High-Time Resolution Astronomy across the e-m Spectrum

Gottfried Kanbach, MPE, Garching

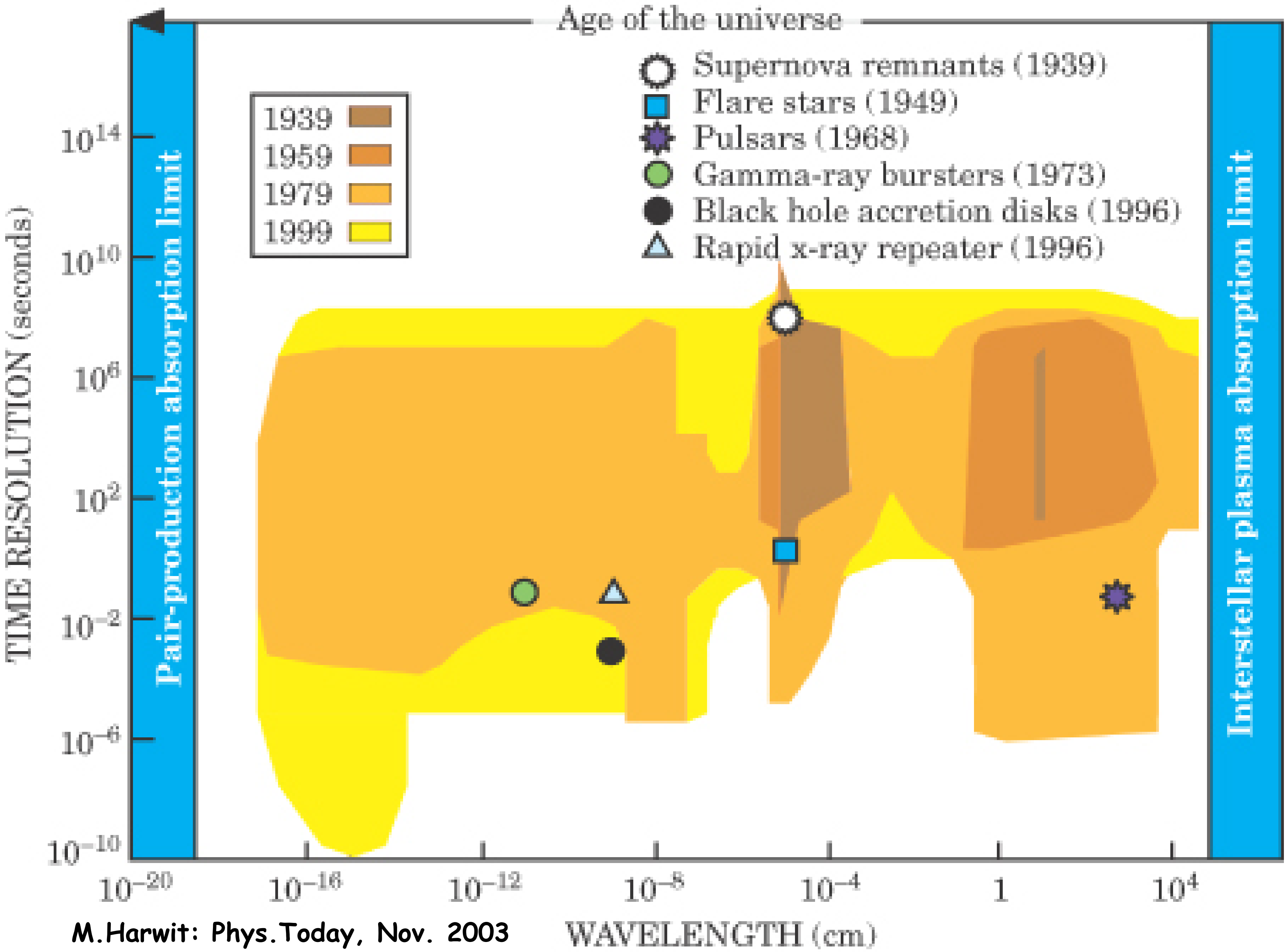
Variability on short timescales in astronomical objects:

- Absorption, Eclipses or Beaming effects
- Luminosity changes

$$I = \mathcal{L} / \Omega d^2 \rightarrow \quad \Delta I \sim \Delta \mathcal{L} \quad \text{if } \Omega \text{ is constant in } \Delta t$$

$$\varepsilon \sim \Delta \mathcal{L}\, \Delta t \,/\, (c\, \Delta t)^3 \sim \Delta \mathcal{L} \,/\, \Delta t^2$$

If ΔI is large enough to be observable, the energy density in the emitting volume can be extremely large if Δt is small. Such values can often only be realized around compact objects (WD, NS, BH) or in explosions.



M.Harwit: Phys.Today, Nov. 2003

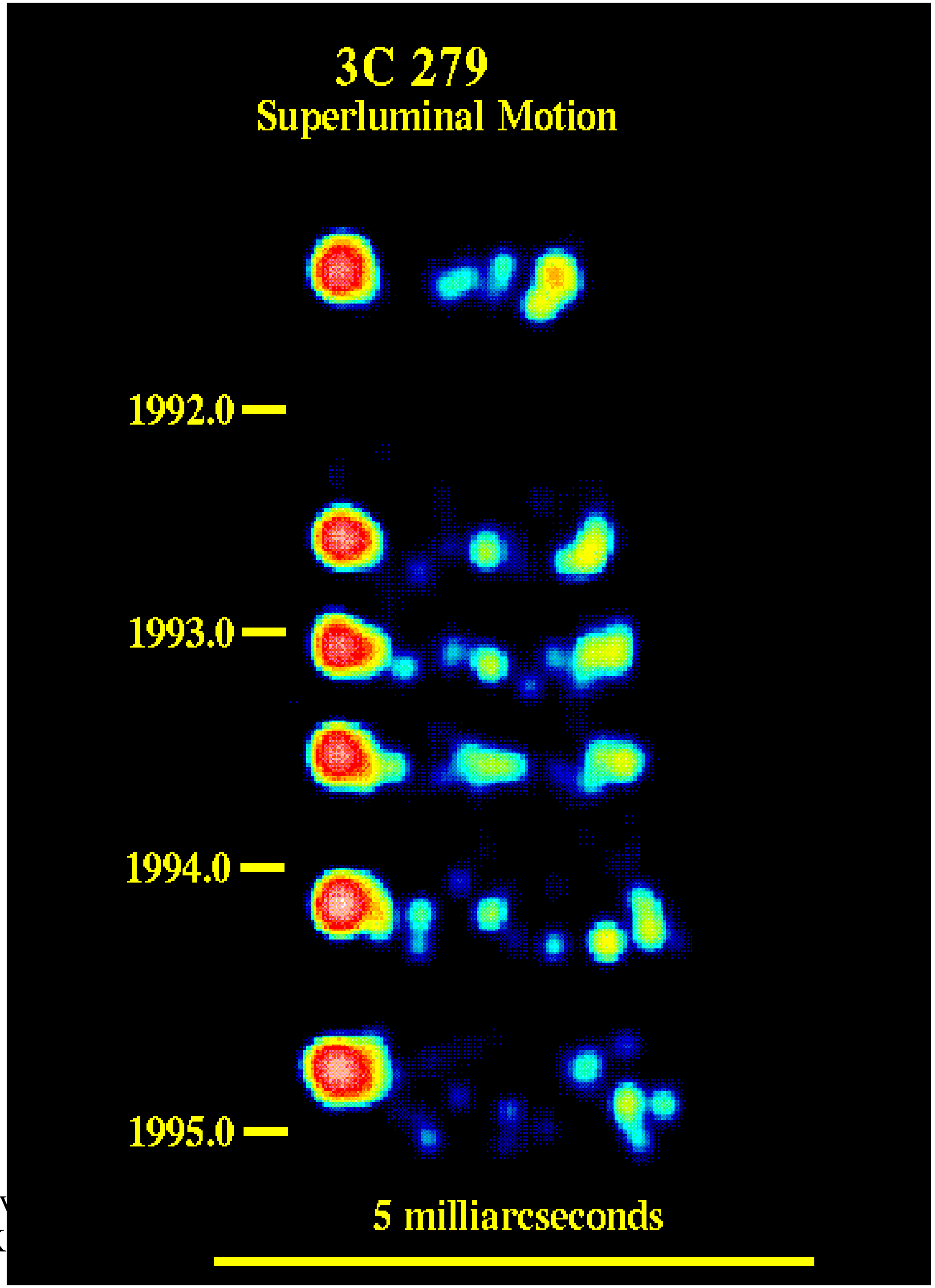
Timescales in Astronomy (long duration):

Months–Days:	Supernovae Microlensing events	mostly optical
Days-Hours:	Pulsating variables Asteroid rotation Close binary stars	
Hours-Mins:	Exoplanet transits Stellar seismology Binary-star interactions	
	AGN outbursts (blazars)	**multiwavelength**

Superluminal (ca 4 c) motion in blazar 3C 279

VLBI 22 GHz / 1.3 cm

(Ann Wehrle & Steve Unwin, JPL/CalTech)



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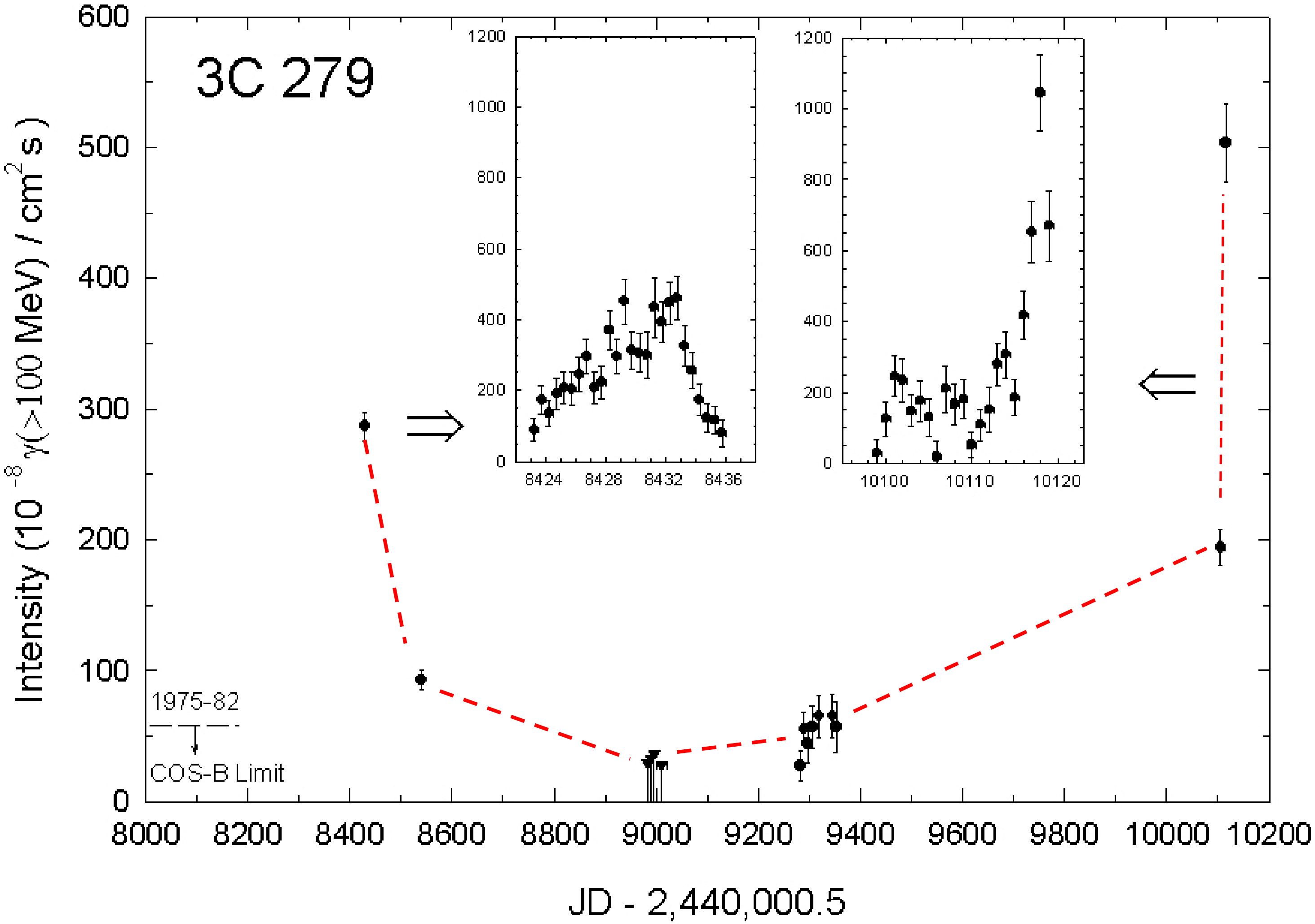
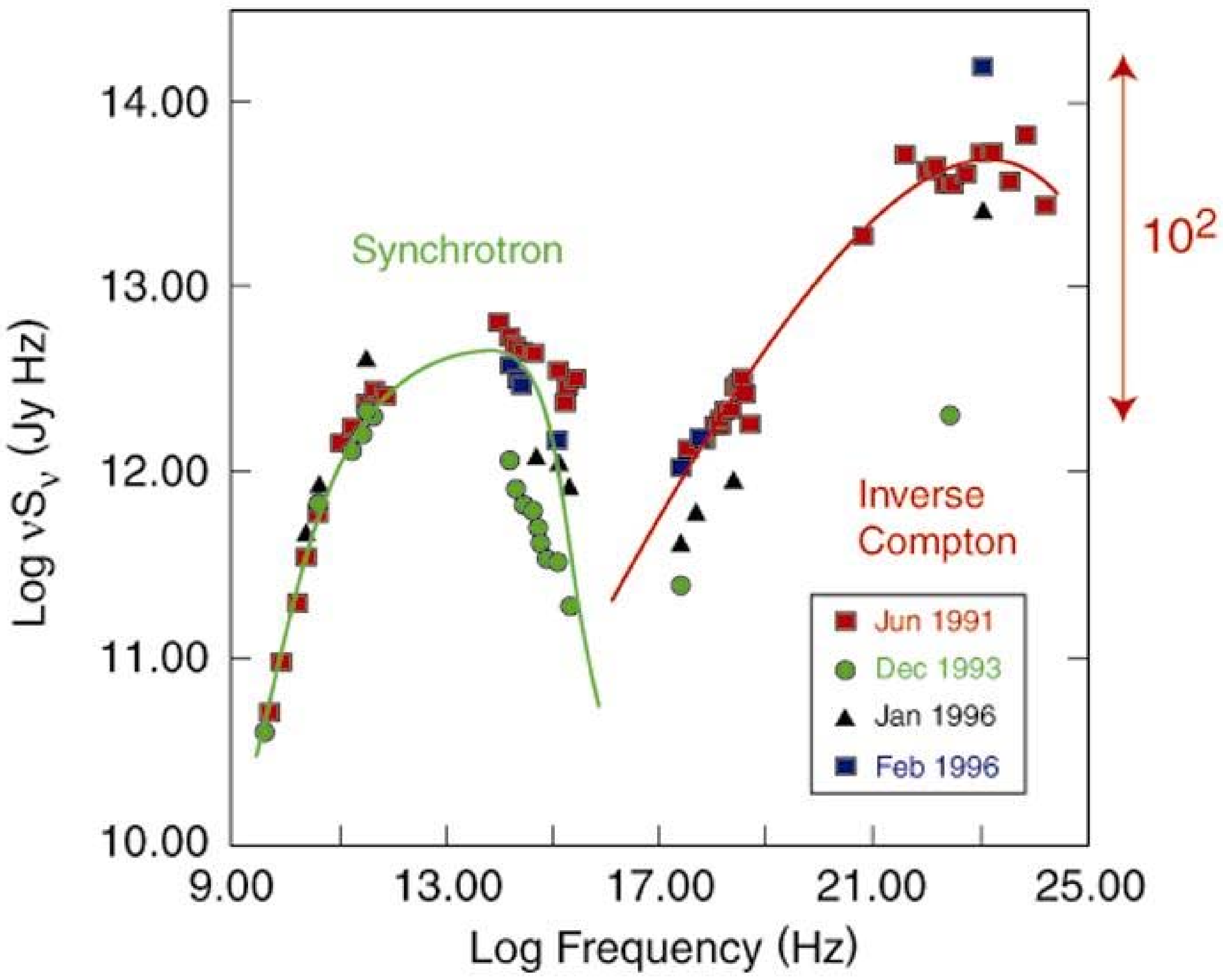
Variability at >100 MeV γ-ray energies

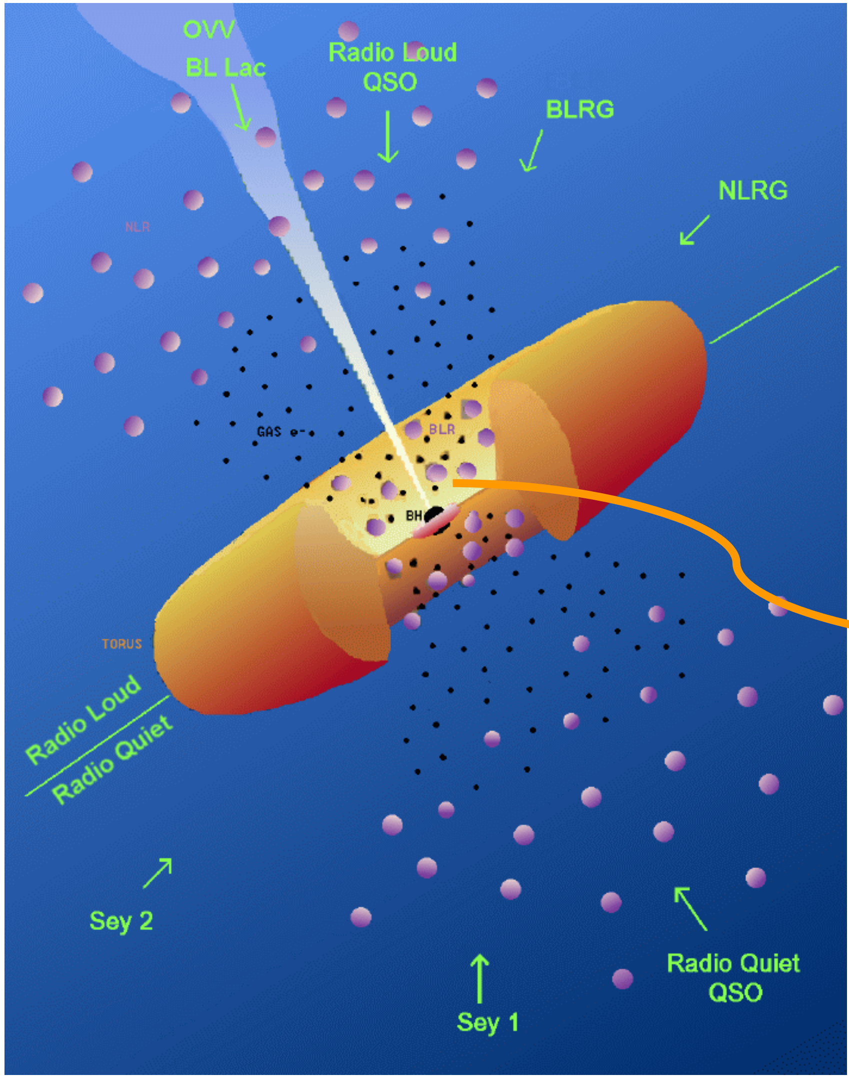


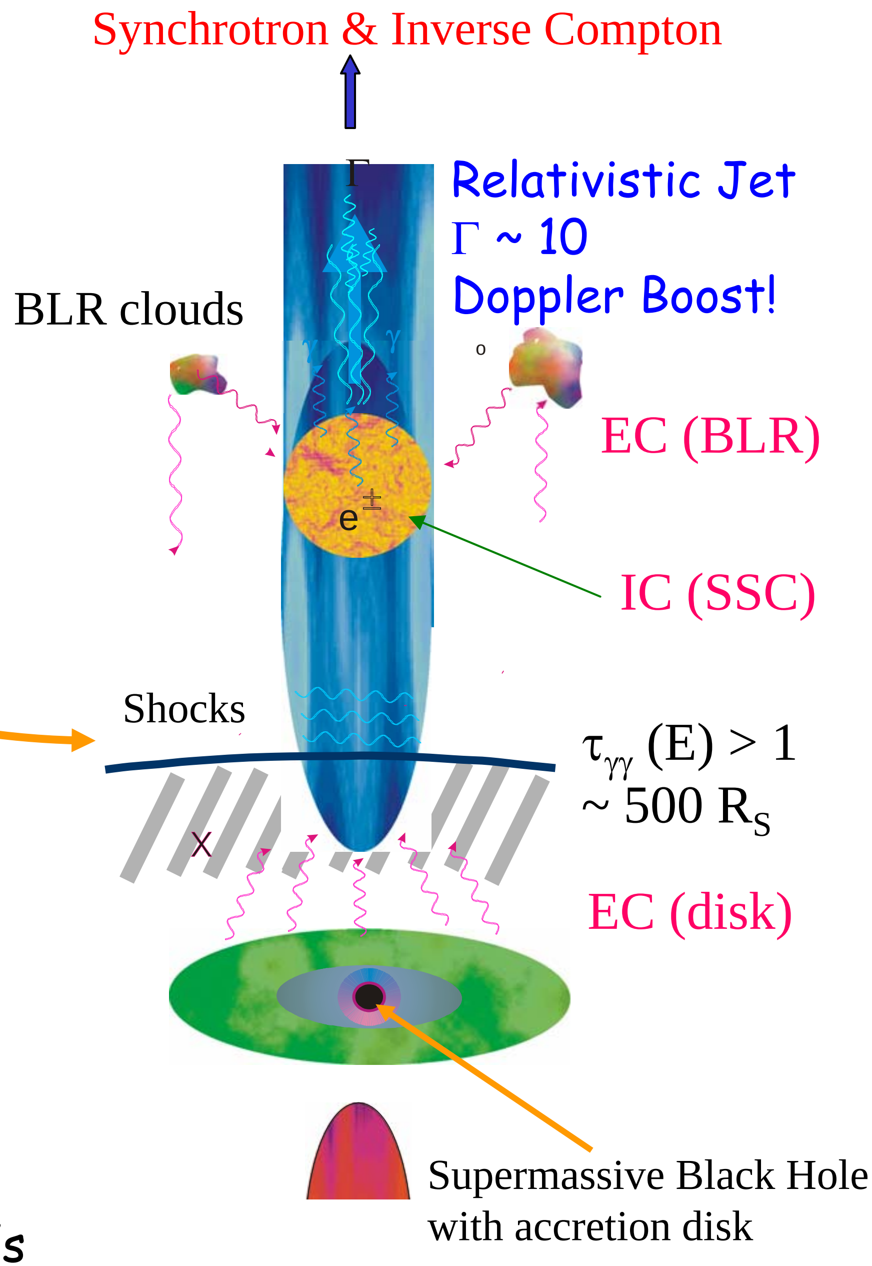
Kashi/Urumqi, China

Spectral Energy Distribution of 3C 279 at Four Epochs



AGN Standard Model:



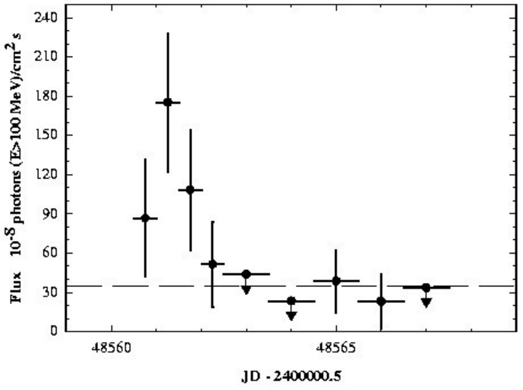


‚Isotropic' Luminosities: 10^{48} - 10^{49} erg/s

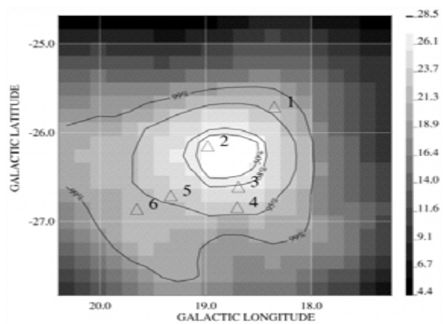
-> reduced to ~ 10^{45} erg/s after Doppler correction

Blazar Identification Example: 3EG J2006-2321

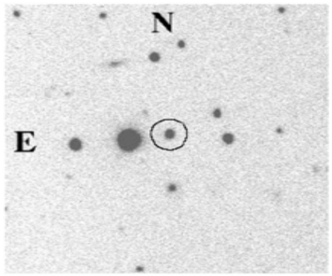
First Clue: Gamma-ray variability



Radio sources in the error box



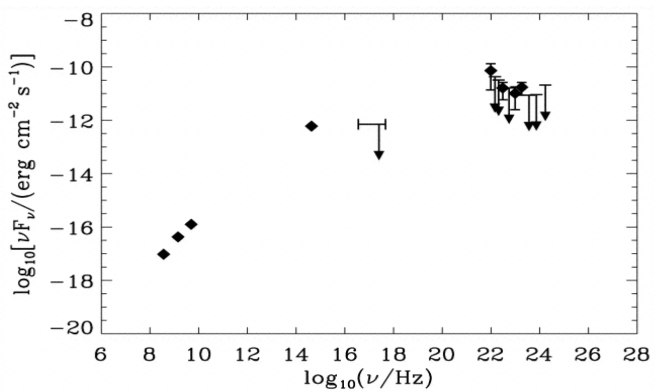
One flat-spectrum radio source, 260 mJy at 5 GHz; one marginally-flat source, 49 mJy; other sources are much weaker



Optical observations:

The 49 mJy source is a normal galaxy;

The 260 mJy source has an optical counterpart with a redshift z=0.83



Variable optical polarization is seen.

Only an X-ray upper limit found.

Spectral energy distribution is bimodal like other blazars

Conclusion: 3EG J2006-2321 is a flat spectrum radio quasar (FSRQ)

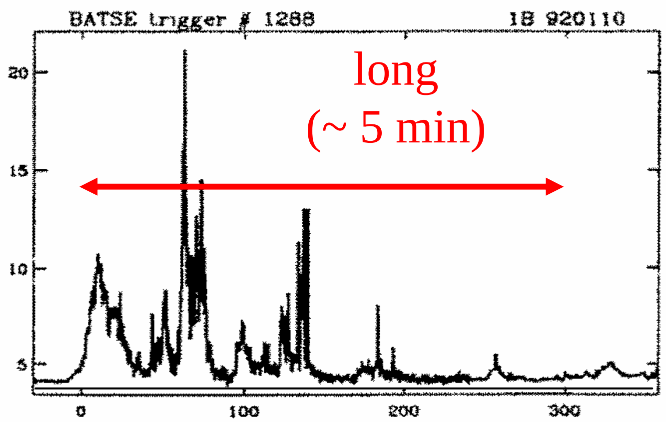
Wallace et al.

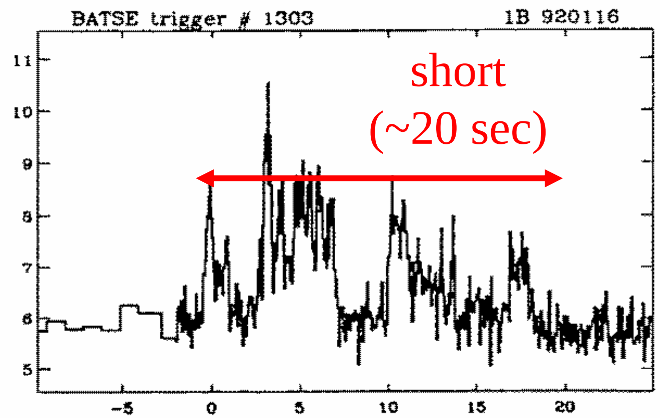
Timescales: (short duration)

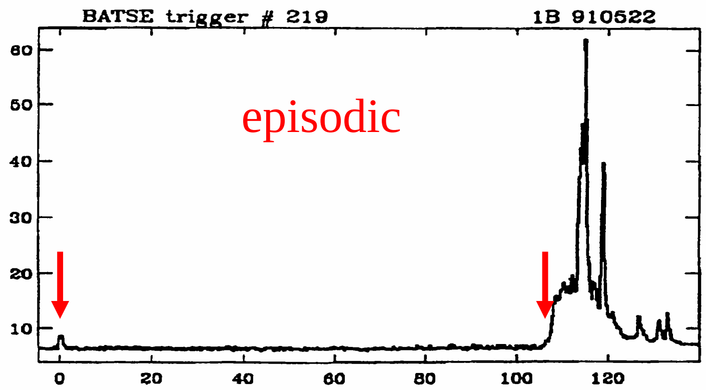
min - sec:	Gamma-ray bursts cataclysmic variables
sec-msec:	Pulsars Quasi-periodic oscillations, QPOs
msec – μsec:	Accretion instabilities Photon-gas effects Neutron-star oscillations
μsec – nsec:	Photon emission mechanisms Giant radio bursts in pulsars Photon quantum statistics

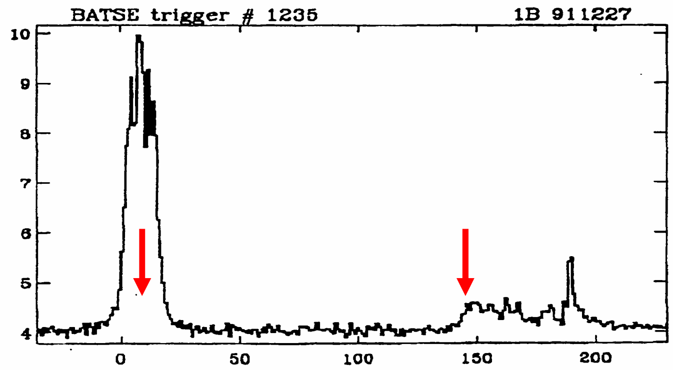
Gamma-Ray Bursts

GRBs show a large variety of lightcurves with rapid variability

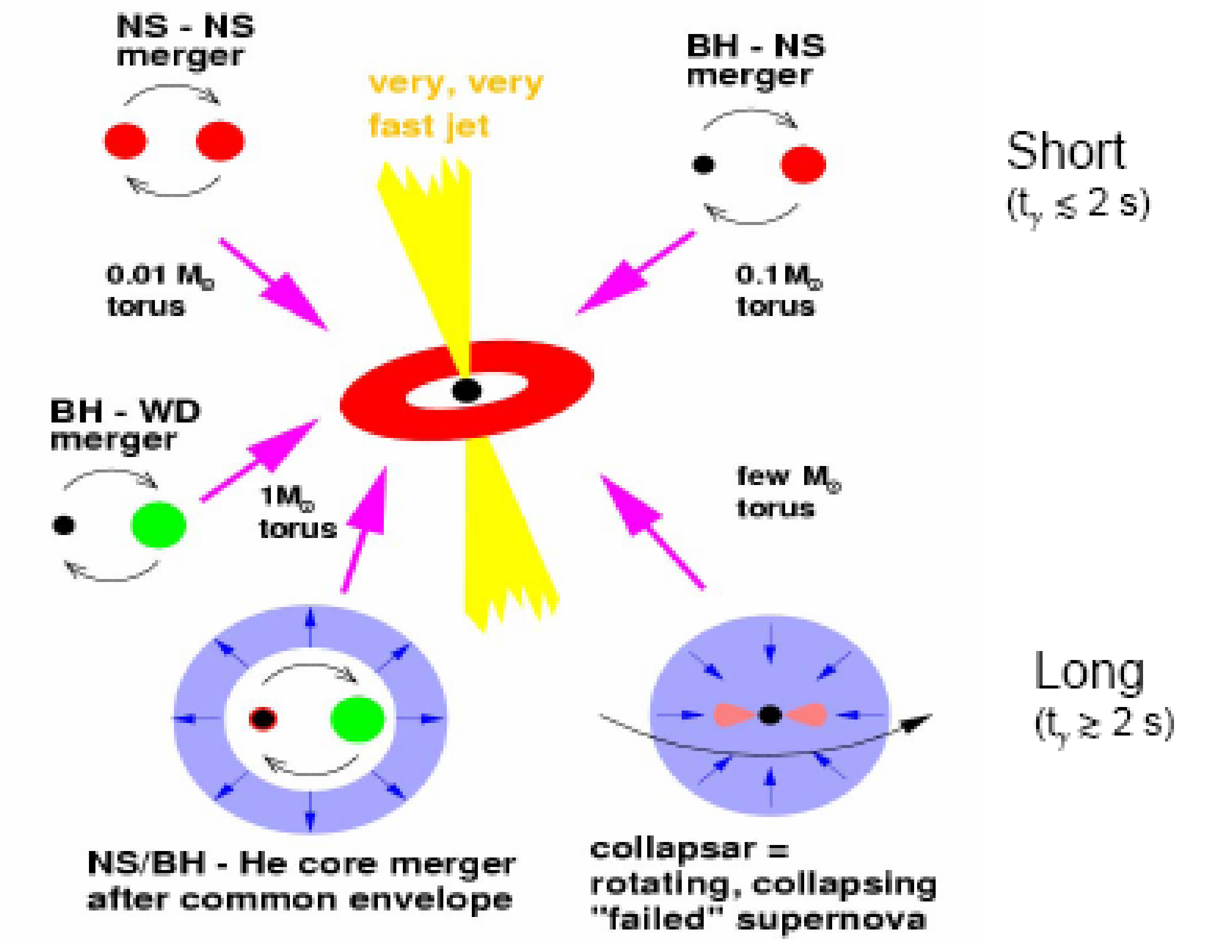








GRB:→ Hyperaccreting Black Holes (current paradigm)



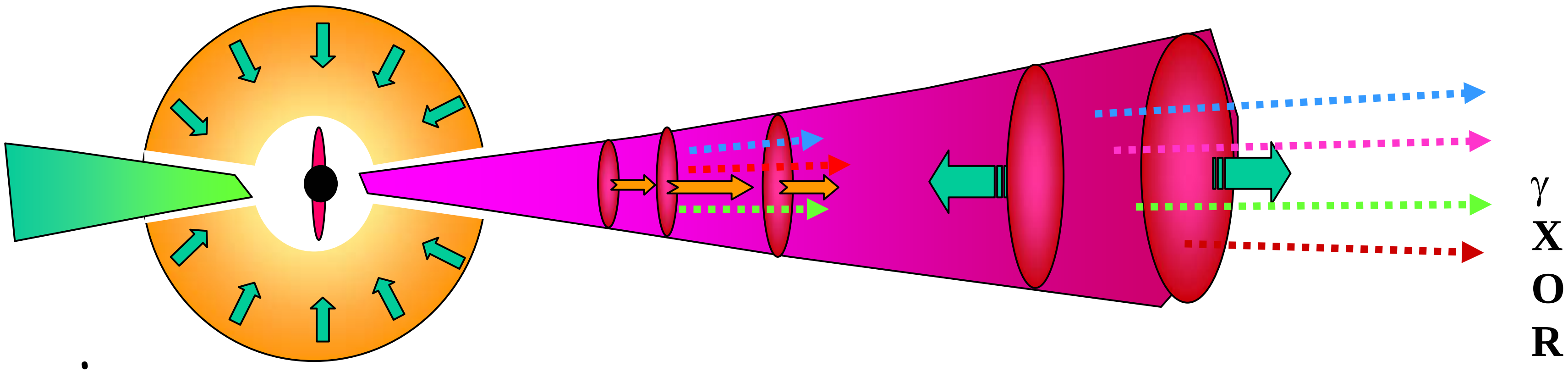
Credit: P.Meszaros, 2004

Generic GRB model

Collapse of a massive star
⇒ black hole with accretion disk and relativistic jet (Γ>100)

Internal Shocks
Delayed Injection:
prompt burst

External Shocks (forward/reverse)
Afterglow



t_{eng} :

b.h.-torus
fall-back times
magnetar

Energy transport:
relativistic particle jet
or Poynting Flux

t_{dec} :
E_o, Γ_o, n

if $t_{eng} > t_{dec}$: signature of central engine should be visible in afterglow

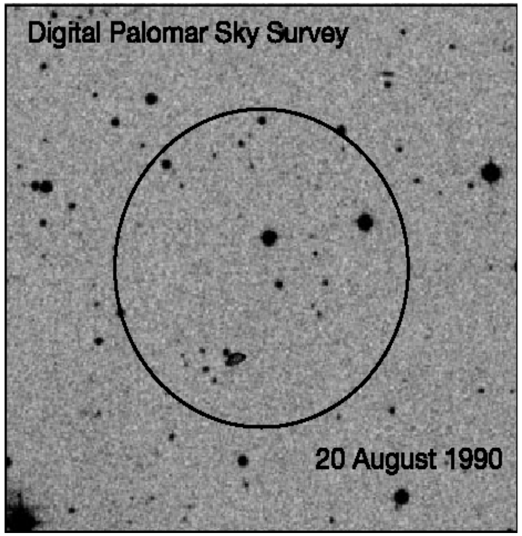
Gamma Ray Bursts:
Optical afterglows

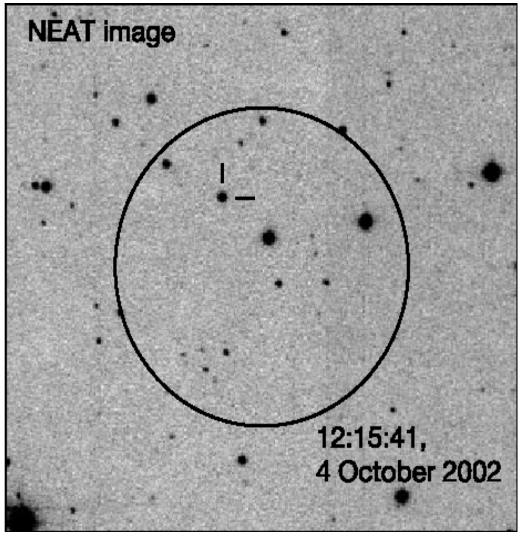
letters to nature Nature, **422**, 286, 20 March 2003

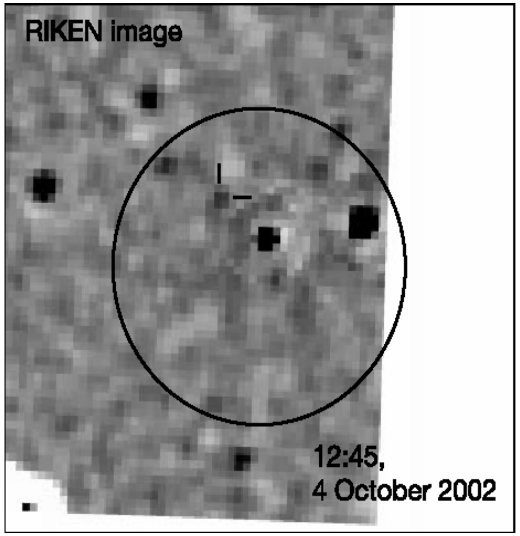
Early optical emission from the γ-ray burst of 4 October 2002

D. W. Fox*, S. Yost†, S. R. Kulkarni*, K. Torii‡, T. Kato§, H. Yamaoka||, M. Sako¶, F. A. Harrison†, R. Sari¶, P. A. Price#, E. Berger*, A. M. Soderberg*, S. G. Djorgovski*, A. J. Barth*, S. H. Pravdo☆, D. A. Frail**, A. Gal-Yam††, Y. Lipkin††, T. Mauch‡‡, C. Harrison# & H. Buttery§§

HETE II
GRB021004



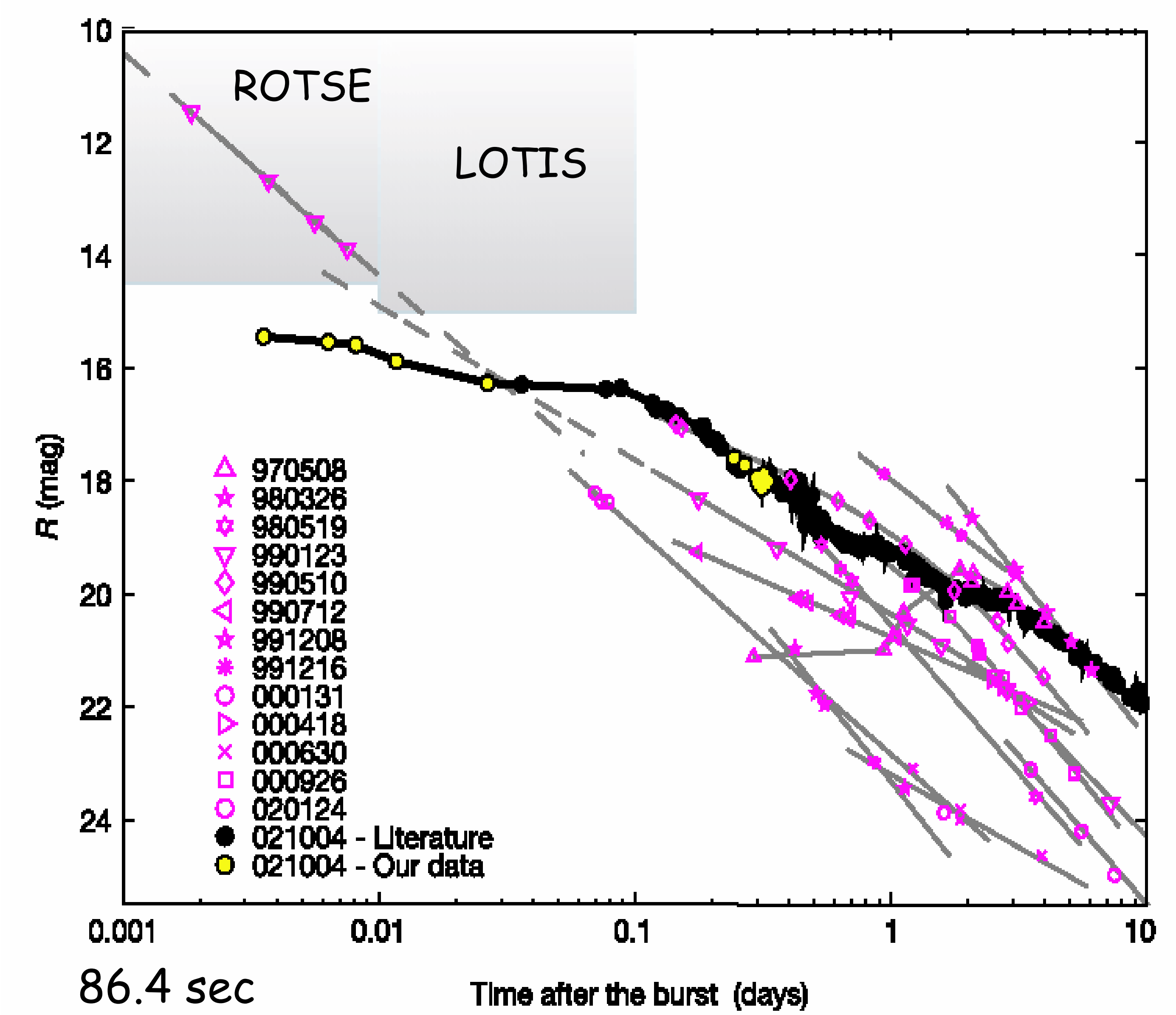




t_o = 12:06:14 UT

+193 sec

+537 sec



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Kashi/Urumqi, China

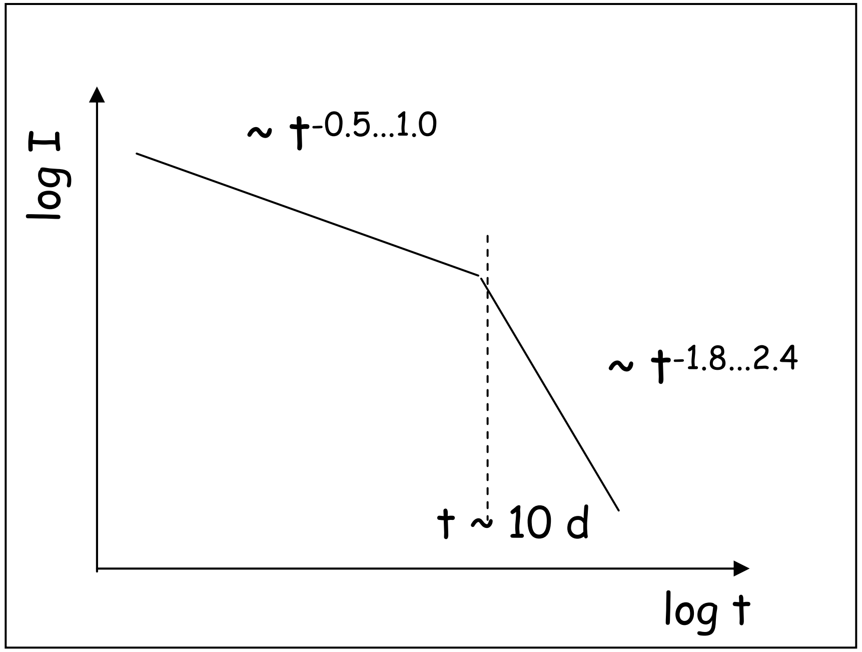
The Afterglow Phase of (some) GRBs

The central GRB engine deposits energies of typically 10^{52} erg (isotropic) into a very small volume ($\Delta t\ c \sim 10^{11}$ cm)

The result is a relativistically expanding fireball (jet) with typical initial Lorentz factors of a few 100.

Onset of Afterglow (deceleration time scale):

$t_{dec} \sim 2.4\text{s}\ (E_{52}/n)^{1/3}\ (\Gamma_o/300)^{-8/3}\ (1+z)$



John M. Blondin

(North Carolina State University)

Hydrodynamics on supercomputers: Interacting Binary Stars

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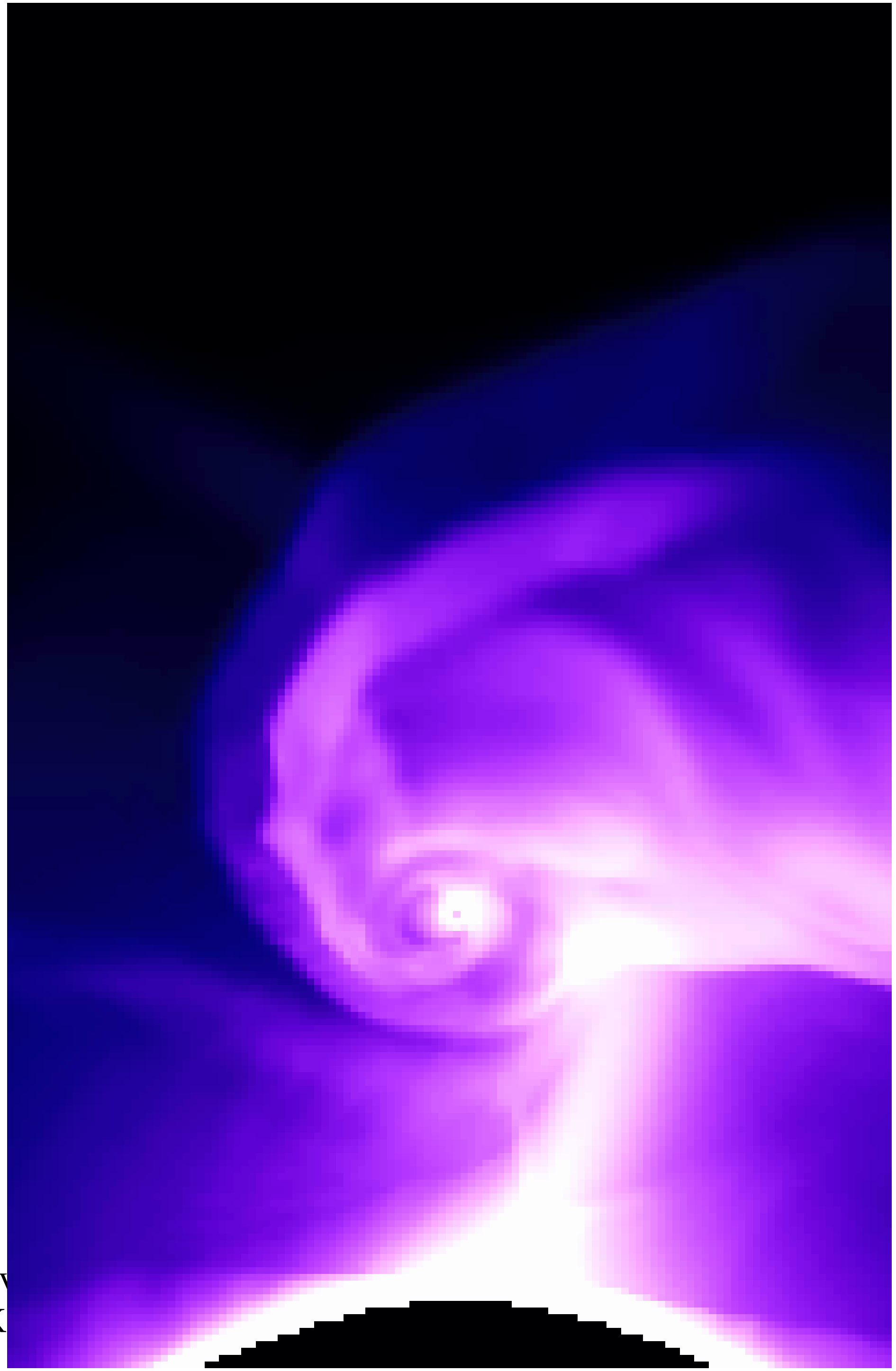
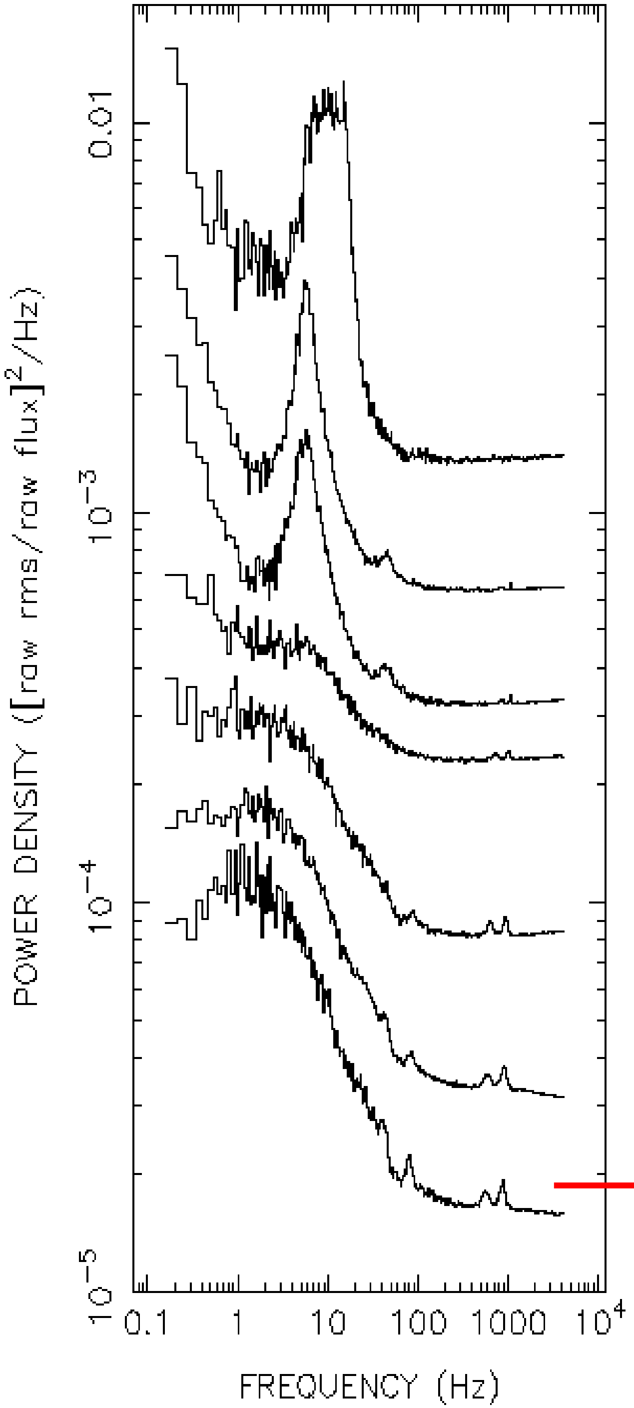


Kilohertz quasiperiodic oscillations in Sco X-1

(Miller, Strohmayer, Zhang & van der Klis, *RXTE*)



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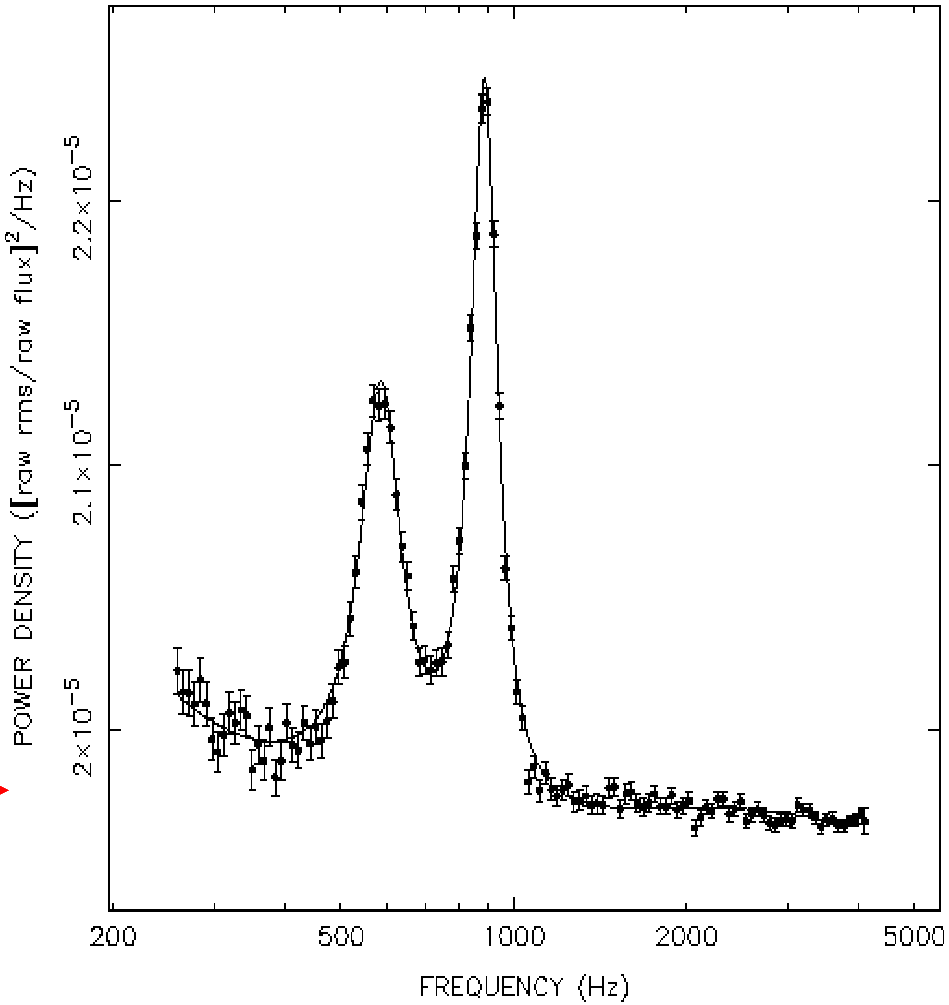
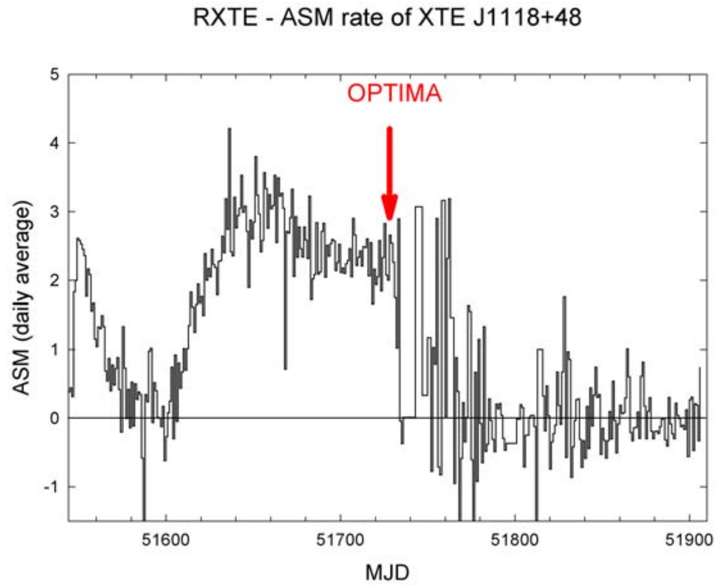


A black hole transient in 2000 : XTE J1118+48 (=KV Uma)

- transient X-ray source during Jan – Jul 2000
- Hard spectral state with high variability
- high optical / X-ray luminosity ratio
- nearby object (~ 2 kpc) at high galactic latitude
- estimated mass of compact star > 6 $M_\odot$

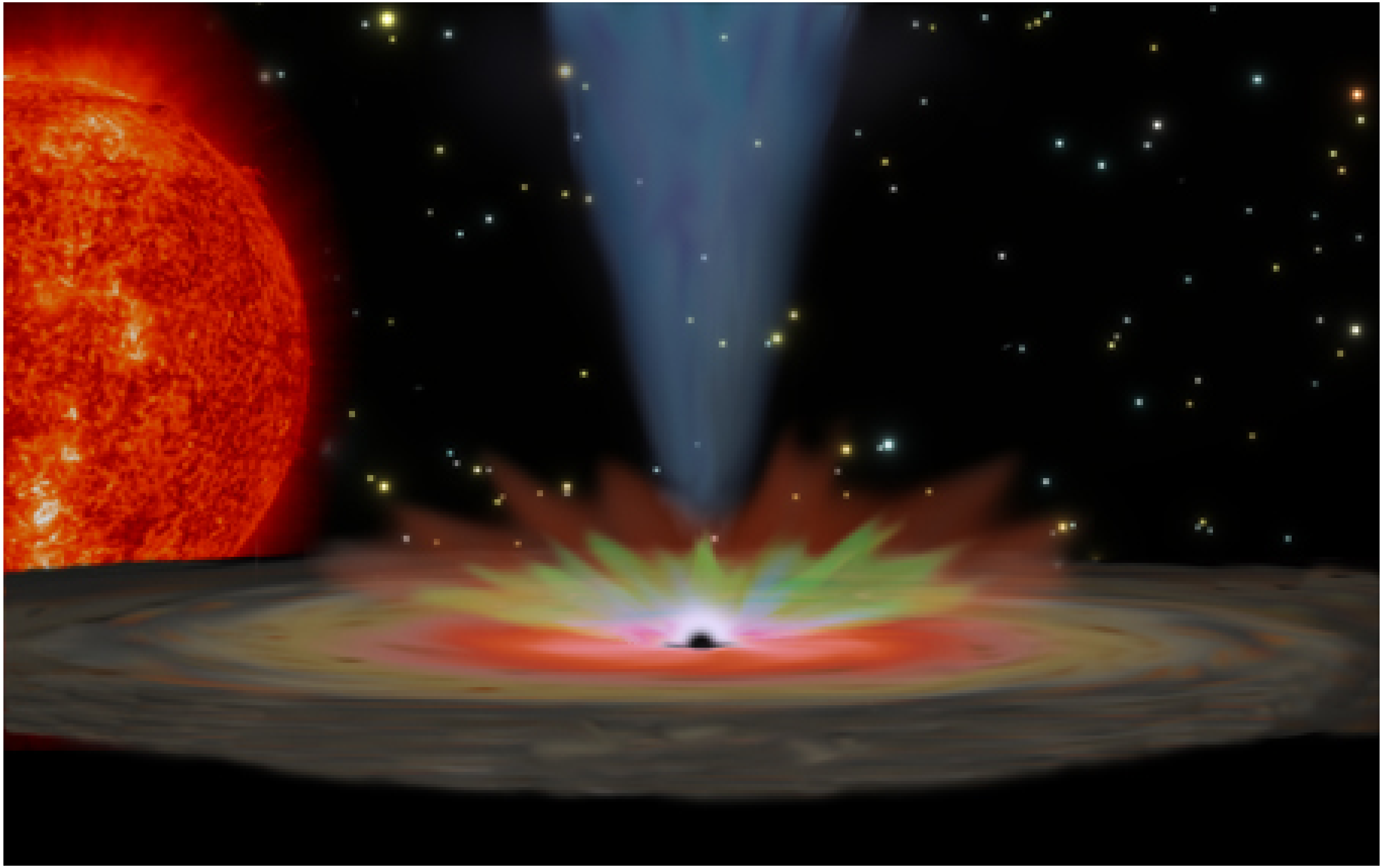


Correlated timing observations between X-rays (RXTE-PCA) and optical (OPTIMA) were carried out during July 4-8, 2000

A total of 2.5 hours of coincident measurements were performed!

(Kanbach, Straubmeier, Spruit, and Belloni, 2001, Nature,414, 180)

Artist's Illustration of XTE J1118+48



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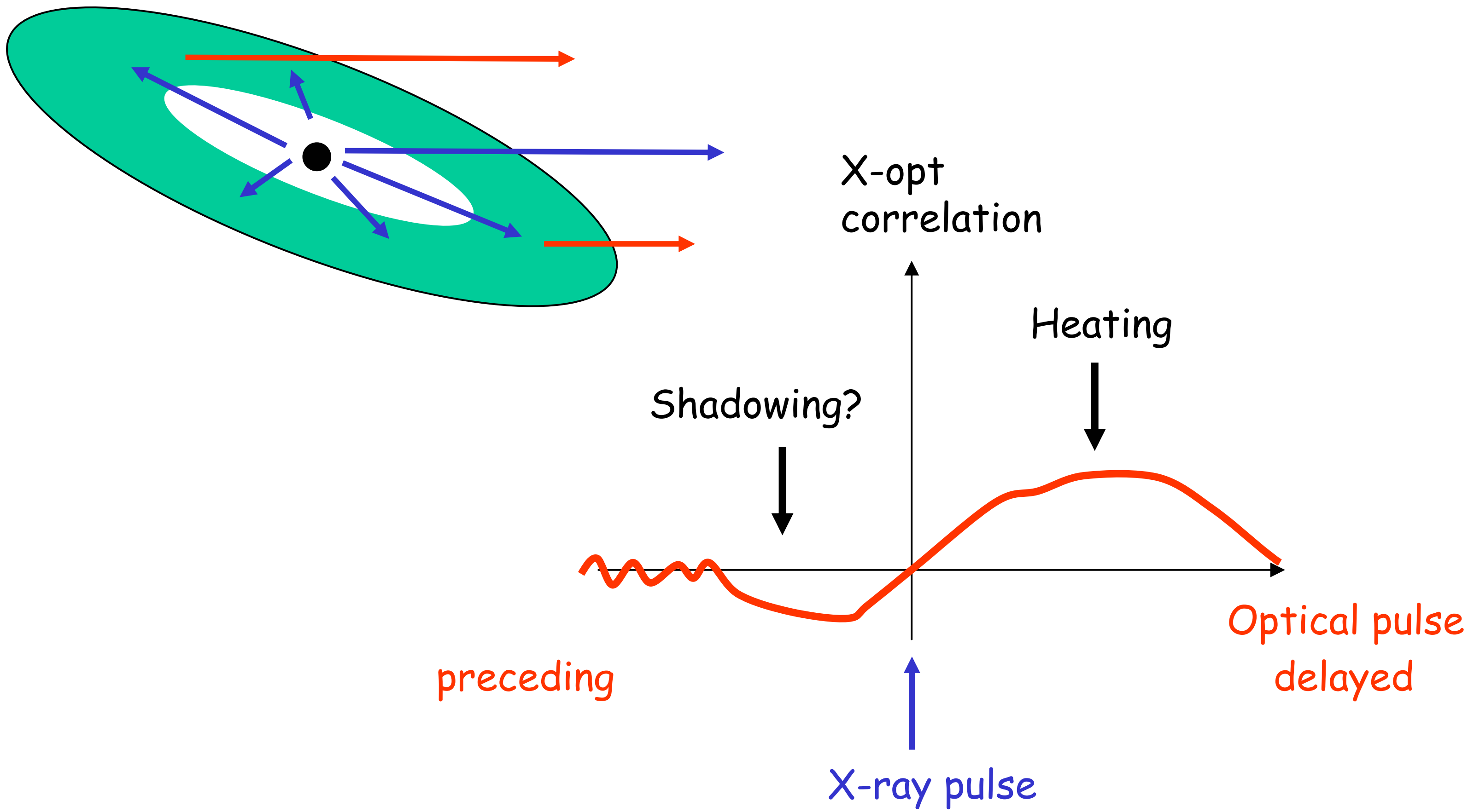
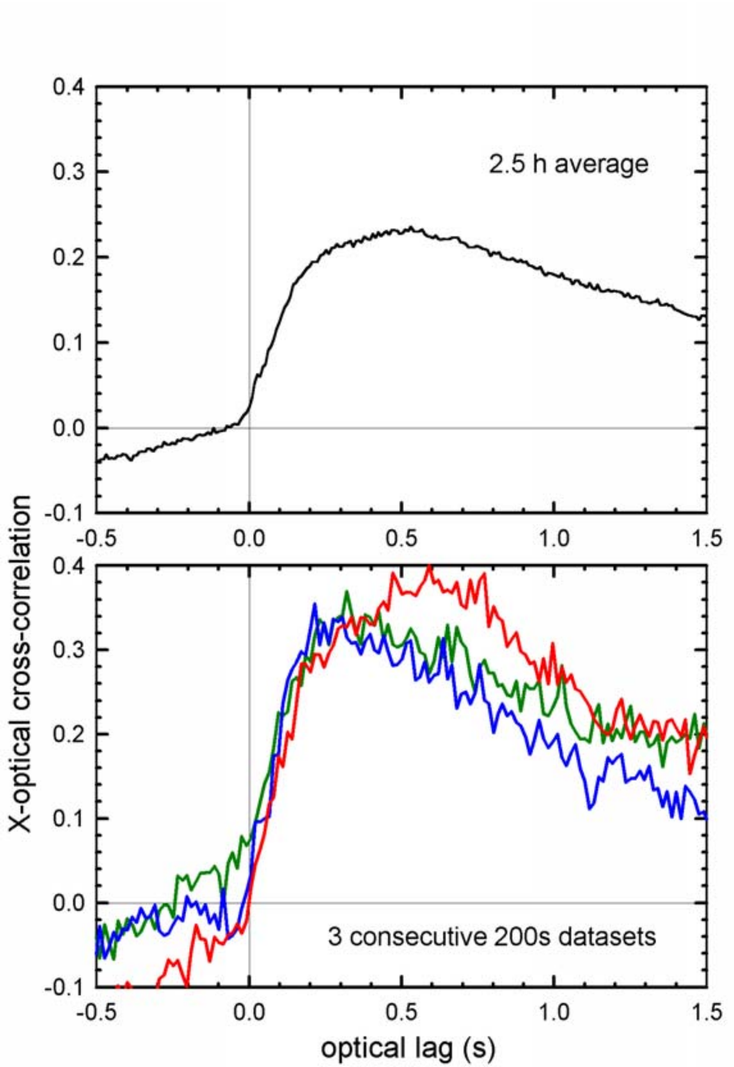
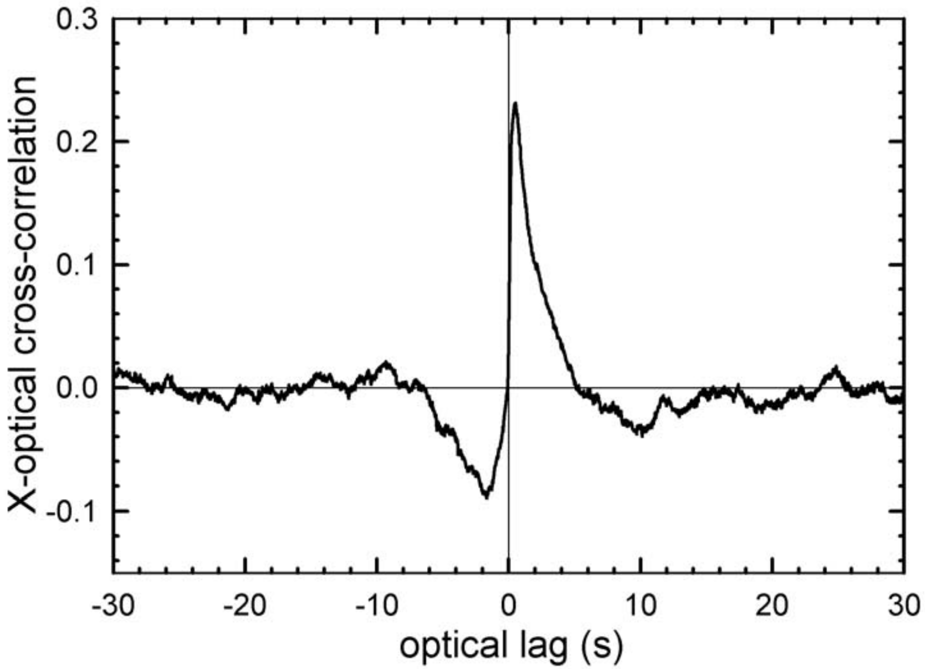
Kashi/Urumqi, China

´Reprocessing´ or ´Light-Echoes´



X-ray optical correlations





Positive correlation with short rise (~ 100ms)
Maximum at ~ 500 ms; length ~ 5 sec

Anti-correlation at –2 sec:´precognition dip´

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Emission Models:

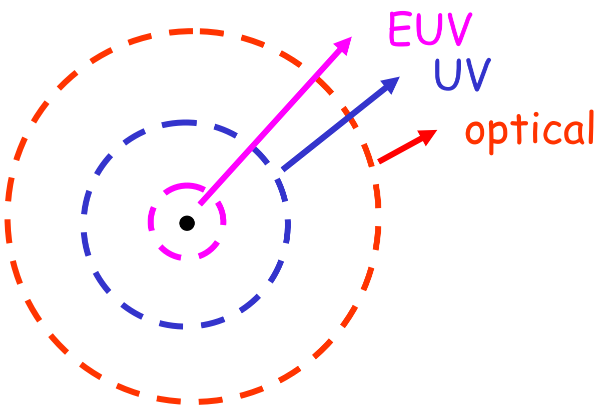
The brightness temperature and the SED indicate that self-absorbed cyclo-synchrotron emission causes the optical signal

The size of the emitting region is < 30,000 km

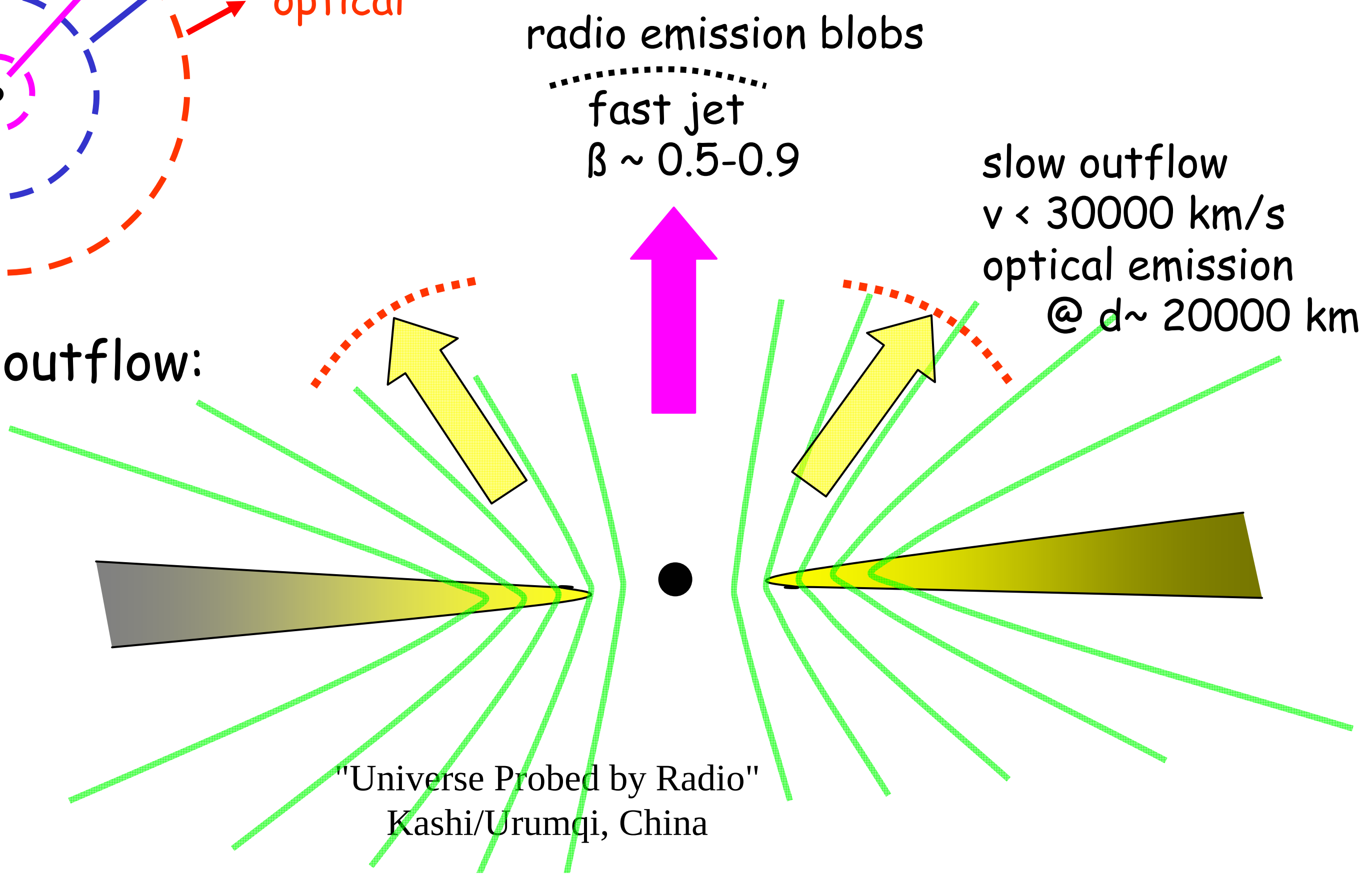
A ´quasi spherical´ slow outflow crossing photospheric surfaces:

EUV @ 10^7- 10^8 G

optical @ 10^6 G, r=20000 km



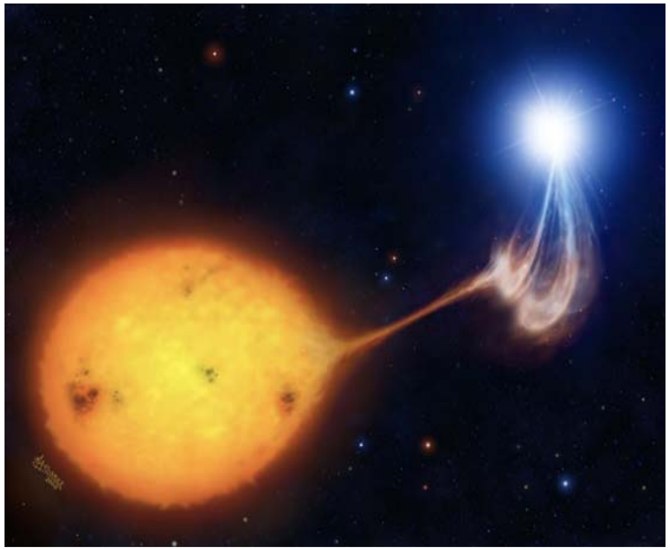
A ´jet-like´ outflow:



Accreting Binary sources

Neutron Star or Black Hole Binary (μBlazar)

Emission from accretion disk and jet



Cataclysmic Variables:

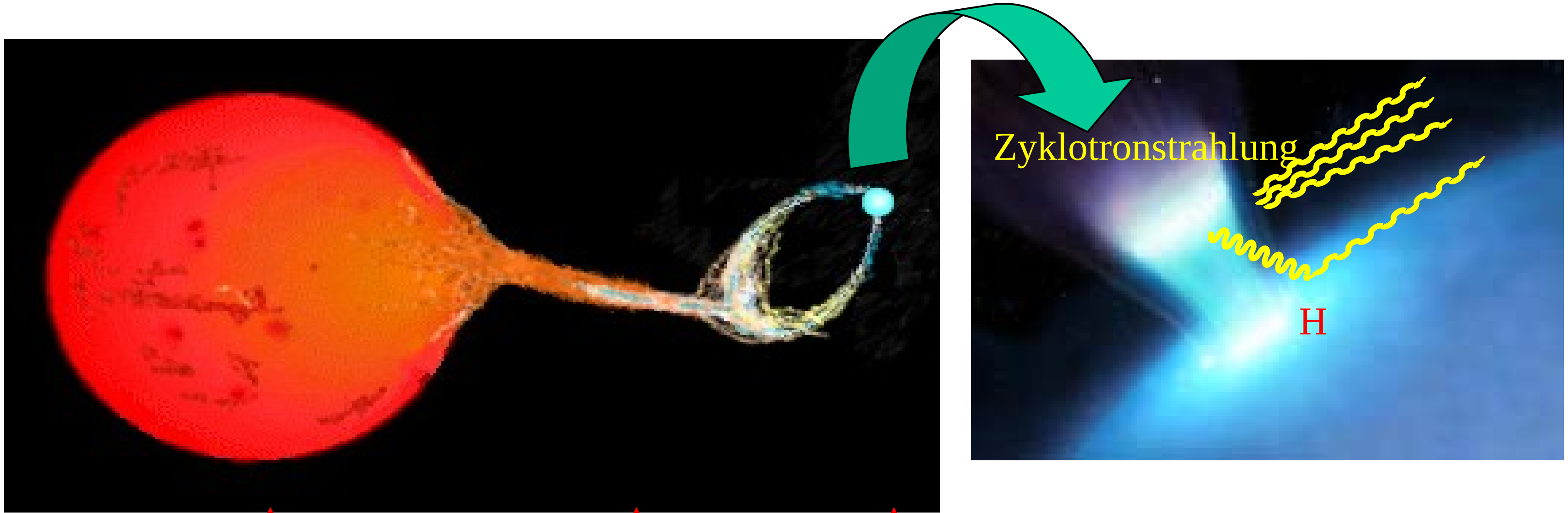
e.g. AM Her type:
A highly-magnetic white dwarf (~10^{7-8} G) in locked rotation around a low mass star (~**0.3 M_o**)

Emission from accretion stream and hot spots (thermal and synchro-cyclotron)

Cataclismic Variable: Type Polar / AM Her

Observations of HU Aqr (Orbital Period 125 min) from ESO/La Silla 2.2 m and Skinakas Observatory/Crete 1.3m

HU Aqr (RE 2107-05): d ~ 200 pc, i>85° Orbitalvelocity ~ 200 km/s



Secondary Star

(M4V, ~0.3 M_o)

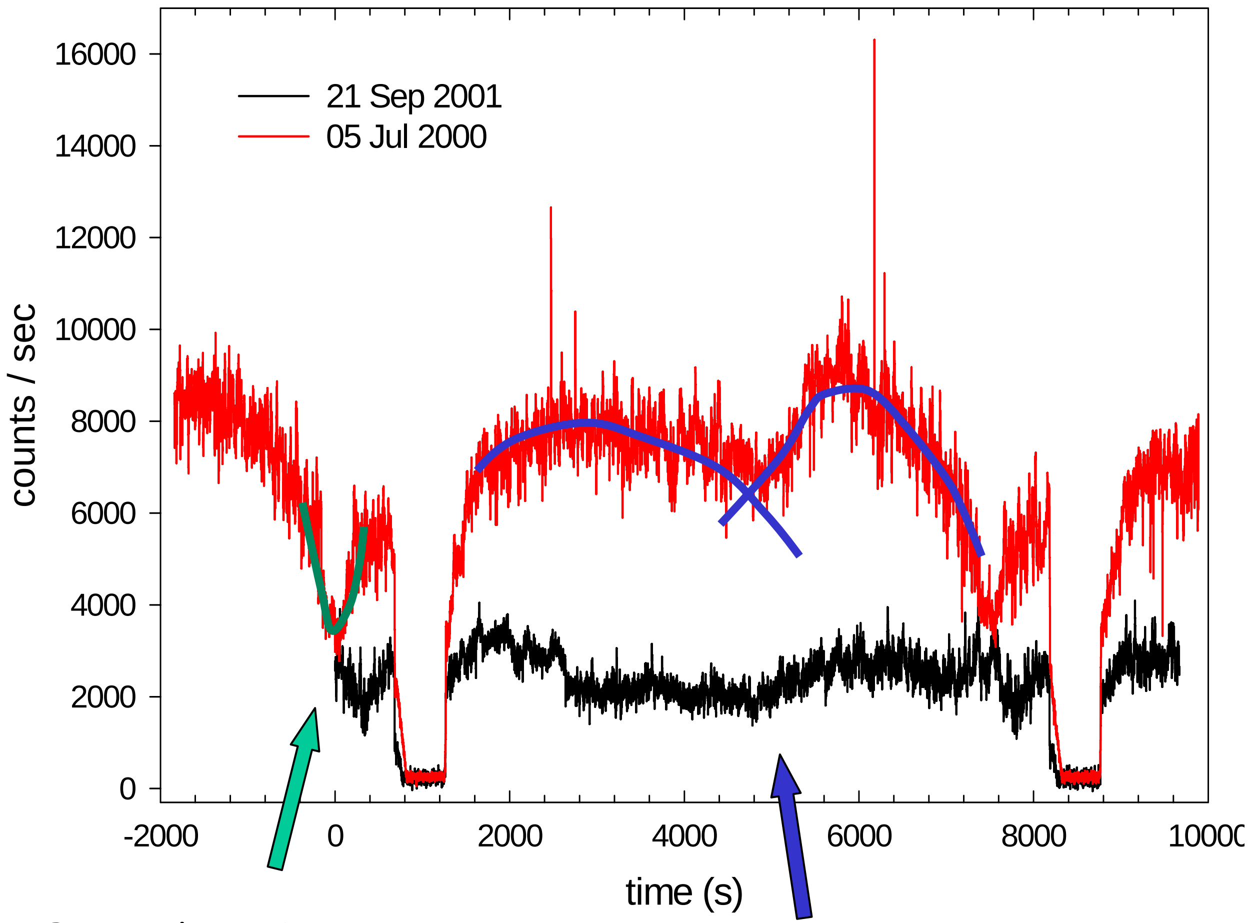
Accretion stream

Magnetic White Dwarf,

B~4x10^7G, m_v ~ 15, ~0.9 M_o

6x10^{10} cm

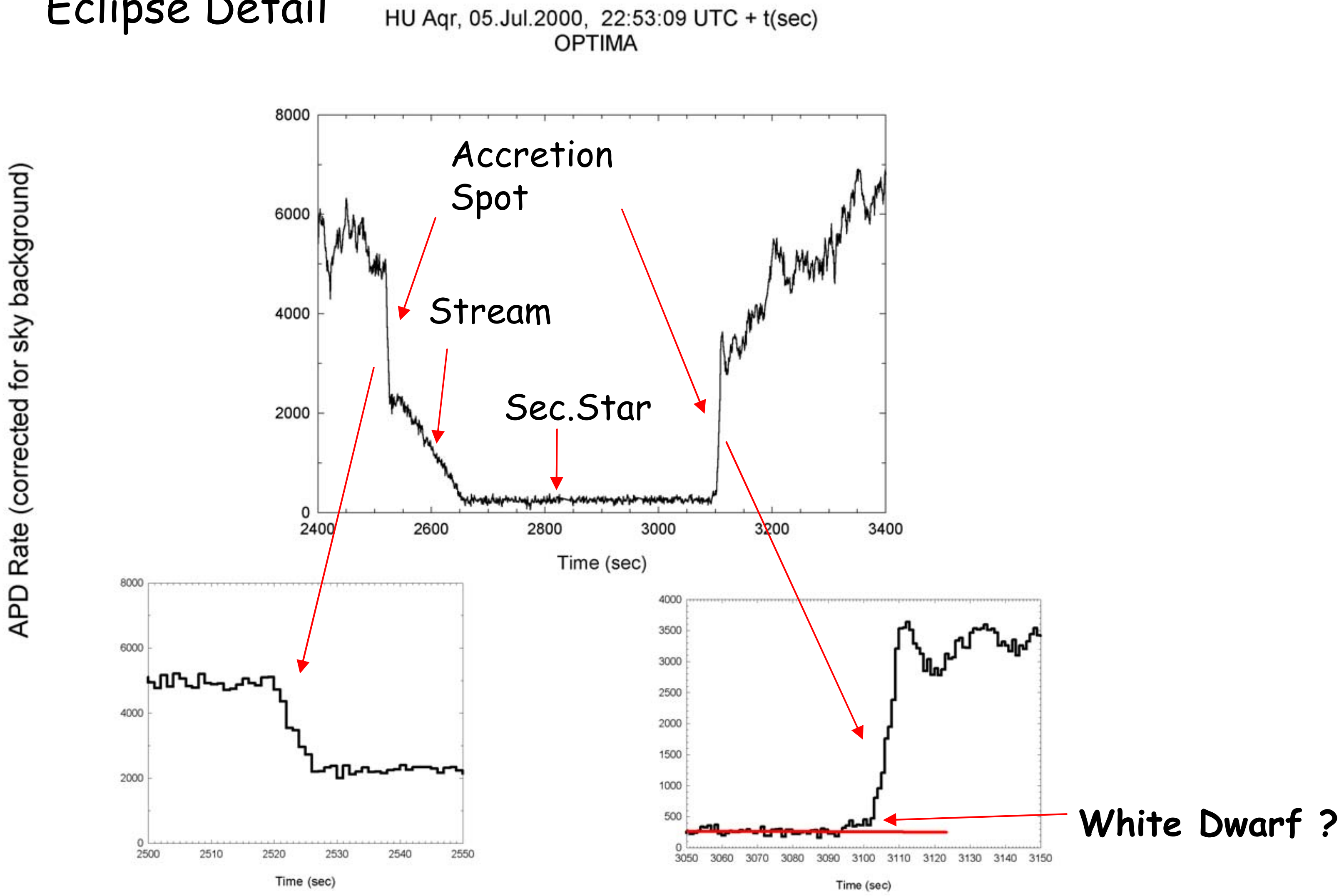
HU Aqr: a cataclysmic variable with an orbital period of 125 min and eclipses



Pre-eclipse Dip
Absorption by
Accretion
Stream

Synchrotron Maxima
$\perp$ to B-field

Eclipse Detail



orbital velocity

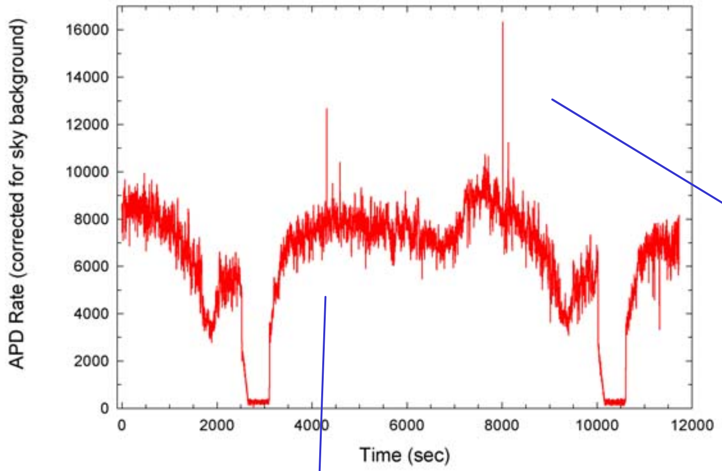
~200 km/s

dt ~ 6 sec = 1200 km

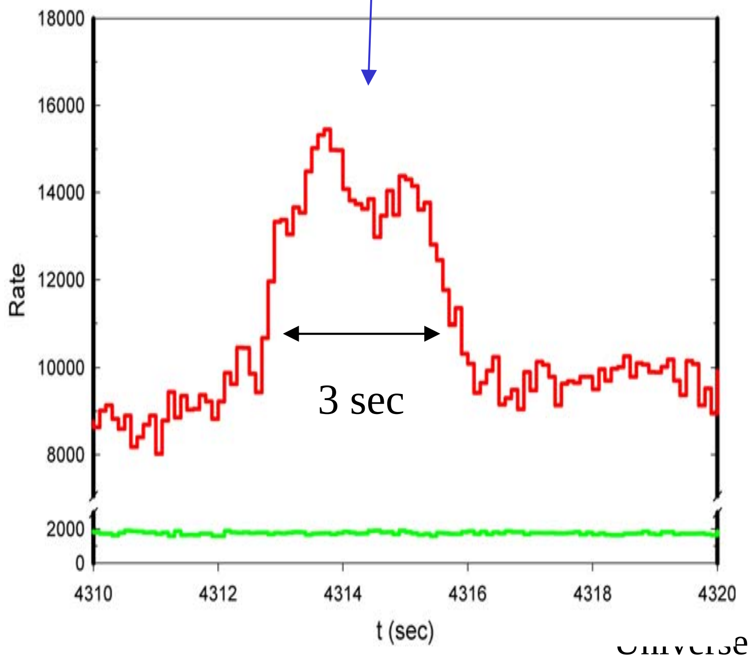
dt~ 7 sec = 1400 km

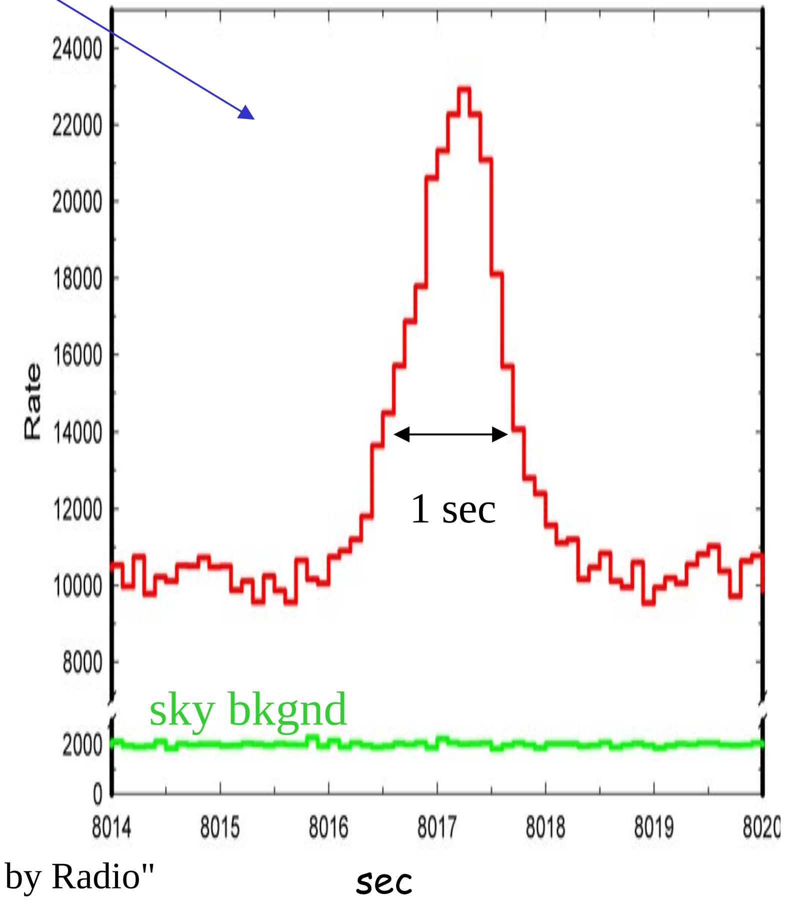
Size of the polar 'hot' spot

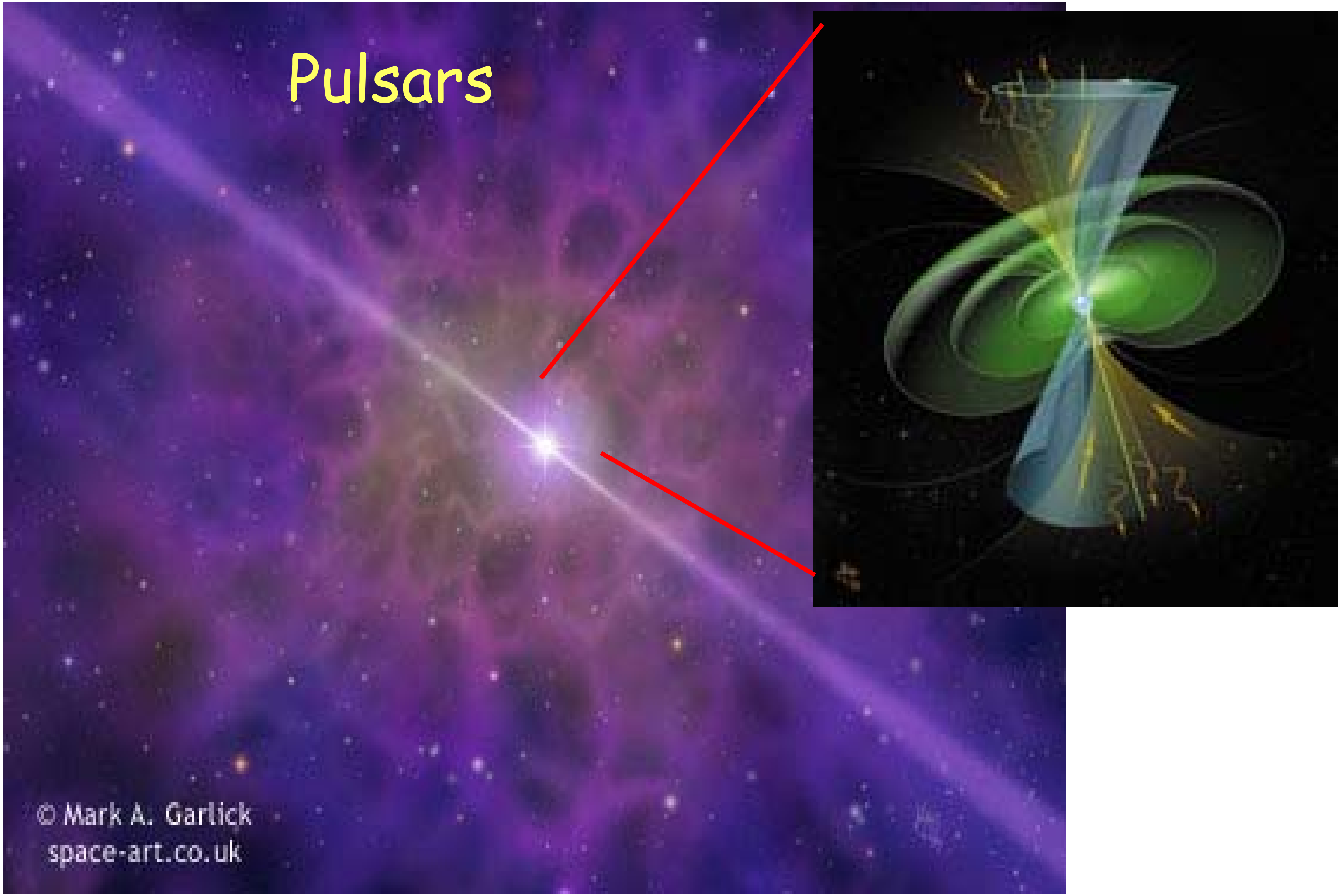
New optical outbursts on HU Aqr:



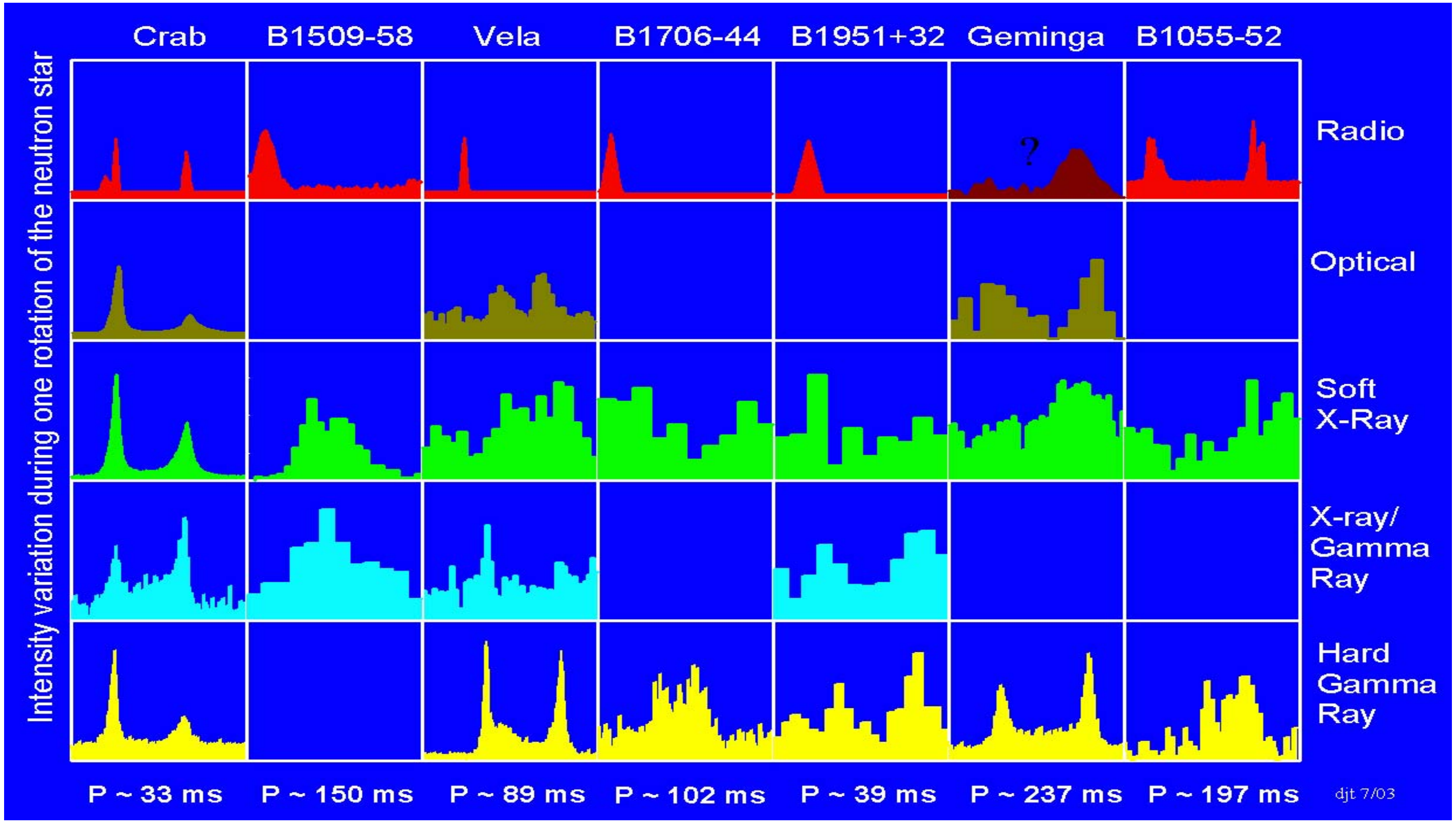
Possible explanation: clumps (inhomogeneities) in the accretion stream






Pulsars
© Mark A. Garlick
space-art.co.uk

PSR Multiwavelength Lightcurves

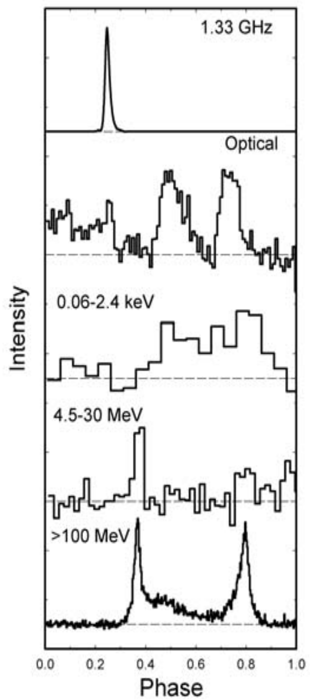


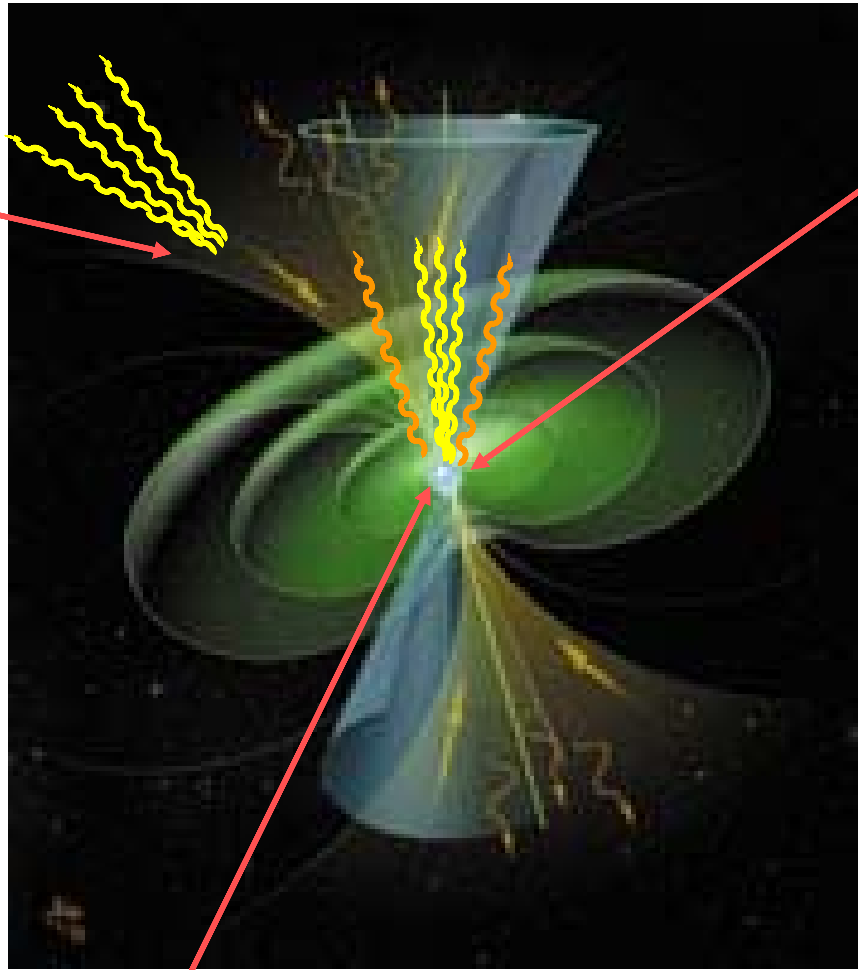
Pulsar Science

Outer Gap
Emission: multi-λ
Lightcurves

Not in Phase

Prototype: Vela

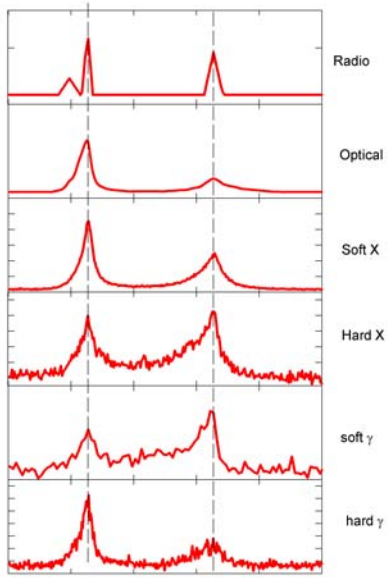




Polar Cap Emission:
multi-λ Lightcurves

in Phase

Prototype: Crab



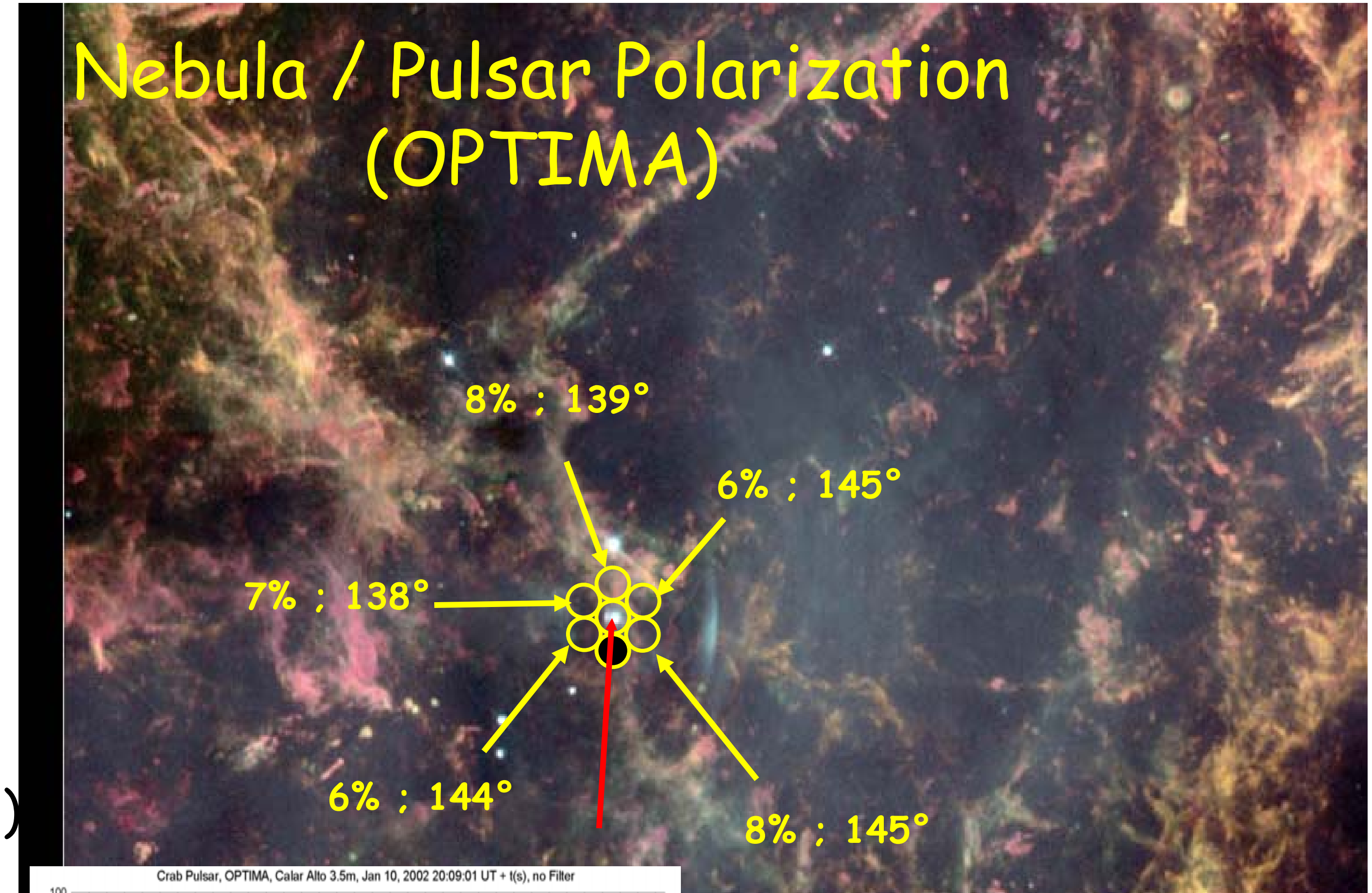
Thermal Emission from NS surface

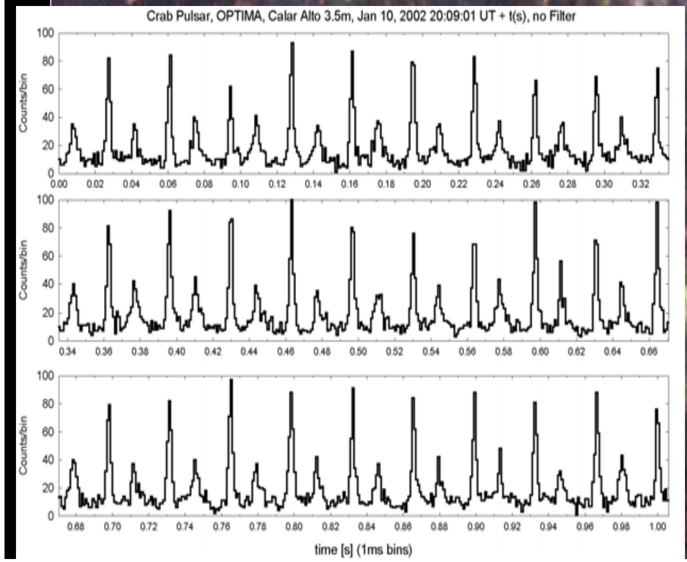
Synchrotron and inverse Compton Emission from Magnetosphere

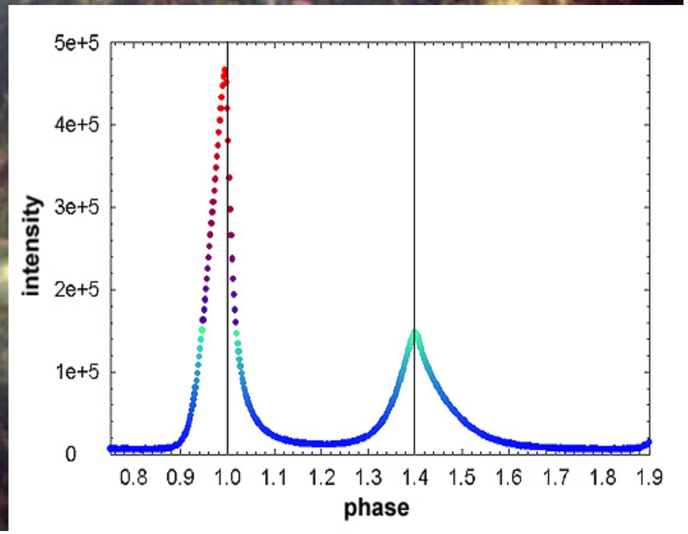
"Universe Probed by Radio"
Kashi/Urumqi, China

Nebula / Pulsar Polarization (OPTIMA)

close to pulsar:
degree: 8-13%
angle ~ 140°
(Schmidt&Angel, 79)

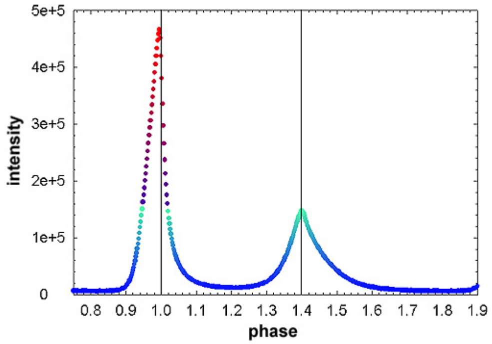




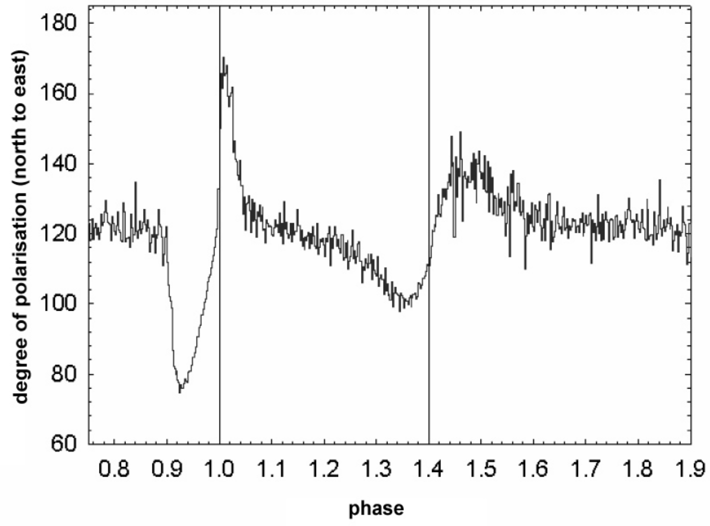


Crab Polarisation (OPTIMA)

Kellner, 2002

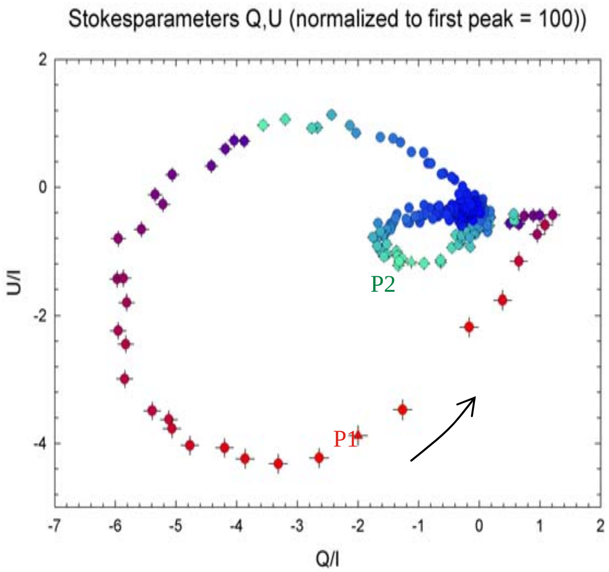


angle of polarisation: $\Theta = \frac{1}{2} \cdot \arctan \frac{U}{Q}$

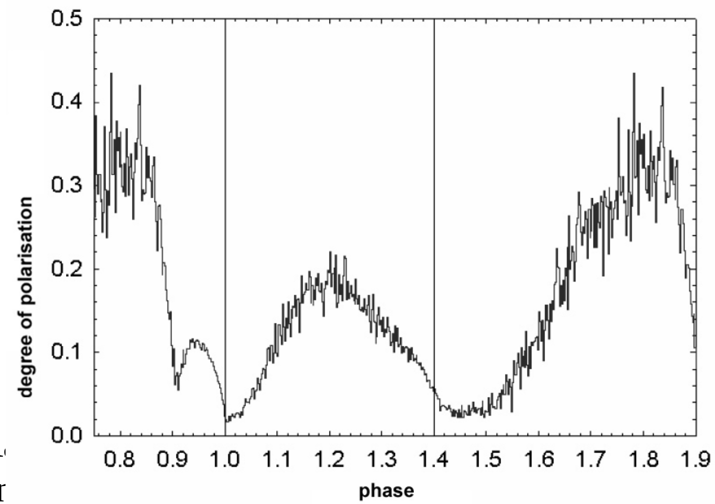


Measure lightcurves for different positions of the rotating polarisation filter at $[\phi_0, \phi_0+90°]$ and $[\phi_0+45°, \phi_0+135°]$.

Calculate Stokes-Parameters:
Q=I(0°)-I(90°), U=I(45°)-I(135°)

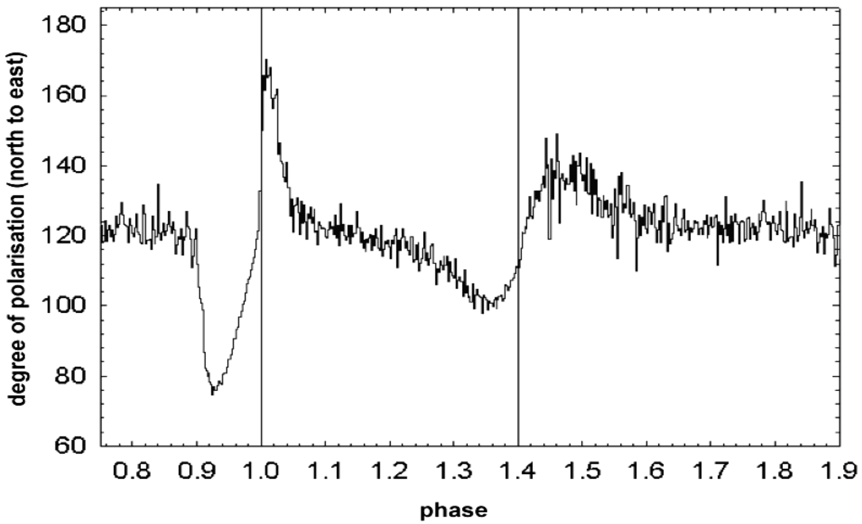


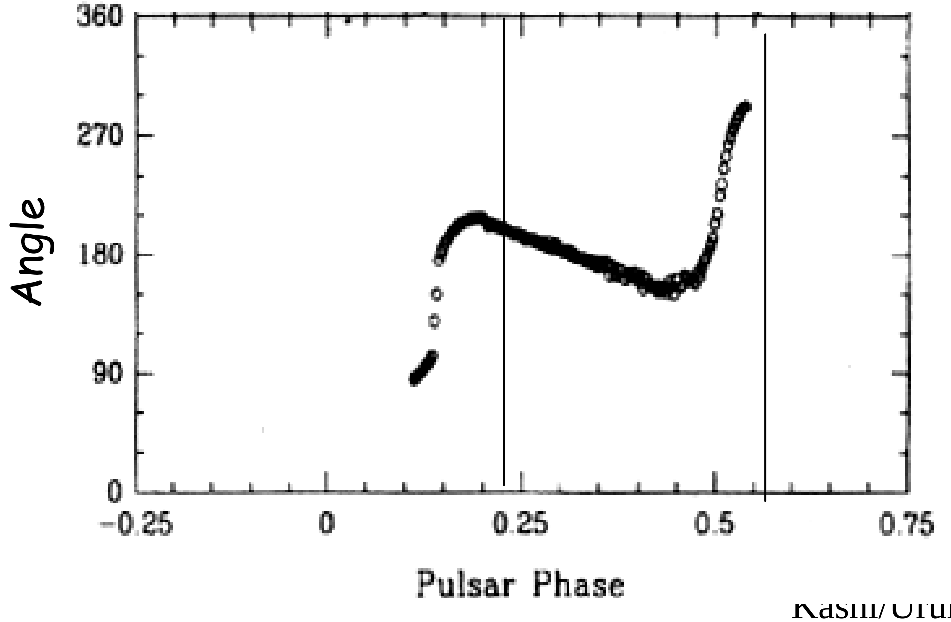
degree of polarisation: $V = \frac{\sqrt{Q^2 + U^2}}{I}$

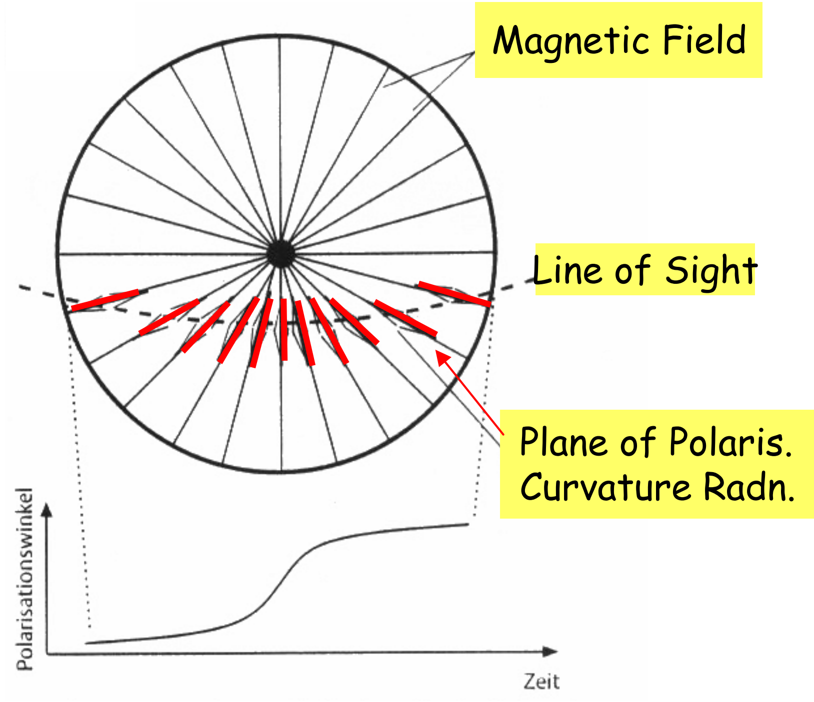


"Universe Probed by R
Kashi/Urumqi, Chir

The polarisation angle:
Magnetic field geometry in the emission regions

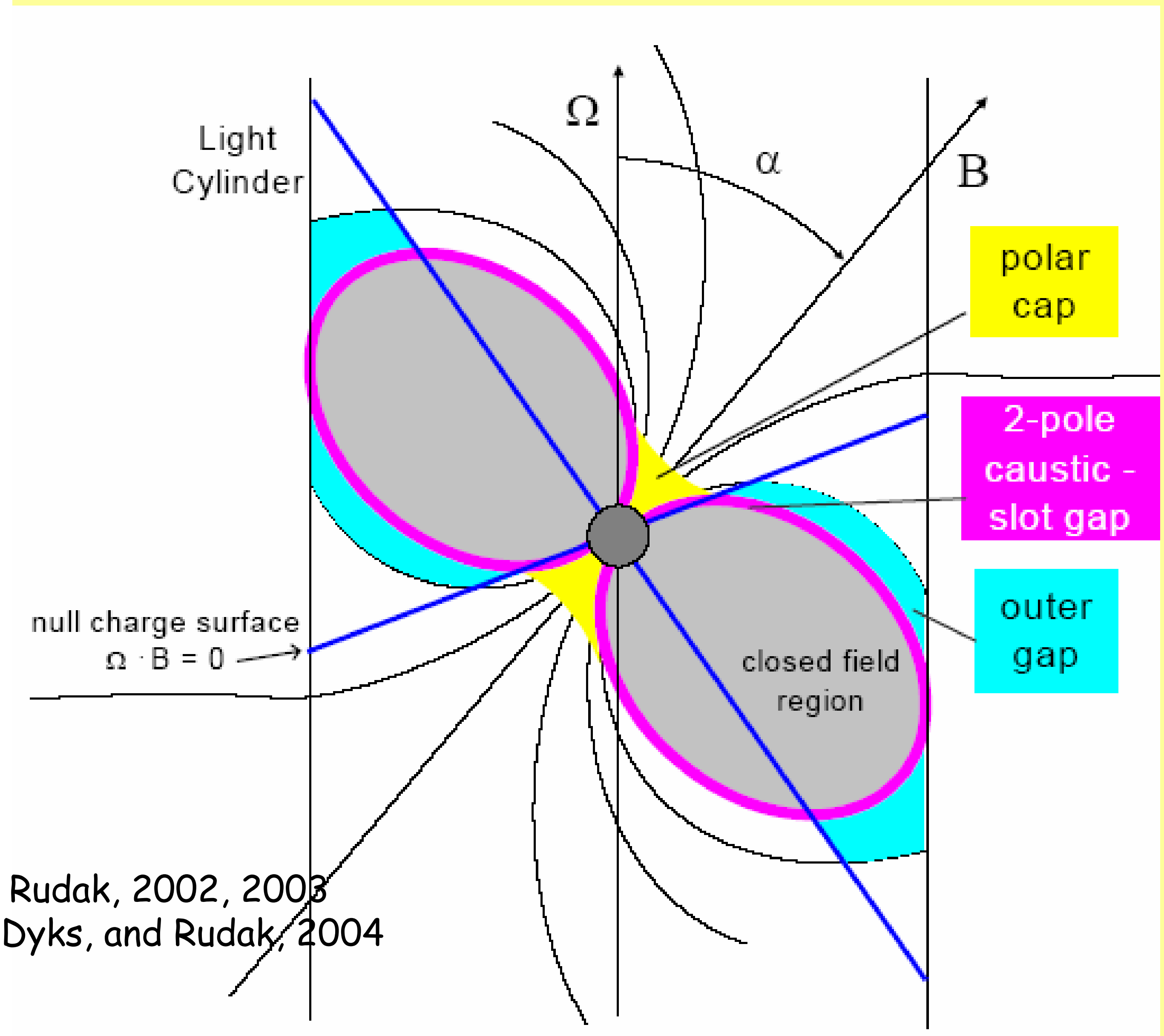






Romani et al., 1995: outer gap model

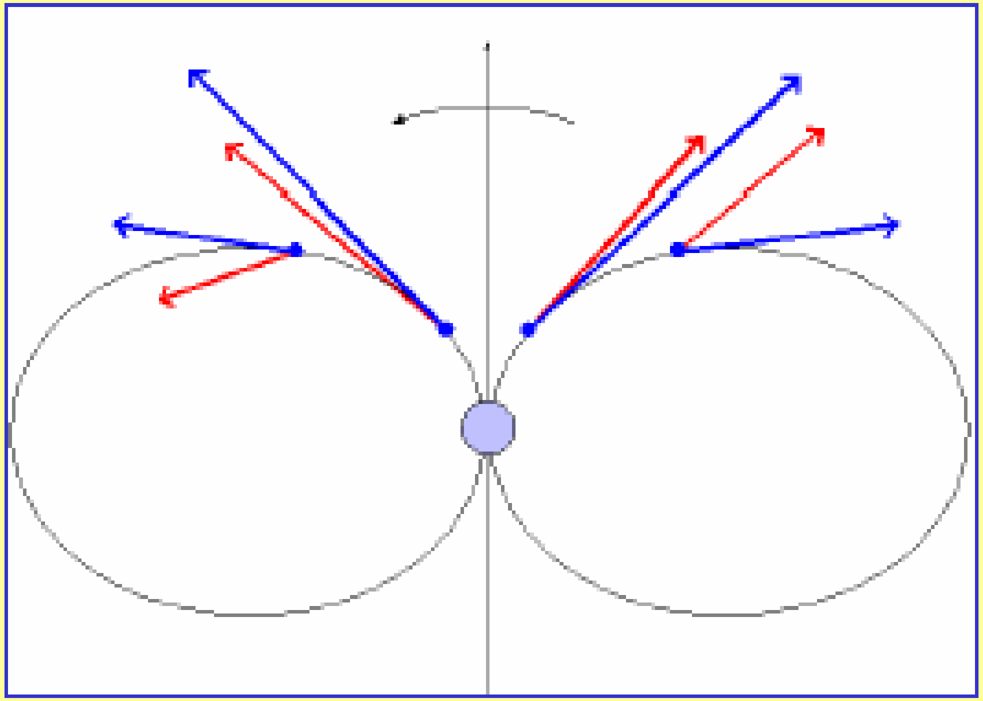
New Emission Model: 2-pole caustic slot gap



Dyks and Rudak, 2002, 2003
Harding, Dyks, and Rudak, 2004

Two-Pole Caustic Model *Dyks & Rudak 2003*

- Particles radiate along last open field line from polar cap to light cylinder
- Time-of-flight, aberration and phase delay cancel on trailing edge → emission from many altitudes arrive in phase → caustic peaks in light curve

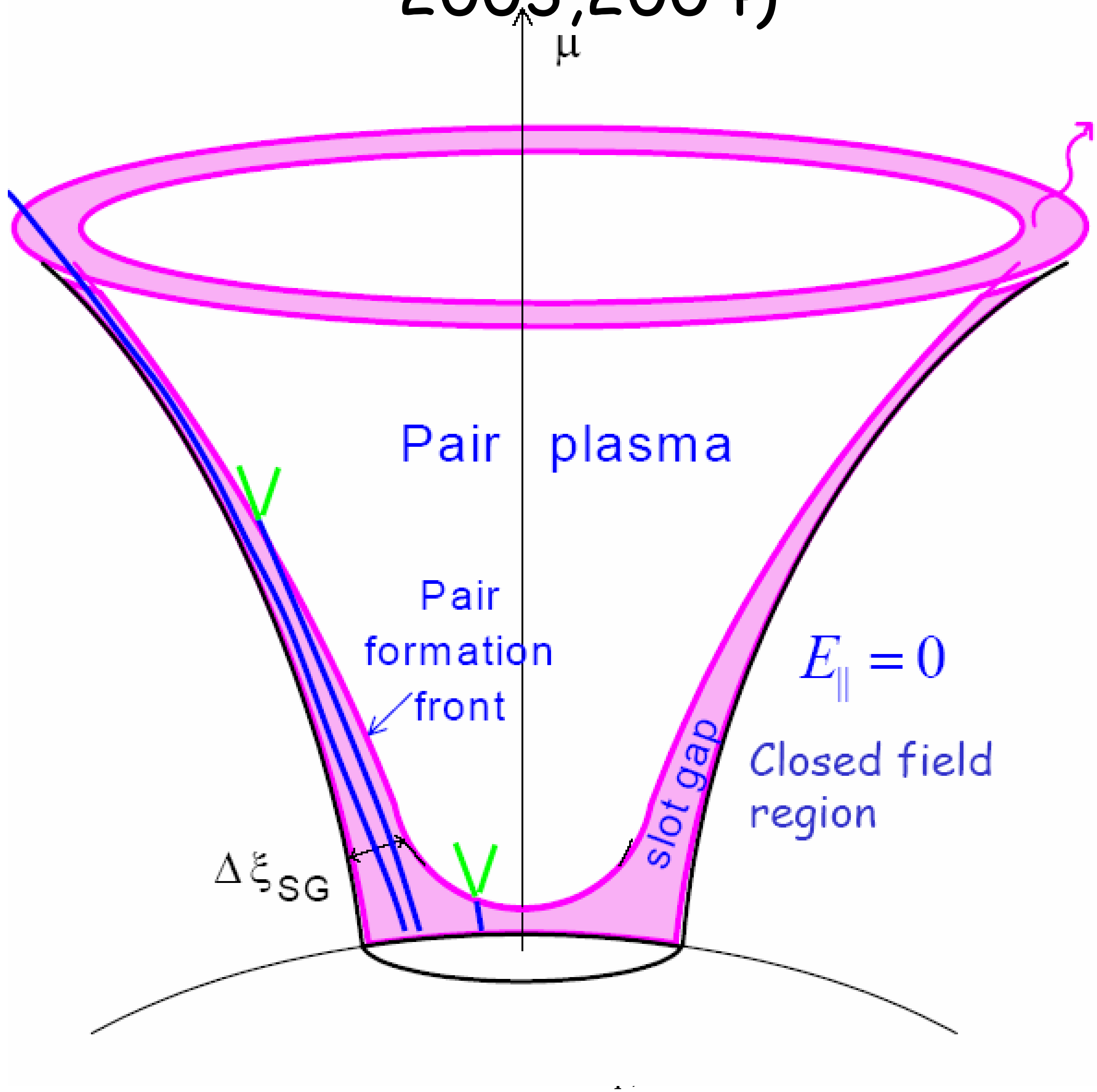


Crab-like pulsars:

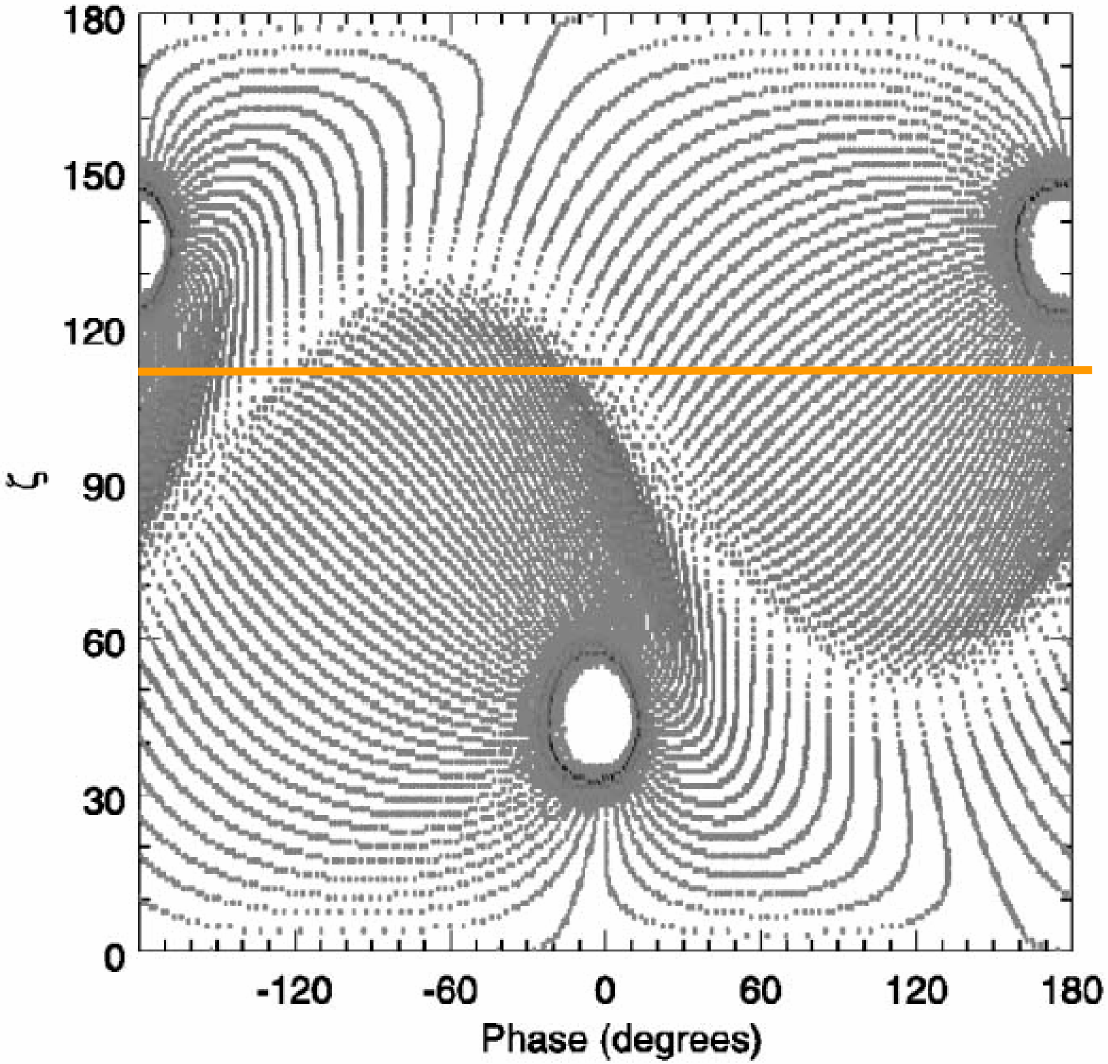
- Peaks at all wavelengths are in phase!
- Double-peaks profiles (both poles) with $\Delta\phi < 180^0$
- Off-pulse emission

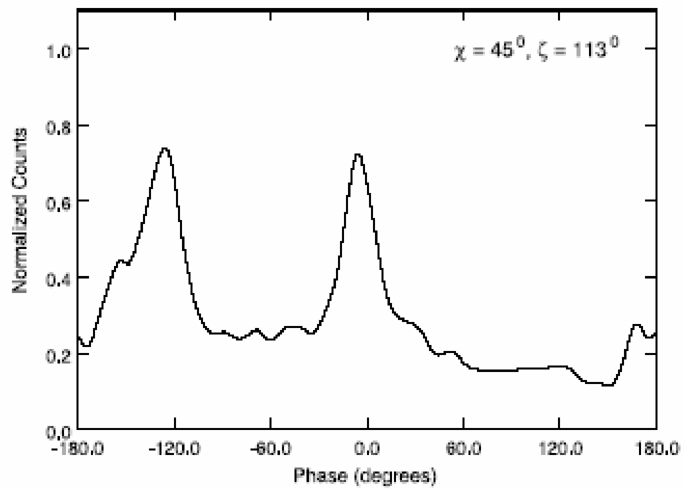
credit: A. Harding, GSFC

Slot-gap Model (Muslimov & Harding, 2003,2004)



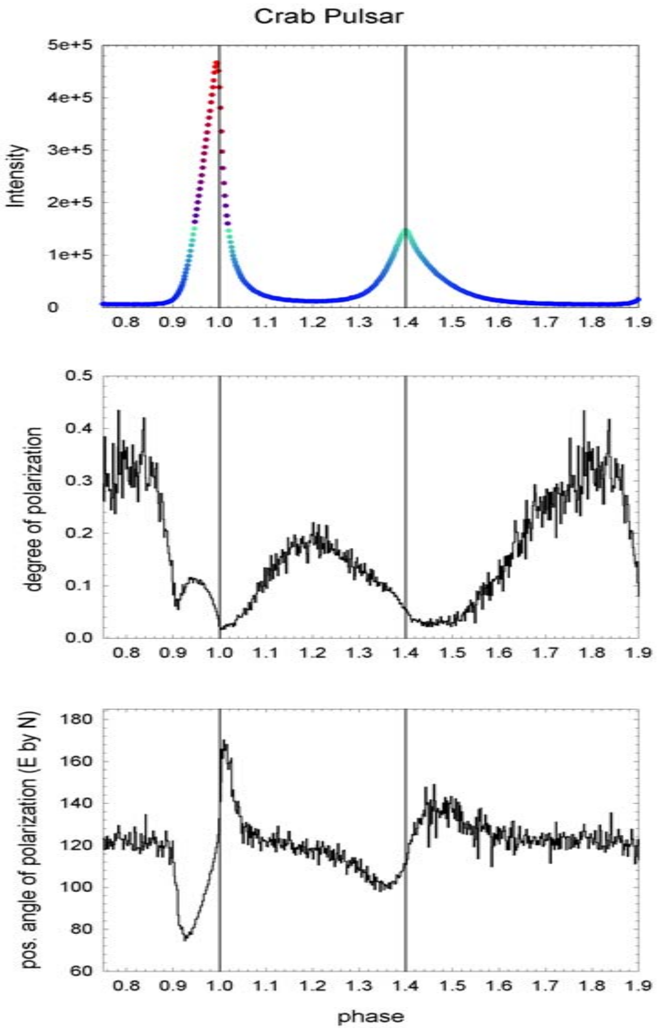
Slot Gap Emission Pattern on the celestial sphere: Magnetic inclination 45°, P= 33ms, B_o=8x10^{12} G





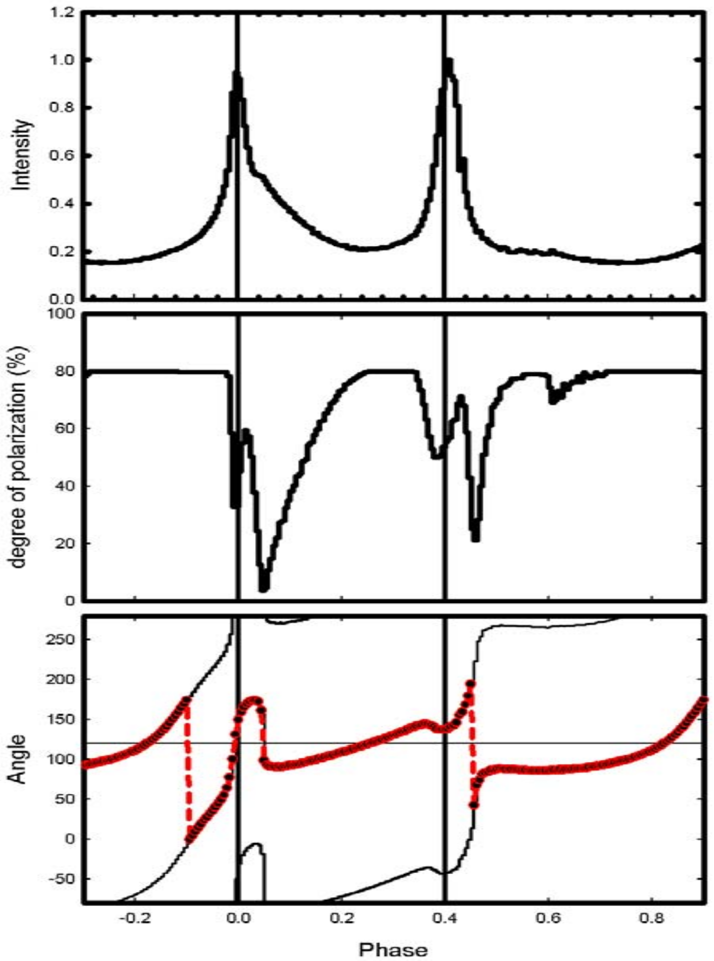
Muslimov & Harding, ApJ, 606, 1143, 2004

~ Correspondence of Polarization Characteristics



Measurement

Model: Dyks et al., 2004



Two Pole Caustic Model (Dyks etal, 2004)

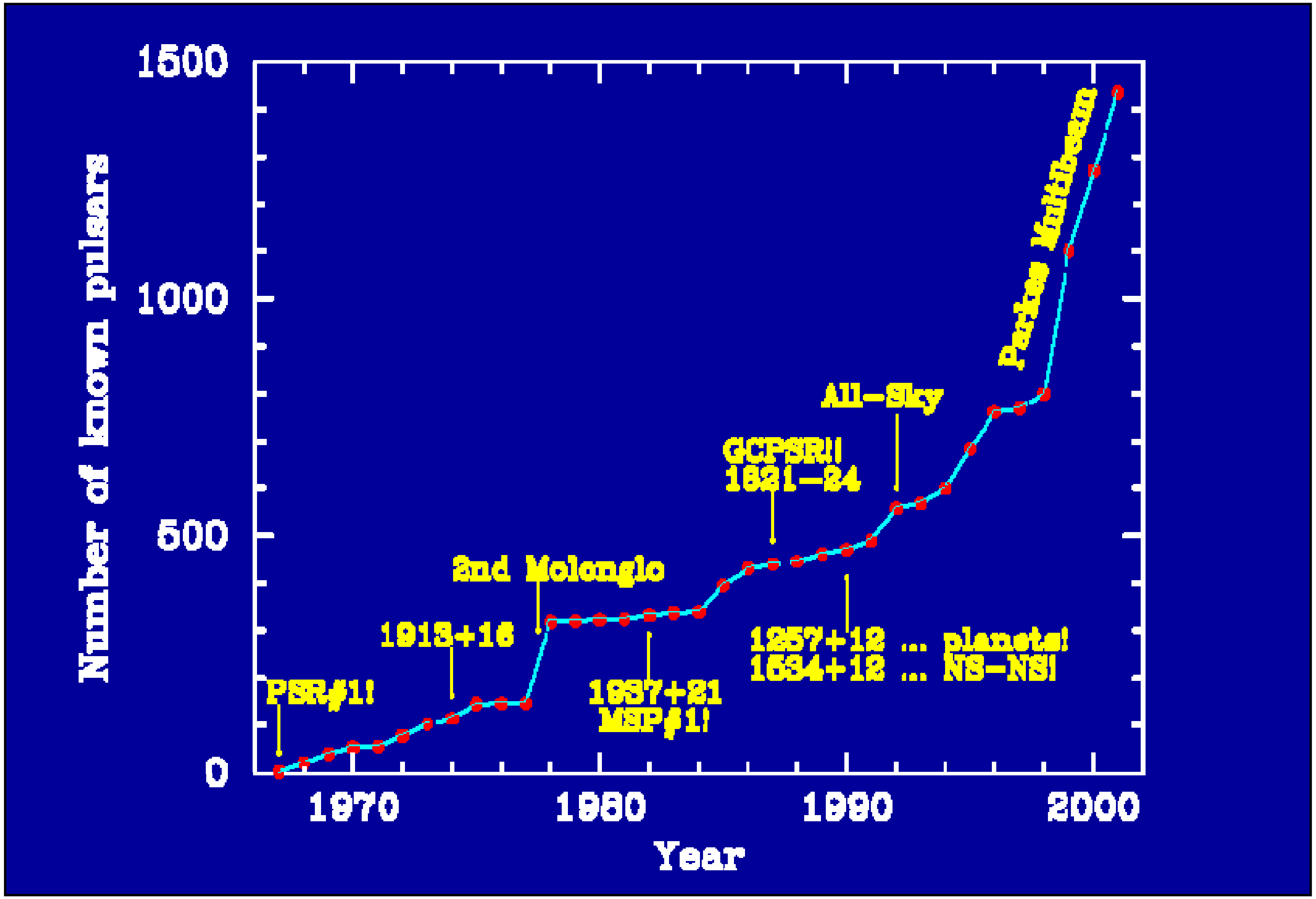
looking ahead....

New multi-beam surveys (Parkes, Swinburne...)

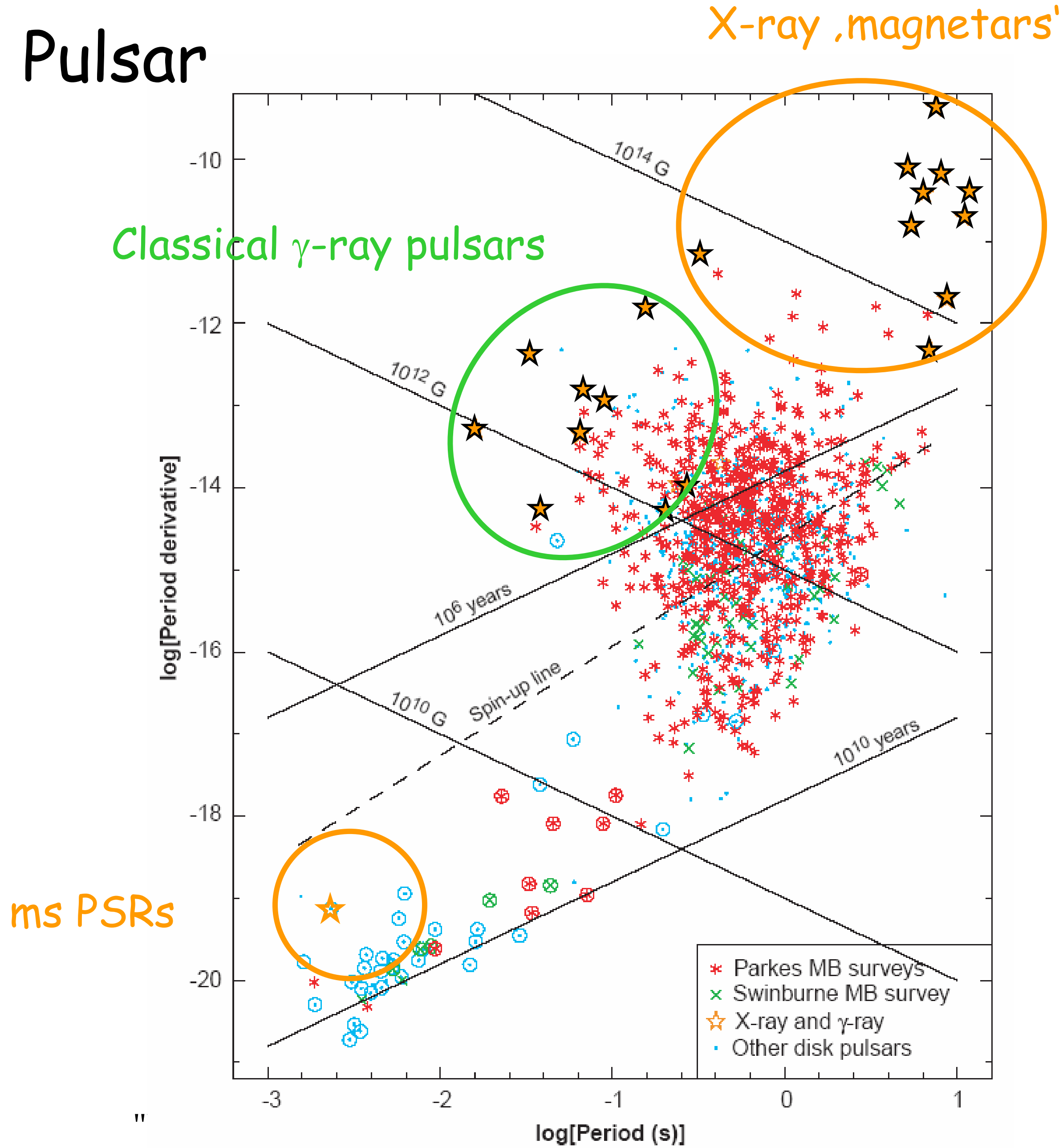
Now about 1700 radio pulsars known

The Parkes Multibeam Pulsar Survey

The most successful survey ever:



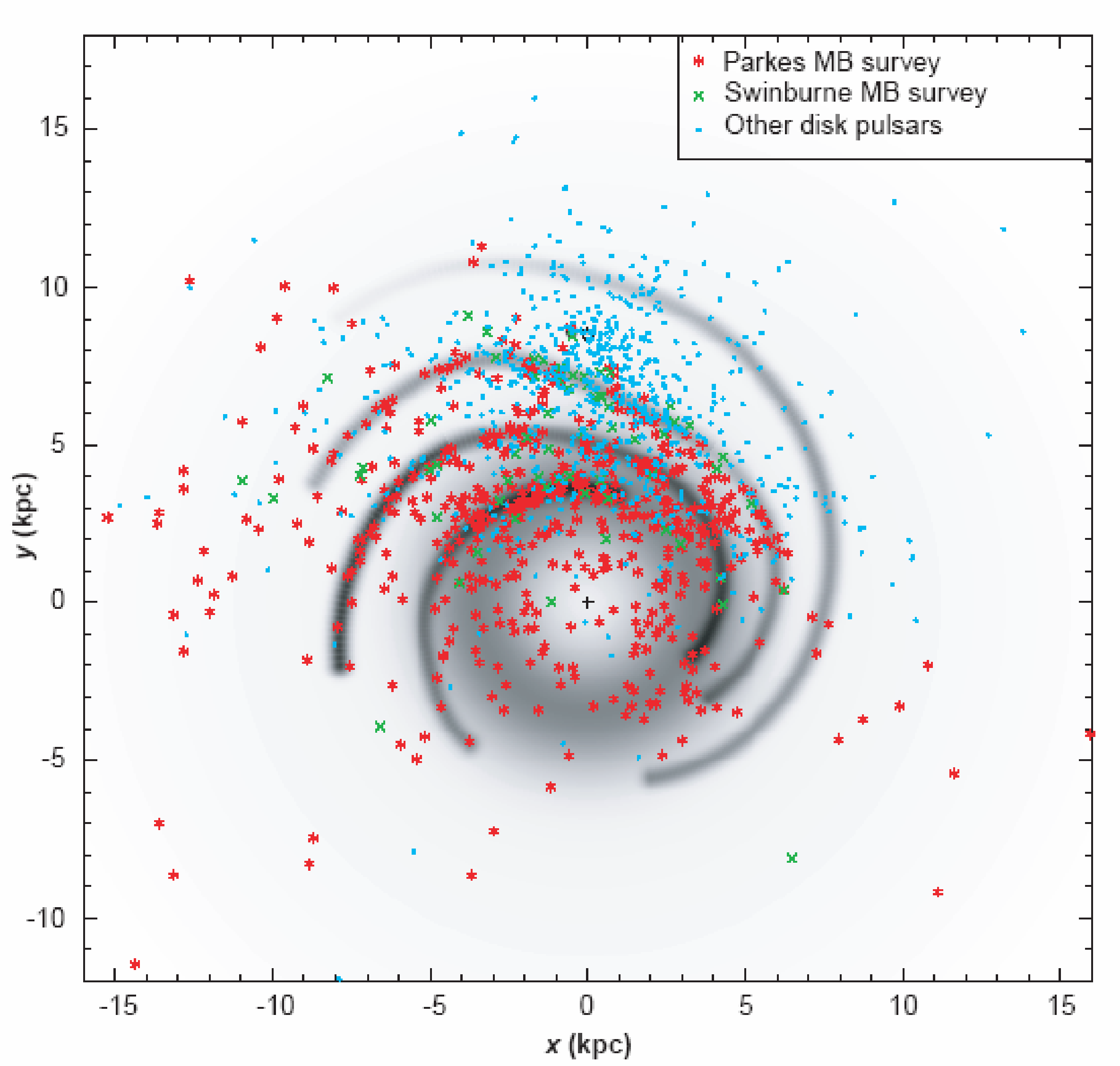
P-P Diagram of Pulsar Population



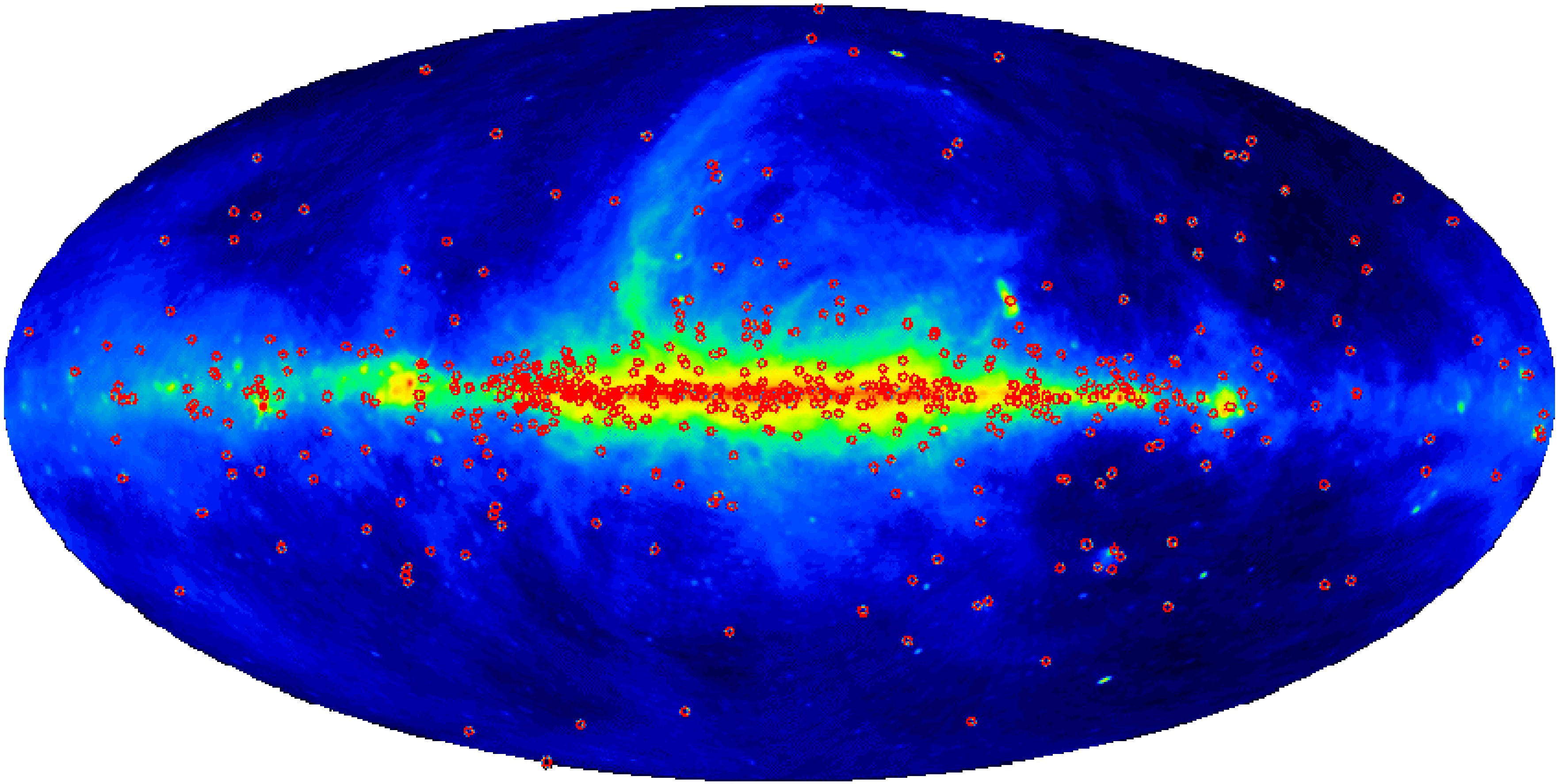
"

Kashi/Urumqi, China

Galactic PSR Population with the new detections (~ 1500 pulsars)

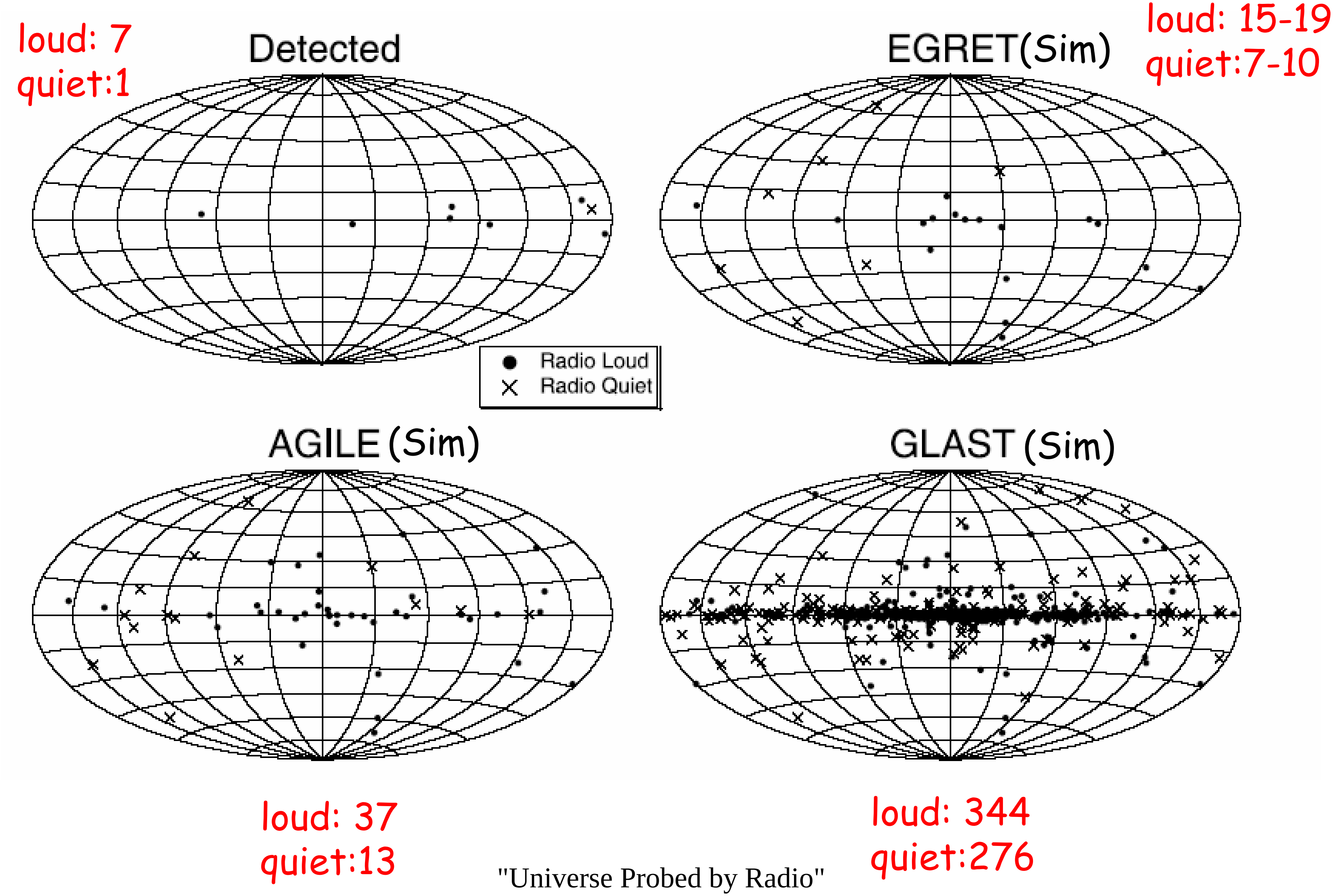


The Galactic Distribution of known Pulsars



"Universe Probed by Radio"
Kashi/Urumqi, China

Population Synthesis of observed γ-ray pulsars (Gonthier et al., 2004)



Some Conclusions

- Multiwavelength observations of variable astronomical sources are essential to determine the physics of these objects

- Radio/optical/X-ray mapping and source characterization will be needed to identify new high-energy sources

- for pulsars continuous monitoring of rotational ephemerides is needed for high-energy data analysis (mostly from radio)