# The Symbiotic Star Population in Nearby Galaxies and its Tenuous Link with SNe Ia Events

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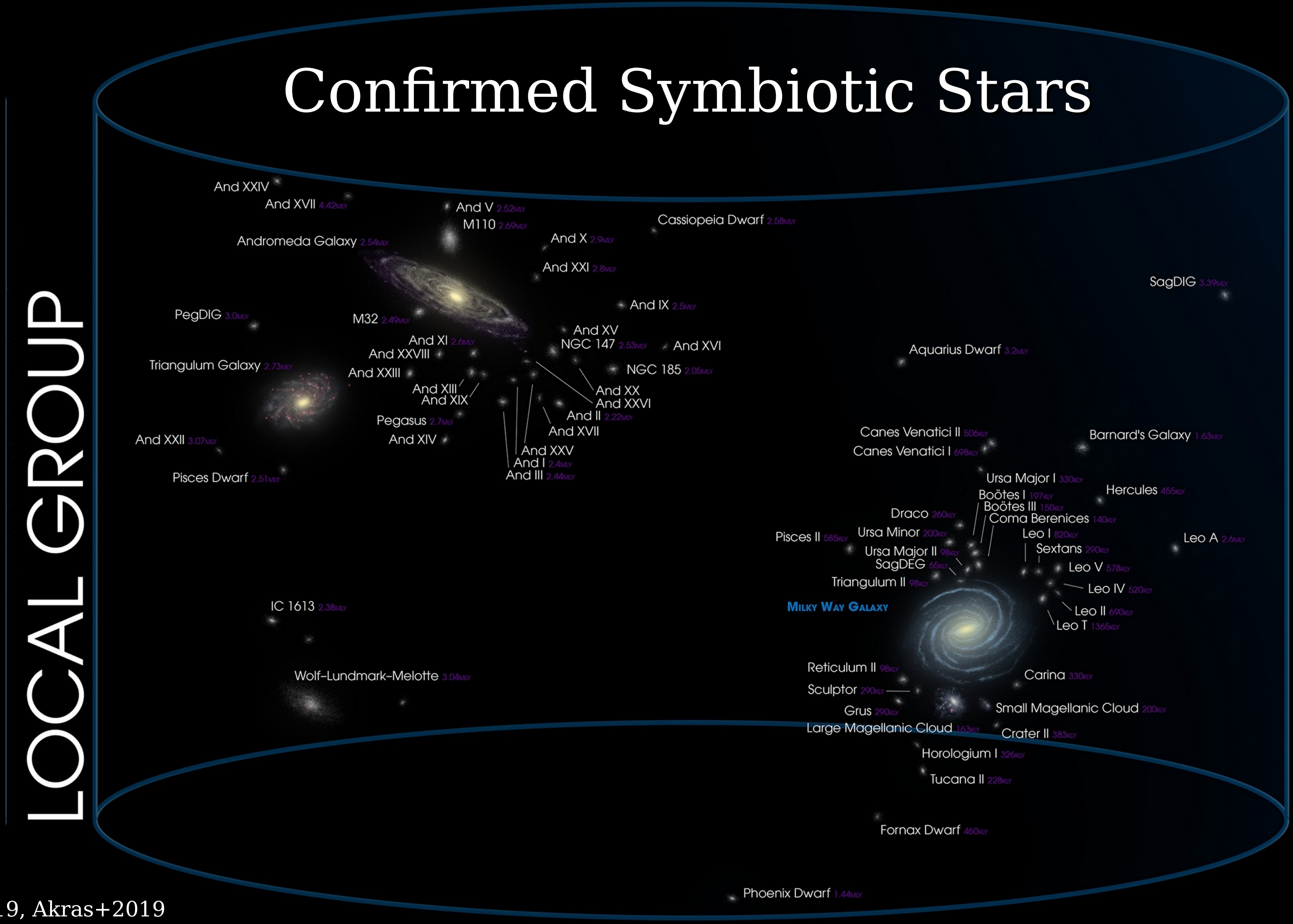
*Symbiotic Stars, Weird Novae, and Related Embarrassing Binaries – Prague, 2024*

# The Local Group Symbiotic Stars

# Confirmed Symbiotic Stars




Data: Merc+2019, Akras+2019

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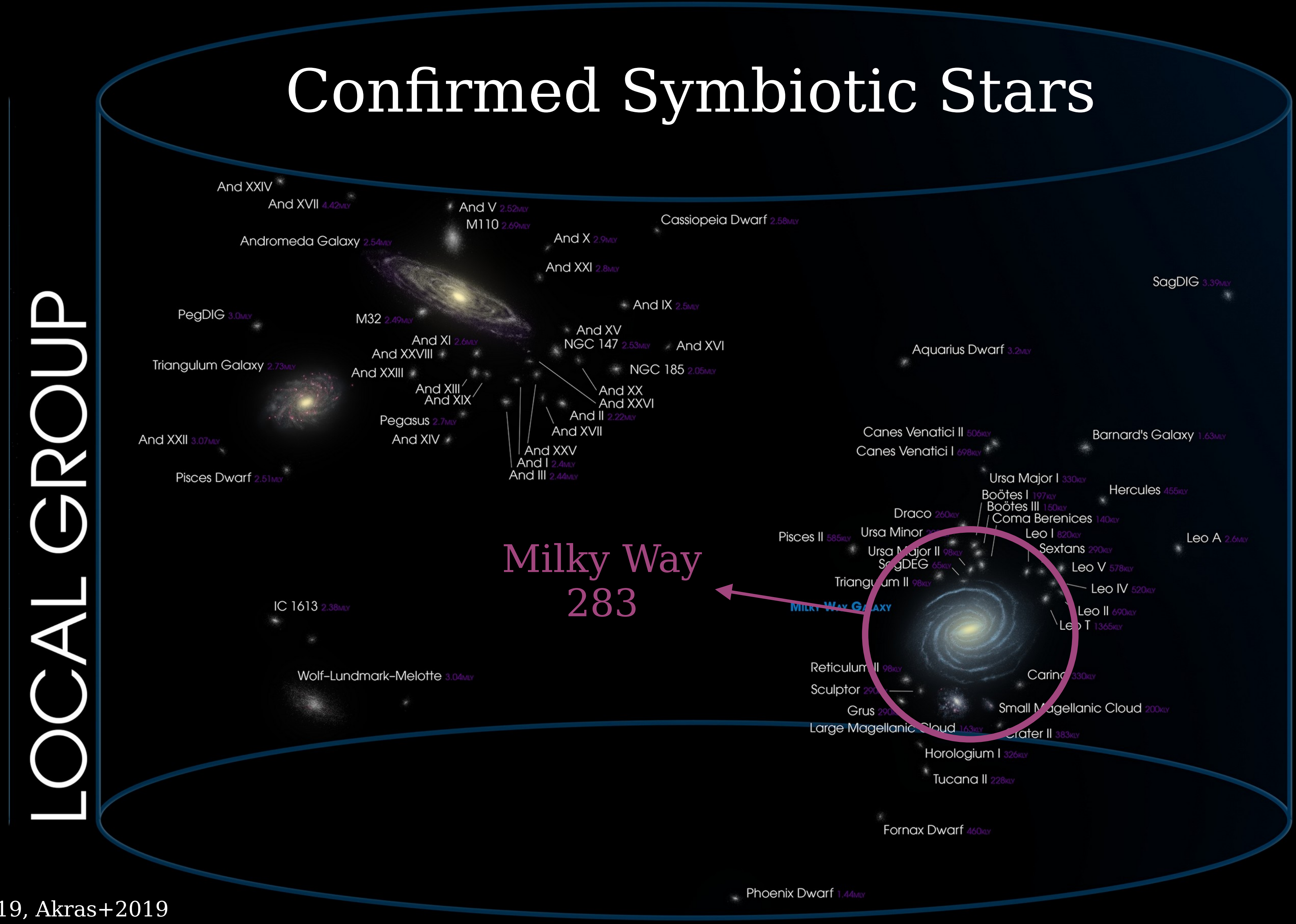


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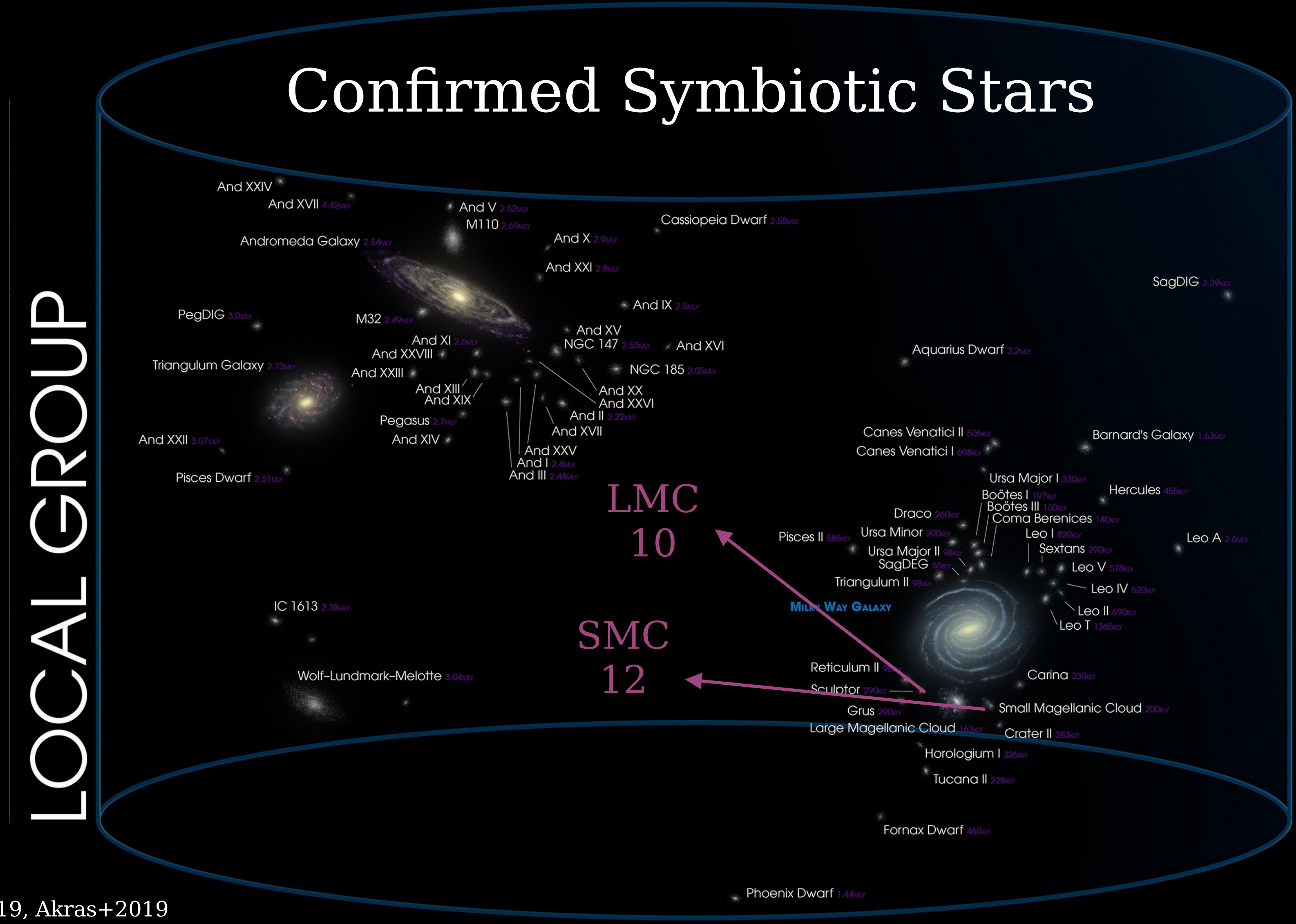


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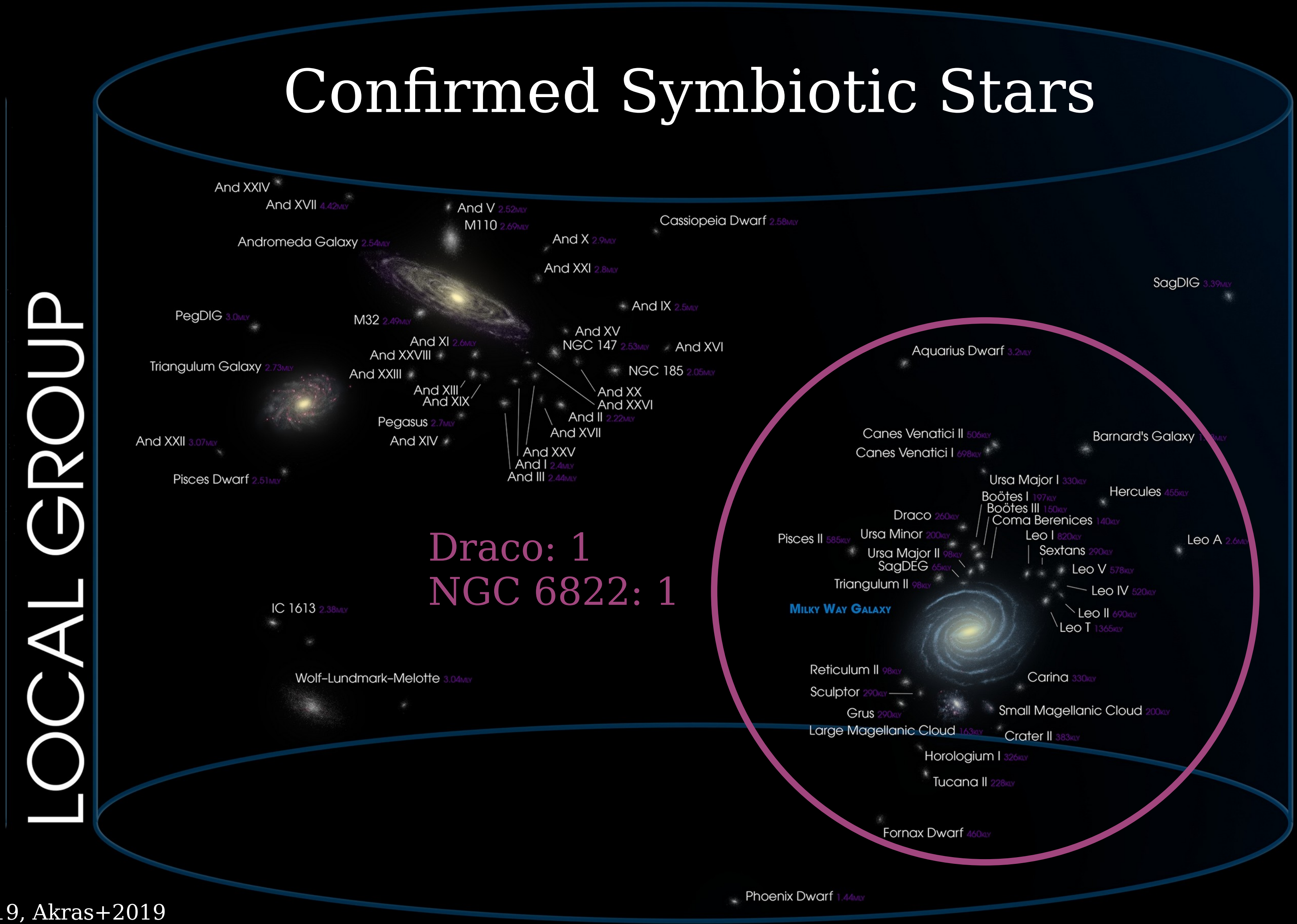


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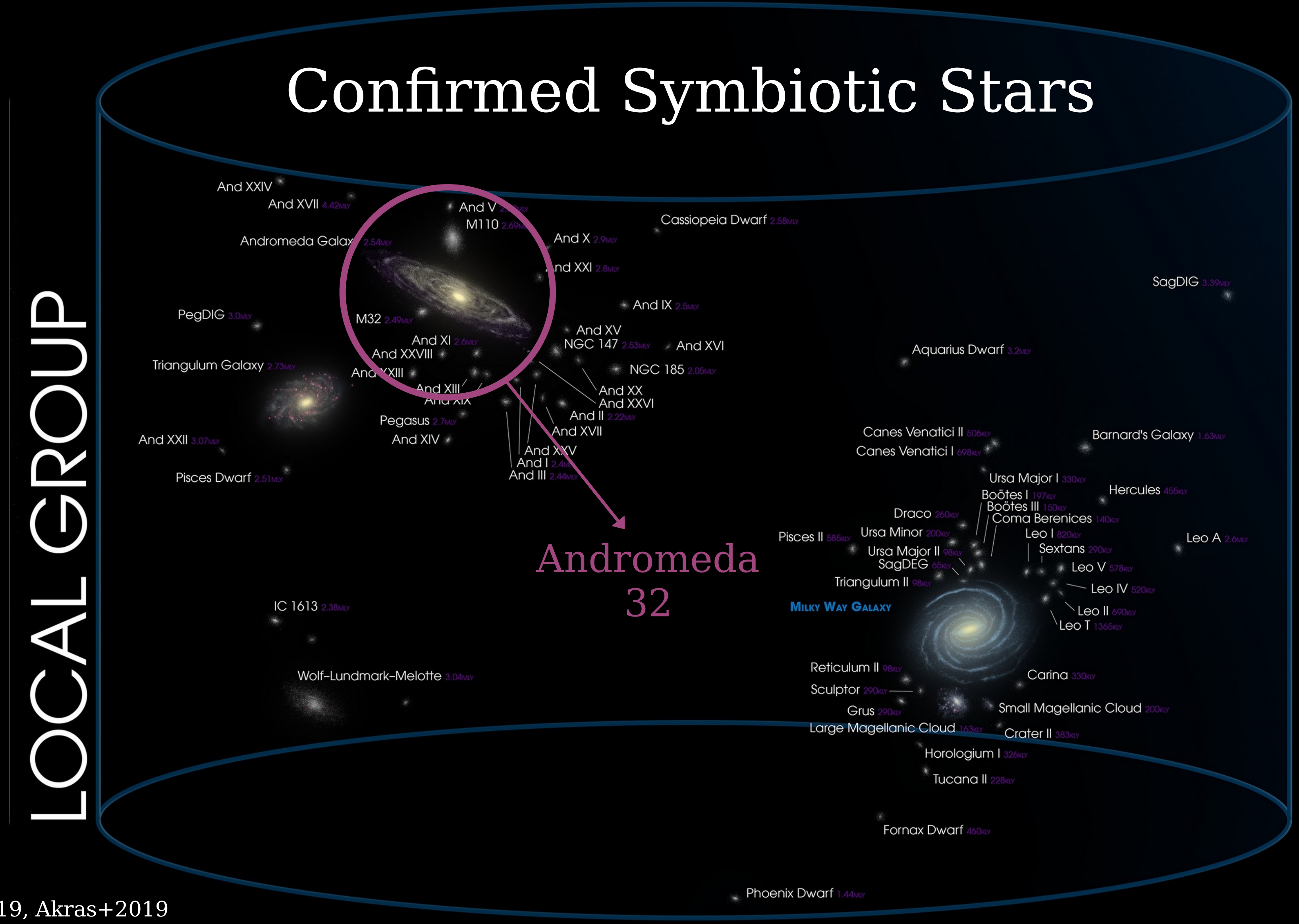


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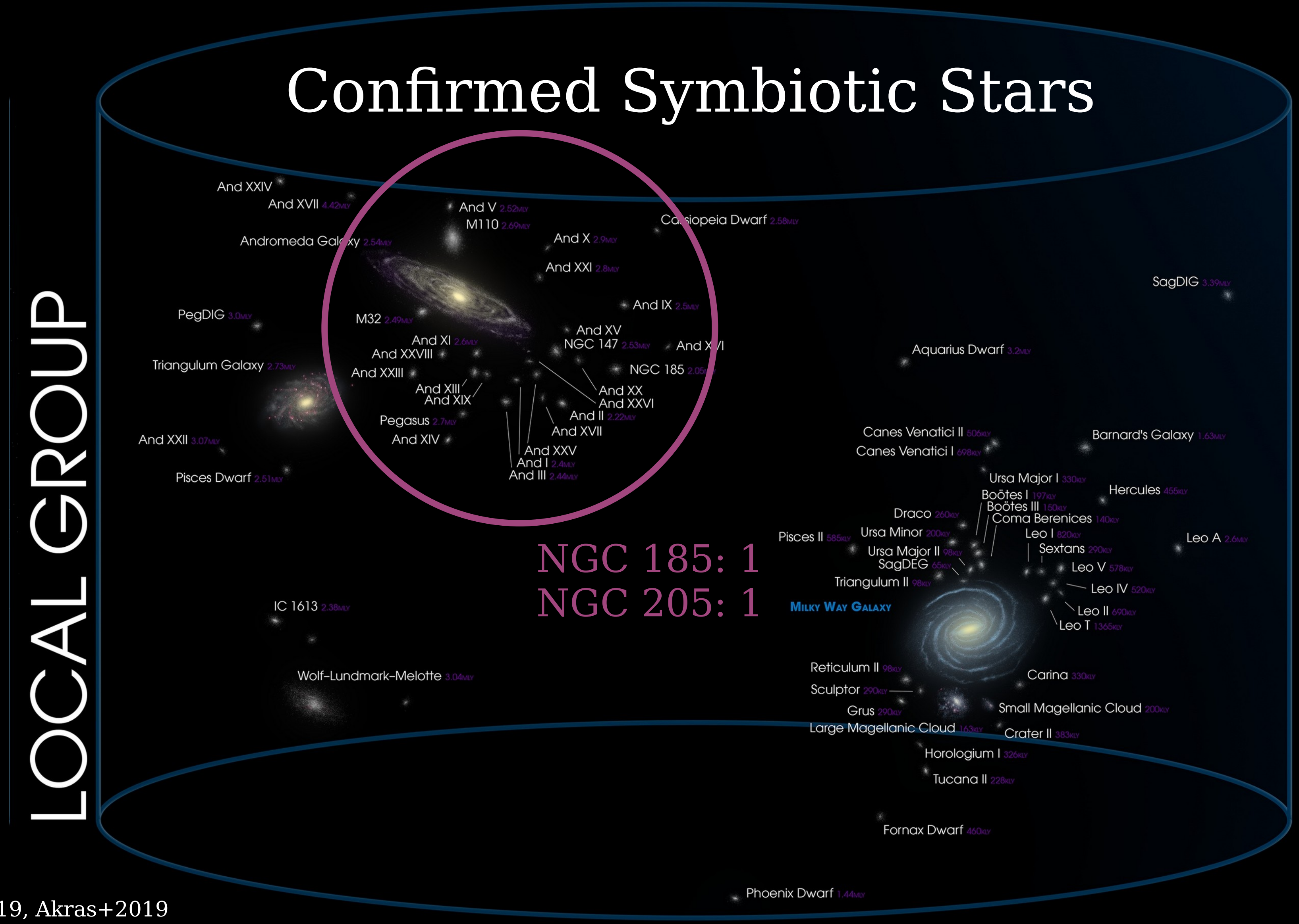


NGC 185: 1
NGC 205: 1

Data: Merc+2019, Akras+2019

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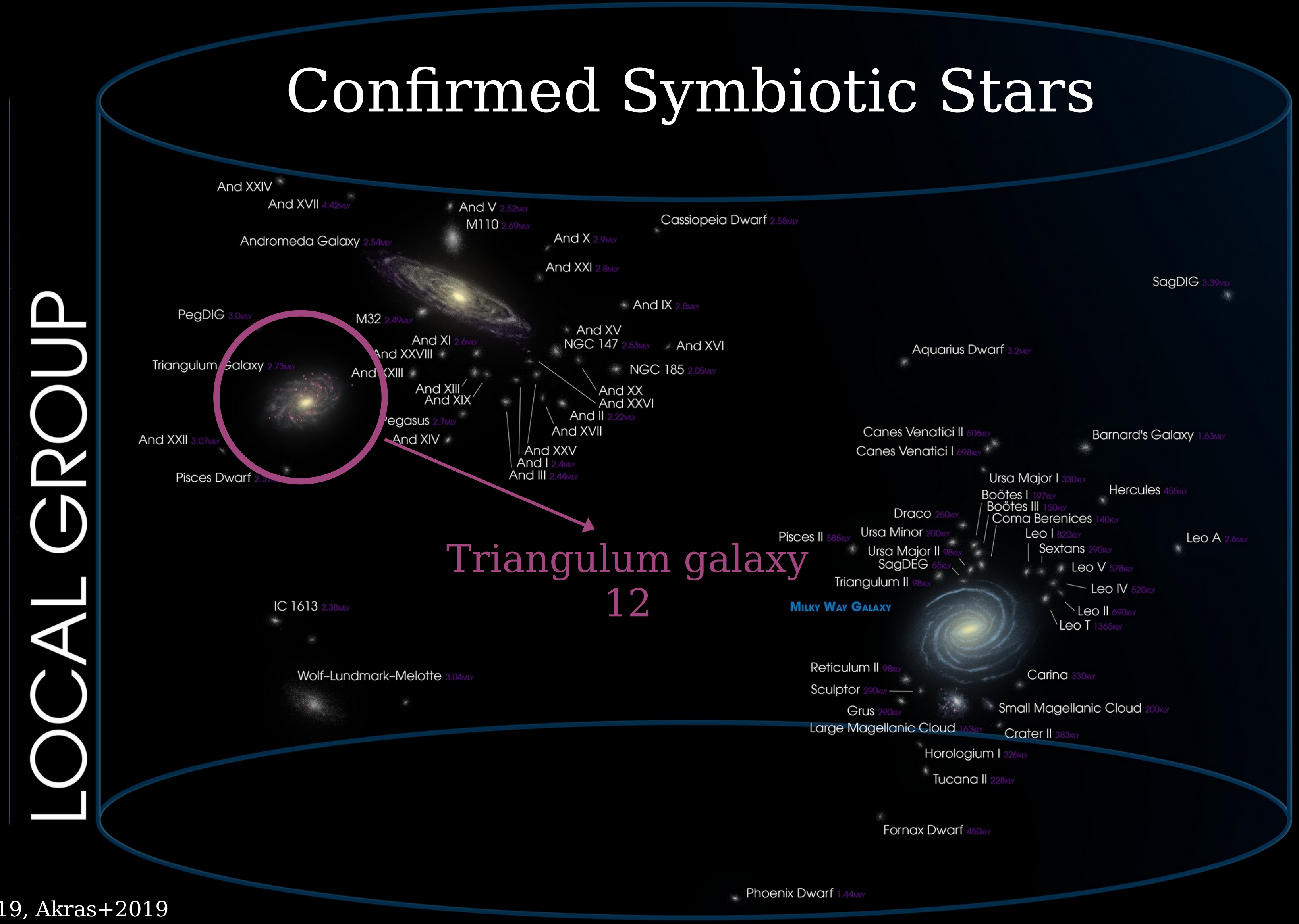


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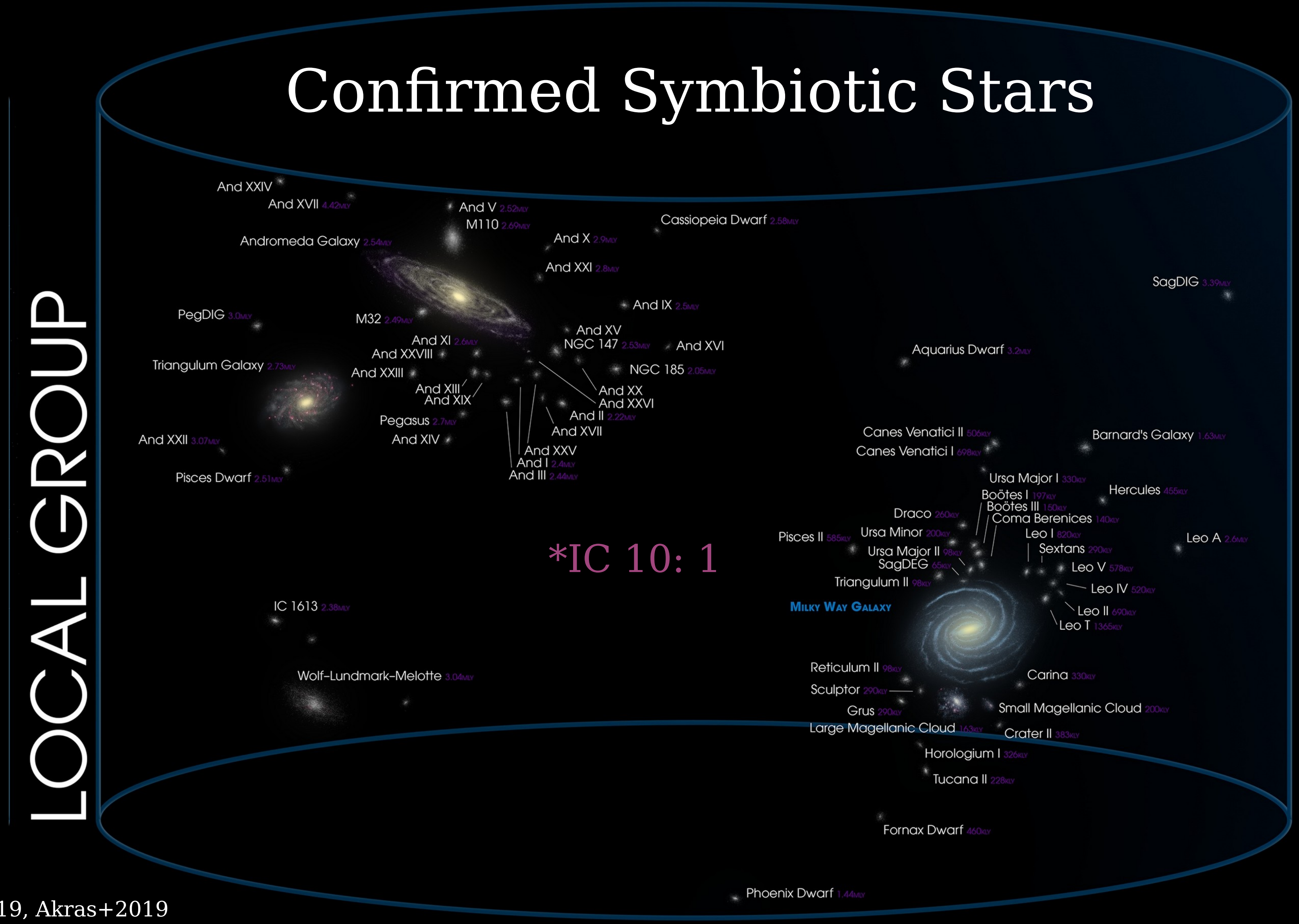


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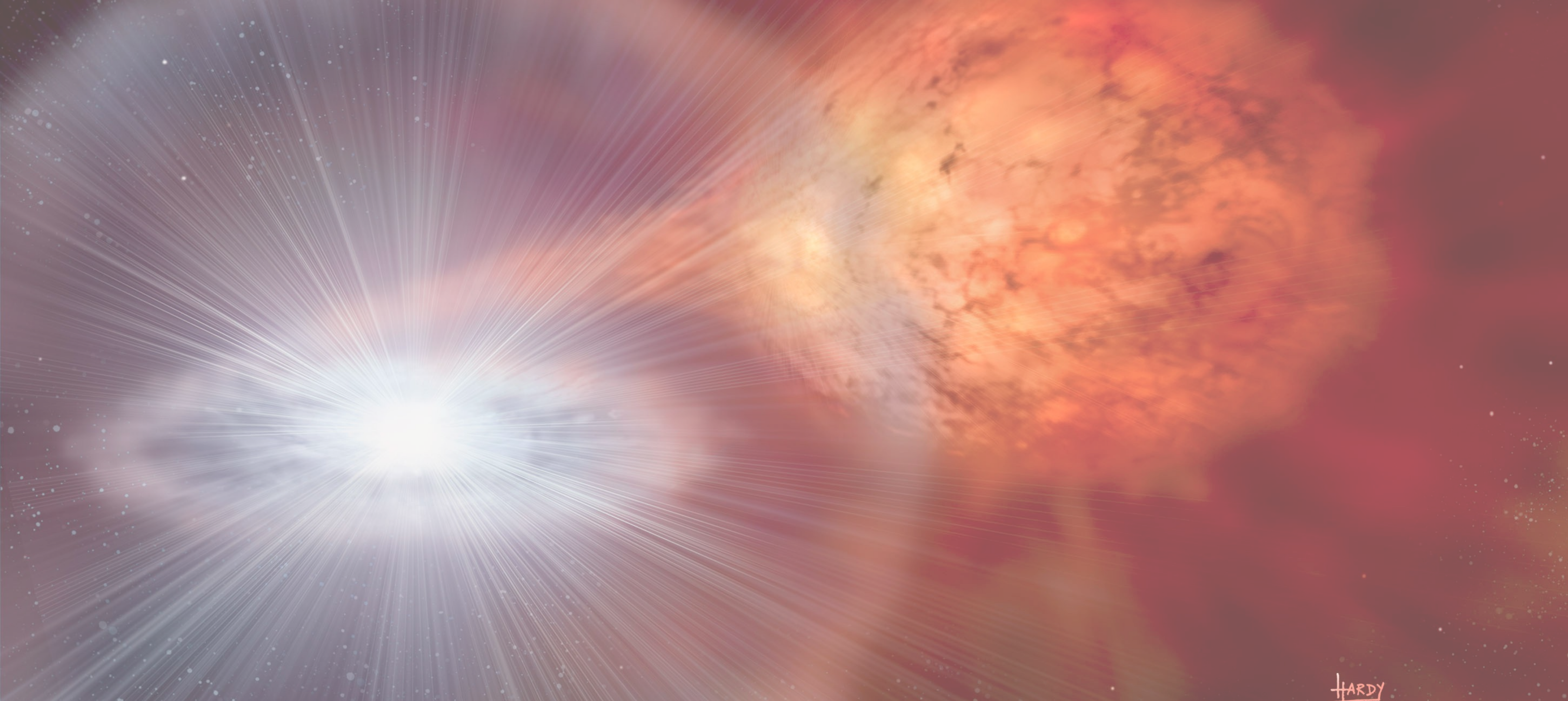
- Ok… but how many symbiotic stars (SySt) are there to be detected?



- Ok… but how many symbiotic stars (SySt) are there to be detected?

- Why are we interested in knowing about it?
  - Better characterize SySt and related phenomena
    - accretion physics, disk formation, mass transfer, novae, outbursts, flickering, pulsations etc
  - Deeper understanding of binary evolution

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- We tackle this problem in two different ways:
  - An empirical (observations)
  - A theoretical-statistical (binary population synthesis)

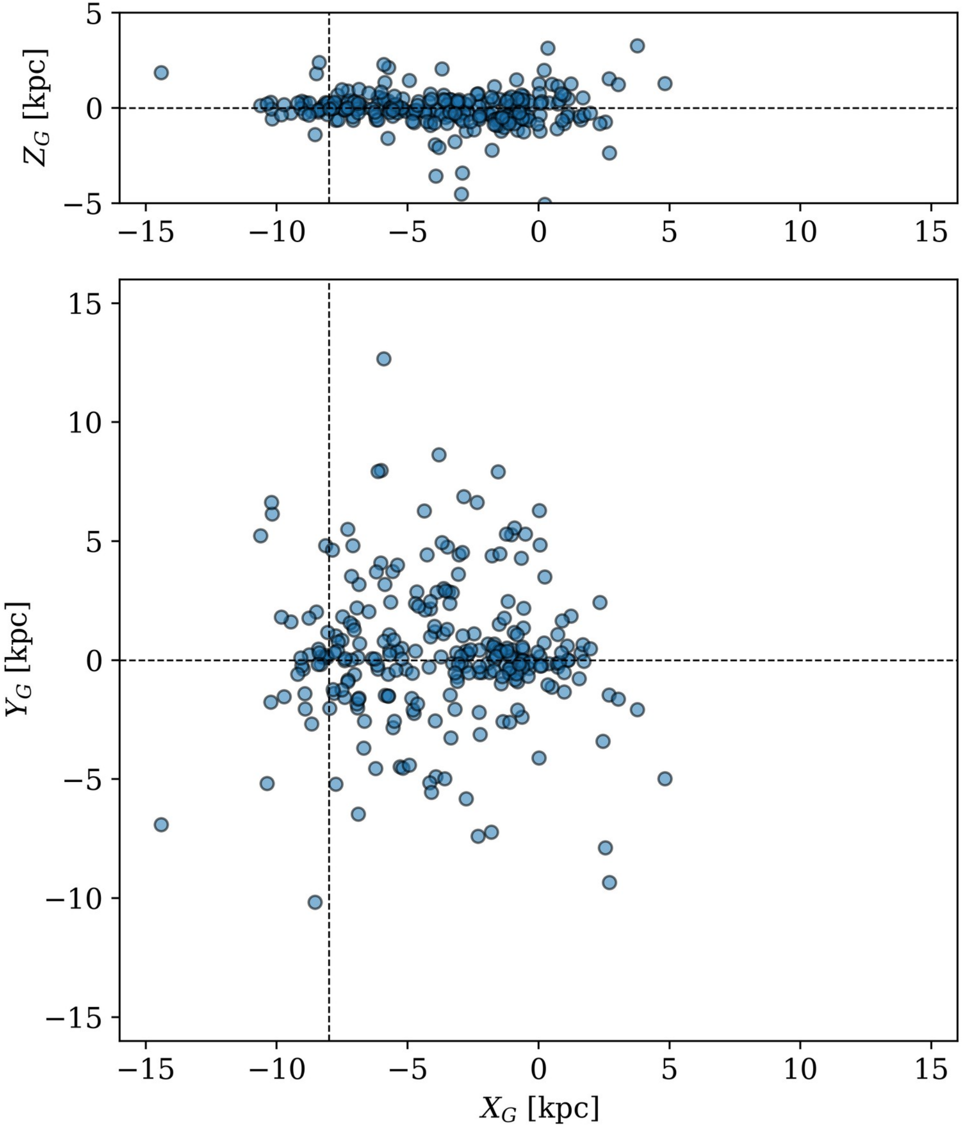
HARDY

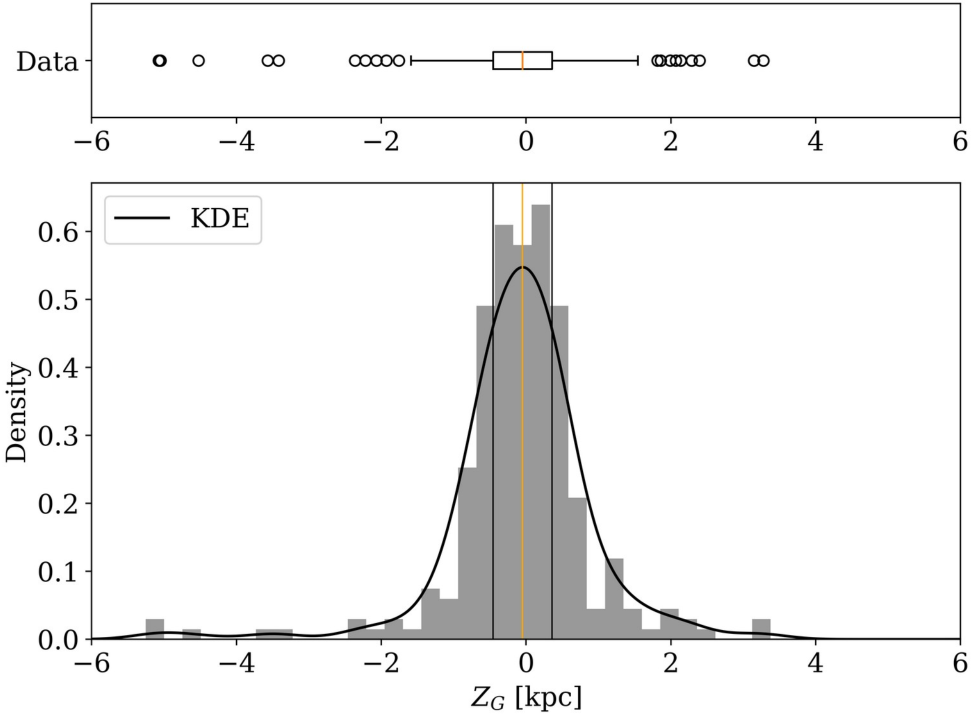
# Empirical Approach

# SySt height distribution

## ***Scale height computated = 0.654 kpc

(Laversveiler & Gonçalves 2023; Laversveiler et al. in prep)

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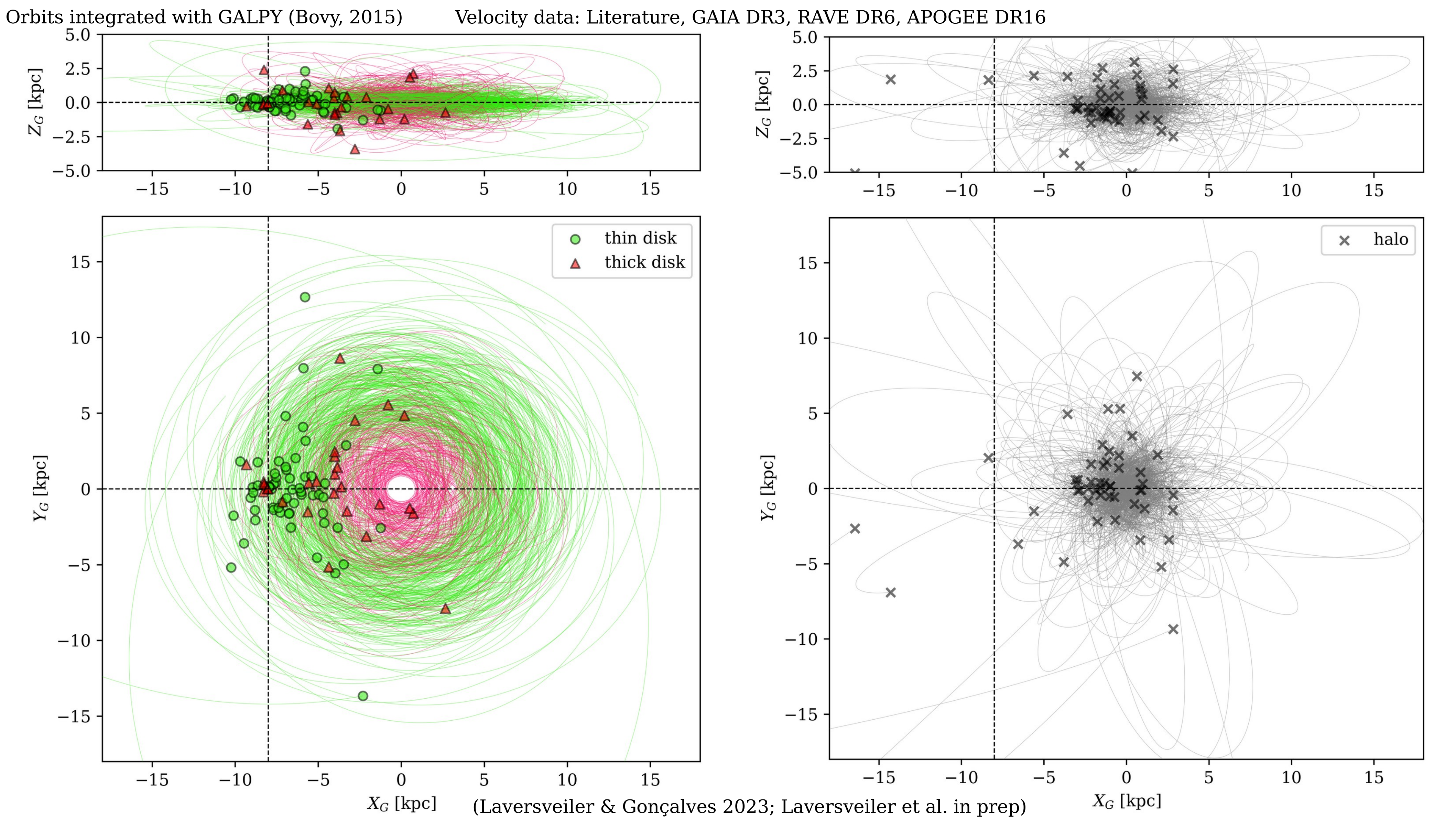
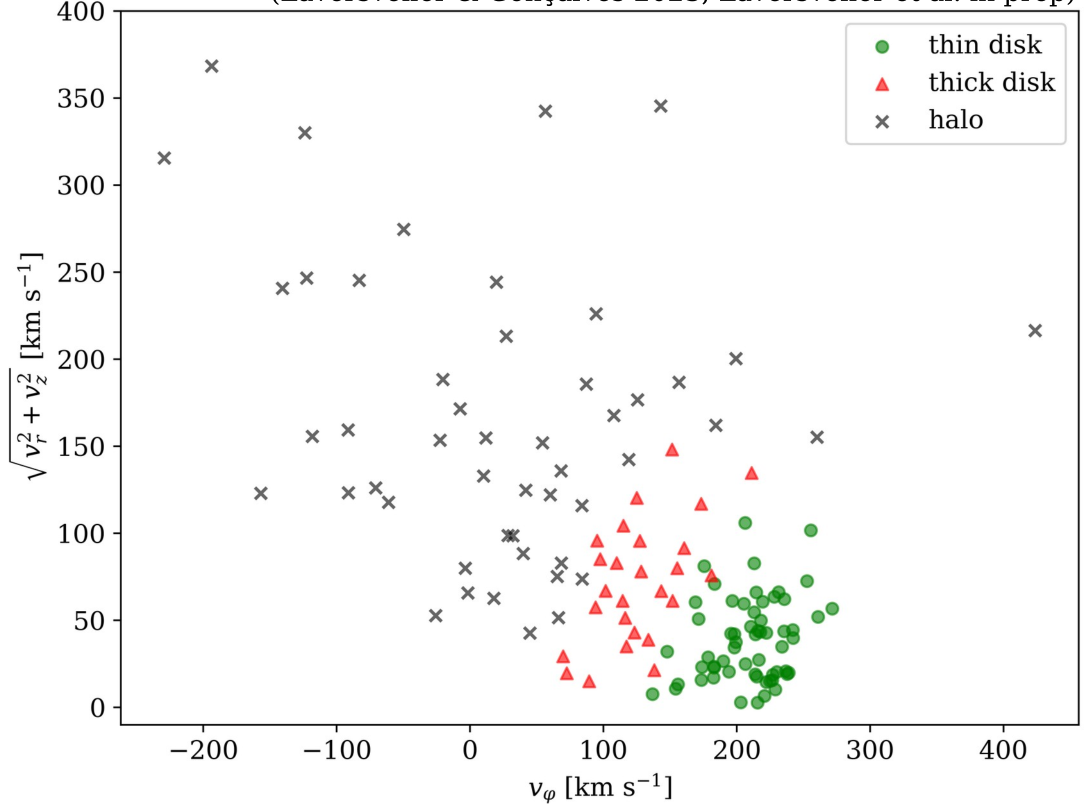


Orbits integrated with GALPY (Bovy, 2015)
Velocity data: Literature, GAIA DR3, RAVE DR6, APOGEE DR16
$Z_G$ [kpc]
$Y_G$ [kpc]
$X_G$ [kpc]
thin disk
thick disk
halo
(Laversveiler & Gonçalves 2023; Laversveiler et al. in prep)

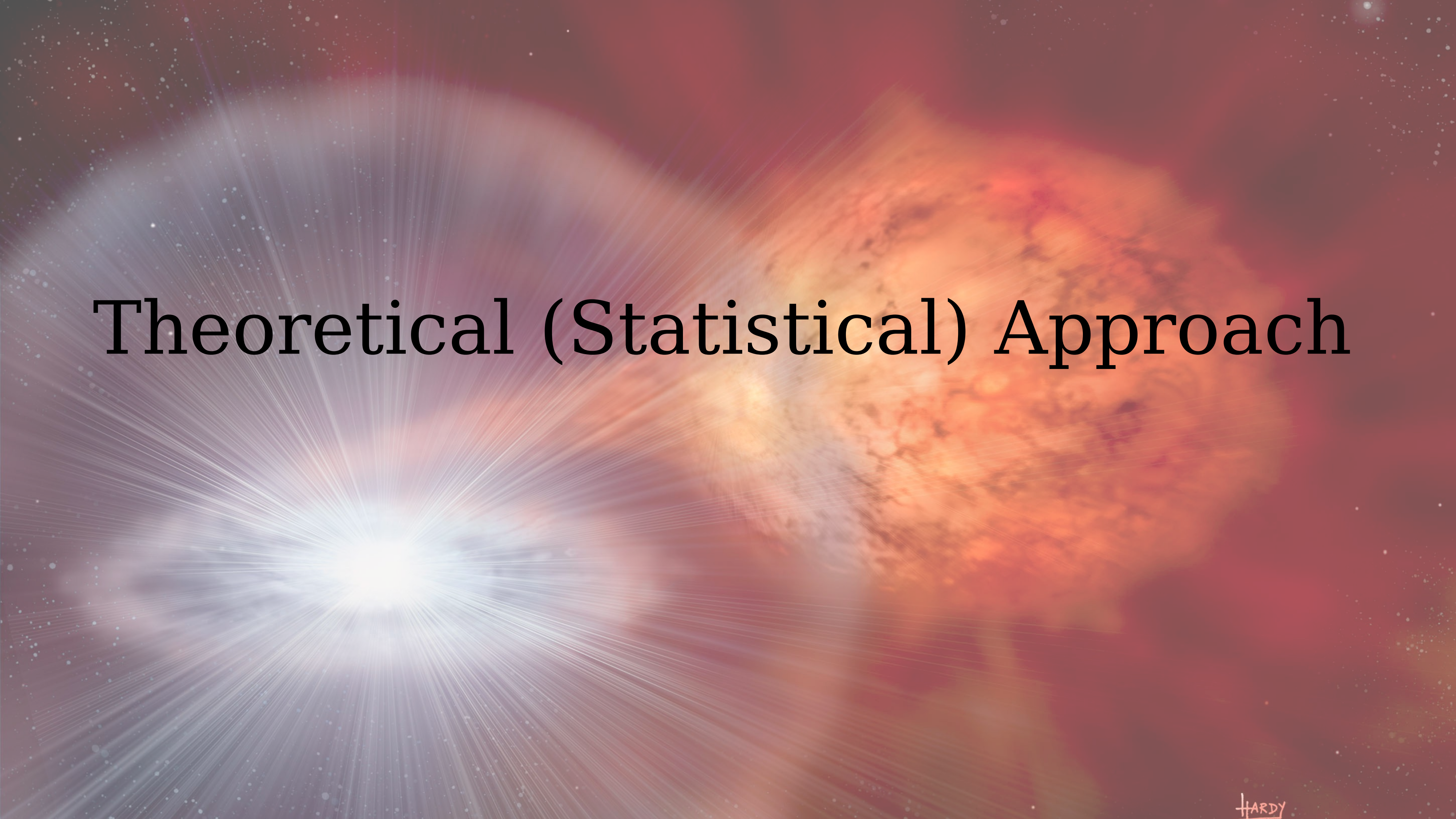
- Known SySt dynamically classified (based on Carrillo+ 2020; Perottoni+ 2021):
  - Thin disk: 45%
  - Thick disk: 19%
  - Halo: 36%
- Clearly separated in the velocity diagram
- Thin disk SySt number density estimated as 13.56 kpc$^{-3}$
- Computation of SySt population lower limit
  - 7200–14500
  - Compatible with Lü+ 2006, Kenyon 1986: 1200–15000, via population synthesis

$$N_{\mathrm{ss,min}} = 2\pi R_{\mathrm{G}}^2 h_{\mathrm{ss}} n_0$$

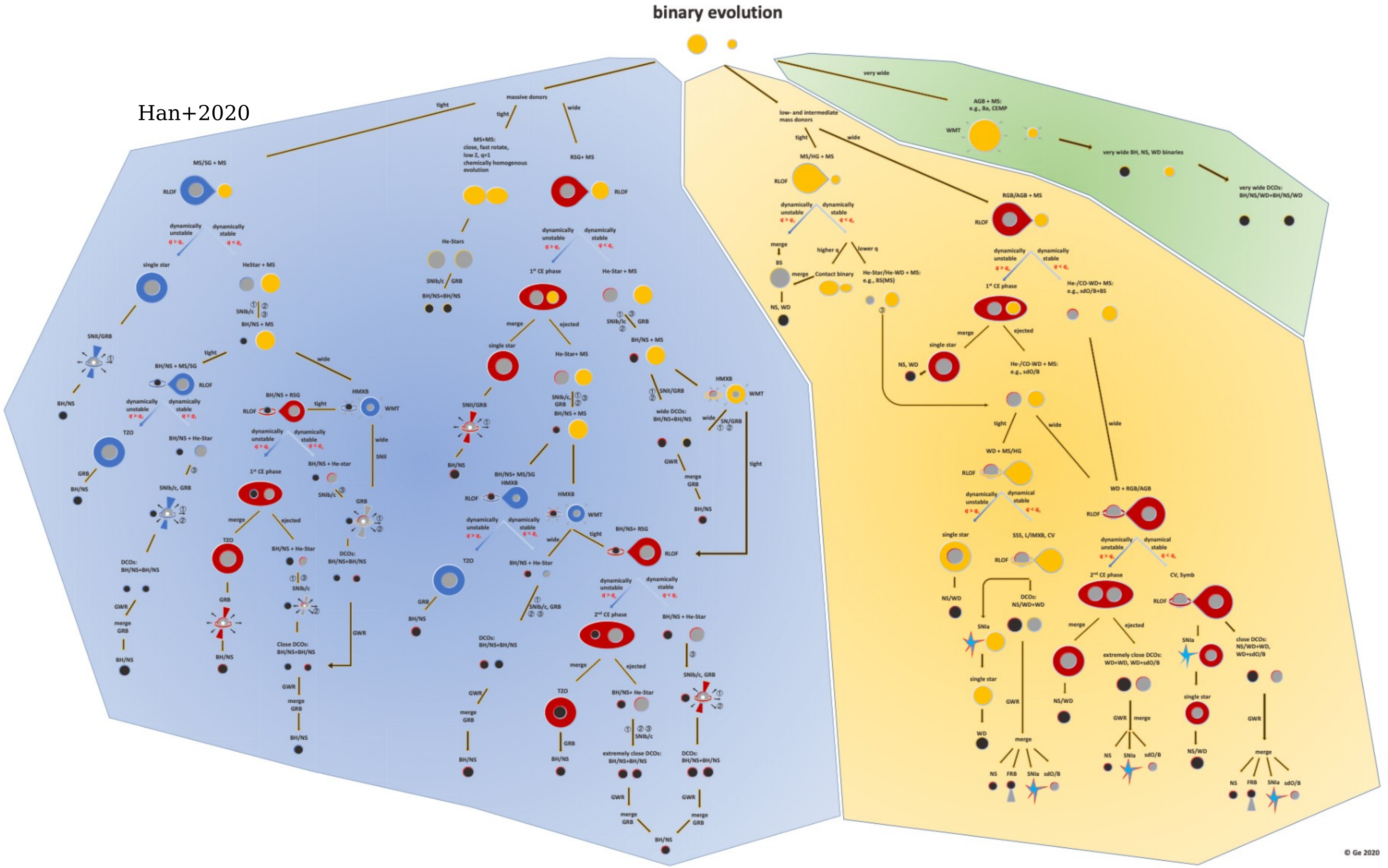
(Laversveiler & Gonçalves 2023; Laversveiler et al. in prep)



# Theoretical (Statistical) Approach

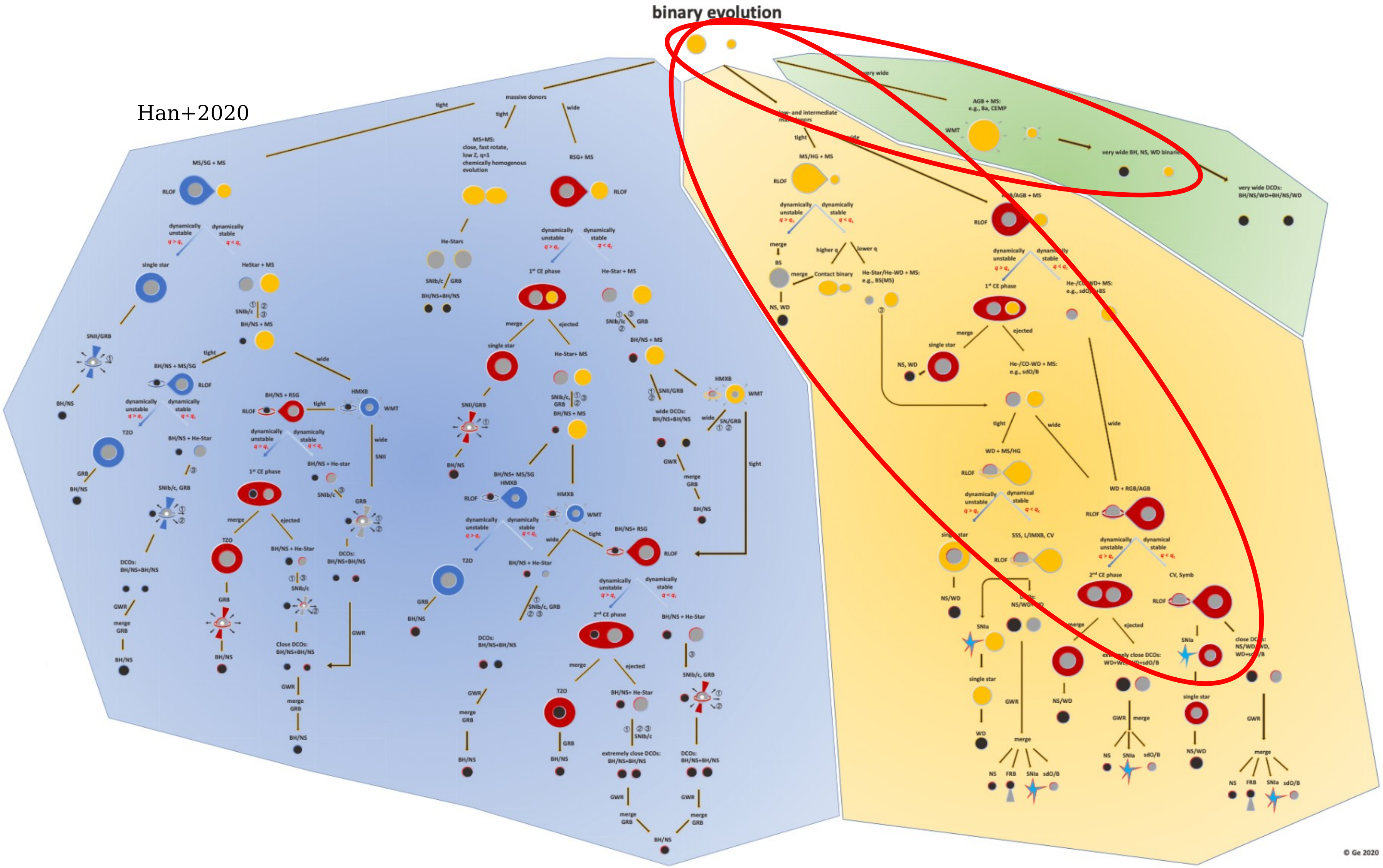


Han+2020



binary evolution
massive donors
tight
wide
very wide
low- and intermediate mass donors
MS/SG + MS
RLOF
MS+MS: close, fast rotate, low Z, q≈1 chemically homogenous evolution
RSG+ MS
He-Stars
AGB + MS: e.g., Ba, CEMP
WMT
very wide BH, NS, WD binaries
very wide DCOs: BH/NS/WD+BH/NS/WD
MS/HG + MS
RGB/AGB + MS
dynamically unstable
dynamically stable
single star
HeStar + MS
1st CE phase
merge
ejected
TZO
HMXB
SNII/GRB
BH/NS
DCOs: BH/NS+BH/NS
GWR
merge GRB
Close DCOs: BH/NS+BH/NS
2nd CE phase
extremely close DCOs: BH/NS+BH/NS
wide DCOs: BH/NS+BH/NS
Contact binary
higher q
lower q
NS, WD
WD + MS/HG
WD + RGB/AGB
SSS, L/IMXB, CV
CV, Symb
DCOs: NS/WD+WD
extremely close DCOs: WD+WD, WD+sdO/B
close DCOs: NS/WD+WD, WD+sdO/B
SNIa
NS
FRB
sdO/B
© Ge 2020

Han+2020



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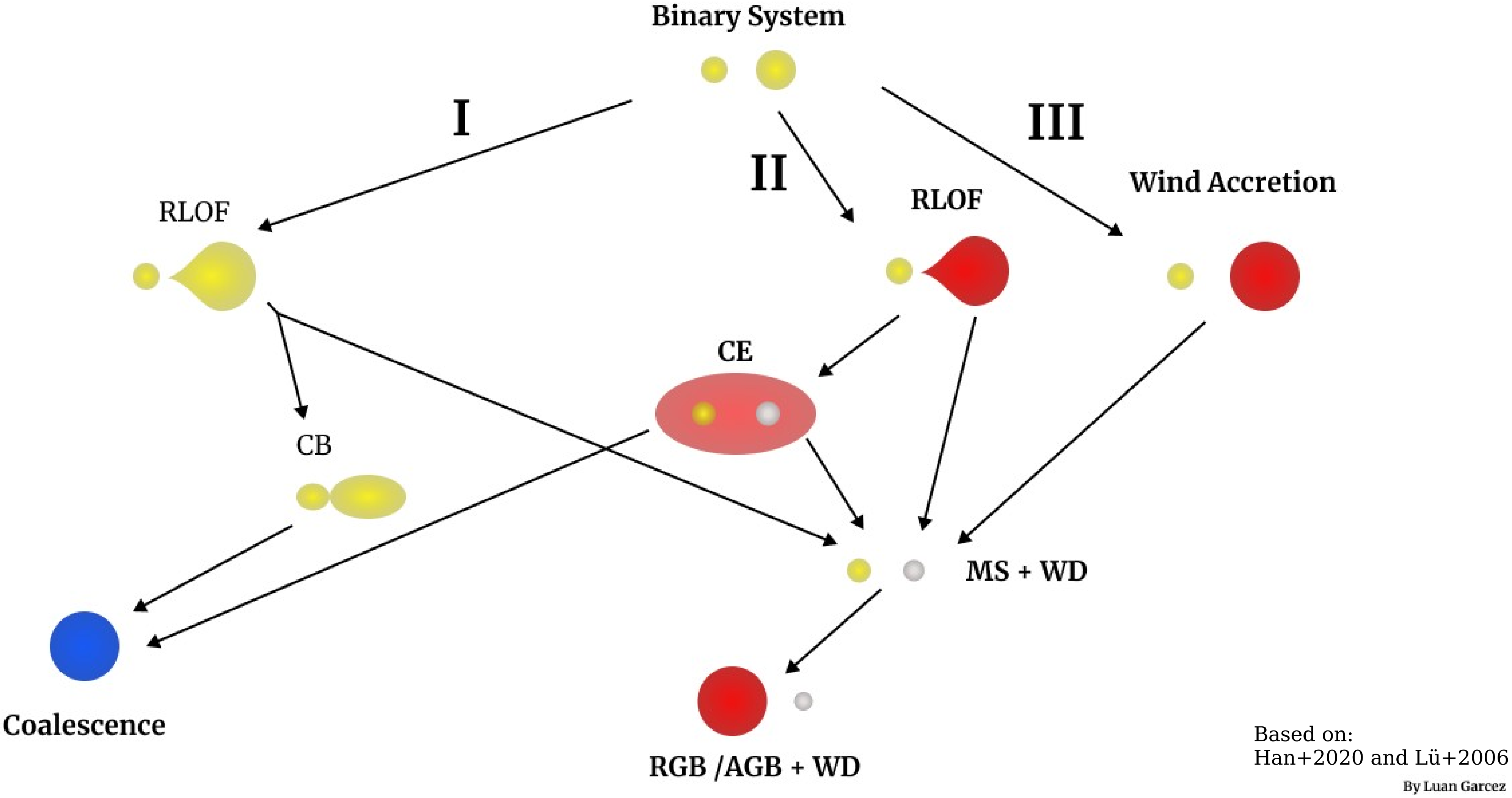
*stars with masses between 0.8 and 8 $M_\odot$




(Laversveiler & Gonçalves 2023; Laversveiler et al. in prep)

# Statistical Binary Evolution

- Observational inputs (MS binaries)
  - Semi-major axis distributions (Duchêne & Kraus 2013)
  - Mass-ratio distributions (Duchêne & Kraus 2013)
  - IMF (Kroupa 2001)
  - Binary fraction / Multiplicity frequency
    - Duchêne & Kraus (2013) – Milky Way
    - Milone+2009 and Rubele+2011 – LMC, SMC (clusters)
    - Spencer+2017 – Leo II
    - Spencer+2018 – Fornax, Leo II, Sculptor, Sextans, Carina, Draco, Ursa Minor
    - Minor+2013 – Fornax, Sculptor, Sextans, Carina
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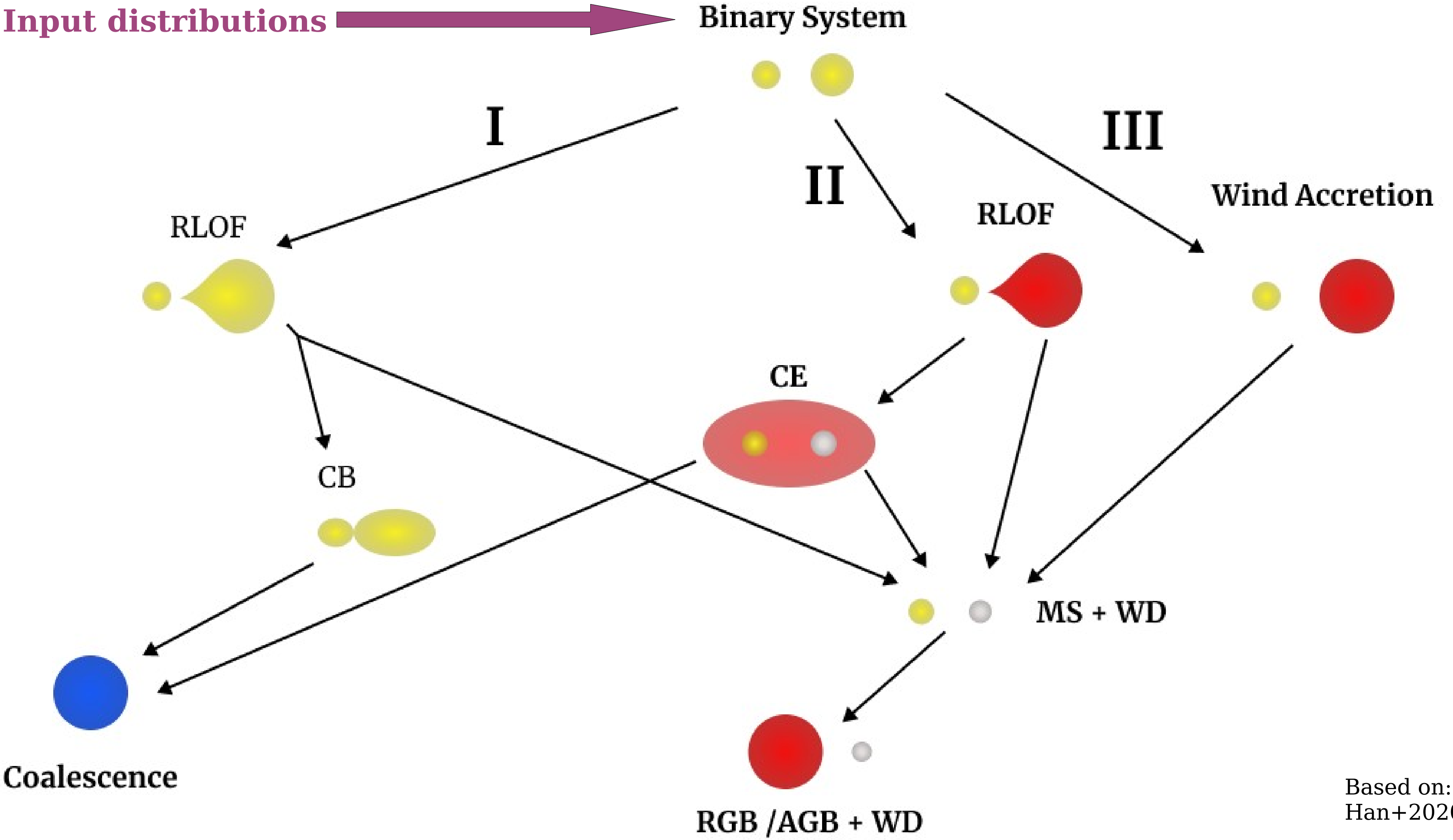
    - Otherwise the range 0.25–0.75 is assumed
- Approximations
  - Mean radii as a function of mass
    - Derived from PARSEC stellar tracks (Bressan+2012) and interpolated
  - Critical mass-ratio as a function of primary mass and evolutionary phase (Chen & Han 2008, Ge+2013)
  - Effective Roche lobe radius (Eggleton 1983)
  - Absolute visual magnitude corrected to bolometric (McConnachie 2012, Reid 2016)
  - Metallicity – $Z$ obtained from average [Fe/H] (McConnachie 2012)

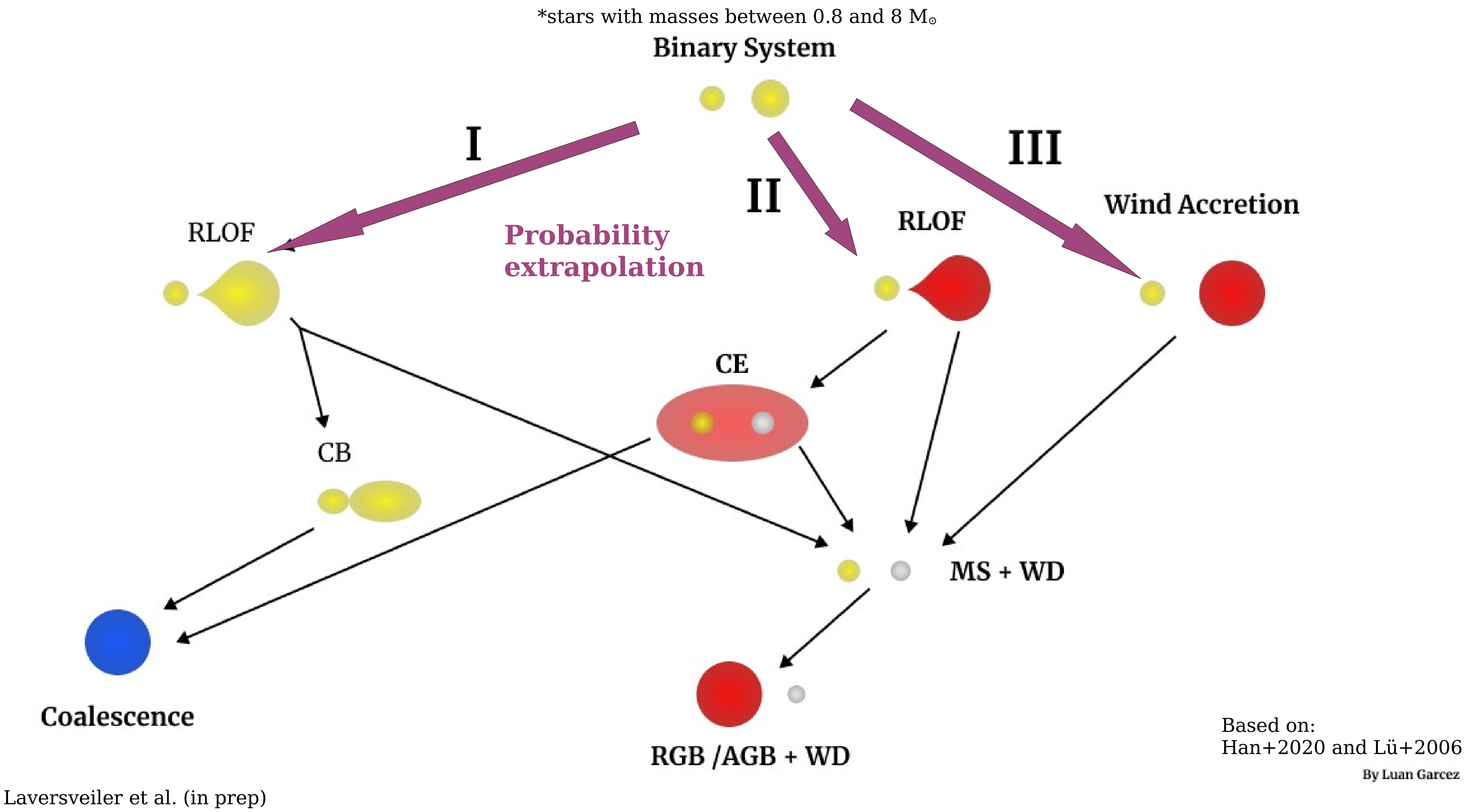
*stars with masses between 0.8 and 8 $M_{\odot}$




Based on:
Han+2020 and Lü+2006

By Luan Garcez

Laversveiler et al. (in prep)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Binary System
I
II
III
RLOF
Probability extrapolation
RLOF
Wind Accretion
CE
CB
MS + WD
Coalescence
RGB /AGB + WD
Based on:
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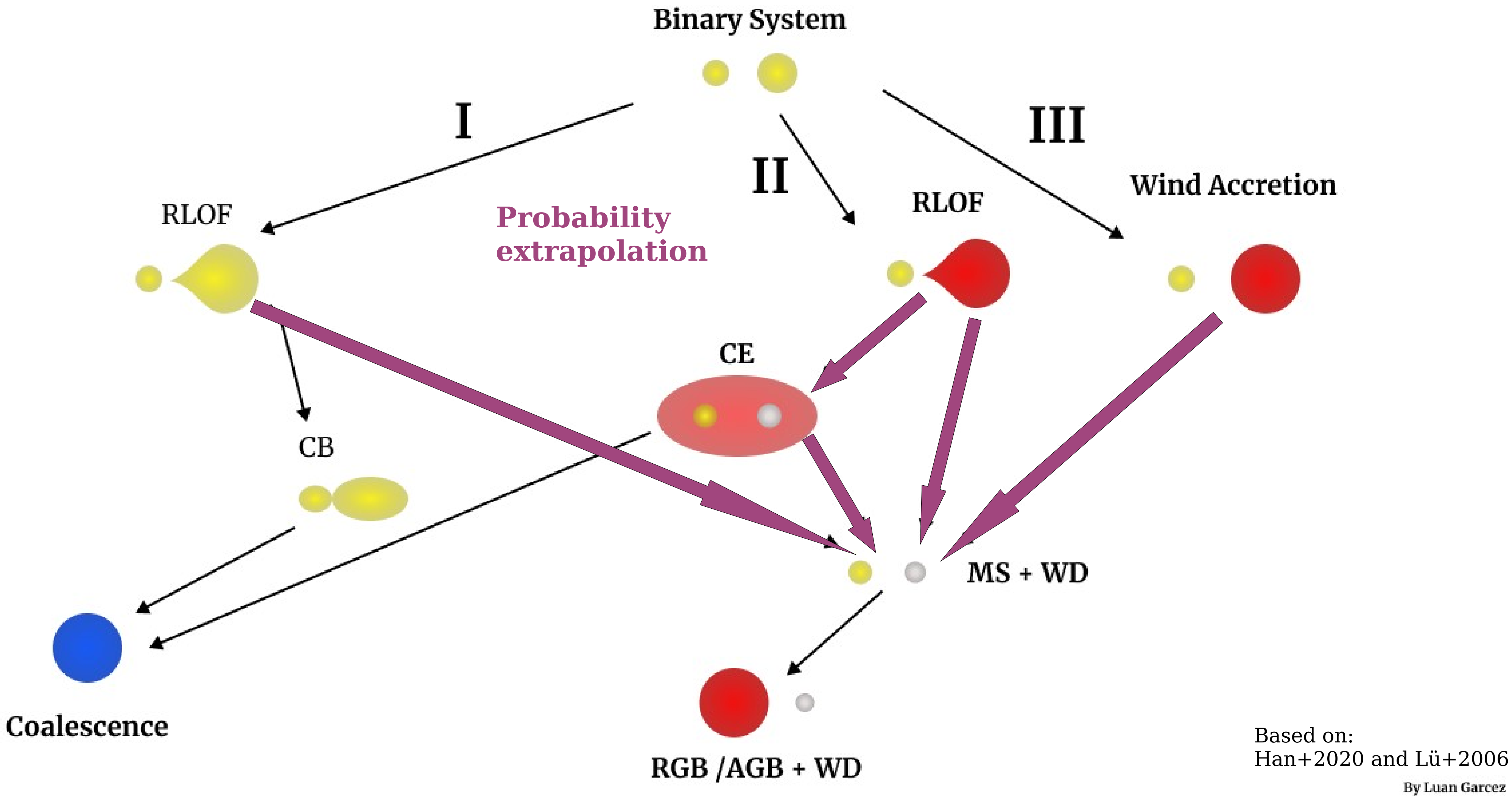


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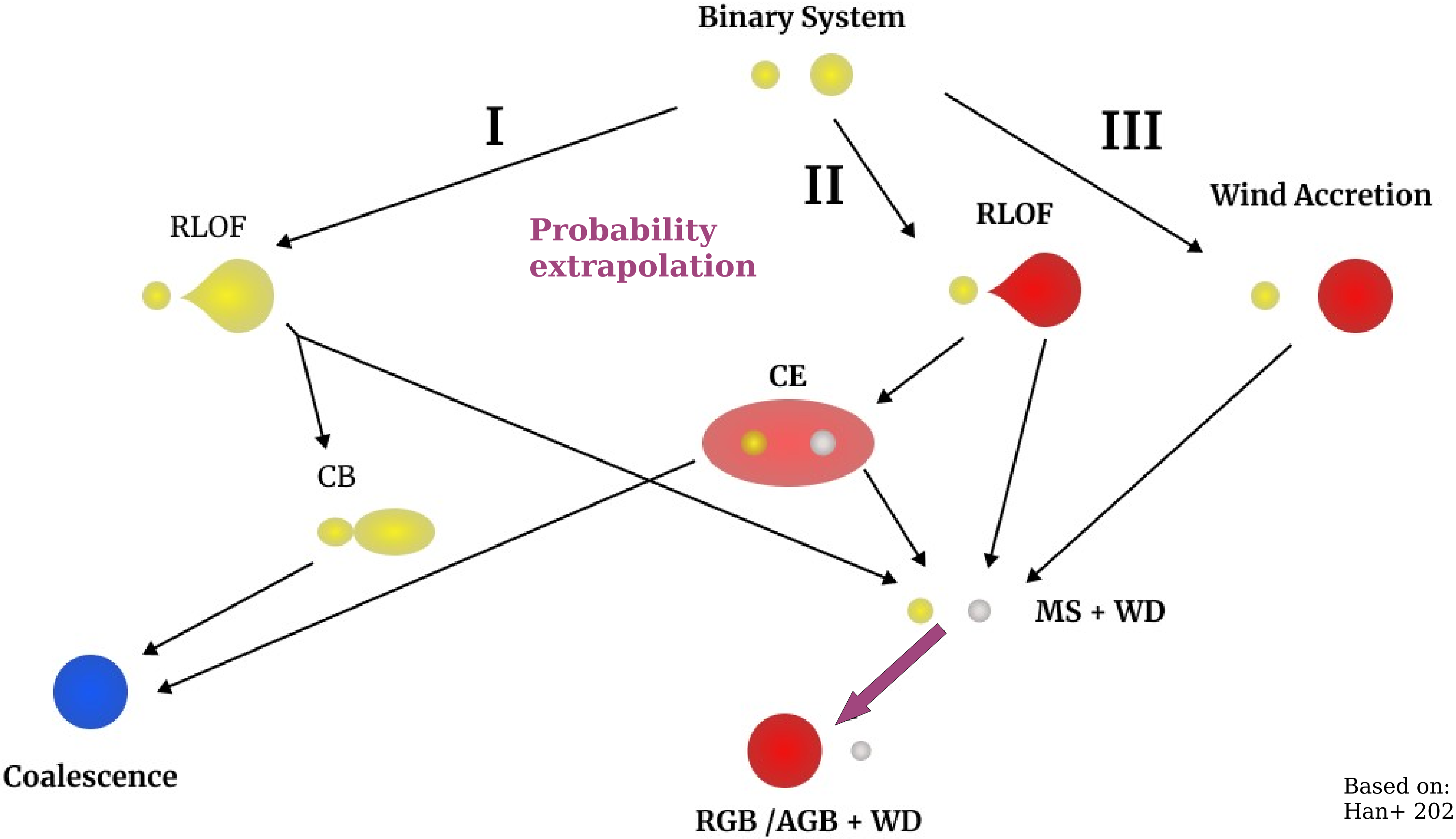


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# Results

- The formation rate density of PNe is used (Phillips 1989; Kenyon+1993)
  - Death rate of low- and intermediate mass stars

| galaxy | #SySt | galaxy | #SySt |
|---|---|---|---|
| Milky Way | $38\,578^{+8\,204}_{-8\,036}$ | Sagittarius | $7^{+1}_{-2}$ |
| LMC | $795^{+168}_{-166}$ | Fornax | $12^{+5}_{-6}$ |
| SMC | $220^{+46}_{-47}$ | Leo II | 0 |
| NGC 205 | $189^{+96}_{-126}$ | Sculptor | 0 |
| IC 10 | $172^{+88}_{-117}$ | Sextans | 0 |
| NGC 6822 | $131^{+67}_{-88}$ | Carina | 0 |
| NGC 185 | $45^{+23}_{-30}$ | Draco | 0 |
| IC 1613 | $70^{+35}_{-46}$ | Ursa Minor | 0 |
| NGC 147 | $57^{+30}_{-38}$ | Hercules | 0 |
| WLM | $15^{+8}_{-10}$ | Leo IV | 0 |

(Laversveiler & Gonçalves 2023; Laversveiler et al. in prep)

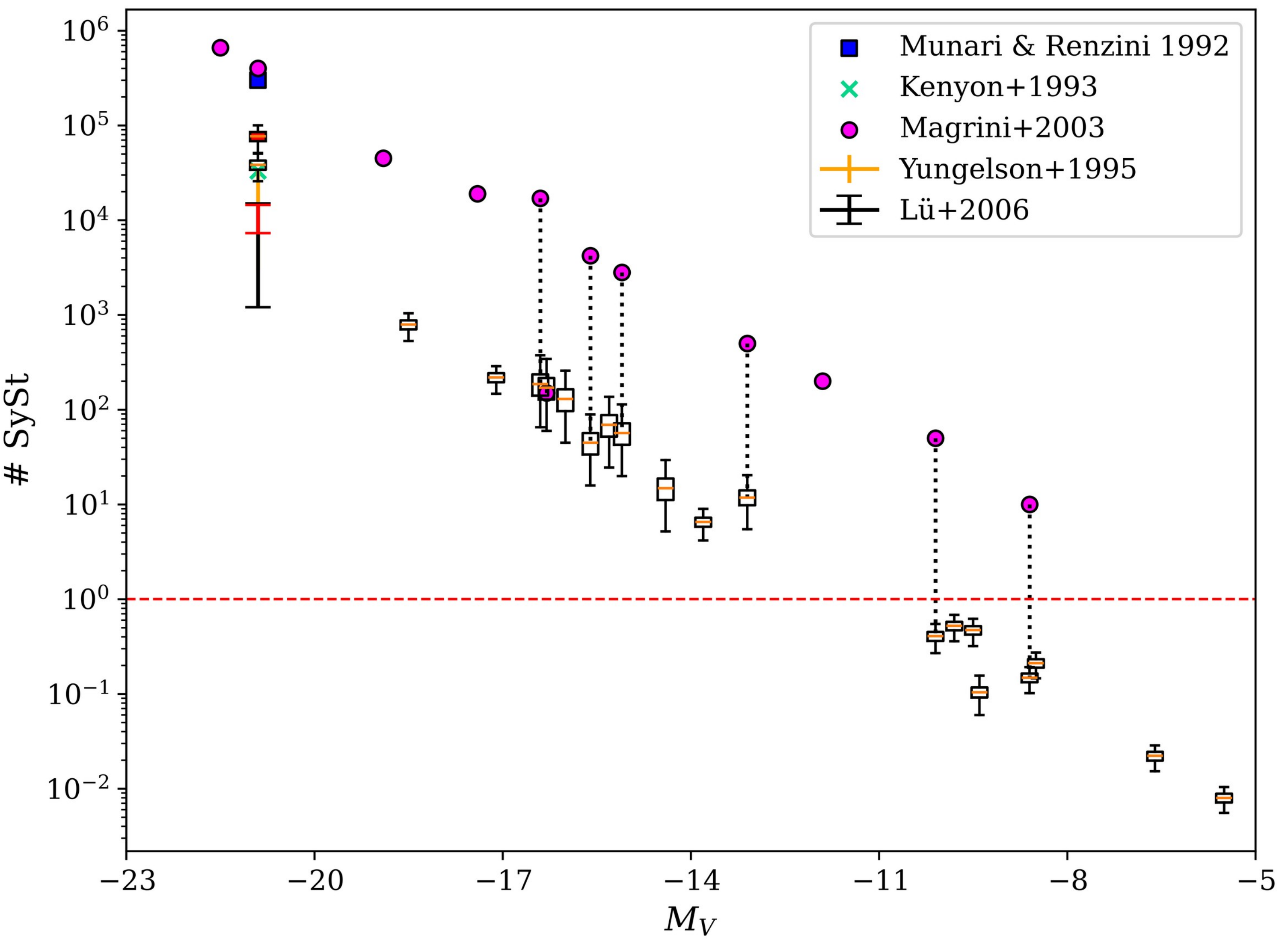
- Computation of the fraction of SySt formed and scaling with galactic properties:
  - Milky Way: same approach as Kenyon+1993, but different derivation of basic parameters.
  - LG dwarf galaxies: preserves the idea of Kenyon+1993, but uses the specific evolutionary flux of PNe from Buzzoni+2006.

$$\mathcal{N}_i = \mathcal{B}\tau_{\rm ss} L_{\odot,\rm bol} \times 10^{0.4(M_{V,\odot}+{\rm BC}_\odot - M_{V,i} - {\rm BC}_i)}$$

$$\mathcal{N}_{\rm G} = 2\pi R_{\rm G}^2 h_{\rm ss} \nu_{\rm PN} \tau_{\rm ss}$$

$$N_{\rm ss} = \mathcal{N} f_{\rm ss}$$

$$f_{\rm ss} = \int_{0.86}^{8.0} \frac{df^*_{\rm bin}(M_1)}{dM_1} \sum_i f^{(i)}_{\rm evol}(M_1)\, dM_1$$

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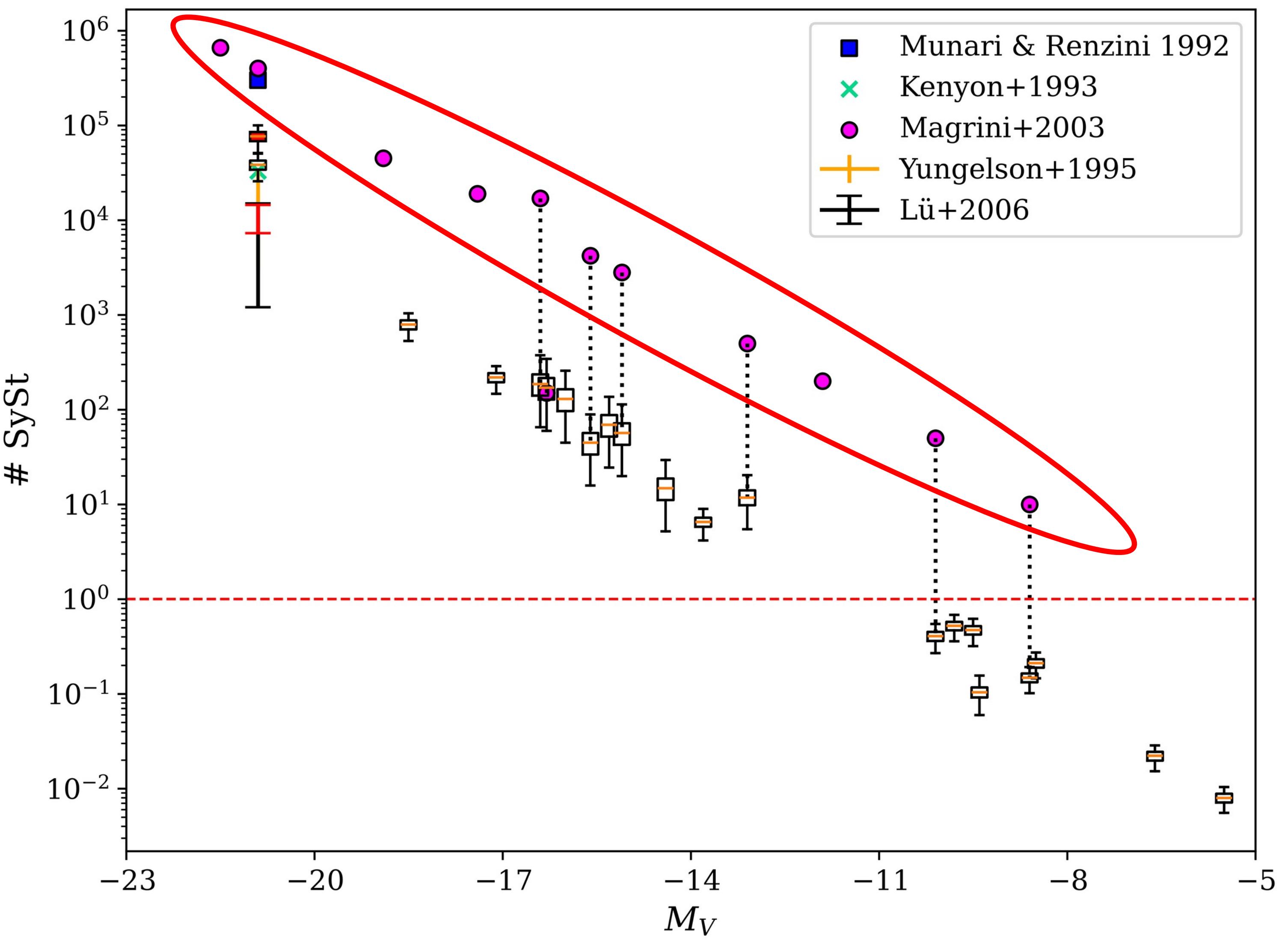


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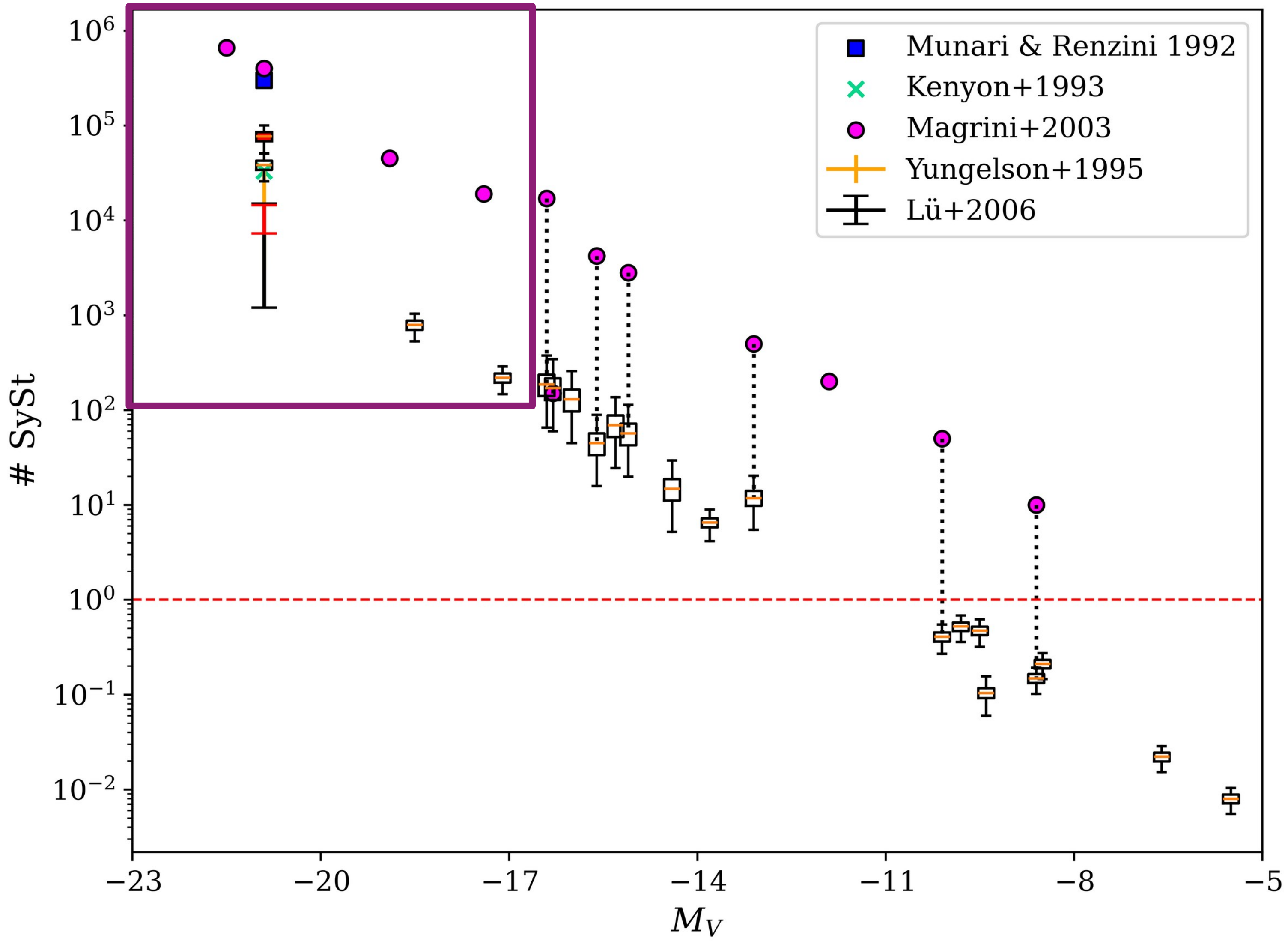
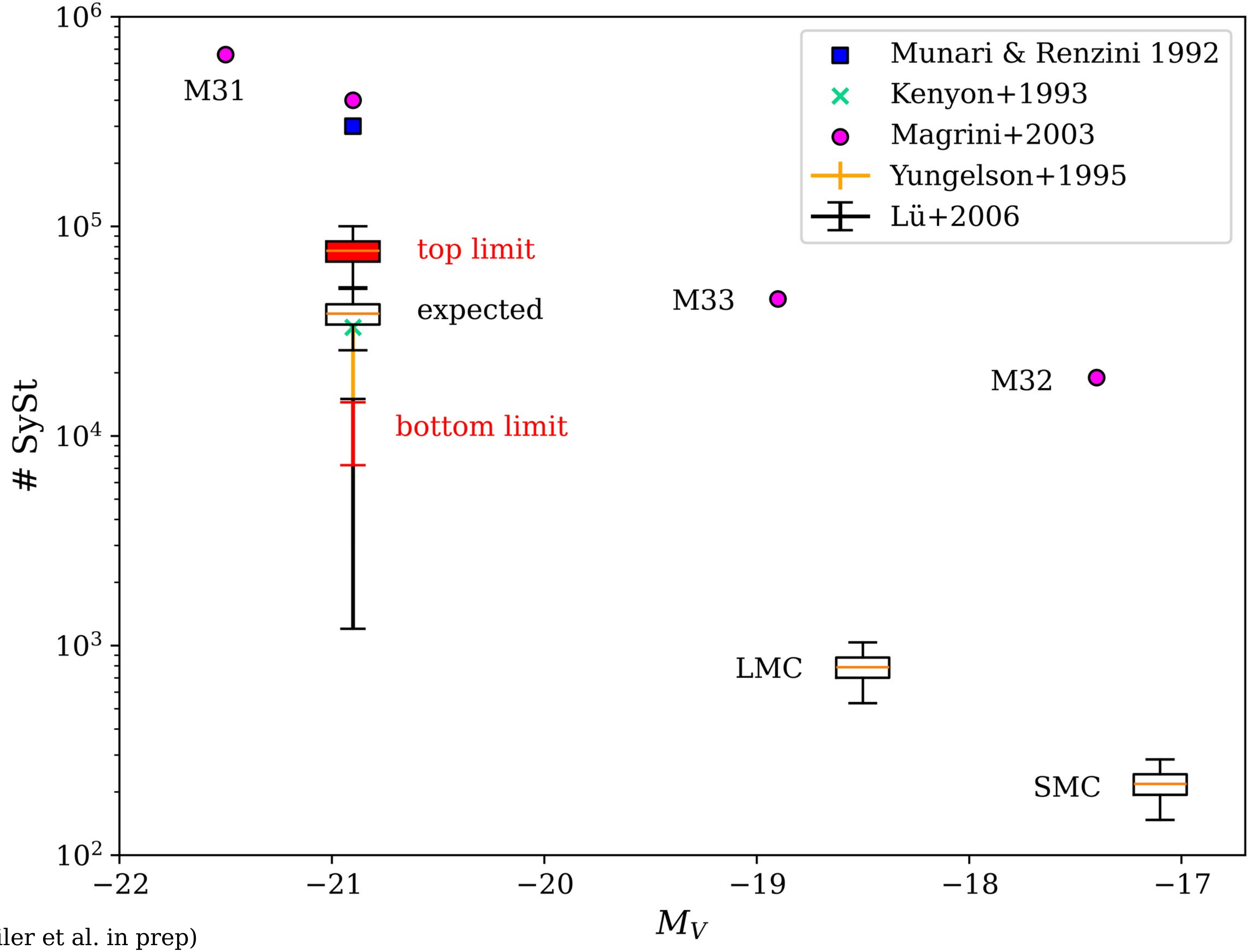


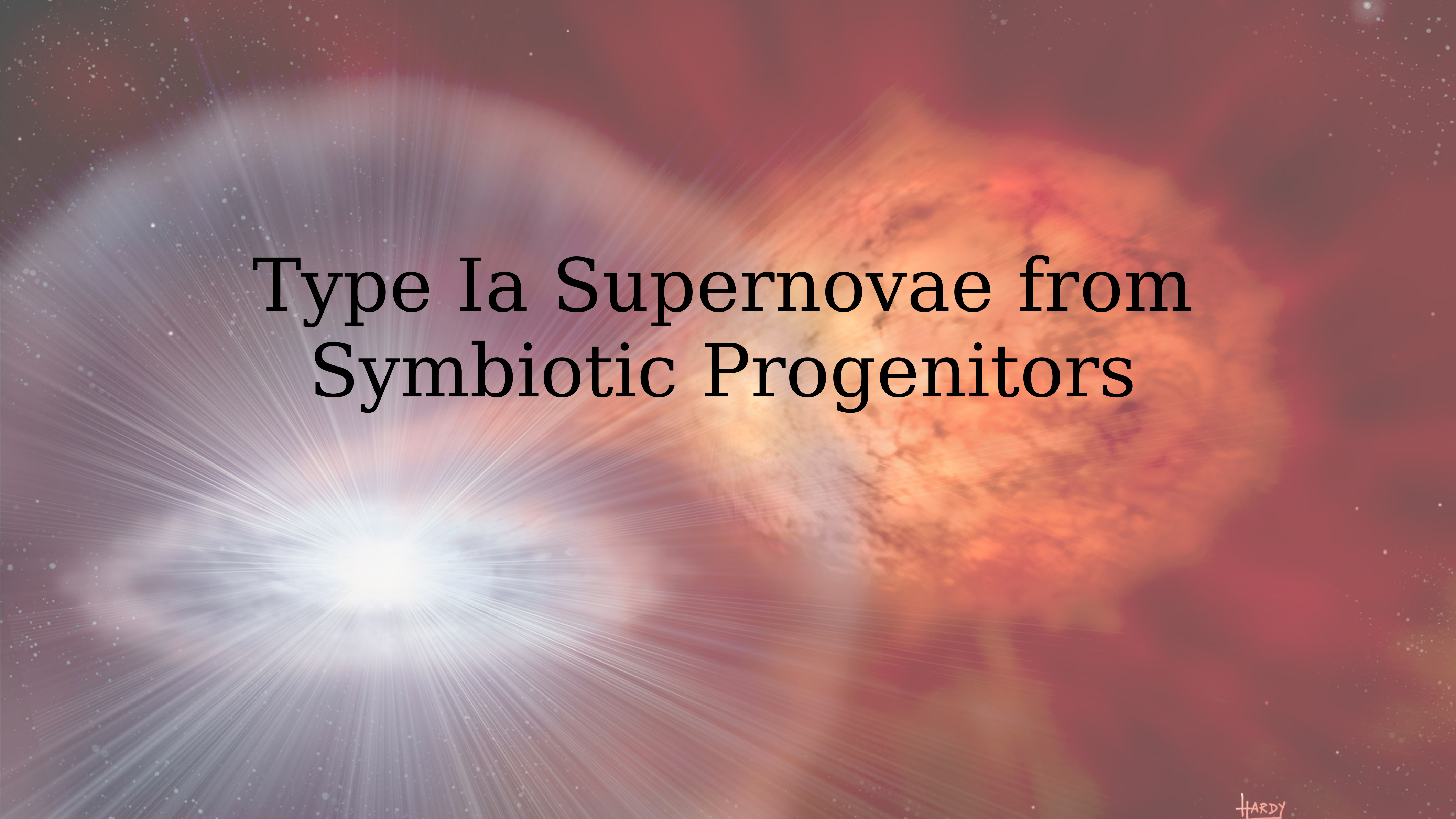

(Laversveiler & Gonçalves 2023; Laversveiler et al. in prep)

- From other authors
  - Kenyon 1986: 3,000 SySt
  - Munari & Renzini 1992: 300,000 SySt
  - Kenyon+1993: 33,000 SySt
  - Yungelson+1995: 3,000–30,000 SySt
  - Magrini+2003: 400,000 SySt
  - Lü+2006: 1,200–15,000 SySt

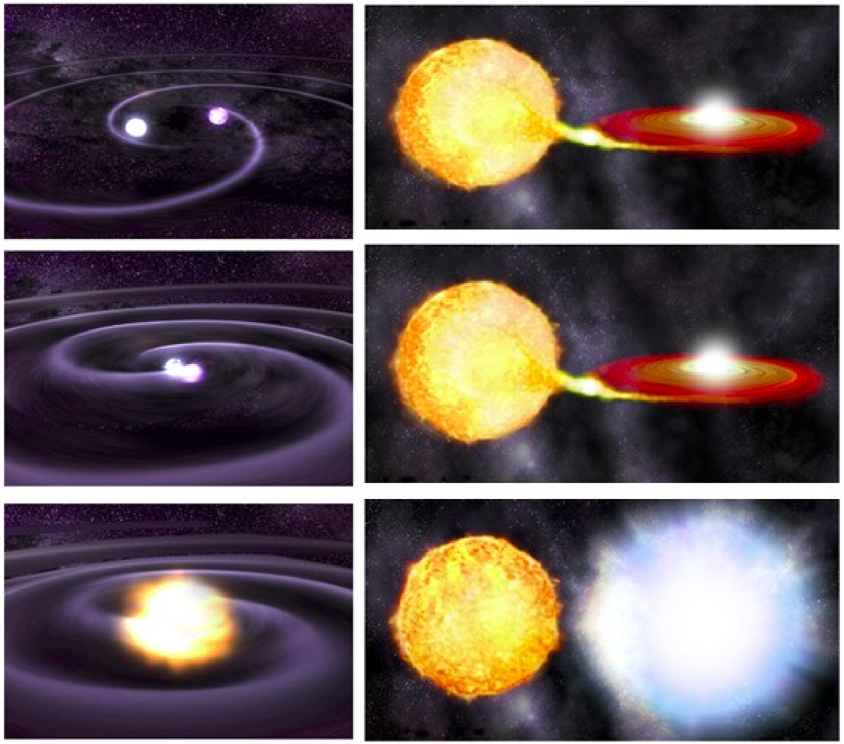



(Laversveiler & Gonçalves 2023; Laversveiler et al. in prep)

# Type Ia Supernovae from Symbiotic Progenitors



# SySt as SN Ia Progenitors?



NASA/CXC/M. Weiss

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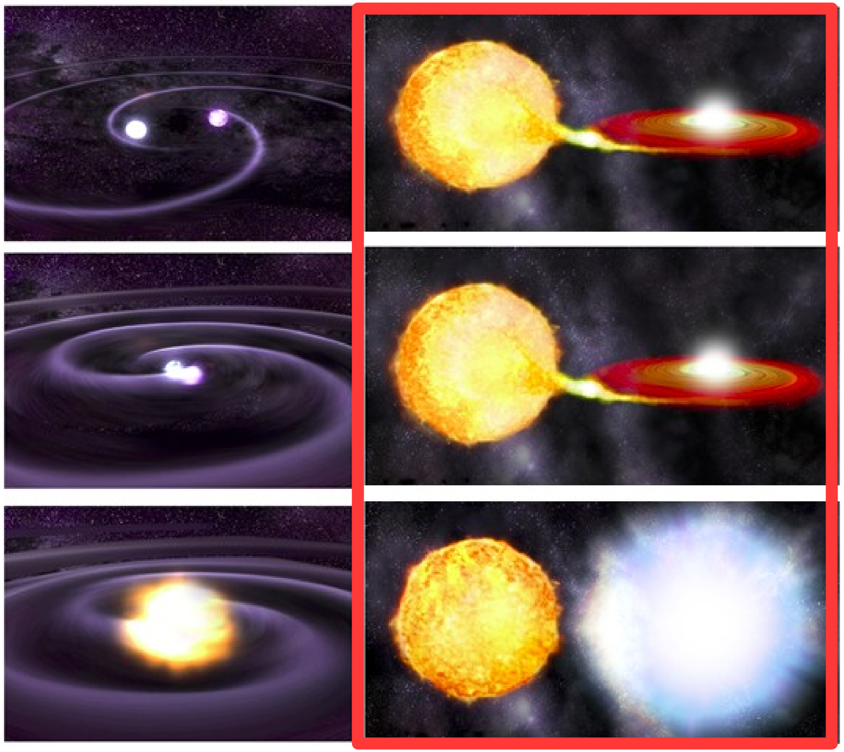


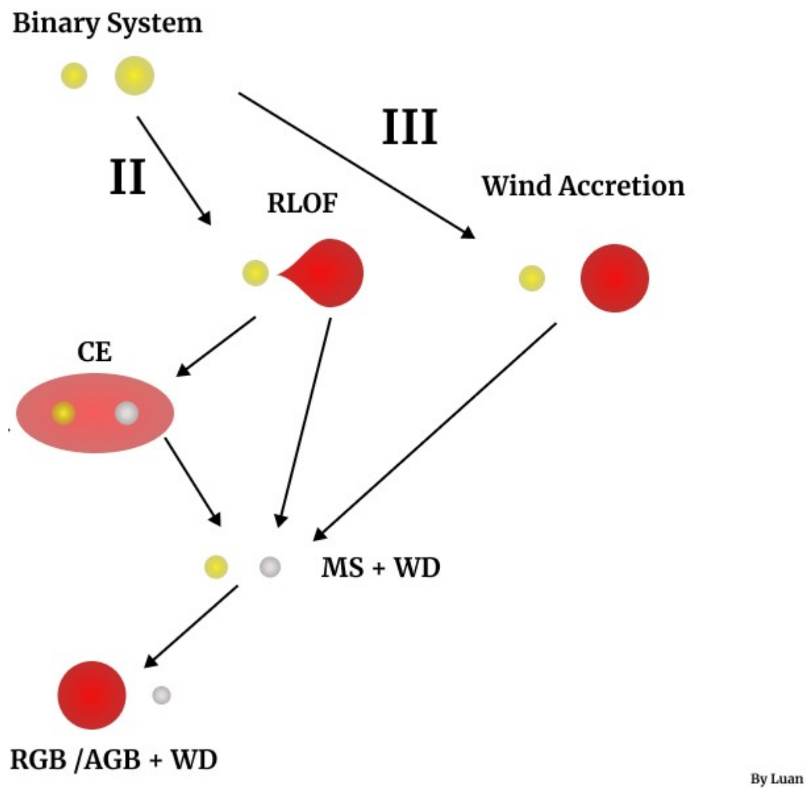
NASA/CXC/M. Weiss

# SySt as SN Ia Progenitors?

- Selection of SySt formed with 1.1 $M_\odot$ (or higher) C+O WDs
  - Restriction to channels II AGB and III
  - The IFMR (Cummings+2018) implies that such WDs have ZAMS masses > 6 $M_\odot$
  - The limit on the WD mass is set by SySt giants: mass loss, envelope mass and lifetime (Munari & Renzini 1992, Kenyon+1993)

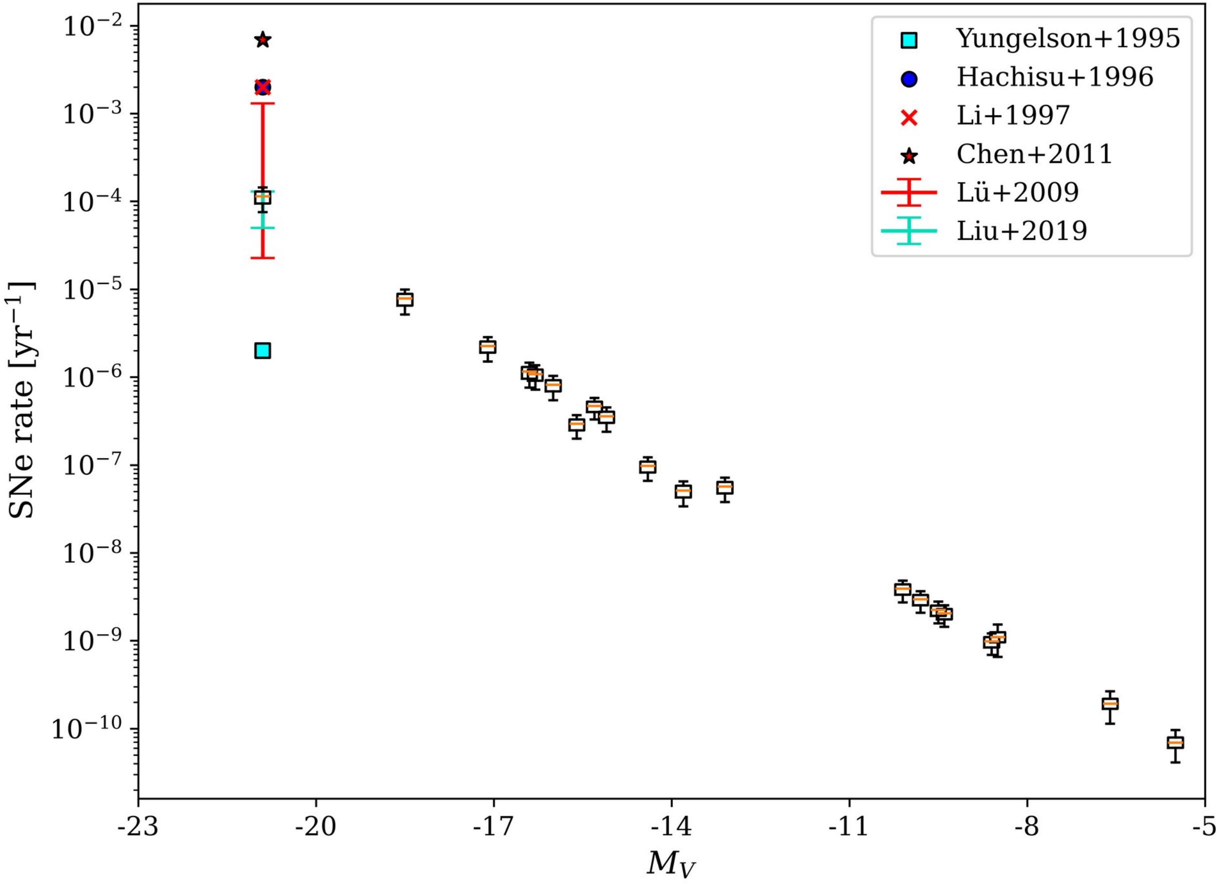
$$r_{\text{SNe Ia}} = \frac{\mathcal{N}}{\tau_{\text{ss}}} \int_{6.0}^{8.0} \frac{df^{*}_{\text{bin}}(M_1)}{dM_1} \sum_i f^{(i)}_{\text{evol}}(M_1)\, dM_1$$

- Our considerations try to extrapolate the maximum contribution of SySt to SNe Ia events.



# Results

| galaxy | SNe rate [yr$^{-1}$] |
|---|---|
| Milky Way | $1.14^{+0.09}_{-0.08} \times 10^{-4}$ |
| LMC | $(7.83 \pm 0.66) \times 10^{-6}$ |
| SMC | $(2.26 \pm 0.20) \times 10^{-6}$ |
| NGC 205 | $(1.15 \pm 0.10) \times 10^{-6}$ |
| IC 10 | $(1.08 \pm 0.09) \times 10^{-6}$ |
| NGC 6822 | $8.19^{+0.72}_{-0.73} \times 10^{-7}$ |
| NGC 185 | $(2.93 \pm 0.25) \times 10^{-7}$ |
| IC 1613 | $4.70^{+0.35}_{-0.36} \times 10^{-7}$ |
| NGC 147 | $3.58^{+0.31}_{-0.32} \times 10^{-7}$ |
| WLM | $(9.72 \pm 0.84) \times 10^{-8}$ |
| Sagittarius | $(5.13 \pm 0.42) \times 10^{-8}$ |
| Fornax | $(5.67 \pm 0.50) \times 10^{-8}$ |
| Leo II | $3.91^{+0.30}_{-0.29} \times 10^{-9}$ |
| Sculptor | $(2.96 \pm 0.22) \times 10^{-9}$ |
| Sextans | $(2.25 \pm 0.17) \times 10^{-9}$ |
| Carina | $2.05^{+0.16}_{-0.15} \times 10^{-9}$ |
| Draco | $9.82^{+0.76}_{-0.73} \times 10^{-10}$ |
| Ursa Minor | $(1.11 \pm 0.25) \times 10^{-9}$ |
| Hercules | $1.95^{+0.45}_{-0.43} \times 10^{-10}$ |
| Leo IV | $7.03^{+1.60}_{-1.61} \times 10^{-11}$ |




(Laversveiler & Gonçalves 2023; Laversveiler et al. in prep)

# Summary and Conclusions

(Laversveiler & Gonçalves 2023; Laversveiler et al. in prep)

- SySt Population in the Milky Way
  - Bottom limit ~ $10^4$ SySt (7200–14500 determined empirically).
  - From (statistical) binary evolution we expect (3.1–4.6) x $10^4$ SySt.
  - Upper limit (6.0–9.2) x $10^4$ SySt; from the disk's truncation radius.

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- Local Group Dwarf Galaxies SySt Population
  - Expected population follows the luminosity; and their binary fraction promotes the dispersion.
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  - Expected population follows the luminosity; and their binary fraction promotes the dispersion.
  - Hundreds of SySt are expected in the larger ones (LMC and SMC), and no SySt in the tiny ones.
- SNe Ia from Symbiotic Progenitors
  - 1.04 x $10^{-4}$ SNe Ia / yr in the Milky Way, representing 3.8% of the observed rate (e.g. Li+2011, Adams+2013).
    - 7.6% if the SySt population is retrieved using the disk's truncation radius.
  - From $10^{-6}$ to $10^{-11}$ SNe Ia / yr, implying no SNe Ia events are expected from the smaller galaxies.
  - SySt can not be the main progenitors of SN Ia events through the classical channel (e.g. Munari & Ranzini 1992, Kenyon+1993, Yungelson+1995,1998, Soker 2019)

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I am looking for a Ph.D. position
in binaries for 2025! 😅

- Local Group Dwarf Gala
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  - Hundreds of SySt are expected in the larger ones (LMC and SMC), and no SySt in the tiny ones.
- SNe Ia from Symbiotic Progenitors
  - 1.04 x $10^{-4}$ SNe Ia / yr in the Milky Way, representing 3.8% of the observed rate (e.g. Li+2011, Adams+2013).
    - 7.6% if the SySt population is retrieved using the disk's truncation radius.
  - From $10^{-6}$ to $10^{-11}$ SNe Ia / yr, implying no SNe Ia events are expected from the smaller galaxies.
  - SySt can not be the main progenitors of SN Ia events through the classical channel (e.g. Munari & Ranzini 1992, Kenyon+1993, Yungelson+1995,1998, Soker 2019)

# Thank you!
# Děkuji!

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CAPES

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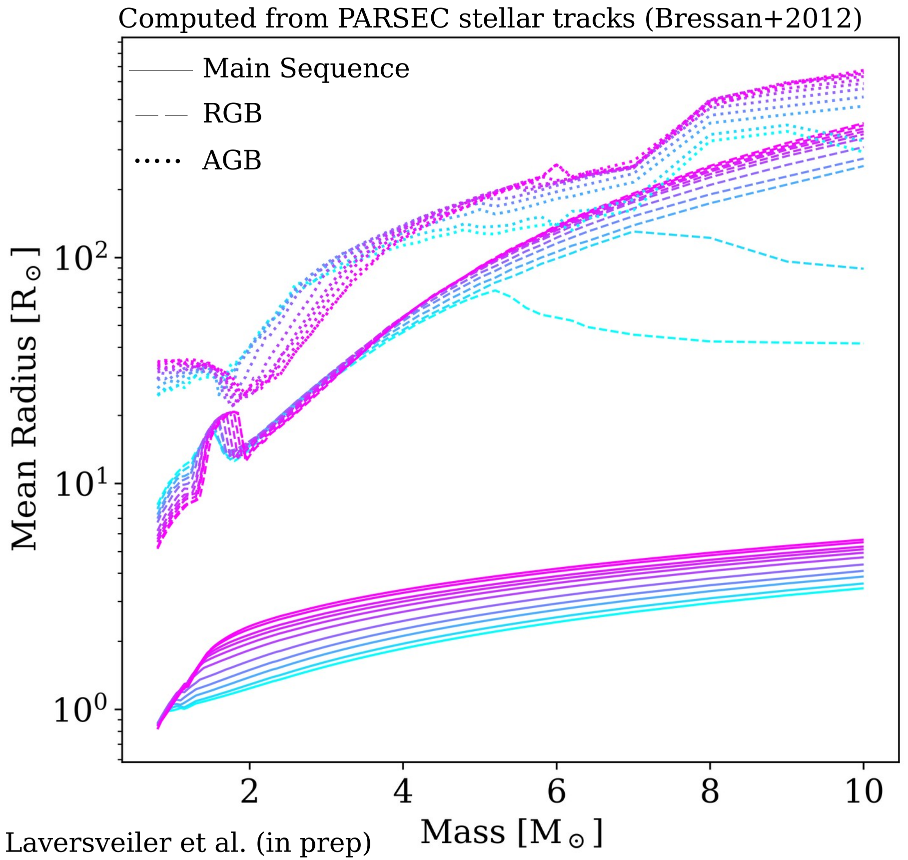
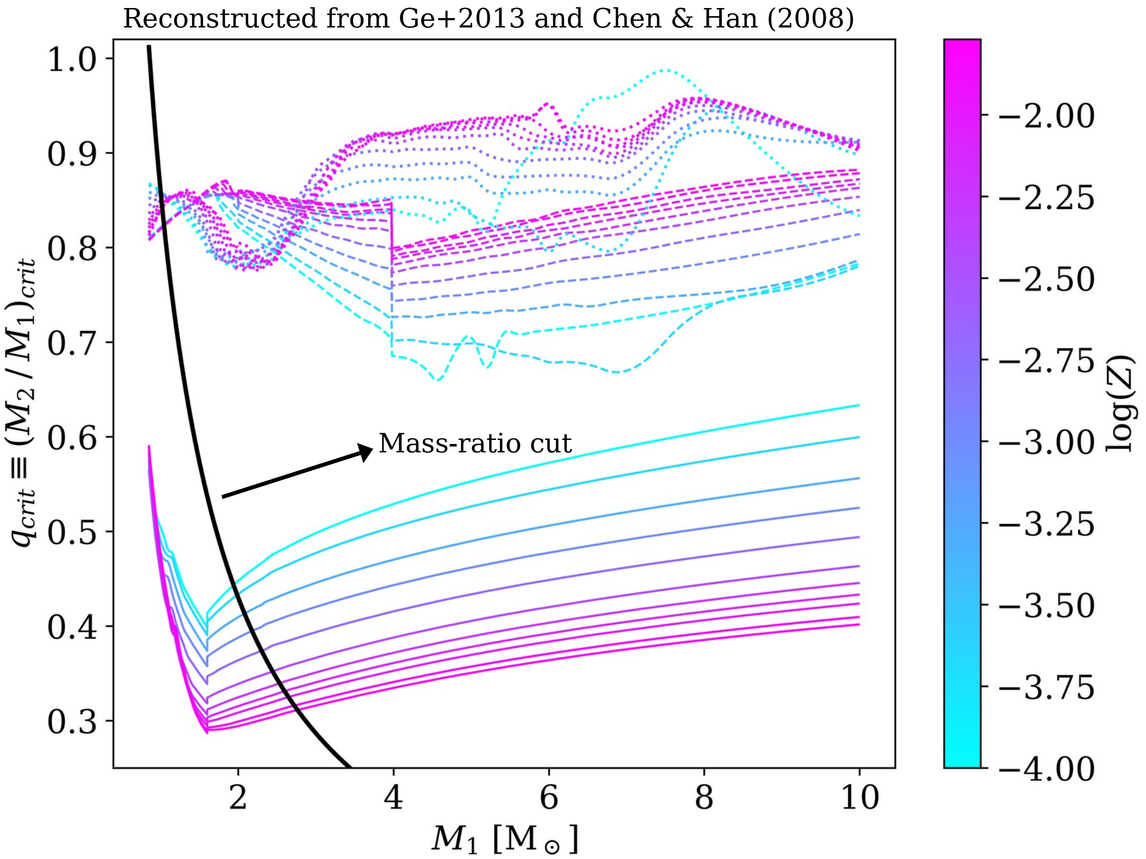
# Extra Slides




Laversveiler et al. (in prep)




- Difference in behavior is due to different envelope responses (radiative or convective).