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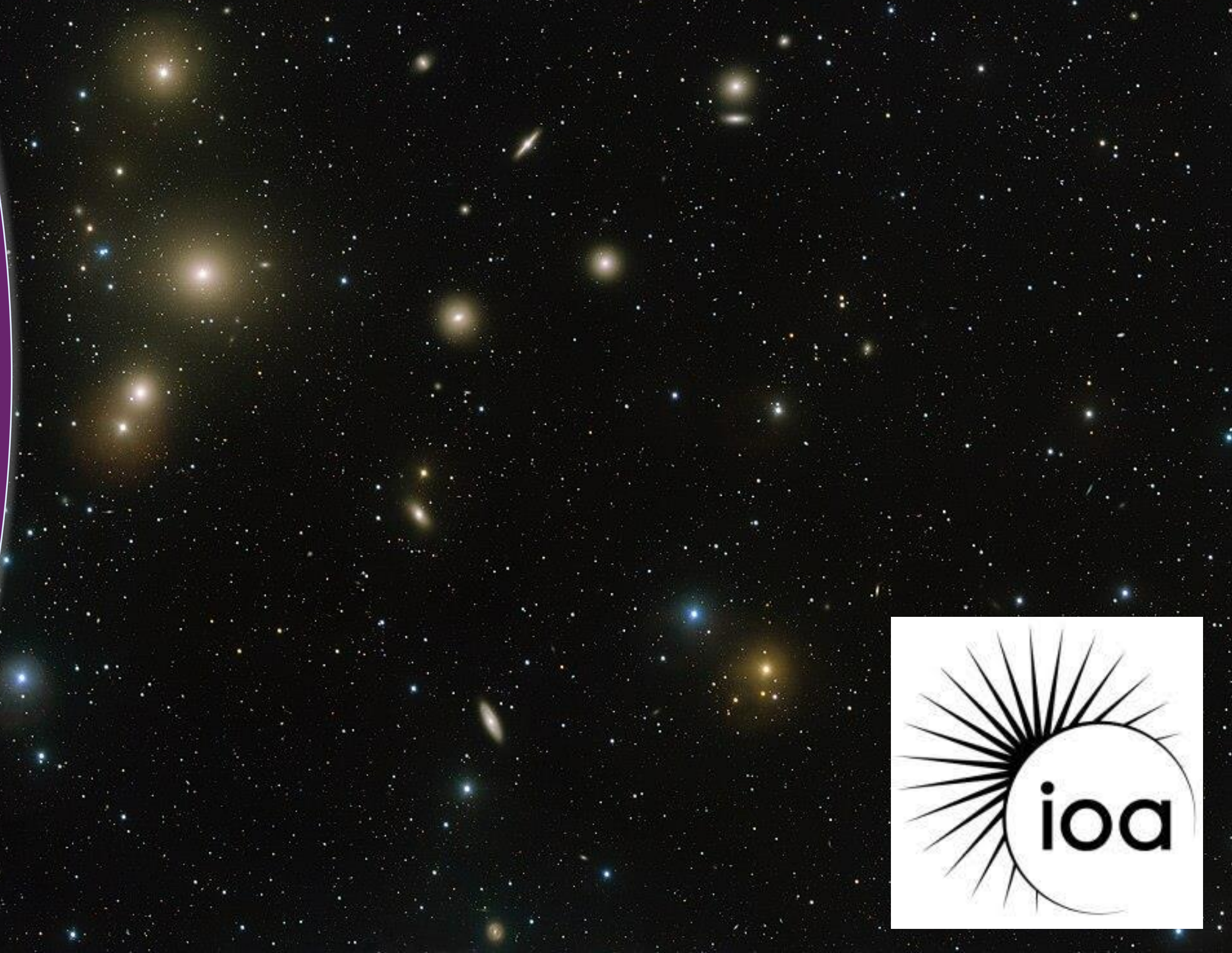
Observations of Cooling Flows in Nearby Elliptical Galaxies and the Fate of Cooled Gas

Lucy Ivey *with* Andrew Fabian et al

Institute of Astronomy

The ultimate fate of multi-phase gas in galaxies



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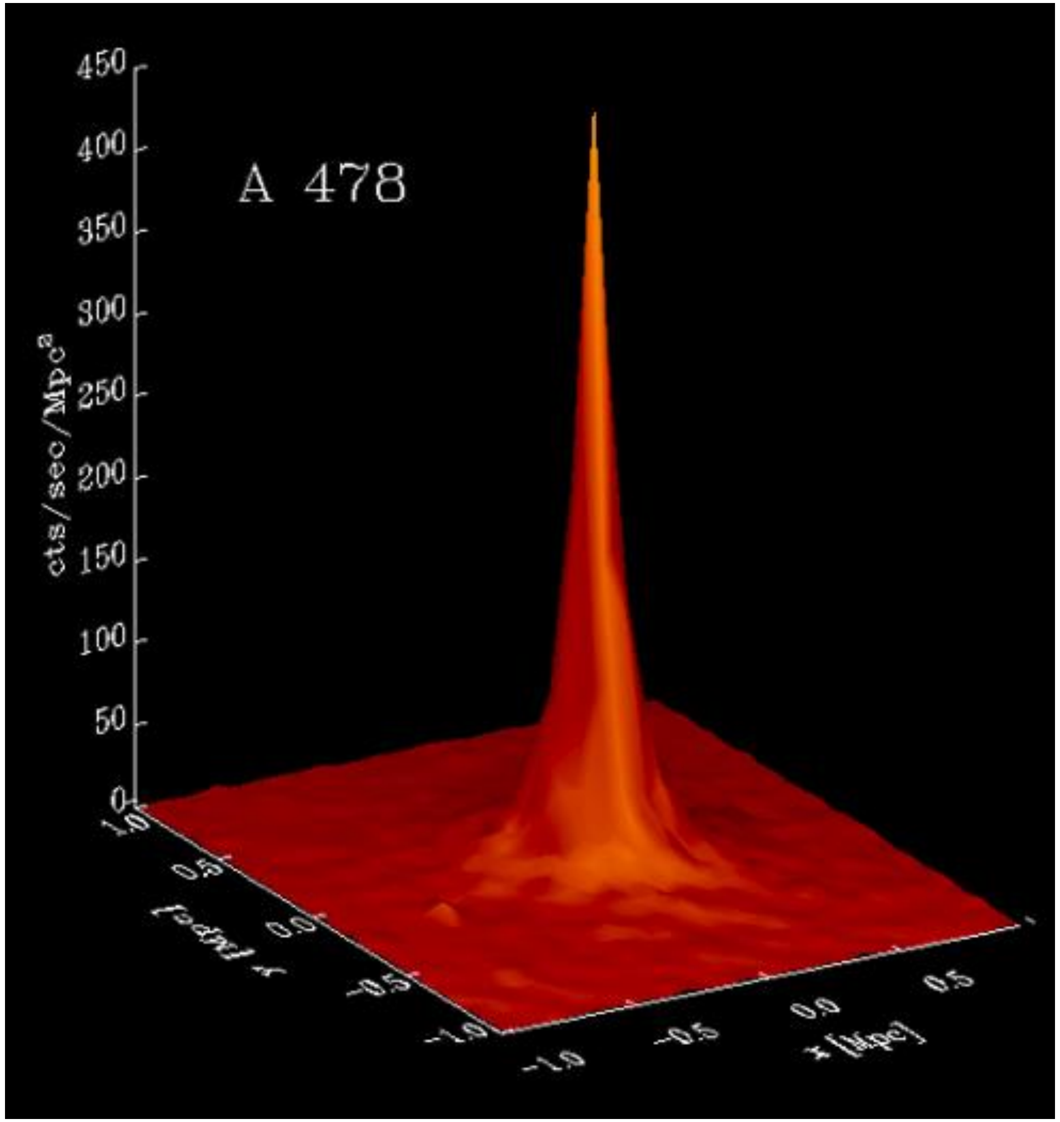
What is a *Cooling Flow*?

- Hot atmosphere **cools by emitting X-rays**
- Short central cooling timescale **(< 1 Gyr**)
- Pressure of overlying gas causes more gas to flow inwards – a ***cooling flow***



What is the *Cooling Flow Problem*?

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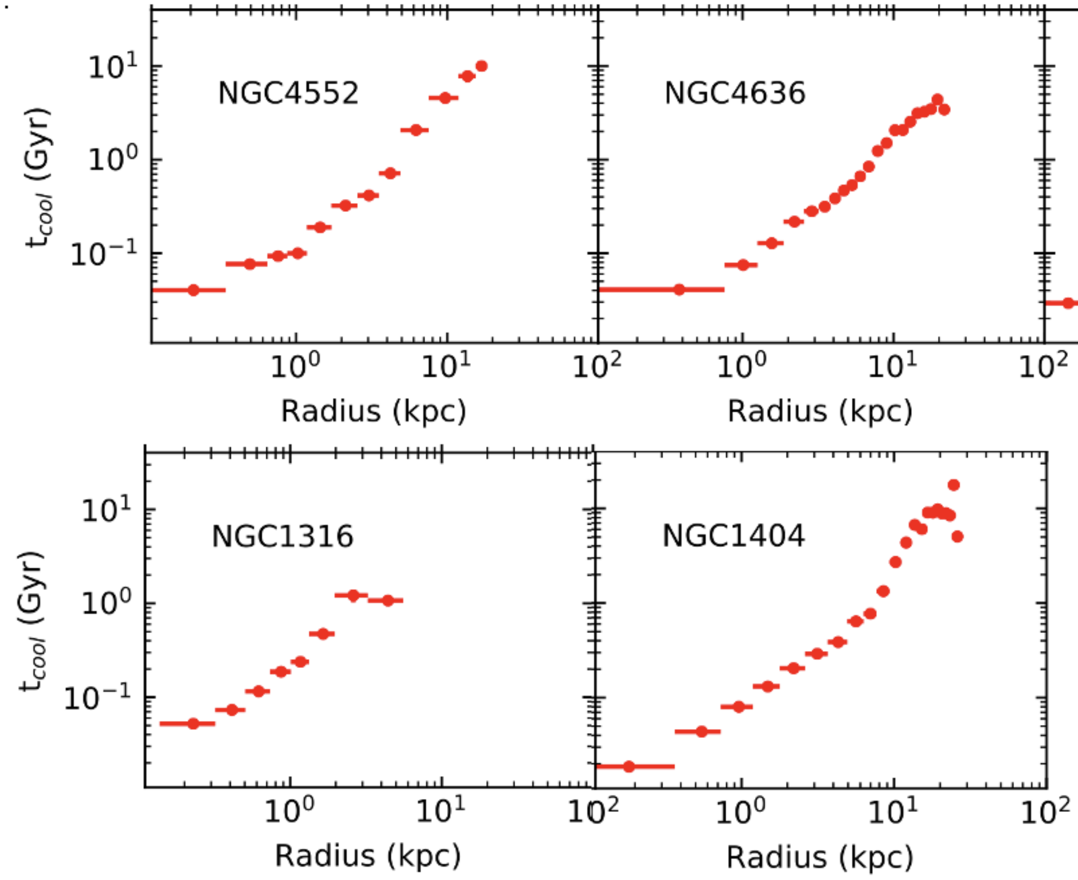
1. ***Lack of observed gas cooling below 1 keV***

   Fe XVII lines overpredicted compared to observations

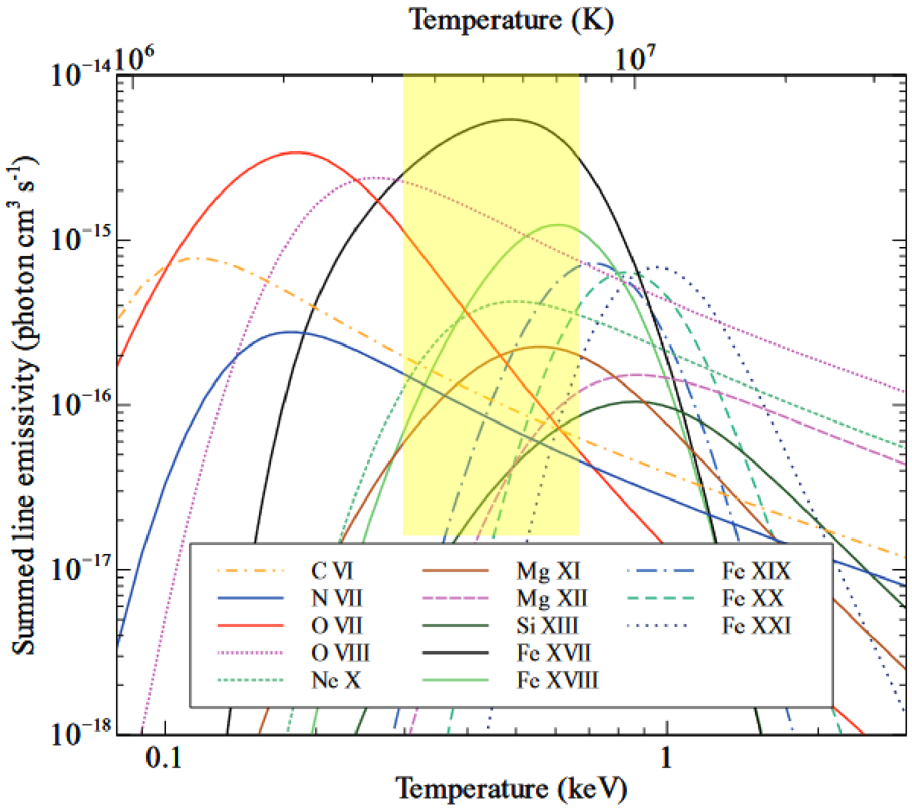
2. ***Fate of cooled material is unclear***

   Observed star formation rates are a fraction of naively predicted mass cooling rates

Cooling Flow Problem in Ellipticals



Sanders & Fabian 2011, Lakhchaura et al 2018, Babyk et al 2019



Where are the missing soft X-rays?

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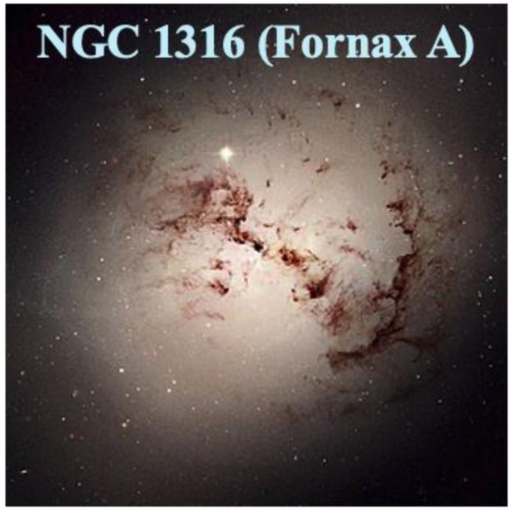
1. **Reheating of cooled gas (AGN feedback)?**
   - not completely efficient
   - fine-tuning problem

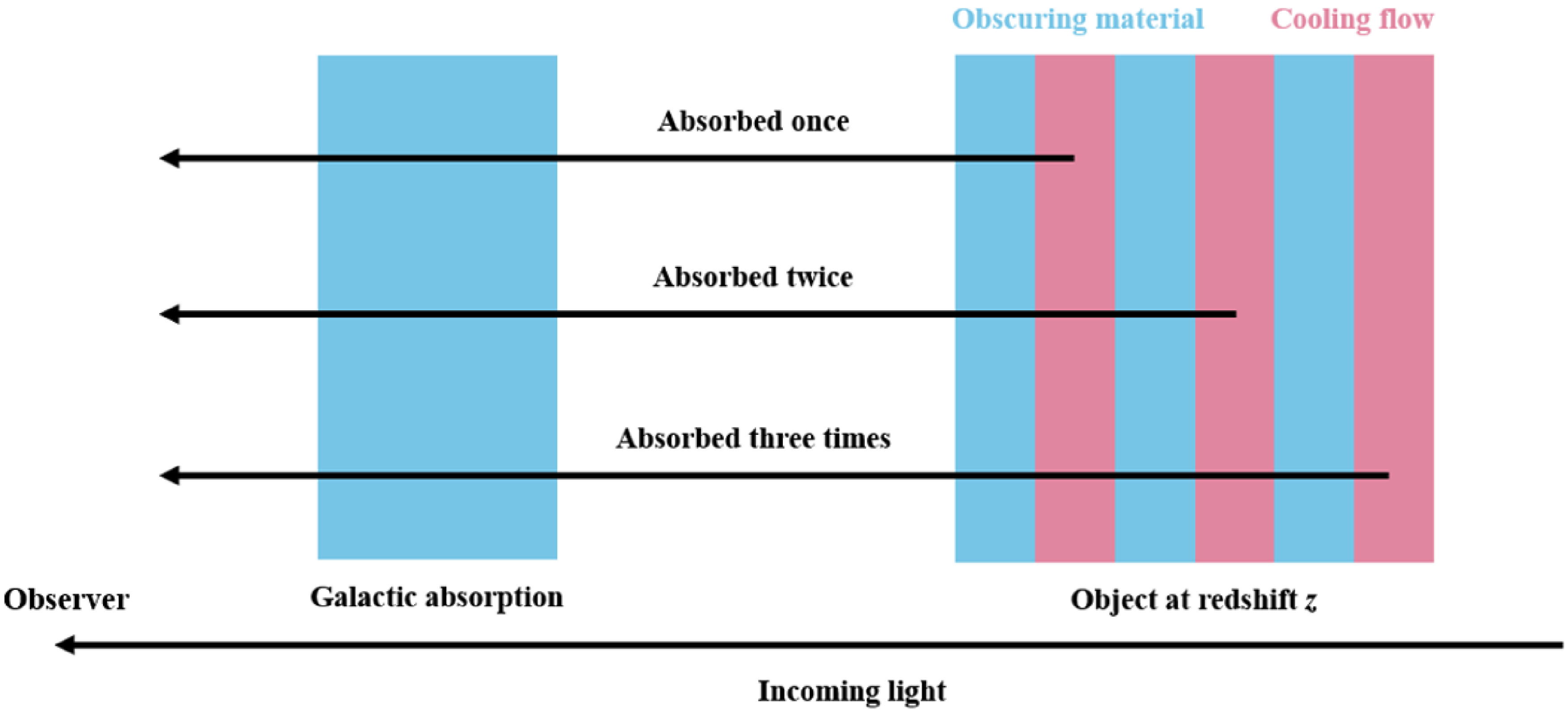
2. **Our key idea: *Intrinsic absorption*?**

7 Nearby Elliptical Galaxies



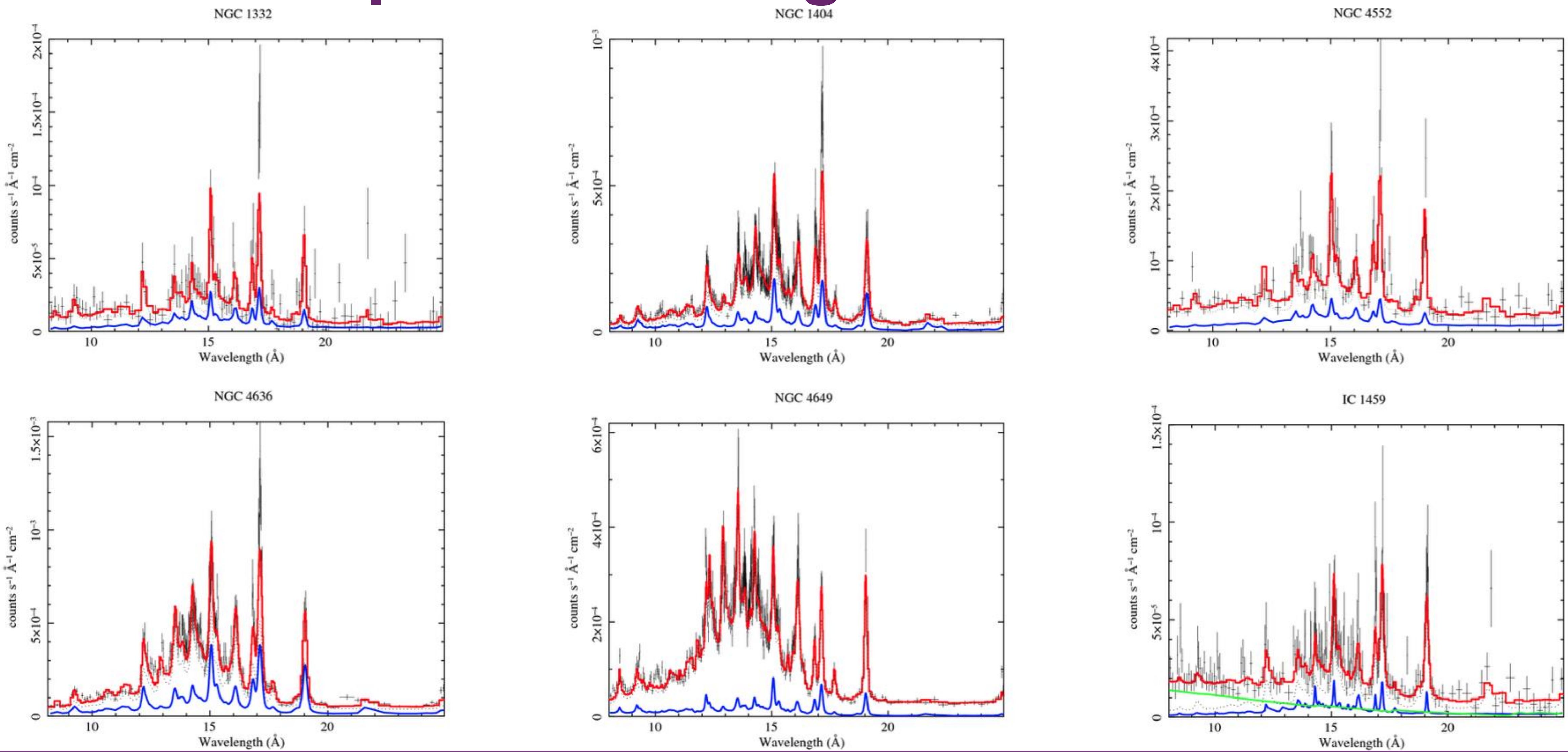
Intrinsic Multi-Layer Absorption Model

$$F_t = \frac{F_e(1 - e^{-\sigma N_H})}{\sigma N_H}$$

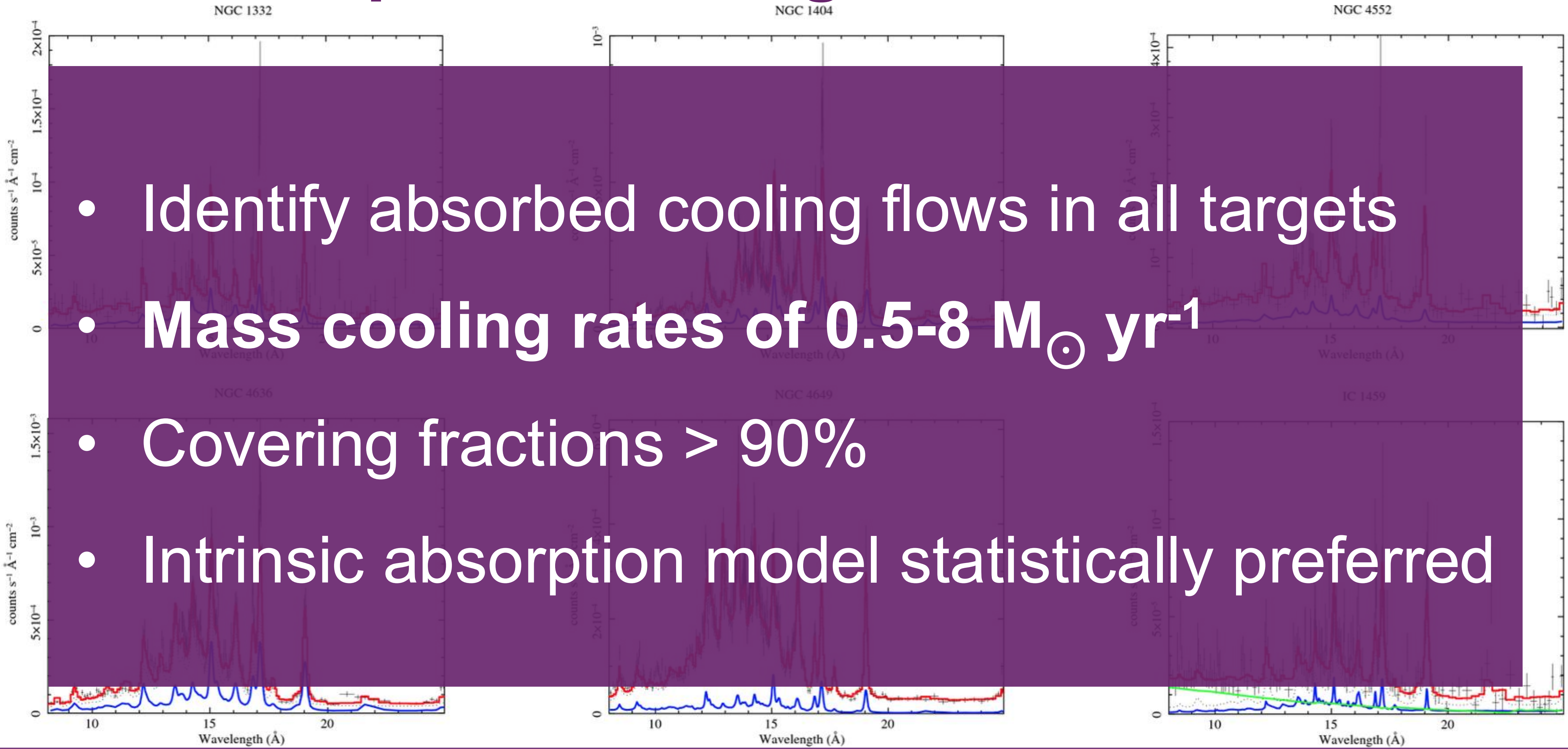


Thomas et al 1986; Allen & Fabian 1997; Liu et al 2021; Fabian et al 2022, 2023a, 2023b; Ivey et al 2024

Results of Spectral Fitting



Results of Spectral Fitting



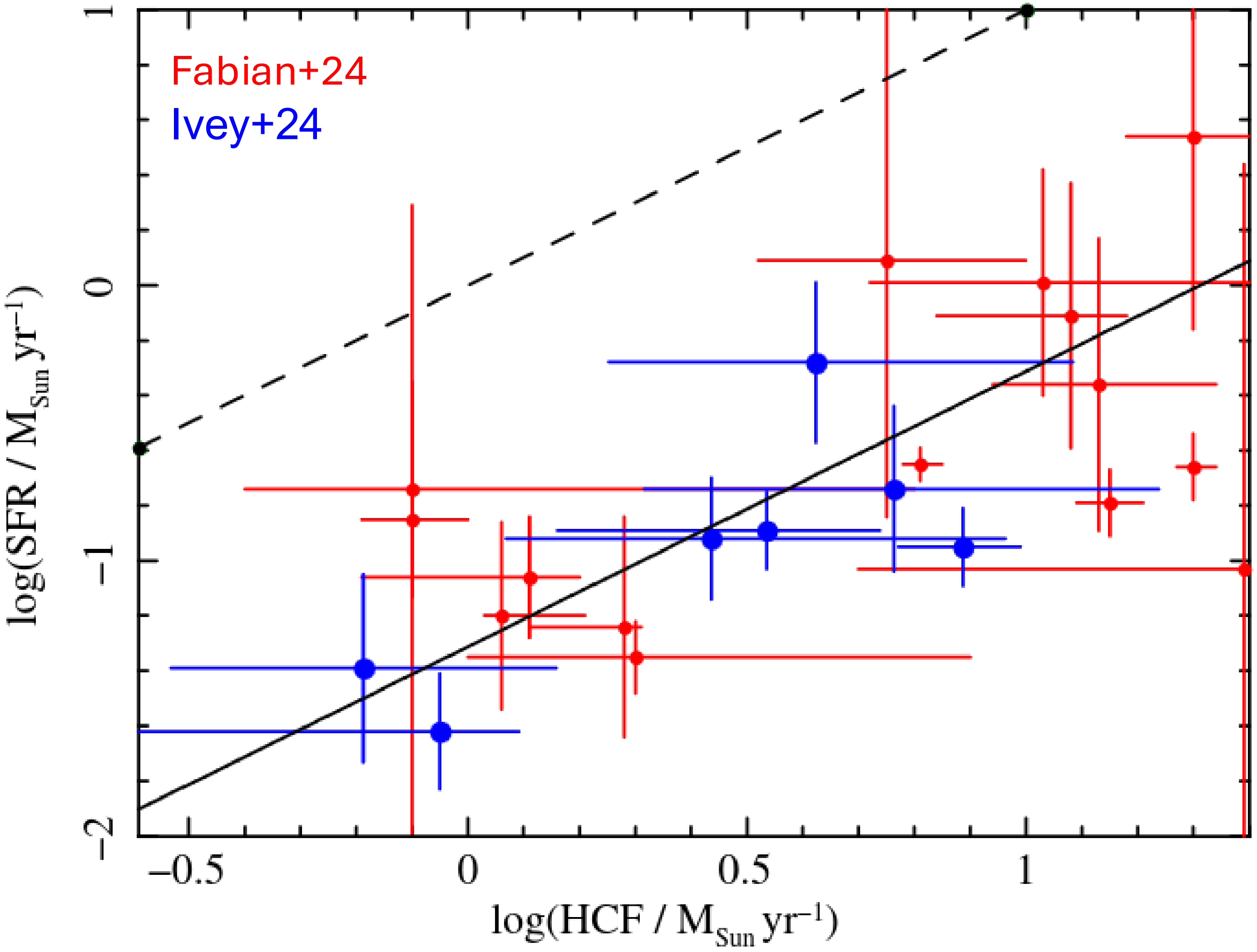
- Identify absorbed cooling flows in all targets
- **Mass cooling rates of 0.5-8 $M_\odot$ yr^{-1}**
- Covering fractions > 90%
- Intrinsic absorption model statistically preferred

Normal Star Formation?

Accumulation of cold gas in galactic centre

⇒ Star formation?

SFRs ~**20 times lower than naively expected** from cooling flow rates



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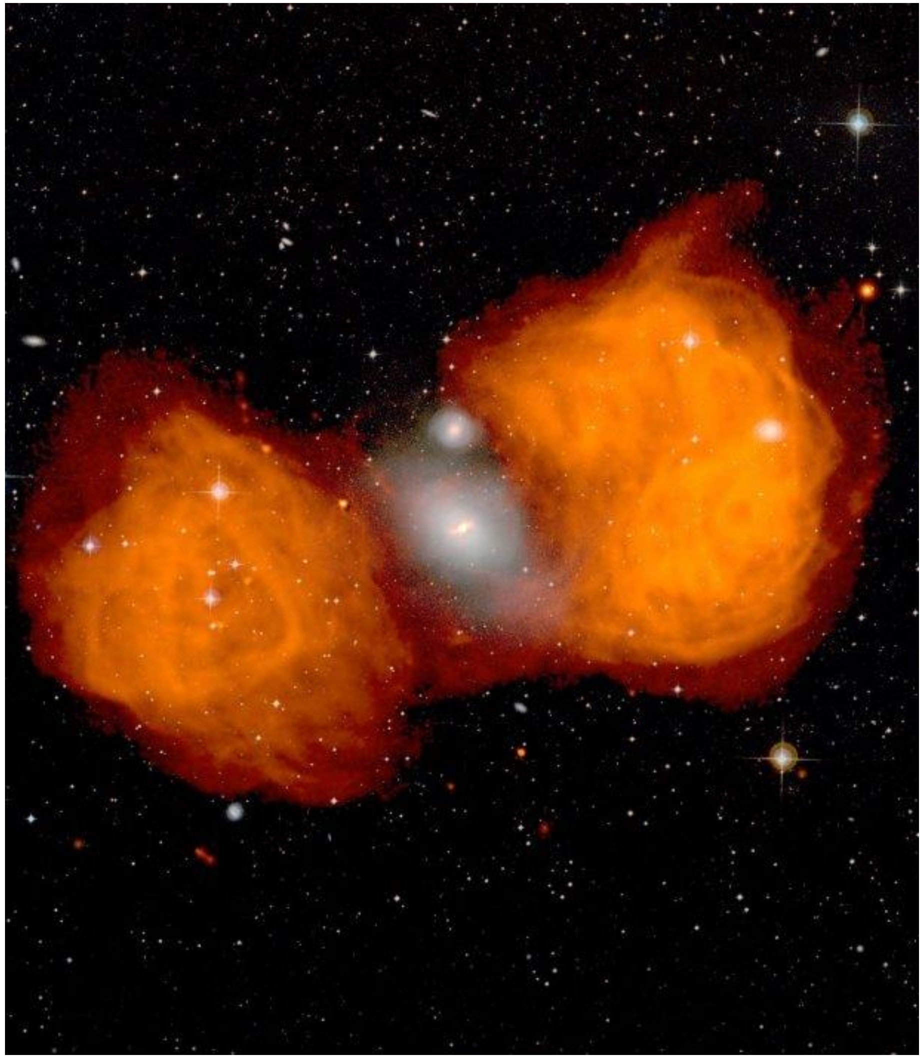
AGN Feedback?

AGN feedback insufficient to explain potential reheating near galactic centre

Additionally: **fine tuning problem**



Credit: NRAO/AUI/NSF

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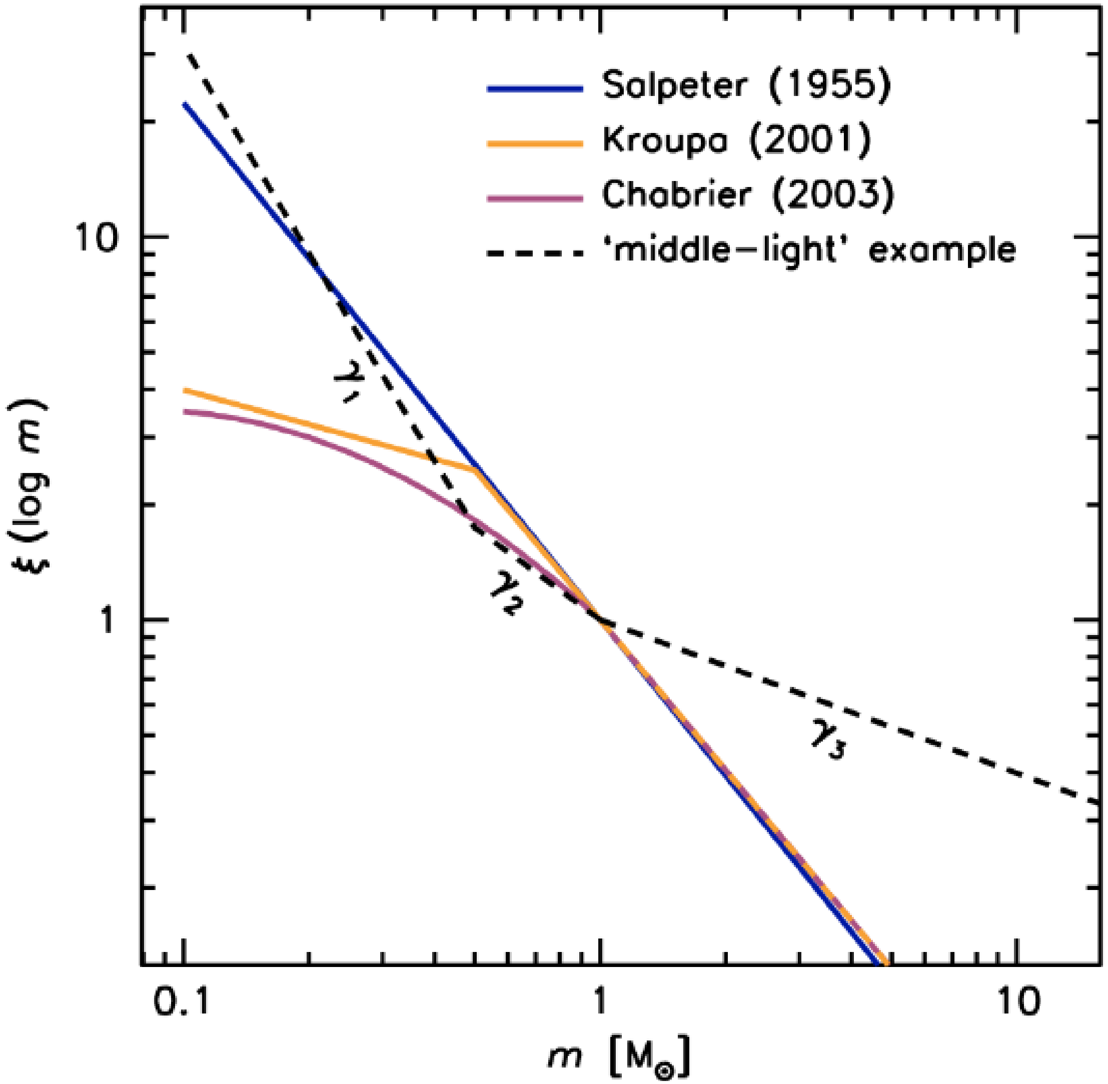
Low Mass Star Formation?

Van Dokkum & Conroy: evidence of **bottom-heavy IMF** in elliptical galaxies

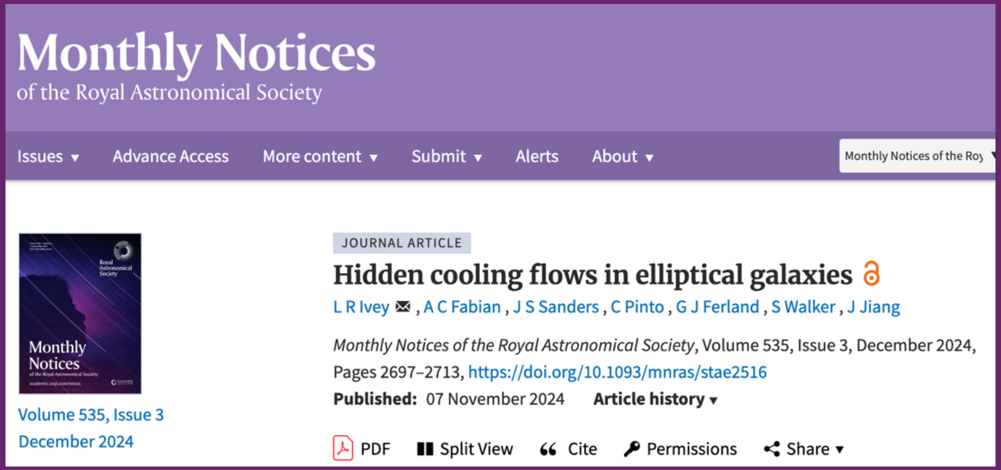
Gu (2022): stellar IMF in nearby massive ETGs requires a **steep low mass IMF slope**

van Dokkum&Conroy+2024



Conclusions

- We **Identified hidden cooling flows of several solar masses per year** in each galaxy, which are **not consistent with normal inference of star formation rates**
- **HCFs result in low mass star formation in the galactic centre**
- **Comparison to FIR luminosity** demonstrated these **absorbed flows are energetically feasible**
- Future studies with JWST/MIRI could help search for these flows by quantifying absorption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JOURNAL ARTICLE

Hidden cooling flows in elliptical galaxies

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Please check out the paper for more detail!

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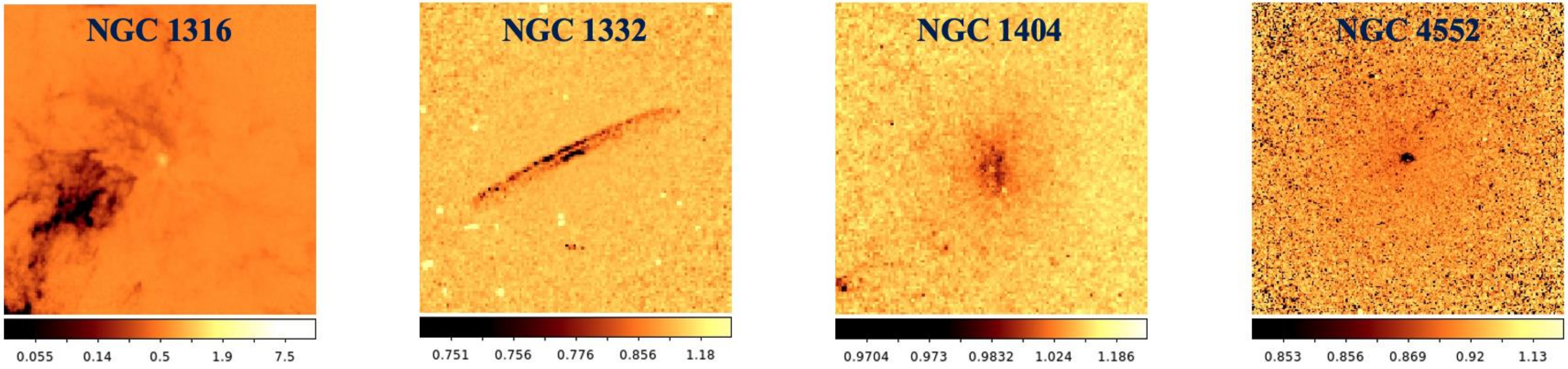
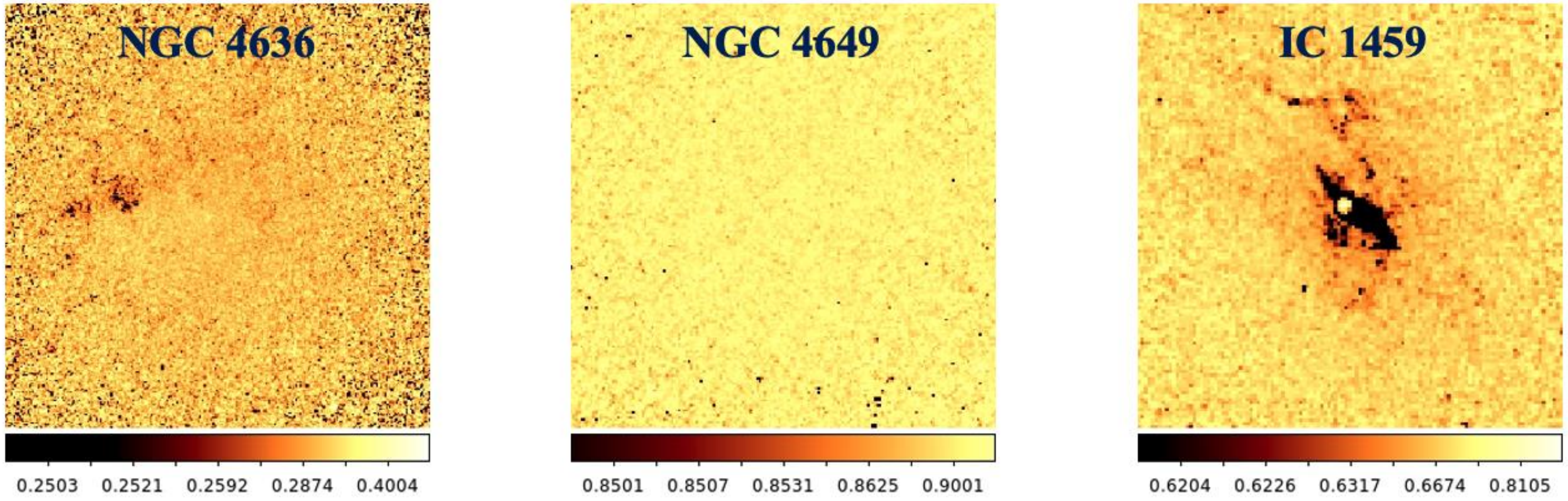
Appendix 1: Dust Absorption

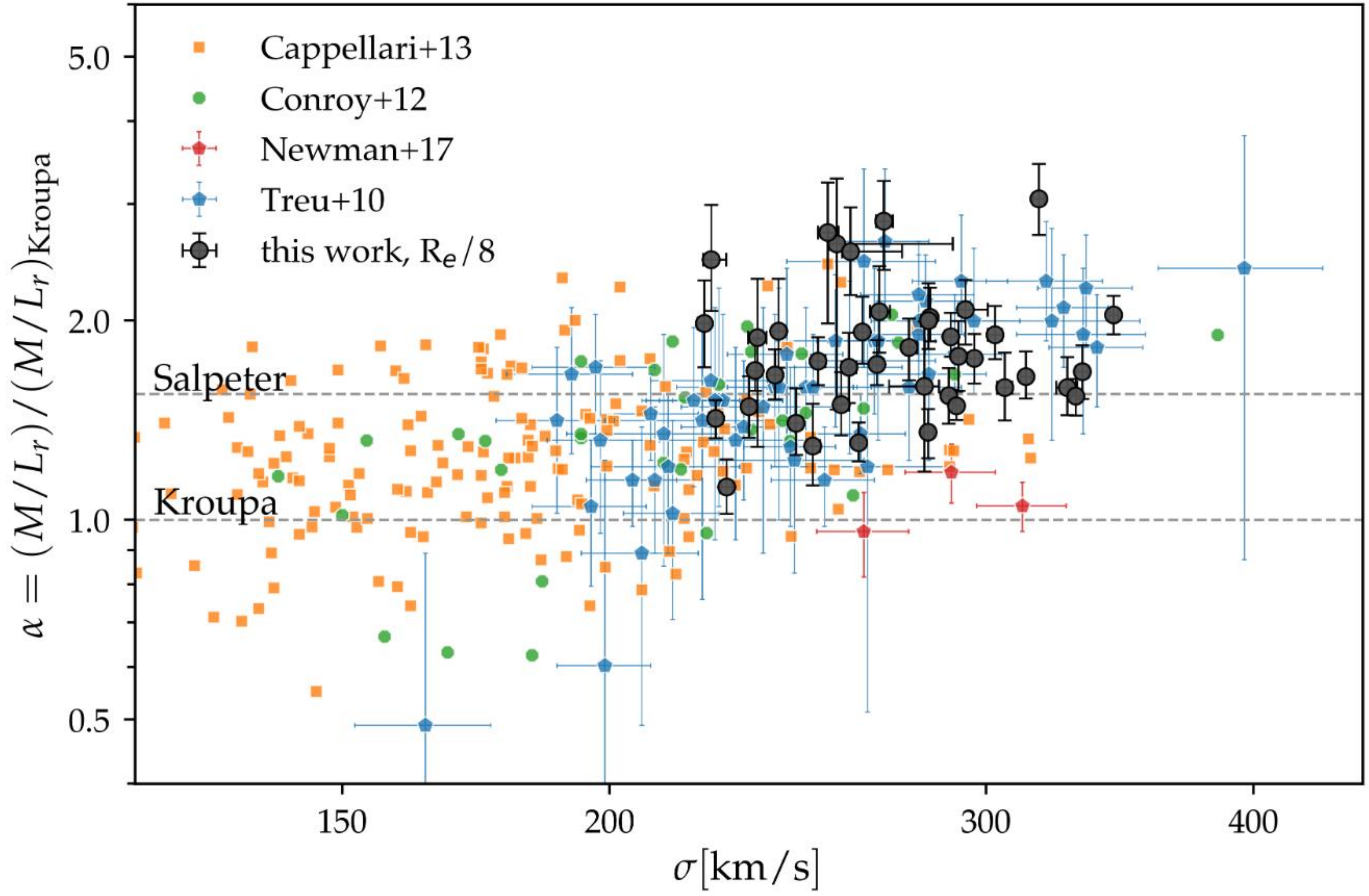


~1 kpc^2 regions
at galactic centre



Appendix 2: M/L Ratio

(Gu+2022)

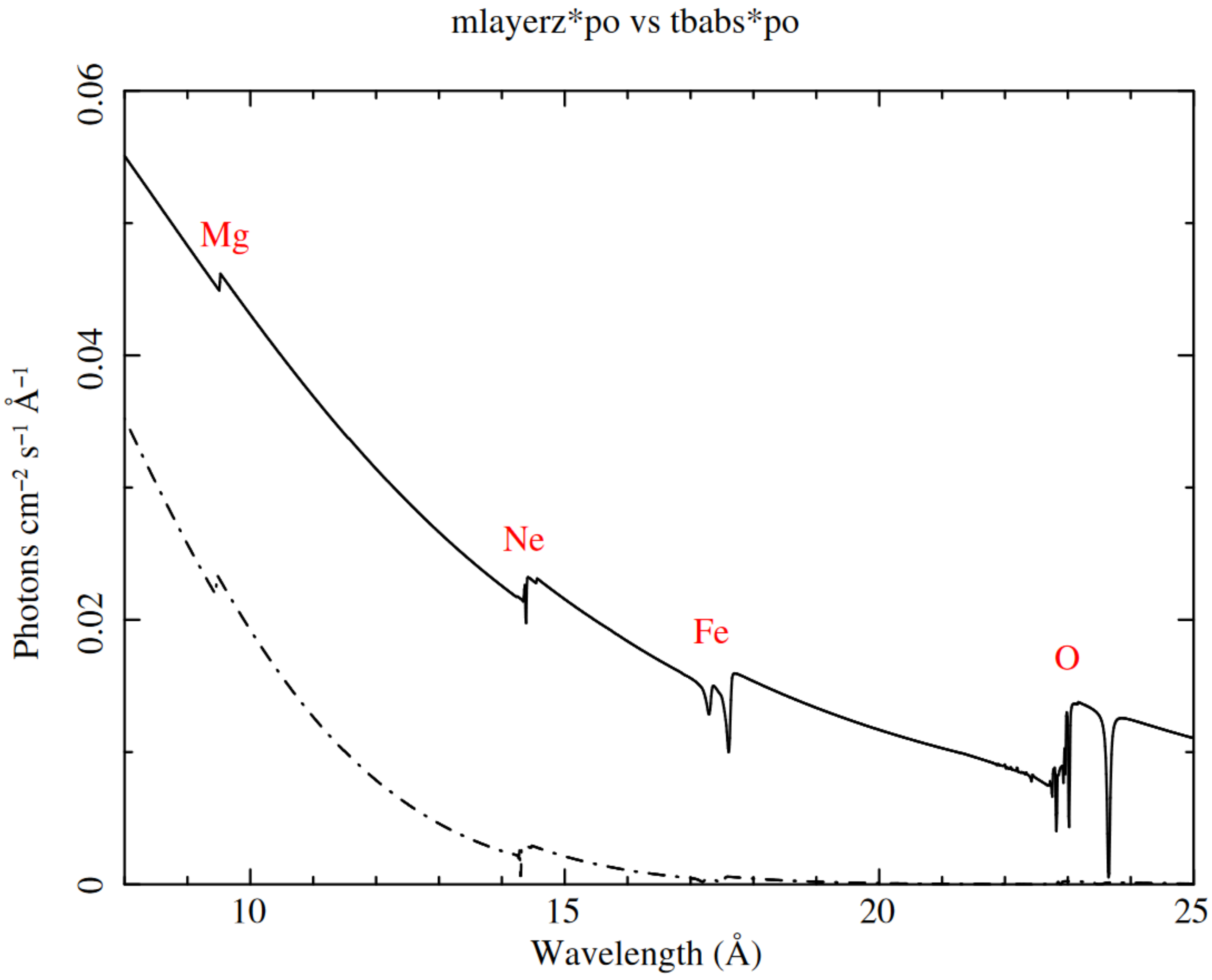


Appendix 3: Absorption Edges

Plot comparing two simple models (**mlayerz*powerlaw**, the upper solid line, and **tbabs*powerlaw**, the lower dashed line), each with intrinsic absorption column density 10^{22} cm^{-2} applied to a power-law index of 2.

This demonstrates the fraction of transmitted emission at each wavelength and the absorption edges associated with individual elements.

Note longer wavelengths are subject to greater absorption, and the O absorption edge is at ~23 Å.



Appendix 4: Impact of Column Density

Intrinsic multi-layer absorption models fitted for a range of N_H values, specified in units of 10^{22} cm^{-2}. All other model parameters were fixed.

Note the suppression of the Fe XVII lines at 15 and 17 Å, as well as the O VII lines at 22 Å.

The effect of line suppression is more dramatic at longer wavelengths.

For a more complete identification of the spectral lines, see *Figure 3 in Sanders & Fabian 2011*.