALYSIS (IN FIGURE 10) IS OUTLINED, AND THE BL NEUTRAL LINE IS SHOWN. (Hα is courtesy Big Bear Solar Observatory.)

LINE- OF- SIGHT MAGNETIC FIELD OF AR 4711, FEB. 03, 1986 1642 UT

FIELD OF VIEW = 5.6 x 5.6 ARC MIN



CONTOURS

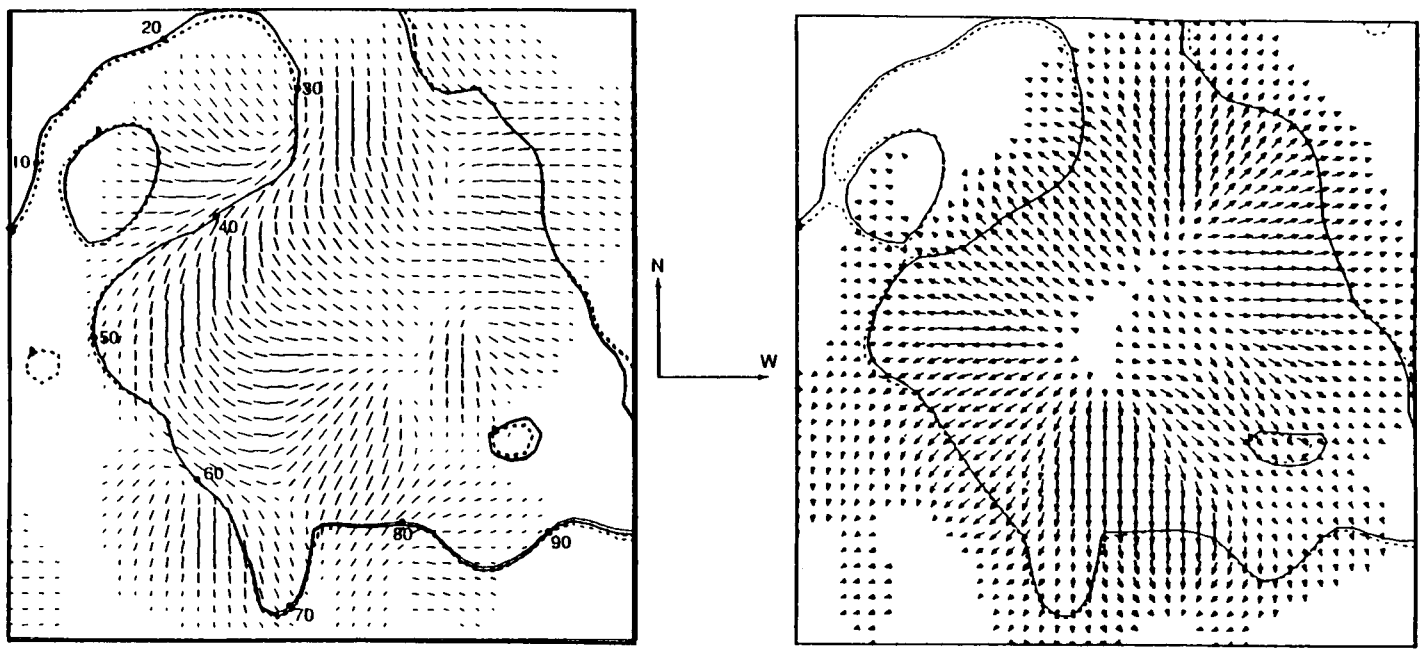
±10 G
100
500
1000
1500
2000
2250

SOLID (DASHED) CONTOURS REPRESENT POSITIVE (NEGATIVE) POLARITIES. THE DARK CONTOUR OUTLINES THE MAGNETIC NEUTRAL LINE SEPARATING POSITIVE AND NEGATIVE POLARITIES.
THE BOX OUTLINES THE AREA (110 x 110 ARC SEC) THAT IS ENLARGED AND SHOWN IN THE DISPLAYS OF THE OBSERVED AND POTENTIAL TRANSVERSE FIELDS (PANELS 5 & 6).

⇐ Here we show the transverse components of the observed and potential magnetic fields over the area of the box in panel 4. The length and direction of the line segments indicate the strength (scaled from 250 to 1000 G) and orientation of the transverse field. The magnetic neutral line has been superposed for reference.

Note how a comparison of these two transverse components shows directly where the photospheric field is stressed, i.e., nonpotential. We define angular shear $\Delta\Phi$ as the difference between the orientations of the potential and observed transverse components. In the next two panels (7 & 8) we plot $|\Delta\Phi|$ and the observed transverse intensity B_T for points along the neutral line. These points are located on the overlay for reference.

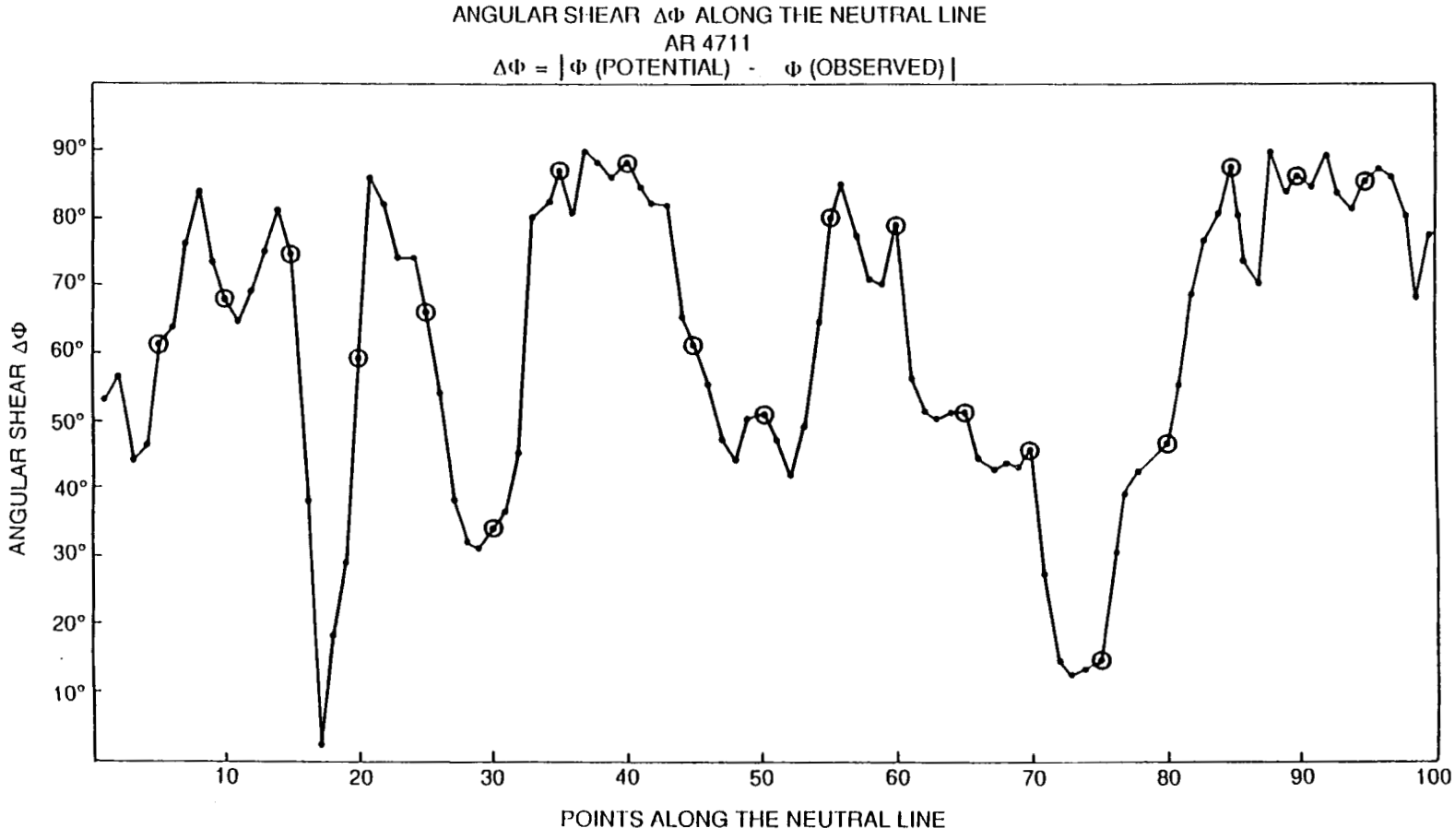
AR 4711
TRANSVERSE MAGNETIC FIELD
1642 UT FEBRUARY 3, 1986

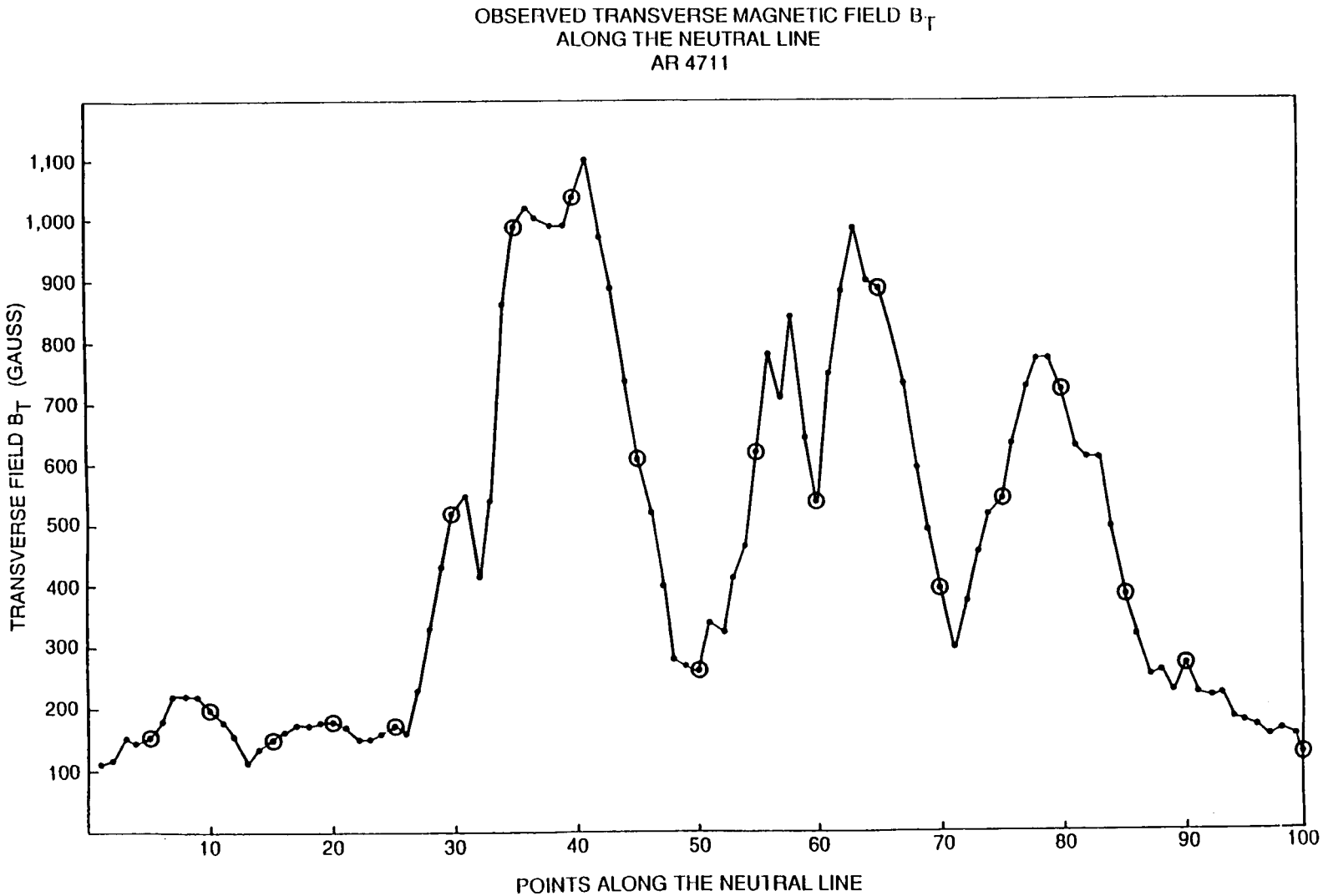


OBSERVED FIELD

POTENTIAL FIELD

FIELD OF VIEW IS 110 X 110 ARC SEC


ANGULAR SHEAR ΔΦ ALONG THE NEUTRAL LINE
AR 4711
ΔΦ = |Φ (POTENTIAL) - Φ (OBSERVED)|
ANGULAR SHEAR ΔΦ
90°
80°
70°
60°
50°
40°
30°
20°
10°
10
20
30
40
50
60
70
80
90
100
POINTS ALONG THE NEUTRAL LINE


OBSERVED TRANSVERSE MAGNETIC FIELD B_T
ALONG THE NEUTRAL LINE
AR 4711
TRANSVERSE FIELD B_T (GAUSS)
1,100
1,000
900
800
700
600
500
400
300
200
100
10
20
30
40
50
60
70
80
90
100
POINTS ALONG THE NEUTRAL LINE

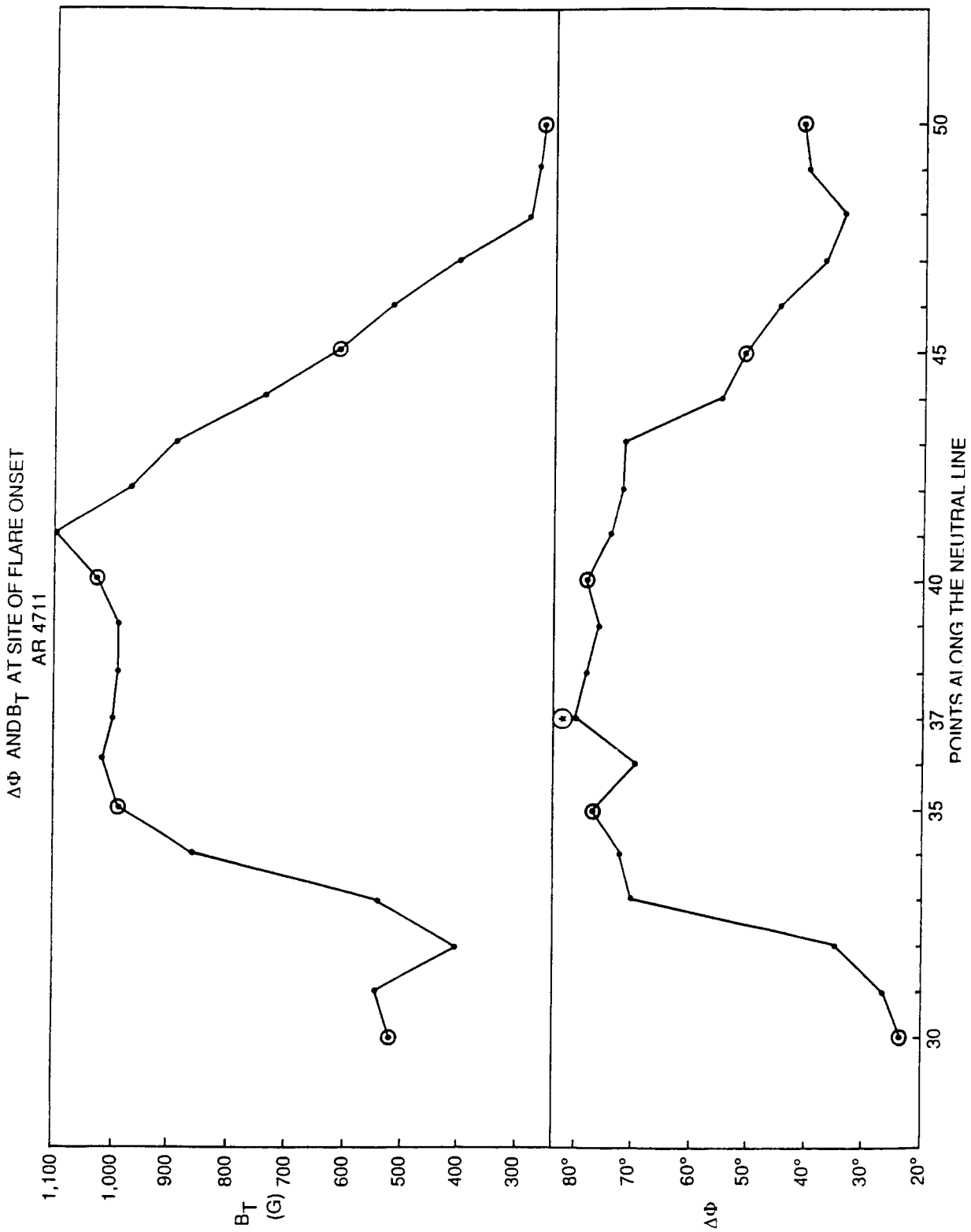
These graphs of $\Delta\Phi$ and B_T at points along the neutral line indicate that both parameters rise to large values at various points. The "shear" $\Delta\Phi$ is $\geq 80°$ over several intervals of points while $B_T \geq 550$ G (the half-maximum value) over three different intervals. However, the highest values of shear - $> 85°$ - coincide with strong - > 1000 G - fields only along the interval 33 - 43 (points). All this comes together when we see where the flare starts, shown in panel 10. The overlay shows that flare onset occurs along this particular interval, where the shear is $\geq 85°$ and the field is ≥ 1000 G.

In panel 11, $\Delta\Phi$ and B_T are shown along the interval 30 - 50 (points). Initial flare points shown in panel 10 are seen to bracket the area of point 37 where $\Delta\Phi$ attains its (local) maximum value.

$\Rightarrow$

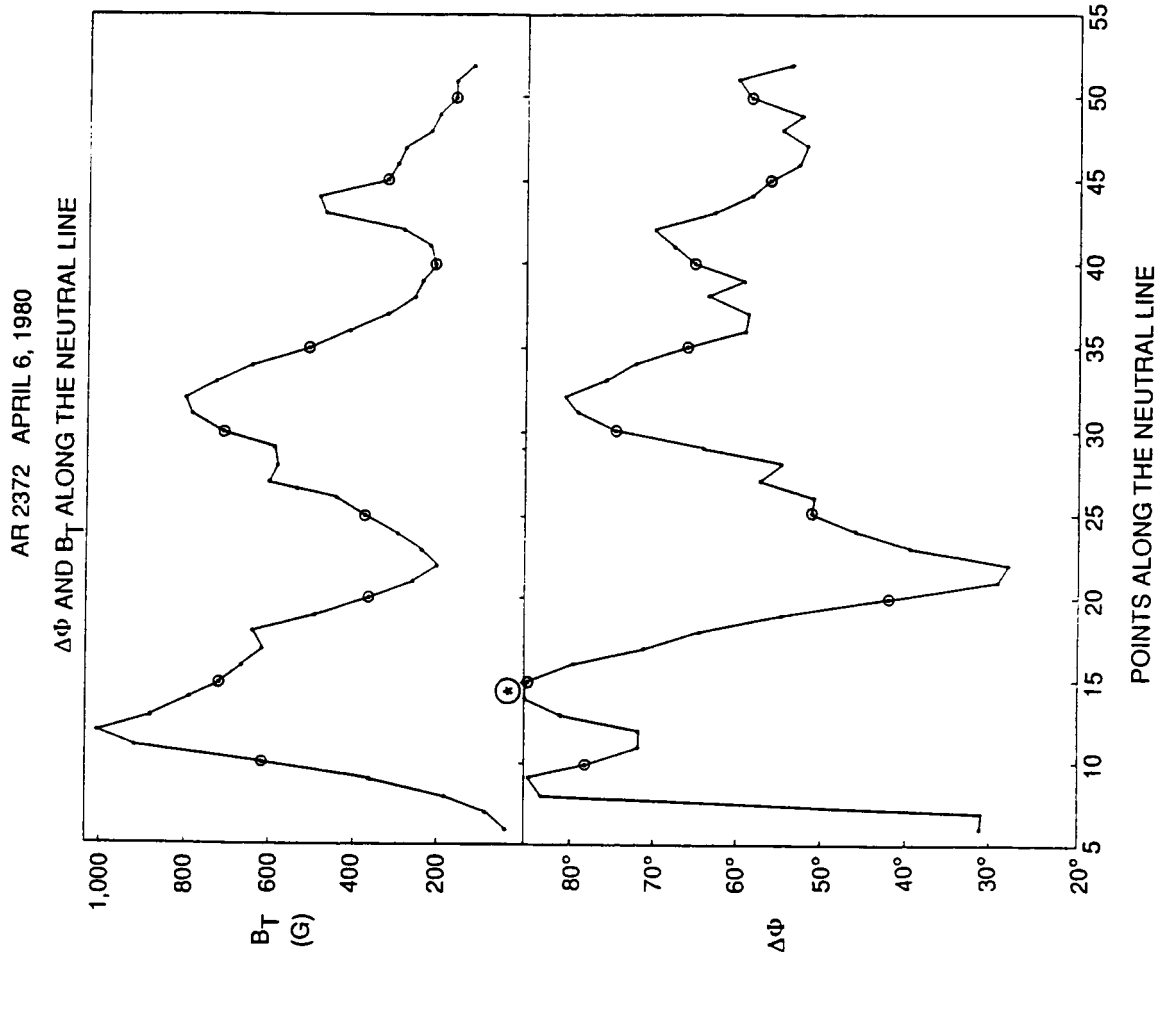
AR 4711 (FLARE ONSET & Bv), FEB. 1986

H-α AT NEAR FLARE ONSET TIME (03/2037 UT) SCALED TO THE VECTOR MAGNETOGRAM; TRANSPARENCY OVERLAY IS THE TRANSVERSE MAGNETIC FIELD (BT) AZIMUTH VECTORS AND THE BL NEUTRAL LINE. NUMBERS IDENTIFY ANALYSIS LOCATIONS; FLARE ONSET KERNELS (OUTLINED IN RED) INDICATE CONNECTING LOOPS CROSS BL NEUTRAL LINE NEAR MAXIMUM SHEAR (POINT 37); COMPARE WITH FIGURE 11. (H-α courtesy Big Bear Solar Observatory.)

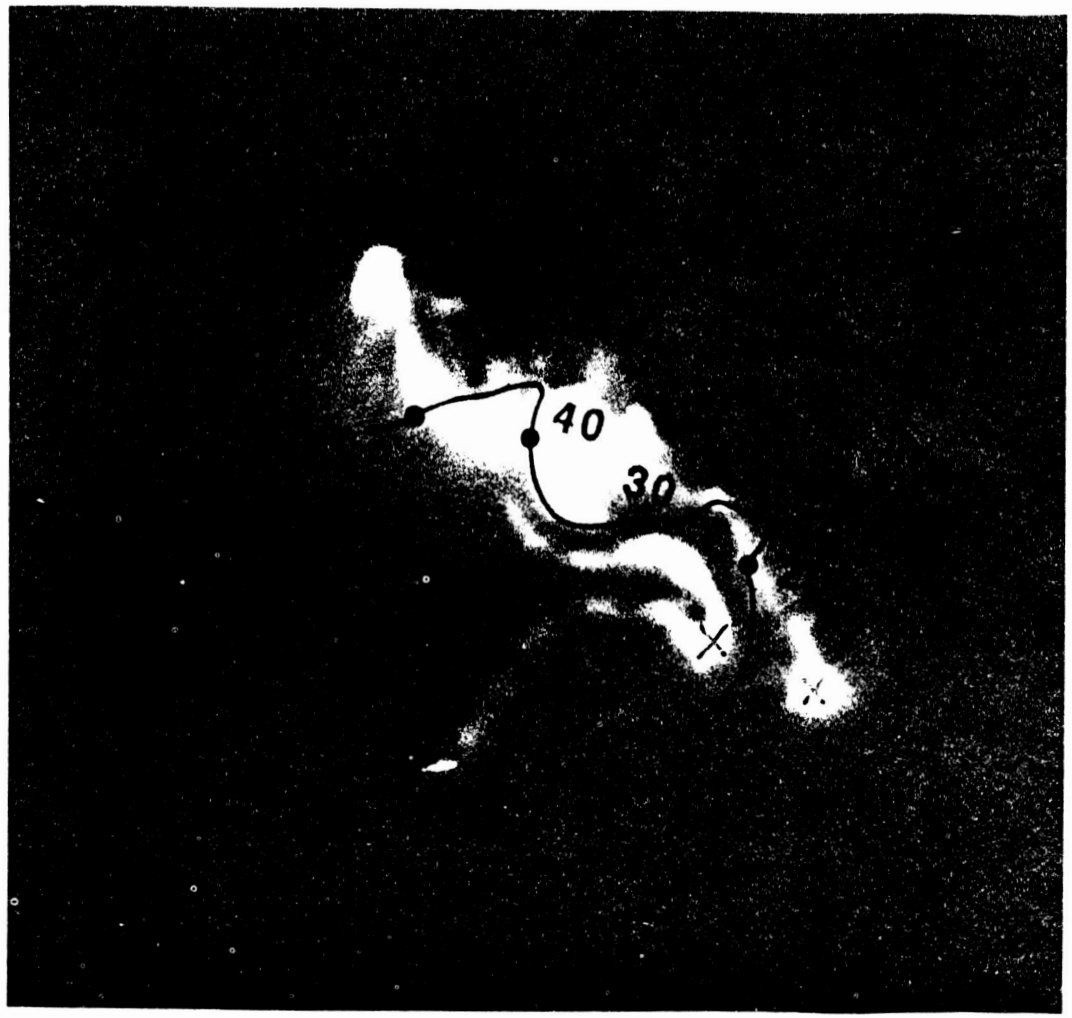

ΔΦ AND B_T AT SITE OF FLARE ONSET
AR 4711
B_T (G)
1,100
1,000
900
800
700
600
500
400
300
ΔΦ
80°
70°
60°
50°
40°
30°
20°
30
35
37
40
45
50
POINTS ALONG THE NEUTRAL LINE

The results of this analysis of AR 4711 show that flare onset occurred at the location where the field was the most "nonpotential," i.e., where there was a coincidence of the area of maximum shear and strong fields. Also, the initial flare brightenings occurred on either side of the neutral line at the location of maximum angular shear.

We have done the same analysis on three other active regions and found similar results. In panel 13 we show the variations of $\Delta\Phi$ and B_T along the neutral line of AR 2372, followed by an H-alpha image in panel 14 that locates the initial flare points. Similar figures follow for AR 2776 (panels 15 & 16) and AR 4474 (panels 17 & 18). ⇓


AR 2372 APRIL 6, 1980
ΔΦ AND B_T ALONG THE NEUTRAL LINE
B_T (G)
1,000
800
600
400
200
ΔΦ
80°
70°
60°
50°
40°
30°
20°
5
10
15
20
25
30
35
40
45
50
55
POINTS ALONG THE NEUTRAL LINE

AR 2372 (EARLY FLARE), APRIL 1980



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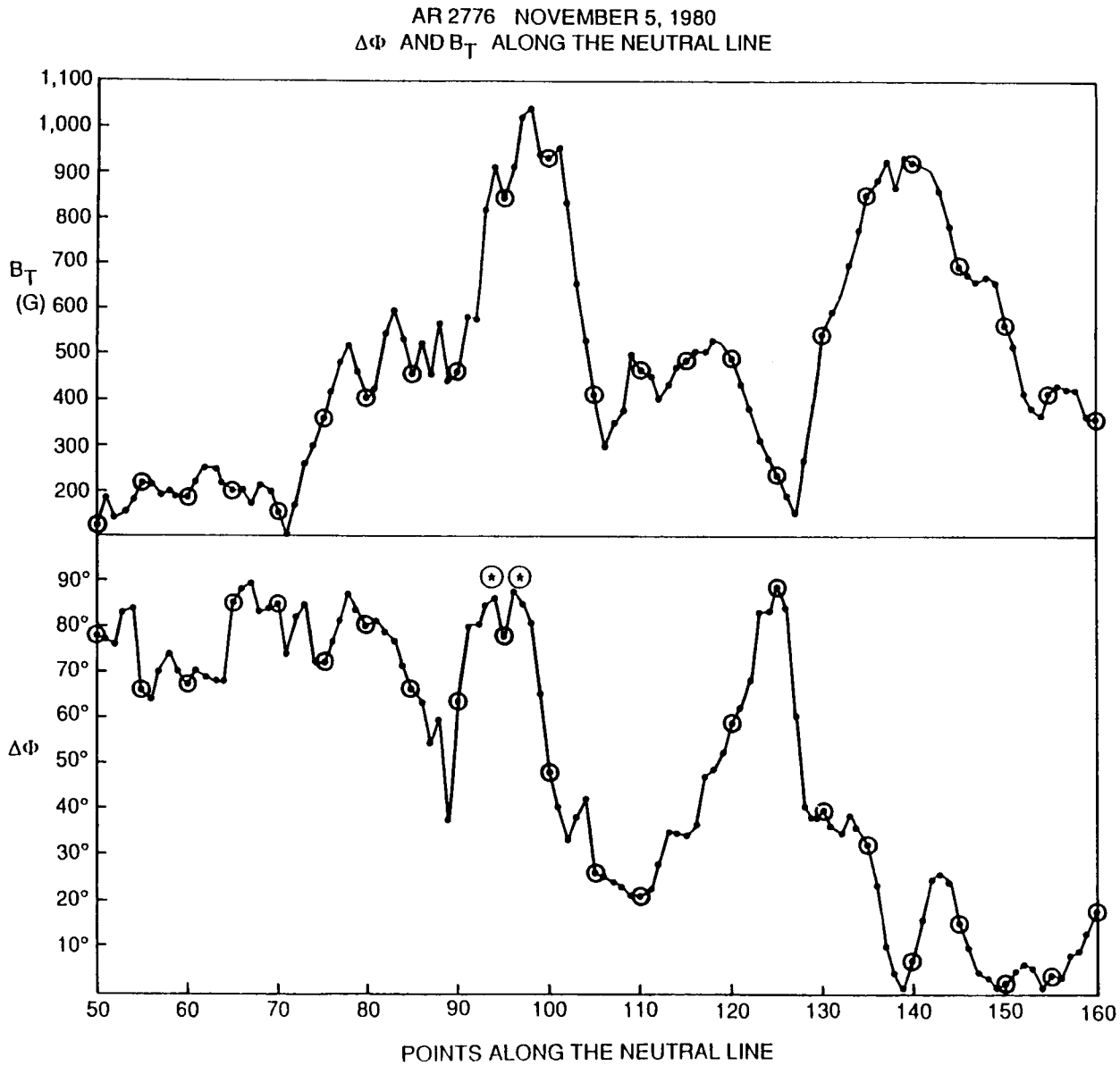
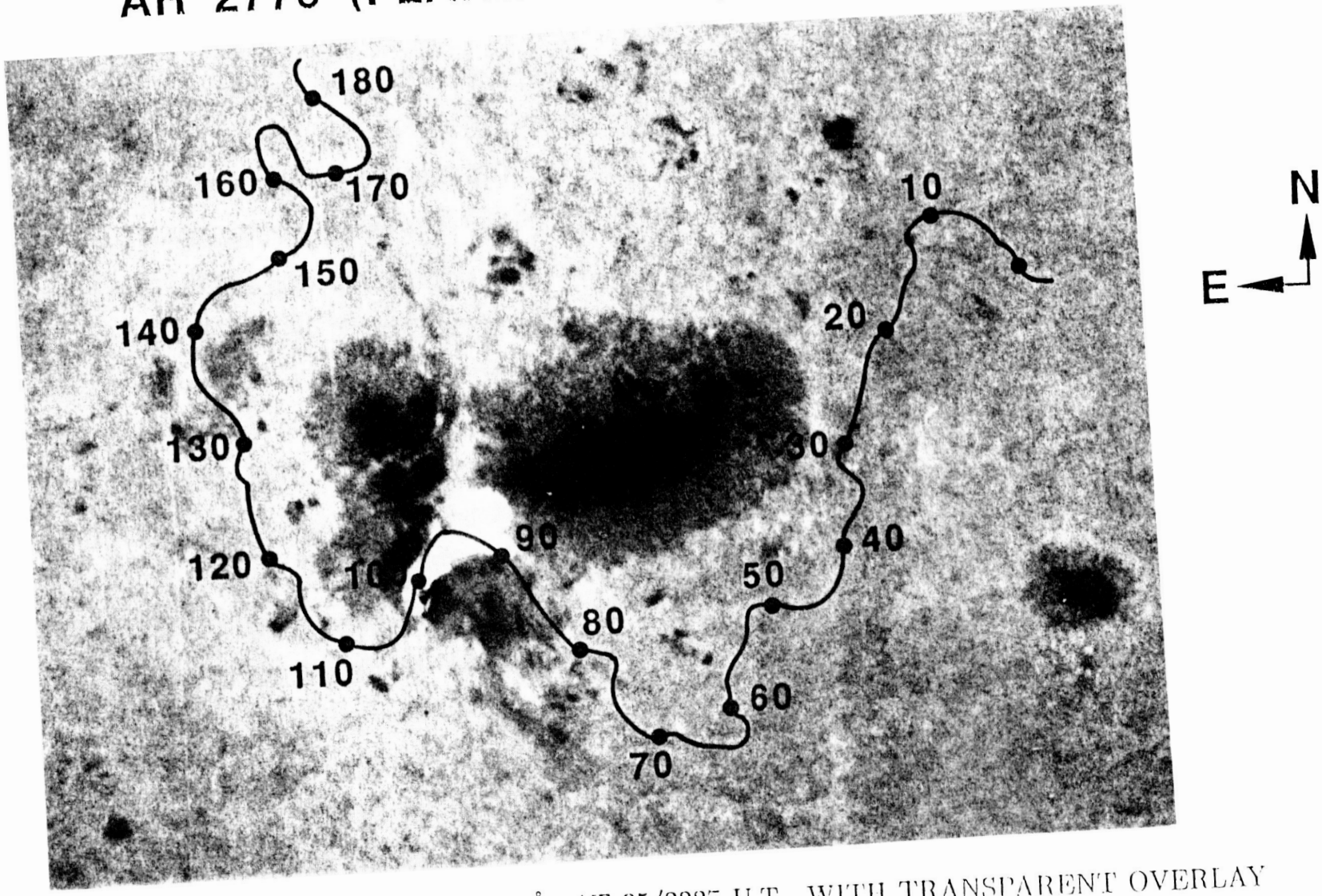
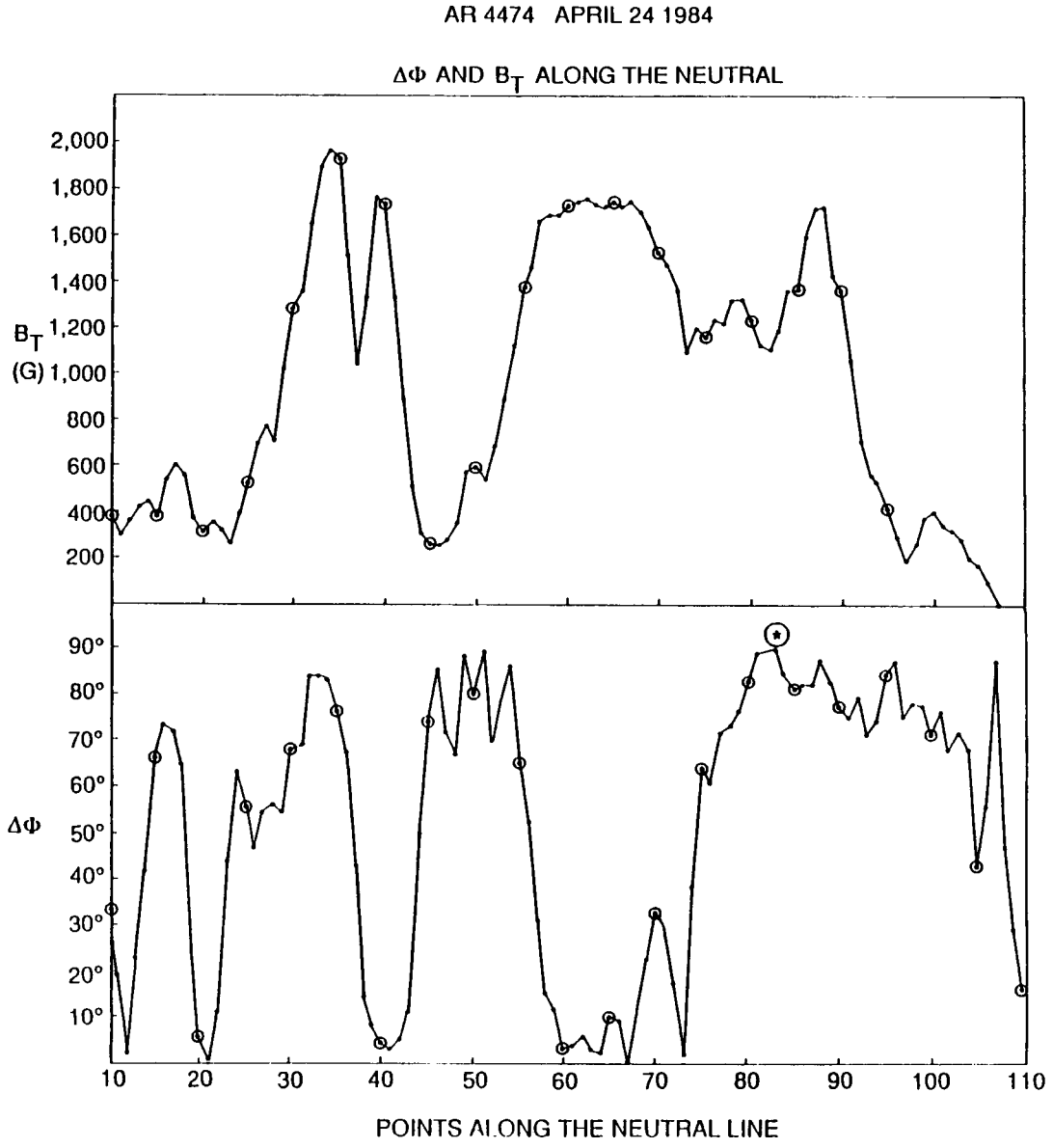
AR2372, Hα (+.5Å), PRE-MAXIMUM (06/1423 U.T.), BUT NOT NEAR ONSET TIME. TRANSPARENT OVERLAY IS PHOTOSPHERIC BL NEUTRAL LINE, WITH NUMBERS INDICATING ANALYSIS LOCATIONS. ONSET LOCATIONS (RED Xs) CONNECT ACROSS AREA OF MAXIMUM SHEAR (POINTS 14-15, FIGURE 13), AND WHERE STRONG TRANSVERSE FIELD IS ALSO OBSERVED. H-α courtesy USAF/Air Weather Service (SOON).


AR 2776 NOVEMBER 5, 1980
ΔΦ AND B_T ALONG THE NEUTRAL LINE
B_T (G)
1,100
1,000
900
800
700
600
500
400
300
200
ΔΦ
90°
80°
70°
60°
50°
40°
30°
20°
10°
50
60
70
80
90
100
110
120
130
140
150
160
POINTS ALONG THE NEUTRAL LINE

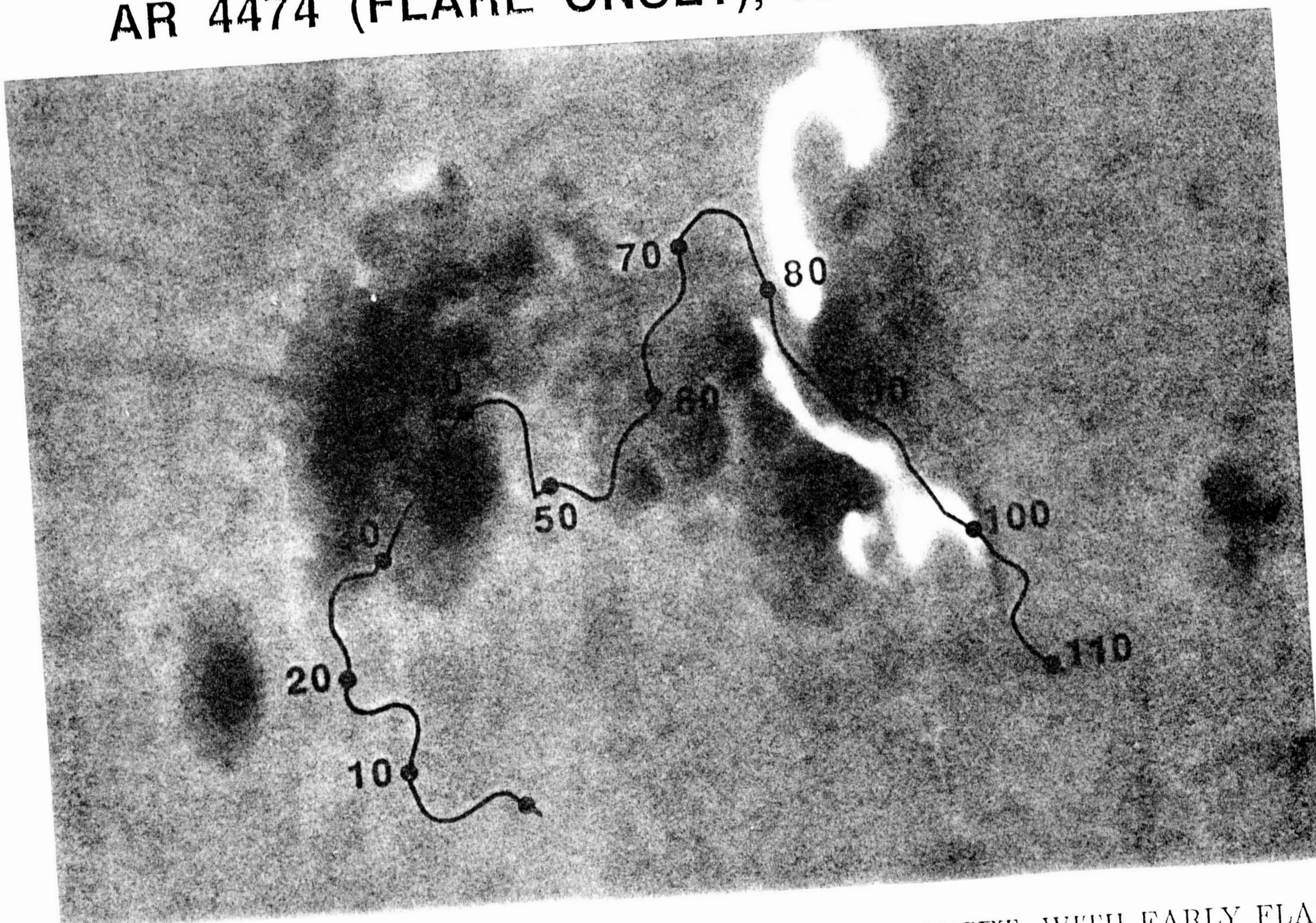
AR 2776 (FLARE ONSET), NOV. 1980



FLARE ONSET IN OFF-BAND H-α (+ 0.7Å) AT 05/2227 U.T., WITH TRANSPARENT OVERLAY OF THE (PHOTOSPHERIC) BL NEUTRAL LINE AND NUMBERS INDICATING ANALYSIS LOCATIONS. OPPOSITE POLARITY FLARE ONSET KERNELS CONNECT ACROSS NEUTRAL LINE NEAR LOCATION OF MAXIMUM SHEAR (POINTS 94-96), AND WHERE STRONG BT OBSERVED (COMPARE WITH FIGURE 15). (H-α courtesy U.S. Air Weather Service/SOON.)


AR 4474 APRIL 24 1984
ΔΦ AND B_T ALONG THE NEUTRAL
B_T (G)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
ΔΦ
90°
80°
70°
60°
50°
40°
30°
20°
10°
10
20
30
40
50
60
70
80
90
100
110
POINTS ALONG THE NEUTRAL LINE

AR 4474 (FLARE ONSET), APRIL 24, 1984



OFF BAND H-α (+- 0.7Å) AT 24/2359:30 U.T., NEAR FLARE ONSET, WITH EARLY FLARE RIBBONS; TRANSPARENT OVERLAY OF BL NEUTRAL LINE, WITH NUMBERS SHOWING ANALYSIS LOCATIONS OF FIGURE 17. LOCATION OF FLARE ELEMENTS INDICATES CONNECTION ACROSS ZONE OF MAXIMUM SHEAR (POINTS 80-90), AND WHERE STRONG BT IS OBSERVED. COMPARE WITH FIGURE 17. H-α is courtesy USAF/Air Weather Service (SOON).

RESULTS OF THESE 3 ANALYSES:

AR 2372

The flare initiated in the area where there was a coincidence of intervals of the strongest shear (85°) and strongest fields (1000 G).

AR 2776

There were two areas of maximum shear (90°) but weak fields (< 200 G) and one area of strong field (> 900 G) but weak shear (< 40°); none of these areas flared. The flare began where there was a coincidence of strong shear (> 80°) and strong fields (> 900 G).

AR 4474

The strongest field (1900 G) coincided with a small area of strong shear (84°); this area was the site of a flare three days later. The 3B/X15 flare erupted at the extended area of strong shear (> 80 °) and strong fields (> 1100 G) with a maximum shear (90°) occurring at three points. ⟹

CONCLUSIONS

The results of this study suggest that flares are likely to erupt where the shear is $\geq 85°$, the field is ≥ 1000 G, and there is strong shear ($\geq 80°$) extending over a length ≥ 8000 km (4 points).

IMPLICATIONS FOR MAX '91 FLARE RESEARCH

We have seen that it is measurements of the transverse field that indicate probable flare sites, i.e., where the field deviates strongly from a potential state. These measurements are essential for any Max '91 flare research relative to flare buildup and onset. Thus it is crucial to have vector magnetographs operating during Max '91 and providing these data for mission planning and basic research. These instruments should have the highest possible polarimetric sensitivity, high temporal and spatial resolutions, and fields of view covering the areas of typical active regions.