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# 影响II型射电暴时间宽度的 关键因素——LOFAR观测

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University  
of Glasgow

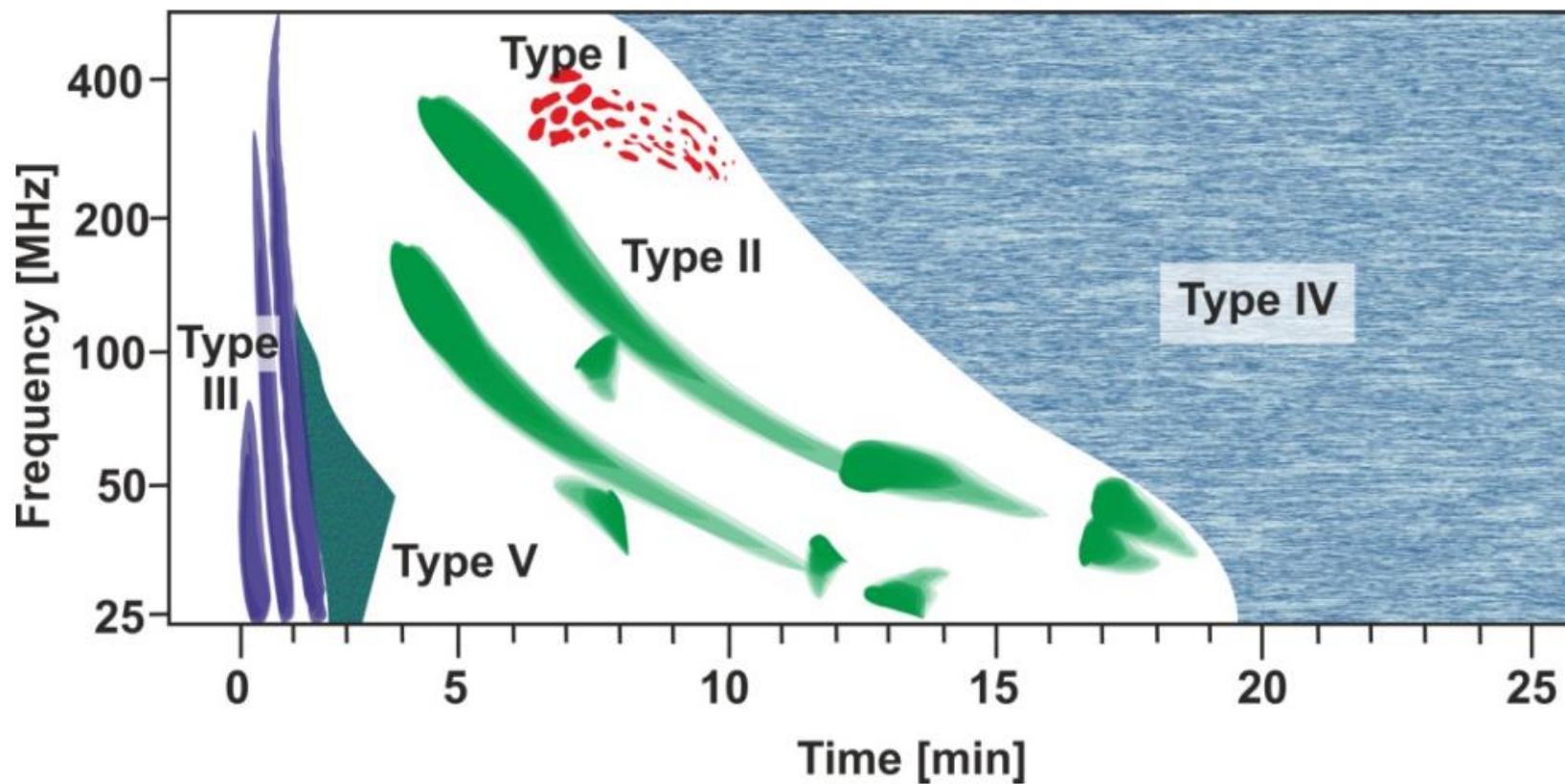
ASTRON



LOFAR

# III型太阳射电电暴

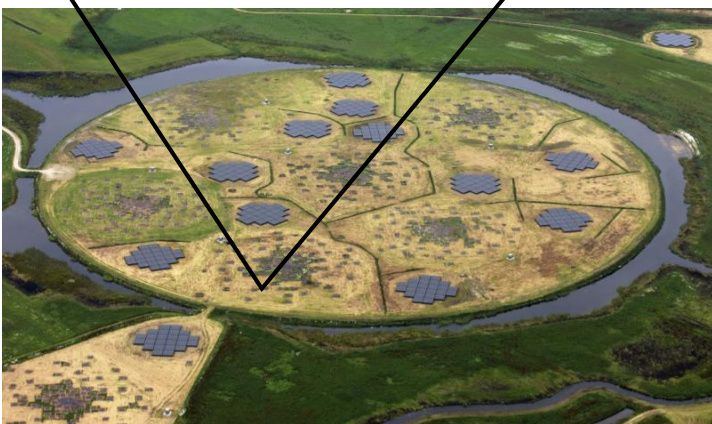
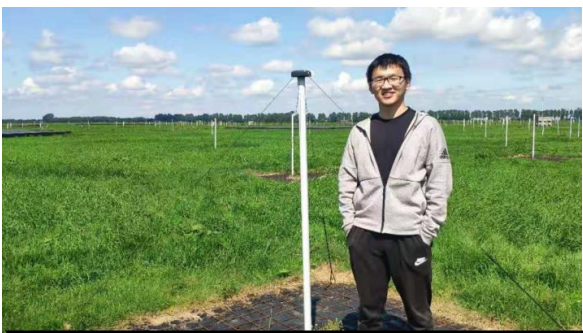
- 由高能电子 ( $\sim 0.3c$ ) 产生
- 快速的频率漂移率
- 有一定时间宽度



# LOFAR低频射电观测阵列

• 25000个单元构成的数字天线阵列

(7PB/年) 太阳射电观测 7%



## Current Radio Astronomy Archives

 **LOFAR**  
Long Term Archive

43 PB

  
6PB

  
4PB

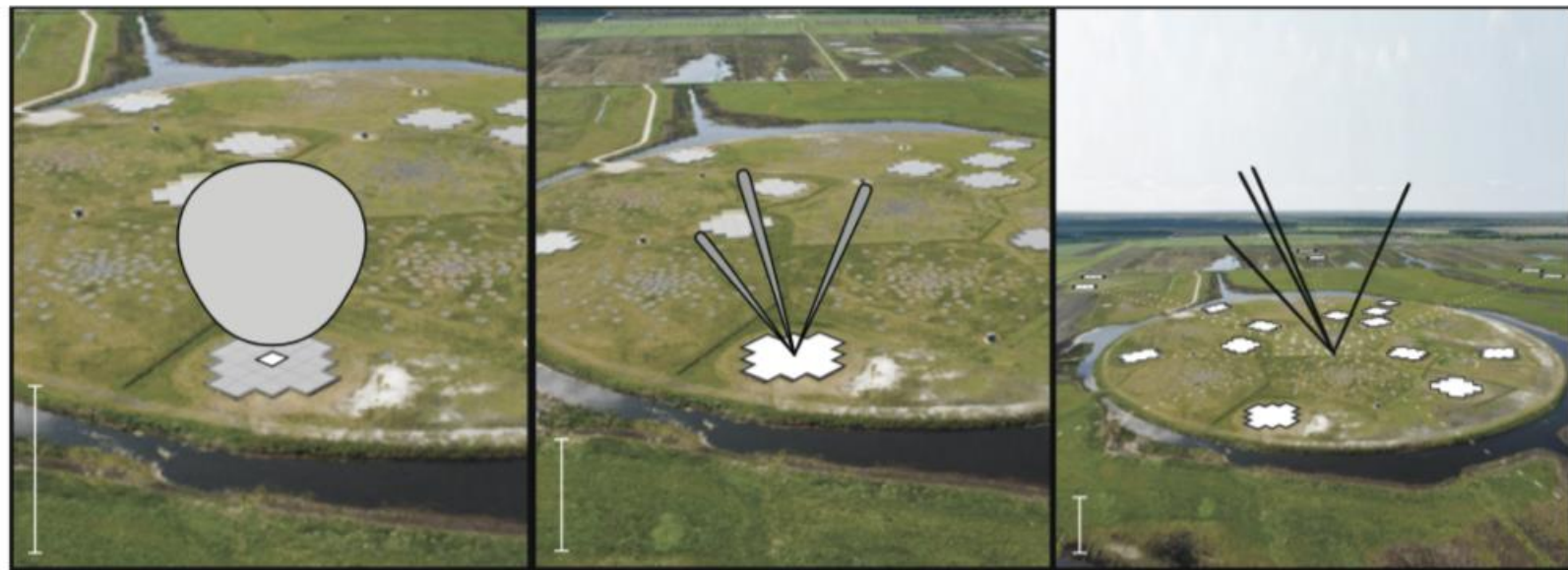
  
3PB

  
5PB

1 Petabyte (PB)

# Beamformed观测

- 天线阵列使用相干的方式生成多个（例如：169个）指向，覆盖天空平面中的一个范围
- 每个指向可以得到一个频谱
- 对于每个时间 ( $t$ ) 和频率 ( $f$ ) 可以使用插值的方法得到指向范围内的射电强度分布
- 时间分辨率 10.7 ms (96fps)
- 频率分辨率 12.5 kHz



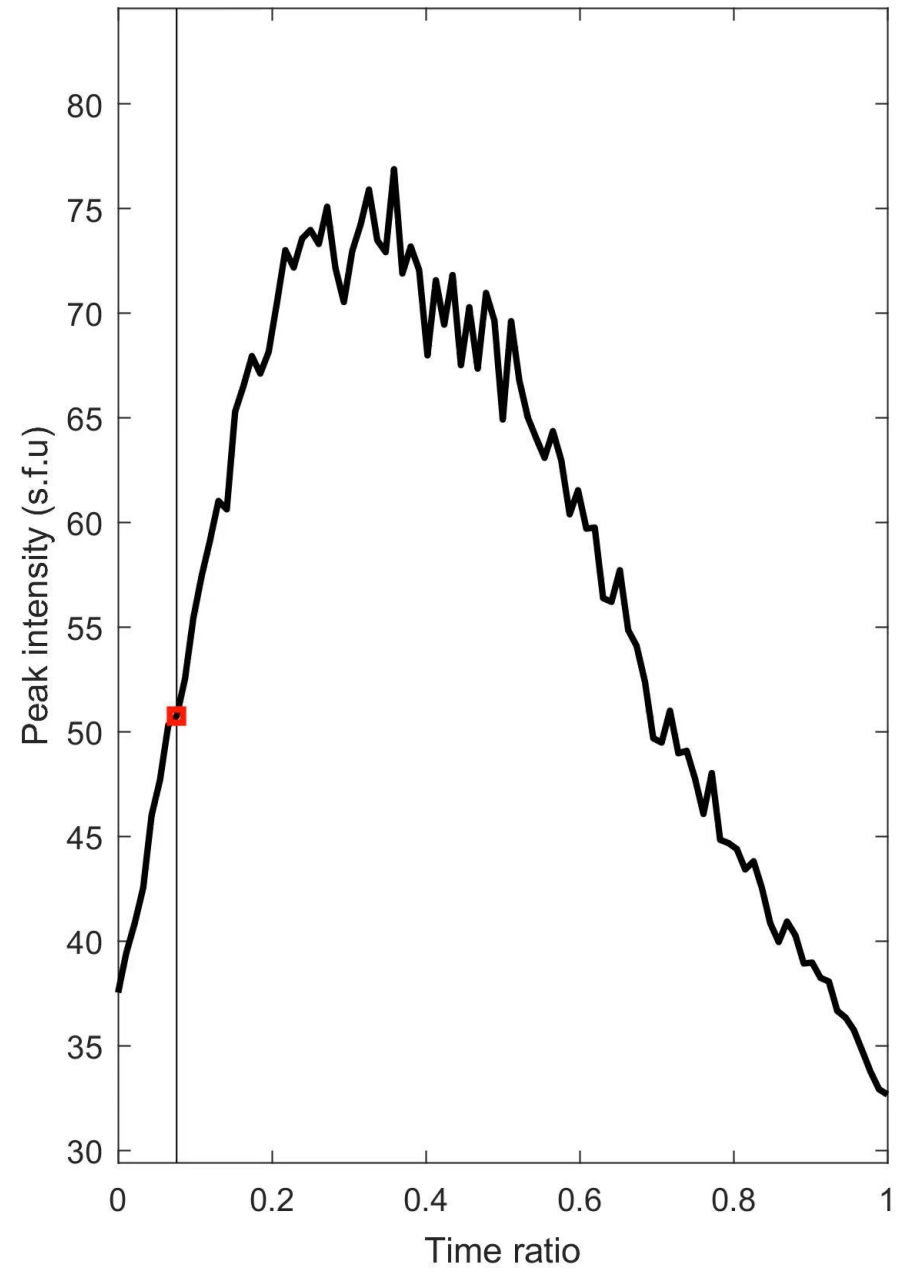
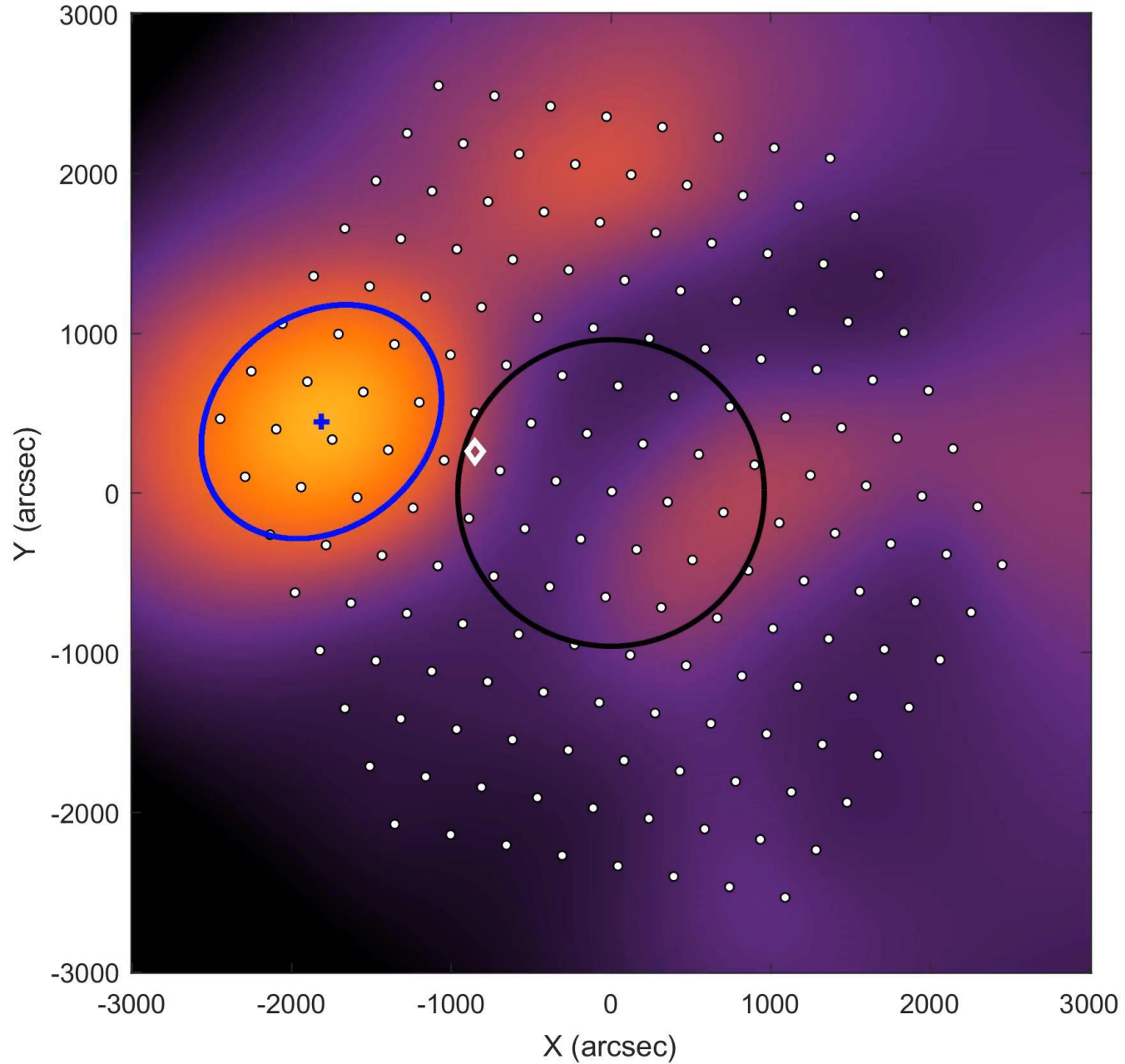
source: astron

Element beam  
or  
Tile beam

Station beam  
or  
Sub-array pointing (SAP)

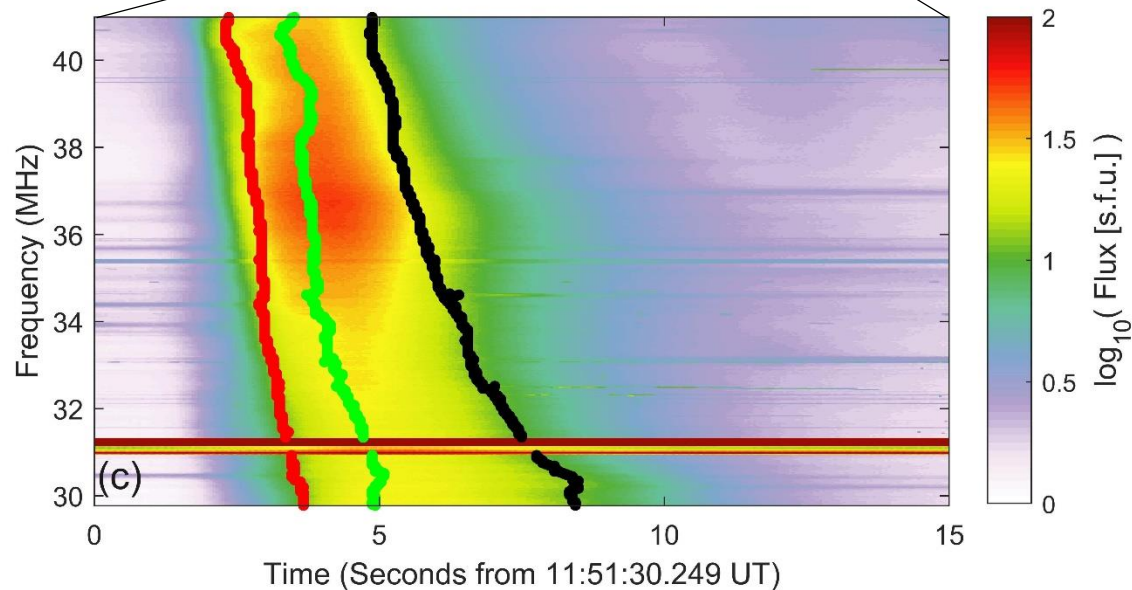
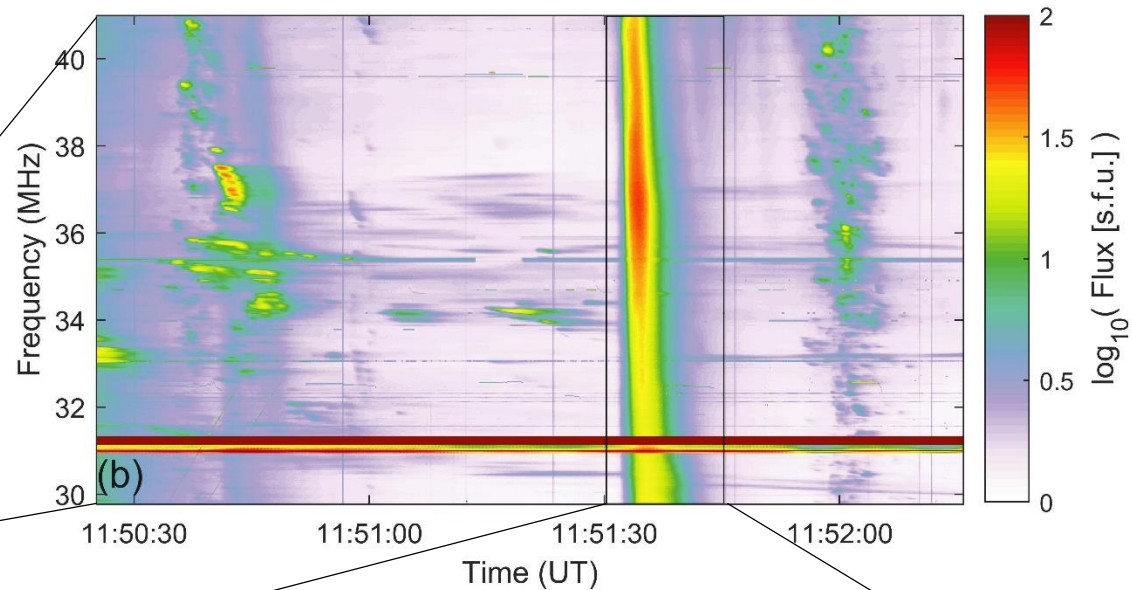
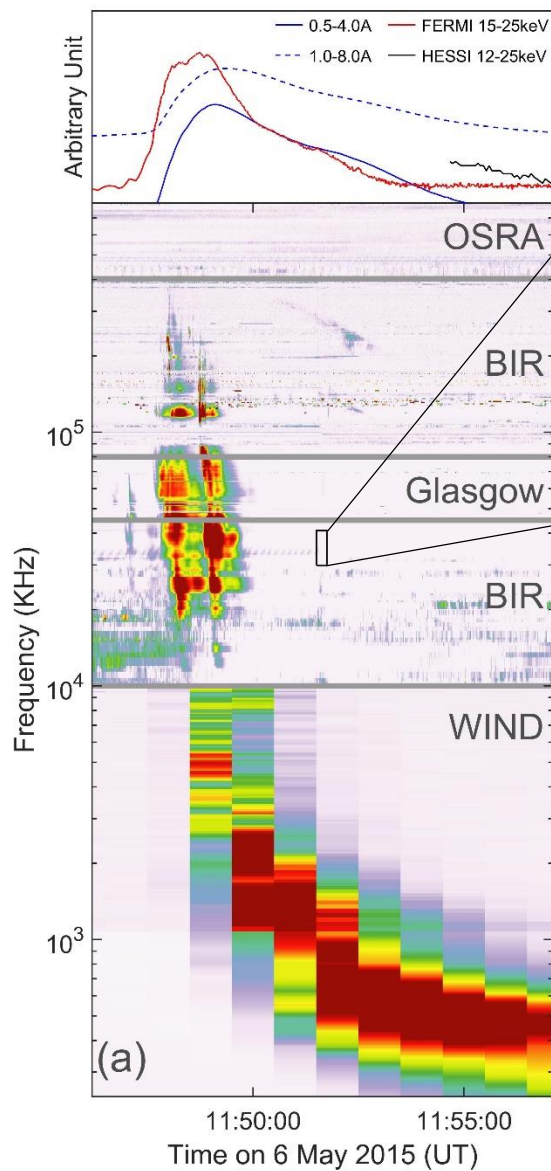
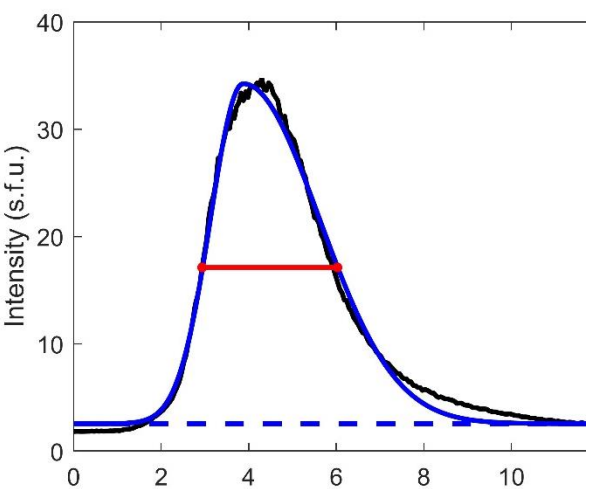
Array beam  
or  
Tied-array beam (TAB)

LOFAR BF Frequency:30.243MHz  $t_r:0.076$



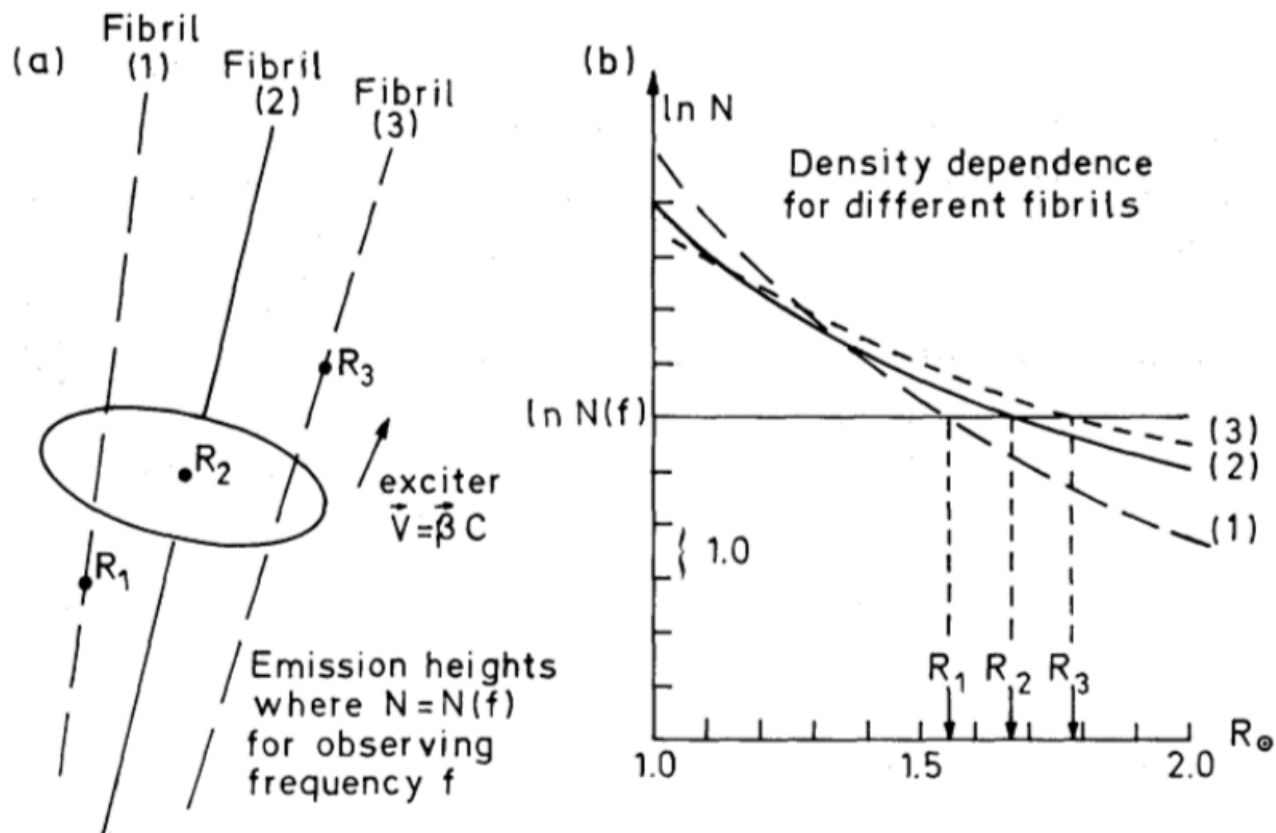
# III型射电暴事件

- 耀斑
- 时间宽度 > 3s

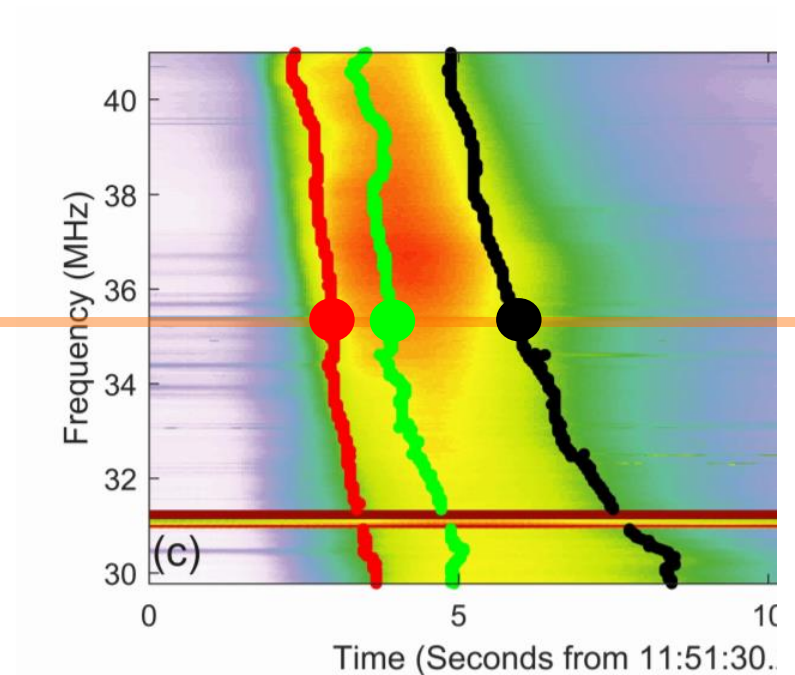
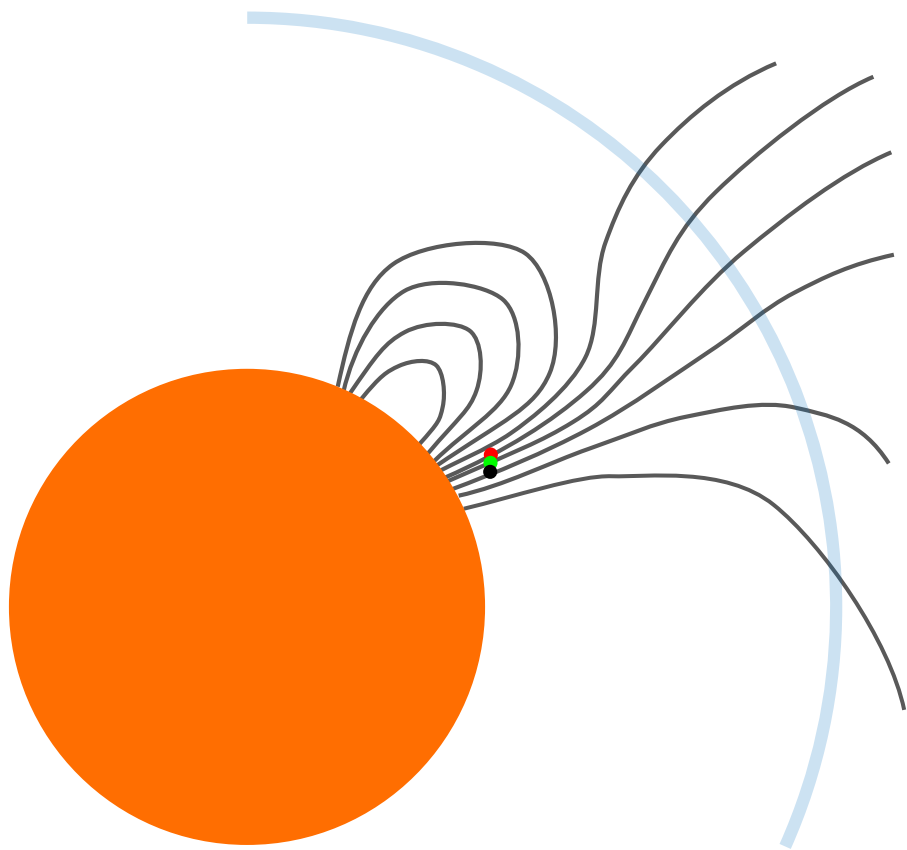


# 密度不均匀对于时间宽度的贡献

- Roelof & Pick 1989
- 日冕中的纤维结构众多，密度沿横向变化很大，导致到达某个高度的电子可以激发出多个频率的波。



# 速度色散对于持续时间的贡献

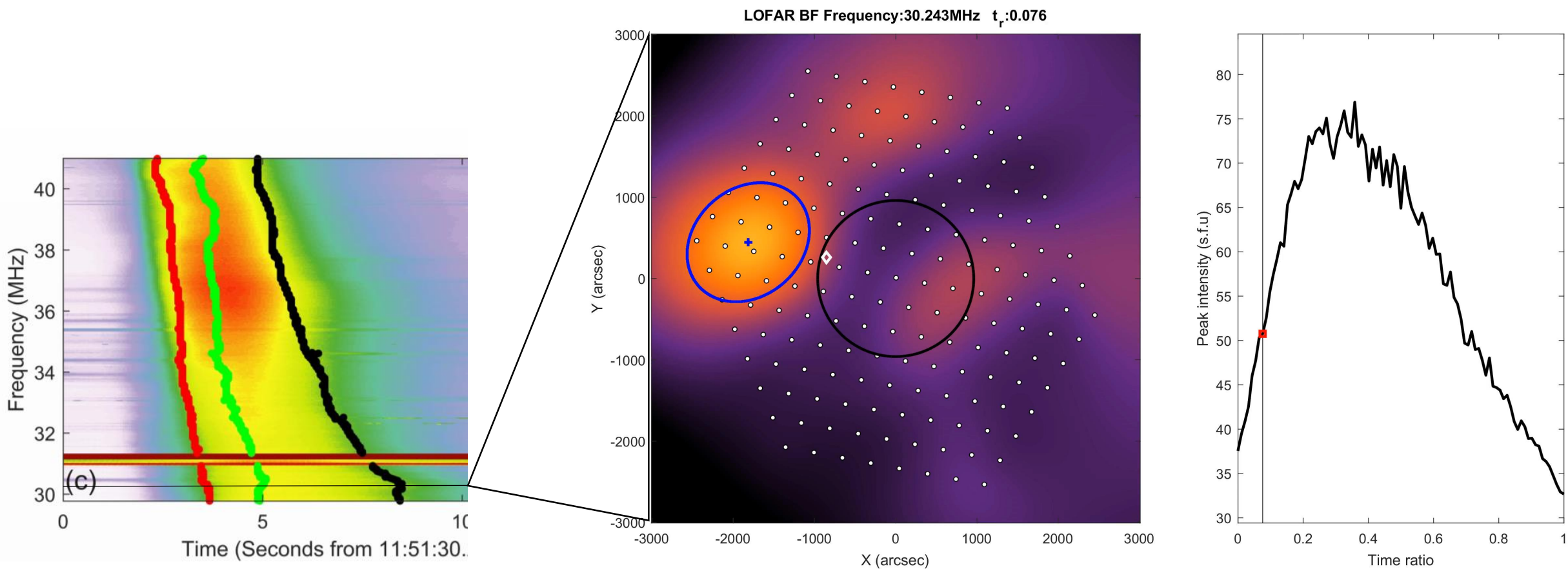


$$\omega_{pe} = \sqrt{\frac{4\pi n_e e^2}{m^*}}, [\text{rad/s}]$$



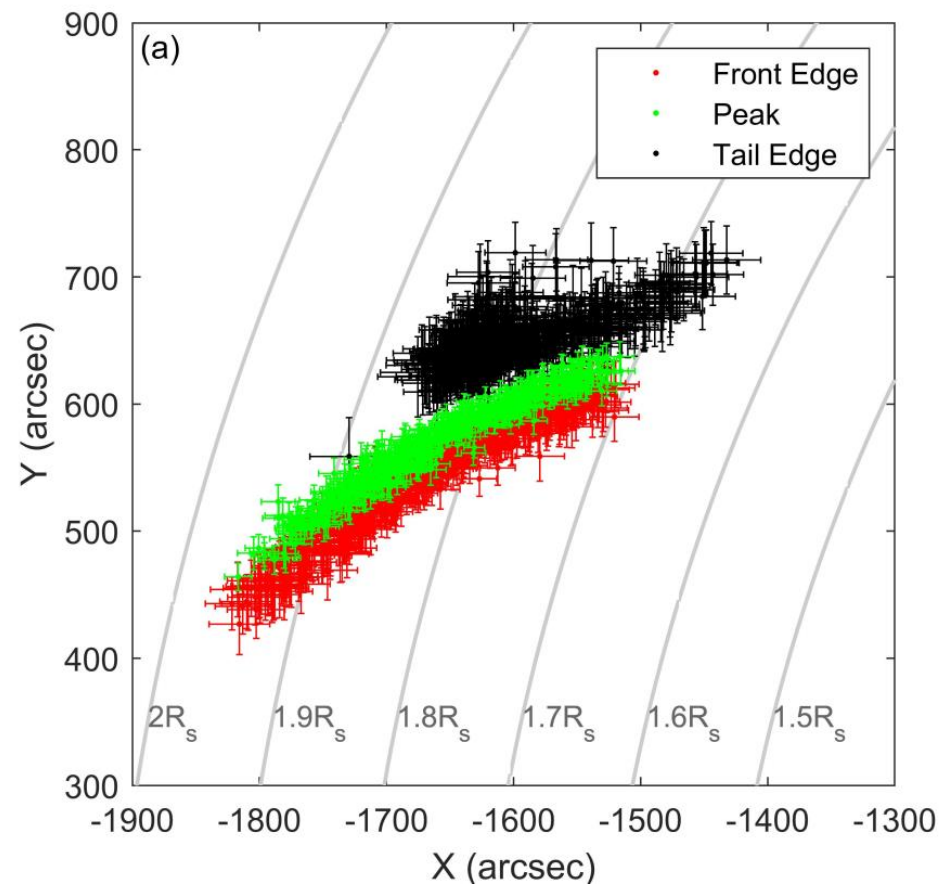
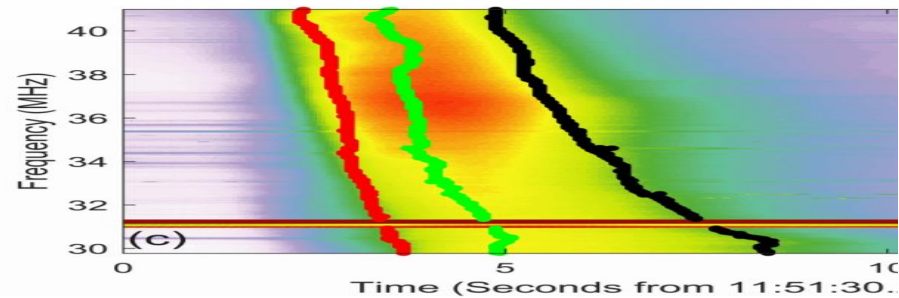
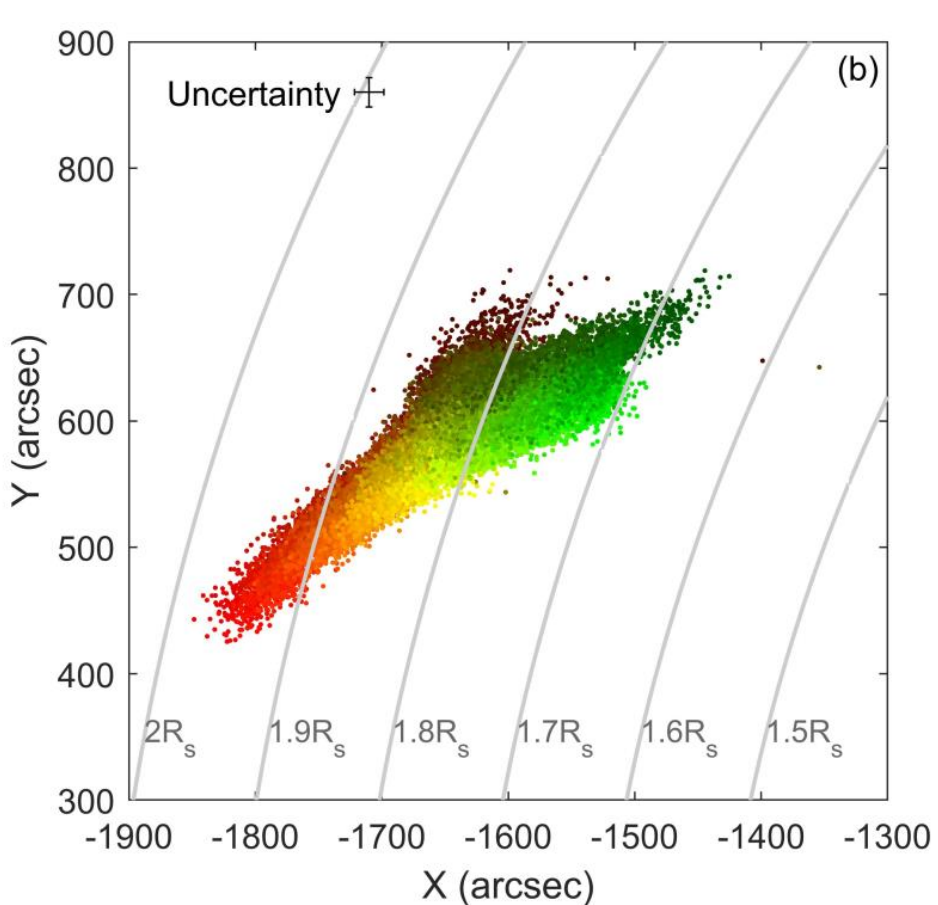
# Beamformed 成像结果

- 定位



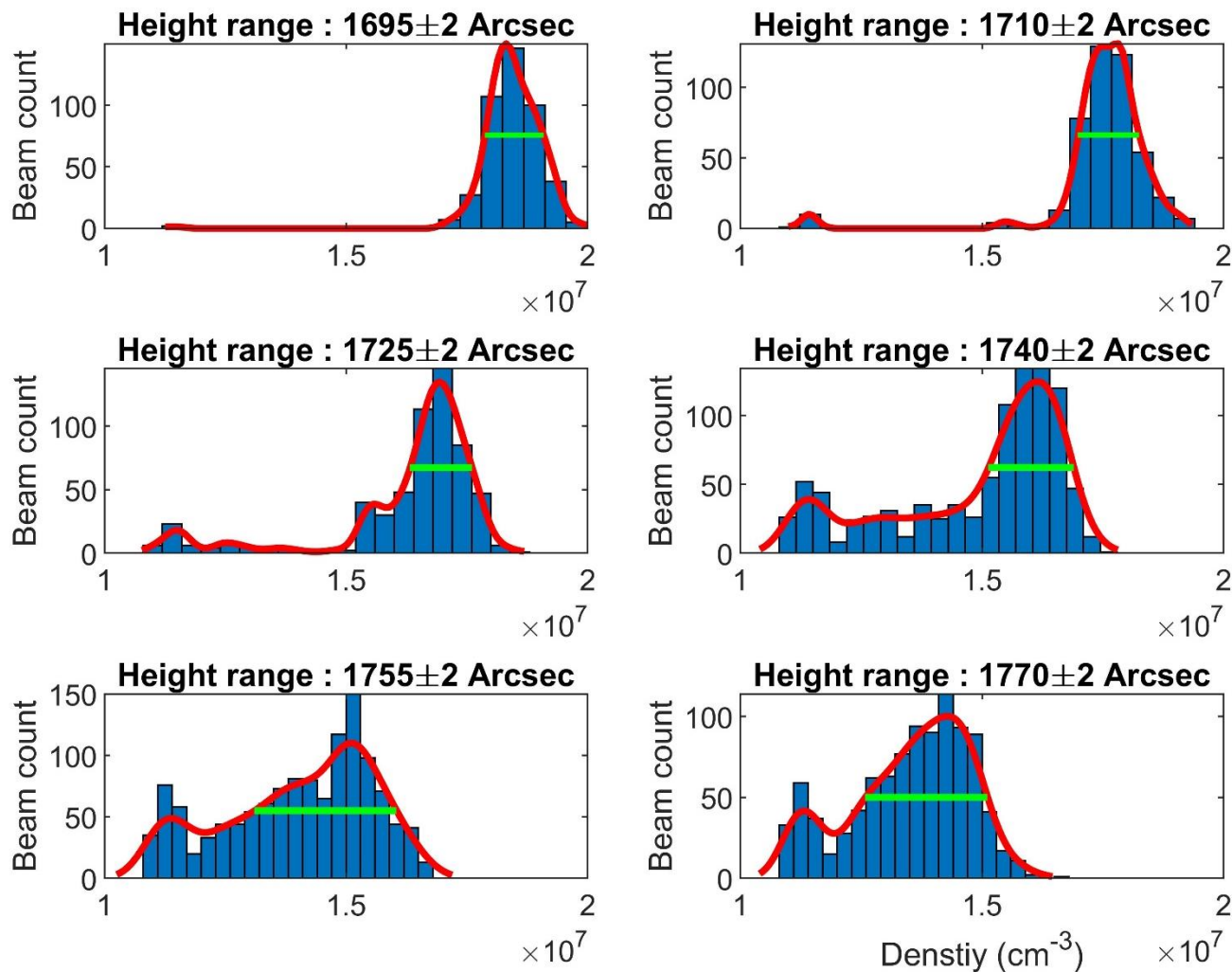
# Beamformed 成像结果

- 不同时间，频率的源的位置



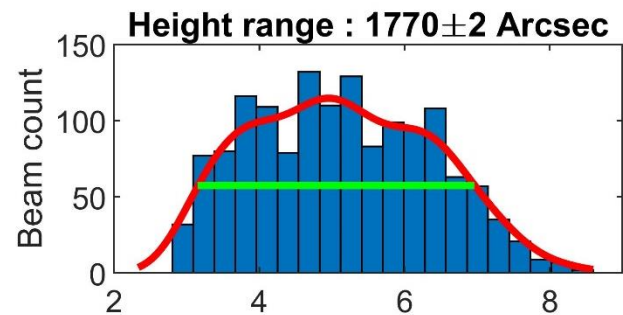
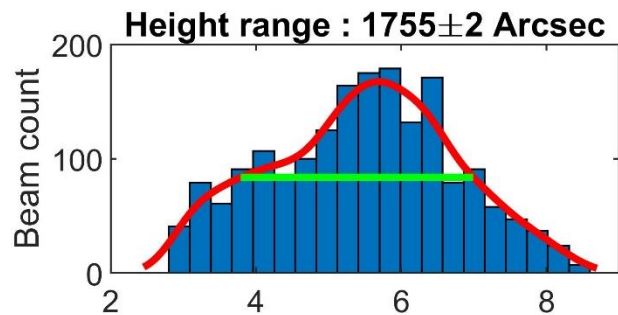
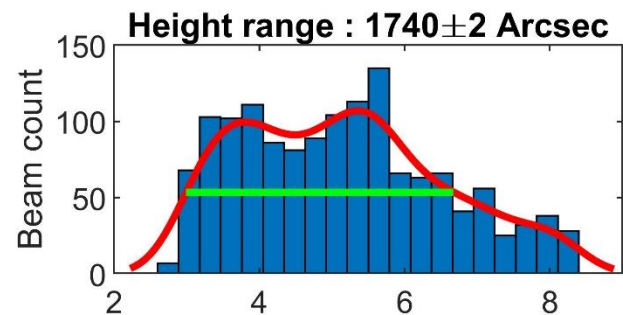
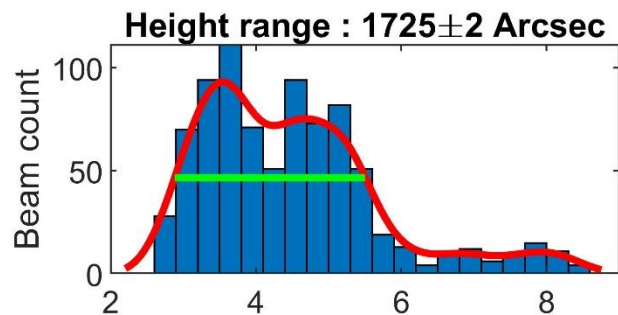
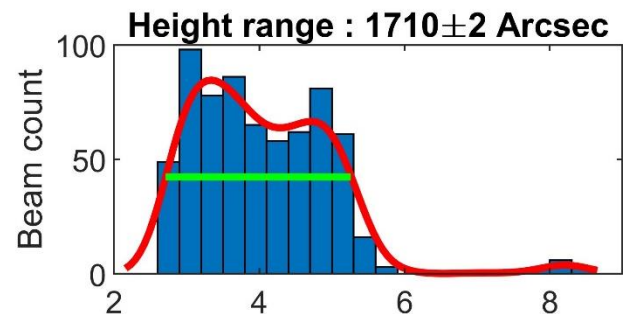
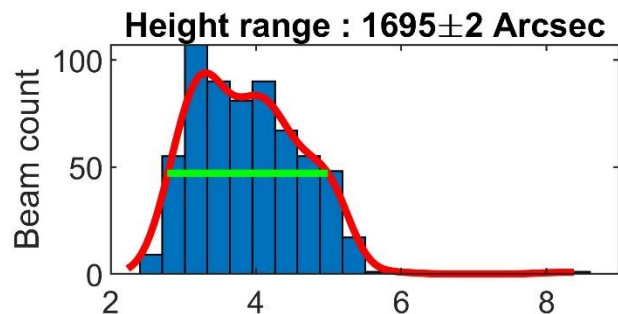
# 统计结果：密度不均匀对时间宽度的贡献

- 纤维结构贡献
- 同一高度的密度不同



# 统计结果：速度色散带来的时间宽度贡献

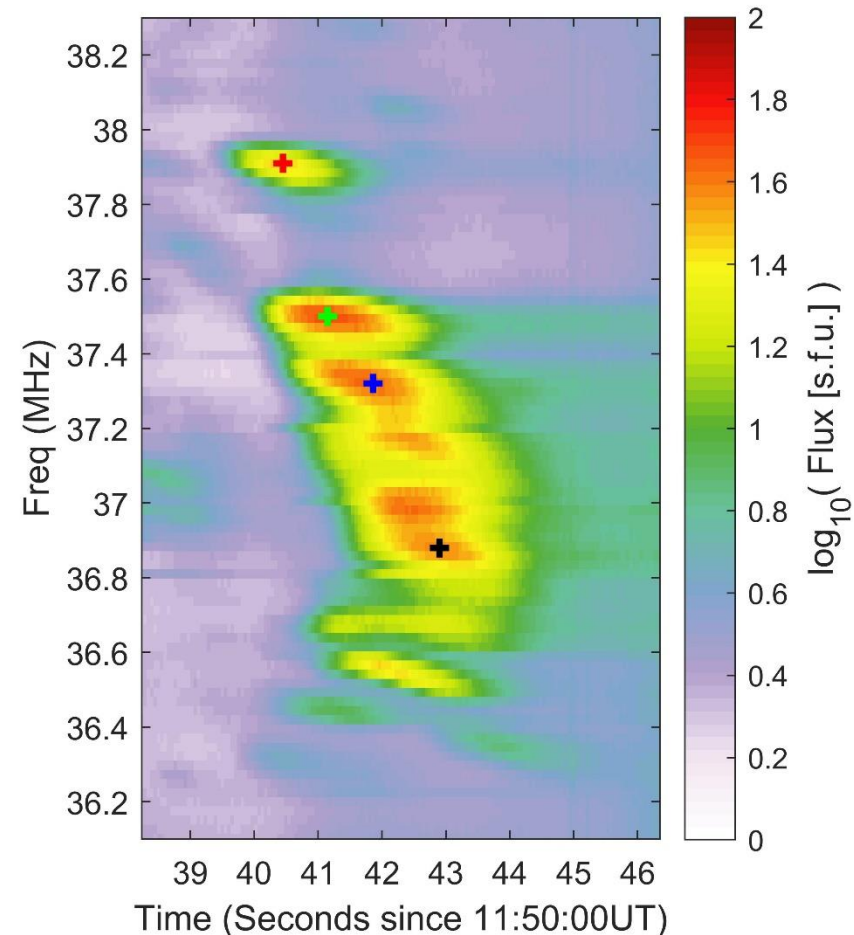
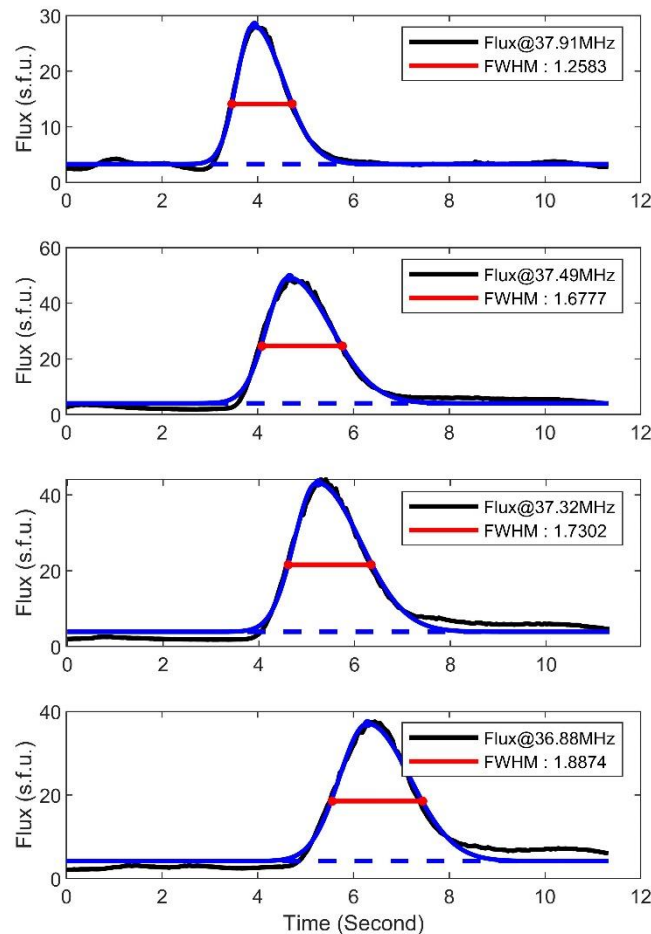
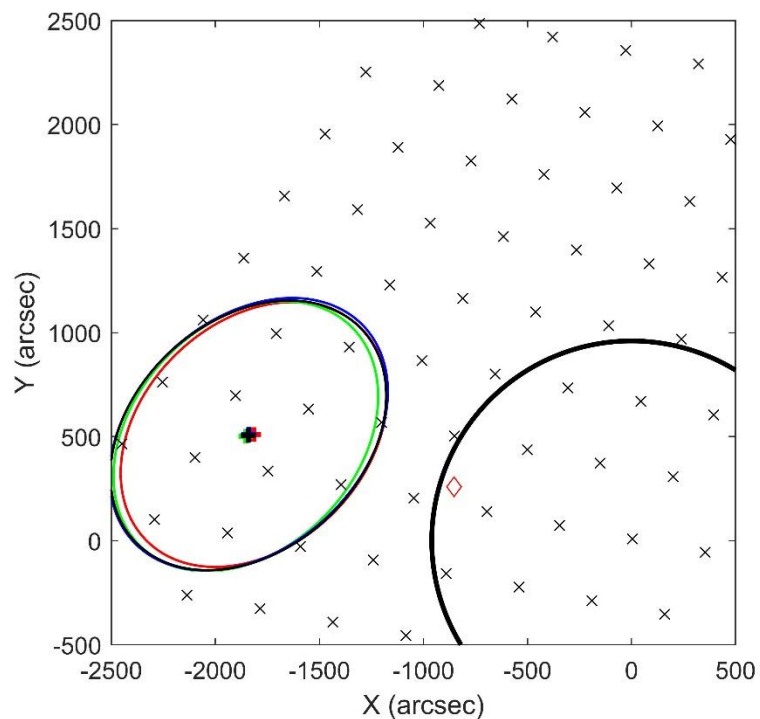
- 统计同一高度的所有粒子的到达时间



Time (s)

# 波动的传播效应带来的时间加宽的上限

- 时间宽度远小于III型暴



# 由源区位置和给出的时间宽度估计和观测的比较

- 各个因素的贡献归纳

$R$ (arcsec)	$\bar{f}$ (MHz)	$\delta N_e/N_e$	$\Delta t_{\delta N_e}^{\text{FWHM}}$ (s)	$\Delta t_{\delta v}^{\text{FWHM}}$ (s)	$\Delta t_{\text{obs}}^{\text{FWHM}}$ (s)
$1695 \pm 2$	$38.51 \pm 0.07$	0.067	0.44	2.21	2.52
$1710 \pm 2$	$37.96 \pm 0.12$	0.071	0.48	2.55	2.52
$1725 \pm 2$	$37.03 \pm 0.15$	0.076	0.52	2.62	2.73
$1740 \pm 2$	$36.17 \pm 0.13$	0.110	0.77	3.68	2.78
$1755 \pm 2$	$34.98 \pm 0.10$	0.195	1.39	3.20	3.09
$1770 \pm 2$	$34.01 \pm 0.09$	0.177	1.29	3.81	3.46

# 结论

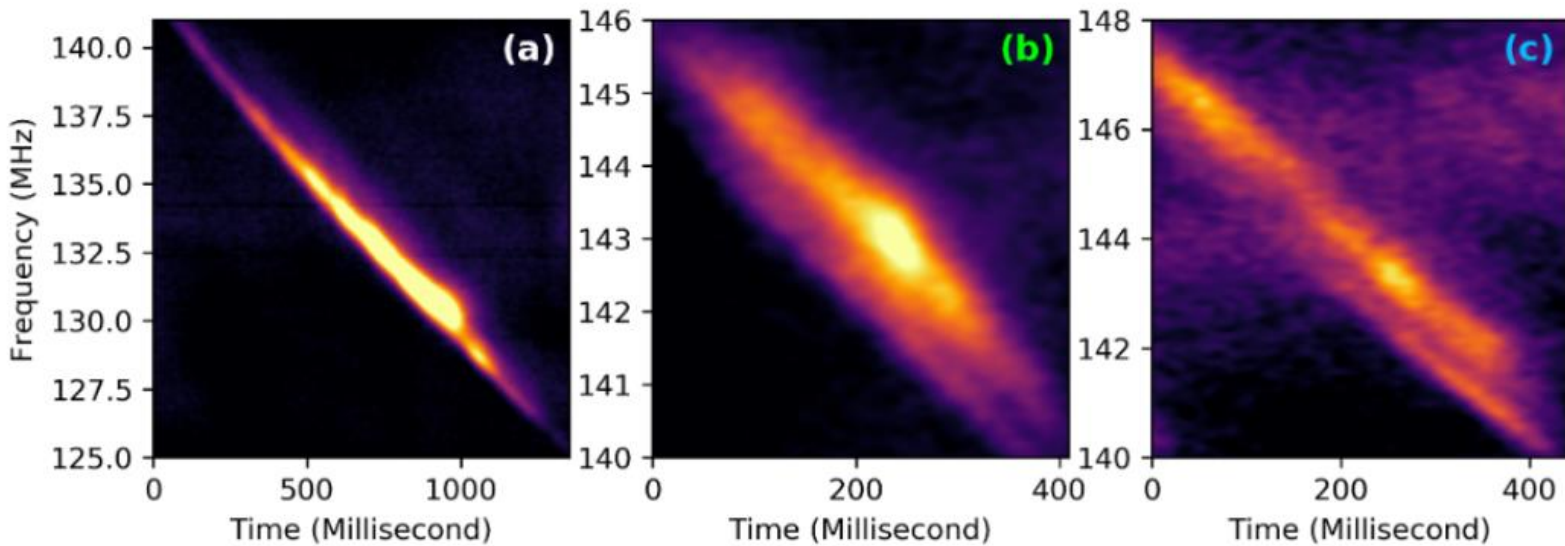
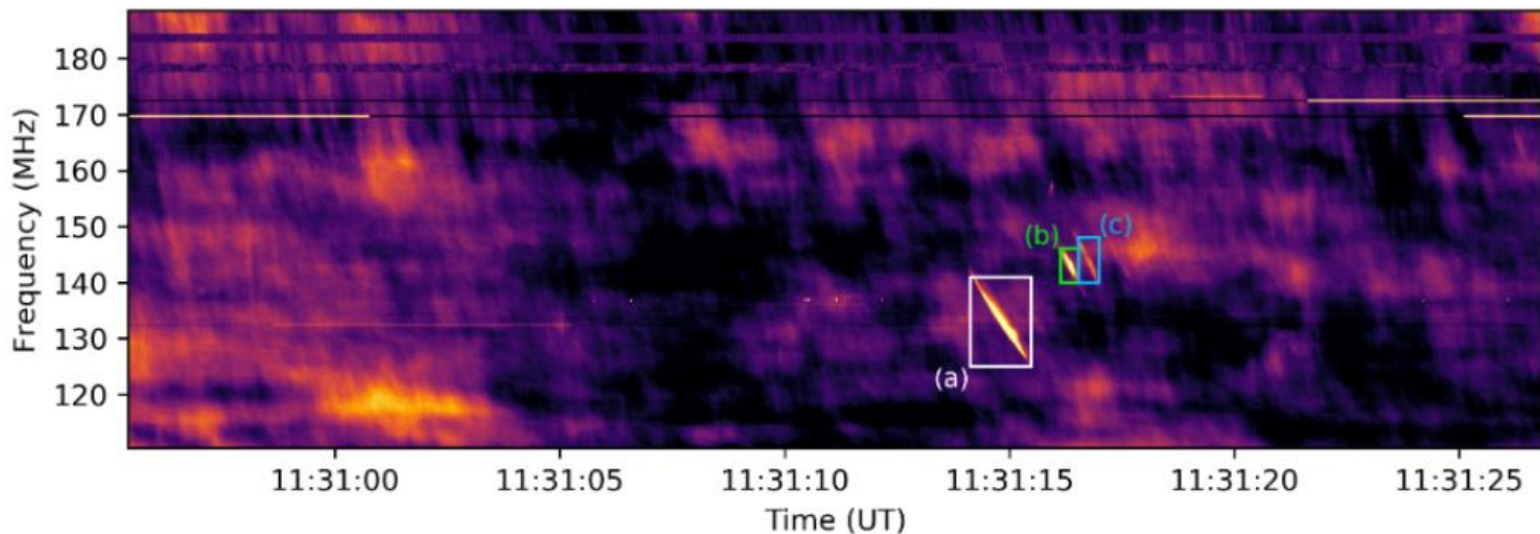
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- Beamformed 观测方法可以很好的给出射电源随时间的变化
- 通过分析不同频率和时间的源区位置可以给出源区具有时间宽度的具体因素
- 在30MHz频段下，速度色散是三型射电暴的主要贡献因素

Zhang. et al 2019-Nov ApJ

# 讨论——太阳低频 (20~200MHz) 波的频谱尺度

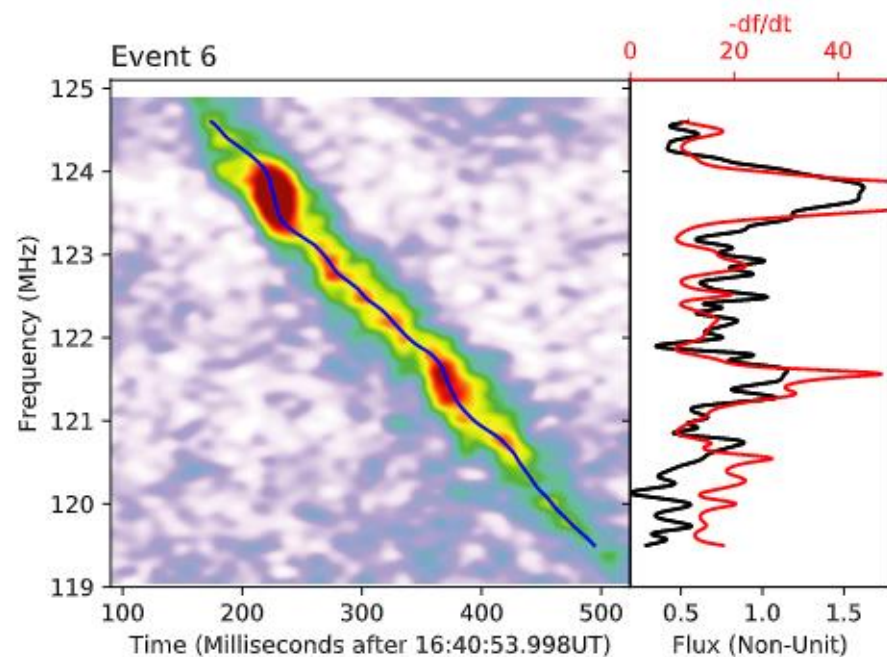
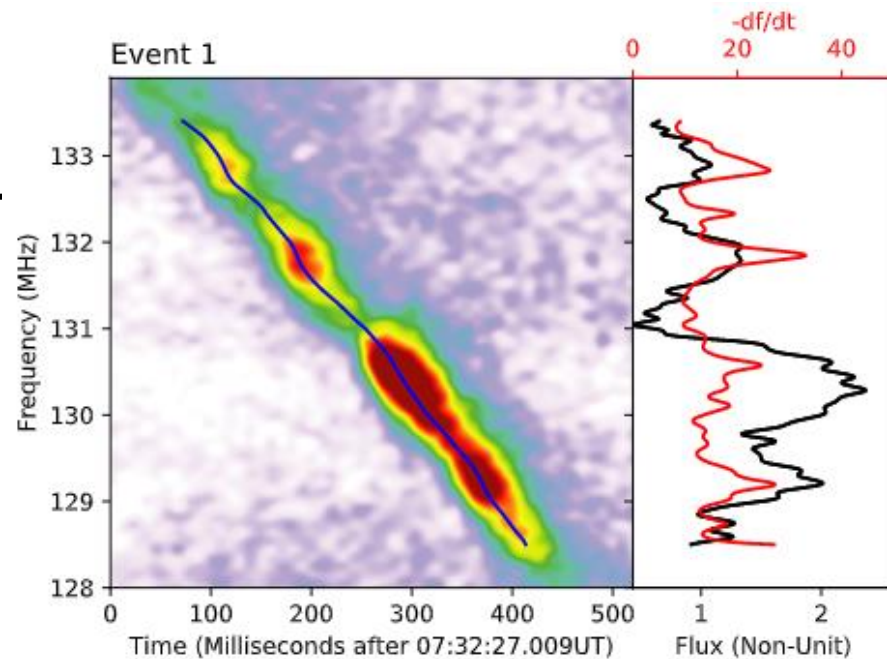
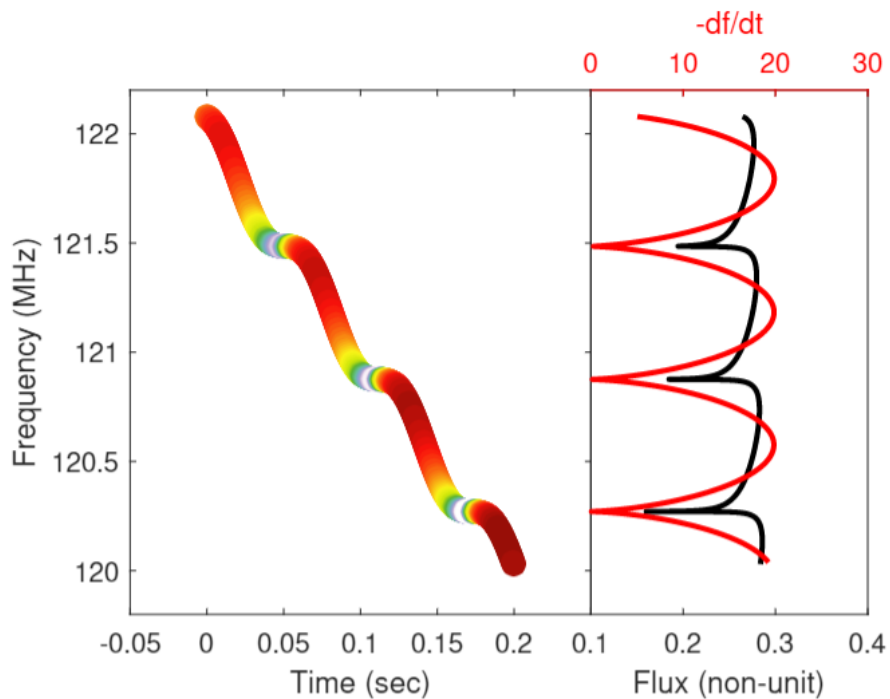
- Type IIIb :  $\sim 3\text{s} * 0.3\text{MHz}$
- Spike :  $\sim 0.1\text{s} * 0.1\text{MHz}$
- **S-burst** :  $\sim 0.05\text{s} * 0.5\text{MHz}$





# 讨论——SBurst精细结构解释

- 密度不均匀
- 库伦吸收



Peijin Zhang. Pietro Zucca, Chuanbing Wang. & LOFAR team  
2020 ApJ In press