FAST RADIO BURSTS

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Spotkania z astronomią

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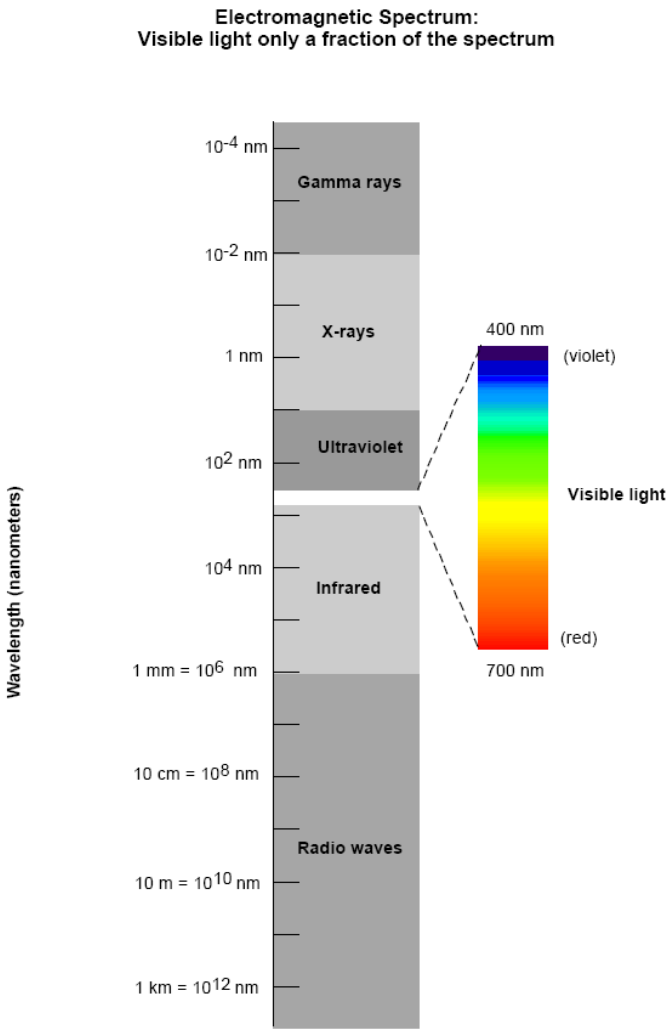
NATIONAL SCIENCE CENTRE
POLAND

Radio astronomy



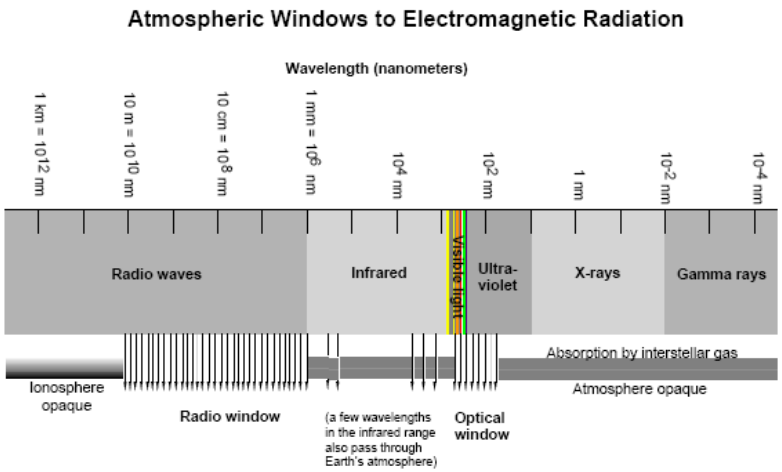
Birth of Radio astronomy

- 1930's, Karl Jansky at Bell Telephone Laboratories: study of the radio frequency interference from thunderstorms in order to improve transatlantic voice transmissions.

- discovered a faint steady 'hiss' of unknown origin;
- its strength varied in time and its peak occured 4min earlier each day (= exact length of a sidereal day);
- source is not terrestrial but is the center of our Galaxy;
- birth of radio astronomy by pure chance!
- a Jansky: unit of flux density (=strength) of a radio source.

Radio astronomy became a branch of astronomy after WWII.

Radio astronomy



Nançay, France

Arecibo ($D \sim$ 300m, R= few ’), Puerto Rico

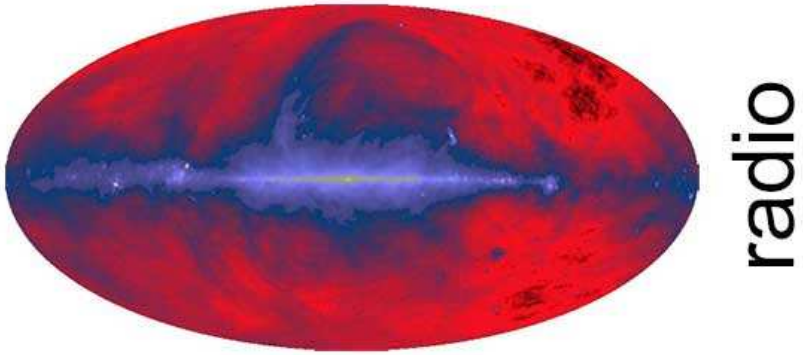
Very Large Array: 27 antennas each with D=25 m (R=0.2 to 0.004”), New Mexico USA

+ our atmosphere transparent to radio waves;
+ observations 24h a day, even during rain or snow storms;
+ radio telescopes can be built with simple material as radio wavelengths $\gtrsim$ 10cm;
- sensitive: total energy received in radio is extremely small;
- big: angular resolution R= wavelength of the signal/size of the telescope $\rightarrow$ even with the largest antennas, resolution to the one of a naked eye (1’);
- interferometer: the farther the antennas the largest telescope they mimic.

- Toruń: two single dish radio telescopes (D=32 and 15 m)
- since 2016: Five-hundred-meter Aperture Spherical radio Telescope (China)
- 2020: Square Kilometer Array (Australia and South Africa)

Radio astronomy: a new window on the Universe

Wavelength= 400-700 nm

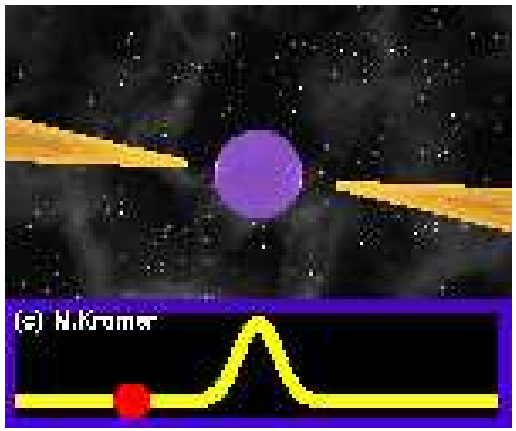


Wavelength= 73.5 cm (Freq.= 408 MHz)

Dust in the interstellar medium obscures the optical emission and not the radio one.
Usually strong radio sources are undetectable in optical wavelengths:

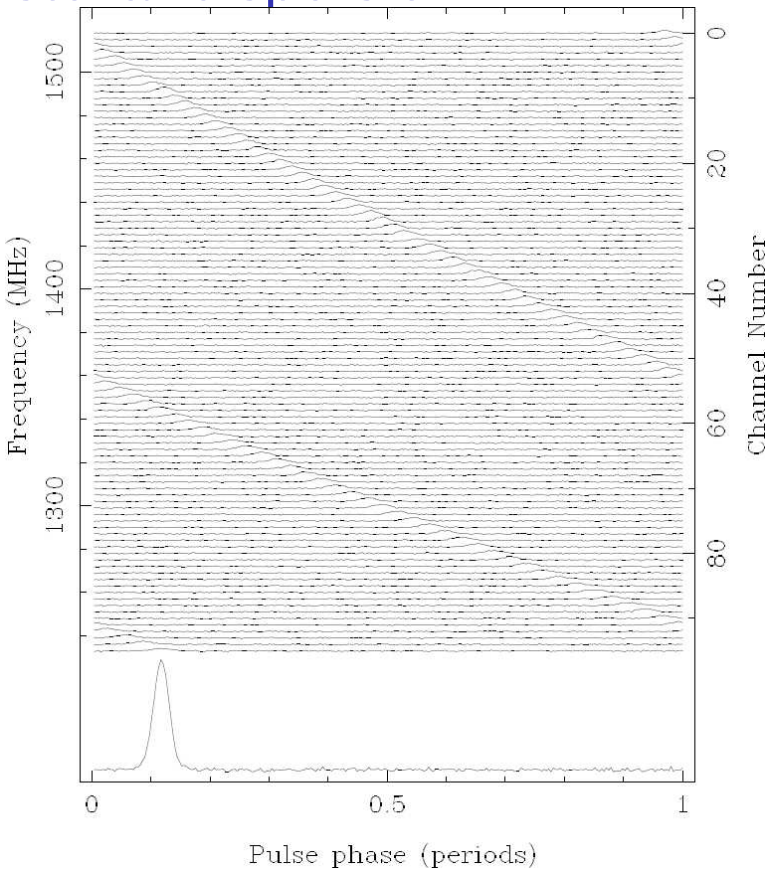
- the center of our Galaxy;
- external galaxies like Centaurus A and the Large Magellanic Cloud;
- North Polar Spur: interstellar bubble created by winds of young, hot stars and several supernova explosions;
- Cas A, Vela: supernova remnants;
- pulsars: radio emitting rotating neutron stars;
- Cosmic Microwave Background;
- in our solar system: the Sun, Jupiter;
- interferences: natural (eg. lightings) or artificial (radar, satellites, cell phones, . . .);
- (extraterrestrial civilisations - SETI)?

Radio pulsars

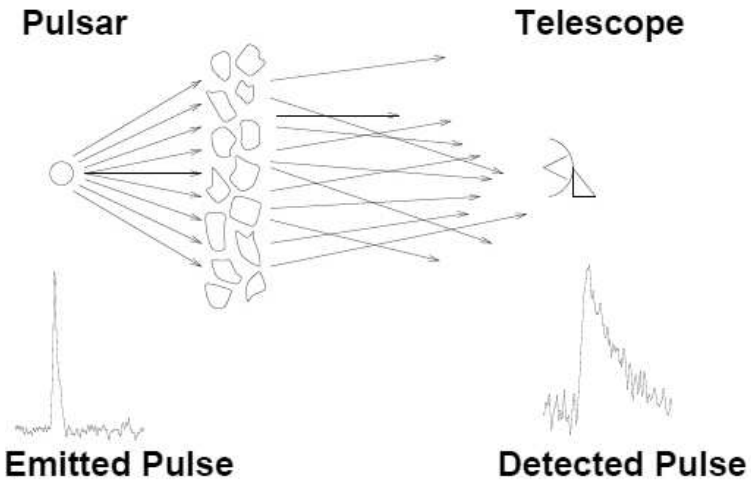


- rotating neutron stars (NSs);
- remnant from the gravitational collapse of a $\sim$ 10 $M_{\odot}$ star during supernova event;
- extreme objects: radius of $\sim$ 10km for a mass of 1-2 the one of the Sun (=10^{30}kg) with magnetic fields up to 10^{16} the one of the Earth;
- period of the pulses = period of rotation, from seconds to few milliseconds;
- extremely stable rotators, as stable or even more than atomic clocks, eg. J0437-4715: P=0.005757451936712637 s;
- not all NSs are seen as pulsars, but all pulsars are NSs;
- $\sim$ 2000 NSs from radio to γ-rays, a majority as radio pulsars.

Interstellar dispersion



Dispersion of the radio signal by the interstellar matter:

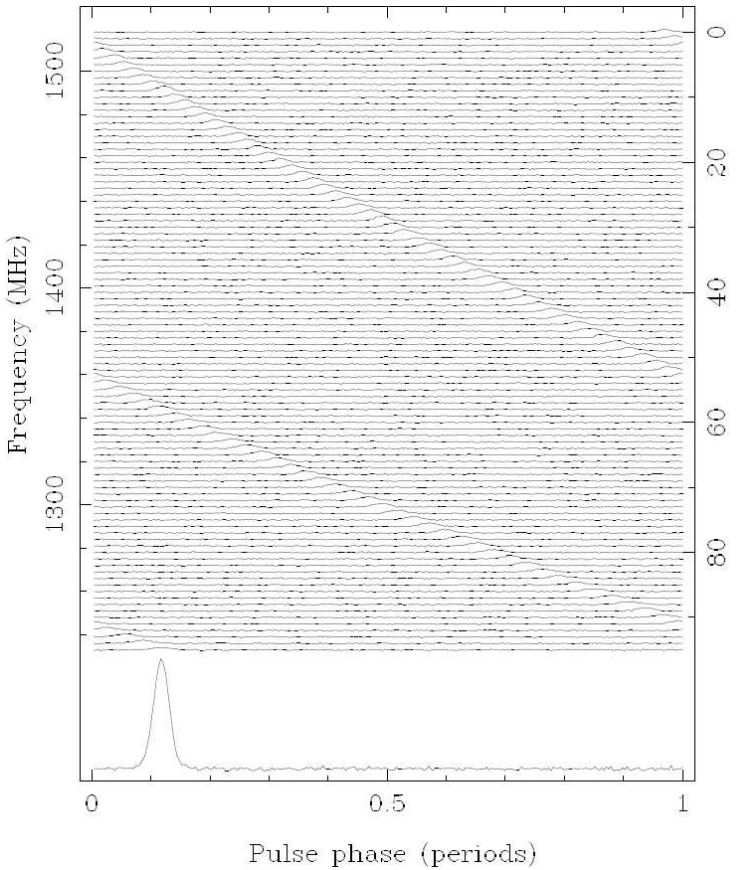


Lorimer, LRR (2008)

High frequencies arrive before the low frequencies ("blue before red").

- DM (dispersion measure): quantifies the amount of interstellar matter between us and the pulsar;
- models for the repartition of interstellar matter;
- if measurement of the DM from radio observations $\rightarrow$ estimate the distance to the pulsar;
- if distance to the pulsar known with a different technique $\rightarrow$ model for the DM.

Interstellar dispersion



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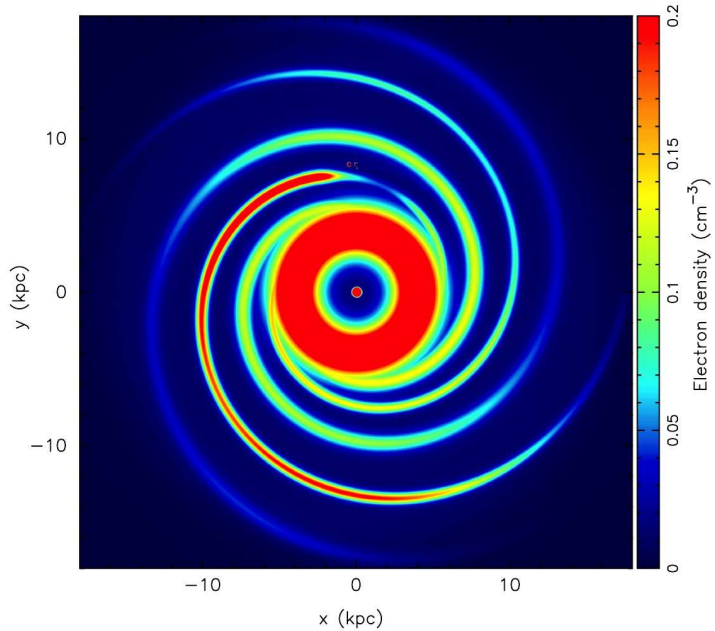

Yao et al., ApJ (2017)

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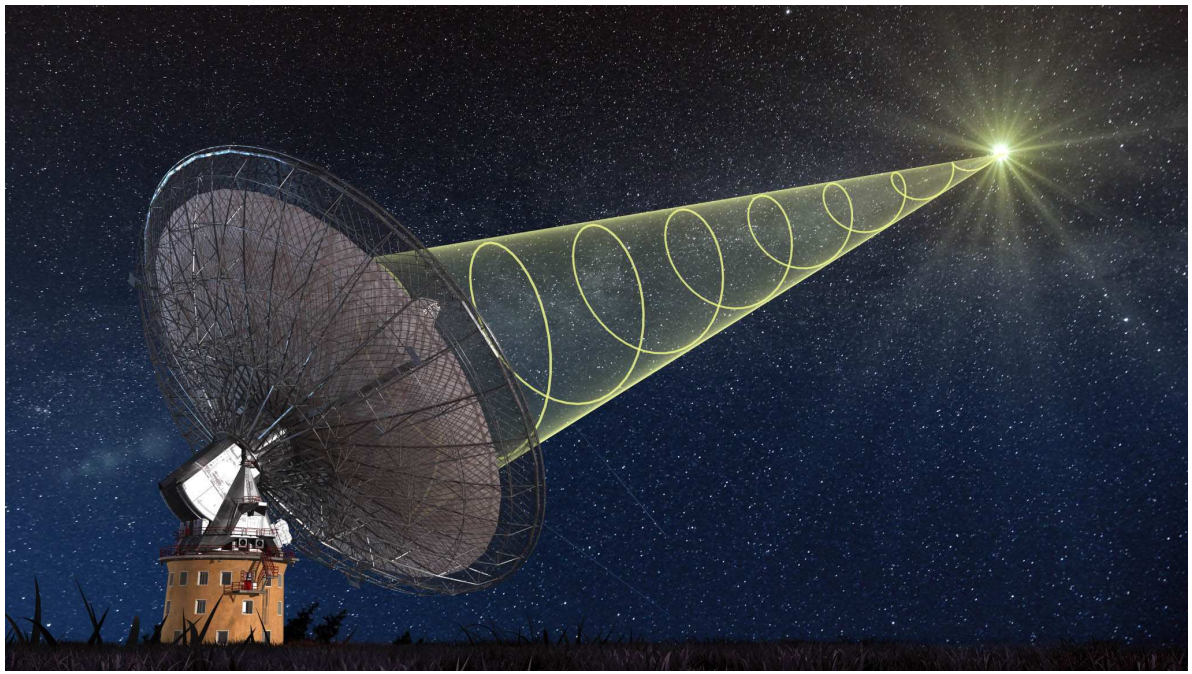
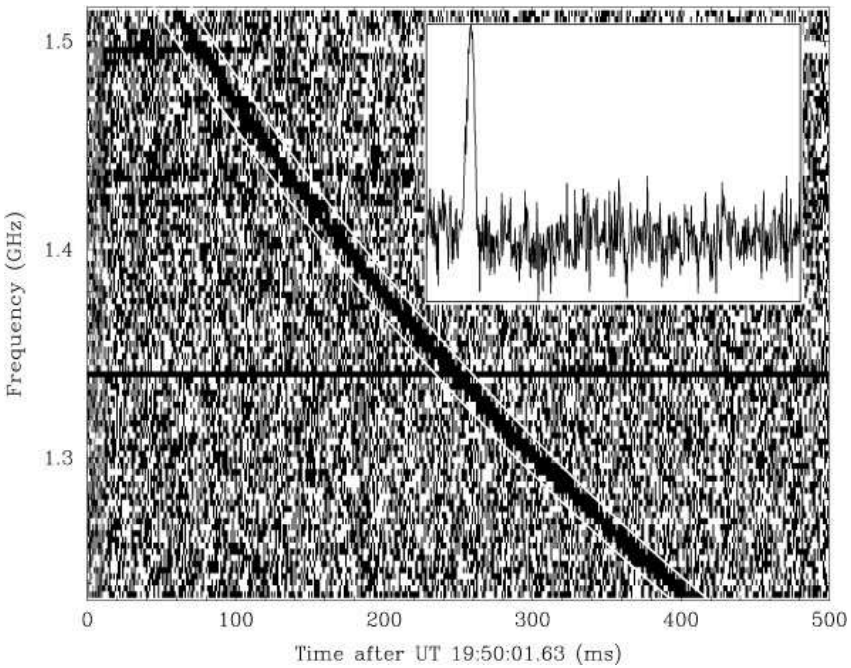
Lorimer burst



Artist impression - Swinburne Astronomy Productions

Lorimer burst



Lorimer et al., Science (2007)

- in archival data taken in 2001 by Parkes Radio Telescope (Australia);
- a very bright (power of 500 million Suns) single radio pulse, lasting few milliseconds = burst;
- very dispersed (very large DM, 10 times the one for a source in our Galaxy) $\rightarrow$ many billion l.y. away = extragalactic?
- no other signal in 90 hours;
- source of the signal unidentified.

First ever **Fast Radio Burst** (FRB) detected; named FRB 010724.

More FRBs

Burke-Spolaor et al., ApJ (2011)

- 16 powerful millisecond bursts with large DM compatible with extragalactic origin;

BUT, unlike the Lorimer burst:

- all have very similar DM and detected during daytime primarily mid-morning;
- source outside of the region the telescope was pointing at;
- most probably of terrestrial origin: signals named 'perytons', a mythological animal hybrid between a deer and a bird.

The origin of perytons

Petroff et al., MNRAS (2015)

- three perytons detected at the usual frequency of observation;
- also signals at a higher frequency = the one of radio interferences from microwave ovens;
- always obtained from the same pointing of Parkes telescope;
- similar DM and time of day

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- always obtained from the same pointing of Parkes telescope;
- similar DM and time of day (office hours spec. lunch time)...
- generated by two 27 y.o. Matsushita-National microwave ovens when the door is open before the end of the cycle;
- signal reproducible when playing with a microwave oven, which mimics large dispersion.
- the Lorimer burst does have the same properties as perytons (and the telescope was not pointing towards the kitchen!).

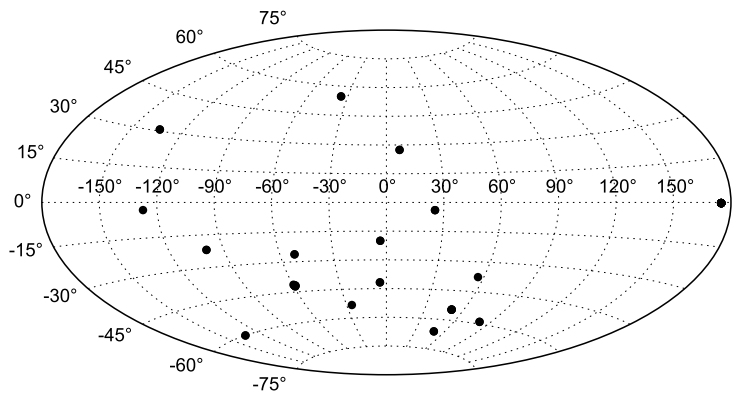
FRBs are real!

Detection with other radiotelescopes

- Arecibo: FRB 121102 (Spitler et al., ApJ 2014)
- Green Bank Telescope (USA): FRB 110523 (Masui et al., Nature 2015)

Current observational status

- FRB catalogue: `astronomy.swin.edu.au/pulsar/frbcat/`
- 18 sources;
- mostly at high galactic latitude;



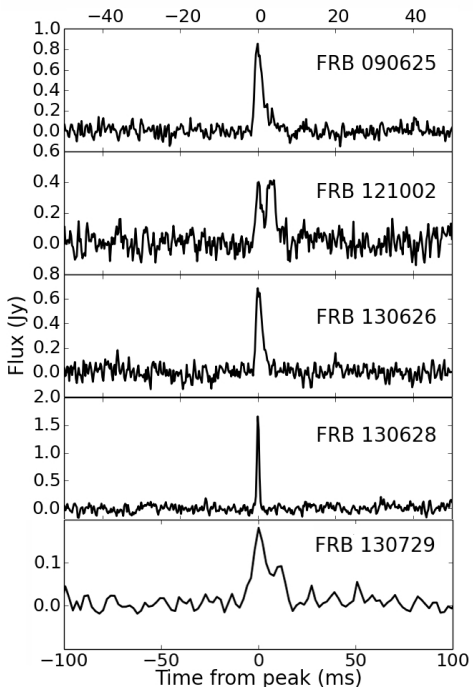
- estimated rate: twice a minute!

Interesting sources

FRB 121002

Champion et al., MNRAS (2016)

- double peak with a separation of 1.0 ms.

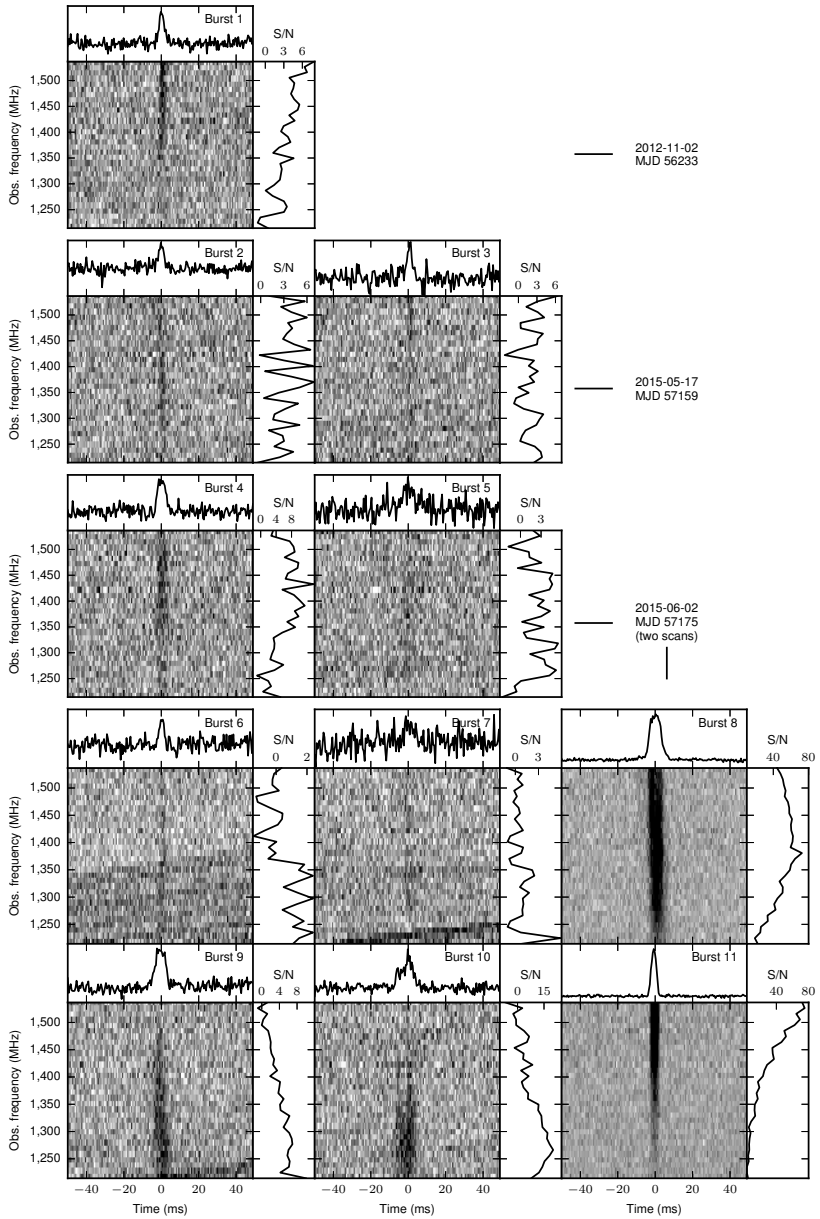


FRB 150418

Keane et al., Nature (2016)

- real-time detection;
- multi-wavelength follow-up observations (radio, optical, X-ray);
- discovered a coincident source of a radio signal that decreases over $\sim$6 days;
- identification of the host: elliptical galaxy located 6 billion l.y. away.
- Controversy: 4 days after paper by Williams & Berger, ApJL (2016);
- the galaxy is brighter and thus variable;
- accidental coincidence? maybe the source is not the galaxy...

Interesting sources



Spitler et al., Nature (2016)

FRB 121102

Scholz et al., ApJ (2016)
Spitler et al., Nature (2014)

- previously discovered source (Spitler et al., ApJ 2014) with Arecibo;
- 17 additional bursts (same DM and sky position) observed with Arecibo, Parkes, & GBT between 2012 and 2016;
- up to 6 in 10 min;
- 20 s between bursts 6 and 7;
- some have a double peak (8 and 10);
- no pulsation detected.

Interesting sources

FRB 121102

Chatterjee et al., Nature (2017), Tendulkar et al., ApJ (2017)

- targeted observations with the VLA detected 9 bursts;
- further observations with the European VLBI and US VLBA: localization with a very high precision;
- faint source in radio and optical light: dwarf galaxy <1/10 the size and <1/1000 the mass of the Milky Way, 3 billion l.y. from us.

FRB 131104

DeLaunay et al., ApJ (2016)

- looked with Swift for γ-ray counterpart of all FRBs;
- detected a γ-ray flare around the same time and from the same direction as FRB 131104;
- lasted between 2 to 6 min!
- released much more energy in γ than in radio;
- controversy: Shannon & Ravi arXiv:1611.05580;
- γ-ray association unlikely;
- observations with the Australia Telescope Compact Array: a variable radio source;
- optical and infrared observations: source is an active galactic nucleus (AGN).

What is the source of FRBs?

Properties

1. extragalactic: the most distant and thus the brightest radio signals;
2. millisecond duration $\rightarrow$ size of the emitting region $c\Delta t < 300$ km;
3. repeating source with $\sim$ 20 s between two bursts;
4. bursts with double peaks observed.

Proposed models

- binary neutron star mergers: 3. ✗
- supernova explosions: 3. ✗
- planet, asteroid, white dwarf orbiting a pulsar and passing through its wind
- magnetars: neutron stars with enormous magnetic fields
- supergiant pulse from radio pulsars à la Crab pulsar
- AGN: a supermassive black hole at the center of its host galaxy that accretes matter.
- 2 types of sources??

Perspectives: dedicated projects

- CHIME (CA), Caltech (US), refurbished 1960's telescope (AU),
- already operating or very soon to be...
- Observations of bigger portions of the sky;
- more FRBs will be detected in the very near future.