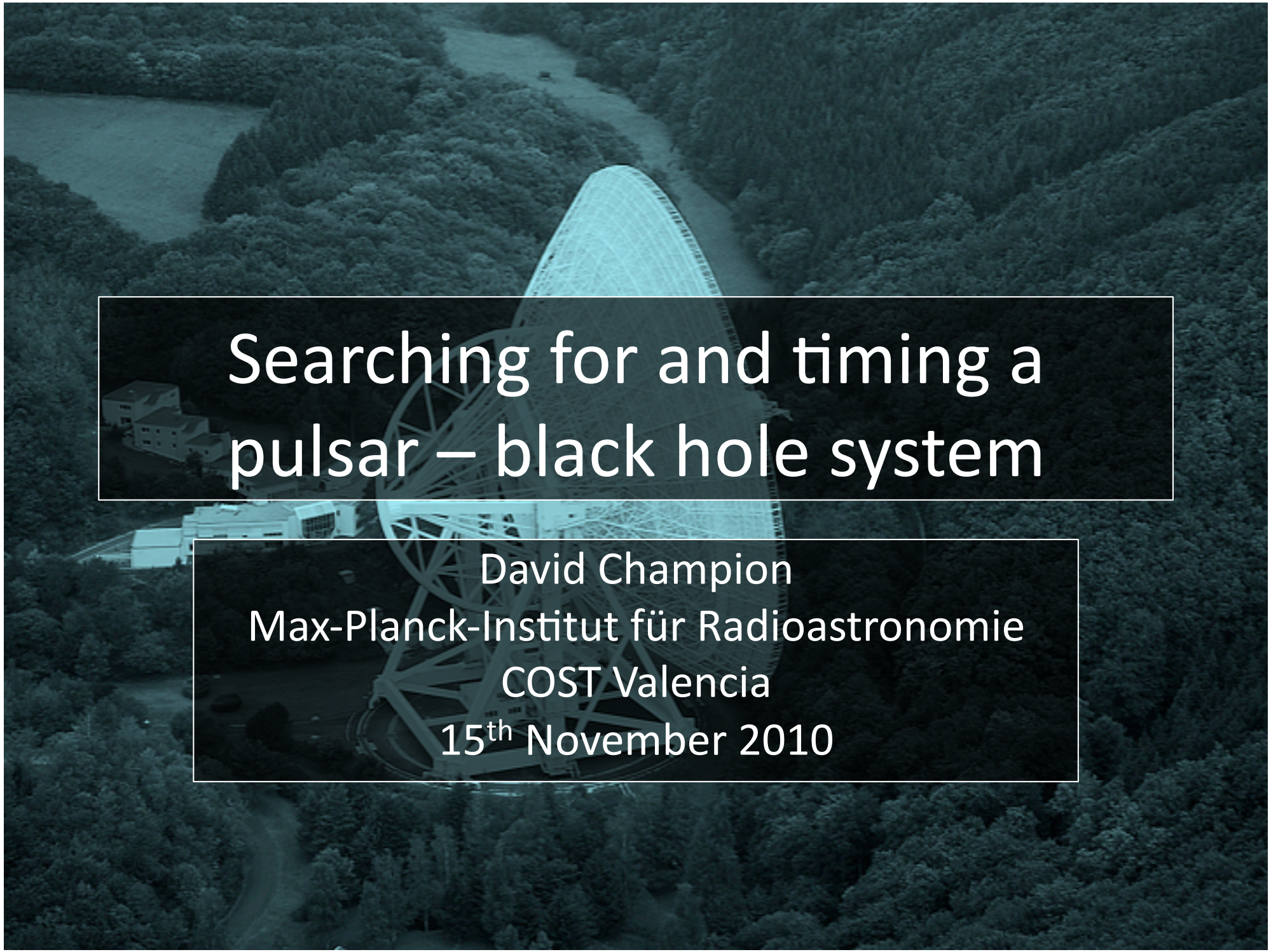
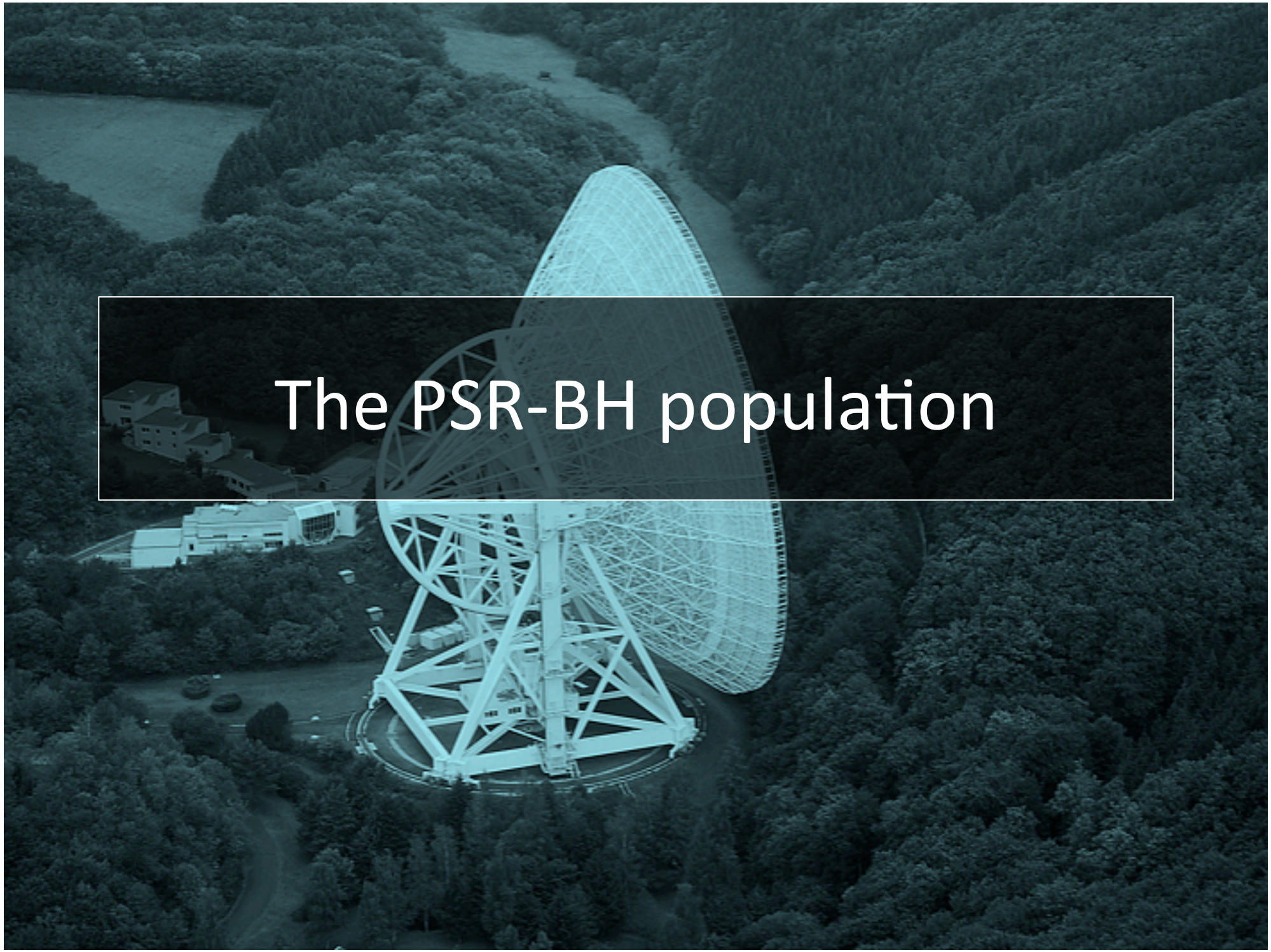


Searching for and timing a pulsar – black hole system

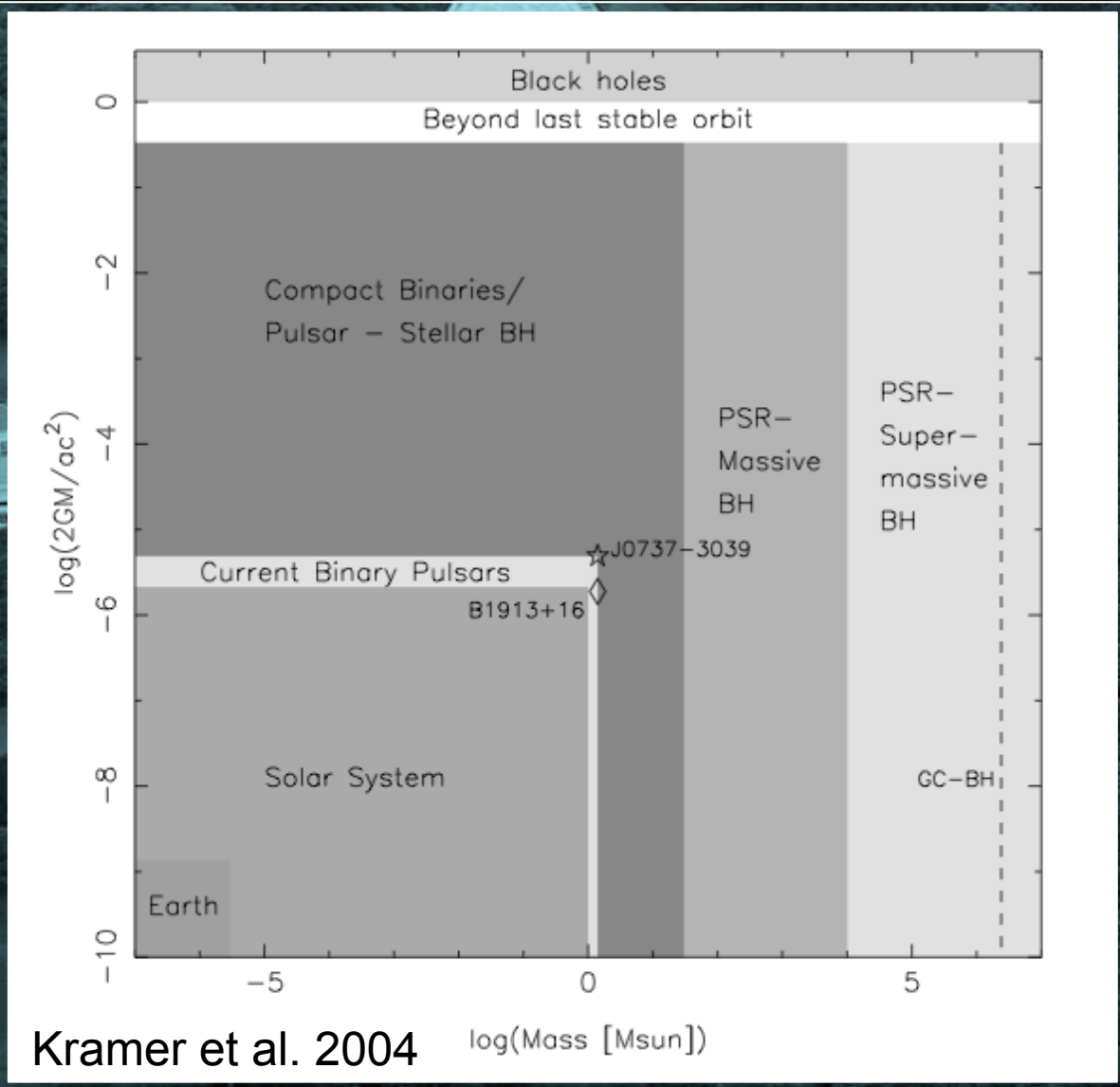
David Champion
Max-Planck-Institut für Radioastronomie
COST Valencia
15th November 2010

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

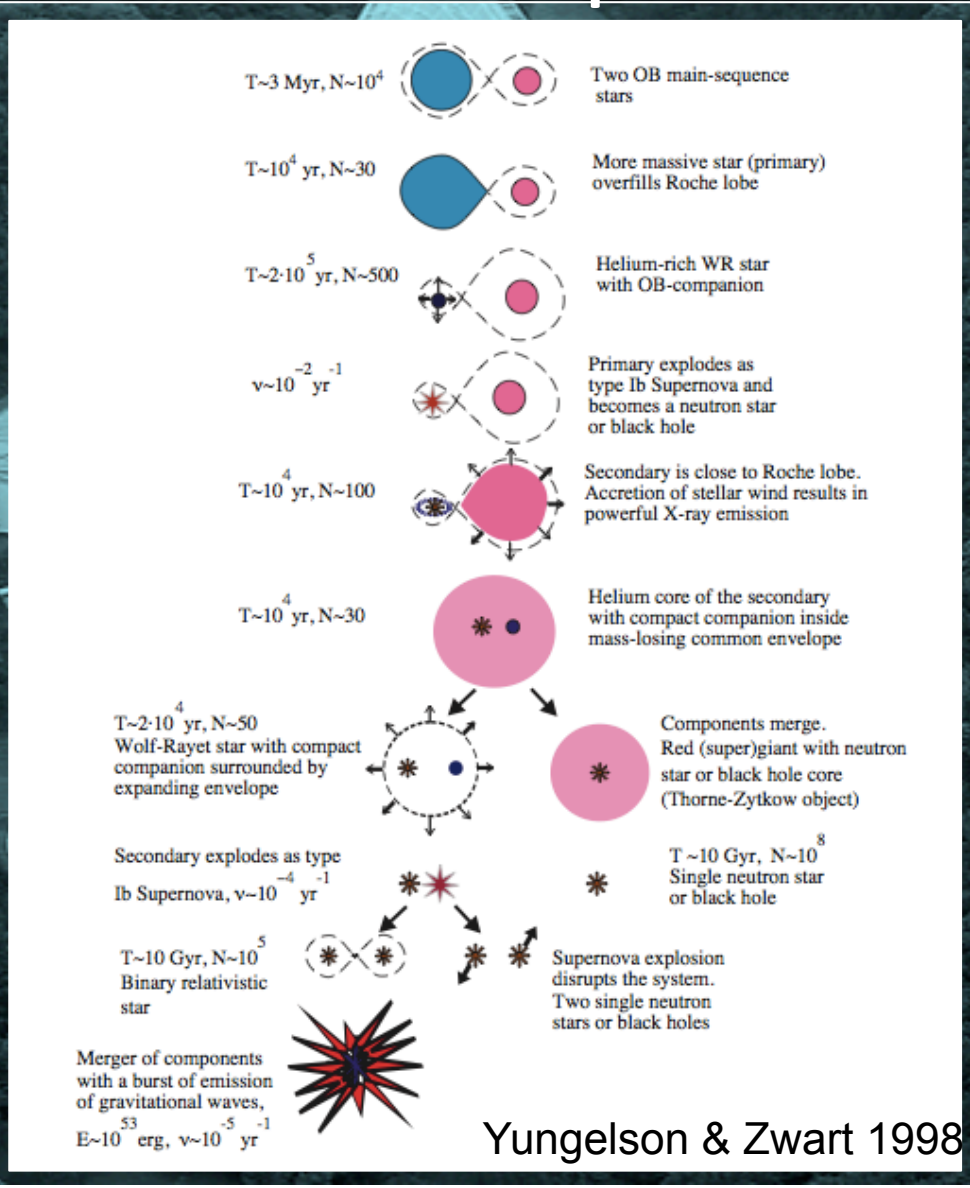

The PSR-BH population

Mass and orbit size



Kramer et al. 2004

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

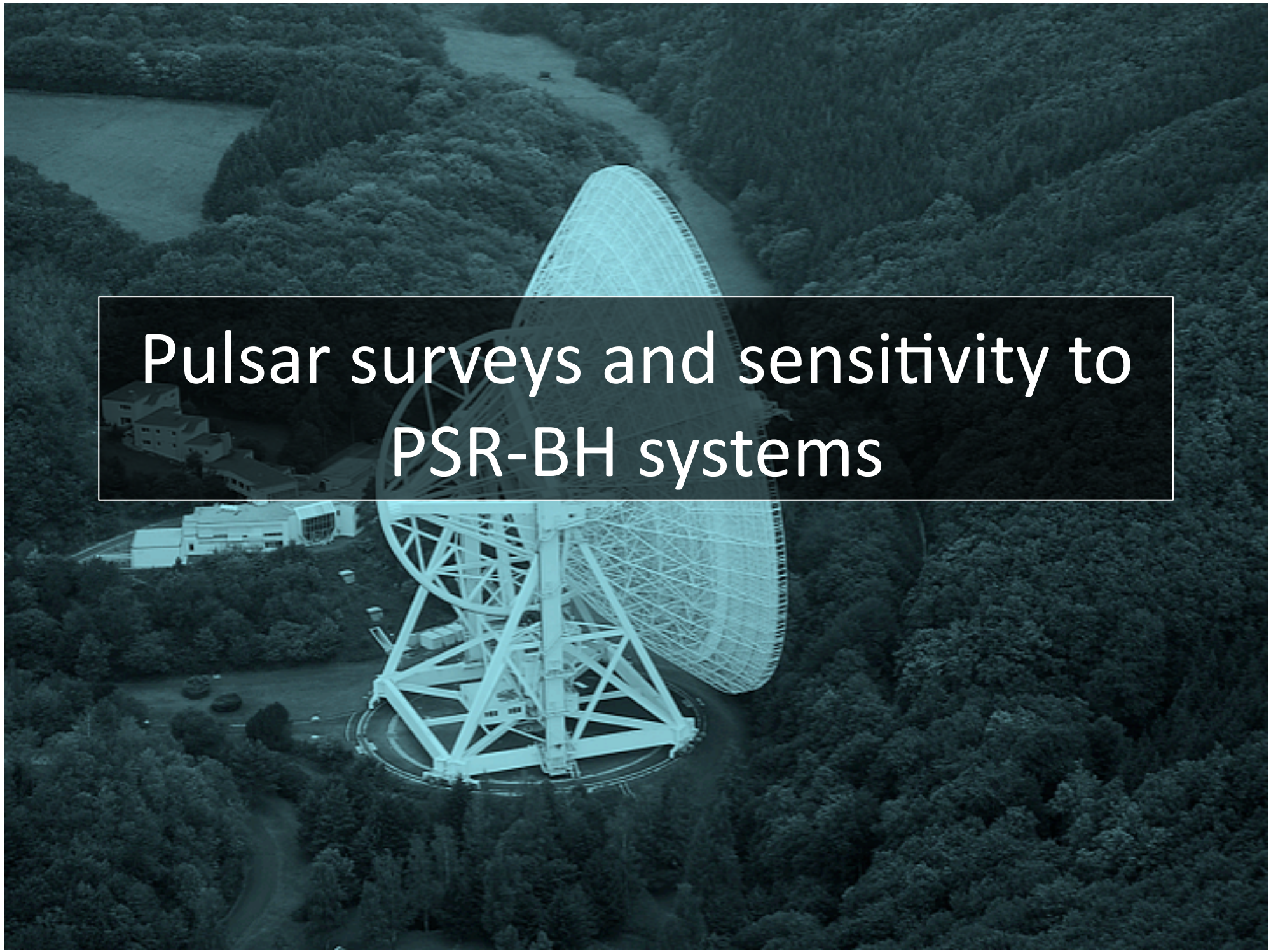
Population synthesis

	Birthrate x $10^{-5}yr^{-1}$		Galactic population	
Study	**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

Eatough

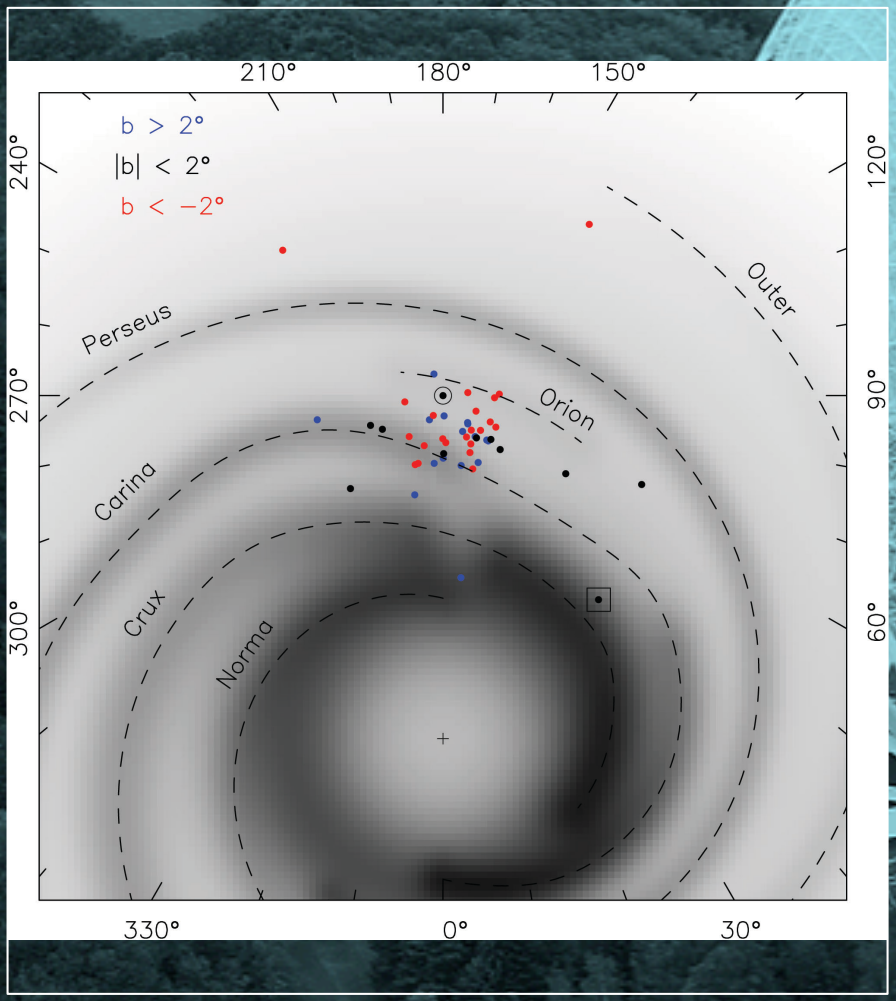
PSR-BH systems

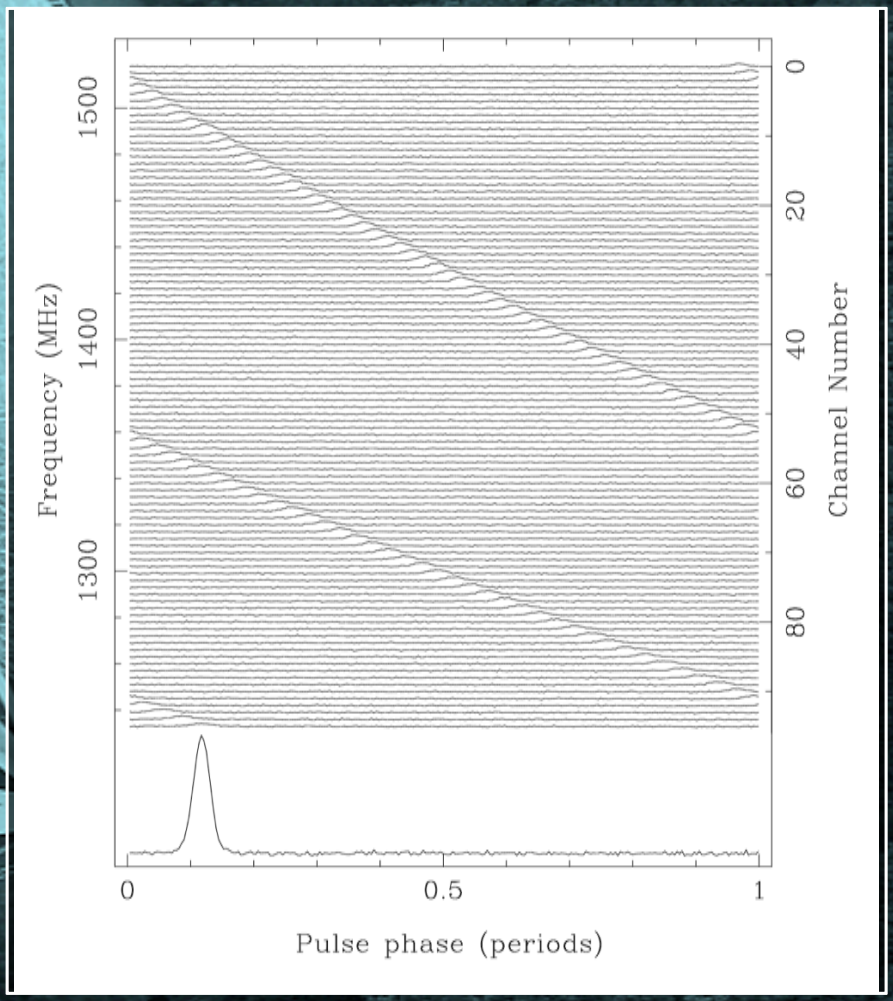
- Are there any?
  - Yes, no, maybe
- Where will they be?
  - In the plane
  - In globular clusters
  - In the Galactic centre



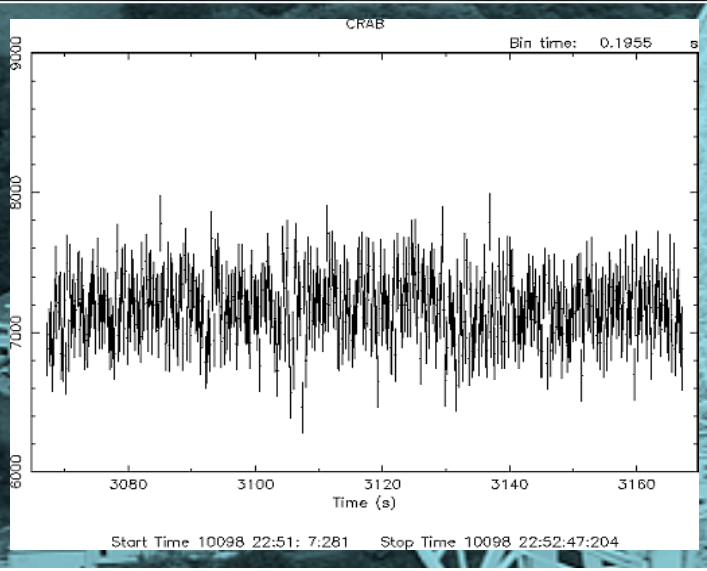
Pulsar surveys and sensitivity to PSR-BH systems

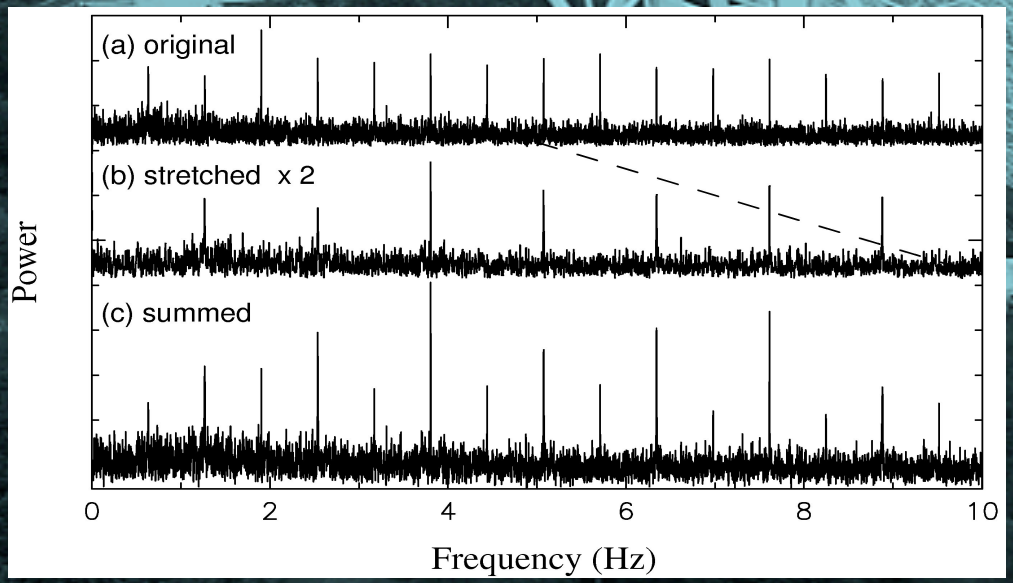
Dispersion


210°
180°
150°
240°
270°
300°
120°
90°
60°
330°
0°
30°
b > 2°
|b| < 2°
b < −2°
Perseus
Outer
Orion
Carina
Crux
Norma


Frequency (MHz)
1500
1400
1300
Channel Number
0
20
40
60
80
0
0.5
1
Pulse phase (periods)

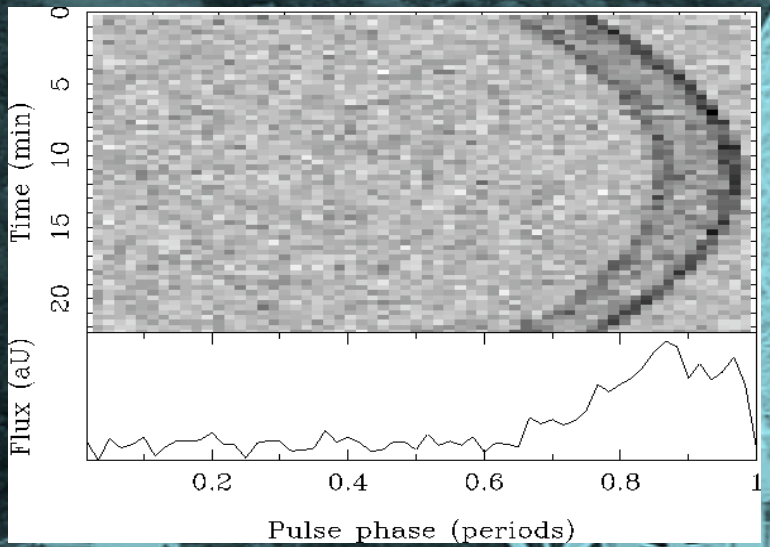
Searching for periodic signals

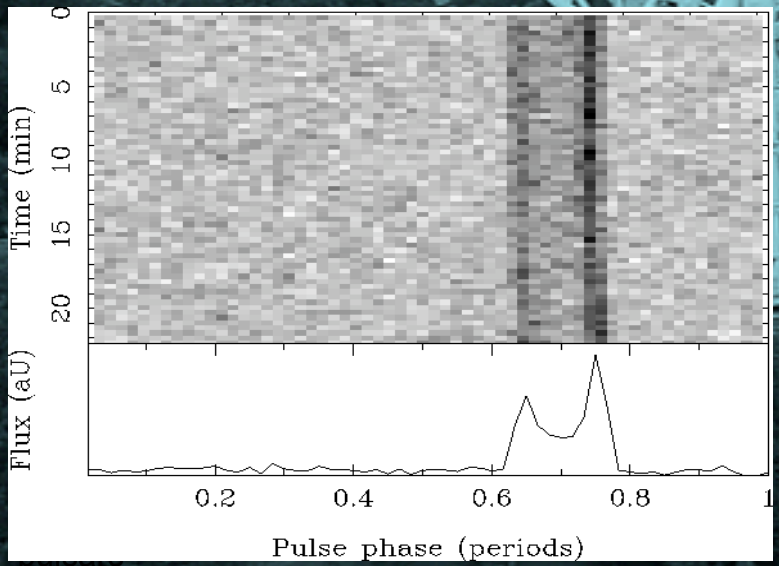




- Single pulses are very weak.
- FFTs are used to detect periodic signals in the time series.
- Harmonic summing increases delectability of low duty cycle pulsars.

Acceleration searches

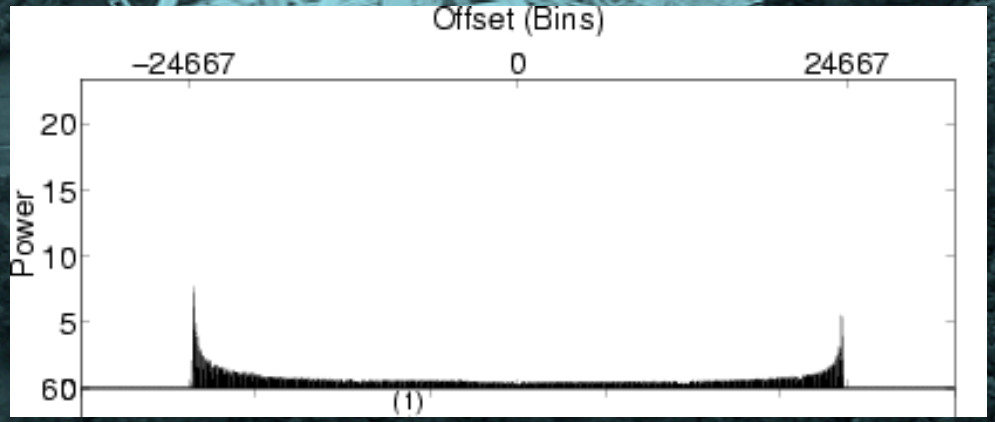




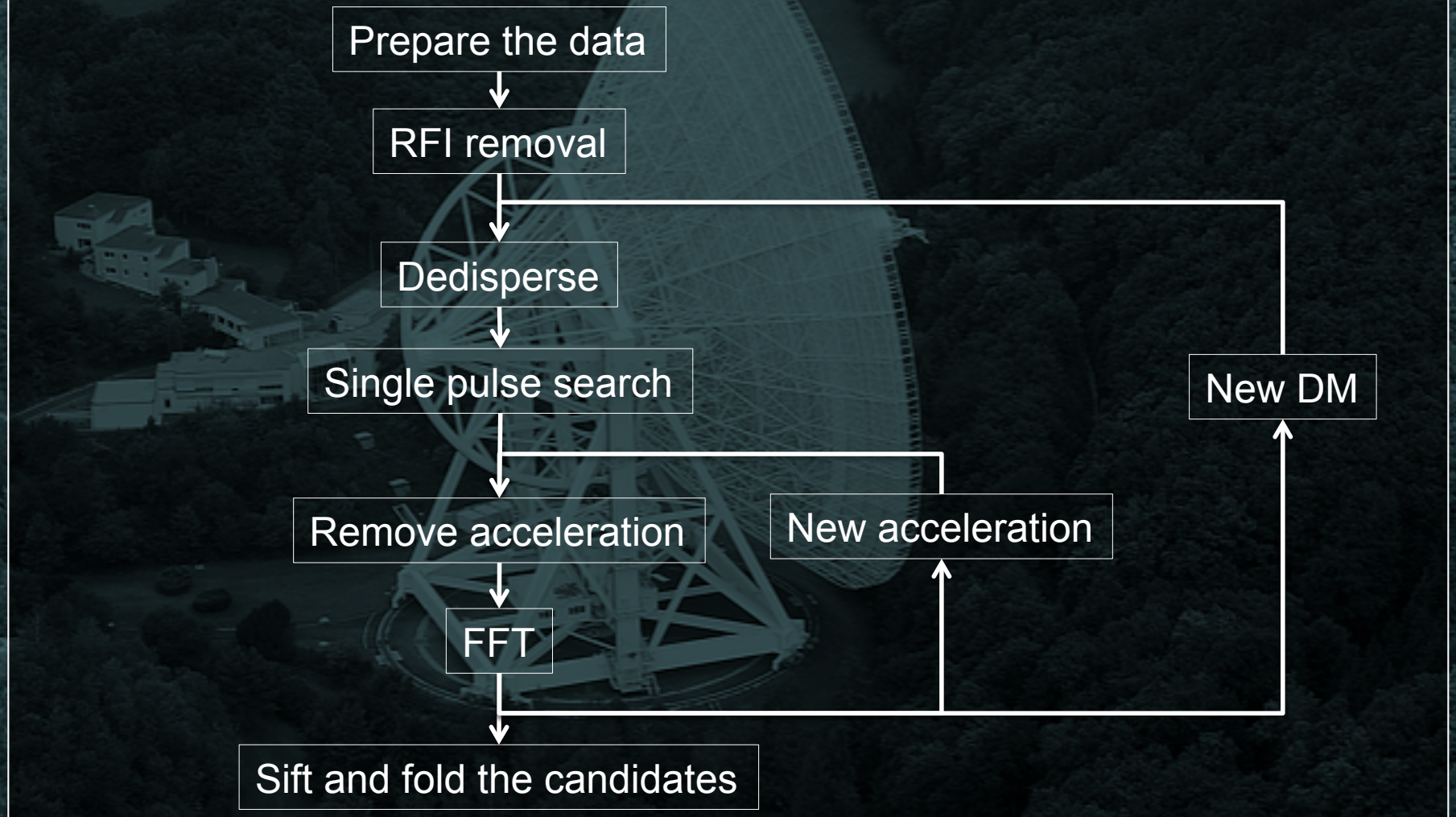
- Pulsars in a binary orbit are accelerated.
- Acceleration smears out the pulse over the period of the observation.
- The pulsar becomes less detectable.
- By searching in acceleration space the signal strength can be recovered.
- Longer observation would require a second derivative.

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



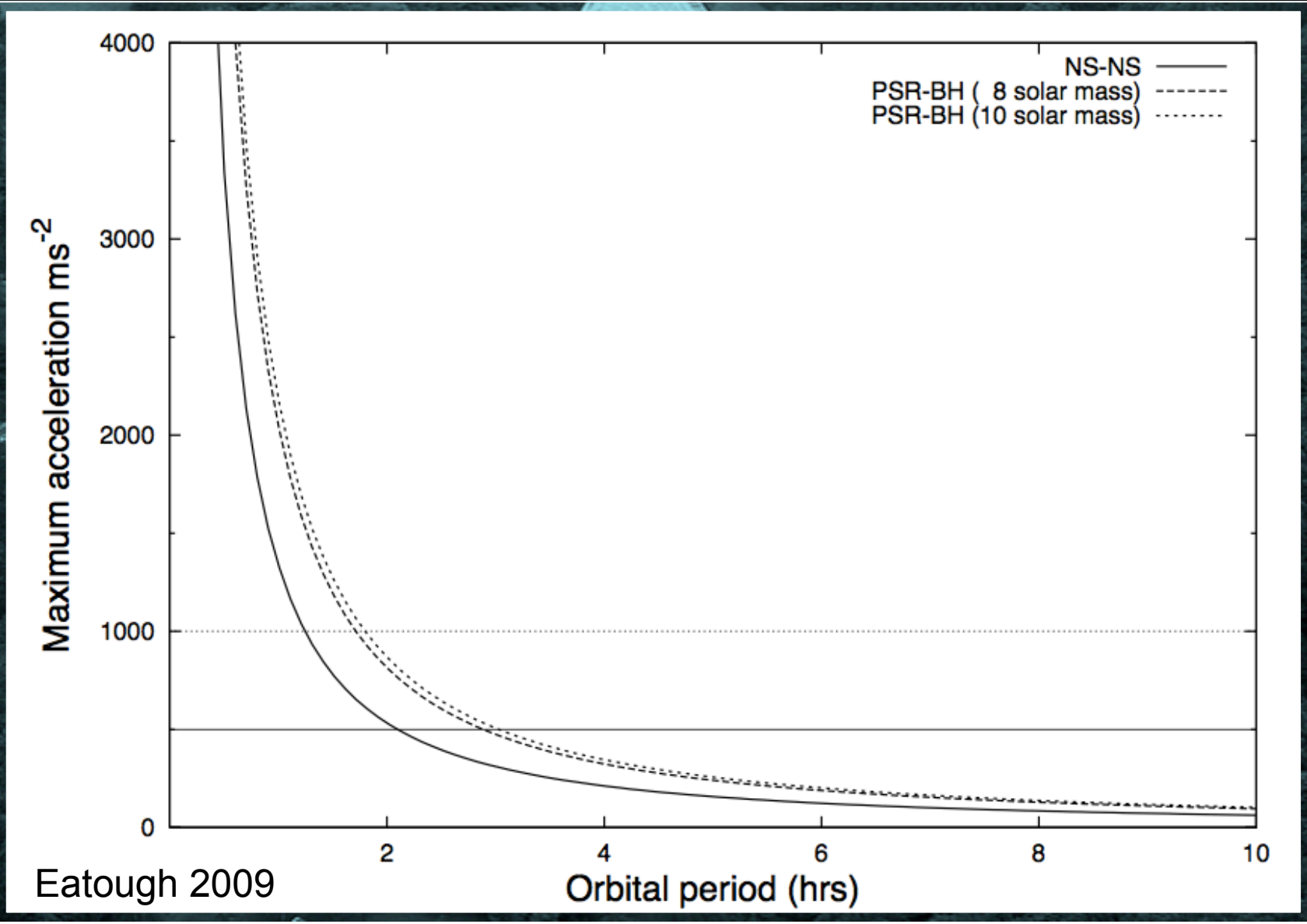
Computational limits

- Processing required to reduce one beam of data: Operations = $N_{Samp}^{3} \log N_{Samp}$
- 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

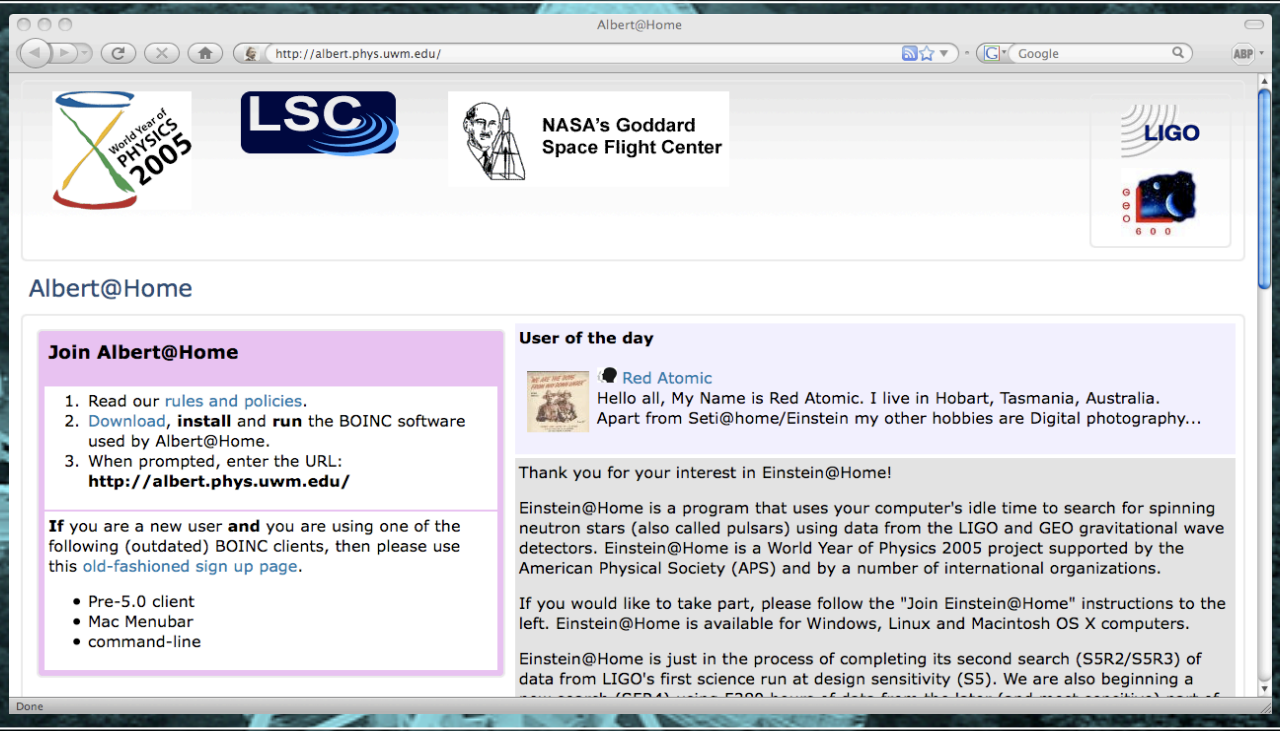
- $P_{MinBin} = 10\ T_{Obs}$ (depending on orbital phase, eccentricity etc)
- For HTRU and SKA P1 P_{MinBin} = 5 hr
- For PALFA P_{MinBin} = 50 min
- Splitting observations increases sensitivity to short orbital periods (and helps with computer power)
- Some power can be regained by incoherent addition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

PSR-NS vs. PSR-BH



Eatough 2009

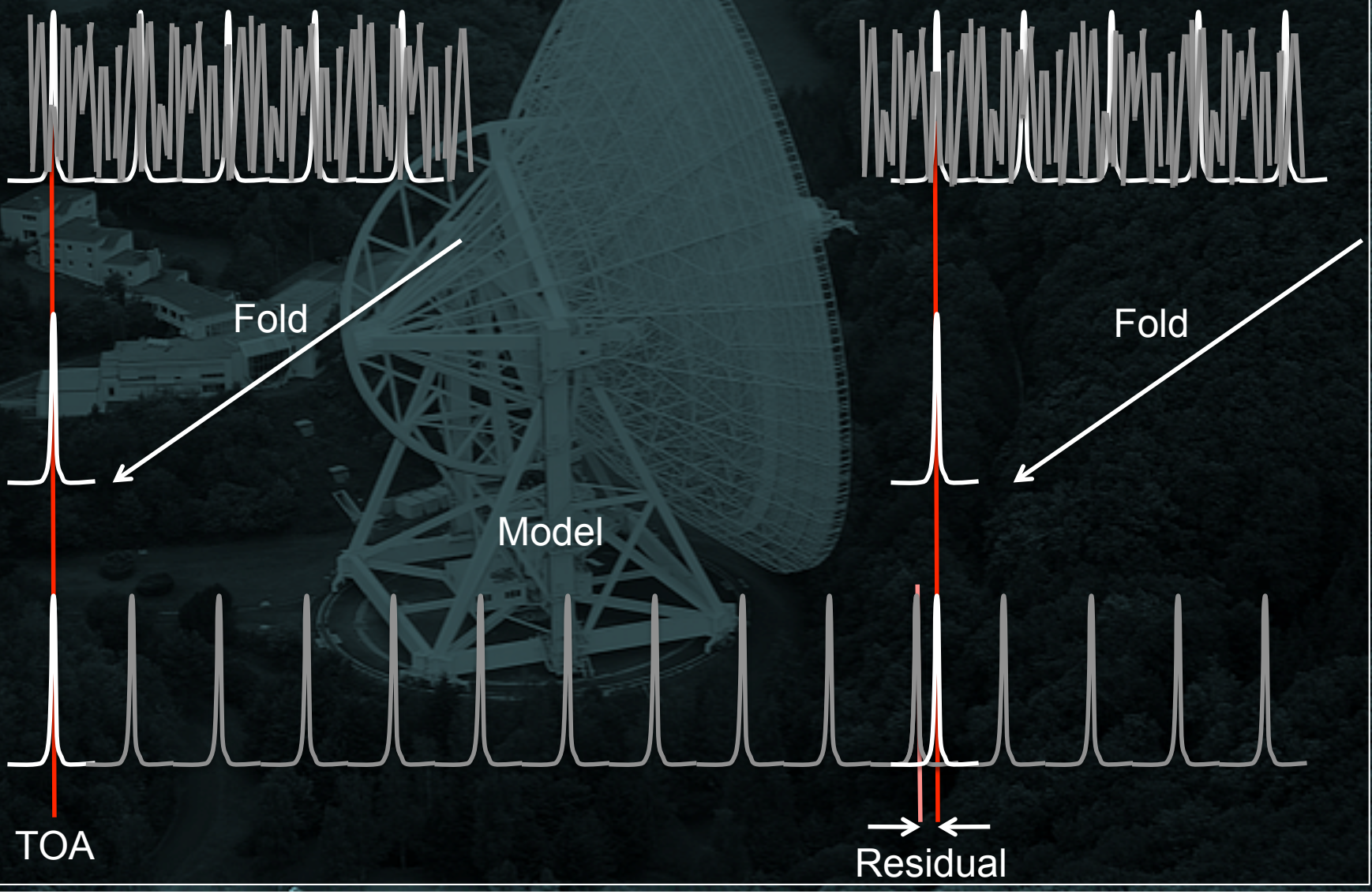
Very short orbital periods



- 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


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