Spiral Galaxy Formation based on Detailed Spectroscopic Studies

Lauren MacArthur (HIA)

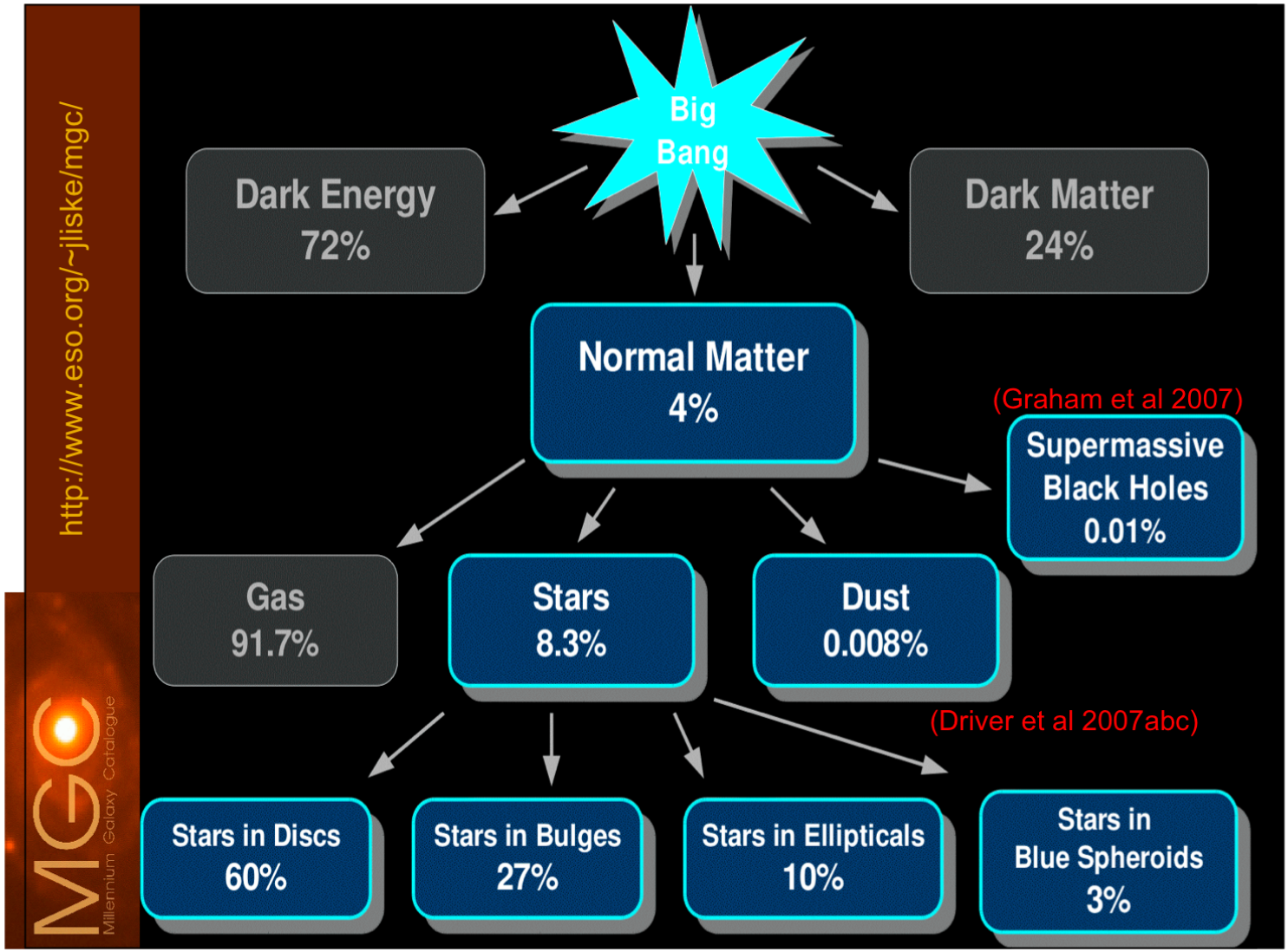
NRC·CNRC Herzberg Institute of Astrophysics

Collaborators:

Stéphane Courteau (Queen's), Jesús González (UNAM), Michael McDonald (UMD)

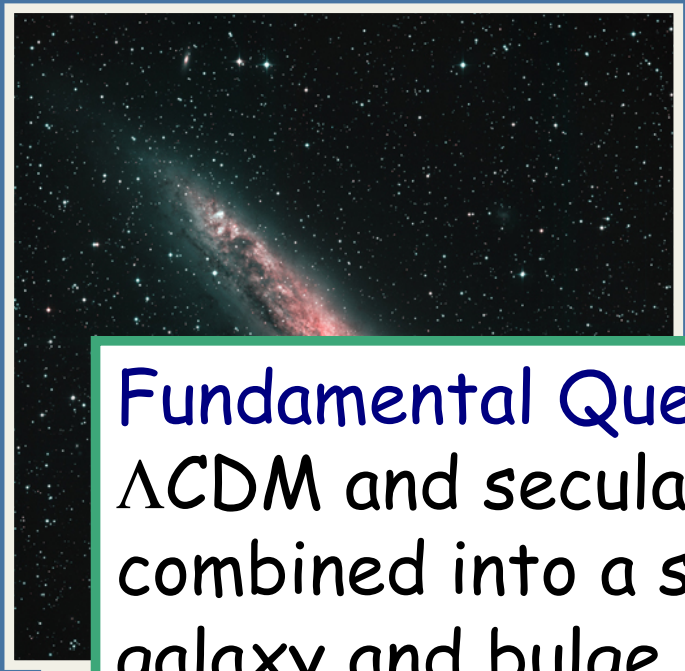
Galaxy Formation, Durham, UK - July 18-22, 2011

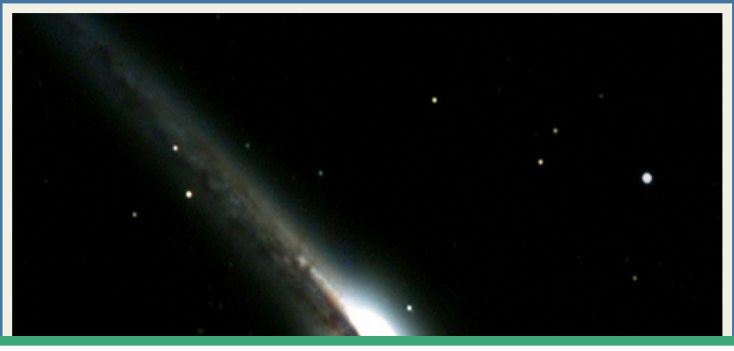
Why Study Spiral Bulges?



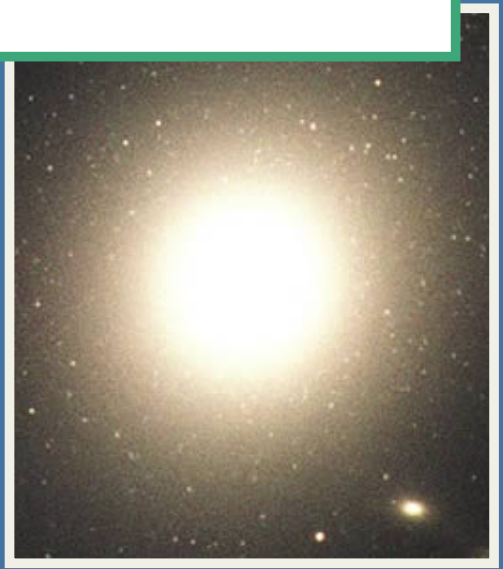
Driver et al. 2007abc

Galaxy "Bulges"/Spheroids



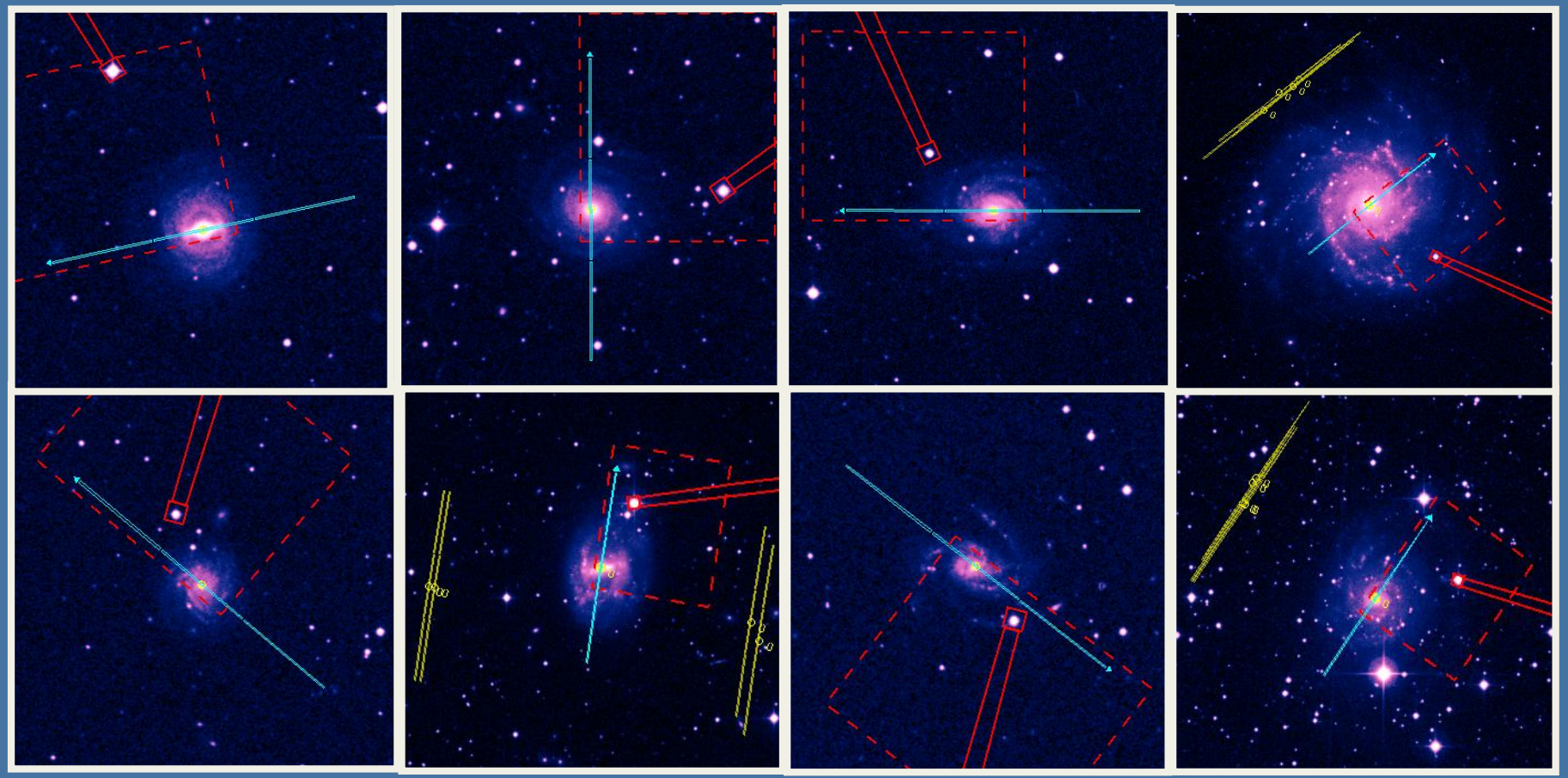


Fundamental Question: Can the hierarchical ΛCDM and secular formation scenarios be combined into a single, coherent view of galaxy and bulge formation?



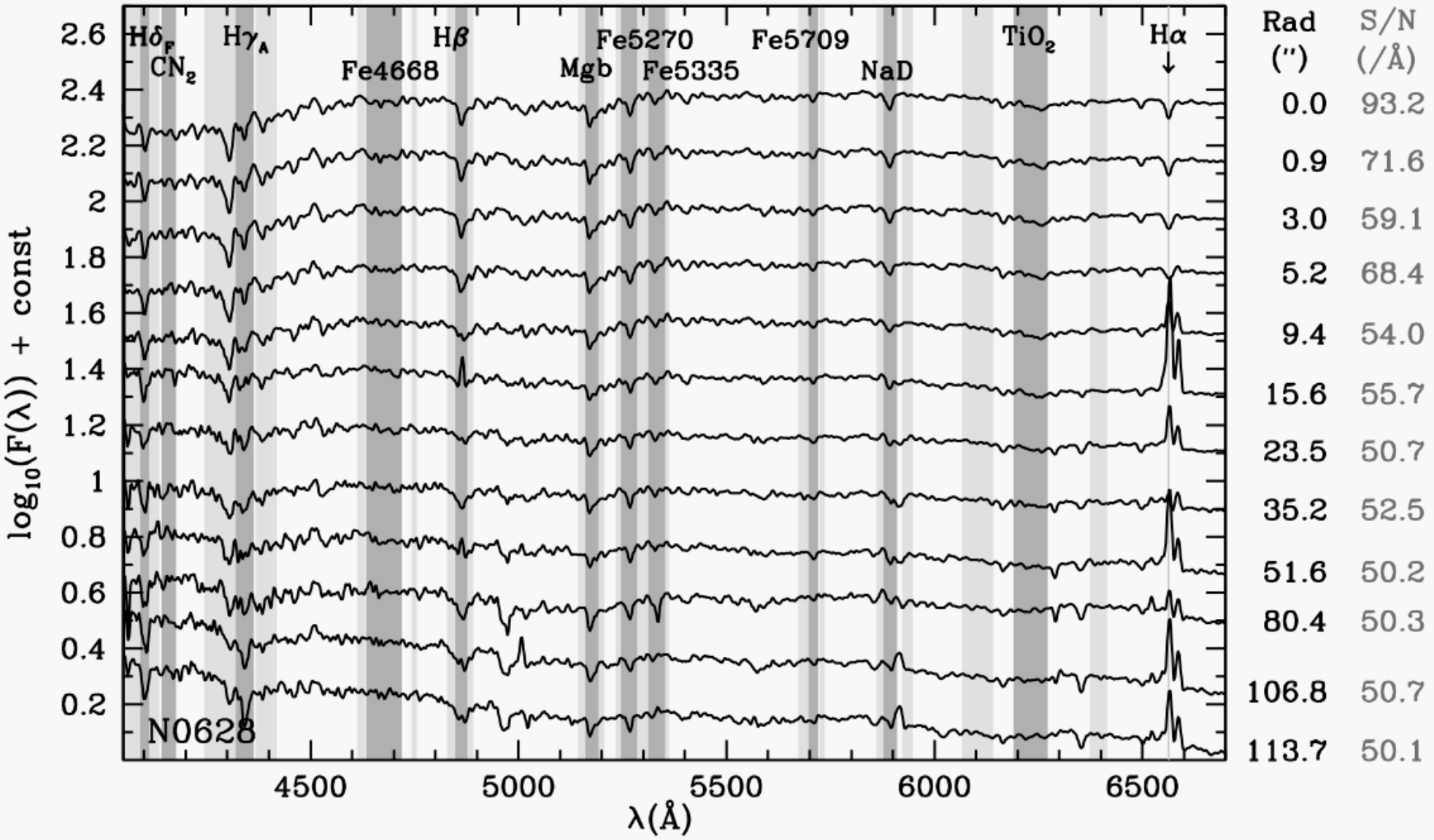
Gemini-GMOS/N Data

UGC 2124 (SBa) NGC 7490 (Sbc) NGC 173 (Sc) NGC 628 (Sc)



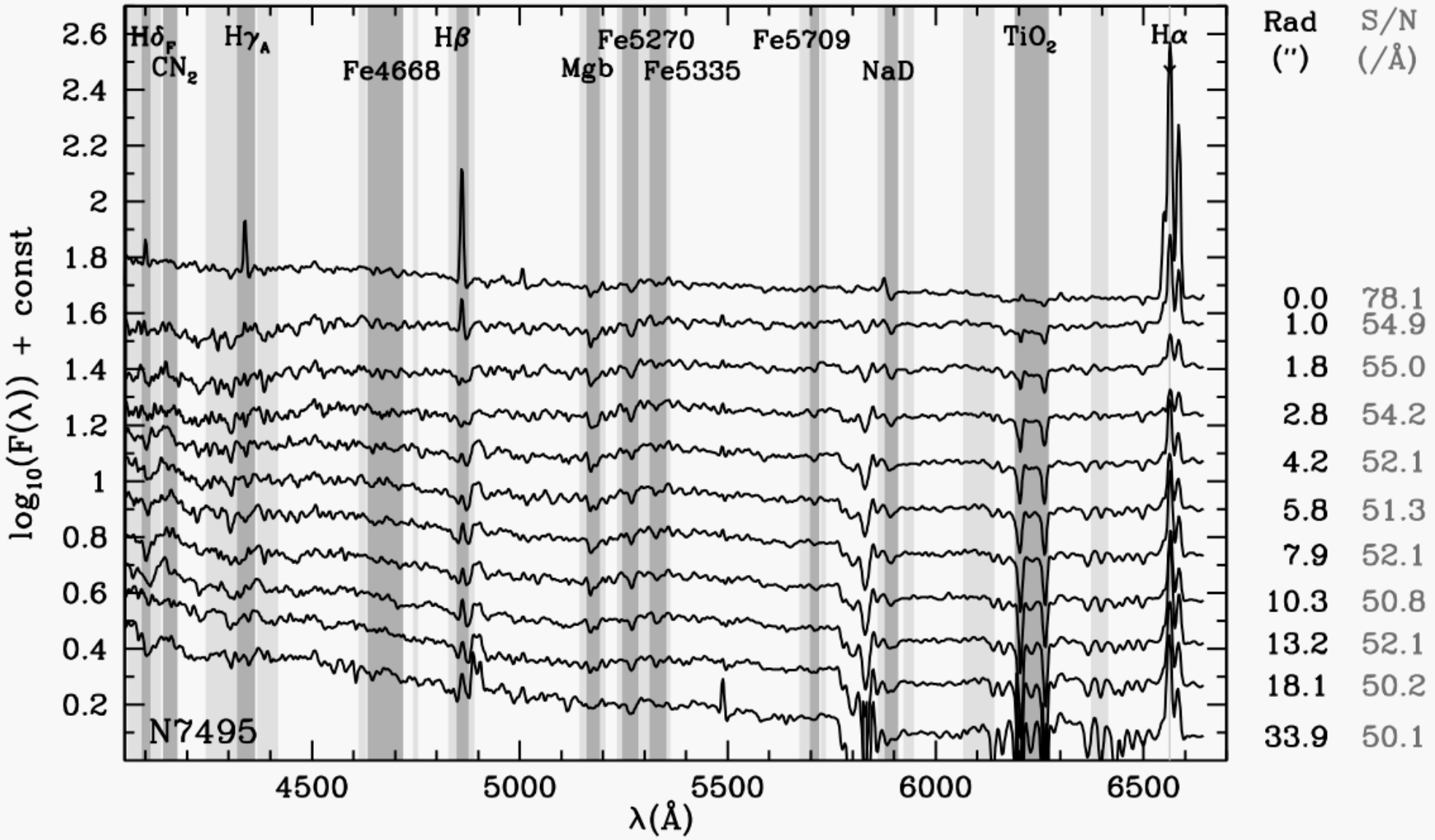
NGC 7495 (SABc) NGC 7741 (SBcd) NGC 7610 (Scd) IC 239 (SABcd)

Radial Spectra: M74 (NGC 628)



MacArthur, González, & Courteau, 2009, MNRAS, 395, 28 r_e = 11.3″ r_d = 70.6″

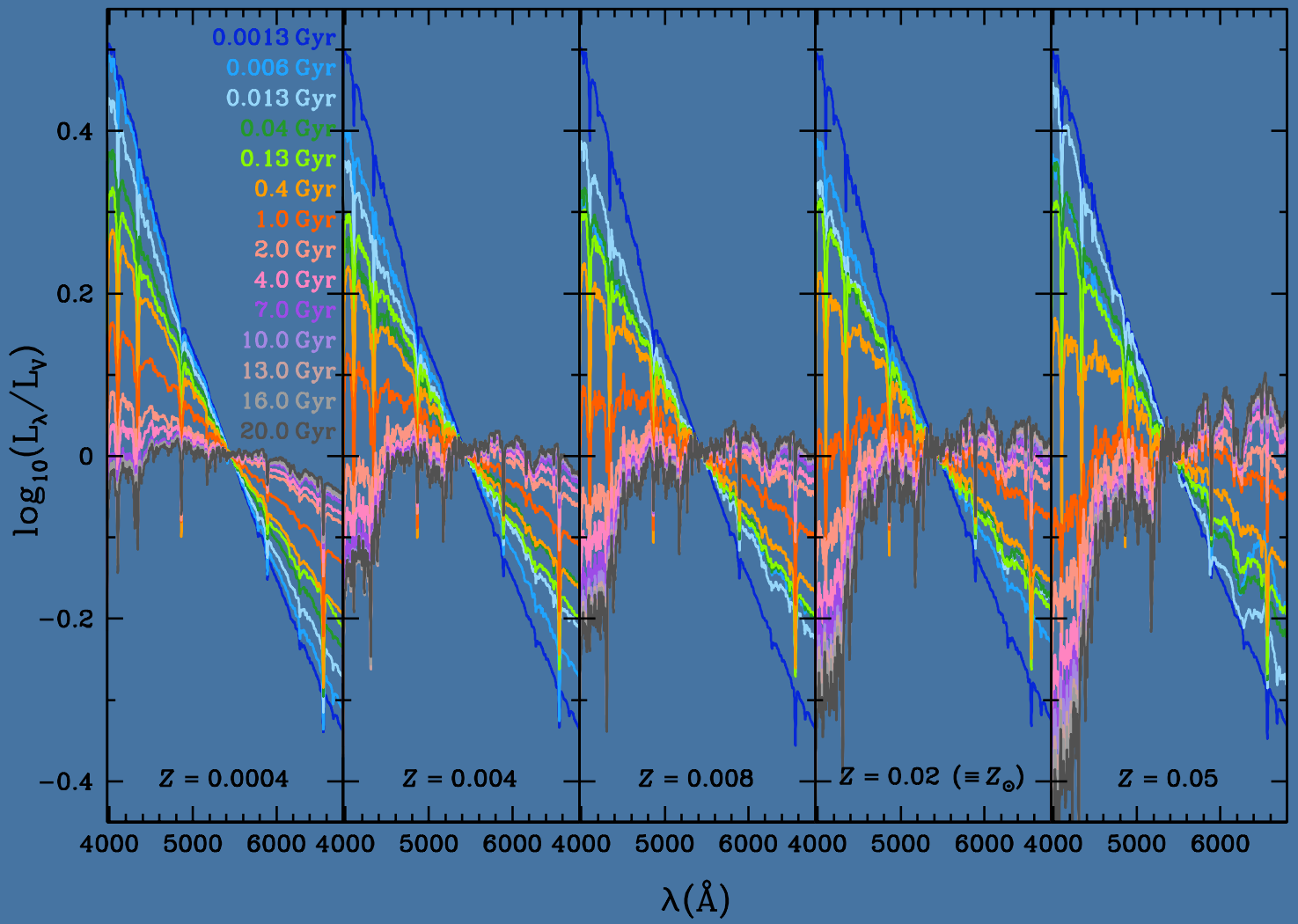
Radial Spectra: NGC 7495



MacArthur, González, & Courteau, 2009, MNRAS, 395, 28 $r_e = 4.8''$ $r_d = 18.4''$

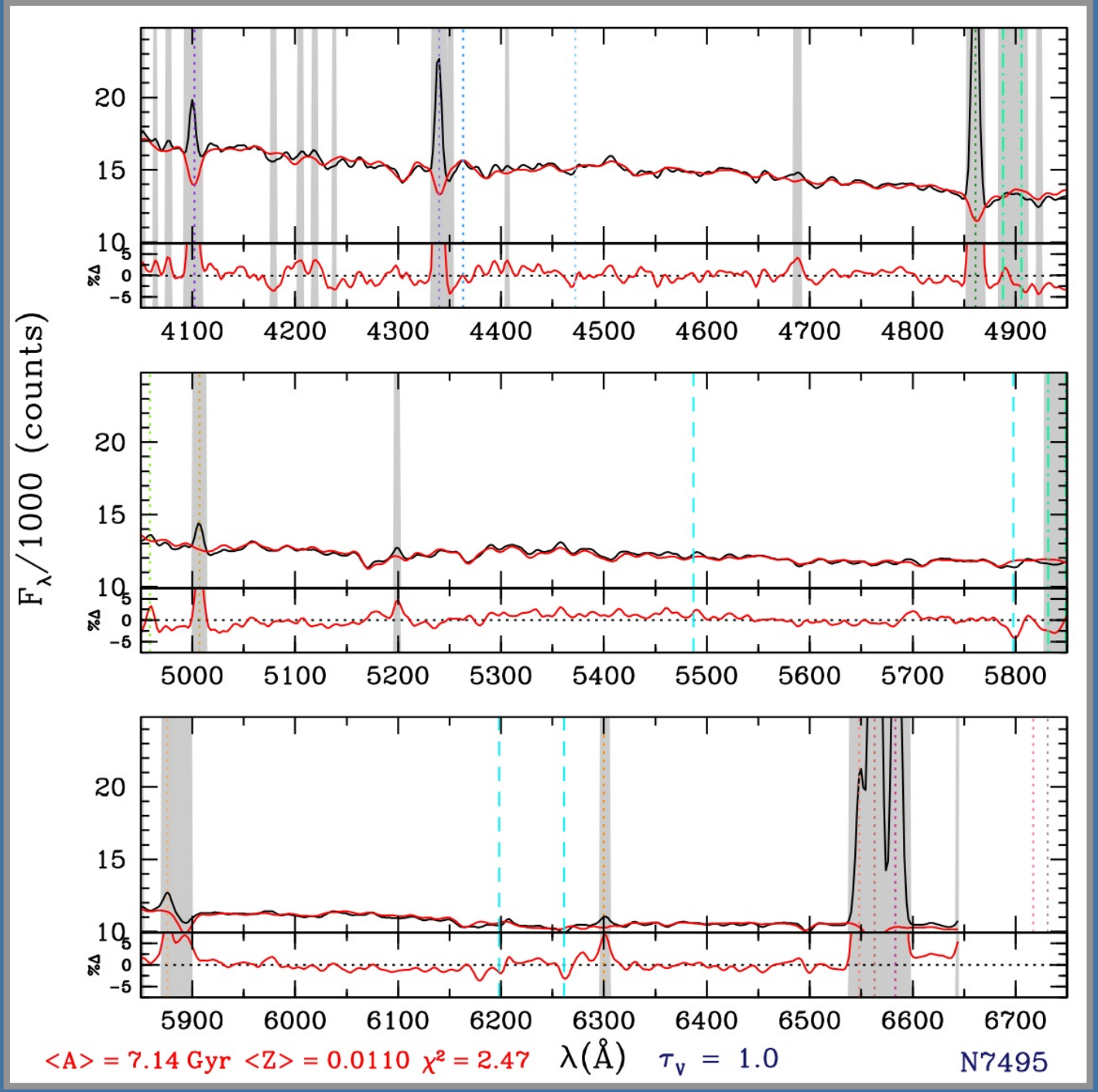
Beyond Single Age/Z Estimates: Full Spectral Synthesis

- bound-constrained optimization: best-fit linear non-zero combination of spectral templates



-> library consists of 70 templates from Bruzual & Charlot 2003 models with full range of age and metallicity

MacArthur, González, & Courteau, 2009, MNRAS, 395, 28

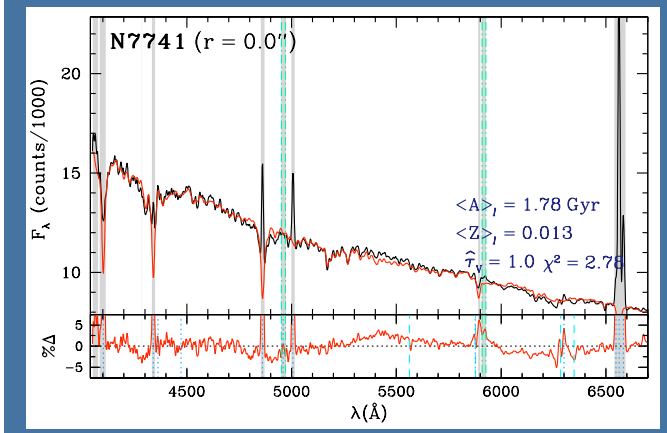


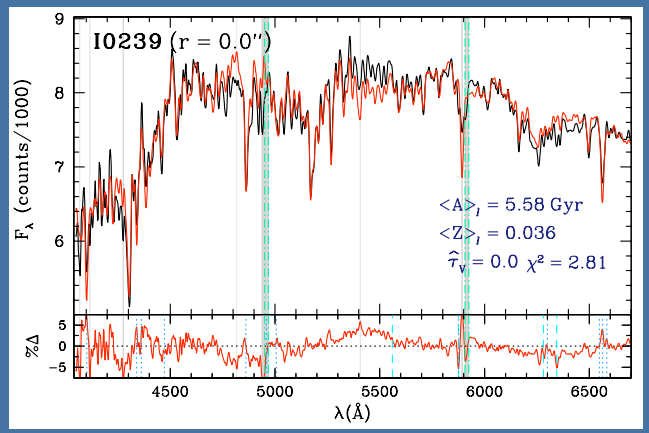
Data

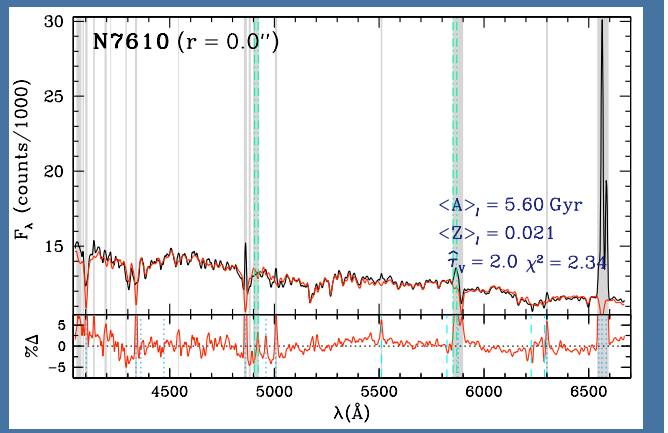
Fit based on bound constrained optimization of a non-zero linear combination of SSP model spectra

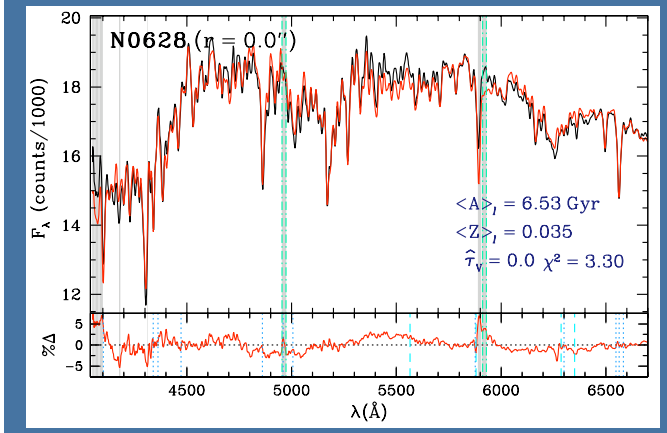
Regions masked from fit

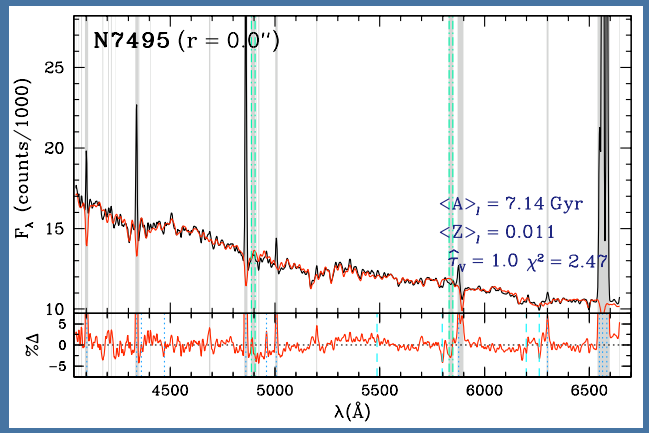
MacArthur, etal., 2009, MNRAS, 395, 28

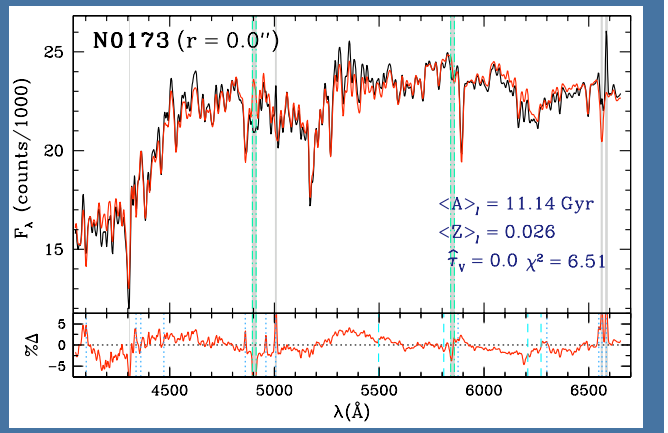


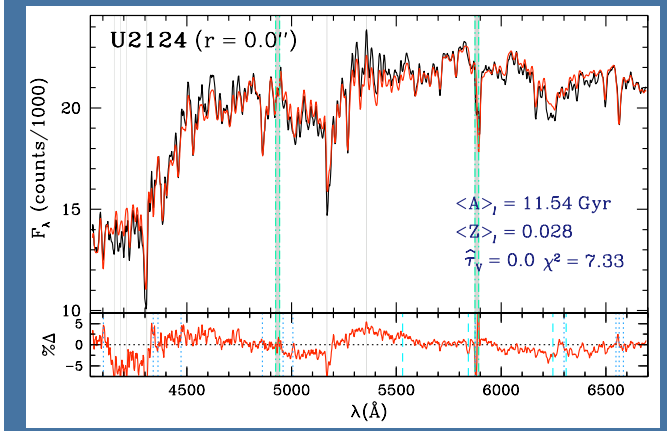


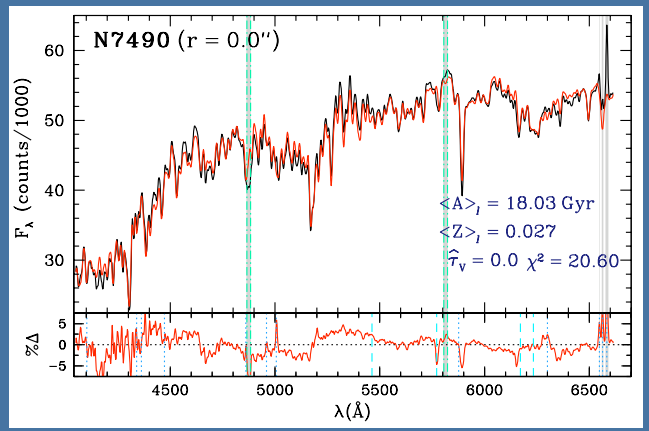








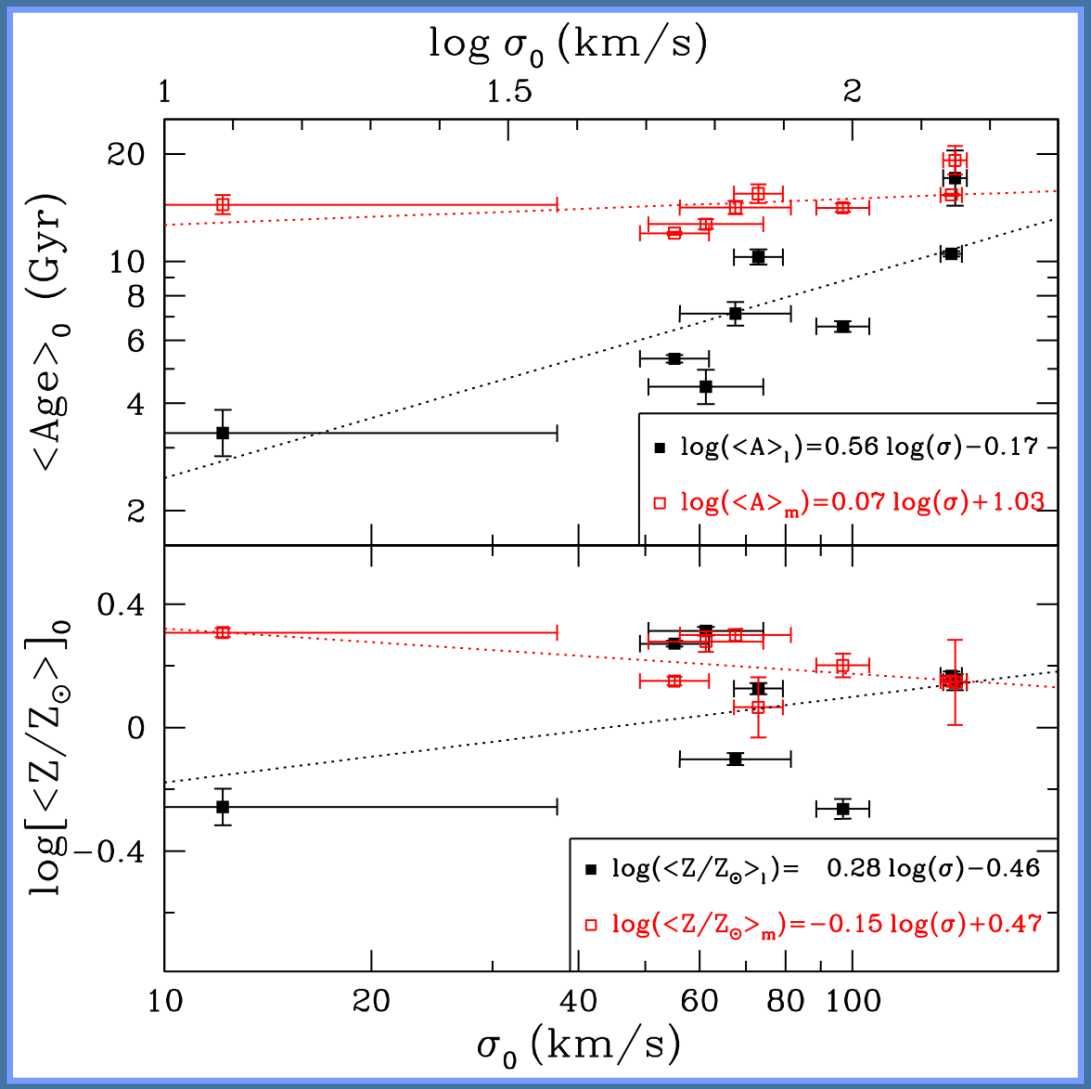




Population Synthesis Fits for R=0 spectra

MacArthur, González, & Courteau, 2009, MNRAS, 395, 28

Age/Z vs. "mass" for Bulges

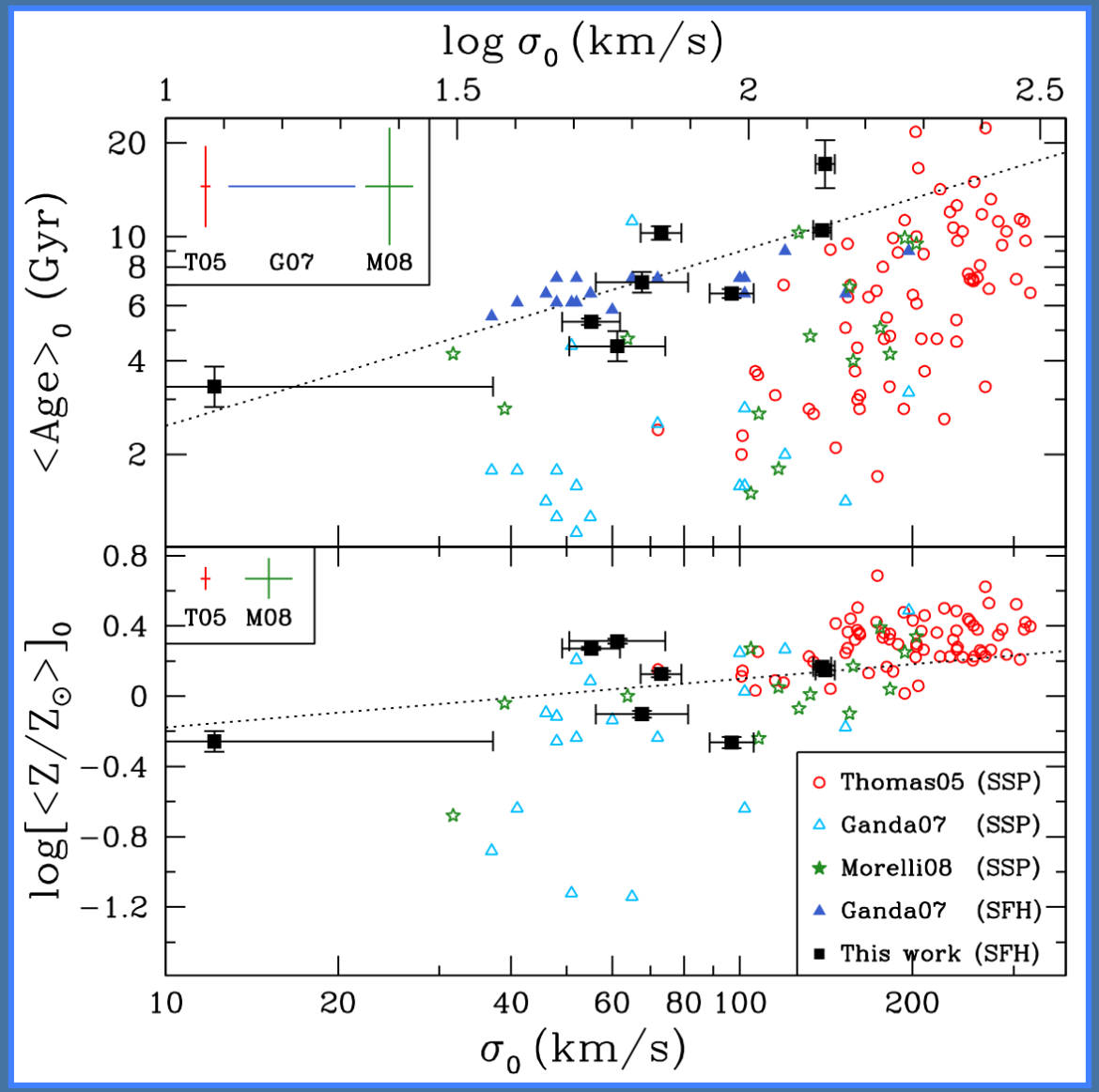


Light-Weighted values

Mass-Weighted values

MacArthur etal. 2009, MNRAS, 395, 28

Age/Z vs. "mass" for Spheroids



Ellipticals from Thomas et al. 2005: SSP

Bulges from Morelli et al. 2008: SSP

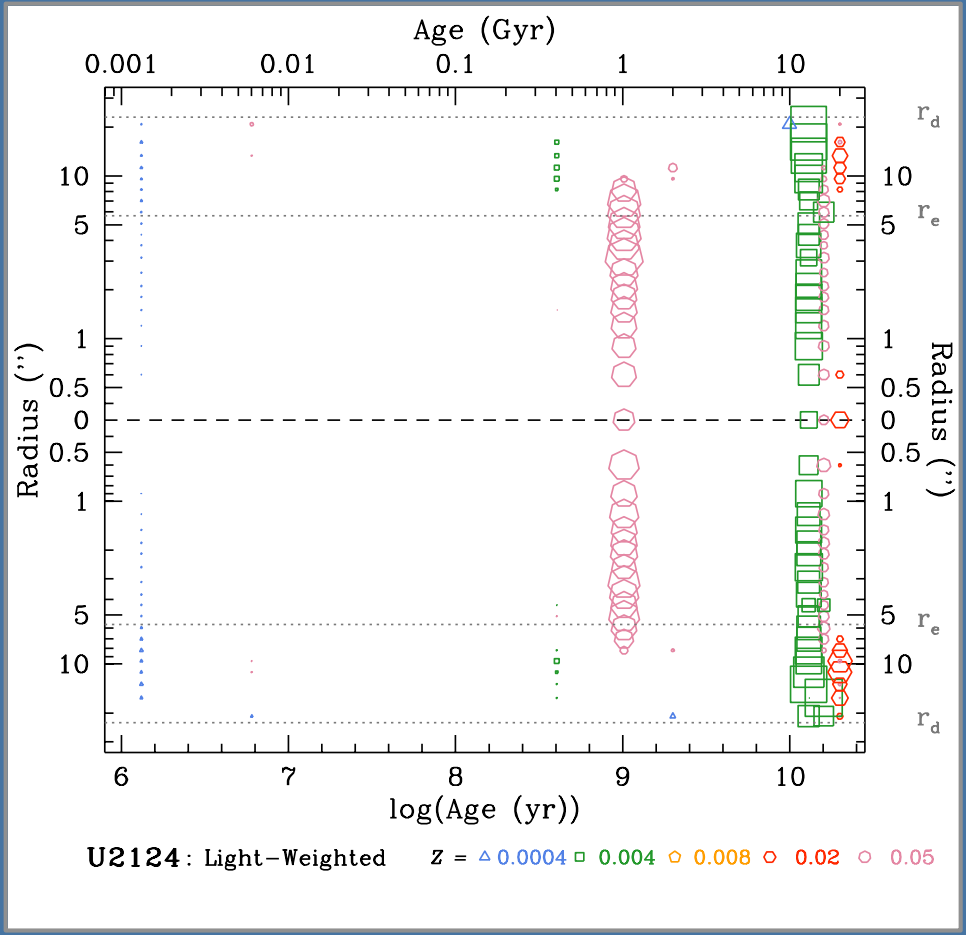
Bulges from Ganda et al. 2008: SSP

Bulges from Ganda et al. 2008: SFH

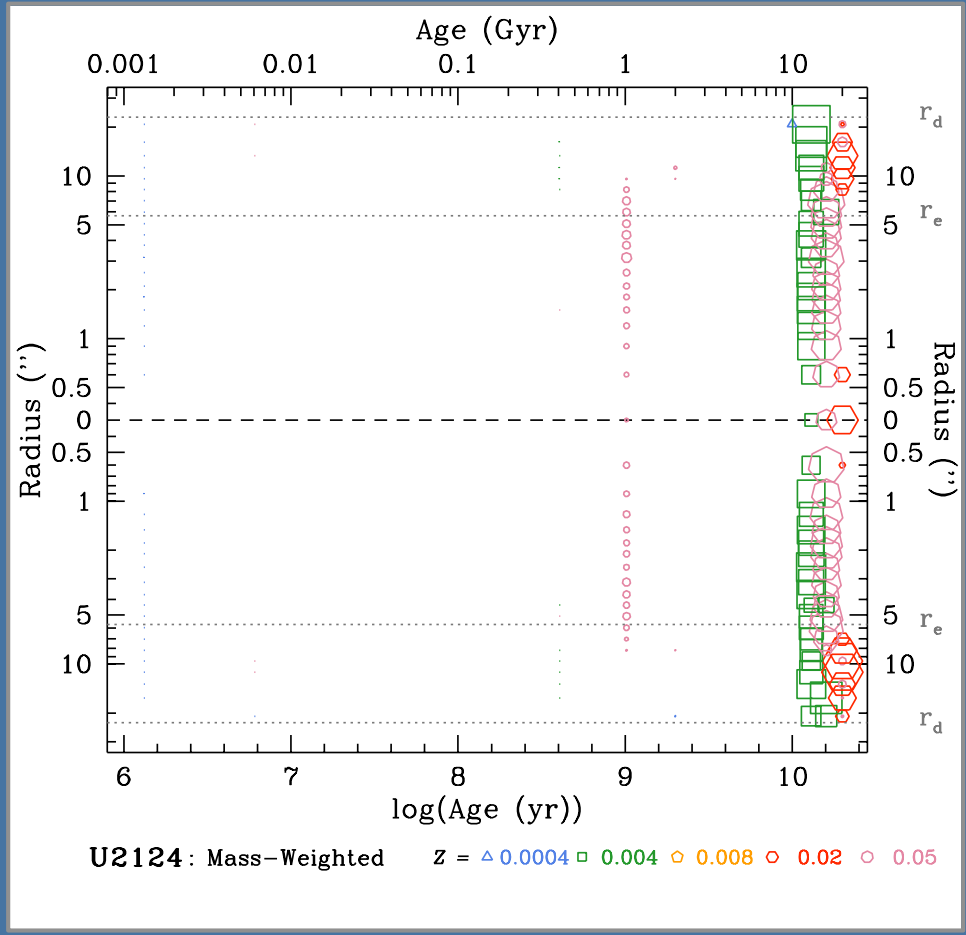
Bulges from MacArthur et al. 2009: SFH

Star Formation History as a fn. of Radius

Light-Weighted



Mass-Weighted



MacArthur, González, & Courteau, 2009, MNRAS, 395, 28

Mass and Light Weight vs. Position in Galaxy

Table 4. Per cent Contributions of all SSPs in given age ranges (young = 0.001–1 Gyr; intermediate = 2–7 Gyr; old = 10–20 Gyr) to fit for spectra at $r = 0$, r_e and r_d (when reached) weighted by light (V-band normalized) and mass.

		Light-weight			Mass-weight		
Name	Rad	0.001–1 (Gyr)	2–7 (Gyr)	10–20 (Gyr)	0.001–1 (Gyr)	2–7 (Gyr)	10–20 (Gyr)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
N0173	0	32.75	0.00	67.24	5.66	0.00	94.34
	r_e	27.98	7.85	64.18	7.10	8.34	84.56
	r_d	7.82	21.44	70.73	0.14	3.54	96.32
N0628	0	62.98	0.00	37.02	19.41	0.00	80.59
	r_e	45.43	6.78	47.80	7.54	2.26	90.20
	r_d	79.53	16.56	3.90	50.20	27.44	22.35
U2124	0	30.00	0.00	70.00	5.03	0.00	94.97
	r_e	45.32	0.00	54.68	10.94	0.00	89.06
	r_d						
N7490	0	10.20	0.00	89.80	0.73	0.00	99.27
	r_e	42.29	0.00	57.71	9.73	0.00	90.27
	r_d	45.31	14.27	40.41	5.56	29.82	64.62
N7495	0	47.02	2.61	50.37	2.17	0.64	97.19
	r_e	61.18	6.46	32.36	5.40	11.27	83.33
	r_d	68.45	0.00	31.55	1.81	0.00	98.19
N7610	0	66.59	0.00	33.41	8.08	0.00	91.92
	r_e	14.48	56.96	28.55	0.70	16.12	83.18
	r_d						
N7741	0	91.16	0.00	8.84	23.51	0.00	76.49
	r_e	53.22	0.00	46.78	4.23	0.00	95.77
	r_d	99.88	0.12	0.00	98.20	1.80	0.00
I0239	0	66.75	3.42	29.83	26.50	1.92	71.58
	r_e	74.87	18.27	6.86	36.37	13.09	50.55
	r_d	60.10	8.83	31.07	12.57	2.83	84.59

Highest σ_0

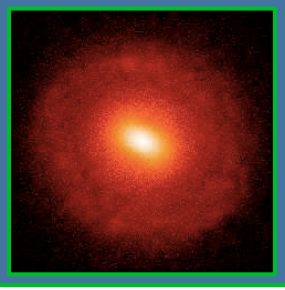
Lowest σ_0

Bulge r_e

Disk r_d

MacArthur, González, & Courteau, 2009, MNRAS, 395, 28

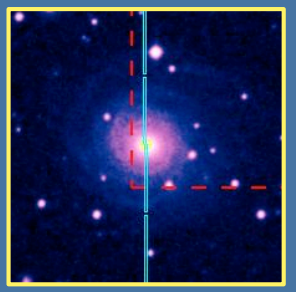
Comparison With Simulations (ΛCDM+SPH)



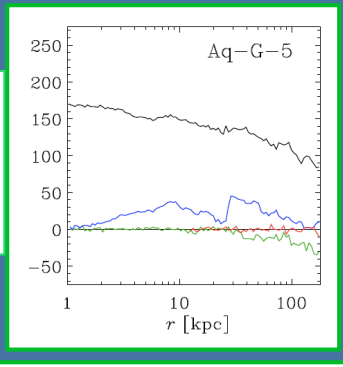
morphology:

Sérsic n ~ 1.5

r_e/r_h ~ 0.1

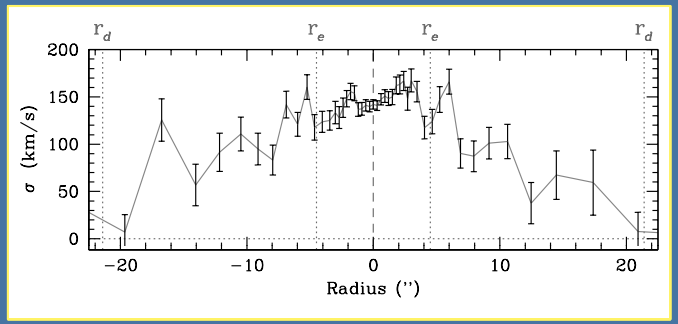


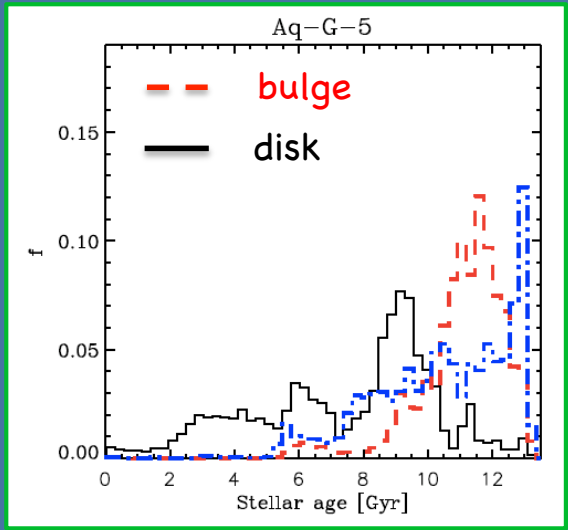
NGC 7490



kinematics:

σ_0 ~ 150 km/s, decreasing profile

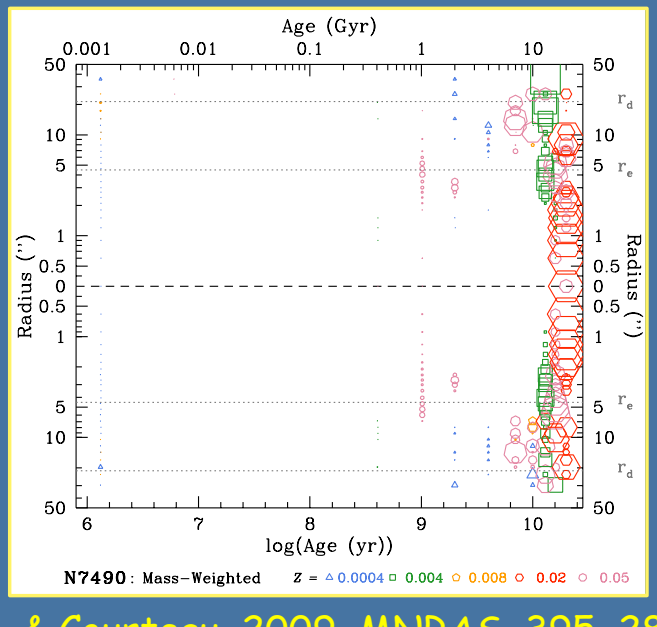




SFHs:

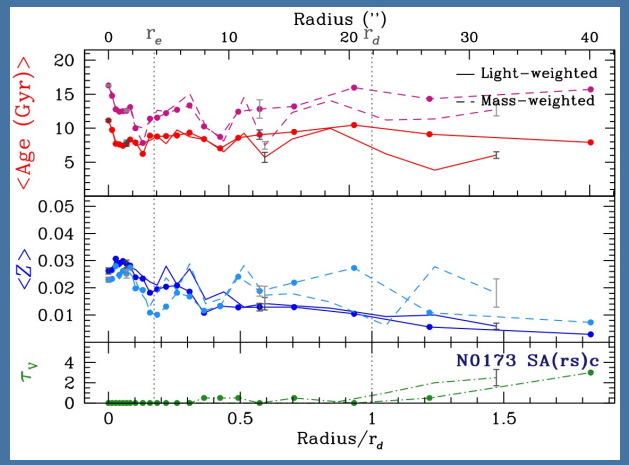
bulges -> old

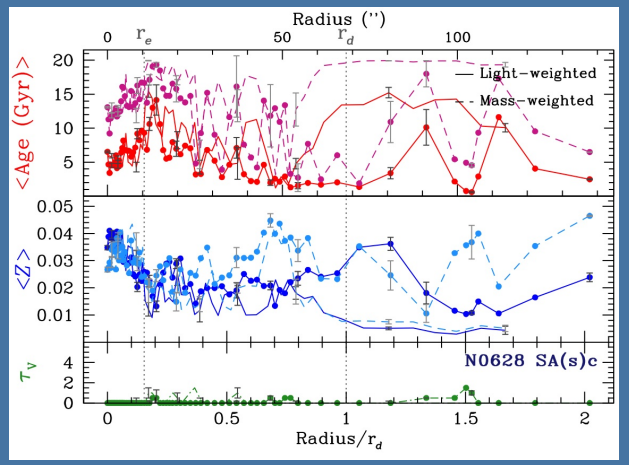
disks -> extended SFH

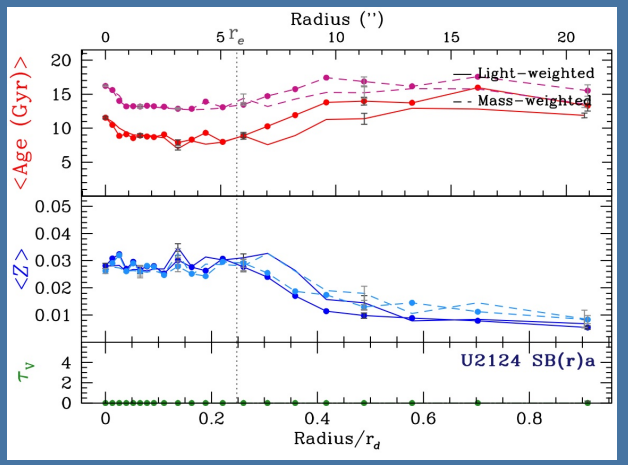


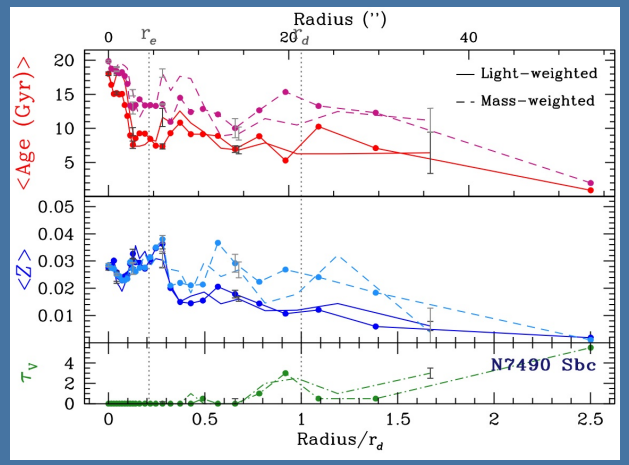
Scannapieco, White, Springel, & Tissera, 2011, MNRAS

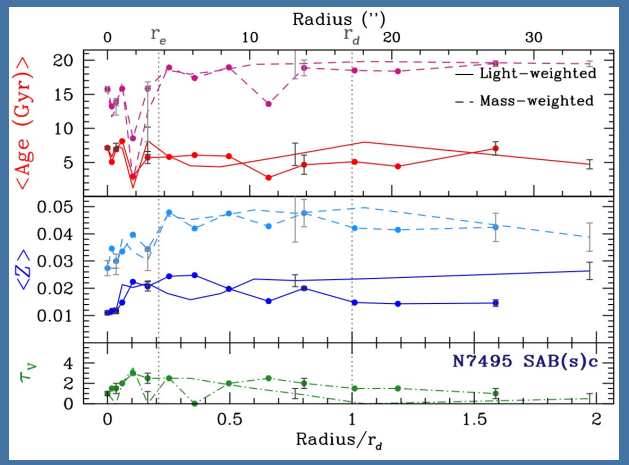
MacArthur, González, & Courteau, 2009, MNRAS, 395, 28

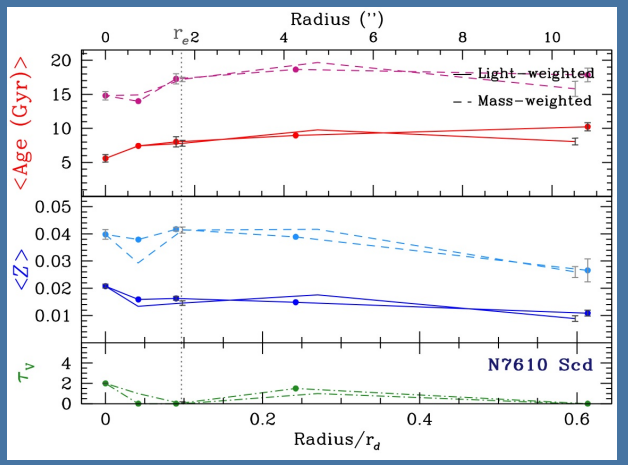


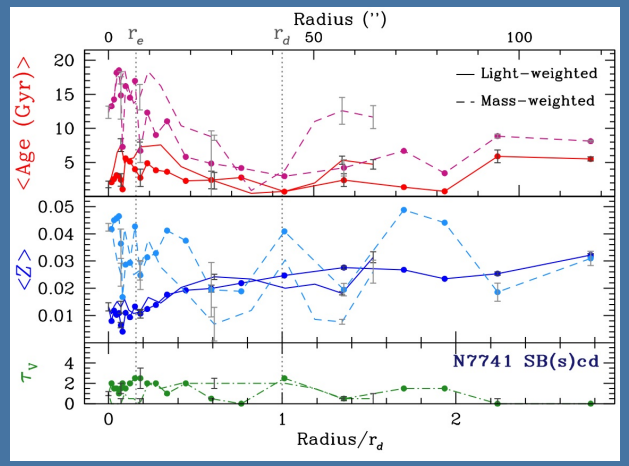


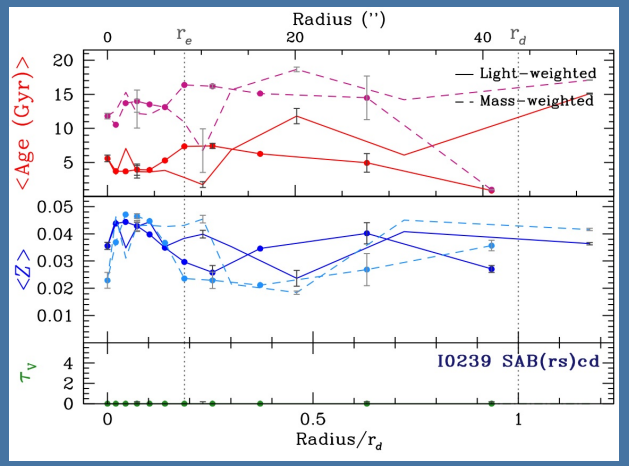








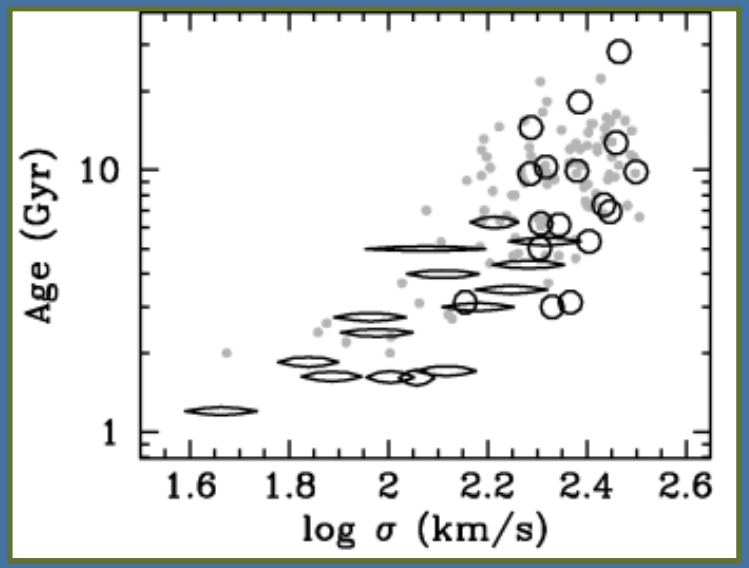


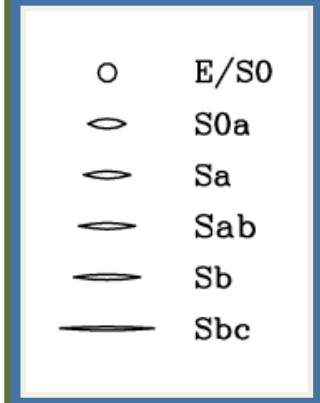


Age/Z Gradients

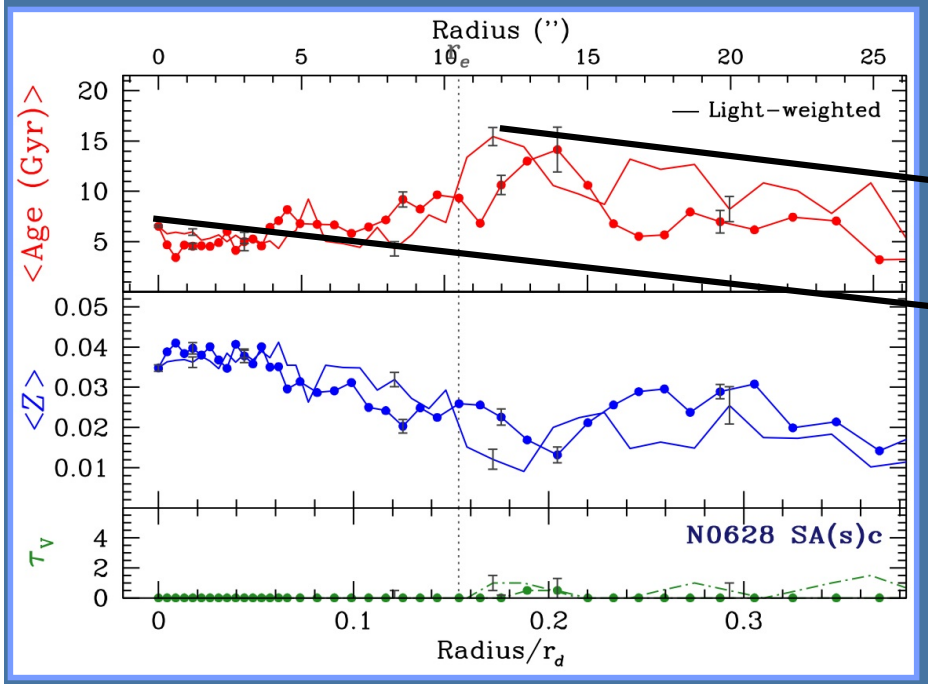
MacArthur etal. 2009

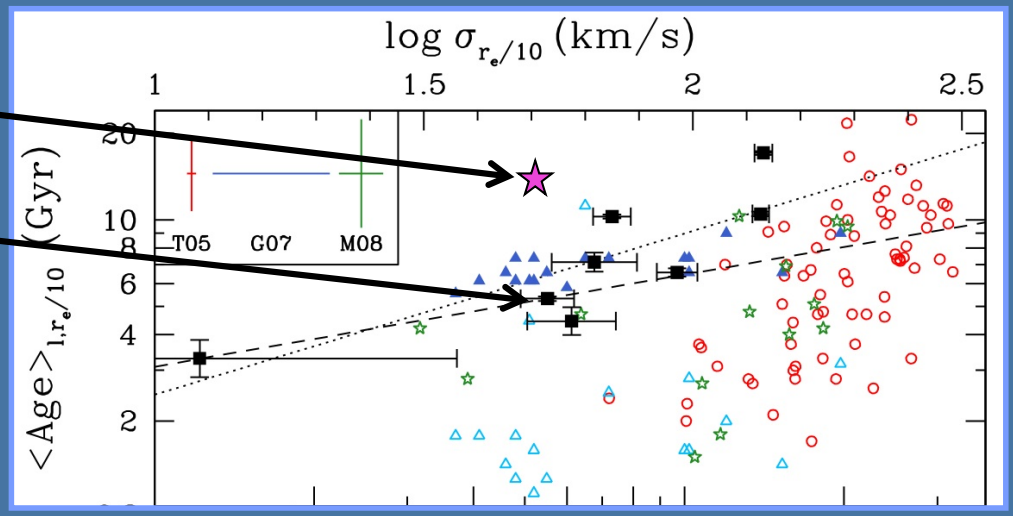
Resolving Milky Way Outlier Conundrum



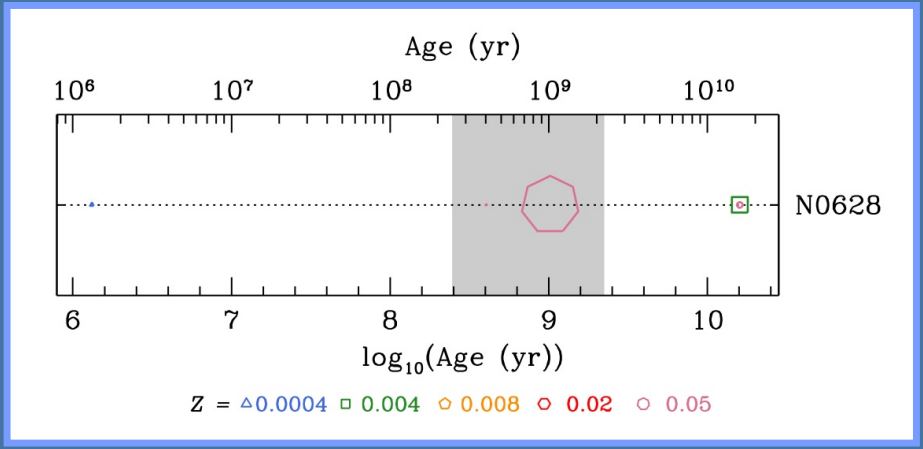


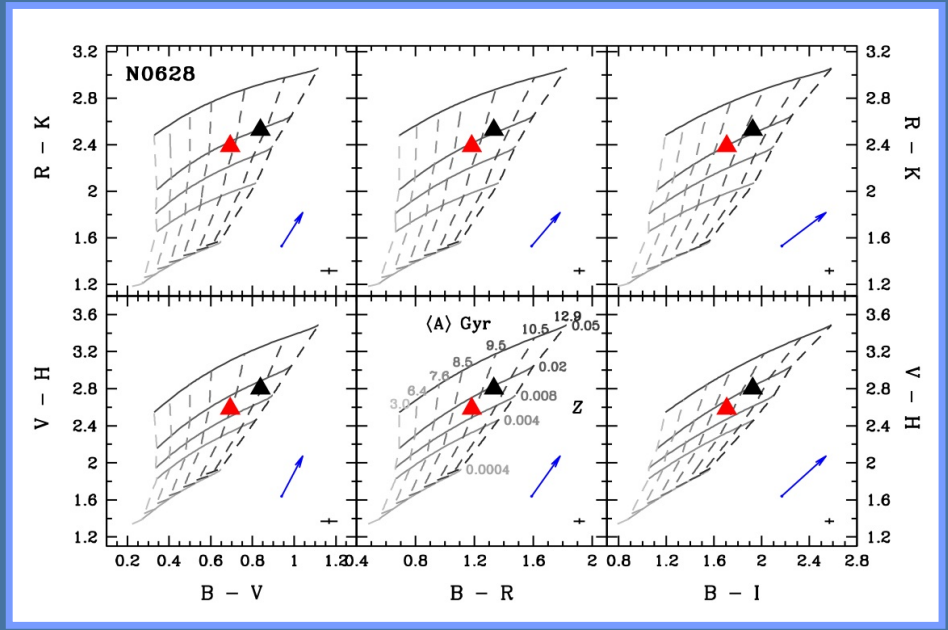
Thomas & Davies, 2006, MNRAS, 366, 510

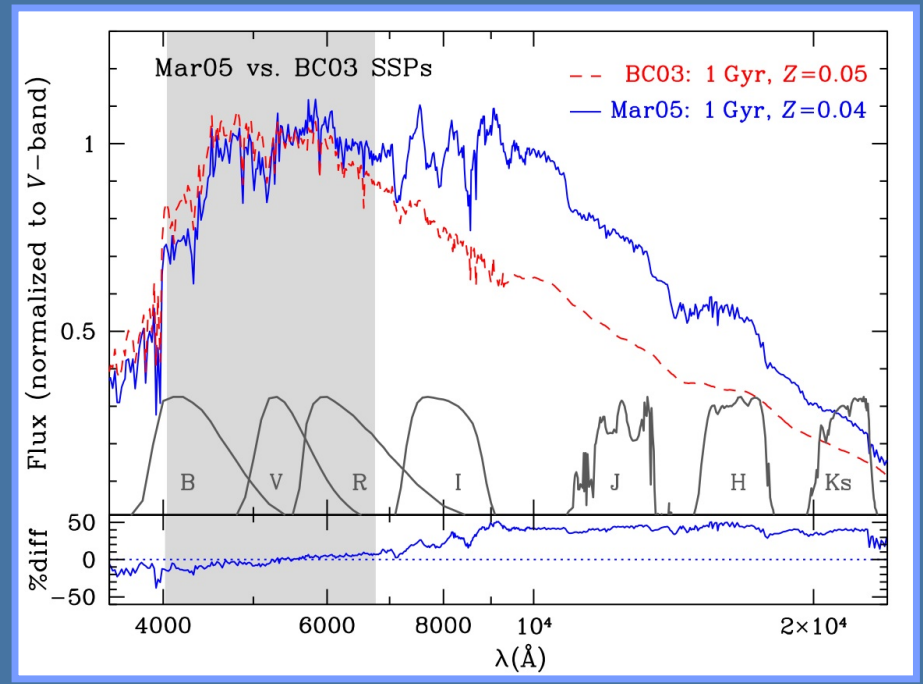


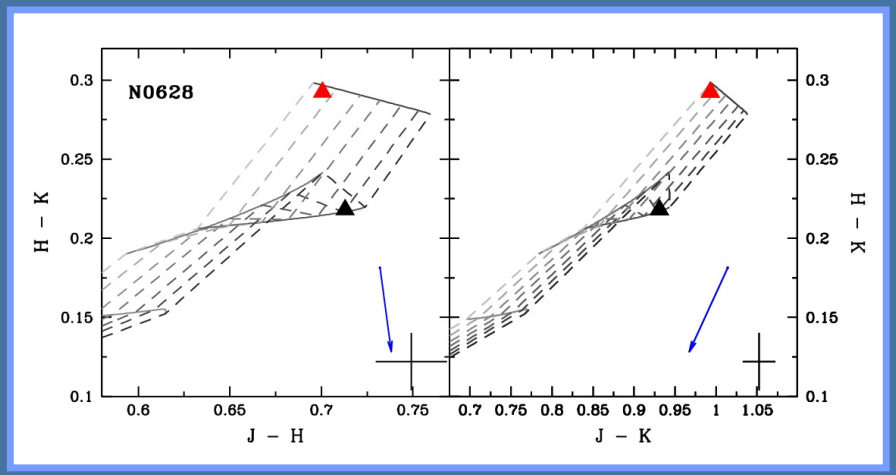


Predicting NIR Colours from Synthesis Fits









MacArthur, McDonald, Courteau, & Gonzalez, 2010, ApJ, 718, 768

Summary

- With moderate spectral resolution, good λ coverage, and high S/N/Å (>50), measurement of light- and mass-weighted ages, metallicities, & dust for late-type galaxies is feasible with full spectrum fitting
- Details are critical: calibration (flux & λ), resolution, velocity dispersion, & rotation must be treated self-consistently (within data & models)

- Bulges follow similar trends to ellipticals in age/Z *at a given mass* (also true at 0.1 < *z* < 1; see MacArthur etal. 2008, ApJ 680, 70)
- All bulges are dominated by OLD stellar pops (>~80% by mass)
- Secular contribution increases in weight with decreasing σ_0
- Spheroid formation dominated by processes common to all spheroids, whether or not they currently reside in disks
- Dominant formation mechanism occurred on shorter timescales for more massive spheroids
- Spectroscopic vs. broadband information can help constrain SPS models and evaluate simulation (N-body+SPH) results