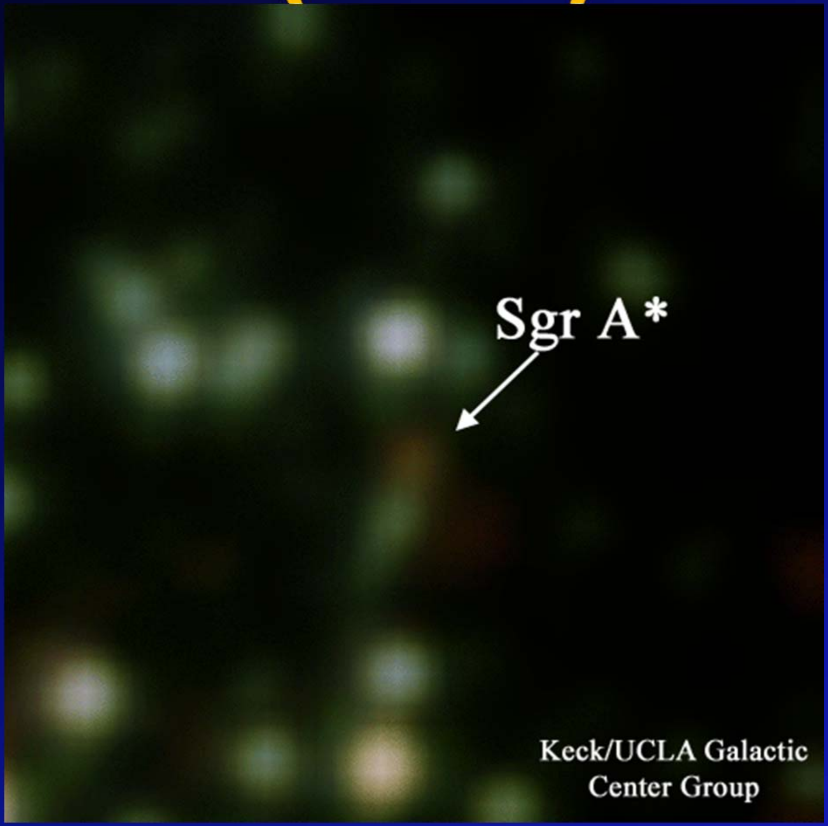
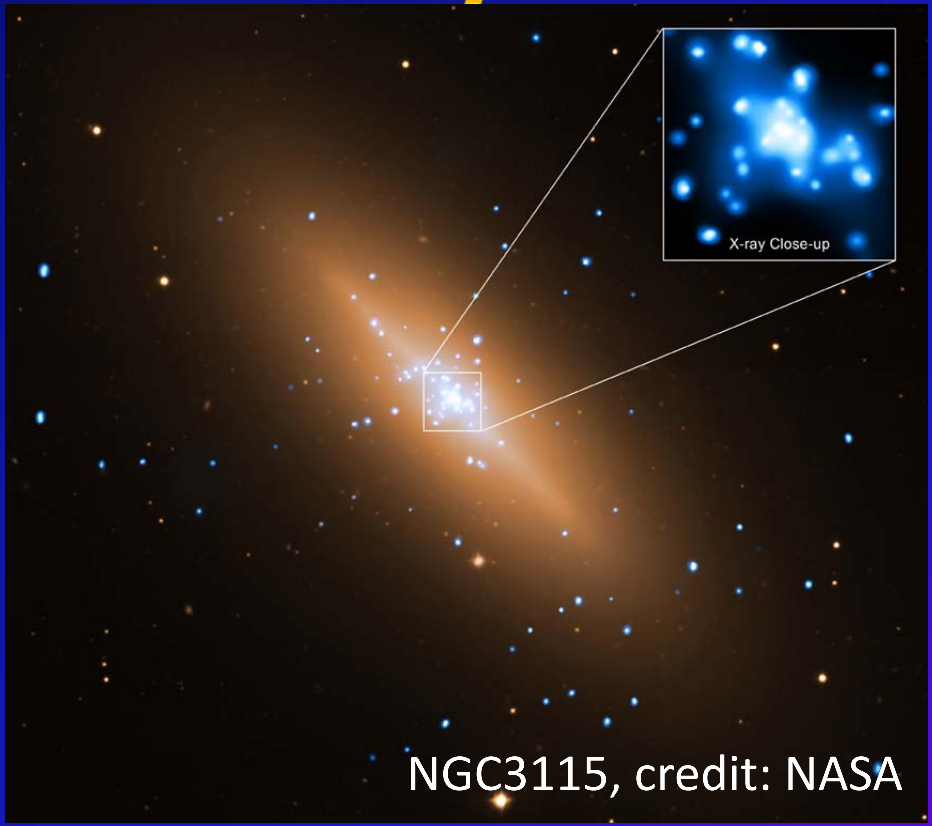
Feeding and small-scale feedback in (ultra) low-luminosity AGNs





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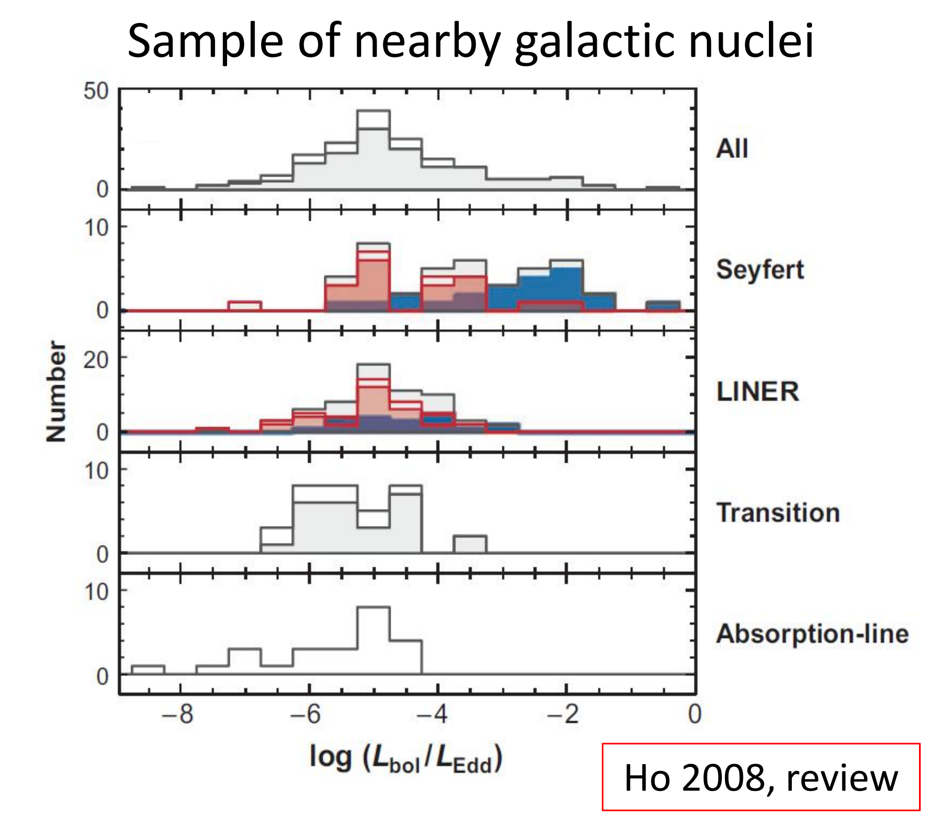
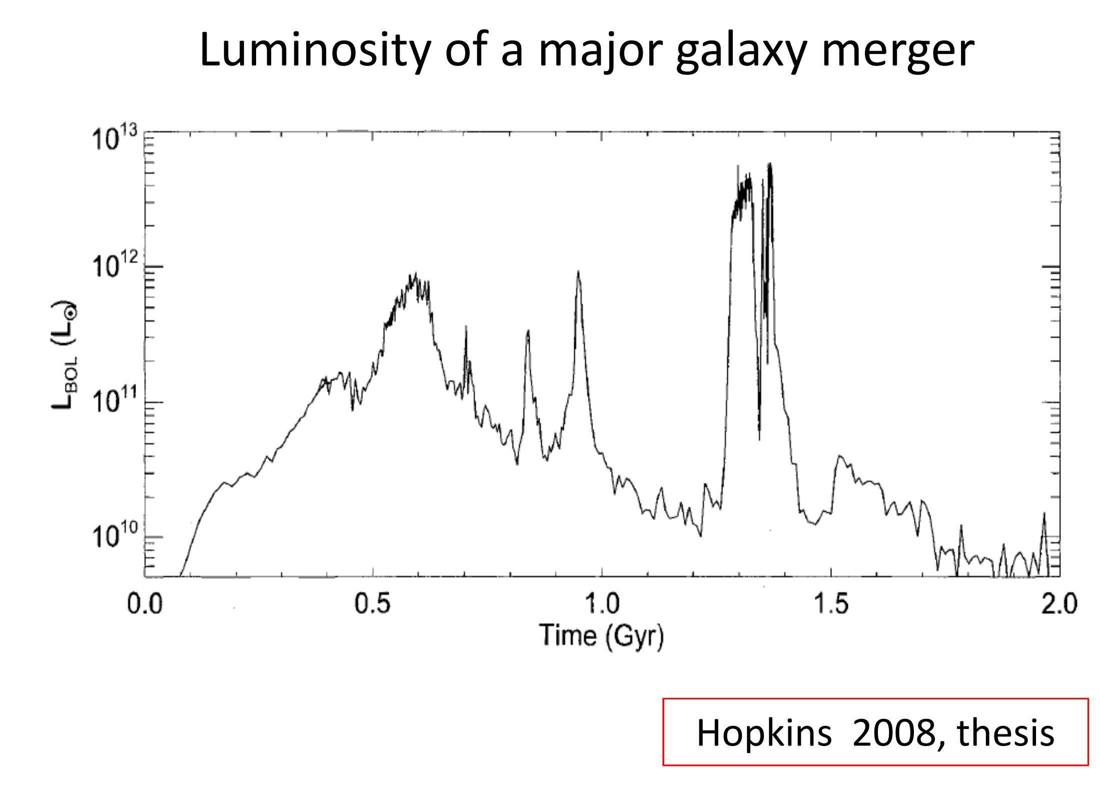
Fred Baganoff (MIT),
Jimmy Irwin(Alabama), Ka-Wah Wong (Alabama)

290th IAU, Beijing, China
21 Aug 2012

Typical AGN is not active





L_{bol} – total luminosity

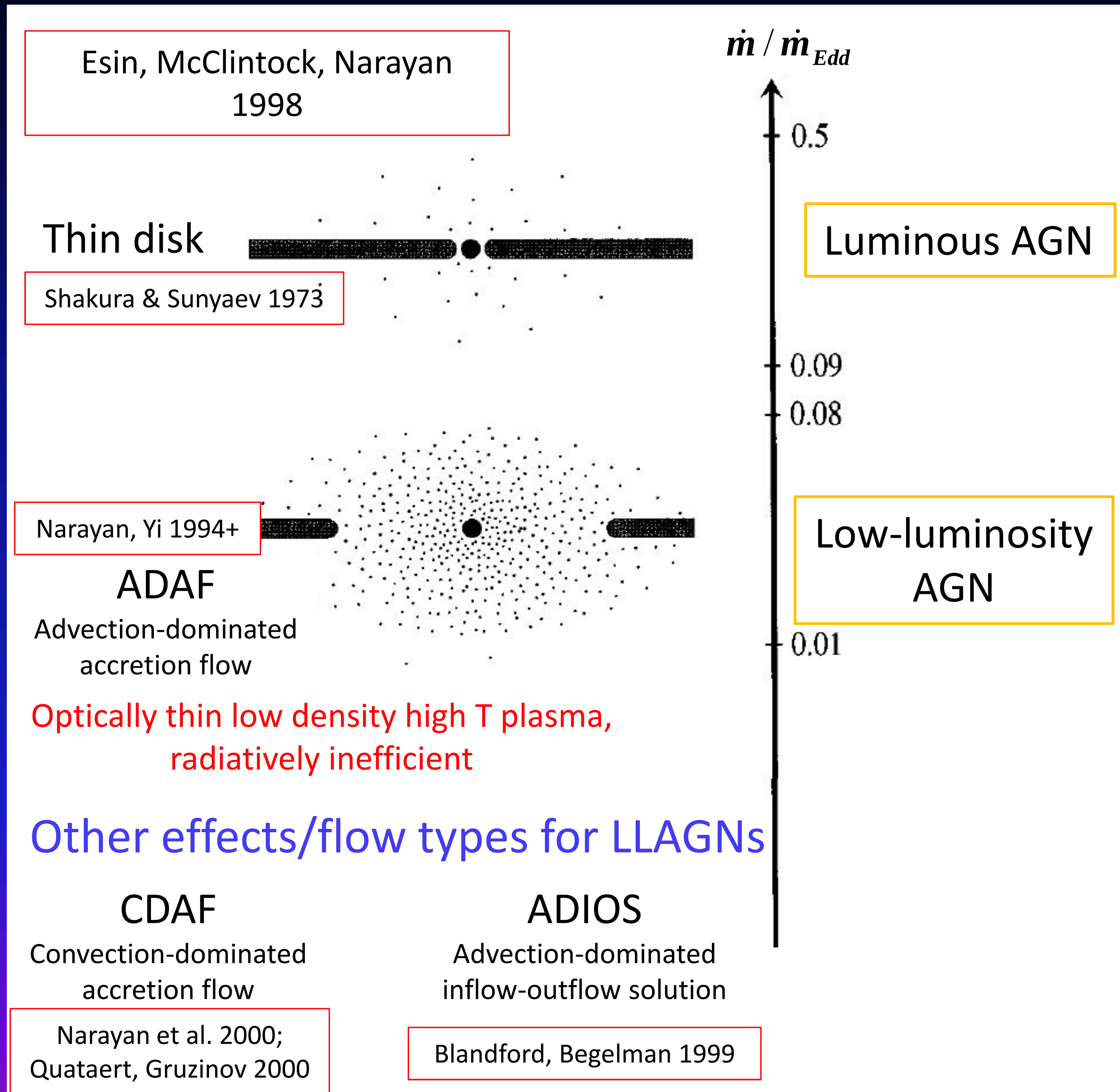
L_{Edd} – Eddington luminosity
(theoretical maximum AGN luminosity)

An AGN shines at Eddington luminosity
for only a short time
(mergers don't happen all the time)

Typical AGN has
$L_{bol}/L_{edd} \sim 10^{-5}$

lower L_{bol} objects may still be missed ⟵ Sgr A* has $L_{bol}/L_{edd} \sim 10^{-8}$

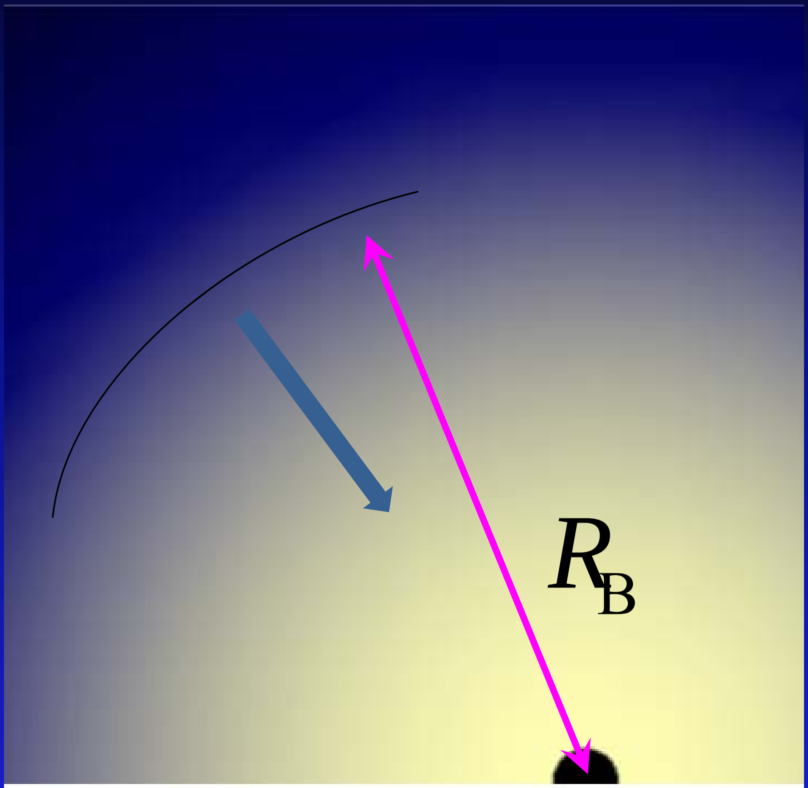
Accretion rate & physics vs state of AGN



No thin disk ⇔ low-luminosity AGN

How does matter get to the BH in LLAGNs?

Accretion from radius of BH gravitational influence (Bondi radius)



Sources with very large R_B (T=0.3-1keV):

Milky Way : M_{BH}=4.3·$10^6 M_\odot$, d=8.3kpc, R_B=2''

Gillessen et al. 2009

M31 : M_{BH}=1.4·$10^8 M_\odot$, d=780kpc, R_B=3''

Bender et al. 2005

NGC3115 : M_{BH}=1.5·$10^9 M_\odot$, d=9Mpc, R_B=4''

Kormendy et al. 1996

Chandra X-ray visionary projects (XVP)
to directly probe gas near Bondi radius

3Ms gratings observations of Sgr A* – underway
1Ms observations of NGC 3115 – observations finished

Bondi accretion

r_B – radius of BH influence

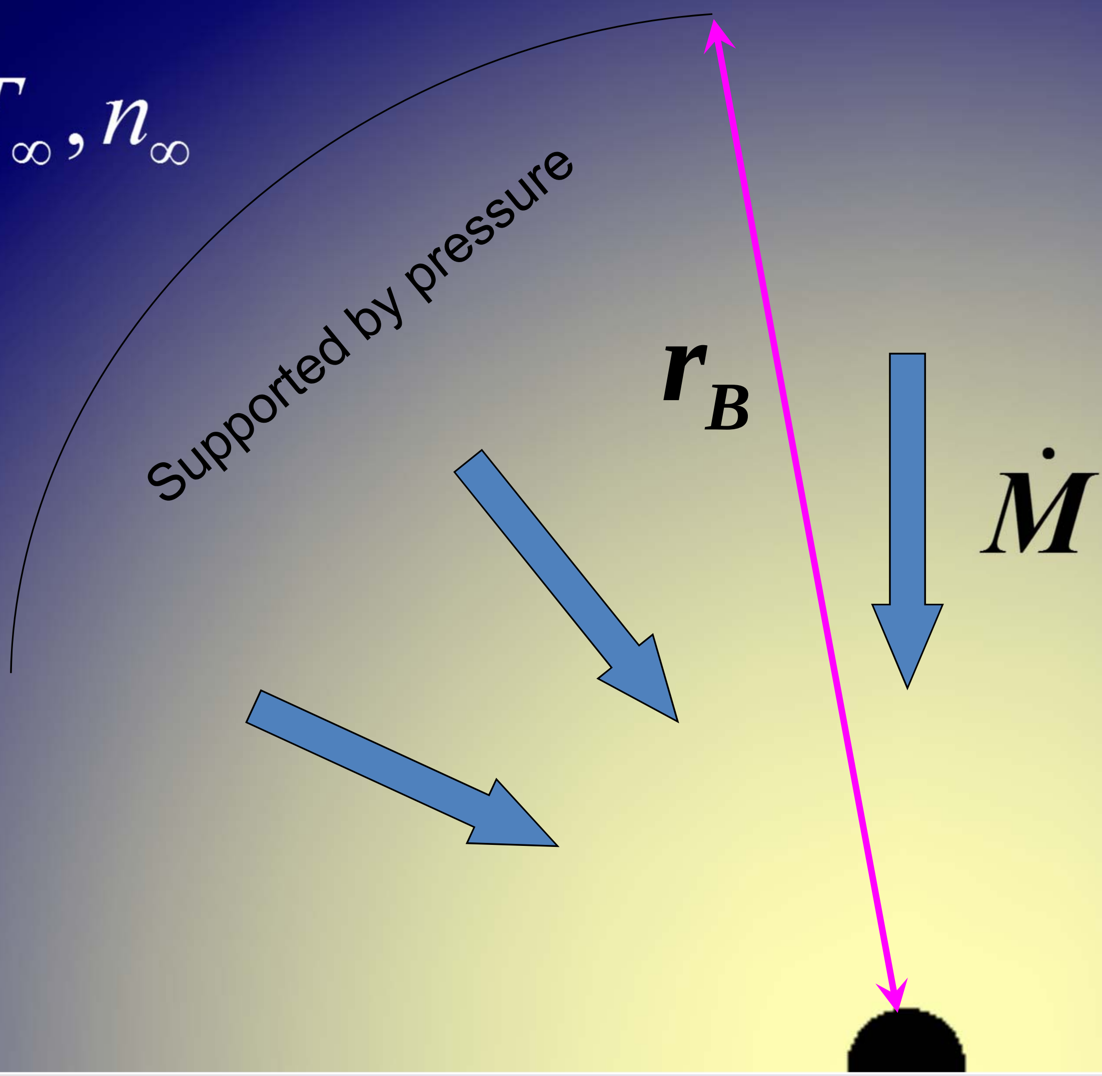
$$k_B T \sim \frac{GMm_p}{r_B}$$

Thermal energy ~ gravitational

$$V_r \sim c_s$$

inflow speed ~ sound speed

$$T_\infty, n_\infty$$



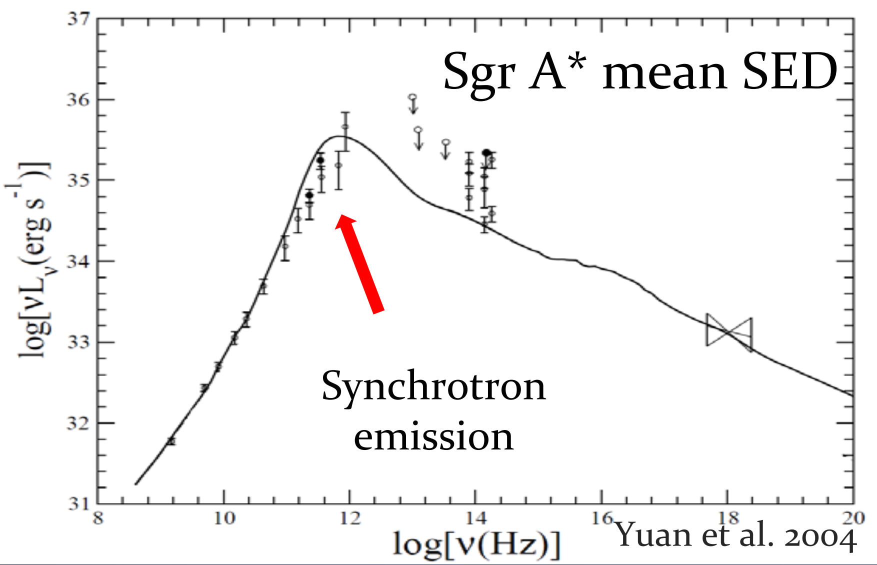
$$\dot{M}_B \sim \frac{n_\infty}{T_\infty^{3/2}}$$

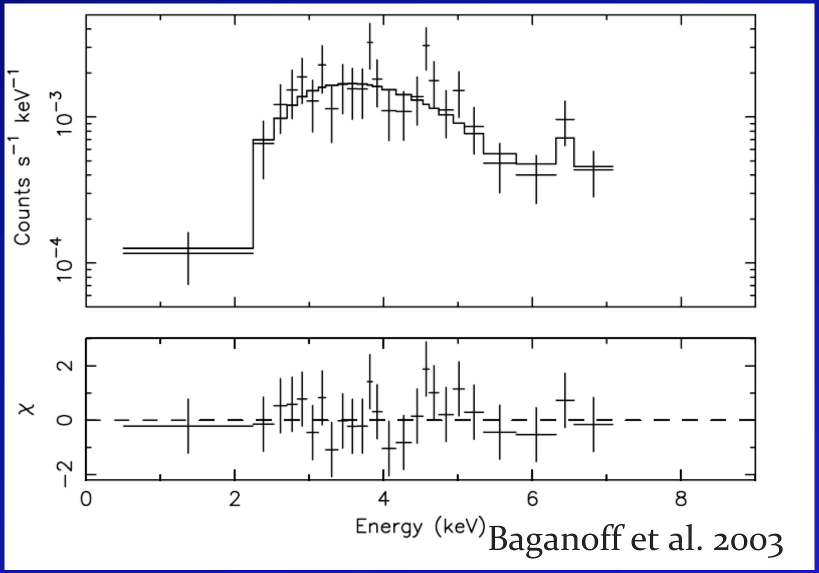
$$T \sim r^{-1}$$

$$n \sim r^{-1.5}$$

Bondi flow is not the whole story

Density profile is very shallow = small % of material reaches the BH





Electron T_e and magnetic field B increase steeply towards the BH

The synchrotron peak is produced near the event horizon

From ν_{peak}=500GHz and $F_\nu(\nu_{peak})$=3Jy: density $n_e \sim 10^6 cm^{-3}$ and $T_e \sim 3 \cdot 10^{10}$K; $M_{dot} \sim 3 \cdot 10^{-8} M_{sun}/yr$

"Ambient" X-ray spectrum consistent with thermal bremsstrahlung kT_e=1.3keV, n=26cm^{-3}

Baganoff et al. 2003

Predicted near the BH:

$n \sim 10^8 cm^{-3}$; $M_{dot} \sim 3 \cdot 10^{-6} M_{sun}/yr$ for Bondi inflow

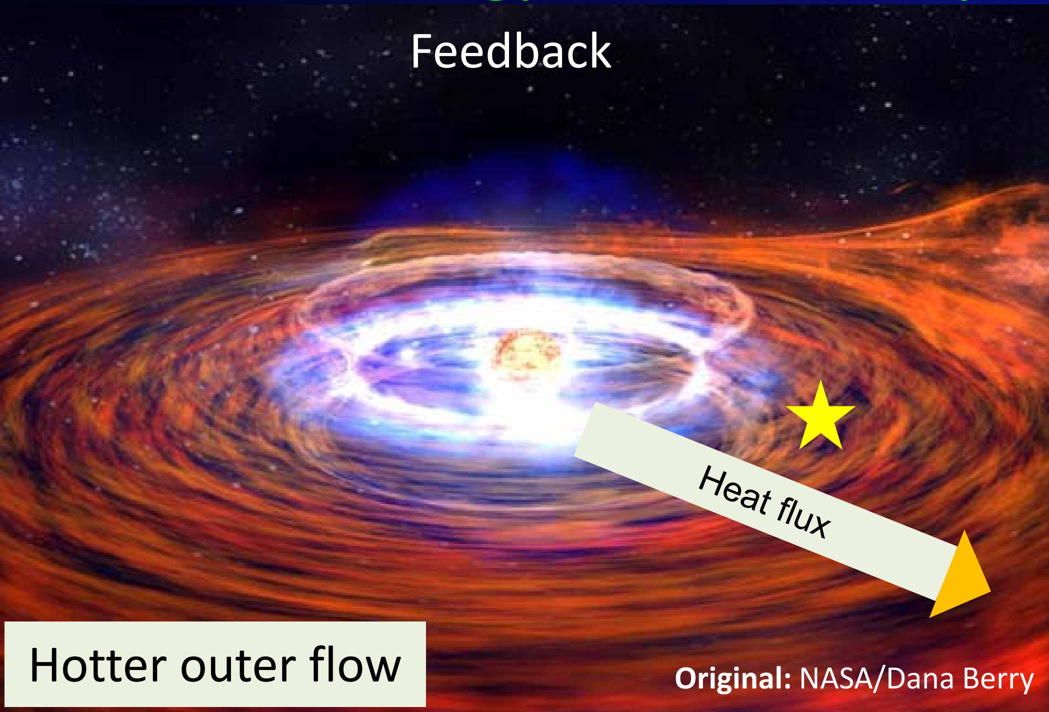
Either 99% of material outflows or it never starts moving towards the BH

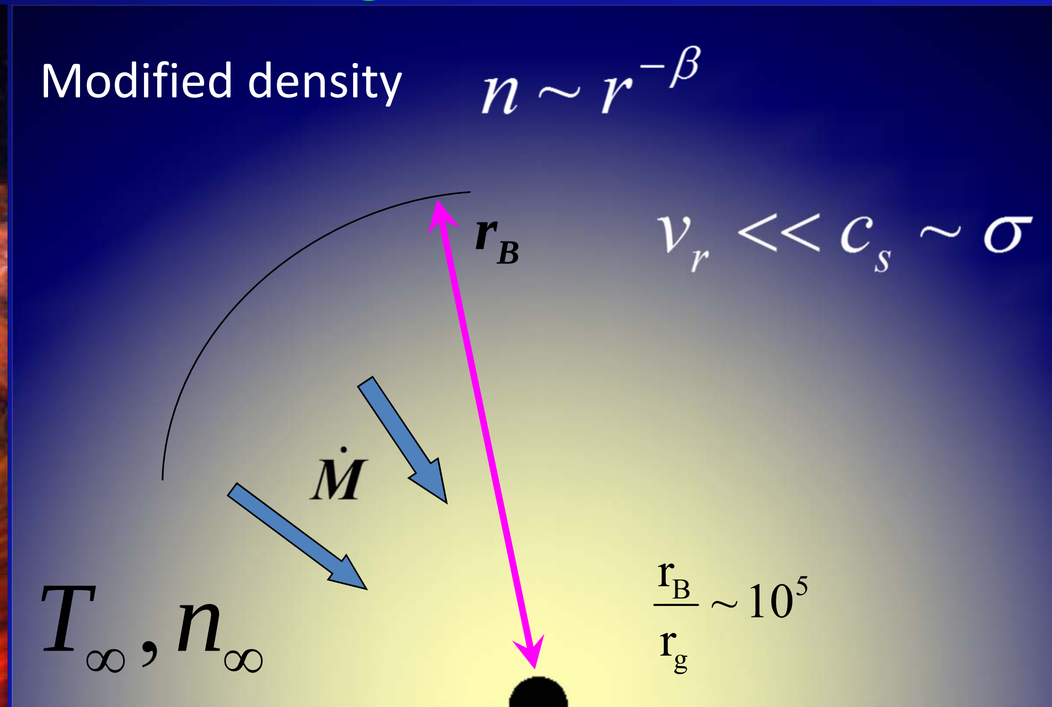
$$n \propto r^{-(0.8-0.9)}$$

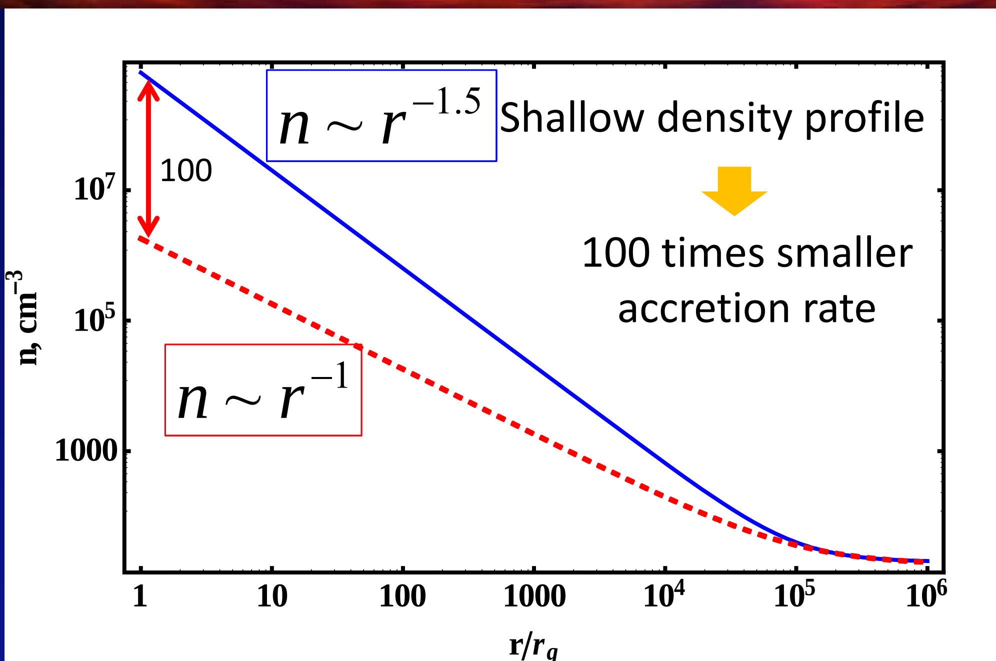
Shcherbakov et al. 2012

Small-scale feedback alters the flow

Outward energy transfer => superadiabatic T, gas too hot to flow in







Pressure equilibrium $$\frac{1}{n}\frac{\partial p}{\partial r} = \frac{\partial (n k_B T)}{n \, \partial r} = -\frac{GMm_p}{r^2}$$

Since now $T_x = c \cdot T_B \quad (c > 1)$

then $\beta = \frac{5}{2c} - 1 \quad (\beta = 1 \quad for \quad c = 1.25)$

Tiny accretion rate $$\dot{M}_X = \dot{M}_B \left(\frac{r_g}{r_B} \right)^{\frac{3}{2} - \beta}$$

25% superadiabatic flow => 100 times lower Mdot

Supply of gas: feeding by stellar winds

Nuclear star clusters produce enough winds to feed the BH

Specific mass loss rate
is lower with population age

$$\dot{f}_g \approx \frac{0.05}{age + 5Myr}$$

e.g. Jungwiert et al. 2001

Direct correlation with V-band
for old population

$$\dot{M} \approx 3\cdot 10^{-11} \frac{L_V}{L_{Sun,V}} (M_{Sun}\, yr^{-1})$$

e.g. Padovani & Matteucchi 1993

Sgr A*: Paumard et al. 2006

$10^4 M_\odot$ star cluster, age 6Myr

↓

$5\cdot 10^{-4} M_\odot$/yr ejection rate
(consistent with directly observed mass loss)

↓

BH accretes only $\sim 3\cdot 10^{-8} M_\odot$/yr

NGC3115*: Kormendy et al. 1996

$5\cdot 10^6 M_\odot$ star cluster, age $\gtrsim$5Gyr

↓

$2\cdot 10^{-4} M_\odot$/yr ejection rate

↓

BH accretion rate $5\cdot 10^{-5} M_\odot$/yr –
if accretes similarly to Sgr A*

BHs can be fed exclusively by stellar winds

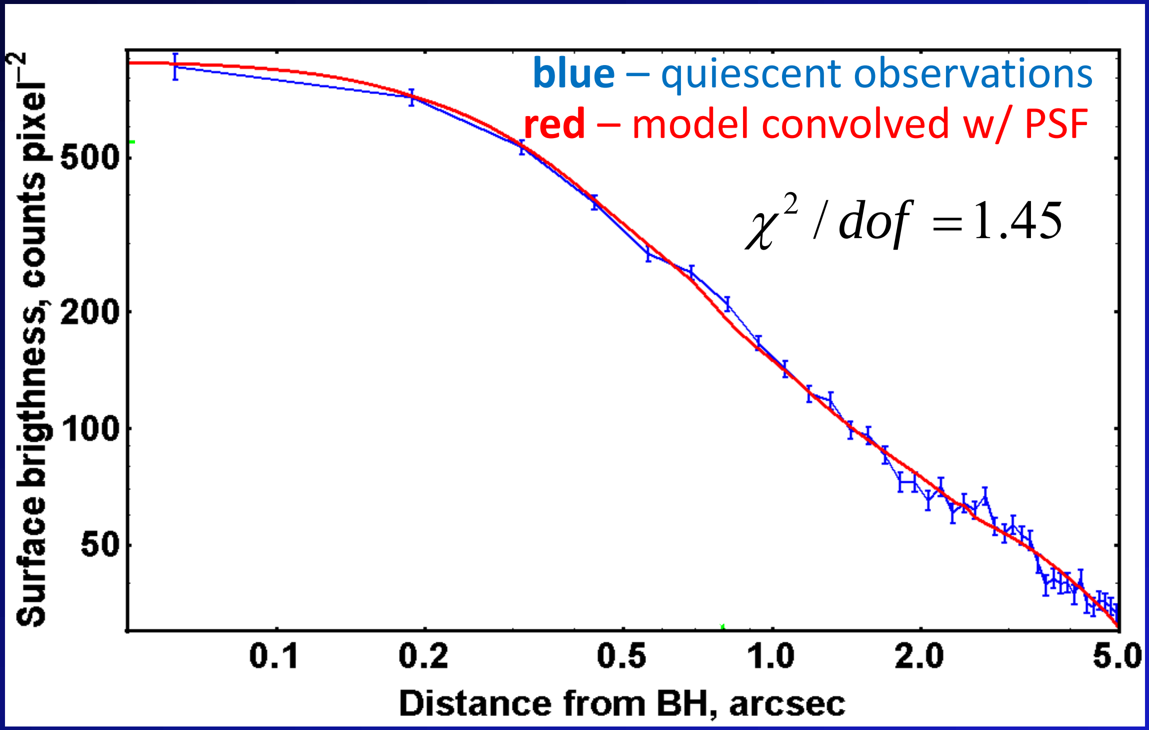
Ho 2009

We study the details

A model with feeding and conduction for Sgr A*

Features:

1. Known mass/energy supply from observed stars
2. Electron heat conduction – feedback mechanism
3. 1-D dynamical model of gas flow
4. Fits X-ray surface brightness profile



Shcherbakov & Baganoff 2010

Very low accretion rate $\dot{M} \sim 6 \cdot 10^{-8} M_{sun} / yr$

Caveats:

1. Model is too simple: 2D instead of 1D
2. Underutilized obs data: could fit spectrum in addition to surface brightness
3. More precise emission model is needed: full CIE emissivity (apec) instead of bremsstrahlung
4. Consider contribution from unresolved point sources

Working to eliminate the caveats

Unresolved point sources vs. gas emission

There always are unresolved point sources in nuclei

Sgr A*

Absorbed power-law fits the spectrum well, no need for thermal emission

40ks exposure | Baganoff et al. 2003

Multi-T emission can be ascribed to coronas of active spun-up stars

1Ms exposure | Sazonov et al. 2012

Nuclei of nearby LLAGNs

Can fit nuclear X-rays with power-law, but we prefer to fit with thermal brems

Pellegrini 2005

Can fit nuclear X-rays with thermal brems, but we prefer to fit with power-law

Soria et al. 2006a

NGC 3115*

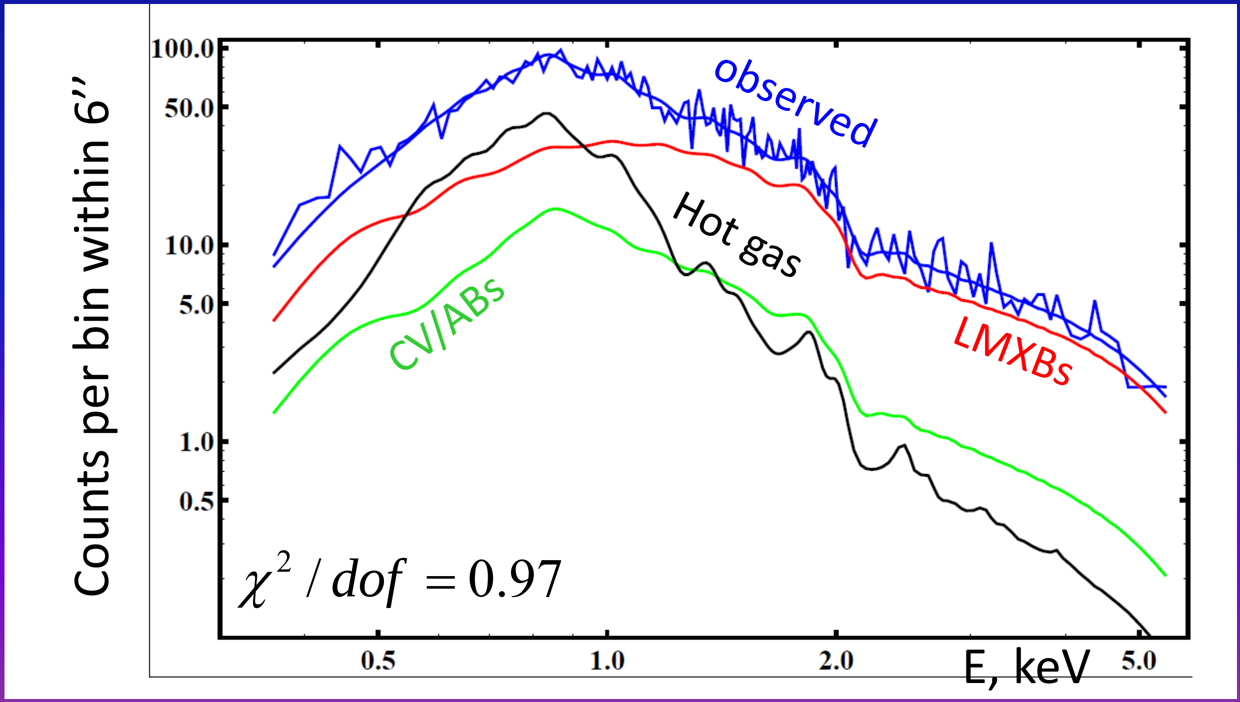
Wong et al. 2011

Wong, Shcherbakov, et al. in prep; Shcherbakov, Wong, et al. in prep

1Ms exposure

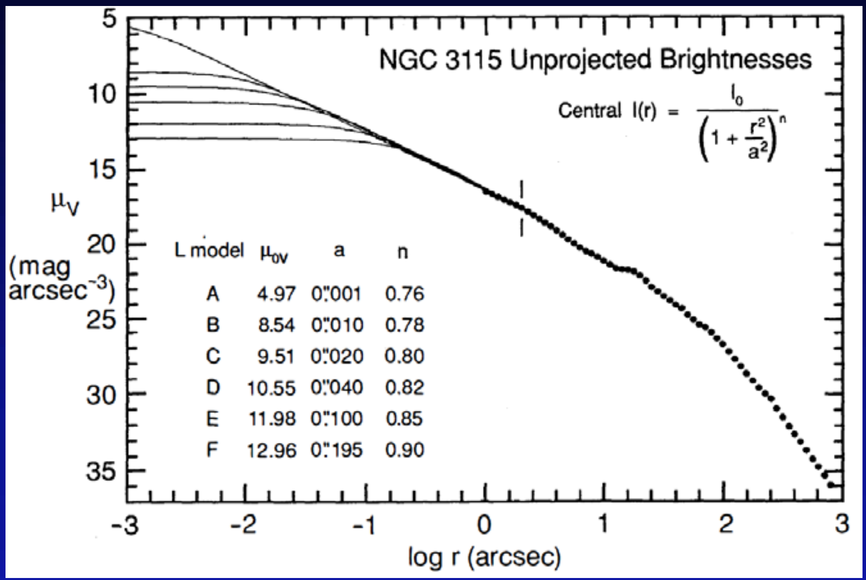
1. Know the spectra of LMXBs (hard power-law), CV/ABs (soft power-law + thermal).
2. Fit the full spectrum with LMXBs, CV/ABs + hot gas component (apec).

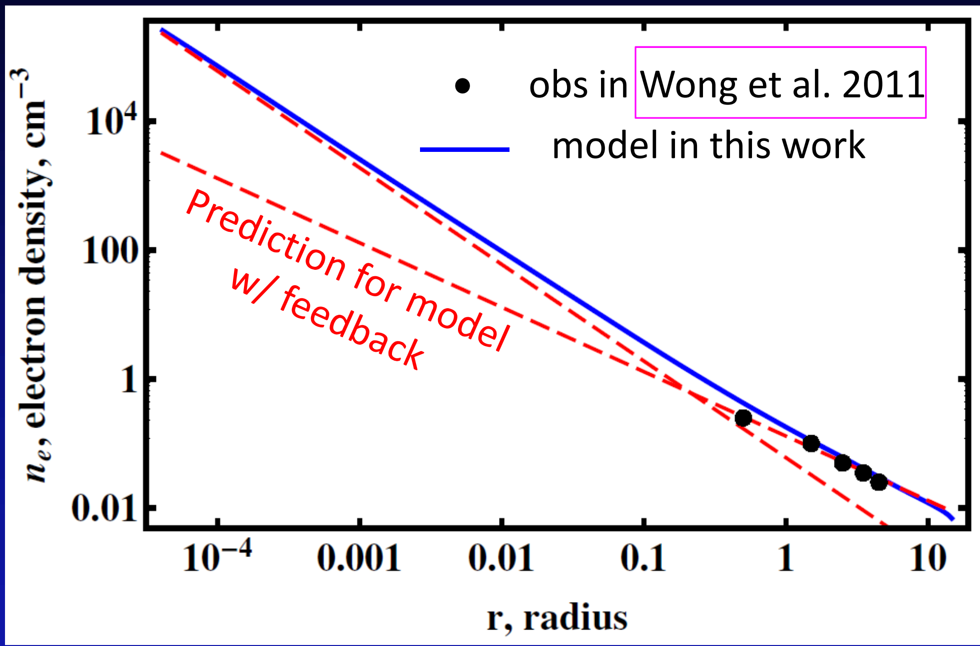
$\min(\chi^2/dof) = 4.3$ without gas



A gas model for NGC3115

Adiabatic gas model w/ stellar winds fits outside density/temperature



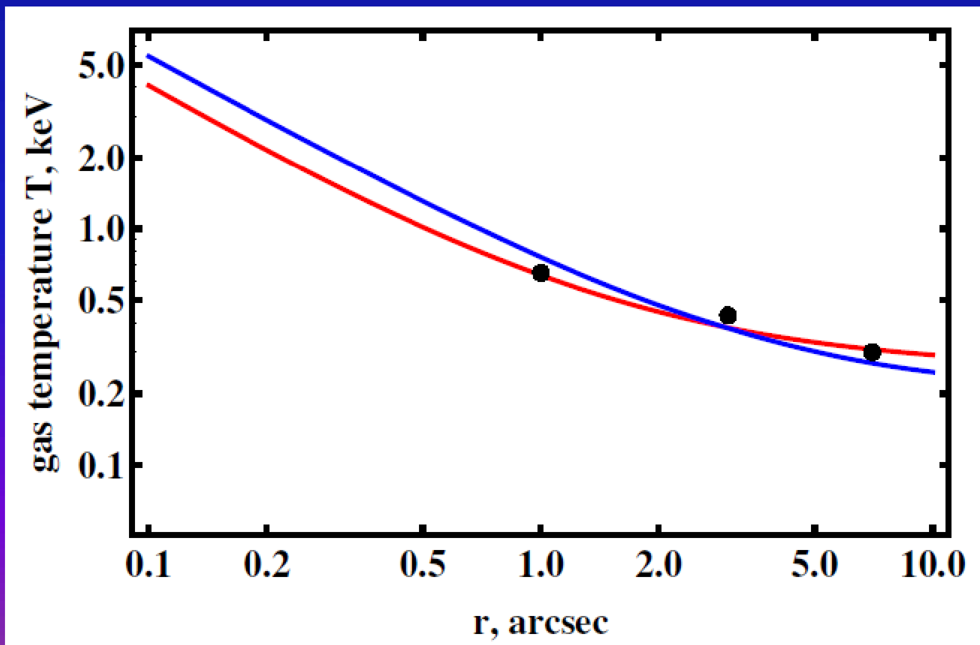


Work in progress…

Kormendy & Richstone 1992

Stellar wind ejection rate – proportional to deprojected V-band brightness

Stellar wind energy – from kinetic energy of stars in the potential of BH + galaxy



Detection F_ν=(0.29±0.03)mJy at 8.5GHz

Wrobel & Nyland, 2012, subm

Actual density profile $n \propto r^{-(0.7-0.8)}$

Consistent with Sgr A*, inconsistent with adiabatic

Conclusions

Details of feeding of low-luminosity AGNs

Observations:

1. X-ray spectrum of ambient gas => T_B and n_B at Bondi radius
2. But… must separate gas emission from unresolved point sources
3. Sub-mm peak from near the BH => T and n at the horizon

⬇

Shallow density profile, suppressed accretion

Theory:

1. Steady-state model w/ stellar winds feeding – reproduces T_B and n_B at R_B
2. Small-scale feedback (conduction) lowers the accretion rate => consistent T and n at the horizon