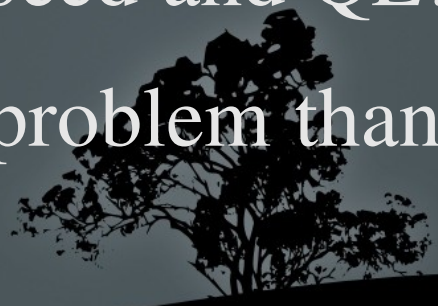
Fast timing in the optical and infrared: past results and prospectus

Tom Maccarone (University of Southampton)
Piergiorgio Casella (Marie Curie Fellow, University of Southampton)
Kieran O'Brien (UCSB)
Much thanks to Andy Shearer, NUI-Galway

What is fast?

- For this talk, I'll loosely define fast timing to be studies of variability on timescales faster than the light crossing time of a typical main sequence star
- Key source classes will be compact objects – X-ray binaries, isolated neutron stars, and CVs
- We are finally through the "slow ages" of the 1990's where CCDs replaced photomultipliers, and have entered an era of high speed and QE!
- Data volume now is often a bigger problem than actual instrument readout time



What works now

- HST with STIS
  - But problems with absolute calibration
- ULTRACAM, GASP, OPTIMA
  - But they have no home
- ISAAC
- Spitzer - IRAC?
  - Probably – we'll be the first to try!

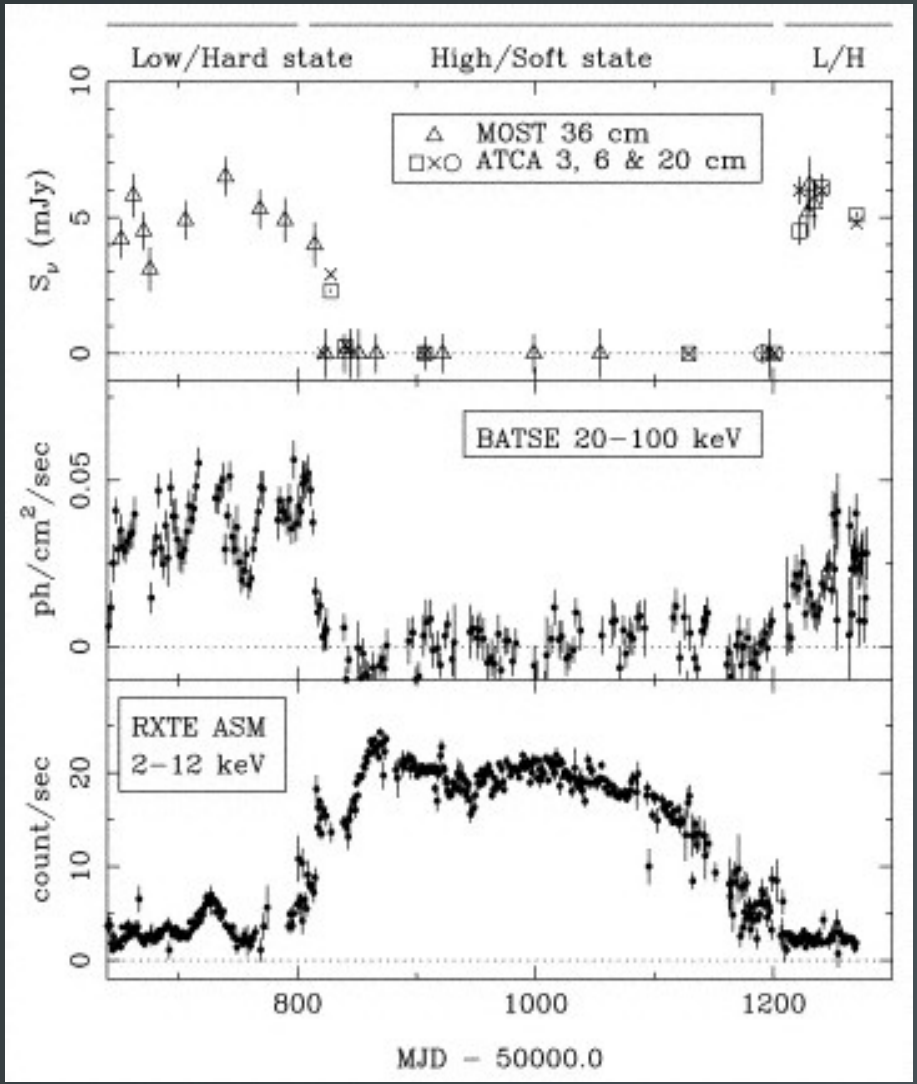
What could work

- Gemini – mid-IR (for example)
  - Problem is the data recording system, not the speed nor the read noise of the detectors!

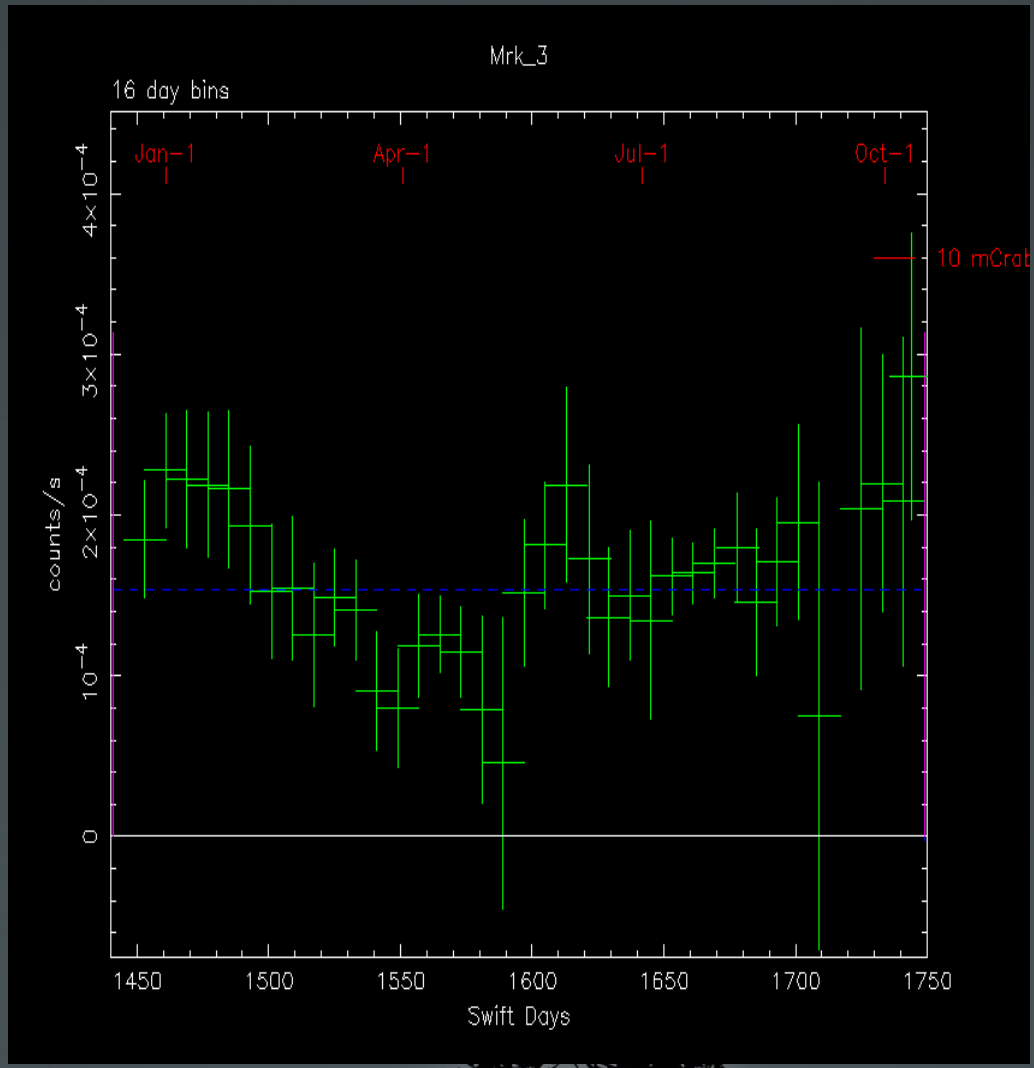
Big telescopes extremely important

- S/N for variability goes *linearly* with count rate
- Also scales with fractional rms amplitude squared
    - Thus exposure time needed to measure timing features in sky-BG limited data scales as D^{-2} !!!
    - Not as good for read-noise limited data, but the improvement is generically more important – always at least D^4.
- For flat spectrum, JWST at ~10 microns can go about 100 times as faint as VLT with ISAAC in K
- E-ELT will be about 25 times better than VLT for non-BG limited sources. For BG limited sources, will be *much* better

X-ray binaries as the key to understanding jets



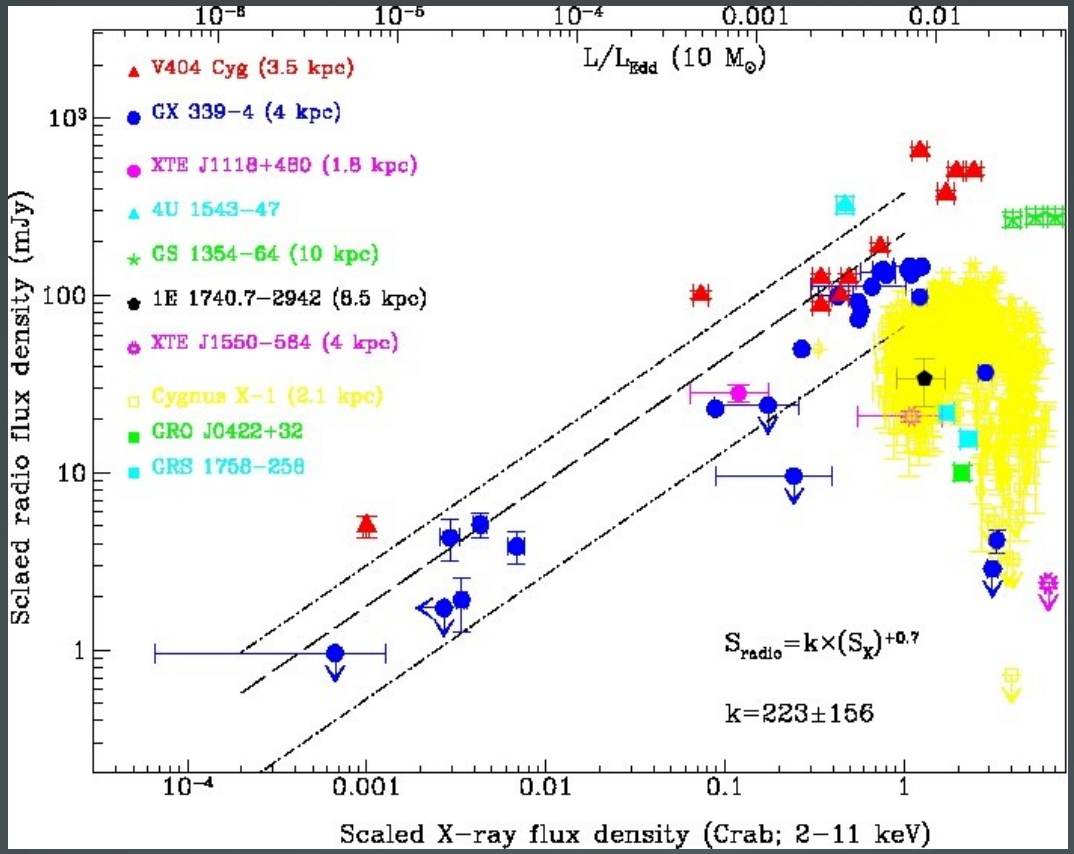
The black hole X-ray binary GX 339-4, from Fender et al. 1999



The AGN Mkn 3, from BAT team light curve generation web page at GSFC

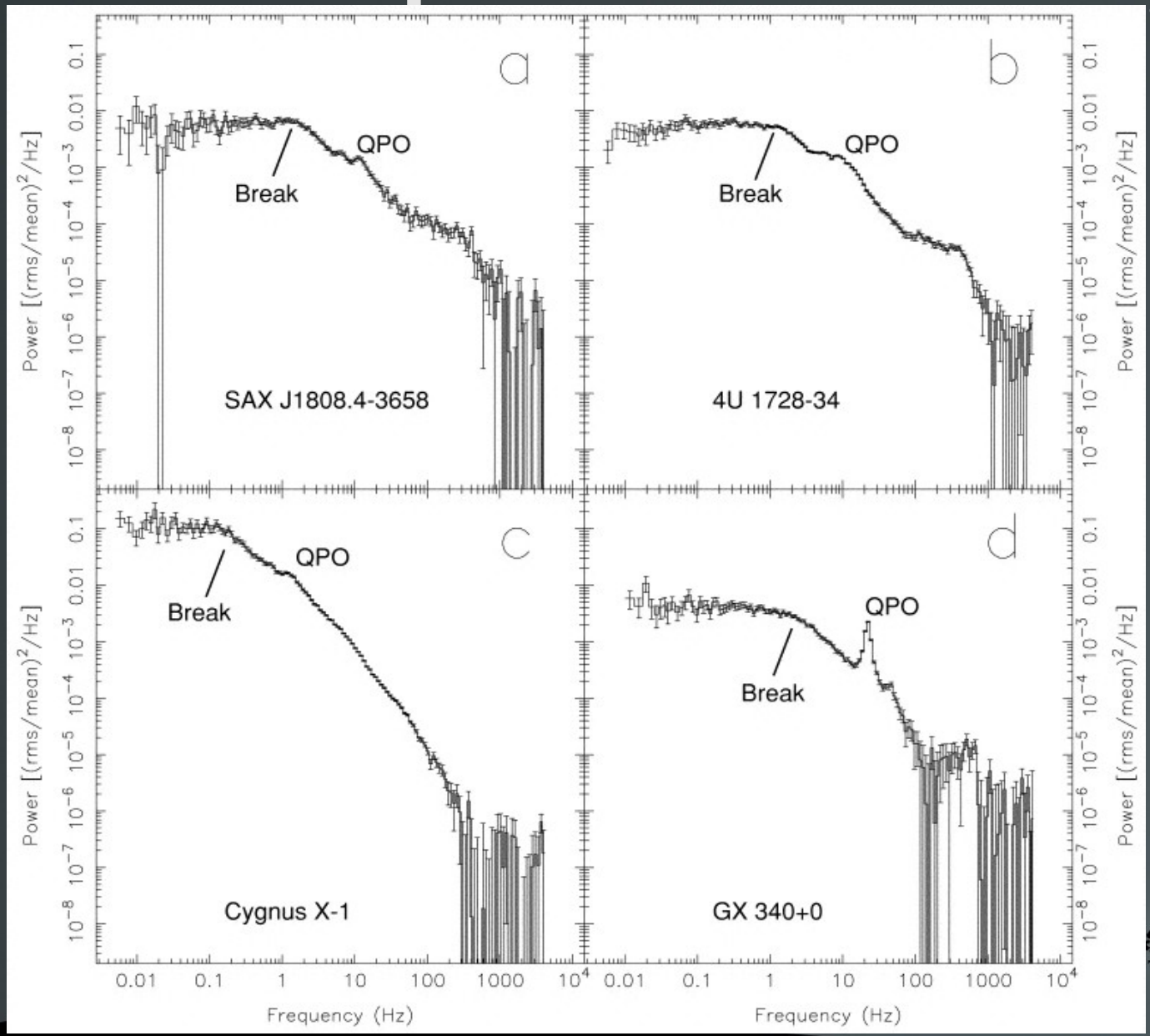
What we know

- Good, but nonlinear correlation between X-rays and radio
- Some scatter which is poorly understood
- Similar correlations seen for optical/infrared



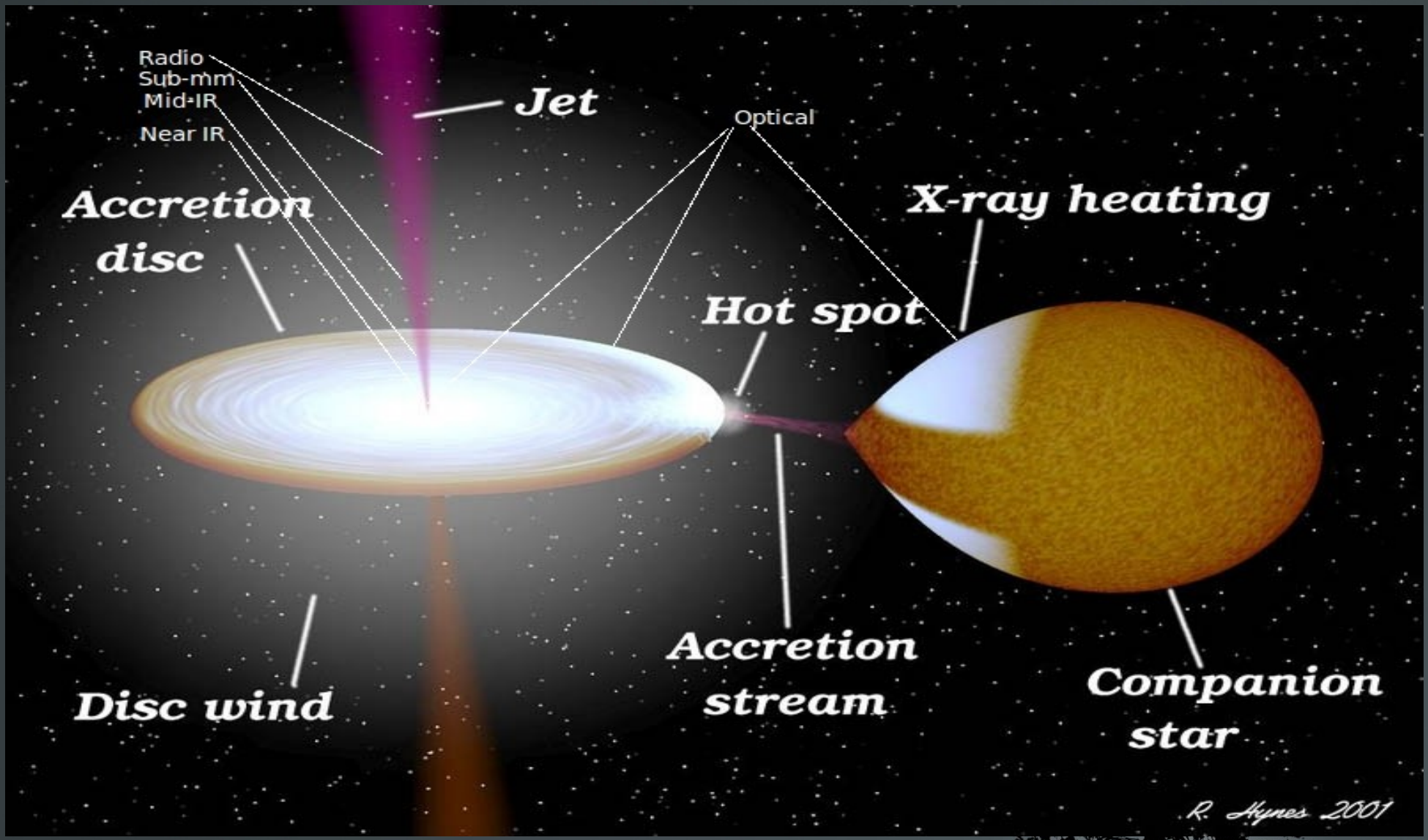
Gallo, Fender & Pooley 2003

Some typical X-ray binary power spectra in the X-rays



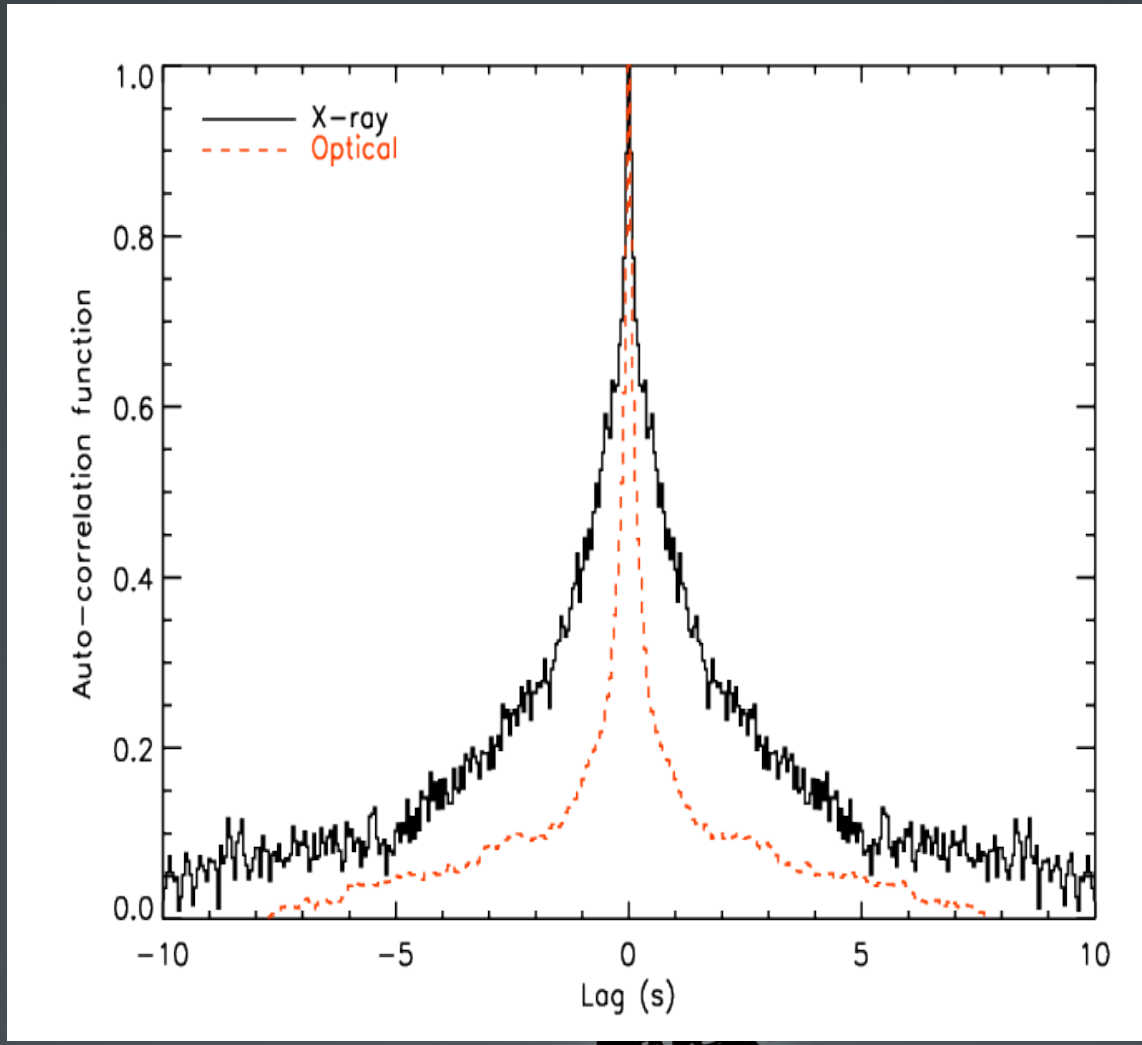
From Wijnands & van der Klis 1999

From where do components come?

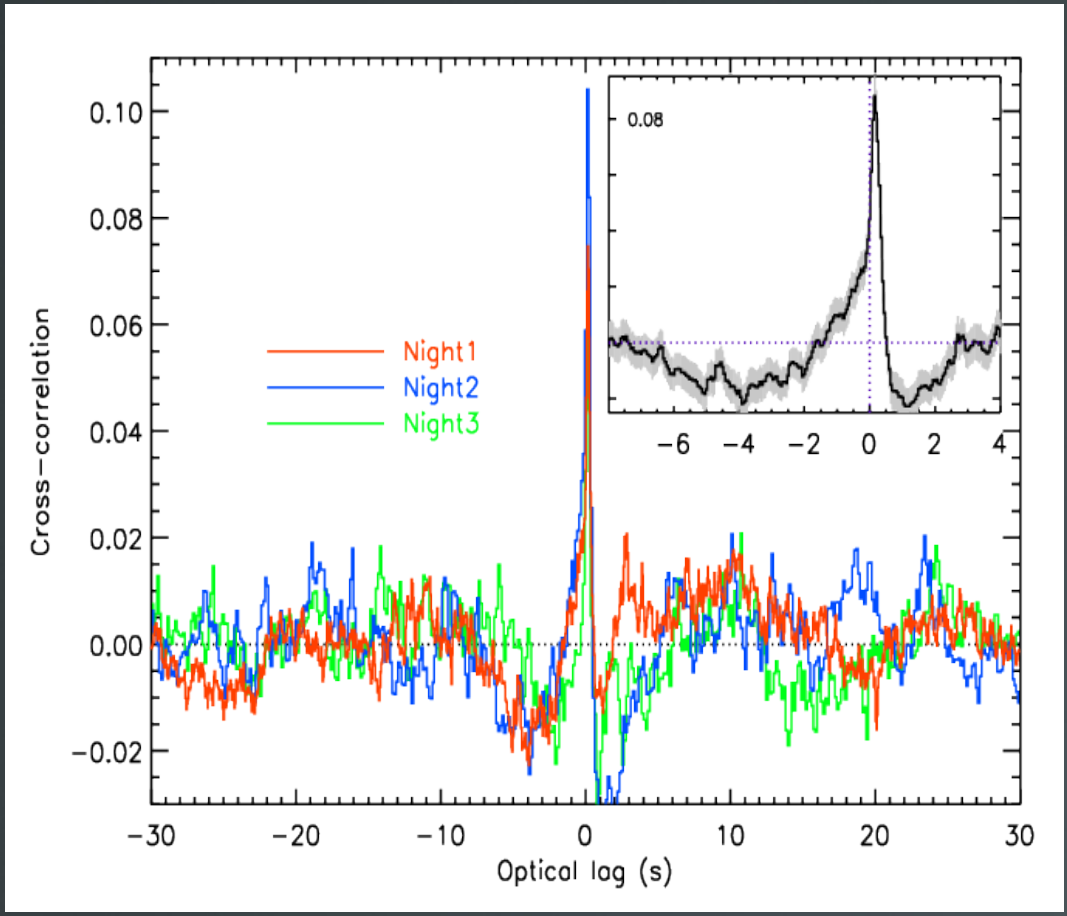


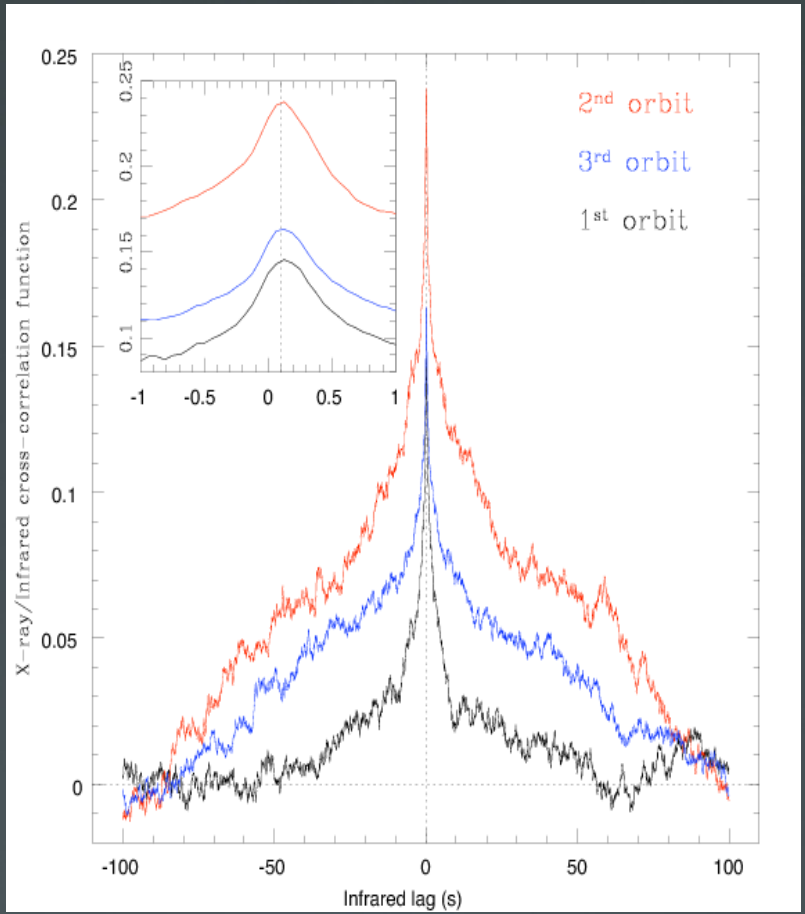
Fast timescale variability

- Characteristic timescale of variability faster in optical than X-rays
- Clearly not reprocessing
- Not certain if jet (e.g. Malzac et al. 2003) or synchrotron from thermal Comptonizing region (e.g. Merloni et al. 2000; Yuan et al. 2005)



Fast timescale cross-correlations





- Opt from Gandhi et al. 2008, IR from Casella et al. 2010: same source, similar luminosity, but nonsimultaneous

Hopes for future work

- Simultaneous measurements in a range of wavelengths
- Standard jet models indicate that the dominant radius of emission scales linearly with distance along the jet for optically thick emission
  - Simultaneous measurements in a range of wavelengths could thus test this model, and possible give propagation speeds
  - Near to mid-IR thus crucial
  - Also, cross-correlations can do a good job of removing some instrumental variability

Fast spectroscopy

- Very little work done so far on sub-second spectroscopy
- May be useful for understanding reprocessing in accretion disks, mapping out temperature and density structures of disks to see if they agree with standard irradiated disk models
- For very bright sources, may also do continuum time lags across wavelength ranges with spectra
- Can use ”normal” X-ray variability, or the Type I X-ray bursts from neutron stars as probes

Current problems

- STIS, ISAAC and HAWK-I only ”permanent” timing instruments on >2 m telescopes
- The bright persistent black hole X-ray binaries all have massive donor stars
- Must catch transients, which makes visitor instruments tough to use in the best possible ways
  - Also want to use transients to sample dynamic range in luminosity
- Even with everything working optimally, we're restricted to the bright parts of transient outbursts
- Neutron star X-ray binaries are much fainter

Pulsars

- Pulsars can make good use of visitor instruments
- Pulsar emission mechanisms, even after more than 40 years of work, not terribly well understood
- Fermi is producing a renaissance of pulsar astronomy
- New radio facilities should, as well
- Optical/IR studies of pulsars are still in relative infancy

Optical pulsars

- Only five known
- Only the Crab has been seen as pulsed in infrared
  - This may be largely for lack of trying with big telescopes – LMC pulsar PSR 0540-69 should be detectable in IR
- IR may become a key for Fermi follow-up – radio emission is very steep spectrum, and pulse smearing in radio is a serious problem in the Galactic Plane
- ELT should be sensitive to Crab-like pulsars at M31 distance, if given good enough time resolution

Summary

- Many exciting questions about compact stars can be addressed best through rapid variability measurements in optical through mid-IR
- Pulsar work may require dedicated instrumentation; guest instruments are OK for pulsars since they don't have much day/month/year timescale variability
- A lot of the other work can be done with existing instruments, with just some effort to set up special sub-array modes and ensure that the data acquisition systems can handle the data rates
- I hope I have convinced people that setting up these modes will be worthwhile