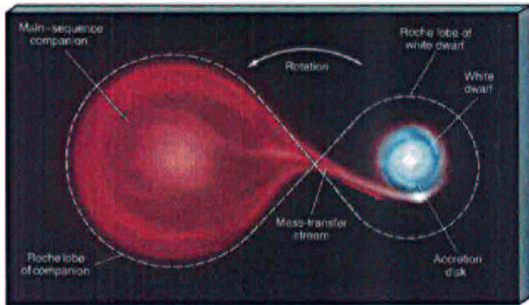


Observations of Cataclysmic Variables and Non-flickerers in 47 Tucanae and NGC 6397

Peter Edmonds

Collaborators: R. Gilliland, J. Grindlay, C. Heinke, A. Cool
F. Camilo, J. Taylor, H. Cohn, P. Lugger

Cataclysmic variables (CVs)



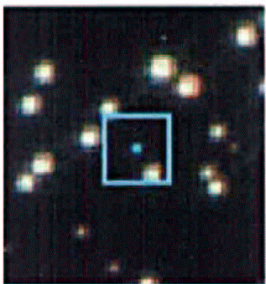
Credit: <http://blueox.uoregon.edu/~jimbrau/ast122/Notes/Chapter22.html>

Properties in field

- blue optical colors
- variable (flickering, outbursts, periodic variations)
- optical emission lines
- X-ray sources
- *many CVs now seen in globulars thanks to HST & Chandra*

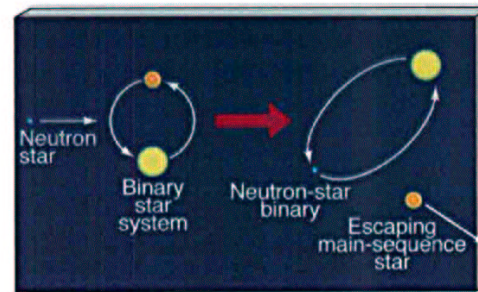
Non-flickerers

- blue, non-variable stars in clusters, but not 'normal' CO WDs
- thought to be He WDs, low-mass WDs that did not undergo He burning
- these often found in binaries in field (e.g. WD and NS star companions)
- *relatively few seen in globulars, but much work remains to be done*



Motivation

- CVs in globulars almost certainly result from stellar interactions
- in solar neighborhood, ~0.01% of stars are CVs, in globulars, typically $\geq 0.1\%$ of stars near core are CVs, (despite lower binary fractions than field)

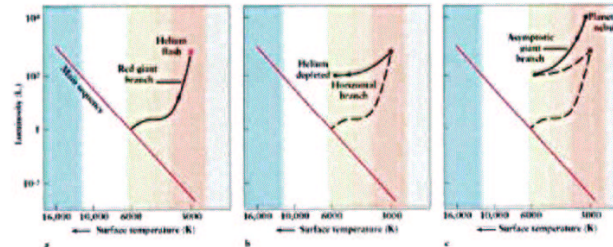


Globular cluster CV formation mechanisms

- similar to neutron star systems (LMXBs)
- 3 or 4 -body interactions
- tidal capture (?)

WD formation

'Normal' WD formation



He WD formation

- any process that strips away giant envelope before He flash
- again, interactions are likely important

Why study these objects?

- CVs and He WDs good diagnostics of stellar interactions
- Compact binaries important for cluster evolution
- First known samples of these objects at same, well-determined distance

Outline

CVs and He WDs in core-collapsed NGC 6397

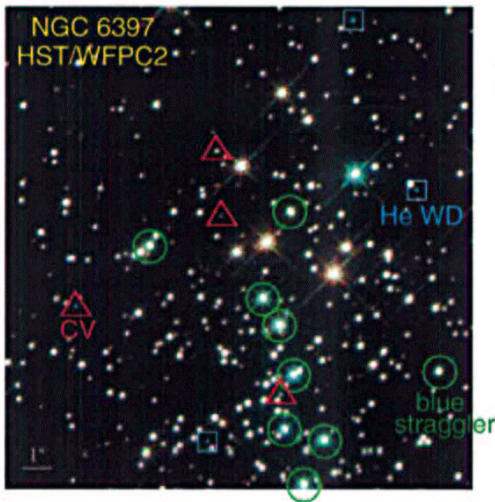
- HST photometry, time series and spectra
- ROSAT and Chandra observations

CVs and He WDs in un-collapsed 47 Tuc

- ROSAT and Chandra observations
- HST photometry and time series
- F_x/F_{opt} for 47 Tuc CVs compared to field CVs

General questions/issues

- Are CVs in clusters magnetic?
- Comparisons between NGC 6397 and 47 Tuc



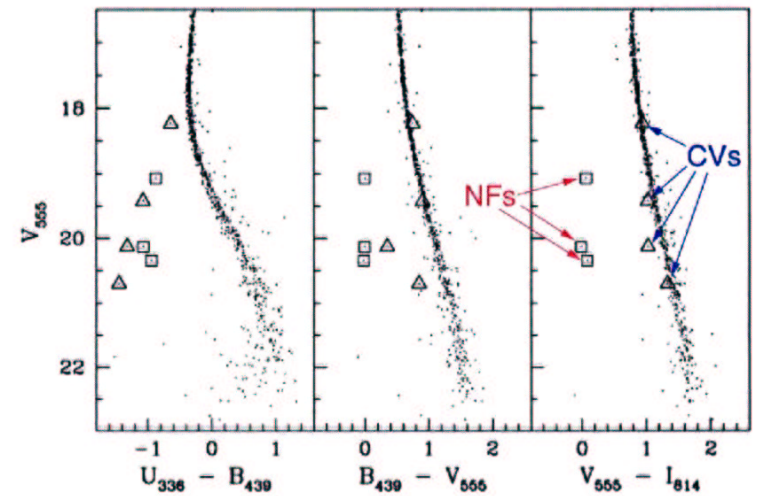
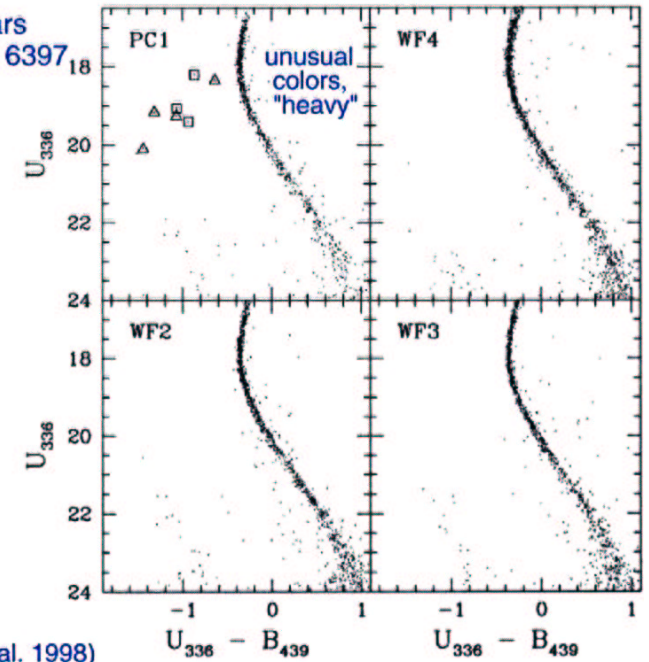
How to find CVs and He WDs in globular clusters?

- (1) get deep HST imaging
- (2) get deep Chandra imaging
- (3) get deep radio data
- (4) preferably all of above!

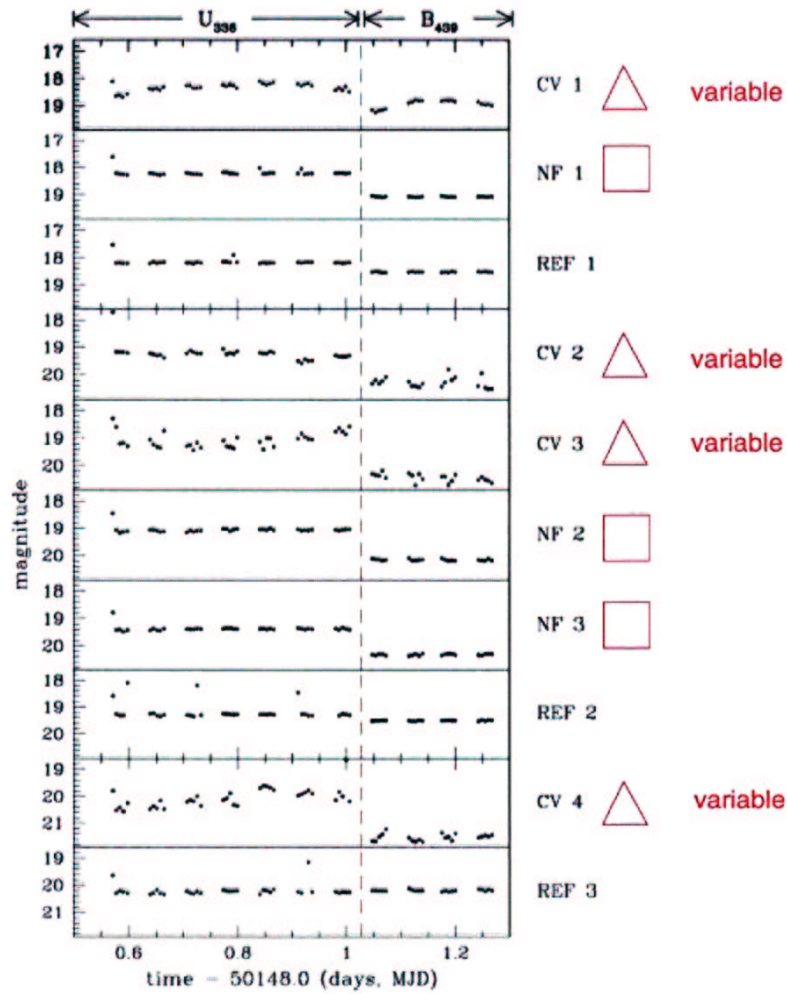
CVs and NFs in NGC 6397

HST photometry of stars near the center of NGC 6397

WFPC2/HST

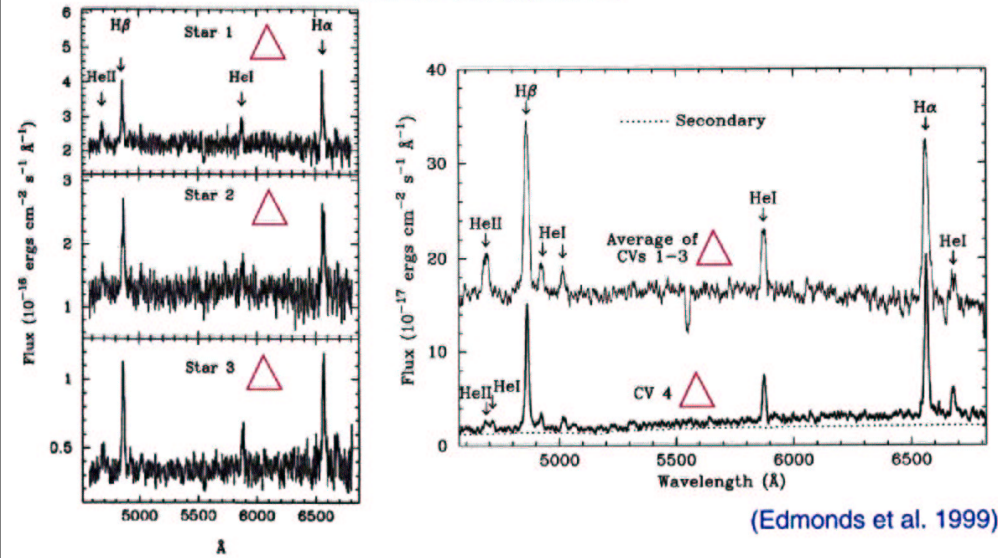


Time series photometry of stars in NGC 6397



Cool et al. (1998)

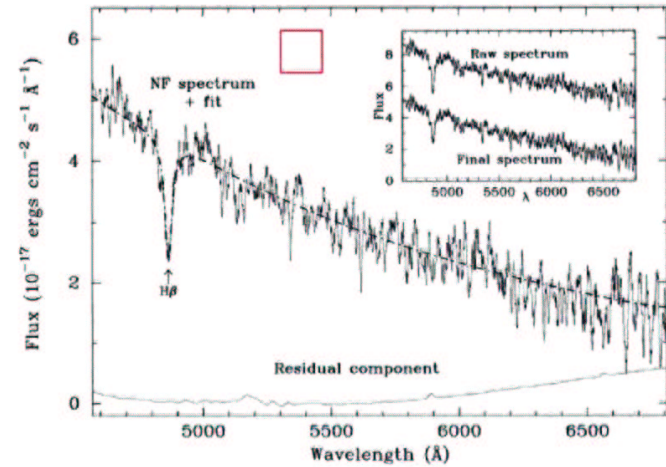
CV optical spectra



(Grindlay et al. 1995)

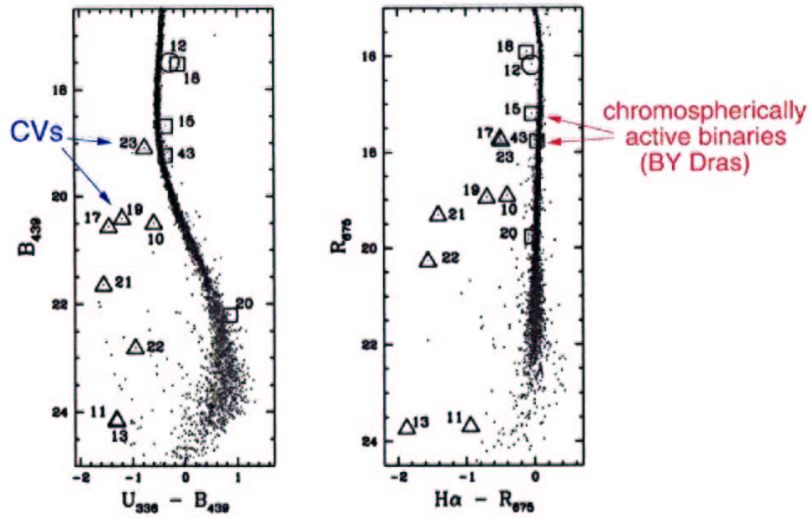
(Edmonds et al. 1999)

NF optical spectrum



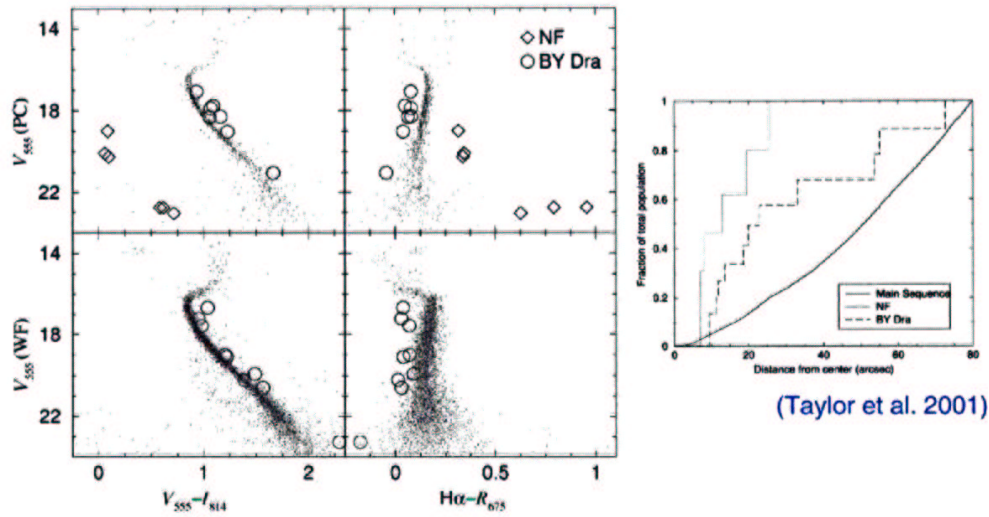
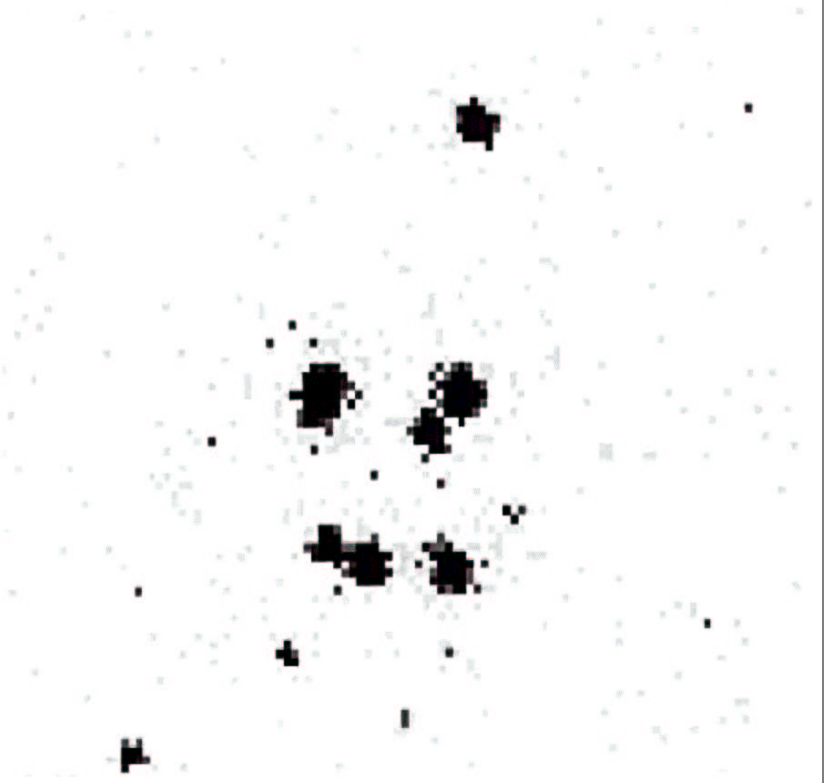
(Edmonds et al. 1999)

Follow-up HST photometry



(Grindlay et al. 2001b)

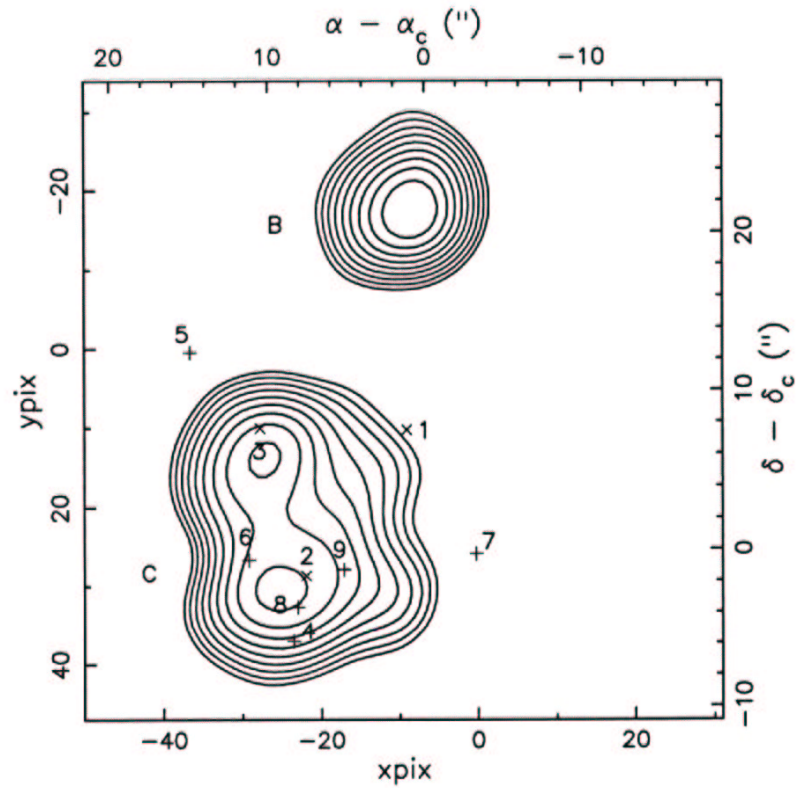
Chandra image of NGC 6397



(Taylor et al. 2001)

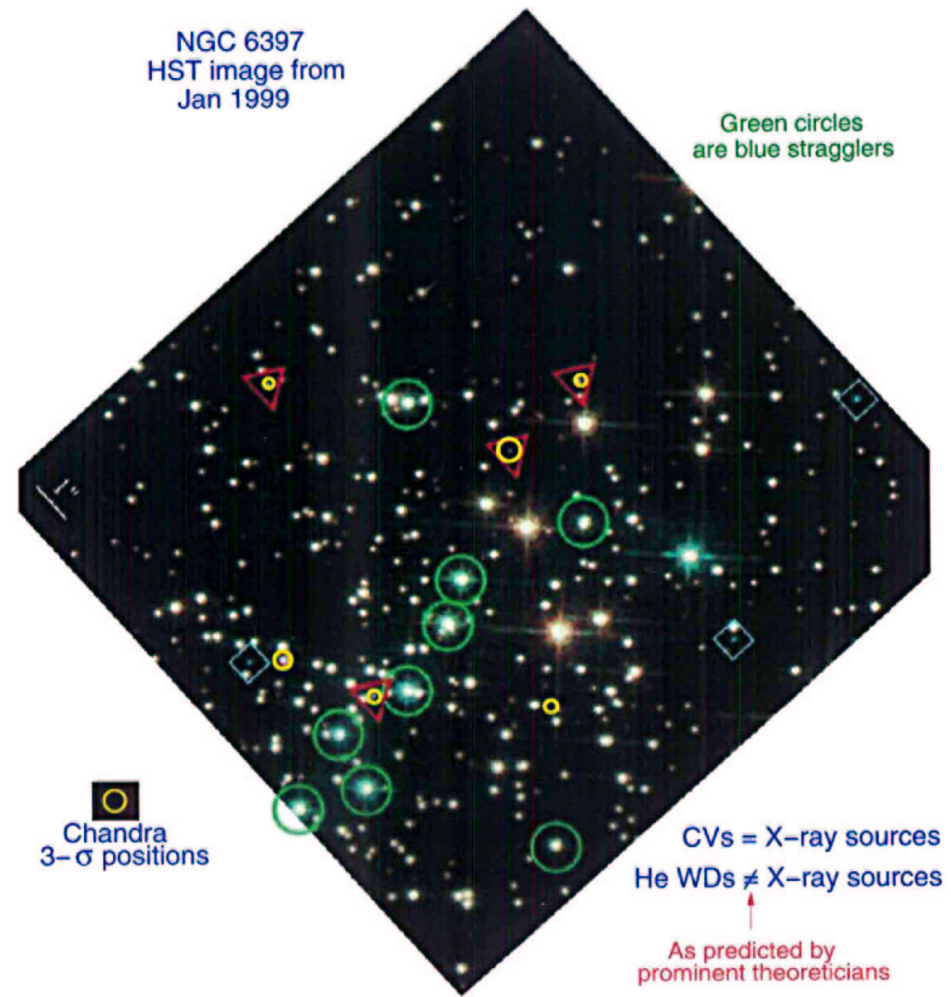
(Taylor et al. 2001)

ROSAT observation of NGC 6397



Verbunt and Johnston (2001)

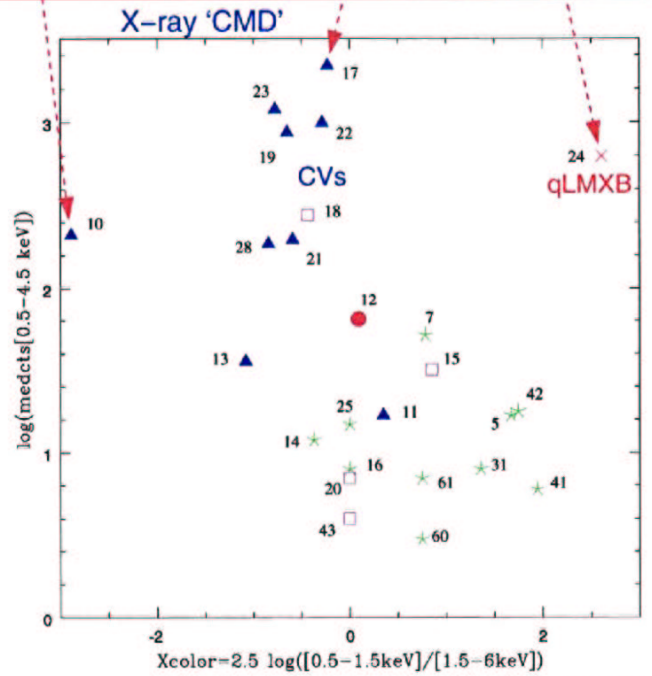
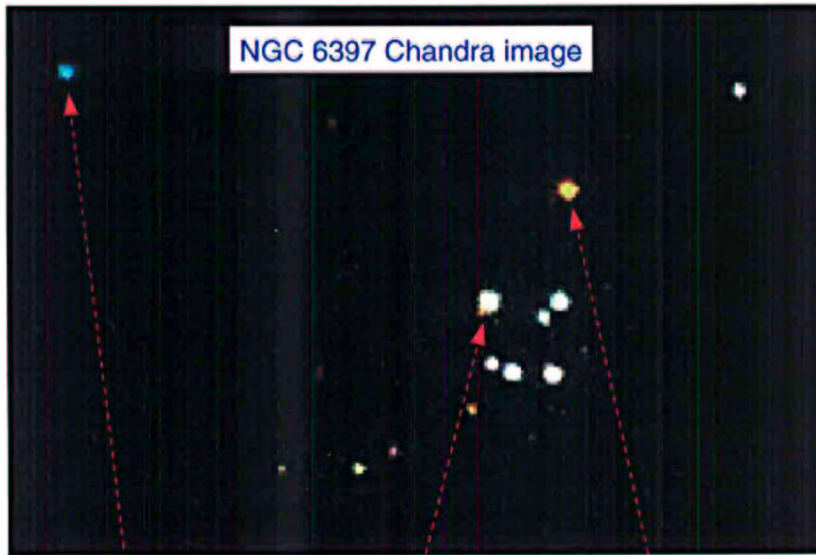
NGC 6397
HST image from
Jan 1999



Chandra
3- σ positions

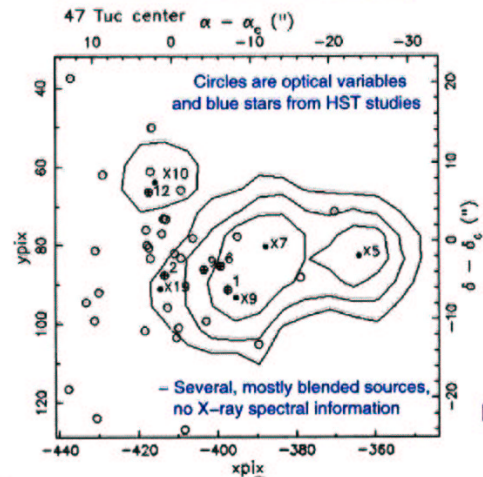
CVs = X-ray sources
He WDs \neq X-ray sources

As predicted by
prominent theoreticians

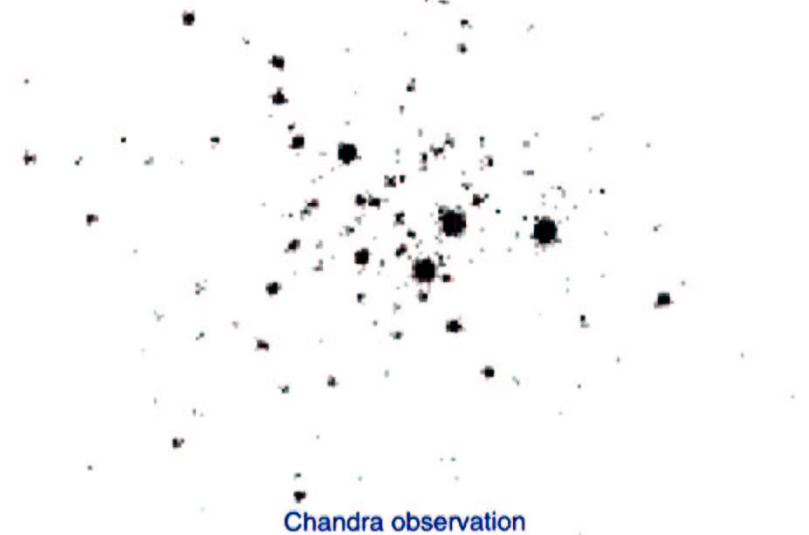


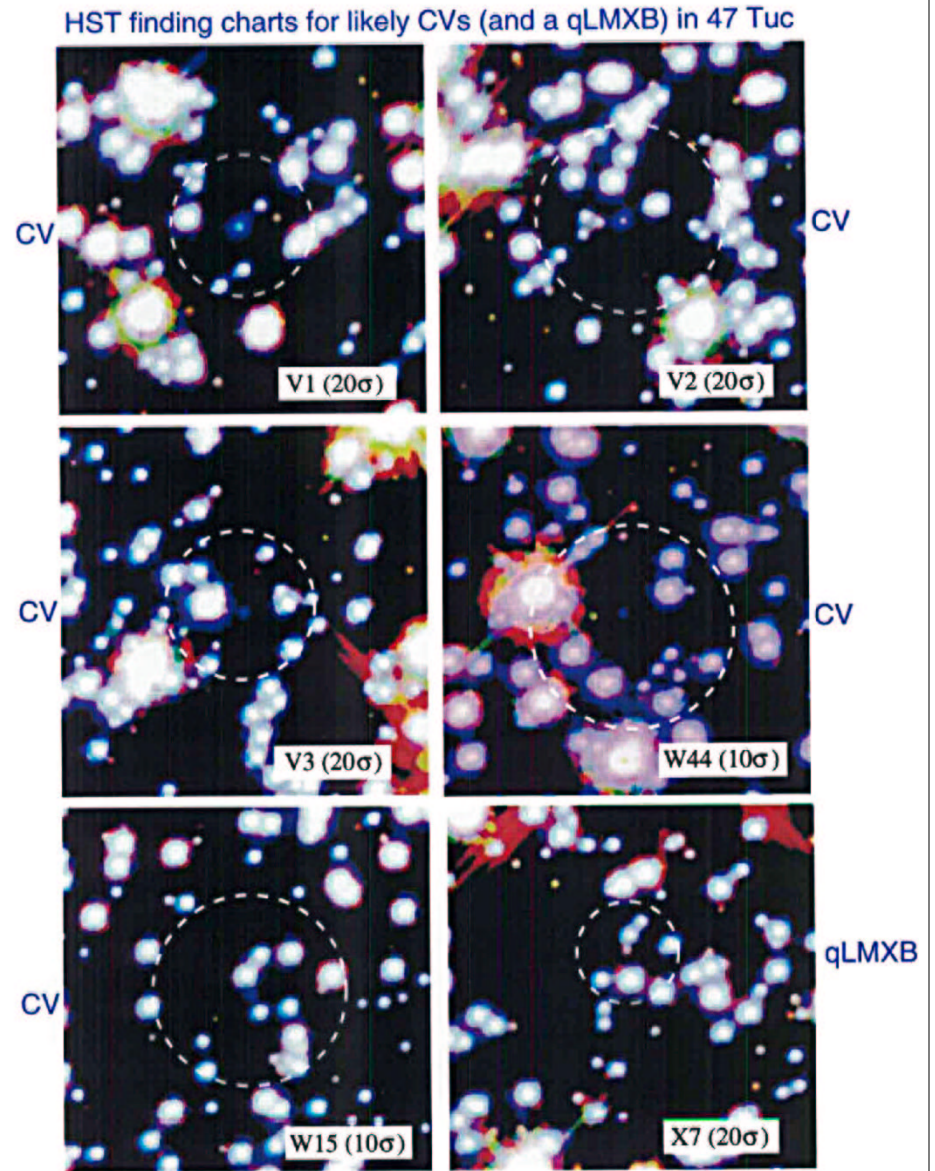
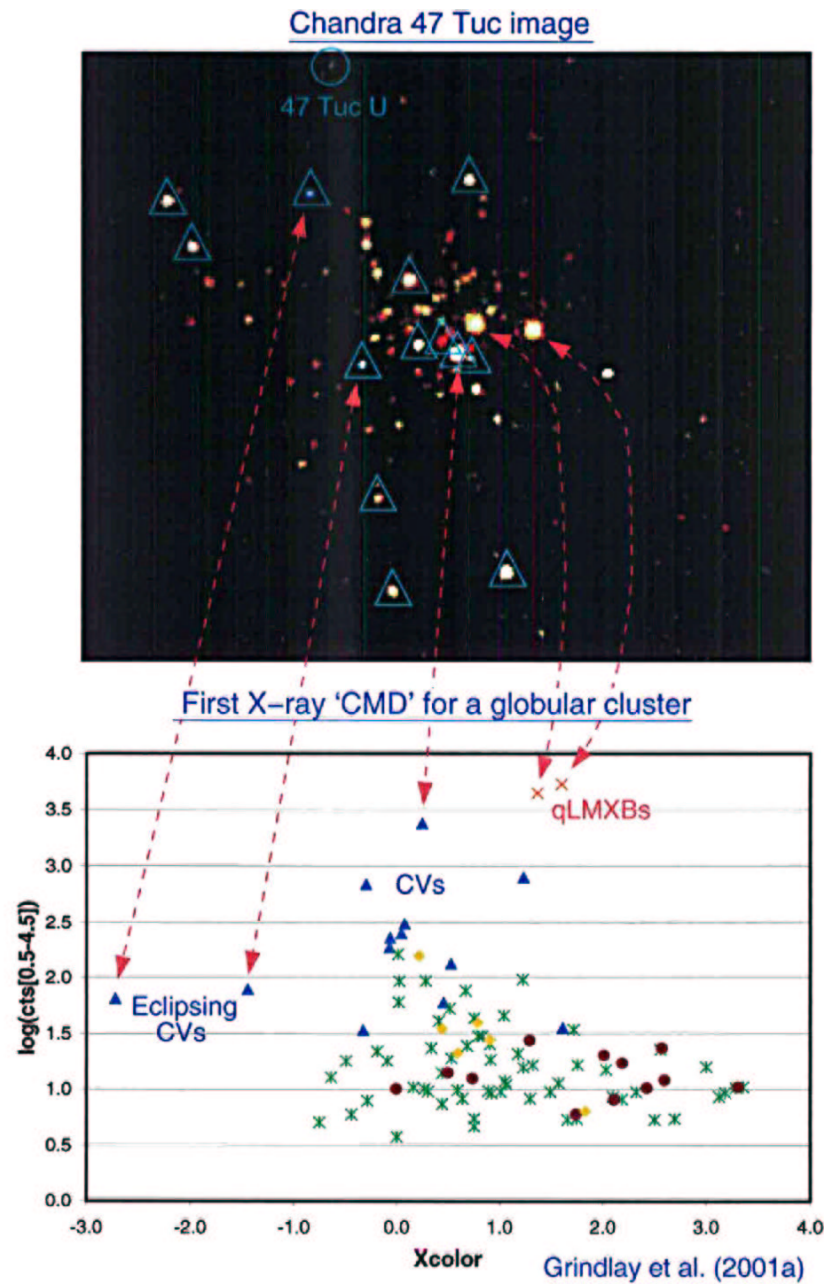
Grindlay et al. (2001b)

ROSAT observation of 47Tuc

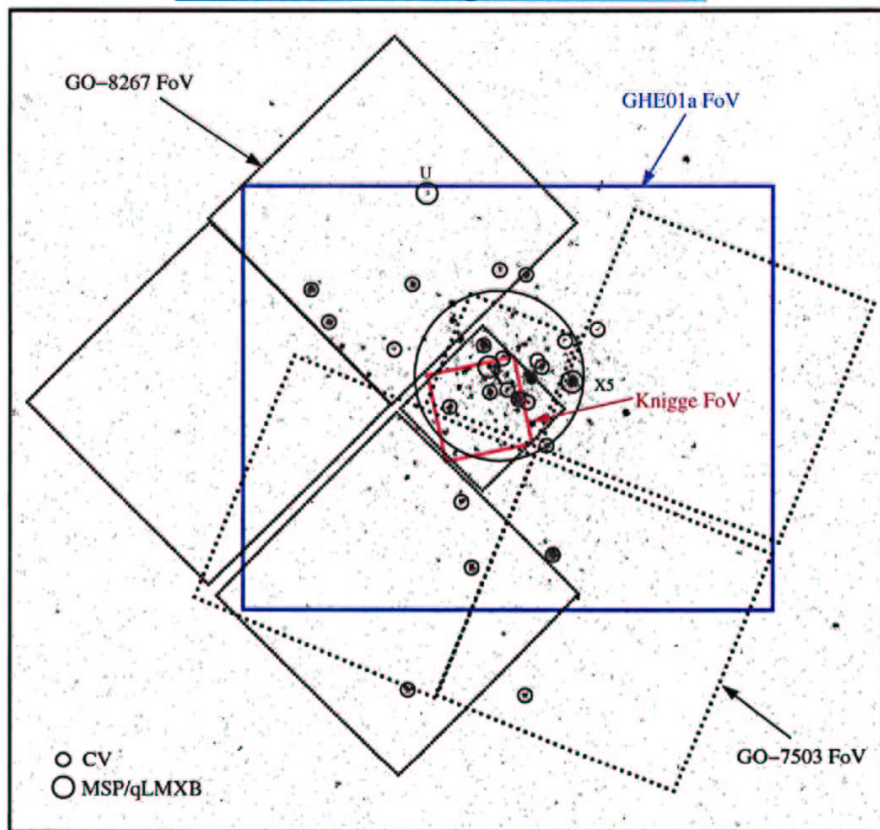


Verbunt & Hasinger (1998)

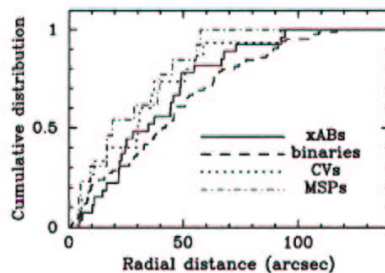




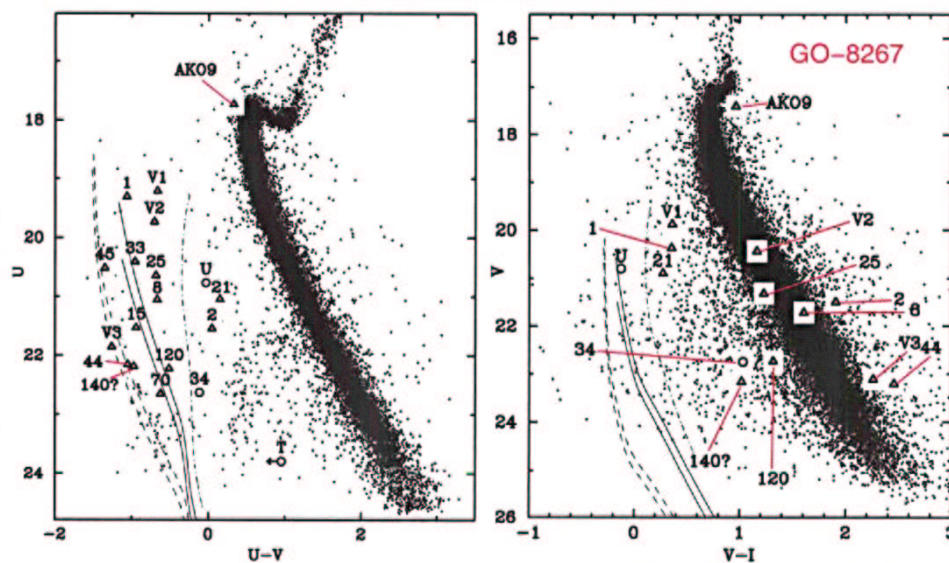
47 Tuc Chandra image with HST FoVs



GHE01a: Grindlay et al. (2001a) Chandra FoV
 GO-8267: WFPC2 U/V/I imaging (120 orbits)
 GO-7503: WFPC2 U/V imaging (6 orbits)
 Knigge: STIS UV imaging (30 orbits)

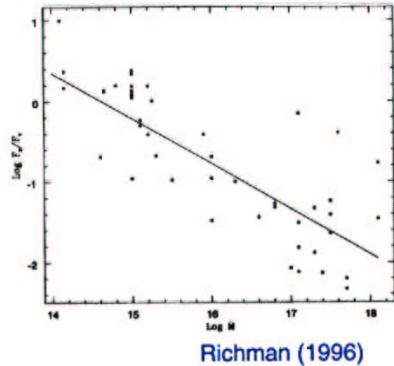


CVs and a He WD in 47 Tuc



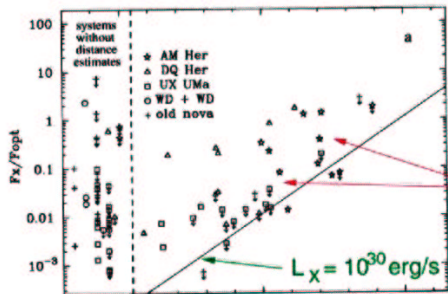
(From Edmonds et al. 2003)

F_x/F_{opt} as an accretion rate diagnostic: field CVs



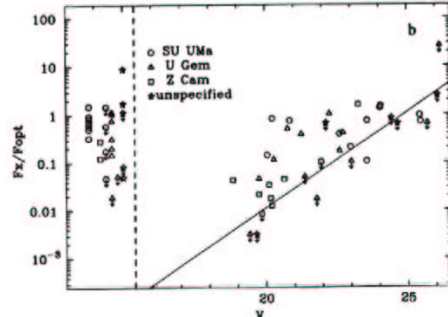
-> lower accretion rate
-> higher F_x/F_{opt}

Richman (1996)



'nova-like' CVs (generally high accretion-rate systems)

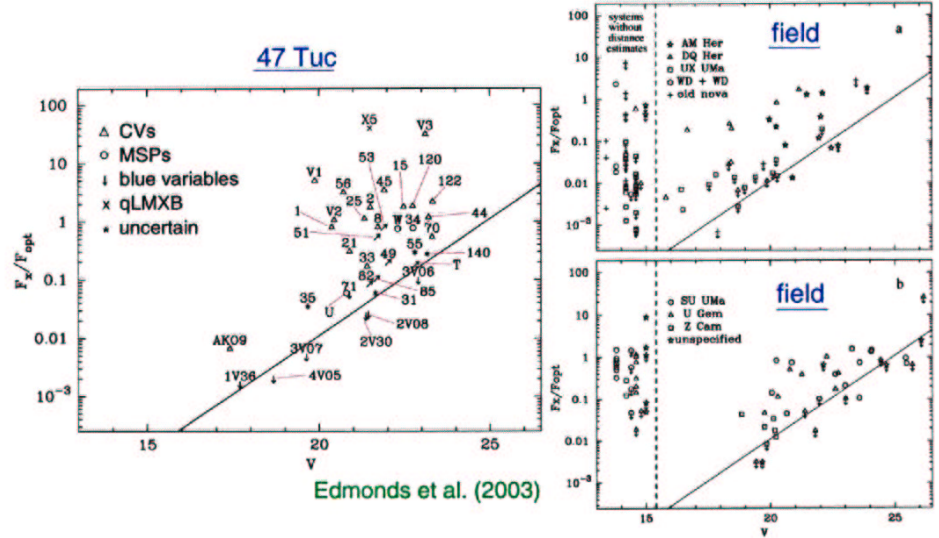
field CVs projected at 47 Tuc distance



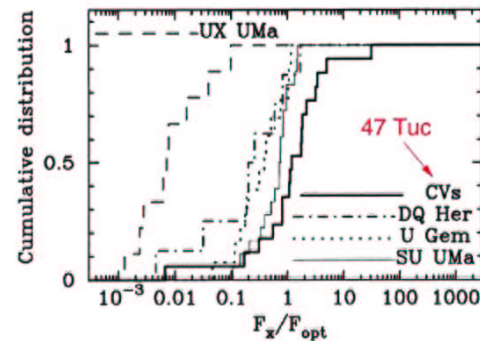
dwarf novae (generally low accretion-rate systems)

Edmonds et al. (2003); Verbunt et al. (1997)

F_x/F_{opt} as an accretion rate diagnostic: 47 Tuc CVs



Edmonds et al. (2003)



Edmonds et al. (2003)

TABLE I
 F_x/F_{opt} VALUES FOR 47 TUC SOURCES AND FIELD CVs

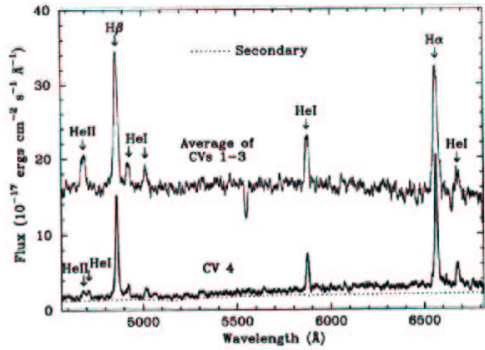
Source type	Number	F_x/F_{opt} (median)
xABs	29	0.0059
MSPs	4	0.46
CVs	17	1.18
Field CVs ^a		
UX Umas	9	0.0072
Z Cams	9	0.043
AM Hers	9	0.22
DQ Hers	8	0.23
U Gems	13	0.39
SU UMas	18	0.73

^aCVs from the study of Verbunt et al. (1997)

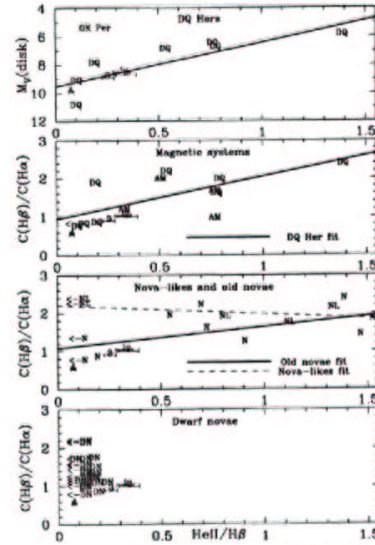
- 47 Tuc CVs appear to have low accretion rates compared to field
- Is this a real effect?
- Caused by different formation?

Are a lot of globular cluster CVs magnetic?

Evidence for NGC 6397 CVs being magnetic

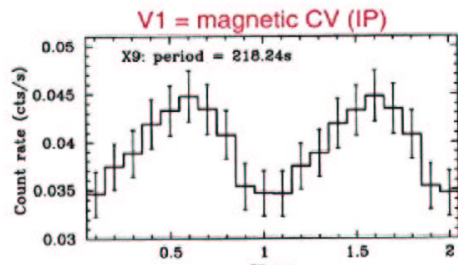


(Edmonds et al. 1999)

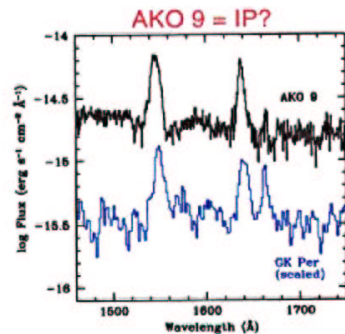


(Edmonds et al. 1999)

Evidence for 47 Tuc CVs being magnetic

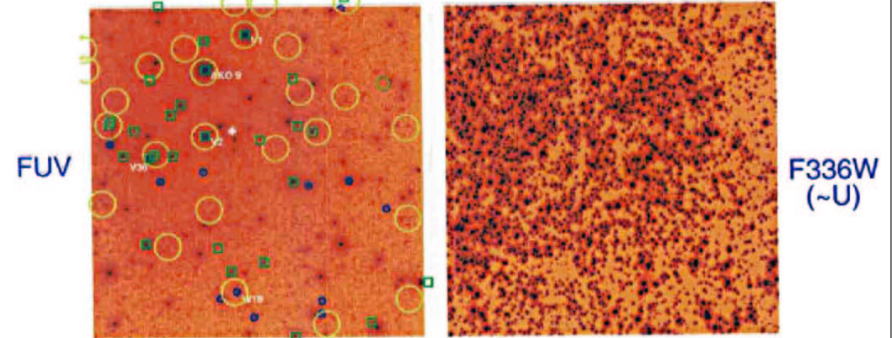


(Grindlay et al. 2001a)

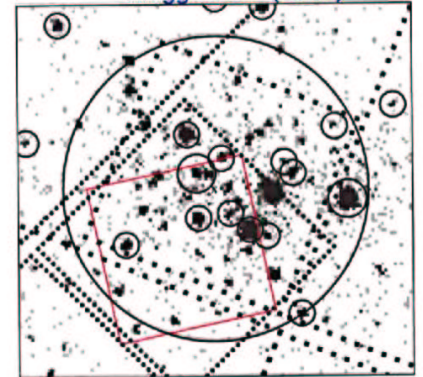
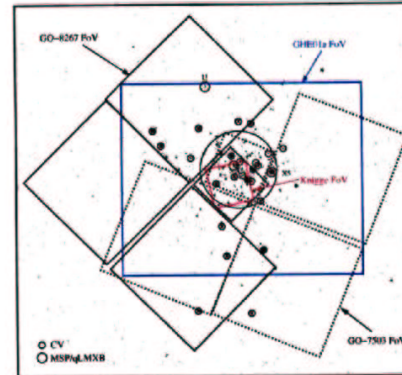


(Knigge et al. 2000)

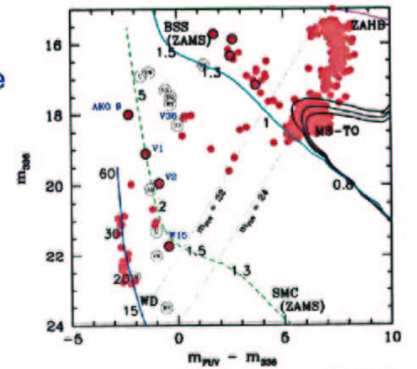
STIS UV image of 47 Tuc



Knigge et al. (2002)



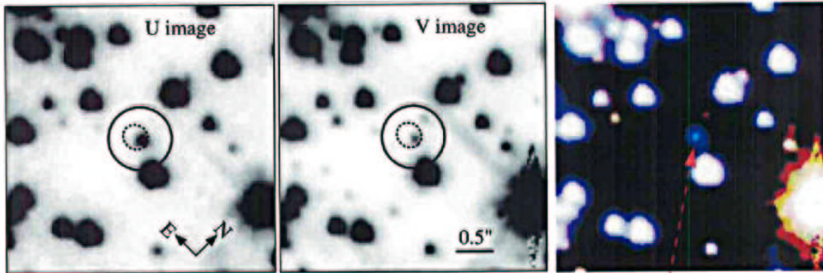
- 4 (previously reported) CVs detected in UV as blue & variable
- other CV candidates found but not (yet) detected in X-rays
- UV spectra also obtained



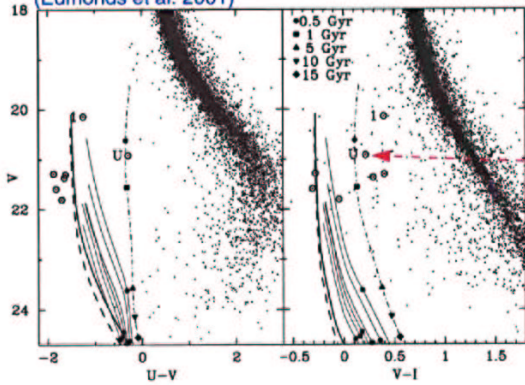
Knigge et al. (2002)

MSP optical companion: 47 Tuc U

47 Tuc HST imaging



(Edmonds et al. 2001)

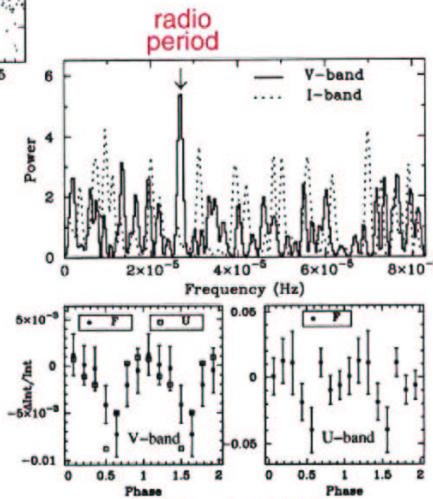


47 Tuc U binary companion:
a relatively bright He WD

- Weak signal in power spectrum at the radio binary period confirms blue star is MSP companion

- Have relatively bright MSP companion for measuring its radial velocity and NS mass

- Several other He WDs inferred from radio observations of binary MSPs (not with optical IDS)



(Edmonds et al. 2001)

Comparison between 2 clusters

Cluster	Cluster M_V	Collision frequency	#CVs	# He WDs	MS-binary fraction
47 Tuc	-9.42	100	~30	1*	~14%
NGC 6397	-6.63	1	9	6	< 5-7%

* No systematic search in optical

- 47 Tuc has more MS binaries, relatively fewer CVs
- NGC 6397 has apparently converted more of its primordial binaries into CVs (perhaps during core collapse)

Future observational work

- Search for faintest CVs, especially in 47 Tuc (less complete)
- Pulsation searches: optical and X-rays (magnetic CV search)
- Search for He WDs in 47 Tuc (have new HST/ACS data with $H\alpha$ imaging)
- More orbital periods needed for CVs
- Radial velocity studies needed for CVs and He WDs (challenging)
- More complete MSP searches in 6397 (NS number comparison)