

An aerial photograph of the Effelsberg radio telescope, a large parabolic dish antenna, situated in a dense forest. The dish is oriented towards the upper right. To the left of the dish, there are several small buildings and a road. The entire scene is overlaid with a semi-transparent dark blue rectangle containing white text.

Searching for and timing a pulsar – black hole system

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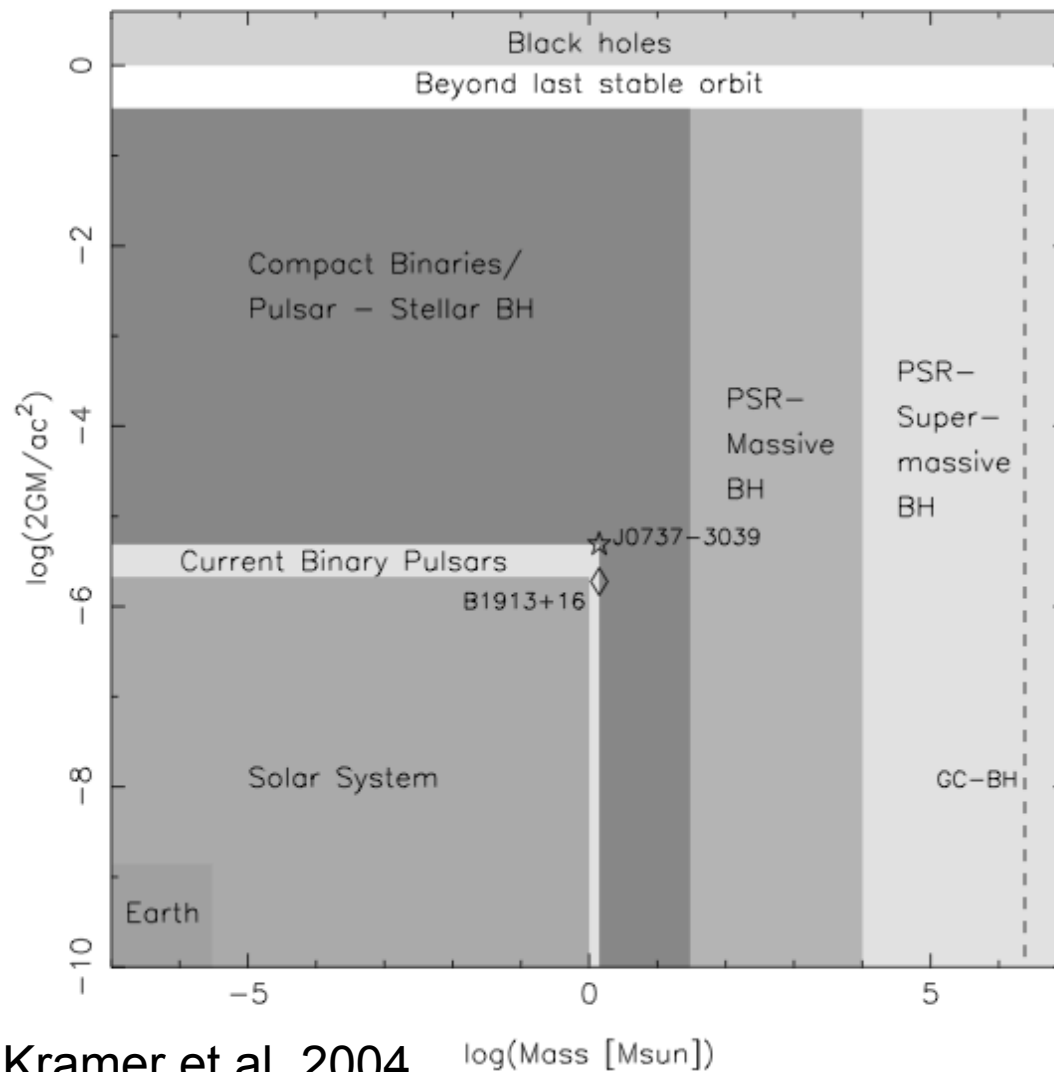
Outline

- The PSR-BH population
 - Are there any?
 - Where are they?
- Pulsar surveys and sensitivity to PSR-BH systems
 - Brief introduction to searches
 - Techniques and sensitivity limitations
- Timing a PSR-BH
 - Brief introduction to timing
 - See Norbert's talk

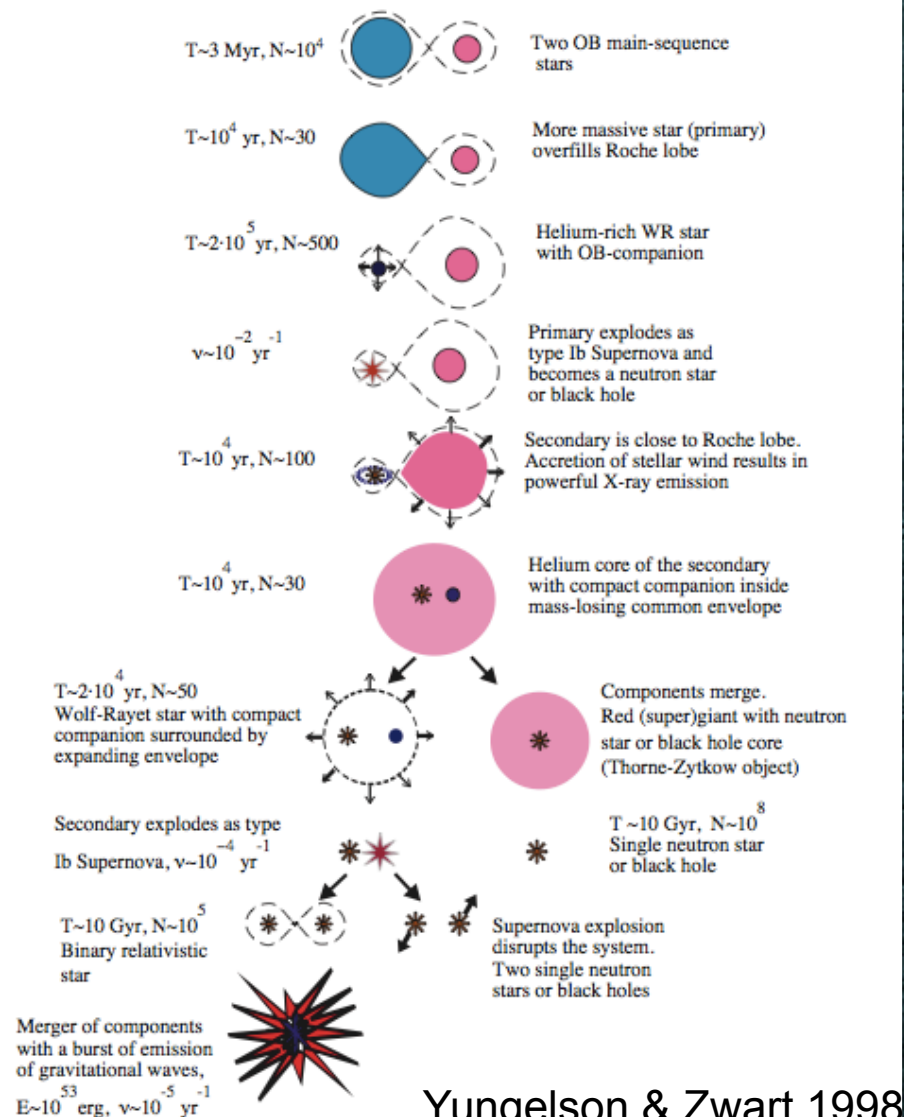
An aerial photograph of a large radio telescope dish, likely the Arecibo radio telescope, situated in a dense, forested landscape. The dish is a large, white, parabolic structure supported by a complex metal framework. To the left of the dish, there are several small, white, rectangular buildings. The surrounding area is covered in thick green trees, and a winding road or path is visible in the lower left. A semi-transparent black rectangular box is overlaid on the center of the image, containing the text "The PSR-BH population" in white.

The PSR-BH population

Mass and orbit size



Potential formation scenarios: an example



Yungelson & Zwart 1998

Formation in high density regions

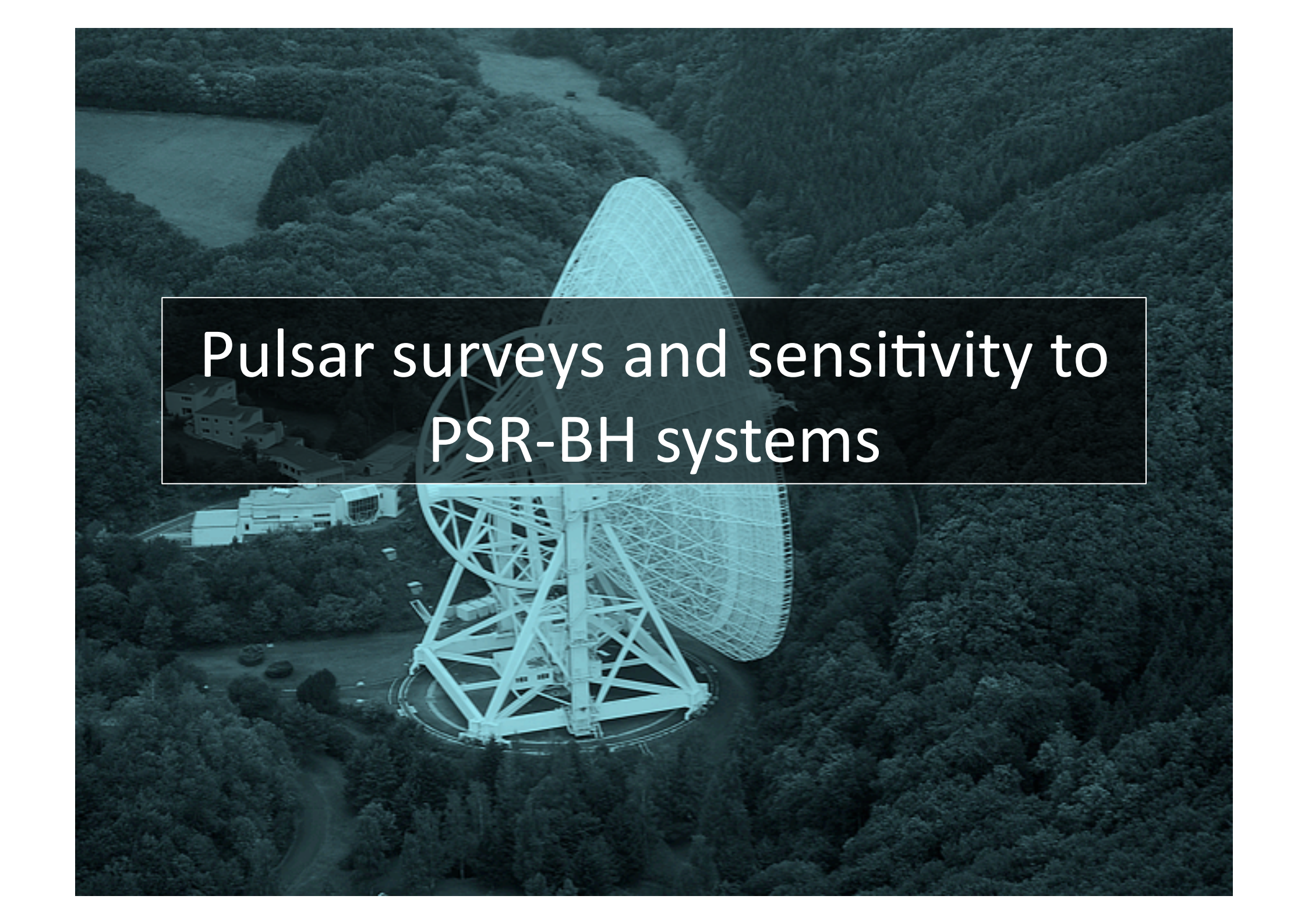
- Globular clusters and the Galactic centre are sufficiently dense for 3-body interactions to occur
- PSR-BH systems could be created by a series of interactions
- Sigurdsson 2003
- Even in the plane hierarchical triples may produce PSR-BH systems

Population synthesis

Study	Birthrate x 10^{-5}yr^{-1}		Galactic population	
	BH-NS	NS-BH	BH-NS	NS-BH
Bethe & Brown (1998)	~10	-	~2000	-
Portegies et al. (1998)	0.6 – 18.7	-	120 – 3740	-
Nelemans et al. (2001)	2.6	-	520	-
Belczynski et al. (2002)	-	-	~400	-
Sipior & Sigurdsson (2002)	0.02 – 3.1	0 – 0.063	4 – 620	0 – 63
Voss & Tauris (2003)	0.11	0.063	22	63
Sipior et al. (2004)	0.65 – 14	0.005 – 16	130 – 13000	5 – 160000
Lipunov et al. (2005)	-	-	~270	-
Pfahl et al. (2005)	-	0.0002 – 1.1	-	0.2 – 1100

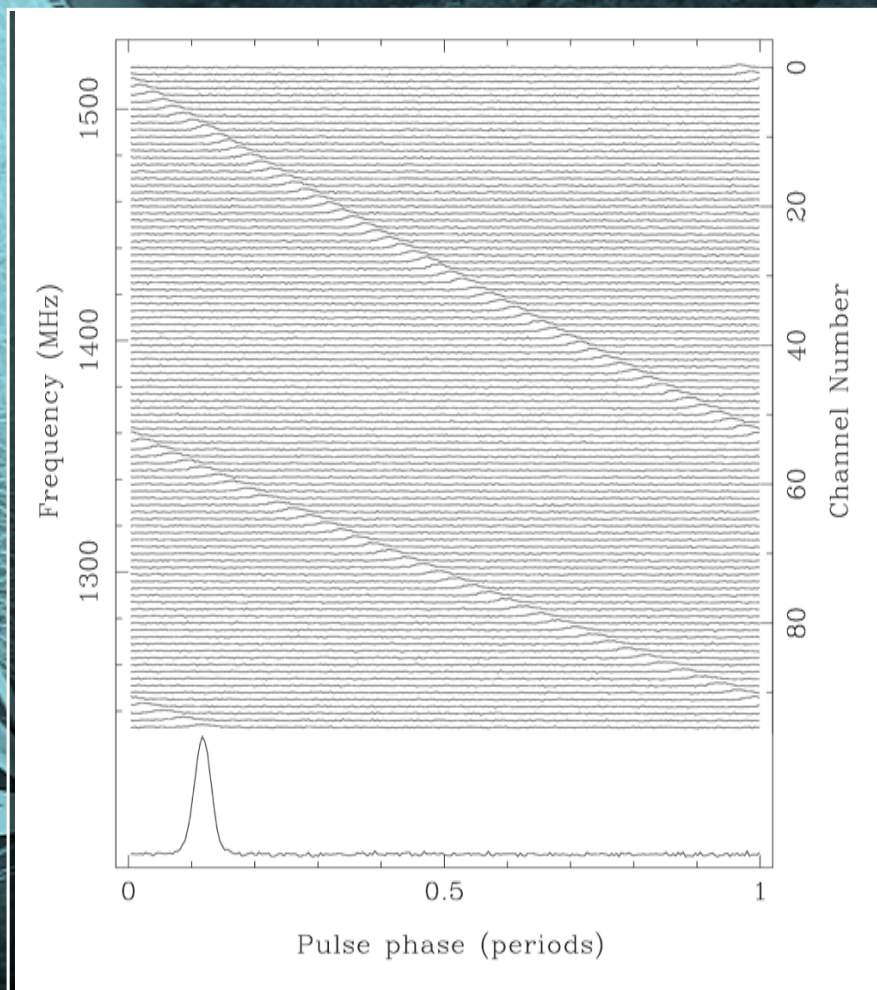
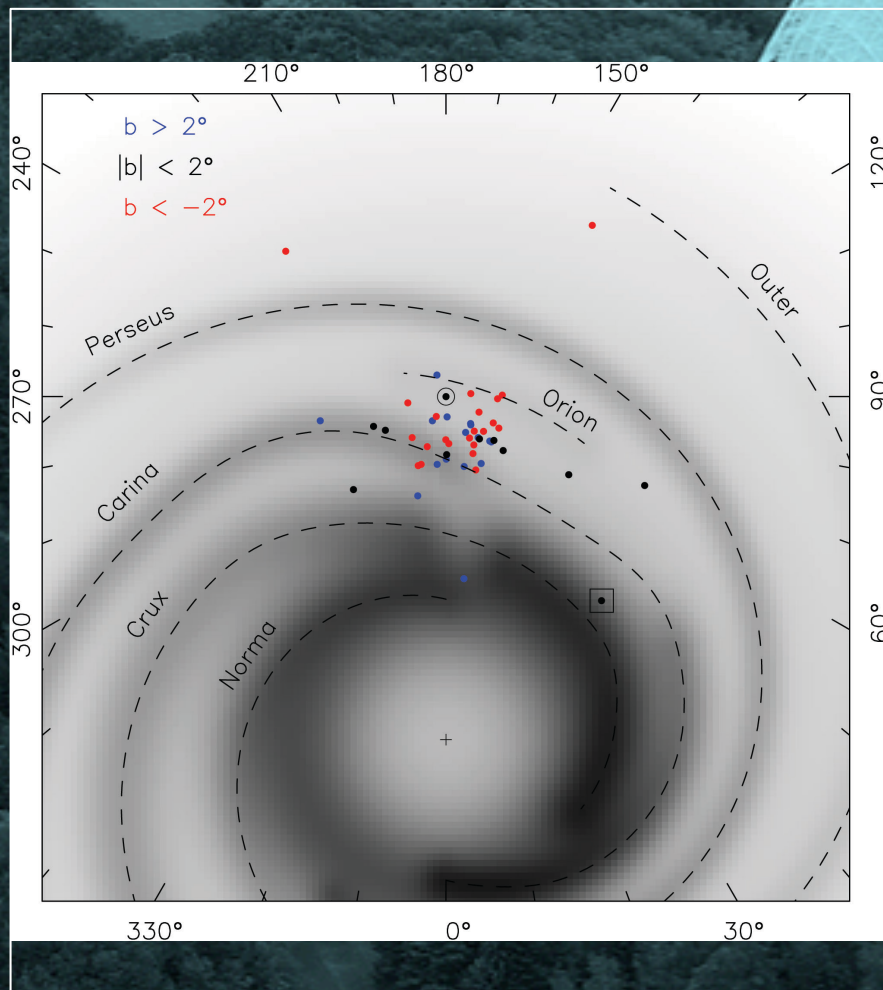
PSR-BH systems

- Are there any?
 - Yes, no, maybe
- Where will they be?
 - In the plane
 - In globular clusters
 - In the Galactic centre

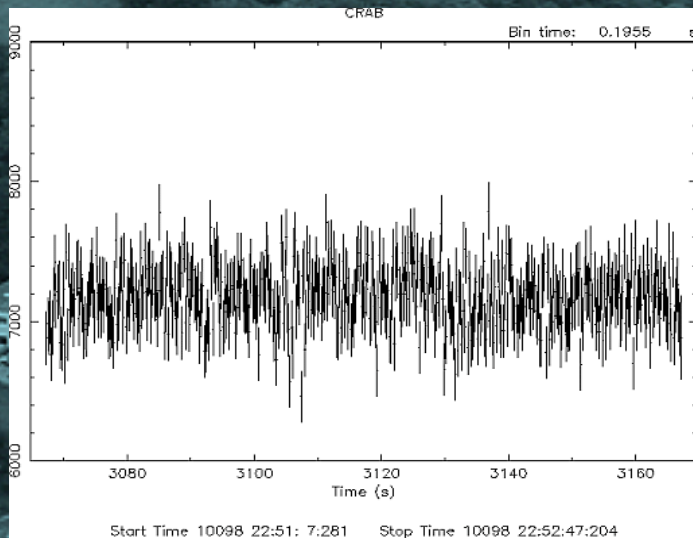
An aerial photograph of a large radio telescope dish, likely the Arecibo Observatory, situated in a dense forest. The dish is a complex metal structure with a large, curved surface. To the left of the dish, there is a small cluster of buildings and a paved area. In the upper left corner, a body of water is visible. The entire scene is captured in a dark, teal-toned aerial view.

Pulsar surveys and sensitivity to PSR-BH systems

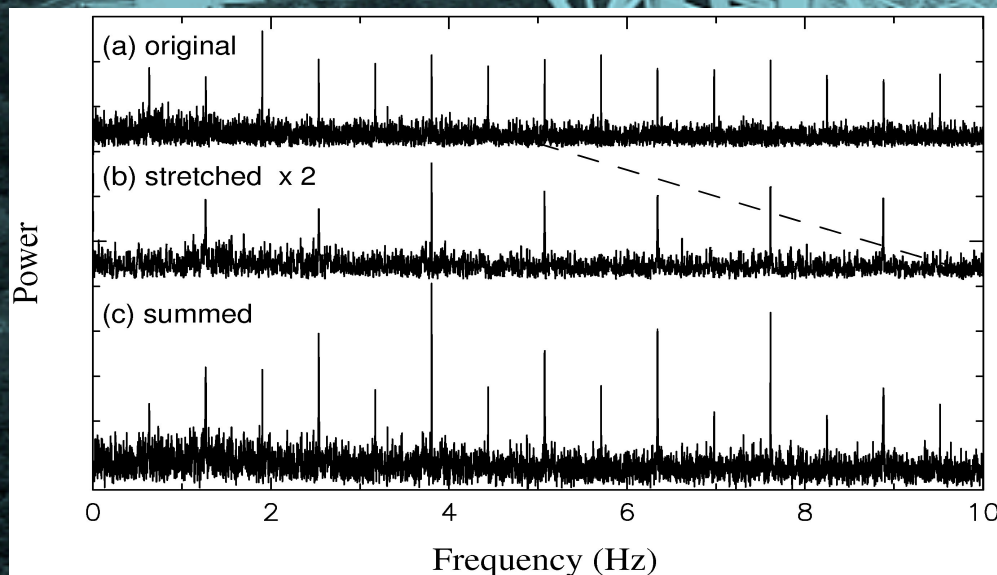
Dispersion



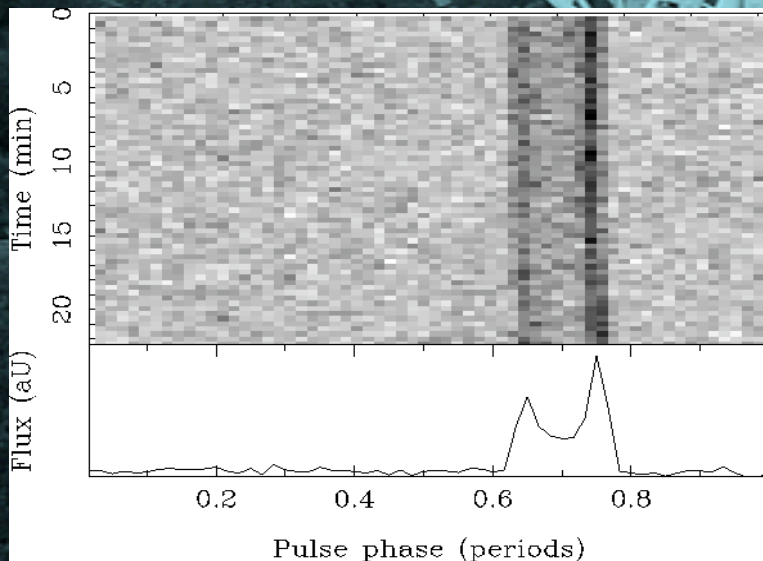
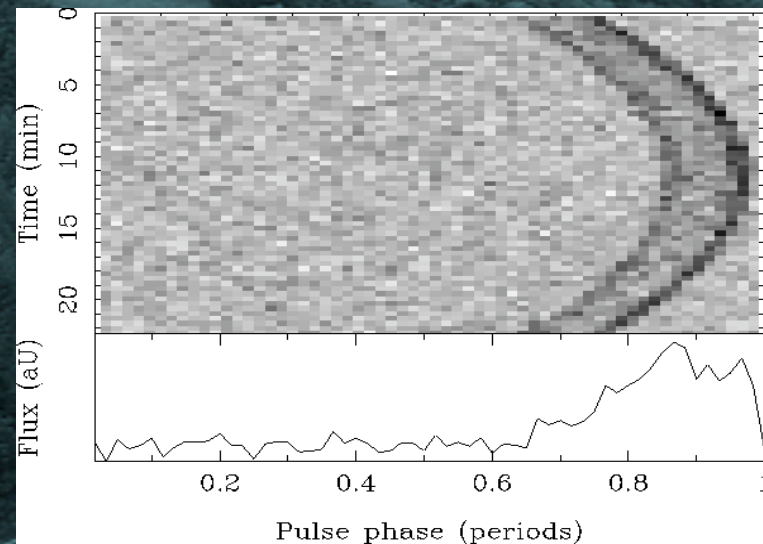
Searching for periodic signals



- Single pulses are very weak.
- FFTs are used to detect periodic signals in the time series.
- Harmonic summing increases detectability of low duty cycle pulsars.



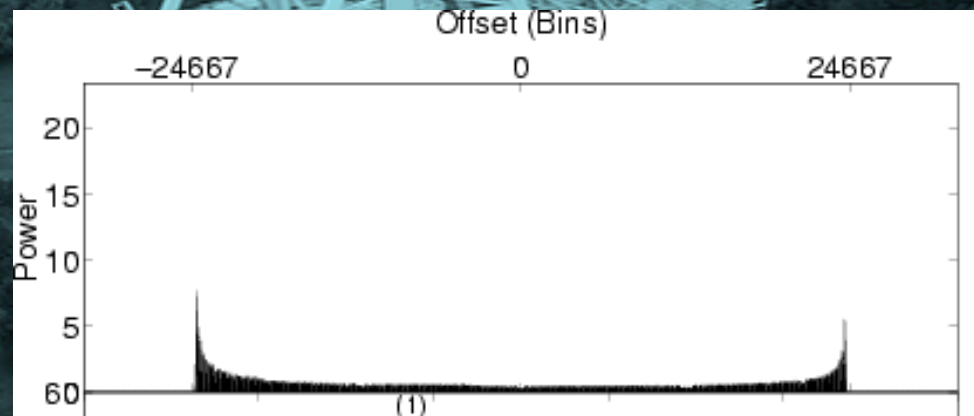
Acceleration searches



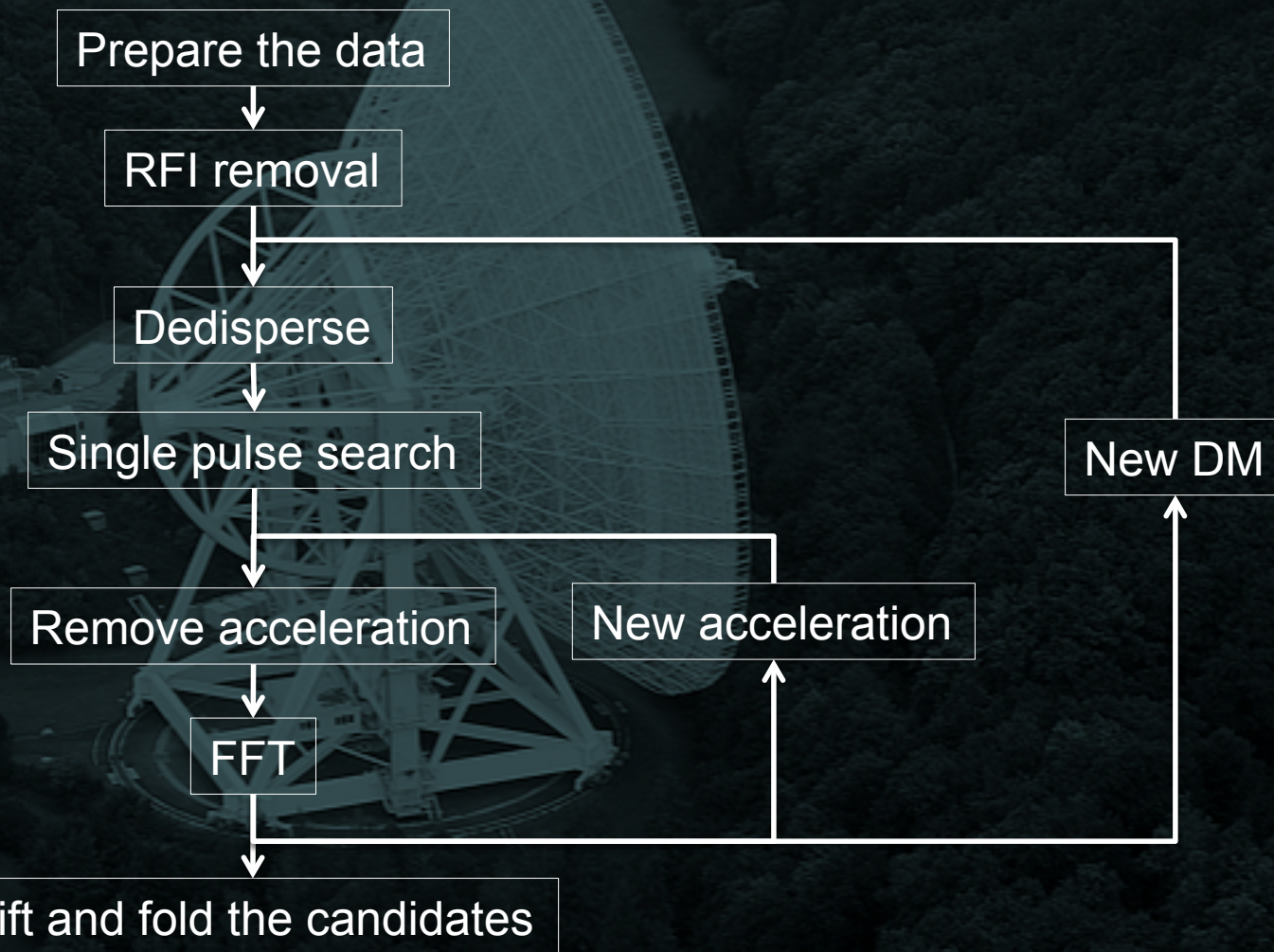
- Pulsars in a binary orbit are accelerated.
- Acceleration smears out the pulse over the period of the observation.
- The pulsar becomes less detectable.
- By searching in acceleration space the signal strength can be recovered.
- Longer observation would require a second derivative.

Binary searches in Fourier space

- Different binary periods will produced specific power distributions in Fourier space
- This power is lost in normal searching
- Using matched filters this power can be summed up and used to estimate the acceleration



An example pipeline



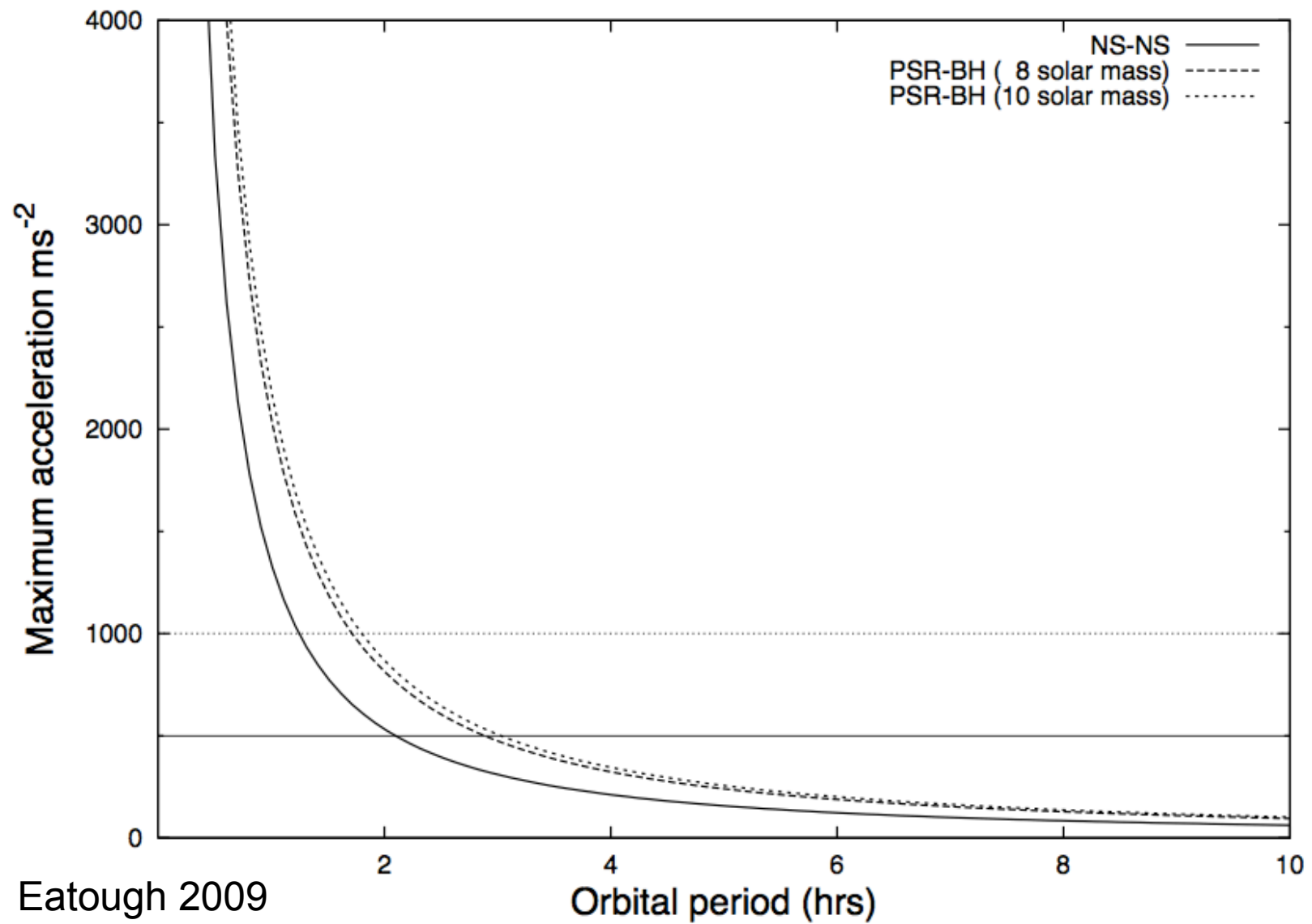
Computational limits

- Processing required to reduce one beam of data: Operations = $N_{\text{Samp}}^3 \log N_{\text{Samp}}$
- Current surveys (e.g. HTRU) require ~ 150 teraFLOPS for realtime processing
- The SKA Phase 1 survey will require ~12 petaFLOPS for realtime processing
- There are currently ~35 petaFLOPS in the World

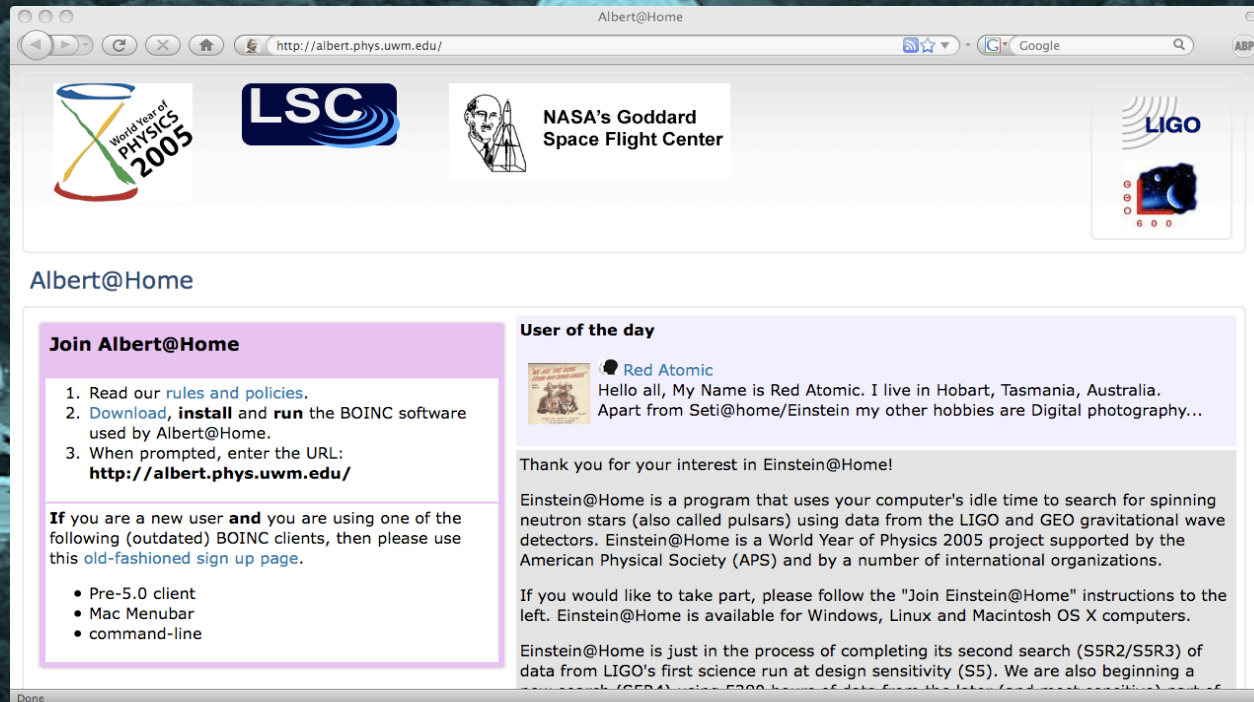
Orbits detectable

- $P_{\text{MinBin}} = 10 T_{\text{Obs}}$ (depending on orbital phase, eccentricity etc)
- For HTRU and SKA P1 $P_{\text{MinBin}} = 5 \text{ hr}$
- For PALFA $P_{\text{MinBin}} = 50 \text{ min}$
- Splitting observations increases sensitivity to short orbital periods (and helps with computer power)
- Some power can be regained by incoherent addition of parts (e.g. stack slide)

PSR-NS vs. PSR-BH



Very short orbital periods

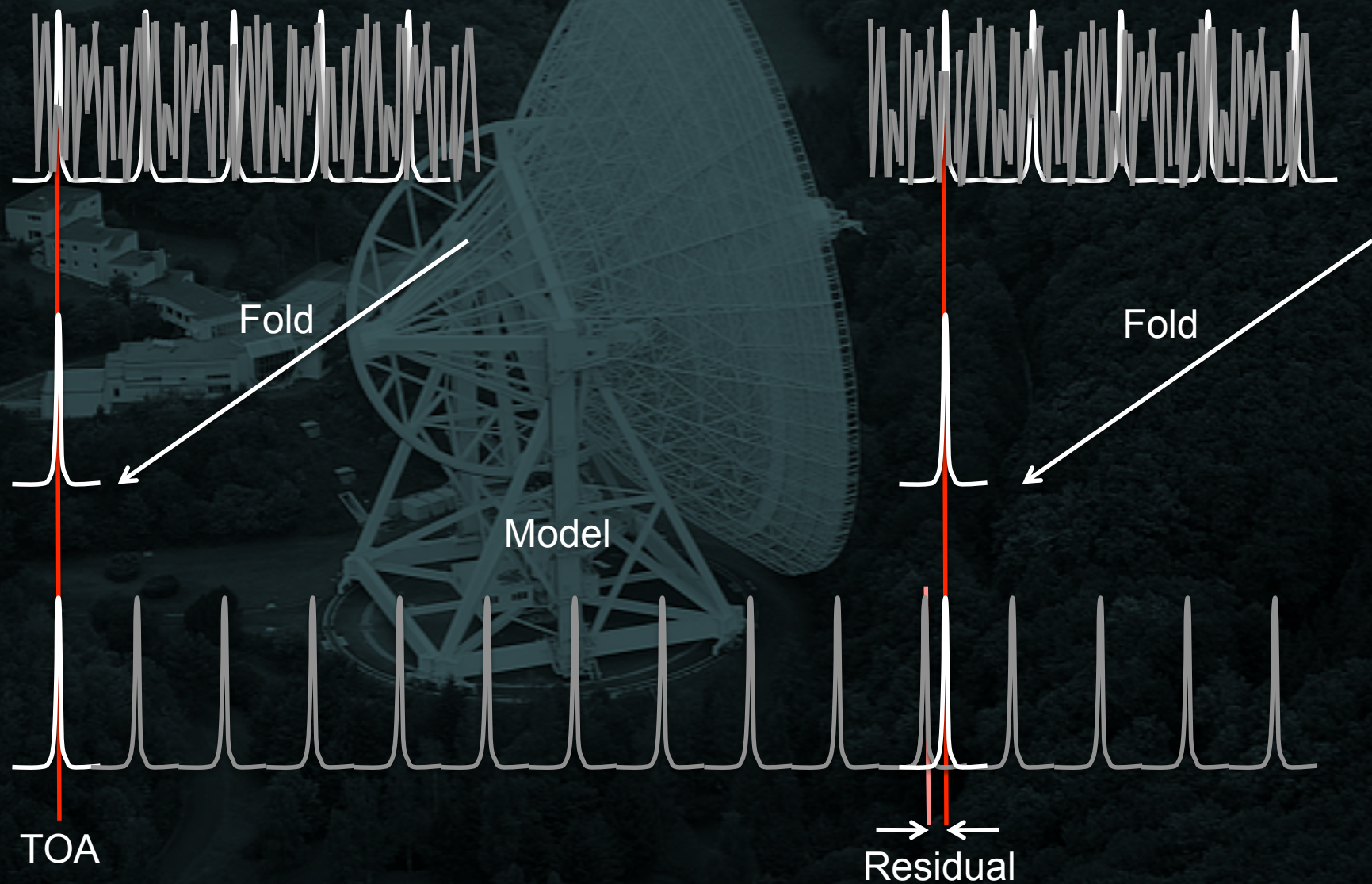


- Trials of P_{Bin} , $A \sin i$, T_0 used to remove orbit
- Non-unique solutions reduce trials required
- Sensitive to short period binaries
- Very computationally expensive, short pointings only

An aerial photograph of a large radio telescope dish, likely the Arecibo Observatory, situated in a dense forest. The dish is a complex structure of white metal trusses forming a large paraboloid. To the left of the dish, there are several small, light-colored buildings. The entire scene is surrounded by thick green trees. A semi-transparent rectangular box is overlaid on the center of the image, containing the word "Timing" in white text.

Timing

Pulsar timing



The pulsar model

- Phase
- Period
- Period derivative (and epoch)
- RA
- Dec
- Any binary parameters
- Proper motion (and epoch)
- Parallax
- But must correct for Earth motion first

Conclusions

- PSR-BH/BH-PSR populations are uncertain
- Current survey data is sensitive to PSR-BH systems (even PMPS)
- Current search pipelines are limited in sensitivity for short orbital periods (ex PALFA)
- Going deeper with Arecibo and SKA will suffer the same problem
- Improving sensitivity requires much more computer power