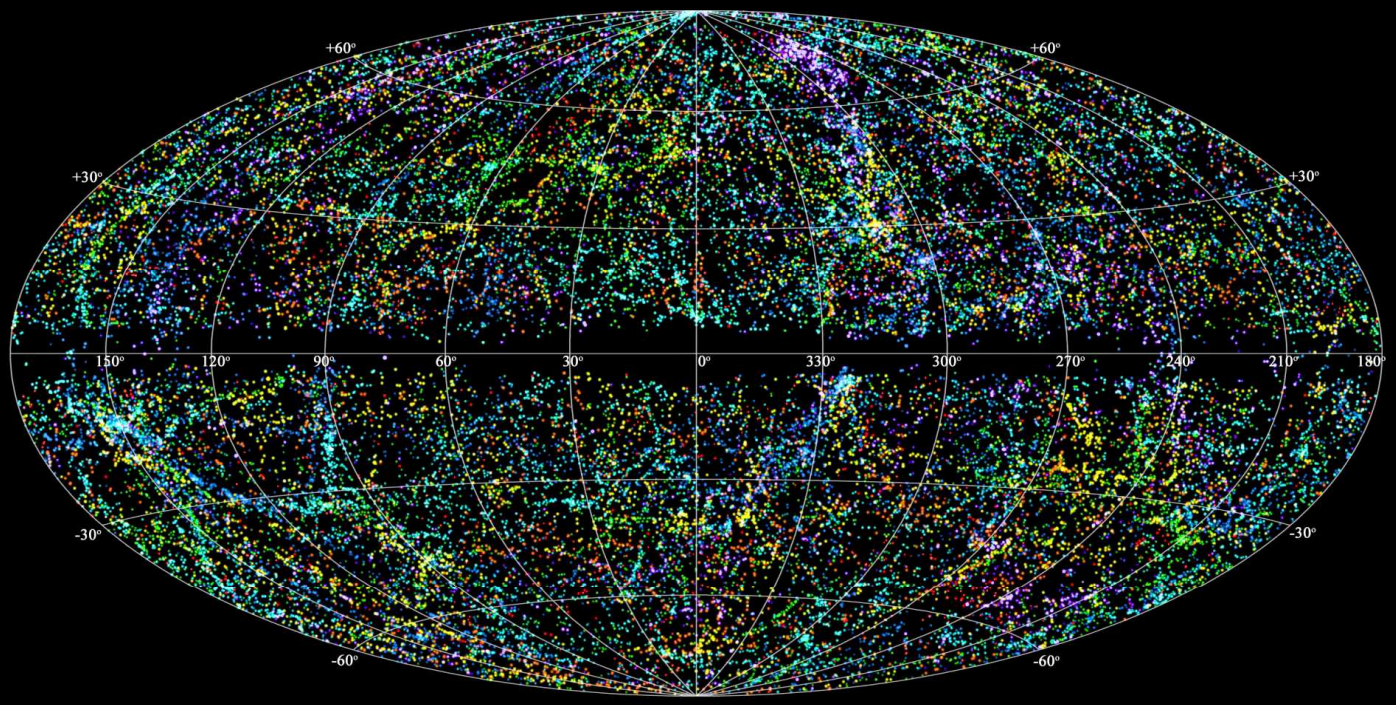
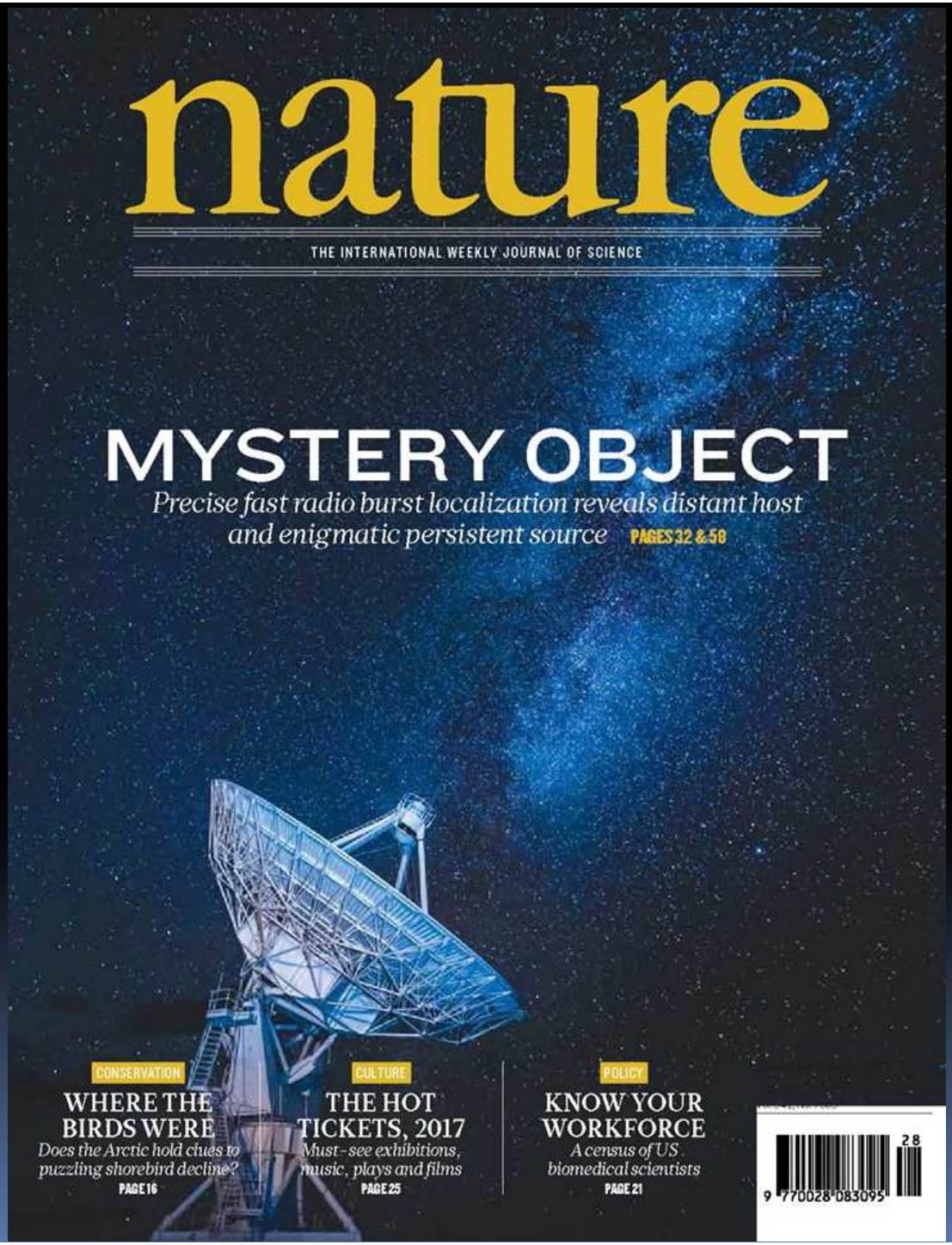


Fast Radio Bursts

Vicky Kaspi
Dept of Physics & McGill Space Institute
McGill University, Montreal, Canada

15th Marcel Grossman Meeting, Rome, Italy, July 5, 2018.


nature
THE INTERNATIONAL WEEKLY JOURNAL OF SCIENCE
MYSTERY OBJECT
Precise fast radio burst localization reveals distant host and enigmatic persistent source PAGES 32 & 58
CONSERVATION
WHERE THE BIRDS WERE
Does the Arctic hold clues to puzzling shorebird decline?
PAGE 16
CULTURE
THE HOT TICKETS, 2017
Must-see exhibitions, music, plays and films
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POLICY
KNOW YOUR WORKFORCE
A census of US biomedical scientists
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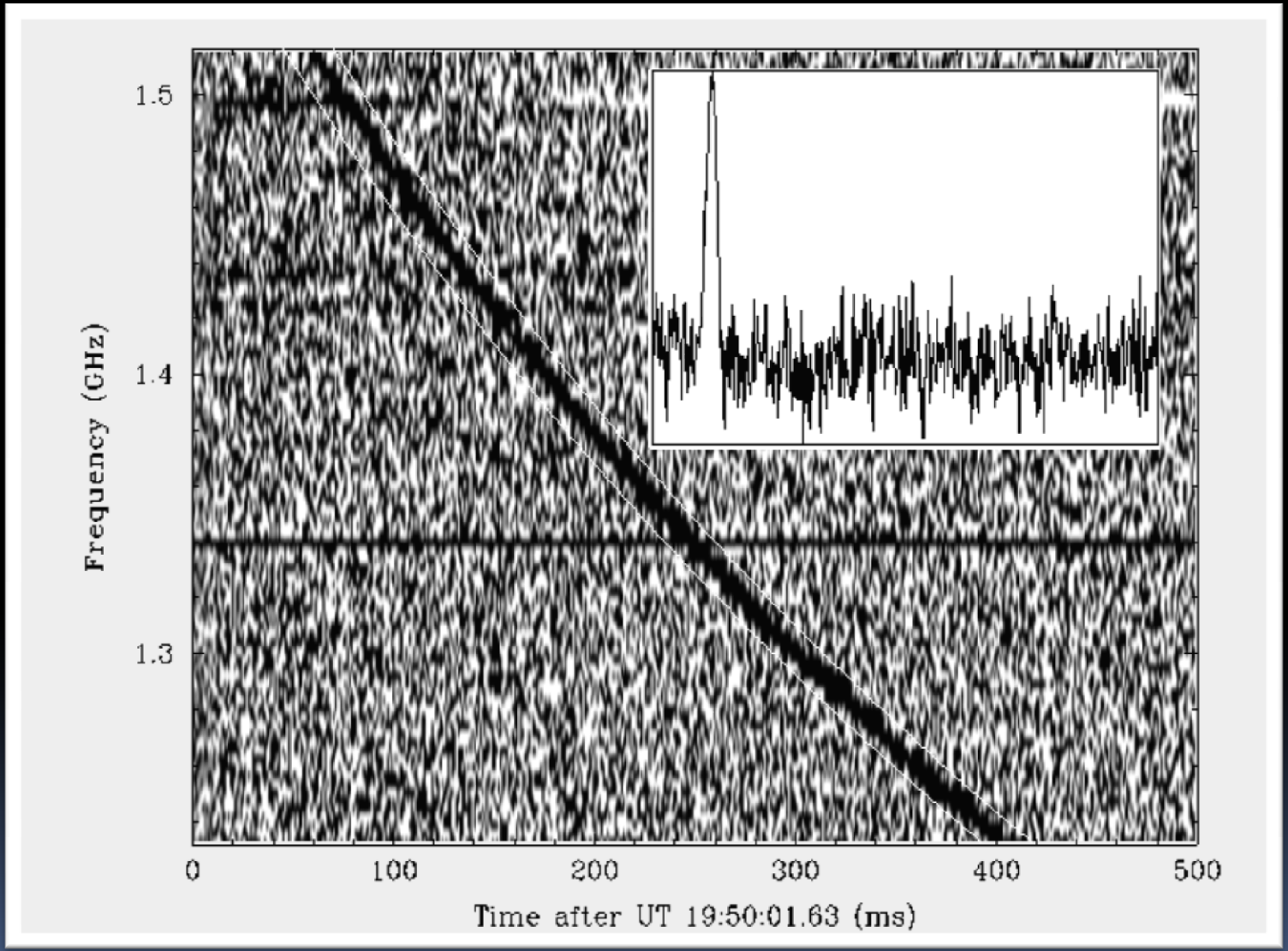
Fast Radio Bursts

- Brief (~ms) radio bursts
- 1st : Lorimer et al. 2007 using Parkes @ 1.4 GHz
- Today: ~30 known
- Estimated rate: ~1,000 /sky/day @ 1.4 GHz
- Extragalactic, probably cosmological
- ORIGIN UNKNOWN!
  - See next talk

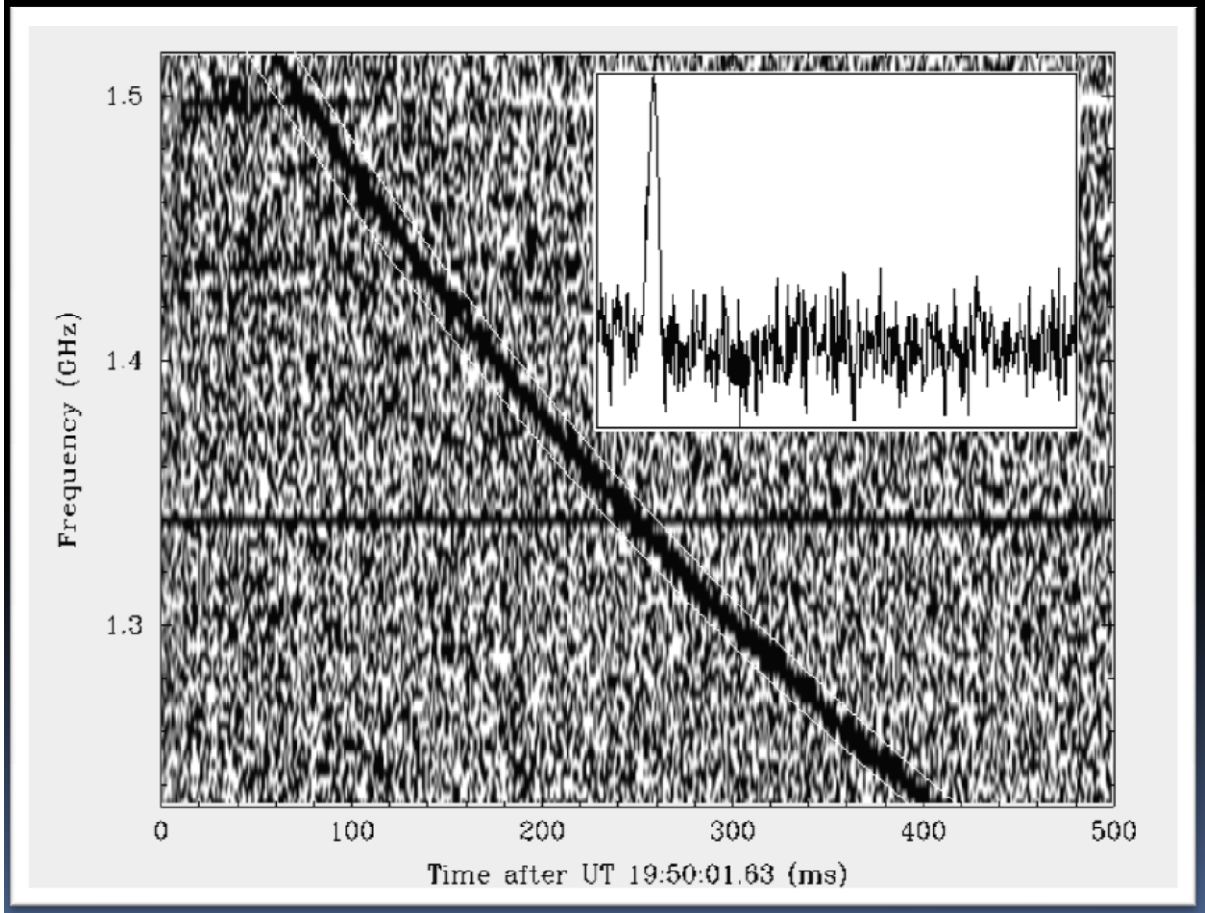
The “Lorimer” Burst



Lorimer et al. 2007 Science

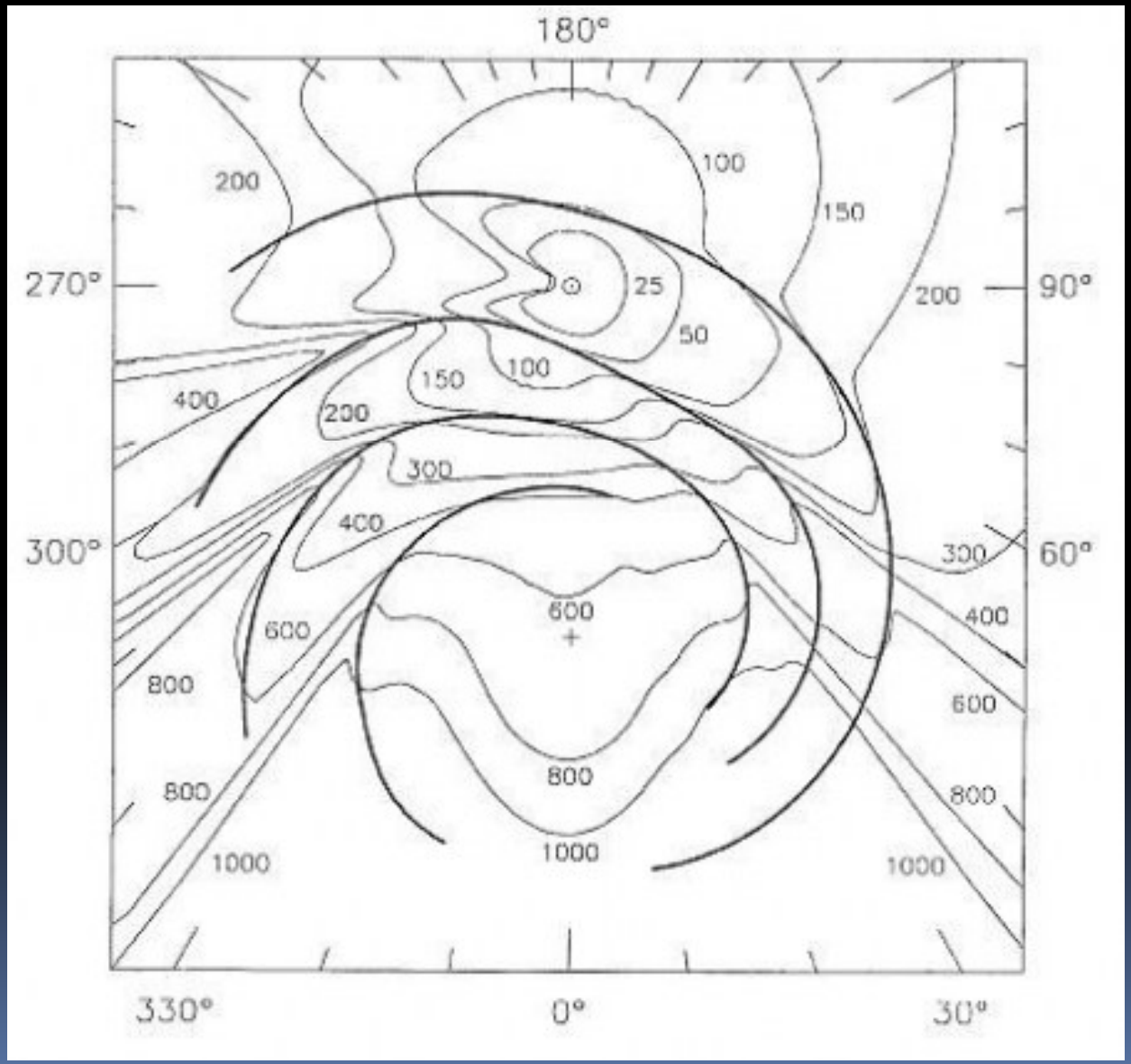
Dispersion of Radio Waves

$$t_2 - t_1 = DM\,(f_2^{-2} - f_1^{-2})$$



$$DM \propto \int n_e dl$$

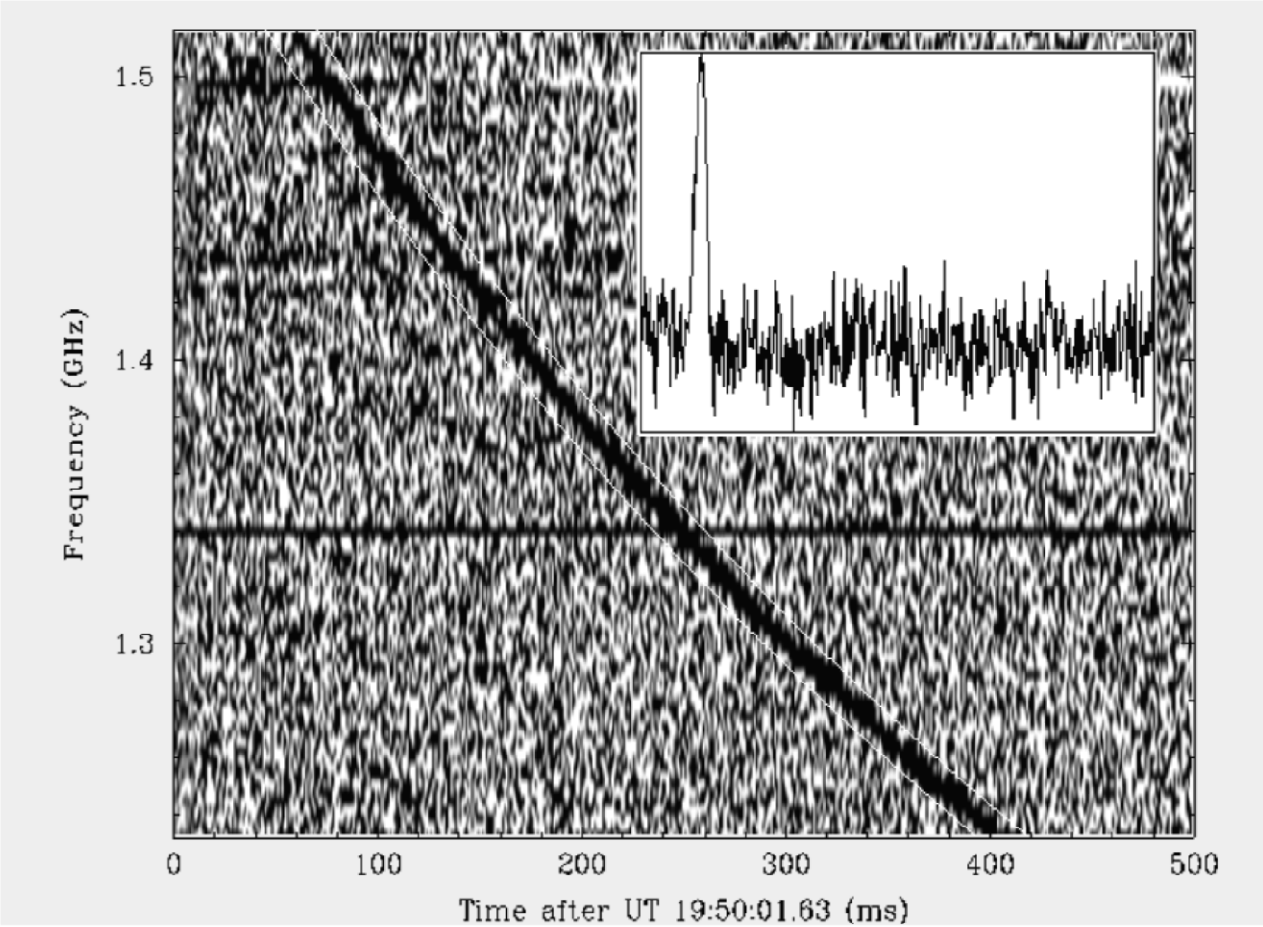
Free Electron Distribution



Milky Way Model: Contours of constant free electron column density

Cordes & Lazio 2002

“The Lorimer Burst”



DM_{max} = 25 pc/cm^3

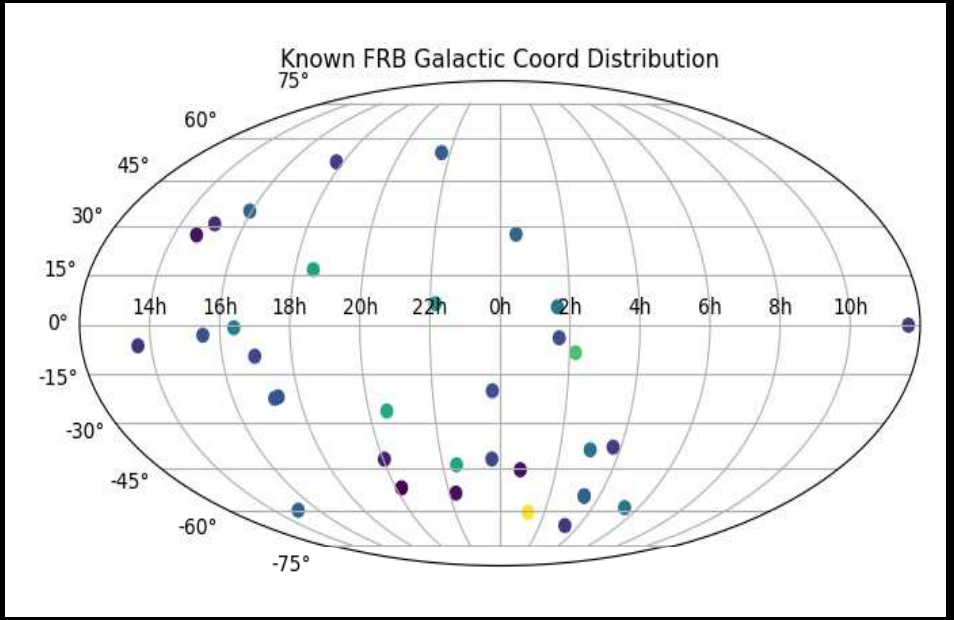
DM_{burst} = 375 pc/cm^3

!!!!!

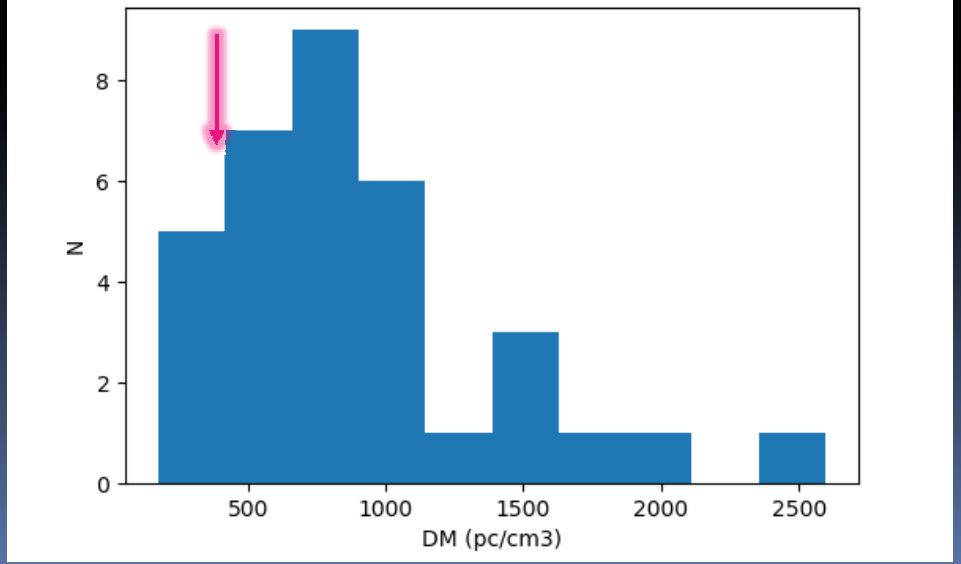
Lorimer et al. 2007, Science

FRBs are at Cosmological Distances

- Roughly isotropic sky distribution
- Dispersion of radio waves strongly suggests extragalactic origin
- Standard models of intergalactic medium suggest cosmological distances
- Could make excellent cosmological probes
  (e.g. McQuinn 2014, Masui & Sigurdson 2015, Yang & Zhang 2016, Fialkov & Loeb 2016, Shull & Danforth 2018)



Data from frbcat.org



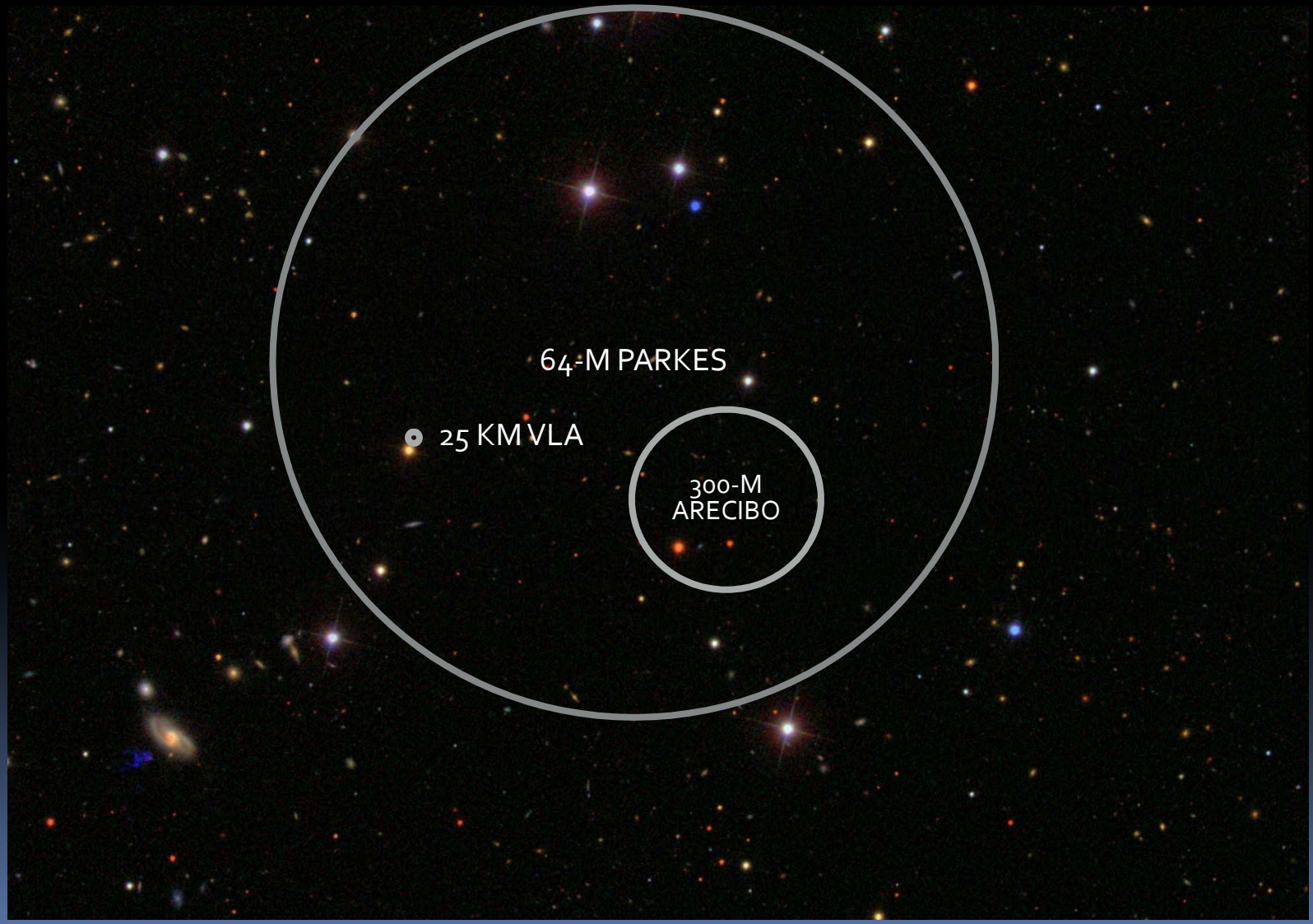
FRB Cosmological Distance

- IGM Models: $DM_{IGM} = 1200\ z$ pc/cm^3
- Implies z=0.3 for Lorimer burst
- Corresponds to ~1 Gpc… really far!
- BUT: likely upper limit
  - some DM may be in host galaxy:

$$DM_{tot} = DM_{MW} + DM_{IGM} + DM_{host}$$

- For d=500 Mpc: radio energy ~ 10^{40} erg or ~10^{43} erg/s [1 erg = 10^{-7} J]

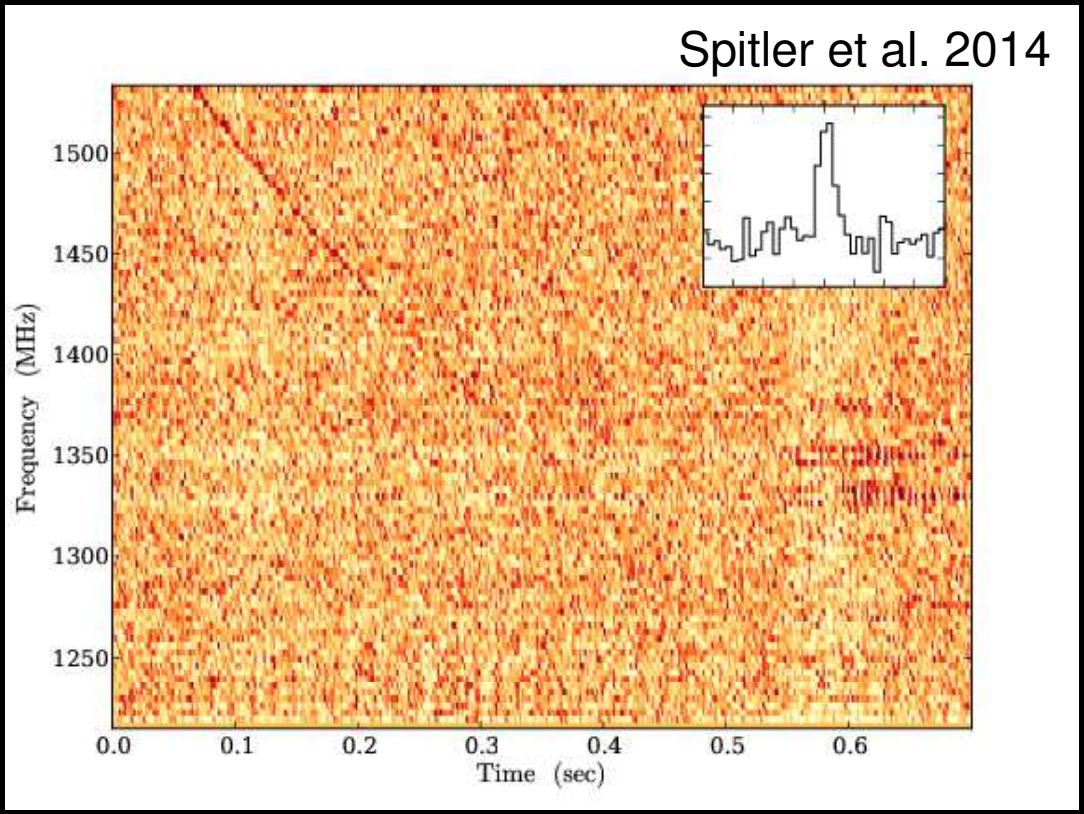
Large Error Regions!



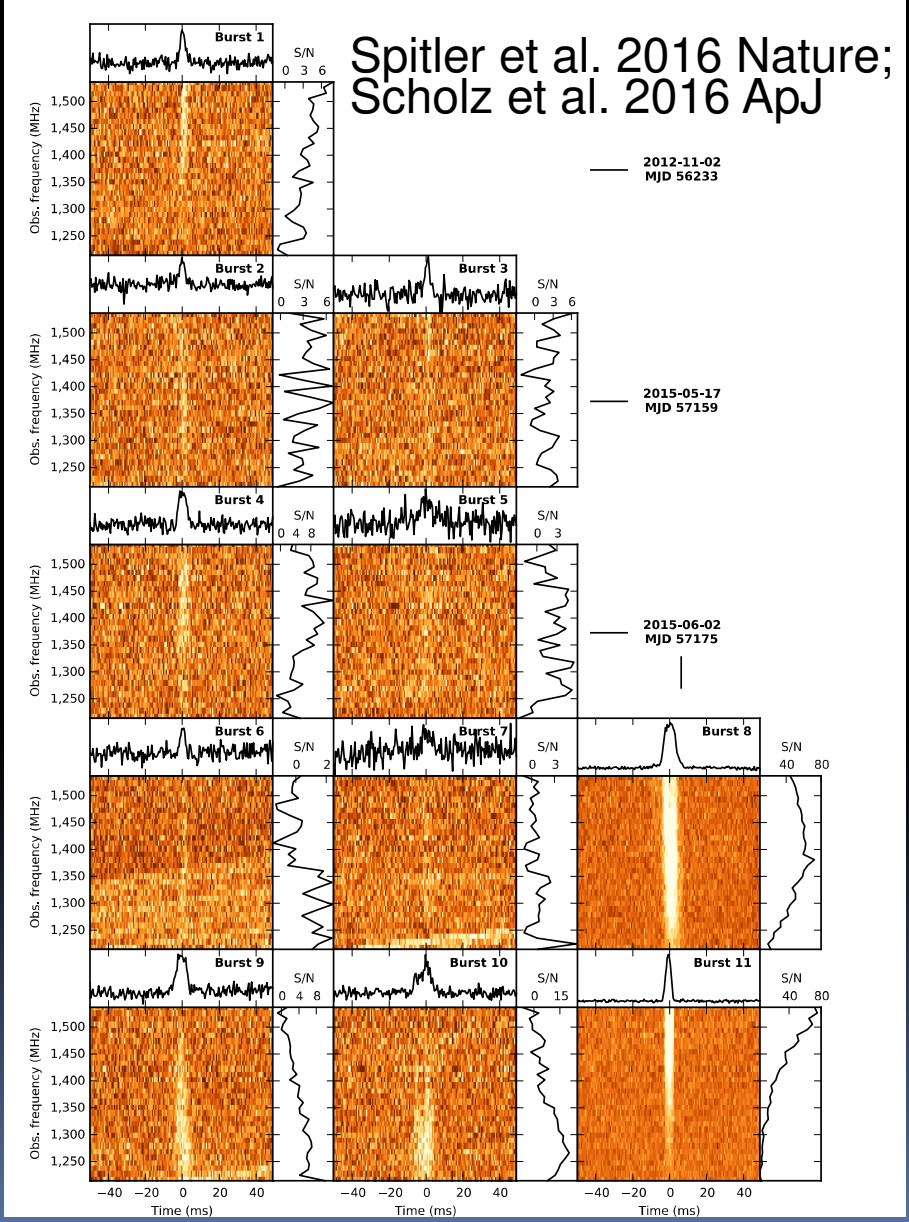
FRB 121102

- Found at Arecibo
- First non-Parkes FRB
- DM = 558 pc/cm^3 = 3DM$_{max}$
- Note unusual spectrum
  - Spectral index ~+9!
- Assumed due to offset from beam centre

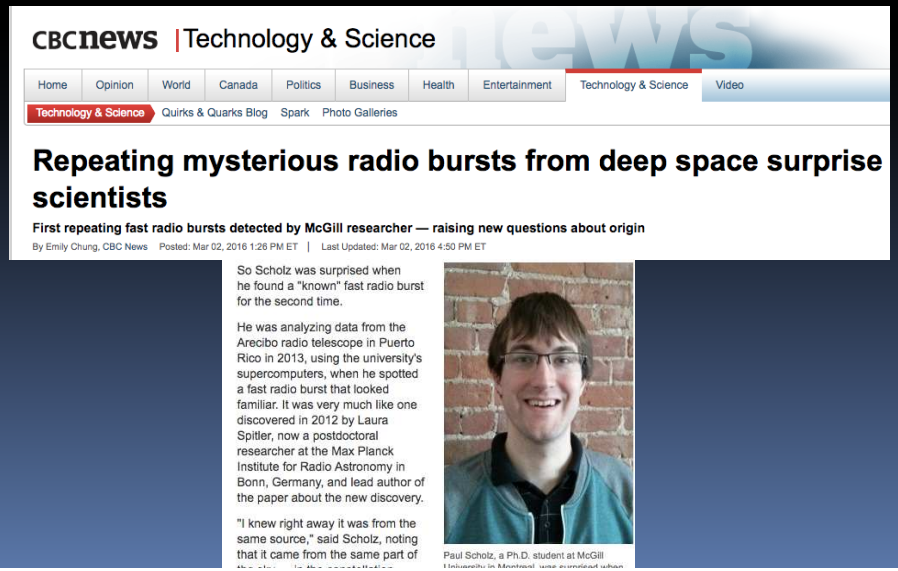
Spitler et al. 2014



Arecibo FRB Repeats!



- Rules out cataclysmic models (for this source)
- >10 more bursts detected in 2016; many more since
- Hugely varying spectra
- Bursts come in clusters



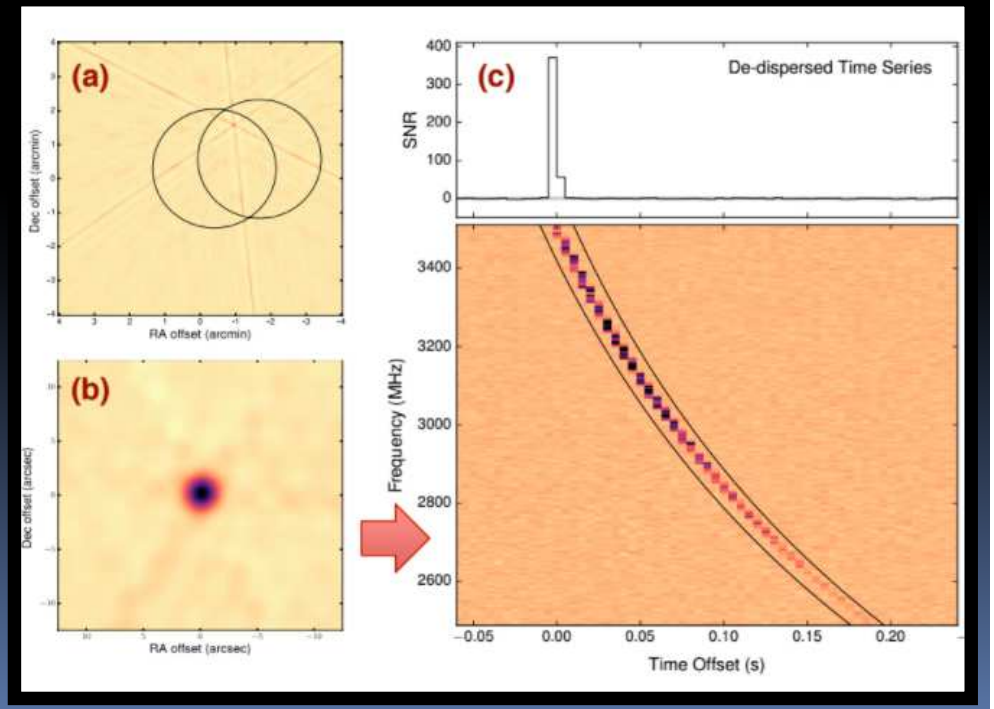
JVLA observes FRB 121102

Computationally demanding!

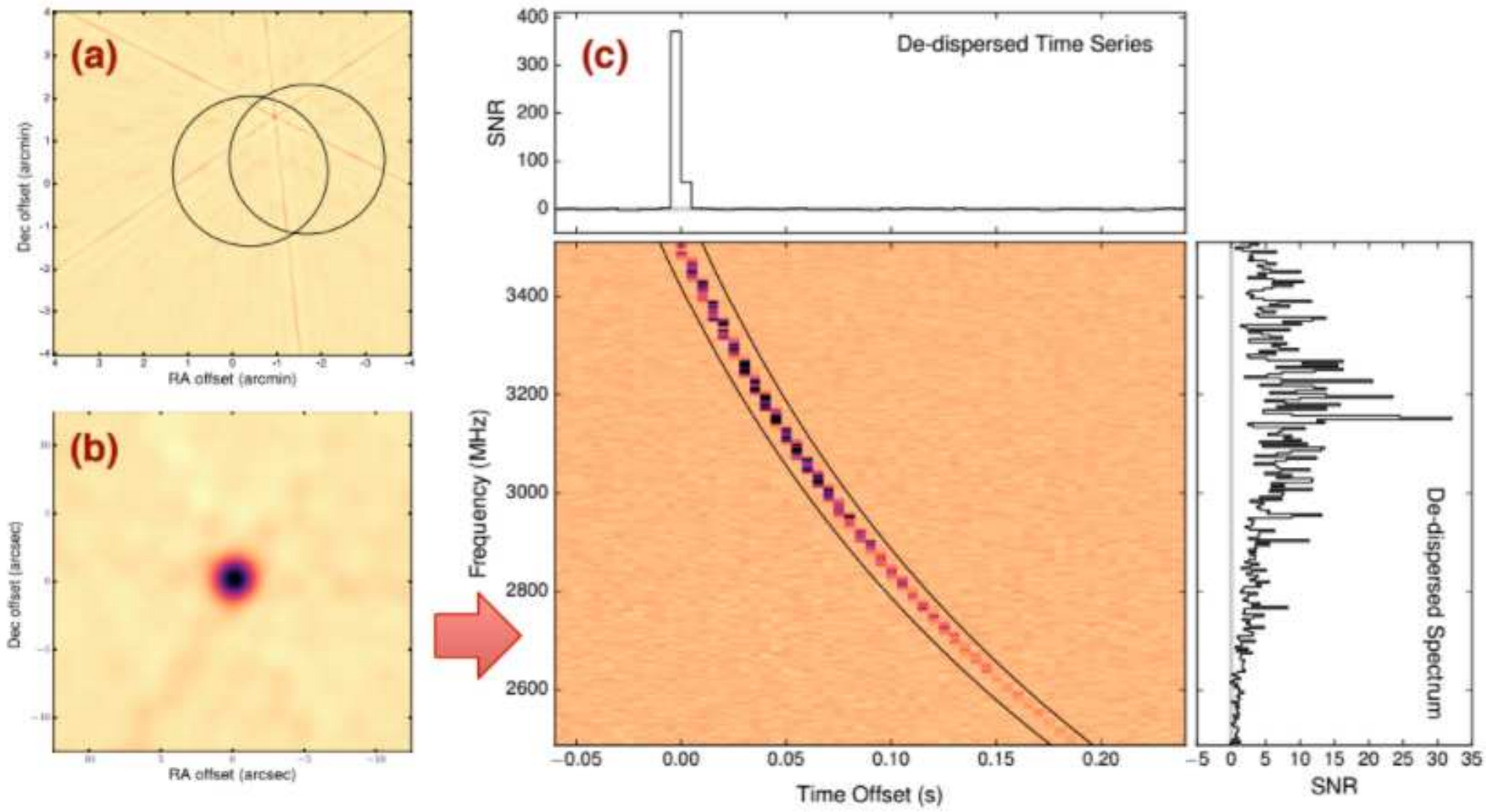
(Law et al 2015)

Fast imaging of FRB 121102:

- Fall 2015, 10 hours: no detection
- Spring 2016, 40 hours: no detection
- Fall 2016, 40 hours
  - In the first hour of a test observation…



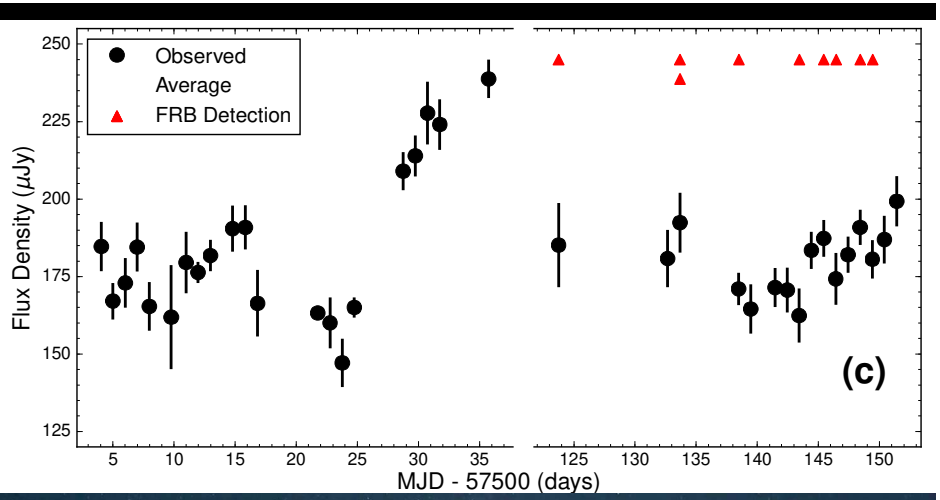
Chatterjee et al 2017, Nature

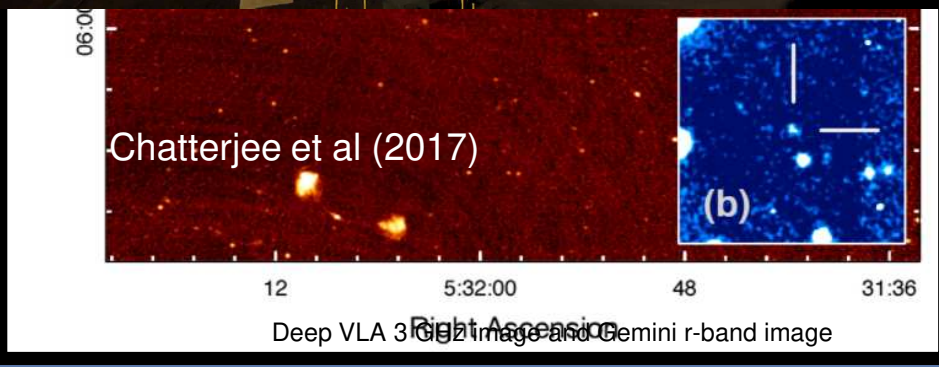


JVLA Detections

- 9 bursts in Fall 2016
- Localization to 0.1″
- Persistent radio source – 200 μJy!
  - 30% variability
- Optical counterpart 25th mag dwarf galaxy at z=0.2

Confirms this source is at cosmological distance





The New York Times

SCIENCE

Radio Bursts Traced to Faraway Galaxy, but Caller Is Probably 'Ordinary Physics'

By DENNIS OVERBYE JAN. 4, 2017

NEW YORK POST

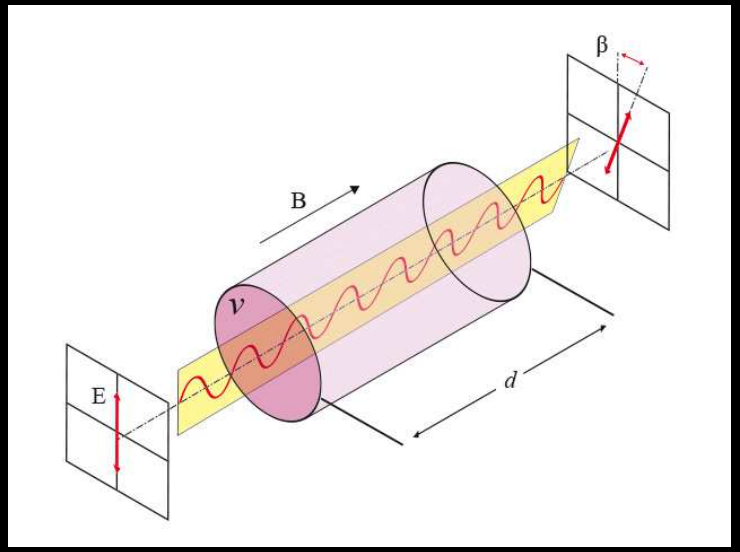
NEWS

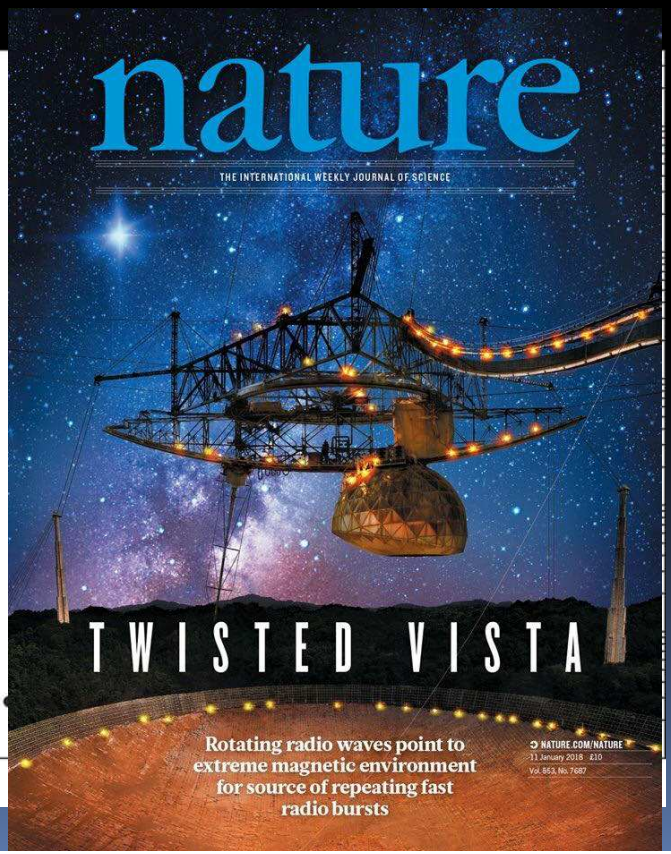
Scientists say radio signals from deep space could be aliens

By Chris Perez December 27, 2016 | 2:55pm

FRB 121102 Rotation Measure

- Recall Faraday Rotation:
  - Linear polarization orientation changes in magneto-ionic material
  - RM = $\int B_{||}\, n_e\, dl$
  - $\theta = RM\, \lambda^2$
- RM for Repeater from Arecibo: ~1.5 x 10^5 rad/m^2
  - *Among the highest RM known!*
    - Supermassive black hole?
  - Pulses are ~100% linearly polarized
  - Narrowest is 30 us!
  - Michilli et al 2018 Nature





FRBs: Where do we stand?

- At least one FRB is proven cosmological!
- Open questions
  - Is repeater representative? Or multiple classes?
    - Coincidence that only Arecibo FRB also only repeater??
  - What is the burst source?
    - Compact object? See next talk for models.
  - What is the persistent source?
  - What is RM source?
  - Is repeater related to SLSNe?

Upcoming FRB Detectors

CHIME: Canadian Hydrogen Intensity Mapping Experiment

- Penticton, BC at DRAO
- 4 20 m x 100 m cylinders
- Transit telescope
- 256 dual-pol feeds per axis, 2048 input signals
- 400-800 MHz
- FOV: E-W 2.5°-1.3°,
  N-S ~120°
- Beam size 0.5°-0.3°

chime-experiment.ca

CHIME/Fast Radio Burst Team

- UBC
  - Dr. Davor Cubranic
  - Deborah Good
  - Prof. Mark Halpern
  - Prof. Gary Hinshaw
  - Dr. Kiyo Masui
  - Dr. Cherry Ng
  - Prof. Kris Sigurdson
  - Prof. Ingrid Stairs
  - Prateek Yadav
- DRAO
  - Dr. Tom Landecker
  - Dr. Paul Scholz
- McGill University
  - Mohit Bhardwaj
  - Dr. Michelle Boyce
  - Dr. Jojo Boyle
  - Shiny Brar
  - Pragya Chawla
  - Prof. Matt Dobbs
  - Dr. Emmanuel Fonseca
  - Prof. David Hanna
  - Alex Josephy
  - Prof. Vicky Kaspi
  - Marcus Merryfield
  - Dr. Arun Naidu
  - Chitrang Patel
  - Ziggy Pleunis
  - Dr. Shriharsh Tendulkar
- University of Toronto
  - Prof. Dick Bond
  - Nolan Denman
  - Prof. Bryan Gaensler
  - Prof. Ue-Li Pen
  - Andre Recnik
  - Prof. Keith Vanderlinde
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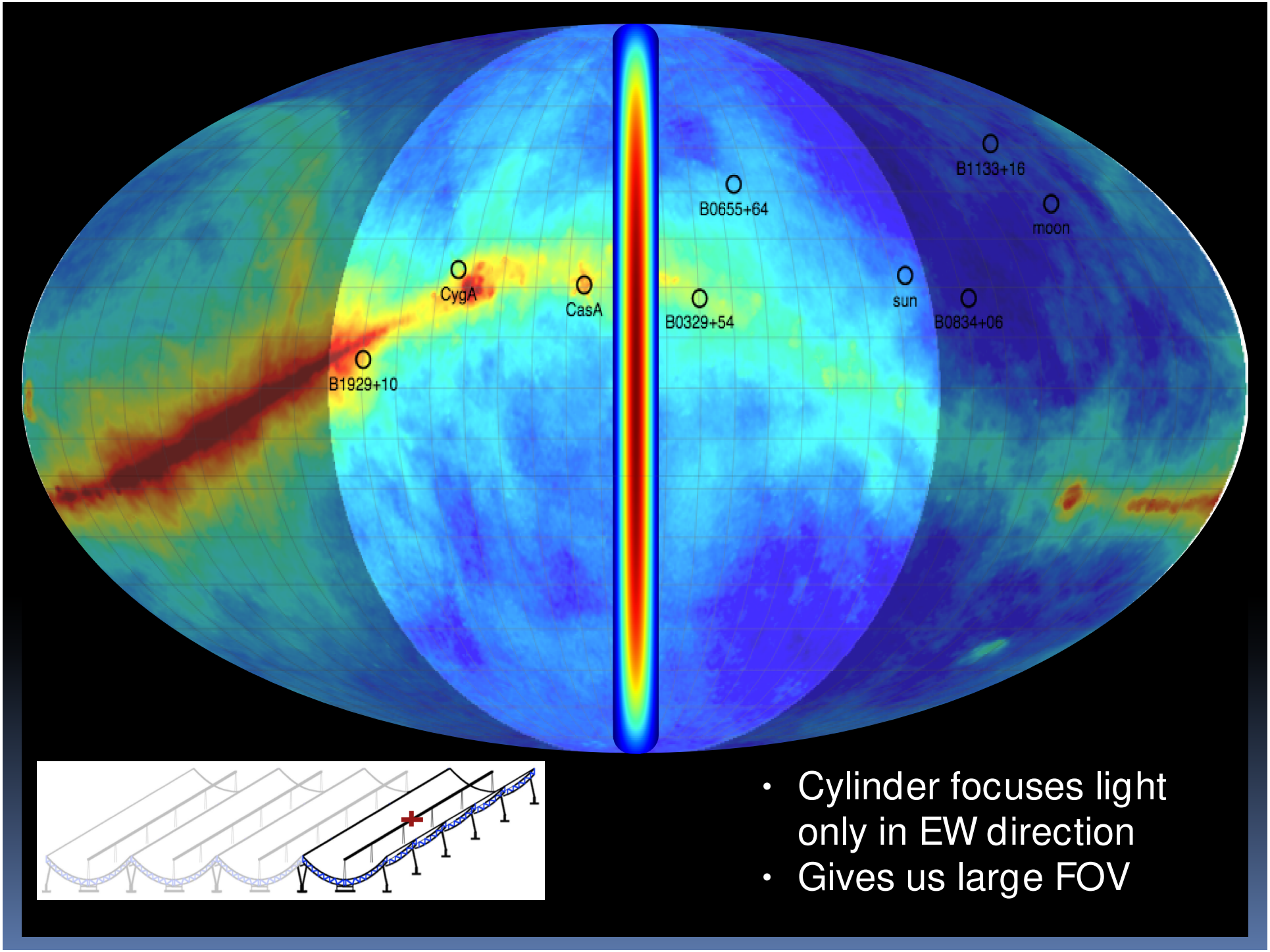
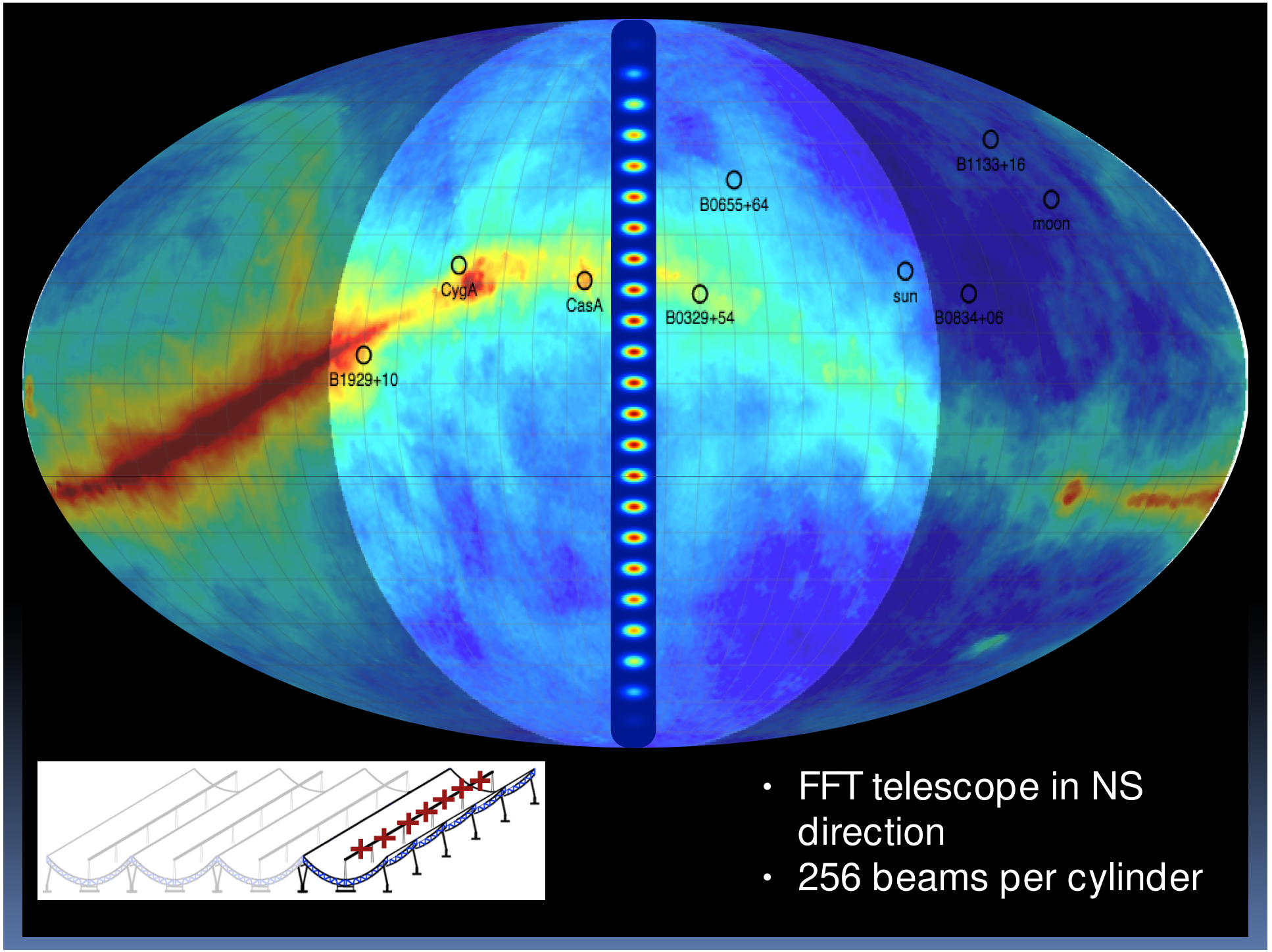
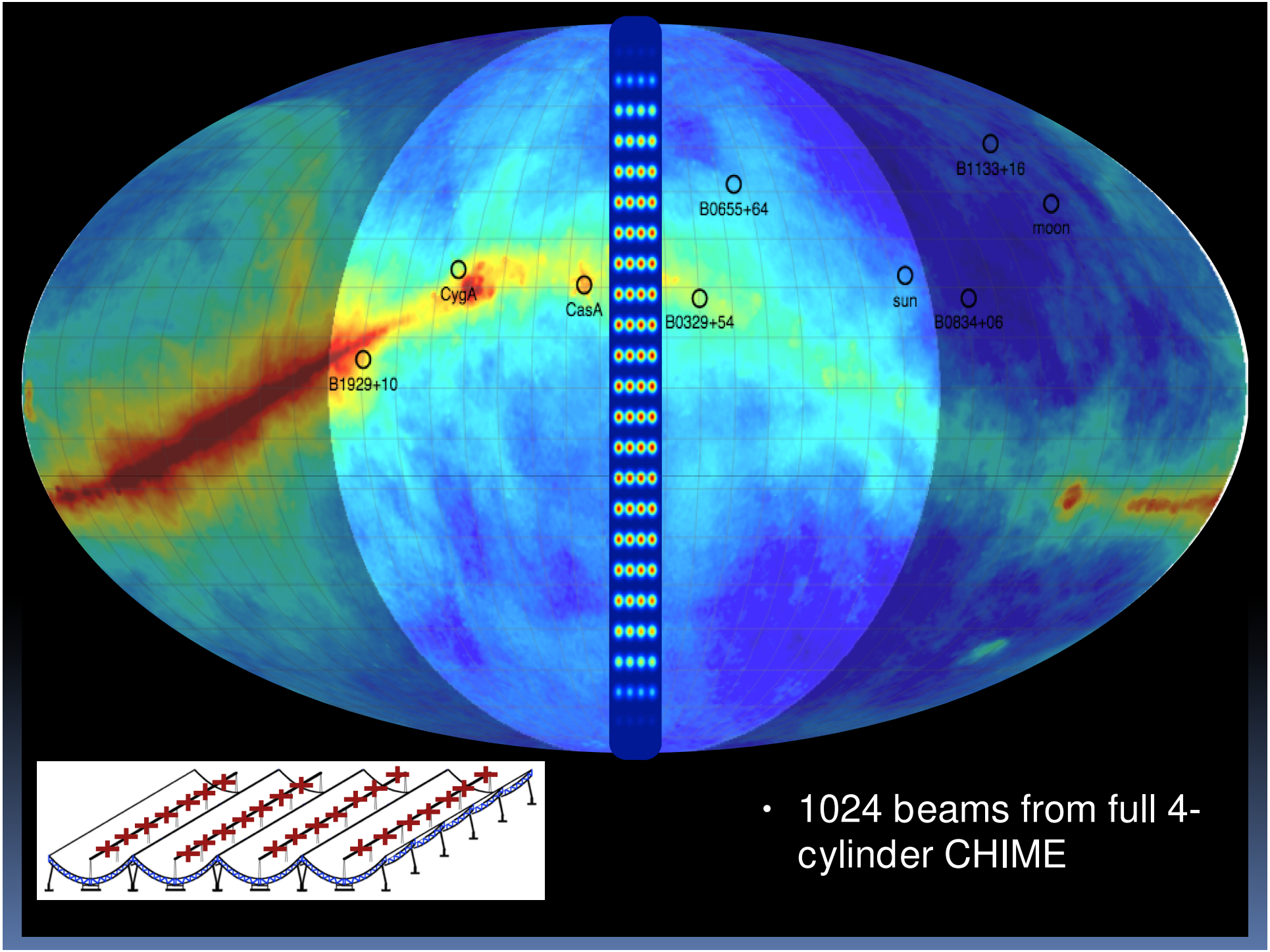


- Cylinder focuses light only in EW direction
- Gives us large FOV



- FFT telescope in NS direction
- 256 beams per cylinder



- 1024 beams from full 4-cylinder CHIME

(NOAA), 5% less than the current level and about $800 million short of Obama's request. The Senate bill would reduce NOAA spending by just 1%.

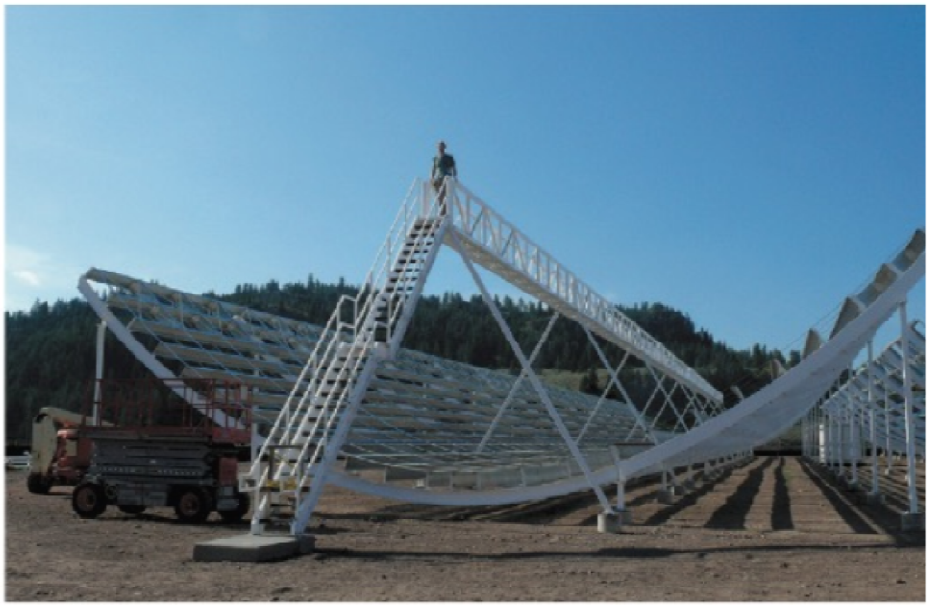
But it is the National Science Foundation (NSF) that has most polarized lawmakers. The House's NSF spending bill would require the agency to award 70% of its $6-billion research fund to biology, computer science, engineering, mathematics and the physical sciences. The unusual provision would effectively impose a 16% cut to geoscience and social-sciences programmes, according to an analysis by the American Institute of Physics. By contrast, the Senate's bill does not set funding levels for particular disciplines.

BASIC FOCUS

Powerful House Republicans, most notably science-committee chair Lamar Smith of Texas, have argued that the NSF should concentrate on basic research. Smith has also tried to highlight what he sees as questionable grants by the science agency, such as funding for a study of mental health in Nepal. But Gloria Waters, vice-president and associate provost for research at Boston University in Massachusetts, says that legislators often misunderstand the role of basic science. "People have this idea that science funding should go to something that should have an immediate and direct impact on society, but that's not how science works," she says.

Deciding which projects to fund is made more difficult by a lack of money, says Hannah Carey, a physiologist at the University of Wisconsin–Madison. "I've experienced it — you put in a grant to continue your work that gets a very, very good score and would have been funded in a better climate," says Carey, who spent a year working as a programme director in the NSF's biosciences division. "It's disheartening."

A short-term spending deal would avert a government shutdown of the sort that ground most research to a halt in October 2013. But a stopgap arrangement could still make life difficult for researchers.



The CHIME telescope array will search for a particular kind of hydrogen emission from ancient galaxies.

COSMOLOGY

Half-pipe array to map teen Universe

Canadian telescope aims to chart cosmic expansion rate between 10 billion and 8 billion years ago.

BY DAVIDE CASTELVECCHI

But that's not all!

mobile phones, will soon be tasked with plugging a crucial gap in the cosmological record: what the Universe did when it was a teenager.

The information will allow cosmologists to expansion rate between 10 billion and 8 billion

Big Bang 13.8 billion years ago, the rate of the Universe's expansion slowed. But somewhere during the 'adolescent' period, dark energy — which eventually turned the Universe's slowing

MARK HALPER/NATURE

CHIME FRB Rate Estimate

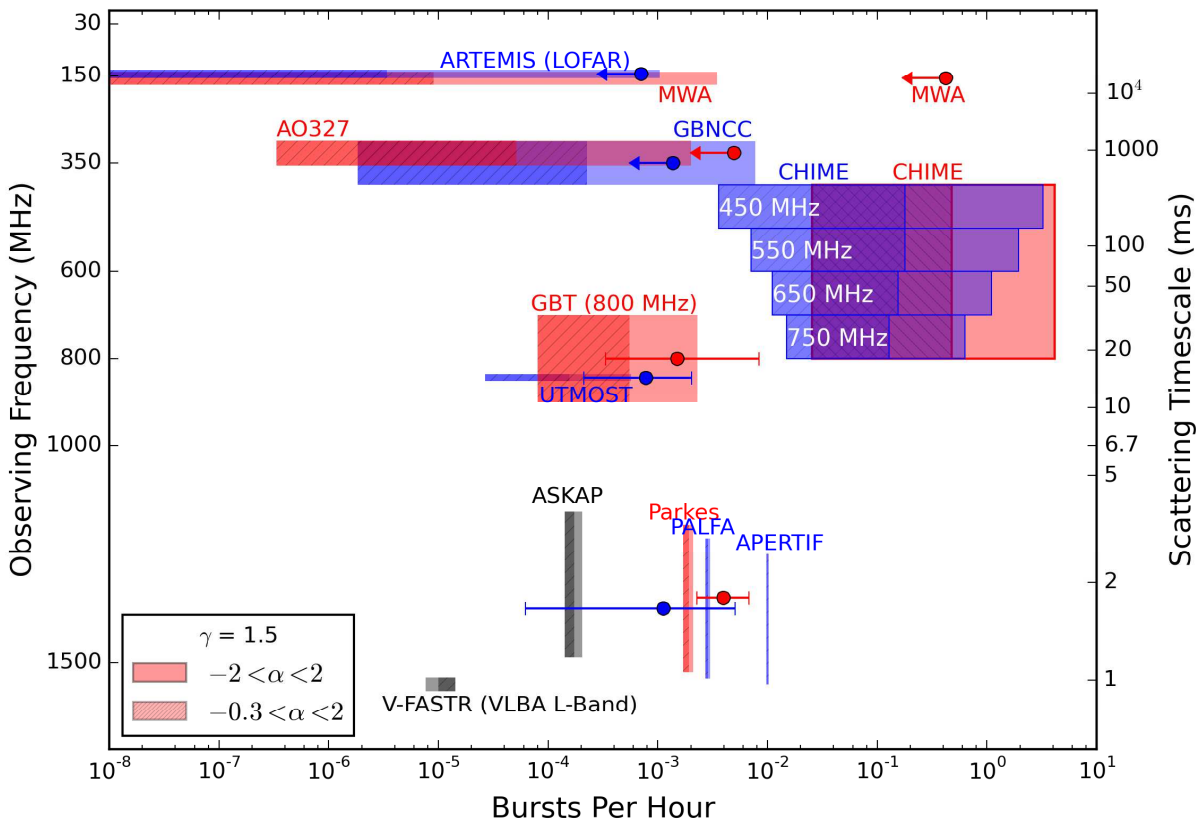
CHIME/FRB rate predictions based on all-sky rate estimate Lawrence et al. (2017)

587^{+924}_{-272} /sky/day

BUT

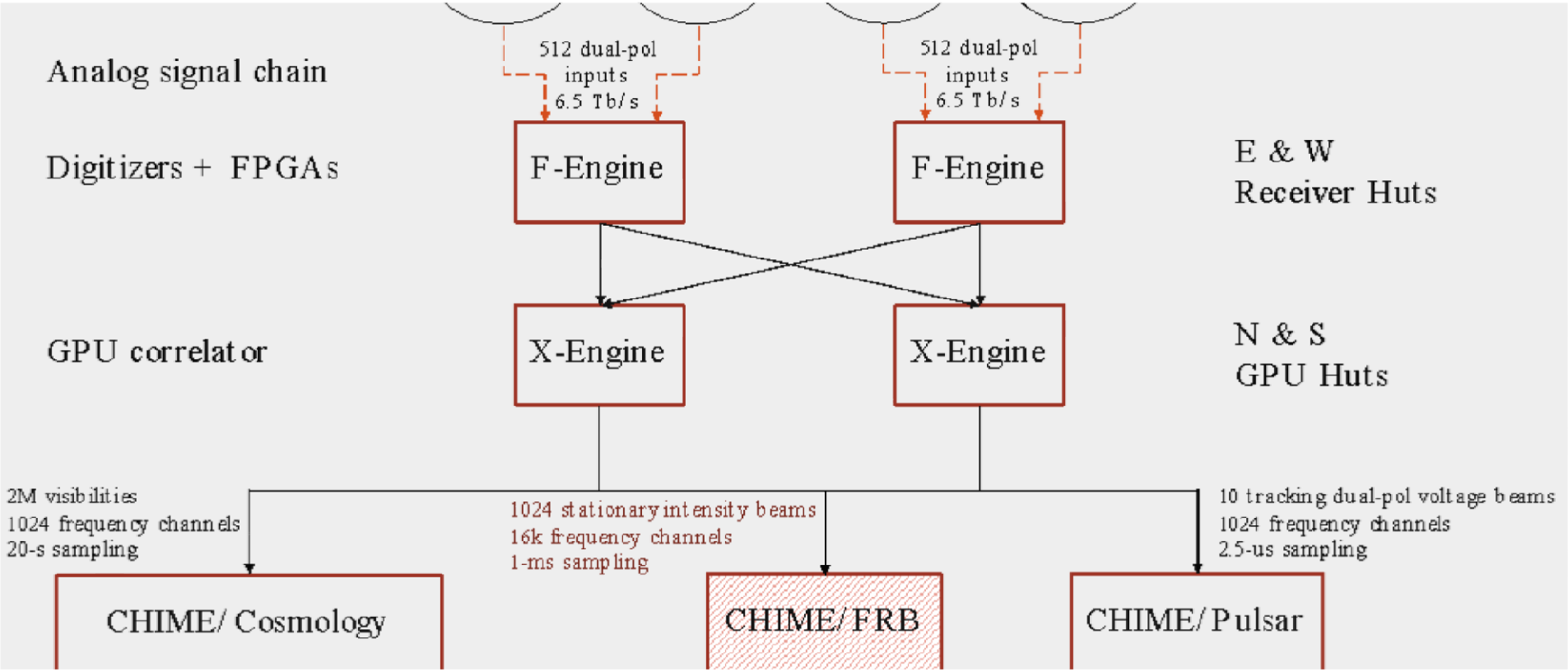
Vander Weil et al. (2016) say

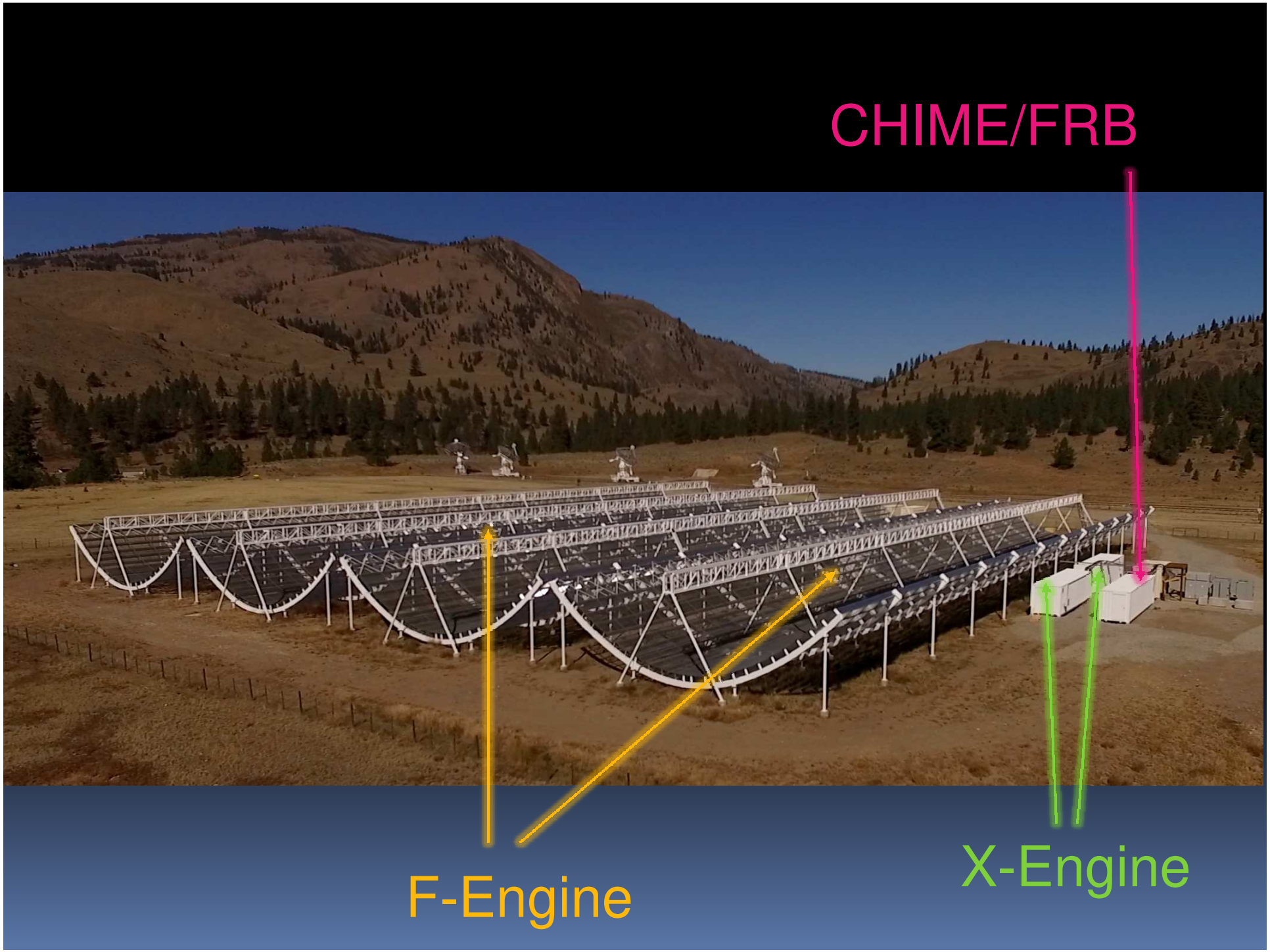
2900^{+7300}_{-1100}/sky/day for high b



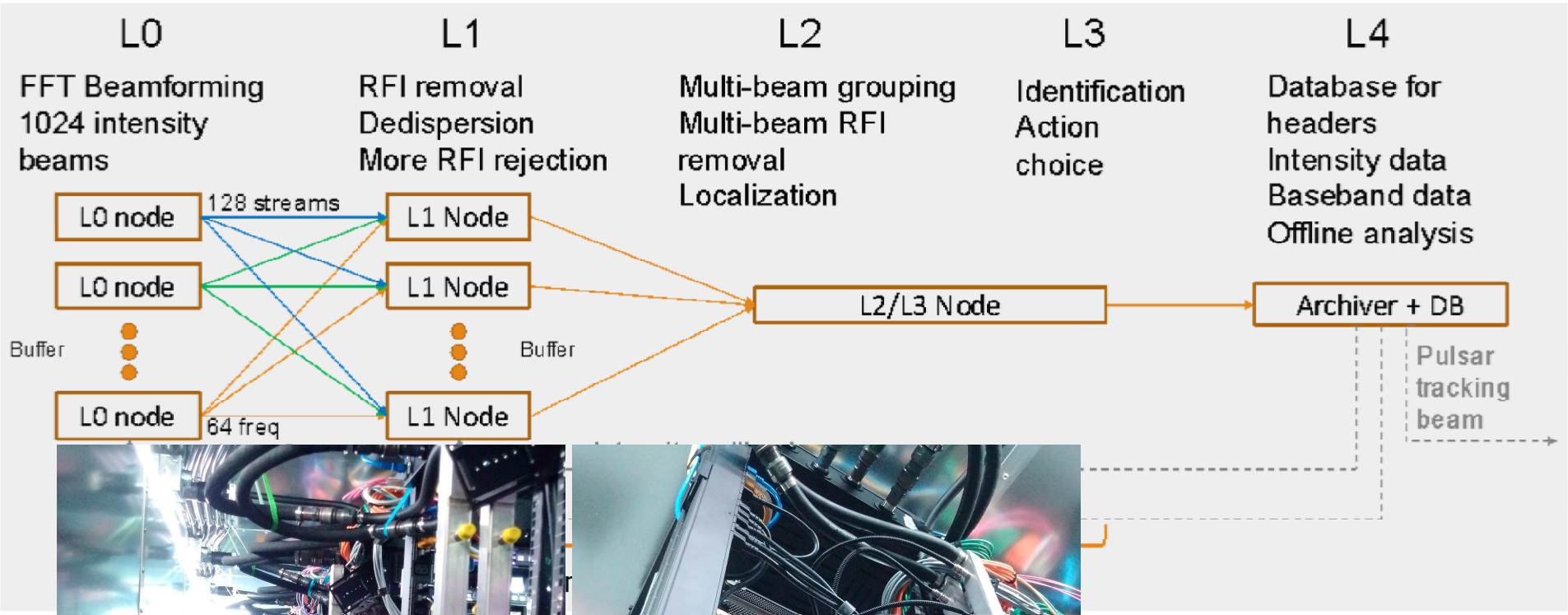
CHIME Collaboration, ApJ, in press

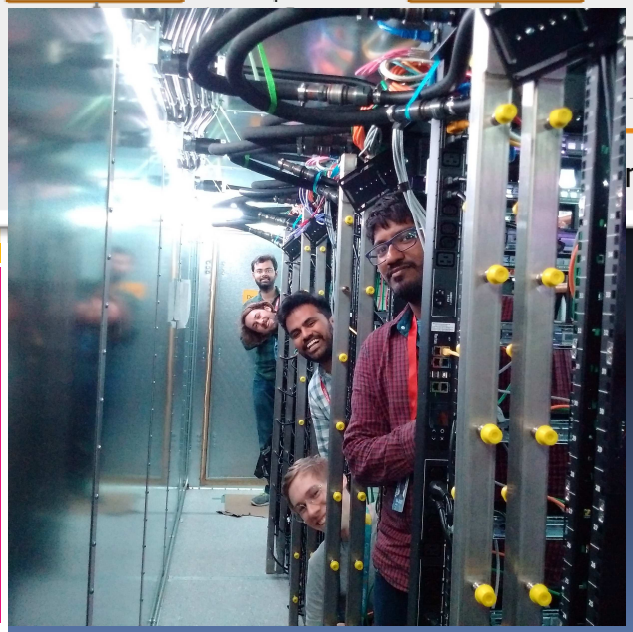
CHIME System Diagram

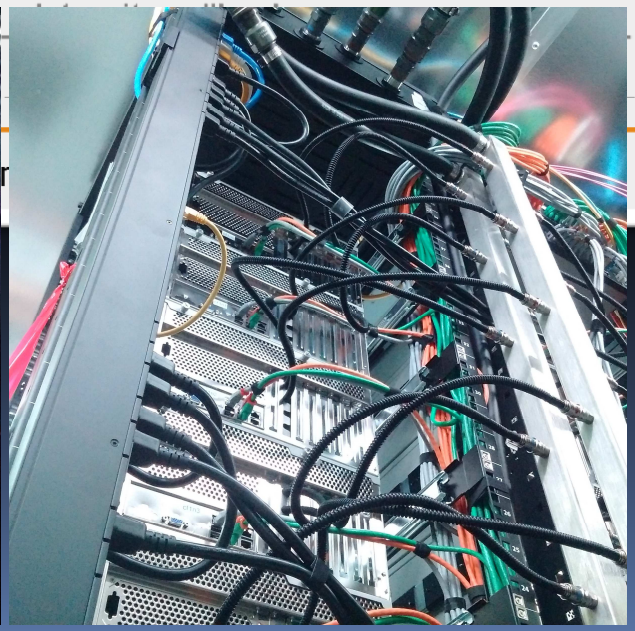



CHIME/FRB
F-Engine
X-Engine

CHIME/FRB Detection Pipeline

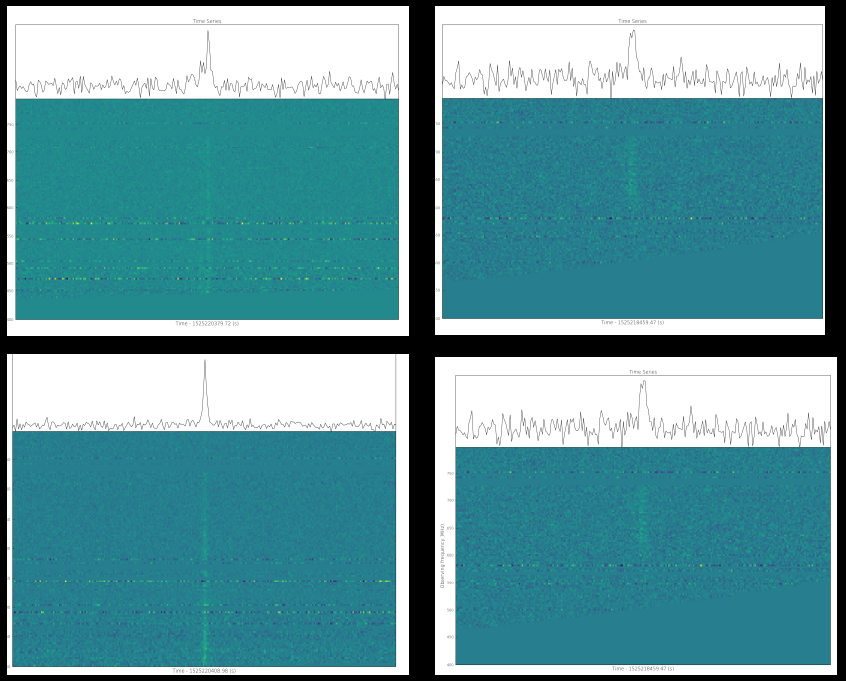


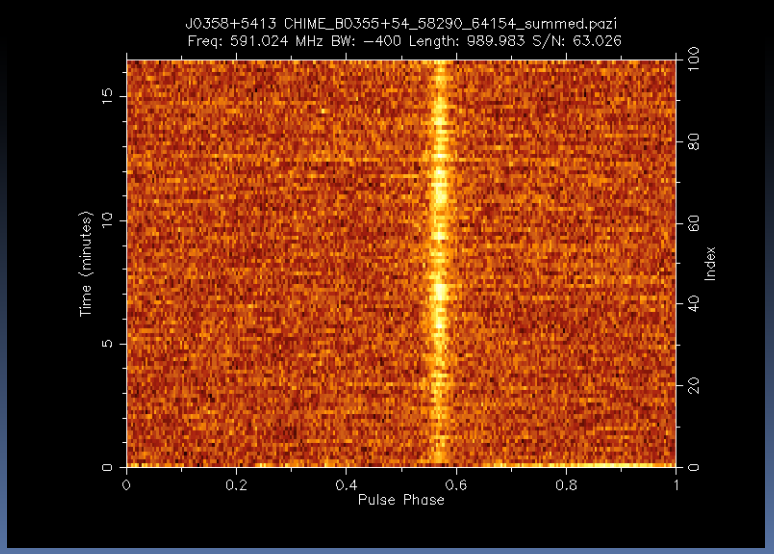




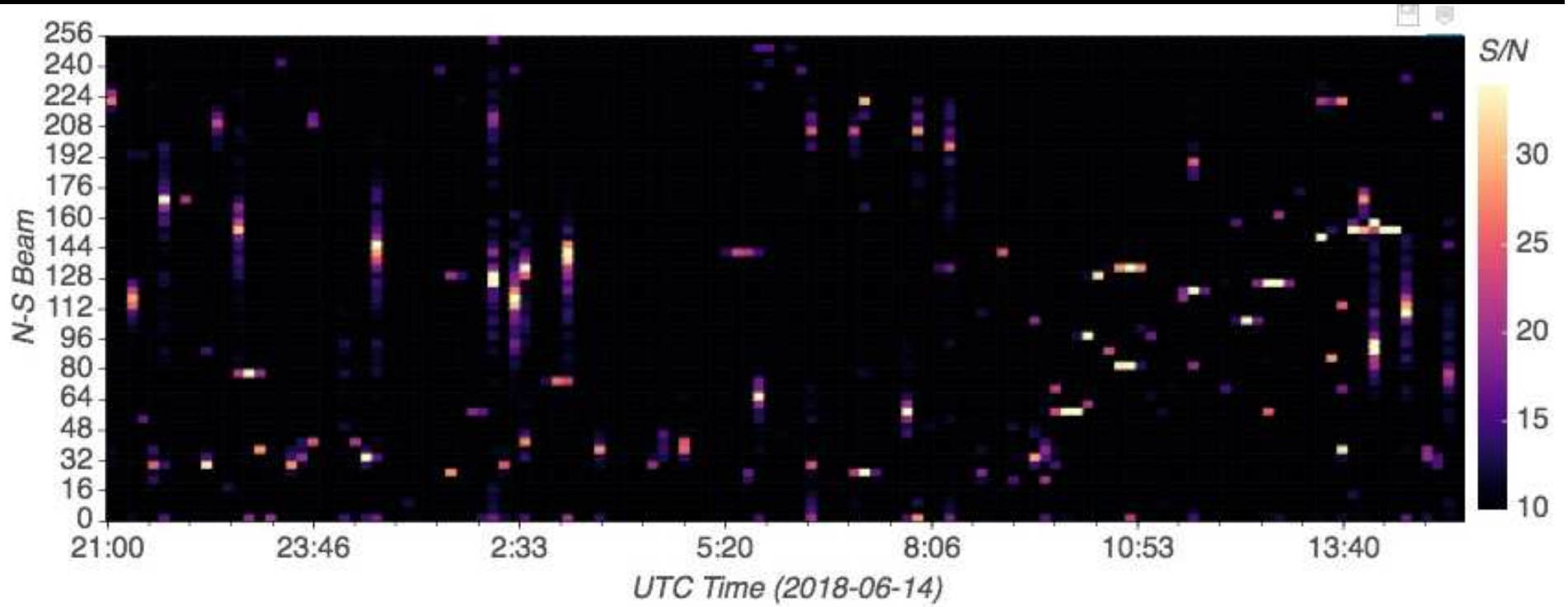
CHIME/FRB Status

- CHIME telescope online, being commissioned
- CHIME/FRB backend online, mostly functional:
  99/130 L1 nodes + L2/L3 + L4 nodes (~600 beams) installed, being commissioned
- Has operated for few-day-long intervals successfully but not yet optimized
- Pipeline working, being commissioned
- CHIME/Pulsar instrument: 10 tracking beams, being commissioned





The CHIME/FRB Sky



Conclusions

- FRBs are here to stay
- Origin remains unknown
- Multiple classes?
- First localization accomplished
  - Cosmological distance confirmed!
- Many new FRB detectors about to come online!

CHIME Drone Fly-by
chime-experiment.ca