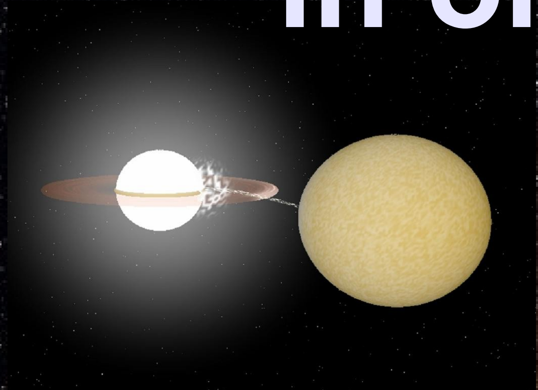
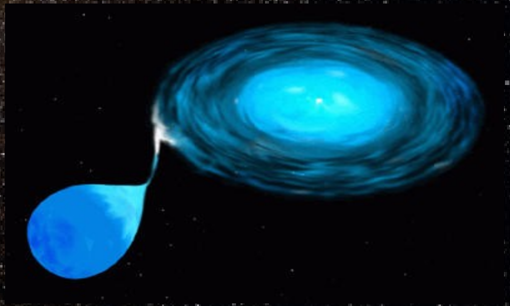
Ultracompacte dubbelsterren in ons Melkwegstelsel

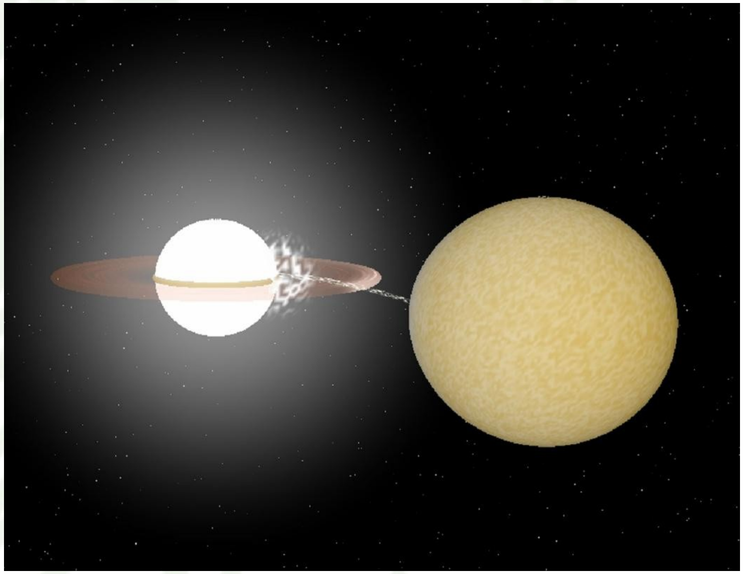




Paul Groot,
Afdeling Sterrenkunde
Radboud Universiteit Nijmegen

Overzicht

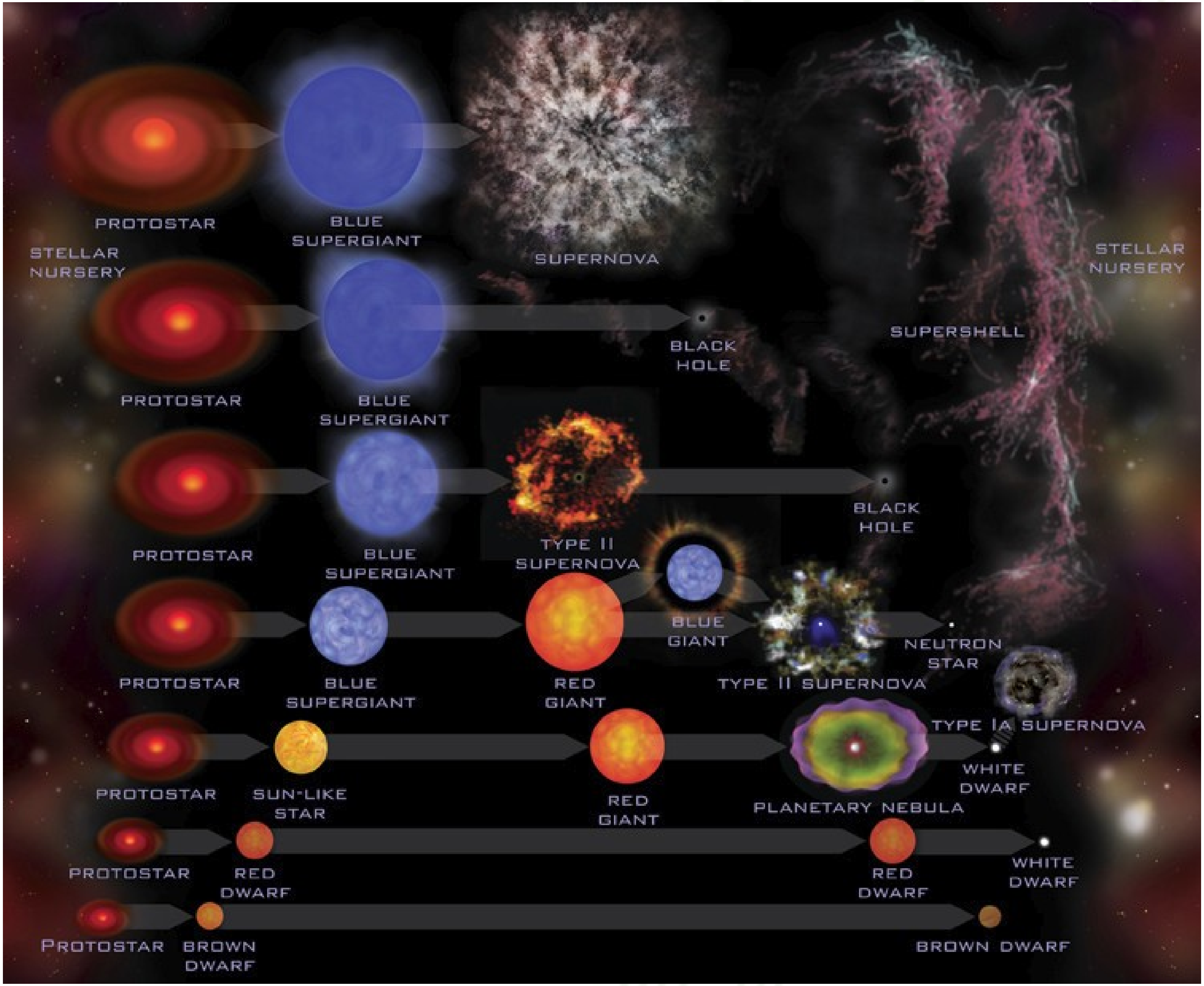
Deel 1:
- Ster-evolutie
- Sterlijken
- Dubbelsterren en hun evolutie
- Ultracompacte dubbelsterren
- Astrofysisch belang



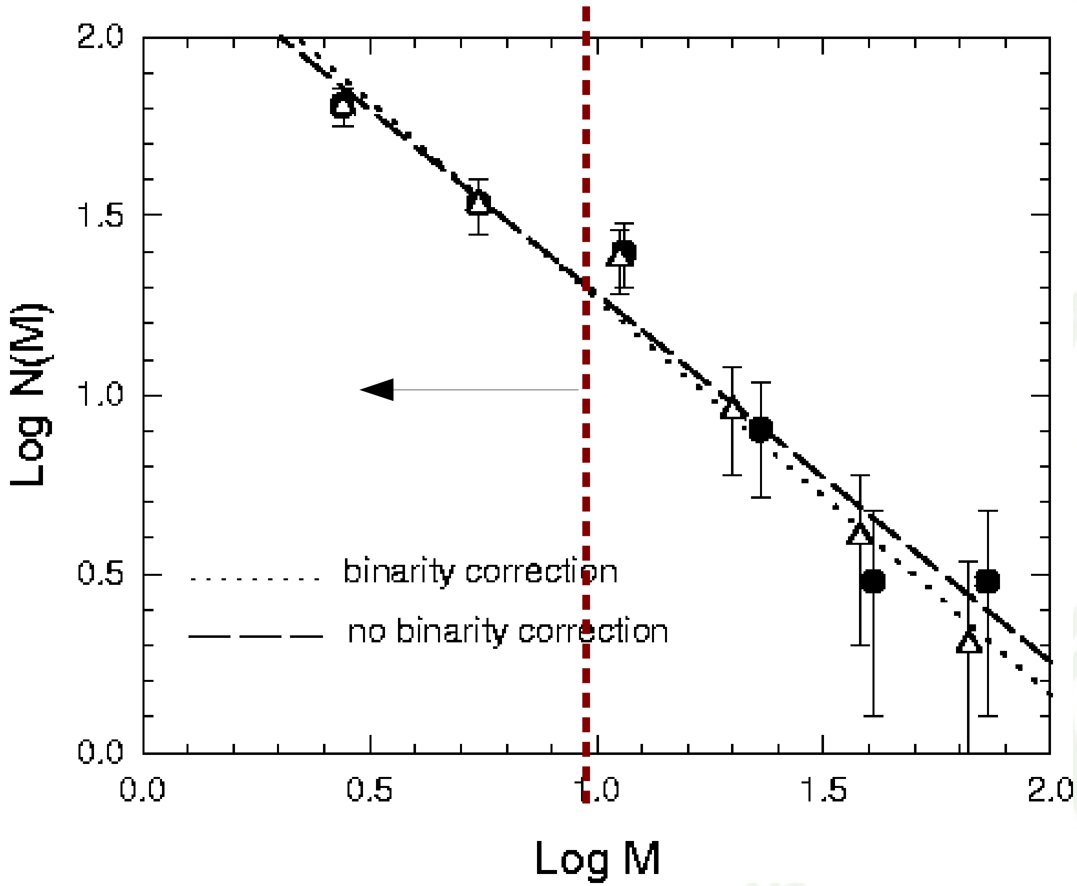
Deel 2:
- Model voorspellingen

Deel 3
- Recente waarnemingen
- Toekomst

Ster evolutie



Initiele Massa functie



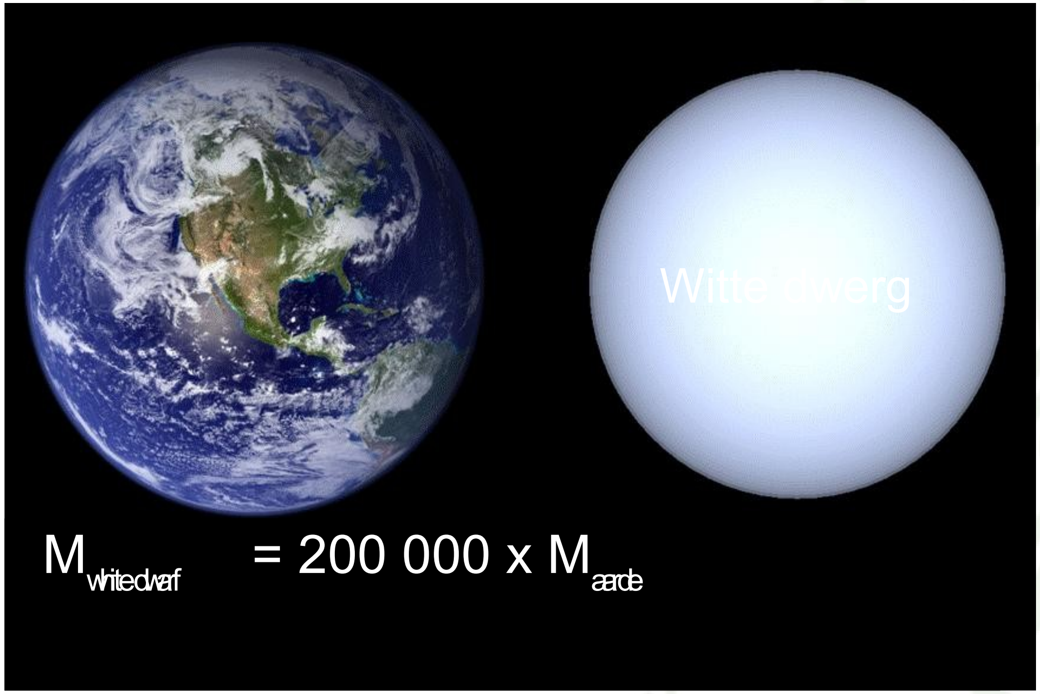
$$\frac{dN}{dM} = a \cdot M^{-\gamma} \qquad \gamma = 2.35$$

Zeer weinig sterren van hoge massa (>8 Zonsmassa) (~10%)
Zeer veel sterren van lage massa (<8 Zonsmassa) (~90%)

Bijna alle sterren worden uiteindelijk een witte dwerg

Planetaire nevel

Witte dwergen



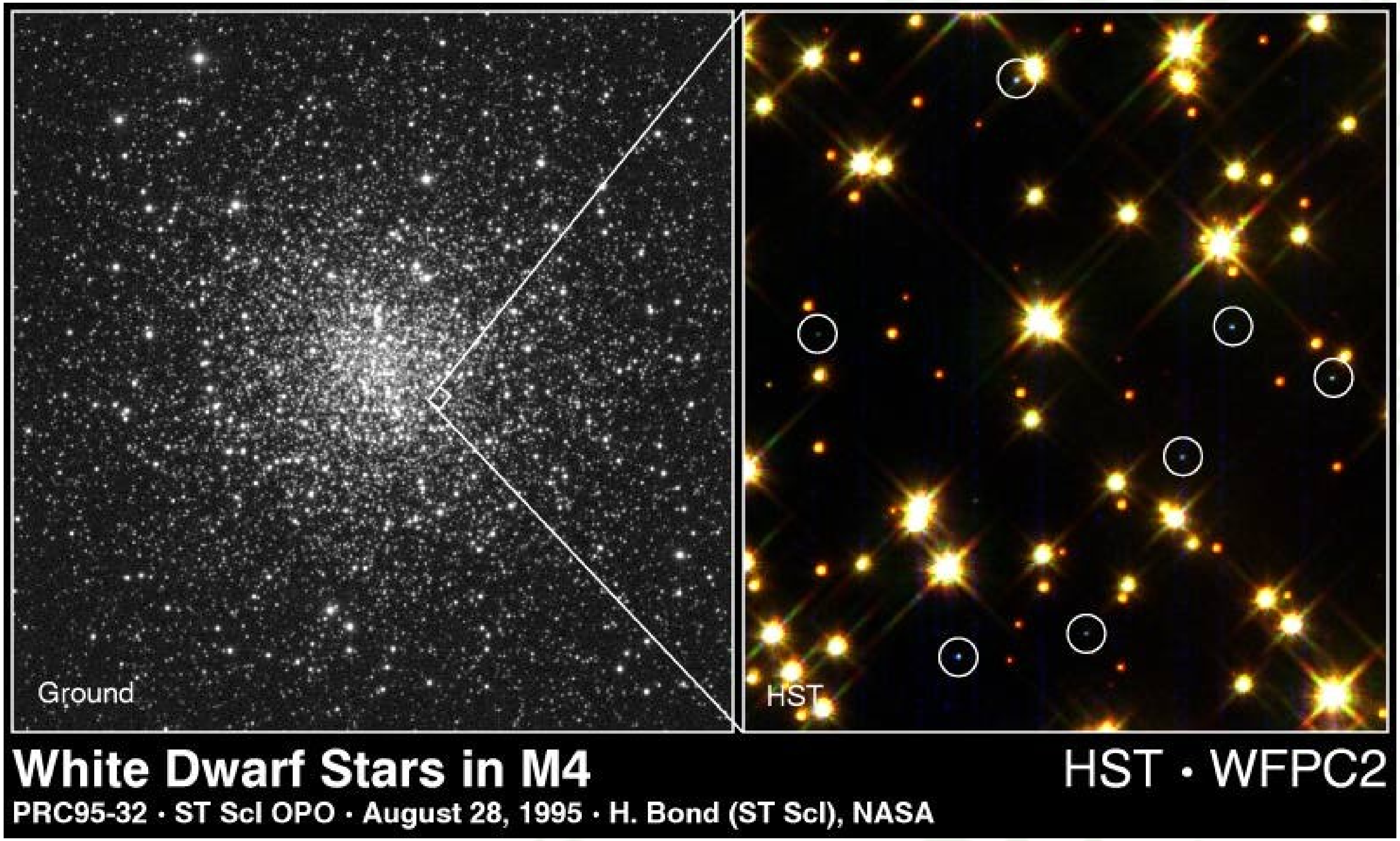
$0.3\ M_{zon} < M_{wd} < 1.4\ M_{zon}$

$\langle M_{wd} \rangle = 0.6\ M_{zon}$

- Uitgebrande kern van een voormalige ster: bestaat uit koolstof en zuurstof

- Dichtheid: > 1 miljoen keer die van water

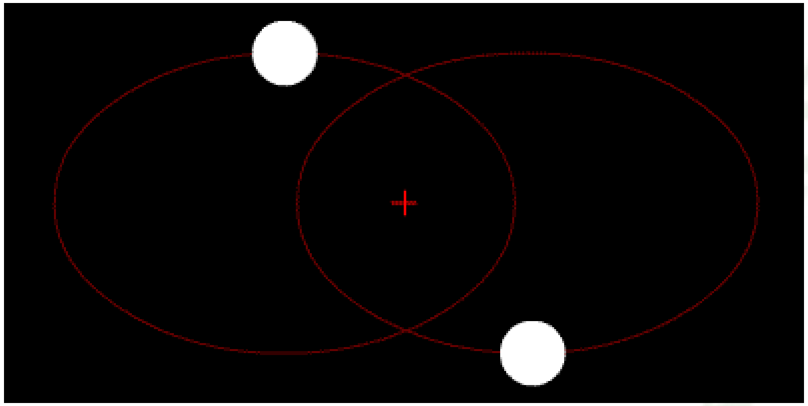
Witte dwergen

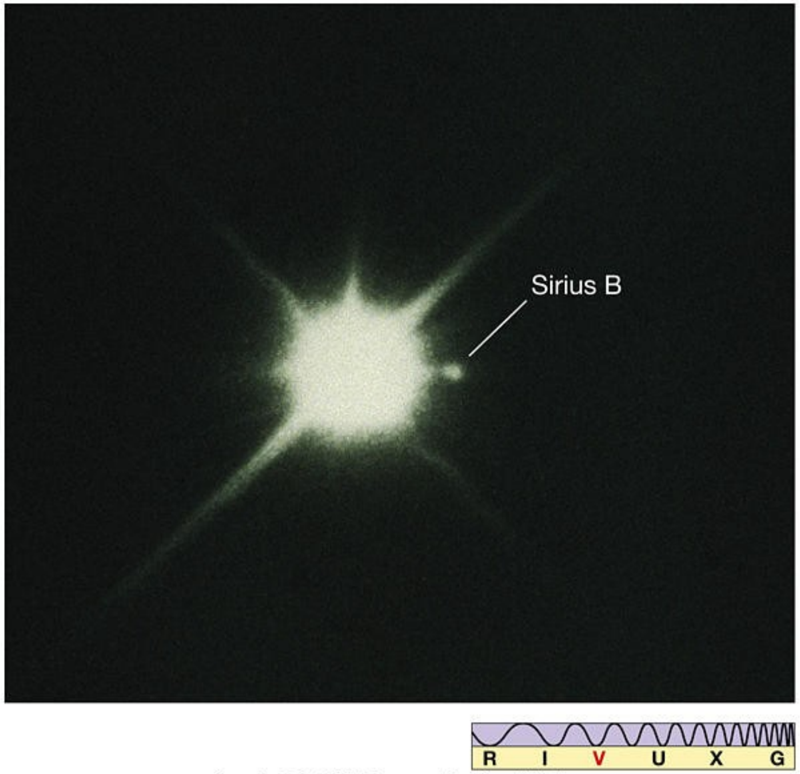


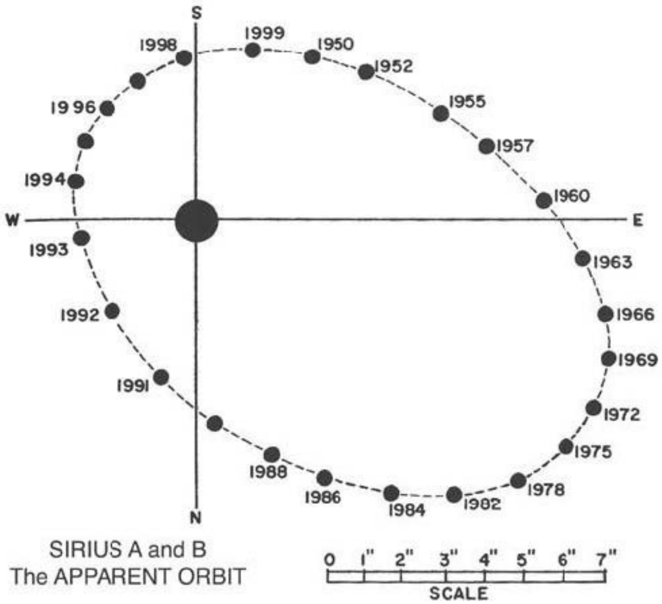
Witte dwergen zijn ontzettend zwak: <1/1000 lichtkracht Zon

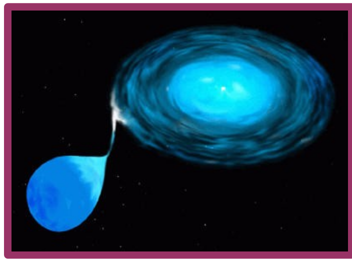
Dubbelsterren

De meeste sterren zitten in een dubbelster systeem:
twee sterren die door de zwaartekracht aan elkaar gebonden zijn,
en om elkaar heen draaien

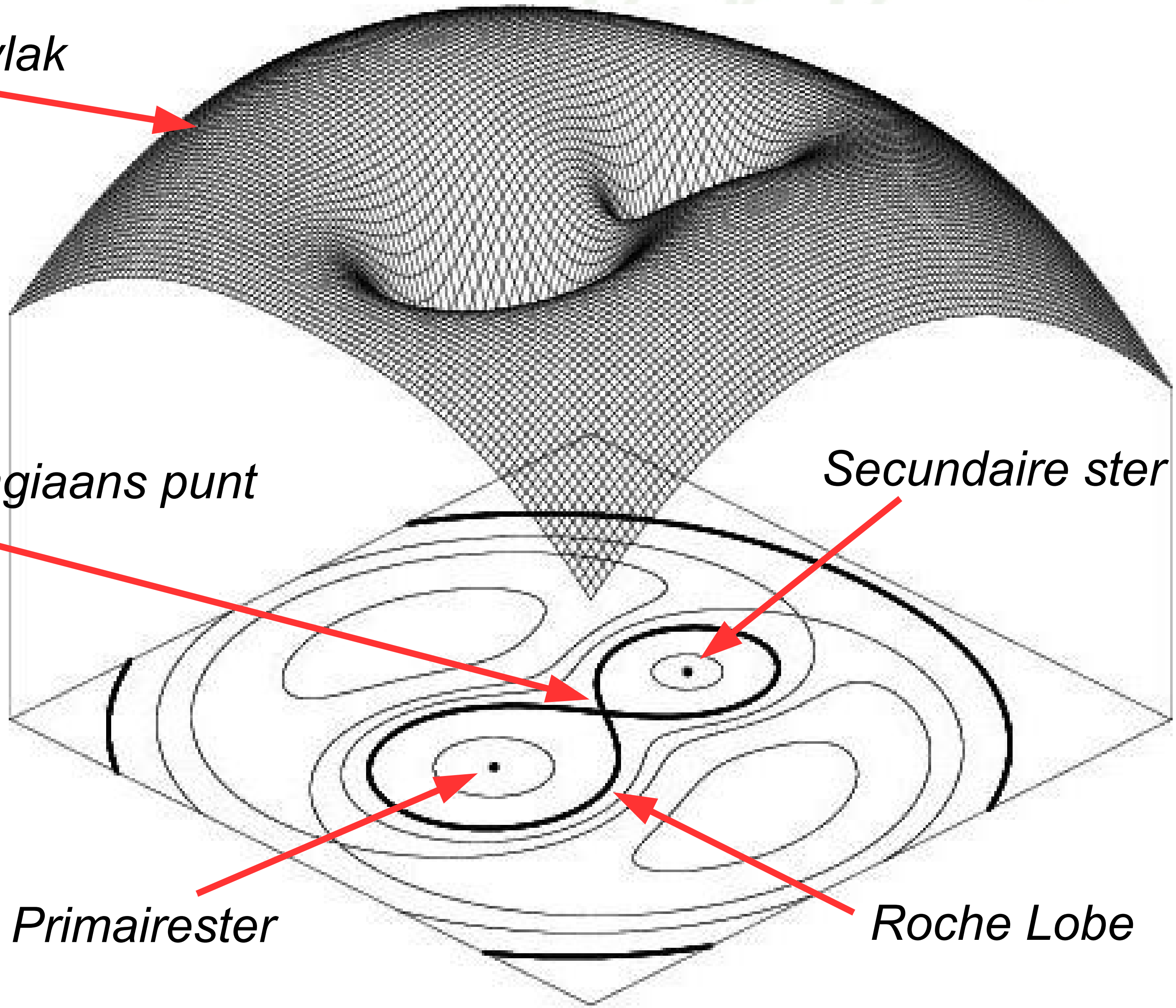




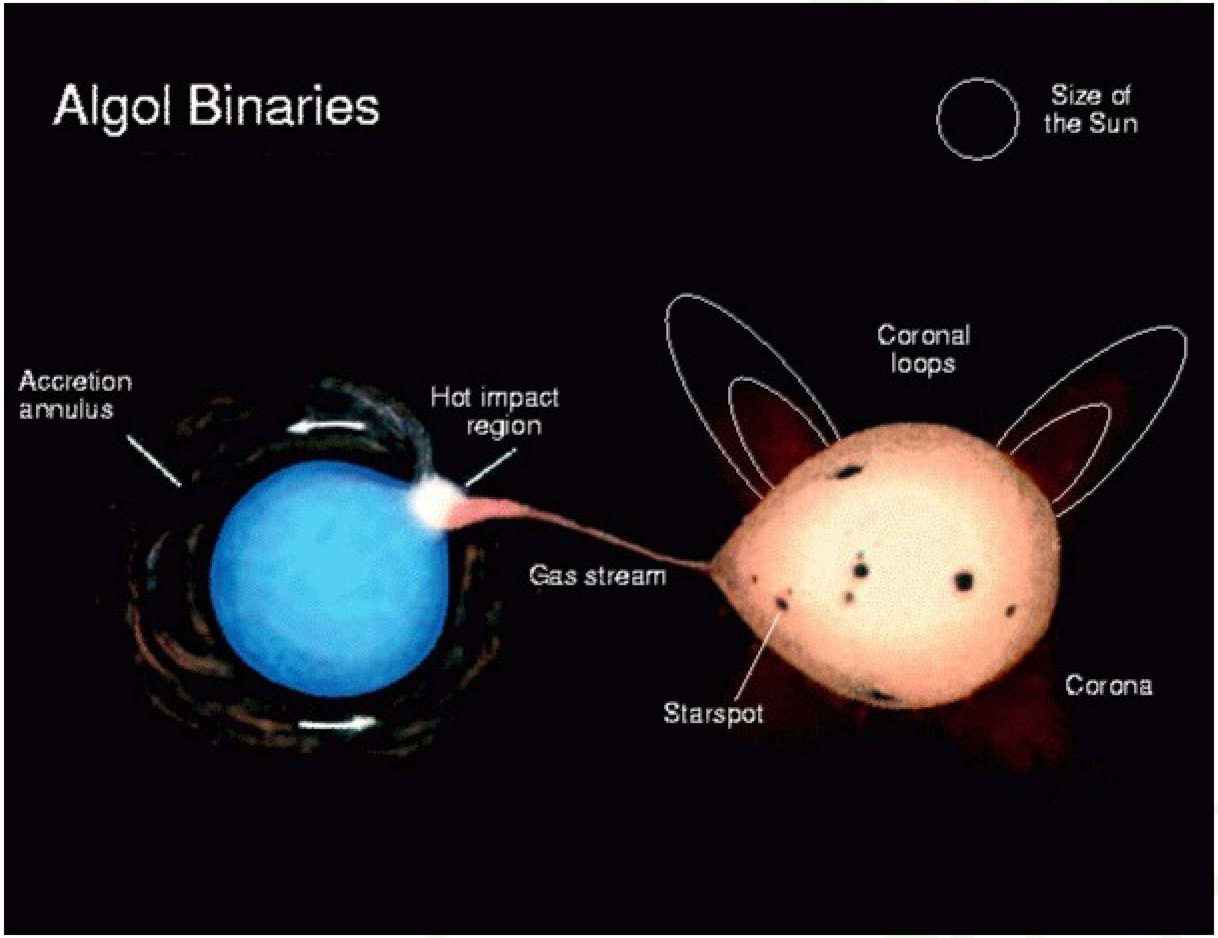




Roche Geometrie

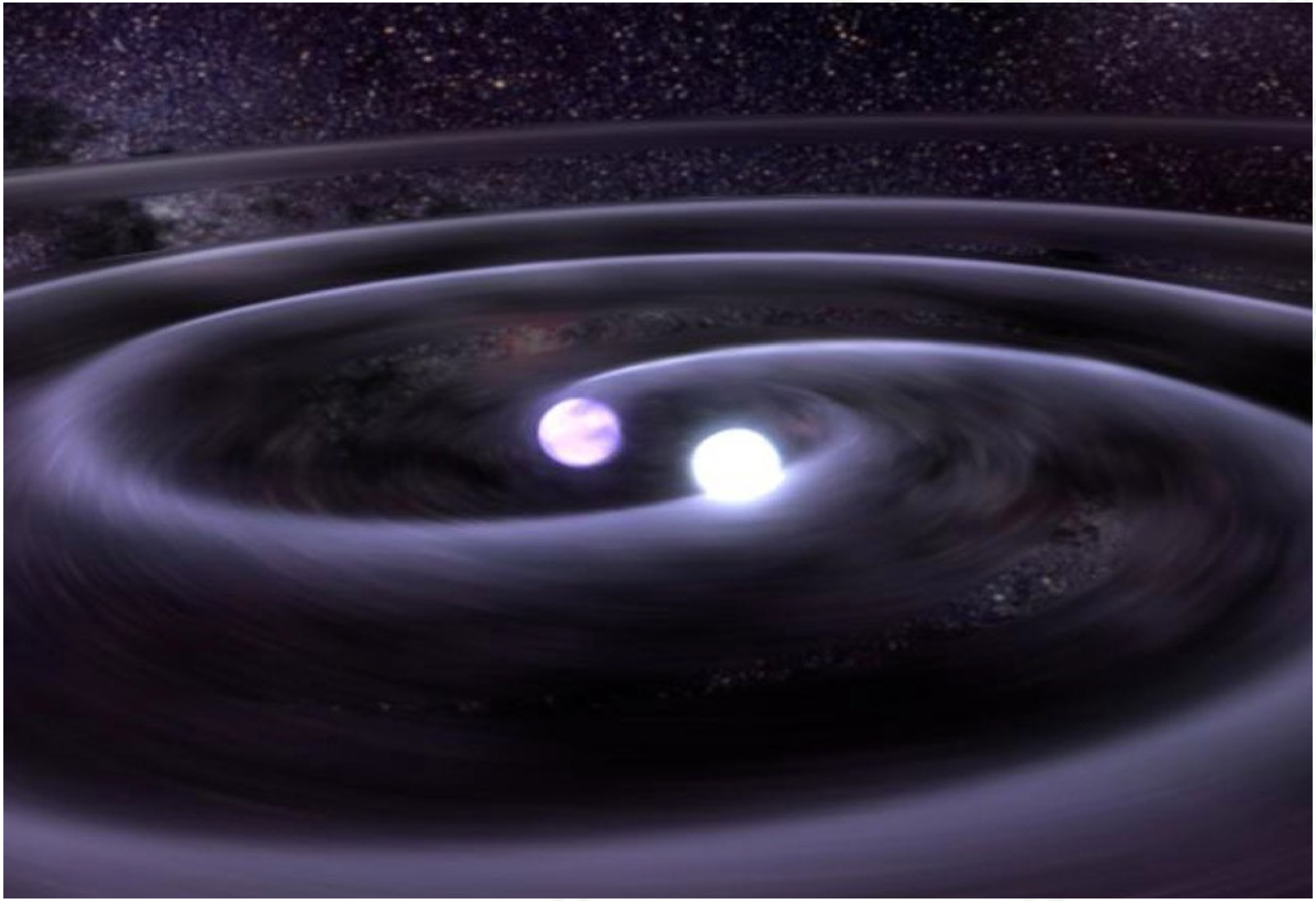


Massa overdacht

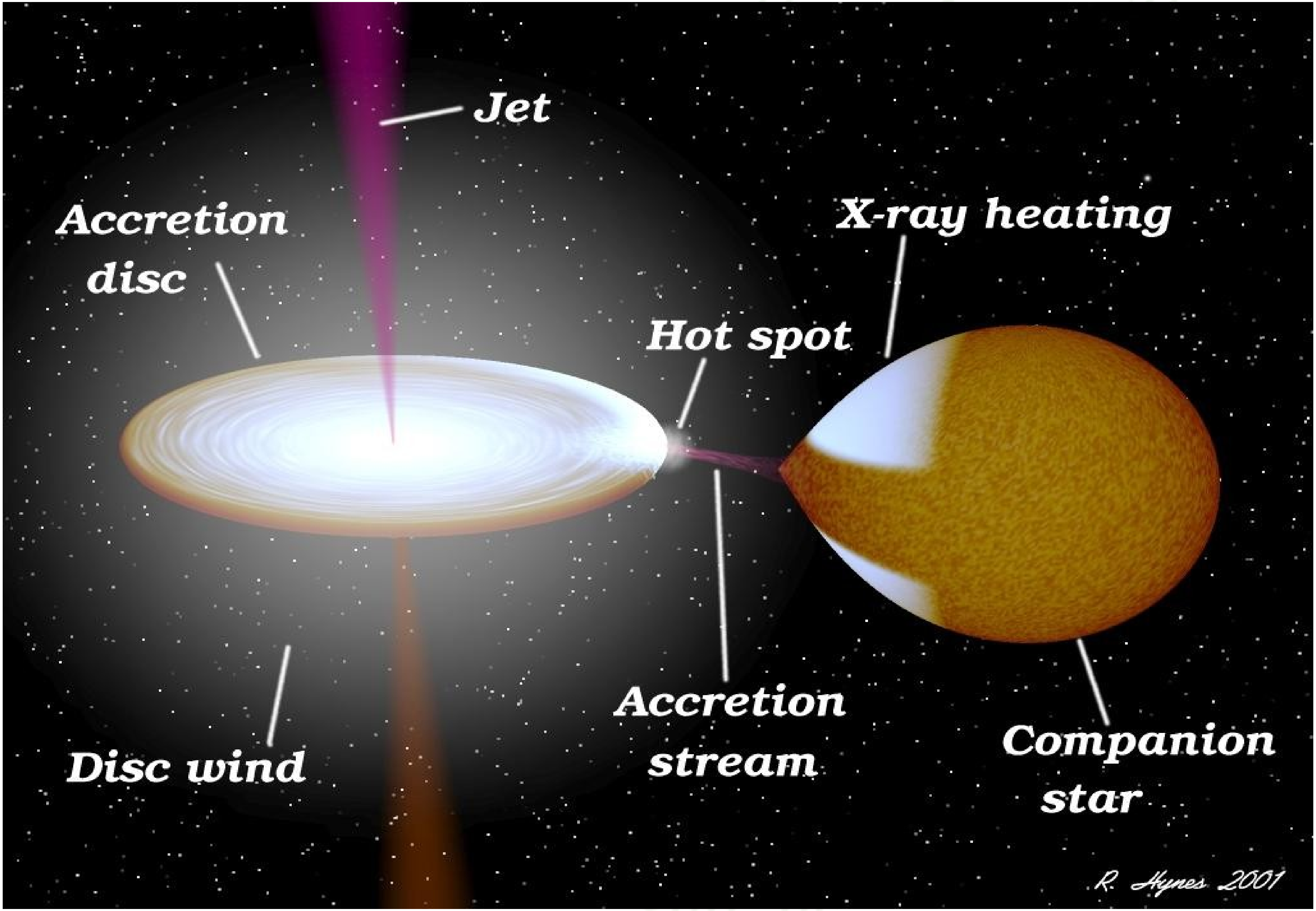


Beperkt volume in Roche Lobe leidt tot massa-overdracht!

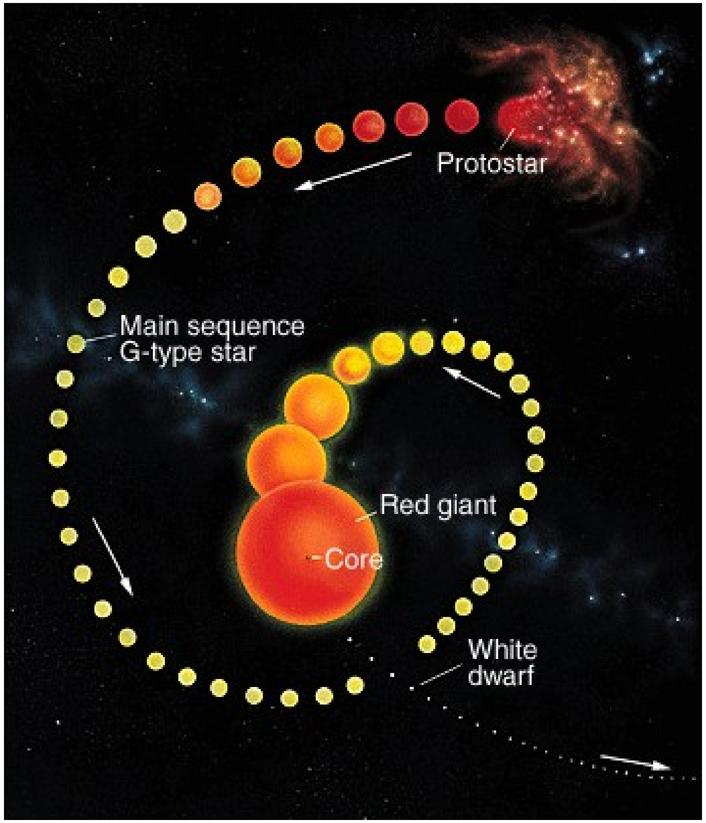
Dubbele witte dwergen



Interactieve dubbelster

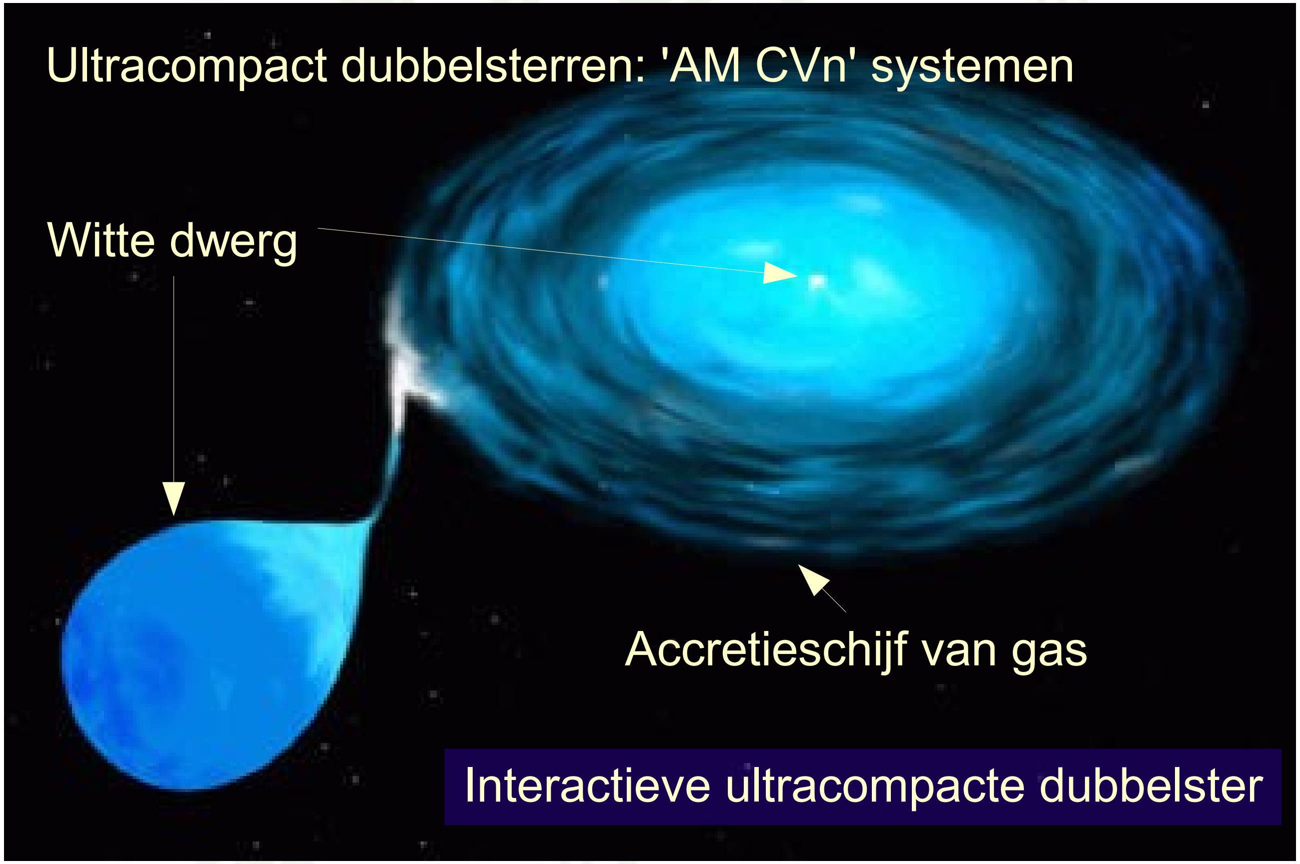


Ultracompacte Dubbelsterren

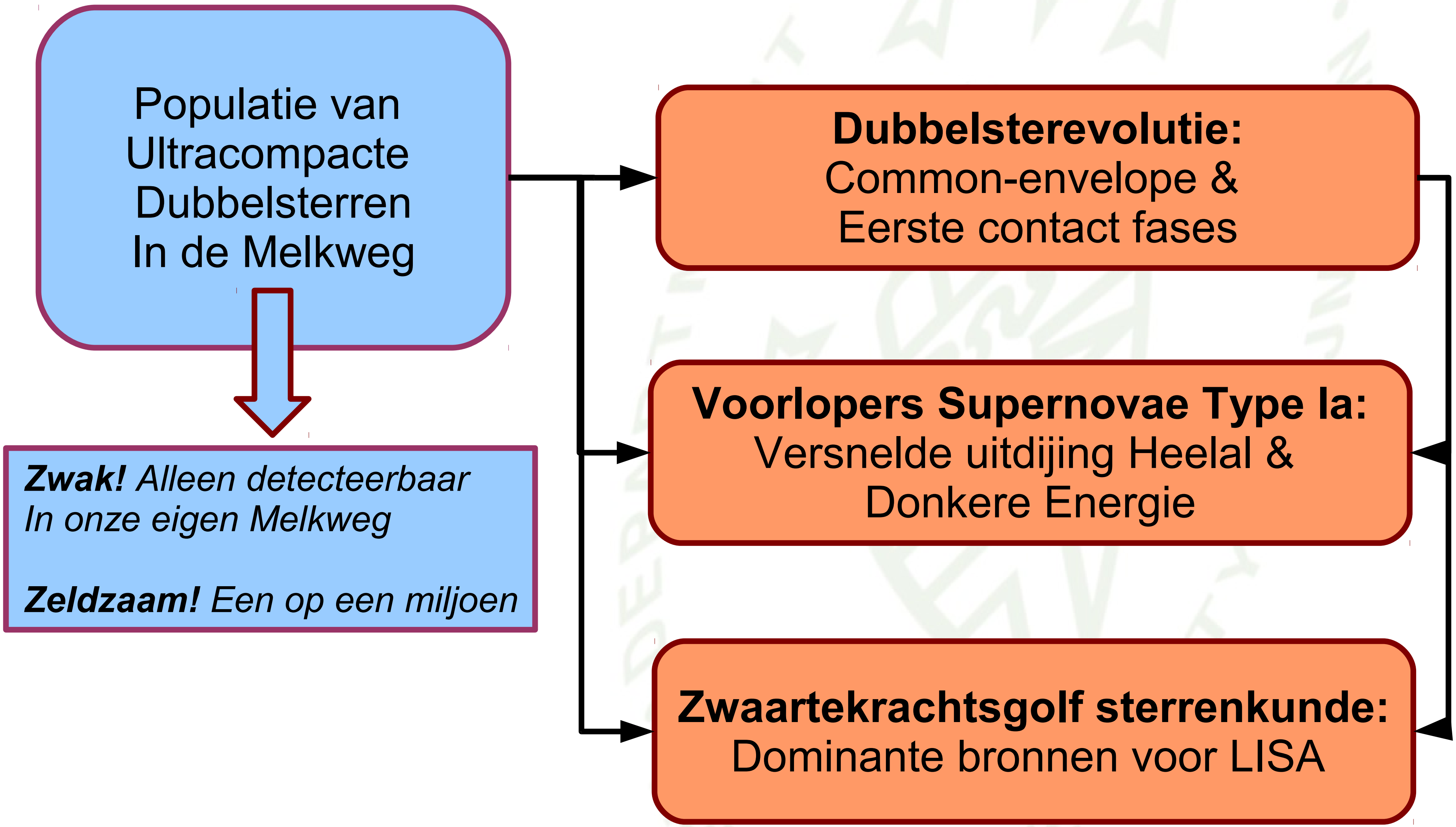


- Witte dwergen: meest voorkomende sterlijk
- Meeste sterren in een dubbelster
- **Ultracompacte dubbelsterren: P_{orb} < 1 uur!**
- Helemaal geen waterstof meer aanwezig
- Massastroom van witte dwerg naar witte dwerg

$M_{whitedwarf} = 200\,000 \times M_{earth}$

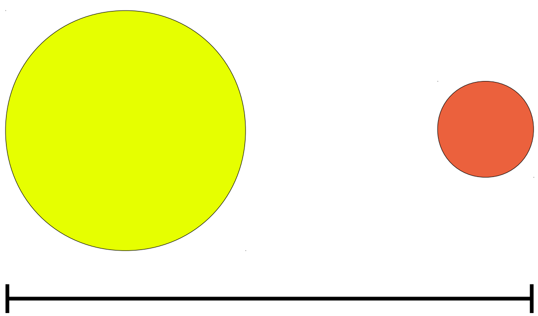


Waarom deze dubbelsterren bestuderen?



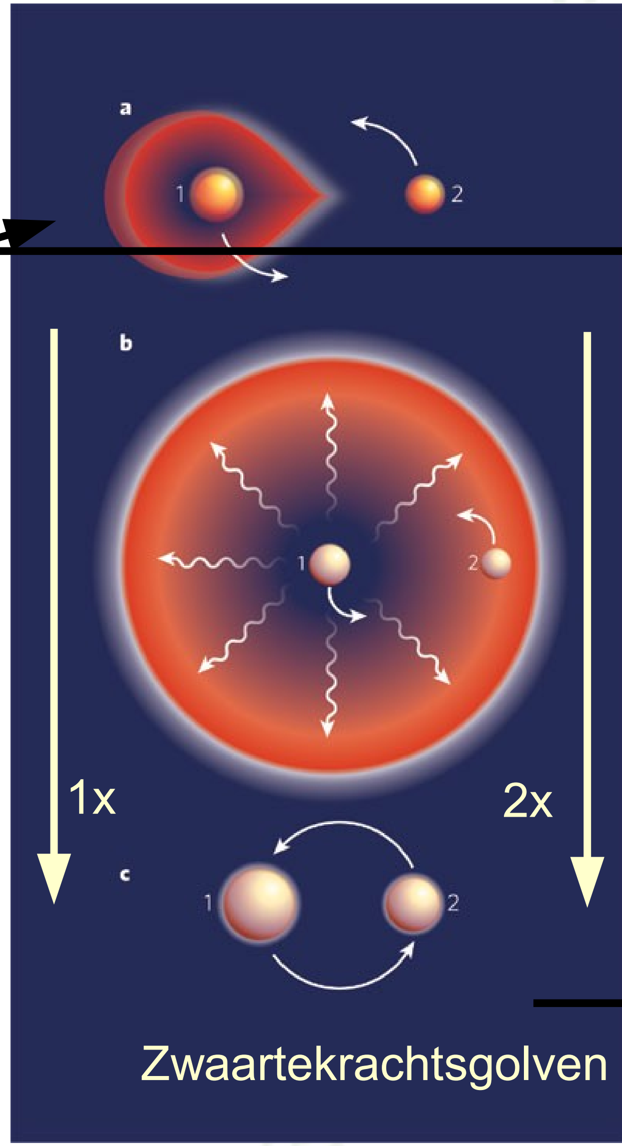
Evolutie naar een ultracompacte ster

Normale sterren



20 Zonstralen

Fysica van de common-Envelope fase slecht bekend!



Ultracompacte Dubbelster

<0.5 Zonstraal

SN Ia ?

Ja

Nee

Overleven?

Populatie van ultracompact dubbelsterren een prima manier om fysica van common-envelope & eerste contact te bepalen

Common-envelope evolutio

First ideas: Paczynski 1976

Problem: *Physics poorly known and hard to model*
- *Expected duration very short (1-100yr)*
- *Many length and time scales involved: 3D models cpu-intensive*

Two parametrized descriptions:

1: Energy conservation (Webbink et al.):

Orbital energy is used to expel envelope

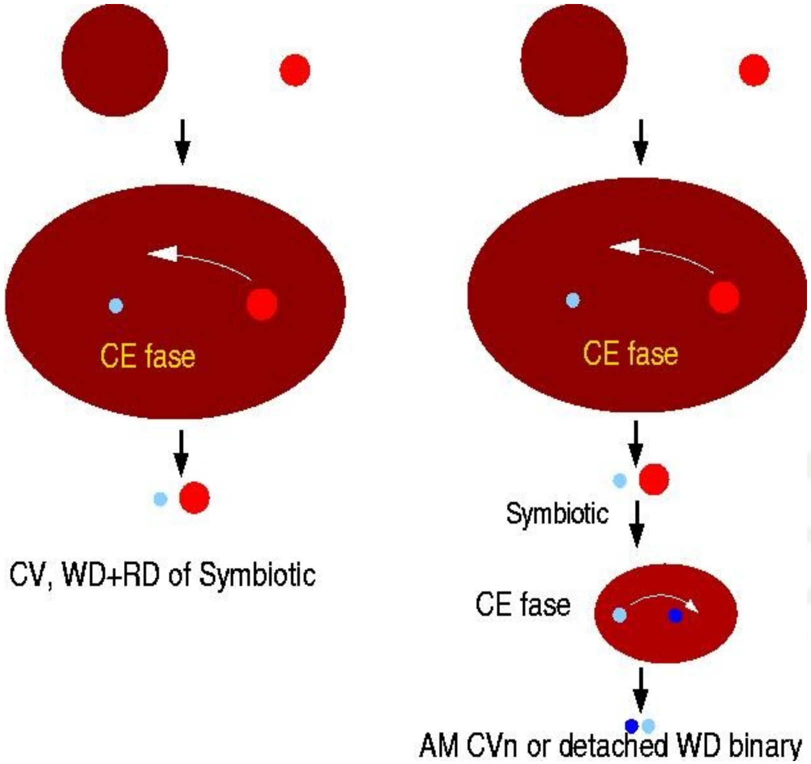
2: Momentum conservation (Nelemans& Tout):

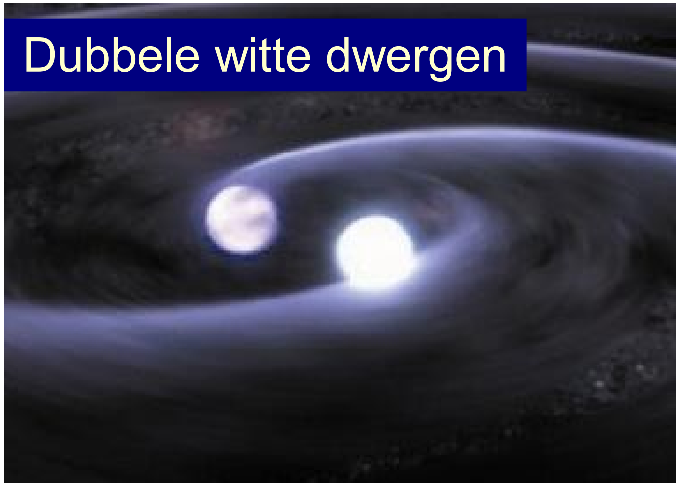
Orbital angular momentum is used

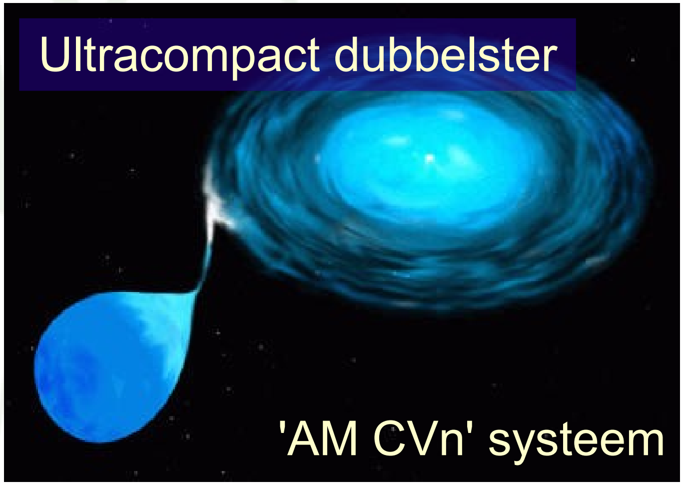
Unclear which is better (or even *correct*) description.

Statistical approach: observe post-common envelope populations and determine relative and absolute numbers, compare with numerical population synthesis modeling

Vergelijk waarnemingen met modellen

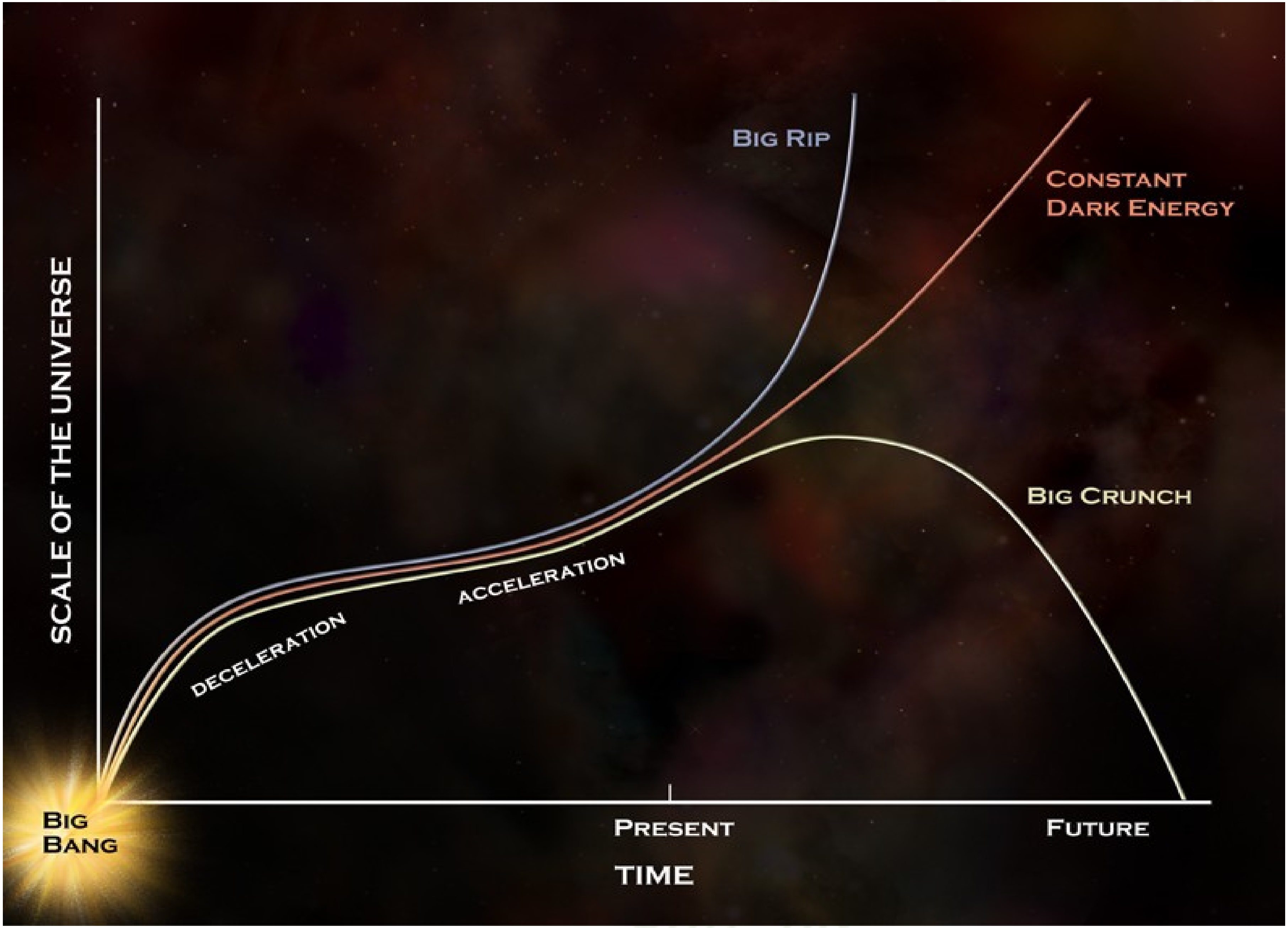






Supernovae Type Ia

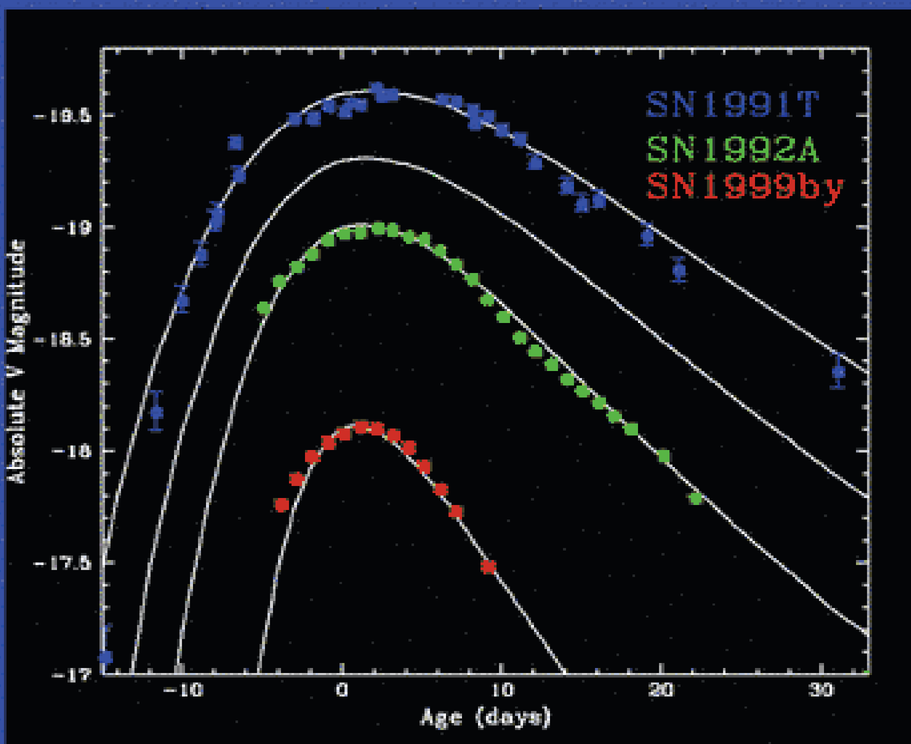
Toekomst van het heelal

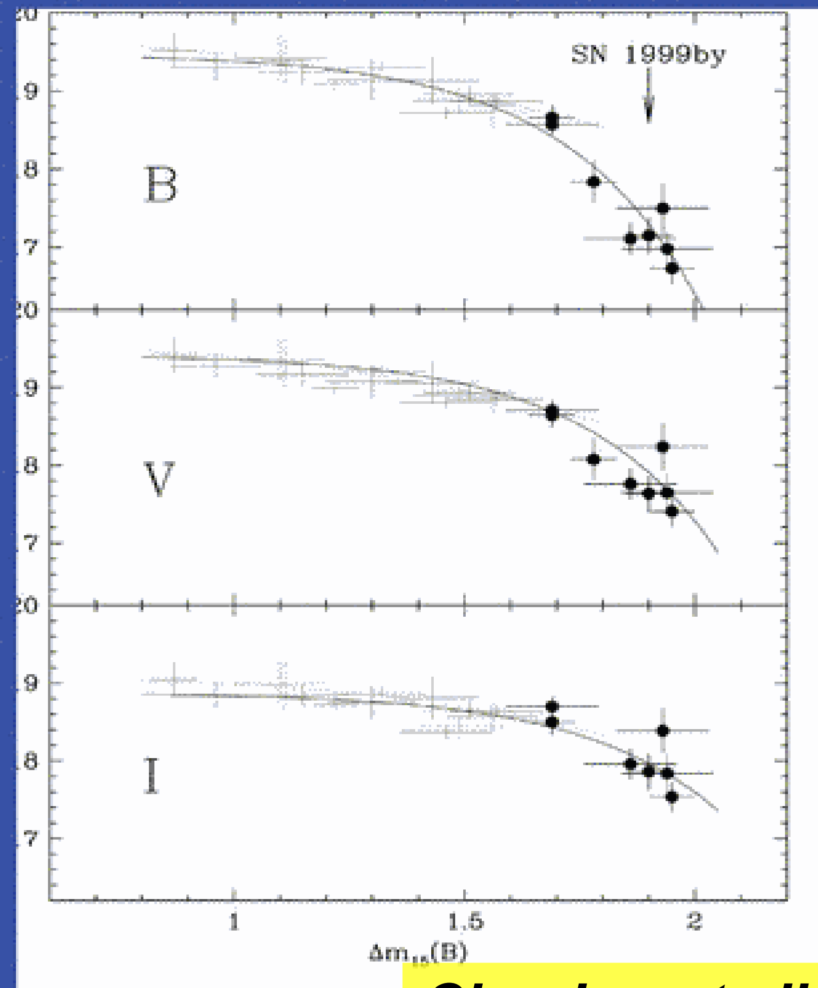


Supernovae Type Ia

Sub-Luminous SNIa = Fast Declining LC

"Phillips Relation": correlation between decline rate and peak luminosity

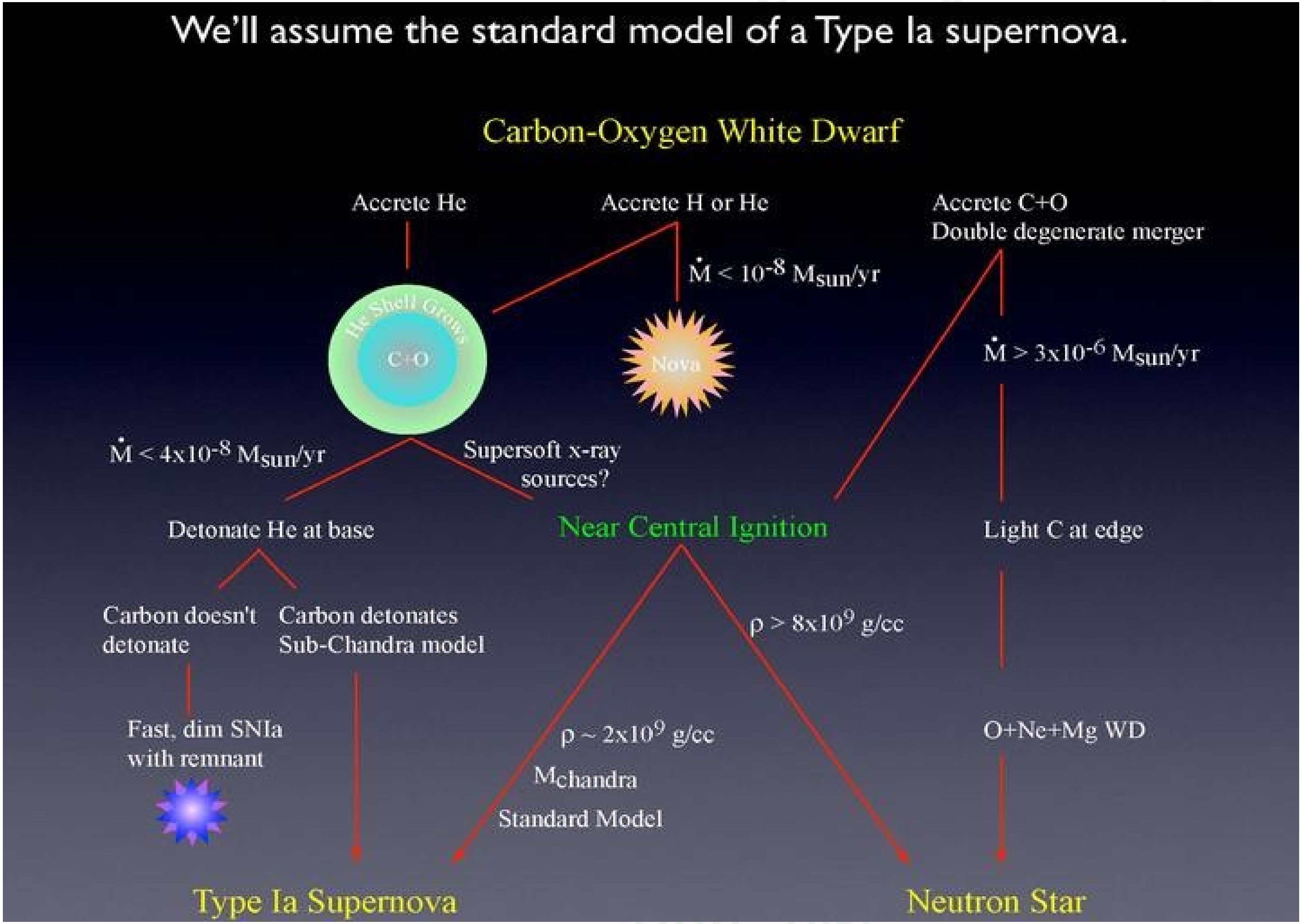




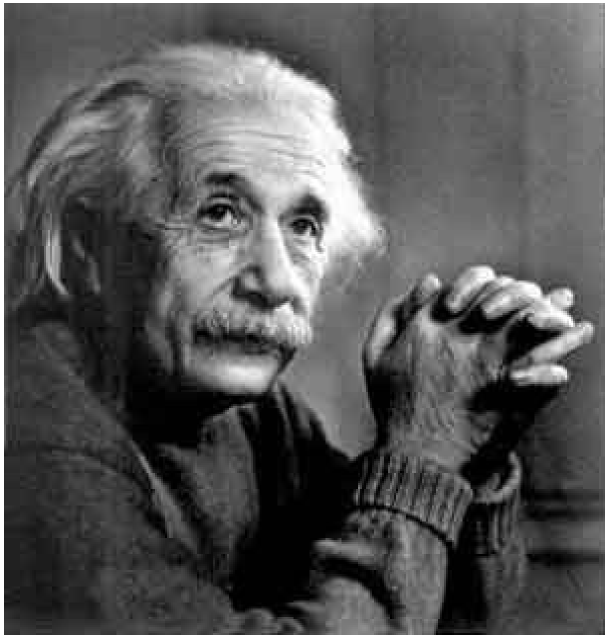
Absolute magnitudes from Hubble Flow (assume H_0) or Cepheids (SN 99by)

Clearly not all the same!

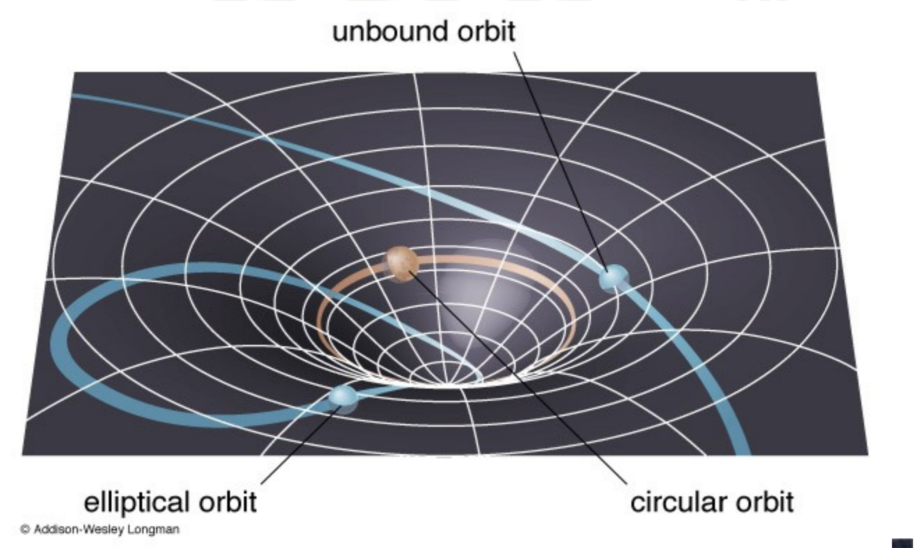
Evolutie naar een SN Ia?

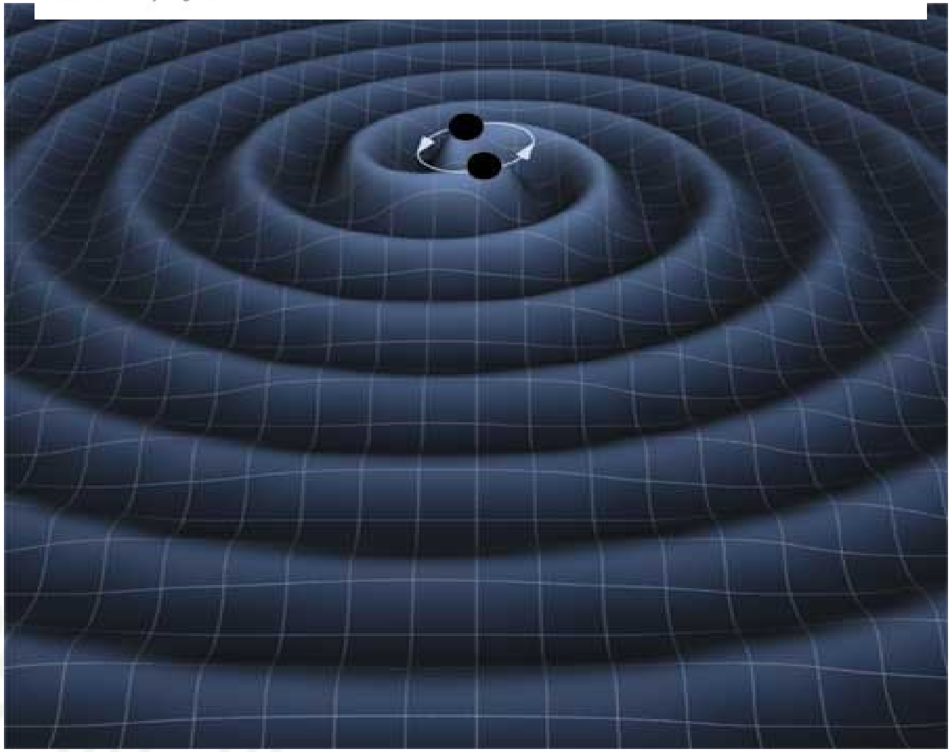


Zwaartekrachtgolven



Voorspelling Algemene
Relativiteitstheorie:
Nog nooit direct waargenomen





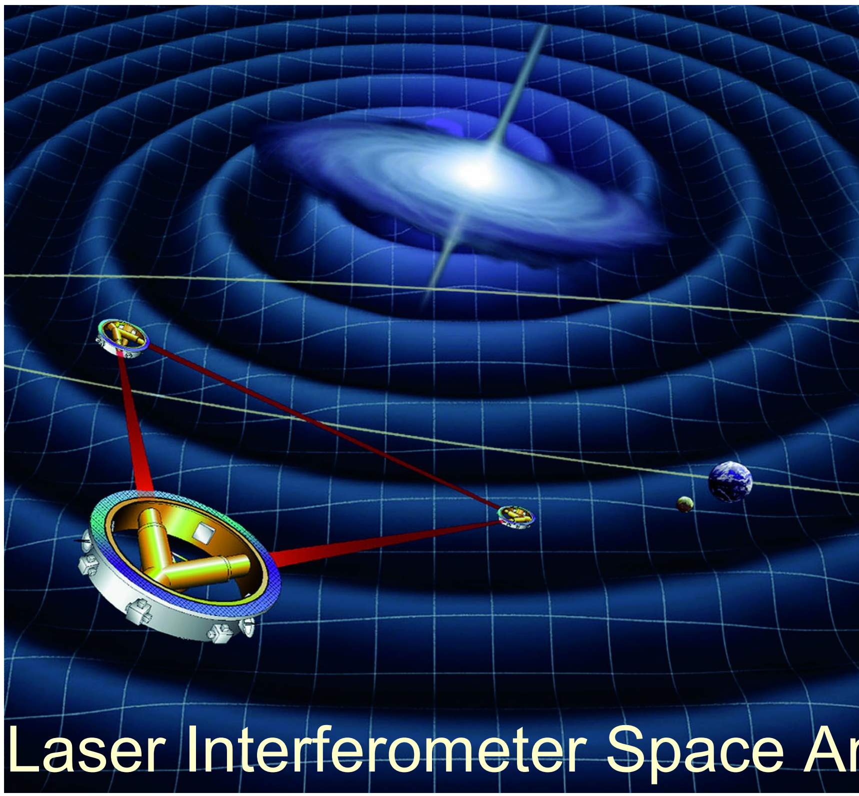
Zwaartekrachtgolven

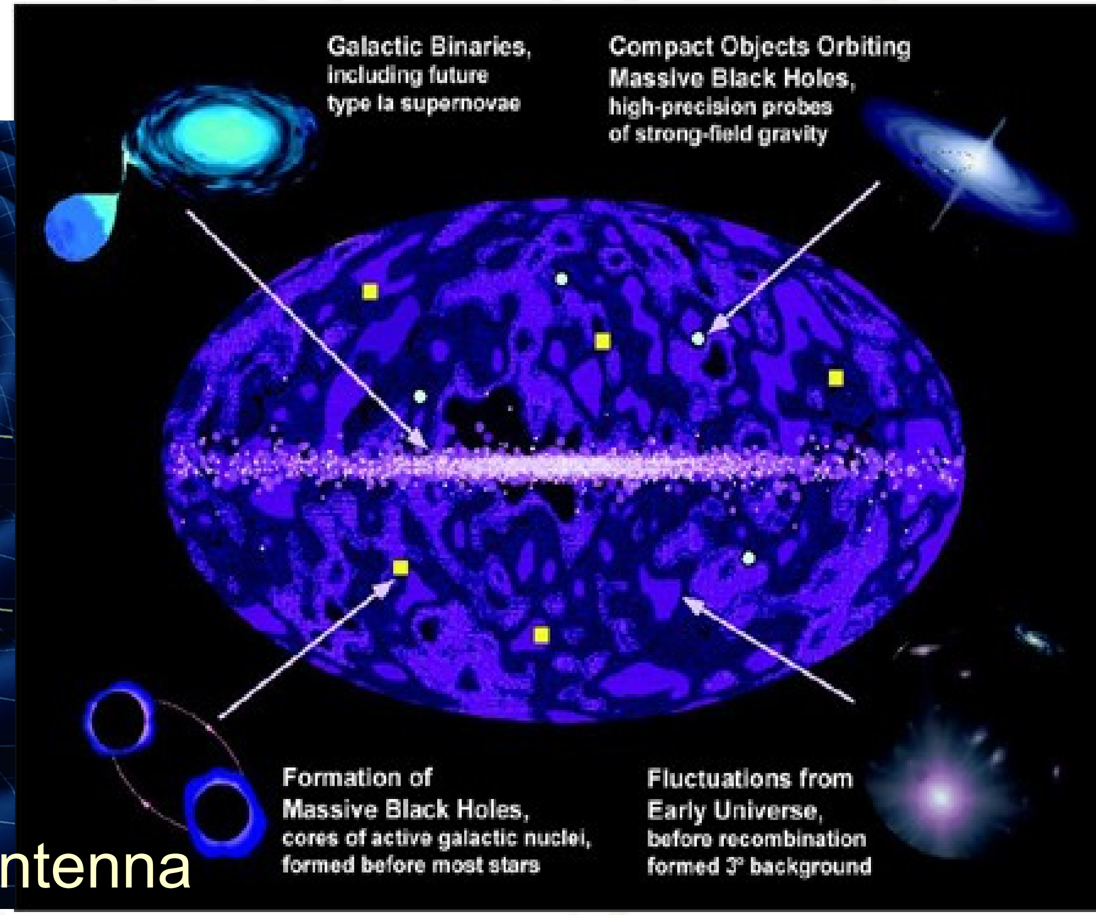
Als directe detectie van zwaartekrachtsgolven:
revolutie in de natuurkunde

Zwaartekrachtgolven

Direct detection: (astro)physics revolution of 21st century

Only *known* LISA sources: ultracompact binaries

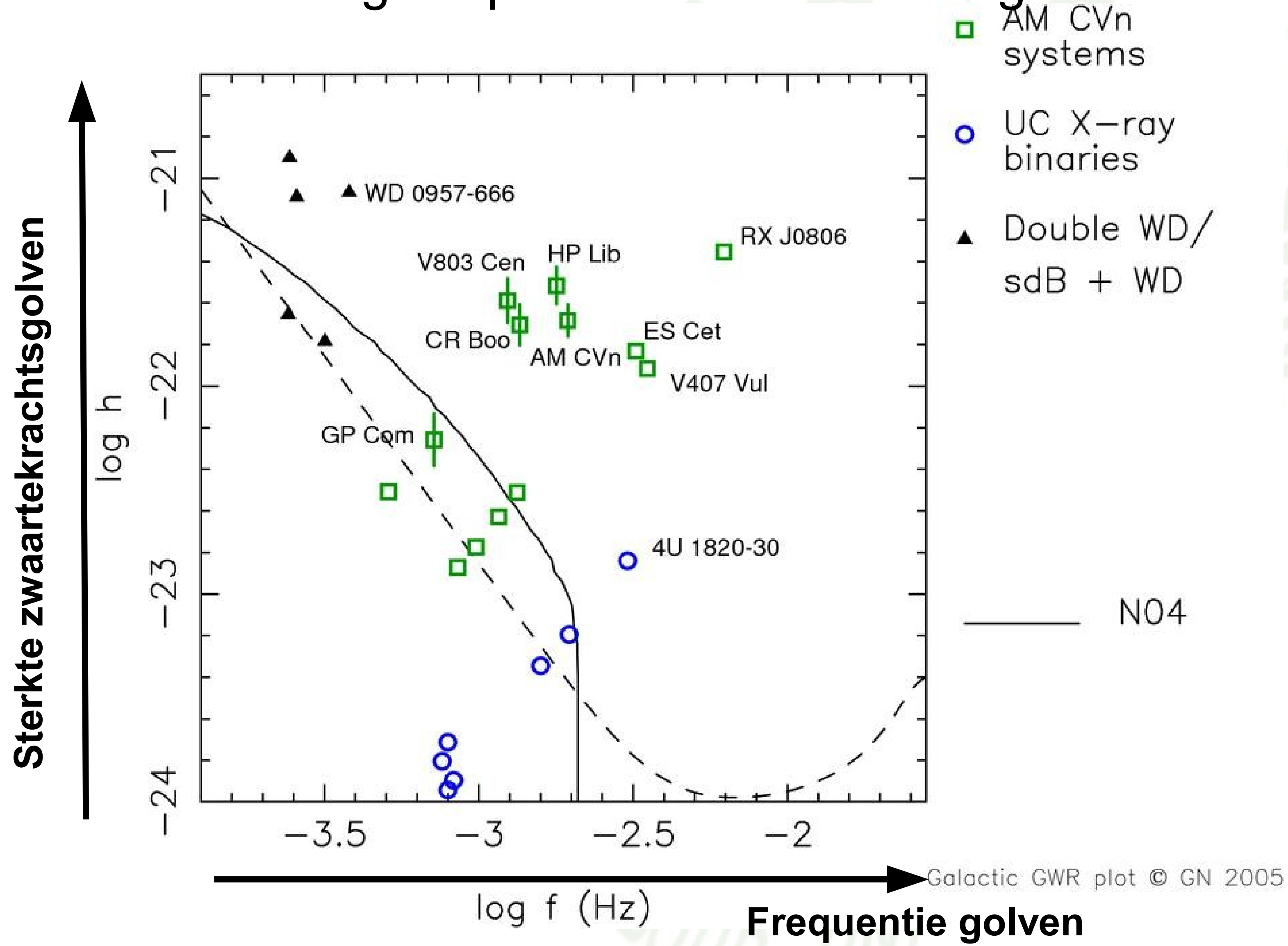




Needed: quantitative prediction on shape and strength of gravitational wave signal from ultracompact binaries in Galaxy

Zwaartekrachtgolven

Ultracompacte dubbelsterren dominante en enig bekende Bronnen van laag-frequente zwaartekrachtsgolven



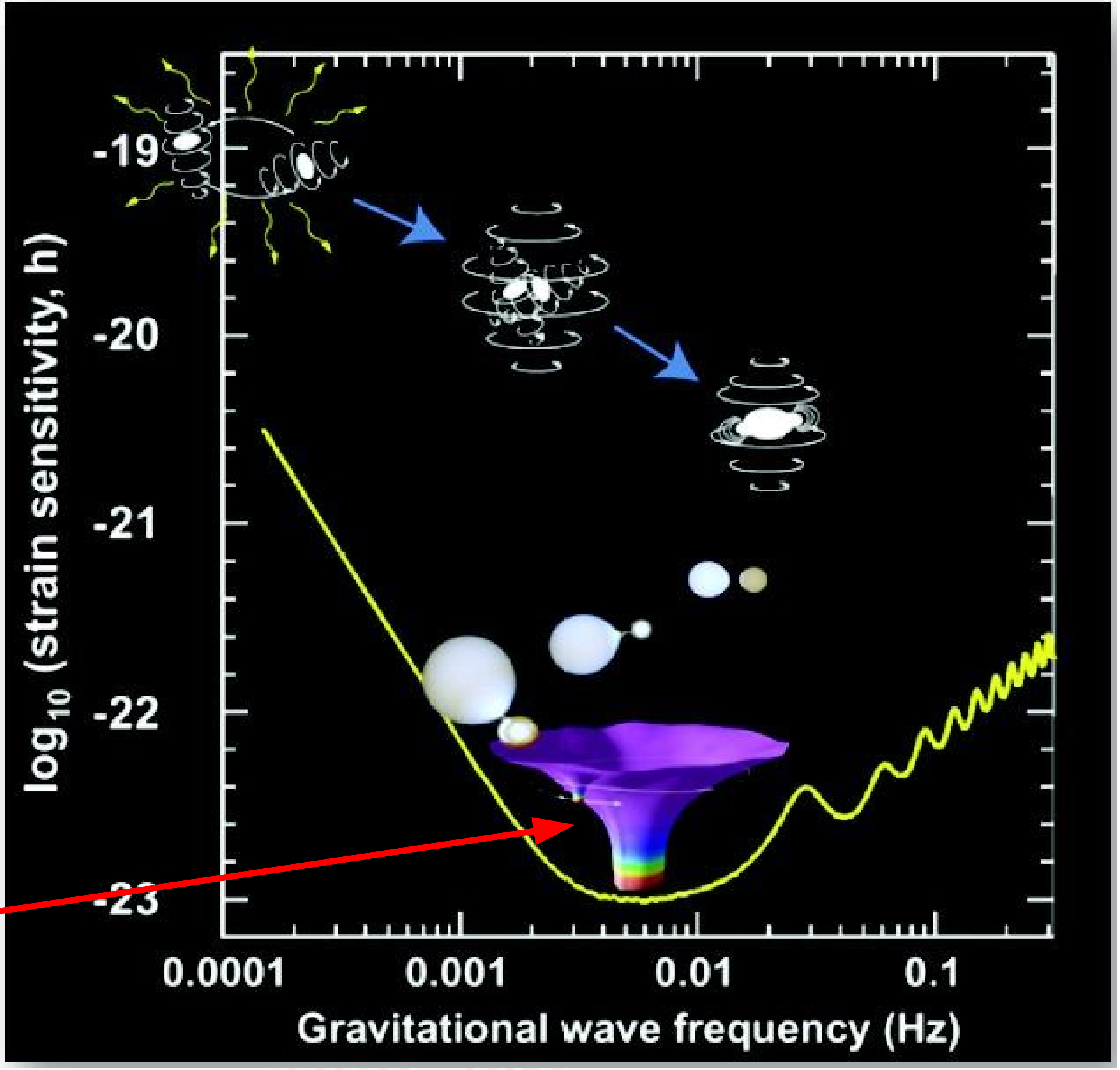
Effects on LISA science

Strain Amplitude

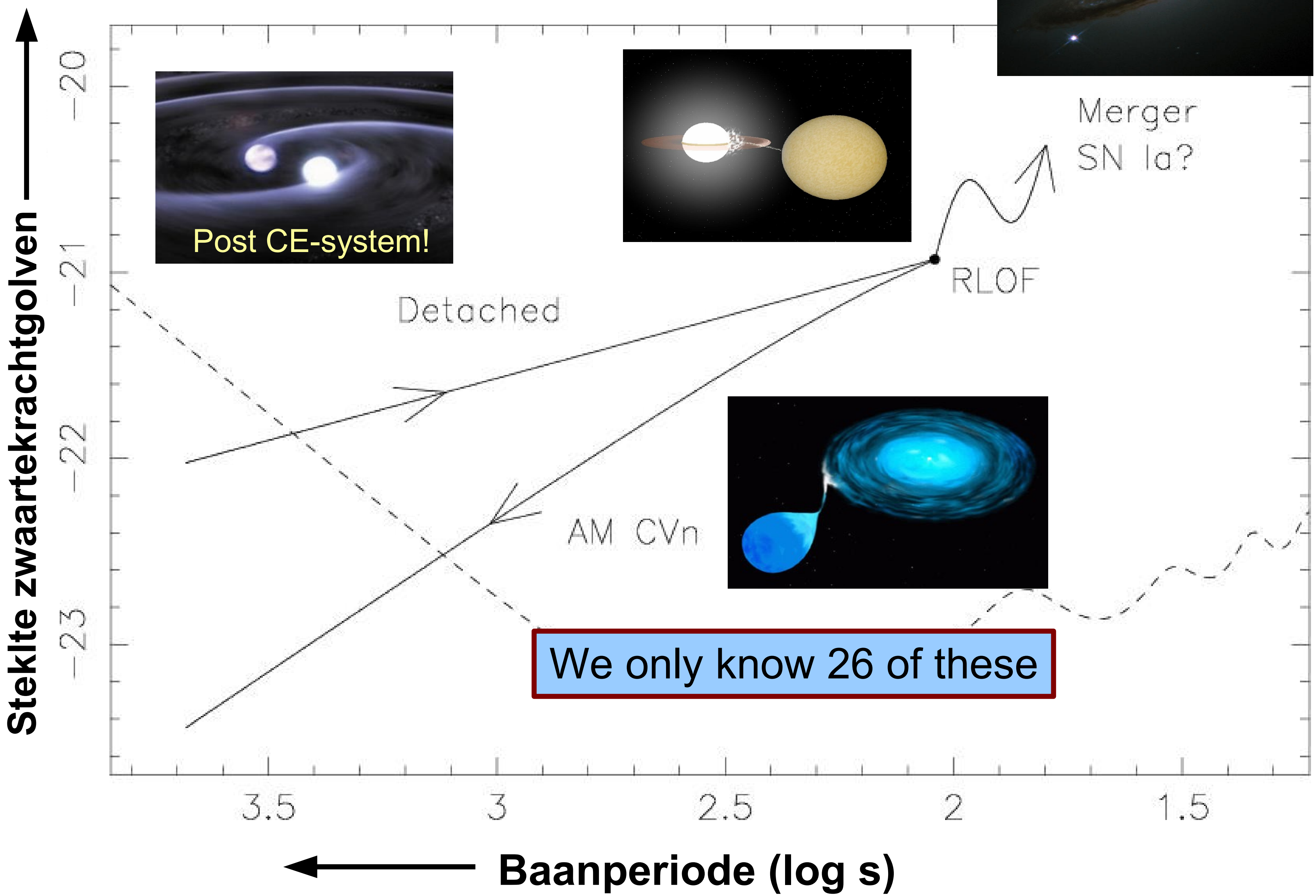
$$h = \left(\frac{GM}{Rc^2}\right)^2 \left(\frac{R}{D}\right)$$

More extreme binaries:
LISA will see no extreme mass-ratio in-spirals

Fewer extreme binaries:
LISA will see extreme mass-ratio in-spirals



Onderlinge samenhang!

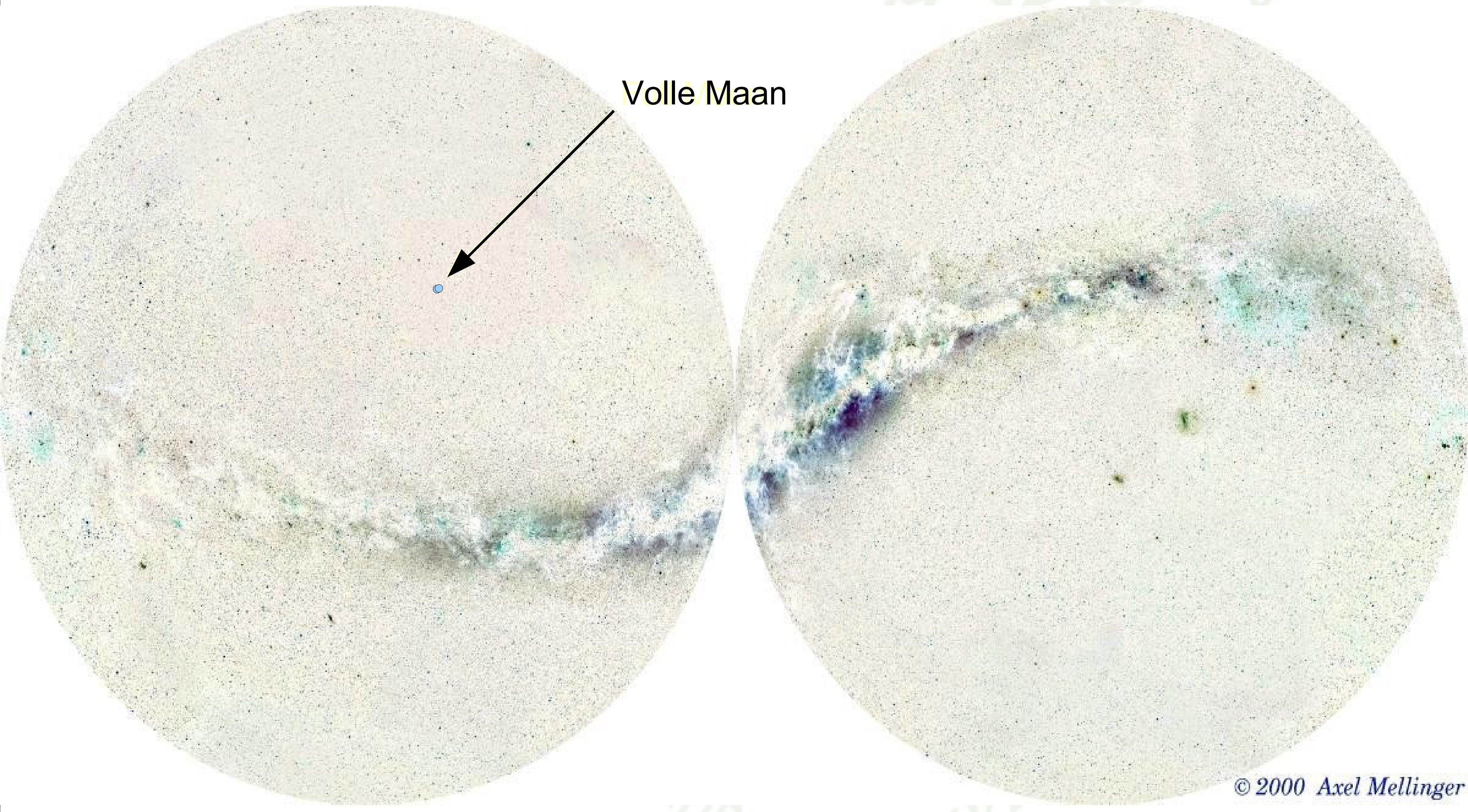


Deel 2:

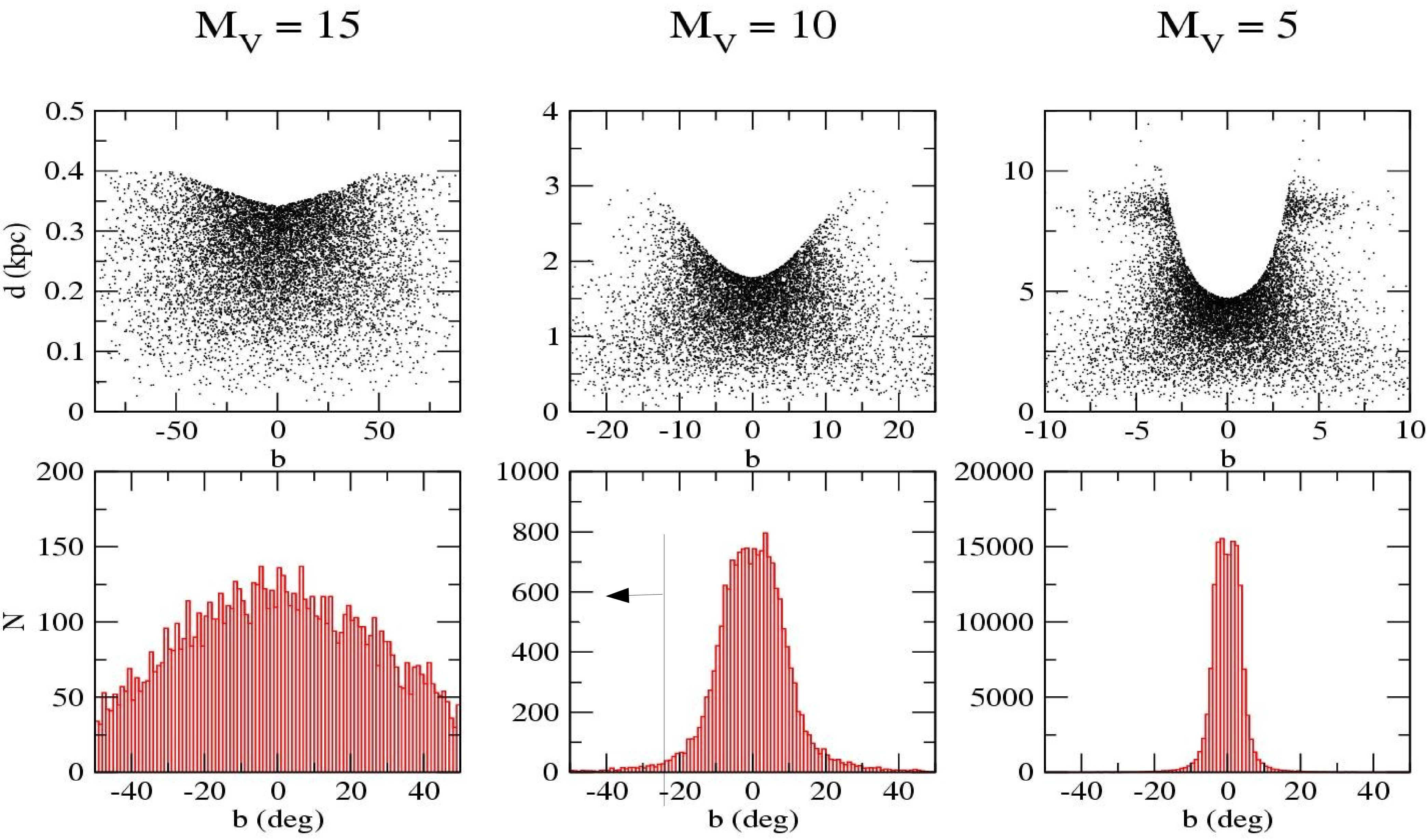
Voorspellingen uit modellen

- Dubbelsterpopulatiesynthese
- Model van onze Melkweg

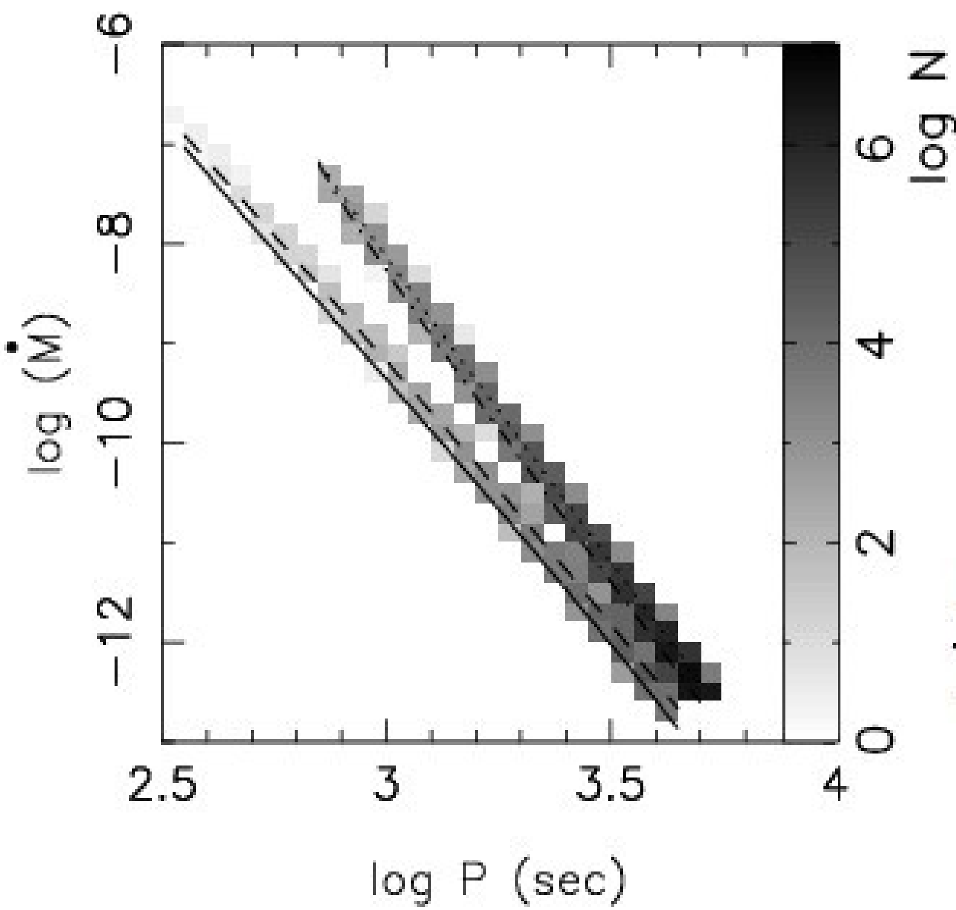
Ons Melkwegstelsel



Model: Verdeling aan de hemel



Model: verdeling in baanperiode



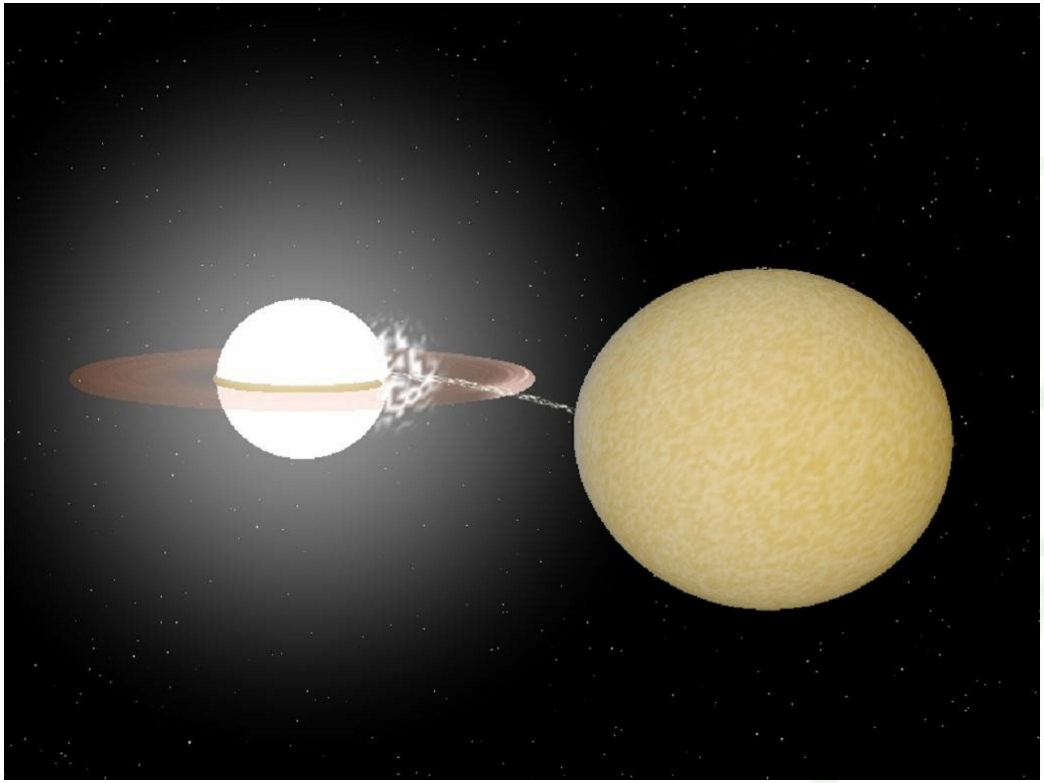
Nelemans et al., 2001
also Tutokov & Yungelson, 1991

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

$$L = \frac{1}{2}\dot{M}_2[\Phi(L_1) - \Phi(R_1)],$$

1: Meeste systemen zitten bij lange baanperiodes (>30 minuten)
2: Meeste systemen zijn zwak (L $\propto$ $\dot{M}$)
3: Systemen zijn zeldzaam ($\rho \sim 10^{-5}$ pc^{-3})

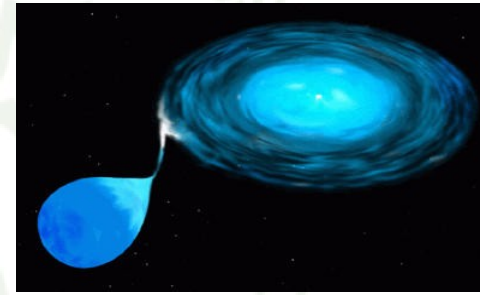
Model: Directe inslag van stroom

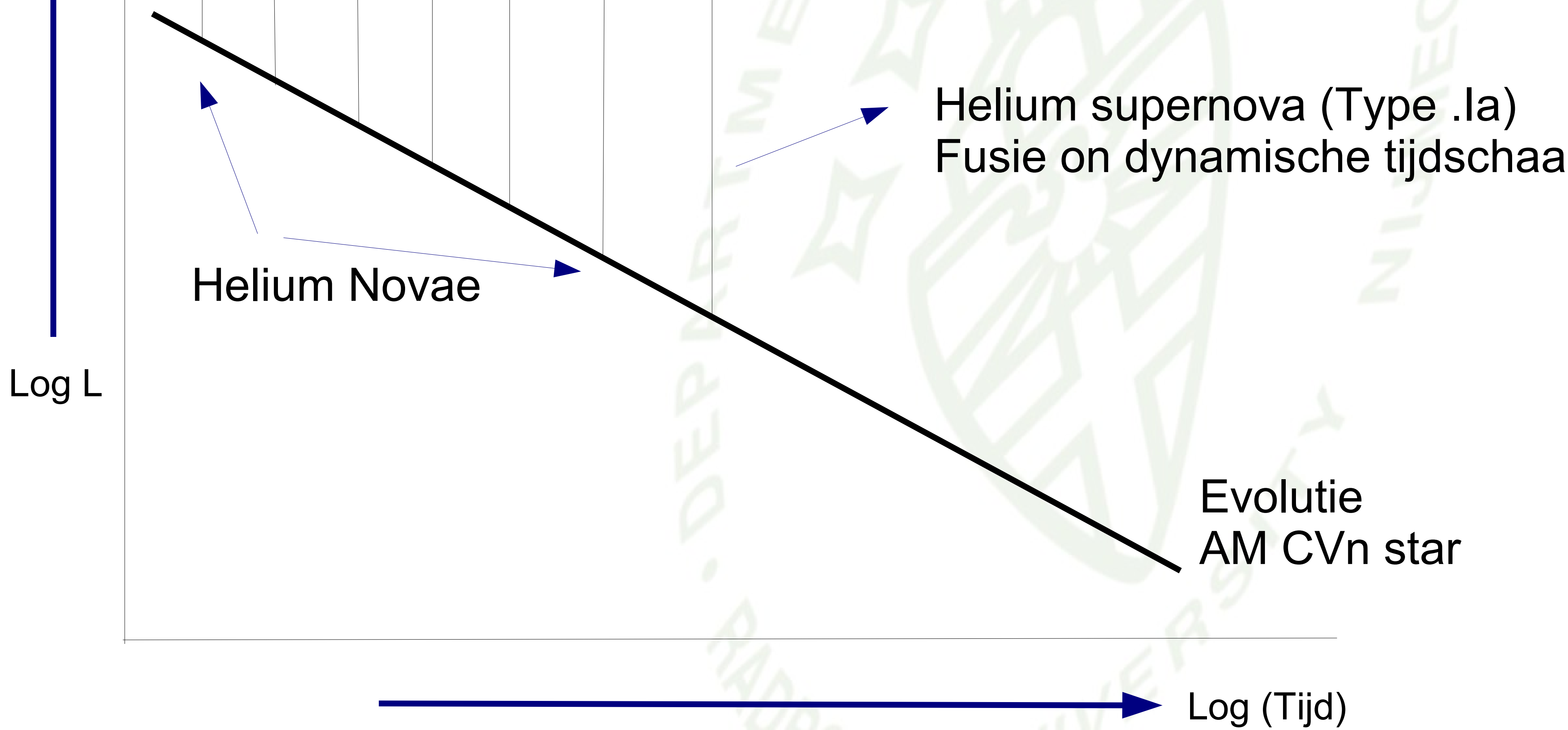


1:Bij hele korte baanperioden (<10 minuten): direct inslag van massa Stroom op de primaire witte dwerg: röntgenstraling!

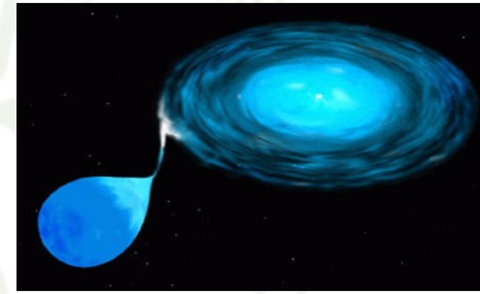
2:Als $\dot{M}$ hoog blijft: helium nova explosie of zelfs Supernovae **.**Ia (punt Ia) *(Bildsten et al., 2007).* Frequentie: 1/(5000-15000) yr^{-1} melkweg^{-1}

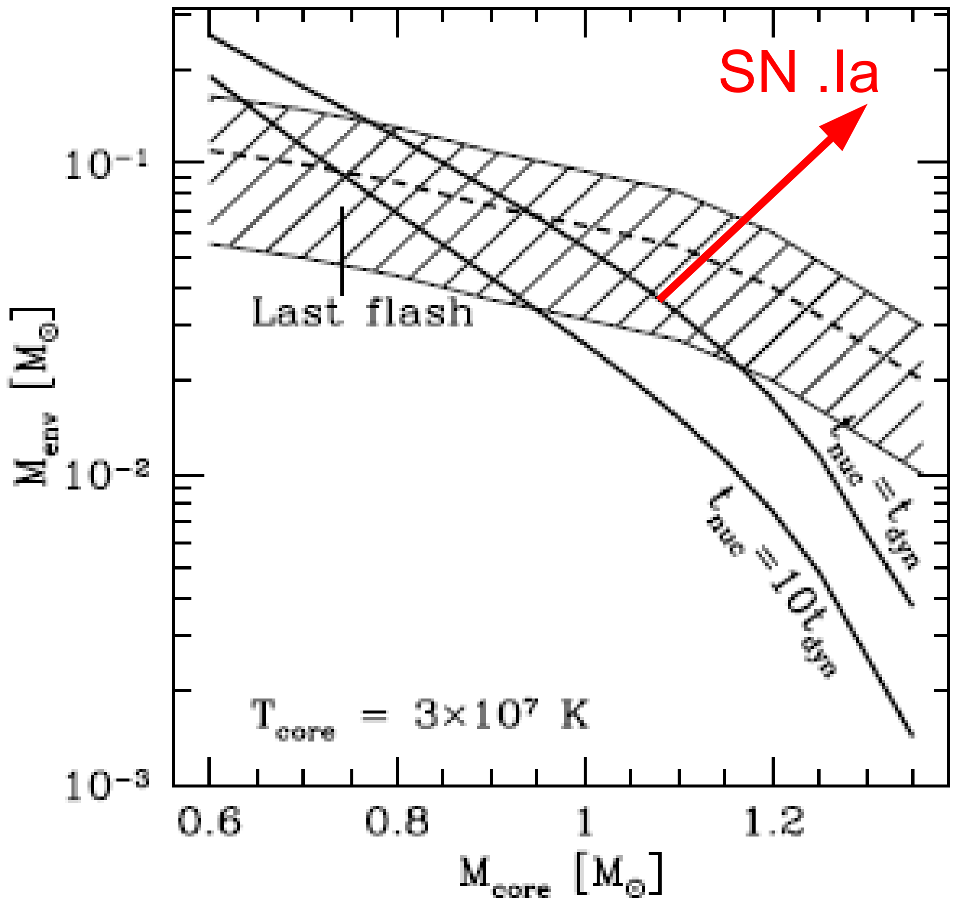
Model: He (Super)novae





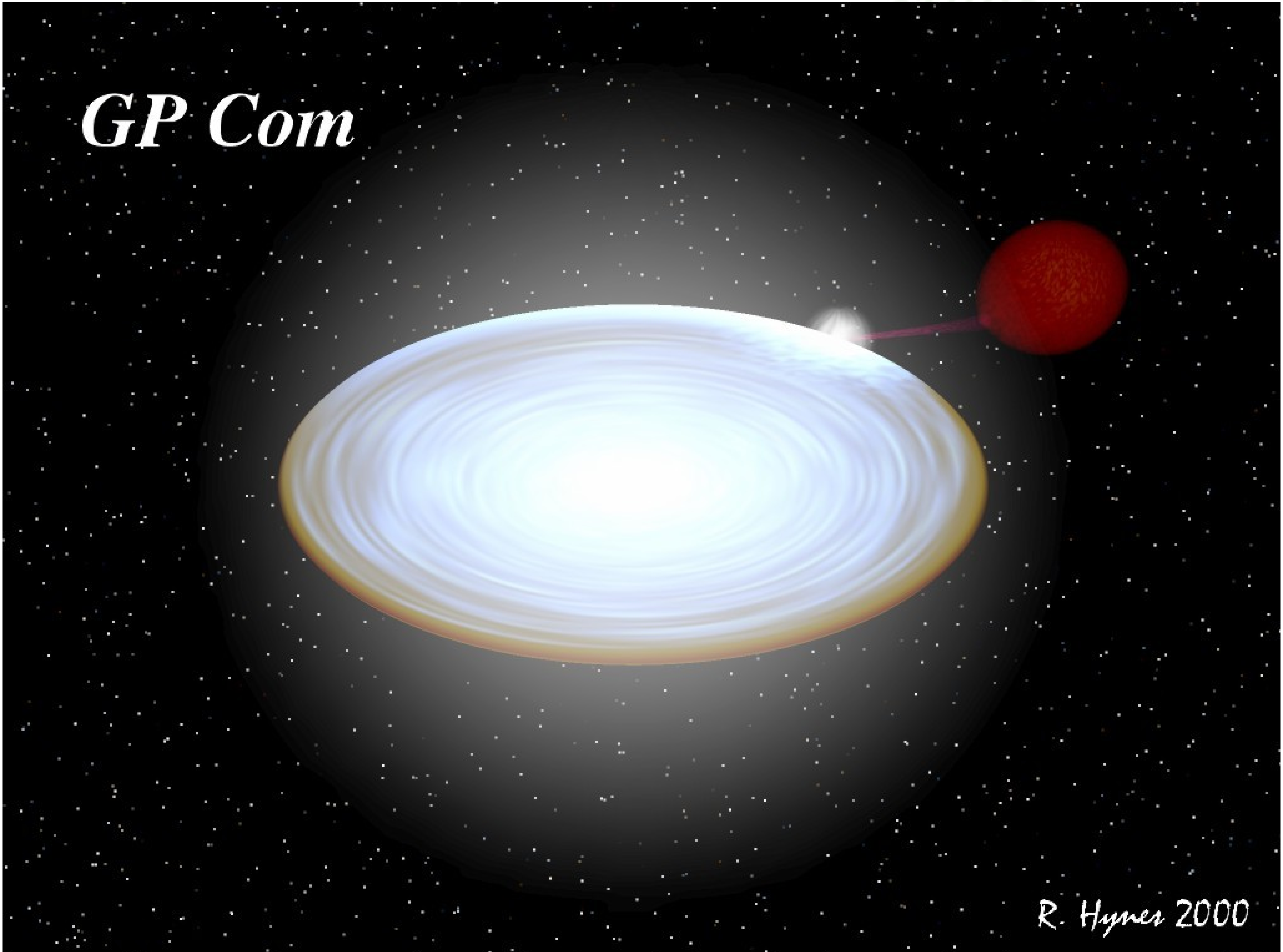
Model: He (Super)novae





Deel III:

- Waarnemingen
- Resultaten
- Toekomst


GP Com
R. Hynes 2000

Status pre-2001

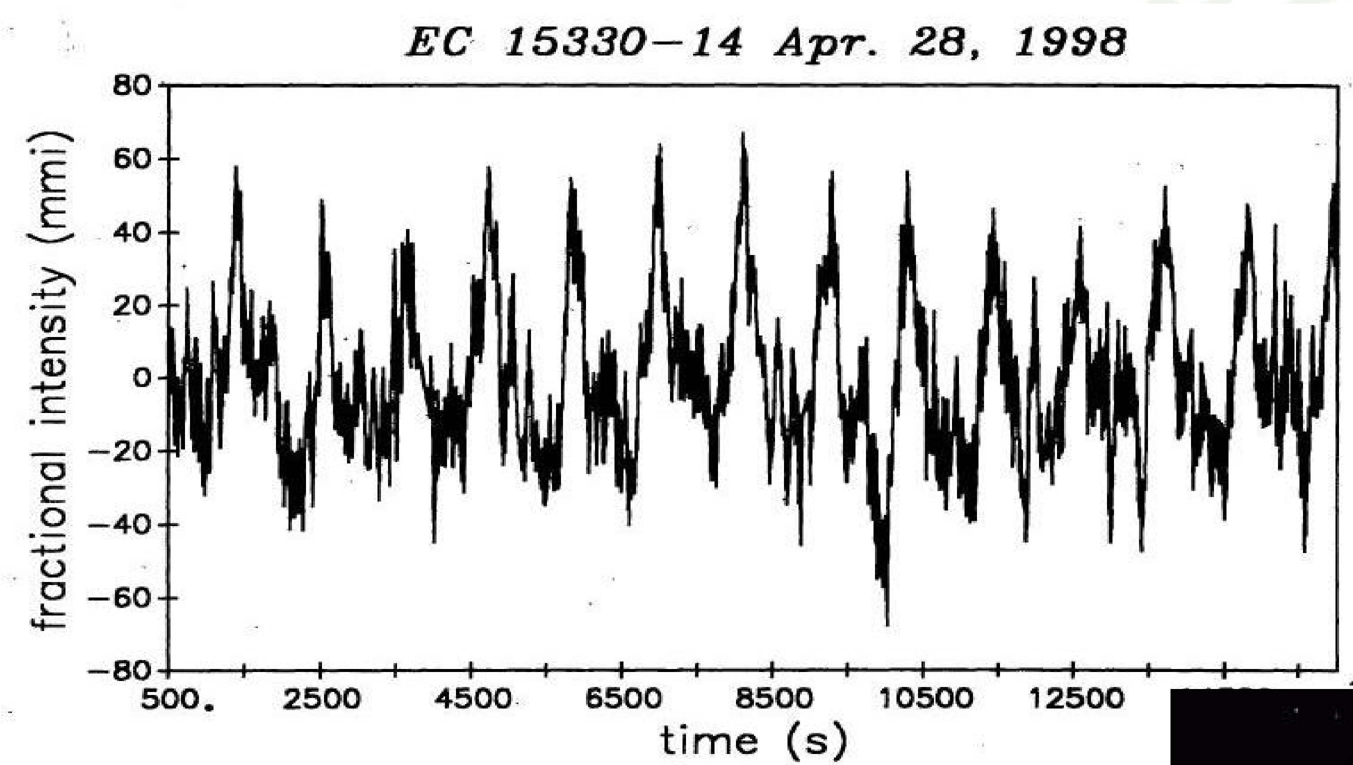
Slechts 10 systemen bekend, eerste was AM CVn

(Zwicky & Humason, 1947)

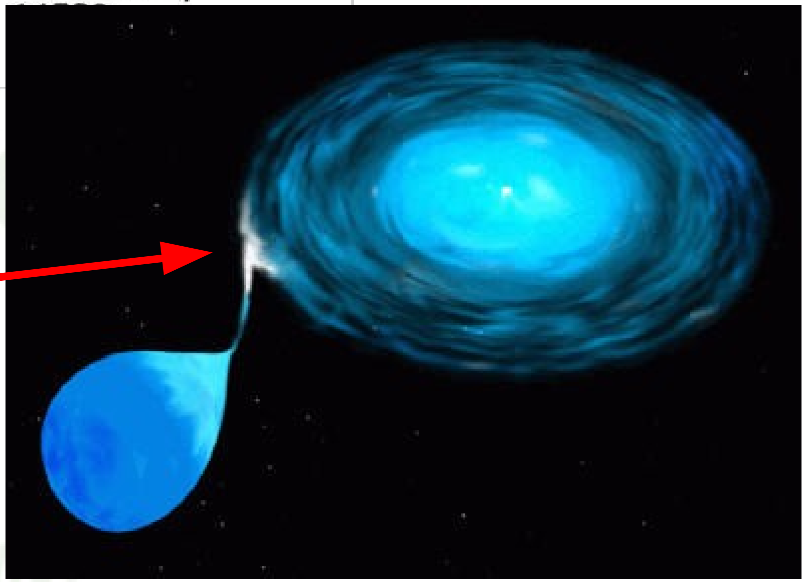
Eigenschappen:

- Blauw (door accretieschijf)
- Zwak (in totale lichtkracht)
- Zeldzaam (allemaal 'per ongeluk' gevonden)
- Helium gedomineerd spectrum
  - Emissielijnen in lange-periode systemen (P>30 min)
  - Absorptielijnen in korte-periode systemen (P<30 min)
- Fotometrische variabiliteit:
  - Korte-periode systemen: ja, op baanperiode (?)
  - Lange-periode systemen: nee, niet variabel

Fotometrische variabiliteit

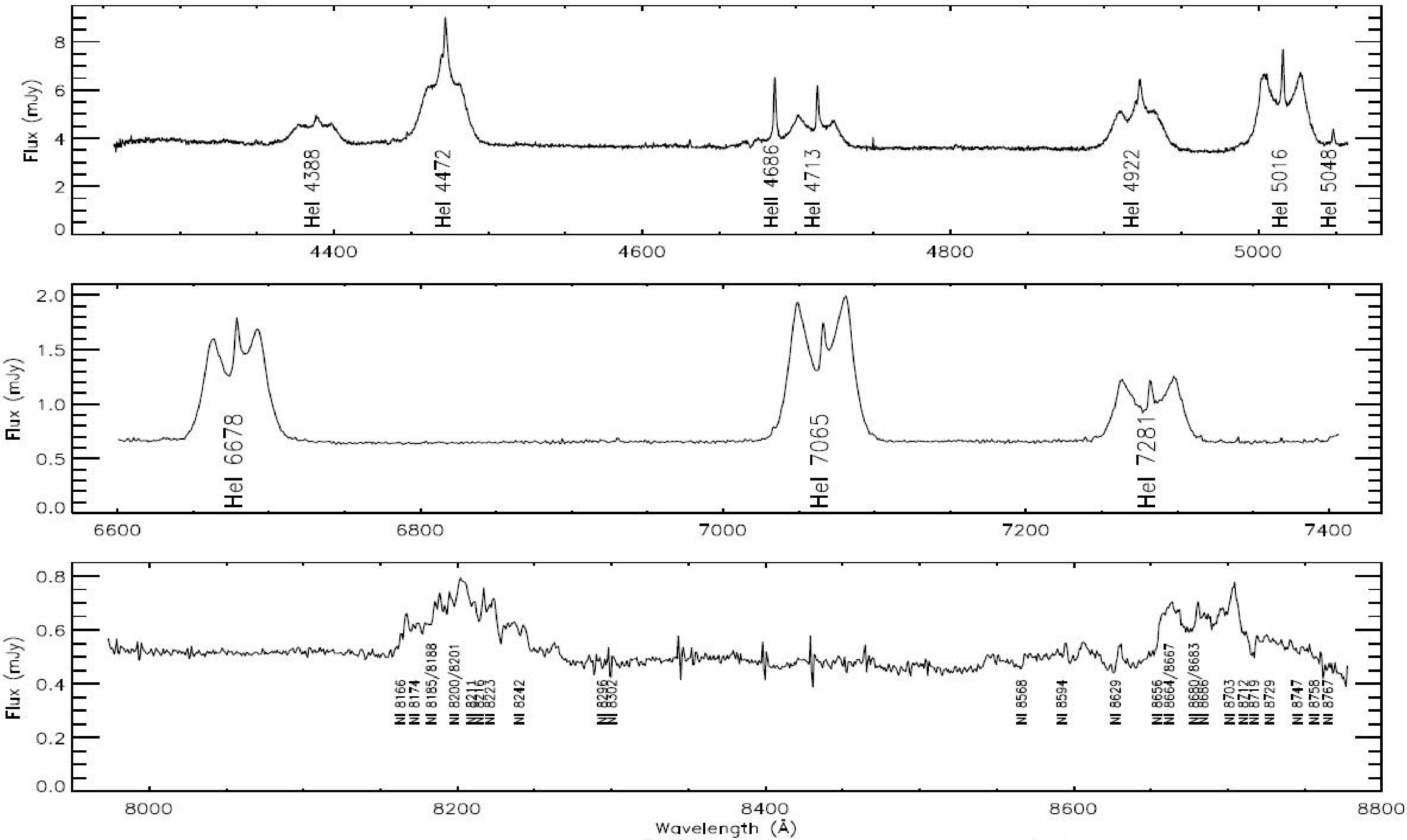


HP Lib,
P_{orb} = 20 min



Variatie op baanperiode
Door anisotrope emissie van 'hot spot'

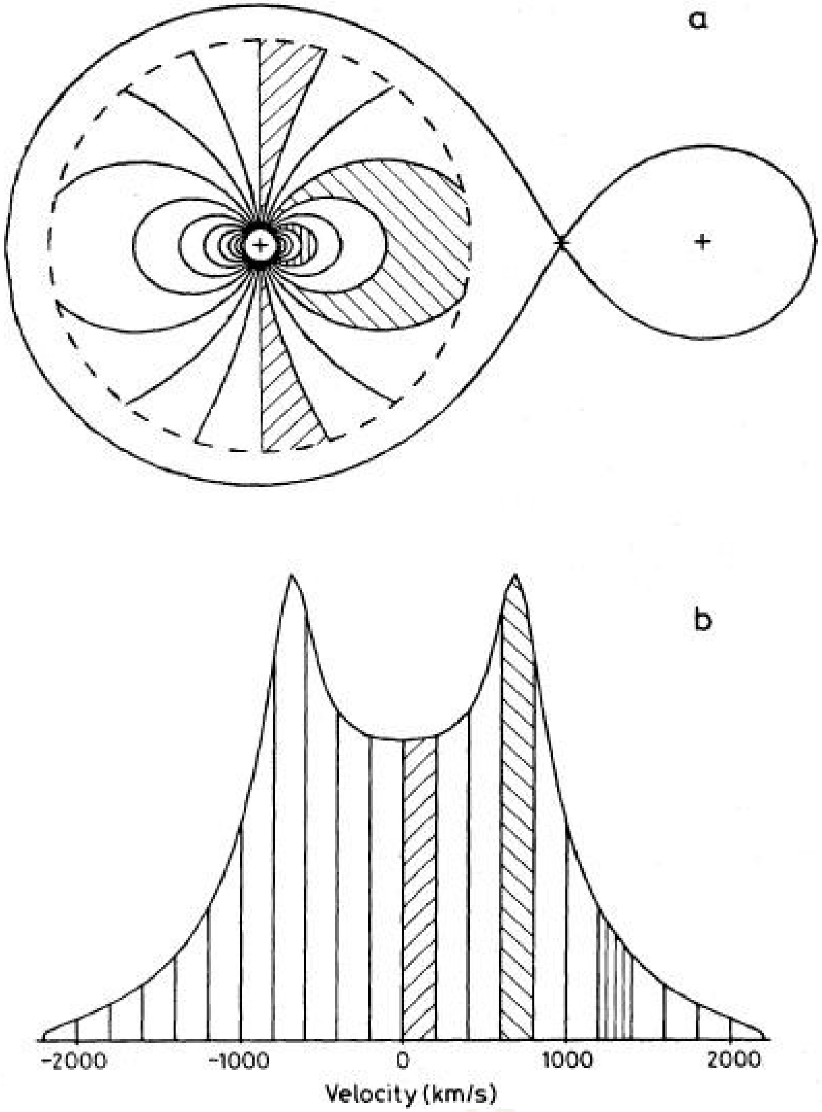
Spectroscopische vingerafdruk



Gedomineerd door dubbelgepiekte (triple-gepiekt) lijnen van Helium

Dubbelgepiekte emissielijnen

Klassieke aanwijzing
Voor een roterende schijf



Derde piek? Lage amplitude: accretor? Lang een puzzel!

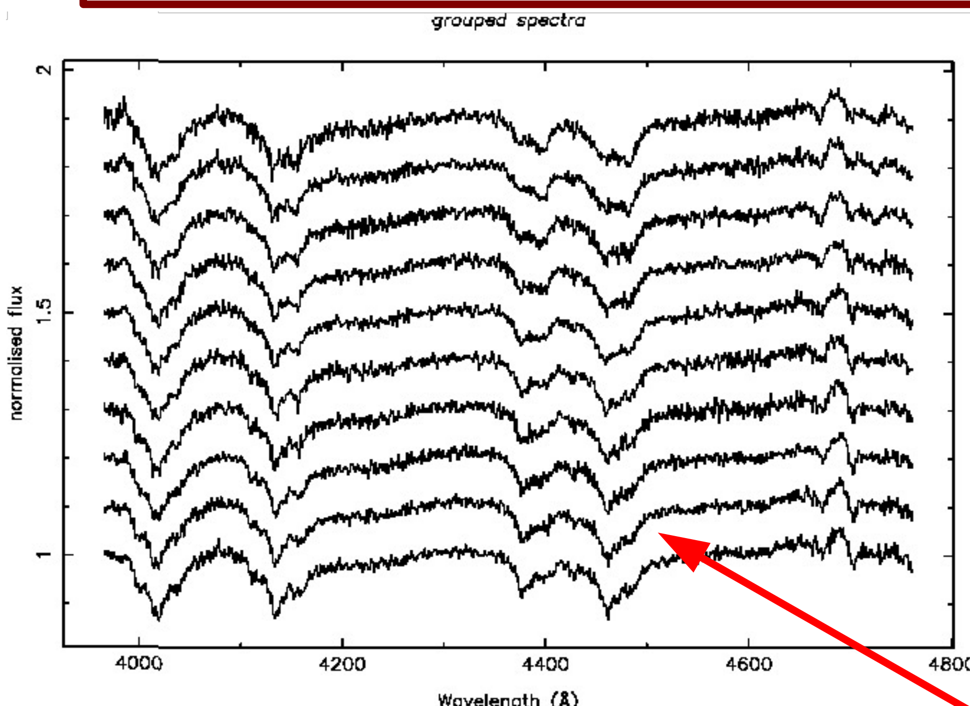
Situatie post-2001

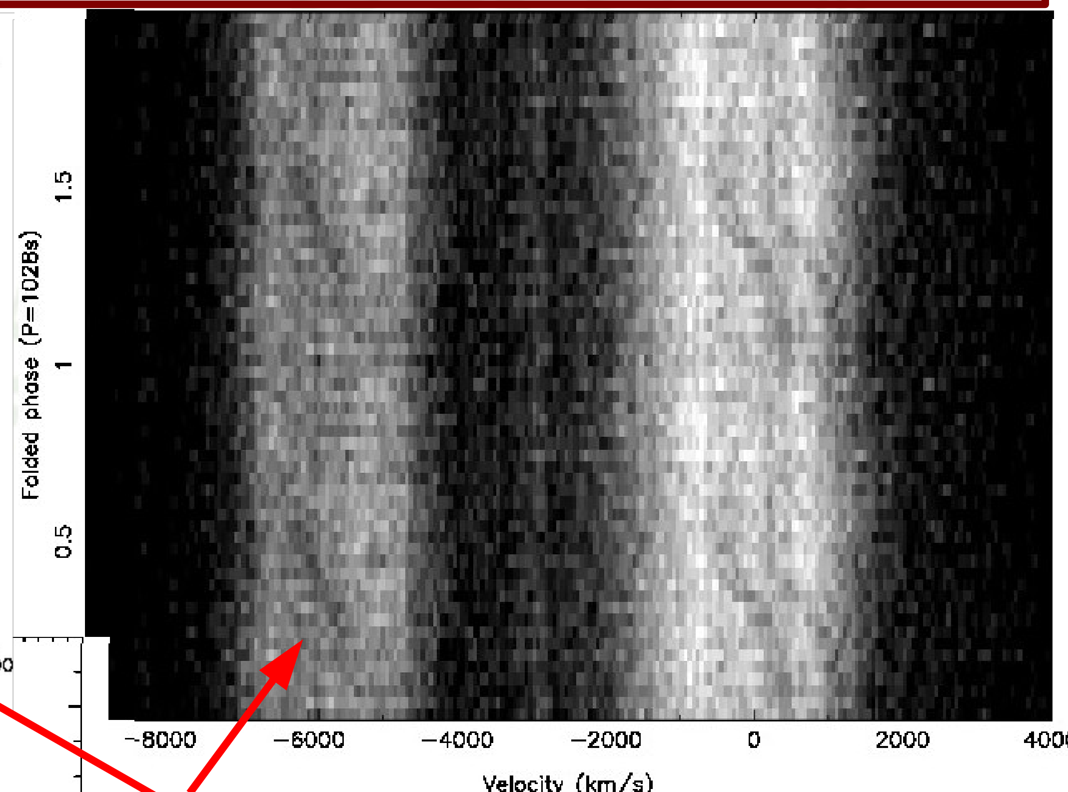
Hernieuwde aandacht voor deze 'rare' dubbelsterren:

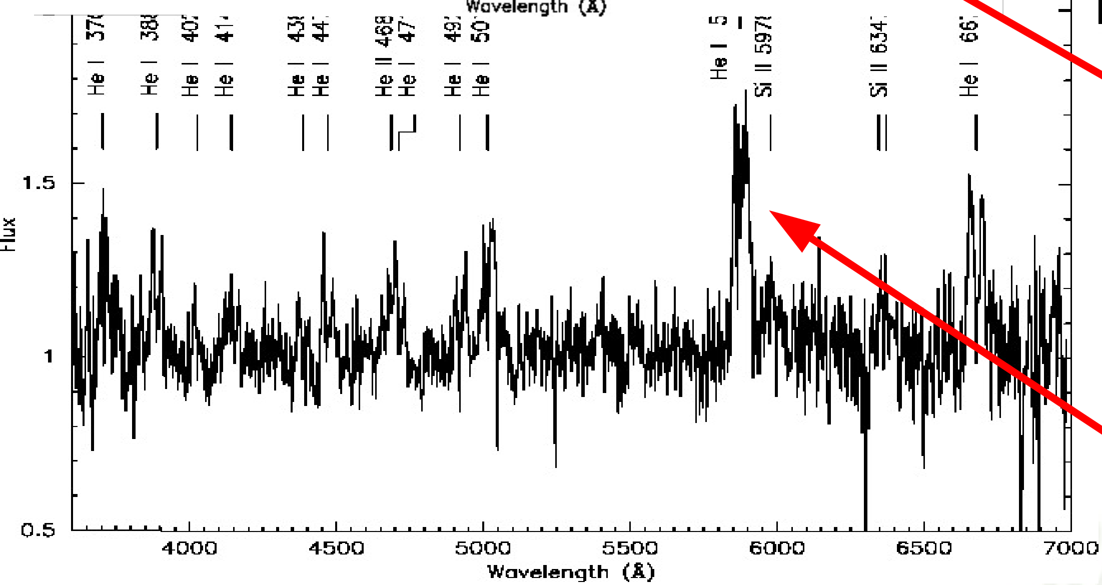
- Begrijpen van de bekende systemen (spectroscopie)
- Ontdekken van nieuwe systemen (homogeniteit)
- Beter begrijpen van de theorie
- Ontdekking van ultra-ultracompacte systemen (P<10 min!)
- Ontdekking van eerste Helium nova
- Ontdekking van de eerste supernovae Type .Ia

In samenwerking met Gijs Nelemans, Gijs Roelofs (RU/CfA),
Danny Steeghs, Tom Marsh (Warwick), Patrick Woudt (Cape Town),
Gavin Ramsay (Belfast), Lars Bildsten (UCSB),
Chris Deloye (Northwestern), Lev Yungelson (Moscow)

Lange en korte periode systemen: hetzelfde soort!







Baanvariaties in spectrum AM CVn zelf.
(Nelemans, Steeghs & Groot, 2001)

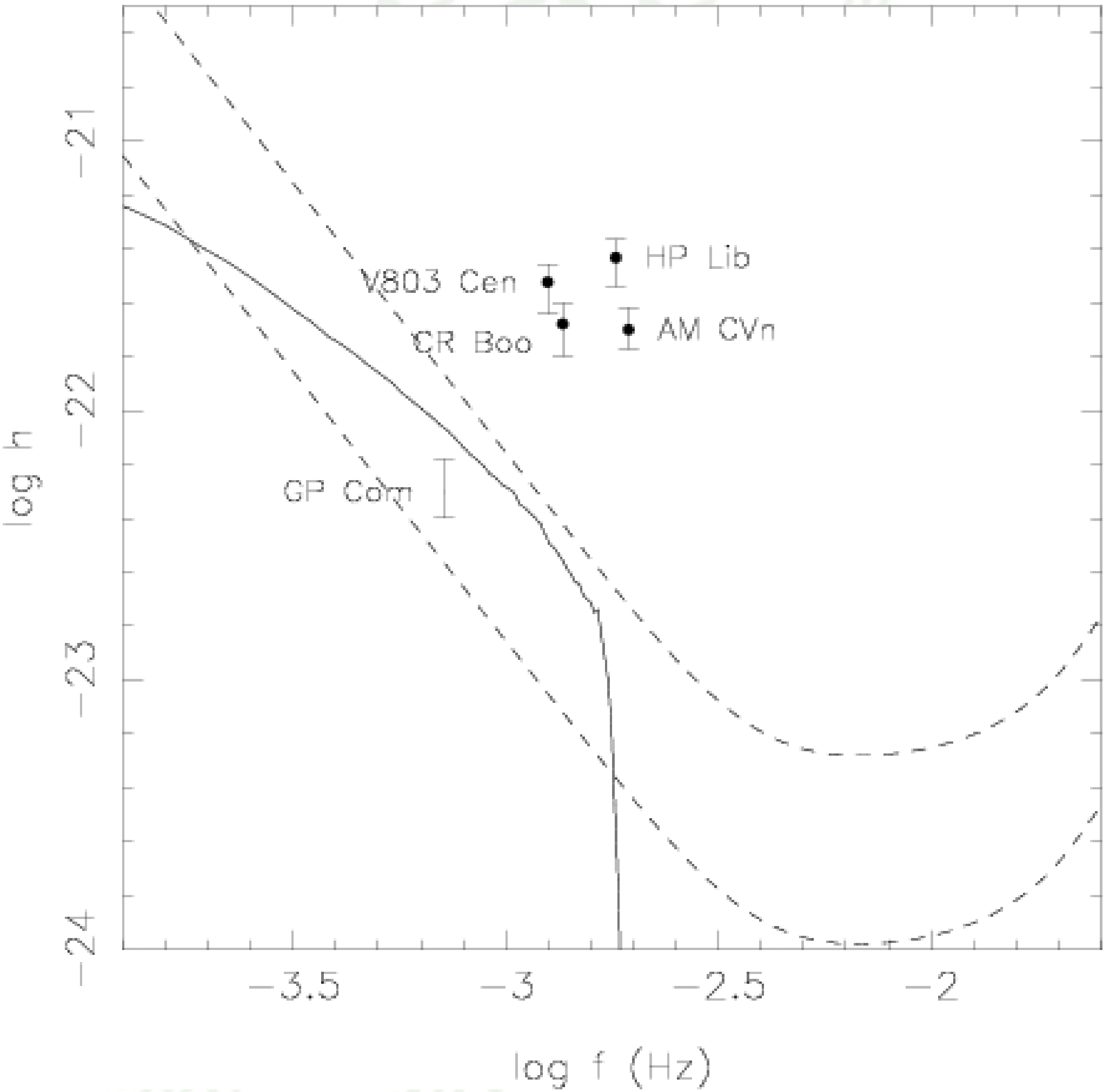
CP Eri in zwakke fase: emissielijnen (Groot, 2001)

Afstanden tot de helderste leden

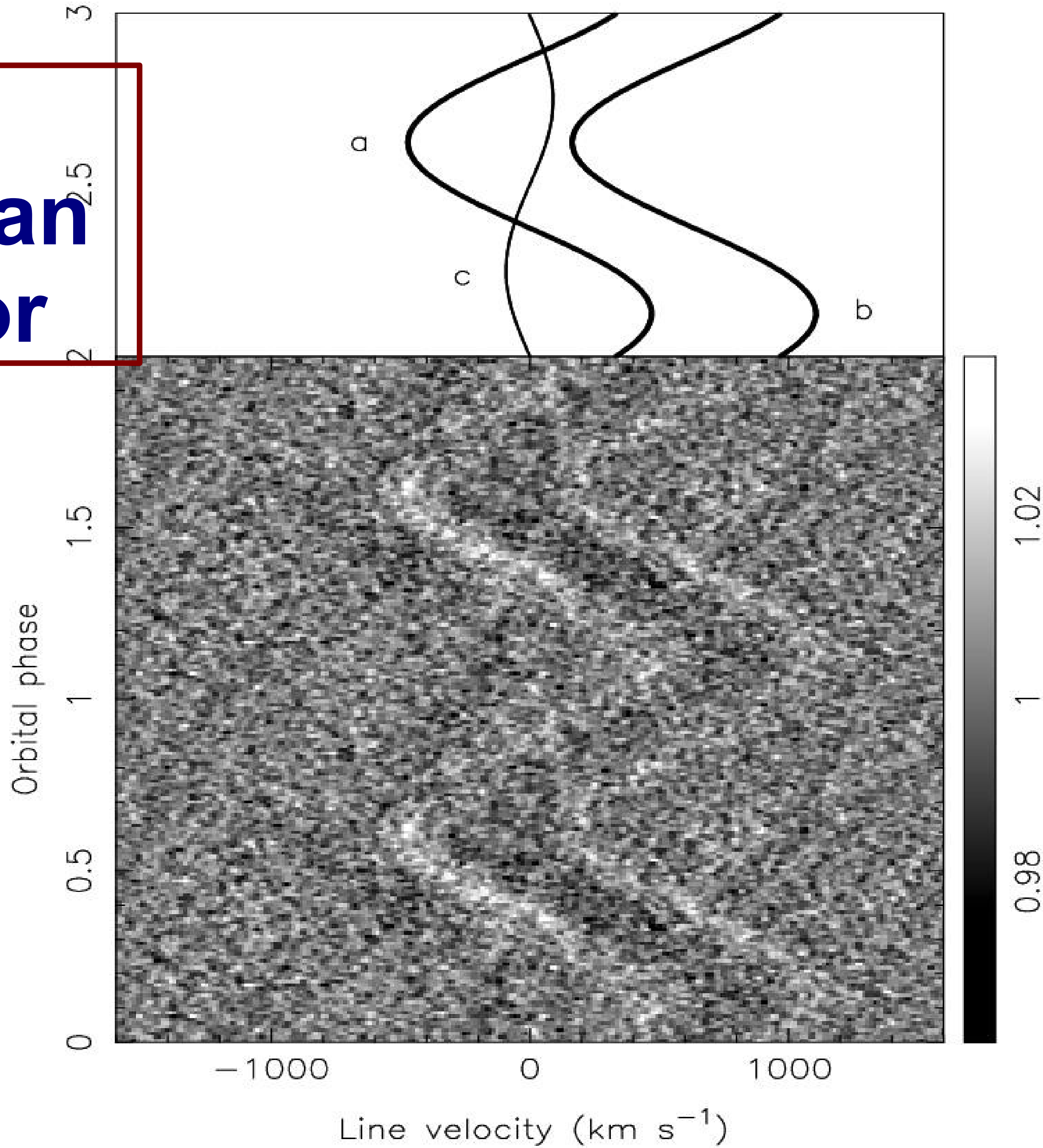
Afstanden geven sterkte van
Het zwaartekrachtsignaal

Systemen zijn eerste en enige
Bekende LISA bronnen

(Roelofs et al., 2007a)



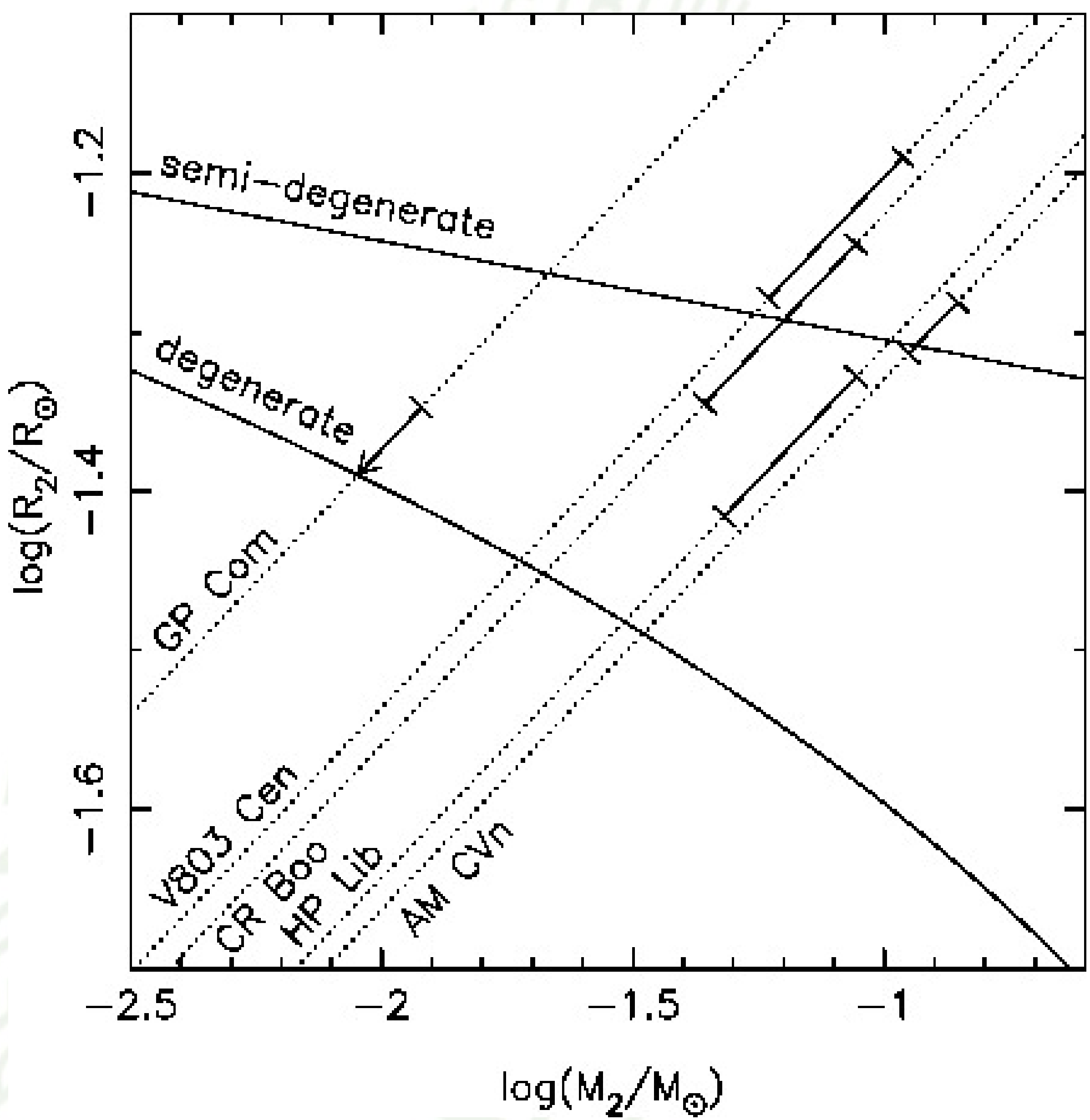
Massa en dichtheid van massadonor



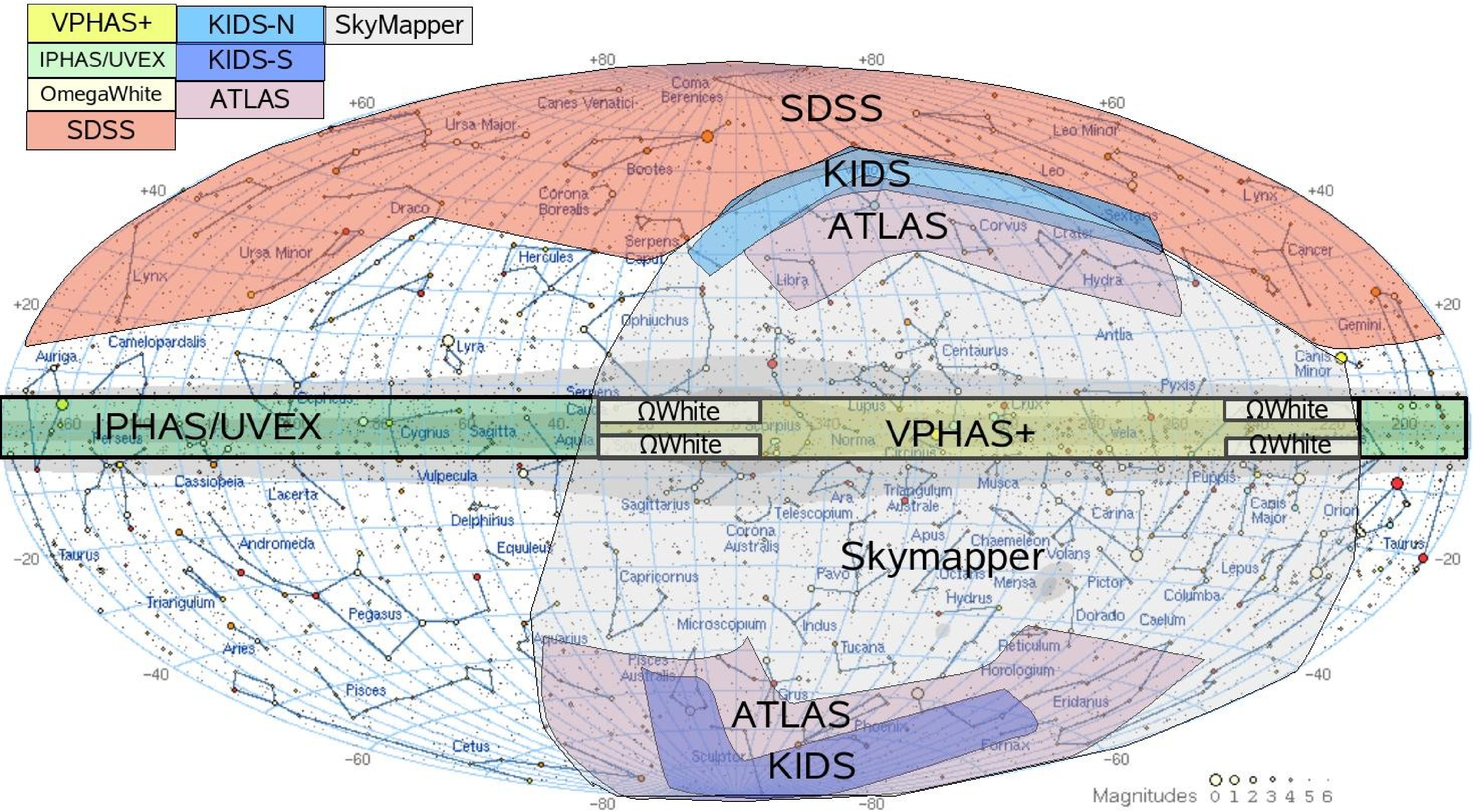
Centrale piek in AM CVn bepaalt massa van beide componenten

(Roelofs et al., 2007b)

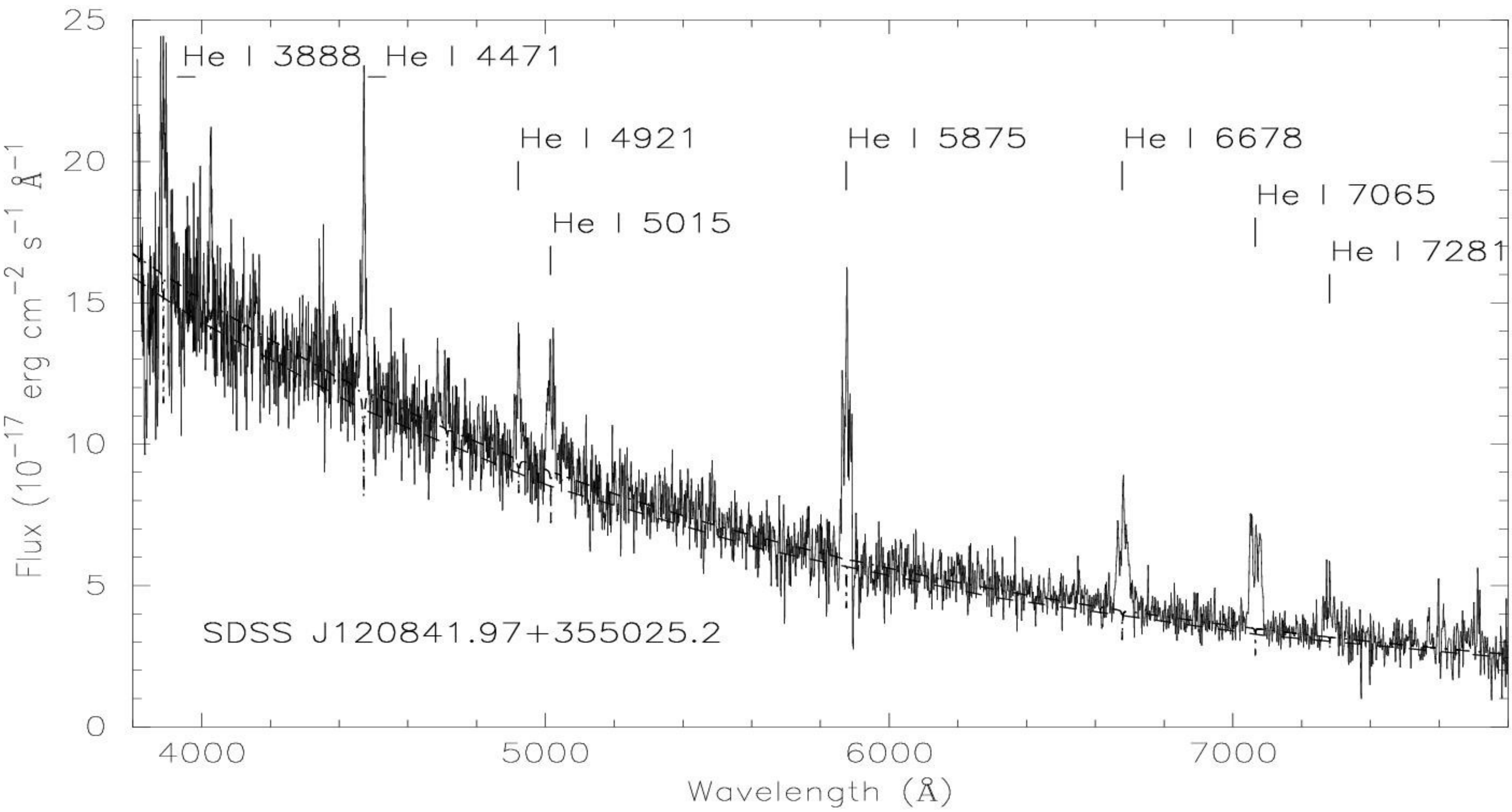
Massa en dichtheid van massadonor



Het vinden van nieuwe systemen (systematisch)

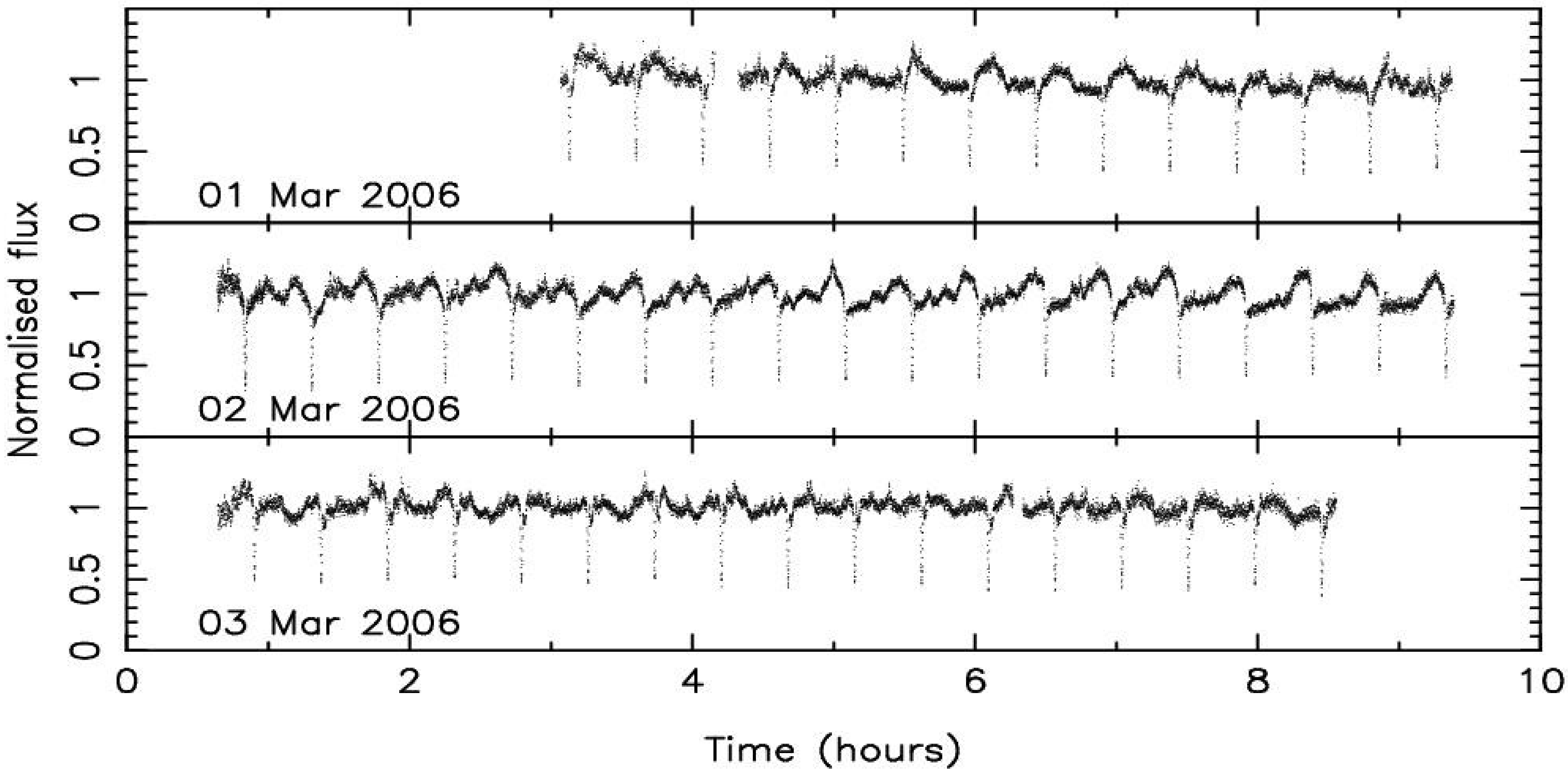


Belangrijke stap: SDSS



SDSS spectroscopie en follow-up heeft 13 systemen extra gegeven (Roelofs et al., 2005, Anderson et al. 2005, 2008, Roelofs et al., 2009, Rau et al., 2009)

Eerste eclipserende systeem



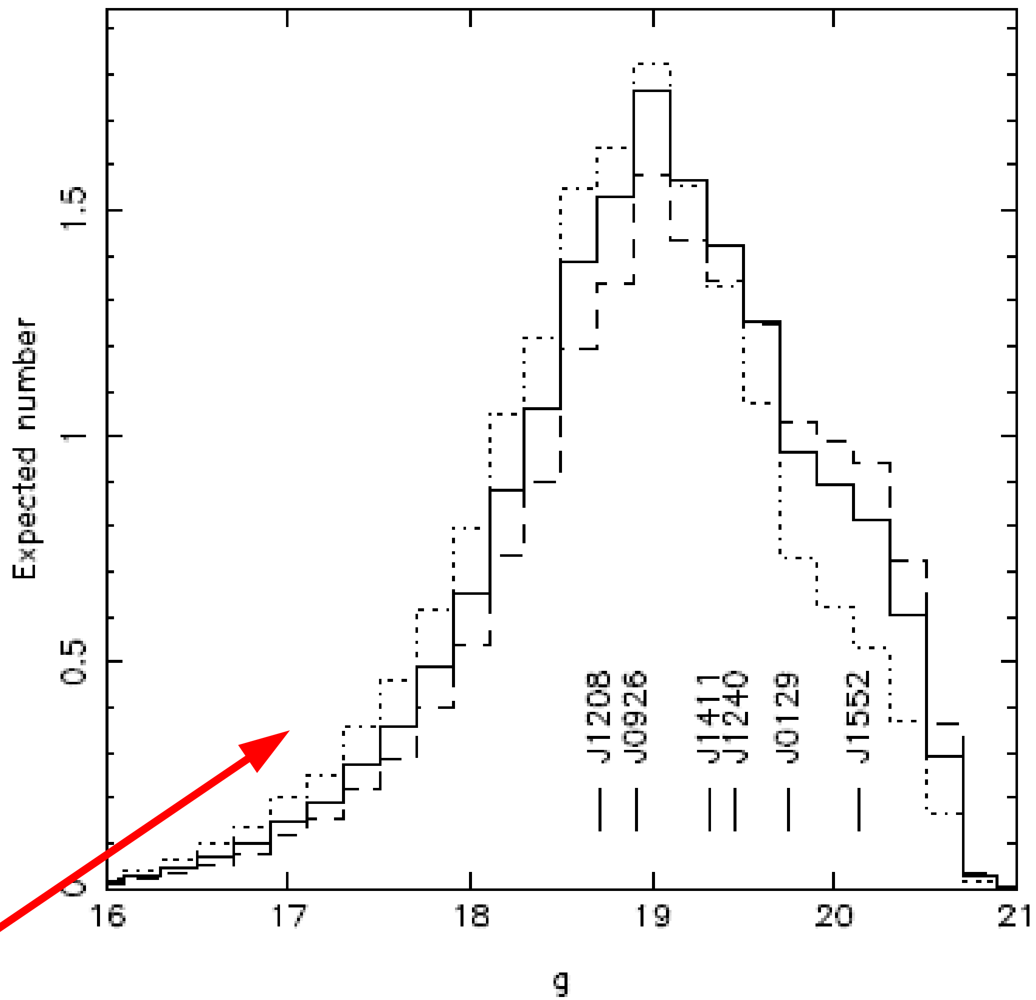
SDSSJ0926+3624 (Marsh et al., 2006; 2010) :

Ruimtelijke dichtheid

ρ = (1-3) x 10^{-6} pc^{-3}

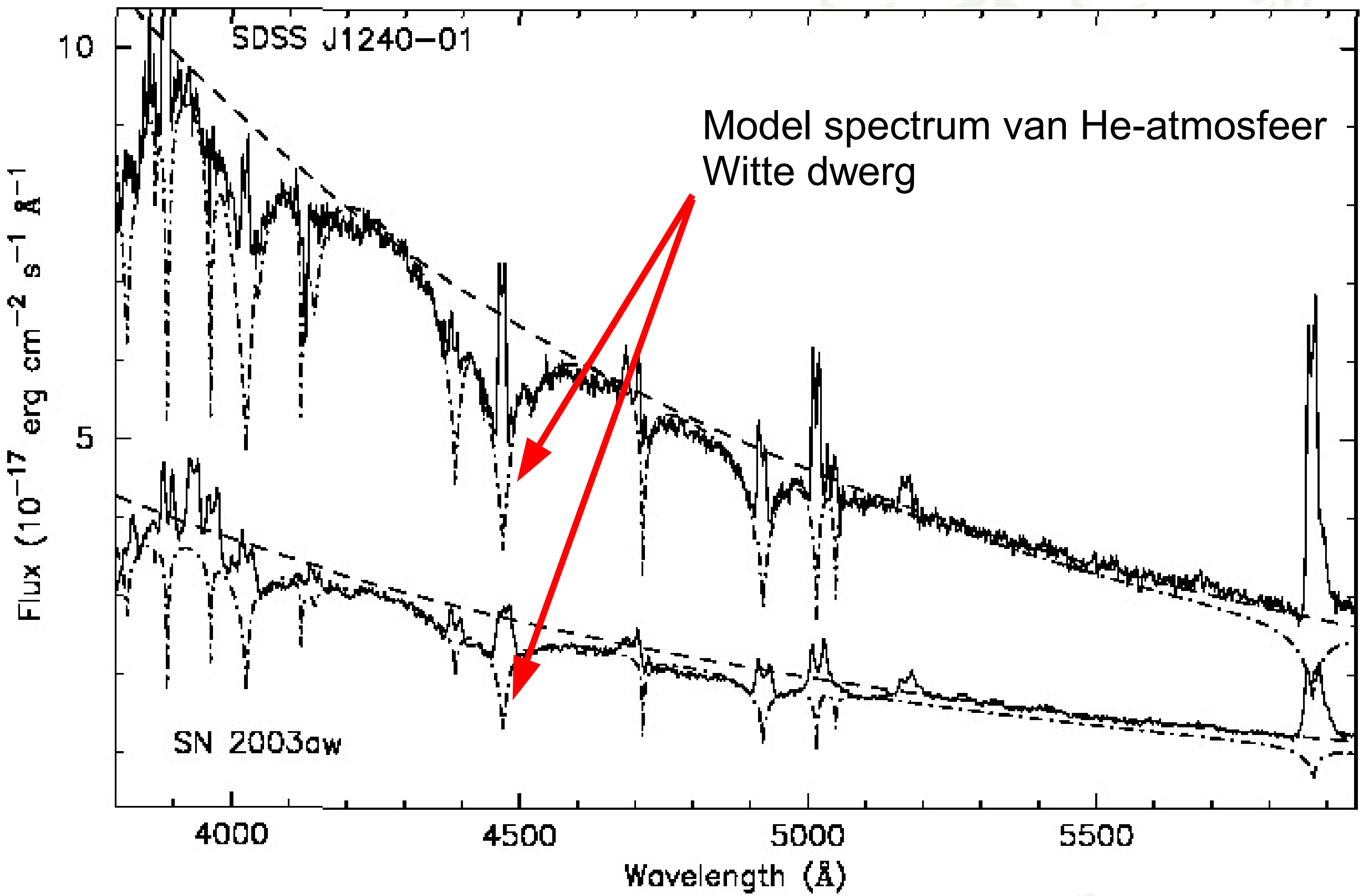
10 keer minder dan eerder verwacht!

(Roelofs et al., 2007c)



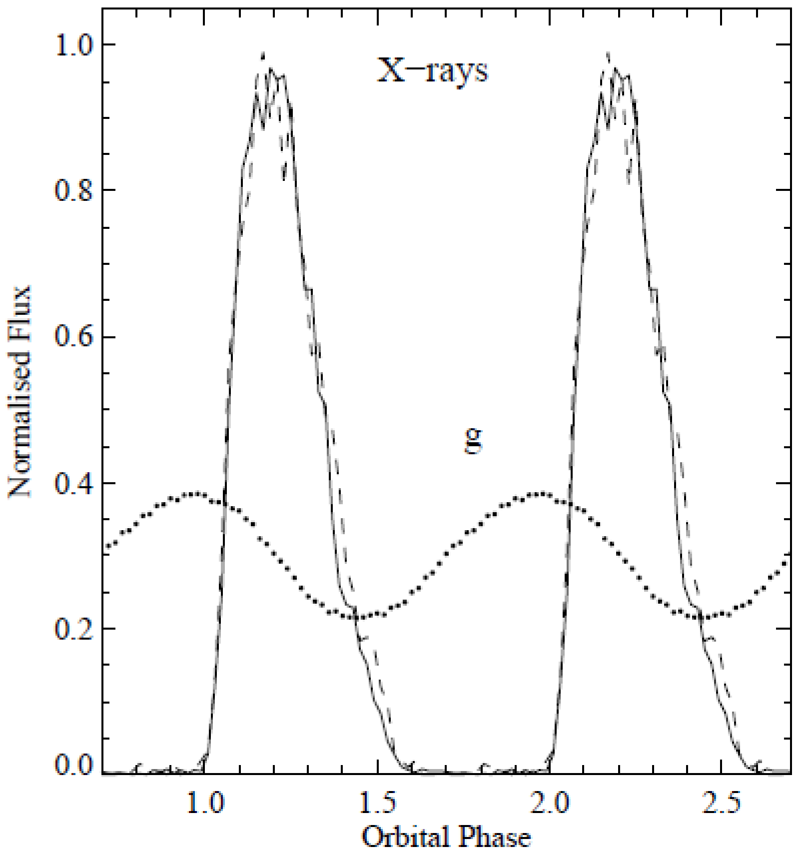
Verwachte verdeling in de Sloan Digital Sky Survey

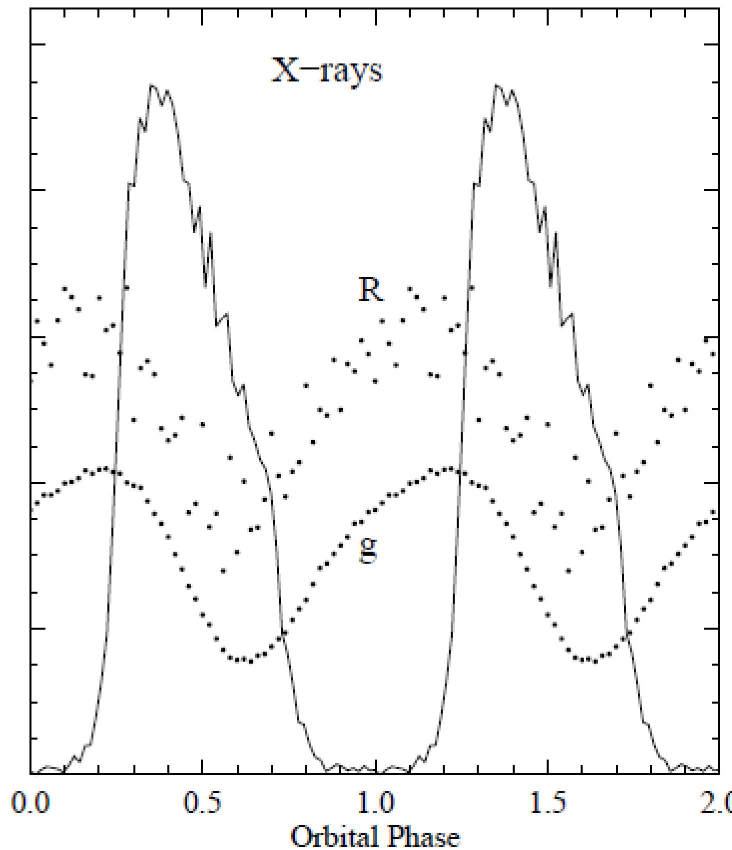
Signaal van accretor in spectrum

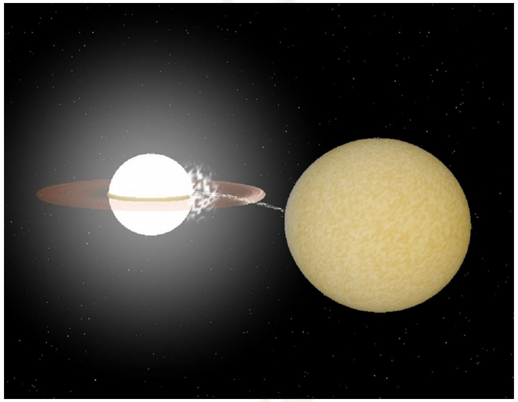


Temperatuur van de accretor vertelt over accretiegeschiedenis van het Systeem Buijs (MSc thesis)

Ultrakorte systemen







P_{orb} = 9.3 minutes? P_{orb} = 5.4 minutes?

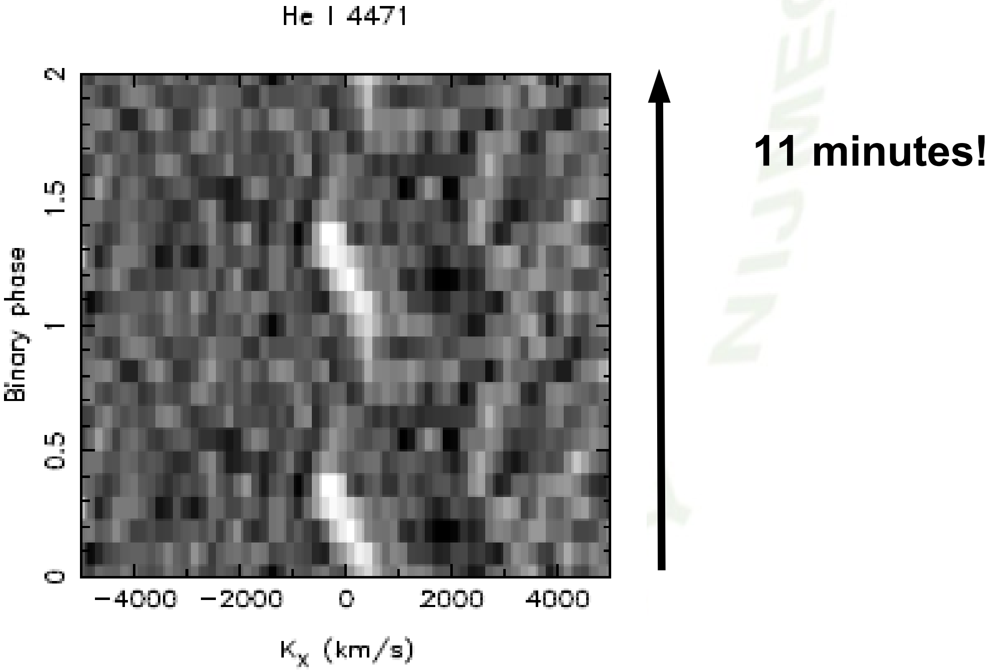
Twee systemen gevonden door hun röntgen emissie
(Motch et al. 1996; Israel et al., 1999; Burwitz & Reinsch 2001)

Ultrakorte perioden? Ja!

Bevestigen van baanperioden: *Een enorme uitdaging!*

HM Cancri (RXJ0806+15): de dubbelster met de kortst bekende Periode: slechts 5.4 minuten!

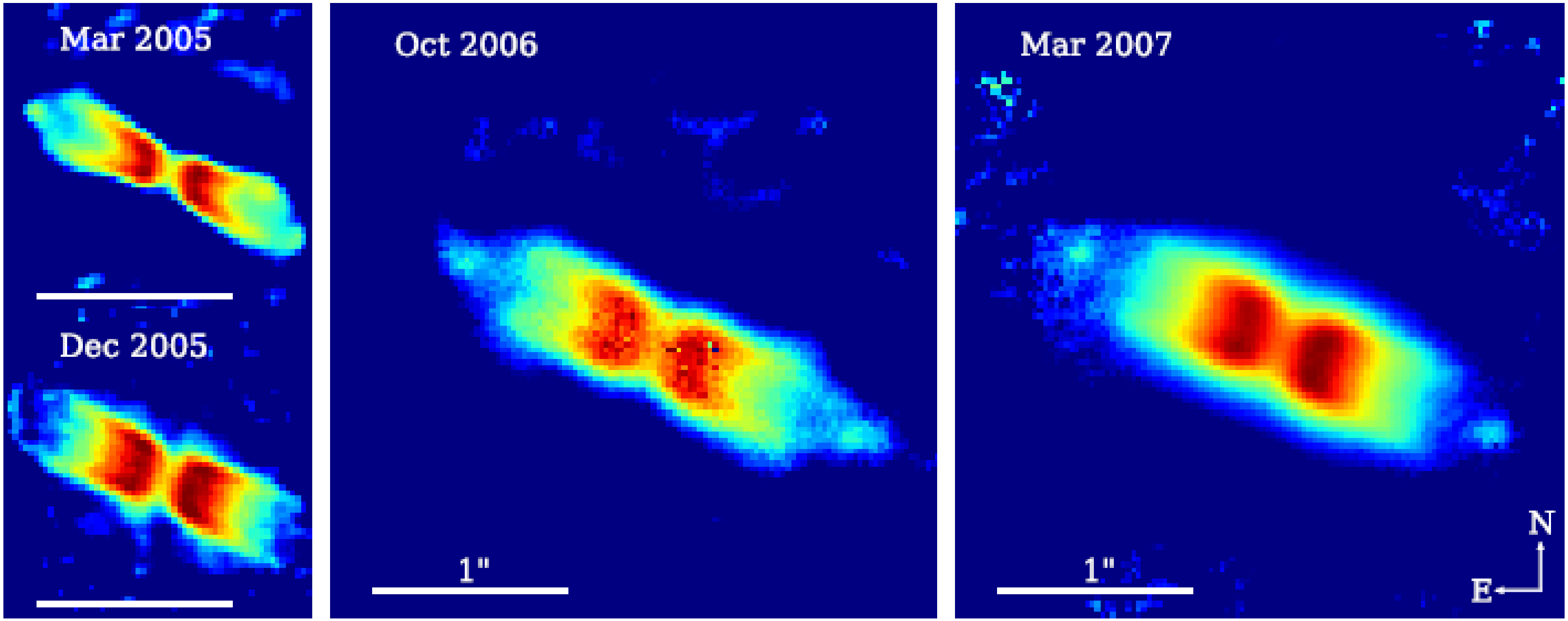
Op schaal!!!!!!



Eerste detectie van radiele snelheidsvariatie in dit systeem
Met 10 meter Keck telescoop op Hawai'i (Roelofs et al., 2010)

Eerste helium nova: V445 Puppis

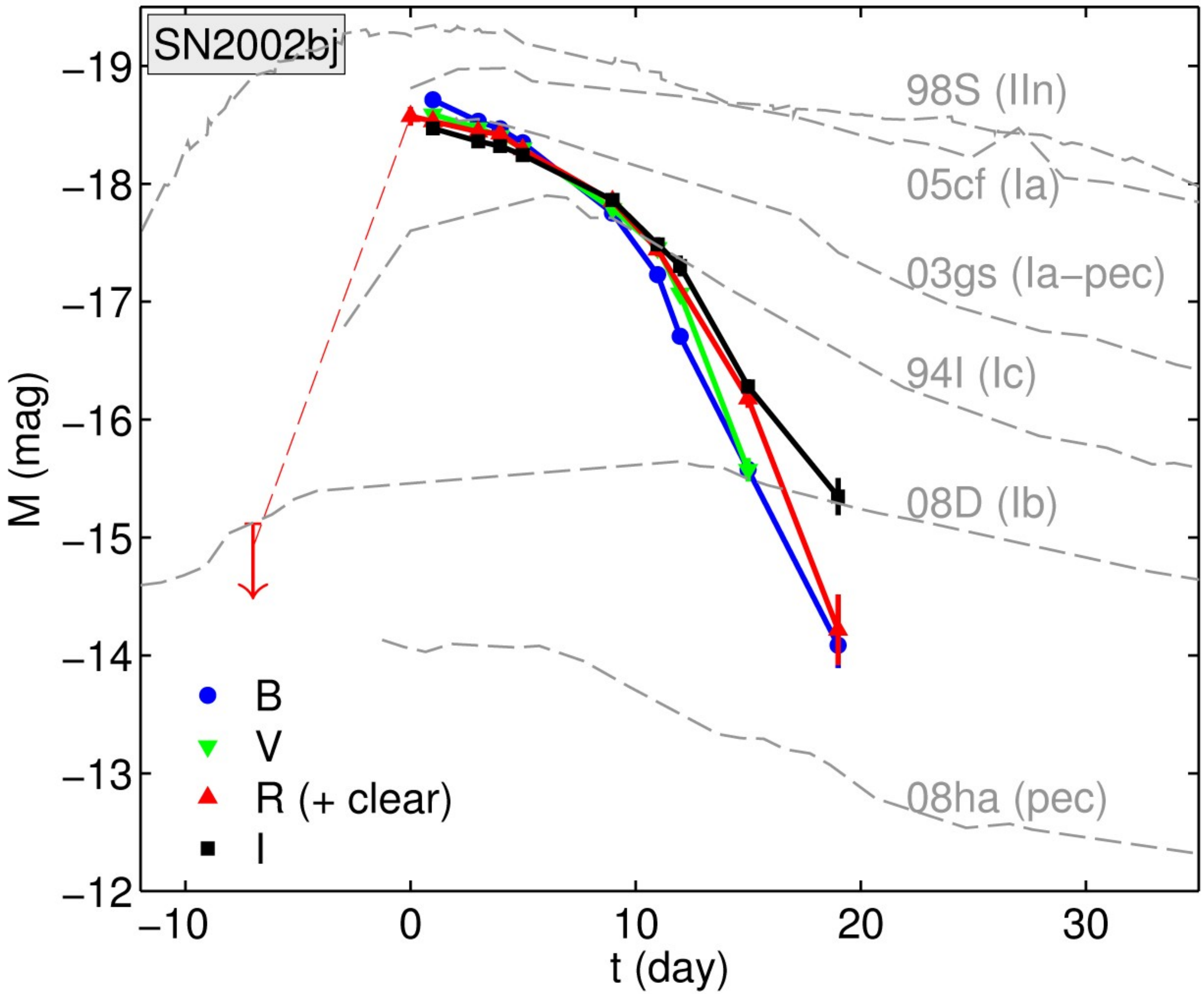
Gevonden in november 2000 (Kato et al., 2001)



Expansie van de nova schil schitterend in kaart gebracht met de adaptieve optiek methode op de Very Large Telescoop in Chili

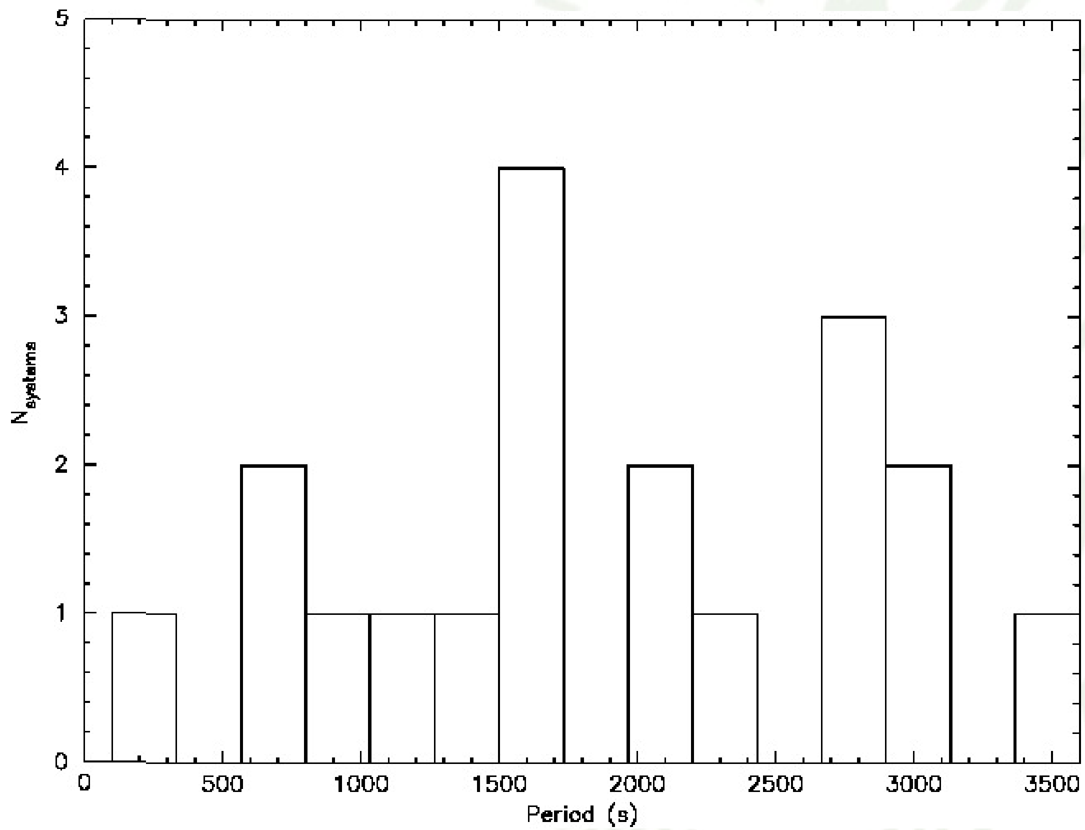
(Woudt et al., 2009)

Eerste supernova Type .Ia ?



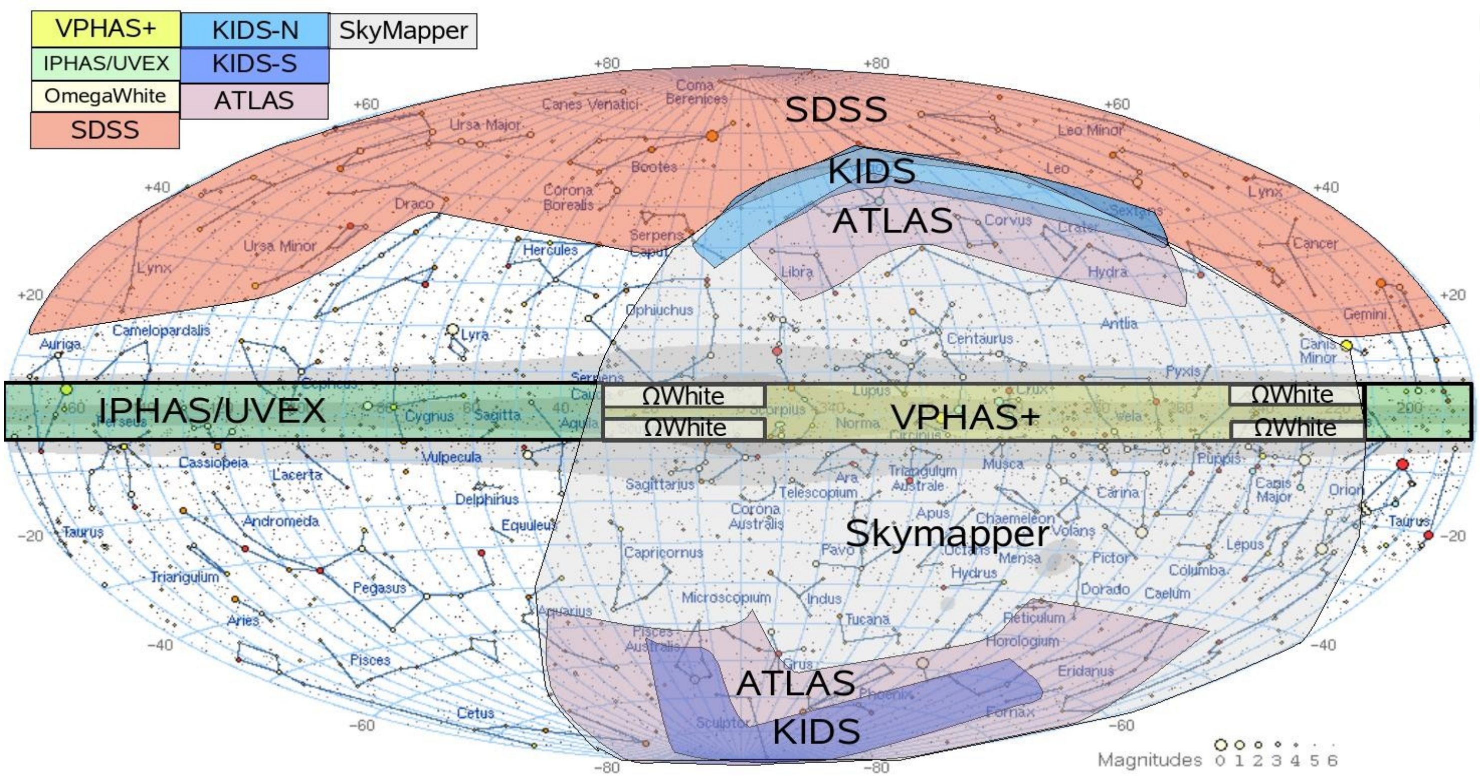
Poznanski et al., 2009, Science

Hoe staan we er voor?



Toekomst

- Vergroot aantal bekende systemen: 26 → 250+
- Gebruik variabiliteits surveys om zeer zeldzame system te vinden
- Gebruik betere spectrografen voor bepalen karakteristieken:
  Baan perioden, massa's, abundanties
- Verbeteren de modellen om de fysica te begrijpen
- Op langere termijn: Gaia en LISA!

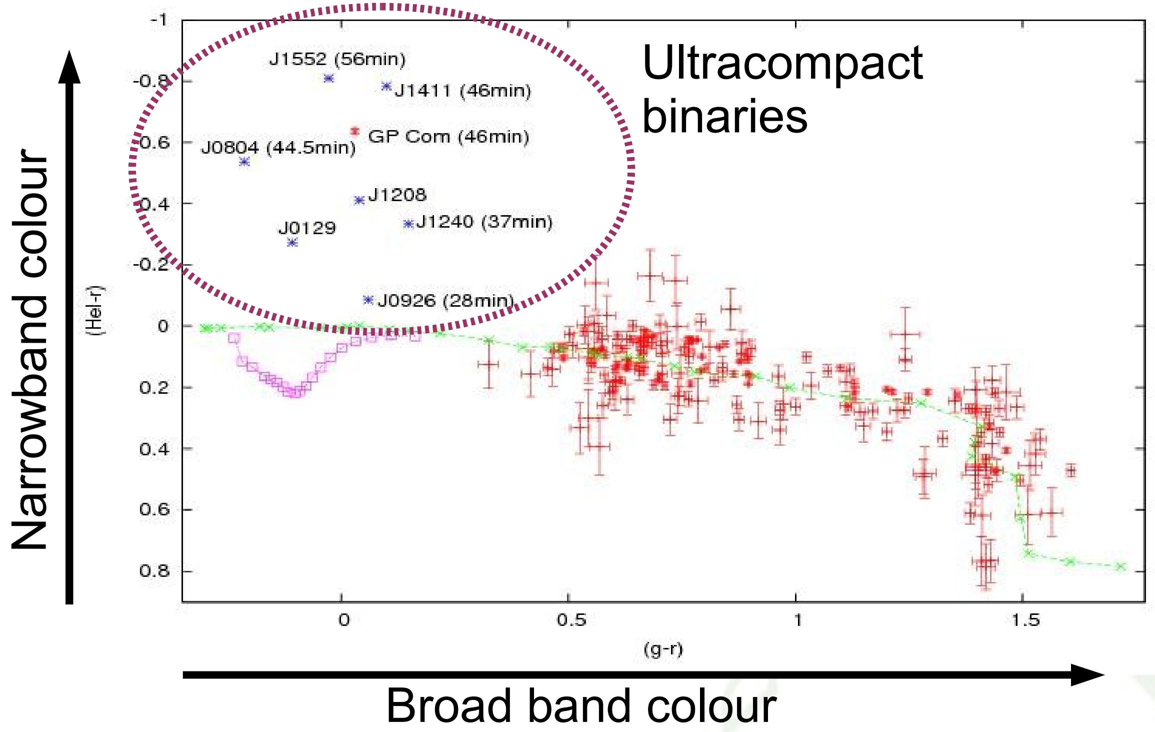


Future systems: 26 → 250+

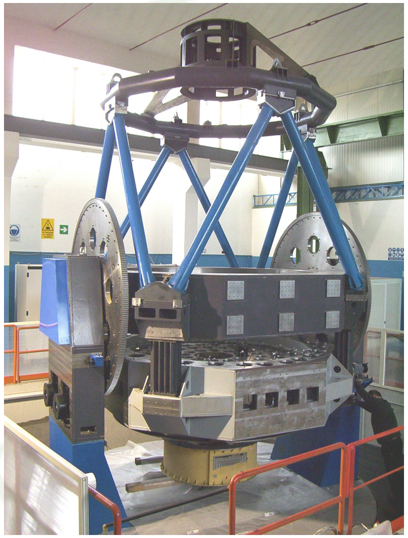
Use large scale optical sky surveys:

European Galactic Plane Surveys

'chart a billion, find a few hundred'



INT +
VST



EGAPS located on the Milky Way: maximum volume
First optical, multicolour survey of the Milky Way

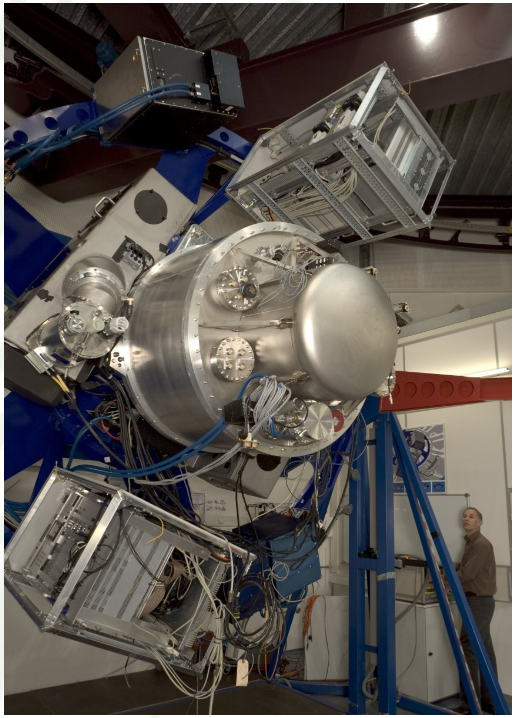
Future: Characterize population

Observationally determine:

- Masses of components
- Mass-ratio's
- Chemical abundances
- Orbital periods
- Temperatures of accretors

Use Spectrographs on large telescopes:

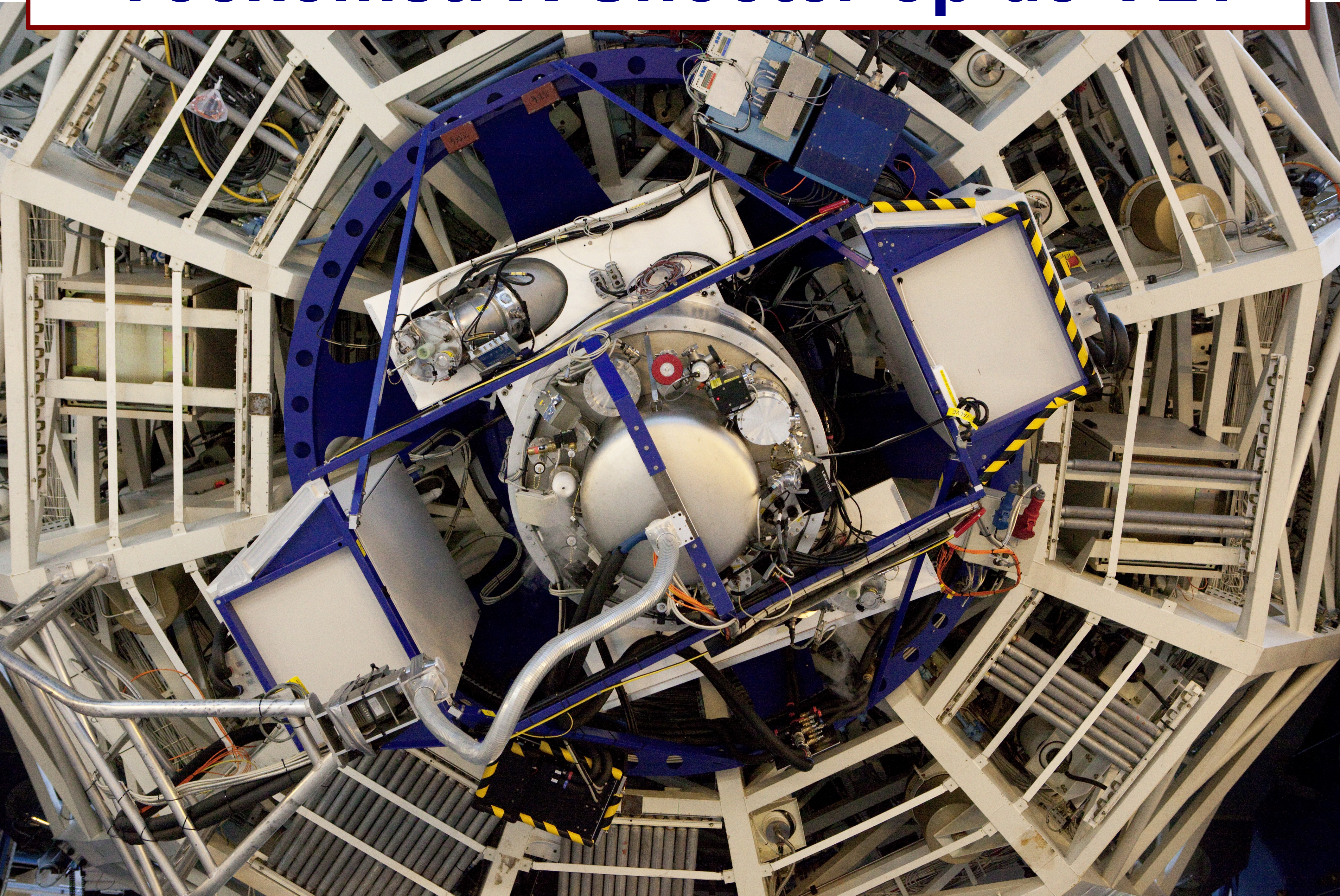
Primarily **X-Shooter** on the Very Large Telescope



X-Shooter

P. Groot: X-Shooter Project Scientist
Ideal for this type of work

Toekomst: X-Shooter op de VLT

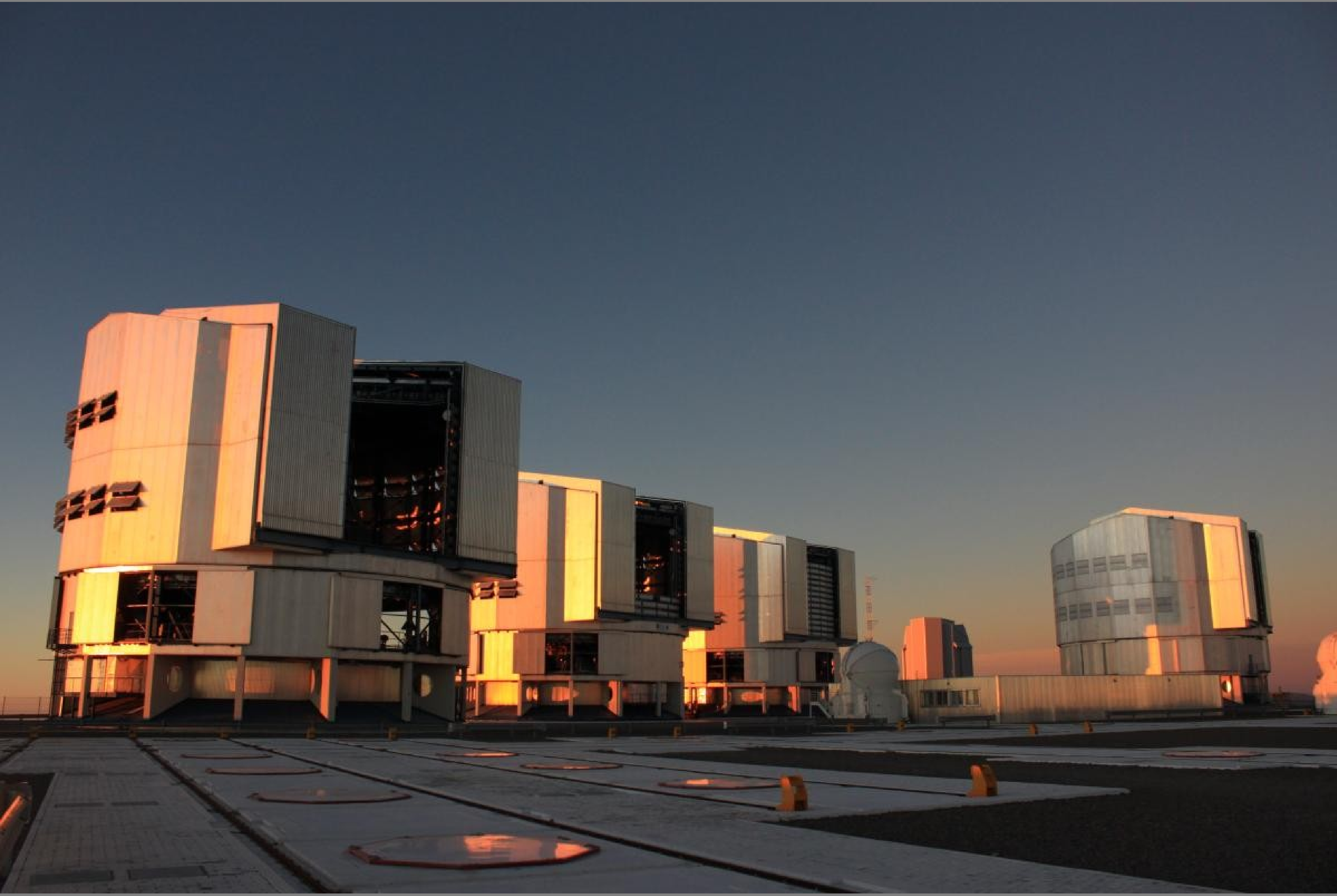


Toekomst: X-Shooter op de VLT

Telescopen van de Europese Zuidelijke Sterrenwacht op berg Paranal

2000 kilometer

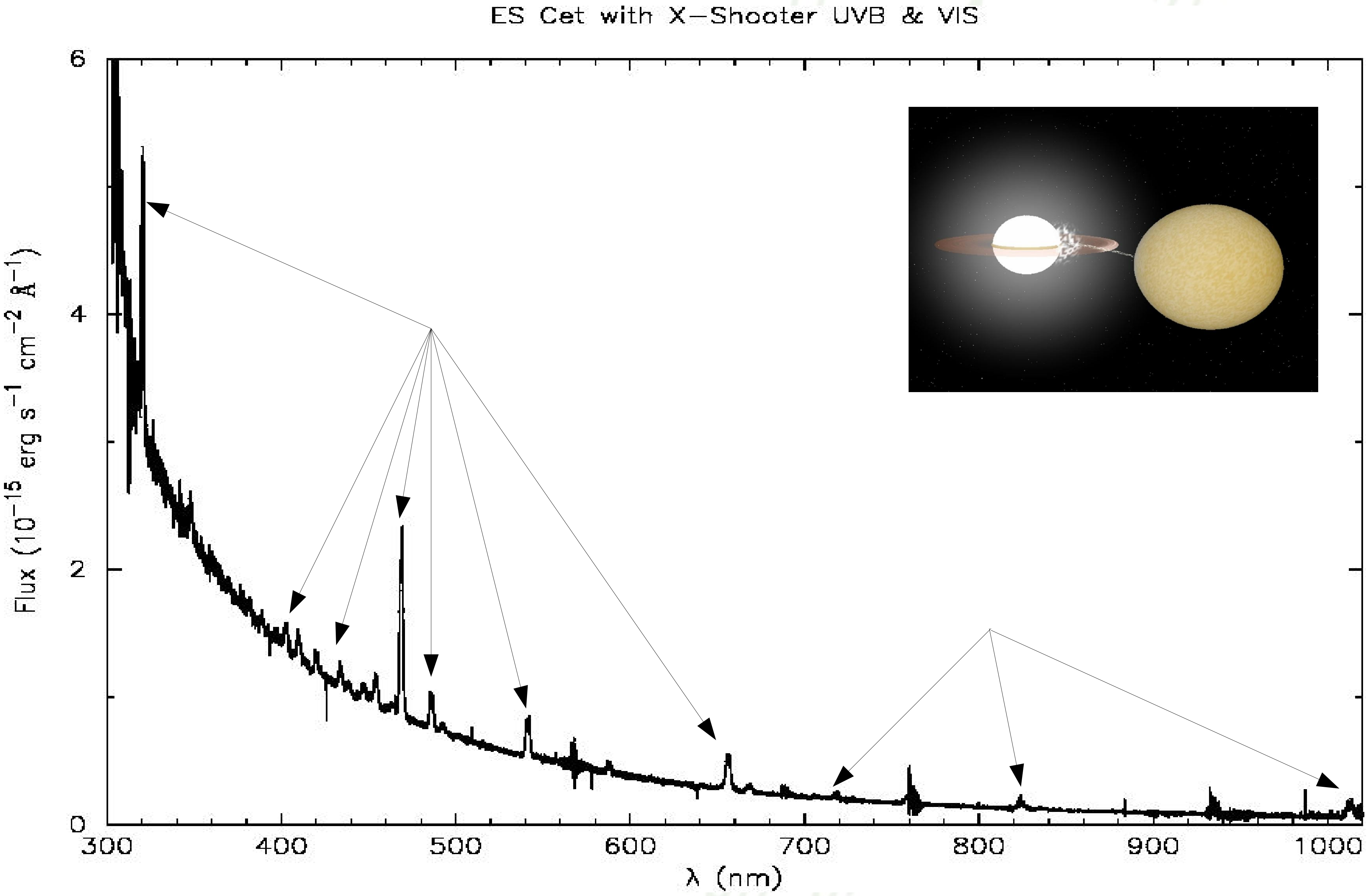
Epi-centrum van zware aardbeving op 26 februari 2010



X-Shooter spectrograaf achter de Very Large Telescope van de Europese Zuidelijke Sterrenwacht


Hartelijk dank voor uw aandacht!

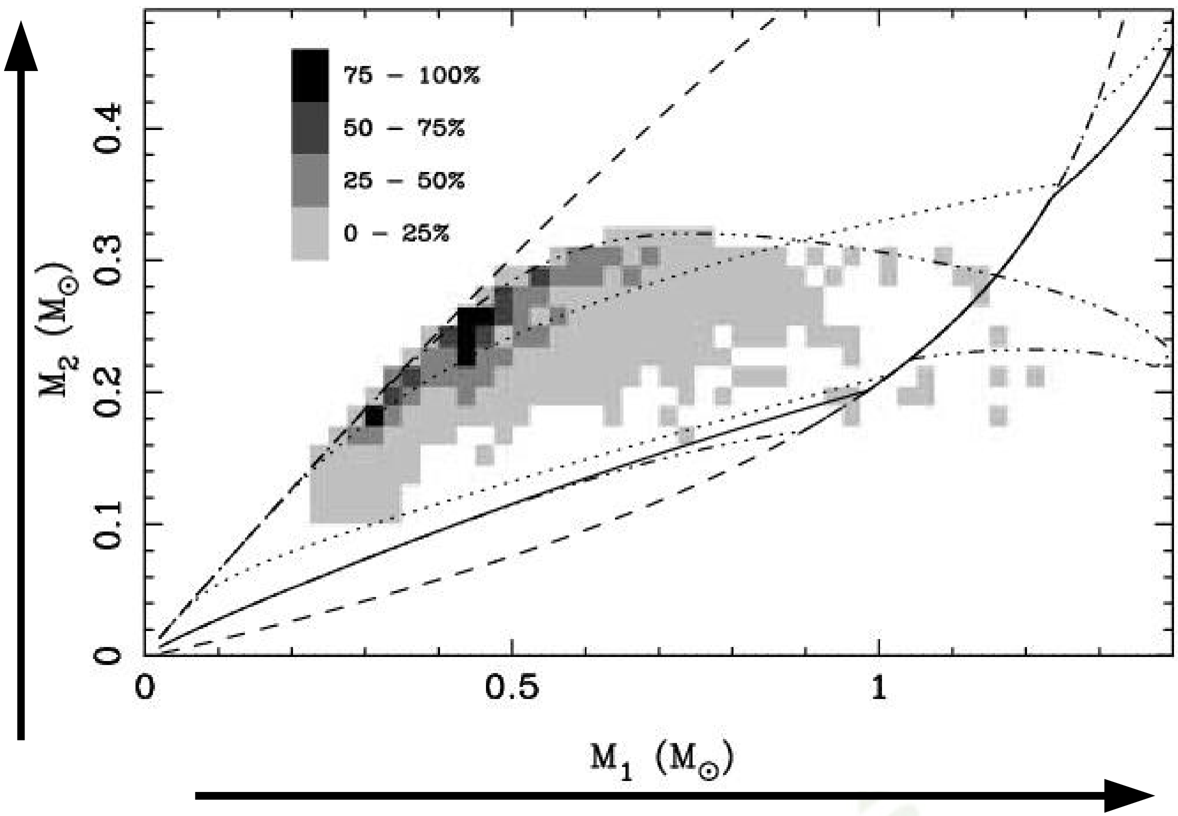
Very first X-Shooter spectrum



Prof. dr. Scott Tremaine

Blaauw professor 2009
KNAW visiting professor

3: Model the population



- Model population of binary systems from first principles in computer
- 'Simulate surveys': Direct comparison with Observations, incorporating selection effects

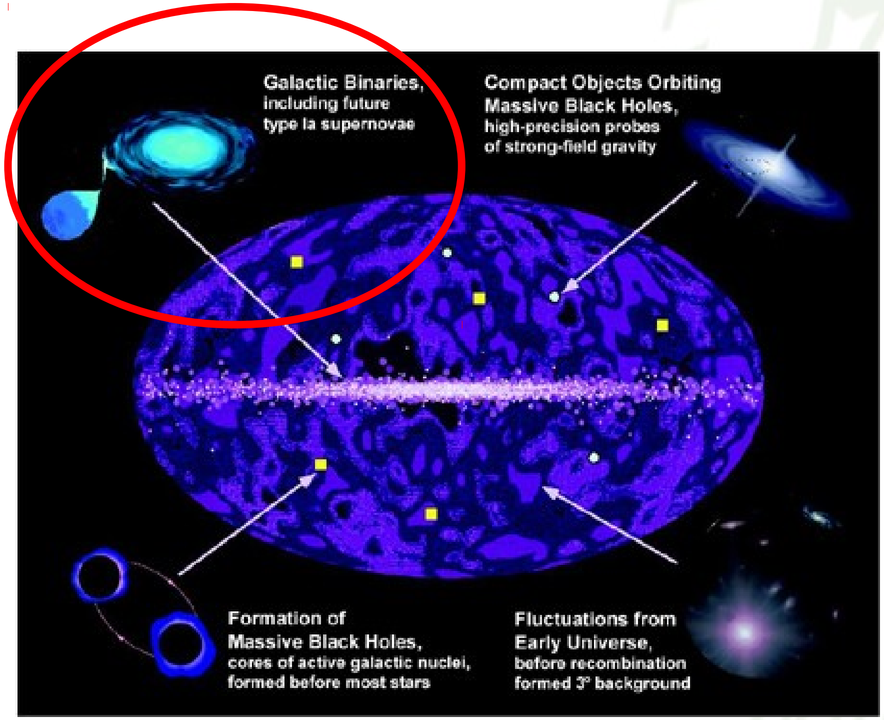
Direct link and interplay between theory & observations: very strong point for Nijmegen group (Groot & Nelemans)

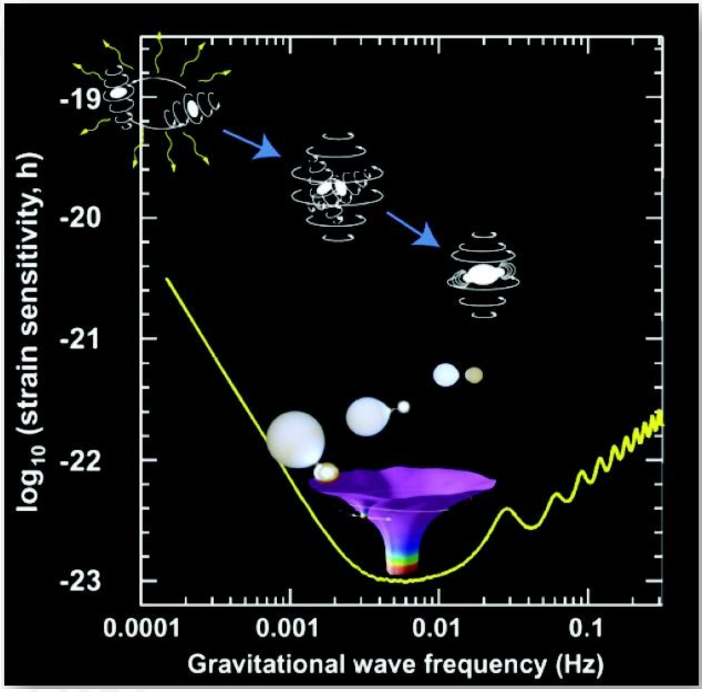
4: Apply the Galatic binary model

Apply generalized Galactic binary population model

- Which white dwarf binary road leads to Supernovae Type Ia?

- What is the strength of interacting and detached ultracompact white dwarf binaries in LISA?

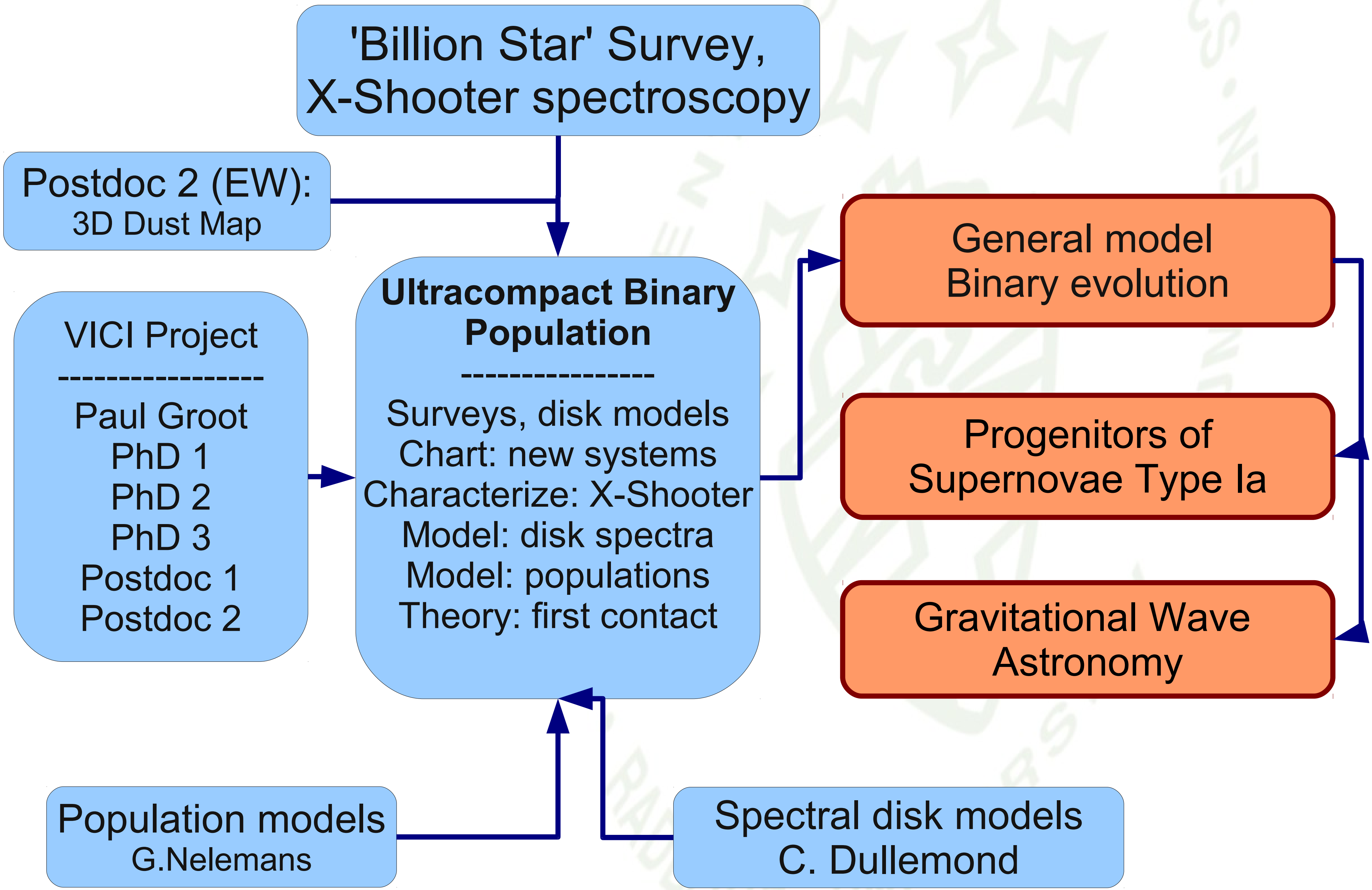




Road to VICI Project

- ✓ Done: (2003-2011): 'billion star' survey: EGAPS Project
- ✓ Being done; data reduced, archived, databased in Cambridge
- ✓ Done: VIDI project; PhD theses Roelofs, vd Besselaar
- ✓ Done: Guaranteed time on X-Shooter spectrograph on VLT
- ✓ Done: Developed for Sloan Survey

VICI: Yield Science

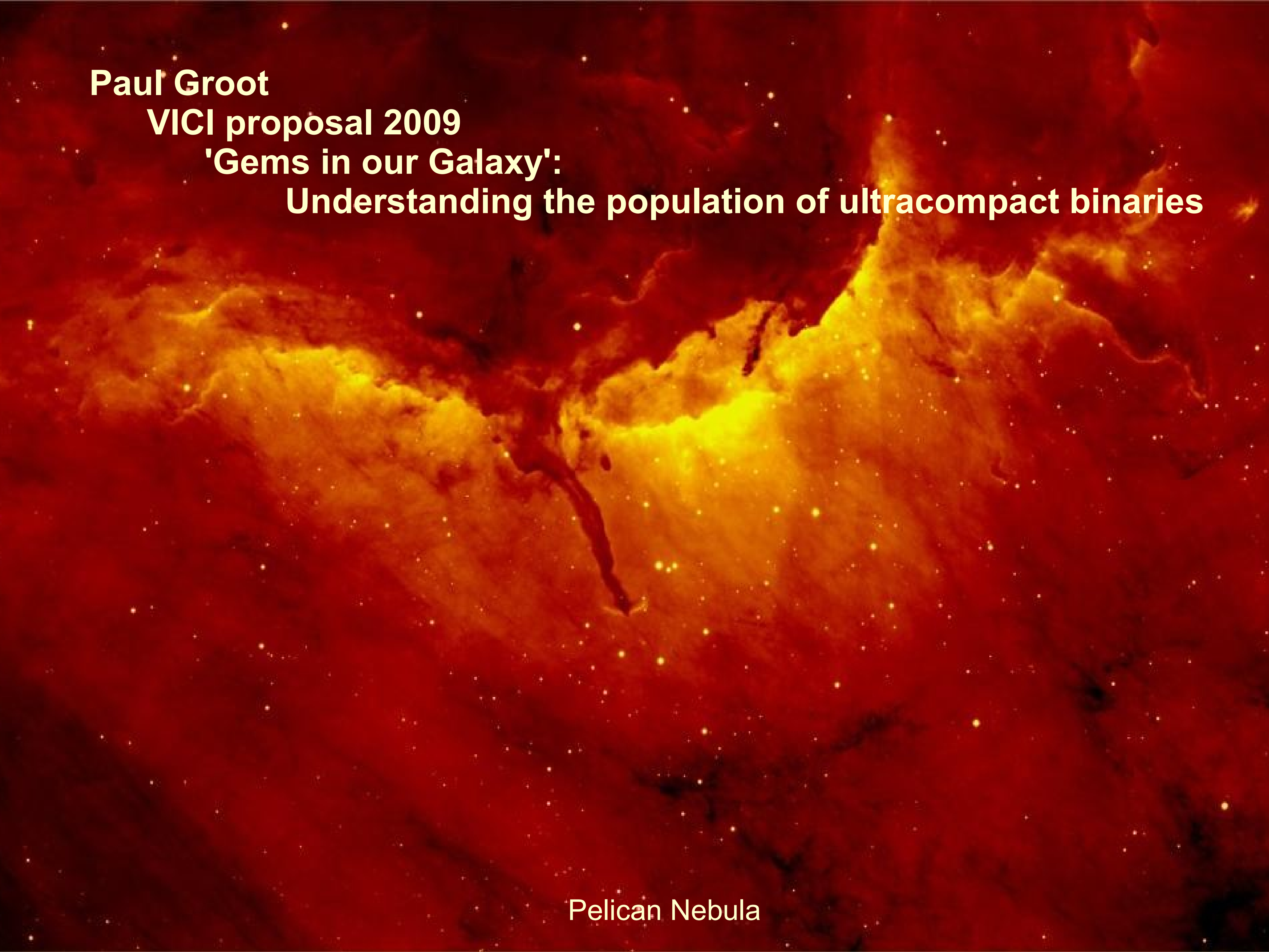


Paul Groot

VICI proposal 2009

'Gems in our Galaxy':

Understanding the population of ultracompact binaries



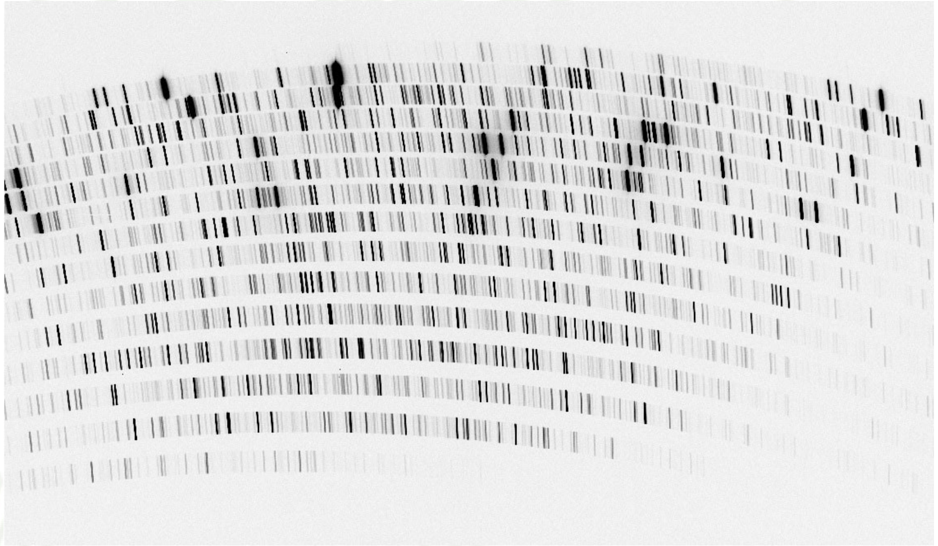
Pelican Nebula

Innovation

Innovation in VICI proposal:

- ☞ ***Direct coupling*** between simulations & observations
- ☞ ***Scale*** of surveys: chart a billion to find 250+
- ☞ ***World's most advanced spectrograph:*** X-Shooter@VLT
- ☞ ***Systematic approach***: homogeneous datasets.
- ☞ ***Accretion disk models:*** adaptation to ultracompact settings

EGAPS: Billion star survey



X-Shooter: Visual arm spectrum

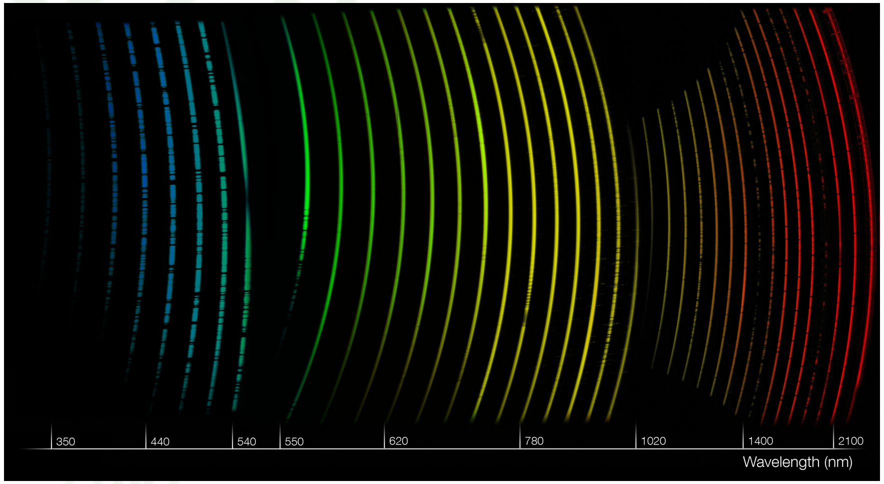
Why now?

Now is the time for this VICI project:

Science questions urgent
NL/Nijmegen will yield scientific return on investment

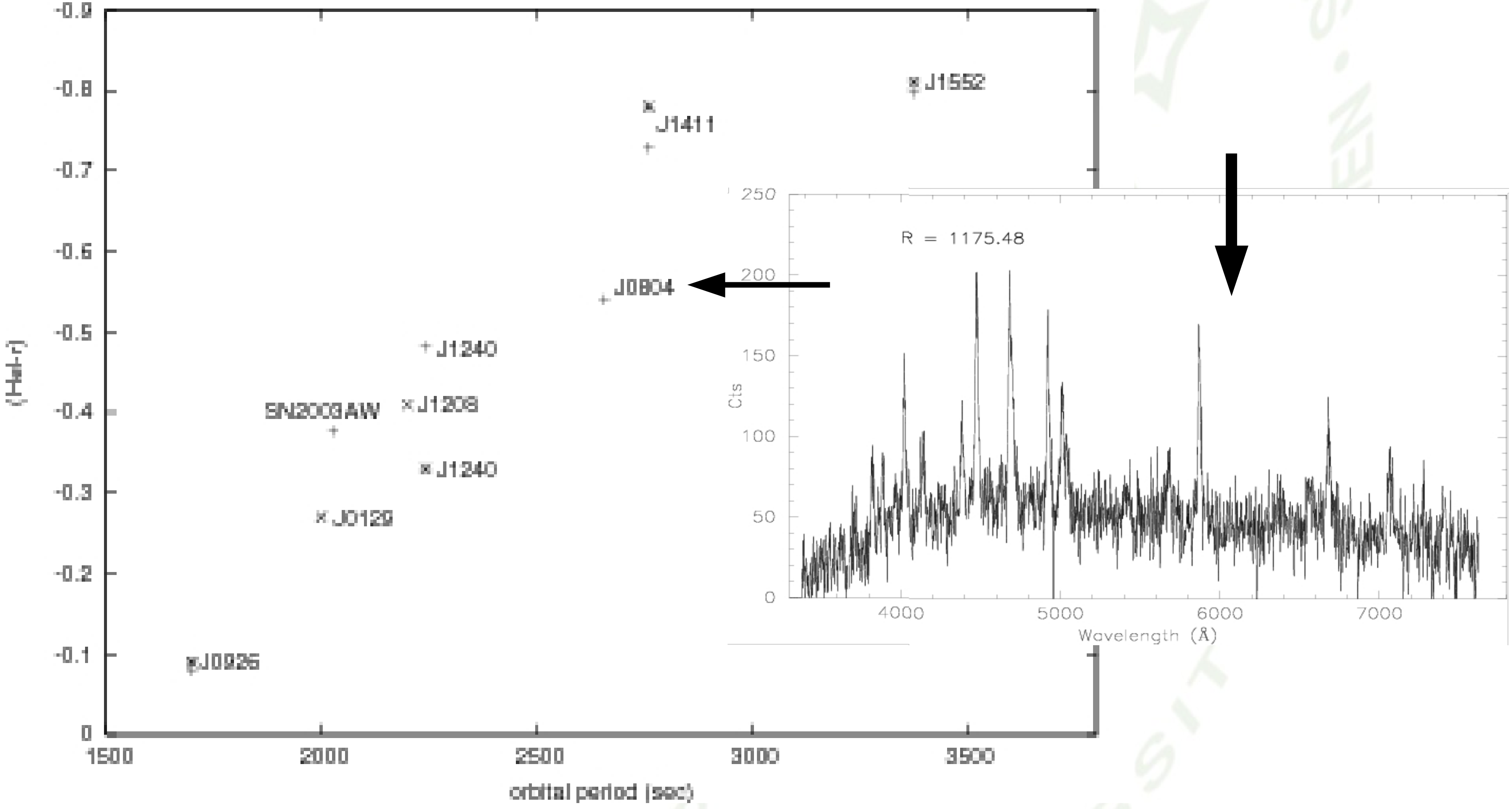
- ☞ EGAPS Survey is now running: 700 nights
- ☞ NL-built VST Omegacam camera: **start 2010**
- ☞ X-Shooter finished and has started **on Oct 1, 2009**

Leading NL role in Galactic Plane Surveys will be maintained
We will do the science: Survey Data will be public!
(first 50%: already public)

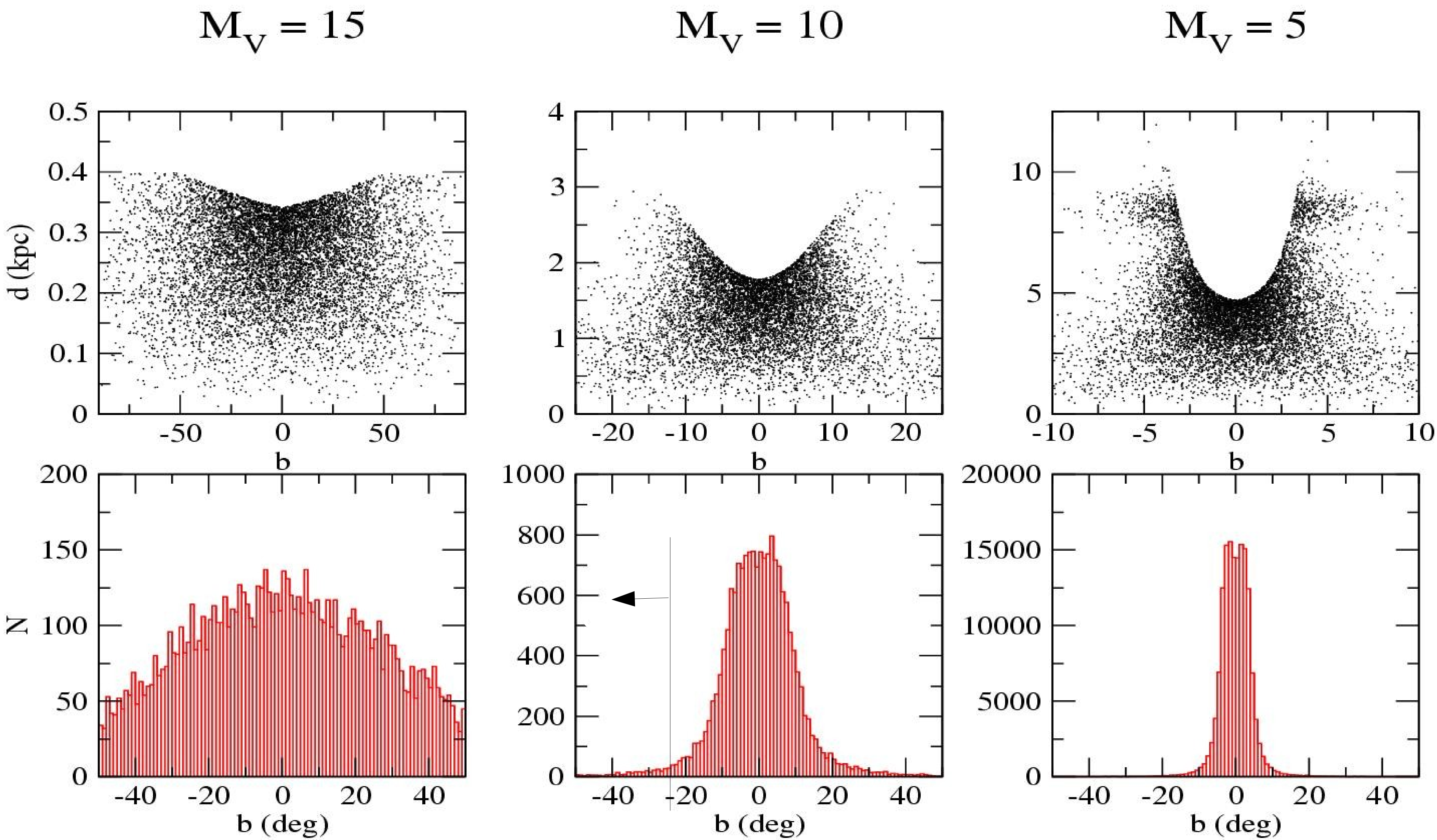


Full X-Shooter spectrum from 0.3-2.3 micron

Period – EW (HeI5875) relation



Distribution on the sky



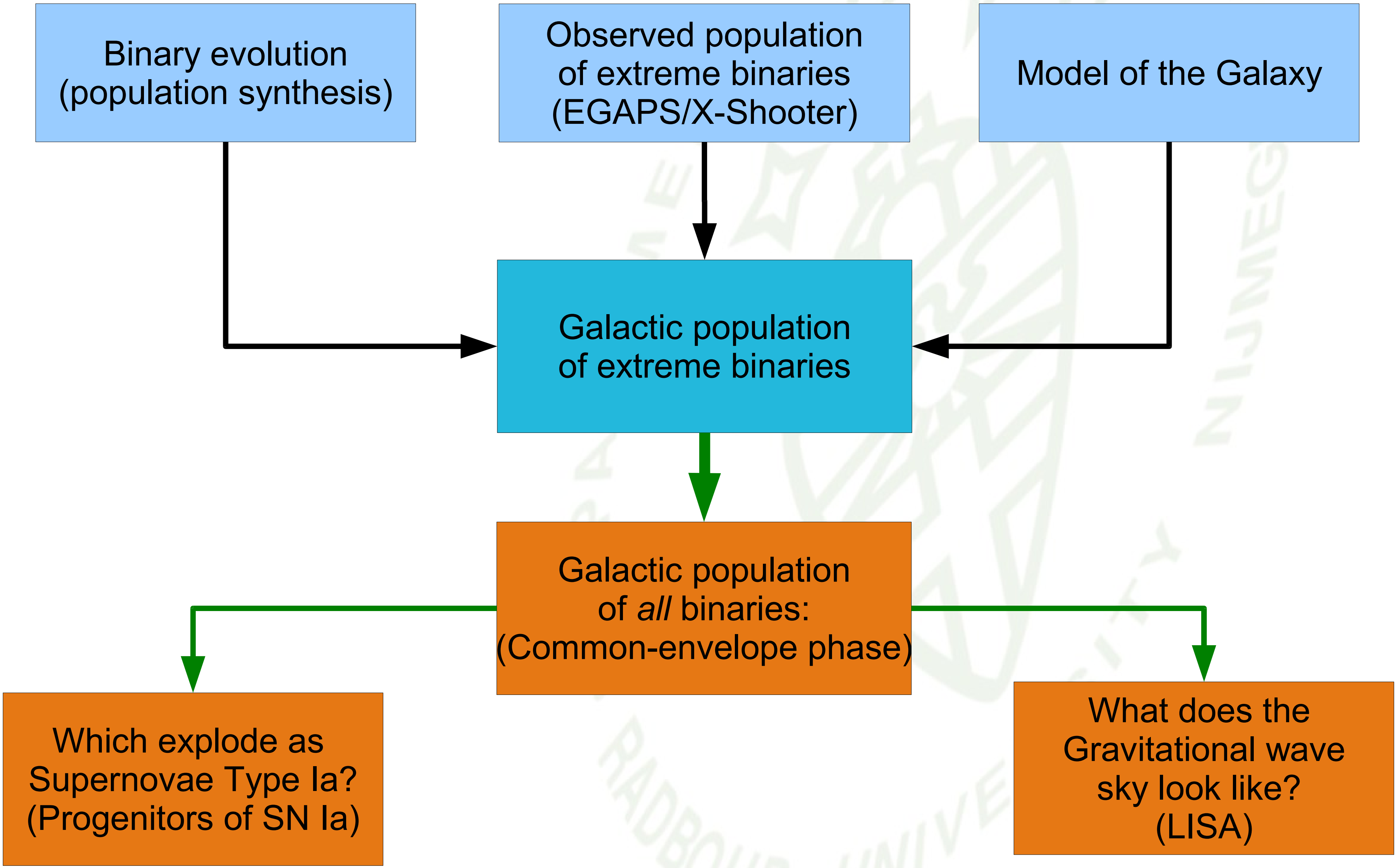
Why Paul Groot?

Why Paul Groot:

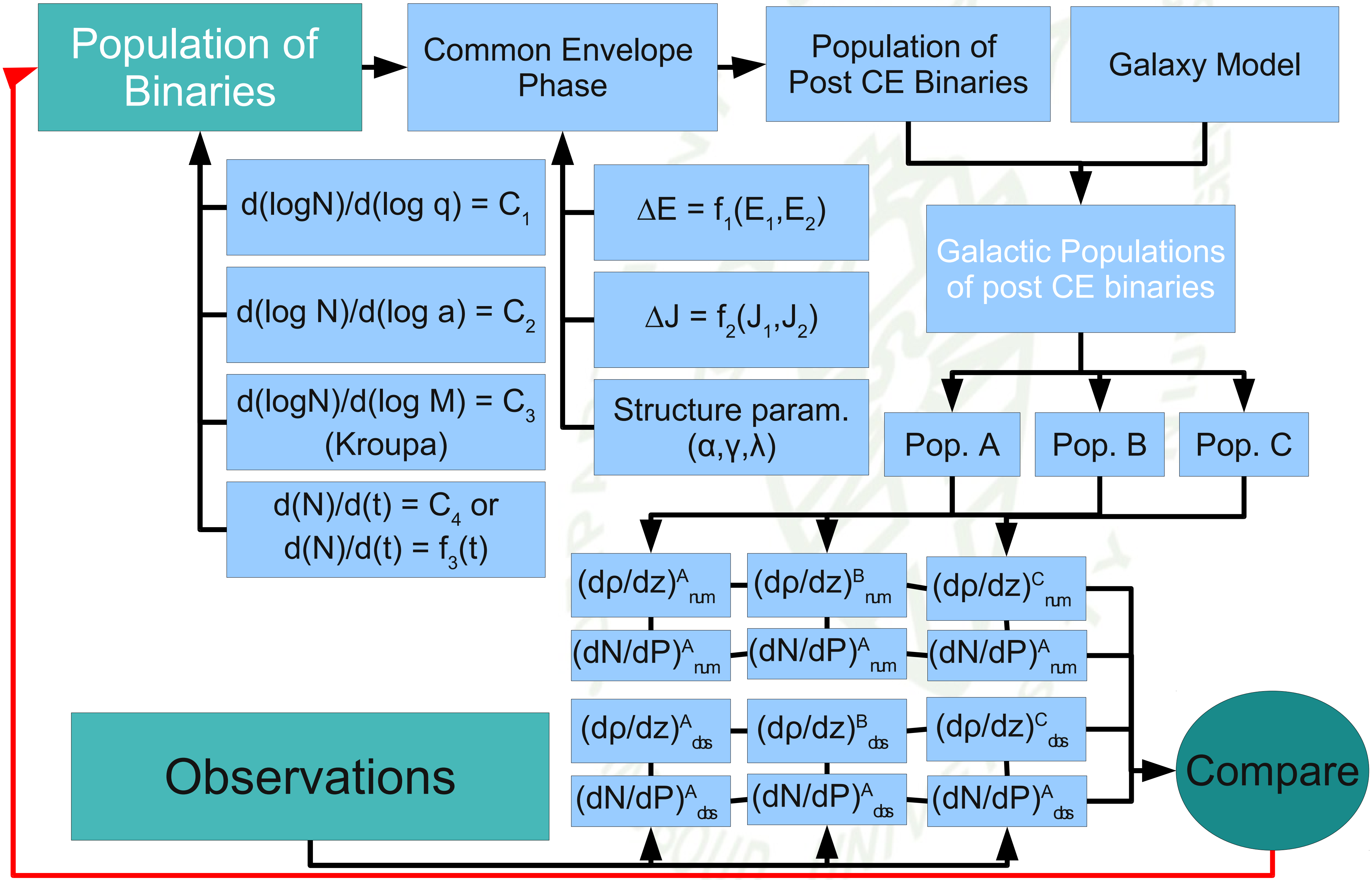
☞ ' Shows foresight to be involved': EGAPS & X-Shooter (Ref. 1)
☞ ' He is leading in the field of close binary evolution' (Referee 1)
☞ ' No other surveys planned than .... is conducting' (Referee 1)
☞ ' Groot really is the world expert in this research' (Referee 2)
☞ ' Cannot think anyone else who could even attempt such a project' (R2)
☞ ' Strength to lead a big project: skill apparent from history' (Ref 3)
☞ ' Leading role in X-Shooter, surveys, excellent team' (Ref 4)

Co PI on European Galactic Plane surveys
Project Scientist on X-Shooter
Leader of Nijmegen team which combined modelling & observations
Proven track record in leading big teams/projects and getting things done

Questions to Answers



Numerical Population Modeling



Highlights VIDI project

Galactic Plane very poorly known

No modern, digital optical survey of Milky Way

Why? **Because it is extremely difficult!**

Extremely crowded: > 100 000 stars per area full Moon

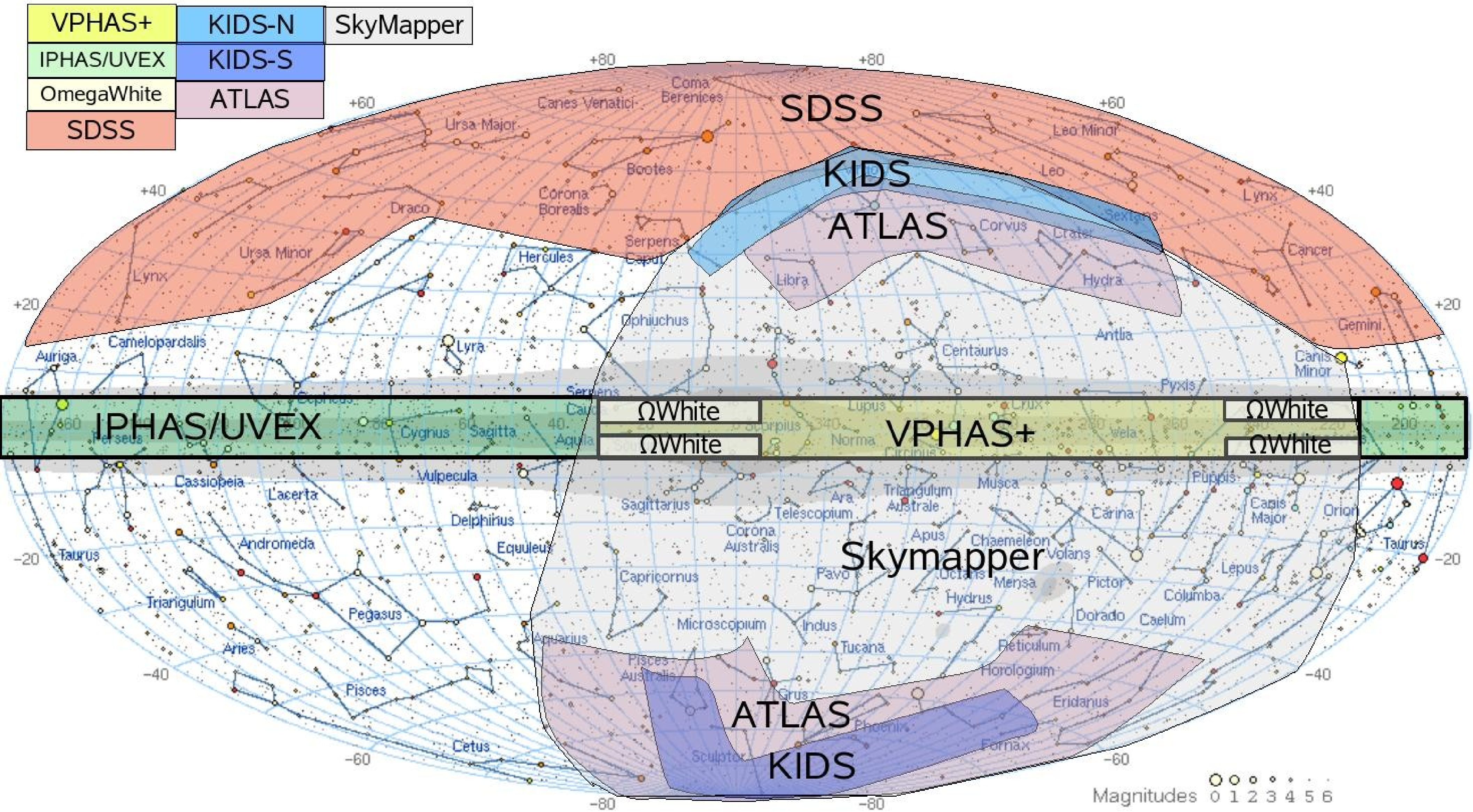
A lot of intervening gas & dust: reddening & extinction

Large: ~10% of all sky: takes a lot of nights (~700)

Spans two hemispheres: need two telescopes

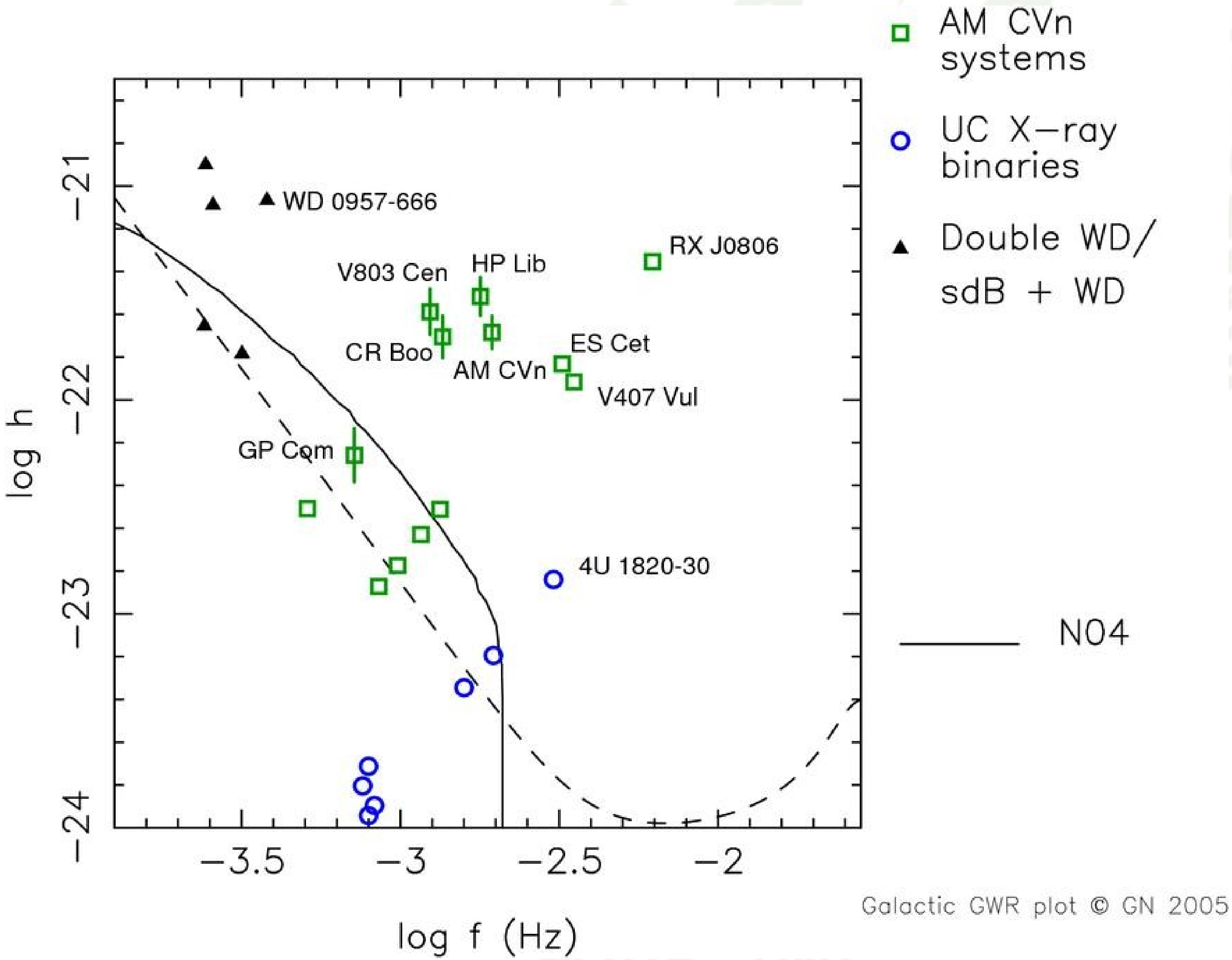
But, we are doing it:
The European Galactic Plane Surveys (EGAPS)

'Chart': Major surveys



Gravitational waves

Extreme binaries are dominant population in LISA frequency regime



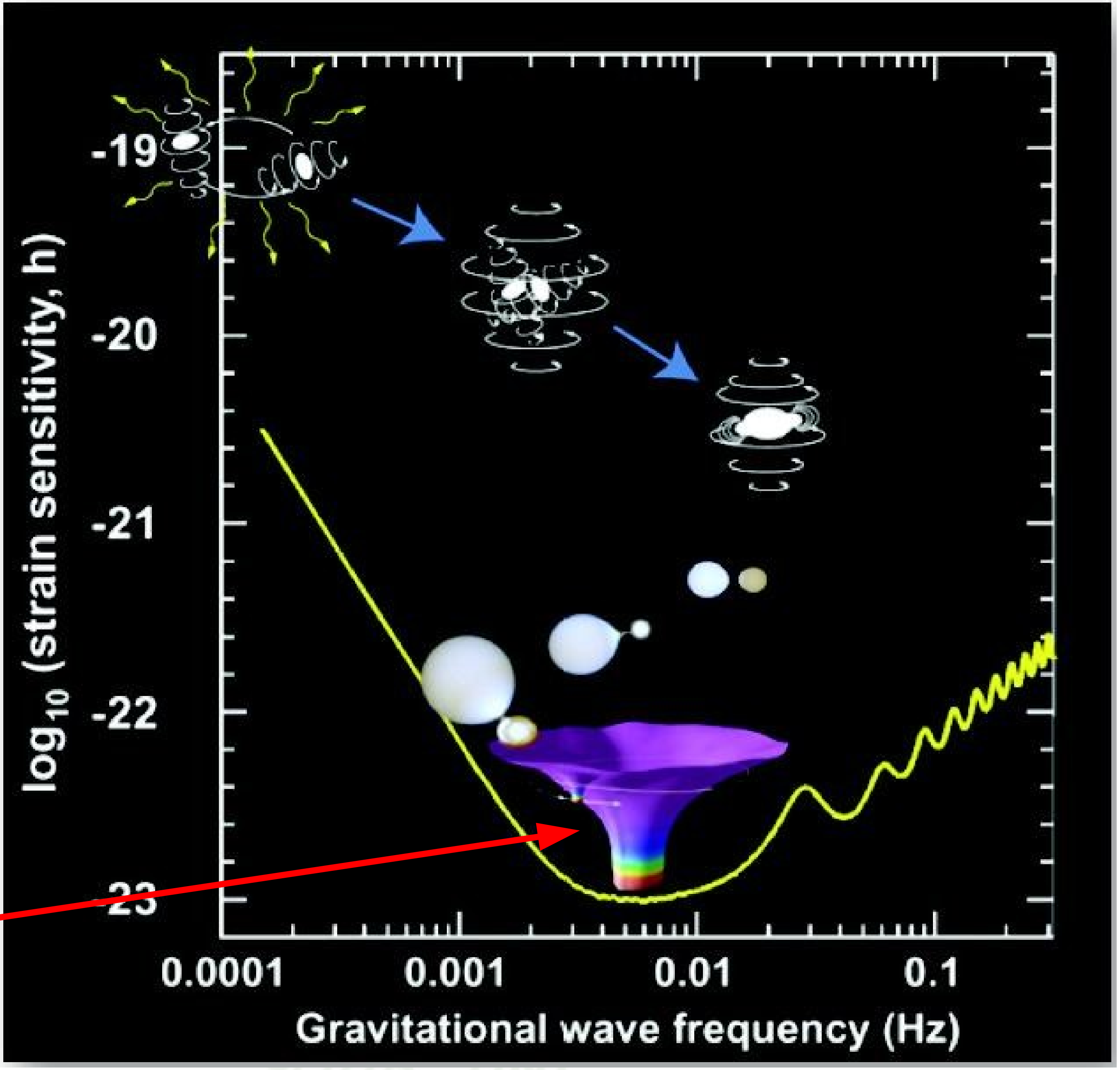
Effects on LISA science

Strain Amplitude, h =

$$h = \left(\frac{GM}{Rc^2}\right)^2 \left(\frac{R}{D}\right)$$

More extreme binaries:
LISA will see no extreme mass-ratio in-spirals

Fewer extreme binaries:
LISA will see extreme mass-ration in-spirals

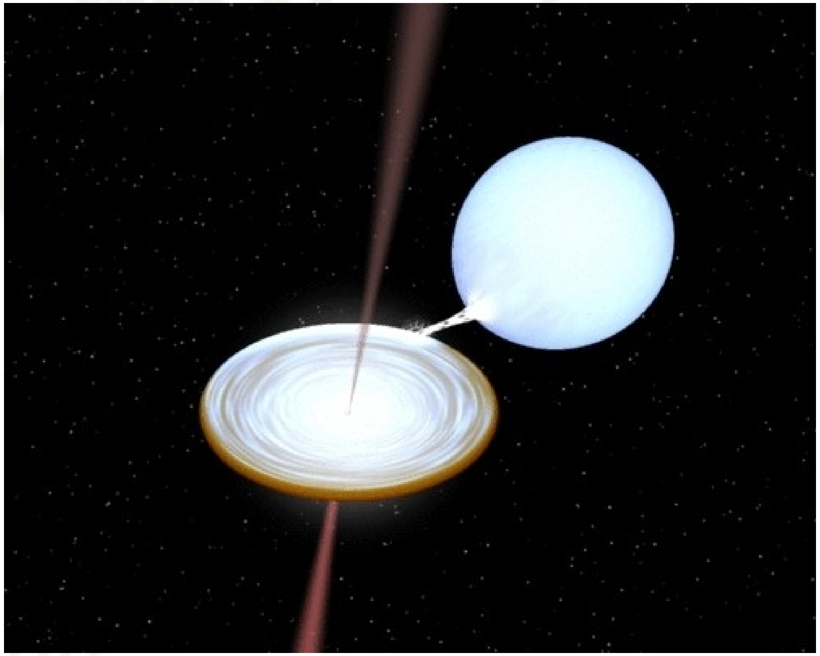


Theoretical linch pins

Common envelope physics:
- Is it αλ (orbital energy) mechanism,
  or γ (angular momentum) mechanism?

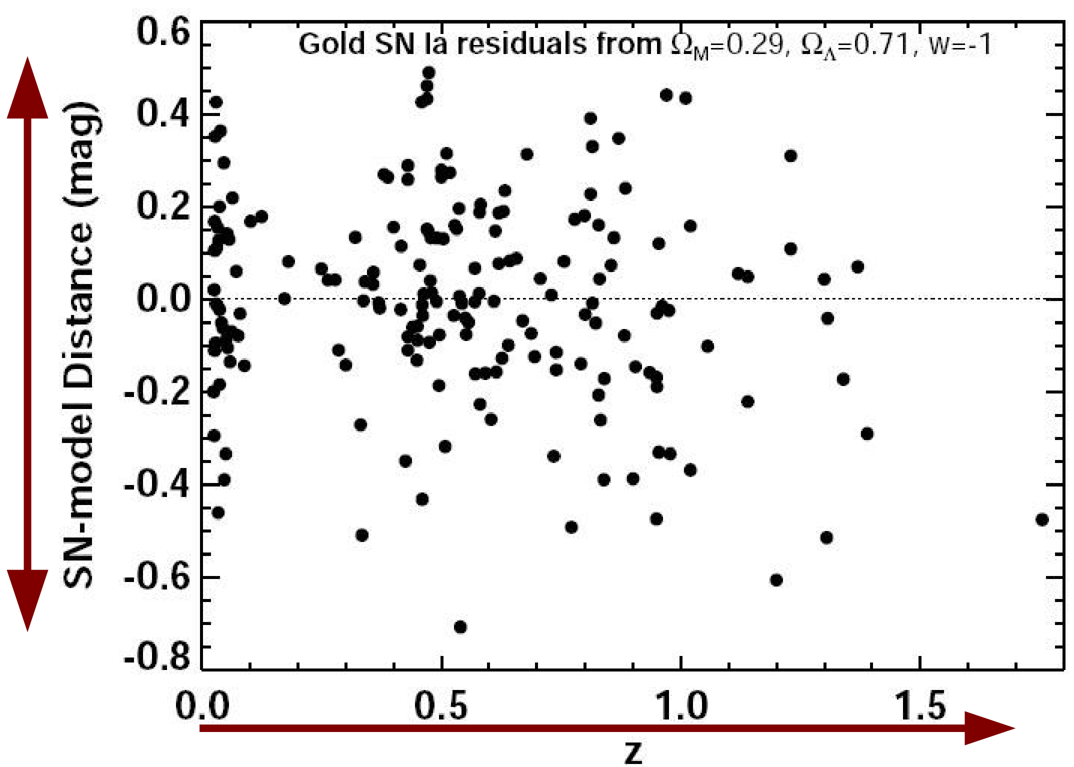
First contact: Angular momentum transfer?
- Feedback into orbit?
- Role of tides?
- Role of tidal heating *before* first contact?
- Direct impact physics?

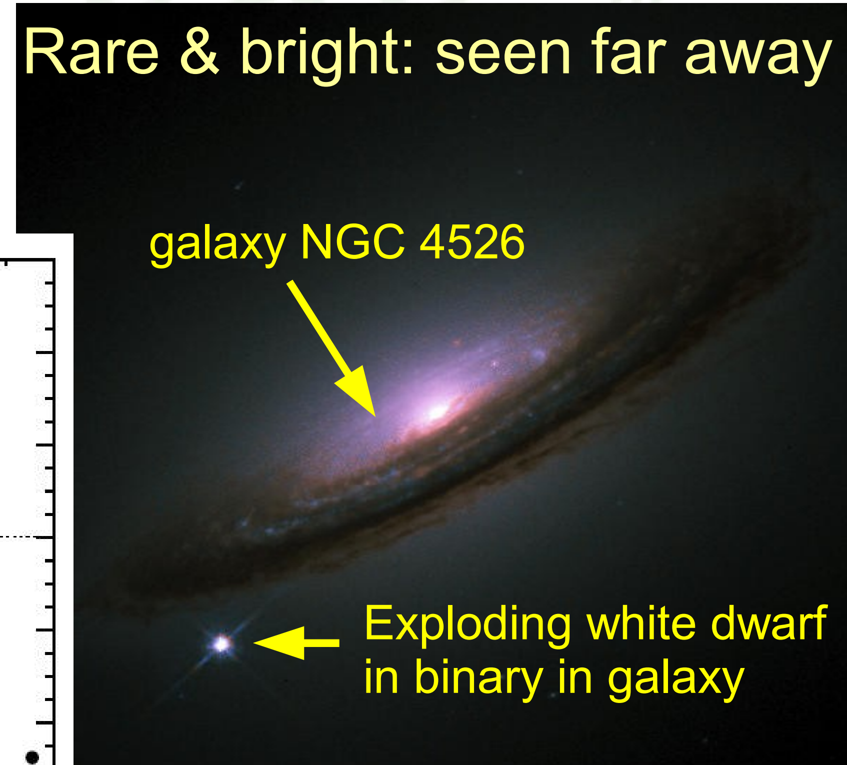
Accretion disk spectra:
from line strengths to abundances



Supernovae Type Ia

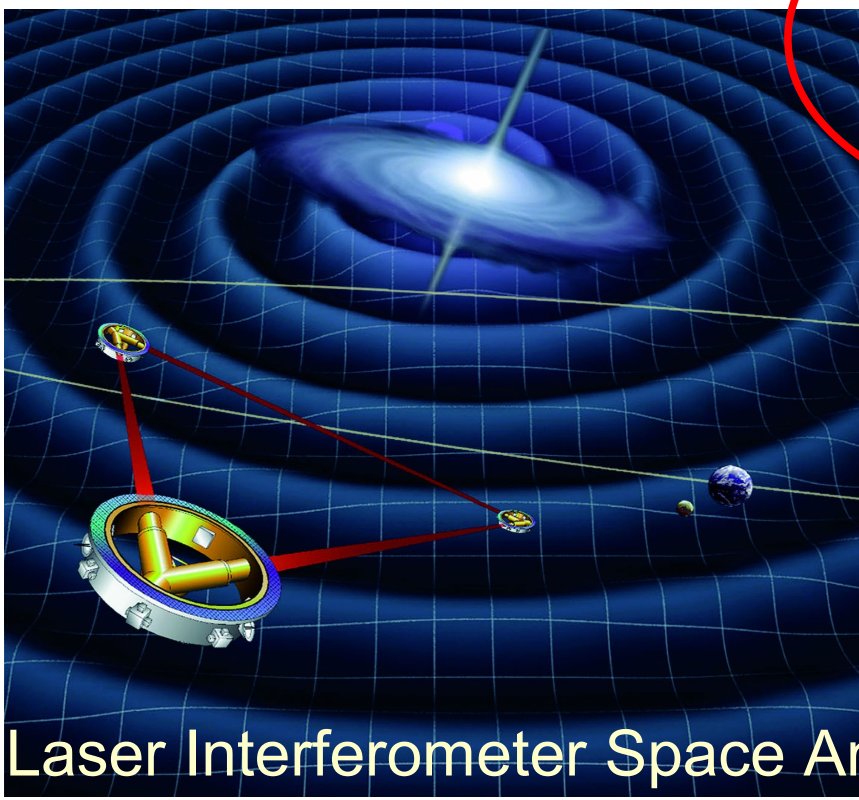
$$f_{Earth} = \frac{\langle L \rangle}{4 \pi d^2}$$

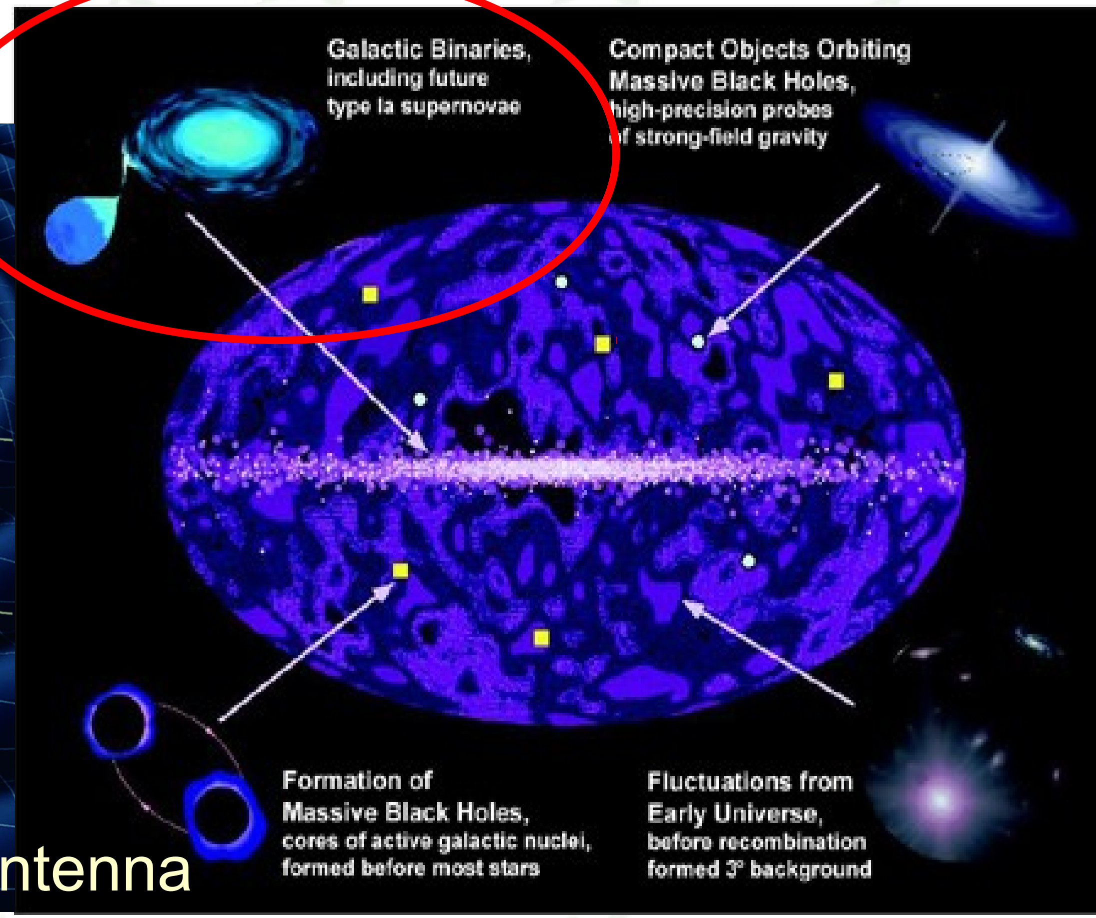




Model of source population ⇨ understanding of luminosity ⇨ better model evolution Universe

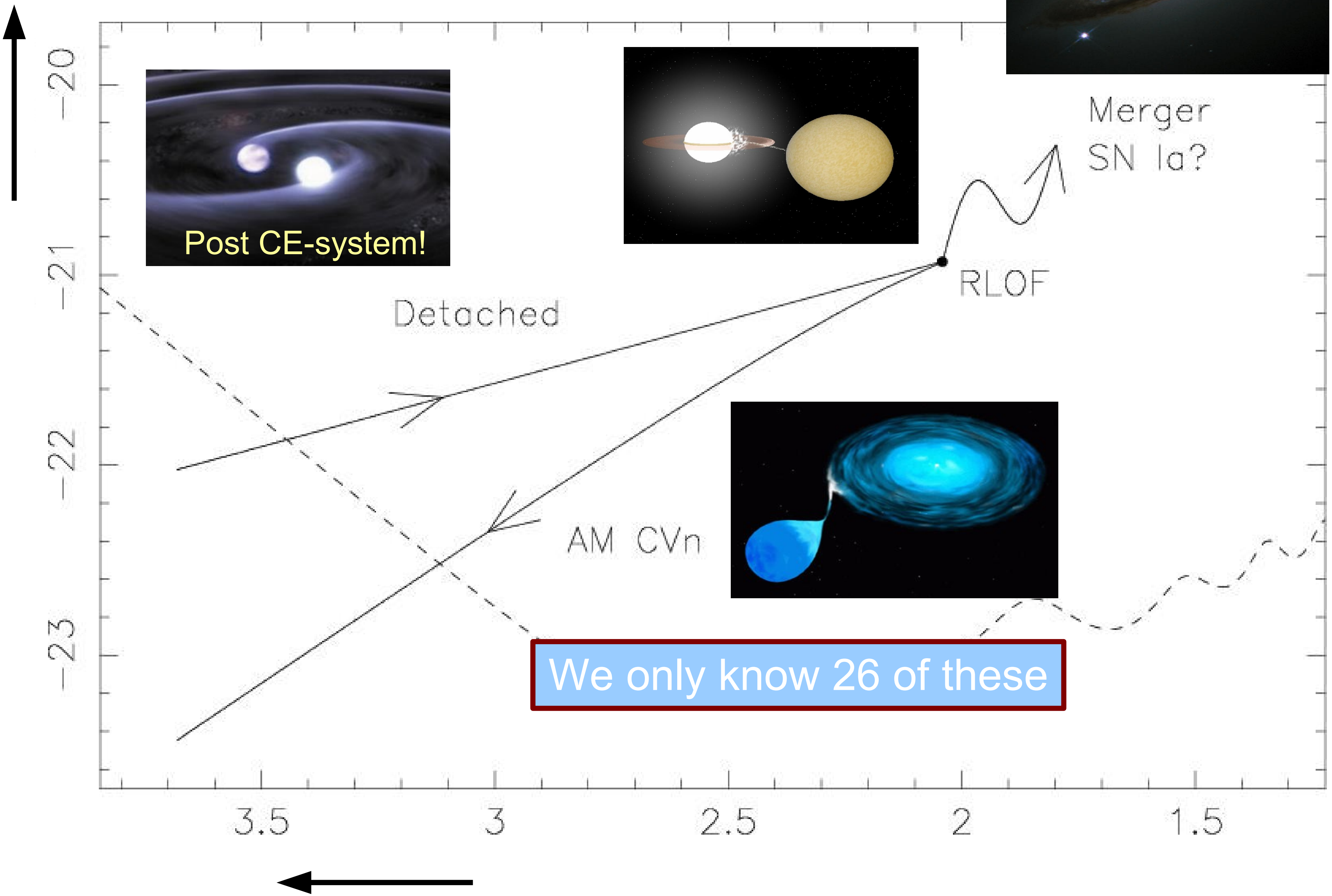
Gravitational waves



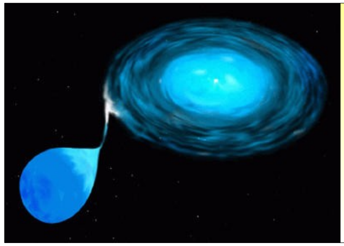


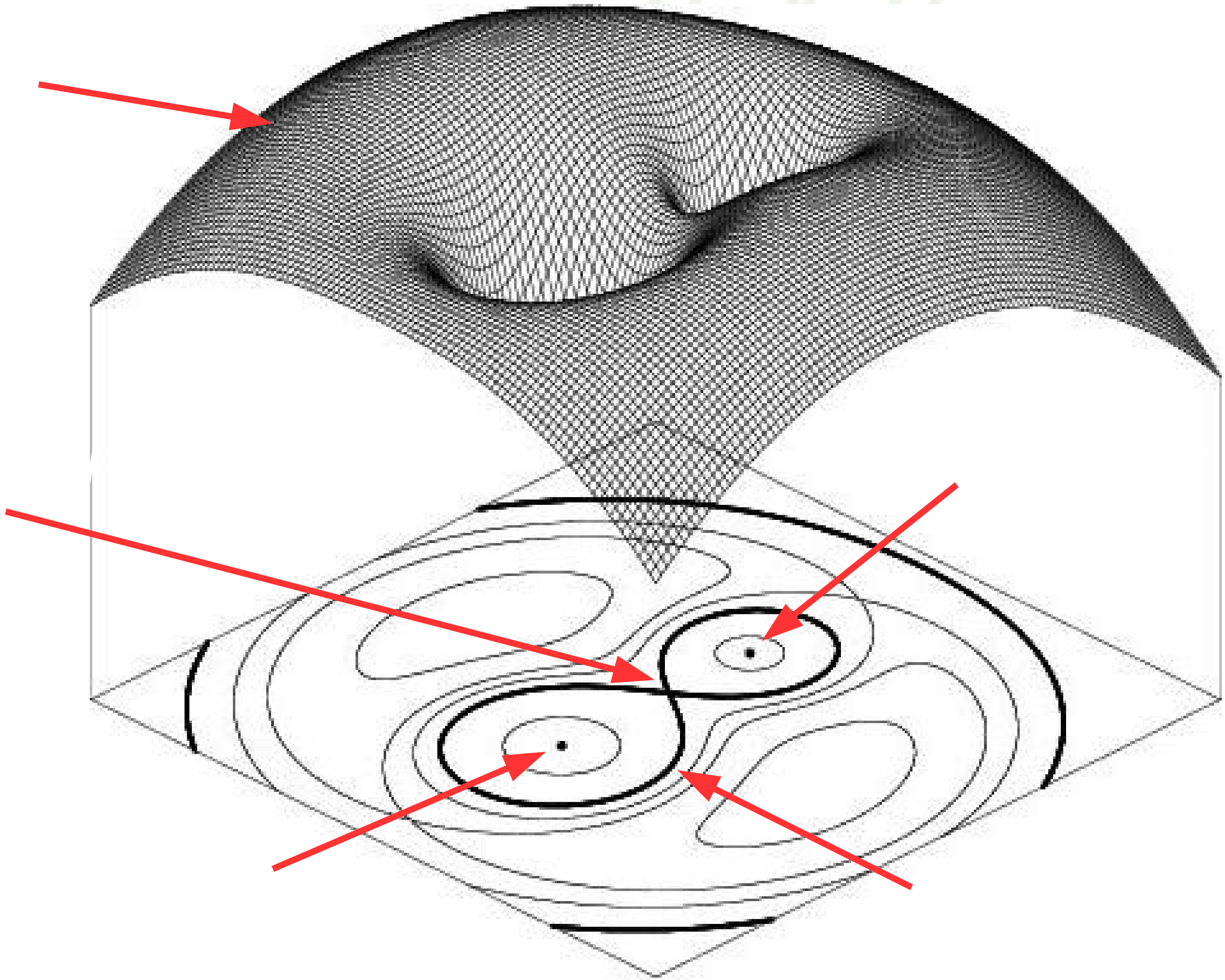
Needed: quantitative prediction on shape and strength of gravitational wave signal from ultracompact binaries in Galaxy

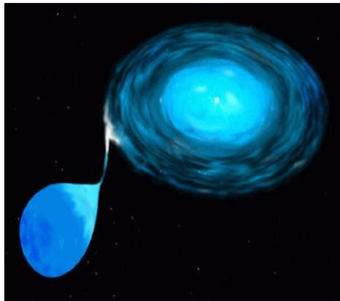
They are all linked!



Roche Geometry







Extreme binarie… …minate High … …e

M31: Andromeda Nevel

Milky Way is pivotal