



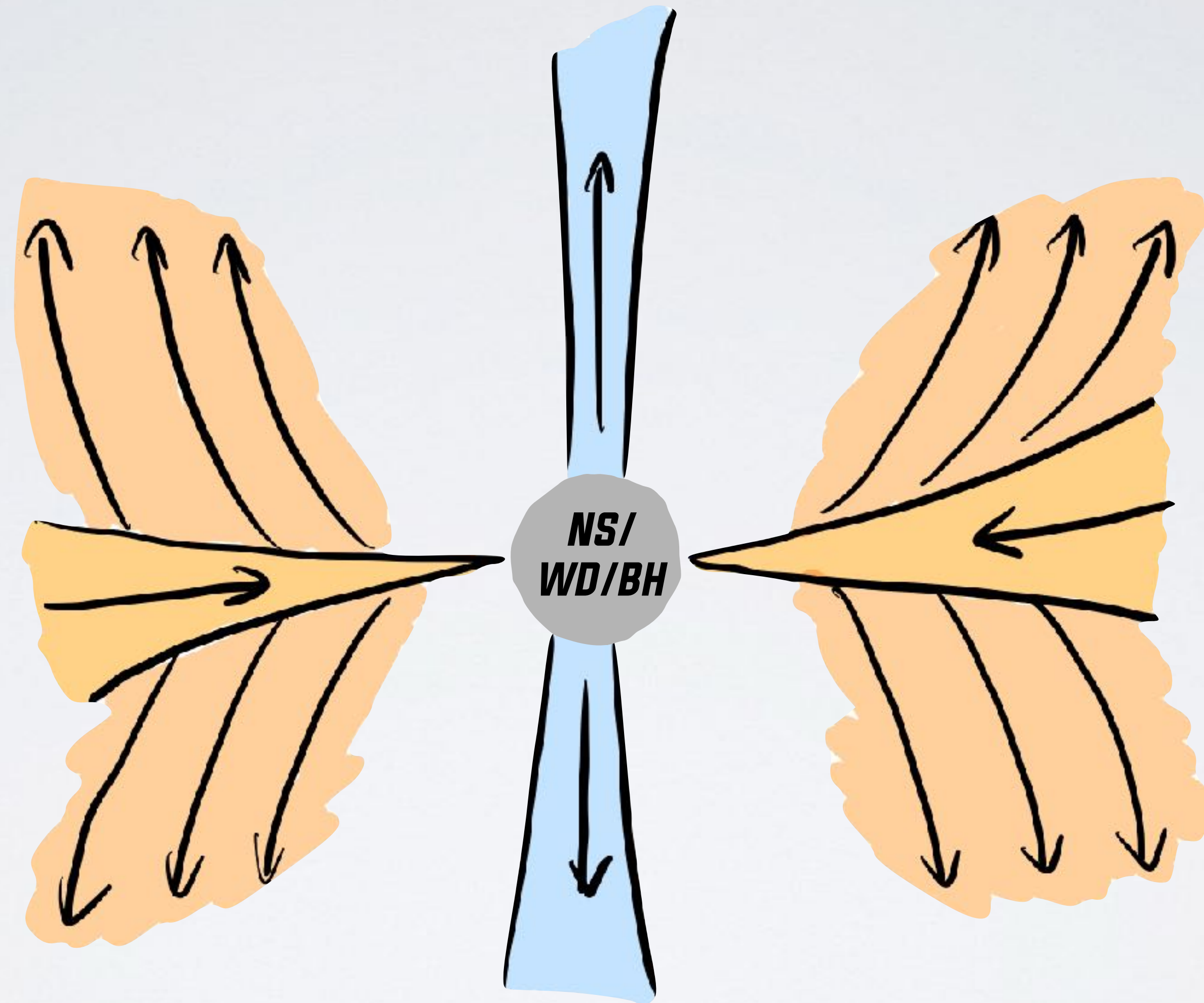
Accretion-outflow connection in binaries: 5 key challenges

James Matthews (Oxford Astrophysics)

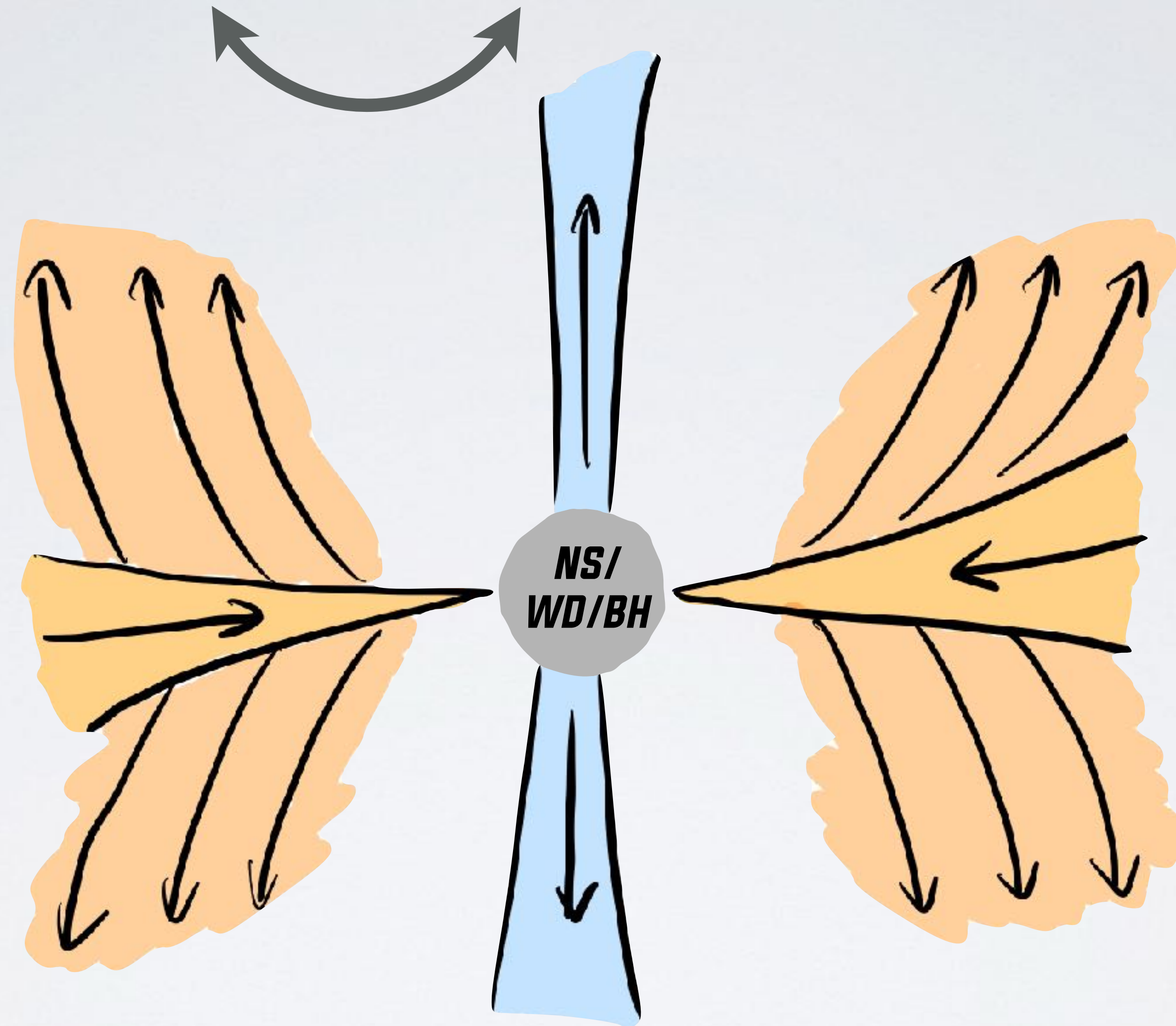
Rob Fender, Katie Savard, Ian Heywood, Alex Cooper, Clara Lilje, Emma Elley (Oxford), Knox Long (STScI, Eureka), Christian Knigge, Nick Higginbottom, Austen Wallis, Amin Mosallenezhad, Edward Parkinson (Southampton), Stuart Sim (Queen's Belfast), Pierre-Olivier Petrucci, Jonathan Ferreira, Nico Scepi, Maxime Parra, Nathan Zimniak (Grenoble), Alessandra Ambrifi, Teo Munoz-Darias (IAC Tenerife), SIROCCO and ThunderKAT++



The ins and outs of accretion



The ins and outs of accretion



5 key questions

1. What is the connection to the disc state?
2. What drives disc winds?
3. What drives jets, including in WDs+NS?
4. What are the mass/energy budgets of jets and winds?
5. What is the connection to AGN?

I'm ignoring propellor systems, highly magnetised WDs and NSs, pulsar-like things, I'M SORRY, but see e.g. Veresvarska poster, Sun talk, Knight talk

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Addressing these 5 challenges would represent a major step forward

(But is unlikely in 12 minutes)

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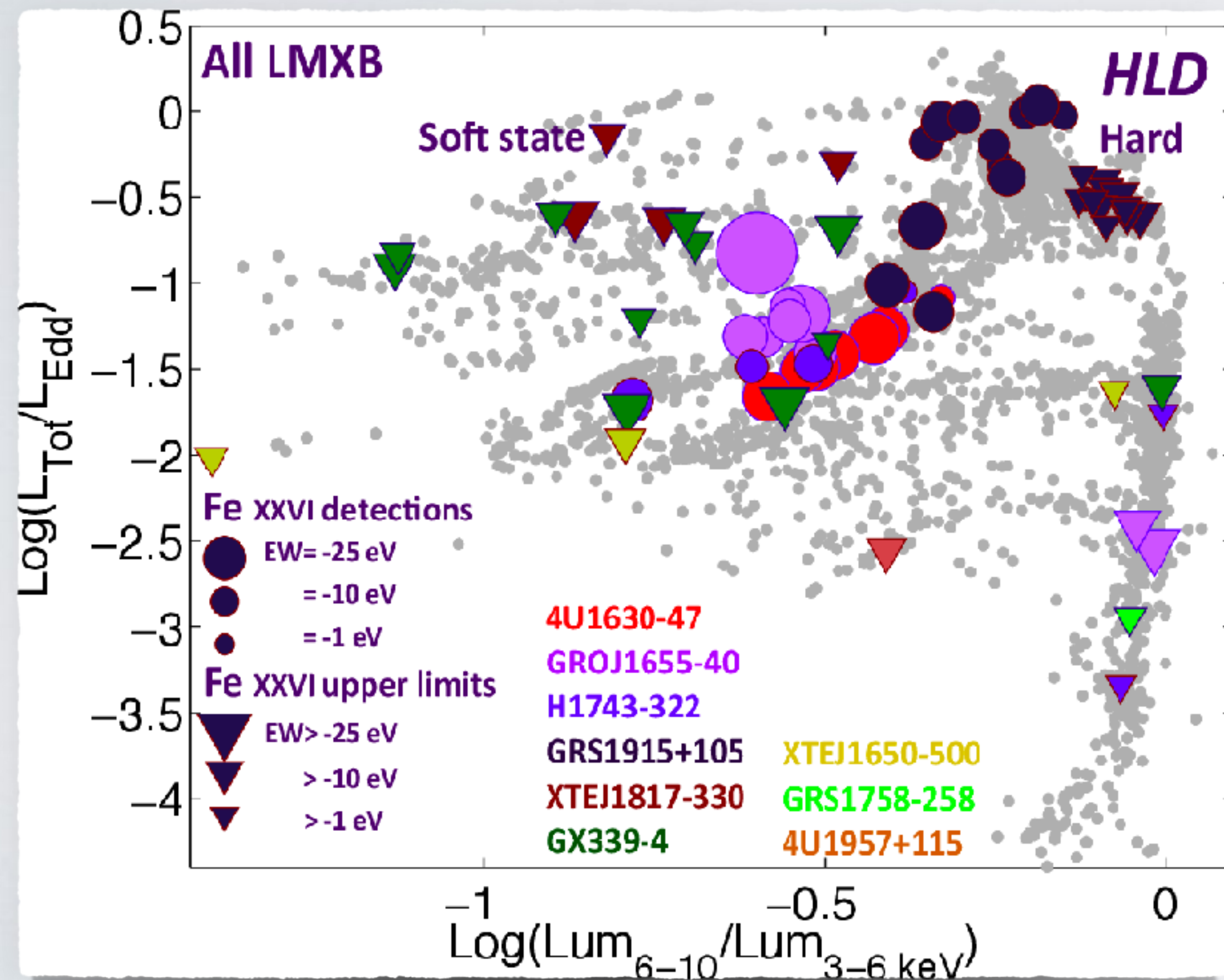
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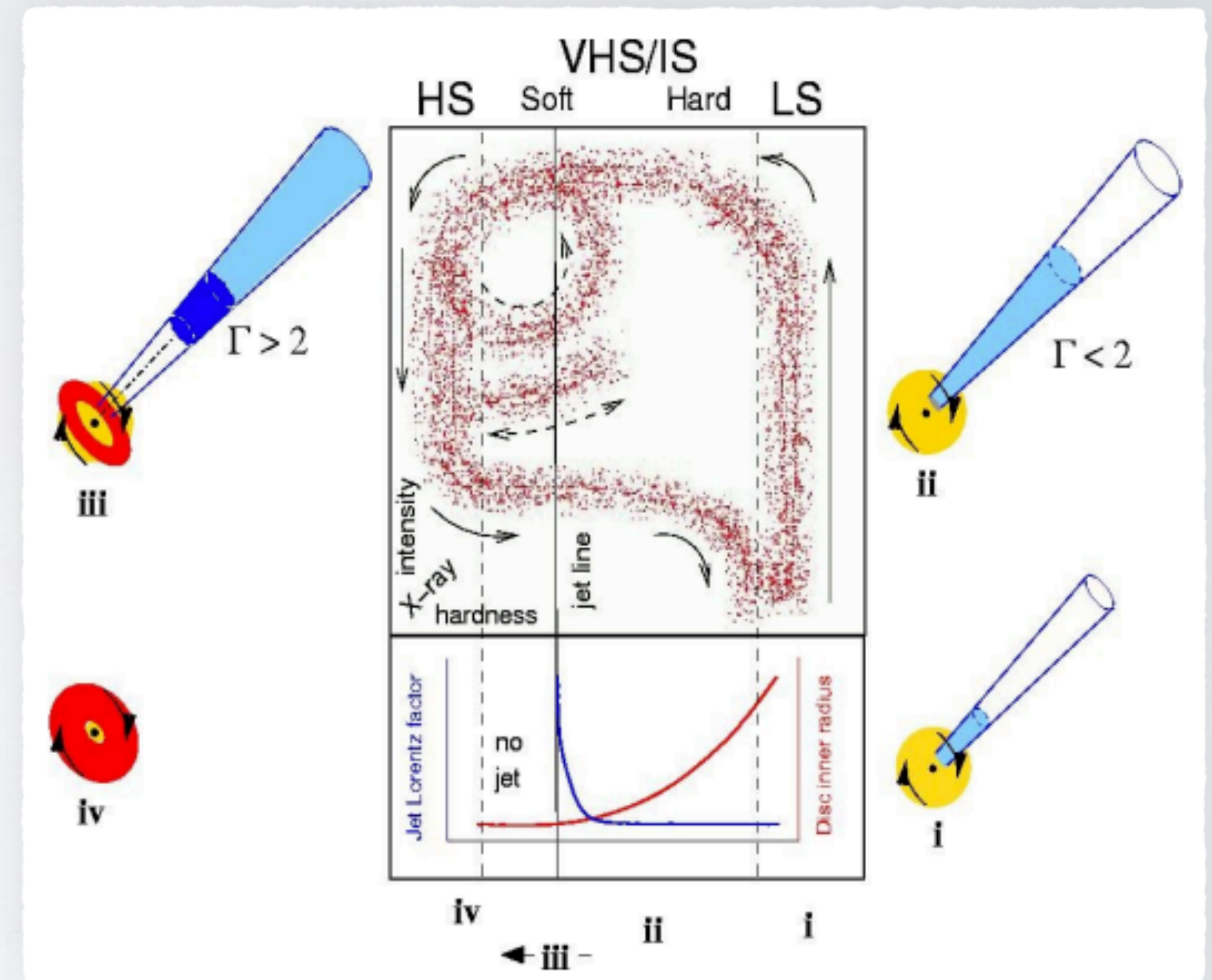
Talk shoutouts

1. What is the connection to the disc state? [XRBs]

- ✦ In XRBs, winds and jets tend to appear in distinct regions of hardness-intensity space*
- ✦ Implies an intrinsic connection between wind/jet mechanism and disc state



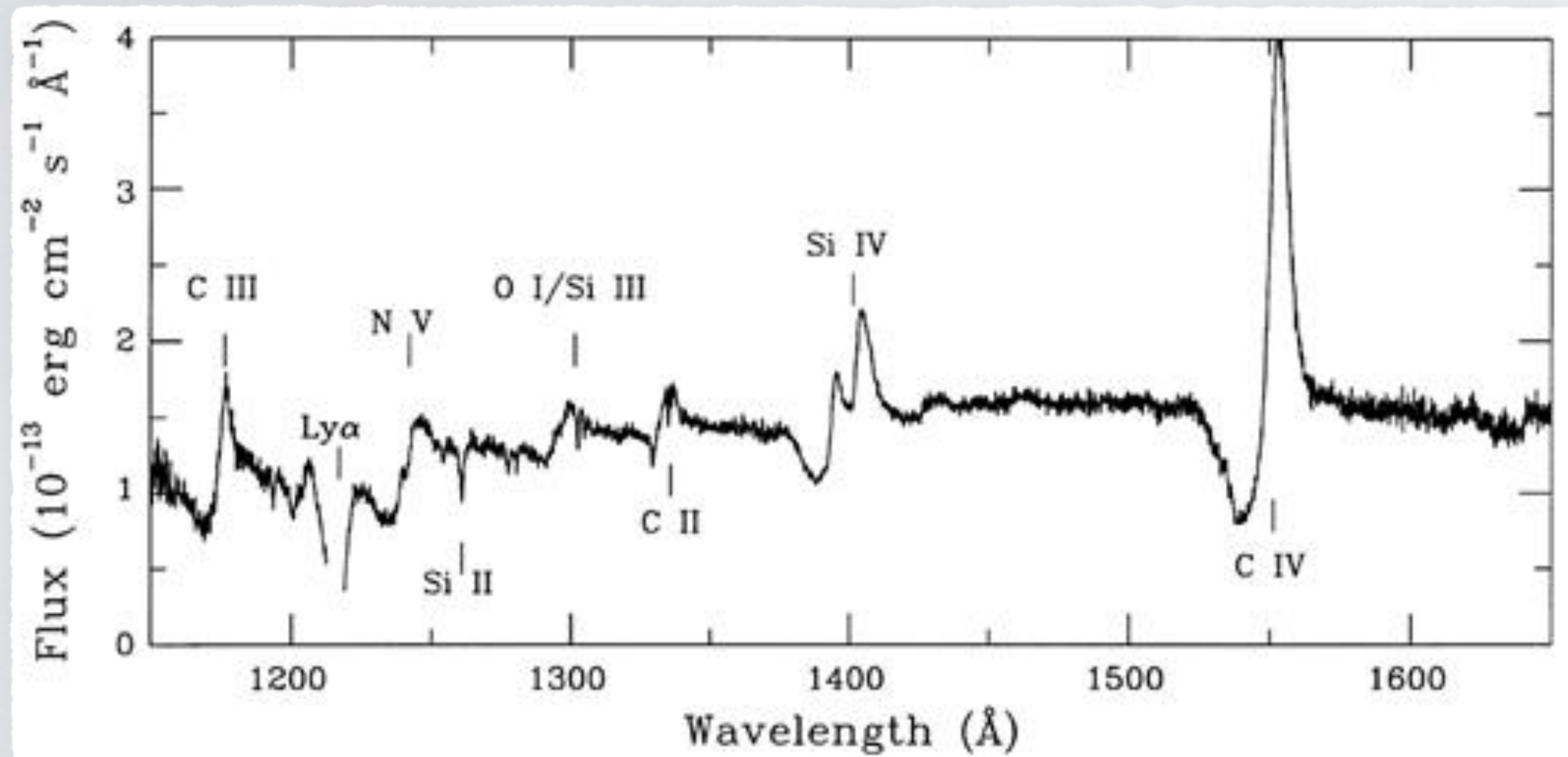
Ponti+ 2012: equatorial X-ray winds in soft states



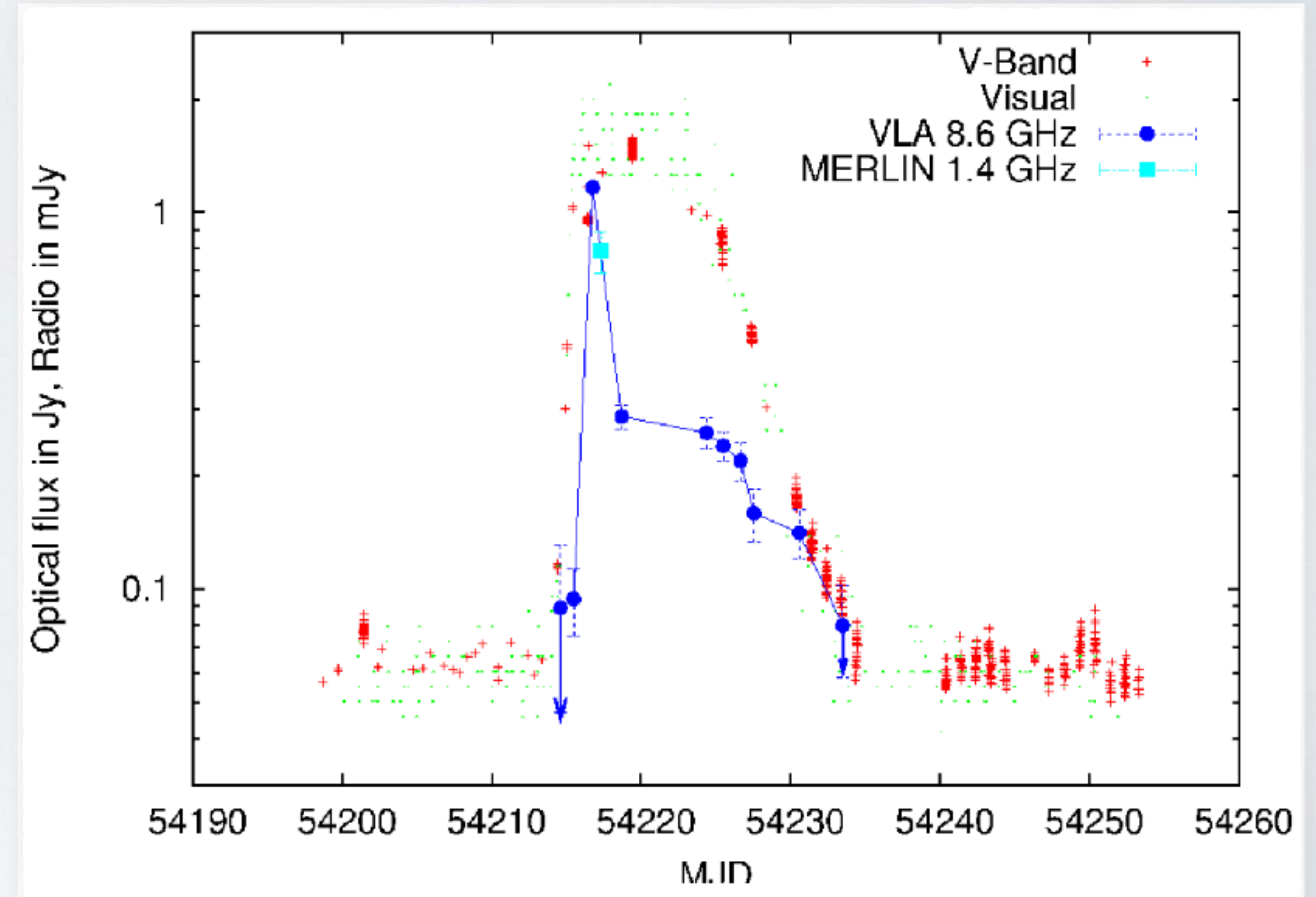
Jet Q-diagram pictures (jet in hard state, relativistic ejection at transition?), Rob Fender

1. What is the connection to the disc state? [CVs]

- CV disc winds observed in UV and optical; in high accretion states (DNe in outburst, Nova-likes)
- Radio landscape is complex; at least some detections in DN outbursts and some NLs
- Analogous “Q-shape” behaviour during DN outbursts ([Kording+2008](#))



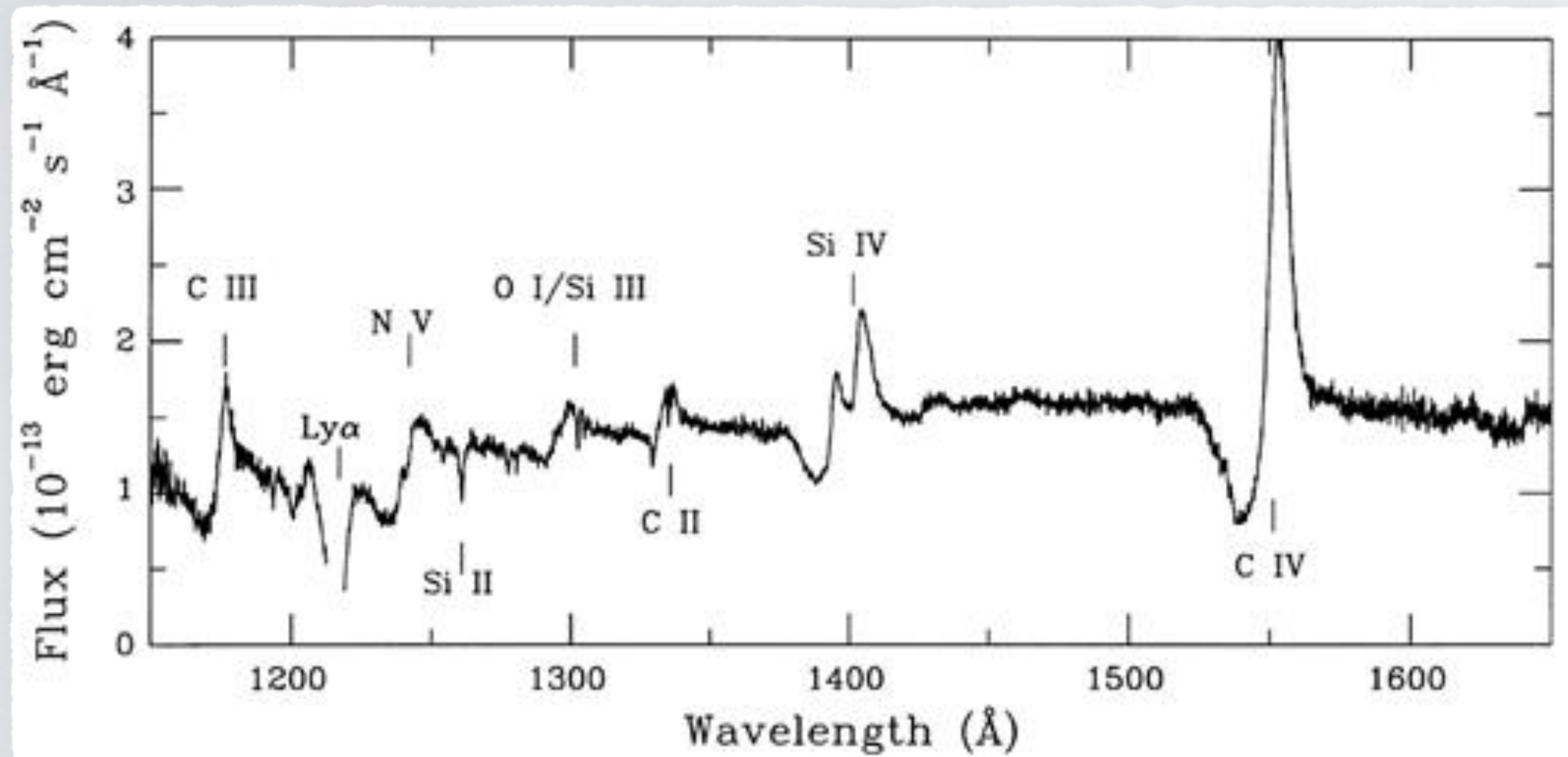
[Prinja+ 00, BZ Cam](#)



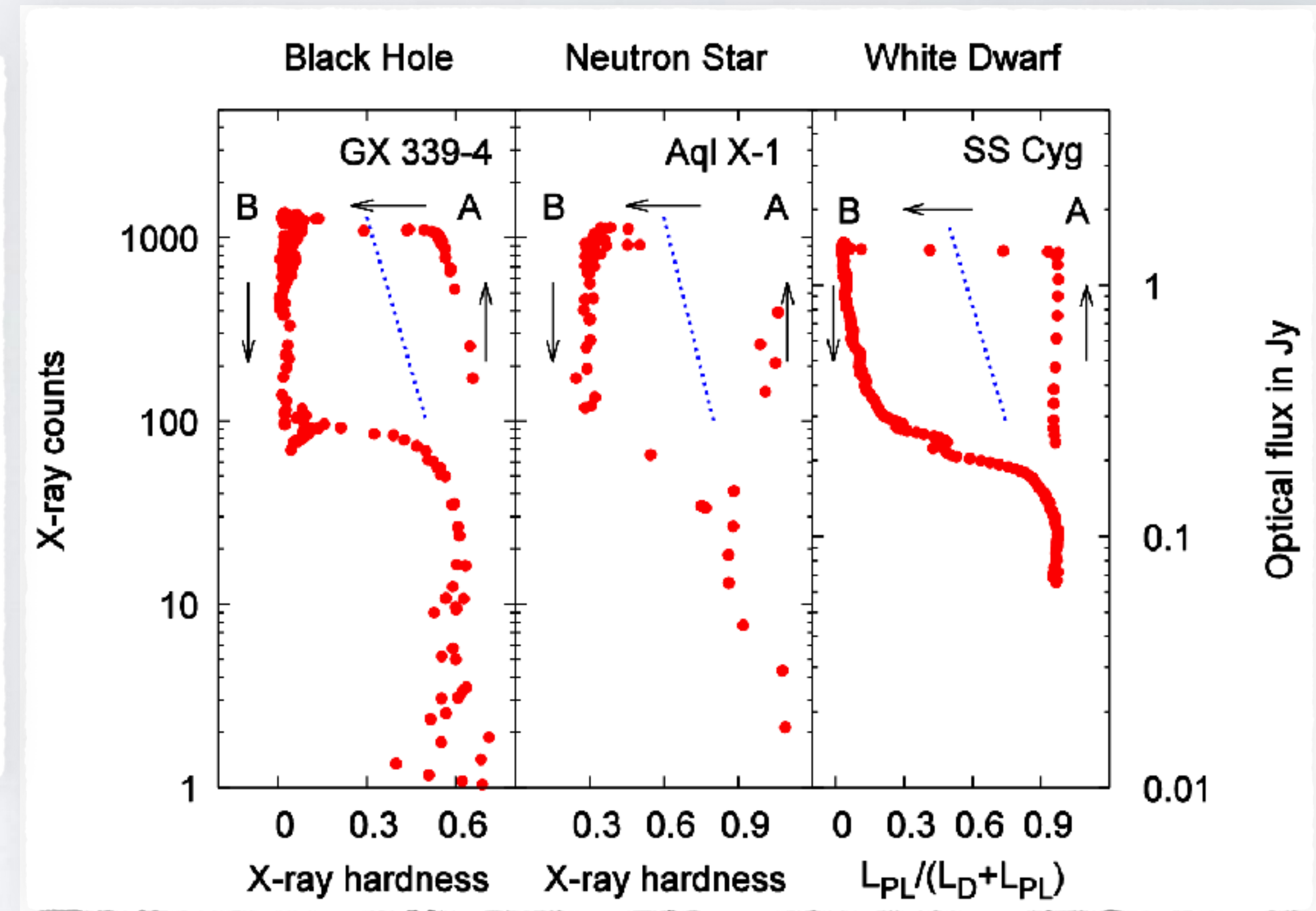
[Kording+2008](#)

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Kording+2008

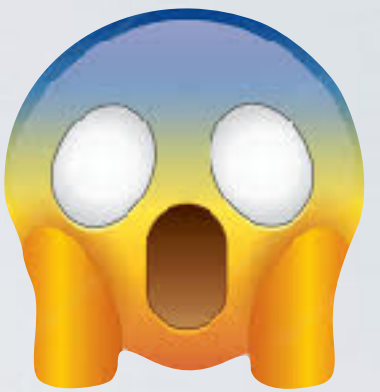
Outflow driving (“Defying Gravity”)



Lagrangian rate of change of momentum

Gravity of compact object

$$\rho \frac{d\vec{v}}{dt} = -\nabla P + \frac{1}{\mu_0} \vec{B} \times (\nabla \times \vec{B}) + \rho \vec{g}_{\text{rad}} - \rho \vec{g}$$



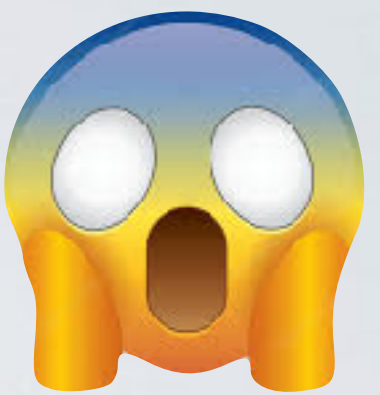
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Pressure gradient

Radiation force

Lorentz force + Ampere's law

Thermal Driving

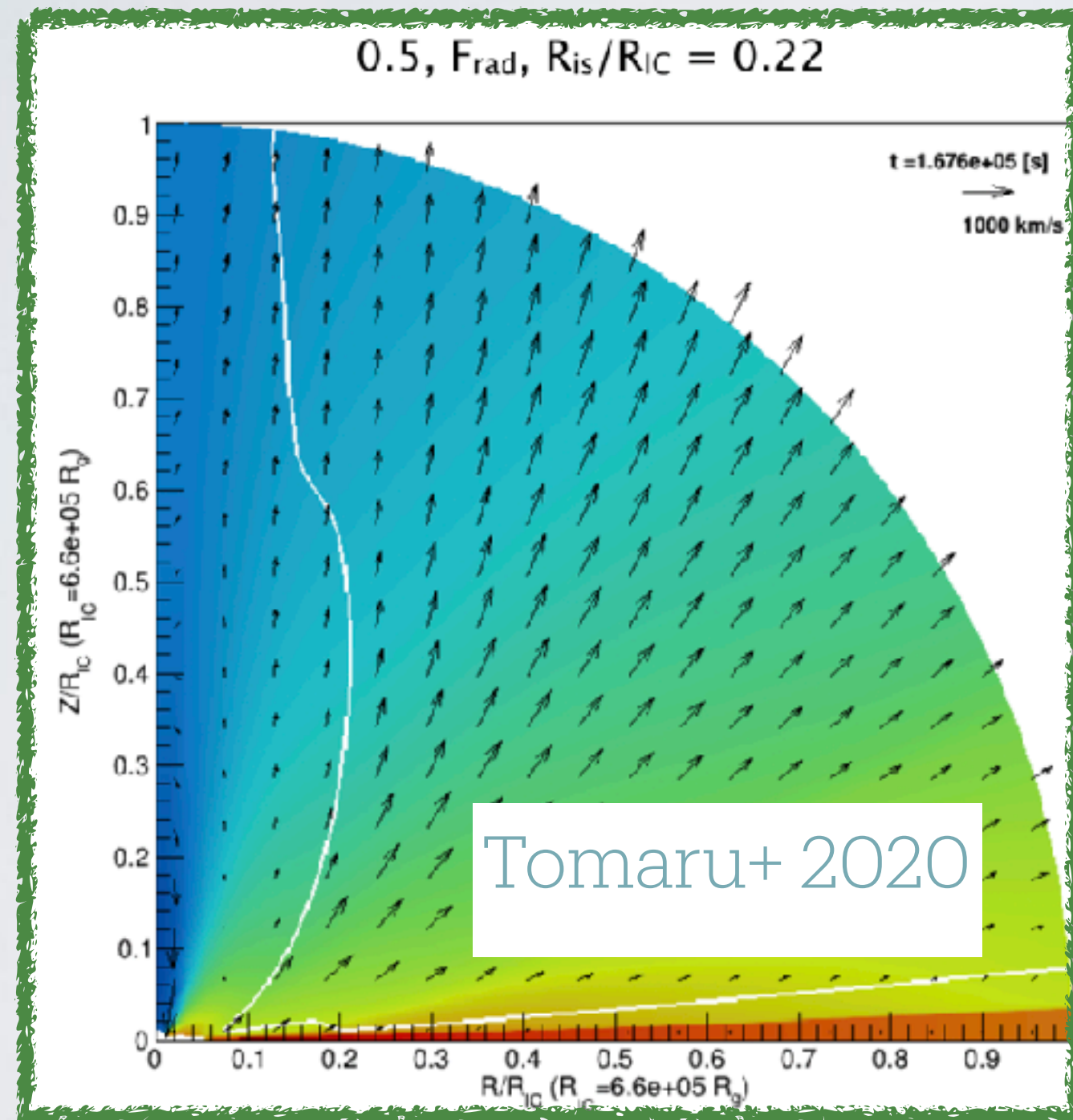
Magnetic Driving

Radiative Driving

Outflow driving (“Defying Gravity”)

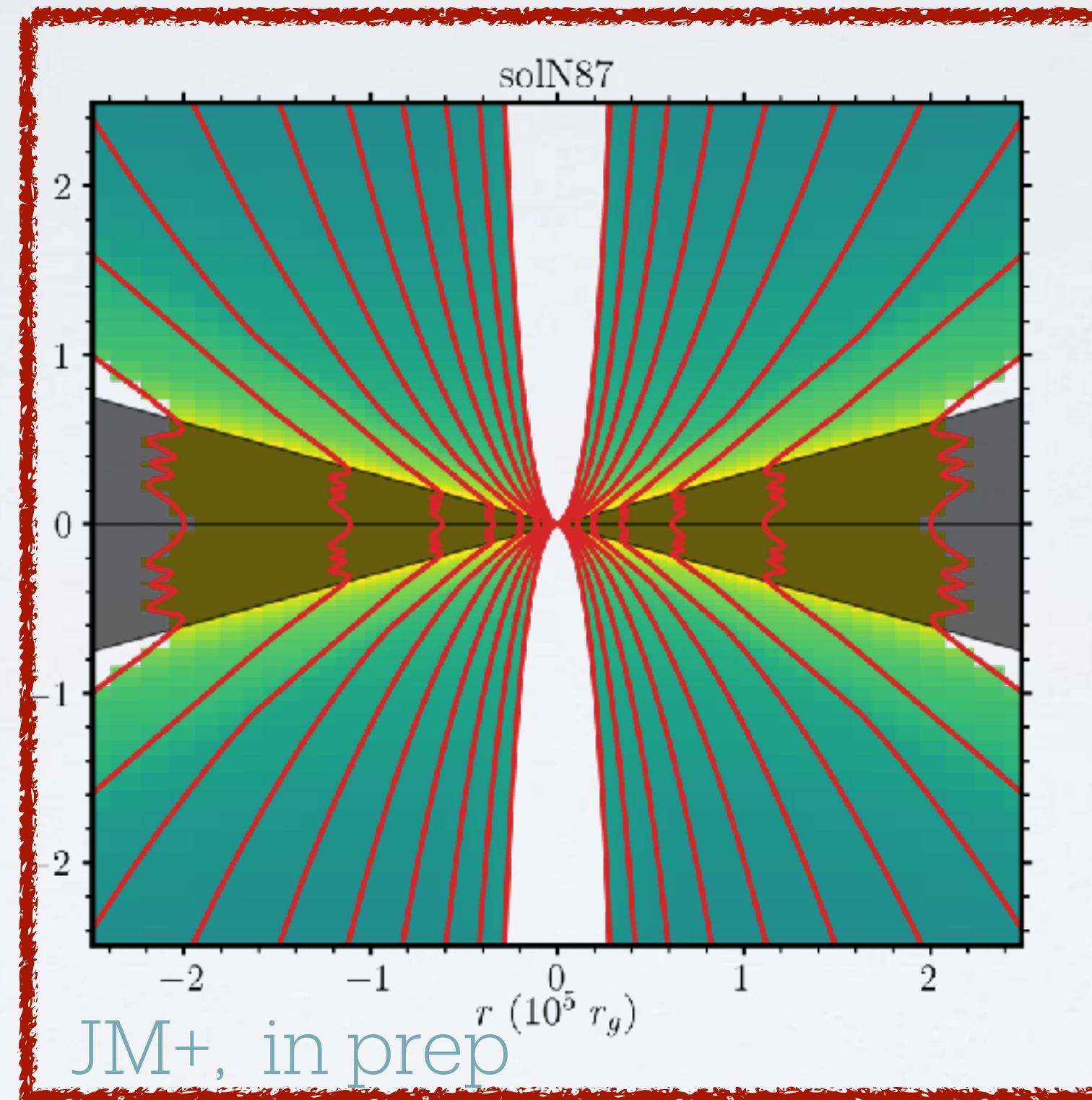


Thermal Driving



Irradiated gas get hot

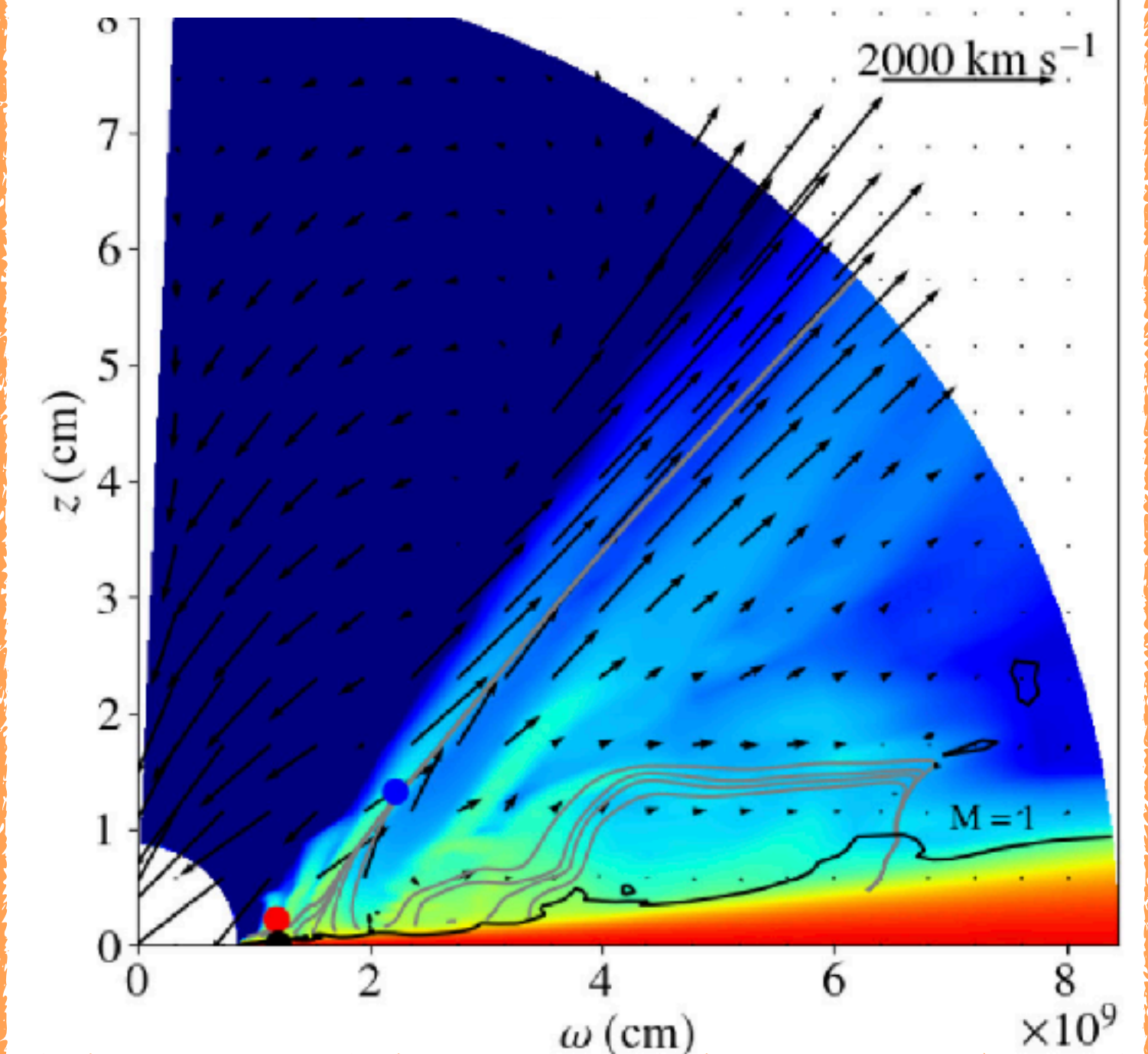
Magnetic Driving



Magnetic field flings
gas around like a
“bead on a wire”

Radiative Driving

Higginbottom, Scepi+ 2023

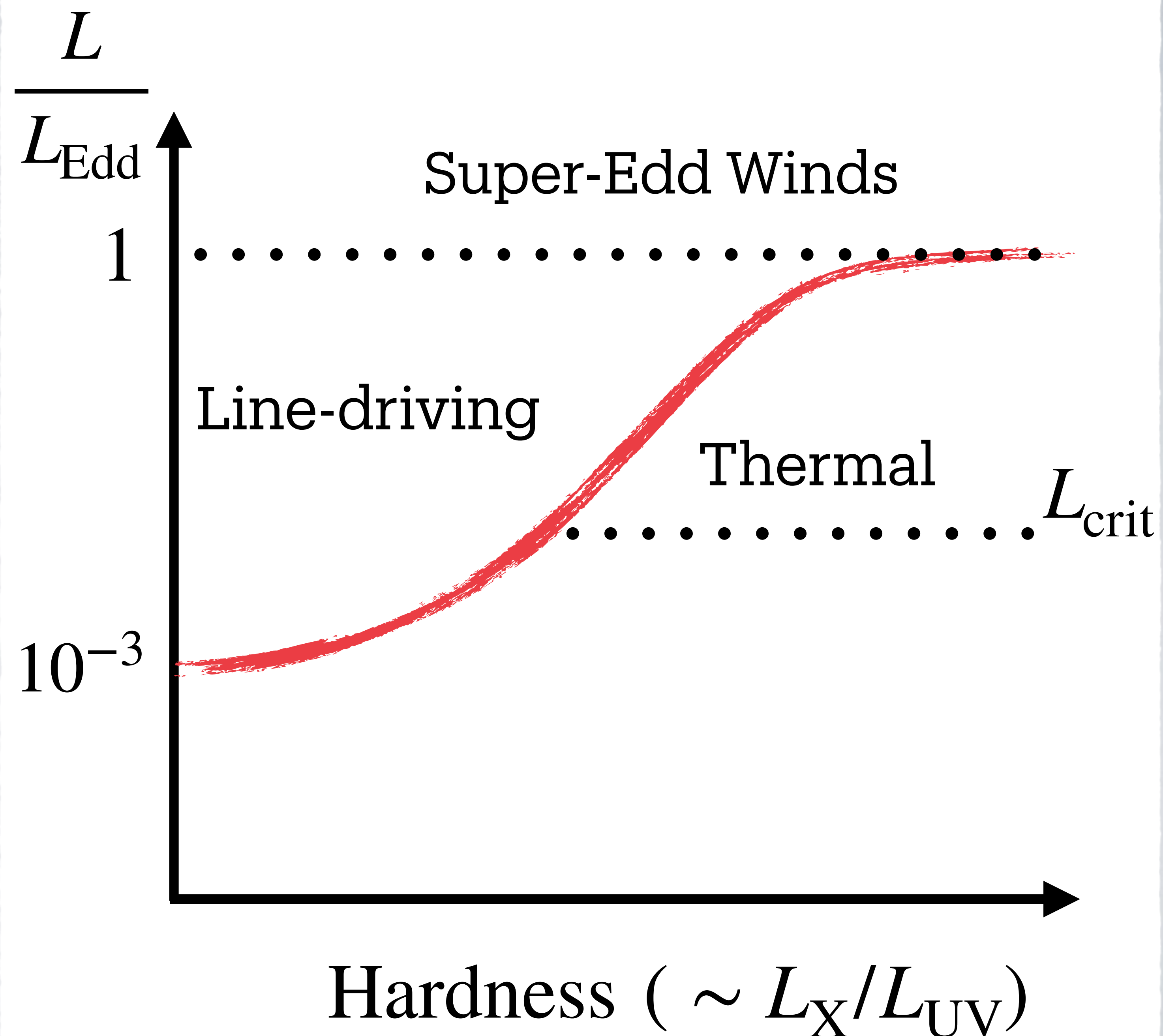


(UV) Light hits (bound
or free) electrons ->
momentum

2. What drives disc winds?

- Line-driving needs bound electrons -> X-rays bad.
- Thermal winds need strong irradiating heat source -> X-rays good.
- Naively, we expect thermal winds in XRBs, line-driven winds in CVs, MHD winds in either?

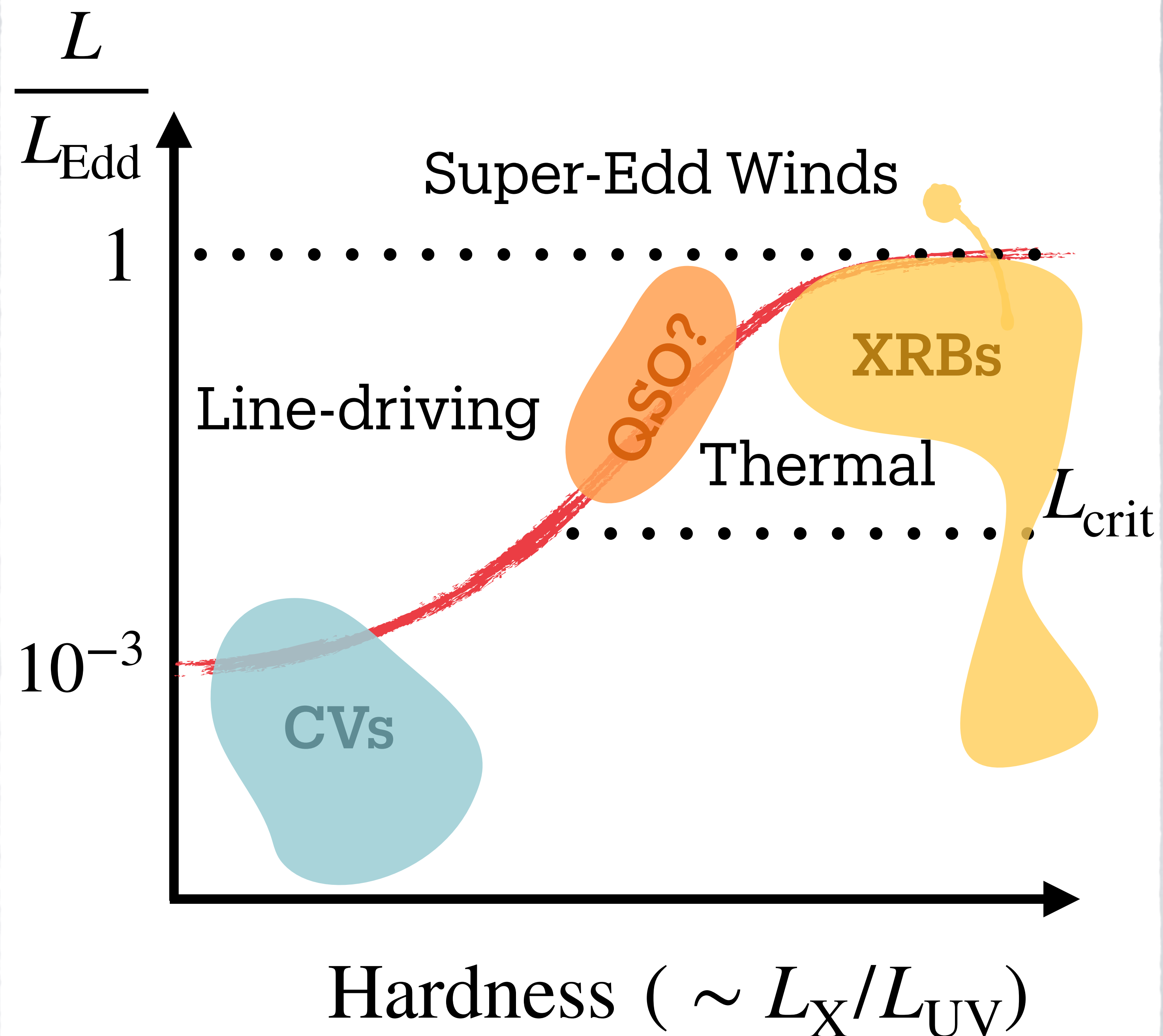
But, it's complicated really...need to be able to model ionization state accurately (Mosallenezhad)



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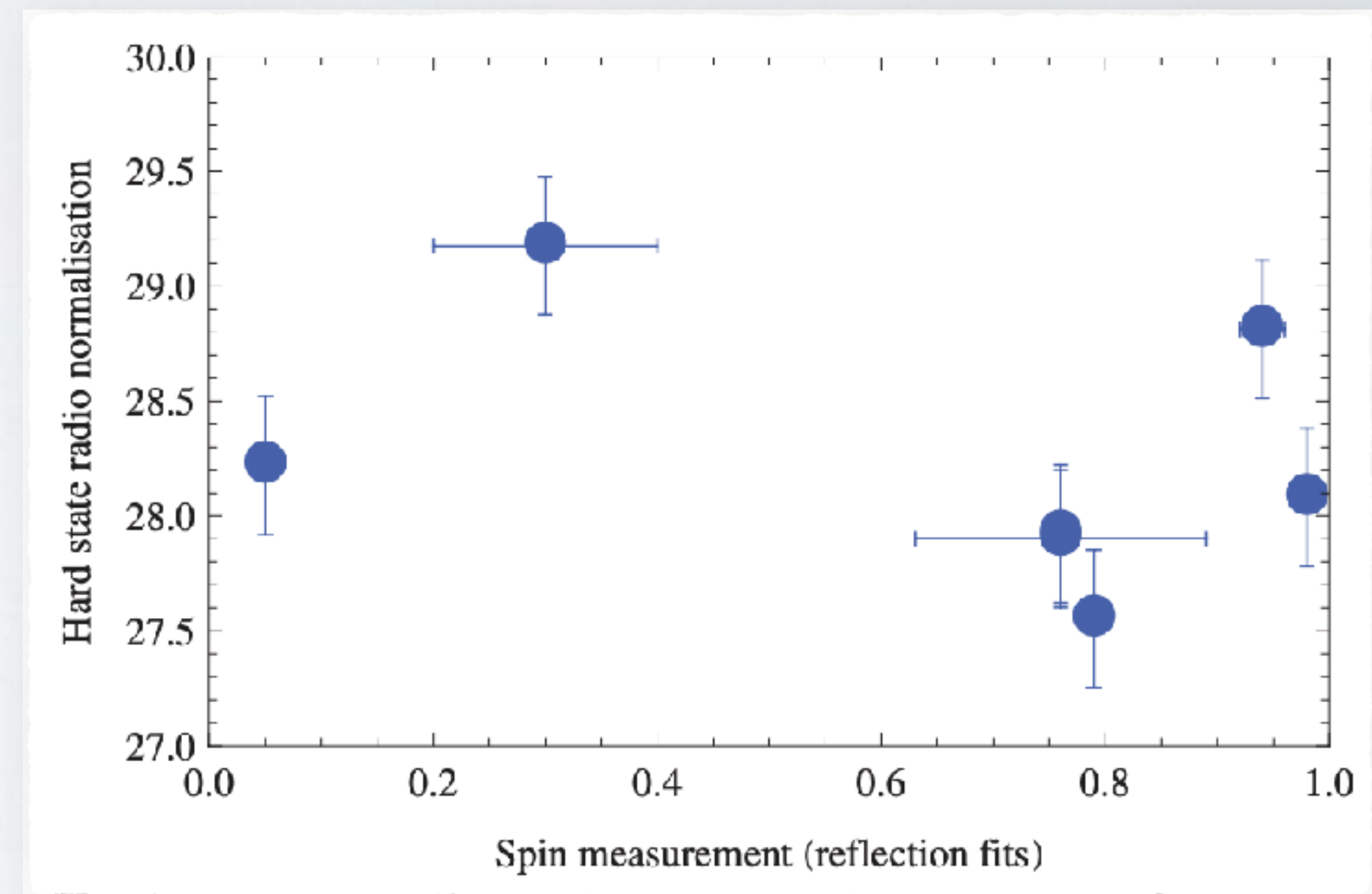
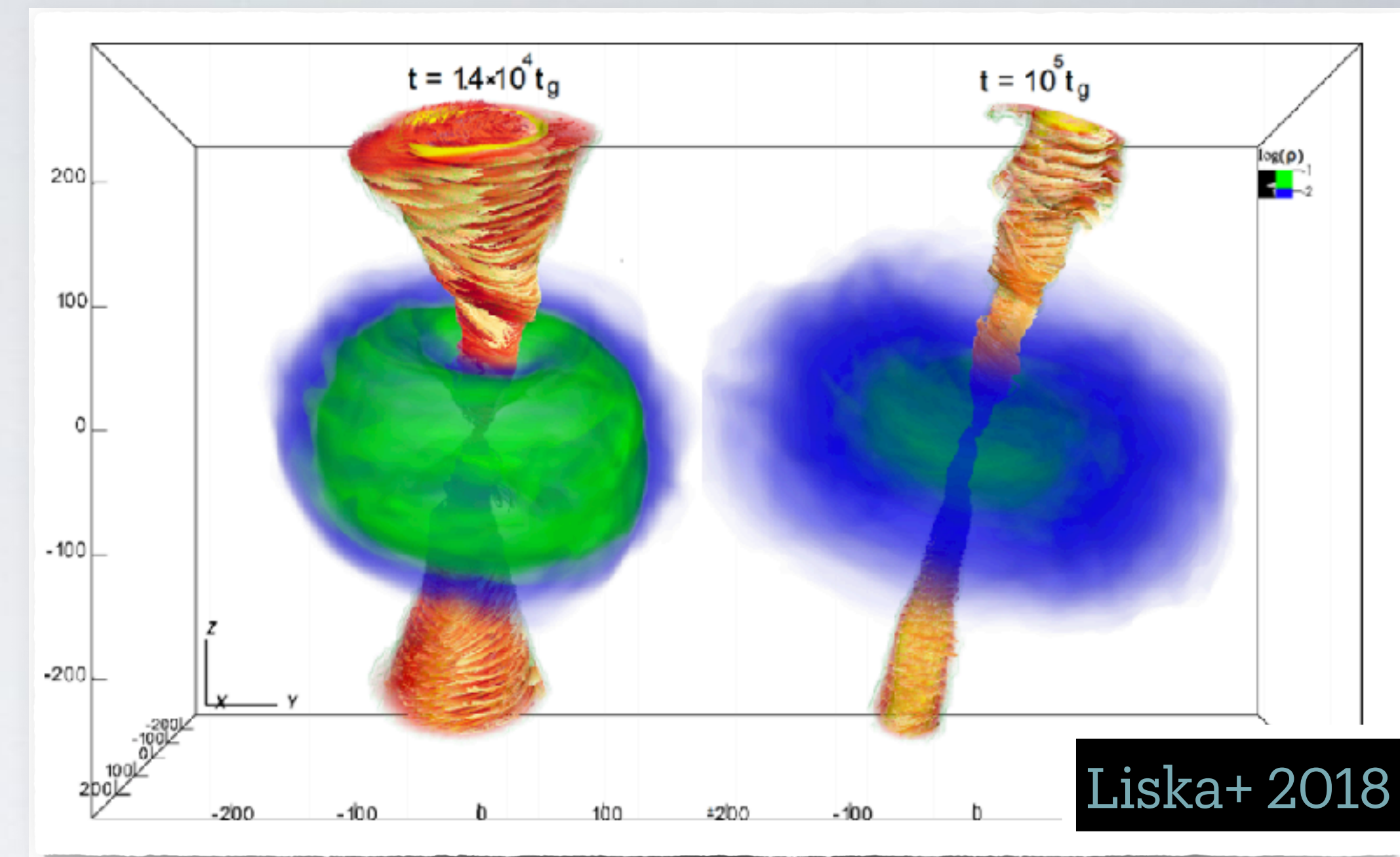
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3a. What drives BH jets?

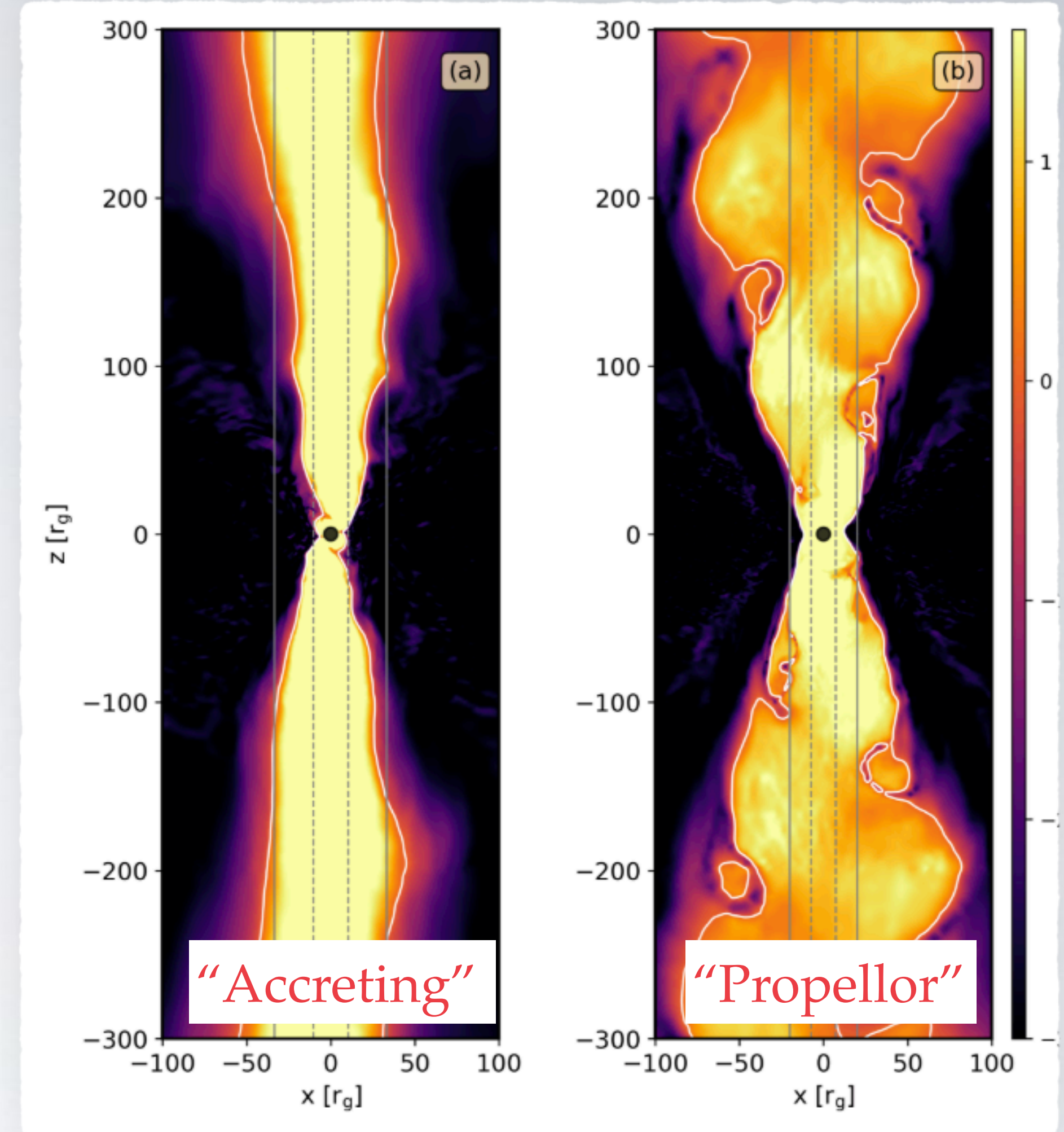
- ✦ Blandford & Znajek (1977) showed that magnetic fields can extract BH spin energy to power a jet
- ✦ Recent-ish GRMHD results:
 - ✦ Powerful jets shown to extract BH spin energy
-> Blandford-Znajek type jets
 - ✦ Magnetically arrested disc gives $P_{\text{jet}} \approx 1.3 a_*^2 \dot{M} c^2$
(Tchekovskoy+ 2015)
- ✦ But MHD “winds” can also be “jets” (Blandford-Payne)
- ✦ Little empirical evidence for spin-jet connection...but SO messy



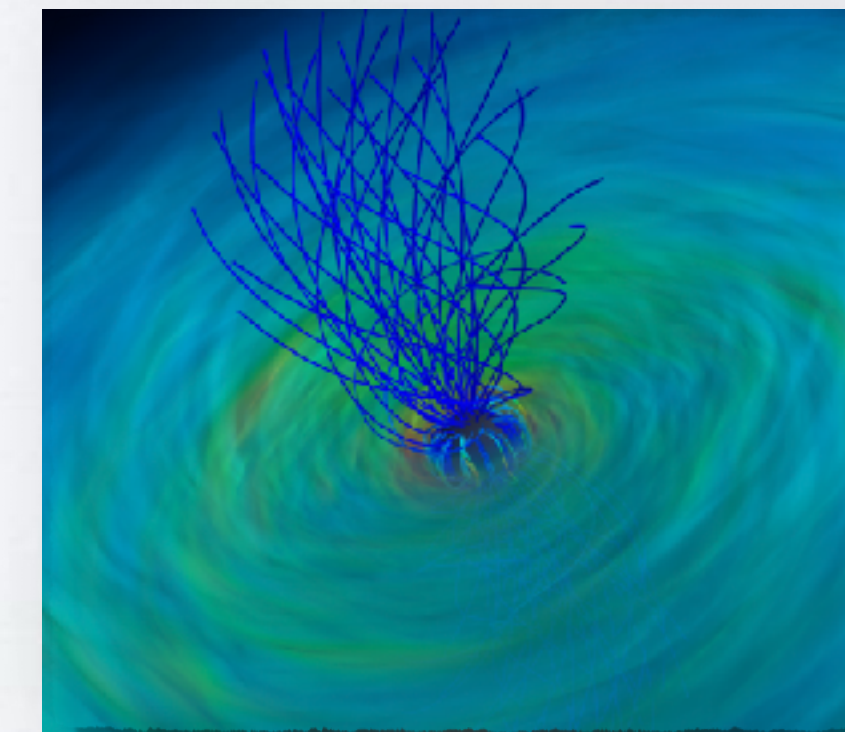
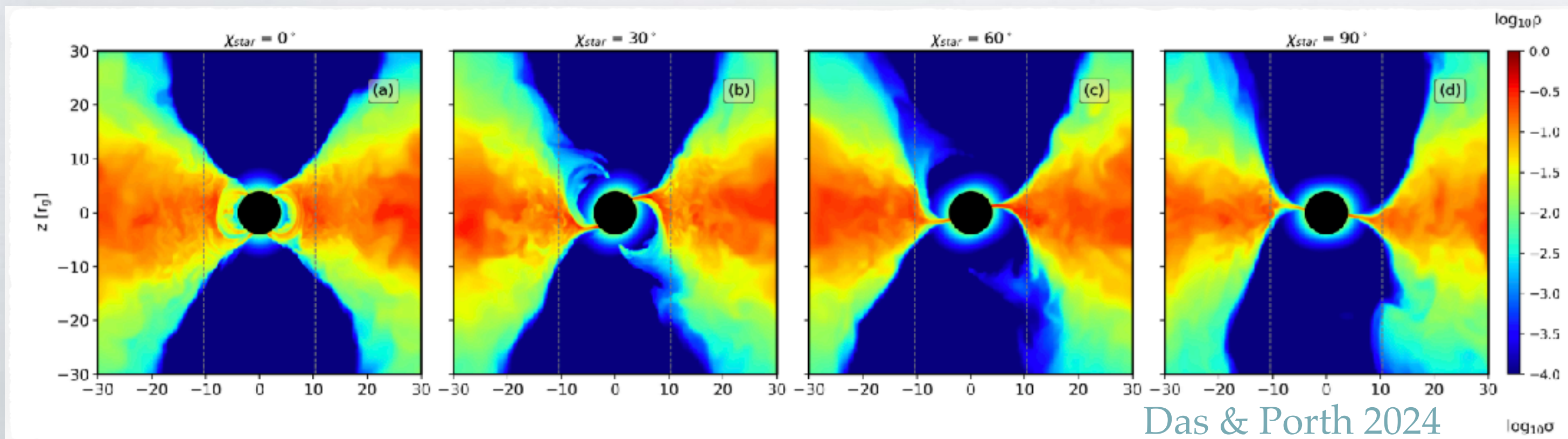
Fender, Gallo & Russell 2010

3b. What about NS and WDs?

- ✦ Less simulation work on NS (because... no supermassive analogue? null results?)
- ✦ Some exciting results (Das & Porth 2024; Parfrey+ 2023)
 - ✦ Both groups use GRMHD to study jets in NS: Varying degrees of magnetisation
 - ✦ Das & Porth: *“The jets in our simulations are produced due to the anchored magnetic field of the rotating star in analogy with the Blandford-Znajek process.”*
- ✦ Similar mechanism in WD systems?

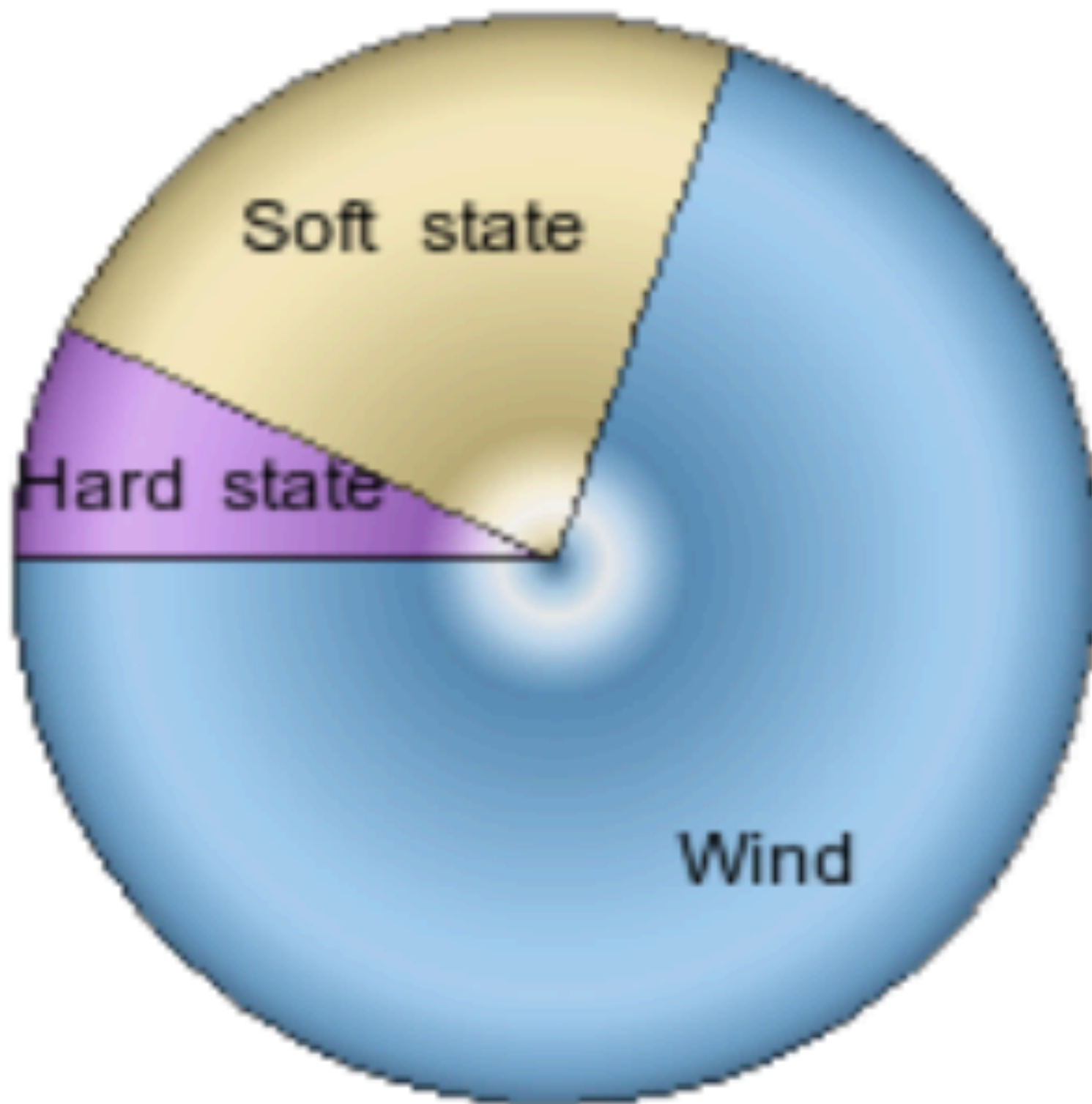


Das & Porth 2024

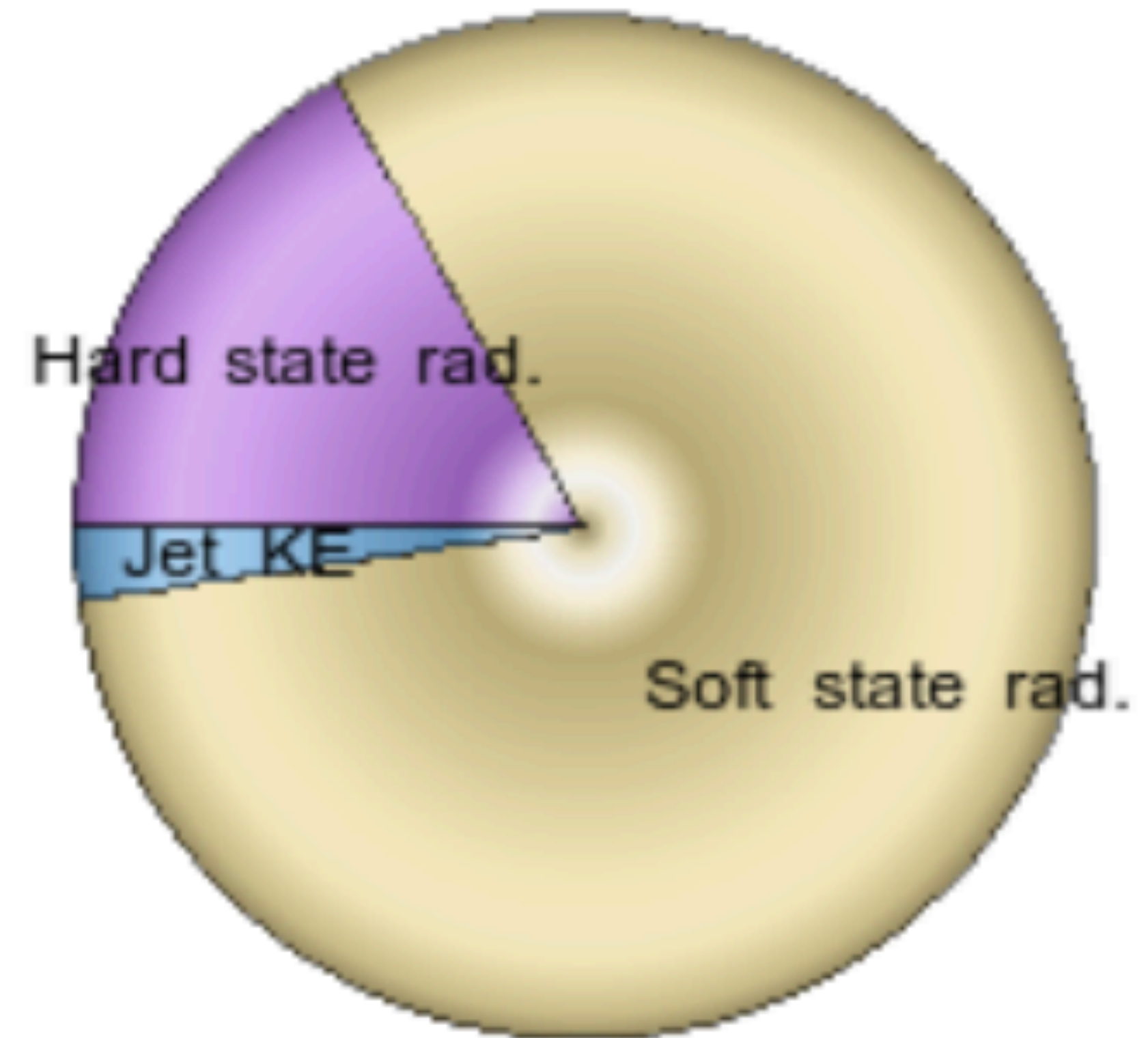


4. What are the mass and energy budgets?

Where the mass goes



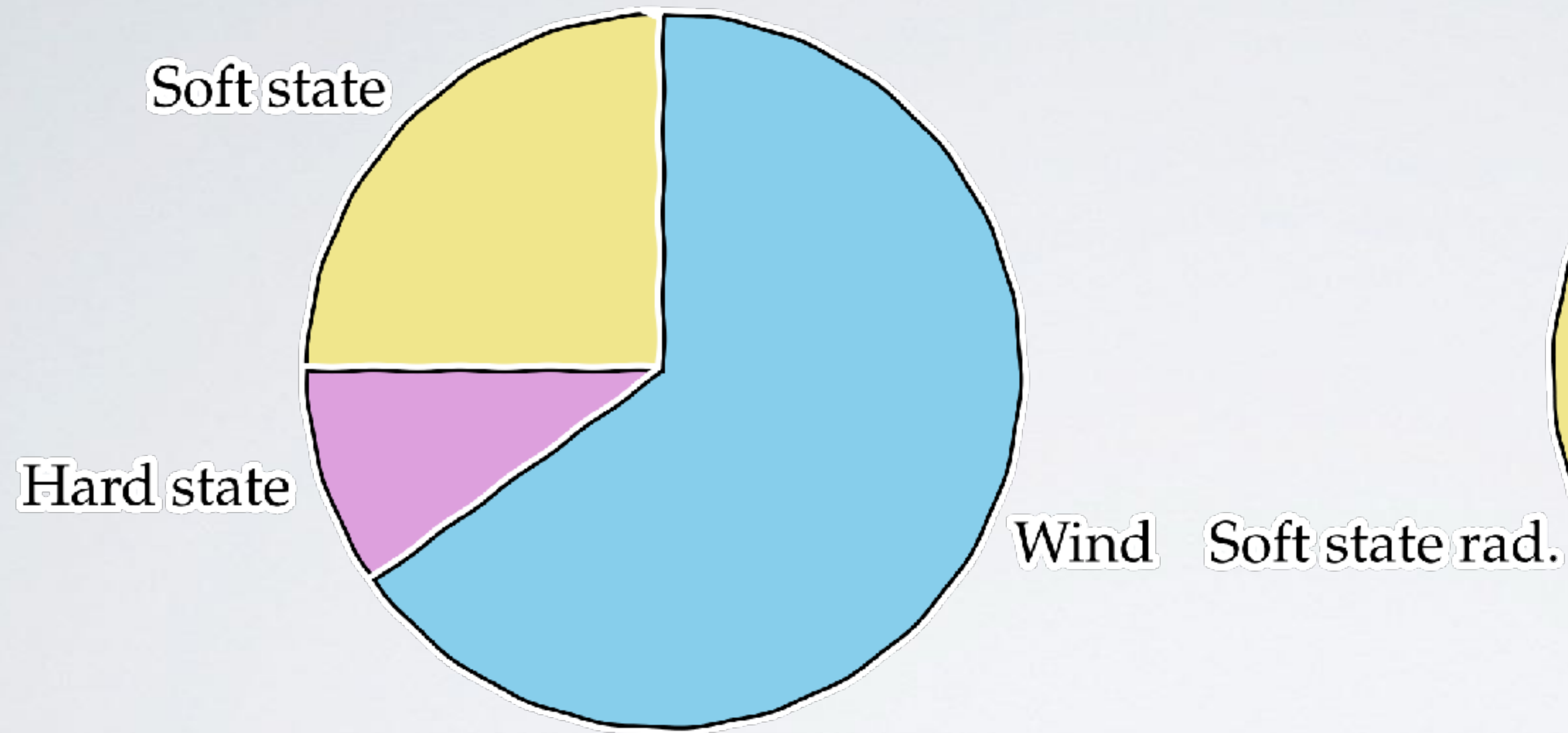
Feedback



as 2015

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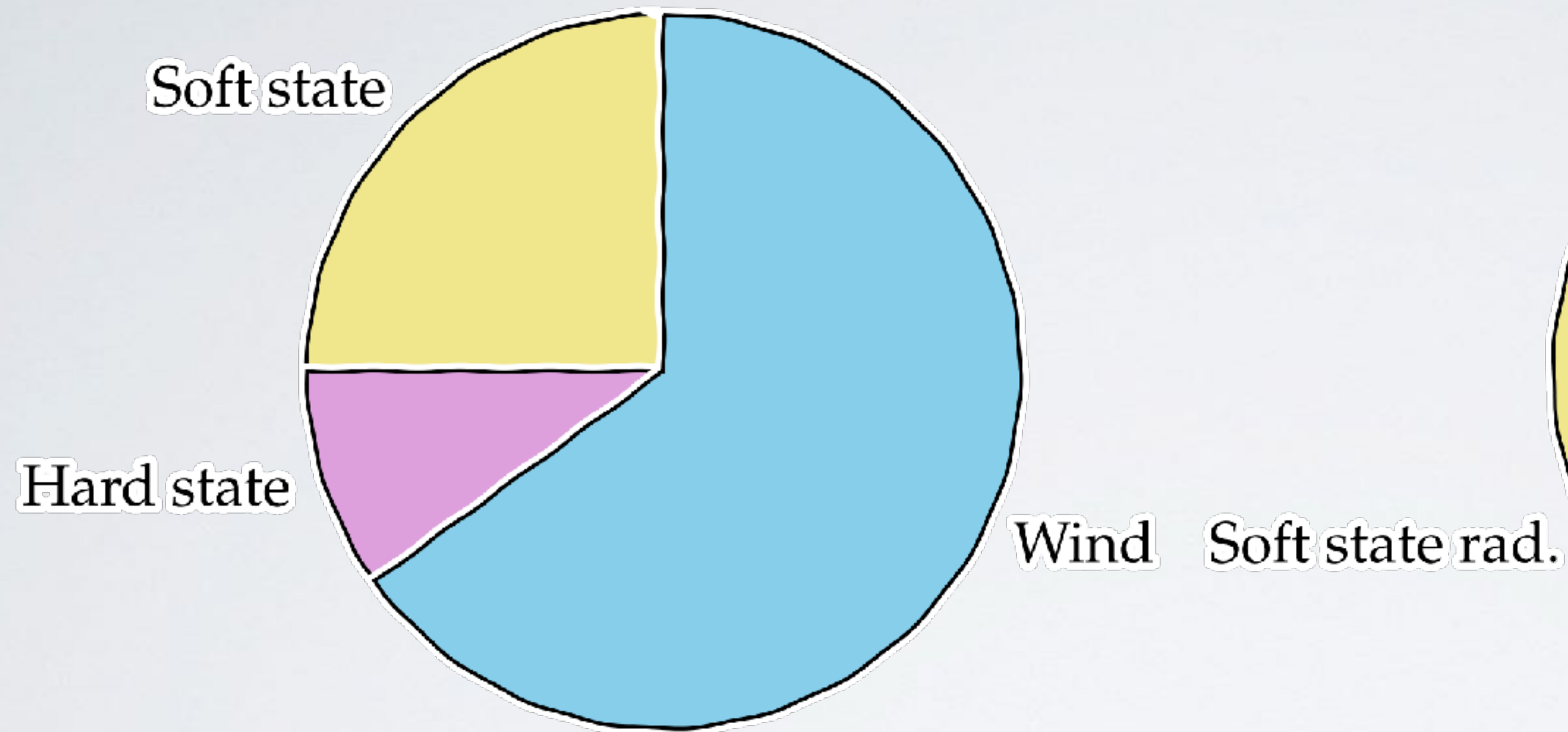
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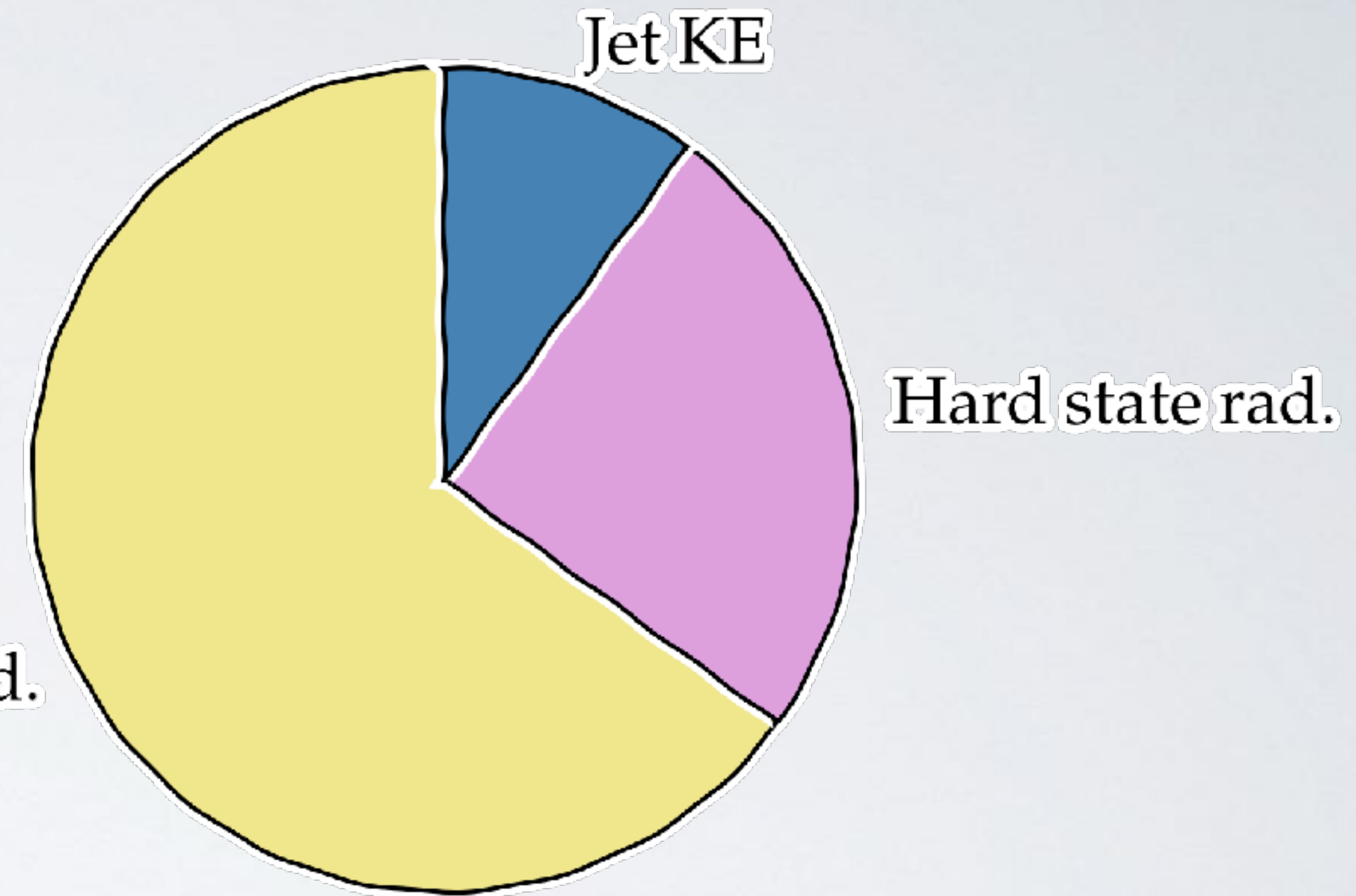
Fender & Munoz-Darias 2015

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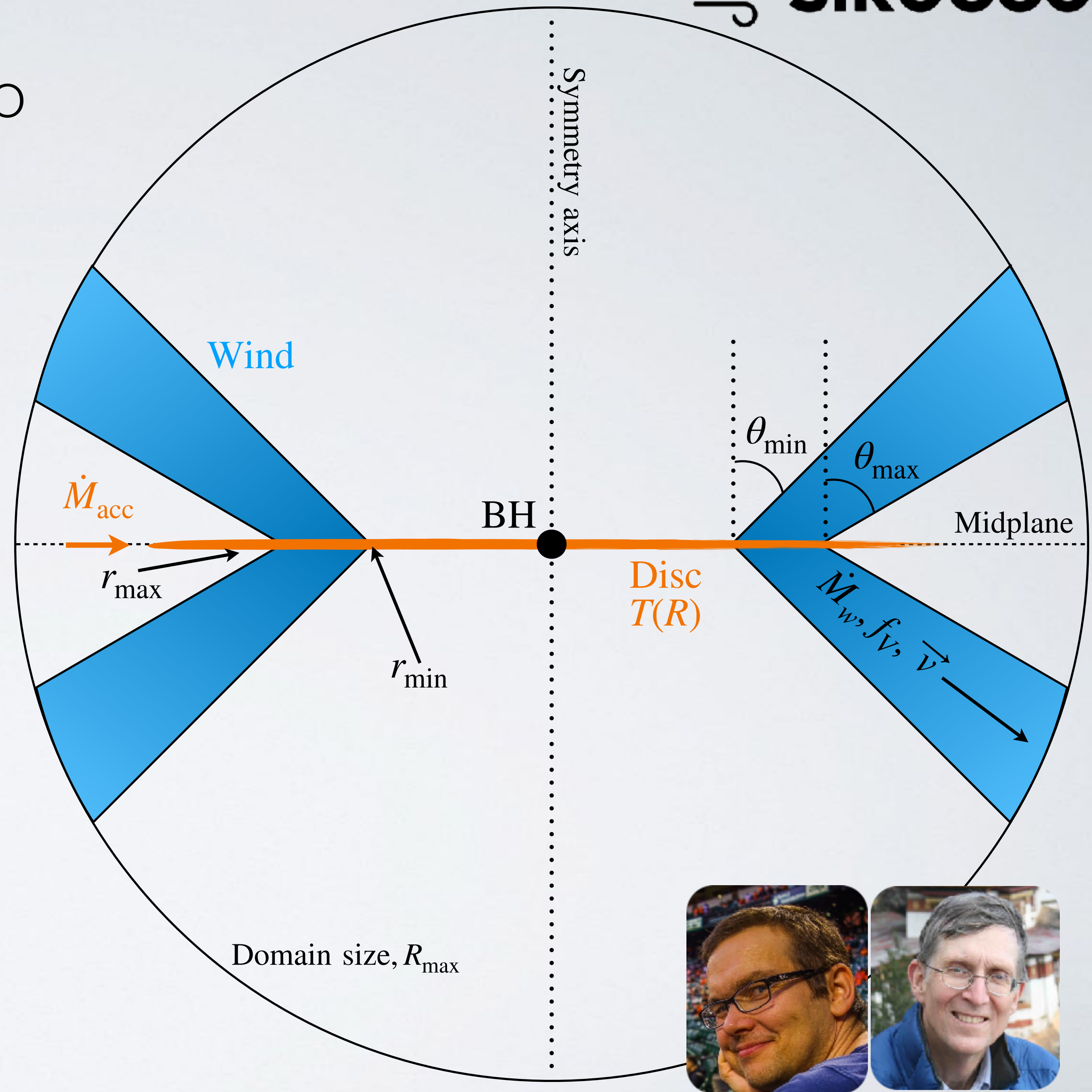
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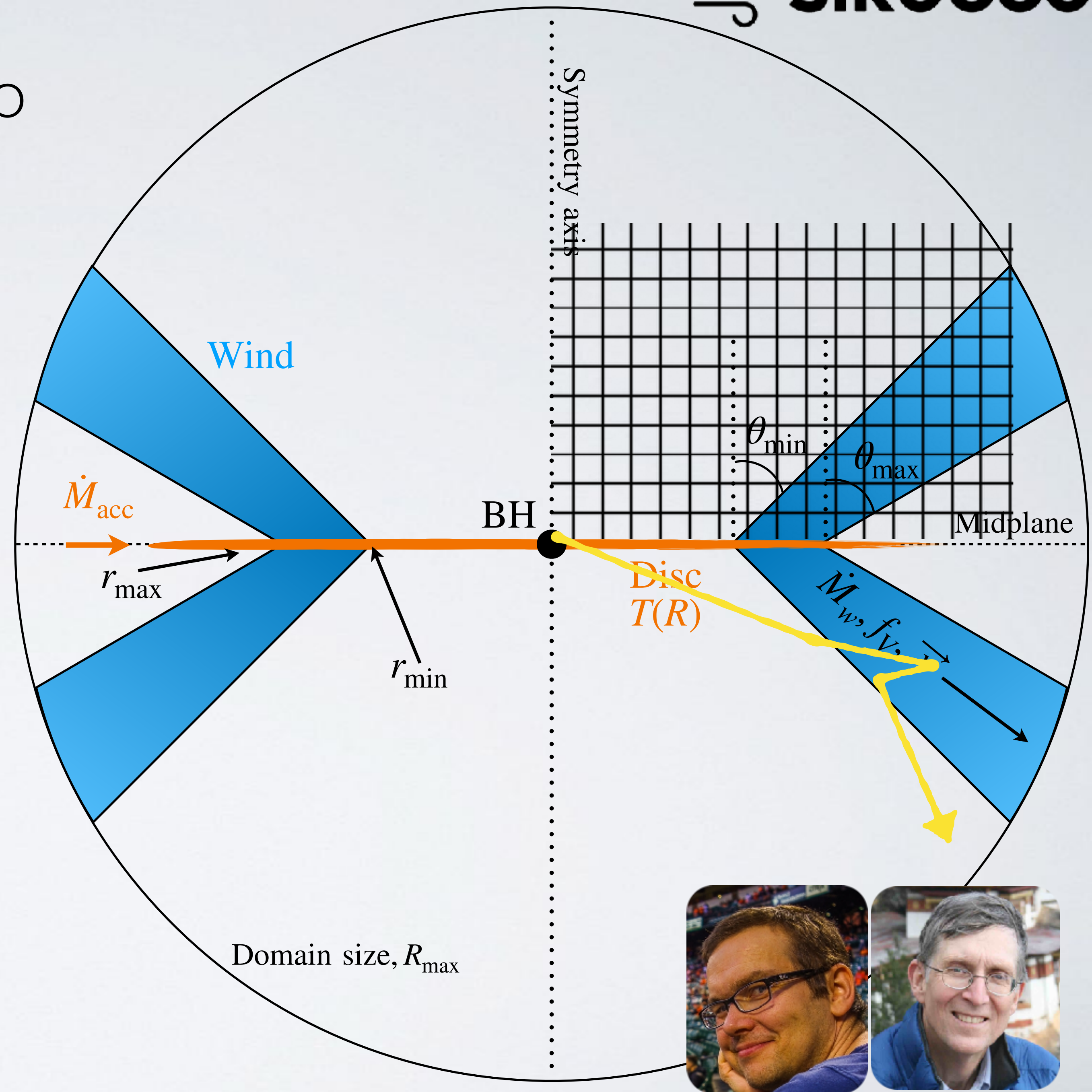
Fender & Munoz-Darias 2015

So winds and jets are significant carriers of mass and energy,
and this is before the discovery of optical winds and ubiquitous large-scale ejecta
We can make more progress using numerical simulations [2 examples...]

- Simulating Ionization and Radiation in Outflows Created by Compact Objects (Long & Knigge 2002; Matthews+ 2025)
- Main strengths: multi-D (2.5D), self-consistent, photoionization+ RT+ thermodynamics
- Can couple to hydro (Amin Mosallenezhad, + work by Nico Scepi and Nick Higginbottom)

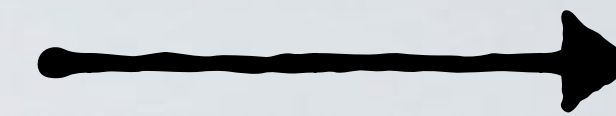


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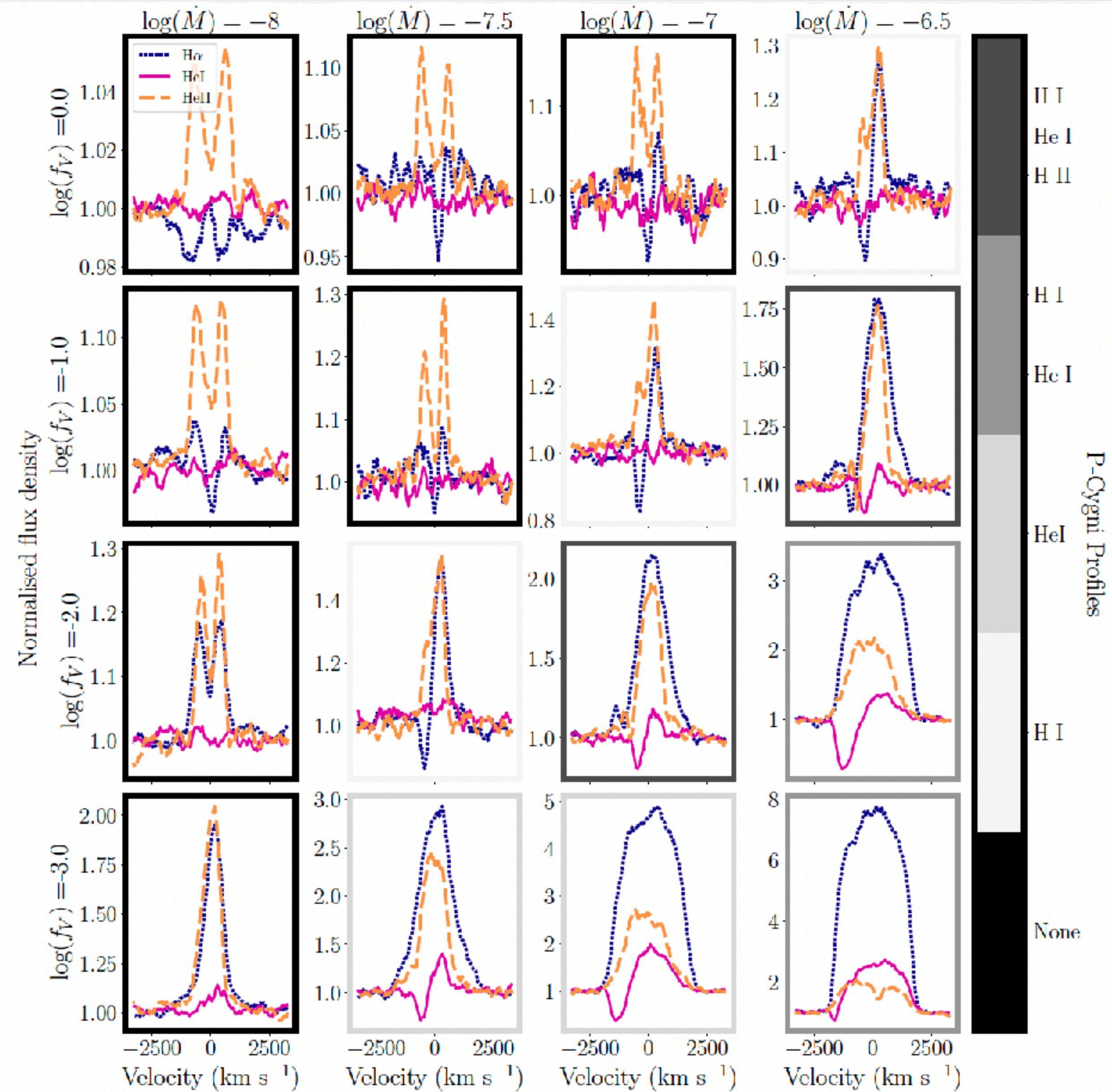
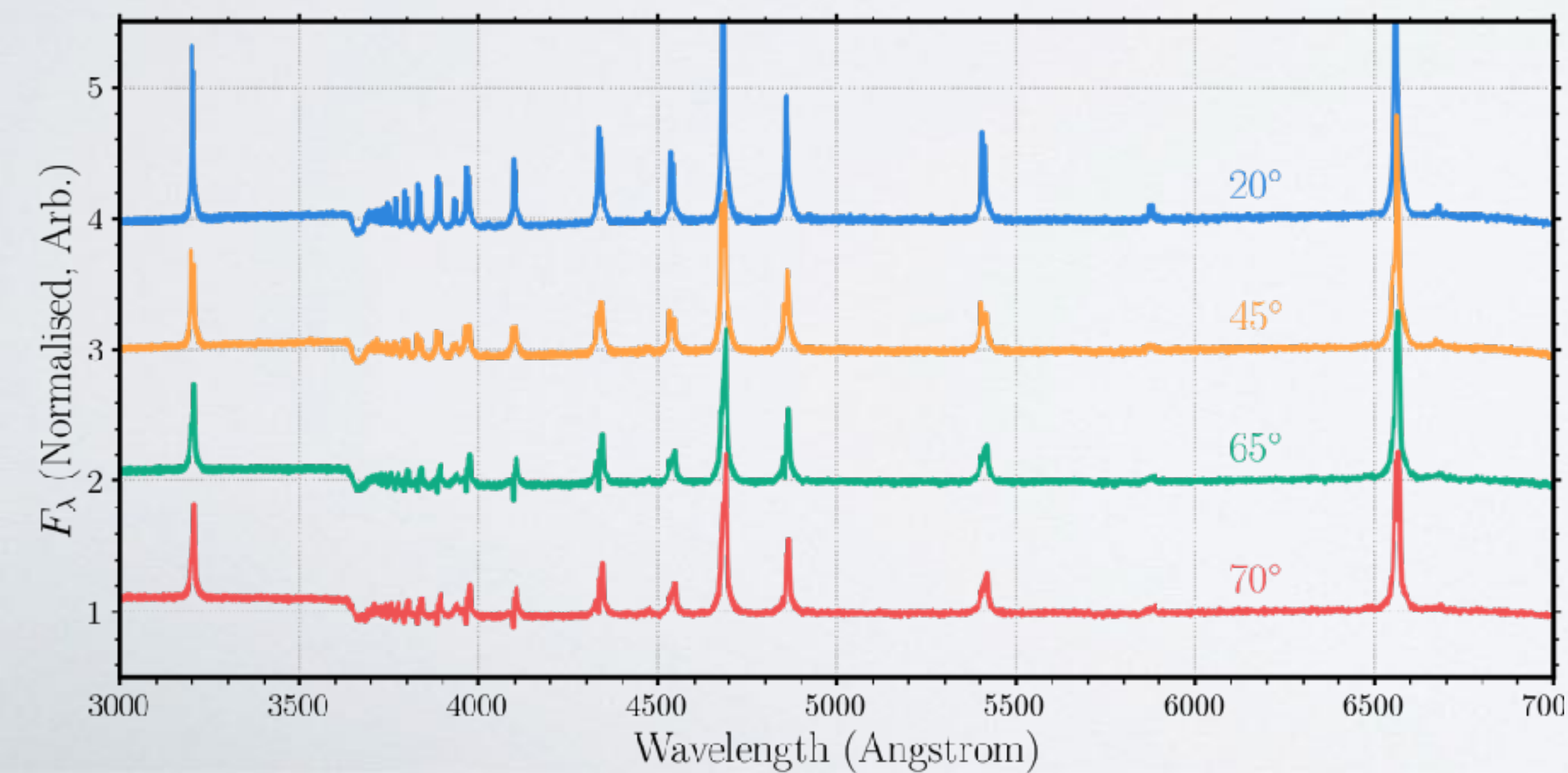


Modelling -> Mass loss rates

P-Cygs only produced for v massive winds

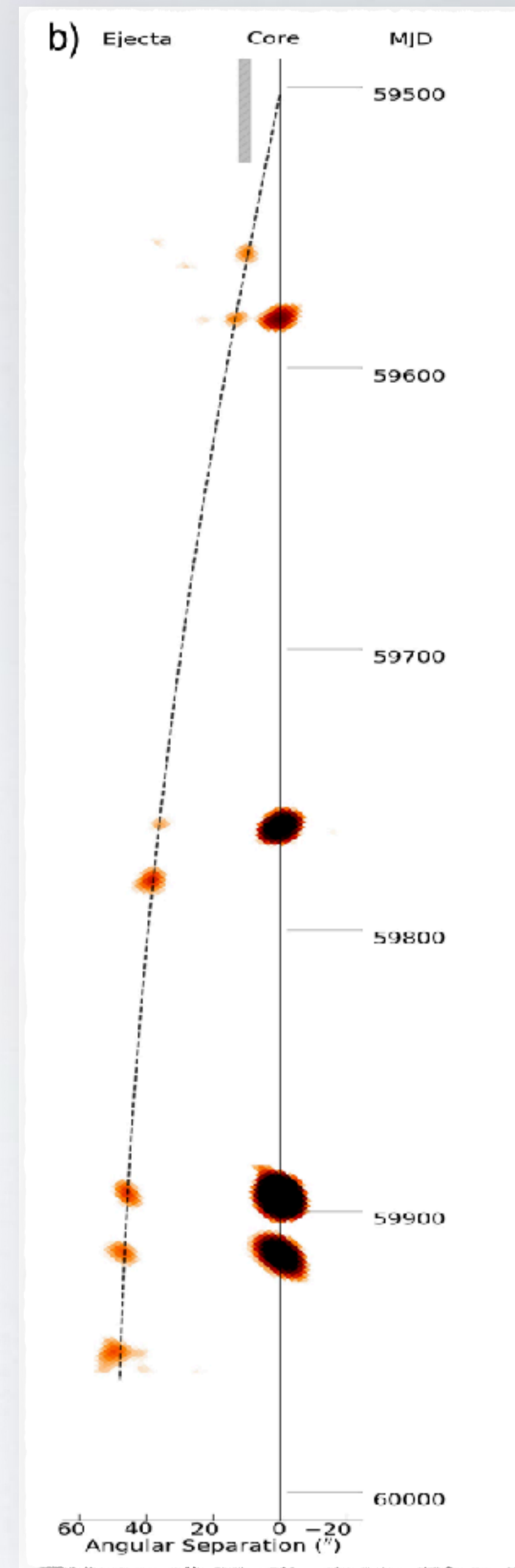
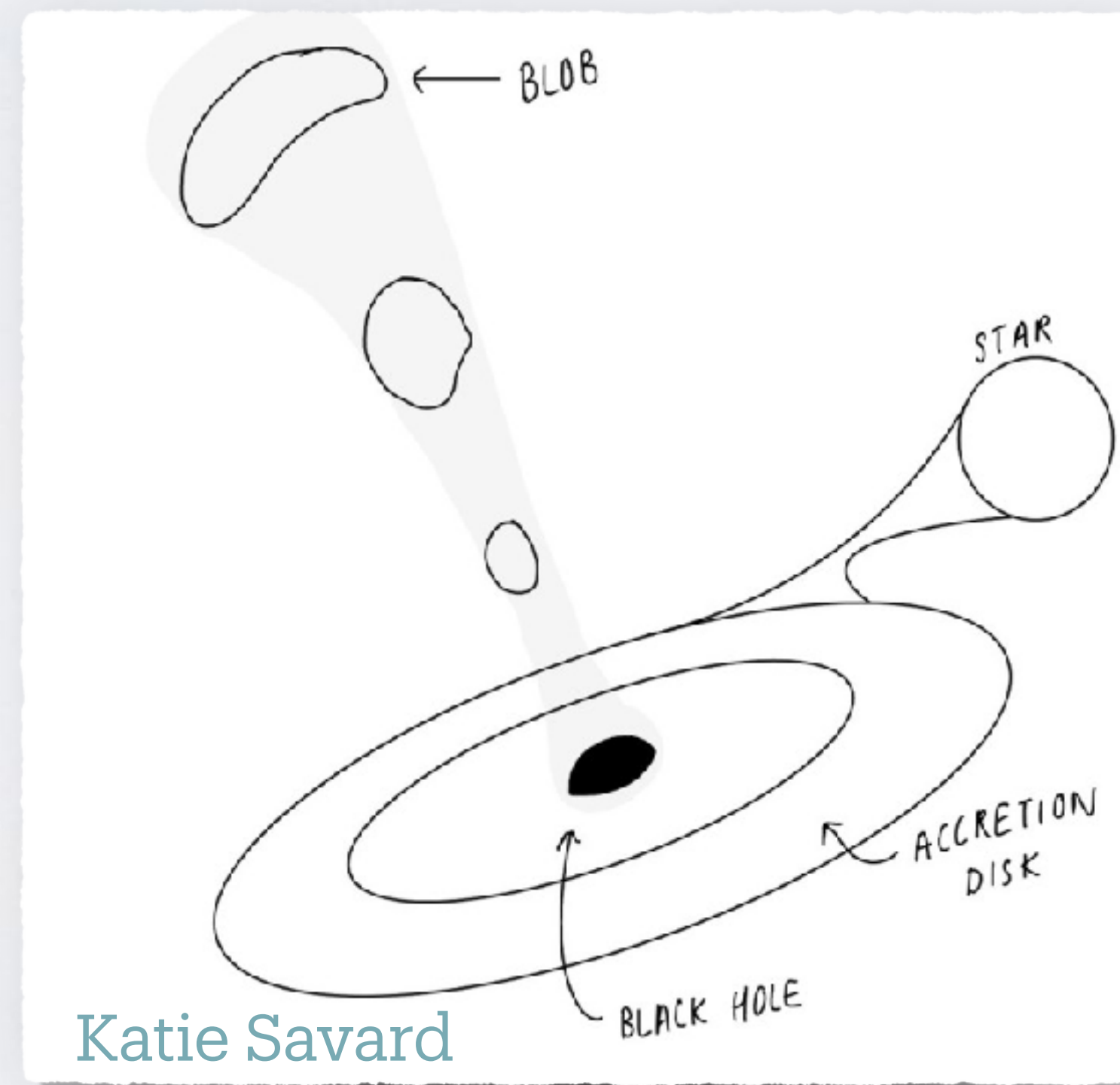


- Can disc winds produce optical absorption features?
- Yes, but need mass-loss rates $>$ Eddington, or very clumpy wind (Ambrifi+ in prep; JM+ in prep)
- Wind is an effective reprocessor

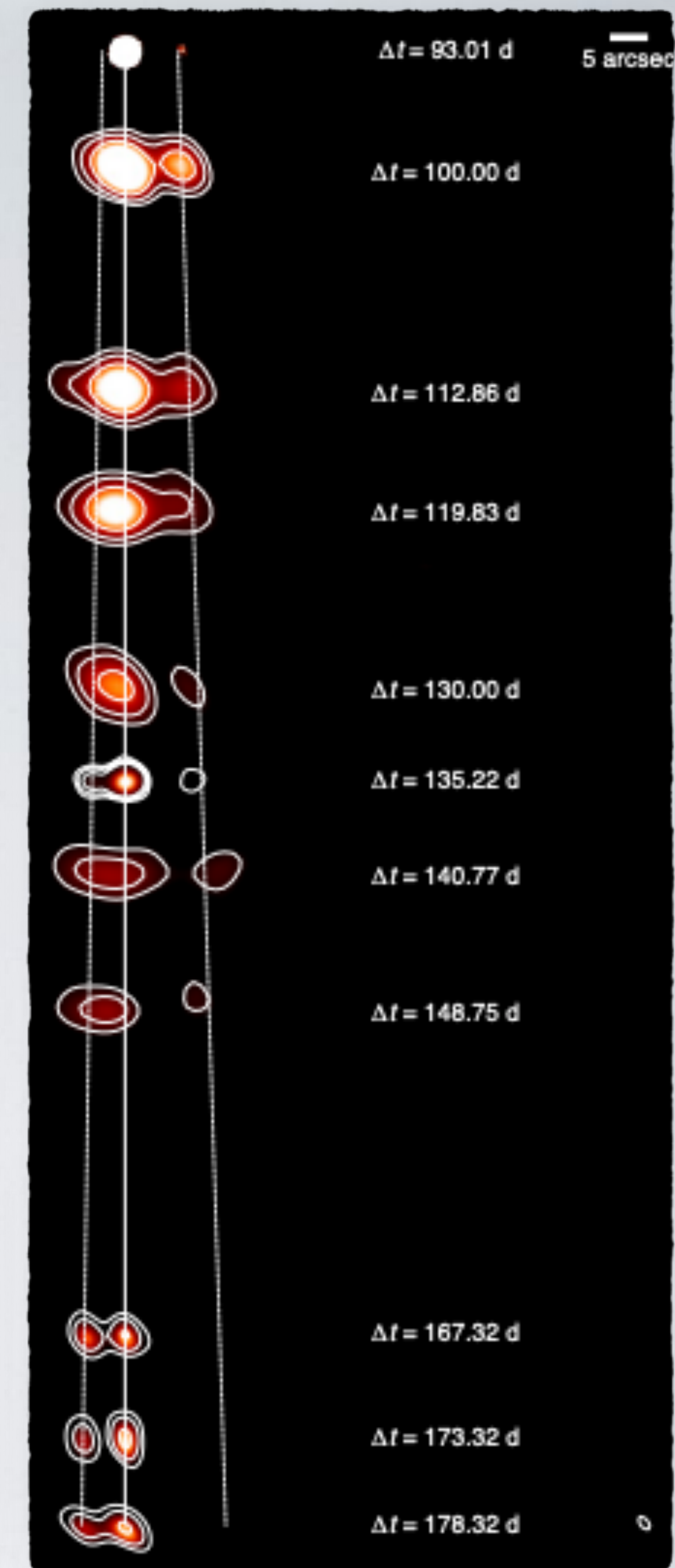


Transient Jet Ejections in XRBs

- Outbursting XRBs often blast away (apparently) discrete ejecta, which gradually decelerate
- ThunderKAT (MeerKAT project) has revolutionised study of these ejecta (e.g. Bright+ 2019; Carotenuto+ 2021, Bahramian+ 2023)
- Deceleration tells us about energetics; more energetic/heavier things go further



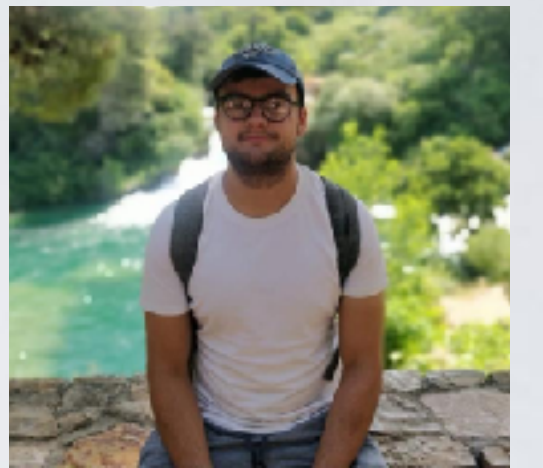
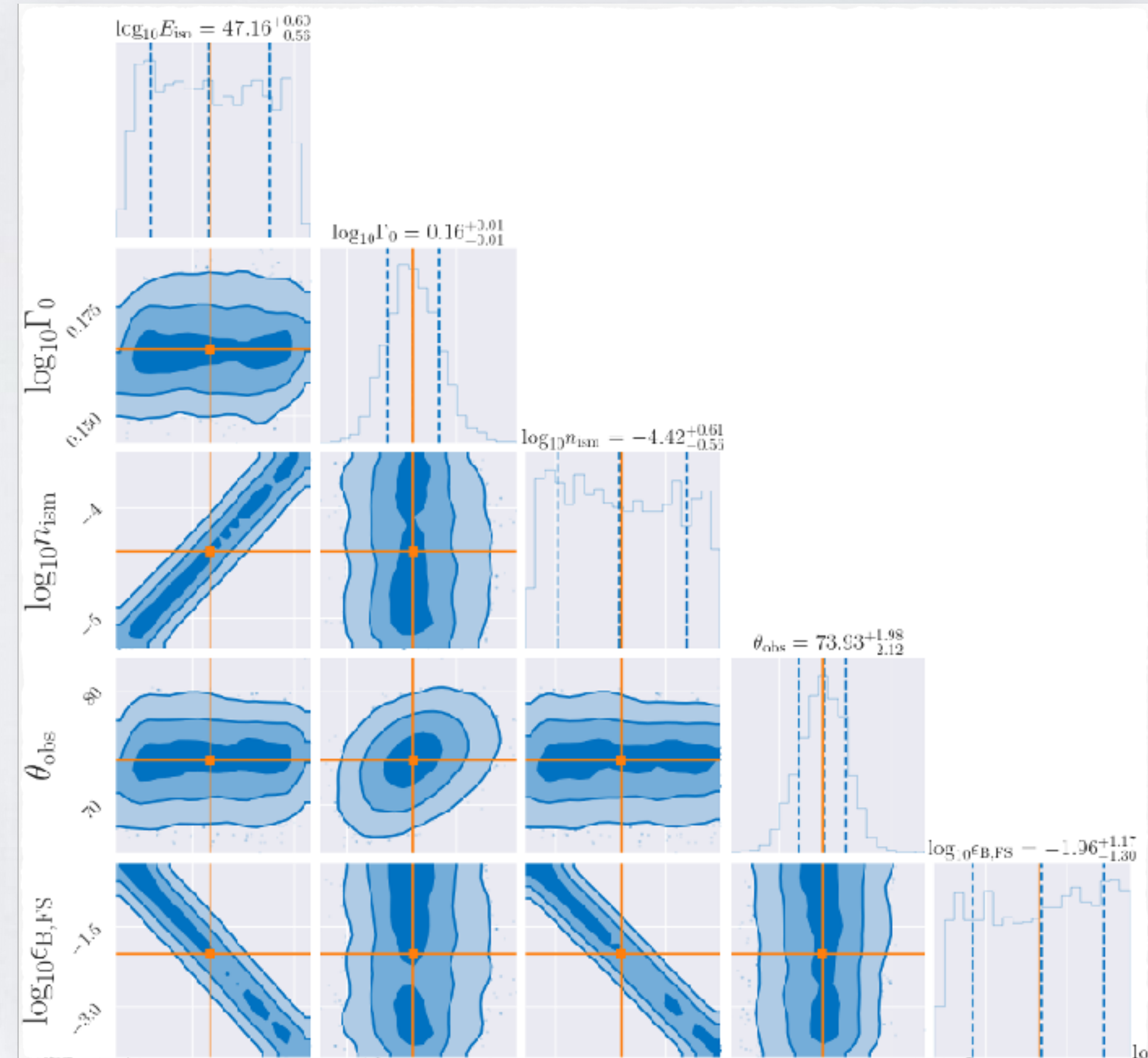
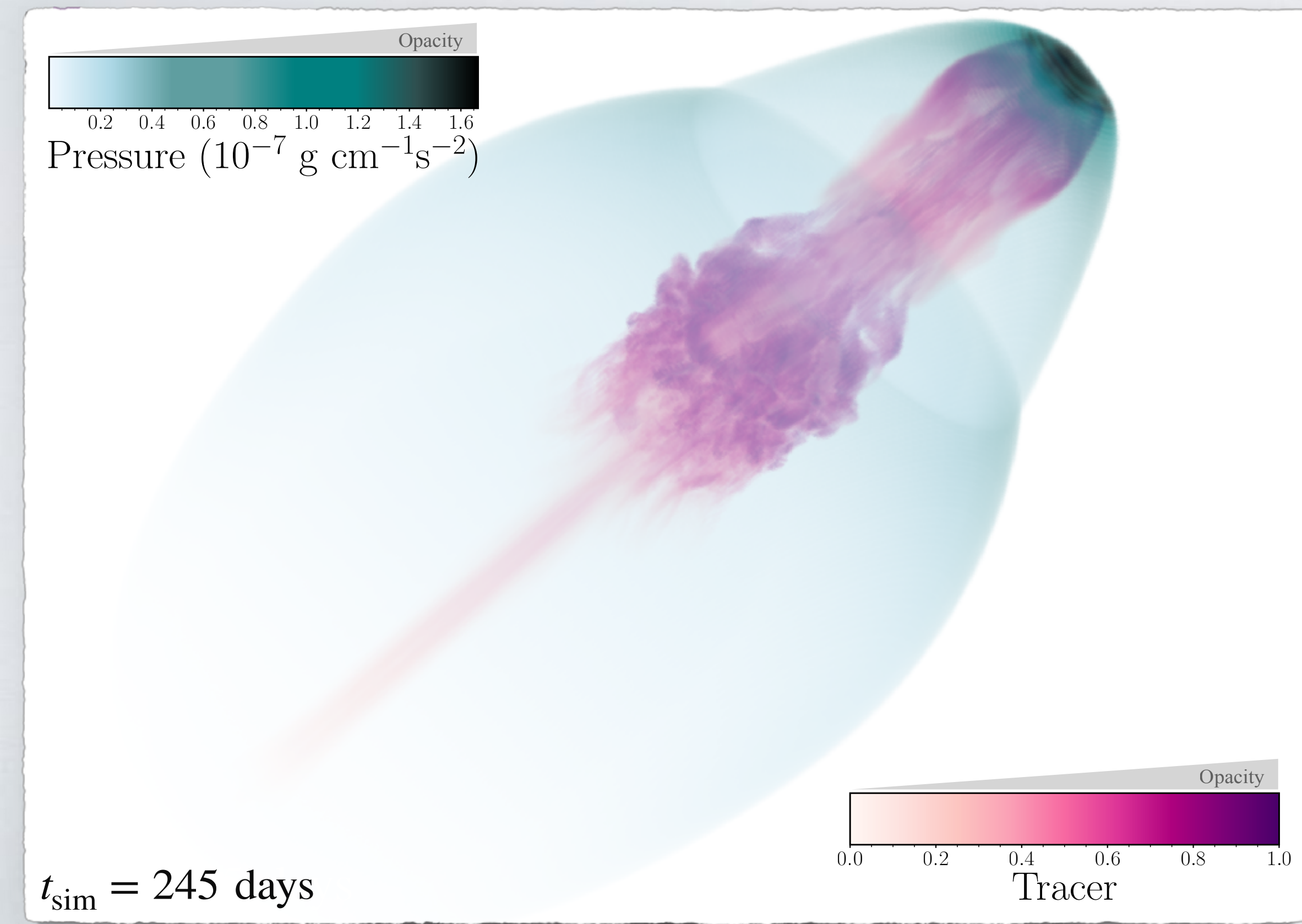
4U 1543-47 (Zhang+25)



J1820+070 (Bright+ 2019)

Modelling -> Energetics

- Distance travelled goes as $E/(n_{\text{ism}}\phi^2)$; degeneracy, but expect high E and low n (Carotenuto+ 2024)
- Relativistic-hydro simulations confirm these expectations (Savard+ 2025)
- Better understanding of shock physics and combined fit allows us to break the degeneracy (Cooper+ 2025; Matthews+ 2025) and start to test the jet driving mechanism



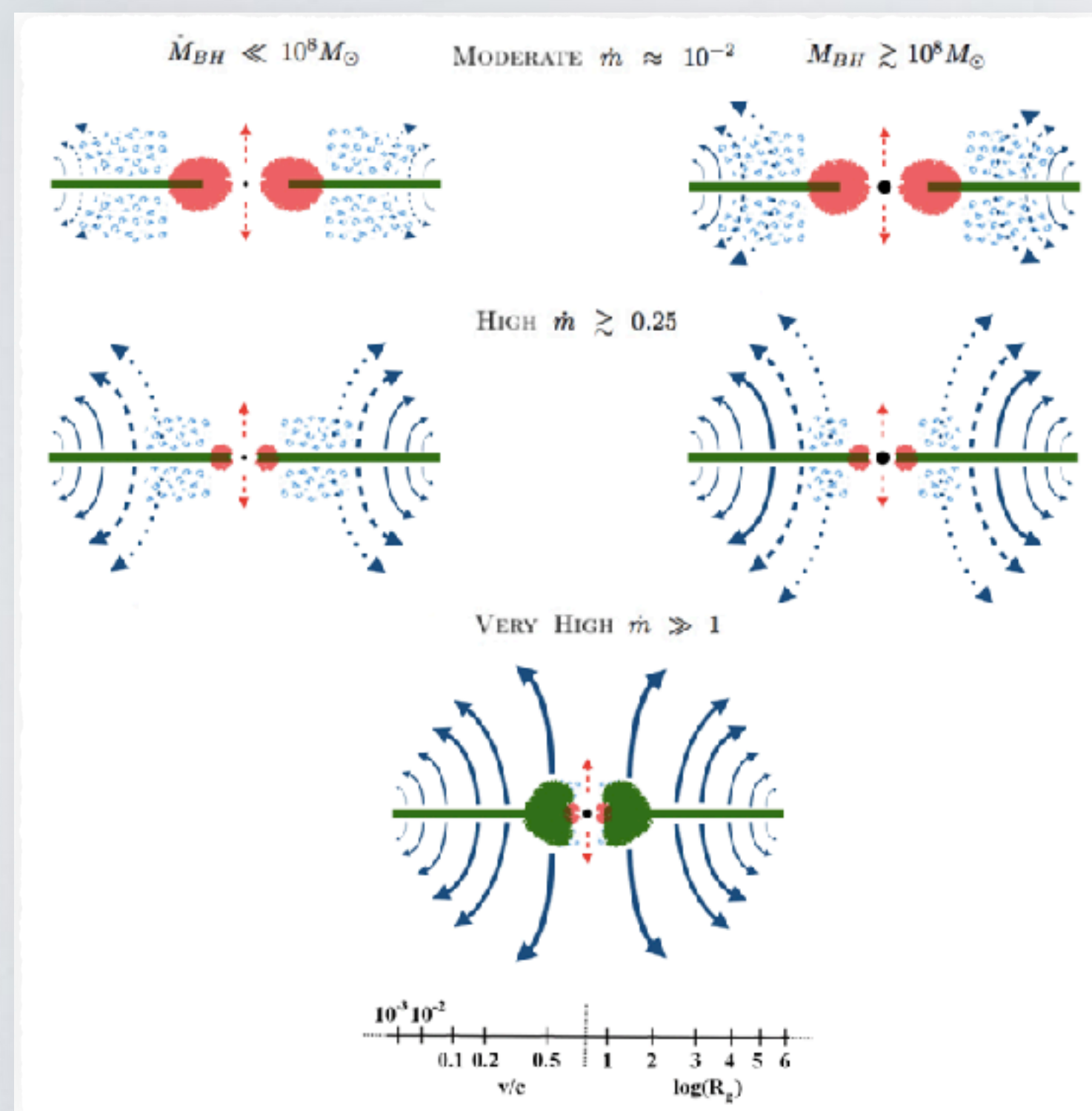
Alex Cooper,
Hintze Fellow



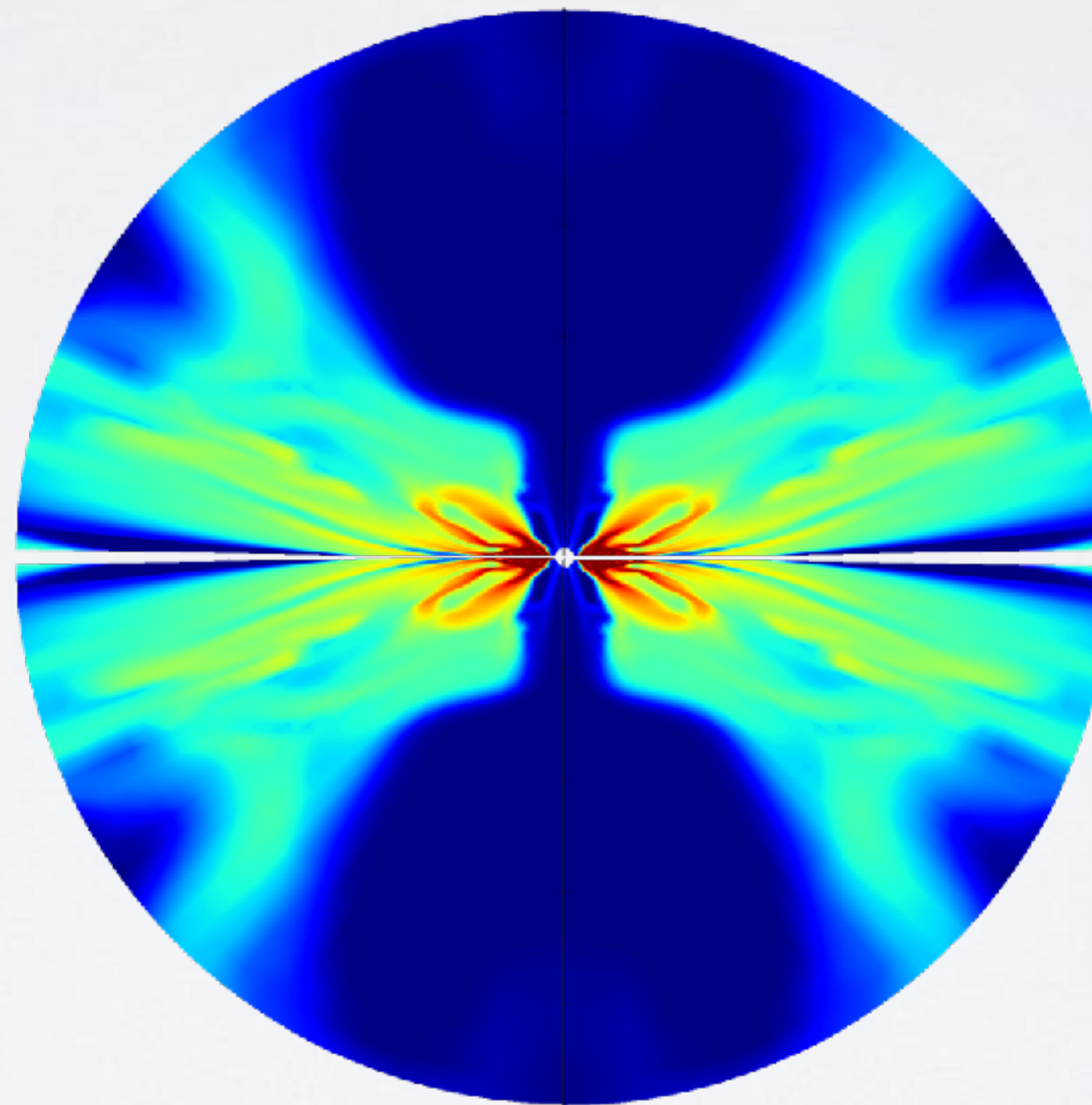
Katie Savard, 3rd
year PhD

5. What is the connection to AGN?

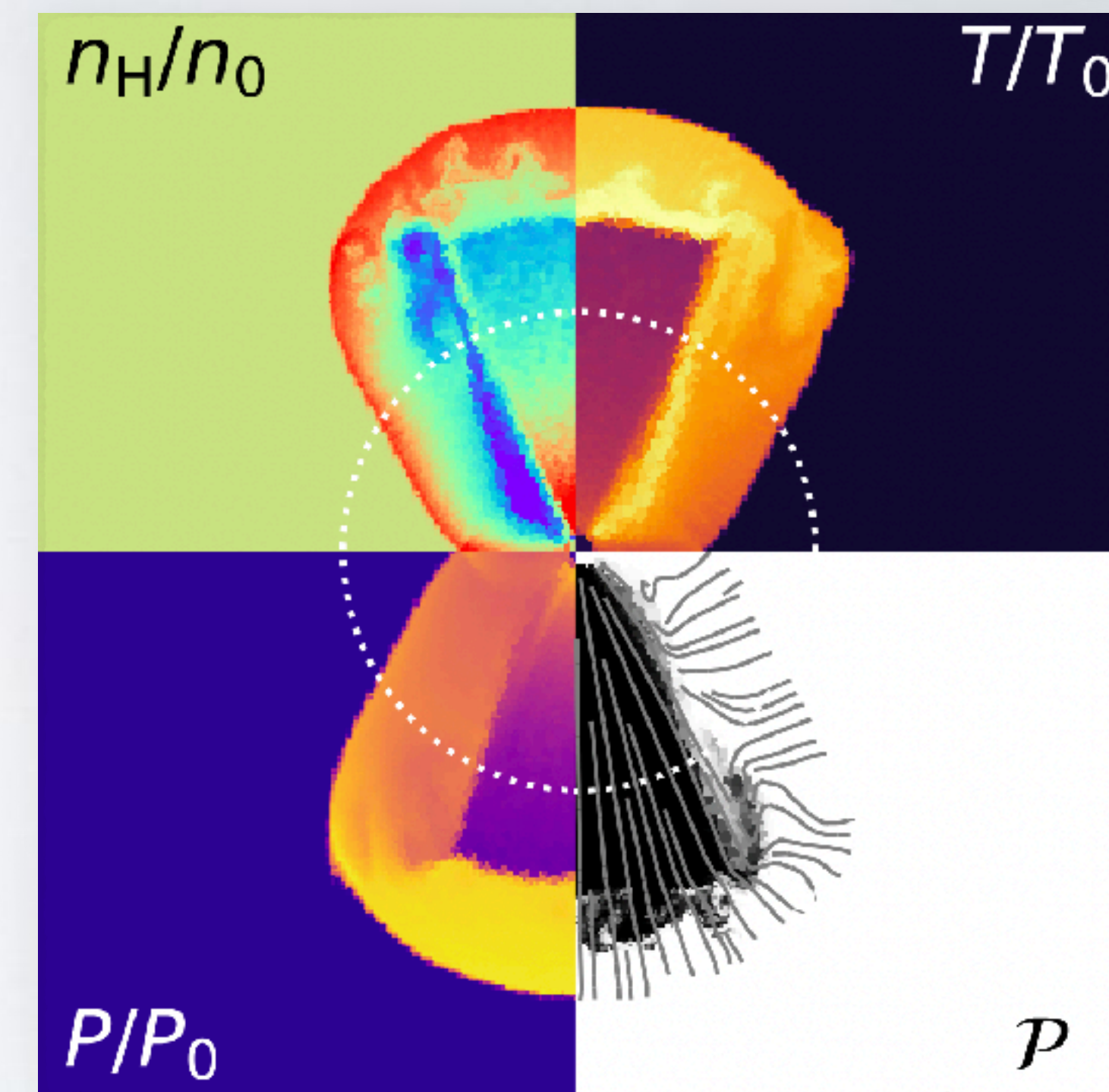
Similar “unified”
frameworks for disc-wind-
jet connection in AGN (e.g.
Giustini & Proga 2019)



But AGN line-driven winds
are also highly “sensitive”
(e.g. Higginbottom+ 2014,
Nico Scepi)



These winds are the
inner flows for “quasar
mode feedback” (e.g.
Tiago Costa)

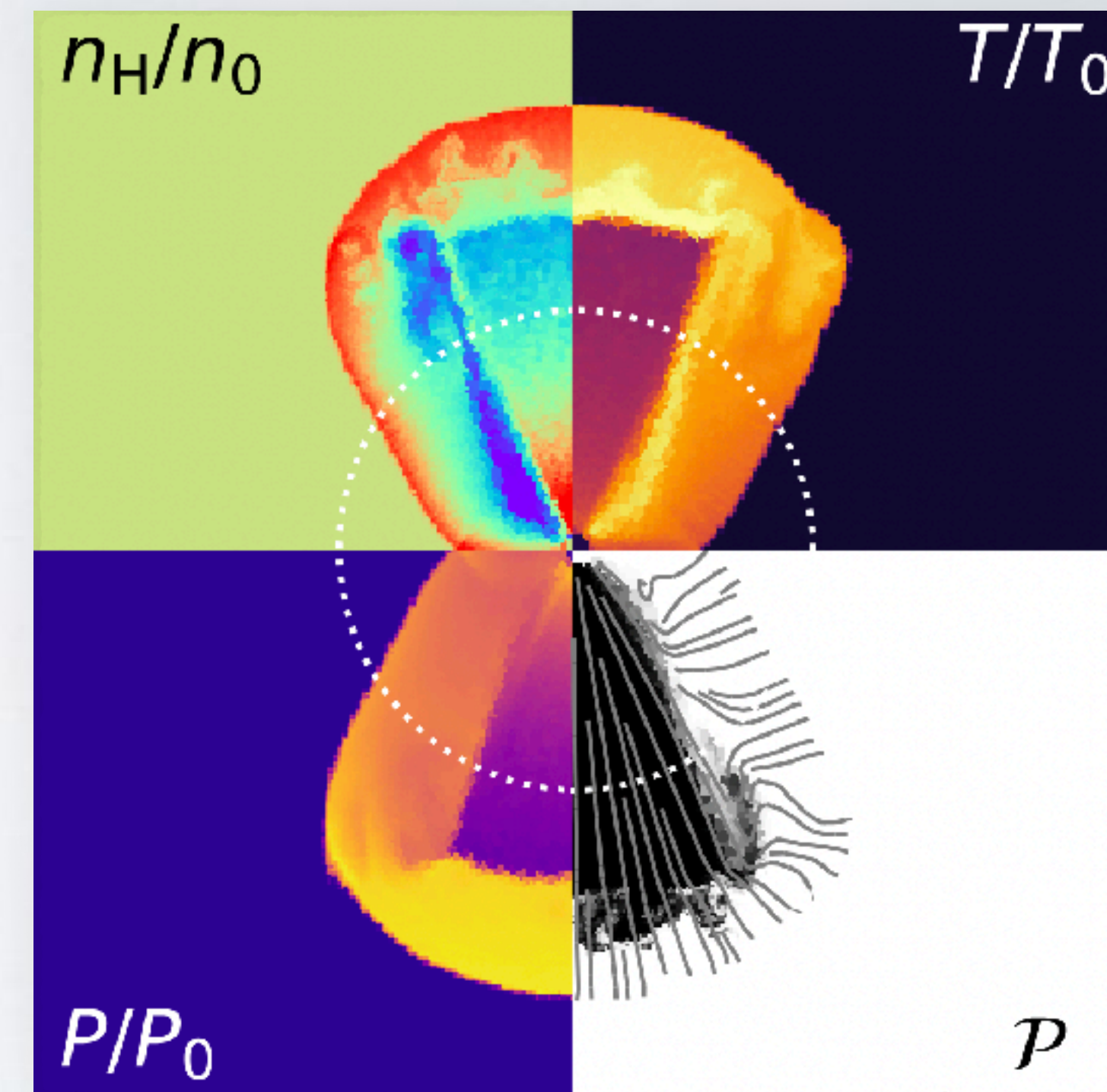
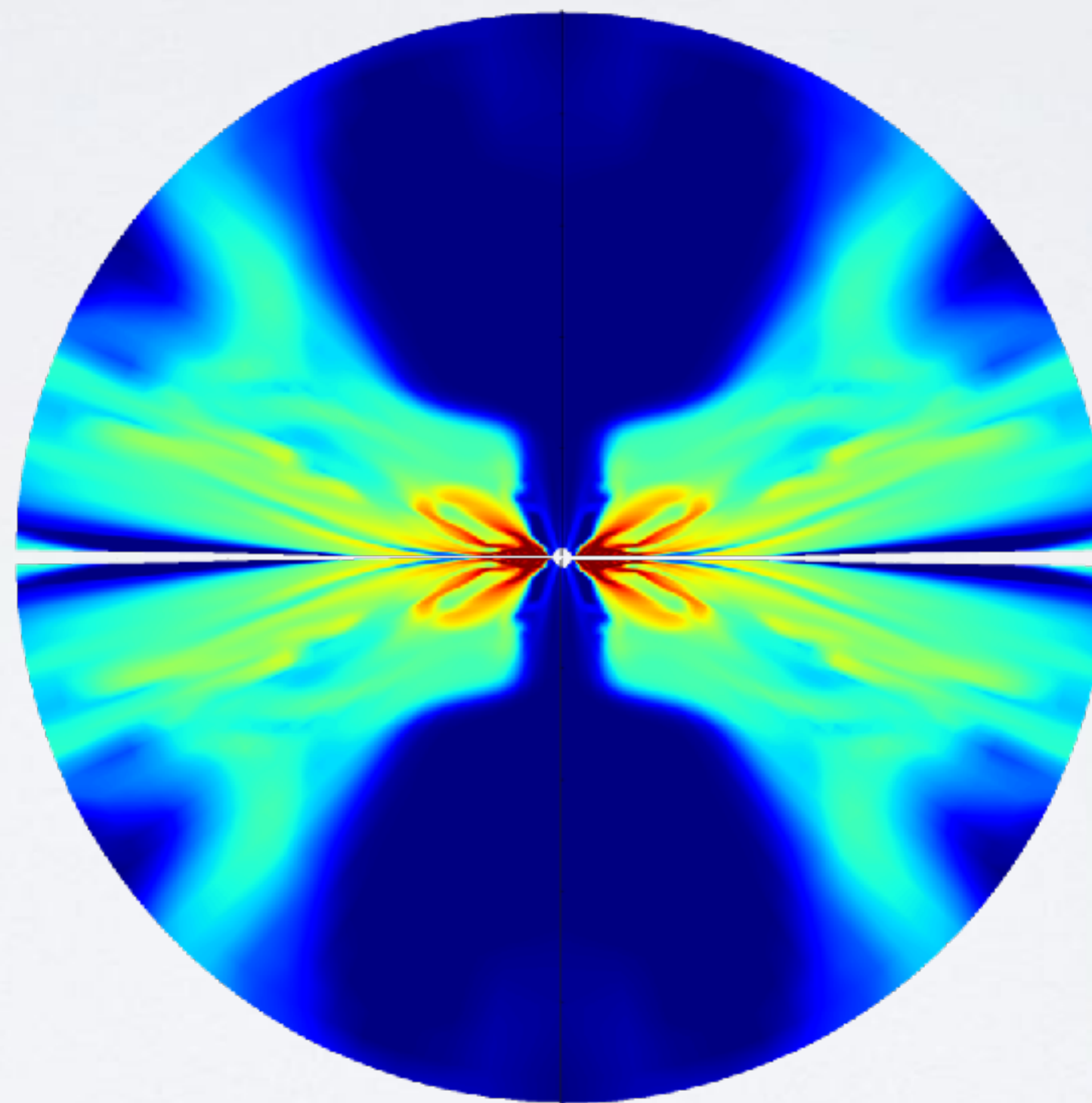
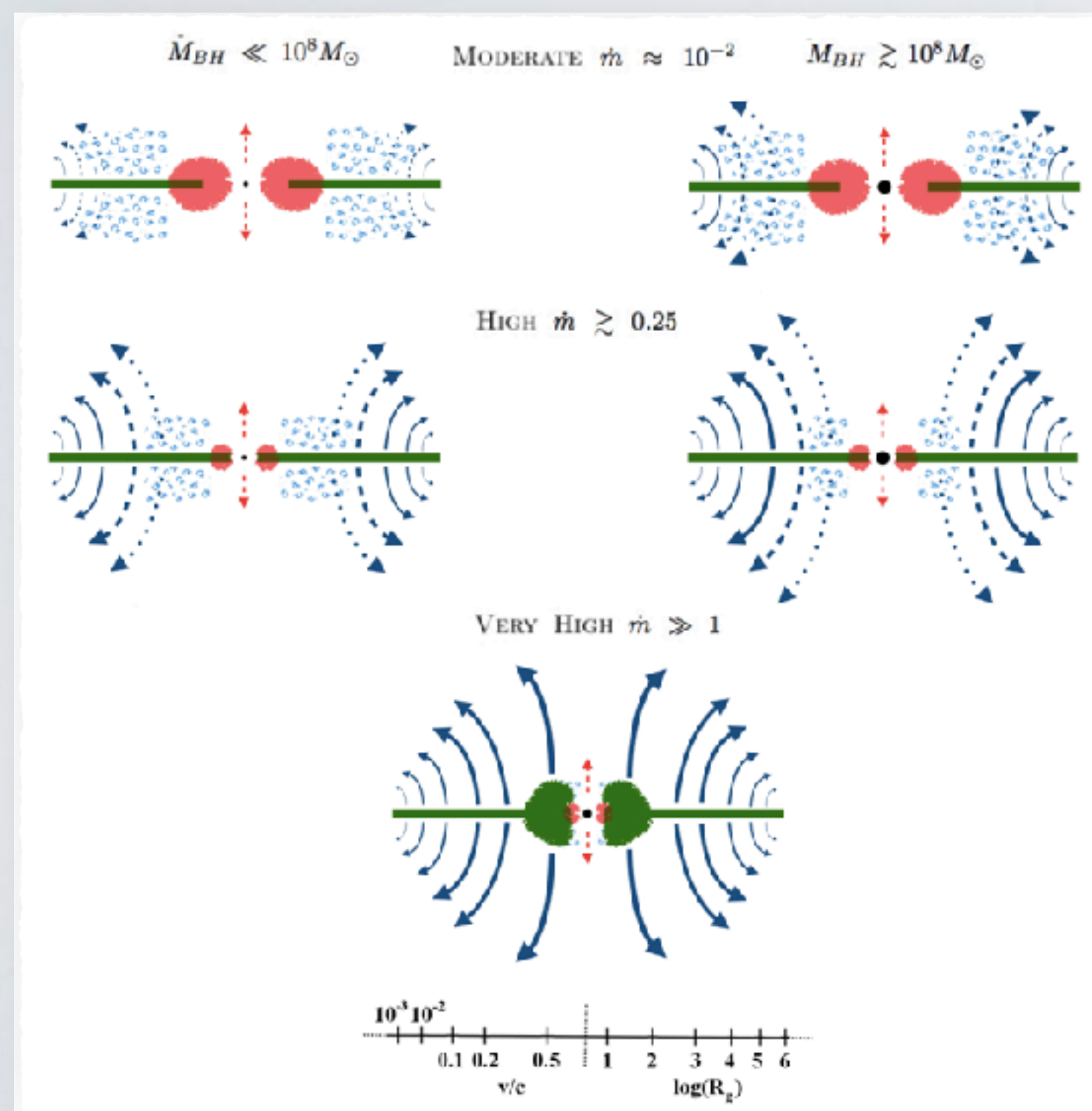


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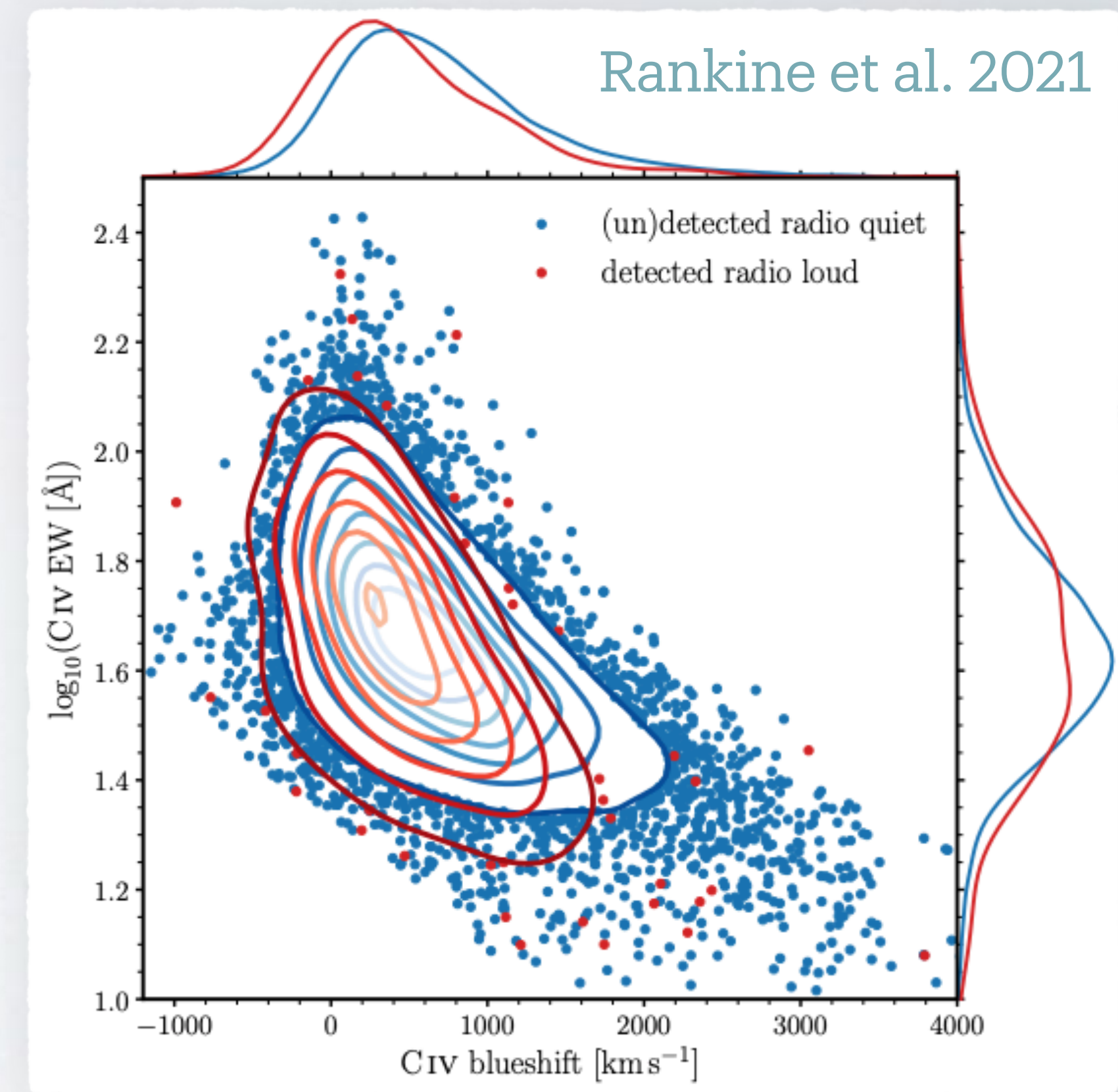
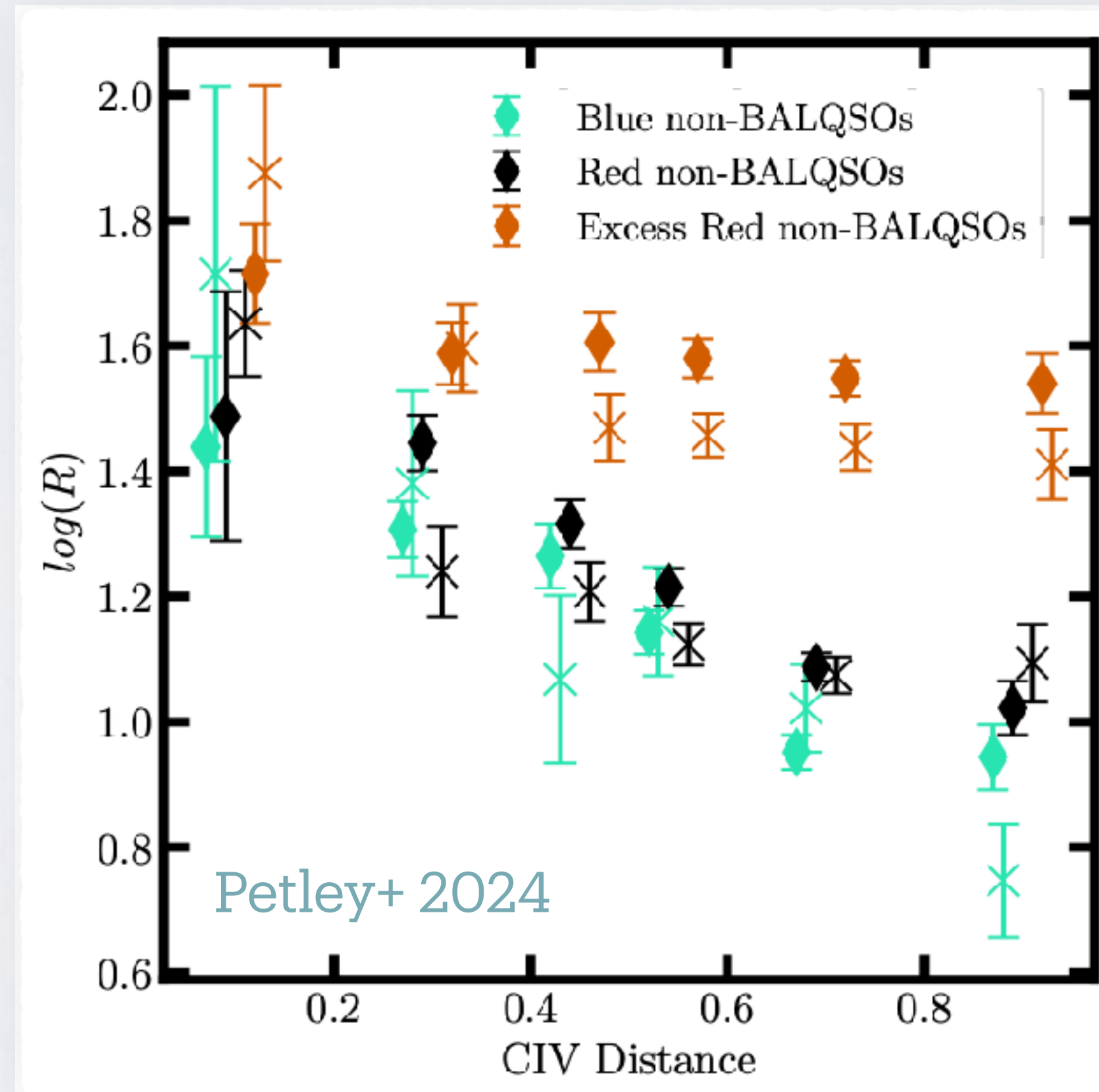
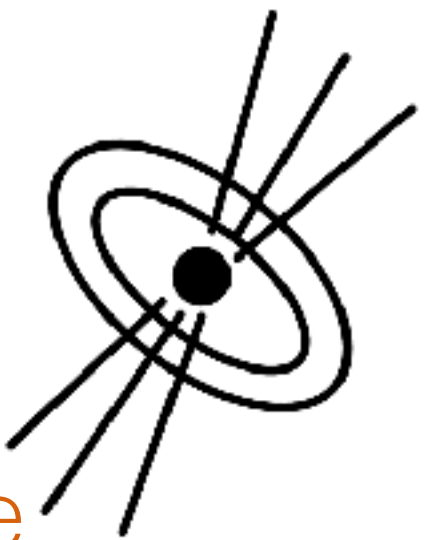
...so binary disc winds help us understand Cosmology.

5. What is the connection to AGN?

- How do XRB jets and AGN jets compare? See Clara Lilje's talk
- Lots of work on quasar populations as a probe of the disc-wind-jet connection (#078: Petley, Yue, Rankine++)

ARE JETS FROM STELLAR MASS BHS
AS FAST AS THE ONES
FROM SUPERMASSIVE BHS?

Clara Lilje



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