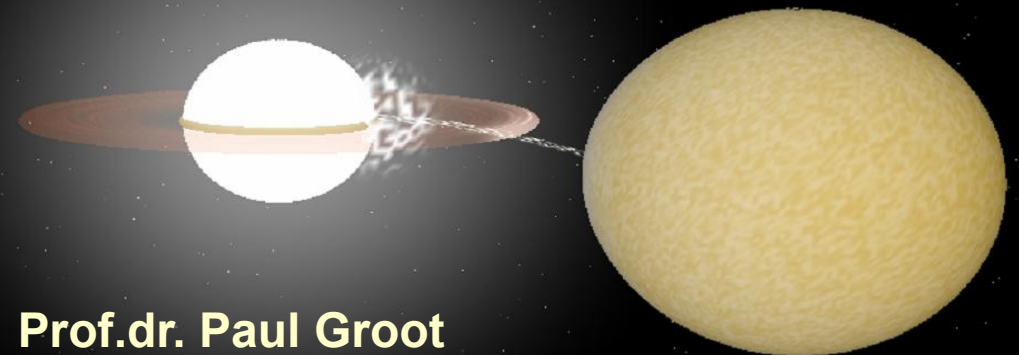
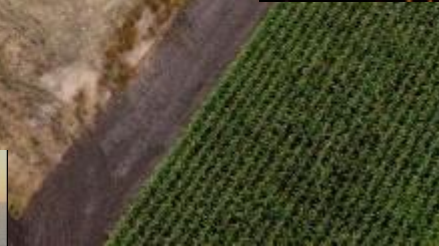


Nijmeegse Sterrenkunde



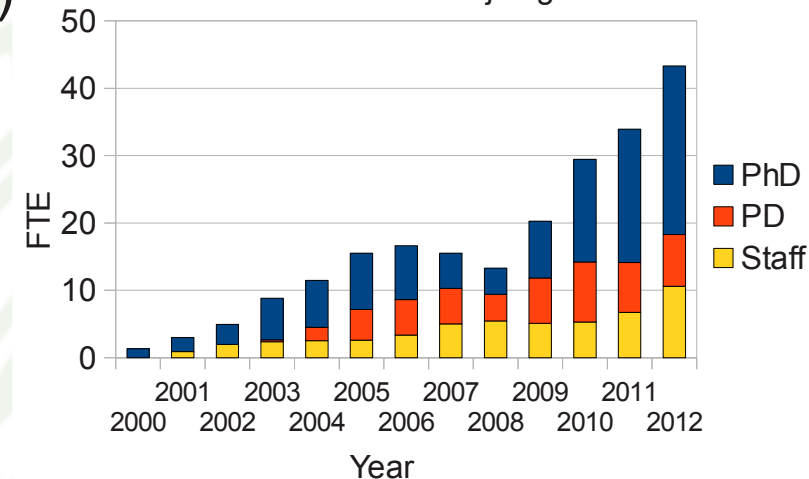
Prof.dr. Paul Groot
Afdeling Sterrenkunde
IMAPP, FNWI, RU

Sterrenkunde in Nijmegen

- Gestart/herstart in 2001
- Nu 10 stafleden, 50 medewerkers
- Verzorgt onderwijs in BSc/MSc
Natuur- en Sterrenkunde
- Internationale afdeling (14 nationaliteiten)
- Review oordeel: top 10% wereldwijd



Scientific staff Nijmegen

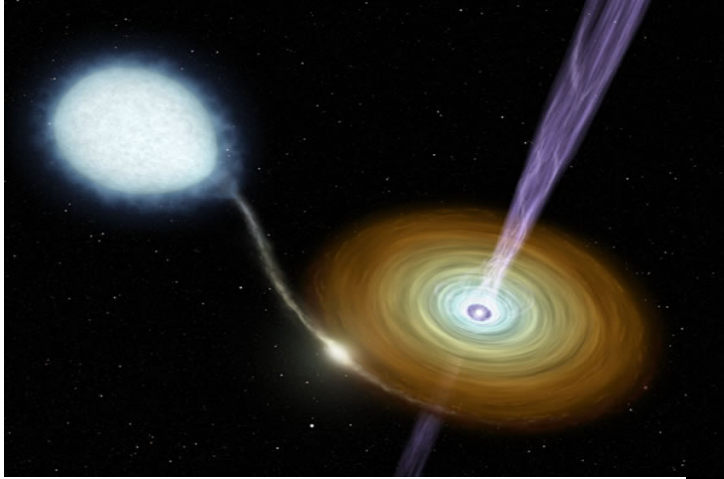


Onderzoek:

- Kosmische straling, radiosterrenkunde, superzware zwarte gaten, jets
- Compact dubbelsterren, zwaartekrachtstraling, Melkwegstructuur, jets, (dubbel-)sterevolutie

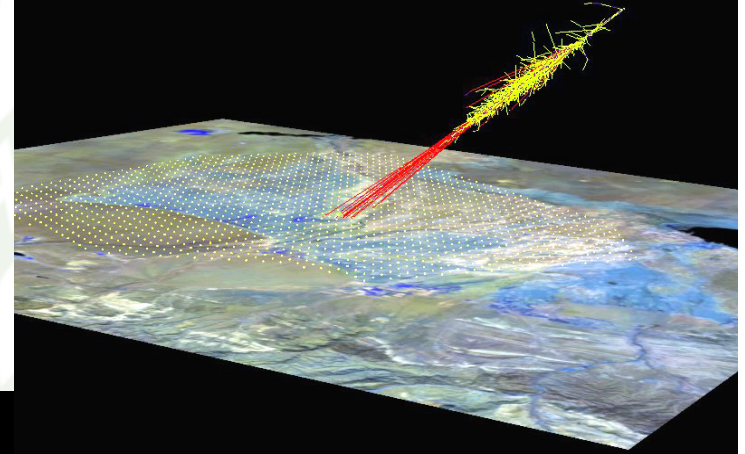
Sterrenkunde in Nijmegen

High Energy Astrophysics



Ultracompact
binaries

Cosmic Rays



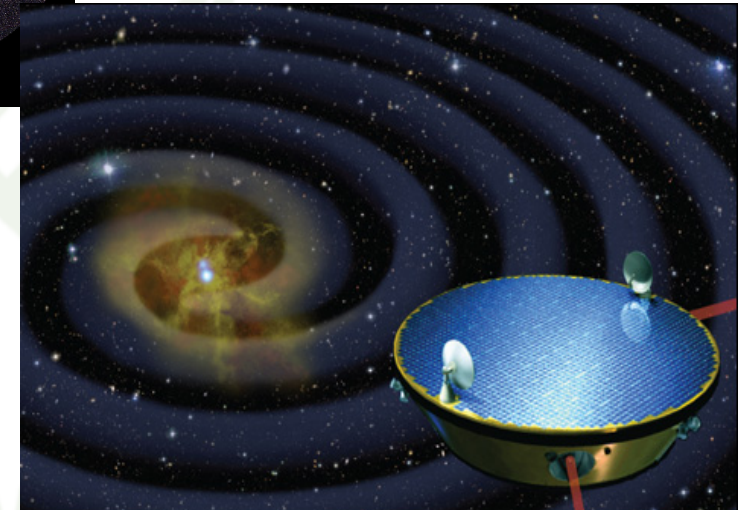
Supermassive black
holes & Jets



The Milky Way

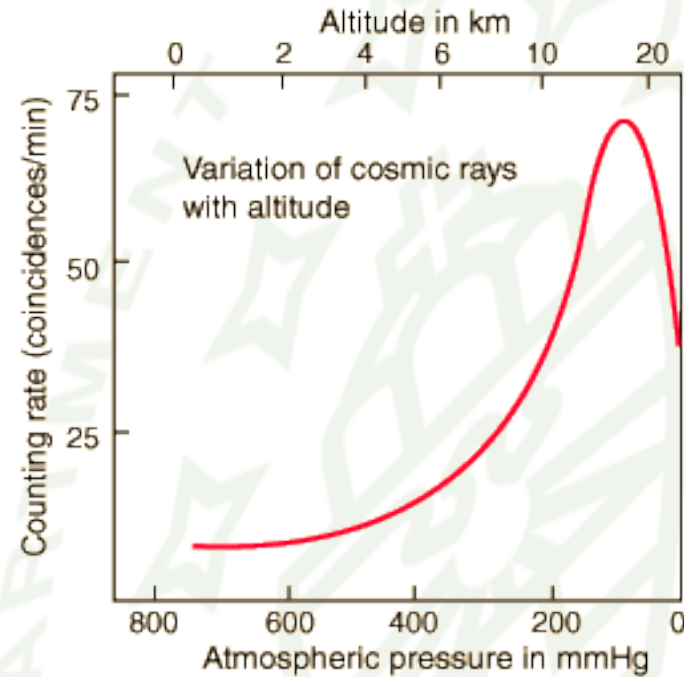


Gravitational
Wave sources



I: Kosmische Straling, Jets en Zwarte Gat

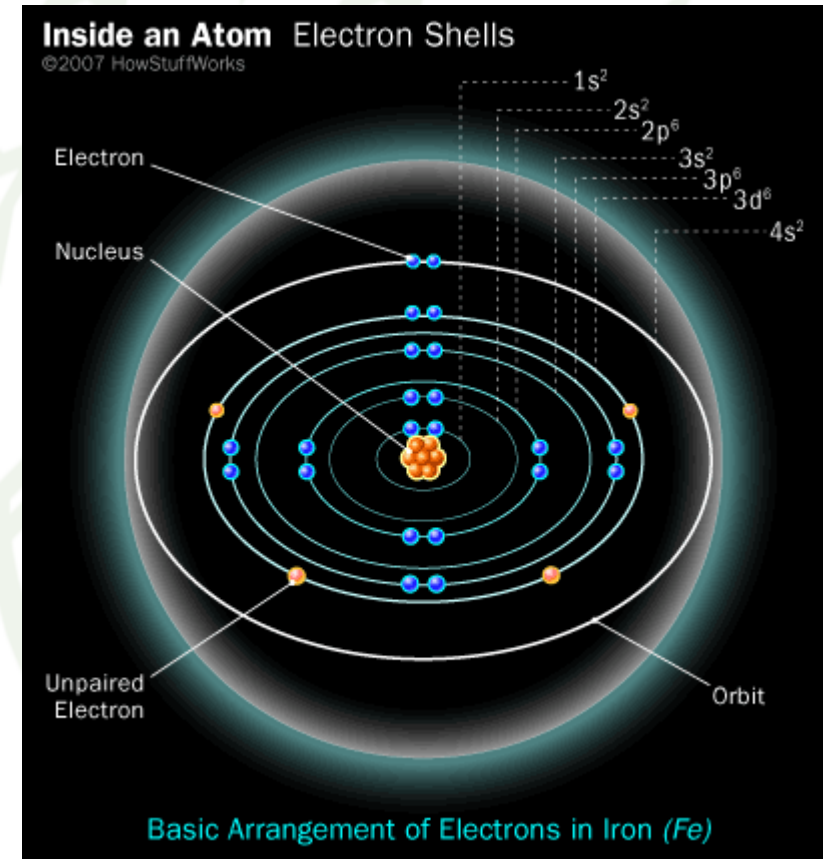
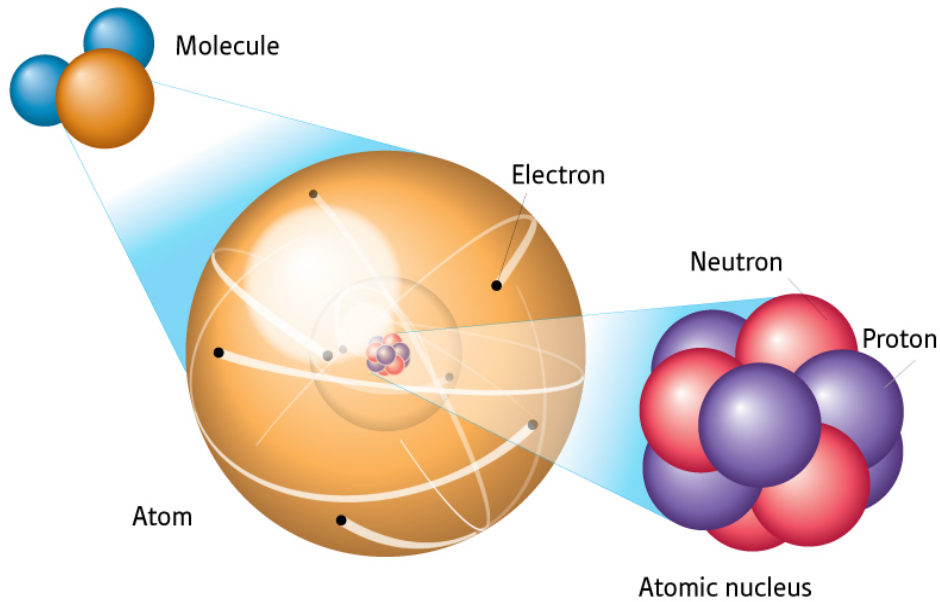
Precies 100 jaar geleden....



Aantal radio-actieve deeltjes neemt toe met Hoogte...: kosmische straling

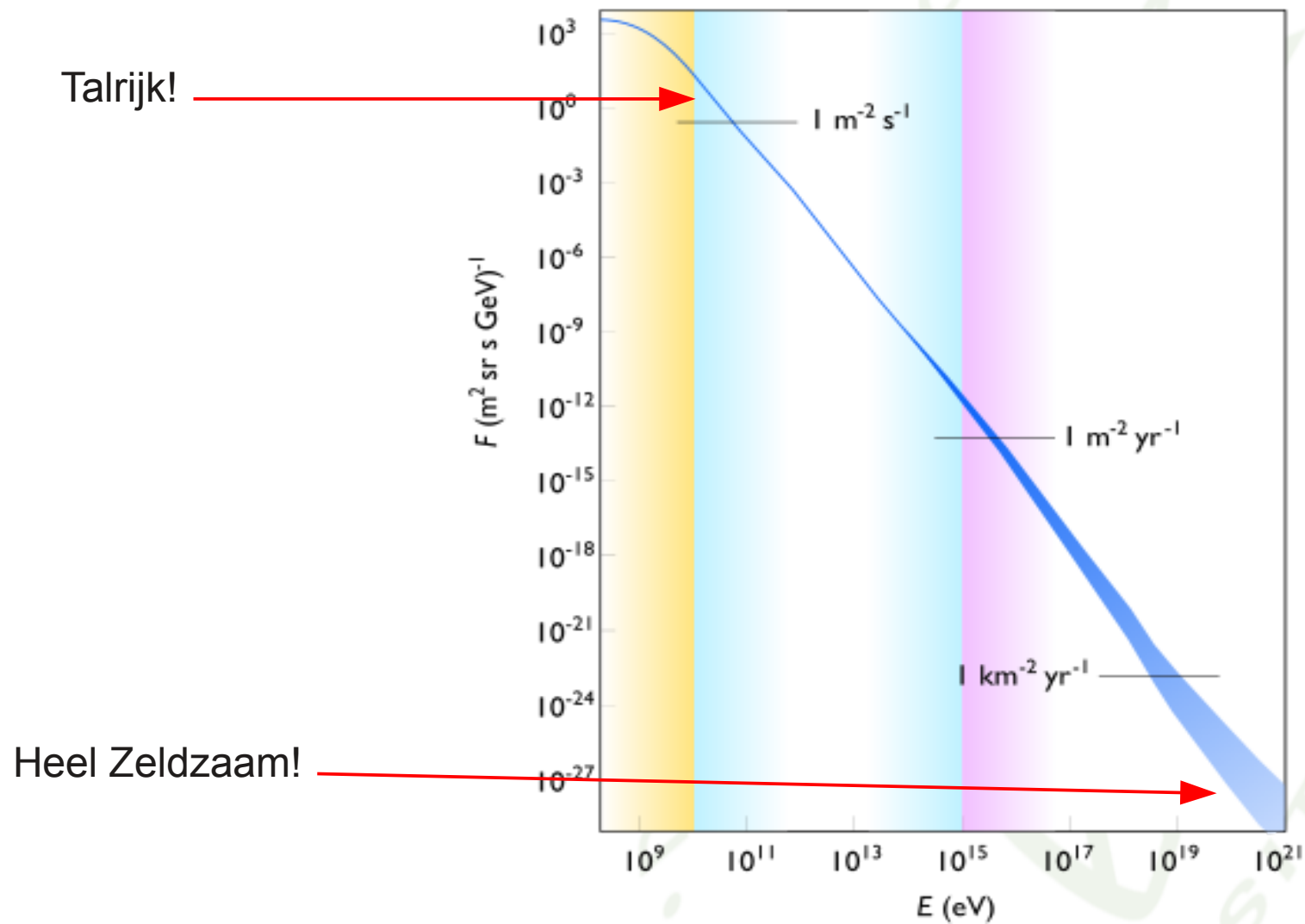
I: Kosmische Straling: compositie

Kosmische straling: geladen deeltjes uit de ruimte.

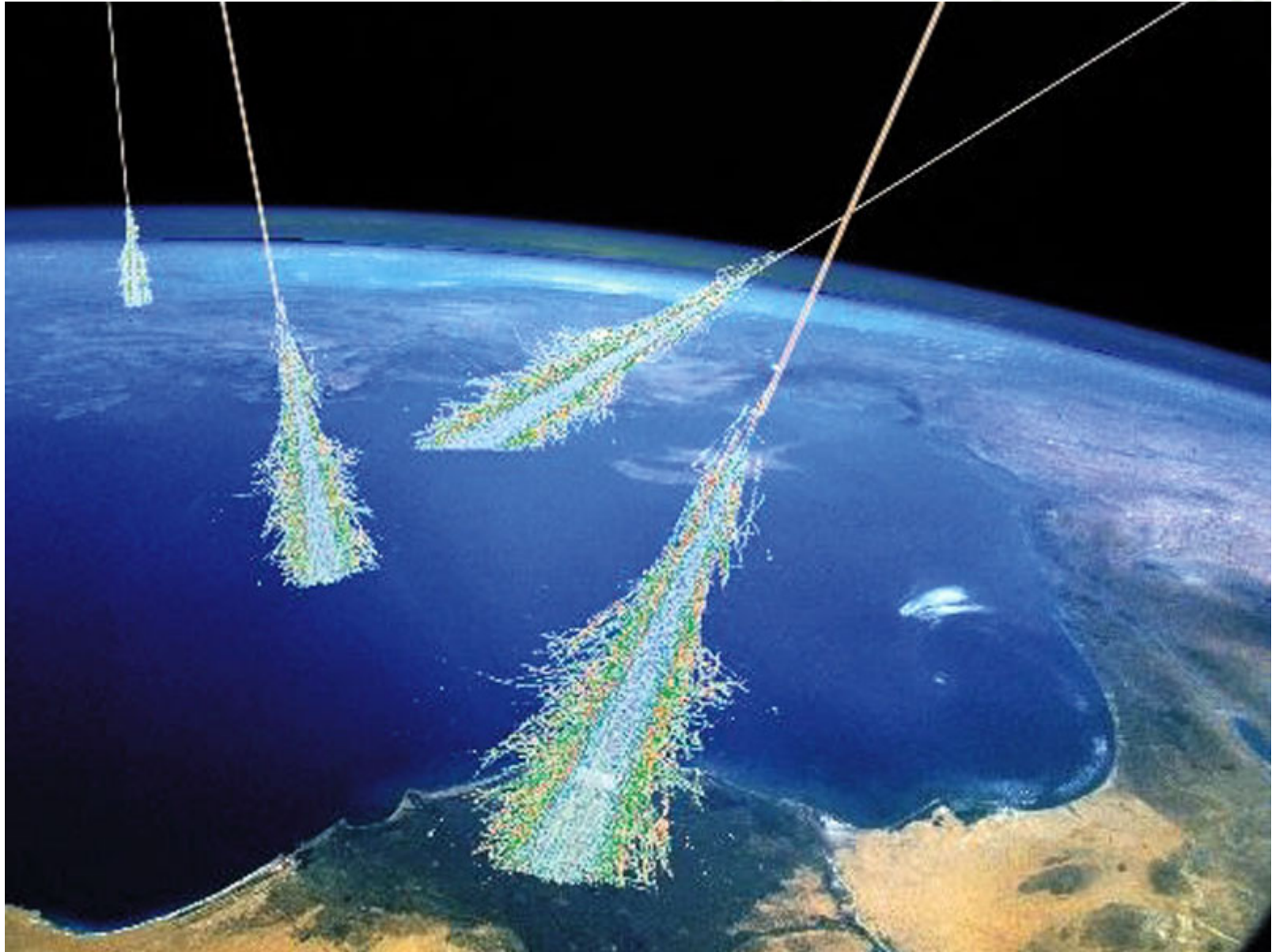


Voornamelijk: protonen, heliumkernen en ijzer!

I: Kosmische Straling: energie



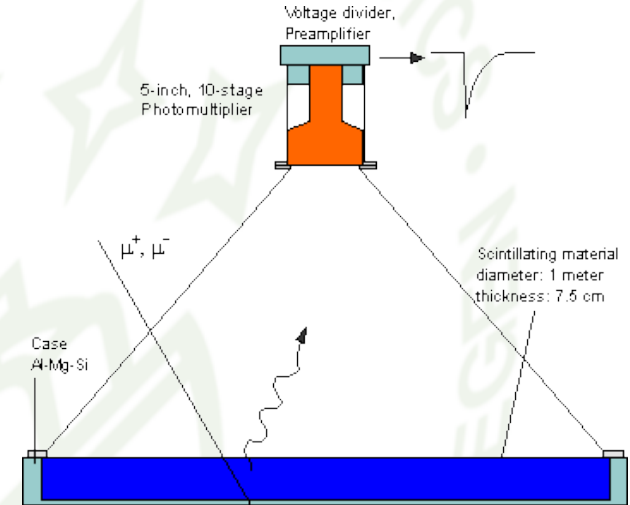
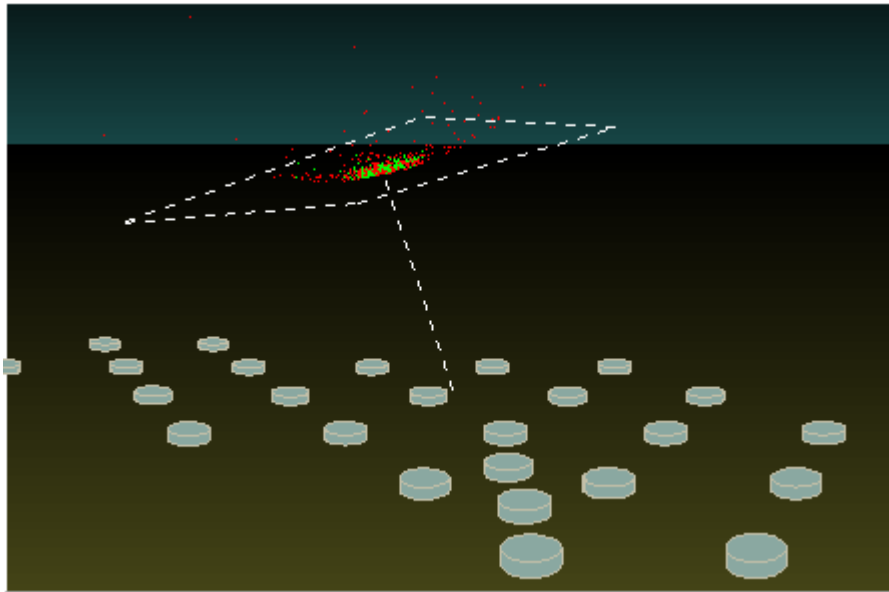
I: Kosmische Straling: licht regens



I: Kosmische Straling: lucht regens

Deze deeltjes zijn te meten met deeltjesdetectoren:

- Scintillator detectoren
- Fluorescentie detectoren
- Cerenkov straling

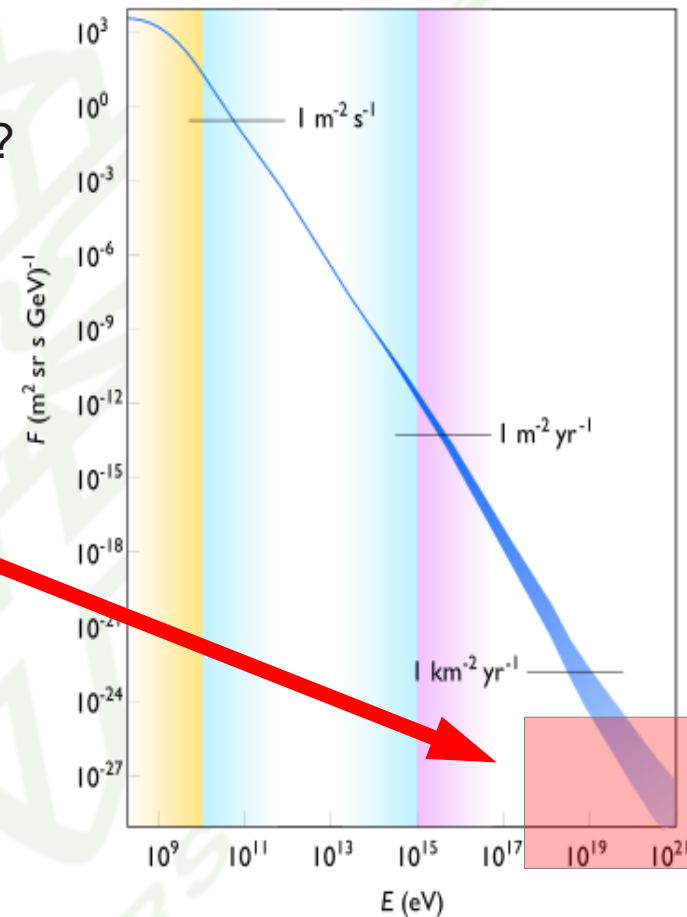


I: Kosmische Straling: Open vragen

- Wat is de hoogst-energetische kosmische straling?
- Waar komen deze hoogst-energetische straling vandaan in het Heelal?
- Hoe krijgen deze deeltjes hun energie?
- Wat kunnen we hier over leren voor de hoge-energiefysica?

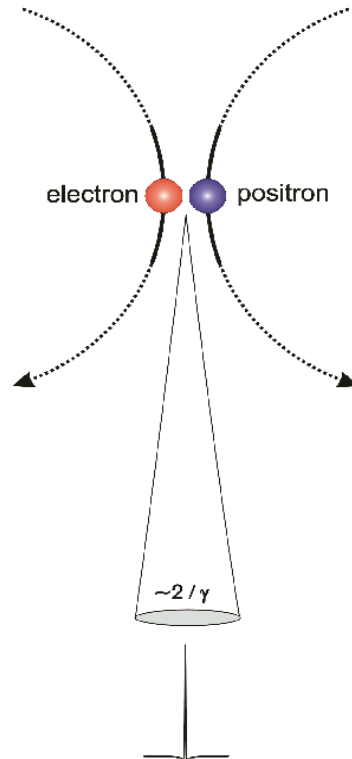
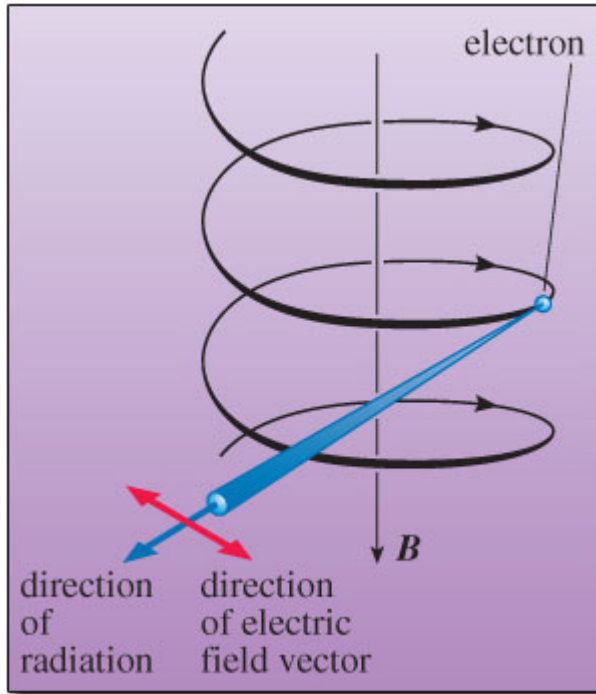
Groot probleem: ze zijn zo zeldzaam!
1 deeltje per km² per eeuw!

Grote detector nodig, of...



I: Kosmische Straling: Radio straling

- Kosmische straling zijn *geladen* deeltjes in onze atmosfeer: Aards magnetisch veld



Al in 1960s bedacht, maar niet mogelijk om te meten: duur van puls is 10 nanoseconden
Eerste meting: 1966, geboortjaar van Heino Falcke...

I: Kosmische Straling: LOFAR

- Meting nu wel mogelijk met LOFAR!



I: Kosmische Strahlung: LOPES prototype

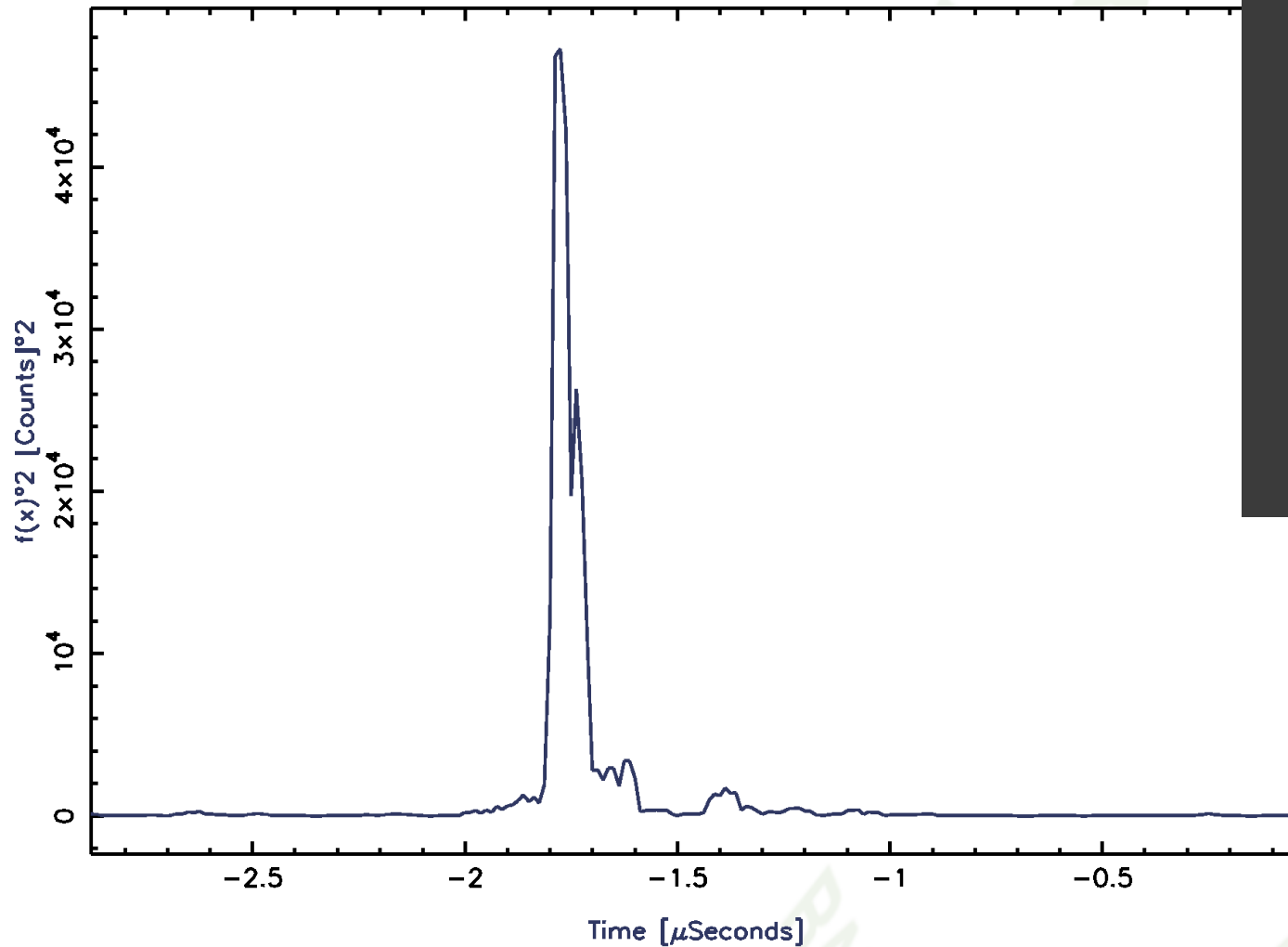
- Prototype: LOPES



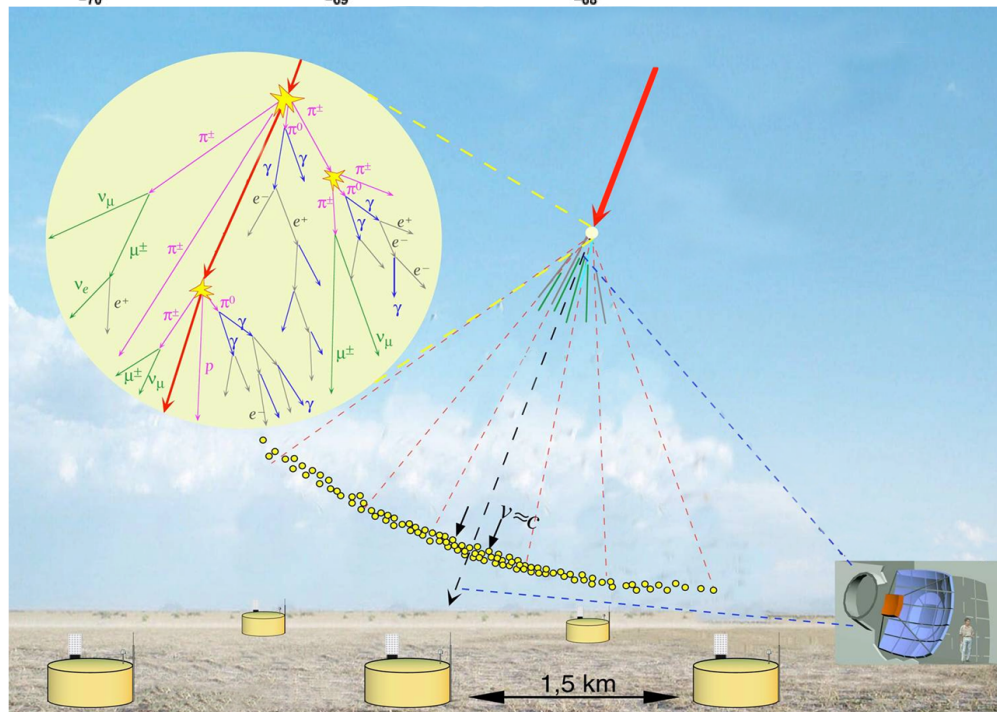
I: Kosmische Strahlung: LOPES prototype

- Prototype: LOPES

[1] Event1073867291-10101



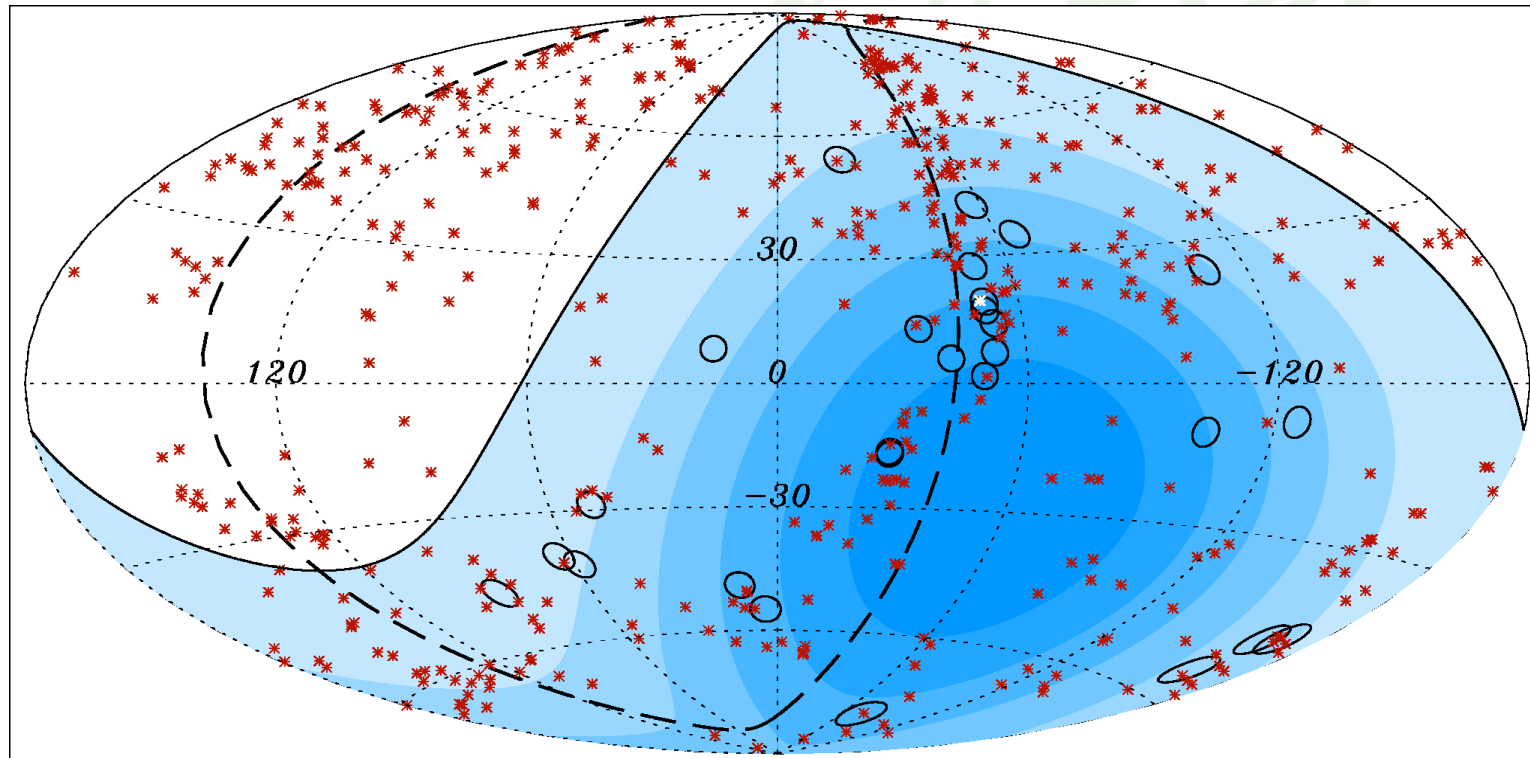
I: Kosmische Straling: Auger uitbreiding: Aera



I: Kosmische Straling: Auger uitbreiding:

Hybride metingen:

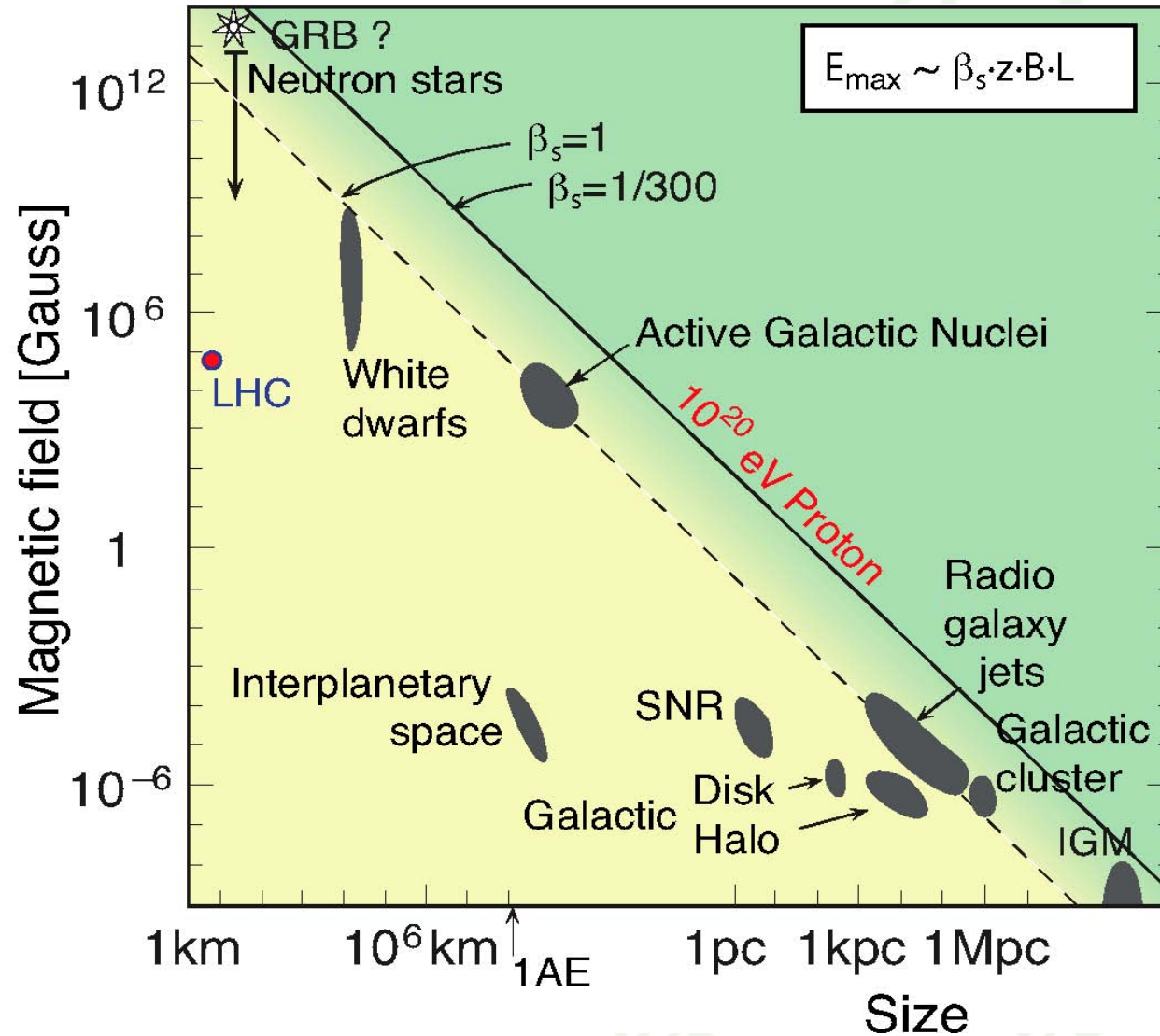
- Fluorescentie: deeltjes track, energie en richting
- Scintillatie: samenstelling, richting
- Radio: richting, totale energie, samenstelling



Cirkels: aankomstrichting kosmische straling met $E > 10^{19}$ eV energie

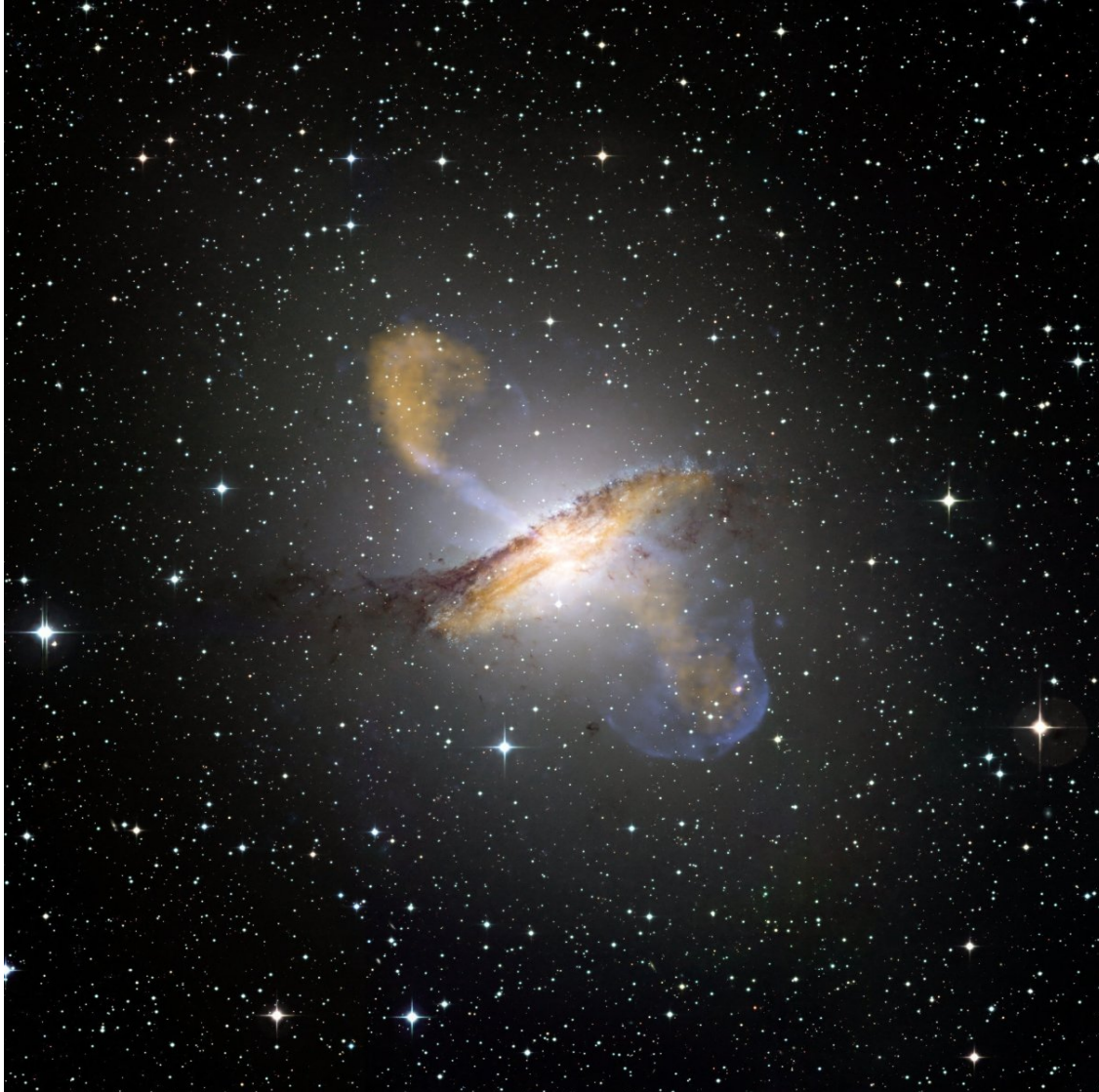
I: Kosmische Straling: Oorsprong?

Waar komen ze vandaan? Hoe komen ze aan hun energie?



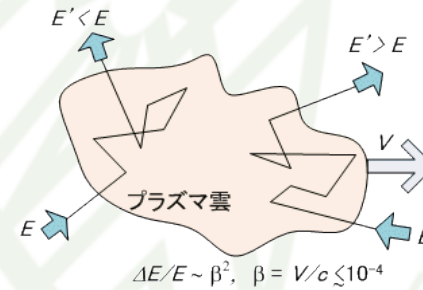
I: Kosmische Straling: Oorsprong?

Waar komen ze vandaan? Hoe komen ze aan hun energie?

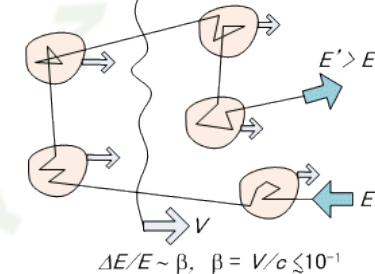


Centaurus A,
Reuzenelliptisch stelsel op
13 miljoen lichtjaar afstand

フェルミの二次加速

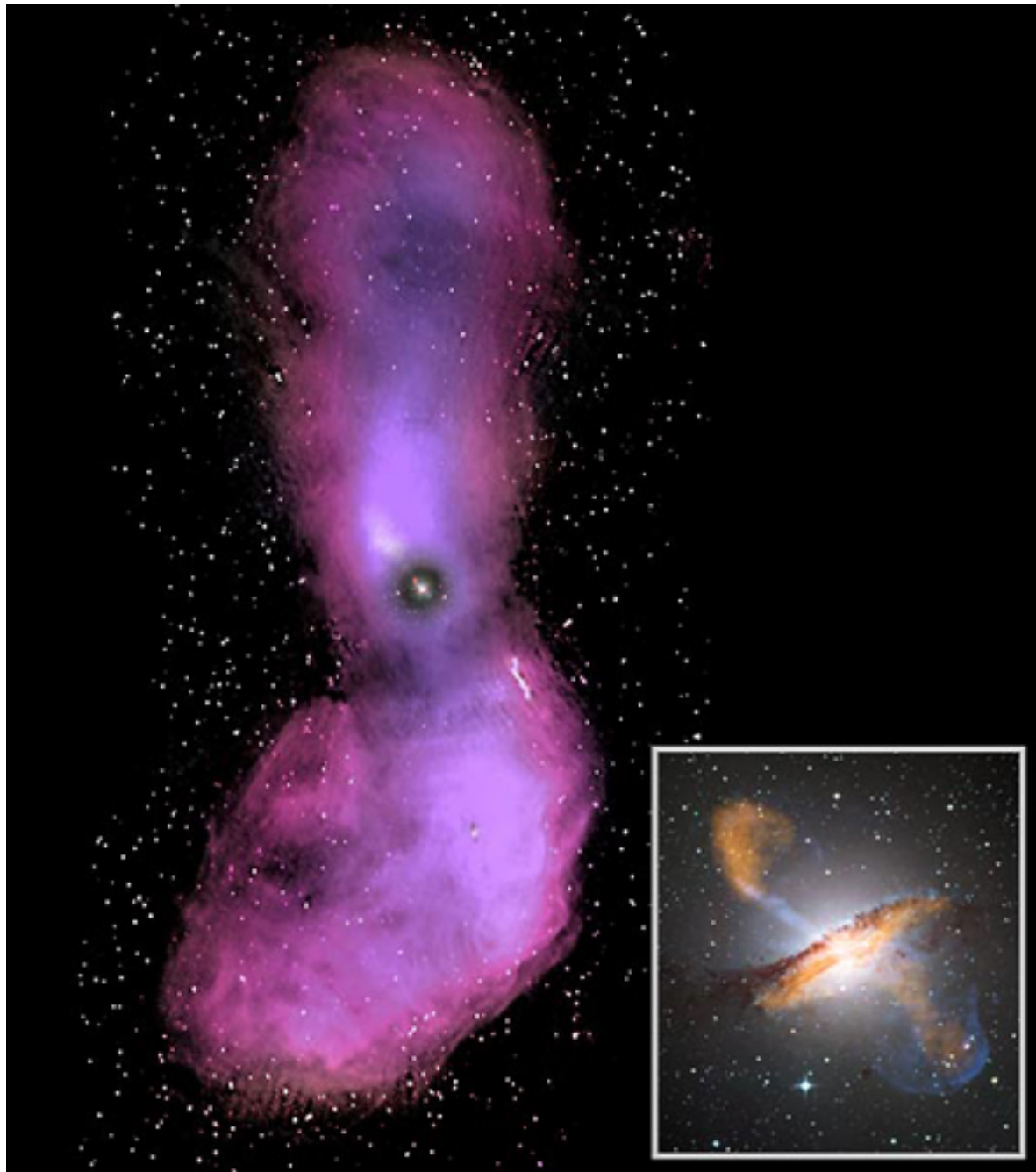


フェルミの一次加速
衝撃波面



Fermi versnelling in schokken

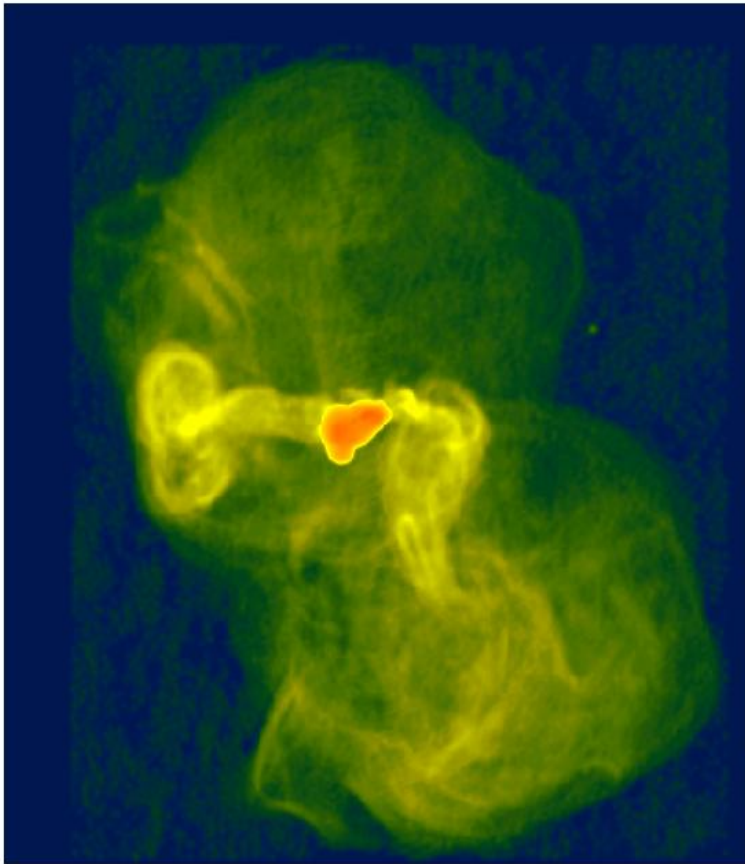
I: Kosmische Straling: Radio Jets in Cen A



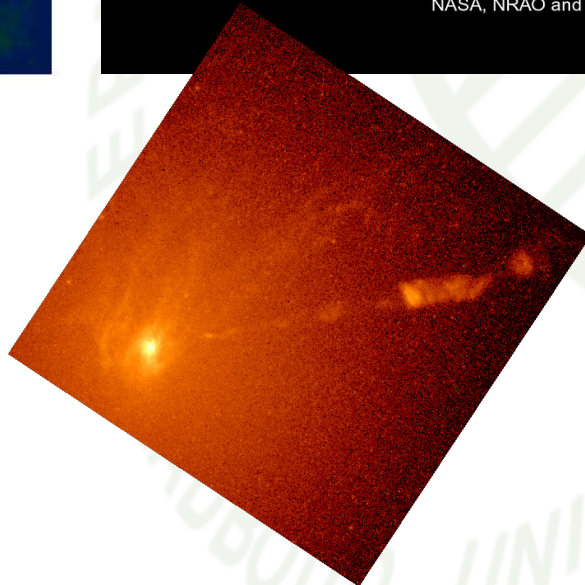
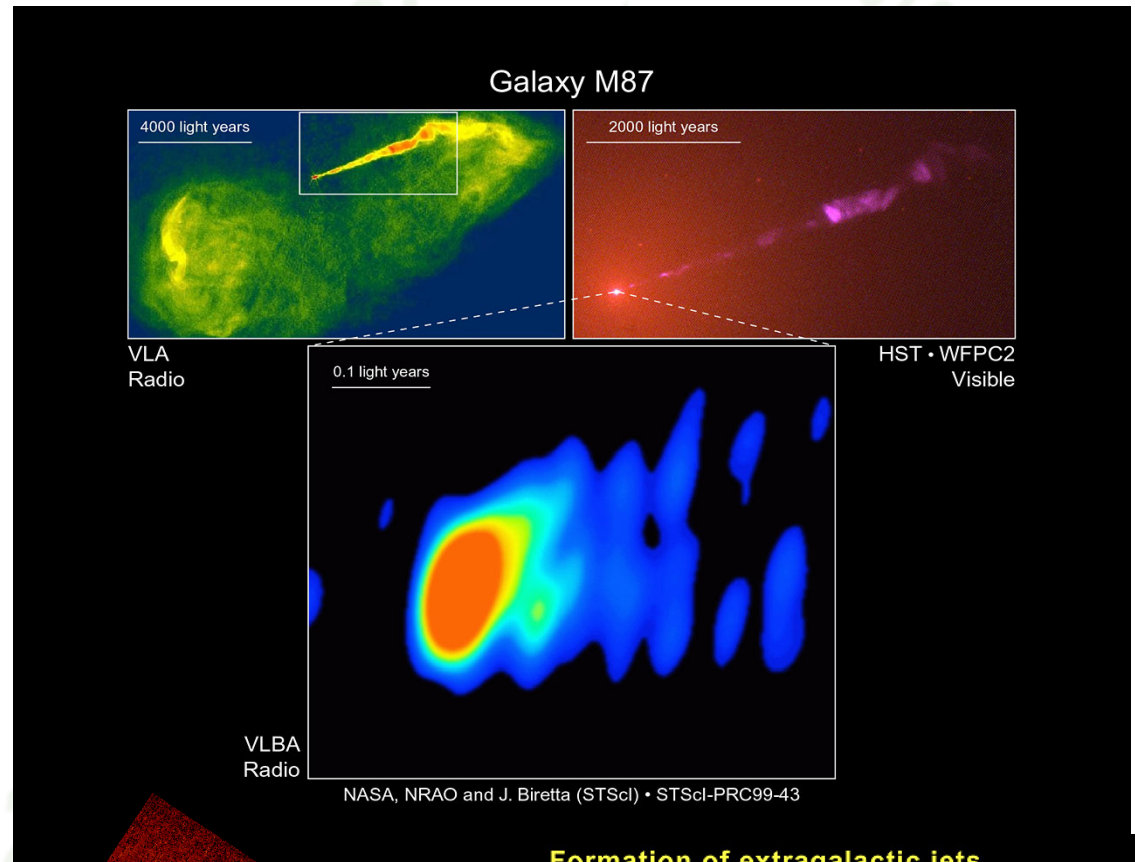
1 miljoen lichtjaar...

Waar komen die jets vandaan?

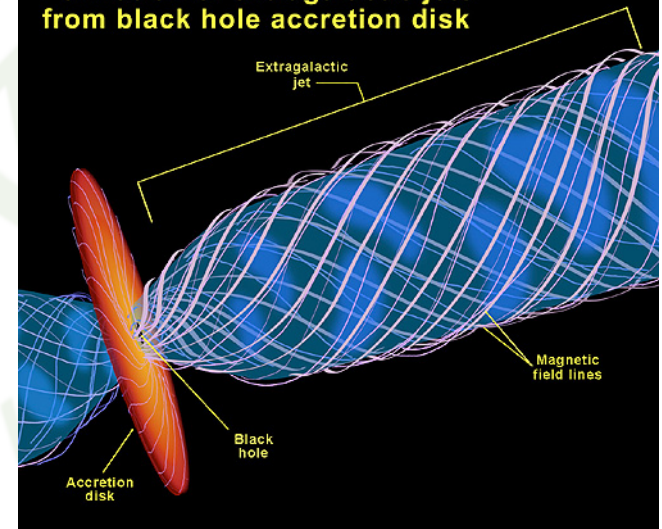
I: Kosmische Straling: Radio Jets in M87



Radio Jet uit exacte centrum van sterrenstelsel

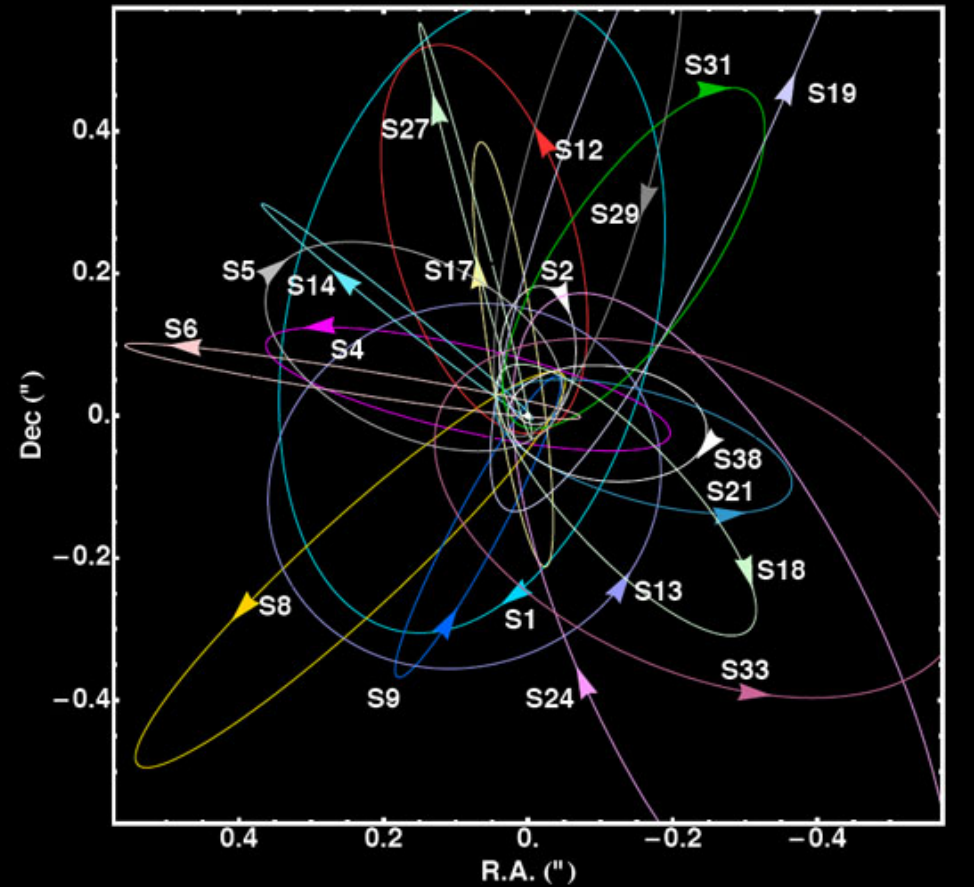


Formation of extragalactic jets from black hole accretion disk





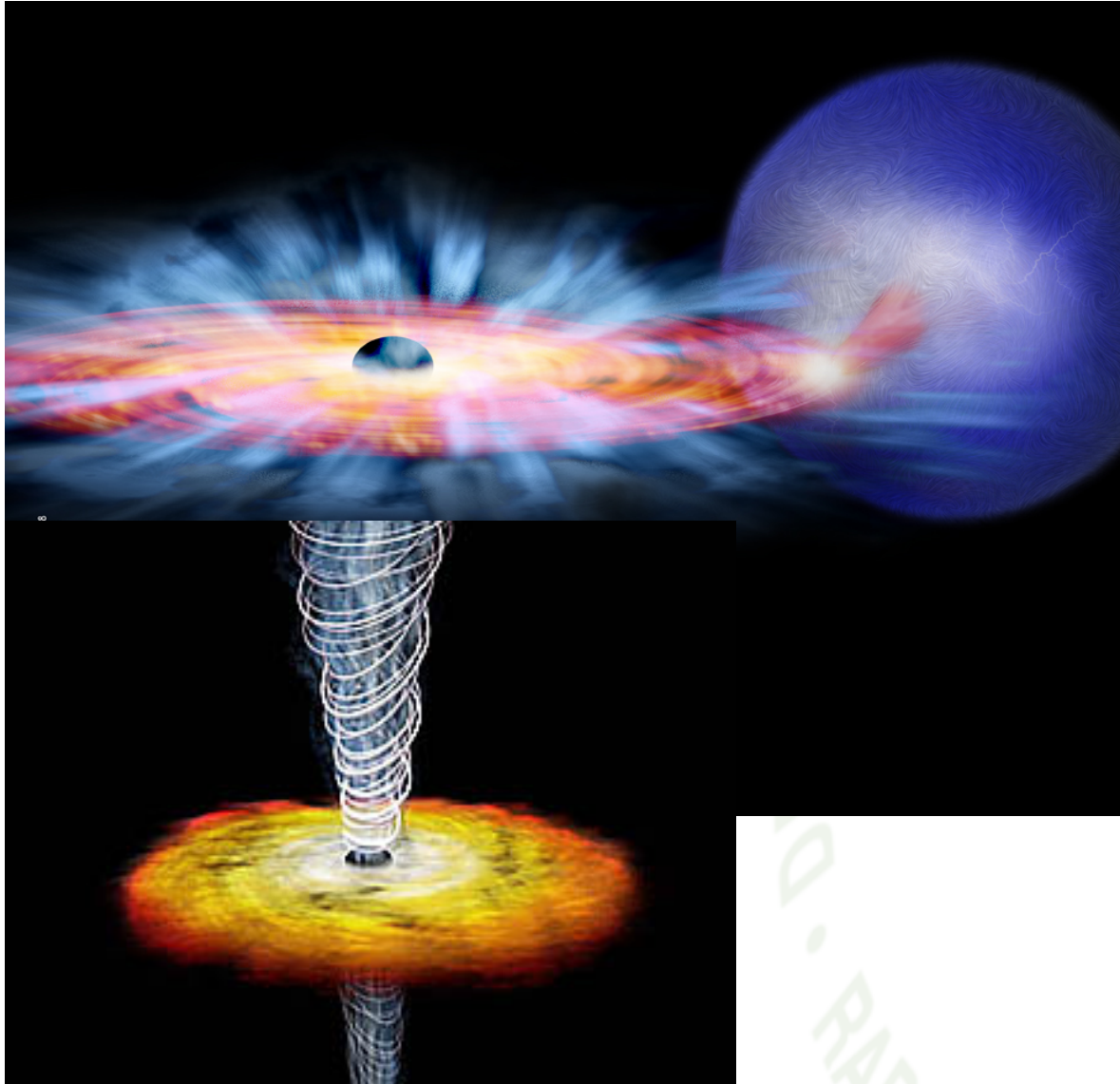
I: Kosmische Straling: Galactisch Centrum



Uit bewegingen:
Zwart Gat met $M > 4$ miljoen Zonsmassa's

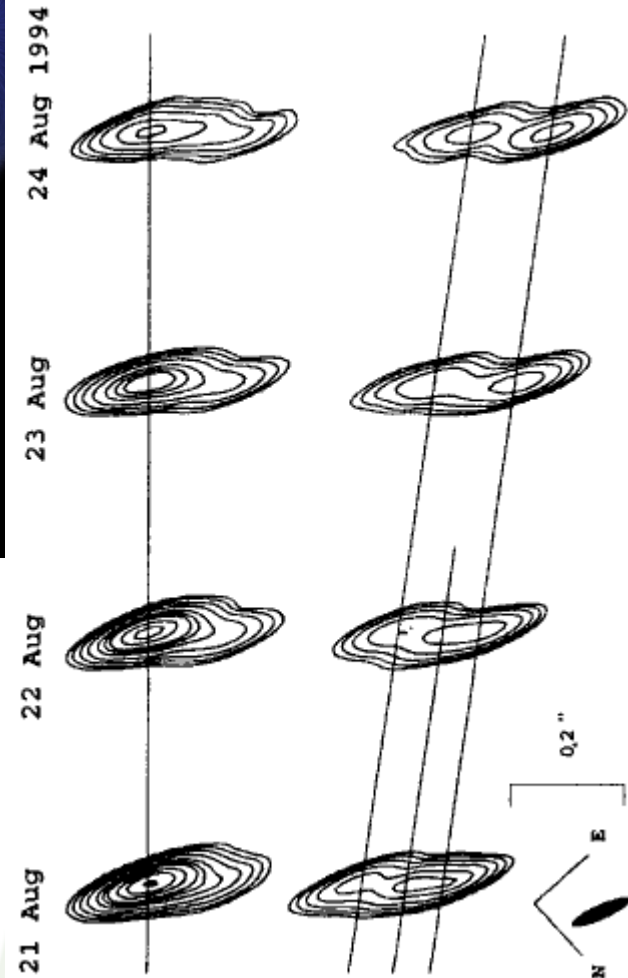
II: Ultracompacte dubbelsterren

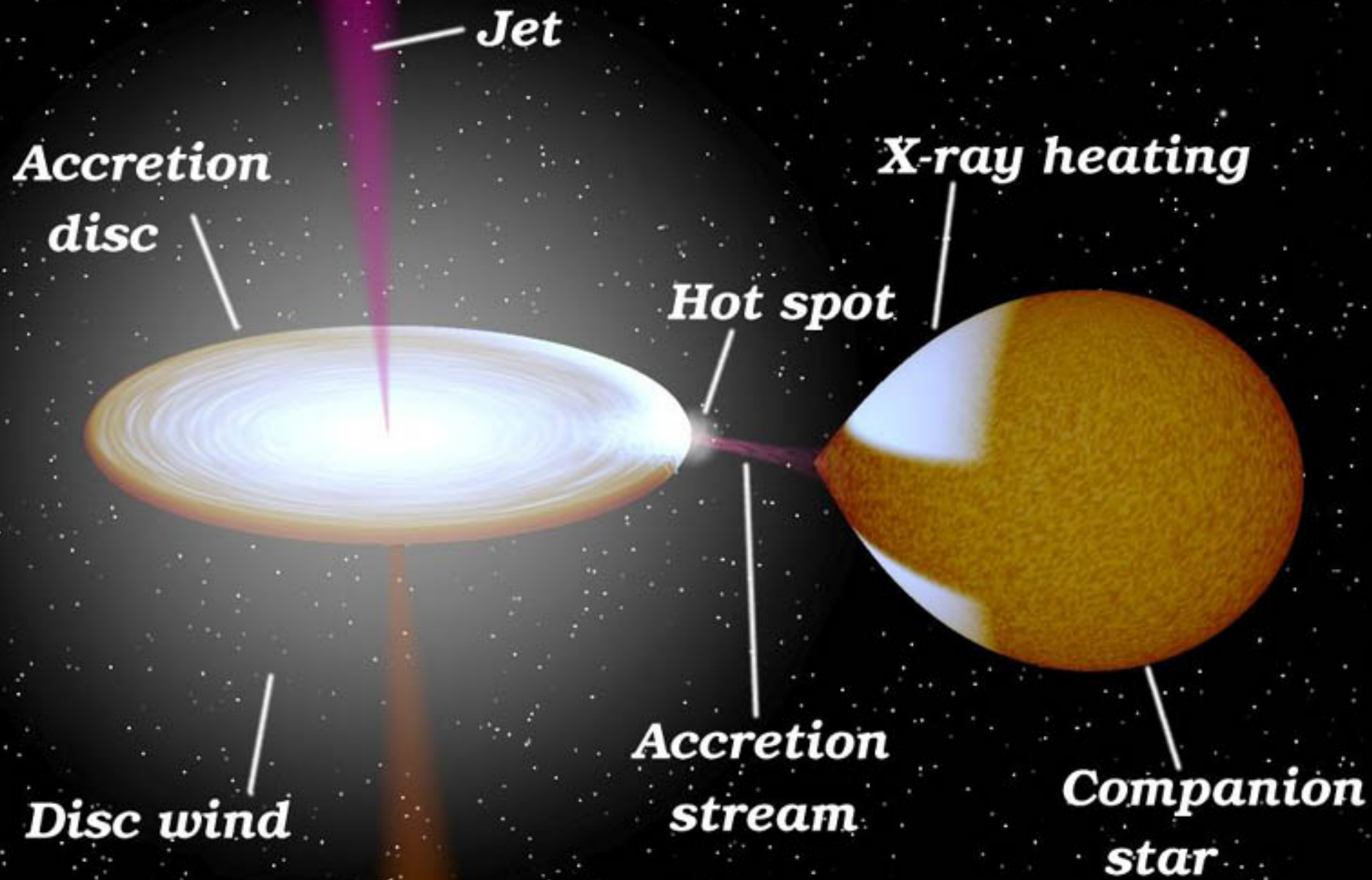
Zwarte Gaten in alle soorten en maten: ook 'stellaire' zwarte gaten



En vertonen ook jets!

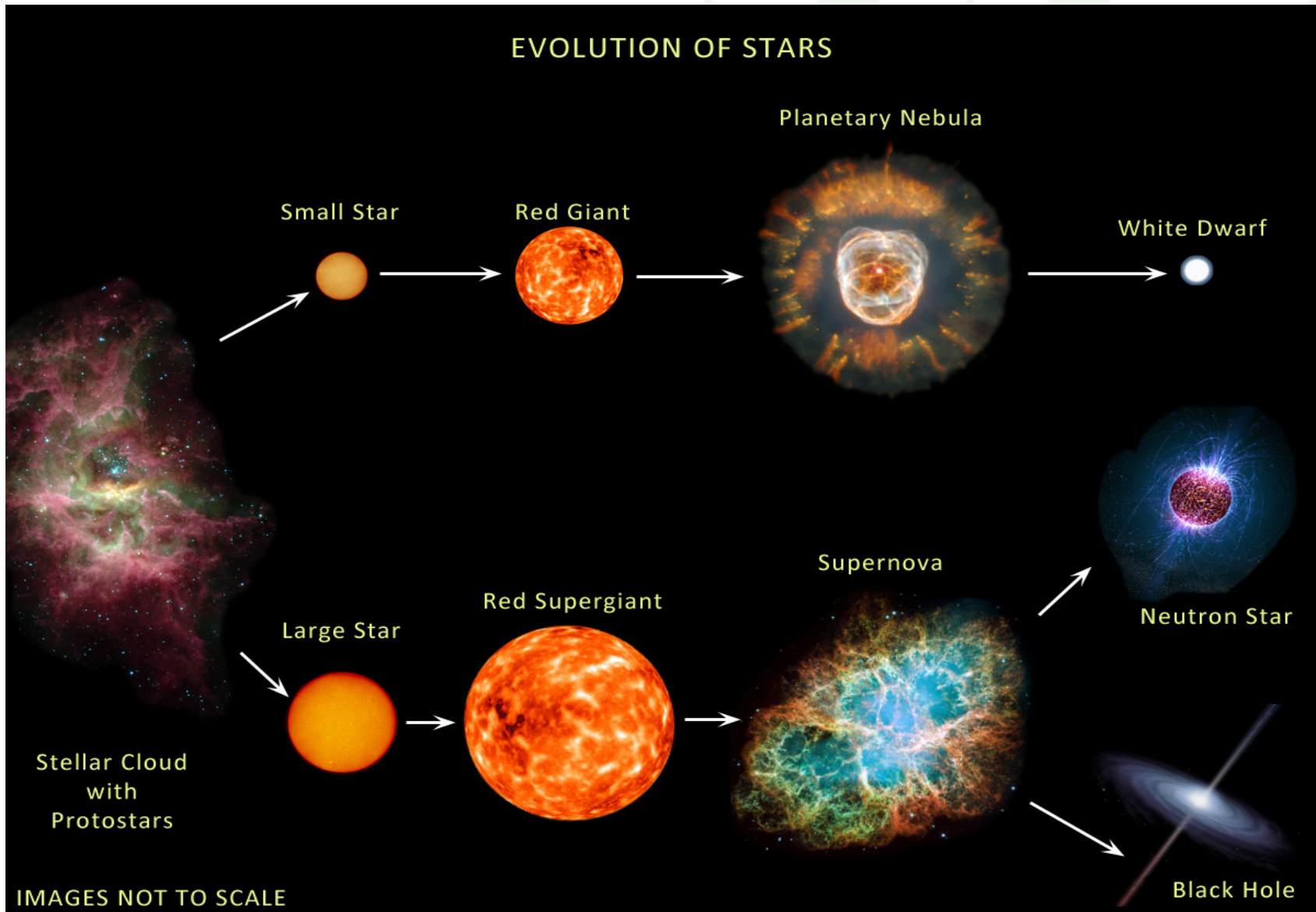
Blijkbaar: versnellingsfysica hetzelfde, ondanks miljoen keer lagere massa...





II: Ultracompacte dubbelsterren

- Hoe ontstaan deze dubbelsterren?
- Hoe lanceren ze (radio)jet, en X-ray straling in centrum
- Wat drijft evolutie? Zwaartekrachtstraling!

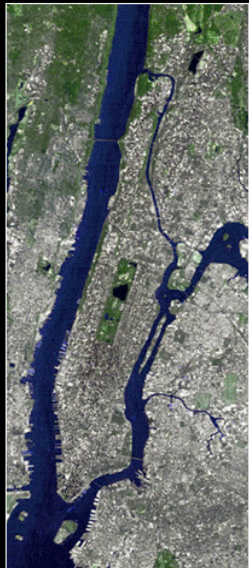
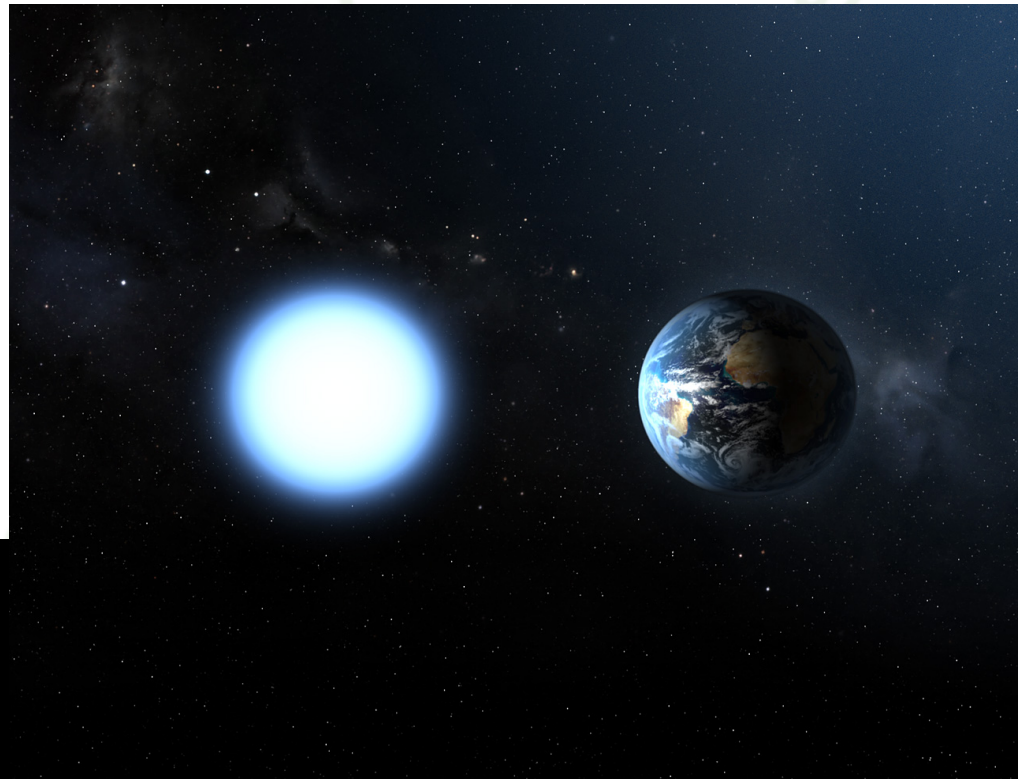


II: Ultracompacte dubbelsterren

WD: $M \sim 0.6M_{\text{Sun}}$, $R \sim R_{\text{earth}}$

NS: $M \sim 1.4M_{\text{Sun}}$, $R \sim 10 \text{ km}$

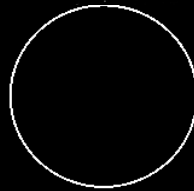
BH: $M > 3M_{\text{Sun}}$, $R_{\text{S}} \sim 10 \text{ km}$



Manhattan
(spaceimaging.com)



Neutron Star
 $M = 1.5 M_{\text{Sun}}$
 $R \approx 10 \text{ km}$

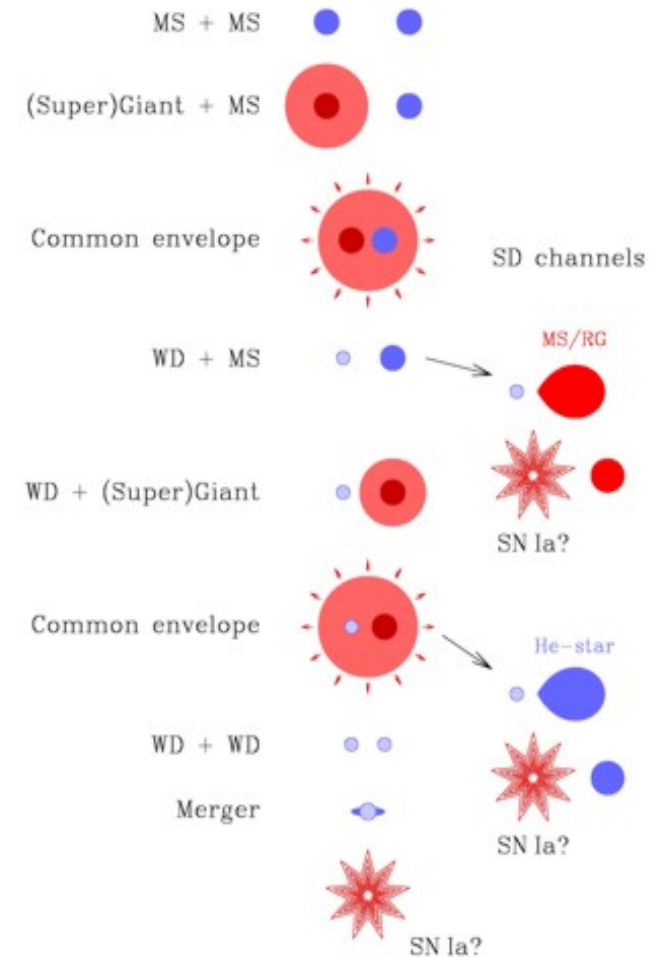
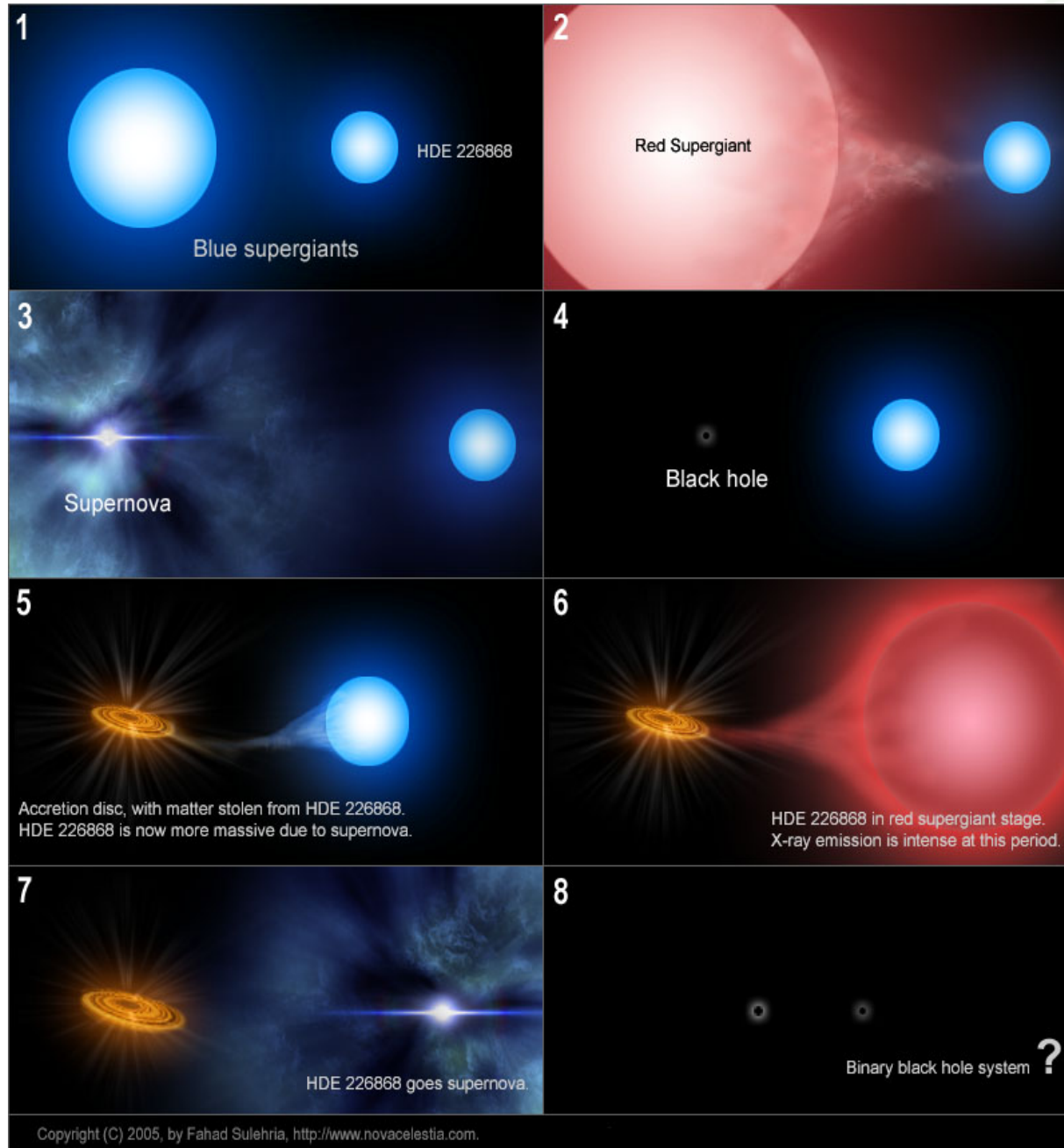


Black Hole
 $M = 1.5 M_{\text{Sun}}$
 $R_{\text{S}} = 4.5 \text{ km}$

Deze *compacte* objecten bestaan uit gedegenerende materie.

Materie zit zo dicht op elkaar dat er druk ontstaat door uitsluitingsprincipe

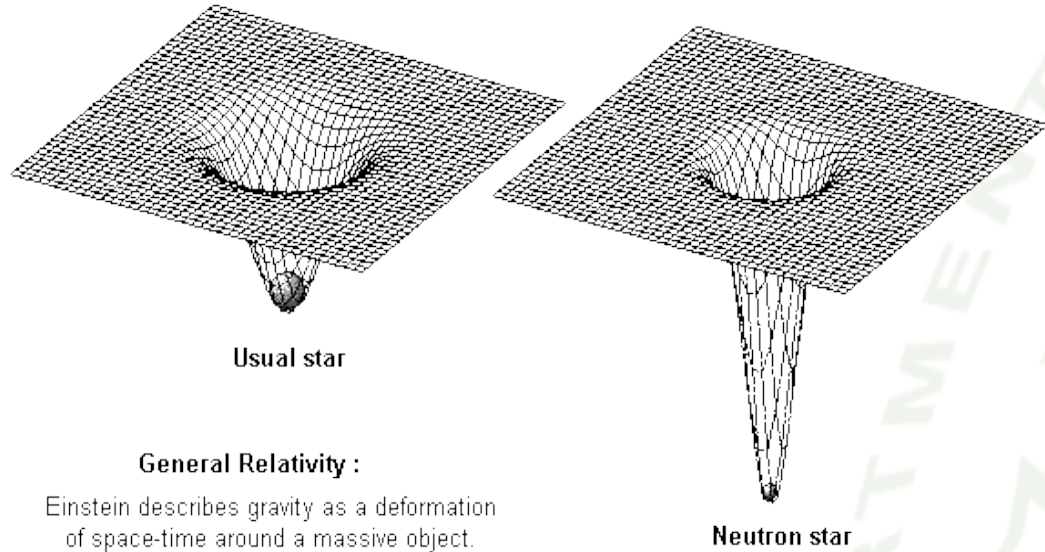
II: Ultracompacte dubbelsterren



Overblijfsel van (uitgebrande)sterren:
zwart gat, neutronenster of witte dwerg

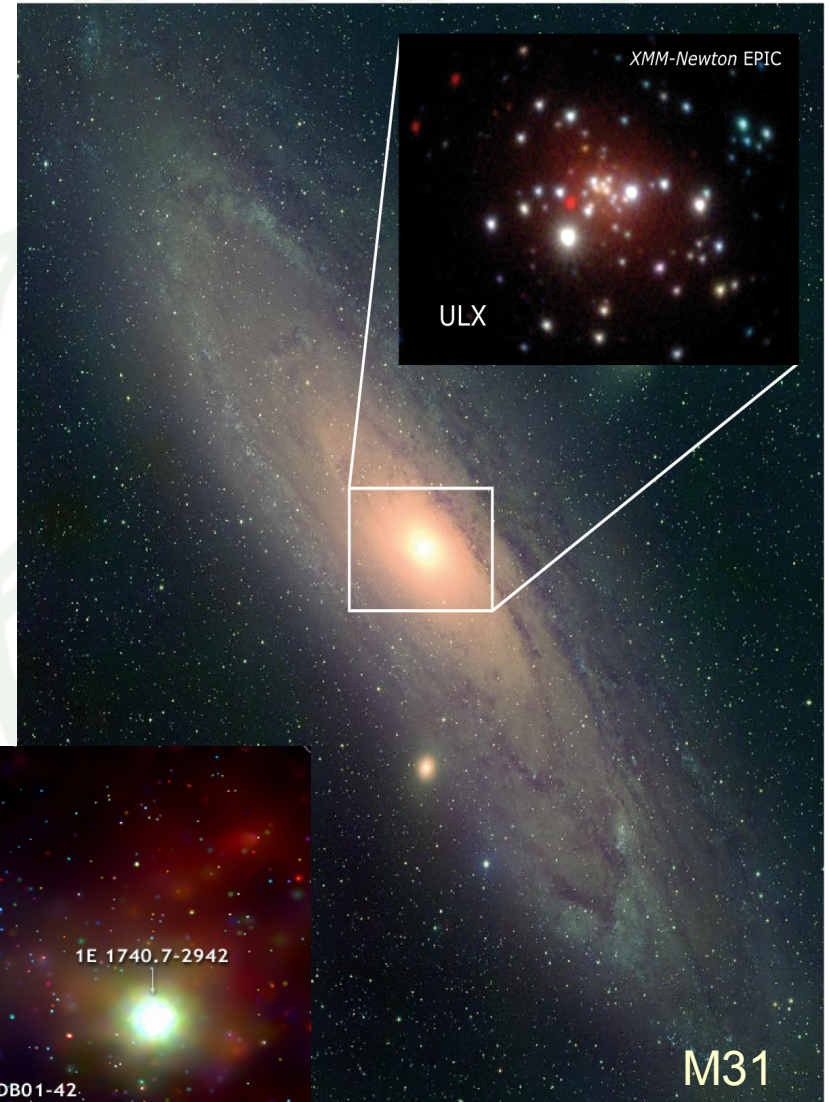
II: Ultracompacte dubbelsterren

Overstroom materie naar compact object: hoge energieën!



numiano

Röntgenstraling, γ -straling en explosies



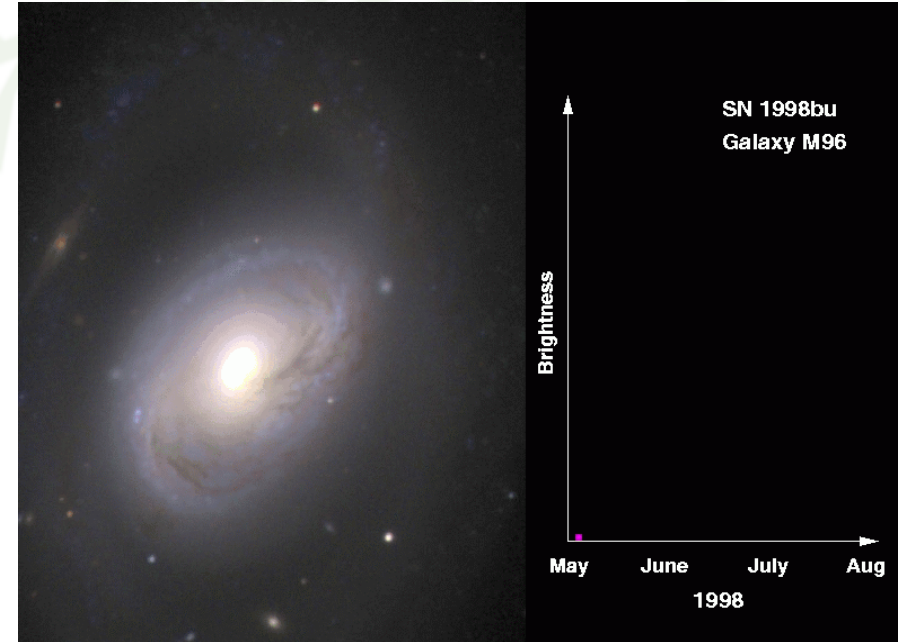
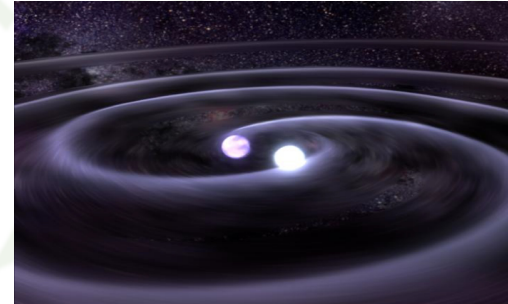
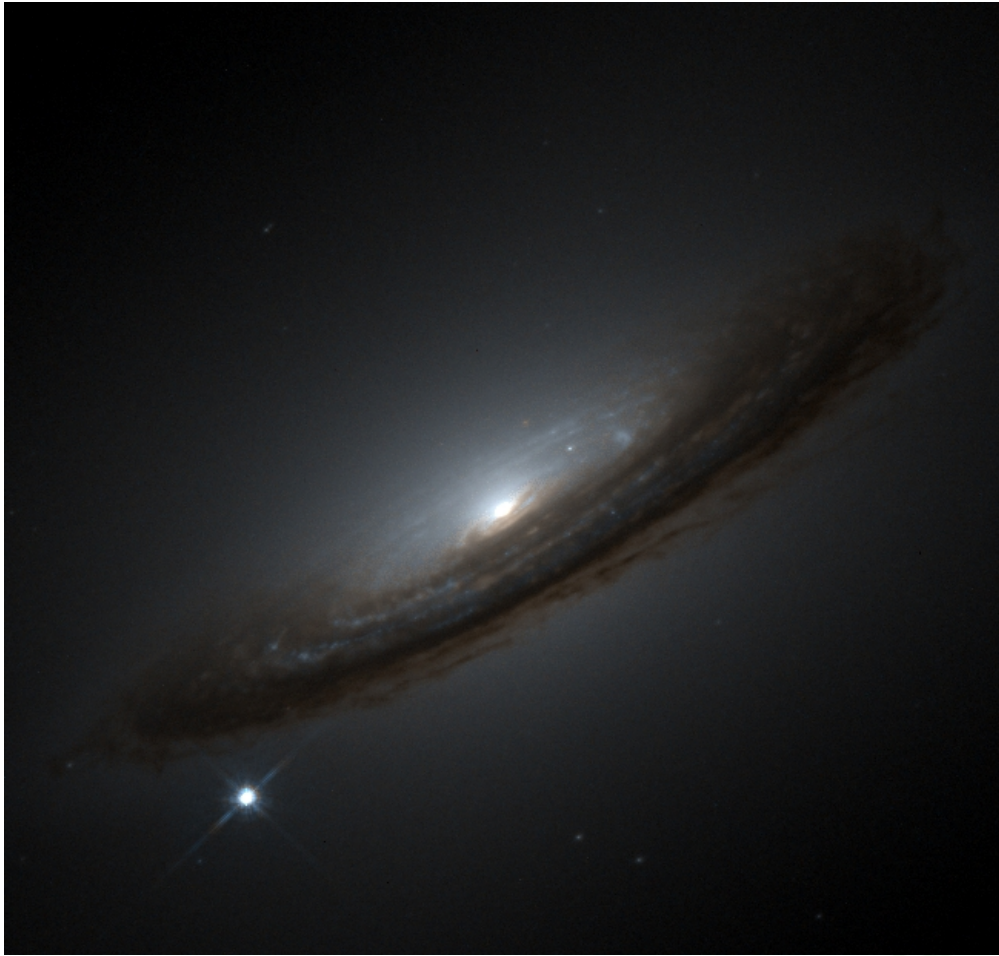
II: Ultracompacte dubbelsterren

Witte dwergen hebben maximum massa: $1.4 M_{\text{sun}}$

Als nabij maximum massa, door accretie, koolstof fuseert : explosie
Supernova Type Ia

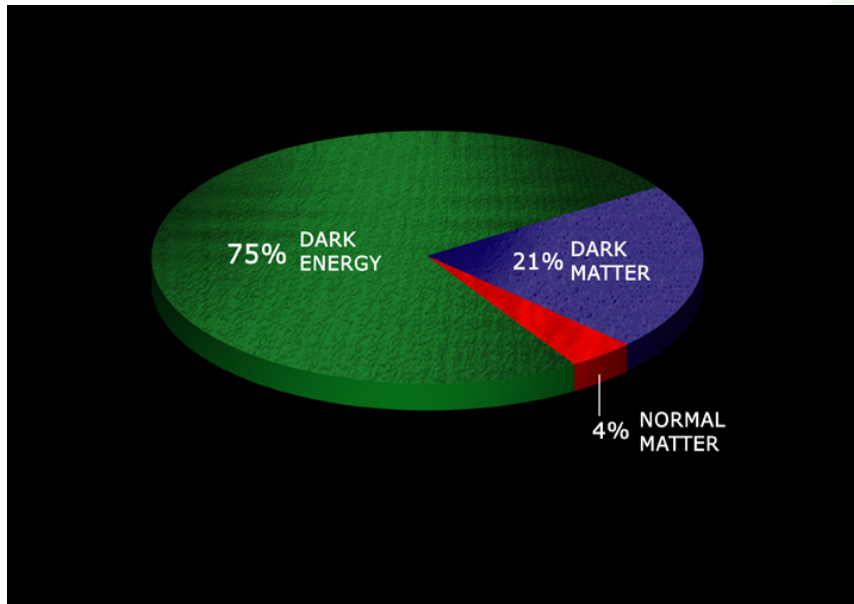
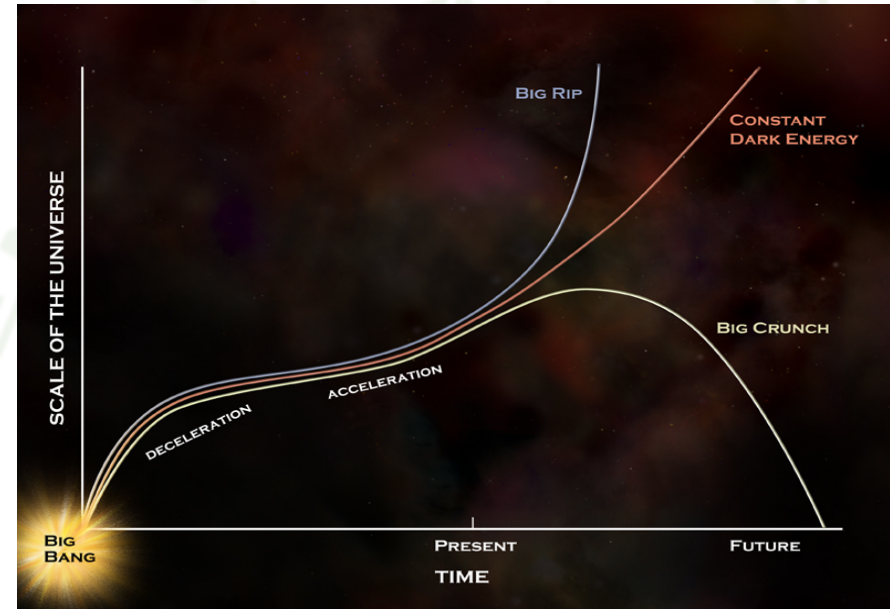
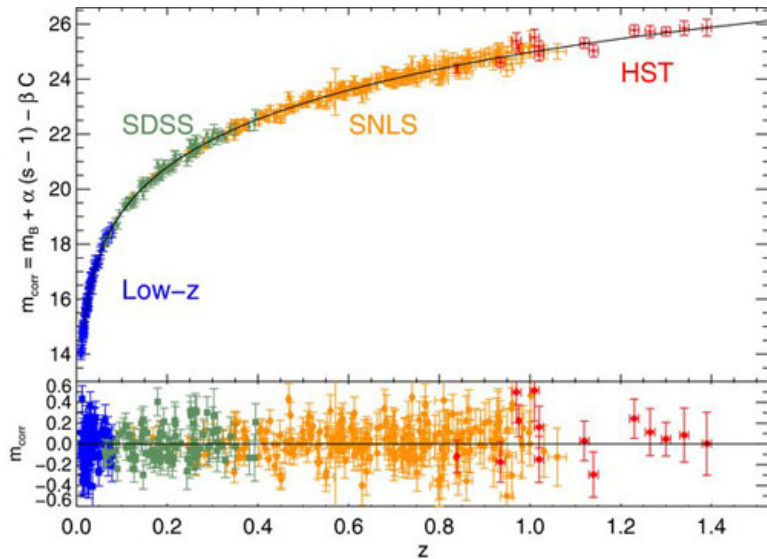


Chandrasekhar



II: Ultracompacte dubbelsterren

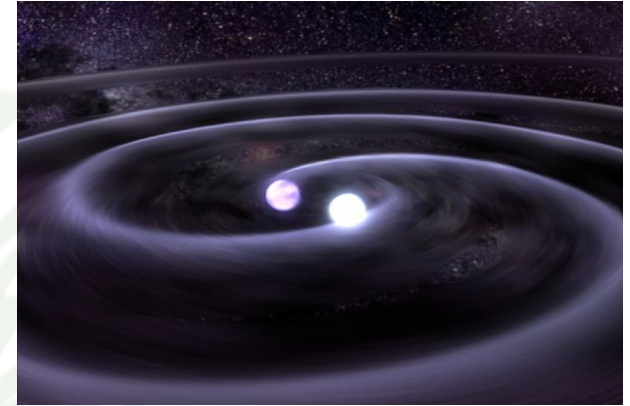
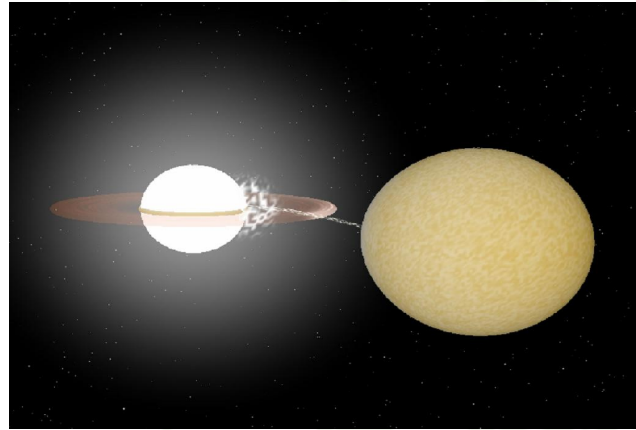
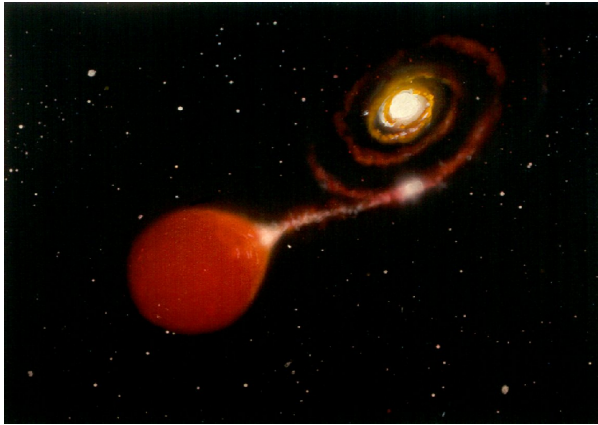
Supernovae Type Ia zijn standaard kaarsen: kilometerpaaltjes voor uitdijend Heelal



We leven in een versneld uitdijend Heelal, en 75% van heelal bestaat uit 'donkere energie' die expansie drijft.

II: Ultracompacte dubbelsterren

Maar hoe ontploft een supernova Type Ia nu precies? We weten het niet...



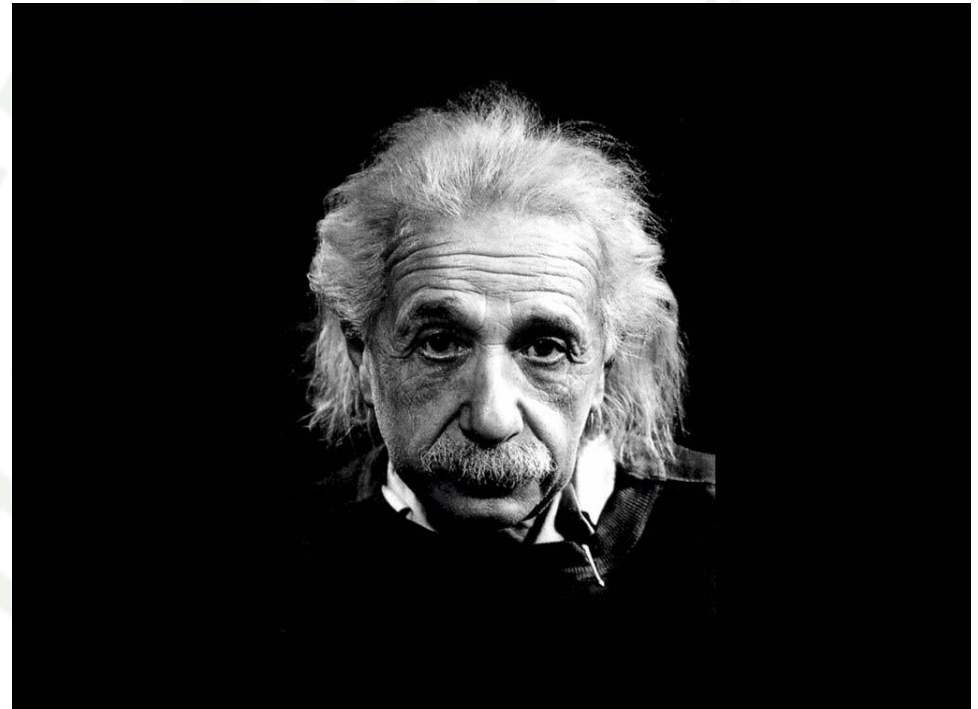
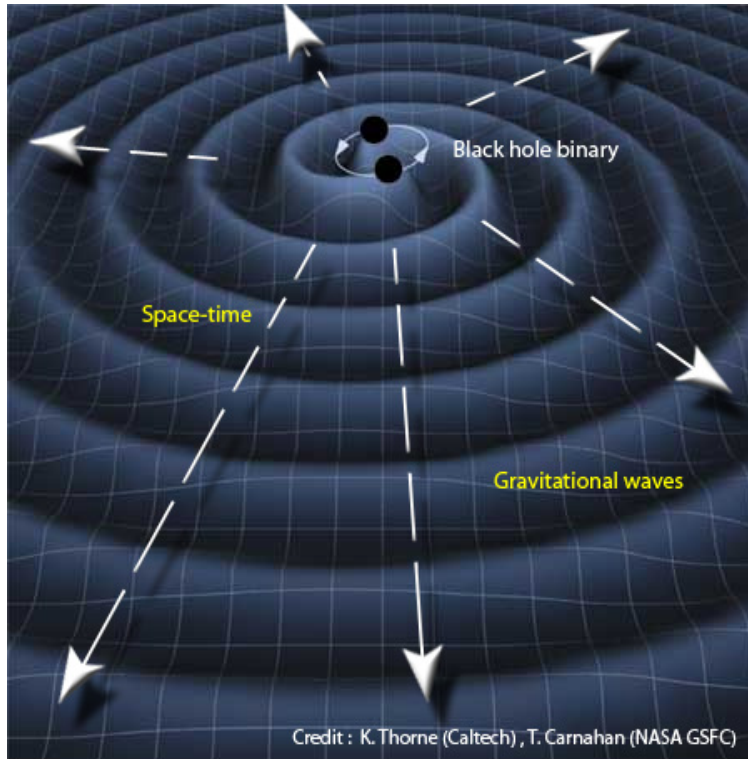
Hoe komen we hier achter?

- Voorlopers zien we alleen in Melkwegstelsel,
- Ontploffingen alleen in andere sterrenstelsels.

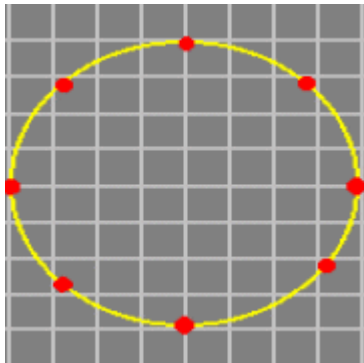
Populaties!

II: Ultracompacte dubbelsterren

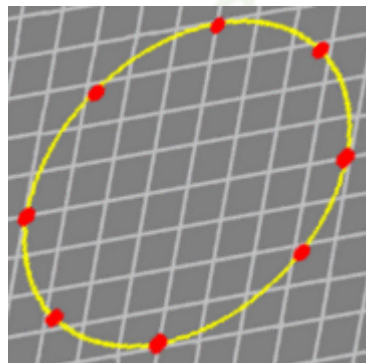
Evolutie van systemen bepaald door uitzending *zwaartekrachtstraling*!



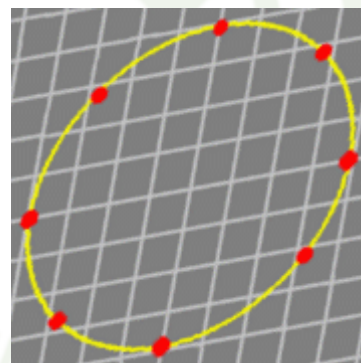
+ pol



x-pol

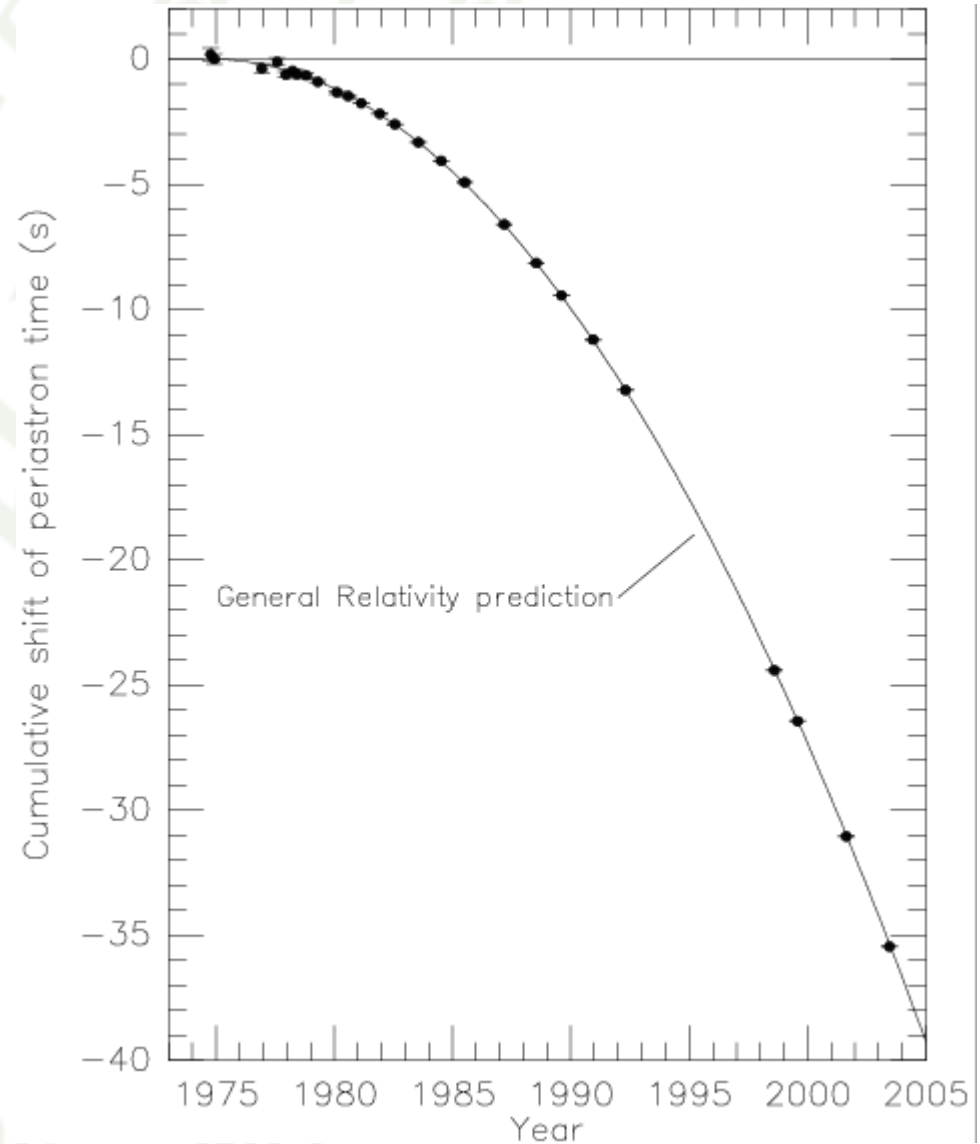
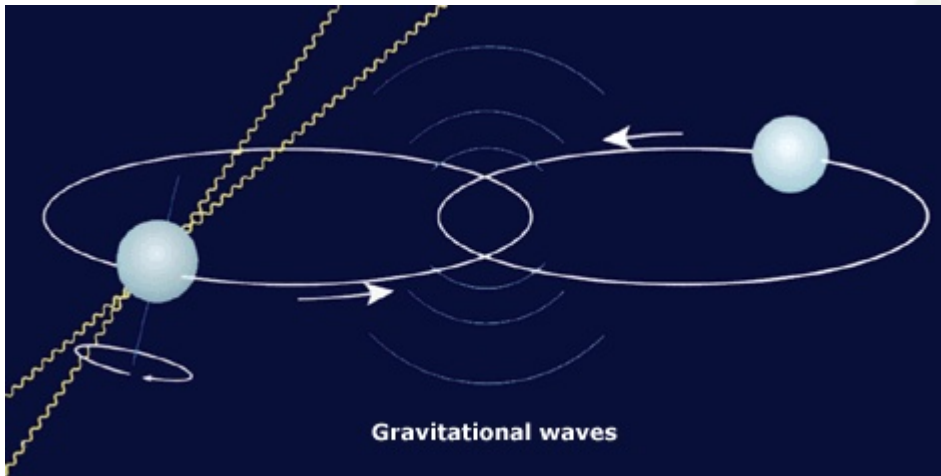


circ-pol

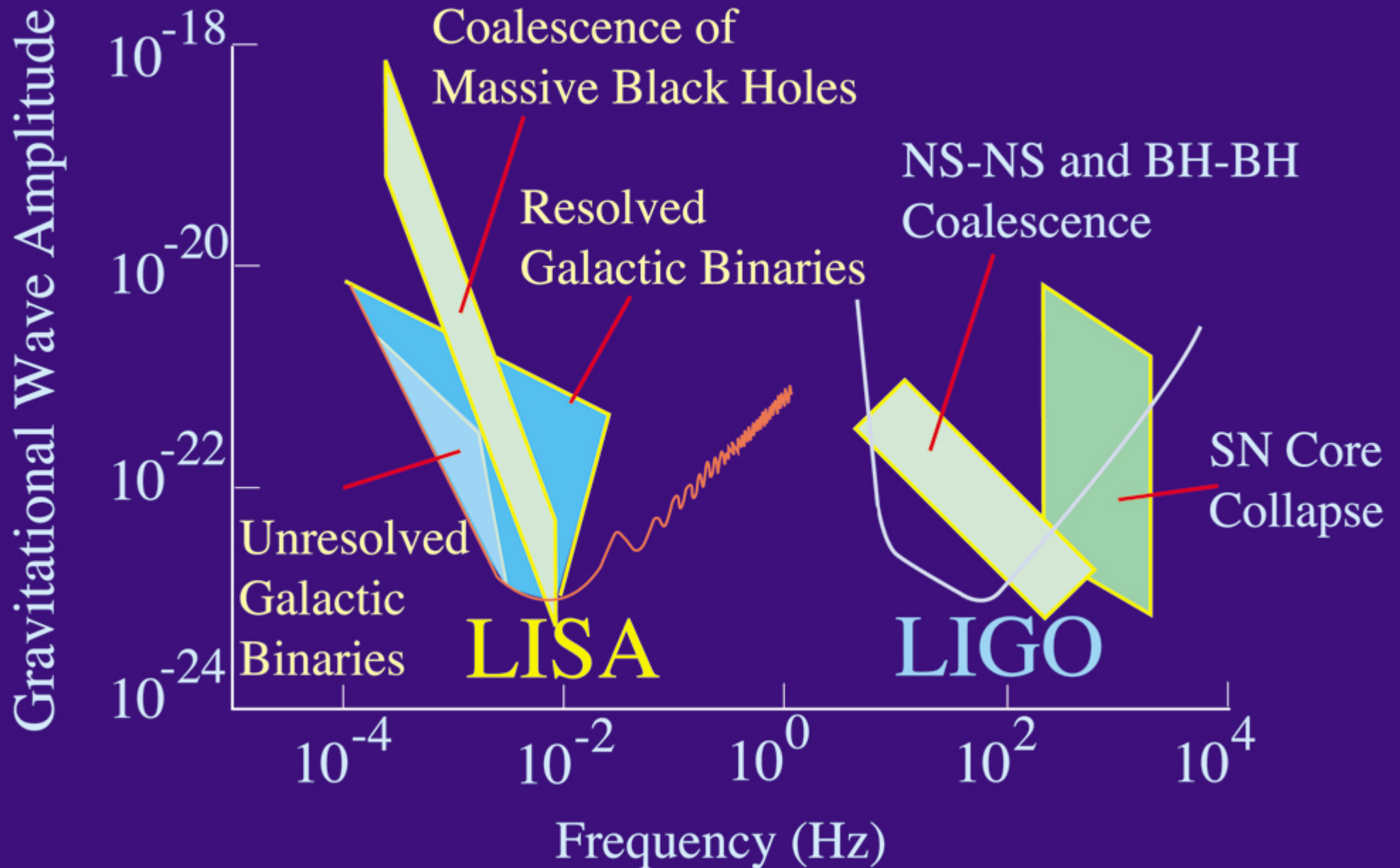


Gravitational Waves: Binary neutron star pulsar

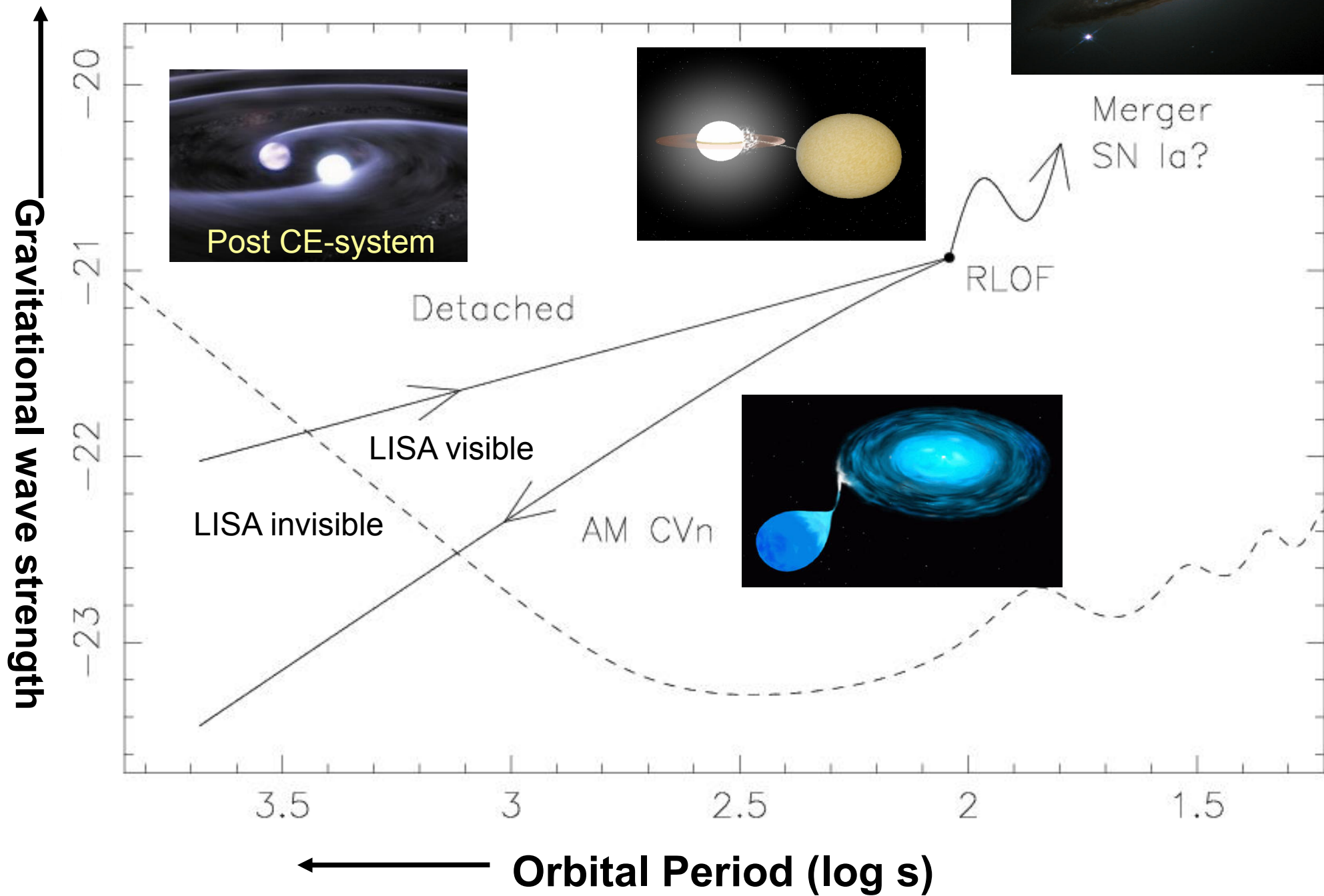
- Indirect measurements only sofar
- Spectacular: PSR1913+16



Gravitational Waves: Bronnen

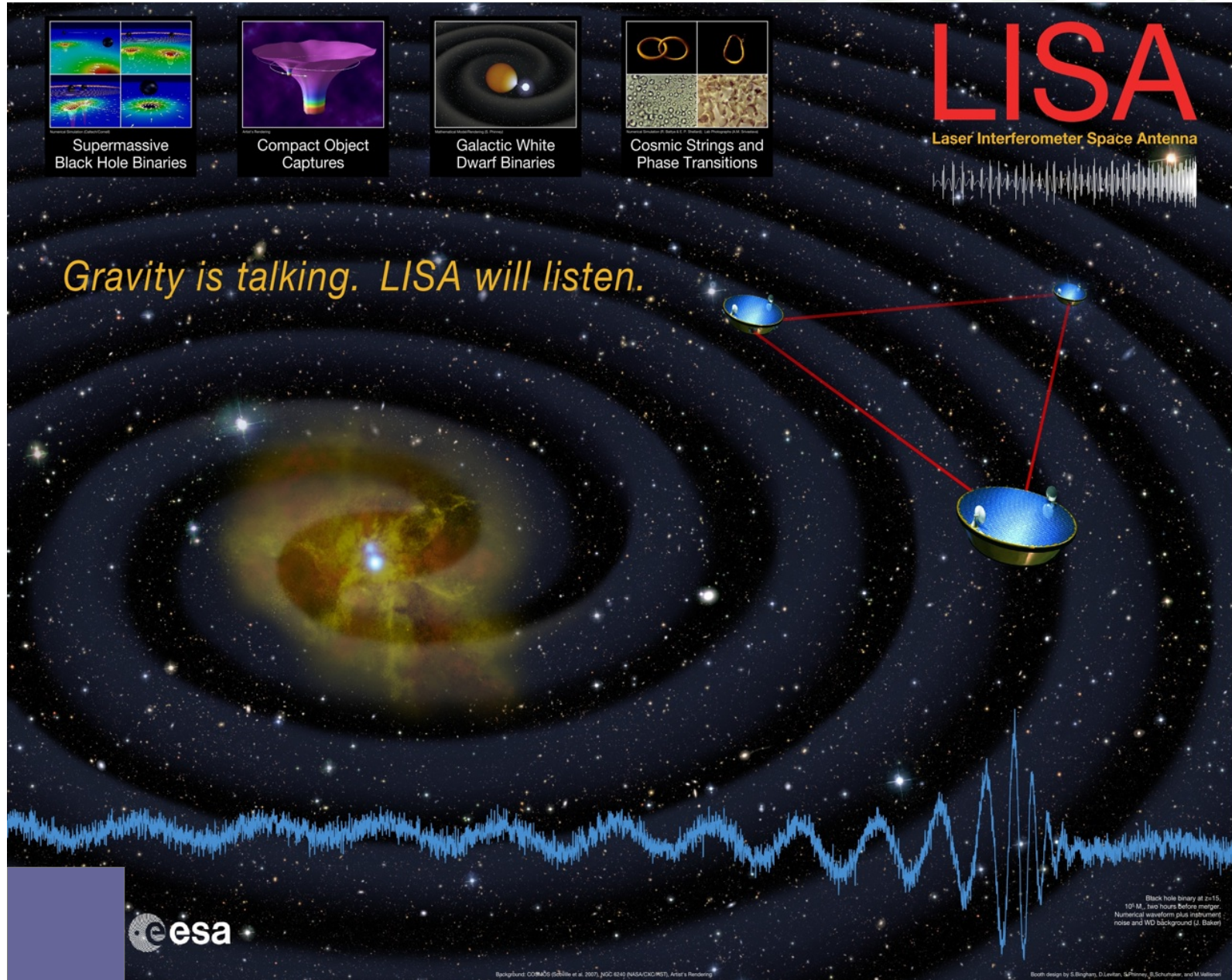


Gravitational wave evolution



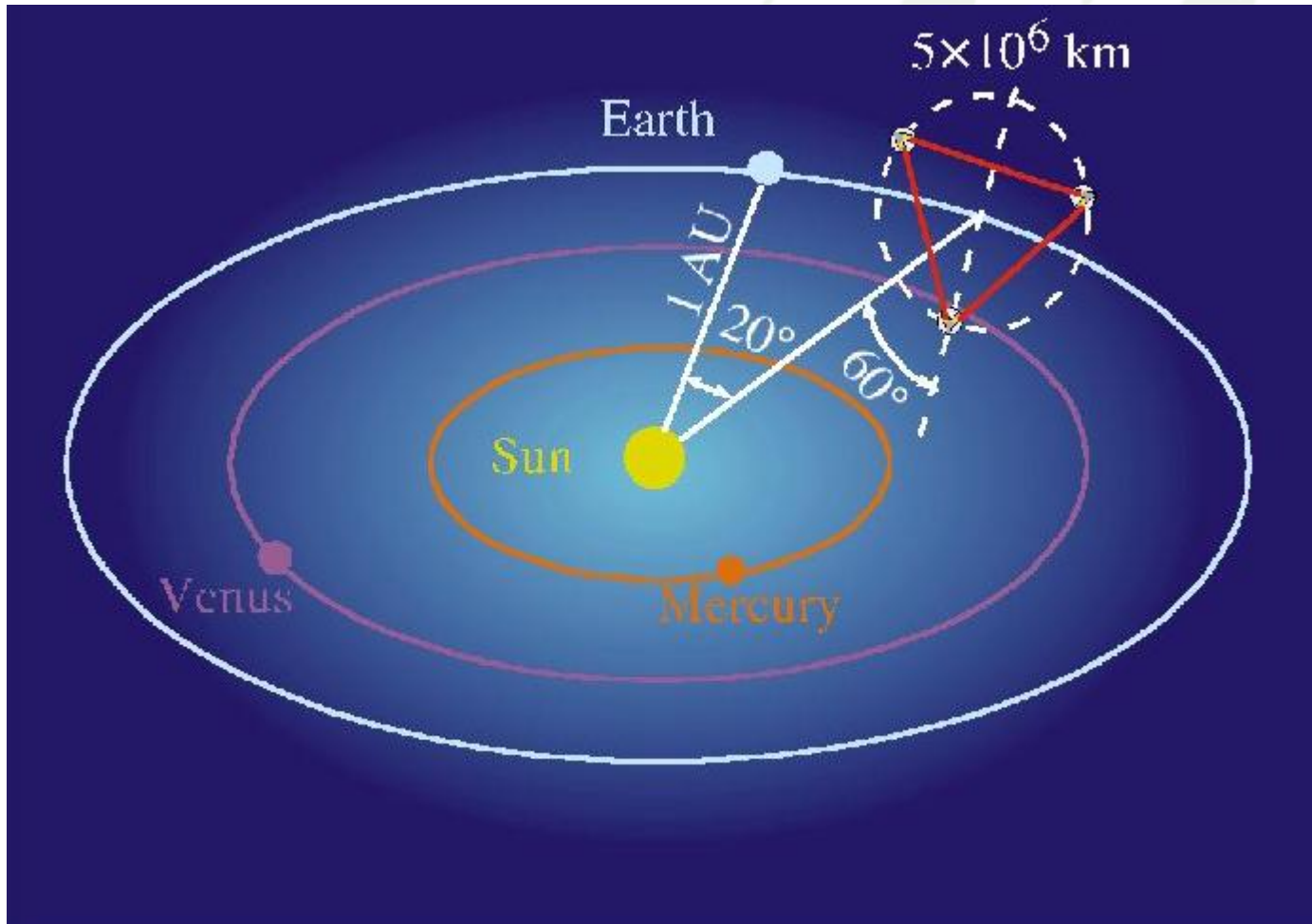
Next Generation Gravitational Wave Observatory

(voorheen LISA/eLISA)



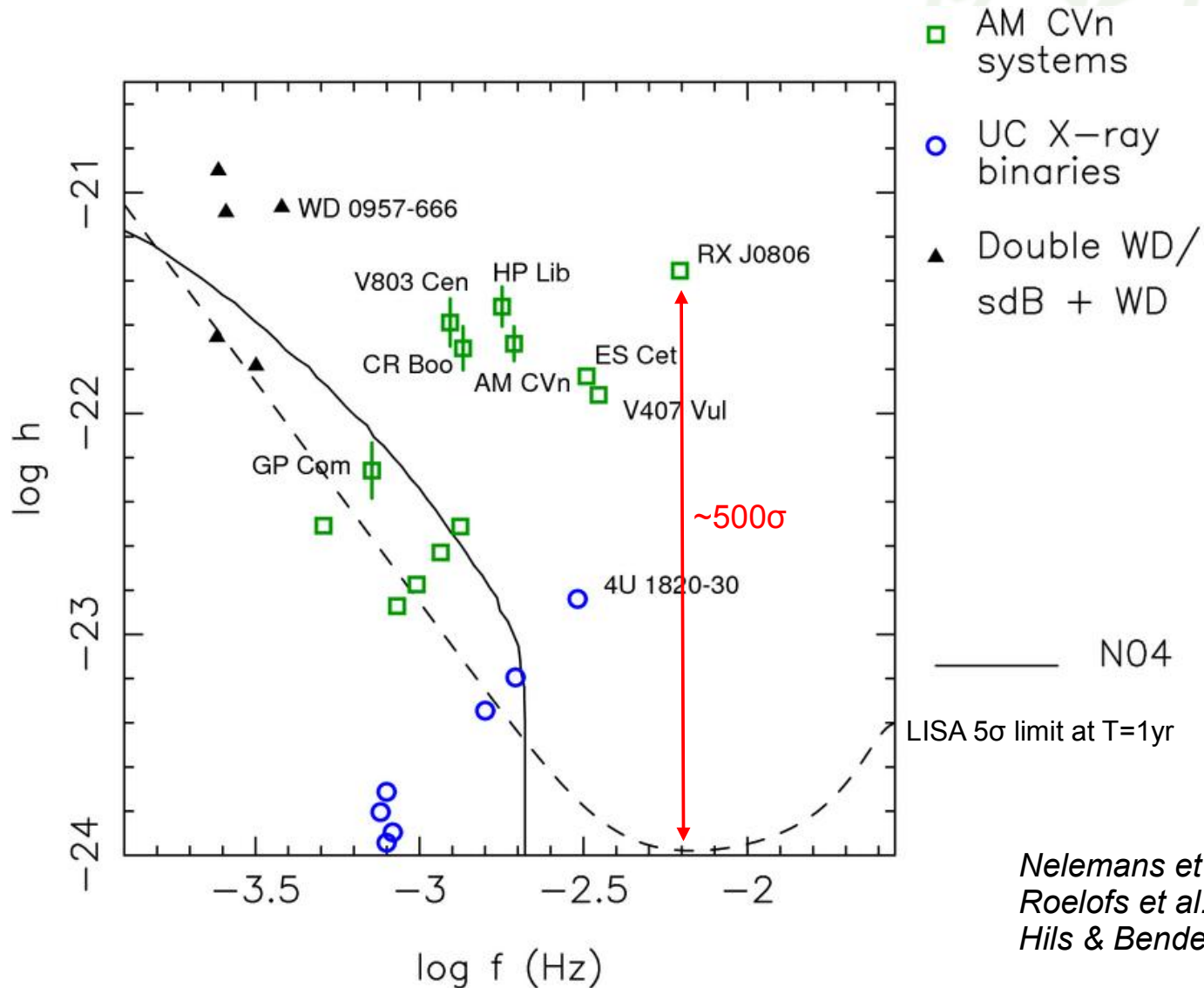
Next Generation Gravitational Wave Observatory

(voorheen LISA/eLISA)



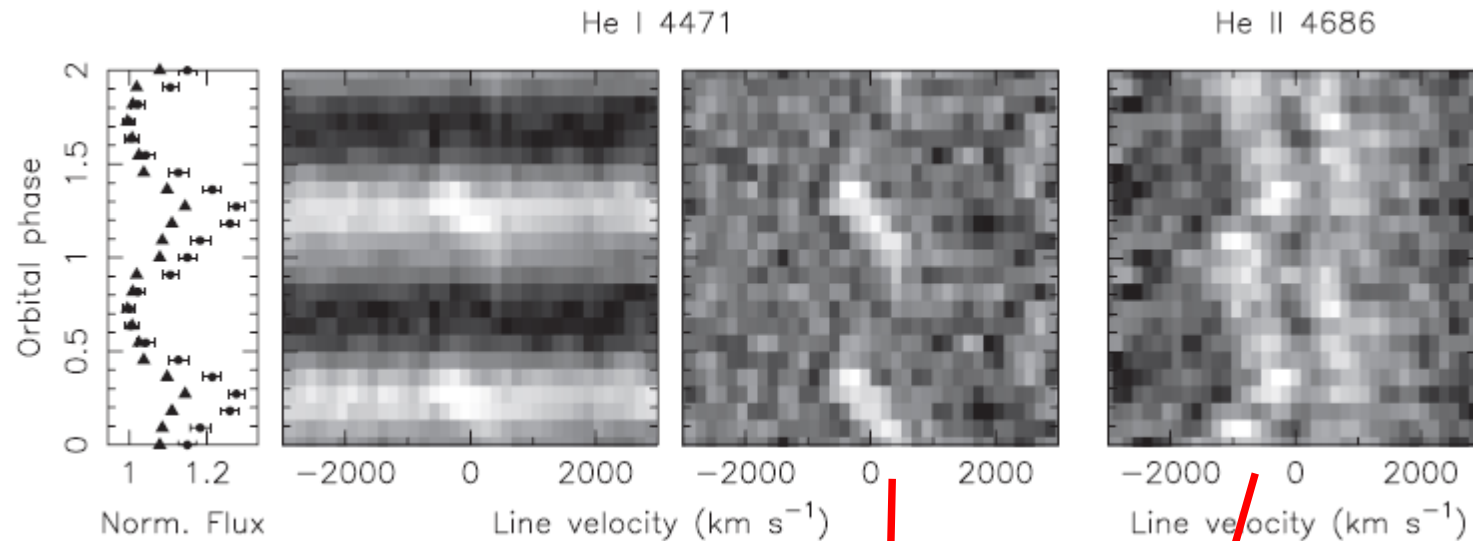
Next Generation Gravitational Wave Observatory

(voorheen LISA/eLISA)



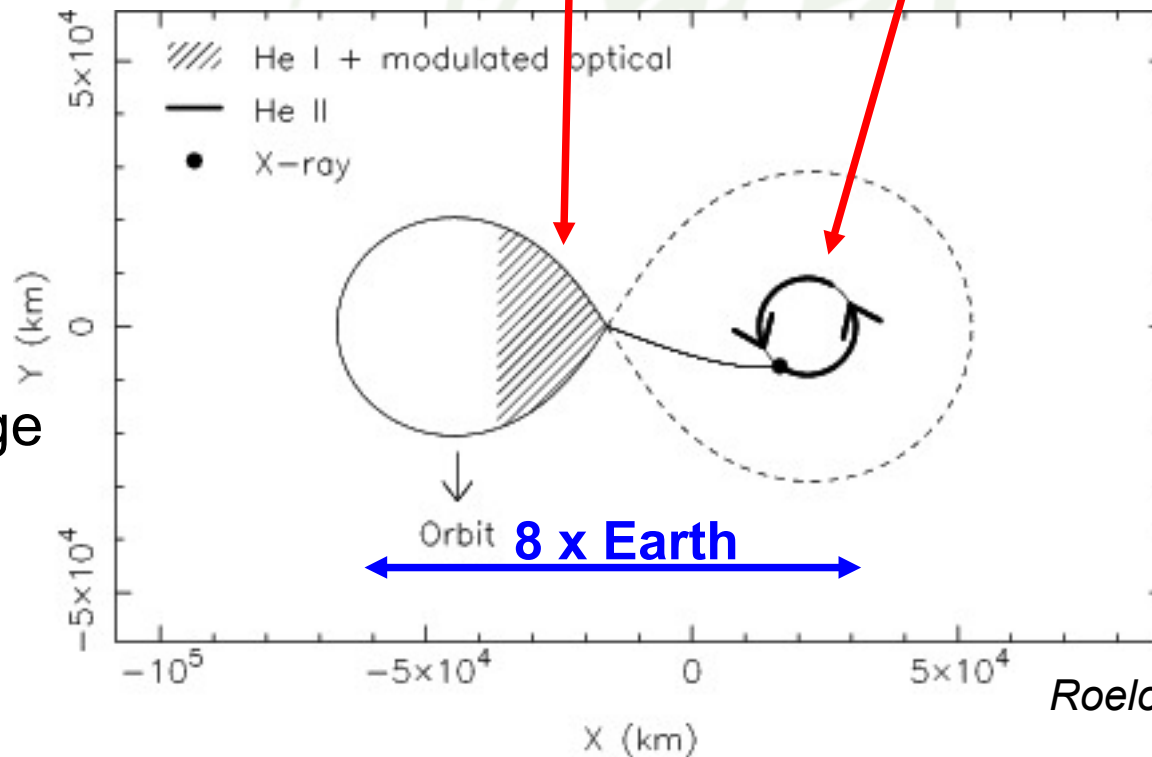
Nelemans et al., 2004
Roelofs et al., 2006
Hils & Bender, 2000

HM Cnc: $P_{\text{orb}} = 5.4$ min



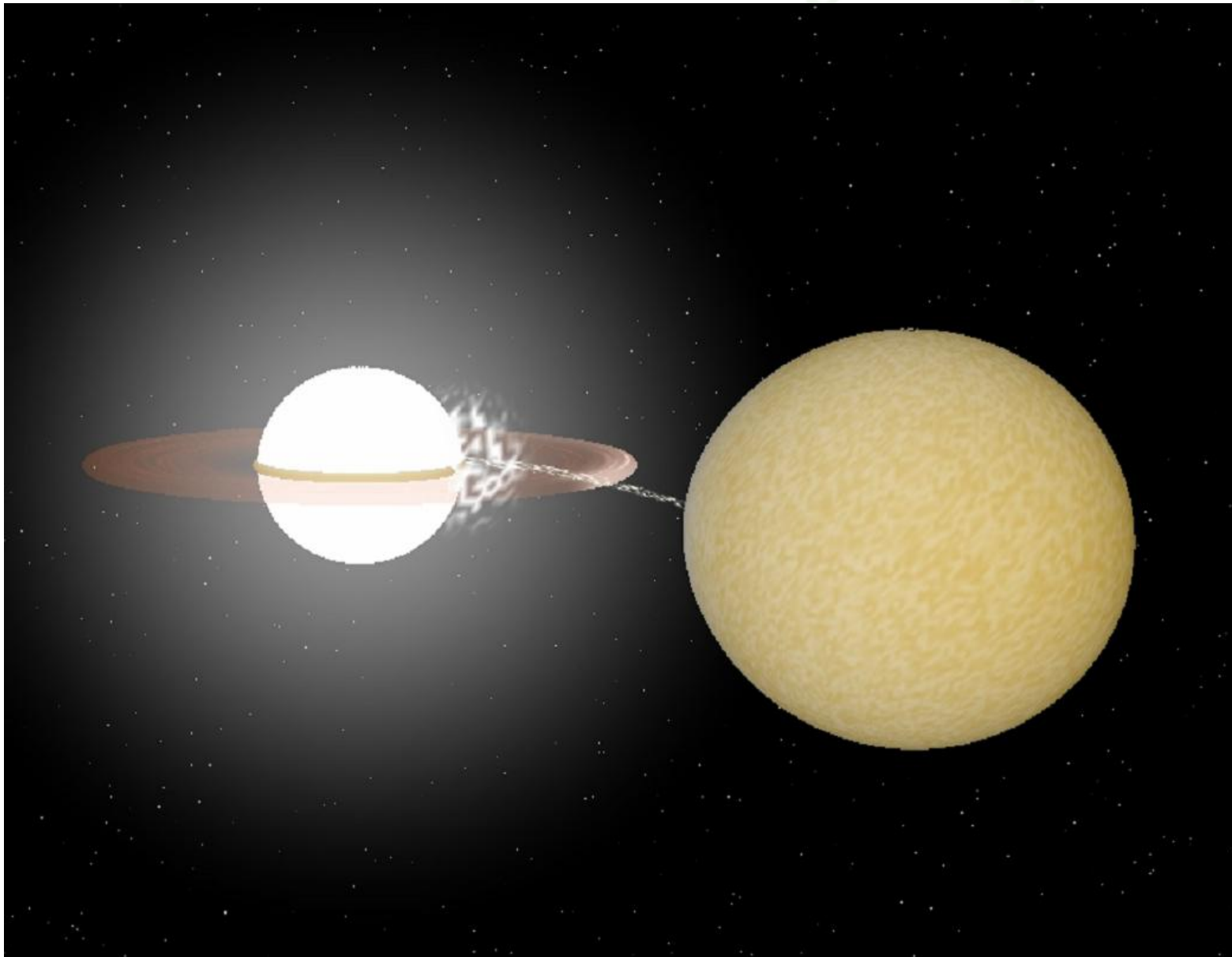
System just started
mass transfer:

Will most likely merge
(Roelofs & Deloye, 2010)

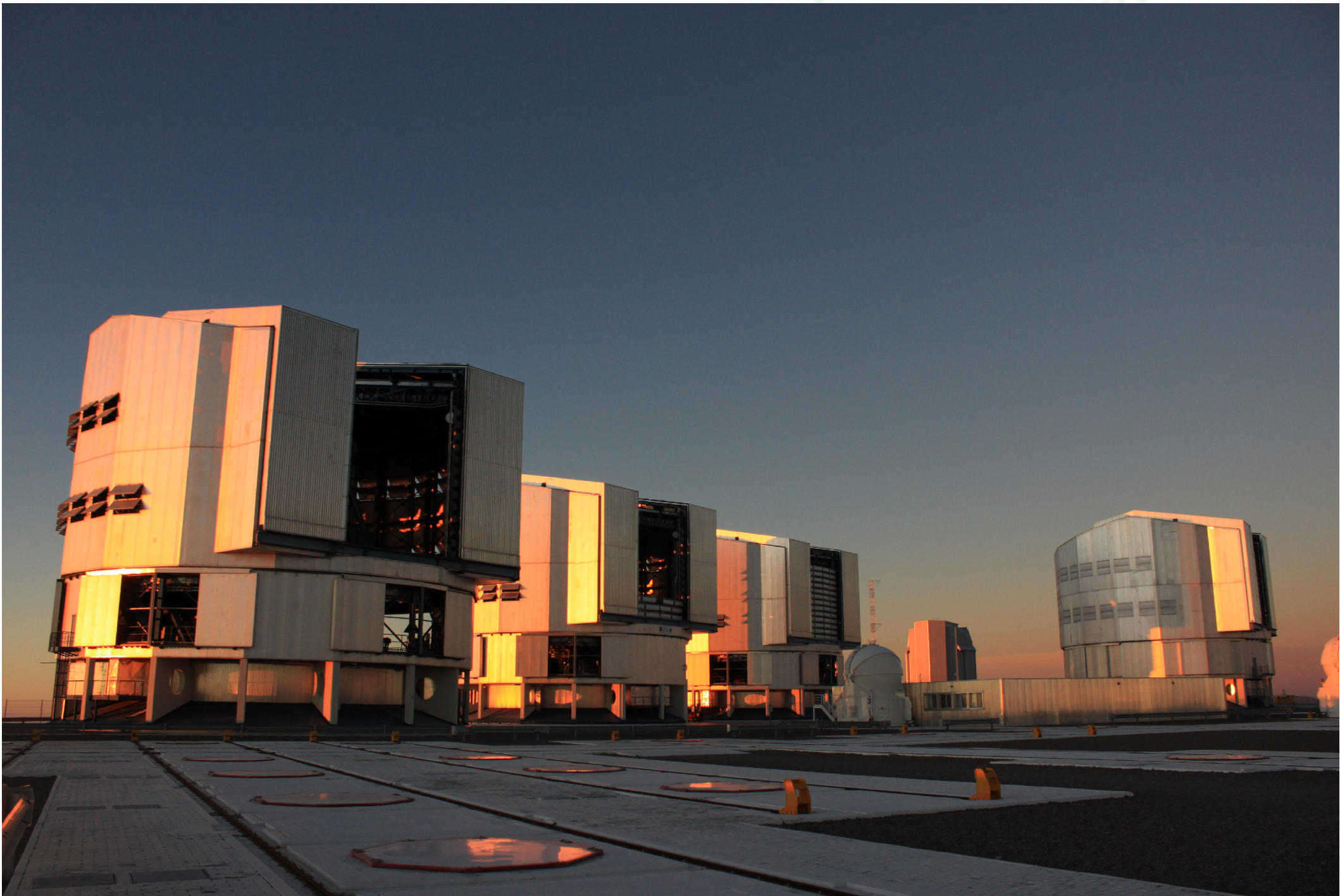


Roelofs et al., 2010

Kortst periodieke dubbelster...



Om deze te bestuderen....

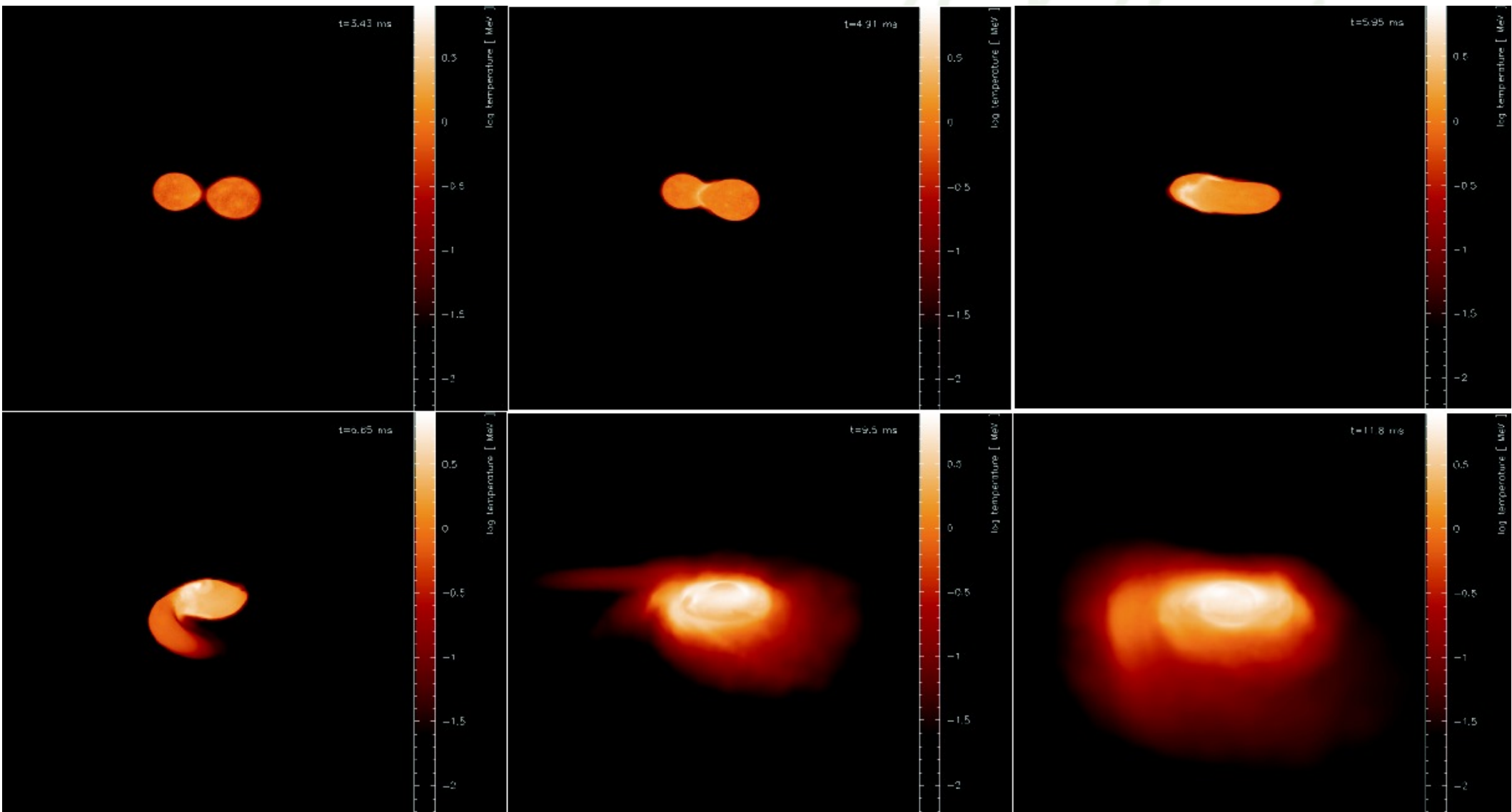


VLT+XShooter



Wat hierna?

Mergende neutronen sterren en zwarte gaten!



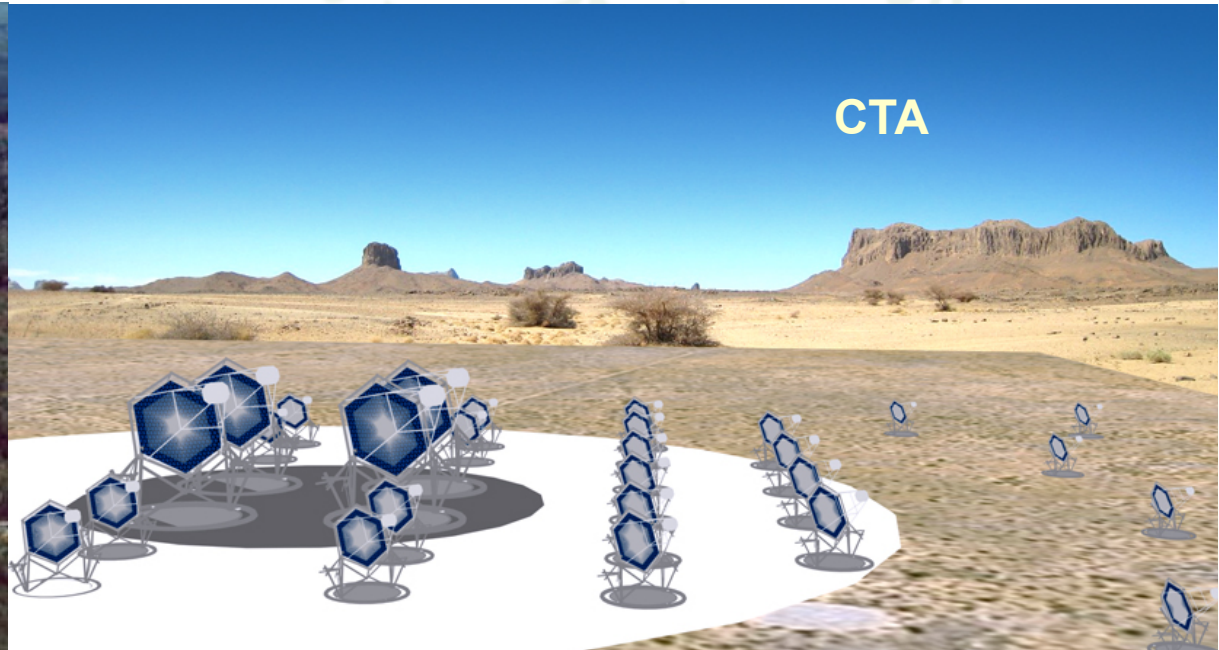
Wat hierna?

Mergende neutronen sterren, zwarte gaten en eerste zwarte gaten!

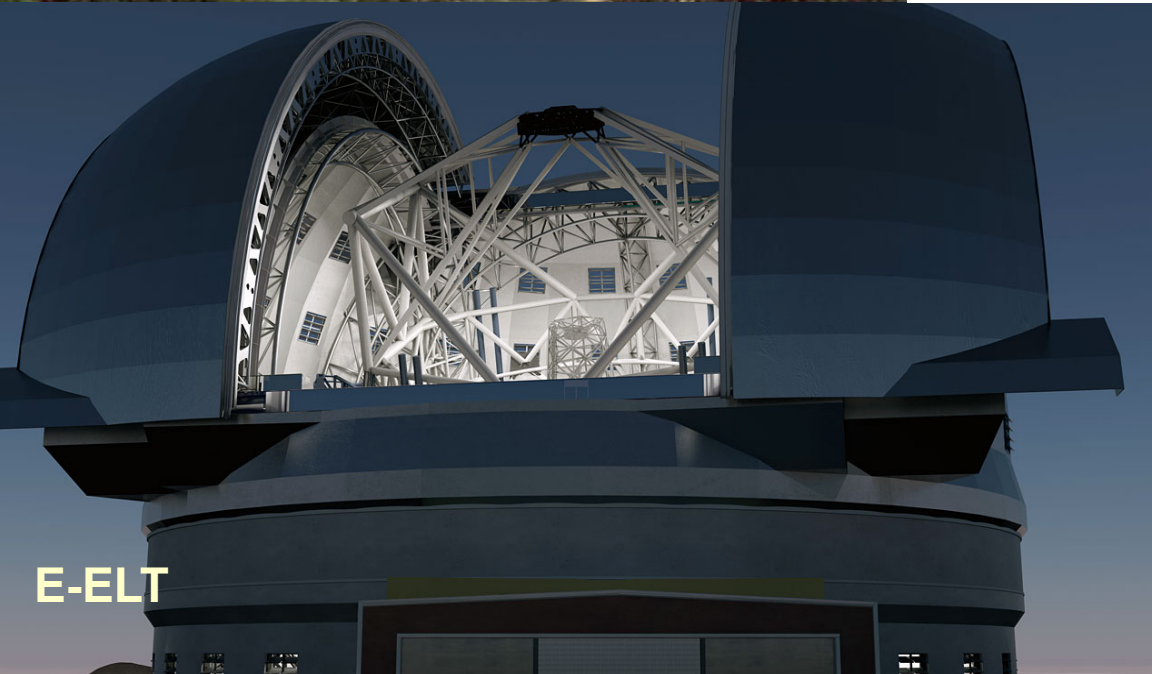
aVIRGO/aLIGO



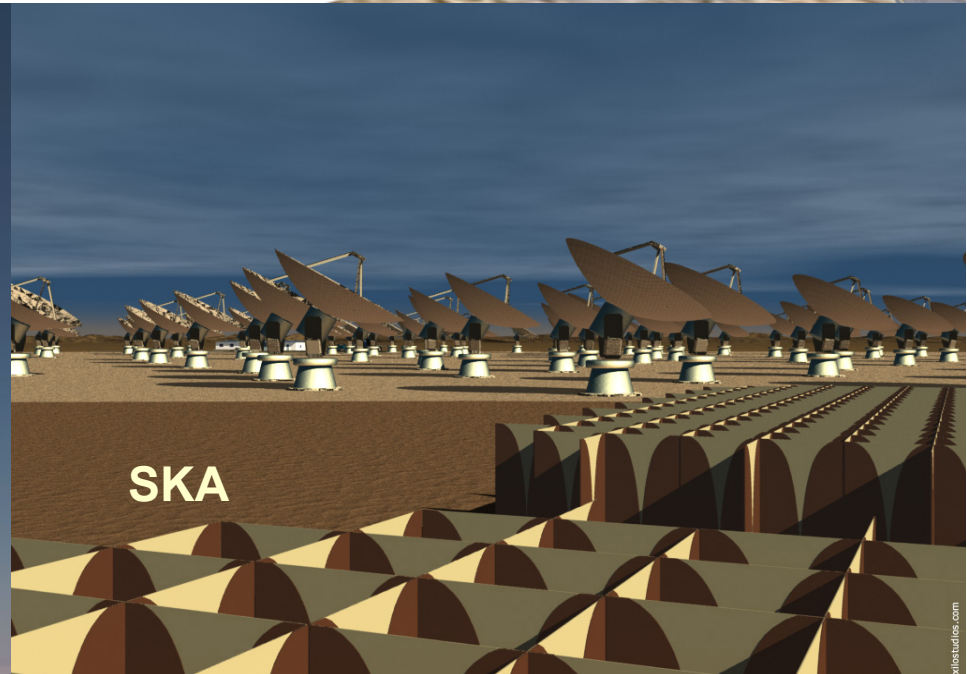
CTA



E-ELT



SKA



Kopie presentatie

aVIRGO/aLIGO

CTA

Www.astro.ru.nl → studiemateriaal

SKA

E-ELT