Fast radio bursts

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FRB: discovery

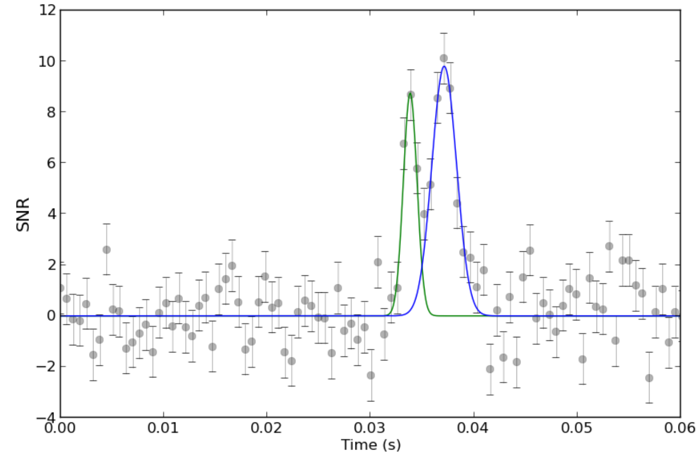
FRB is a transient radio pulse lasting a few milliseconds. They are bright, unresolved, non-repeating, broadband flashes.

So far 17 FRBs have been detected, all but one by the Parkes radio telescope (Australia).

The origin of fast radio bursts is not known: they are generally thought to be extragalactic due to the anomalously high amount of pulse dispersion observed.

Some facts

- FRB 121002 had a double pulse 5.1 ms apart.
- FRB 140514 was found to be 21% (+/- 7%) circularly polarized.
- FRB 110523 (discovered in archival data from the Green Bank Telescope). Detection of both circular and linear polarization.
- FRB 150418, detection of linear polarization. Possible association to an elliptical galaxy with z=0.5.



Dispersion

Dispersion occurs because electromagnetic waves traversing an ionized medium (ISM or IGM) experience a frequency dependent change in group velocity. For steady sources dispersion is not observable, but for short time-scale pulsed emission, like pulsars, dispersion of the signal becomes important and measurable. In general, due to dispersion the broadband, temporally narrow pulses at the source are observed smeared in time.

Dispersion measure

For small electron densities, $n_\mathrm{e} \approx 0.03\ \mathrm{cm}^{-3}$, typical of the ISM (Ables & Manchester, 1976),

$$v_g^2 = c^2 \left(1 - \frac{n_e e^2}{2\pi m_\mathrm{e} \nu^2}\right), \tag{1.2}$$

where v_g is the group velocity of the radiation, m_e and e are the electron mass and charge respectively, and ν is the propagating wave frequency. This means that the light travel time over a distance L is

$$T = \int_0^L \frac{\mathrm{d}l}{v_g} = \frac{L}{c} + \frac{e^2 \int_0^L n_\mathrm{e} \mathrm{d}l}{2\pi m_\mathrm{e} c \nu^2}. \tag{1.3}$$

These two terms are the light travel time in a vacuum plus the additional delay introduced by the frequency dependent group velocity of the waves. In this way the dispersion measure DM is defined as

$$\mathrm{DM} = \int_0^L n_\mathrm{e} \mathrm{d}l \tag{1.4}$$

Large DM as an indication for extragalactic origin

- With a variety of techniques, including pulsar measurements, the approximate 3-dimensional mapping and modeling of ionized material in the Milky Way has been possible.
- By using this map one can approximate the maximum DM that a source located in the Galaxy could have as function of position on the sky.
- Calculations performed for the “Lorimer Burst”, FRB 010724, give DM=25 cm^-3pc, while the observed one is DM=375 cm^-3pc, indicating the distance of 500 Mpc.

FRB 150418

- DM=776 cm^-3pc, 4.1 larger than the Galactic contribution in this direction.
- Frequency 1.382 GHz.
- Observed pulse width 0.8+/-0.3 ms. Intrinsic pulse width is unresolved.
- Radio afterglow is discovered lasting about 6 days.
- Host galaxy is identified as elliptical galaxy at z=0.492+/-0.008 with M=10^11 solar masses.

Host galaxy for FRB 150418?

LETTER

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The host galaxy of a fast radio burst

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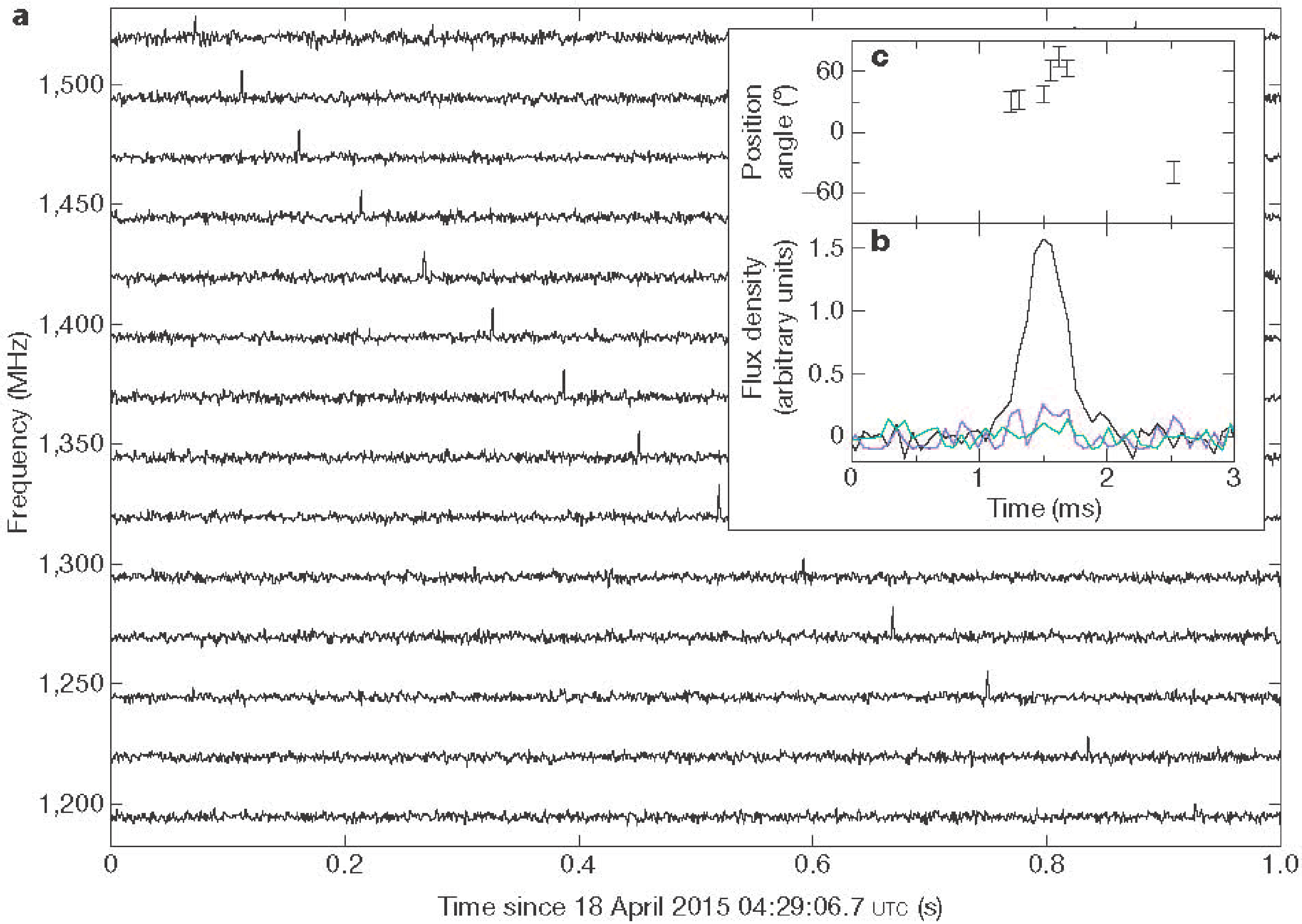
In recent years, millisecond-duration radio signals originating in distant galaxies appear to have been discovered in the so-called fast radio bursts[1–9]. These signals are dispersed according to a precise physical law and this dispersion is a key observable quantity, which, in tandem with a redshift measurement, can be used for fundamental physical investigations[10,11]. Every fast radio burst has a dispersion measurement, but none before now have had a redshift measurement, because of the difficulty in pinpointing their celestial coordinates. Here we report the discovery of a fast radio burst and the identification of a fading radio transient lasting ~6 days after the event, which we use to identify the host galaxy; we measure the galaxy's redshift to be $z = 0.492 \pm 0.008$. The dispersion measure and redshift, in combination, provide a direct measurement of the cosmic density of ionized baryons in the intergalactic medium of $\Omega_{IGM} = 4.9 \pm 1.3$ per cent, in agreement with the expectation from the Wilkinson Microwave Anisotropy Probe[12], and including all of the so-called 'missing baryons'. The ~6-day radio transient is largely consistent with the radio afterglow of a short γ-ray burst[13], and its existence and timescale do not support progenitor models such as giant pulses from pulsars, and supernovae. This contrasts with the interpretation[8] of another recently discovered fast radio burst, suggesting that there are at least two classes of bursts.

Upon detection of FRB 150418 at Parkes, a network of telescopes was triggered across a wide range of wavelengths (see Methods). Beginning two hours after the FRB, observations with the Australia Telescope Compact Array (ATCA) were carried out at 5.5 GHz and 7.5 GHz, identifying two variable compact sources. One of the variable sources is consistent with a GHz-peaked-spectrum source, with a positive spectral index, as previously identified in observations at these frequencies[16]. The other variable source (right ascension, RA 07 h 16 min 34.6 s; declination, dec. $-19° 00' 40''$), offset by 1.944 arcmin from the centre of the Parkes beam, was seen at 5.5 GHz at a brightness of 0.27(5) mJy per beam just 2 h after the FRB. The source was then seen to fade over subsequent epochs, settling at a brightness of ~0.09(2) mJy per beam (Fig. 2). The source is also seen at 7.5 GHz at 0.18(3) mJy per beam in the first epoch but subsequently not detected. These observations indicate a ~6-day transient with a negative spectral index; we obtain $\alpha = -1.37$ in the first epoch, for a power-law spectrum of the form $F_\nu \propto \nu^\alpha$. The subsequent quiescent level is consistent with the level expected[17] from an early-type galaxy at $z \approx 0.5$. To estimate the likelihood that this transient could occur by chance we consider the results of radio imaging surveys (see Methods). By comparing to a recent survey with the Very Large Array[18] in the 2–4 GHz band, we expect a 95% (99%) confidence upper limit of <0.001 (<0.002) such transients

The burst



a
1,500
1,450
1,400
1,350
1,300
1,250
1,200
Frequency (MHz)
0
0.2
0.4
0.6
0.8
1.0
Time since 18 April 2015 04:29:06.7 UTC (s)
c
Position angle (°)
60
0
−60
b
Flux density (arbitrary units)
1.5
1.0
0.5
0
0
1
2
3
Time (ms)

Baryonic density measurement

- The intergalactic baryonic density can be measured:

Dispersion in the intergalactic medium is related to the cosmic density of ionized baryons $\Omega_{\rm IGM}$ and the redshift[19,20] according to the following expression:

$$\mathrm{DM_{IGM}} = \frac{3cH_0\Omega_{\rm IGM}}{8\pi G m_{\rm p}} \int_0^z \frac{(1+z')f_{\rm e}(z')\mathrm{d}z'}{[(1+z')^3\Omega_{\rm m}+\Omega_\Lambda]^{0.5}} \qquad (1)$$

Here, we take $\mathrm{DM_{IGM}} = \mathrm{DM_{FRB}} - \mathrm{DM_{MW}} - \mathrm{DM_{halo}} - \mathrm{DM_{host}}(1+z)^{-1}$ (see Methods). It is appropriate to account for a Milky Way halo con-

- DM(halo)= 30 cm^-3pc,
- DM(MW)= 189 cm^-3pc,
- DM(host)= 37 cm^-3pc (modelled).

It implies: Ω(IGM)=0.049+/-0.013, for fe=0.88. It is consistent with WMAP result Ω(baryons)=0.046+/-0.002.

Possible progenitor

- Elliptical galaxy: compact merger?
- The afterglow is similar to radio afterglows of short GRBs.
- High brightness temperature 10^14 K above the Compton cooling limit of 10^12 K imply modest Lorentz factor.
- If variability in brightness and specral index are caused by scintillations, then the source is very compact.

Different viewpoint

Cosmological Origin for FRB 150418? Not So Fast

P. K. G. Williams, E. Berger

Abstract: Keane *et al.* (2016) have recently claimed to have obtained the first precise localization for a Fast Radio Burst thanks to the identification of a contemporaneous fading slow (∼week-timescale) radio transient. We show that the quiescent radio luminosity of the proposed host galaxy points to the presence of an AGN, and therefore that the claimed transient may instead represent common AGN variability. We further show that the expected number of variable (rather than transient) sources in the Parkes localization region of FRB 150418 is order unity. Finally we show that the properties of the radio counterpart are incompatible with a synchrotron-emitting blastwave. Taken together, these results indicate that the claimed radio source is unlikely to be associated with FRB 150418, and hence that a precise localization and redshift determination cannot be justified.

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Arguments against afterglow interpretation

- Observed radio spectral luminosity imply high star formation rate of 10^2-10^3 Msol/year. This is inconsistent with <0.2 Msol/year inferred from the optical spectrum.
- Chance discovery of another variable source is non-negligible (up to 5 conicident variable sources per Parkes beam).
- Incompatibility with ultrarelativistic blast waves: assuming Lorentz factor 10^2, one obtains kinetic energy 10^44 erg and ISM density 10^8 cm^-3.

Conclusions

- Due to large dispersion measure FRBs are likely cosmological.
- If so, there is a possibility to measure independently baryonic content of the Universe with FRBs.
- At present association with eliptic galaxy looks doubtful.