ANTON PANNEKOEK INSTITUTE

ASTRON

European Research Council

MILLISECOND PULSAR POPULATION

Amruta Jaodand

11th Bonn Neutron Star Workshop on
Formation and Evolution Of Neutron Stars
11/12/2017

Outline

1. Millisecond Pulsars

2. Current Population

3. Applications

4. Future Prospects

    4.1. Potential Science Questions

1

Millisecond Pulsars

Introduction

DISCOVERY

1982, D. Backer, Millisecond Pulsar, PSR J1937+21

P < 10ms in this talk.

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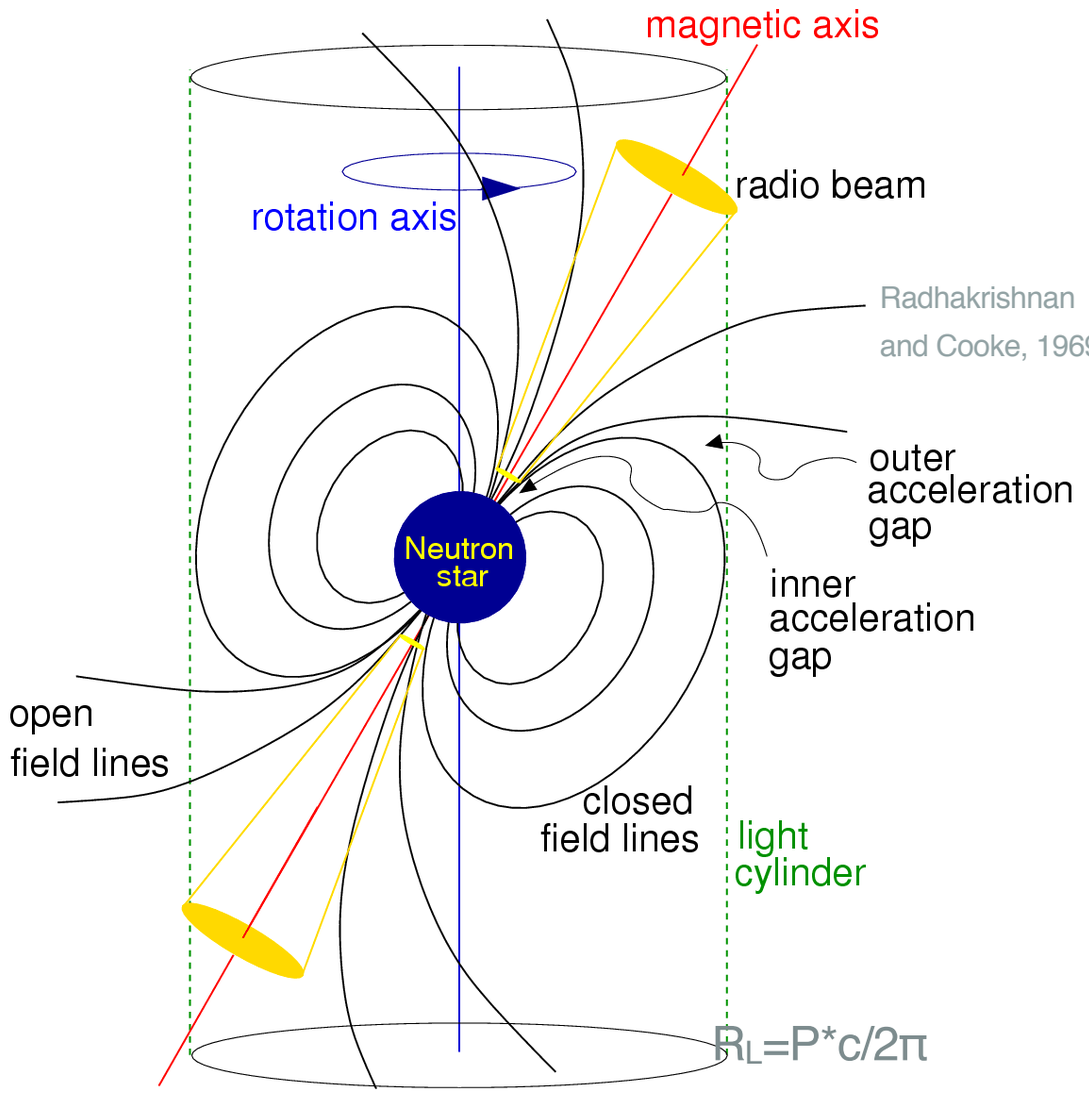


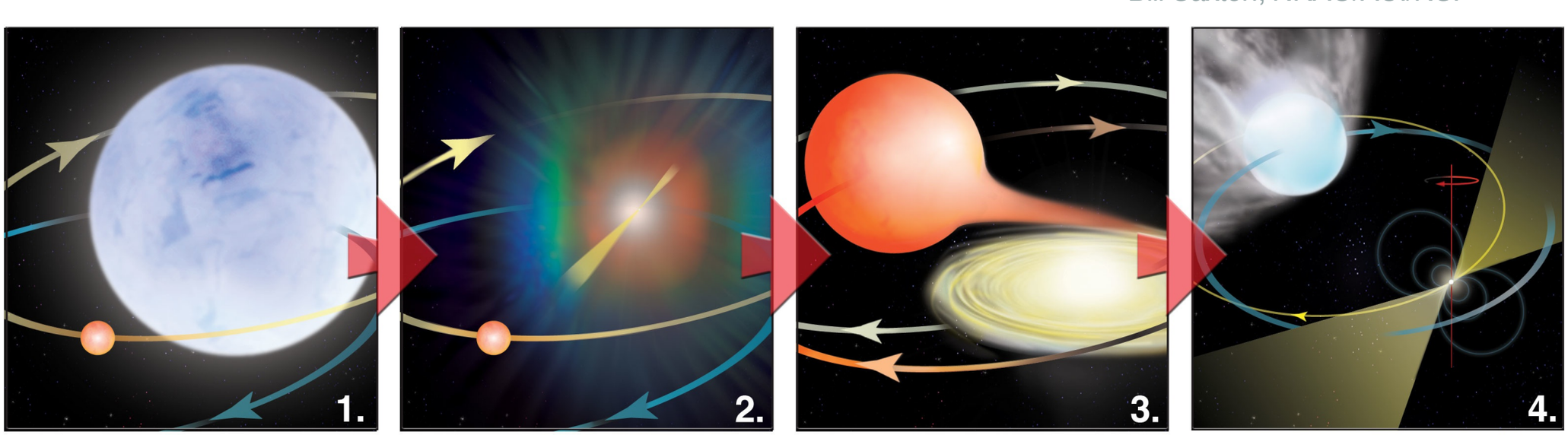
P < 10ms in this talk.

PULSAR RECYCLING

Backer, Kulkarni et al. 1982 - Short period, small period derivative

Alpar, Cheng, Ruderman & Shaham, A new class of radio pulsars, Nature, 300, 728, 1982
Radhakrishnan & Srinivasan 1982

Bill Saxton; NRAO/AUI/NSF



Binary

SN

Low Mass X-ray Binary State

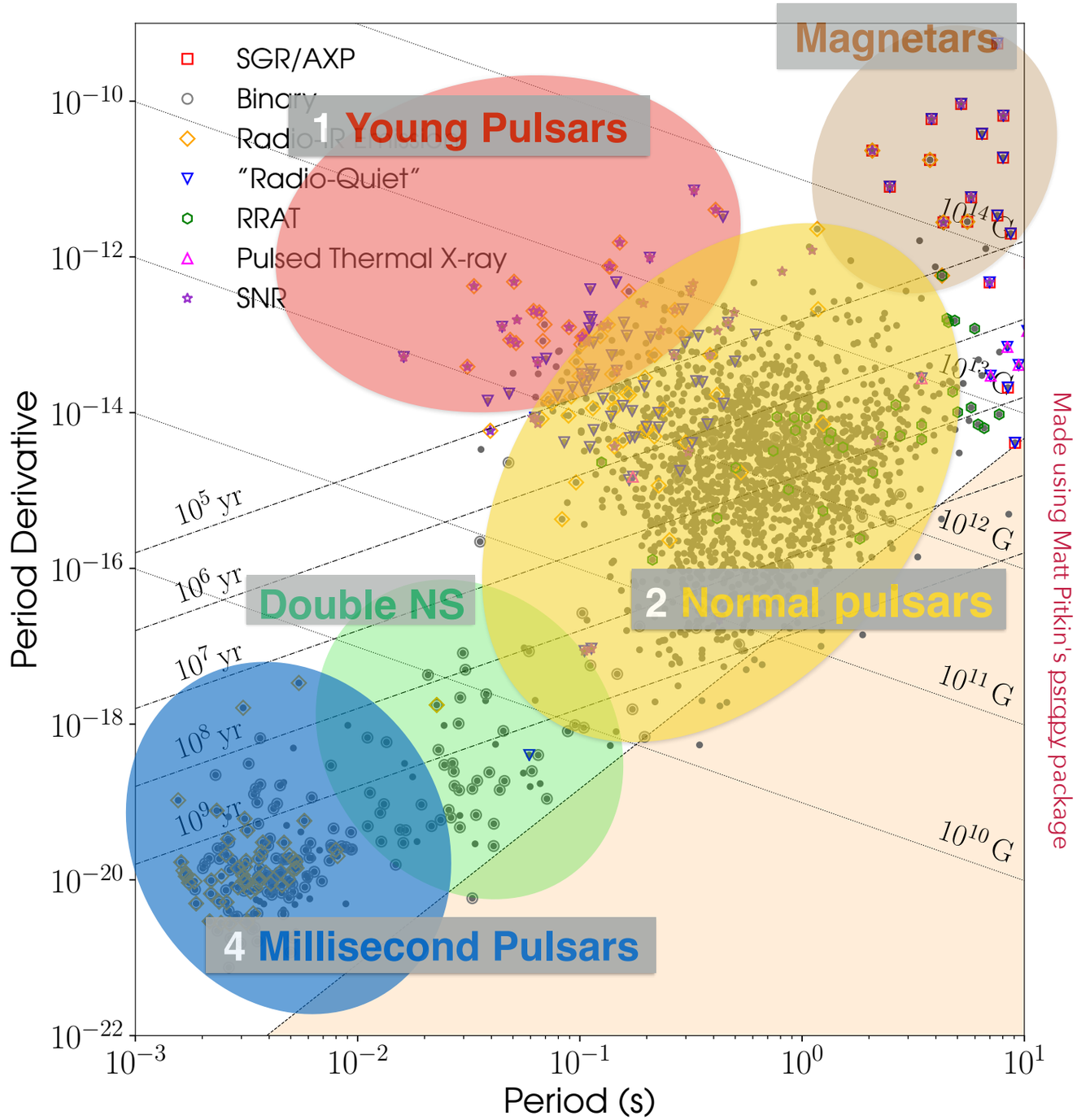
Radio Millisecond Pulsar State

2

Current Population

Diverse Manifestations

CURRENT STATUS



Made using Matt Pitkin's psrqpy package

2976 pulsars in total

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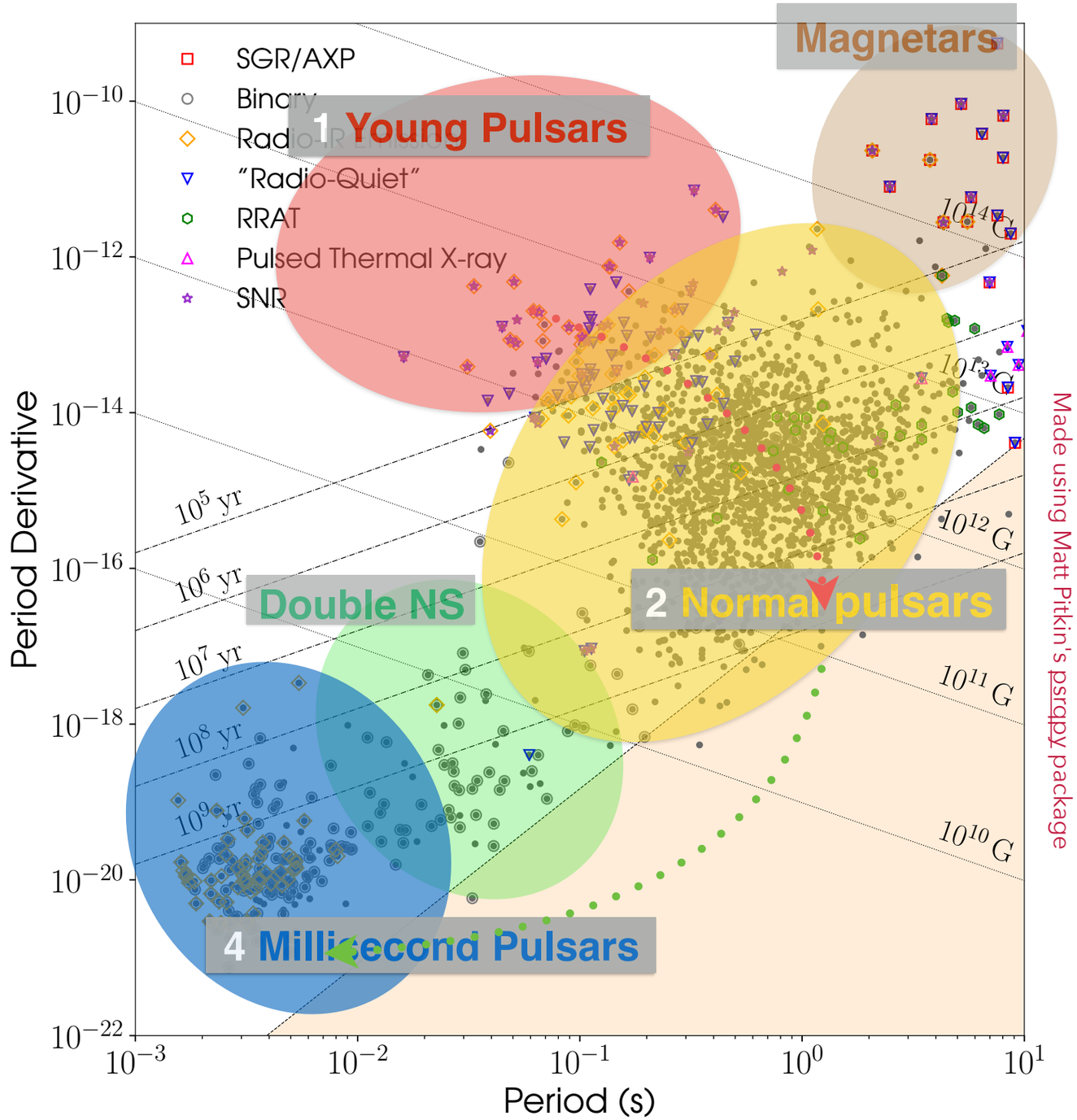

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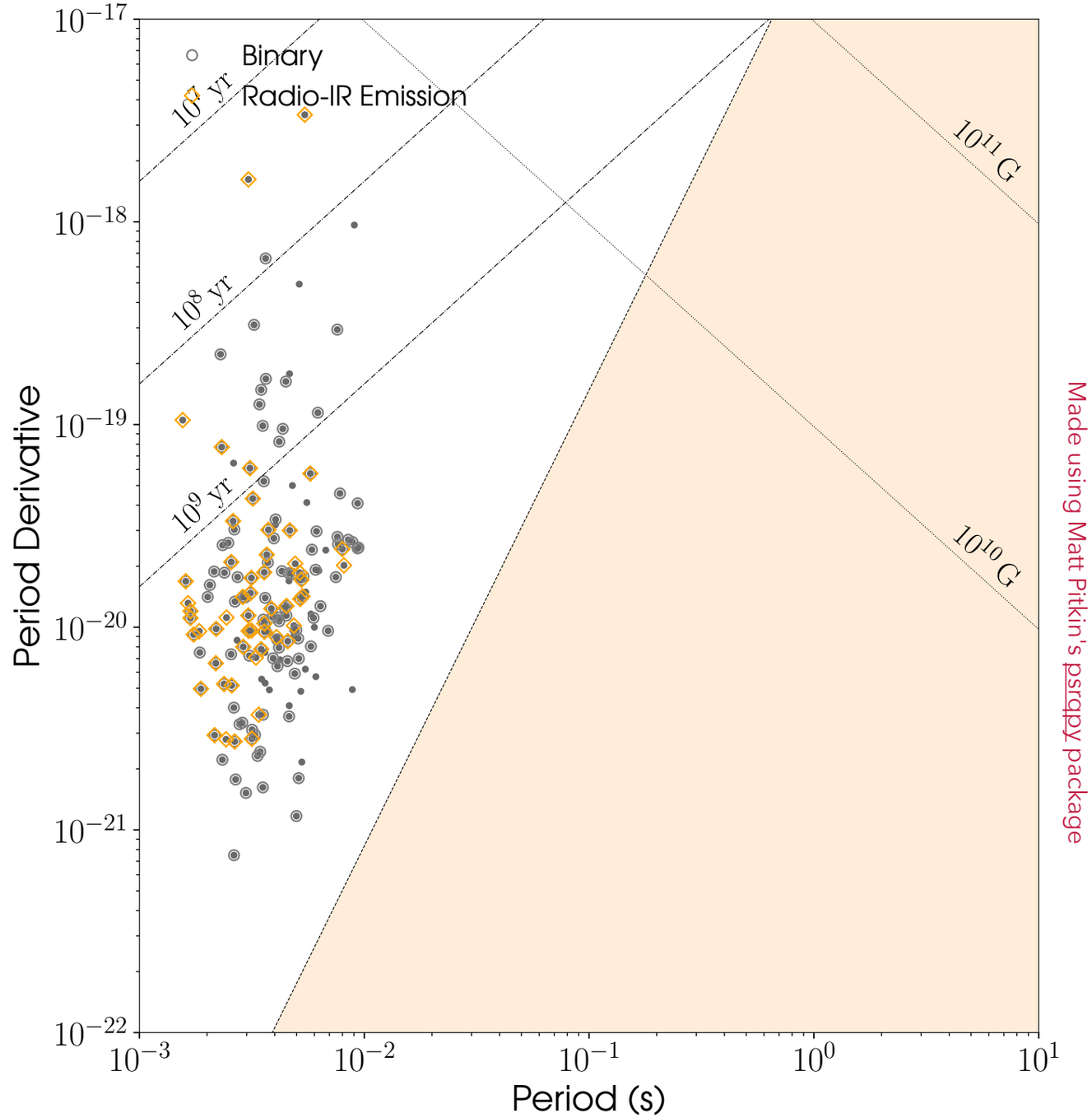

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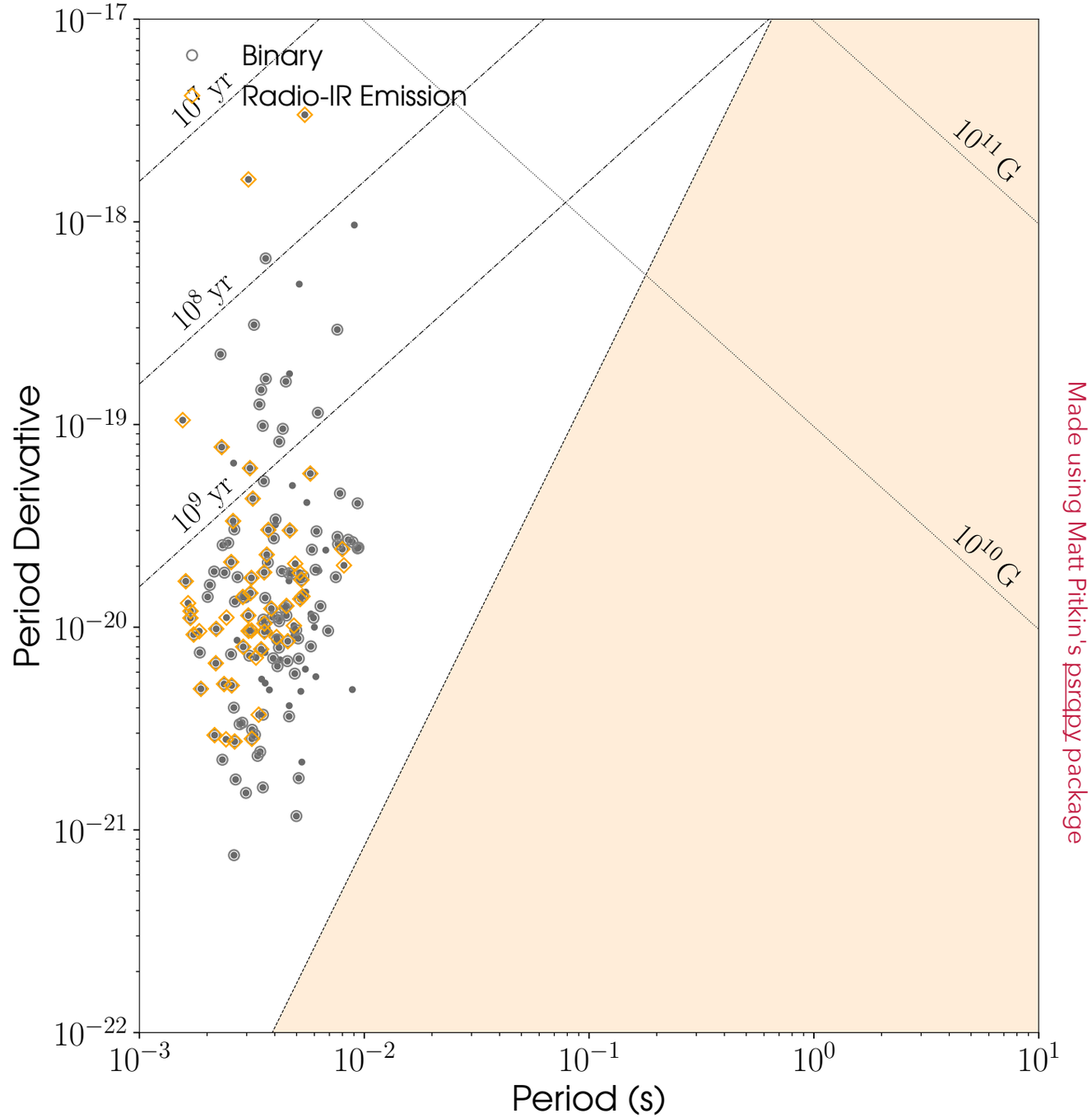


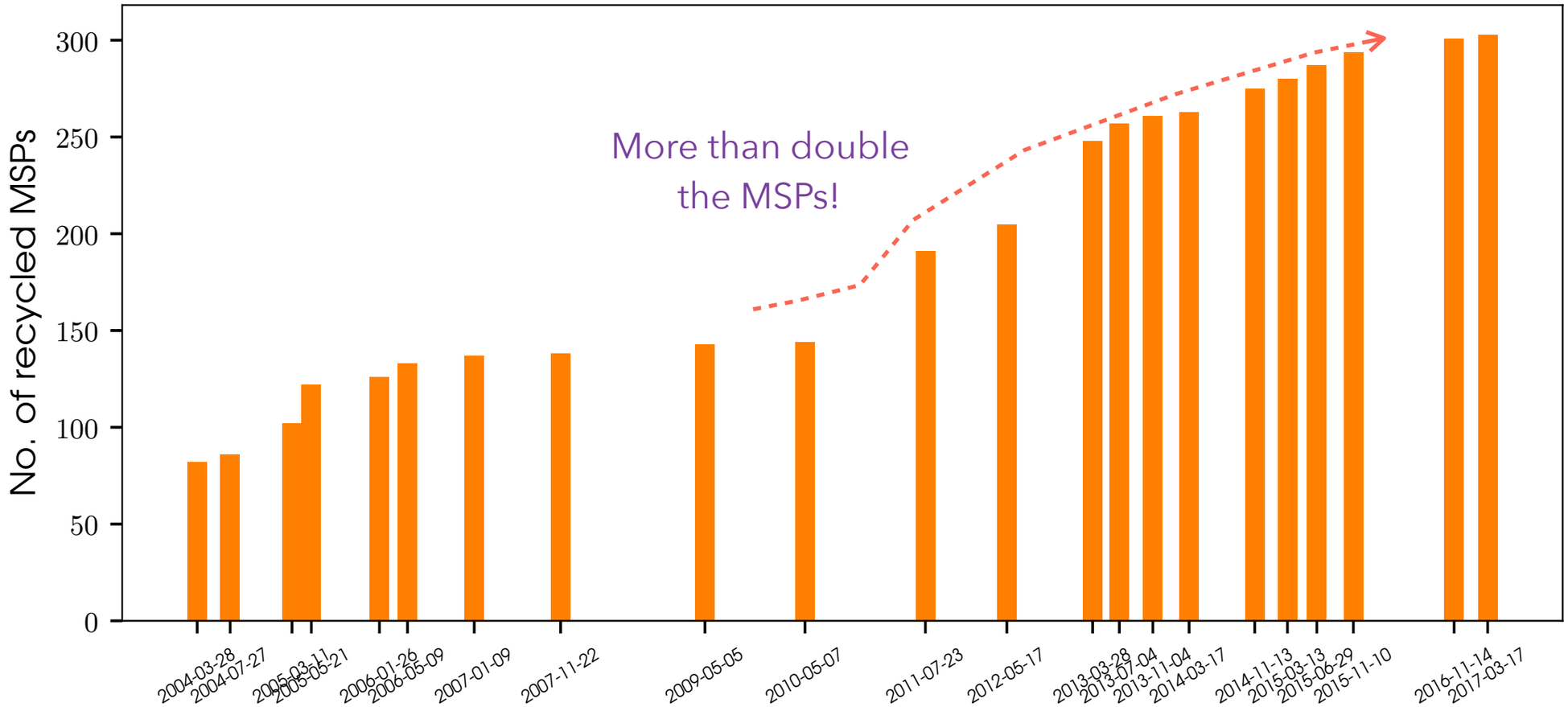
2976 pulsars in total

308 millisecond pulsars (F0>100Hz)

18 millisecond pulsars (F0>500Hz)

2 millisecond pulsars (F0>700Hz)

PSR BOOM



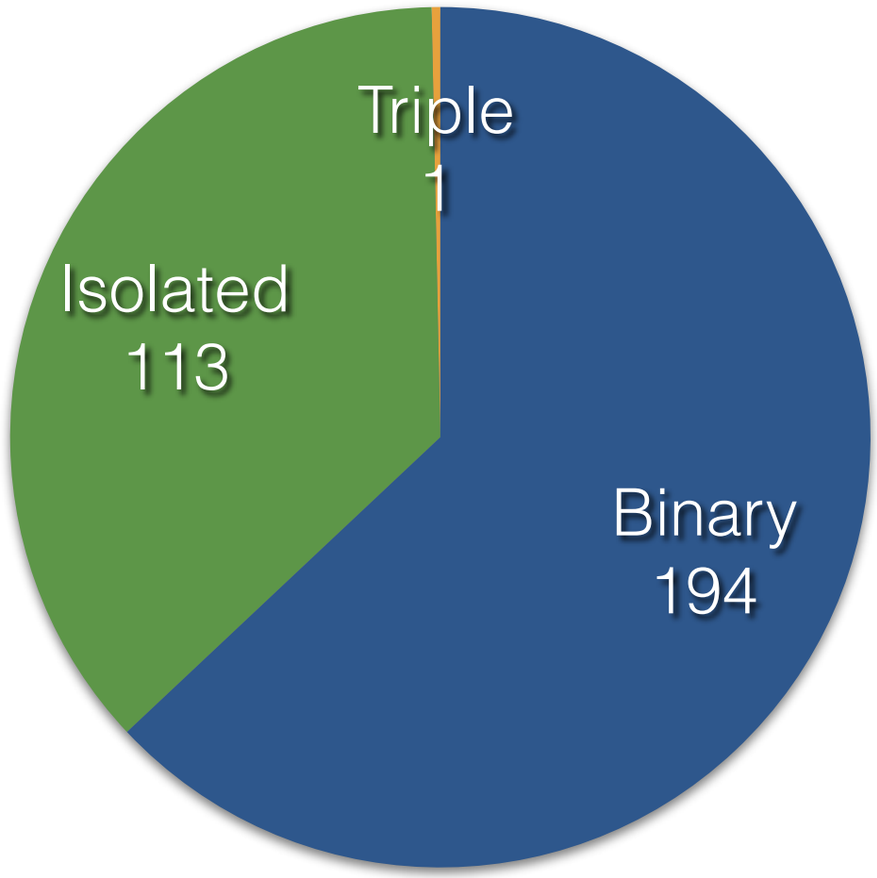
Sky surveys: Parkes Multi-Beam led the way!
GBT-drift scan and North Celestial Cap surveys;
Arecibo - 327 MHz drift-scan and ALFA survey;
HTRU- Northern and Southern sky surveys

Fermi Treasure Map

New telescopes, new backends, new algorithms - acceleration searches

MSP MANIFESTATIONS

Diversity in MSPs (P< 10ms)



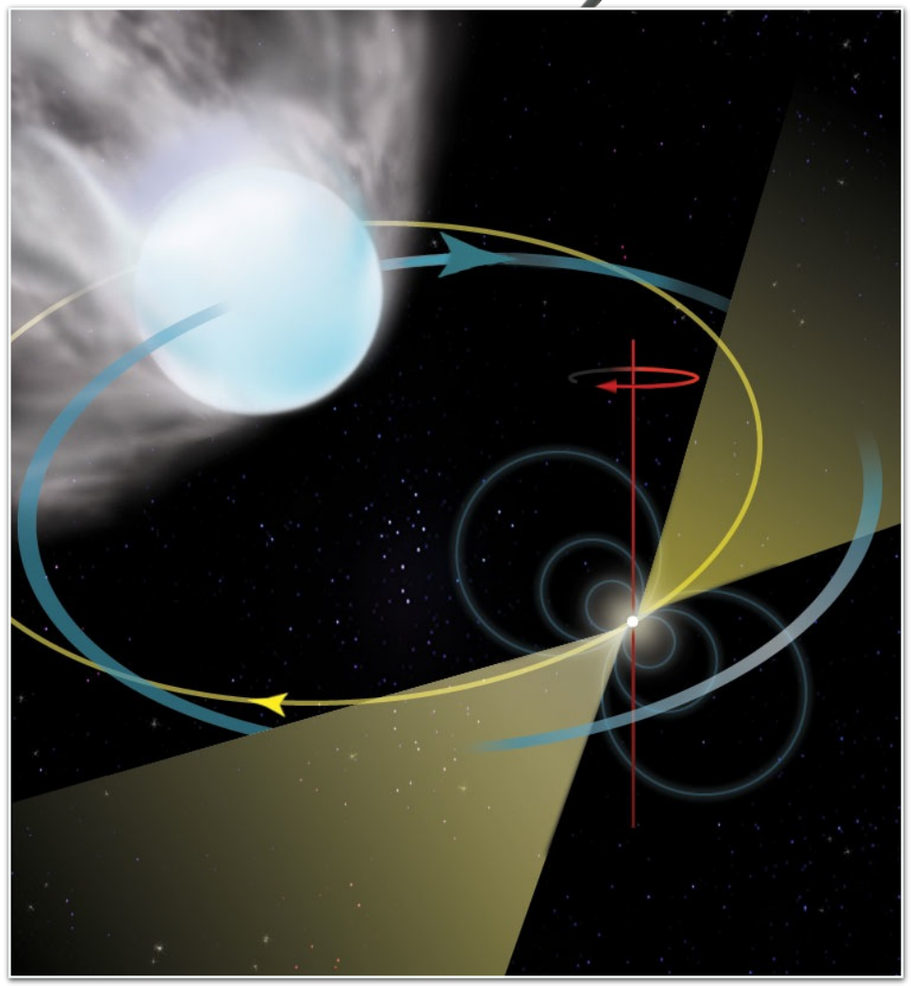
120 are in Globular Clusters, 116 Radio sources,
73 Gamma-ray sources, 51 X-ray sources

MSP BINARIES

Black Widows

"Black Widow" pulsar,

B1957+20, Fruchter et al.(1988)



Companion Mass, <0.01-0.1 M_sun

Orbital Period, short <3.5 hrs

Orbital evolution, peculiar, spin-orbit coupling

Known Black Widows, 40

MSP BINARIES

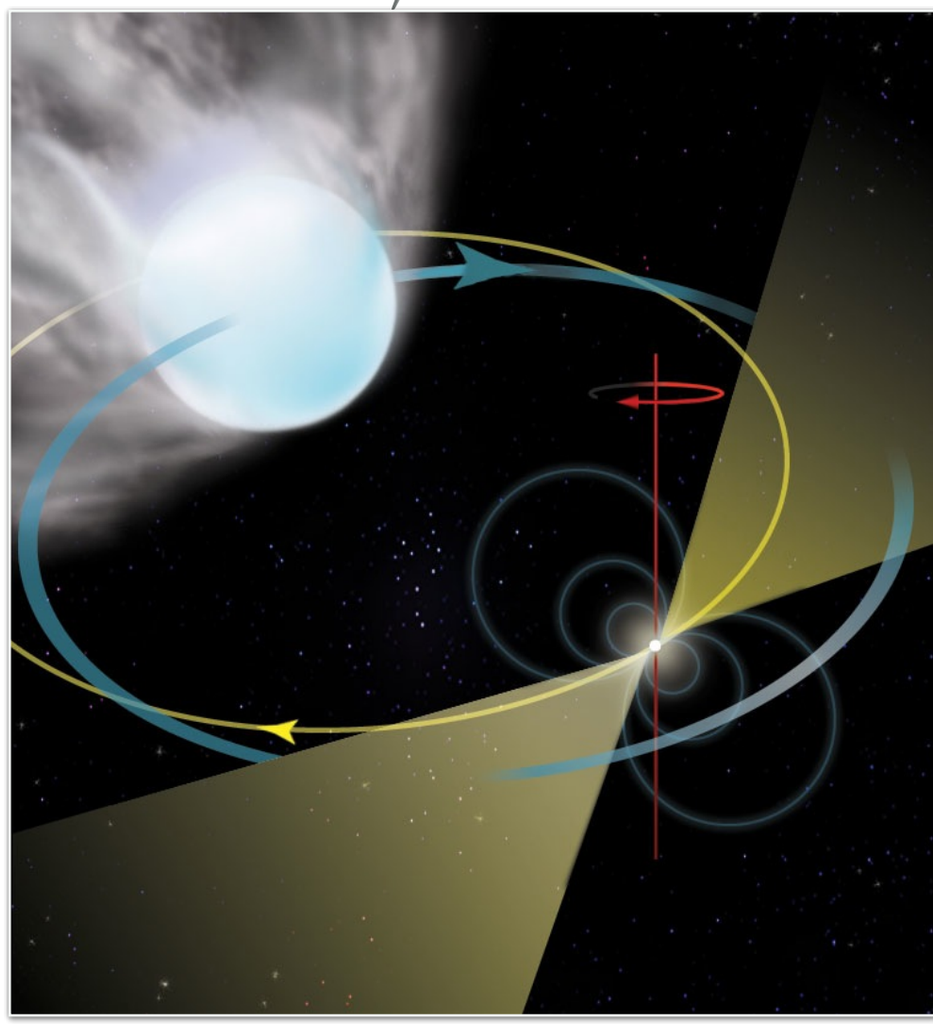
Redbacks

“Redback” pulsars,

Companion Mass, 0.15-0.4 M_sun

Orbital periods, 4-15 hr

Non-deterministic orbital variations



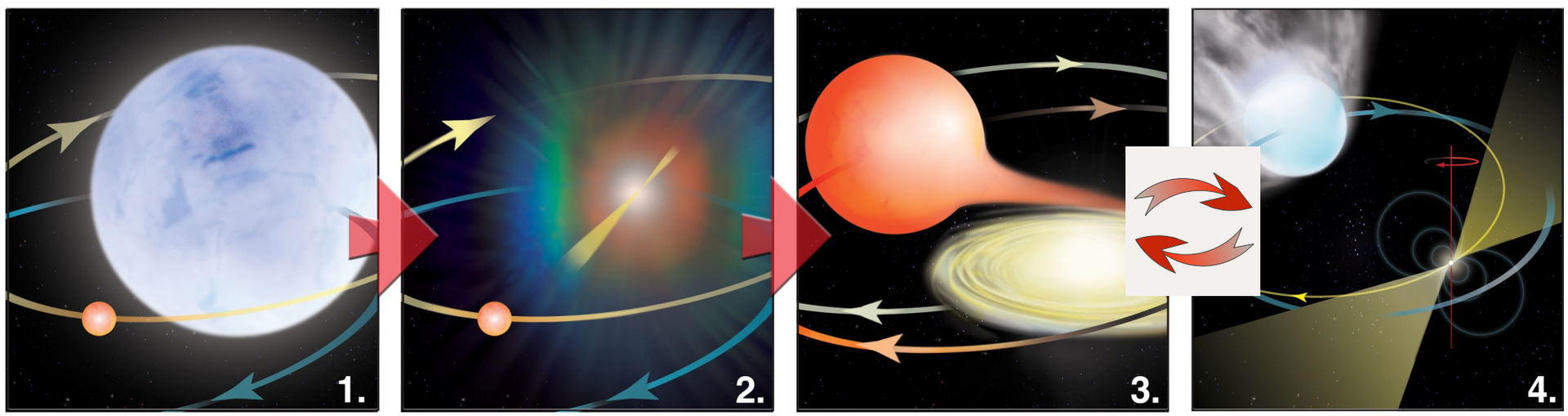
Almost Roche Lobe Filling, Breton et al.(2010)

Known Redbacks, 22

MSP BINARIES

Transitional Millisecond Pulsars

Bill Saxton; NRAO/AUI/NSF



Binary SN Low Mass X-ray Binary State Radio Millisecond Pulsar State

PSR J1023+0038, (1.69 ms) Archibald et al. (2009)

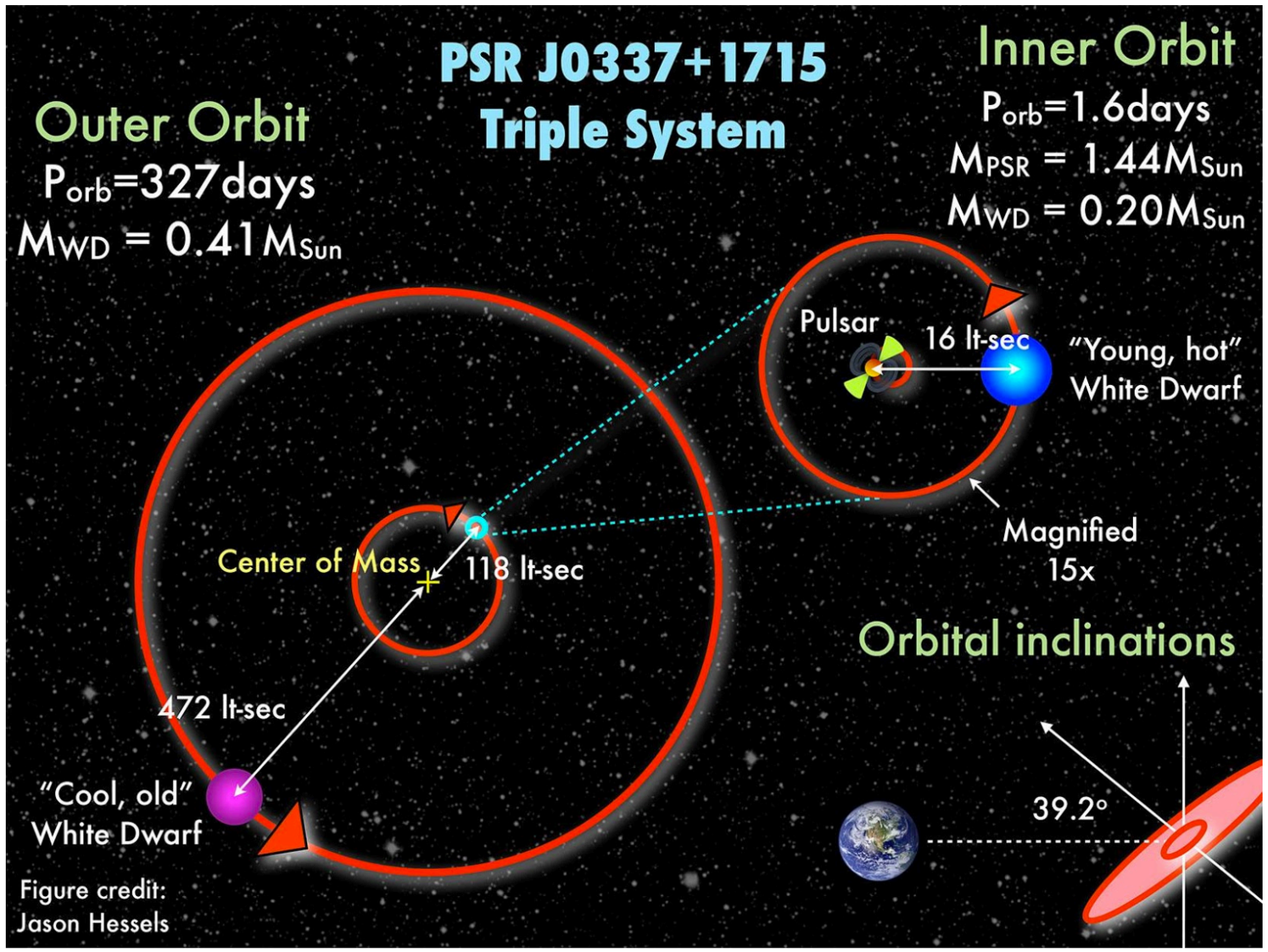
XSS J12270–4859, (1.69 ms) Bassa et al. (2014)

PSR J1824–2452I (3.9 ms) Papitto et al. (2013)

3FGL J1544-1125 (?? ms) Bogdanov & Halpern (2015)

MSP BINARIES

Triple MSP System



Ransom et al. 2014

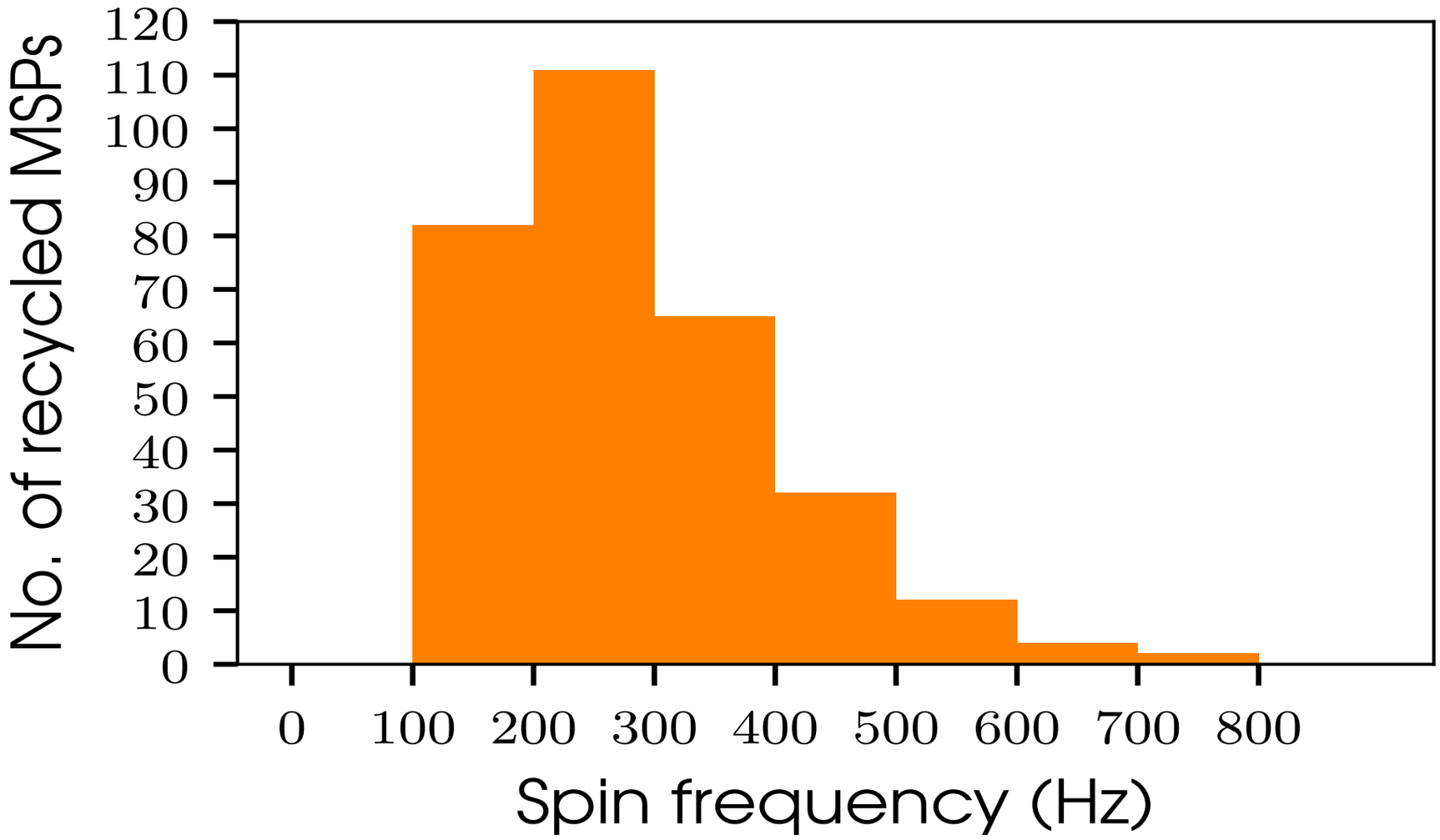
Fig. : Jason Hessels

PSR J0337+1715: 365.95 HZ

See talk by Anne Archibald

OUTLIERS

Spin frequency Distribution



Observational bias or formation mechanism?

Bassa et al 2017 - 707 Hz first galactic field MSP
Plenius et al. 2017 - 411.89 Hz

OUTLIERS

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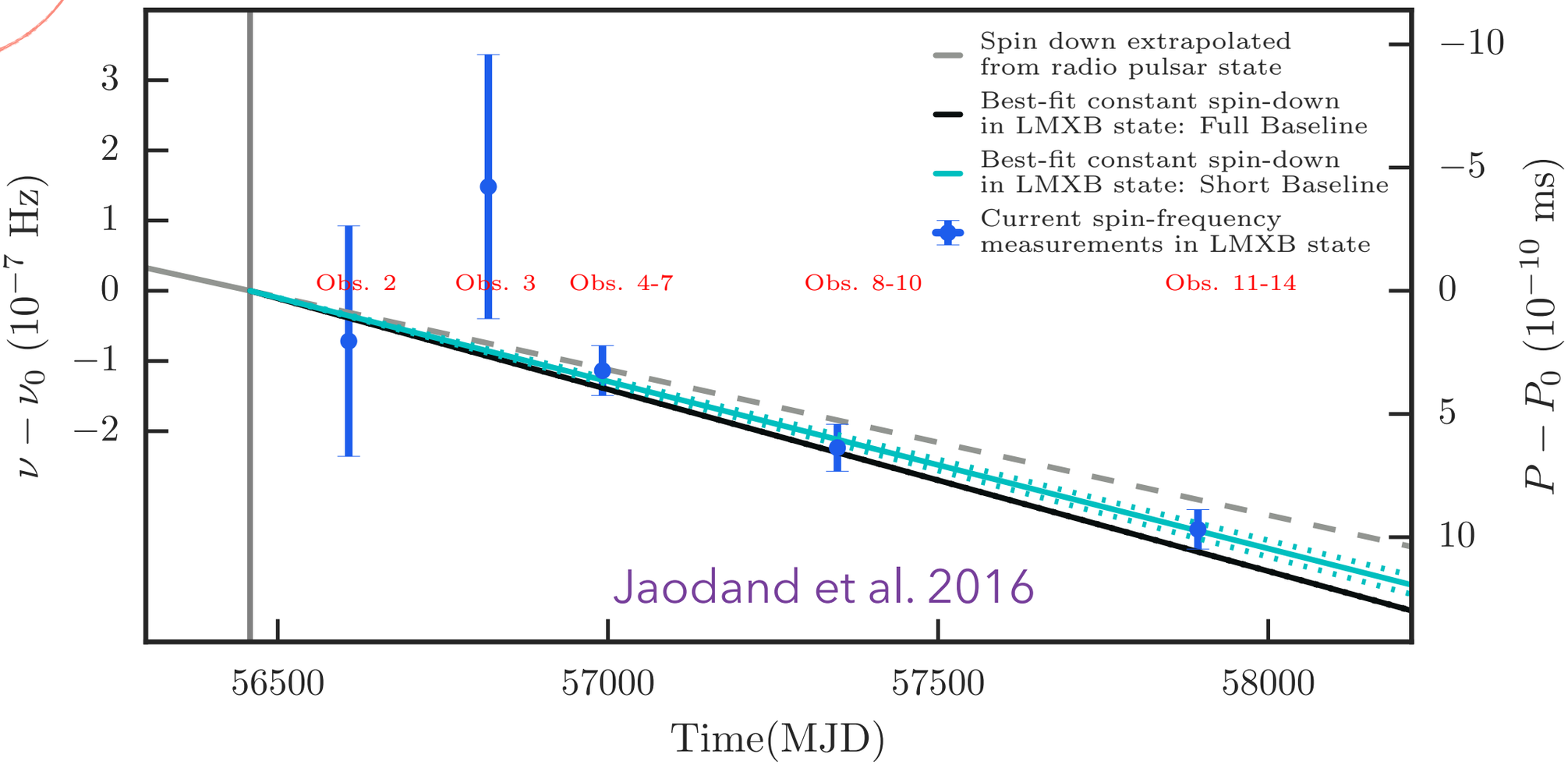

Jaodand et al. 2016

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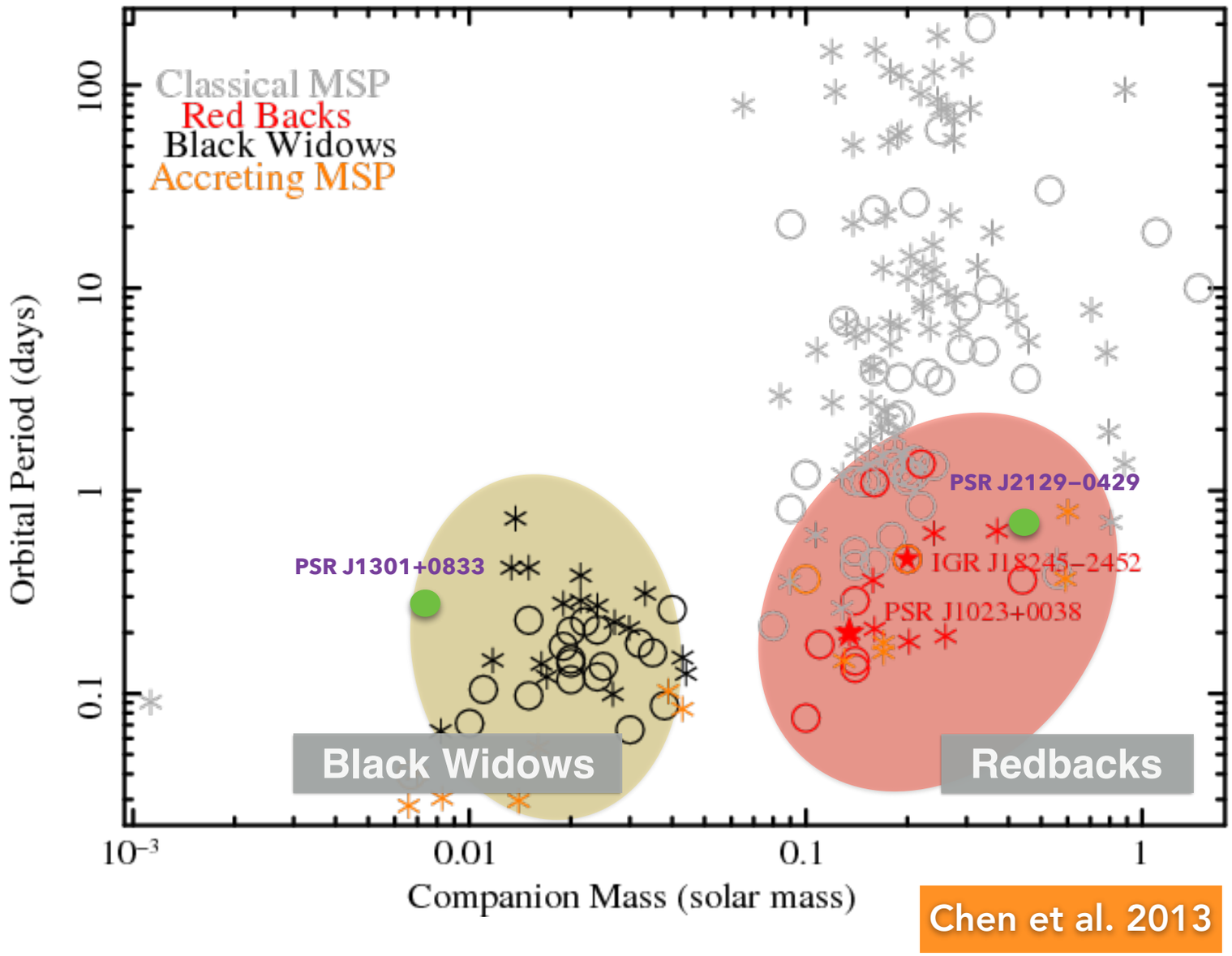
OUTLIERS

Image from Papitto et al. 2014, arXiv:1310.7803



Chen et al. 2013

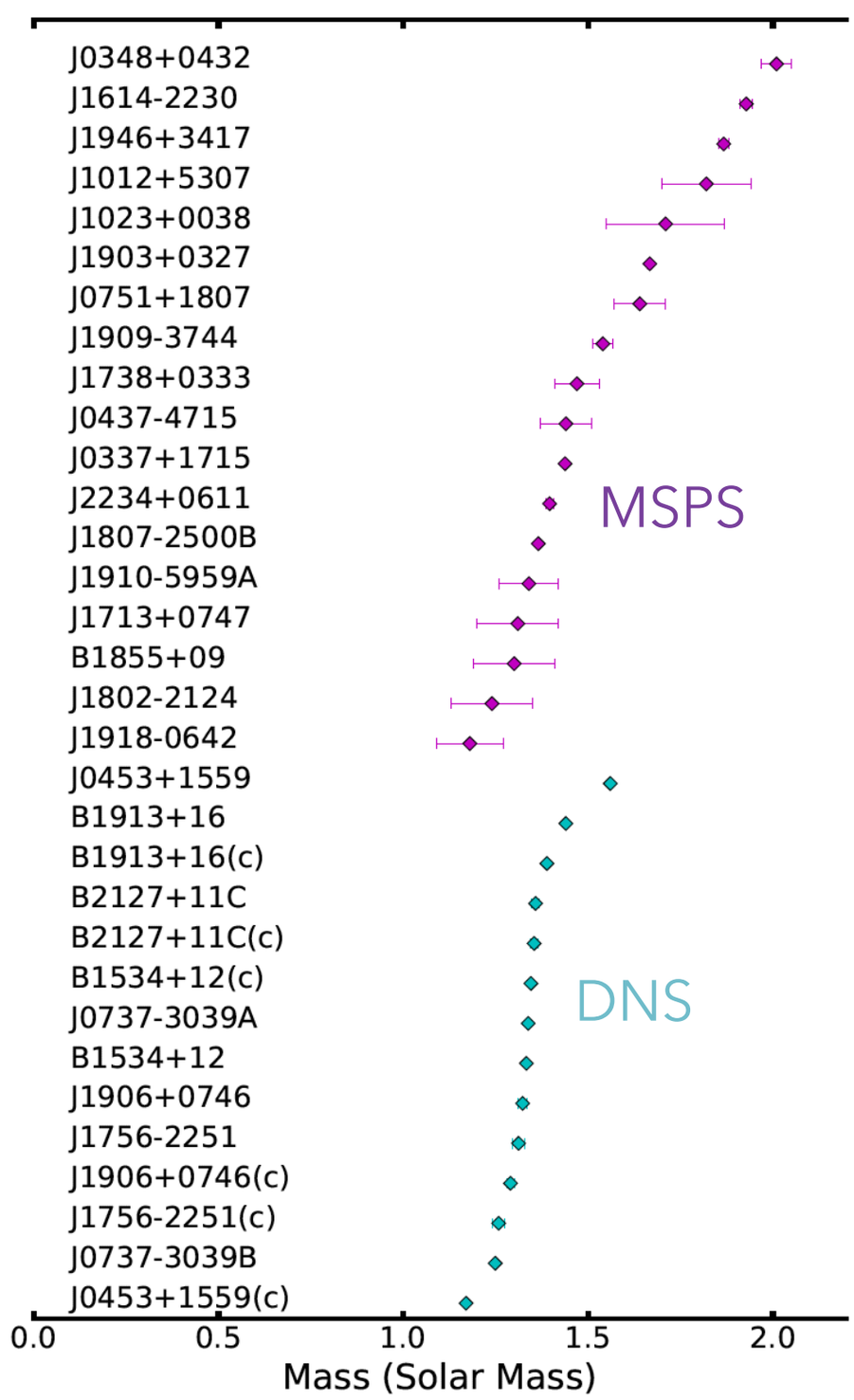
Extreme Black Widows – **Tidarreans**: **PSR J1301+0833**, Companion Mass $< 0.01\ M_{sun}$

Romani et al. 2016

Redback at bifurcation – **PSR J2129−0429**, Companion Mass $= 0.44\ M_{sun}$, $P_{orb}=15.2$ hr

Bellm et al.2015

OUTLIERS



PSR J0348+0432 :
2.01+/-0.04 ,M_sun

Bimodal mass distribution:
With low mass (1.39 M_sun)
and high mass (1.8 M_sun)

1) Precise known mass
2) Known total mass
3) Known mass ratio

Antoniadis et al. 2013, Antoniadis et al. 2016

3

Applications

Precise Timers & Strongly Self-Gravitating

PULSAR TIMING ARRAYS

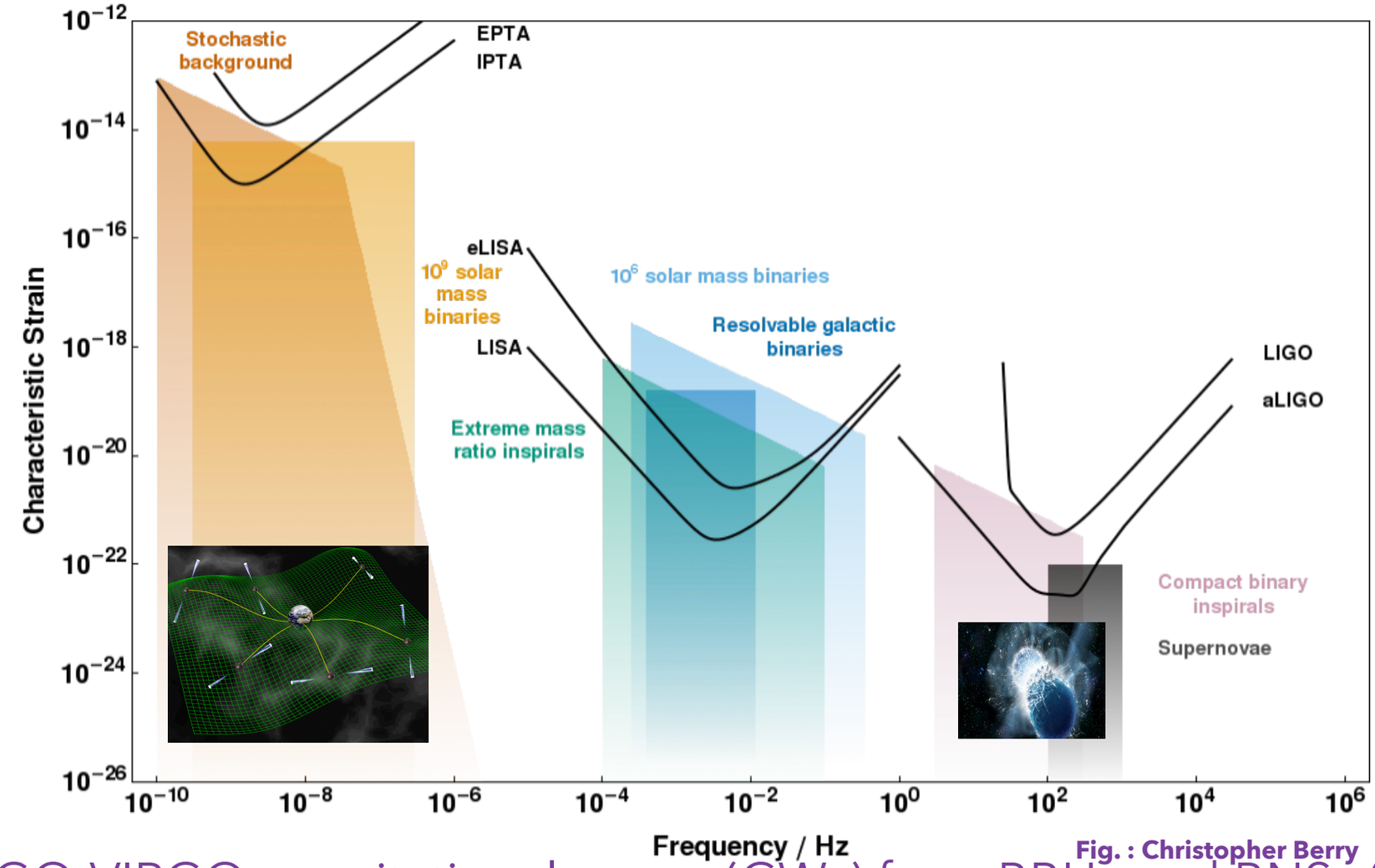


Fig. : Christopher Berry

LIGO-VIRGO: gravitational waves (GWs) from BBHs and BNSs (GW170817)

PTAs probe GWs in the nHz regime from:

a) Cosmic strings Sanidas et al. 2012, Jose J. Blanco-Pillado et al. 2017

b) Supermassive black hole merger - stochastic signal and merger event

Lentati et al. 2015, Verbiest et al. 2016, Mingarelli et al. 2017

See talk by H. Middleton

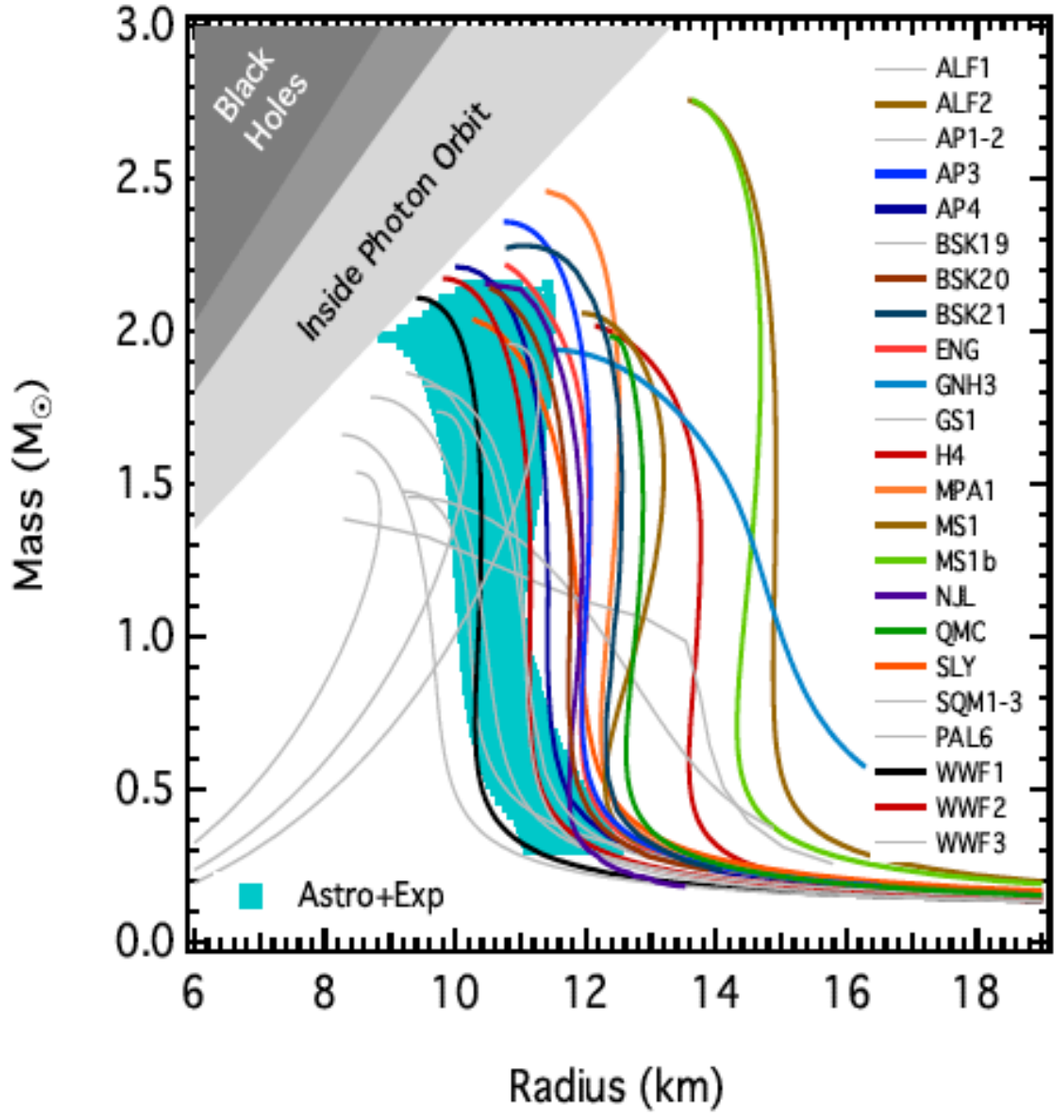
EQUATION OF STATE

Millisecond pulsar mass measurement:
Fantastic timers, low orbital eccentricities

1. Pulsars in GCs - eccentricity due to interaction
   Ransom et al. 2005, Freire et al 2008
2. Shapiro delay measurement
   Jacoby et al. 2005, Demorest et al. 2010
3. Spectroscopic measurement - Balmer lines
   Callanan et al. 1998, Antoniadis et al. 2012
4. Stellar triples
   Champion et al 2008, Ransom et al. 2014

Millisecond pulsar radius measurement:

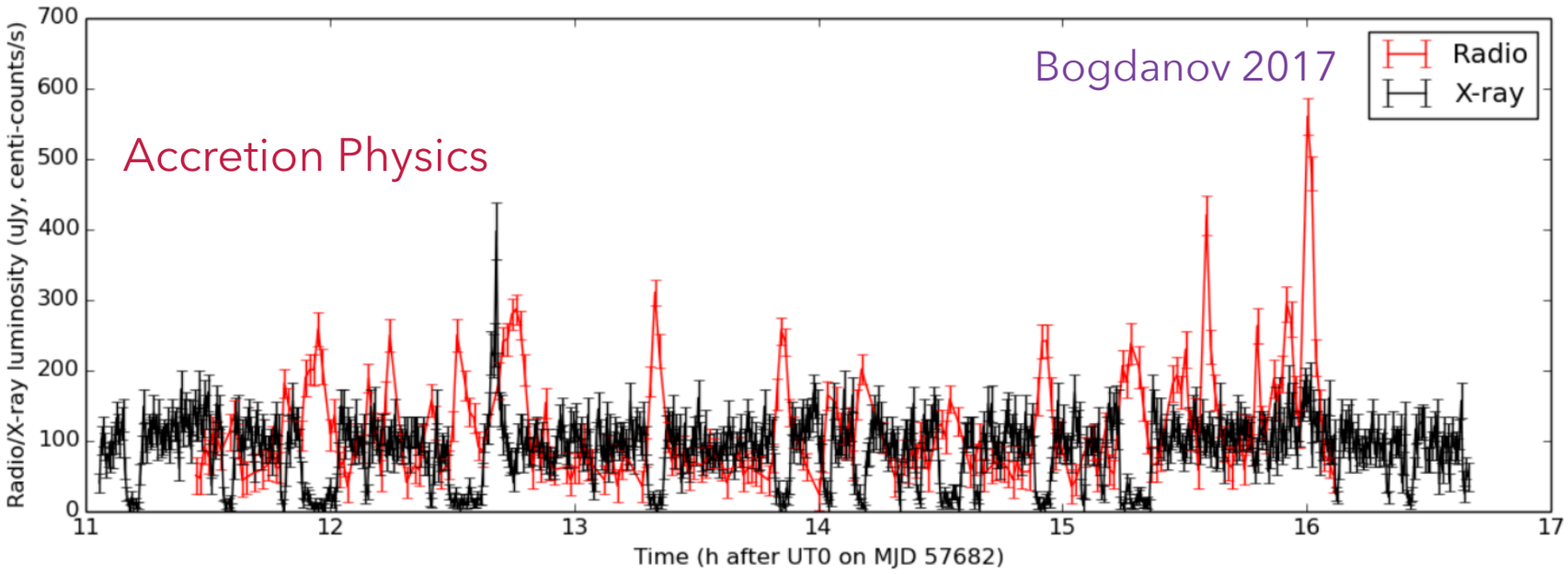
1. Spectroscopic measurement
2. Timing Measurements



Review: Ozel and Freire 2016

See talk by N.U.Bastian for more details

OTHER APPLICATIONS



tMSPs are fantastic probes of low-level accretion onto neutron stars

Jaodand, Hessels & Archiabld 2017

Accreting millisecond X-ray pulsars Review: Patruno and Watts 2012

Understanding of pulsar emission physics

Galactic centre excess?

See talks by:

Stellar Evolution - John Antoniadis

Inter stellar medium - Caterina Tiburzi

Strong field tests of gravity - Shao and Archibald

4

Future Prospects

New Means To Find MSPS & Holy Grails

INTERFEROMETRIC ERA

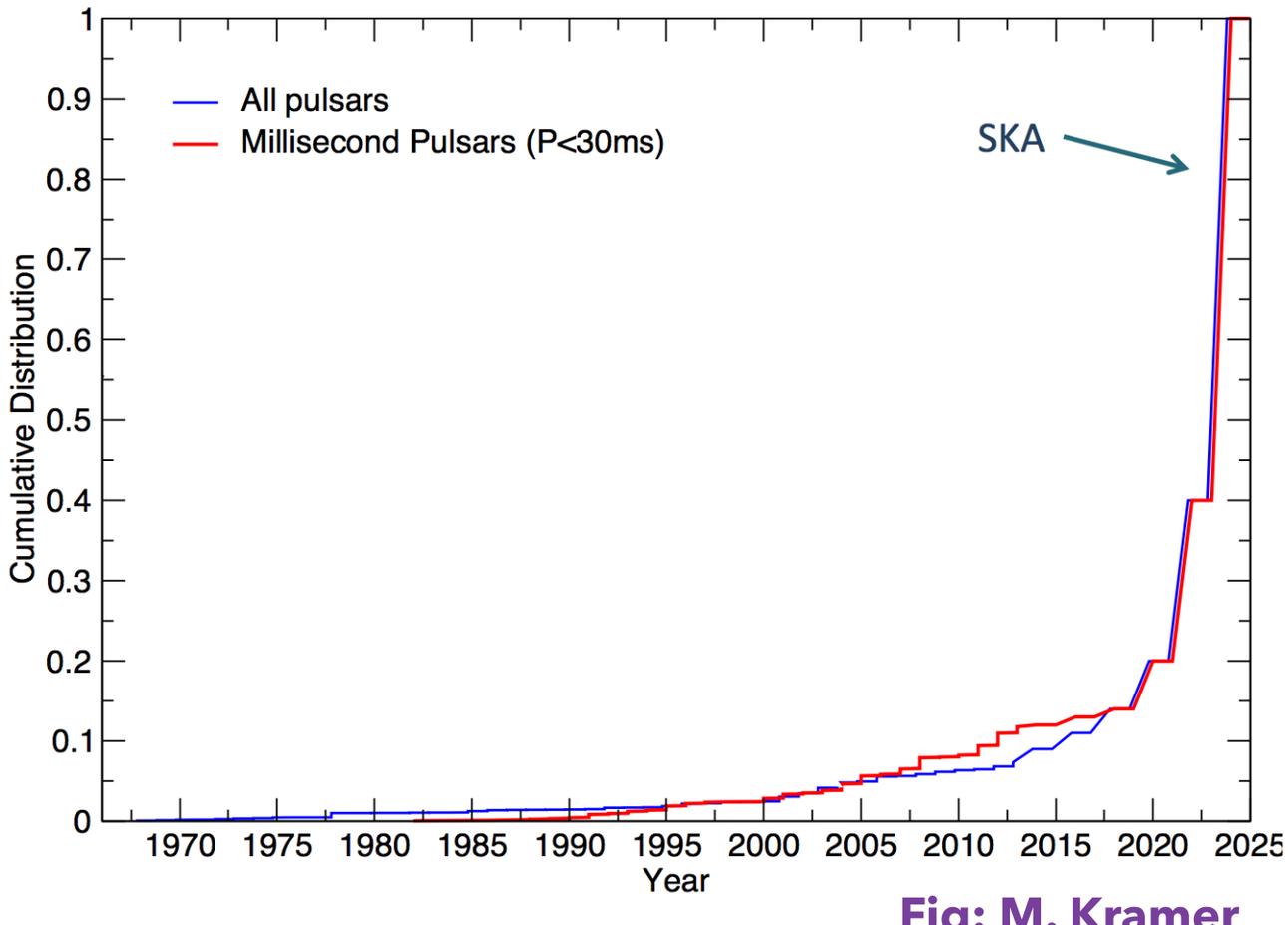


Fig: M. Kramer

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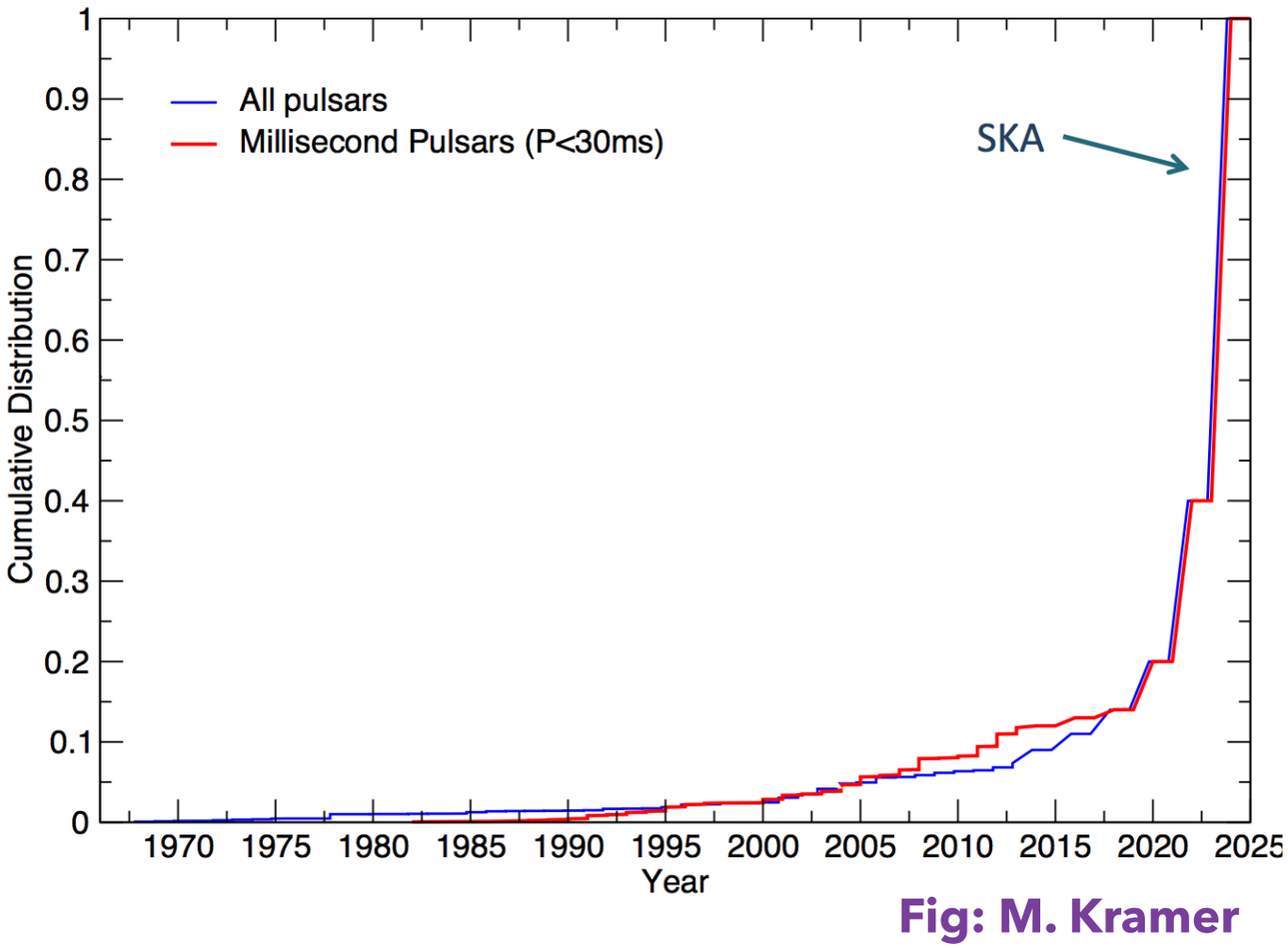

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Higher instantaneous sensitivities for SKA, MeerKAT and pathfinders

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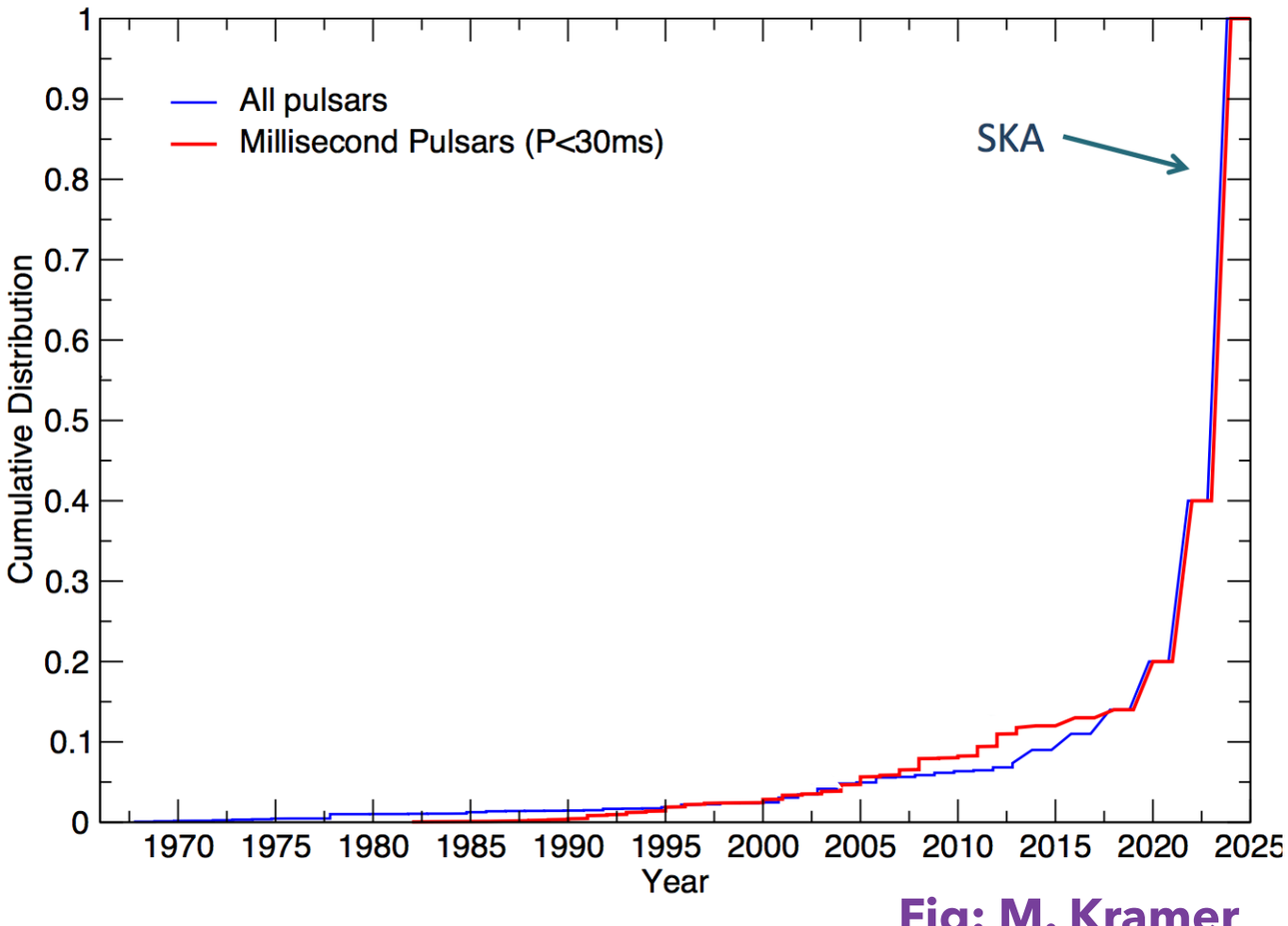

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Higher instantaneous sensitivities for SKA, MeerKAT and pathfinders
SKA's large field of view, collecting area, bandwidth

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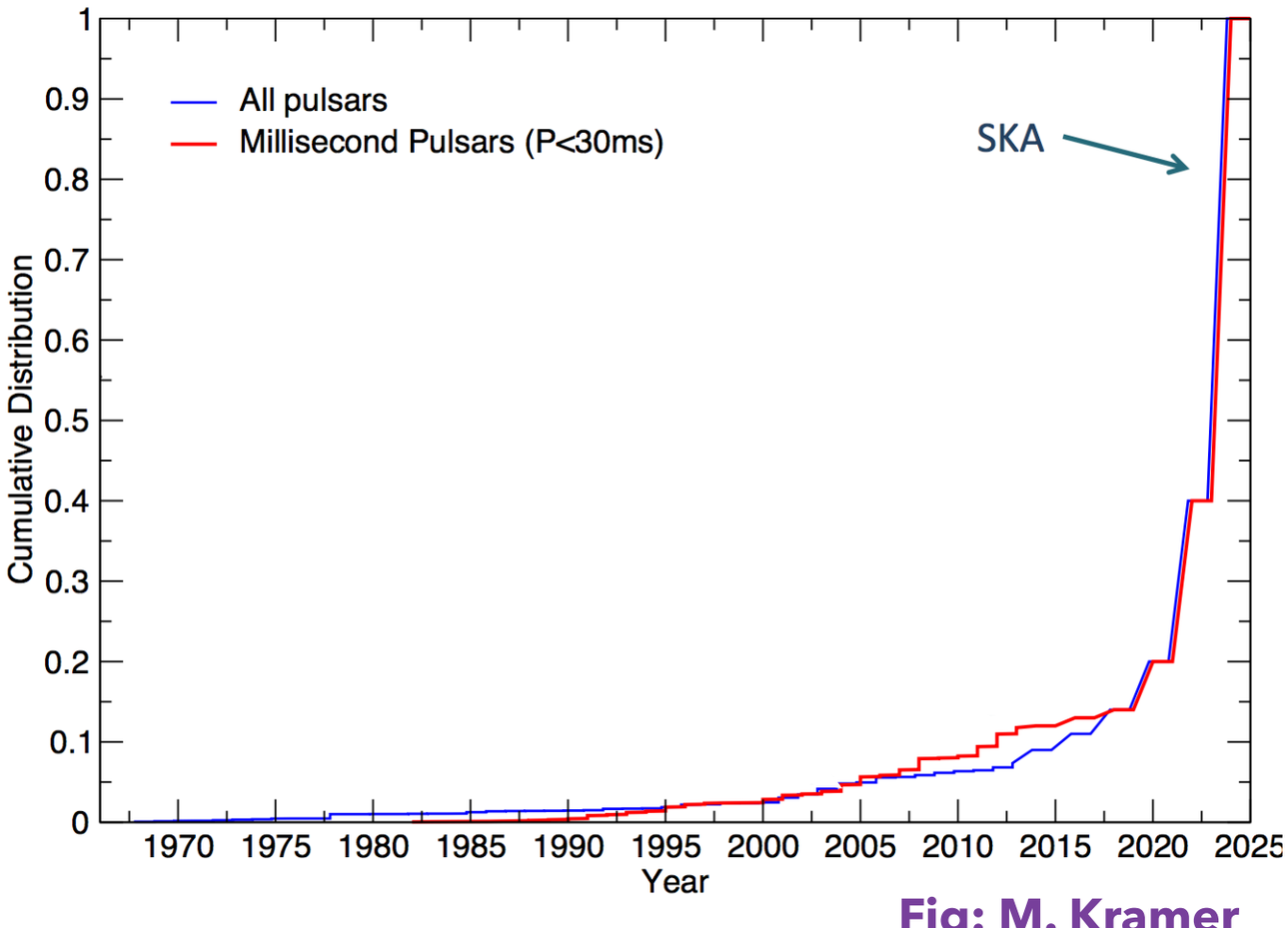

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Millisecond pulsar yield : ~3000 MSPs, 1000 in globular clusters

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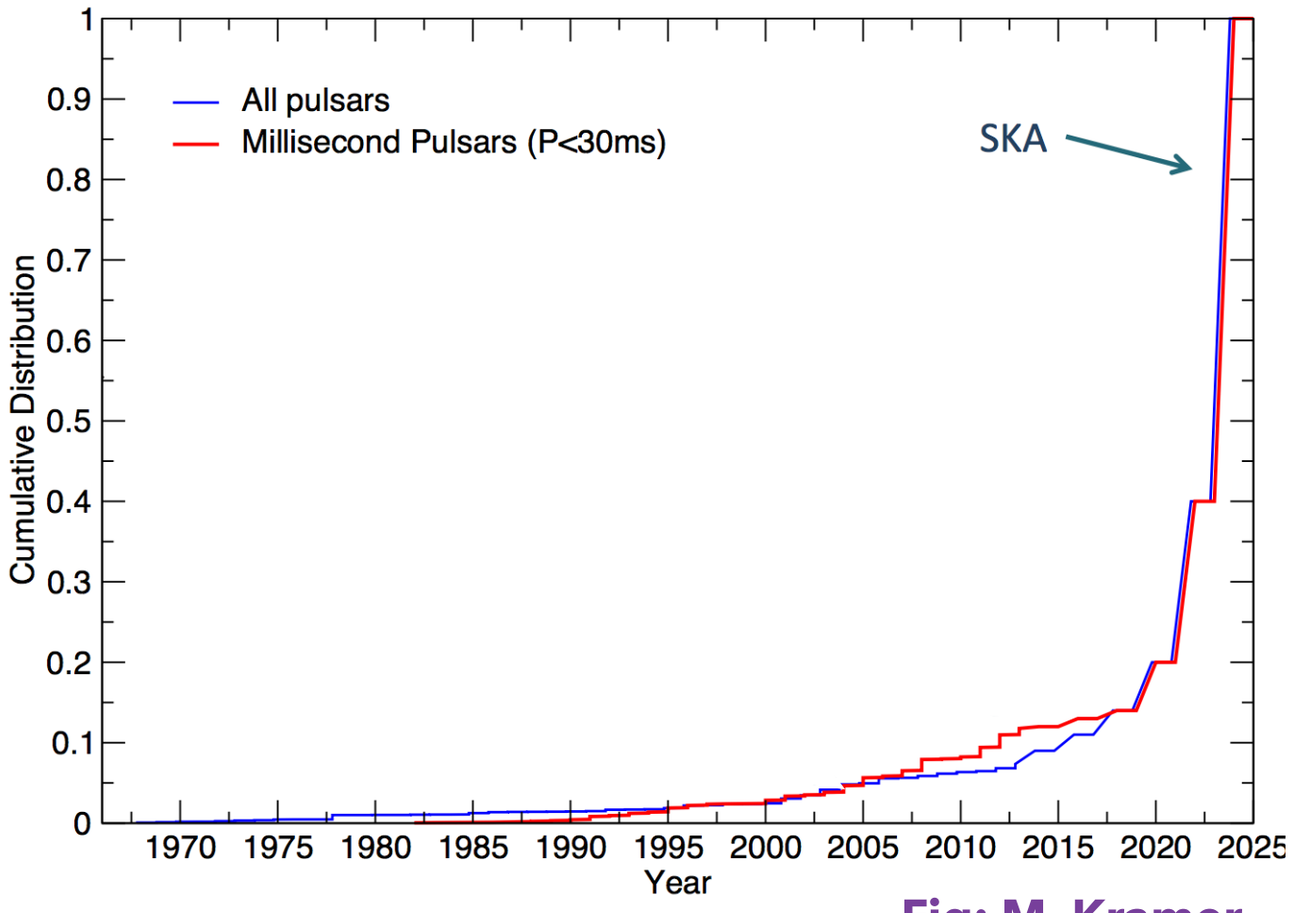

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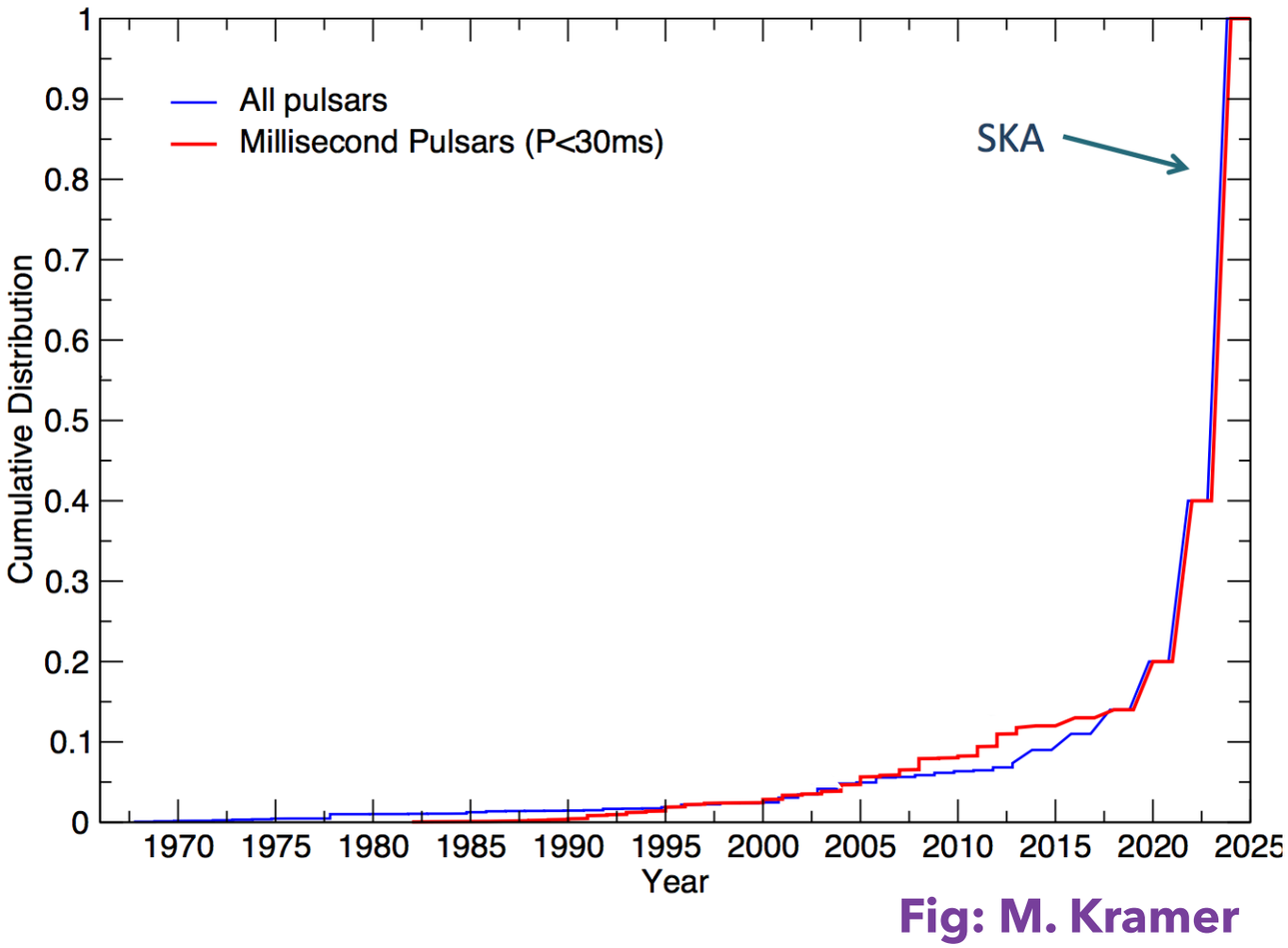

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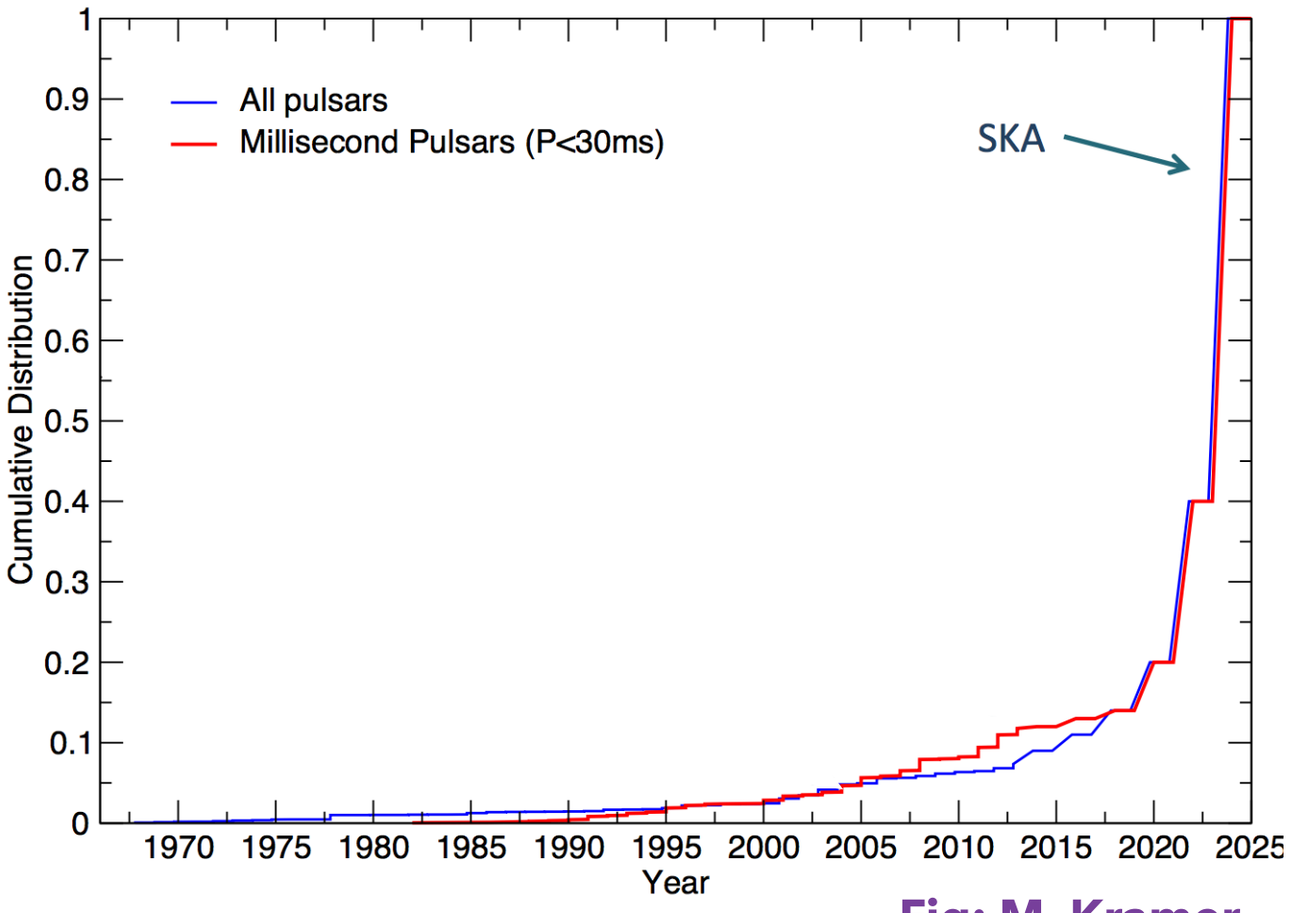

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Computational challenges: First we need to find PSRs

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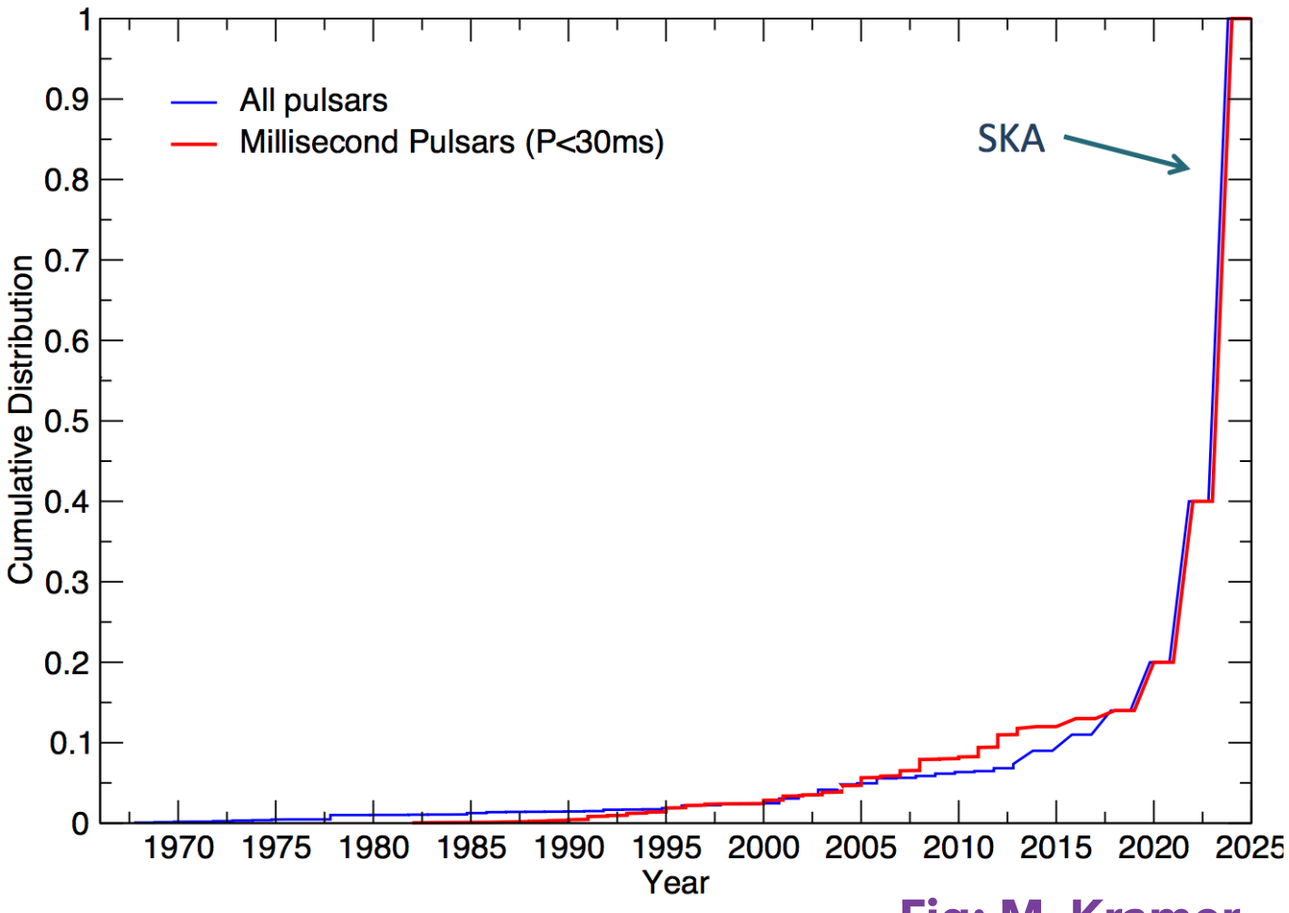

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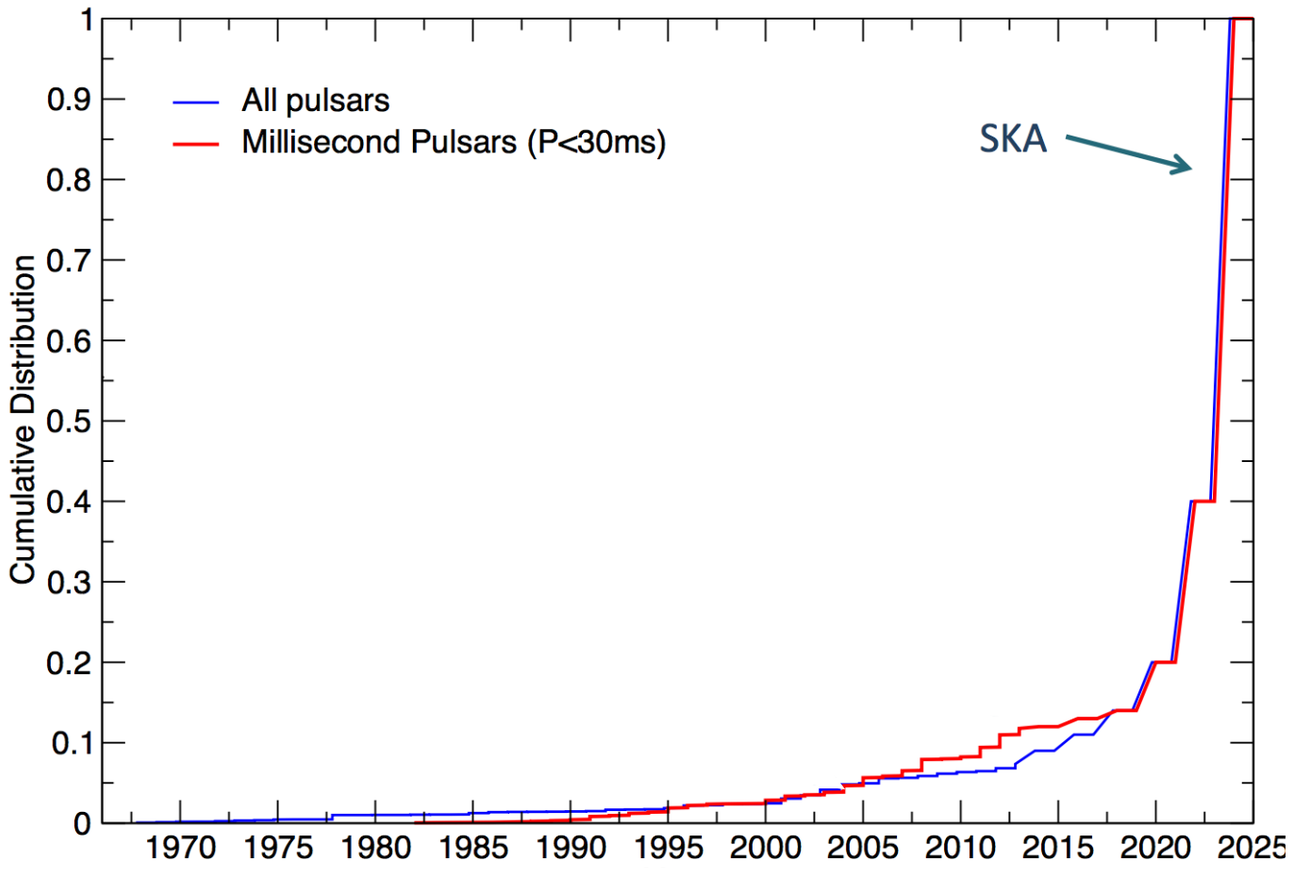

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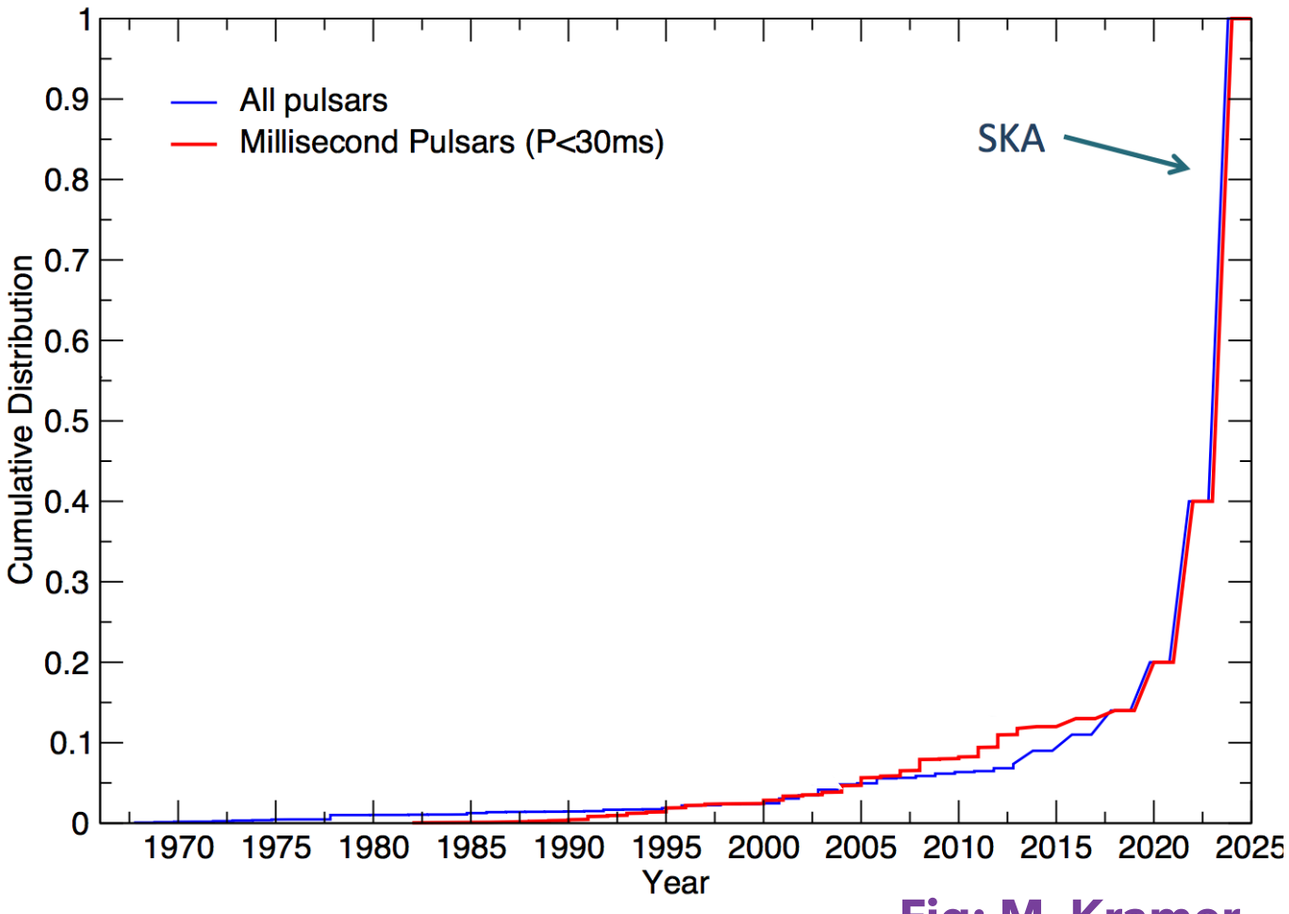

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Astron Hackathon

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NEW SKY
SURVEYS

NEW SKY SURVEYS

- **VLA Sky Survey (VLASS)** - 3 epochs of high cadence observation (4504 hr, 34000 deg2, 6 sources at SNR of 10/deg2)
  - First epoch commenced in this year in Sep.
  - 2-4GHz survey : Flat as well as modest spectrum sources

VLASS white papers , Bhakta et al. 2017

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- **NICER** Gendreau and Arzoumanian, *Nature Astronomy 1, (2017)*

Fantastic pulsars and how to find them?

Formation Mechanisms? Specific observation strategies.

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Sub-ms pulsars

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HOLY GRAILS

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MSP with planets

Formation Mechanisms? Specific observation strategies.

SUMMARY

- Population of MSPs has nearly doubled since 2010
- We expect a new burst in MSP discoveries with new surveys such as SKA
- New discoveries lead to diversity and **diversity in pulsar population translates to fantastic new probes of physics!**
- Extragalactic pulsars?
- Creative use of MSPs - scintillometry -
- Open to new finds during MSP searches such as FRBs and unknowns

Amruta Jaodand: amruta.jaodand@gmail.com
Tweet: @amrutajaodand

Acknowledgments

- **Plots supported by Matt Pitkin's Psrqpy package**
- **ATNF pulsar catalogue**
- **P. Freire's globular cluster catalogue**
- **D. Lorimer's Galactic MSP catalogue**
- **A.Patruno's MSP catalogue**
- ***Jason Hessels for guidance!***
- **Wonderful reviews**