Models of FRB that fit observations

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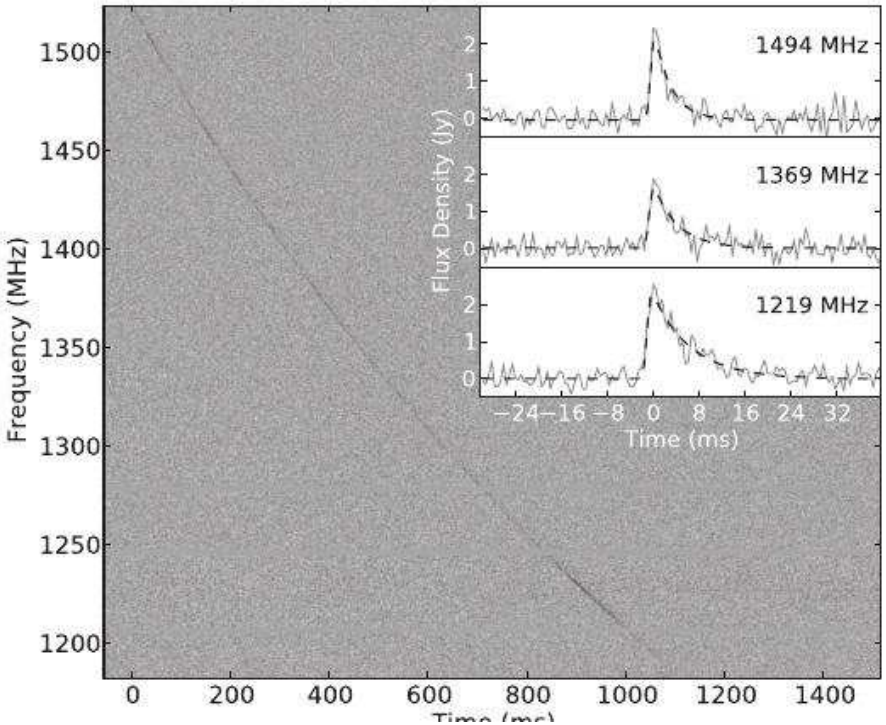
Common properties of fast radio bursts (FRB)



One of the Fast Radio Bursts observed by Thorton et al. [2013]

- One isolated radio pulse ($\sim$ GHz) similar to a PSR pulse.
- Duration : ~ 5 ms at a given freq.
- $\sim$ 18 events in Parkes.
- Also observed in Arecibo, Greenbank...
- As any PSR-like signal, they have a dispresion measure (DM).
- A few events exhibit scattering : characteristic of turbulence in ISM an/or IGM.
- Their DMs correspond to distances of $100-1000$ Mpc ! =DM excess problem

Meaning of a DM excess

DM excess = excess relative to the DM from propagation inside one or two galaxies.

Time delay from source (at distance L) to observer

$$(\frac{t}{s}) = 4.2 \times 10^3 (\frac{\nu}{MHz})^{-2} DM \quad (1)$$

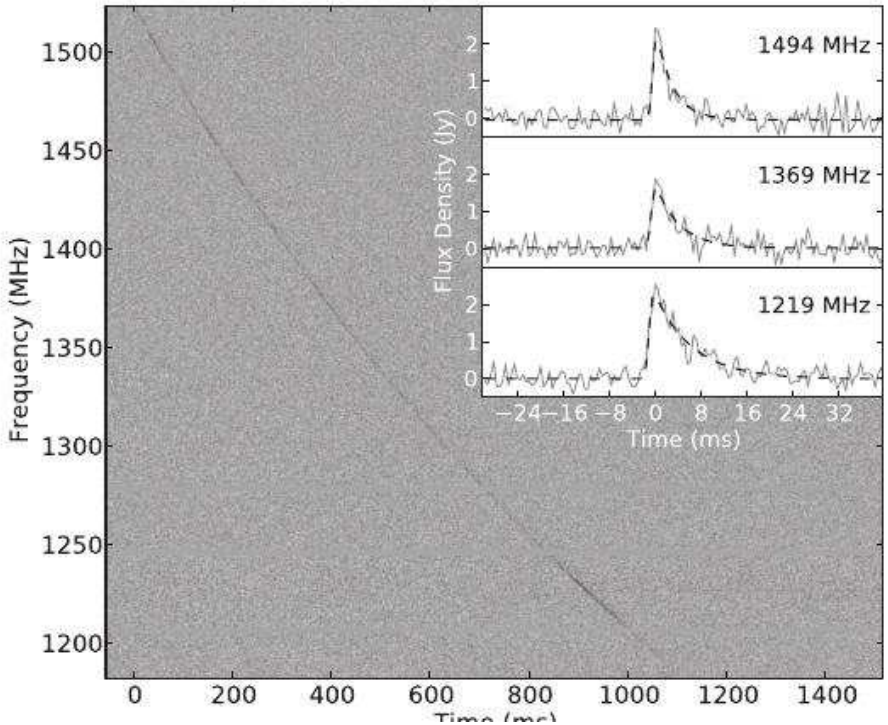
and

$$DM = \int_0^d n_e dz \quad (2)$$

A large DM $\Longrightarrow$ a lot of electrons encountered.

- Distance d is large. Source is outside our galaxy, and only "normal" ISM and inter galactic medium (IGM) is met;
- or electron density n_e is high. The source can be inside the Galaxy, but there is a nebulae/corona... between us.

A priori possible distances of FRB



One of the Fast Radio Bursts observed by Thorton et al. [2013]

- Close to the antenas, artefact (RFI, microwave oven...)
- Near the antenas, artefact (RFI, satellite...)
- In the solar system
- In the Galaxy
- In a galaxy in the neighbourhood
- In a $z \sim 0.2 - 1.$ galaxy
- Cosmic source not in a galaxy

A priori possible locations of FRB

- Close to the antenas. (only 1 lobe sees the FRB : discarded)
- Near the antenas (pb. of DM *and* scattering, at least for FRB110220)
- In the solar system (no corresponding source : discarded)
- In the Galaxy. But large range of galactic latitudes.
- In a galaxy in the local group.
- In a $z \sim 0.2 - 1$ galaxy.
- Cosmic source not in a galaxy. (not discussed here)

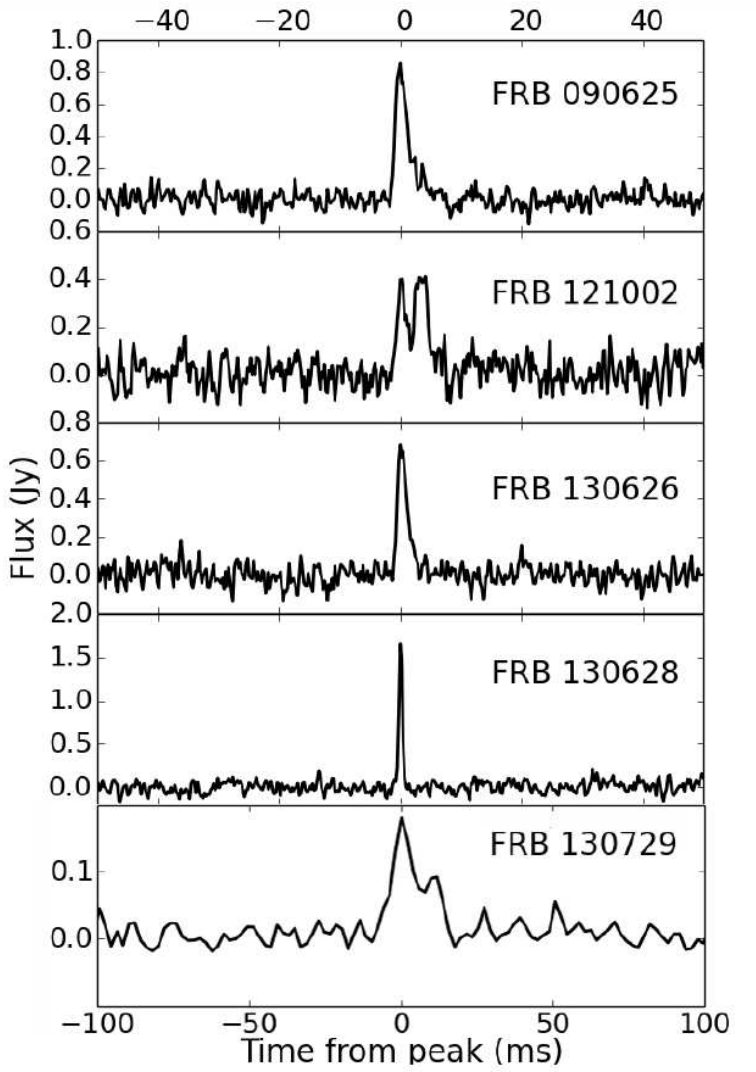
Models versus locations of FRB

- In the Galaxy. DM caused near the source.
  - Giant flares from star / contact binary stars [Loeb+ 2014]
  - Giant flares from magnetar
- In a galaxy in the local group. DM caused near the source.
  - Magnetar near a galactic nucleus. [Pen and Connor 2015]
  - Young PSR + SNR. [Connor+ 2015]
- In a $z \sim 0.2 - 1$ galaxy. DM caused in inter galactic medium (IGM).
  - Super-giant flare from magnetar or super-giant-Crab-like pulse. [Katz 2015]
  - Body in pulsar wind [Mottez, Zarka 2014]
  - Collision asteroid/neutron star [Huang, Geng 2015]
- Cosmic source not in a galaxy. DM caused in inter galactic medium (IGM).
  - Radiation from cosmic strings. [Vachaspati 2008] (not discussed here)

Models should explain

- Large dispersion measure DM (>300 $pccm^{-3}$)
- Brevity (5 ms)
- Production rate (10^4 per sky per day)
- Locations in galactic coordinates
- Lack of counterpart (up to now) at other frequencies

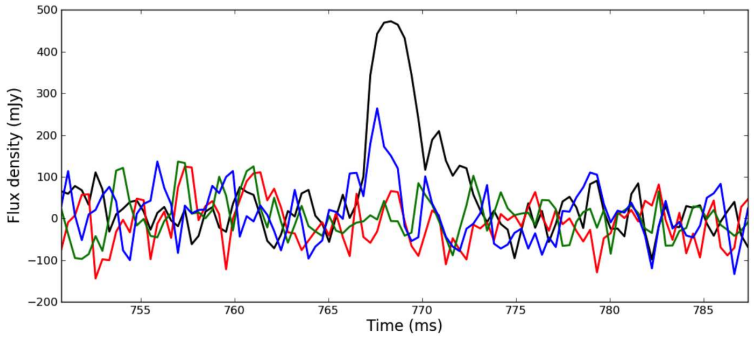
Special FRBs that could validate/invalidate models



Champion+ [2015]

- FRB 121002 has a double peak D. Champion+ MNRAS 2015
- A measurement of some circular polarization E. Petroff+ 2015, E. Keane
- FRB 121102 is a repeating one ! Seen in Parkes, Arecibo, Greenbelt and more Spitler+ 2016, Scholz+ 2016

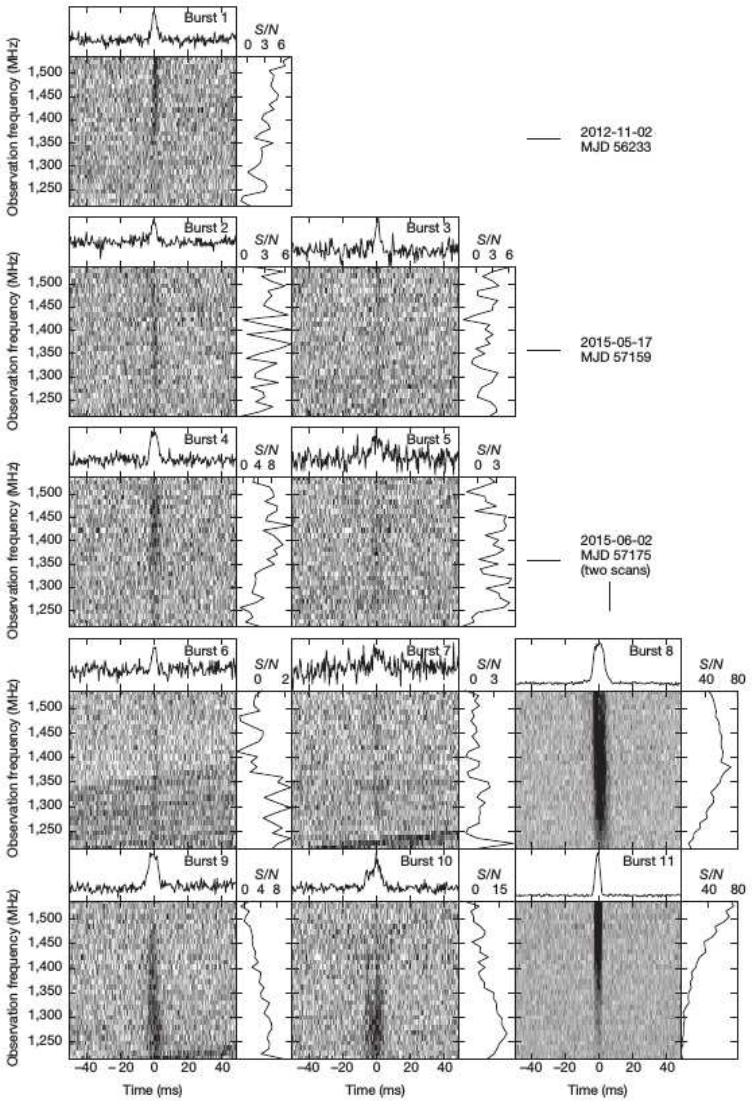
Special FRBs that could validate/invalidate models



FRB 140514 Total intensity (I) in black, circular pol. (V) in blue [Petrov+ 13]

- FRB 121002 has a double peak D. Champion+ MNRAS 15
- FRB140514 has 21% circular polarization E. Petroff+ 15, E. Keane
- FRB 121102 is a repeating one ! Seen in Parkes, Arecibo, Greenbelt and more Spitler+ 2016, Scholz+ 16

Properties of repeating FRB 121102



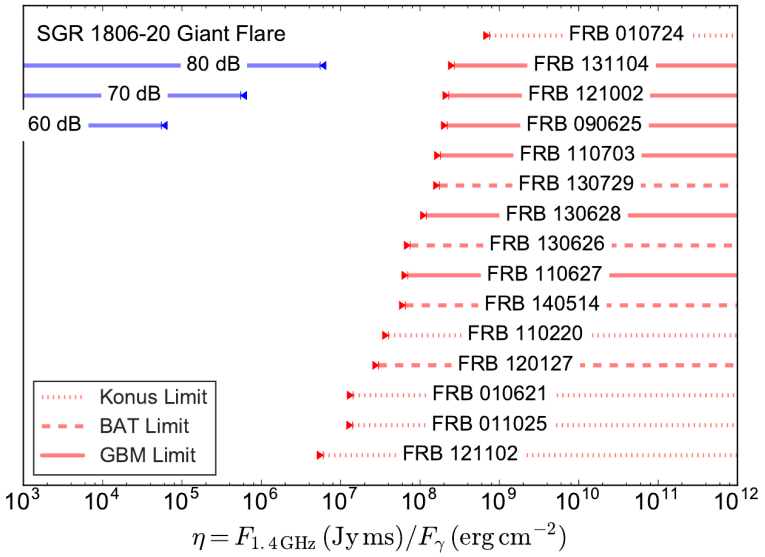
FRB121102 11 bursts recorded in Arecibo [Spitler+ 16]

- 17 bursts with Arecibo at 1.4 GHz, 1 in Parkes, 5 bursts with GBT at 2 GHz, between 2012 and 2016. 0 burst in Lovell, Jansky VLA, and Effelsberg.
- 60 hours of observations. 6 bursts seen during a 10-min period and 4 in a 20-min period.
- Same dispersion DM=599 pc cm^{-3} (but two), same δ and RA.
- Varied amplitudes (or S/N)
- Varied spectral shapes. Not power laws.
- Peaks # 8 and 10 are double peaked at high freq., blended at lower freq.
- No circular or linear polarization.
- No periodicity found.
- No hard X /soft γ-ray burst counterpart (Swift, Fermi, MAXI, INTEGRAL)

What causes repeating FRB 121102 ?

- Exclude neutron star merger, neutron star collapse and all other kinds of unique events.
- Magnetar in the Galaxy : no soft γ-ray $\Longrightarrow$ $D >$few100 pc [Younes, Telegram, 16]
- If in the Galaxy, there is a nebula (HII cloud). It absorbs and reemits radiation that should be detected if in the Galaxy [Kulkarni+ 15, Spitler+ 16]
- Do not exclude giant flares from pulsar or magnetar outside the Galaxy [Spitler+ 16]
- Do not exclude totally radio emission from small pulsar companion. Clusters of small bodies ? (not mentioned in Spitler+ 16)

Another case against flare in the Galaxy



Ratio radio fluence/γ ray fluence for the 1802-20 giant flare [Tendulkar+ 16]

- 1806-20 is a gamma repeater. A magnetar in a star cluster at $\sim$ 9 kpc.
- Giant flare 1806-20, 2004 Dec. 27 = the most intense γ ray event in the Galaxy.
- Parkes RT was pointing 36^o away from the source.
- What upper value for radio fluence ?
- Compute range of allowed ratios of X-ray to radio fluences.
- Conclusion : Giant flare of 1806-20 does not compare with known FRBs.
- Not in favour of FRBs as magnetar's giant flares in the Galaxy.

Models that predict repeating bursts

- Mainstream: Non-catastrophic events in NS magnetospheres, DM from local environment, $d < 100 Mpc$ [Masui, 15, Katz, 16]
  - Flares from magnetars in another galaxy (magnetically powered)[Popov Postnov 10, Kean 12, Lyubarsku 14, Pen Connor 15]
  - Crab-like giant flare from a young pulsar (rotationally powered)[Cordes Wasserman, 16 Connor+ 16,Lyutikov, 16]
- Outsiders: Non-catastrophic events in NS magnetospheres, DM from IGM, $d > 100 Mpc$
  - Planets/companions in a pulsar wind [Mottez, Zarka, 14]
  - Asteroids falling onto a neutron star [Huang, Geng, 16]

Models that could explain repeating FRB 121102

- Four models remain.
- Sources are outside the Galaxy.

model property	Young PSR giant pulse	Magnetar flare	Companion +PSR wind	Asteroid fall onto NS
DM excess	IGM+local	IGM+local	IGM	IGM
Brevity	OK	OK	OK	OK
Prod. rate				
Loc. d, l	OK	OK	OK	OK
Other freq.	OK$*$	ongoing search	OK$*$	not clear to me
Repeats	OK	OK	OK	OK
Non-periodic	OK	OK	if many companions	OK

OK$*$: is OK by extrapolation of observations of the Crab pulsar, but not explained on physical grounds.

OK$*$: is OK based on theoretical ground. No unambiguous observation yet.