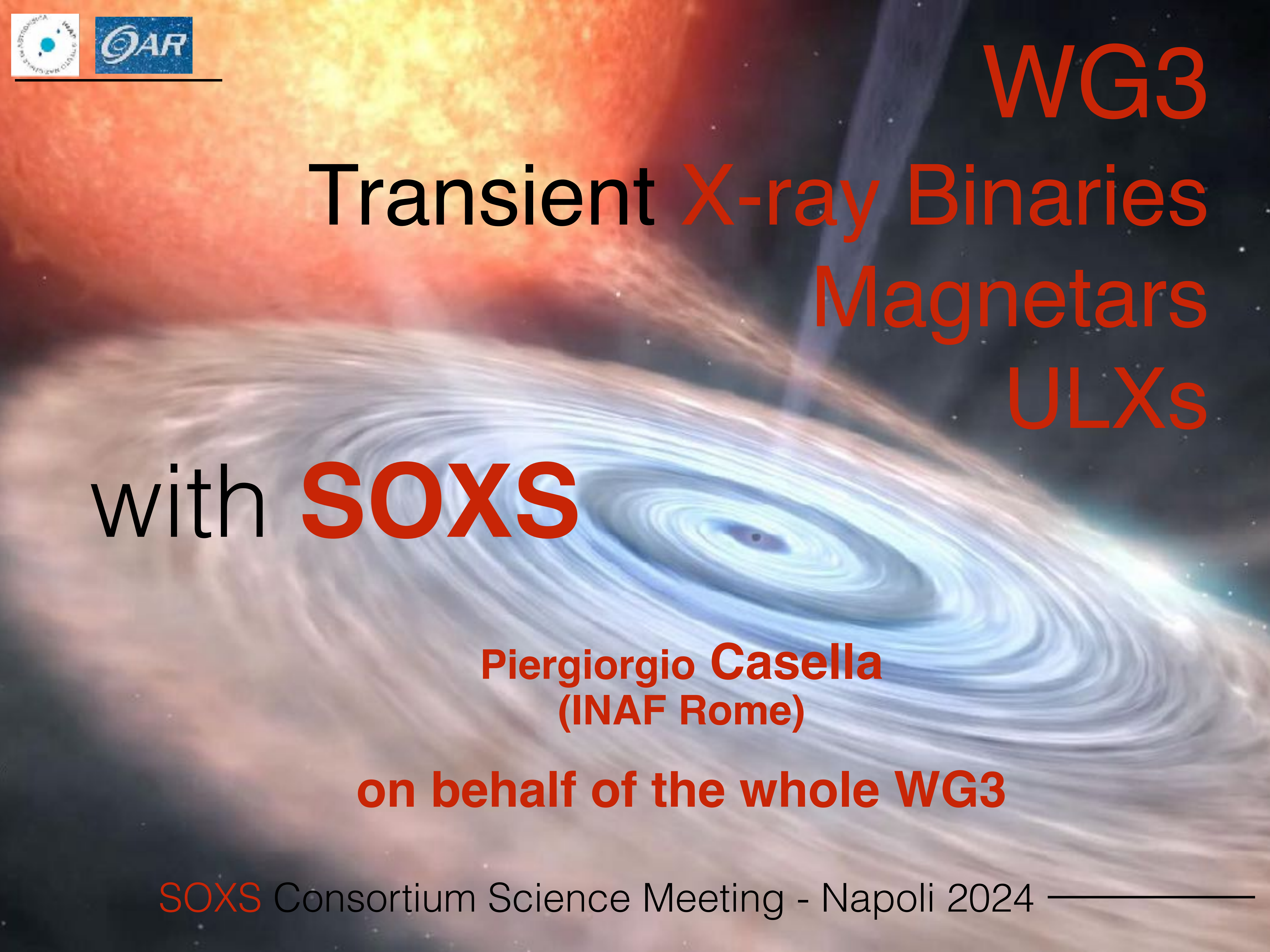


WG3

Transient X-ray Binaries
Magnetars
ULXs

with **SOXS**

Piergiorgio Casella
(INAF Rome)

on behalf of the whole WG3

SOXS Consortium Science Meeting - Napoli 2024

WG3

22 members (Italy, Finland)

~25 ideas/proposals received

Black Hole-Transients

Accreting Millisecond Pulsars

New Transient X-ray pulsators

Transitional Millisecond Pulsars

Neutron-Star Transients

Z-sources

Magnetars

High-mass X-ray Binaries

Ultra-luminous X-ray Sources

Accretion

Strong Gravity

Dense Matter

Magnetic fields

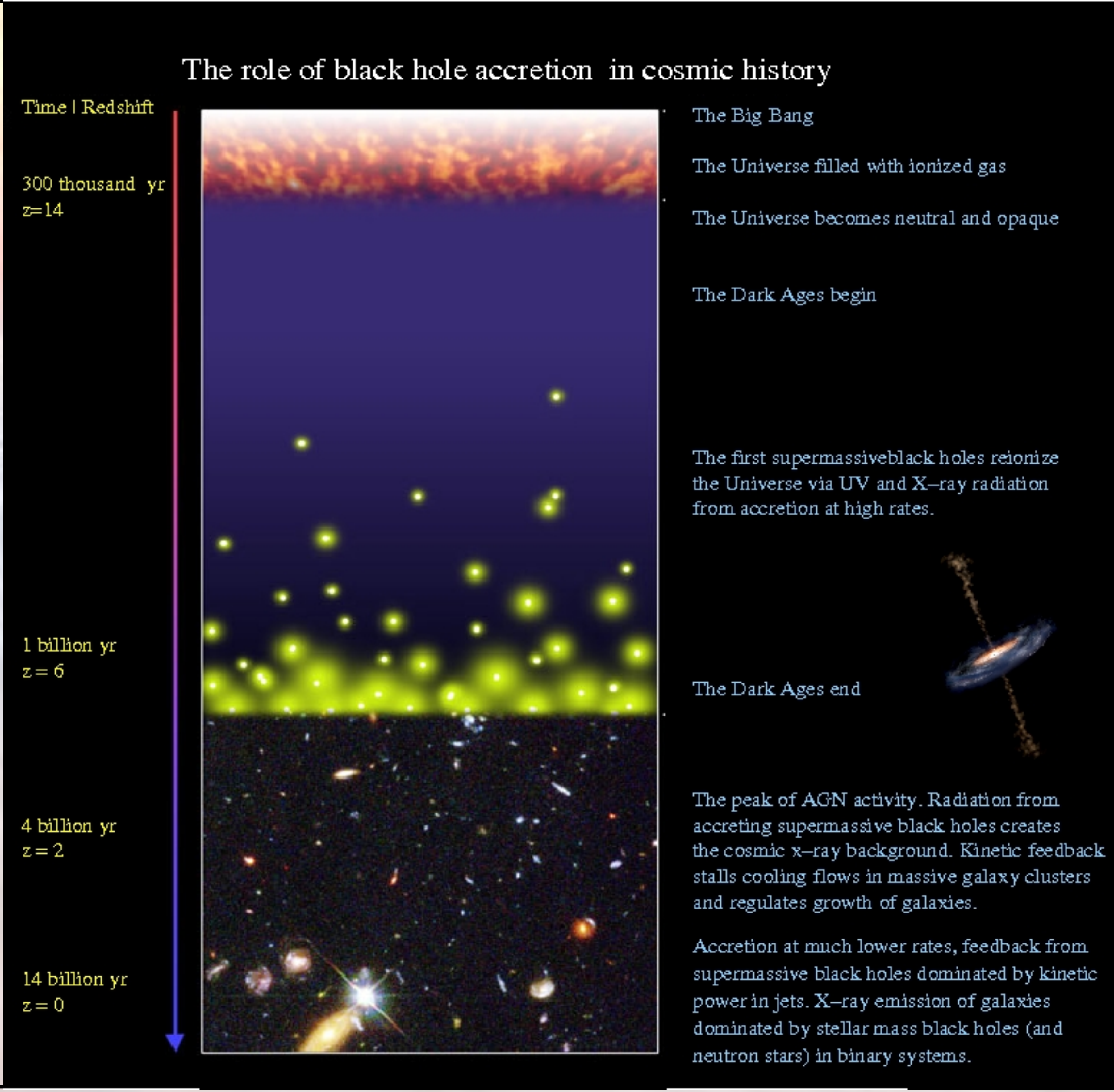
The importance of accretion in the Universe

6<z<14 first 'AGN' reionize universe

1<z<6 peak of AGN activity: feedback regulates galaxy growth, reheats cooling flows, creates X-ray background

z<1 AGN accretion rates drop, feedback dominated by jets (kinetic), X-ray luminosity dominated by binaries

courtesy of R.Fender



The role of black hole accretion in cosmic history

The Big Bang

The Universe filled with ionized gas

The Universe becomes neutral and opaque

The Dark Ages begin

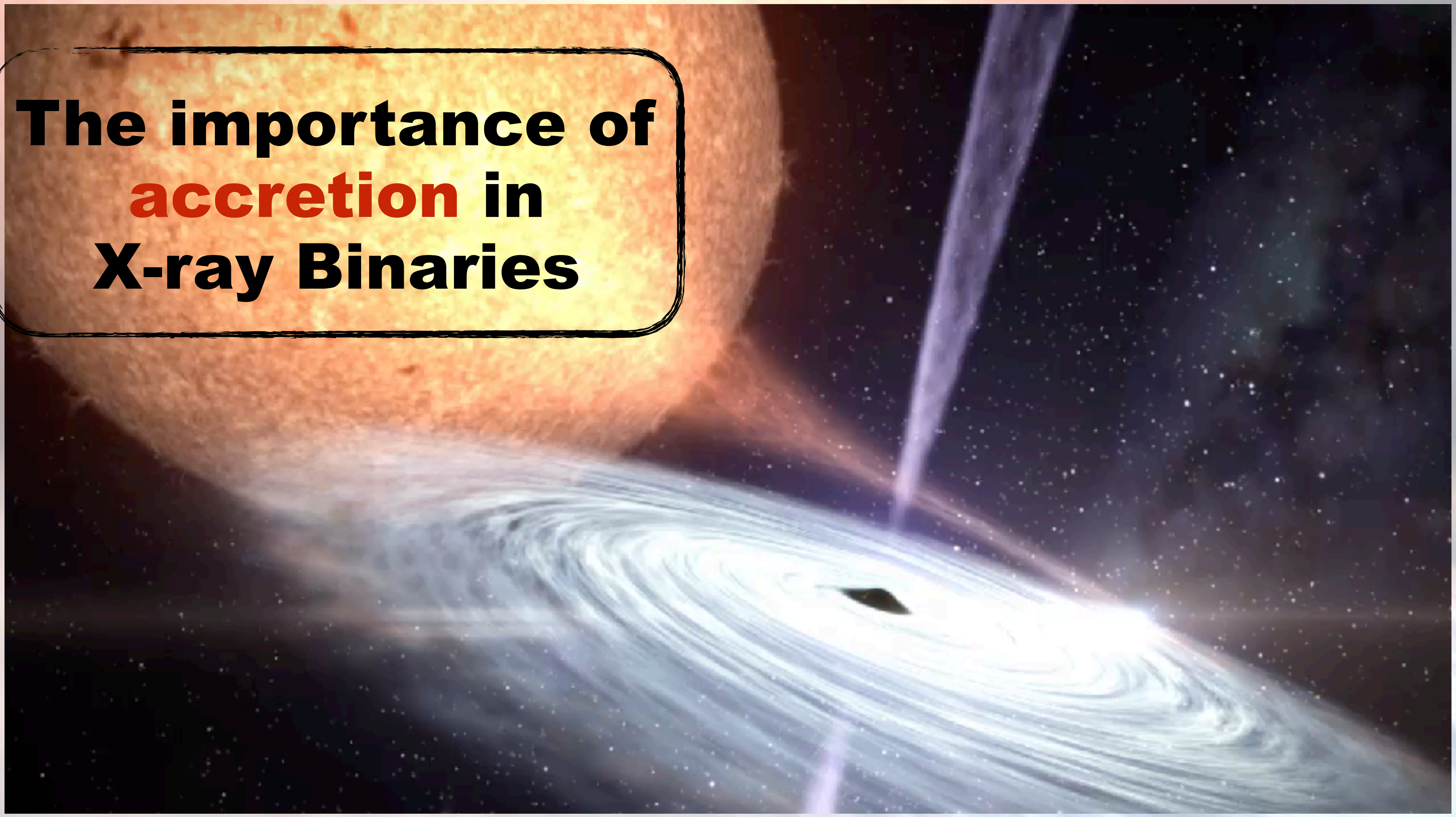
The first supermassiveblack holes reionize the Universe via UV and X–ray radiation from accretion at high rates.

The Dark Ages end

The peak of AGN activity. Radiation from accreting supermassive black holes creates the cosmic x–ray background. Kinetic feedback stalls cooling flows in massive galaxy clusters and regulates growth of galaxies.

Accretion at much lower rates, feedback from supermassive black holes dominated by kinetic power in jets. X–ray emission of galaxies dominated by stellar mass black holes (and neutron stars) in binary systems.

WG3 : Transient X-ray Binaries, Magnetars, ULXs



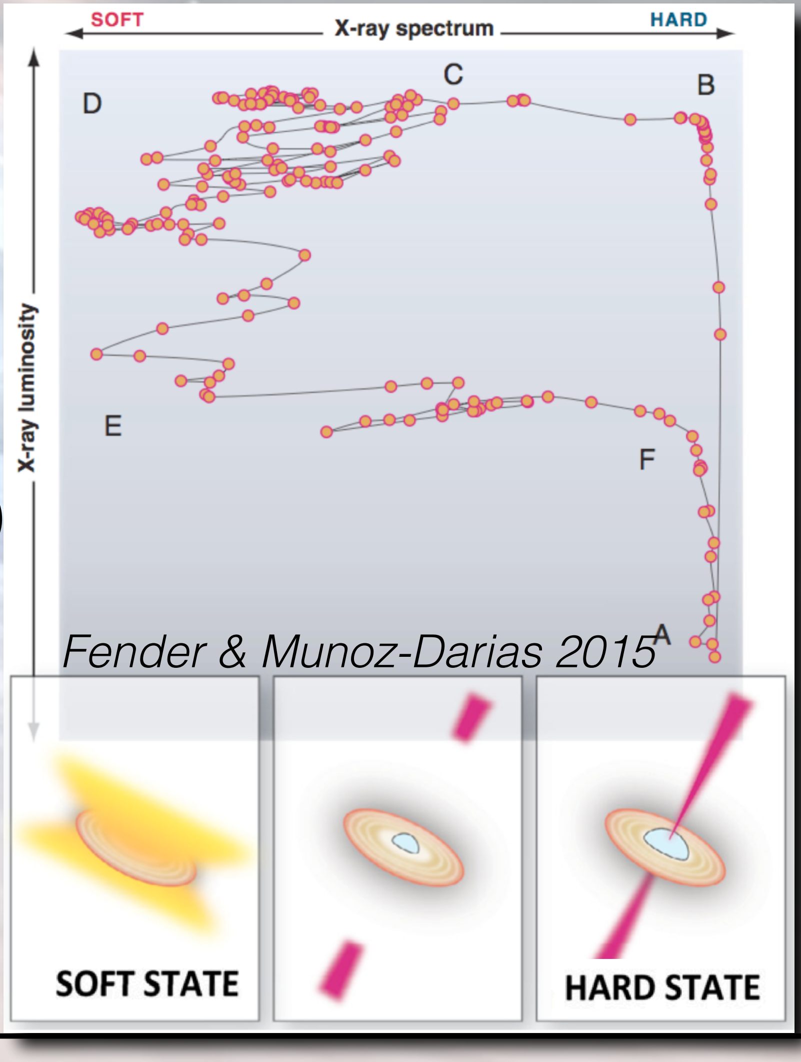
The importance of accretion in X-ray Binaries

strong GRAVITY

relativistic JETS

clean ACCRETION (BH)

~dipolar B-FIELDs (NS)



Fender & Munoz-Darias 2015

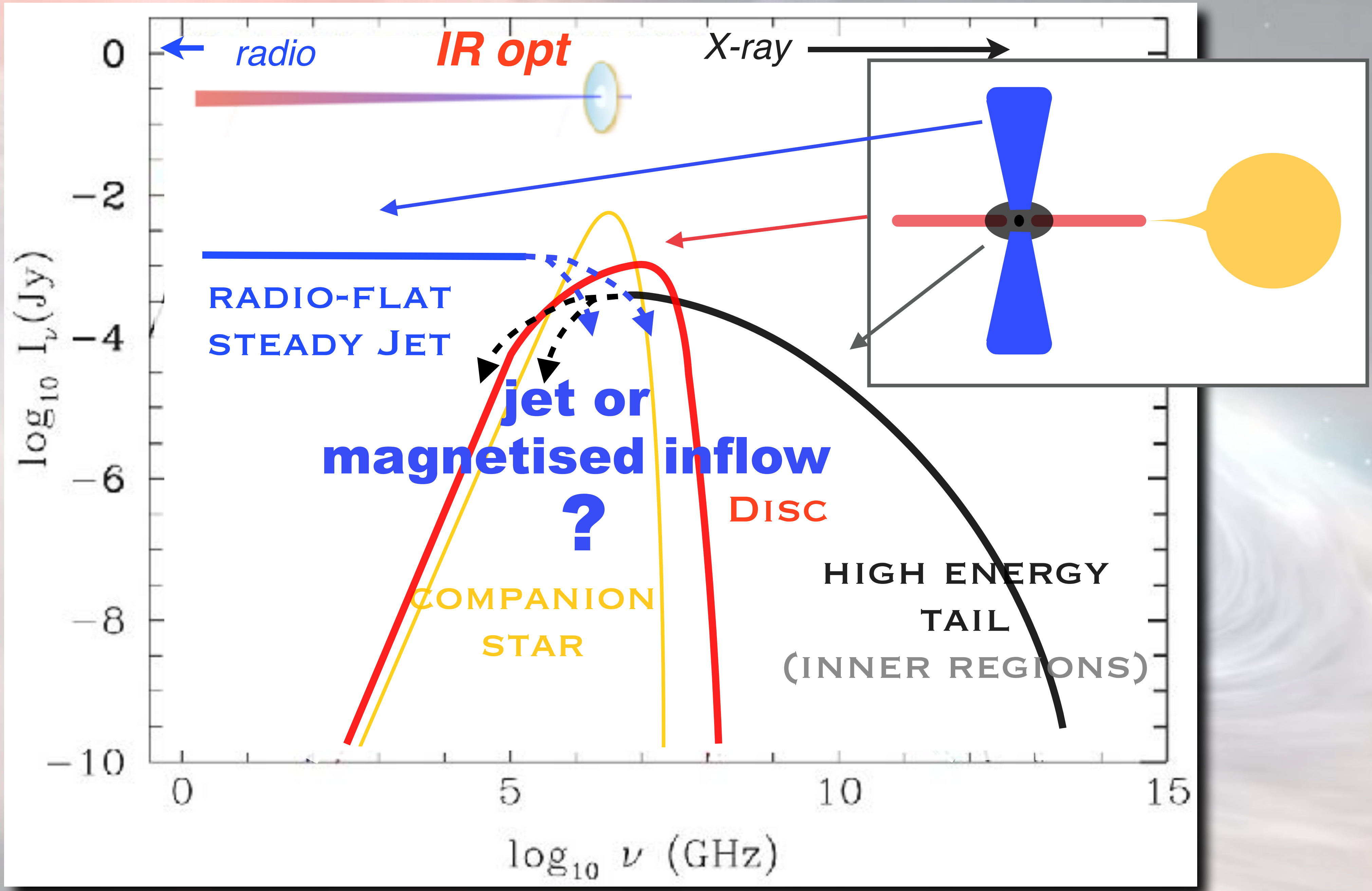
many orders of magnitude in luminosity ($10^{31} \sim 10^{39}$ ergs/s)

accessible timescales (< PhD project duration)

different accretion regimes ⟵ VERY COMPLEX

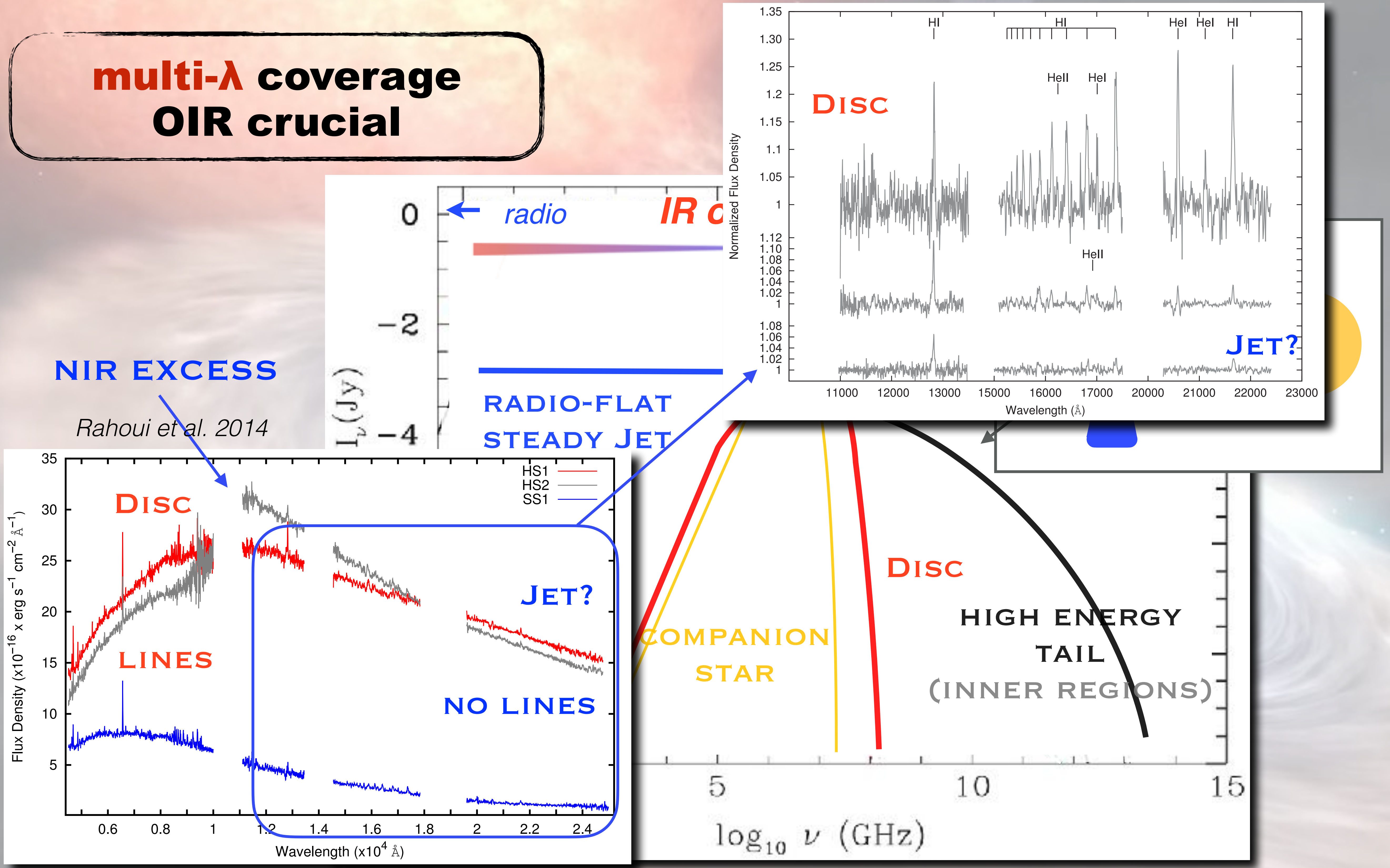
multi-λ coverage
OIR crucial

black-hole transients



WG3 : Transient X-ray Binaries, Magnetars, ULXs

multi-λ coverage
OIR crucial


Rahoui et al. 2014

Rahoui et al. 2014

transitional MSPs

multi-λ coverage
OIR crucial

de Martino et al. 2014
Coti Zelati et al. 2014
Ambrosino, Papitto et al. 2017
Hakala & Kajava 2018
Baglio et al. 2023

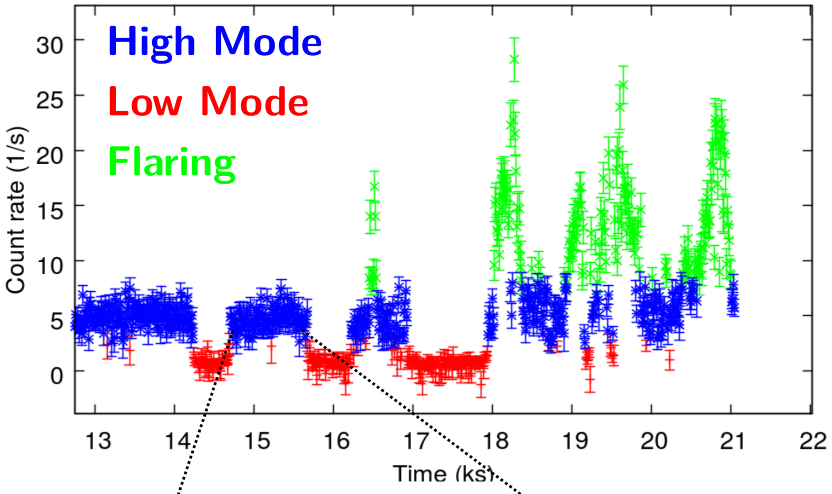
A peculiar accretion disk state

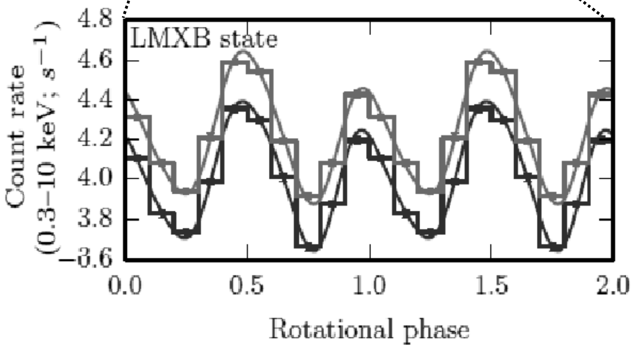
X-rays:
L~5x10^{33} erg/s
Persistent (years)
Distinctive variability

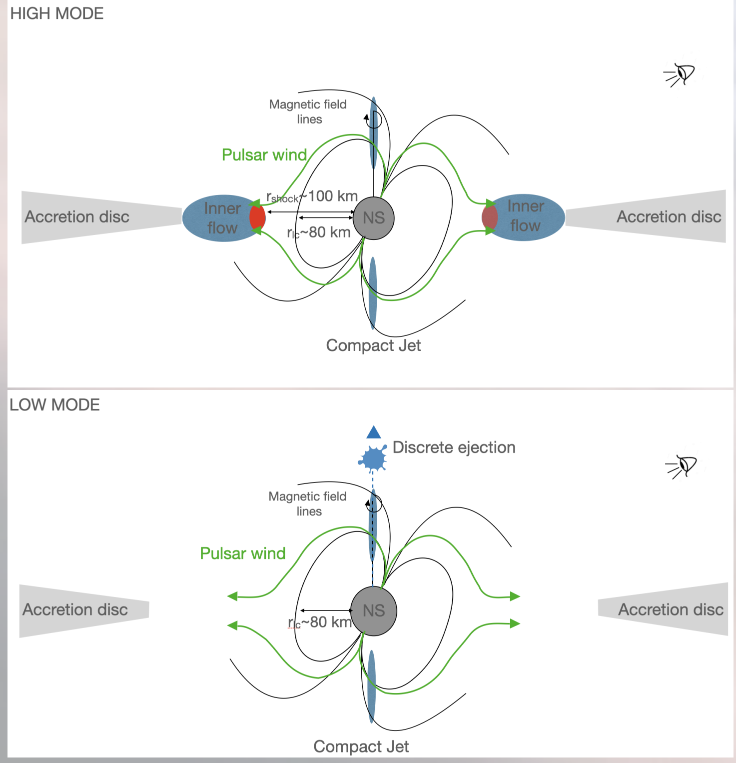
Optical:
Flares, Disk emission lines

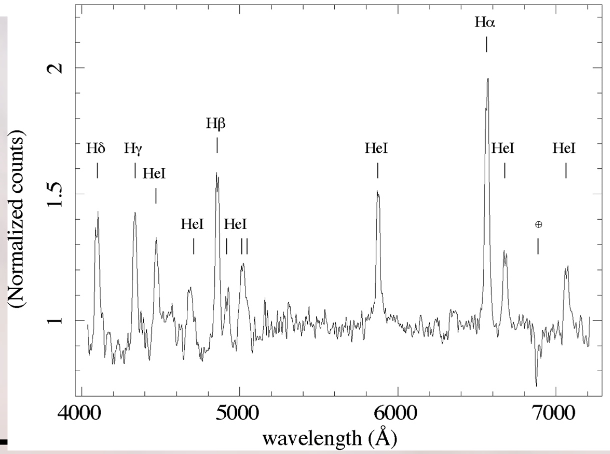
Gamma-rays:
5x brighter than radio PSR

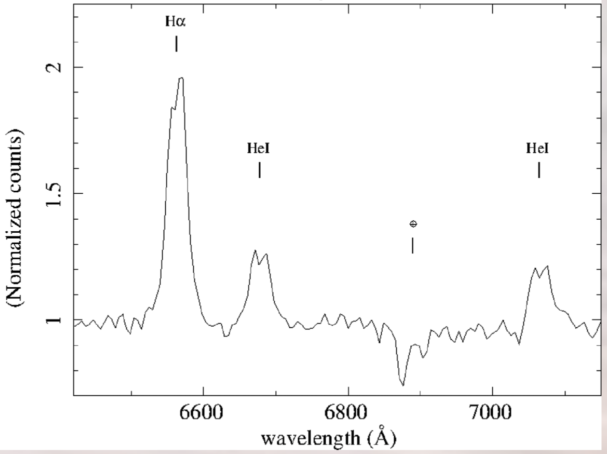
Radio:
Not pulsed
Variable jet emission





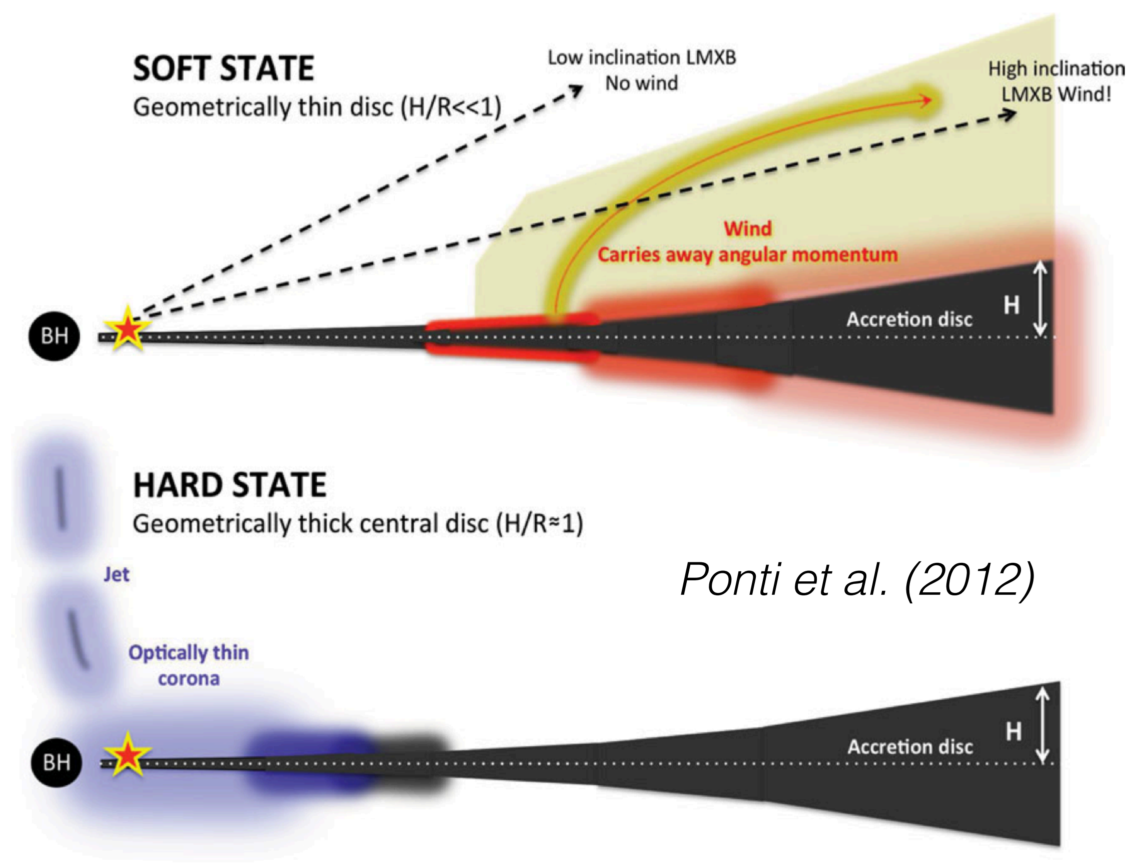




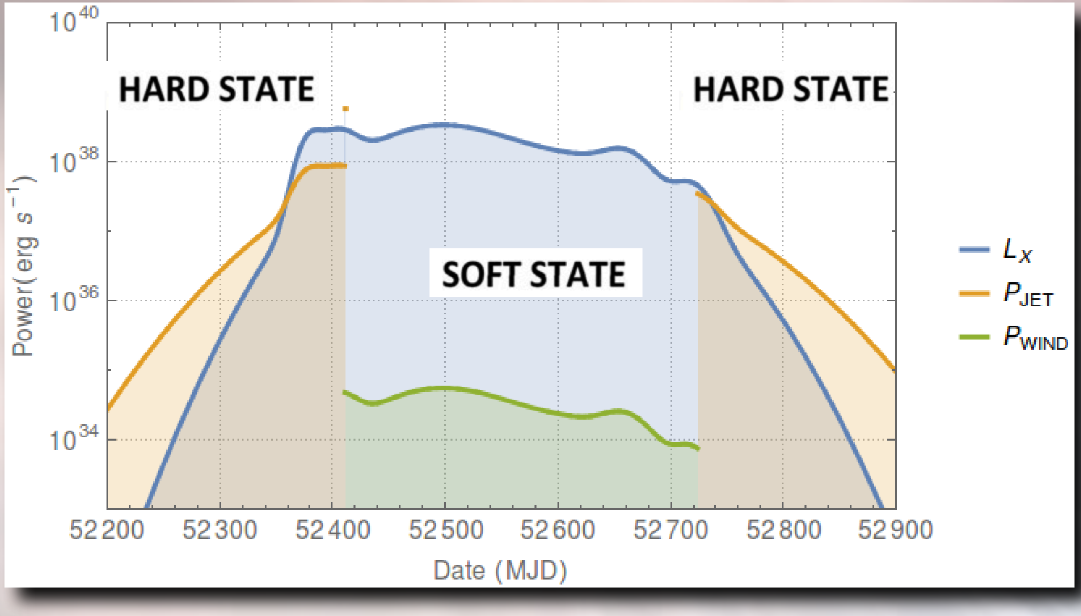


WG3 : Transient X-ray Binaries, Magnetars, ULXs

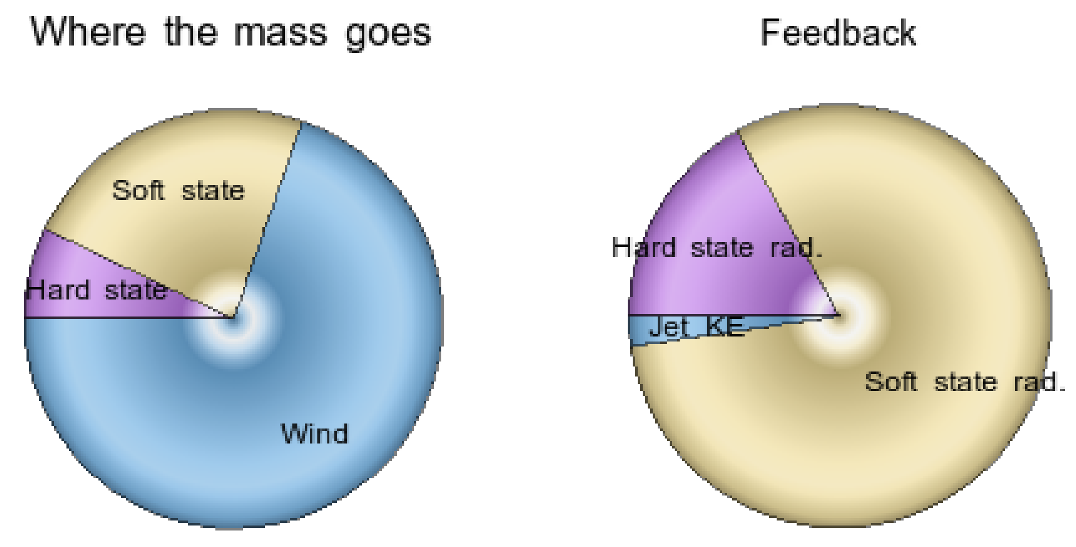
tracking the **matter**

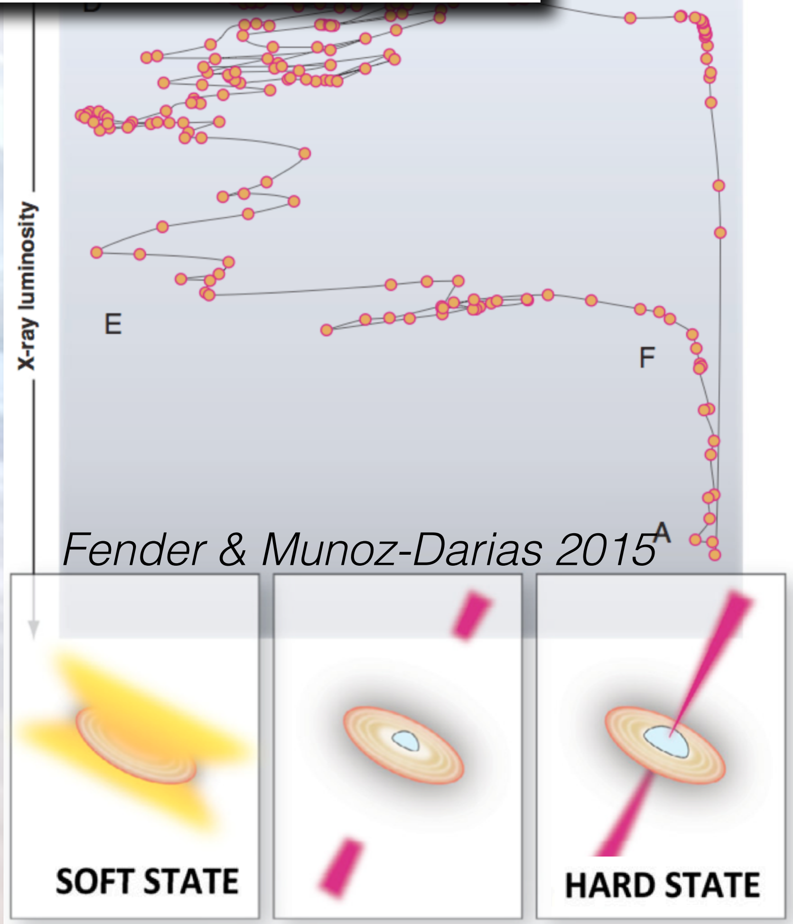


Ponti et al. (2012)



Fender & Munoz-Darias 2015





Fender & Munoz-Darias 2015

tracking the matter

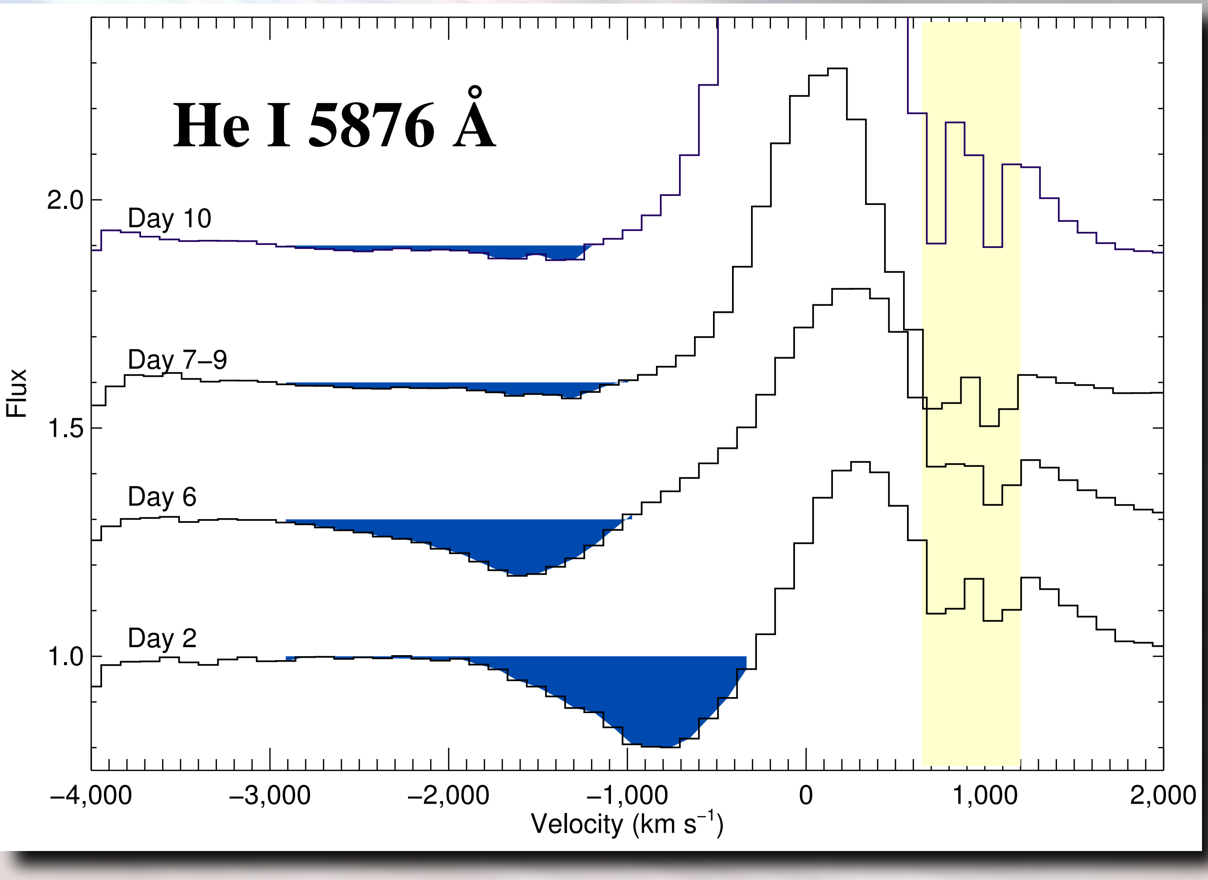
2015: extremely luminous OUTBURST from the nearby BH V404 Cygni

short (15 days)
extreme (from 20 mCrab to 60 Crab)
reach (~50 papers - inc. 3 Nature)

P Cygni profile in 12 emission lines

—> high-velocity massive wind

Munoz-Darias et al. 2016

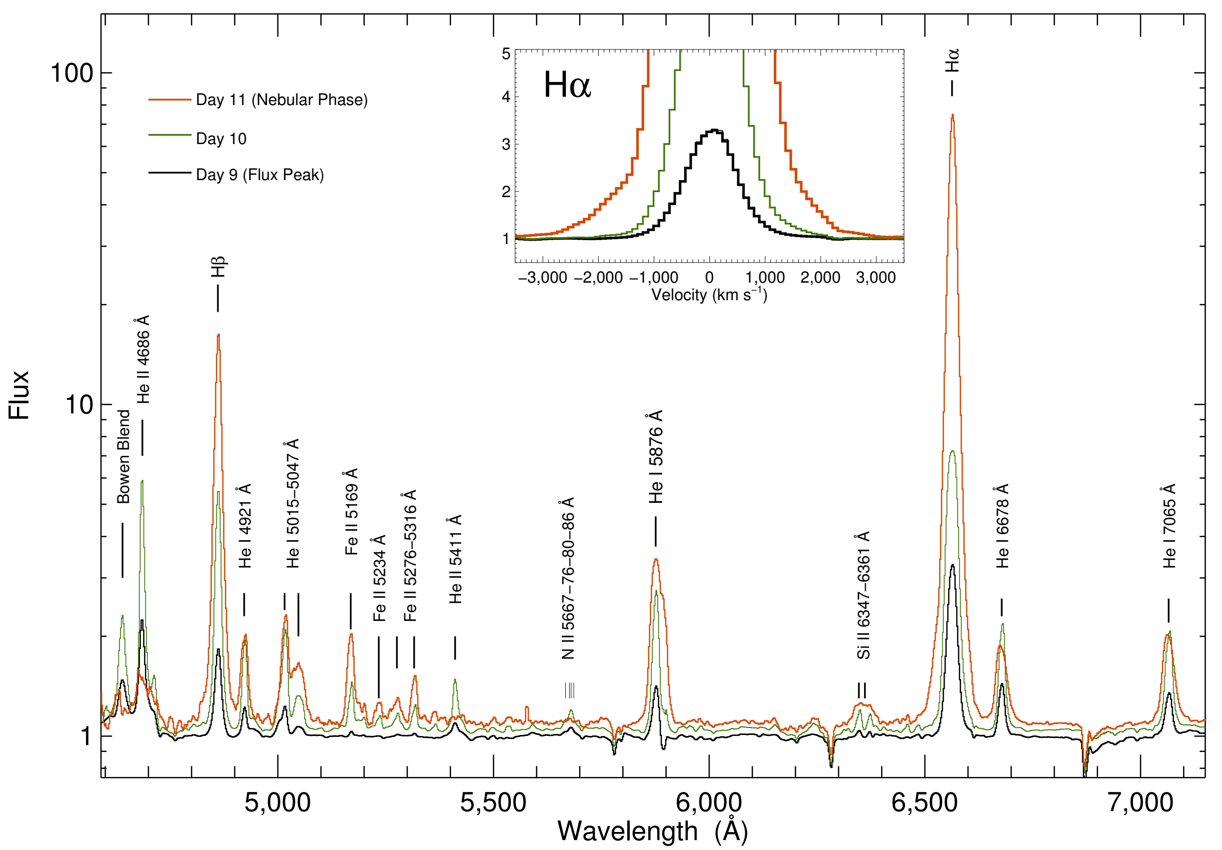


tracking the matter

2015: extremely luminous OUTBURST from the nearby BH V404 Cygni

short (15 days)
extreme (from 20 mCrab to 60 Crab)
reach (~50 papers - inc. 3 Nature)

Munoz-Darias et al. 2016



followed by
broad Balmer lines
(up to 3000 km/s)

—> short-lived
nebular phase

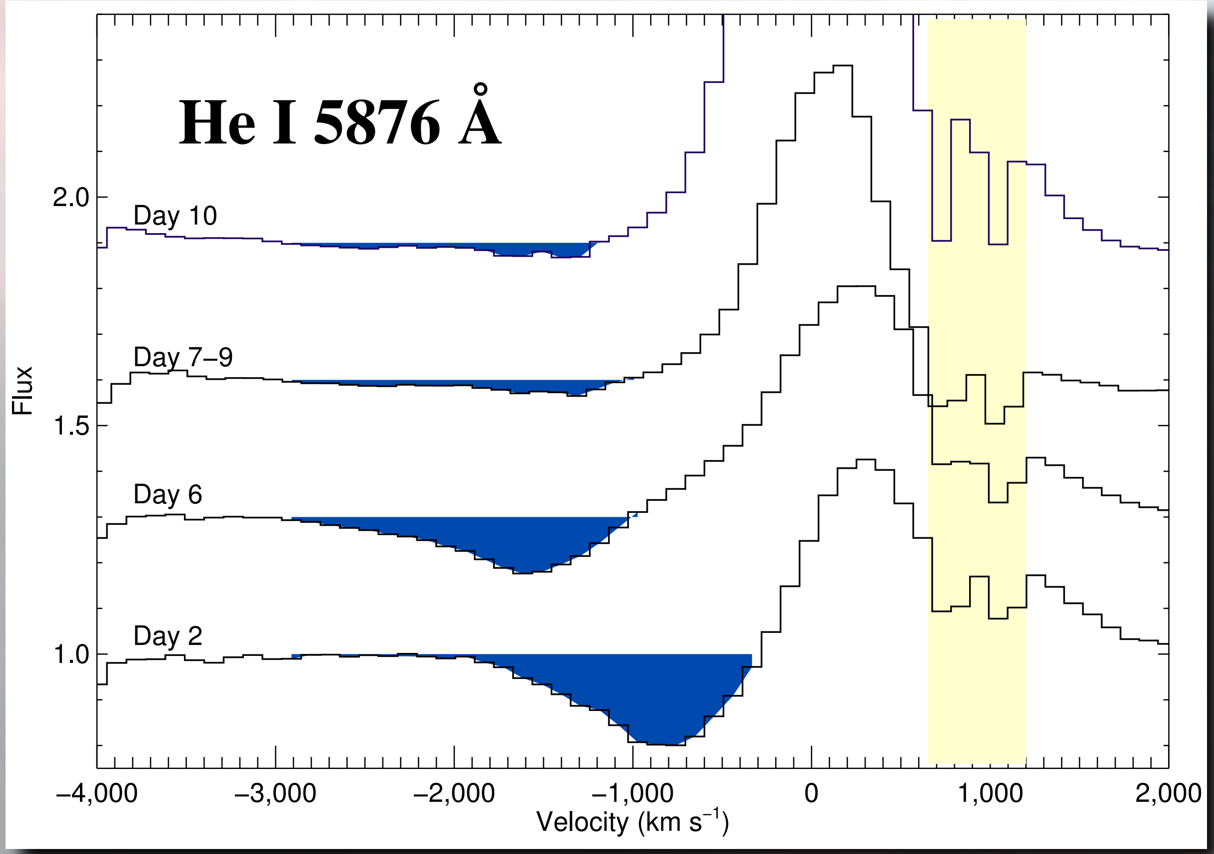
tracking the **matter**

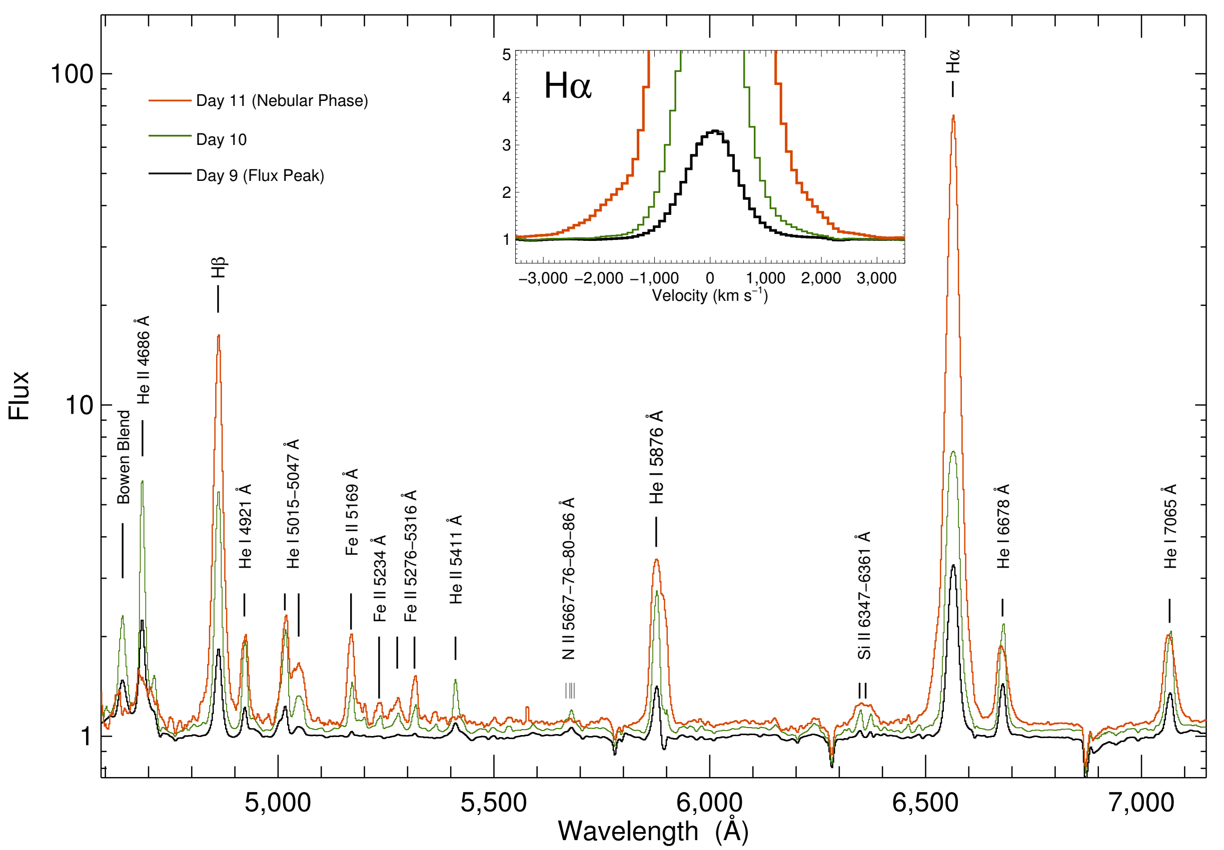
Wind velocity (V_T~1.5–3 x 10^3 km s^{-1})

(escape velocity at 0.5—2 light seconds)

Temperature < 3 x 10^4 K

Munoz-Darias et al. 2016





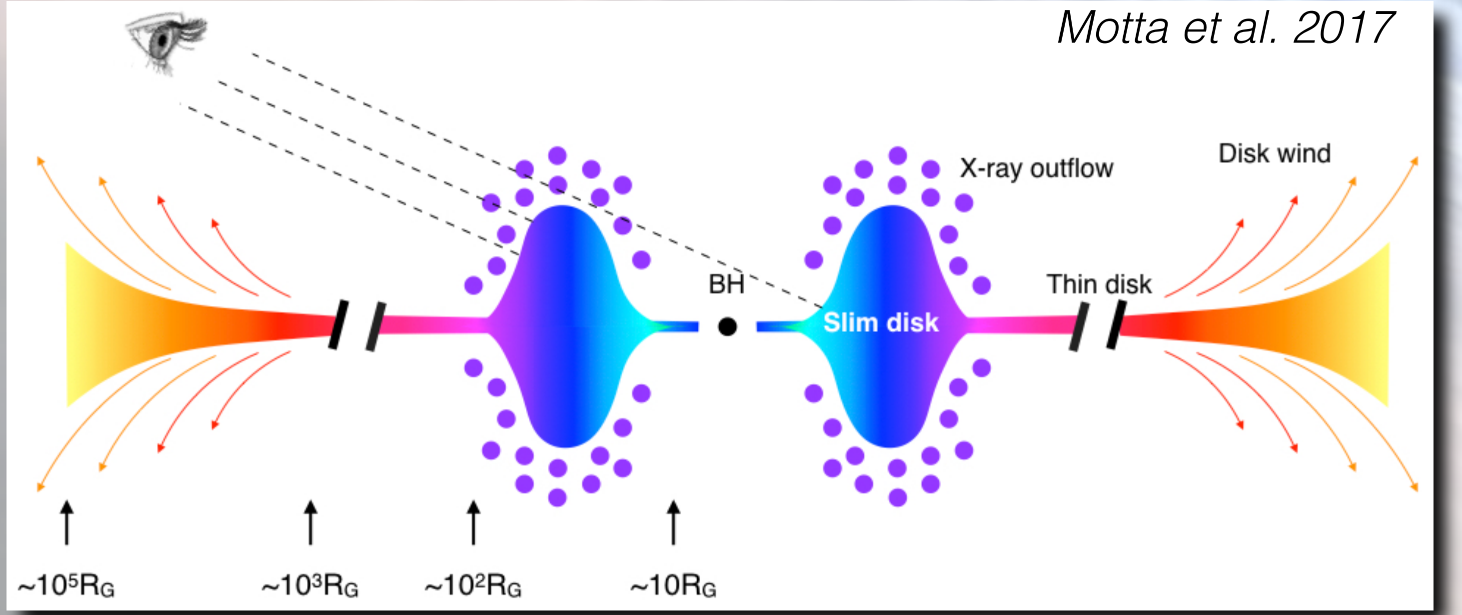
tracking the matter

Matter transferred by the donor ~ 10^{-8} $M_\odot$

Disc contains M_{disc} ~ 10^{-5} $M_\odot$

Matter accreted onto the BH ~ 10^{-8} $M_\odot$

Matter expelled ~ 10^{-8} - 10^{-5} $M_\odot$ ← (transition time - calibrated from SNe)


Motta et al. 2017

Powerful thermal WIND

from the outer disc

regulating the outburst

Munoz-Darias et al. 2016

tracking the matter

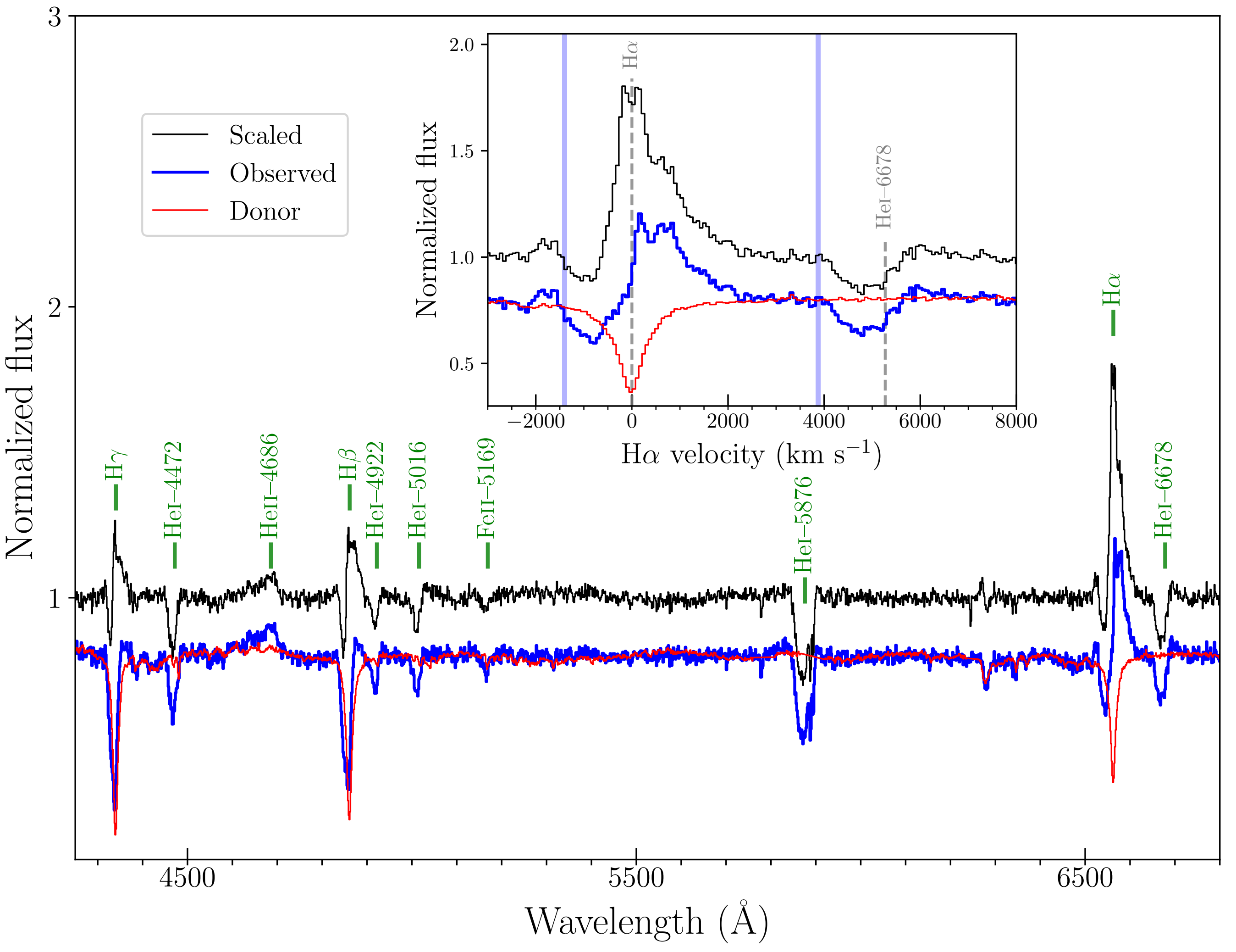
The WIND from the outer disk

is regulating the outburst

another object

(V4641 Sagittari)

archival data



UBIQUITOUS?

BHs & NSs

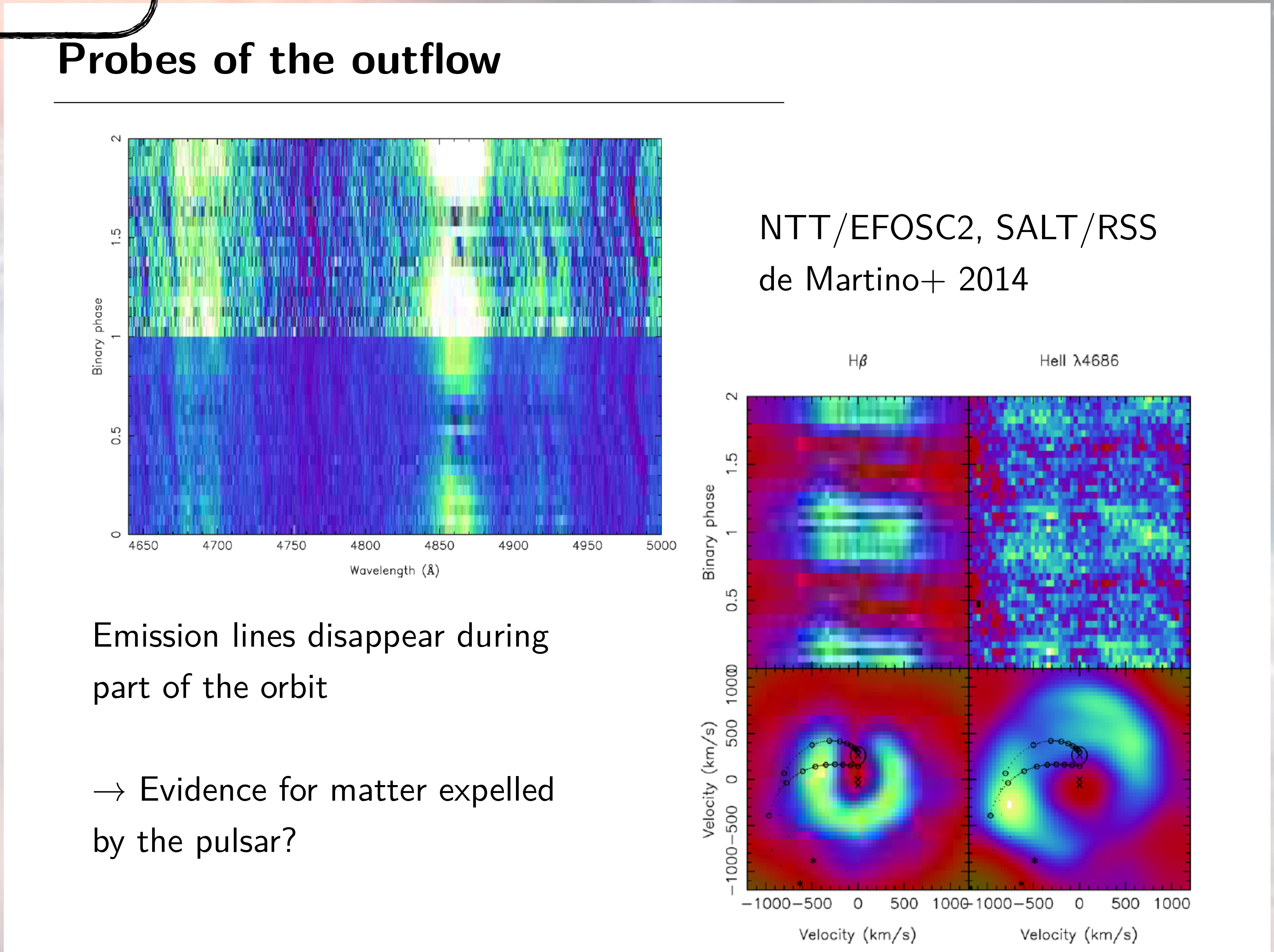
Munoz-Darias et al. 2017

this source was fainter…and was done with a 1.5m telescope

tracking the matter

transitional MSPs

de Martino et al. 2014
Ambrosino, Papitto et al. 2017
Hakala & Kajava 2018
Baglio et al. 2023



Probes of the outflow

NTT/EFOSC2, SALT/RSS
de Martino+ 2014

Emission lines disappear during part of the orbit

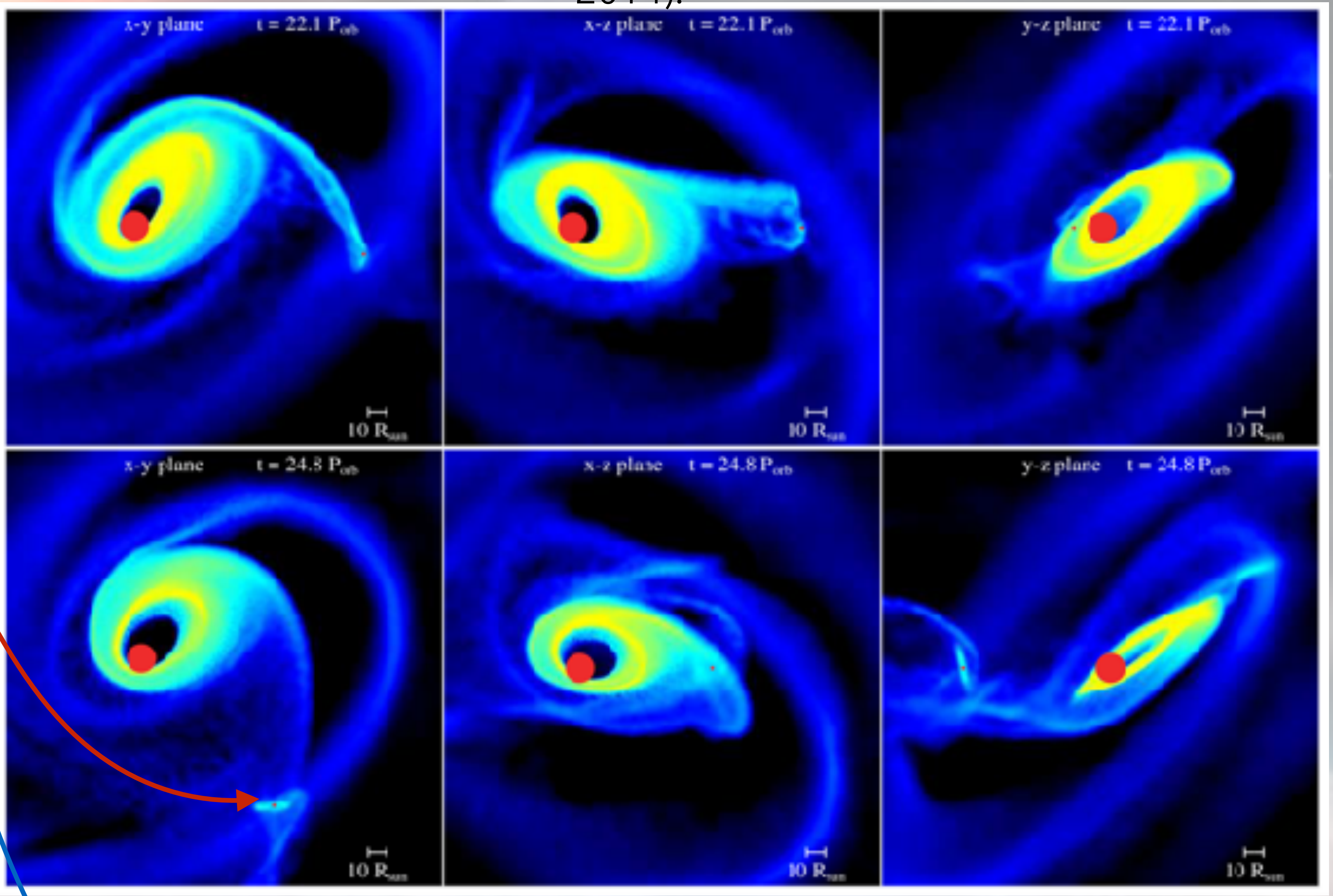
→ Evidence for matter expelled by the pulsar?

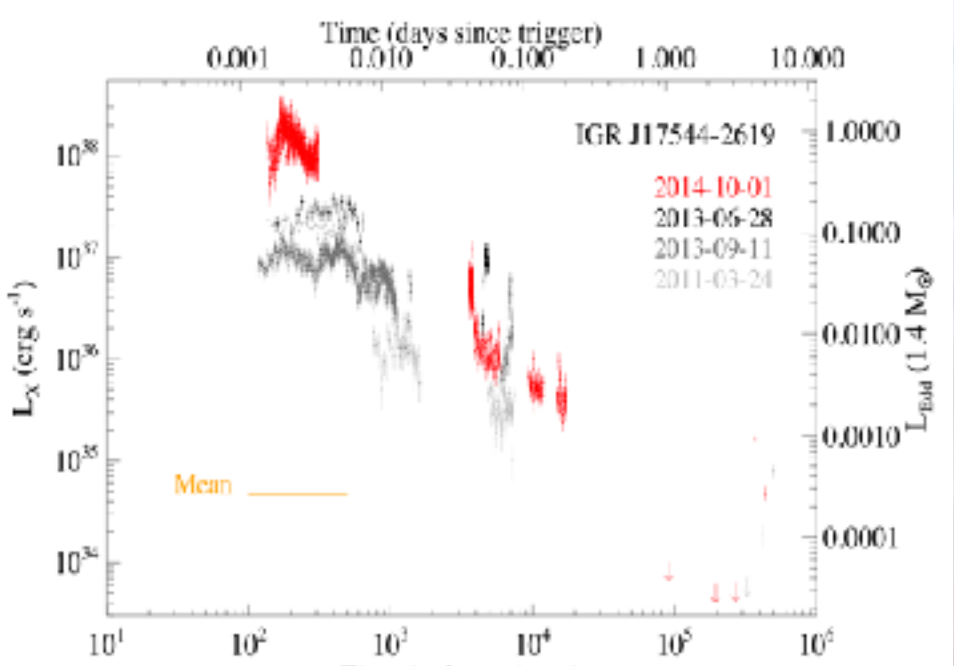
ACCRETION AND EXCRETION DISKS IN HIGH-MASS XBS

DISRUPTION AND FORMATION OF DISKS DURING GIANT OUTBURSTS IN HMXBS

SOXS observations of transient HMXBs during the giant outbursts will allow us to track the possible formation of a transient acceretion disk, the disruption of the excretion disk in BeXRBs, and follow the impact of the outburst event to the local environment of the compact object through spectral line studies.

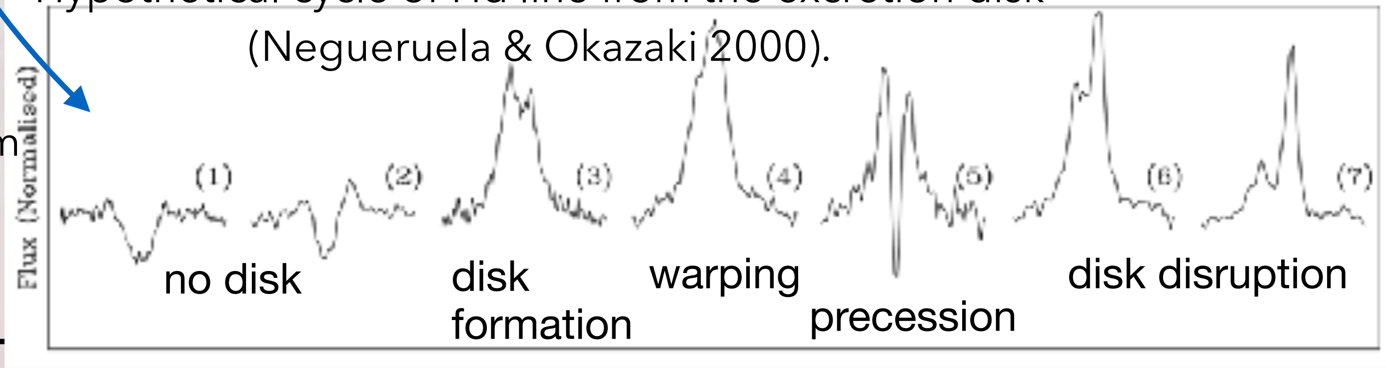
Simulation of the disruption of the Be-star excretion disk and formation of the accretion disk around the compact object during type II outburst (Martin et al. 2014).





Romano et al. 2015

Hypothetical cycle of Hα line from the excretion disk (Negueruela & Okazaki 2000).



Giant outbursts from SFXTs are rare and fast, and the mechanism producing the transient X-ray emission is still an open issue. SOXS will probe the changing stellar wind properties that could be the driving force of the SFXT outbursts.

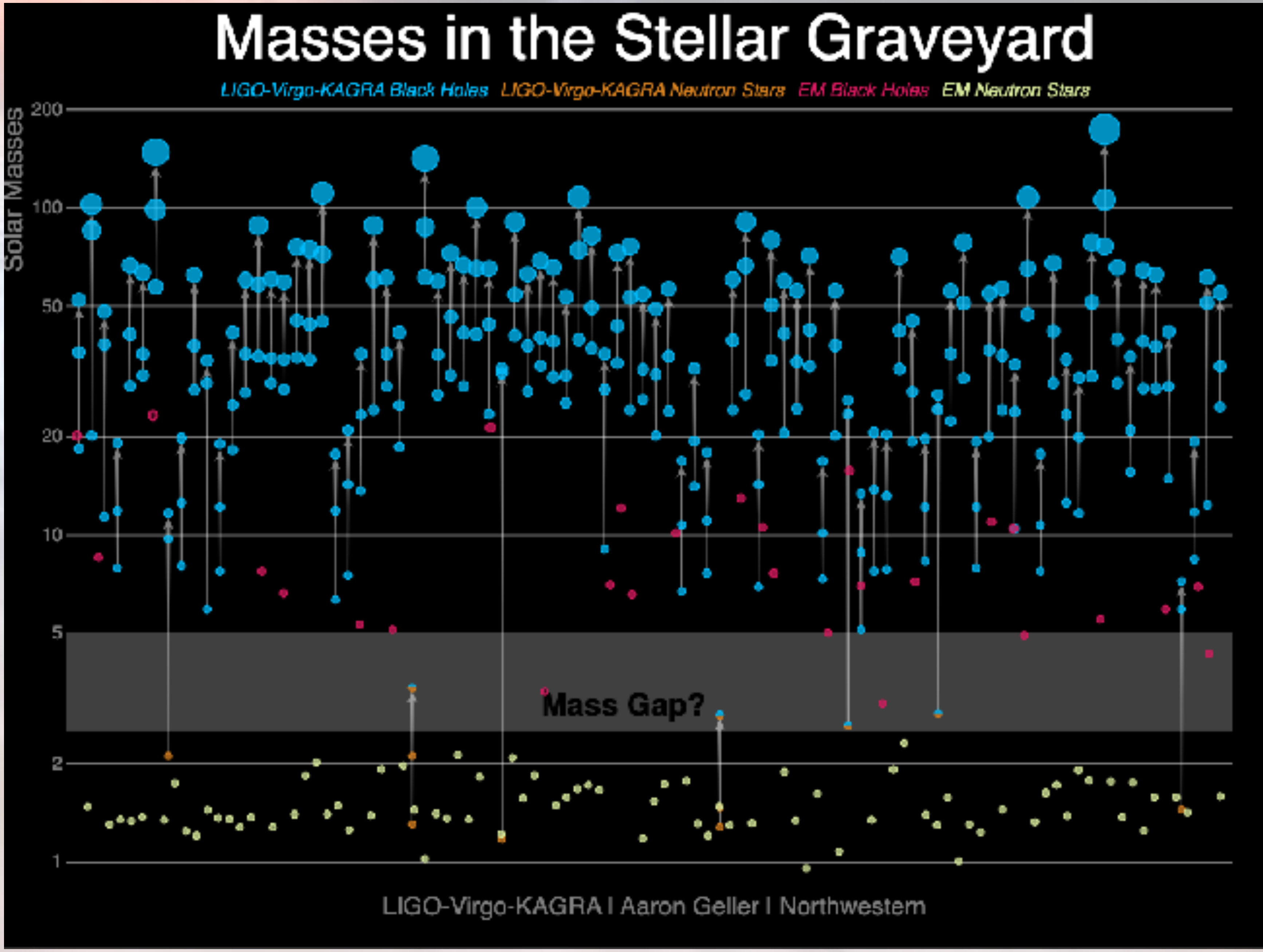
The importance of MASSes

Is the gap real?

..or is it a bias?

Crucial for

Accretion processes



The importance of MASSes

Is the gap real?

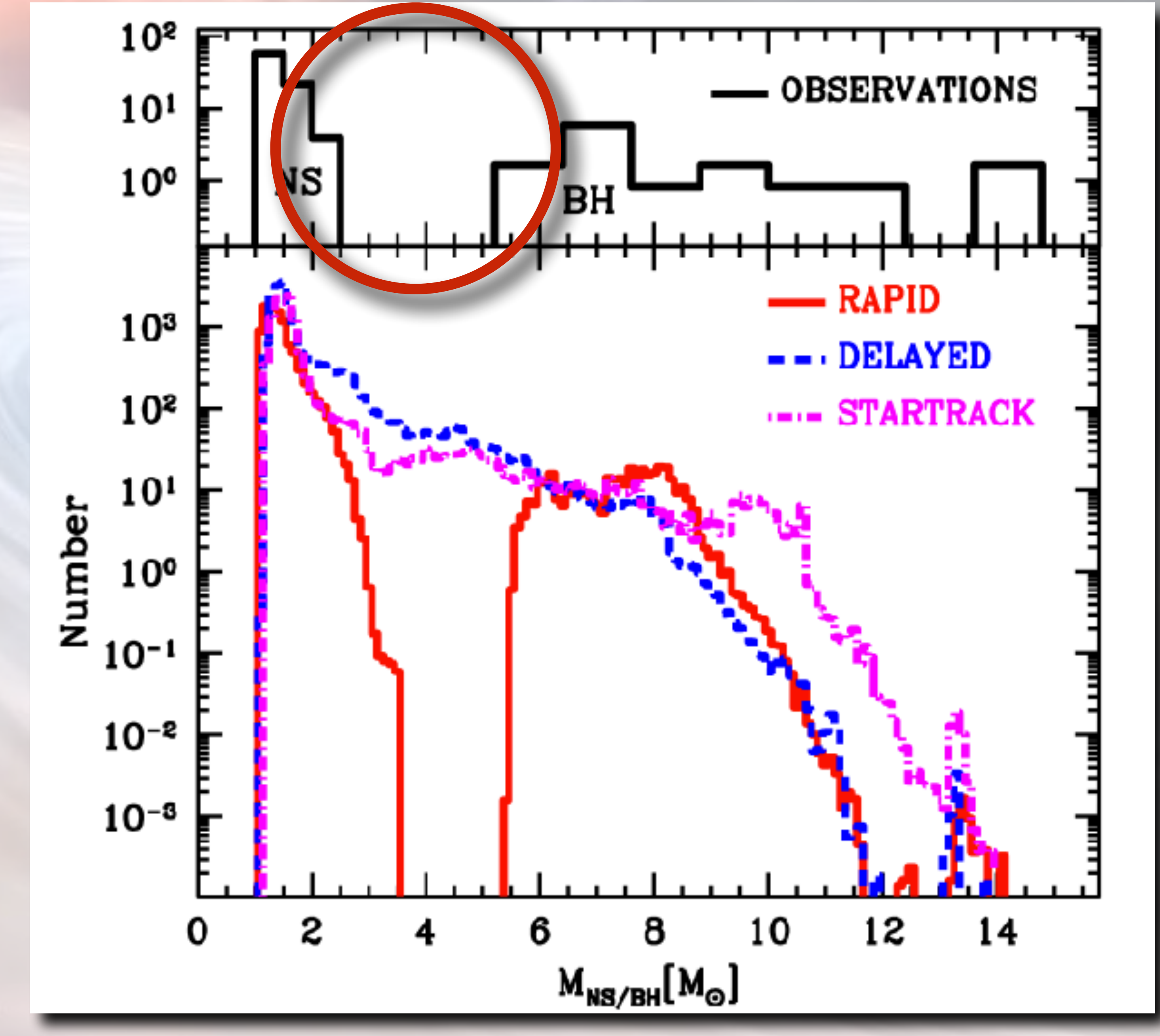
..or is it a bias?

Crucial for

Accretion processes

&

SNe models



Belczynski et al. (2012)

The importance of MASSes

HOW do you obtain a MASS?

1 ~~You trust your X-ray spectral fitting~~

2 ~~You trust your broad-band X-ray timing interpretation~~

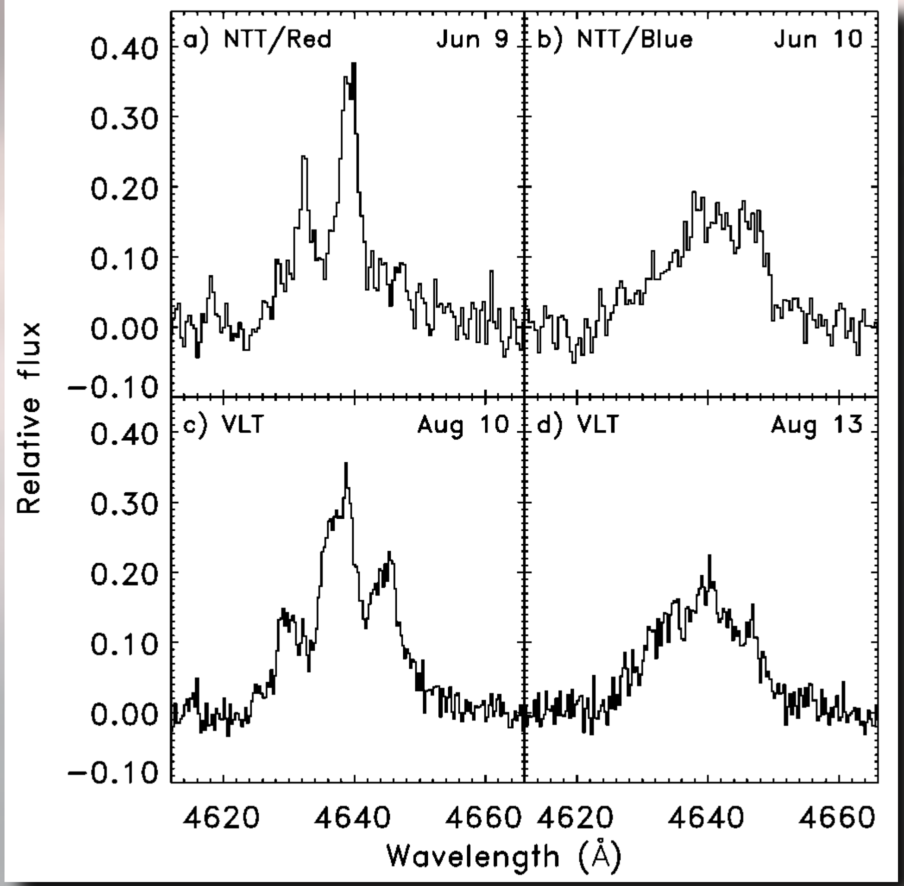
3 You measure it

$$f(M) = \frac{P_{\mathrm{orb}} K^3}{2\pi G} = \frac{M_X \sin^3 i}{(1+q)^2}$$

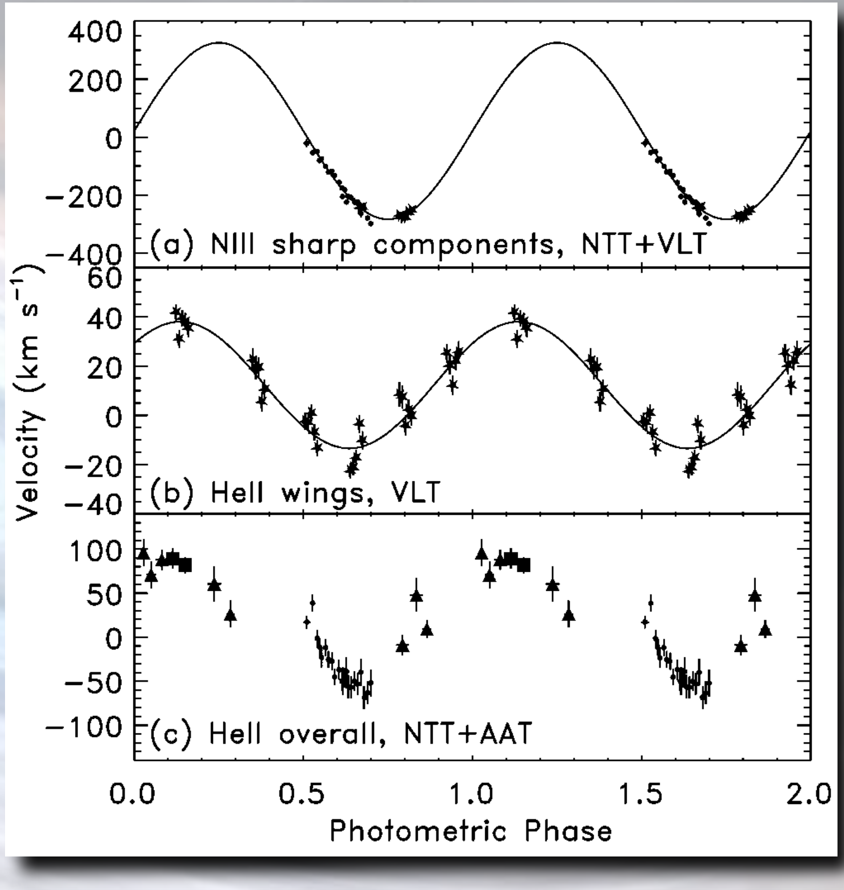
The importance of MASSes

Bowen blend emission lines from the irradiated donor

Outburst
(here GX 339-4 with NTT & VLT in 2002)



Hynes et al. (2003)



$$f(M) = \frac{P_{\mathrm{orb}} K^3}{2\pi G} = \frac{M_X \sin^3 i}{(1+q)^2}$$

f(M) = 5.8 +/- 0.5 Mo

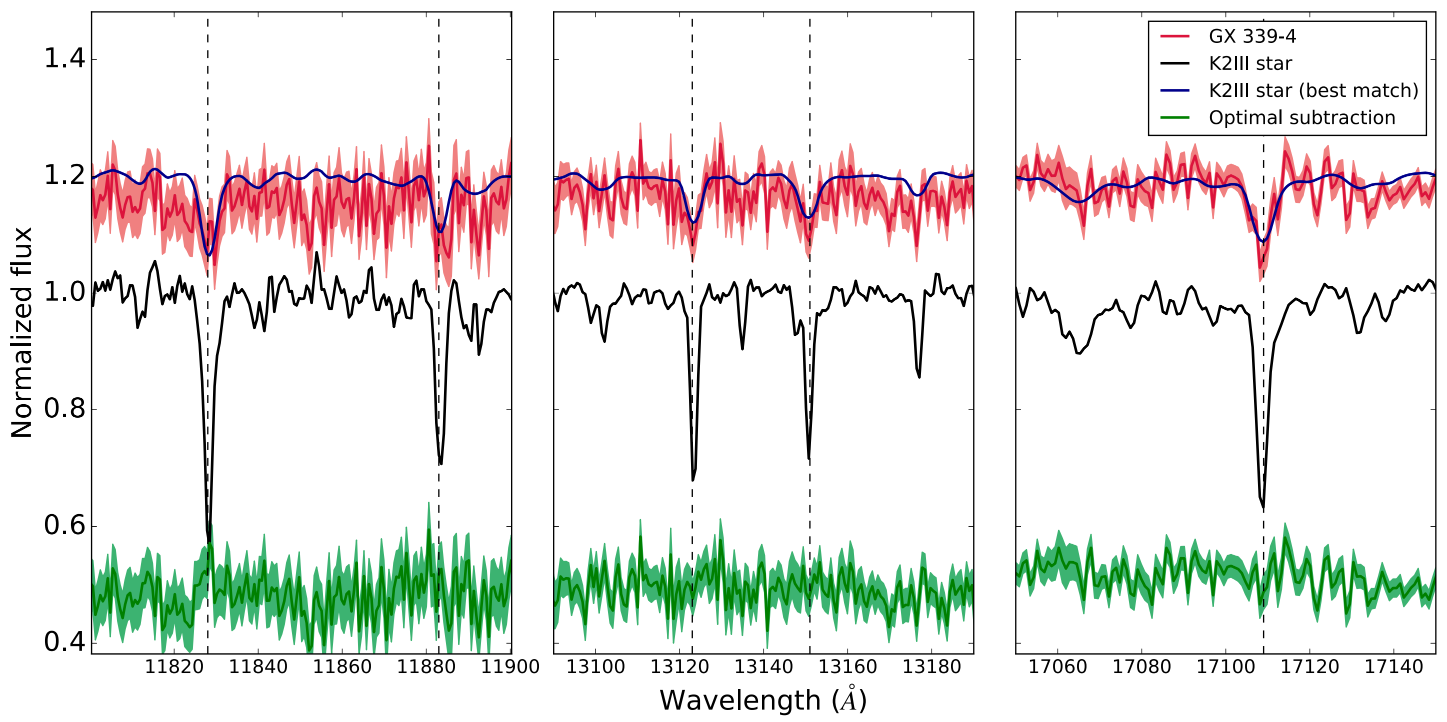
P ~ 1.76 days

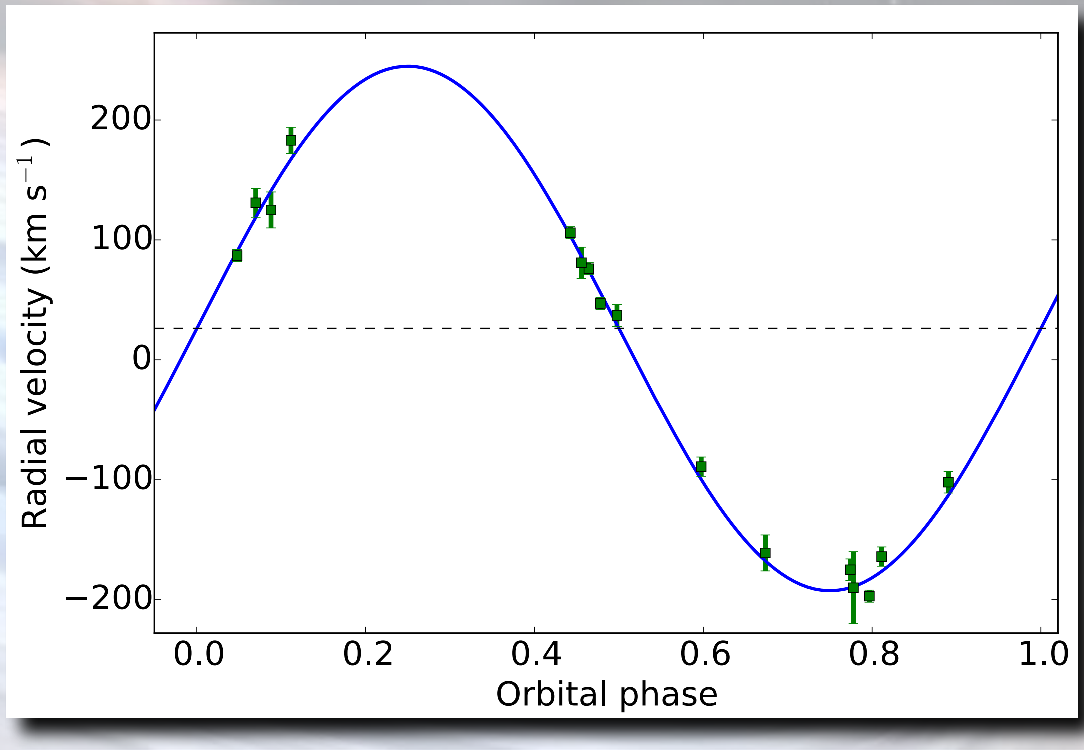
The importance of MASSes

absorption lines from the donor

Decay to quiescence
(here GX 339-4 with X-Shooter)

Heida et al. (2017)





better S/N in infrared

$$f(M) = \frac{P_{orb} K^3}{2\pi G} = \frac{M_X \sin^3 i}{(1+q)^2}$$

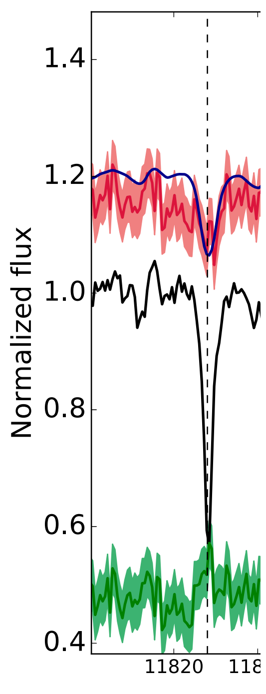
f(M) = 1.91 +/- 0.08 Mo

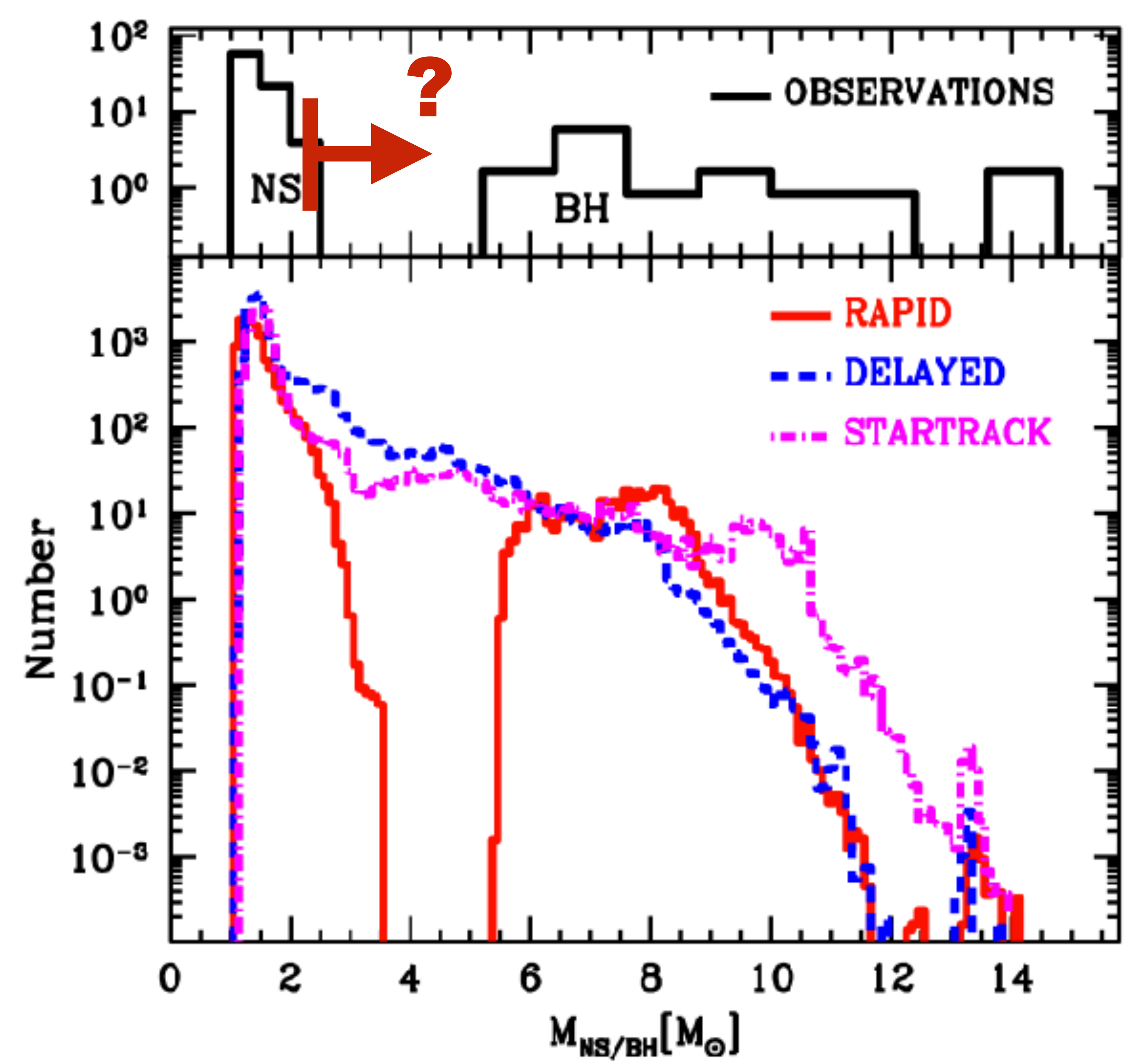
P ~ 1.76 days

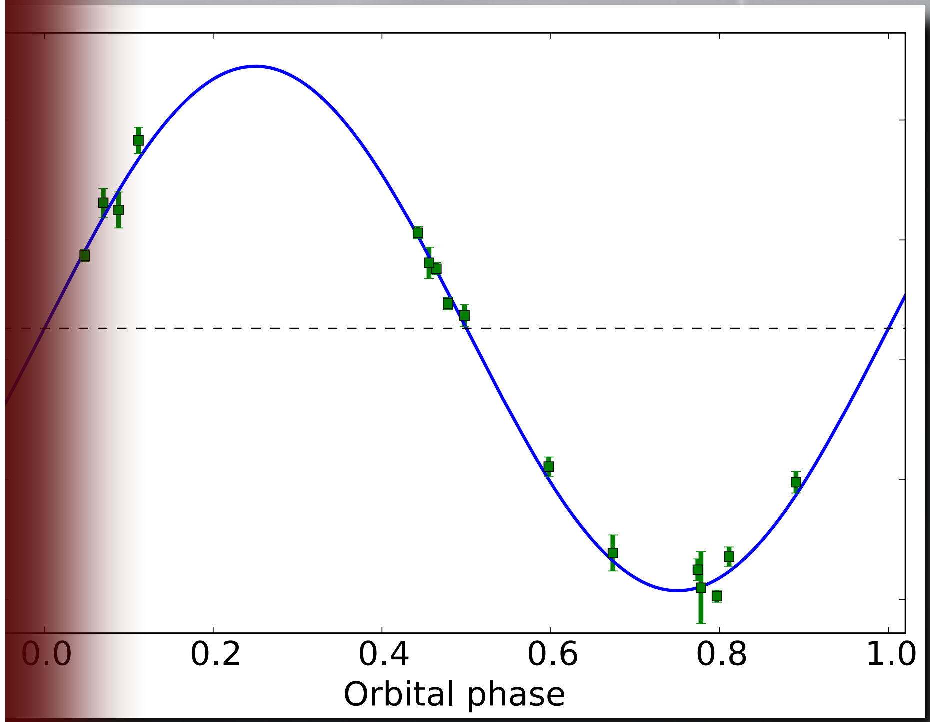
The importance of MASSes

absorption lines from the donor

oter)







f(M) = 1.91 +/- 0.08 Mo

P ~ 1.76 days

better

WG3 : Transient X-ray Binaries, Magnetars, ULXs

- Black Hole-Transients

- 1 outburst / semester
- outburst duration: few weeks - several months
- each spectrum: 200s - 1500s (up to 1.5 hr extreme cases)

1 target

1 obs / week	4-40	full outburst long-term evolution
1 obs / day	3-7	initial stages (outer outflow)
1 obs / day	5-20	bright transition (wind onset)
1 obs / day	3-20	Ultra-luminous State (rare)
1-2 obs / week	5-20	decay transition (jet onset)

- if short orbital period: 10-20 obs in 1 night

over 5 years:

- **MINIMUM = 100 hr**

(very few goals on very bright targets)

- **OPTIMAL = 900 hr**

(all goals on all targets)

- **REALISTIC = 300 hr**

- **transitional MSPs**

- 3 transitions (in 5 years)
- each spectrum: 1 hr

1 target

- 1-2 obs / 3-5 days	10-20	SED evolution
- 15 obs / day	60	tomography, orbital, outflows

<u>over 5 years:</u>

- **MINIMUM = 90 hr**

  (1 target, minimal coverage)

- **OPTIMAL = 312 hr**

  (3 targets, optimal coverage)

WG3 : Transient X-ray Binaries, Magnetars, ULXs

- **Accreting MSPs**

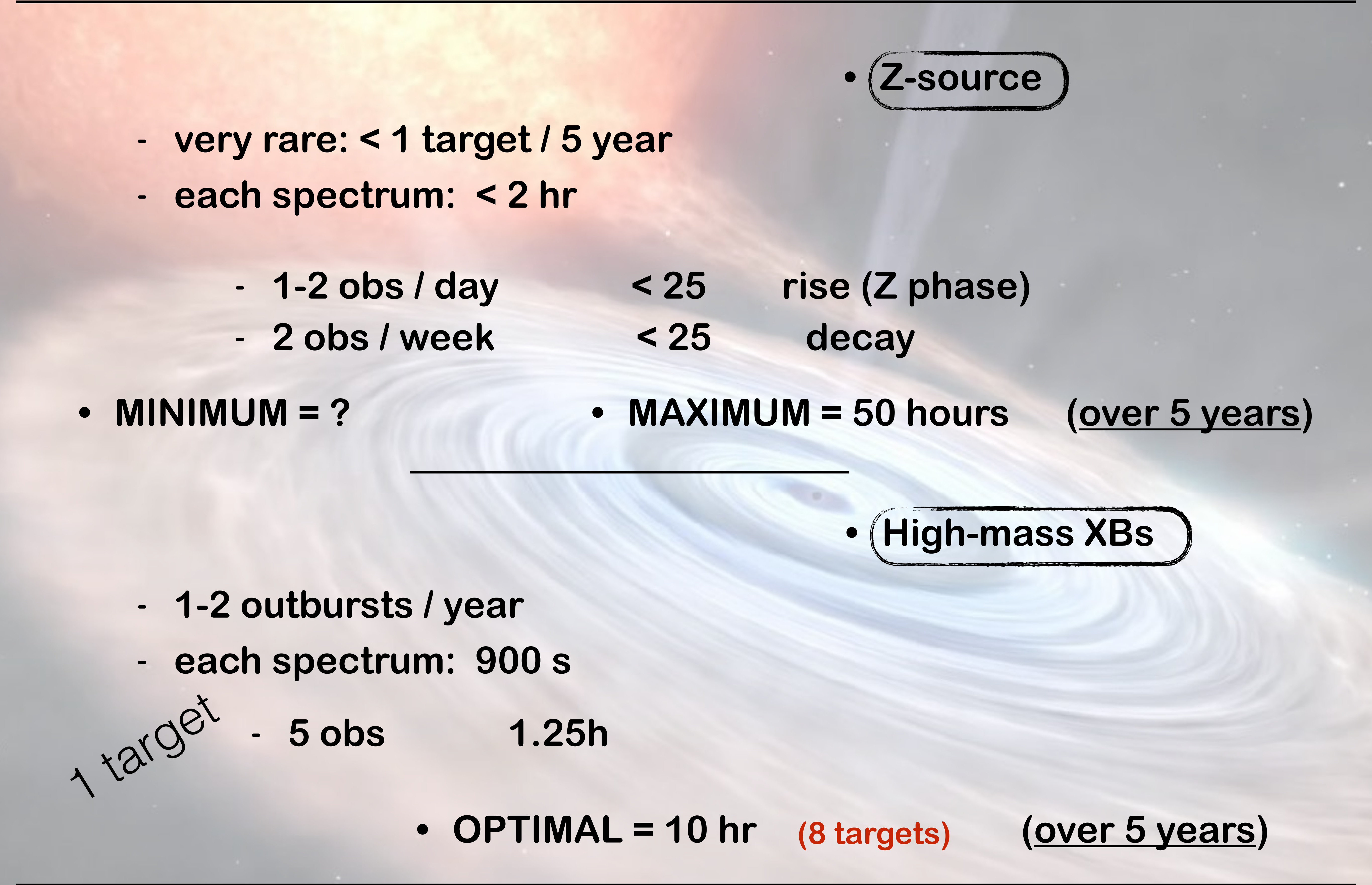
- **2-3 targets (in 5 years)**
- **outburst duration: 1-2 weeks**
- **each spectrum ~ 1 hr**

1 target

- **1 x 10**	**10**	**SED evolution, outflows**
- **5 x 5**	**25**	**tomography, orbital**

over 5 years:

- **MINIMUM = 35 hr**
  (1 target)
- **OPTIMAL = 100 hr**
  (3 targets)



- Z-source

  - very rare: < 1 target / 5 year
  - each spectrum: < 2 hr

    - 1-2 obs / day   < 25   rise (Z phase)
    - 2 obs / week   < 25   decay

- **MINIMUM = ?**
- **MAXIMUM = 50 hours**   (over 5 years)

- High-mass XBs

  - 1-2 outbursts / year
  - each spectrum: 900 s

1 target

    - 5 obs   1.25h

- **OPTIMAL = 10 hr**   (8 targets)   (over 5 years)

- **NS transients**

- 1 outburst / year
- each outburst duration: ~ 1 month
- each spectrum: ~3 hours

1 target

- 2 obs / week 30

- OPTIMAL = 150 hours (5 targets) (over 5 years)

- **Magnetars**

(à la SWIFT J195509+261406)

- very rare: 1 target / 5 year
- activity phase: a few days

- OPTIMAL = 10 hr (over 5 years)

WG3

20 members (Italy, Finland)
~25 ideas/proposals received

Black Hole-Transients
Accreting Millisecond Pulsars
New Transient X-ray pulsators
Transitional Millisecond Pulsars
Neutron-Star Transients
Z-sources
Magnetars
High-mass X-ray Binaries
Ultra-luminous X-ray Sources

over 5 years:

- **MINIMUM = 750 hr**
- **OPTIMAL = 1600 hr**

The importance of
OIR spectroscopy
in the Universe

SOXS in 5 years CAN
(for many new XBs & friends)

- **Systematically measure mass functions**
- **Detect and study outflows (jets and winds)**
- **Provide excellent spectra to track various components**
- **Perform Doppler tomography**
- **Identify and Classify unknown objects**

- MINIMUM = 750 hr
- OPTIMAL = 1600 hr