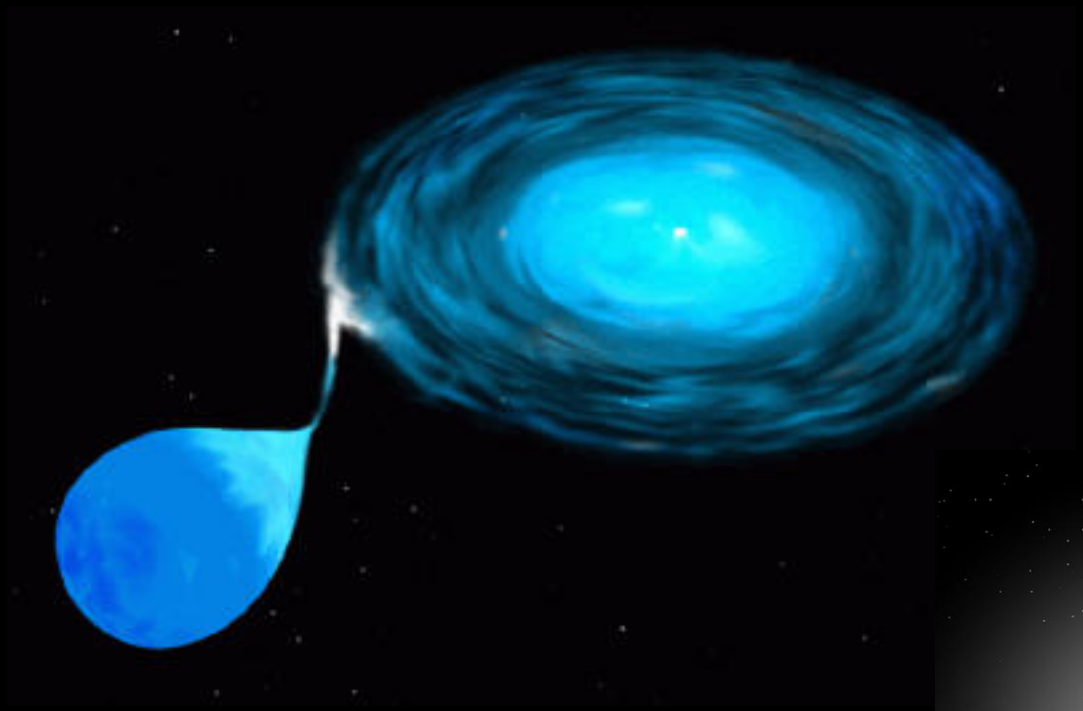
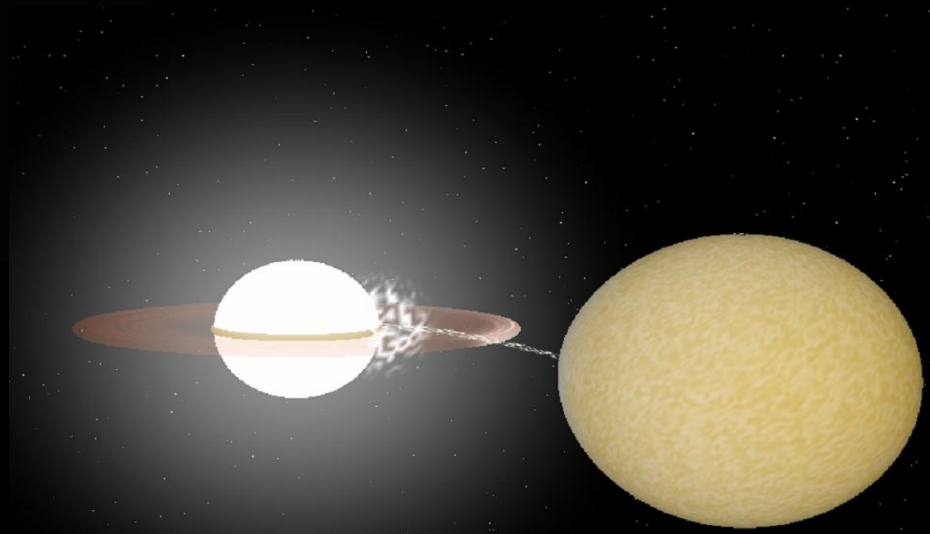
3rd AM CVn Workshop

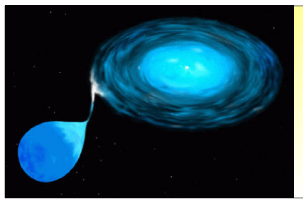


Warwick
April 16 – 20, 2012



Paul Groot
Department of Astrophysics
Radboud University Nijmegen

Radboud University Nijmegen



2008: Increasing numbers

> Resolution 1: *Let's do better in the coming three years...*

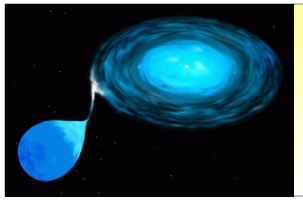
- Number of systems at 1st AM CVn workshop in 2005: 18[a]
- Number of systems at 2nd AM CVn workshop in 2008: 22[b]
- Number of systems at 3rd AM CVn workshop in 2012: **36**

New systems since 2005: SDSS J2047, SNF2006, SDSS J1208+35, SDSS J0804+16

> Resolution 2: *Let's do this in a homogeneous way*

- For modeling purposes: obtaining them homogeneously is as important as increasing numbers

[a] See contribution Brian Warner to 2005 workshop proceedings
[B] See contribution PJG to 2008 workshop proceedings



2012 Situation: 36 systems

Name	P_{orb} (min)
HM Cnc (RXJ0806+15)	5.4
V407 Vul (RXJ1914+24)	*9.5*
ES Cet	10.4
SDSSJ1908+34	15.8
AM CVn	17.1
HP Lib	18.4
CR Boo	24.5
KL Dra	*25.0*
V803 Cen	26.6
PTF1J0719+48	26.8
SDSSJ0926+36	28.3
CP Eri	28.4
V406 Hya (SN 2003aw)	33.8
PTF1J0857+07	*34.3*
2QZ1427-01	*36.6*
SDSSJ0129+38	37.3
SDSSJ1240-01	37.4
SDSSJ1525+36	44.2

Dark Green: Direct Impact
Dark Brown: High state, stable systems
Dark Blue: Outbursting systems

Name	P_{orb}(min)
SDSSJ0804+16	44.5
SDSSJ1411+48	46.0
GP Com	46.6
SDSSJ0902+38	48.3
SDSSJ1208+35	52.6
SDSSJ1642+19	54.1
SDSSJ1552+32	56.3
V396Hya/CE 315	65.1
SDSSJ1721+27	?
SDSSJ2047+00	?
SDSSJ1730+55	?
PTF1J0435+00	?
PTF1J0943+10	?
PTF1J1523+18	?
PTF1J1632+35	?
PTF1J1919+48	?
PTF1J2219+31	?
MOA-2010-BLG-087	?

Dark Red: Low state, stable systems
Period *italics:* needs spectroscopic confirm.
Black: unknown

Outstanding Questions

1: ***Evolutionary Channels: chemical abundances***

1a) Evolutionary models
1b) Observational abundances: disk simulations
1c) Physics of atmospheres/impacts/

2: ***Status at Direct Impact/First Contact/Triple Point***

2a) Connection with detached systems
2b) Helium Novae, Supernovae Type '.Ia'
2c) Post-merger *single* systems?

3: ***Galactic Populations***

3a) Where the h*** are they?
3b) Disk vs. Halo populations?
3c) Short vs. Long periods

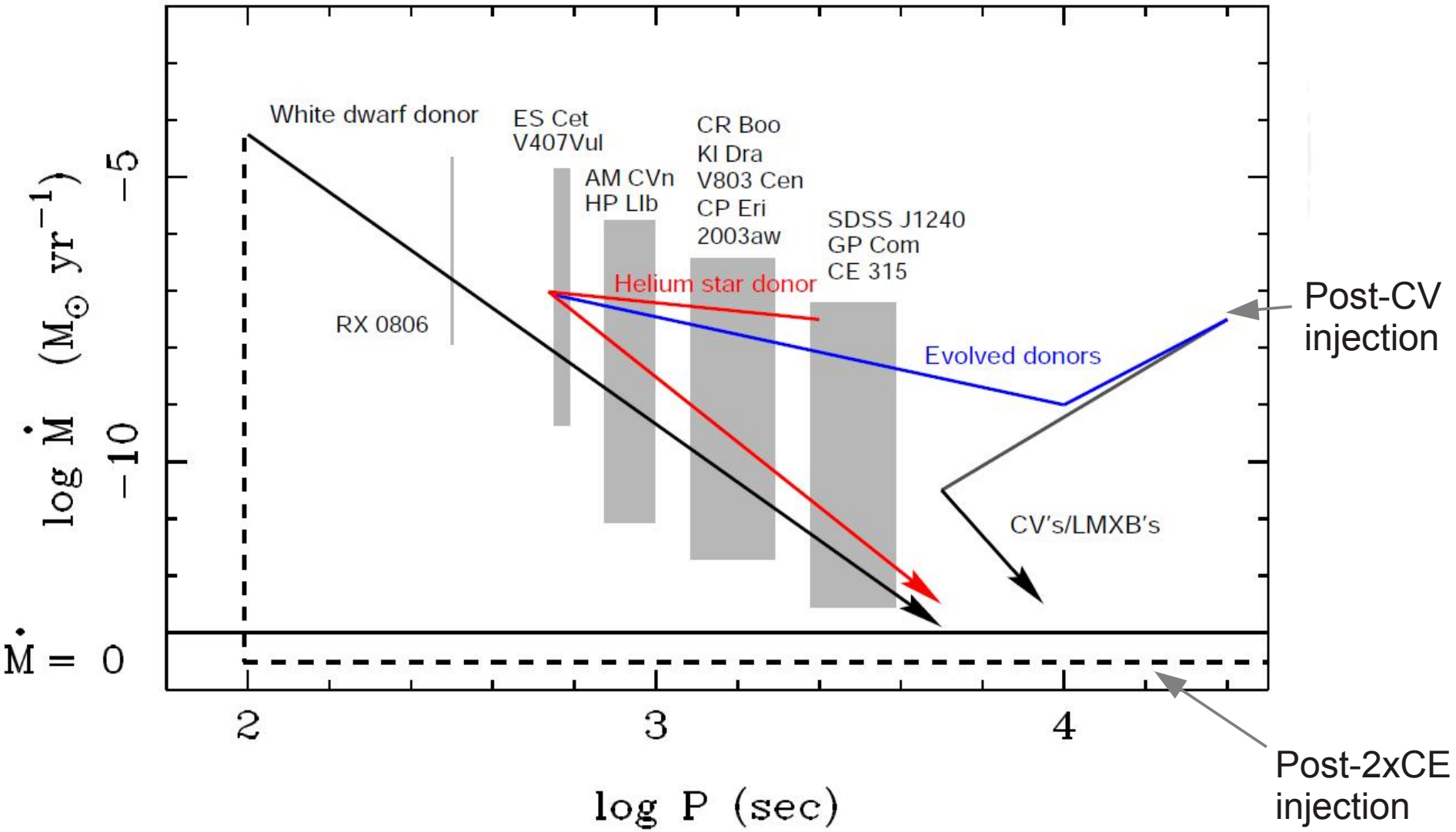
4: ***The next three years***

4a) Short-period systems: more HM Cnc's?
4b) Follow-up of systems: photometry/spectroscopy: **bottleneck?**
4c) Preparation for NextGen surveys: VST, Gaia, PTF2/SkyMapper, NGO, Euclid

Recent reviews om AM CVn stars:

Solheim, 2010, PASP
Nelemans, 2005, AIPC,

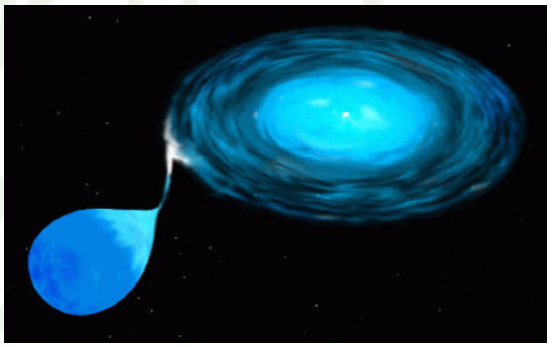
Evolutionary paths

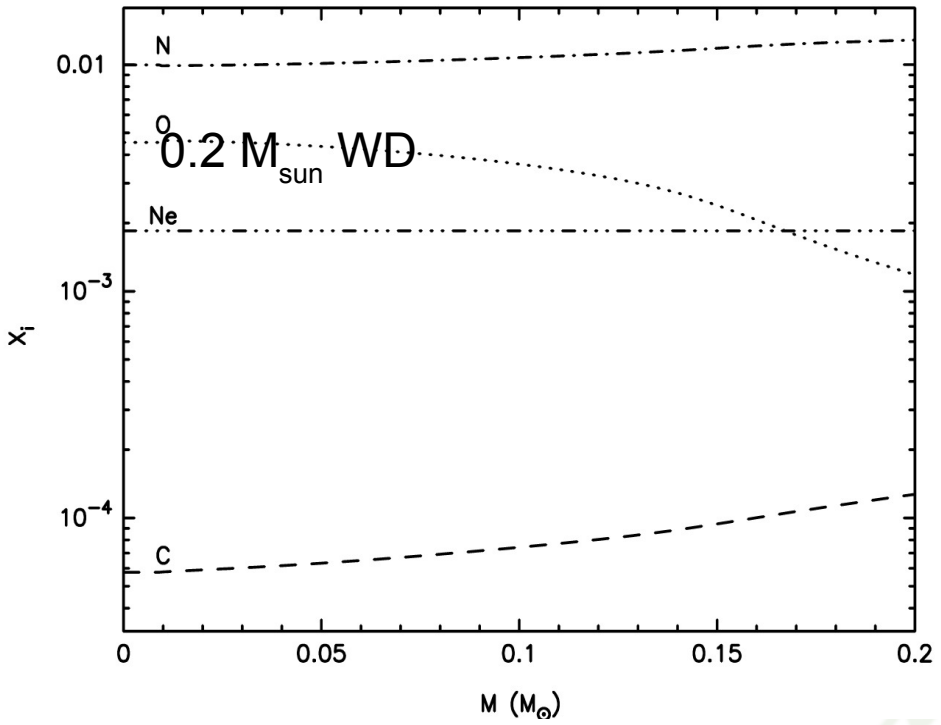


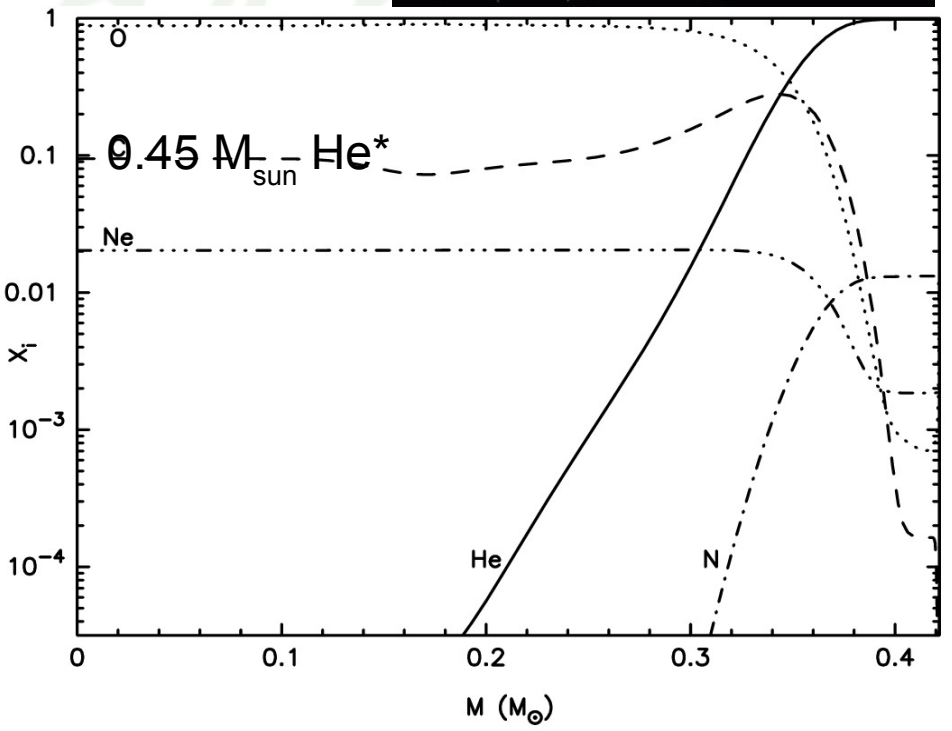
Tutukov & Yungelson 1979,1981,1996, Iben & Tutukov, 1991; Nelemans et al. 2001; Thorstensen 2003, Podsiadlowski et al., 2003.

Unravelling evolutionary histories

Accretion disk is mass spectrometer for secondary composition



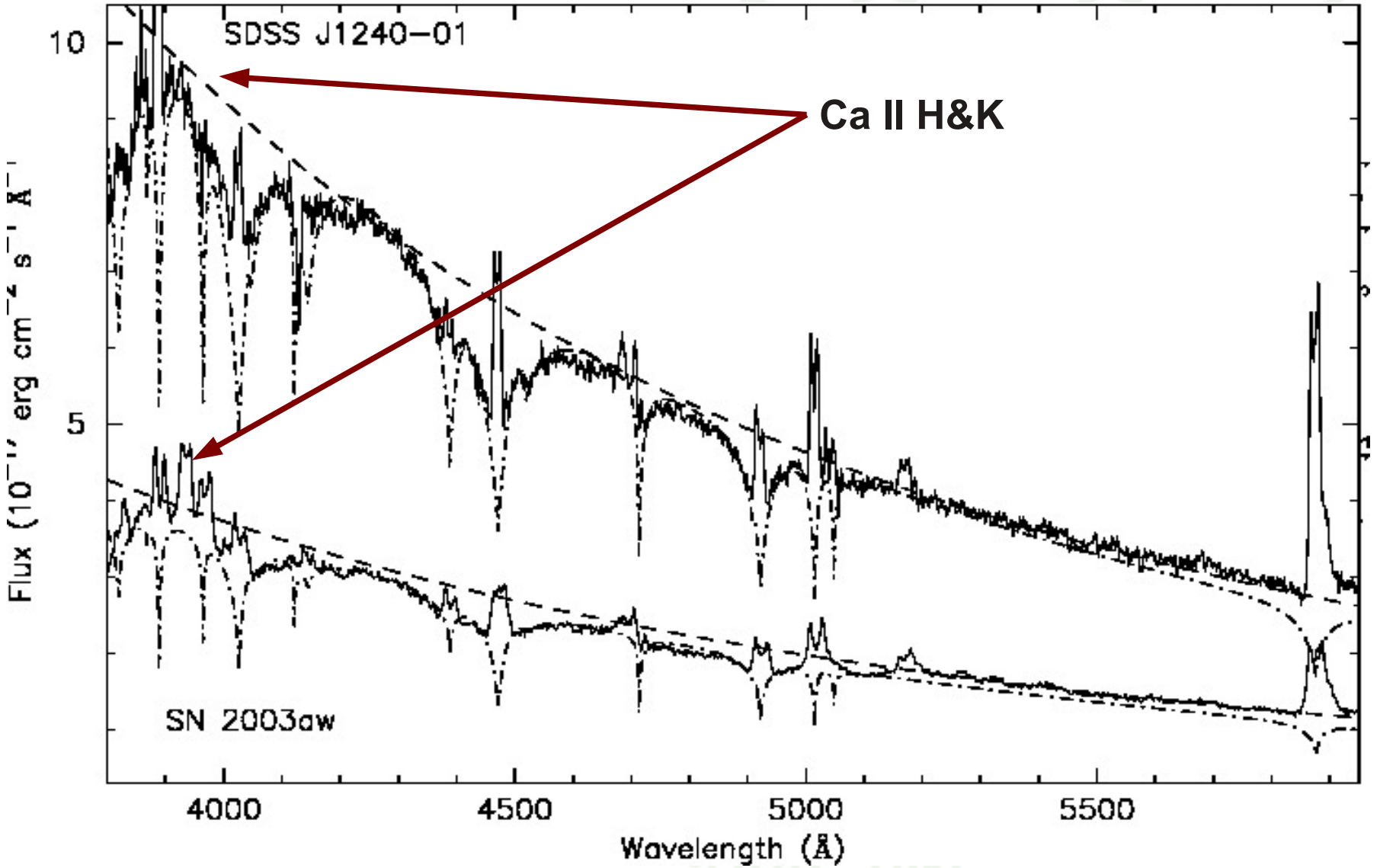




(Nelemans, Yungelson, Vd Sluys, 2010)

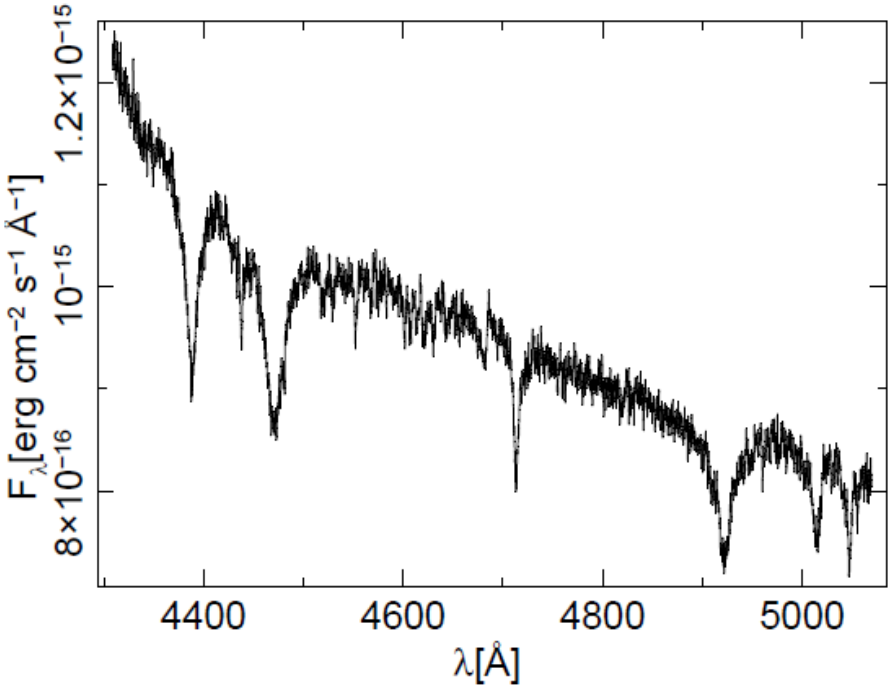
Really increasing the population: SDSS

Primary star, accretor is visible: disk is optically thin
(Roelofs et al., 2006)

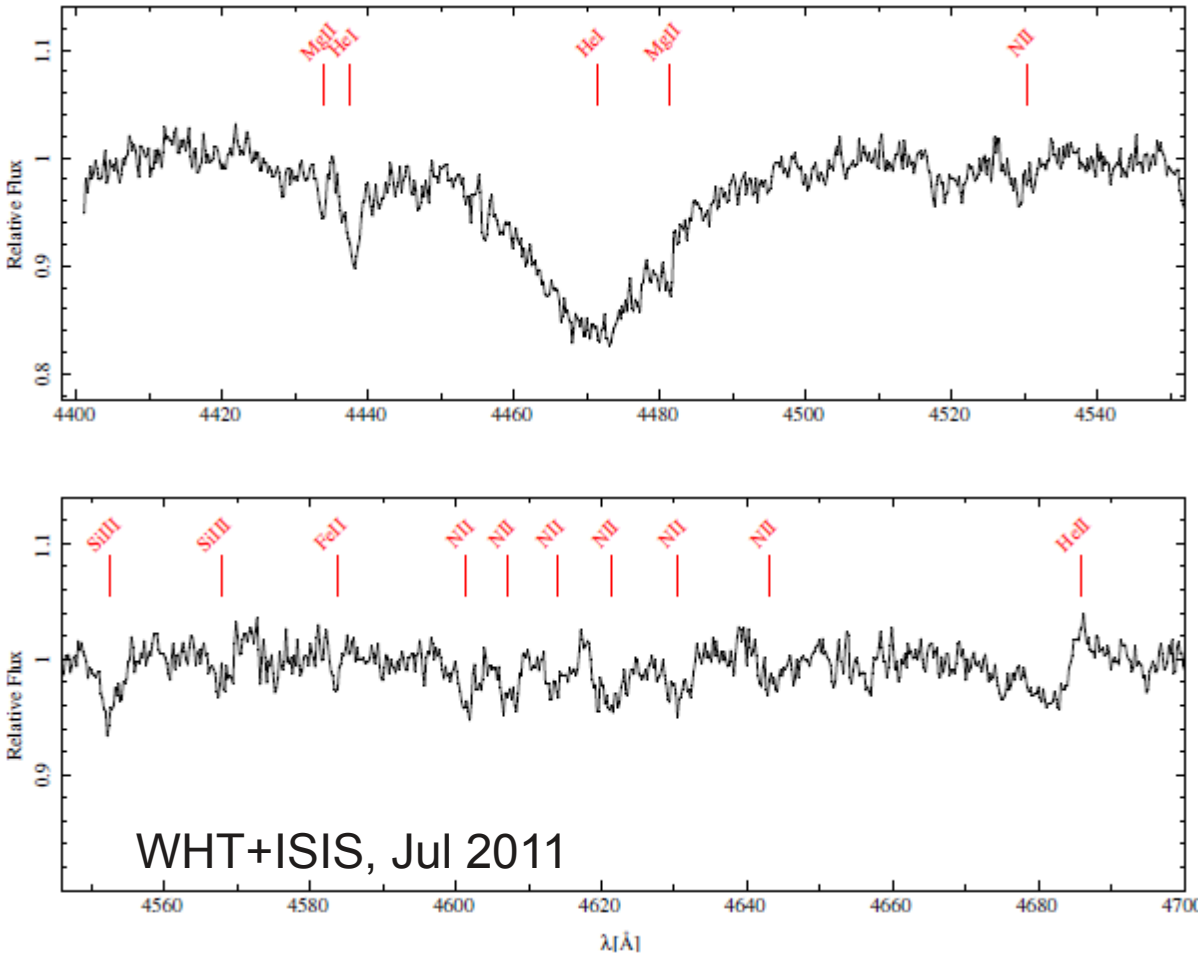


Metal lines in SDSSJ1908+3940

Accretion disk is mass spectrometer for secondary composition

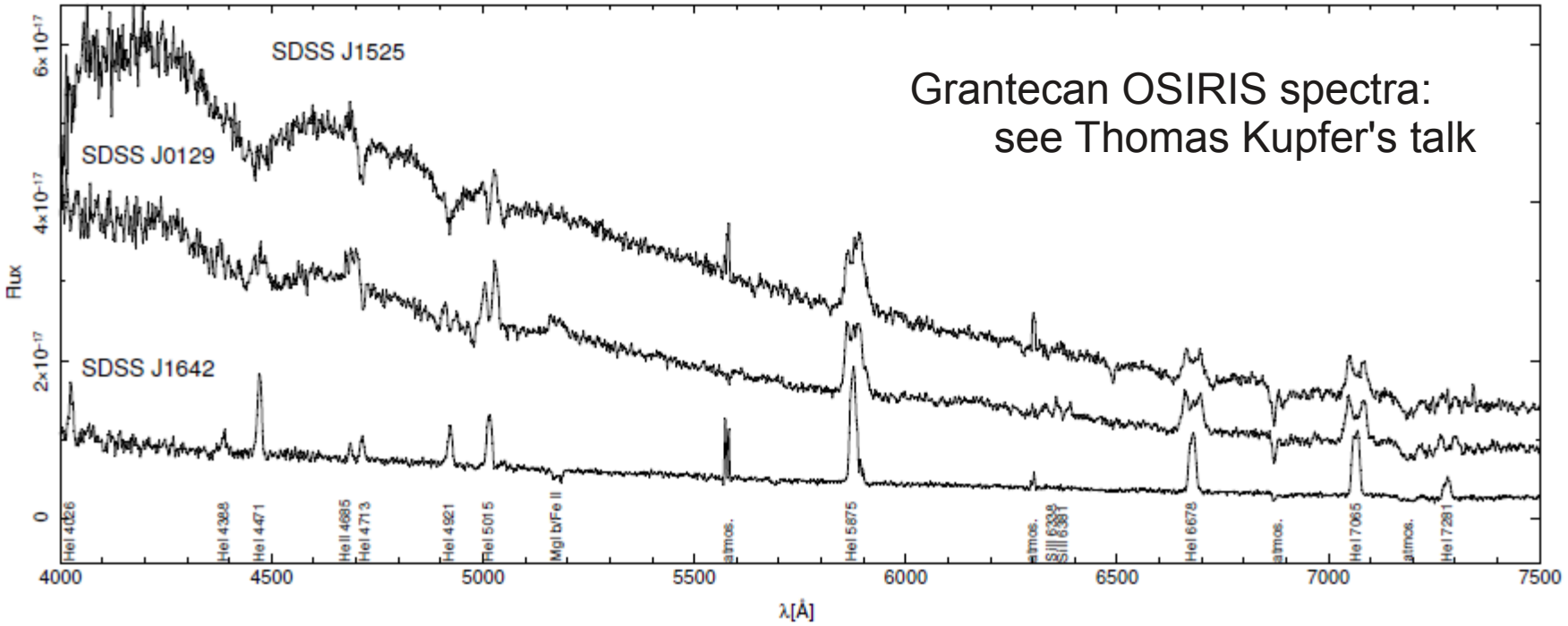


(Nelemans, Yungelson, Vd Sluys, 2010)



Metal lines in SDSSJ1908+3940
(15 min AM CVn in Kepler field)
(Kupfer et al., in prep.)

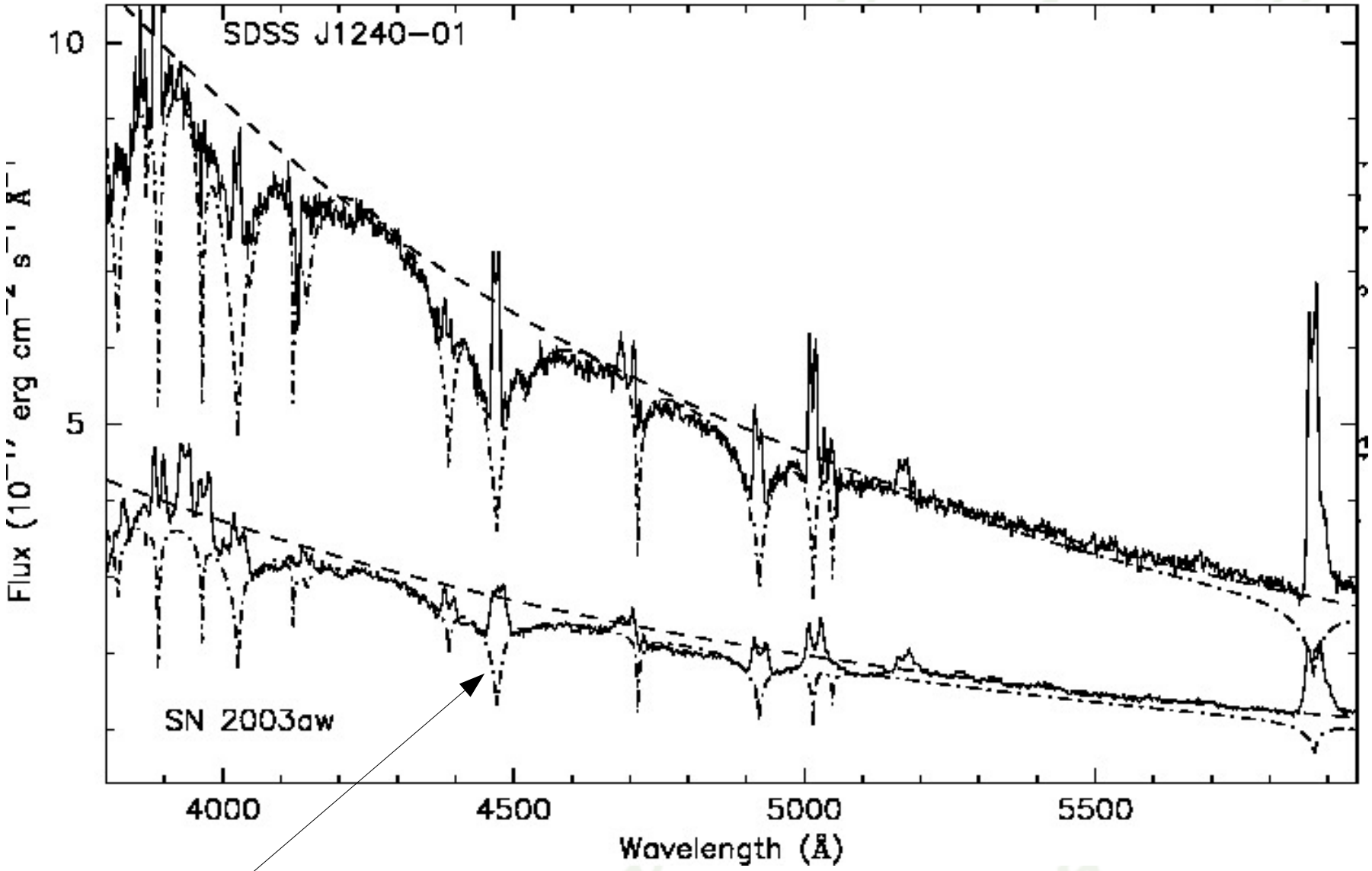
Disk modeling: a crucial tool, badly needed



As instruments get better, the need for accurate models will increase:

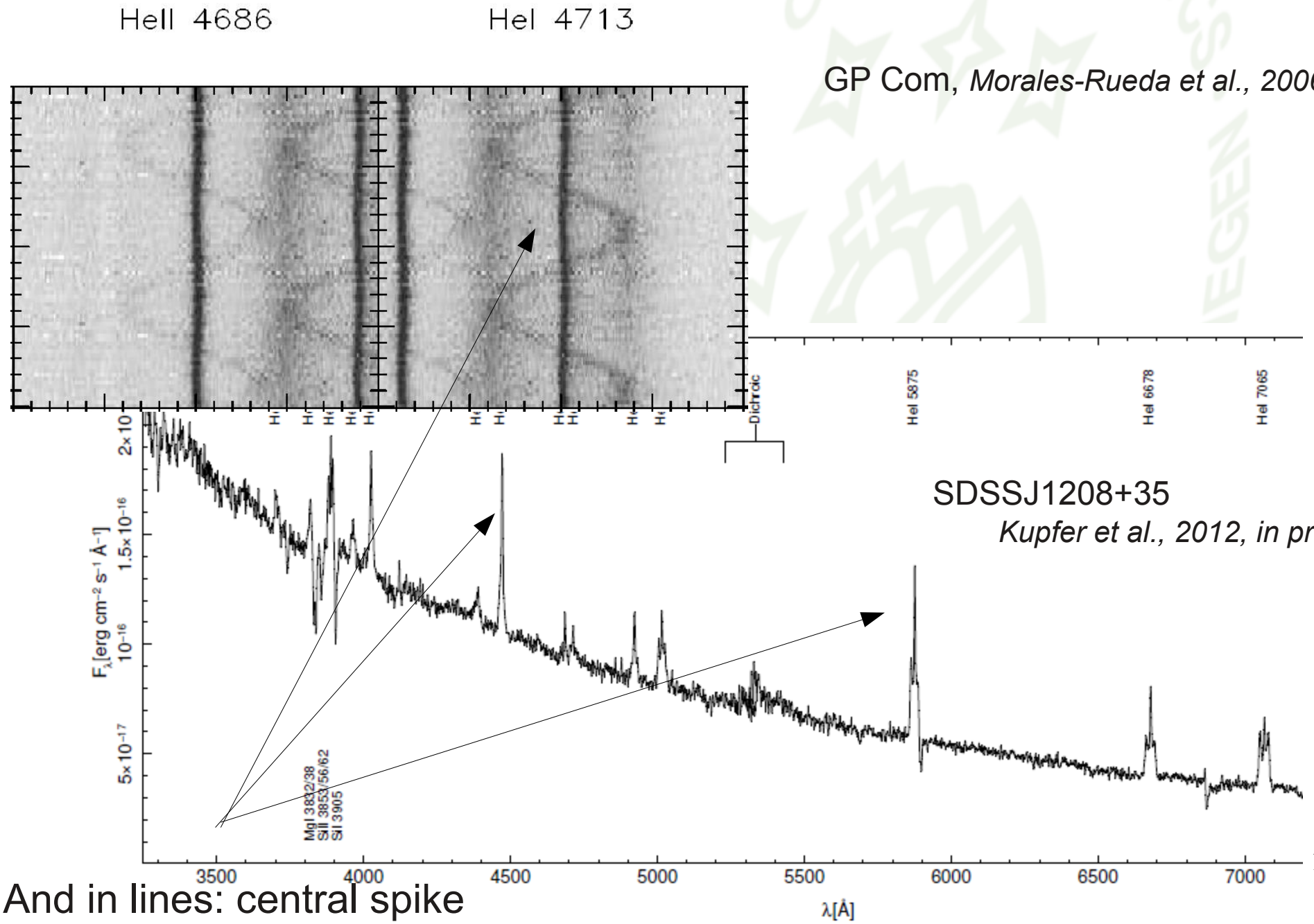
X-Shooter @ VLT, ESI @ Keck, RSS @ SALT

Physics of atmospheres: primaries



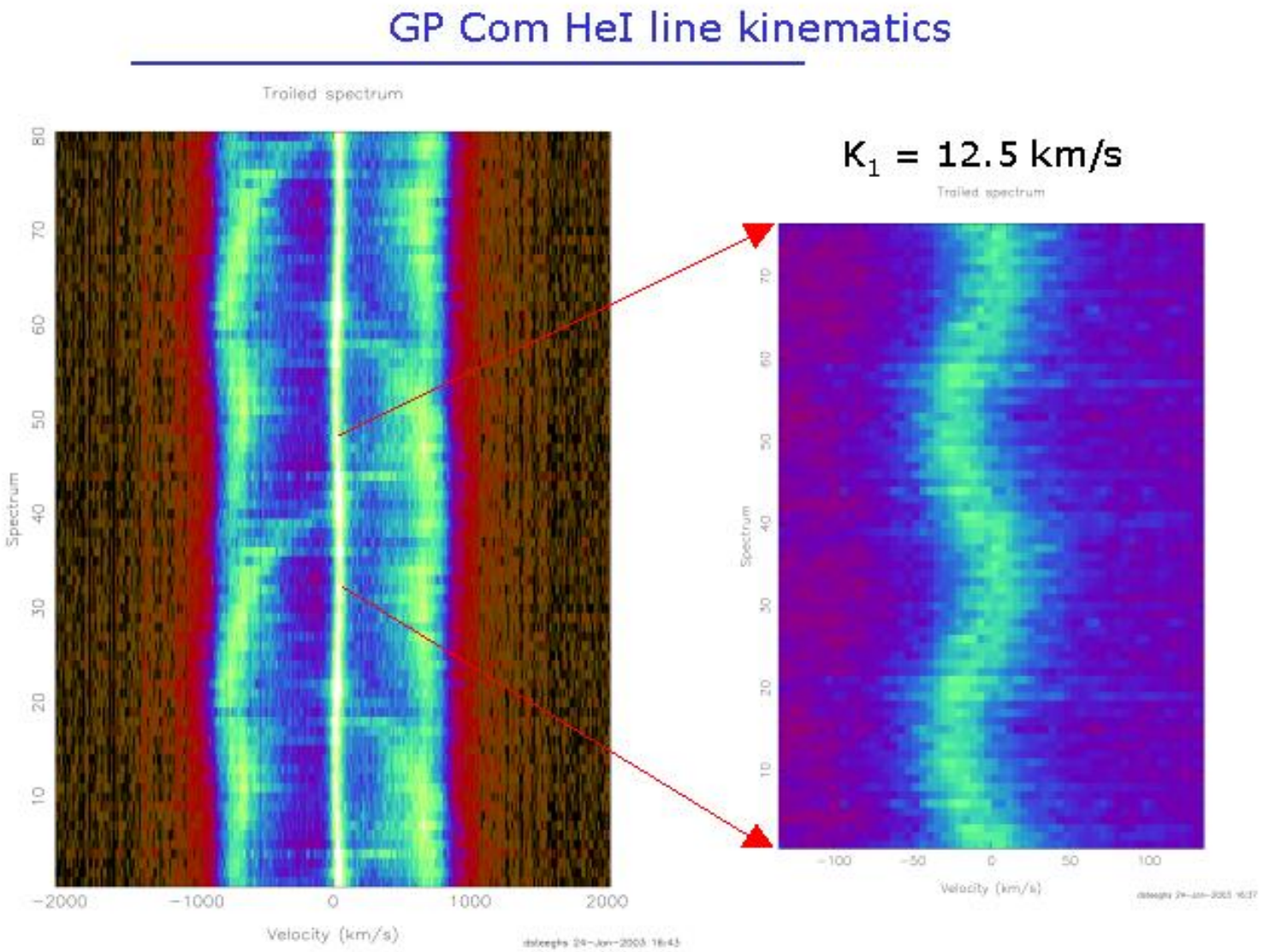
Primaries are visible in continuum

Physics of atmospheres: primaries



And in lines: central spike

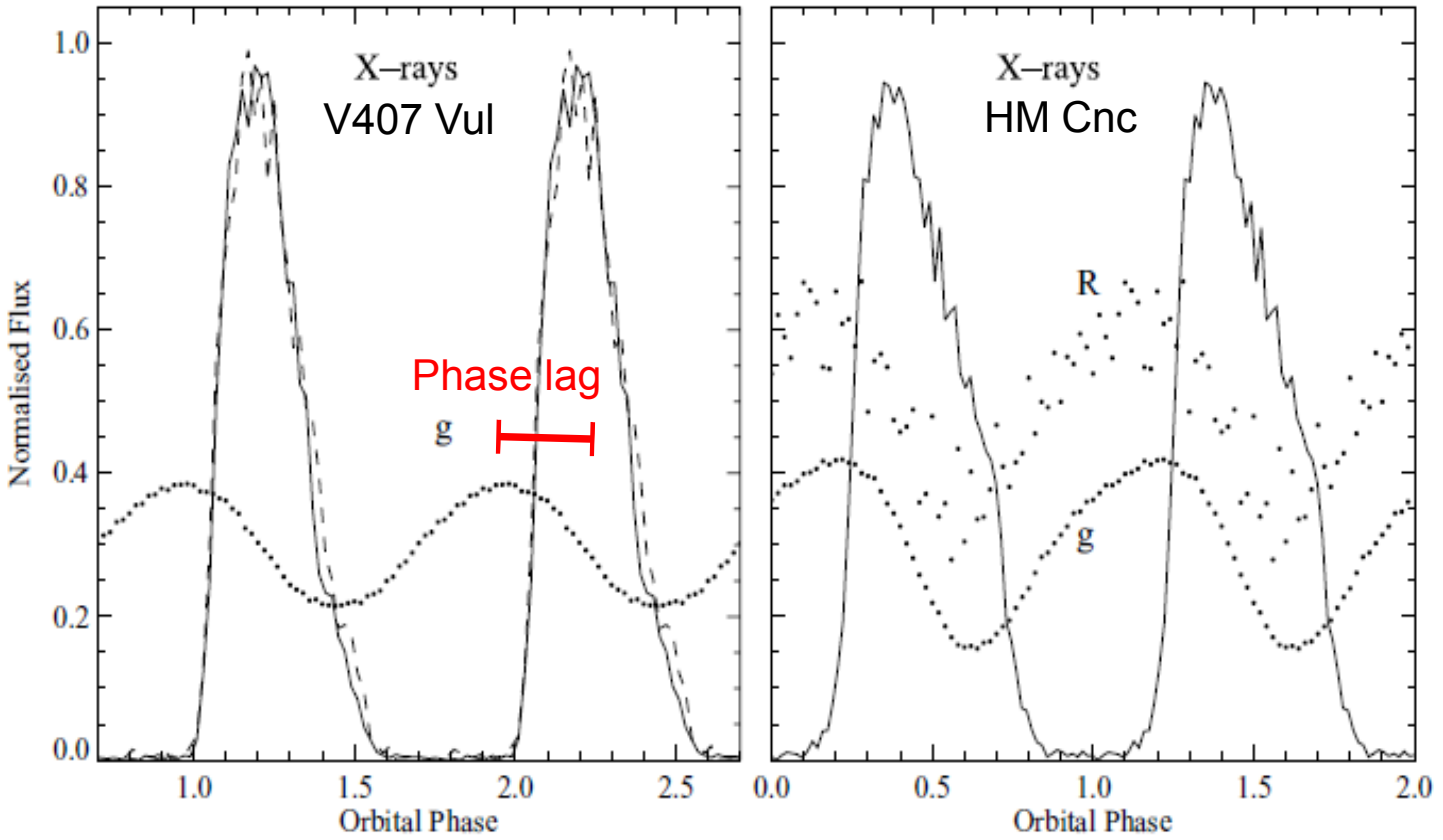
Physics of atmospheres: primaries



Talk by Danny.... Feb 1, 2003, KITP, Santa Barbara

HM Cnc & V407 Vul

- Detected as soft X-ray sources with ROSAT *(Motch et al. 1996; Israel et al. 1999)*
- X-ray and optical photometric period of 321s & 569s
- These are also *only* detected periods
- Period is currently *decreasing* at 1×10^{-17} and 3×10^{-16} s s^{-1} *(Strohmayer 2005)*
- Optically faint: V=19.9 (V407 Vul) and V=21.1 (HM Cnc)

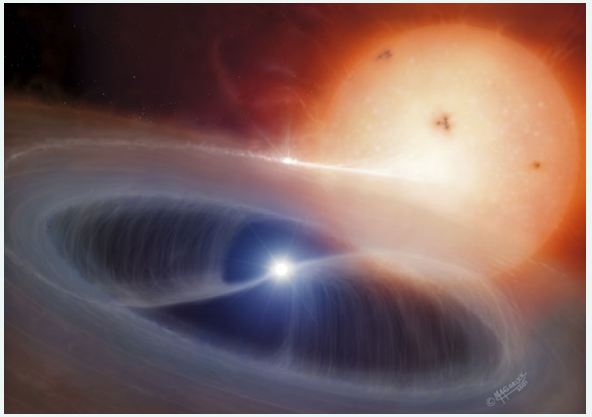


Barros et al., 2007

Three models

Intermediate polar

Motch/Israel/Norton et al.

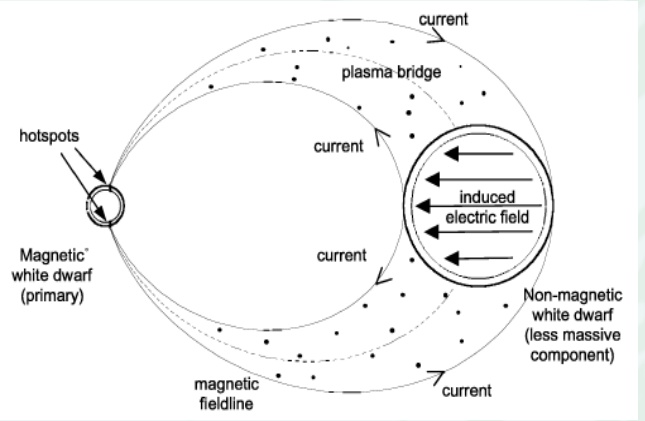


Period is not *orbital* but *spin*

→ *What is orbital period?*
→ *What causes phase lag?*

Electric Star

Wu/Dall'Osso et al.

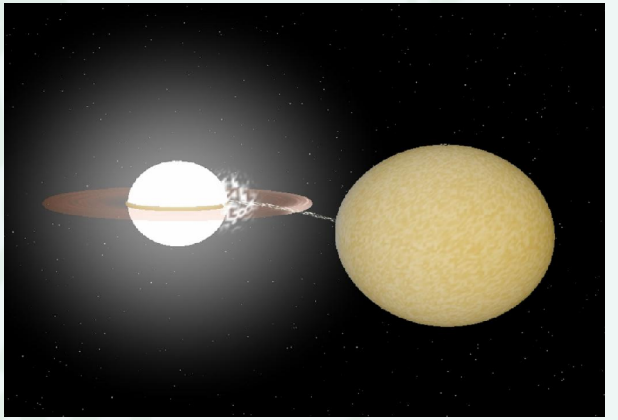


No transfer, period is orbital

→ *Phase lag? Emission lines?*
→ *Physics? Slipping footpoints*

Direct impact

Nelemans/Steeghs/Marsh et al.

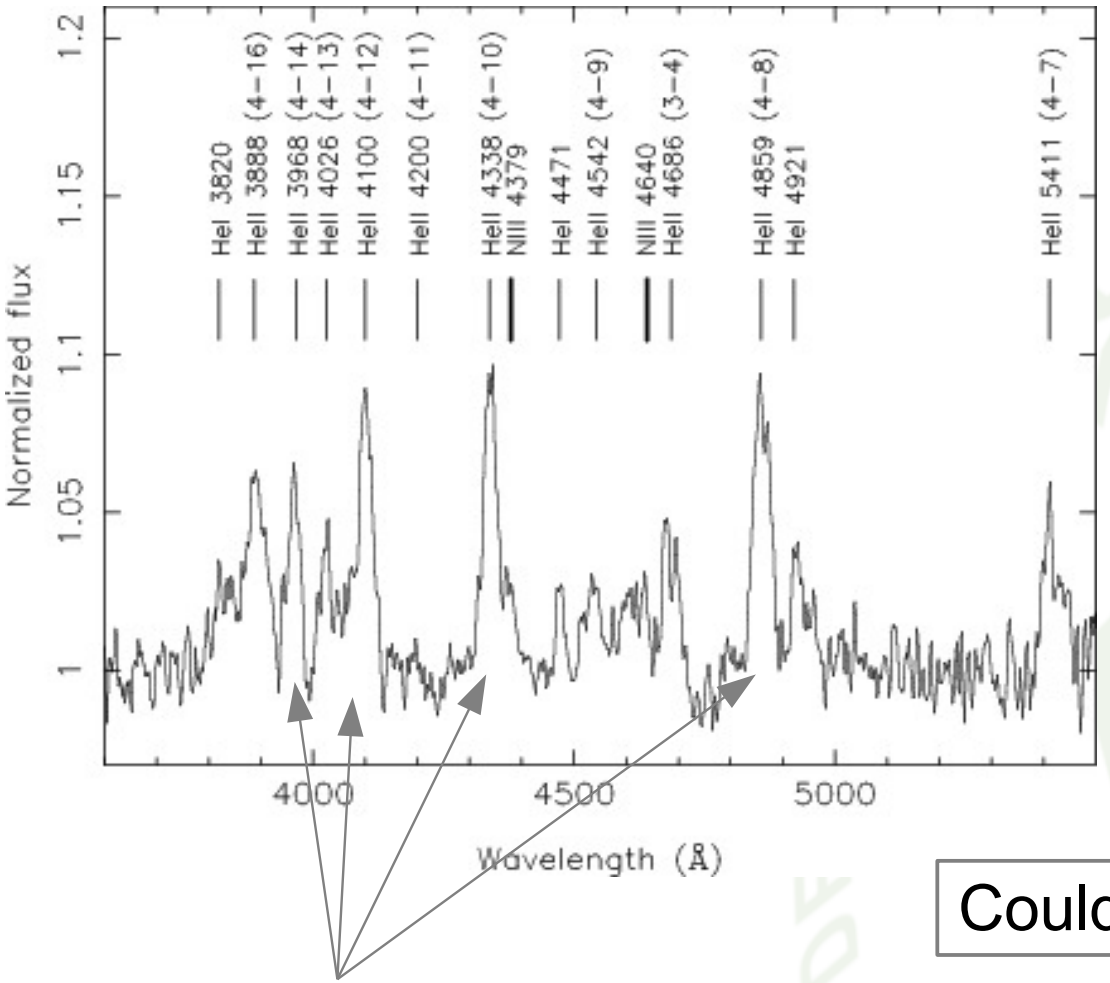


Mass transfer, period is orbital

→ *Decreasing orbital period?*
→ *Presence hydrogen?*

Radial velocity changes needed to set orbital period

HM Cnc: radial velocity changes



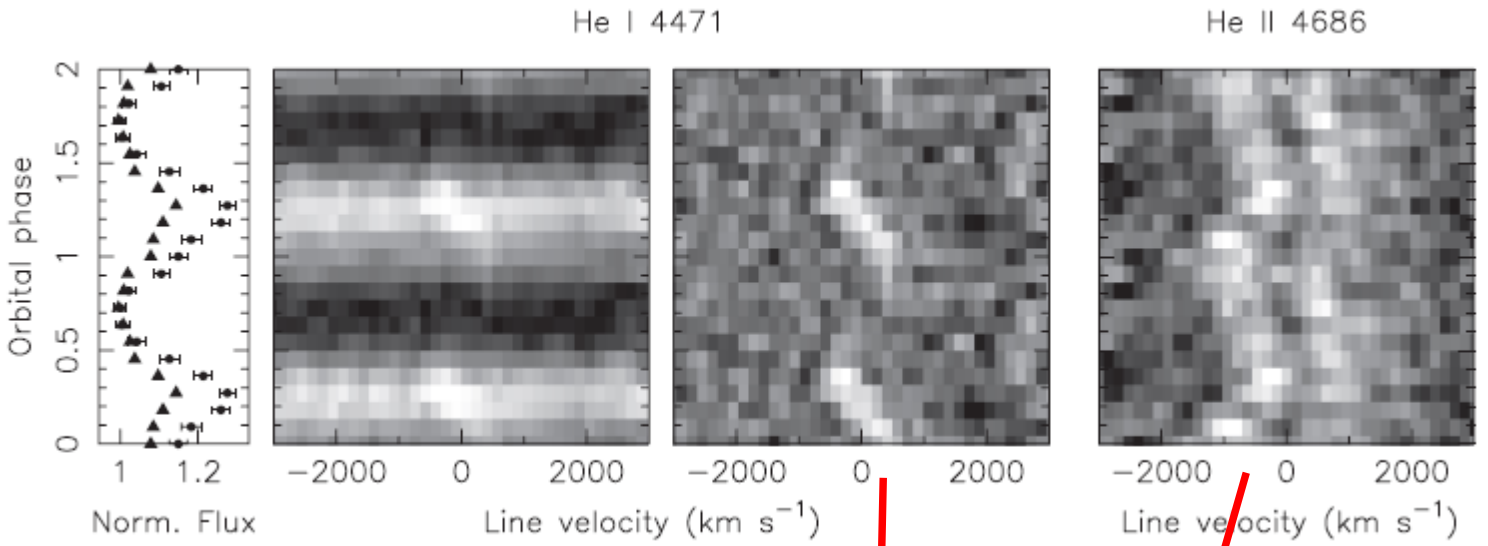
Hydrogen, not HeII

Difficult!

- HM Cnc is faint (V=21.1)
- Need to resolve orbital motion (T_{int} < 1 min)
- Emission lines are weak (< 10%)

Could only be done on Keck +LRIS

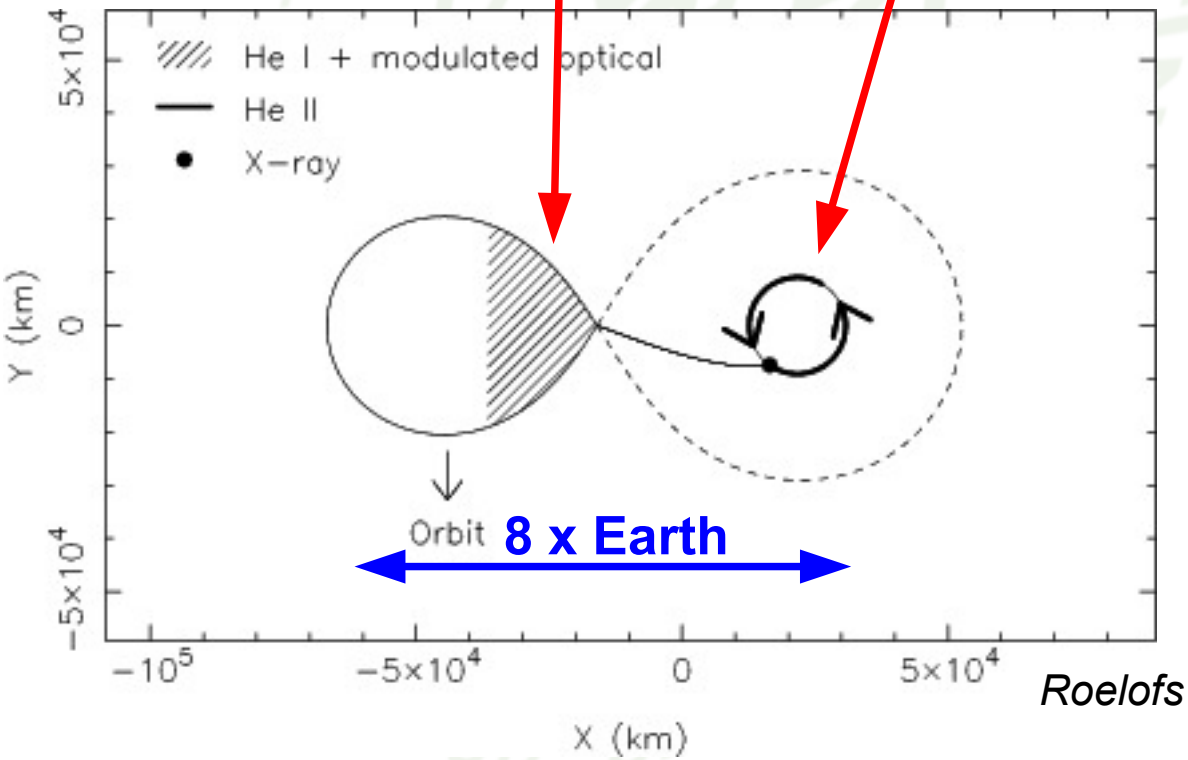
HM Cnc: P_{orb} = 5.4 min



System just started mass transfer:

Will most likely merge
(Roelofs & Deloye, 2010)

$M_1 = 0.55\ M_{sun}$
$M_2 = 0.27\ M_{sun}$

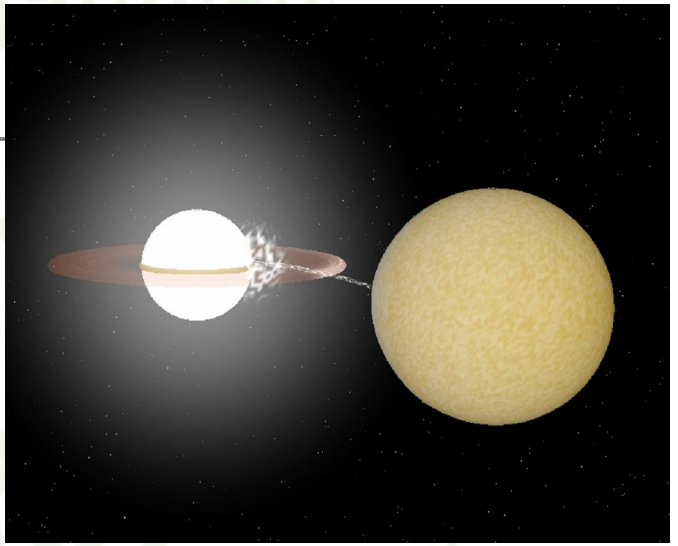


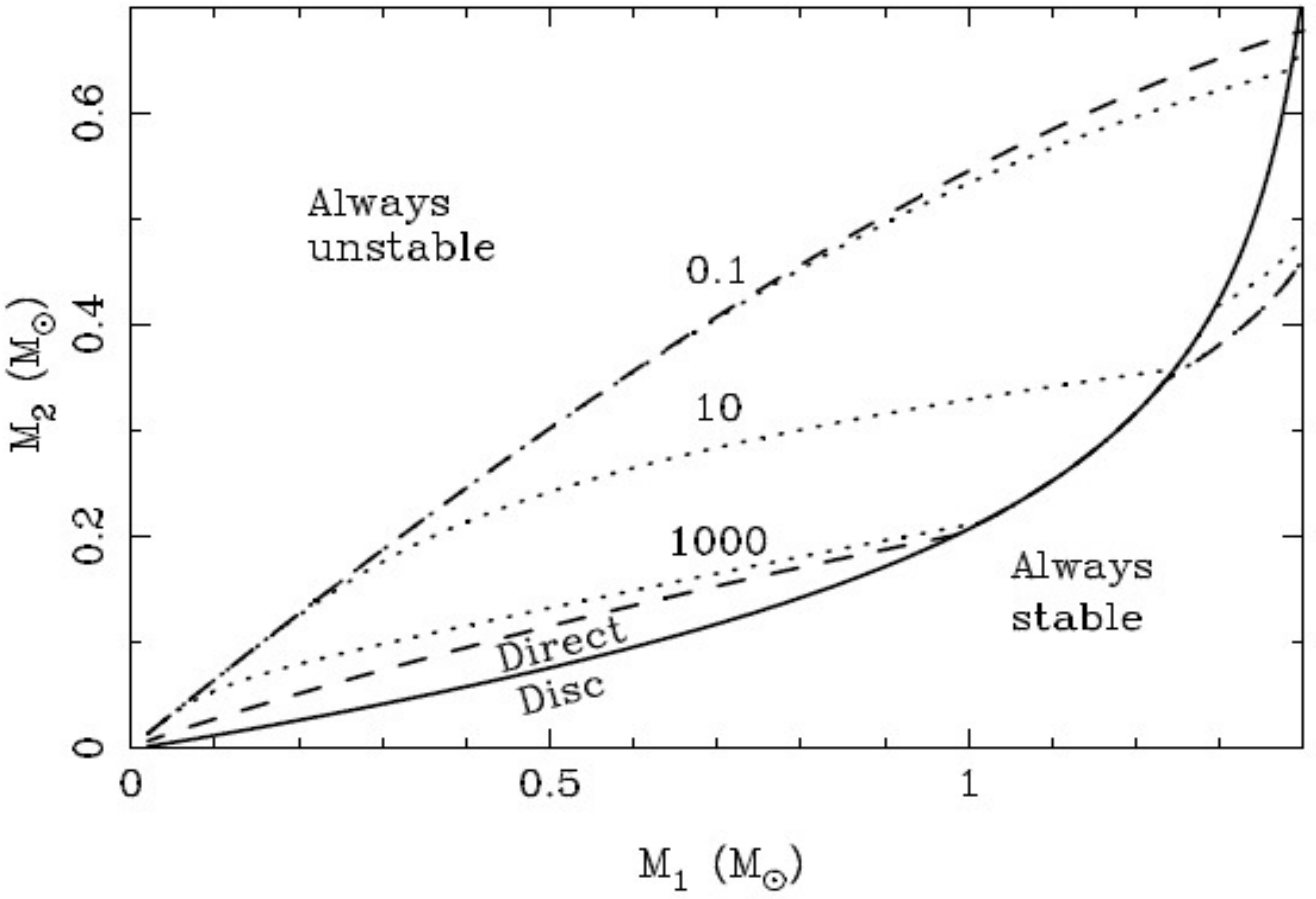
Roelofs et al., 2010

Direct impact phase

At first contact between 2 white dwarfs: separation so small that direct impact occurs

$P_{orb} \leq$ 10 min (HM Cnc, V407 Vul)



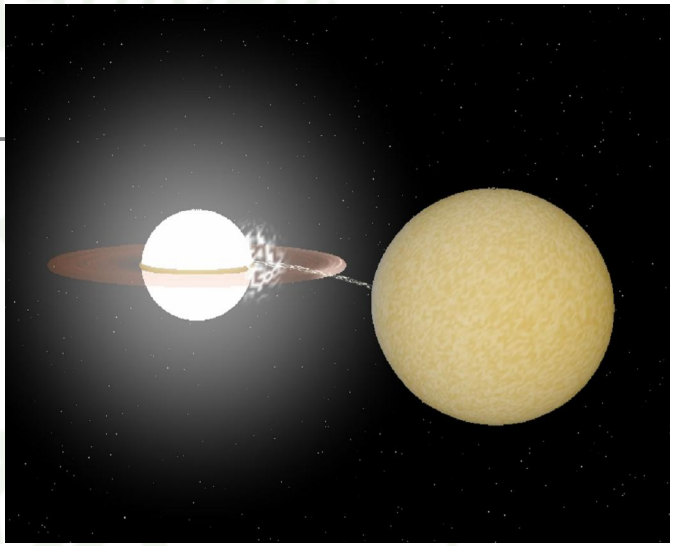


Stability depends on synchronization timescale of spin-orbit coupling:

short=stable
long = unstable

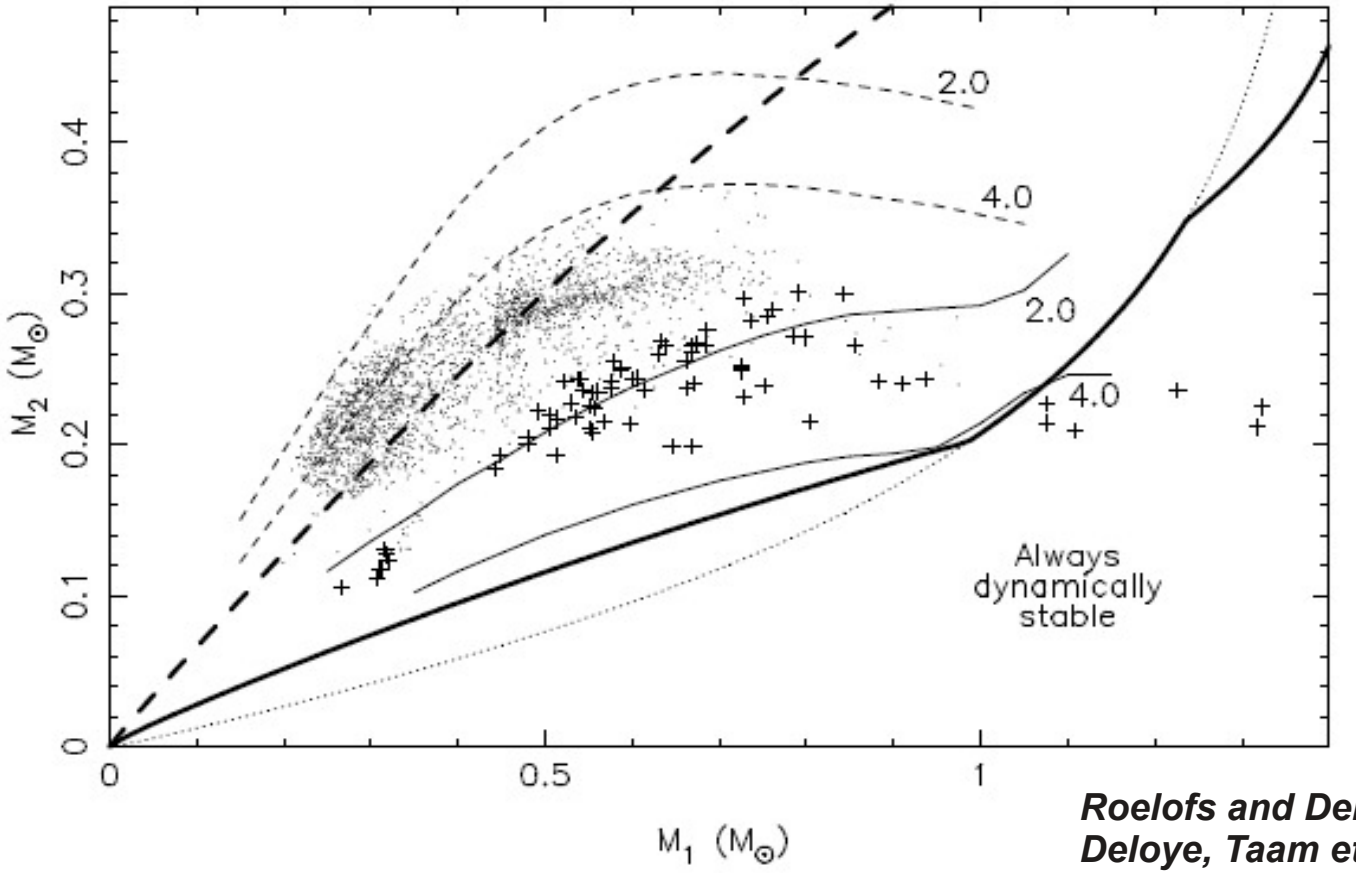
Marsh, Nelemans, Steeghs, 2004
Nelemans et al., 2001
Webbink, 1984
Smarr & Blandford, 1976
Campbell, 1984

Direct impact phase



And on degeneracy (entropy) of the donor star at start of mass transfer

Log $E_{F,c}/kT_c$ = "(degeneracy/thermal)" = 2.0, 4.0

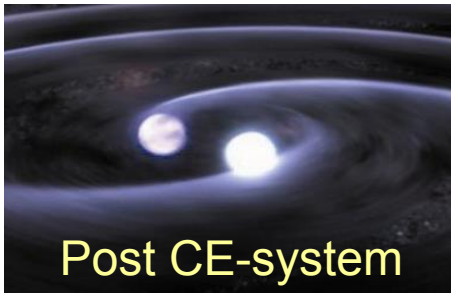


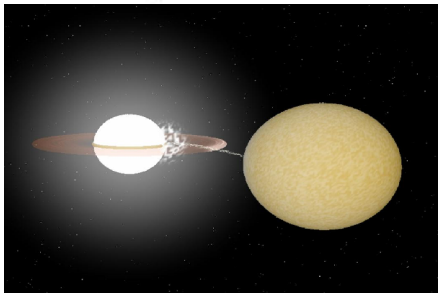
High entropy =
More stable

Low entropy =
Less stable

Roelofs and Deloye, 2010, in prep.
Deloye, Taam et al, 2007

Gravitational wave evolution





Merger
SN Ia?

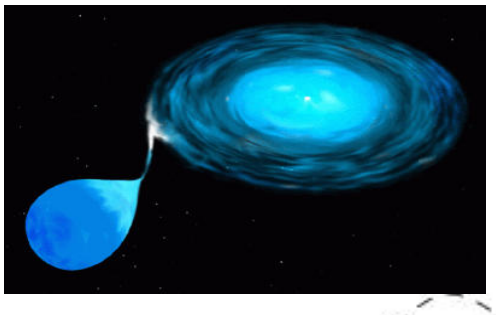
RLOF

Detached

LISA visible

LISA invisible

AM CVn



Gravitational wave strength

−20
−21
−22
−23

3.5
3
2.5
2
1.5

Orbital Period (log s)

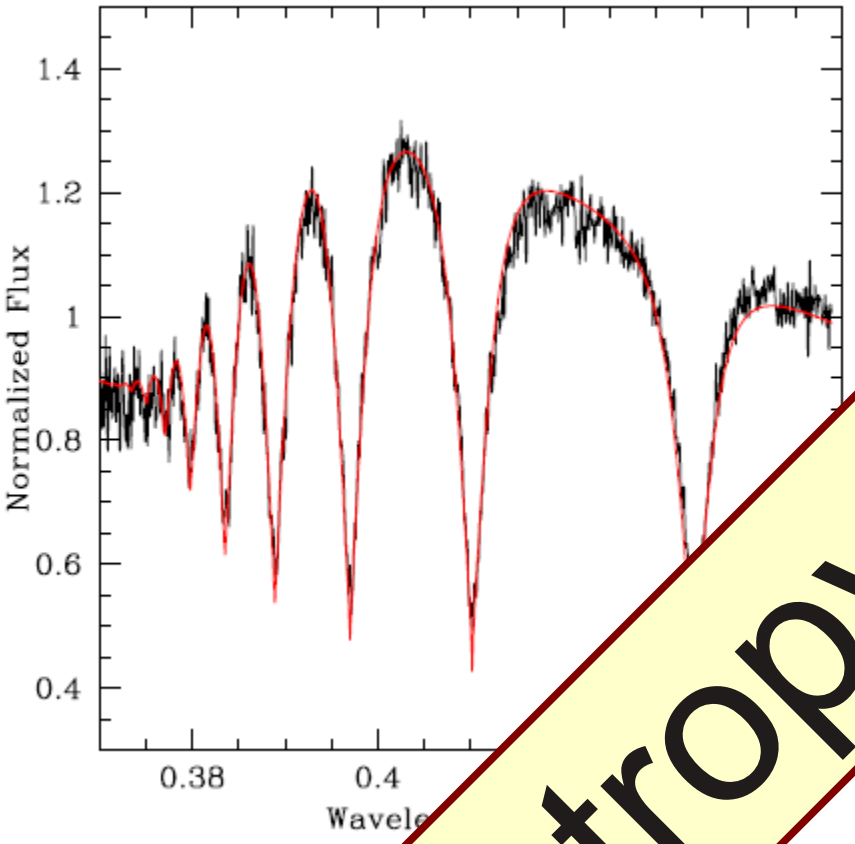
Pre-contact heating of secondary

- Tidal Torques *(e.g. Piro, 2011; Fuller et al., 2011, Benacquista ea 2011)*
- Unipolar Inductor *(Wu et al., 2002; Dall'Osso et al. 2006, 2007)*
- Accretion irradiation heating *(Roelofs et al., 2010)*
- Magnetic irradiation heating *(Kuijpers & Groot, in prep.)*

With only one 1 clear pre-contact system (SDSSJ0651+28):
still unclear, but will grow into rich field!

Hot secondary in 12 min DD

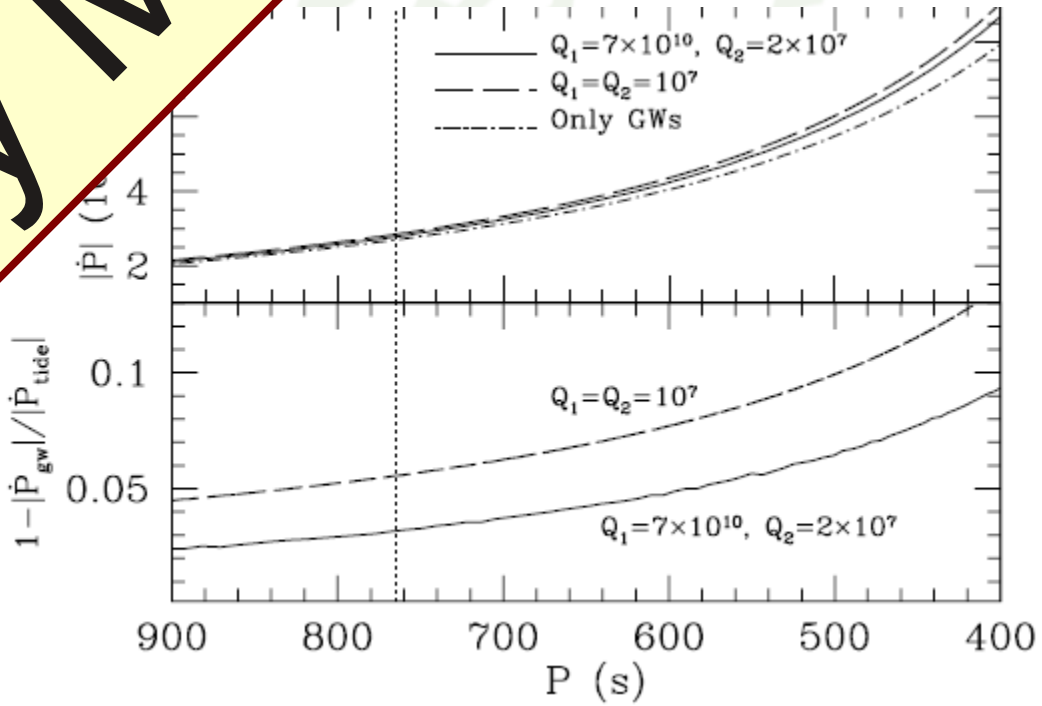
$M_1 = 0.55\ M_{sun}$, $M_2 = 0.25\ M_{sun}$, ***T_2 = 17000 K***



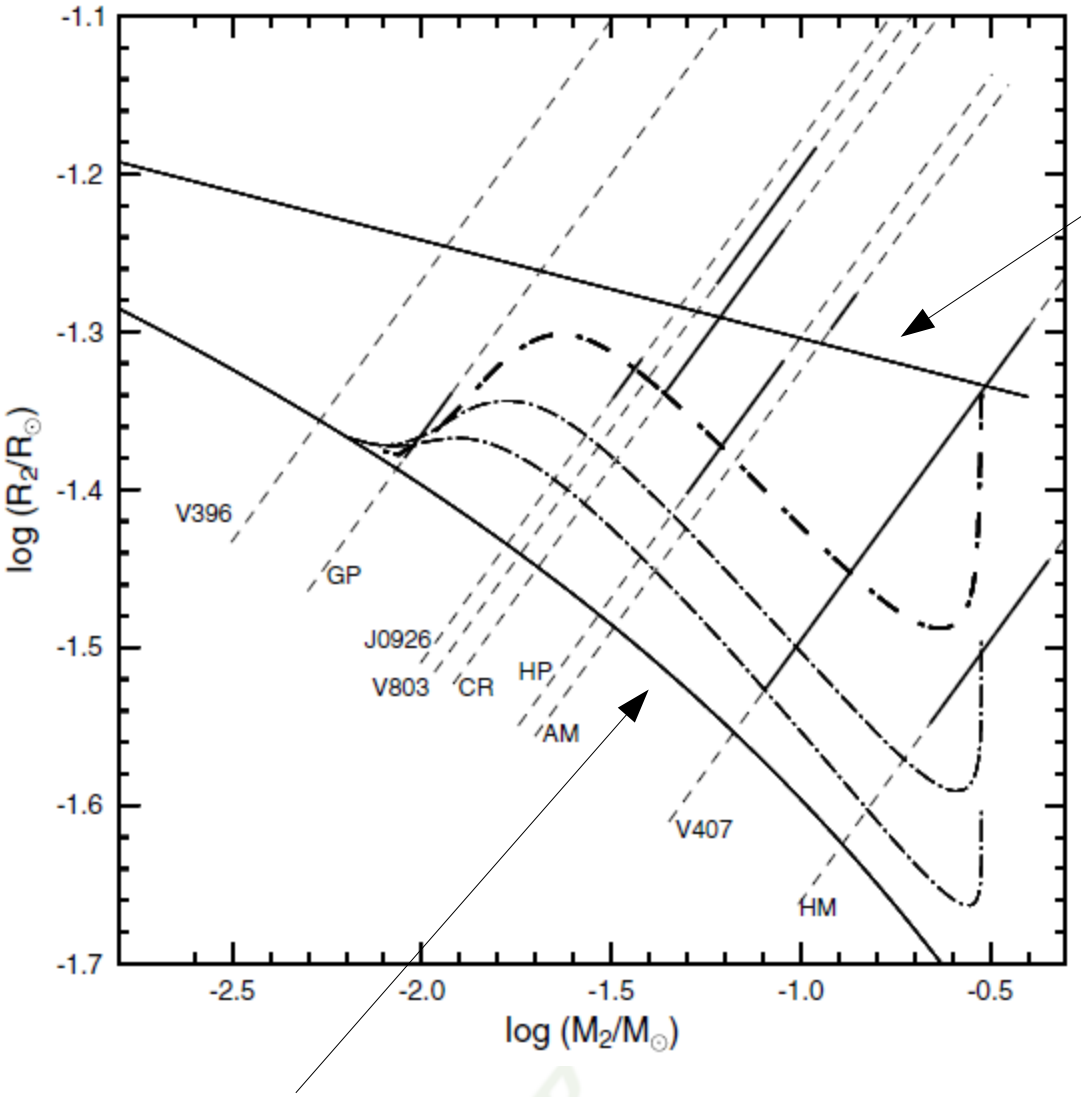
- Remnant he… …it
  …ivelope (~20min)
  → …e
- Late… …y 1 flash *(see Sterl & Jing)*
- …rques *(Fuller et al., 2011; Piro 2011; Benacquista 2011)*

Shift in … …lipse over 1 ye… …nds!

Entropy Matters!



AM CVn secondaries: Basic data and EoS

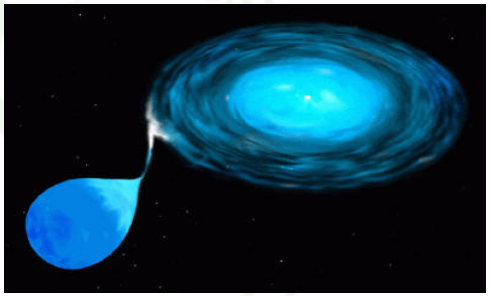


Semi-degenerate

Fully denegerate

Solheim, 2010, combining data and models

Helium (super)novae



Log L

Log M_{dot}

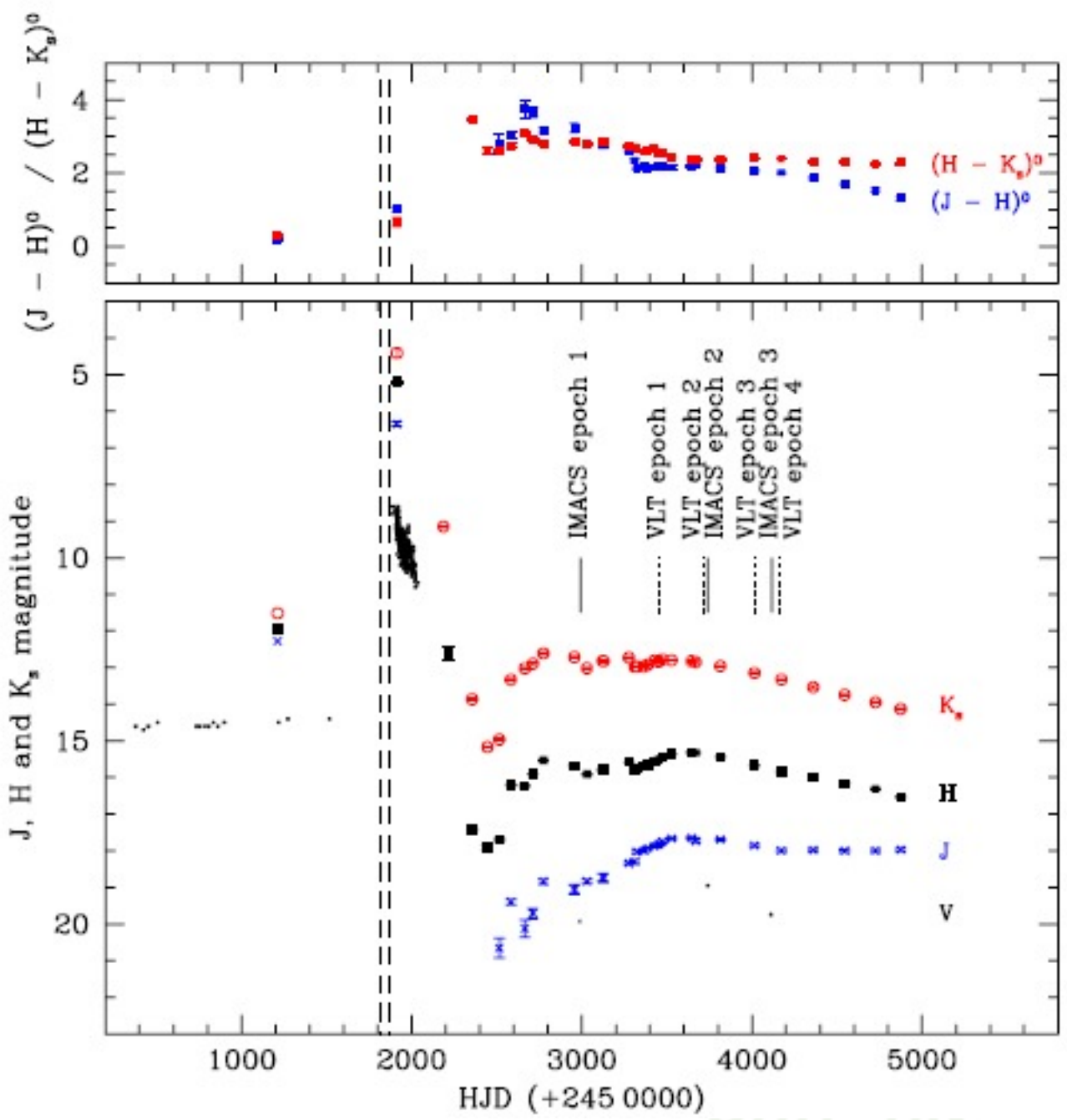
Log t

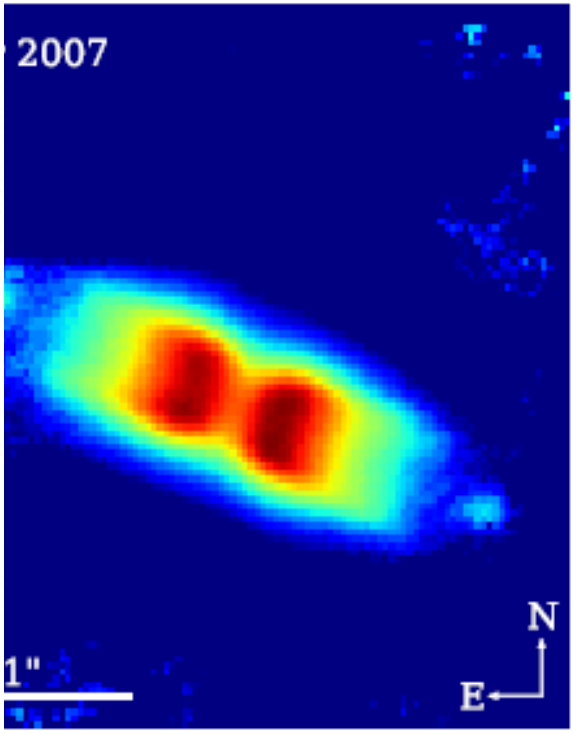
Helium Novae

Helium supernova (Type .Ia)
Fusion on dynamical timescale
(Bildsten et al., 2007; Shen et al., 2009,2011)

Evolution
AM CVn star

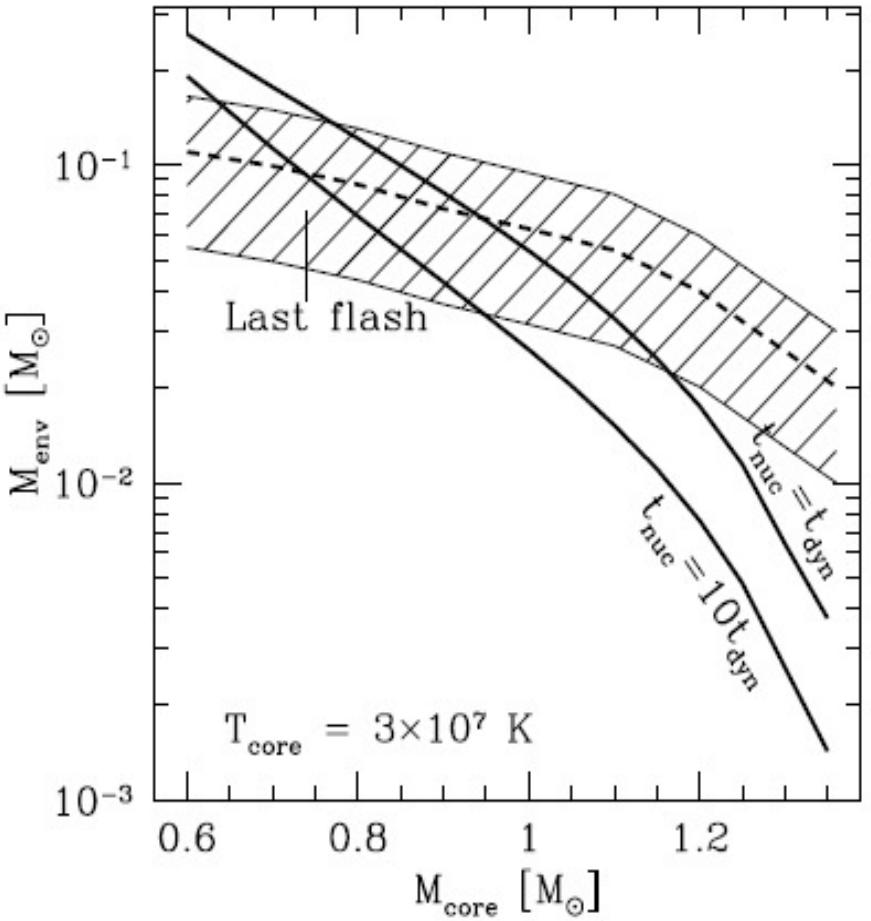
First helium nova: V445 Puppis





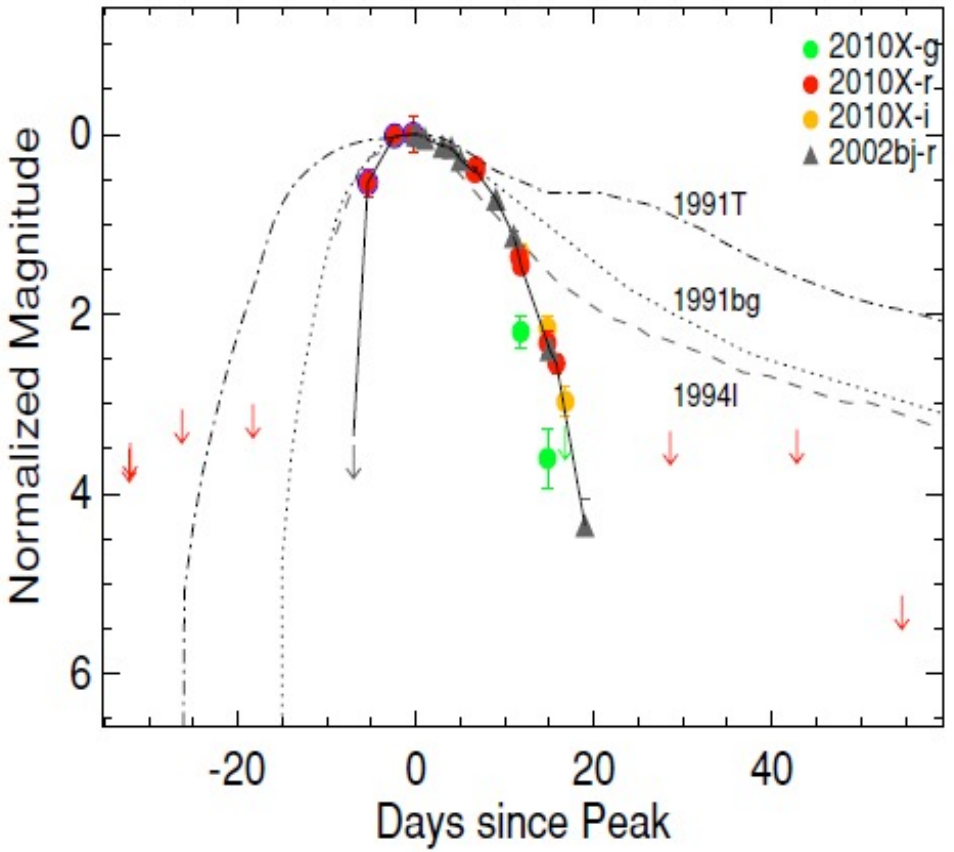
ar)

Supernovae Type .Ia ('point Ia')



Thermonuclear flashes in high state systems: L ~ 0.1 L_{SNIa}, $\tau \sim 0.1\ \tau_{SNIa}$, $f = 0.1\ f_{SNIa}$

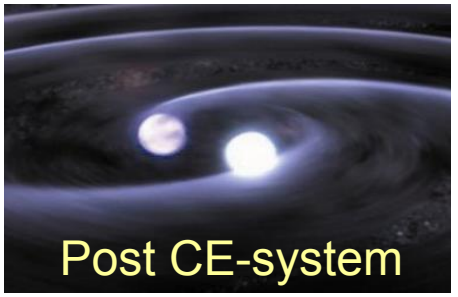
Bildsten et al., 2007
Shen et al., 2009, 2011

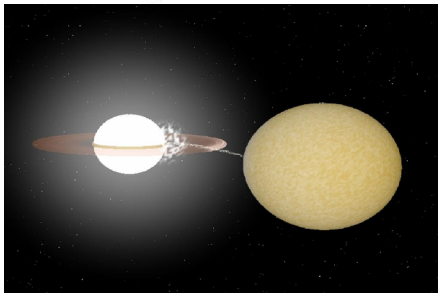


SN2002bj: SN .Ia?
Poznanski et al., 2009

SN2010X: PTF discovery
Kasliwal et al., 2010

Gravitational wave evolution





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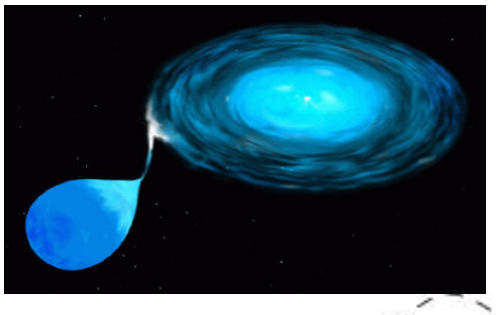


Gravitational wave strength

−20

−21

−22

−23

3.5

3

2.5

2

1.5

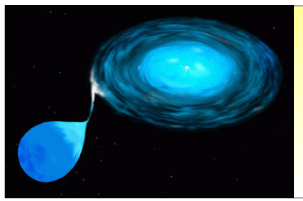
Orbital Period (log s)

Post-Merger systems

- What are they?
  Single massive WD, R CorBor, sdB, NS, low-mass BH?
- Where are they?
  Are they lurking in our knowledge/archives?
- How do we recognize them?
  How do we tie them to their DD past?

Populations

- Certainly doing much better on the *numbers*
- But do we understand them?

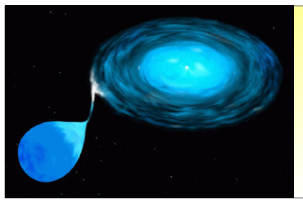


Results of/Predictions for Sloan

Model	Modelled # ($N'_{\rm spec}$)	Total in SDSS-I ($N_{\rm phot}$)	Modelled ρ'_0 (pc^{-3})	Observed ρ_0 (pc^{-3})	Observed σ (deg^{-2})
Optimistic	107	52	2.6×10^{-5}	1.5×10^{-6}	6.5×10^{-3}
Pessimistic	12	67	6.2×10^{-6}	3.2×10^{-6}	8.4×10^{-3}
He star only, optimistic	16	67	8.8×10^{-6}	3.4×10^{-6}	8.4×10^{-3}
He star only, pessimistic	11	68	5.9×10^{-6}	3.3×10^{-6}	8.5×10^{-3}
WD only, optimistic	91	50	1.7×10^{-5}	1.1×10^{-6}	6.2×10^{-3}
WD only, pessimistic	0.85	57	2.4×10^{-7}	1.7×10^{-6}	7.1×10^{-3}

Table 1. Observed space densities of AM CVn stars for different assumptions regarding their populations; the observed ρ_0 is obtained by multiplying the modelled ρ'_0 by $N_{\rm spec}/N'_{\rm spec}$ where $N_{\rm spec} = 6$. 'Optimistic' and 'pessimistic' models from Nelemans et al. (2001) with the Galactic model of Nelemans et al. (2004). The total $N_{\rm phot}$ is the number of emission-line AM CVn stars in the SDSS-I photometry down to $g_{\rm max} = 21$. The measured surface density σ down to $g = 21$ holds for Galactic latitudes $b \gtrsim 30°$. The observed ρ_0 and σ are accurate to an estimated factor of 2.

Total number of AM CVn stars in Sloan: ≥ 50



Predictions from/for Sloan

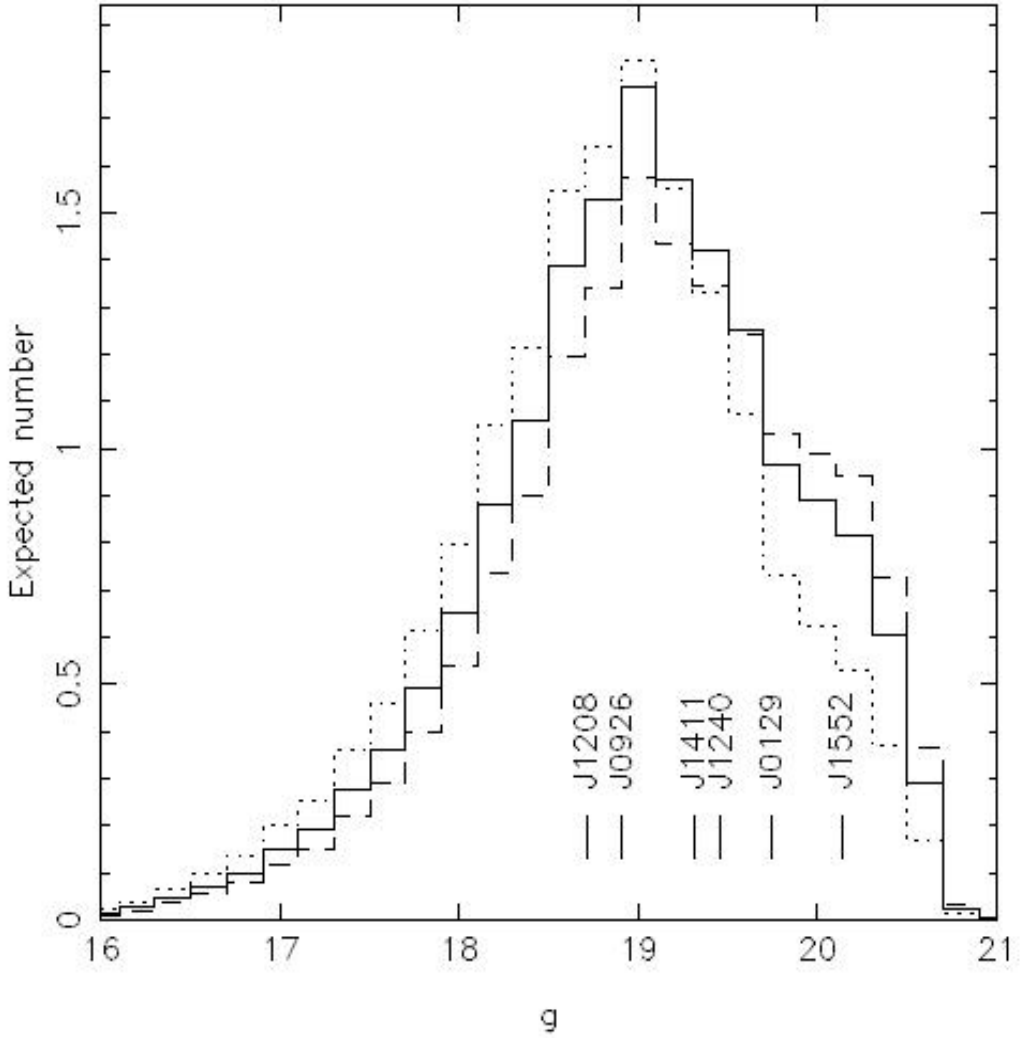


Figure 5. Modelled distribution of spectroscopically identified AM CVn stars in SDSS-I as a function of apparent magnitude g, in the *pessimistic* model. The dotted, solid and dashed lines represent model population scale heights of 200, 300 and 400 pc, respectively.

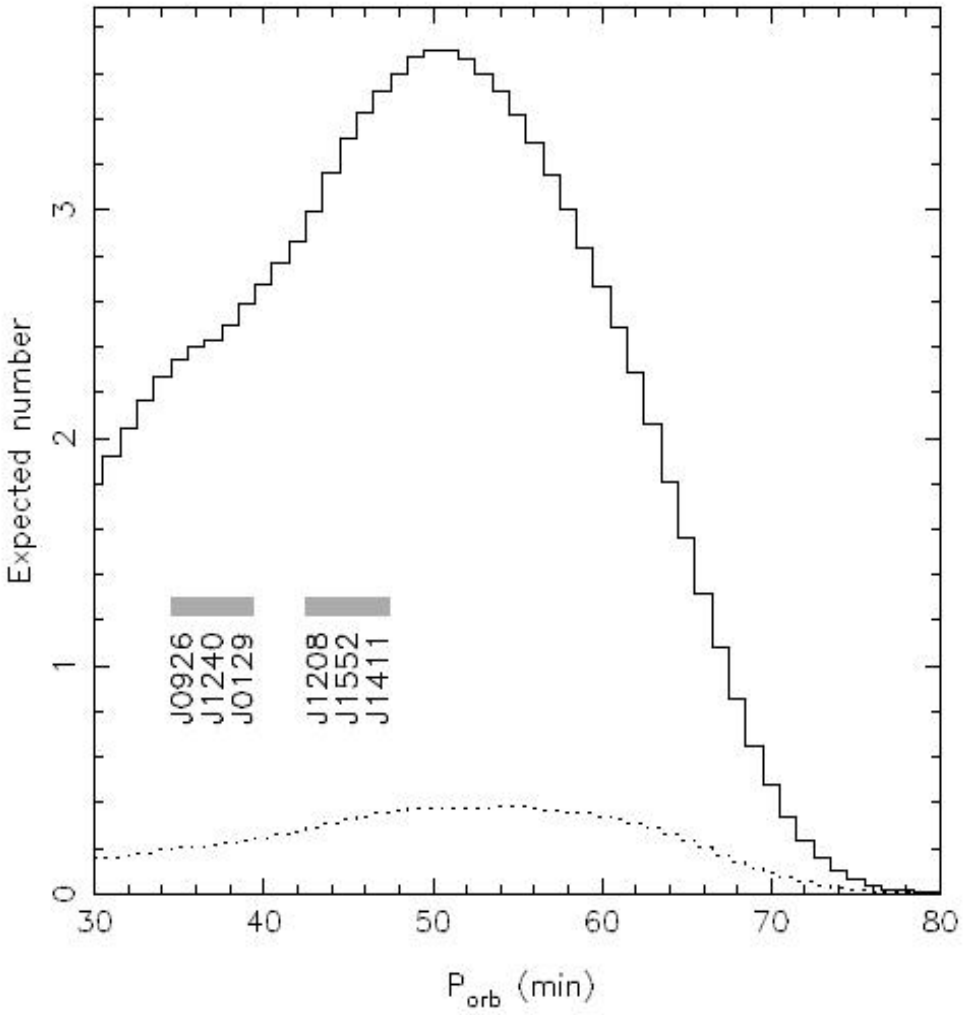
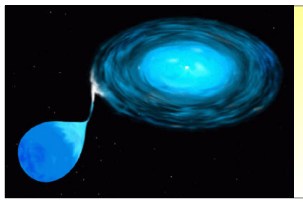
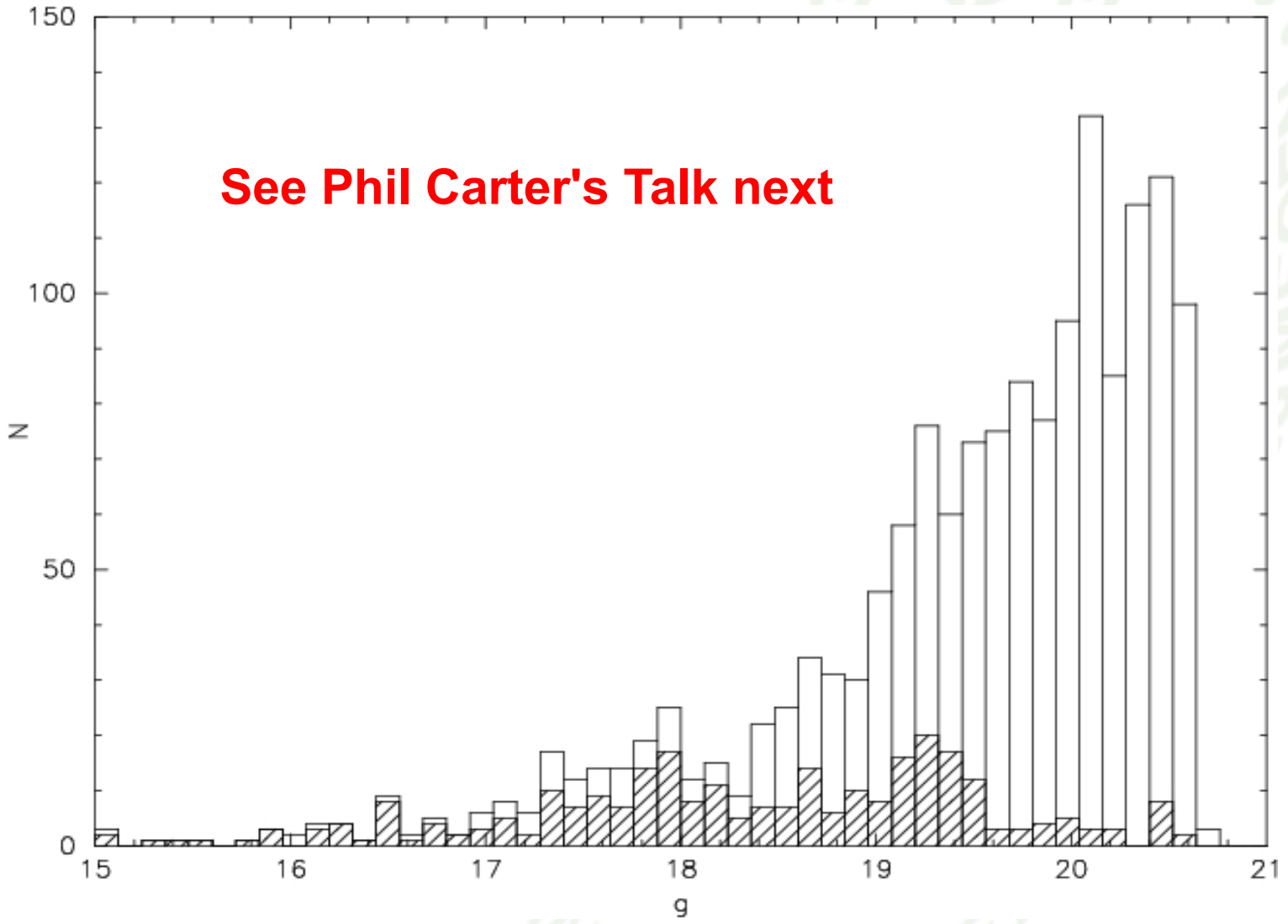


Figure 6. Modelled distribution of spectroscopically identifiable AM CVn stars in SDSS-I as a function of orbital period, along our modelled cooling track. The periods of the 6 detected AM CVns are *not* their measured orbital periods, but their modelled values based on their colours. The solid and dotted lines are the optimistic and pessimistic models, respectively.

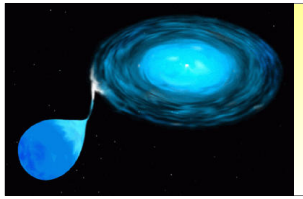


2008: Go Hunt in SDSS...



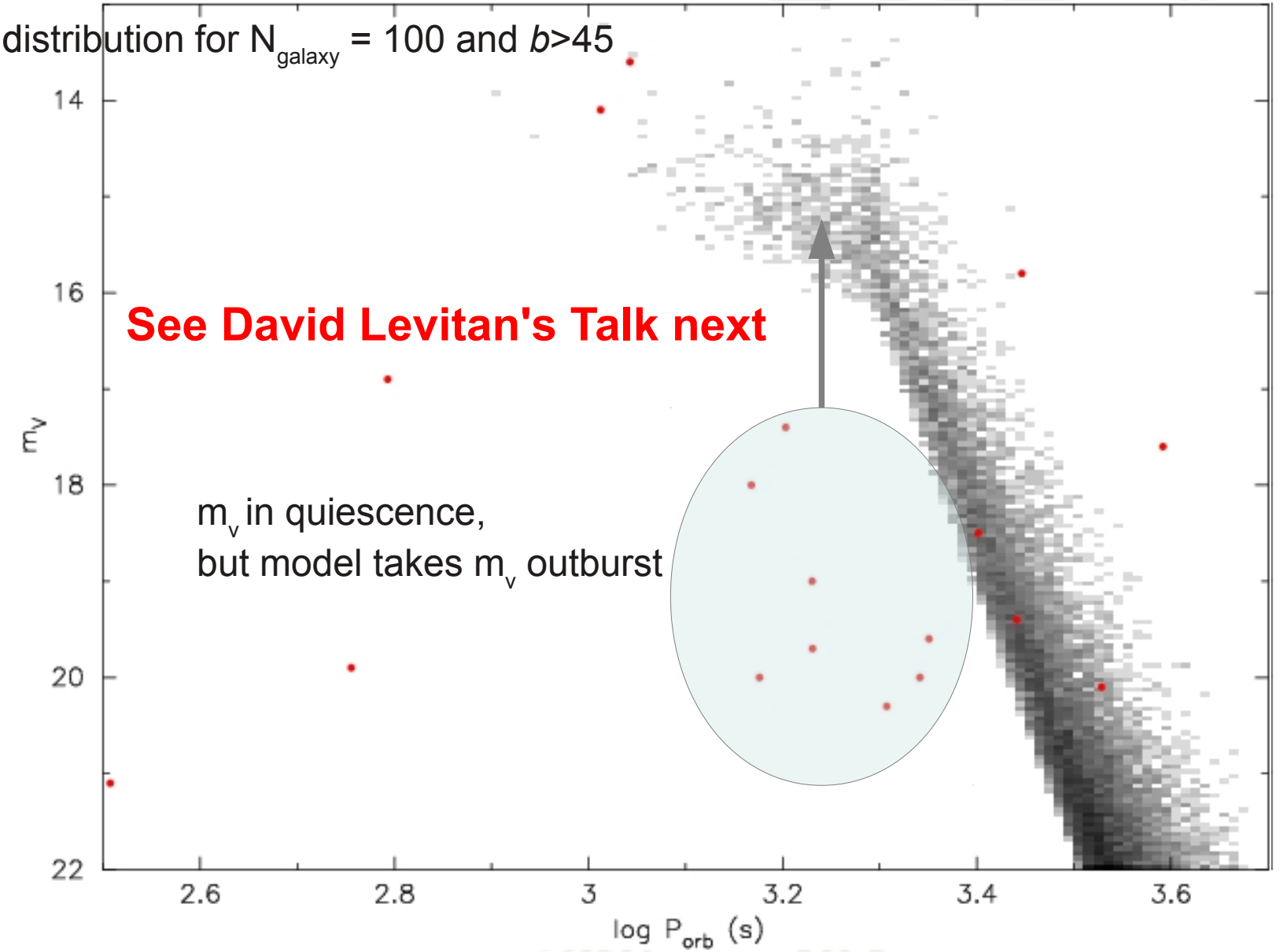
19% done

Ongoing program on 1.5m Tillinghast, INT, WHT, VLT, Keck, Hale



Expected distribution

Probability distribution for N_{galaxy} = 100 and *b*>45



The next three years

1: ***Short period systems and progenitors***

2: ***Follow-up of systems: transients and broad-band...***

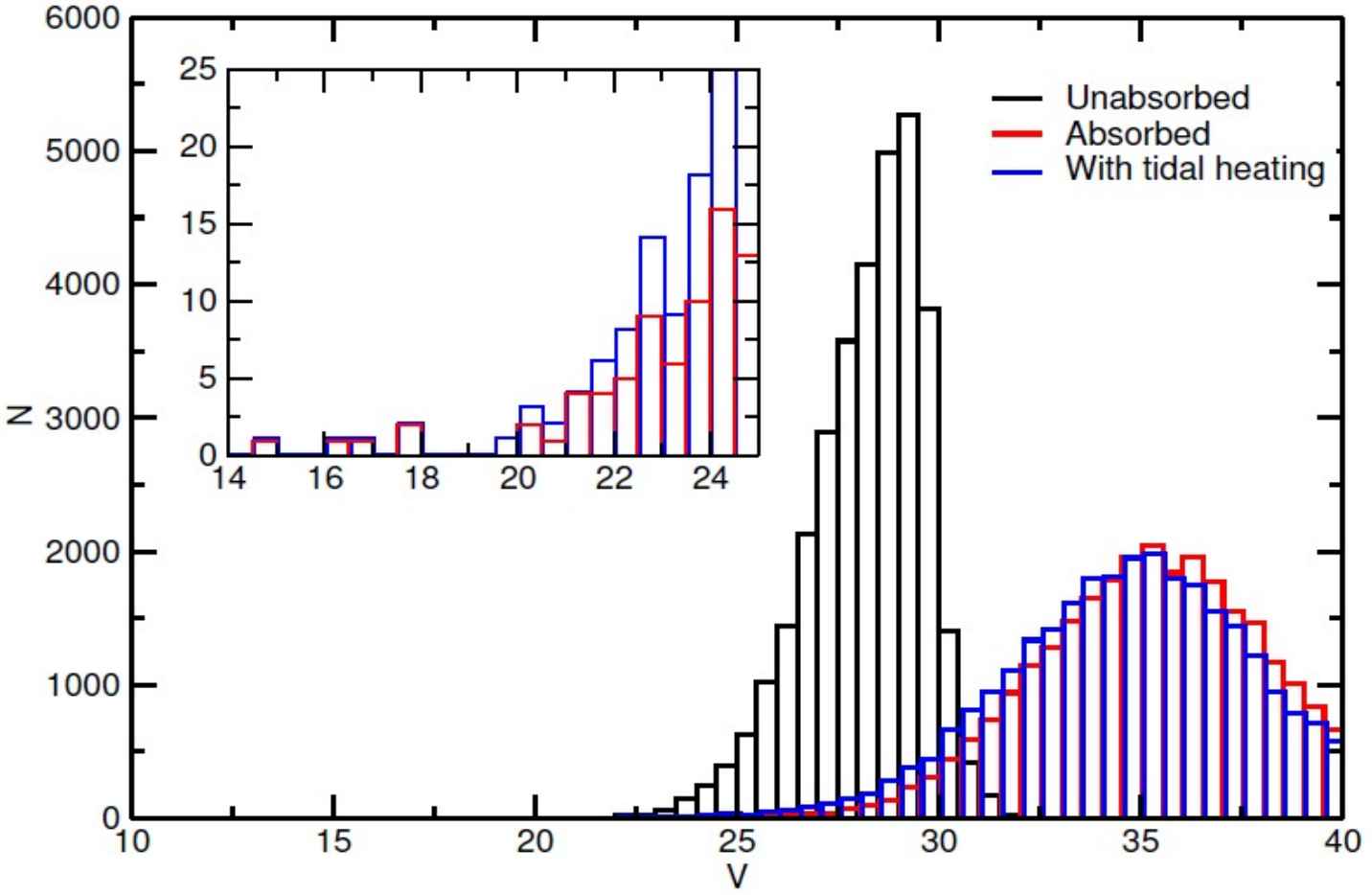
3: ***NextGen surveys: what needs to be done***

1: Short period systems & progenitors

→ How do we find more HM Cncs and V407 Vuls?

- Optical wide field surveys:
  - EGAPS (IPHAS, UVEX, VPHAS+)
  - VST
  - SDSS-*N*
- UV/X-ray surveys: XMM & Chandra (GBS/Plane), *GalexGalaxy*
- Radio: LOFAR, MeerKAT, ASKAP ***(Radio flare of HM Cnc!)***
- Transient surveys:
  - PTF (2), SkyMapper, PanStarrs, LOFAR, ThunderKATS, VVV

Follow-up



- Already 10m class work: VLT, Keck, GTC, SALT. Bottleneck?
- Availability 2-4m class telescopes for ID-ing and photometry

Can we 'sell' ourselves as necessary for Gaia, Euclid, aLIGO/VIRGO, NGO/eLISA?

NextGen surveys: ready?

- EGAPS (IPHAS, UVEX & VPHAS+)
- PTF(2), SkyMapper, PanStarrs
- VST-Kids
- LOFAR TSKP, ThunderKATS, ASKAP
- Gaia
- Euclid
- LSST & NGO

Are we on the starting block to take full advantage?
What is still needed? (except manpower, which is very clear)