THE DISCOVERY AND SCIENTIFIC POTENTIAL OF FAST RADIO BURSTS

Prof Matthew Bailes
Swinburne University of Technology

Prof Duncan Lorimer
West Virginia University

Prof Maura McLaughlin
West Virginia University

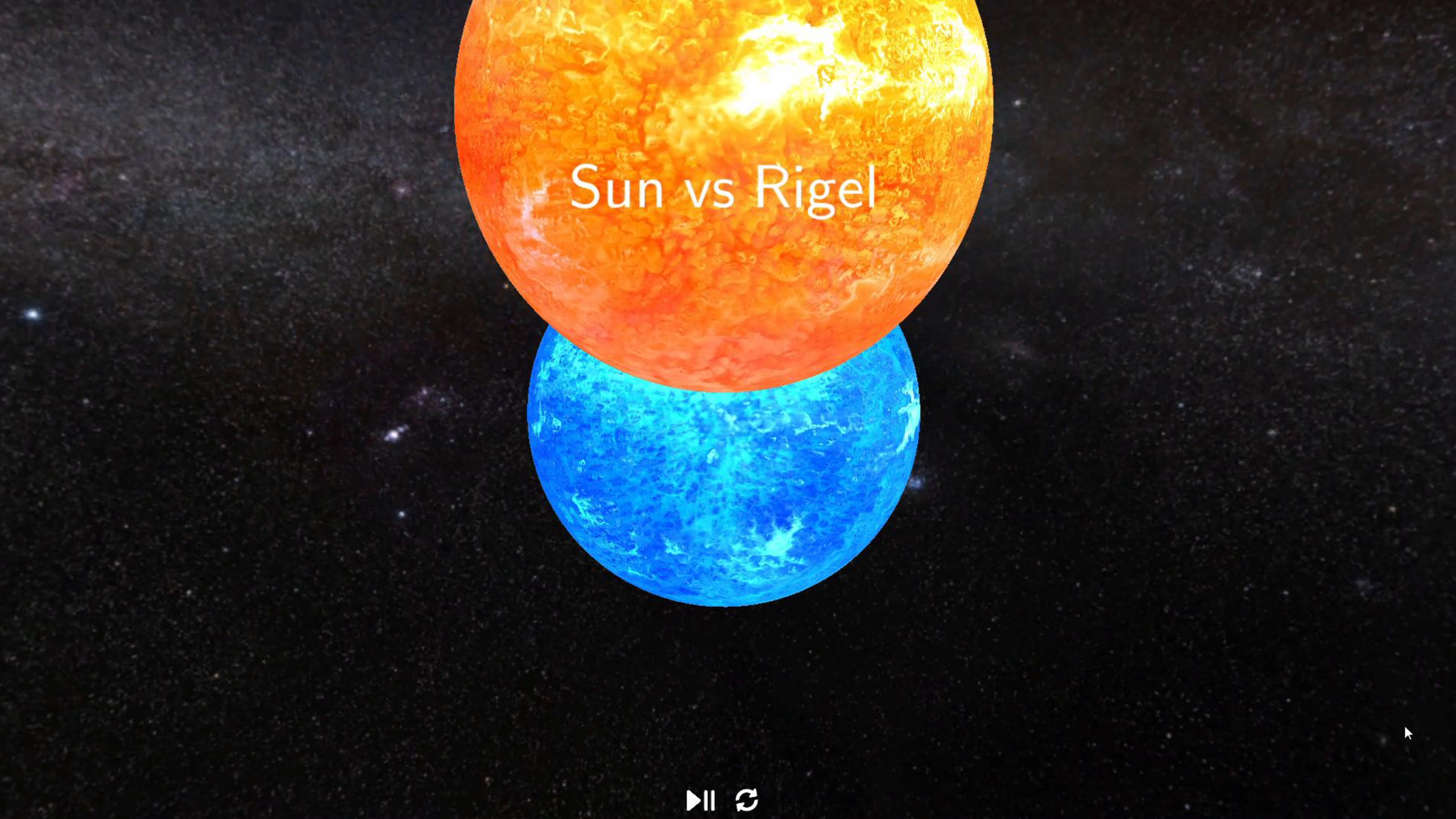

THE SHAW PRIZE
邵逸夫獎
20
Anniversary

SOME BIG ASTRONOMY QUESTIONS:

- WHAT IS THE SIZE AND AGE OF THE UNIVERSE?
- HOW MANY ATOMS ARE THERE IN THE UNIVERSE?
- WHAT LAWS OF PHYSICS GOVERN THE UNIVERSE?
- WHAT CLASSES OF OBJECT EXIST IN THE UNIVERSE?
  - PLANETS, STARS, BLACK HOLES, NEUTRON STARS, QUASARS, ???

TALK OUTLINE

- **OUR UNIVERSE**
- THE TRANSIENT RADIO SKY
- DISCOVERY OF THE LORIMER BURST
- THE COSMOLOGICAL POPULATION OF FAST RADIO BURSTS
- REPEATING FAST RADIO BURSTS
- FRB APPLICATIONS AND THE FUTURE


Sun vs Rigel

Rigel is a 20 solar mass star

- 80 times the Sun’s radius
- Temperature is > 20,000 K
- 100,000 times brighter
- Only 5 Myr left to live
- Will leave behind a neutron star

STELLAR DEATH

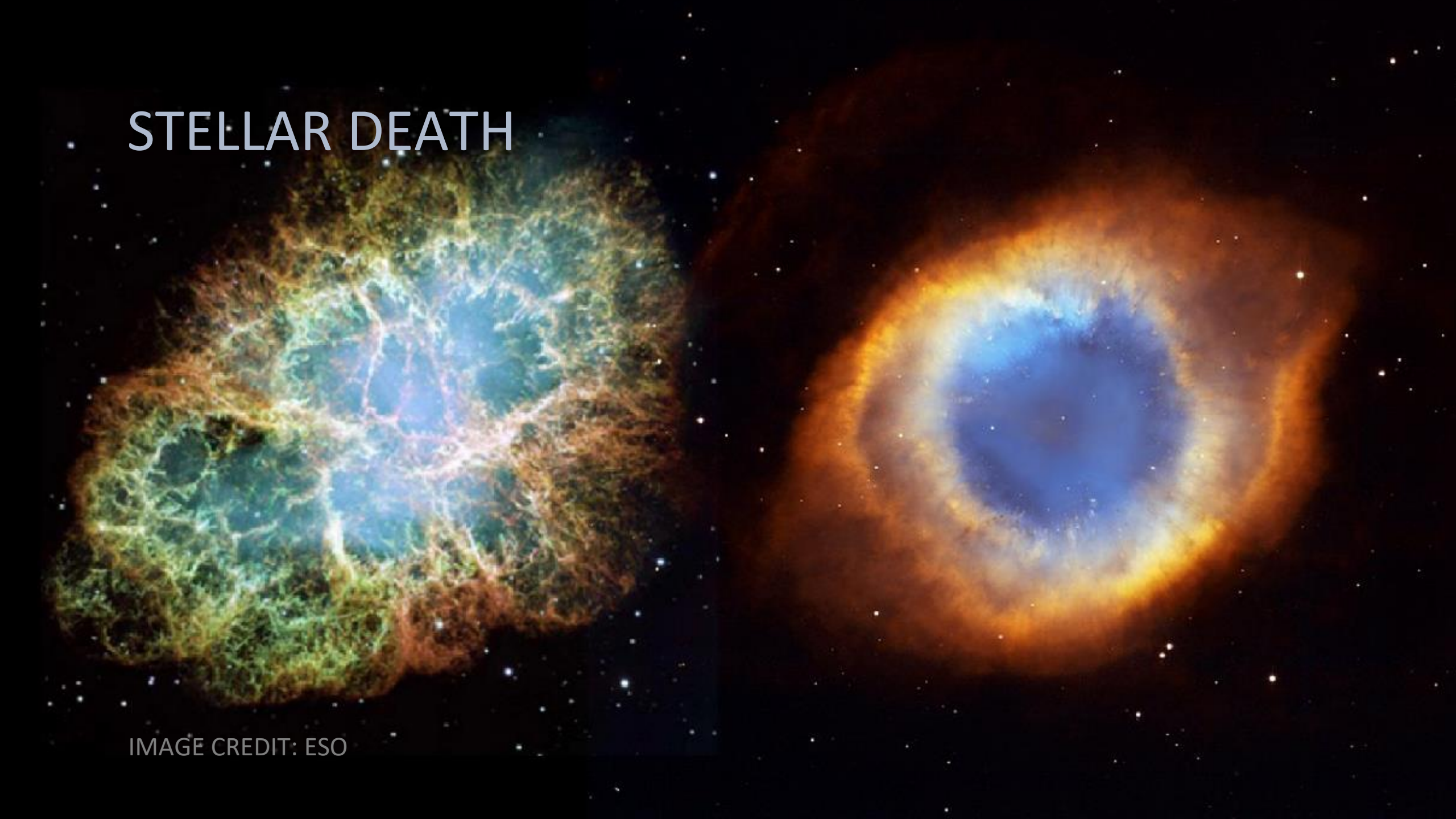
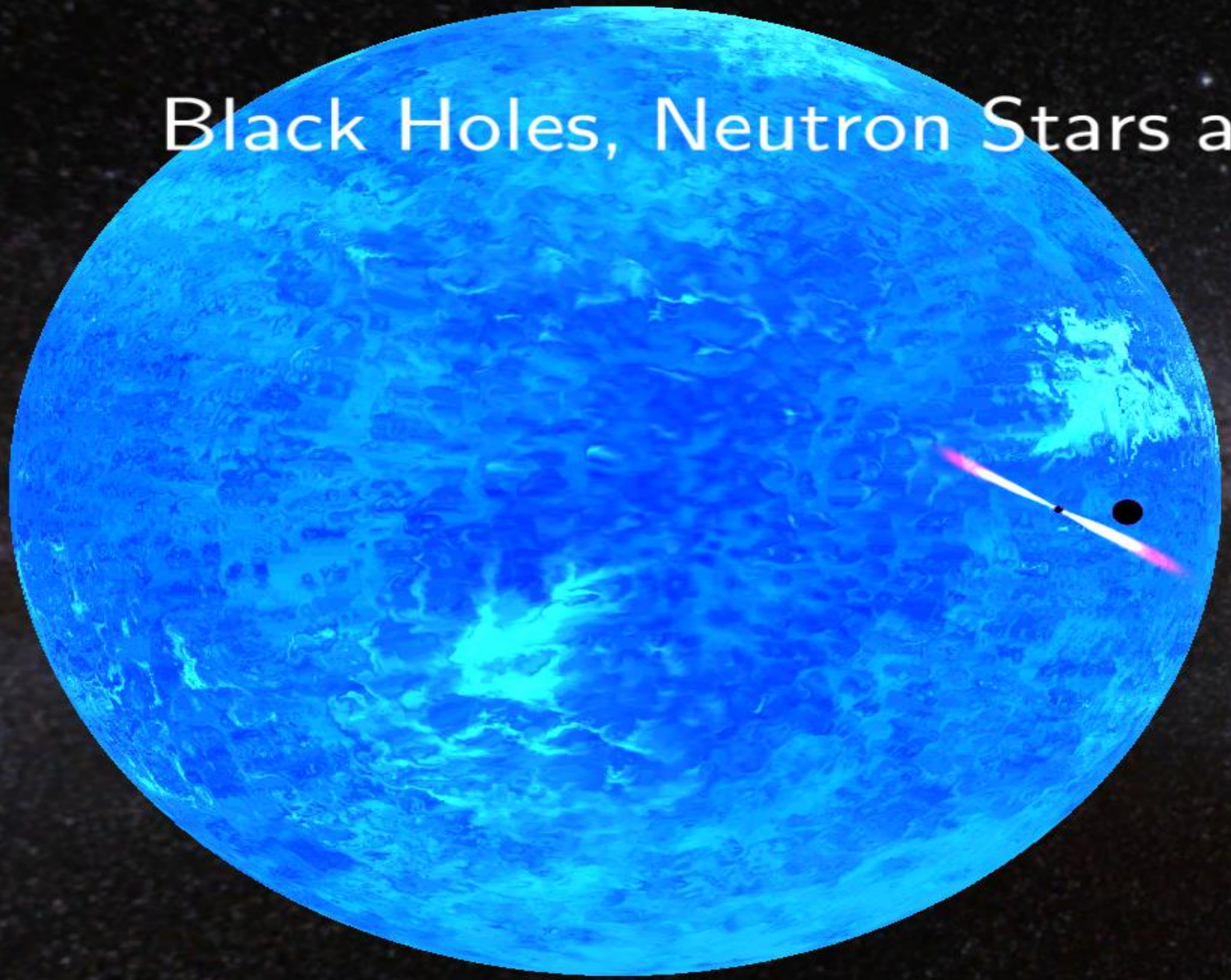


IMAGE CREDIT: ESO

Black Holes, Neutron Stars and White Dwarfs



ANDROMEDA GALAXY

IMAGE CREDIT: NASA/ESA

ELLIPTICAL GALAXY

IMAGE CREDIT: NASA/ESA

THE MAGELLANIC CLOUDS IRREGULARS

IMAGE CREDIT: ESO/S BRUNIER

THE RADIO SKY

IMAGE CREDIT: SARAO

RADIO TELESCOPES

IMAGE CREDIT: CSIRO

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THE QUASARS (3C 31) - “RADIO STARS” THAT TWINKLED

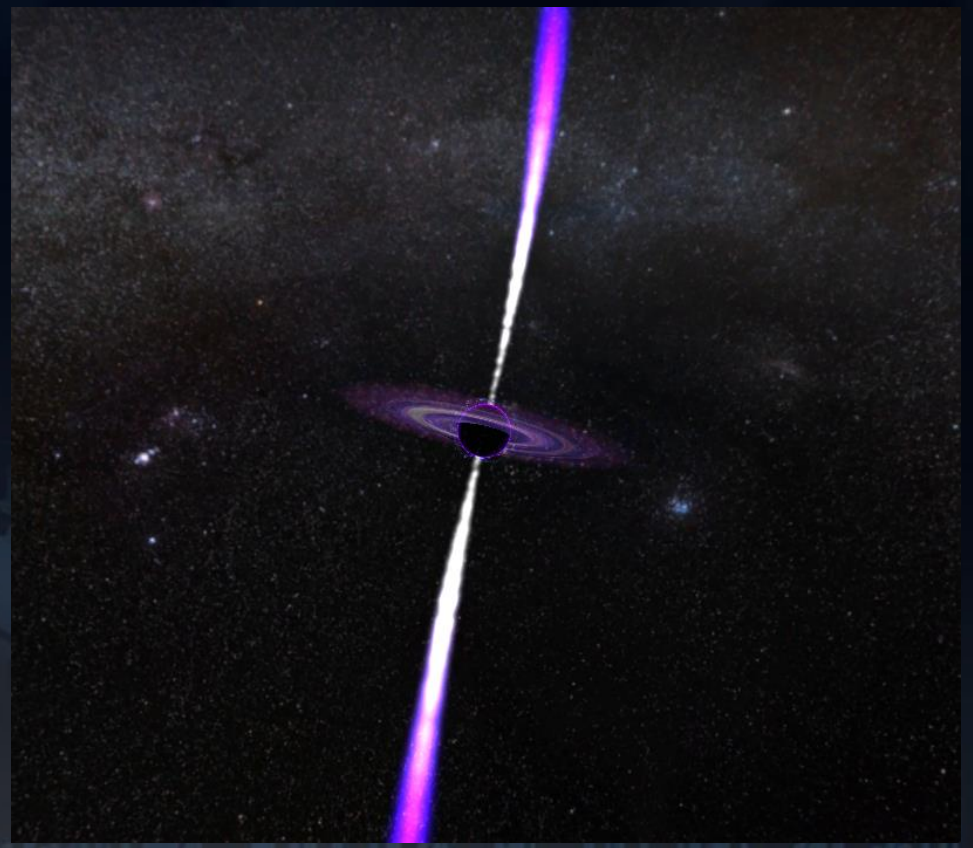
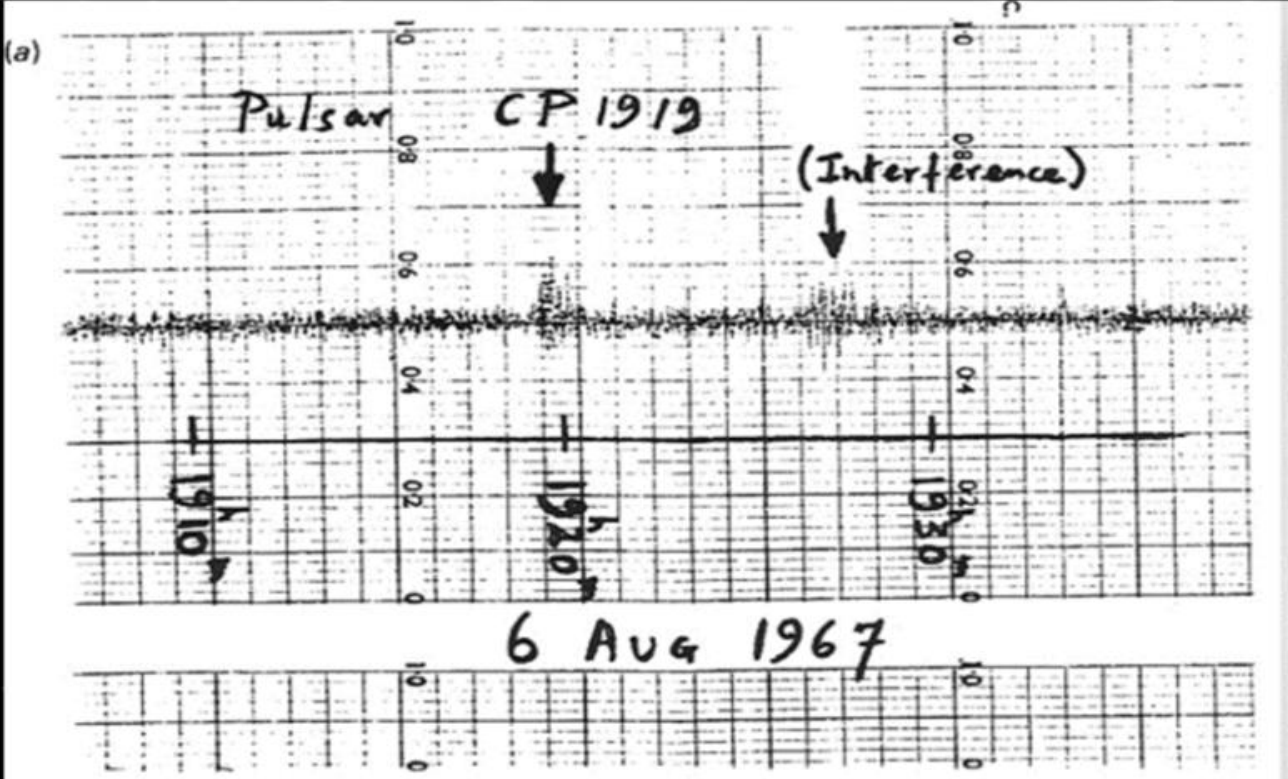


IMAGE CREDIT: CREDIT: NRAO (LAING ET AL.)

TWINKLING IN THE RADIO SKY

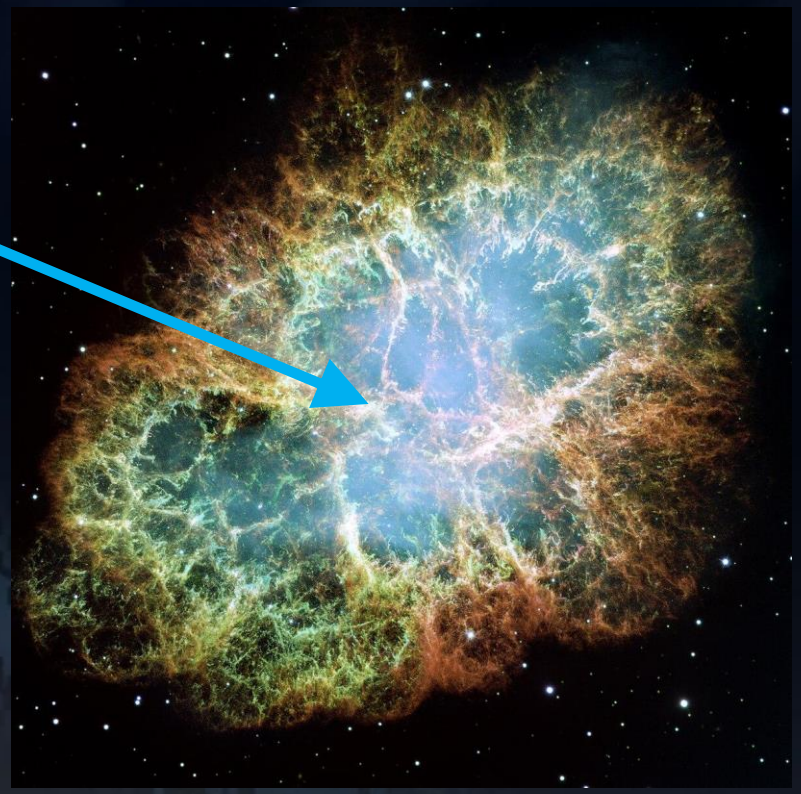
HEWISH AND BELL STUDIED QUASAR SCINTILLATION

IMAGE CREDIT: CAMBRIDGE UNIVERSITY


(a)
Pulsar CP 1919
(Interference)
19h10m
19h20m
19h30m
6 Aug 1967
(b)
SEFRAM • PARIS 5 V 40 A
19h 20m
00s
10s
20s
First observation of pulses
from CP 1919
28 November 1967

NEUTRON STARS

PULSAR DISCOVERED IN THE CRAB NEBULA IN 1968 PULSARS ARE BORN IN THE SUPERNOVA EXPLOSIONS OF MASSIVE STARS!

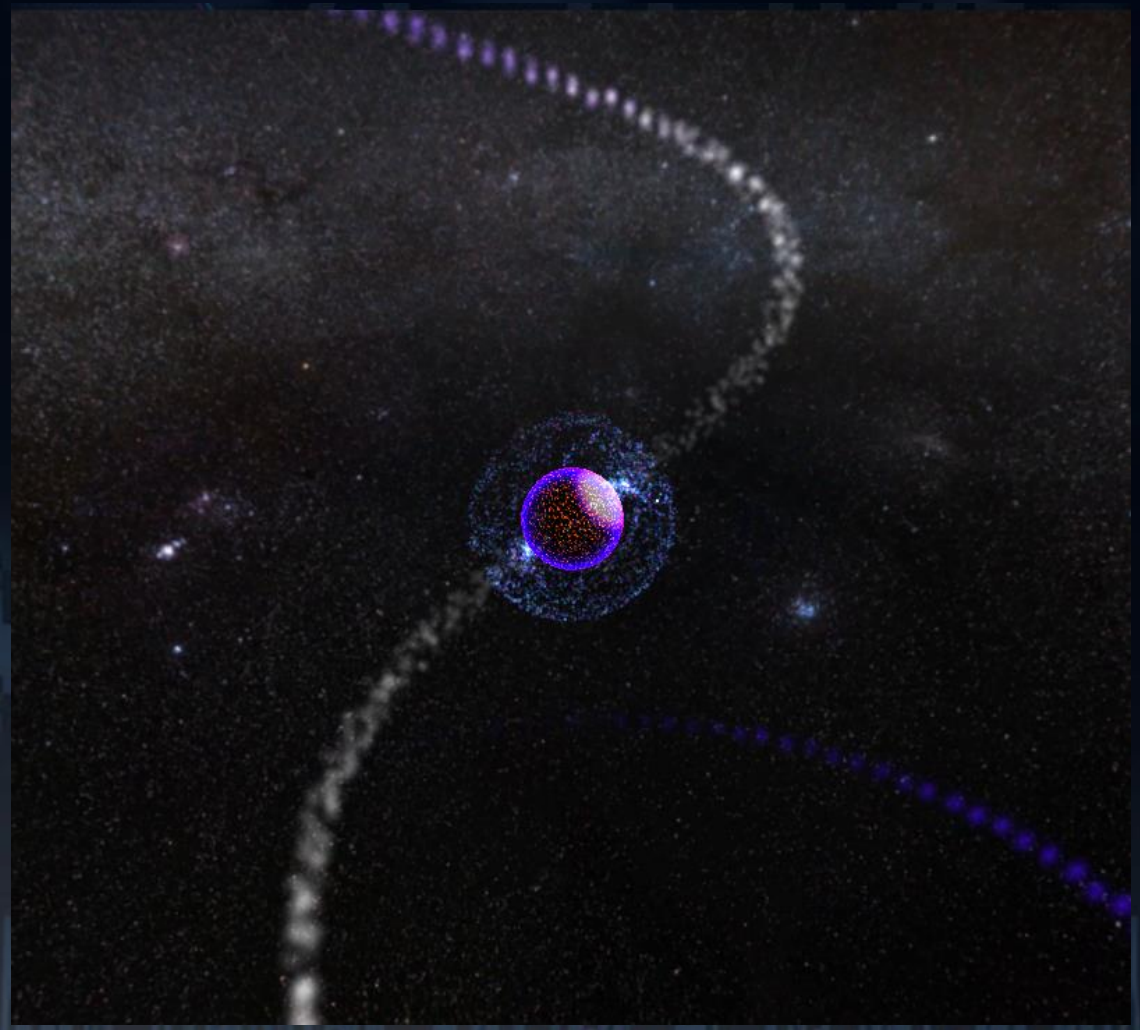


THE CRAB NEBULA

ARECIBO OBSERVATORY

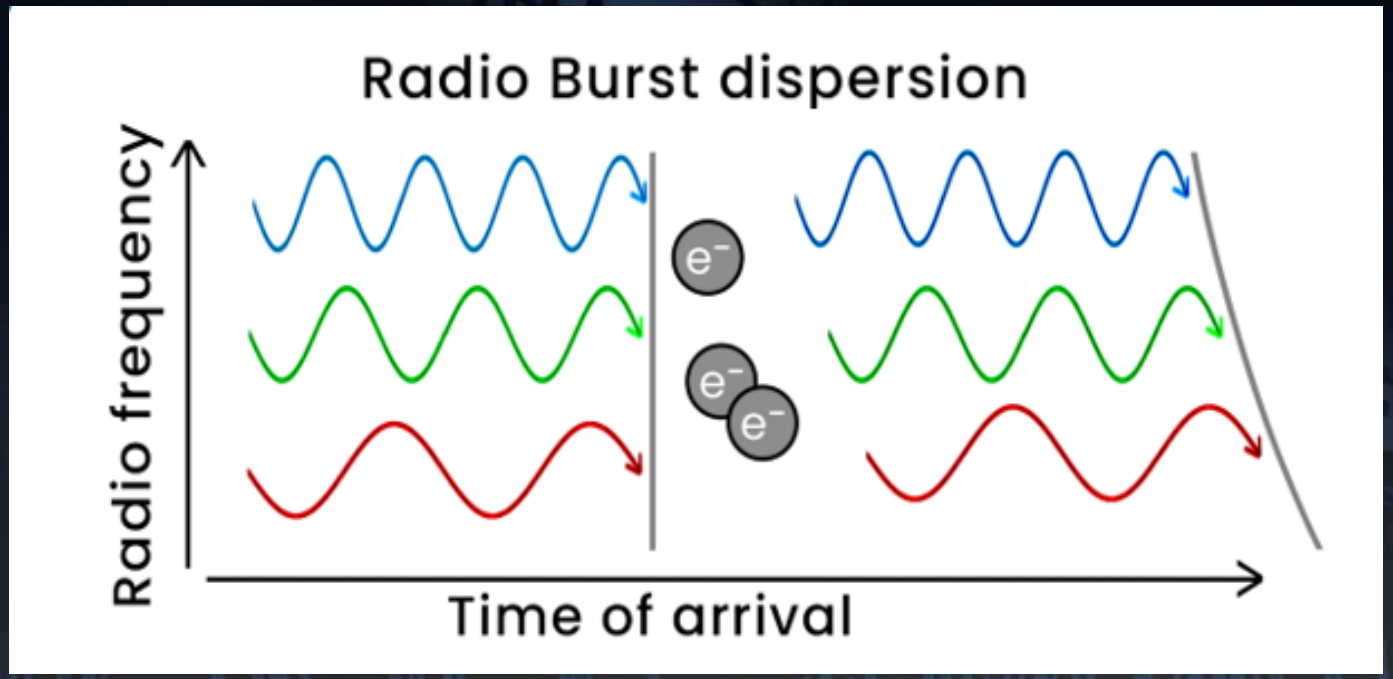
PULSAR MODEL

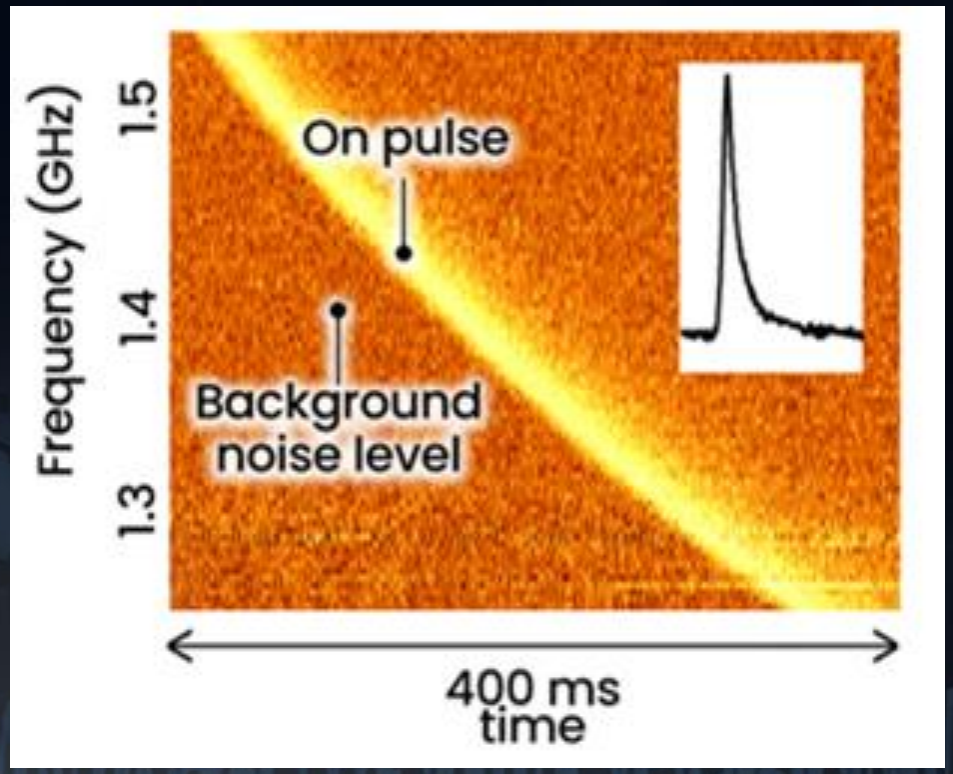
- SPIN PERIODS FROM 1.4 MILLISECONDS TO MANY 10S OF SECONDS
- MAGNETIC FIELDS 10^8-10^{14} GAUSS
- RADII ~ 10 KM
- MASSES 1.3-2.0 SOLAR MASSES
  - ~ 500,000 EARTH MASSES
- DENSITY 1 CC = BILLION TONS
- OVER 3500 NOW KNOWN
- MOST KNOWN LIVE IN OUR GALAXY



PULSAR DISPERSION MEASURES (DMS)

DISTANCE ESTIMATION IN THE GALAXY
- A BONUS (FREE) ELECTRON COUNTER



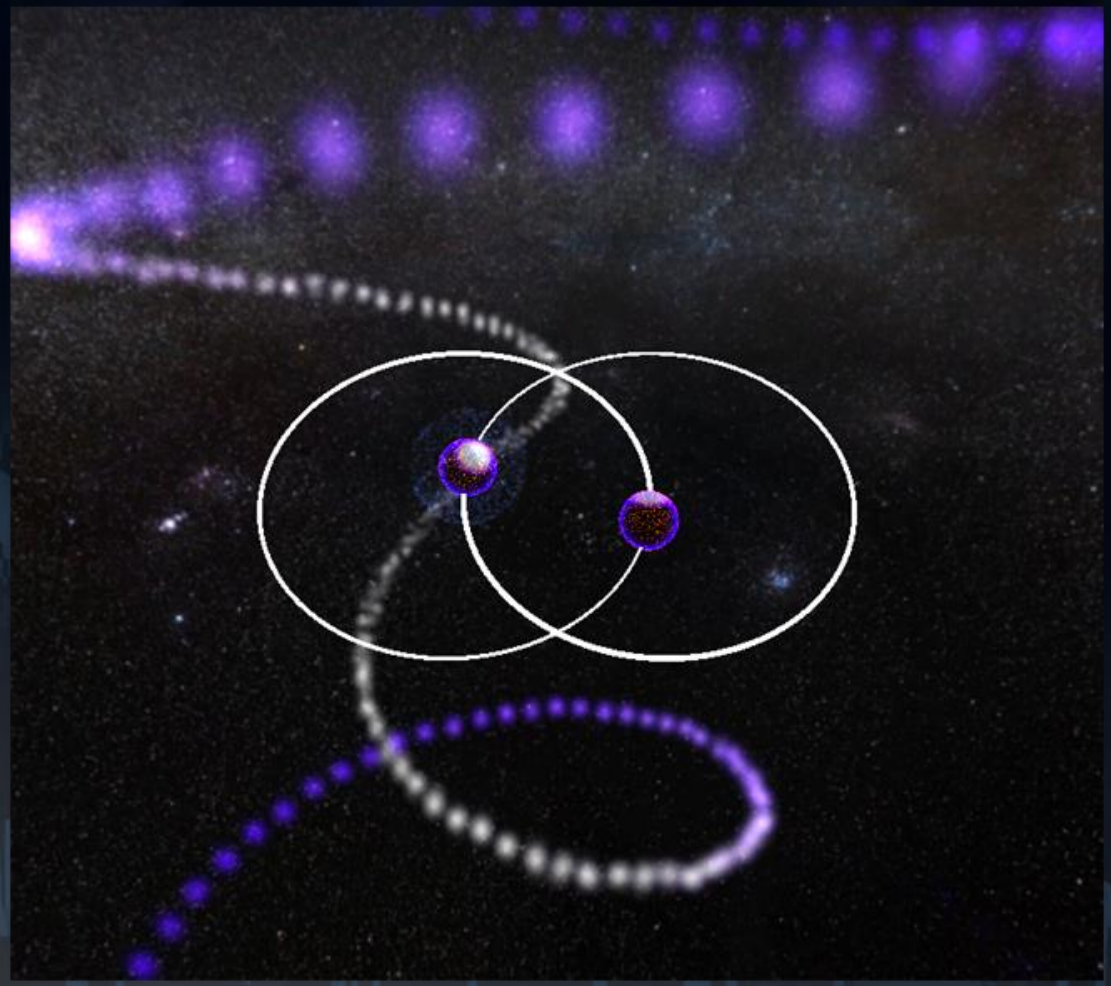


THE 1970S: COMPUTERISED SEARCHES

- LONGER, MORE SENSITIVE SEARCHES
  - HULSE AND TAYLOR (1974) – **40** PULSARS
  - MANCHESTER ET AL. (1978) – **155** PULSARS

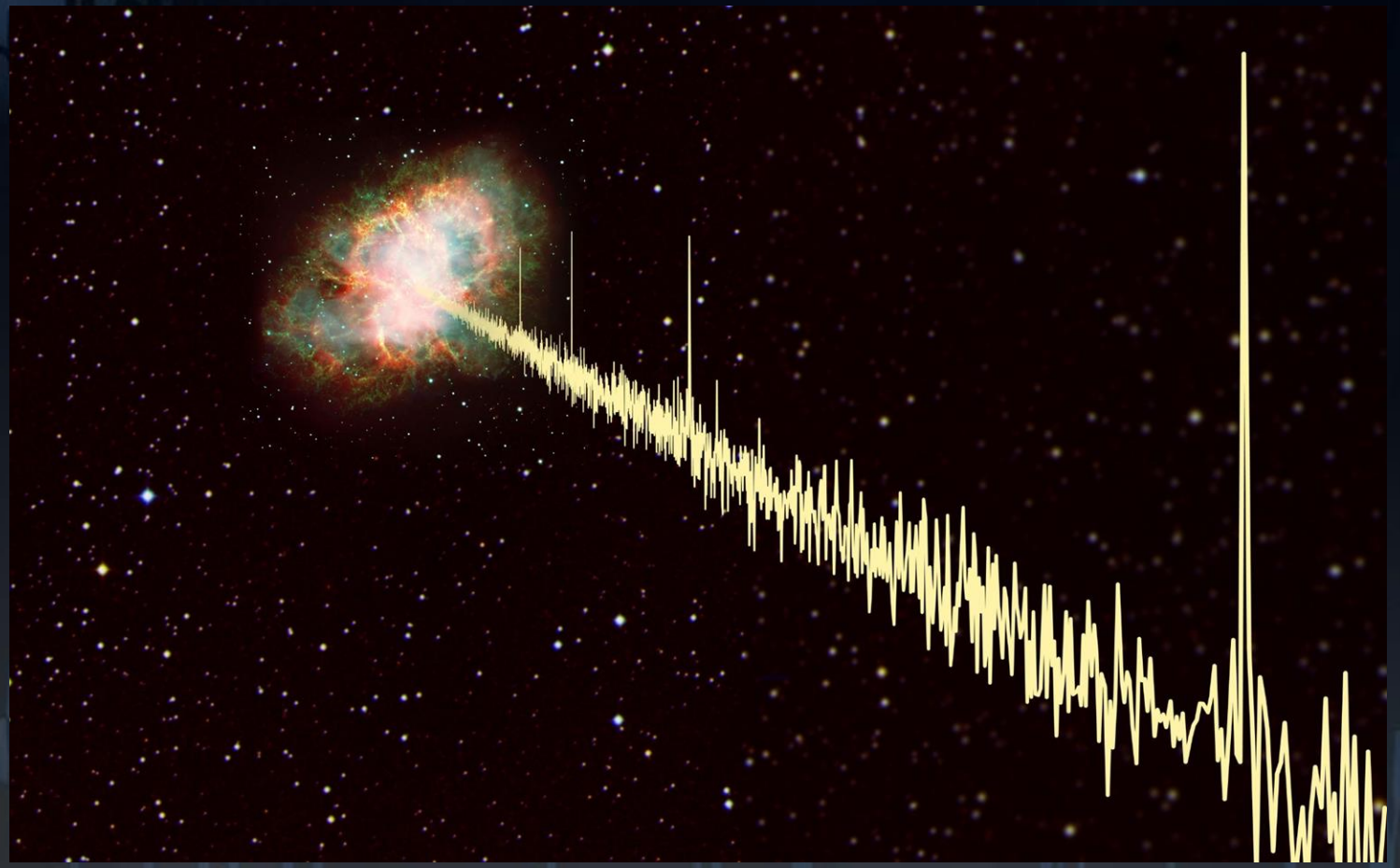
- EMPLOYED THE “FOURIER TRANSFORM”

- DISCOVERED A “BINARY PULSAR”
  - 1993 NOBEL PRIZE IN PHYSICS
    - (HULSE & TAYLOR)



GIANT PULSE-EMITTING PULSARS

> **100 X** NORMAL



CREDIT: NRAO/AUI

THE CRAB NEBULA AND PULSAR

2003: EXTRAGALACTIC PULSE HUNTING

MCLAUGHLIN & CORDES (2003)

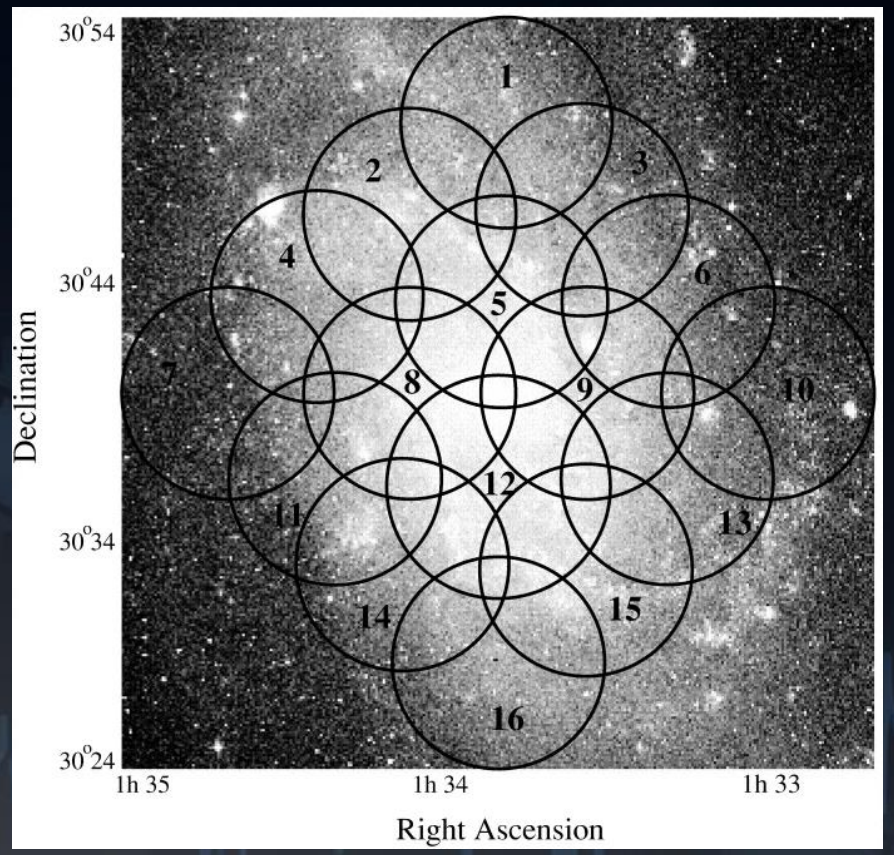
- BUT NOTHING

SEARCHES FOR FAST RADIO TRANSIENTS

J. M. CORDES[1] AND M. A. MCLAUGHLIN[2]

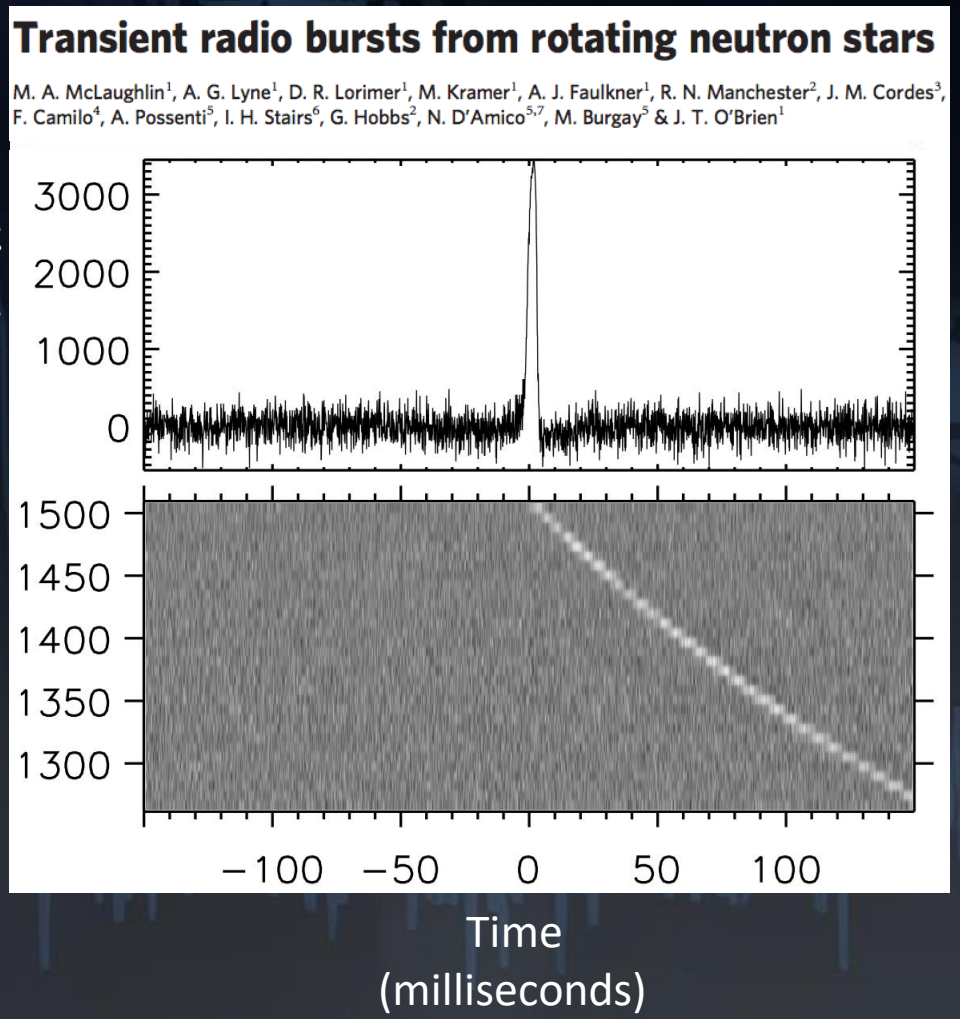
Received 2003 April 21; accepted 2003 July 2

M33, OR THE TRIANGULUM GALAXY
3 MILLION LIGHT YEARS AWAY



2006: THE DISCOVERY OF THE ROTATING RADIO TRANSIENTS (RRATS)

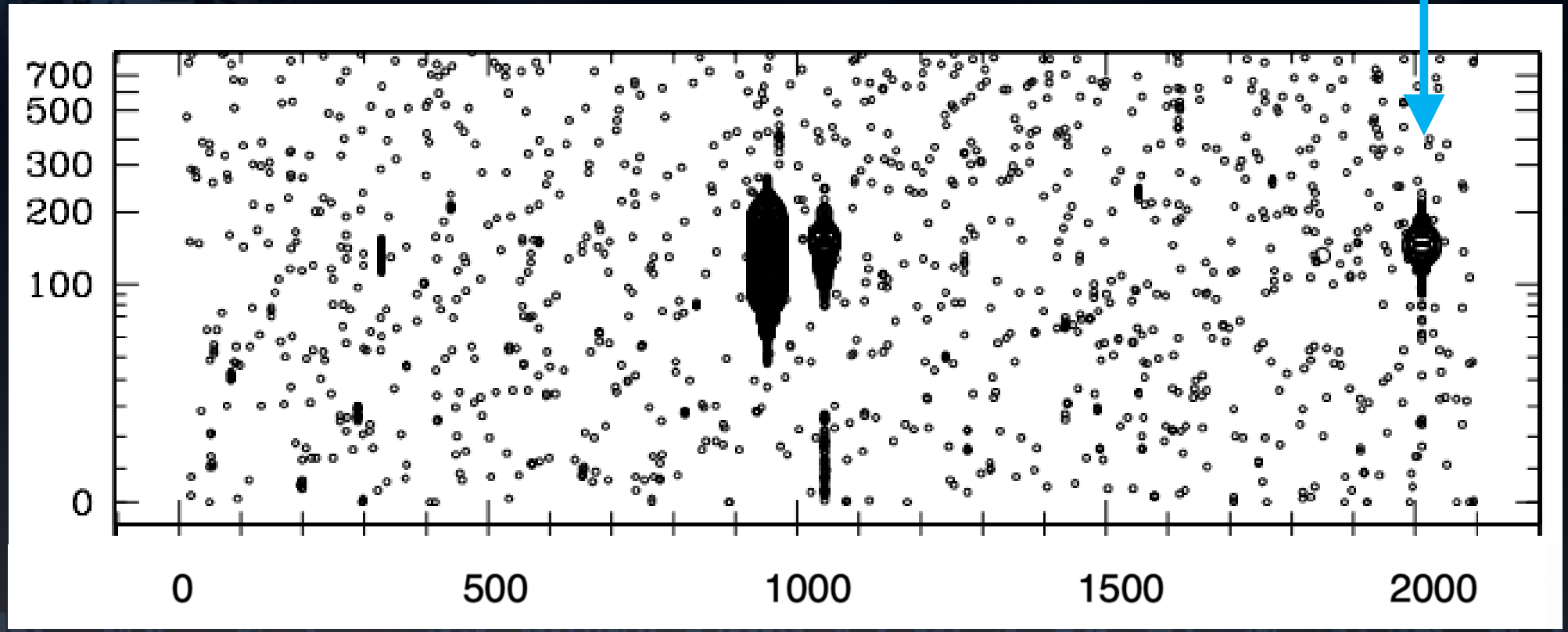
WOOLY MCLAUGHLIN (1980-1985)

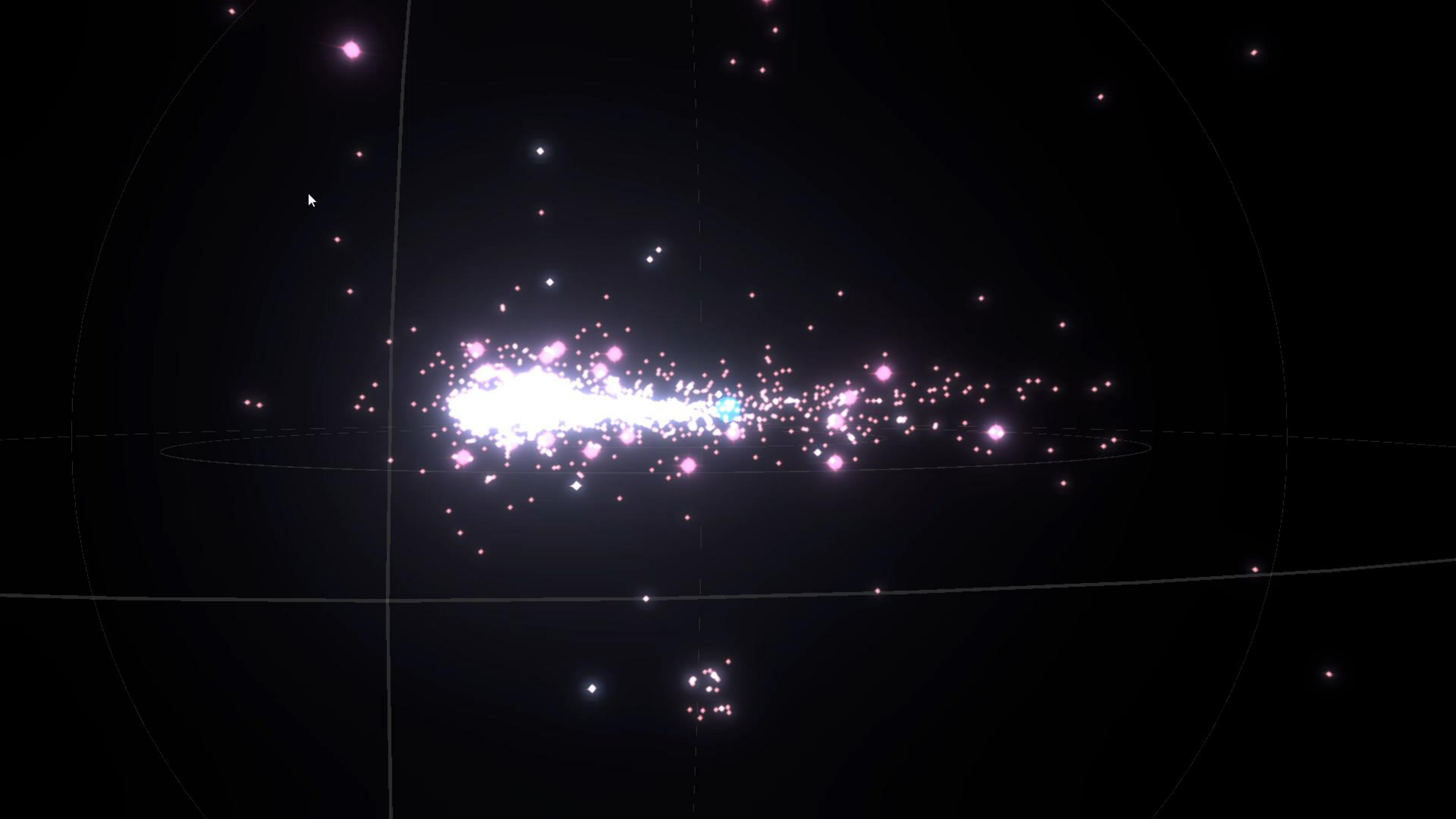


"DESPITE THE SMALL NUMBER OF SOURCES PRESENTLY DETECTED, THEIR EPHEMERAL NATURE IMPLIES A TOTAL GALACTIC POPULATION WHICH SIGNIFICANTLY EXCEEDS THAT OF THE REGULARLY PULSING RADIO PULSARS."

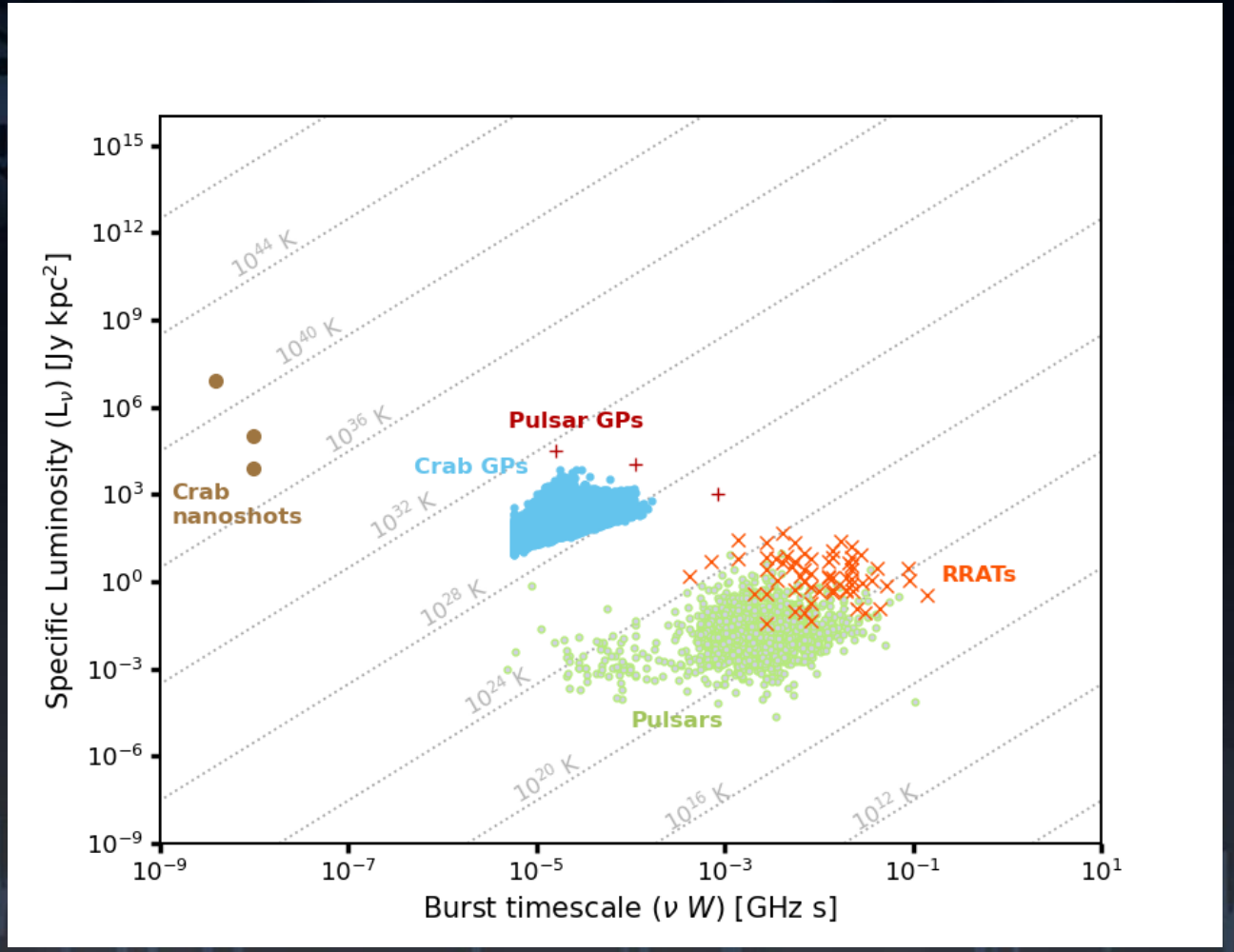
RRAT HUNTING DIAGNOSTIC PLOT:

DM = 145 PC CM^{-3}





THE 2006 TRANSIENT RADIO SKY



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DISCOVERY OF FRB 010724

THE LORIMER BURST

- 2006 MAURA/DUNCAN ARRIVE AT WVU
  - THEIR 9 MONTH OLD BABY IS NOW 18
- AMONG INITIAL STUDENTS IS ASH NARKEVIC
- SEARCH EXISTING TELESCOPE DATA
  - PARTICULAR INTEREST ARE MAGELLANIC CLOUDS

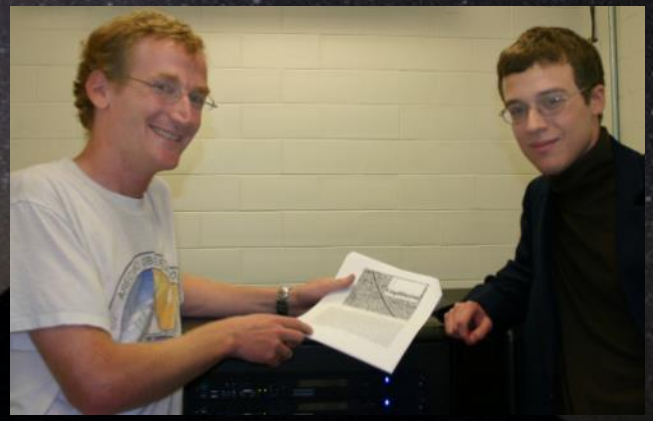
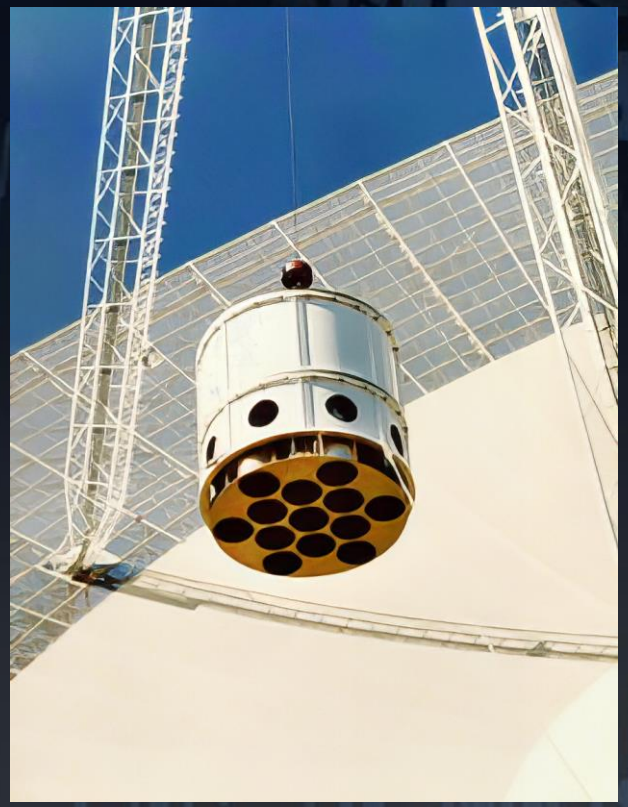


IMAGE CREDIT: NATIONAL GEOGRAPHIC

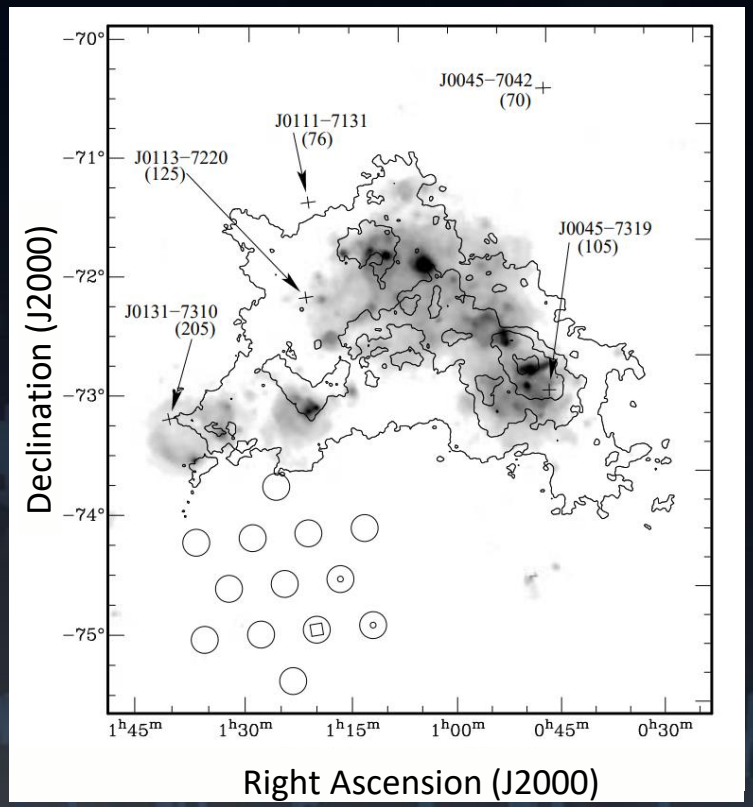
DISCOVERY OF 14 RADIO PULSARS IN A SURVEY OF THE MAGELLANIC CLOUDS

R. N. MANCHESTER,[1] G. FAN,[2,3] A. G. LYNE,[4] V. M. KASPI,[3] AND F. CRAWFORD[5]

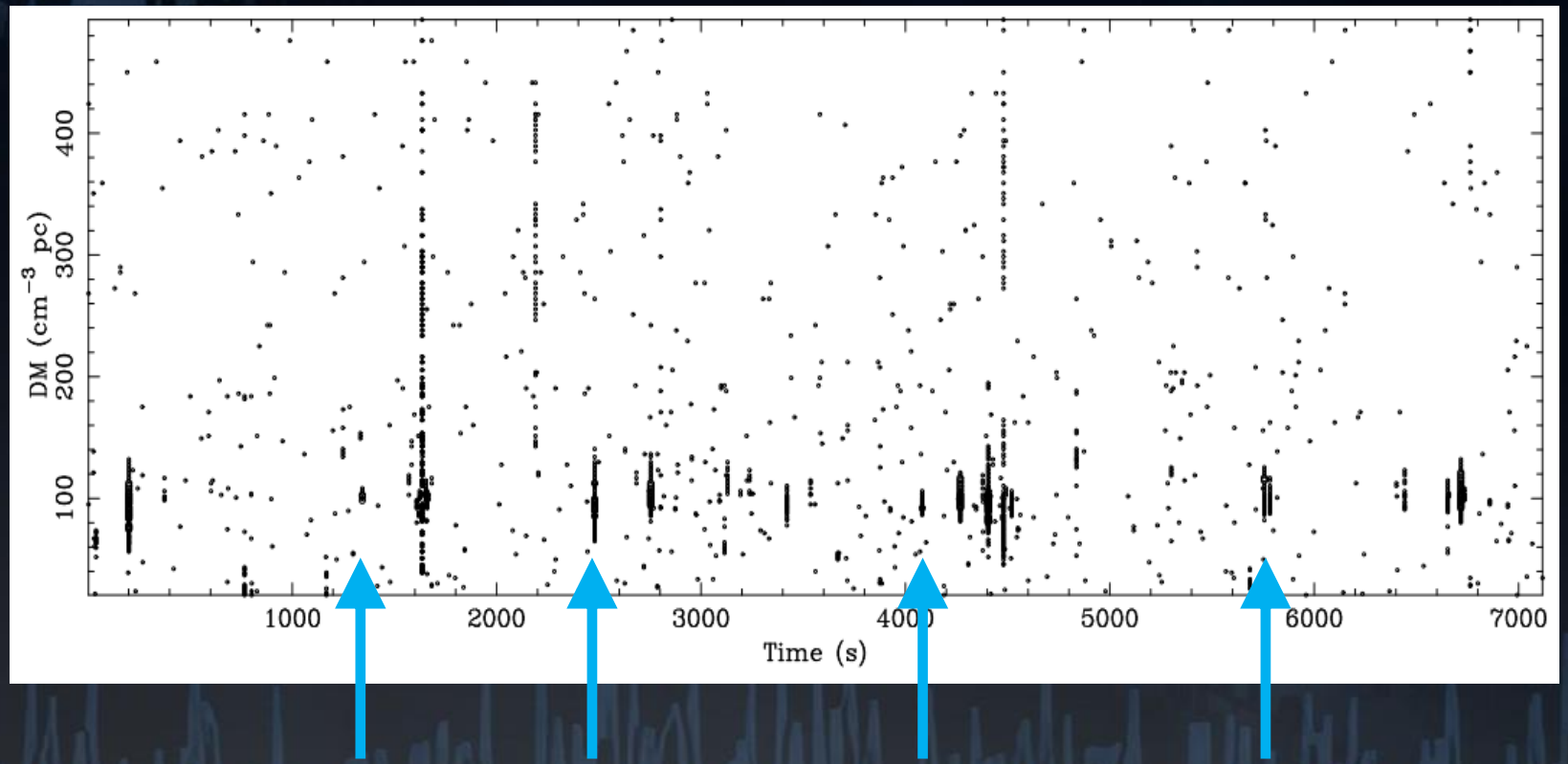
Received 2006 February 23; accepted 2006 April 19



FRONEY
CRAWFORD



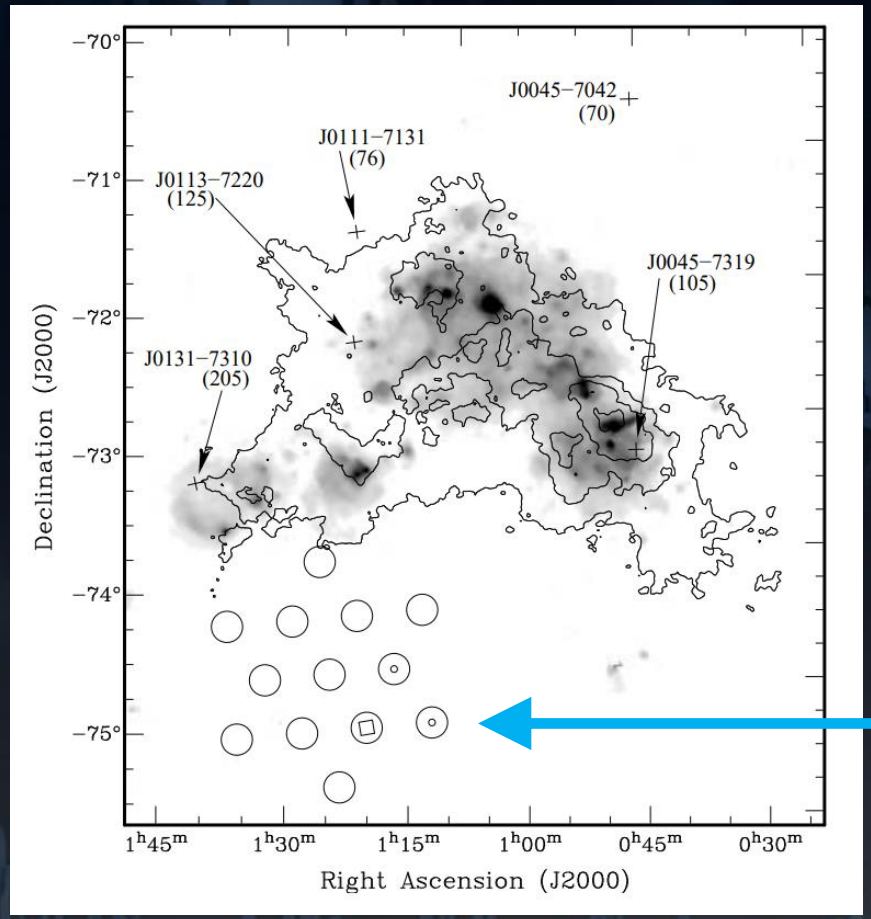
SEARCHING FOR PULSES IN THE MAGELLANIC CLOUDS

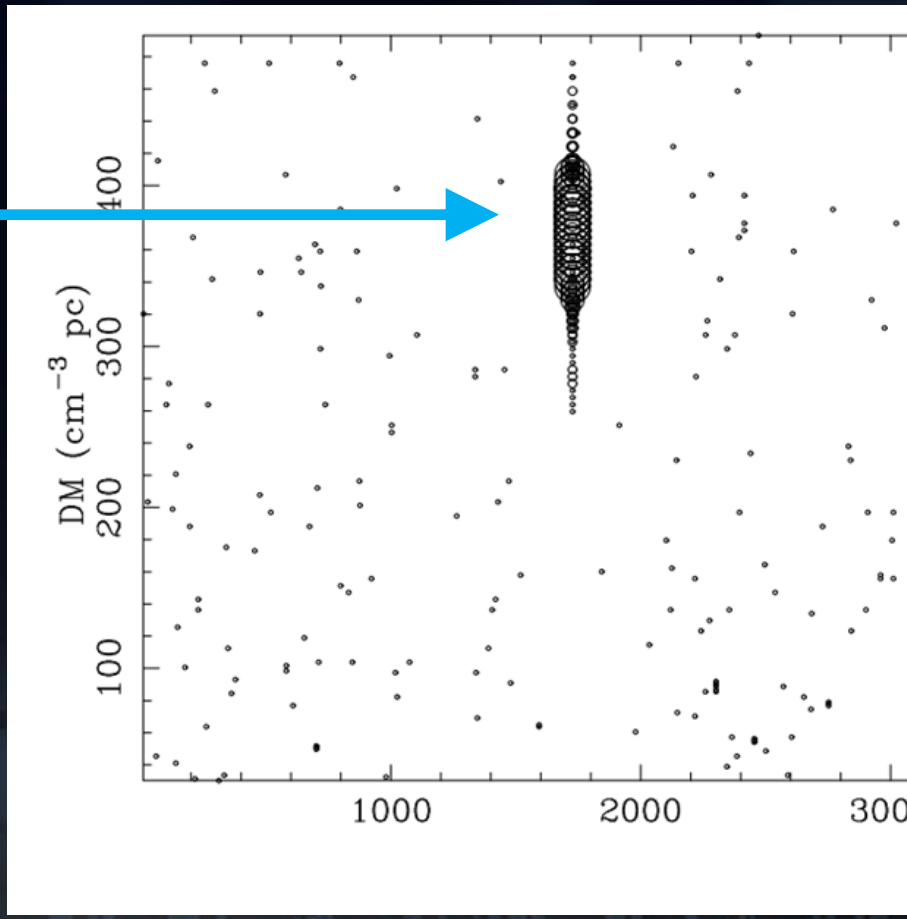


PULSAR PULSES

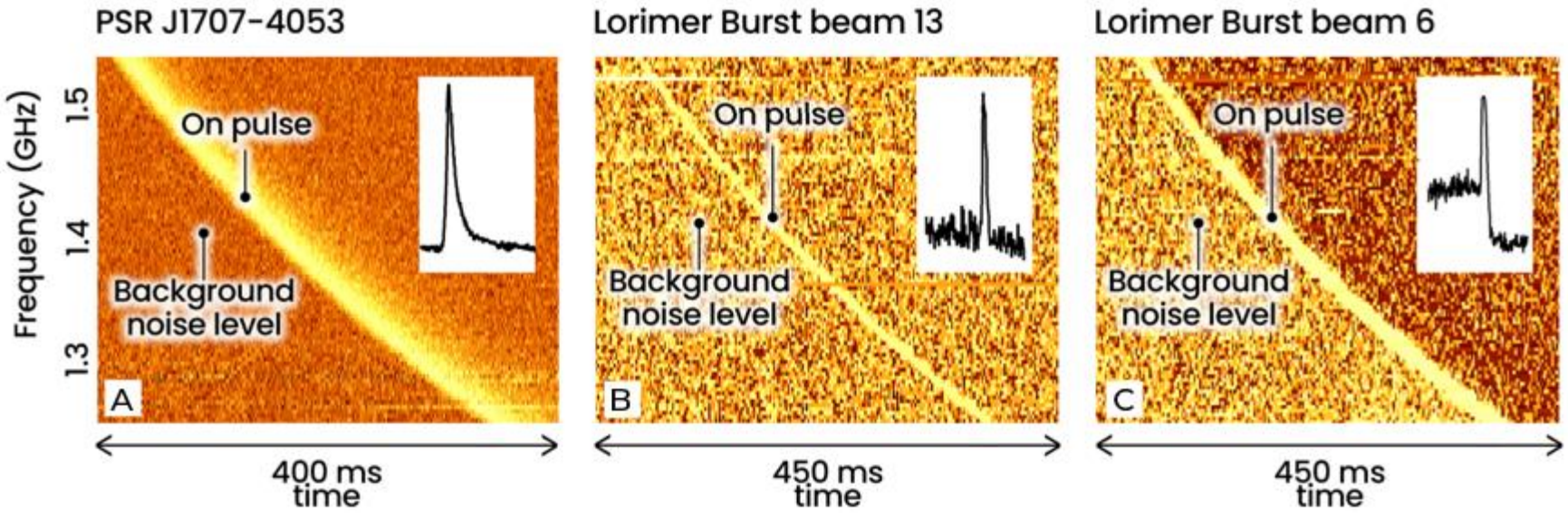
UNEXPECTED SIGNAL

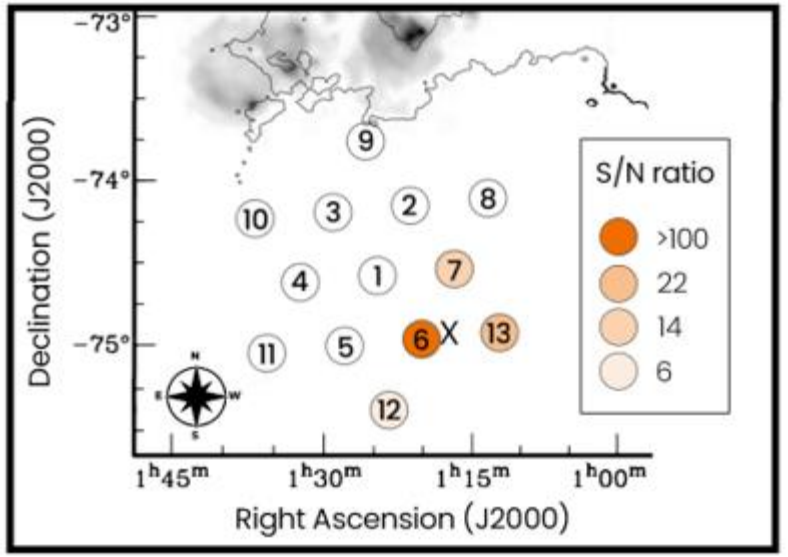
UNEXPECTED SKY POSITION





THE PARKES MULTIBEAM DETECTIONS WIDTH: 5 MS





DISTANCE ESTIMATED TO BE 3 BILLION LIGHT YEARS

HOST GALAXY

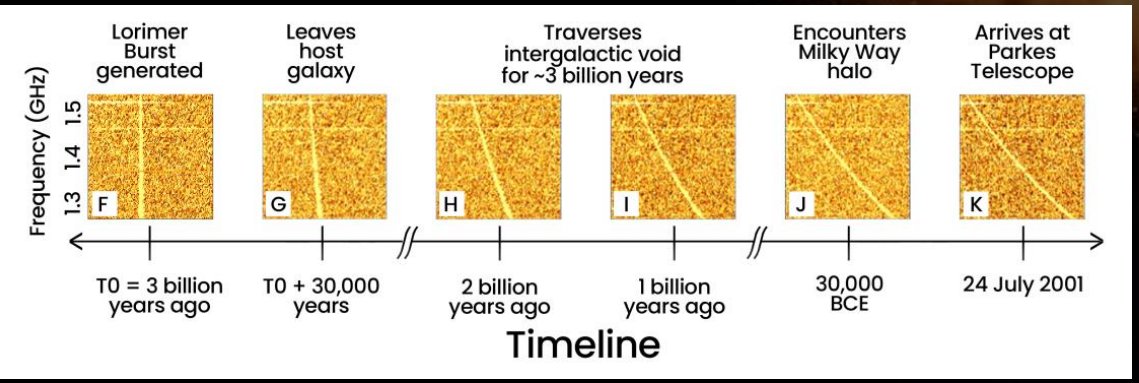
FRB

CIRCUMGALACTIC MEDIUM

DMSource + **DM**Host

DMIGM

MILKY WAY



DMMW HALO + **DM**MW ISM + **DM**IONOSPHERE

IMAGE INSPIRED BY: CALEB AND KEANE

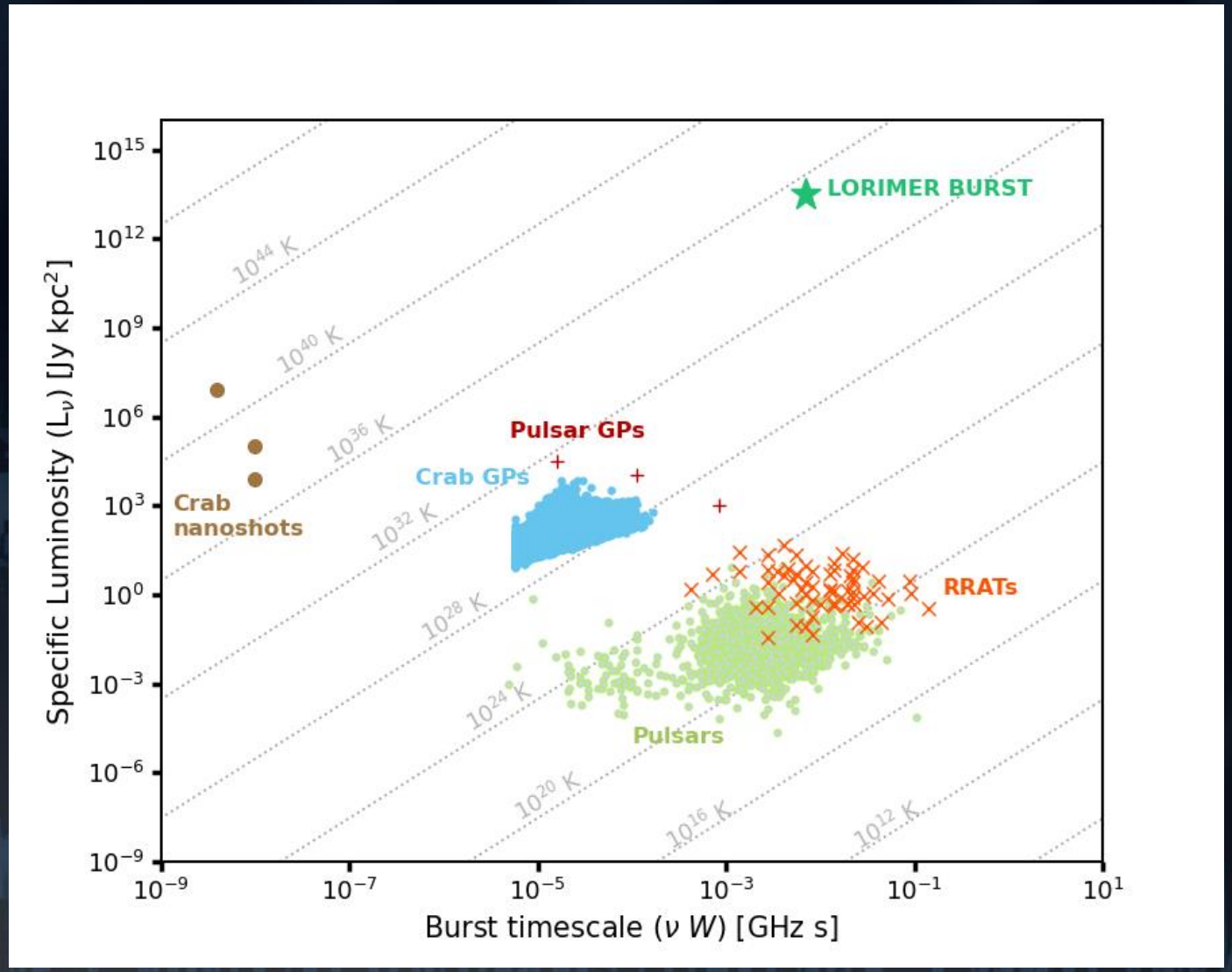
IMAGE CREDIT: NASA/ESA/HUBBLE

LUMINOSITY

- A TRILLION TIMES MORE LUMINOUS THAN PSRS

- ONE SOLAR LUMINOSITY FOR A MONTH IN 5 MS!
- NO REPEATS IN 90 HOURS

- *d* Log *N*/*d* log *S*????
- ONLY ONE EXAMPLE?
- A NEW CLASS OF OBJECT???



FROM THE ABSTRACT OF OUR (SCIENCE) PAPER

Abstract

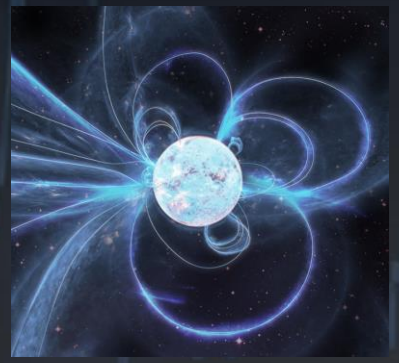
Pulsar surveys offer a rare opportunity to monitor the radio sky for impulsive burst-like events with millisecond durations. We analyzed archival survey data and found a 30-jansky dispersed burst, less than 5 milliseconds in duration, located 3° from the Small Magellanic Cloud. The burst properties argue against a physical association with our Galaxy or the Small Magellanic Cloud. Current models for the free electron content in the universe imply that the burst is less than 1 gigaparsec distant. No further bursts were seen in 90 hours of additional observations, which implies that it was a singular event such as a supernova or coalescence of relativistic objects. Hundreds of similar events could occur every day and, if detected, could serve as cosmological probes.

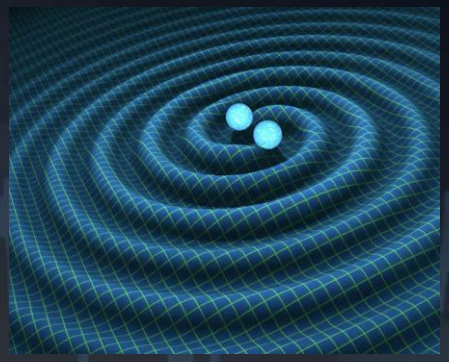
HOW MANY ARE WE MISSING?

WHAT WAS IT?

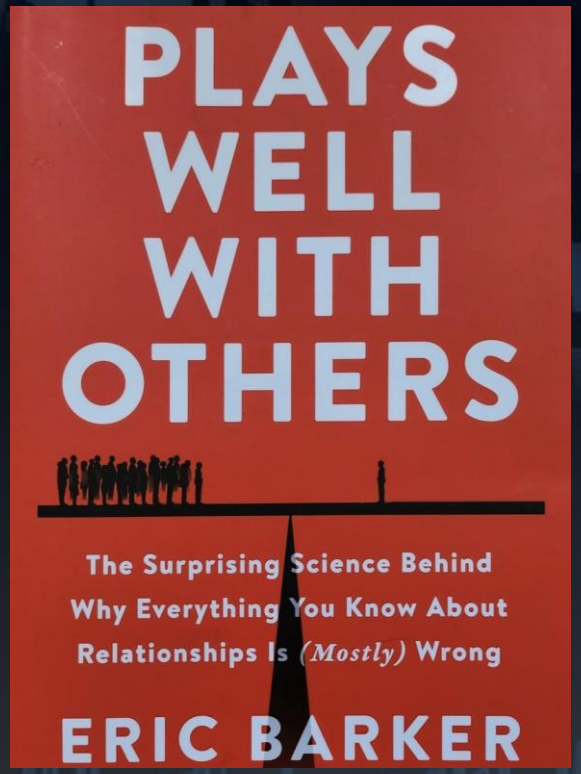
ENERGY WIDTH

SMALL/COHERENT
(MAYBE ONE-OFF?)





FAST RADIO BURSTS IN POP CULTURE



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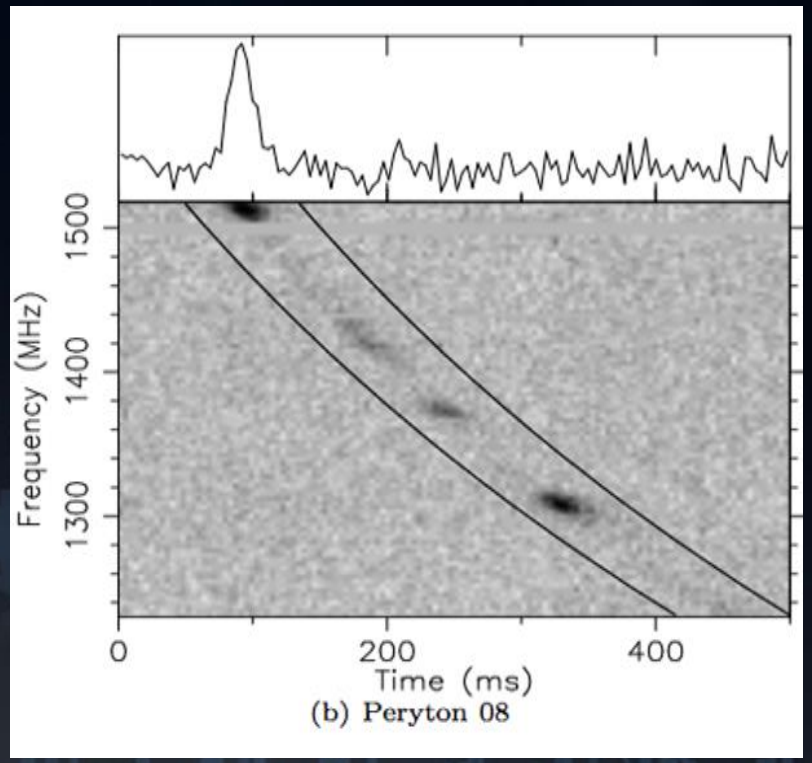
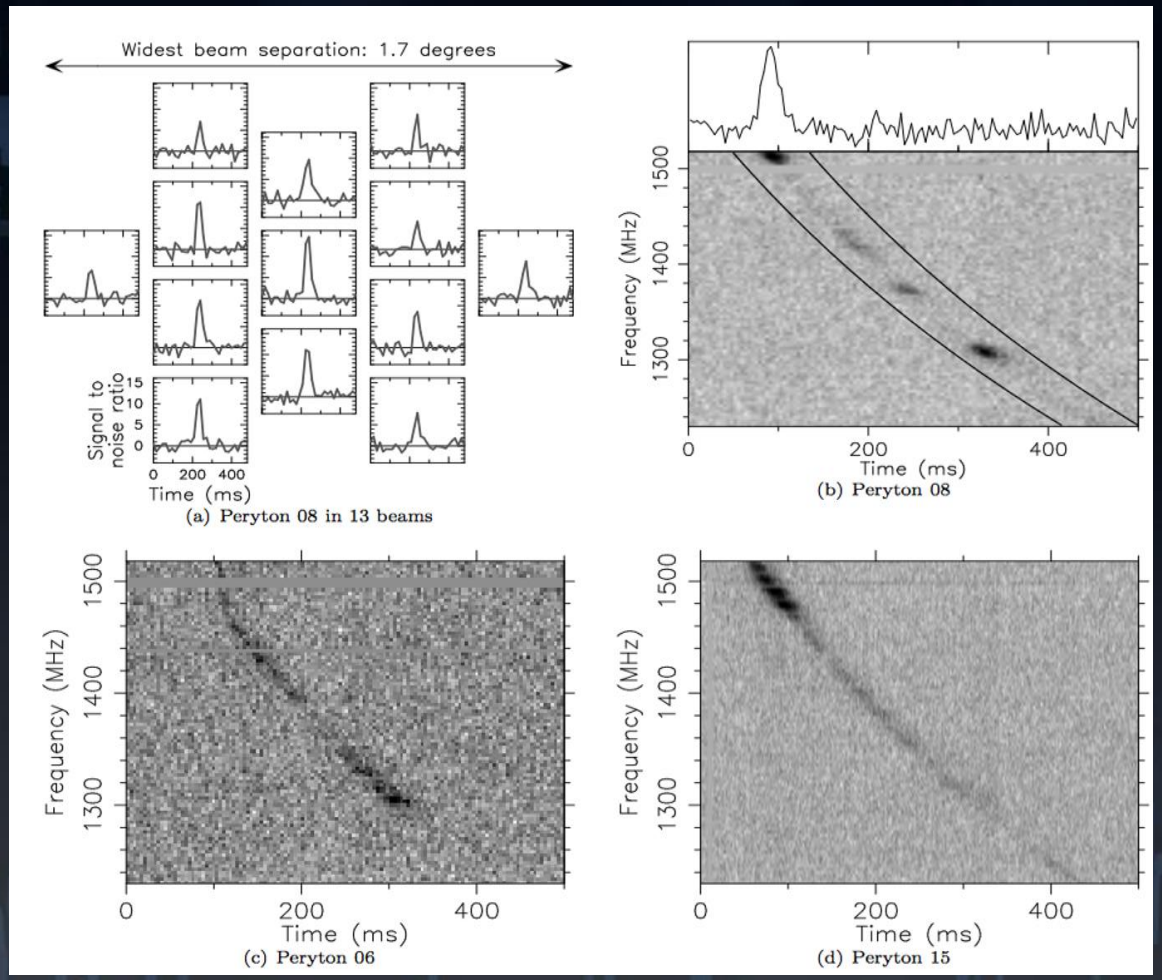
2007-2012: THE EARLY SEARCHES

- NO REPEATS FROM PARKES
- NO BURSTS FOUND
  FROM DEDICATED SURVEYS
- NO BURSTS IN OTHER ARCHIVAL SURVEYS
- DISCOVERY OF “THE PERYTONS”
  SARAH BURKE-SPOLAOR



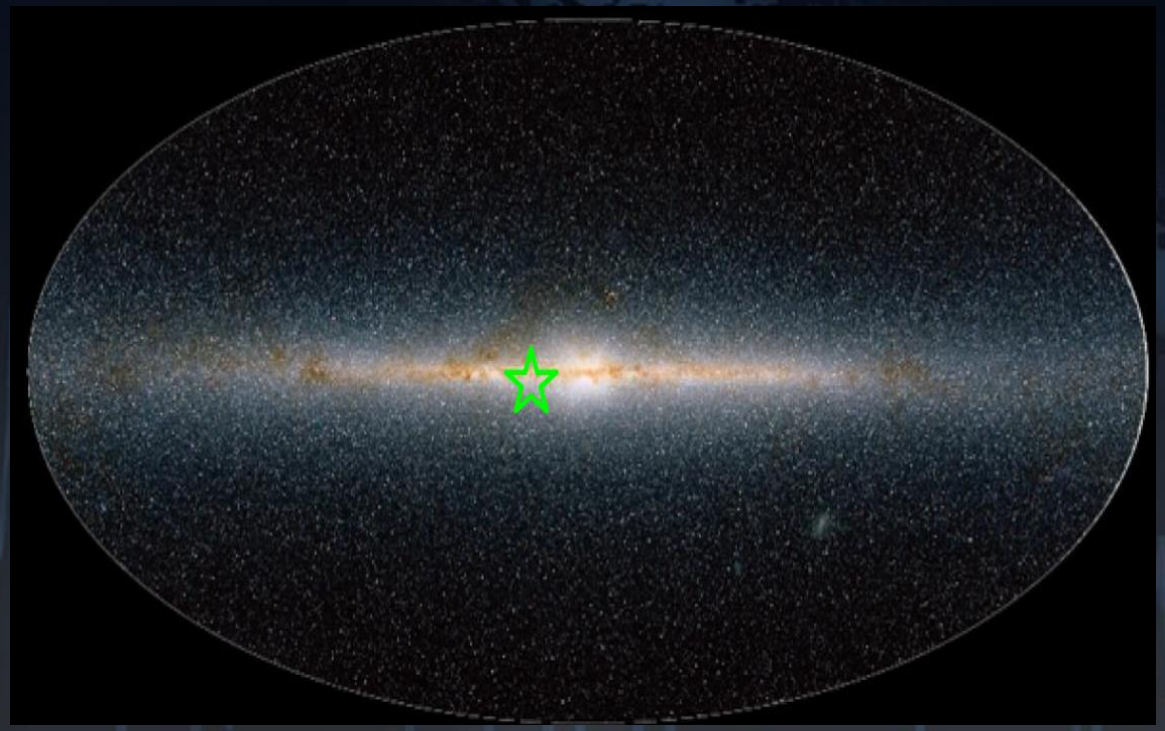
EXAMPLE PERYTONS:

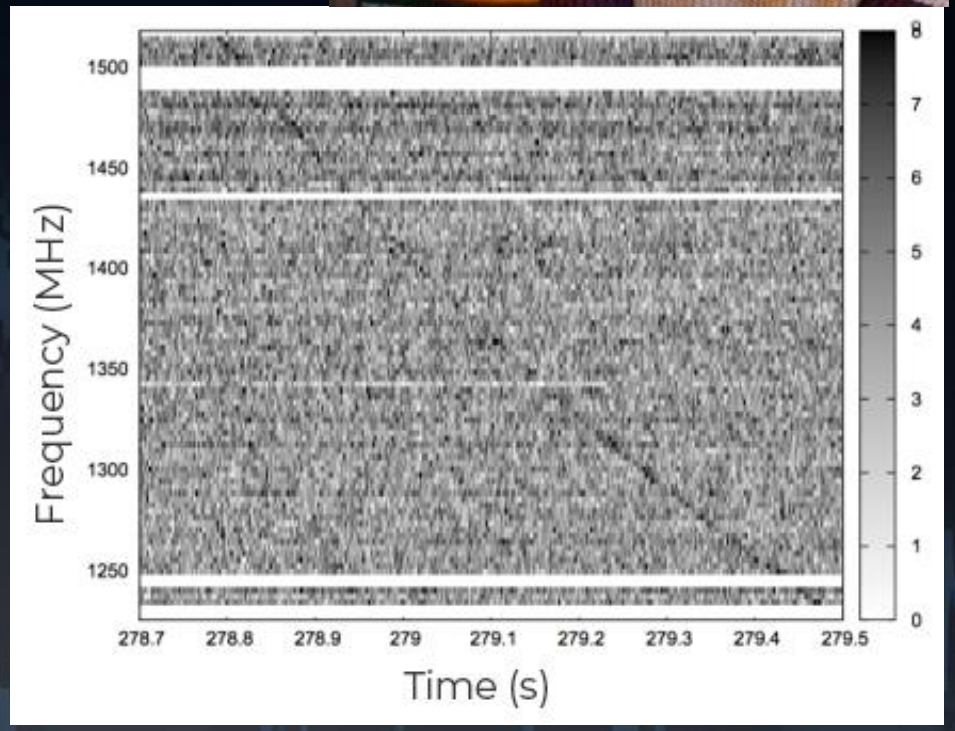


2012: THE “KEANE BURST”

DM = 746 PC/CC

NEAR THE GALACTIC PLANE?



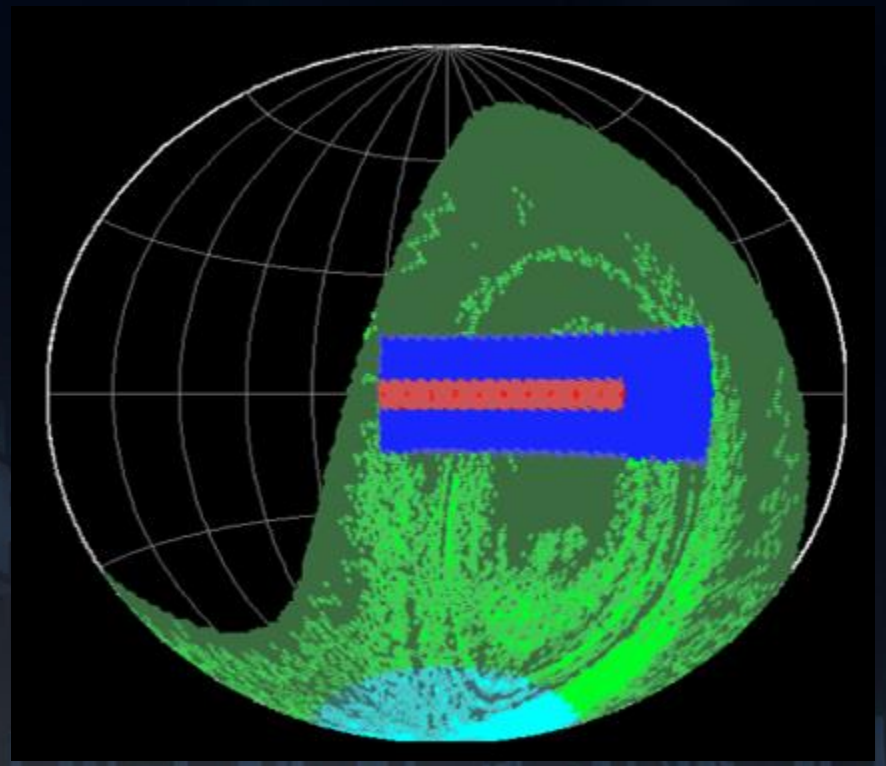


THE HIGH TIME RESOLUTION UNIVERSE SURVEYS

KEITH ET AL. (2012)

- NEW “DIGITAL FILTERBANKS
  A LOT LESS SMEARING
- GREATER “SENSITIVITY”

- DAN THORNTON ASSIGNED
THE “LORIMER BURST SEARCH”



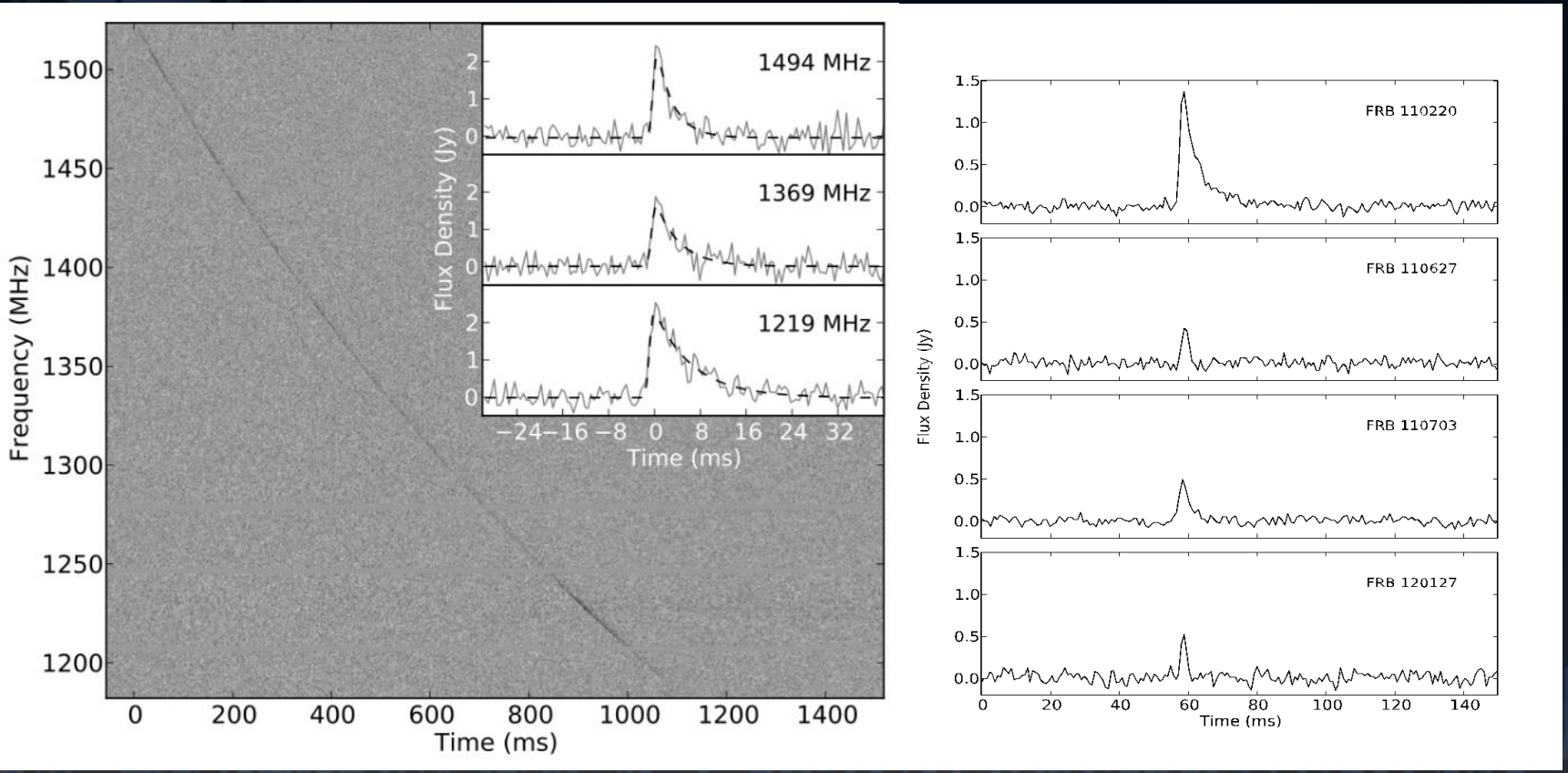
2013: THE THORNTON BURSTS

A Population of Fast Radio Bursts at Cosmological Distances

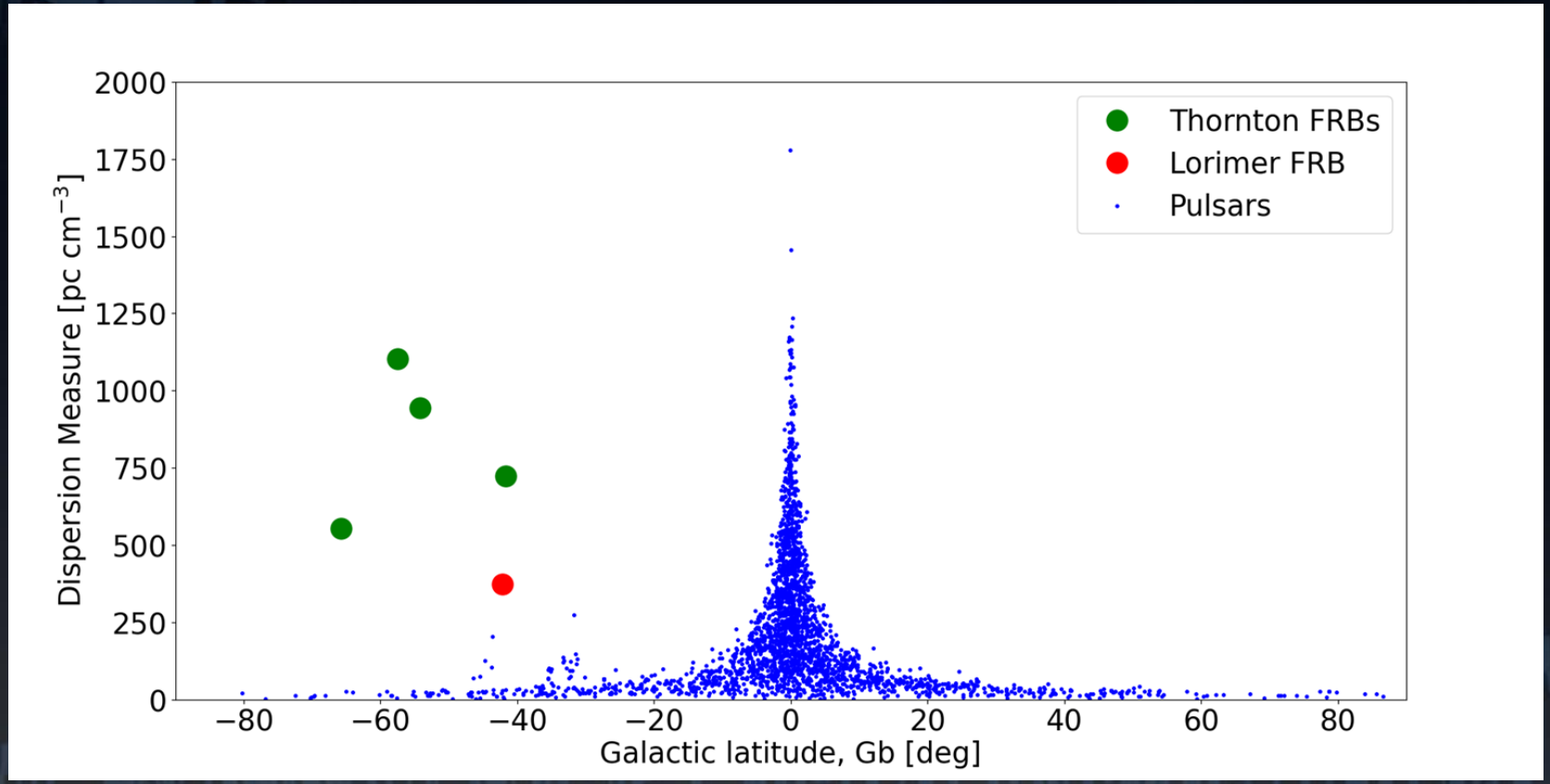
D. Thornton,[1,2*] B. Stappers,[1] M. Bailes,[3,4] B. Barsdell,[3,4] S. Bates,[5] N. D. R. Bhat,[3,4,6] M. Burgay,[7] S. Burke-Spolaor,[8] D. Champion,[9] P. Coster,[2,3] N. D'Amico,[7,10] A. Jameson,[3,4] S. Johnston,[2] M. Keith,[2] M. Kramer,[9,1] L. Levin,[5] S. Milia,[7] C. Ng,[9] A. Possenti,[7] W. van Straten[3,4]

Searches for transient astrophysical sources often reveal unexpected classes of objects that are useful physical laboratories. In a recent survey for pulsars and fast transients, we have uncovered four millisecond-duration radio transients all more than 40° from the Galactic plane. The bursts' properties indicate that they are of celestial rather than terrestrial origin. Host galaxy and intergalactic medium models suggest that they have cosmological redshifts of 0.5 to 1 and distances of up to 3 gigaparsecs. No temporally coincident e- or gamma-ray signature was identified in association with the bursts. Characterization of the source population and identification of host galaxies offers an opportunity to determine the baryonic content of the universe.

FRB 110220: DM=995 PC CM^{-3}



LOCATIONS OF THE THORNTON BURSTS



FRB 121102

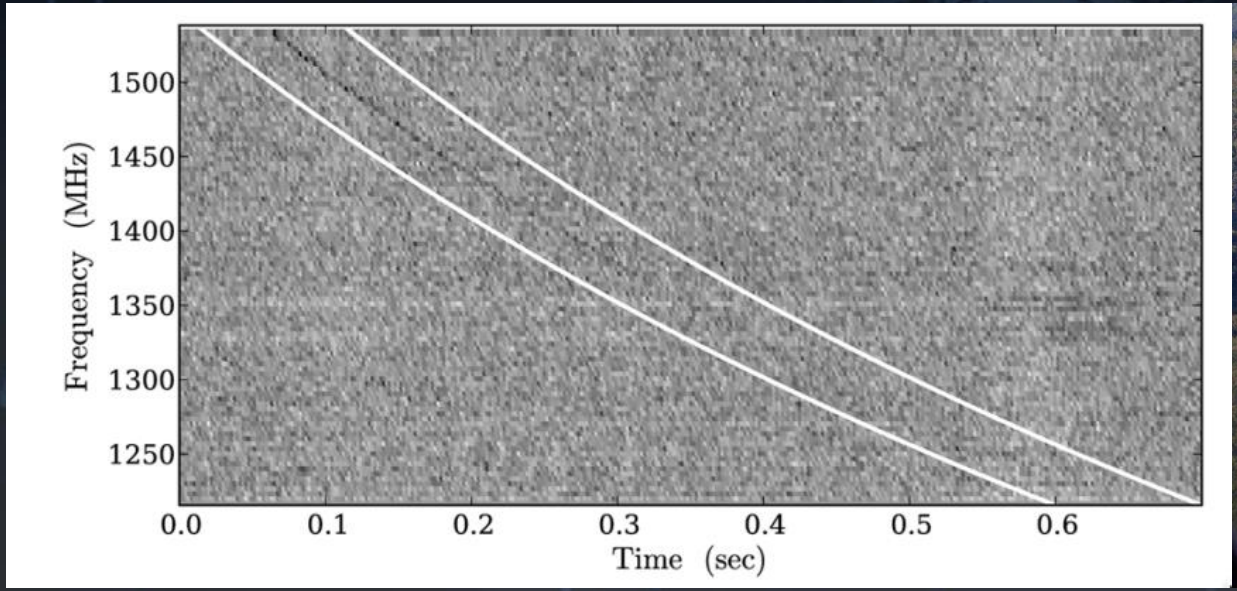
ARECIBO'S FIRST FRB (FOUND BY LAURA SPITLER)

FAST RADIO BURST DISCOVERED IN THE ARECIBO PULSAR ALFA SURVEY

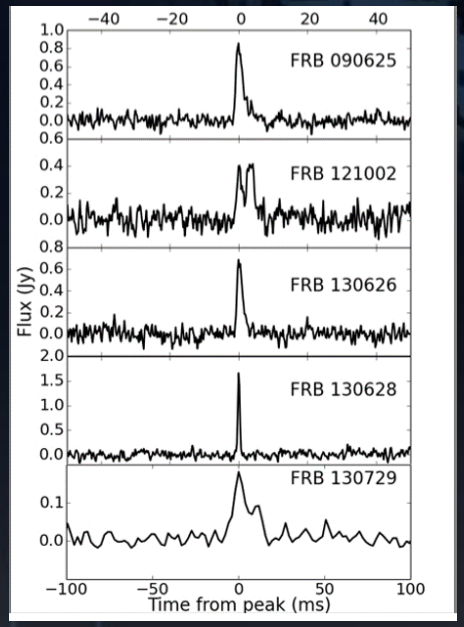
L. G. Spitler[1], J. M. Cordes[2], J. W. T. Hessels[3,4], D. R. Lorimer[5], M. A. McLaughlin[5], S. Chatterjee[2], F. Crawford[6], J. S. Deneva[7], V. M. Kaspi[8], R. S. Wharton[2], B. Allen[9,10,11], S. Bogdanov[12], A. Brazier[2], F. Camilo[12,13], P. C. C. Freire[1], F. A. Jenet[14], C. Karako–Argaman[8], B. Knispel[10,11], P. Lazarus[1], K. J. Lee[15,1], J. van Leeuwen[3,4], R. Lynch[8], A. G. Lyne[16], S. M. Ransom[17], P. Scholz[8], X. Siemens[9], I. H. Stairs[18], K. Stovall[19], J. K. Swiggum[5], A. Venkataraman[13], W. W. Zhu[18], C. Aulbert[11], H. Fehrmann[11]

- DM=557 PC CM^{-3}

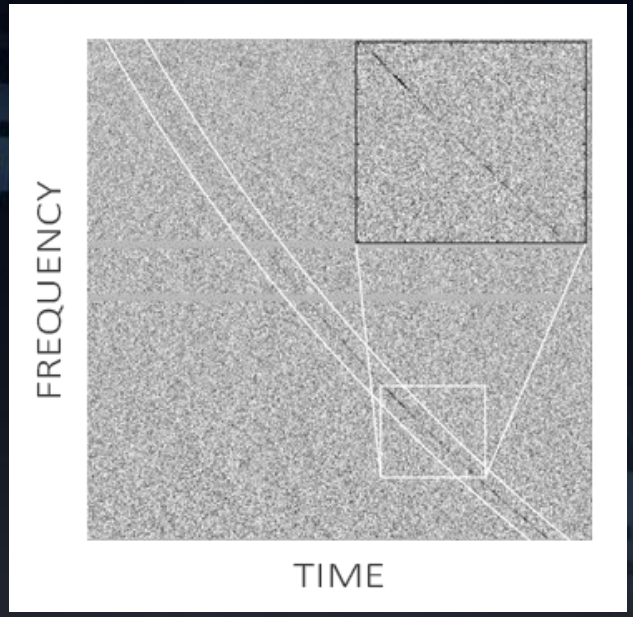
- GALACTIC ANTI-CENTRE



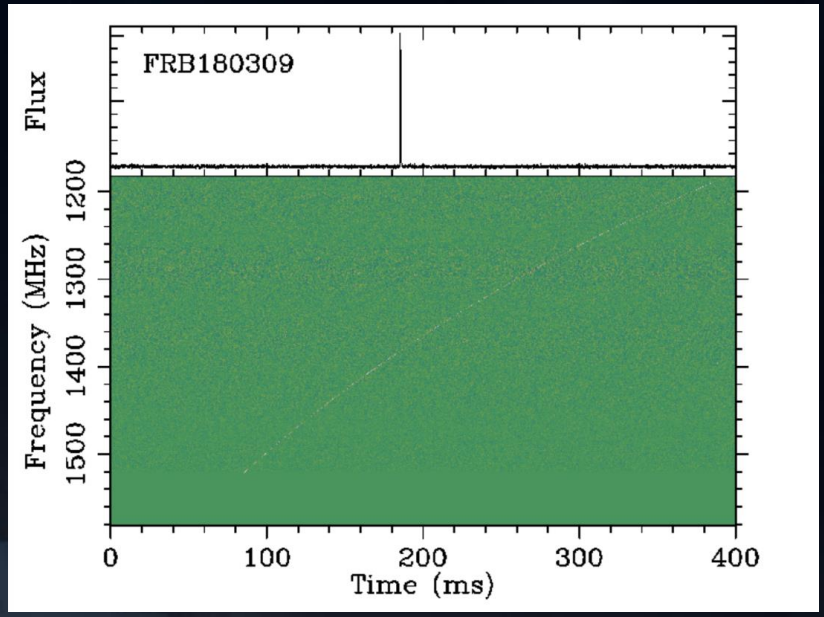
MORE BURSTS



CHAMPION ET AL. 2016
5 NEW FRBS
DMS 469 TO 1629 PC/CC
FIRST "TWO-COMPONENT" BURST



MASUI ET AL. 2015
A GBT BURST:
HIGHLY MAGNETIC

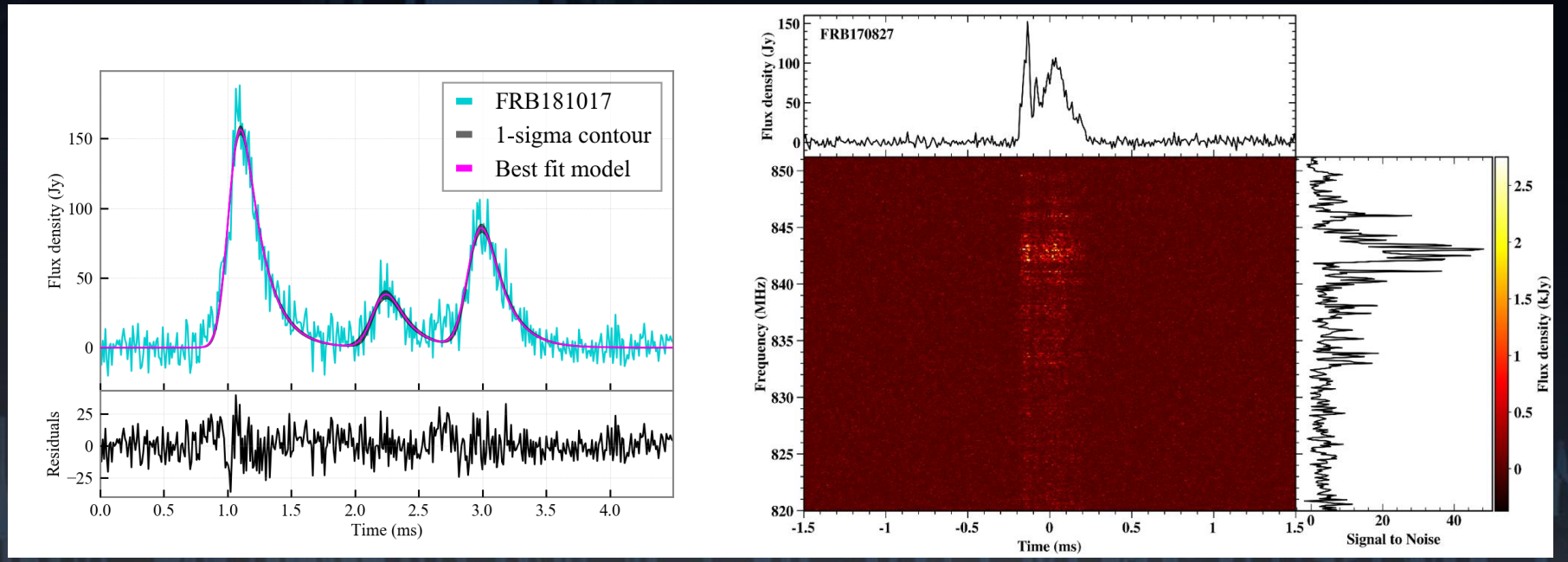


AGGARWAL ET AL. 2021
A SUPER-BRIGHT
PARKES BURST

FRB FINE STRUCTURE

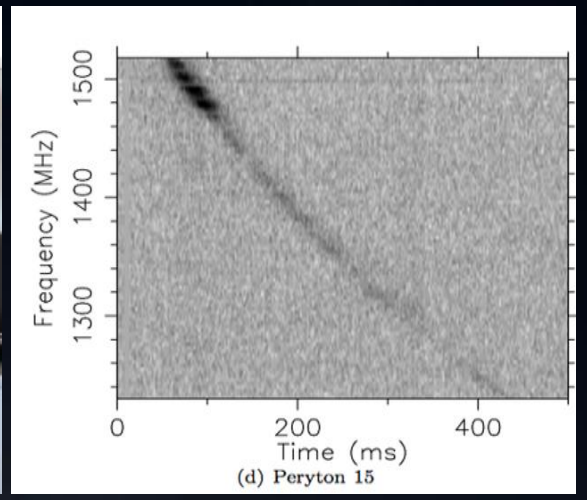
FEW 10S OF MICROSECONDS

MULTIPLE COMPONENTS?



FARAH ET AL. (2018, 2019)

FINALLY. THE CAUSE OF THE PERYTONS



(d) Peryton 15

TALK OUTLINE

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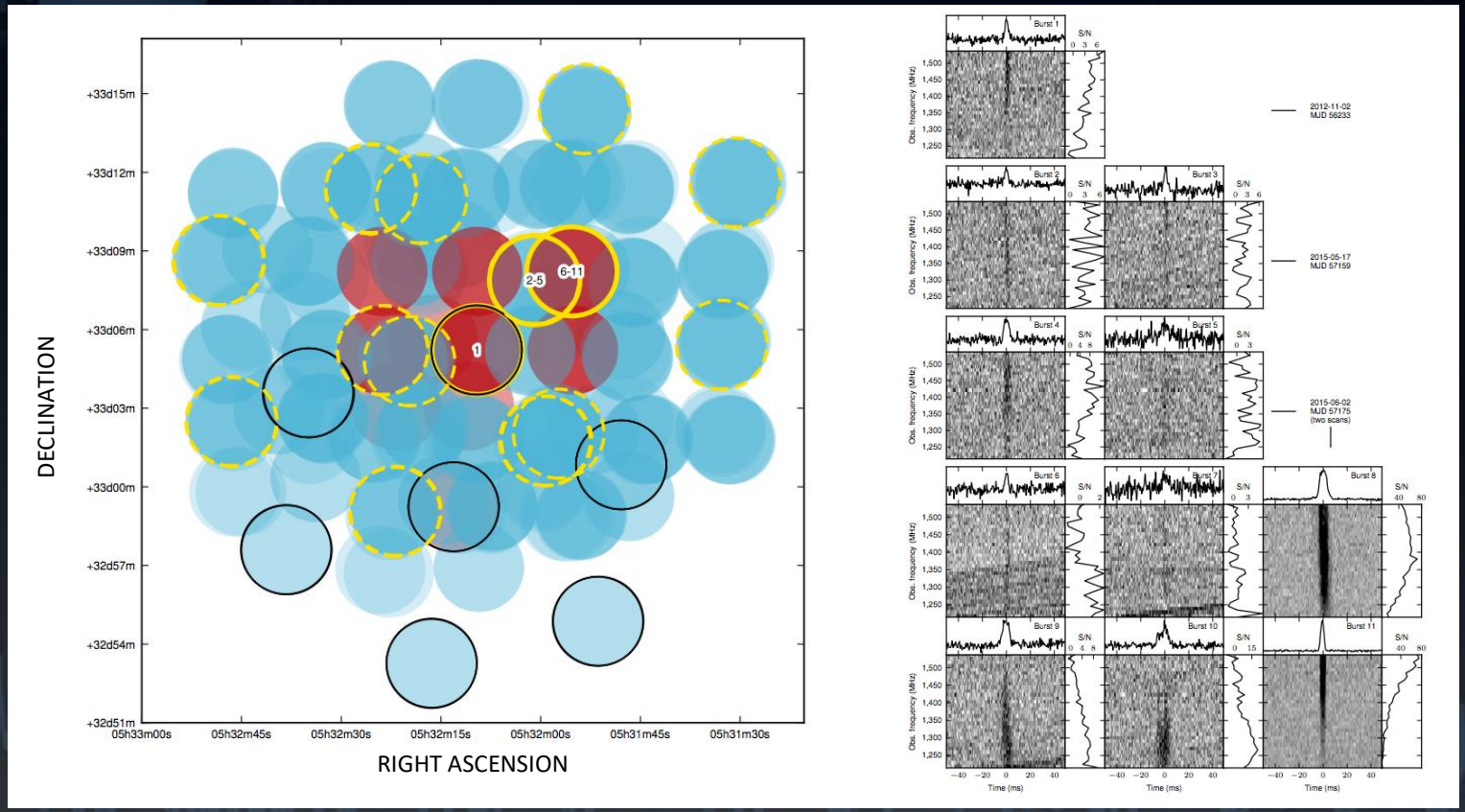
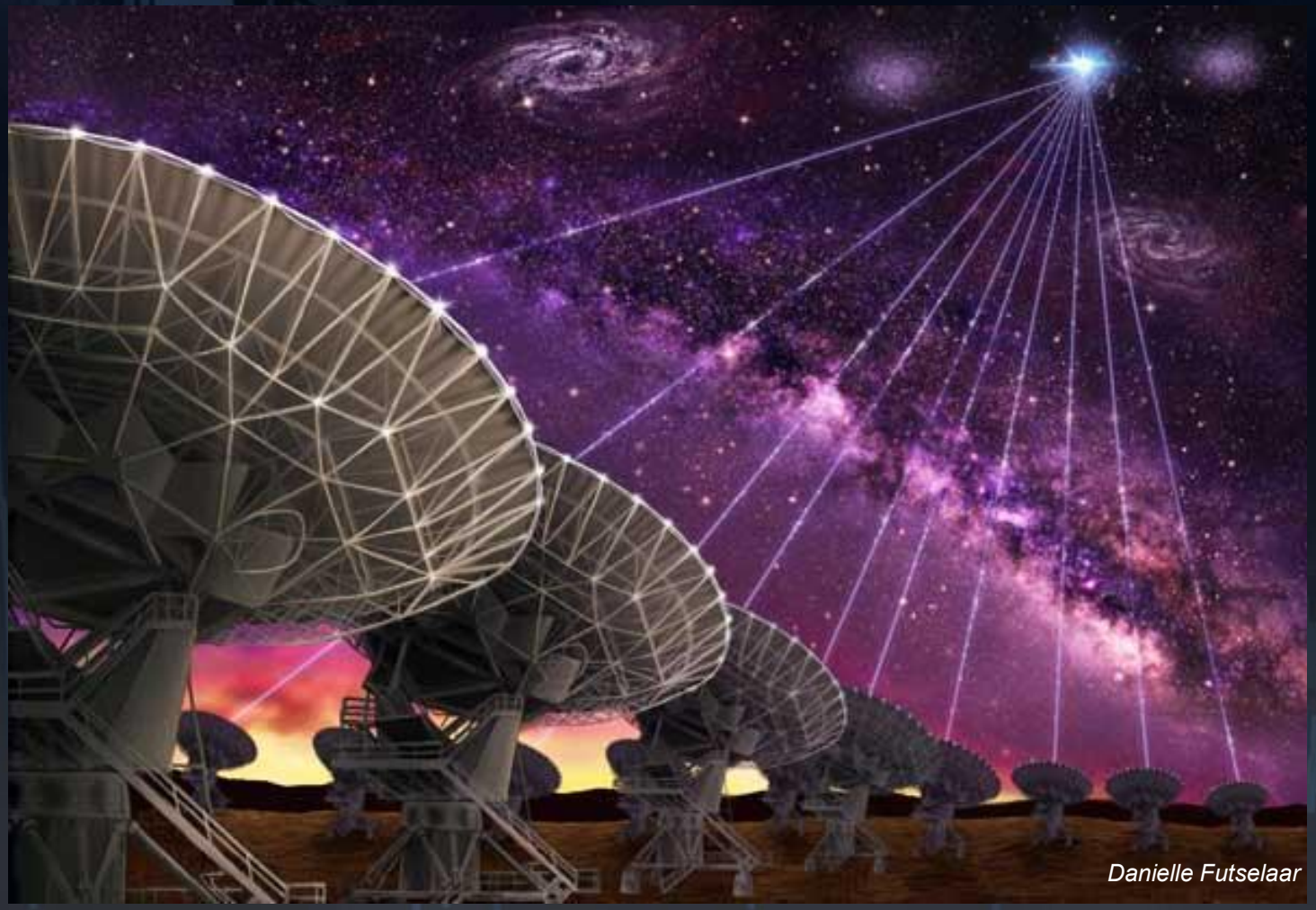
“A MINOR POINT OF INTEREST”

FRB 121102 REPEATS



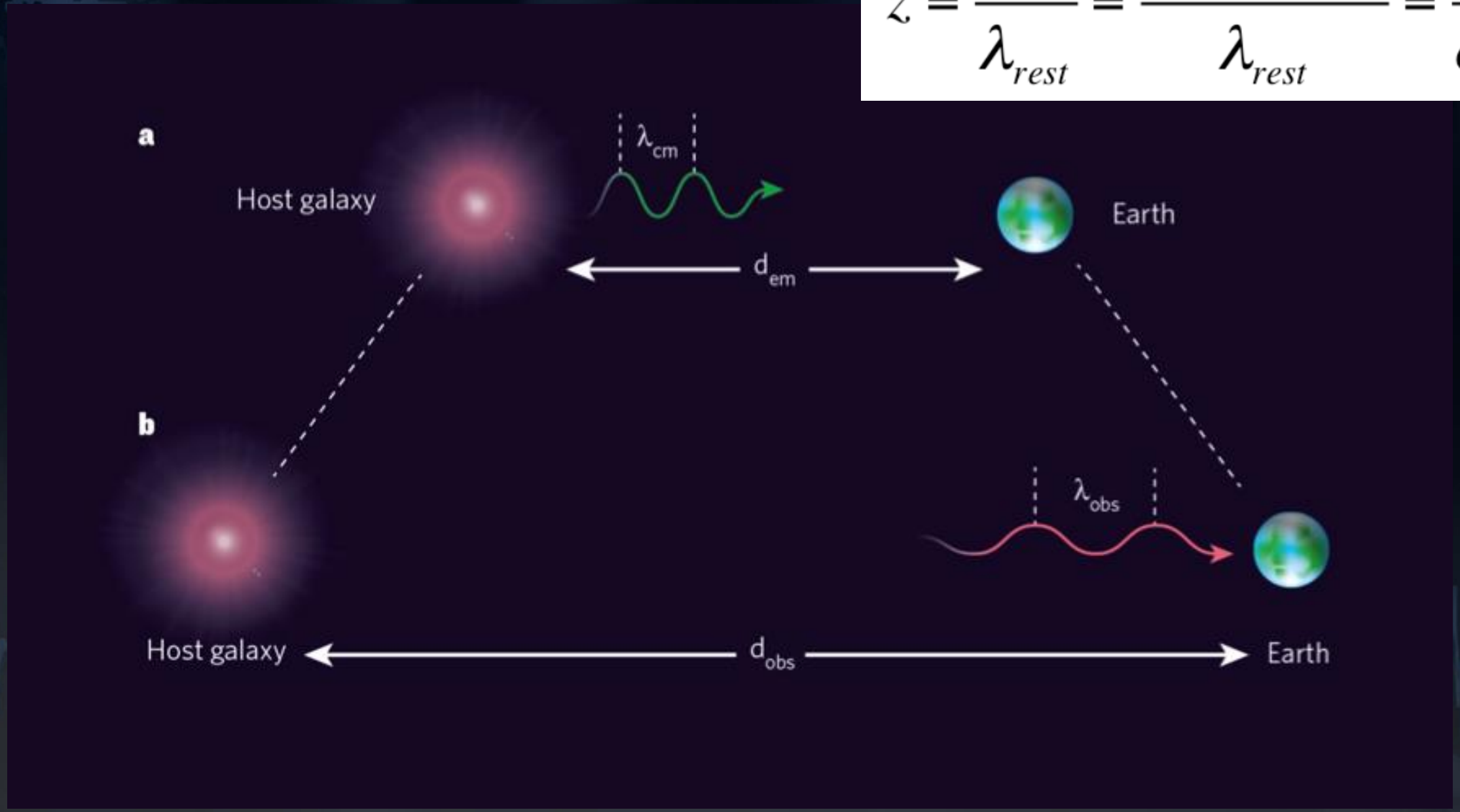
AND WE LOCATED THE GALAXY IT CAME FROM!



SHAMI CHATTERJEE

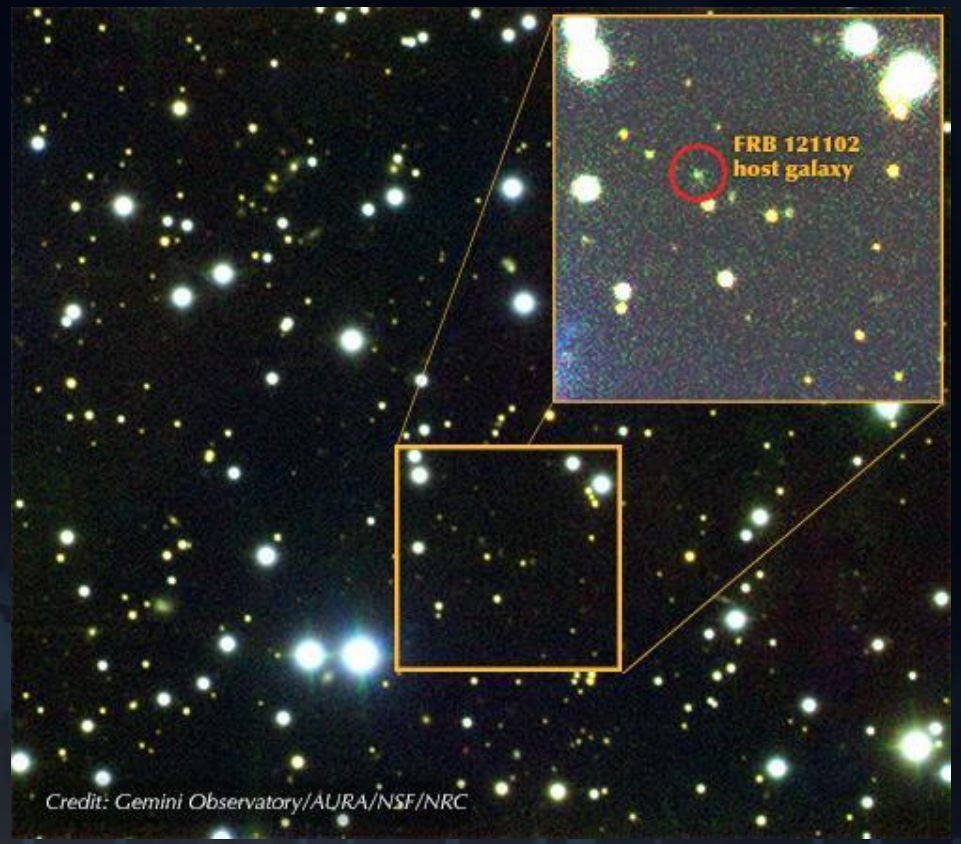
COSMOLOGICAL REDSHIFT

$$z = \frac{\Delta\lambda}{\lambda_{rest}} = \frac{\lambda_{obs} - \lambda_{rest}}{\lambda_{rest}} = \frac{v}{c}$$



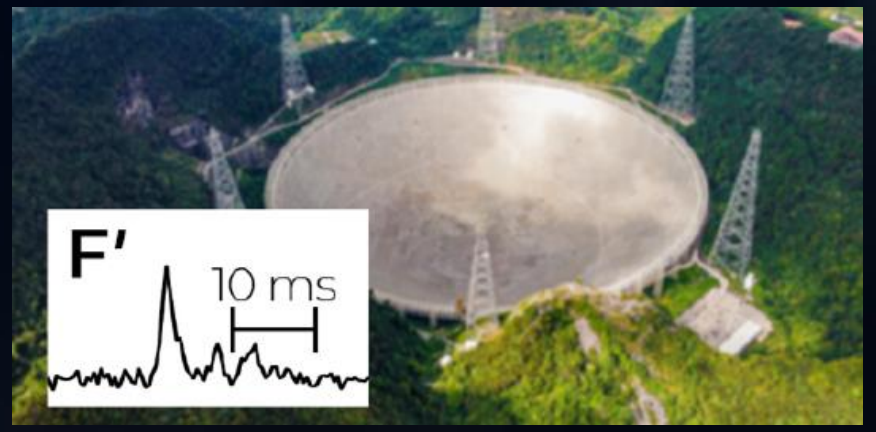
THE HOST GALAXY

- REDSHIFT = 0.19273(8)
  - FRBS ARE COSMOLOGICAL
- DISTANCE OF 3 BILLION LIGHT YEARS
- GALAXY ONLY 50 MILLION SOLAR MASSES
  - OVER 10,000 TIMES SMALLER THAN MILKY WAY!
- HUGE ROTATION MEASURE (MAGNETISM)
  - ~100,000 RAD M^{-2}
- VERY HIGH STAR FORMATION RATE



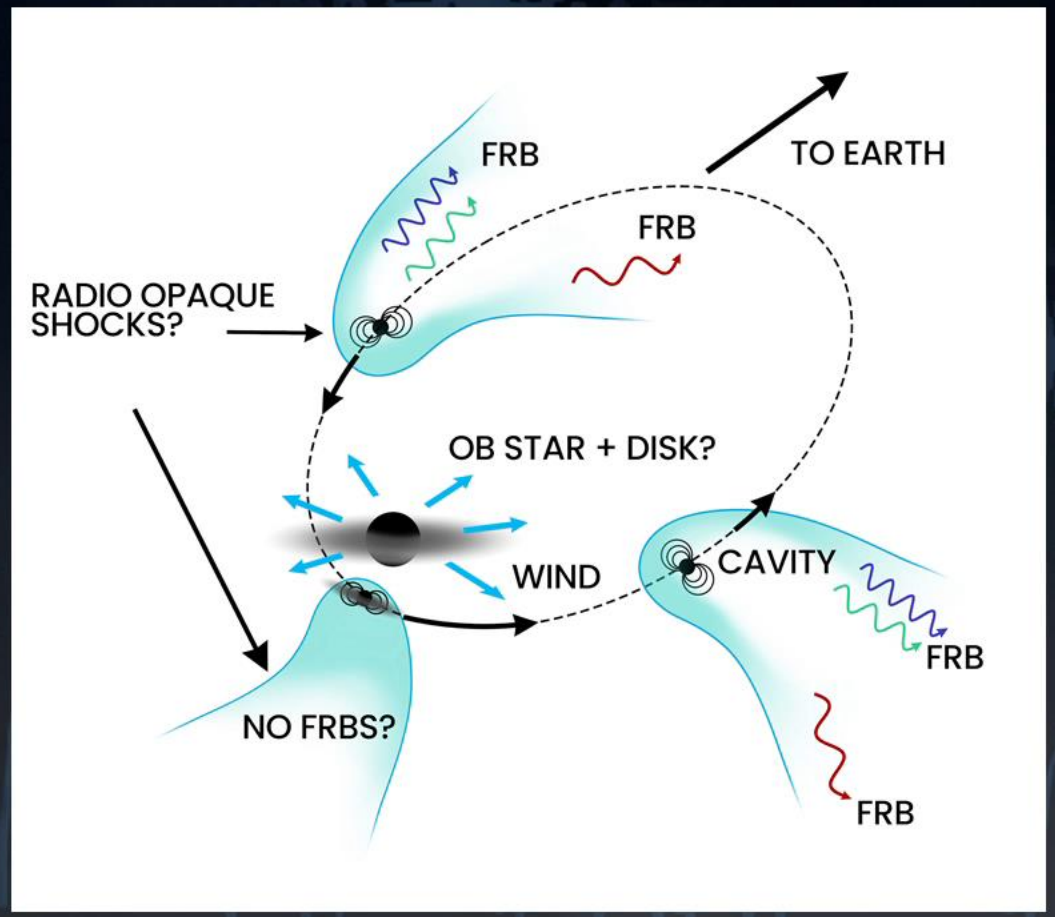
REPEATS ARE “SEASONAL”?

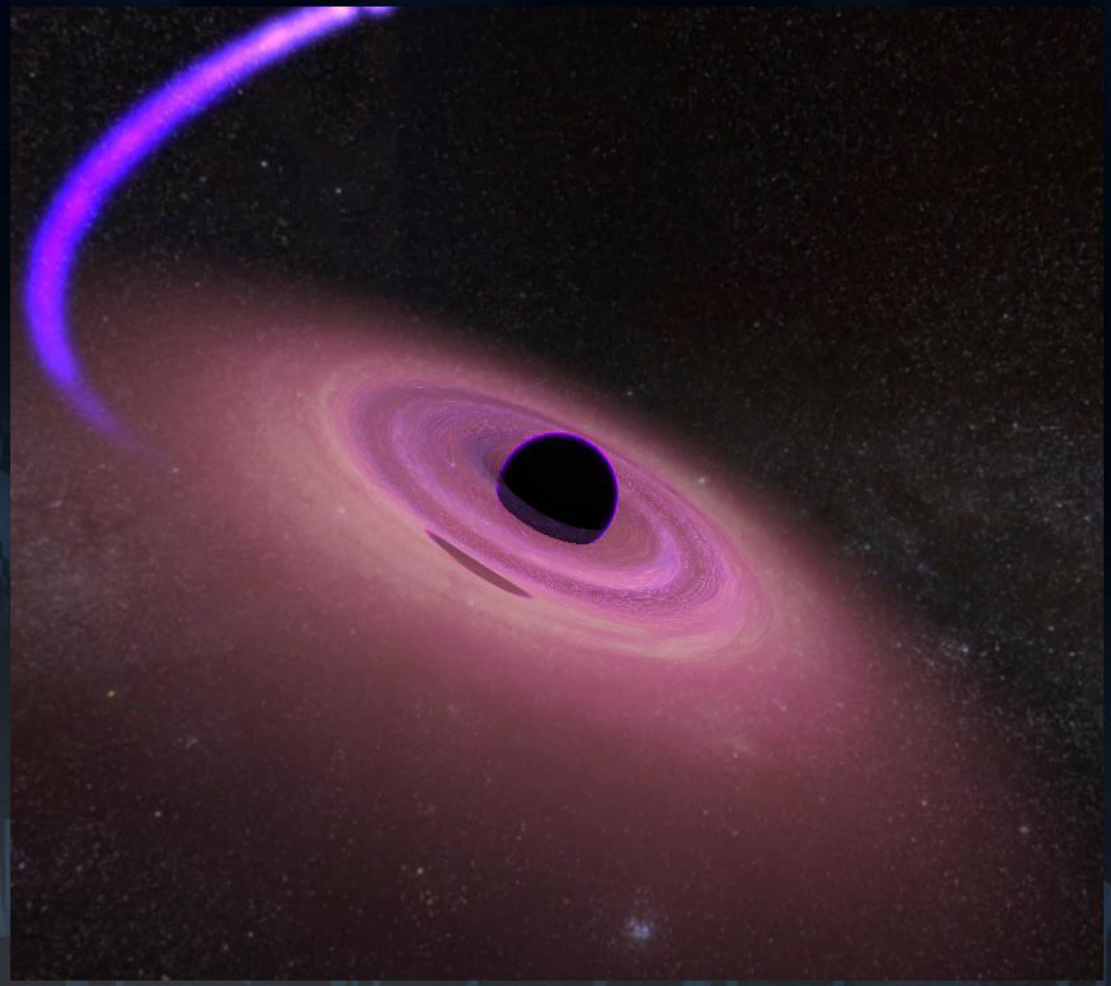
FRB 180916.J0158+65: P=16.35 DAYS
CHIME COLLABORATION (2020)
FRB 121102: P= 157 DAYS
RAJWADE ET AL. (2020)



- REPEATERS SEEM “BROADER”
- EXHIBIT DRIFTING BEHAVIOUR
  LIKE SOLAR BURSTS
- FAST 500M DETECTS 1652 BURSTS FROM ORIGINAL REPEATER

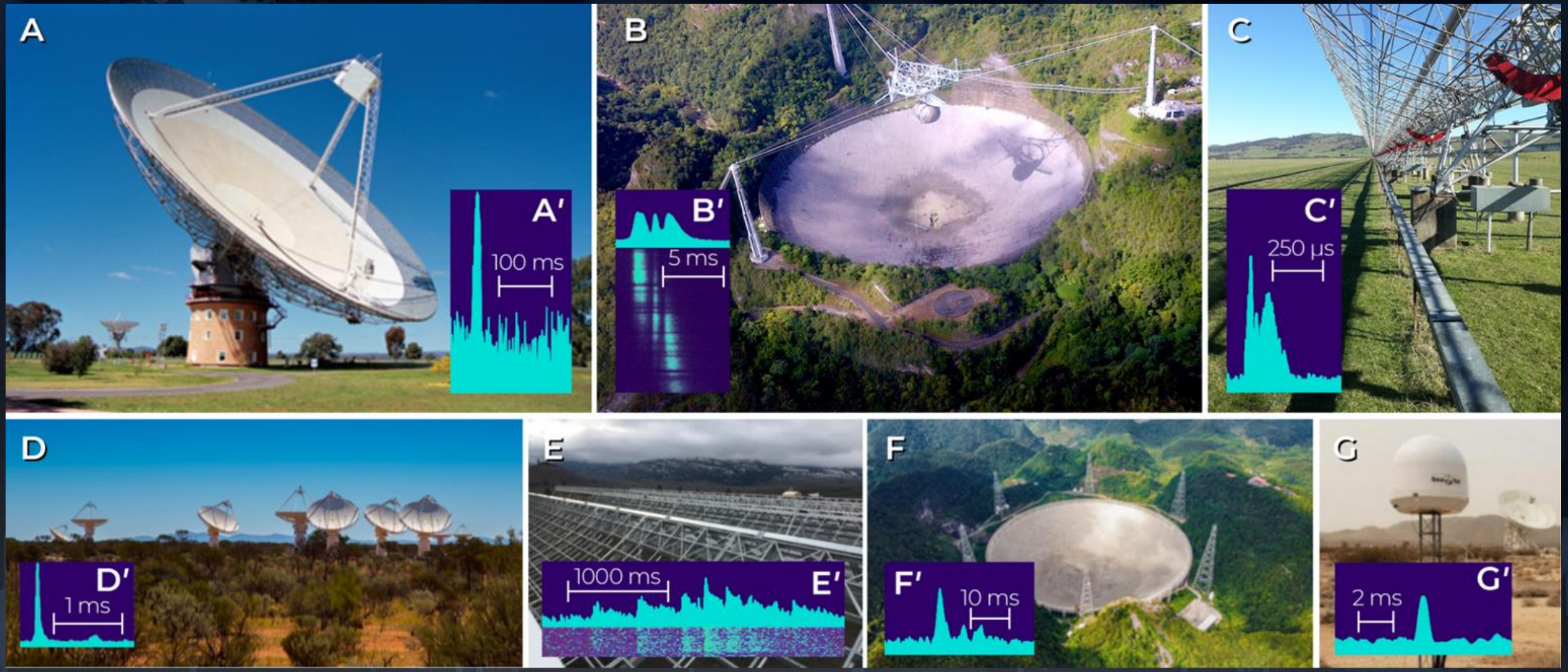
BINARY REPEATER MODEL





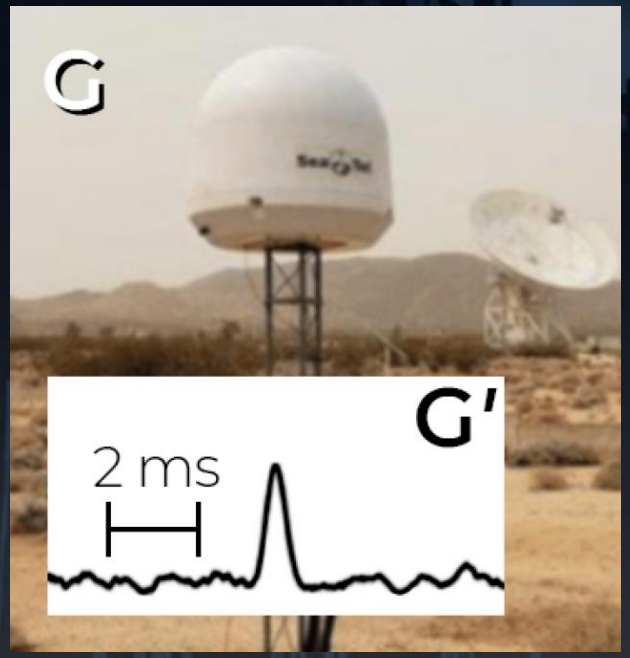
SOME OF OUR FAVOURITE DISHES

FRBs BEING FOUND BY RADIO TELESCOPES OF ALL SHAPES AND SIZES

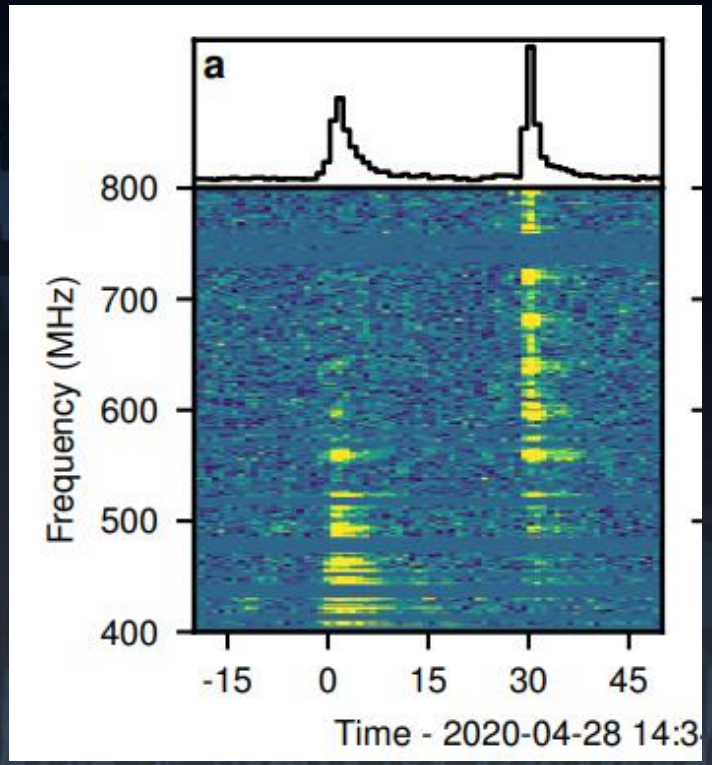


AN FRB FROM A MAGNETAR IN OUR GALAXY

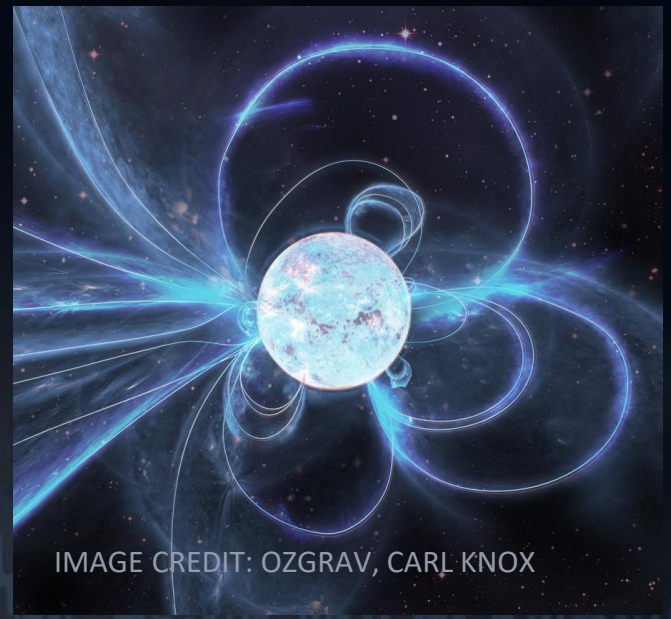
MAGNETARS ARE NEUTRON STARS WITH VERY HIGH MAGNETIC FIELDS, 1000 TIMES HIGHER THAN PULSARS!



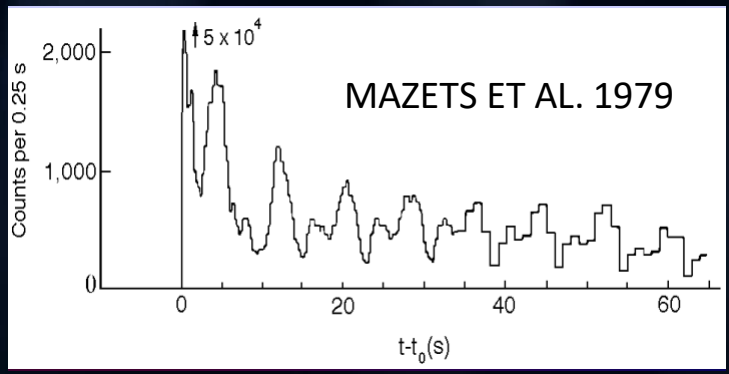
STARE: WORLD'S SMALLEST FRB DETECTOR

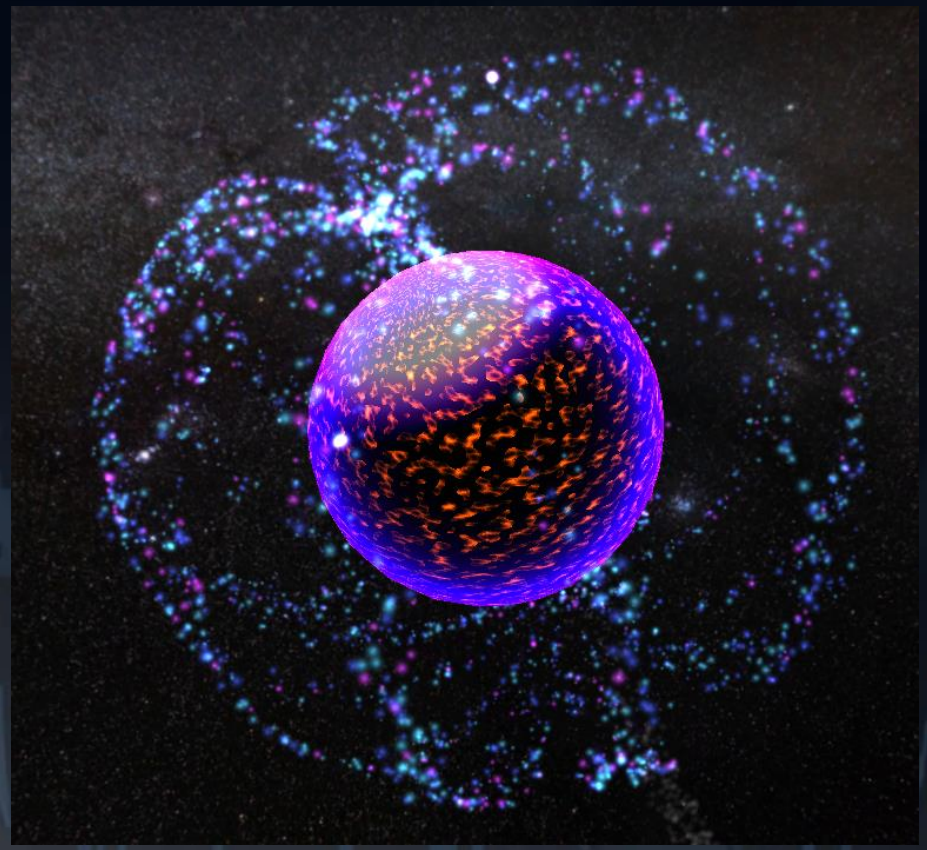


CHIME DETECTION



MAGNETARS ARE IMPORTANT





VICKY KASPI CHRYSSA KOUVELIOTOU

2021 SHAW ASTRONOMY LAUREATES

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CHIME FINDS FRBS ALMOST EVERY DAY,

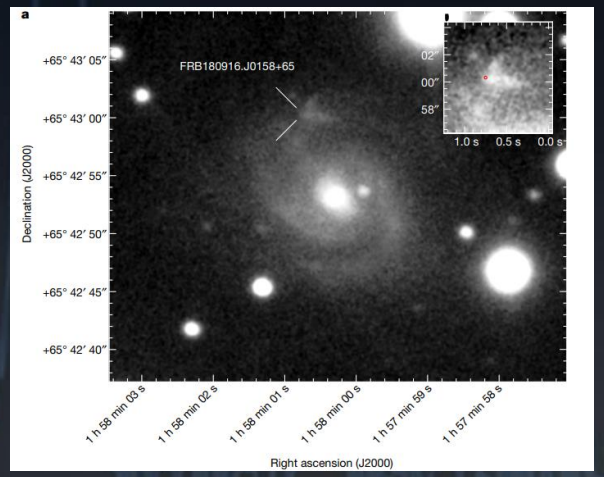
LOTS OF REPEATERS

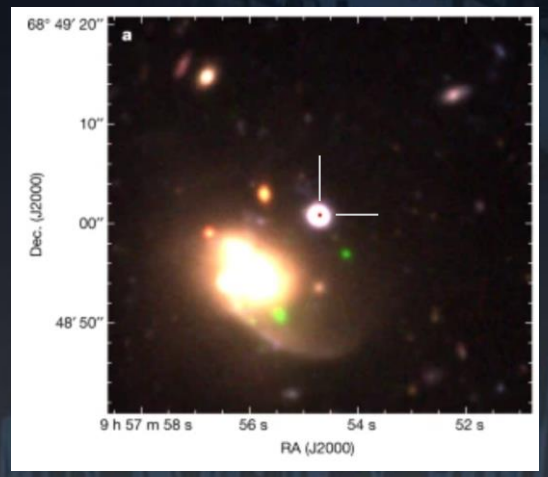
- ONE IS IN A NEARBY SPIRAL

  “ONLY” 170 Mpc AWAY, z = 0.0337

- ONE IS IN A GLOBULAR CLUSTER IN M81

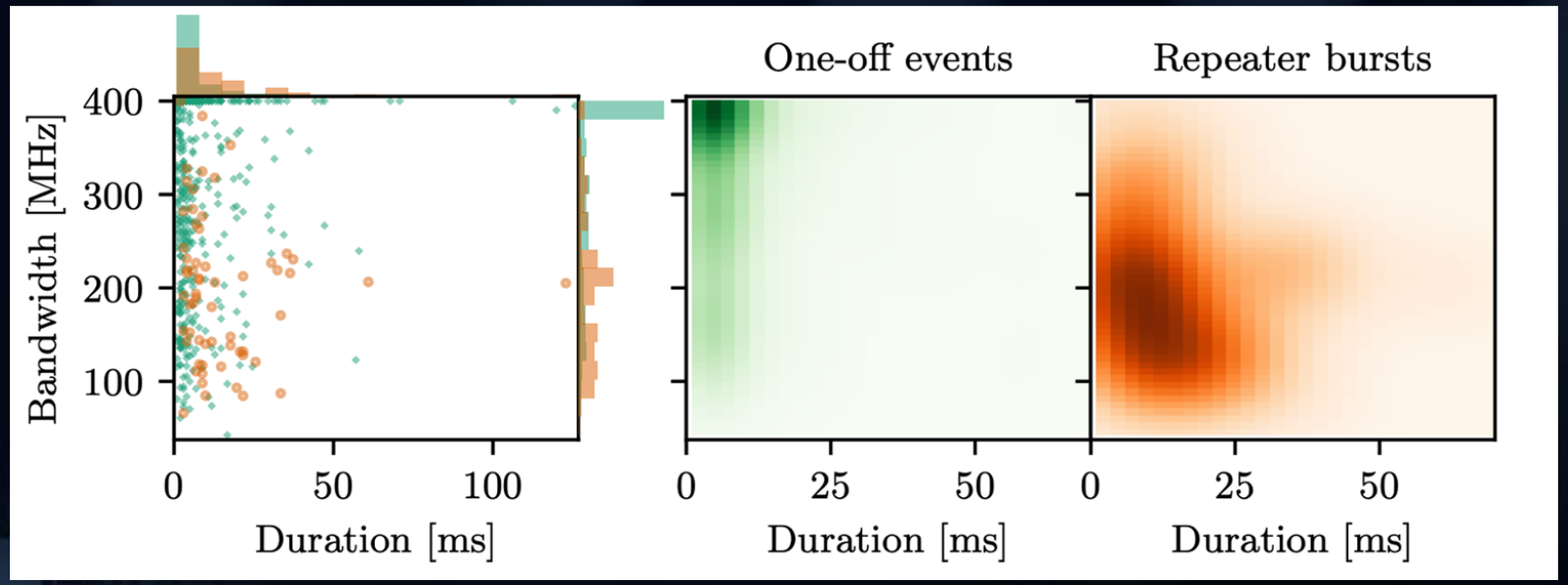
  3.6 Mpc AWAY

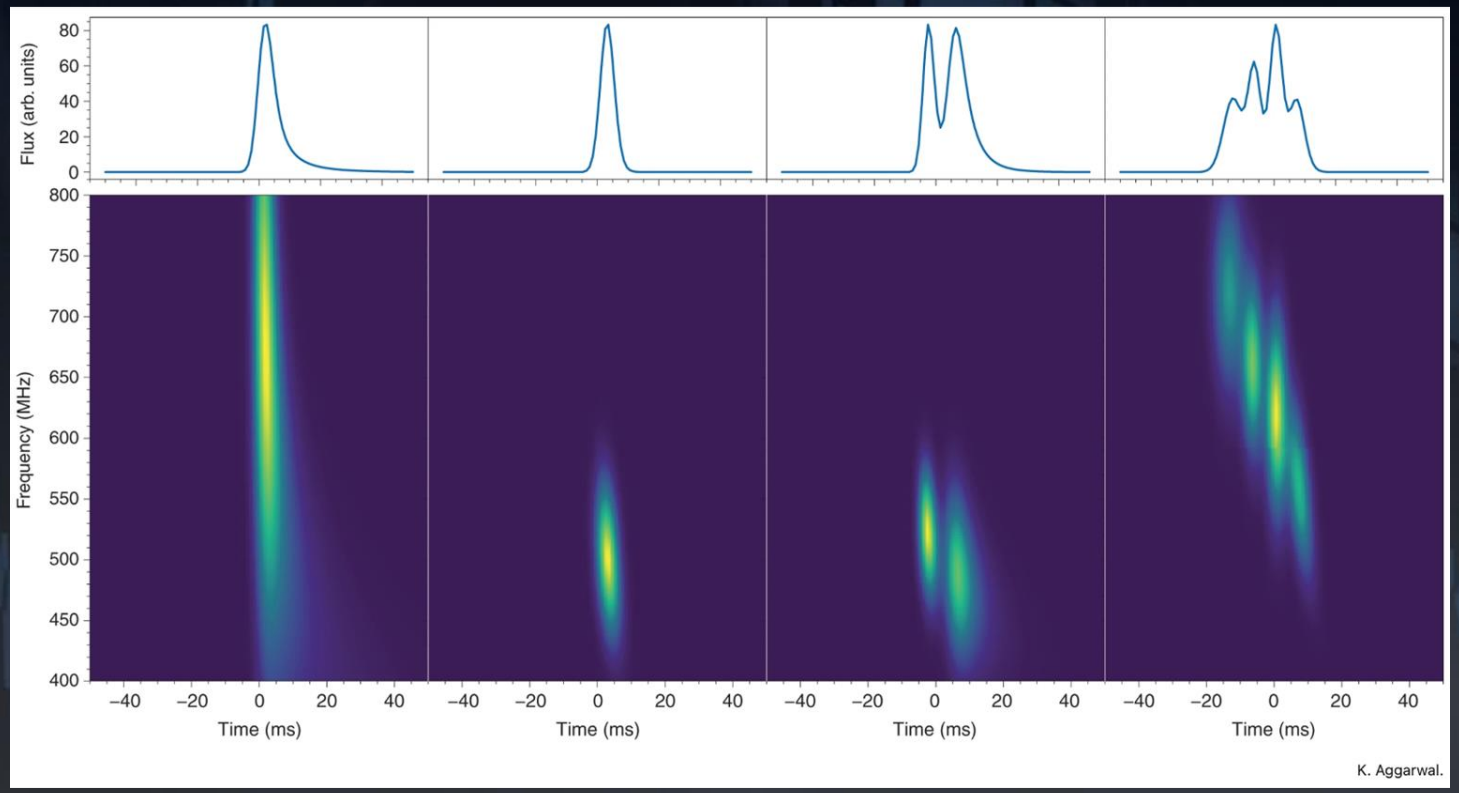




MULTIPLE FRB CLASSES?

CHIME/FRB, PLEUNIS ET AL. 2021





REPEATERS HAVE BROADER PULSES AND ARE NARROW BAND

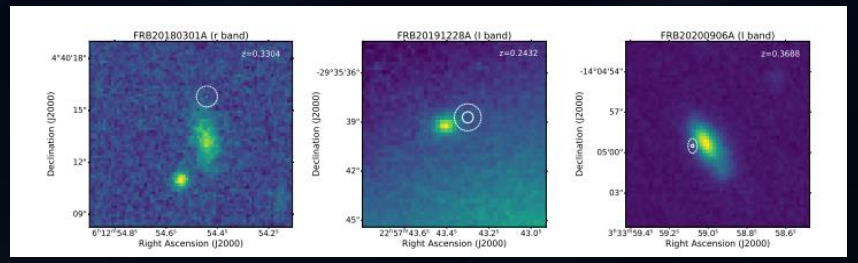
ONE-OFFS HAVE NARROWER PULSES AND ARE BROAD BAND

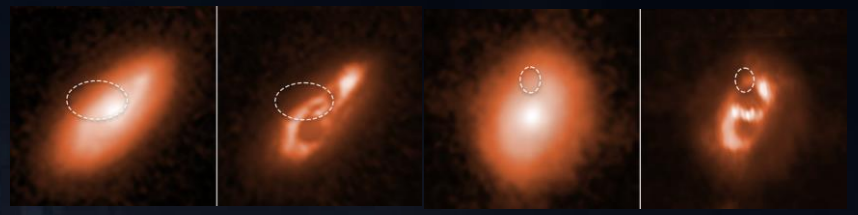
ASKAP LOCALISES MANY FRBS

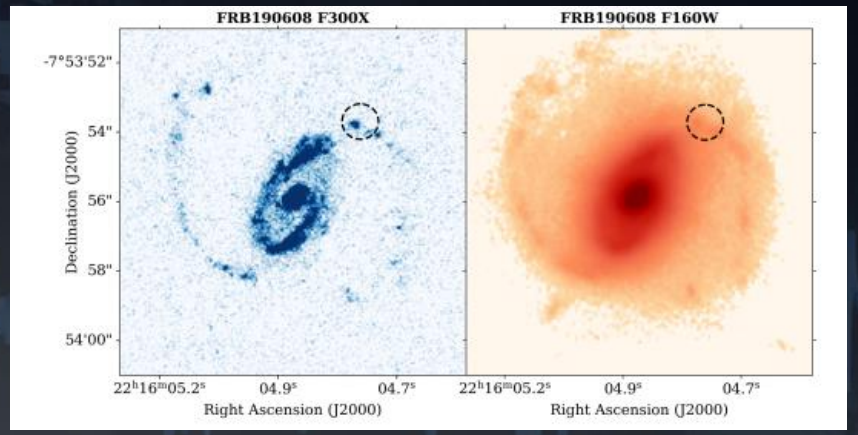
-OFTEN IN STAR-FORMING GALAXIES
NON-REPEATER HOST GALAXIES

-RARELY “RED AND DEAD” ONES

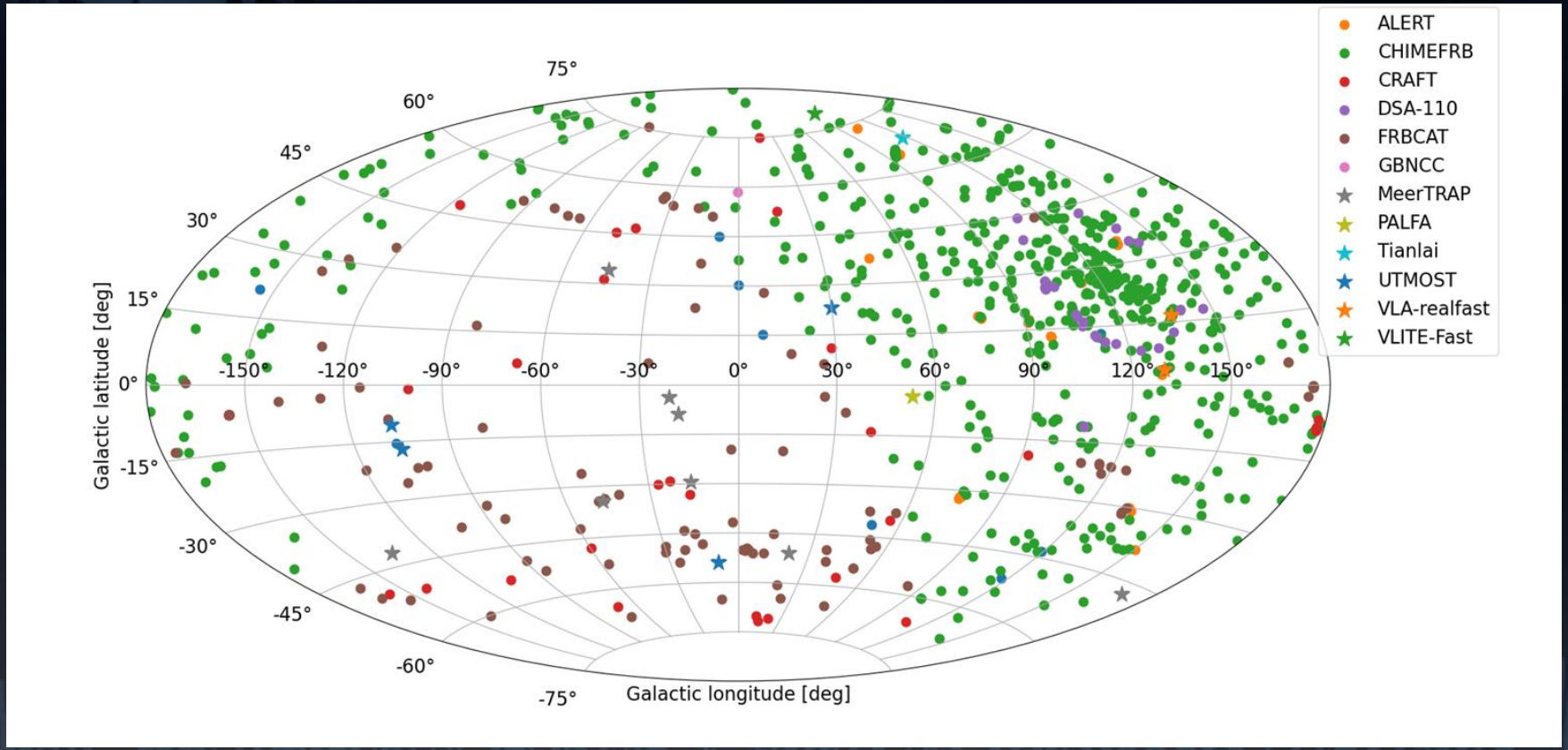
-NEAR AND FAR FROM SPIRAL ARMS







WHERE KNOWN FRBs ARE IN THE SKY



THE MACQUART RELATION

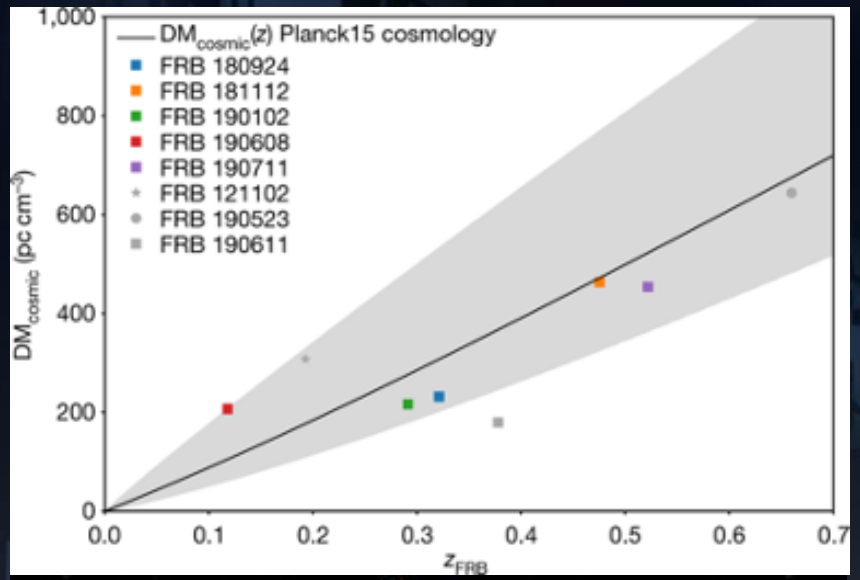
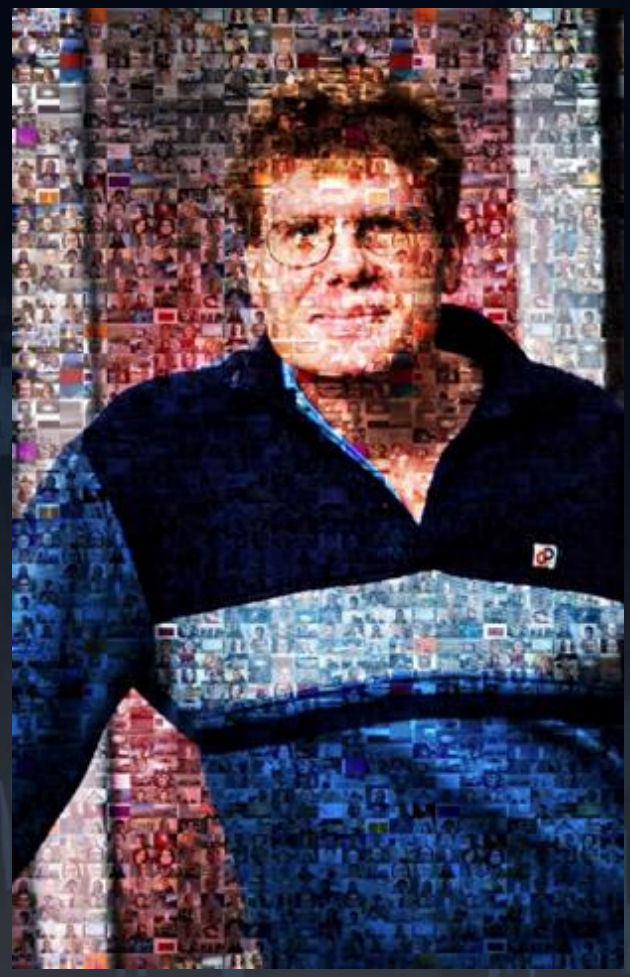


IMAGE CREDIT: MACQUART ET AL. 2020

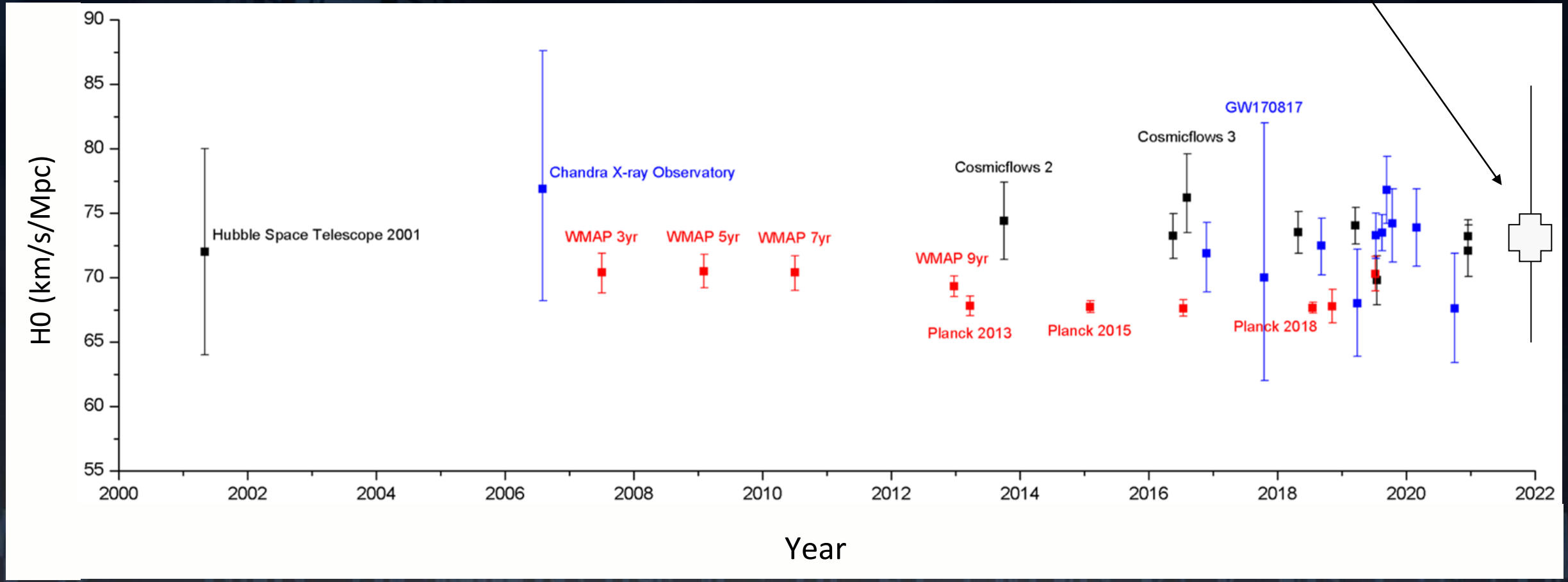


J-P MACQUART
1975 – 2020

IMAGE CREDIT:
BILOUS & SANPA-ARSA

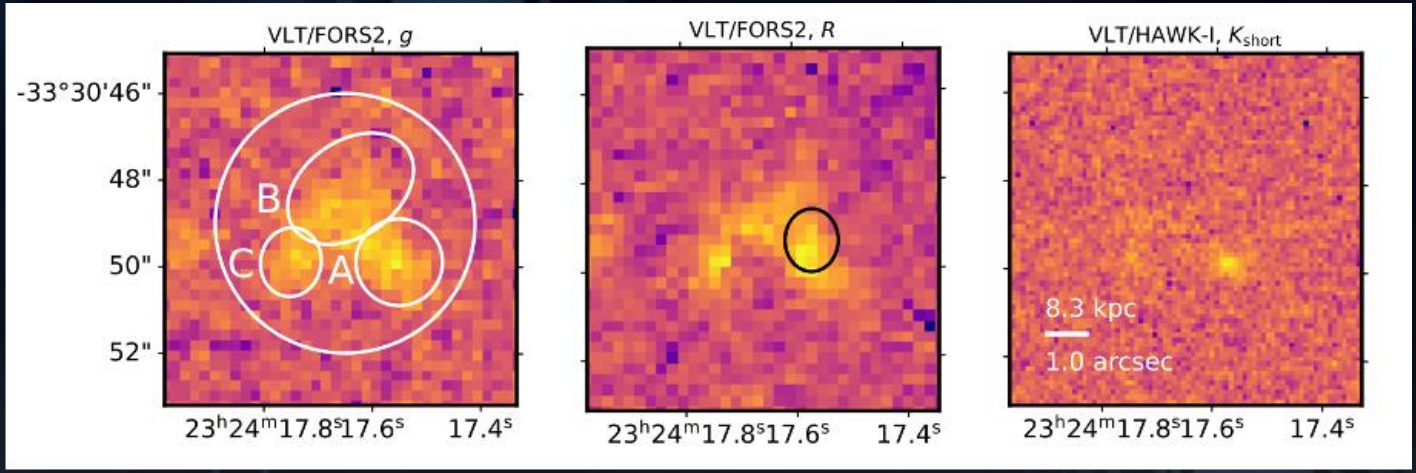
FRBs AND THE HUBBLE CONSTANT

JAMES ET AL. (2022)



AN FRB AT REDSHIFT OF 1

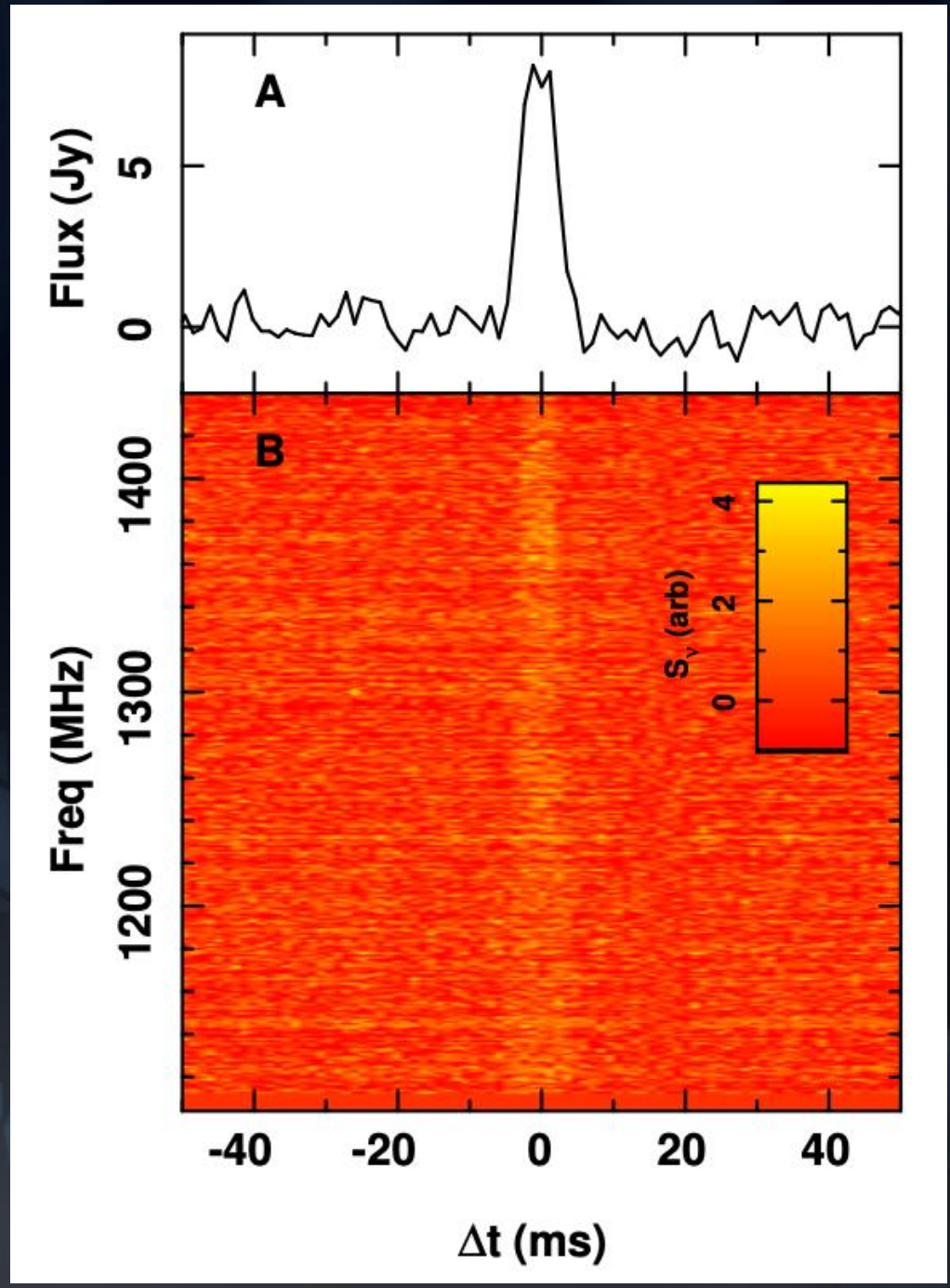
RYDER ET AL. (2023)



-BURST TRAVELLED 8 BILLION LY!

-BURST ENERGY = 16 YR OF SUN!

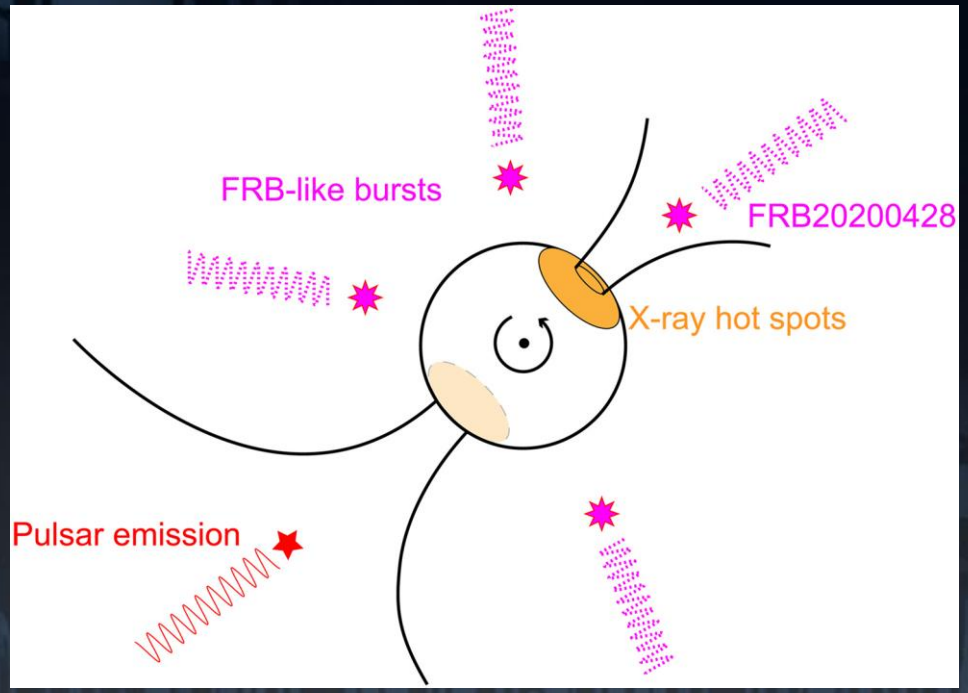
-IMPLIES FRBS IN HIGH-Z UNIVERSE

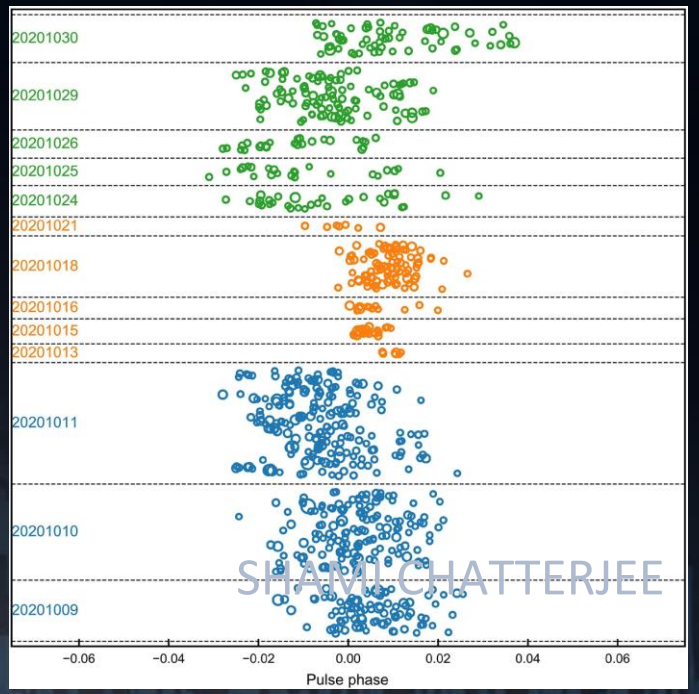


FAST SHOWS FRB PHASE NOT ASSOCIATED WITH REGULAR PULSAR PHASE (ZHU ET AL. 2023)

WEIWEI ZHU

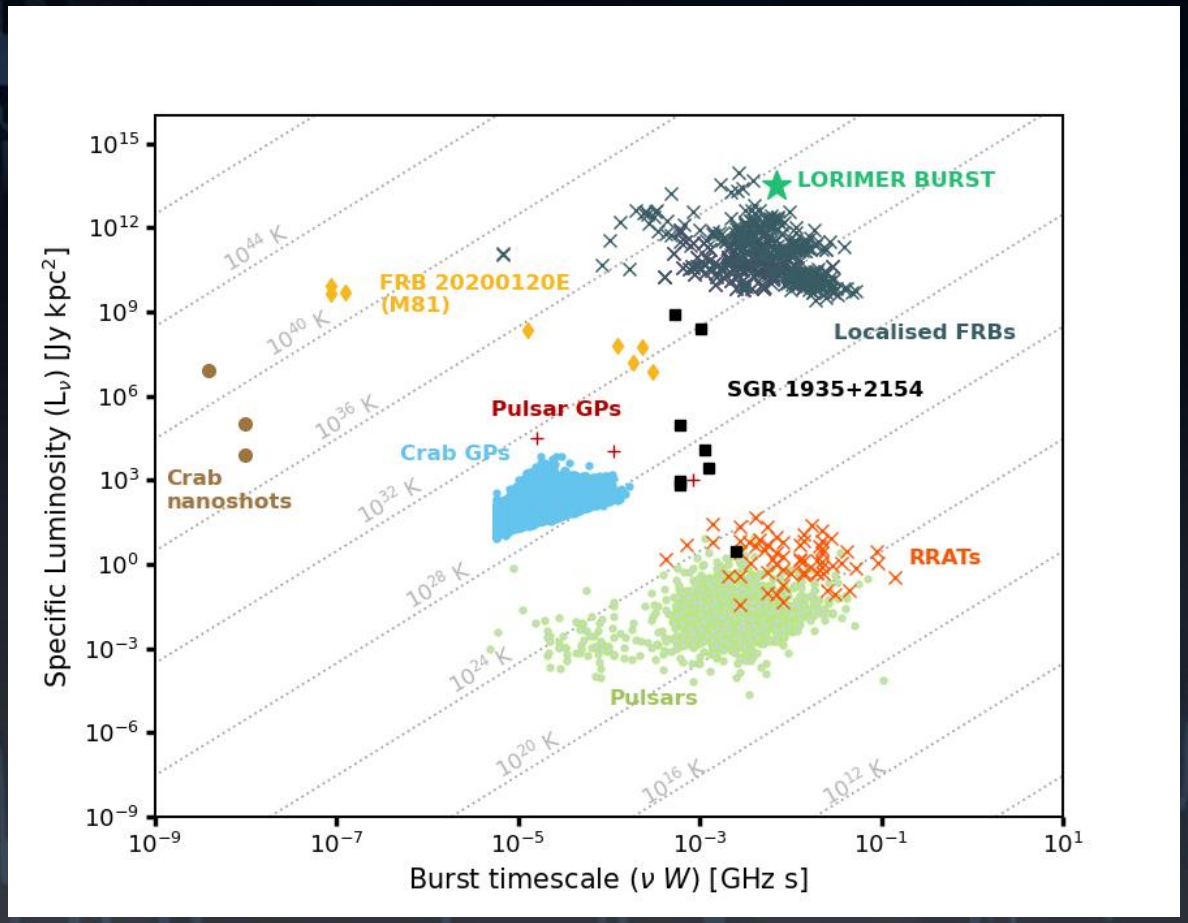
DI LI





SHAMI CHATTERJEE

LOOK LEFT AND RIGHT
STILL MUCH TO EXPLORE



SOME (OF THE MANY) OPEN QUESTIONS…

DO ALL FRBs REPEAT?
- REPEATER PULSES APPEAR TO BE DIFFERENT
- OR IS IT JUST SOME ORIENTATION EFFECT?

HOW MANY POPULATIONS ARE THERE?
- DIFFERENT TYPES OF REPEATING AND NON-REPEATING SOURCES

WHAT ARE THE HOST GALAXIES TELLING US?
- FRBs SEEM TO BE UBIQUITOUS

WHAT IS/ARE THE EVENT RATE(S)?
- DIFFERENT SUB-CLASSES?

WHAT ABOUT THE PERIODICITIES?
- SUGGESTIVE OF BINARY/PRECESSIONAL NATURE?

WHAT SURPRISES LIE AHEAD?
- OTHER PARTS OF THE EM SPECTRUM?
- GRAVITATIONAL WAVES

WHAT ABOUT DIFFERENT TIMESCALES?
- ULTRA-FAST FRBs?
- NOT-SO-FAST FRBs?

WILL WE EVER UNDERSTAND THE EMISSION MECHANISM?
- LESSONS FROM PULSARS

USE AS PROBES?
- FUNDAMENTAL PHYSICS
- COSMOLOGICAL PROBES

THANK YOU!

COLLABORATORS


- FRONEY CRAWFORD
- ASH NARKEVIC
- OUR STUDENTS, COLLEAGUES AND POSTDOCS

ORGANIZATIONS

- SHAW FOUNDATION
- NATIONAL SCIENCE FOUNDATION
- AUSTRALIAN RESEARCH COUNCIL
- RESEARCH CORPORATION FOR SCIENCE ADVANCE
- WEST VIRGINIA UNIVERSITY
- WEST VIRGINIA NASA SPACE GRANT
- SWINBURNE UNIVERSITY OF TECHNOLOGY