# The Chandra Galactic Bulge Survey

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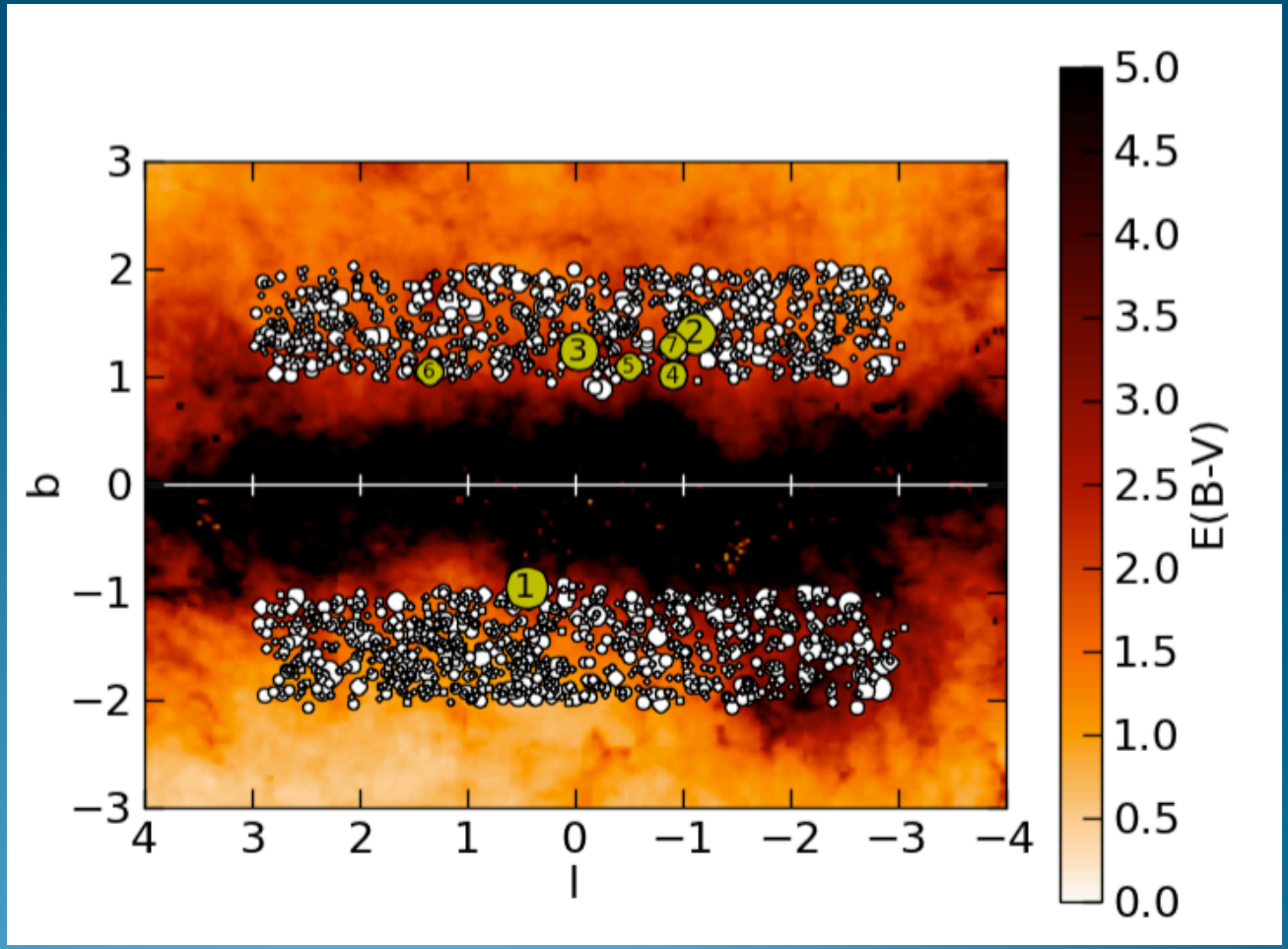
# What is the Chandra Galactic Bulge Survey?

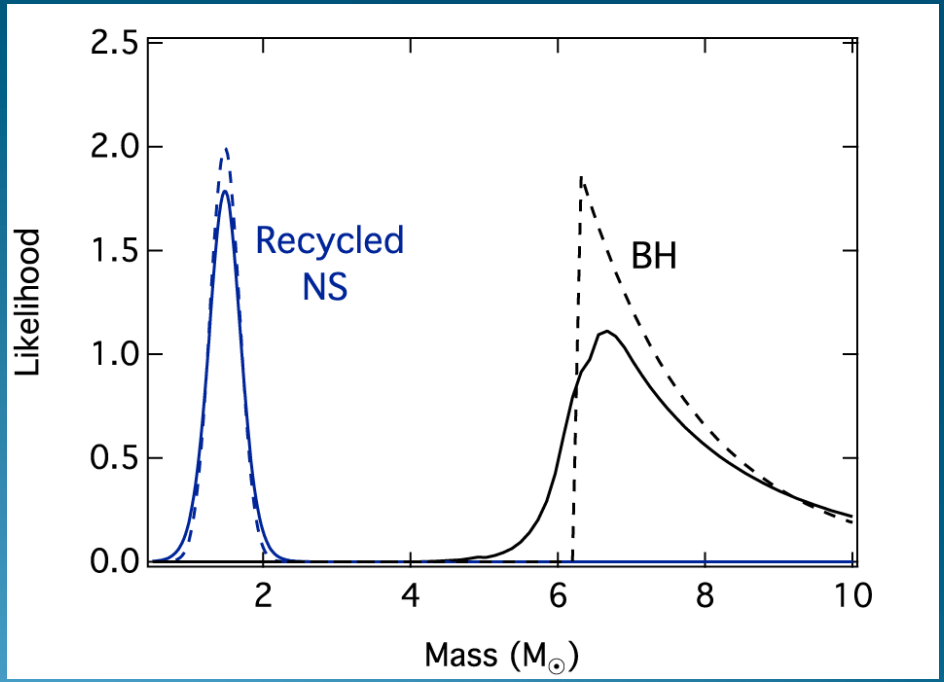
- X-ray survey of Galactic Bulge
- Less extinction
- Less crowding
- Maintain high source density




Gonzalez et al (2012)

# Goals

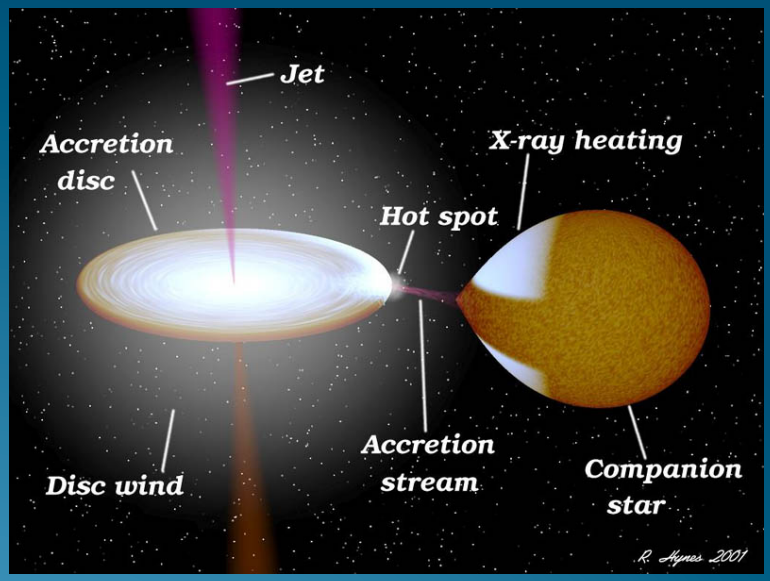
- Get masses of Neutron Star and Black Hole systems, constrain NS EoS and fill out BH mass distribution
- Hope to find first eclipsing BH binary in the galaxy
- Constrain binary evolution models
  - Expect ~120 new qLMXBs (Jonker et al, 2011)
- Produce flux limited survey of many types of X-ray producing objects




Özel et al (2012)

# Many Sources of X-rays

- Accreting Binaries
  - Infalling material produces X-rays
  - X-ray Binaries, Cataclysmic Variables, Polars, Intermediate Polars, Ultra Compact X-ray Binaries
- Other Interacting Binaries
  - RS CVn systems, W Ursa Majoris systems (W Uma)
- Active single stars with flares
- AGN



# Classification Toolkit

- Period Analysis
- Ratio of X-ray to Optical Flux
- Lightcurve Morphology
- Spectral features
- Mass determinations
- Behavior in other wavelengths (UV, IR, Radio)

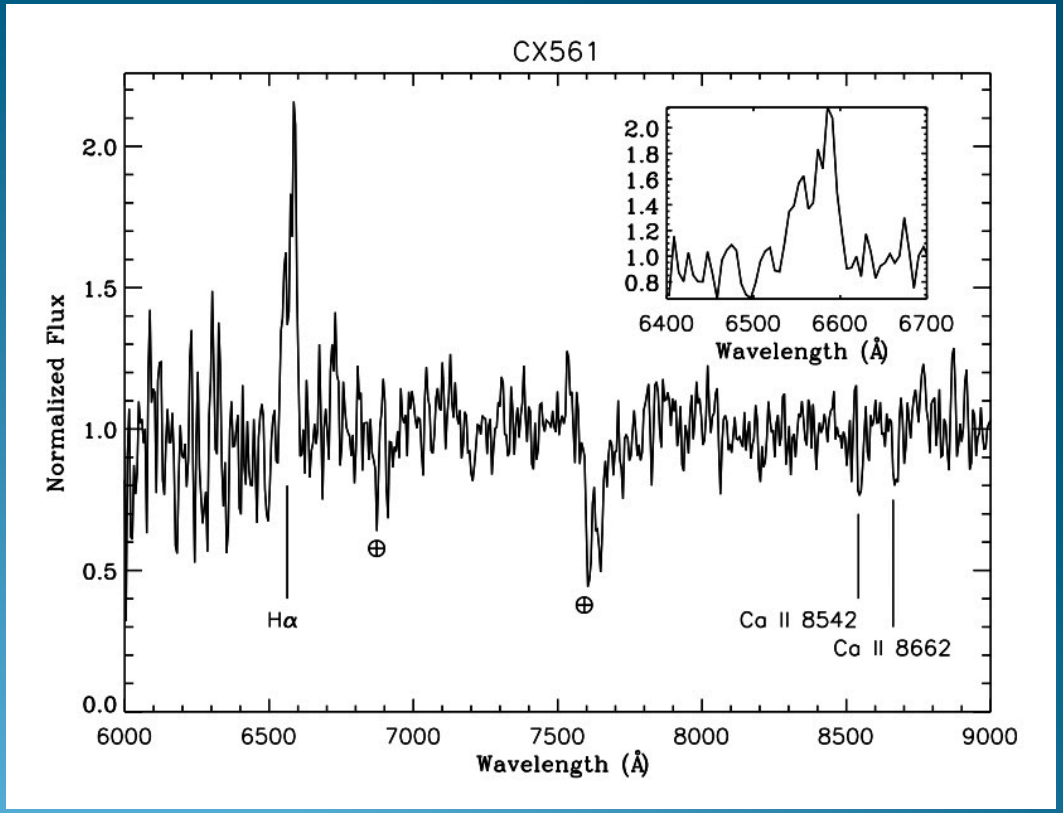
Almost all of these rely, at least in part, on facilities at NOAO

# Optical/NIR Spectroscopy

- Gemini-S, VIMOS, NTT – Manuel Torres, Peter Jonker
- Lay slit over variable sources, if present
- Look for emission lines
- Some interesting sources have no emission lines – CX332, observed with Gemini, has spectrum of Carbon star

# CX561 – Possible Black Hole?

- Double Peaked Hα, 1460 km/s separation
- Ca II lines from donor
- No ellipsoidal modulations – low inclination?
- Obvious next step is phase resolved spectroscopy

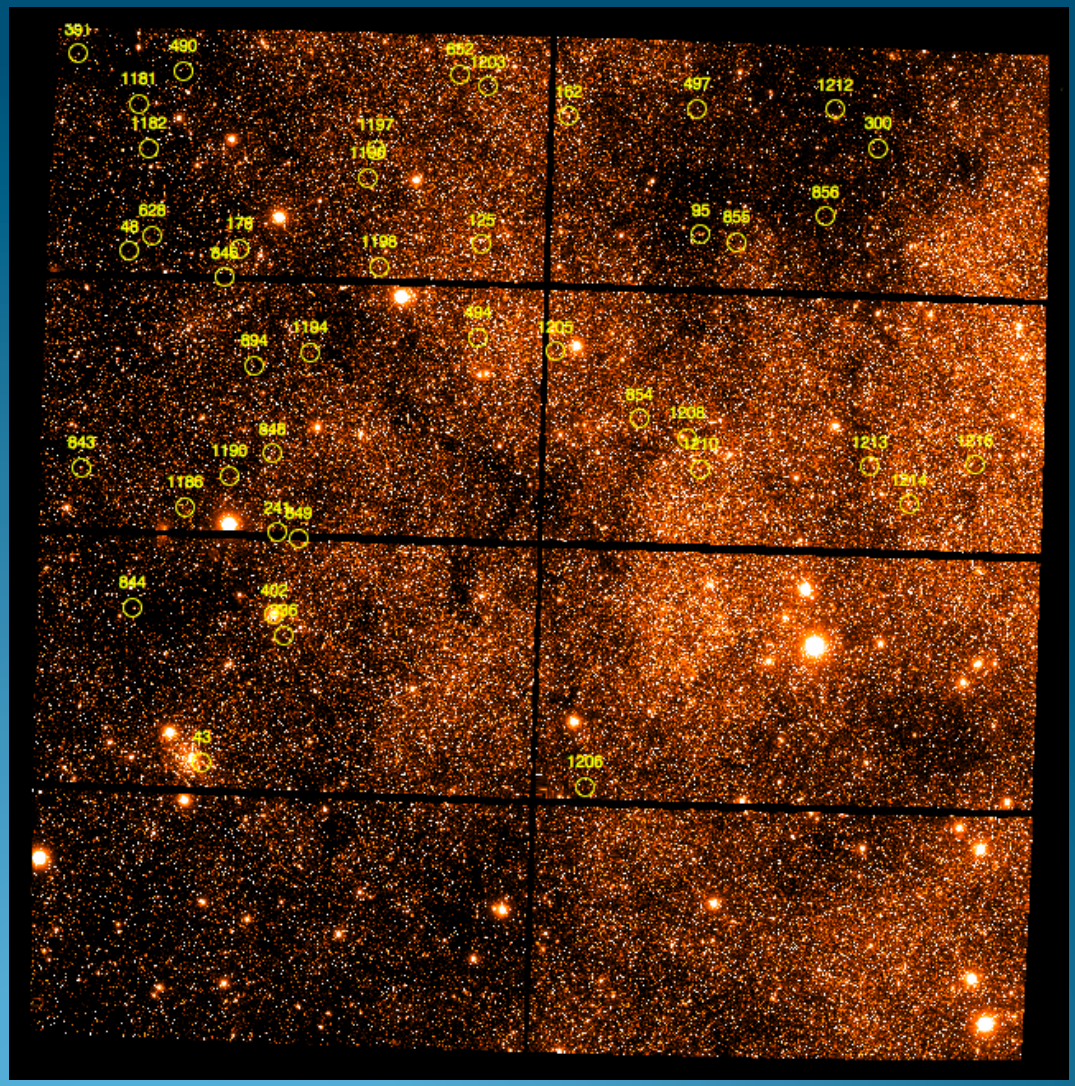


# Why use Variability?

- Most stars aren't variable.  Compact binaries likely are for a variety of reasons
- Other sources of X-rays are also likely to be variable; RS CVns, W UMas, active stars with starspots
- If there's a variable in the X-ray error circle, it is *likely* the counterpart.  Have already identified exceptions to this (CX561). Expect ~25 chance alignments with variables in field.

# Optical Variability Data

- Current data collected with BLANCO 4m at CTIO, Mosaic-II instrument
- 16 < r' < 23
- Planned observations with DECam this June.
- Follow-up for standards, some bright sources done on CTIO's 0.9m June 2012

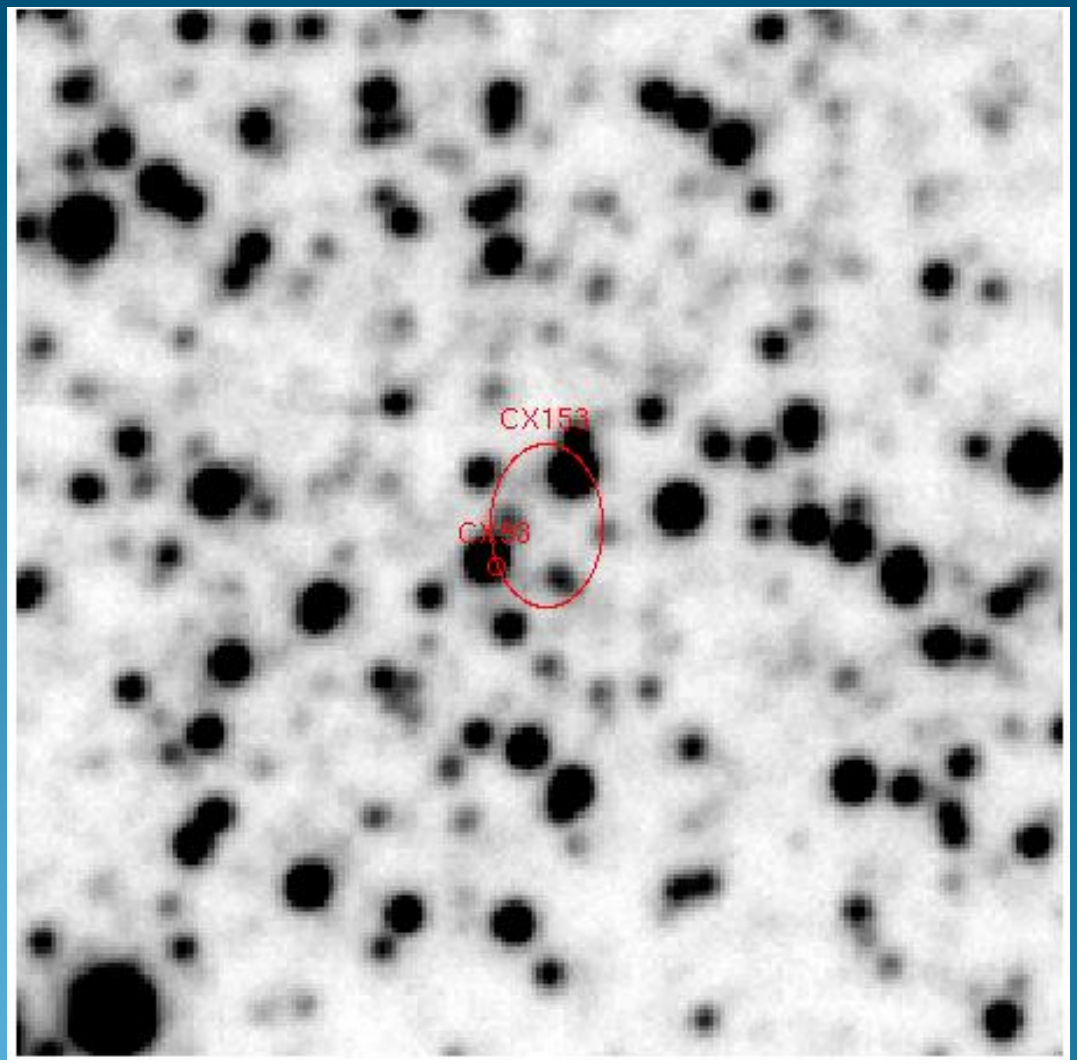


# Periodic Sources

- CX153 /93

Covered in depth in Ratti et al, 2013 MNRAS, 428, 3543

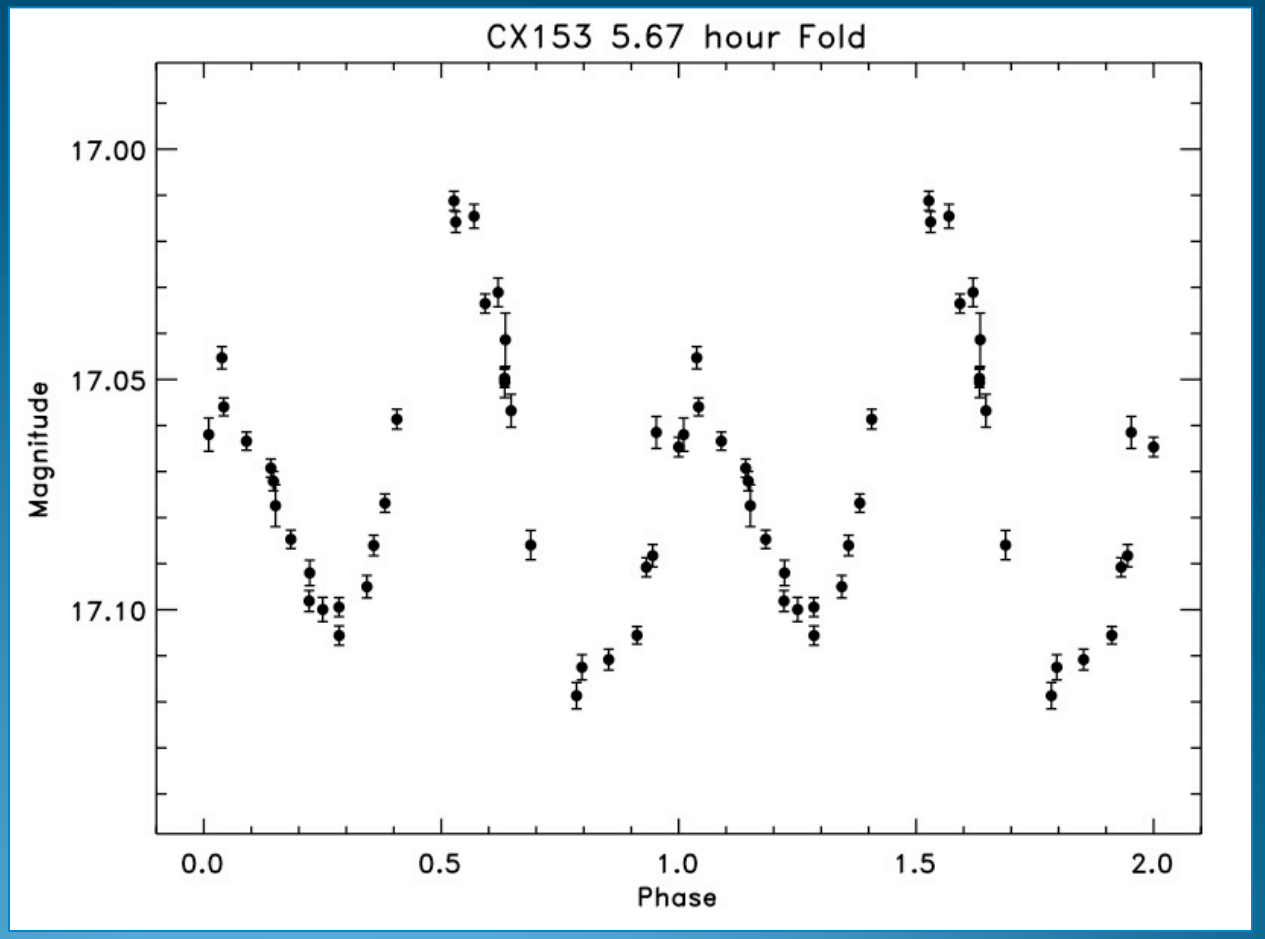
Photometry with ISIS



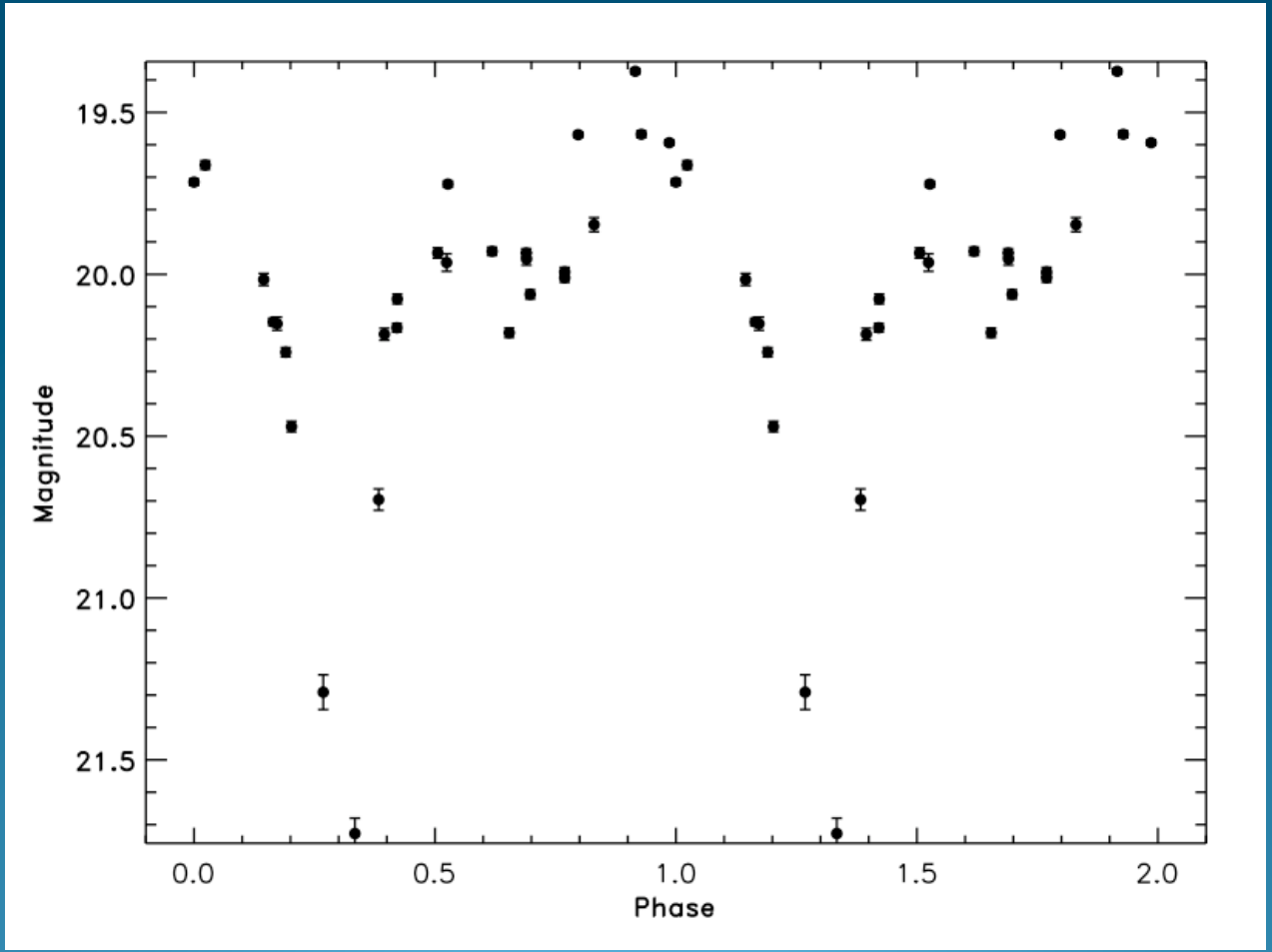
# Period Search

- Lomb-Scargle
- Fold: Looks bi-modal ➔ Double the period
- Fit ellipsoidal modulations to estimate sin *i*

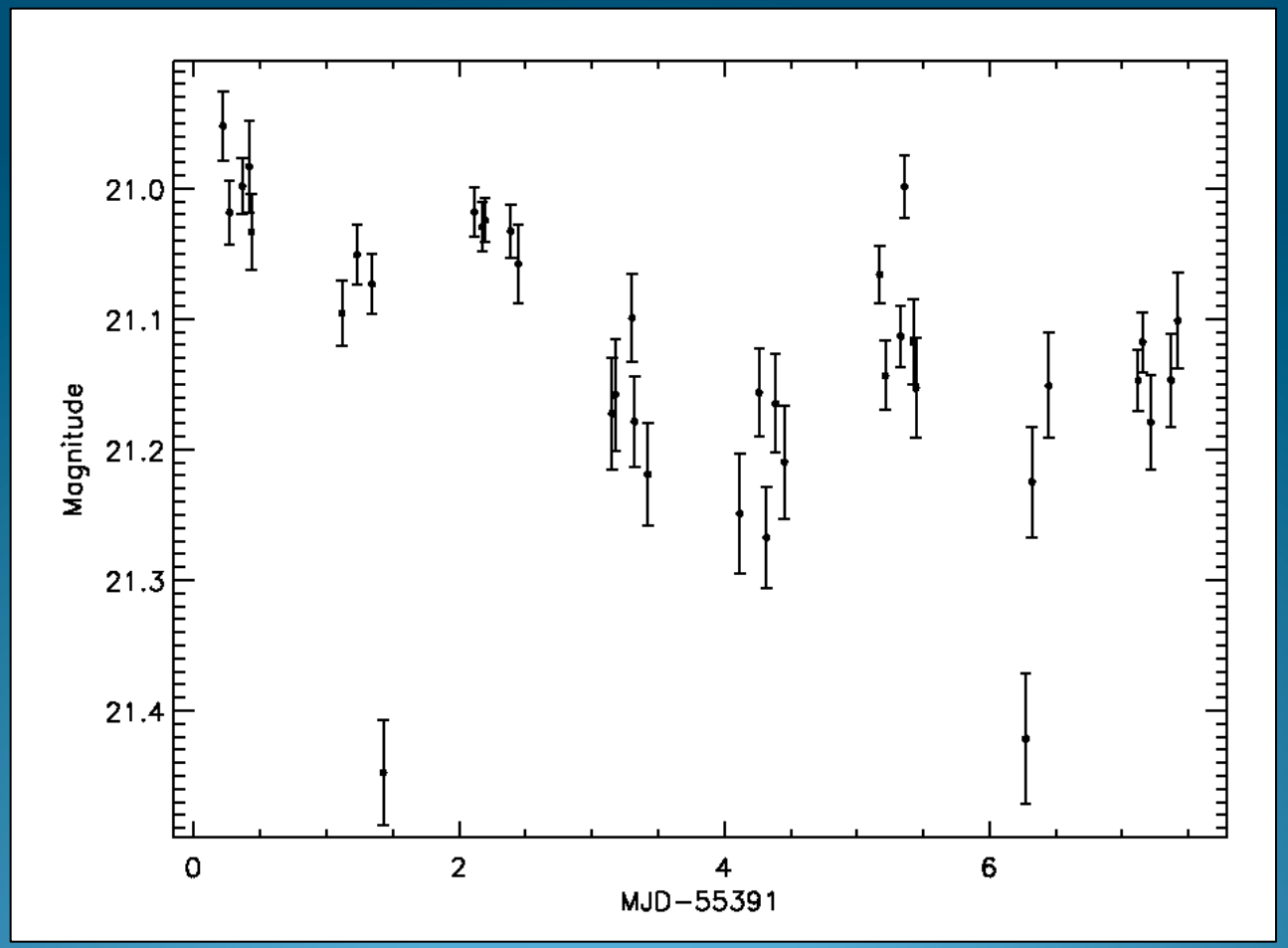
Phase resolved spectroscopy reveals $M_1$=0.8 $M_\odot$ $M_2$=0.6 $M_\odot$ (Ratti 2013)



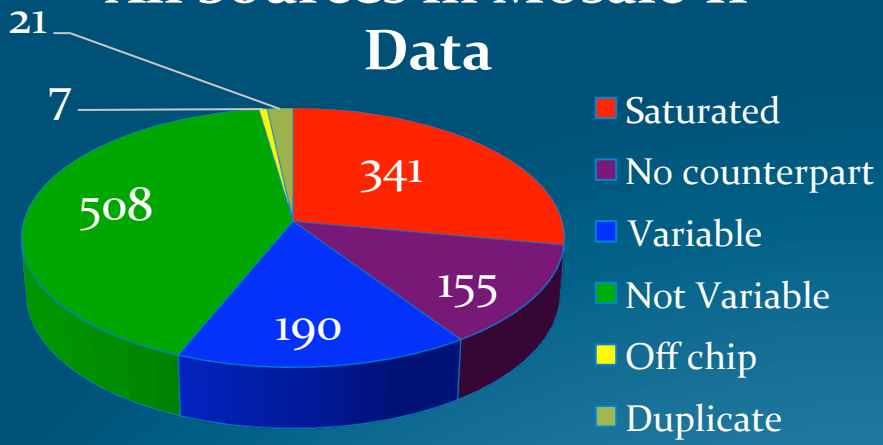
# Eclipsing Sources



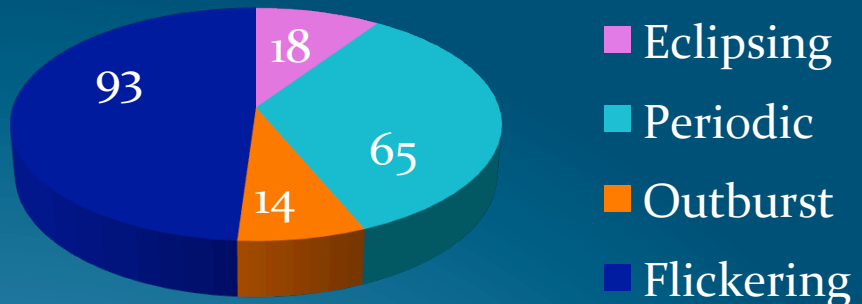
# Even at Low Luminosity



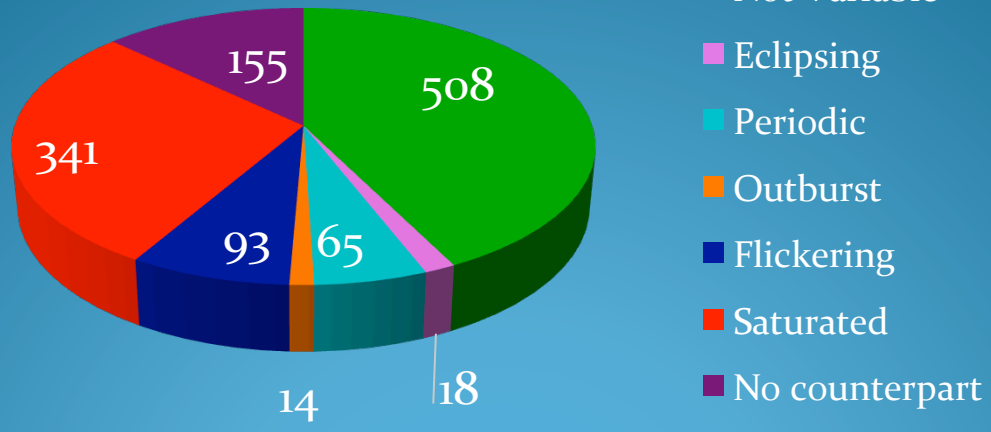
## All Sources in Mosaic-II Data




## Type of Variability

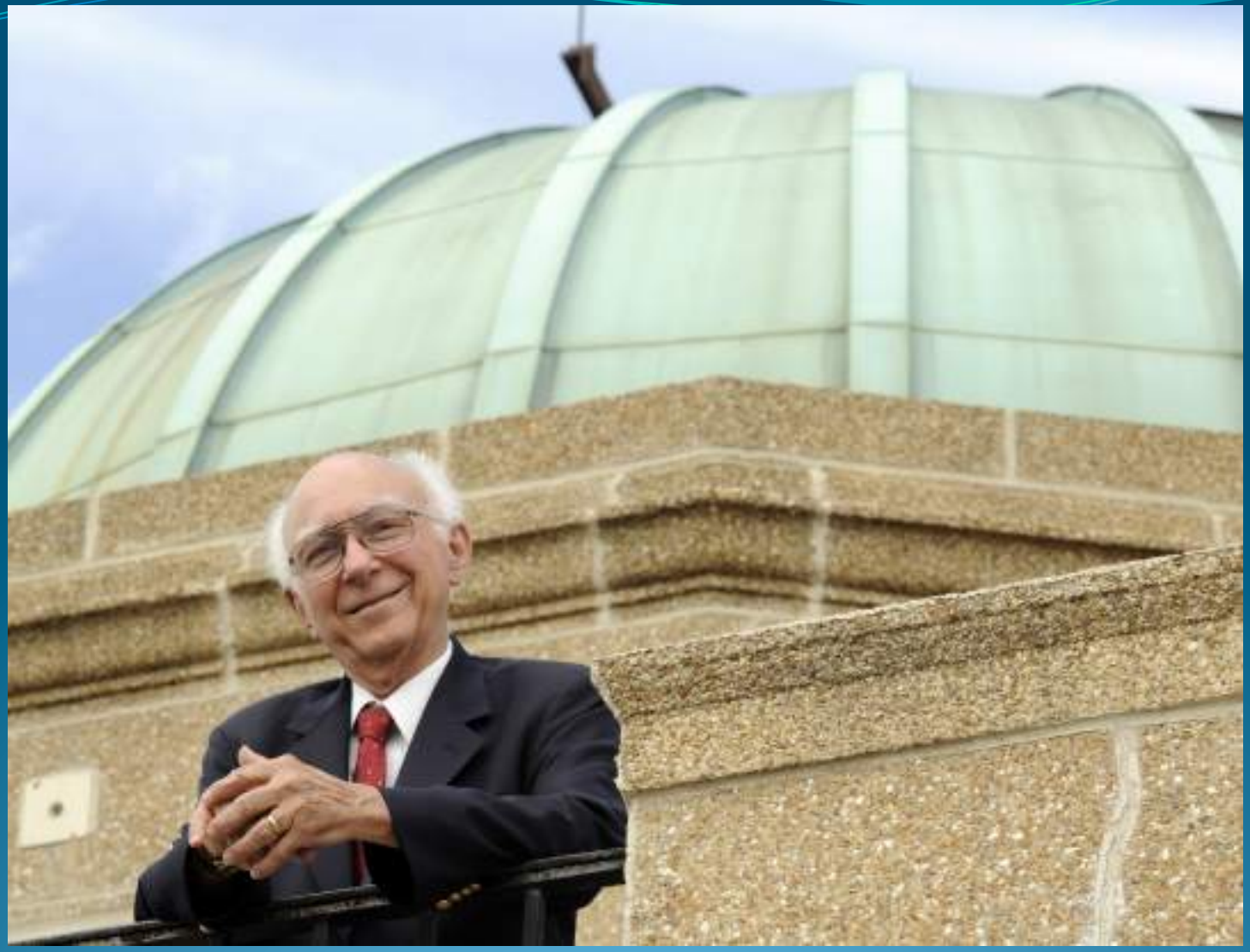



## Counterpart Numbers



# Conclusions

- We are successfully finding eclipsing counterparts even when optically faint
- We are successfully classifying sources based on spectroscopy and photometry of counterparts (Britt et al, accepted; Torres et al, in preparation)
- Finding low number of ellipsoidal modulations which could have implications for population synthesis
- Still need to get spectroscopy for remainder of variable counterparts



# Arlo Says Hi

| | $\text{Log}(F_X/F_{Opt})$ | Variability | RV limit (km/s) | Spectral features |
|---|---|---|---|---|
| CV | -2 – 0 | Flickering, ellipsoidal, DN | low 100's | H, He I emission. Possible weak He II. Possible absorption lines from donor |
| mCV | -1 – 1 | Flick., Orbital Side Band, rarely DN | low 100's | H, He I, strong He II emission. He II/Hβ ≥0.4 |
| qLMXB | -2 – 0 (BH/NS) | Ellipsoidal, Flick., flares τ~min - hr | high 100's | H, faint He I, no He II, broader than CV lines. Possible donor lines |
| LMXB | ≥ 2 | Flick., Outbursts τ~weeks/months, NS - reprocessed X-ray bursts. | high 100's | H, He I, He II, disk continuum dominates |
| RS CVn | -3 – -2 | Sine wave P ~ days | 10's | Ca II H & K emission lines |
| W UMa | -3 – -2 | Broad eclipse, P ~ hours | low 100's | Balmer, CaII H & K, Ca I, Fe I, Mg I all in absorption |
| M Dwarf | -3 | Star spots P~days, flares | 10's | In absorption: TiO, CaH, K I, Mg I, Na I, Fe I<br>Balmer emission |