Optical and Interpretative Astronomy Group (OPINAS)

An Ultramassive Black Hole in the unusual Galaxy Holm 15A

- Image credit: Jordy Davelaar et al./Radbound University/BlackHoleCam

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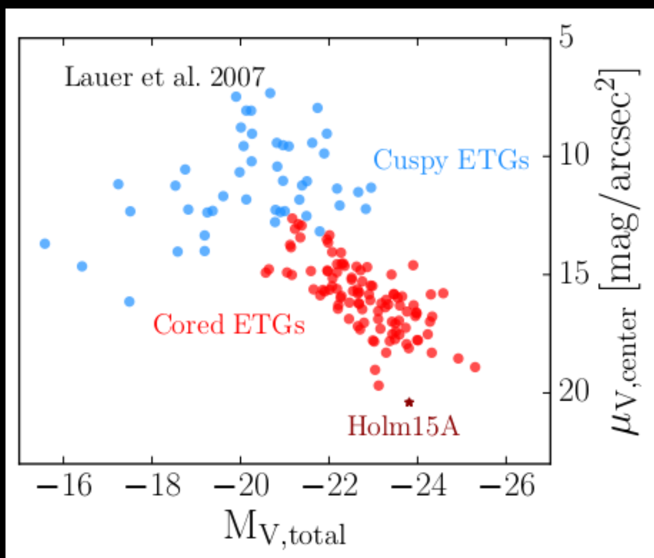
MAX-PLANCK-GESELLSCHAFT

Holm 15A: Brightest Cluster Galaxy of Abell 85

Credit: Matthias Kluge, with Wendelstein observatory

Cusps & Cores: Centers of ETGs

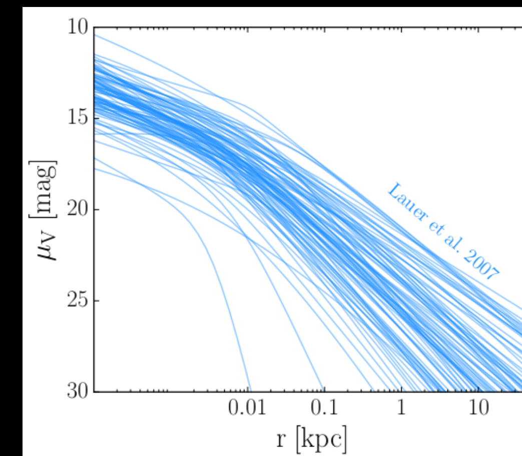


Surface brightness center

Total brightness galaxy

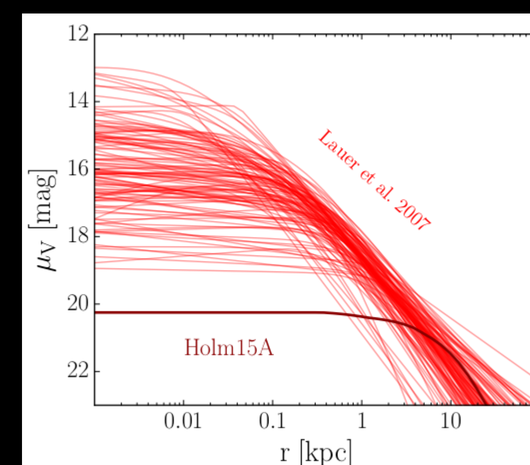
<u>Less massive ETGs</u>

Steep power-law
surface brightness
'cusps'



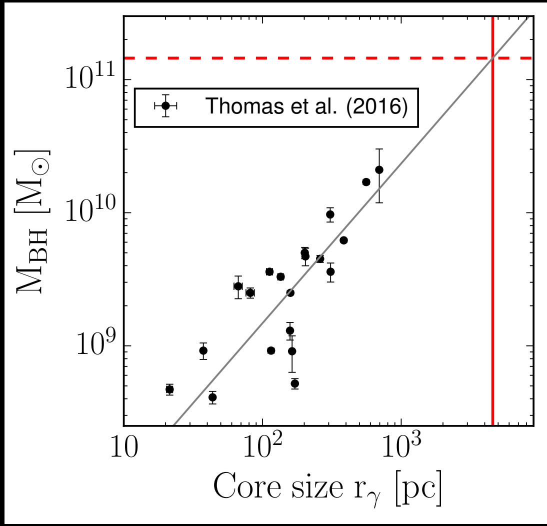
<u>Massive ETGs</u>

Shallow central
Surface brightness
'cores'



Holm 15A: Huge, Ultra-Diffuse Core

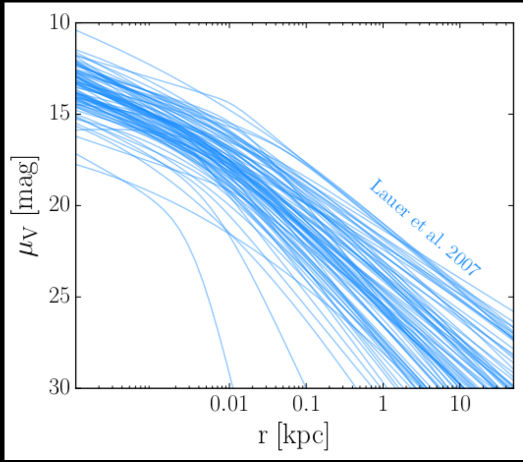
Thomas et al. 2016, Nature 532, 340



Cores grow linearly with BHs
-> Holm 15A expected to host UMBH with $M_{BH} \sim 10^{11}\ M_\odot$

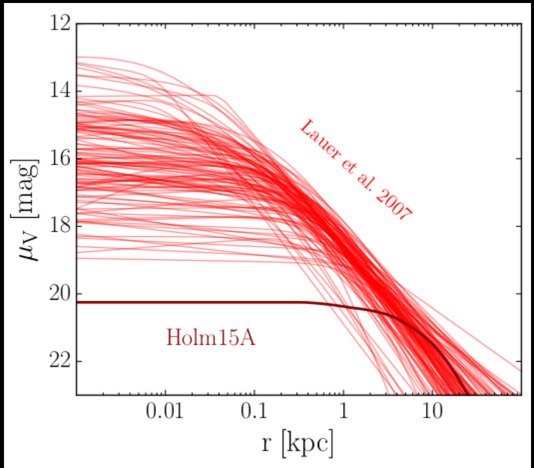
<u>Less massive ETGs</u>

Steep power-law surface brightness **'cusps'**



<u>Holm 15A</u>

~ 2 mag fainter than any Core with dynamical study
Largest known Core: (4.57 ± 0.06) kpc
López-Cruz et. al 2014, ApJ 795, 31



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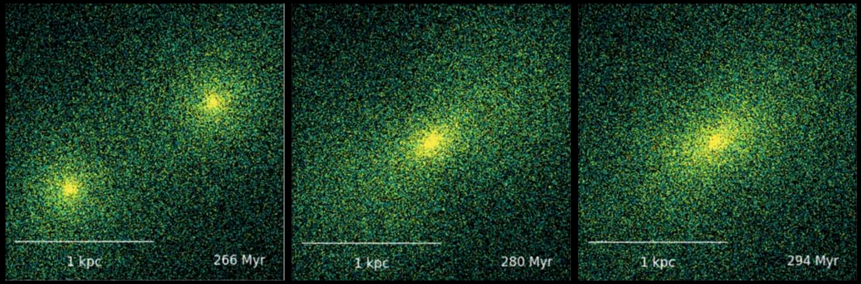
Core Scouring

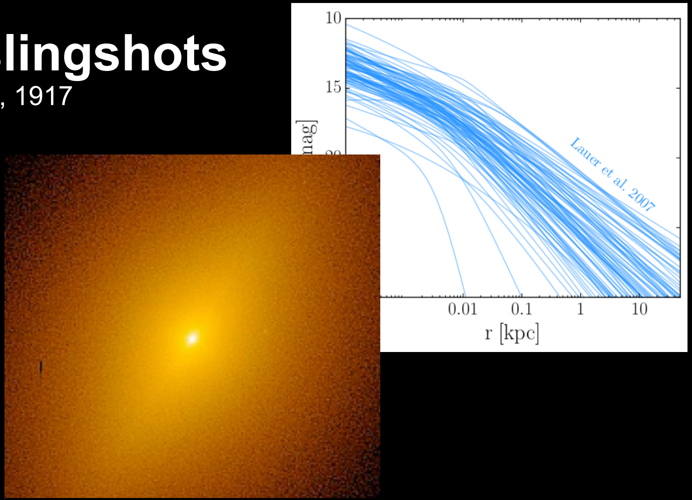
Merging SMBHs ejecting central stars via gravitational slingshots

e.g. Begelman et al. 1980, Nature 287, 307; Milosavljević & Merritt, 2001, ApJ, 563, 34; Trujillo et al. 2004, AJ, 127, 1917

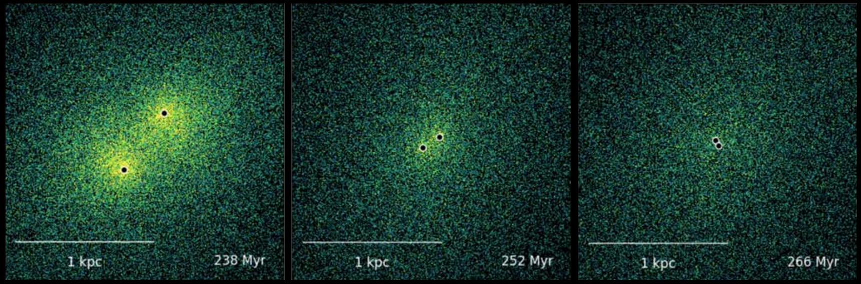
Cuspy + Cuspy dissipationless Merger:



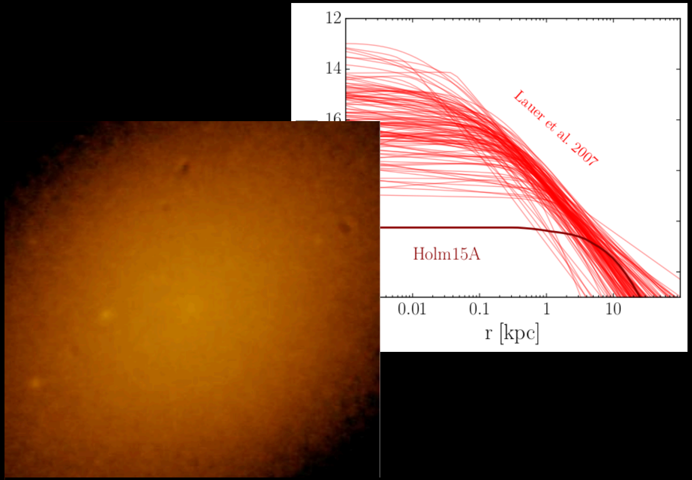
Without Black Holes
-> Cuspy Remnant



NGC 4621: Cuspy ETG



With Black Holes
-> Cored Remnant



NGC 720: Cored ETG

N-body Merger Simulations

Rantala et al. 2018, ApJ, 864, 113; Rantala et al. 2019, ApJ, 872, 113

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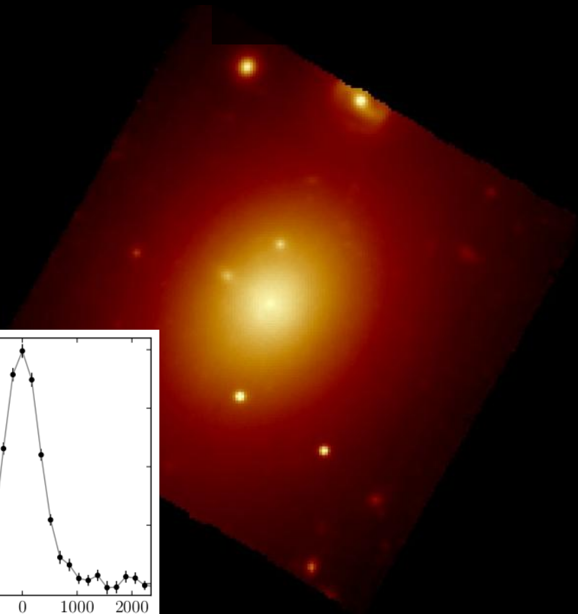
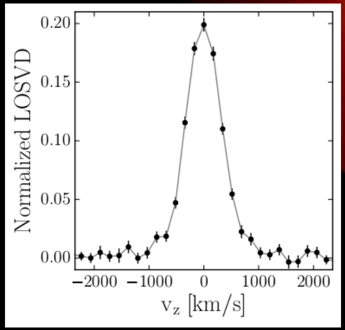
MUSE wide-field Spectroscopy



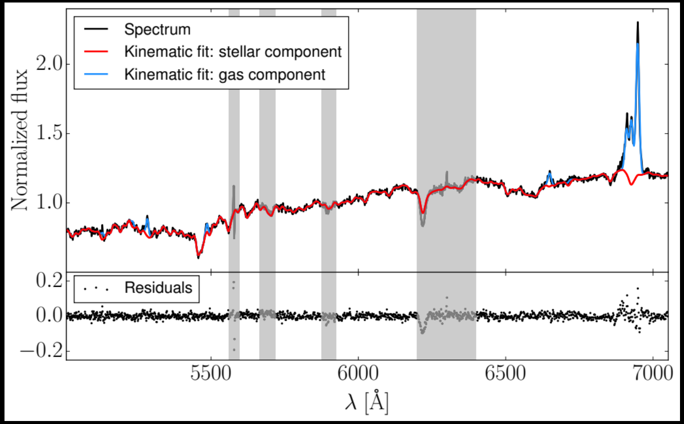


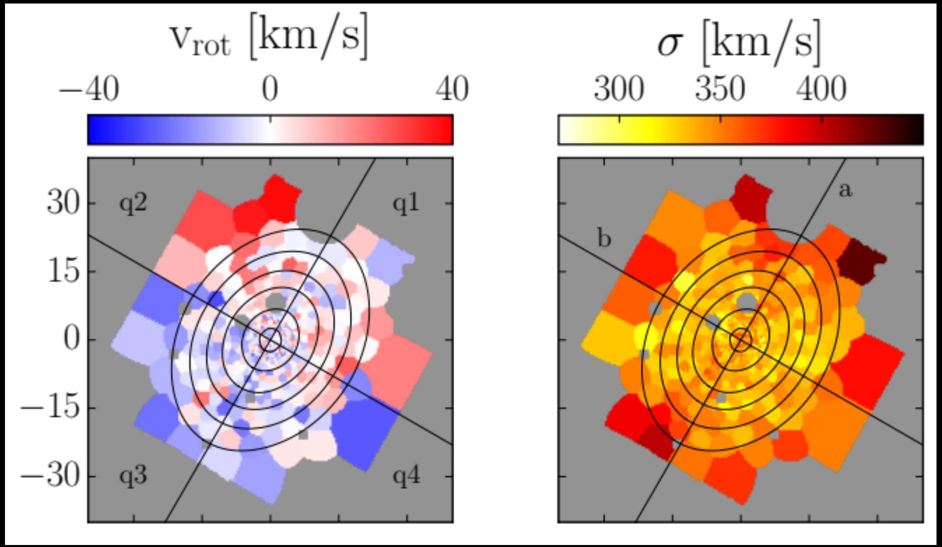
- 60 x 60 arcsec^2 ≙ 60 x 60 kpc^2 at z = 0.055
- Sphere-of-influence of BH: $M(r < r_{SOI}) \equiv M_{BH}$
- Min. expected BH ~ 5 x 10^9 $M_\odot$, SOI with 2 x r_{SOI} = 4''

-> Our PSF = 0.72'' FWHM -> **can resolve BH by factor > 5**

Resolution sufficient for robust BH detection!

Rusli et. al 2013a, AJ, 146, 45



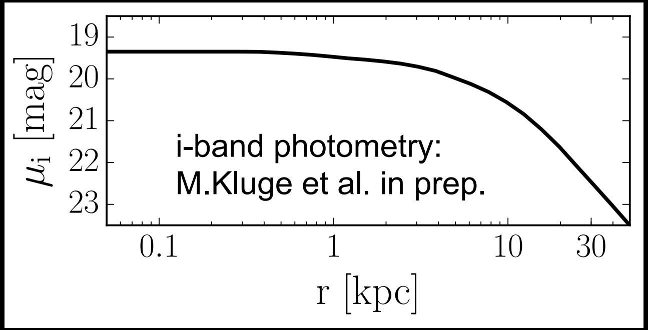


Schwarzschild Dynamical Modeling

Previously used for M87 Black Hole:

Gebhardt & Thomas 2009, ApJ, 700, 1690: $M_{BH} = (6.4 \pm 0.50) \times 10^9\, M_\odot$

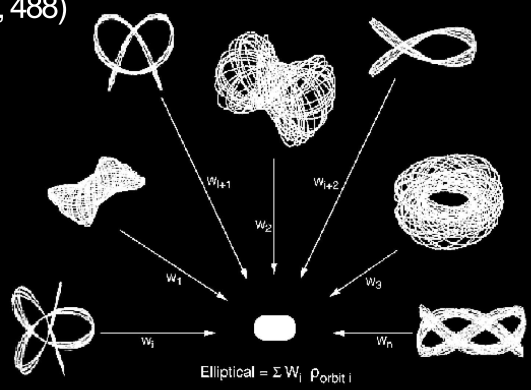
Event Horizon 2019 (ApJ 875, L4): $M_{BH} = (6.5 \pm 0.80) \times 10^9\, M_\odot$

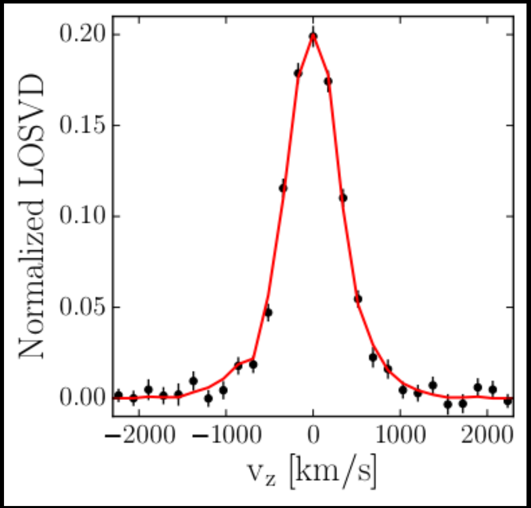


- Gravitational Potential **ϕ + 10.000+ stellar orbits**
- Orbits **constrained** to reproduce observed Photometry
- ϕ -> defined by set of 5 Parameters which we optimise for:

M_{BH}, Υ_* +Generalised NFW DM-Halo, defined by **r_s, γ, ρ_{10}**

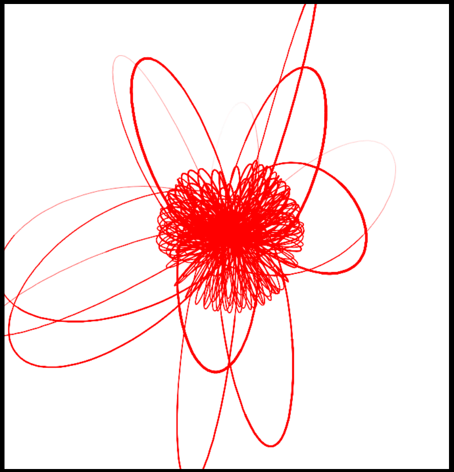
(Zhao 1996, MNRAS, 278, 488)

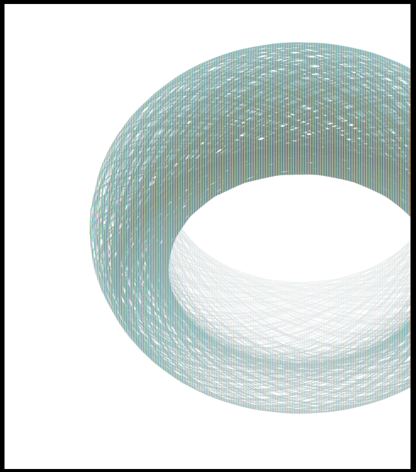




updated version Thomas et al. (2004), MNRAS, 353, 391

Detecting BH-Binary Core Scouring





Stars on radial orbits three-body with BHs:
Gravitational slingshots

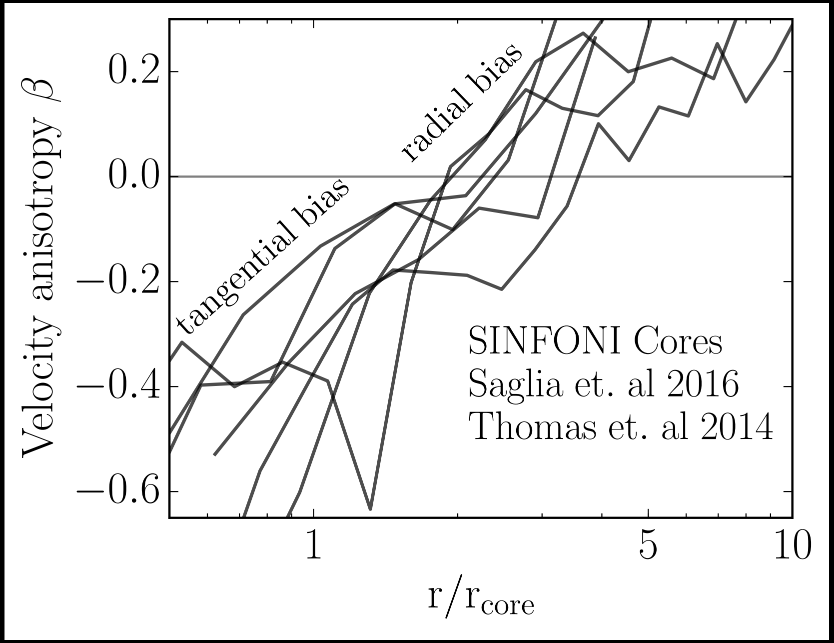
Tangential orbits angular momentum:
Don't interact with BHs

=> Tangential bias in cores, β < 0 !!

$$\beta = 1 - \frac{\sigma_t^2}{\sigma_r^2}$$

Our Models, unlike Jeans-Models,
Allow velocity anisotropy variation

->Dynamical imprint of merger history!



SINFONI BH Survey: Saglia et al. 2016, ApJ, 818, 47
Dynamics: Thomas et al. 2014, ApJ ,782, 39

Results

<u>Most massive dynamically determined Black Hole so far:</u>

Holm15A: M_{BH} = $(4.0 \pm 0.8) \times 10^{10}\ M_{\odot}$ (Mehrgan et al. 2019 soon in submission)

NGC 4889: $M_{BH} = (2.1 \pm 0.99) \times 10^{10}\ M_{\odot}$ (McConnell et al. 2012, ApJ, 765, 179)

NGC 1600: $M_{BH} = (1.7 \pm 0.15) \times 10^{10}\ M_{\odot}$ (Thomas et al. 2016, Nature, 532, 340)

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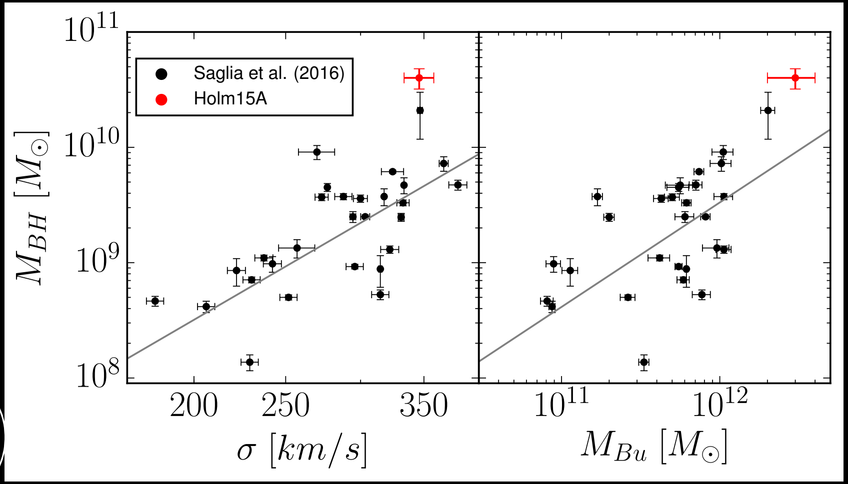
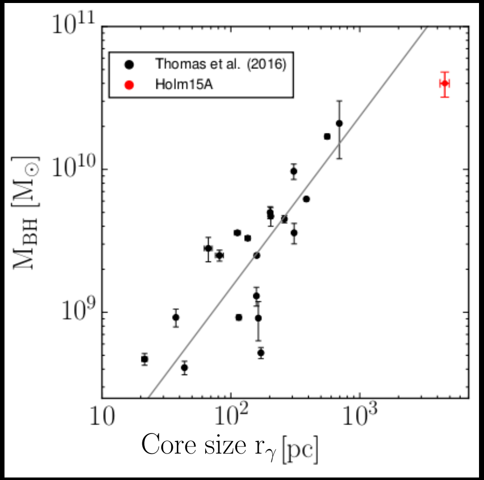
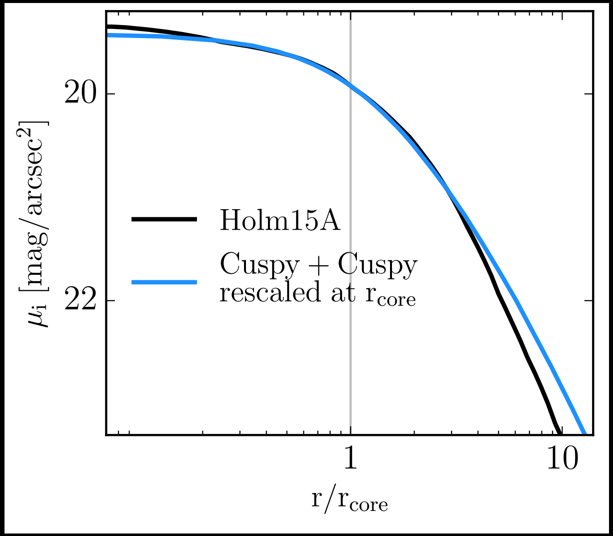
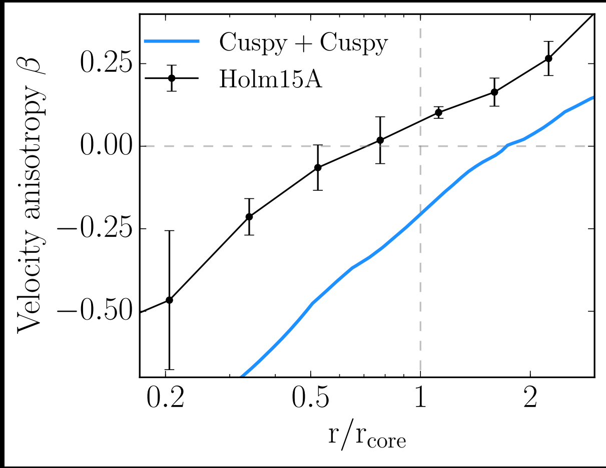




assembly Holm 15A different
from dominant growth processes of less massive ETGs/BHs/ Cores

Comparison N-Body Merger Simulations





Cuspy + Cuspy = 1st gen Cored

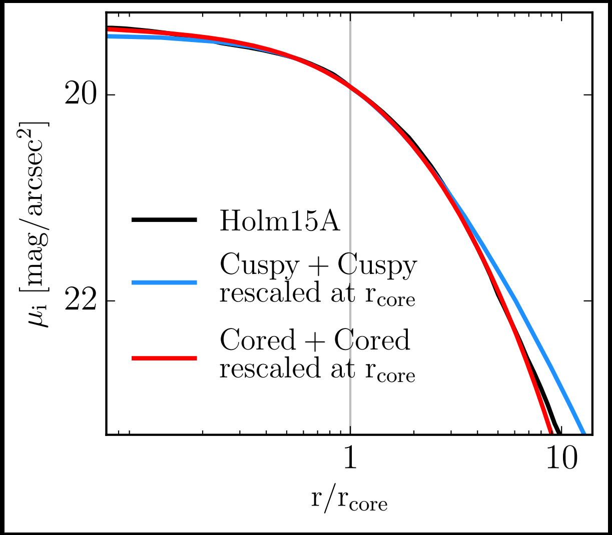
2 x (M_{BH} = 8.5 x 10^9 $M_\odot$)

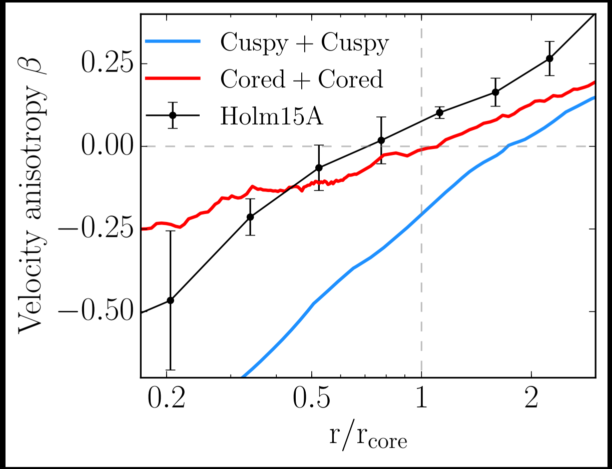
~ NGC 1600

Holm15A is too smooth and exponential-like compared to known shallow power-law cores?!

Holm15A has less tangential bias in core…

Comparison N-Body Merger Simulations





Cuspy + Cuspy = 1st gen Cored

2 x (M_{BH} = 8.5 x 10^9 $M_\odot$)

~ NGC 1600

Cored + Cored = 2nd. gen Cored

2 x (M_{BH} = 1.7 x 10^{10} $M_\odot$)

~ NGC 1600 + NGC 1600

→ Similiar to Holm15A's

Repeated binary BH core-scouring dilutes tangential bias in cores!

Closer to Holm15A

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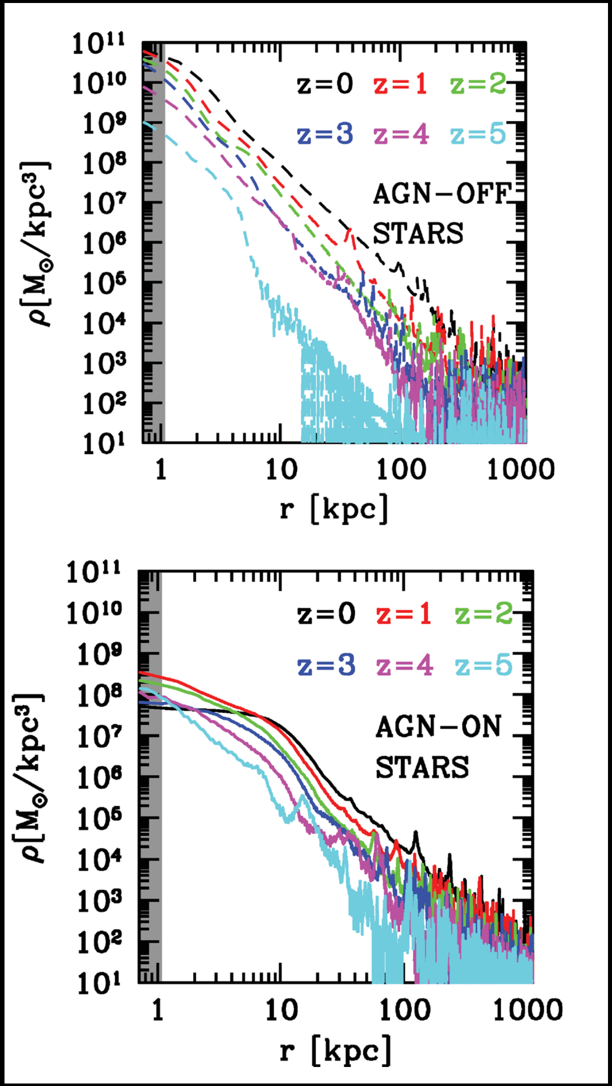
Alternative: AGN Feedback?



Holm 15A at center of cool core!

- no counter rotating core
- hosts AGN (LINER)

AGN outflow simulations

Martizzi et al. 2012, MNAS, 422, 3081:

=> Irreversibly transfer energy to stars & DM

- equal stellar & DM density in core??
- Many cores: stellar mass 1.5-2 x Kroupa IMF
  e.g. Thomas et al. 2011, MNRAS, 415, 545; Spinello et al. 2011, MNRAS, 416, 3000; Cappellari et al. 2012, Nature, 484, 485
- Holm 15A ~ 1.6 x Kroupa! DM tracing stars?

Conclusions & Outlook

- **Abell 85 BCG, Holm15A hosts UMB with M_{BH} = (4.0 ± 0.80) x 10^{10} $M_\odot$**
- **2^{nd} gen. BH merger: exponential light profile & orbits & scaling**
- AGN feedback: **exponential light profile & (orbits??) & (scaling??)**
- Found ~30 **rare Holm15A-like exponential (n < 1.5) BCGs**

… all ultra-faint cores!

Might hold the key to understanding different core formation channels