COMPACT STELLAR CLUSTERS HOSTING AN INTERMEDIATE MASS BLACK HOLE

magnetohydrodynamic study of inflow—outflow dynamics

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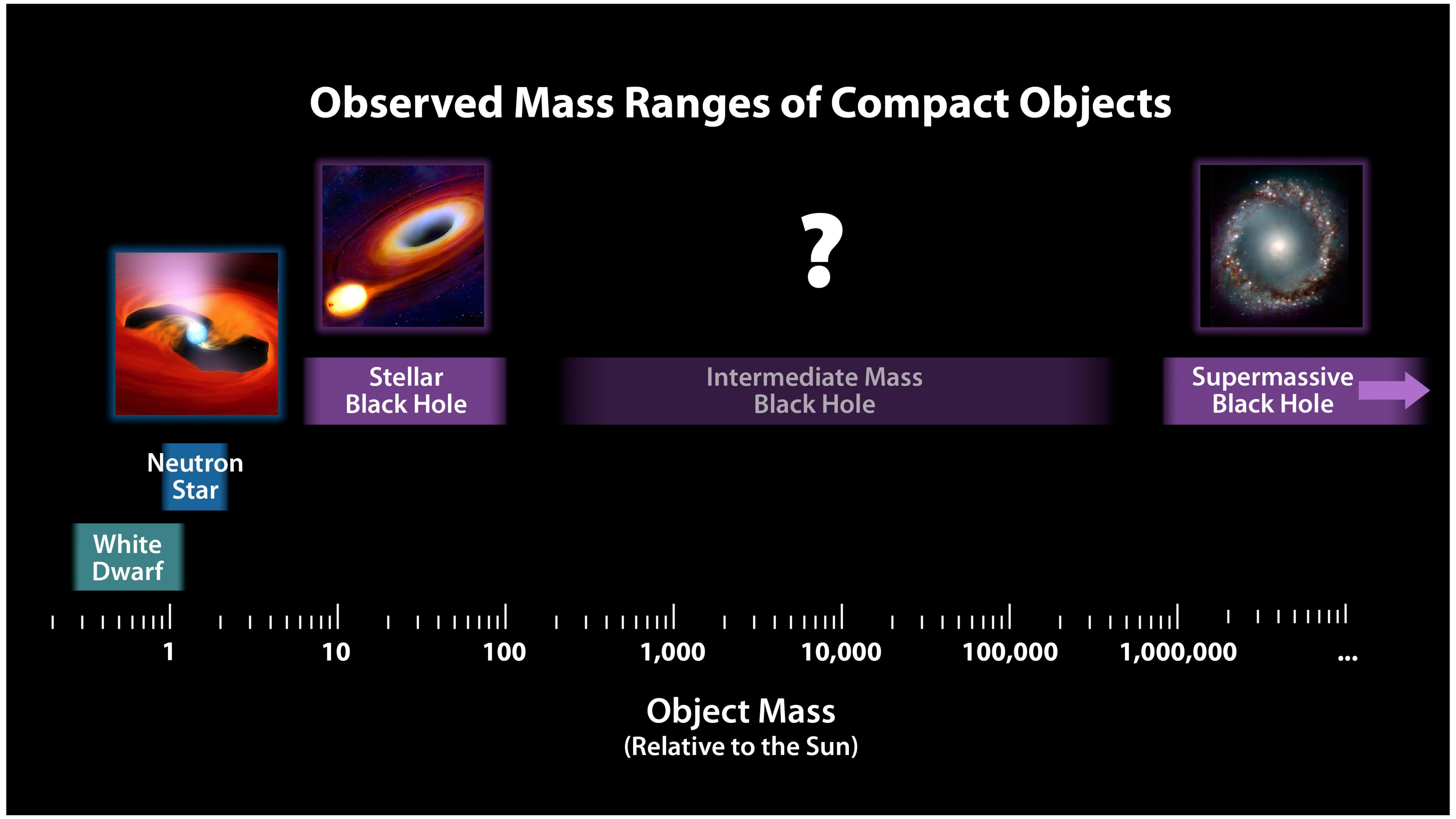
why intermediate-mass black holes matter

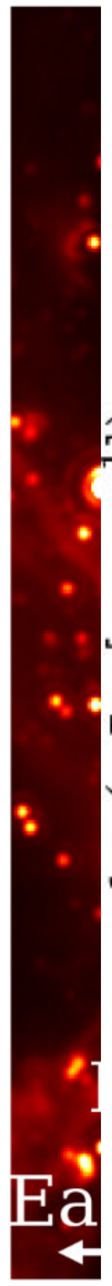
- **MBHs fill the gap** between stellar-mass black holes (a few $M_{\odot}$) and supermassive black holes ($10^6 - 10^{10}\, M_{\odot}$), with typical masses of $10^2 - 10^5\, M_{\odot}$
- **Globular clusters** show dynamical hints (e.g., velocity dispersions), but could be explained by concentrated stellar remnants
- **Nuclear star clusters** near galactic centers are also promising - many massive stars that could feed an IMBH via winds

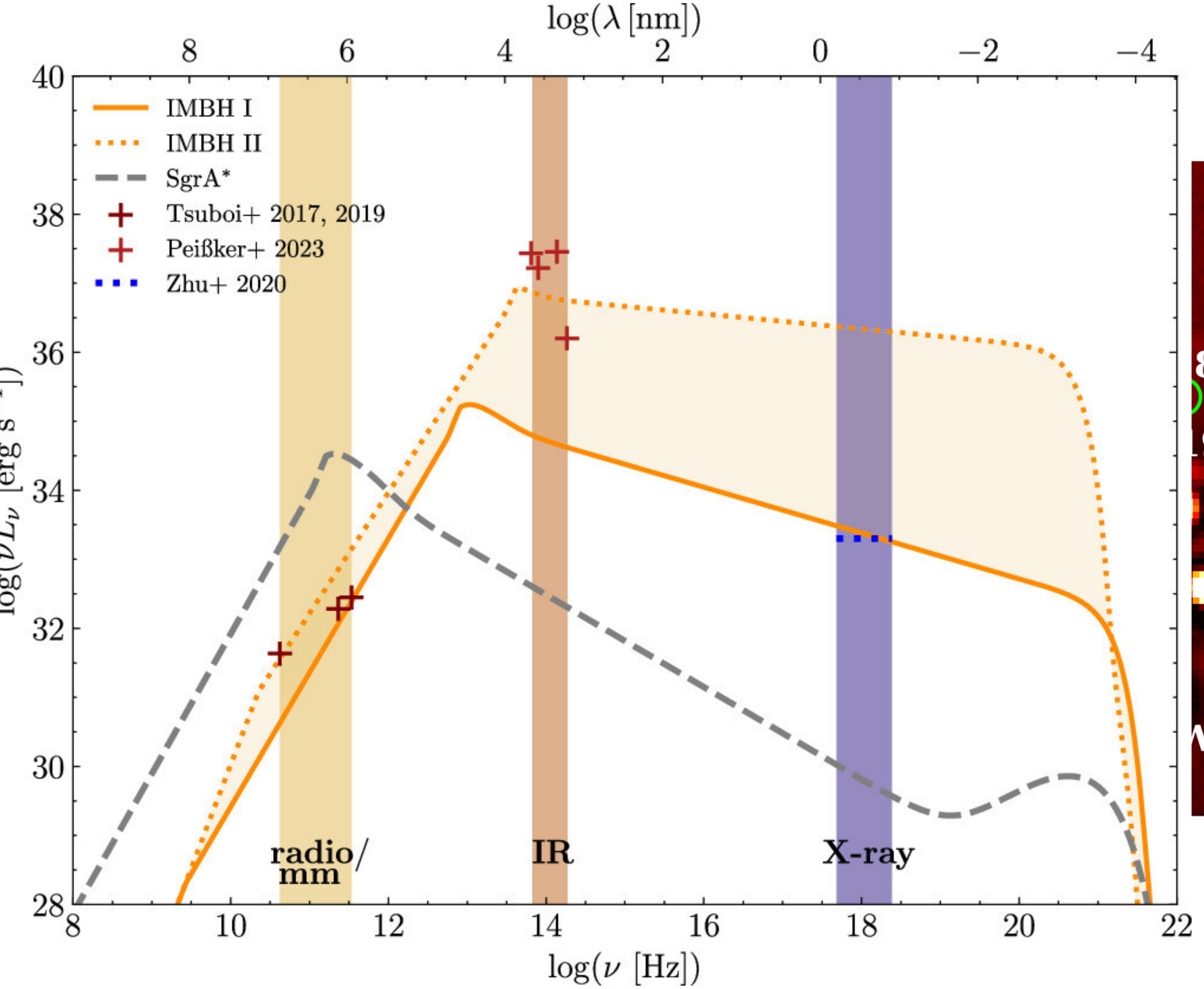


Greene et al. 2020; Madau & Rees 2001 | IMBHs are the “missing link” in BH demographics

IRS 13E: a prototype IMBH host

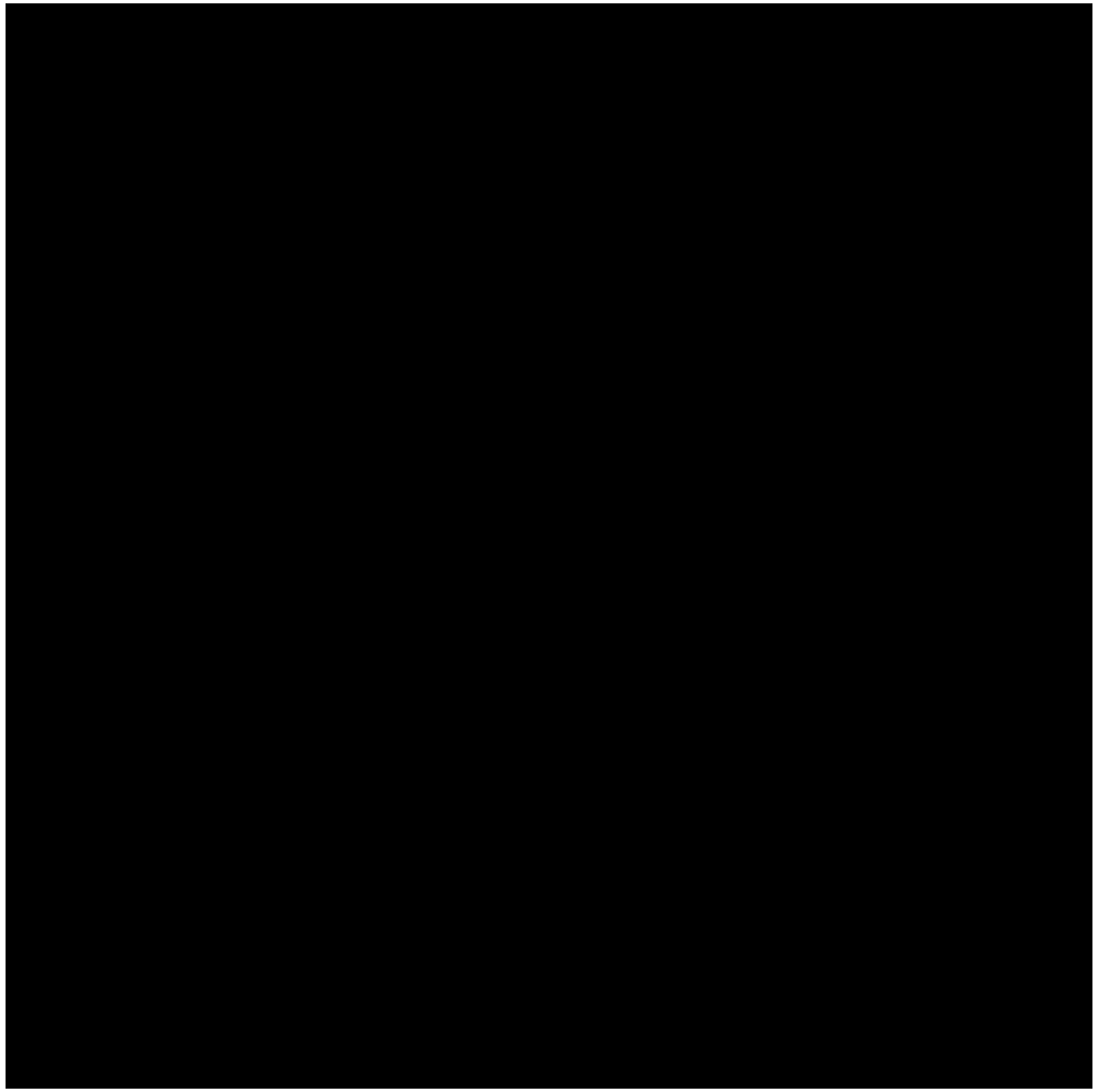
- **IRS 13E**, ~ 0.13 pc away from Sgr A*, contains six massive Wolf–Rayet (WR) or OB stars densely packed
- Dynamical studies suggest an unseen mass of $\sim 3 \times 10^4\, M_\odot$, possibly an IMBH
- If present, the IMBH would be **fed by fast, dense WR winds** (each WR star loses ~$10^{-5}\, M_\odot$/yr at ~1000 km/s) rather than a standard gas disk





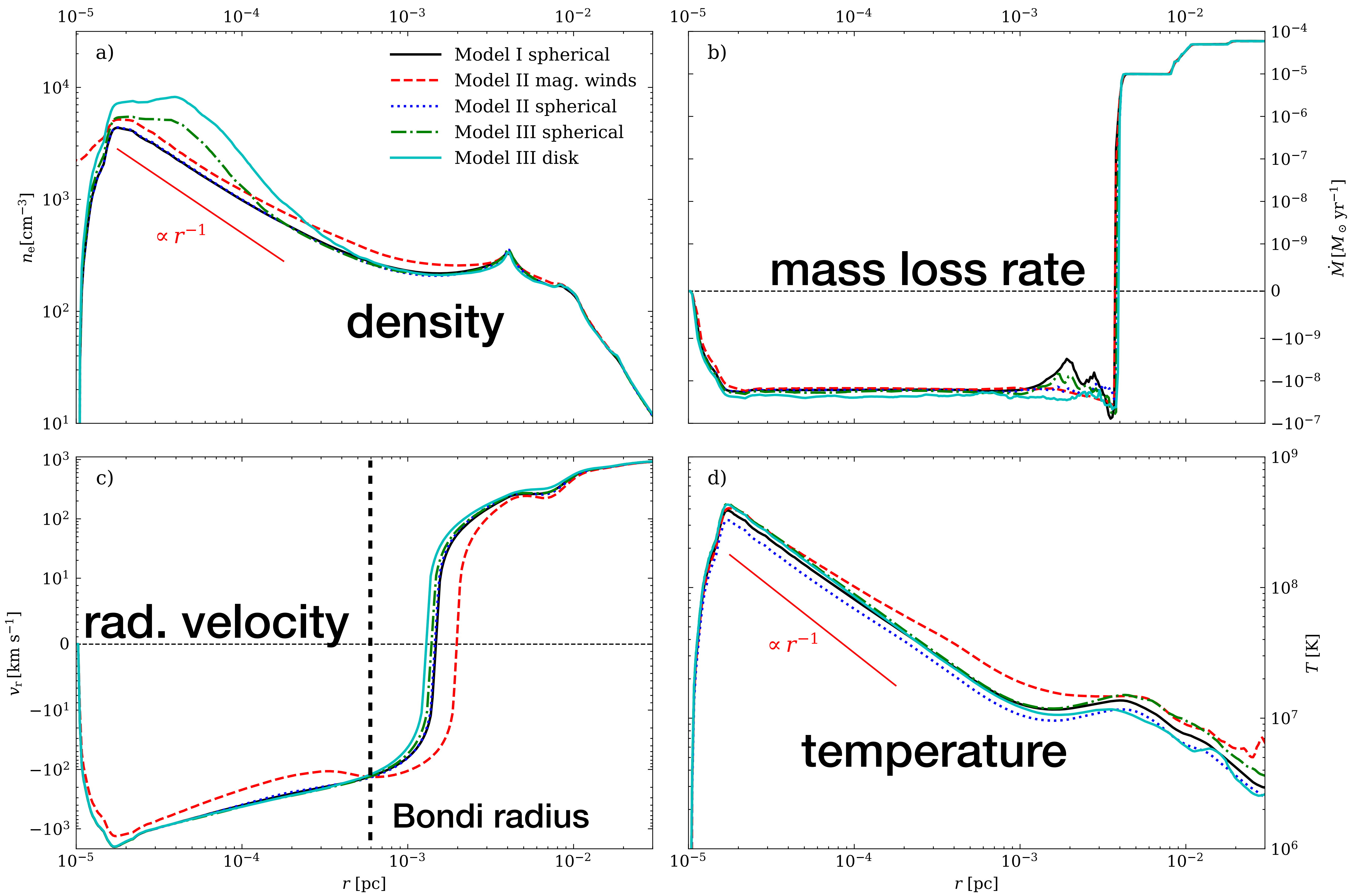
Mock SED calculations for 2 possible IMBHs (30 000 solar masses, different Eddington ratios) could fit multi-band observations

simulation overview & setup



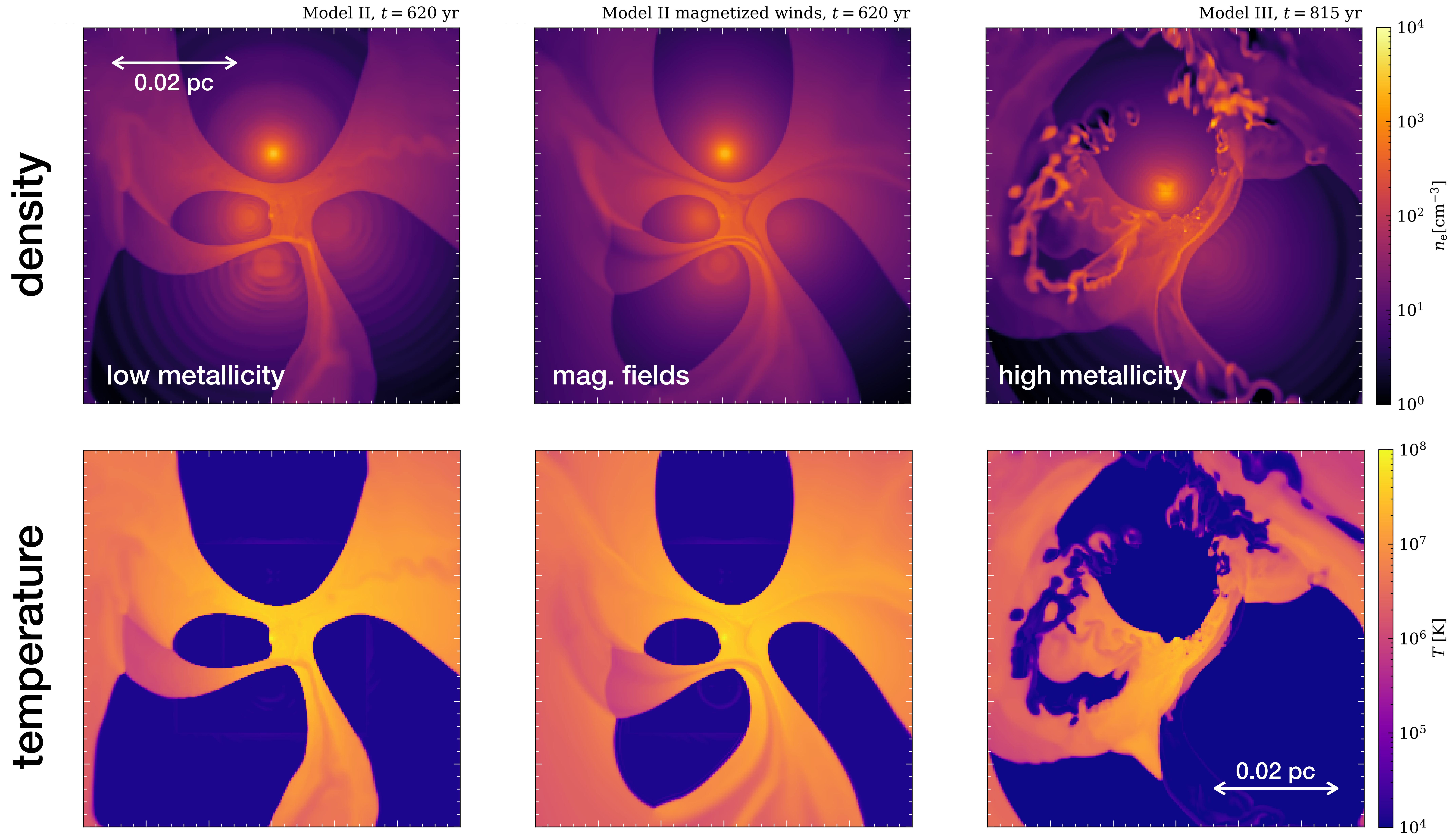
- **Athena++** solves 3D MHD equations with source terms for stellar winds of 6 WR stars, each injecting mass, momentum, energy, and toroidal magnetic field
- Cartesian box **(0.06 pc)^3** with **256^3** resolution and five levels of SMR (finest resolution around $10^4\, r_g$)
- "Stars" move on fixed circular Keplerian orbits around $3 \times 10^4\, M_\odot$ IMBH approximated as a point source potential
- Parameter variation: moderate vs. high metallicity; isotropic vs. disk-like (i±15°) configuration; magnetic vs. pure hydrodynamic

turbulent outflows dominate



Radial profiles of density, mass loss rate, radial velocity, and temperature for 5 simulations comparing effects of cluster geometry, wind chemical composition, and magnetic field

- Simulations confirms that nearly all wind-injected mass is **expelled via outflows**, driven by strong wind–wind shocks
- Net inward mass flux at inner boundary minimal - **only 10^{-5} of the available matter accretes**
- Net angular momentum is too low for anything disk-resembant to form



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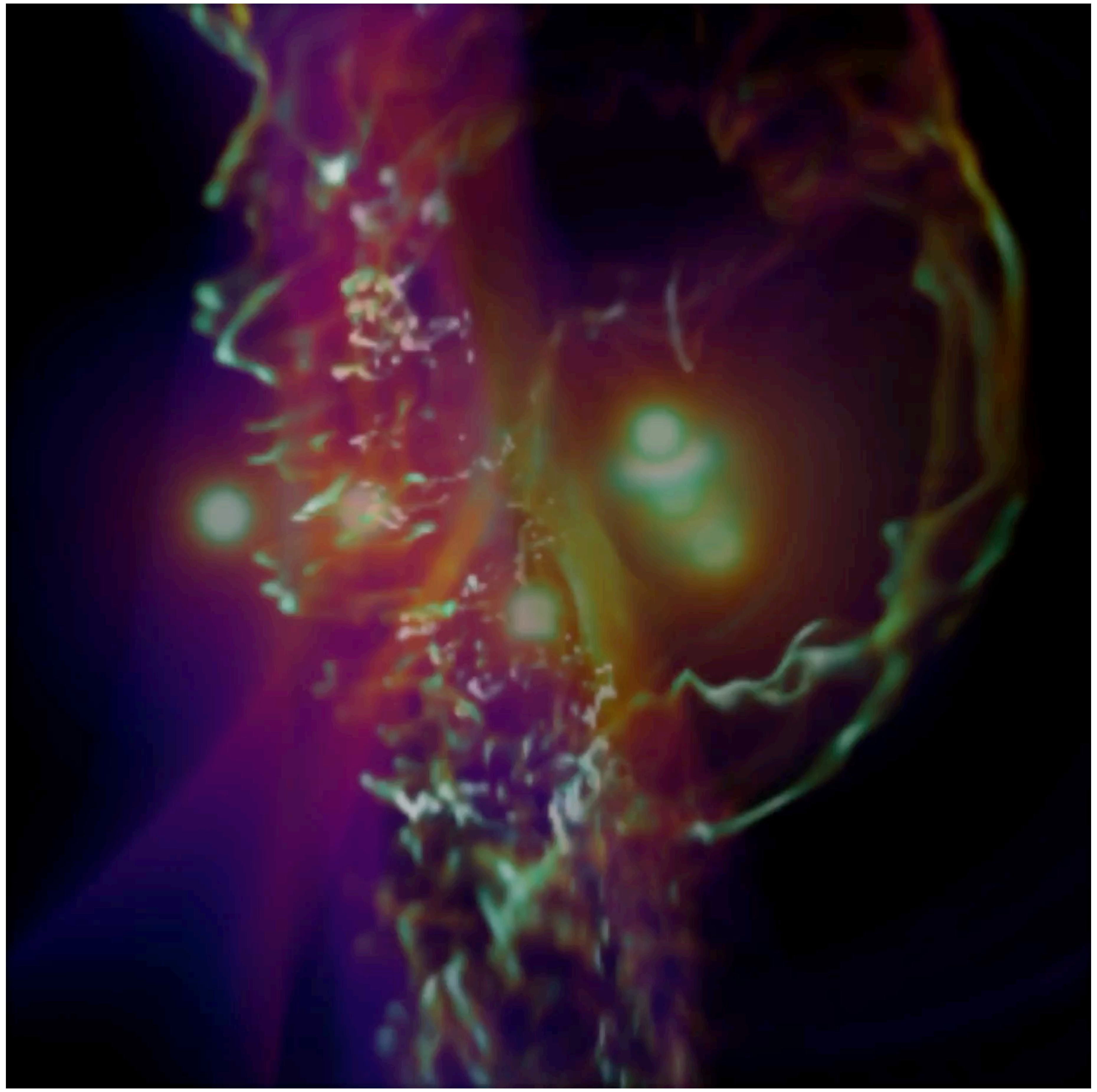
Plane-parallel cuts through the face-on plane of density and temperature; Model II 3Z$_\odot$, Model III Z = 0.4

cooling-induced clumps

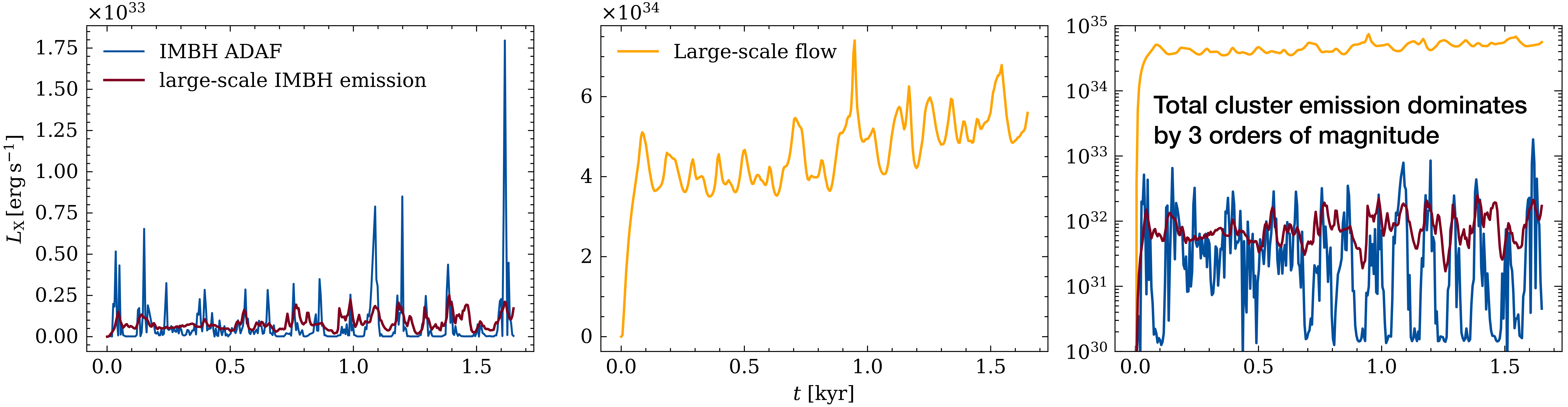
- In high-metallicity runs (Z = 0.4 modeled after WC8-9), post-shock gas rapidly cools to $T \lesssim 10^5$ K, forming **dense clumps** via thin-shell instability
- Cooling does not produce sustained cold inflow; overall accretion remains suppressed
- Few clumps penetrate inside r_B; most are shredded or **ejected outward**



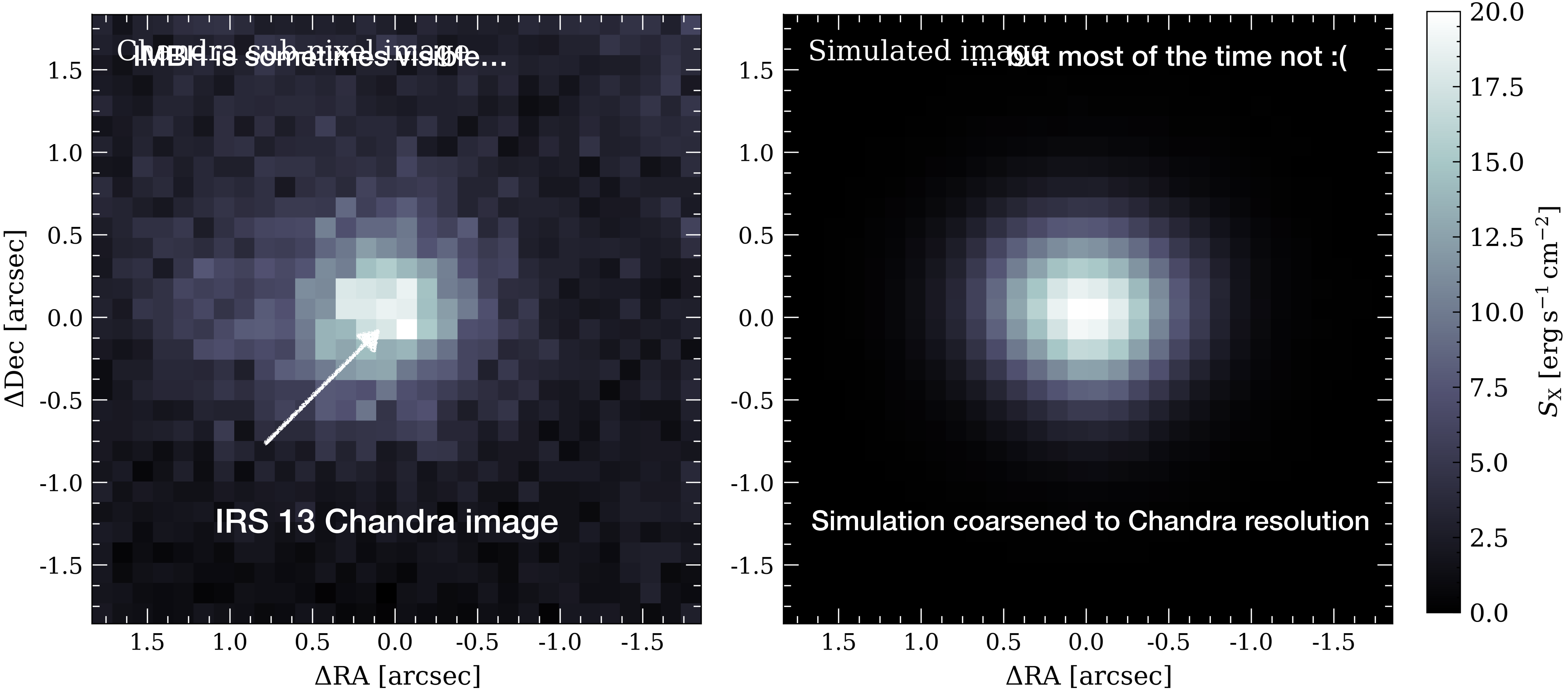
Spatial density rendering 1065 years into the simulation.

observational predictions: X-ray signatures

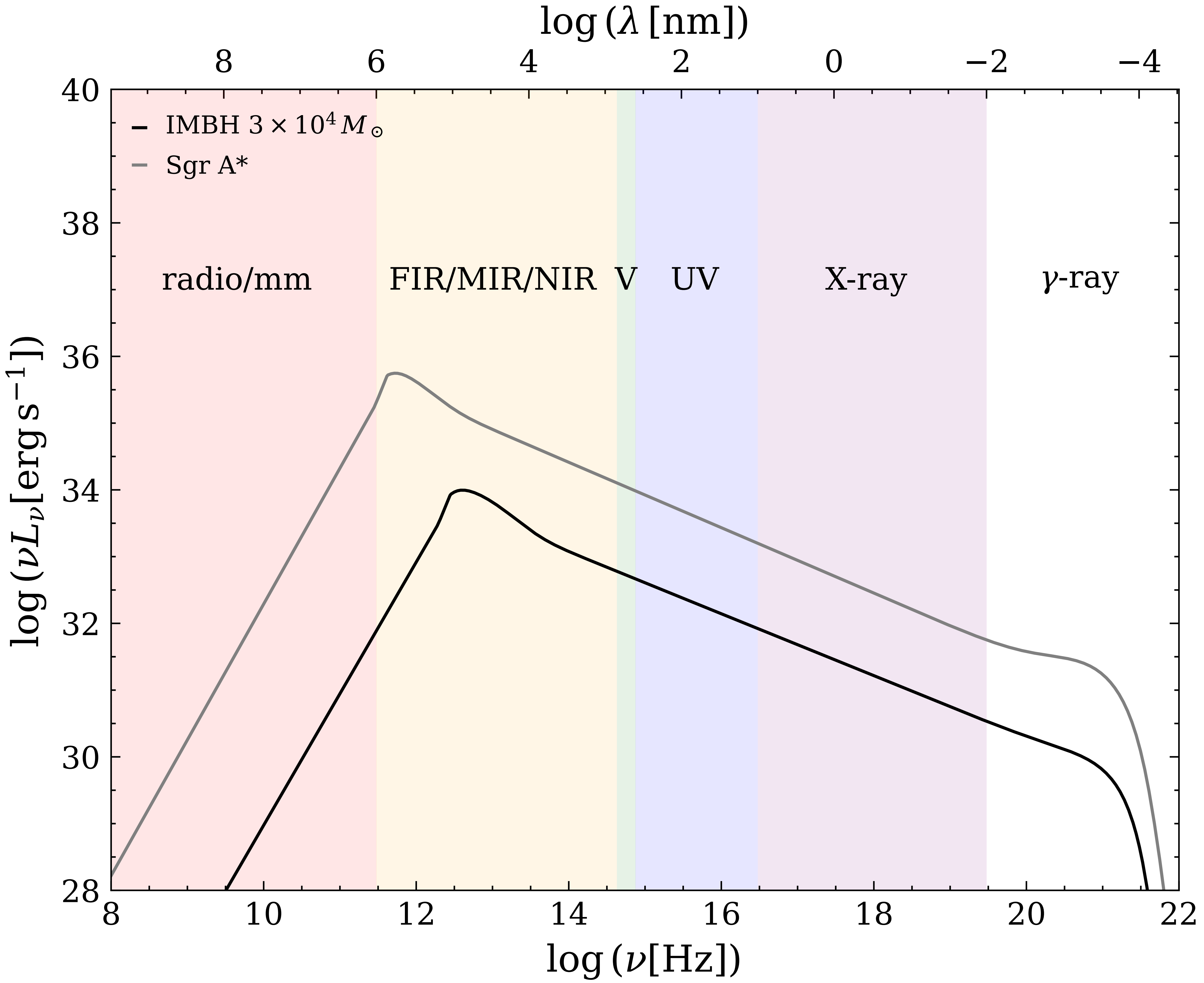
- **diffuse wind shocks dominate** ($L_X \sim 10^{34} - 10^{35}$ erg/s)
- Signs of variability caused by close stellar passages; IMBH x-ray strongest periodicity **~ 100 yr**, total cluster at **~ 200 yr**



X-ray surface brightness maps



observational implications & future missions



- Need for future missions: **Lynx** and **AXIS** in X-ray band
- IMBHs accreting in RIAF mode could exhibit faint **synchrotron** in radio - **SKA**
- Assuming the IMBH's SED and its FIR peak, if the variability is similar to that of Sgr A* - possibly detectable by **JWST/MIRI**

conclusions

- **Turbulent Outflows:** colliding WR winds generate highly turbulent outflows, expelling nearly all of the injected mass
- **Suppressed Accretion:** net $\dot{M}_{\bullet} = 2 \times 10^{-10}\, M_{\odot}\, \mathrm{yr}^{-1}$ (≪ wind injection), with angular momentum cancellation preventing disk formation
- **Cooling Effects:** high metallicity leads to transient dense clumps that do not significantly alter the suppressed inflow
- **Unobservable IMBH Signature:** Cluster wind-shock emission ($L_X \sim 10^{34} - 10^{35}$ erg/s) overwhelms IMBH ADAF ($L_X \sim 10^{32}$ erg/s)
- **Future Outlook:** Next-generation X-ray telescopes (Lynx, AXIS) combined with multiwavelength campaigns (JWST, SKA) are essential to detect and characterize IMBHs in dense stellar systems