Precision astrometry, neutron stars and fundamental physics

Tom Maccarone

Texas Tech University

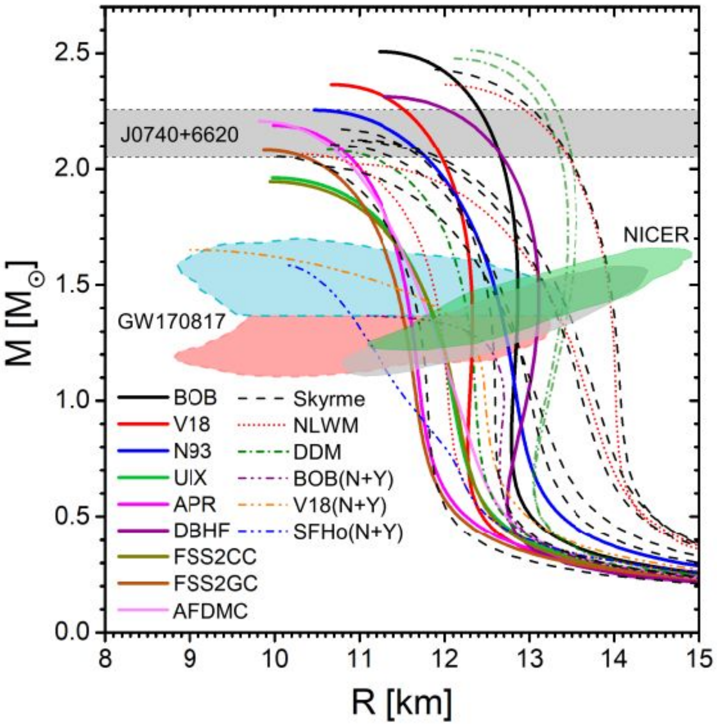
Department of Physics & Astronomy

Goals

1) Equation of state of dense, cold matter
2) Understanding binary evolution
3) Making better use of timed pulsars for PTA searches

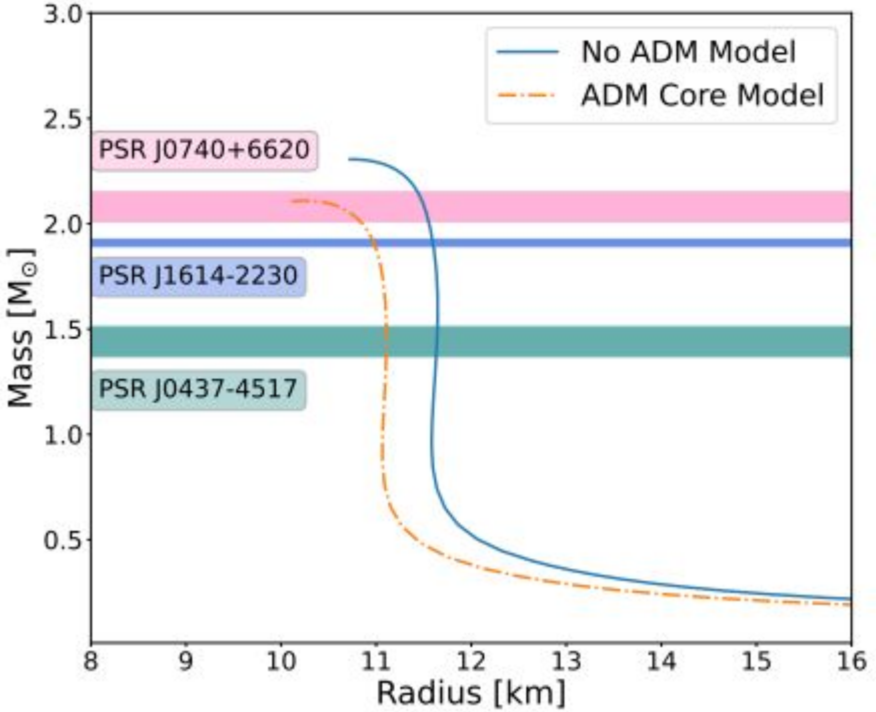
Neutron stars as probes of nuclear physics

- Probe cold, dense matter (accelerator experiments can probe hot dense matter)
- A variety of techniques work
  - High mass neutron stars
  - AIC formed neutron stars
  - Measure both mass and radius
  - Measure moment of inertia
- Finite number of curves in these diagrams is wishful thinking
- Key questions: How do 3-body forces work? Do hyperons exist? How do hyperons interact?



Burgio et al. 2021

Dark Matter and Neutron Stars



Rutherford et al. 2024

- Dark matter in neutron stars can affect equation of state
- Gives possibility of multiple radius values at a given mass

Limitations of distance independent approaches (that don't need Theia)

Gravitational waves:

Get moment of inertia from waveforms

May not have higher mass NS merging

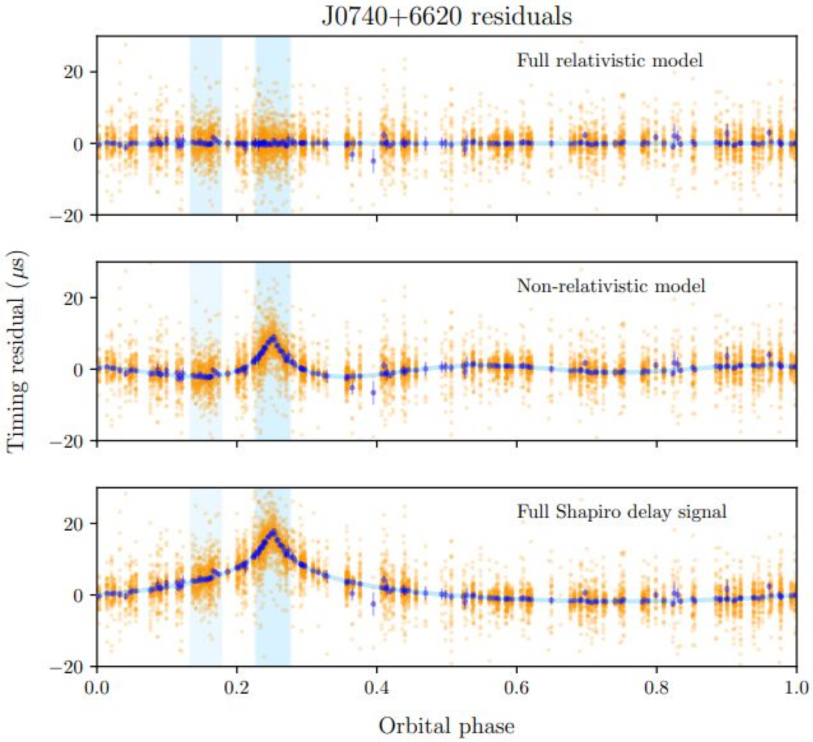
Tidal deformability scales as M^6

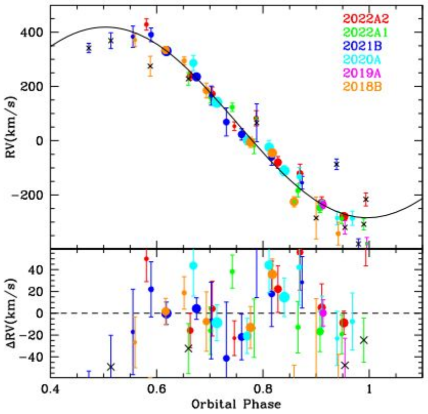
Maximum masses of pulsars

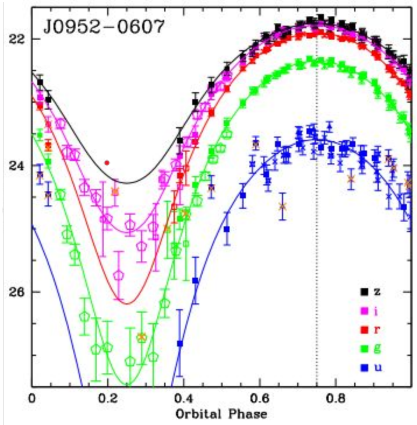
No radius information, different equations of state have similar maximum masses, not clear maximum mass is reached often

Distances can still help!

Mass measurements of neutron stars

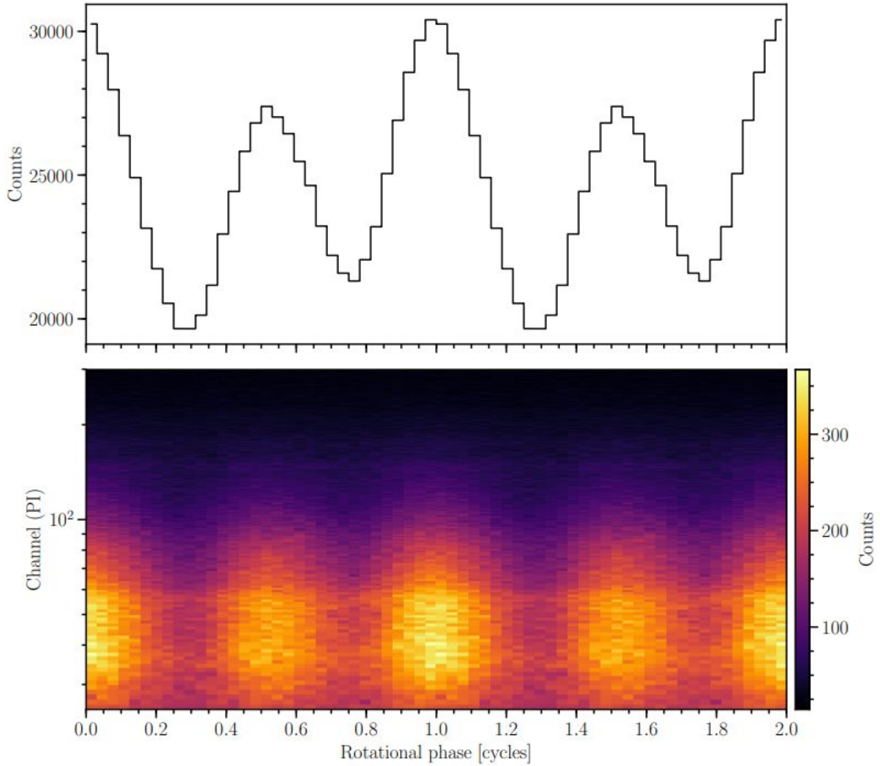


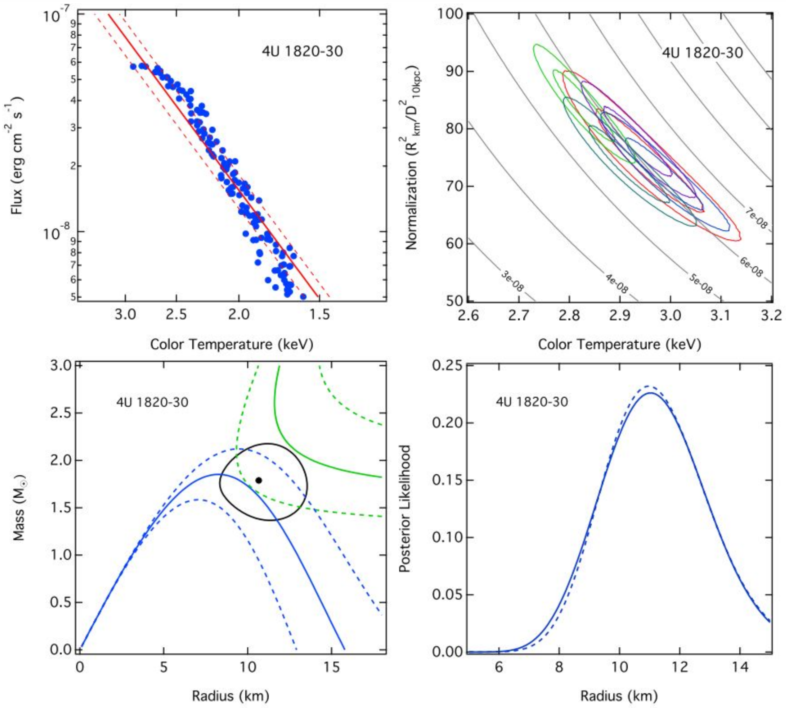




Cromartie et al. 2020; Romani et al. 2022

Radius measurements





Left: Riley et al. 2019; Right:Özel et al. 2015

Alternative approaches, which need distances

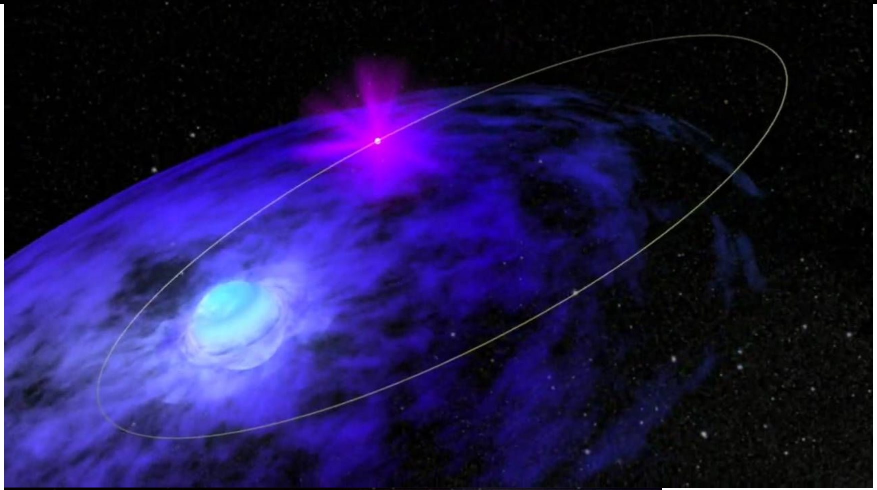
Minimum masses of neutron stars

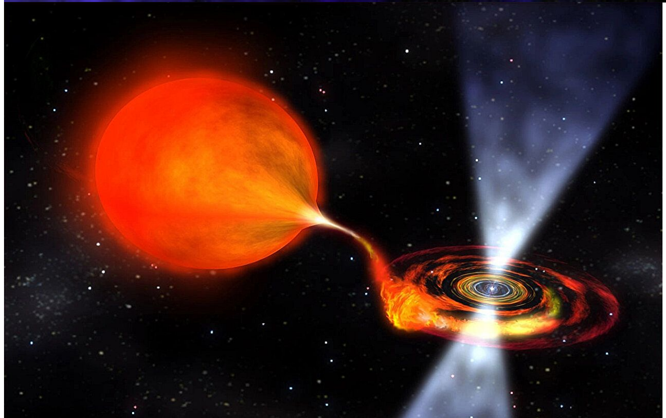
Harder maximum mass problems

Measure masses & radii (shown before, but improved with good distances)

Minimum masses

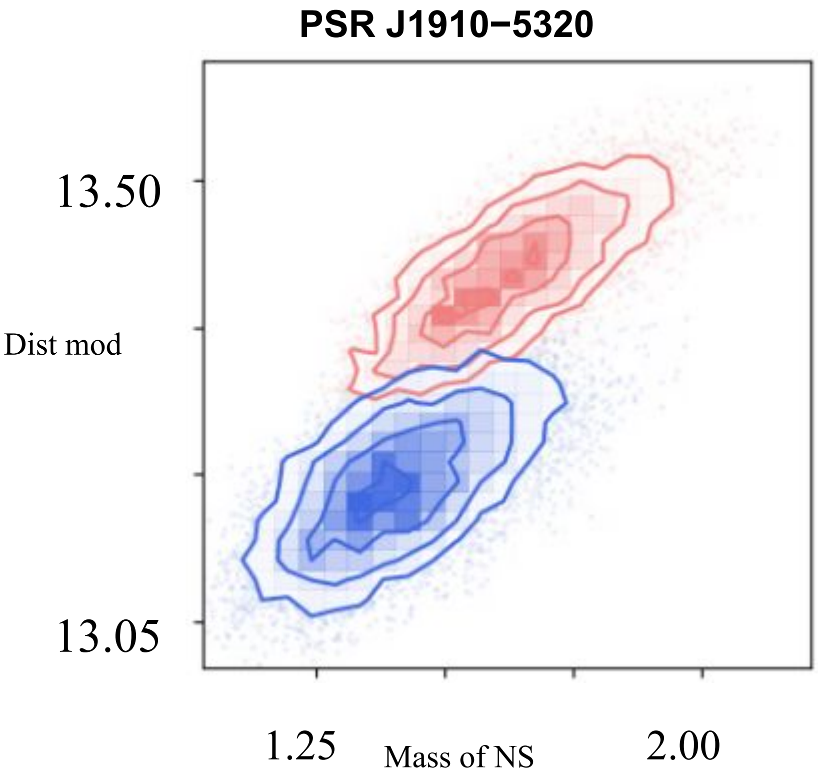
- Electron capture supernovae/accretion induced collapse
  - NS mass should be Chandrasekhar - binding energy
- Circular Be X-ray binaries should have these neutron stars (Pfahl et al. 2002)
- Several of these exist. Two best cases are d<1 kpc, P>100 days
- Also about 5 symbiotic X-ray binaries (Lü et al. 2012)
- Not enough time to accrete more in either case



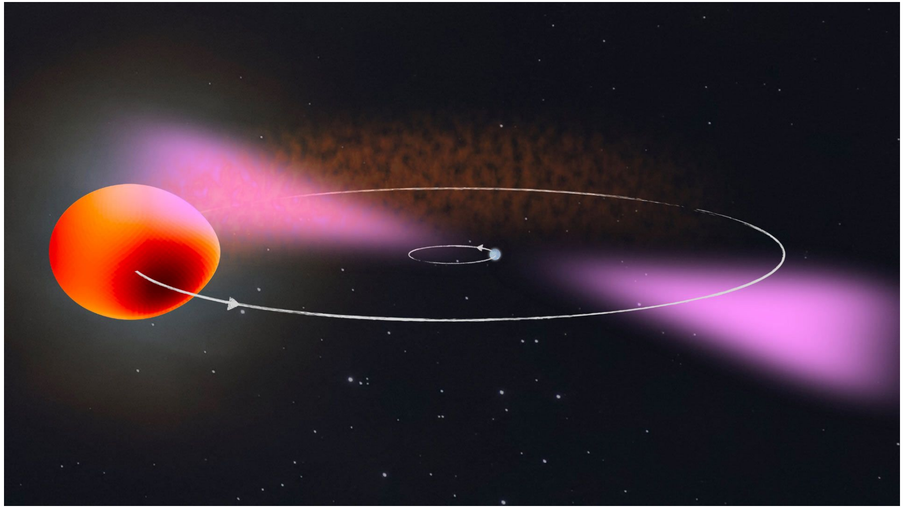


NASA

Redback pulsars (distances break degeneracies)

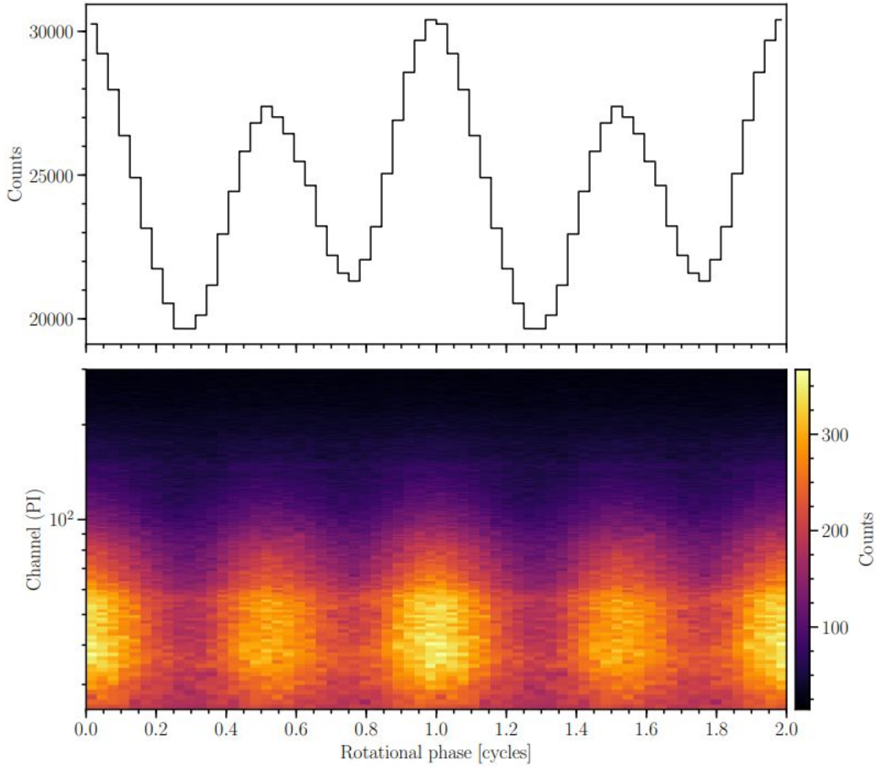


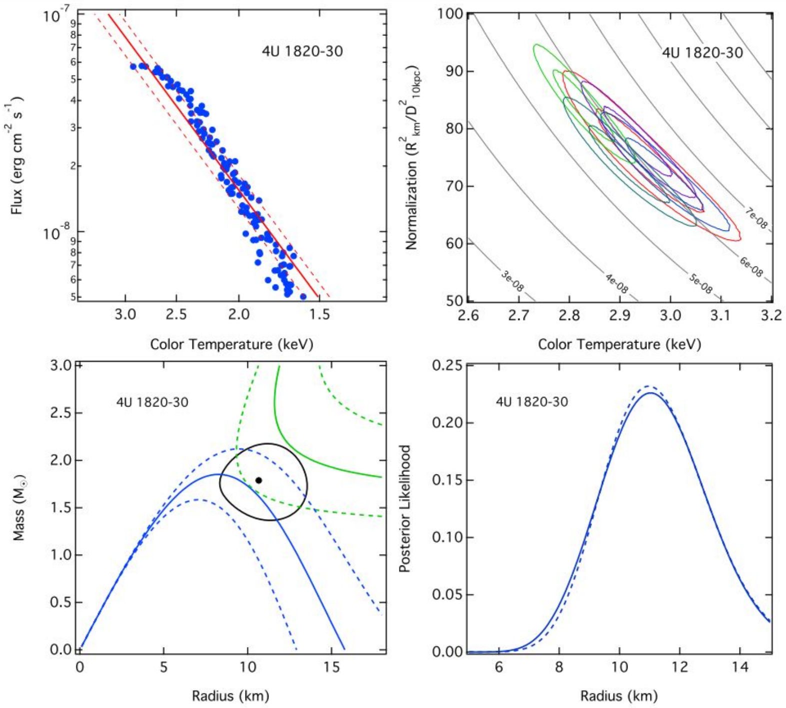
Dodge et al. 2024



MPIFGP/NASA GSFC

Radius measurements benefit from distance measurements





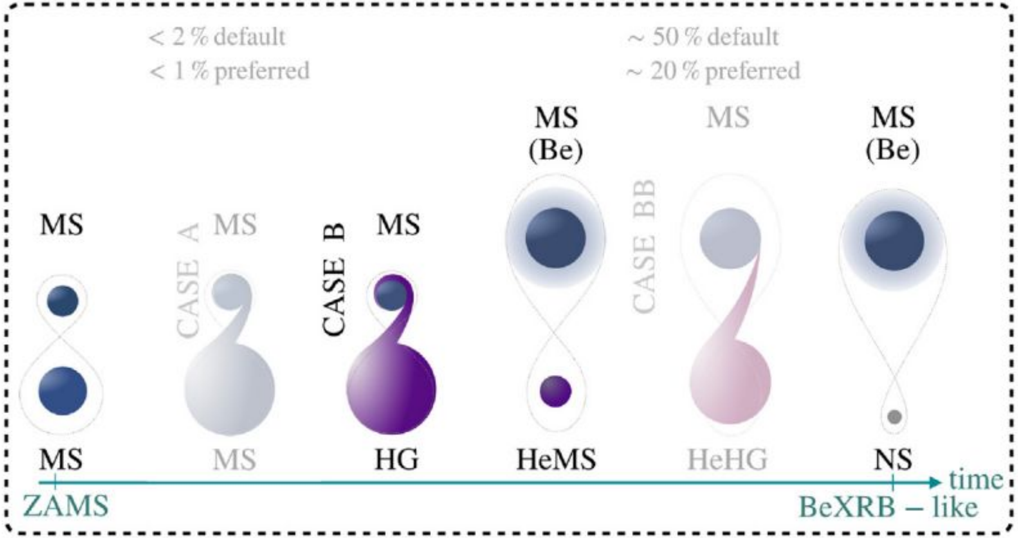
Left: Riley et al. 2019; Right:Özel et al. 2015

Evolution of binary stars

Precise donor and accretor masses

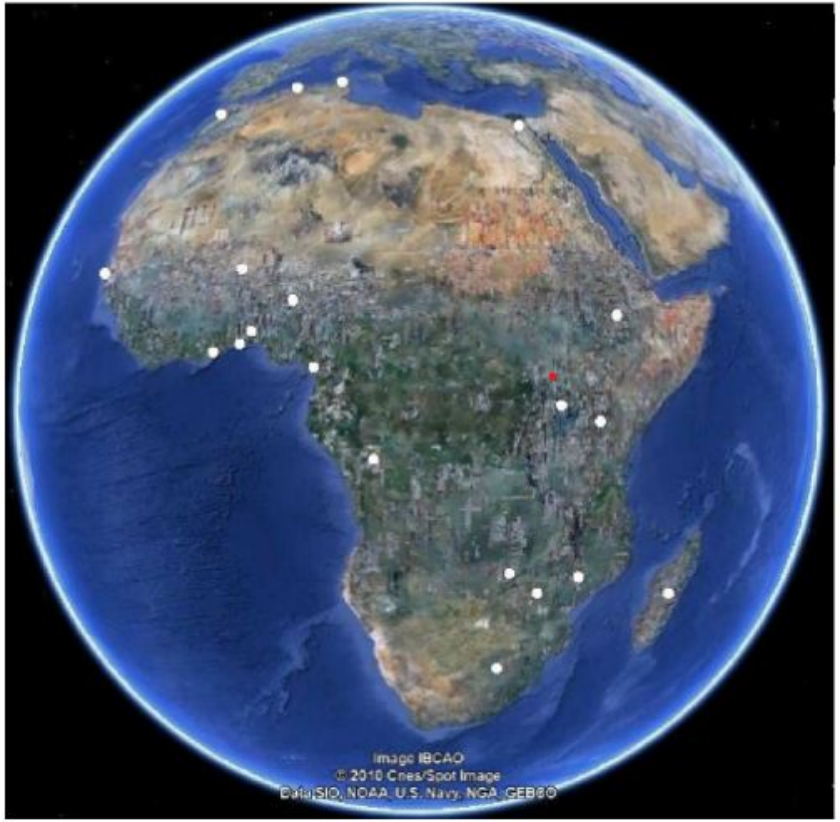
Astrometry and pulse timing

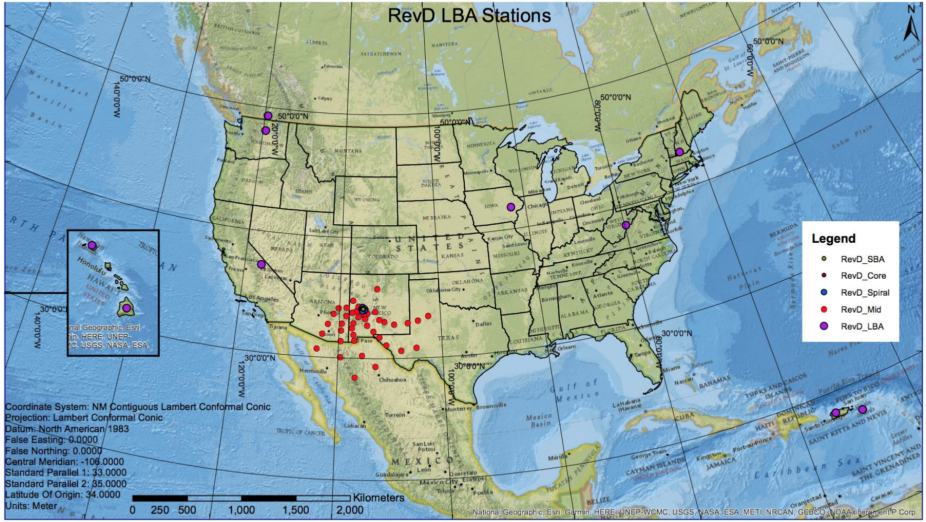
For long period systems, optical spectroscopy can be unreliable



Vinciguerra et al. 2020

Radio astrometry





SKA better for finding new pulsars, ngVLA better for astrometry, so optical may be needed in many cases

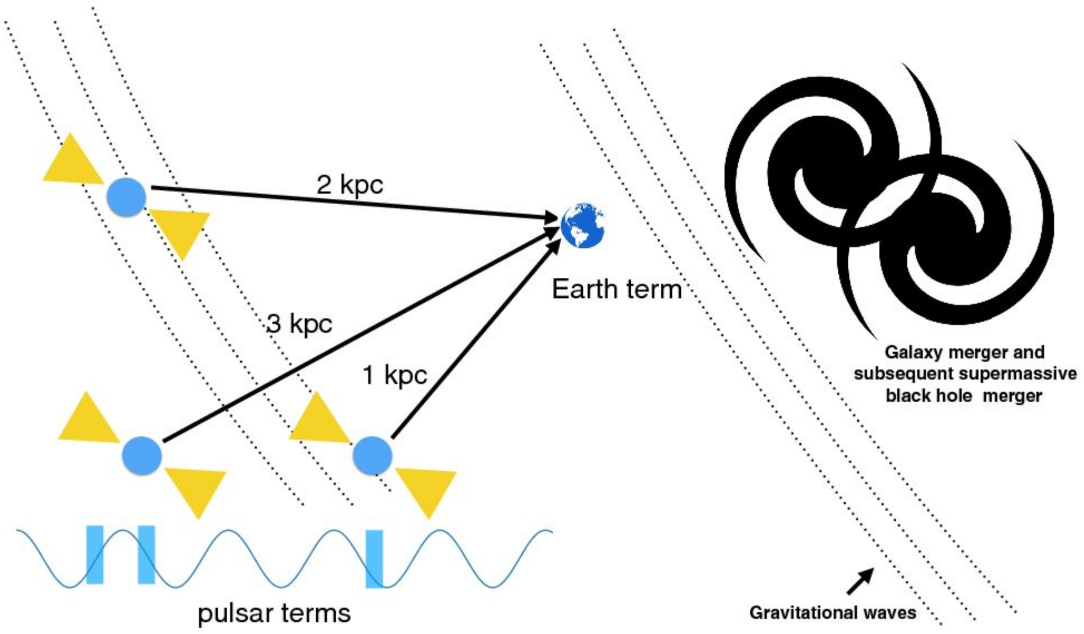
Improving Pulsar Timing Arrays

Currently, use just Earth term

With ~1 pc distances, can use source term, too.

May be possible for "spiders"

(Swihart et al. 2022,Voisin et al. 2020)



Burke-Spolaor et al 2019

Conclusions

A variety of fundamental physics and astrophysics can be done with optical astrometry of neutron star binaries

Most of this work cannot be done any other way