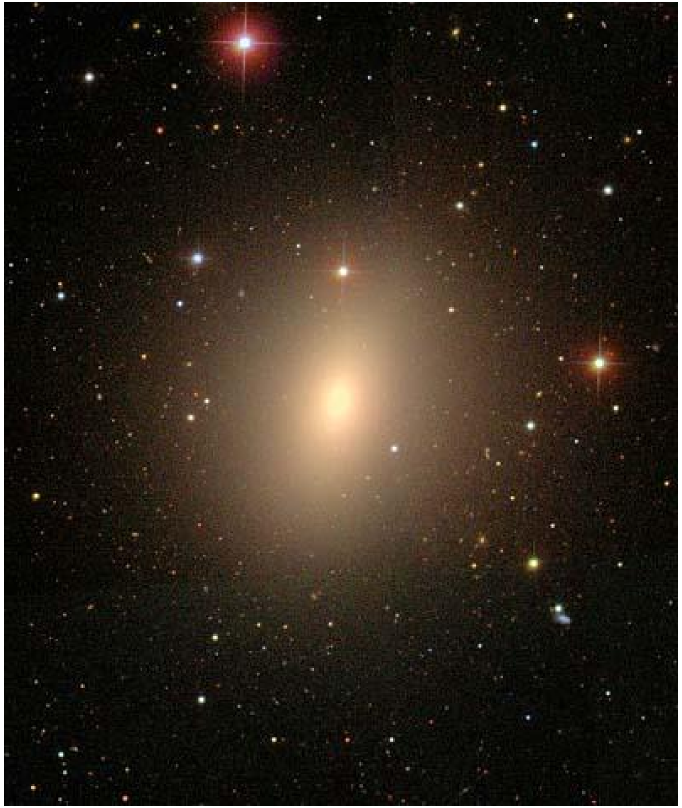
The Low-Mass IMF From Integrated Light

Conroy & Van Dokkum (2012)
McConnell et al. (2016)

Can we measure the IMF without counting stars?

- Outside the Milky Way, measuring the low-mass IMF through star counts is hopeless. Even in the nearest galaxies, only high mass and giant stars can be resolved. Everything gets blurred out.

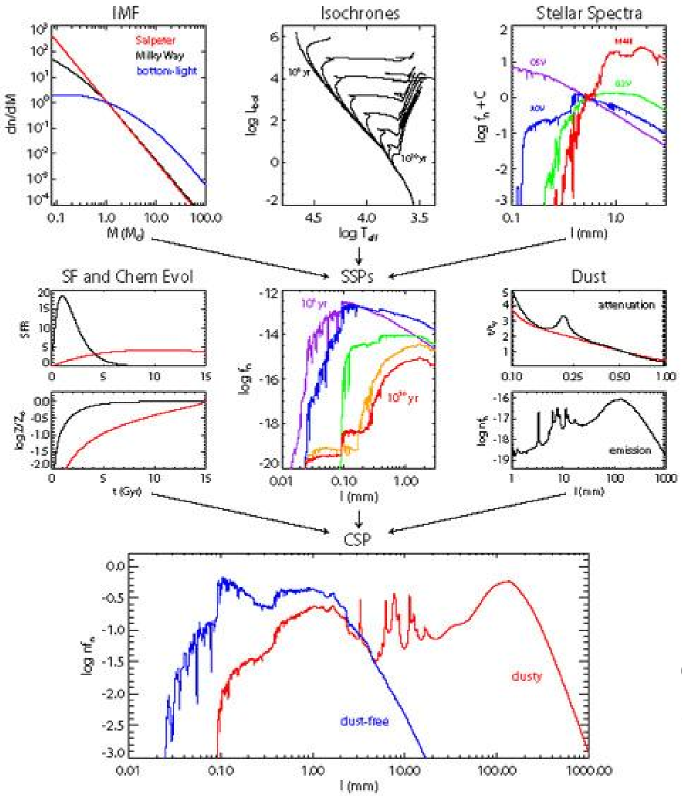


CvD12: Galaxy spectra are the sum of all the stars in the galaxy. We can reconstruct the IMF from spectra.

- Using SPS, predict the spectra for model galaxies with different IMFs, SFHs, metallicities, etc.
- Find the model parameters which most closely predict the observed spectrum. Marginalize over everything except IMF.

SPS in a nutshell

- Measure spectrum. Working backwards, fit parameterized models of IMF, stellar evolution, SFH, abundance pattern, and dust.
- But, this is not your mother's SED fitting!
    - There's lots of information in individual line shapes compared to broadband photometry.



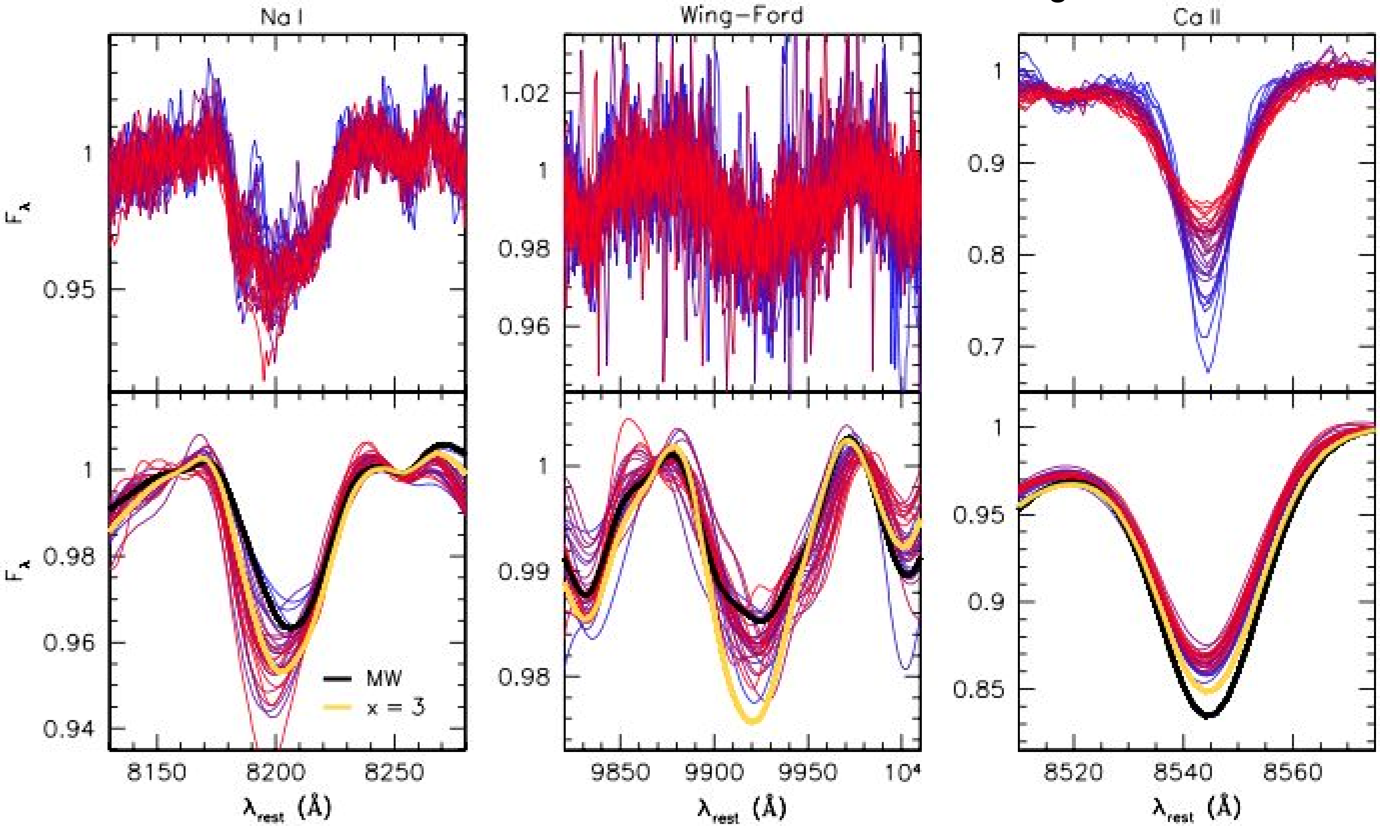
Conroy (2013)

van Dokkum & Conroy (2012)

Main idea: Certain spectral absorption lines are sensitive to stellar surface gravity and thus to the IMF.

dwarf-sensitive line indices

giant-sensitive



Why you should start skeptical

- Main-sequence stars contribute only 5-10% of these galaxies’ integrated light.
- Low-mass (<0.4 M_sun) main-sequence stars contribute only ~1% of the light. So you need to be able to measure spectra with < 1% errors.
- Spectral indices are sensitive to surface gravity, but they’re ALSO sensitive to age and abundance patterns.
- There are additional uncertainties in SPS due to dust and poorly understood phases of stellar evolution (TP-AGB, HB, BS, etc.).

What CvD have going for them:

- SFR(t) is simple and less uncertain
    - Still not that simple, though. There’s “frosting” from young stars and arbitrary addition of giant stars.
- Don’t have to separate binary and single-star IMFs
- Pretty high resolution spectra
- Different line indices have different dependences on metallicity and abundance pattern. So, in principle, using lots of different indices should make it possible to disentangle the IMF from abundance degeneracies.

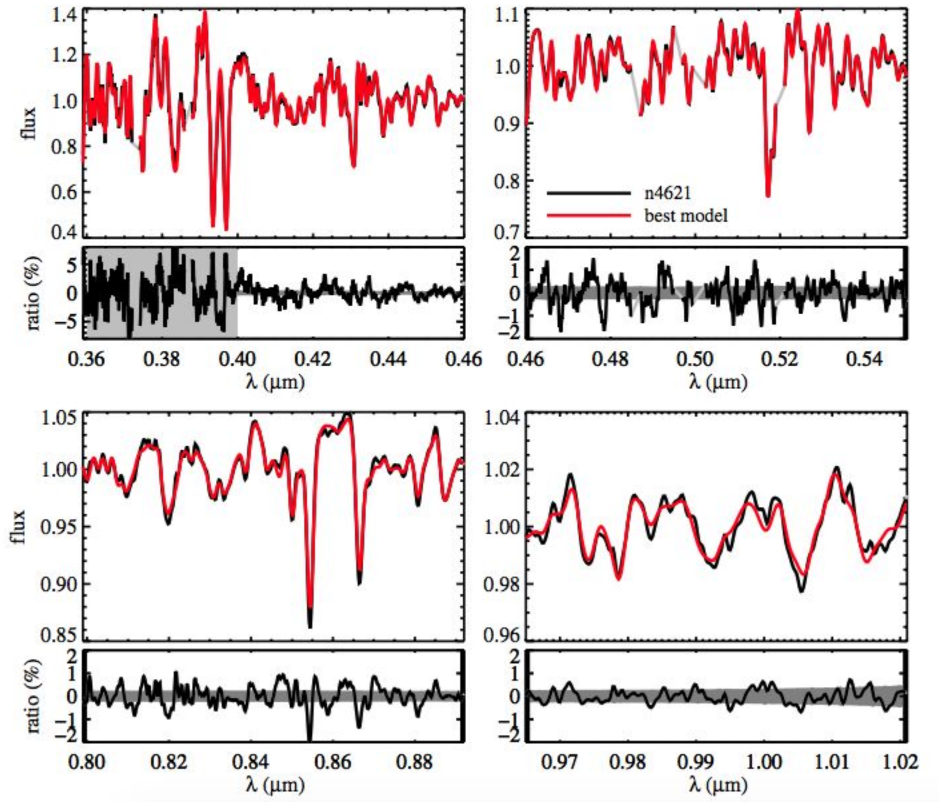
Table 1
Model Parameters

Parameter	Prior	Units	Notes
v_z	(−1,000,10,000)	$\mathrm{km\,s^{-1}}$	Recession velocity
σ	(20,400)	$\mathrm{km\,s^{-1}}$	Velocity dispersion
[Fe/H]	(−0.4,0.4)		Iron abundance
[O,Ne,S/Fe]	(−0.4,0.6)		Oxygen, neon, sulfur abundance
[C/Fe]	(−0.4,0.4)		Carbon abundance
[N/Fe]	(−0.4,0.8)		Nitrogen abundance
[Na/Fe]	(−0.4,1.3)		Sodium abundance
[Mg/Fe]	(−0.4,0.6)		Magnesium abundance
[Si/Fe]	(−0.4,0.4)		Silicon abundance
[Ca/Fe]	(−0.4,0.4)		Calcium abundance
[Ti/Fe]	(−0.4,0.4)		Titanium abundance
[Cr/Fe]	(−0.4,0.4)		Chromium abundance
[Mn/Fe]	(−0.4,0.4)		Manganese abundance
age	(4,15.0)	Gyr	Age of bulk population
$\log(f_y)$	(−5.0,−0.3)		Fraction of young (3 Gyr) stars
α_1	(0.0,3.5)		IMF slope over $0.1\,M_\odot < M < 0.5\,M_\odot$
α_2	(0.0,3.5)		IMF slope over $0.5\,M_\odot < M < 1.0\,M_\odot$
α_3	2.3		IMF slope over $1.0\,M_\odot < M < 100\,M_\odot$
$\Delta(T_{\mathrm{eff}})$	(−50,50)	K	Temperature offset applied to all stars
log(M7III)	(−5.0,−0.3)		Fraction of additional M7III light
$\log(f_{\mathrm{hot}})$	(−5.0,−0.3)		Fraction of additional hot stars
T_{hot}	(1,3)	10^4 K	Temperature of additional hot stars

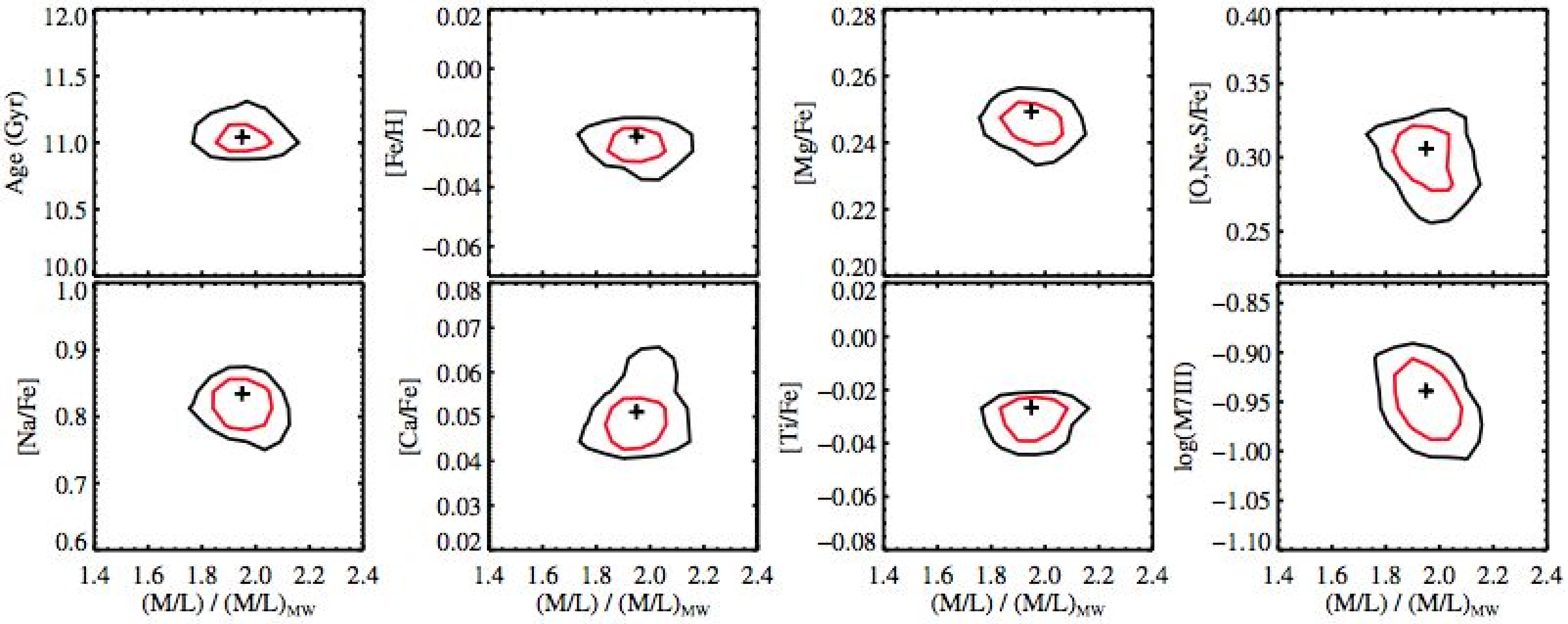
Notes. The prior is flat within the range defined in the table and cuts off sharply outside of the prior range. The parameter α_3 is fixed to the value 2.3.

Model fits

Yep, you can fit a spectrum pretty well if you have 21 free parameters.



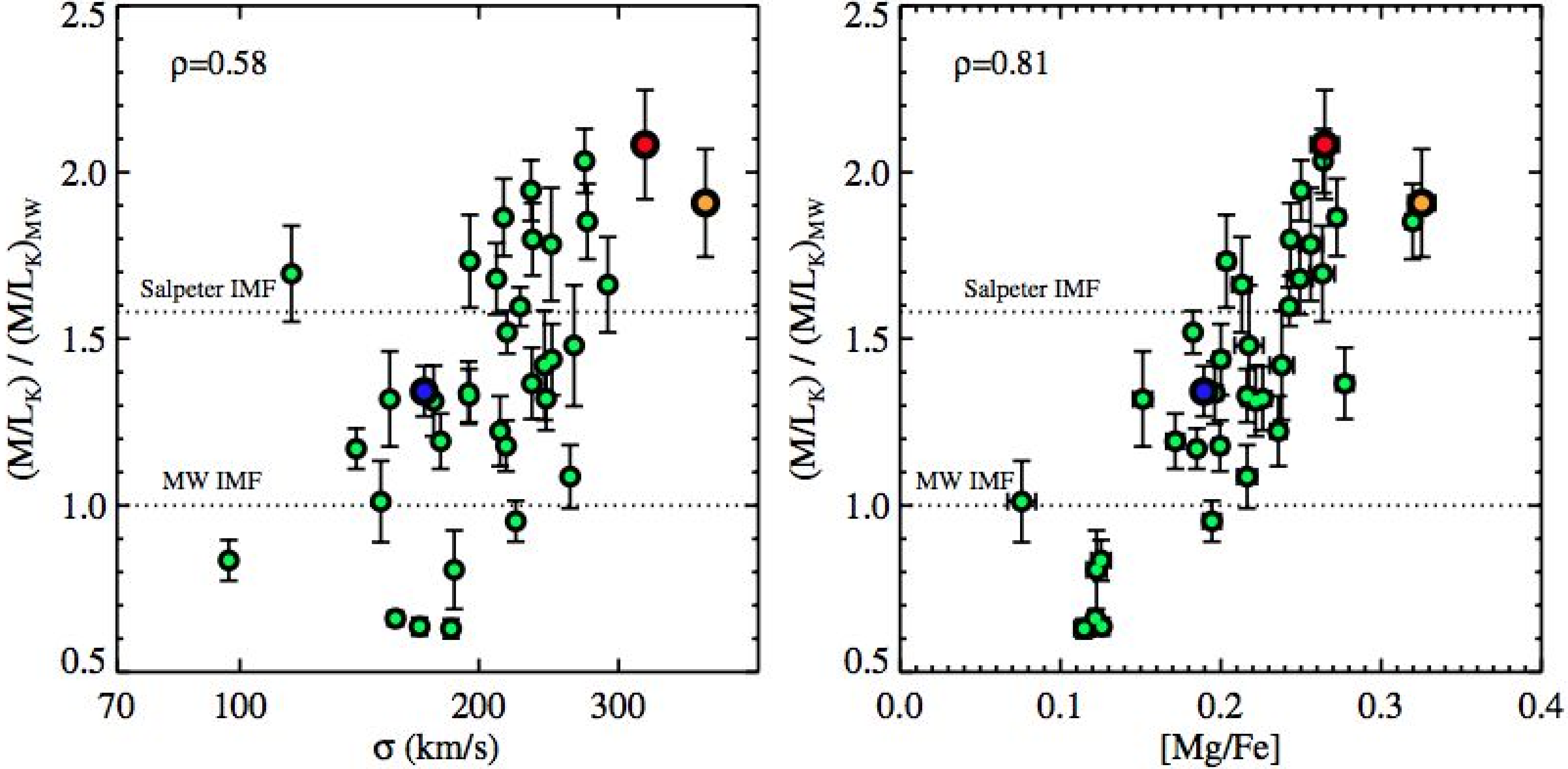
No strong degeneracies between IMF and abundance ratios. (this is weird, I think.)



IMF, basically

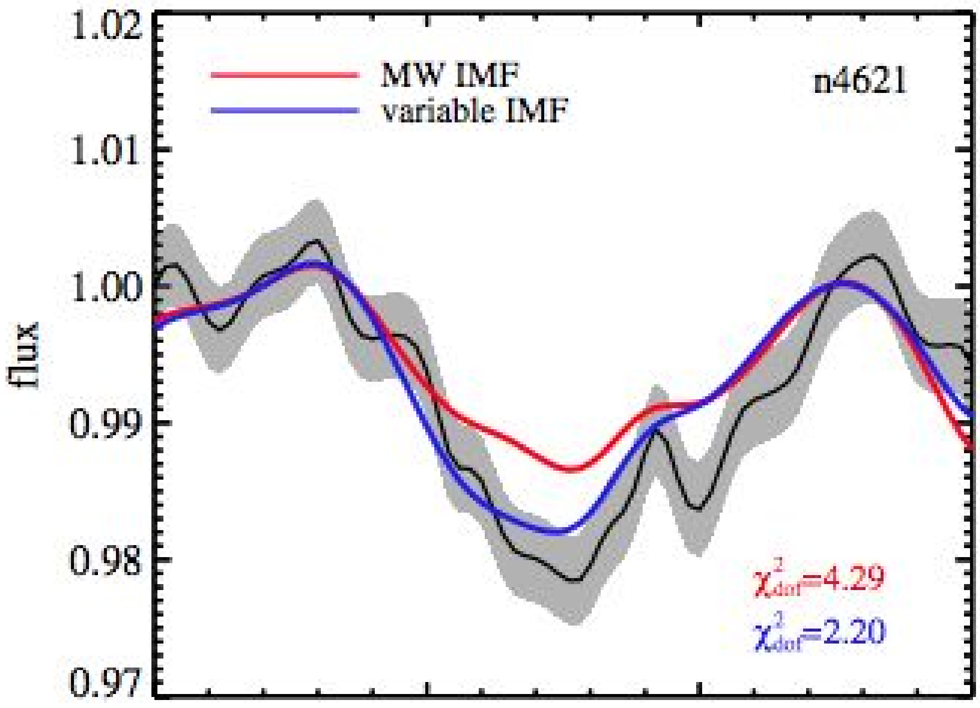
Do this for a bunch of galaxies → doesn’t always yield the same best-fit IMF.

IMF, basically



Sometimes it isn't possible to match the observed spectrum without varying the IMF.

This is nice, but keep in mind that there are large uncertainties in other parts of the SPS model.



AIC “decisively” prefers a variable IMF!

… but this is a pretty hand-wavy rule of thumb; be wary.

Also, it doesn’t make any sense to me that for two of the galaxies, they get a higher chi^2 value for a fixed IMF. They should always be able to recover the ML IMF and get the same chi^2!

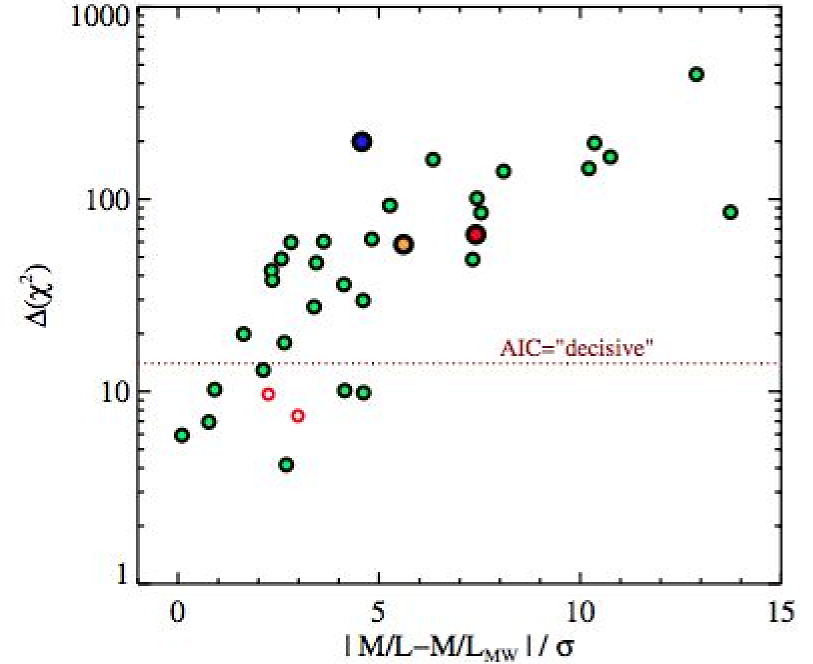
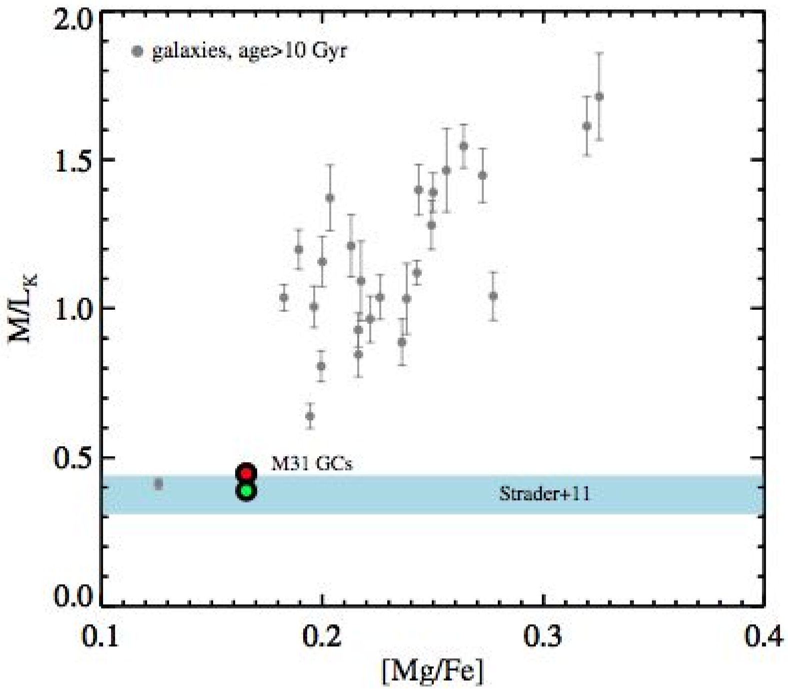


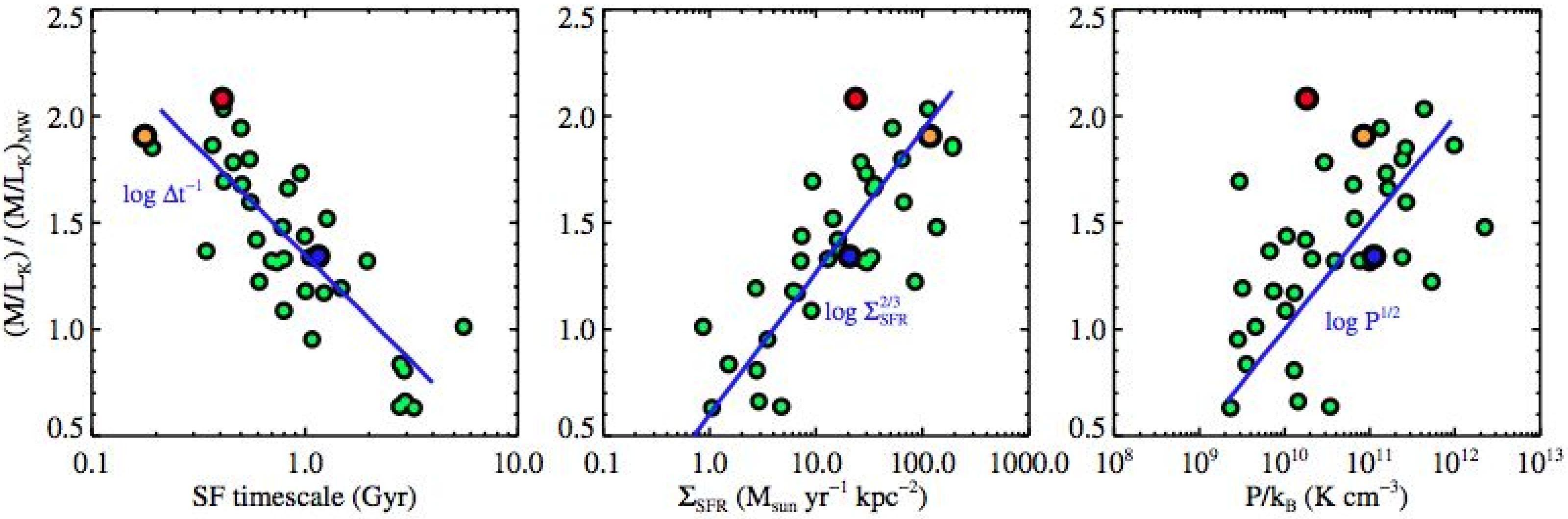
Figure 8. Difference in the minimum of χ^2 between models with and without variation in the IMF, as a function of the difference in best-fit M/L_K in units of the uncertainty. Symbol colors are as in Figure 5. The two open symbols have $\Delta(\chi^2) < 0$ and so for these galaxies we plot $|\Delta(\chi^2)|$. The model with IMF variation has two additional degrees of freedom compared to the fixed IMF model. In the context of the AIC, the variable IMF model is ‘decisively preferred for $\Delta(\chi^2) > 14$; see the text for details.

Some validation of SPS: for 4 globular clusters, they get similar M/L ratios to those inferred from dynamics

(implying a bottom-light IMF compared to Kroupa).



What else could be driving variability in IMF?



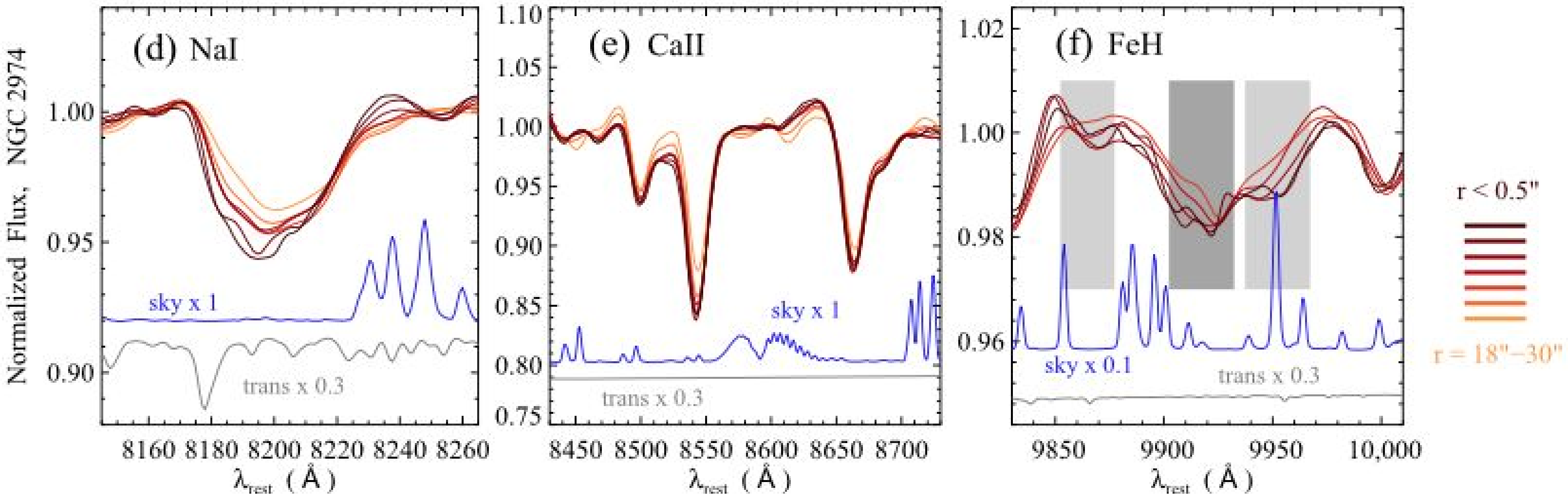
“Galaxies with higher sustained Σ_SFR have a rate per unit volume of SNe which can drive more highly supersonic turbulence, resulting in a higher typical Mach number in molecular clouds that in turn lowers the characteristic mass of the IMF.”

Theorists gonna theorize… but there’s lots of disagreement about whether it’s turbulence, gas metallicity, or something else that sets the characteristic mass in the IMF.

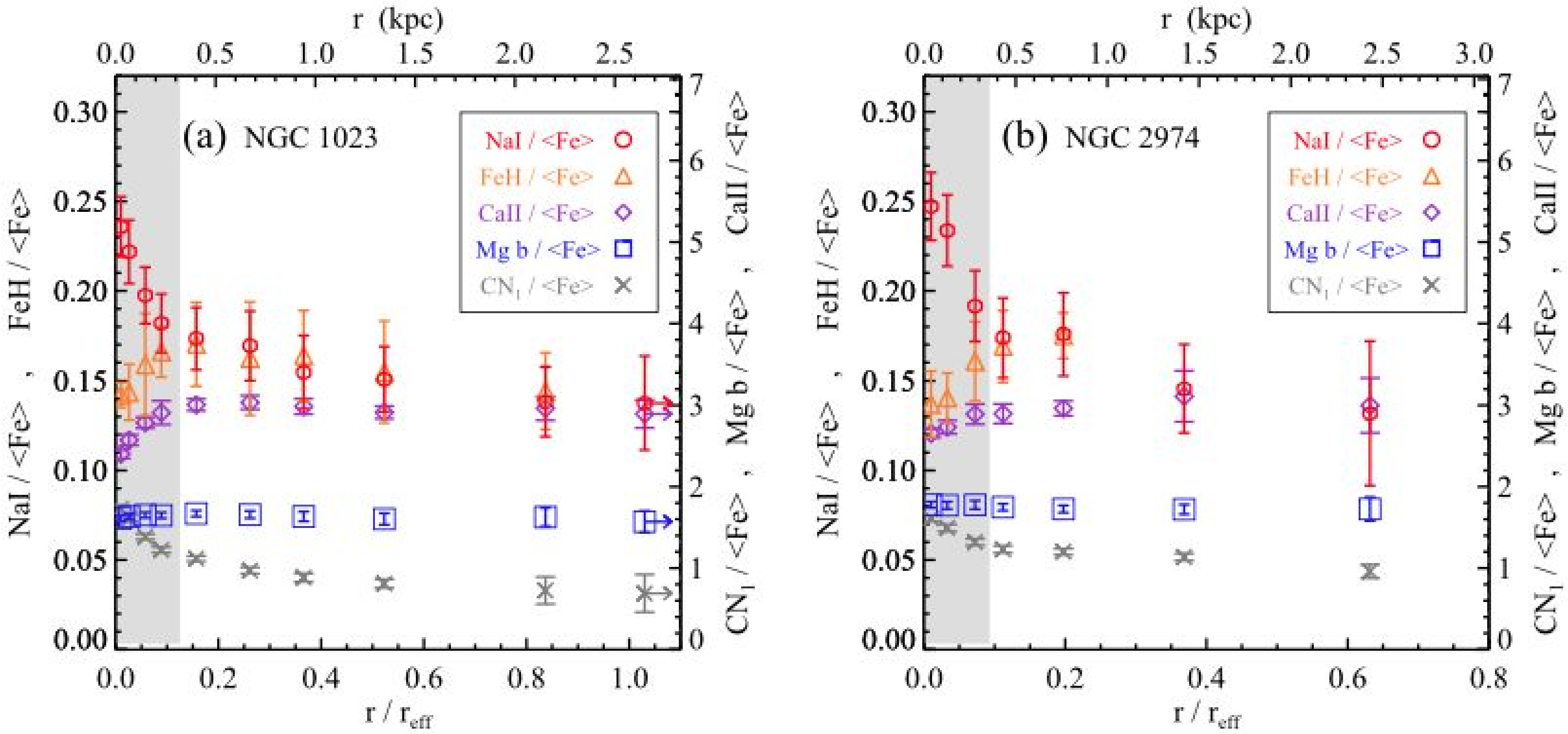
McConnell et al. 2016

- Response to CvD12
- "Here's a bunch of stuff you missed"
  - Metallicity and alpha abundances vary with radius, and CvD12 only look at r < R_eff/8.
  - Let's see whether your method also predicts variation in the IMF with radius.
  - Then let's check whether the radial scaling of different line indices are consistent with each other under the hypothesis of a variable IMF.
  - If they aren't, then they probably aren't consistent across different galaxies, either.
- Also, your errors are wrong:
  - "we note that our empirically derived errors [~10%] are much larger than the estimate of 0.1%-0.2% by van Dokkum & Conroy (2012) ... despite the higher S/N of our data"

Same “IMF-sensitive” line-indices as CvD12, but varying with radius.



Radial trends in NaI vs Wing-Ford (FeH) are inconsistent with being IMF-driven



Main point of McConnell et al. 2016:

- Just from the radial variation of different line indices, it seems like the interpretation of NaI and Wing-Ford indices as tracing just the IMF is too simplistic.
- Most likely, there are radial variations in abundance ratios as well, or line-indices depend on additional parameters.
  - E.g., if galaxies grew by accreting satellites, one might expect stars in the outskirts of the galaxy (which formed elsewhere) to have different ages and compositions to stars in the center.
- This might also be true across different galaxies. So, @CvD12, your galaxies might have different [Na/Fe] ratios, *not* different IMFs.

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- “The physical properties of stellar populations are highly degenerate with individual line indices, and some of the trends we have presented—most notably the relative variations in Na I, FeH, and <Fe>—defy simple qualitative arguments.”
- Would have been nice to see how different line indices vary with σ and [α/Fe] across different galaxies rather than with radius in a single galaxy, for a more direct comparison with CvD12.