Accreting Neutron Stars and Black Holes in X-ray, UV, optical, infra-red, radio

Nathalie Degenaar & group
Why Study X-ray Binaries?

1. Black holes and neutron stars are fascinating!
   Extreme objects, very energetic phenomena
   Study their properties + effect on environment

2. Accretion is a fundamental physical process
   Occurs everywhere in the universe
   Many similarities between different systems
X-ray Binaries
outer accretion disk

outflow (jet)

low-mass companion star

inner accretion flow

outer accretion disk

neutron star or black hole
outer accretion disk
outflow (wind)
in inner accretion flow
neutron star or black hole
low-mass companion star
outer accretion disk
radio → optical/infrared

X-ray → UV/optical/infrared
Absorption or emission lines (X-rays or UV)
Transient X-ray Binaries
Transient X-ray Binaries

OUTBURST

QUIESCENCE

$L_x$ (erg s$^{-1}$)

Time (days)

10$^{37}$

10$^{36}$

10$^{35}$

10$^{34}$

10$^{33}$
Studying Accretion

Easily studied with many instruments

Typical sensitivity limit of past + present X-ray missions
Studying Accretion

Typical sensitivity limit of past + present X-ray missions

Need sensitive instruments
Open Questions

How are jet, inner disk and outer disk connected?

How/when is the accretion disk moving away?

How is the hot flow developing?

What happens in quiescence?
Studying Accretion

X-rays tell only a small part of the story
Studying Accretion

Need observations across the electromagnetic spectrum
Difficult Challenge

Requires different observatories and techniques
+ need best sensitivity
Current Group @ API

Nathalie Degenaar
API faculty
(all wavelengths)

Aastha Parikh
postdoc
(X-ray + UV)

Jakob vd Eijnden
PhD student
(X-ray + radio)

Mitchel Stoop
Yr-2 MSc student
(X-ray + radio)

Radio

X-rays

UV

Optical + Infra-red

Yr-1 MSc students
Astrovaria
(X-ray)

Jelle Groot

Stefanie Fijma

Jorinde Kleverlaan

Marieke van Etten
My Multi-Wavelength Toolkit

NuSTAR/NASA X-ray
Chandra/NASA X-ray
XMM-Newton/ESA X-ray
Swift/NASA X-ray + UV
Magellan (6.5)
HST/NASA UV
Gemini (8 m)
ATCA (Australia)
VLT (8 m)
VLA (New Mexico)
Possible MSc Projects

What happens in quiescence?
I. Does SAX J1808 become a radio pulsar?
II. Origin of the X-rays of quiescent neutron stars

Connection between different wavelengths
III. Studying accretion through X-ray and nIR
IV. Studying accretion through X-ray and UV

Jets and disk winds
V. Are radio jets and X-ray reflection connected?
VI. Can thermonuclear X-ray bursts blow disk winds?

See also: nathaliedegenaar.com/student-projects
Techniques and Skills Gained

1. Handling astronomical data
   - Data reduction + analysis skills
   - X-ray spectroscopy
   - UV/optical/nIR/radio imaging

2. Presentation skills
   - Talks + thesis + (possibly) journal paper

3. Coding/scripting
   - Efficient + systematic reduction/analysis

4. Requesting new observational data
   - Proposal writing skills
Being part of the group

1. One-on-one with supervisor
   Weekly + when needed
2. Group meeting: news, results, progress
   Weekly
3. Accretion meeting: with group Rudy Wijnands
   Weekly
4. Social meetings: Celebrations, drinks, dinner
   Few times per year

Ask your fellow students for their experience!
(Mitchel, Stefanie, Jorinde, Marieke, Jelle)
General Advice

You spend ~1 year on your MSc research. Should be fun, possibly a preparation for a PhD.

1. Find a topic that you like
   Observations vs theory, subject, technique

2. Find a supervisor that you like
   Need to feel comfortable, have a click

3. Find a supervision style that you like
   Frequency of meetings, daily supervision, group

Ask your fellow students for their experience!
Get in Touch!

nathaliedegenaar.com/student-projects
degenaar@uva.nl
Brief Description of Possible MSc Research Projects
(see my webpage for more details)
I. What happens in Quiescence?

Project: Does SAX J1808 become a radio pulsar? 
Connection between different NS populations?

Image courtesy: Anne Archibald
I. What happens in Quiescence?

**Project:** Does SAX J1808 become a radio pulsar?

**Test if there is still accretion in quiescence**

**Data:** UV satellite + optical telescope data

Hubble Space Telescope, SOAR
II. What happens in Quiescence?

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

EXO 0748-676

Thermal emission of the hot neutron star →
Measure temperature + study interior of neutron star
II. What happens in Quiescence?

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

Non-thermal emission of unknown origin!
→ From accretion?
From magnetosphere?
Is it the same in all neutron stars?
II. What happens in Quiescence?

**Project:** What causes X-rays of quiescent NSs?
**Ongoing accretion or magnetosphere emission?**

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

XMM-Newton, Chandra
III. The radio/X-ray connection

**Open Question:** What determines the radio brightness? Is it connected to accretion?
Studying Inner Accretion Flow

X-ray spectroscopy: Disentangle emission components
Study connection X-ray reflection & radio properties

X-rays of hot flow reflecting off the disk create a bump
III. The radio/X-ray connection

**Project:** How are jets coupled to accretion?

**Is reflection weak when the radio is weak?**

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

NuSTAR, Swift
IV. The nIR/X-ray connection

Near-infrared can be from disk, jet, donor, hot flow: **What dominates at what accretion rate?**
IV. The nIR/X-ray connection

Some old studies done at high X-ray luminosity

What happens at low X-ray luminosity?
IV. The nIR/X-ray connection

Project: How does the accretion flow change?
Do the nIR emission mechanisms change?
Data: nIR telescope data many NSs and BHs
Magellan

? ?

![Graph showing correlation between OIR and X-ray emission for LMXBs.]
Open Question: Is the UV coming from the disk, jet, or a hot flow? Does this change?
V. The UV/X-ray connection

**Open Question:** Is the UV coming from the disk, jet, or a hot flow? Does this change?

Different slopes during different outburst phases:

- **Dominant UV mechanism changing?**
- **Is this common behavior?**

Study sample of sources!
V. The UV/X-ray connection

Project: A census of the UV properties
Same for all X-ray binaries? BHs versus NSs?

Data: UV and X-ray satellite data NSs and BHs
Swift, XMM-Newton, Hubble Space Telescope

Common behavior?
VI. Producing Disk Winds

**Open Question:** How are disk winds produced? Can a thermonuclear X-ray burst do it?
Thermonuclear X-ray Bursts

Thermonuclear fusion on the surface of a neutron star

Emission peak: Eddington limit
Repetition rate: hours-days
X-ray bursters known: ~125

EXO 0748-676
Boirin et al. 2007
Wind Induced by an X-ray Burst

Pinto+2014

Chandra/LETG detection of wind after a bright X-ray burst (SAX J1808.4-3658)
VI. Creating Winds

Project: Can thermonuclear bursts blow winds? Can we often see winds after bursts go off?

Data: X-ray (UV) satellite data of different NSs XMM-Newton, Chandra, Hubble Telescope