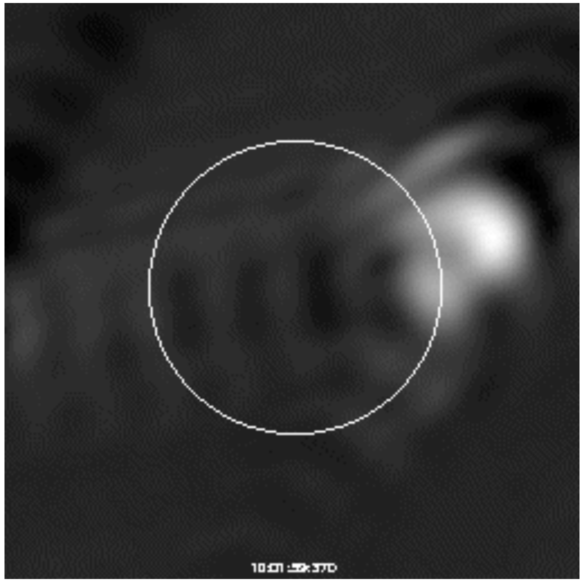
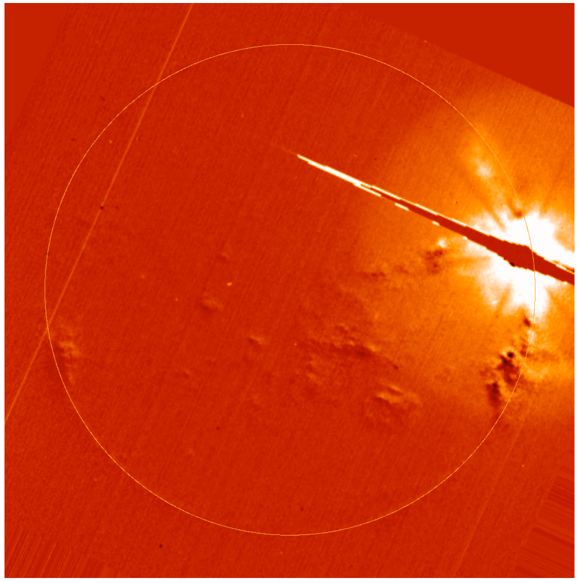
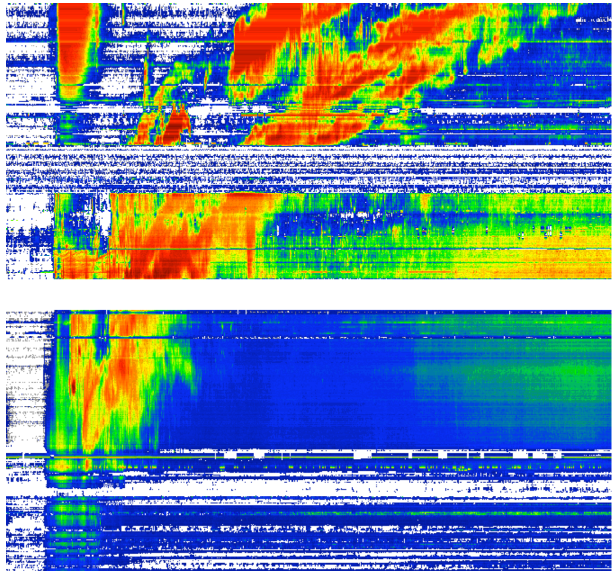
Using radioheliographs to study global coronal waves







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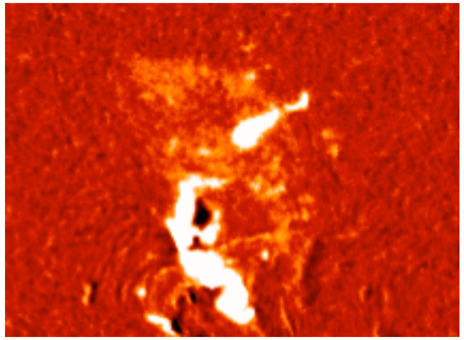
Overview

1. Introduction: Coronal waves
2. Observations of coronal waves with radioheliographs
3. Kinematics
4. Relationship with type II bursts
5. Interaction with coronal structures
6. Physics of waves & emission mechanism
7. Possible launching mechanisms

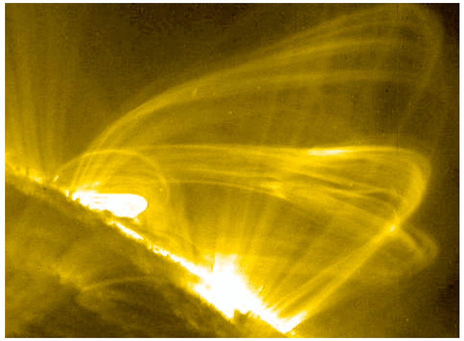
Signatures of large-scale wave-like coronal disturbances

1. Globally propagating wavefronts



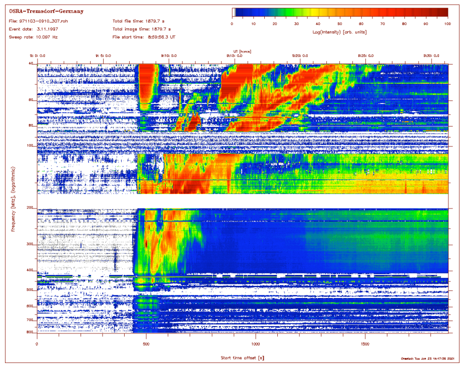
- **Corona:** wavefronts in EUV & SXR
- **Chromosphere:** wavefronts in Hα and HeI

2. Excitation of local oscillations



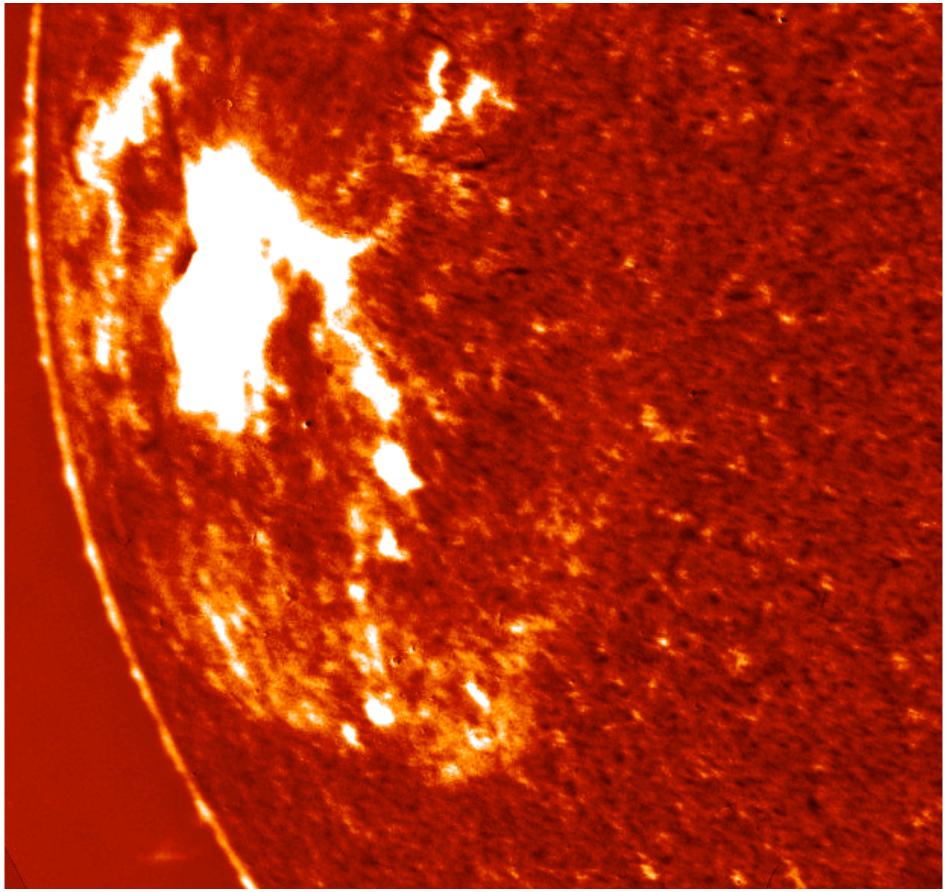
- **Corona:** oscillating loops in EUV
- **Chromosphere:** oscillating filaments in Hα

3. Metric type II radio bursts



- plasma emission generated by shocks
- observed in dynamic radio spectra and radioheliograms

Moreton waves



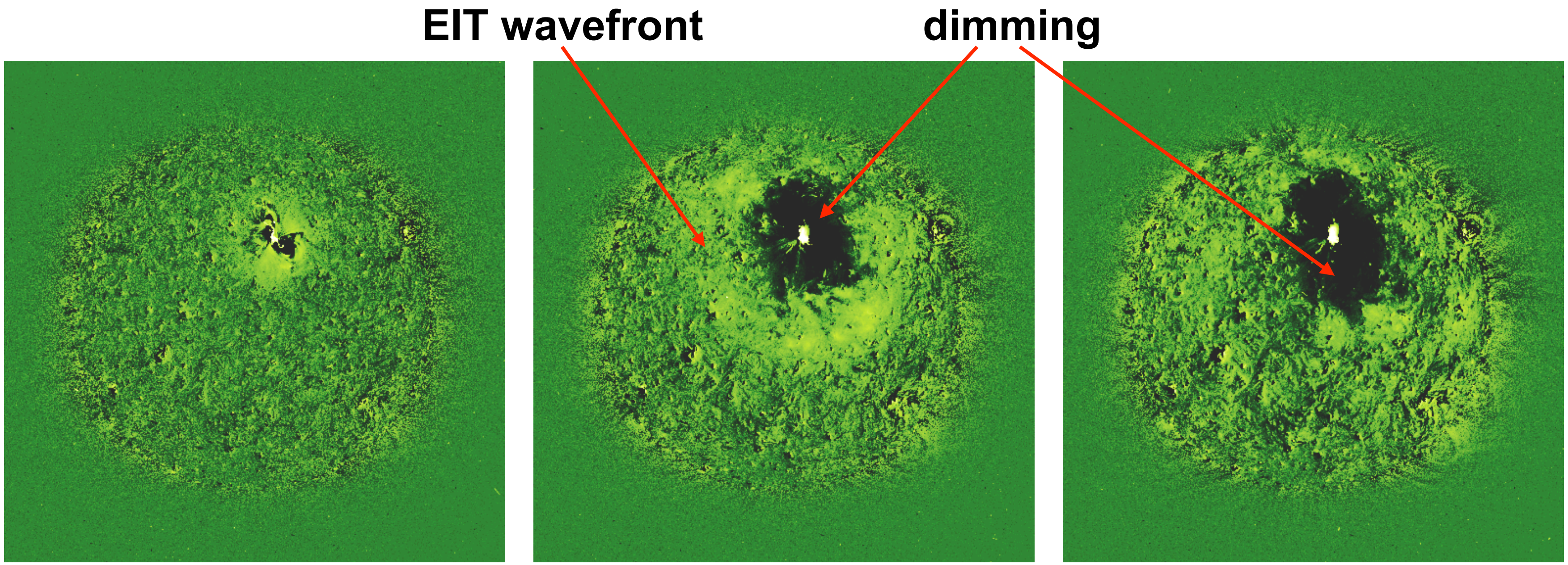
2006 Dec 06 (OSPAN)

- observed in emission in Hα line center & blue wing, in absorption in red wing
  → depression of chromosphere

- propagating away from flaring AR

- speeds of 600-1000 km/s
  → coronal origin of phenomenon

EIT waves:
Basic characteristics



EIT wave of 1997 May 12 *difference images*

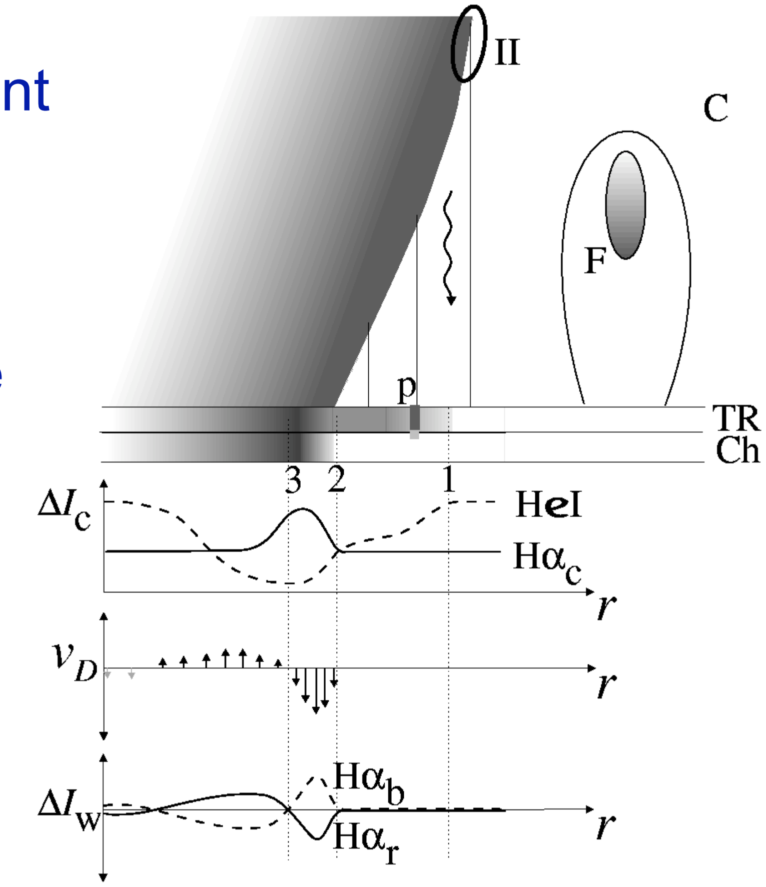
- observed at 195 Å (Fe XII; 1.5 MK)
- diffuse globally propagating disturbances

“Classical” wave/shock scenario

- dome-shaped fast-mode wavefront expands through corona
  (EUV, SXR)

- flanks sweep over chromosphere
  → create Moreton signature
  (Hα)

- where wave steepens to shock
  → type II burst source
  (radio)



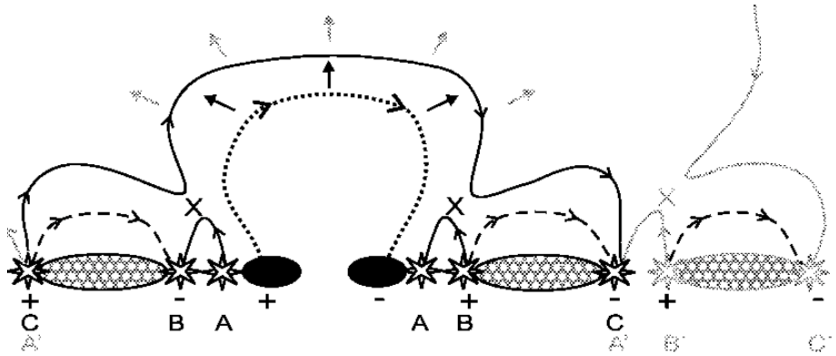
...however, not everything fits this picture...

- most EIT waves without Moreton counterpart
- speeds below 400 km/s
  → much slower than Moreton waves
- stationary EIT fronts
- coronal dimming
- rotation of EIT waves
- speed of many EIT waves lower than magnetosonic speed
- large differences in velocity of EIT waves (25-438 km/s)
- EIT waves retain coherence over large distances

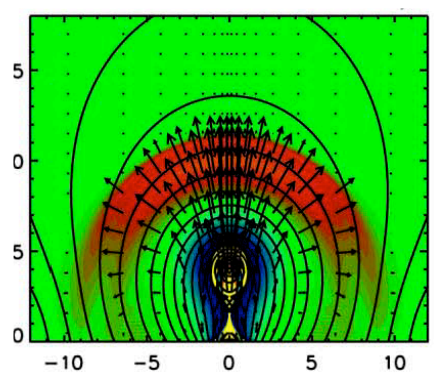
Alternative models

- **Solitons** (*Wills-Davey et al. 2007*)
  - nonlinear MHD waves
  - remain coherent
  - velocity dependent on amplitude

- **Magnetic reconfiguration** *(e.g. Delannée & Aulanier 1999, Attrill et al. 2007)*
  - restructuring of magnetic field in framework of CME leads to stationary and propagating brightenings



- **Hybrid model** (*Chen et al. 2002*)
  - CME-driven shock → fast Moreton wave & type II
  - successive opening of field lines → slow EIT wave



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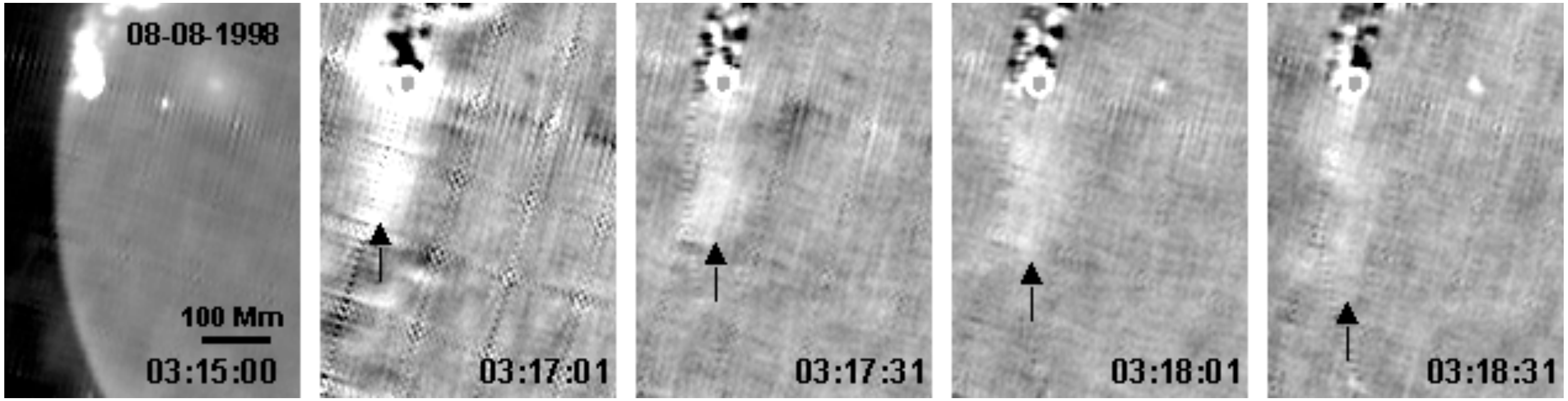
Can we observe coronal waves with radioheliographs?

First observation of a coronal wave with the Nobeyama Radioheliograph at 17 GHz

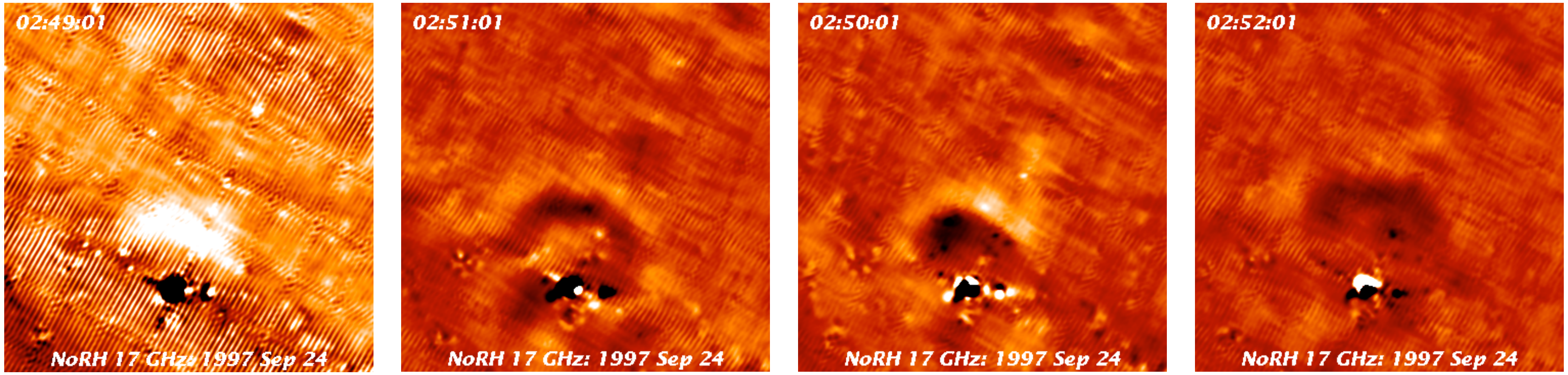


1998 Aug 08 *difference images*

- wave seen as enhanced emission front
- kinematics consistent with associated Moreton wave

Warmuth et al. 2004

On-disk event with NoRH



1997 Sep 24 images

runnning difference

- spectrum consistent with optically thin thermal free-free emission from corona → disturbance is compressive
- constant speed (835 km/s)

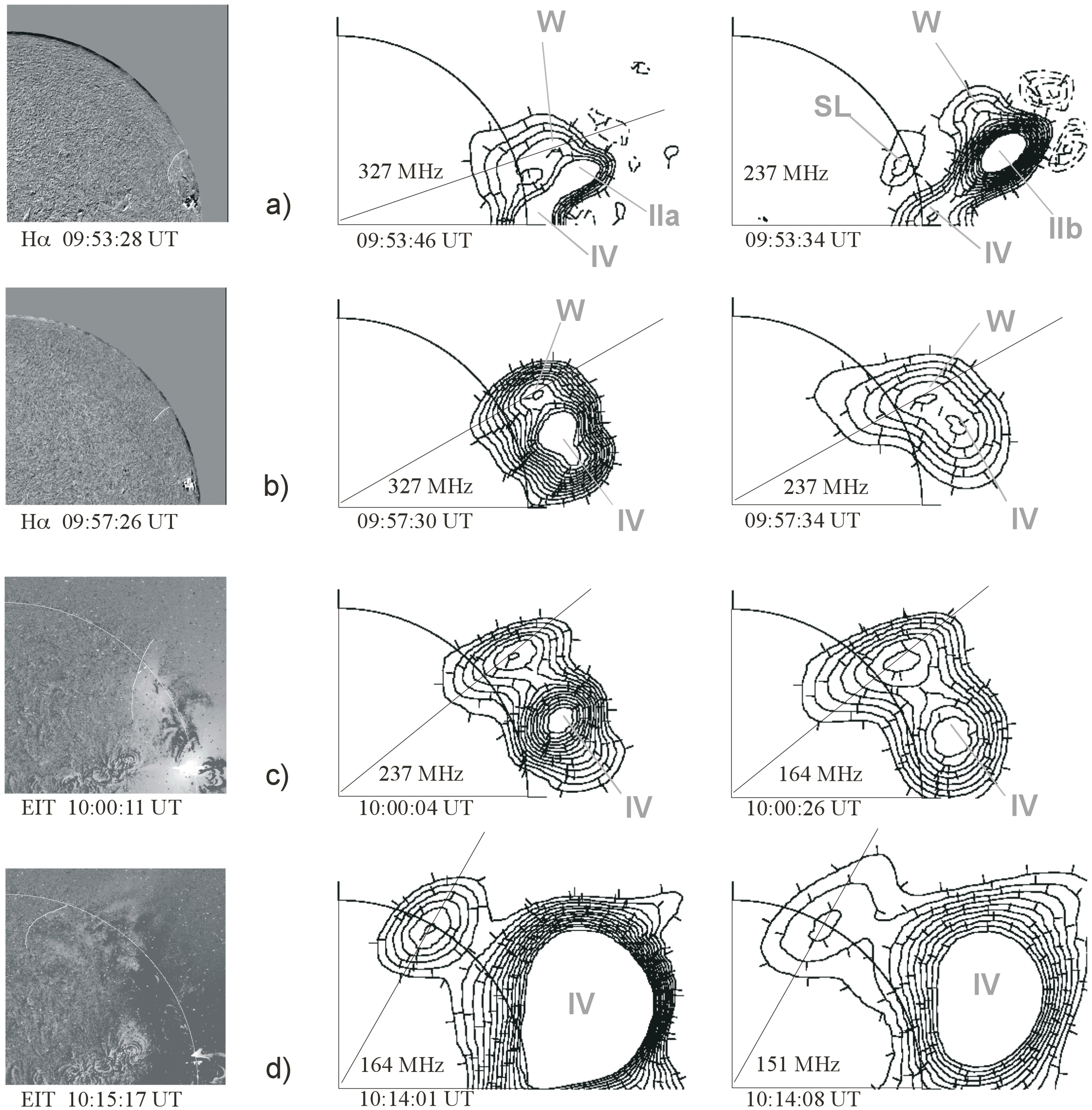
White & Thompson 2005

First observation of a coronal wave with the Nancay Radioheliograph

151 MHz 164 MHz 235 MHz

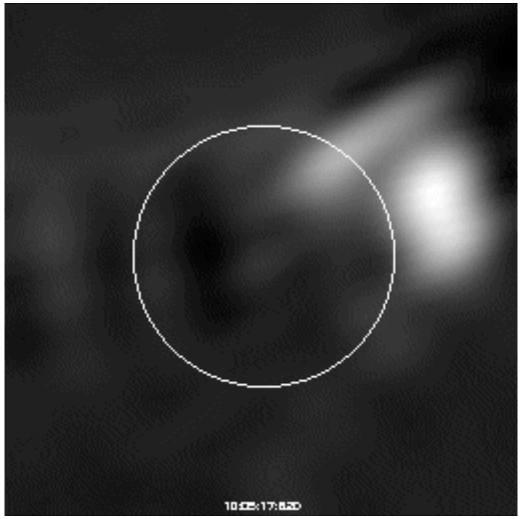
Vrsnak et al. 2005

NRH sources: type II, type IV, wavefront

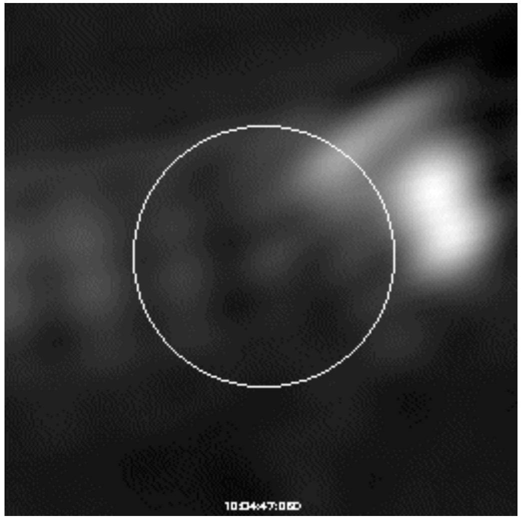


Vrsnak et al. 2005

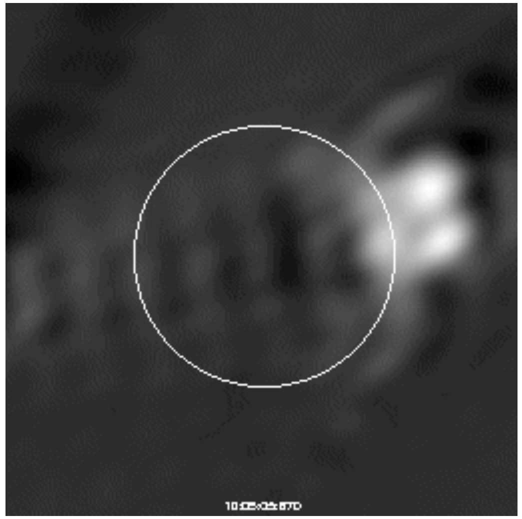
NRH wave characteristics



151 MHz



164 MHz

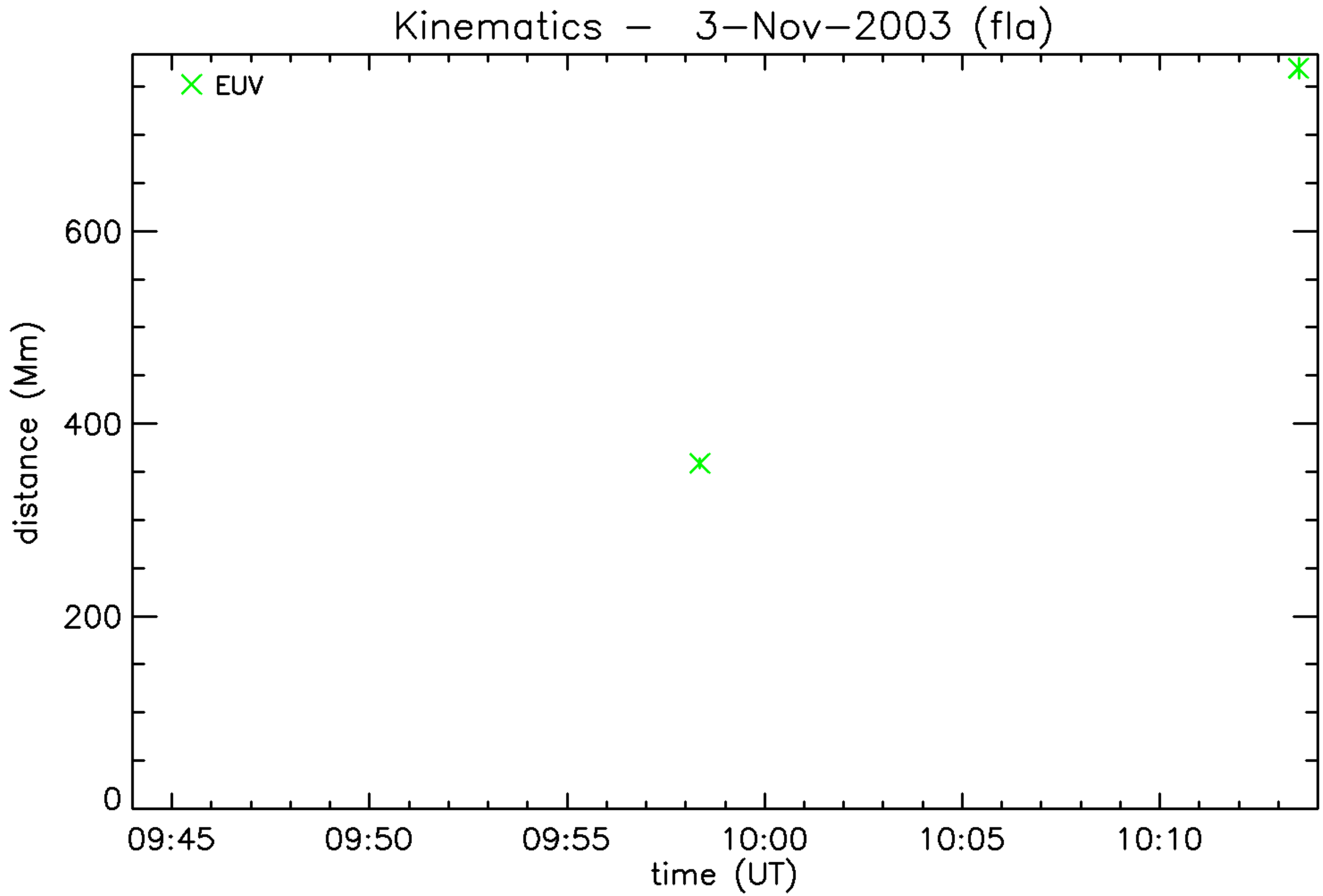


235 MHz

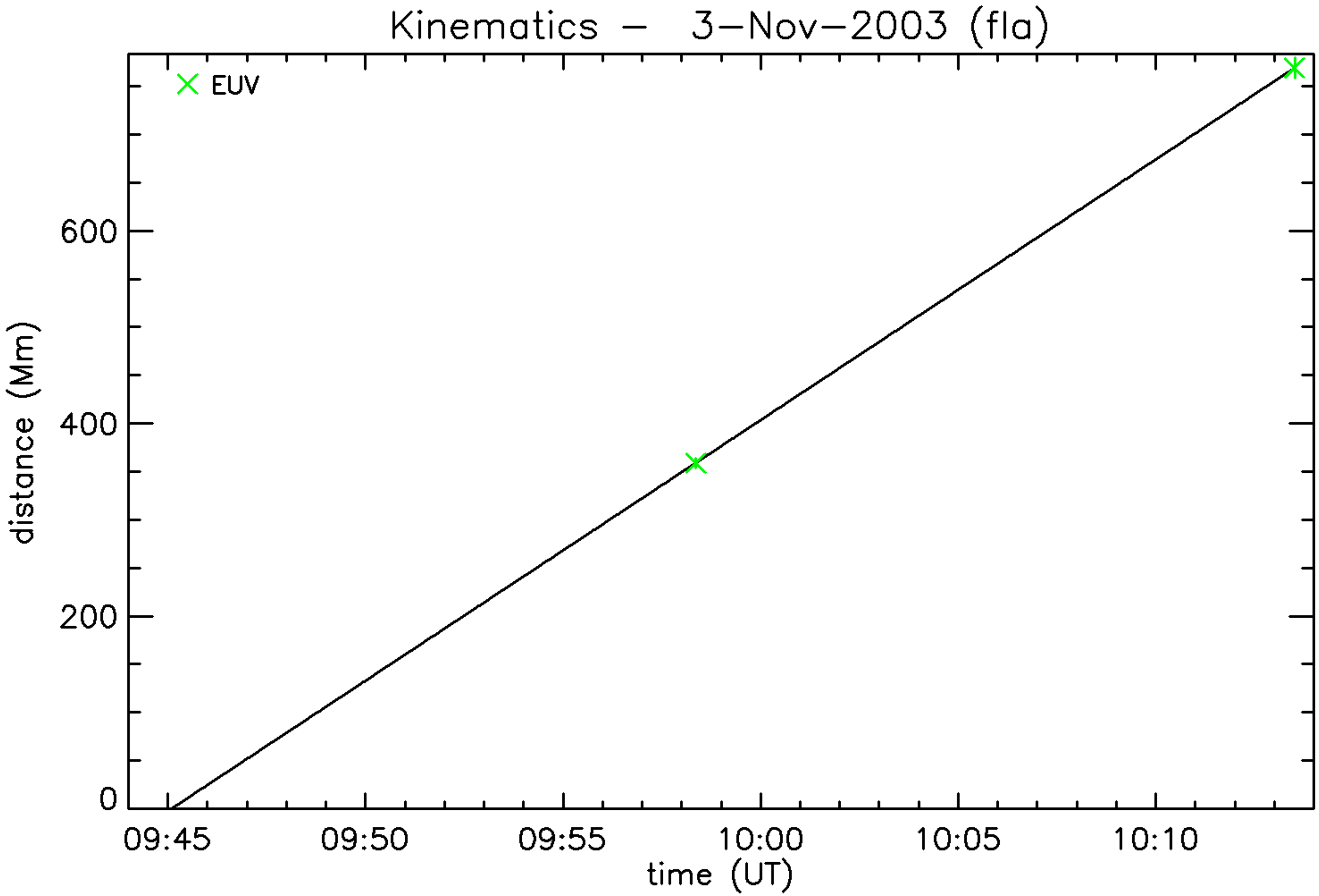
- weak broad-band source at all NRH freqencies ≤ 327 MHz
- centroid at heights between 0 and 200 Mm
- horizontal extension equal beam width, vertical extension larger → narrow, vertically elongated source

What can we learn about kinematics?

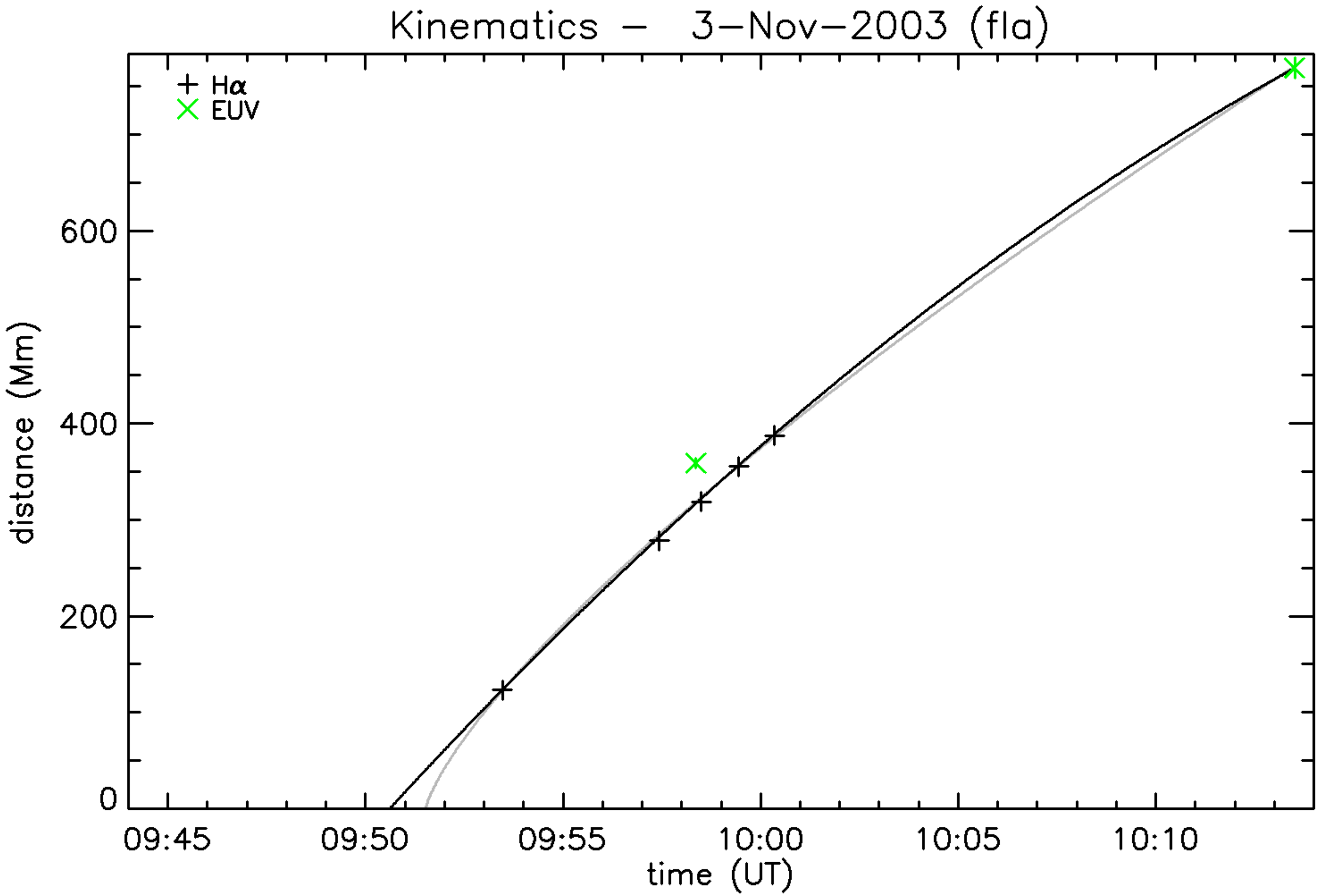
Coronal wave of 2003 Nov 3: two EIT wavefronts



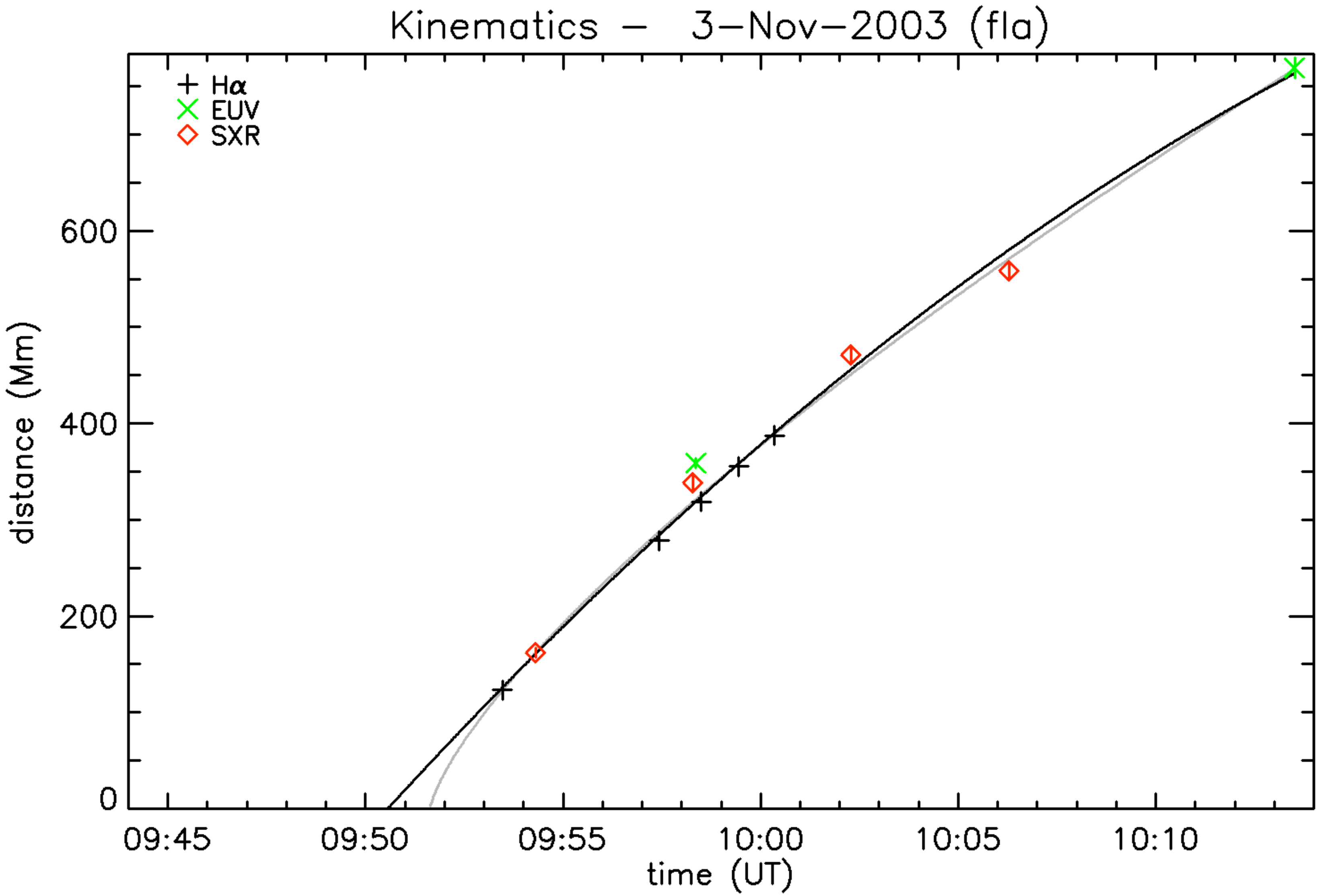
Coronal wave of 2003 Nov 3: two EIT wavefronts & linear fit



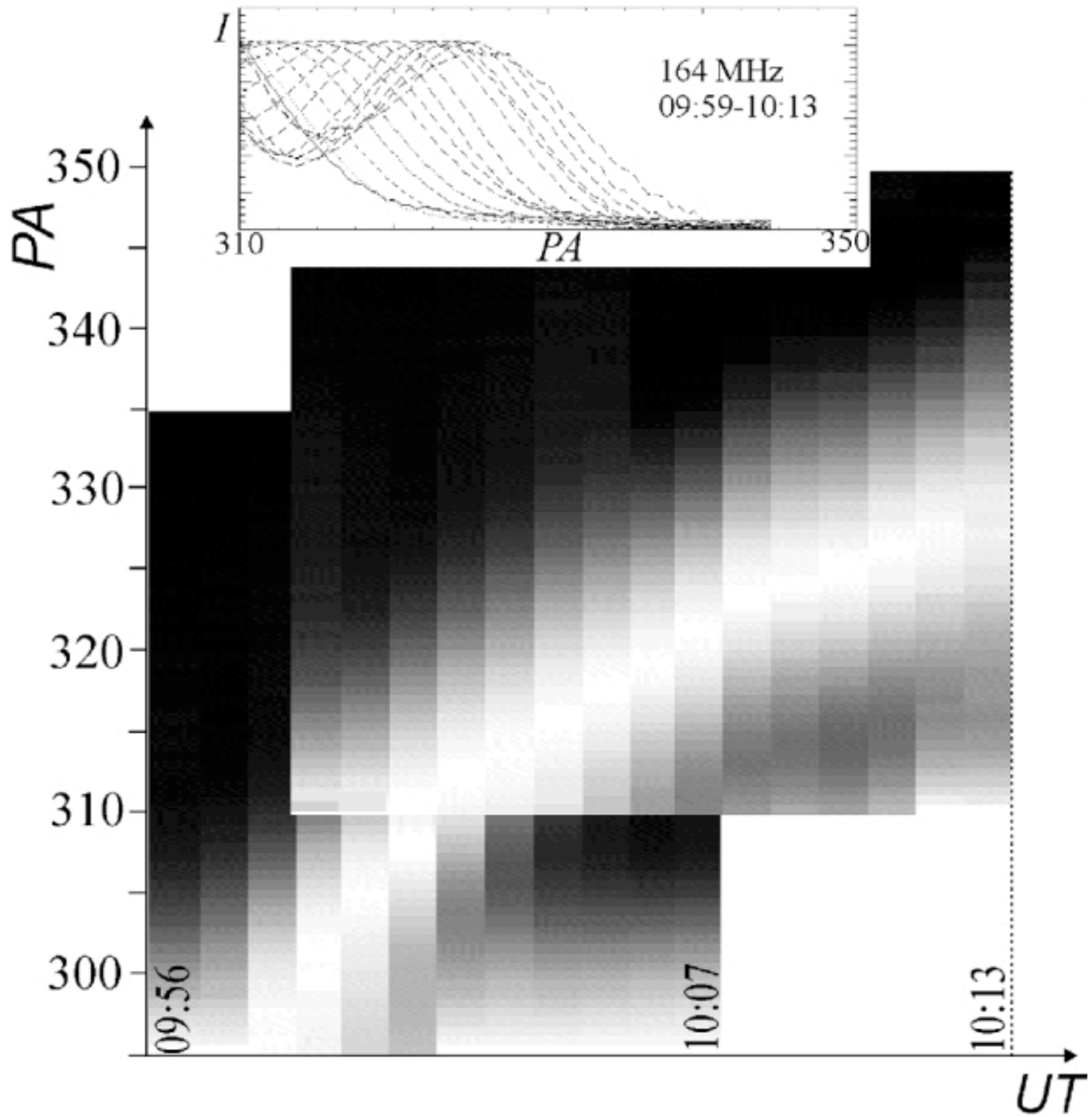
Coronal wave of 2003 Nov 3:
EIT & Hα kinematics & back-extrapolation



Coronal wave of 2003 Nov 3: EIT, Hα & SXI kinematics

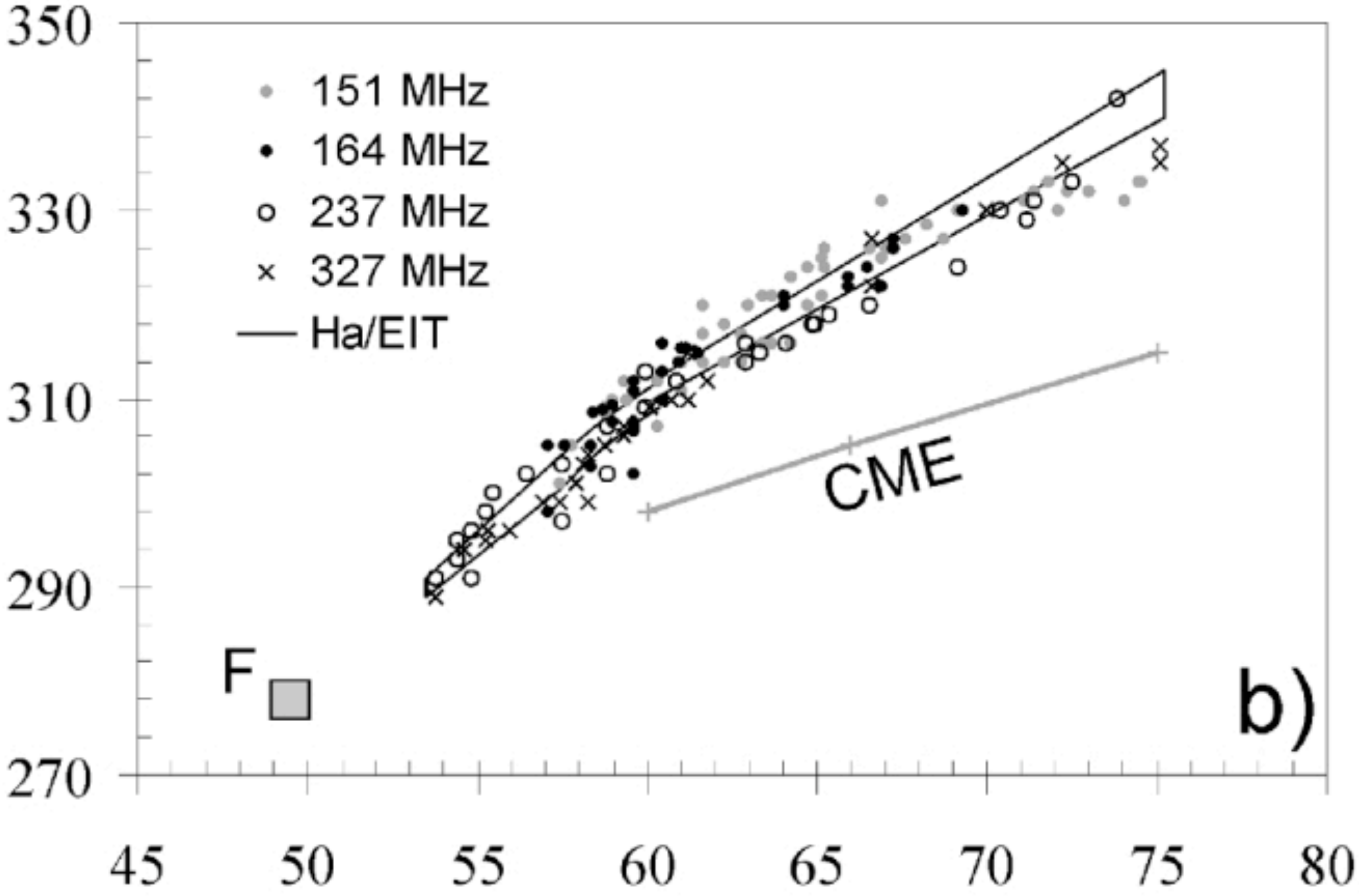


NRH wave intensity profile (along limb) versus time (237 & 164 MHz)



Vrsnak et al. 2005

NRH wave source centroid PA versus time

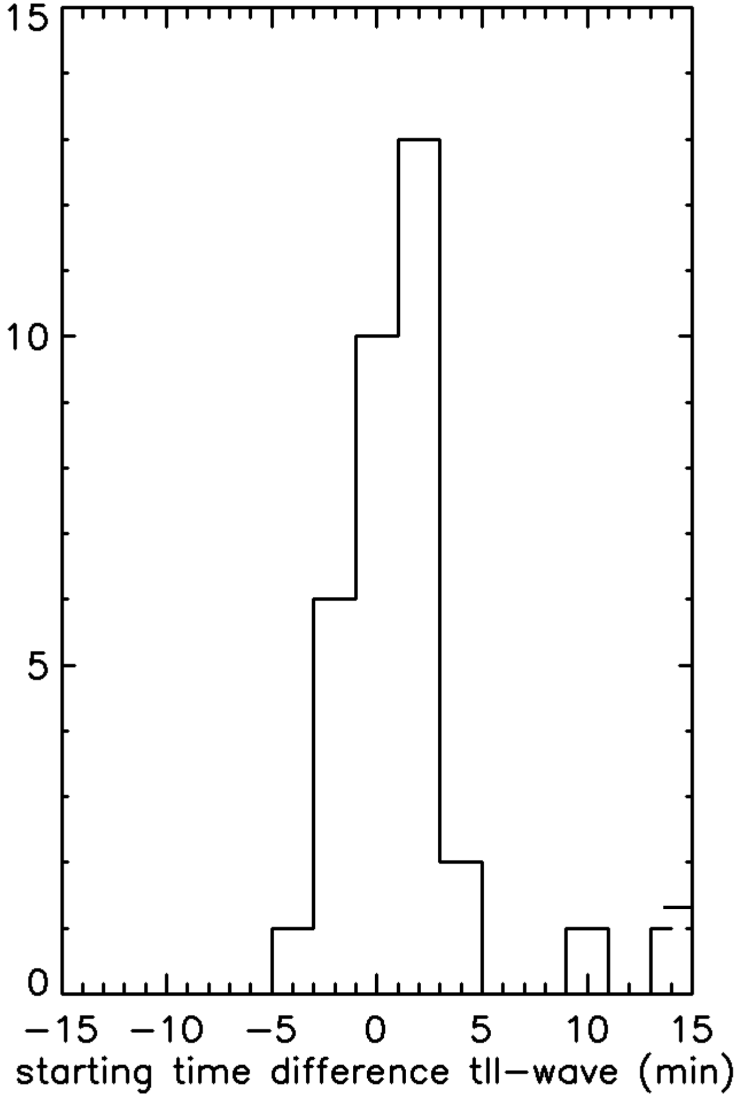


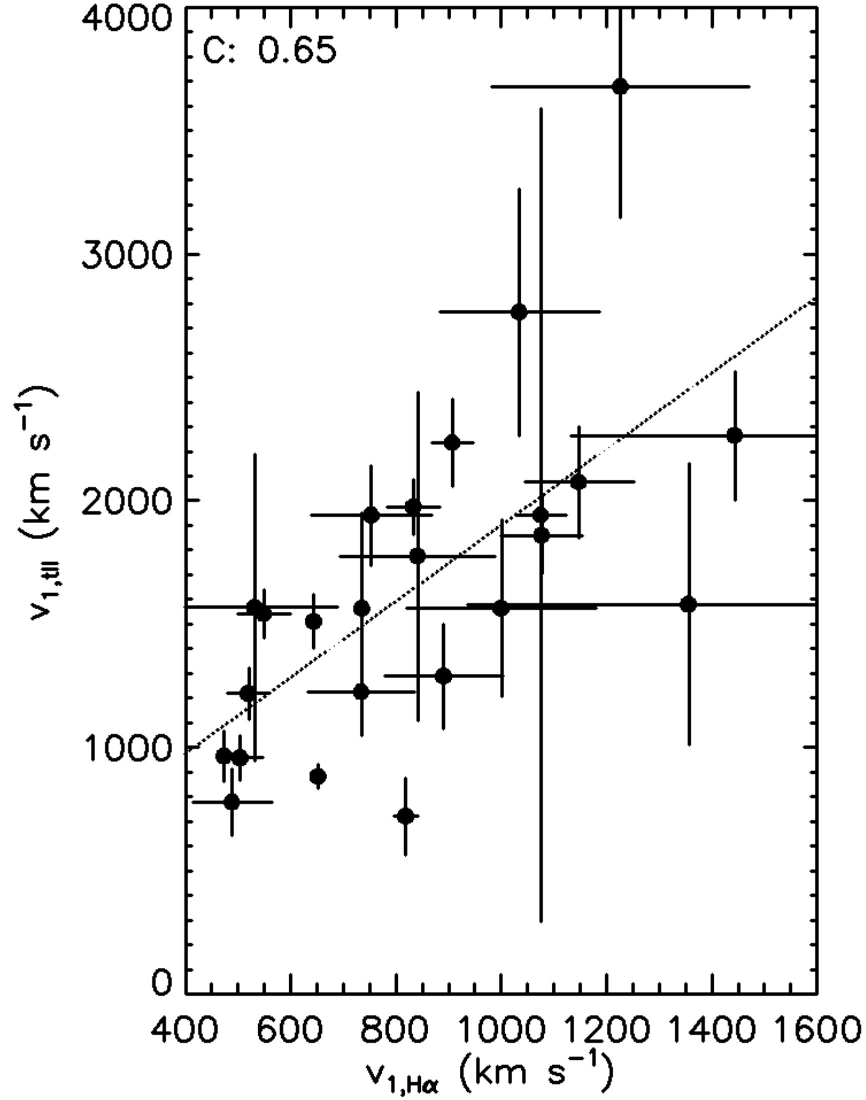
→ NRH, Hα, and EIT wavefronts lie on same kinematical curve

Vrsnak et al. 2005

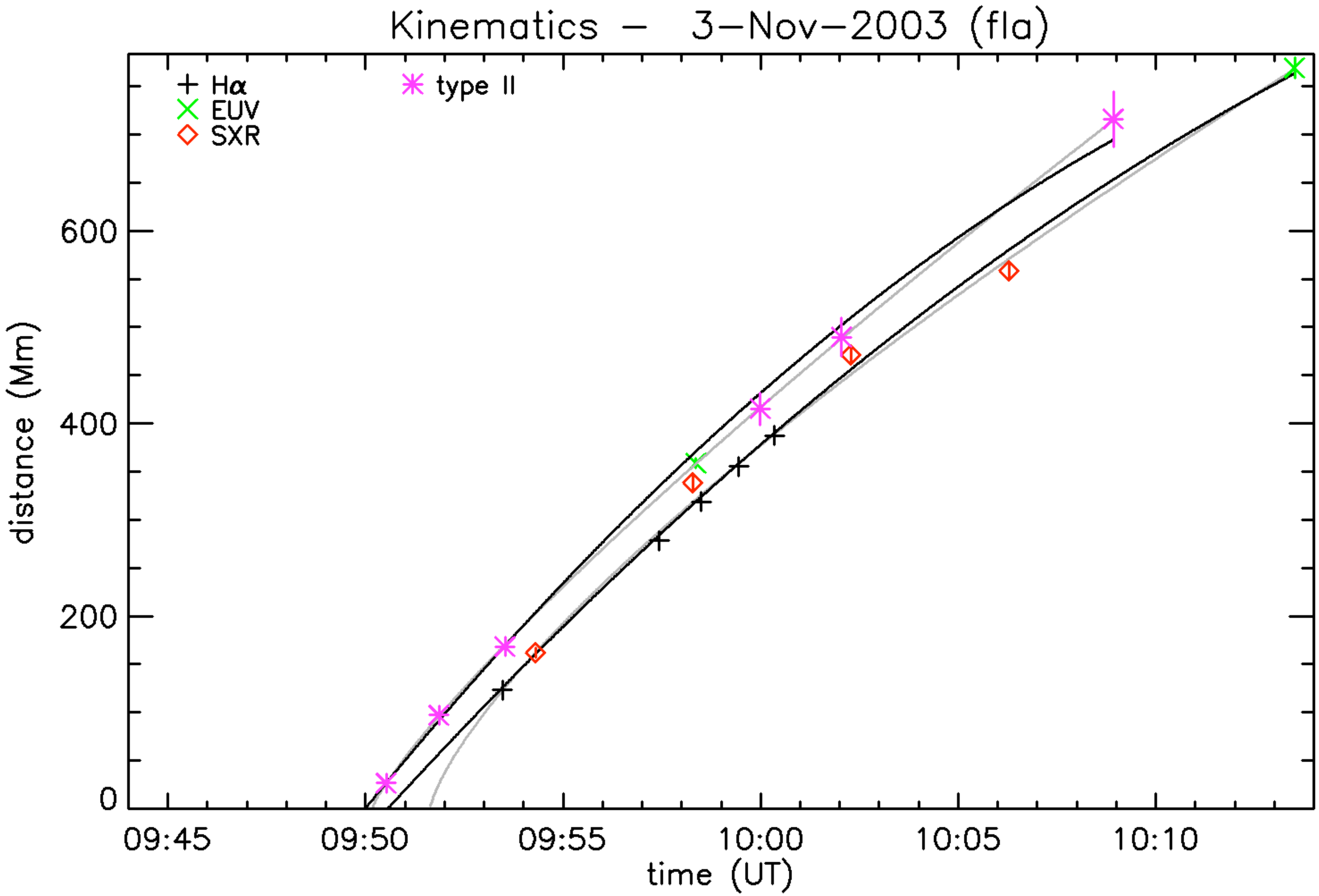
What can we learn about the relationship with type II bursts?

Correlation between wave and type II burst kinematics

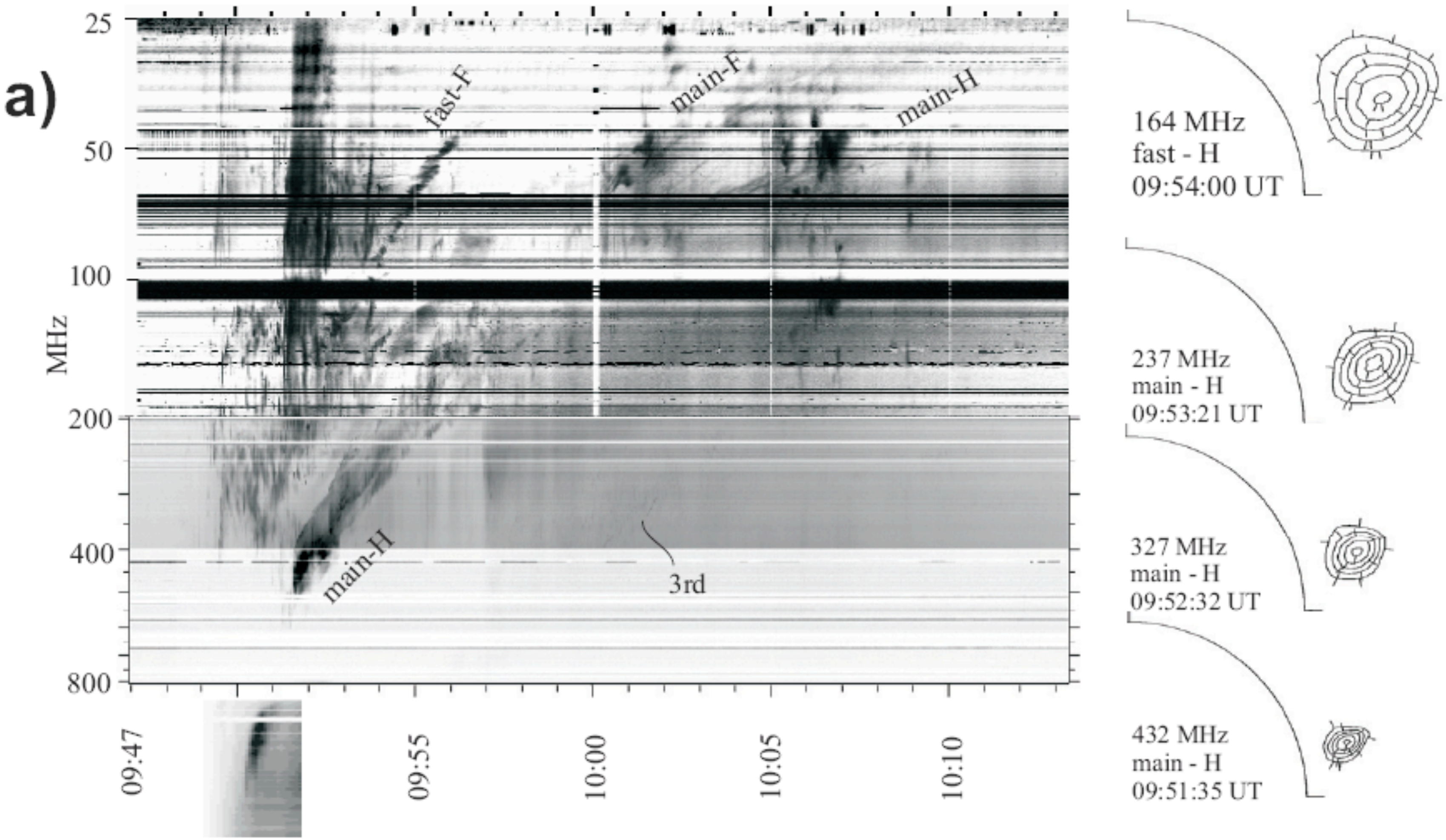




Coronal wave of 2003 Nov 3:
Type II radio burst kinematics

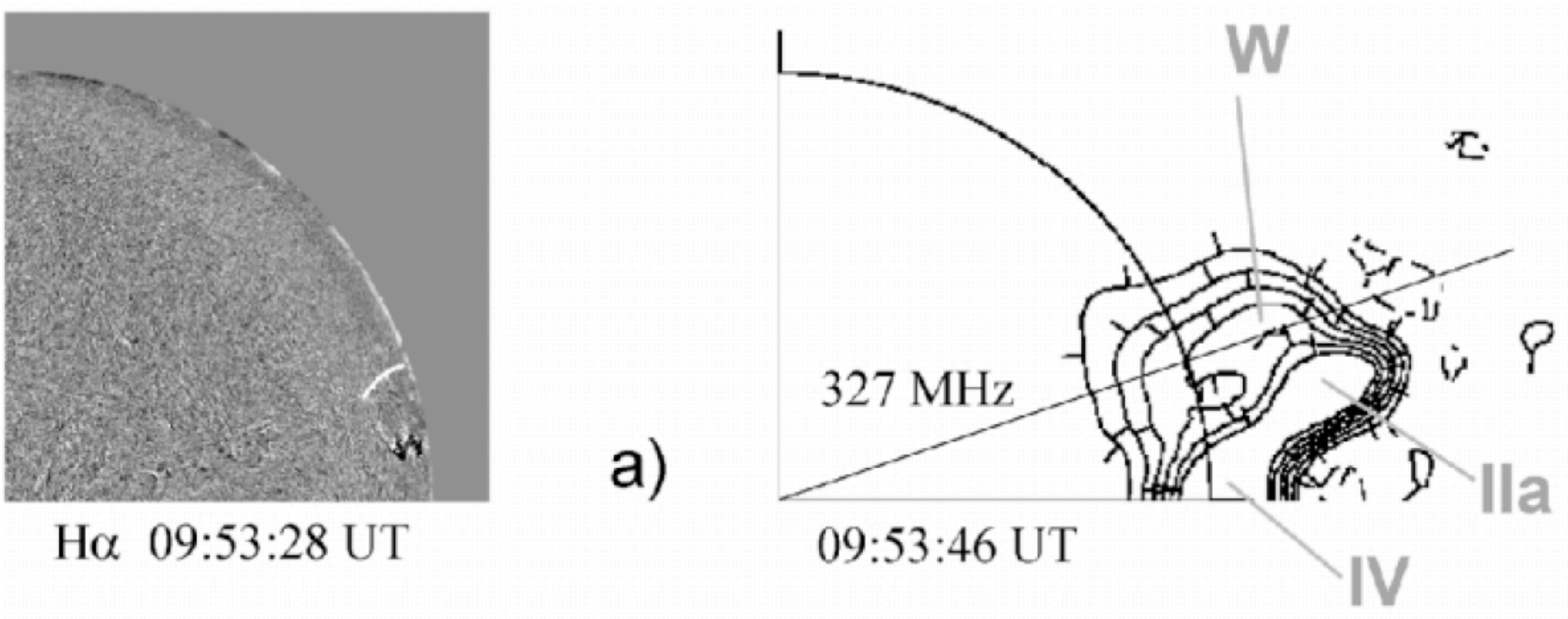


Dynamic spectrum and imaging of the type II burst source



Vrsnak et al. 2006

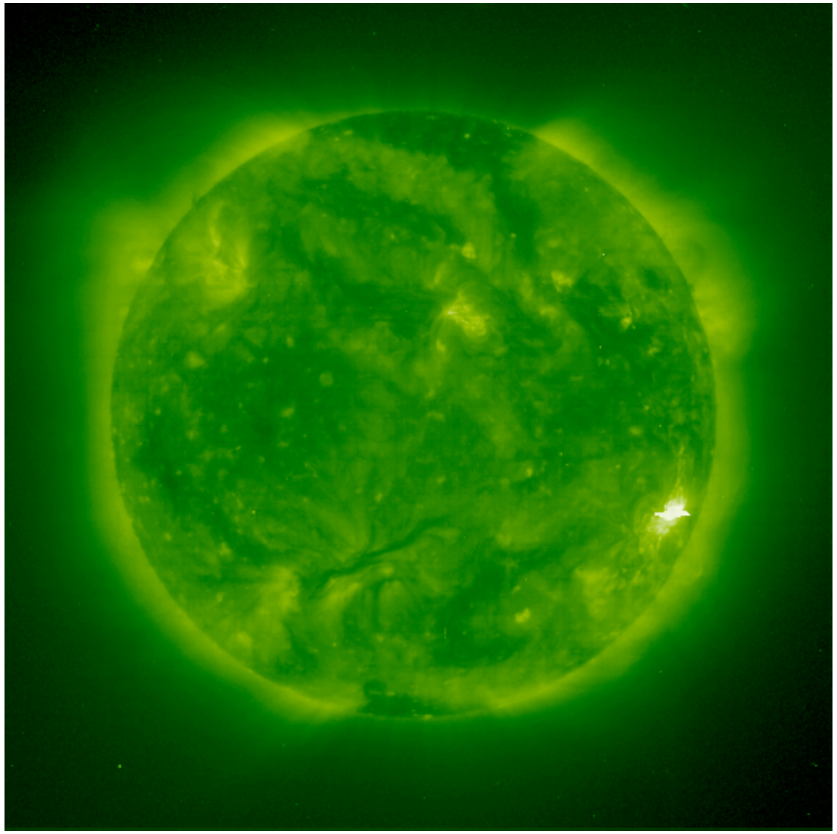
NRH emission pattern connects Moreton wave to type II burst source

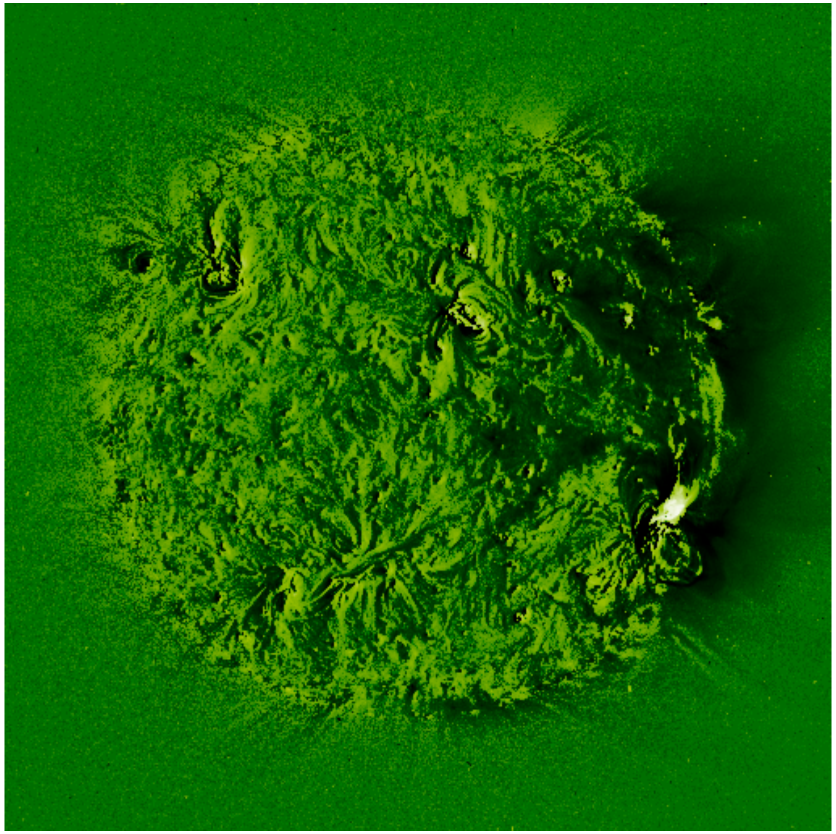


Vrsnak et al. 2005

What can we learn about the interaction with coronal structures?

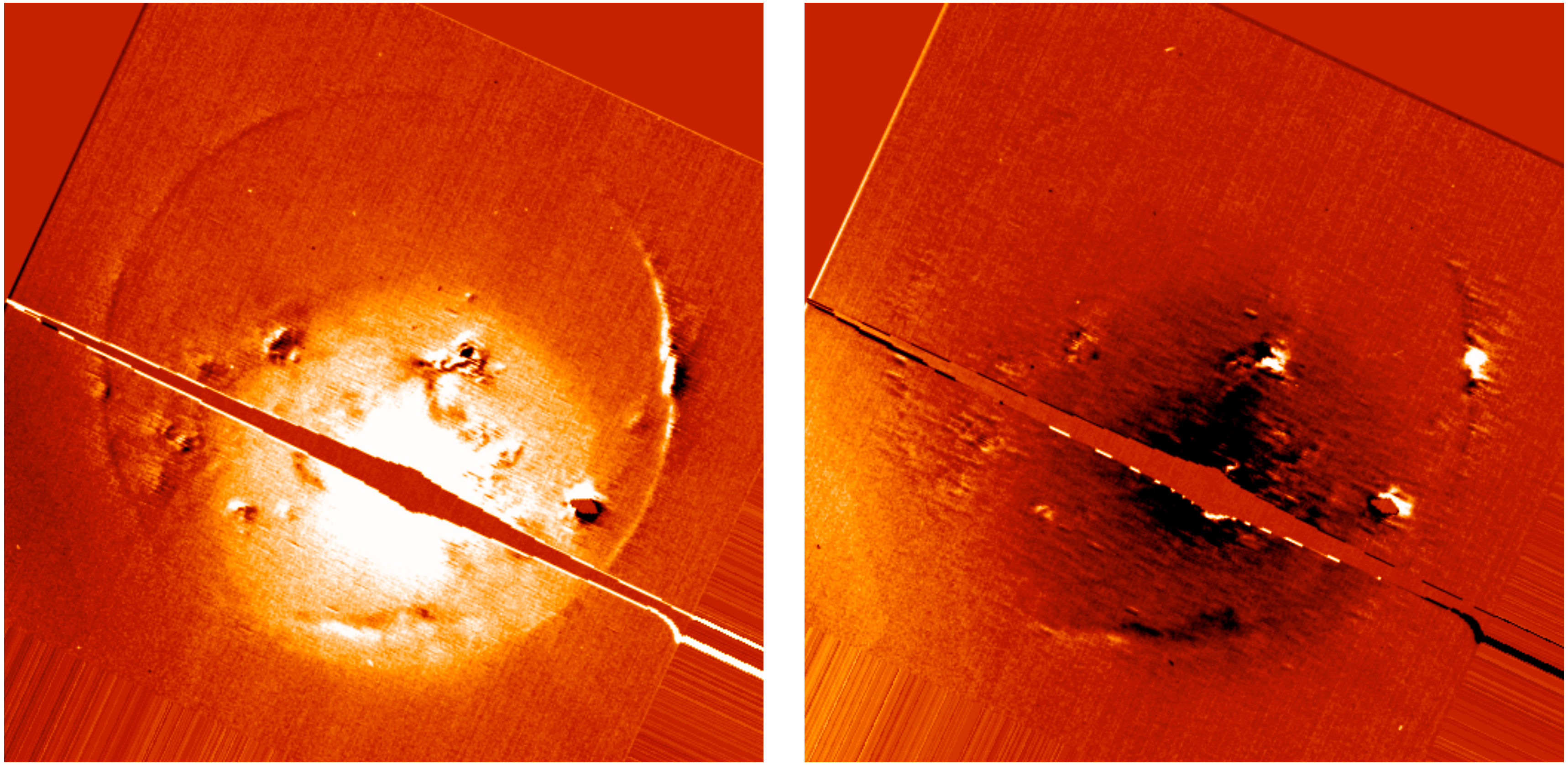
Interaction with coronal holes: stopping at CH boundary





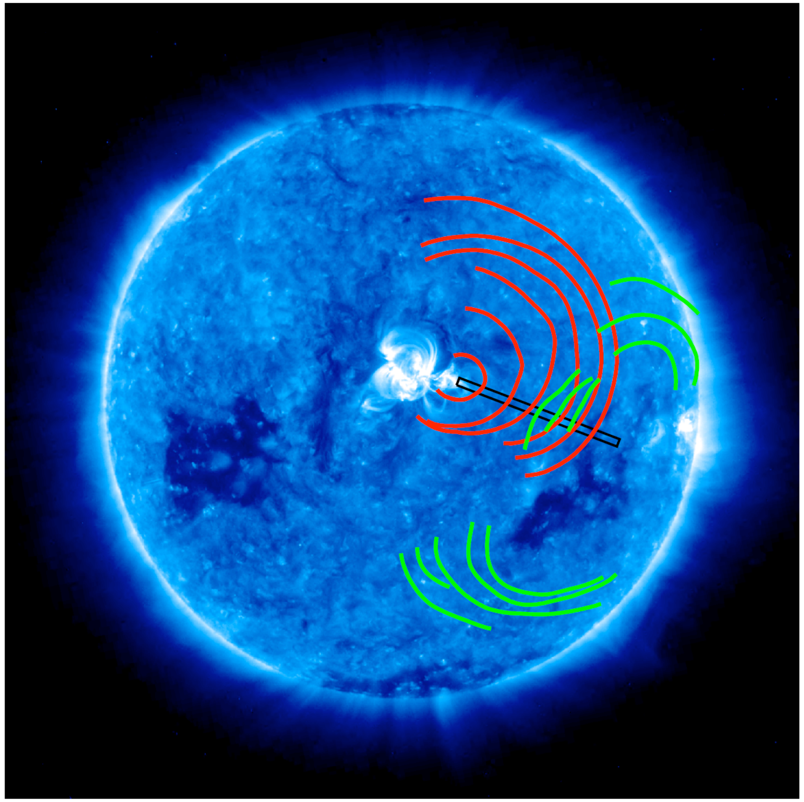
EIT wave of 1997 Nov 06

Interaction with coronal holes: refraction around CH boundary

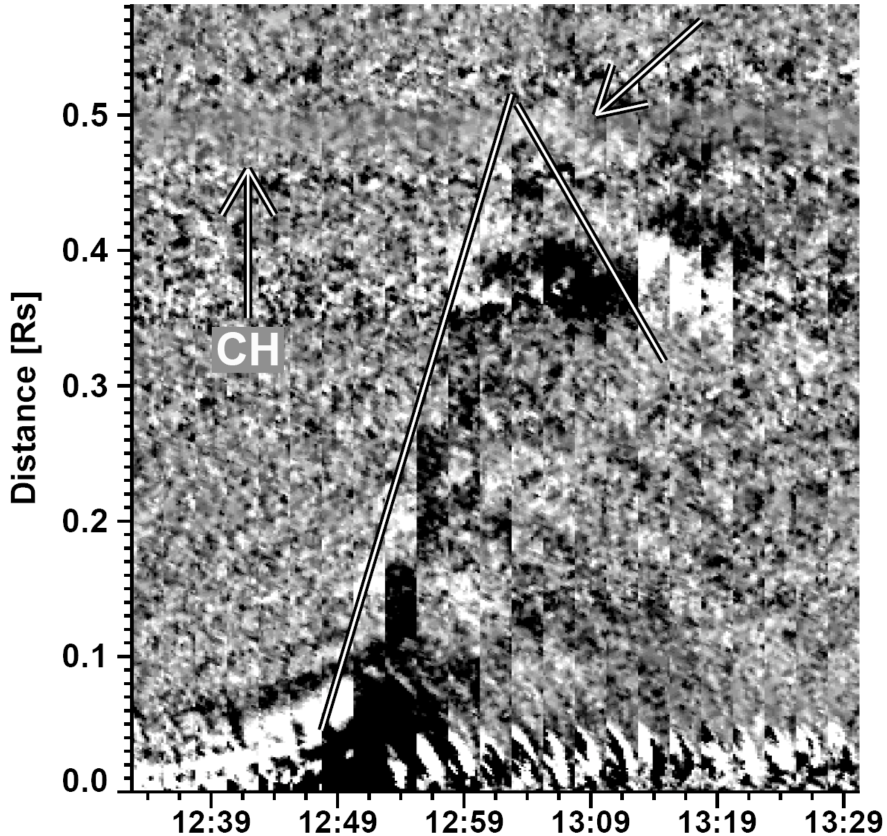


SXI wave of 2003 Oct 29

Interaction with coronal holes: reflection from a coronal hole



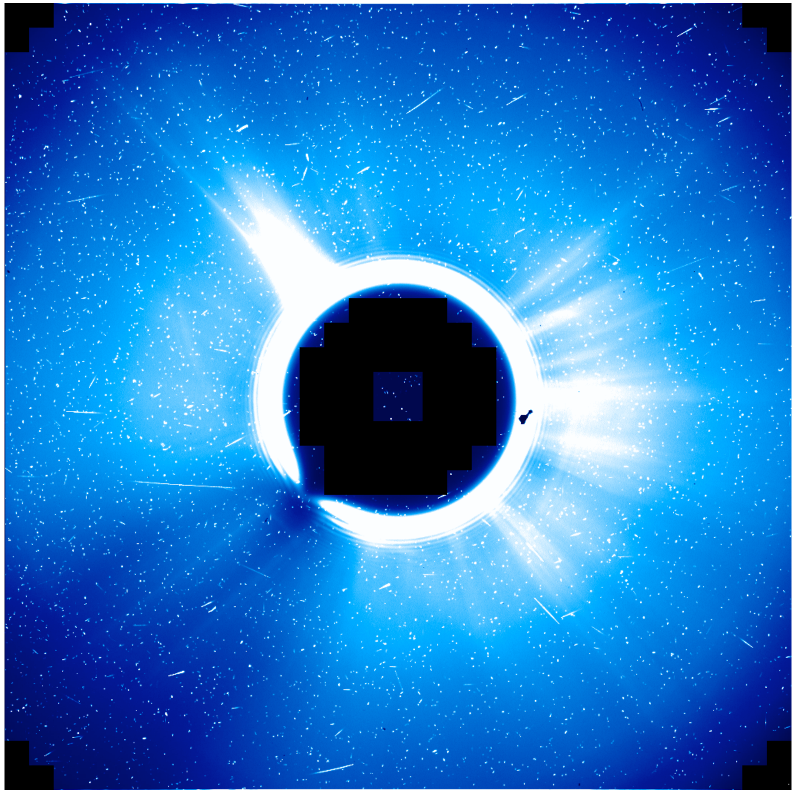
STEREO B EUVI 171: 2007/05/19 12:32:19



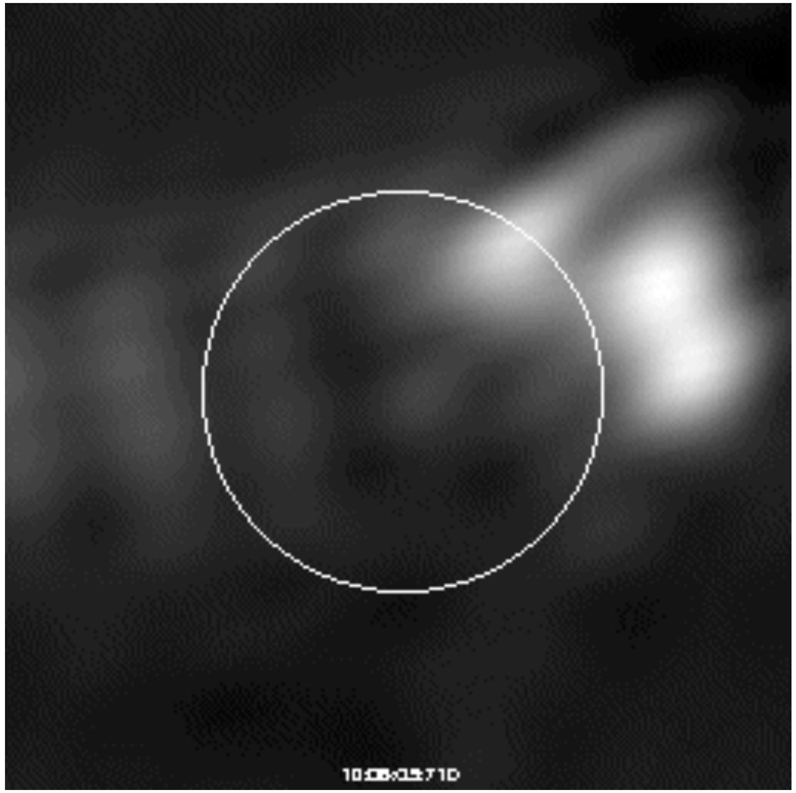
- observation enabled by high cadence of EUVI
- EUV transients are truly waves

Gopalswamy et al. 2009

Interaction with enhanced coronal structures



2003 Nov 03 *LASCO C2*

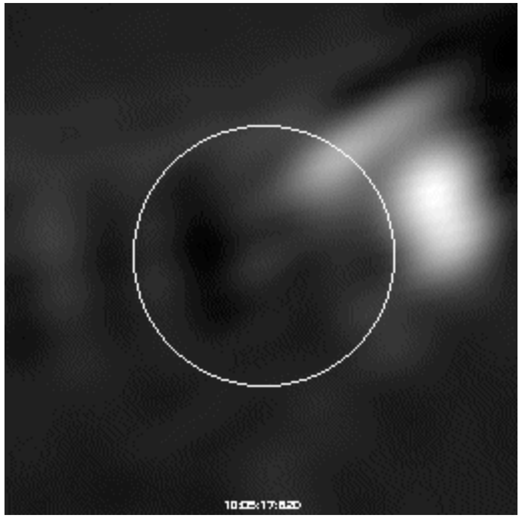


NRH 164 MHz

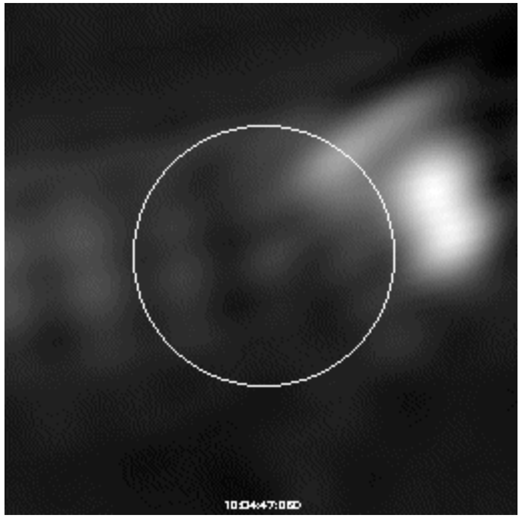
- NRH wave brightest when passing enhanced coronal structures, prolonged radio emission
  → localized energy release has been triggered

What can we learn about the physics of the waves?

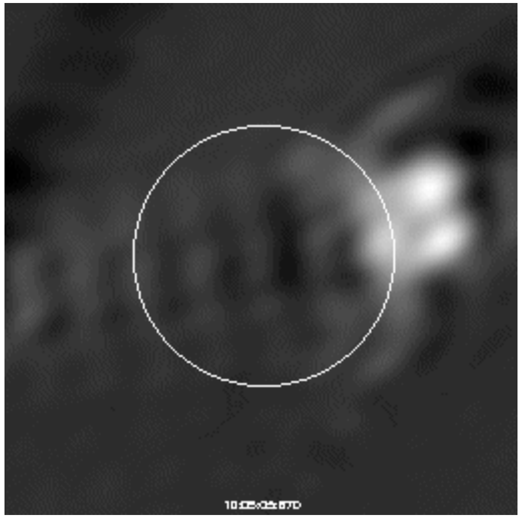
NRH wave brightness



151 MHz



164 MHz



235 MHz

- brighter at lower frequencies
- weaker than type II source by factor of 10 to 1000
- intensity decreases with time/distance by factor of 2-10
- bright & prolonged emission when passing enhanced coronal structures → localized energy release triggered

NRH wave: physical interpretation

- emission stronger at lower frequencies
  → optically thin gyrosynchrotron emission

- connection between wave and type II source
  → fast-mode MHD wave/shock generates signatures

- shock enhances magnetic field and increases electron density and energy
  → enhanced gyrosynchrotron emission

What can we learn about the origin of coronal waves?

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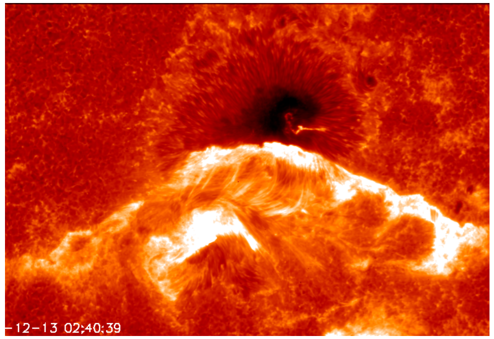
Possible generation mechanisms of global coronal waves

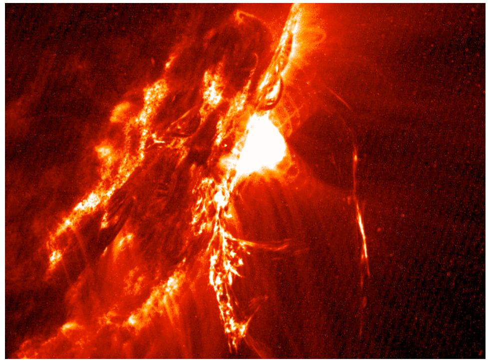
1. Flares

- Plasma or magnetic pressure pulse launching blast wave



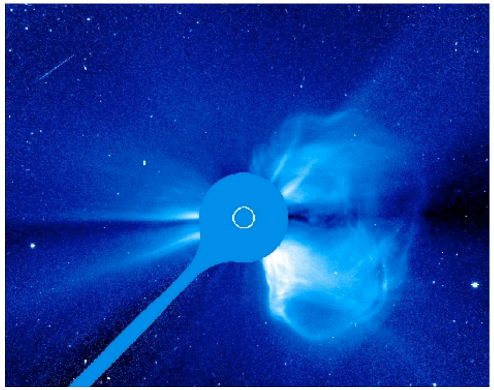
2. Small-scale ejecta

- temporary piston launching blast wave

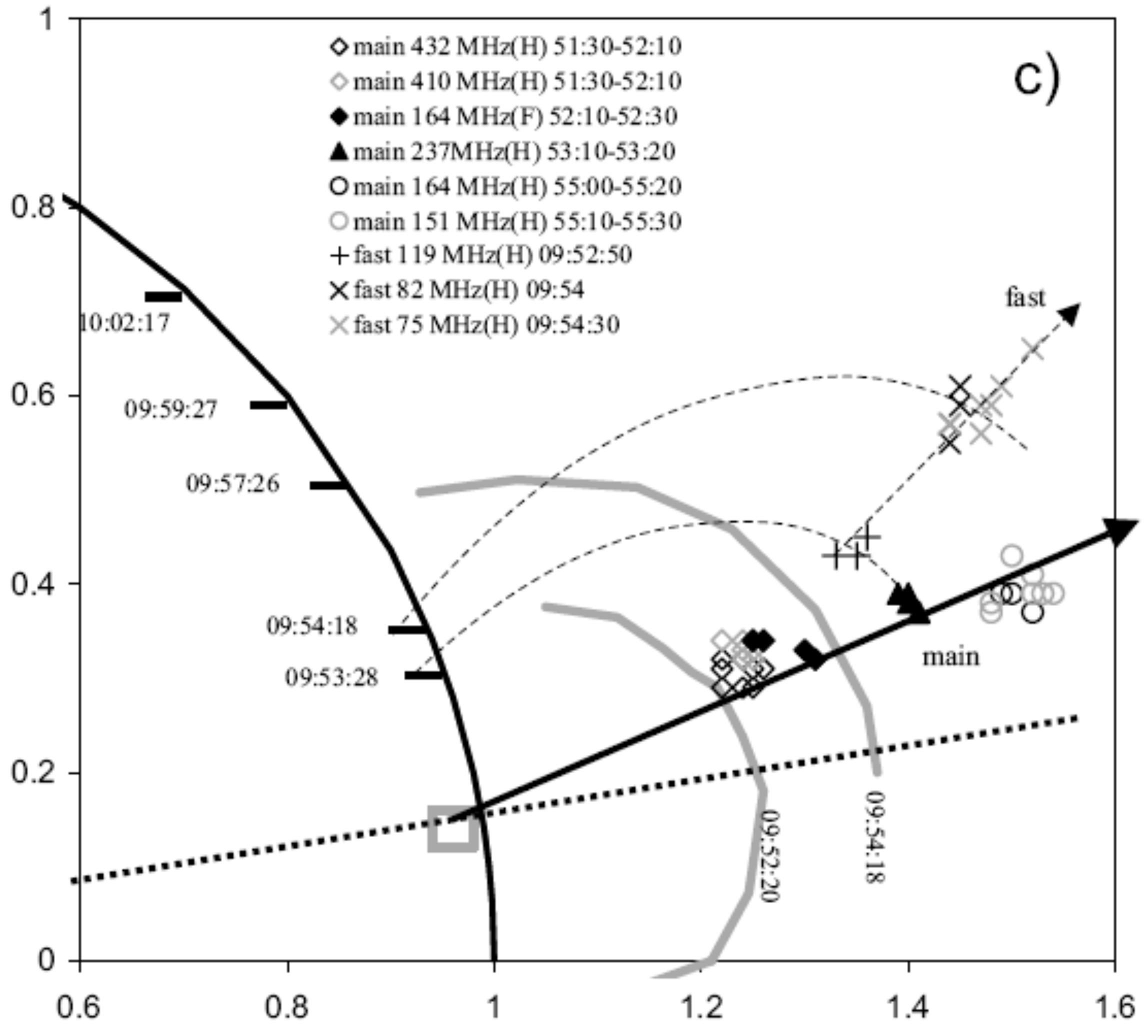


3. CMEs

- piston-driven shock / bow shock
- blast wave (only initially driven)
- successive brightenings due to field line opening/reconfiguration/ reconnection



POS positions of type II sources, wavefronts, and CME fronts



→ type II sources and wavefronts inconsistent with driving by CME

Vrsnak et al. 2006

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Conclusions

- coronal waves can be observed with radioheliographs

- radioheliographic observations offer:
  - complementary information (different emission process)
  - unrivaled temporal cadence
  - precise characterization of type II burst kinematics

- NRH wave supports notion of single physical disturbance creating different wave signatures

- NRH observations link coronal wave to type II-producing shock

Outlook

- search for more events in the existing radioheliographic observations

- use radioheliographic data both for study of waves and associated type II bursts

- upcoming new instruments: LOFAR, FASR

  - use improved spectral resolution to understand emission process