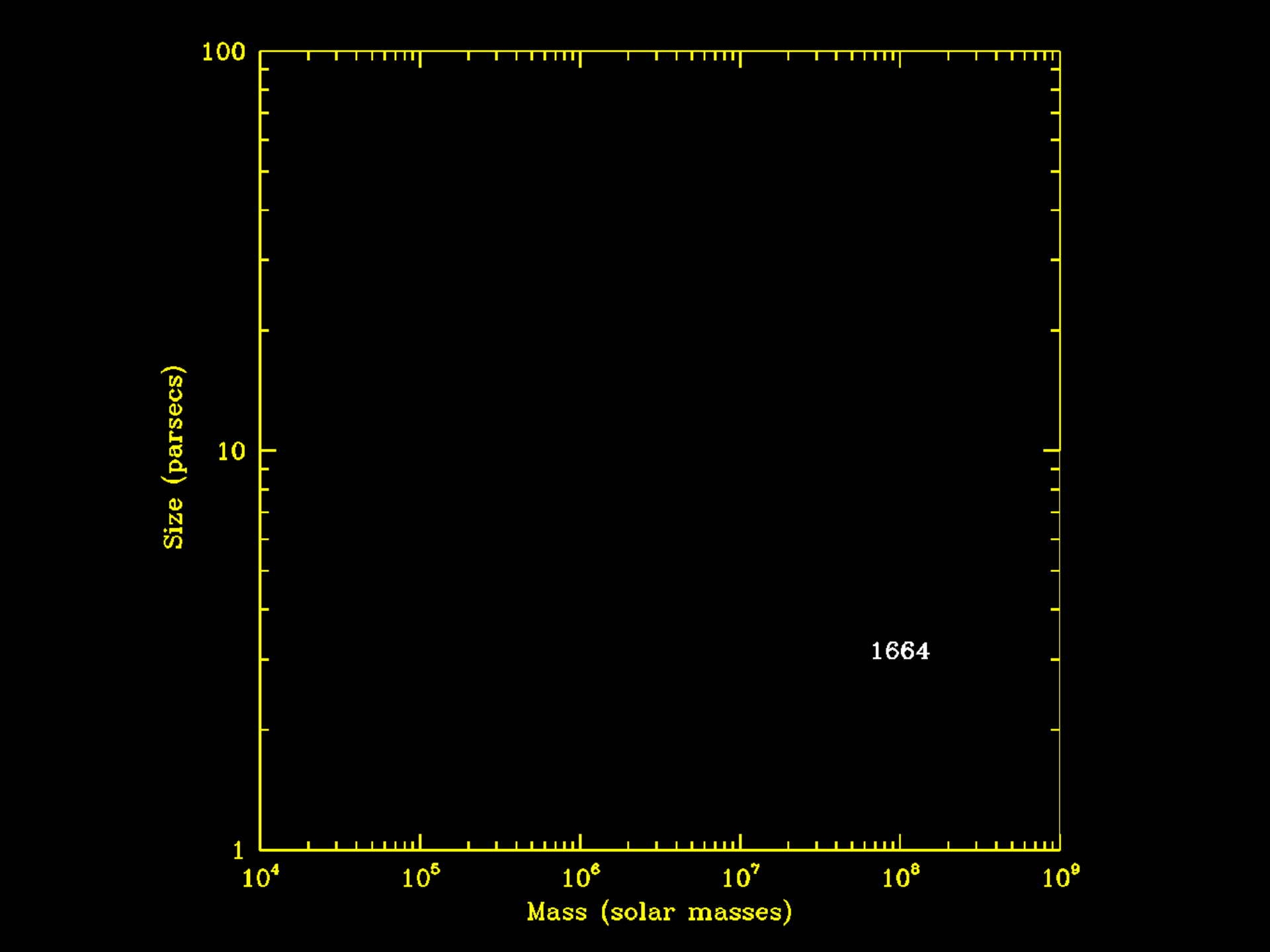
New insights for Ultra Compact Dwarfs

Insights still remaining on Friday

Duncan Forbes
Swinburne University

Key collaborators at this meeting

- Aaron Romanowsky
- Jay Strader
- Jean Brodie
- Mark Norris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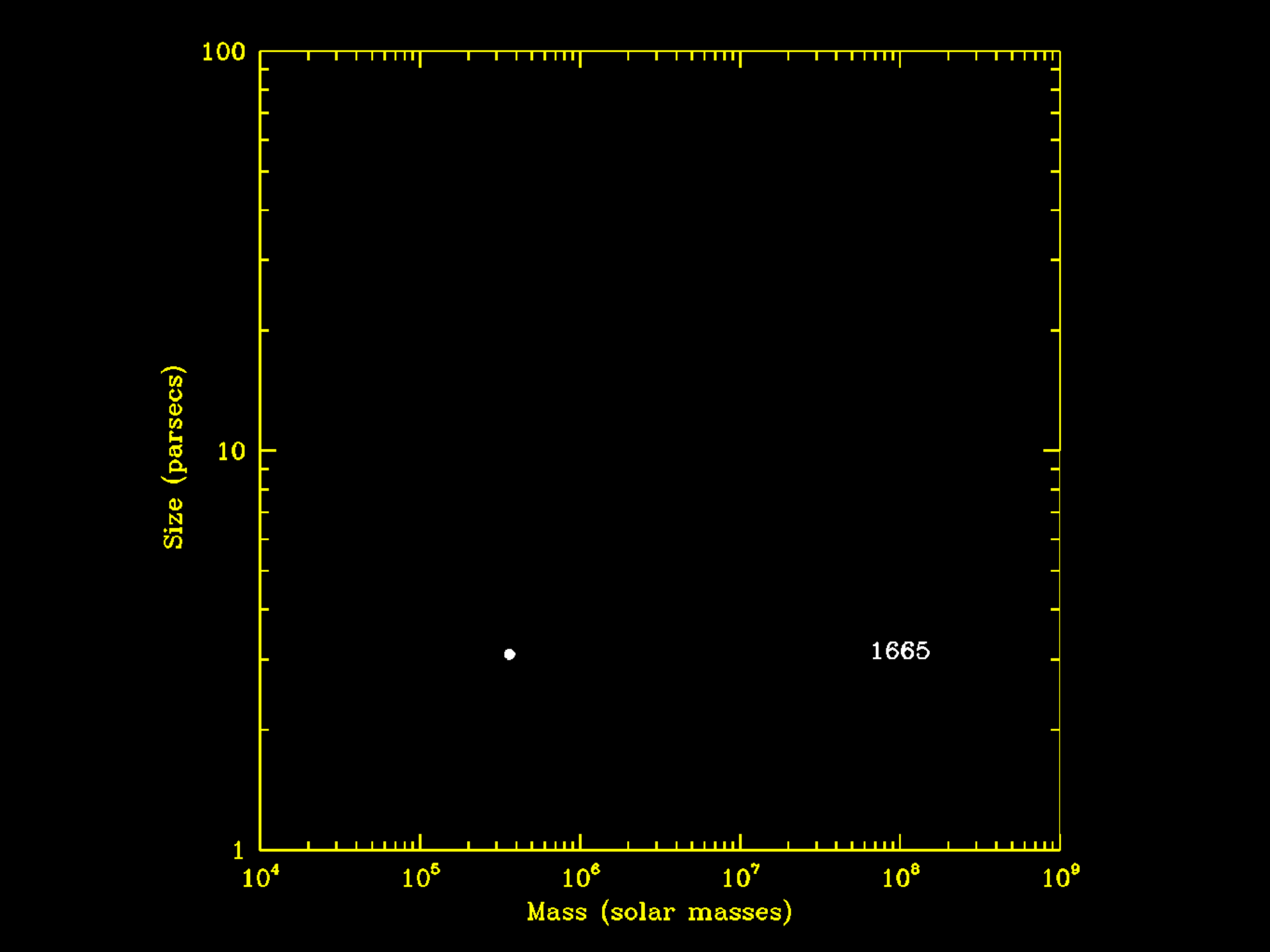
10^9
Mass (solar masses)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10^8
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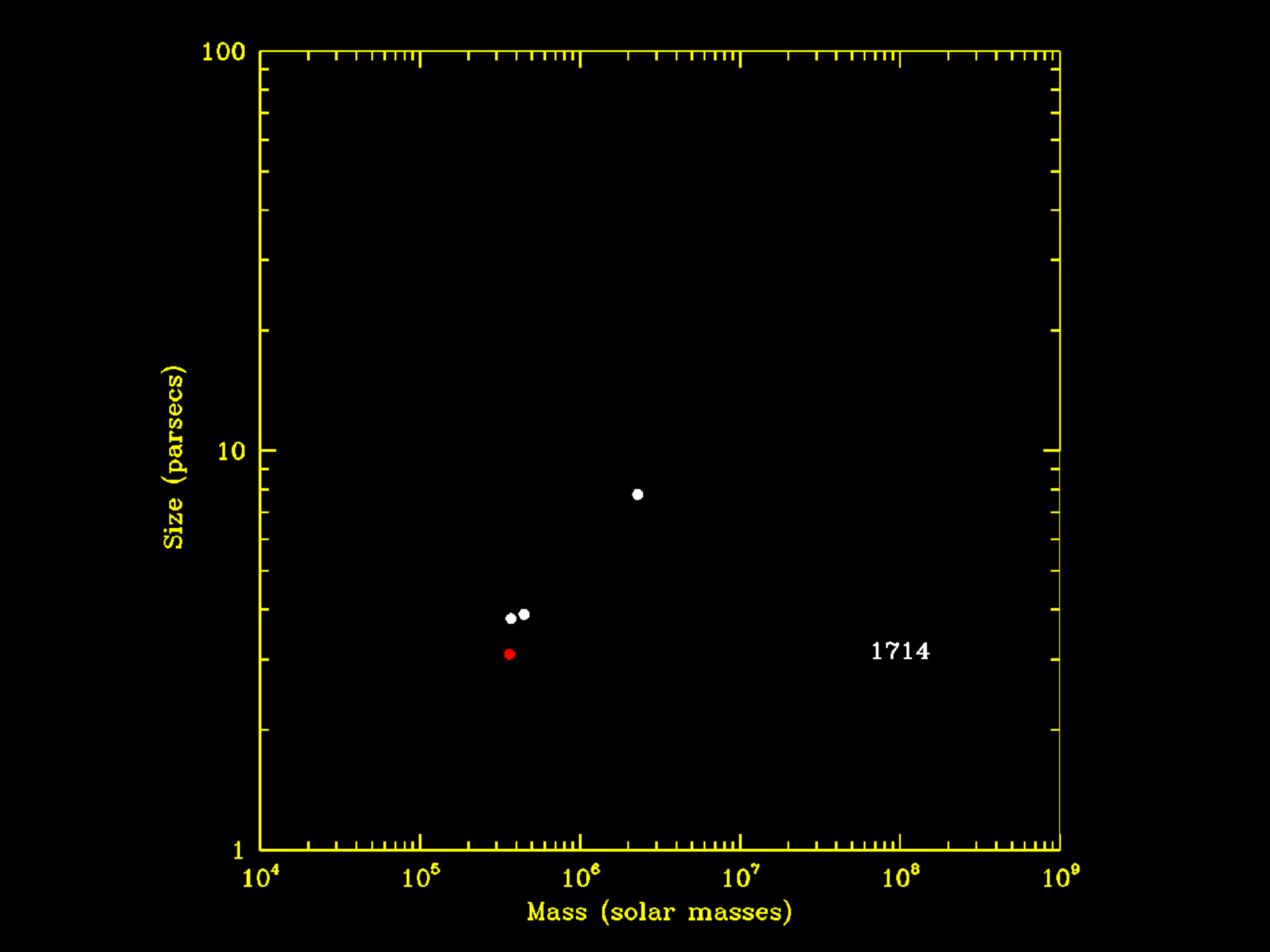
Mass (solar masses)
1665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Mass (solar masses)
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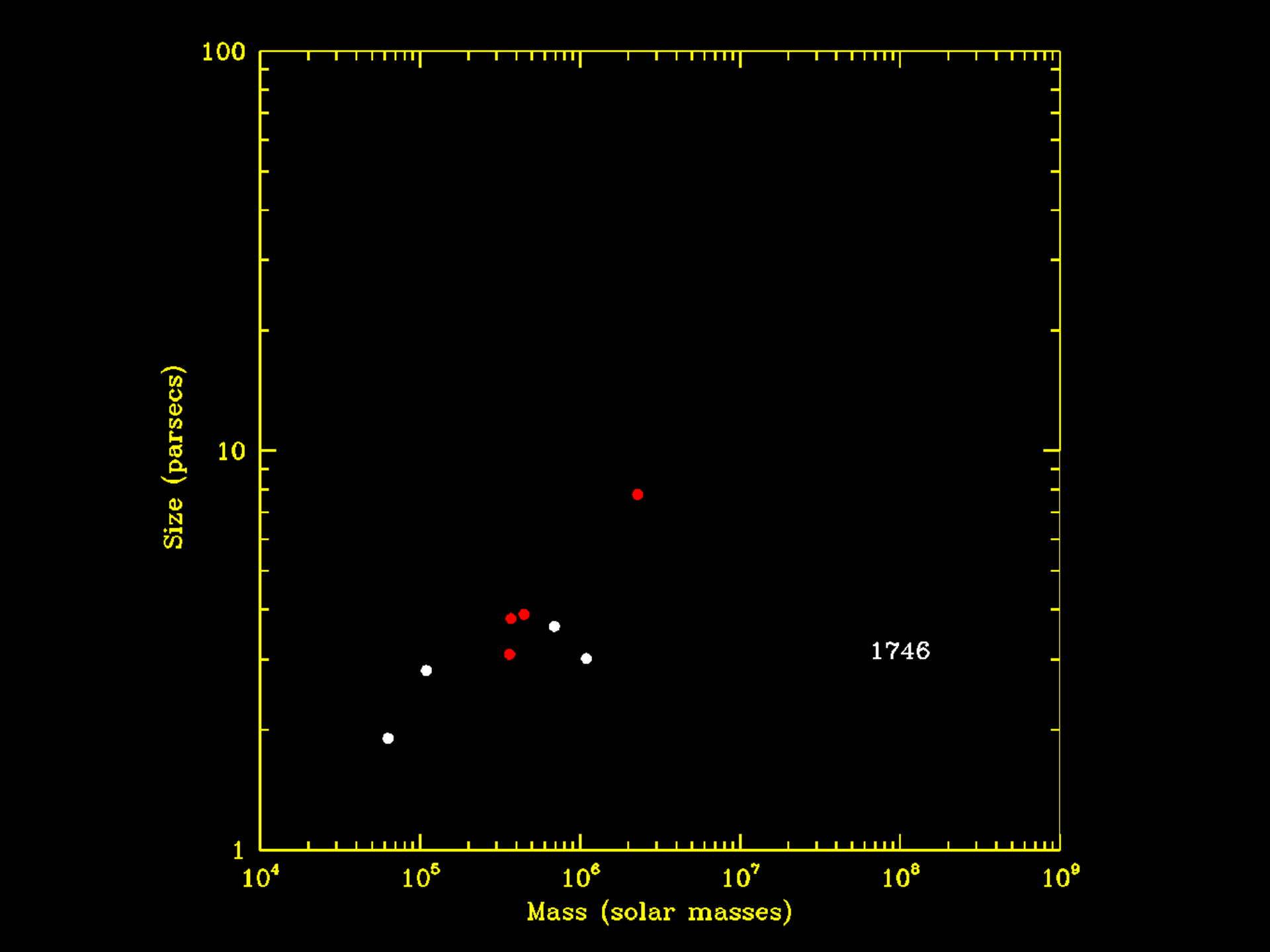
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10^5
10^6
10^7
10^8
10^9
Mass (solar masses)
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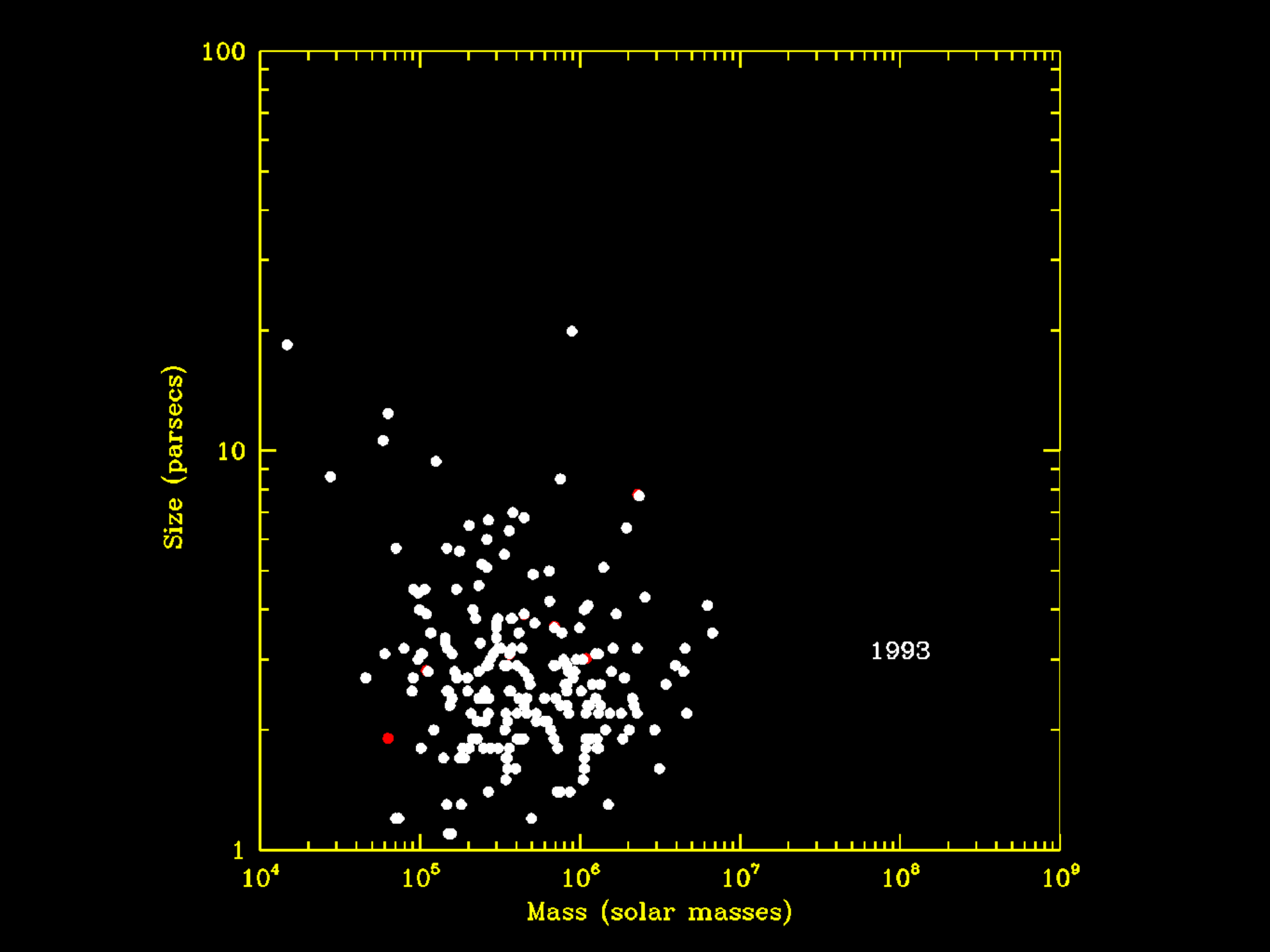
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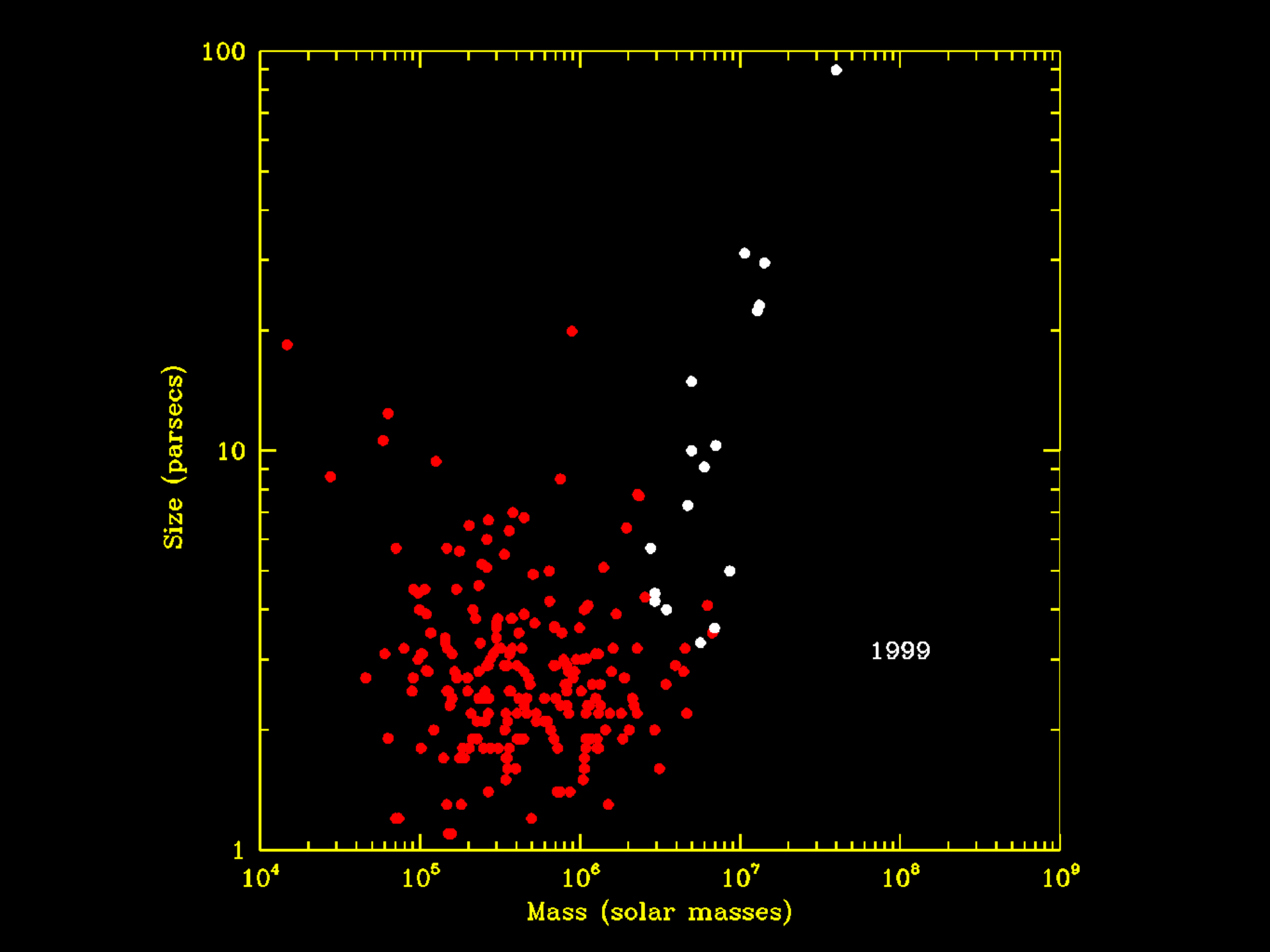
10^5
10^6
10^7
10^8
10^9
Mass (solar masses)
1993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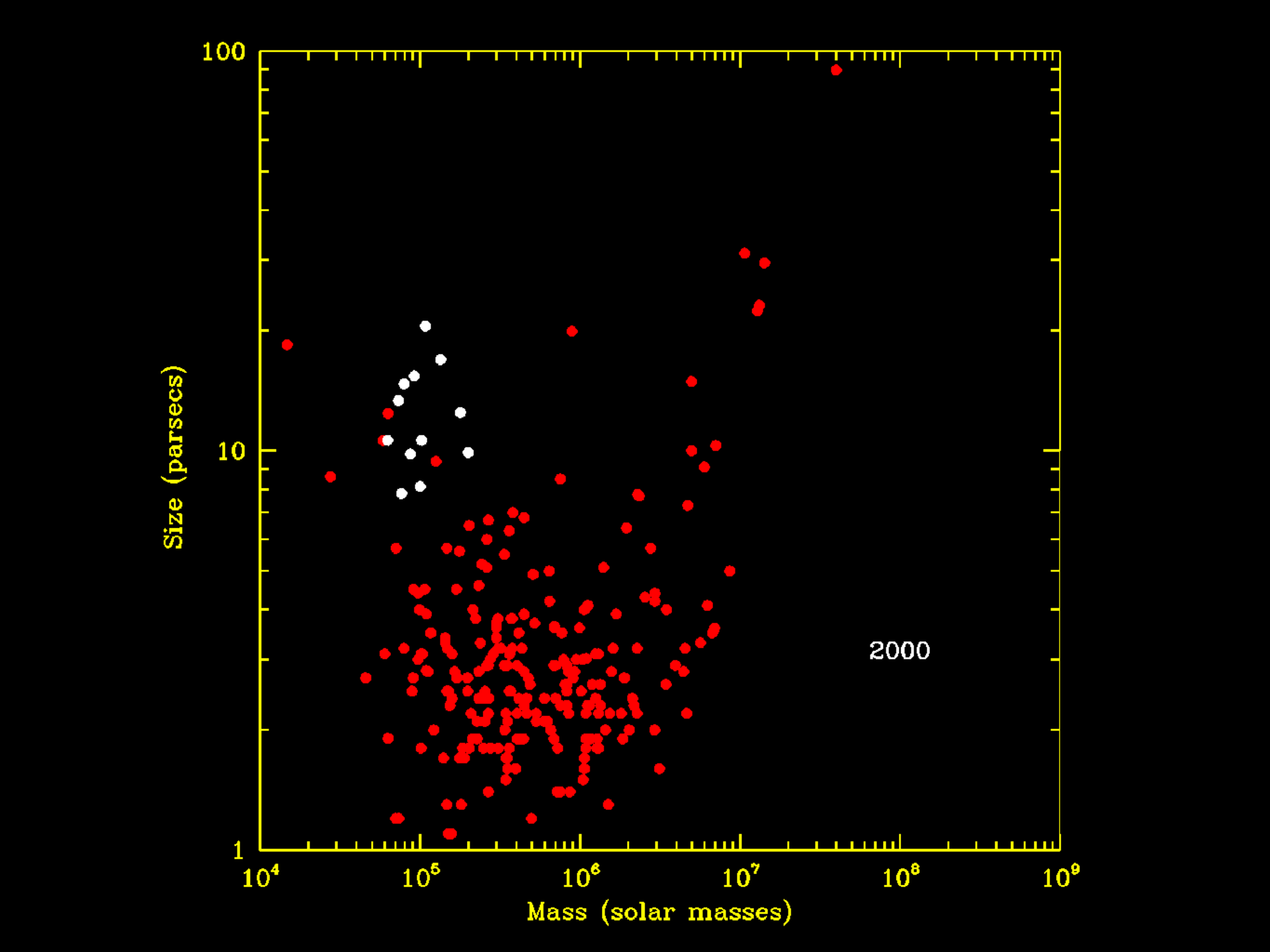
10^5
10^6
10^7
10^8
10^9
Mass (solar masses)
1999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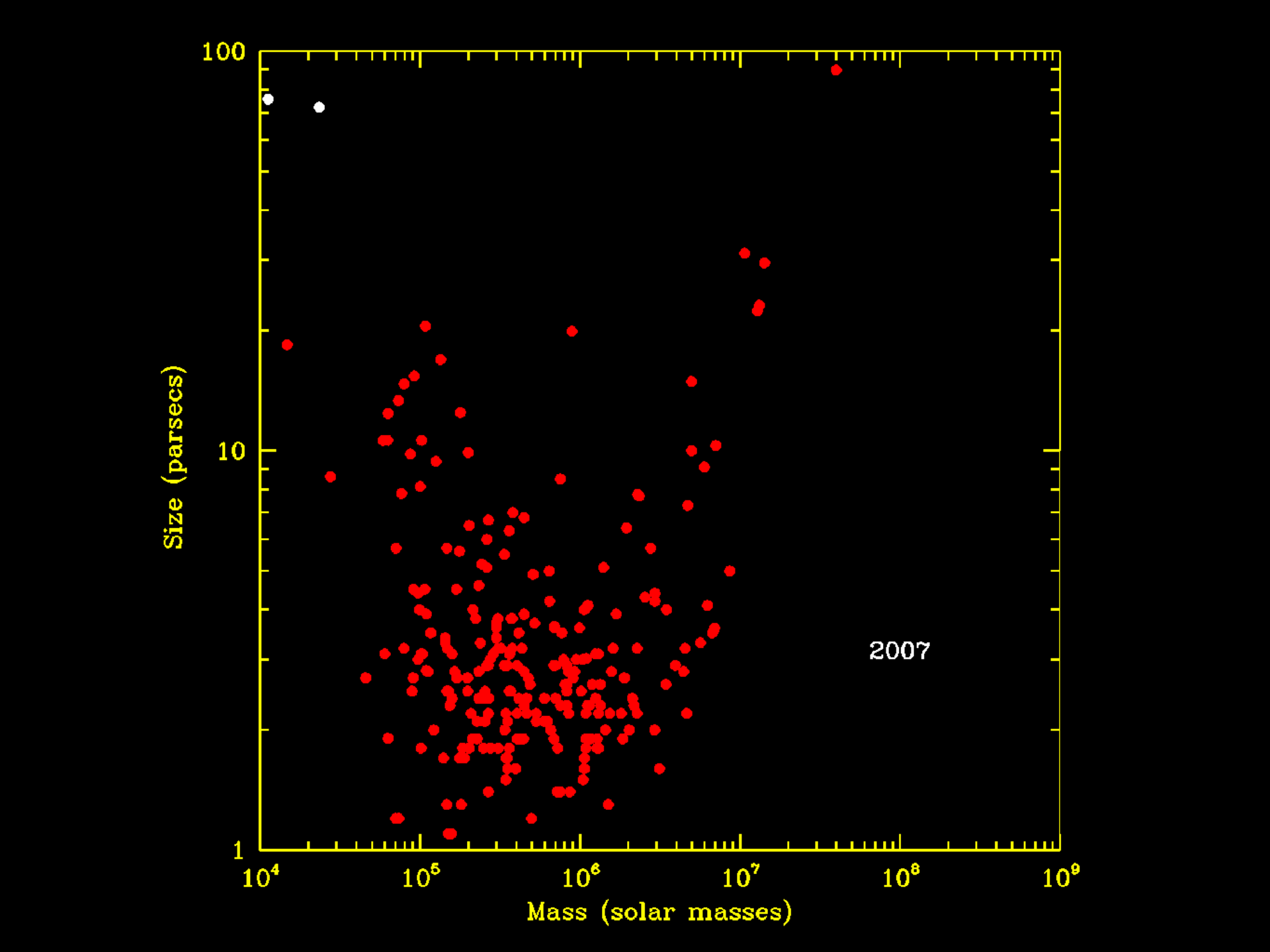
10^6
10^7
10^8
10^9
Mass (solar masses)
2000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10^5
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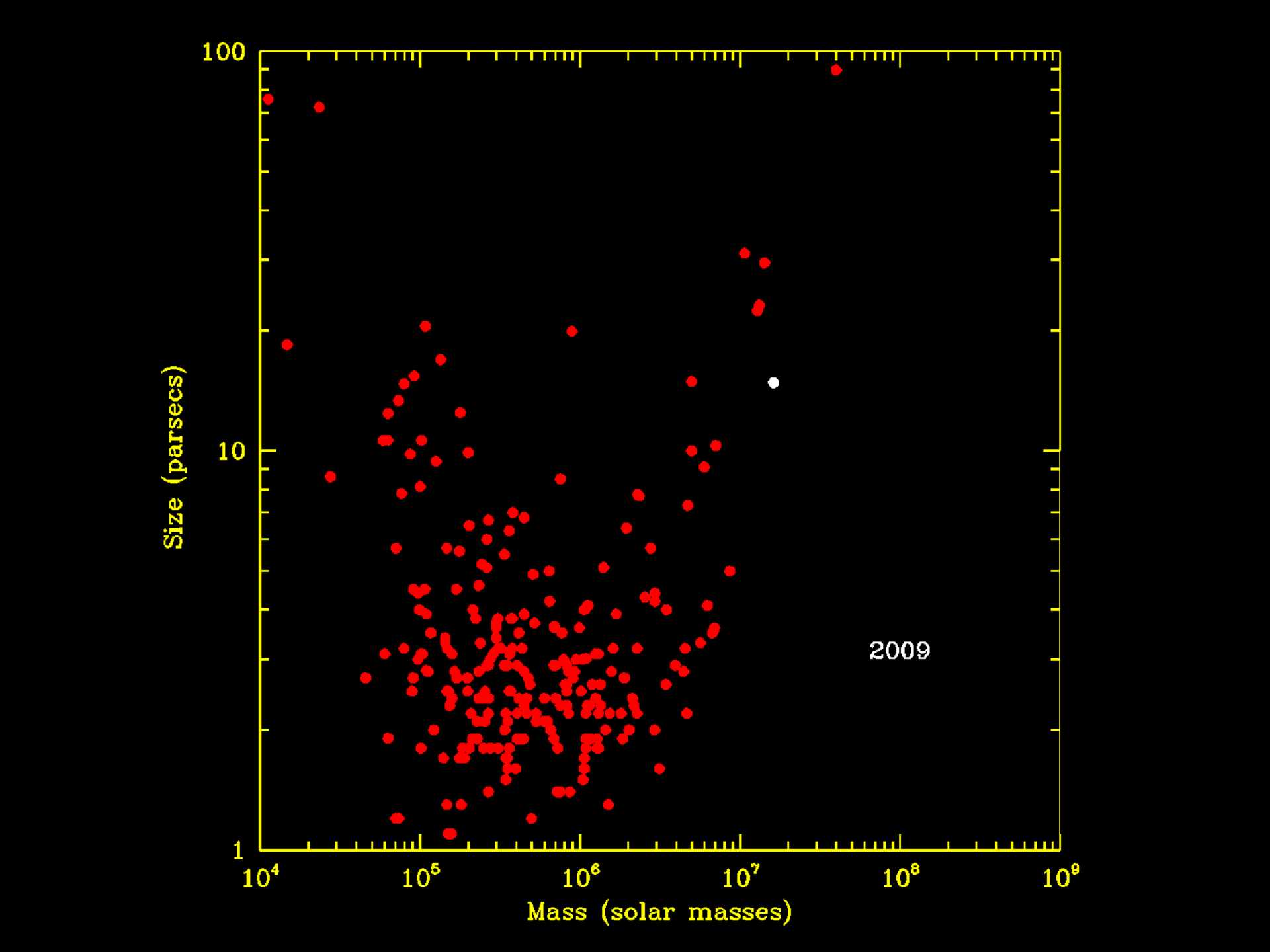
10^7
10^8
10^9
Mass (solar masses)
2007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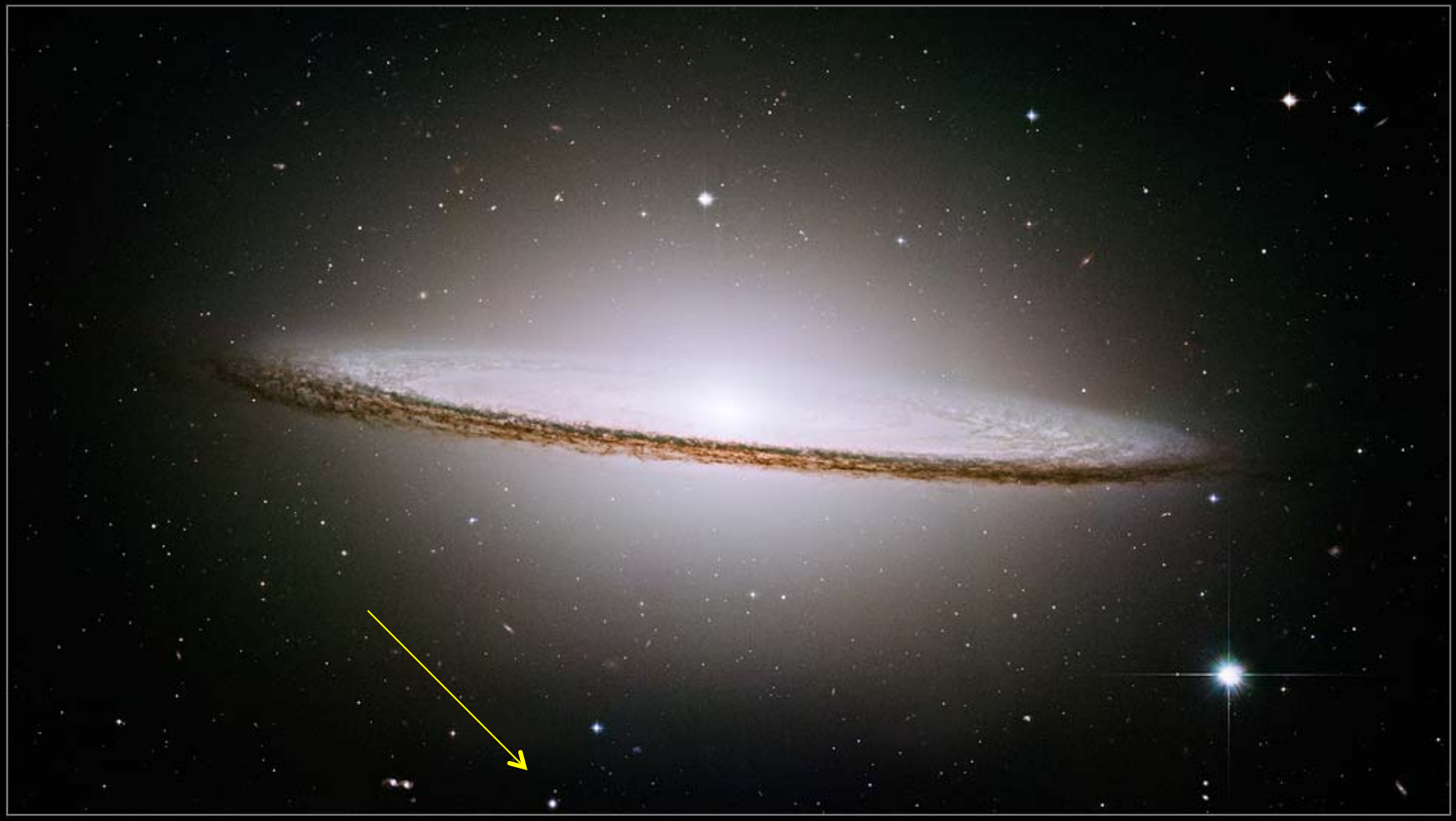
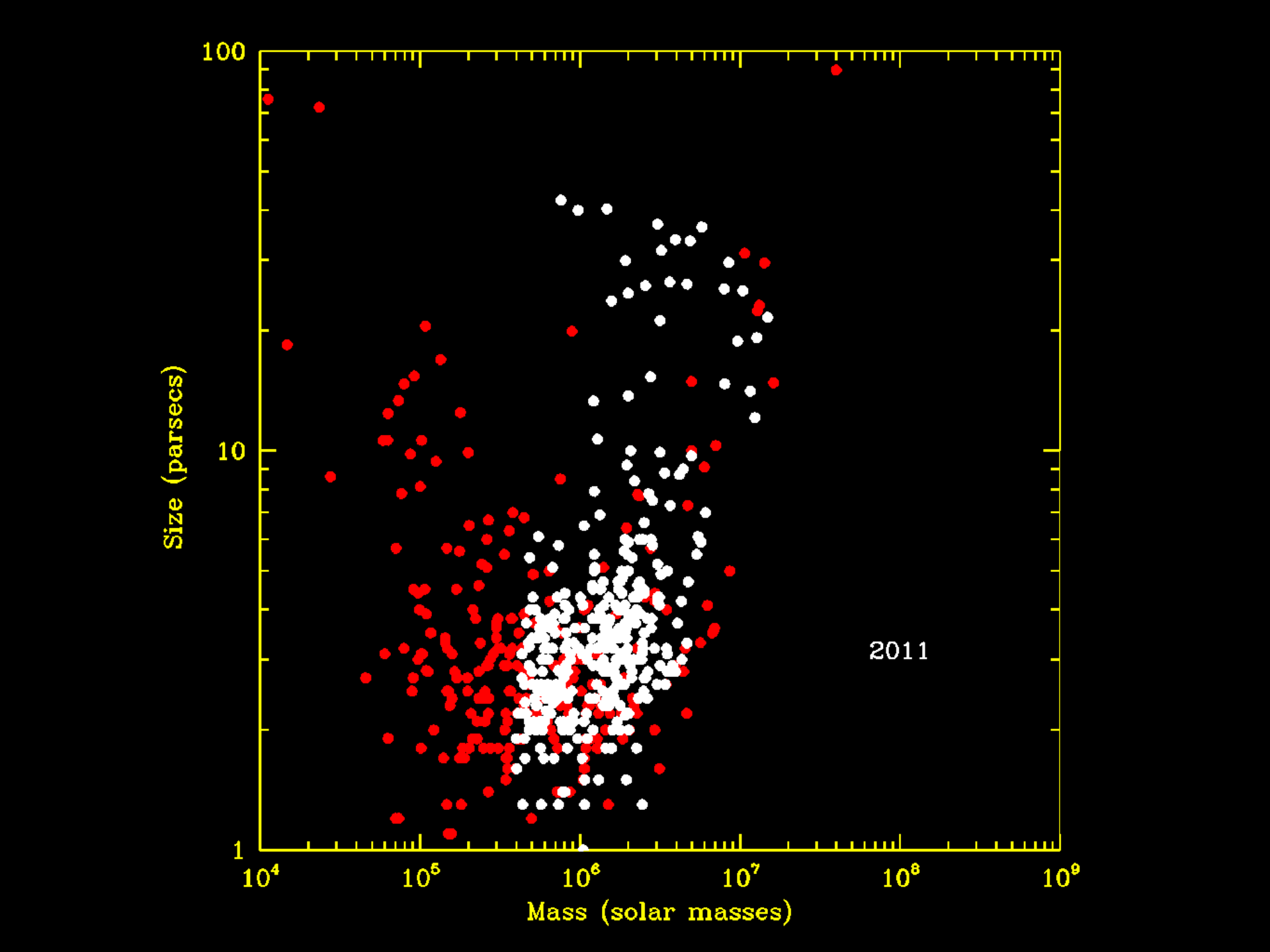
10
1
Size (parsecs)
10^4
10^5
10^6
10^7
10^8
10^9
Mass (solar masses)
2009

Sombrero Galaxy • M104



Hubble Heritage

NASA and The Hubble Heritage Team (AURA/STScI) • Hubble Space Telescope ACS • STScI-PRC03-28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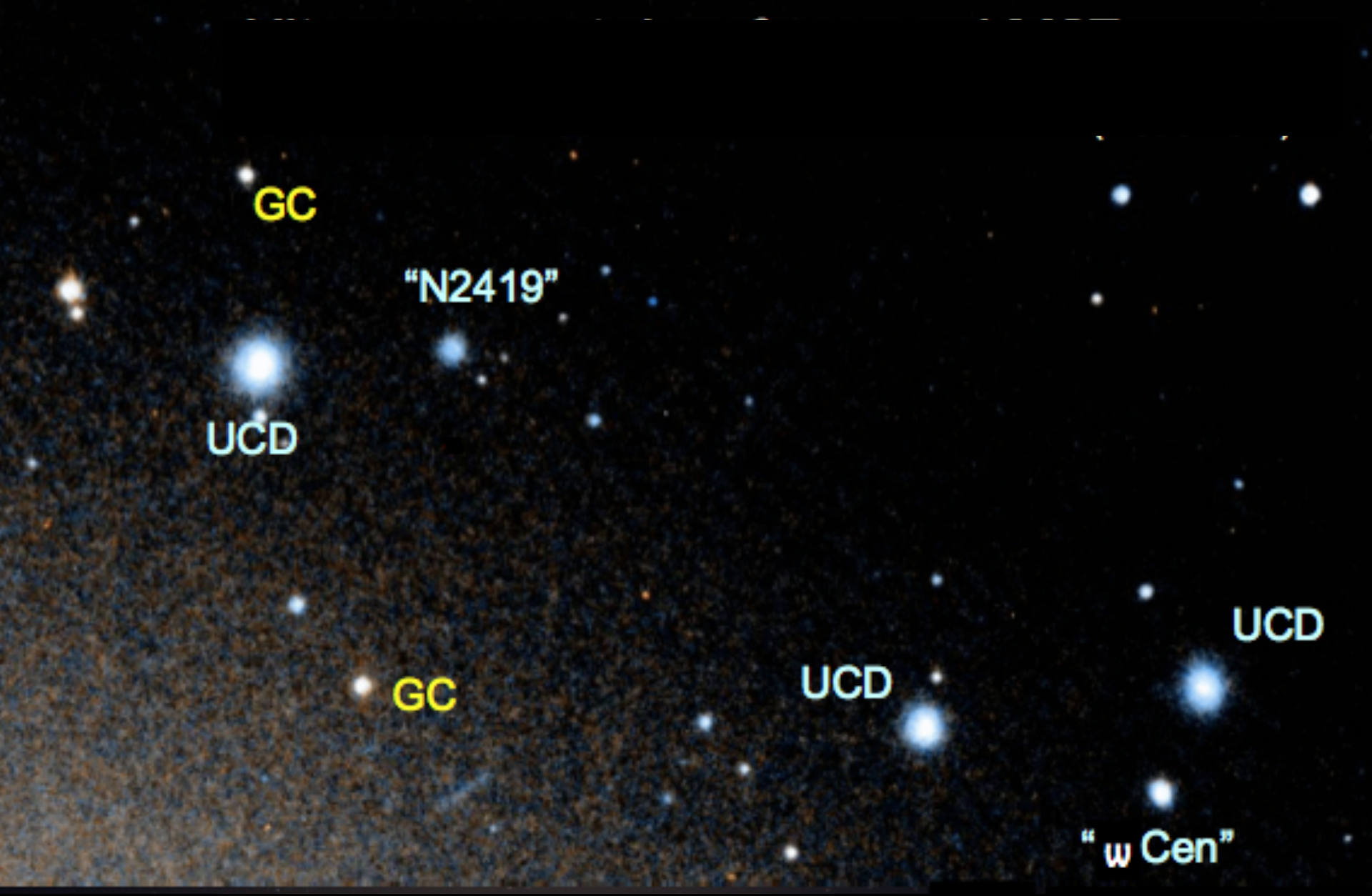
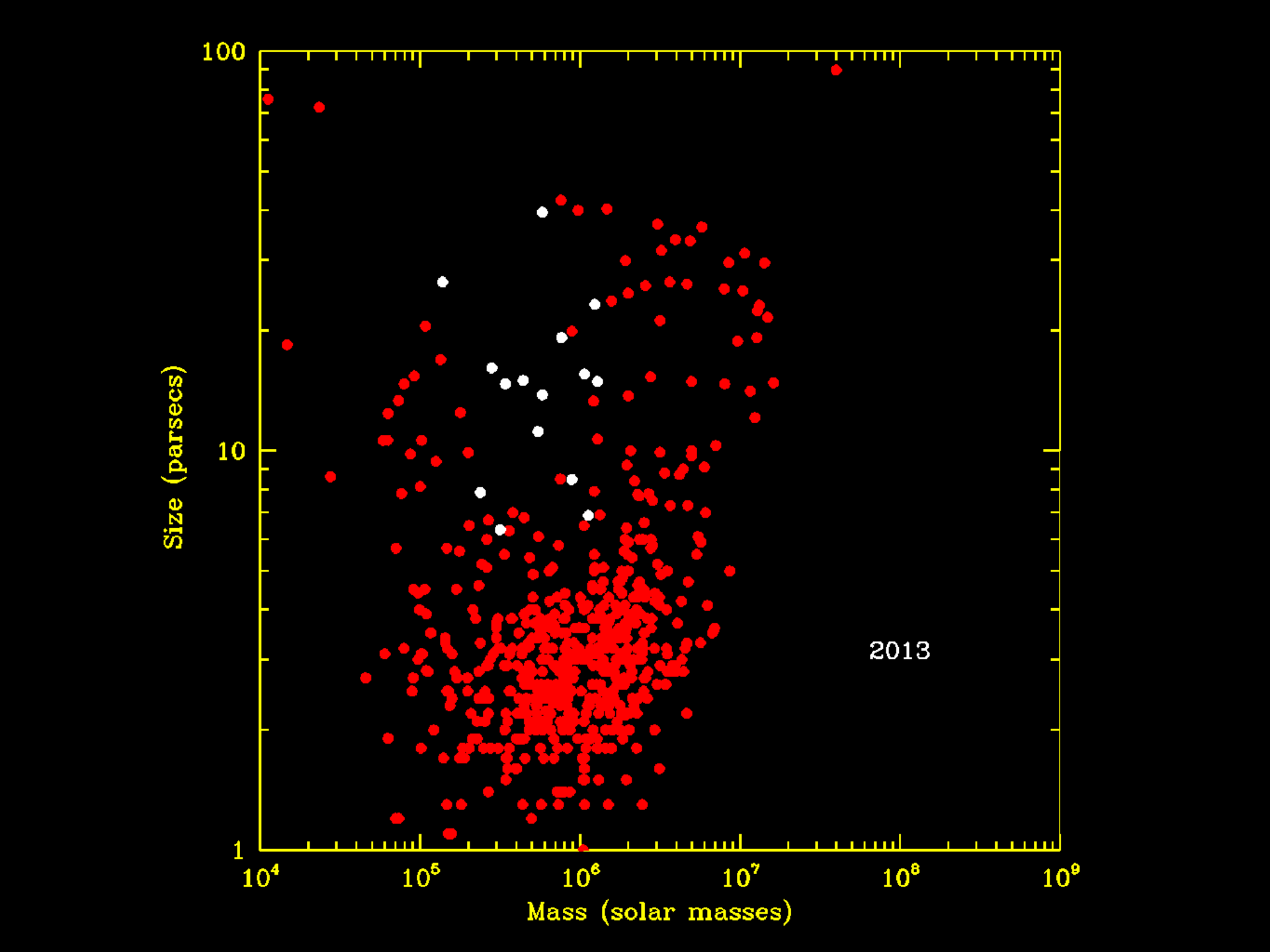
Size (parsecs)
10^4
10^5
10^6
10^7
10^8
10^9
Mass (solar masses)
2011


GC
"N2419"
UCD
GC
UCD
UCD
"ω Cen"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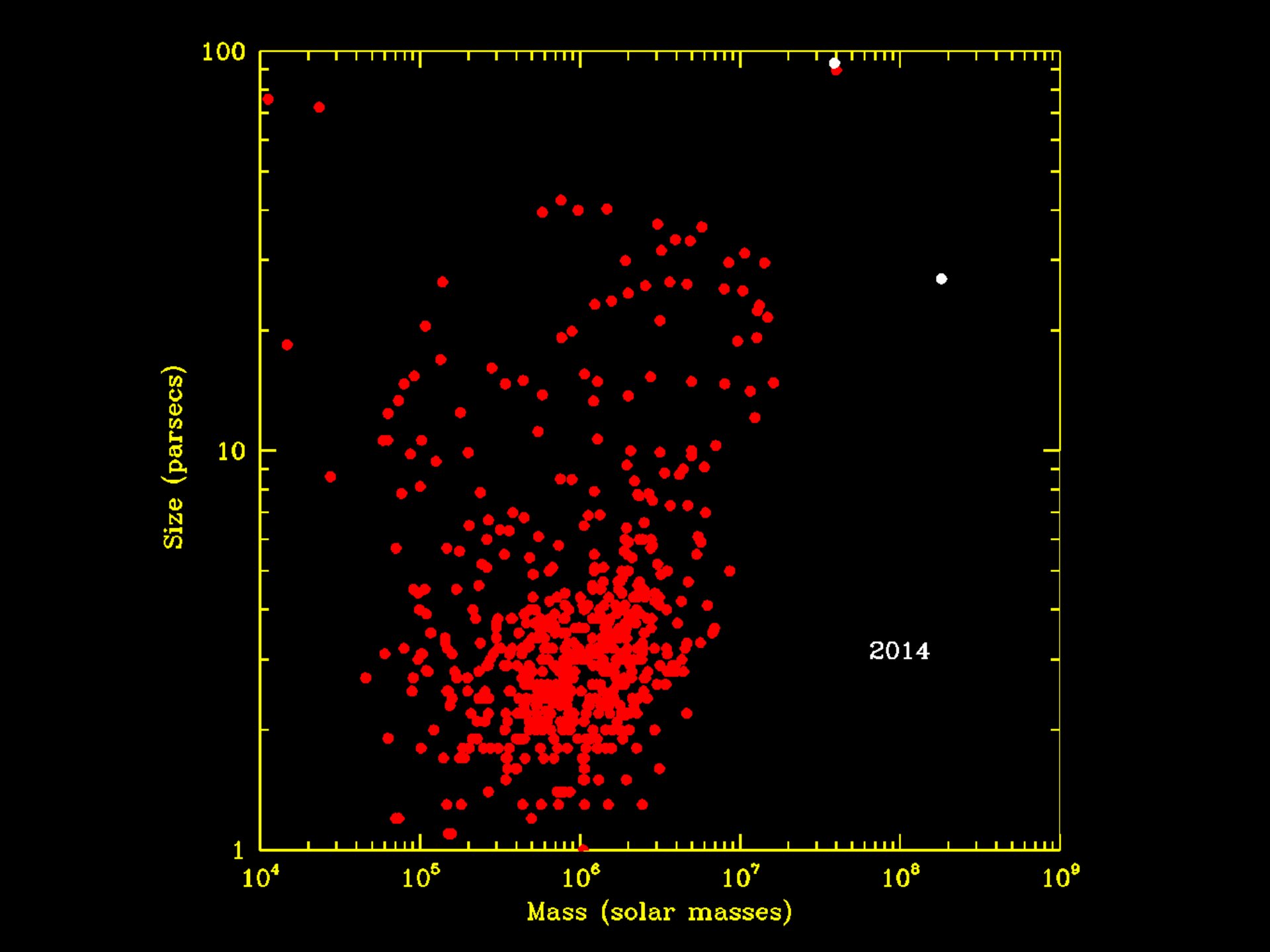
10
1
Size (parsecs)
10^4
10^5
10^6
10^7
10^8
10^9
Mass (solar masses)
2013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1
Size (parsecs)
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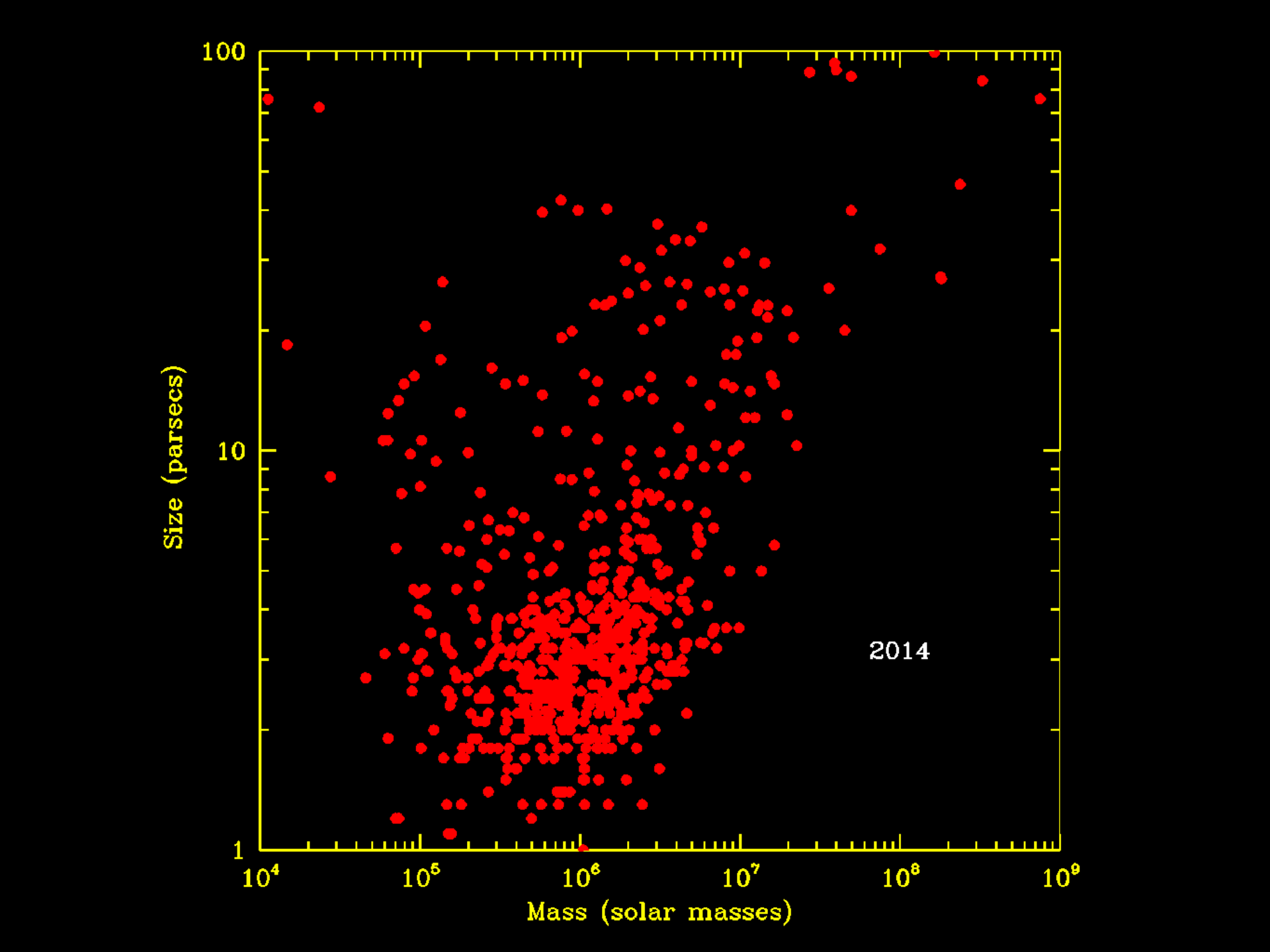
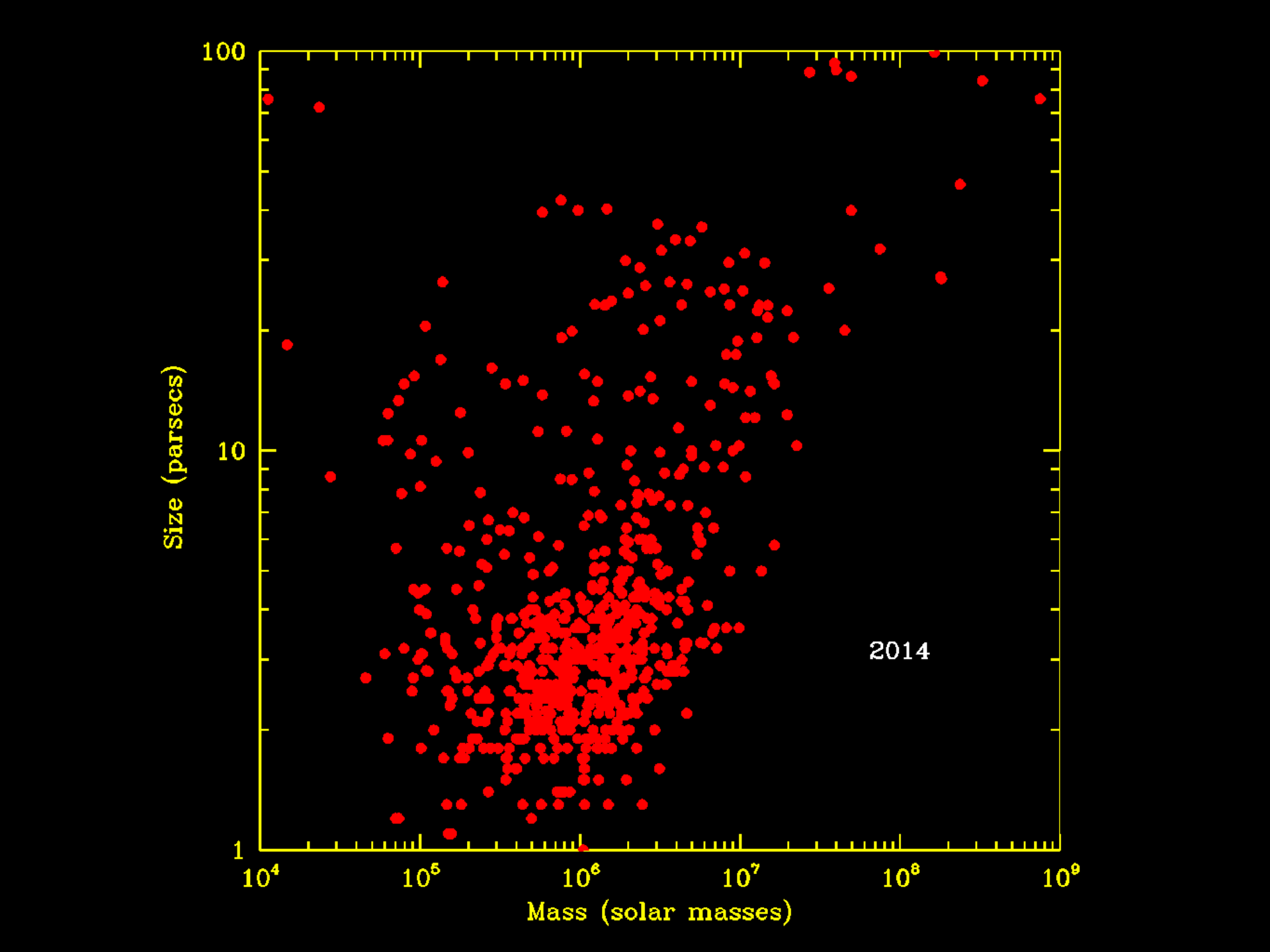
10^5
10^6
10^7
10^8
10^9
Mass (solar masses)
2014


100
10
1
Size (parsecs)
10^4
10^5
10^6
10^7
10^8
10^9
Mass (solar masses)
2014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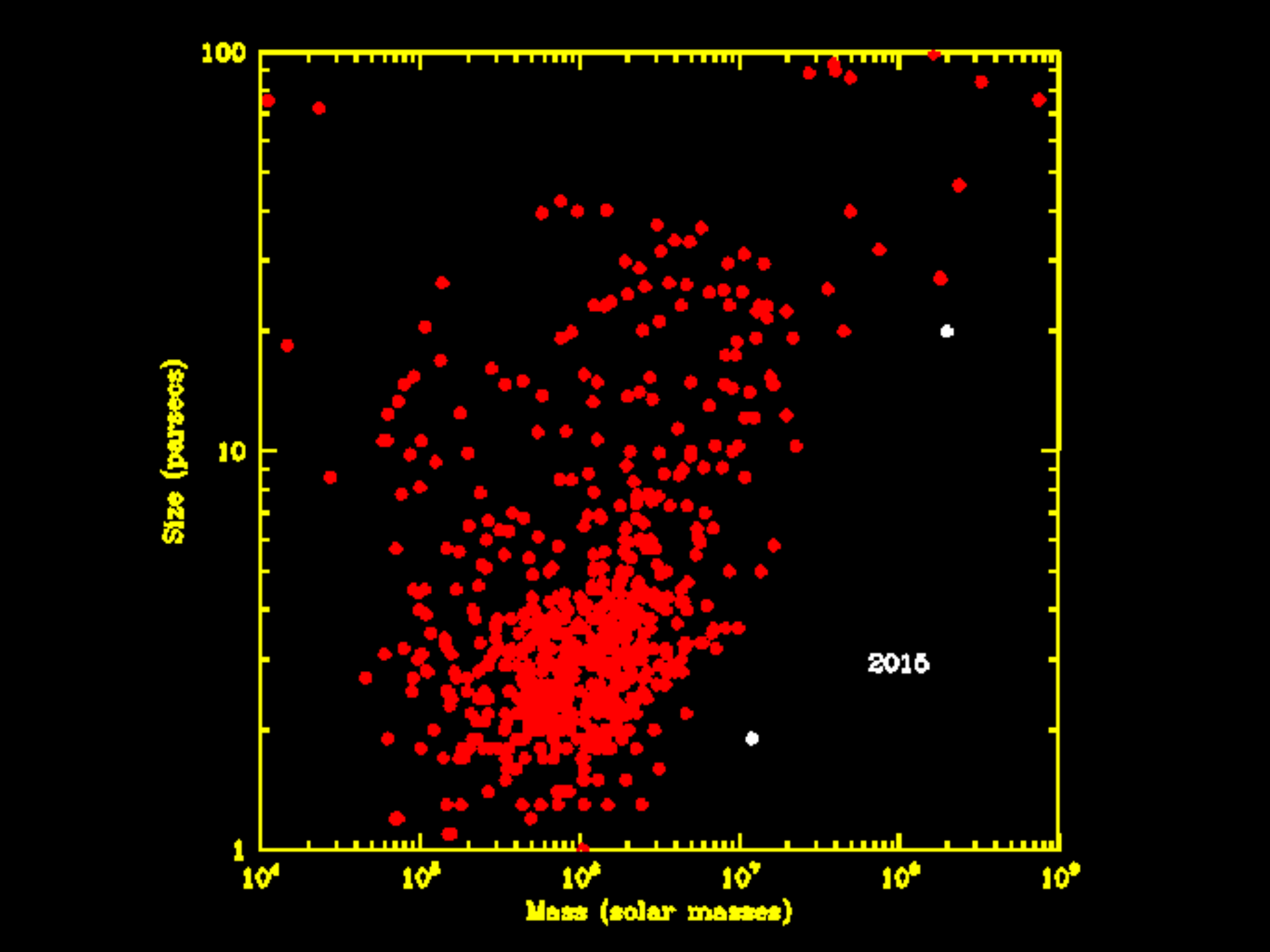
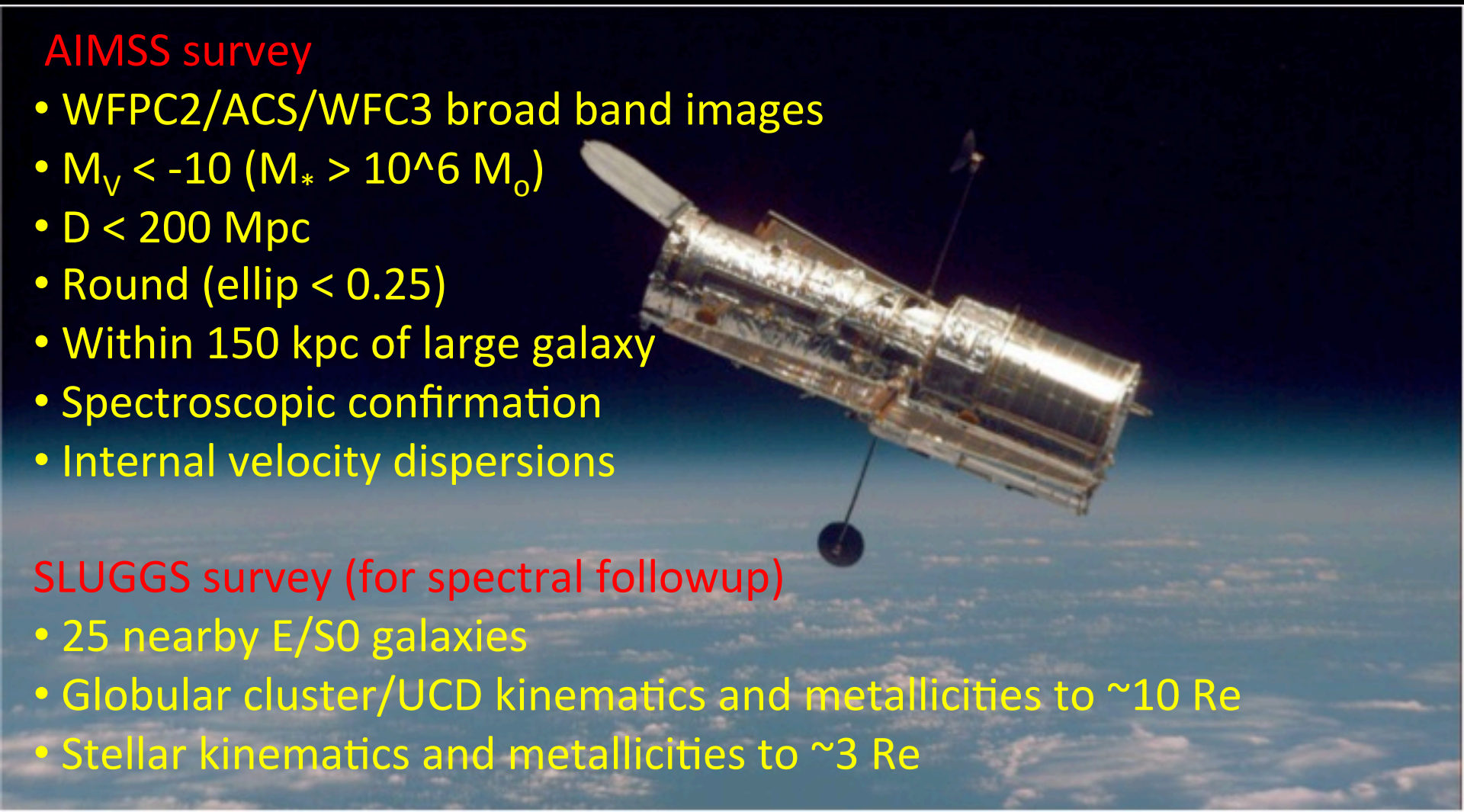
10
1
Size (parsecs)
10^4
10^5
10^6
10^7
10^8
10^9
Mass (solar masses)
2014


100
10
1
Size (parsecs)
10^4
10^5
10^6
10^7
10^8
10^9
Mass (solar masses)
2015

Small stellar systems in the HST archive
Norris et al. 2014 and Forbes et al. 2014

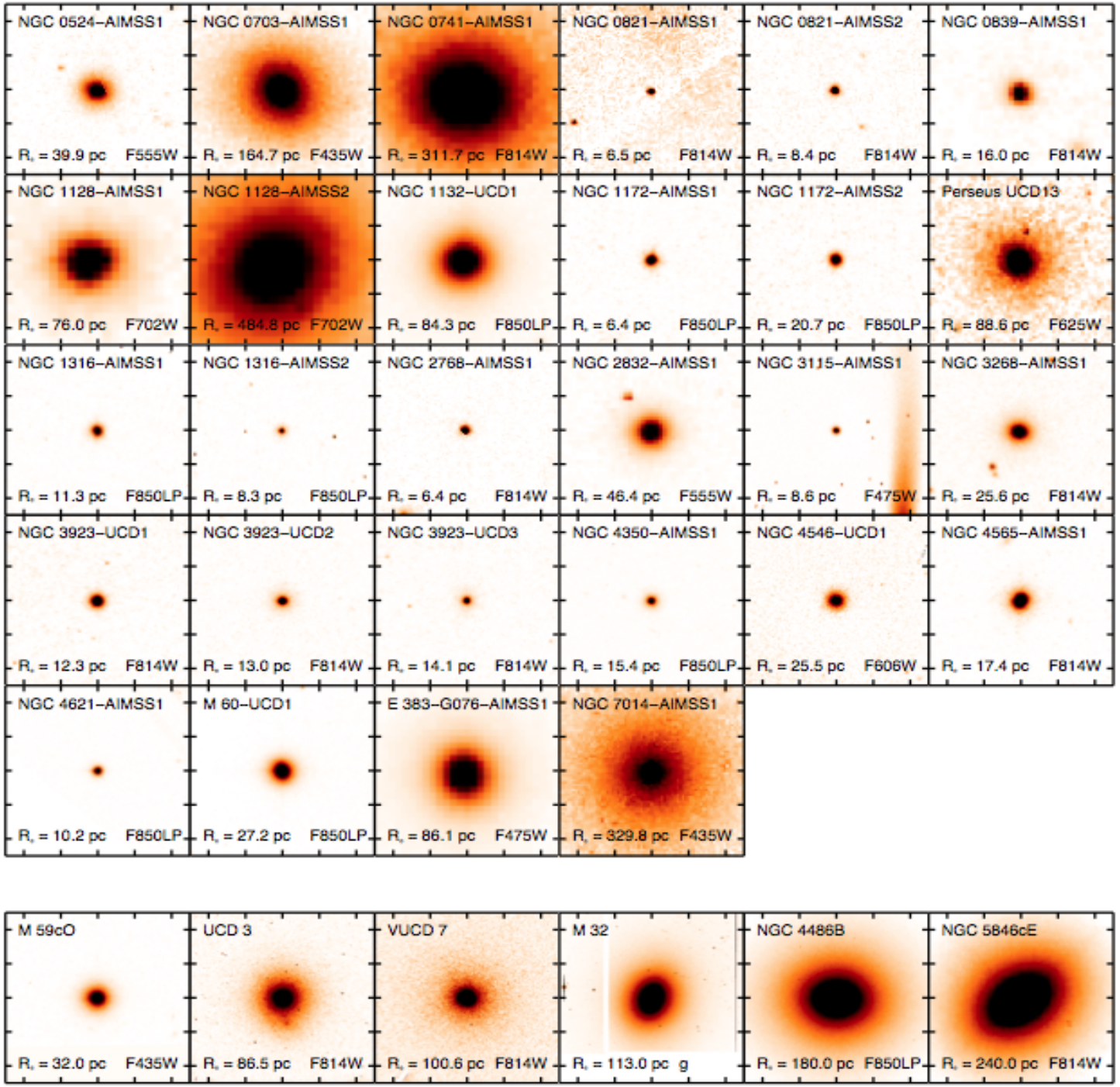


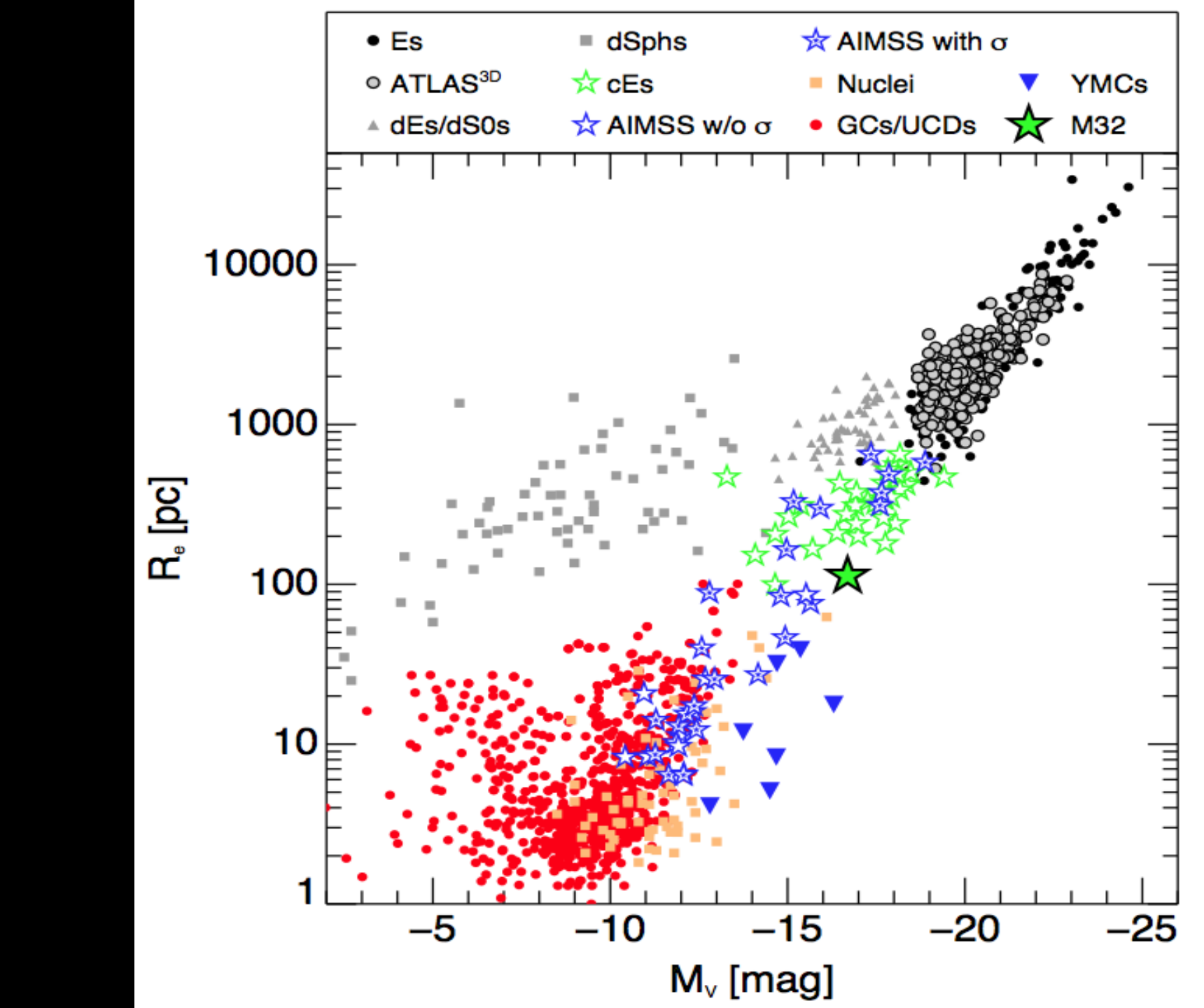
AIMSS survey

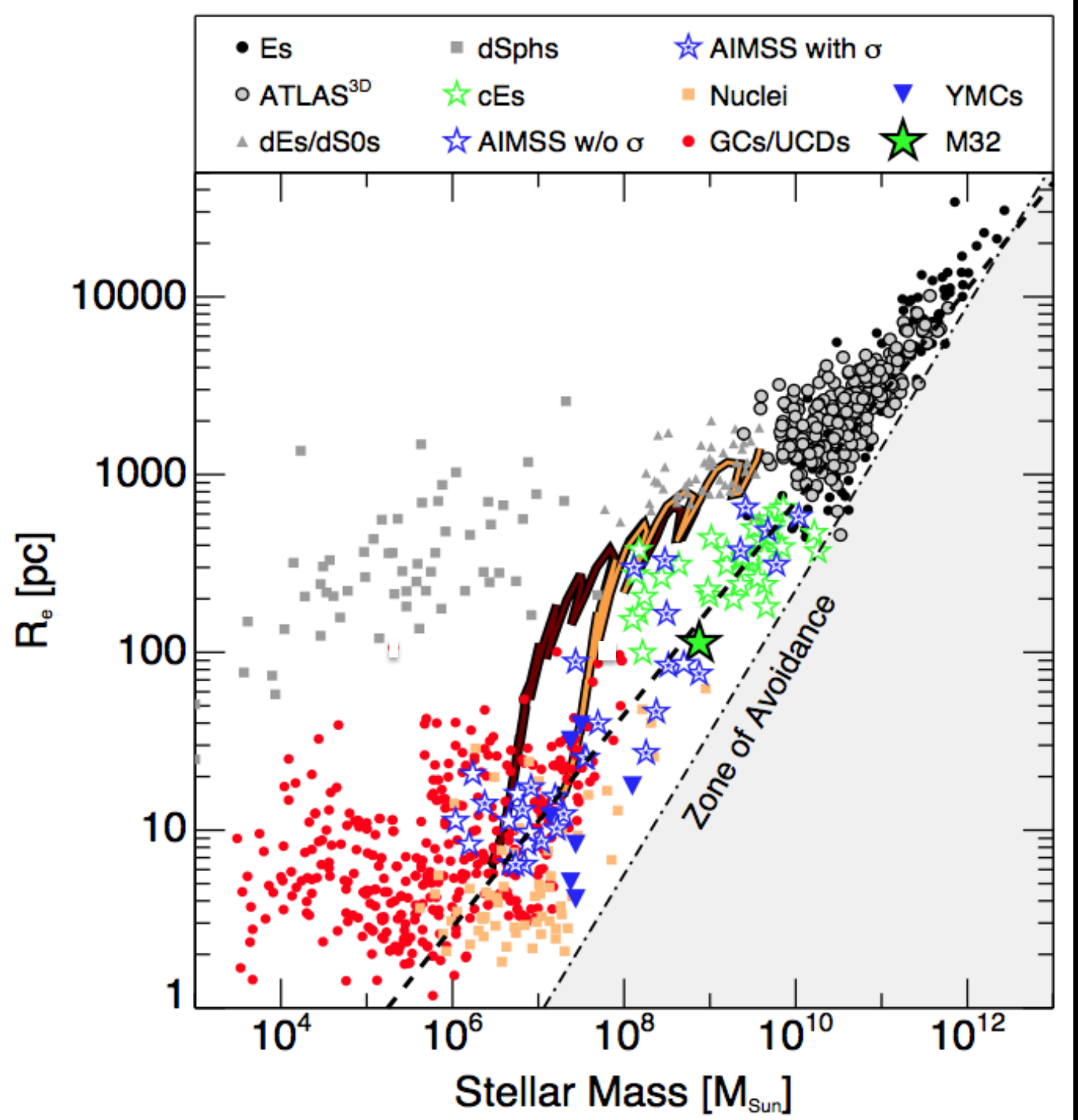
- WFPC2/ACS/WFC3 broad band images
- M_V < -10 (M_* > 10^6 M_o)
- D < 200 Mpc
- Round (ellip < 0.25)
- Within 150 kpc of large galaxy
- Spectroscopic confirmation
- Internal velocity dispersions

SLUGGS survey (for spectral followup)

- 25 nearby E/S0 galaxies
- Globular cluster/UCD kinematics and metallicities to ~10 Re
- Stellar kinematics and metallicities to ~3 Re

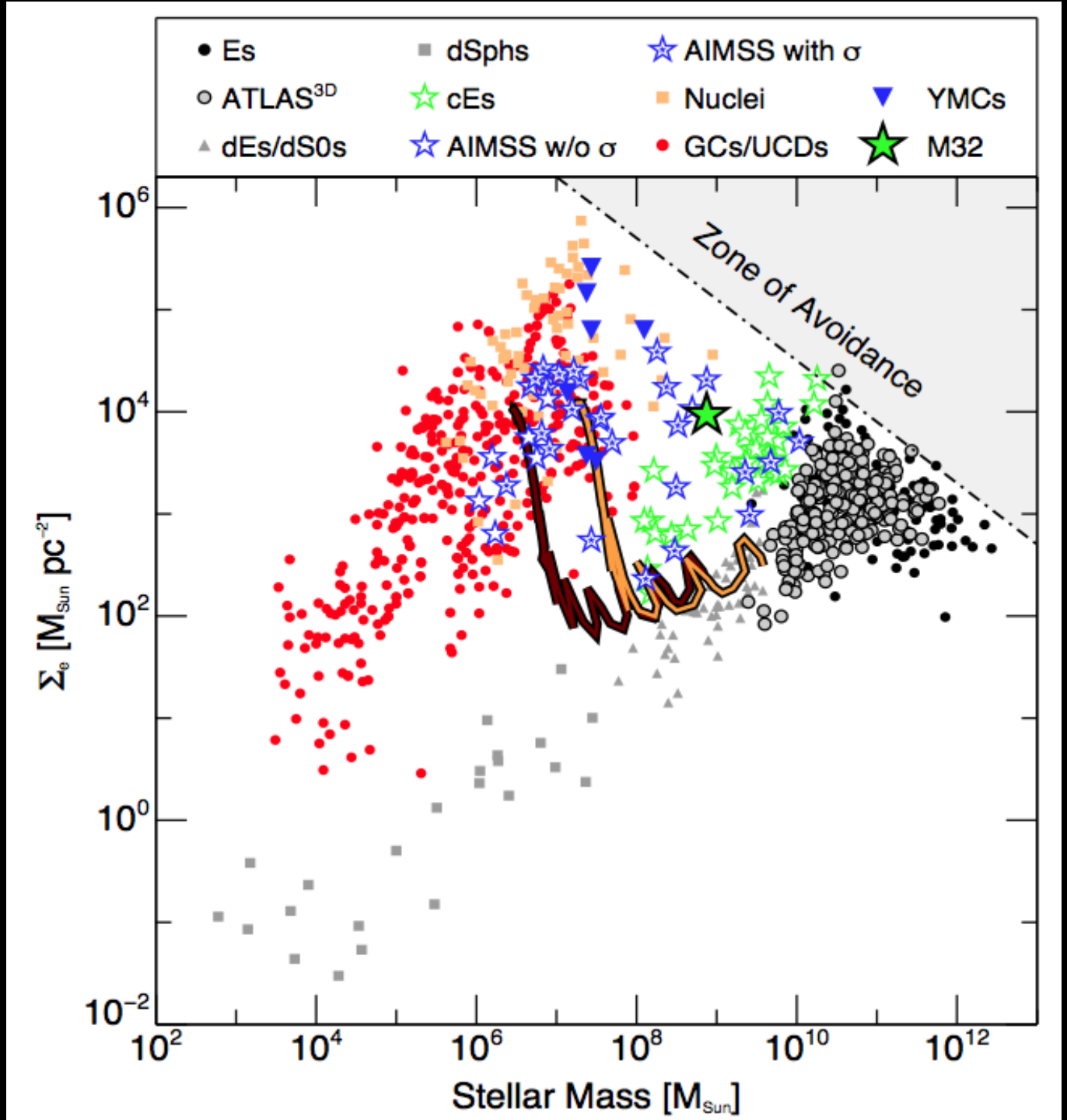

NGC 0524–AIMSS1
R$_e$ = 39.9 pc F555W
NGC 0703–AIMSS1
R$_e$ = 164.7 pc F435W
NGC 0741–AIMSS1
R$_e$ = 311.7 pc F814W
NGC 0821–AIMSS1
R$_e$ = 6.5 pc F814W
NGC 0821–AIMSS2
R$_e$ = 8.4 pc F814W
NGC 0839–AIMSS1
R$_e$ = 16.0 pc F814W
NGC 1128–AIMSS1
R$_e$ = 76.0 pc F702W
NGC 1128–AIMSS2
R$_e$ = 484.8 pc F702W
NGC 1132–UCD1
R$_e$ = 84.3 pc F850LP
NGC 1172–AIMSS1
R$_e$ = 6.4 pc F850LP
NGC 1172–AIMSS2
R$_e$ = 20.7 pc F850LP
Perseus UCD13
R$_e$ = 88.6 pc F625W
NGC 1316–AIMSS1
R$_e$ = 11.3 pc F850LP
NGC 1316–AIMSS2
R$_e$ = 8.3 pc F850LP
NGC 2768–AIMSS1
R$_e$ = 6.4 pc F814W
NGC 2832–AIMSS1
R$_e$ = 46.4 pc F555W
NGC 3115–AIMSS1
R$_e$ = 8.6 pc F475W
NGC 3268–AIMSS1
R$_e$ = 25.6 pc F814W
NGC 3923–UCD1
R$_e$ = 12.3 pc F814W
NGC 3923–UCD2
R$_e$ = 13.0 pc F814W
NGC 3923–UCD3
R$_e$ = 14.1 pc F814W
NGC 4350–AIMSS1
R$_e$ = 15.4 pc F850LP
NGC 4546–UCD1
R$_e$ = 25.5 pc F606W
NGC 4565–AIMSS1
R$_e$ = 17.4 pc F814W
NGC 4621–AIMSS1
R$_e$ = 10.2 pc F850LP
M 60–UCD1
R$_e$ = 27.2 pc F850LP
E 383–G076–AIMSS1
R$_e$ = 86.1 pc F475W
NGC 7014–AIMSS1
R$_e$ = 329.8 pc F435W
M 59cO
R$_e$ = 32.0 pc F435W
UCD 3
R$_e$ = 86.5 pc F814W
VUCD 7
R$_e$ = 100.6 pc F814W
M 32
R$_e$ = 113.0 pc g
NGC 4486B
R$_e$ = 180.0 pc F850LP
NGC 5846cE
R$_e$ = 240.0 pc F814W

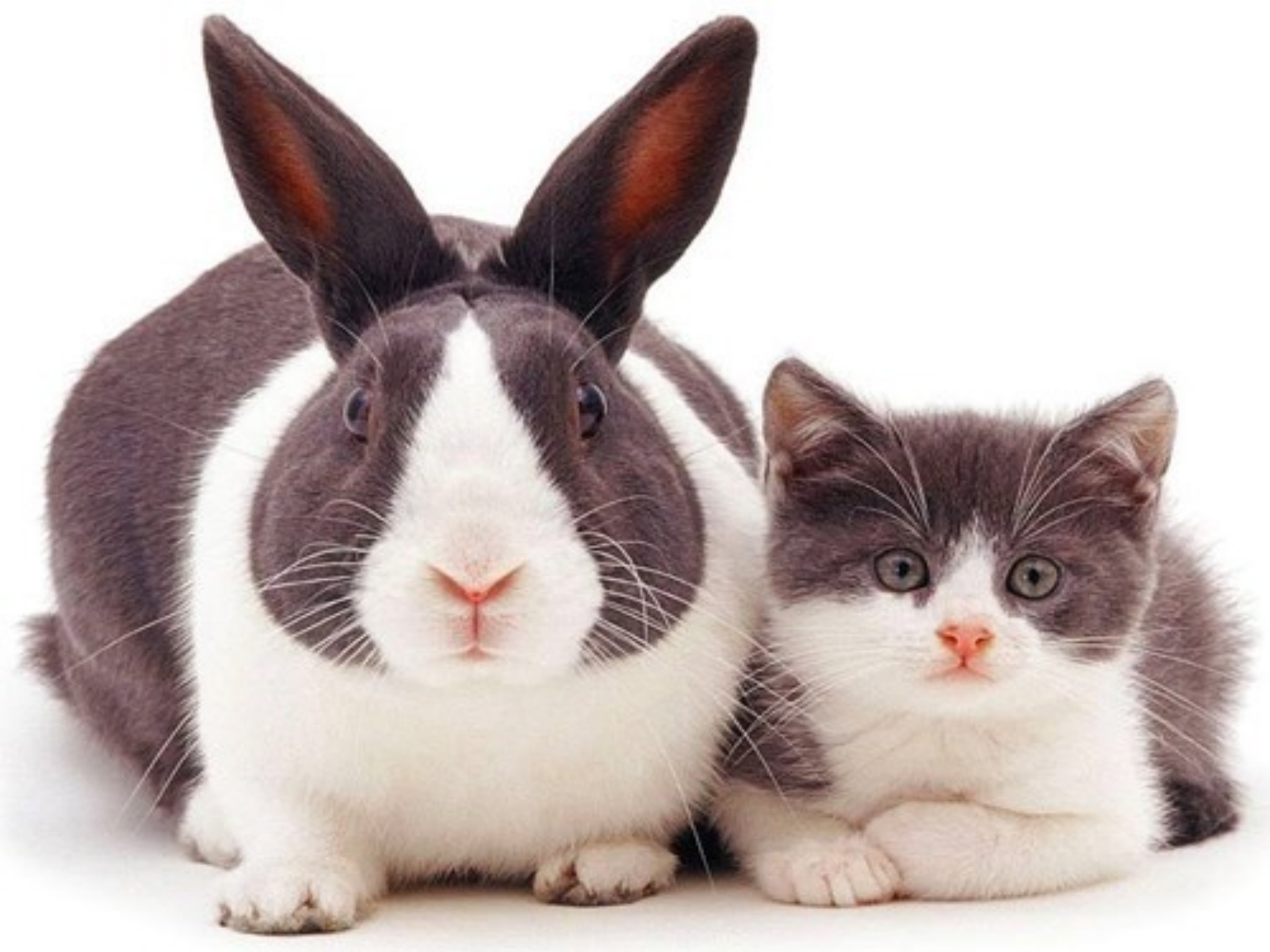

Es
dSphs
AIMSS with σ
ATLAS3D
cEs
Nuclei
YMCs
dEs/dS0s
AIMSS w/o σ
GCs/UCDs
M32
10000
1000
100
10
1
Re [pc]
−5
−10
−15
−20
−25
Mv [mag]

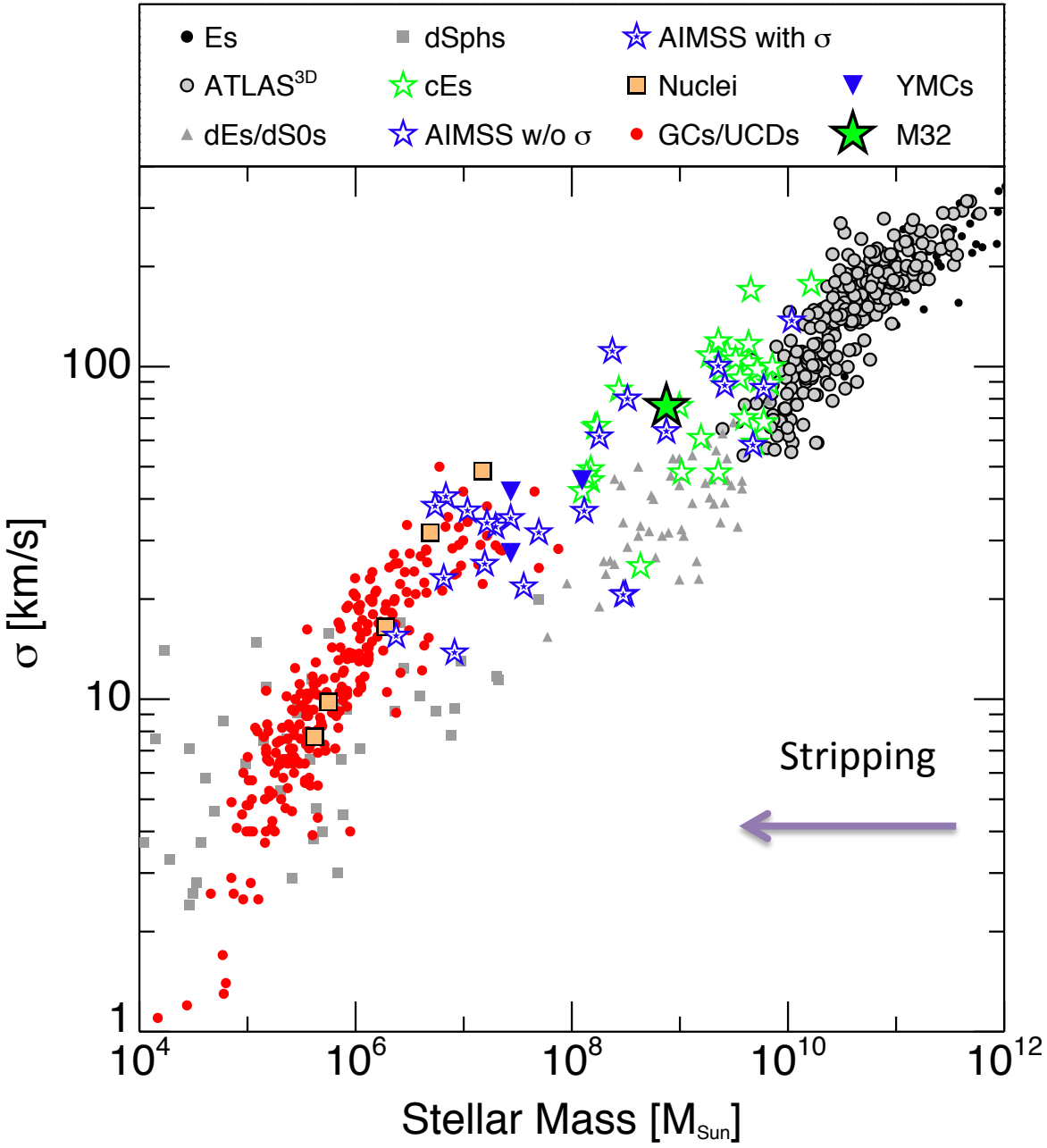


UCDs:

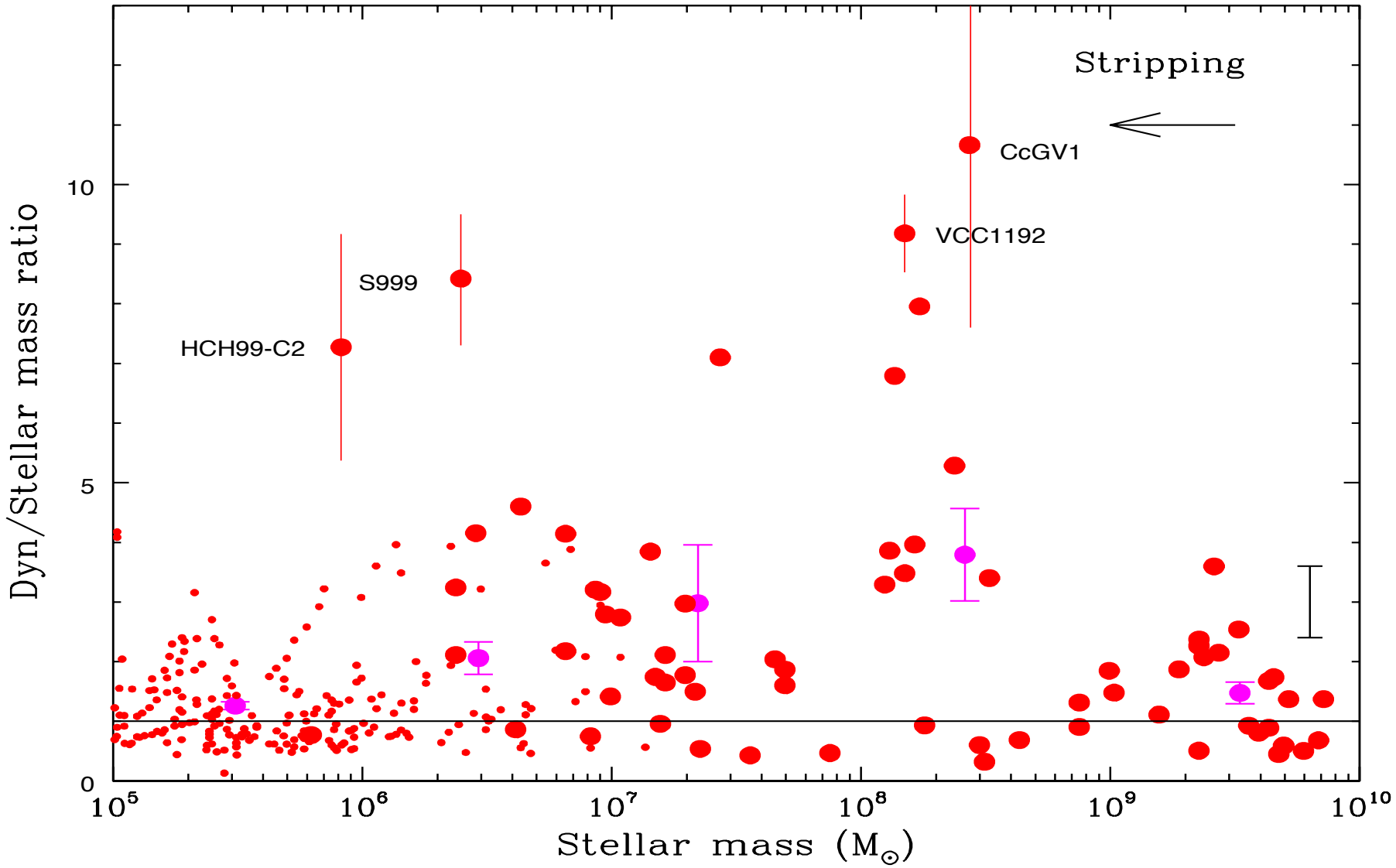
Stripped Galaxies OR Massive Star clusters


Es
dSphs
AIMSS with σ
ATLAS3D
cEs
Nuclei
YMCs
dEs/dS0s
AIMSS w/o σ
GCs/UCDs
M32
Zone of Avoidance
Σe [MSun pc−2]
Stellar Mass [MSun]
10^6
10^4
10^2
10^0
10^−2
10^2
10^4
10^6
10^8
10^10
10^12

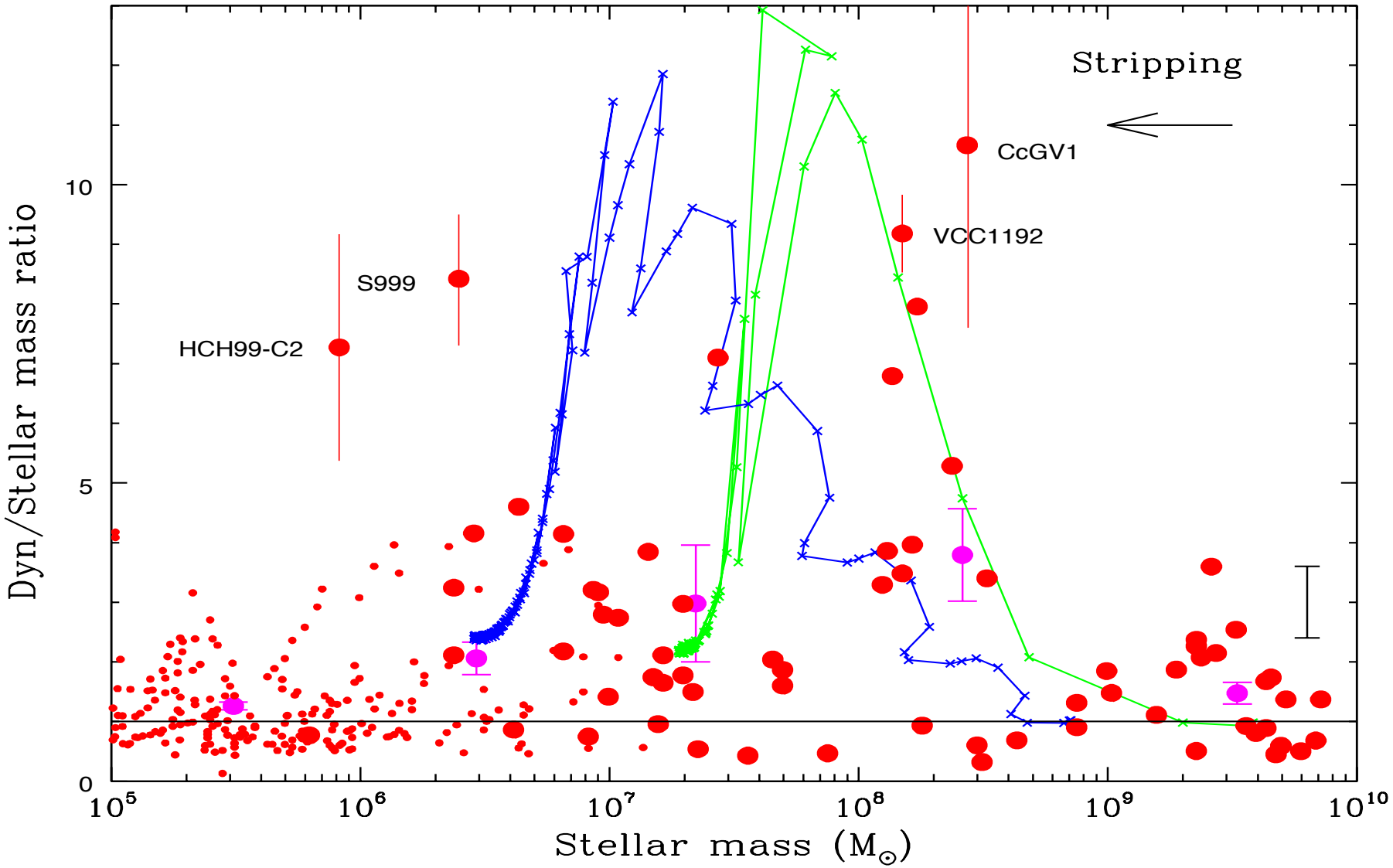



Es
dSphs
AIMSS with σ
ATLAS3D
cEs
Nuclei
YMCs
dEs/dS0s
AIMSS w/o σ
GCs/UCDs
M32
100
10
1
σ [km/s]
Stripping
10^4
10^6
10^8
10^10
10^12
Stellar Mass [M_Sun]

Mass ratio = K σ_0^2 R_e / M_*



Mass ratio = $K\,\sigma_0^2\,R_e\,/\,M_*$



Why do UCDs have elevated mass ratios compared to GCs?

- Spurious measurements

Eg massive UCD M59c0

Literature σ = 48 +/- 5 km/s (SDSS fibre)

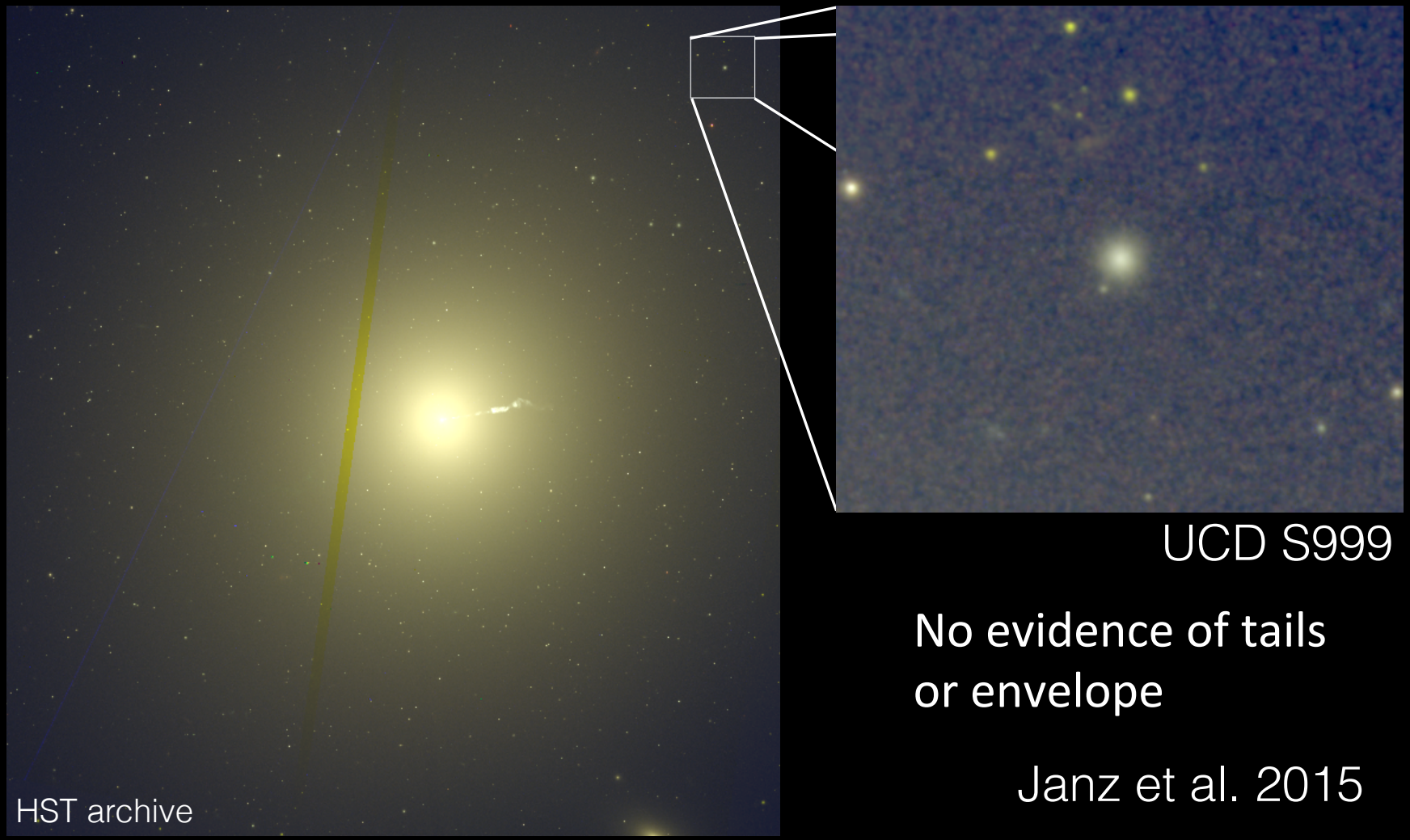
Our σ = 25.7+/- 2.2 km/s (longslit)

So mass ratio down by 3.5x

Object no longer has elevated mass ratio

How elevated is the dynamical-to-stellar mass ratio of the ultracompact dwarf S999?

M87



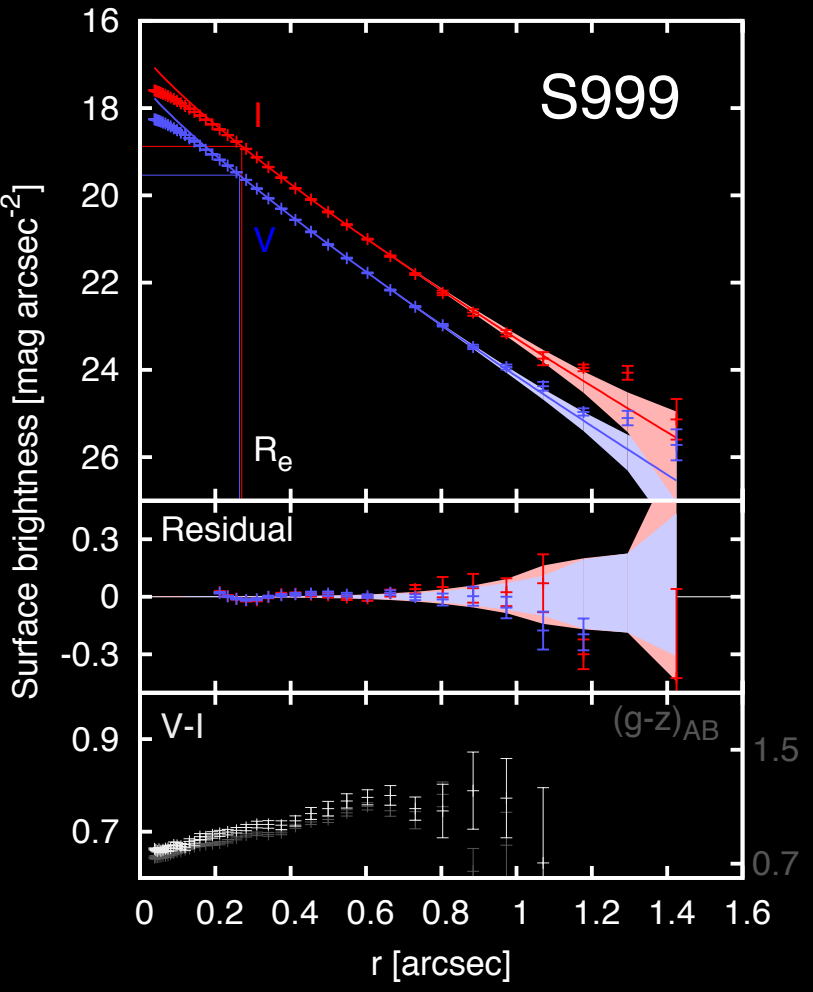
HST archive

UCD S999

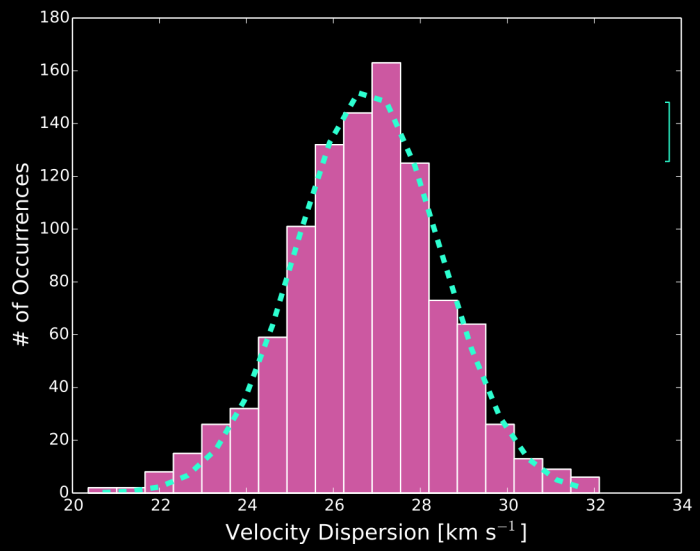
No evidence of tails or envelope

Janz et al. 2015

How elevated is the dynamical-to-stellar mass ratio of the ultracompact dwarf S999?



$\sigma = 27 \pm 2$ km s^{-1}



Age $7.6^{+2.0}_{-1.6}$ [Z/H] $-0.95^{+0.12}_{-0.10}$

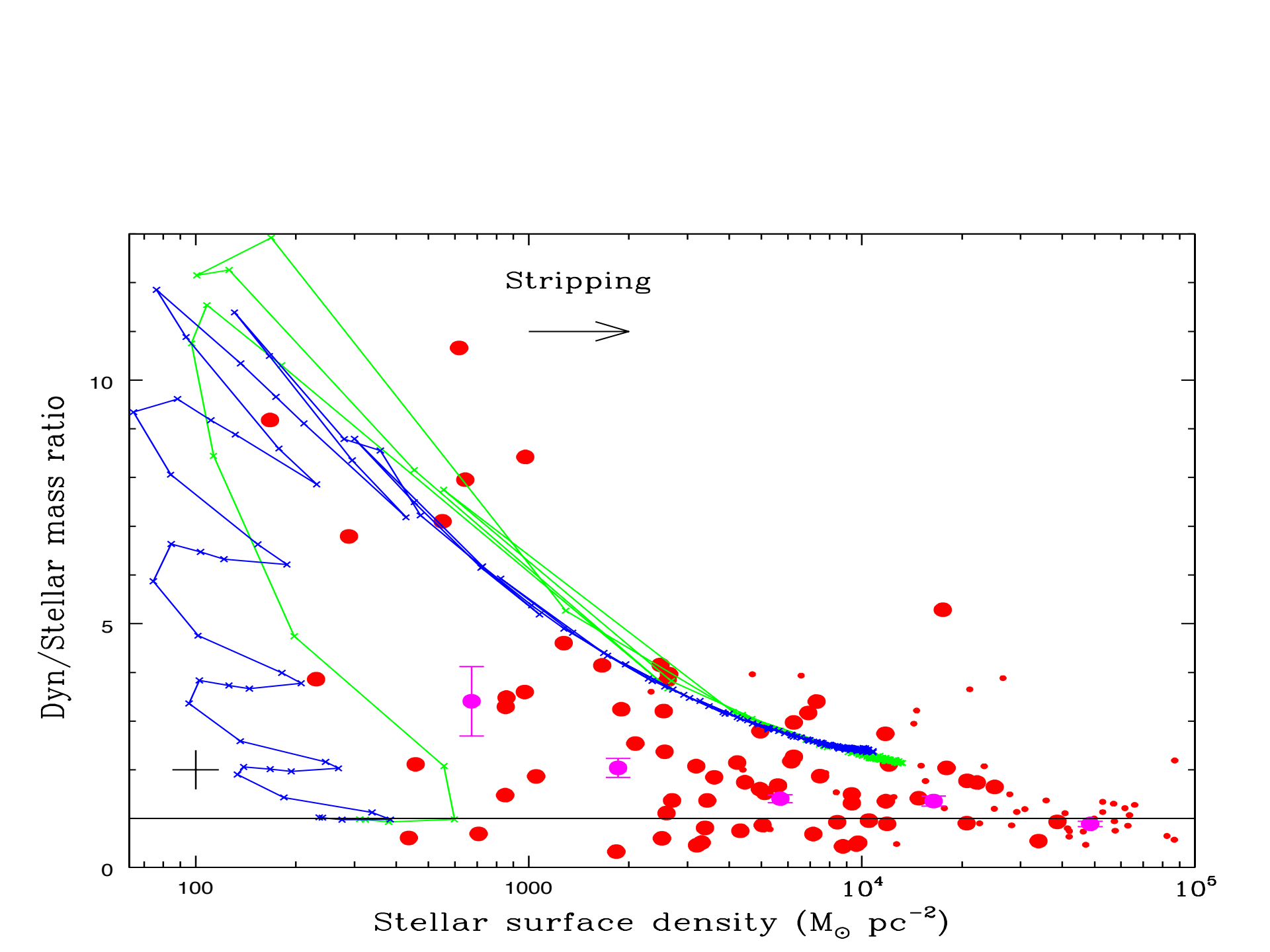
[α/Fe] $0.34^{+0.10}_{-0.12}$

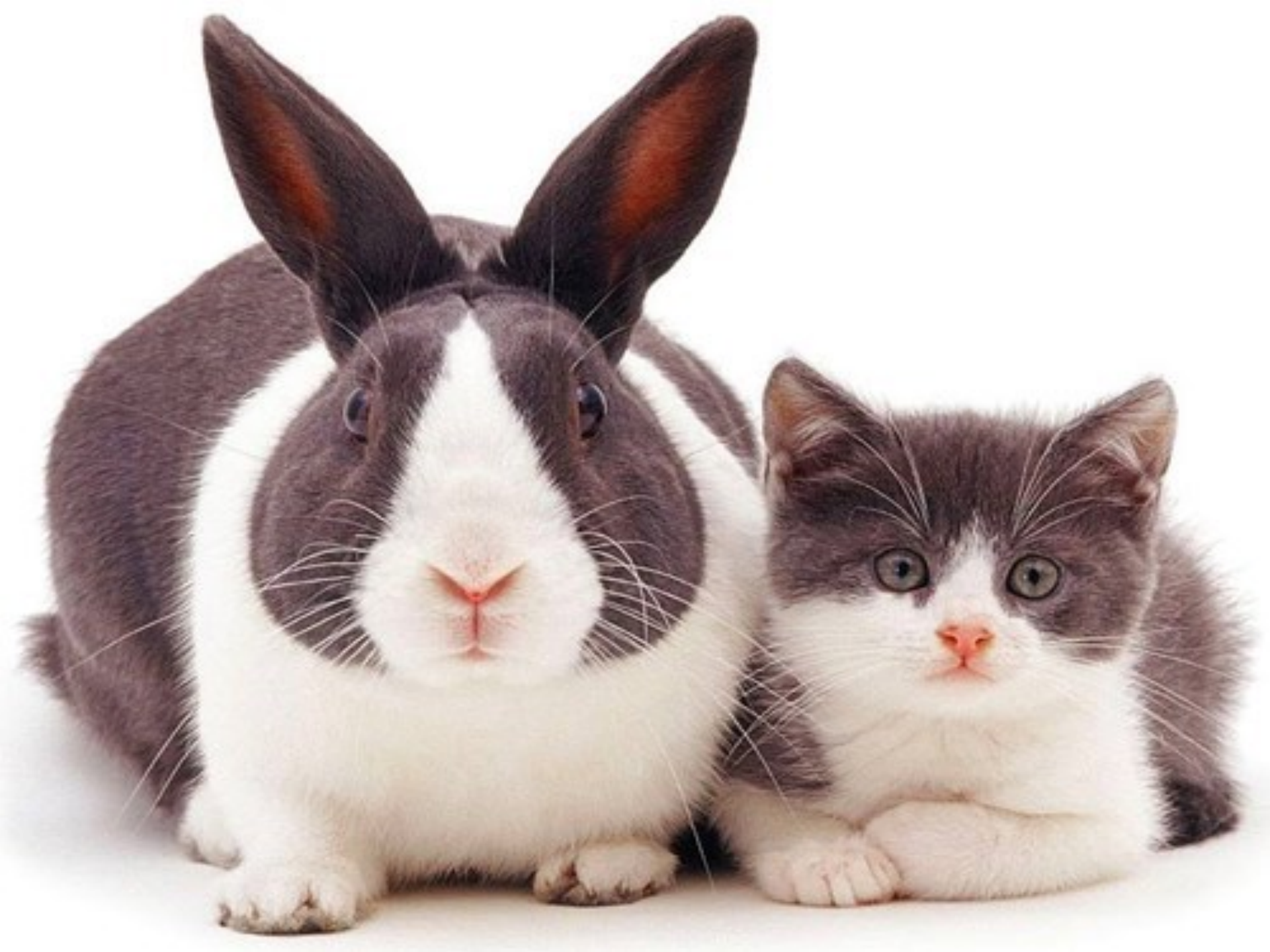
$5.6 < M_{dyn}/M_* < 11.2$

Janz et al. 2015

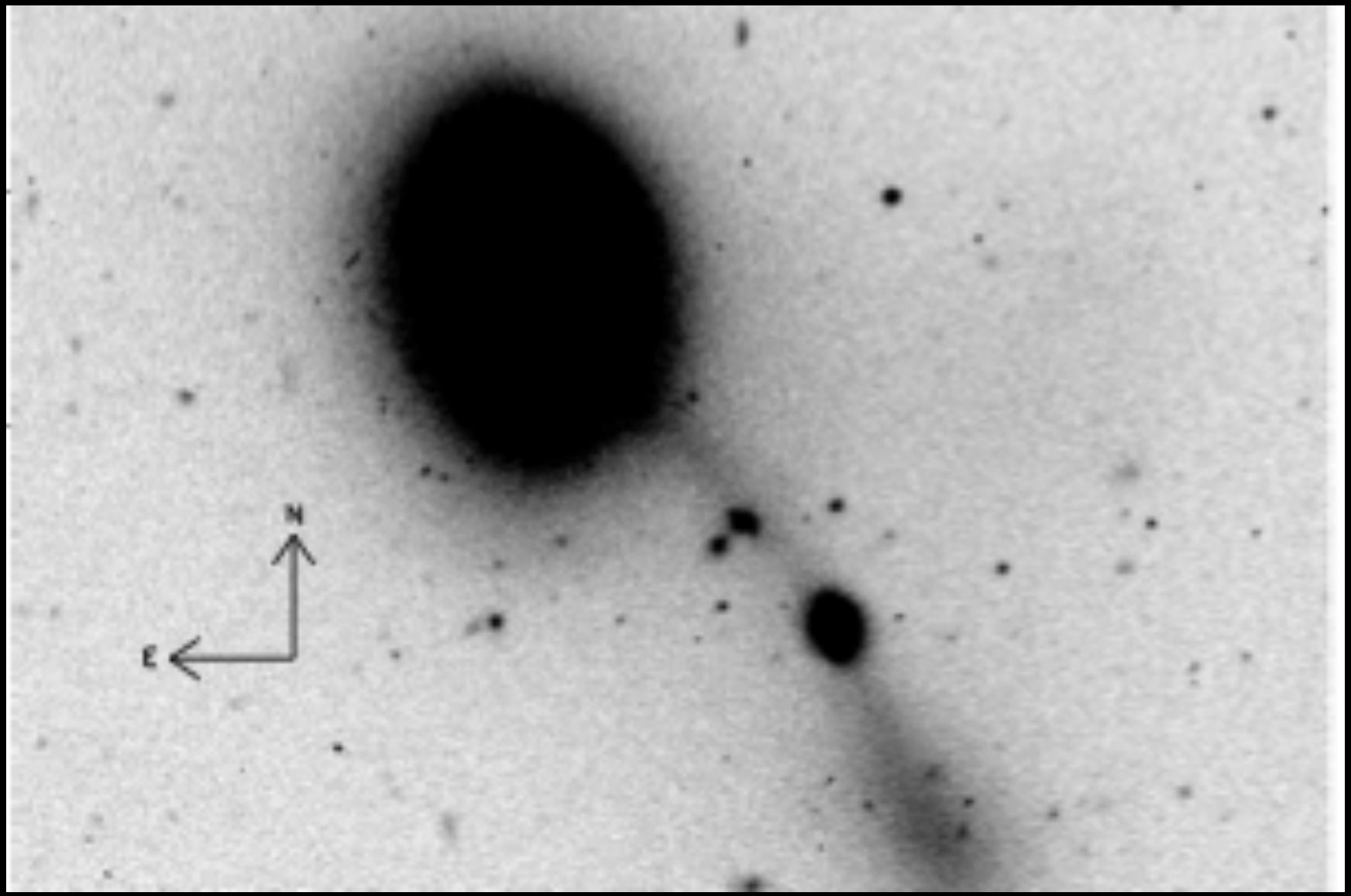
Why do UCDs have elevated mass ratios compared to GCs?

- Top-heavy or bottom-heavy IMF. Bottom-heavy IMFs observed when $\sigma > 200$ km/s
- Dark matter. Expect most dark matter to be stripped before any stars. UCDs have high stellar densities, ie little room for DM
- Central black holes. Detection of a 10^7 M_o black hole in the dense UCD M60-UCD1
- Tidal stripping. Extreme `apparent' mass ratios at early stages of stripping. Evidence?

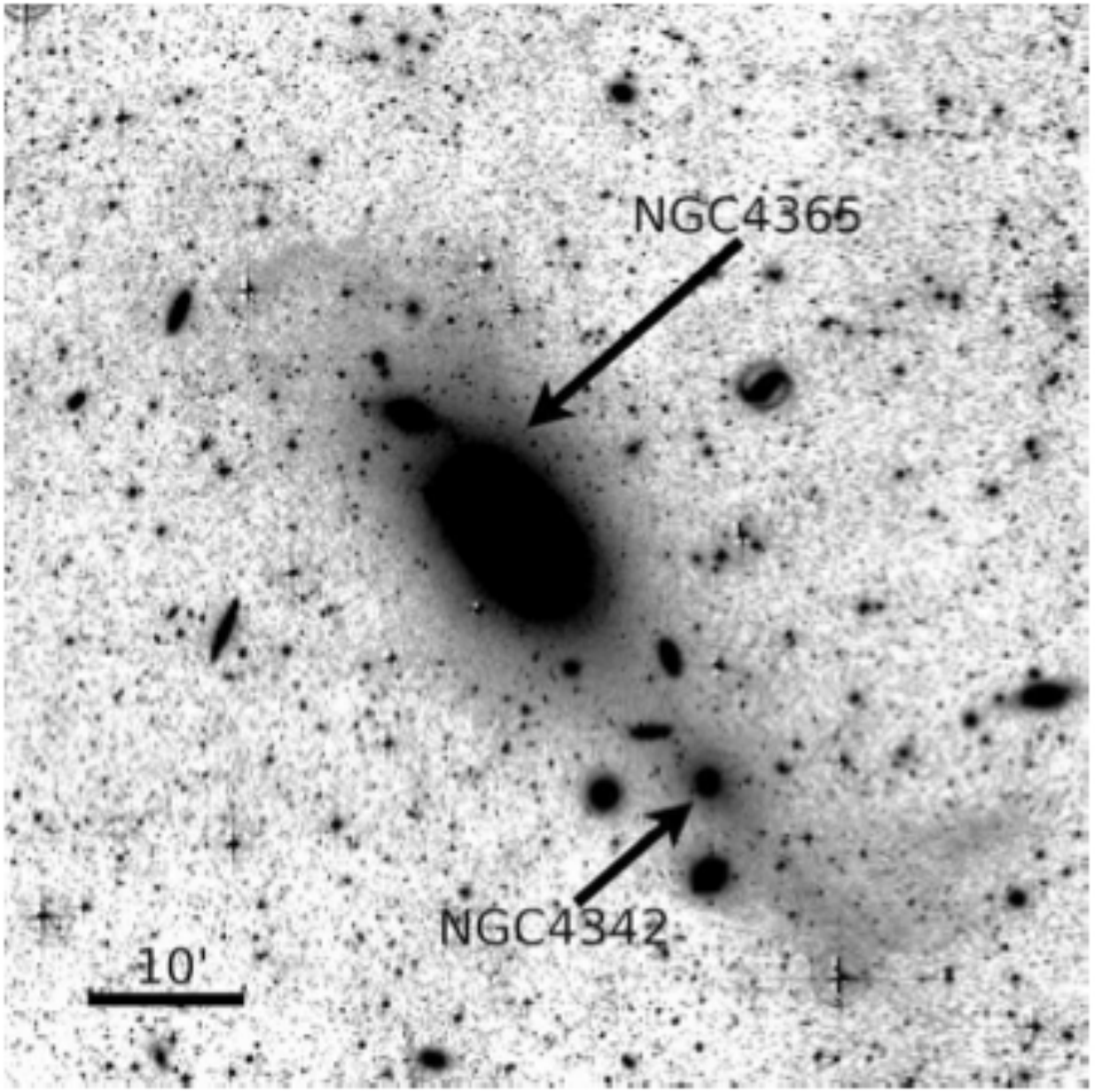

Stripping
Dyn/Stellar mass ratio
0
5
10
100
1000
10^4
10^5
Stellar surface density ($M_\odot$ pc^{-2})



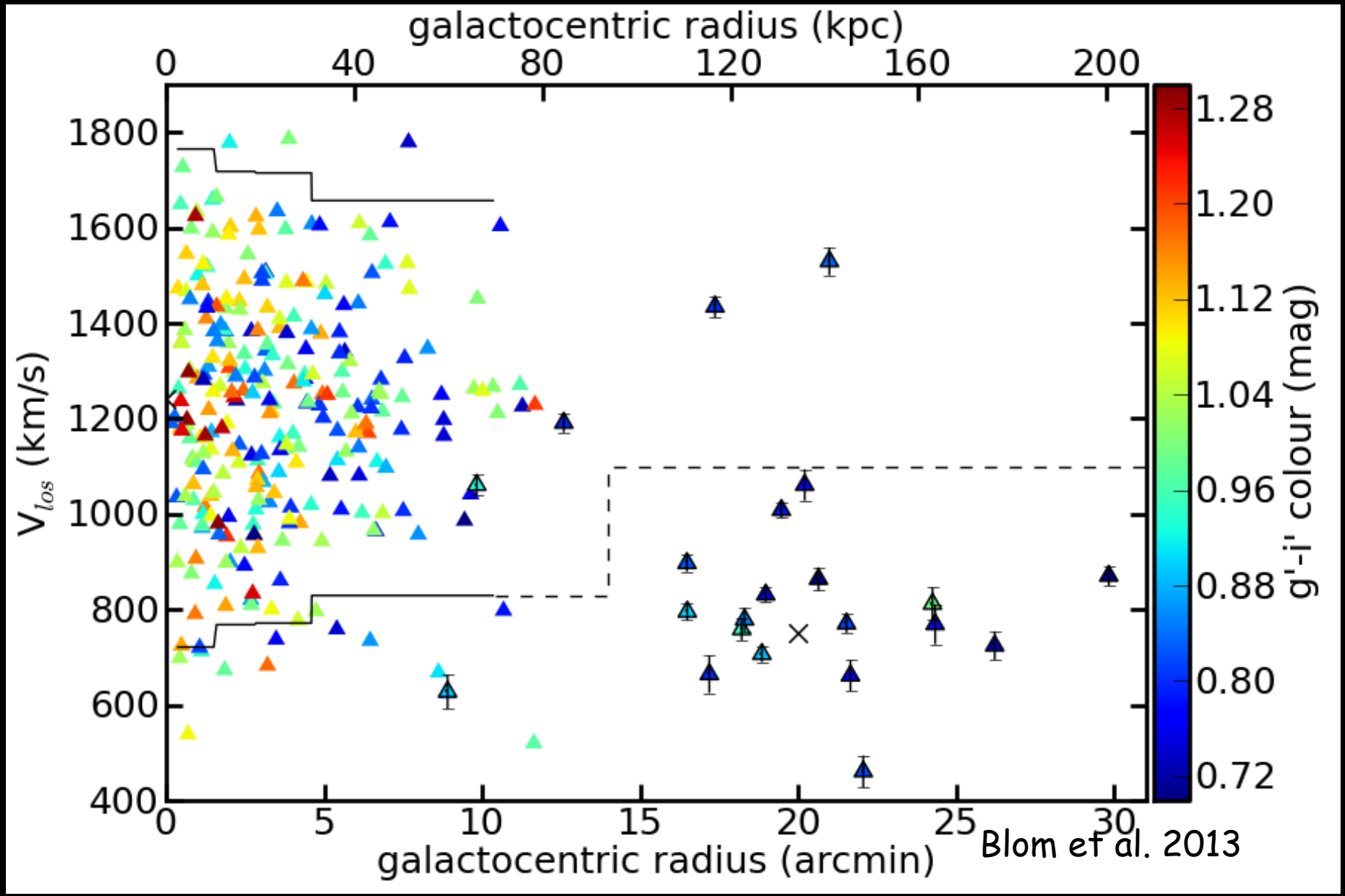
Compact elliptical in formation; Huxor et al. 2011



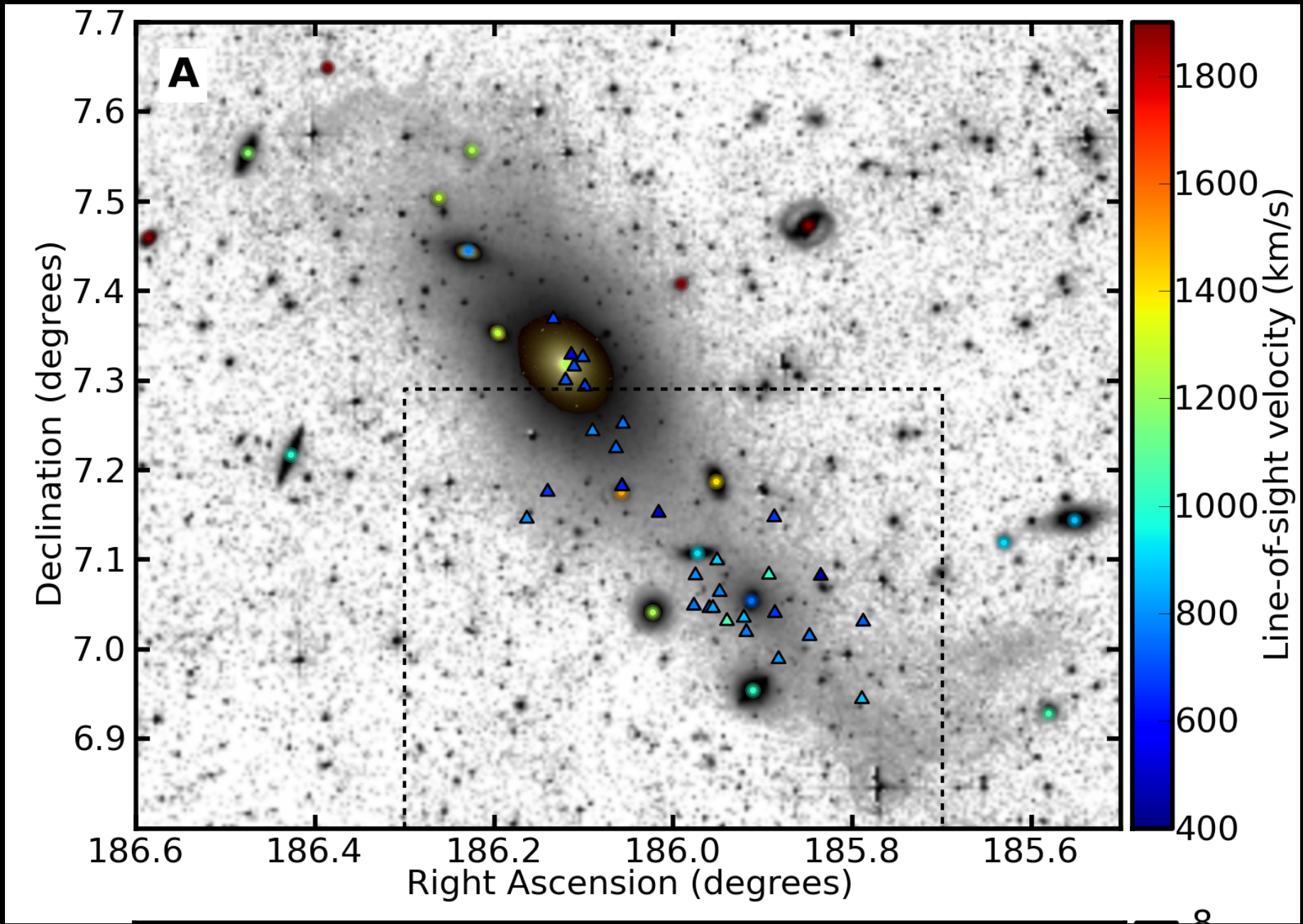
Compact elliptical with plume; Bogdan et al. 2012



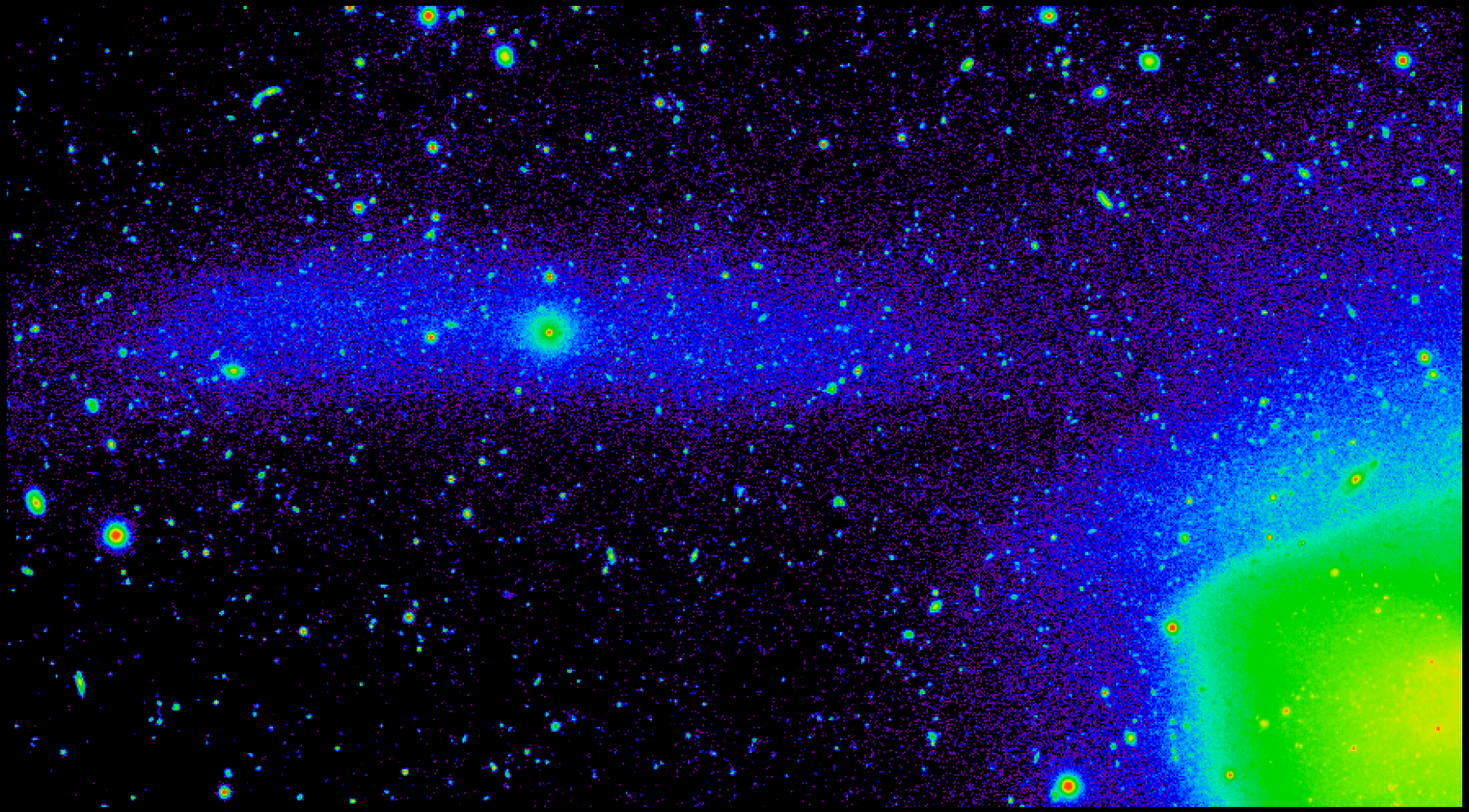
NGC 4365 Globular clusters



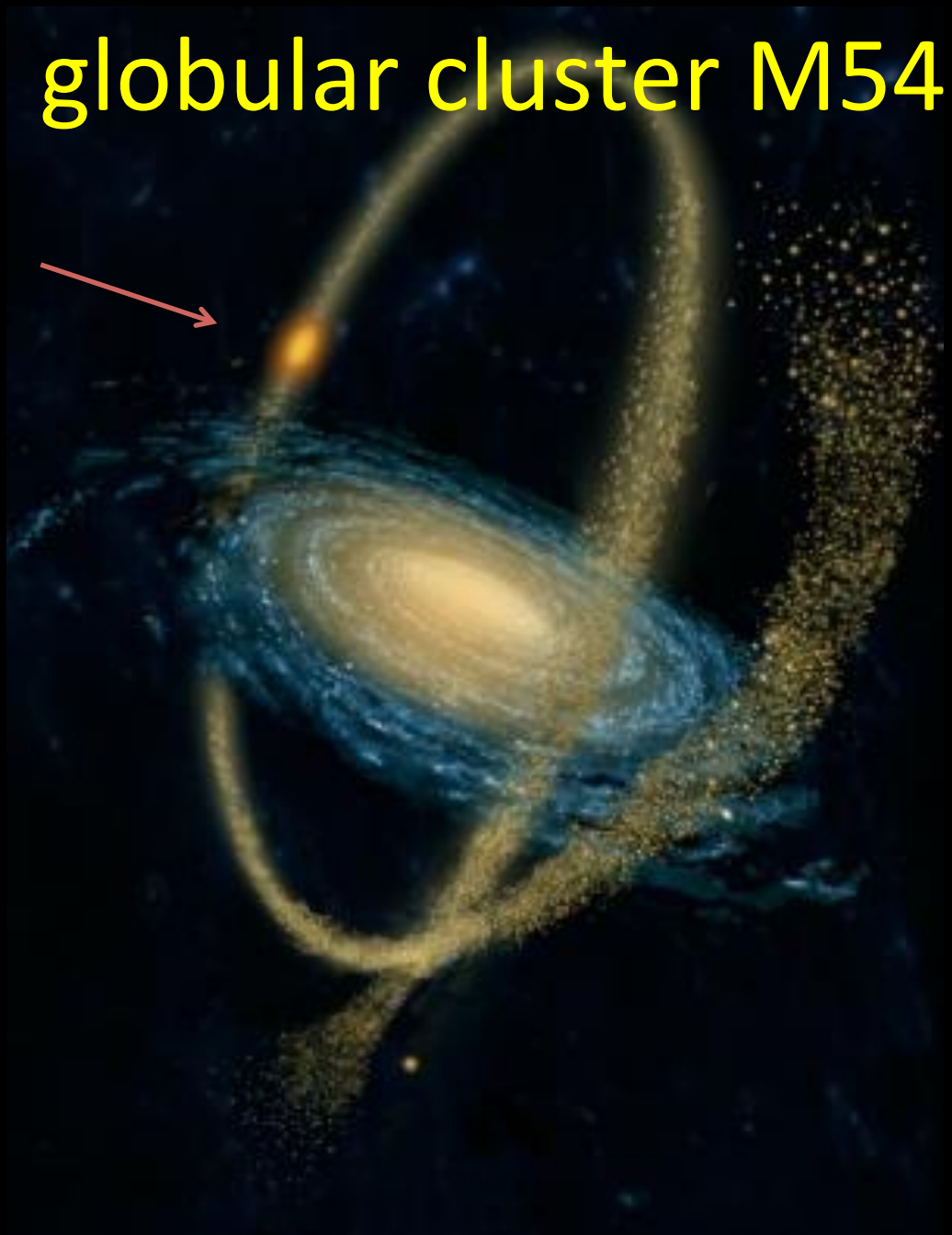
Globular clusters tracing plume; Blom et al. 2014



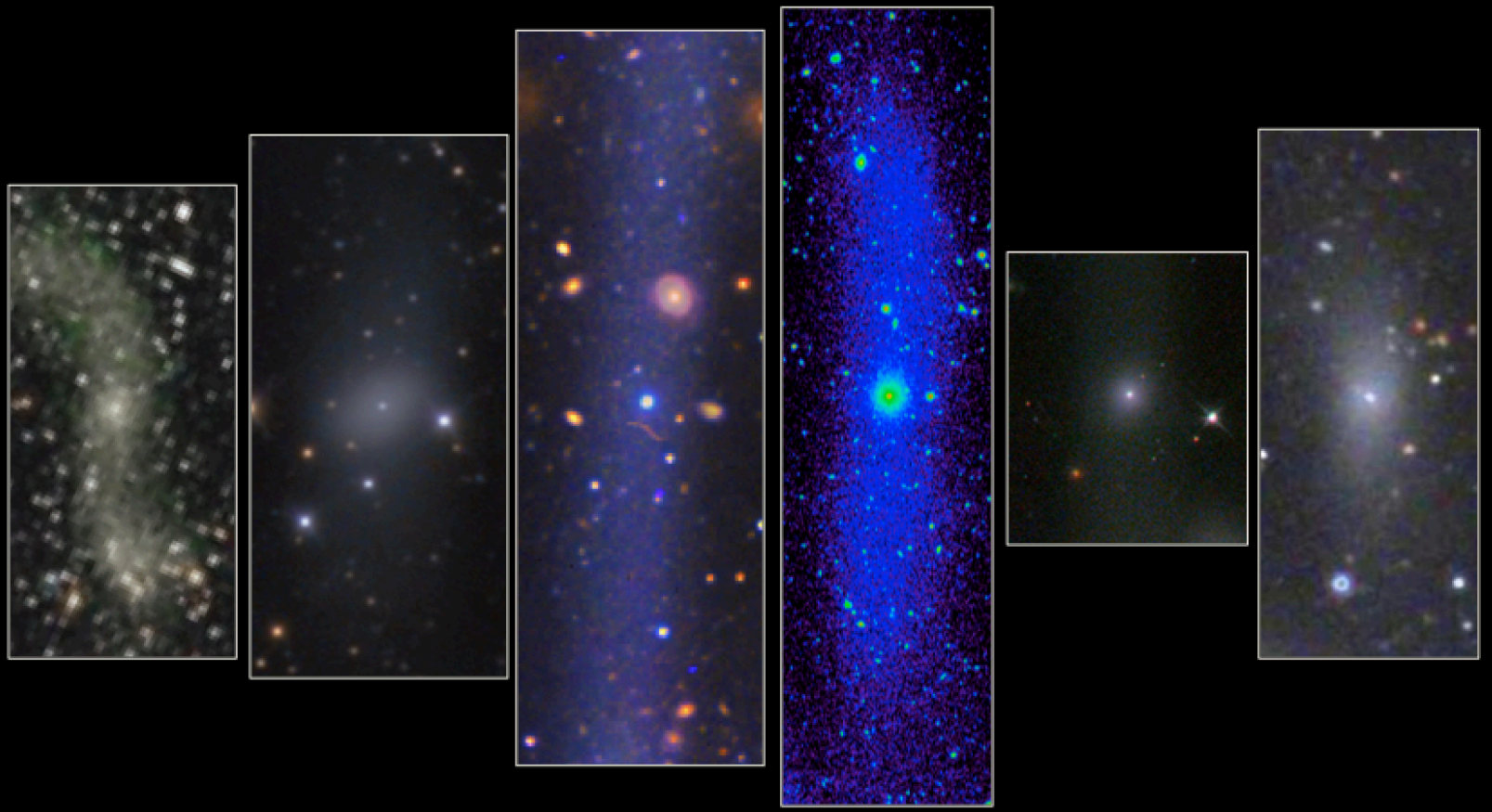
UCD in formation; Jennings et al. 2014

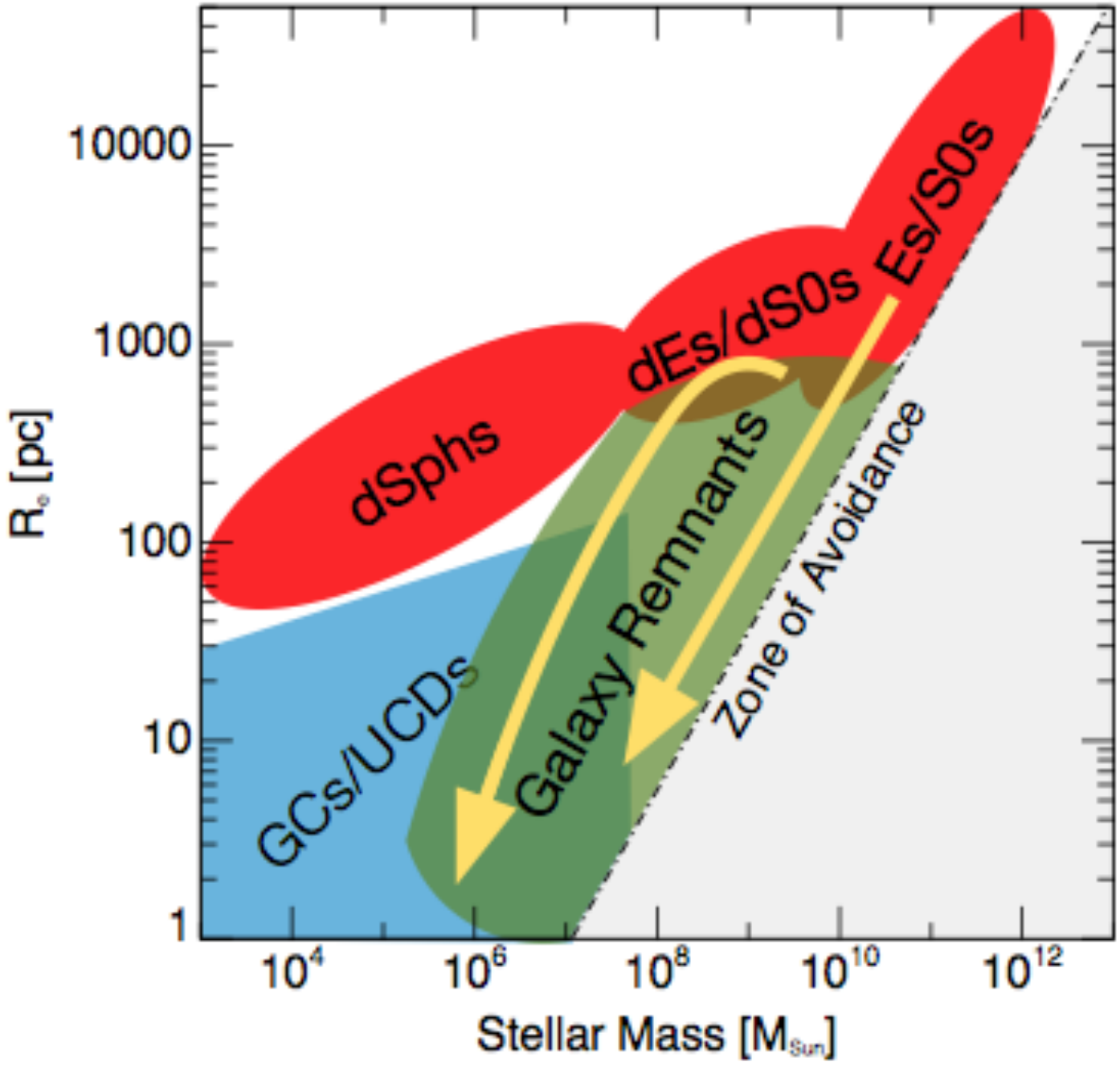


Sagittarius stream and its nucleus – the globular cluster M54



GCs and UCDs in Formation




10000
1000
100
10
1
R$_e$ [pc]
dSphs
dEs/dS0s
Es/S0s
GCs/UCDs
Galaxy Remnants
Zone of Avoidance
10^4
10^6
10^8
10^{10}
10^{12}
Stellar Mass [M$_{Sun}$]

Conclusions

- New types of compact stellar systems are still being discovered in the nearby Universe.
- Some formed via stripping: dE -> UCD, E -> cE
- UCDs have elevated dyn-to-stellar mass ratios (although some may be spurious, some are real eg S999)
- Massive black holes may be the cause (M60-UCD1 with a MBH has a low mass ratio)
- But cEs have mass ratios ~ 1, why ?