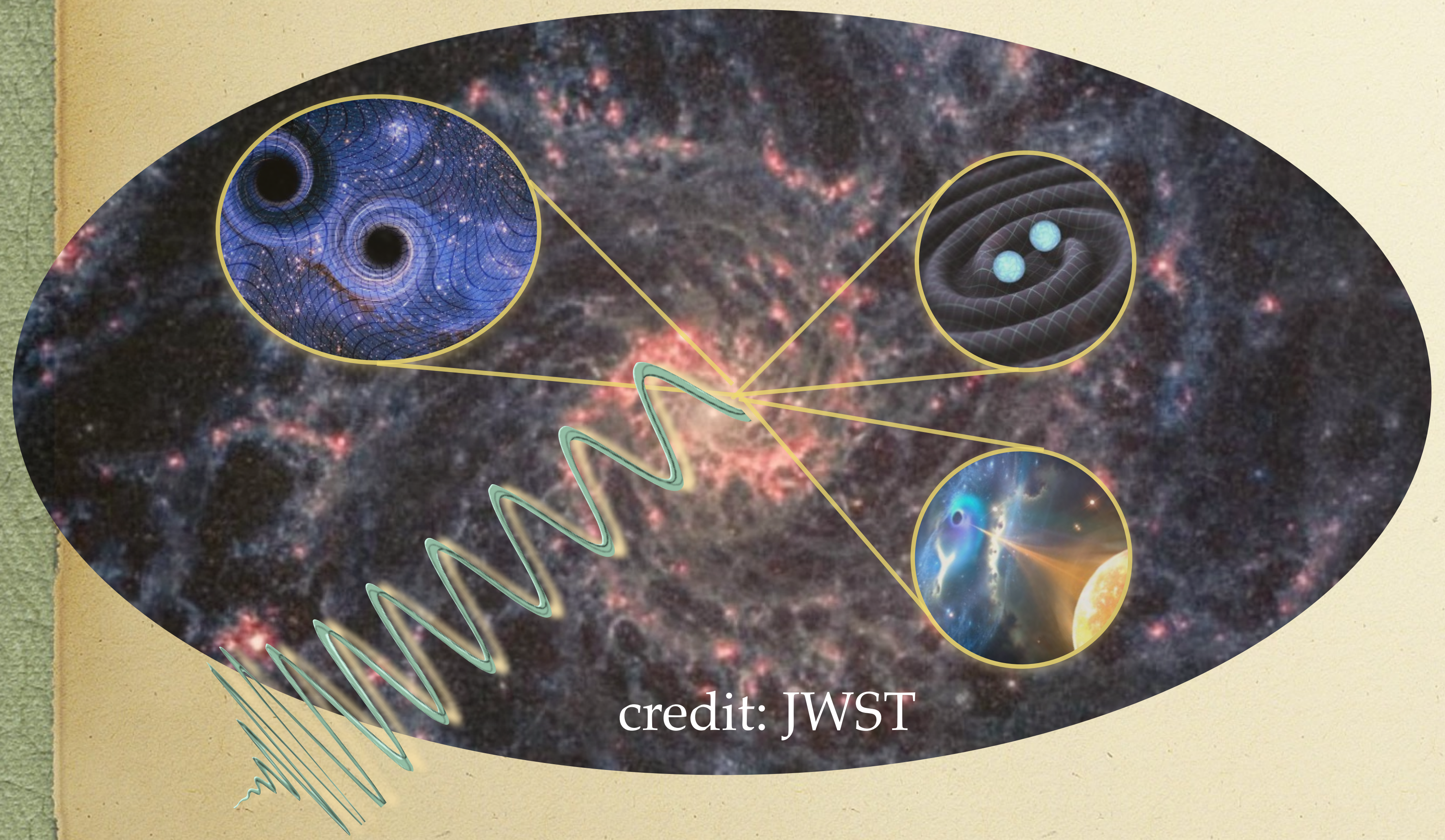
Mergers and Collisions at the Heart of Galaxies



UCLA

Smadar Naoz

December 2022

Unsolved Problems in Astrophysics and Cosmology

A special thanks to Howard and Astrid Preston for their generous support

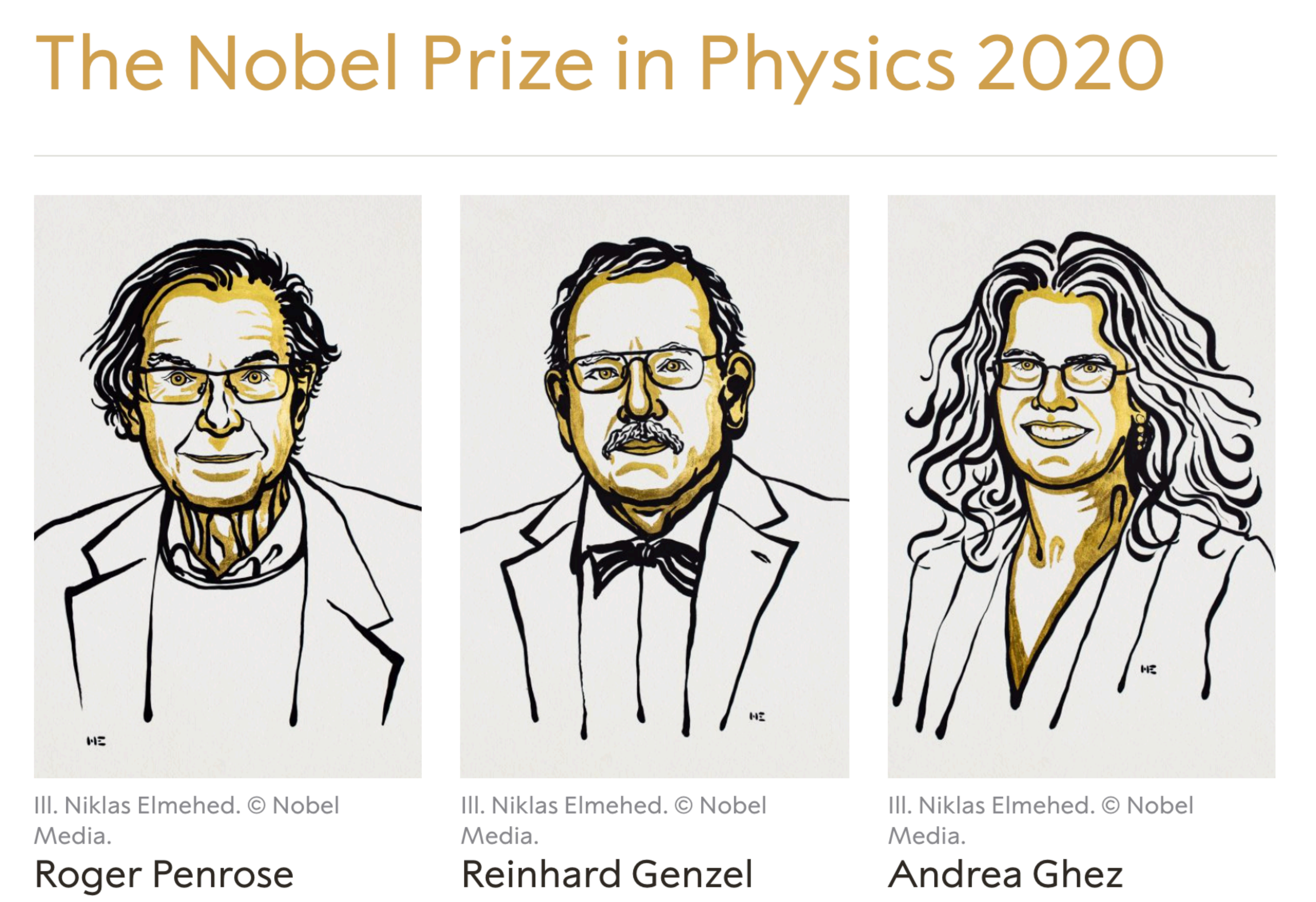
The Densest Places in the Universe

~Every galaxy has a Supermassive Black Hole $10^{6\text{-}9} M_\odot$

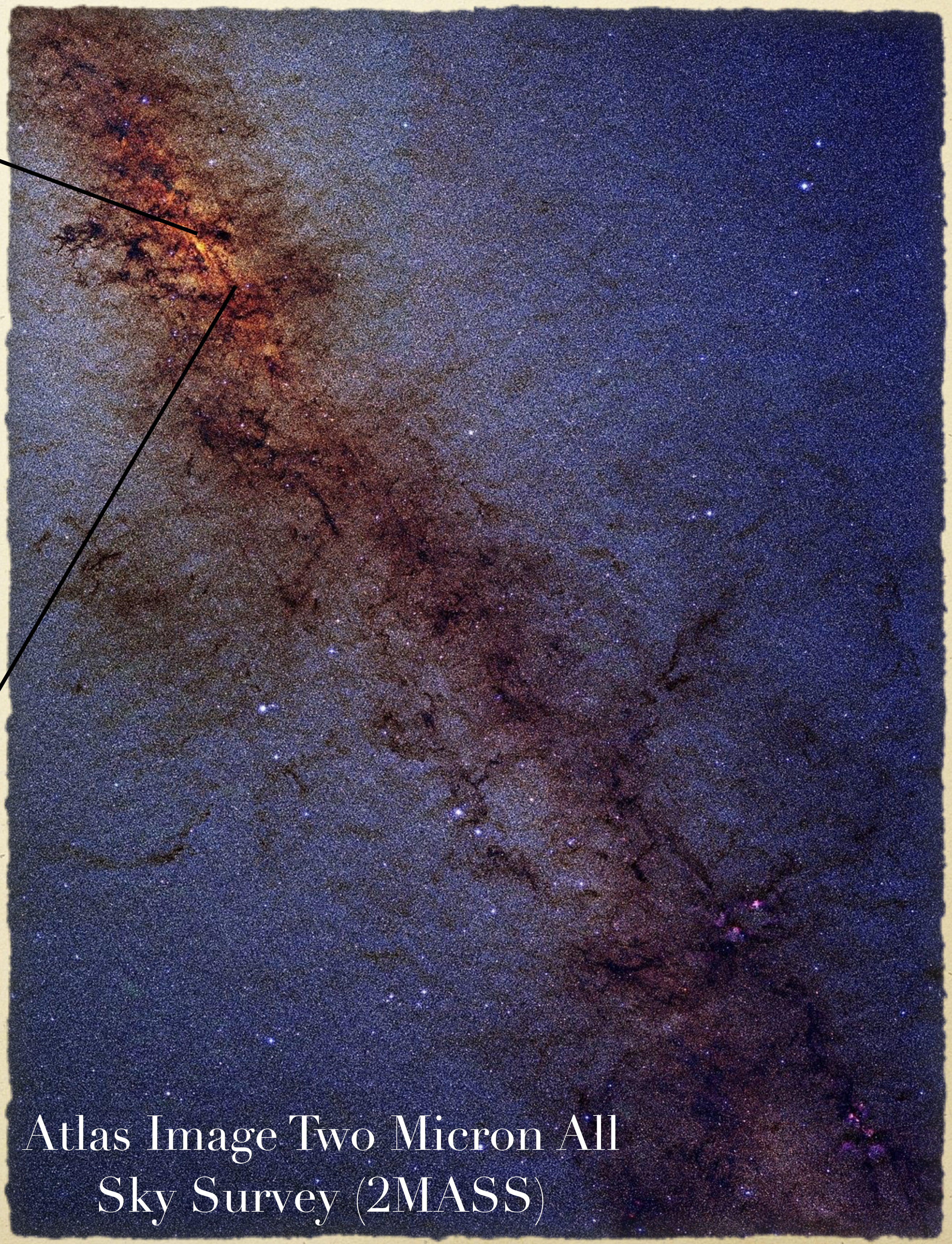
Densest environments

A monster in our backyard

Infer on other galactic nuclei { Binary population / Dense environment

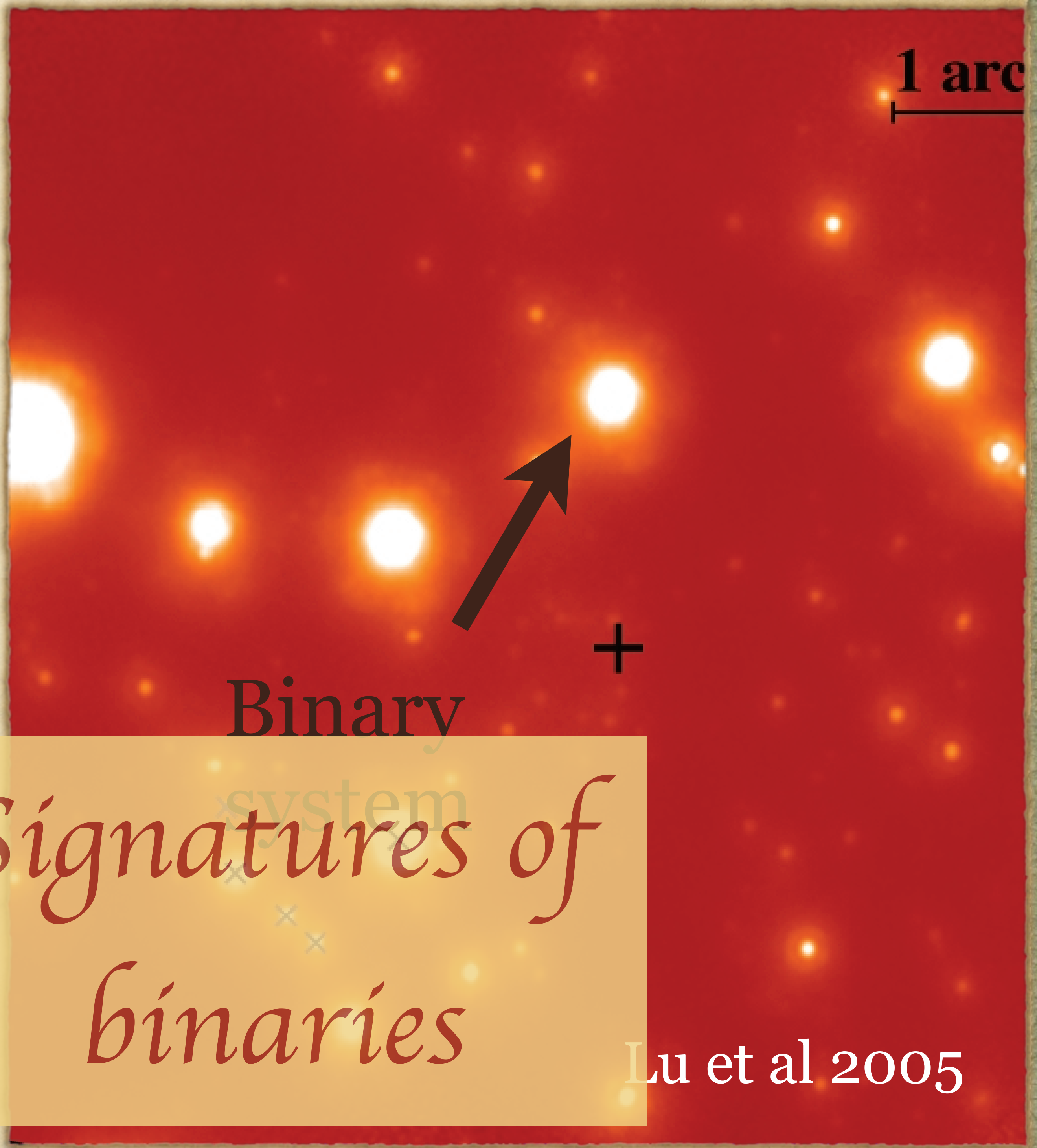


The central 10 arcsec ~ 0.4pc ~ 1.3 lightyear



Binaries near the monster in our backyard

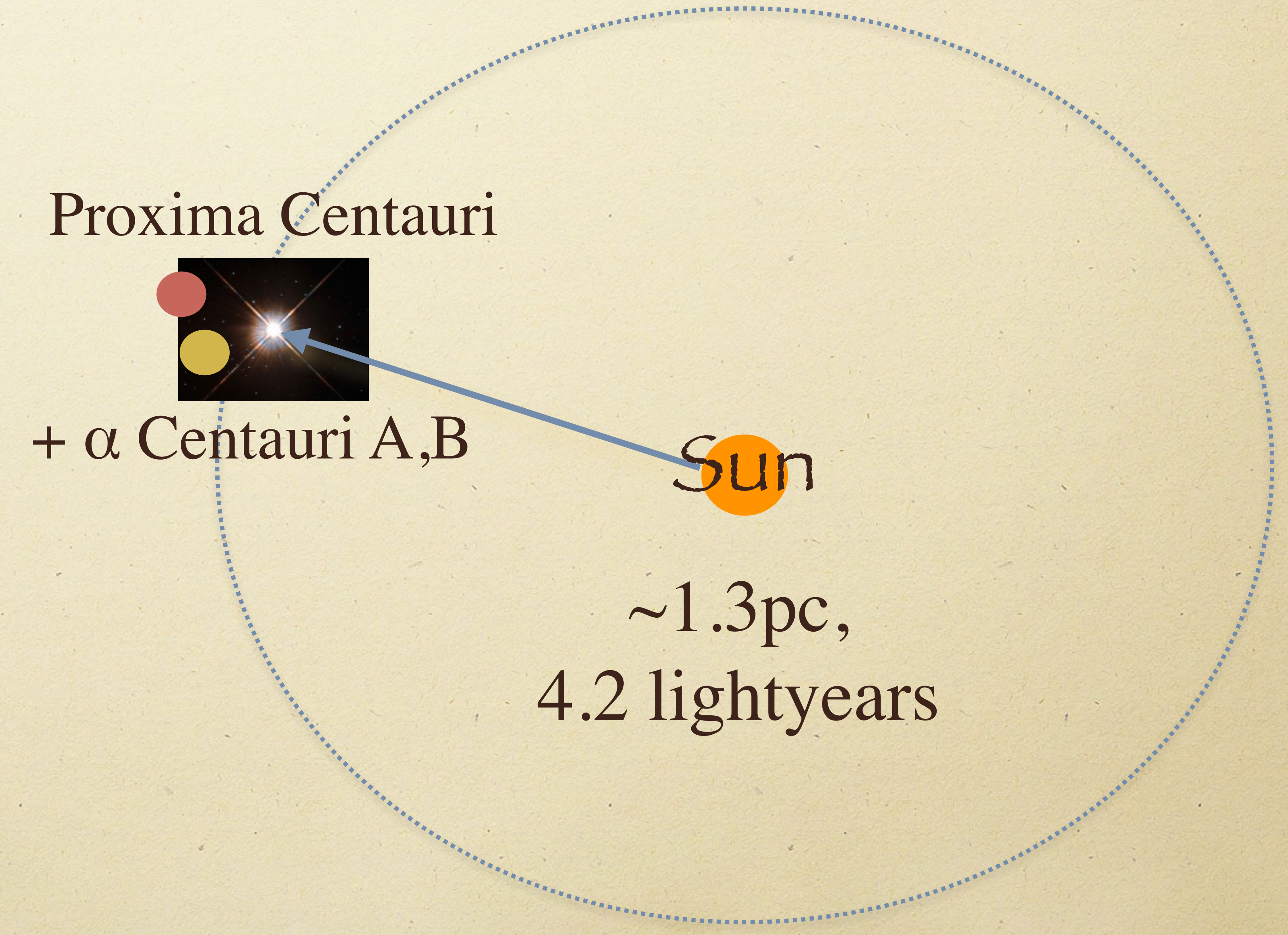
- 3 confirmed Binaries:Ott et al. 1999; Martins et al. 2006, Pfuhl et al. 2014.
- Binary fraction of massive stars may be comparable to young clusters or larger (e.g., Ott et al. 1999; Rafelski et al. 2007;Pfuhl et al. 2014; Alexander et al 2008); Similar to local OB eclipsing binary fraction Gautam et al.
- X-ray Binaries (e.g., Muno et al 2005a,b, Haggard et al 2017, Hailey et al 2018)
- Hypervelocity stars (e.g., Brown et al 2005,2008, Hills 1988; Miralda-Escude & Gould 2000; Yu and Tremaine 2003; Perets et al. 2009)
- Stellar disk properties = Large binary fraction (**Naoz** et al 2018)



Signatures of binaries

A monster in our backyard

Densest Environment

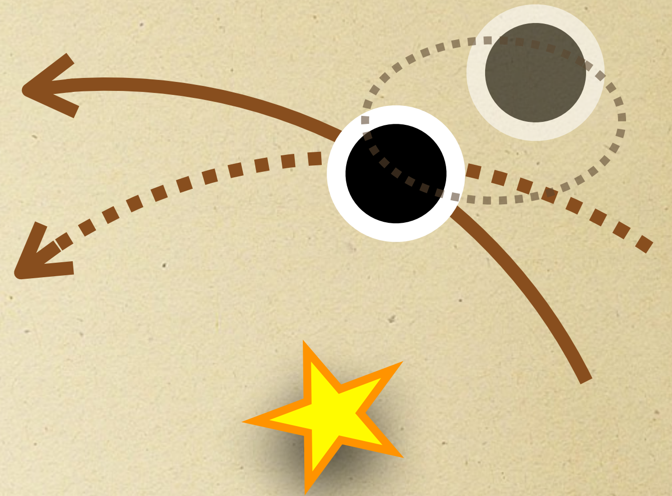


A monster in our backyard

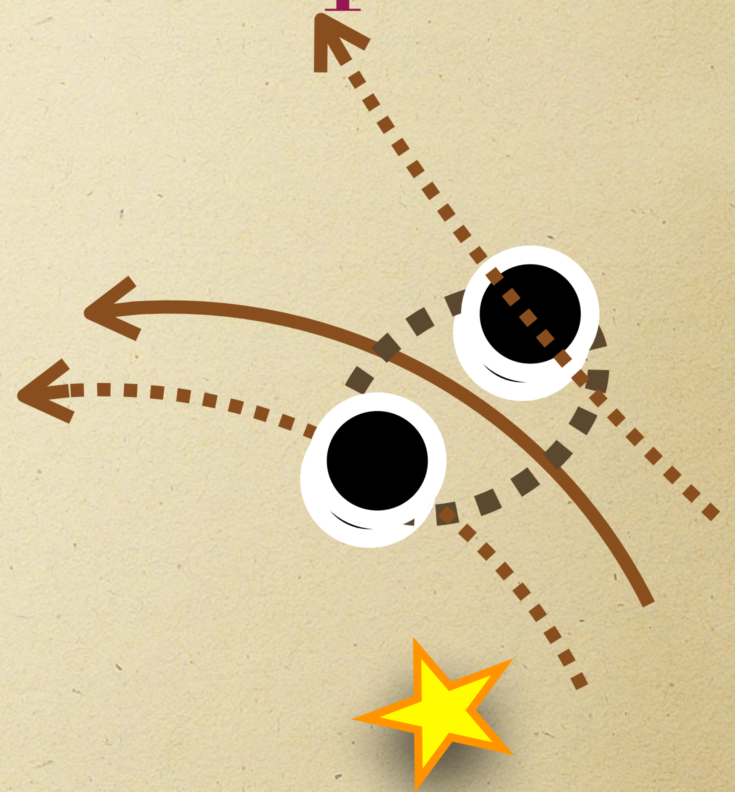
Densest Environment

Weak kicks with passing neighbors

Relaxation



Evaporation



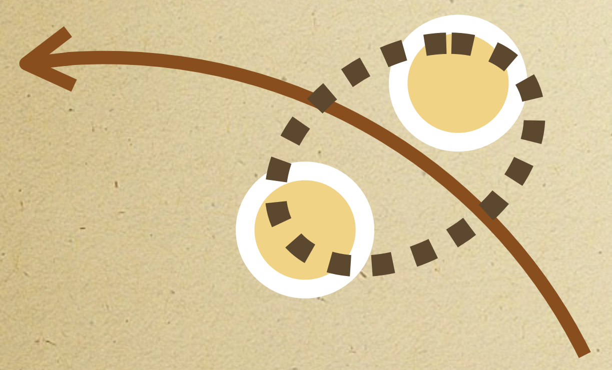
Collisions with passing neighbors

Collision

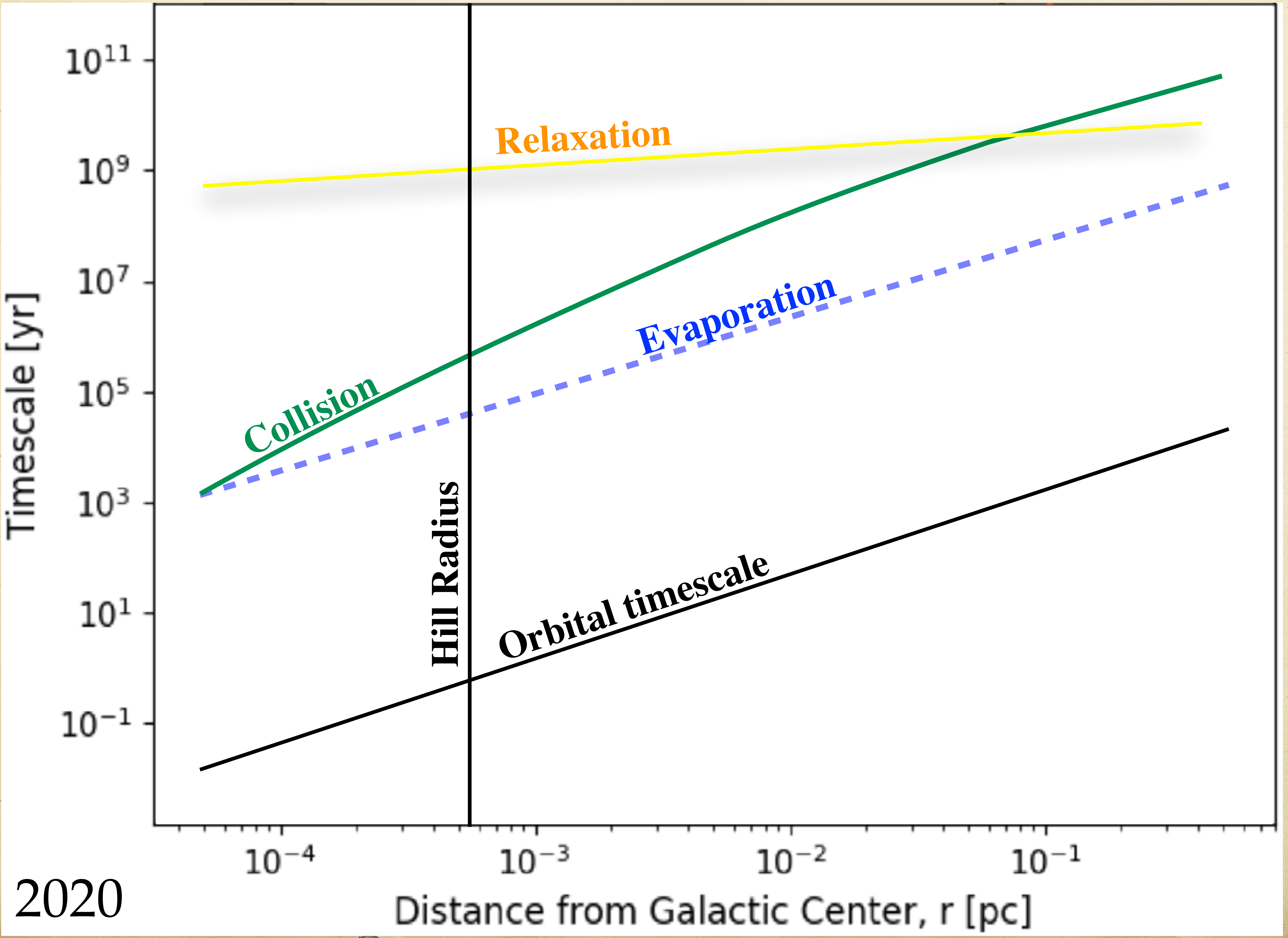
A monster in our backyard

Timescale hierarchy

Sanaea Rose

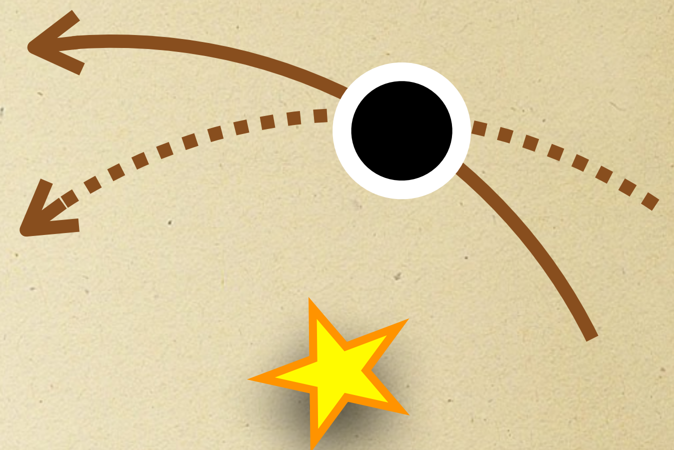


For a stellar binary @ 0.5au

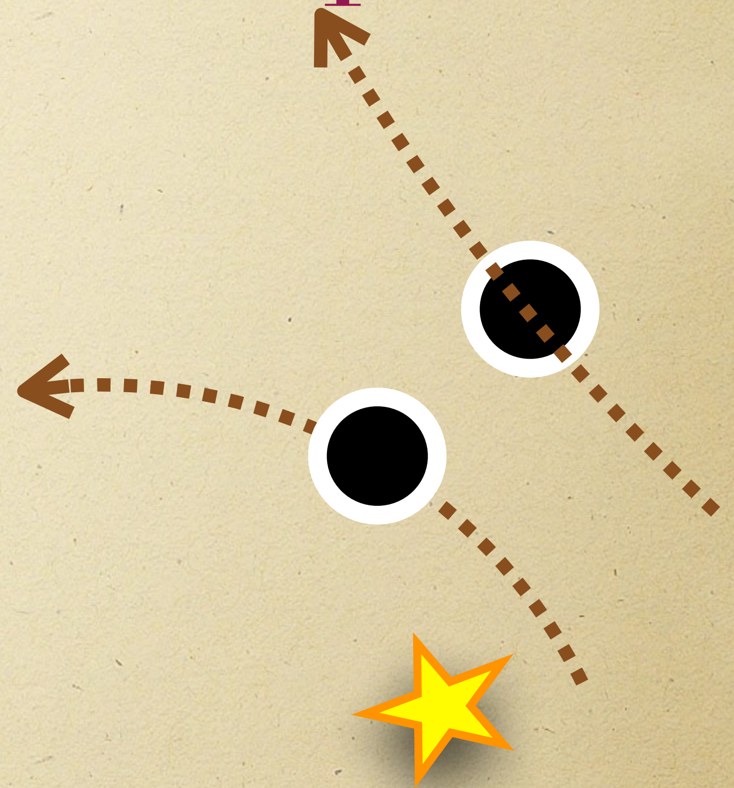


Rose, **Naoz** et al. 2020

Relaxation



Evaporation



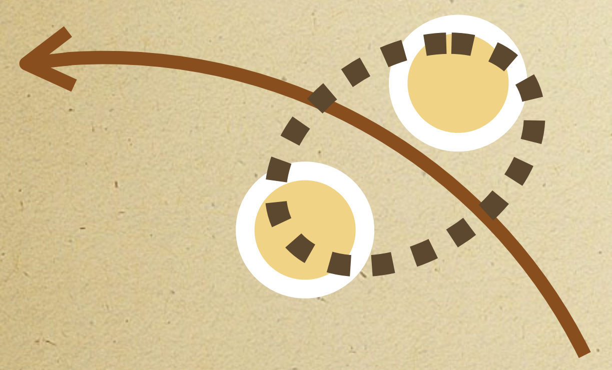
Collision

A monster in our backyard

$\rho \sim r^{-\alpha}$

Timescale hierarchy

Sanaea Rose



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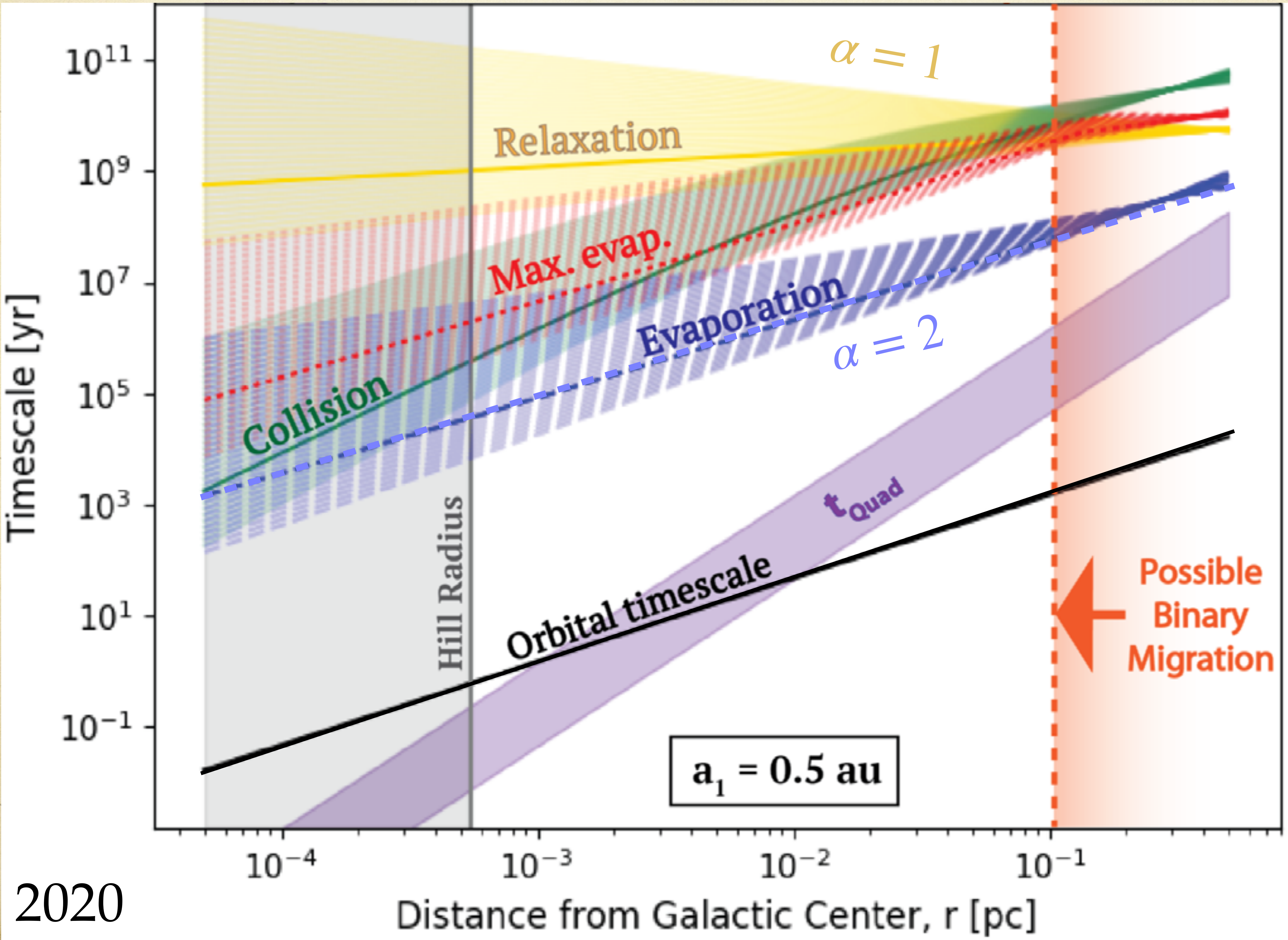
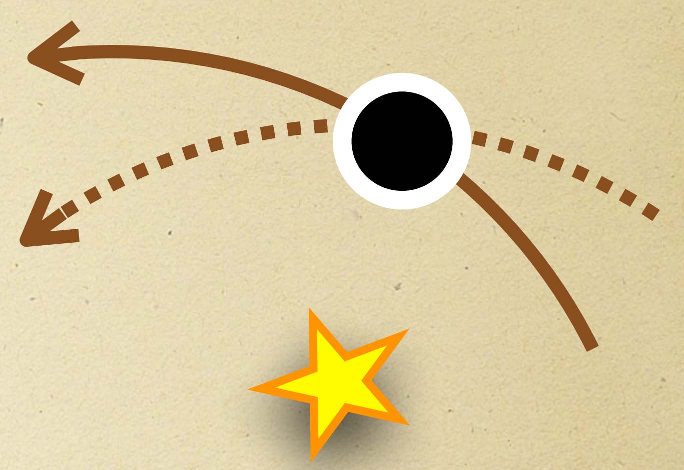
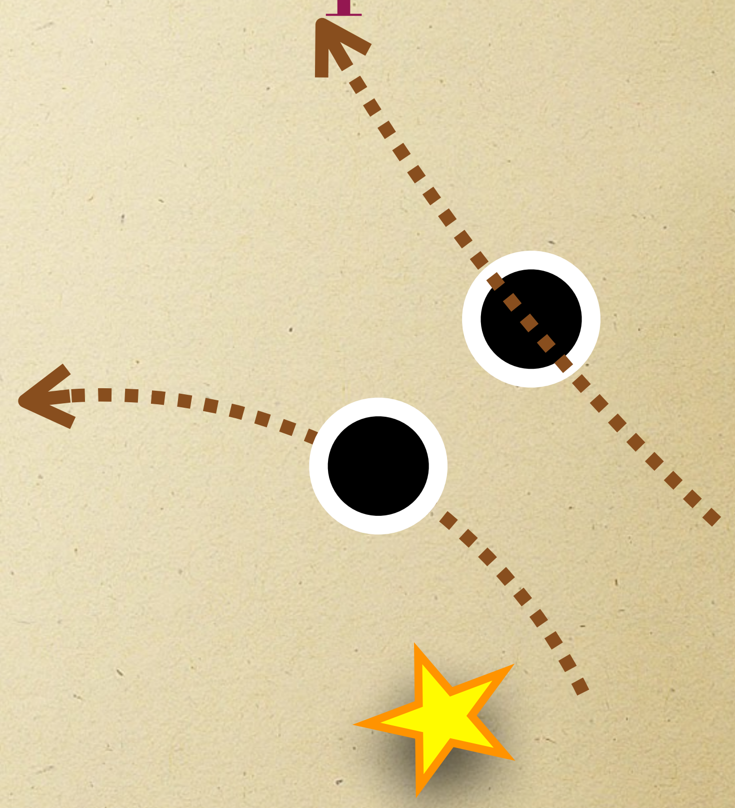


Relaxation



Evaporation



Collision

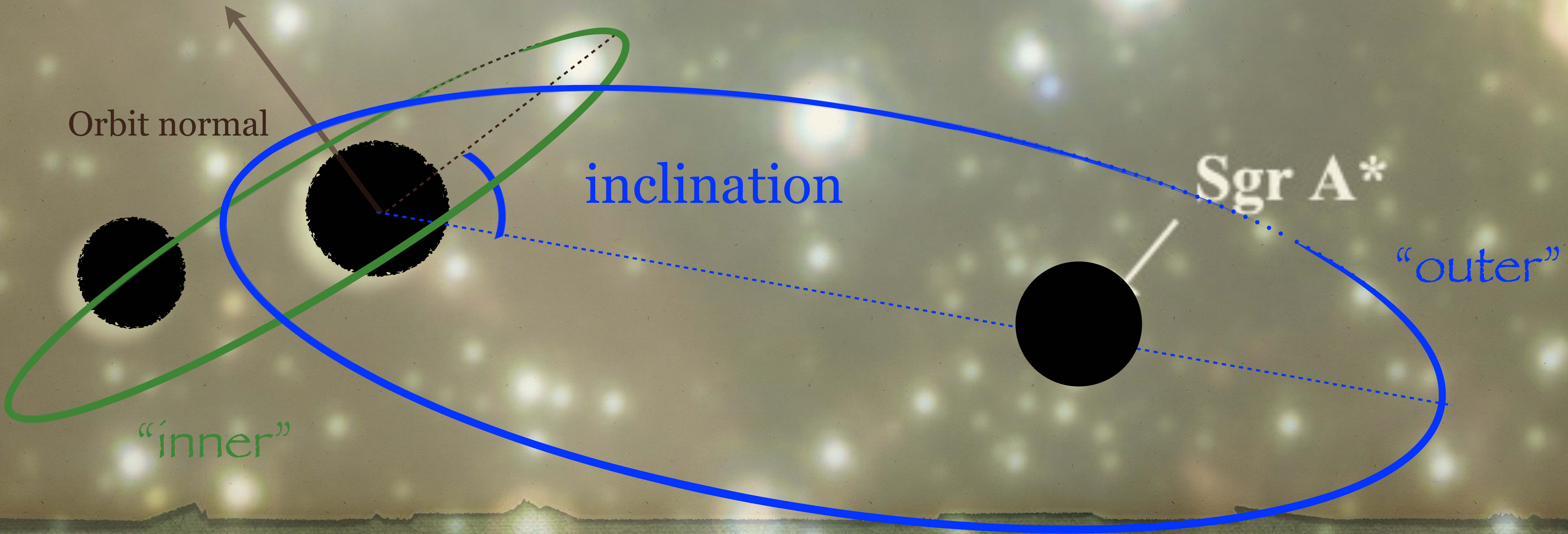
Rose, **Naoz** et al. 2020

Binaries at the heart of galaxies

The Eccentric Kozai-Lidov (EKL) mechanism

Kozai 1962, Lidov 1962, Naoz et al. 2011

Not to scale!



Binaries at the heart of galaxies

The Eccentric Kozai-Lidov (EKL) mechanism

GR effects: Naoz et al (2013)

Compare to: "Standard" (quadrupole) Kozai

$m_1 = 10 M_\odot$

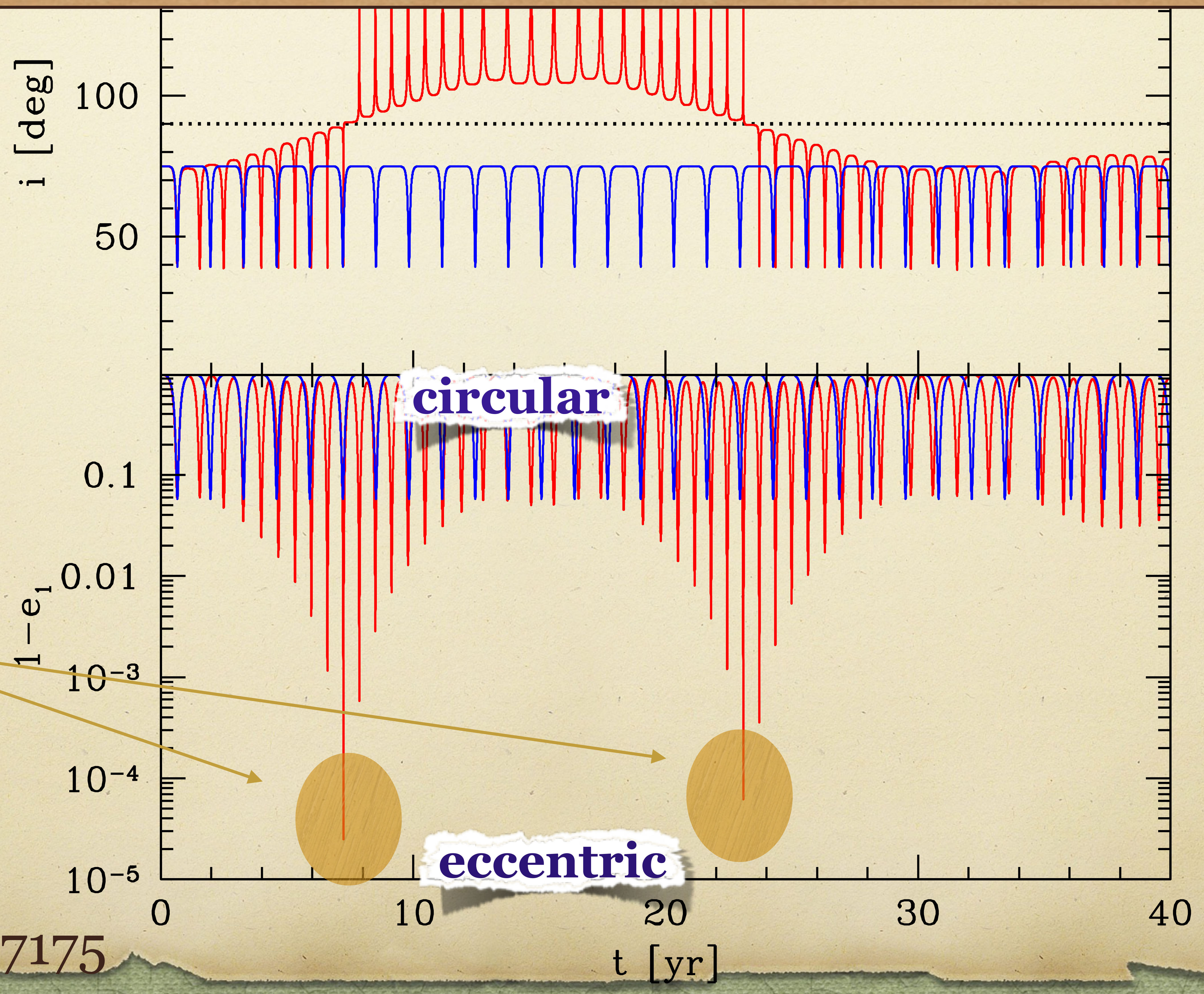
$m_2 = 1 M_\odot$

$M_{SMBH} = 4 \times 10^6 M_\odot$

$a_1 = 10 AU$

$a_2 = 0.003 pc$

$e_2 = 0.8$



extreme eccentricity peaks cause mergers!

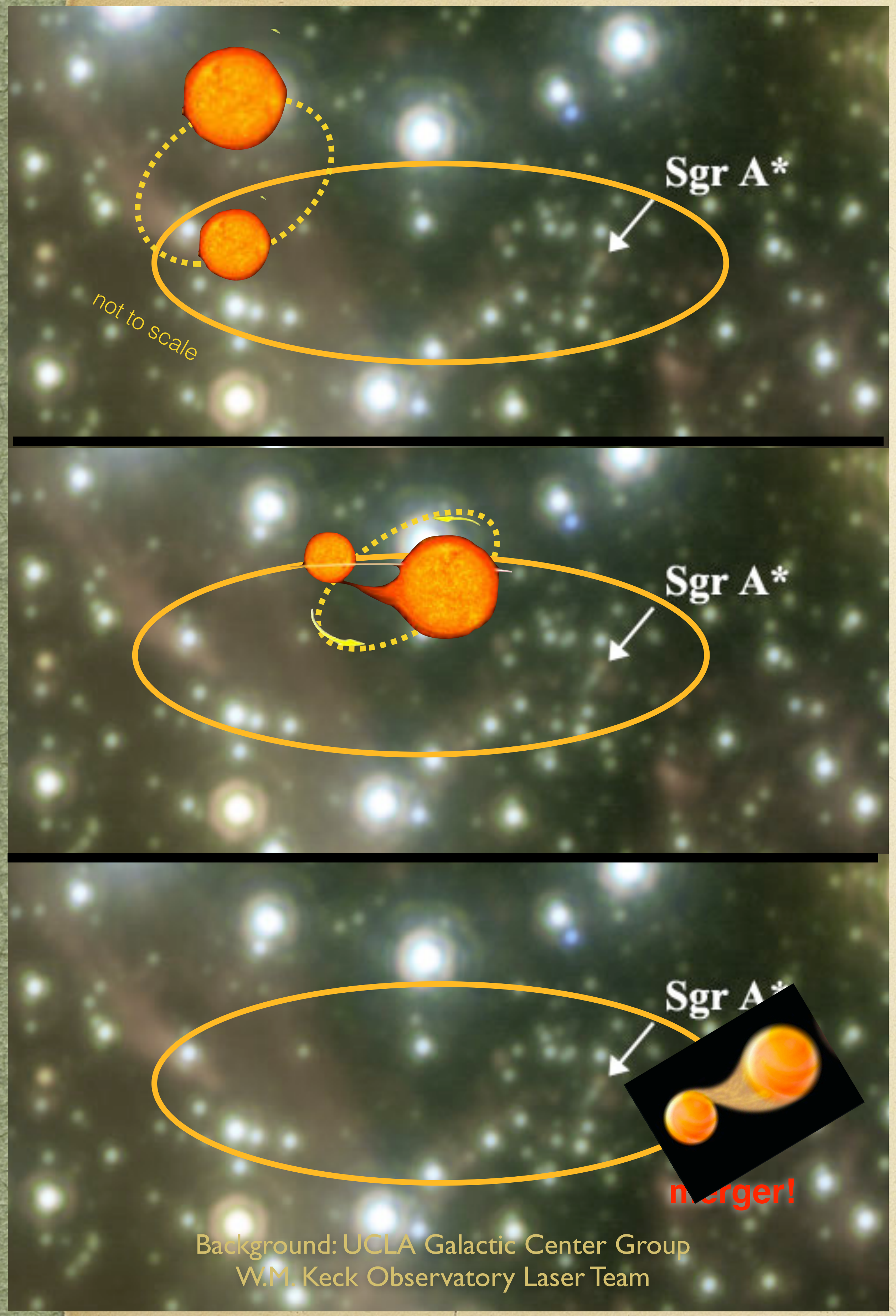
Extreme eccentricities are common throughout the parameter space

Li, **Naoz** et al, (2014), ApJ 785, 116 + ApJ 791, 86

Teyssandier, **Naoz**, Lizarraga Rasio (2013), ApJ 779, 166

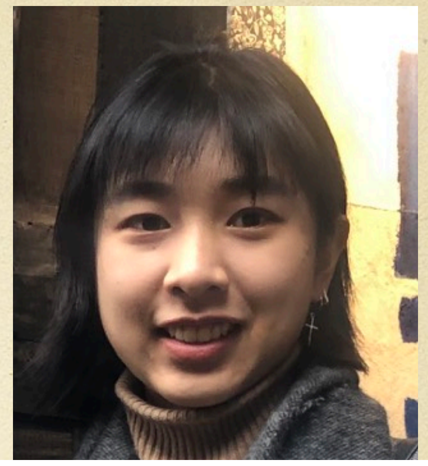
Naoz (2016) ARA&A arXiv:1601.07175

Binaries at the heart of galaxies

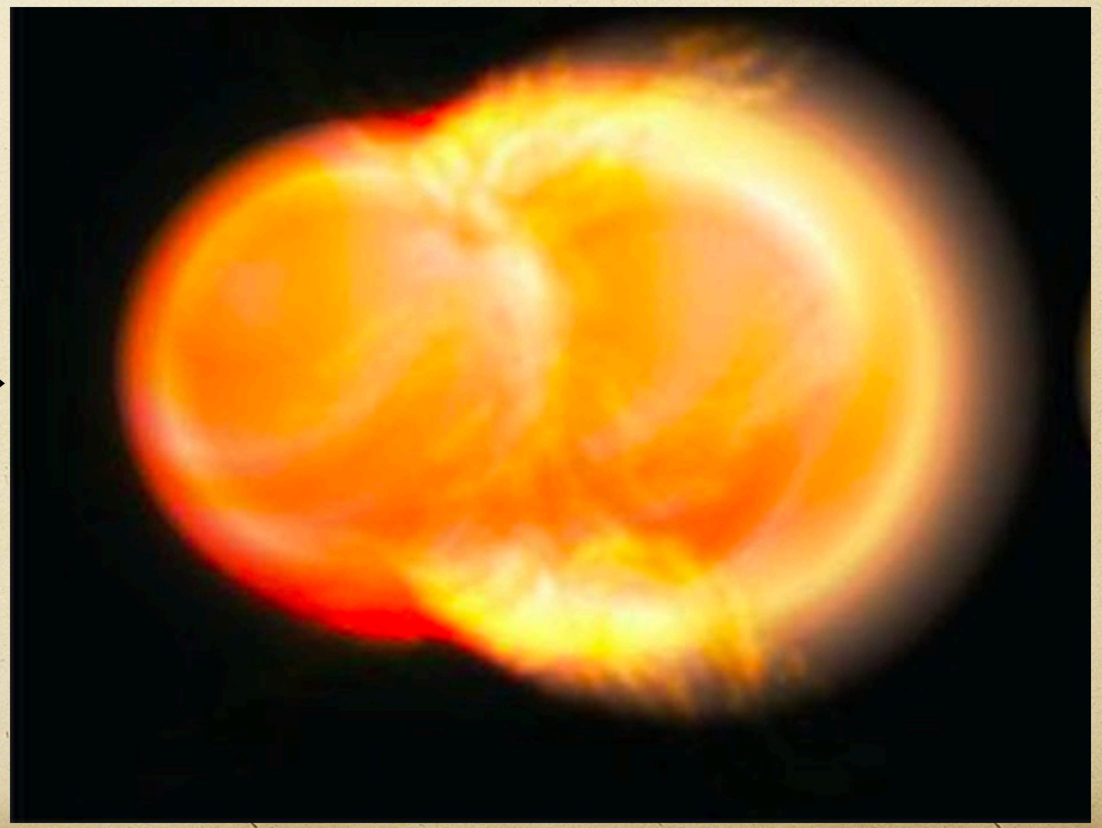


- EKL (eccentric Kozai-Lidov)
- General relativity (1PN) + GW
- Tides
- Post main sequence stellar evolution (single and binary)
- Unbinding the binary (fly-by) (see Rose, **Naoz** et al 2020)
- Disruption due to the SMBH
- Updated binary stellar evolution for solar and sub solar metallicities (e.g., Breivik et al 2019)


Bao-Minh Hoang

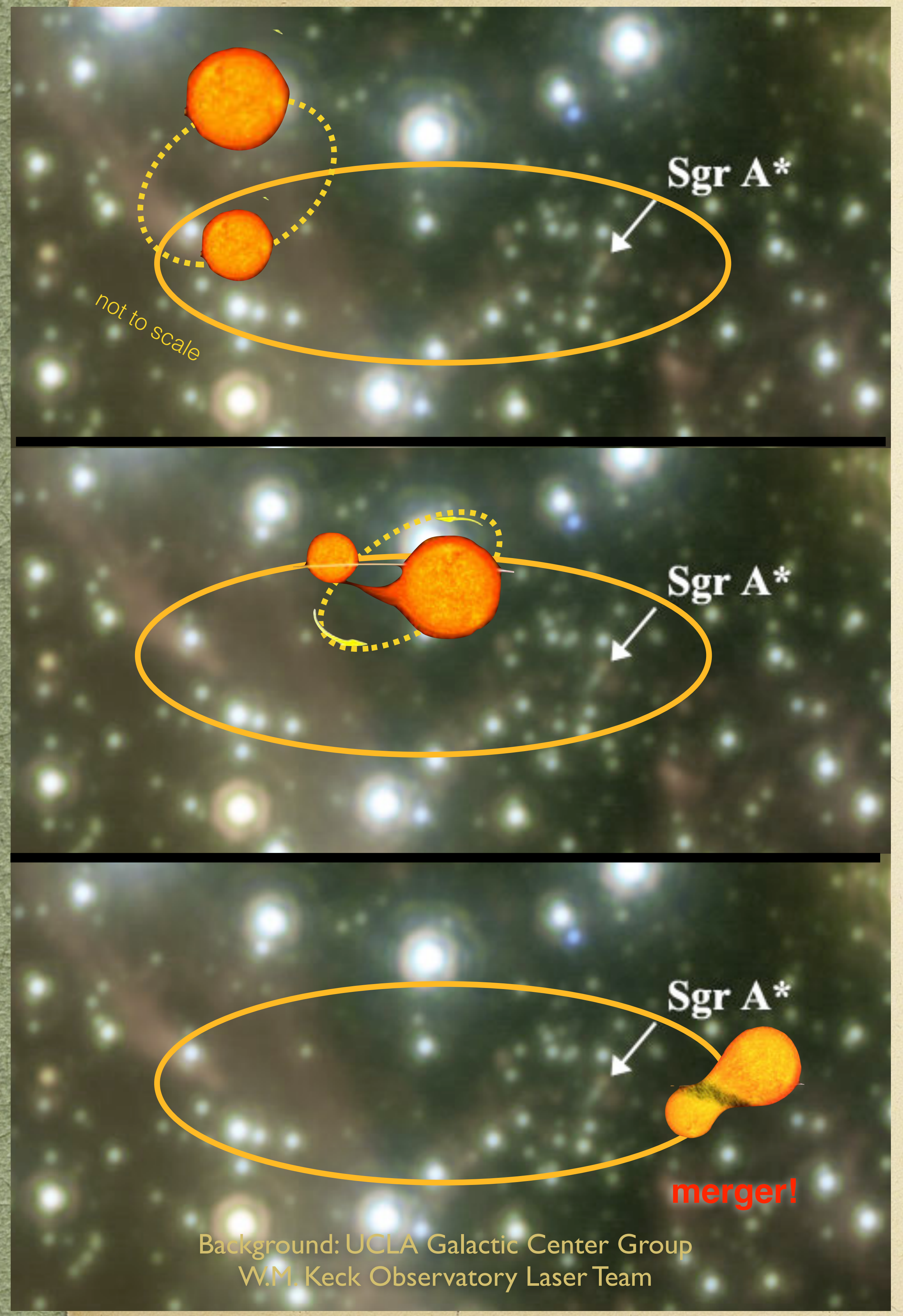

Huiyi (Cheryl) Wang


Alexander Stephan



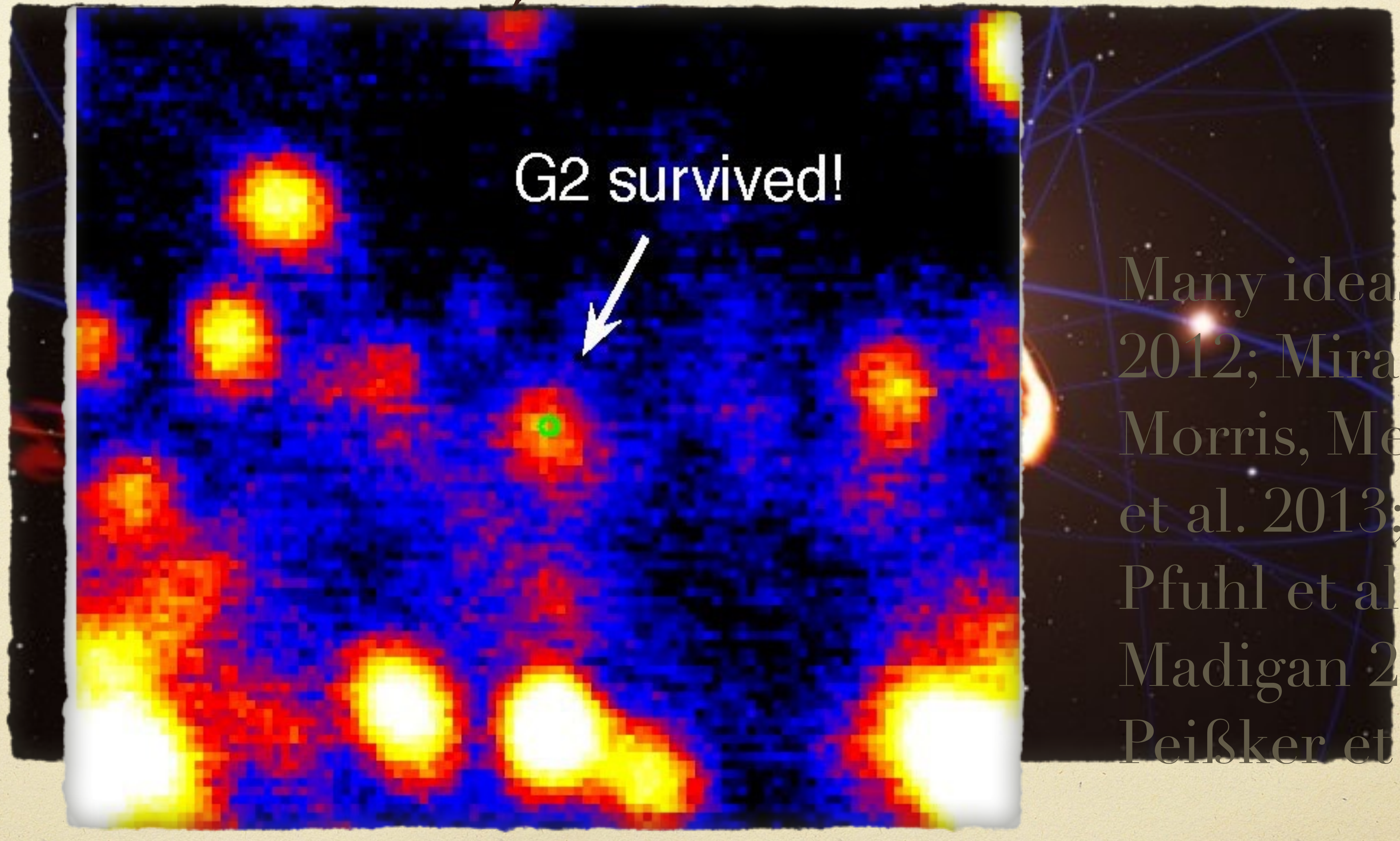
Hoang, **Naoz** et al (2018,2022)
Stephan, **Naoz** et al (2016,2019)
Wang, Stephan, **Naoz** et al (2021)

Binaries at the heart of galaxies



Formation of G2-like objects

G2 object

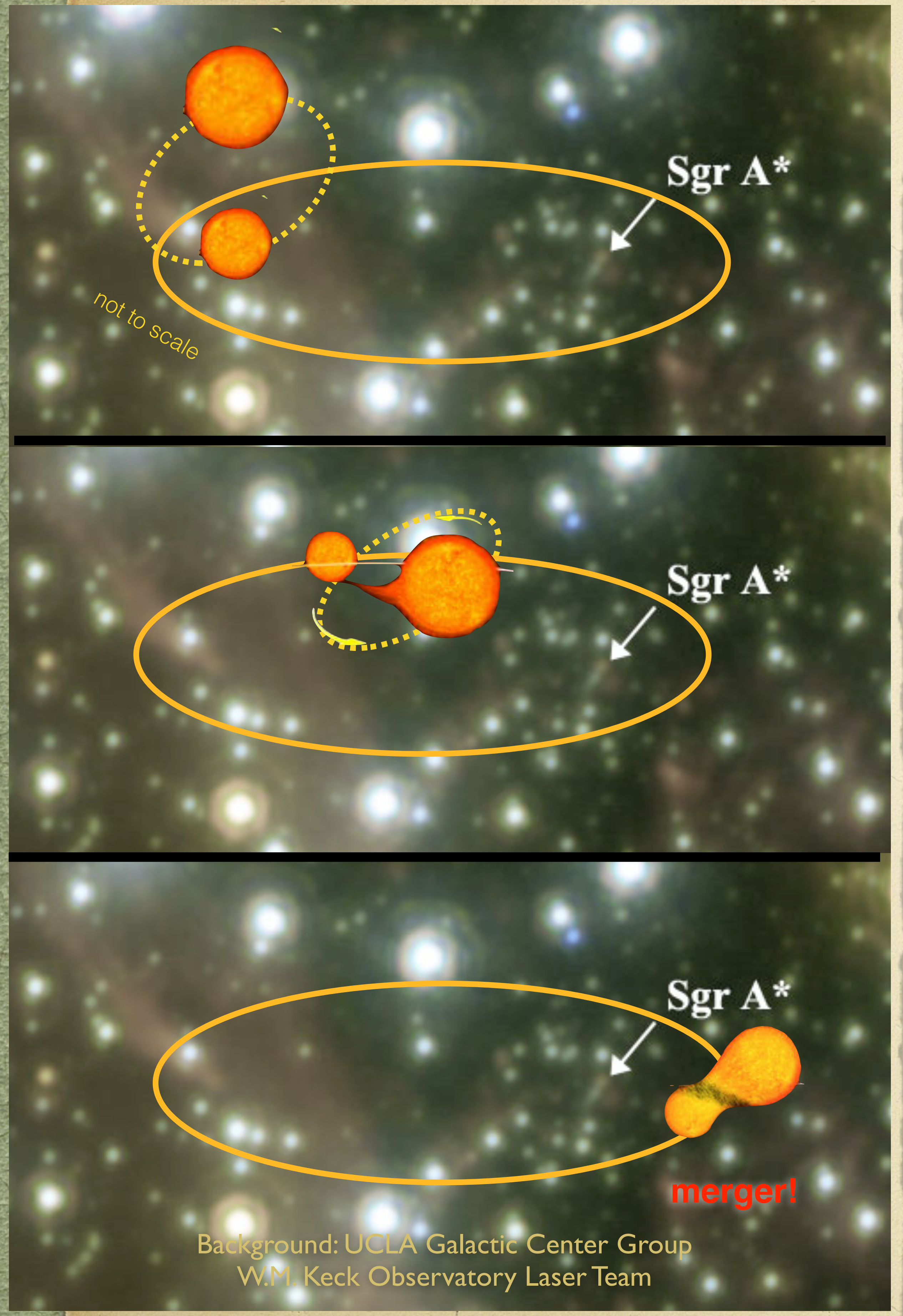


Many ideas: Murray-Clay & Loeb 2012; Miralda-Escude´ 2012; Morris, Meyer & Ghez 2012; Phifer et al. 2013; Guillochon et al. 2014; Pfuhl et al 2015; McCourt, & Madigan 2016; Madigan et al 2017; Peißker et al. 2021…

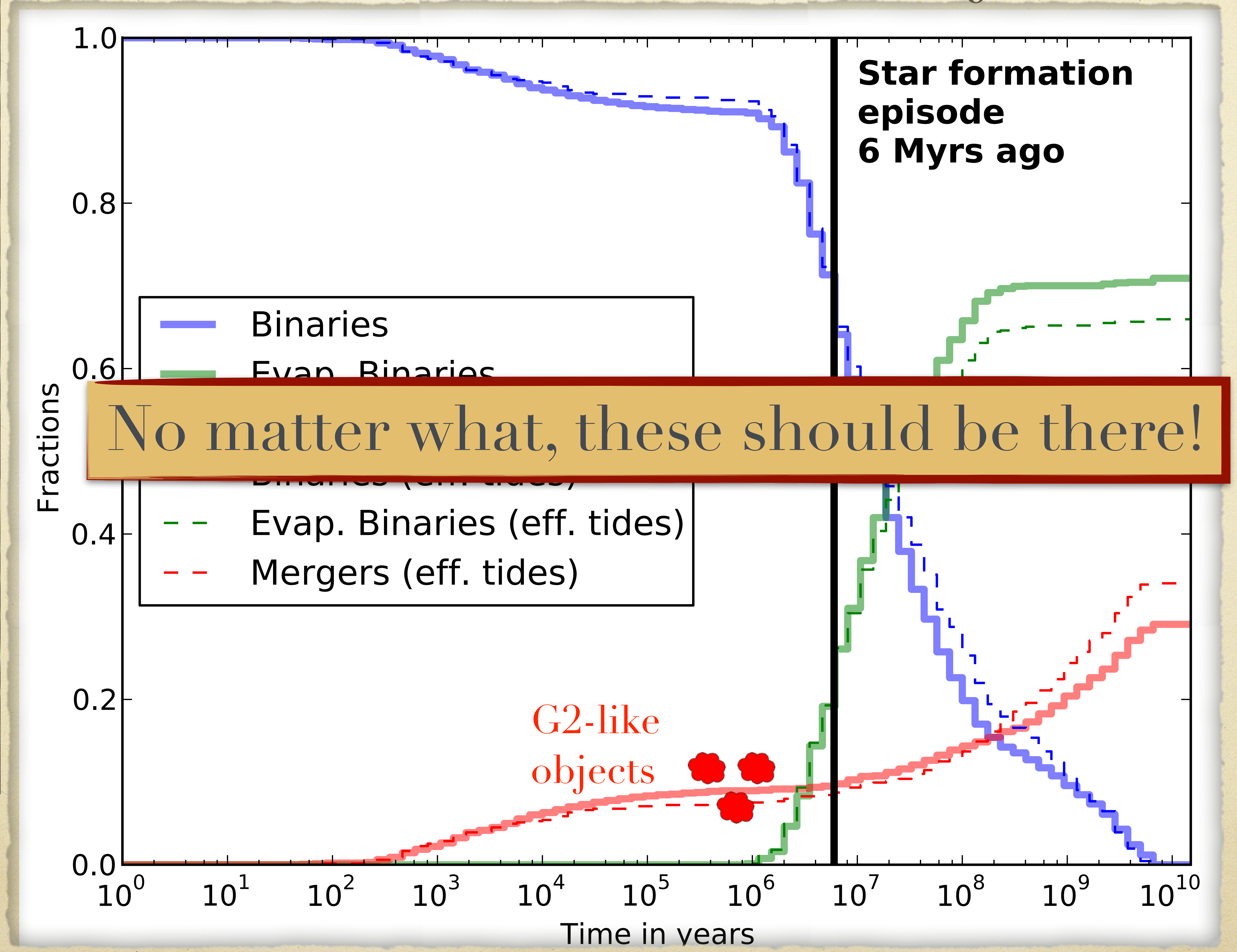
Witzel … **Naoz** et al (2014)

Gillessen et al (2012,2018)

Binaries at the heart of galaxies



Formation of G2-like objects

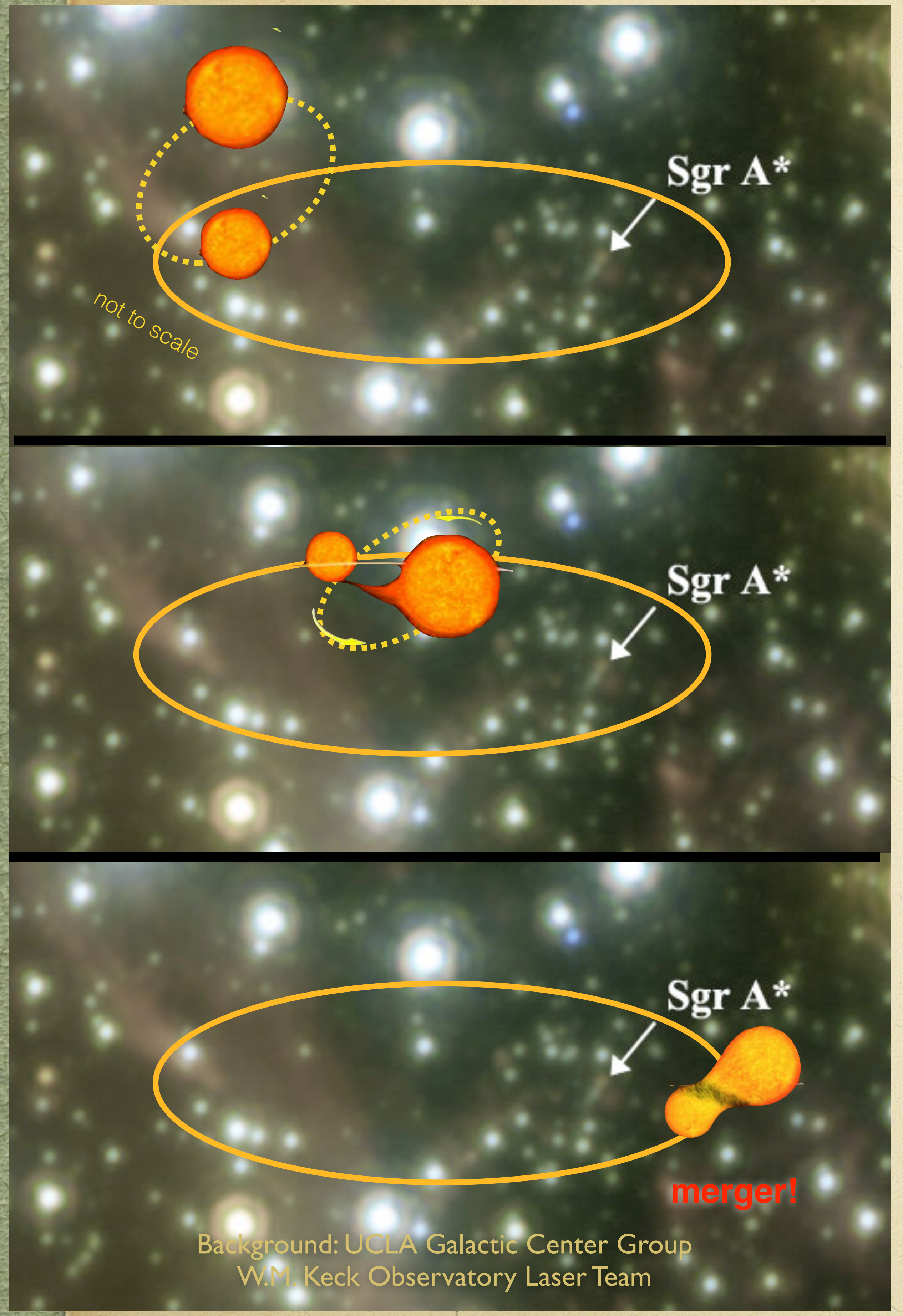


No matter what, these should be there!

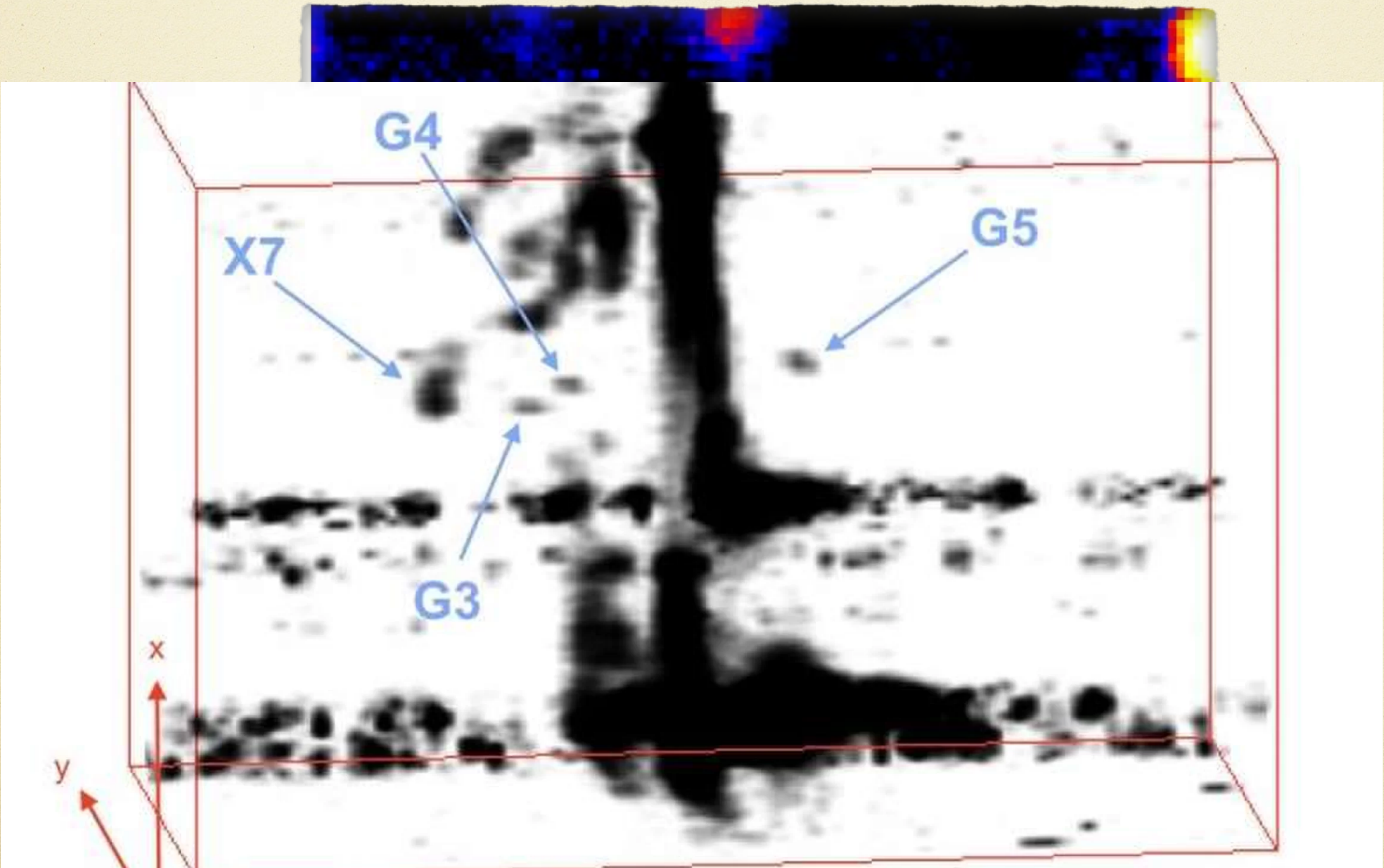
Stephan, **Naoz** et al (2016,2019)

Binaries at the heart of galaxies

Formation of G2-like objects



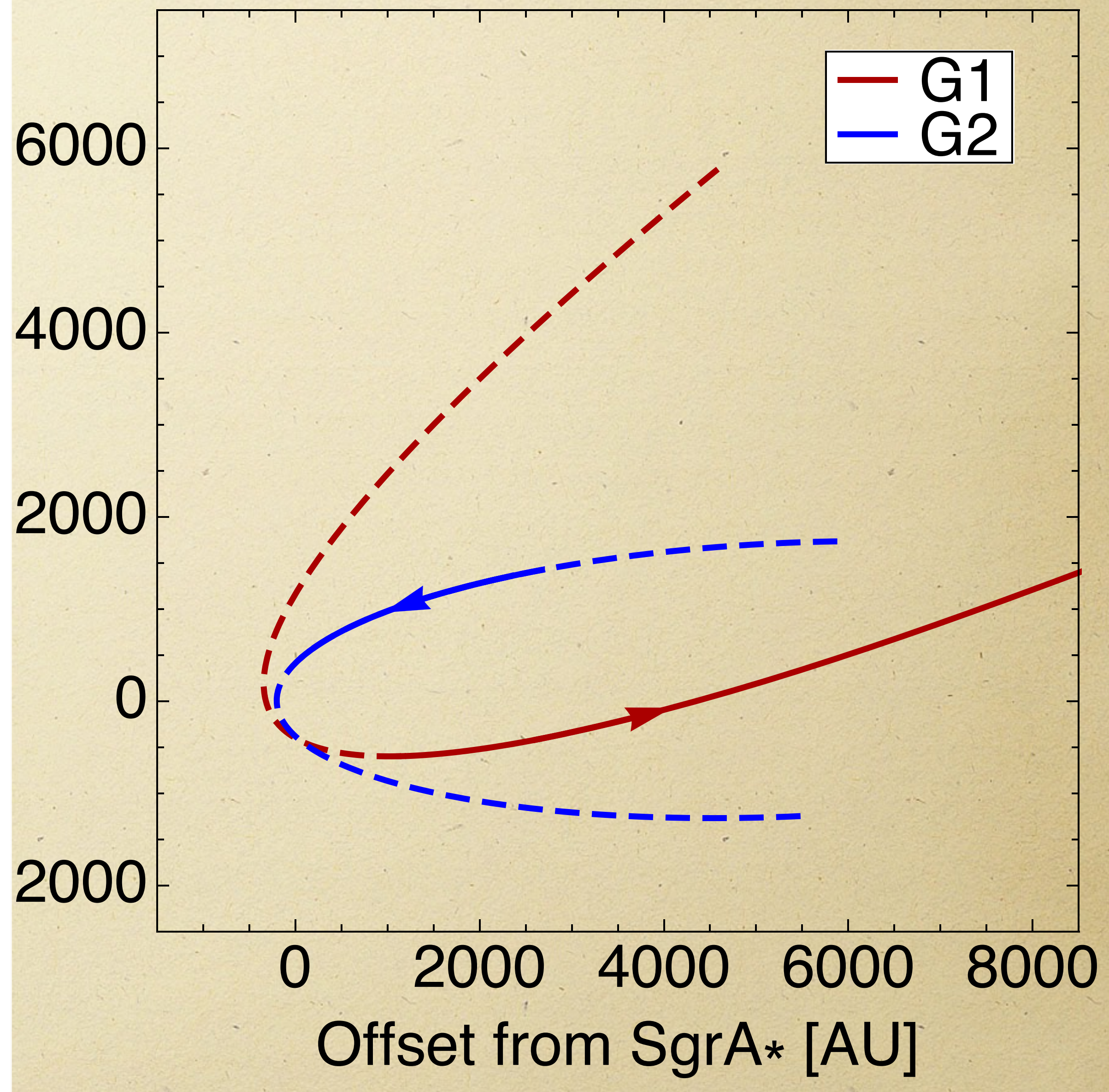
Stephan, **Naoz** et al (2016,2019)



Ciurlo… **Naoz** et al. 2020

Alexander Stephan

+ G1(!)

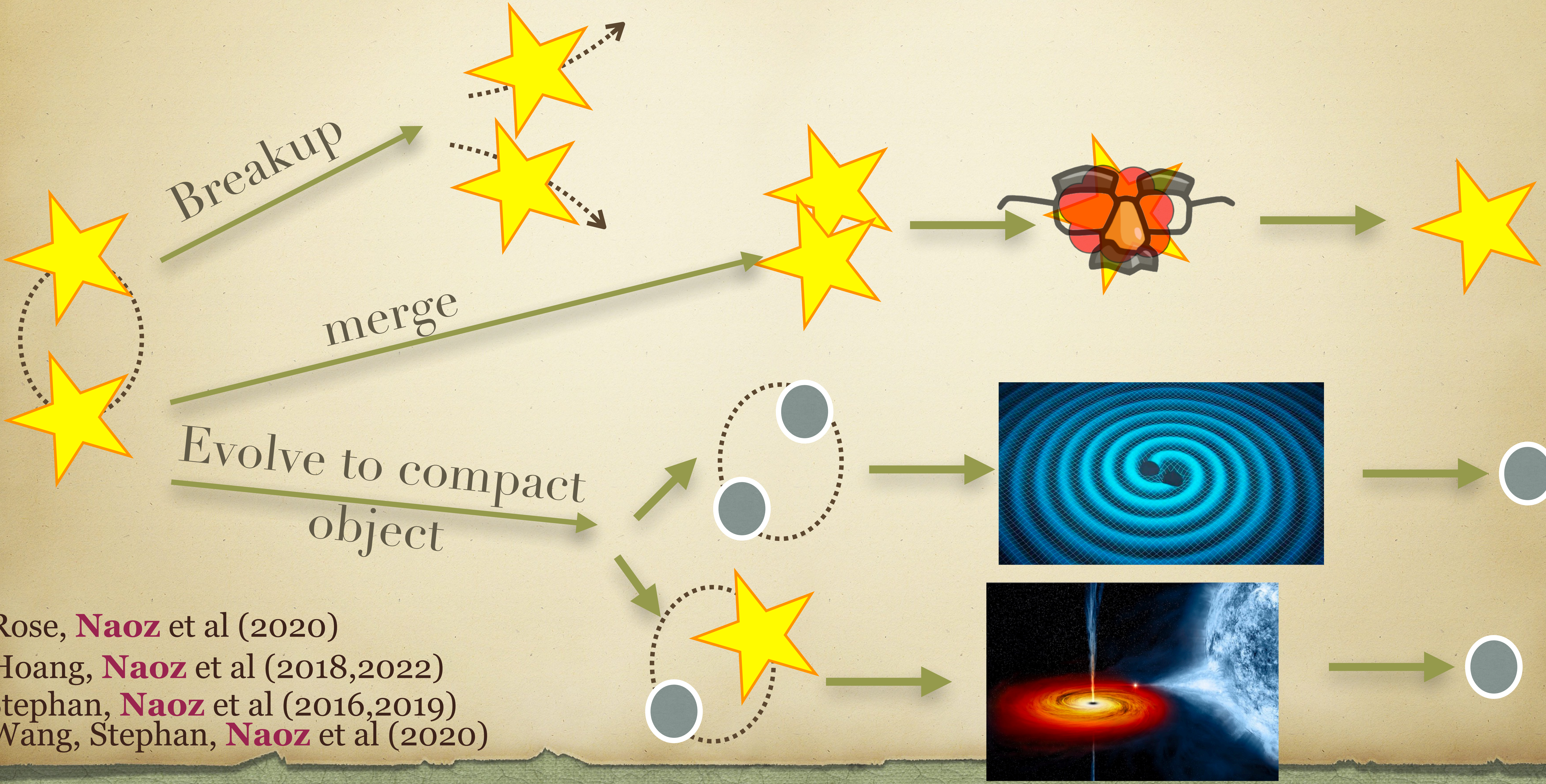


Witzel … **Naoz** et al (2017)

Binaries at the heart of galaxies

Hoang, **Naoz** et al (2018,2022)
Stephan, **Naoz** et al (2016,2019)
Wang, Stephan, **Naoz** et al (2021)

Tough life for a binary…

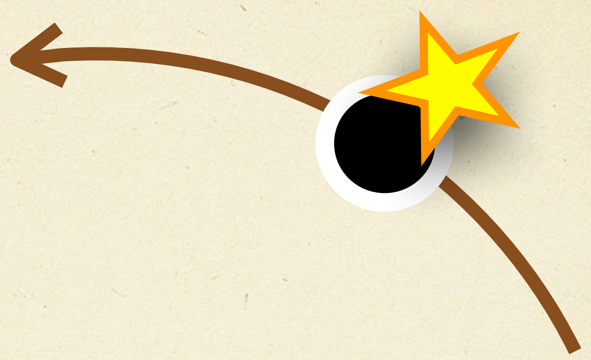


Rose, **Naoz** et al (2020)
Hoang, **Naoz** et al (2018,2022)
Stephan, **Naoz** et al (2016,2019)
Wang, Stephan, **Naoz** et al (2020)

Dense Environment

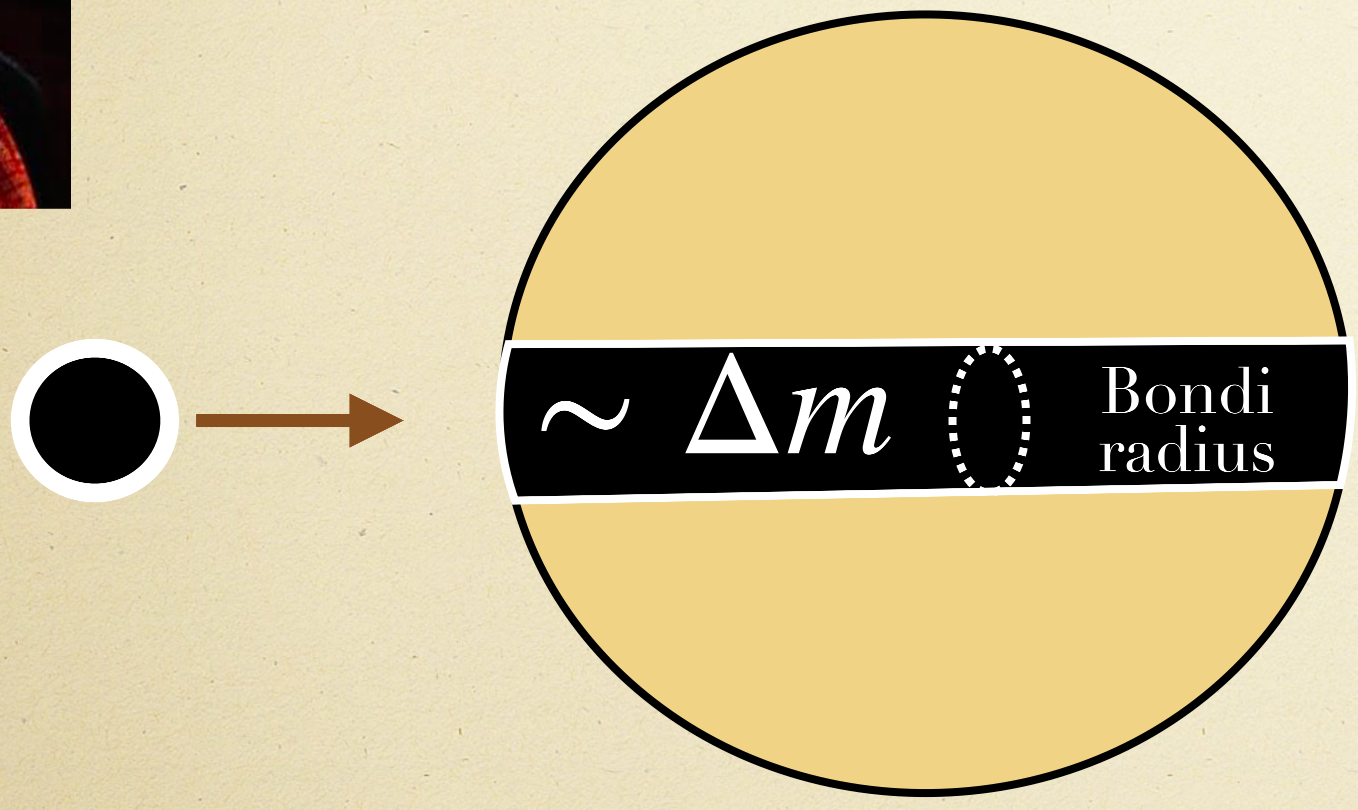
Collisions in a Dense Environment

BH - stellar collision



Sanaea
Rose

For efficient accretion

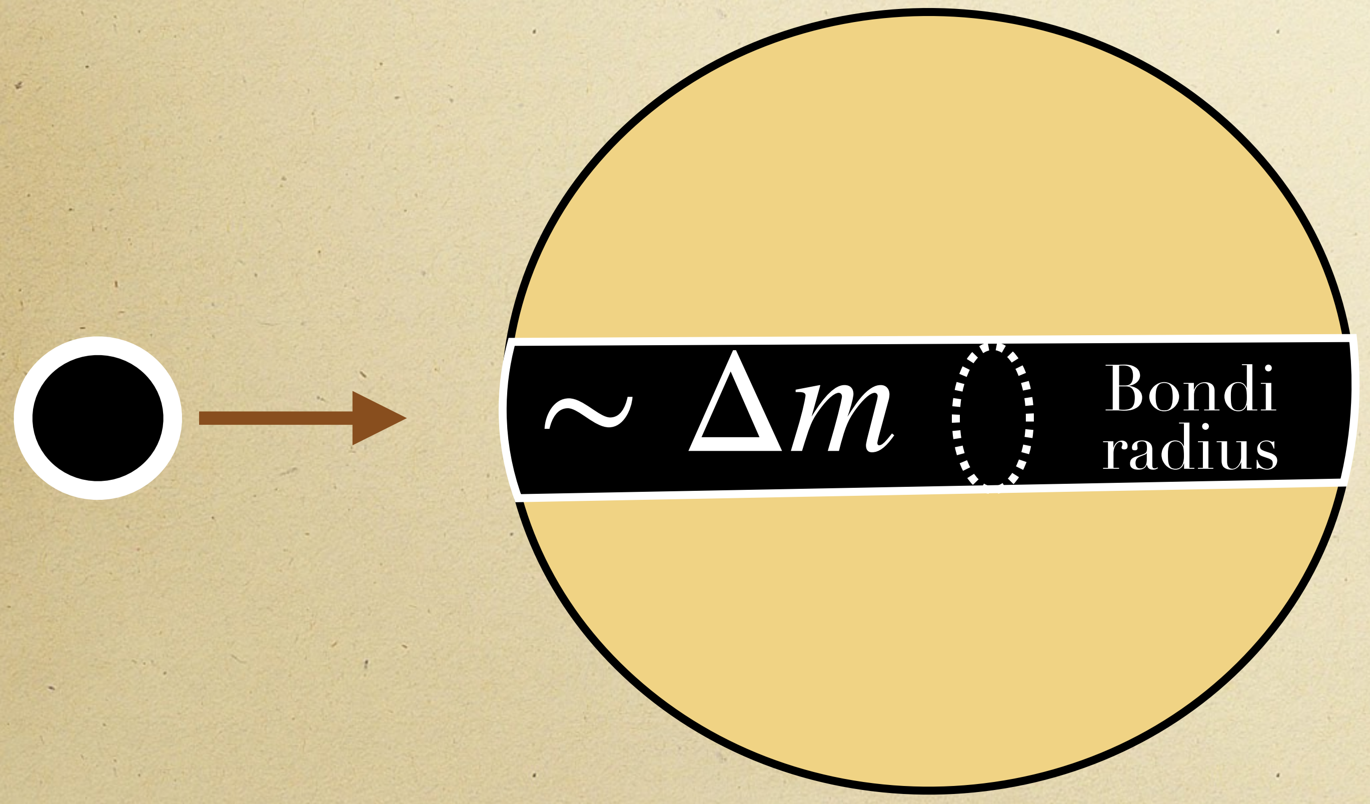


Rose, **Naoz**, Sari, Linial 2022

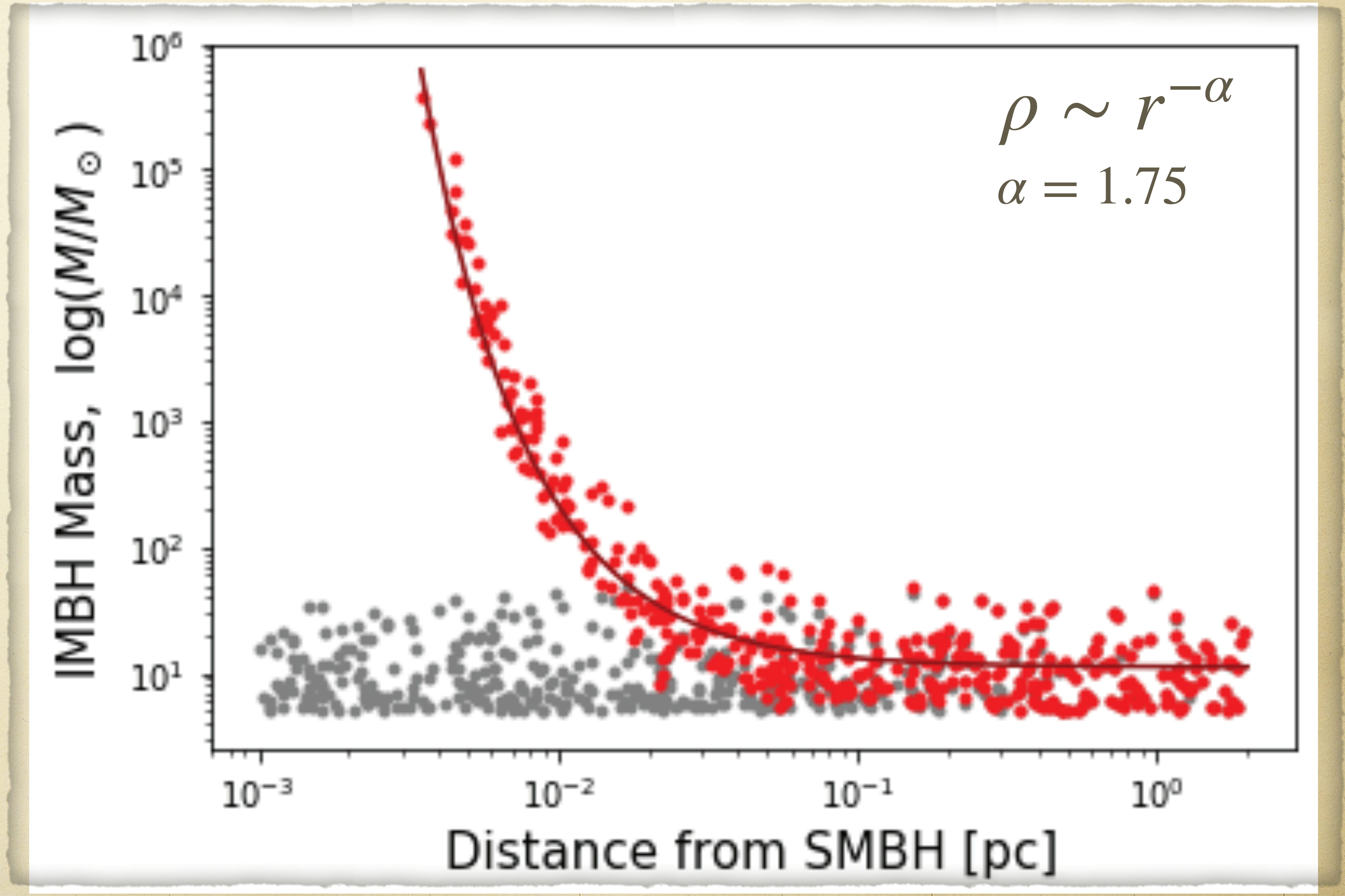
Collisions in a Dense Environment

BH - stellar collision

Sanaea
Rose



For efficient accretion

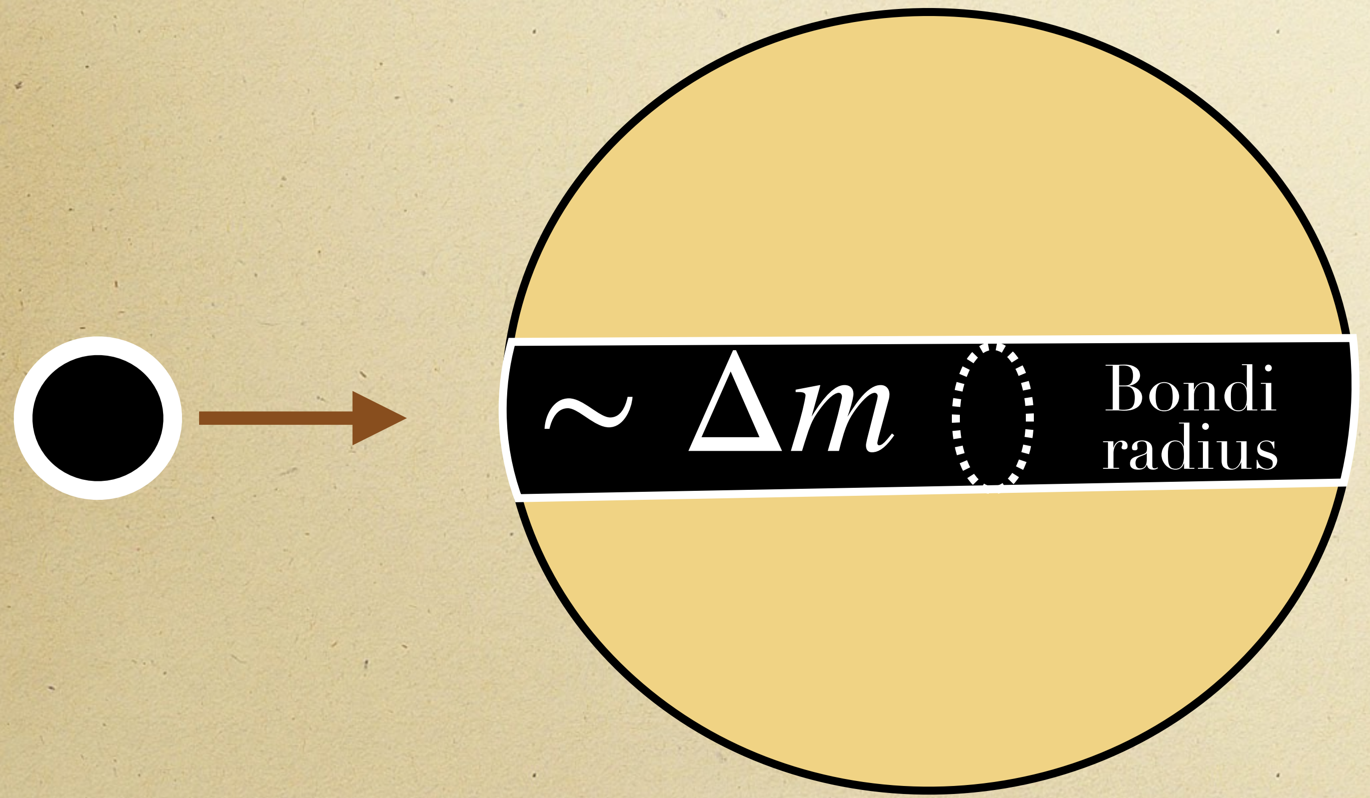


Rose, **Naoz**, Sari, Linial 2022

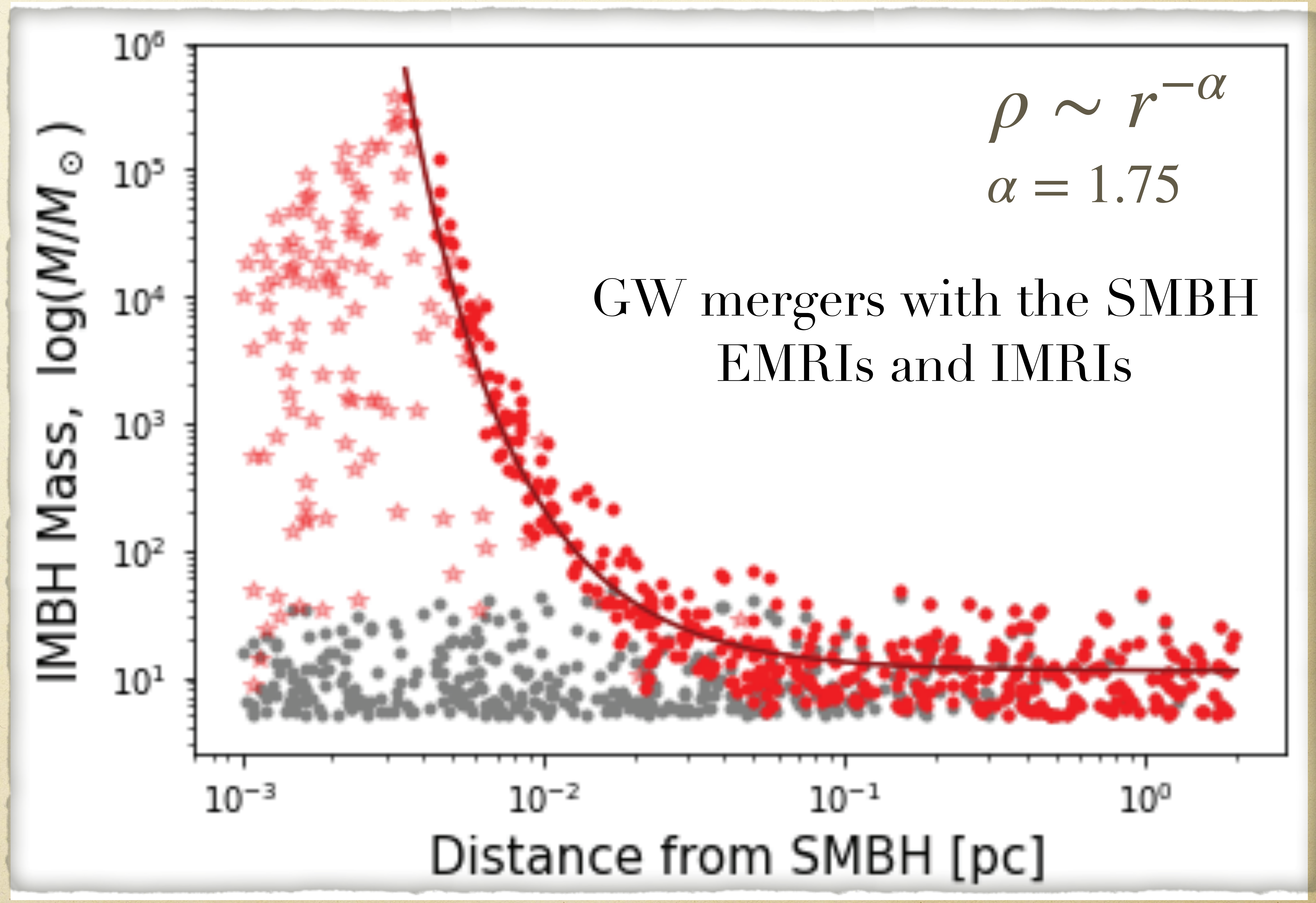
Collisions in a Dense Environment

BH - stellar collision

Sanaea Rose



For efficient accretion

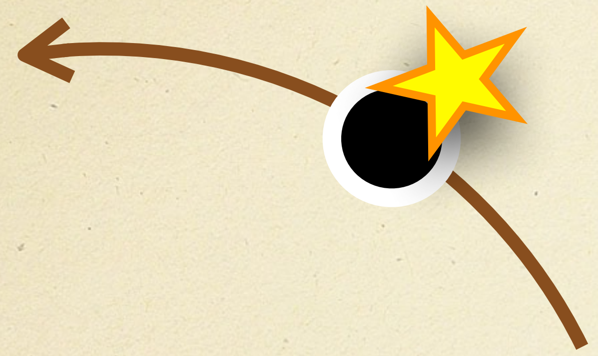


Rose, **Naoz**, Sari, Linial 2022

Collisions in a Dense Environment

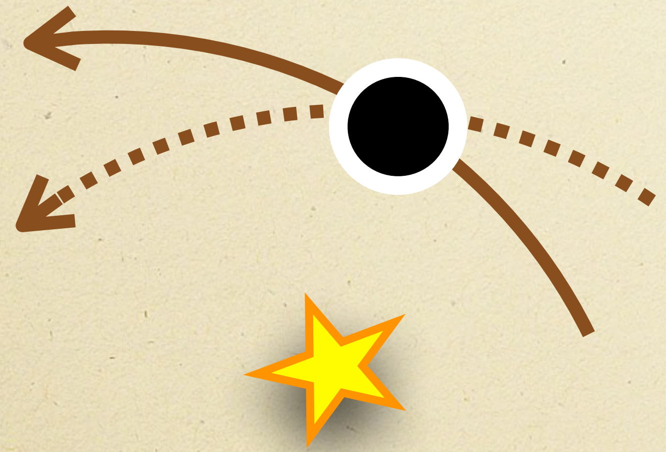
BH - stellar collision

Sanaea
Rose



+

Relaxation



For efficient accretion

Rose, **Naoz**, Sari, Linial 2022

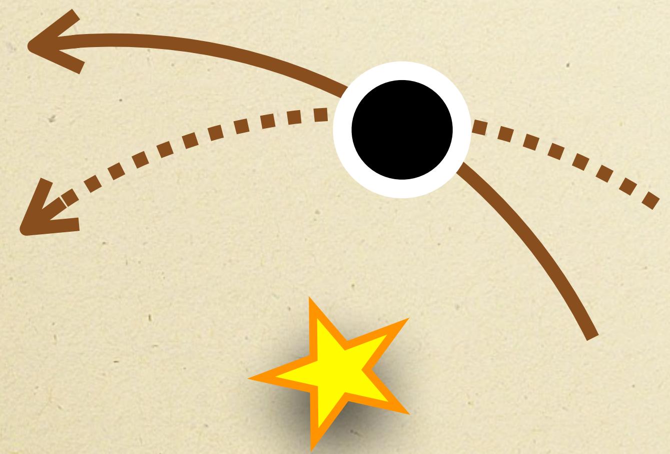
Collisions in a Dense Environment

BH - stellar collision

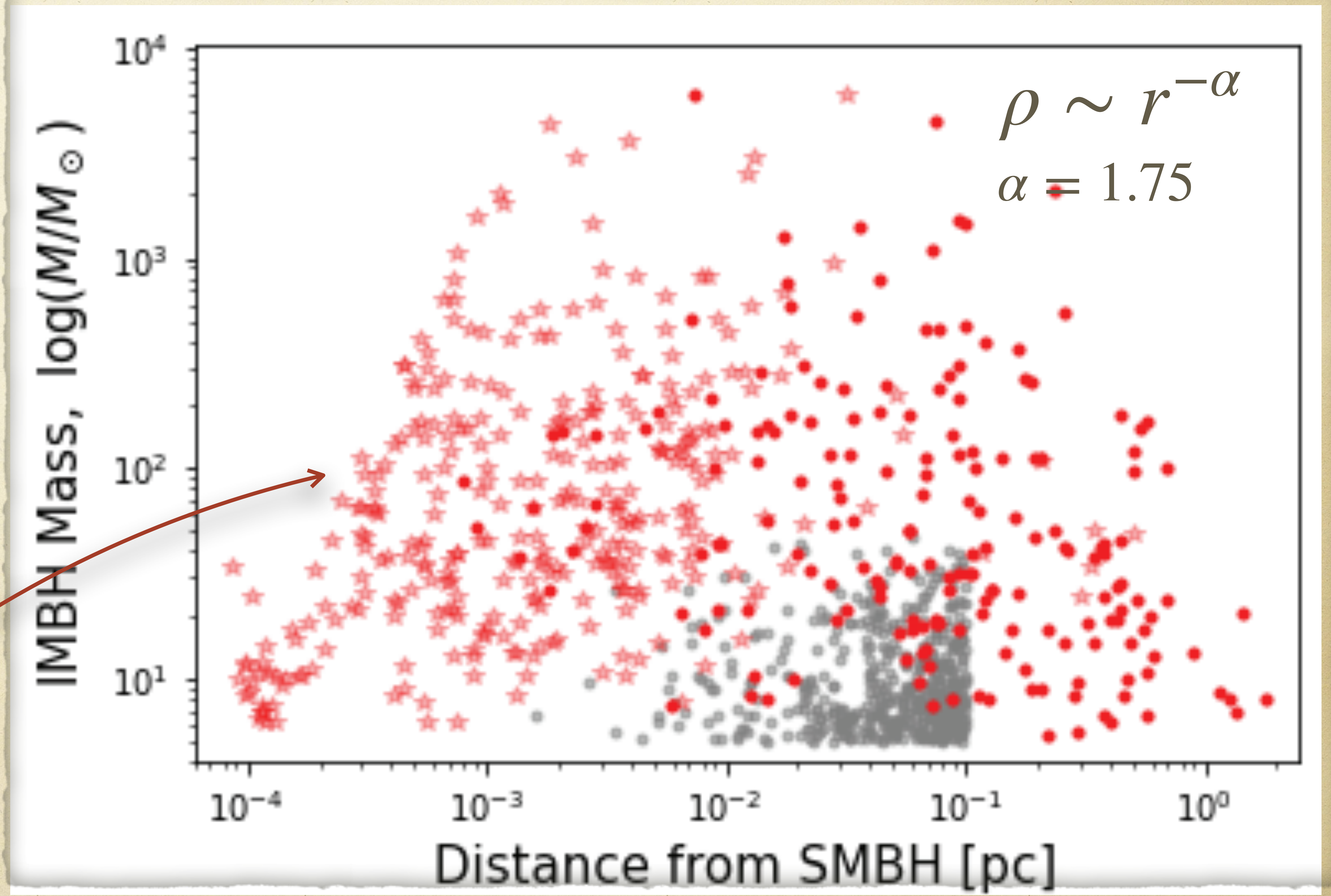
Sanaea Rose

+

Relaxation



For efficient accretion



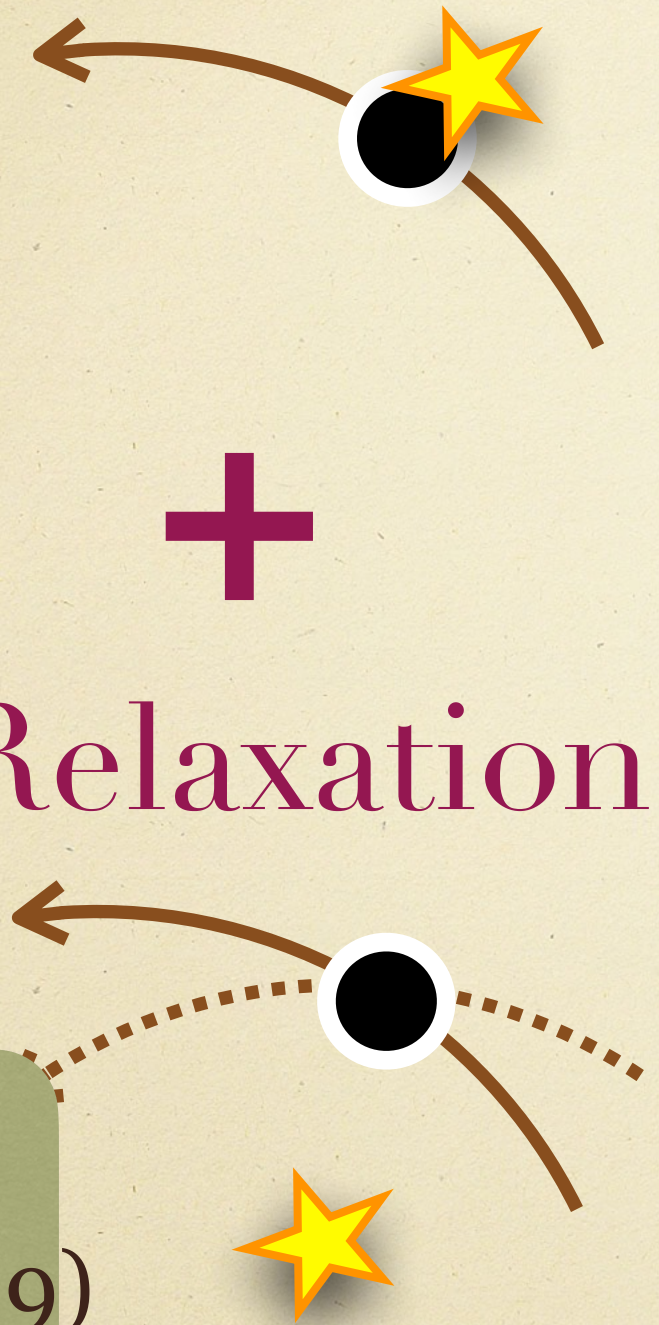
GW mergers with the SMBH
EMRIs and IMRIs

Rose, **Naoz**, Sari, Linial 2022

Collisions in a Dense Environment

BH - stellar collision

Sanaea Rose



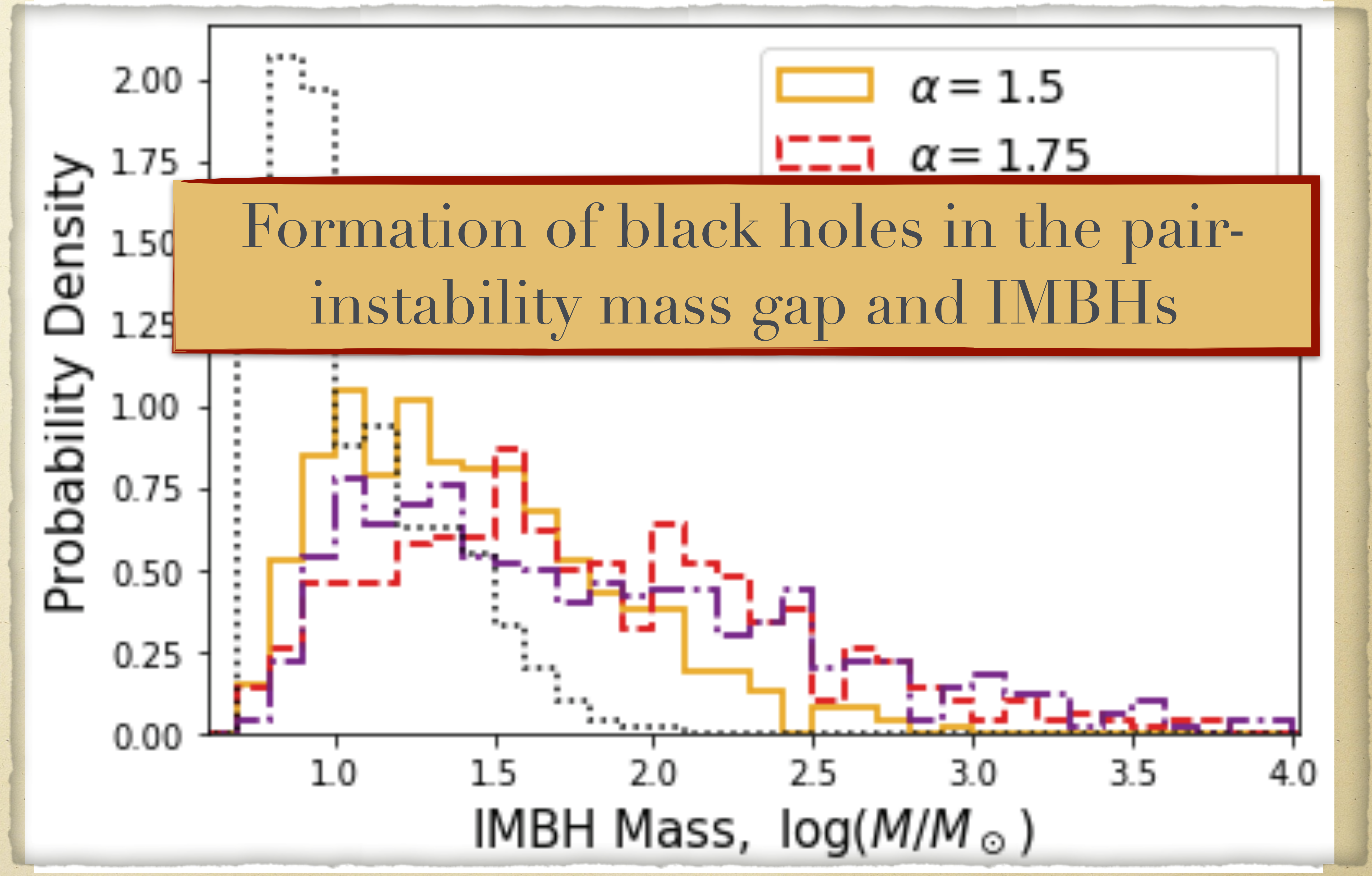
+

Relaxation

$\Gamma \sim 1.5\ \mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$
e.g. O'Leary et al (2009)
Gondan et al (2018)

$$\rho \sim r^{-\alpha}$$

+ Wind accretion



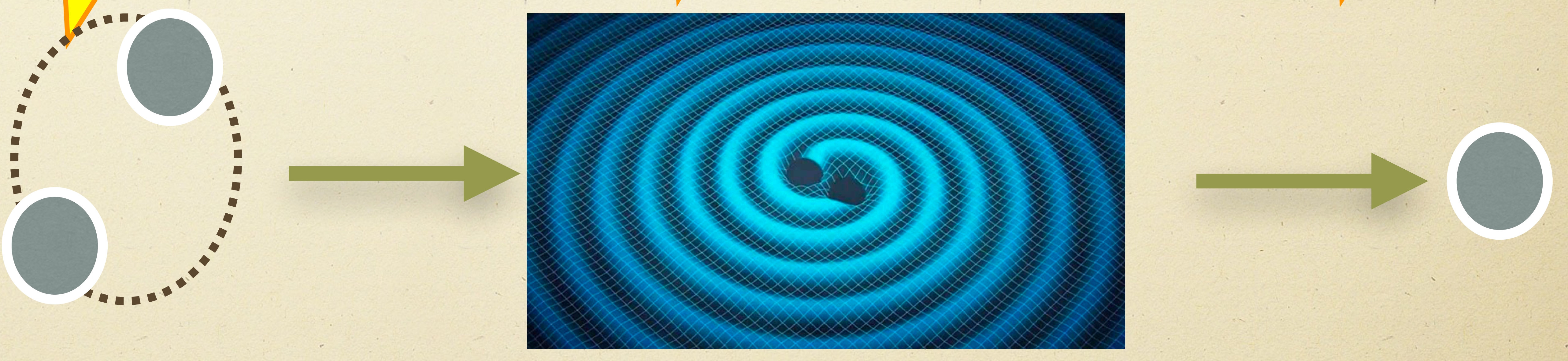
Formation of black holes in the pair-instability mass gap and IMBHs

Rose, **Naoz**, Sari, Linial 2022

Mergers and Collisions at the Heart of Galaxies

Merging stars

Merging compact objects



Merging a compact object with a star