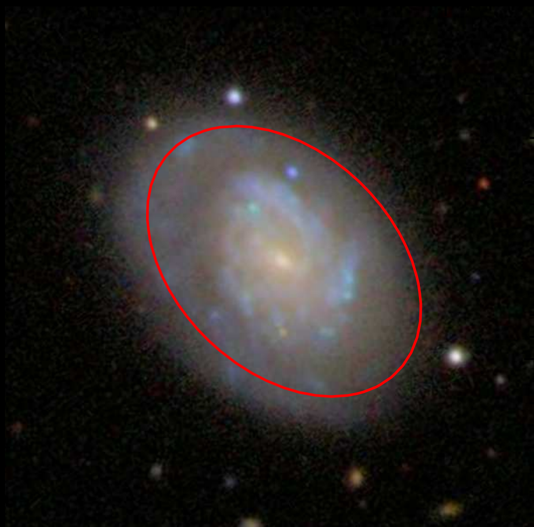
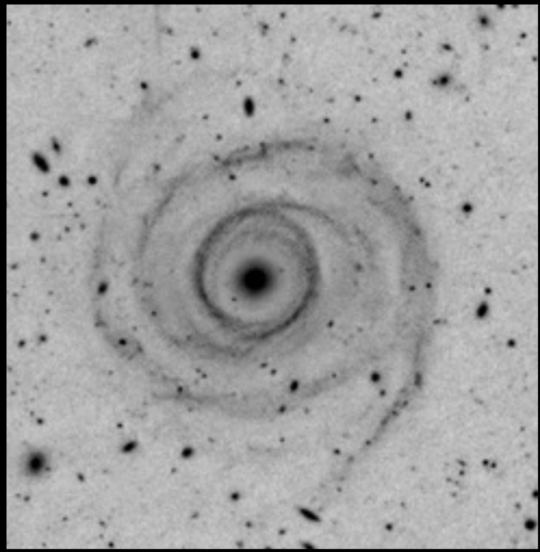




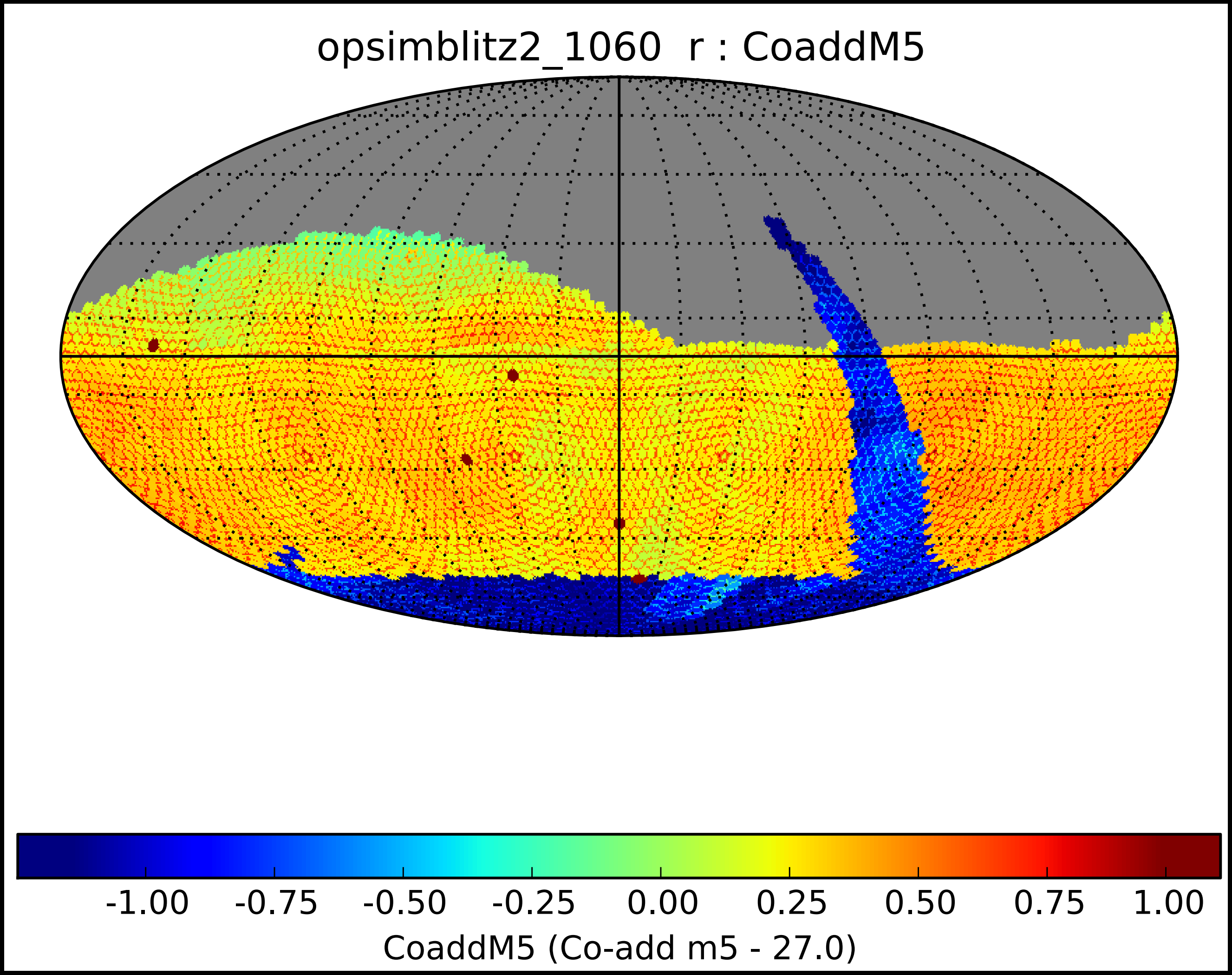
Spectroscopic Star Formation Histories in a Variety of Exponential Disks

Peter Yoachim
University of Washington (LSST)
@ianpaulfreeley

A plug for my day job:

Coadded depth of LSST in *r*

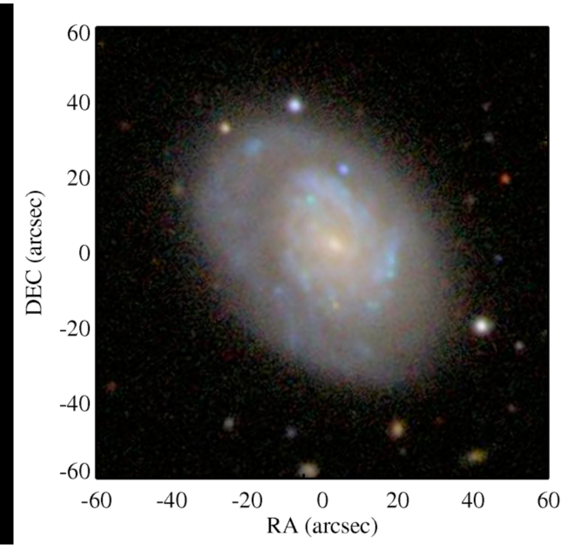
If you were going to take ~800 exposures (30s each) of every point in the sky with an 8-meter telescope, how would you want those distributed (in time, filters, observing conditions, etc)?

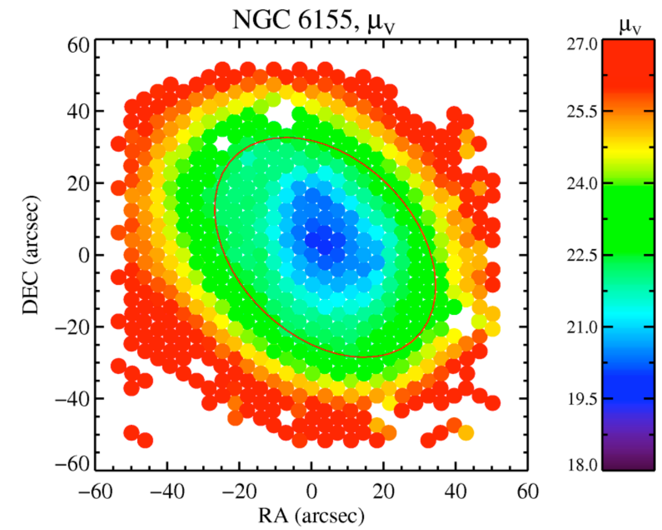


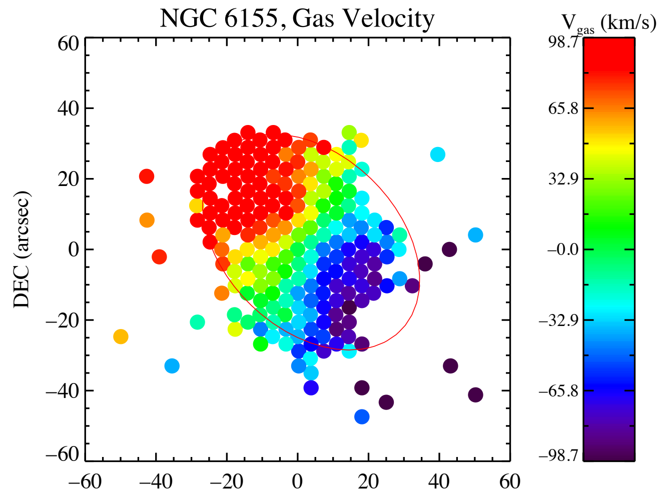
I'm worried the galaxies community isn't ready for the coming LSST Cadence Wars.

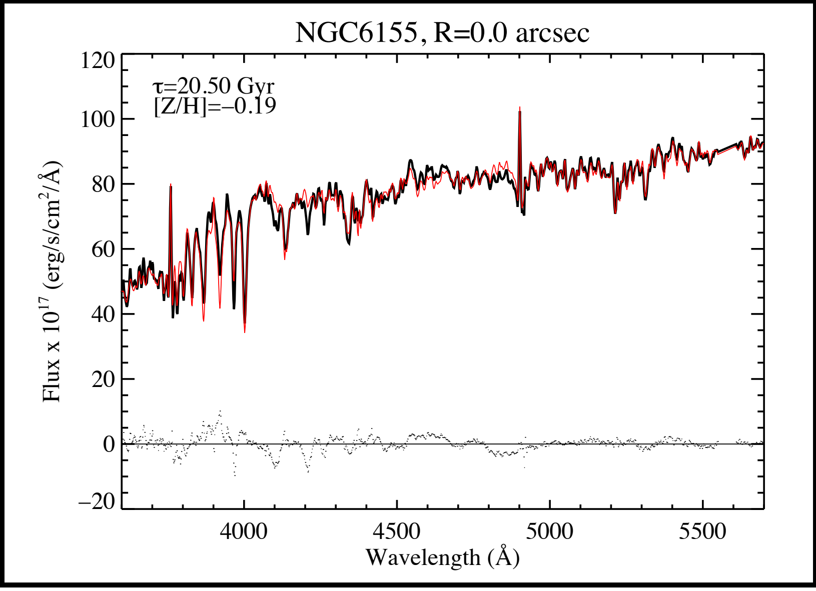
Common Theme of This Talk:

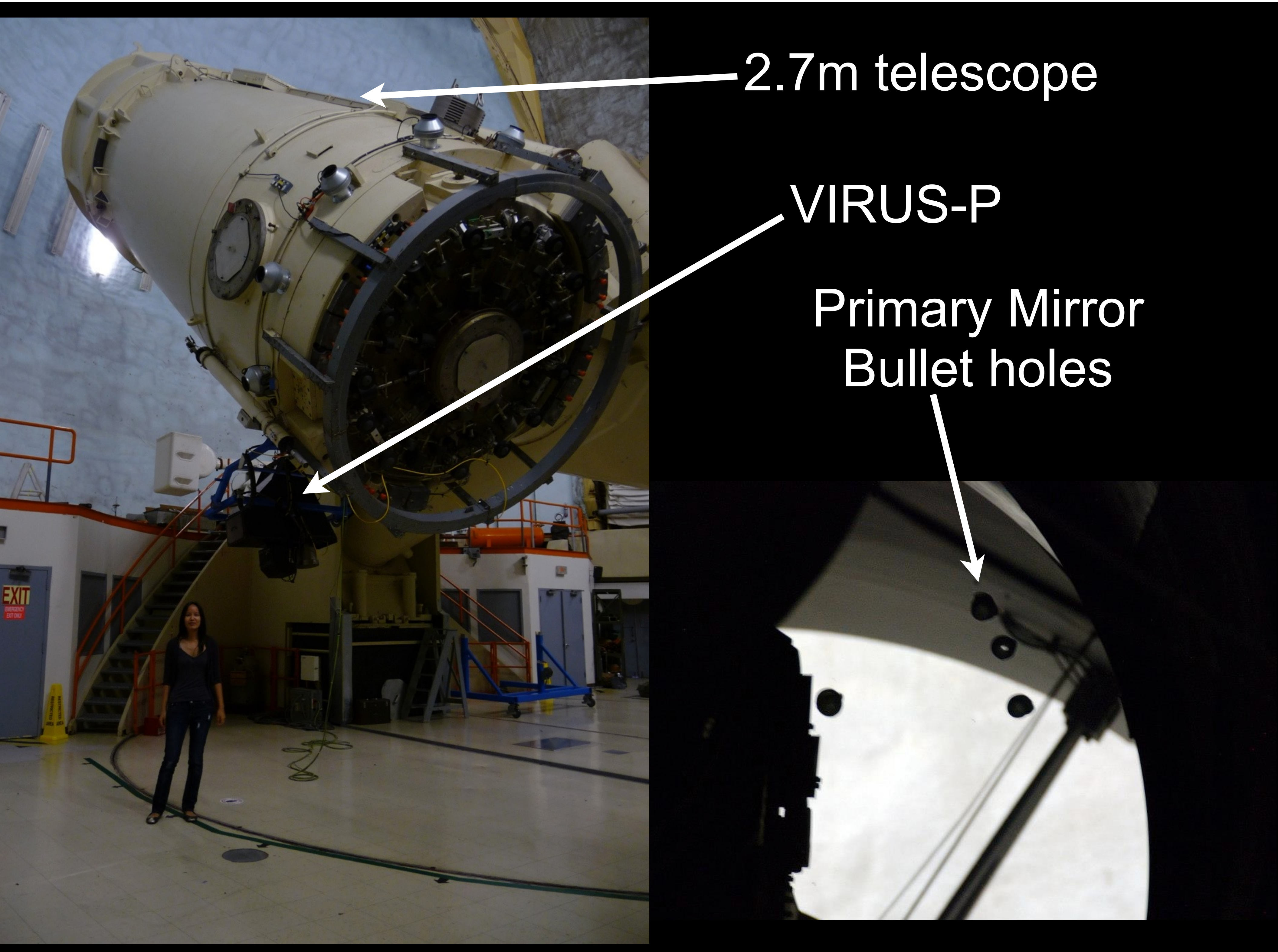
- Find some interesting galaxy
- Observe with VIRUS-P
- Bin fibers to reach low surface brightness levels
- Fit the star formation history by *parametrizing the SFH in a useful way*










2.7m telescope
VIRUS-P
Primary Mirror
Bullet holes
EXIT

Not Photometric

Star Formation History
Full Spectrum Fitters

- STARLIGHT
- MOPED/VESPA
- NBURSTS
- STECMAP
- GANDALF
- and more...

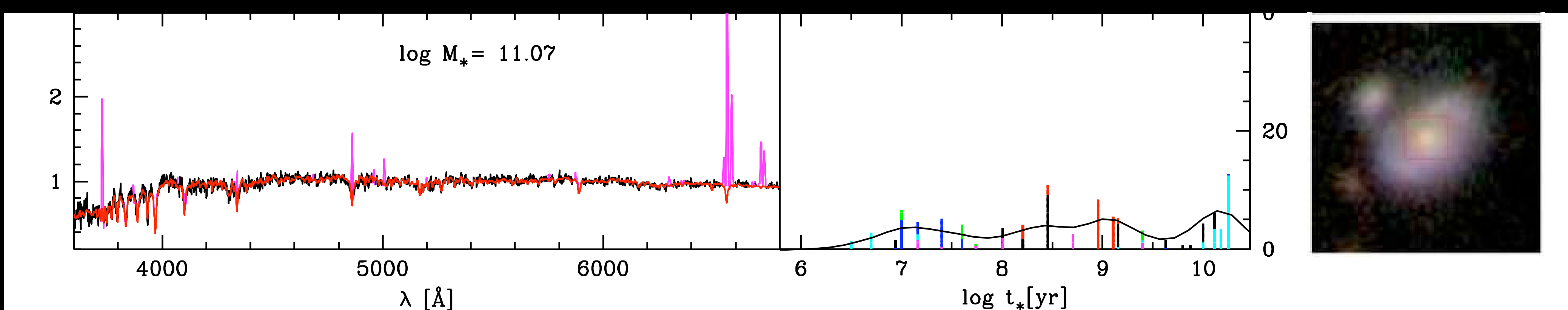
Model

Kinematics

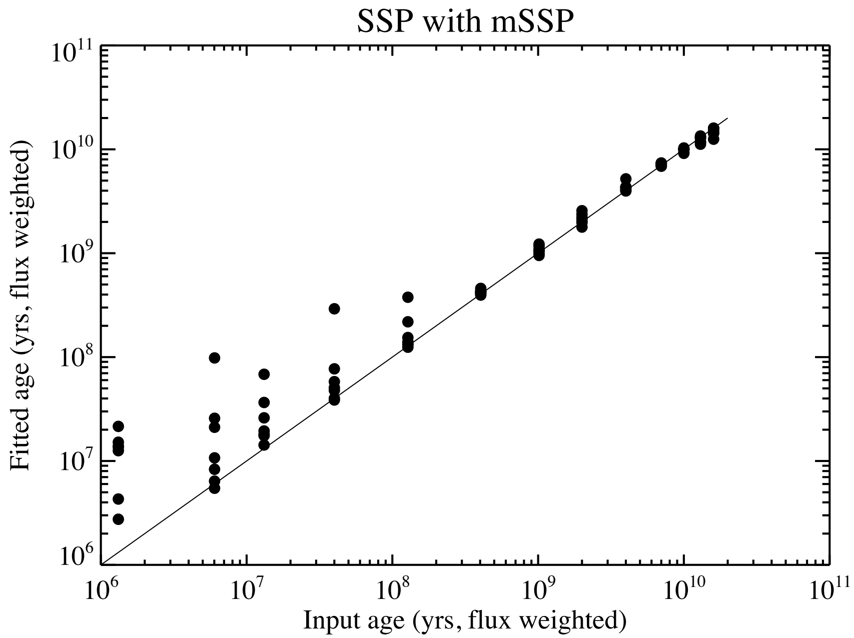
$$M_\lambda = \sum_{j=1}^{N_\star} L_{\lambda,j} = \sum_{j=1}^{N_\star} L^0_{\lambda,j} \otimes G(v_\star, \sigma_\star)\, 10^{-0.4 A_{\lambda,j}}$$

Template spectra (variable ages and metallicities)

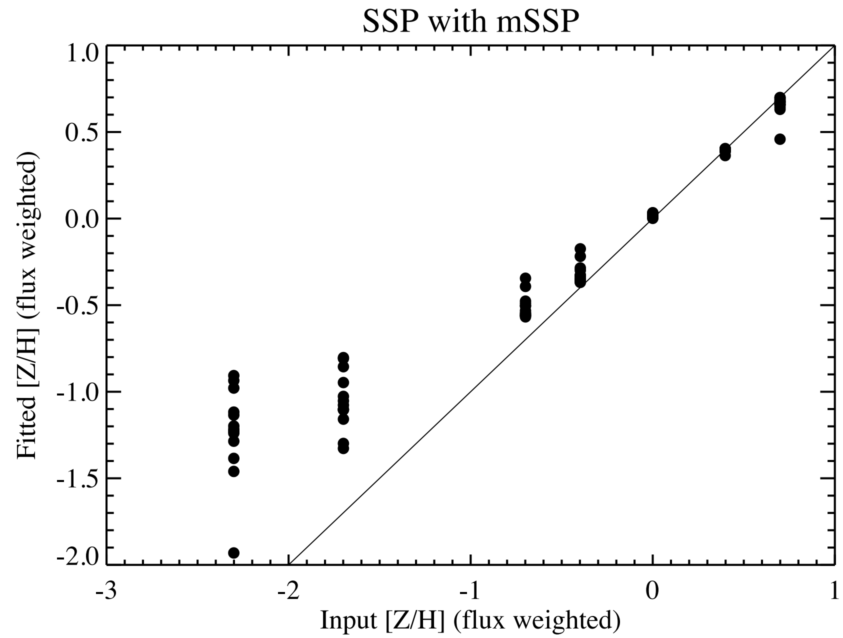
Dust



Ages



Metallicities

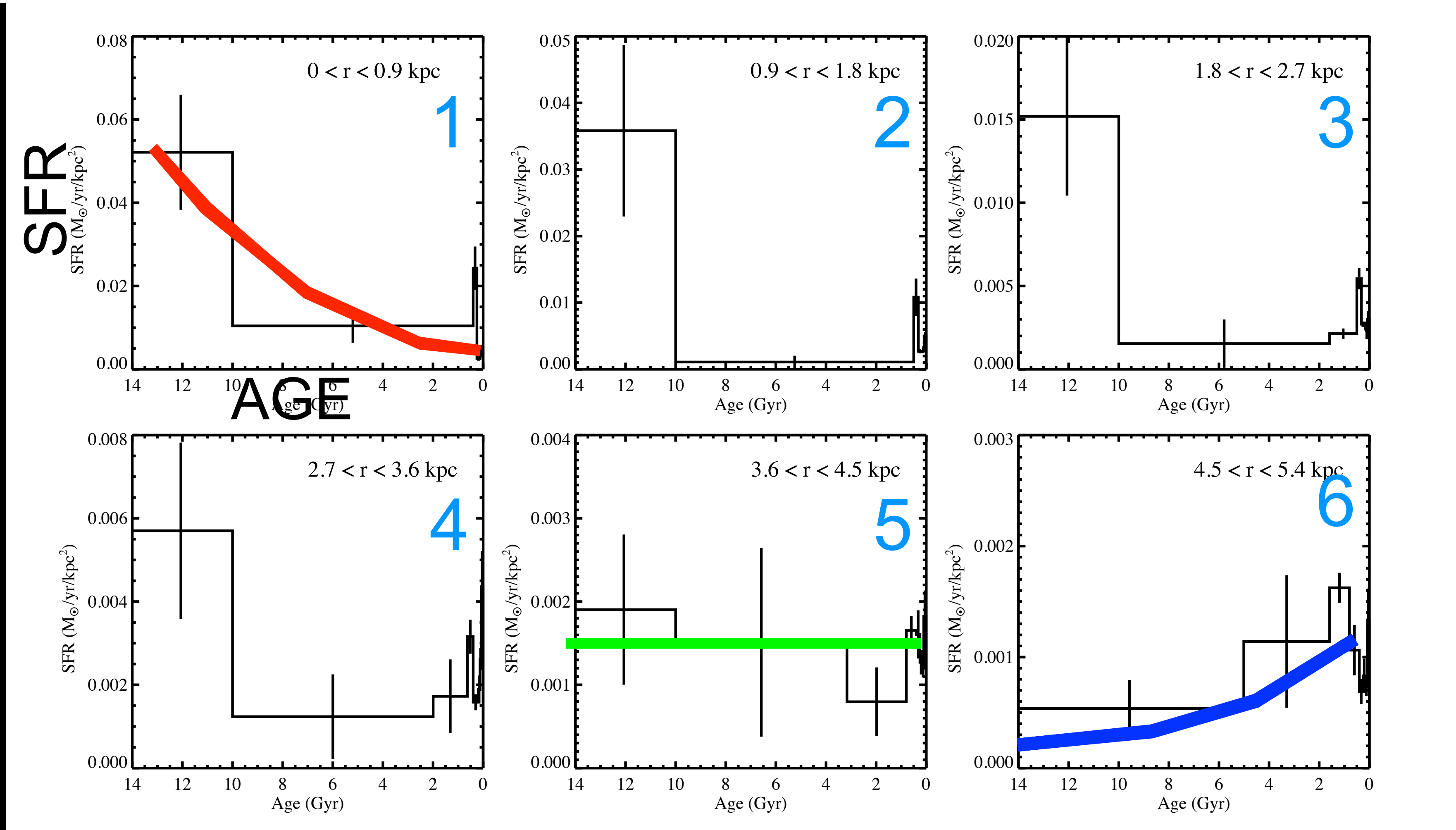


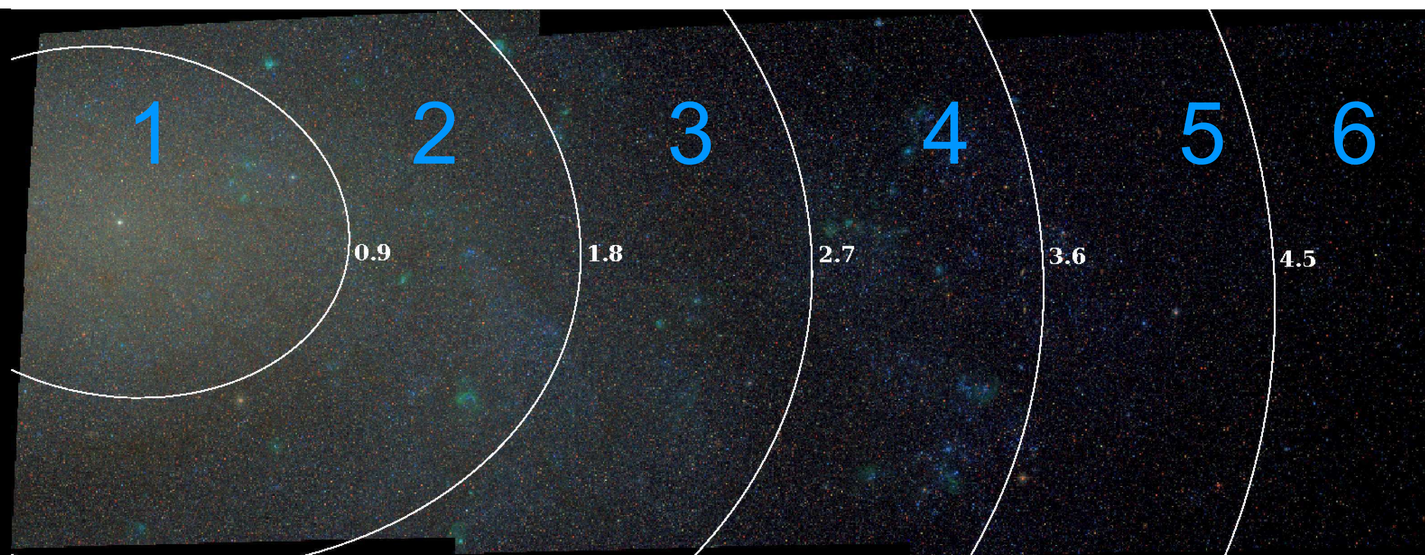
In the **trivial** case of trying to fit an SSP spectra with SSPs, the code fails!

Results can change wildly with signal-to-noise,wavelength coverage, template library, etc.

In math speak, the problem is **non-linear** and **ill-conditioned**

Yoachim, Roškar, Debattista, 2012

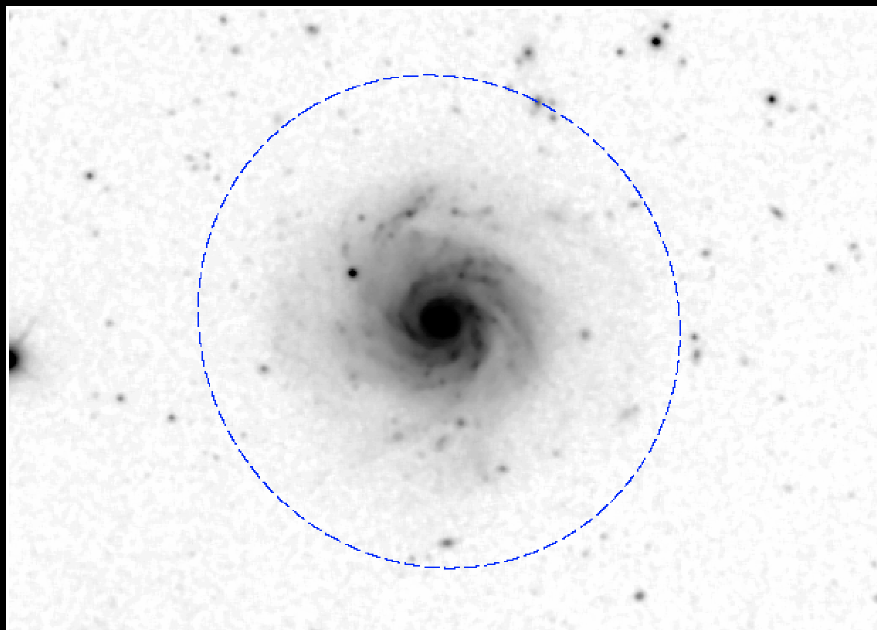


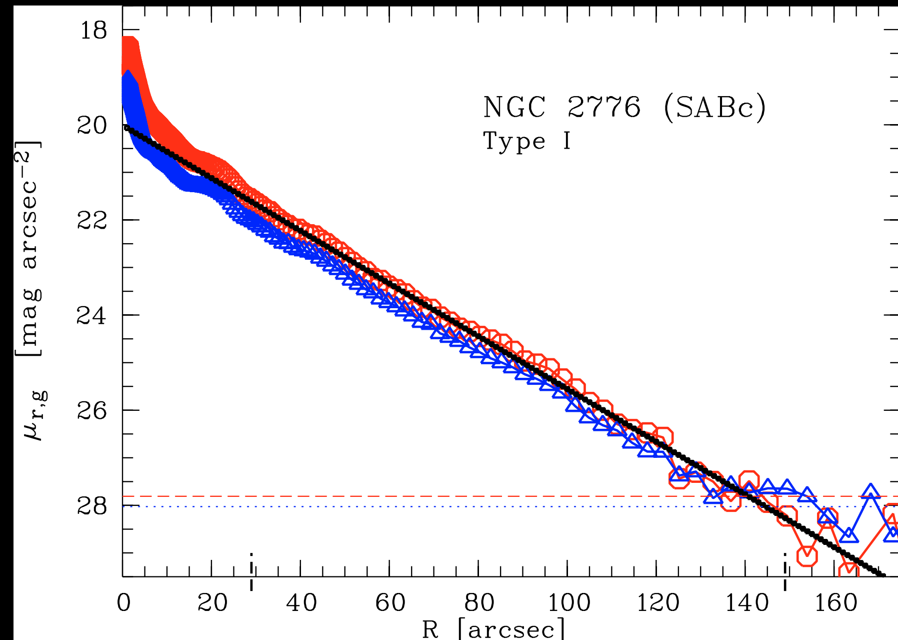


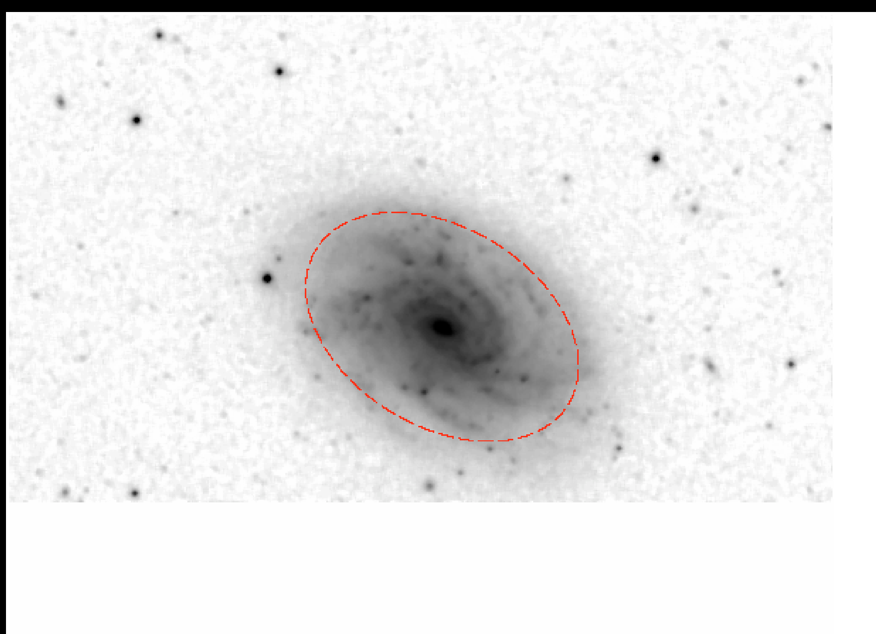
SFH of NGC 300 using resolved stars w/HST

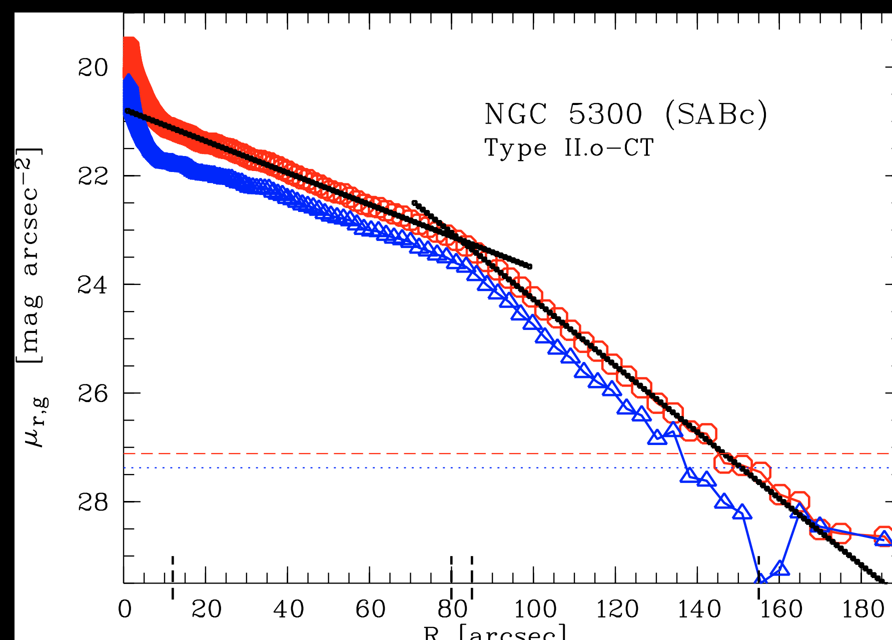
Gogarten et al 2010

Radial Profile Breaks

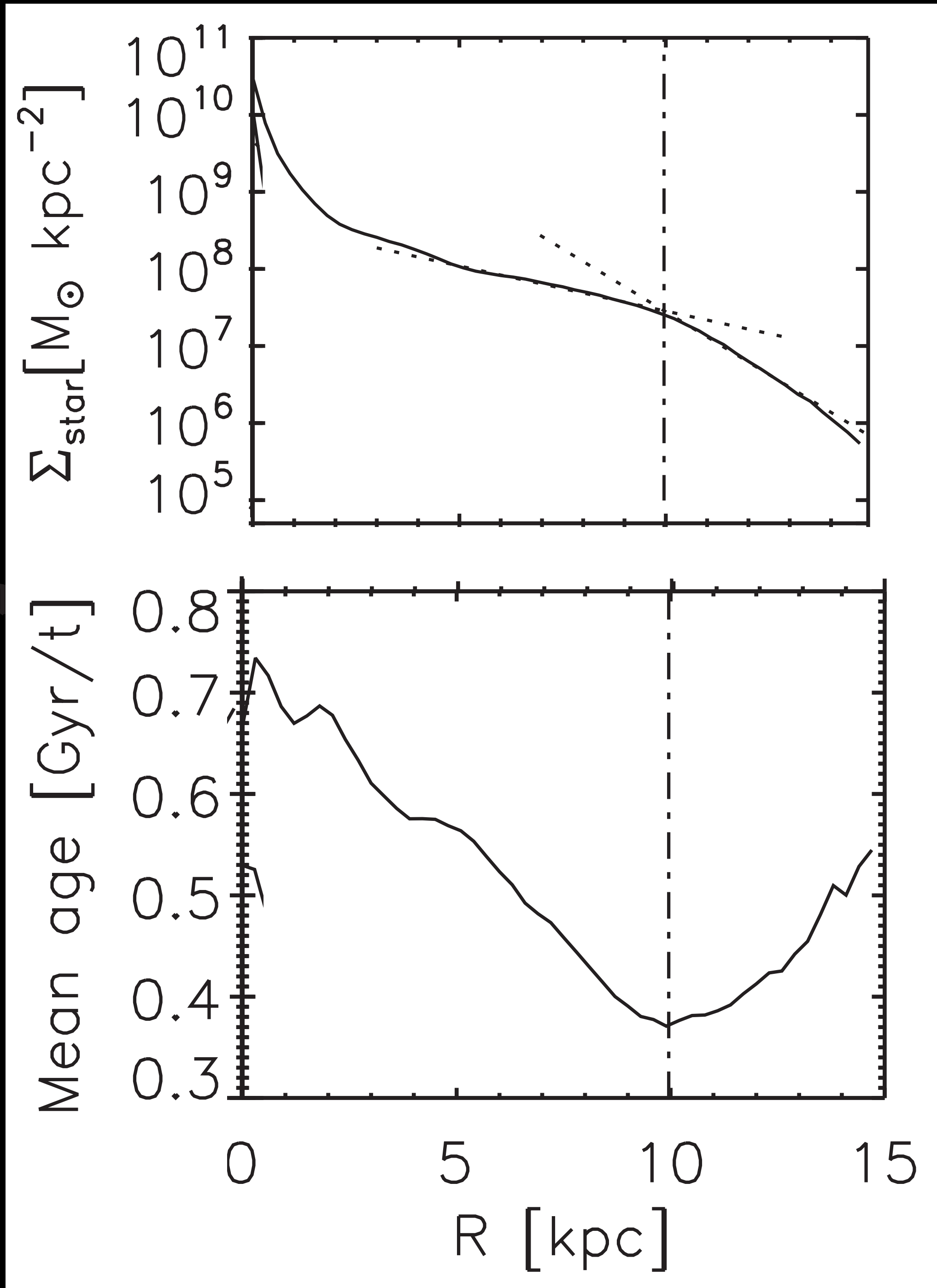








Pohlen & Trujillo, 2006

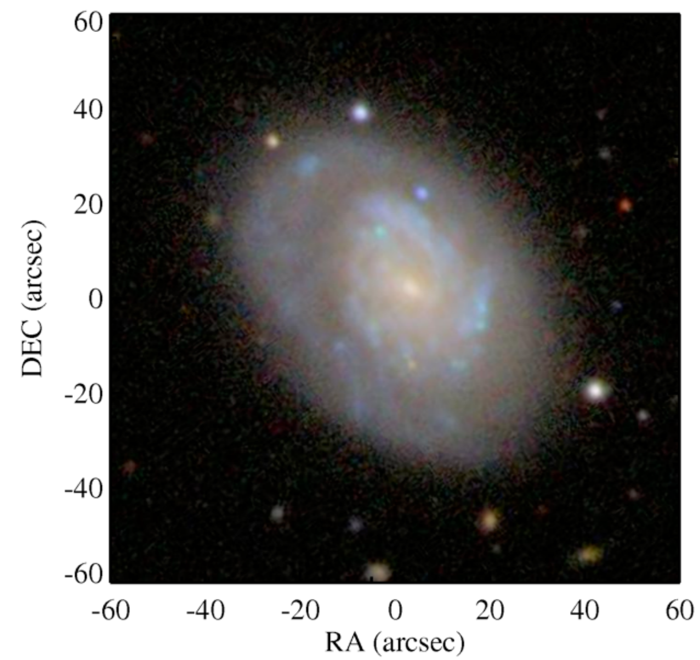


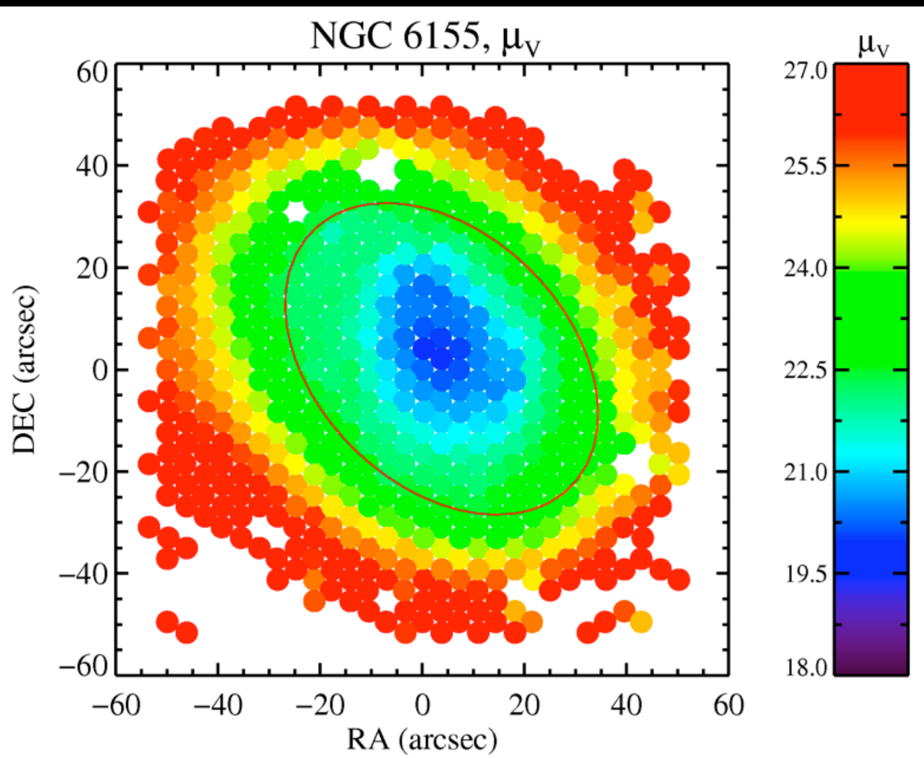
Simulations suggest profile break a sign of stellar migration

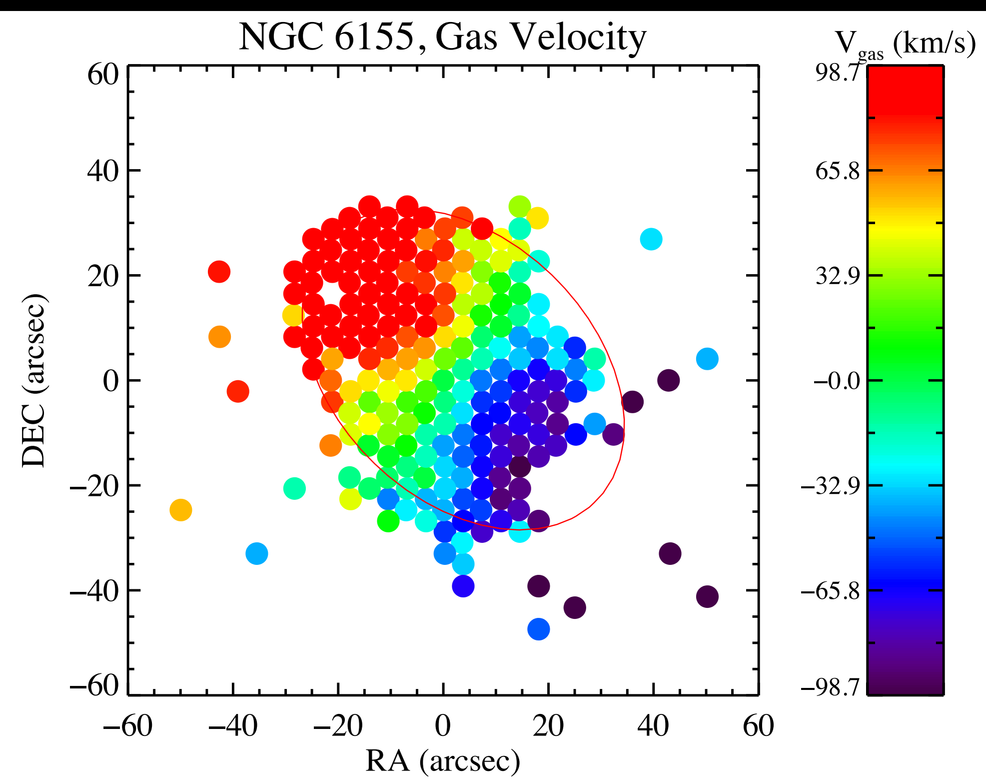
If true, stellar ages should increase beyond the break

Roškar et al 2008

Targeted 12 galaxies, got good signal on 6 beyond the break radius





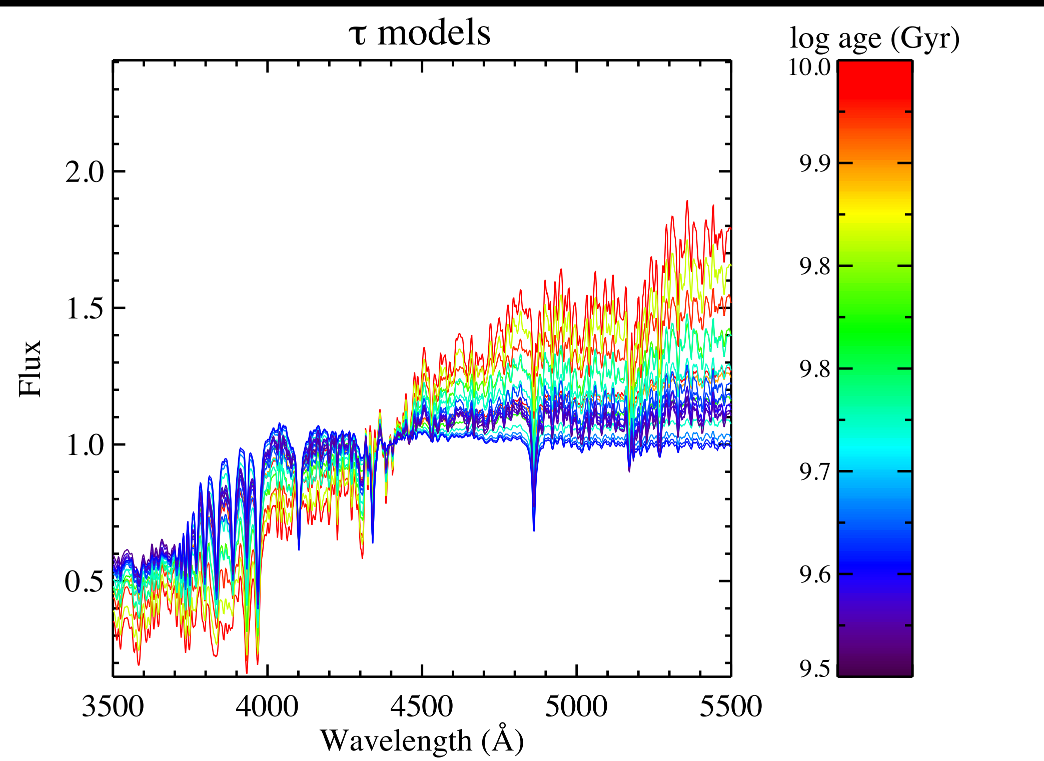


Spectral Synthesis

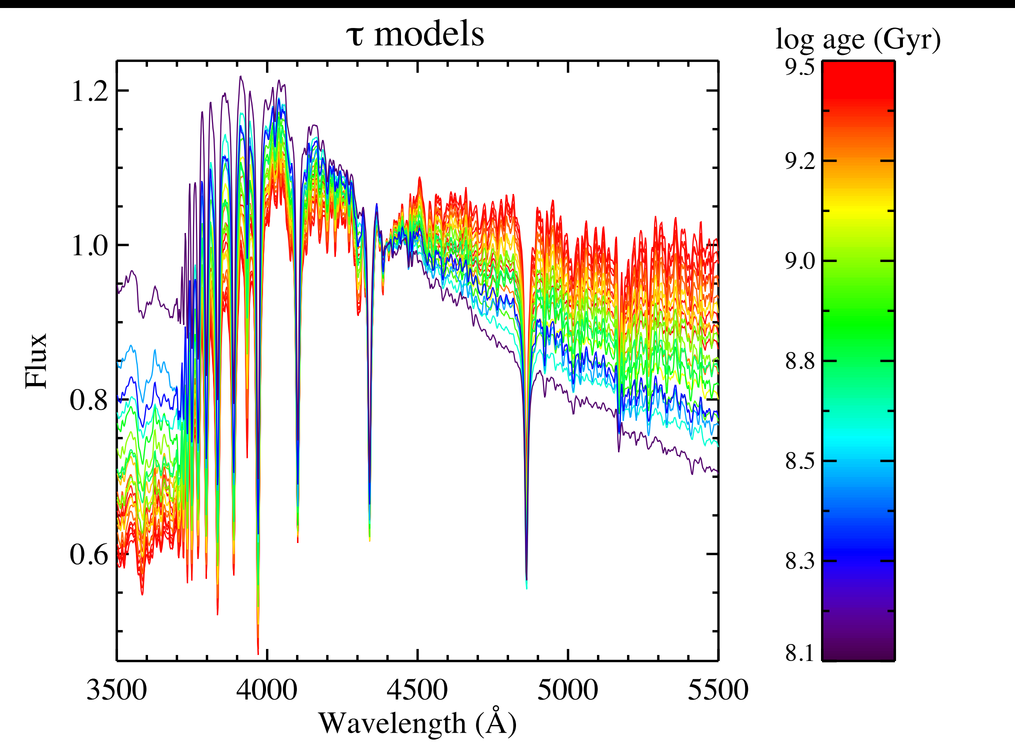
Rather than a linear combination of spectral templates, parametrize SFH and find the best *single* model

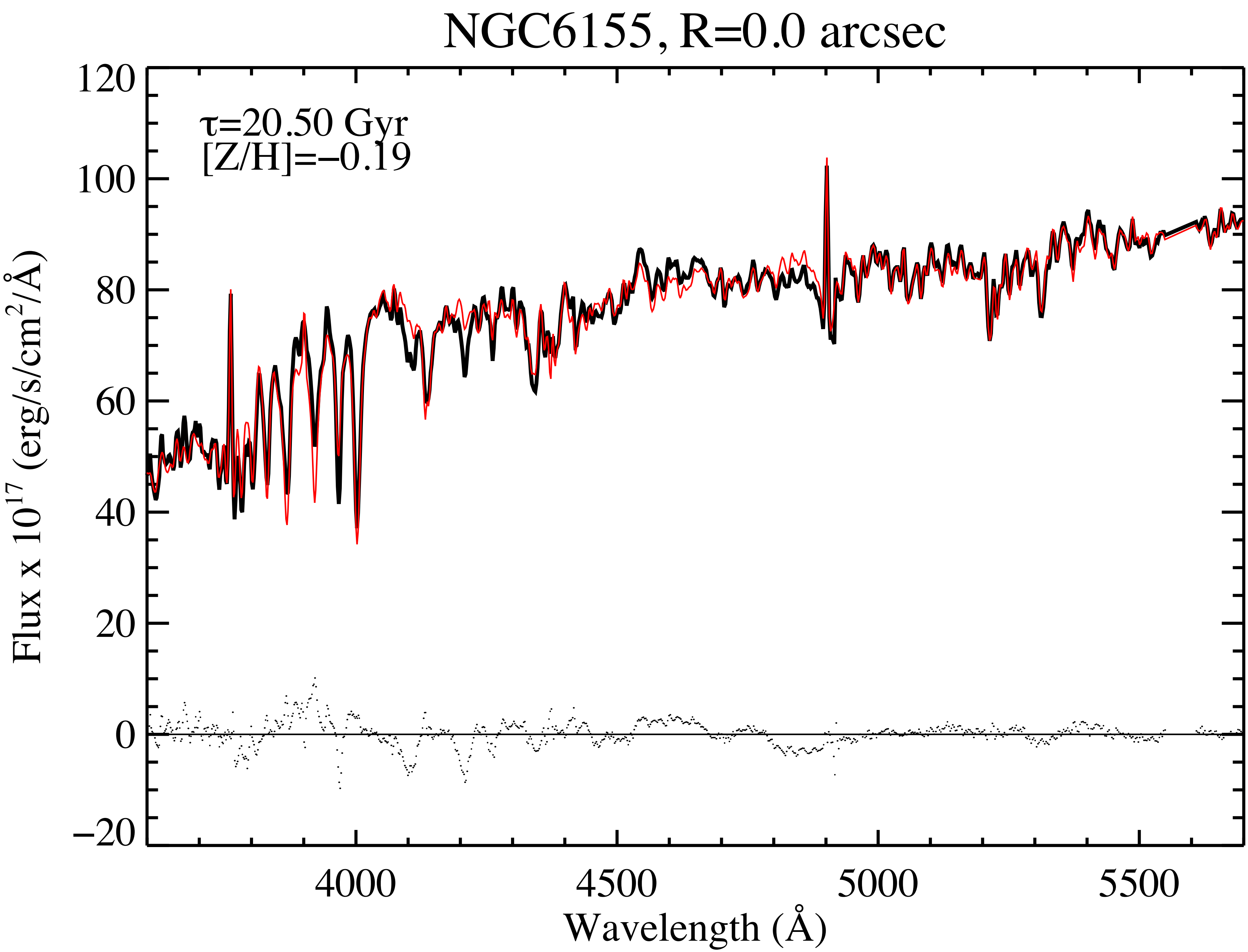
varying only SFR decay (τ) and metallicity

Decreasing SFR

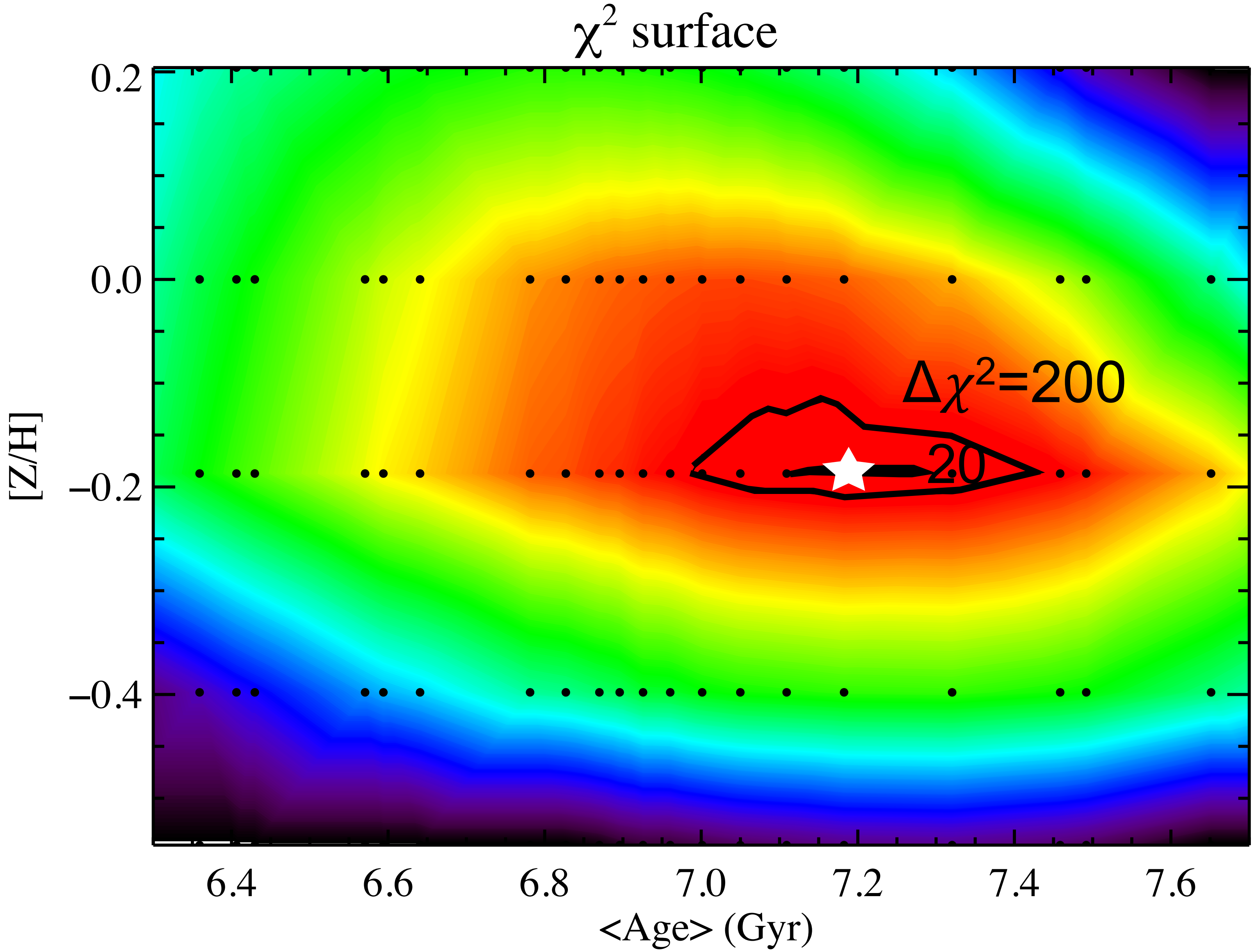


Increasing SFR

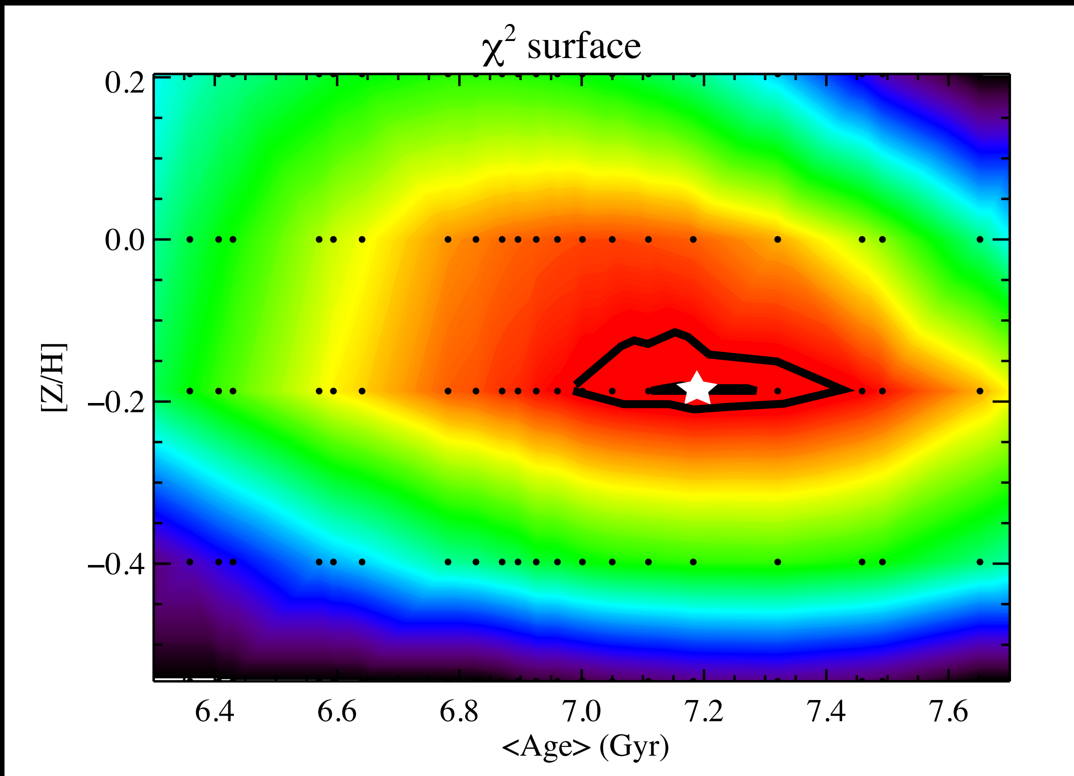


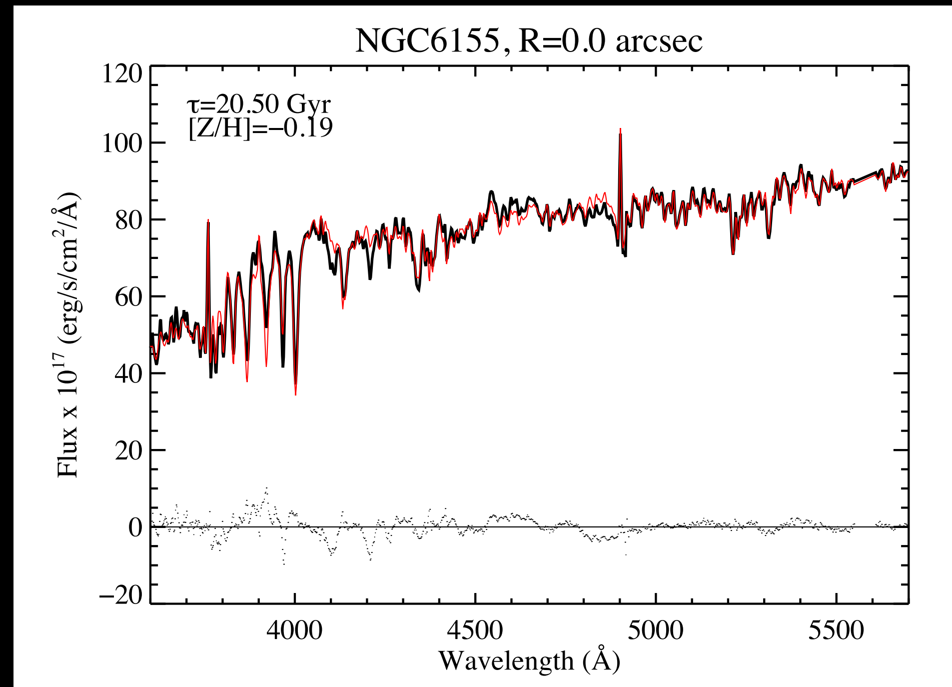


NGC6155, R=0.0 arcsec
τ=20.50 Gyr
[Z/H]=−0.19
Flux x 10^17 (erg/s/cm^2/Å)
Wavelength (Å)
120
100
80
60
40
20
0
−20
4000
4500
5000
5500



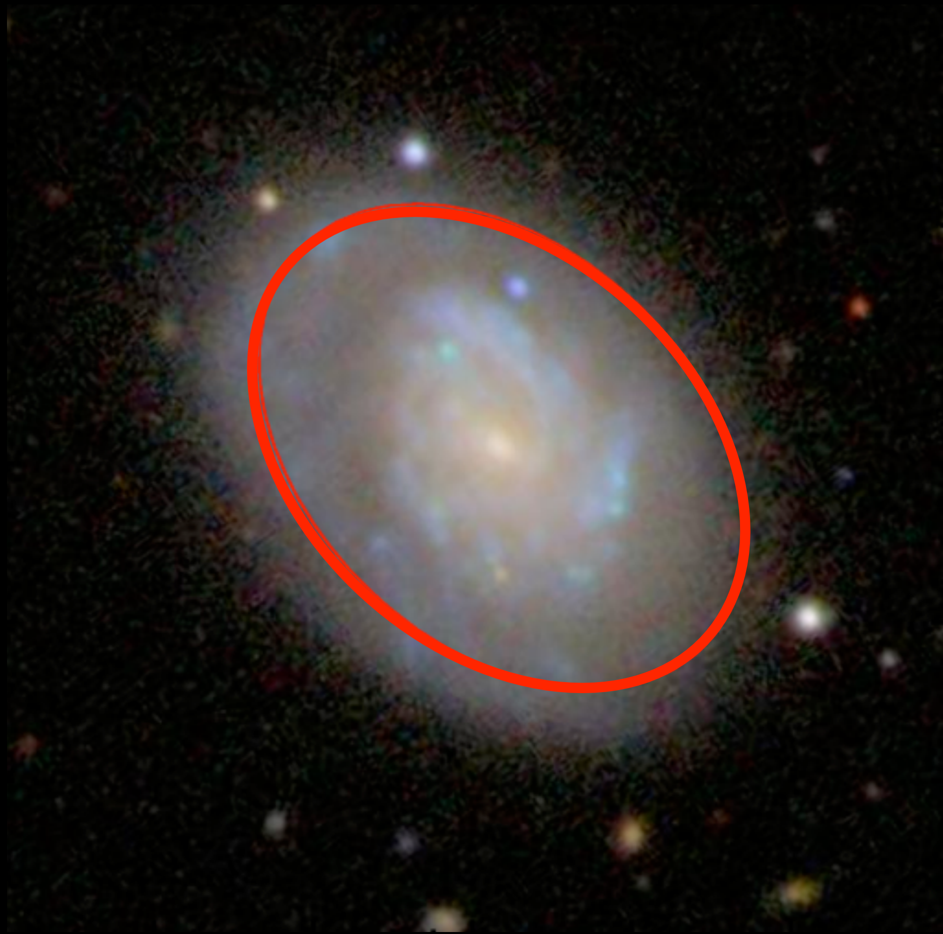
Well-behaved chi-squared surface!
Solution does not jump around with changing SNR, wavelength range, etc.

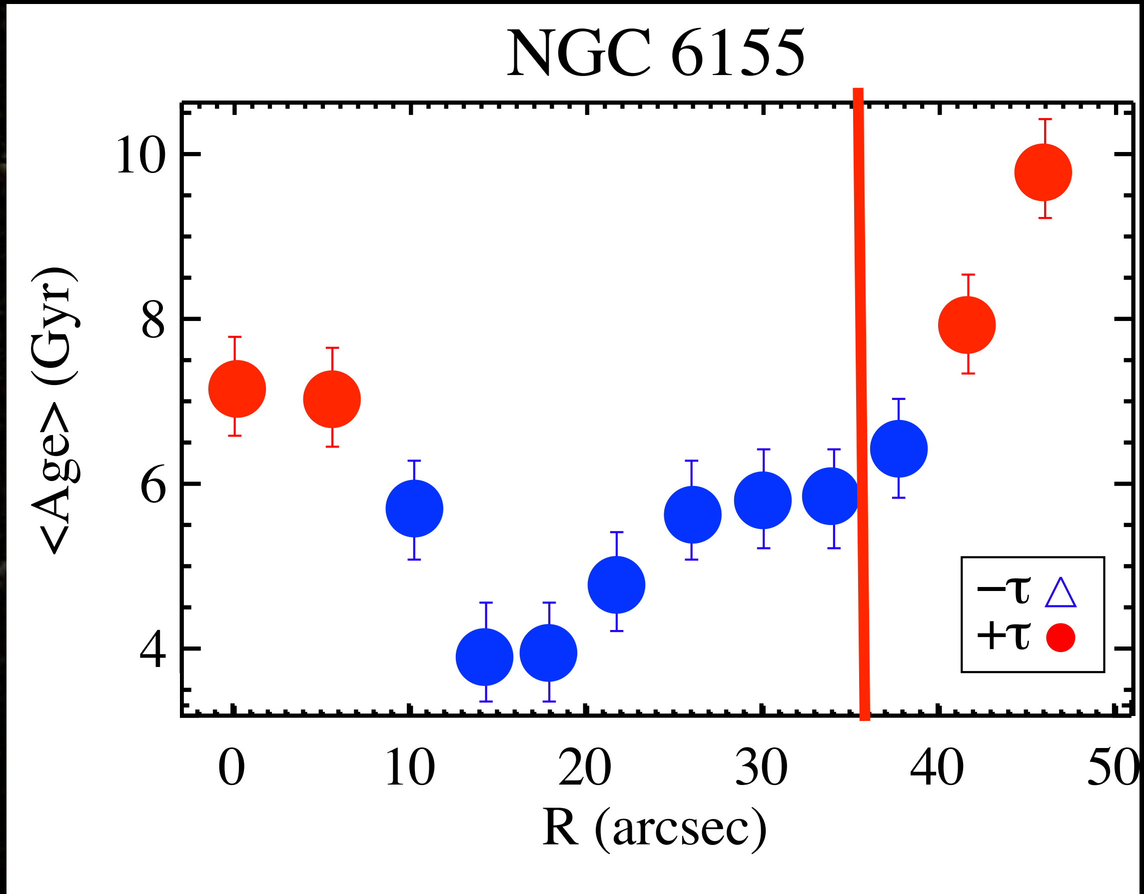




"Well behaved", but not well calibrated chi-squared surface. Residuals are non-Gaussain—dominated by things like errors in AGB stellar evolution and errors in modeling of stellar atmospheres.

Results

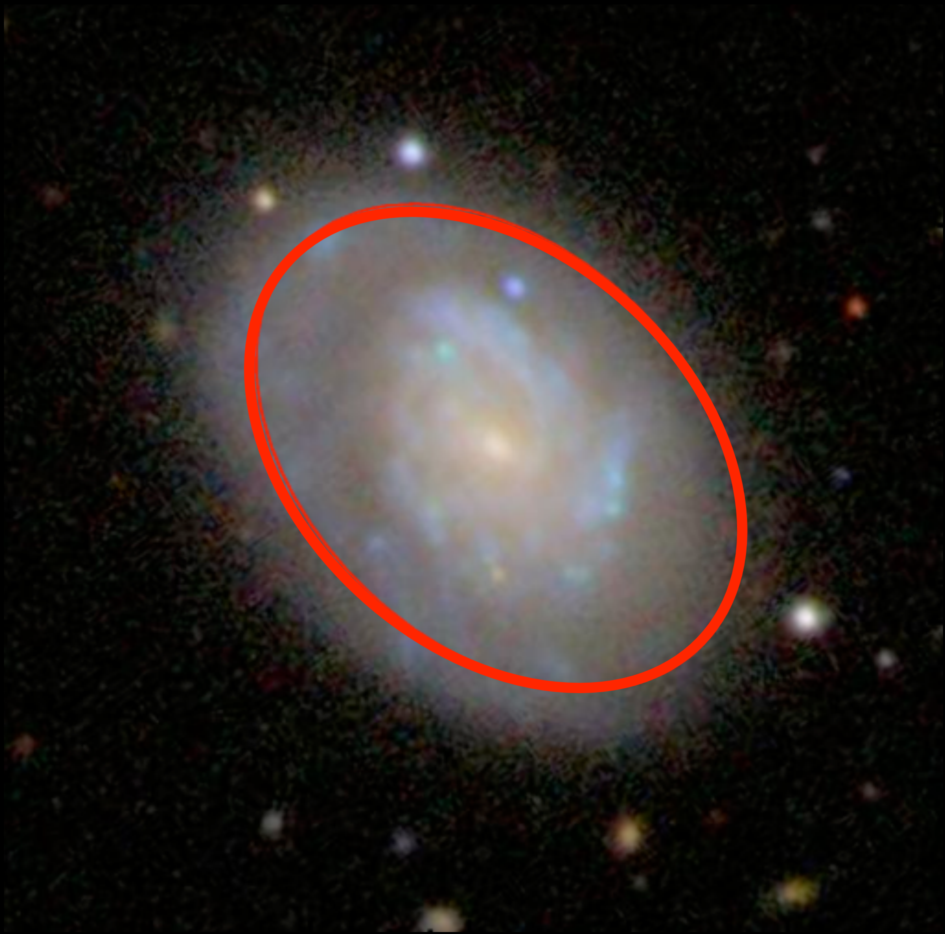


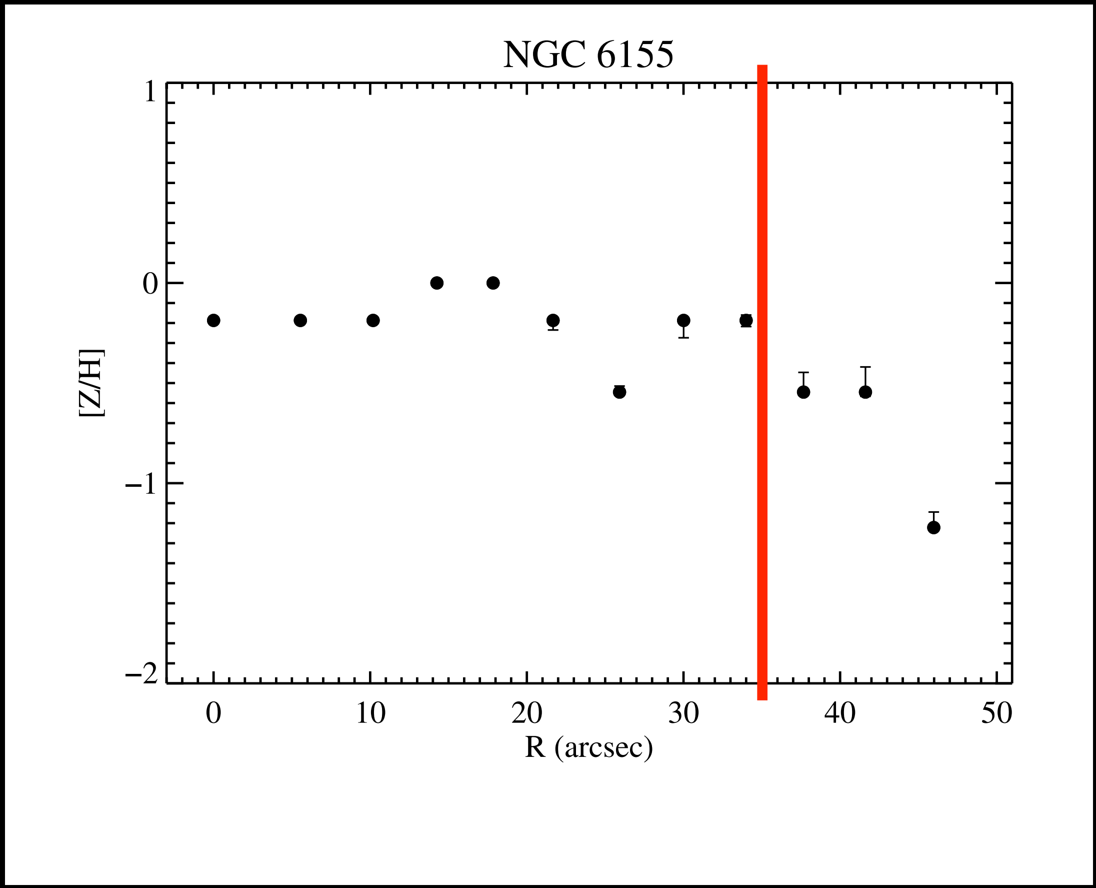


Decreasing SFH
Increasing SFH

Yoachim, Roškar, & Debattista, 2010

Because it was asked yesterday…



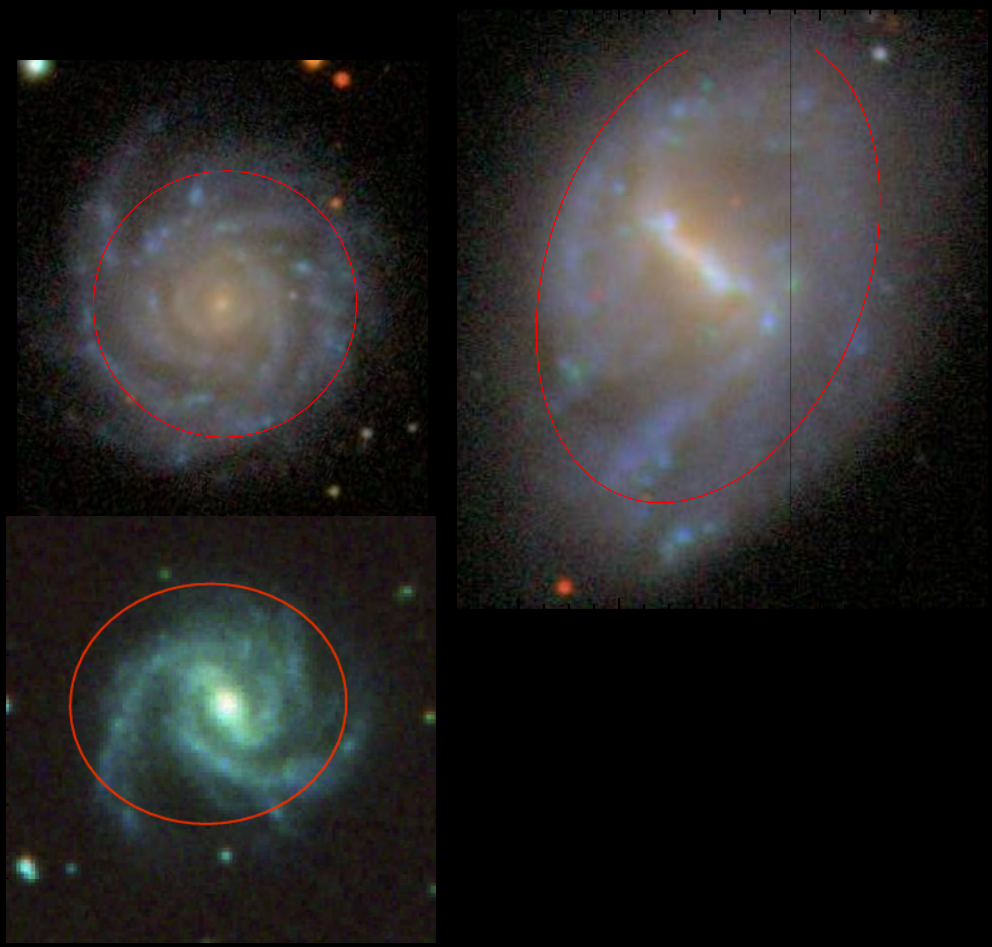


The metallicity does drop after the break
(at least for this one, usually stays constant)

Radial Migration? Sometimes.

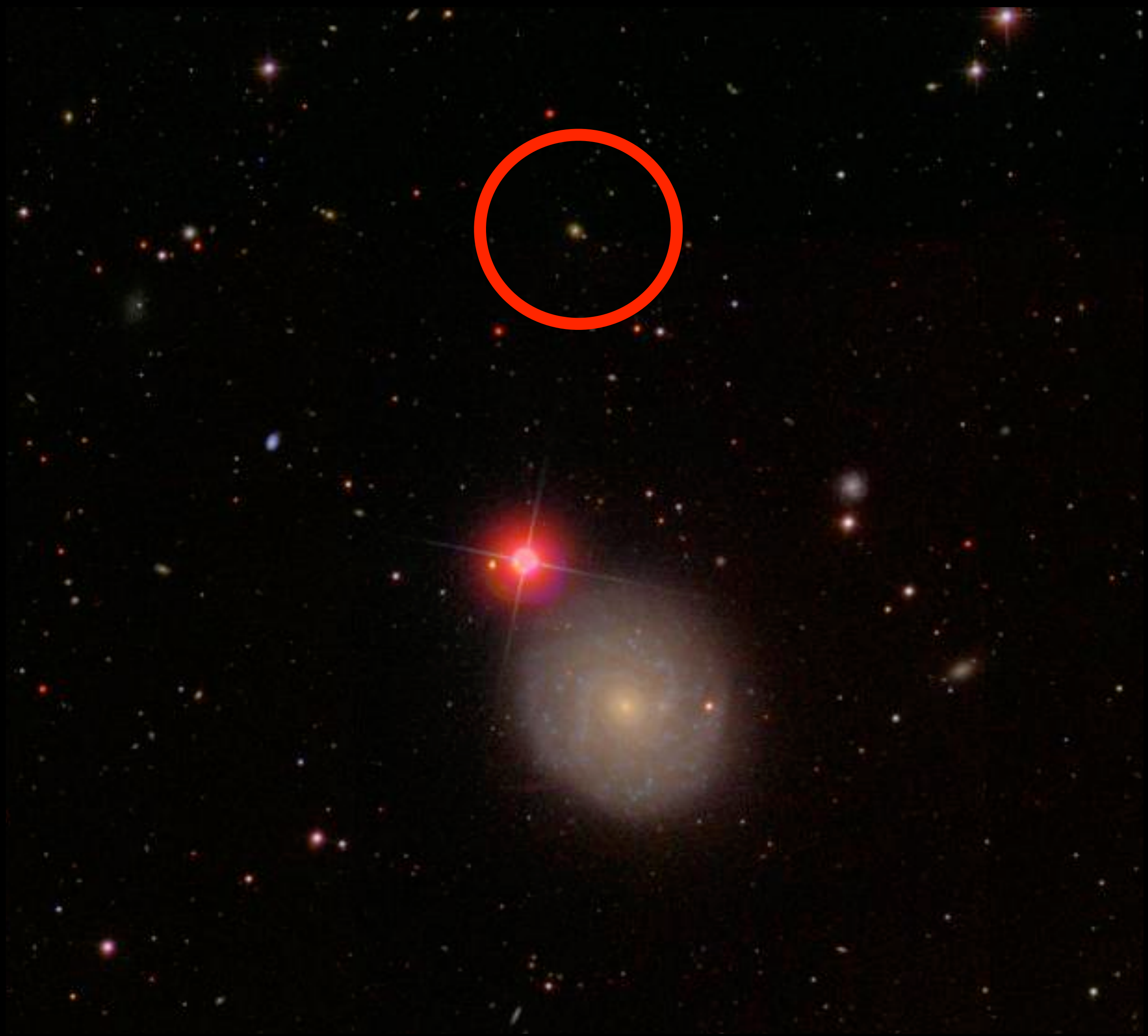
3 Galaxies showed an increase in age beyond the break

3 Galaxies had young stars beyond the break

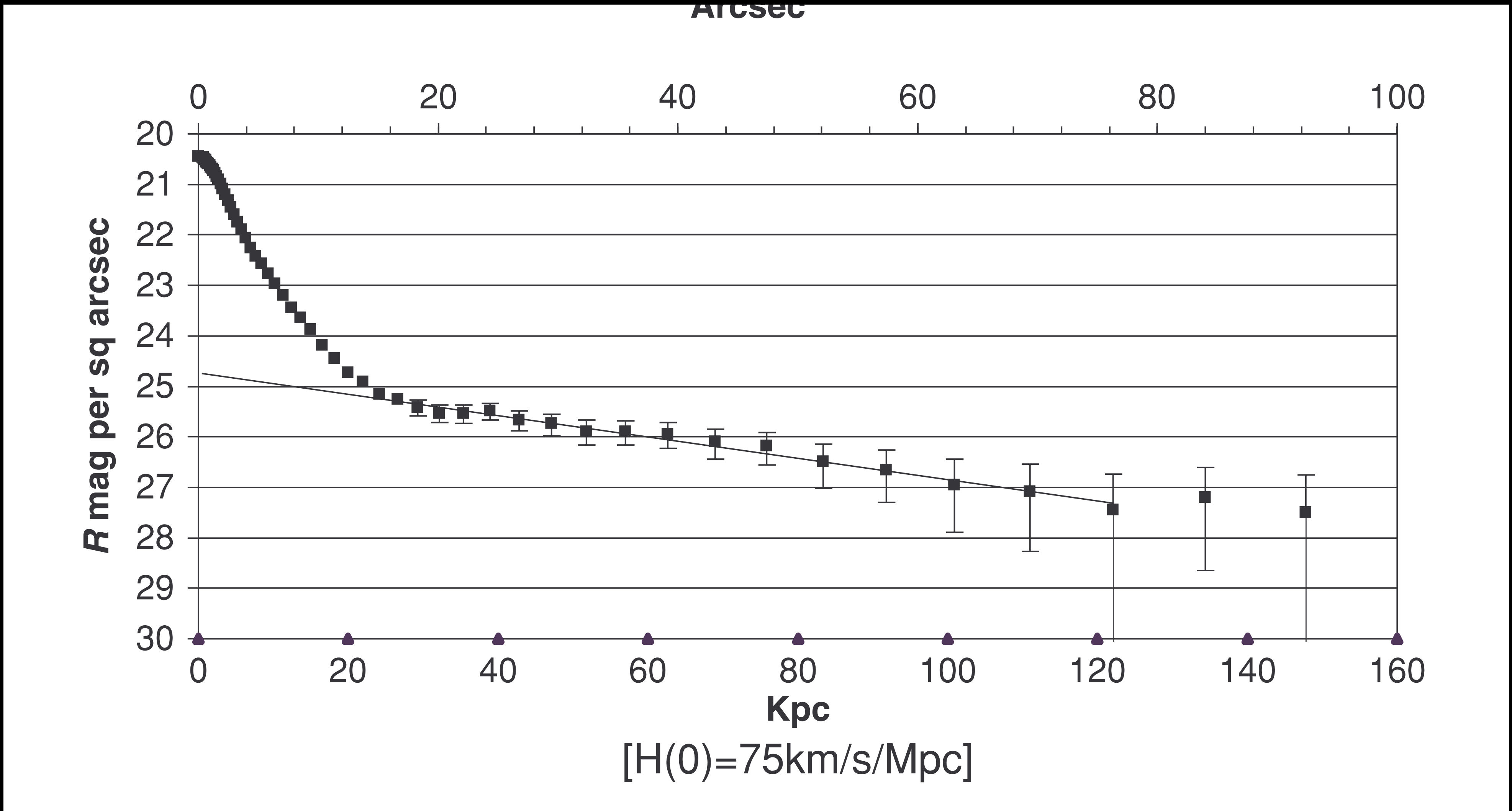


Yoachim, Roskar, Debattista, 2010 & 2012

The Largest Disk in the Universe!

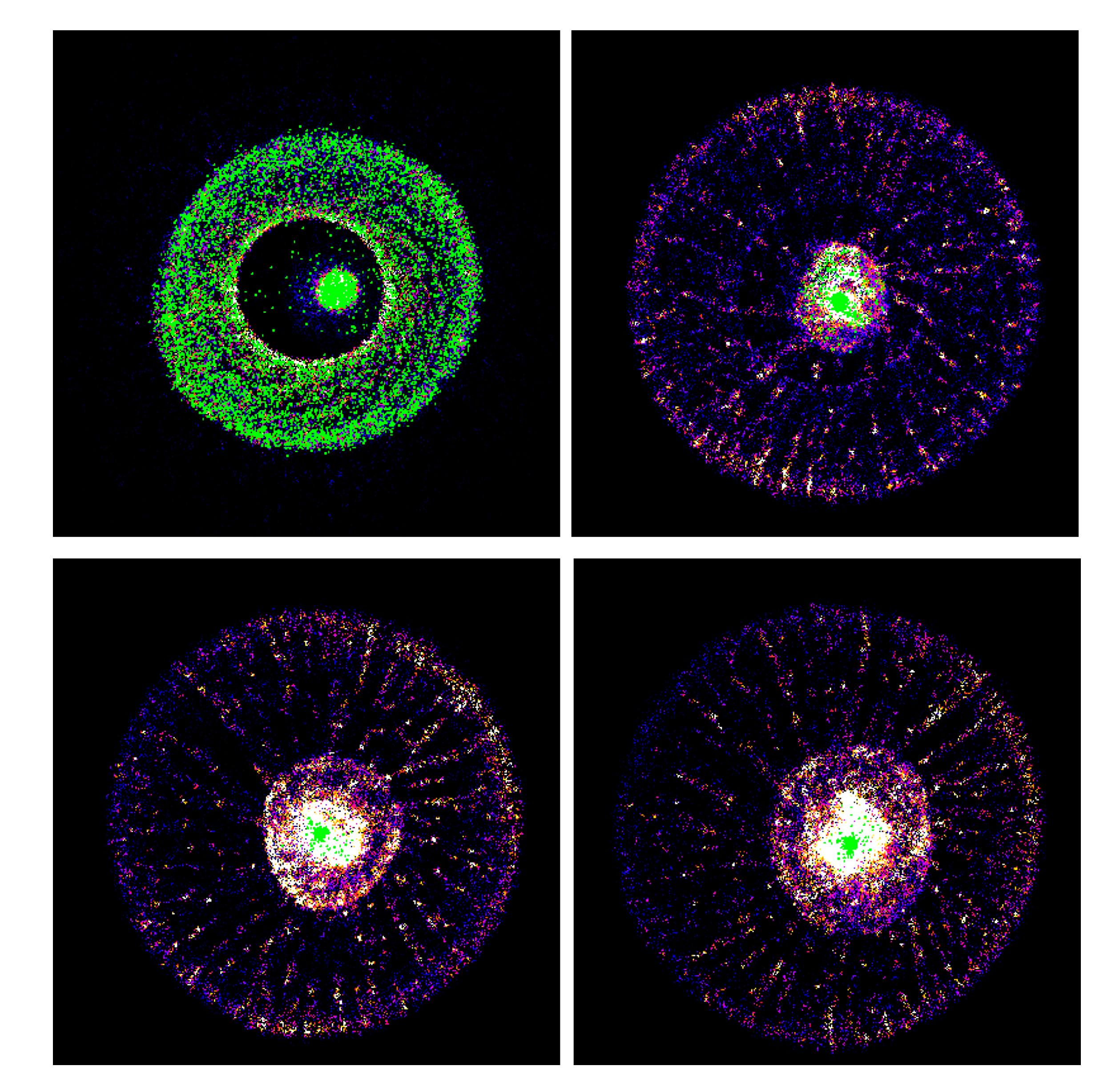


Malin 1



Moore et al 2006

How to make a 100 kpc stellar disk?

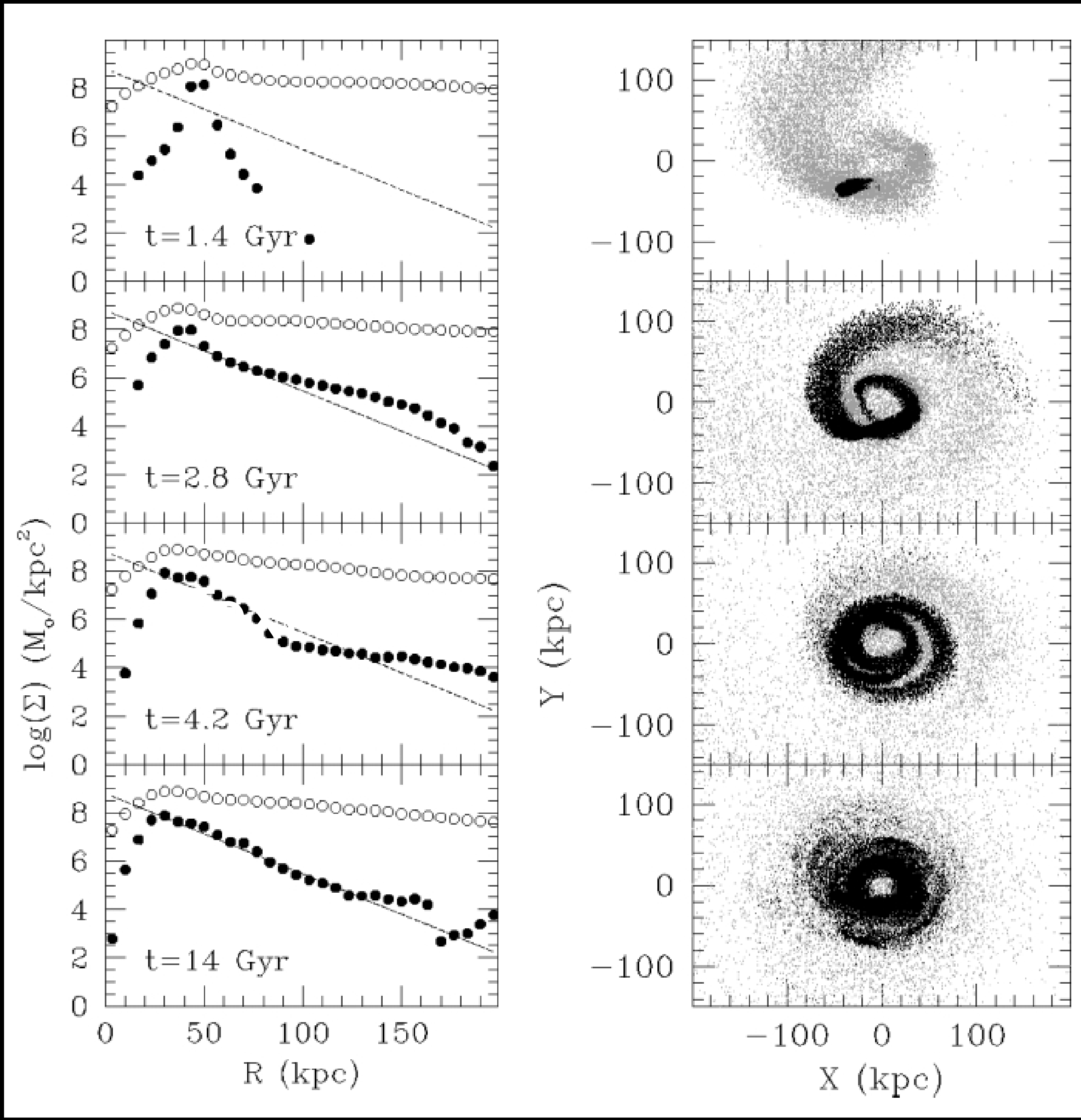


Mapelli et al 2009

Ring Galaxy AM 0644-741

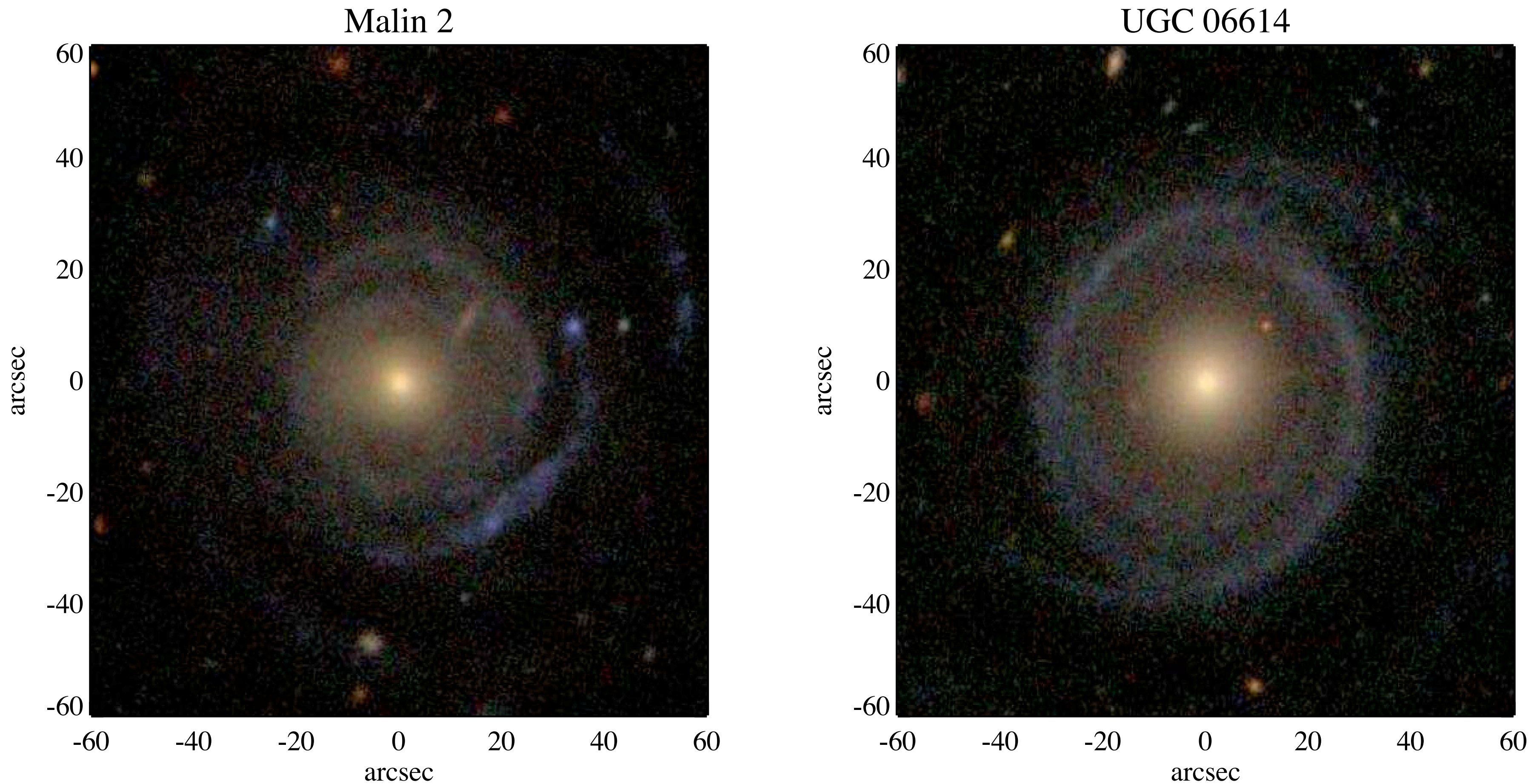
NASA, ESA, and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope ACS • STScI-PRC04-15

Or, just disrupt a satellite galaxy to make a large exponential disk



Peñarrubia, et al, 2006

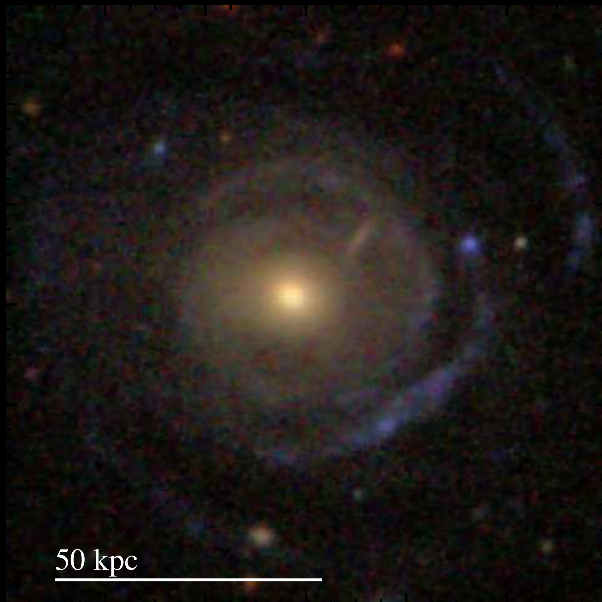
Two Giant Low Surface Brightness Galaxies

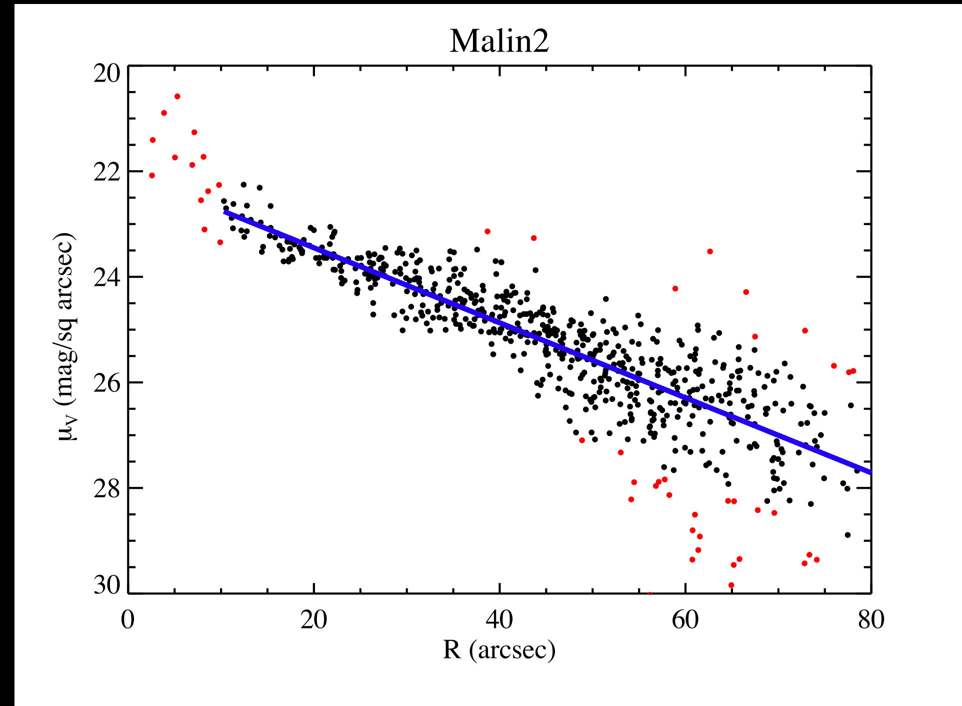


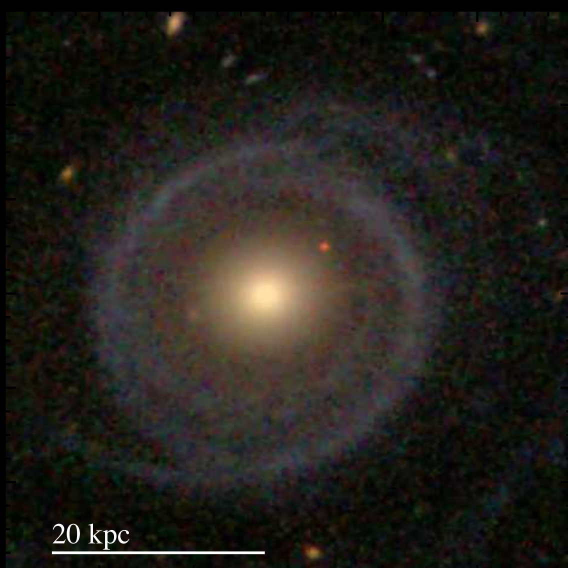
80-150 kpc diameter

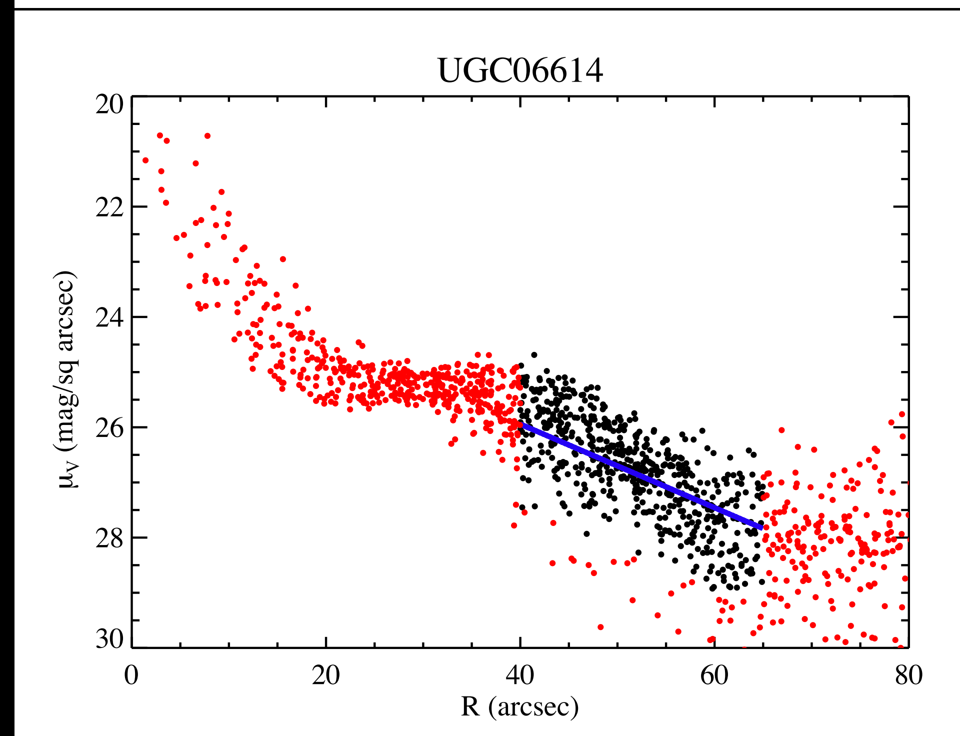
~75 kpc diameter

See also Anna Saburova's poster on Malin 2

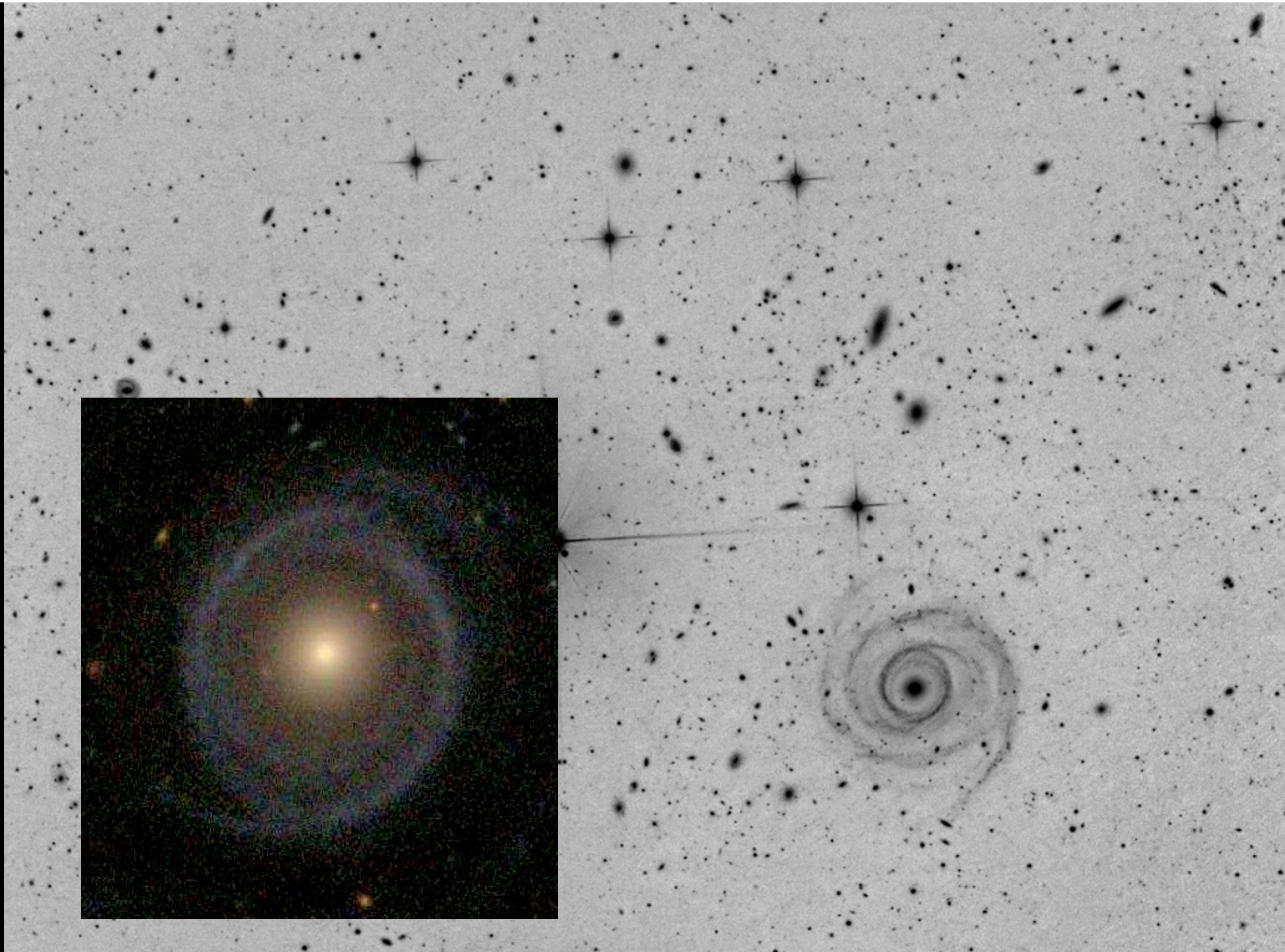






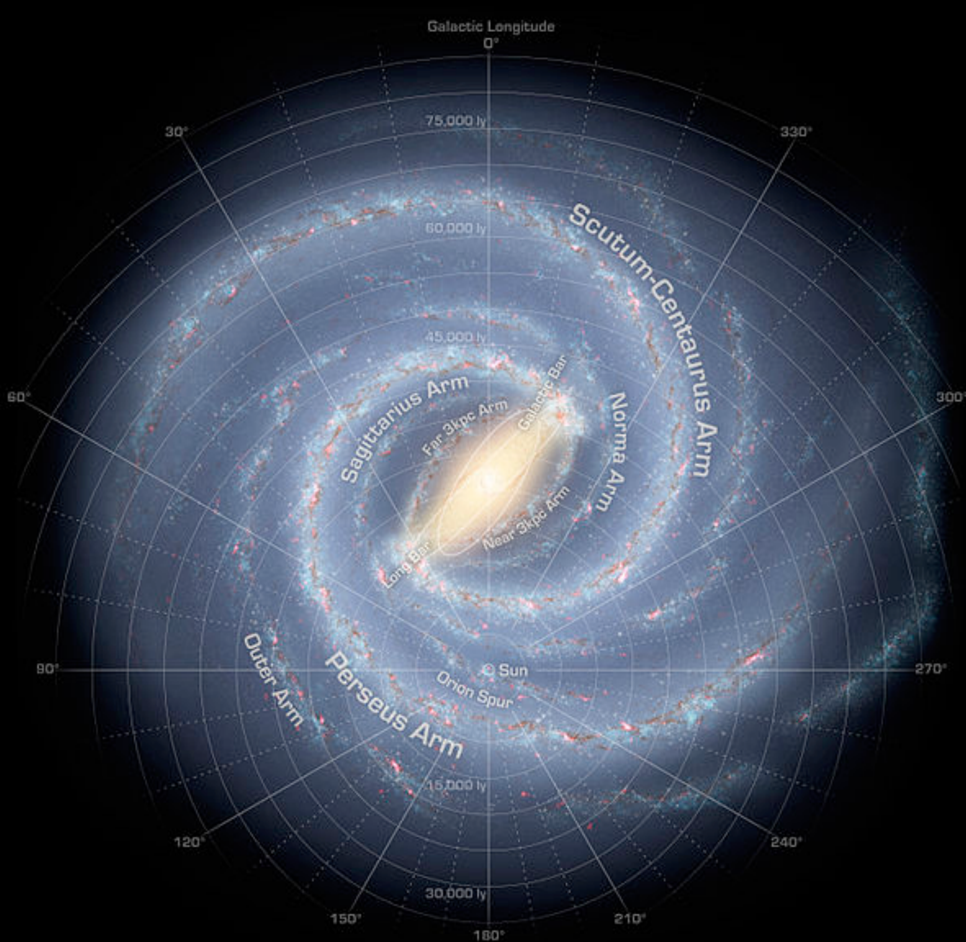


Malin 2 at least has a very nice exponential disk

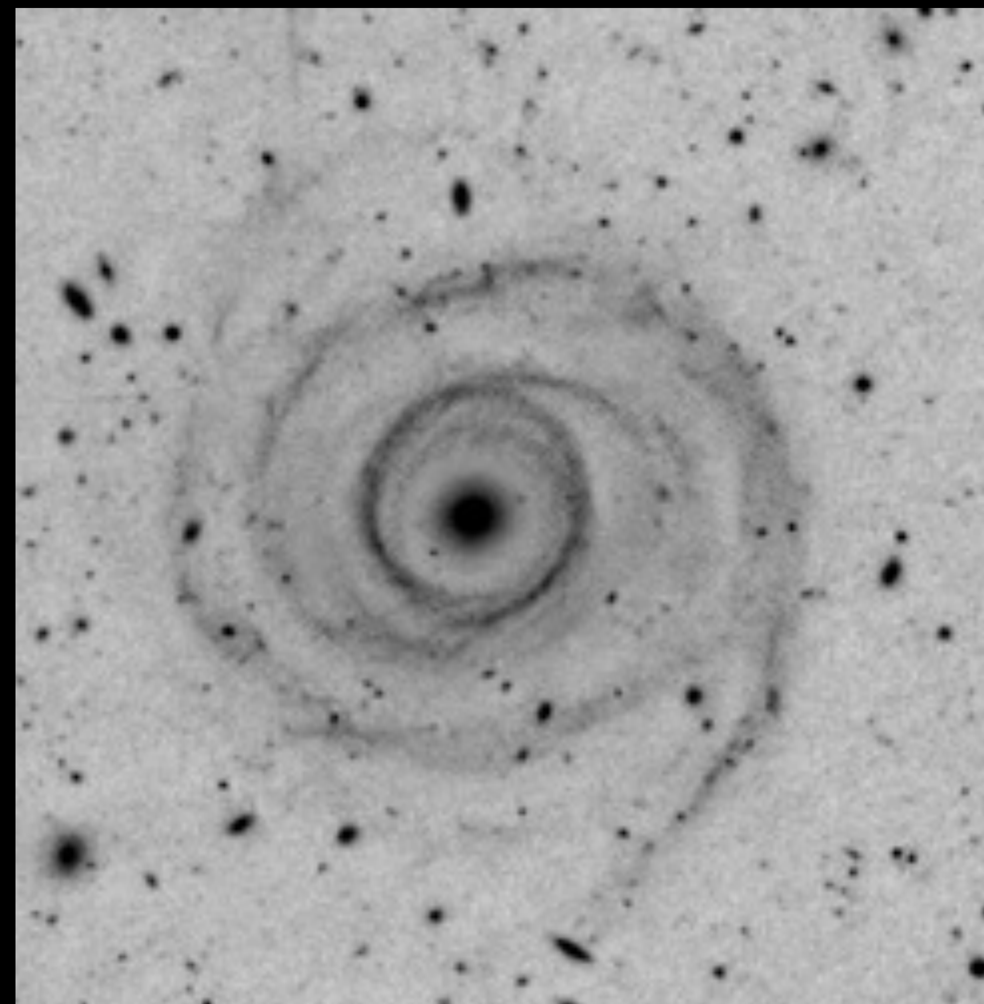


Stefan Binnewies, Josef Popsel. 11 hours on 0.6m

Milky Way



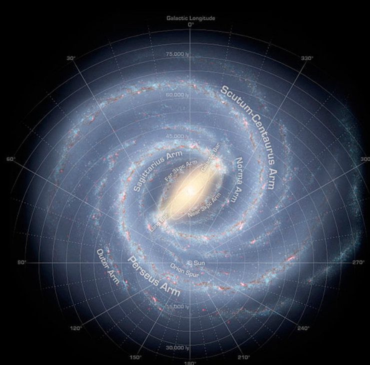
UGC 6614

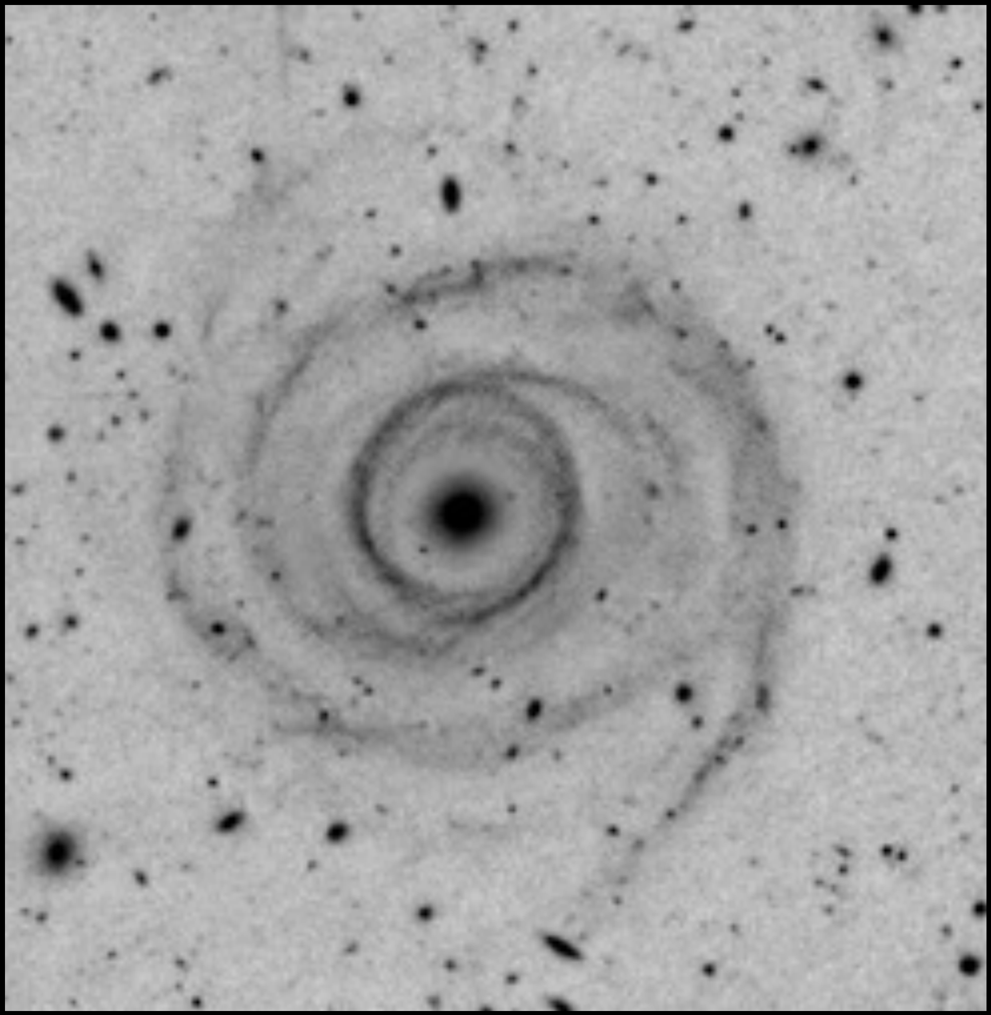


Milky Way

UGC 6614

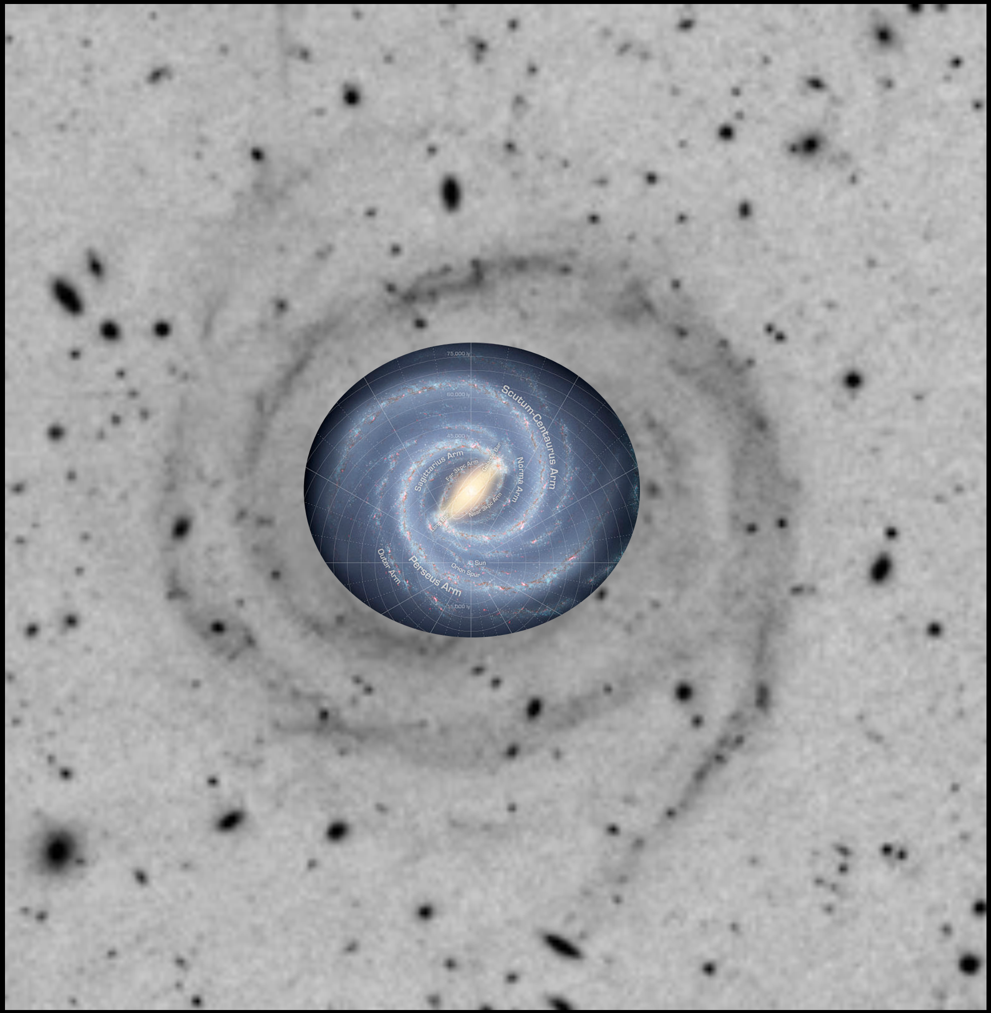
To scale

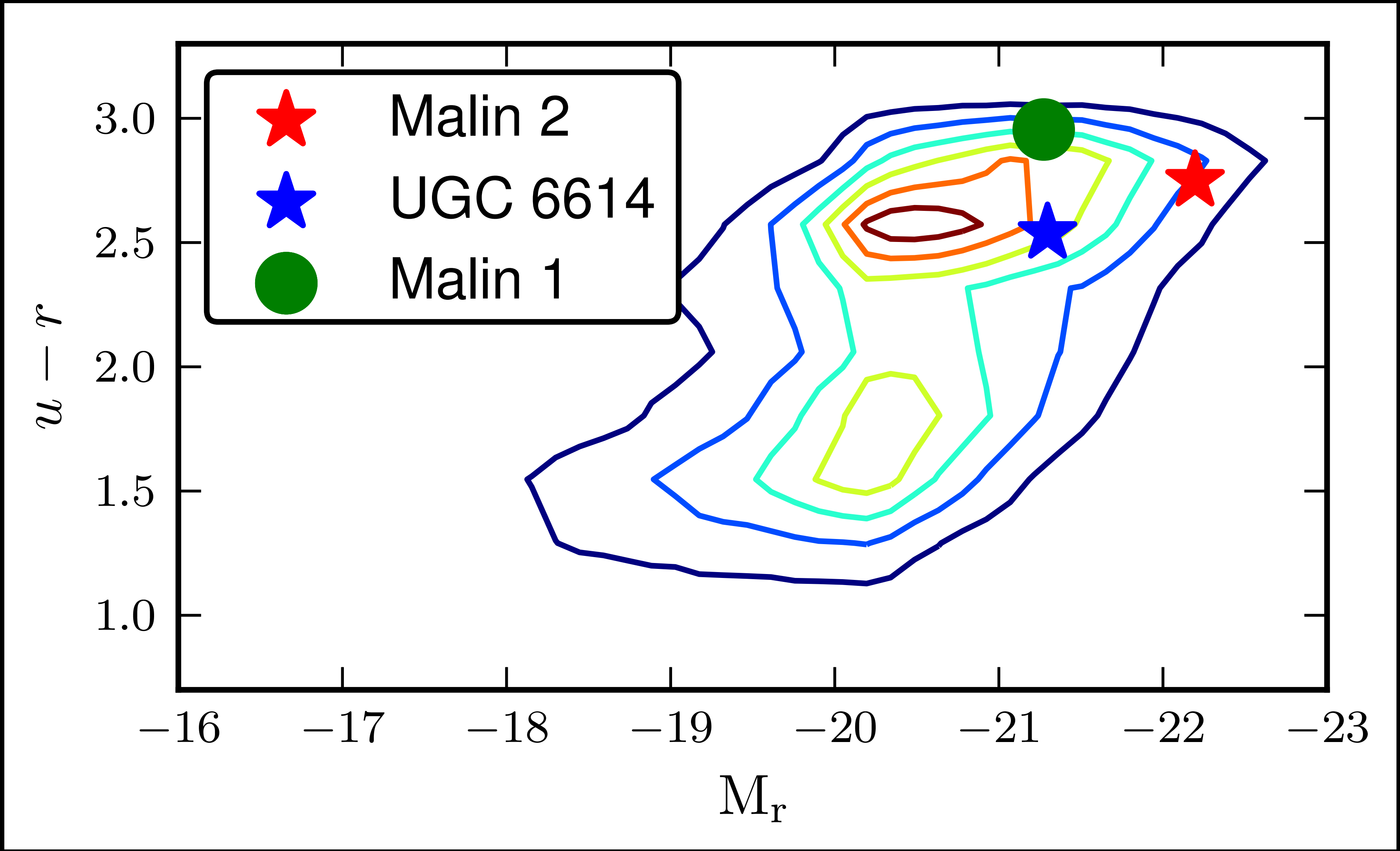




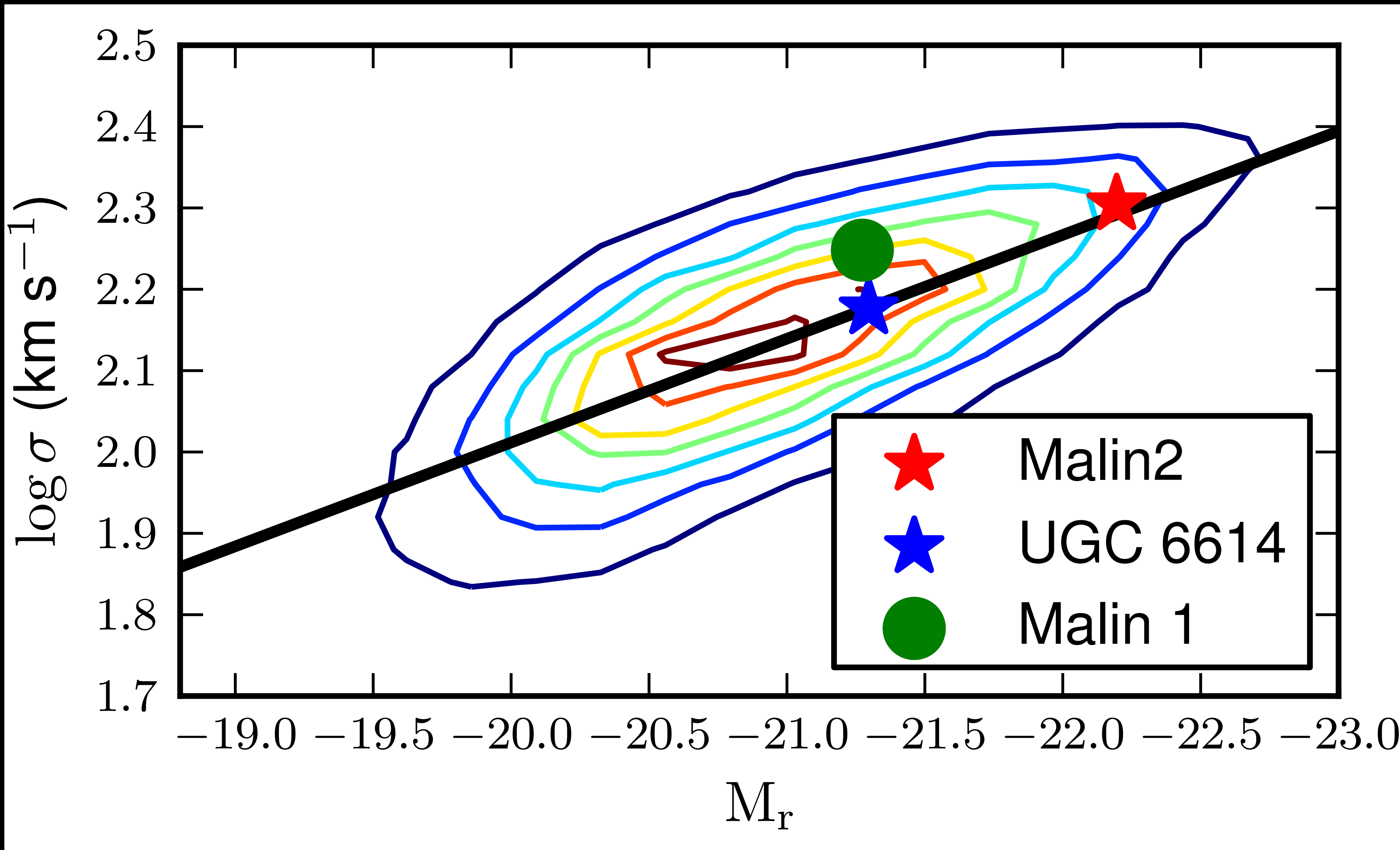
Milky Way UGC 6614

To scale

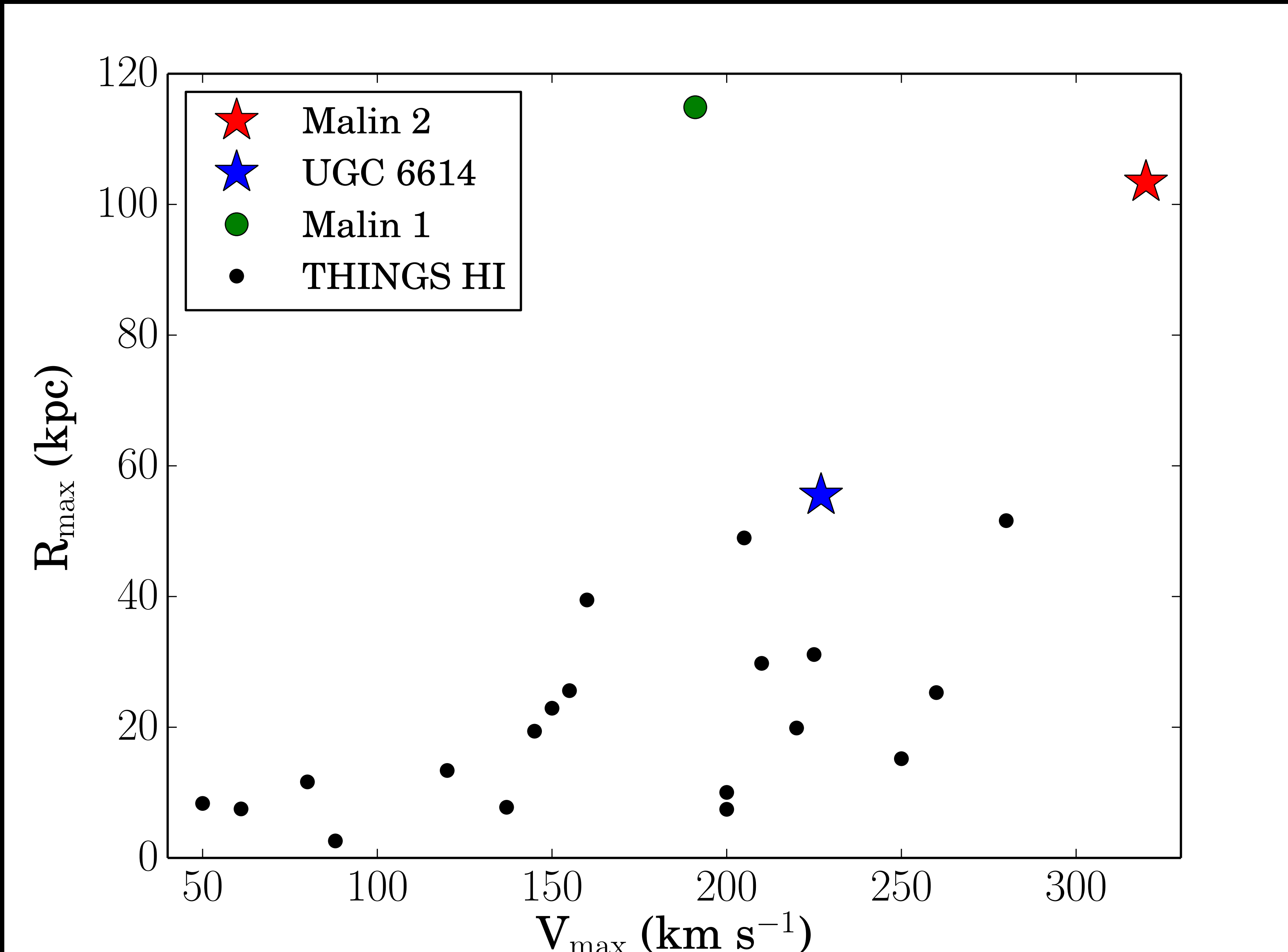




The centers of GLSBs lie on the red sequence

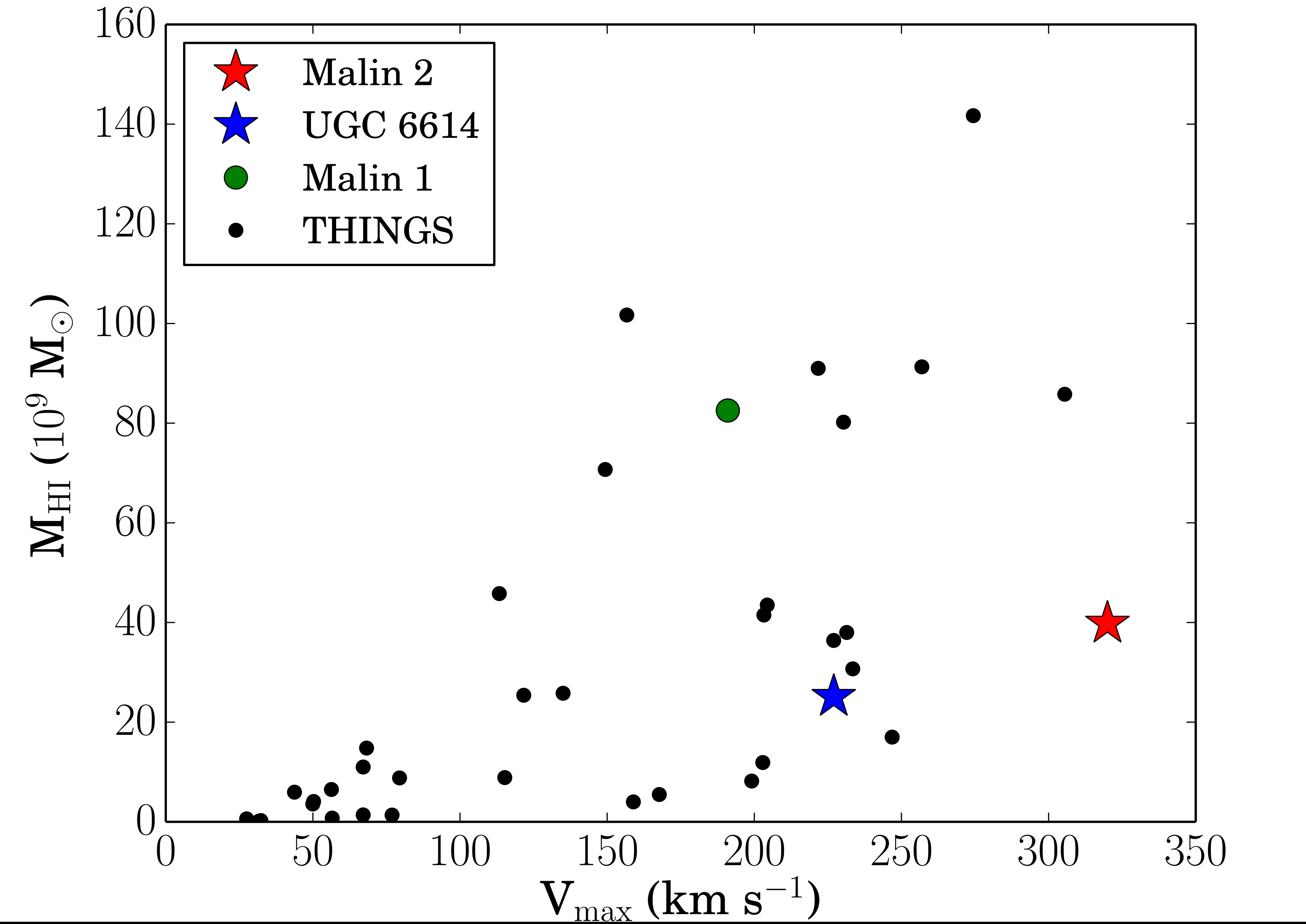


These look like normal elliptical galaxies. Here they are on the Faber-Jackson relation with 45,700 SDSS galaxies



GLSB stellar disks compared to local HI disks

These things are huge!

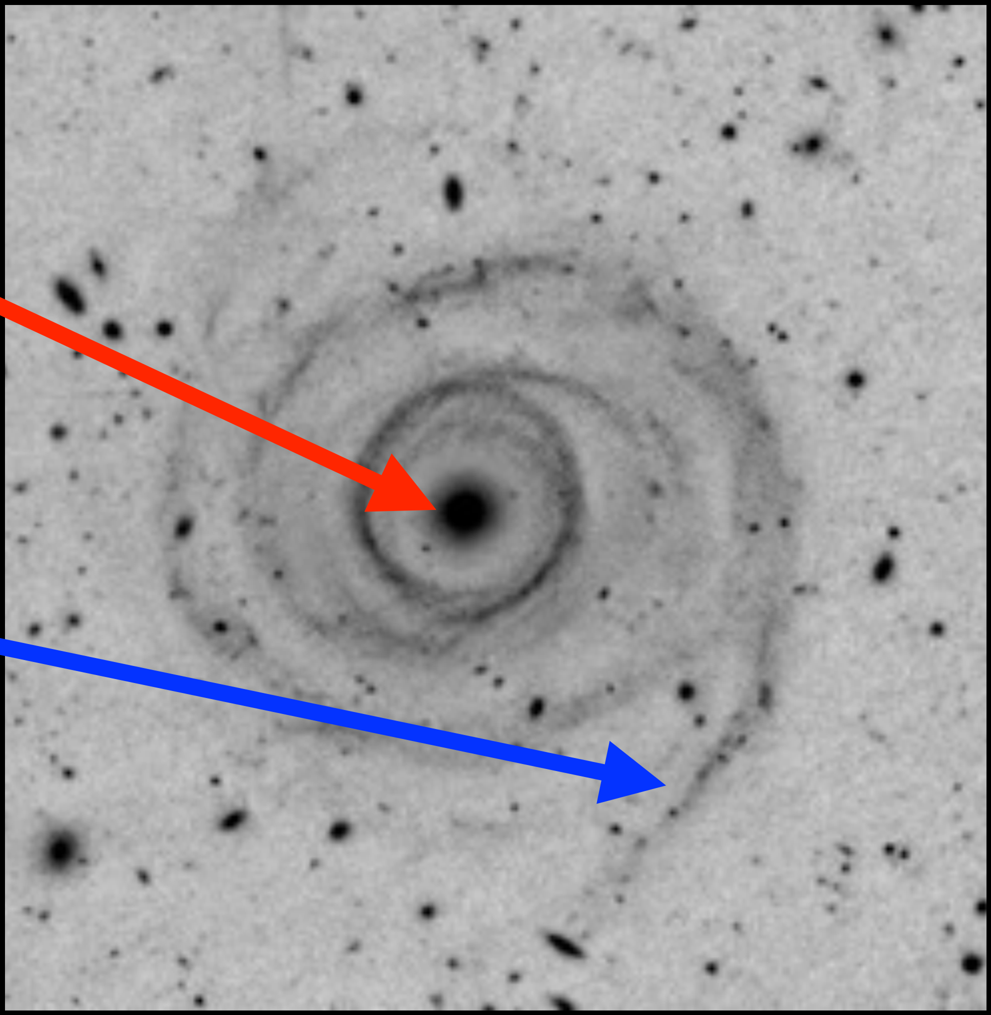


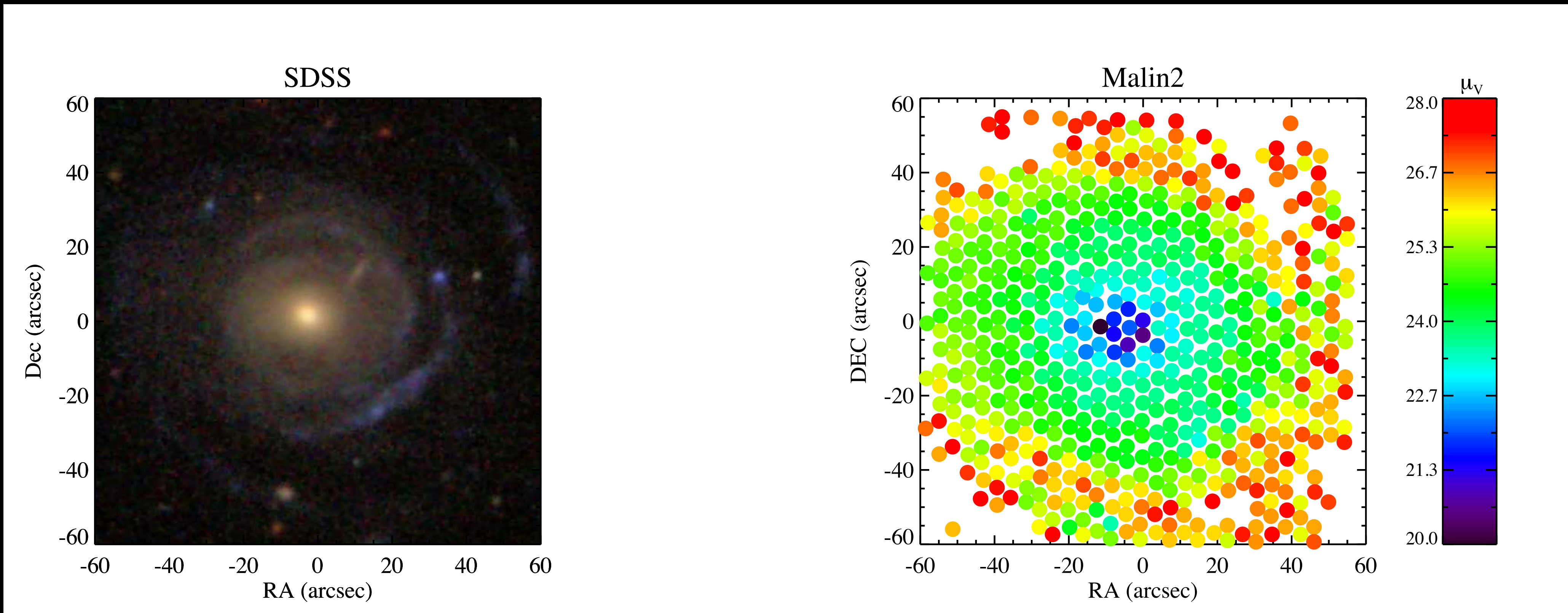
GLSB HI masses compared to local HI disks

Very normal looking elliptical galaxy

Surrounded by **huge** stellar spiral disk

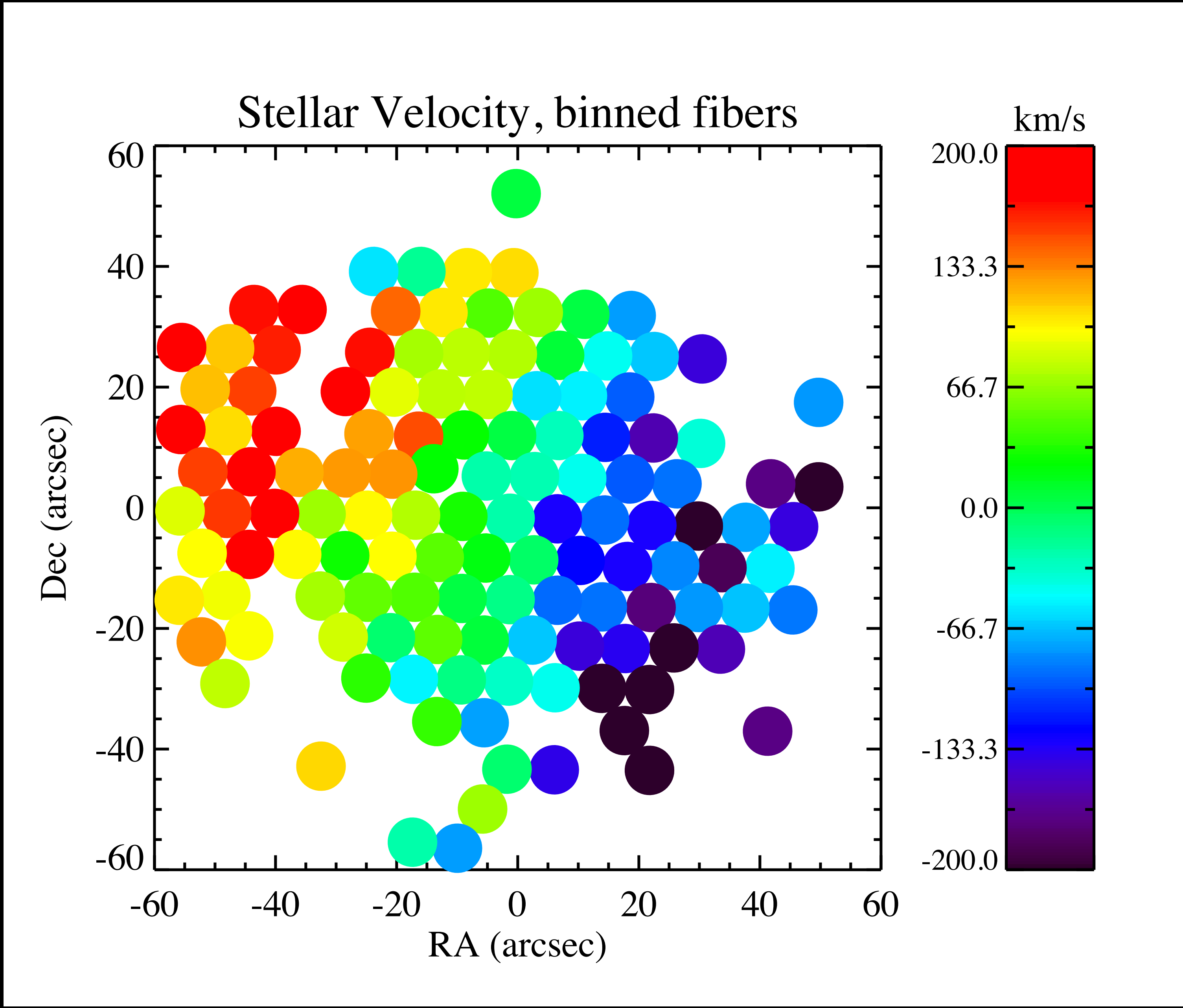
Surprisingly little HI





11 hours with VIRUS-P reaching 25-26 mag/□"

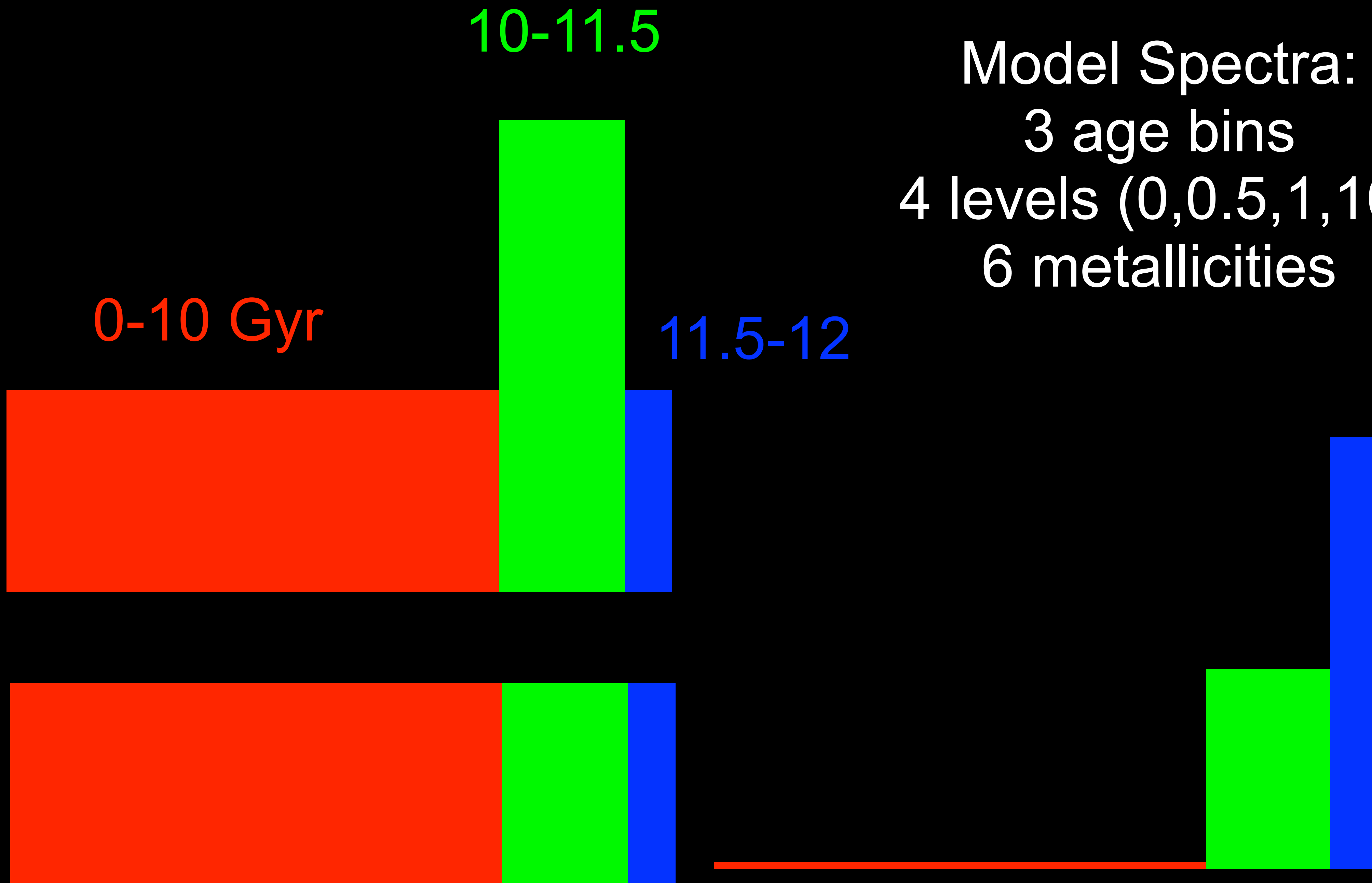
with Victor Debattista and Denise Schmitz



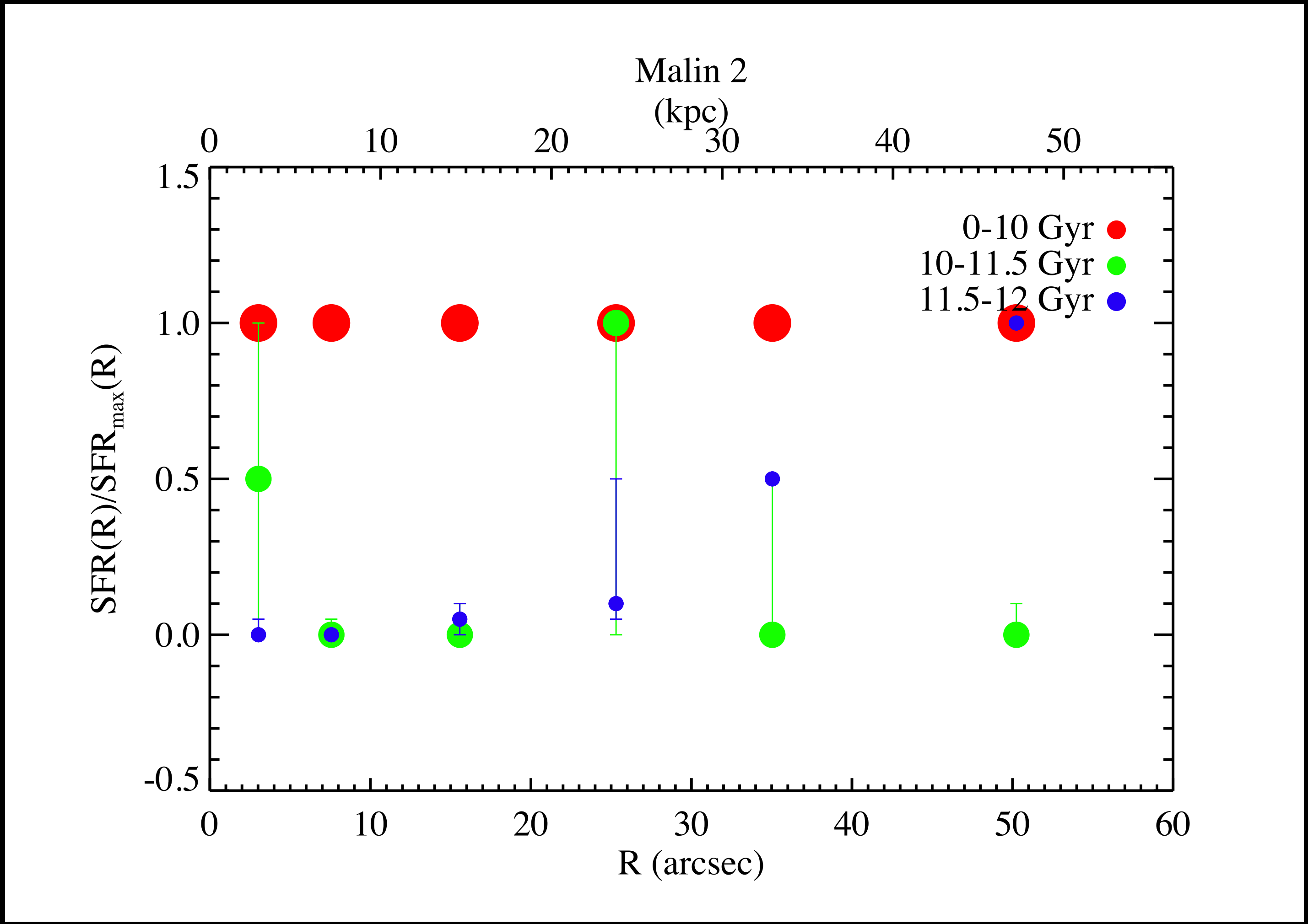
Stellar kinematics look very disk-like

Rather than use exponential SFHs, construct templates where we can look for a recent burst

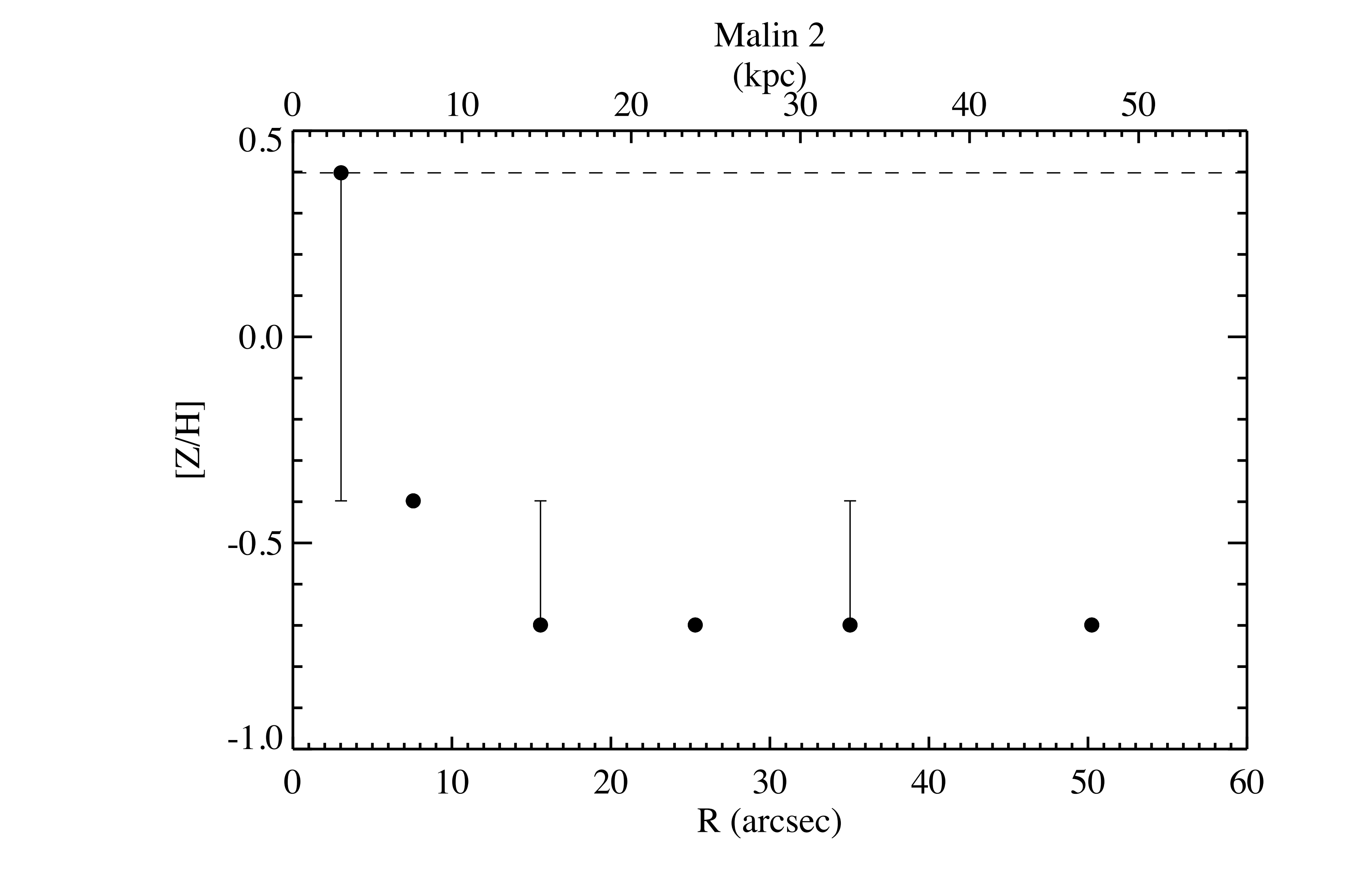
Model Spectra:
3 age bins
4 levels (0,0.5,1,10)
6 metallicities



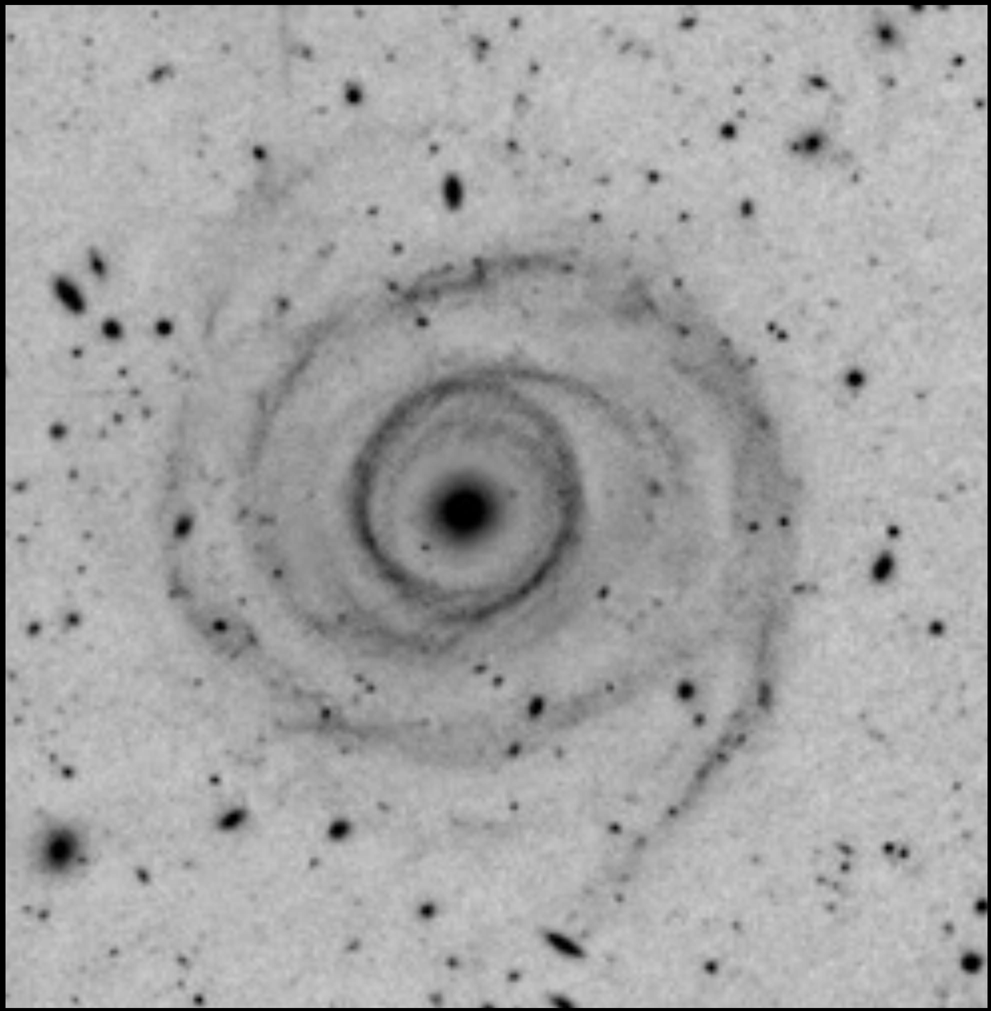
Lots of old stars!
No evidence for a collisional ring burst of formation



Some star formation at large radius, but old stars dominate at all radii.



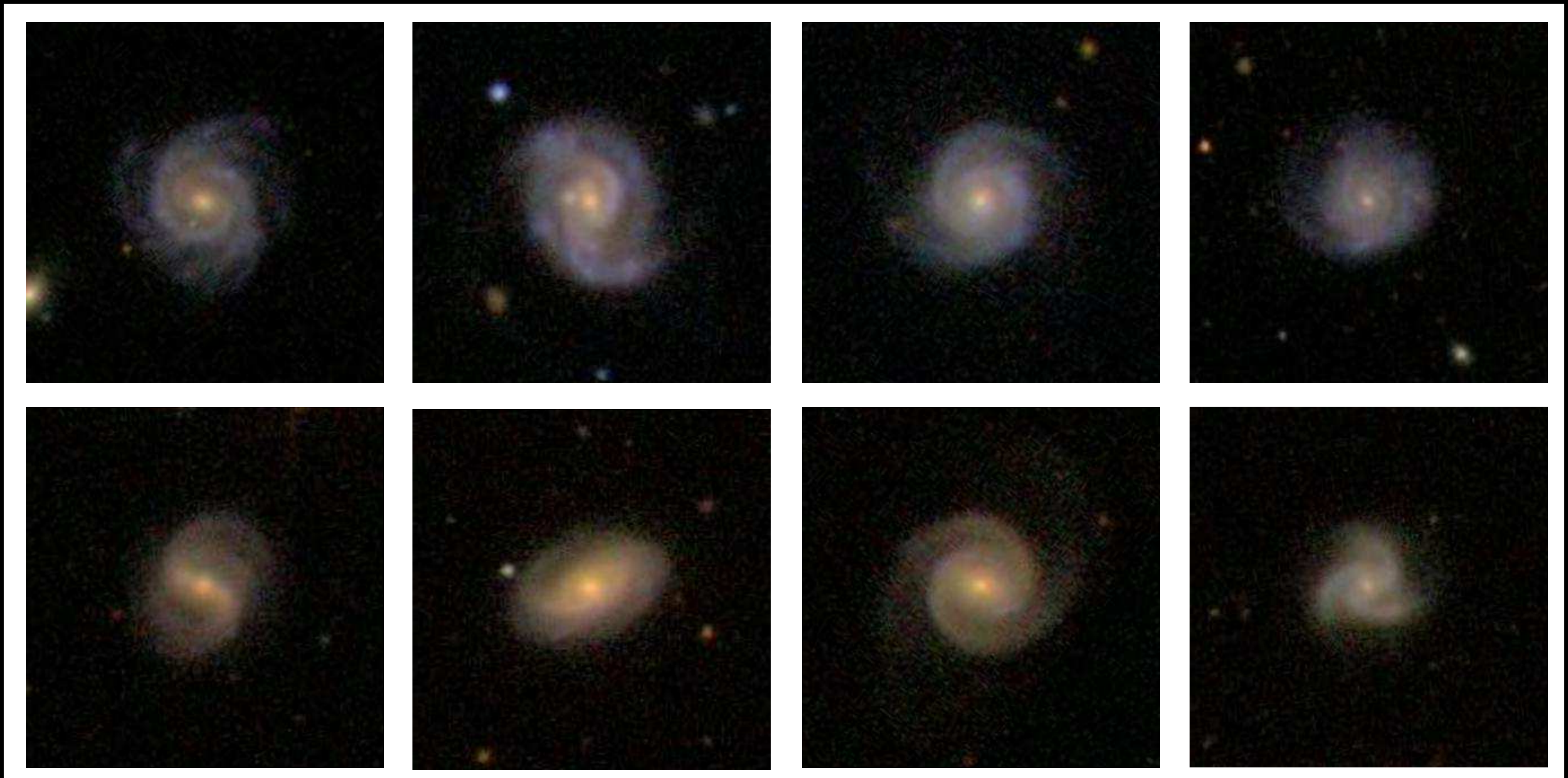
A sharp metallicity transition
(dashed line is max possible)



Next steps:

- Higher resolution of the central object to see if it is kinematically decoupled from the outer disk (Gemini Proposal just went in)
- Dynamical modeling with the extended rotation curves. Extended dark matter halo of an elliptical?

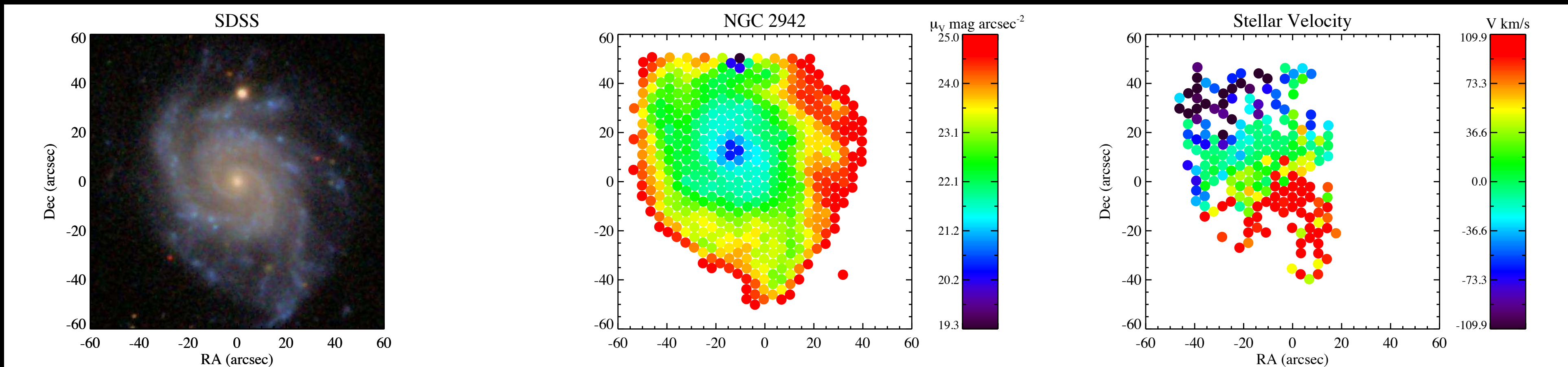
GALAXY ZOO 2



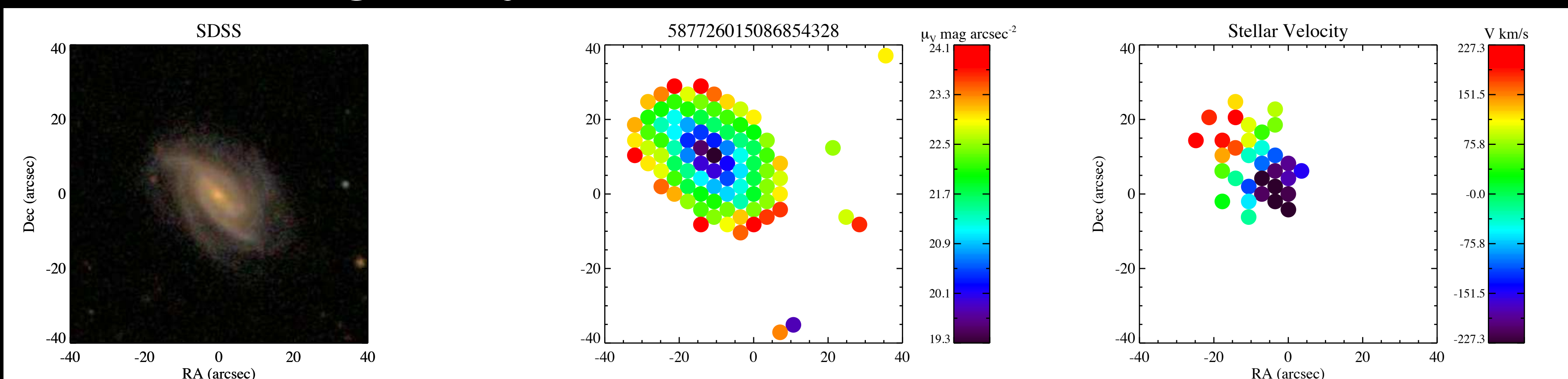
Morphological spirals that are on the Red Sequence. How does star formation shut off without a major merger?

In collaboration with Karen Masters (Portsmouth) and Galaxy Zoo

Typical blue galaxy

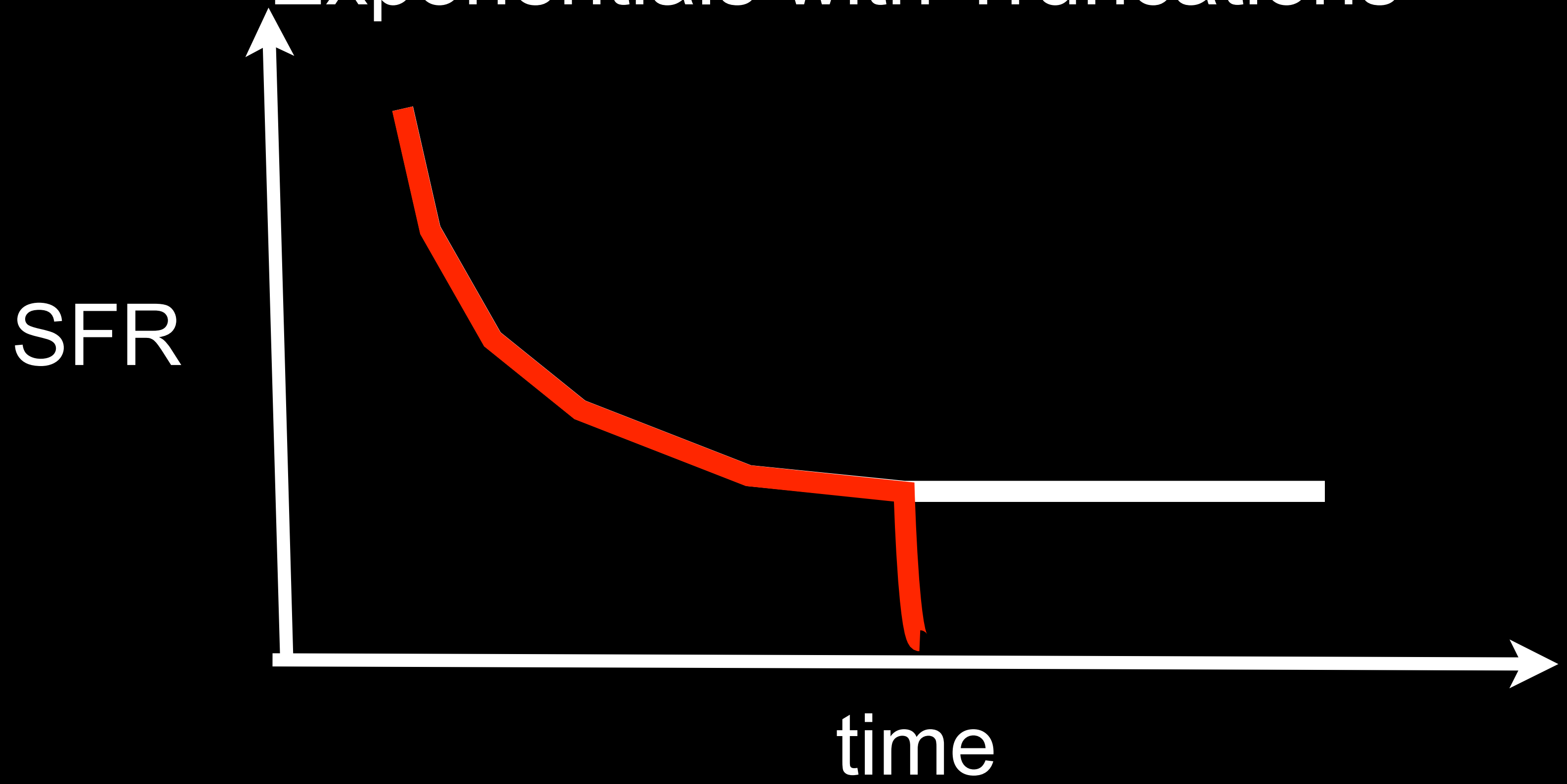


Red spiral galaxy

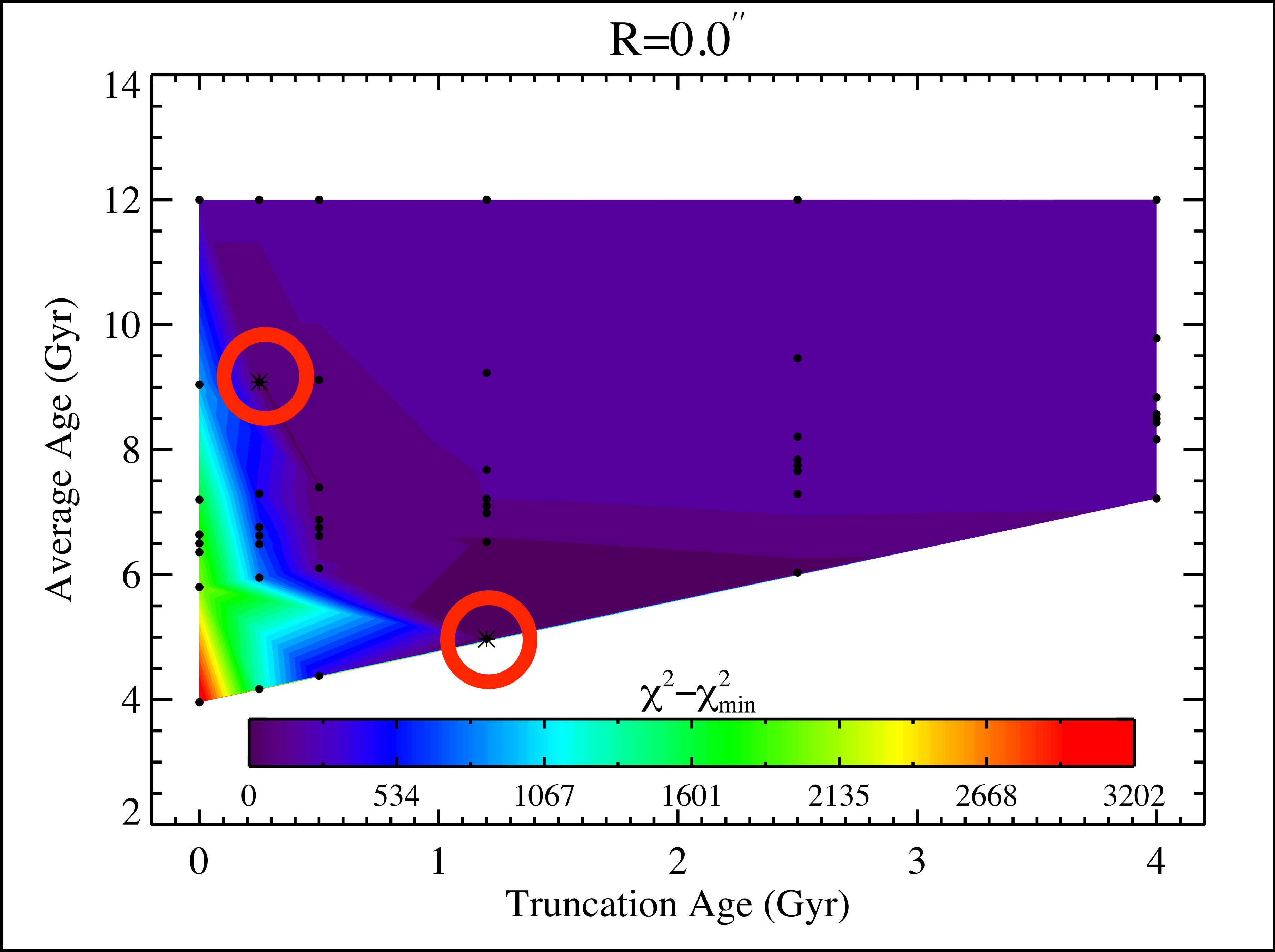


Are these objects really red and dead?
When and where did star formation end?

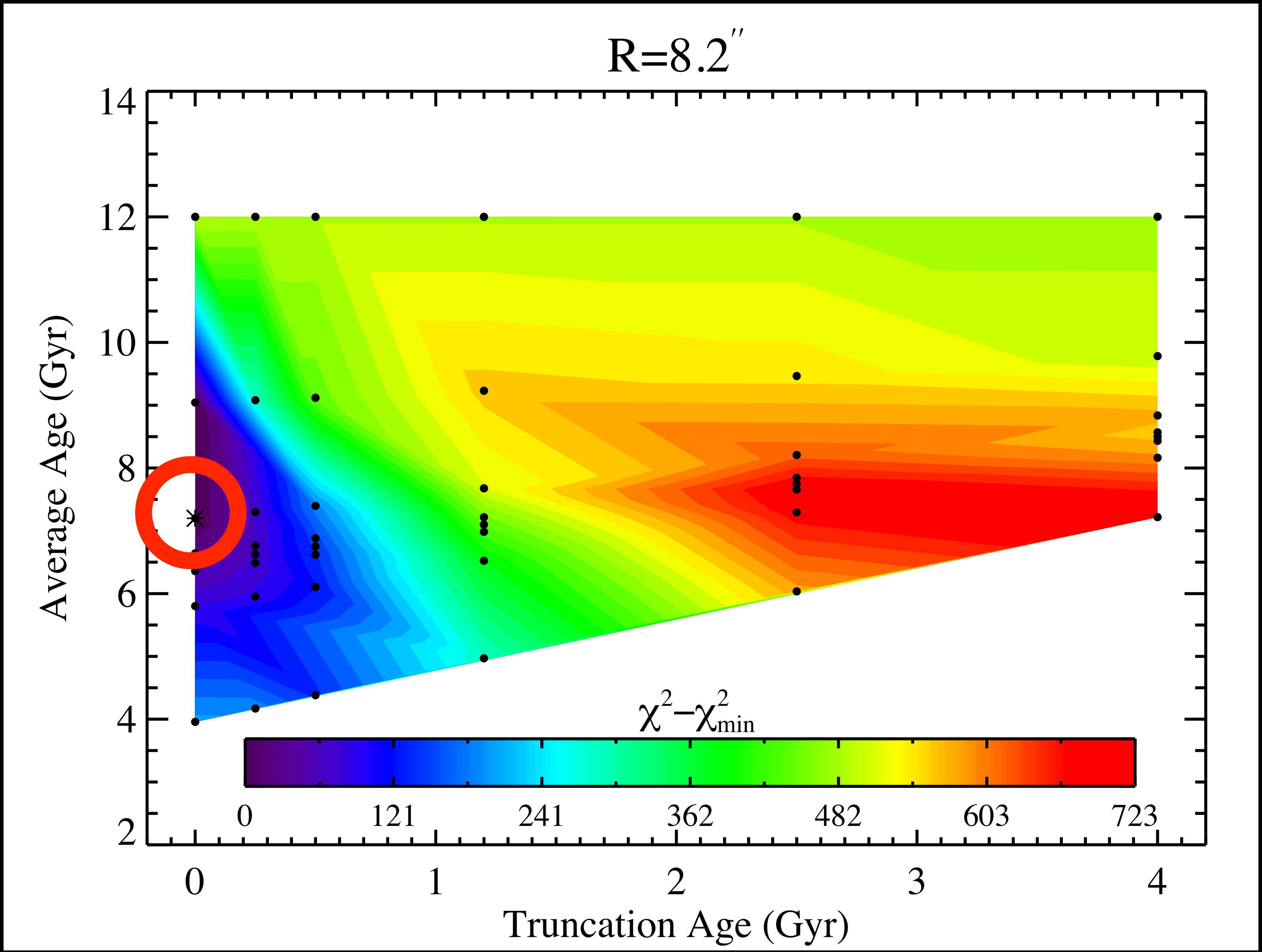
Star Formation Models
Exponentials
+
Exponentials with Truncations



8 exponential SF rates
6 truncation times
5 metallicities

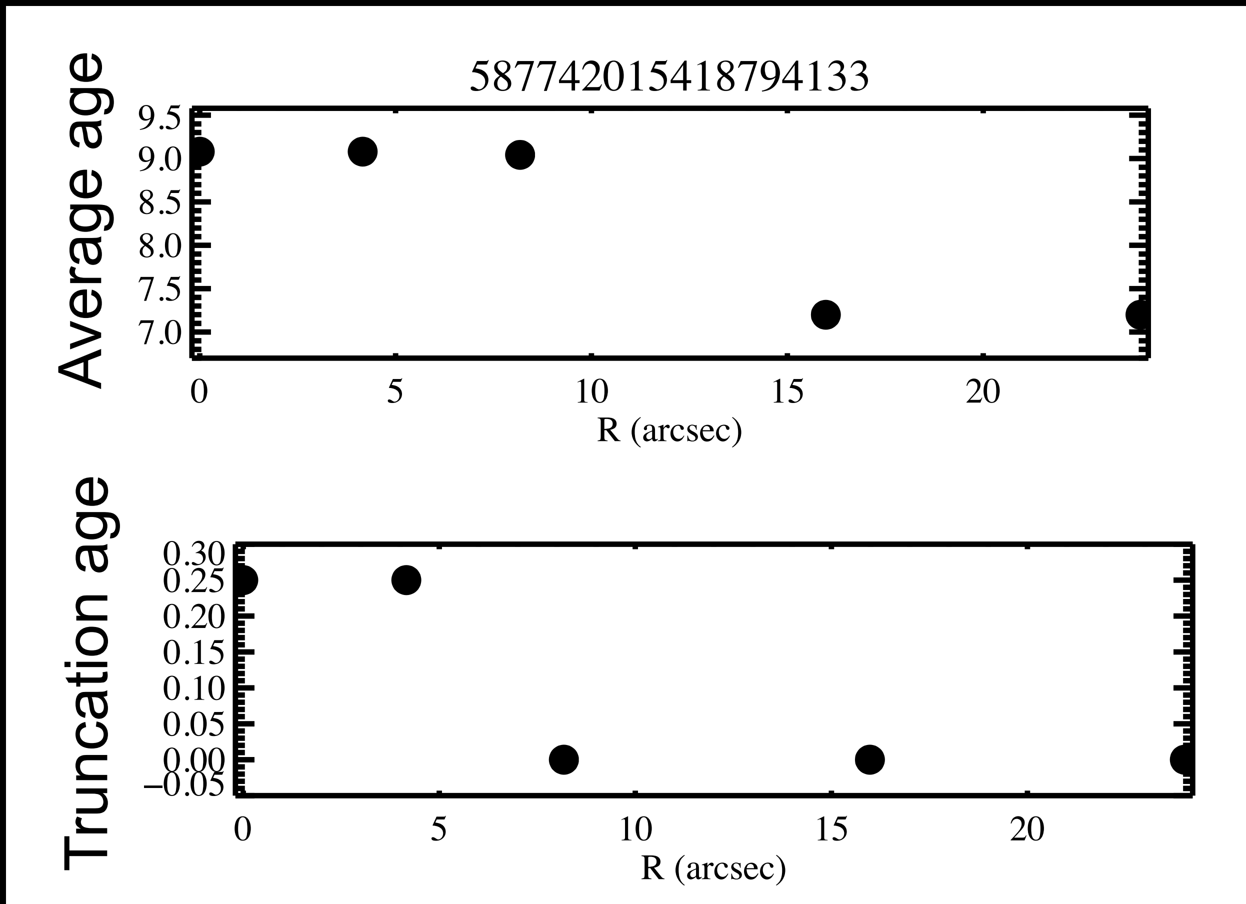


degenerate, but both minima have a truncation age



At larger radii, clear minimum with no truncation
Outer disk still forming stars

Early results on red spirals



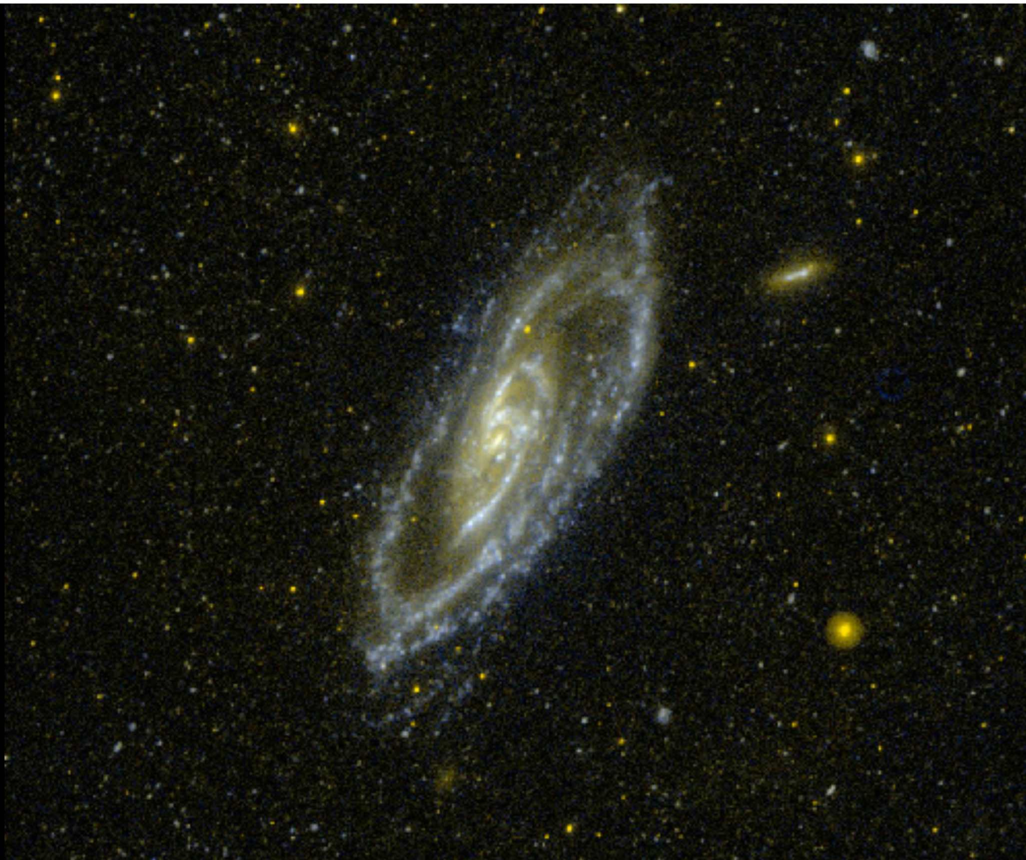
Sample of 7 red spirals

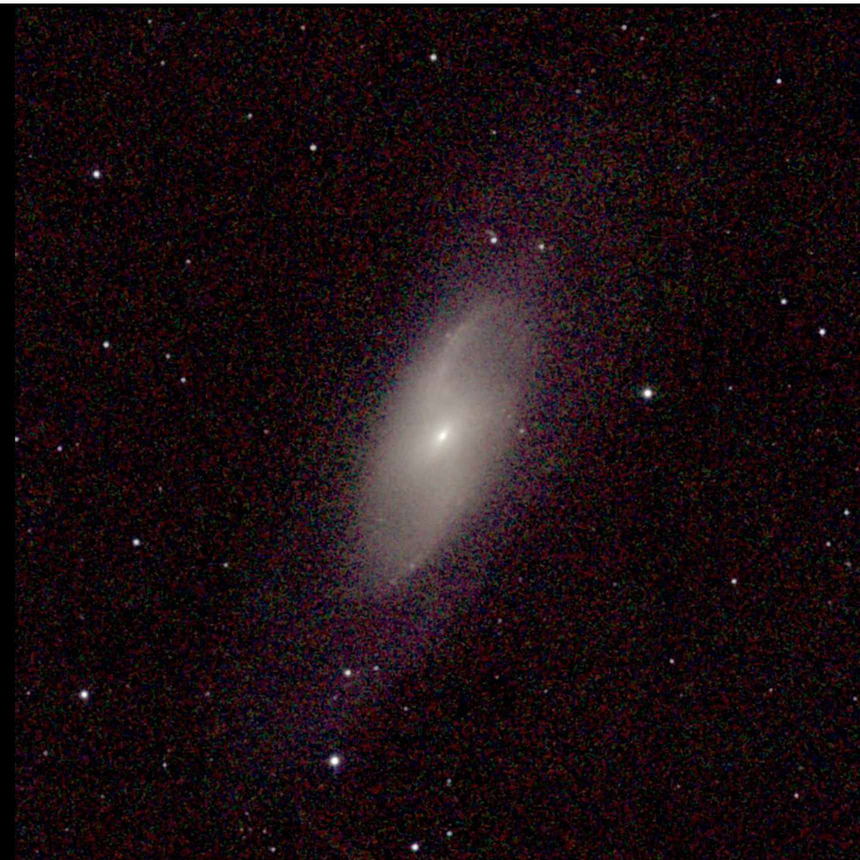
- Massive galaxies (v_{rot} > 220 km/s)
- Inside-out formation followed by inside-out quenching
- Still some star formation in the outskirts

Decomposing spectra into linear combination templates is **probably wrong**, *especially* with star-forming galaxies

Parameterizing SFH and finding best fit (what I've been doing) is **maybe slightly less wrong**

How can we move forward to **almost right**?



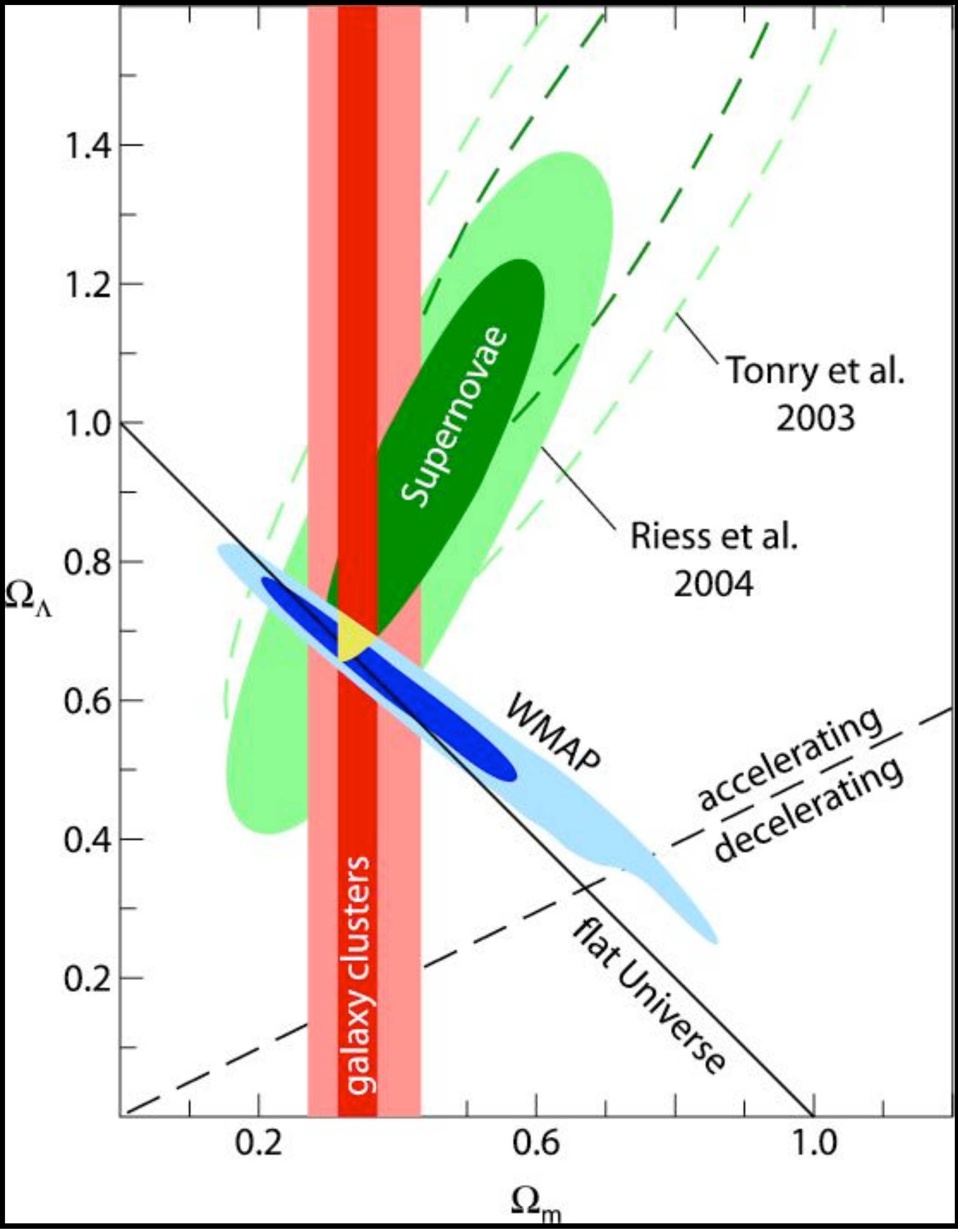


Let's fit the spectra and the photometry simultaneously!

UV --> current star formation

IR --> total stellar mass

Optical Spectra --> extinction, metallicity



We can deal with the non-Gaussian residuals by going Bayesian

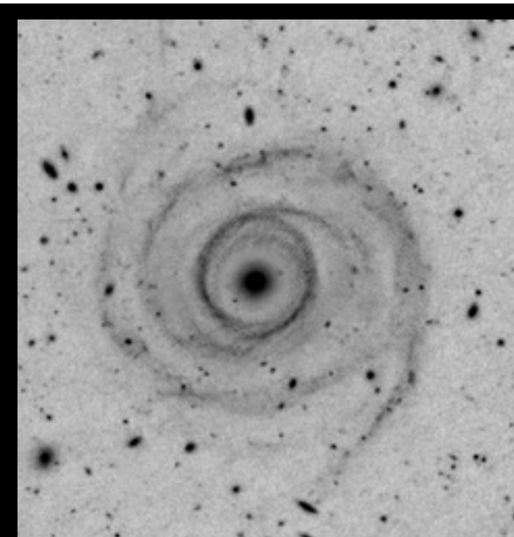
$$p(spectra|\tau) = \exp(-\chi^2/2)$$

blah blah, priors, blah blah, PDF, marginalize, blah

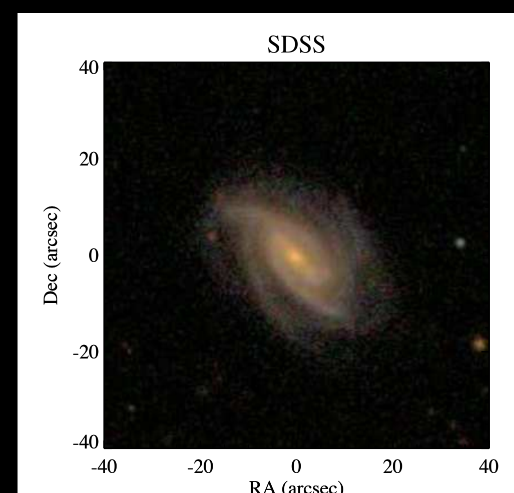
poster by Jason Young on combining spectra and photometry

There are a lot of different exponential disks out there!

- Evidence for extended exponential disks built through radial migration
- Very massive disks are quenching from the inside-out
- GLSB disks were probably formed through a minor-merger



- We need to do a better job combining IFU spectra with photometry for fitting SFH's. I advocate using parametric SFH models
  - Don't forget to think about how LSST should be scheduled
    - Everyone feel free to nag me to finally get all of this stuff published



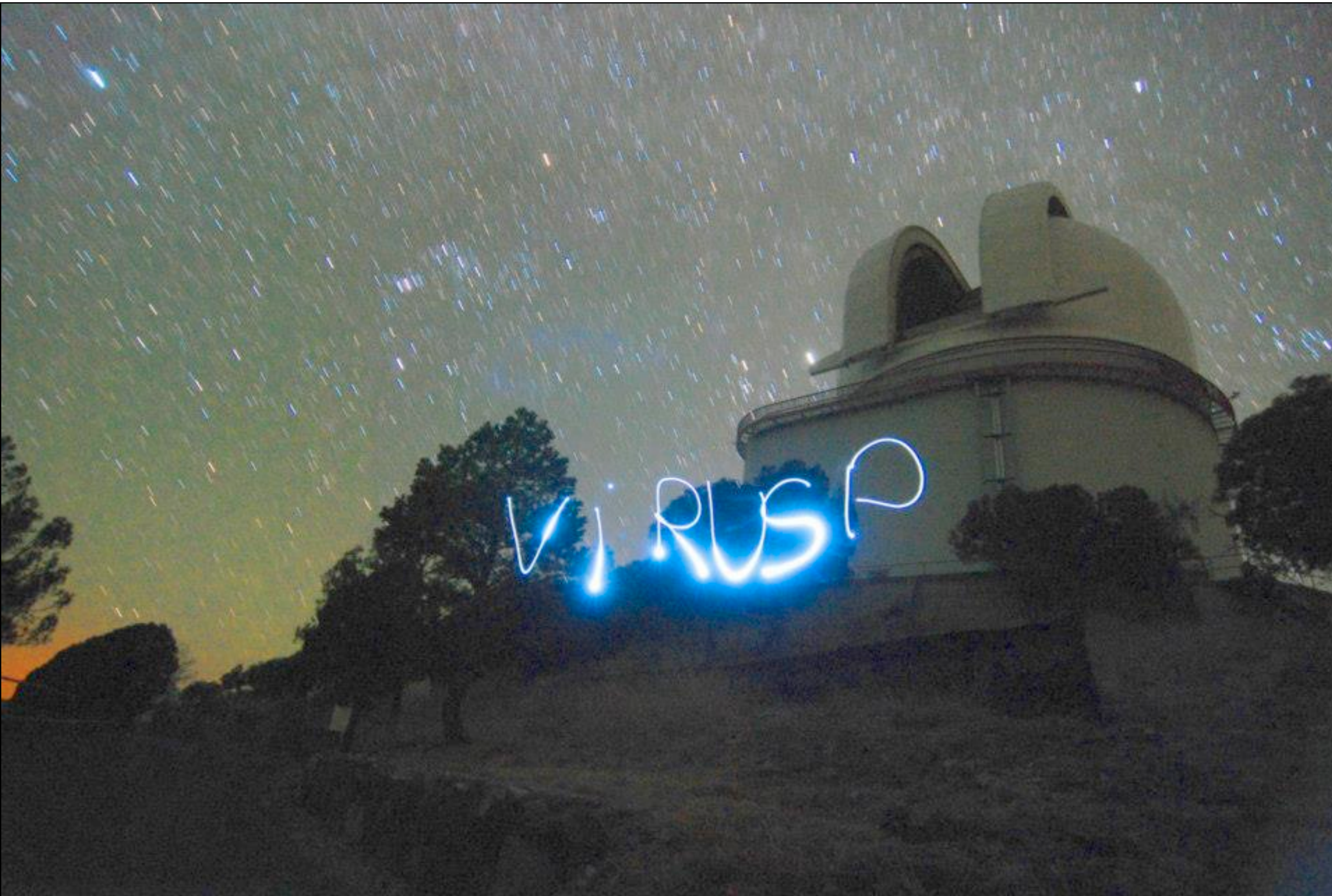


Photo credit David Radburn-Smith