X-ray Binaries
Accreting Neutron Stars and Black Holes

Nathalie Degenaar
Why X-ray Binaries are Exciting

1. Black holes and neutron stars are fascinating!
   Probe extreme physics
   (ultra-dense matter, strong gravity, extreme magnetic fields)
   Involved various explosive phenomena
   (FRBs, gravitational wave mergers, supernova explosions)

2. Accretion is a very important process
   Occurs everywhere in the universe
   (formation stars + planets, evolution galaxies, cosmic web)
   Jets and winds have huge impact
   (on binaries themselves + surroundings)

Study properties of NSs/BHs + many physical processes
What are X-ray binaries and how do they work?
outflow (jet) → low-mass companion star → gas transfer → inner accretion flow → outer accretion disk → neutron star or black hole.
outflow (wind)
inner accretion flow
neutron star or black hole
outer accretion disk
low-mass companion star
gas transfer
radio → optical/infrared → X-ray → UV/optical/infrared
Different Accretion States

X-ray binary table manners

We see the brightness and outflows of X-ray binaries change depending on how fast they are accreting (= eating)

Disk wind state

Radio jet state

Quiescence
No/little accretion
Important Open Questions

How are disk winds launched?

What determines the properties of radio jets?

What happens in quiescence?

- Disk wind state
- Radio jet state
- Quiescence
  - No/little accretion
Connecting to these open questions:
Available MSc projects 2021
Project I: Disk Winds

**How** are disk winds launched?

You will take a completely new angle to investigate this!
Project I: Disk Winds

**Observables**
- line species
- line shift
- line width
- line depth

**Physical information**
- velocity of plasma
- ionization state
- (column) density
- where the plasma is
How are disk winds launched? **New angle** to investigate this:

How to the line spectra change in response to violent explosions?
Thermonuclear X-ray Bursts

Gas accreted onto the surface of a neutron star undergoes explosive thermonuclear burning → X-ray burst

Brief (~1 min) and bright (Eddington limit) flash of X-rays
Repeats on hours-days timescale

EXO 0748-676
Boirin et al. 2007
Project I: Disk Winds

How are disk winds launched?
How do violent explosions affect the line spectra?

Data: Satellite data several neutron stars (X+UV)
XMM-Newton, Chandra, Hubble Telescope
Project I: Disk Winds

How are disk winds launched?
How do violent explosions affect the line spectra?

Data: Satellite data several neutron stars (X+UV)
XMM-Newton, Chandra, Hubble Telescope

Project co-supervision:

dr. Elisa Costantini
SRON in Leiden

dr. Maria Diaz Trigo
ESO in Garching (Germany)
What determines the properties of radio jets?
Project II: X-rays and Radio Jets

Strong correlation between X-ray (= gas inflow) and radio (= gas outflow) brightness
Project II: X-rays and Radio Jets

Strong correlation between X-ray (= gas inflow) and radio (= gas outflow) brightness

But why are black holes and neutron stars different?

What causes the scatter?
Project II: X-rays and Radio Jets

What determines the properties of radio jets?
Correlate to X-ray spectra (not only luminosity)

X-ray spectra have several emission components

Difference in radio = difference in X-ray spectrum?
Project II: X-rays and Radio Jets

What determines the properties of radio jets? Correlate to X-ray *spectra* (not only luminosity) 

**Data**: X-ray satellite data several neutron stars

*NuSTAR* + *Swift*
Project II: X-rays and Radio Jets

What determines the properties of radio jets?
Correlate to X-ray spectra (not only luminosity)

Data: X-ray satellite data several neutron stars
NuSTAR + Swift

Project co-supervision:

Stefanie Fijma
PhD @ API

dr. Jakob vd Eijnden
Uni. of Oxford
(UK)
Project III: Quiescence

What happens in quiescence?

- Disk wind state
- Radio jet state
- Quiescence
  No/little accretion
Project III: Quiescence

What causes X-rays of quiescent neutron stars?
Thermal glow neutron star

Thermal emission of the hot neutron star:
Measure temperature + study interior of neutron star
Project III: Quiescence

What causes X-rays of quiescent neutron stars?
Thermal glow neutron star + some other process

Non-thermal emission: unknown origin!
Weak accretion? Magnetosphere?

Is it the same in all neutron stars?
Project III: Quiescence

What causes X-rays of quiescent neutron stars? Ongoing accretion or magnetosphere emission?

Data: X-ray satellite data several neutron stars

**XMM-Newton, Chandra**

![Normalized counts vs. Energy (keV)](image)
Summary Projects

I. Disk winds & explosions

II. Connection radio jets and X-ray spectra

III. What happens in quiescence
Techniques and Skills Gained

All projects: focus on X-ray data analysis are completely unexplored

1. Handling astronomical data
   Data reduction + analysis skills
   Using NASA software

2. Simple coding/scripting
   Efficient + systematic analysis

3. Presentation skills
   Talks + thesis + journal paper?
Get in Touch!

Message me @API SLACK
degenaar@uva.nl
More projects at nathaliededegenaar.com
MSc Project Life

1. One-on-one with daily supervisor (= me)
   Weekly + when needed (open door policy)
2. Group meeting: news, results, progress
   Weekly
3. Joint meeting: with group Rudy Wijnands
   Weekly
4. Social meetings: lunches, celebrations, dinners
   Few times per year

Ask (former) fellow students for their experience
(e.g. Mitchel, Stefanie, Jorinde, Marieke, Luna)
Current Group @ API

Nathalie Degenaar
API faculty

Stefanie Fijma
PhD student

Luna van Haastere
Yr-2 MSc student

Jari van Opijnen
Post-MSc researcher

Marieke van Etten
Yr-2 MSc (Astrovaria)

Jelle Groot
Yr-2 MSc (Astrovaria)
Black Holes versus Neutron Stars

Companion stars + accretion disks very similar
But: neutron stars have a solid surface + magnetic field
→ Can affect inner part of accretion disk + winds & jets