Super-Eddington Flows and Spectra

Ken OHSUGA
University of Tsukuba, JAPAN

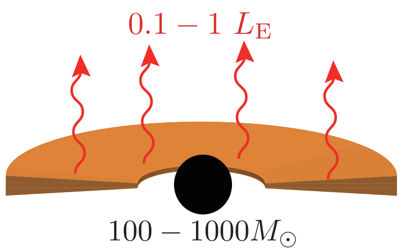
T. Kawashima, H. R. Takahashi, Y. Asahina, H. Kobayashi (NAOJ)
T. Kitaki, S. Mineshige (Kyoto Univ.)

Sub-Eddington or Super-Eddington

IMBH + sub-Eddington disk

If the IMBHs exist, sub-Eddington disk can explain the huge luminosity of ULXs;

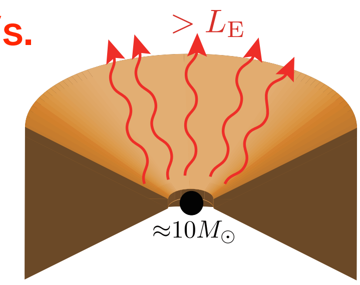
$0.1 L_{Edd}(10^3 Msun) \sim 10^{40}$ erg/s.



Makishima et al. 00, Miller et al. 04, Farrell et al. 09, Servillat et al. 11, etc.

Super-Eddington Disk

Even if the BH mass is around 10Msun, super-Eddington disks can reproduce the huge luminosity; **$10 L_{Edd}(10 Msun) \sim 10^{40}$ erg/s.**

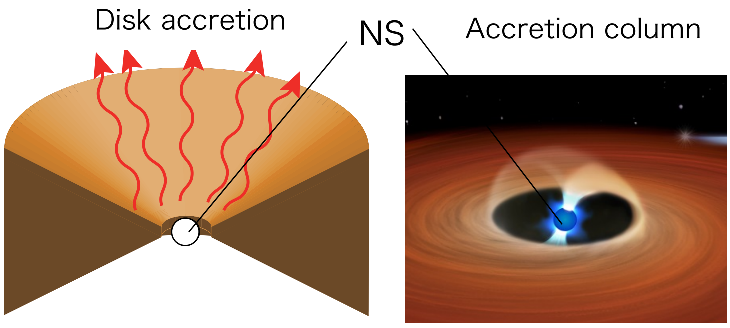


King 04, 08; Ohsuga+ 05, 09, 11, Poutanen+07; Gladstone+09; Middleton +11, Sadowski+13,15, Takahashi+16

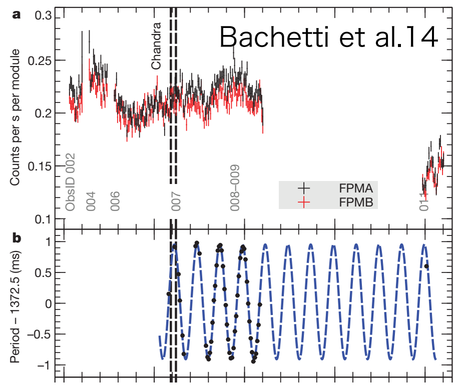
Super-Edd. accretion onto NSs

NS + Super-Eddington flow

If the central objects of ULXs are NSs, super-Eddington is necessary because the mass of NSs is a few Msun.



Basko & Sunyaev 76; Ohsuga 07; Mushtukov+15, 18; King & Lasota 16; Kawashima et al. 16; Takahashi & Ohsuga 17, 18; Chashkina+17



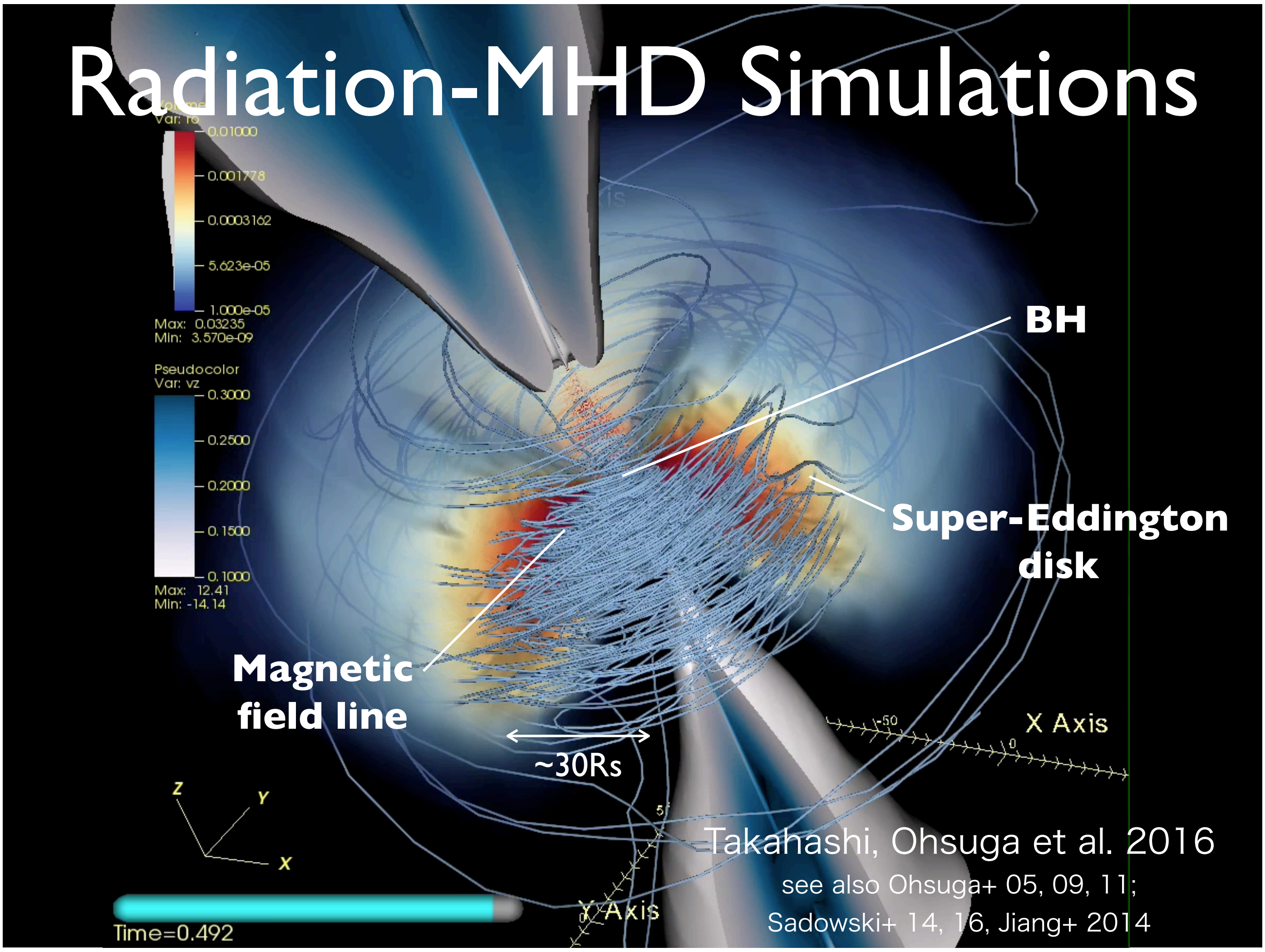
ULX pulsar;
Engine is super-Eddington accretion onto NS.

also Fuerst+16, Israel+17, Carpano+18, etc.

Today’s plan

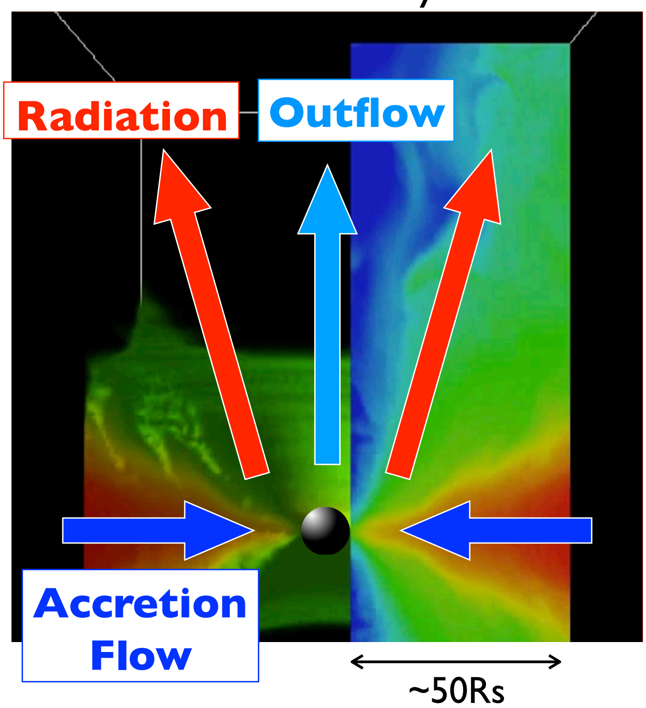
- We introduce our **Radiation-HD/MHD simulations** of super-Eddington flows around BHs and explain the **basic features of the super-Edd. flows**.
- We show that the **super-Edd. flows can explain observations of ULXs** (Luminosity, spectra, clumpy outflow, ULX bubbles).
- We show the simulation results of **the super-Edd. flows around NSs** (Powerful outflows and accretion column appear).

Radiation-MHD Simulations



Super-Eddington disk & outflows

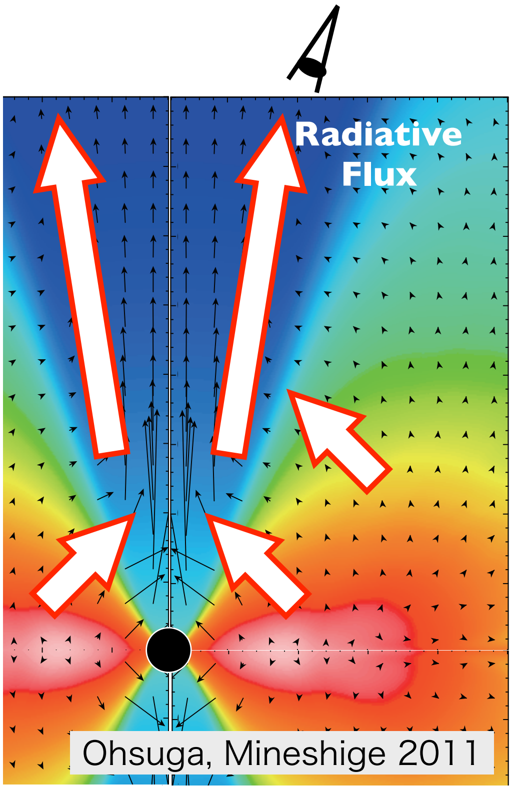
Mass density



Radiation-pressure supported disk
&
radiatively-driven jet
(~0.3-0.5c)

Ohsuga et al. 2009
Ohsuga & Mineshige 2011
see also Ohsuga et al. 2005

Luminosity



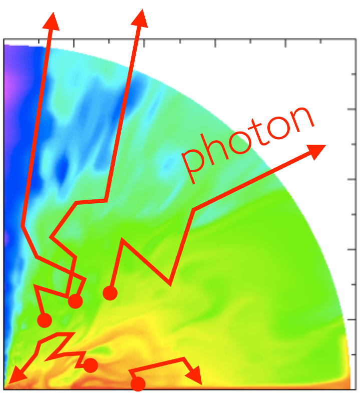
The radiative flux is mildly collimated since the disk is optically and geometrically thick.

Thus, observed luminosity is much larger than the Eddington luminosity except for the edge-on view (e.g., **22L$_{Edd}$** for ≲20° in the case of Mdot~100L$_{Edd}$/c^2, L$_{disk}$~3L$_{Edd}$).

Super-Eddington flows can explain the large X-ray luminosity of ULXs.

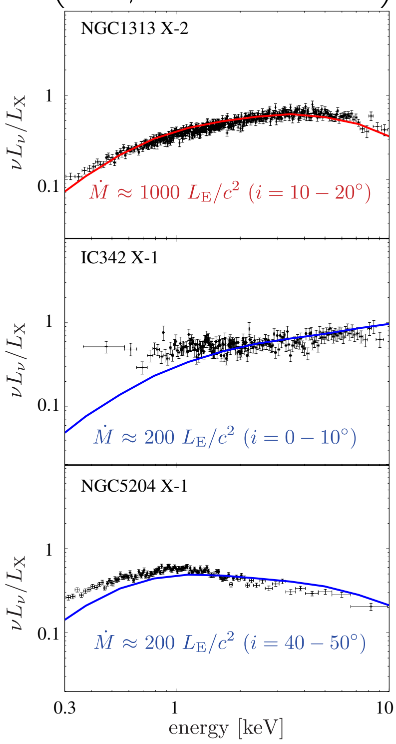
X-RAY SPECTRA

Monte Carlo Radiation transfer
(fee-free, thermal & bulk compton)
Kawashima, Ohsuga et al. 2012



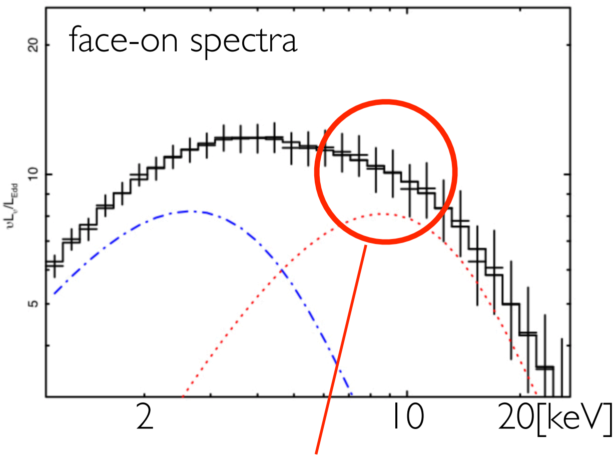
Simulated spectra nicely fit the observations.

Kawashima et al. 2012
(data; Gladstone 2009)



X-RAY SPECTRA

Kitaki, Mineshige, Kawashima, Ohsuga+ 2017



We find roll over
at around several keV.

fitting parameters

Model	Parameter (unit)	numerical values
DISKBB	T_{in} (keV)	1.0
DISKPBB	T_{in} (keV)	3.1
	p	0.86
SIMPL	Γ	2.9

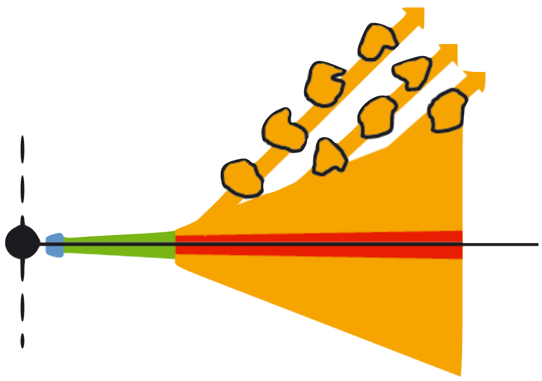
Resulting Γ~2.9 is consistent with the observations of Γ~3.1 (Walton+15).

*Tin is too high. But it would decrease when we employ larger computational box.

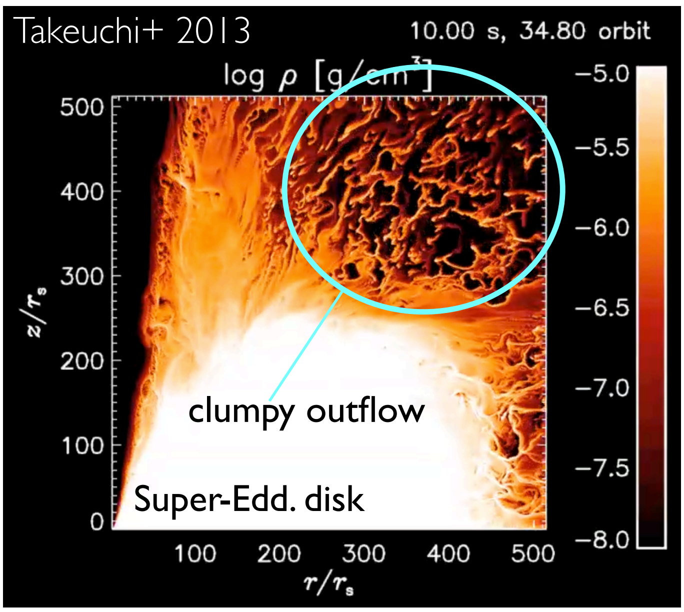
Our results are consistent with the recent observations.

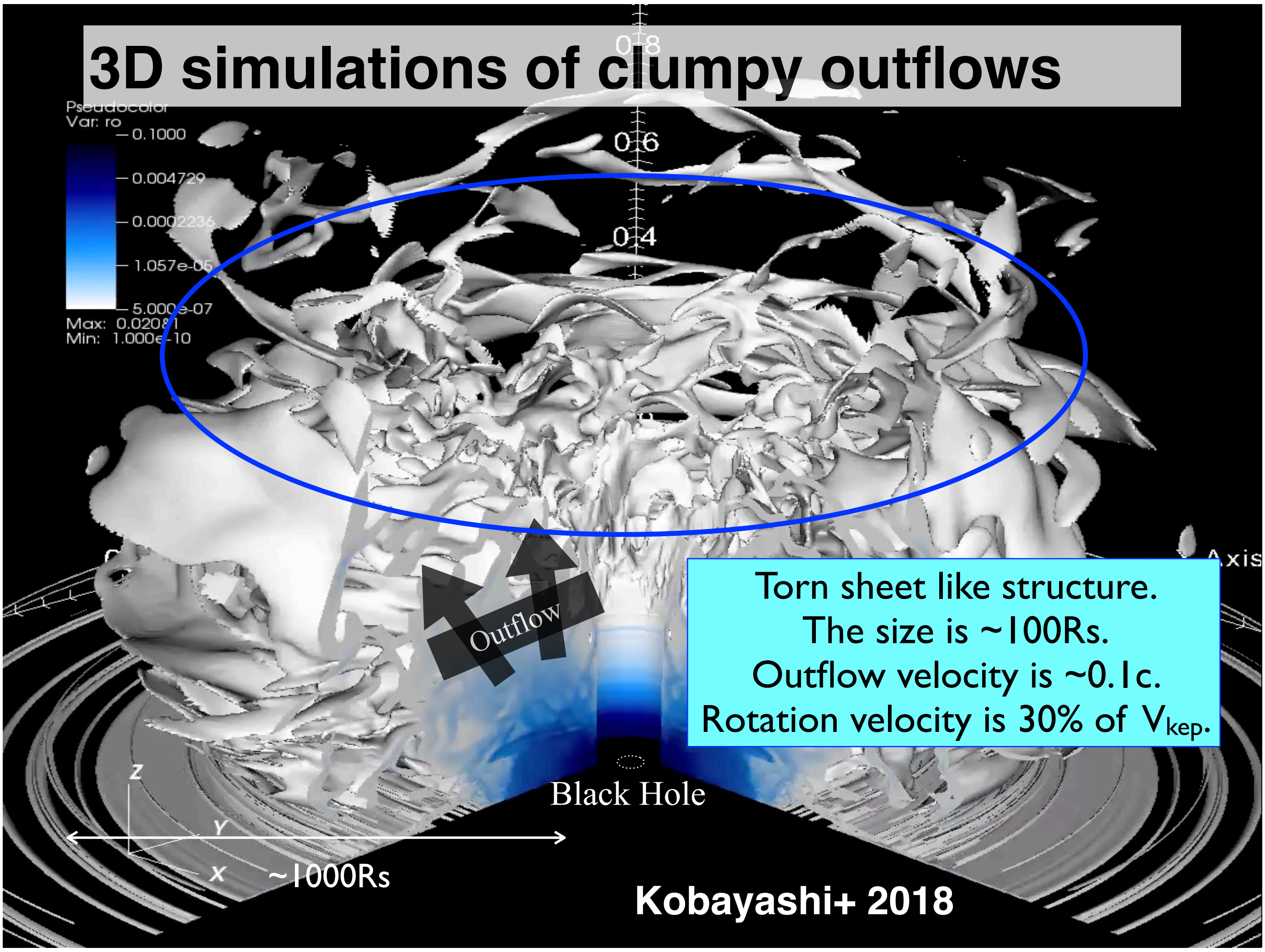
CLUMPY OUTFLOWS

Some ULXs exhibit the time variations of X-ray luminosity, implying the launching of clumpy outflows (Middleton+2011).



2D simulations reveals that the outflows fragments into many clouds via RT instability.





Comparison with Observations

Sheet like structure

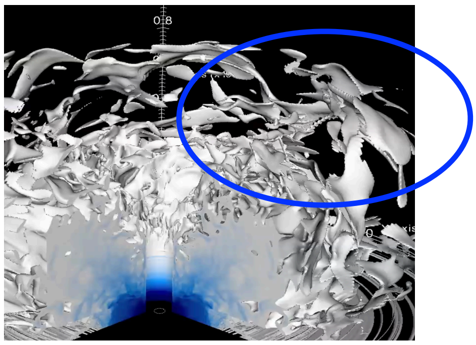
Size (azimuthal direction) ~ 100Rs
Outflow velocity ~ 0.1-0.2c
Rotation velocity ~ 30% of V_{kep}

(1)Time variation

Timescale of the luminosity variation ($100Rs/0.3V_{kep}$) is

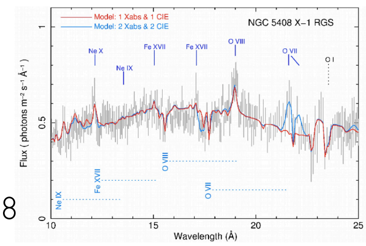
$$\sim 2.5 \left(\frac{M_{\rm BH}}{10\,M_\odot}\right)\left(\frac{\ell^{\theta}_{\rm cl}}{10^2\,r_{\rm S}}\right)\left(\frac{r}{10^3\,r_{\rm S}}\right)\,{\rm s}$$

consistent with the observations (Middleton+11) in the case of M_{BH}~10-100Msun.



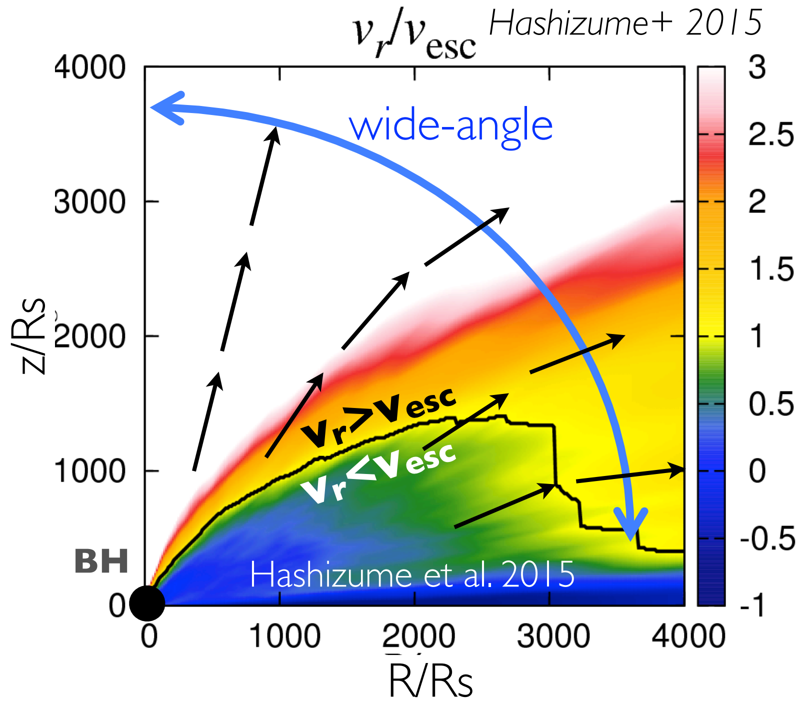
(2)Absorption lines

Outflow velocity of ~0.1-0.2c agrees with the observations of blueshifted absorption lines.



Pinto+16,
see also Kosec+18

ULX BUBBLE



At the direction of 45°, we find $v_r>v_{esc}$ near the black hole.

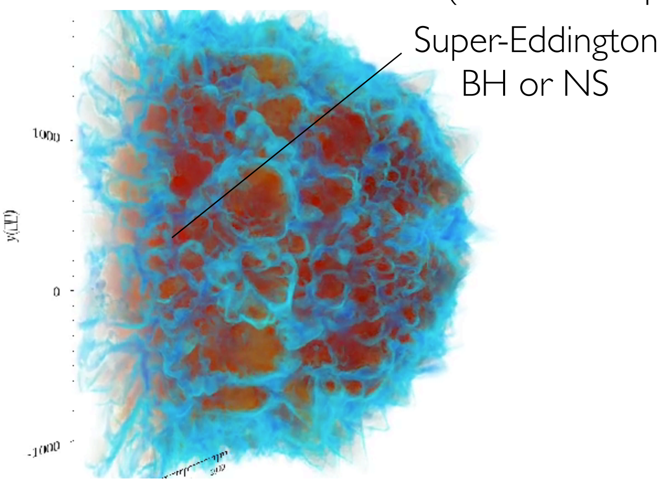
In θ~45°-80°, outflow velocity gradually increases and exceeds v_{esc} at r ~1000-4000Rs.

Such a wide angle outflow is accelerated by radiation force.

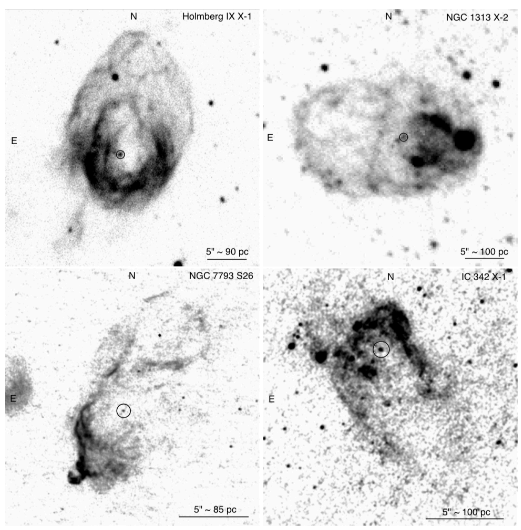
ULX BUBBLE

Simulated kinetic power is comparable to the X-ray luminosity (L_{kin}~L_X~$10^{39\text{-}40}$erg/s).
Such feature agrees with the observed ULX bubbles.

Simulations of ULX Bubbles (Asahina+ in prep.)

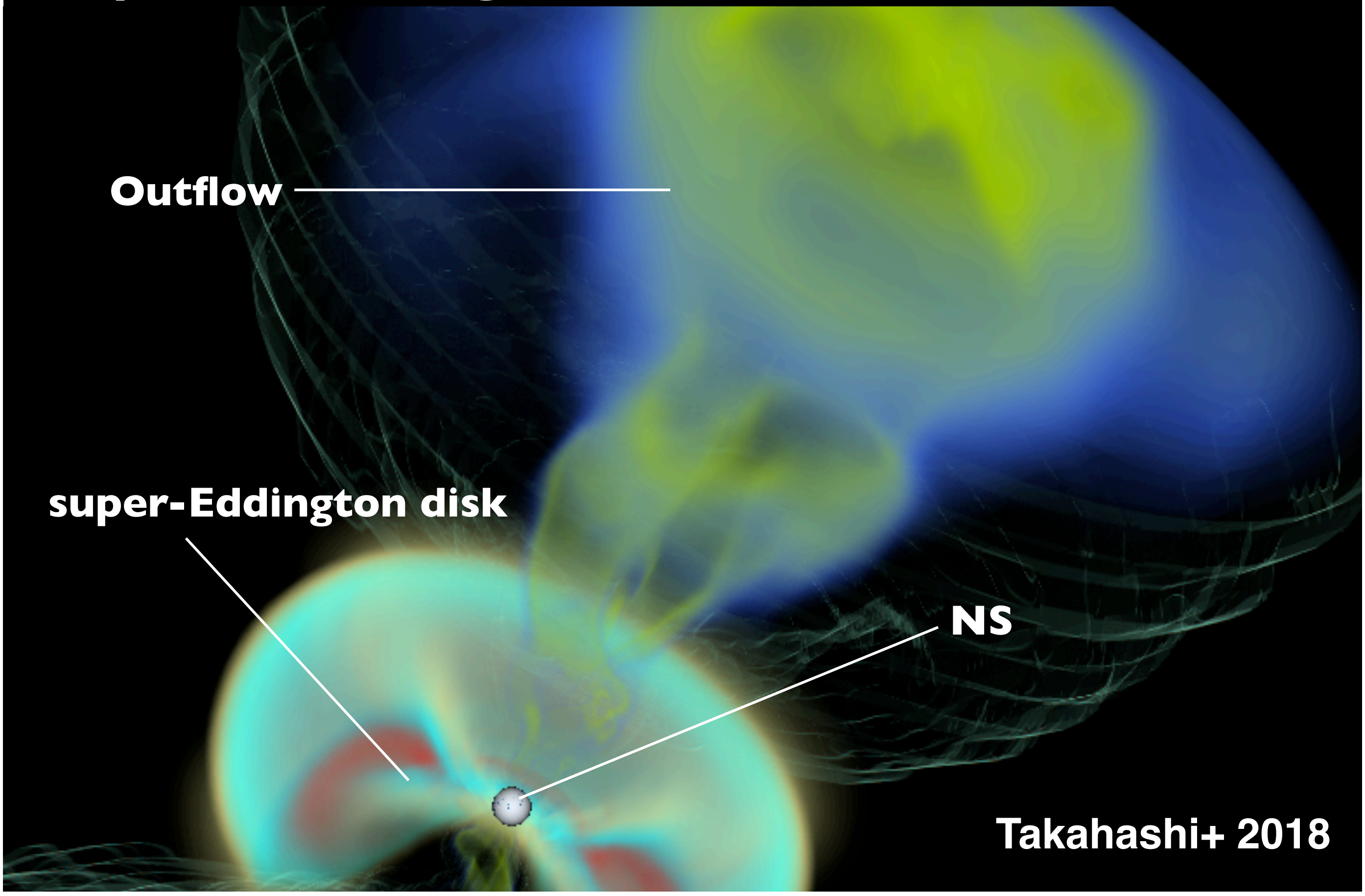


Feng & Soria 11

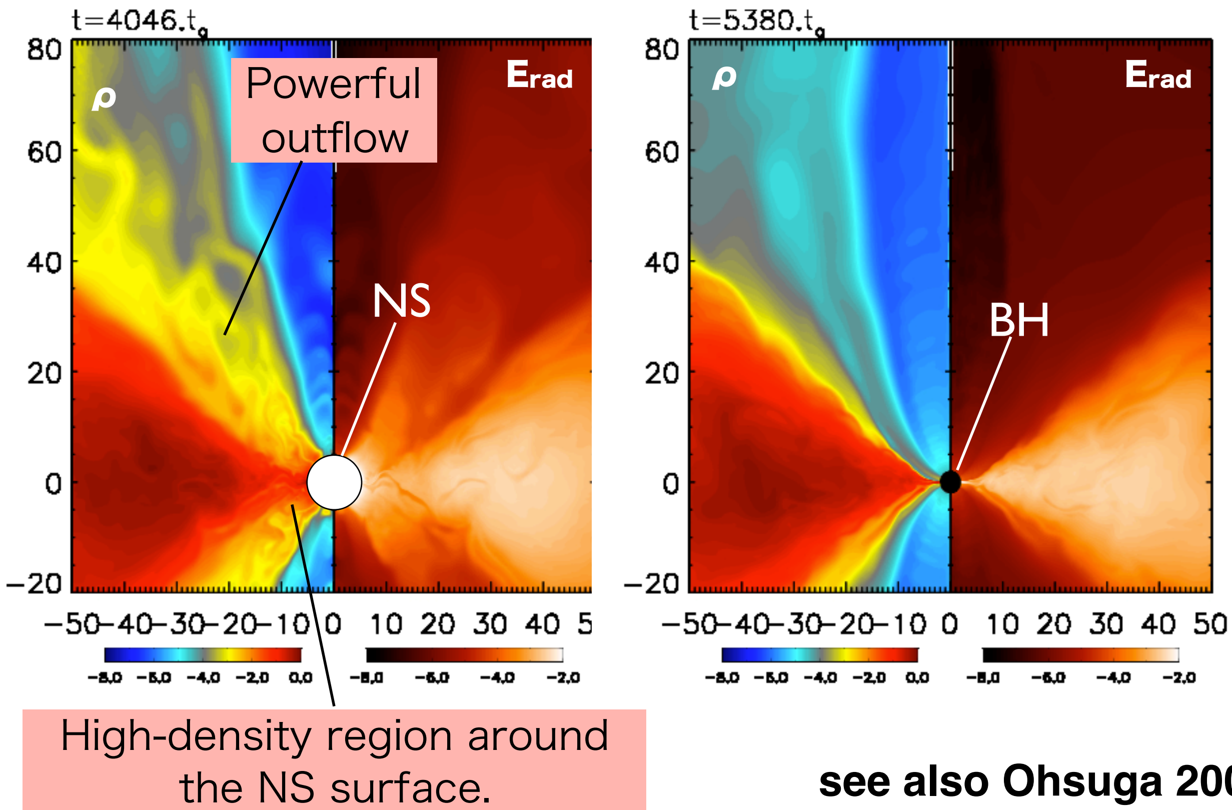


also Pakull & Mirioni (2003), Grise et al. (2006), Pakull et al. (2010), Soria et al. (2010) Cseh et al. (2015)

Super-Eddington Flows around NSs

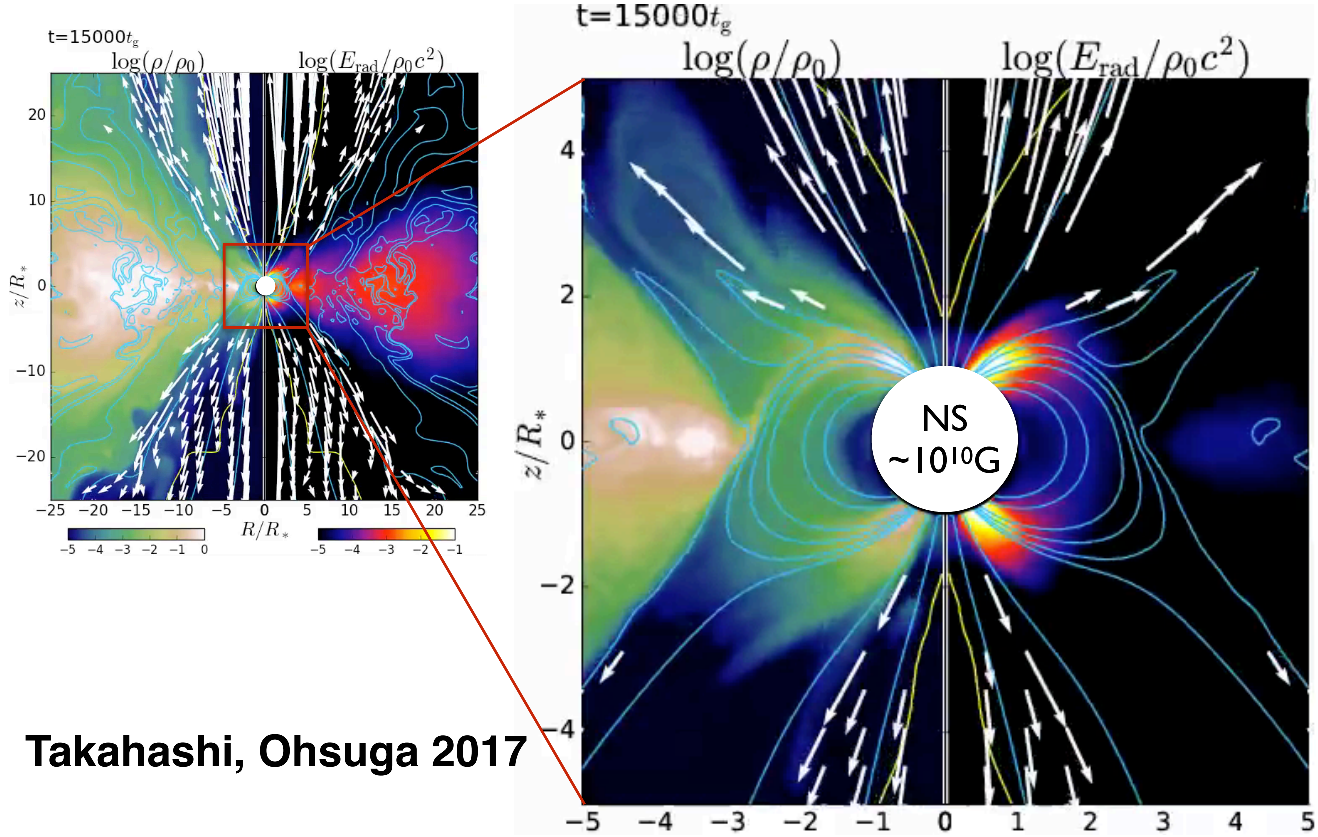


Non-magnetized NS



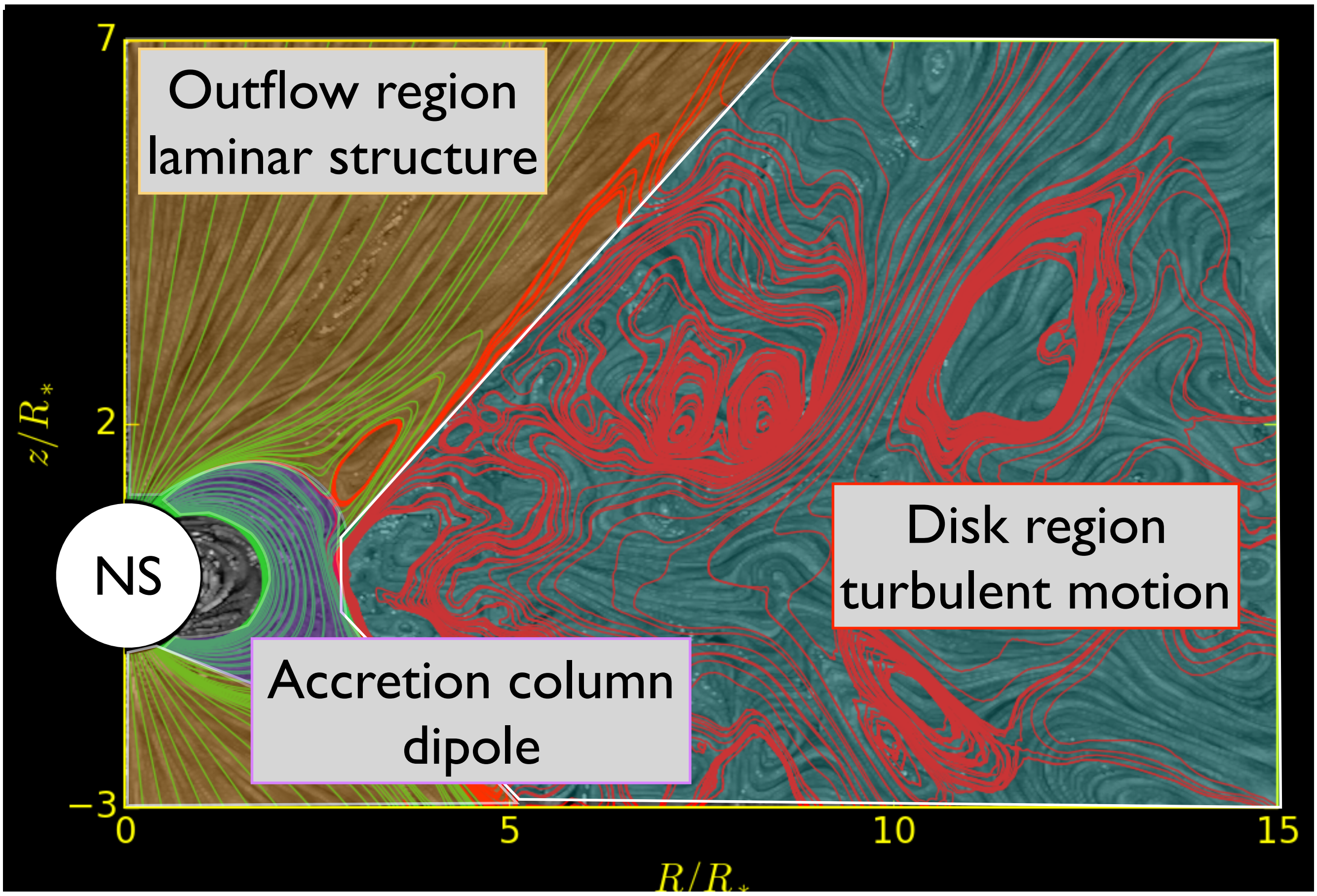
see also Ohsuga 2007

Magnetized NS



Takahashi, Ohsuga 2017

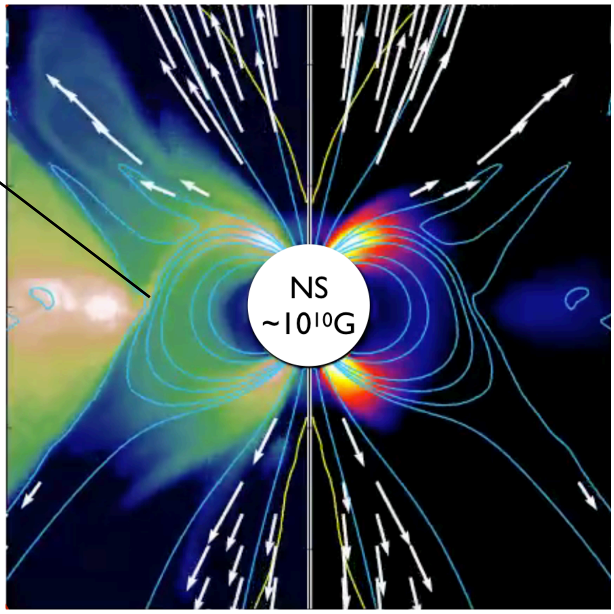
Flow structure



Spin-up rate

Magnetospheric radius (R_M) is determined by **Pmag ~ Prad**, since radiation pressure-dominated disk is truncated.

Gas loses angular momentum at around R_M, leading to the spin-up of NS. Estimated spin-up rate is about **-3×10^{-11} s s^{-1}**. It roughly agrees with the observations of ULXPs.



SUMMARY

- Super-Eddington flows can explain the basic features of the ULXs (X-ray luminosity, spectra, clumpy outflow, ULX bubbles).
- Super-Eddington accretion onto NS is more powerful engine, since the energy as well as the matter is not swallowed.
- ULXPs would be powered by the super-Eddington flows onto magnetized NS (super-Eddington accretion column).