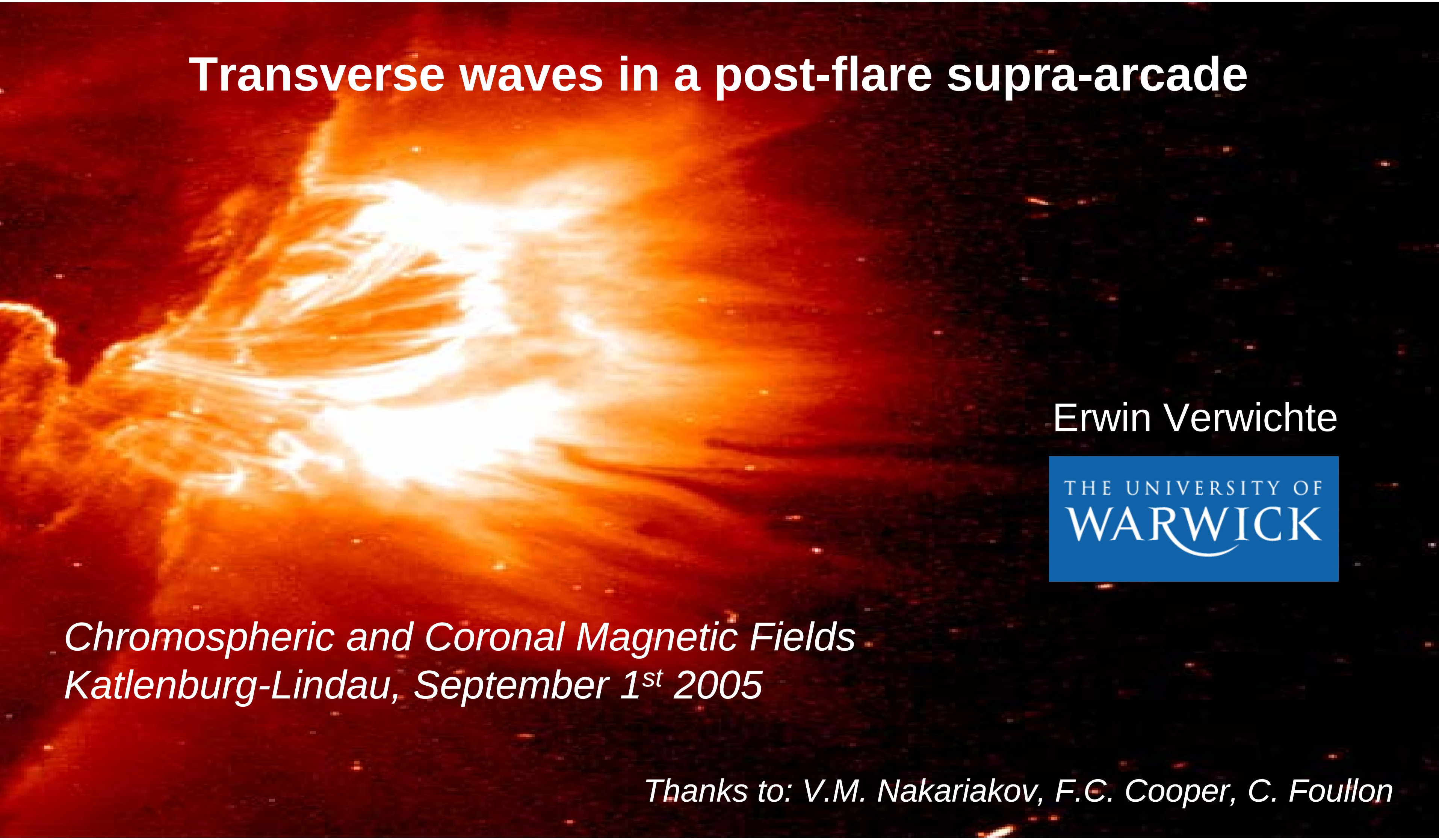

Transverse waves in a post-flare supra-arcade

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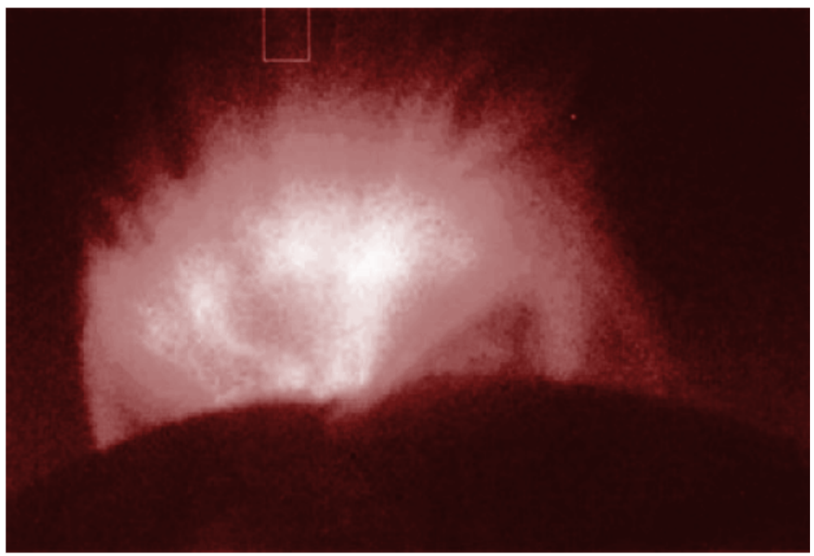
Chromospheric and Coronal Magnetic Fields
Katlenburg-Lindau, September 1st 2005

Thanks to: V.M. Nakariakov, F.C. Cooper, C. Foullon

Natural history of tadpoles

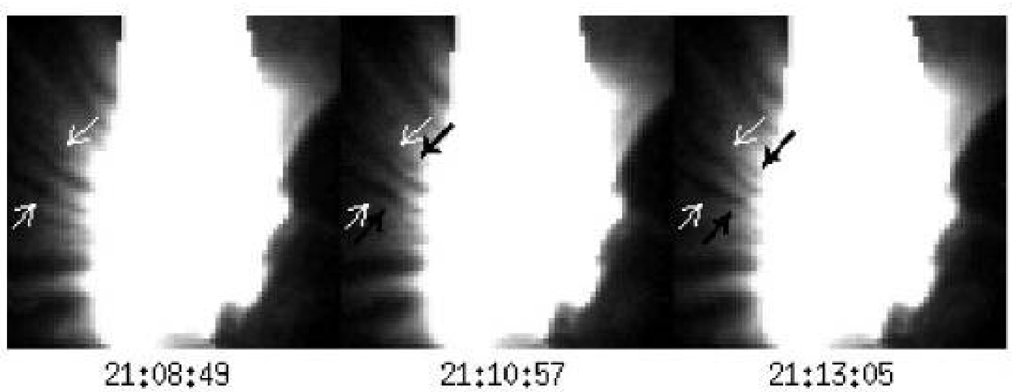
► *Svestka et al. (1998)*: Fan-like structure above post-flare loops

- Fans of rays are temporary multiple ministreamers or plume-like structures
- Mass flow into interplanetary space



Natural history of tadpoles

- *Svestka et al. (1998)*: Fan-like structure above post-flare loops
- *McKenzie & Hudson (1999):* See downflows in supra-arcade
  - Coherent blob-shaped X-ray depressions (**tadpole**) moving downwards in lanes between supra-arcade rays (100-200 km/s)
  - Slow down and narrow
  - Rays pushed sideways



	T (MK)	ne (10^9 cm^{-3})
ray	7.9	2.3
lane	8.6	1.4
void	9.1	1.3

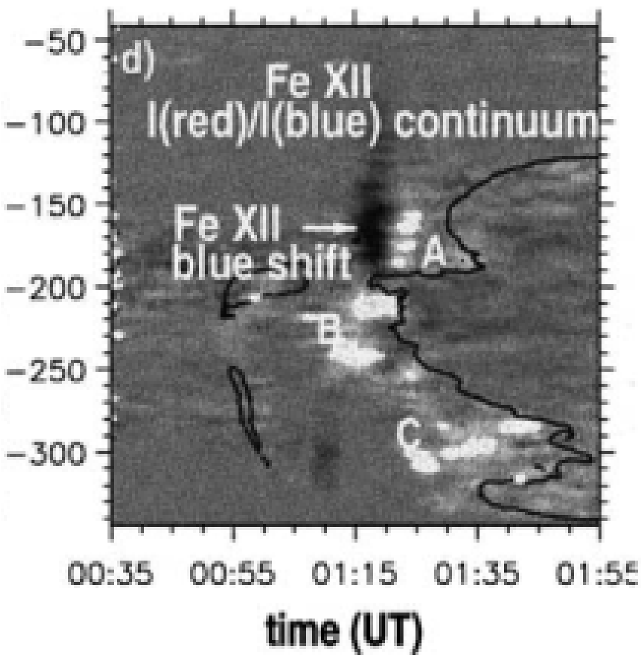
Natural history of tadpoles

- *Svestka et al. (1998)*: Fan-like structure above post-flare loops
- *McKenzie & Hudson (1999):* See downflows in supra-arcade
- What are tadpoles?

- Fieldline shrinkage (Forbes & Acton, 1996; McKenzie & Hudson, 1999)
- Sinking columns (Wang et al., 1999; Sheeley & Wang, 2002)
- Reconnection downflows (Asai et al, 2004)
- Plasma acceleration past infalling dense clouds (Innes et al., 2003)
- Sinking reconnection point?

Natural history of tadpoles

- *Svestka et al. (1998)*: Fan-like structure above post-flare loops
- *McKenzie & Hudson (1999):* See downflows in supra-arcade
- What are tadpoles?
- Joint TRACE, RHESSI, SUMER and radio observations



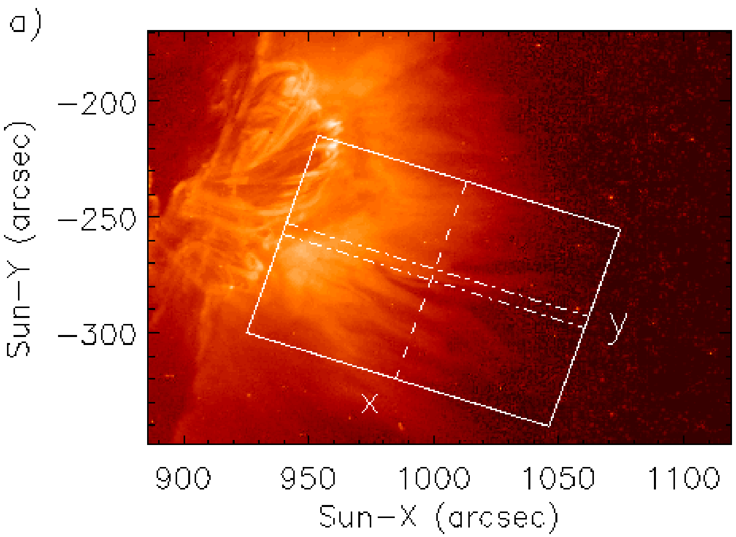
- Fe XXIV line in TRACE 195Å
- Bright front (V > 120 km/s), later CME
- Dark sinuous lanes in the supra-arcade head and transversely swaying tail (***tadpole***)
- Cospatial TRACE and RHESSI emission
- SUMER Doppler shifts of 800-1000 km/s

movie

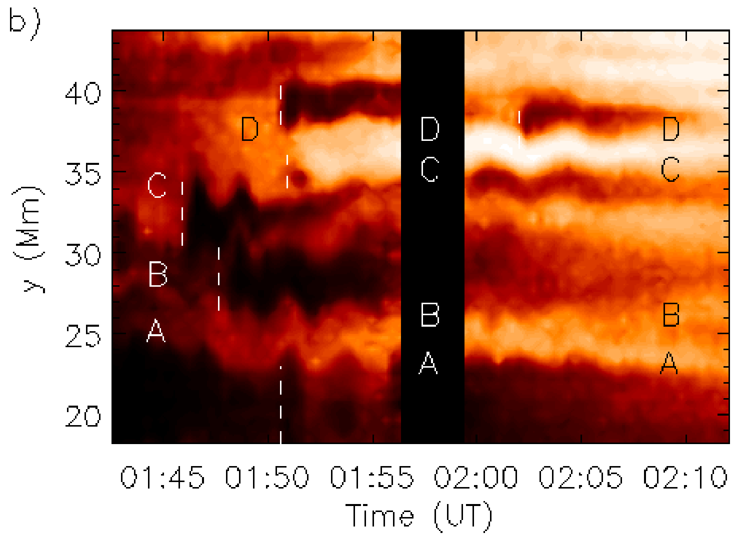
Natural history of tadpoles

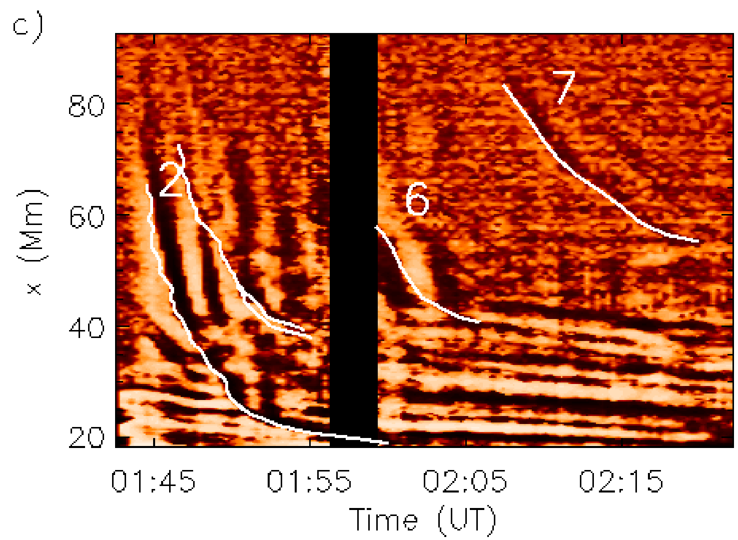
- *Svestka et al. (1998)*: Fan-like structure above post-flare loops
- *McKenzie & Hudson (1999):* See downflows in supra-arcade
- What are tadpoles?
- Joint TRACE, RHESSI, SUMER and radio observations
- Investigate tadpole-tail transverse oscillations with TRACE
  Verwichte, Nakariakov & Cooper (2005)

Working data cube



- x: longitudinal, y: transverse
- Select 4 tadpole-ray edges
- Multiple tadpoles per edge

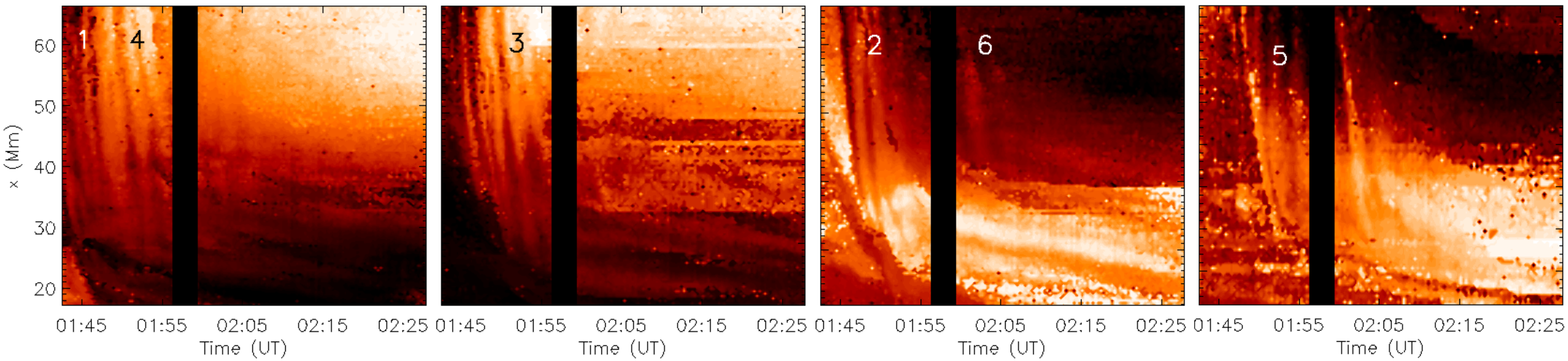




Transverse waves in a post-flare supra-arcade

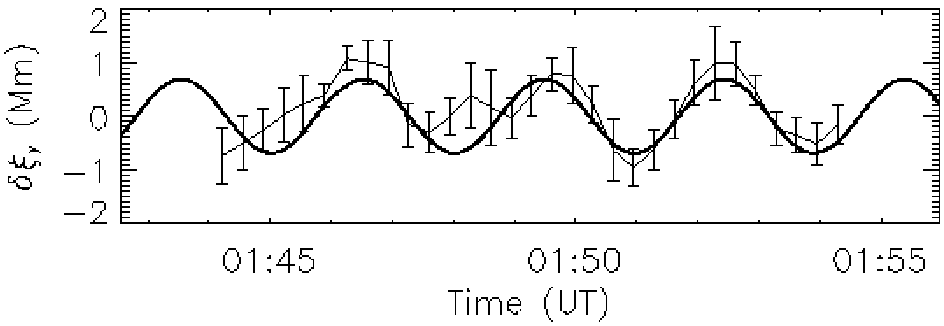
Tadpole-ray edge displacement

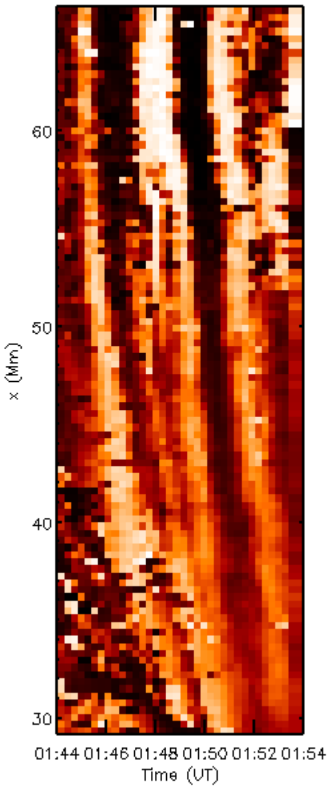
- Extract edge displacement ξ_y at each fixed height x
- Fit locally Gaussian to dI/dy to find ξ_y and error σ
- $\xi_y(x,t)$ for four edges A,B,C & D



Measuring wave packets

- Select wave packet and subtract smooth background: $\xi_y \Rightarrow \delta\xi_y$
- Phase speed is measured using correlation
- Amplitude and period is measured using curve fitting
  - Fit for each height x: $\delta\xi_y = A\cos\left(\frac{2\pi}{P}t - \phi\right)$





- Have V_{ph}(x), *A*(x), *P*(x) for six wave packets

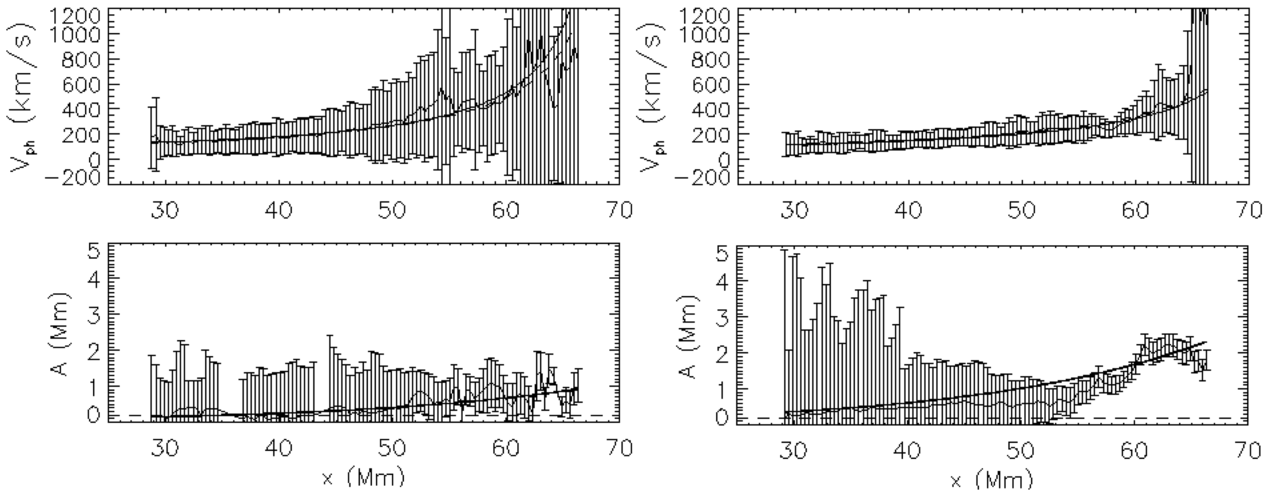
Characterising wave packets

- Fit functions to V_{ph}(x), *A*(x) and *P*=constant
  - Phase speed V_{ph}(x): $$\frac{V_{ph}}{V_{ph0}} = \left[1 - \frac{(x-45.6)}{L_v}\right]^{-1}$$
  - Amplitude *A*(x): $$\frac{A}{A_0} = e^{\frac{(x-45.6)}{L_A}}$$
  - Wavelength λ(x) and deceleration *a*(x) follow from

$$\lambda(x) = V_{ph}(x)\,P \quad \text{and} \quad a(x) = V_{ph}(x)\,\frac{dV_{ph}(x)}{dx}$$

Characterising wave packets

- Fit functions to V_{ph}(x), *A*(x) and *P*=constant



Phase speeds and periods decrease as wave packets propagate sunwards!

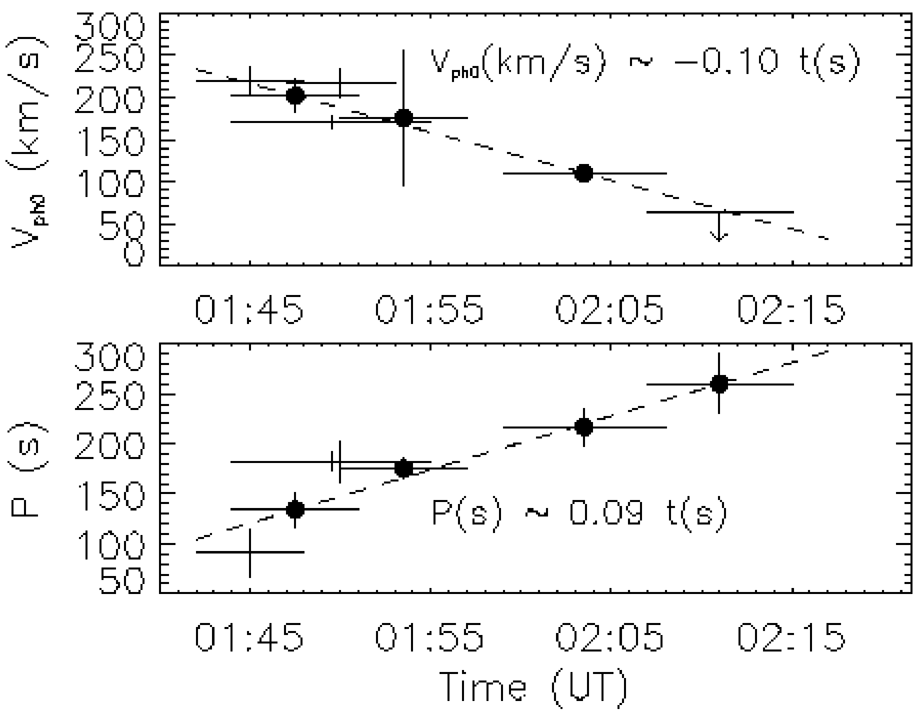
Characterising wave packets

- Fit functions to $V_{ph}(x)$, $A(x)$ and P=constant

Nr	Edge	P(s)	λ_0 (Mm)	$V_{ph,0}$ (km/s)	L_V (Mm)	a0 (km/s^2)	A0 (km)	L_A (Mm)
1	A	91±24	20.1±5.5	220±16	24.6±1.9	1.97±0.32	328±18	20.0±1.9
2	C	134±17	27.1±4.4	202±20	40.6±4.6	1.01±0.23	906±32	34.0±7.2
3	B	182±9	31.1±2.1	171±8	30.5±1.5	0.96±0.10	811±81	9.8±0.2
4	A	182±21	39.7±5.4	218±17	54.2±5.3	0.88±0.16	594±18	11.7±0.4
5	D	175±10	30.8±14.3	176±81	14.3±6.8	2.17±2.24	246±20	11.5±0.8
6	C	217±18	23.9±2.9	110±10	62.0±7.6	0.20±0.04	375±19	19.4±2.5
7	D	260±30	< 17	< 65	-	- -	-	

Evolving medium

- Take measurements of each wave packet and study temporal behaviour



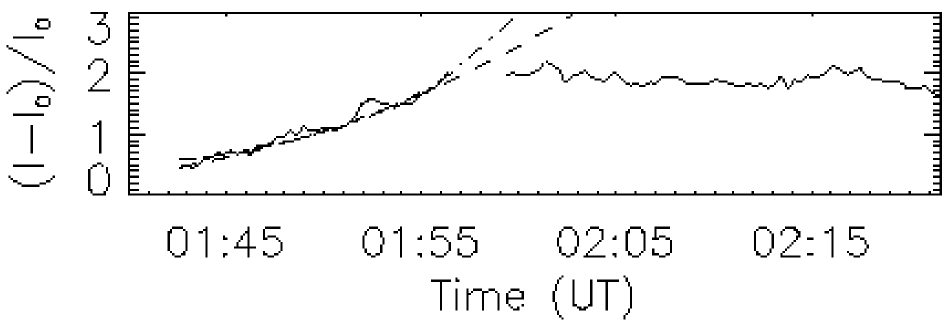
$$V_{\mathrm{ph,f}}(t) = 188\left[1 - \frac{(t(s) - t_{\mathrm{ref}})}{1880}\right]$$

$$P_{\mathrm{f}}(t) = 147\left[1 + \frac{(t(s) - t_{\mathrm{ref}})}{1633}\right]$$

t_{ref} = 01:49:57 UT

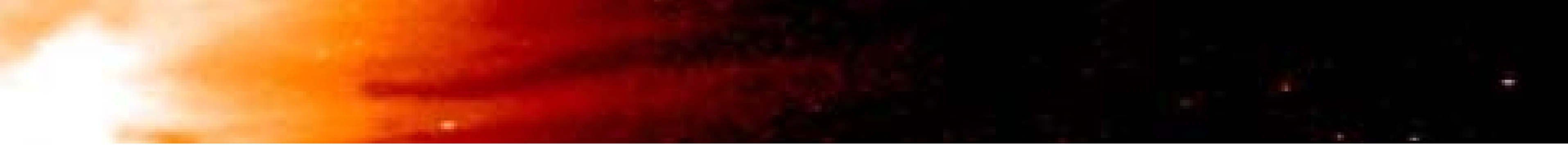
Evolving medium

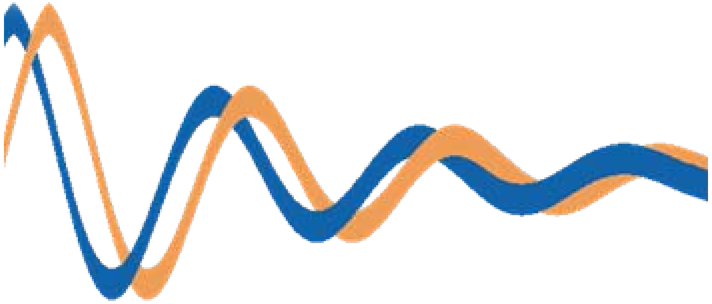
- Take measurements of each wave packet and study temporal behaviour
- A simple calculation
  - Assume that ray intensity $I\text{-}I_0 \sim n_e^2$ & $V_{ph} \sim V_A$
  - with B_0 & T_e constant
  - with I_0 and arbitrarily chosen constant background
  - then: $I\text{-}I_0 \sim V_{ph}^{-4}$ & $I\text{-}I_0 \sim P^4$



Conclusions

- Transverse nature of wave packets
  Fast magnetoacoustic kink wave trains
- Modelling in slab geometry
- Surface or body modes?
- Phase speed < Alfvén speed
  angles of propagation, upflows
- Decrease of phase speed and amplitude
  dissipation, vertical structuring
- Evolving rays medium changes wave signatures





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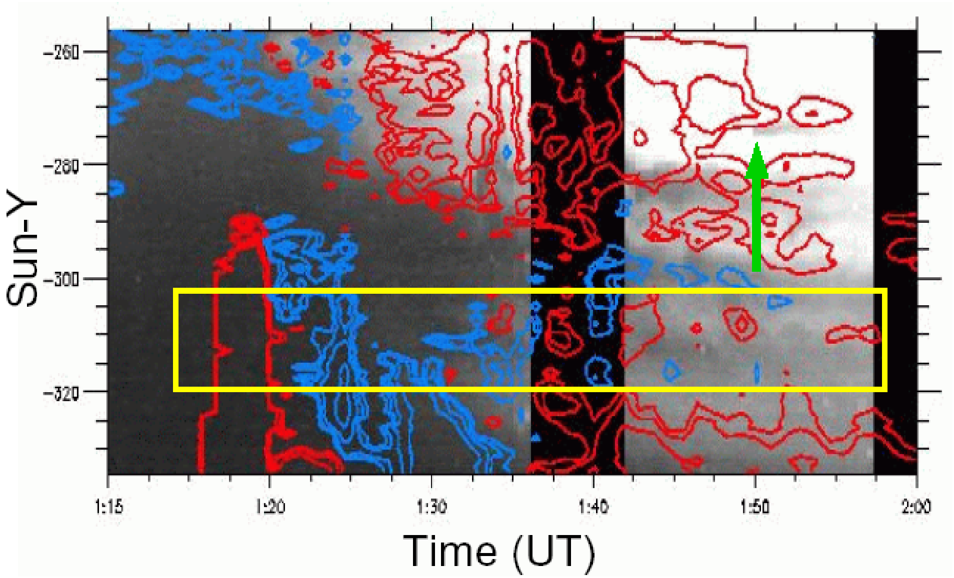
Doppler shifts

- SUMER slit measured periodic Doppler shifts *(Innes & Wang, 2003)*



Doppler speeds of 10 km/s, same order of magnitude.

Plane of wave polarisation lies between line-of-sight and plane-of-sky!