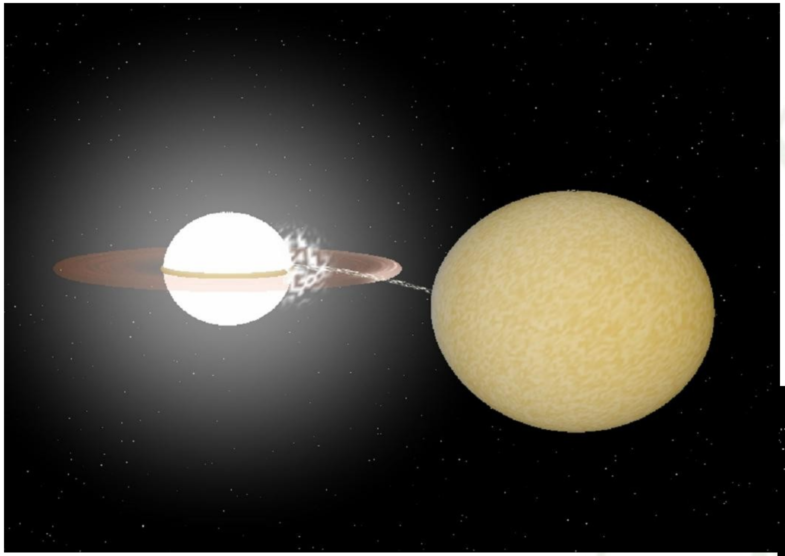
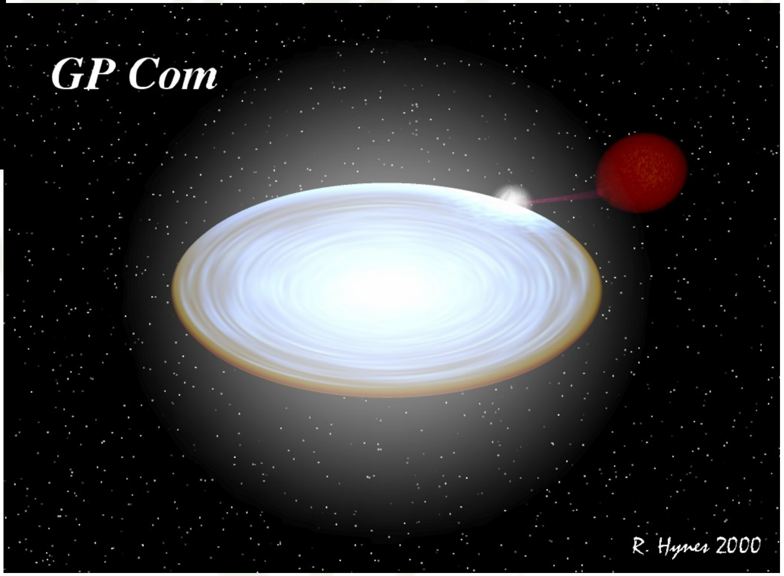
Ultracompact binaries





Paul Groot,
Radboud University Nijmegen
& Caltech

Collaboration:
Gijs Nelemans, Tom Marsh, Danny Steeghs, Patrick Woudt, Lev Yungelson,
Lars Bildsten, Tom Prince, Shri Kulkarni, Gijs Roelofs, David Levitan, Thomas Kupfer

Ultracompact Binaries

Stellar binaries with degenerate primary and secondary star

White dwarf

+ WD **10**

- Detached
  Double degenerates
- Semi-detached:
  AM CVn stars **32**

Neutron Star

+ WD

- Detached WD+NS systems: **1**
  WD+pulsar
- Semi-detached:
  Ultracompact X-ray binary **9**

+NS

- NS+NS system: **double pulsars** **3**

Black Hole

+ WD **0**
?

+ NS **0**
?

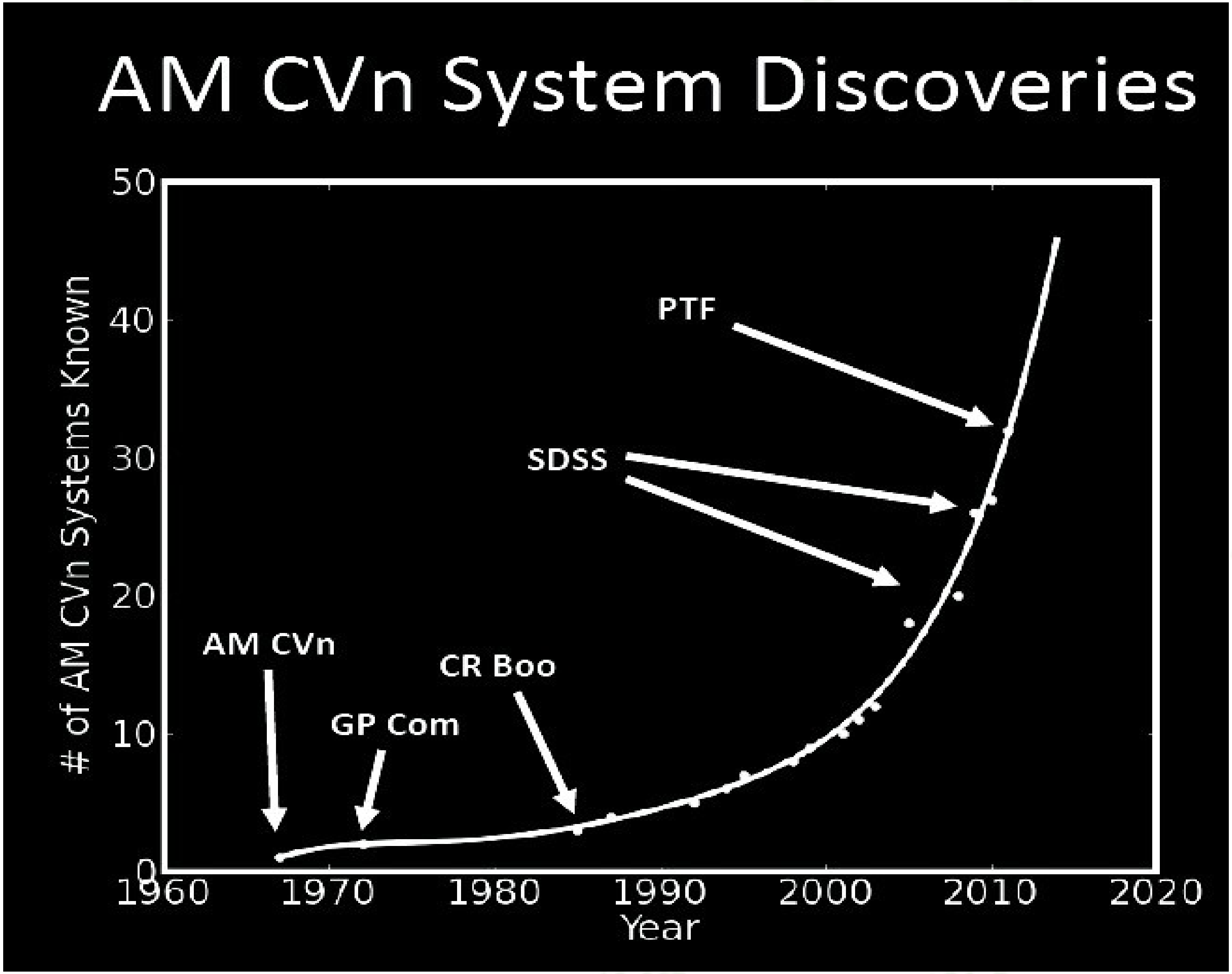
+ BH **0**
?

Short period systems: $P_{orbital}$ < few hrs
Intrinsically *rare!* Observationally rare!

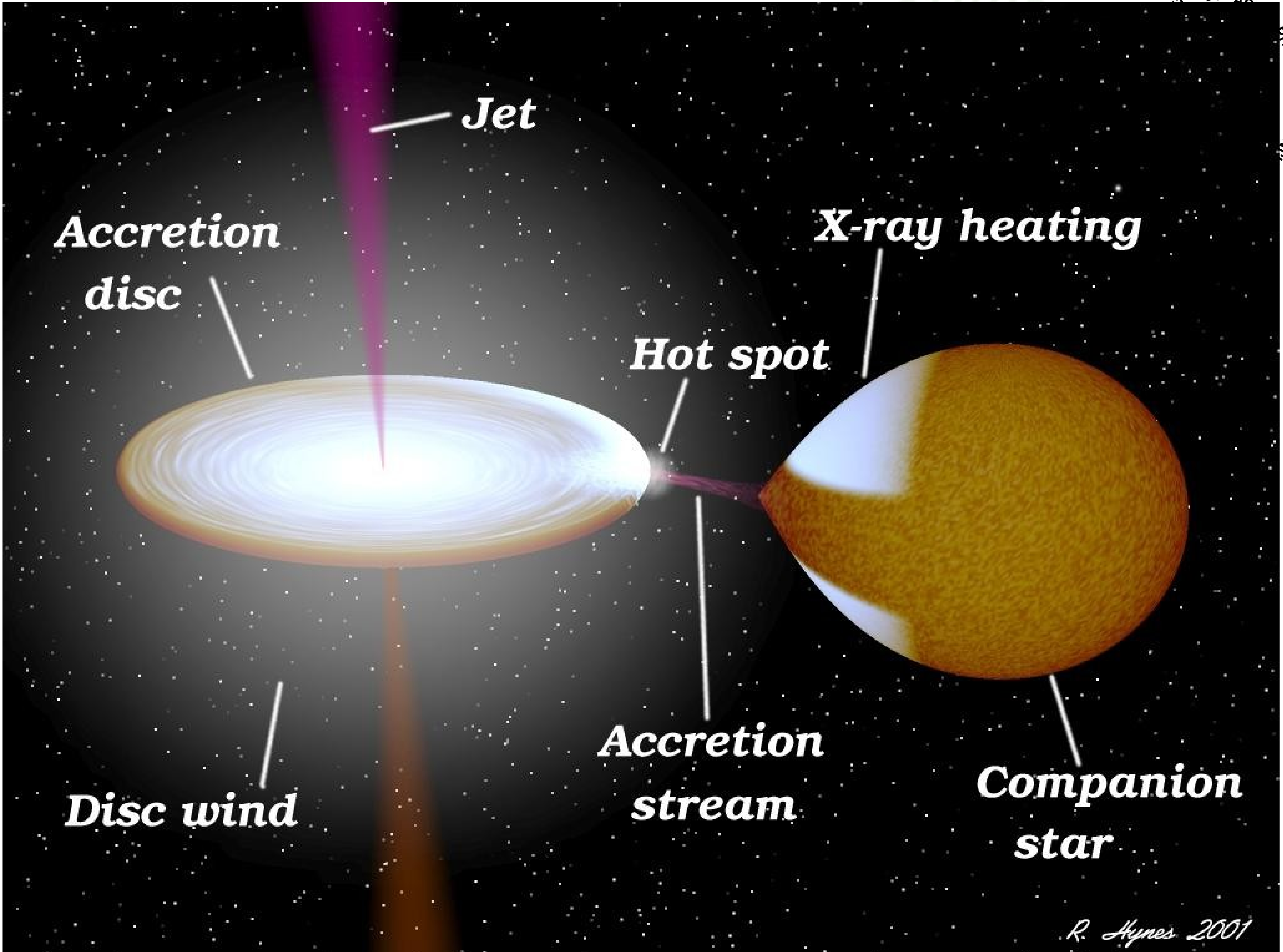
Astrophysical Interest

- Endpoints of binary evolution: common-envelope physics
- Gravitational wave sources: LISA/LIGO domain
- Accretion disk & Jet physics:
  - Chemical composition
  - AGN connection
- Explosive phenomena
  - Dwarf novae outburst
  - Nova outbursts
  - Supernovae Type .Ia
  - Supernovae Type Ia
  - (Short) Gamma-ray bursts

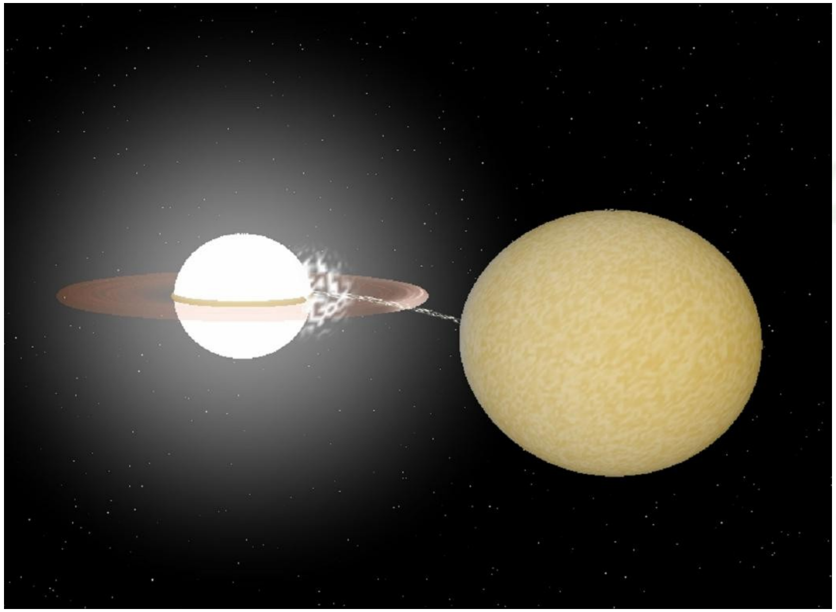
Number of AM CVn stars

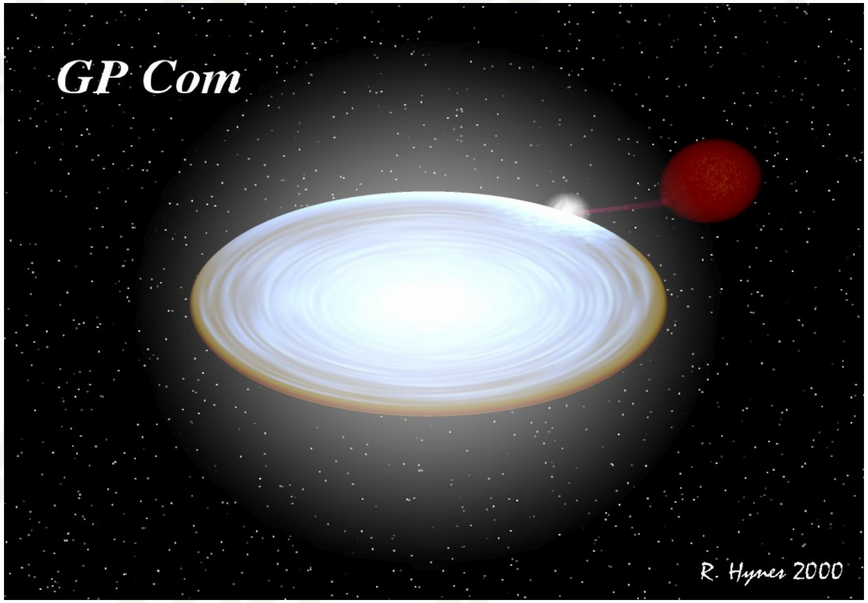


Courtesy David Levitan


Jet
Accretion disc
X-ray heating
Hot spot
Accretion stream
Companion star
Disc wind
R. Hynes 2001

AM CVn stars:
An evolutionary challenge

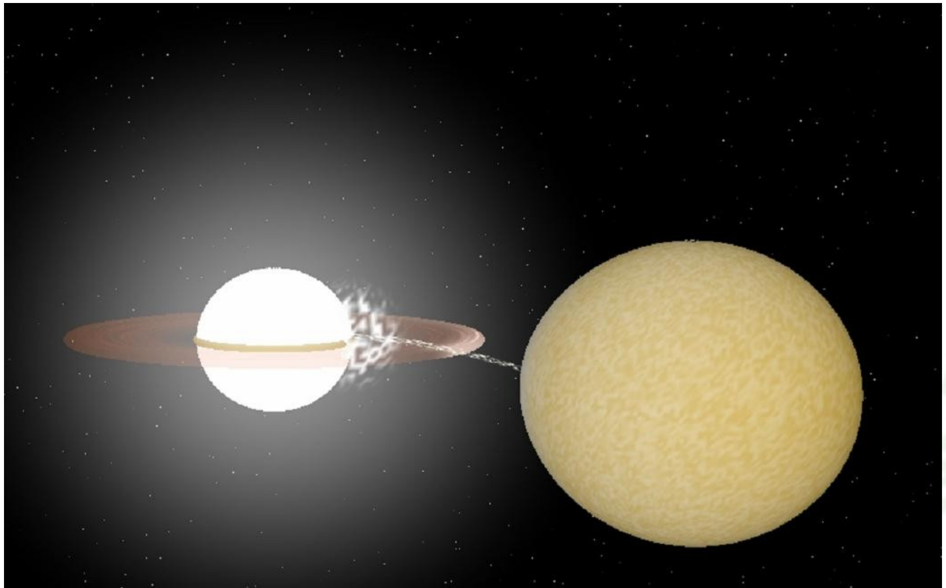


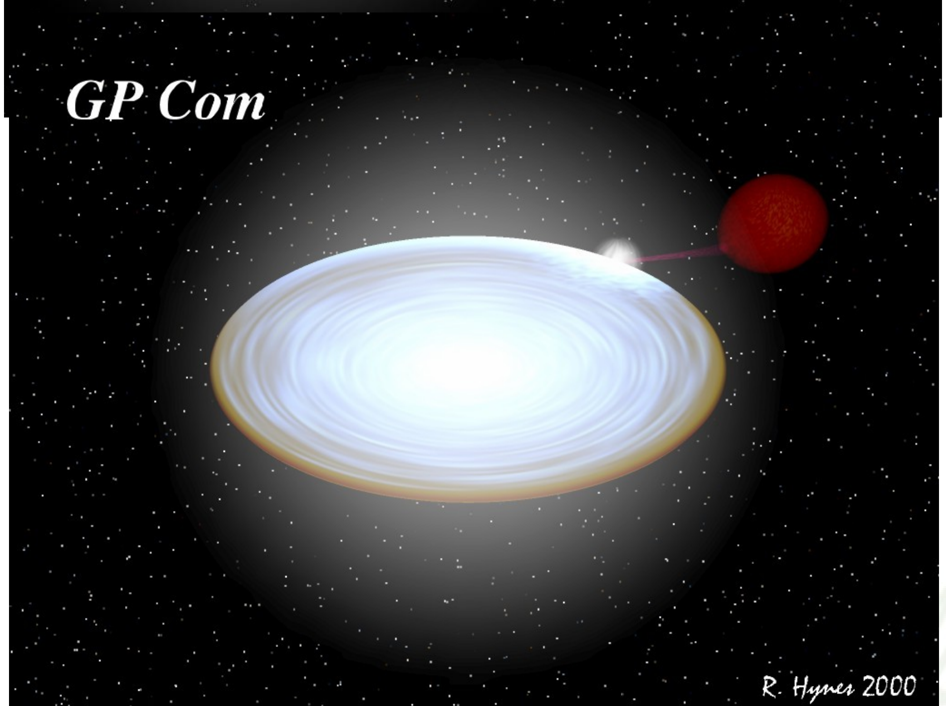


Paul Groot (*Radboud University Nijmegen*)

Gijs Nelemans, Gijs Roelofs, Danny Steeghs, Tom Marsh, Patrick Woudt, Lev Yungelson, Lars Bildsten, Chris Deloye, Brian Warner, Matt Wood, Gavin Ramsay, Chris Copperwheat, Dean Townsley

AM CVn stars



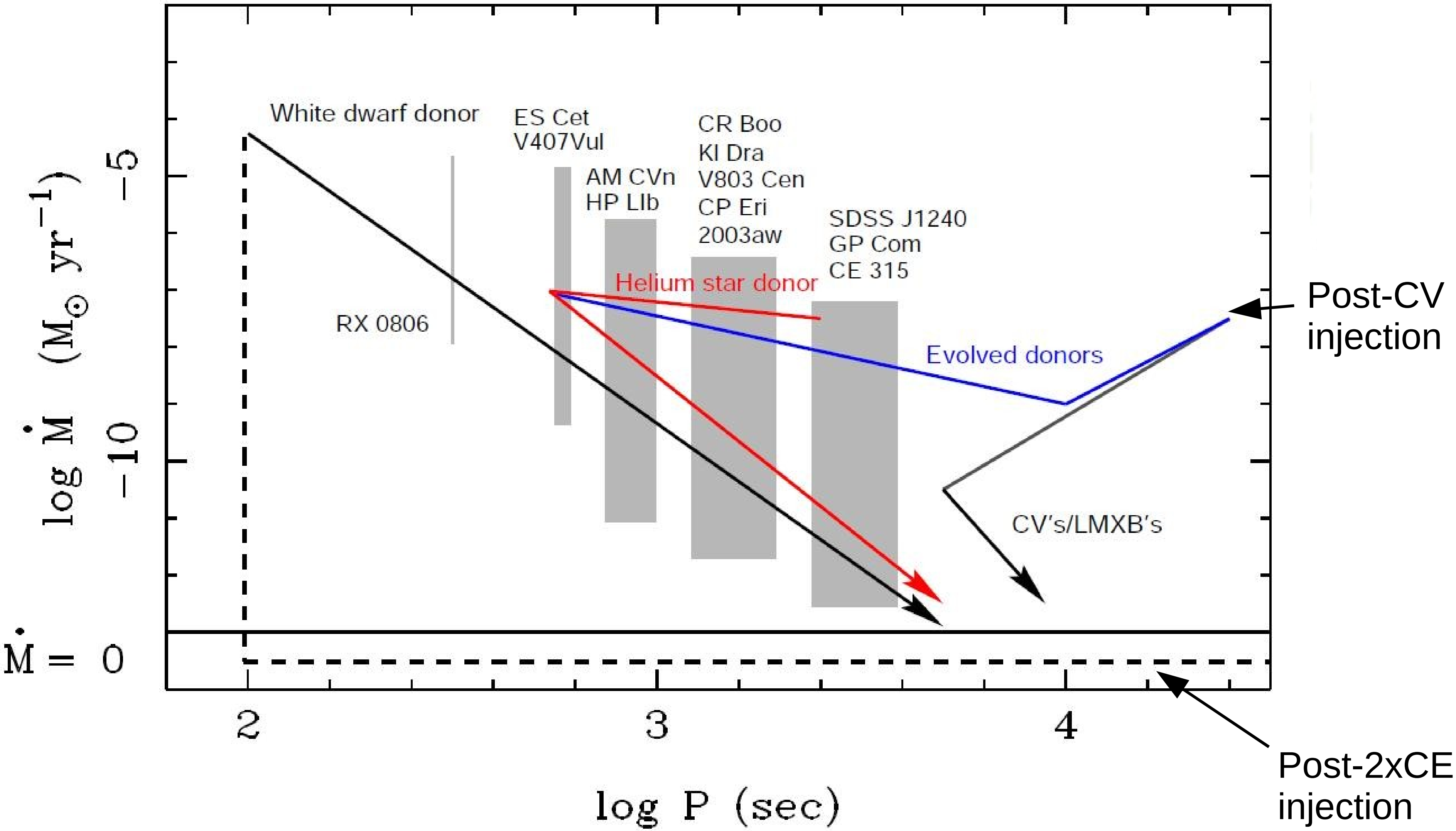


- Interacting binary white dwarfs
- Completely hydrogen deficient
- Orbital periods: 5.4-65 minutes
- Only 32 systems known
- Only known LISA sources
- Ultimate survivors:
  2 x CE phase + Direct impact phase
- Evolution fully (?) set by GWR losses

$$\frac{\dot{J}}{J} = -\frac{32}{5}\frac{G^3}{c^5}\frac{M_1 M_2 (M_1 + M_2)}{a^4}$$

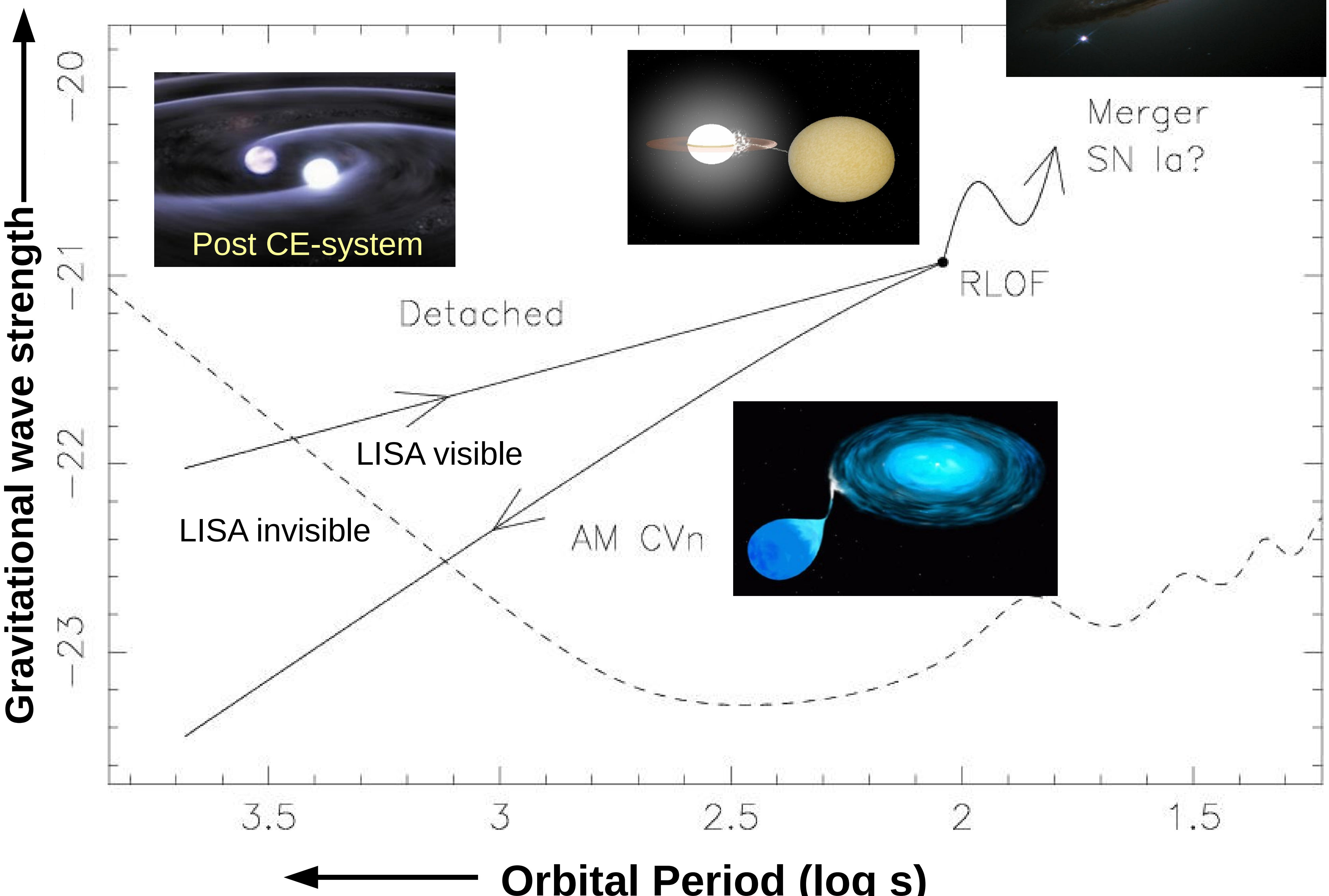
$$\frac{\dot{M}_2}{M_2} = \frac{\dot{J}}{J}\frac{2}{\zeta_2 + 5/3 - 2q},$$

Evolutionary paths

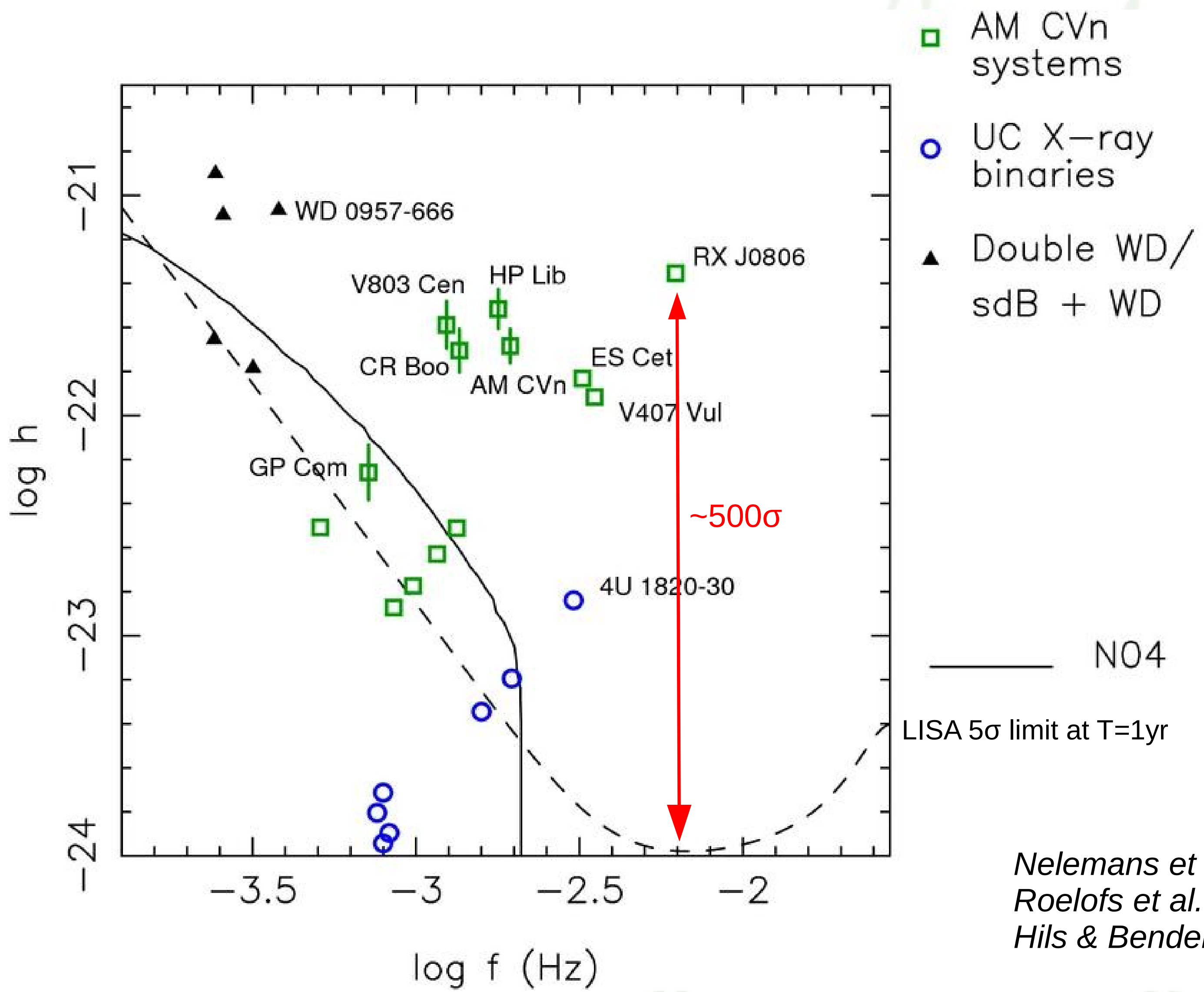


Tutukov & Yungelson 1979,1981,1996, Iben & Tutukov, 1991; Nelemans et al. 2001; Thorstensen 2003, Podsiadlowski et al., 2003.

Gravitational wave evolution

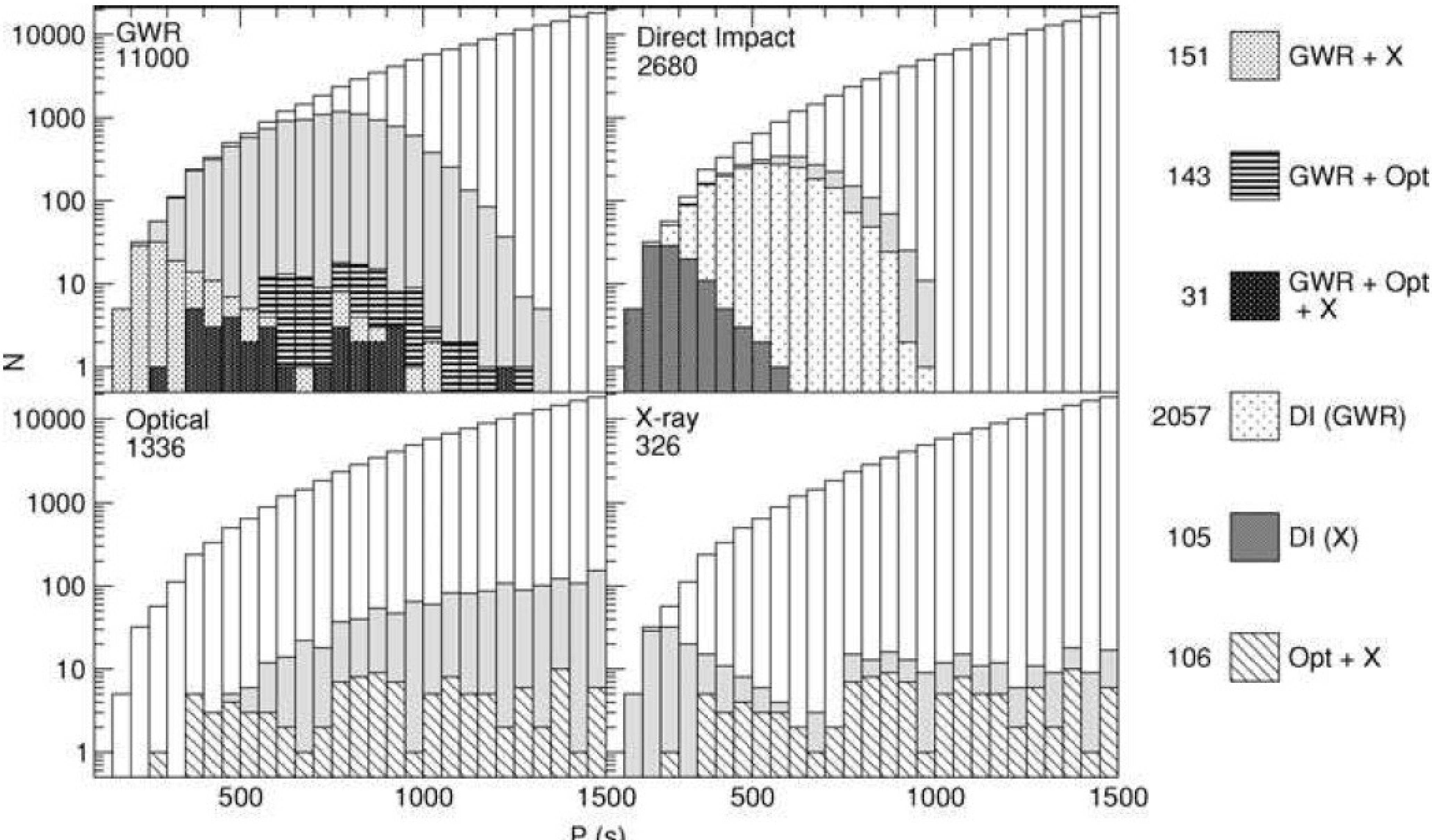


Gravitational wave evolution



Nelemans et al., 2004
Roelofs et al., 2006
Hils & Bender, 2000

Galactic population in Gravitational waves



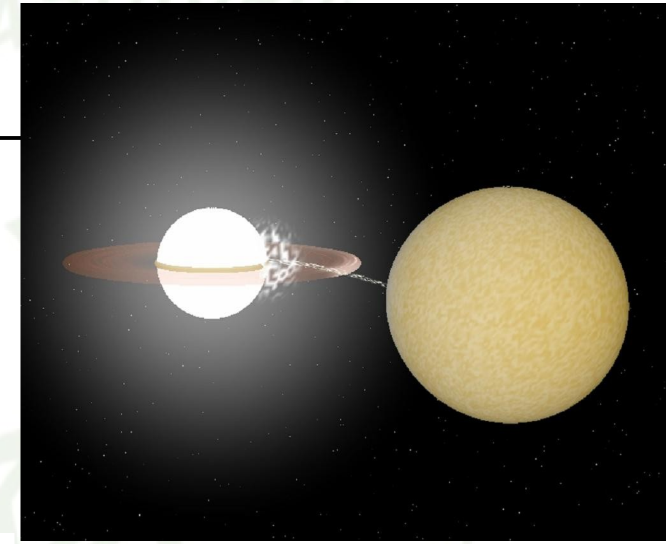
Nelemans, Yungelson & Portegies Zwart, 2004

Follow the evolution:

Start at 'first contact': at shortest orbital periods

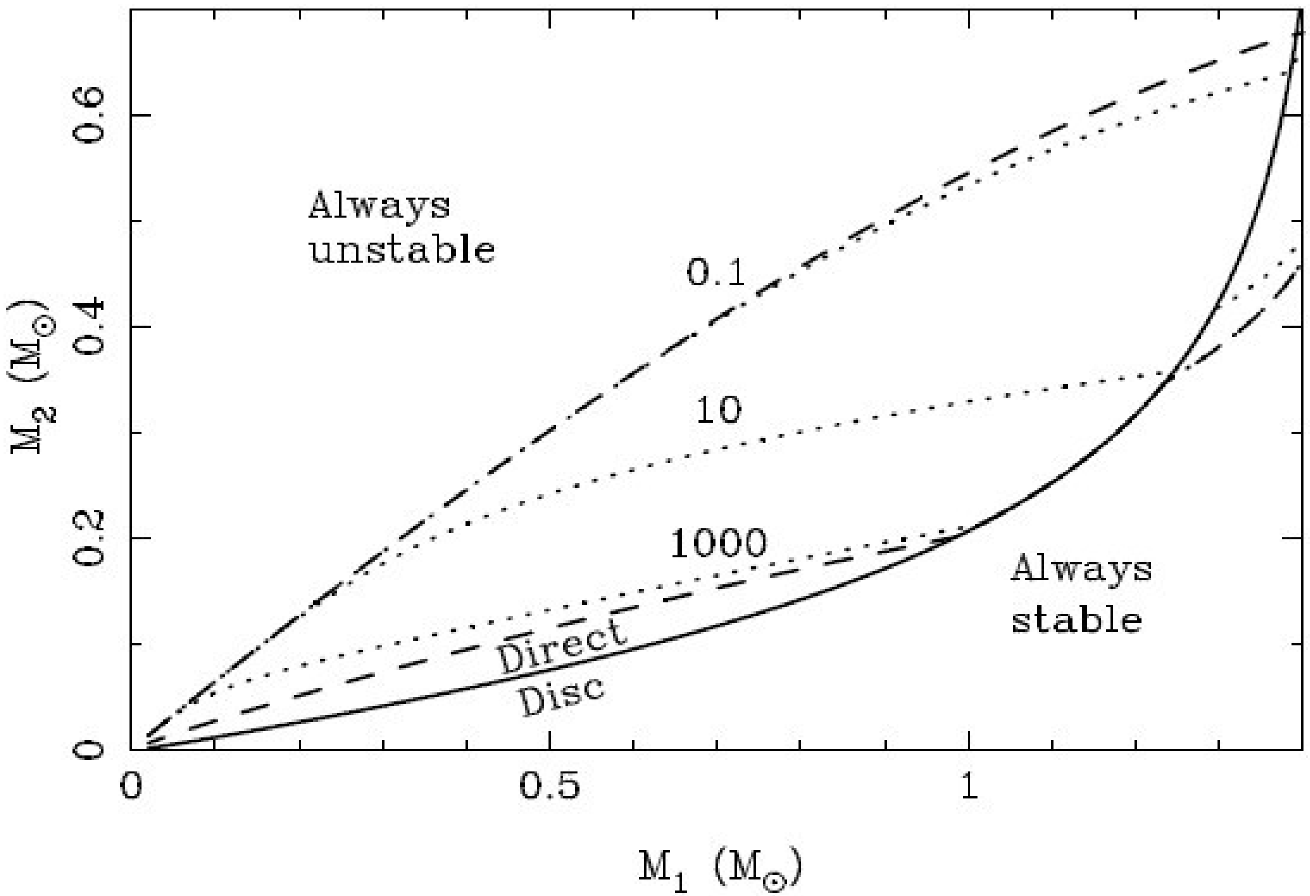
Move out to longer periods.

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)

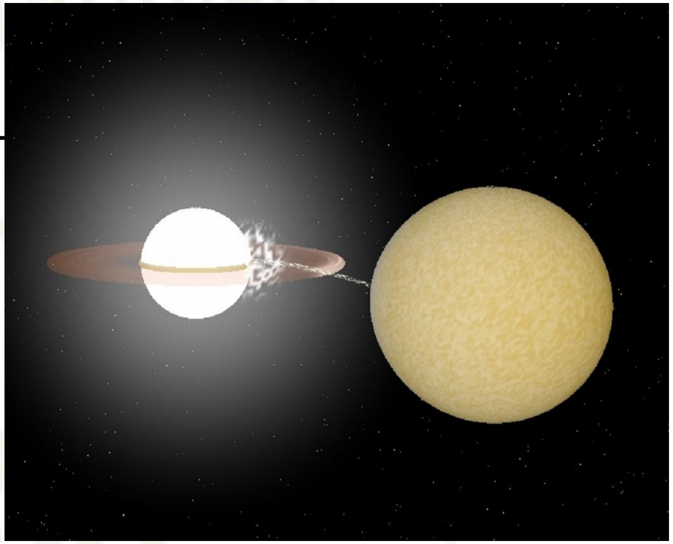


Stability depends on synchronization timescale of spin-orbit coupling:

short=stable
long = unstable

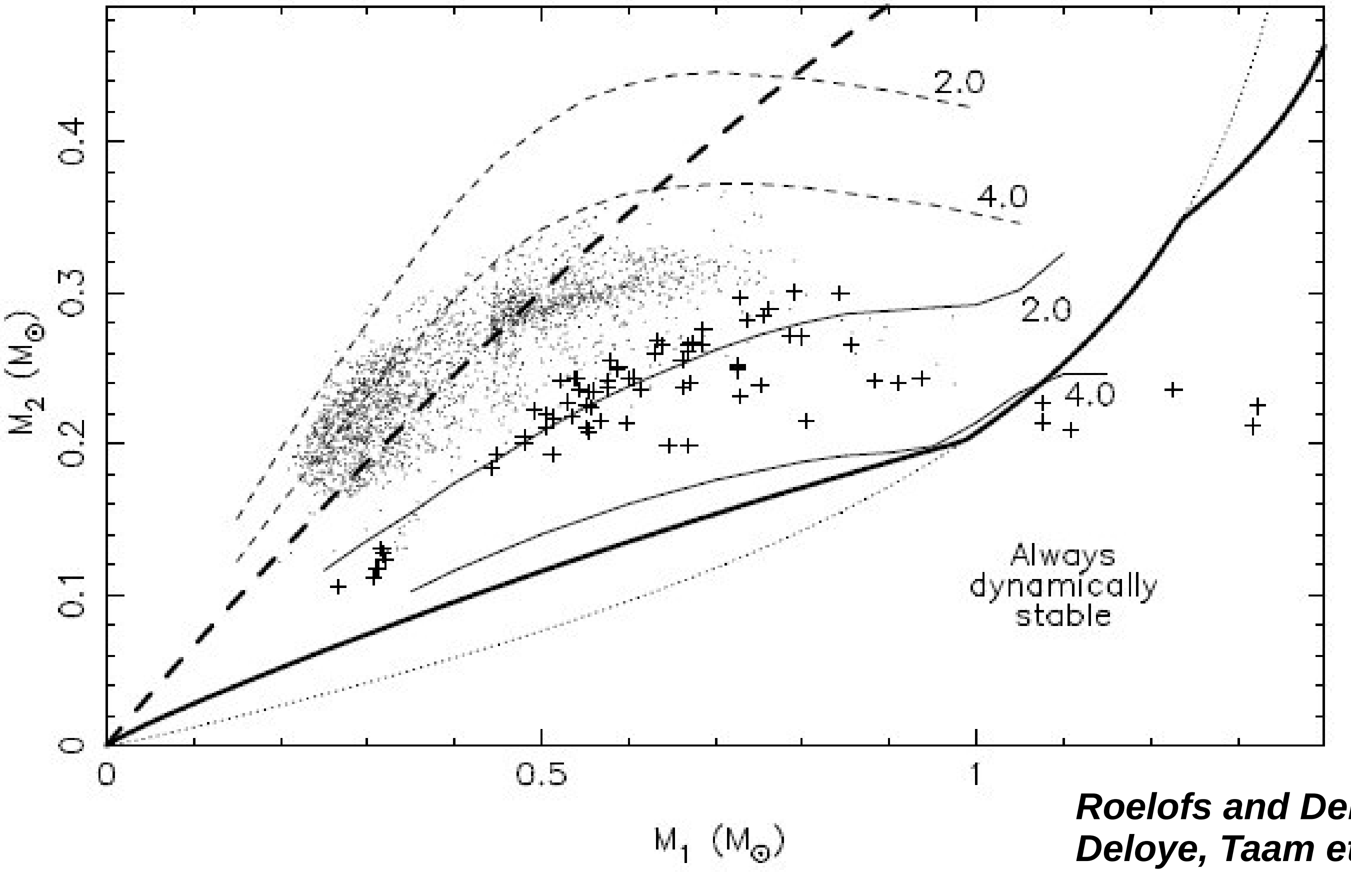
Marsh, Nelemans, Steeghs, 2004
Nelemans et al., 2001
Webbink, 1984
Smarr & Blandford, 1976
Campbell, 1984

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



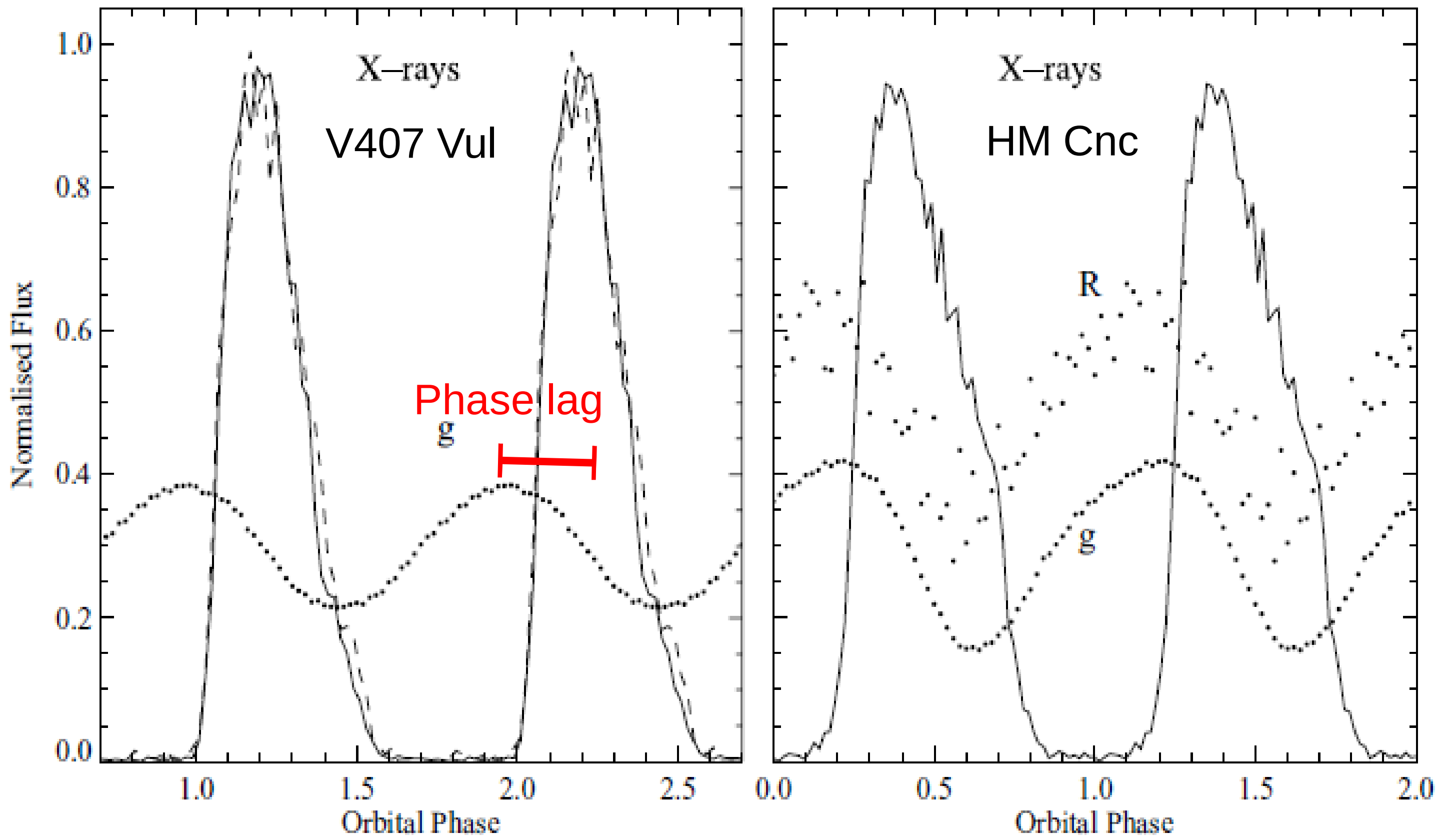
High entropy = More stable

Low entropy = Less stable

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

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 $1x10^{-17}$ and $3x10^{-16}$ s s^{-1} *(Strohmayer 2005)*
- Optically faint: V=19.9 (V407 Vul) and V=21.1 (HM Cnc)



Barros et al., 2007

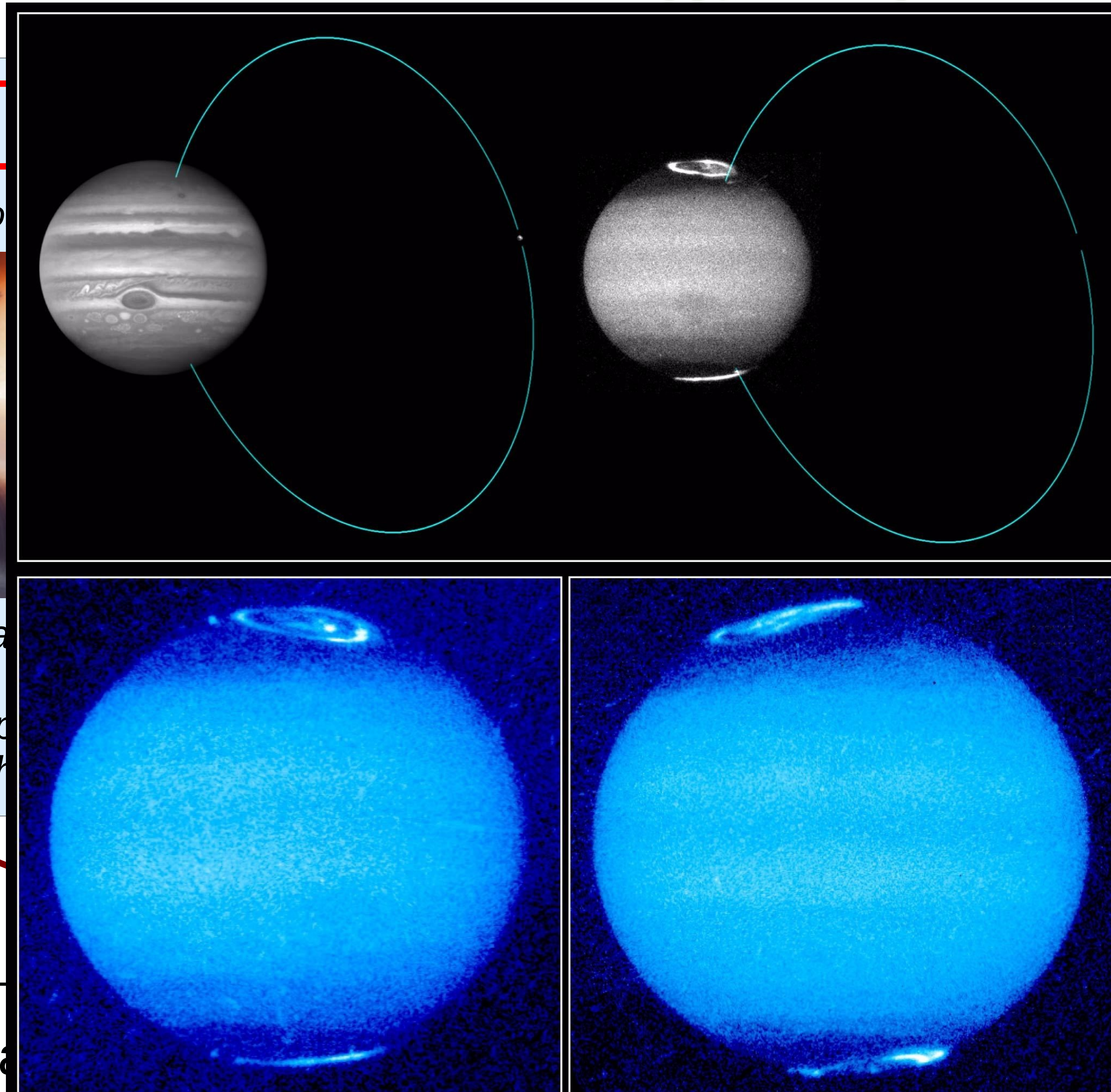
Three models

Intermediate

Motch/Israel/Norto

Period is not *orbita*

→ *What is orbital p*
→ *What causes ph*



impact

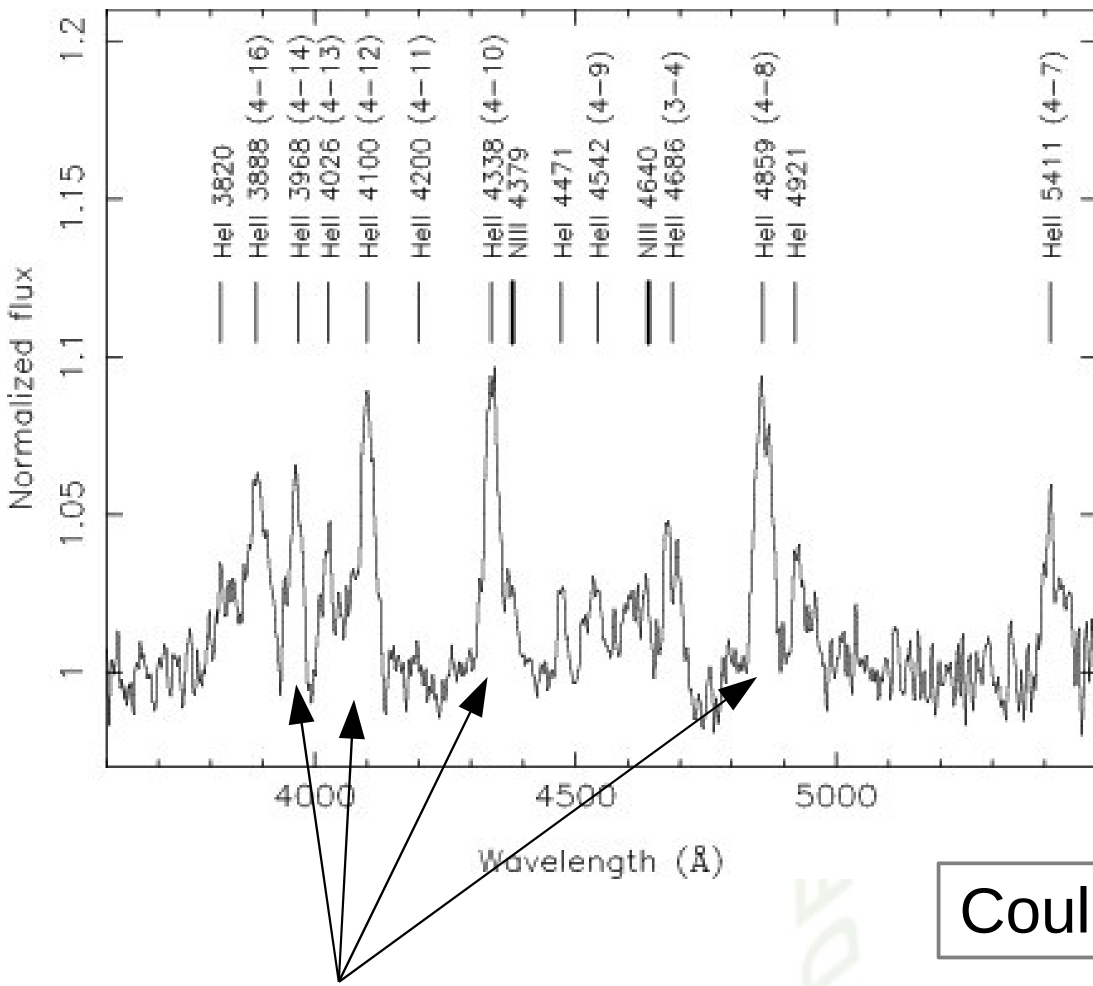
ns/Marsh et al.

eriod is orbital

bital period?
rogen?

Radi

HM Cnc: radial velocity changes



Hydrogen, not HeII

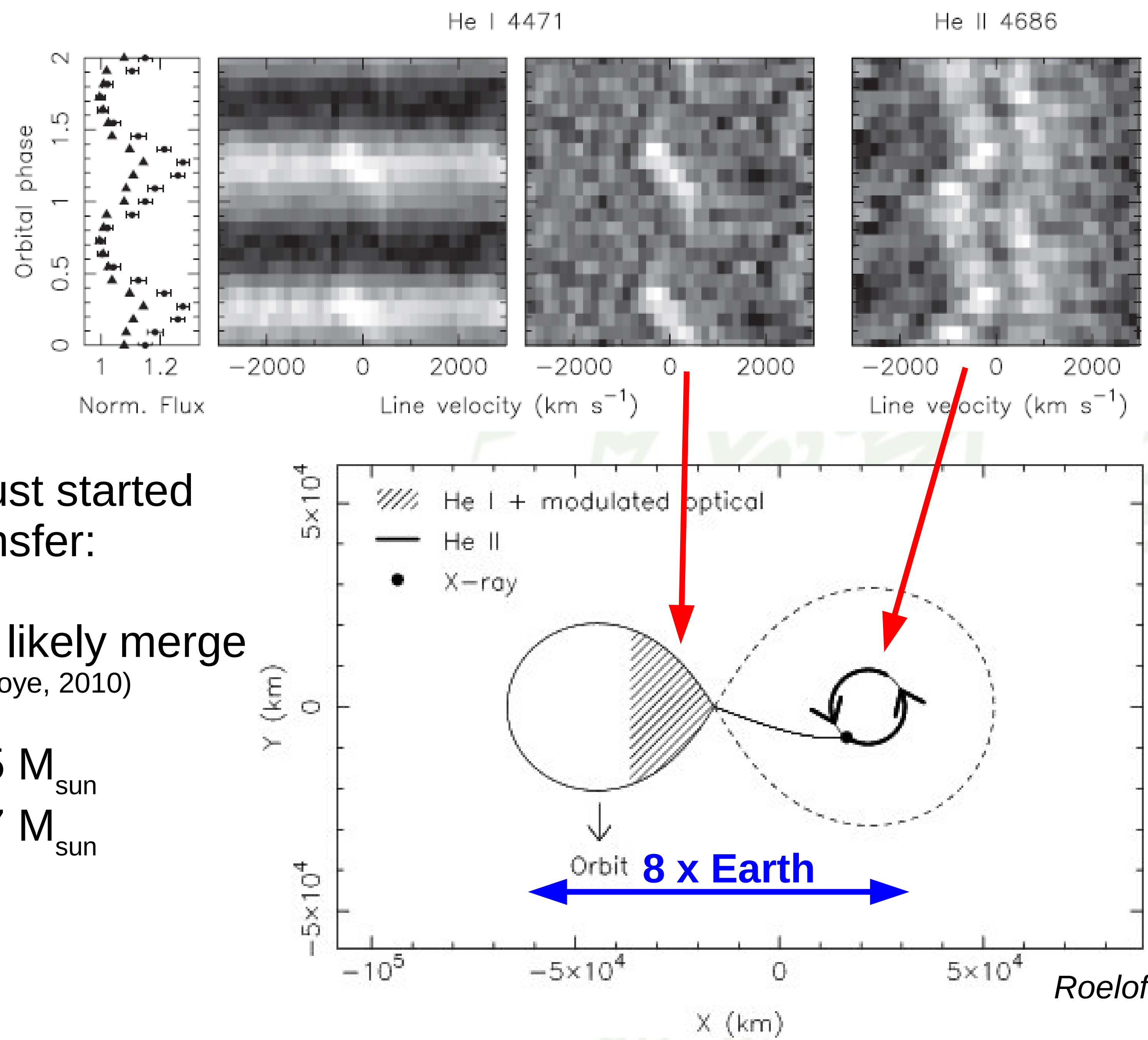
Difficult!

- 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


2005
2006
2007

HM Cnc: P_{orb} = 5.4 min



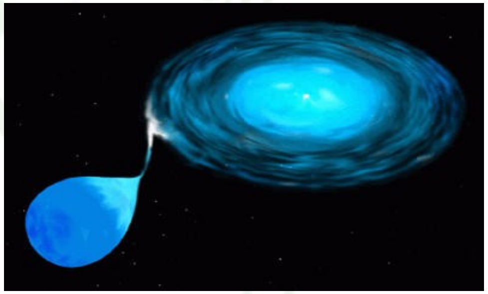
System just started mass transfer:

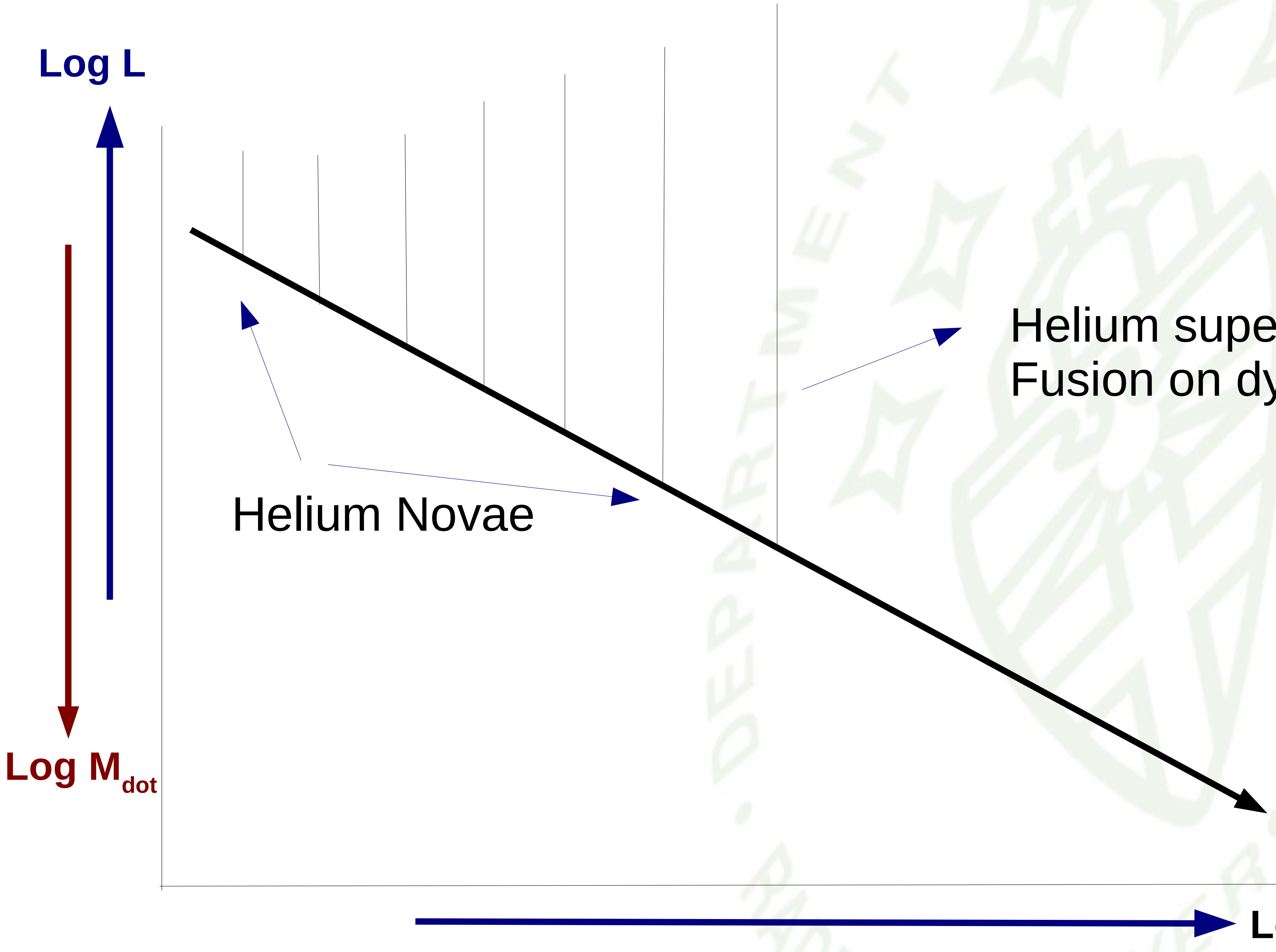
Will most likely merge
(Roelofs & Deloye, 2010)

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

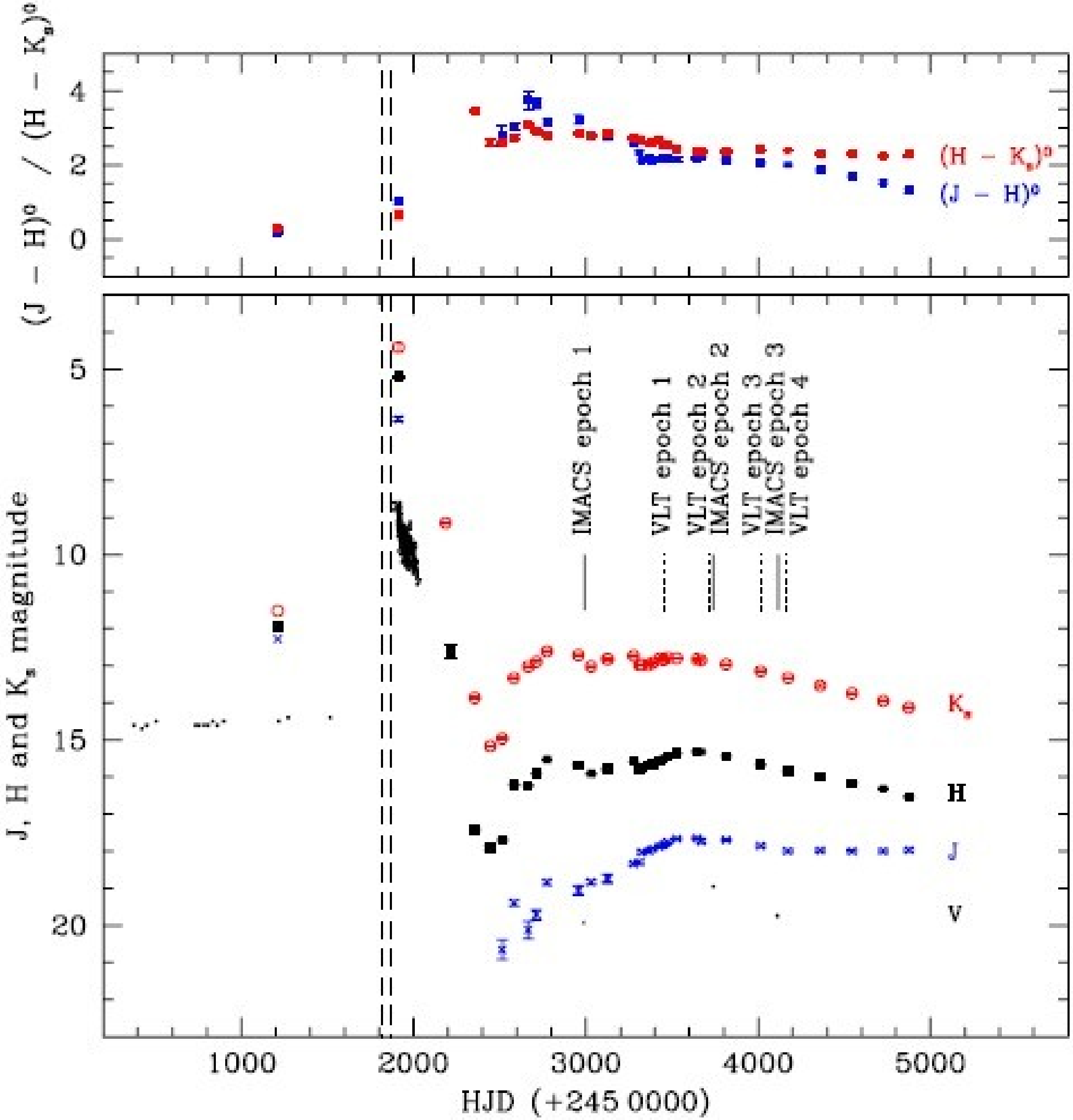
Roelofs et al., 2010

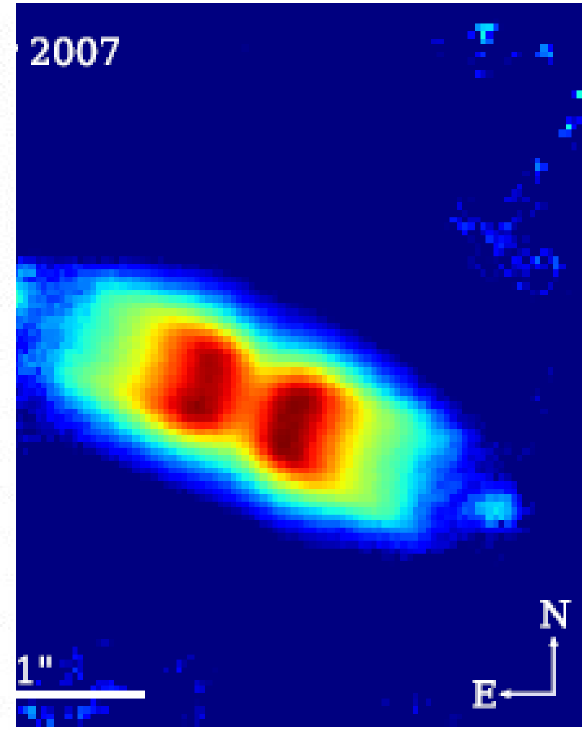
Helium (super)novae





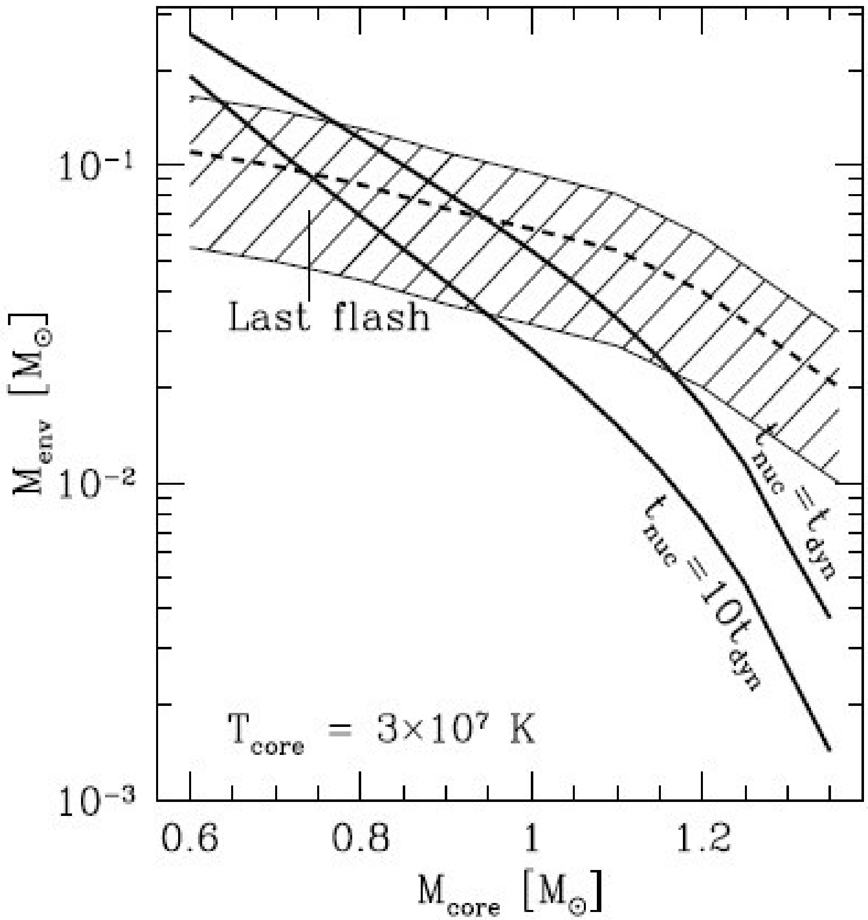
First helium nova: V445 Puppis

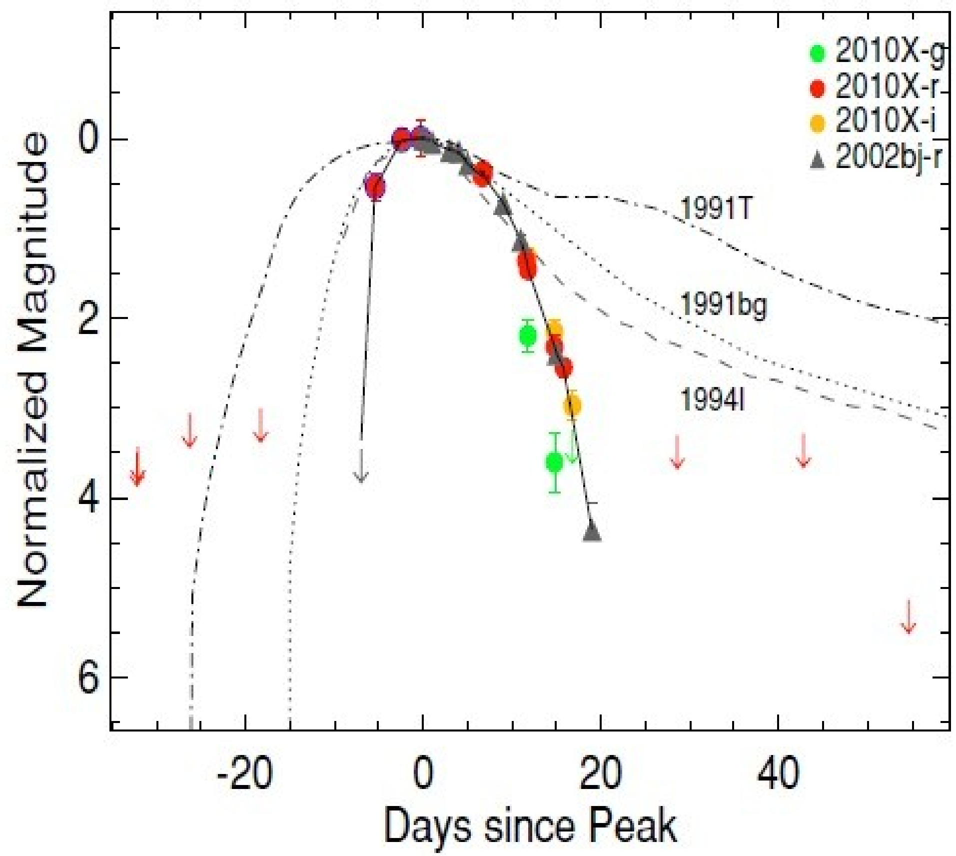




ar)

Supernovae Type .Ia ('point Ia')





Thermonuclear flashes in high state systems: $L \sim 0.1\ L_{SNIa}$,

$\tau \sim 0.1\ \tau_{SNIa}$, $f = 0.1\ f_{SNIa}$

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

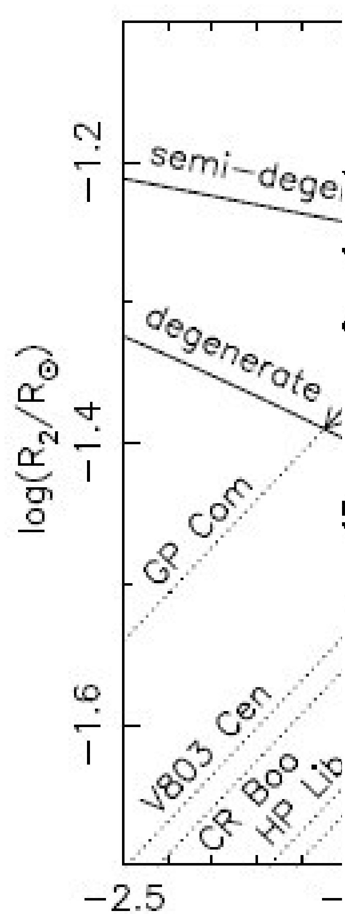
SN2002bj: SN .Ia?
Poznanski et al., 2009

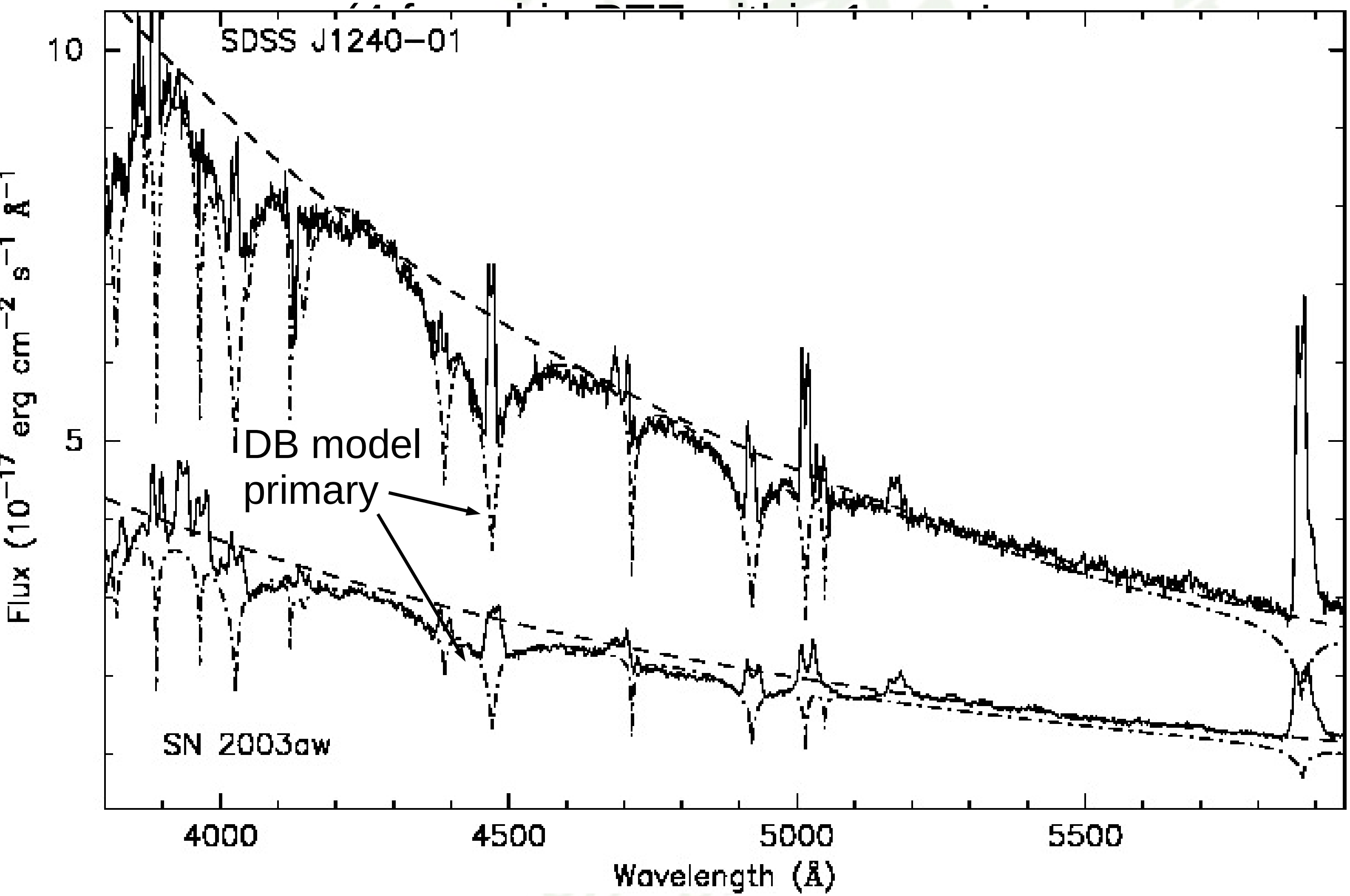
SN2010X: PTF discovery
Kasliwal et al., 2010

Intermediate period systems

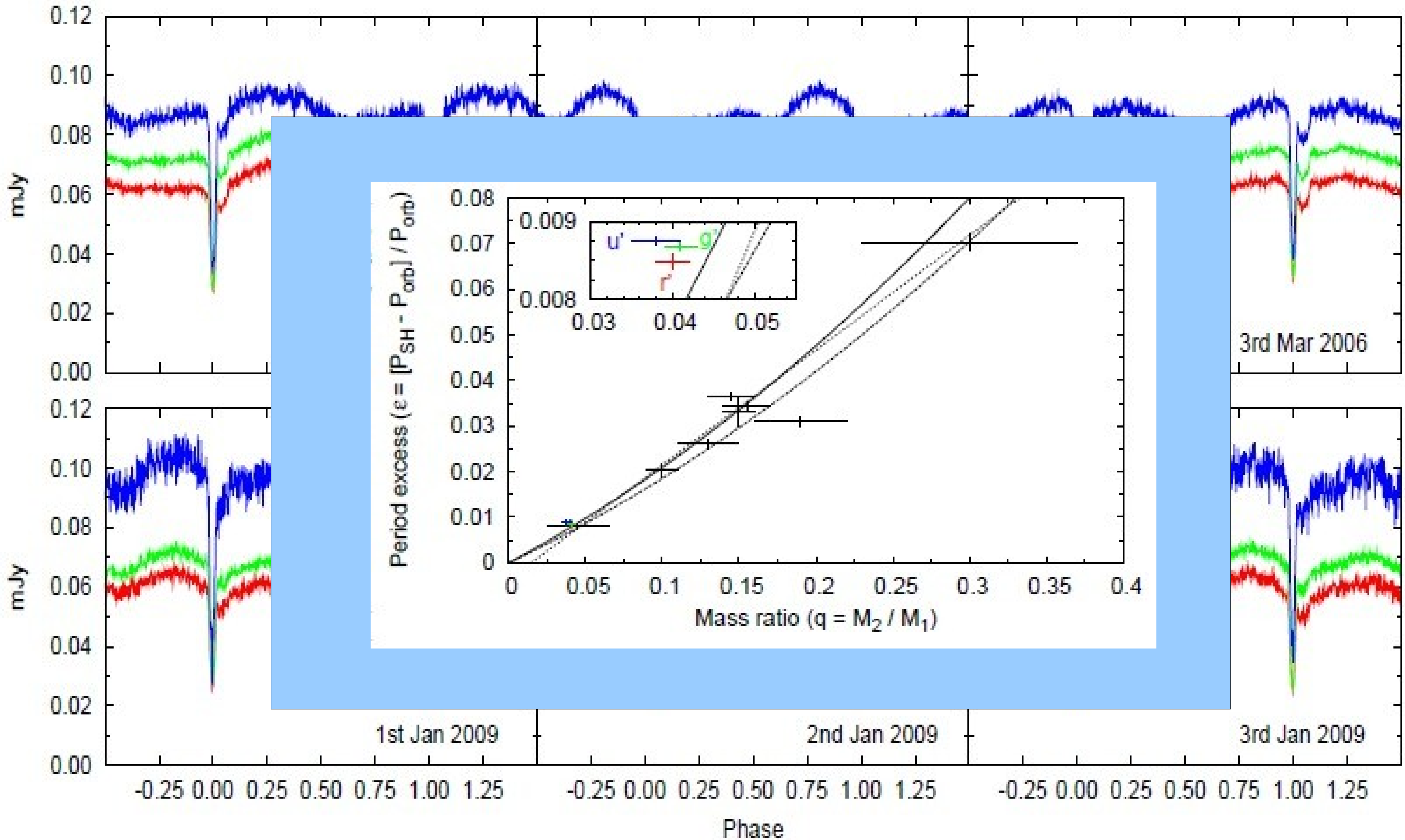
- 10 min < P_{orb} < 20 min: Three systems in high, stable $\dot{M}$ state (AM CVn, HP Lib)

- 20 min < P_{orb} < 40 min: Ten systems showing DN-type outbursts





First eclipsing system: SDSSJ 0926+38



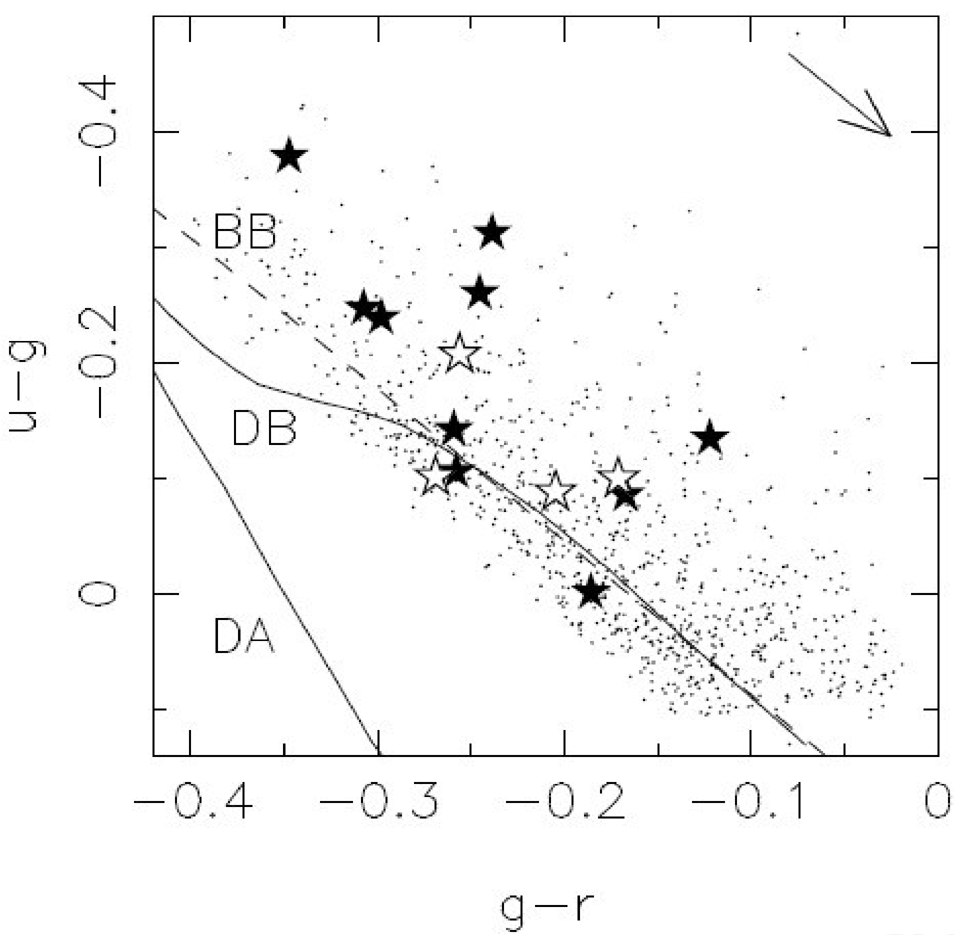
P_{orb} = 28 min

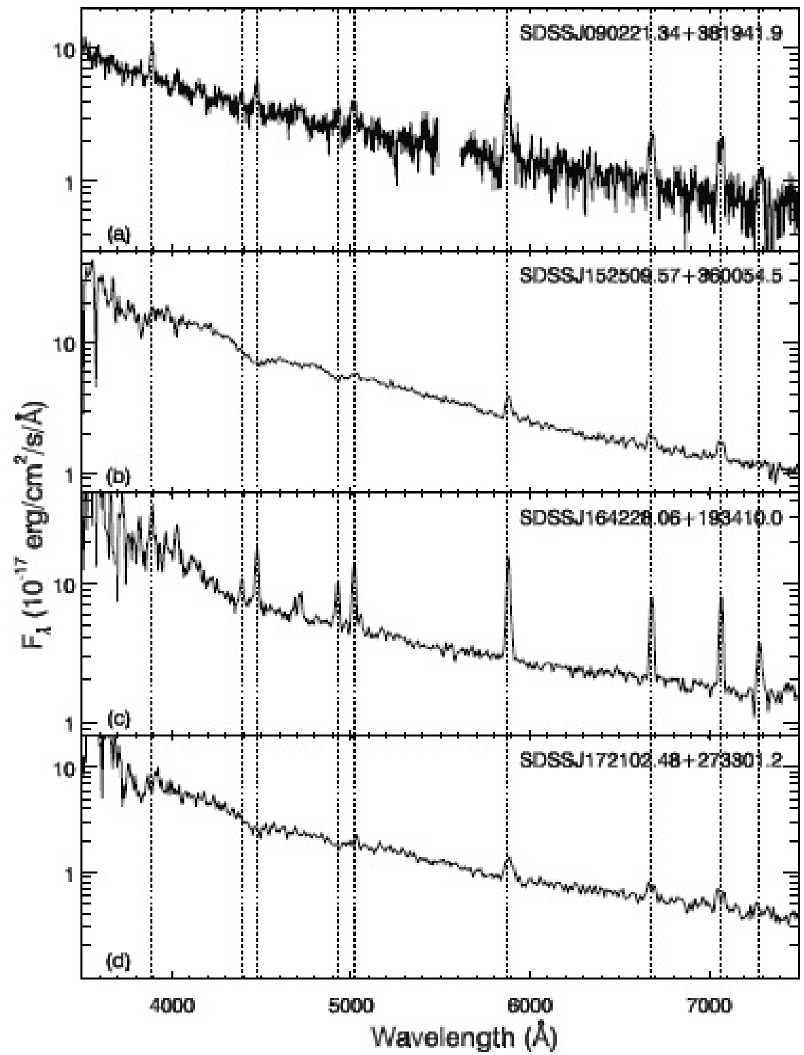
Copperwheat et al., 2010

Long period systems from SDSS (>35min)

Thirteen systems found in SDSS photometry/spectroscopy
(Roelofs et al., 2005; Anderson et al., 2005;2008; Roelofs et al., 2009; Rau et al., 2010)

Space density: 2 x 10^{-6} pc^{-3} (...seems to be even lower)
(Roelofs, Nelemans & Groot, 2007)





Observational/Theoretical questions

Five major outstanding, theory related, questions

Observational/Theoretical questions: I

What is the 'real' orbital period distribution?

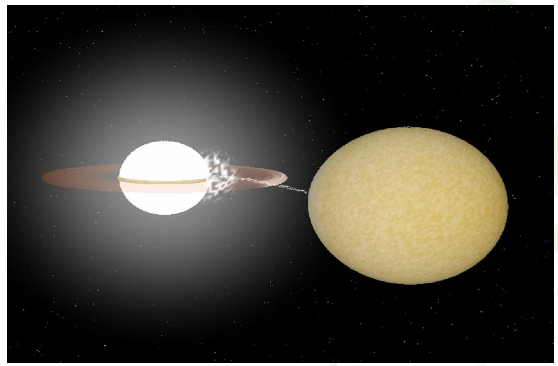
- SDSS Follow-up: 5 long period systems instead of 25
- PTF: already 4 shorter period systems without trying..
  (work by David Levitan)
- Kepler: A 15-minute system in 100 sq.degr.: what are the odds?

All seems to point at steeper orbital period profile:

More at shorter periods, fewer at longer.
- Extra angular momentum loss over GR (winds, braking)?
- Influence of chemical evolution Galaxy?
- Age of the Galaxy?
- Destruction/Decoupling at long periods?

Observational/Theoretical questions: II

What happens during direct impact?

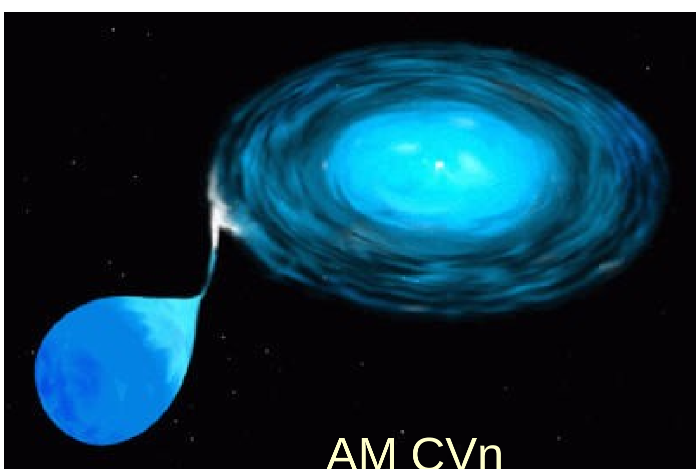


Stable

Unstable
$M_{tot} < M_{ch}$

?

Unstable
$M_{tot} > M_{ch}$

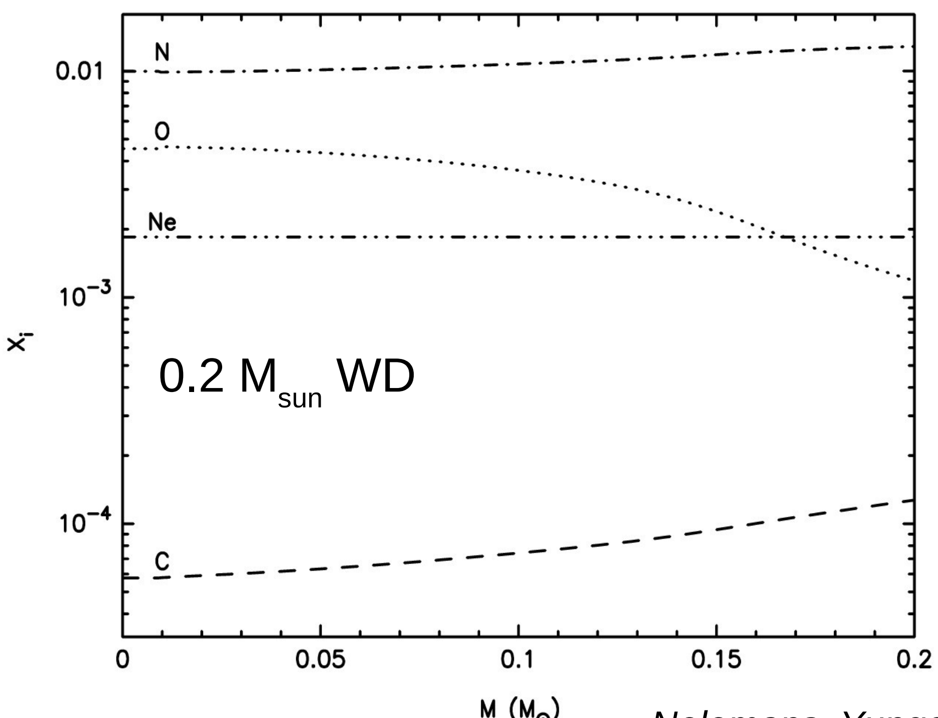


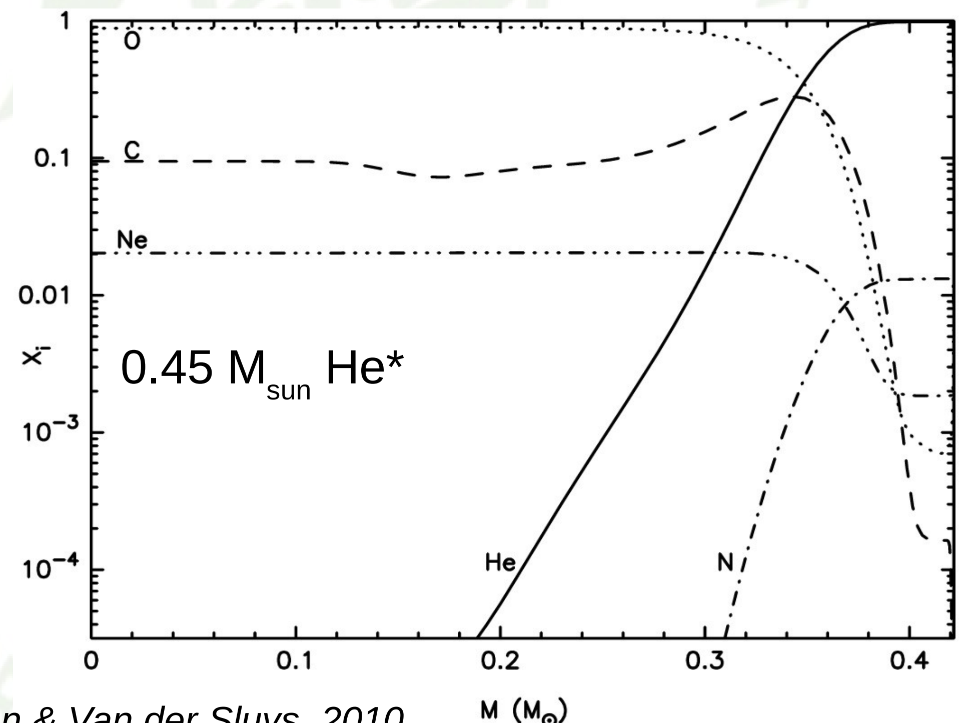
Observational/Theoretical questions: III

Which evolutionary channel dominates/exists/contributes?

- Determine M_{dot} at a given P_{orb} :
  Difficult, requires distances *(Roelofs et al., 2006)*

- Determine abundances of the secondary!

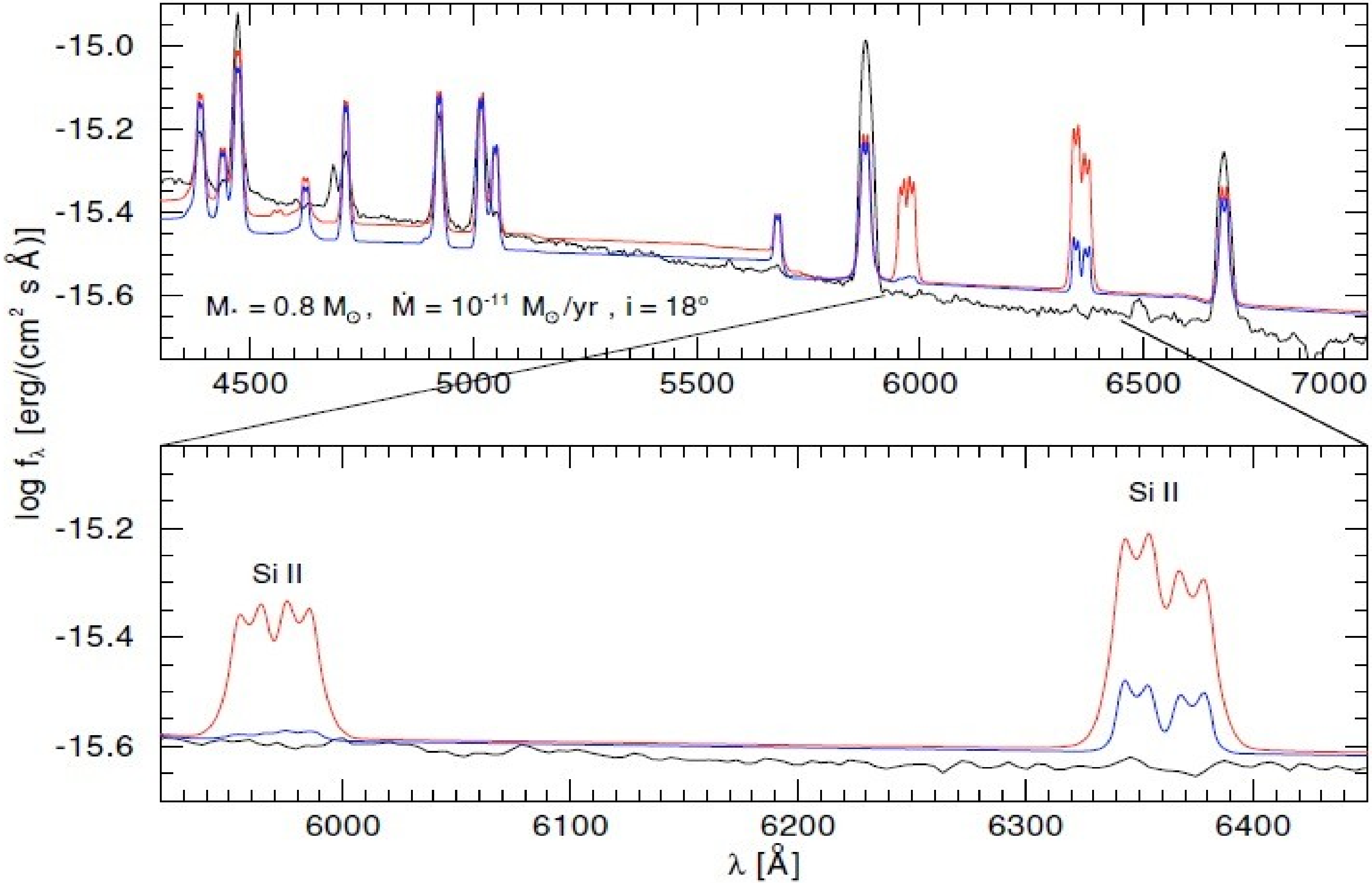




Nelemans, Yungelson & Van der Sluys, 2010

Observational/Theoretical questions: IV

How do we translate abundances into spectra and vice versa?



Nagel, et al., 2009

- Stability of disk models at low M_{dot}
- Vertical structure of the disk?

Observational/Theoretical questions: IV

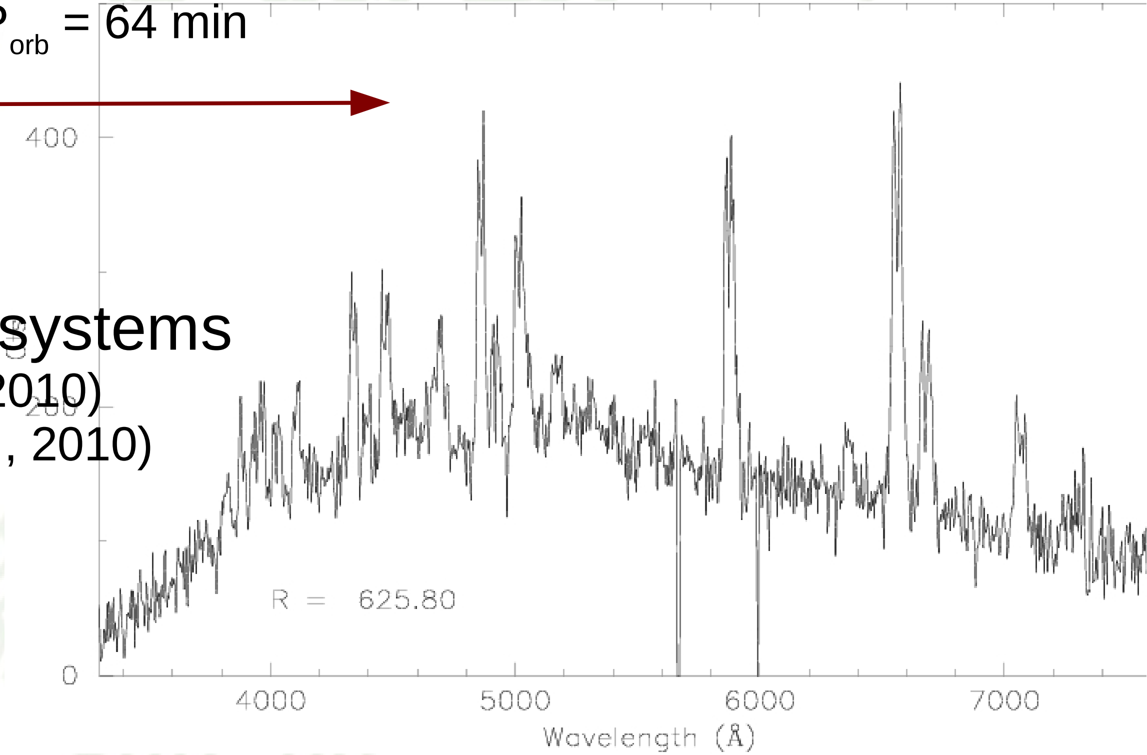
Precusors! Which, where, what, how

WD Channel: Low mass WD binaries found in SDSS,

- SDSS J1257+5428 (Marsh et al., 2010; Kulkarni & Van Kerkwijk, 2010)
- SDSS J1436+5010 & SDSSJ1053+5200 (Mullaly et al. 2010)
- Short period systems by Kilic et al., 2011 **(48, 40 and 12(!) minutes)**

Evolved CV Channel: Short period, high He-content CVs

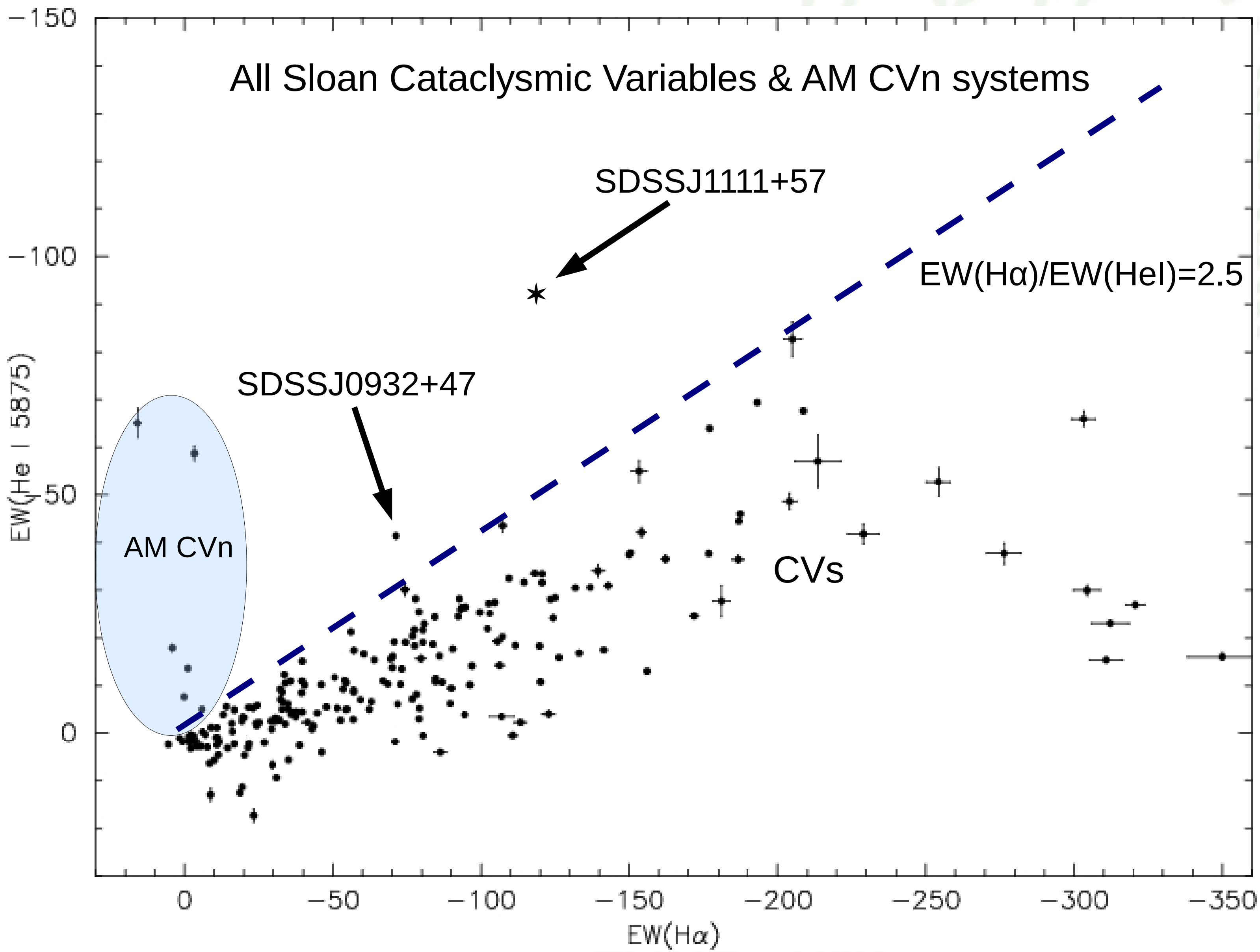
- V485 Cen; P_{orb} = 59 min; EI Psc, P_{orb} = 64 min
- SDSS J1111+57



Helium Channel: sdB+WD systems

- GALEX 2349+3844 (Kawka et al. 2010)
- NLTT 11748 & 54331 (Kawka et al., 2010)

Pre-cursor systems



Open questions

Only 32 systems known (but inceasing rapidly)

• Formation channel? *Abundances!* (Nelemans, Yungelson et al., 2010)
Disk modeling (e.g. Nagel et al., 2010)

• Space density? Population characteristics?
• Gravitational wave sources/LISA Population:

Large-scale (variability) surveys: EGAPS, Omegawhite, PTF, etc.

• Connection to SN Ia, SN .Ia, helium novae?

Variability surveys (see above)

Theory: physics of direct impact, synchronization,
accretion disk physics, common-envelope physics

Thanks!

I'll be at Caltech until the end of 2011

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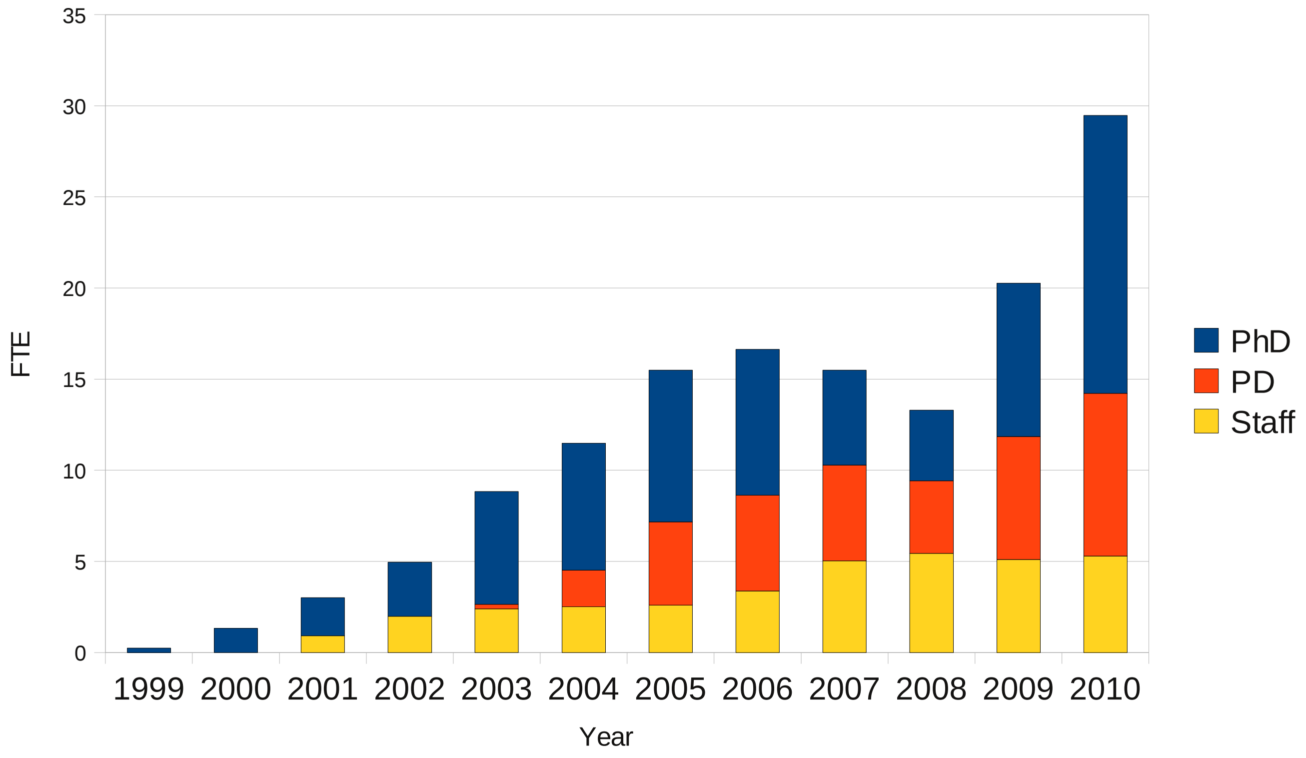
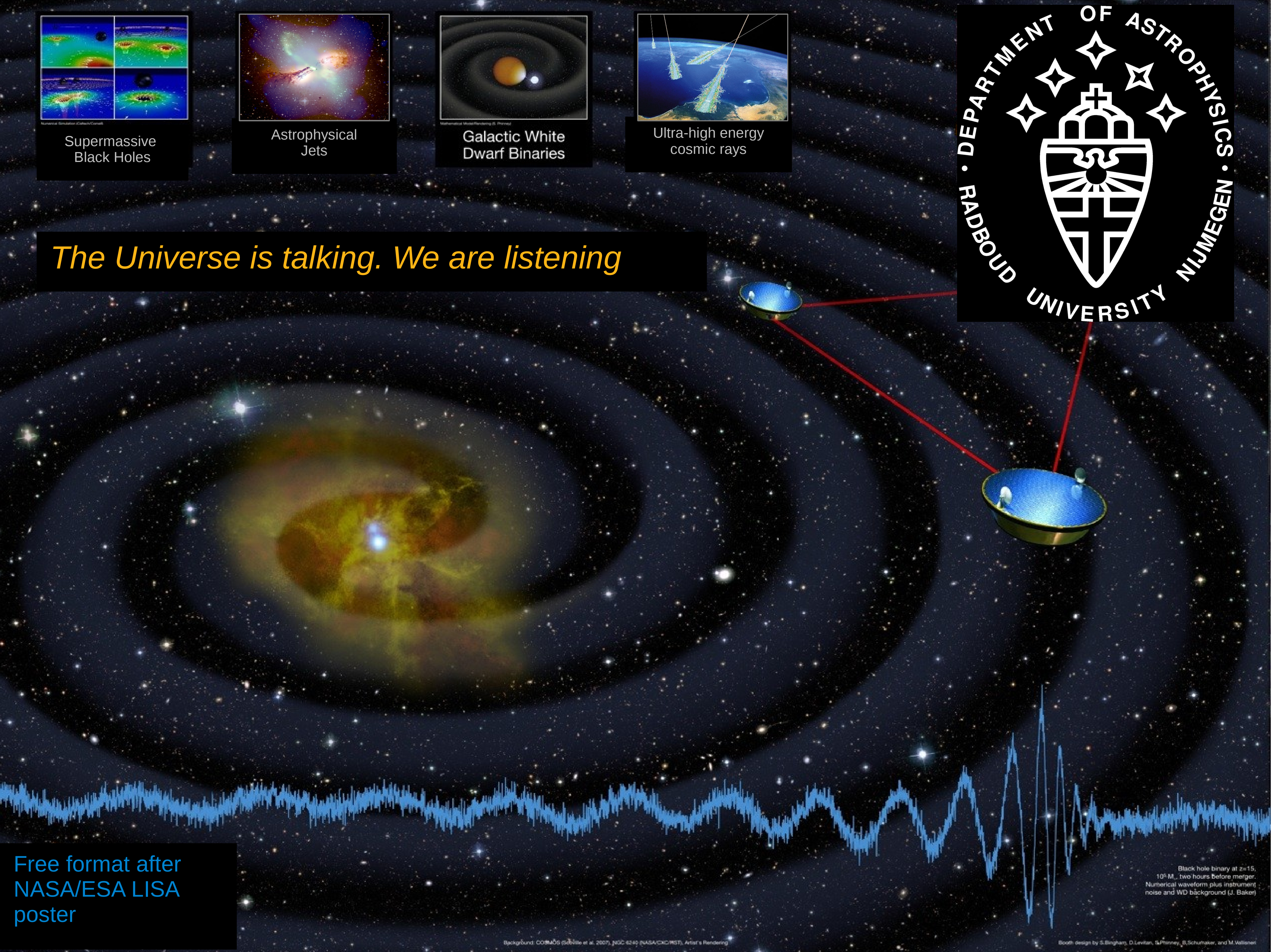
Jan Kuijpers, Elmar Körding, Marijke Haverkorn

Adjunct staff members:
Conny Aerts (Leuven), Carsten Dominik (Amsterdam), Peter Jonker (SRON)



Radboud University Nijmegen



Supermassive Black Holes
Astrophysical Jets
Galactic White Dwarf Binaries
Ultra-high energy cosmic rays
DEPARTMENT OF ASTROPHYSICS · RADBOUD UNIVERSITY NIJMEGEN ·
The Universe is talking. We are listening
Black hole binary at z=15,
two hours before merger.
Numerical waveform plus instrument
noise and WD background (J. Baker)
Free format after NASA/ESA LISA poster
Background: COSMOS (Scoville et al. 2007), NGC 6240 (NASA/CXC/HST), Artist's Rendering
Booth design by S.Bingham, D.Levitan, S.Phinney, B.Schumaker, and M.Vallisneri

Astrophysics in Nijmegen

- Compact objects and binaries:
  White dwarfs, neutron stars and
  (supermassive) black holes

- Astroparticle physics:
  Ultra-high energy cosmic rays and
  gravitational waves