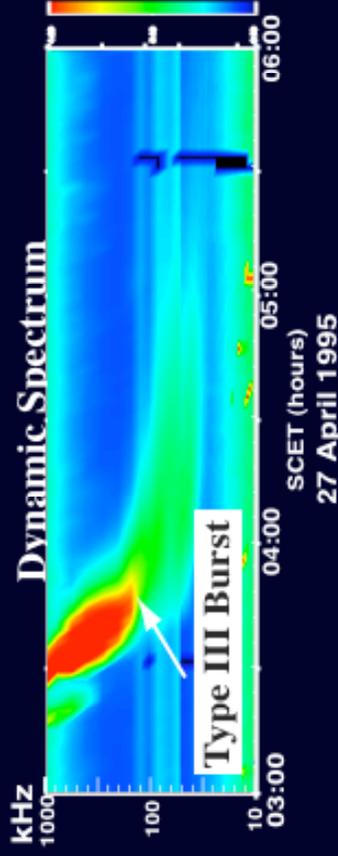
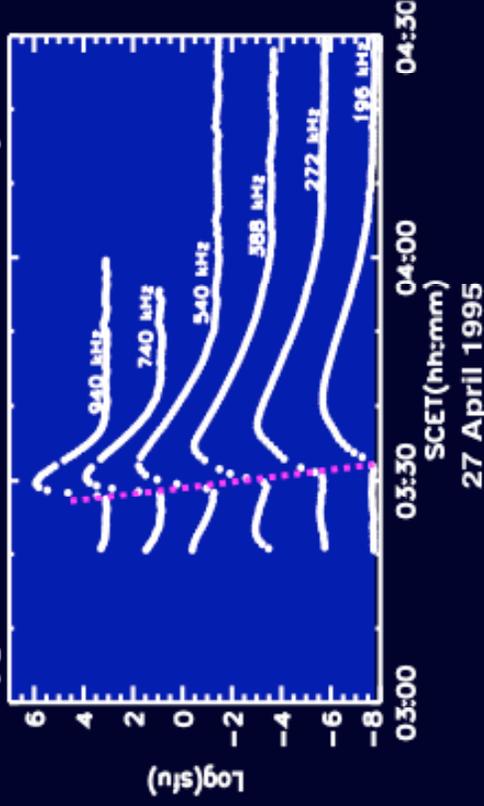


Everything you NEVER wanted to know about Solar Radio Emissions

Most conspicuous solar radio emissions Type III radio bursts



Type III Radio Burst Intensity Profiles



Remote emission

- Diagnostic of coronal electron acceleration
- Signature of propagating suprathermal electrons
- Provide precise timing information
- Provide information on acceleration site

Associated with flares

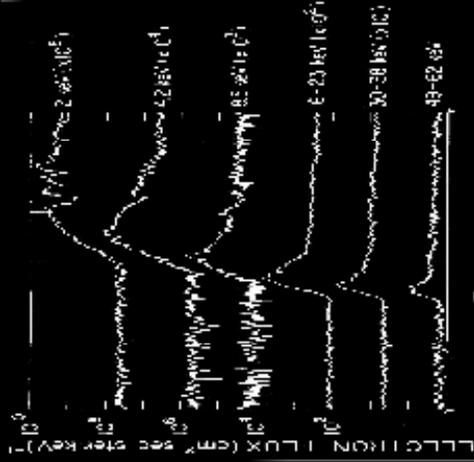
Generated at fundamental & harmonic of plasma frequency by electron beam propagating through IPM

Negative frequency drift rate
⇒ decreasing plasma density

Characteristic Intensity Profile

In-situ Type III Electrons

(Lin et al., ApJ, 308, 954, 1986)

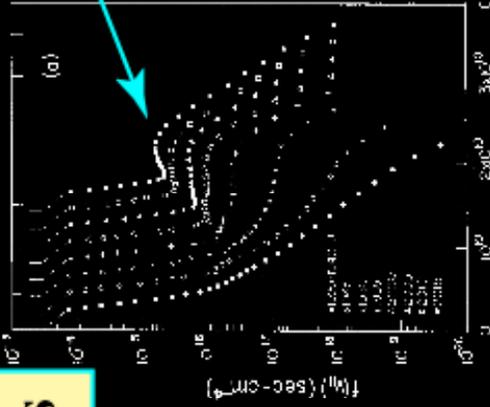


electron velocity dispersion

t_0 = solar release time

L = path length

$\beta = v/c$



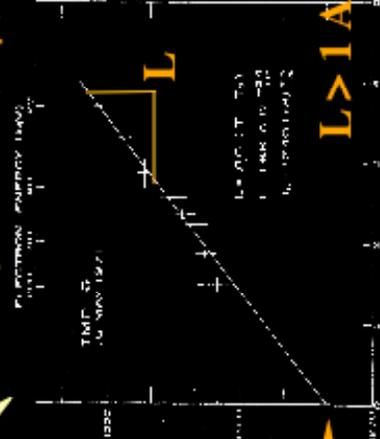
"bump-on-tail" velocity distribution function

Langmuir waves

radio waves

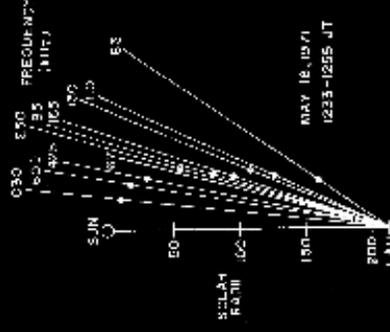
(Lin et al., ApJ, 251, 364, 1981)

$$t - t_0 = L/c (1/\beta)$$



$L > 1 \text{ AU} \Rightarrow$ spiral path

$1/\beta$

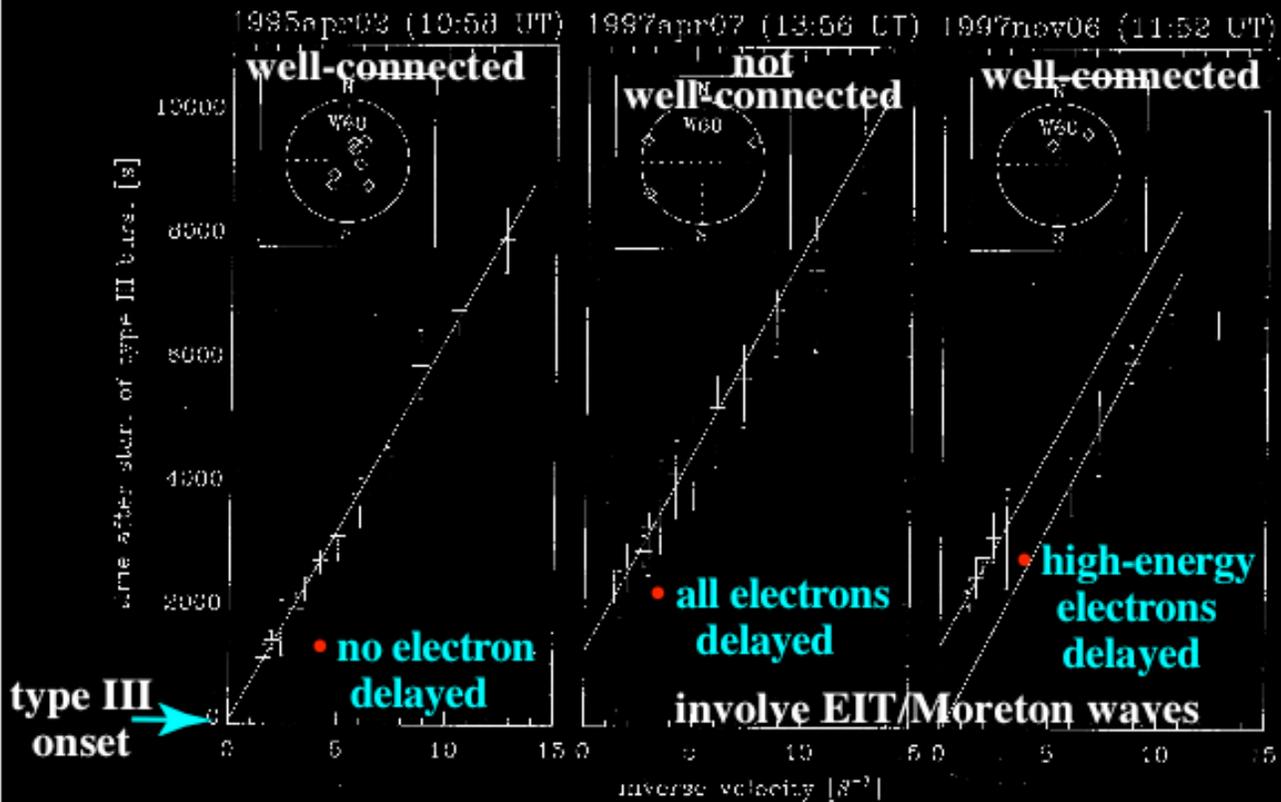


(Lin et al., Astrophys. Lett., 14, 191, 1973)

(Krucker et al., ApJ, 519, 864, 1999)

studied relative timing of remote radio & in-situ electrons

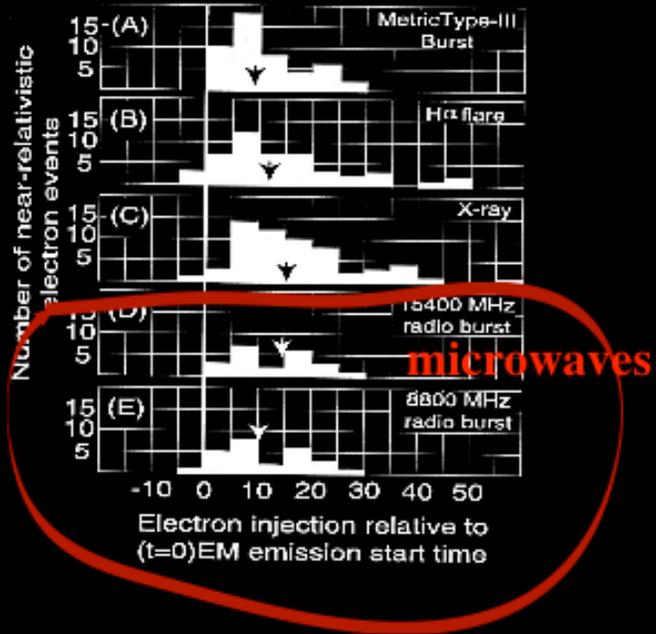
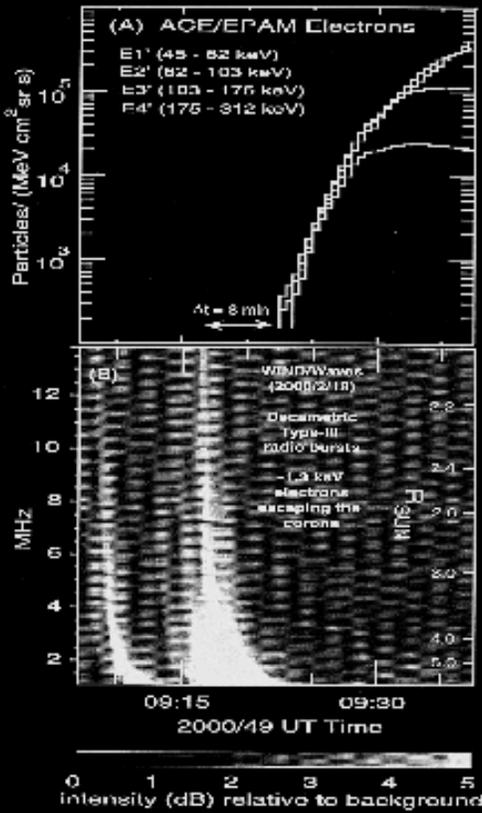
3 - classes of In-situ Electron Events



- coronal electron acceleration more complex than originally thought
- seem to be two populations of accelerated electrons in the corona
 - EIT/Moreton waves seem to be at origin of the different populations

Near-relativistic electrons delayed at ACE

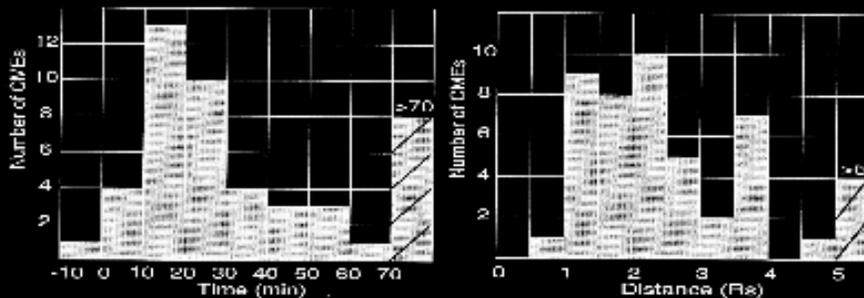
Haggerty & Roelof, ApJ, 579, 841 (2002)



- near-relativistic e- most likely produced by a distinct acceleration mechanism

Near-relativistic electrons accelerated by CMEs

Simnett, Roelof, & Haggerty, ApJ, 579, 854 (2002)



- Quantative characteristics of ACE near-relativistic electrons consistent with CME/shock acceleration from 2 - 4 Rs

e^- delays due to interplanetary transport ?

(Cane, ApJ 598, 1403, 2003)

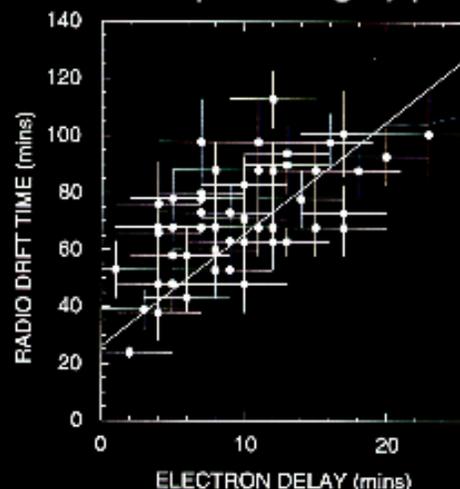
how to understand a second population of accelerated electrons that do not generate type III radio emissions?

Proposed that a single population of electrons are responsible for the generation of the type III emissions AND for the "delayed" electrons observed in-situ

The observed "delays" must be produced during the interplanetary transport of the particles

The observed "delays" in the electrons must be manifested in the frequency drift rate of the corresponding type III bursts

Looked for correlation between type III drift time and "delays"



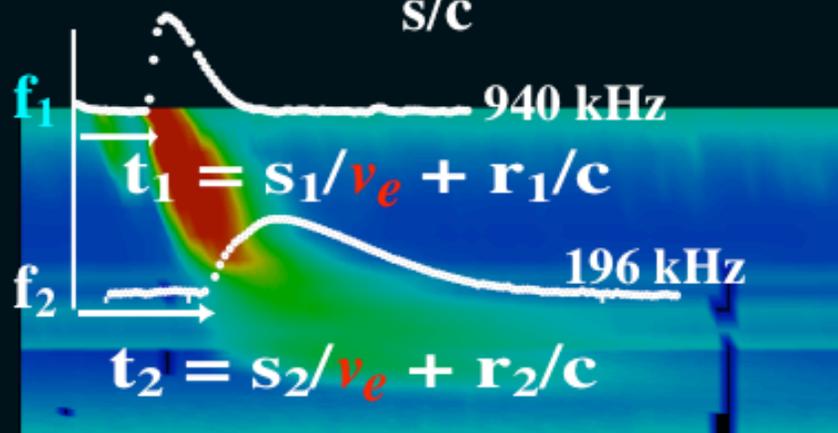
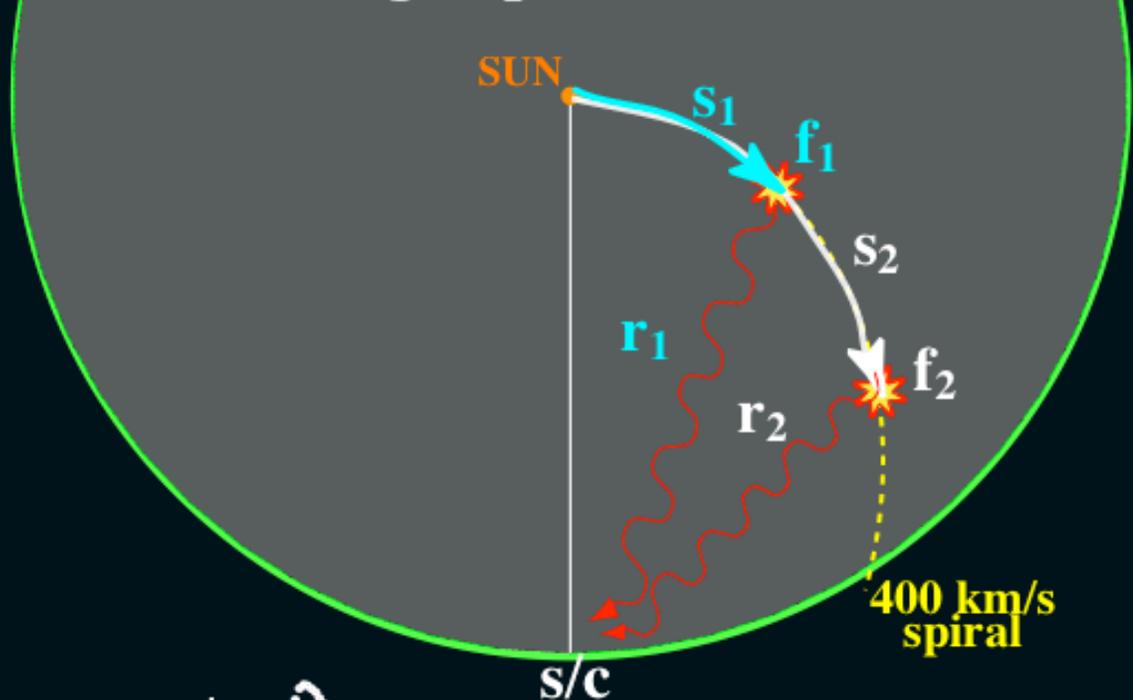
Radio drift time defined as the time between the generation of the radio emissions near the sun and "locally" at 1 AU

The correlation between the radio drift time and the electron "delay" time suggests the delays are produced during interplanetary transport

the argument depends critically on the relation of the frequency drift rate, or exciter speed, to the "delays"

**very simple model to determine the
exciter speed from the type III
frequency drift rate**

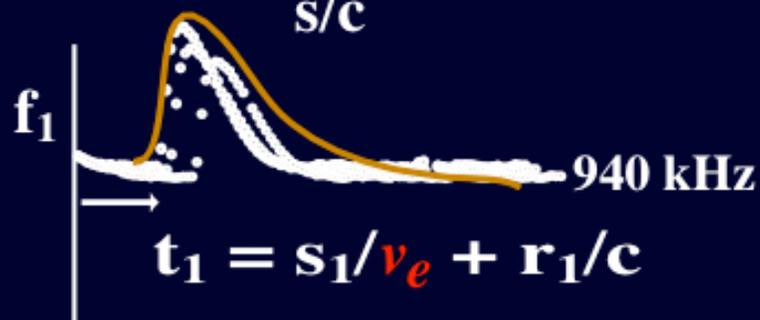
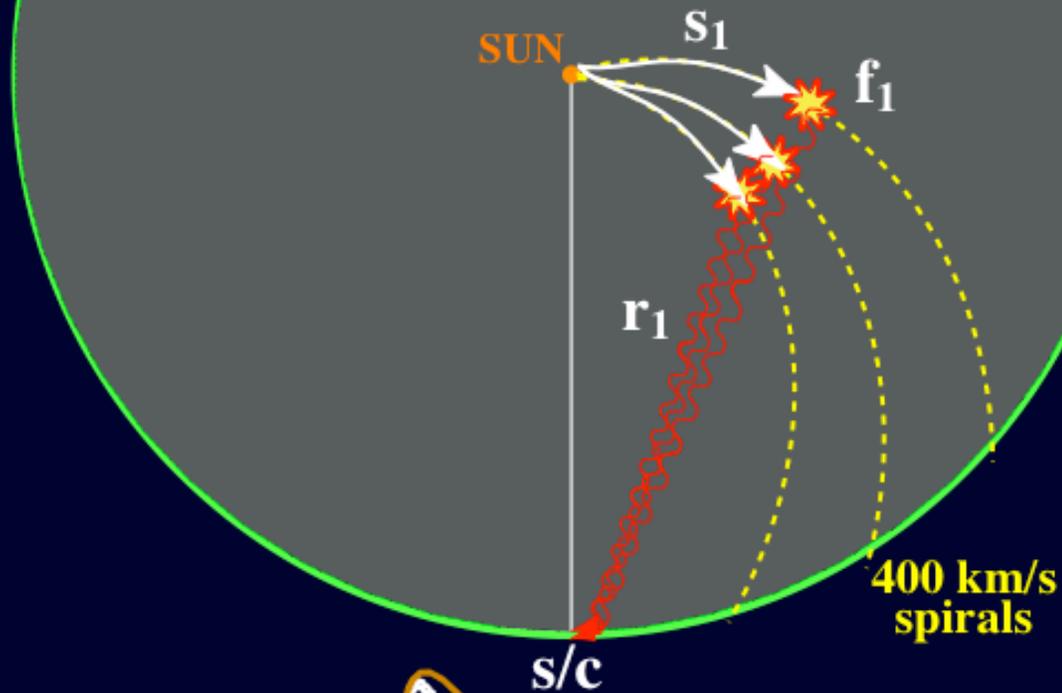
assume that e^- beam propagates along
a single spiral field line



using this method, together with a density
model, the e^- exciter speed, v_e , can be
precisely determined

**more realistic model of the
type III frequency drift rate taking
into account the finite beamwidth**

the e^- beam propagates along
many different spiral field lines

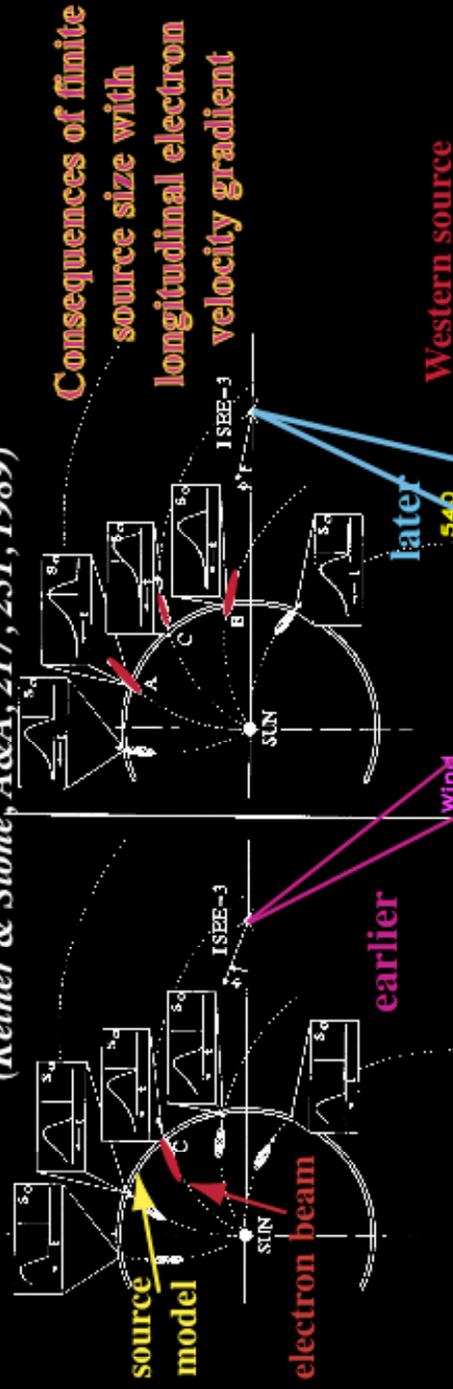


the type III profile is now a **superposition**
of many individual source profiles

What is the correct onset time?

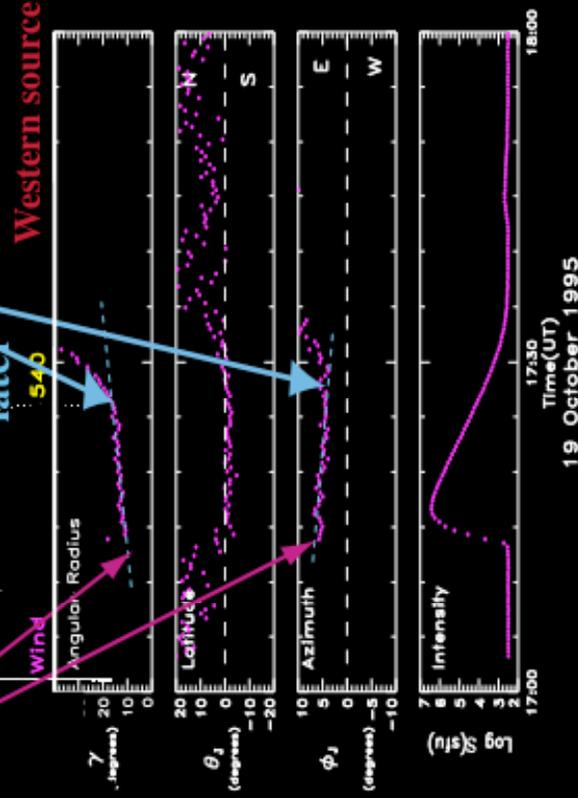
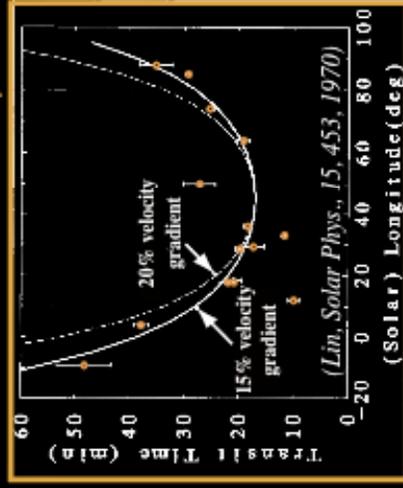
Model for finite type III radio source: II

(Reiner & Stone, A&A, 217, 251, 1989)



Consequences of finite source size with longitudinal electron velocity gradient

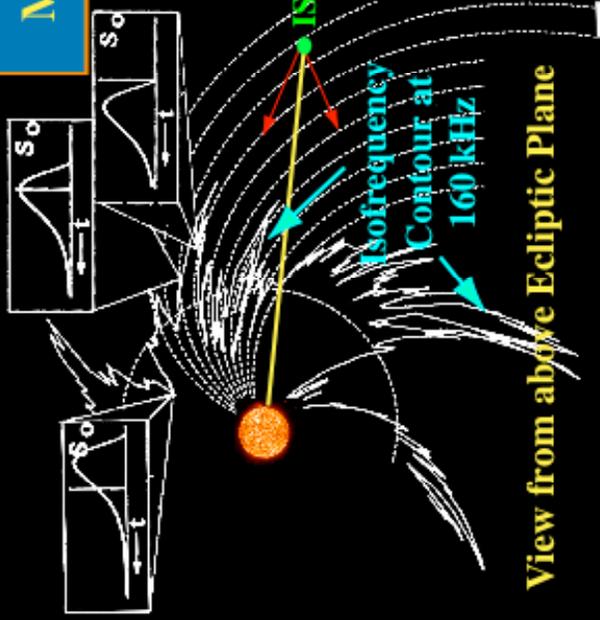
Measured transit times for 14 electron events observed over 8 days



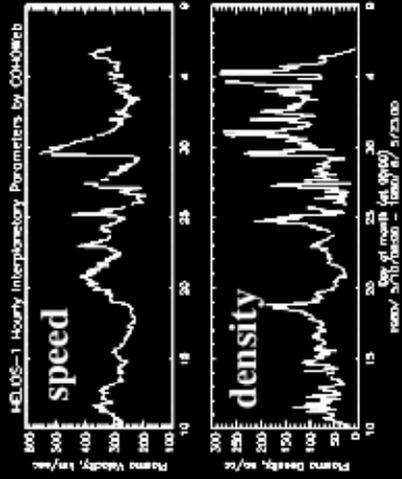
Electron & radio observations suggest a 15 - 20% velocity gradient

Model for finite type III radio source: III

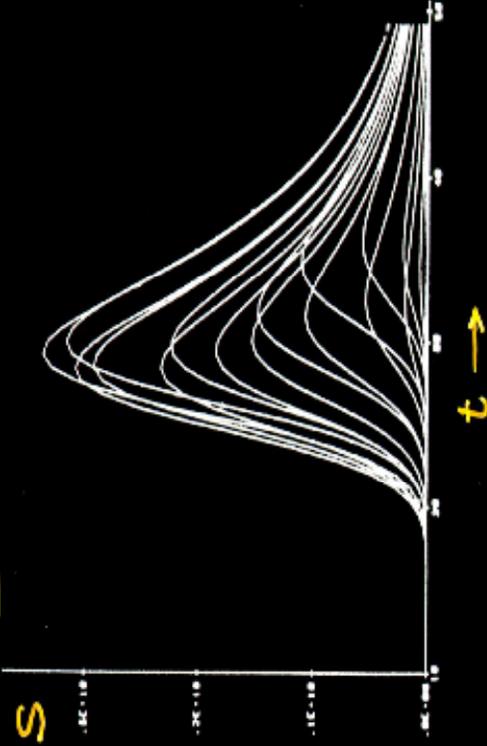
(Reiner, Space Sci. Rev., 97, 129, 2001)



View from above Ecliptic Plane



Helios I Solar Wind Parameters



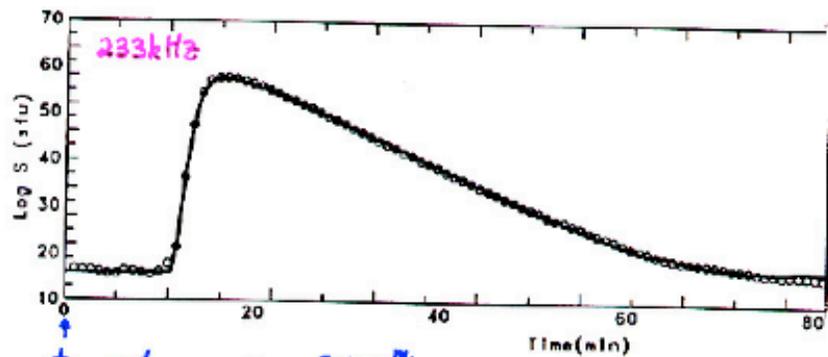
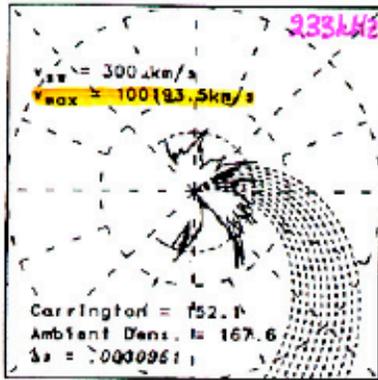
Radio intensity at s/c is superposition of contributions from each source element with different amplitude and time displacement

Determination of Exciter Velocities

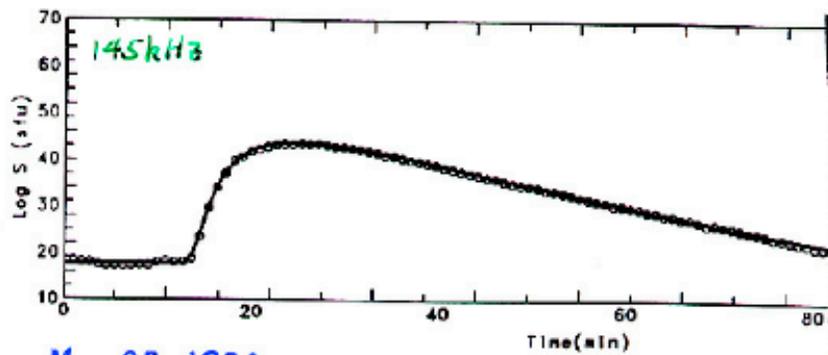
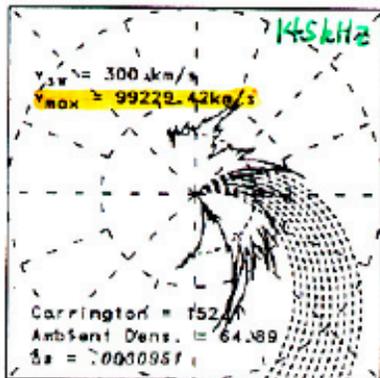
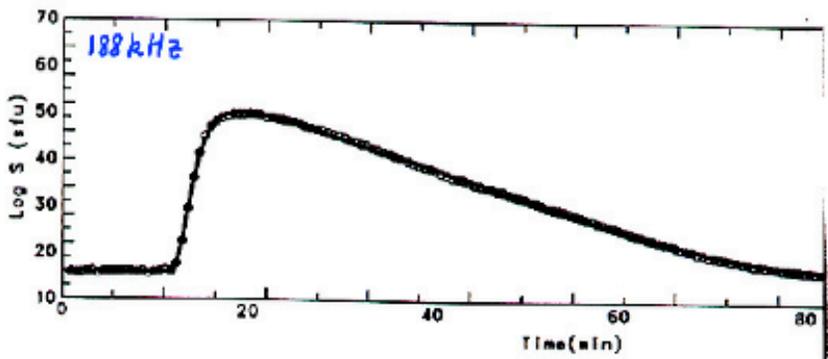
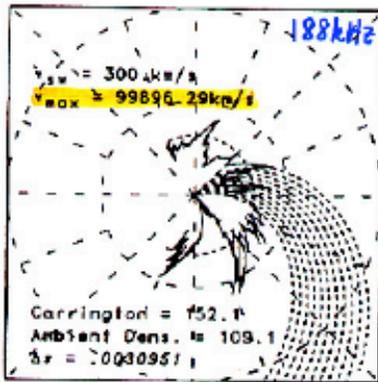
Exciter velocity enters model through

$$t_{oi} = t_{sun} + \frac{S_i}{v_i} + \frac{d_i}{c}, \text{ where } v_i = v_{max} e^{-\epsilon(\theta_i - \theta_c)^2}$$

Vary v_{max} (and intensity profile param.), while keeping model param. fixed, until model burst profile fits observed burst profile at each freq.

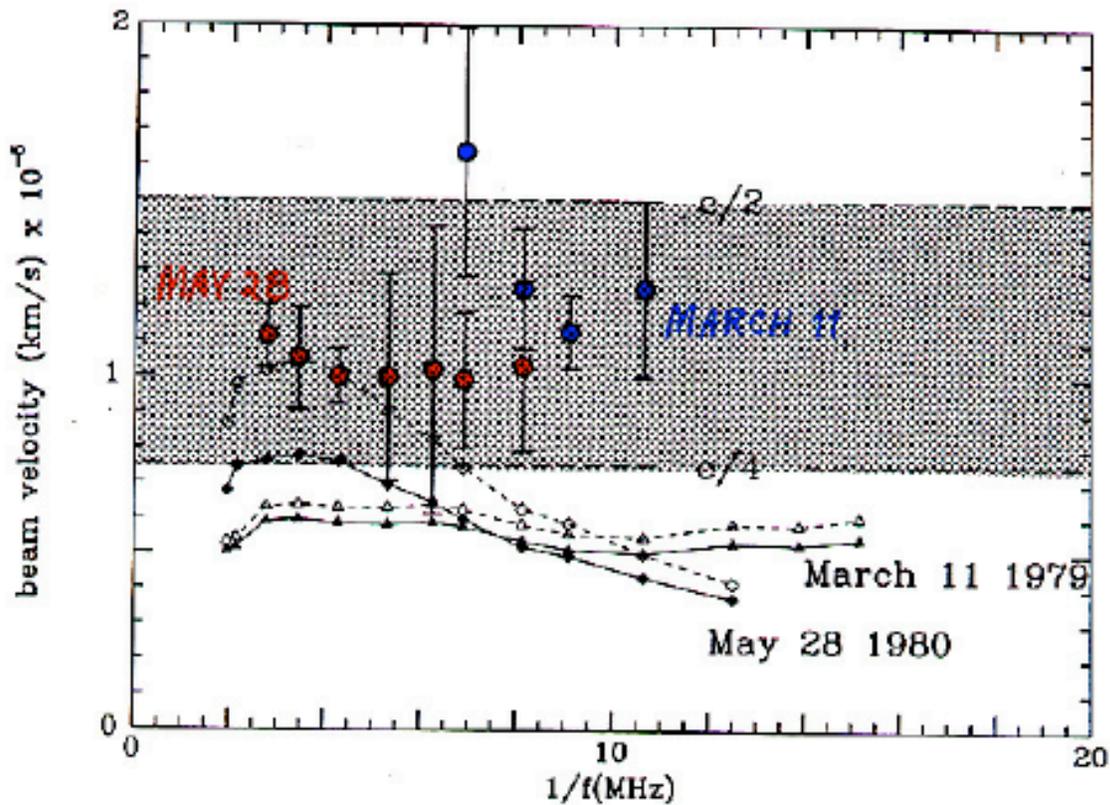


$$t_{sun} = t_{metric III} - 8.333^m$$



MAY 28, 1980

III. Preliminary Results



Assume emission at harmonic, $2f_p$

MAY 28 Event:

- exciter velocity \approx const = $c/3$, independent of frequency

MARCH 11 Event:

- Velocities higher than Dulk et al
- Seems to be a deceleration, but error are large

(Cane, ApJ 598, 1403, 2003)

(Cane & Erickson, JGR 108, A5, 2003)

Cane does not use the frequency drift along the type III burst, but only one point, when the type III frequency reaches the local plasma frequency

It is argued that that this corresponds to "local" radiation, i.e., radiation very near the s/c

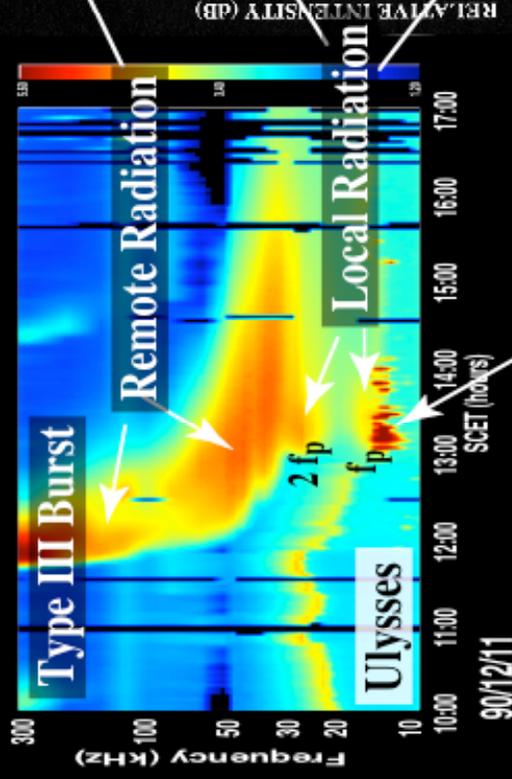
"...we suggest that any emission near the observer's local plasma frequency is locally generated."

Two problems:

- **Radiation at the local plasma frequency is not necessarily "local" emission**
- **Propagation and other effects can be very important at low frequencies**

Local Type III Solar Radio Emissions

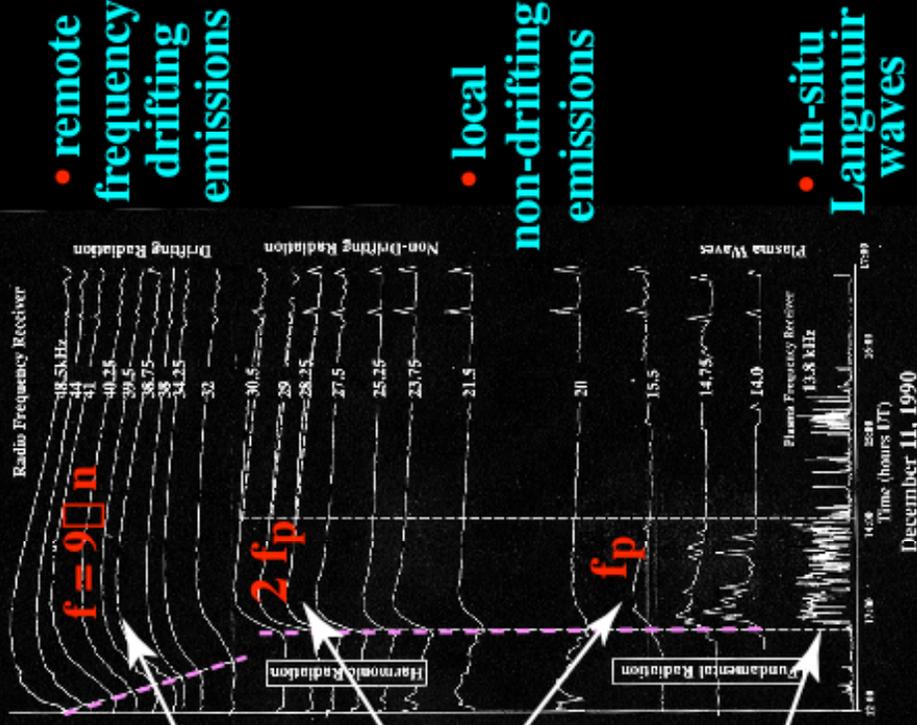
(Reiner et al., *Astrophys. J.*, 394, 340, 1992)



Langmuir Waves

Stochastic-Growth Theory (SGT) provides a framework for describing

- burstiness of LWs
- spatial nonuniformity (clumpiness) of LWs

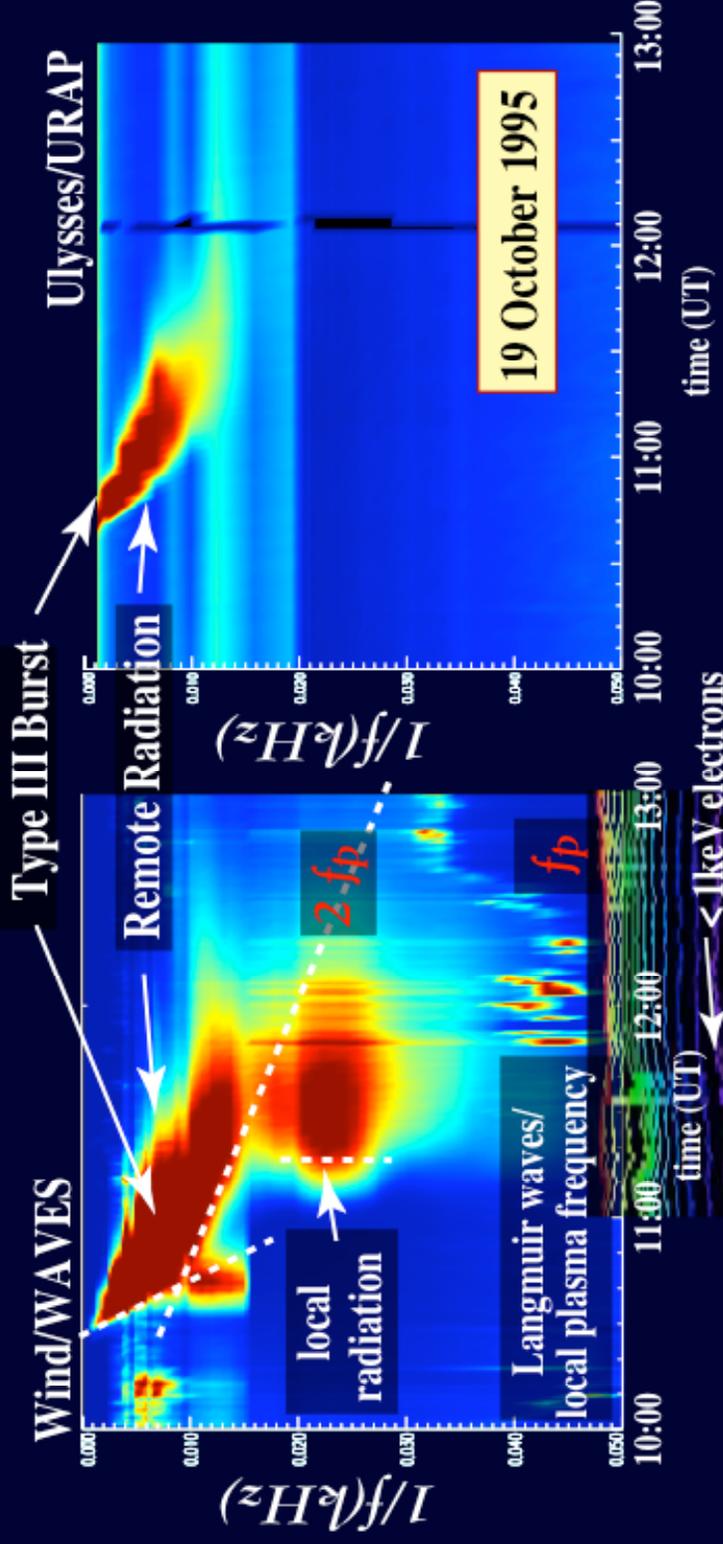


- remote frequency drifting emissions

- local non-drifting emissions

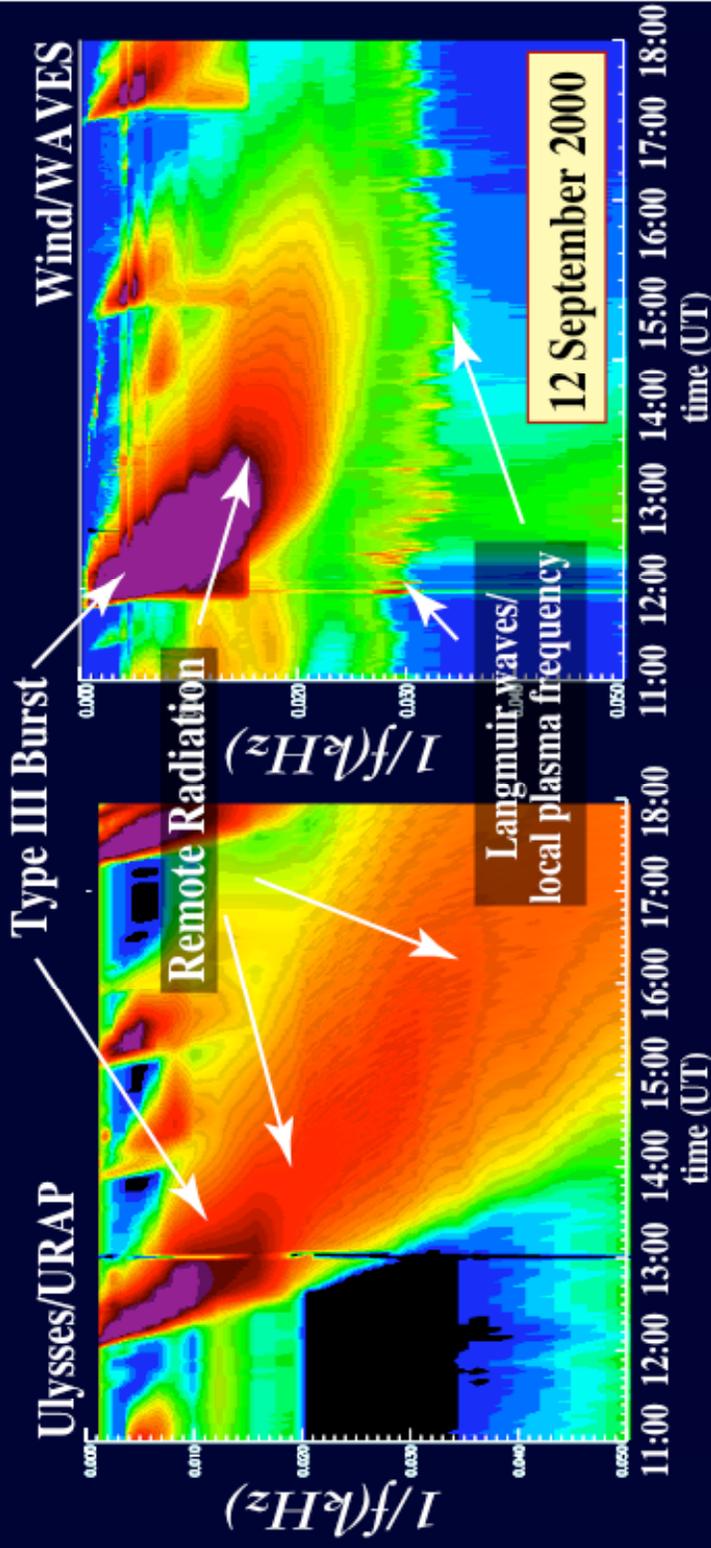
- In-situ Langmuir waves

Local Type III Solar Radio Emissions II



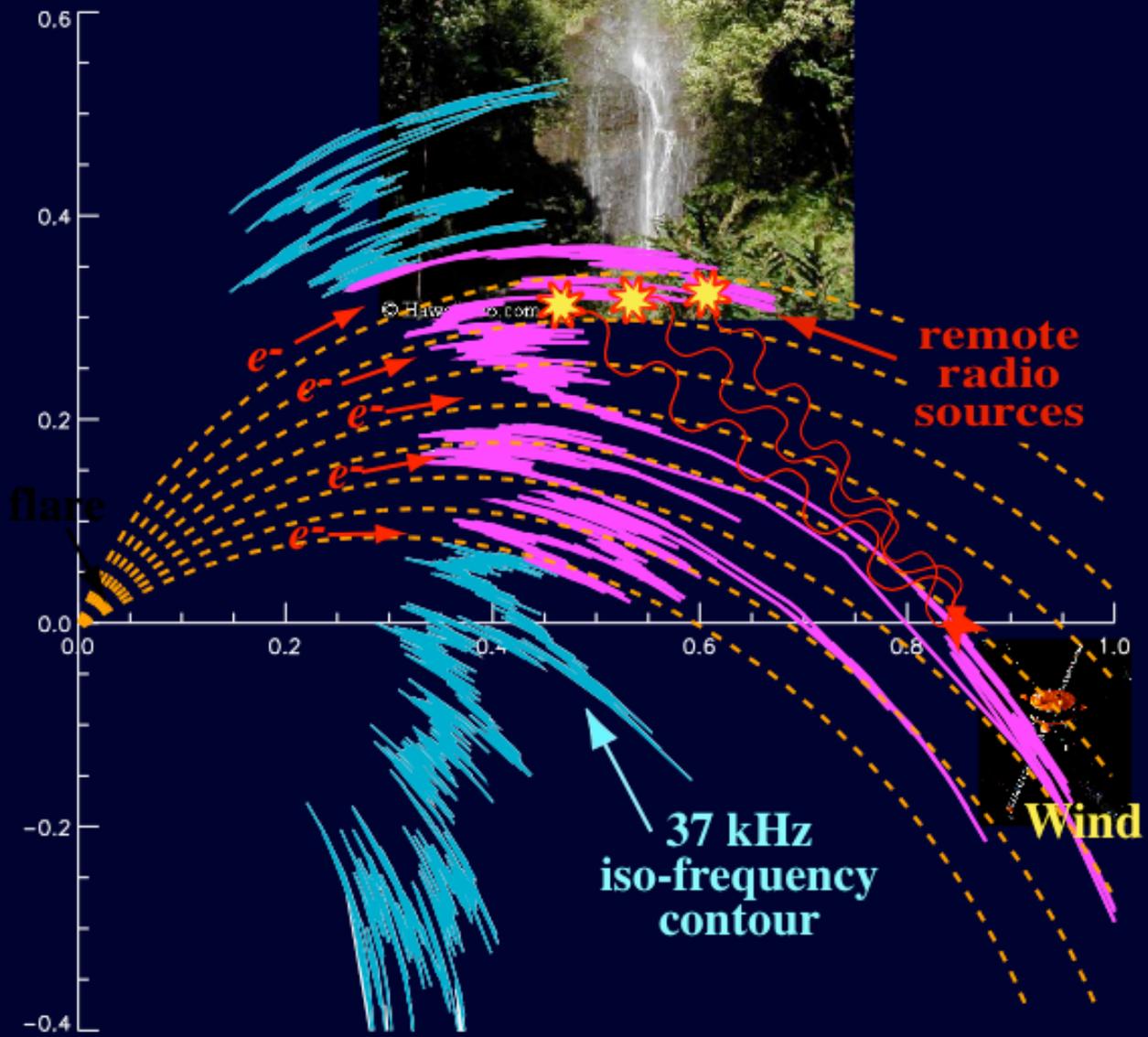
- Both Wind & Ulysses observe the remote type III radiation
- Local (in-situ) emissions are observed at Earth at the 2nd harmonic of the plasma frequency
- Ulysses does not observe the local radio emissions, seen by Wind

Remote Type III Solar Radio Emissions II



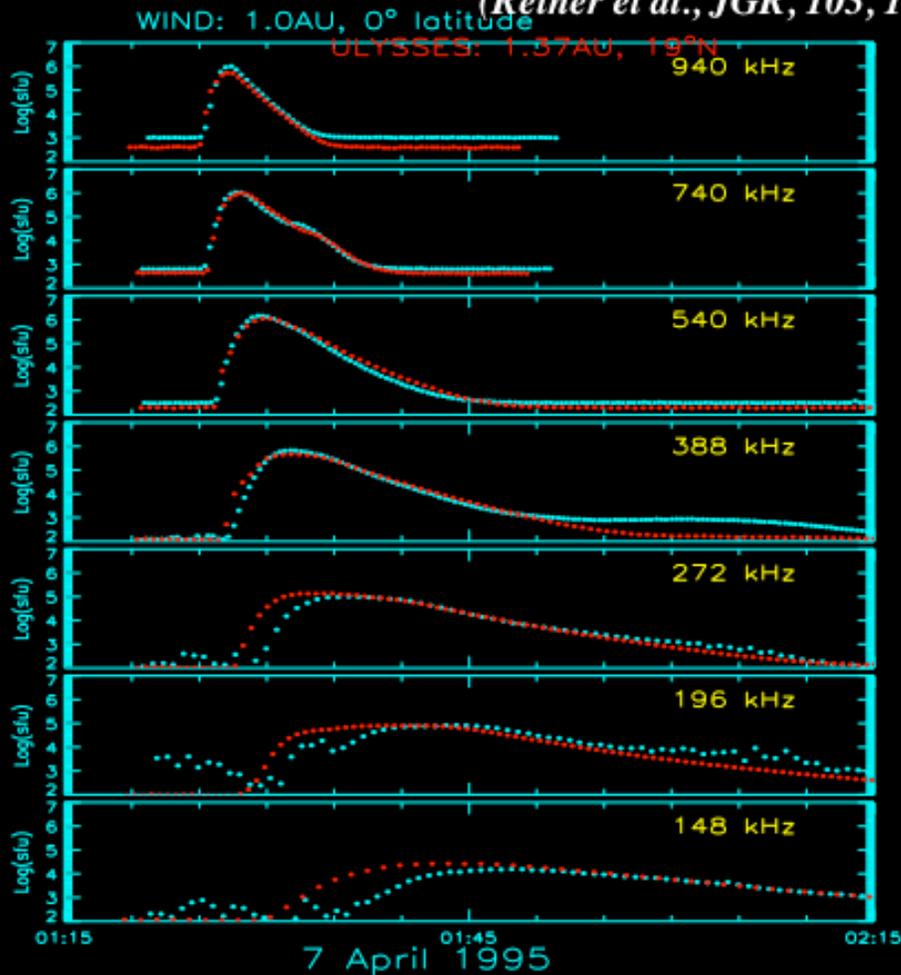
- Both Wind & Ulysses observe the remote type III radiation
- On Ulysses local plasma density is very low, so the type III radiation extends to very low frequencies
- On Wind low-frequency type III radiation is cutoff by the local plasma density

*Wailua Falls
Maui*



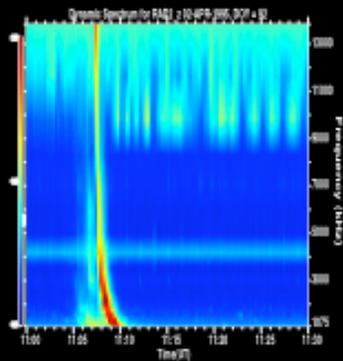
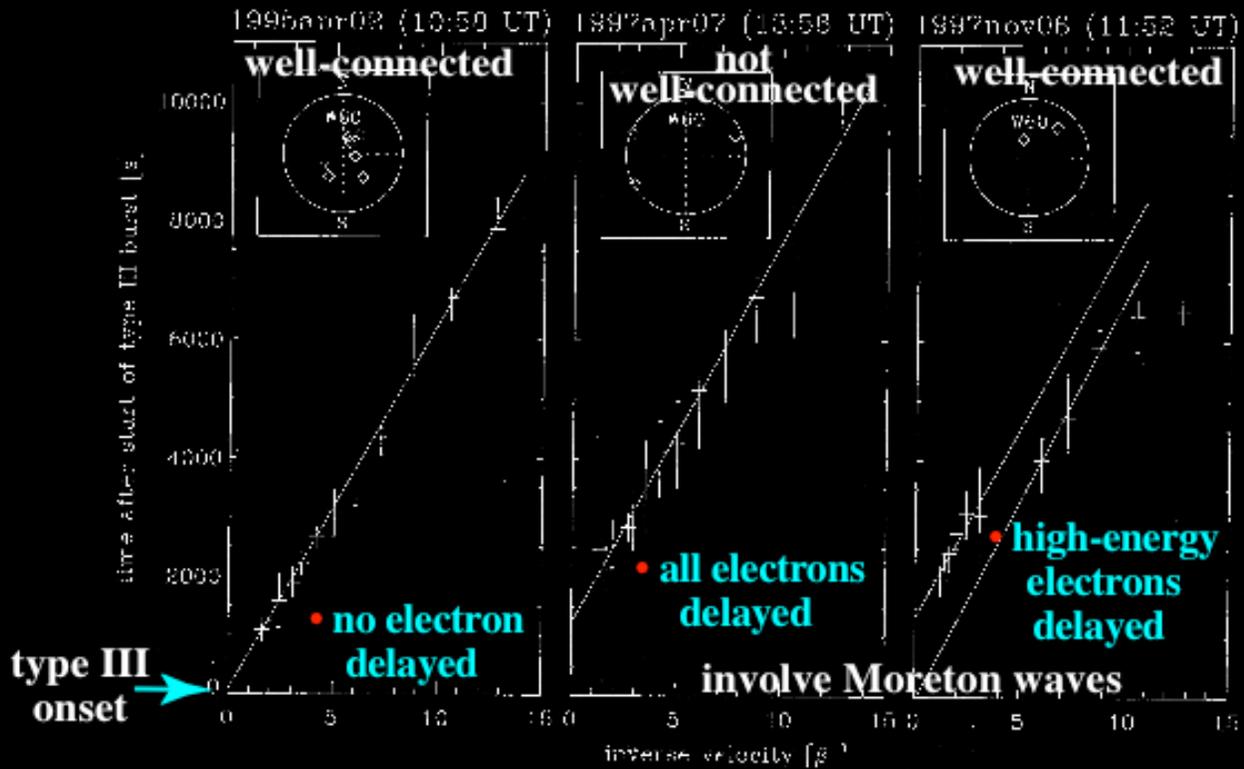
Results of Triangulation of type III burst from Wind & Ulysses

(Reiner et al., JGR, 103, 1923, 1998)

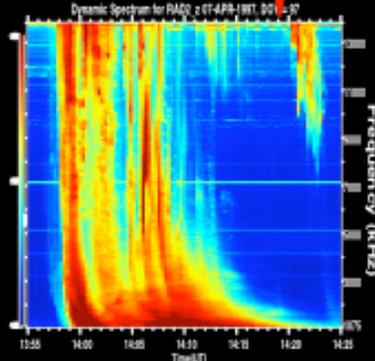


- At high frequencies the burst profiles observed at Wind & Ulysses exactly correspond when light propagation times are taken into account
 - At low frequencies the burst profiles are more complex showing evidence for multiple components and even when light propagation times are taken into account
- ⇒ dangerous to use low-frequency type III burst profiles to make quantitative physical arguments

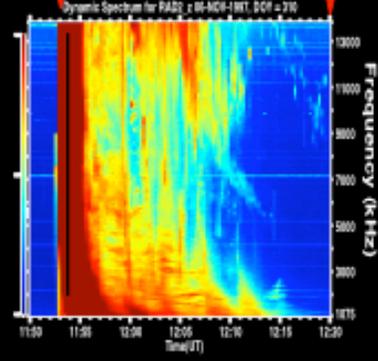
Back to the Corona



simple
type III



complex type III-like bursts



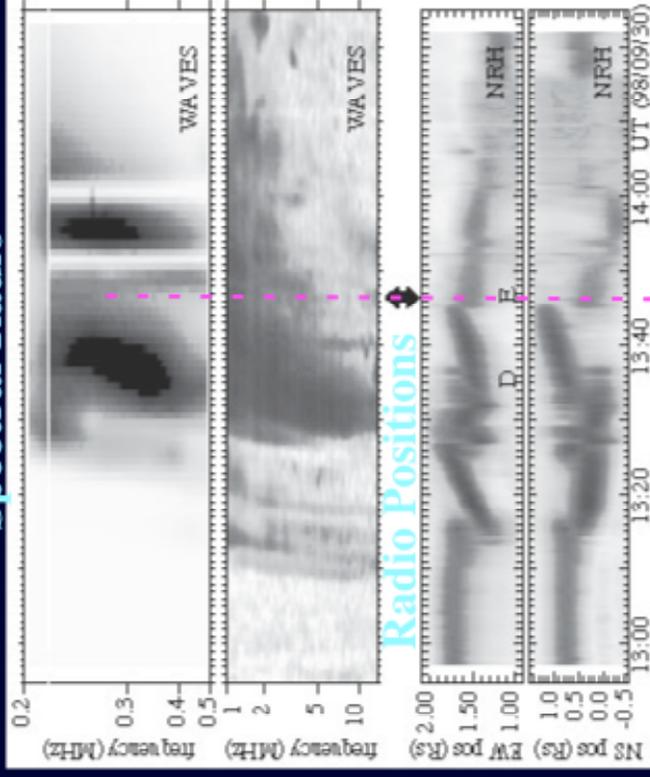
Complex type III-like bursts appear to be generally produced by electrons accelerated over extended periods of time low in corona, near the flare site

⇒ "delays" may result from complex acceleration processes in the low corona

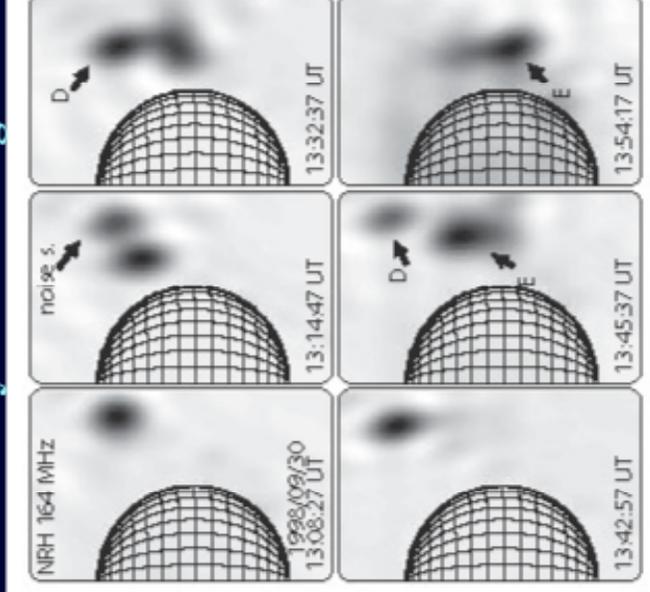
Radio Evidence for Coronal Acceleration of delayed electrons

(Maia & Pick, *ApJ* 609, 1082, 2004)

Spectral Radio



Nancay Radio Images



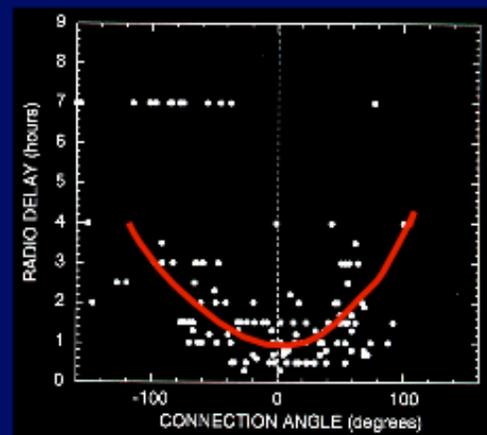
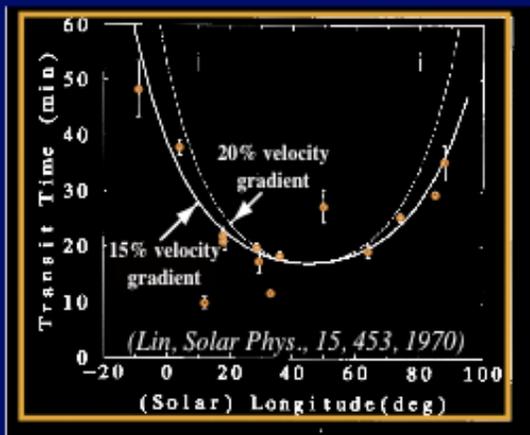
! ← inferred e^- injection

- for complex events, inferred release time of NR electrons occurred at start of abrupt radio modifications suggesting new sources of coronal acceleration
- delayed acceleration of NR electrons results from coronal restructuring behind the leading edge of the CME

Summary

Interplanetary Transport

- No convincing evidence for significant delays produced during interplanetary transport
- However, need to look carefully at transport models, particularly in comparison with the radio emissions



- Note different time scales: anomalous electron delays require an $\sim 100\%$ velocity gradient across the beam
- Probably impossible to model complex type III events

Coronal Acceleration

- Number & diversity of coronal radio sources suggest that coronal acceleration of particles is a very complex and multi-faceted process
 - Best chance for success is from multi-frequency studies using both spectral & image radio data, together with white-light, X-ray, EUV
 - Still very preliminary