High Time Resolution Astrophysics Science and Detector Requirements now and for the next decade.

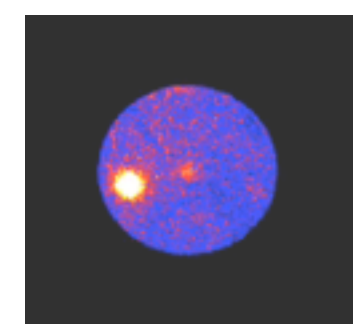
Andy Shearer

Centre for Astronomy

NUI, Galway

andy.shearer@nuigalway.ie

Additional info at **astro.nuigalway.ie/staff/ashearer**

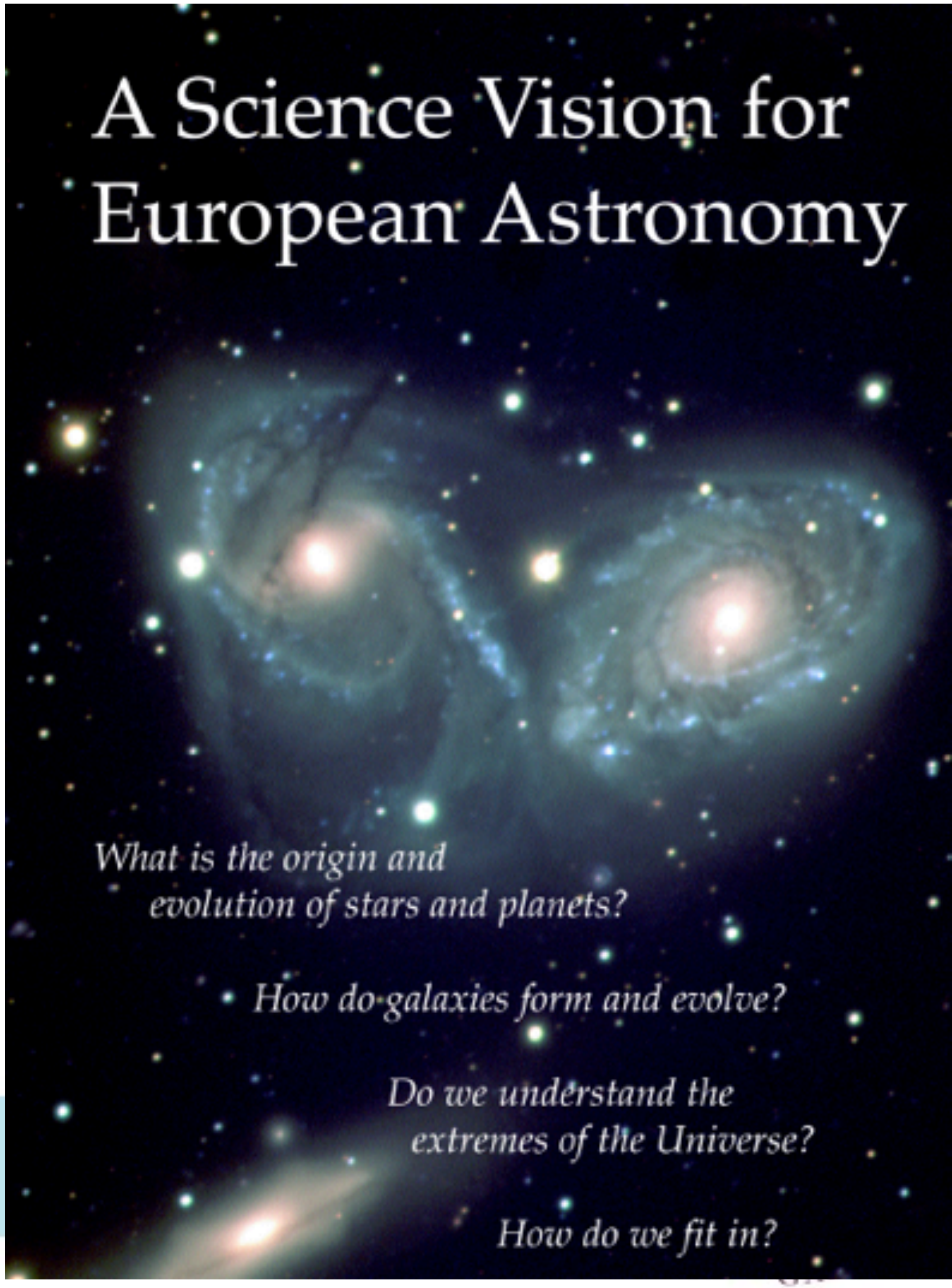


Why is HTRA important?

Astronet's Panel A, developing A Science Vision for European Astronomy, identified six fundamental questions in the area of understanding extreme physics:

- How did the universe begin?
- What is dark energy and dark matter?
- Can we observe strong gravity in action?
- How do supernovae and γ-ray bursts work?
- How do black hole accretion, jets and outflows operate?
- What do we learn from energetic radiation and particles?

HTRA addresses the last 4 - possibly all



What is HTRA?

- Science from Crete 2010 HTRA workshop
  - magnetars, pulsars and neutron stars
  - black hole binary systems
  - white dwarf binary systems
  - gamma ray bursts and supernovae
  - normal stars - stellar oscillations
  - solar system objects through transits and occultations
    - Planets and satellites
    - Kuiper belt objects

UltraCam usage from Vik Dhillon's talk in Crete - 2010

accreting white dwarfs/cataclysmic variables	20%
black-hole/neutron star X-ray binaries	16%
sdB stars/asteroseismology	12%
eclipsing, detached white-dwarf/red-dwarf binaries	11%
extrasolar planet transits and eclipses	9%
occultations by Titan, Pluto, Uranus, Kuiper Belt Objects	6%
flare stars	6%
pulsars	5%
isolated white dwarfs	5%
ultra-compact binaries	4%
isolated brown dwarfs	3%
GRBs	2%
Miscellaneous objects (AGN, contact binaries, etc)	1%

Important questions

1.How can we best exploit the current generation of astronomical instruments?

2. What about future developments - in ten years the next generation of telescopes will be coming on stream - what HTRA can be done then?

3. As the E-ELT's optimal wavelength will be around 2.2 μm what are the detector implications for HTRA in the region 1-2 μm?

4. What HTRA Science can be done with the next generation of detectors, instruments and telescopes?

Why multi-wavelength HTRA

- Fast Timing a natural component of high-energy observations
  - not true for optical HTRA
  - HTRA is a natural in other wavebands - future large facilities (e.g. SKA and IXO) will have timing, the E-ELT shouldn't be left behind.
  - Look towards the IR
- Suggestion of redefining HTRA as the astrophysics on dynamical time scales
  - Astrophysics of Compact Objects $\tau \sim \sqrt{R^3 / GM}$ or $\sqrt{1 / G\rho}$
    - White Dwarf ~ 1s dynamical vs 0.02s light crossing
- Observations on time scales < 1 sec?
- My preference - **low noise observations - hence a detector problem**

HTRA Targets

Shearer et al - HTRA White Paper
2010arXiv1008.0605S

		Time-Scale Now	Time Scale ELT era
Stellar flares and pulsations		Seconds/ minutes	10-100ms
Stellar Surface Oscillations	White Dwarfs Neutron Stars	1-1000 μs -	1-1000 μs 0.1 μs
Close Binary Systems accretion & turbulence	Tomography Eclipse in/egress Disk flickering Correlations (e.g. X & optical)	100ms++ 10ms+ 10ms 50ms	10ms+ < 1ms < 1ms < 1ms
Pulsars	Magnetospheric Thermal	1 μs- 100ms	ns ms
AGN		Minutes	Seconds

Table 1: Science timescales showing current and future possibilities

NUI Galway
OÉ Gaillimh

Current Detector Zoo -

Shearer et al - HTRA White Paper
2010arXiv1008.0605S

Detector	Time Resolution	Quantum Efficiency	E/ΔE	No. of Pixels	Instrument
CCD	5ms+	90% +	-	$>> 10^6$	UltraCam[42]
EMCCD	1ms+	40%	-	10^6	UltraSpec[42]
EMCCD	1ms+	40%	-	10^6	LuckyCam[43]
sCMOS	1ms+	60%	-	10^6	GASP[44]
pn CCD	0.01 ms+	90% +	-	10^6	[45]
Active Pixel Detectors	a few μs	80% +	-	10^5	[46]
SPADs	ns+	80% +	-	a few	Optima[47]
	ns+	15%		one[a]	GASP[44]
	100ps	50%+	-	a few	Iqueye[48]
STJ	ns+	90% +	5	10s	SCAM[49]
TES	ns+	90% +	20+	10s	[50]
MKID	ns+	90% +	500+	10s	[51]
Photo-Cathodes	ns+	<30%	-	$1-10^6$	Many
	1ms	40%	-	10^6	wavefront sensor

NUI G OÉ Ga

Current Detector Zoo -

Shearer et al - HTRA White Paper
2010arXiv1008.0605S

Detector	Time Resolution	Quantum Efficiency	E/ΔE	No. of Pixels	Instrument
CCD	5ms+	90% +	-	$>> 10^6$	UltraCam[42]
EMCCD	1ms+	40%	-	10^6	UltraSpec[42]
EMCCD	1ms+	40%	-	10^6	LuckyCam[43]
sCMOS	1ms+	60%	-	10^6	GASP[44]
pn CCD	0.01 ms+	90% +	-	10^6	[45]
Active Pixel Detectors	a few μs	80% +	-	10^5	[46]
SPADs	ns+	80% +	-	a few	Optima[47]
	ns+	15%		one[a]	GASP[44]
	100ps	50%+	-	a few	Iqueye[48]
STJ	ns+	90% +	5	10s	SCAM[49]
TES	ns+	90% +	20+	10s	[50]
MKID	ns+	90% +	500+	10s	[51]
Photo-Cathodes	ns+	<30%	-	$1 - 10^6$	Many
	1ms	40%	-	10^6	wavefront sensor

NUI G
OÉ Ga

Current Detector Zoo -

Shearer et al - HTRA White Paper
2010arXiv1008.0605S

Detector	Time Resolution	Quantum Efficiency	E/ΔE	No. of Pixels	Instrument
CCD	5ms+	90% +	-	$>> 10^6$	UltraCam[42]
EMCCD	1ms+	40%	-	10^6	UltraSpec[42]
EMCCD	1ms+	40%	-	10^6	LuckyCam[43]
sCMOS	1ms+	60%	-	10^6	GASP[44]
pn CCD	0.01 ms+	90% +	-	10^6	[45]
Active Pixel Detectors	a few μs	80% +	-	10^5	[46]
SPADs	ns+	80% +	-	a few	Optima[47]
	ns+	15%		one[a]	GASP[44]
	100ps	50%+	-	a few	Iqueye[48]
STJ	ns+	90% +	5	10s	SCAM[49]
TES	ns+	90% +	20+	10s	[50]
MKID	ns+	90% +	500+	10s	[51]
Photo-Cathodes	ns+	<30%	-	$1 - 10^6$	Many
	1ms	40%	-	10^6	wavefront sensor

Current Detector Zoo -

Shearer et al - HTRA White Paper
2010arXiv1008.0605S

Detector	Time Resolution	Quantum Efficiency	E/ΔE	No. of Pixels	Instrument
CCD	5ms+	90% +	-	$>> 10^6$	UltraCam[42]
EMCCD	1ms+	40%	-	10^6	UltraSpec[42]
EMCCD	1ms+	40%	-	10^6	LuckyCam[43]
sCMOS	1ms+	60%	-	10^6	GASP[44]
pn CCD	0.01 ms+	90% +	-	10^6	[45]
Active Pixel Detectors	a few μs	80% +	-	10^5	[46]
SPADs	ns+	80% +	-	a few	Optima[47]
	ns+	15%		one[a]	GASP[44]
	100ps	50%+	-	a few	Iqueye[48]
STJ	ns+	90% +	5	10s	SCAM[49]
TES	ns+	90% +	20+	10s	[50]
MKID	ns+	90% +	500+	10s	[51]
Photo-Cathodes	ns+	<30%	-	$1 - 10^6$	Many
	1ms	40%	-	10^6	wavefront sensor

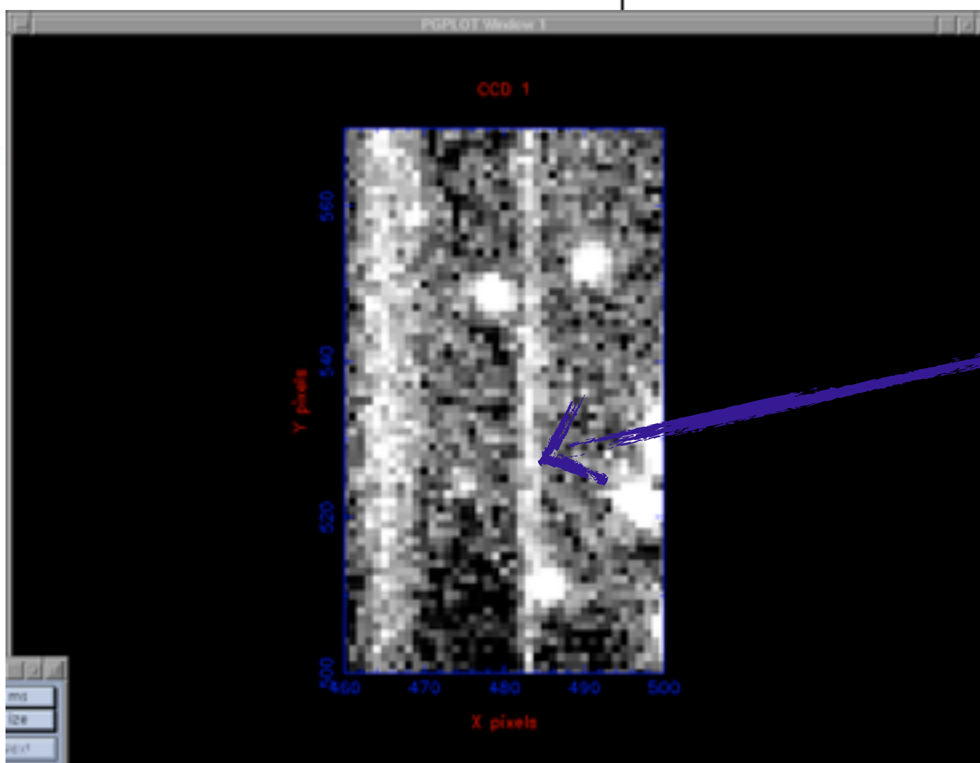
Current Detector Zoo -

Shearer et al - HTRA White Paper
2010arXiv1008.0605S

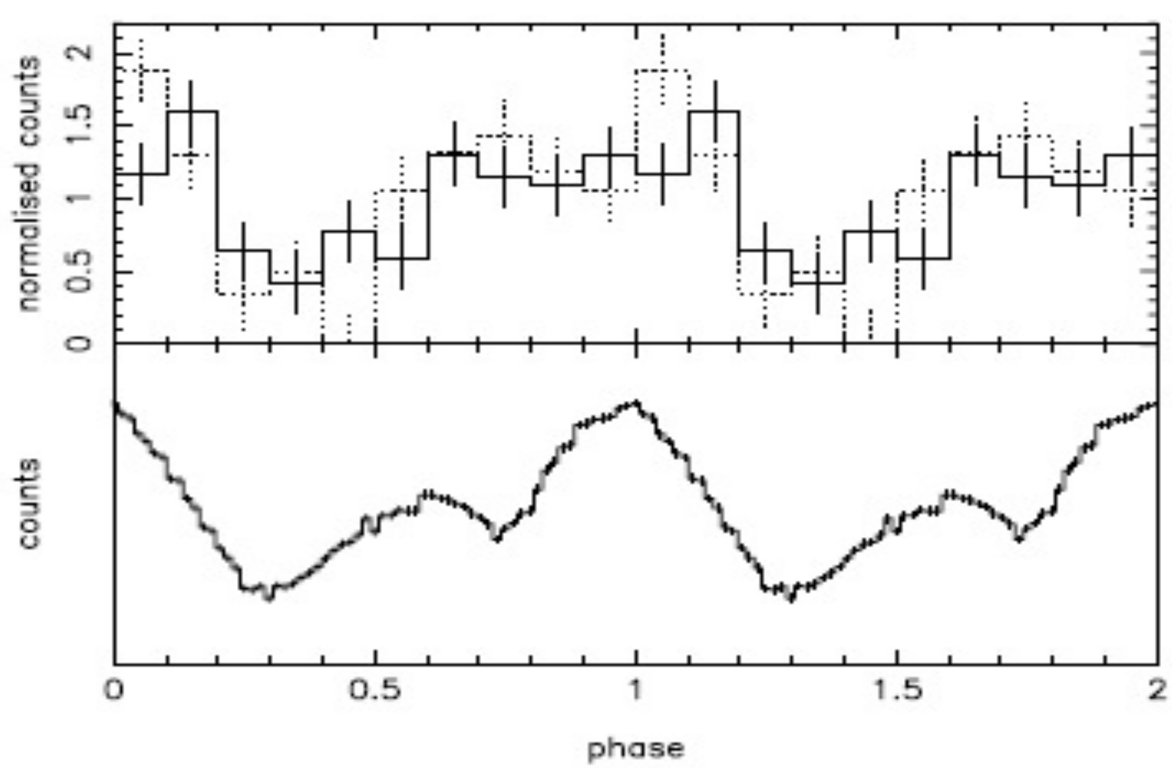
Detector	Time Resolution	Quantum Efficiency	E/ΔE	No. of Pixels	Instrument
CCD	5ms+	90% +	-	$>> 10^6$	UltraCam[42]
EMCCD	1ms+	40%	-	10^6	UltraSpec[42]
EMCCD	1ms+	40%	-	10^6	LuckyCam[43]
sCMOS	1ms+	60%	-	10^6	GASP[44]
pn CCD	0.01 ms+	90% +	-	10^6	[45]
Active Pixel Detectors	a few μs	80% +	-	10^5	[46]
SPADs	ns+	80% +	-	a few	Optima[47]
	ns+	15%		one[a]	GASP[44]
	100ps	50%+	-	a few	Iqueye[48]
STJ	ns+	90% +	5	10s	SCAM[49]
TES	ns+	90% +	20+	10s	[50]
MKID	ns+	90% +	500+	10s	[51]
Photo-Cathodes	ns+	<30%	-	$1 - 10^6$	Many
	1ms	40%	-	10^6	wavefront sensor

NUI G
OÉ Ga

Current Detector Zoo - Magnetars



Detector	Time Resolution	Quantum Efficiency	E/ΔE	No. of Pixels	Instrument
	5ms+	90% +	-	$>> 10^6$	UltraCam[42]
	1ms+	40%	-	10^6	UltraSpec[42]
	1ms+	40%	-	10^6	LuckyCam[43]
	1ms+	60%	-	10^6	GASP[44]
	0.01 ms+	90% +	-	10^6	[45]
	a few μs	80% +	-	10^5	[46]
	ns+	80% +	-	a few	Optima[47]
				one[a]	GASP[44]
				a few	Iqueye[48]
				10s	SCAM[49]
				10s	[50]
				10s	[51]
				$1 - 10^6$ 10^6	Many wavefront sensor



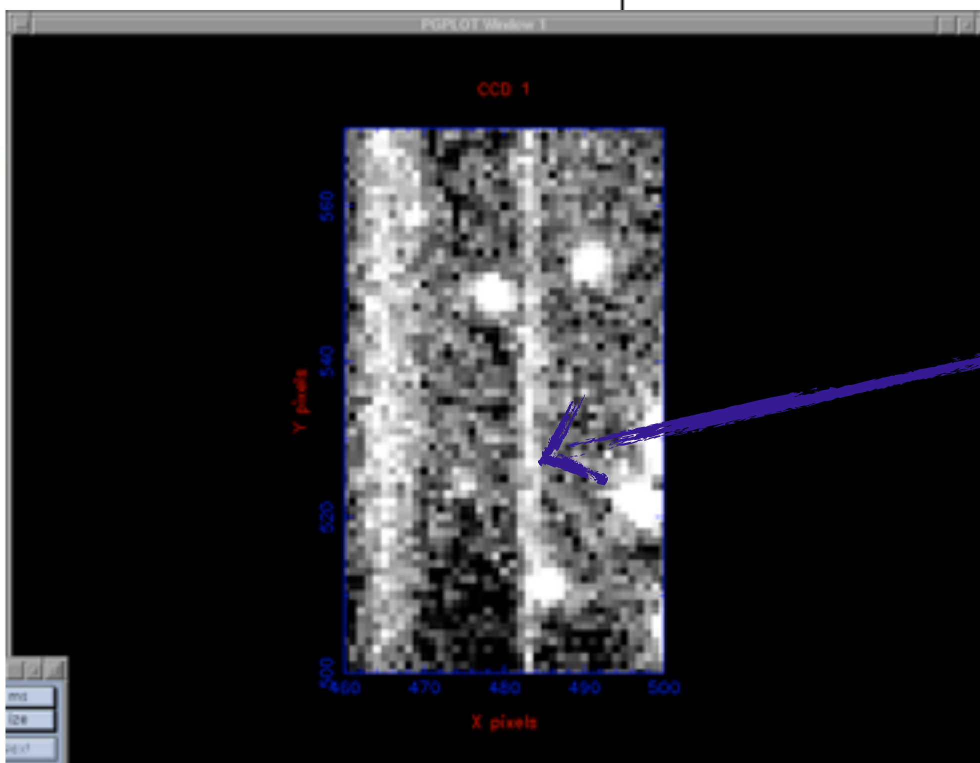
4U 0142+42

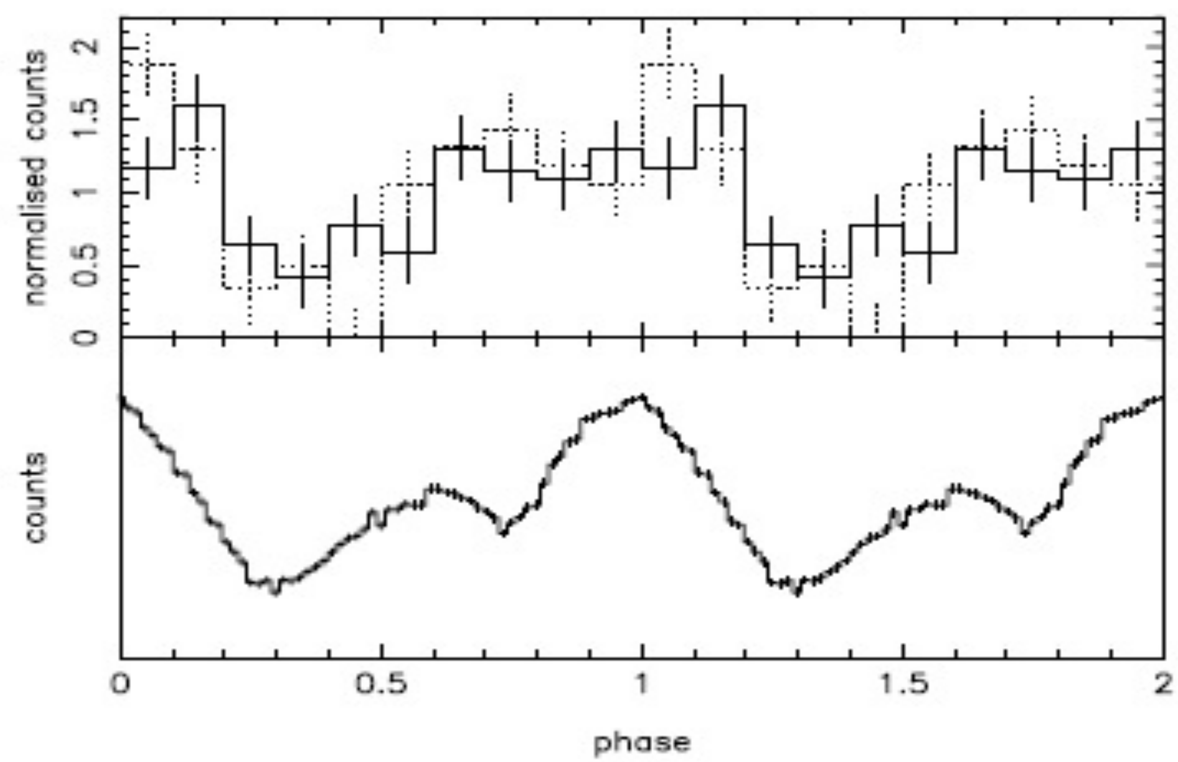
– Dhillon et al, 2005, MNRAS, 203, 609

NUI G OÉ Gai

Current Detector Zoo - Magnetars

Detector	Time Resolution	Quantum Efficiency	E/ΔE	No. of Pixels	Instrument
	5ms+	90% +	-	$>> 10^6$	UltraCam[42]
	1ms+	40%	-	10^6	UltraSpec[42]
	1ms+	40%	-	10^6	LuckyCam[43]
	1ms+	60%	-	10^6	GASP[44]
	0.01 ms+	90% +	-	10^6	[45]
	a few μs	80% +	-	10^5	[46]
	ns+	80% +	-	a few	Optima[47]
				one[a]	GASP[44]
				a few	Iqueye[48]
				10s	SCAM[49]
				10s	[50]
				10s	[51]
				$1 - 10^6$	Many
				10^6	wavefront
					sensor



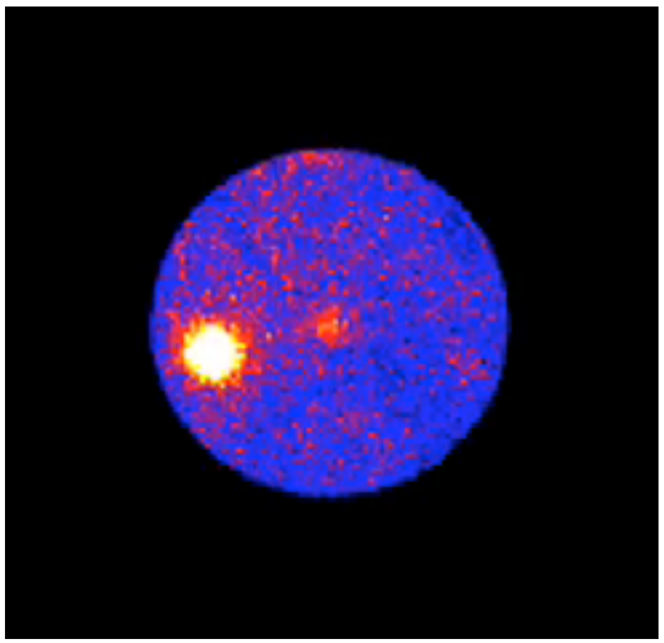


4U 0142+42

– Dhillon et al, 2005, MNRAS, 203, 609

Current Detector Zoo - Pulsars

Crab
Too many to mention

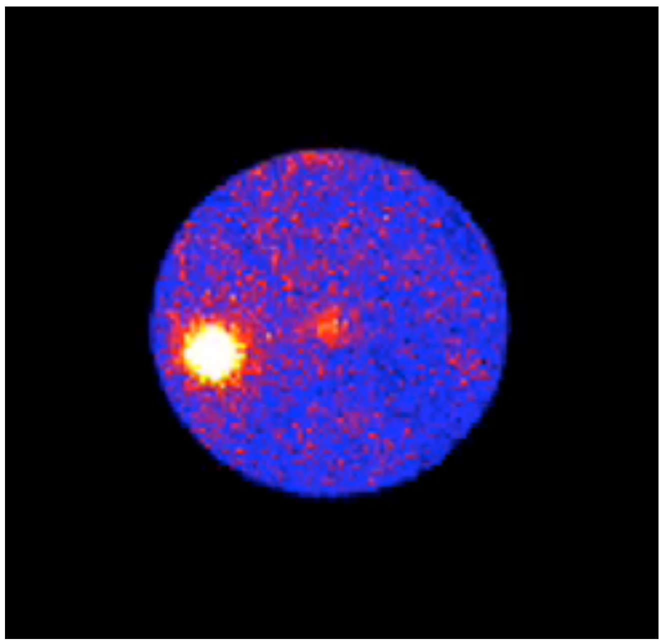


1 ms MAMA images

Detector	Time Resolution	Quantum Efficiency	E/ΔE	No. of Pixels	Instrument
CCD	5ms+	90% +	-	$>> 10^6$	UltraCam[42]
EMCCD	1ms+	40%	-	10^6	UltraSpec[42]
EMCCD	1ms+	40%	-	10^6	LuckyCam[43]
sCMOS	1ms+	60%	-	10^6	GASP[44]
pn CCD	0.01 ms+	90% +	-	10^6	[45]
Active Pixel Detectors	a few μs	80% +	-	10^5	[46]
SPADs	ns+	80% +	-	a few	Optima[47]
	ns+	15%		one[a]	GASP[44]
	100ps	50%+	-	a few	Iqueye[48]
STJ	ns+	90% +	5	10s	SCAM[49]
TES	ns+	90% +	20+	10s	[50]
MKID	ns+	90% +	500+	10s	[51]
Photo-Cathodes	ns+	<30%	-	$1-10^6$	Many
	1ms	40%	-	10^6	wavefront sensor

Current Detector Zoo - Pulsars

Crab
Too many to mention

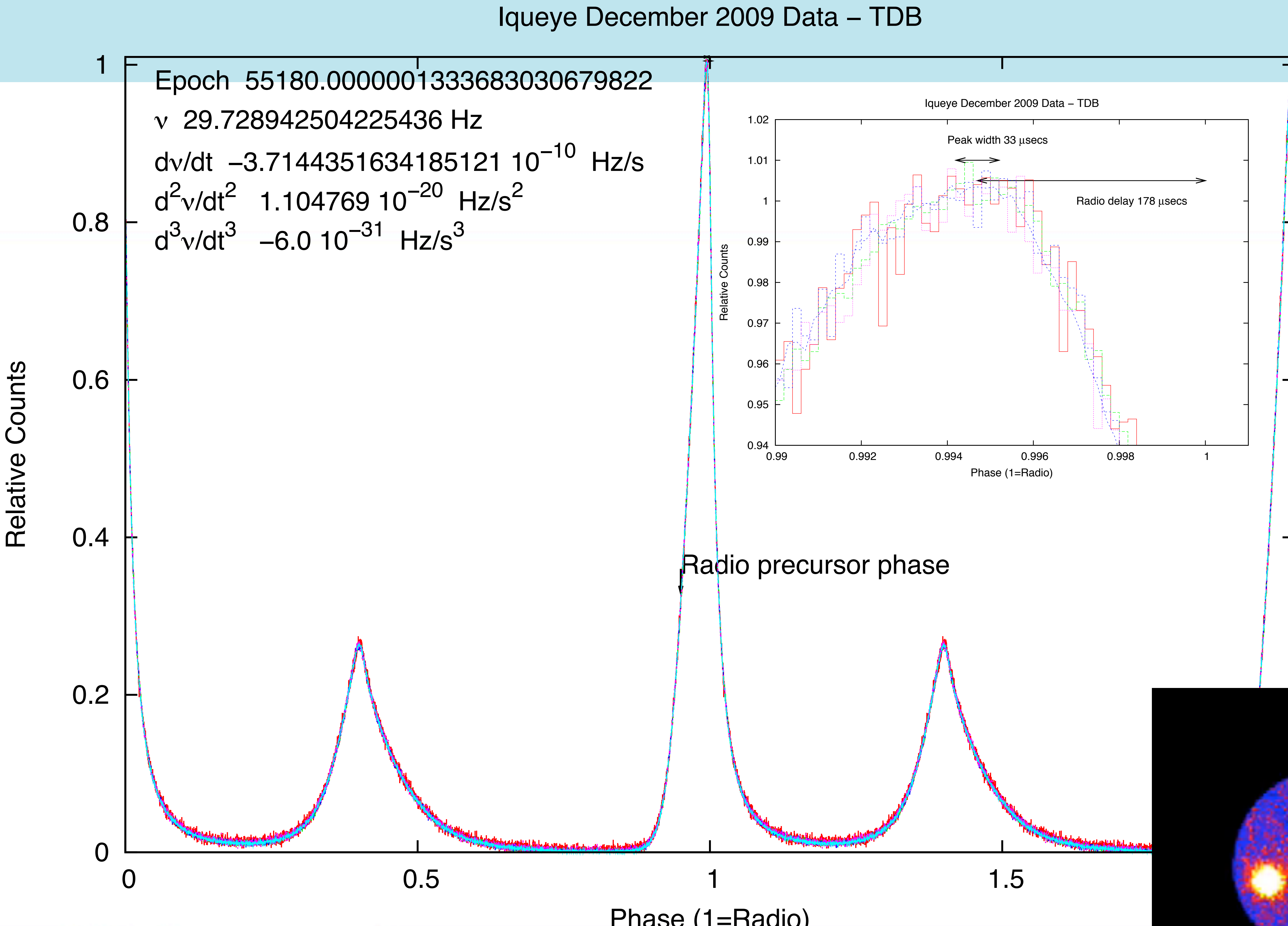


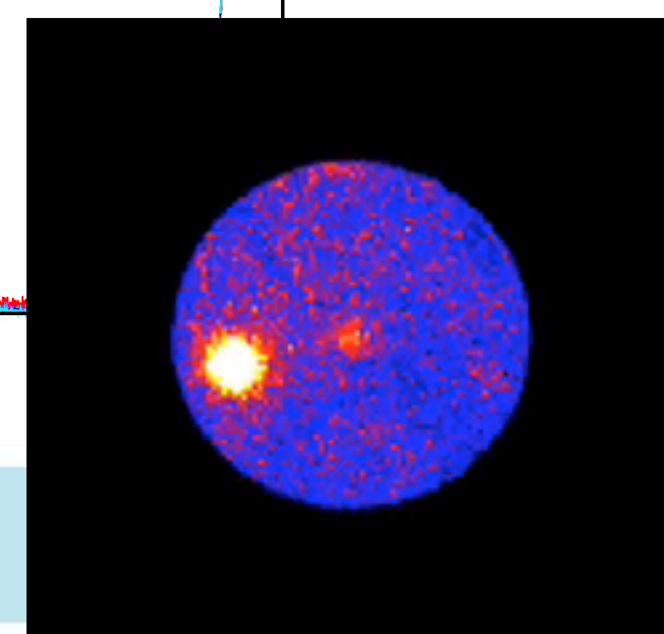
1 ms MAMA images

Detector	Time Resolution	Quantum Efficiency	E/ΔE	No. of Pixels	Instrument
CCD	5ms+	90% +	-	$>> 10^6$	UltraCam[42]
EMCCD	1ms+	40%	-	10^6	UltraSpec[42]
EMCCD	1ms+	40%	-	10^6	LuckyCam[43]
sCMOS	1ms+	60%	-	10^6	GASP[44]
pn CCD	0.01 ms+	90% +	-	10^6	[45]
Active Pixel Detectors	a few μs	80% +	-	10^5	[46]
SPADs	ns+	80% +	-	a few	Optima[47]
	ns+	15%		one[a]	GASP[44]
	100ps	50%+	-	a few	Iqueye[48]
STJ	ns+	90% +	5	10s	SCAM[49]
TES	ns+	90% +	20+	10s	[50]
MKID	ns+	90% +	500+	10s	[51]
Photo-Cathodes	ns+	<30%	-	$1-10^6$	Many
	1ms	40%	-	10^6	wavefront sensor

NUI Ga
OÉ Gail

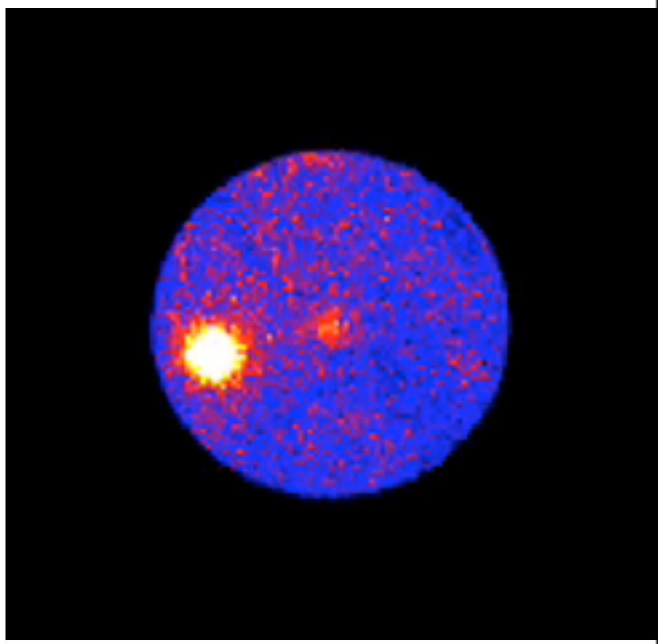
Iqueye Data Single Pixel APD system





Current Detector Zoo - Pulsars

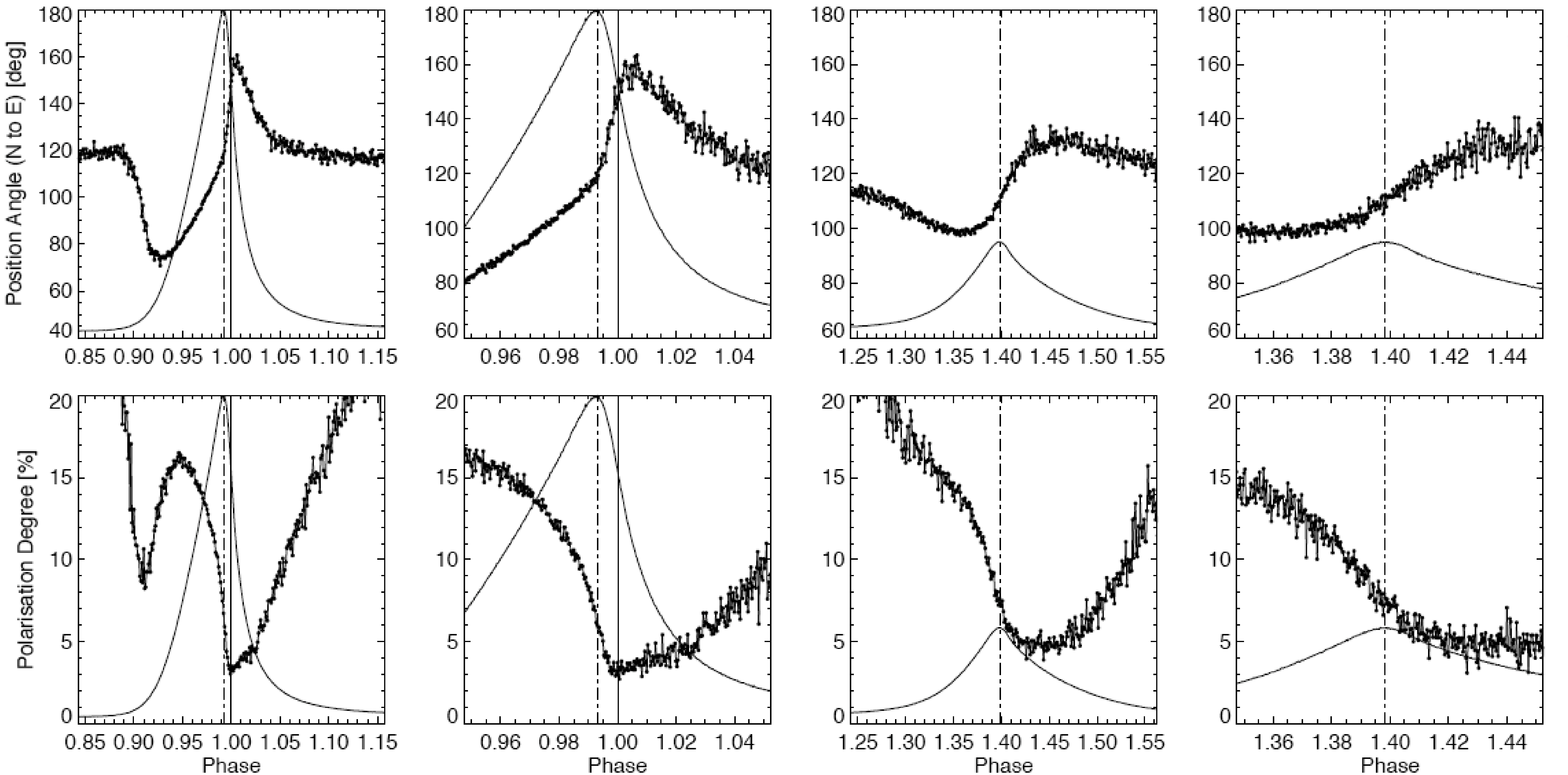
Crab
Too many to mention



Detector	Time Resolution	Quantum Efficiency	E/ΔE	No. of Pixels	Instrument
CCD	5ms+	90% +	-	$>> 10^6$	UltraCam[42]
EMCCD	1ms+	40%	-	10^6	UltraSpec[42]
EMCCD	1ms+	40%	-	10^6	LuckyCam[43]
sCMOS	1ms+	60%	-	10^6	GASP[44]
pn CCD	0.01 ms+	90% +	-	10^6	[45]
Active Pixel Detectors	a few μs	80% +	-	10^5	[46]
SPADs	ns+	80% +	-	a few	Optima[47]
	ns+	15%		one[a]	GASP[44]
	100ps	50%+	-	a few	Iqueye[48]
STJ	ns+	90% +	5	10s	SCAM[49]
TES	ns+	90% +	20+	10s	[50]
MKID	ns+	90% +	500+	10s	[51]
Photo-Cathodes	ns+	<30%	-	$1-10^6$	Many
	1ms	40%	-	10^6	wavefront sensor

Crab - Optima Observations

Słowikowska et al., 2009, MNRAS.397, 103



Current Detector Zoo - The future?

Shearer et al - HTRA White Paper
2010arXiv1008.0605S

Detector	Time Resolution	Quantum Efficiency	E/ΔE	No. of Pixels	Instrument
CCD	5ms+	90% +	-	$>> 10^6$	UltraCam[42]
EMCCD EMCCD sCMOS	1ms+ 1ms+ 1ms+	40% 40% 60%	- - -	10^6 10^6 10^6	UltraSpec[42] LuckyCam[43] GASP[44]
pn CCD	0.01 ms+	90% +	-	10^6	[45]
Active Pixel Detectors	a few μs	80% +	-	10^5	[46]
SPADs	ns+ ns+ 100ps	80% + 15% 50%+	- -	a few one[a] a few	Optima[47] GASP[44] Iqueye[48]
STJ TES MKID	ns+ ns+ ns+	90% + 90% + 90% +	5 20+ 500+	10s 10s 10s	SCAM[49] [50] [51]
Photo-Cathodes	ns+ 1ms	<30% 40%	- -	$1-10^6$ 10^6	Many wavefront sensor

NUI Ga
OÉ Gail

Current Detector Zoo -

The future?

Shearer et al - HTRA White Paper
2010arXiv1008.0605S

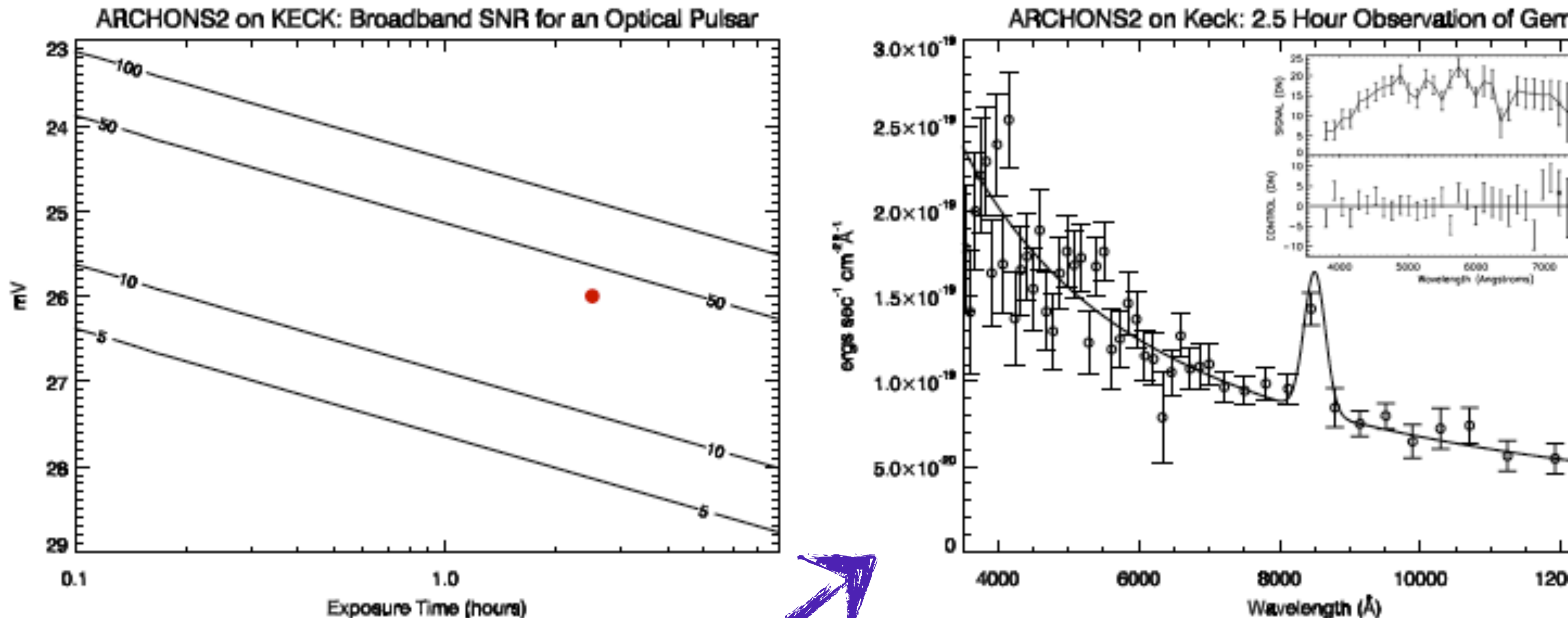


Figure 5. Left: Simulation of the broadband signal to noise (SNR) ratio of an optical pulsar with a Geminga-l law spectrum ($f_\nu = \nu^{-0.8}$)[20] observed with ARCONS on Keck in 0.8" seeing with an energy resolution R=50. dot represents the 2.5 hour simulated observation of Geminga shown in the right panel. Right: A 2.5 hour observation of Geminga showing the clear detection of a hypothetical cyclotron emission line at 850 nm with a of twice the continuum and a FWHM of 35 nm. The black line shows the model spectra used to simulate the ob The inset shows an the actual spectra of Geminga taken in a 2.5 hour observation with LRIS on Keck by Marti The ARCONS spectra is superior mainly because of the ability to take advantage of the 0.8" second seeing to g sky count rate and better control of systematics, such as variations in the intensity and spectrum of the night the 30 minute LRIS exposures.

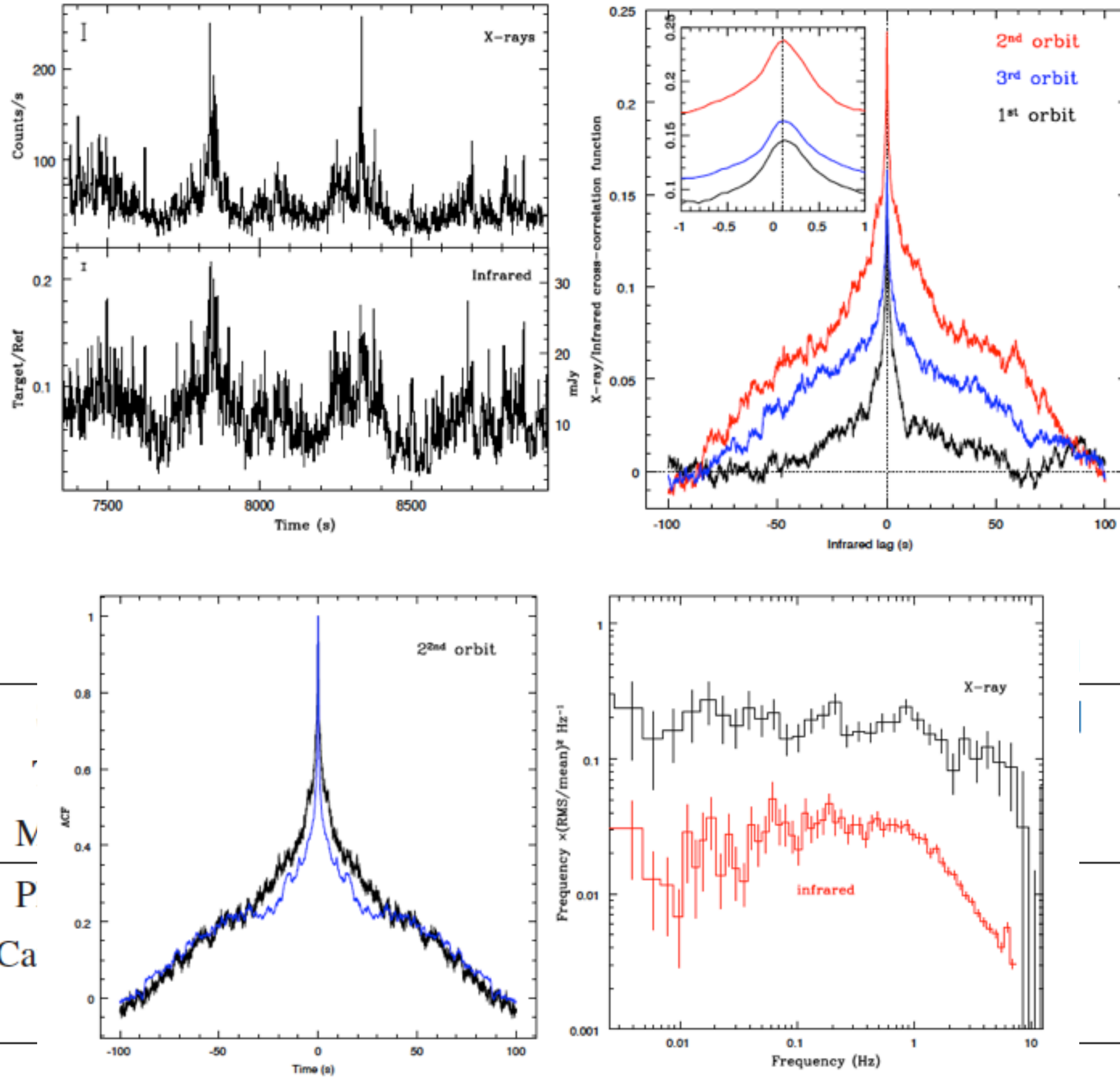
TES	ns+	90% +	20+	10s	[50]
MKID	ns+	90% +	500+	10s	[51]
Photo-Cathodes	ns+ 1ms	<30% 40%	- -	$1-10^6$ 10^6	Many wavefront sensor

NUI Ga
OÉ Gail

Current Detector Zoo - Close Binary Systems

Multiwavelength Observations X-ray - Near IR

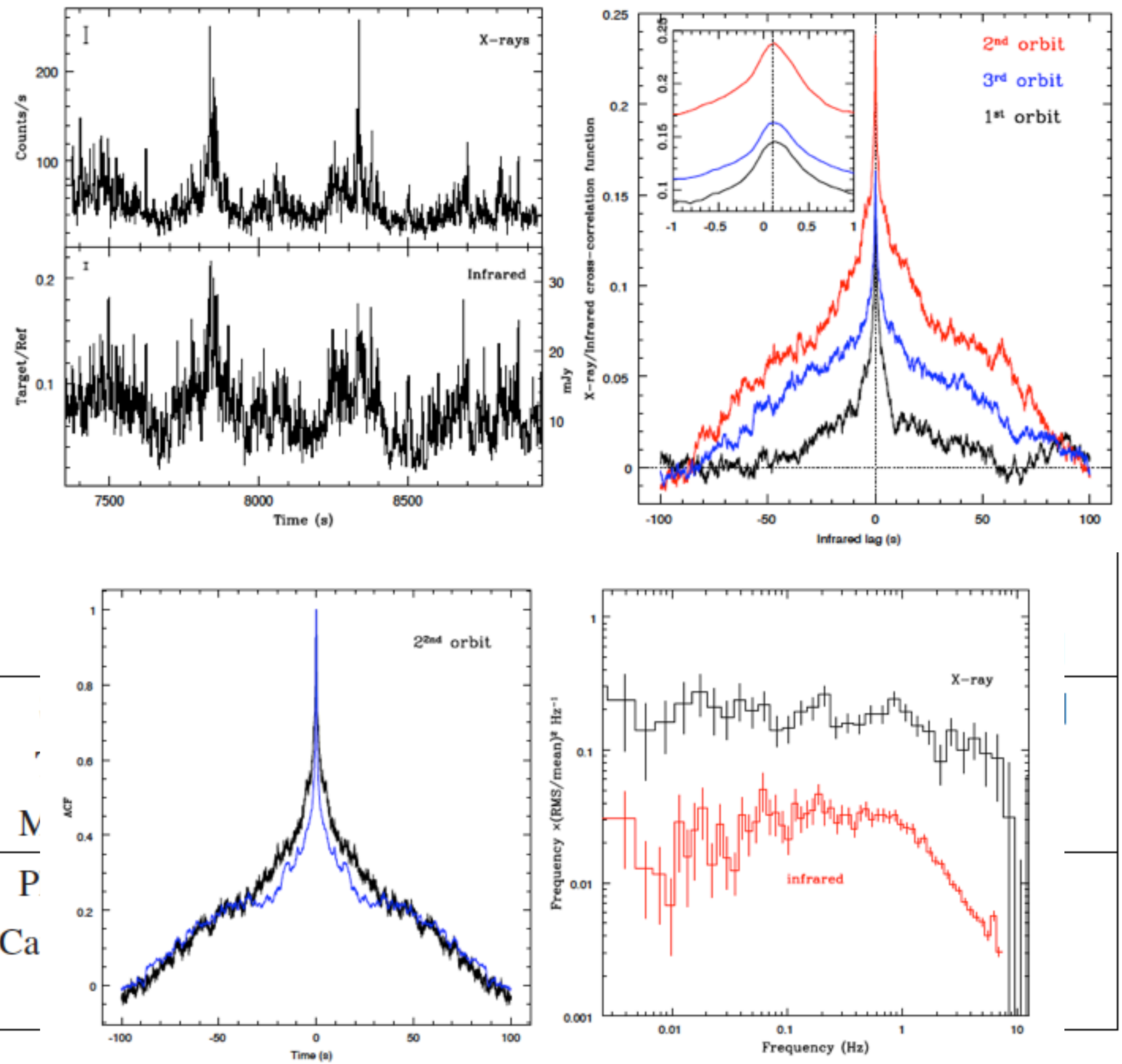
GX 339-4
Casella, Maccarone O'Brien, 2010, Proceedings Crete HTRA workshop



Current Detector Zoo - Close Binary Systems

Multiwavelength Observations X-ray - Near IR

GX 339-4
Casella, Maccarone O'Brien, 2010, Proceedings Crete HTRA workshop



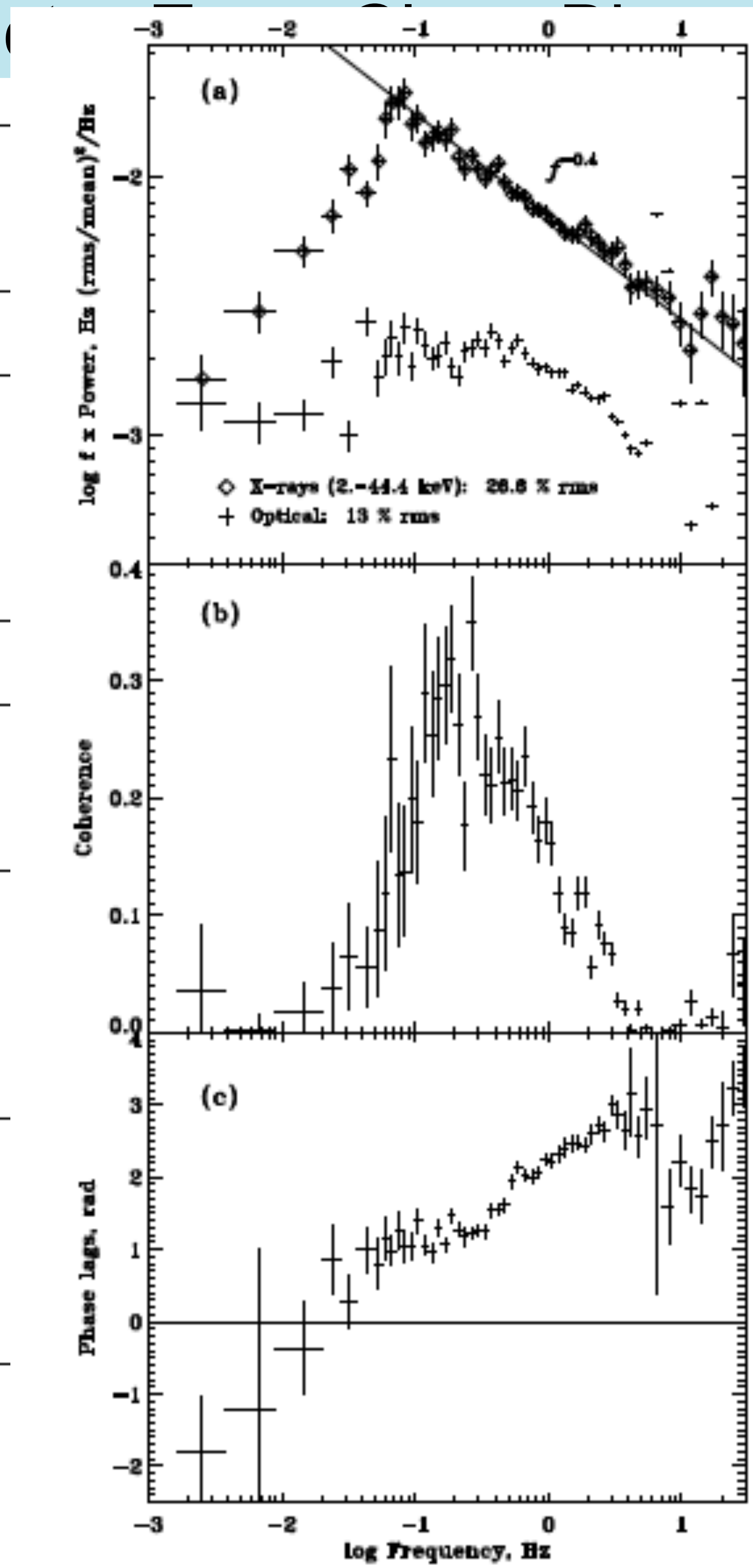
Current Dete... Systems

Multiwavelength Observations X-ray NIR

XTE J1118+480
Malzac et al, 2003, A&A, 407, 335

um | E/ΔE | No. of | Instrument

nc



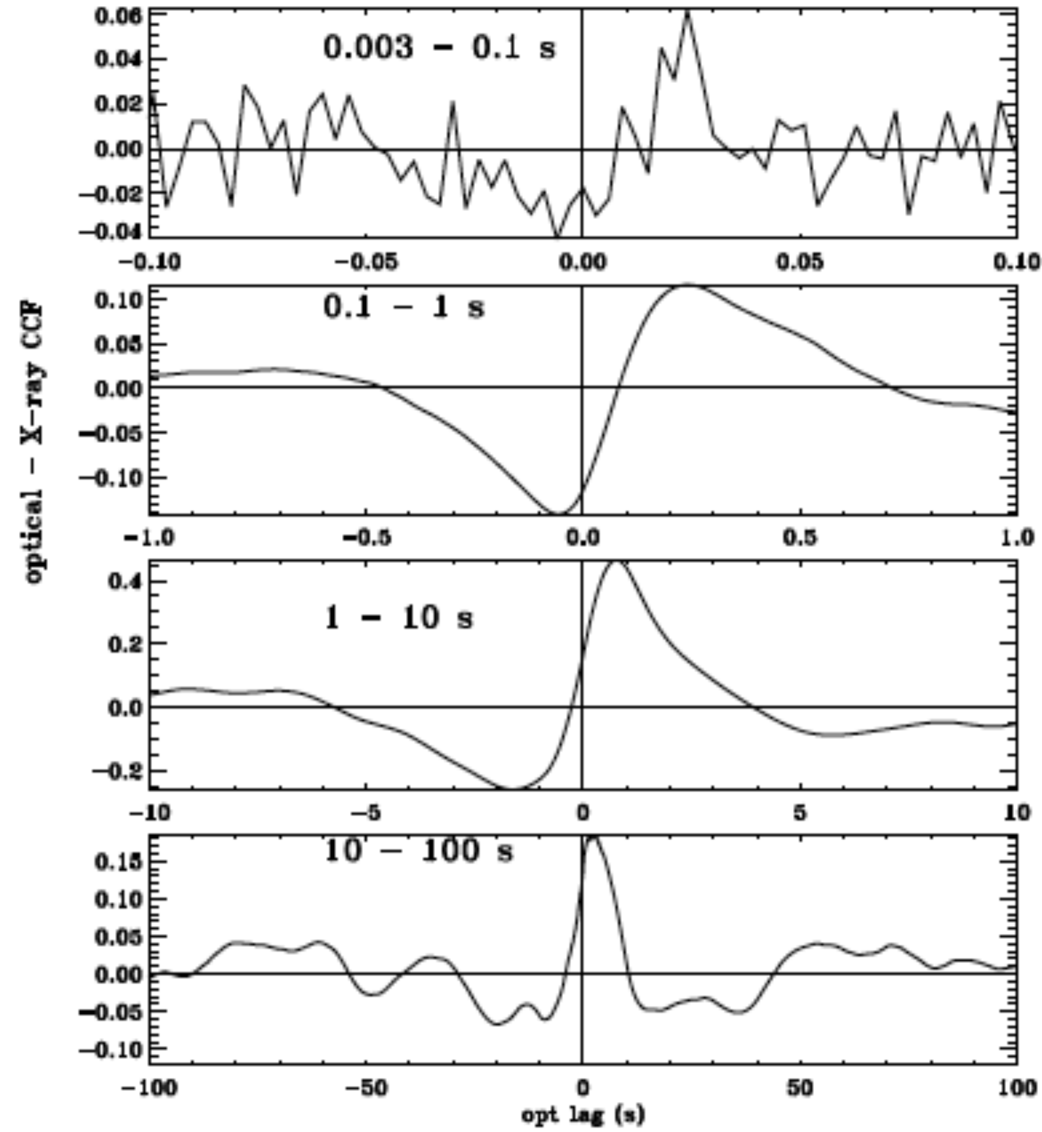


Fig. 4. Optical vs X-ray CCFs for different time-scales of the fluctuations. The CCFs were computed after both light curve have been filtered keeping only the time-scales in the range indicated. High frequency noise was removed applying a box car filter, the low frequency noise was removed by dividing the light curve by the piecewise linear trend.

sensor

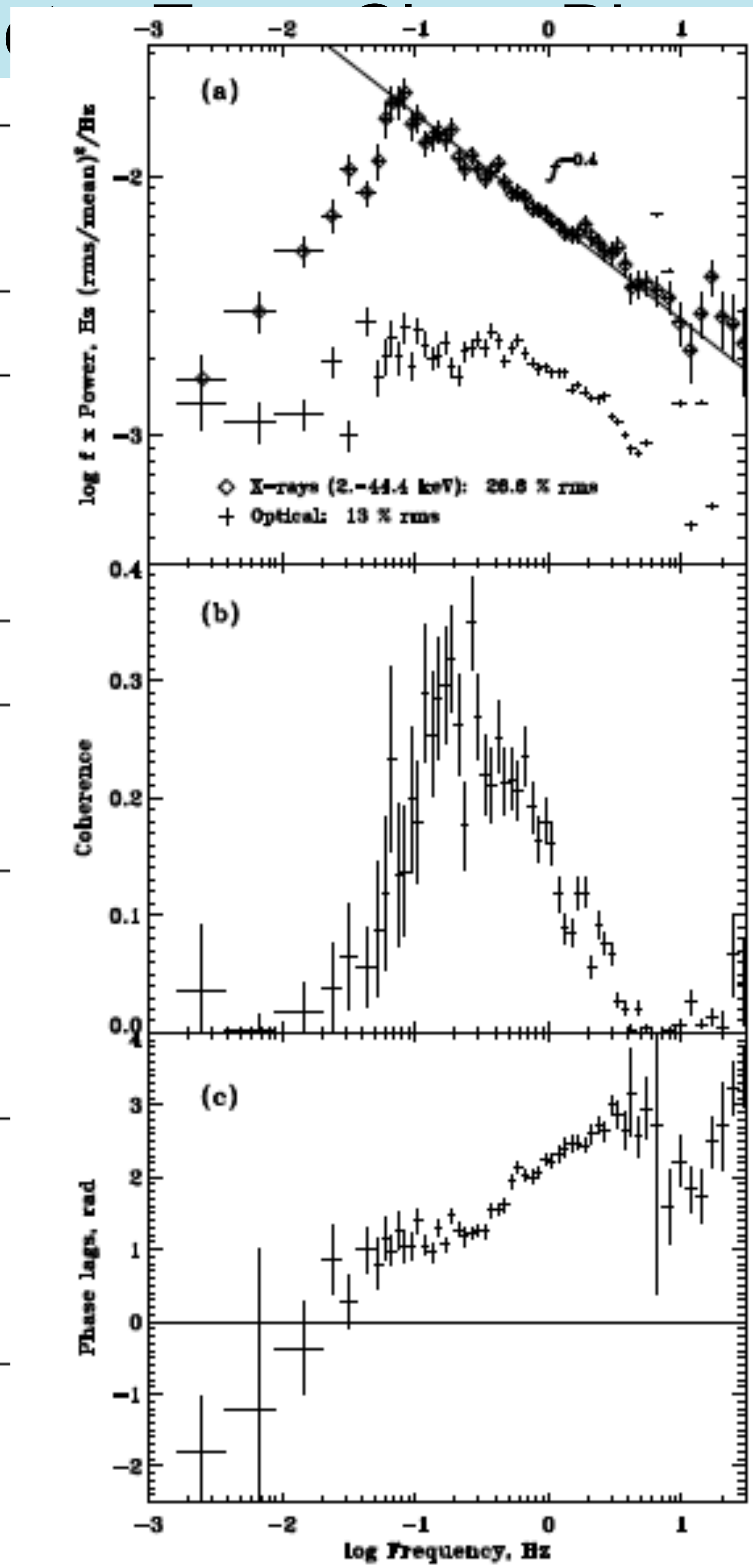
NUI Ga...
OÉ Gail...

Current Dete[…] Systems

Multiwavelength Observations X-ray NIR

XTE J1118+480
Malzac et al, 2003, A&A, 407, 335

…um	E/ΔE	No. of	Instrument
…nc			
			sensor



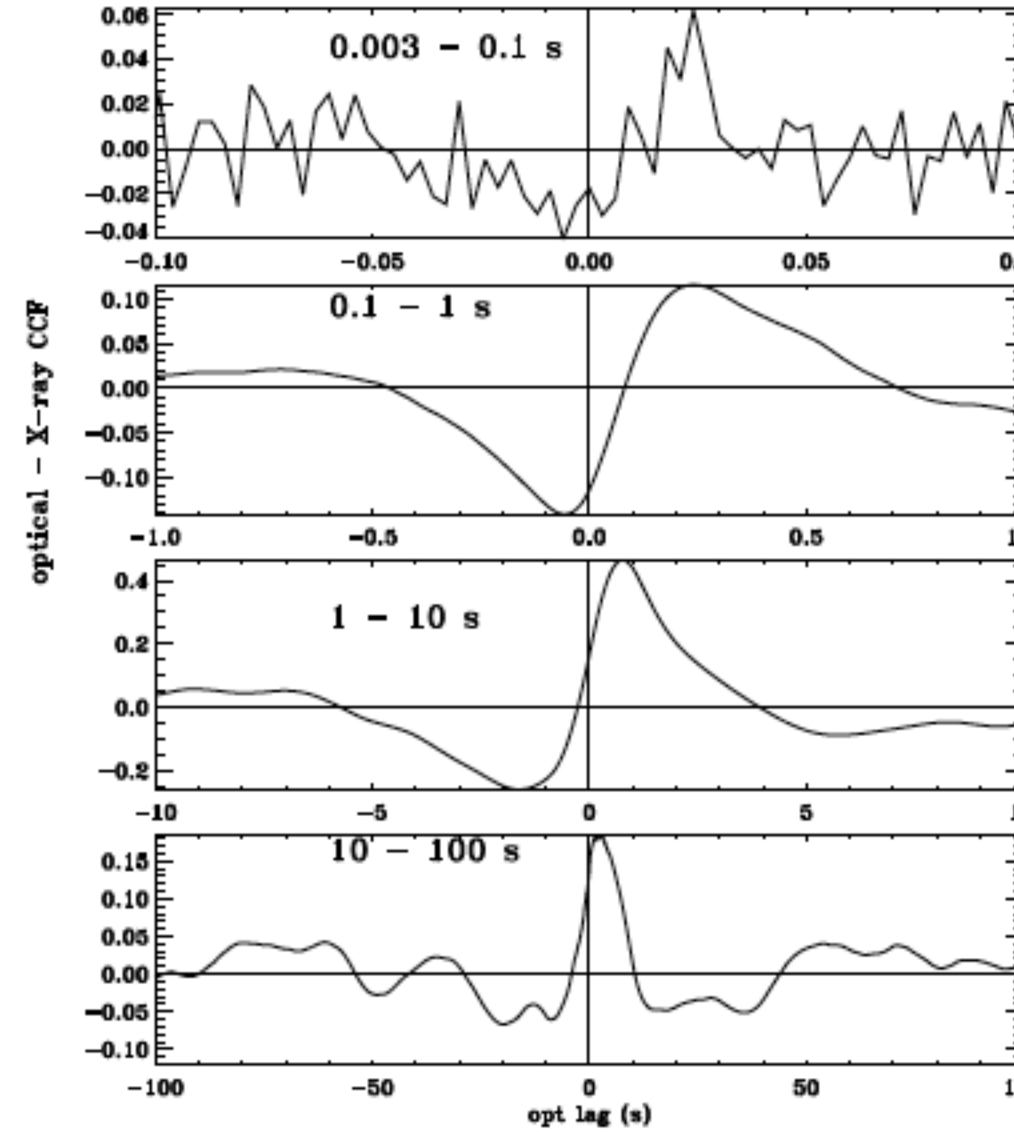


Fig. 4. Optical vs X-ray CCFs for different time-scales of the fluctuations. The CCFs were computed after both light curve have been filtered keeping only the time-scales in the range indicated. High frequency noise was removed applying a box car filter, the low frequency noise was removed by dividing the light curve by the piecewise linear trend.

NUI Ga[…]
OÉ Gail[…]

Current Detector Zoo - Transits and Occultations

Ultracam Titan

Detector	Time Resolution	Quantum Efficiency	E/ΔE	No. of Pixels	Instrument
CCD	5ms+	90% +	-	$>> 10^6$	UltraCam[42]
EMCCD	1ms+	40%	-	10^6	UltraSpec[42]
EMCCD	1ms+	40%	-	10^6	LuckyCam[43]
sCMOS	1ms+	60%	-	10^6	GASP[44]
pn CCD	0.01 ms+	90% +	-	10^6	[45]
Active Pixel Detectors	a few μs	80% +	-	10^5	[46]
SPADs	ns+	80% +	-	a few	Optima[47]
	ns+	15%		one[a]	GASP[44]
	100ps	50%+	-	a few	Iqueye[48]
STJ	ns+	90% +	5	10s	SCAM[49]
TES	ns+	90% +	20+	10s	[50]
MKID	ns+	90% +	500+	10s	[51]
Photo-Cathodes	ns+	<30%	-	$1 - 10^6$	Many
	1ms	40%	-	10^6	wavefront sensor

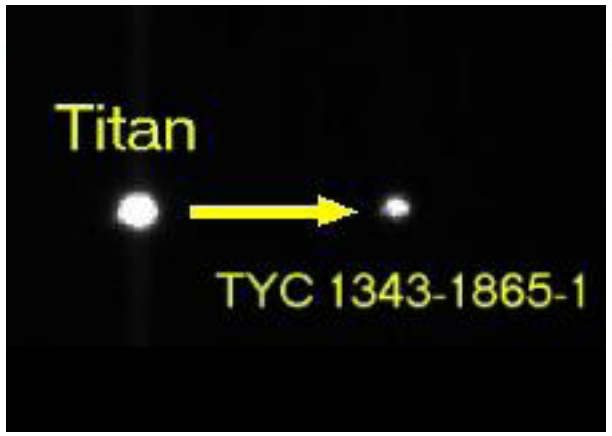
Current Detector Zoo - Transits and Occultations

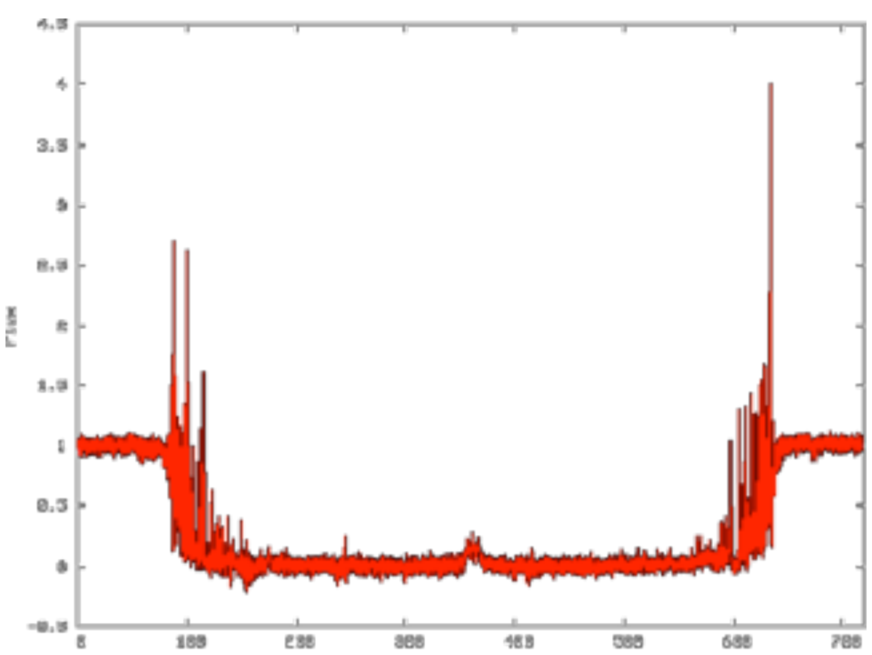
Ultracam Titan

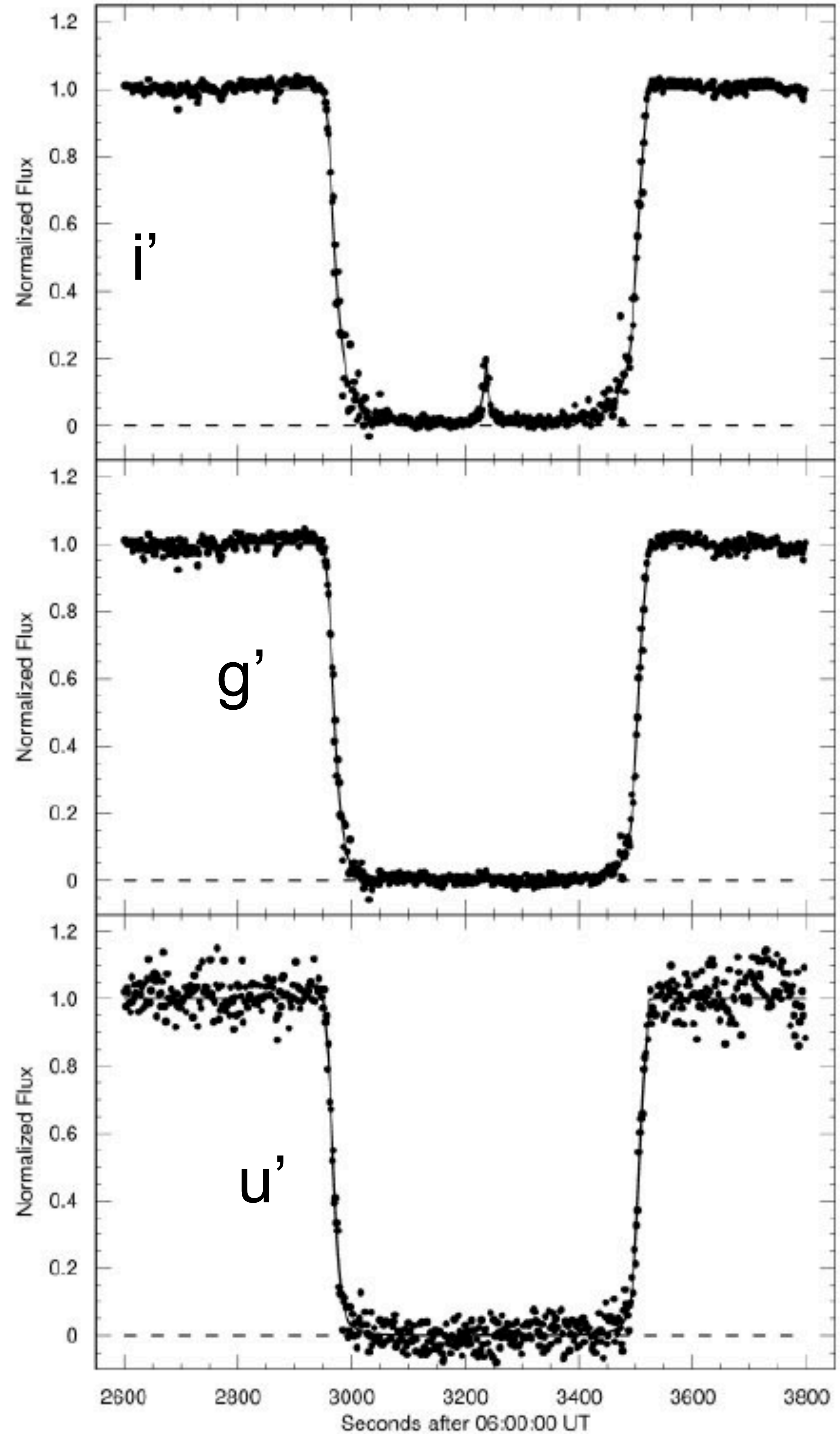
Detector	Time Resolution	Quantum Efficiency	E/ΔE	No. of Pixels	Instrument
CCD	5ms+	90% +	-	$>> 10^6$	UltraCam[42]
EMCCD	1ms+	40%	-	10^6	UltraSpec[42]
EMCCD	1ms+	40%	-	10^6	LuckyCam[43]
sCMOS	1ms+	60%	-	10^6	GASP[44]
pn CCD	0.01 ms+	90% +	-	10^6	[45]
Active Pixel Detectors	a few μs	80% +	-	10^5	[46]
SPADs	ns+	80% +	-	a few	Optima[47]
	ns+	15%		one[a]	GASP[44]
	100ps	50%+	-	a few	Iqueye[48]
STJ	ns+	90% +	5	10s	SCAM[49]
TES	ns+	90% +	20+	10s	[50]
MKID	ns+	90% +	500+	10s	[51]
Photo-Cathodes	ns+	<30%	-	$1 - 10^6$	Many
	1ms	40%	-	10^6	wavefront sensor

Current Detector Zoo - Transits

Ultracam Titan
Zalucha et al, 2007, Icarus, 192, 503

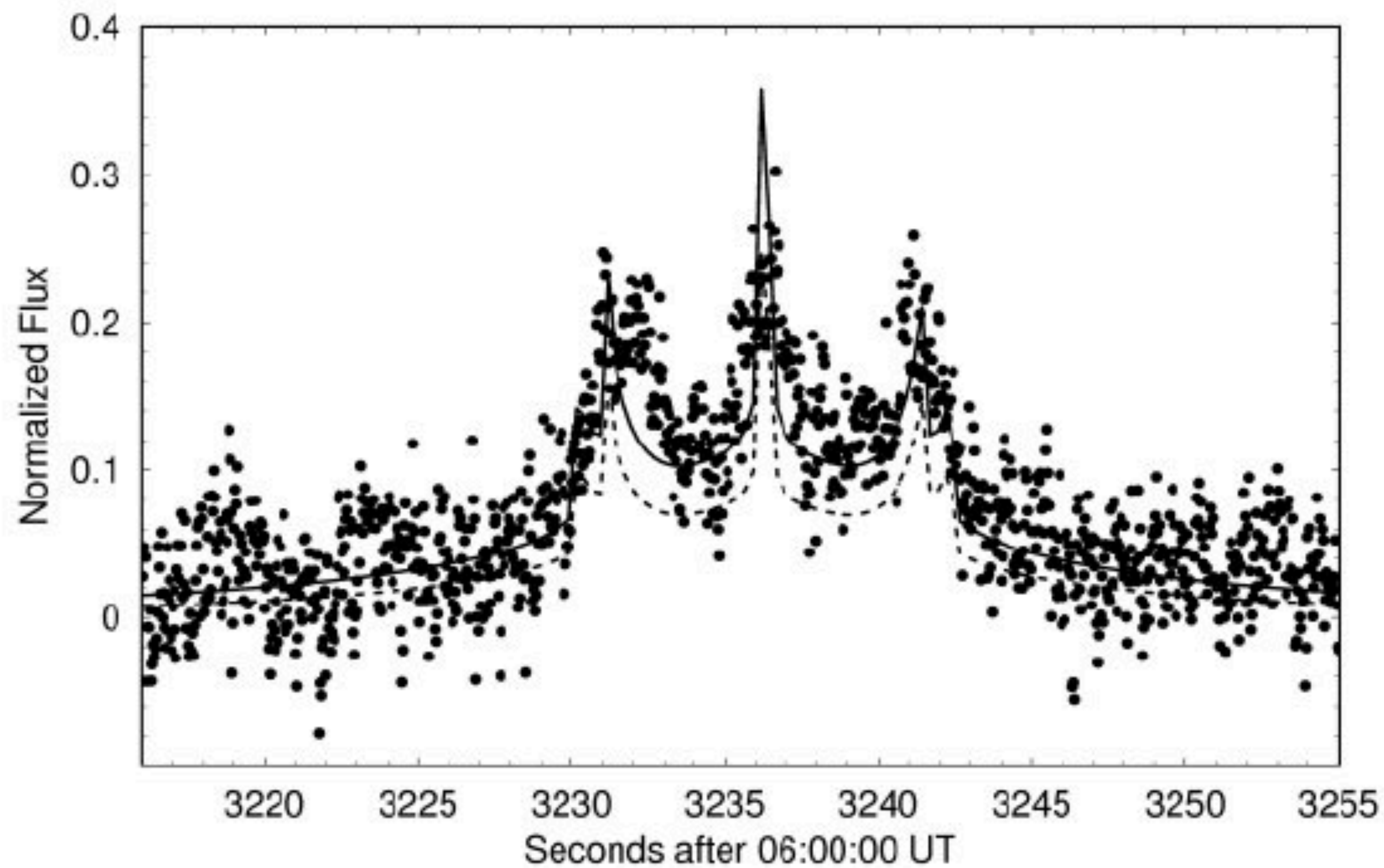


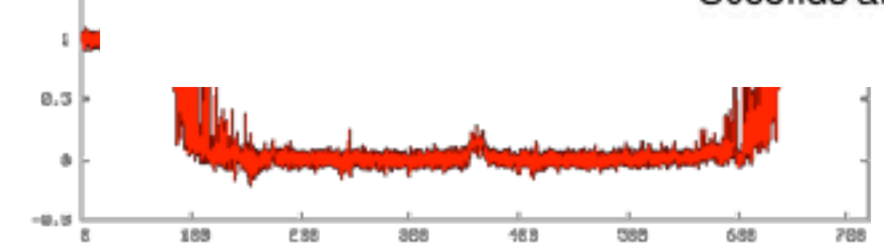


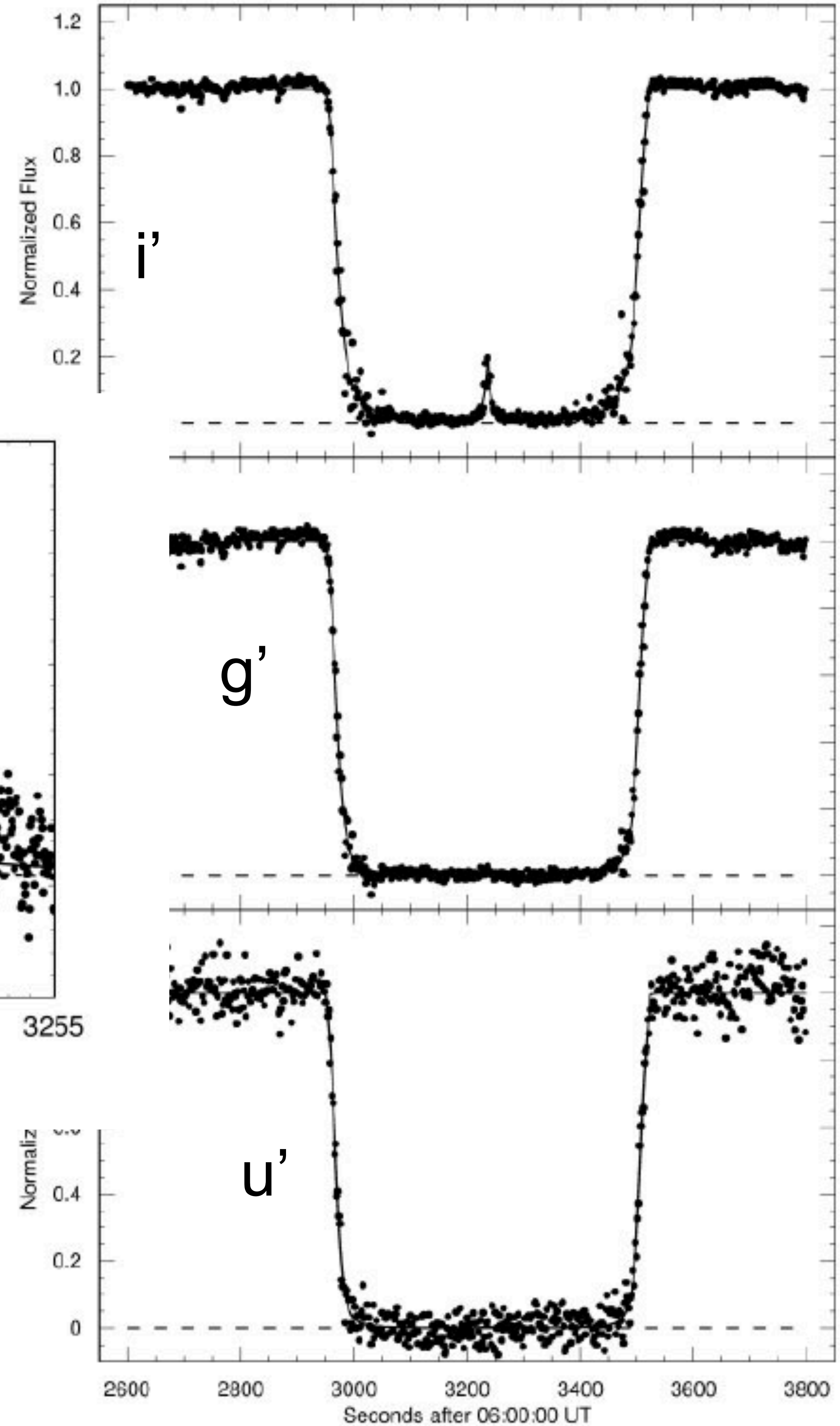


Current Detector Zoo - Transits

Ultracam Titan
Zalucha et al, 2007, Icarus, 192, 503







What is the Ideal HTRA Detector?

What is the Ideal HTRA Detector?

1. Low noise read noise < e^-

2. Fast timing

What is the Ideal HTRA Detector?

1. Low noise read noise < e^-
2. Fast timing
   i. t ~ msec - most applications

What is the Ideal HTRA Detector?

1. Low noise read noise < e^-

2. Fast timing

   i. t ~ msec - most applications

   ii. t ~ µsec - pulsars

What is the Ideal HTRA Detector?

1. Low noise read noise < e^-
2. Fast timing
    i. t ~ msec - most applications
    ii. t ~ μsec - pulsars
    iii. t ~ nano-picosecs ~ quantum effects
3. Energy resolution E/ΔE > 5 - i.e. broad band and better
4. Spectral Range 0.35-2.5 microns
5. Pixels > 100 x 100 - most are point sources
6. Polarisation sensitivity?

HTRA science satisfies the fundamental E-ELT rationale of opening up new parameter space.

What is the Ideal HTRA Detector?

1. Low noise read noise < e^-

2. Fast timing

    i. t ~ msec - most applications

    ii. t ~ μsec - pulsars

    iii. t ~ nano-picosecs ~ quantum effects

3. Energy resolution E/ΔE > 5 - i.e. broad band and better

4. Spectral Range 0.35-2.5 microns

5. Pixels > 100 x 100 - most are point sources

6. Polarisation sensitivity?

HTRA science satisfies the fundamental E-ELT rationale of opening up new parameter space.

What is the Ideal HTRA Detector?

1. Low noise read noise < e^-

2. Fast timing

   i. t ~ msec - most applications

   ii. t ~ μsec - pulsars

   iii. t ~ nano-picosecs ~ quantum effects

3. Energy resolution E/ΔE > 5 - i.e. broad band and better

4. Spectral Range 0.35-2.5 microns

5. Pixels > 100 x 100 - most are point sources

6. Polarisation sensitivity?

HTRA science satisfies the fundamental E-ELT rationale of opening up new parameter space.

What is the Ideal HTRA Detector?

1. Low noise read noise < e^-

2. Fast timing

   i. t ~ msec - most applications

   ii. t ~ μsec - pulsars

   iii. t ~ nano-picosecs ~ quantum effects

3. Energy resolution E/ΔE > 5 - i.e. broad band and better

4. Spectral Range 0.35-2.5 microns

5. Pixels > 100 x 100 - most are point sources

6. Polarisation sensitivity?

HTRA science satisfies the fundamental E-ELT rationale of opening up new parameter space.

What is the Ideal HTRA Detector?

1. Low noise read noise < e^-
2. Fast timing
   i. t ~ msec - most applications
   ii. t ~ µsec - pulsars
   iii. t ~ nano-picosecs ~ quantum effects
3. Energy resolution E/ΔE > 5 - i.e. broad band and better
4. Spectral Range 0.35-2.5 microns
5. Pixels > 100 x 100 - most are point sources
6. Polarisation sensitivity?

HTRA science satisfies the fundamental E-ELT rationale of opening up new parameter space.

What is the Ideal HTRA Detector?

1. Low noise read noise < e^-
2. Fast timing
   i. t ~ msec - most applications
   ii. t ~ µsec - pulsars
   iii. t ~ nano-picosecs ~ quantum effects
3. Energy resolution E/ΔE > 5 - i.e. broad band and better
4. Spectral Range 0.35-2.5 microns
5. Pixels > 100 x 100 - most are point sources
6. Polarisation sensitivity?

HTRA science satisfies the fundamental E-ELT rationale of opening up new parameter space.

What is the Ideal HTRA Detector?

1. Low noise read noise < e^-

2. Fast timing

   i. t ~ msec - most applications

   ii. t ~ µsec - pulsars

   iii. t ~ nano-picosecs ~ quantum effects

3. Energy resolution E/ΔE > 5 - i.e. broad band and better

4. Spectral Range 0.35-2.5 microns

5. Pixels > 100 x 100 - most are point sources

6. Polarisation sensitivity?

HTRA science satisfies the fundamental E-ELT rationale of opening up new parameter space.

What is the Ideal HTRA Detector?

1. Low noise read noise < e^-
2. Fast timing
   i. t ~ msec - most applications
   ii. t ~ μsec - pulsars
   iii. t ~ nano-picosecs ~ quantum effects
3. Energy resolution E/ΔE > 5 - i.e. broad band and better
4. Spectral Range 0.35-2.5 microns
5. Pixels > 100 x 100 - most are point sources
6. Polarisation sensitivity?

HTRA science satisfies the fundamental E-ELT rationale of opening up new parameter space.

What is the Ideal HTRA Detector?

1. Low noise read noise < e^-
2. Fast timing
   i. t ~ msec - most applications
   ii. t ~ µsec - pulsars
   iii. t ~ nano-picosecs ~ quantum effects
3. Energy resolution E/ΔE > 5 - i.e. broad band and better
4. Spectral Range 0.35-2.5 microns
5. Pixels > 100 x 100 - most are point sources
6. Polarisation sensitivity?

HTRA science satisfies the fundamental E-ELT rationale of opening up new parameter space.

What is the Ideal HTRA Detector?

1. Low noise read noise < e^-
2. Fast timing
   i. t ~ msec - most applications
   ii. t ~ μsec - pulsars
   iii. t ~ nano-picosecs ~ quantum effects
3. Energy resolution E/ΔE > 5 - i.e. broad band and better
4. Spectral Range 0.35-2.5 microns
5. Pixels > 100 x 100 - most are point sources
6. Polarisation sensitivity?

HTRA science satisfies the fundamental E-ELT rationale of opening up new parameter space.

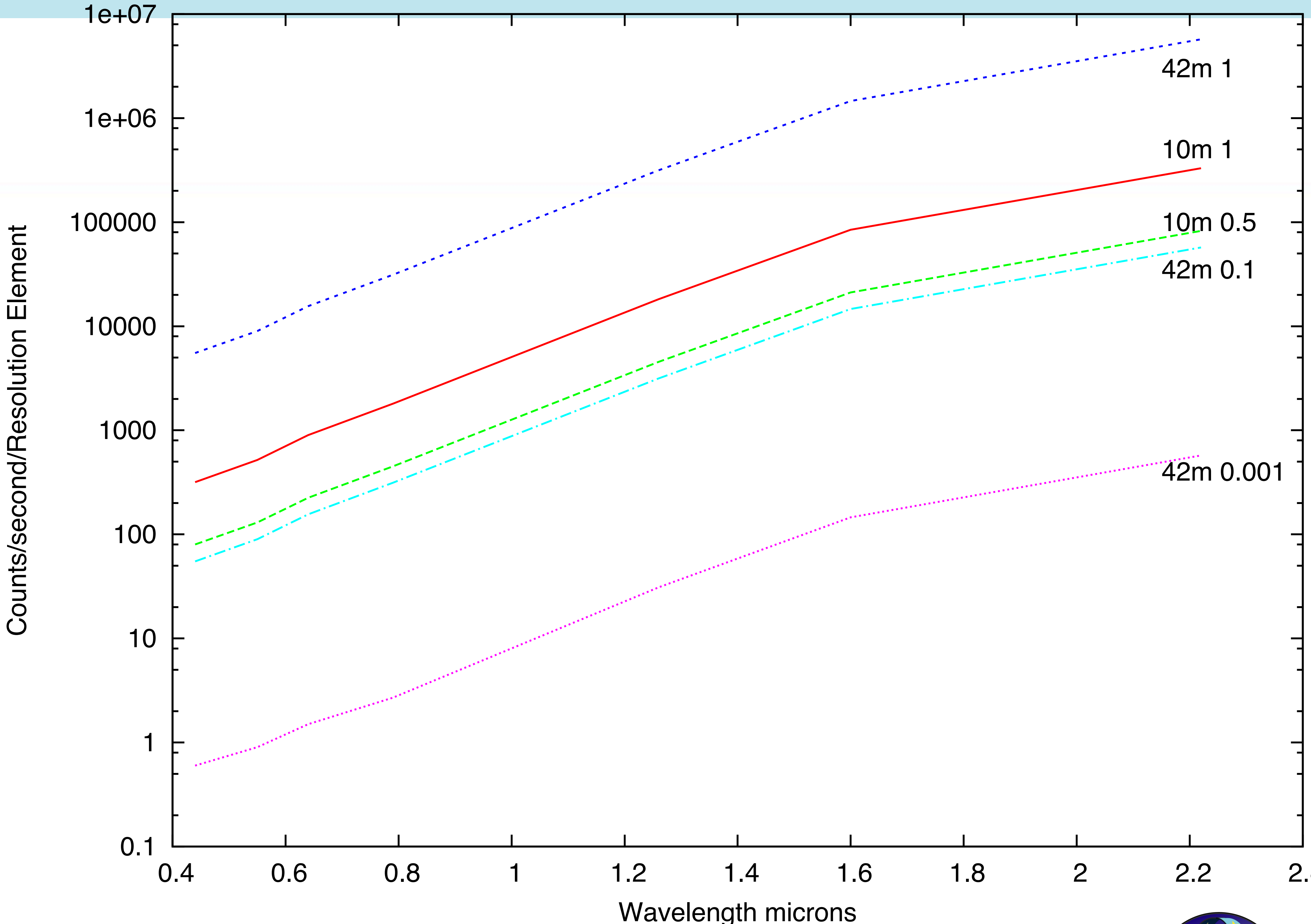
Main Optical HTRA instruments in Opticon

- UltraCam/UltraSpec : Sheffield and Warwick
  - Frame transfer CCD - UltraCam
  - EMCCD - UltraSpec
- Optima : Max Planck Garching,
  - SPAD
- Iqueye : Padova
  - SPAD
- *GASP : Galway*
  - *SPAD / sCMOS*
- *All optical out to 1 micron*

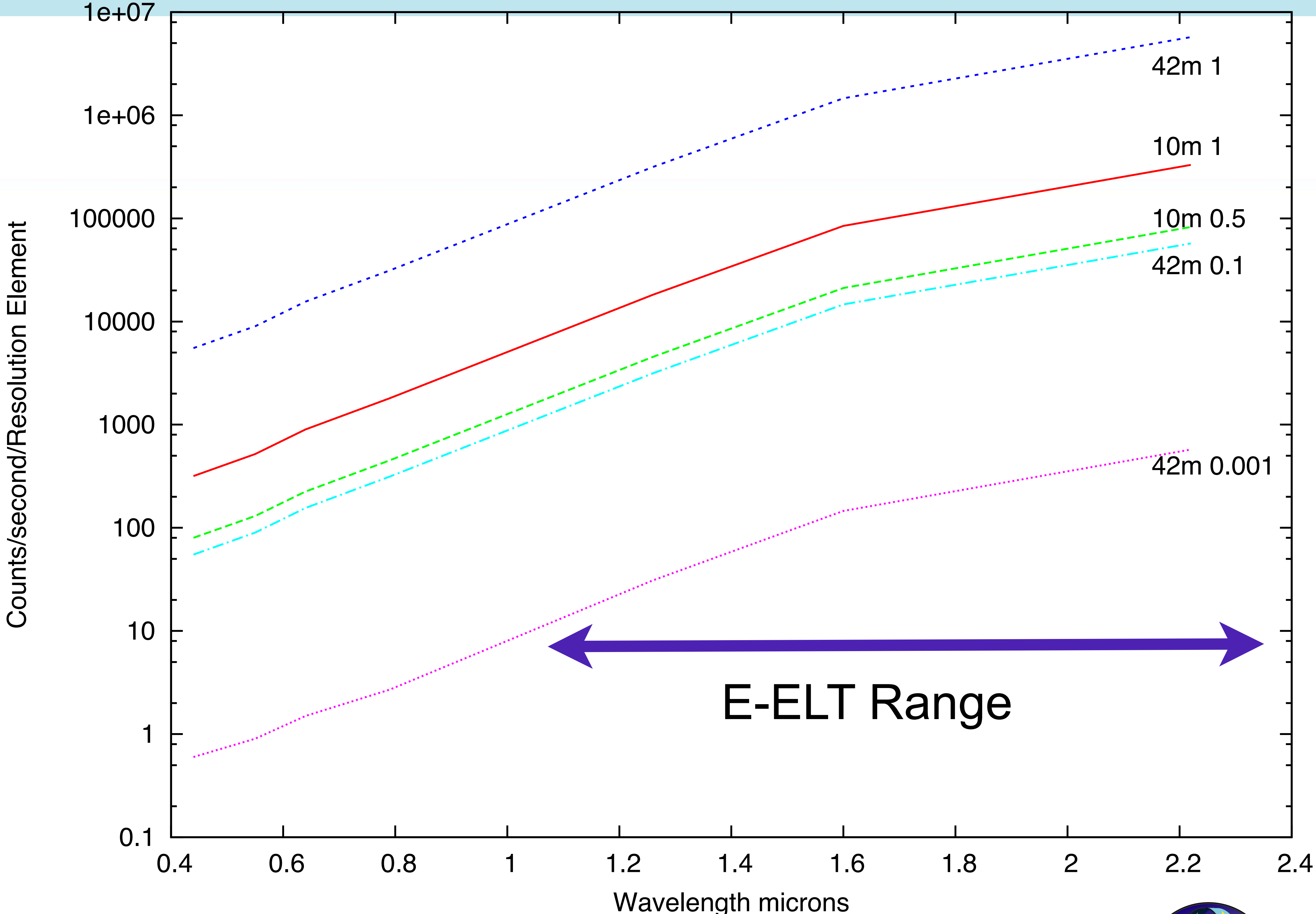
Observatory HTRA instruments

- General Purpose Instruments
  - HTRA component often an after thought
  - Read noise 2-3 e^- (visible) - >20 e^- (near-IR)
    - ISAAC (τ~ 3.2 ms, read >3 e^-)
    - HAWK-I (τ~ 30 ms, read >4 e^-)
    - SALTICAM (τ ~100 ms, >3 e^-)
  - Read-Noise dominated at fast frame rates
  - HTRA data pipeline often an afterthought

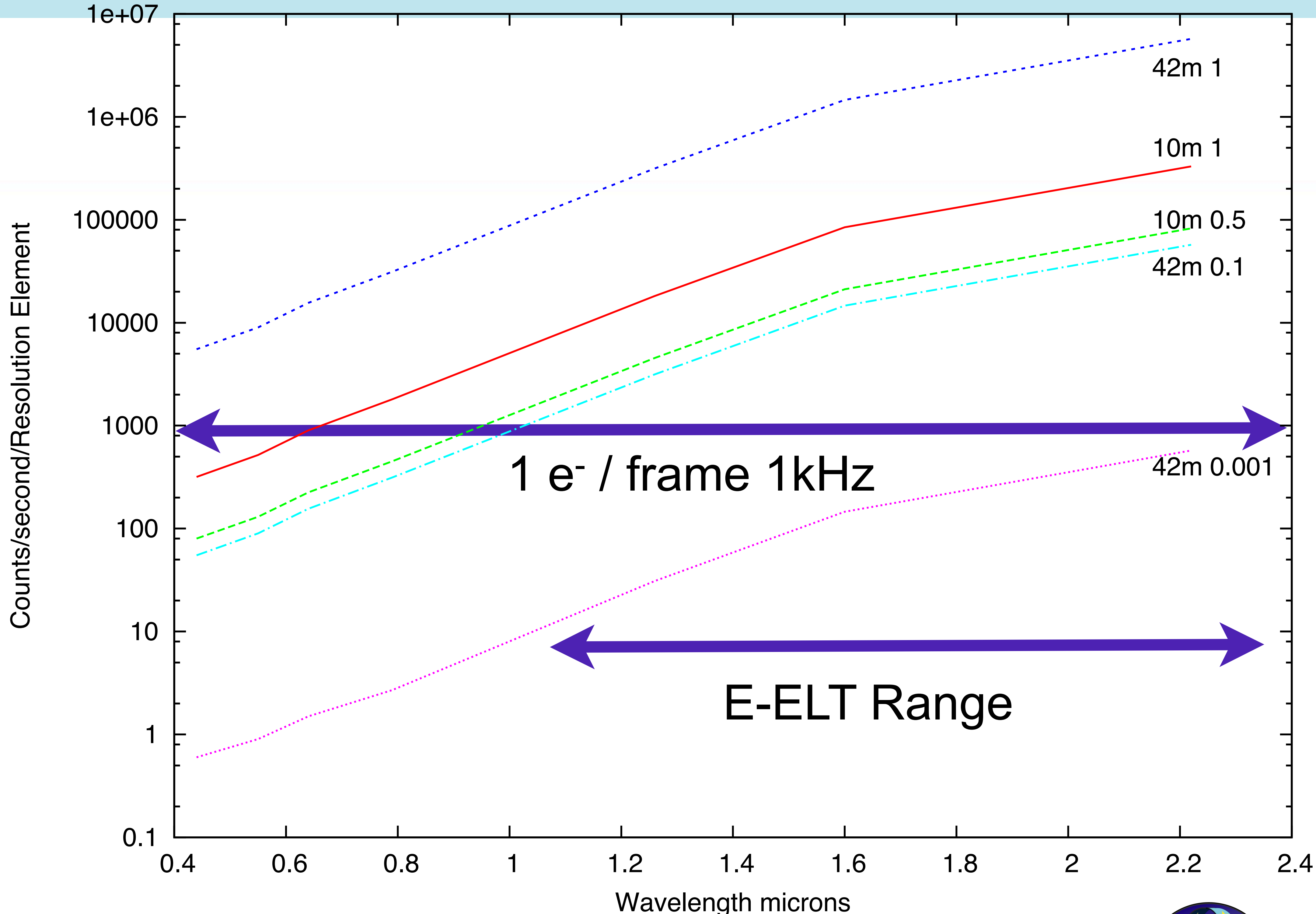
Sky noise vs read noise



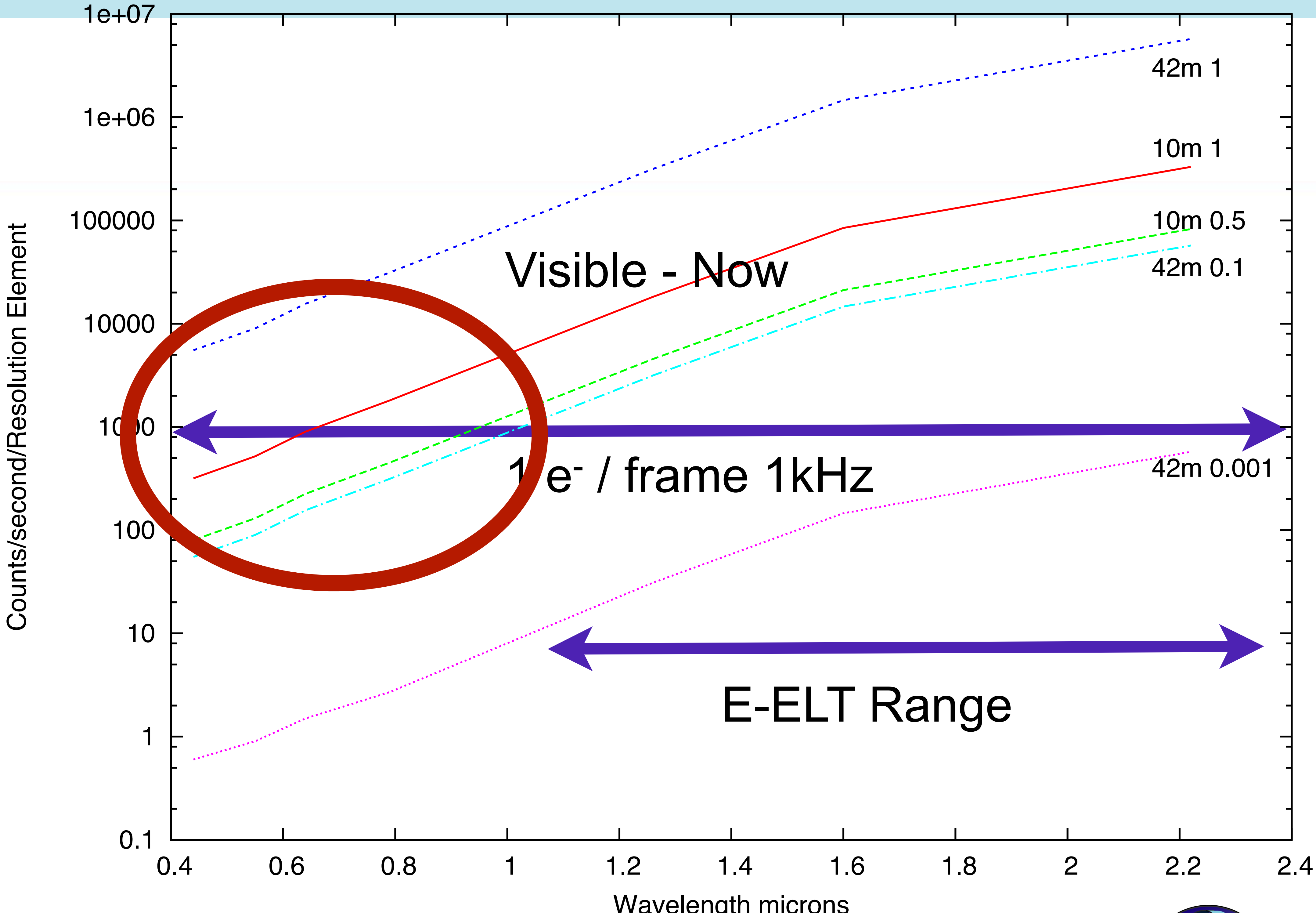
Sky noise vs read noise



Sky noise vs read noise



Sky noise vs read noise



HTRA for the E-ELT

milli-arcsec imaging in near-IR

Pass Band	Wavelength (microns)	Sky Brightness (10^6 counts /sec/arcsec^{-2})	counts/millisecond within aperture		
			1"	0".2	0".02
J	1.25	0.3	300	12	0.012
H	1.65	1.4	1400	54	0.054
K	2	5.3	5300	210	0.2

Table 4: E-ELT Sky counts for given sky apertures of 1", 0".2 and 0".02. This shows that for excellen seeing very low noise detectors with read noise of $< 1e^-$ / frame or integration time will be needed.

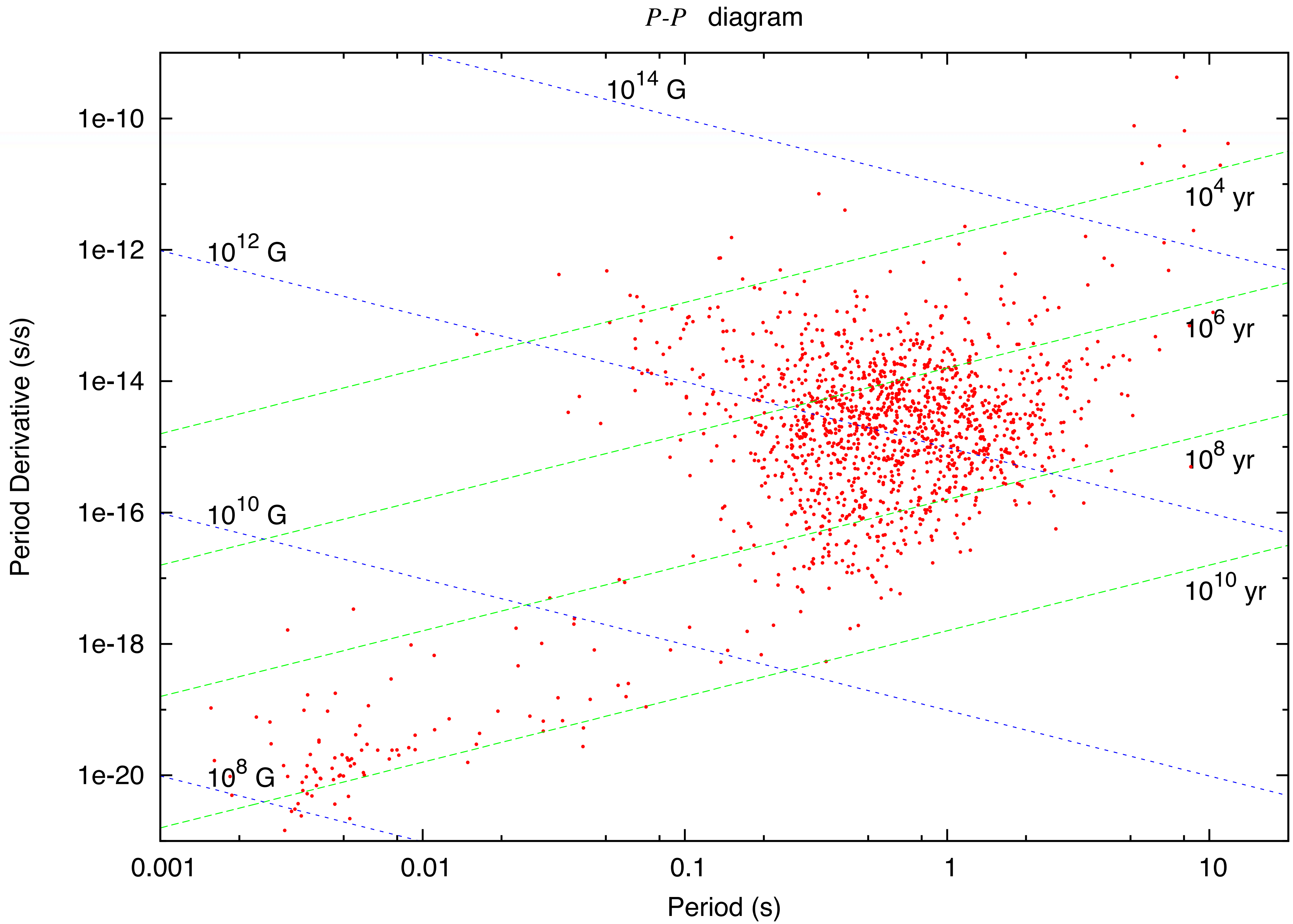
Why HTRA now?

- Low noise detectors are available now
  - EMCCDs, sCMOS
  - APDs - single pixel and arrays
- Larger telescopes are available now
  - GTC, SALT ..... all working
  - TMT, EELT planned
- Bigger community
- Multi-wavelength opportunities
  - LOFAR, Fermi, ALMA ......

Case Study - what can we do with HTRA

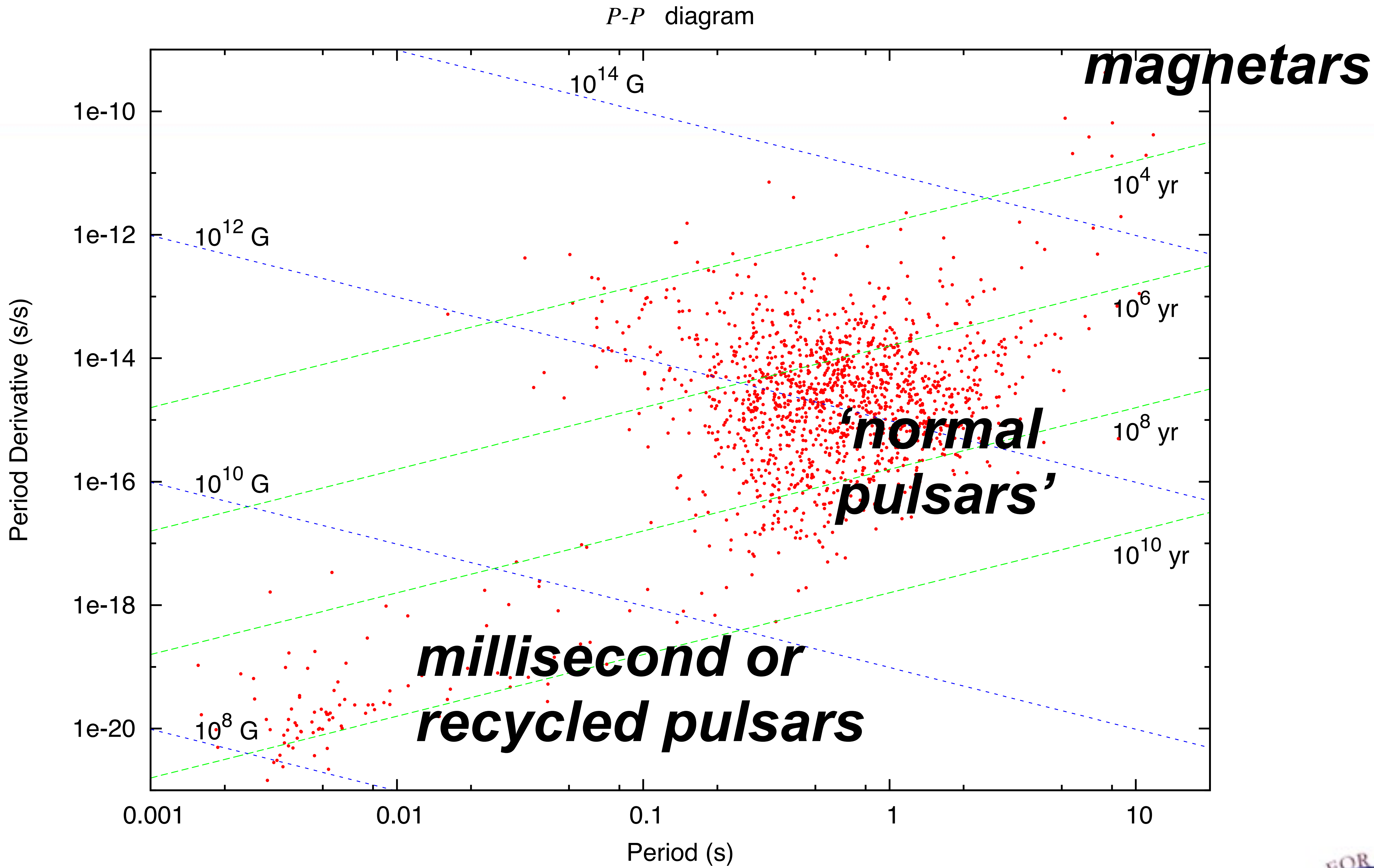
- Optical Pulsars
  - what do we know?
- Crab Pulsar
  - Observations by three Opticon Groups
    - Optima, Iqueye and GASP

Pulsars 101 - Life on the $P\dot{P}$ diagram



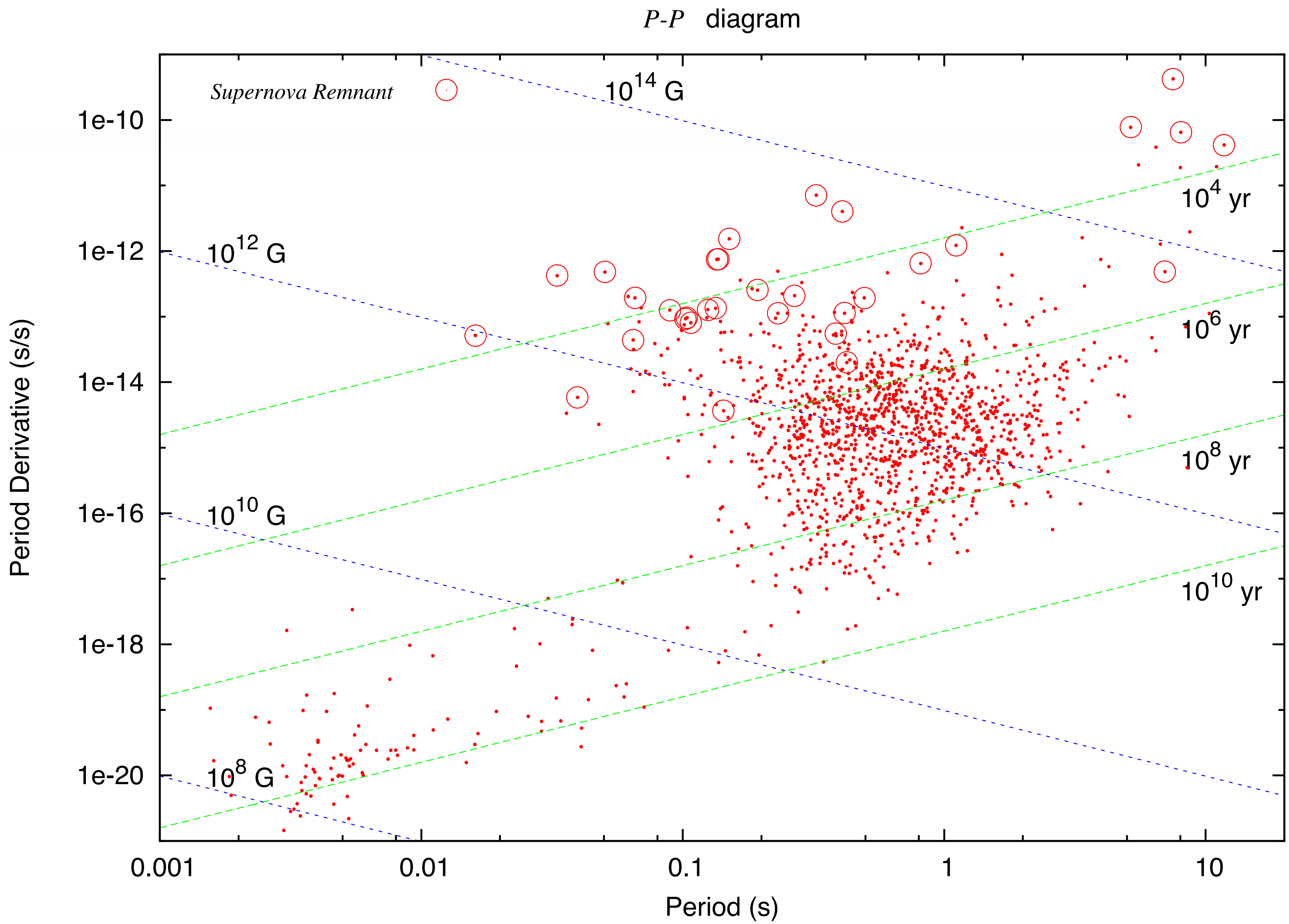
NUI Galway
OÉ Gaillimh

Pulsars 101 - Life on the $P\dot{P}$ diagram

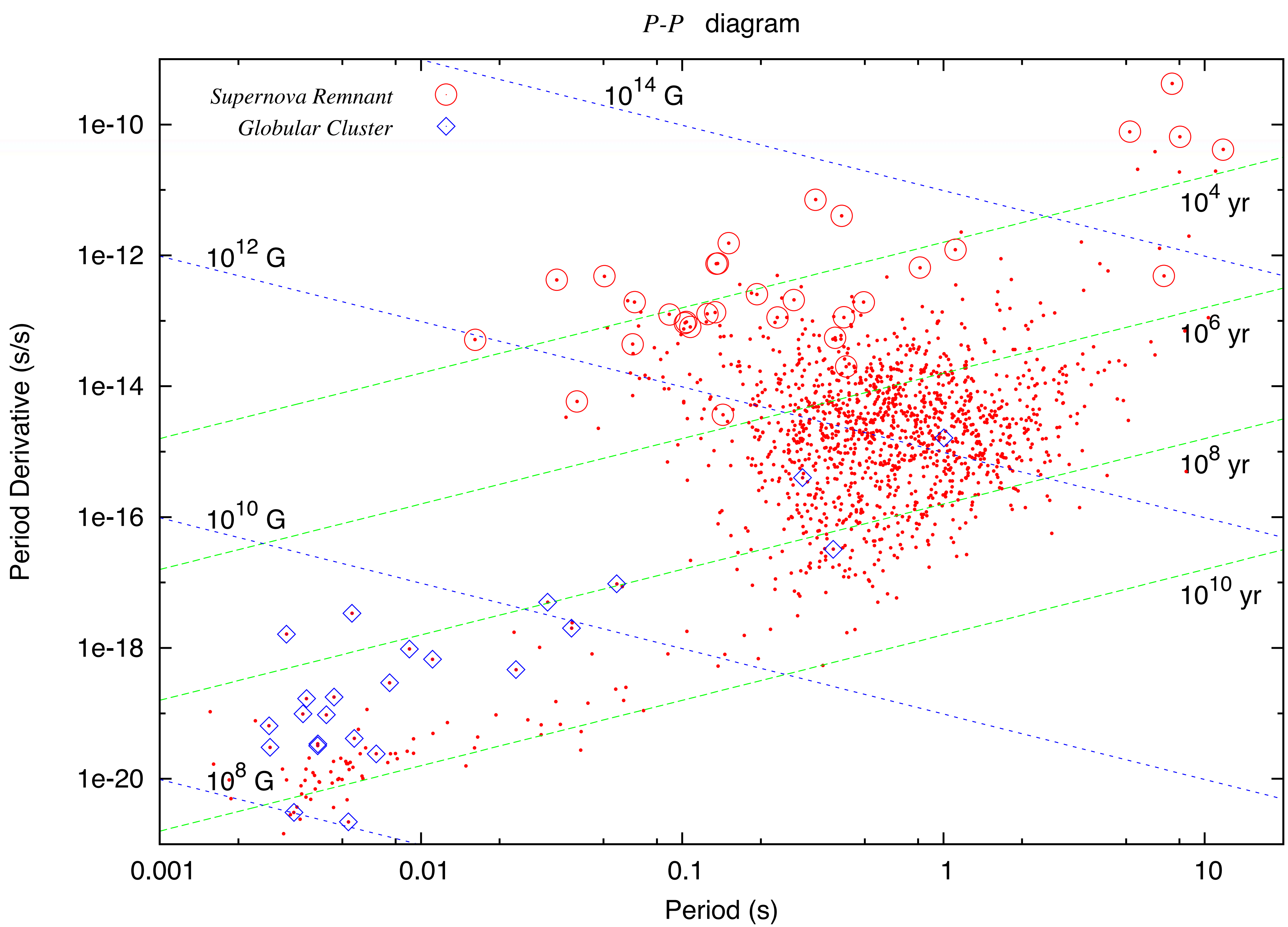


NUI Galway
OÉ Gaillimh

Pulsars 101 - Life on the $P\dot{P}$ diagram

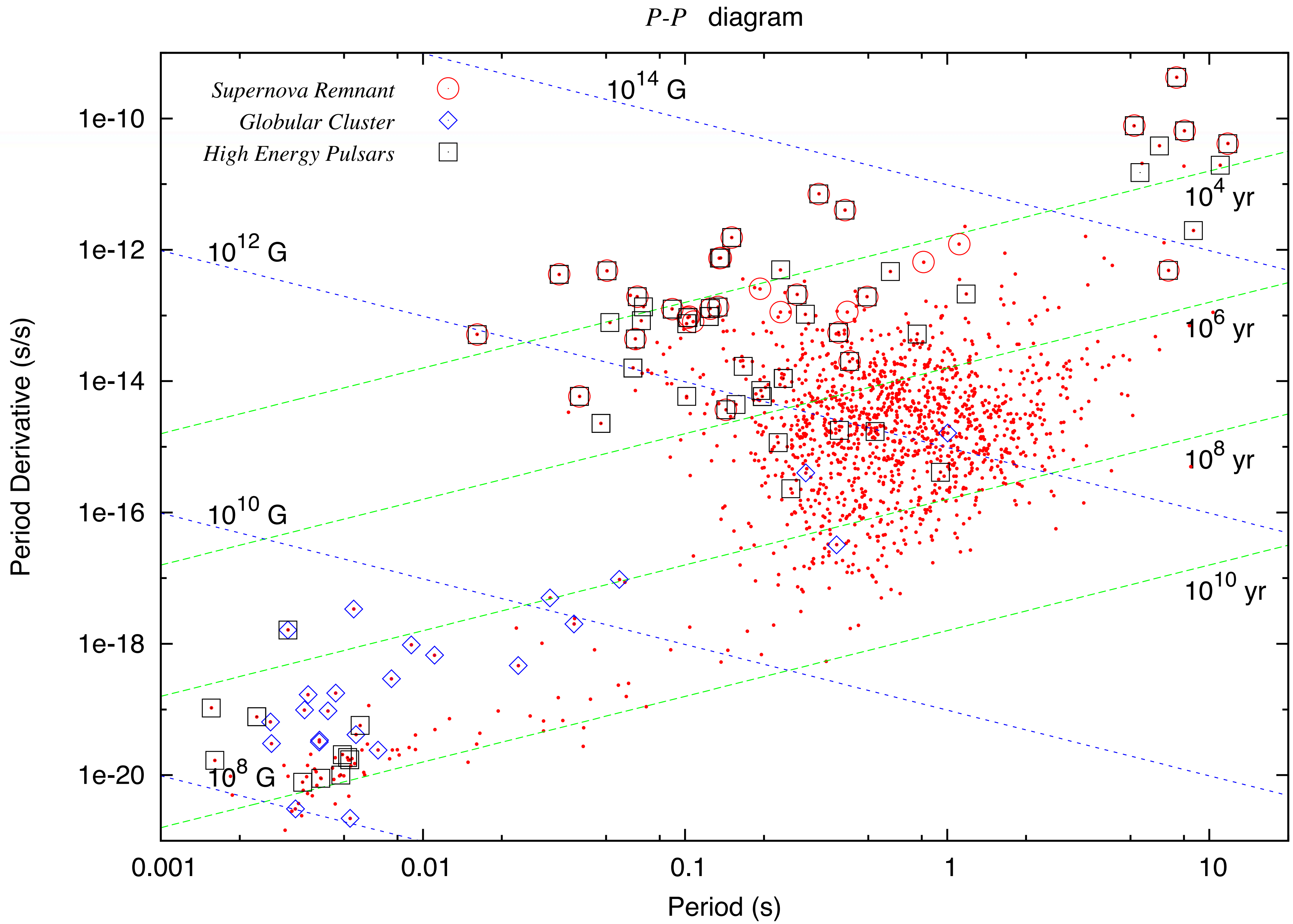


Pulsars 101 - Life on the $P\dot{P}$ diagram



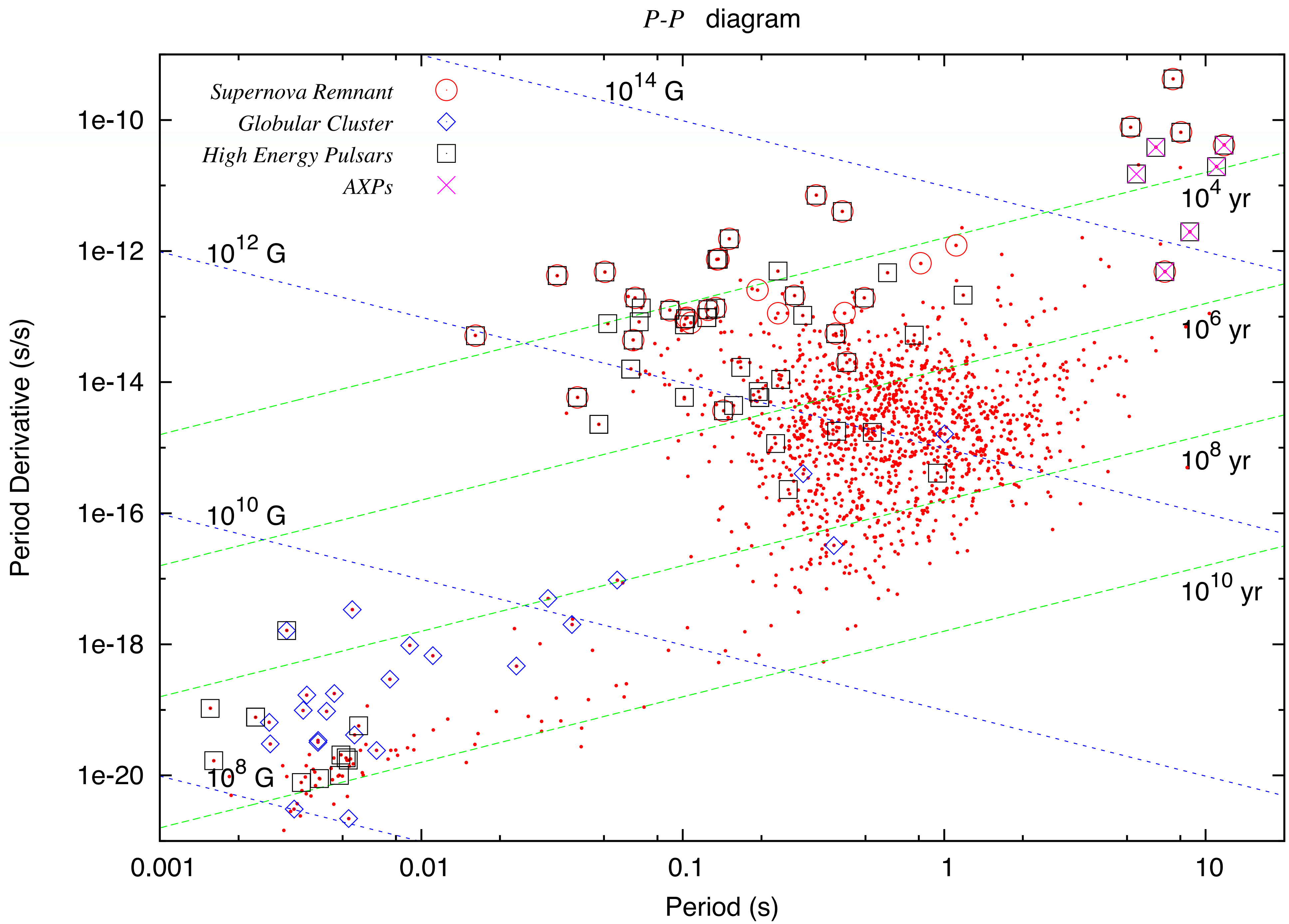
NUI Galway
OÉ Gaillimh

Pulsars 101 - Life on the $P\dot{P}$ diagram



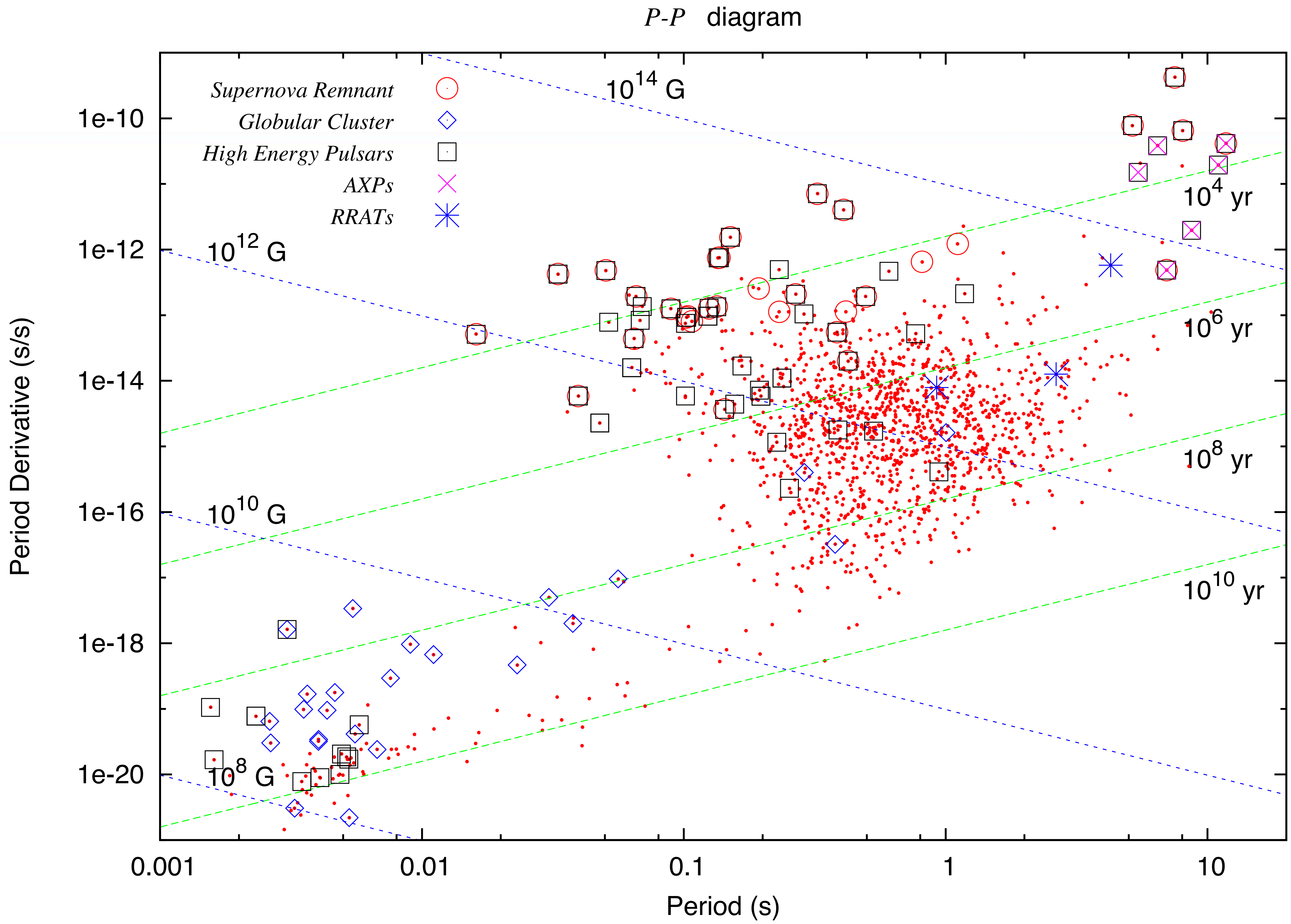
NUI Galway
OÉ Gaillimh

Pulsars 101 - Life on the $P\dot{P}$ diagram

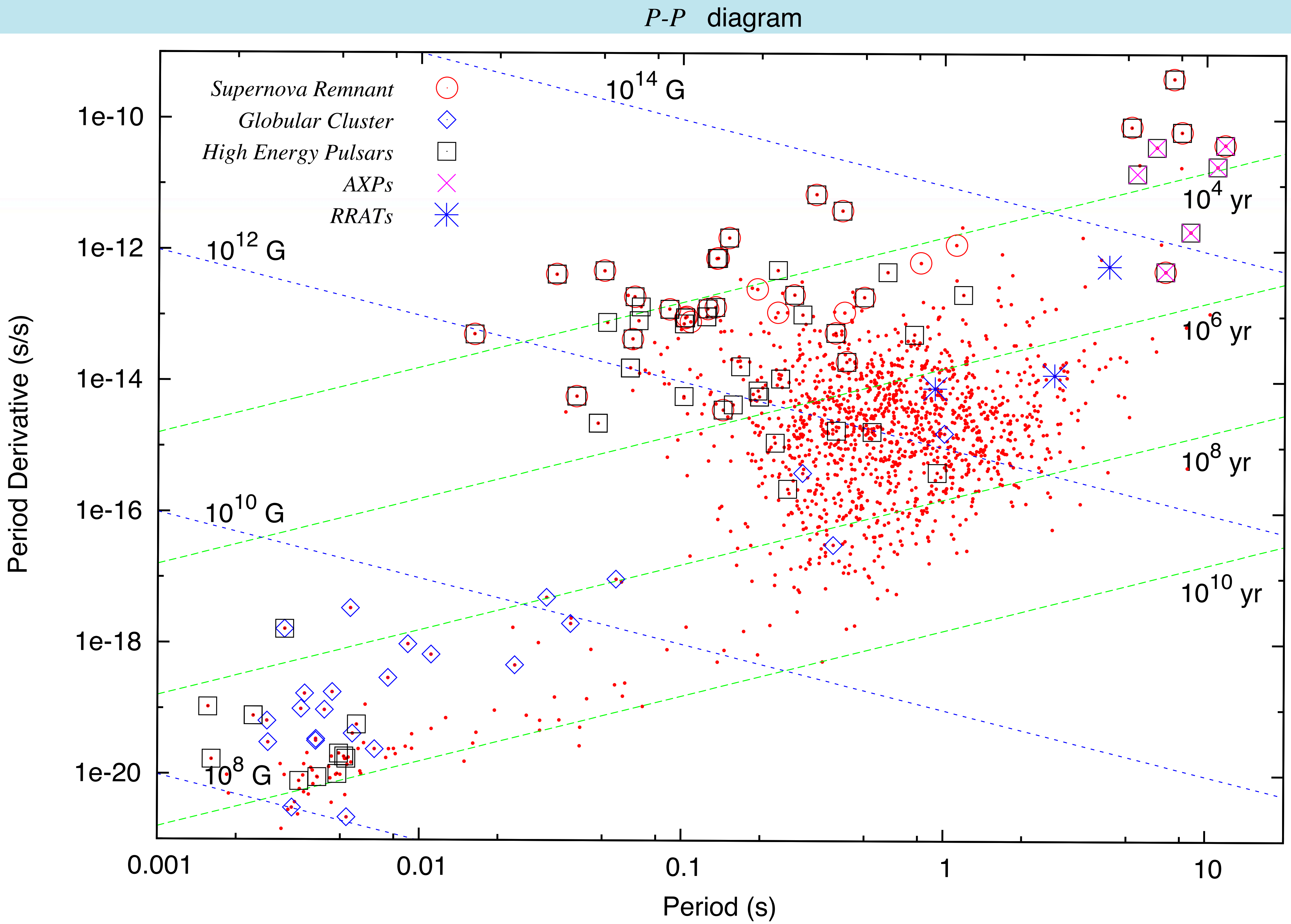


NUI Galway
OÉ Gaillimh

Pulsars 101 - Life on the $P\dot{P}$ diagram



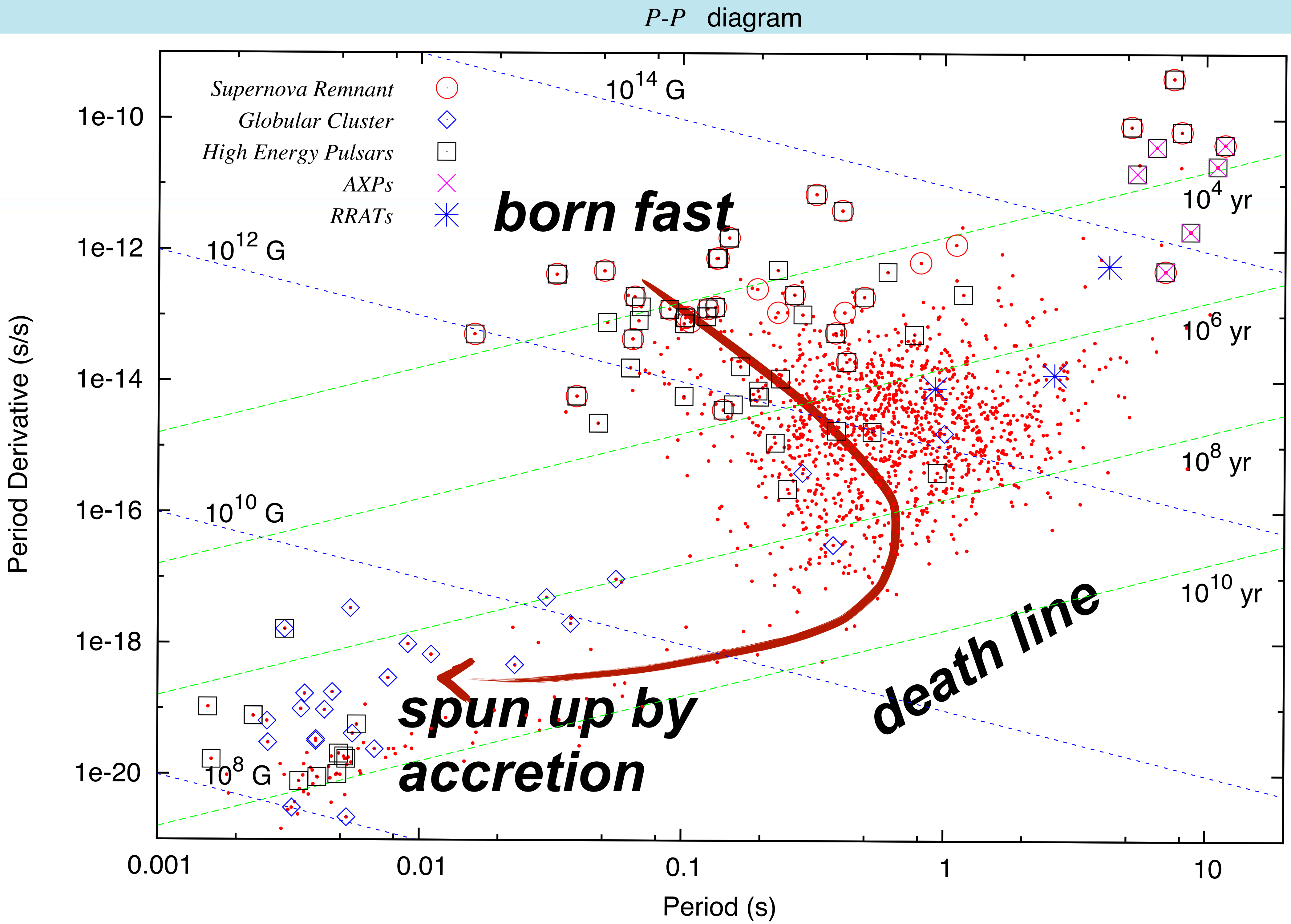
Pulsars - Life on the $P\dot{P}$ diagram



NUI Galway
OÉ Gaillimh

CENTRE FOR ASTRONOMY NUI GALWAY

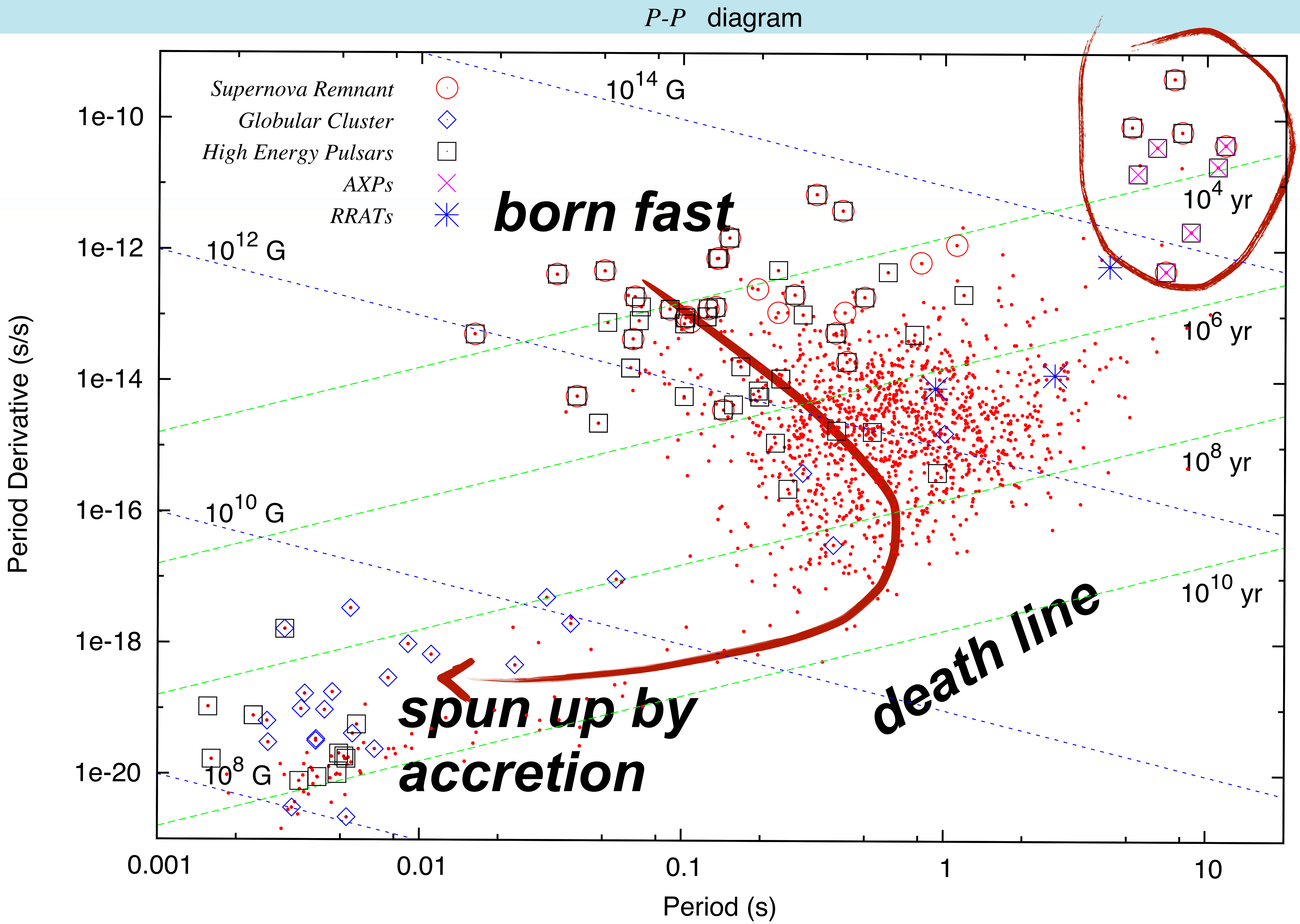
Pulsars - Life on the $P\dot{P}$ diagram



NUI Galway
OÉ Gaillimh

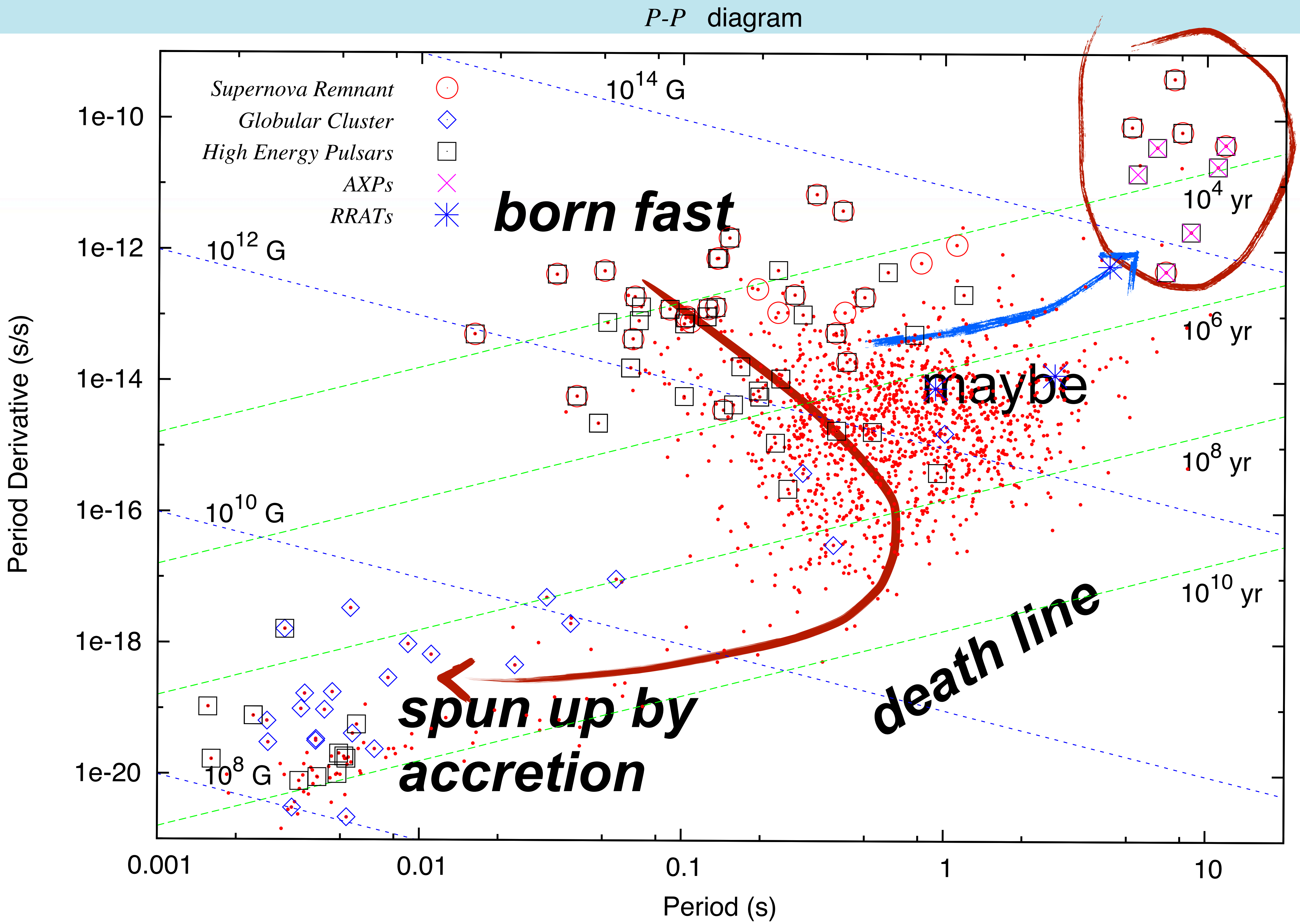
CENTRE FOR ASTRONOMY NUI GALWAY

Pulsars - Life on the $P\dot{P}$ diagram



what about these magnetars or anomolous X-ray pulsars

Pulsars - Life on the $P\dot{P}$ diagram

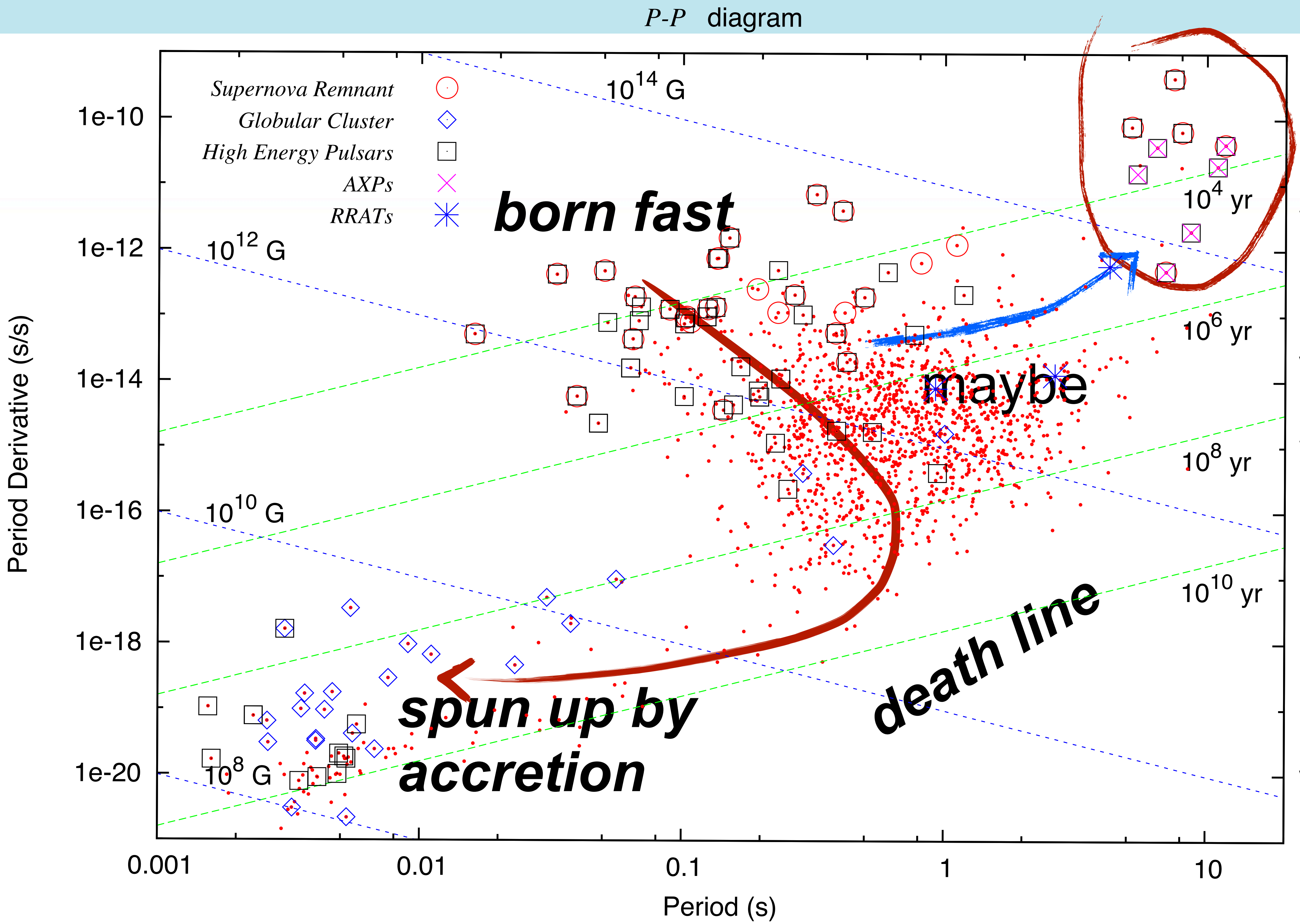


what about these magnetars or anomolous X-ray pulsars

NUI Galway
OÉ Gaillimh

CENTRE FOR ASTRONOMY NUI GALWAY

Pulsars - Life on the $P\dot{P}$ diagram



what about these magnetars or anomolous X-ray pulsars

What don't we know?

How do pulsars work?

What is the birth rate of neutron stars?

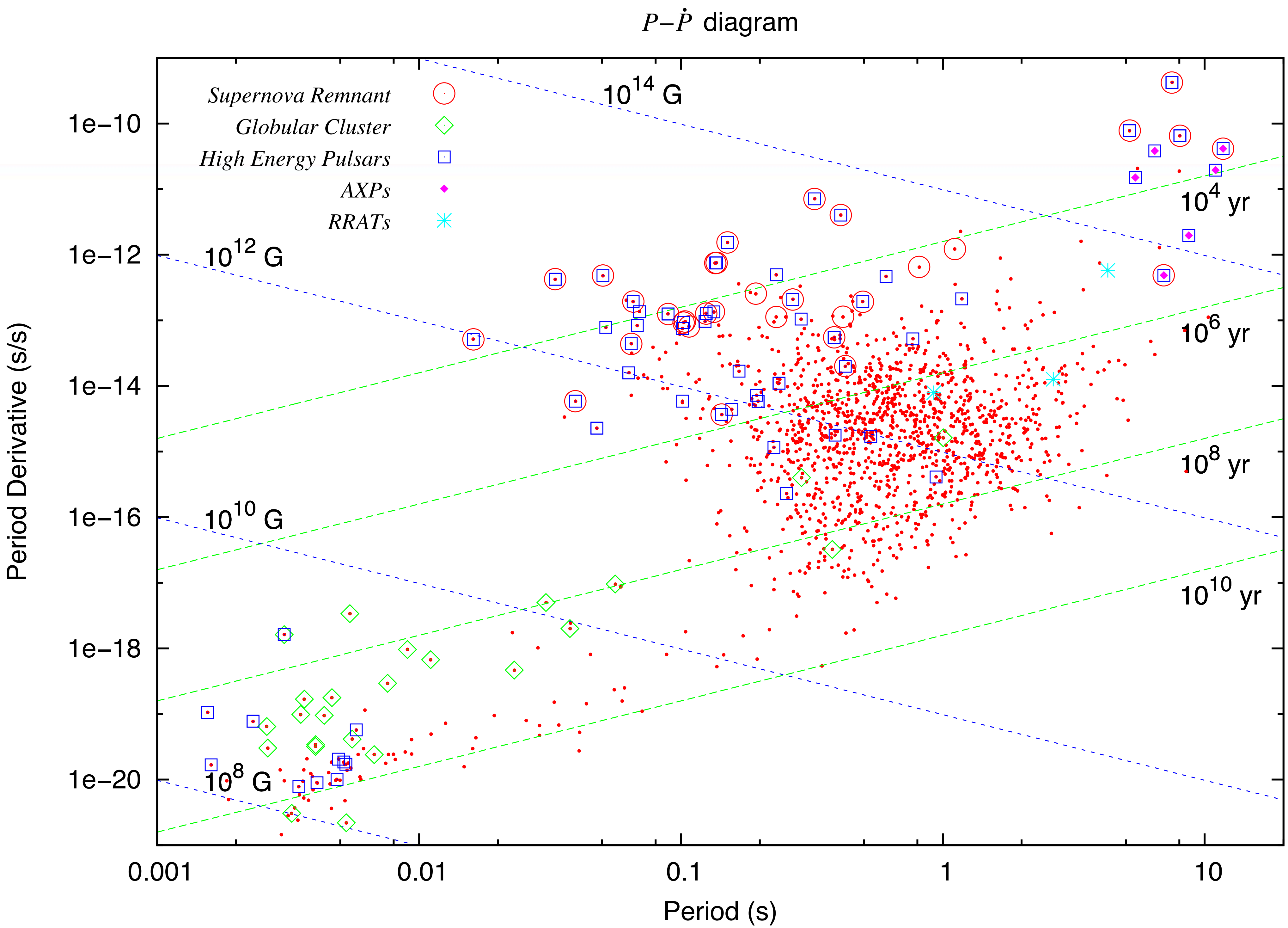
How many SNII end up as magnetars?

How do magnetars work?

NUI Galway
OÉ Gaillimh

CENTRE FOR ASTRONOMY NUI GALWAY

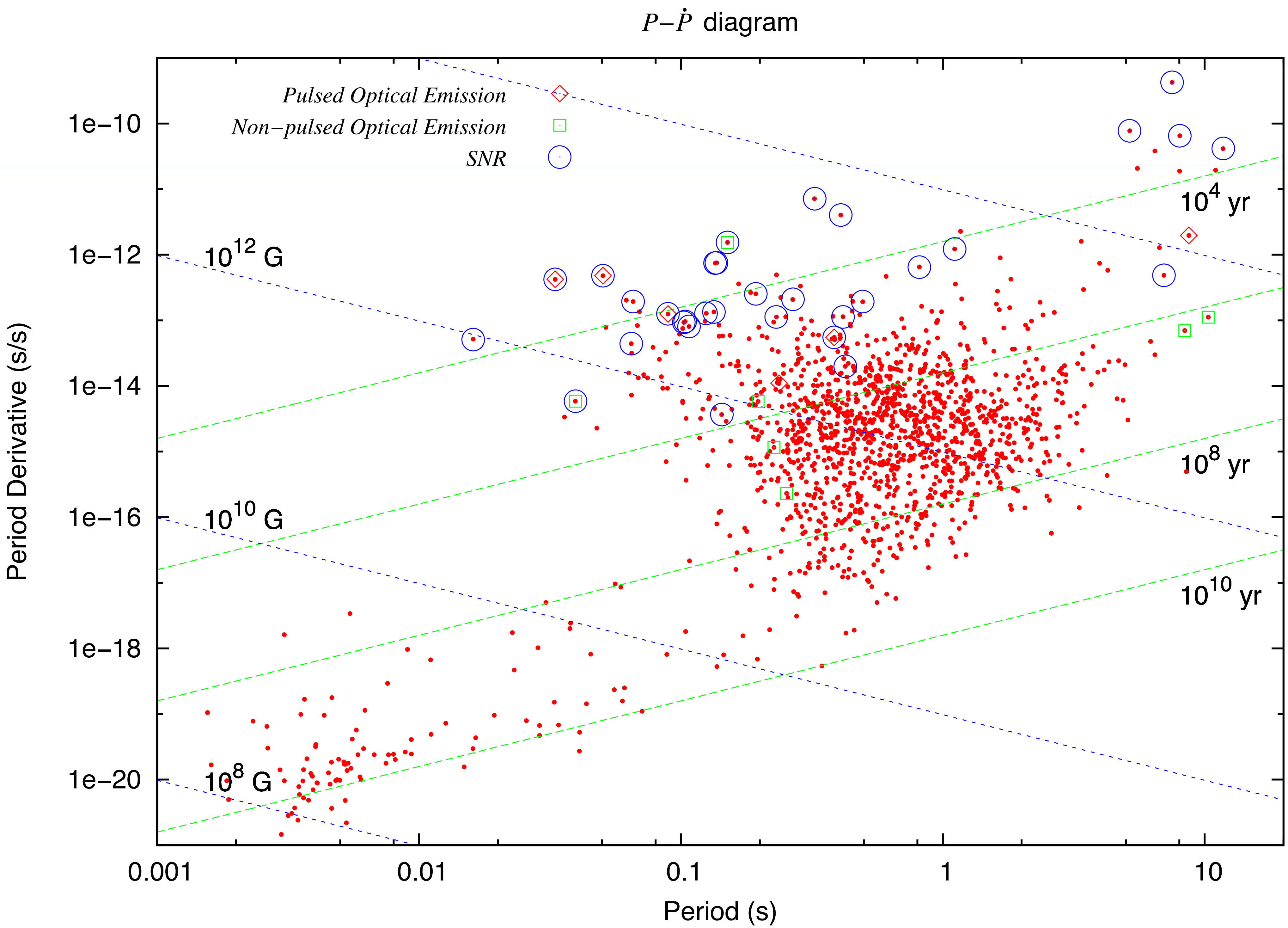
Optical Pulsars - Position on the $P\dot{P}$ diagram



NUI Galway
OÉ Gaillimh

CENTRE FOR ASTRONOMY NUI GALWAY

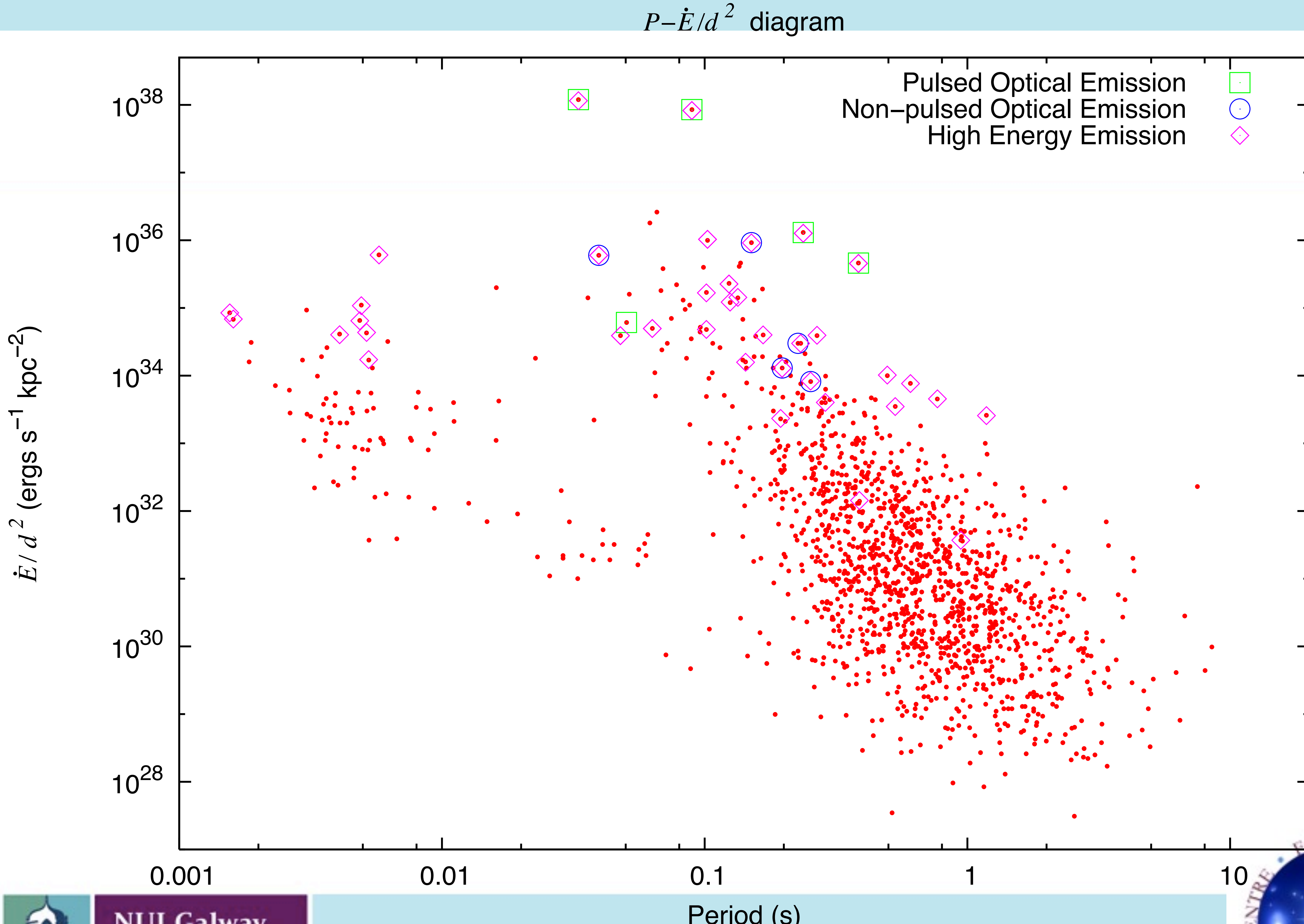
Optical Pulsars - Position on the $P\dot{P}$ diagram



NUI Galway
OÉ Gaillimh

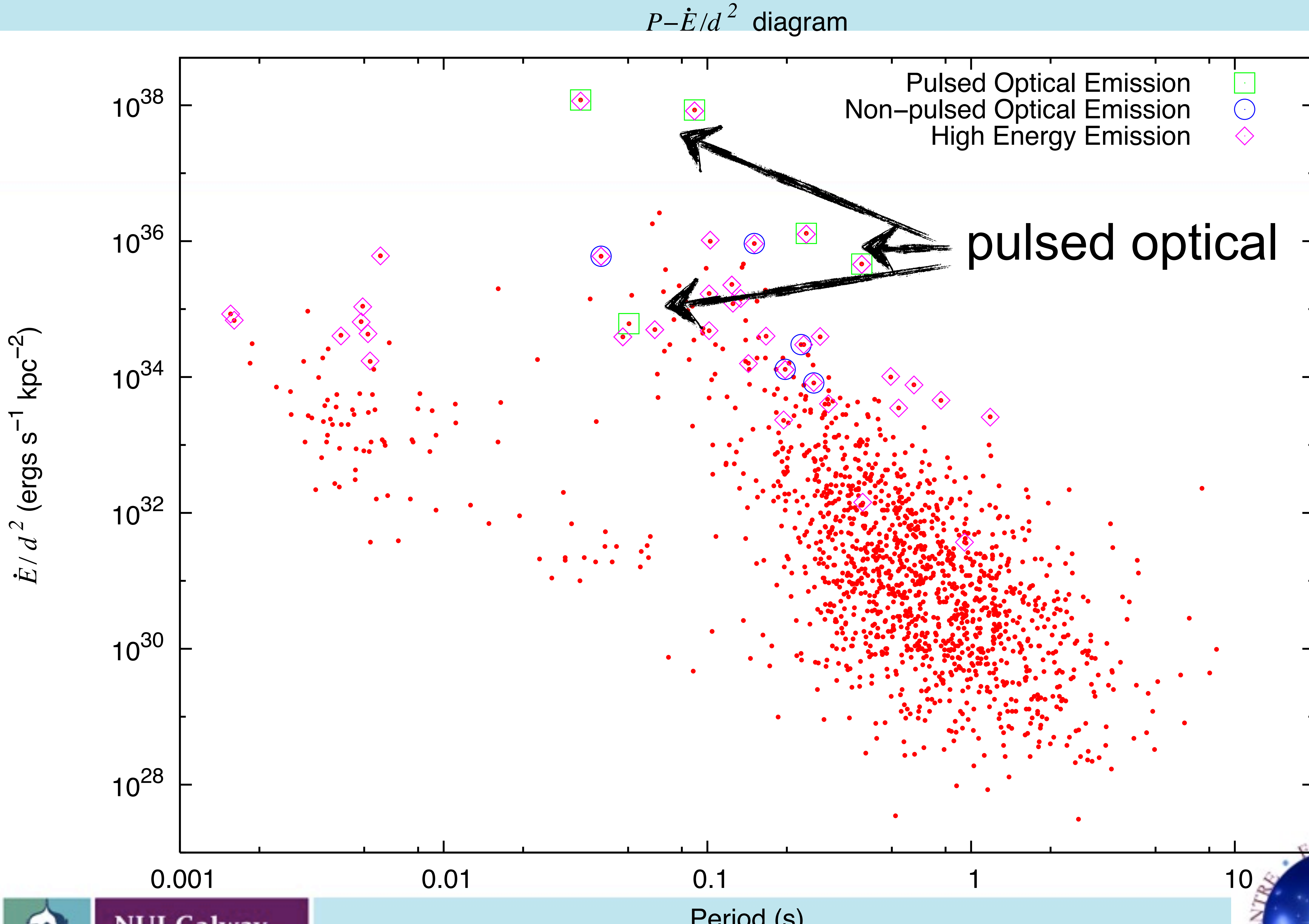
CENTRE FOR ASTRONOMY NUI GALWAY

Optical Pulsars - Position on the $P\dot{P}$ diagram



NUI Galway
OÉ Gaillimh

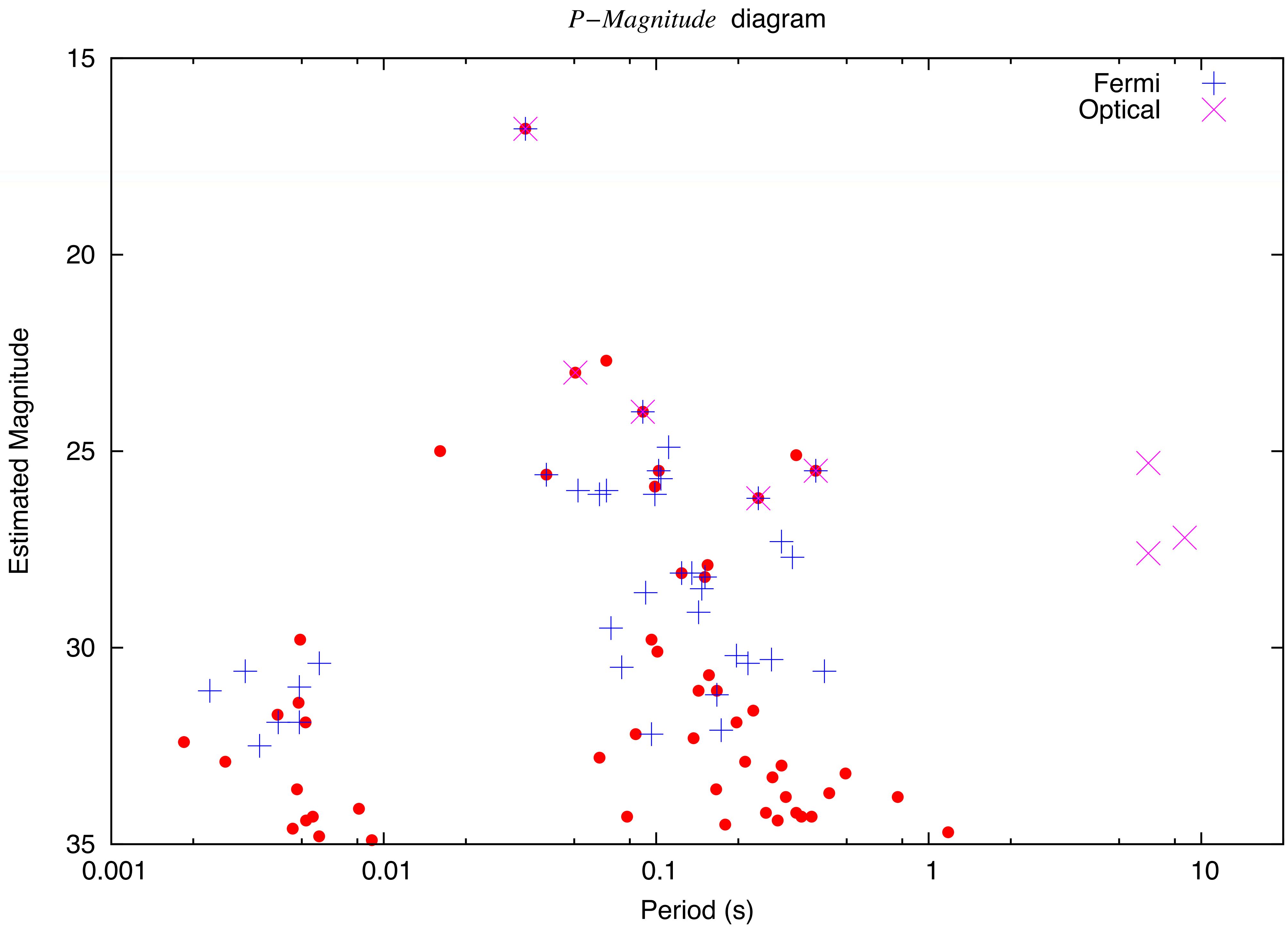
Optical Pulsars - Position on the $P\dot{P}$ diagram



NUI Galway
OÉ Gaillimh

Wednesday 26 October 11

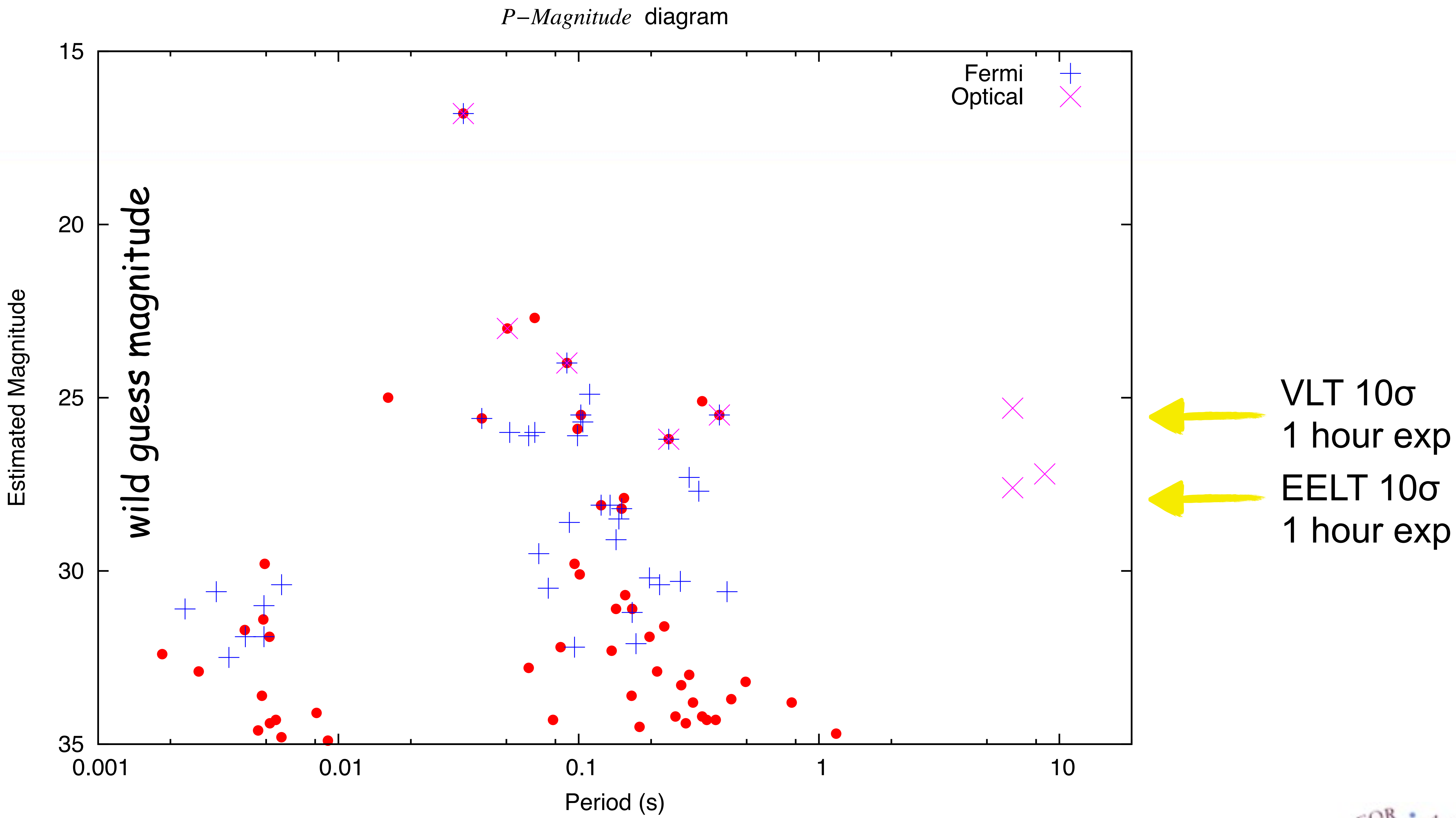
Optical Pulsars - the problem and future



VLT 10σ
1 hour exp

EELT 10σ
1 hour exp

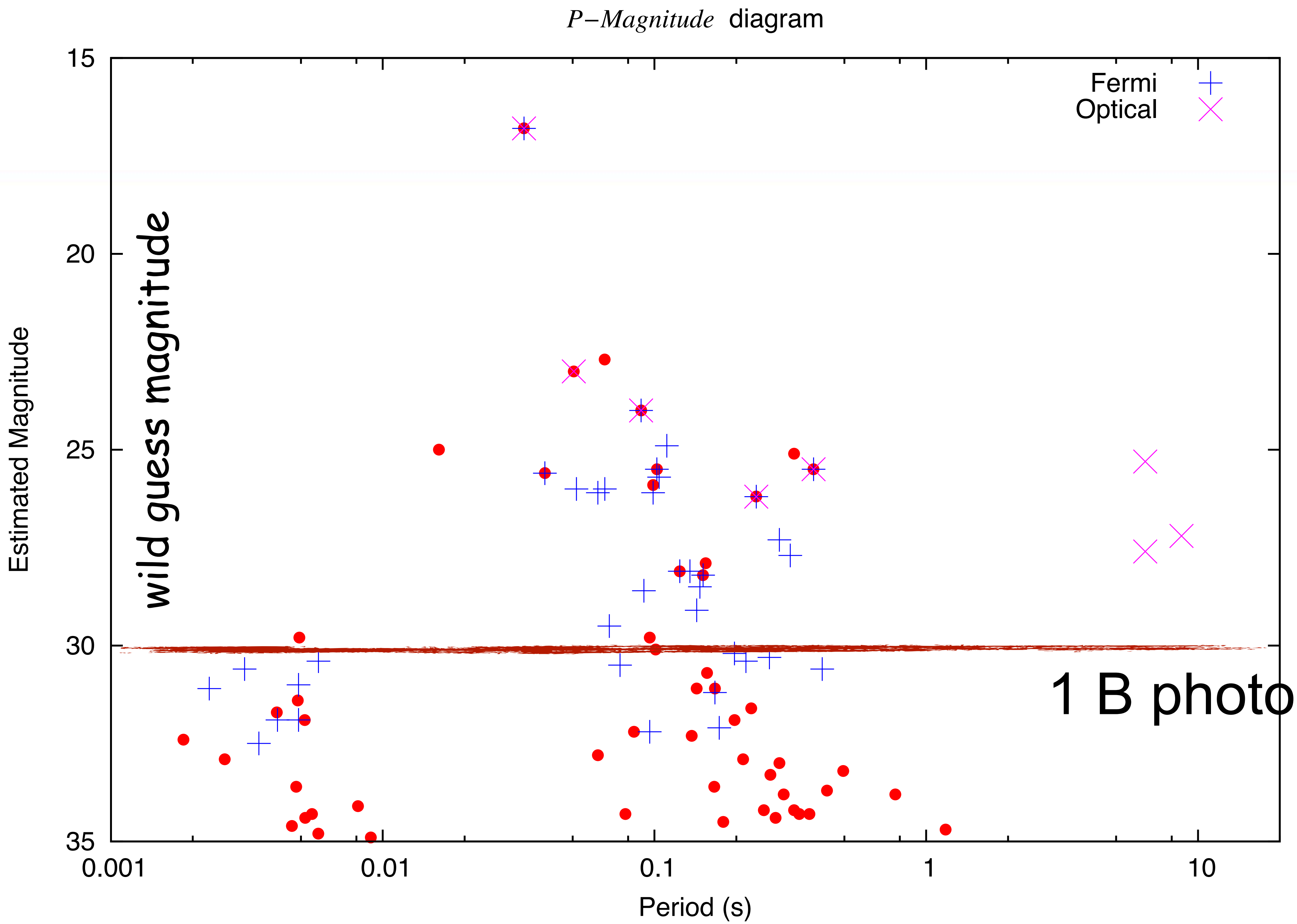
Optical Pulsars - the problem and future



NUI Galway
OÉ Gaillimh

CENTRE FOR ASTRONOMY NUI GALWAY

Optical Pulsars - the problem and future



VLT 10σ
1 hour exp

EELT 10σ
1 hour exp

1 B photon/sec/Keck

NUI Galway
OÉ Gaillimh

Optical Pulsars the problem

Optical Pulsars the problem

	m_B	period (ms)	B photon Fluxes photons/rotation	
			VLT	EELT
Crab	17.2	33	2761	69,000
Vela	23.6	50	14	355
PSR 0540-69	22.5	89	22	549
PSR 0656+14	25.5	385	11	267
Geminga	26.2	237	3	86
PSR B0950+08	27.1	253	2	40
PSR B1929+10	25.6	227	6	143
PSR B1055-52	24.9(U)	197	9	237
PSR B1509-58	25.7	151	4	87
PSR B1113+16	28.1	1188		
Crab at M31	29.7	33	0.01	0.5

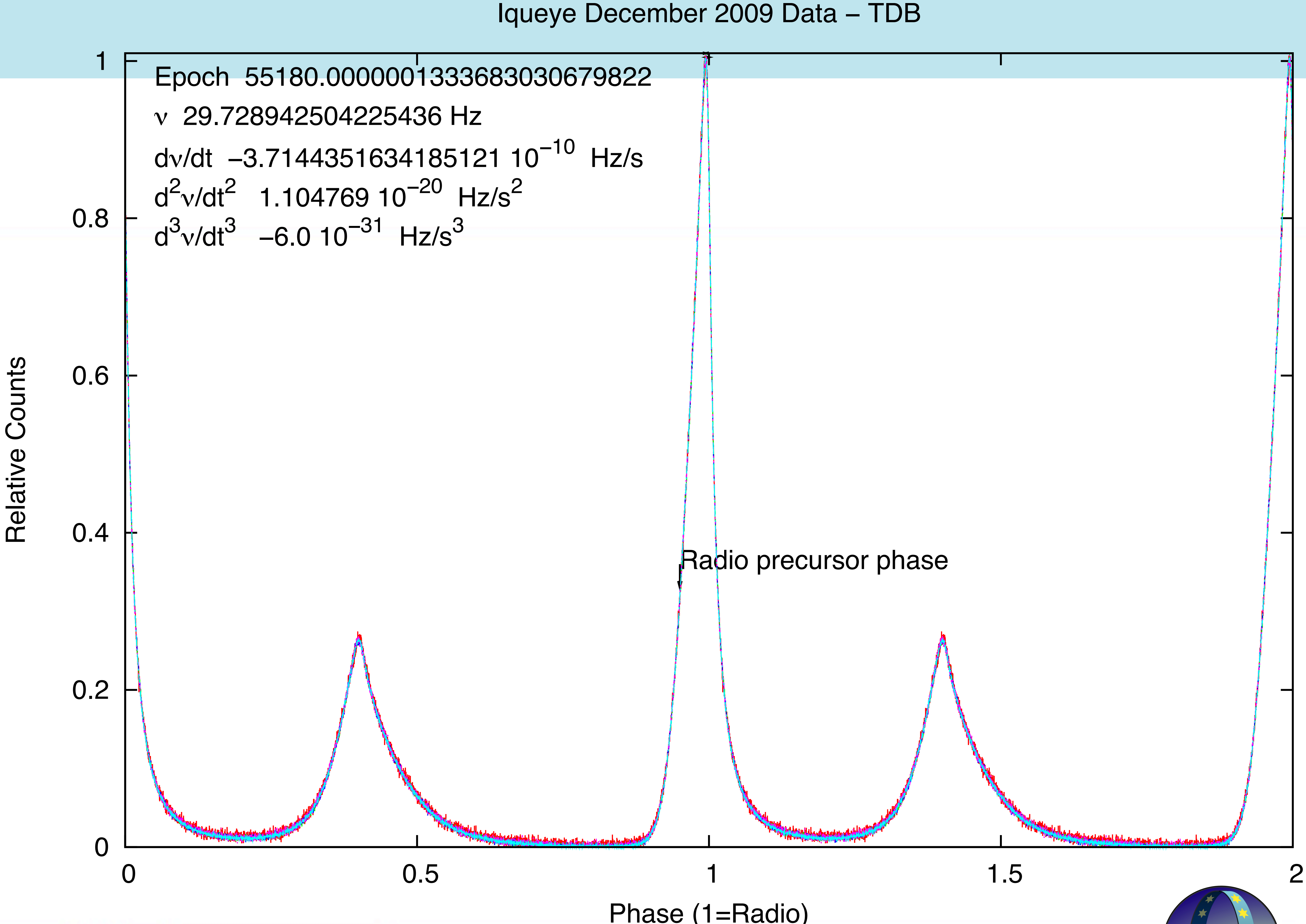
Optical Pulsars the problem

	m_B	period (ms)	B photon Fluxes counts/rotation	
			VLT	EELT
Crab	17.2	33	700	17,000
Vela	23.6	50	3	90
PSR 0540-69	22.5	89	5	140
PSR 0656+14	25.5	385	3	65
Geminga	26.2	237	1	21
PSR B0950+08	27.1	253	0.5	10
PSR B1929+10	25.6	227	1.5	35
PSR B1055-52	24.9(U)	197	2	60
PSR B1509-58	25.7	151	1	22
PSR B1113+16	28.1	1188		
Crab at M31	29.7	33	0.01	0.1

Optical Pulsars the problem

	m_B	period (ms)	B photon Fluxes counts/rotation	
			VLT	EELT
Crab	17.2	33	700	17,000
Vela	23.6	50	3	90
PSR 0540-69	22.5	89	5	140
PSR 0656+14	25.5	385	3	65
Geminga	26.2	237	1	21
PSR B0950+08	27.1	253	0.5	10
PSR B1929+10	25.6	227	1.5	35
PSR B1055-52	24.9(U)	197	2	60
PSR B1509-58	25.7	151	1	22
PSR B1113+16	28.1	1188		
Crab at M31	29.7	33	0.01	0.1

How can optical observations help?



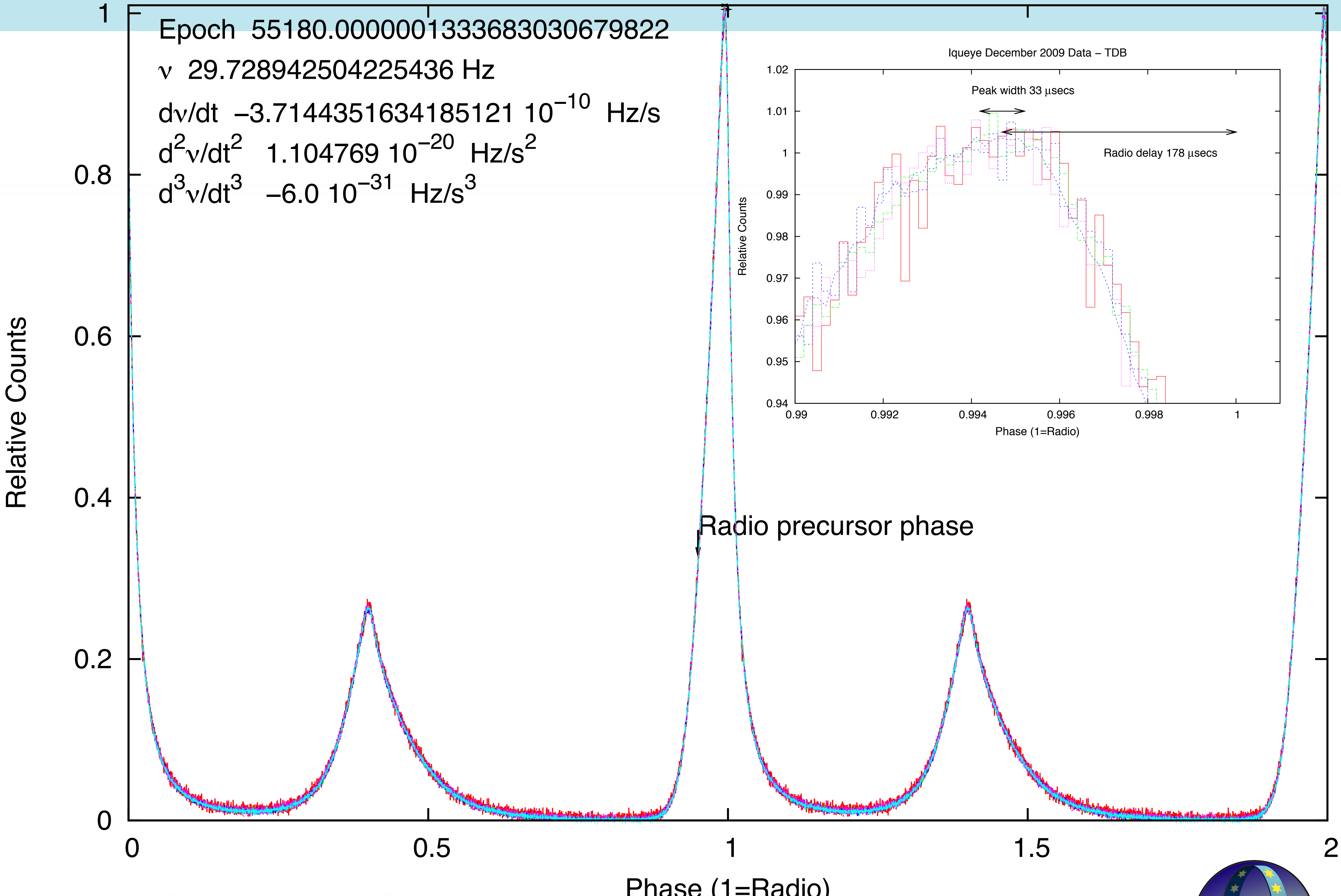
NUI Galway
OÉ Gaillimh

HTRA Detectors

OPTICON

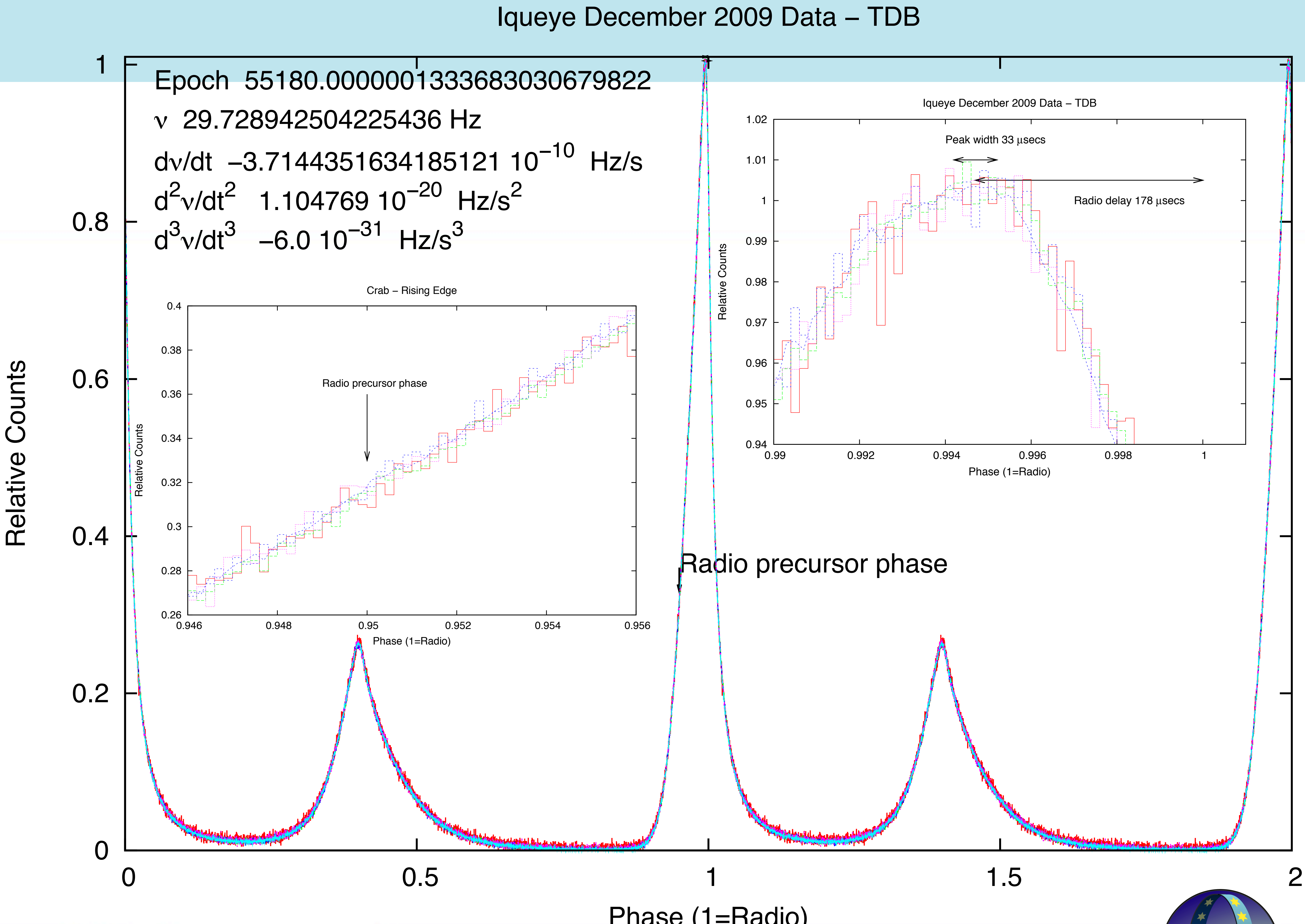
CENTRE FOR ASTRONOMY NUI GALWAY

How can optical observations help?



HTRA Detectors

How can optical observations help?

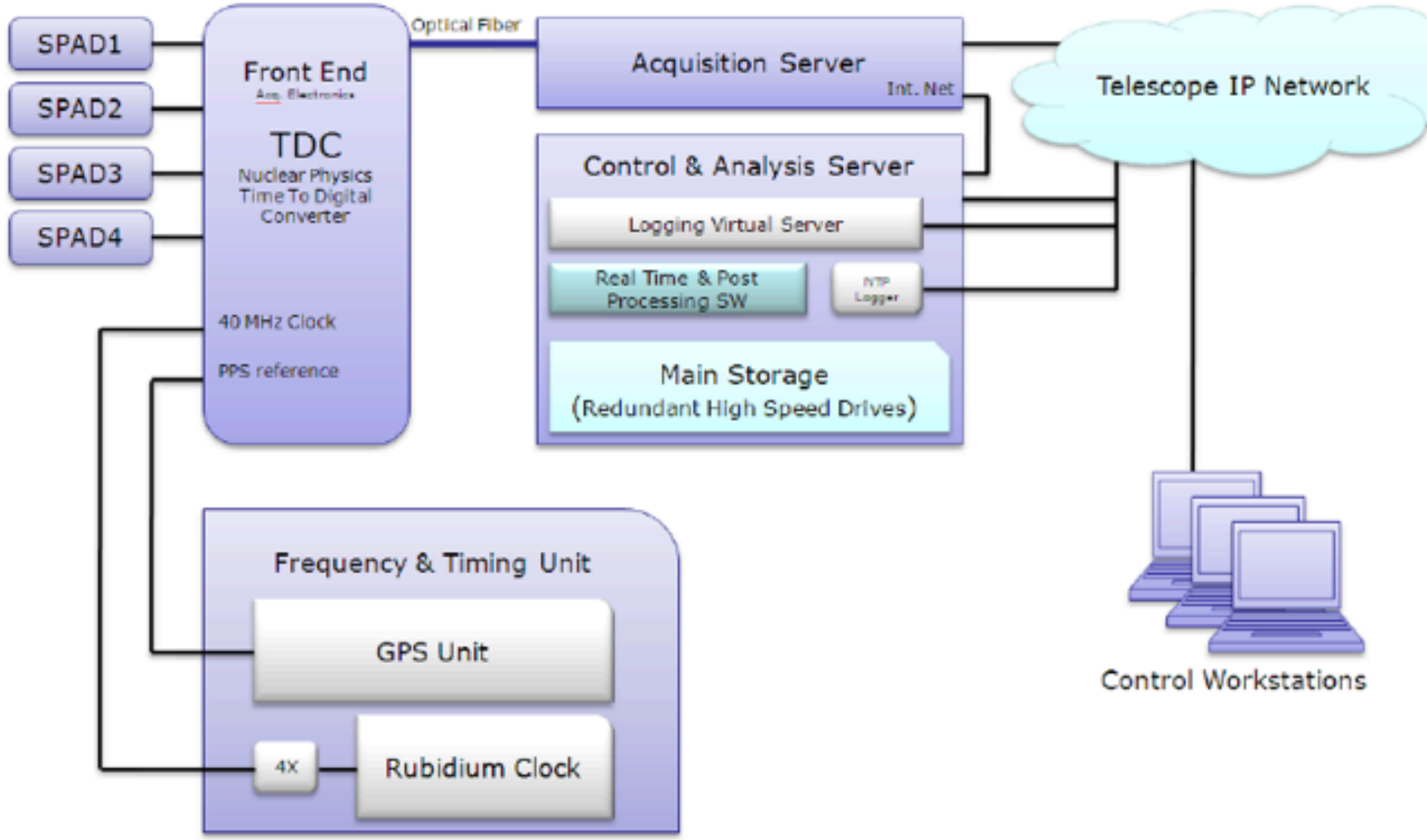


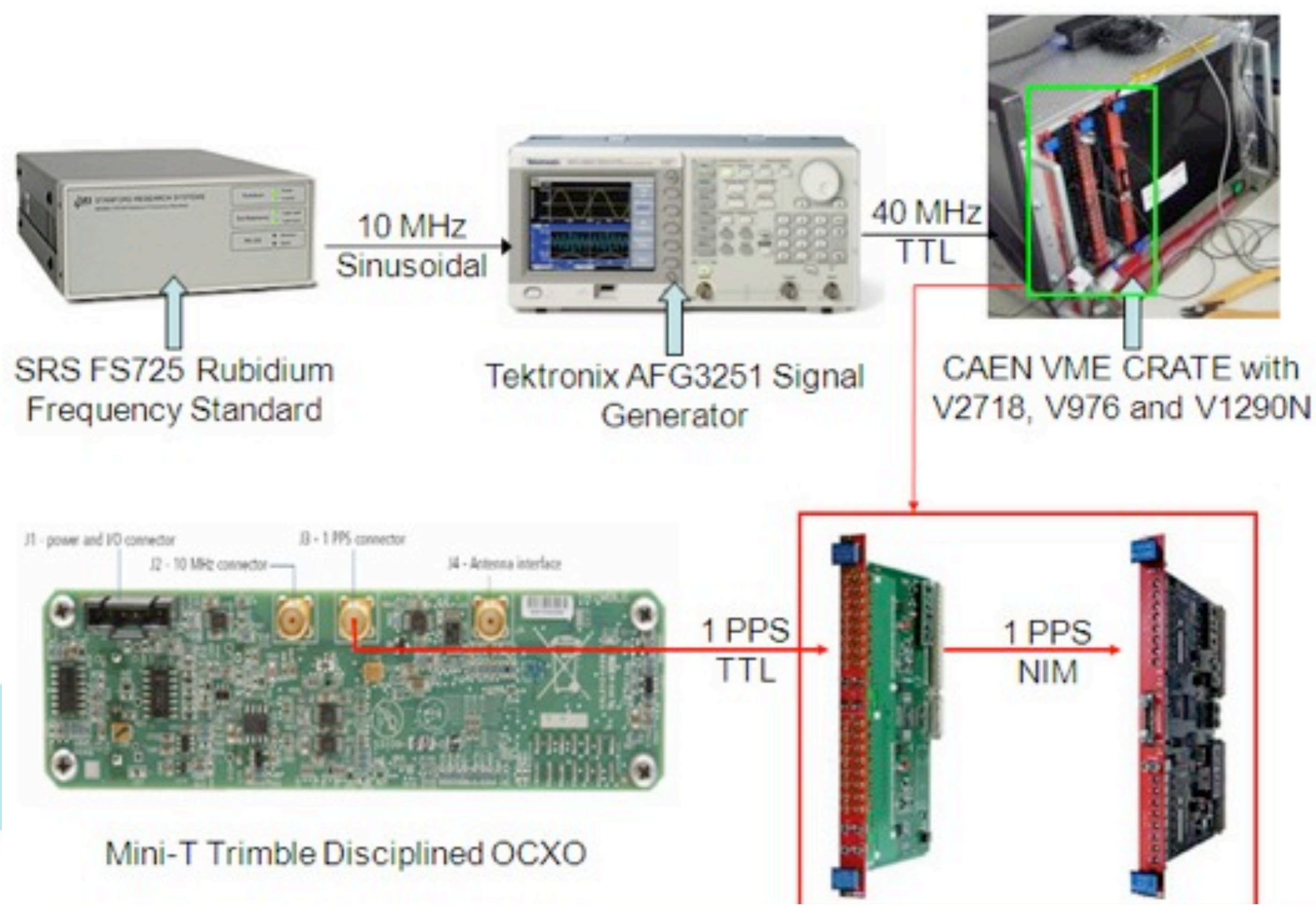
Iqueye - NTT
Naletto, 2009, A&A, 508, 513

Digitiser Accuracy - 24ps
Relative accuracy ~ 100 ps RMS

Count rate ~ 8 M cps

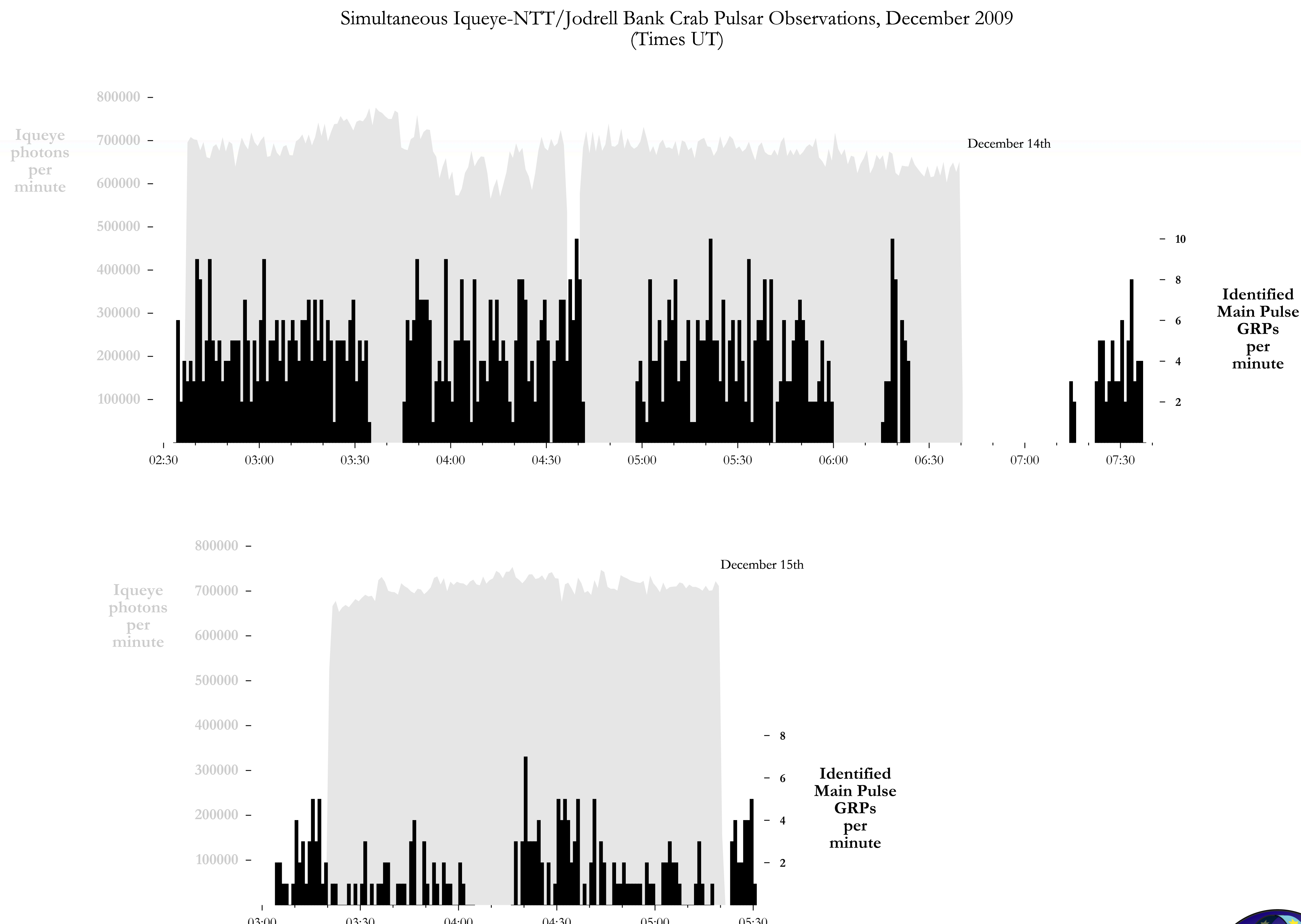
Quantum Efficiency ~ 30%
Dark Count < 100 cps





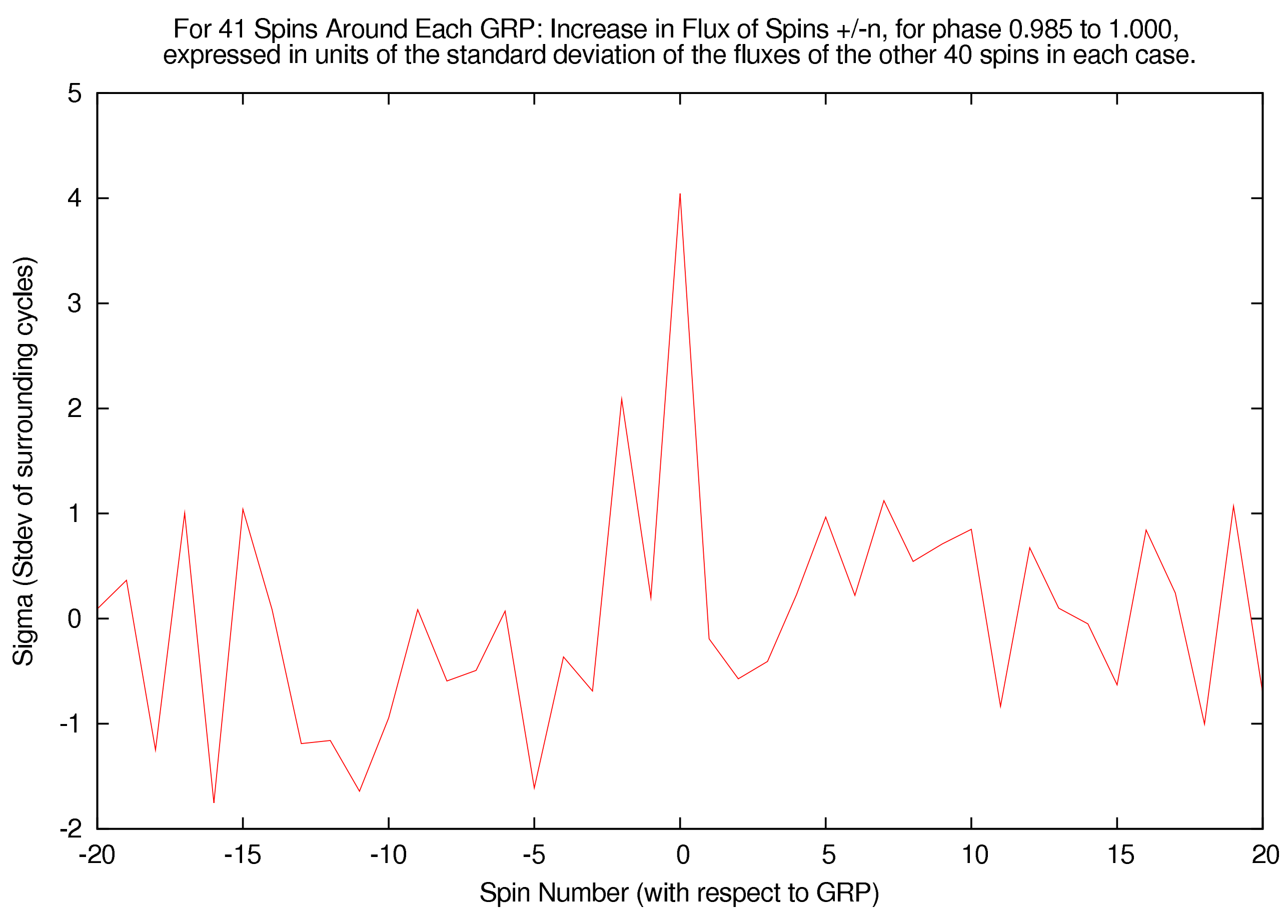
Optical-Radio Coverage

Optical : Iqueye - 3.5m NTT : Radio: Lovell Jodrell Bank



Iqueye Optical-Radio Results - Dec 2009

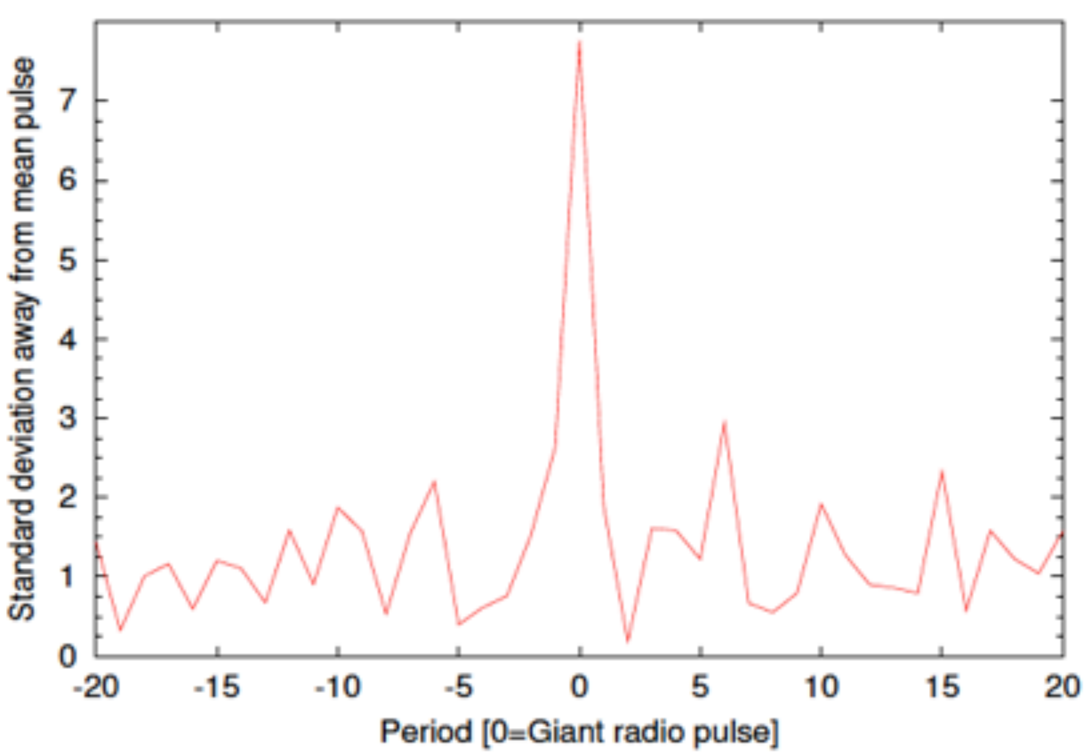
- NTT - 14520 seconds IQUEYE
- Jodrell Bank - 11040 simultaneous
- Preliminary 724 GRPs ~ 1 every 17 seconds



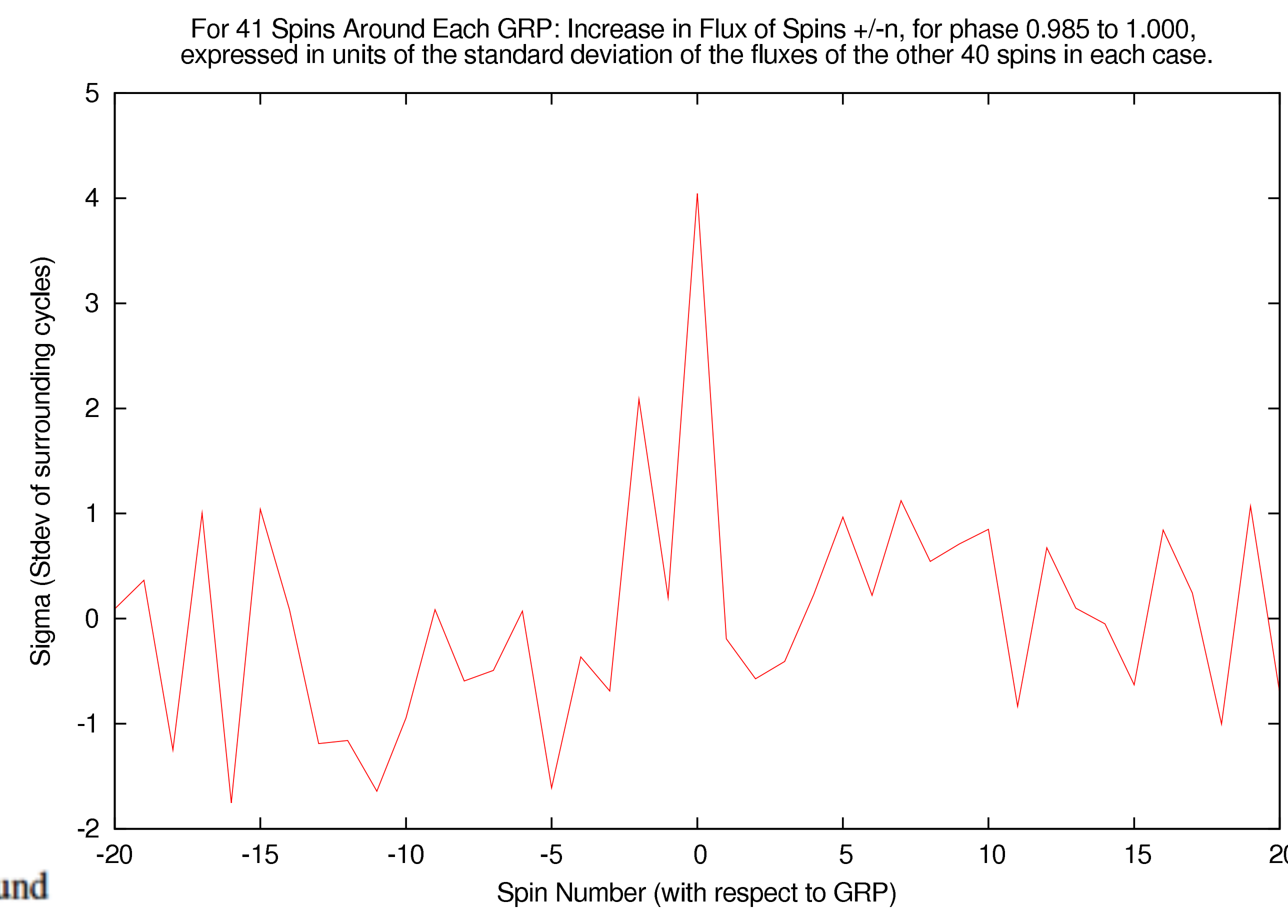
Iqueye Optical-Radio Results - Dec 2009

- NTT - 14520 seconds IQUEYE
- Jodrell Bank - 11040 simultaneous
- Preliminary 724 GRPs ~ 1 every 17 seconds

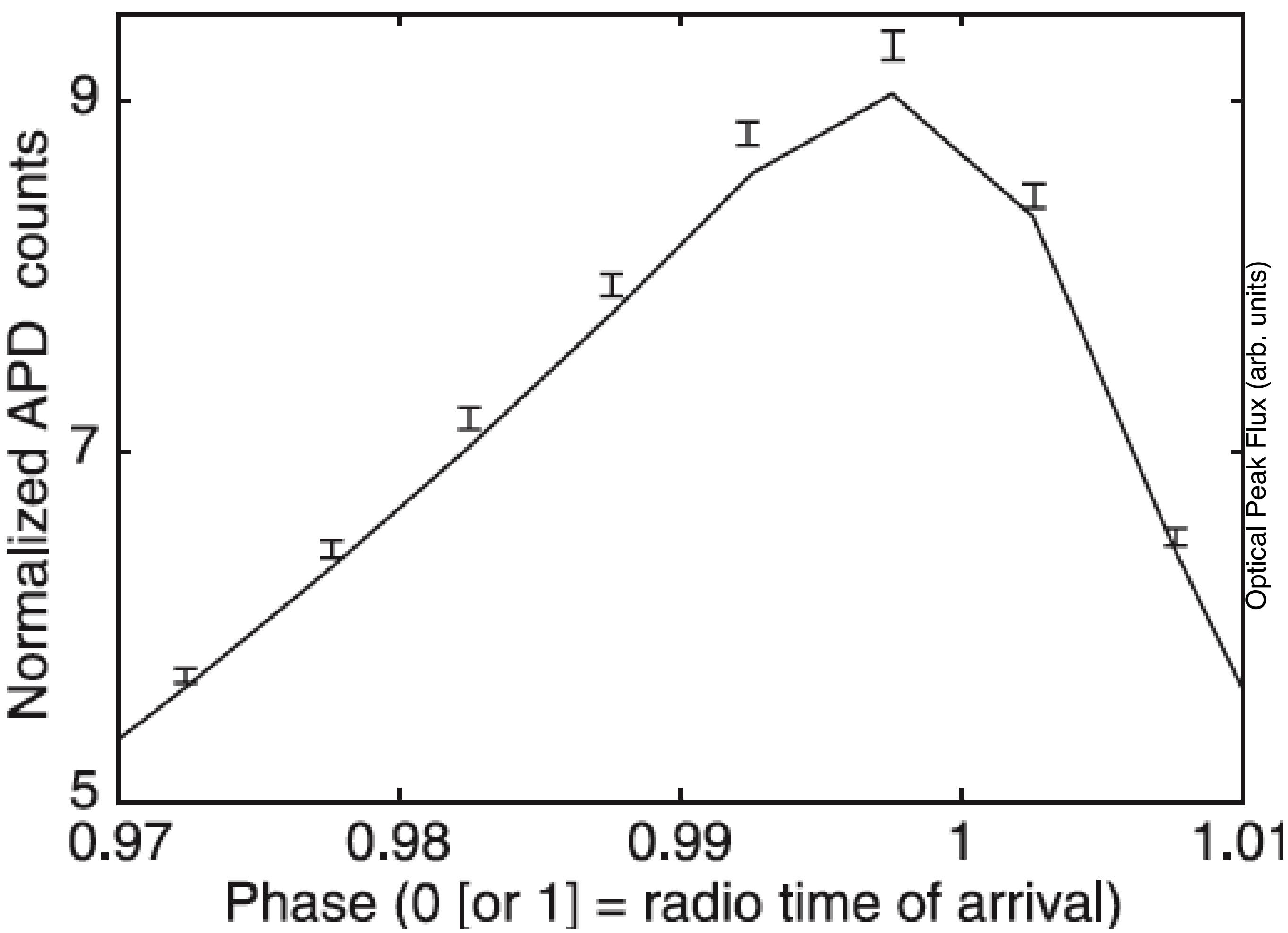
Shearer et al, 2003, Science, 301, 493



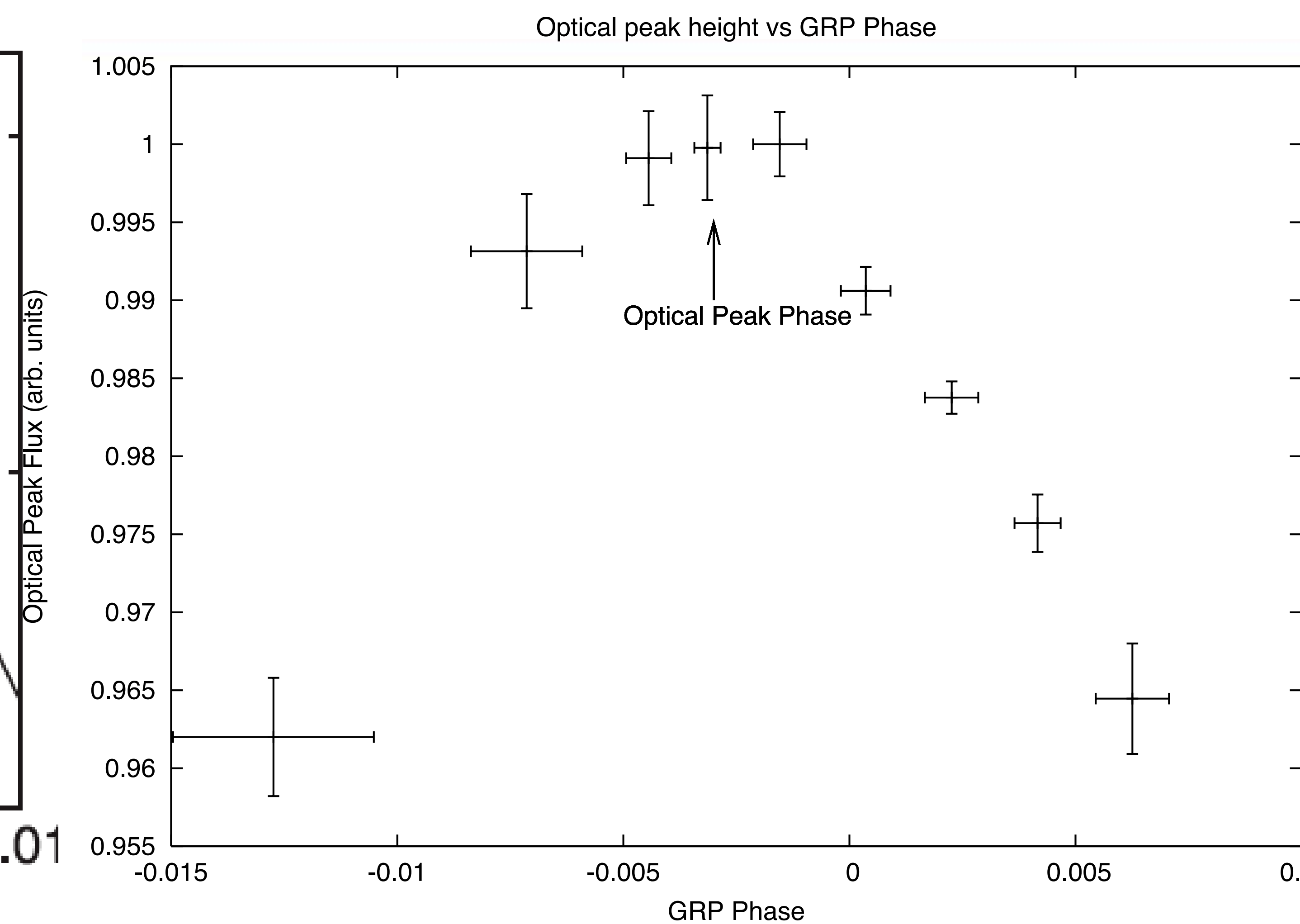
gure 2: The mean peak height of the main optical pulse - defined as the 3 phase bins around e peak - for the 20 periods on either side of the giant pulse and for period associated with te ant pulse. The plot is for all GRPs with a phase of ±0.1 with respect to the JBE. The height the pulse is expressed as the number of standard deviations (added in quadrature) away from e mean of the optical pulse height. The mean and standard deviation have been determined om the 20 pulses on either side of the giant radio pulse.



Crab - Optical Radio link - Giant Radio Pulses



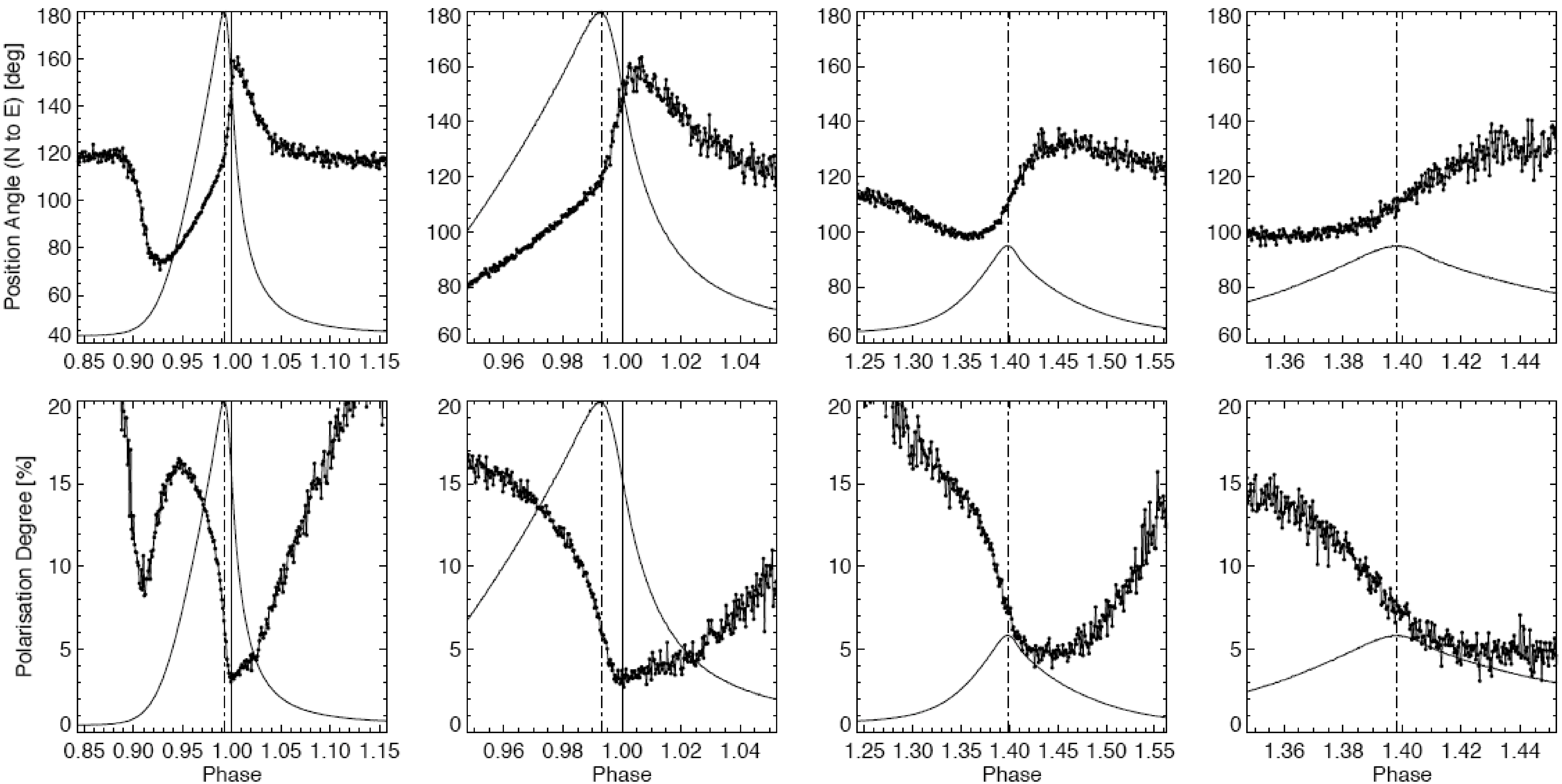
Shearer et al, 2003, Science, 301, 493



Shearer et al, 2012, in preparation

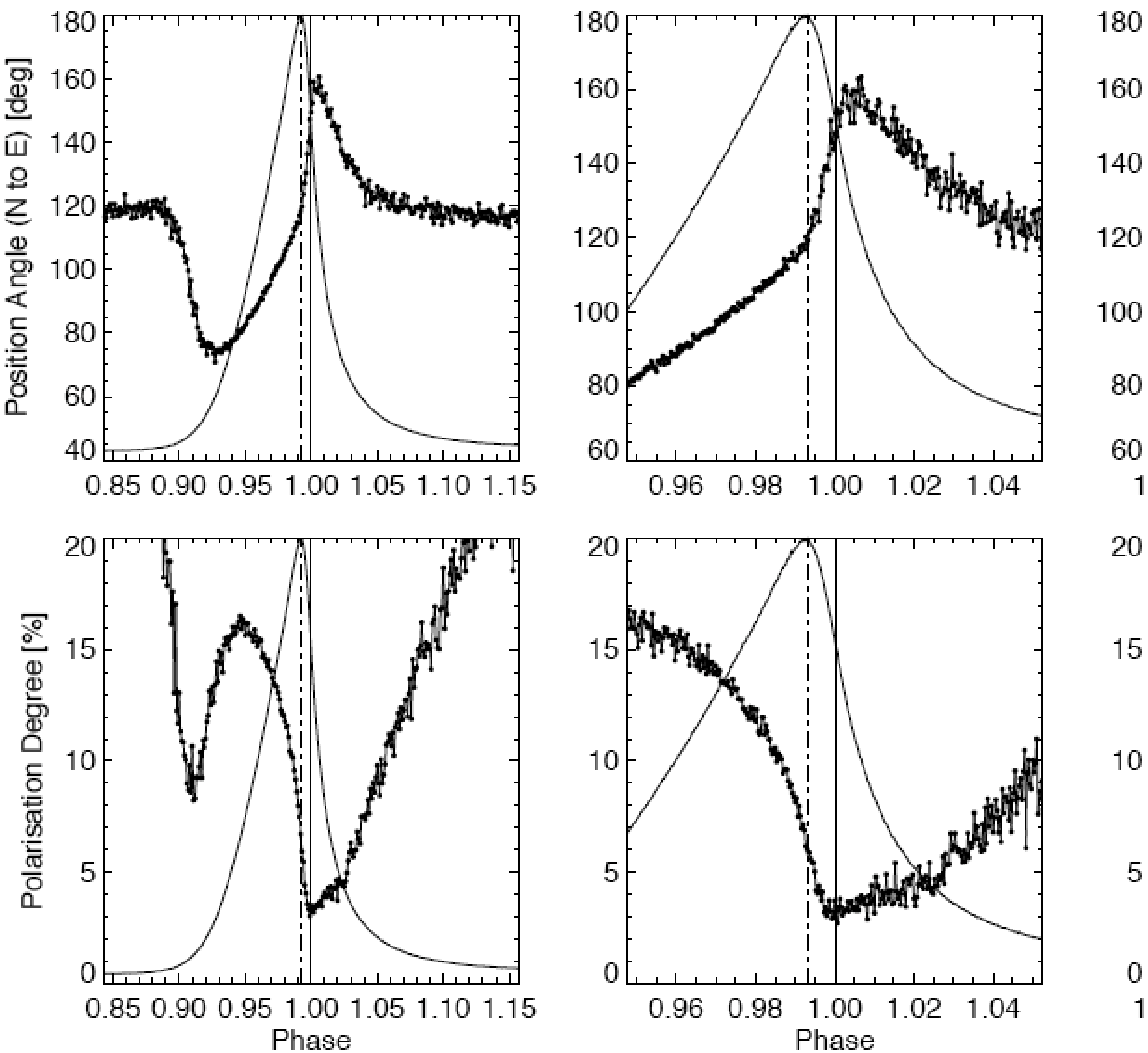
Crab - Optima Observations

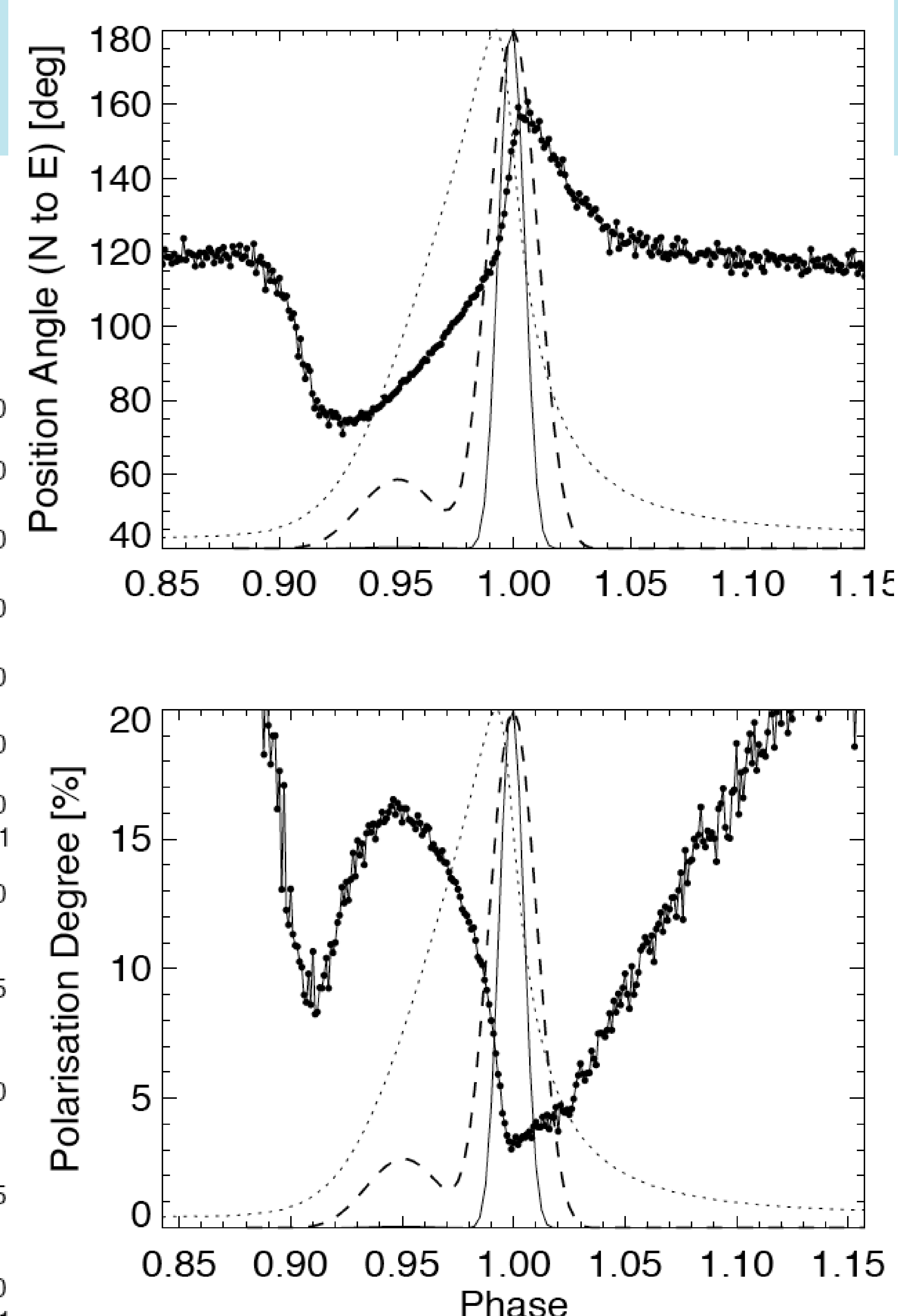
Słowikowska et al., 2009, MNRAS.397, 103



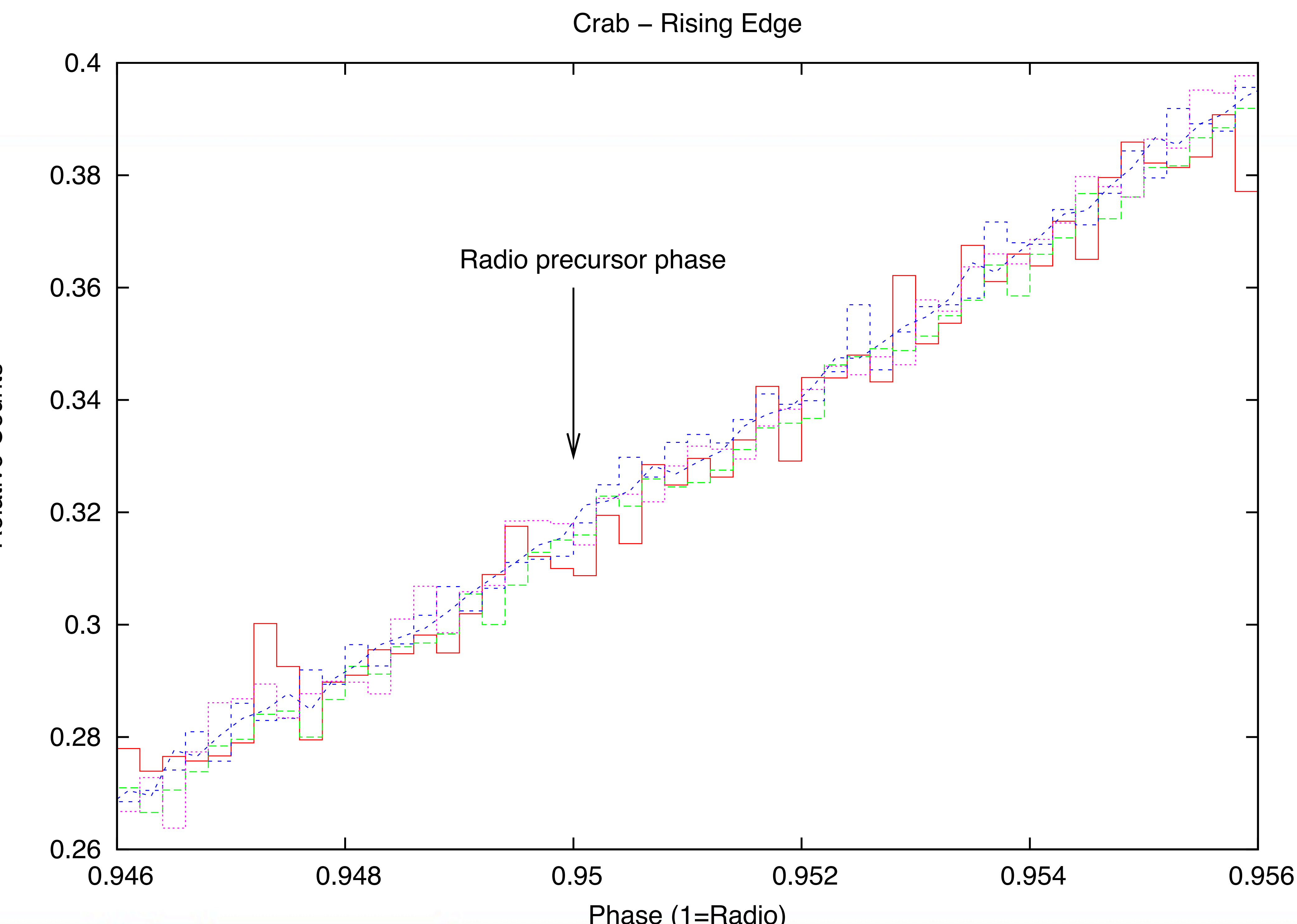
Crab - Optima Observations

Słowikowska et al., 2009, MNRAS.397, 103

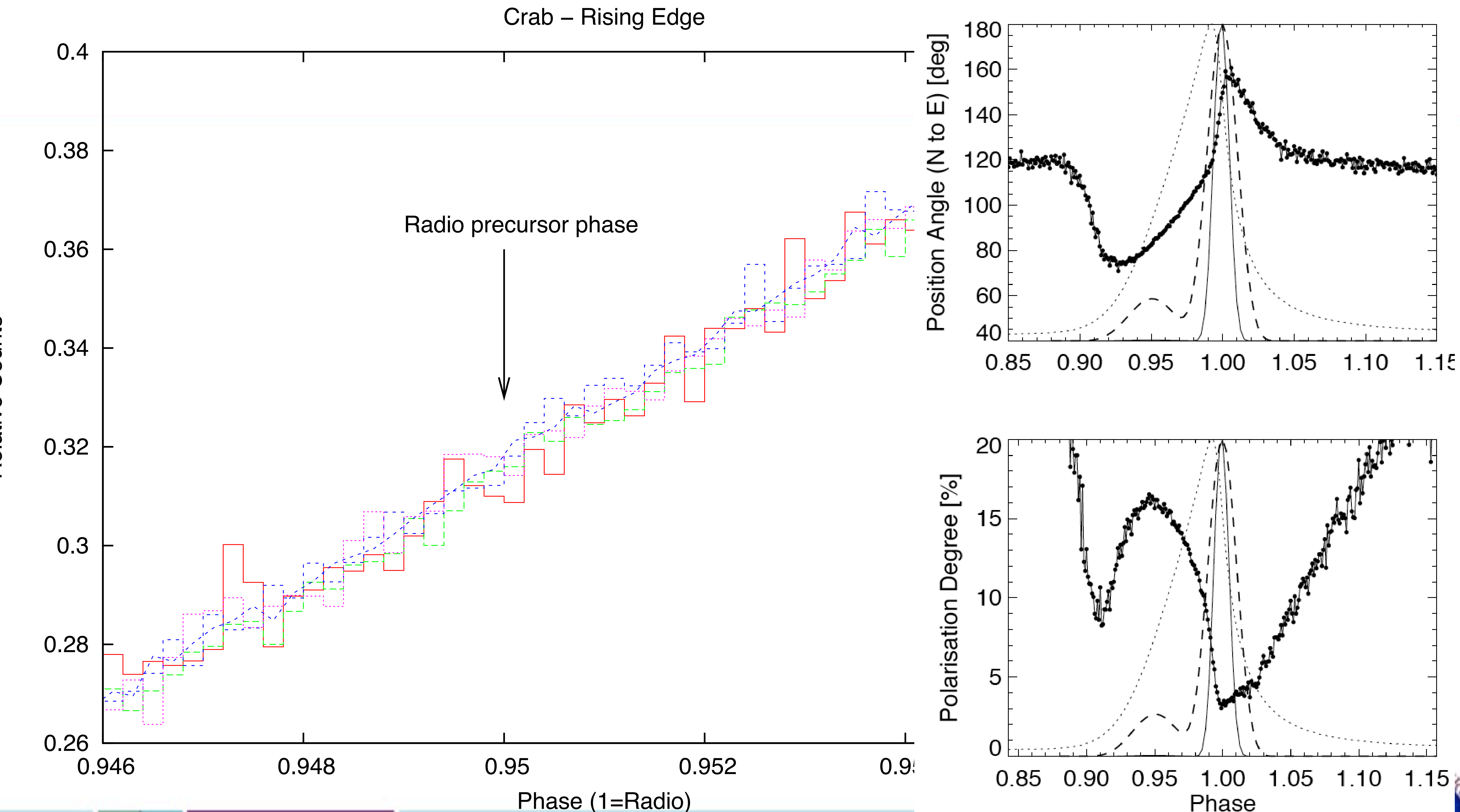




Crab - rising edge

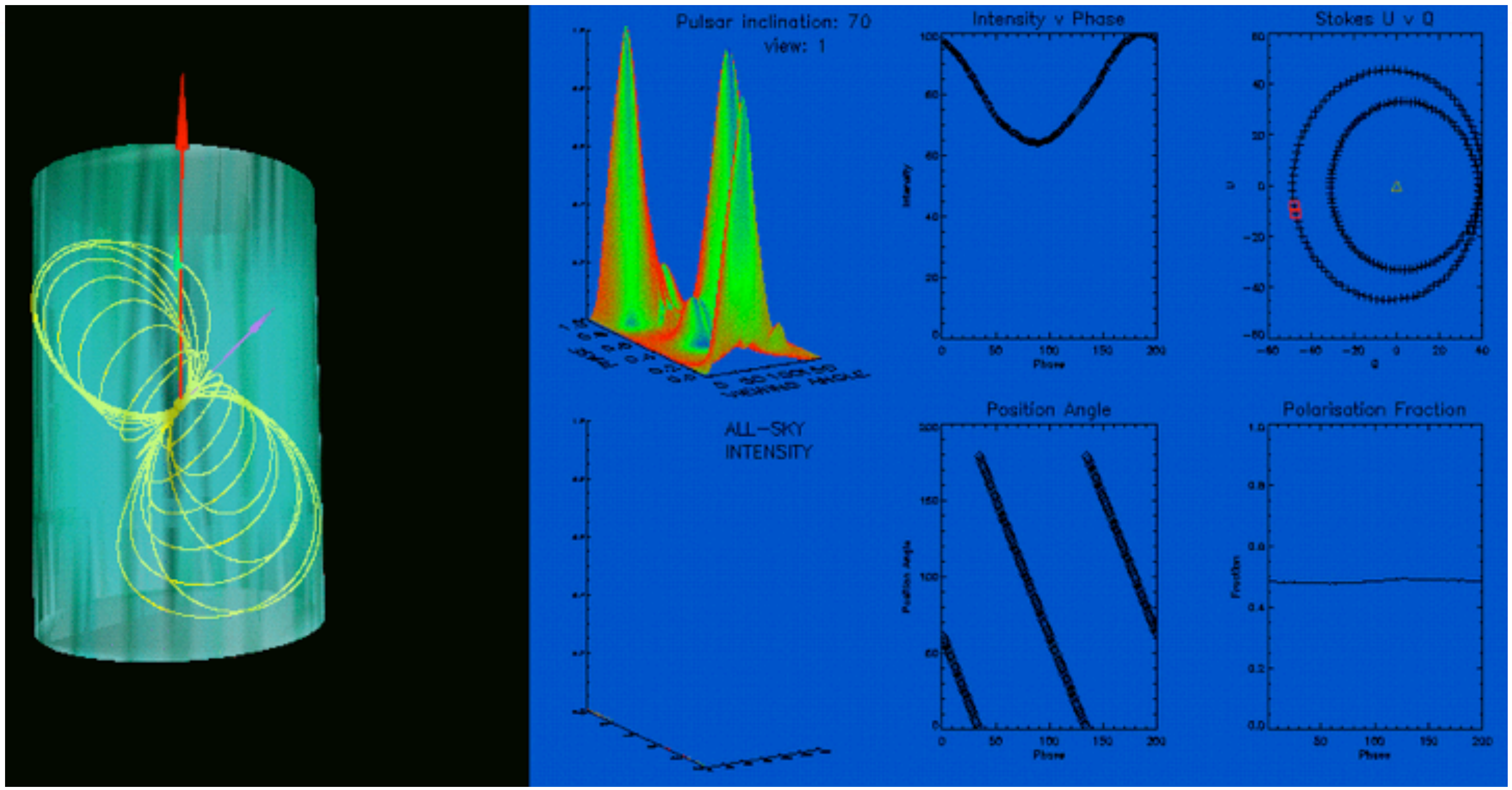


Crab - rising edge



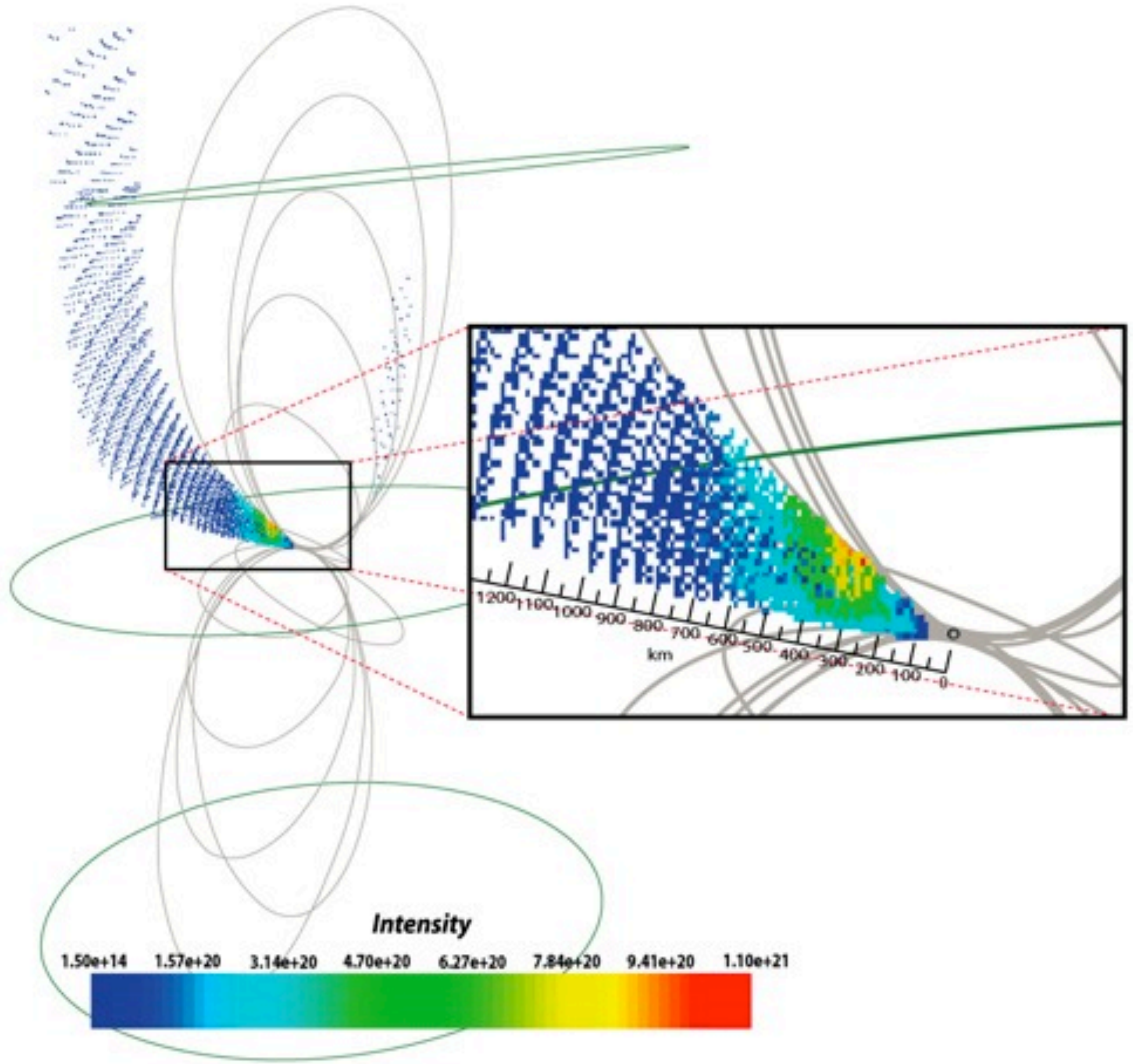
Crab - Polarisation reverse engineering

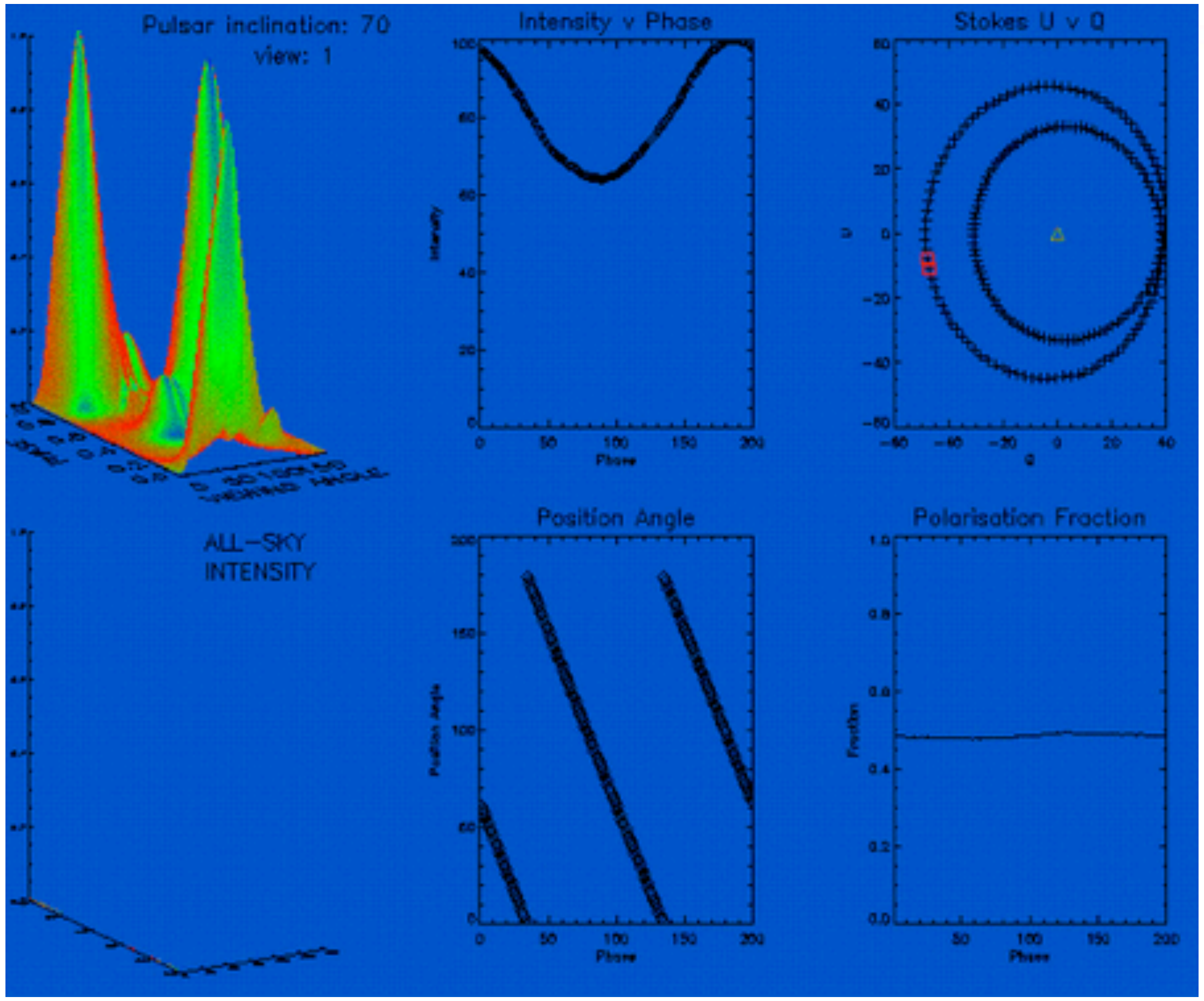
Mc Donald et al, 2011, MNRAS, 417, 730



Crab - Polarisation reverse engineering

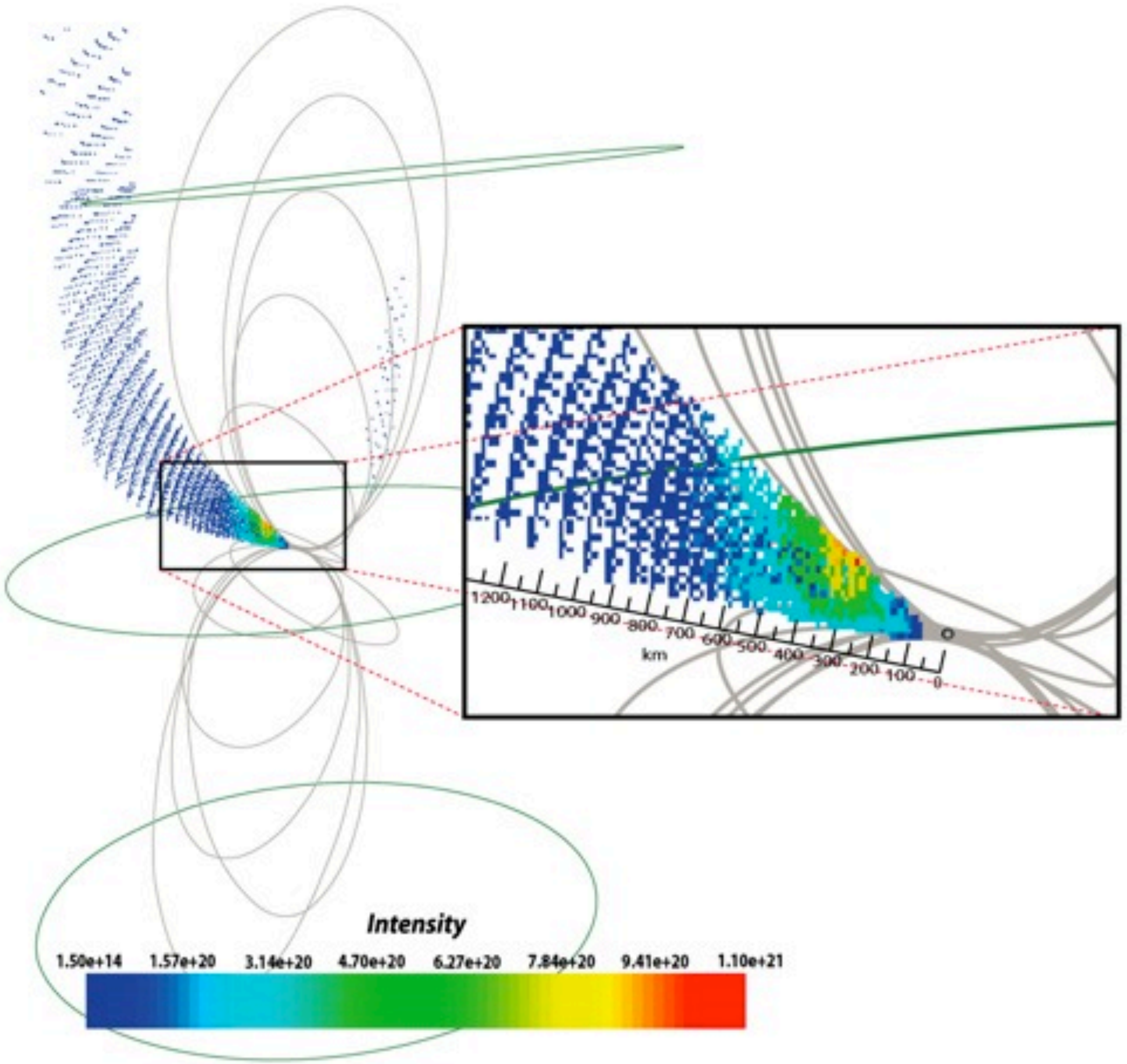
Mc Donald et al, 2011, MNRAS, 417, 730

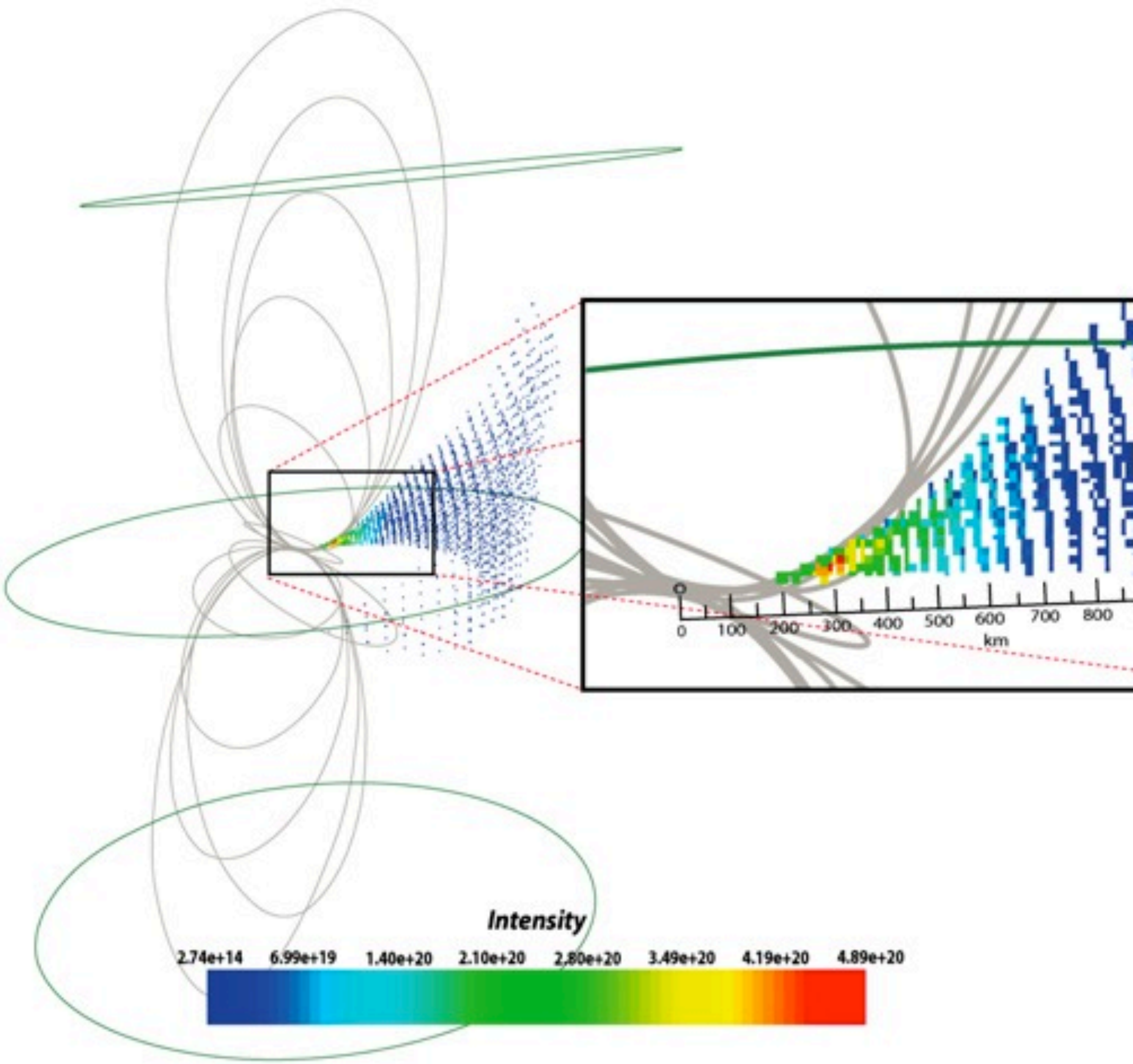




Crab - Polarisation reverse engineering

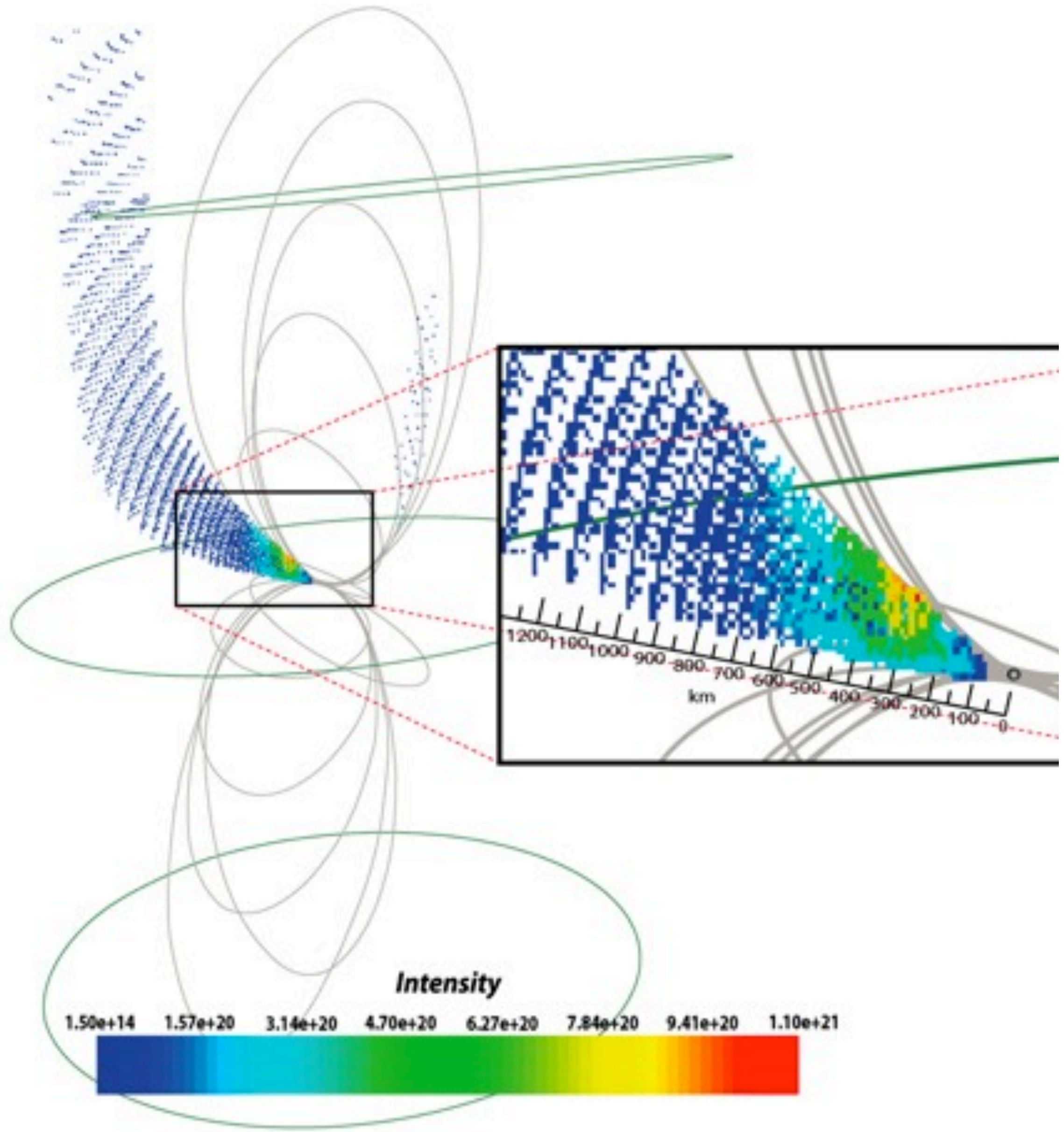
Mc Donald et al, 2011, MNRAS, 417, 730

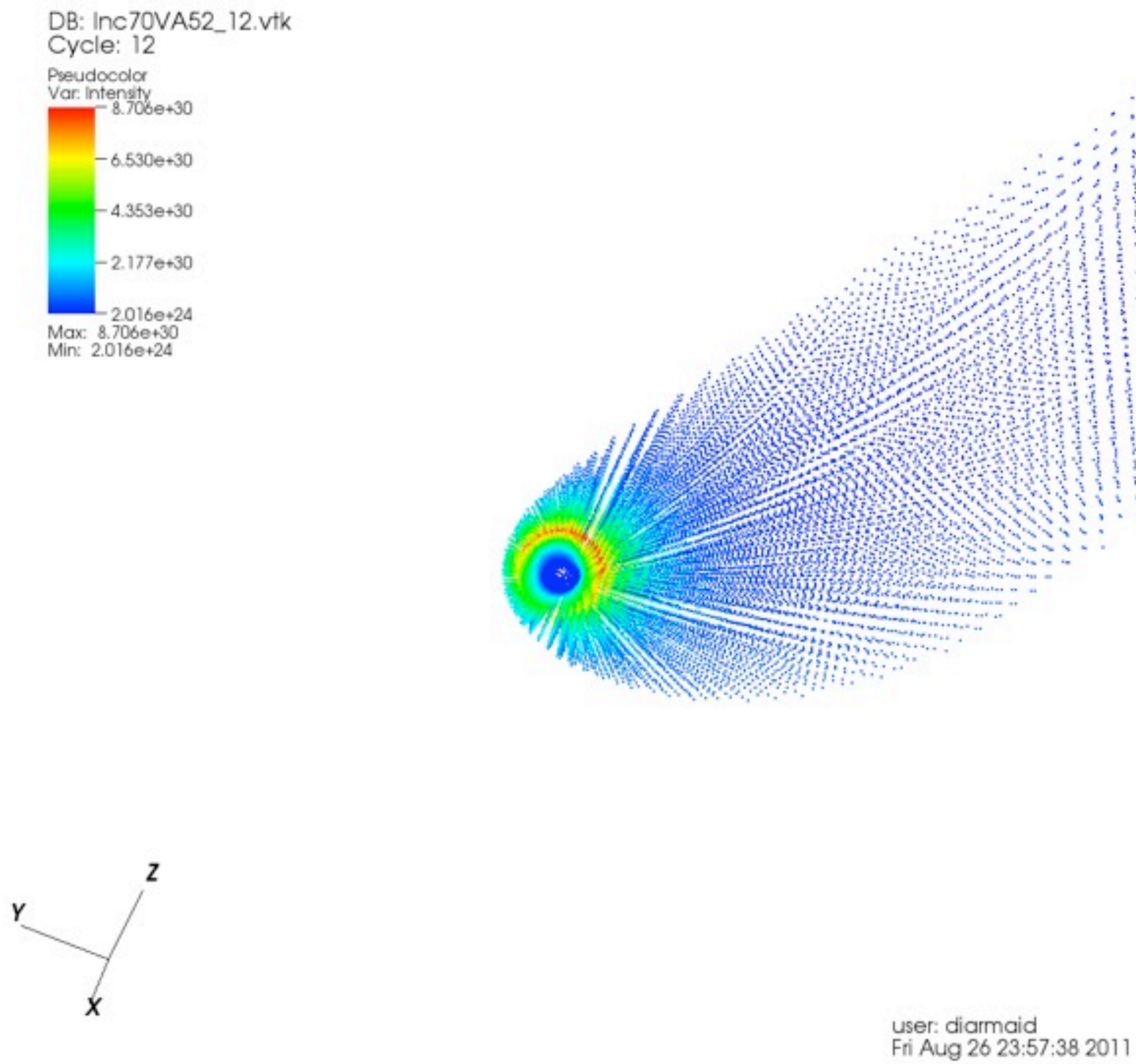




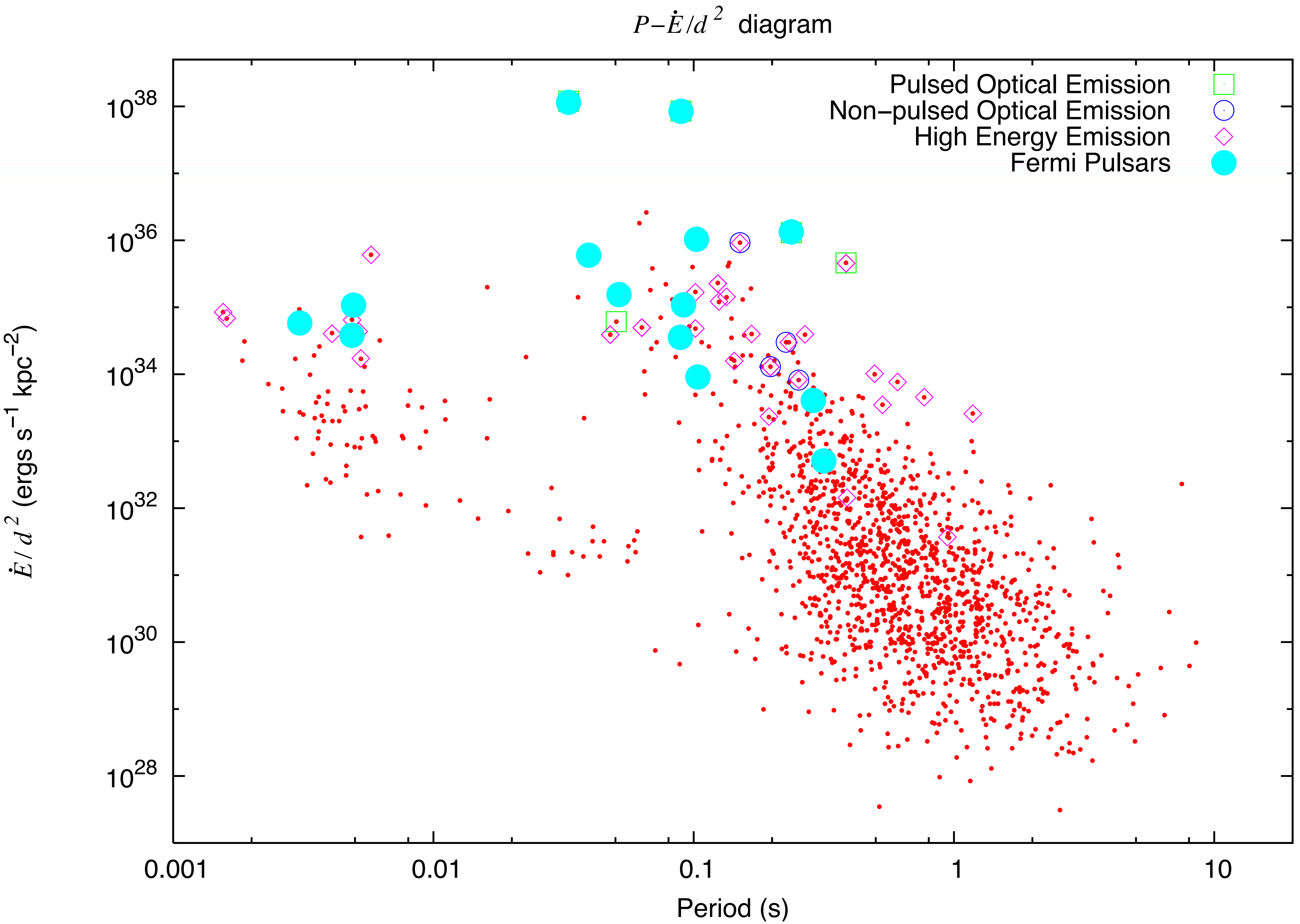
Crab - Polarisation reverse engineering

Mc Donald et al, 2011, MNRAS, 417, 730



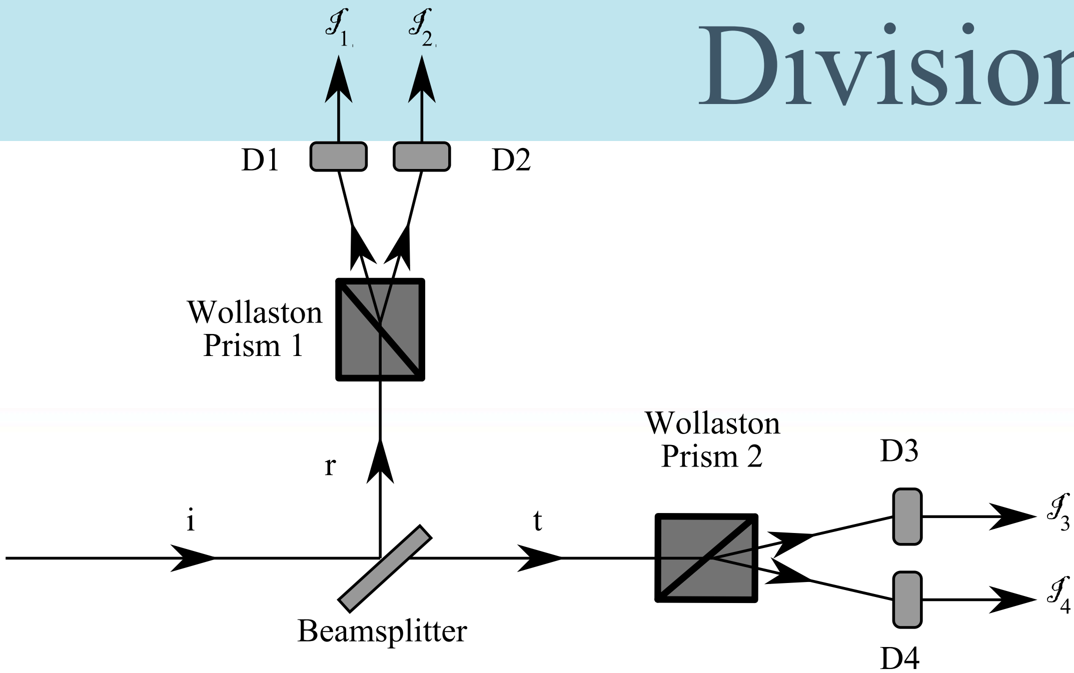


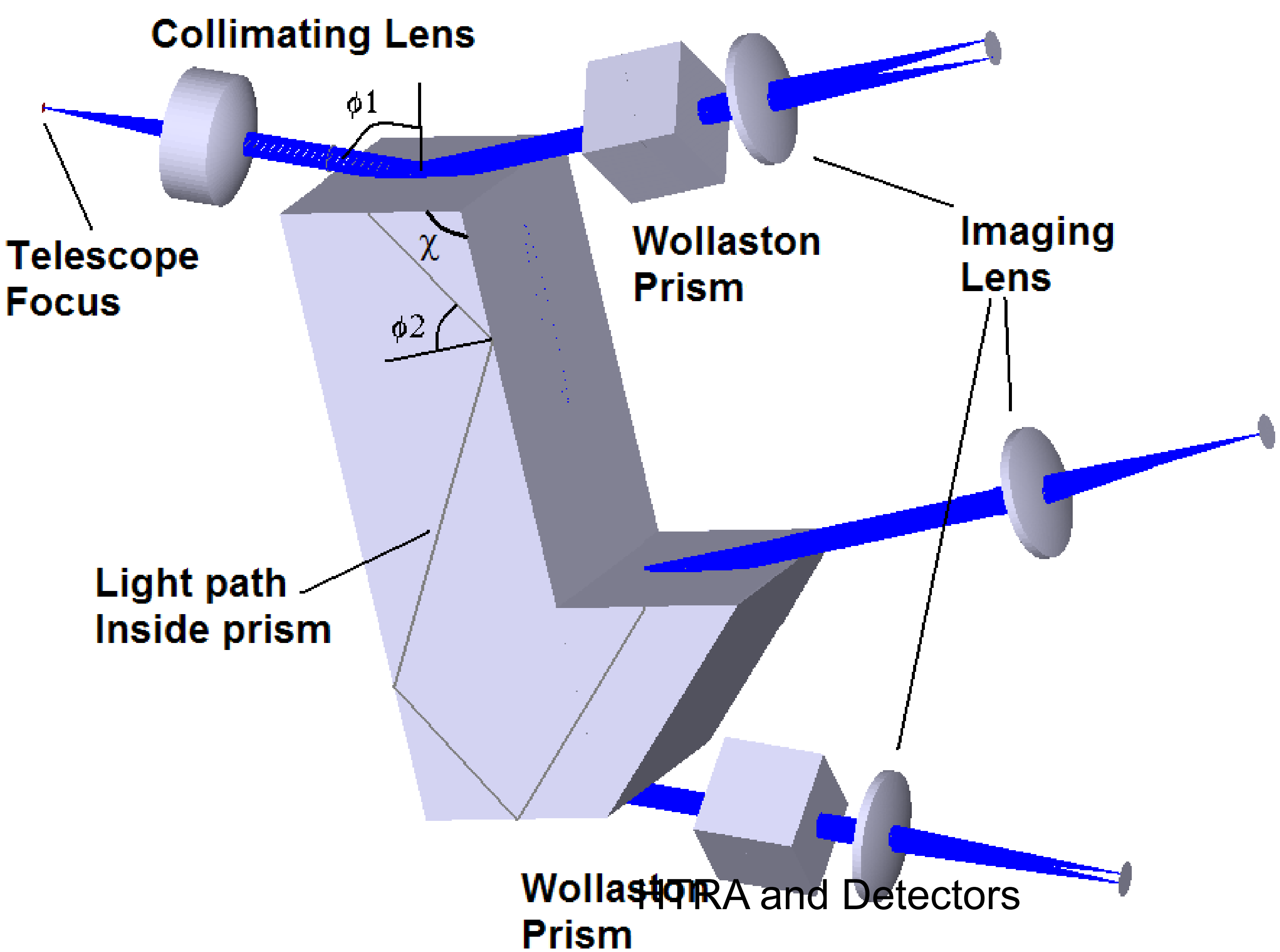
Fermi Probabilities - optical follow-up observations currently underway



Abdo et al, astro-ph 0902:1340

GASP - Galway Astronomical Stokes Polarimeter
Division of Amplitude Polarimetry





High Throughput
No moving parts
Two versions
  GASP I - 2 L3CCDs

  GASP II - 8 APDs
Measures I, Q, U and V
To be mounted on
Palaomar 5m in April 2012
Final tests Loiano
November 2011

Conclusion

- HTRA can deliver important science
- But, we need
  - fast, low noise detectors
  - large telescopes
  - good data pipelines with HTRA built in at the design phase
  - near IR detectors up to and beyond the silicon limit are needed.