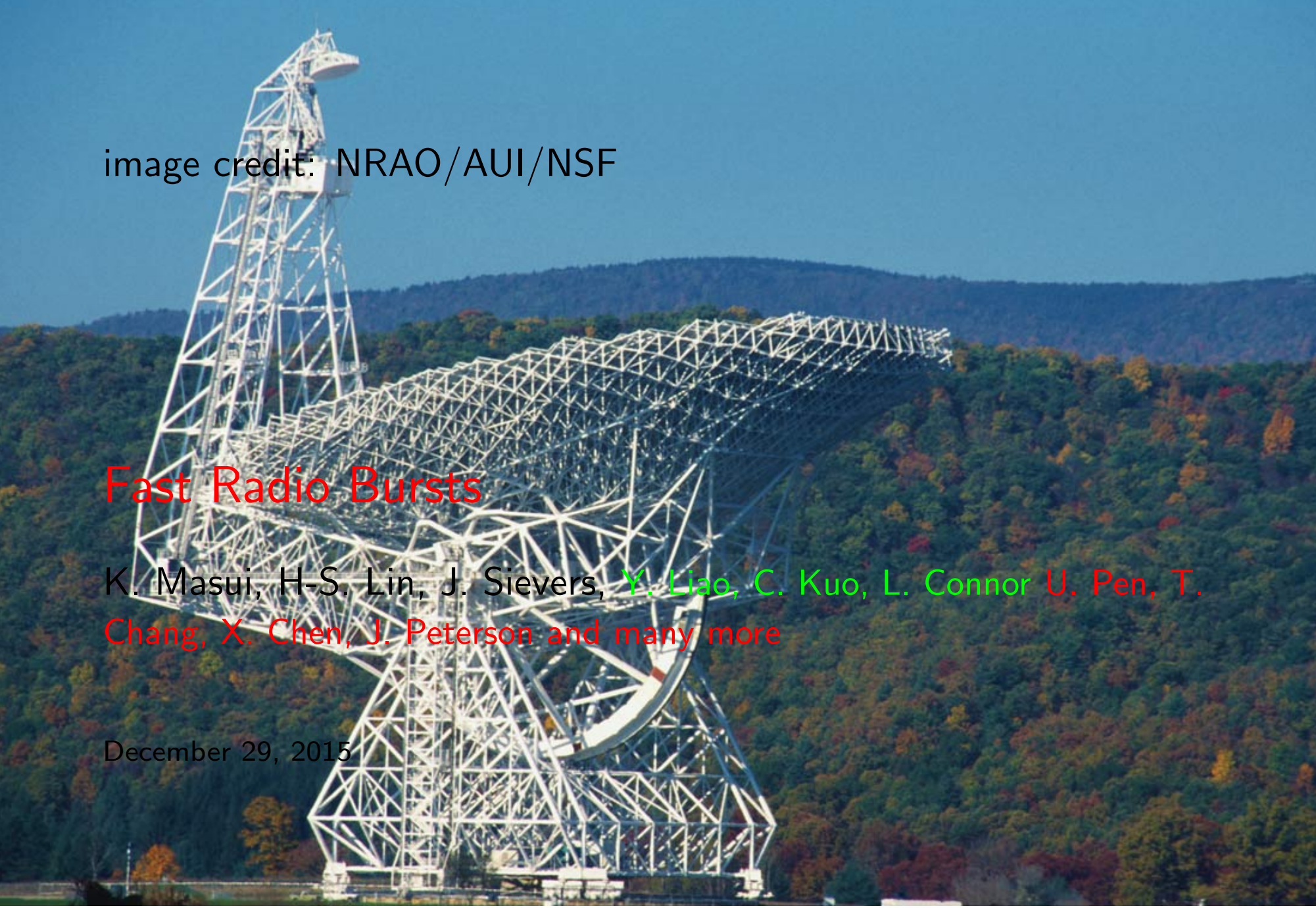


Fast Radio Bursts

K. Masui, H-S. Lin, J. Sievers, Y. Liao, C. Kuo, L. Connor U. Pen, T. Chang, X. Chen, J. Peterson and many more

December 29, 2015

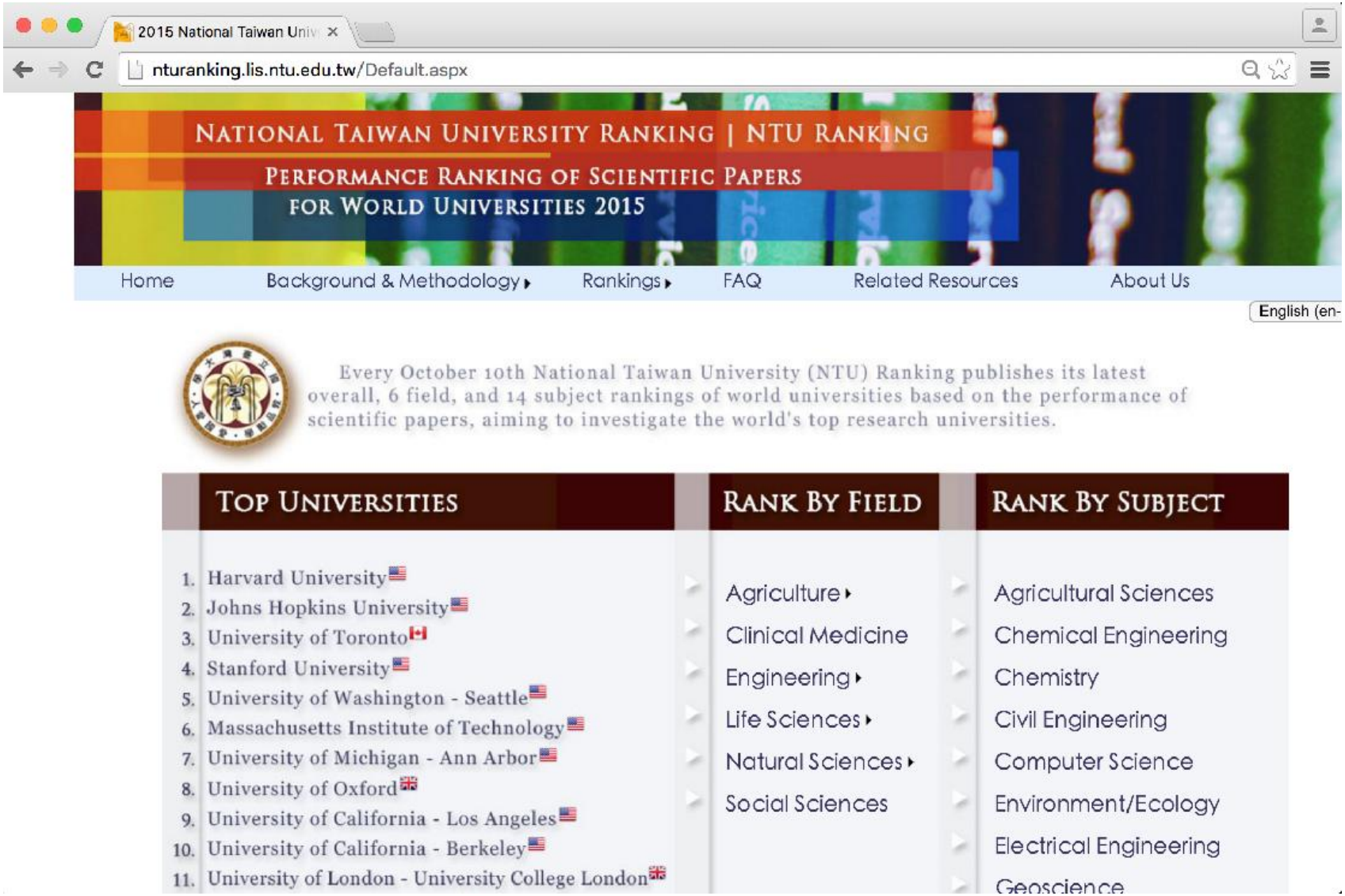
Overview

- Toronto
- FRB
- Candidates
- Plasma Lensing
- Controversies
- next steps

Toronto

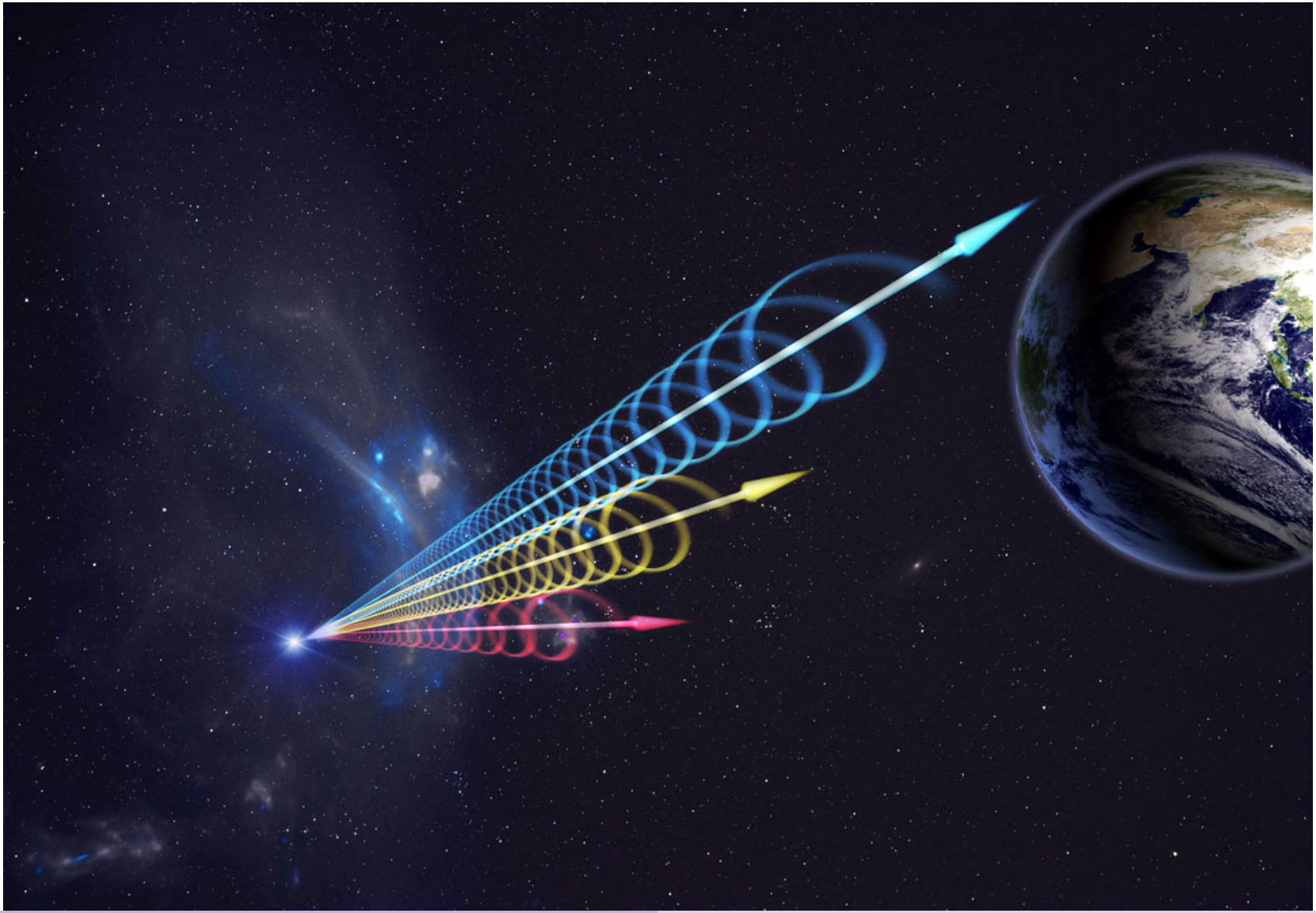
Liu et al 2015, arvix:1507.00884

Toronto

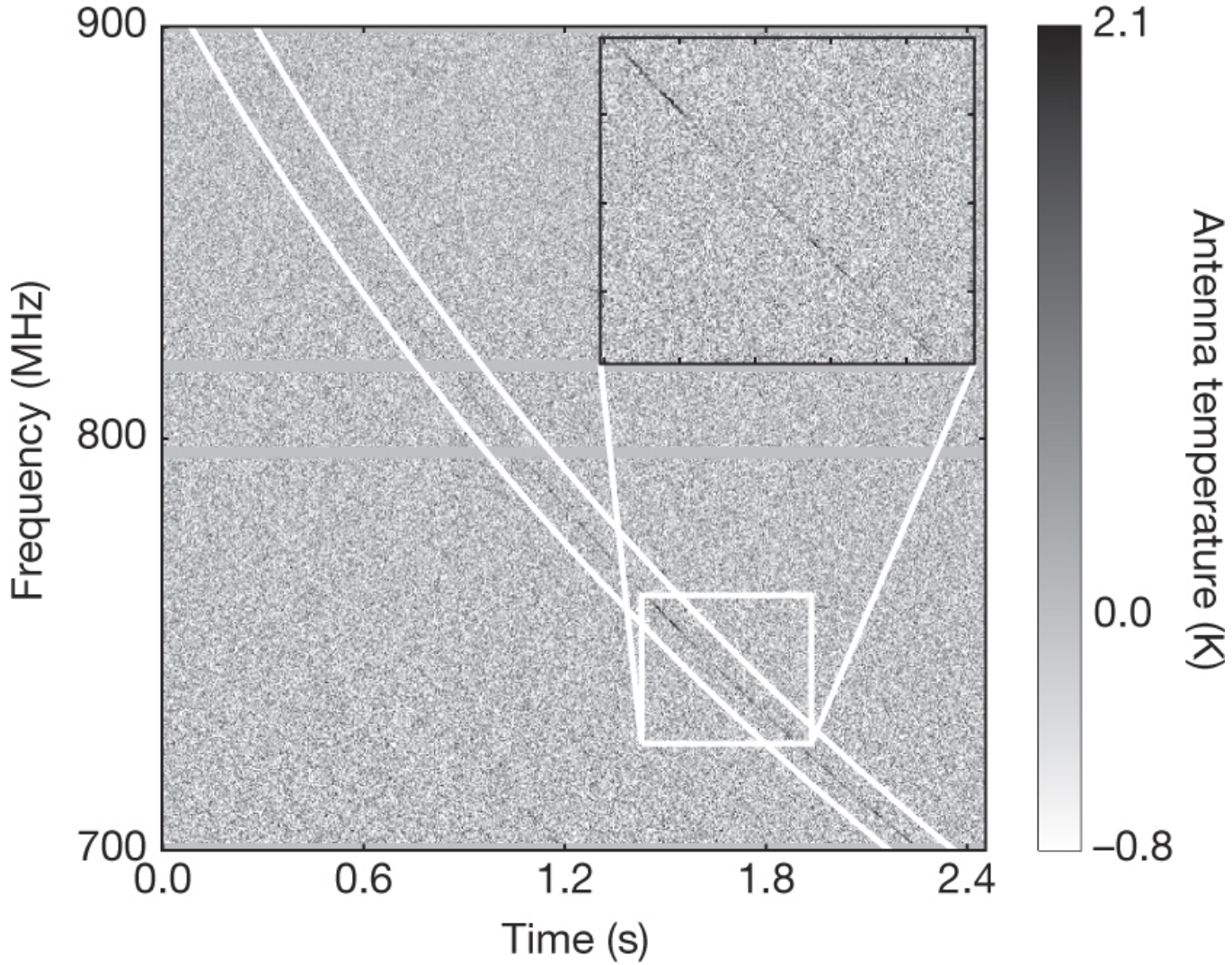


Toronto ranked #3 research university by NTU

FRB



FRB110523



Cold Plasma Dispersion (from Masui et al, Dec 3, 2015, Nature

Basic Properties

- about 20 FRBs detected
- high dispersion measure: DM ~ 1000 pc/cm^3 $\sim 3 \times 10^{21}$/cm^2
- DM is major source of noise for GPS, uses dual freq to reduce noise.
- ms duration
- some are scattered
- some are polarized
- likely extragalactic
- possibly cosmological $z \sim 1$
- duration infers size of 300km
- R-J brightness: 10^{36}K is $\sim 10^4\, T_p$:
- highest brightness temperature in the universe, except maybe crab nanoshot

Candidates

- cataclysmic: exploding Hawking black holes, merging neutron stars, blitzars
- repeating: magnetar flares, planet-neutron star, supergiant pulse
- local: flare stars, microwave ovens

Applications

- misconceptions: cosmological standard ruler, etc
- cross correlation analysis: baryonic clustering, cosmic magnetic fields (McQuinn 2014)
- new high energy phenomena

Candidates

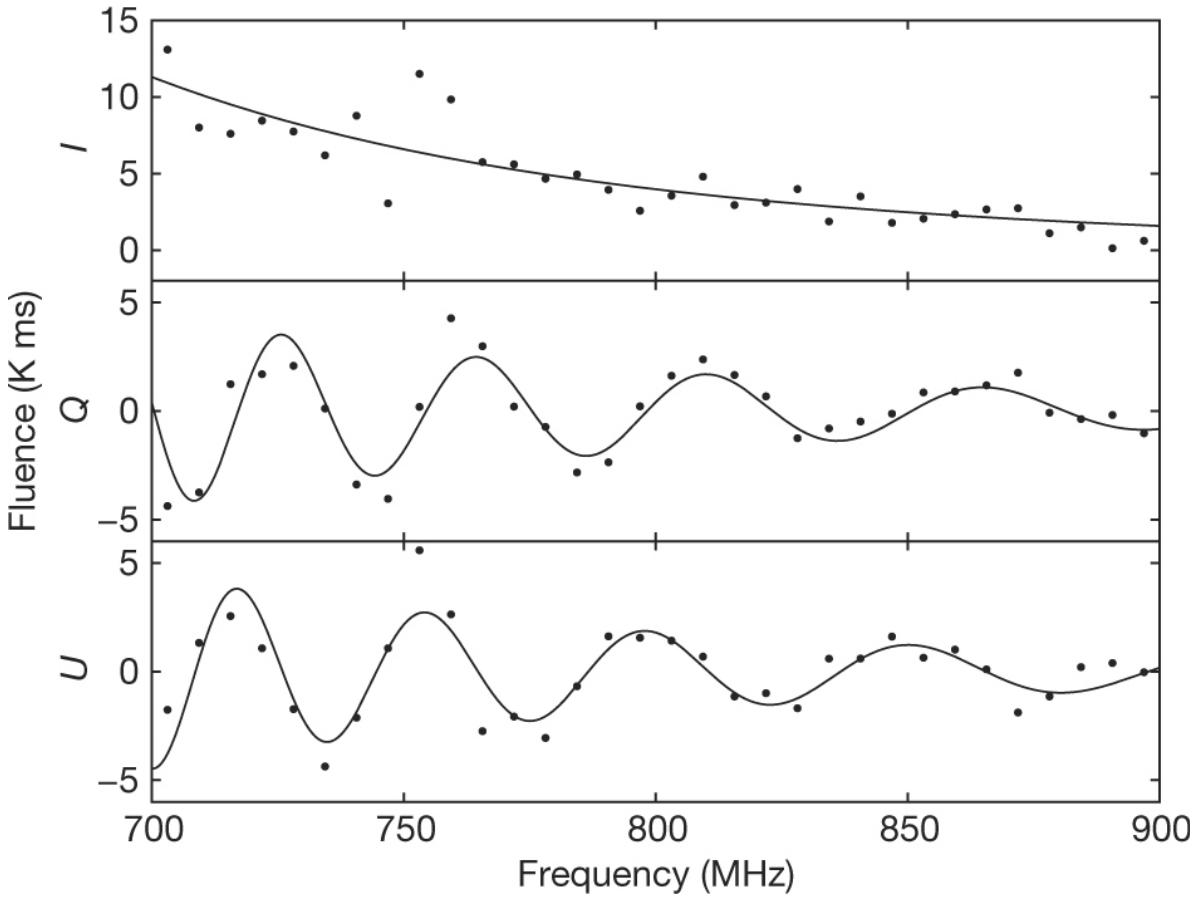
Location	Model	Galactic scintillation	Faraday rotation	$\frac{d\ln N_{FRB}}{d\ln S_\nu}$	Counterpart	DM range (pc cm^{-3})	Pol angle swing
Cosmological ($>1h^{-1}$Gpc)	Blitzars	×	< 7 rad m^{-2}	?	gravitational waves	300-2500	×
	Merging COs	×	< 7 rad m^{-2}	?	type Ia SNe, X-ray, γ-ray	300-2500	×
	Primordial BHs	×	< 7 rad m^{-2}	?	$\sim$TeV	300-2500	×
	Magnetar flare	×	< 7 rad m^{-2}	?	$\sim$ms TeV burst	300-2500	✓
Extragalactic, local ($<200h^{-1}$Mpc)	Edge-on disk	✓	50-500 rad m^{-2}	-3/2	?	10-2000	?
	Nuclear magnetar	✓	10^{3-5} rad m^{-2}	-3/2	none	10-3000	✓
	SNR pulsar	✓	20-10^3 rad m^{-2}	-3/2	archival CC SNe or nearby galaxy	10^2-10^4	✓
Galactic ($<$ 100 kpc)	flaring MS stars	✓	$\mathrm{RM_{gal}}$	-3/2	main sequence star	> 300	×
Terrestrial ($< 10^5$ km)	RFI	×	$< \mathrm{RM_{ion}}$	$\begin{cases} -1/2 \text{ if } 2D \\ -3/2 \text{ if } 3D \end{cases}$	none	?	×

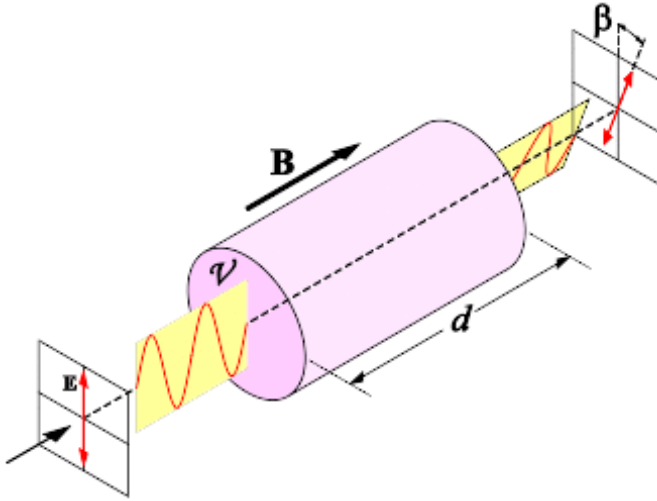
Table: This table summarizes a number of FRB models by classifying them as cosmological, extragalactic but non-cosmological, Galactic, and terrestrial. The seven columns are potential observables of FRBs and each row gives their consequence for a given model (Blitzars, compact object mergers, exploding primordial blackholes, bursts from magnetars, edge-on disk galaxies, circumnuclear magnetars, supernova remnant pulsars, stellar flares and terrestrial RFI. For the latter, we subdivide the RFI into planar RFI (2D) coming from the earth's surface, and 3D RFI coming from objects like satellites. Since scintillation only affects unresolved images, cosmological sources that are not scattered near the source will not scintillate in our Galaxy, while non-cosmological sources whose screens are intrinsic will. For Faraday rotation and scintillation we assume the RM and SM comes from the same place as the DM, e.g. the IGM for cosmological sources, though such models could introduce a more local Faraday effect or a scattering screen. Even though all models have to explain the observed 375-1600 pc cm^{-3}, some models predict a wider range of DM. For instance, in the circumnuclear magnetar or edge-on disk disk scenarios there ought to be bursts at relatively low DM that simply have not been identified as FRBs. In our supernova remnant model DMs should be very large early in the pulsar's life, though this window is short and therefore such high DM bursts would be rare. (from Connor et al 2015)

FRB110523

- Masui et al, Dec 3, 2015, Nature 15769
- recorded on May 23, 2011
- part of GBT-IM survey, for 21cm intensity mapping (Chang et al 2010, Nature, 466, 463)
- beat double odds with data: intensity mapping, FRB

Polarization



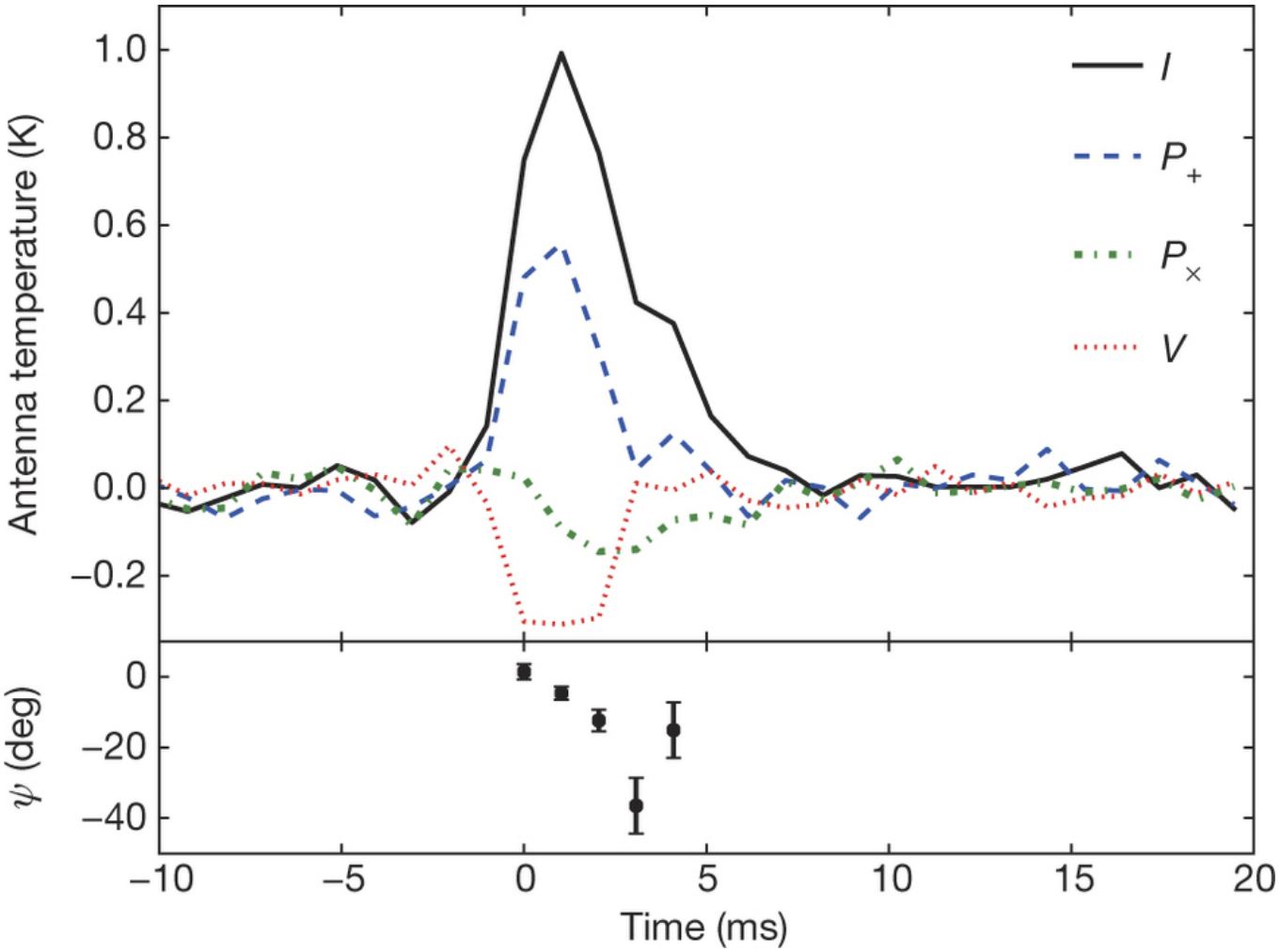


Faraday Rotation: circular polarization birefringence

interpretation

- RM=-186.1 $\pm$ 1.4
- galactic+extragalactic RM=18$\pm$3 for this LOS measured from quasars (Opperman et al 2015)
- $\Longrightarrow$ magnetic field local to FRB or host galaxy
- if DM also local, implies B$\sim$ 0.3μG

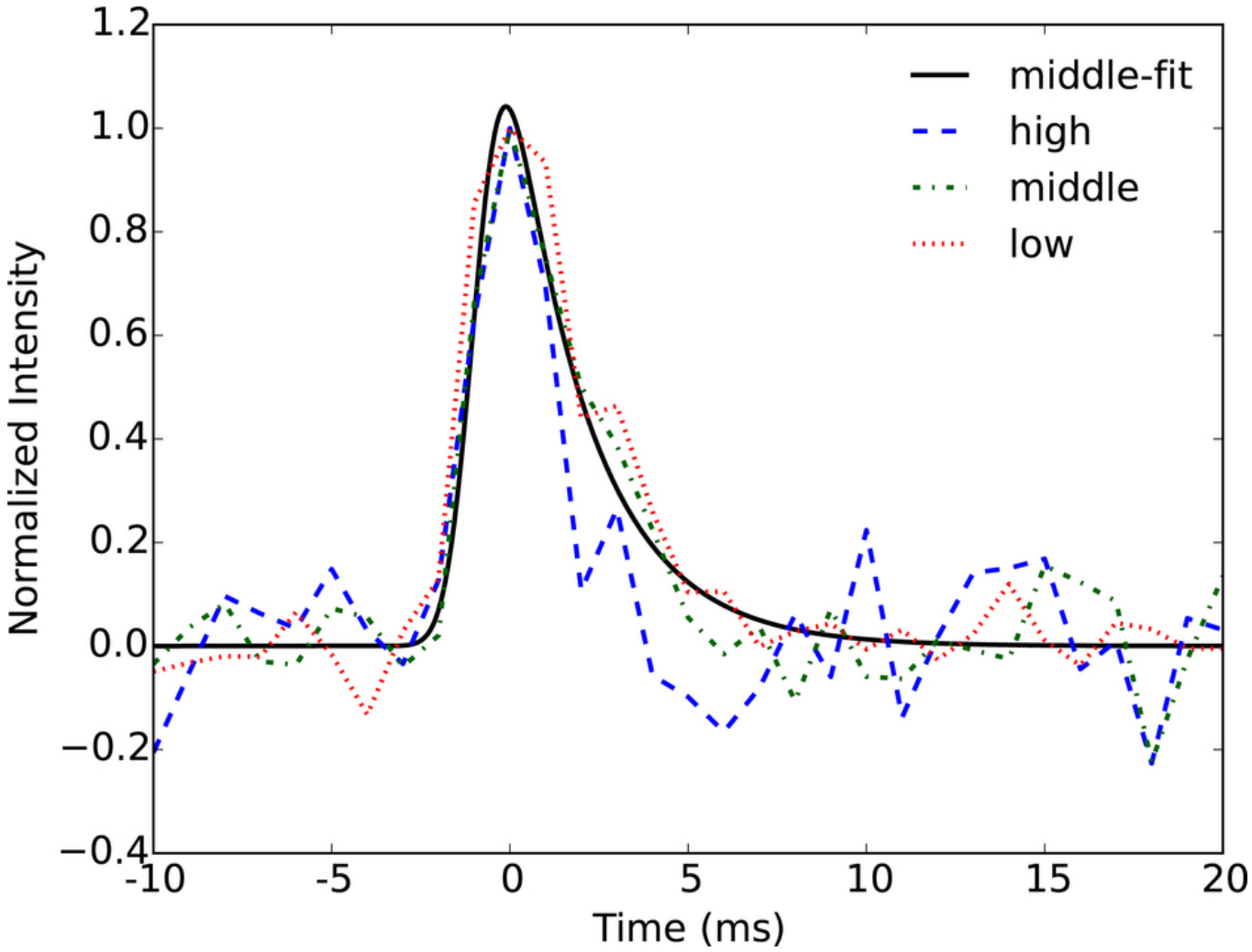
Angle swing


Antenna temperature (K)
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
I
P+
P×
V
ψ (deg)
0
−20
−40
−10
−5
0
5
10
15
20
Time (ms)

interpretation

- $5-\sigma$ significance of polarization angle swing
- generic for pulsars
- unknown for most other processes

Scattering


middle-fit
high
middle
low
Normalized Intensity
Time (ms)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
-10
-5
0
5
10
15
20

interpretation

- ms scattering is generally due multipath propagation
- location was previously thought to be IGM
- FRB110523 shows μs scintillation from Galactic multipath
- scattering tail scintillates!
- *stars twinkle, planets don't*
- constrains source size less than $\sim$ microarcsecond
- scattering screen is physically associated with FRB, not intergalactic

inferred properties

Barycentric $\nu = \infty$ arrival (MJD)	55704.62939511
GBT boresight at 900 MHz arrival	RA $= 21^h45^m31^s$ Dec $= -00^d15^m23^s$ $l = 56.0795^\circ$ $b = -37.9435^\circ$
GBT boresight at 700 MHz arrival	RA $= 21^h45^m12^s$ Dec $= -00^d09^m37^s$ $l = 56.1215^\circ$ $b = -37.8234^\circ$
Dispersion measure (pc cm^{-3})	623.30(6)
Fluence at 800 MHz (K ms)	3.79(15)
Spectral index	−7.8(4)
Unscattered pulse FWHM (ms)	1.73(17)
Scattering time at 800 MHz (ms)	1.66(14)
Linear polarization fraction (%)	44(3)
Rotation measure (rad m^{-2})	−186.1(1.4)
Polarization rotation rate (rad ms^{-1})	−0.25(5)
Dispersion measure index	−1.998(3)
Scattering index	−3.6(1.4)
Faraday rotation index	−1.7(2)

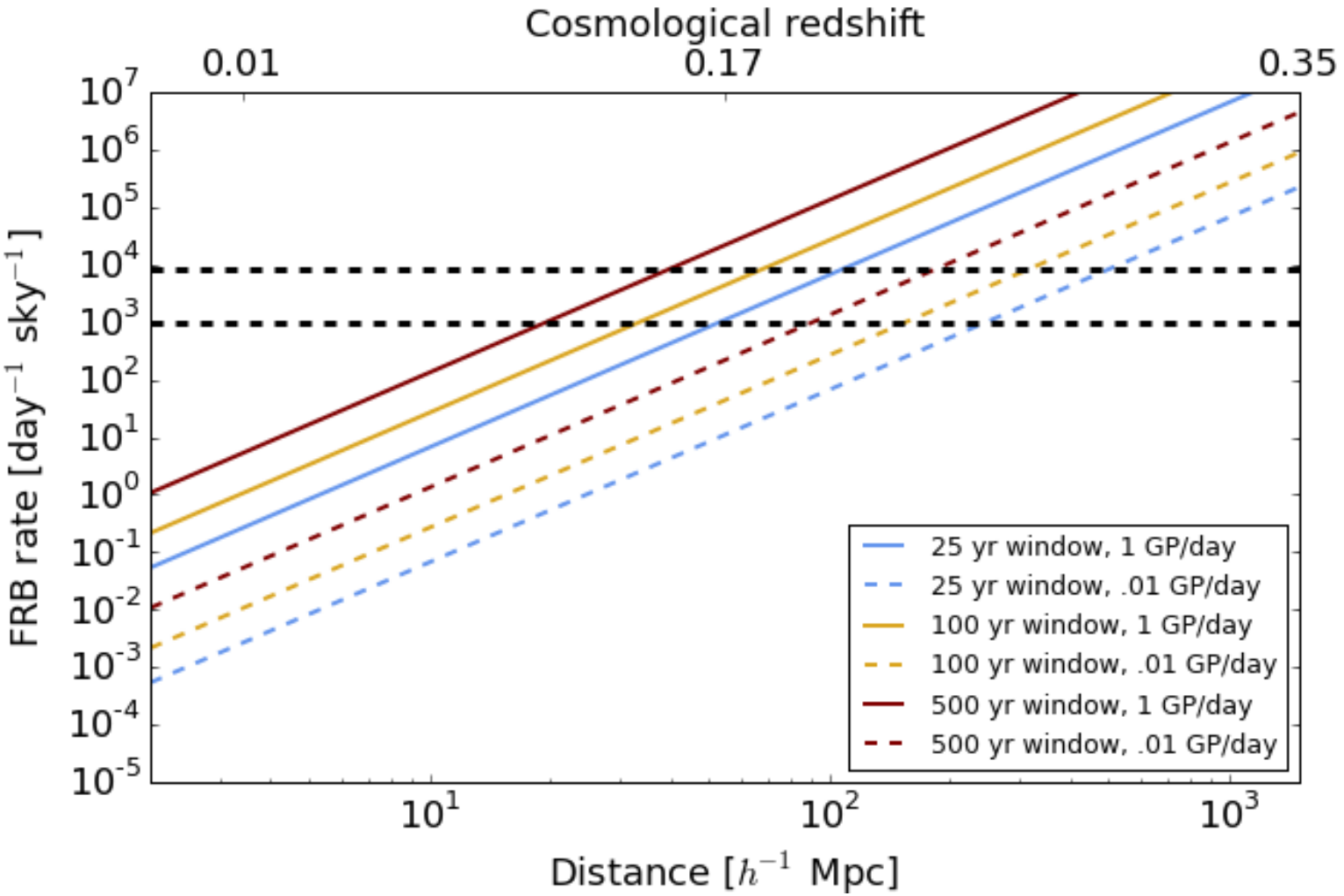
more interpretations

- flare stars ruled out: not enough deviation from λ^2 law, lower bound of plasma cloud $R > 10$AU, bigger than any plausible star
- scattering index consistent with refractive lensing scaling (Pen&Levin 2014)

Looking forward

- how do we reduce the allowed model space?
- 1. repeat rate (Connor et al 2015)
- 2. precision localization within host: nuclear, SNR, SFR?
- 3. host galaxy redshift
- more unpublished bursts with new claims
- thousands of bursts with GBT-MB, CHIME, HIRAX, UTMOST
- localization with VLBI

repeat rates



Connor, Sievers, Pen 2015

Conclusion

- most plasma properties due to local environment, not cosmological
- FRBs likely extragalactic, but not cosmological
- extragalactic ISM structure: mapping cosmic plasma and magnetic fields