Isolated versus clustered formation of massive stars

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in collaboration with
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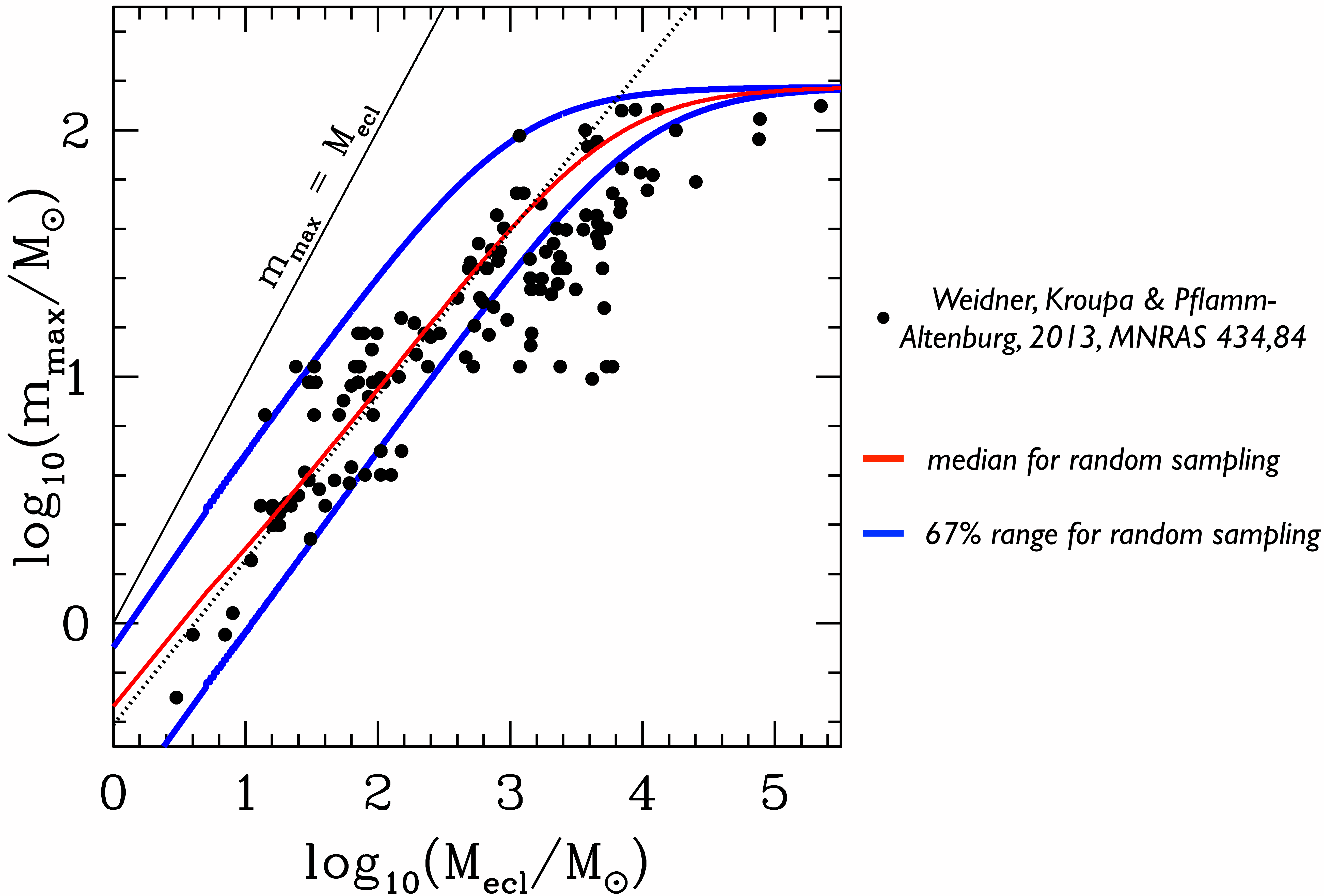
MODEST 14
The dance of stars: dense stellar systems from infant to old
June 4th, 2014, Bad Honnef, Germany

Motivation

- Different star-formation theories allow/exclude isolated formation of O stars.
- Monolithic collapse (*McKee & Tan 2003; Krumholz 2006*): O stars form from massive cores, in isolation or in clusters.
- Competitive accretion/cluster assisted accretion etc. (e.g. *Bonnell et al. 1997*): O stars form in the centre of star clusters.
- Observational evidence in star clusters (m_{max}-M_{ecl} relation) points against O stars formed in isolation (*Weidner & Kroupa 2006; Weidner, Kroupa & Bonnell 2010; Weidner, Kroupa & Pflamm-Altenburg 2013*).

The m_{max}-M_{ecl}-relation



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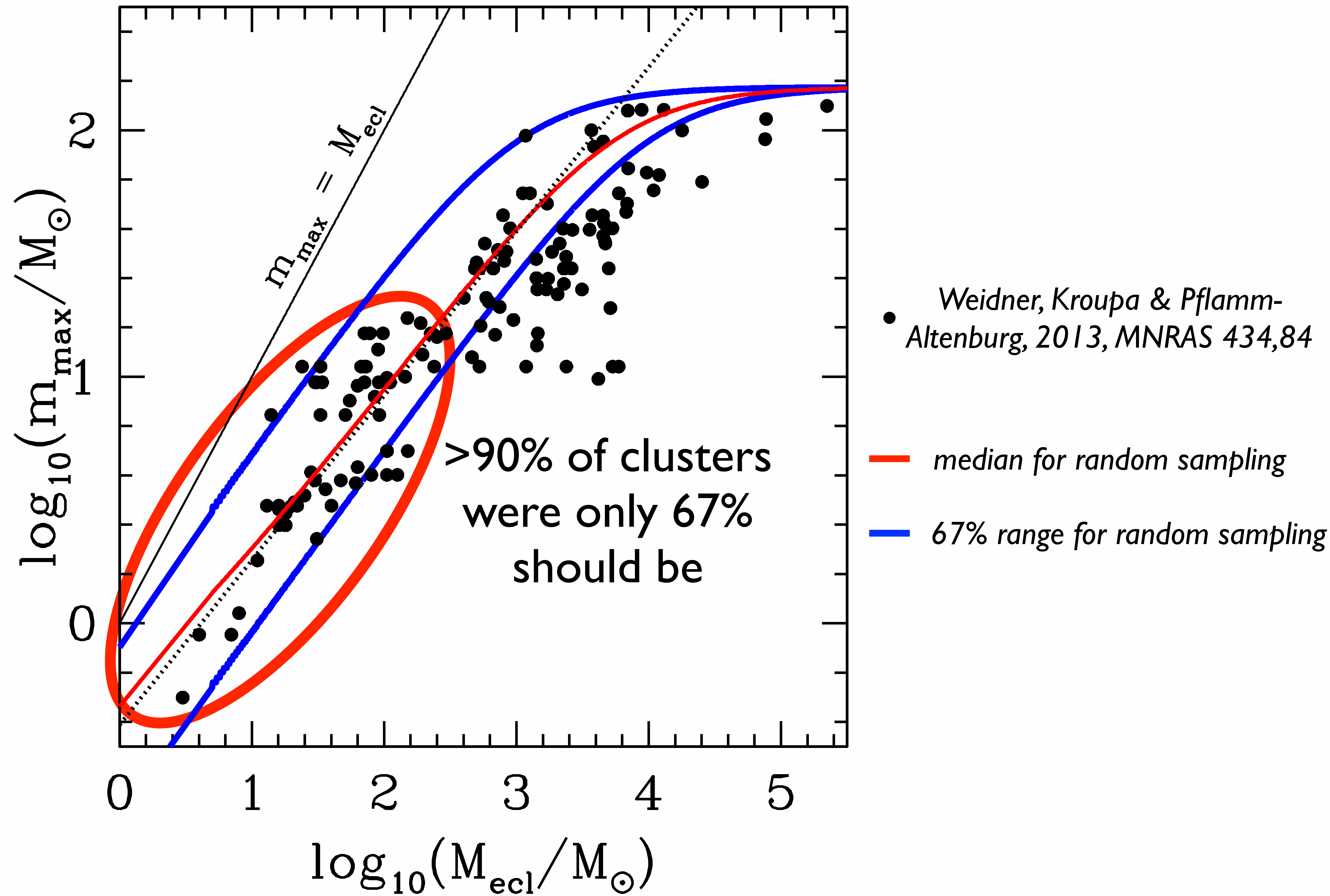

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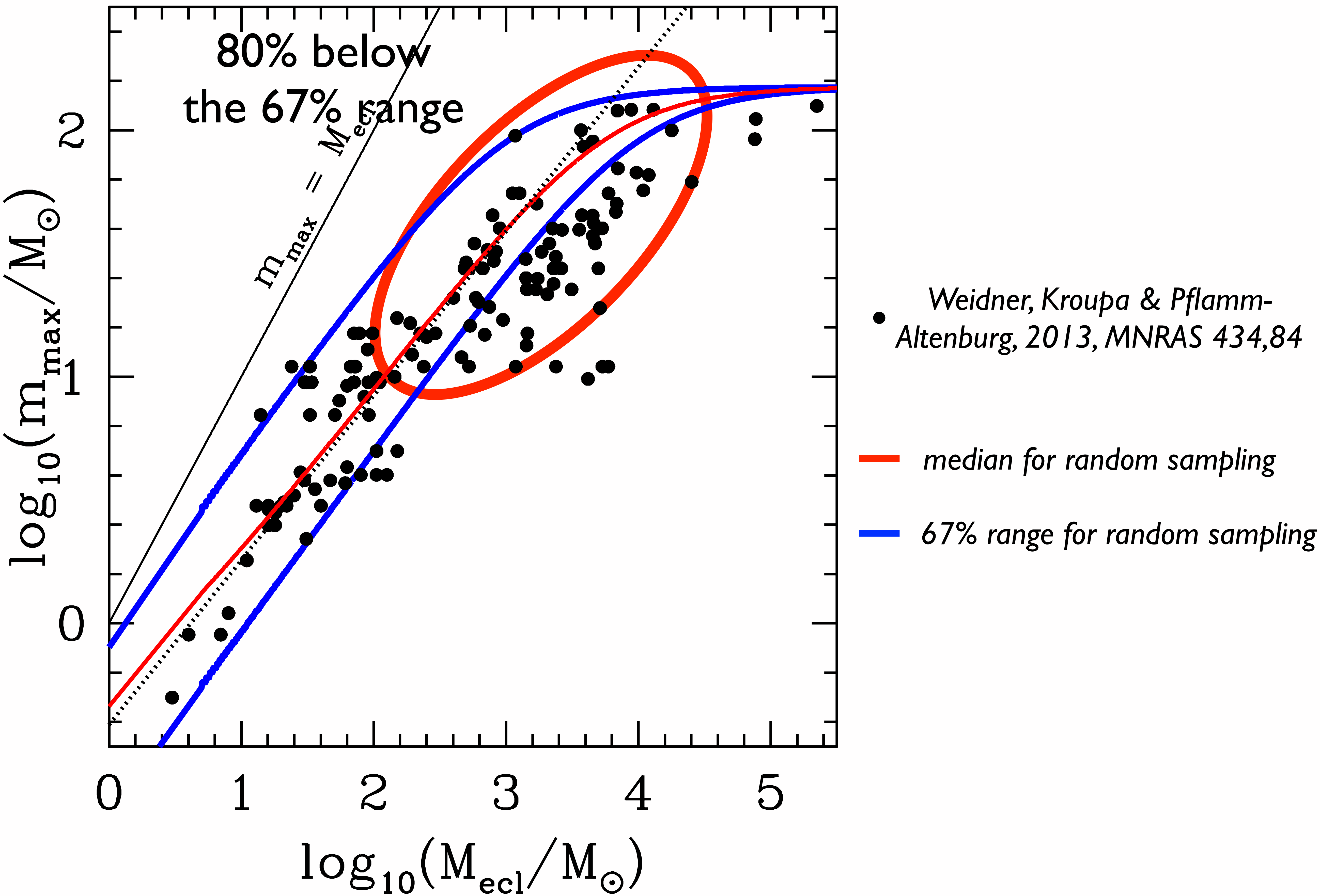

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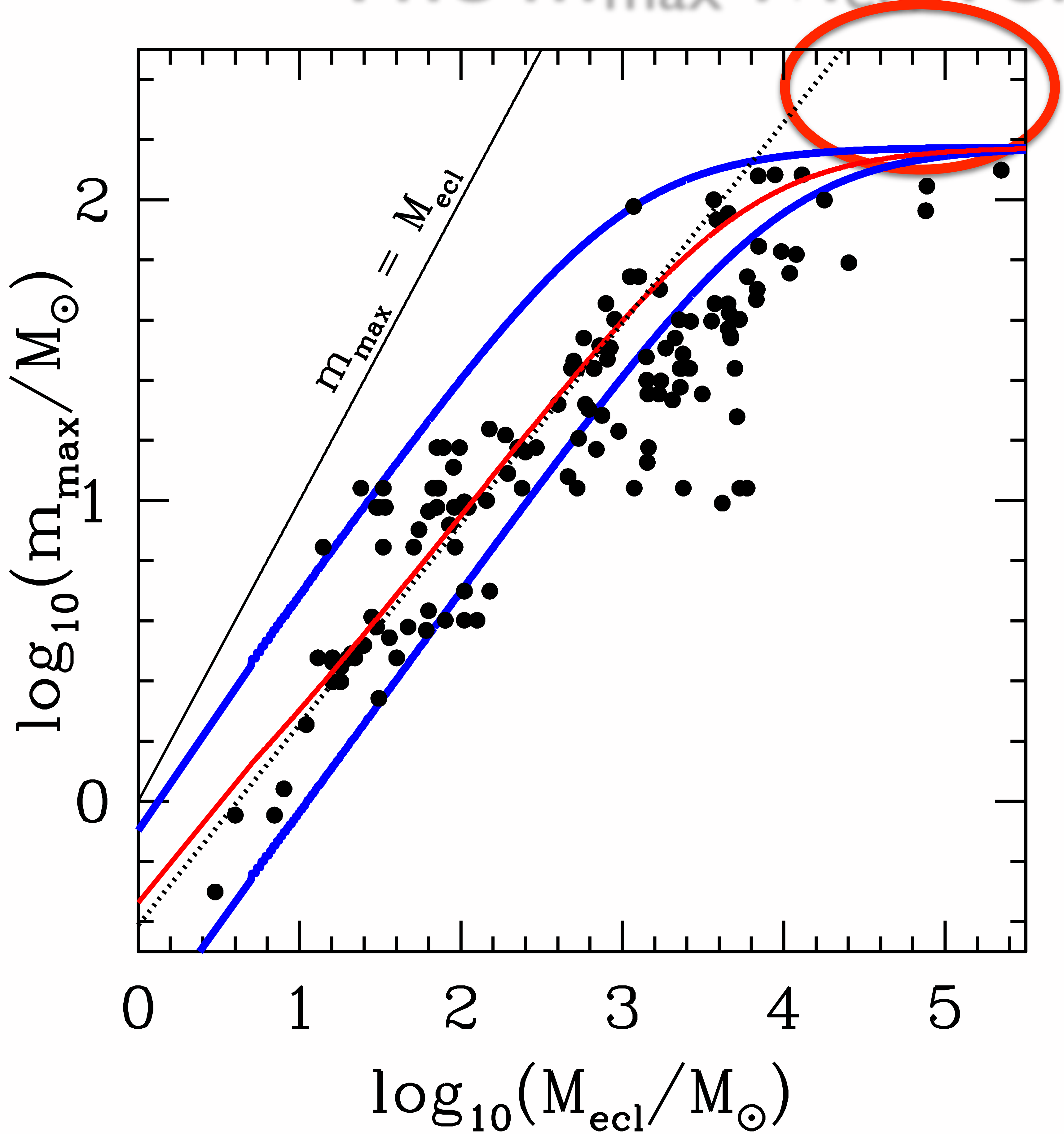
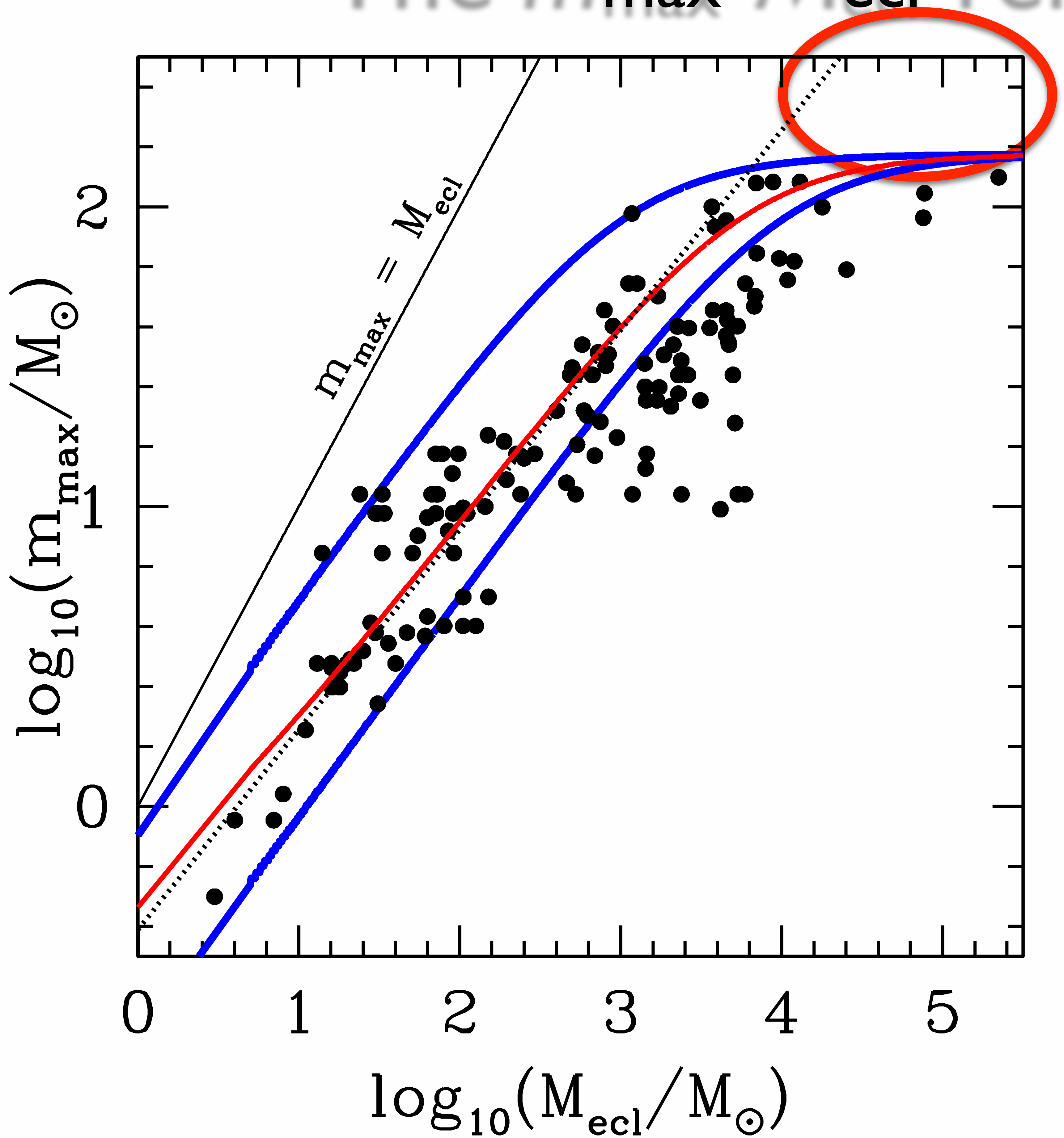


super-canonical stars?
(m > 150 $M_{\odot}$)

The m_{max}-M_{ecl}-relation

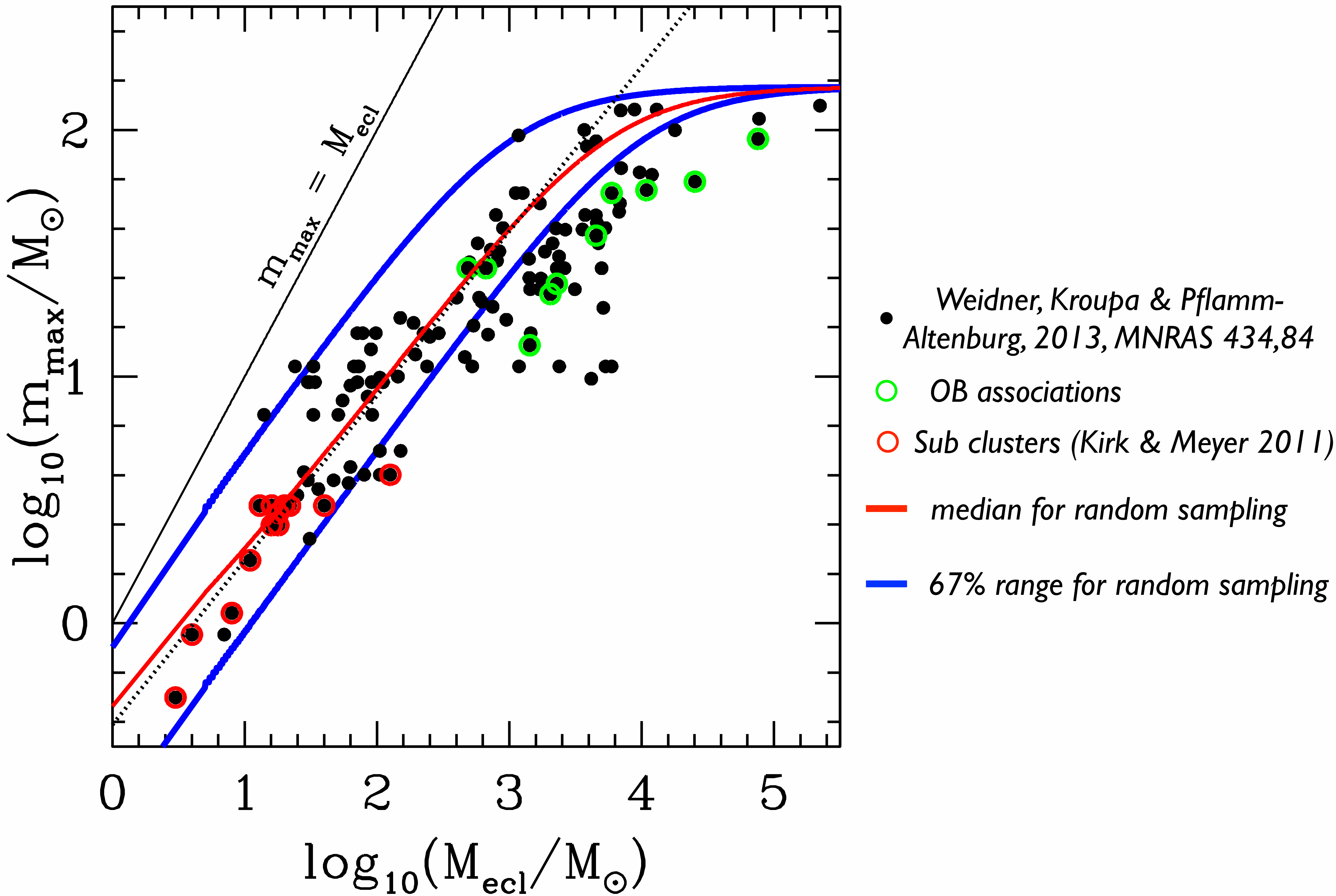


super-canonical stars?
(m > 150 $M_\odot$)

all single stars

possible mergers of massive binaries

The m_{max}-M_{ecl}-relation



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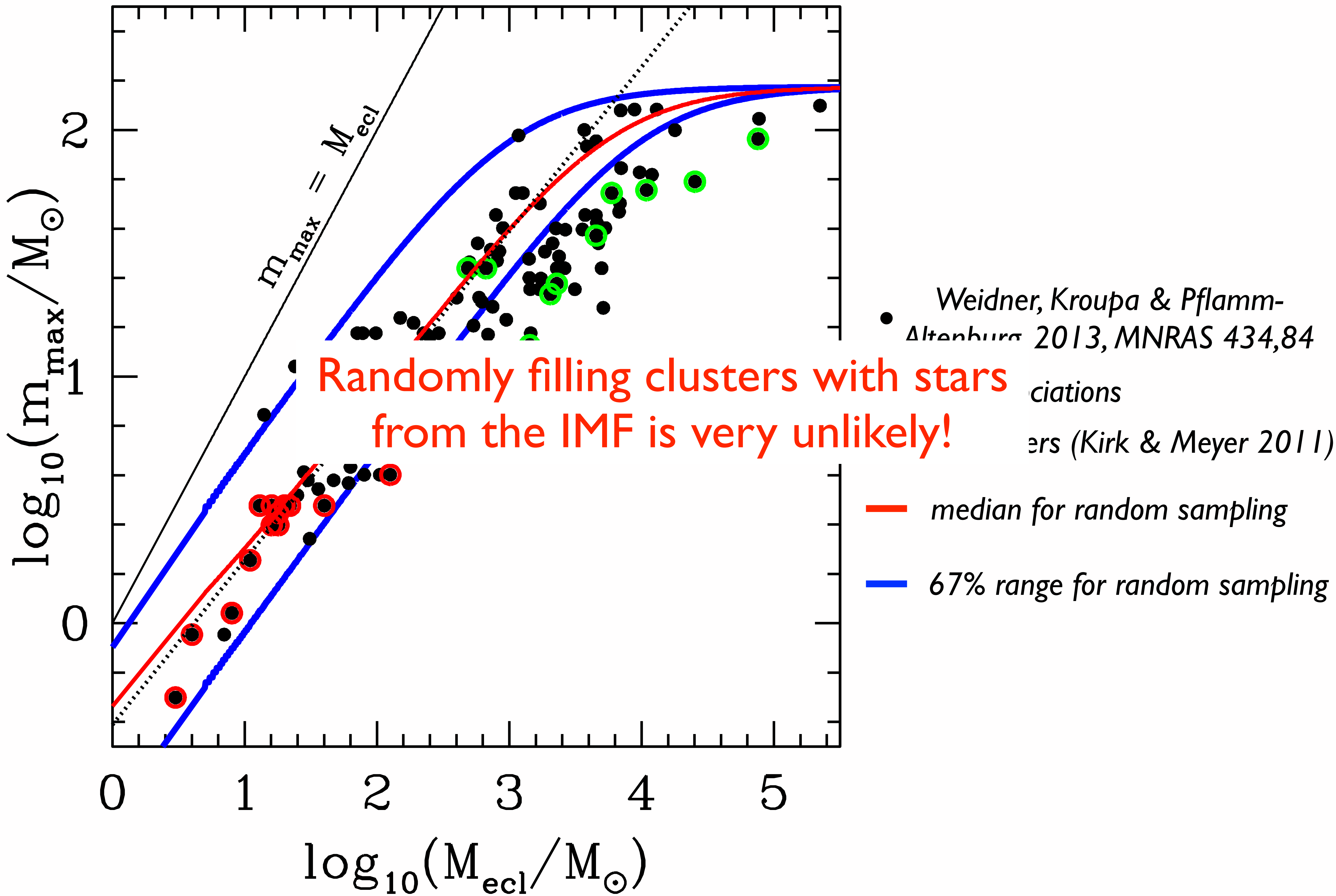


Randomly filling clusters with stars from the IMF is very unlikely!

Taurus-Auriga and L1641s

- Taurus-Auriga has 352 YSO in 8 small clusters.
- 42 stars have $m \geq 1\ M_\odot$ and $m_{max} \approx 3.3\ M_\odot$.
- The probability for this to occur randomly is $6 \cdot 10^{-5}$.
- L1641s is a star-forming cloud in Orion close to the ONC (Hsu et al. 2012).
- 2362 stars have $m \geq 0.1\ M_\odot$ and $m_{max} \approx 16\ M_\odot$.
- The probability for this to occur randomly is $4 \cdot 10^{-3}$.

Criticism

- Maschberger & Clarke (2008) claim there is no evidence for a non-trivial m_{max}-M_{ecl}-relation.
- Only use clusters up to ~3200 stars (~1200 $M_{\odot}$).
- The probability for their data set to origin from random sampling is 10^{-17}.
- Only a sub-sample of their data agrees (20%) with random sampling.
- As no other sampling methods are tested it is not clear if their test can differentiate between models.

Massive field stars

- OB stars that are not members of any known star cluster, OB association or star-forming region.
- ~30% of all Galactic O stars are in the field (*Gies 1987*).
- Two subgroups of field O stars:
  - ~25% are high-velocity OB stars (typical > 30 km/s; runaway stars; *Blaauw 1961, 1993; Gies 1987*),
  - ~75% low-velocity OB stars.
- 27% of ALL *Hipparcos* stars are runaways (v_{pec} > 28 km/s; Tetzlaff et al. 2011).
- 41% of the *Hipparcos* OB stars (55 of 133) are runaways (Tetzlaff et al. 2011).

Origin of runaway OB stars

It is thought that runaway OB stars obtain their high velocities through two/three processes:

- Either disruption of a short-period binary after a supernova explosion (*Blaauw 1961, Stone 1991*),
- or through three- or many-body interactions in star clusters (*Poveda et al. 1967, Gies & Bolton 1986*),
- or by combining SN and dynamical interactions to two-step ejections (*Pflamm-Altenburg & Kroupa 2010*).

Keep in mind that ~69% of all runaways are binaries (Chini et al. 2012)!

Origin of low-velocity field OB stars

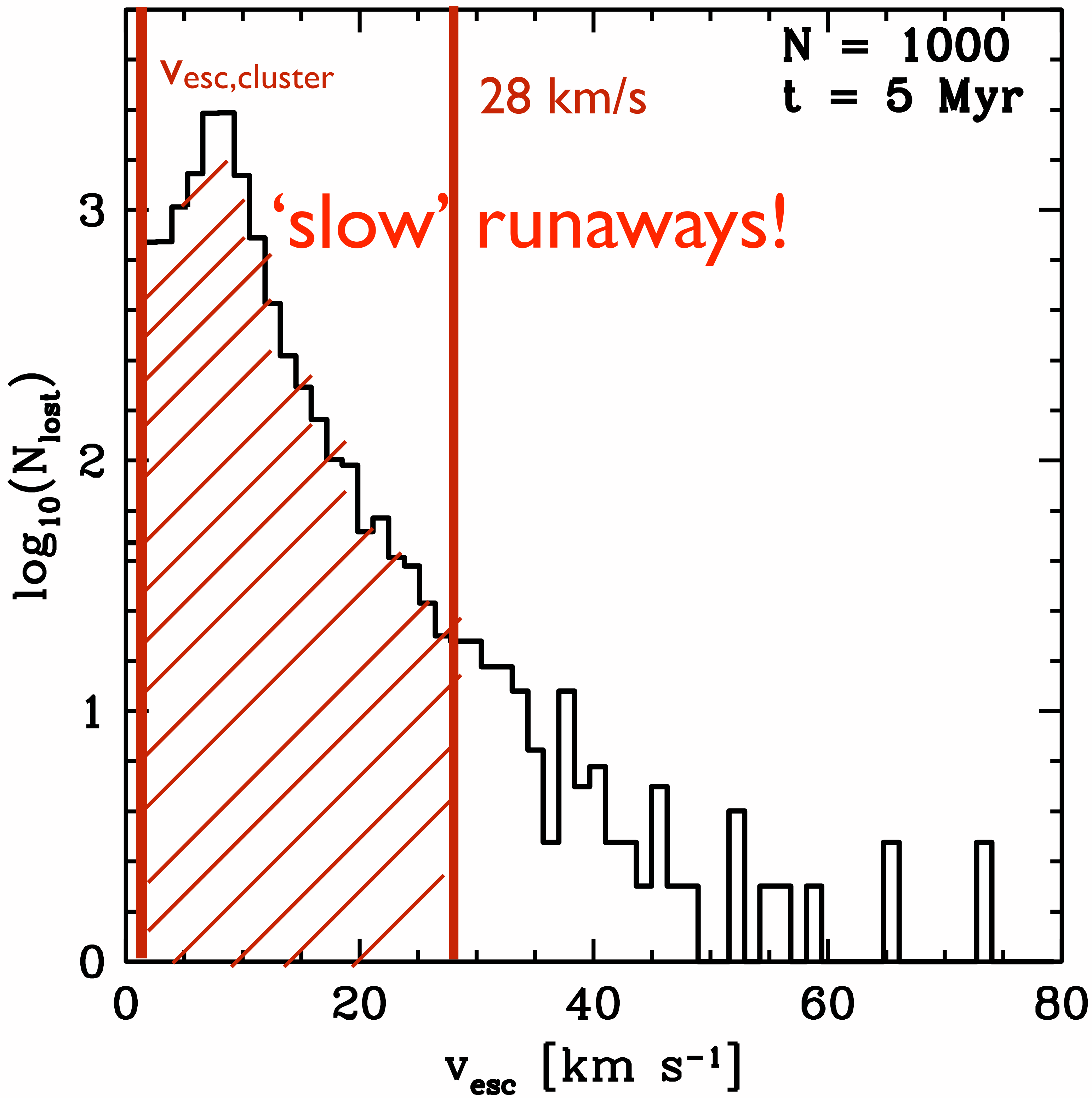
- Formed in isolation?
- Unrecognised runaways?
- Members of undetected/dissolved star clusters?
- Merged ejected binary (blue straggler)?
- Two-step ejection?
- Low-velocity tail of the ejected stars?

Stellar dynamics

100 *N*body6 models of a 1000 stars, each evolved for 5 Myr.

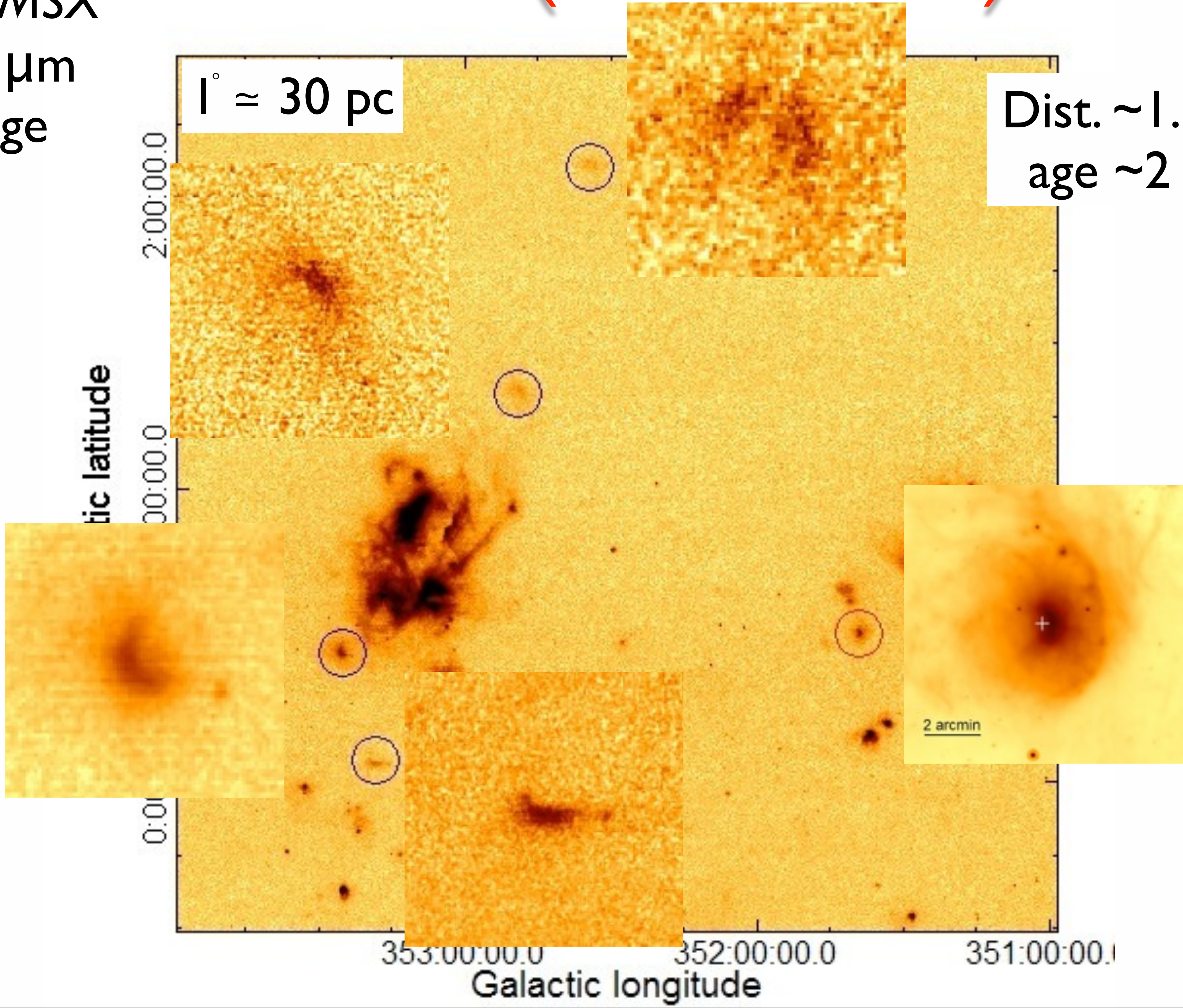
Weidner, Bonnell & Moeckel, 2011, MNRAS 410, 1861

cluster mass [Msol]	$v_{esc,cluster}$ [km/s]
360	2.4
1000	3.7
10000	10.2



Pismis 24 (NGC 6357)

3° x 3° *MSX* 21.3 µm image



Dist. ~1.7 kpc
age ~2 Myr

Isolated high-mass star-formation?

11 of 193 stars which cannot be associated with clusters.

4 'best examples for isolated Galactic high-mass star-formation' (*de Wit et al. 2004, 2005*).

HD39680	HD48279	HD96917	HD112244
HD120678	HD123056	HD124314	HD154811
HD165319	HD193793	HD202124	

11/193 = 6%   4/193 = 2%   =>   4 ± 2%

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Parker & Goodwin (2007) need 4.6% isolated O stars for star-formation to be fully random.

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HD39			
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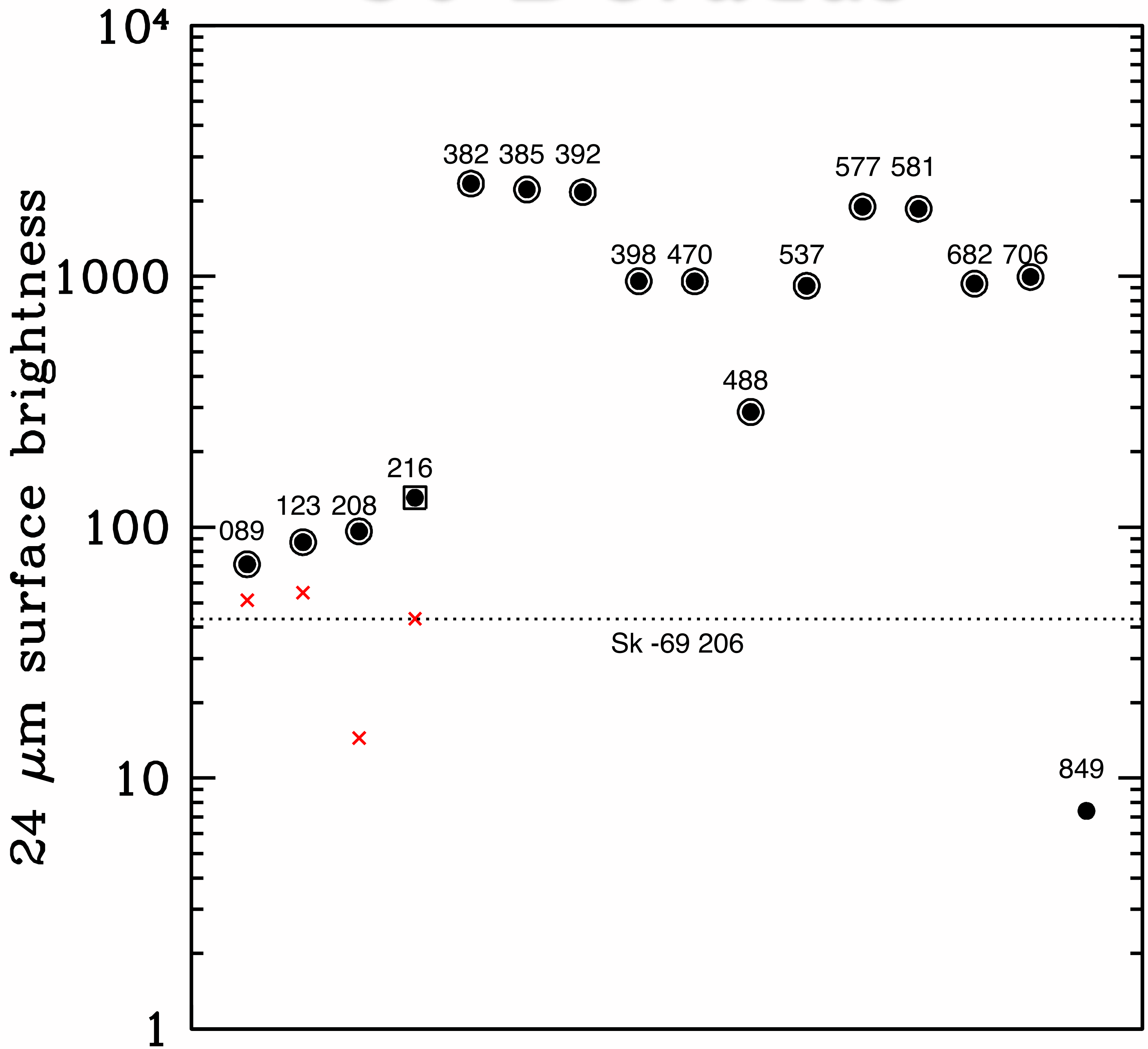
Isolated high-mass star-formation in the Magellanic Clouds?

- Bressert et al. (2012) found 16 candidates in the LMC.
  - Distributed around R136 in 30 Doradus. Assuming an age of 1 Myr velocities of 20 to 120 km/s are necessary.
  - Only one bow-shock detected. Rest formed in isolation?
- Oey et al. (2013) 14 candidates in the SMC.
  - The stars are in the 'centre' of HII regions but should be off-centre if they have velocities of 100 km/s.
  - No bow-shocks. Formed in isolation?

The LMC candidates

- For 15 of the 16 stars young clusters/OB associations closer than R136 can be found and many of the stars are older than 1 Myr.
- This combined results in 14 of the 16 stars having minimal peculiar velocities less than 10 km/s. Bow-shocks can not form.
- The star with a bow-shock has a $v_{pec,min}$ of about 10 to 20 km/s. The other star has a $v_{pec,min}$ of 15 to 60 km/s.
- The high background surface brightness of 30 Doradus makes the detection of bow-shocks difficult or even impossible.

Detectability of bow-shocks near 30 Doradus



The SMC candidates

- 2 of 14 are members of known young clusters of relatively low-mass with most members below the limiting magnitude.
- Because of the limiting magnitude of the observations only a dozen cluster members could be observed.
- Using probable ages for the stars only 3 stars have $v_{pec,min}$ above 15 km/s (up to 31 km/s).
- The fastest star possibly has a bow-shock.
- Actually measuring the off-centre distances of the stars to the HII regions results in velocities of 10 to 260 km/s.
- Runaway stars in the Milky Way are known to have HII regions which are very well centred on them.

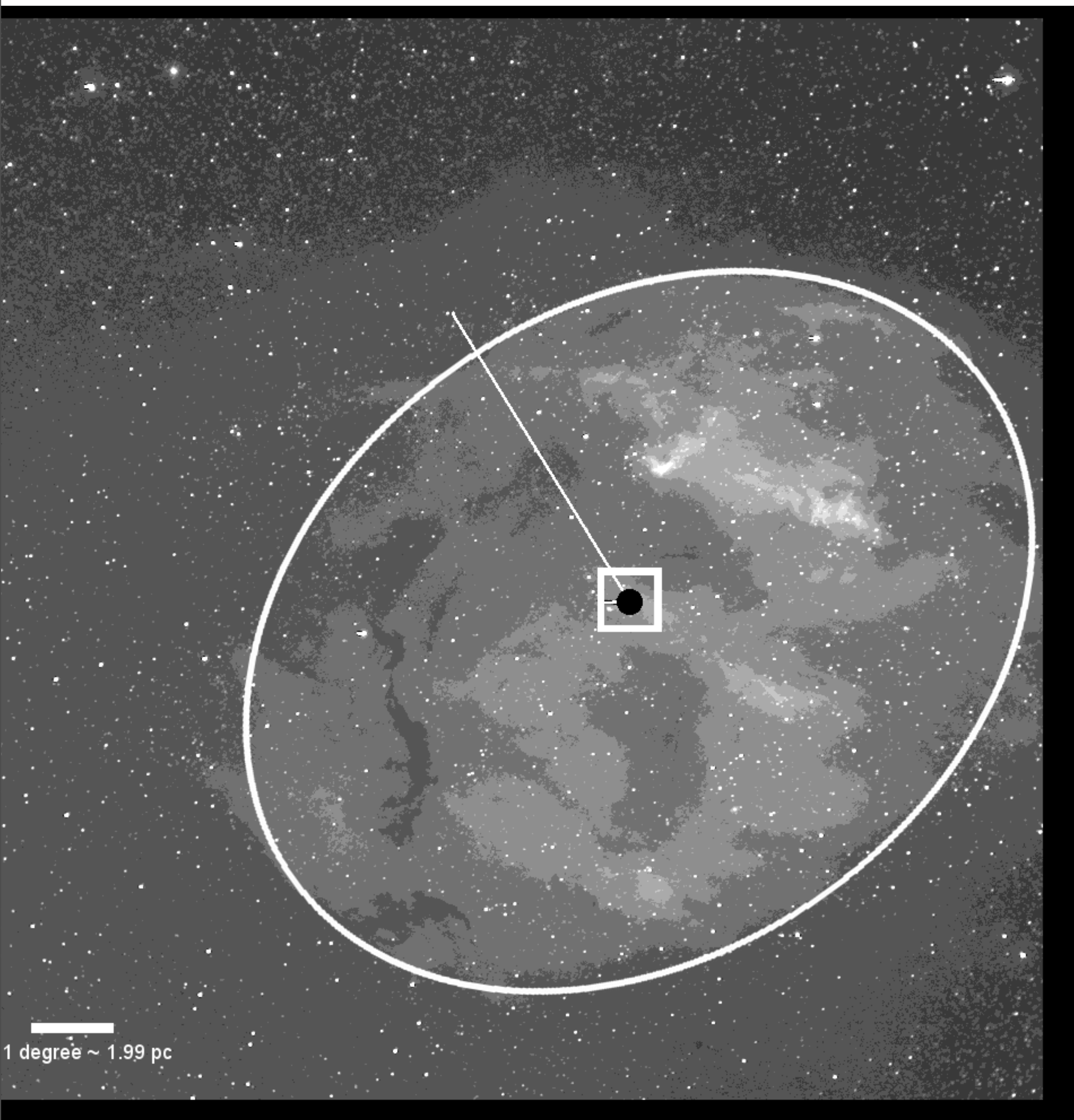
ζ Ophiuchi

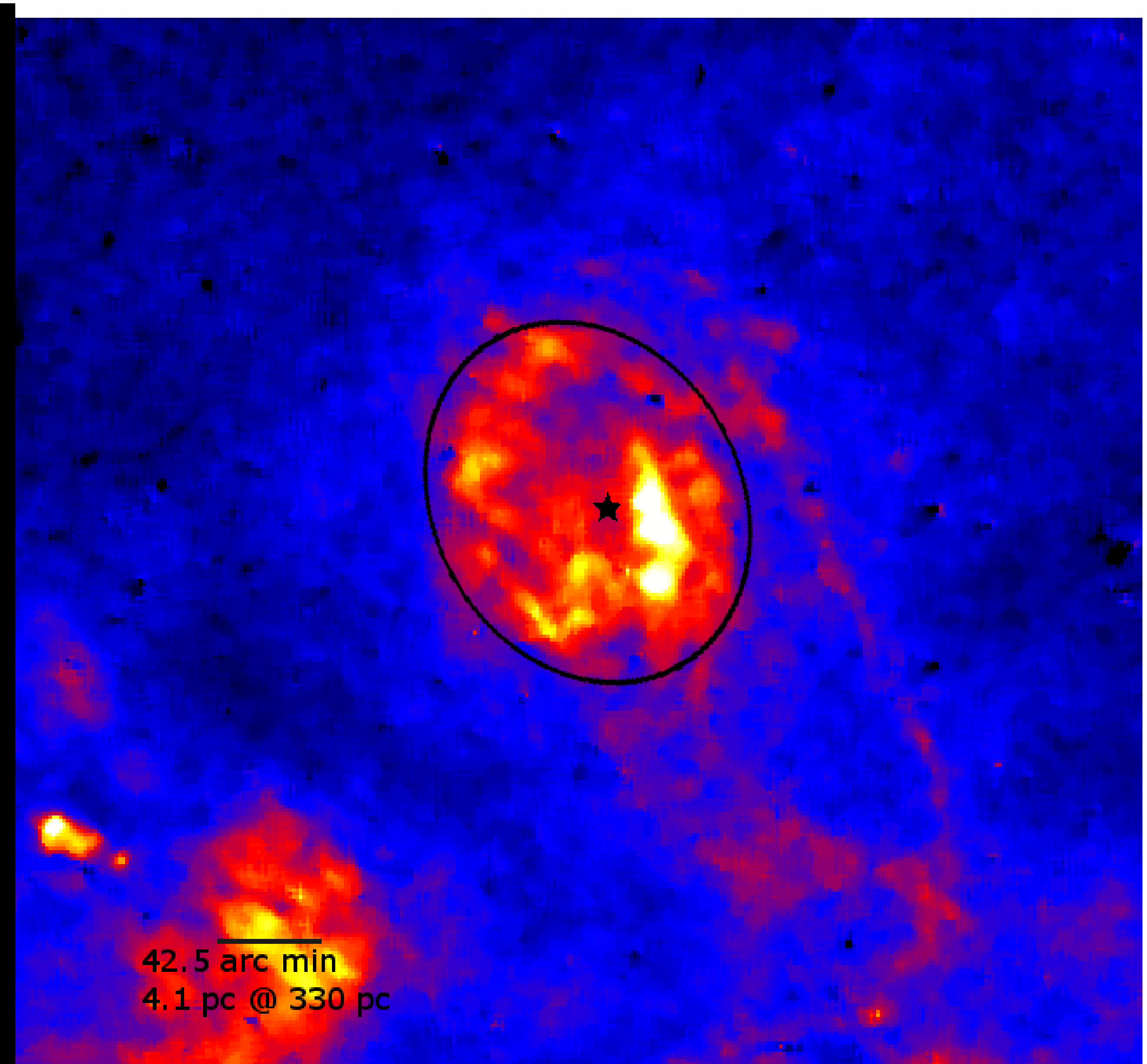
Credit: NASA/JPL-Caltech/WISE Team

HII regions around MW runaways

ζ Oph

HD 130298





Credit: Southern H-Alpha Sky Survey Atlas (SHASSA)

Conclusions

No unambiguous arguments for the formation of massive stars in the field in the Milky Way or the Magellanic Clouds!