Type III burst time characteristics at LOFAR frequencies.

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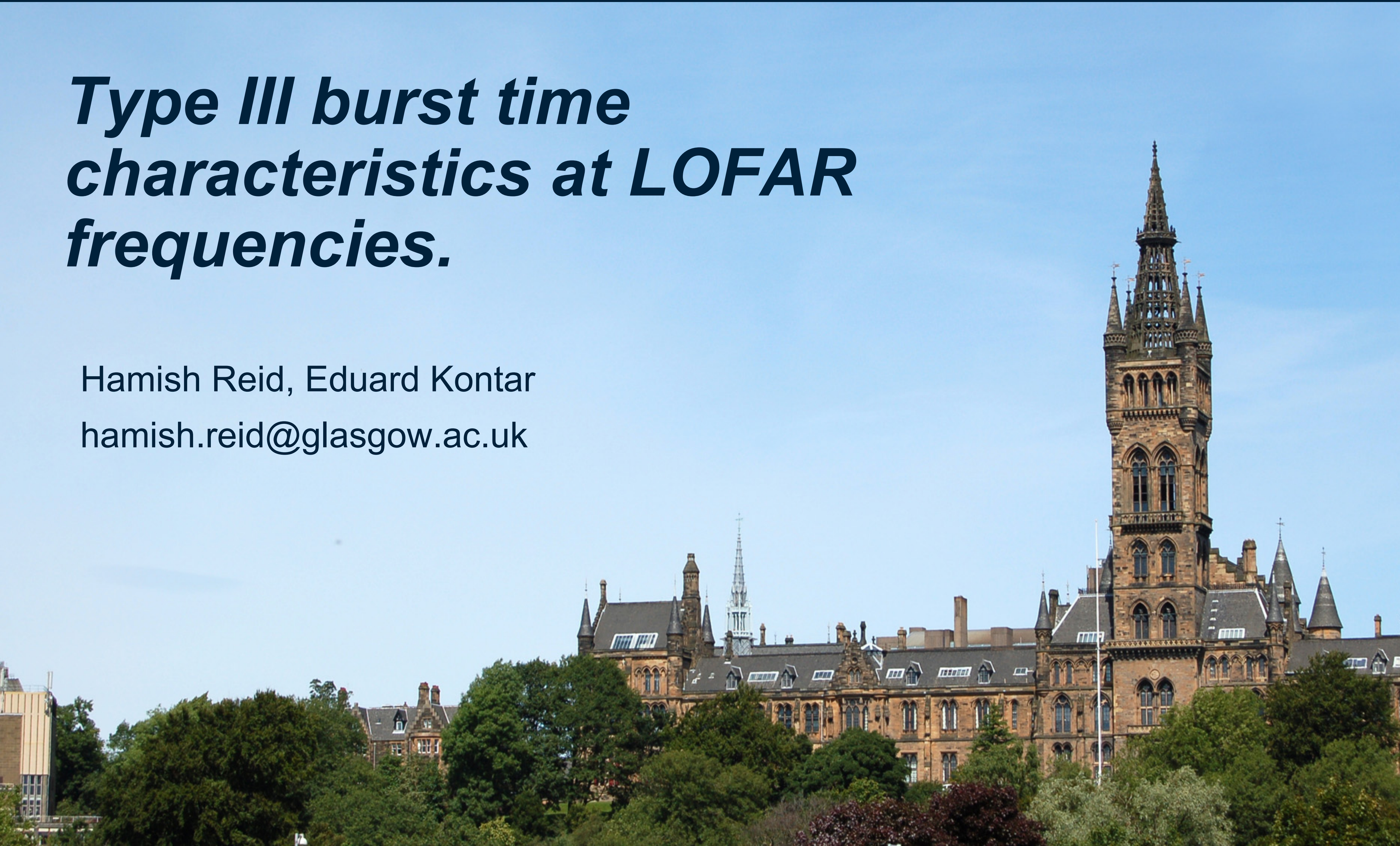
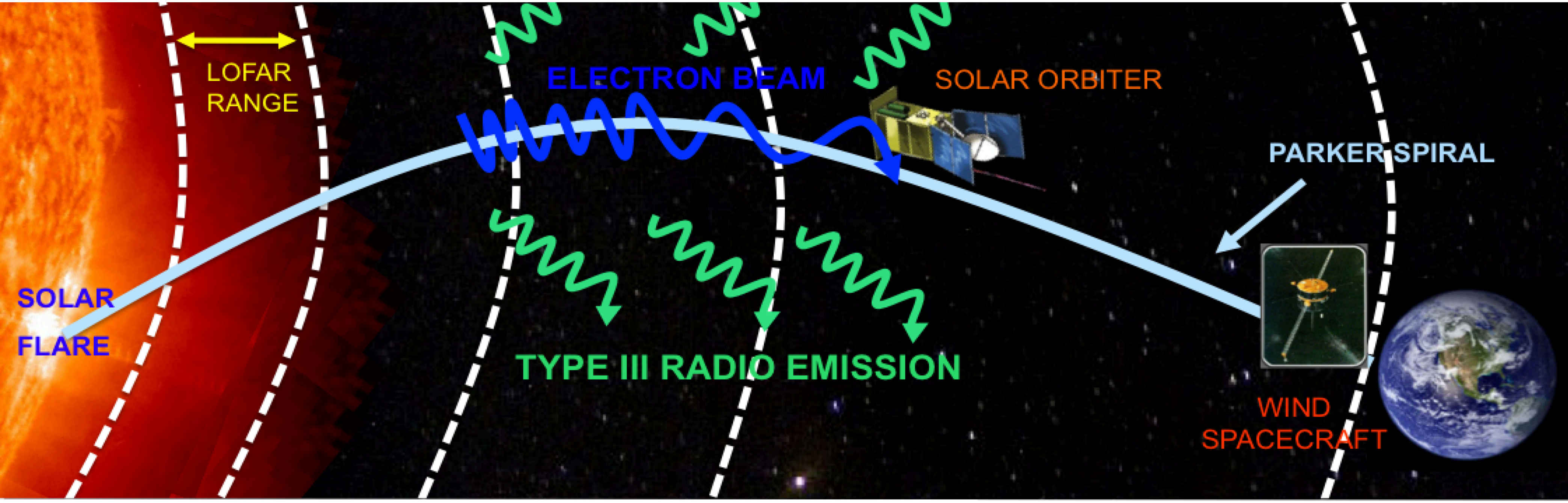


Solar Electron Beams

Solar electron beams propagate through the heliosphere and can be detected in-situ and via their electromagnetic emission. Theory was proposed by Ginzburg & Zheleznikov 1958.



250 MHz	0.16 R_{SUN}	1.2x10^8 m	MID CORONA
10 MHz	1.5 R_{SUN}	10^9 m	HIGH CORONA
1 MHz	7.5 R_{SUN}	5.7x10^9 m	INTER-PLANETARY SPACE
0.15 MHz	0.18 AU	2.7x10^{10} m	ORBIT OF MERCURY
0.02 MHz	1.2 AU	1.8x10^{11} m	PARKER SPIRAL LENGTH AT EARTH

Motivation

- Type III bursts frequency-time evolution can provide a wealth of information about solar electron beams.

- The peak radio flux has been used to provide bulk speed estimates but what about the rise and decay?

- Can we use these to estimate how different parts of the electron beam (e.g. front and back) move through the corona?

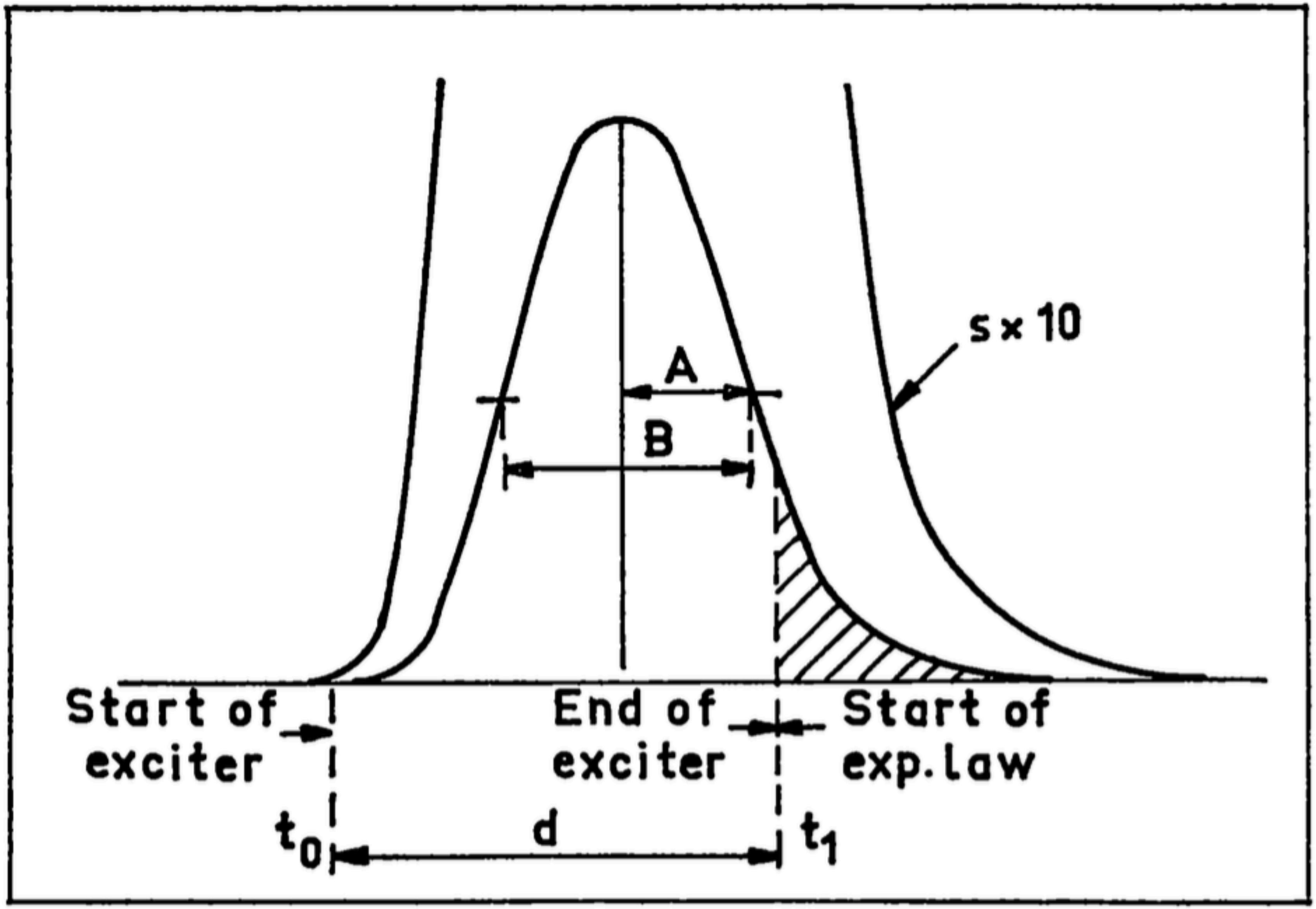
- Reid and Kontar 2018, A&A, http://arxiv.org/abs/1802.01507

Type III time profile

- The time profile of type III radio bursts has been studied by numerous authors *e.g. Hughes & Harkness 1963; Aubier & Boischot 1972; Evans et al. 1973; Alvarez & Haddock 1973a; Barrow & Achong 1975; Poquerusse 1977; McLean & Labrum 1985; Tsybko 1989; Melnik et al. 2011*

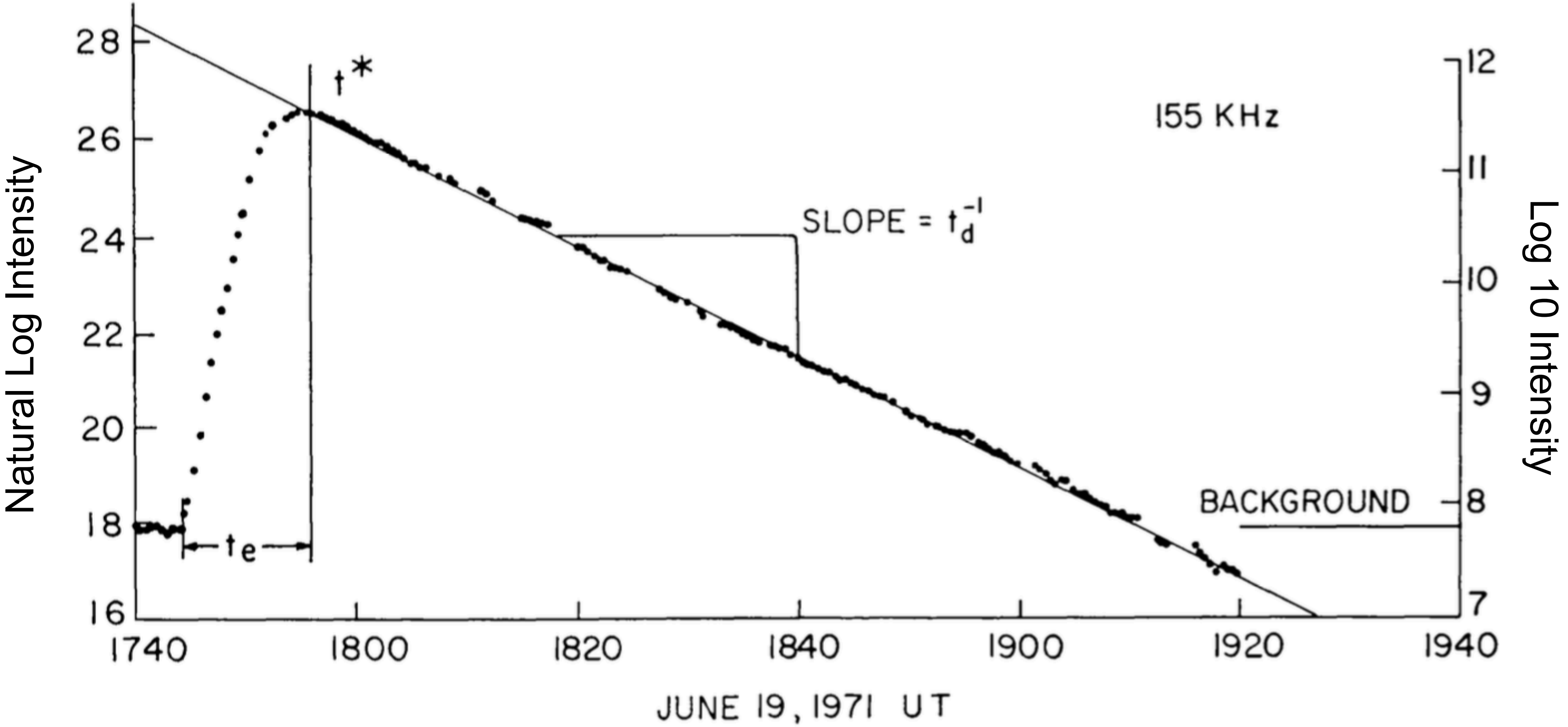
- Typically attributed to an exciter function followed by an exponential decay.

Type III time profile



Aubier & Boischot 1972

Type III time profile



Evans et al 1972

$$t_e = (4.0 \pm 2.7) \times 10^8 \, f^{-(1.08 \pm 0.05)}$$

$$t_d = (2.0 \pm 1.2) \times 10^8 \, f^{-(1.09 \pm 0.05)}$$

2.8 – 0.067 MHz

Exponential Decay

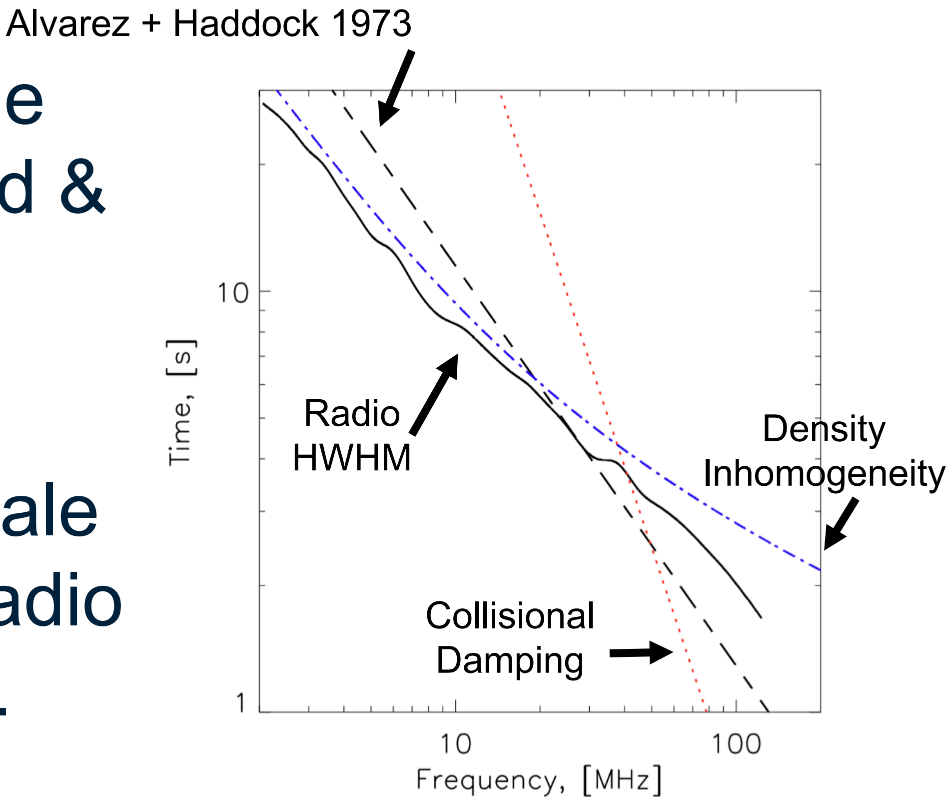
- Langmuir wave collisional time – estimate temperature.
- Studies *(e.g. Evans et al. 1973; Alvarez & Haddock 1973a; Takakura et al. 1975; Poquerusse et al. 1984; Ratcliffe et al. 2014)* found incorrect temperature, particularly at 1 AU.

- Scattering from source-observer (e.g. Kontar et al 2017).

- Density inhomogeneity….

Density Inhomogeneity

- Large scale density inhomogeneities (expanding solar wind, length scales > Mm) refract Langmuir waves to lower phase velocities - Landau damped. e.g Kontar 2001

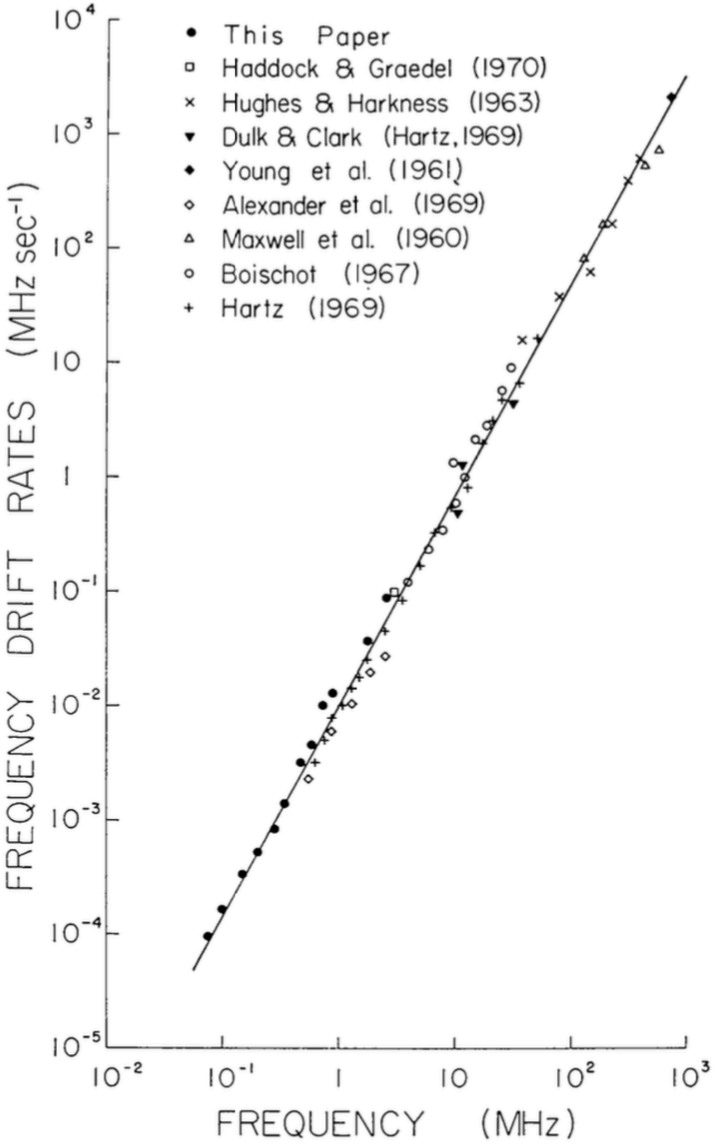


- Energy is depleted from the the beam-plasma system e.g. Reid & Kontar 2010, 2013.
- Density inhomogeneity timescale is similar to the HWHM from radio emission (Ratcliffe et al 2014).

Type III drift rate

- Drift rate varies as a power-law over many orders of magnitude e.g. Alvarez and Haddock 1973, Achong & Barrow 1975; Melnik et al. 2011

$$\frac{\mathrm{d}f}{\mathrm{d}t} = -0.01 f^{1.84}, \quad \mathrm{MHz\,s^{-1}}$$



Type III bursts

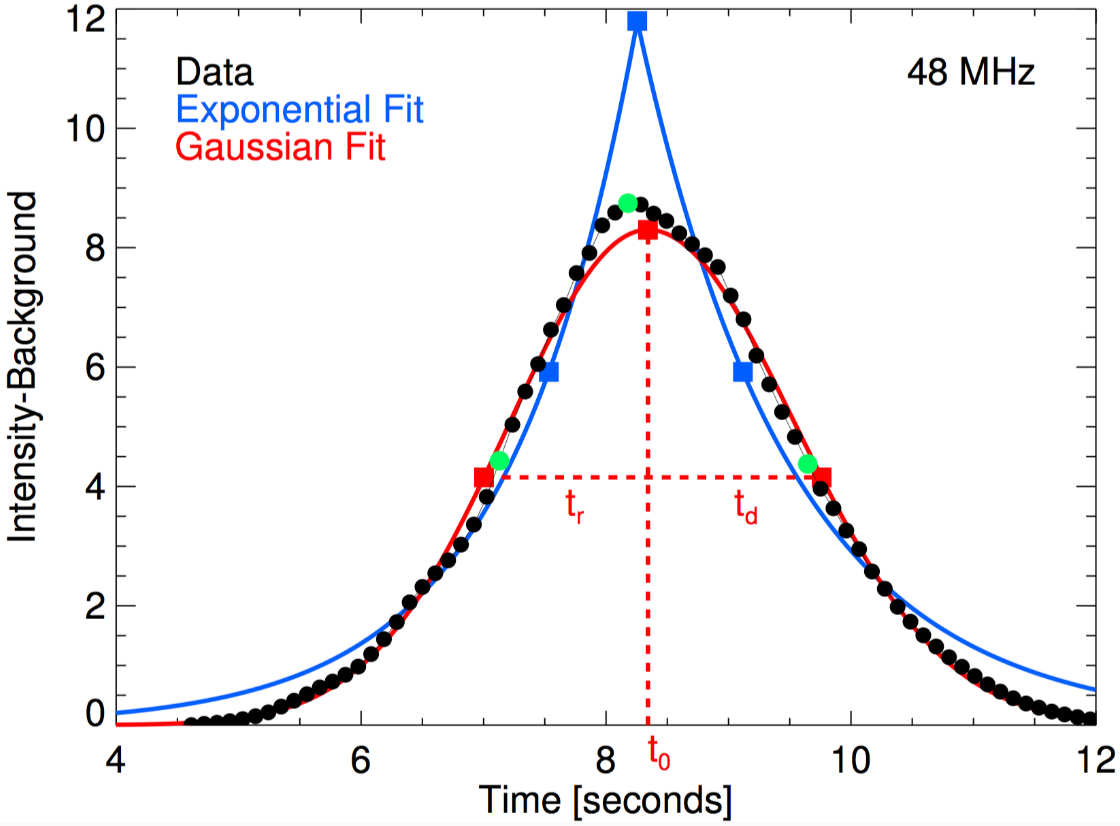
- We selected 31 type III bursts between April-Sept 2015.
- Frequency range within 70-30 MHz.
- Time resolution of 0.1 sec, integrated from 0.01 sec.
- Freq resolution of 0.195 MHz integrated from 12 kHZ.

Time profile

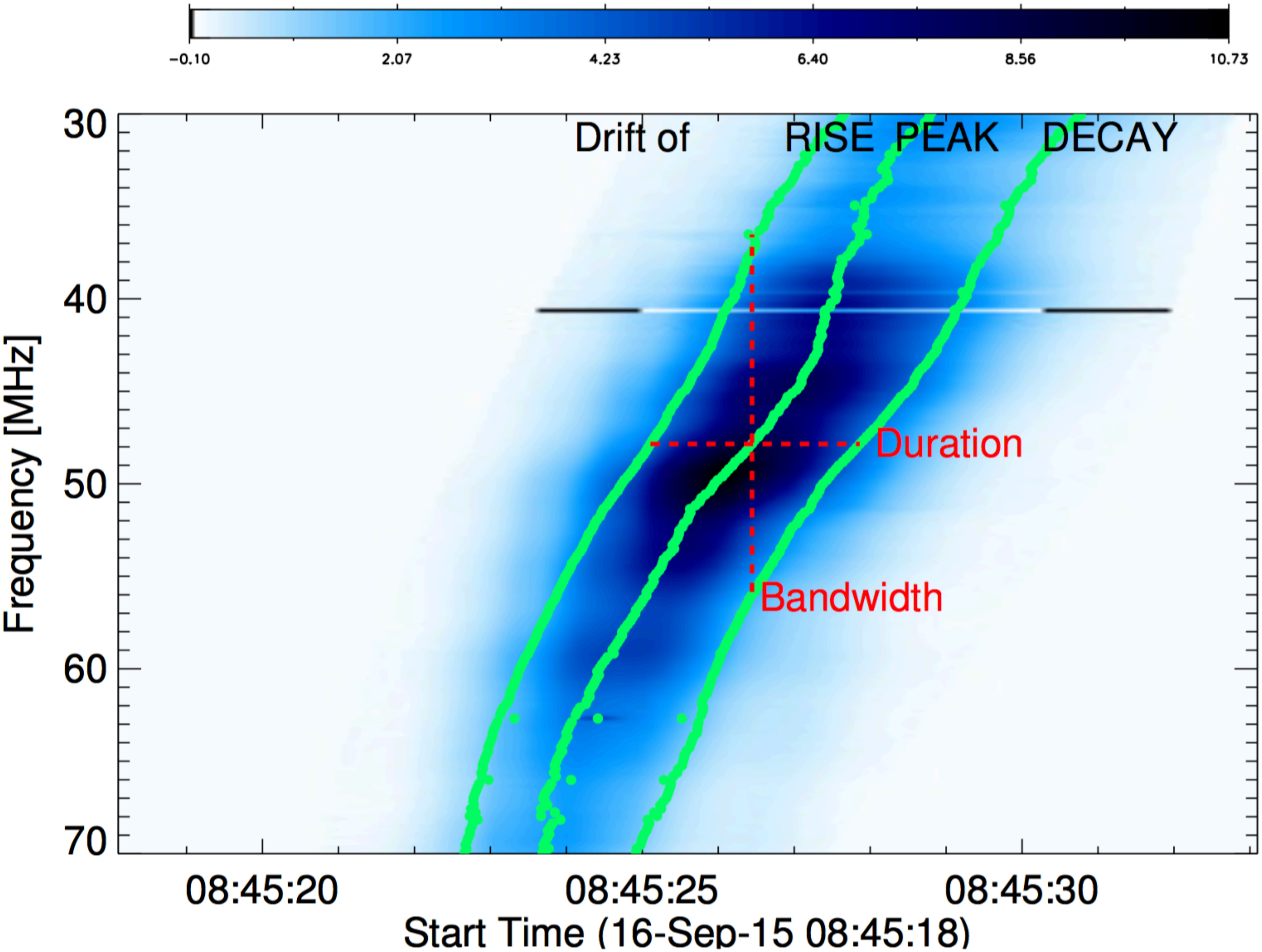
- Tried Exponential and Gaussian fit for the time profile.

$$I(t) = A\exp\left(-\frac{|t-t_0|}{\tau}\right), \quad \tau = \begin{cases} \tau_r, & \text{if } t \le t_0 \\ \tau_d, & \text{if } t > t_0 \end{cases}$$

$$I(t) = A\exp\left(-\frac{(t-t_0)^2}{2\tau^2}\right), \quad \tau = \begin{cases} \tau_r, & \text{if } t \le t_0 \\ \tau_d, & \text{if } t > t_0 \end{cases}$$



Drift and Bandwidth

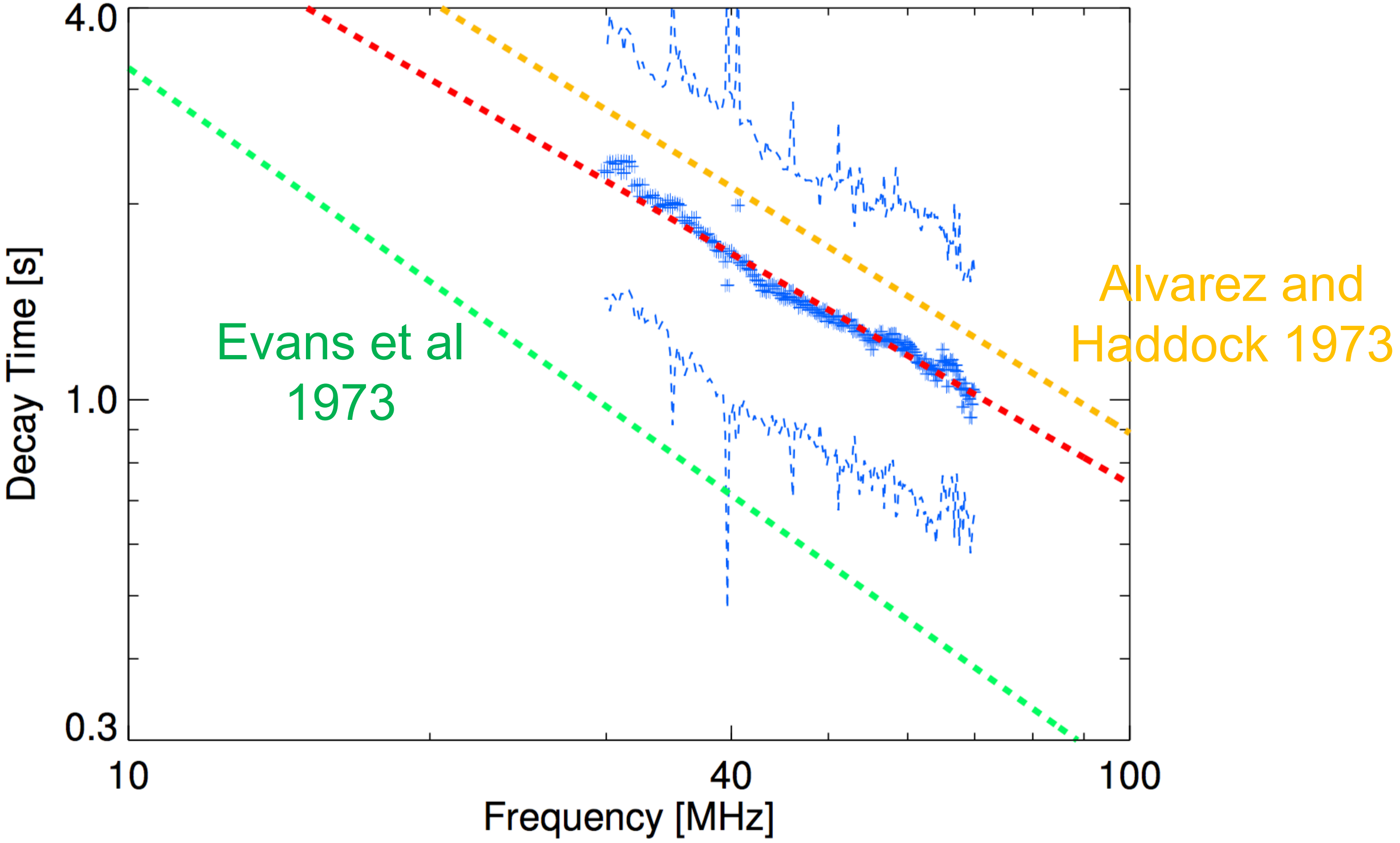


Type III quantities

- Rise time t_r at $t < t_0$ from HWHM, $\tau_r\sqrt{2\log(2)}$
- Decay time t_d at $t > t_0$ from HWHM $\tau_d\sqrt{2\log(2)}$
- Duration t_D is found using FWHM.
- Drift rate is change in rise, peak and decay time as a function of frequency.
- The bandwidth is found from the frequency width between the HWHM at different frequencies.
- Mean is calculated from weighted fun

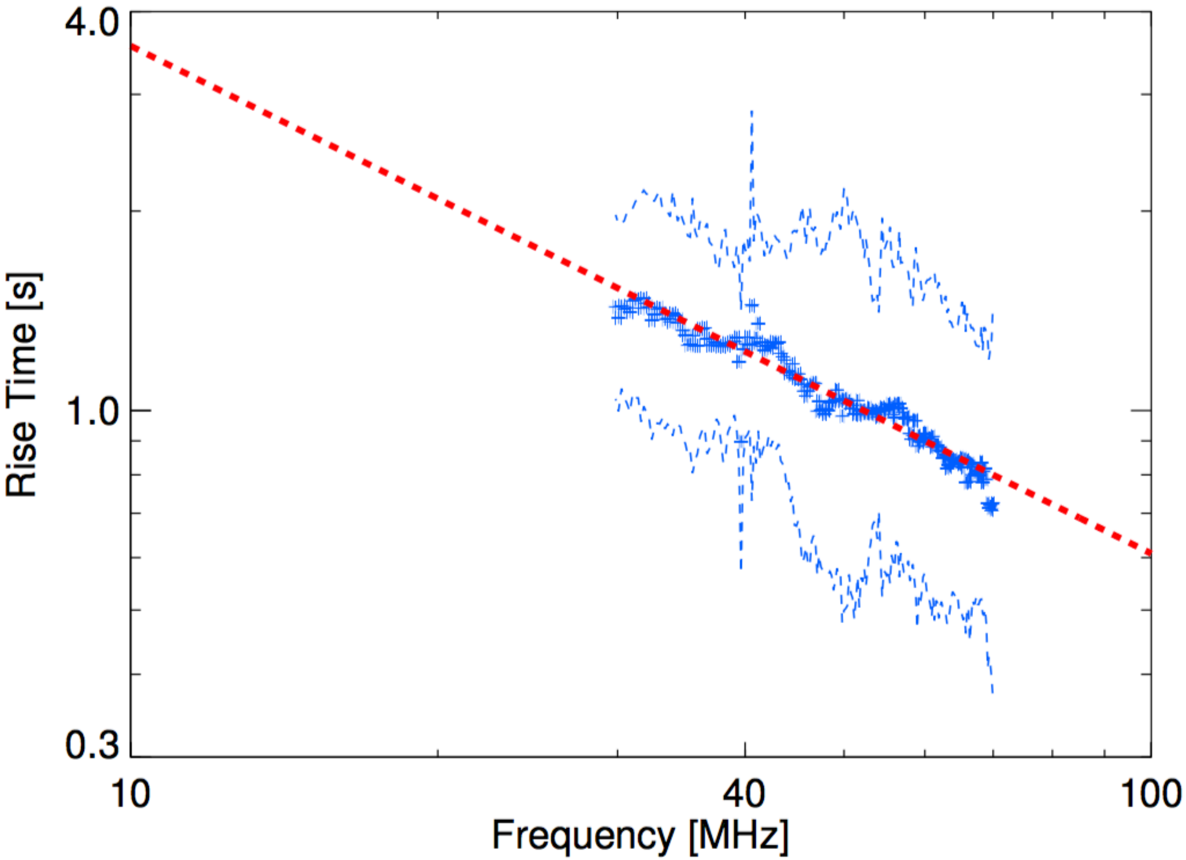
Decay time

$$t_{\mathrm{d}} = (2.2 \pm 0.2)\left(\frac{f}{30\ \mathrm{MHz}}\right)^{-0.89\pm0.15}$$



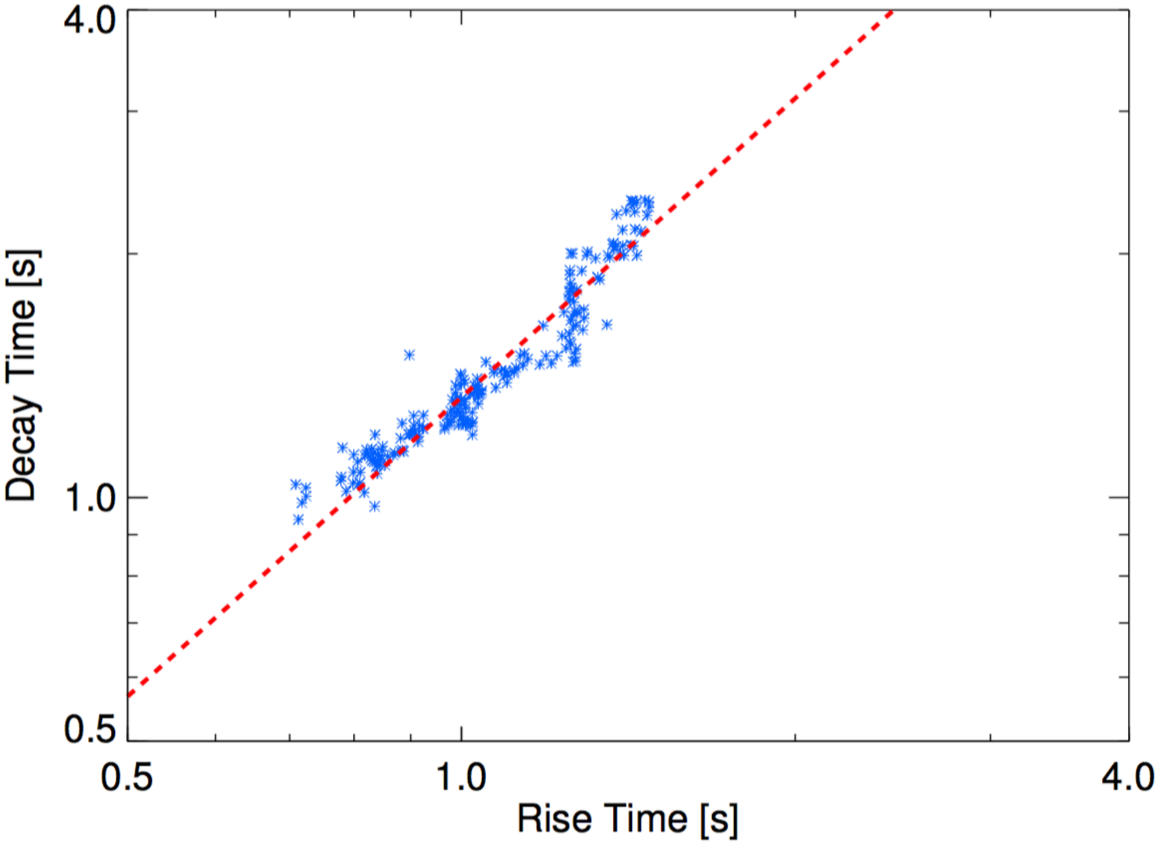
Rise time

$$t_\mathrm{r} = (1.5 \pm 0.1)\left(\frac{f}{30\ \mathrm{MHz}}\right)^{-0.77\pm0.14}$$



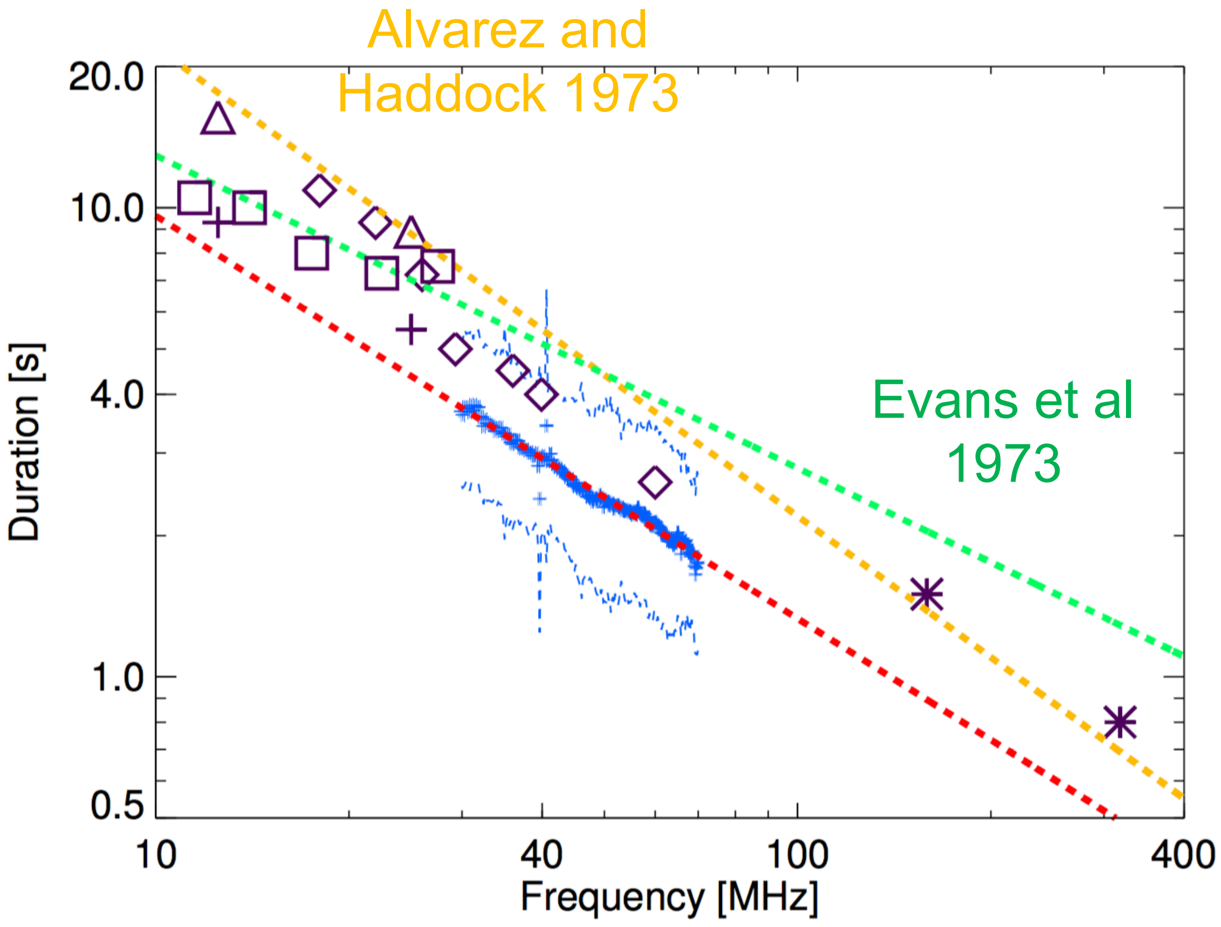
Asymmetry

$$t_{\mathrm{r}} = (1.33 \pm 0.07)\left(\frac{t_{\mathrm{d}}}{1\ \mathrm{Second}}\right)^{1.23\pm0.27}$$



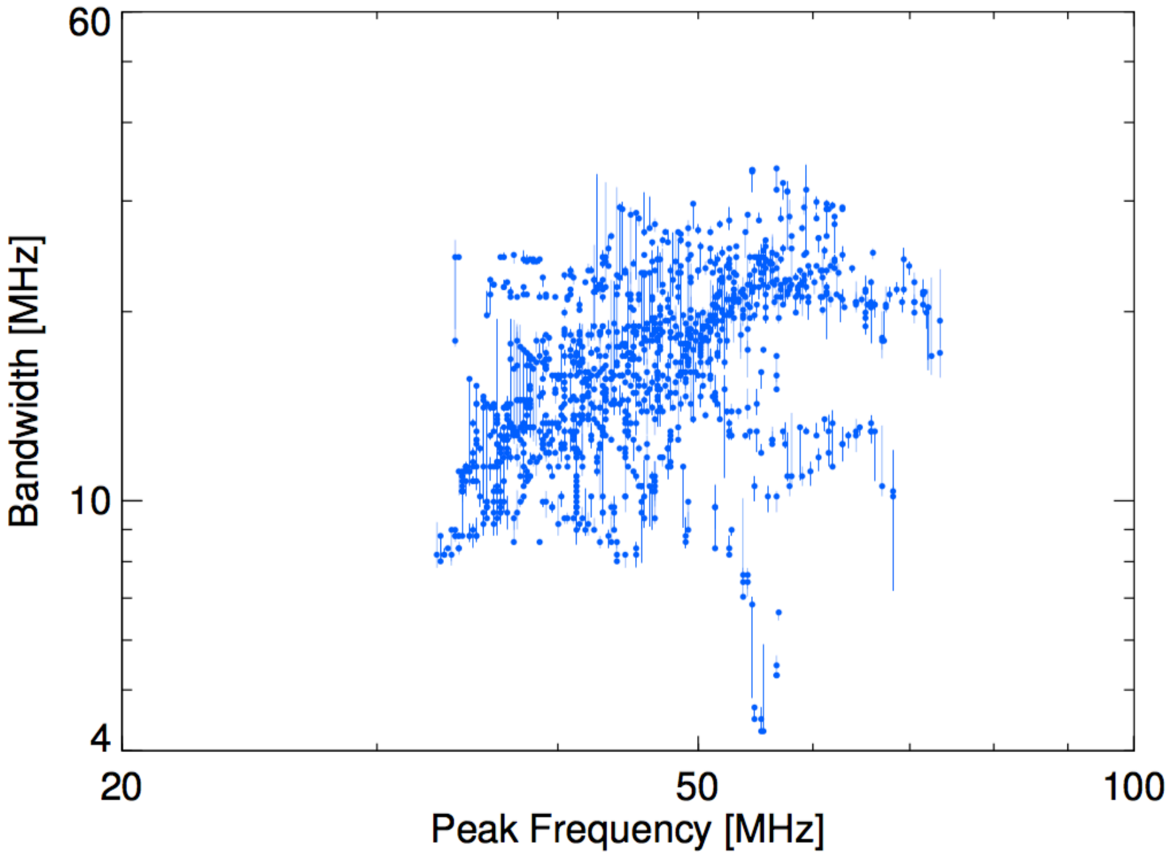
Duration

$$t_D = (3.7 \pm 0.2)\left(\frac{f}{30\ \mathrm{MHz}}\right)^{-0.86\pm0.11}$$

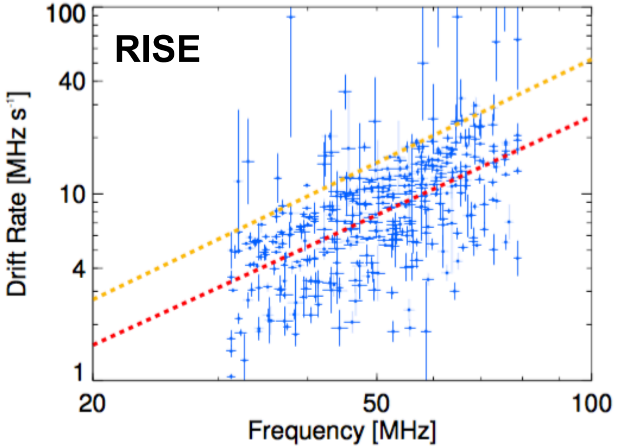


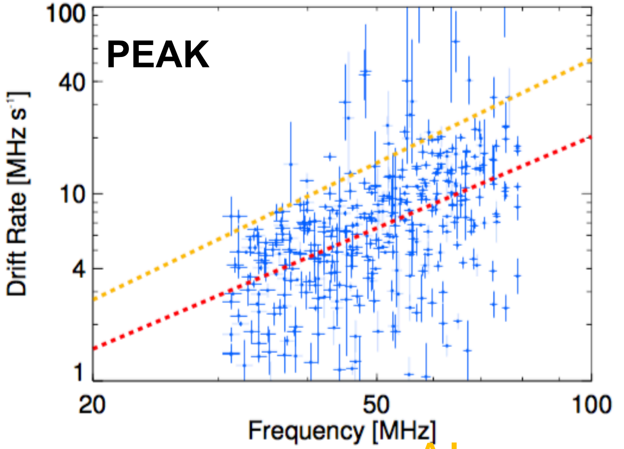
Bandwidth

- Width in frequency space at a central (peak) frequency.
- Approximately straight line through $\frac{\Delta f}{f}$.

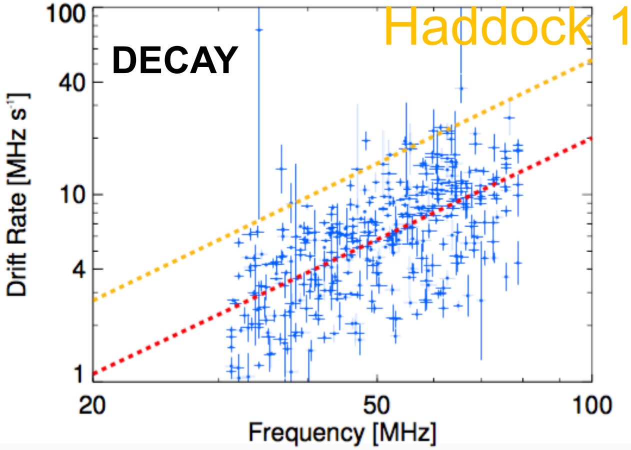


Drift rate





Alvarez and Haddock 1973



- Drift rate was found using the rise, peak and decay times.

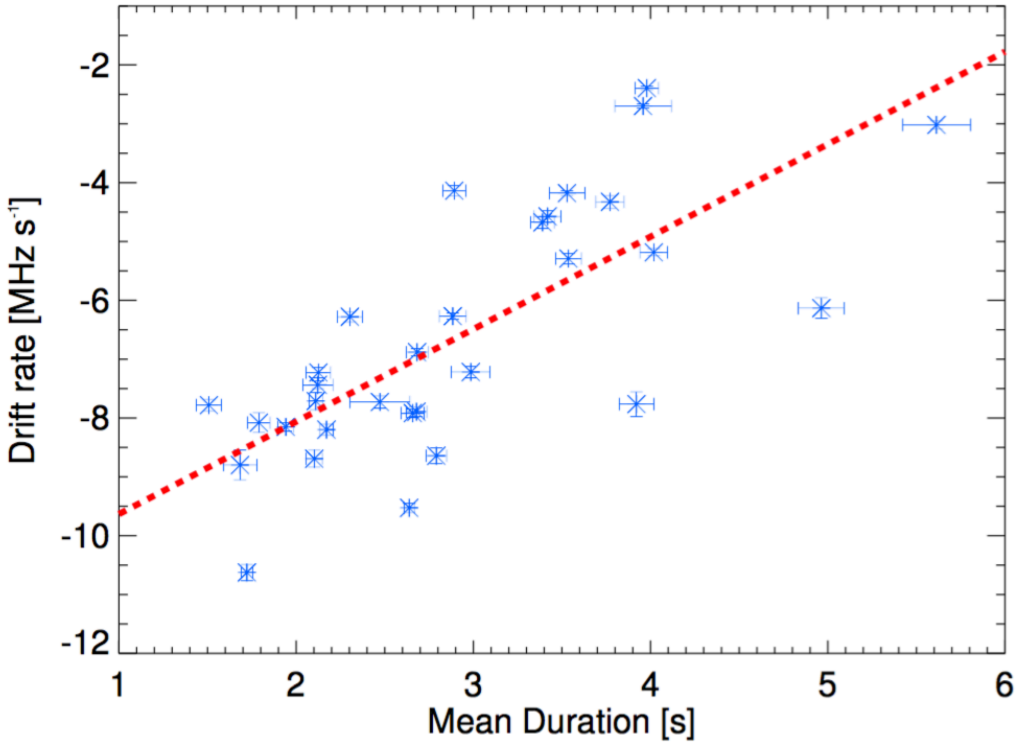
$$\frac{\partial f}{\partial t} = -A\left(\frac{f}{30\ \mathrm{MHz}}\right)^{\alpha}$$

Time	A	α
rise	3.1 ± 0.2	-1.75 ± 0.11
peak	3.8 ± 0.2	-1.63 ± 0.13
decay	1.9 ± 0.1	-1.80 ± 0.11

Drift rate vs duration

- Correlation between mean drift rate and mean duration.
- Taking the mean removes frequency dependent effects.

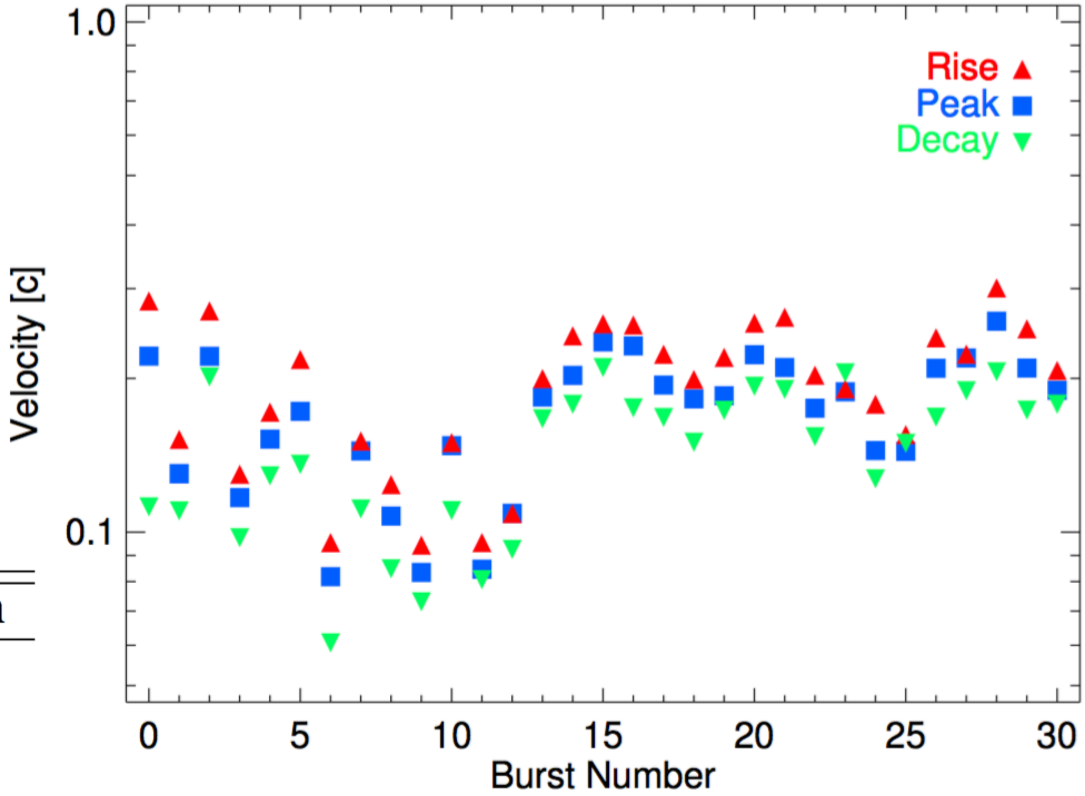
- Faster drift rates lead to smaller durations.



Electron beam velocities

- Use drift rates to estimate velocities assuming Parker 1958 density model.

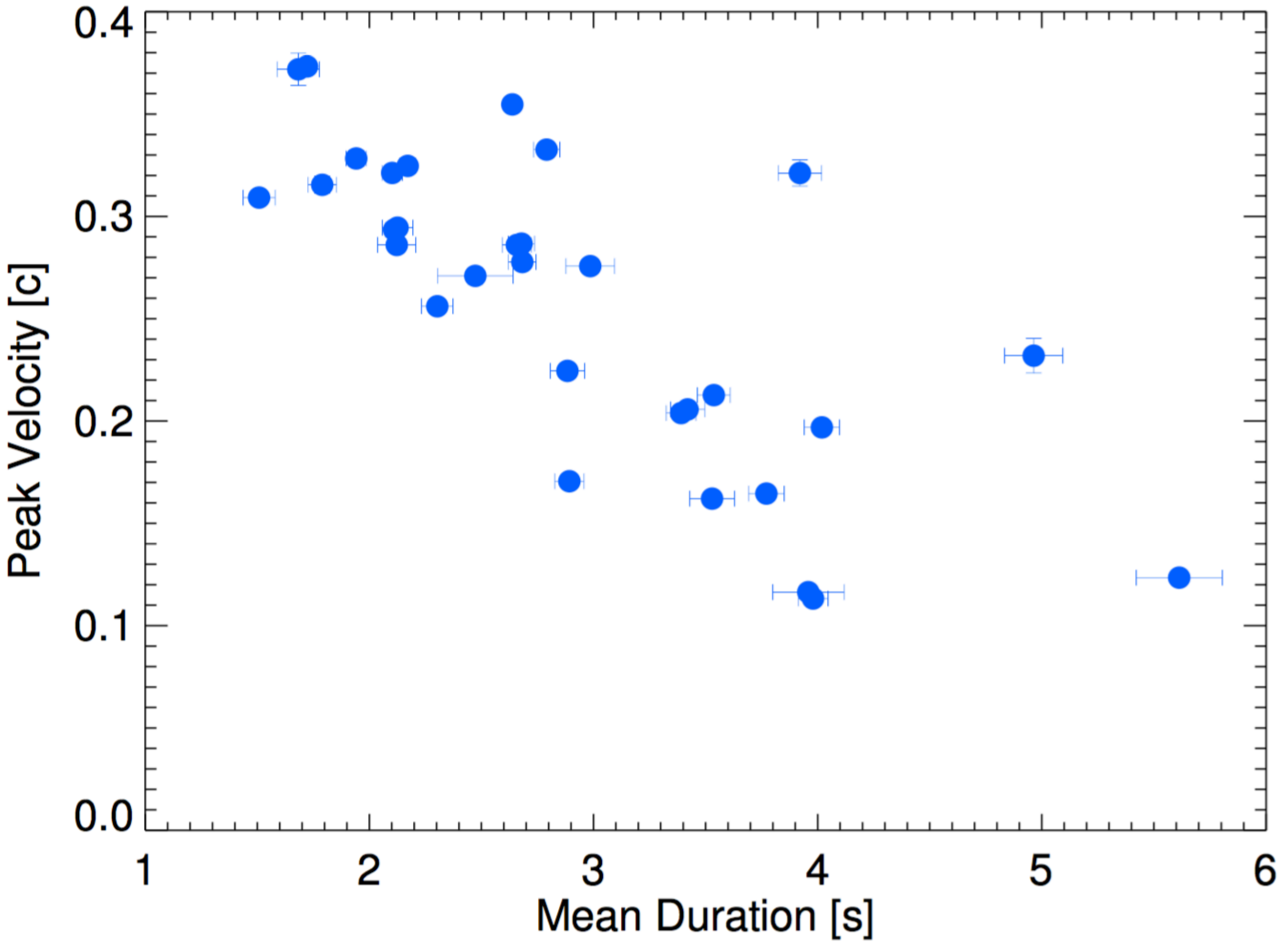
Velocity [c]	Mean	Standard Deviation
front	0.20	0.06
middle	0.17	0.05
back	0.15	0.04



- For velocity, typically front > middle > back

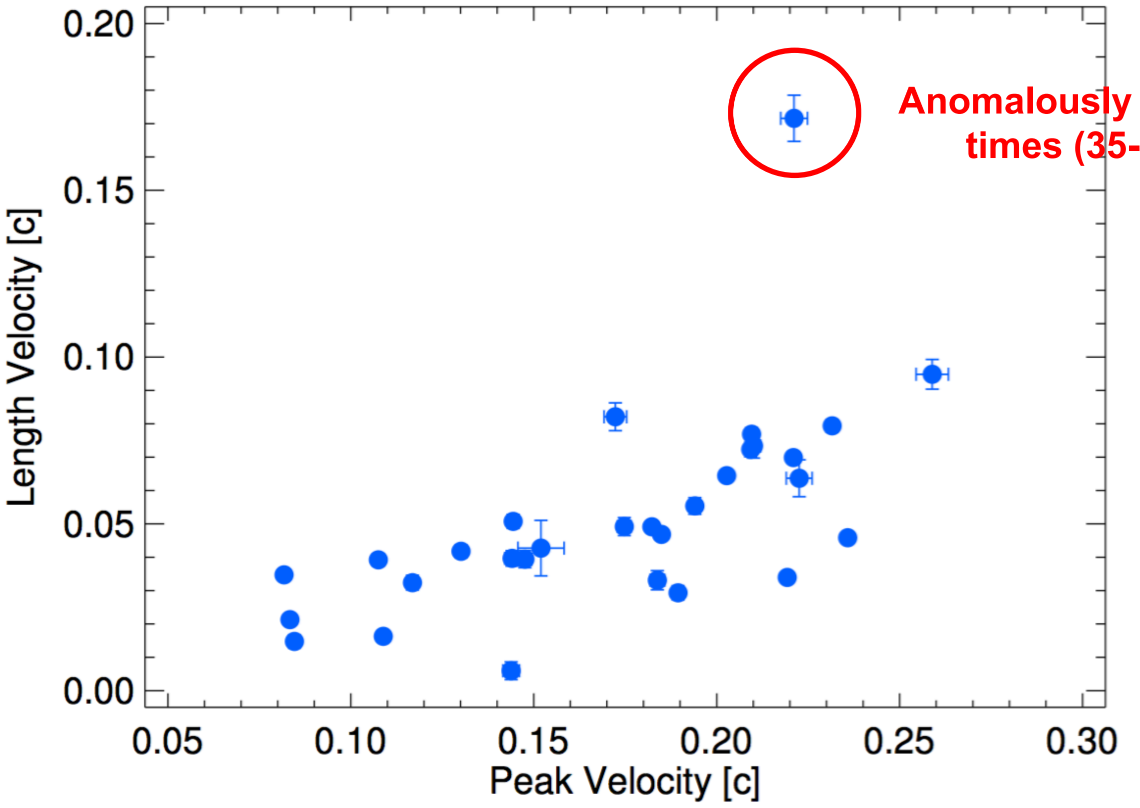
Peak velocity vs duration

- Correlation (0.73) in peak velocity vs mean duration.
- Faster electron beams create radio with shorter durations.



Length vel vs peak vel

- Length velocity is correlated with peak velocity.
- Faster electron beams have a larger spread between the front and back velocities.

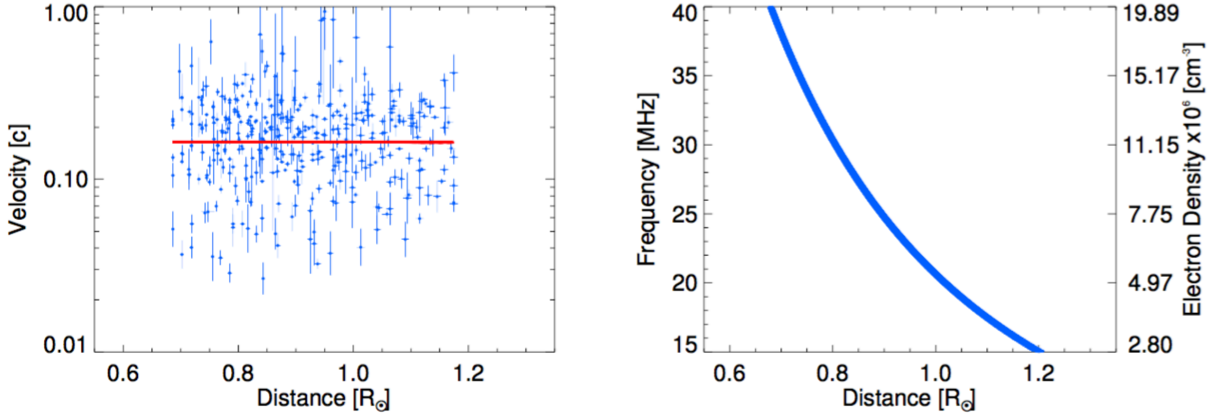


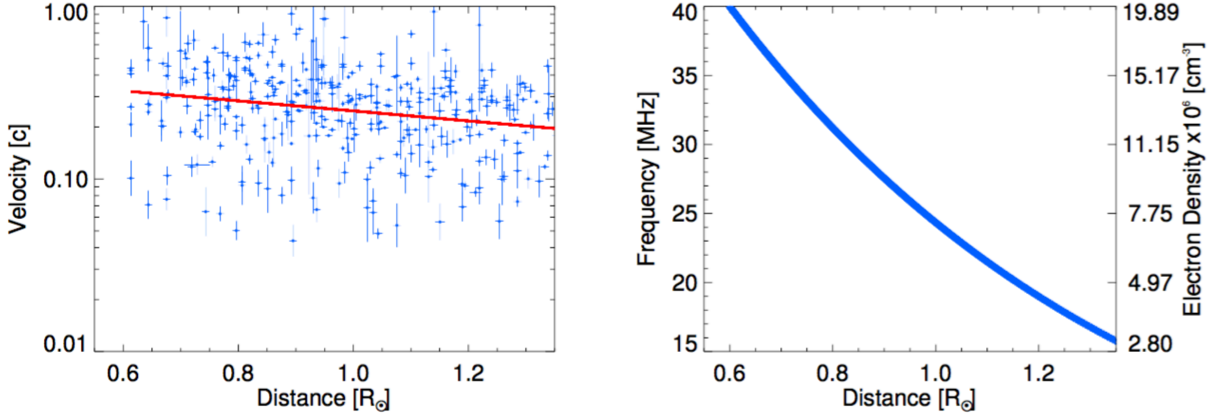
Anomalously large decay times (35-40 MHz)

Electron density model

- Density model is important.
- Not conclusive whether velocity varies as a function of distance.

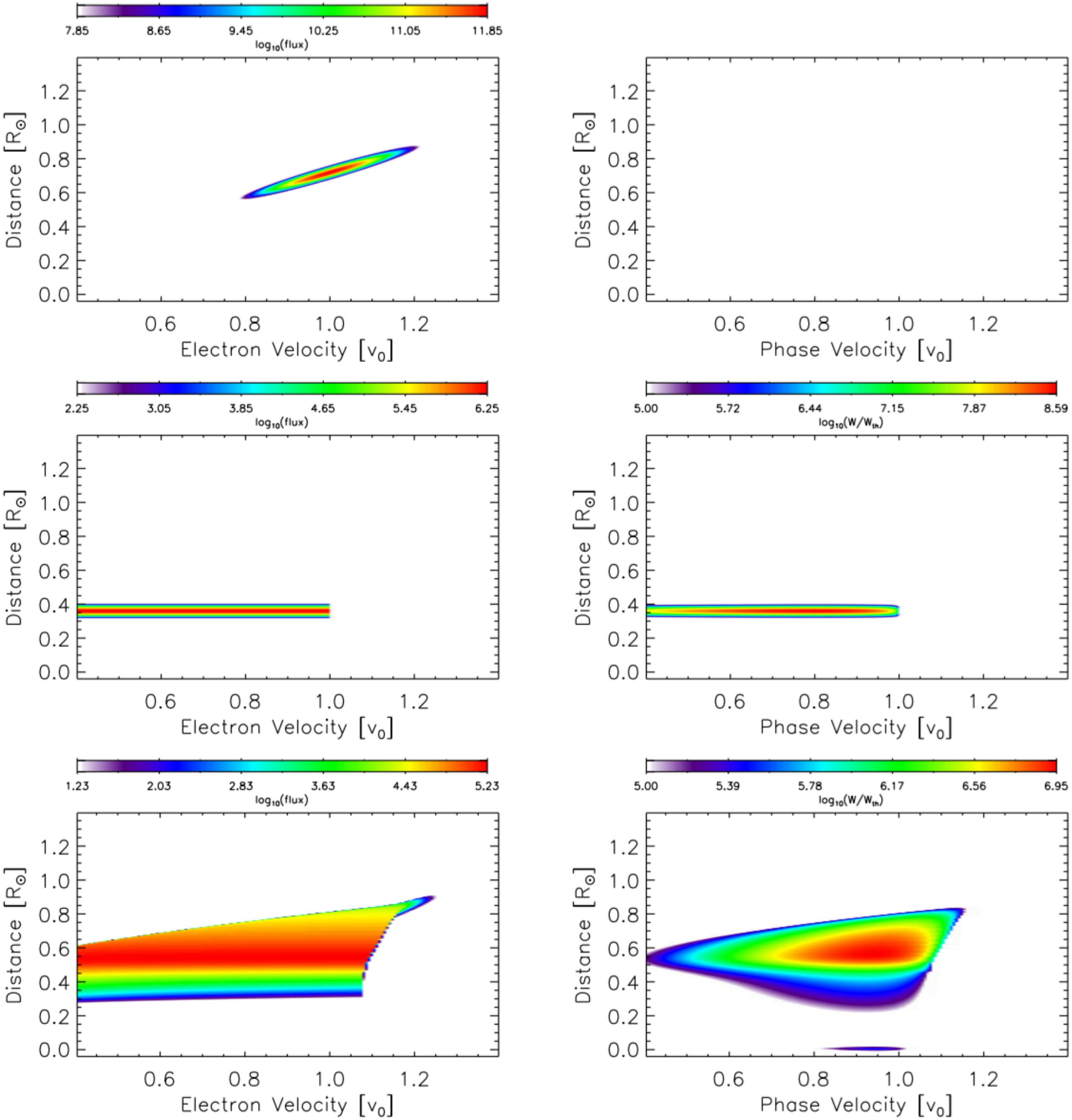
PARKER DENSITY MODEL





DULK DENSITY MODEL

Gaussian Beam



FREE STREAMING

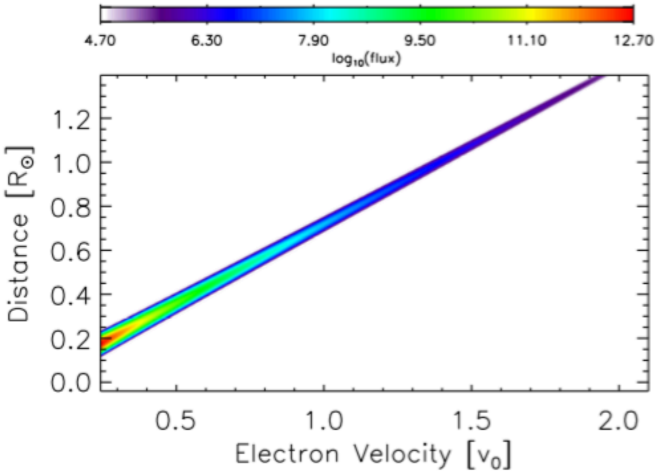
GAS DYNAMIC
(e.g. Kontar et al 1998)

QUASILINEAR
SIMULATIONS

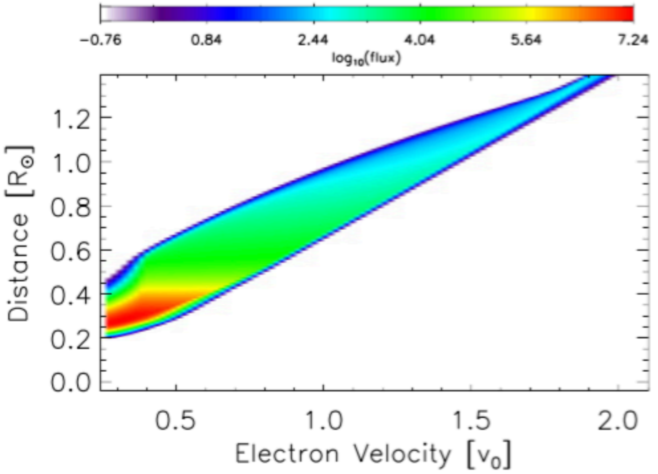
ELECTRON BEAM

LANGMUIR WAVES

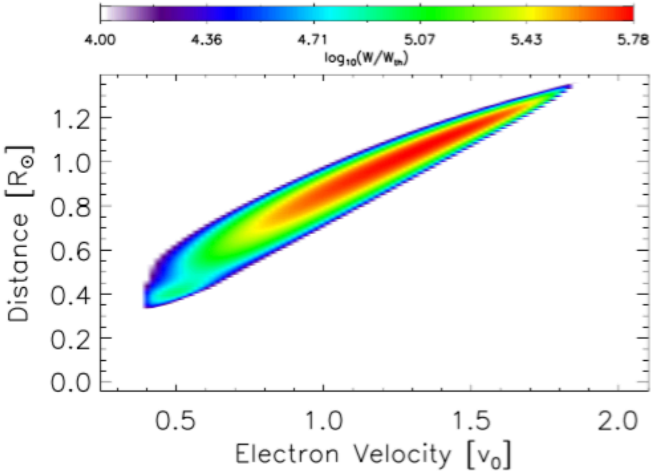
Power-law Beam



FREE STREAMING ELECTRONS



SIMULATED ELECTRONS

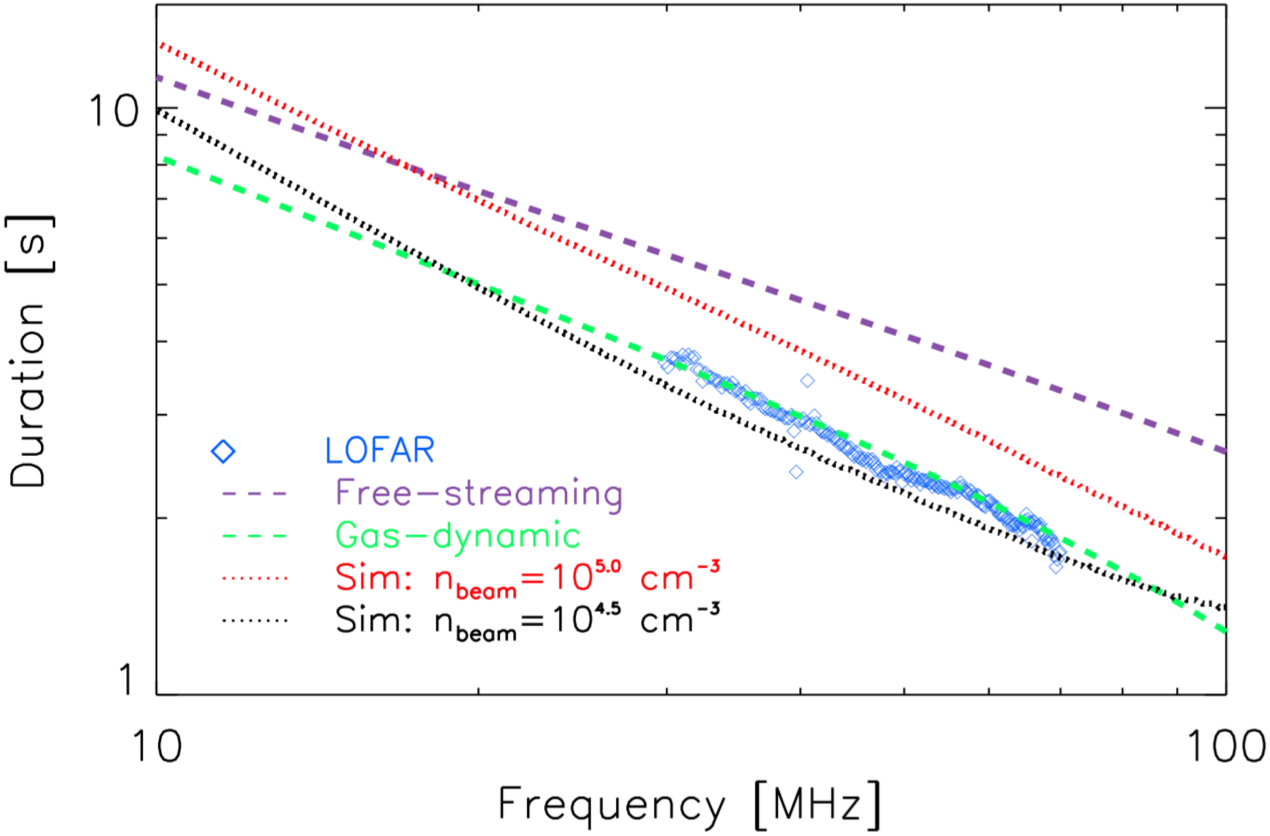


SIMULATED LANGMUIR WAVES

- Initial power-law electron beam can capture the change in duration as a function of frequency.

Duration vs frequency

- Using v_{front} and v_{back} from LOFAR obs, we can estimate velocities using free-streaming, gas-dynamic and sims.



Conclusions

- Rise, decay and durations decrease with increasing frequency, showing an asymmetric time profile between 30-70 MHz.
- Type III drift rates from rise times were higher in magnitude than decay times and all drift rates were smaller than AH73.
- Beam speed estimates of 0.2, 0.17, 0.15 c for front, middle, back.
- Different speeds naturally explain beam elongation through the solar system; faster beams expand faster.
- Initial power-law electron beams can explain the increase in duration with decreasing frequency.
- Reid and Kontar 2018, A&A, http://arxiv.org/abs/1802.01507