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Intermediate-Age Globular Clusters (in Merger Remnants)

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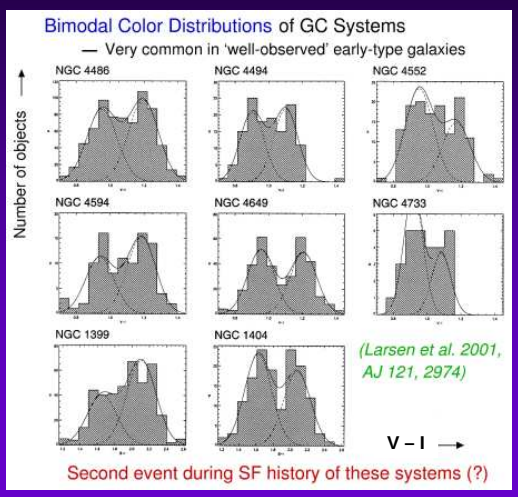
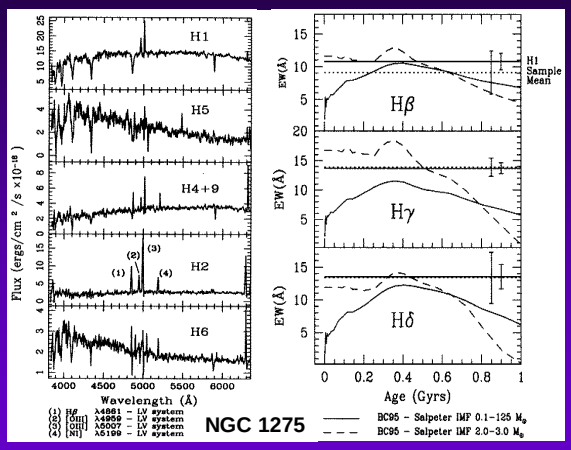
- Why study Intermediate-Age GCs?
- Impact on Early-type Galaxy Formation Scenarios

The Big Picture:
How were Red GCs in Giant E/S0's formed?

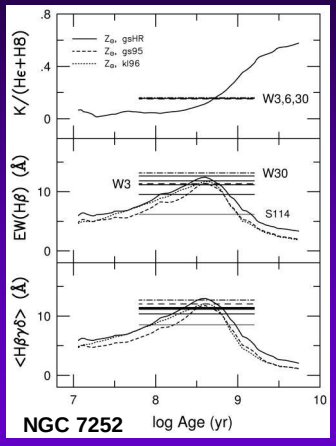
- During Gas-rich Mergers?
  - IMF steep enough for GCs to survive to old age?
  - Metallicities OK?
  - GCLF: PL → Gaussian?
  - Yielding high enough S_N?
- Multi-phase Collapse?
- Accretion of dwarfs?



Testing the Merger Scenario:
IMF steep enough to survive to old age?

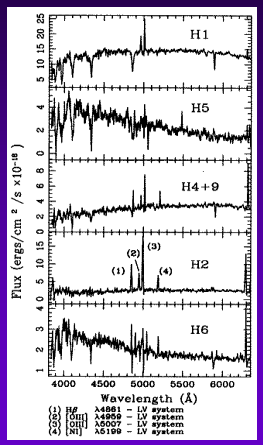


Brodie et al. 1998, AJ 116

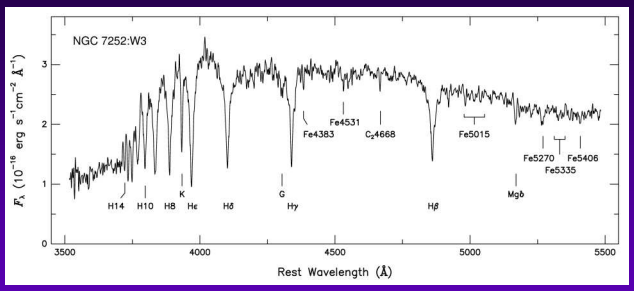


Schweizer & Seitzer, 1998, AJ 116

Testing the Merger Scenario:
Are the metallicities of the new GCs right?

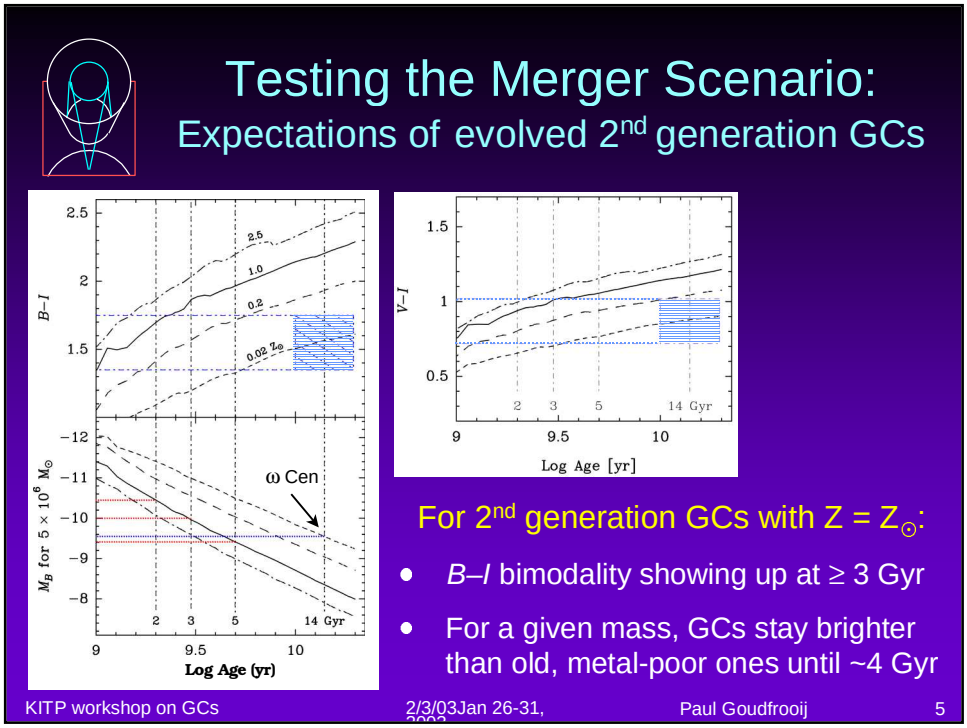


Brodie et al. 1998



Schweizer & Seitzer 1998

- Hard to measure accurately at age of ~0.5 Gyr
- Older 2nd-generation GCs would be 'better'


Testing the Merger Scenario:
Expectations of evolved 2nd generation GCs
B–I
V–I
ω Cen
Log Age (yr)
Log Age [yr]
14 Gyr
For 2nd generation GCs with Z = Z⊙:
• B–I bimodality showing up at ≥ 3 Gyr
• For a given mass, GCs stay brighter than old, metal-poor ones until ~4 Gyr
KITP workshop on GCs
2/3/03Jan 26-31,
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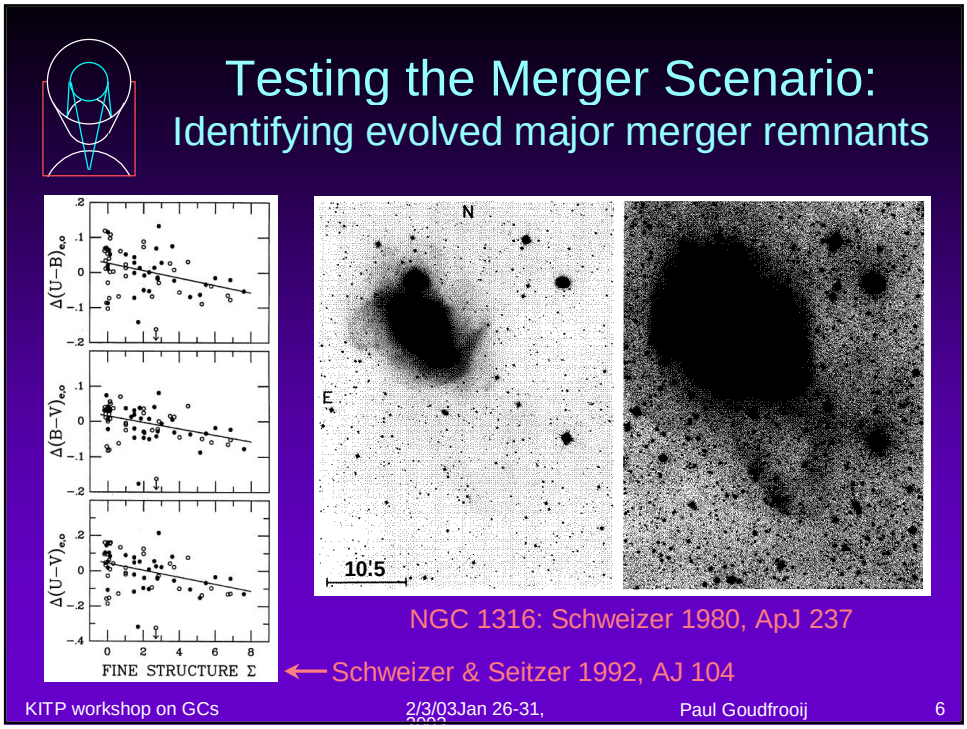
Testing the Merger Scenario:
Identifying evolved major merger remnants
FINE STRUCTURE Σ
N
E
10.5
NGC 1316: Schweizer 1980, ApJ 237
← Schweizer & Seitzer 1992, AJ 104
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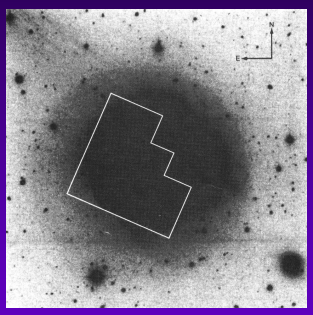
Testing the Merger Scenario:
Insights from evolved merger remnants

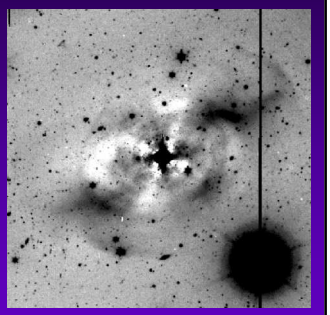
NGC 1316

(Goudfrooij et al. 2001a,b)



NGC 3610

(Whitmore et al. 1997, 2002)



NGC 1700

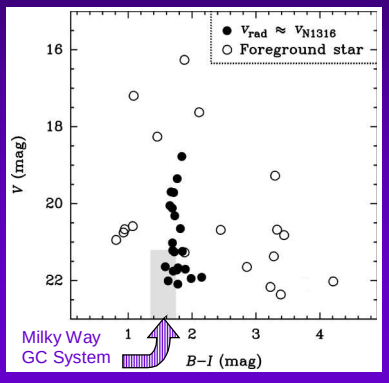
(Brown et al. 2000)

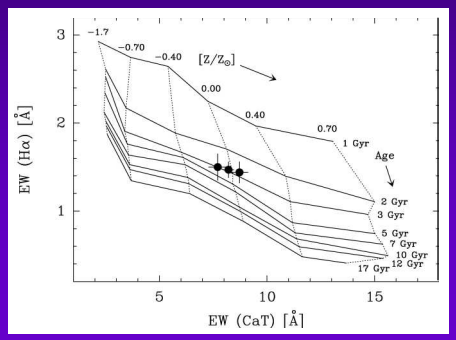
Testing the Merger Scenario:
Spectroscopy of Luminous GCs in NGC 1316

NTT Imaging + MOS Spectra
(Goudfrooij et al. 2001, MN 322)

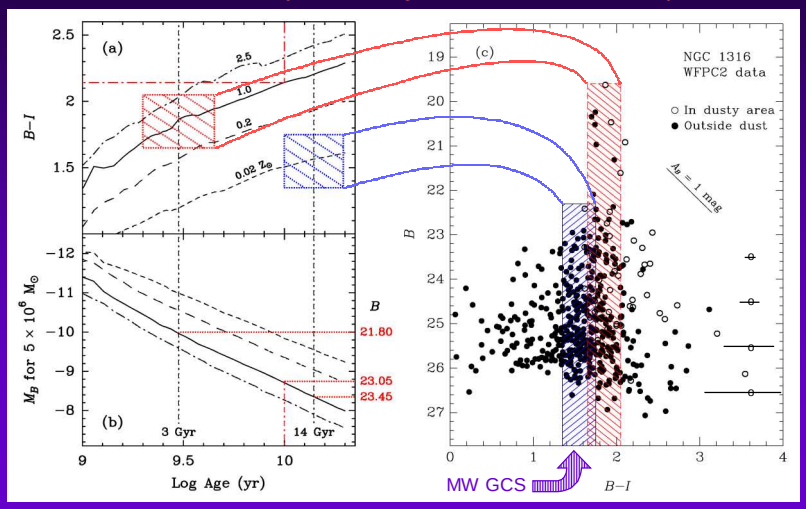
EW (Hα) vs. EW (CaT) diagram along with age-Z grid based on measurements on BC2000 model spectra:

- The luminous GCs are ~ 3 Gyr old
- Their Z = $Z_{\odot}$ ± 0.15 dex



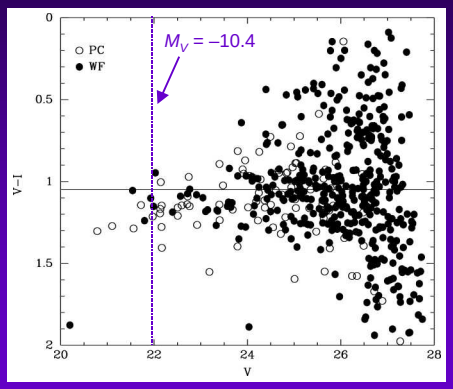


Testing the Merger Scenario:
WFPC2 imaging of GCs in NGC 1316
(Goudfrooij et al. 2001b, MN 328)

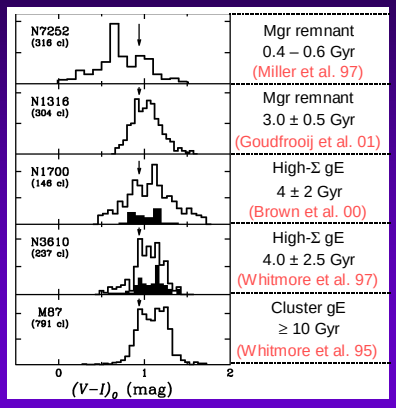


GC Systems of Merger Remnants:
Tracers of Systemic Evolution

GCs in High-Fine-Structure Ellipticals: NGC 3610 & NGC 1700



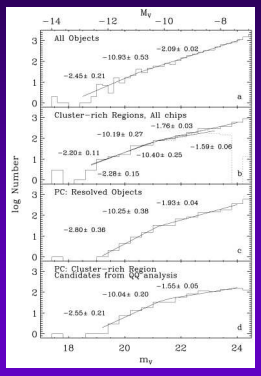
NGC 3610: Whitmore et al. 2002, AJ 124



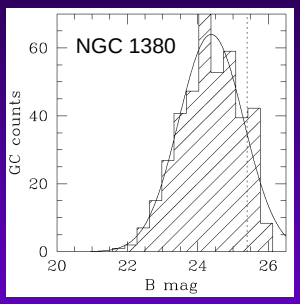
(From Schweizer 2002, Pucon Proc.)

GC Systems of Merger Remnants:
Tracers of Systemic Evolution

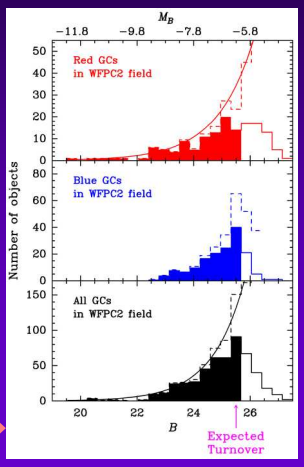
Luminosity Functions of Blue vs. Red GC Populations



Whitmore et al. 1999, AJ 118 (Antennae)



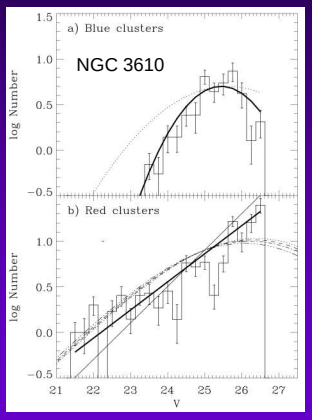
Kissler-Patig et al. 1997, A&A 327

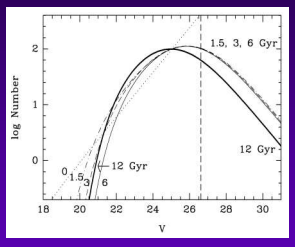


Goudfrooij et al. 2001, MN 328 (NGC 1316)

GC Systems of Merger Remnants:
Tracers of Systemic Evolution

Luminosity Functions of Blue vs. Red GC Populations





Whitmore et al. 2002:
Fall & Zhang '01 models
+ lumin. fading (BC96)

Upcoming:

B,V,I HST/ACS imaging of NGC 1316 & NGC 3610 down to 2 mag beyond anticipated m_{TO}

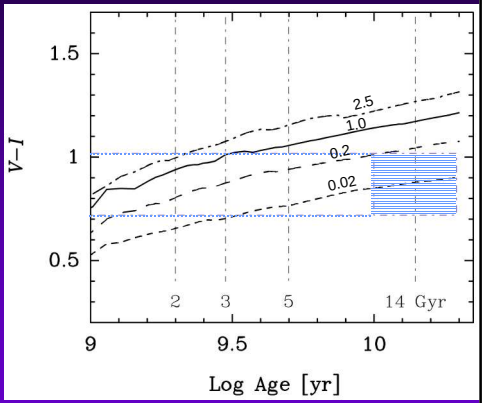
➔ Much better distinction (blue ↔ red population)

- Destruction rate ≈ fading rate near/beyond turnover
- Turnover ~ 1 mag fainter than old, metal-poor GCs

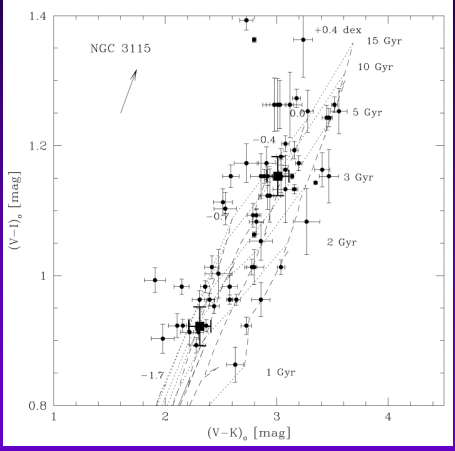
Whitmore et al. 2002, AJ 124

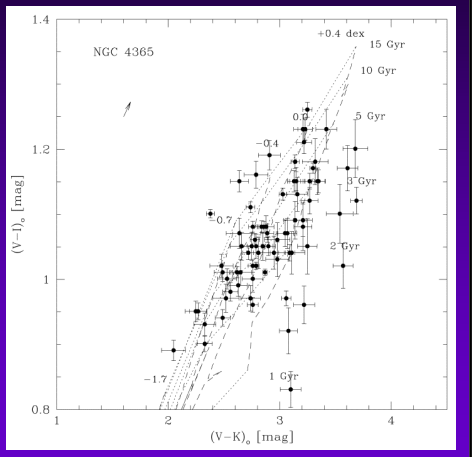
K-band follow-up of GC Systems with *WFPC2 V & I* data

- *V–I* doesn't discriminate very well between old, low-[Fe/H] and intermediate-age, high-[Fe/H] GCs
- *K*-band dominated by giants, whose color is mostly metallicity-dependent → try *V–K*
- VLT+ISAAC: Southern Es & S0s with WFPC2 *V–I* color distributions
- Combining HST resolution with large color baseline
- Subject of Maren Hempel's thesis (@ESO)



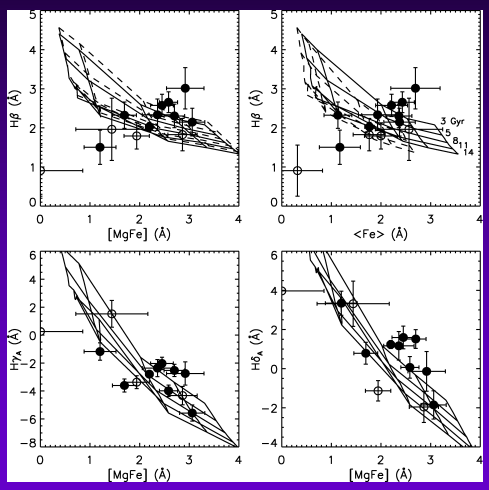
K-band follow-up of GC Systems with *WFPC2 V & I* data





Puzia et al. 2002, A&A, 391, 453

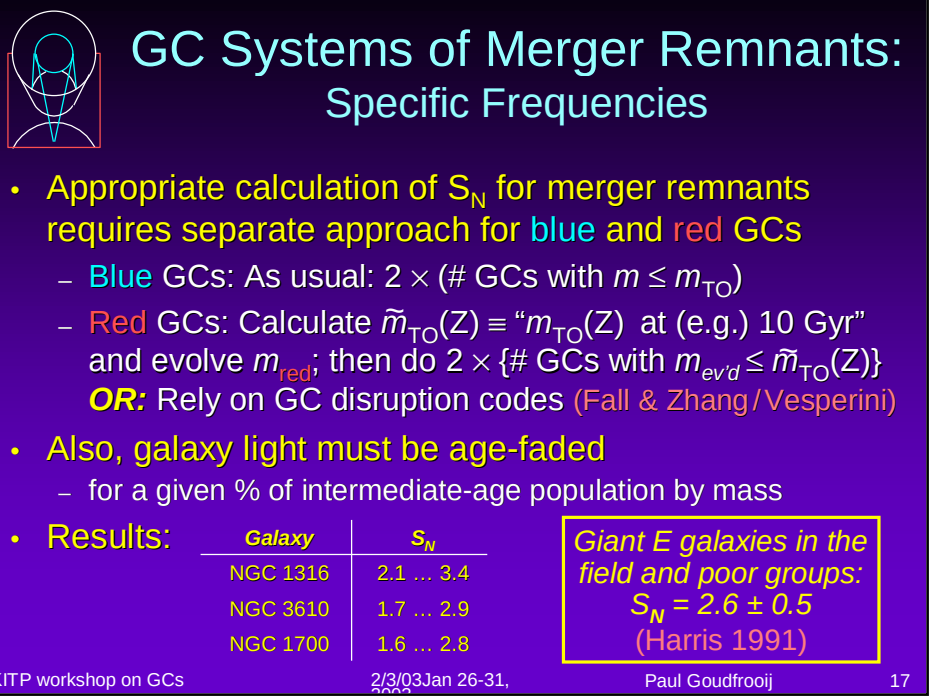
PR and Spectroscopic Confirmation of Intermediate-Age GCs in NGC 4365



Larsen et al. 2003, ApJ in press

Concluding Remarks and Outlook

- Can red GCs have been formed during gas-rich mergers?
  - IMF steep enough for such GCs to survive to old age?
    - YES, given the 3 Gyr old population of GCs in NGC 1316 + intermediate-age GCs in NGC 4365 & NGC 3610
  - Metallicities OK?
    - YES, NGC 1316 & NGC 4365 w/Spectroscopic measurements; Other studied remnant (NGC 1700) has consistent colors
  - GCLF: Power Law → Gaussian?
    - Models: YES; Deeper photometry needed (and coming) to verify
- Caveat:
  - Need more than 2-3 intermediate-age systems with consistent properties to establish consensus


GC Systems of Merger Remnants:
Specific Frequencies
• Appropriate calculation of S_N for merger remnants requires separate approach for blue and red GCs
– Blue GCs: As usual: 2 × (# GCs with $m \le m_{TO}$)
– Red GCs: Calculate $\tilde{m}_{TO}(Z) \equiv$ "$m_{TO}(Z)$ at (e.g.) 10 Gyr" and evolve m_{red}; then do 2 × {# GCs with $m_{ev'd} \le \tilde{m}_{TO}(Z)$}
OR: Rely on GC disruption codes (Fall & Zhang / Vesperini)
• Also, galaxy light must be age-faded
– for a given % of intermediate-age population by mass
• Results:
Galaxy | S_N
NGC 1316 | 2.1 … 3.4
NGC 3610 | 1.7 … 2.9
NGC 1700 | 1.6 … 2.8
Giant E galaxies in the field and poor groups:
$S_N = 2.6 \pm 0.5$
(Harris 1991)
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