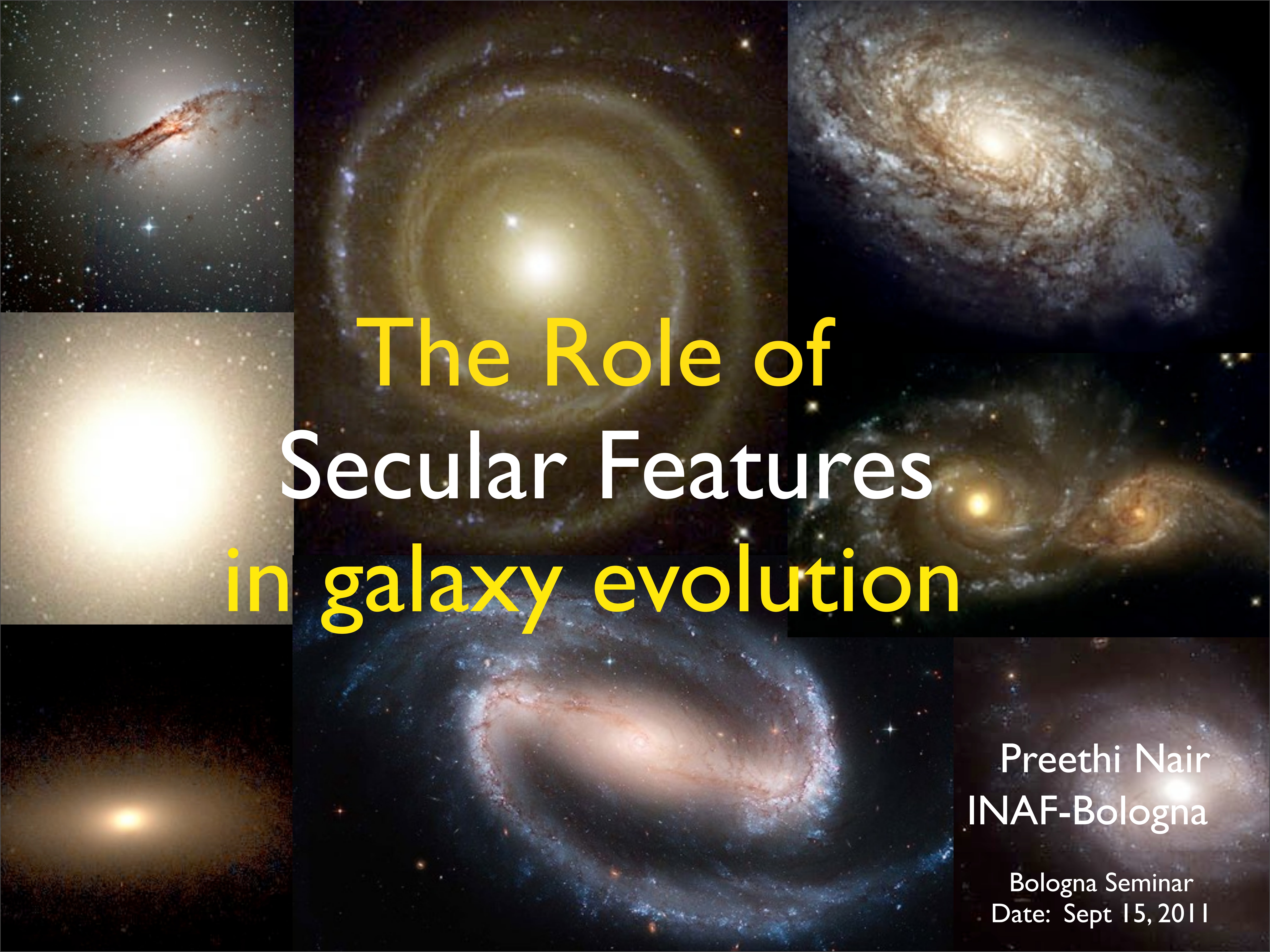


The Role of Secular Features in galaxy evolution

Preethi Nair
INAF-Bologna

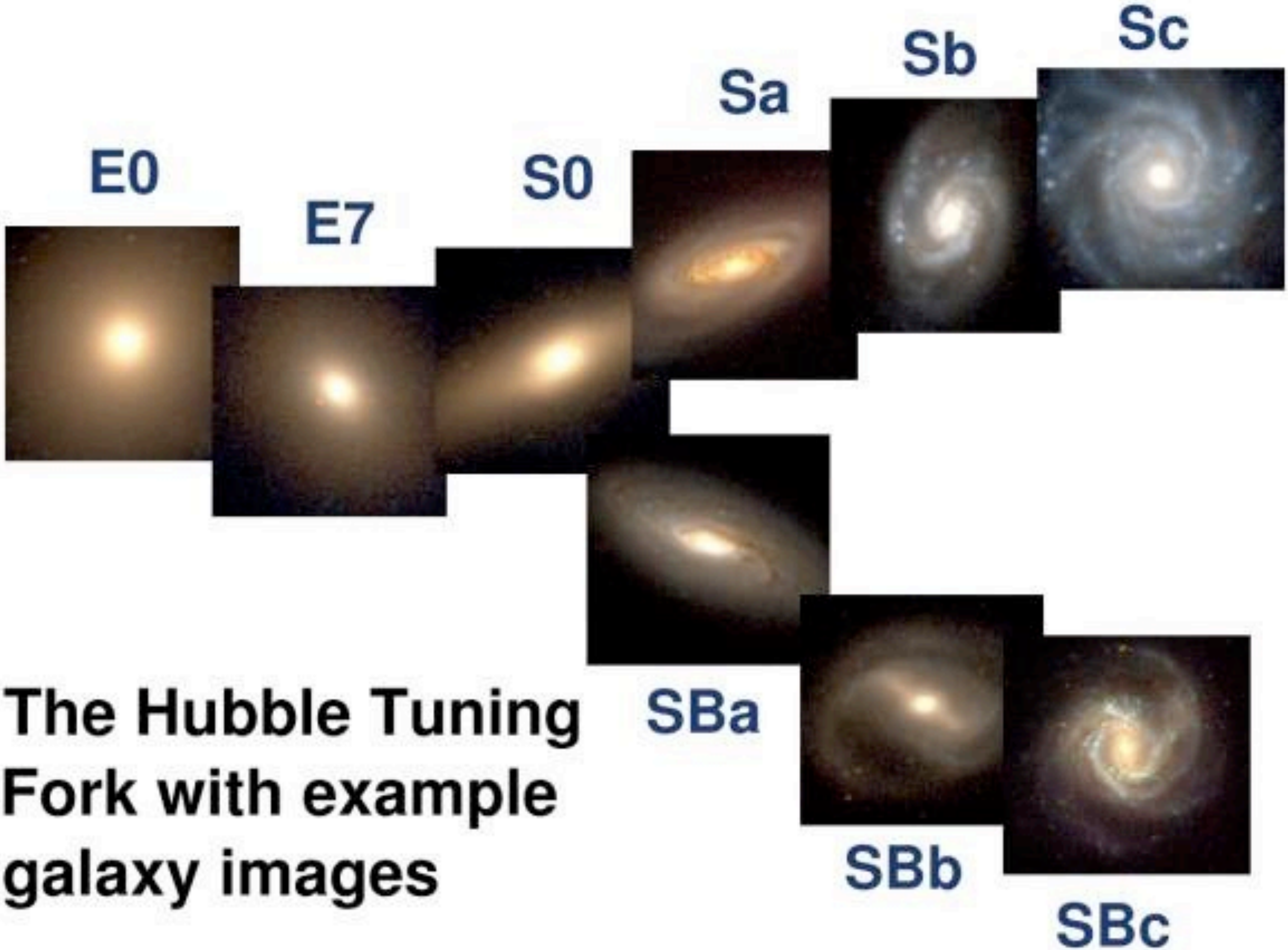
Bologna Seminar
Date: Sept 15, 2011

Collaborators

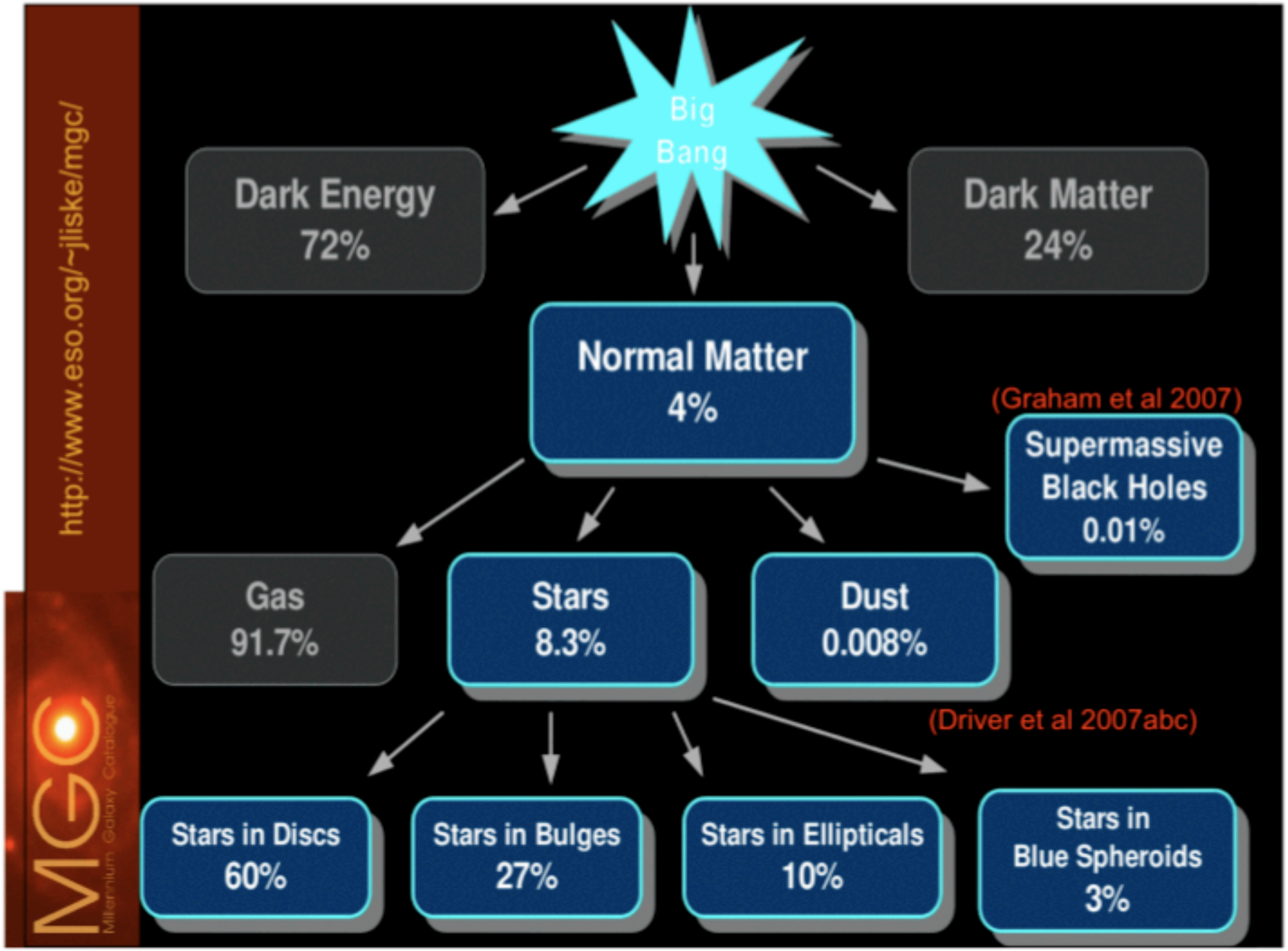
- zCOSMOS team, specifically:
  - Micol Bolzonella, G. Zamorani, E. Zucca, L. Pozzetti, Sandro Bardelli, C. Maier, C. Knobel, S. Lilly, L. Tasca, et al.
- COSMOS team:
  - Kartik Sheth, Ewan Cameron, M. Carollo
- For SDSS
  - Bob Abraham, Sidney van den Bergh
  - Sara Ellison, Dave Patton, Luc Simard

Bars build bulges and drive galaxy evolution at z<1

- Background
  - Bars are important!
  - Internal/External Merger/Secular processes
  - Observable signatures
- Results from low redshift
- Results from high redshift
- Conclusions



The Hubble Tuning Fork with example galaxy images

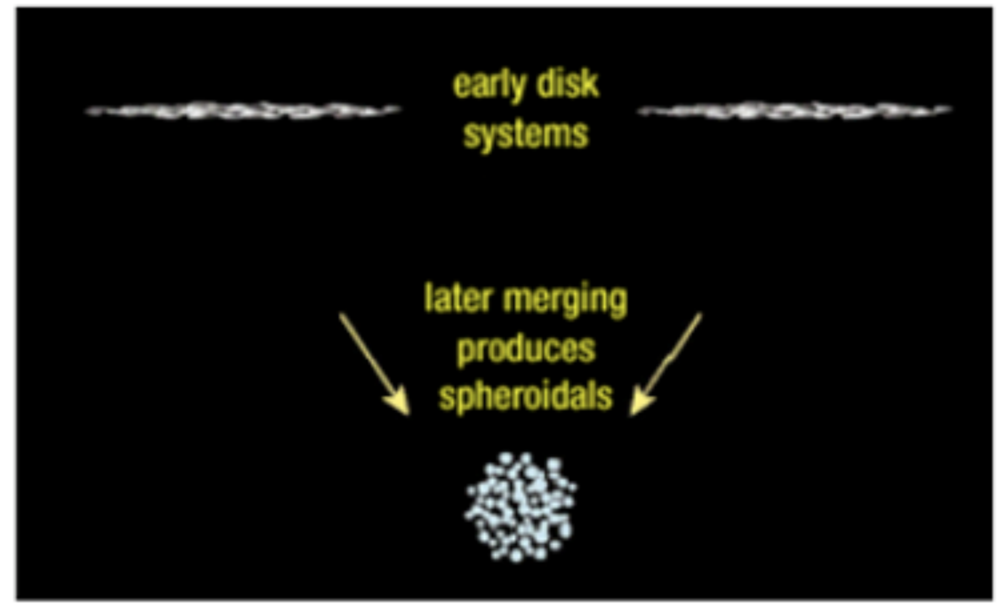

http://www.eso.org/~jliske/mgc/
MGC
Millennium Galaxy Catalogue
Big Bang
Dark Energy 72%
Dark Matter 24%
Normal Matter 4%
(Graham et al 2007)
Supermassive Black Holes 0.01%
Gas 91.7%
Stars 8.3%
Dust 0.008%
(Driver et al 2007abc)
Stars in Discs 60%
Stars in Bulges 27%
Stars in Ellipticals 10%
Stars in Blue Spheroids 3%

Two modes to assemble and redistribute mass

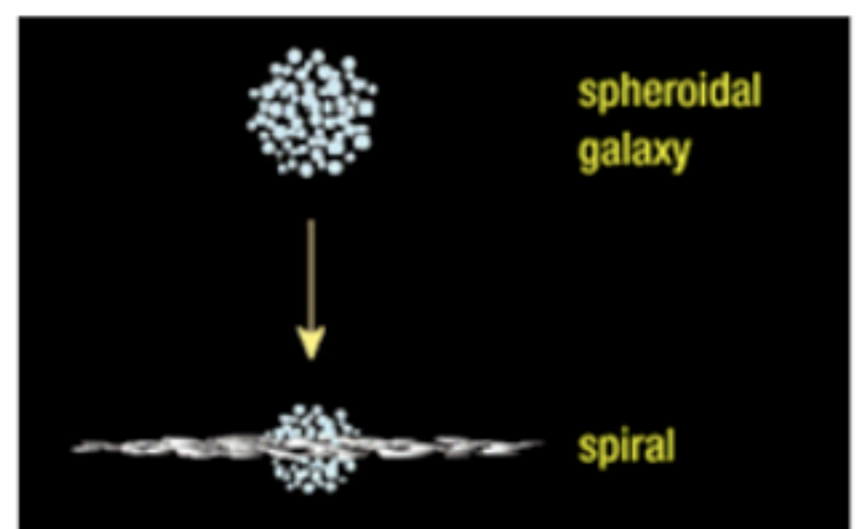
➔according to epochs and environment

Cosmological or Hierarchical scenario

Spheroids form through major spiral mergers

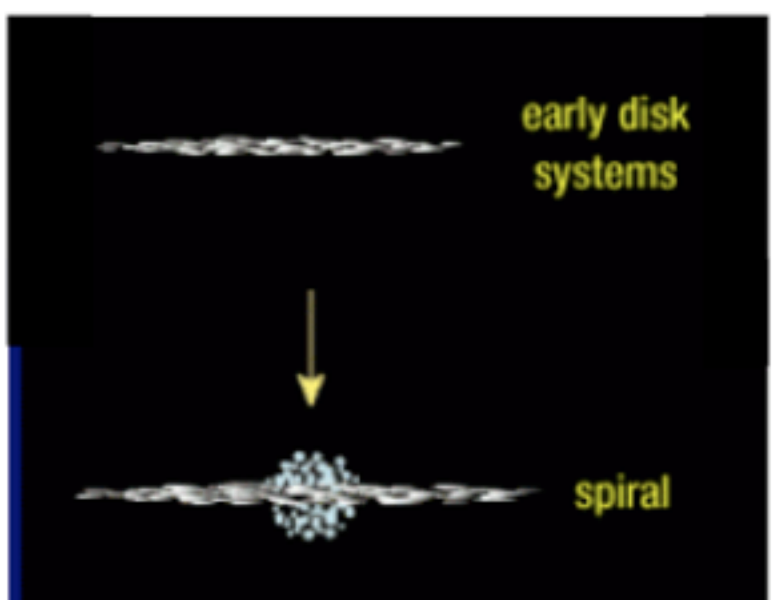


Gas accretion can then reform disks



Secular evolution

Internal slow evolution



Cosmological vs. Secular Evolution

Triggers of Radial Gas Inflows.

Cosmological vs. Secular Evolution

- Mergers

Triggers of Radial Gas Inflows.

Cosmological vs. Secular Evolution

- Mergers
- Close pair interactions

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- Barred Galaxies

Triggers of Radial Gas Inflows.

Cosmological vs. Secular Evolution

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- Oval distortions (lenses, rings)

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Triggers of Radial Gas Inflows.

Cosmological vs. Secular Evolution

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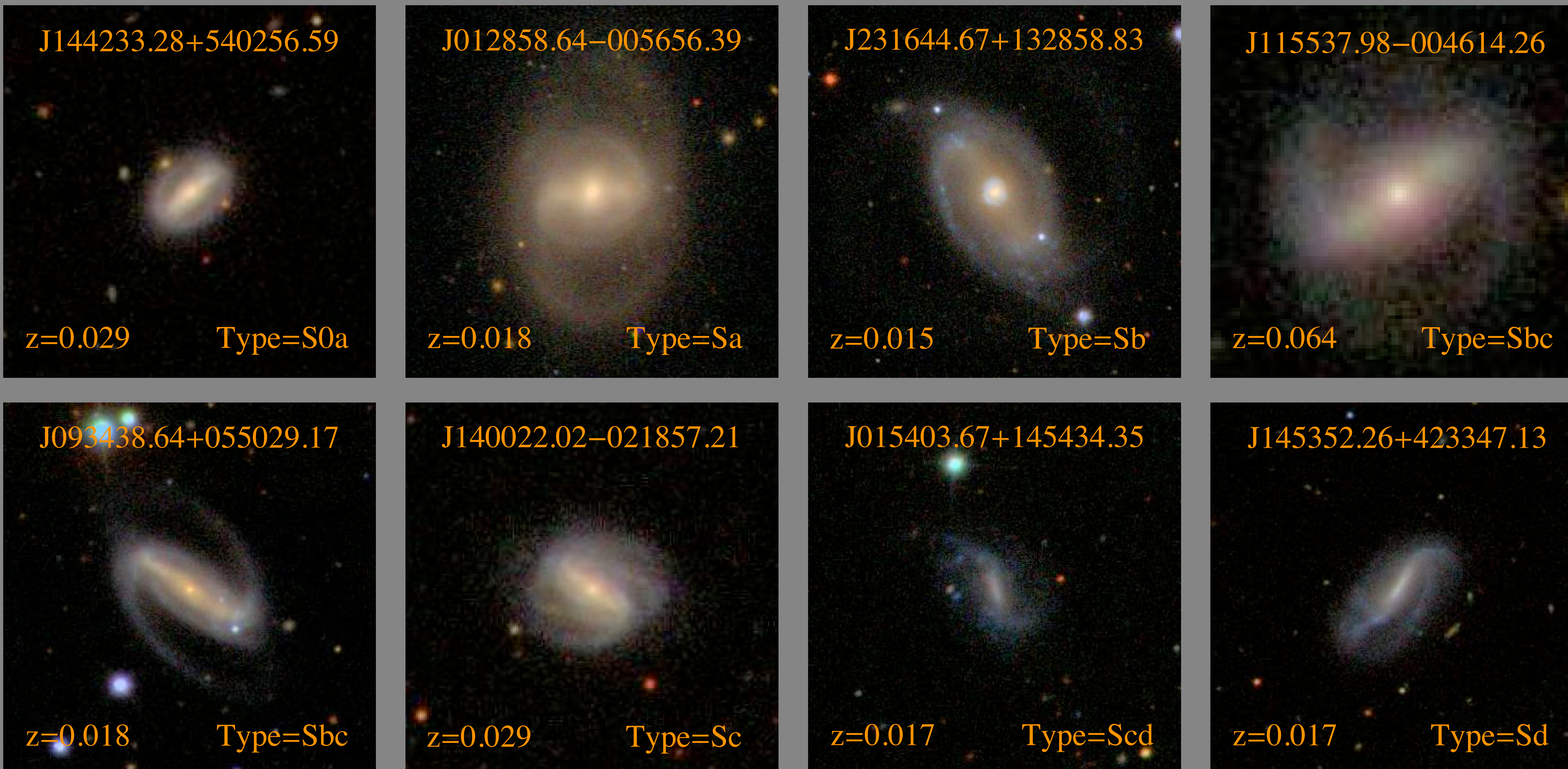
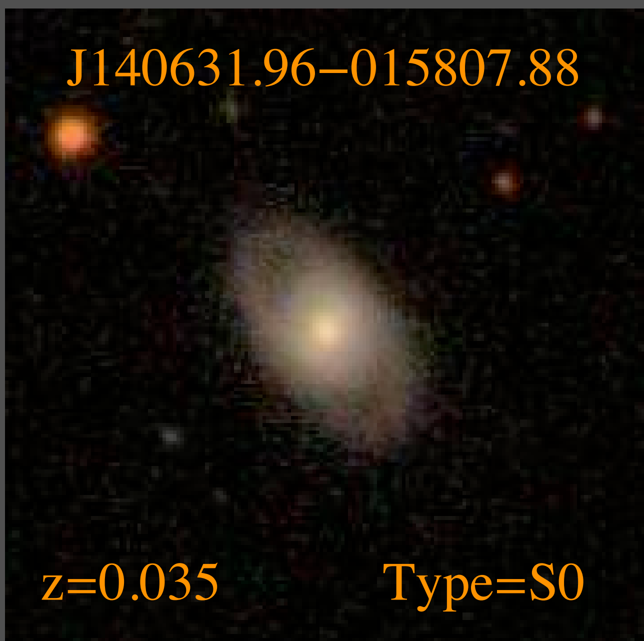
- Barred Galaxies
- Oval distortions (lenses, rings)
- Spiral arms/non-axisymmetric dist.
- Gas Infall

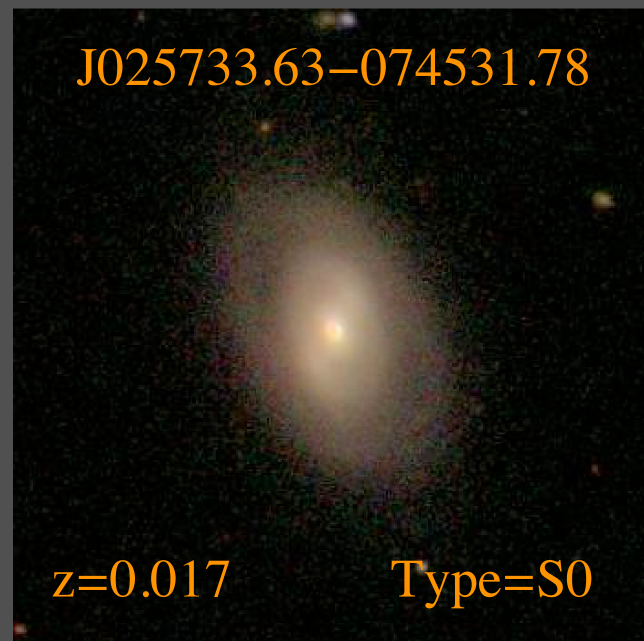
Triggers of Radial Gas Inflows.

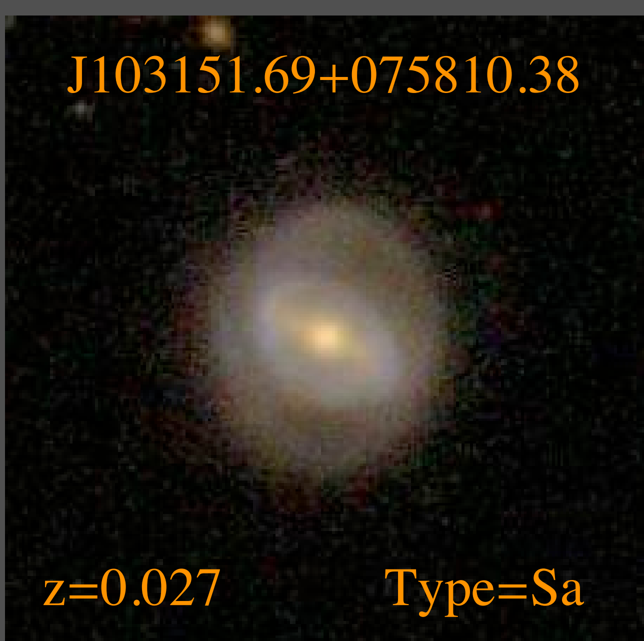
Secular Structures

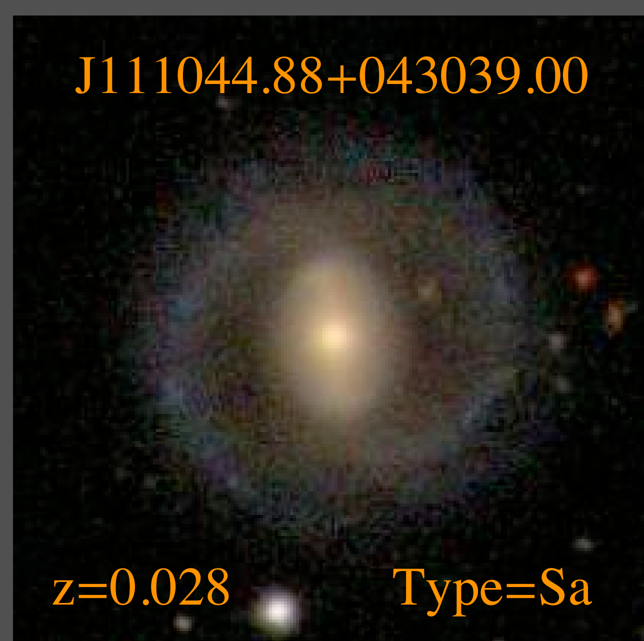


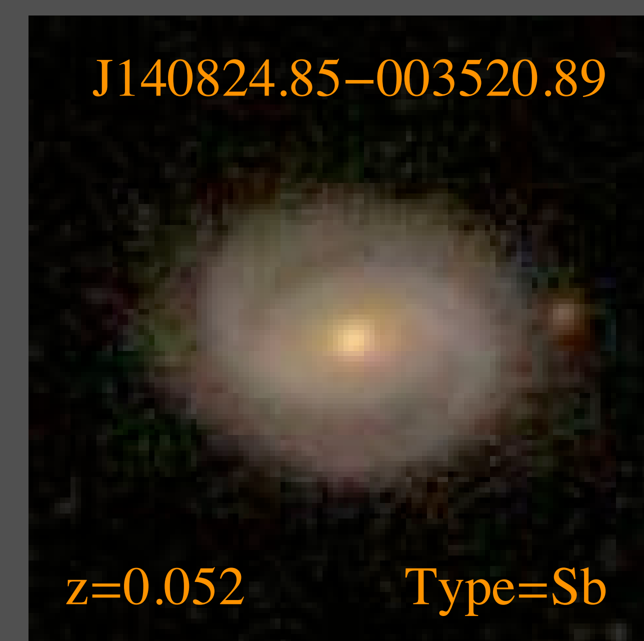
Secular Structures











2 main mechanisms for gas inflow to build bulge.

Galaxy-galaxy mergers
(e.g. the mice)

Galaxy bars
(e.g. NGC 1300)

Theory vs. Observations for pairs

Theory vs. Observations for pairs

- Close pair interactions should show enhanced star formation rates.

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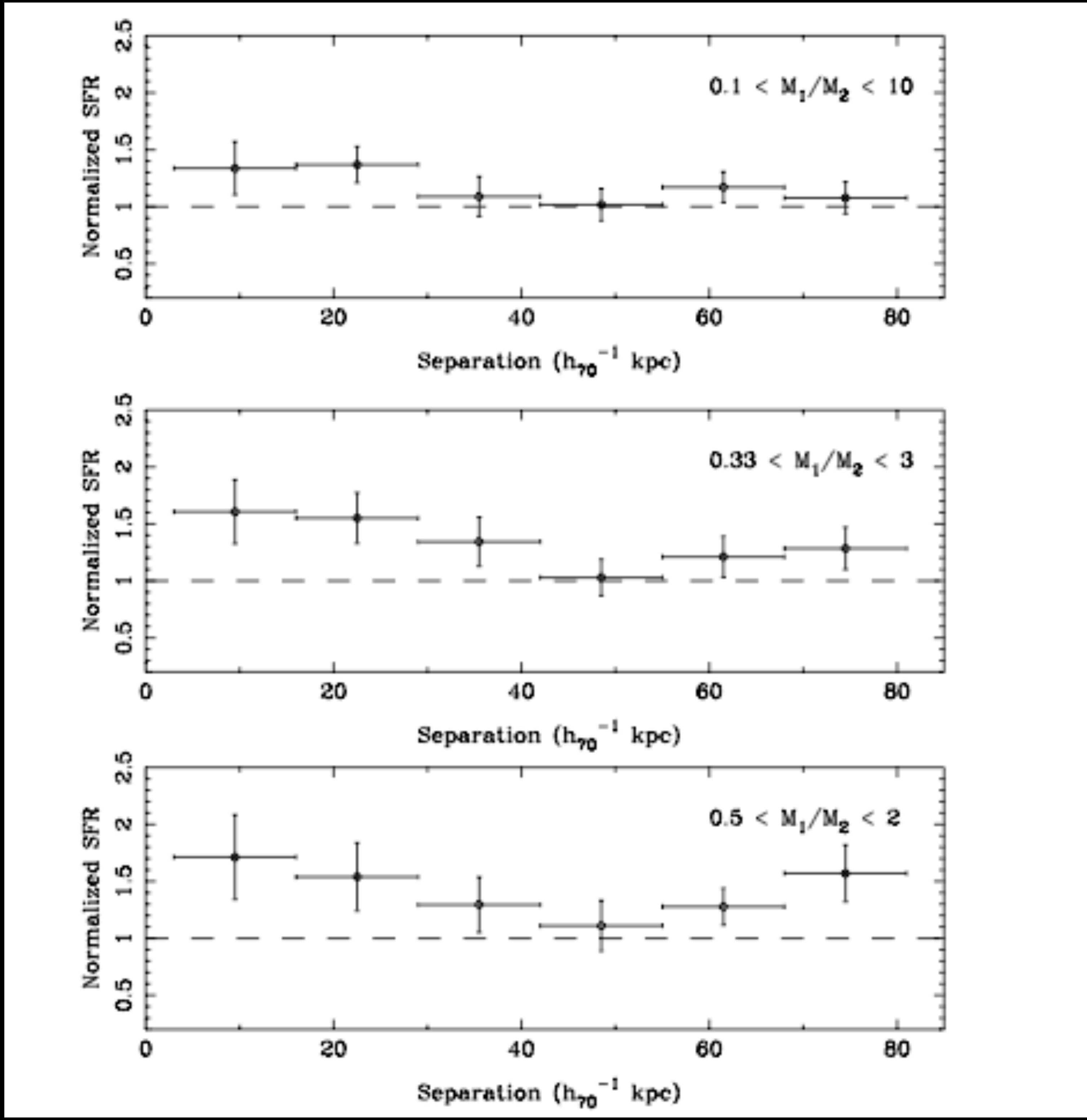
Star formation rates in ~2000 SDSS galaxy pairs



Enhancement depends on mass ratio: Ellison et al. (2008)

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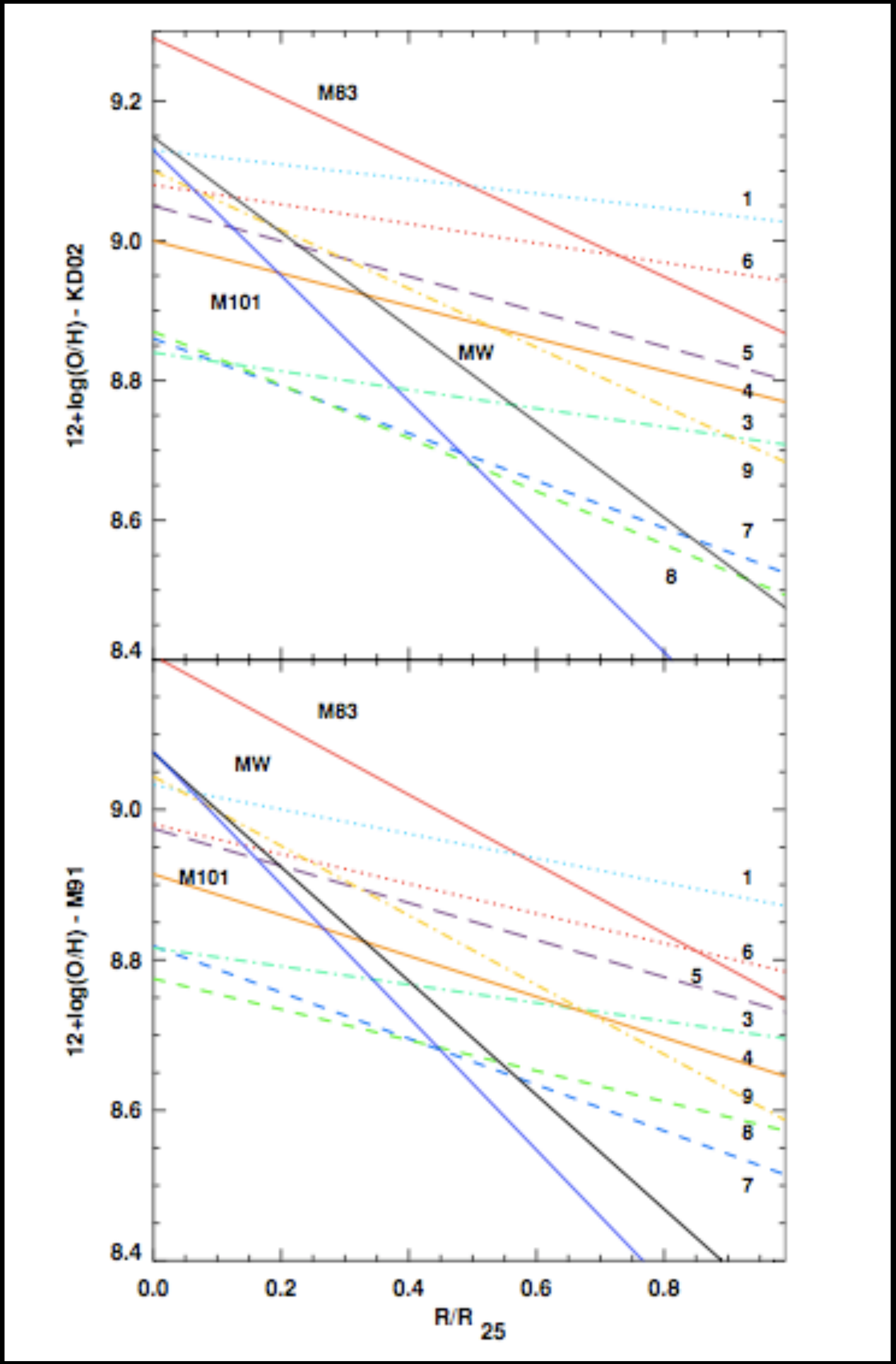
Metallicity gradients in pairs



Kewley et al. 2010

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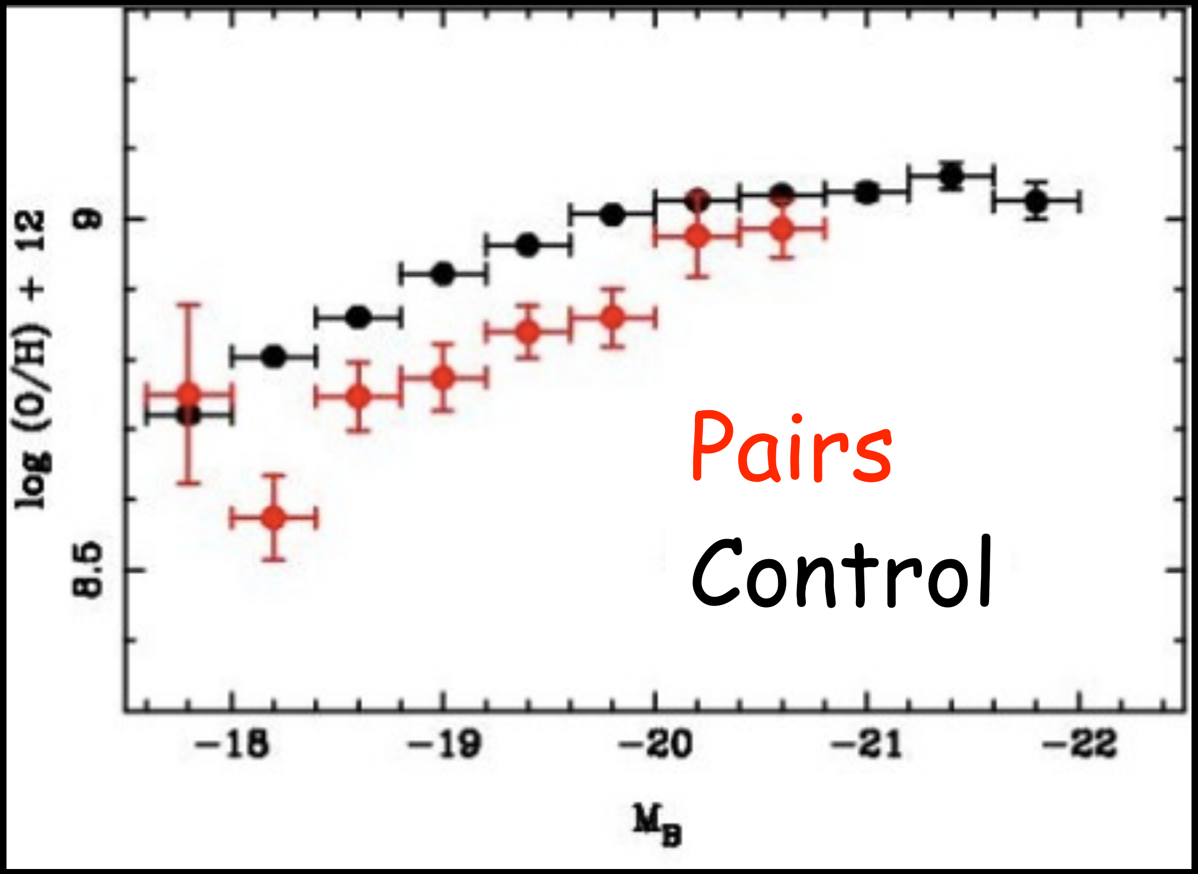
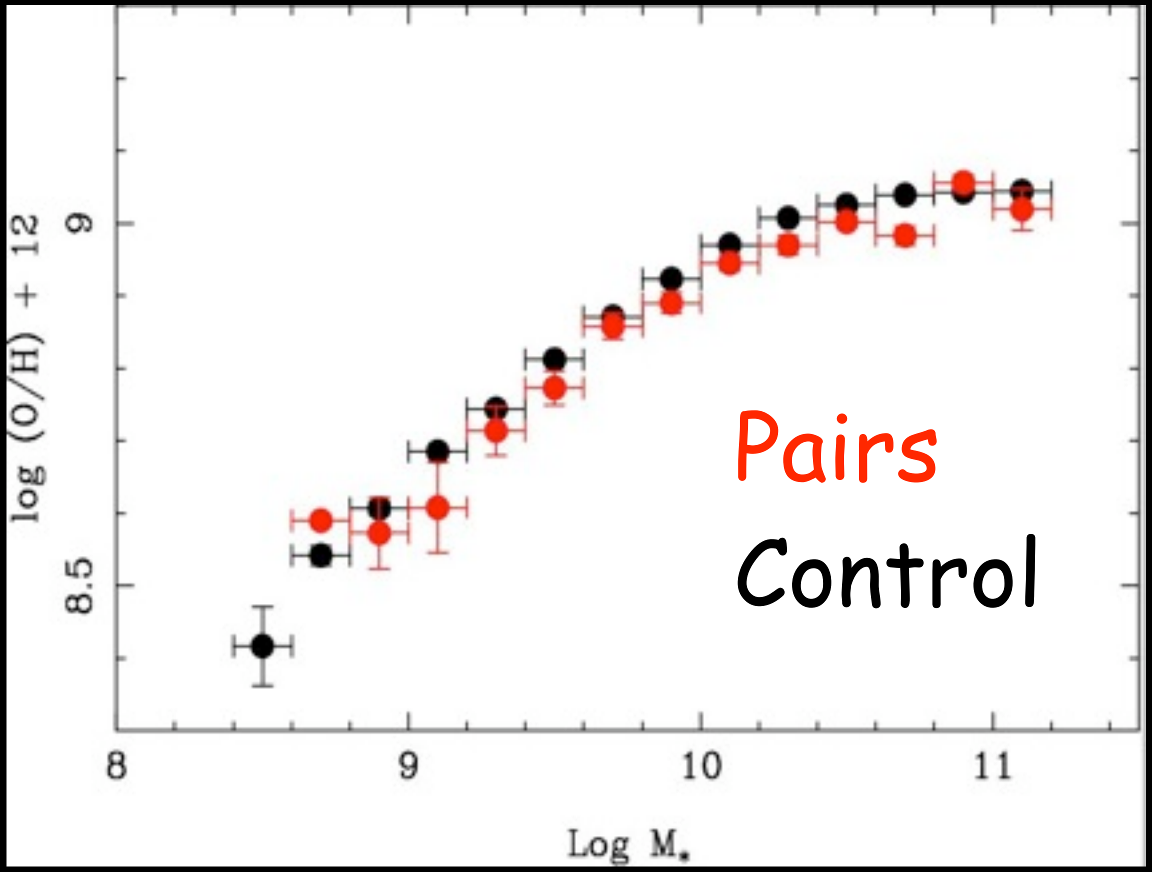
- Central metallicities are lower in close pair galaxies - (0.05 dex to 0.1 dex decrement).

Metallicities in galaxy pairs





Luminosity-metallicity relation is lower by 0.1 dex in pairs relative to the control.

Mass-metallicity relation is lower by 0.03 dex in pairs relative to the control.

About half of the offset in the LZR is due to changes in luminosity (due to triggered star formation). Ellison et al. 2008

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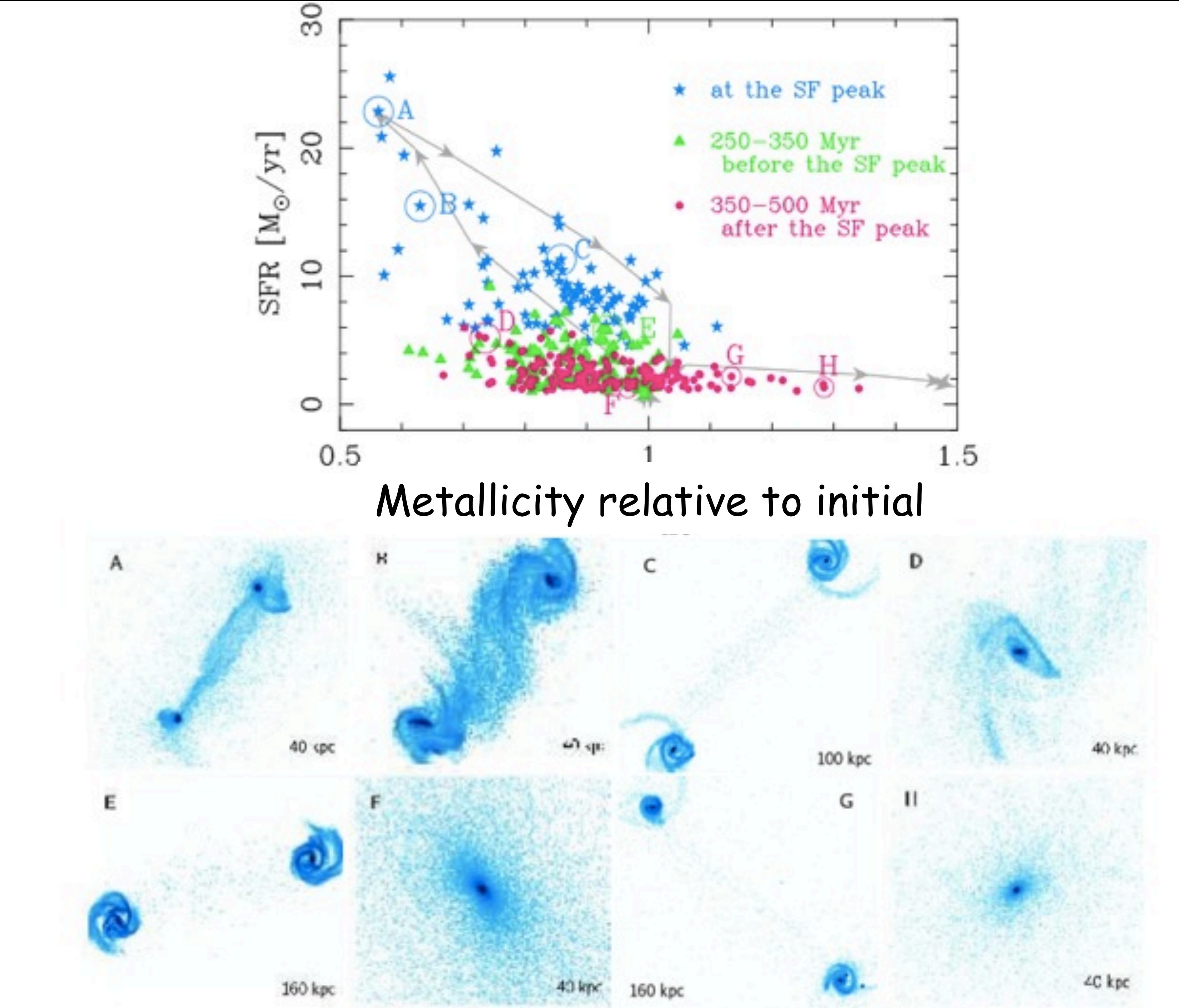
- AGN triggers? Bar triggers?

Signature of Gas Inflows



Montuori et al (2010)

Metal-poor gas flows to galaxy centre and triggers star formation.
Star formation is preceded by dilution of metallicity in galaxy centre before eventual enrichment.

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Theory vs. Observations for bars

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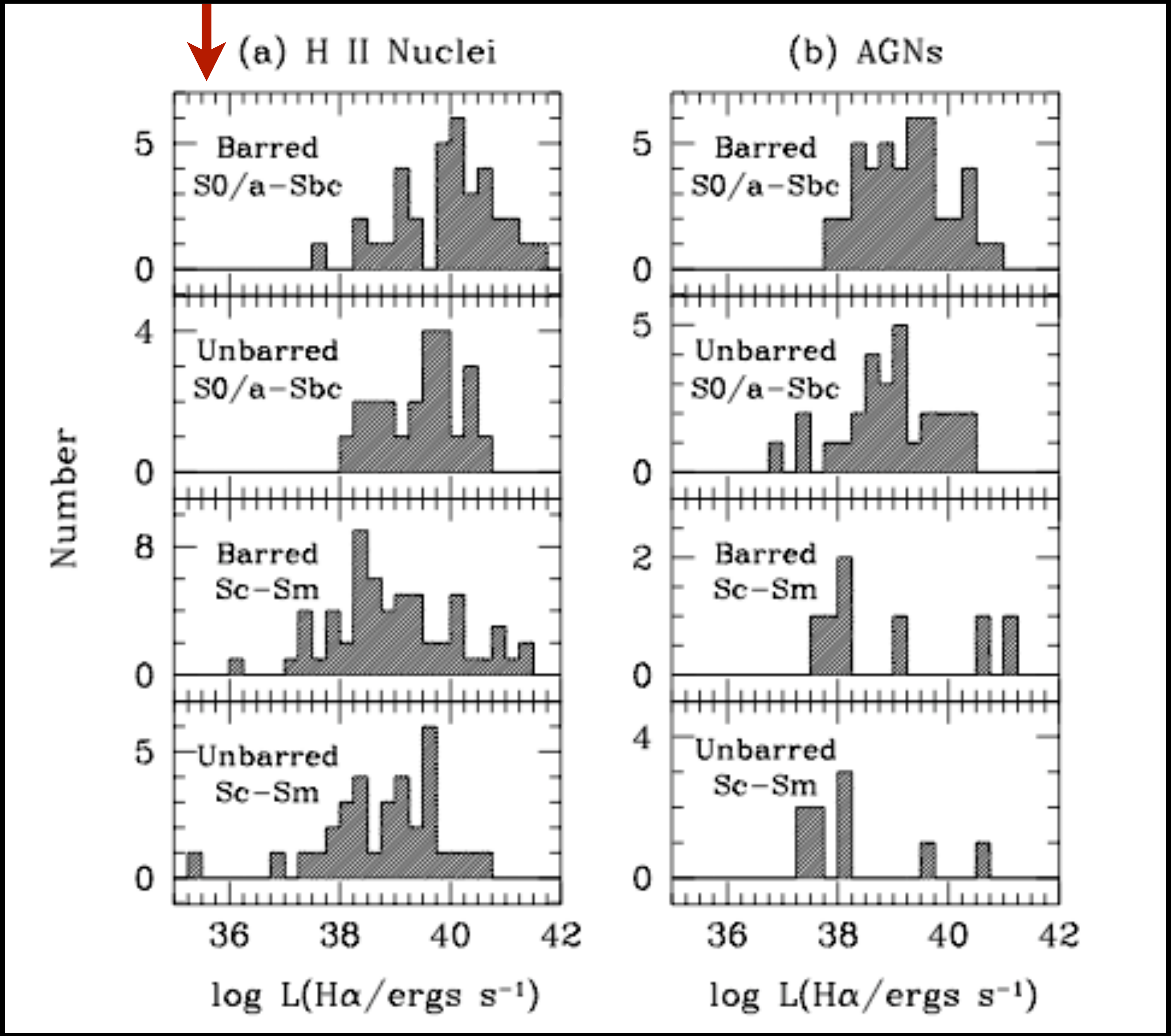
  - depends on length of bars?
  - Hubble type

Distribution of SFR for barred vs. unbarred



Ho et a. 1997

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- Metallicity gradients of barred galaxies predicted to be shallower than normal star forming galaxies.

Metallicity gradients

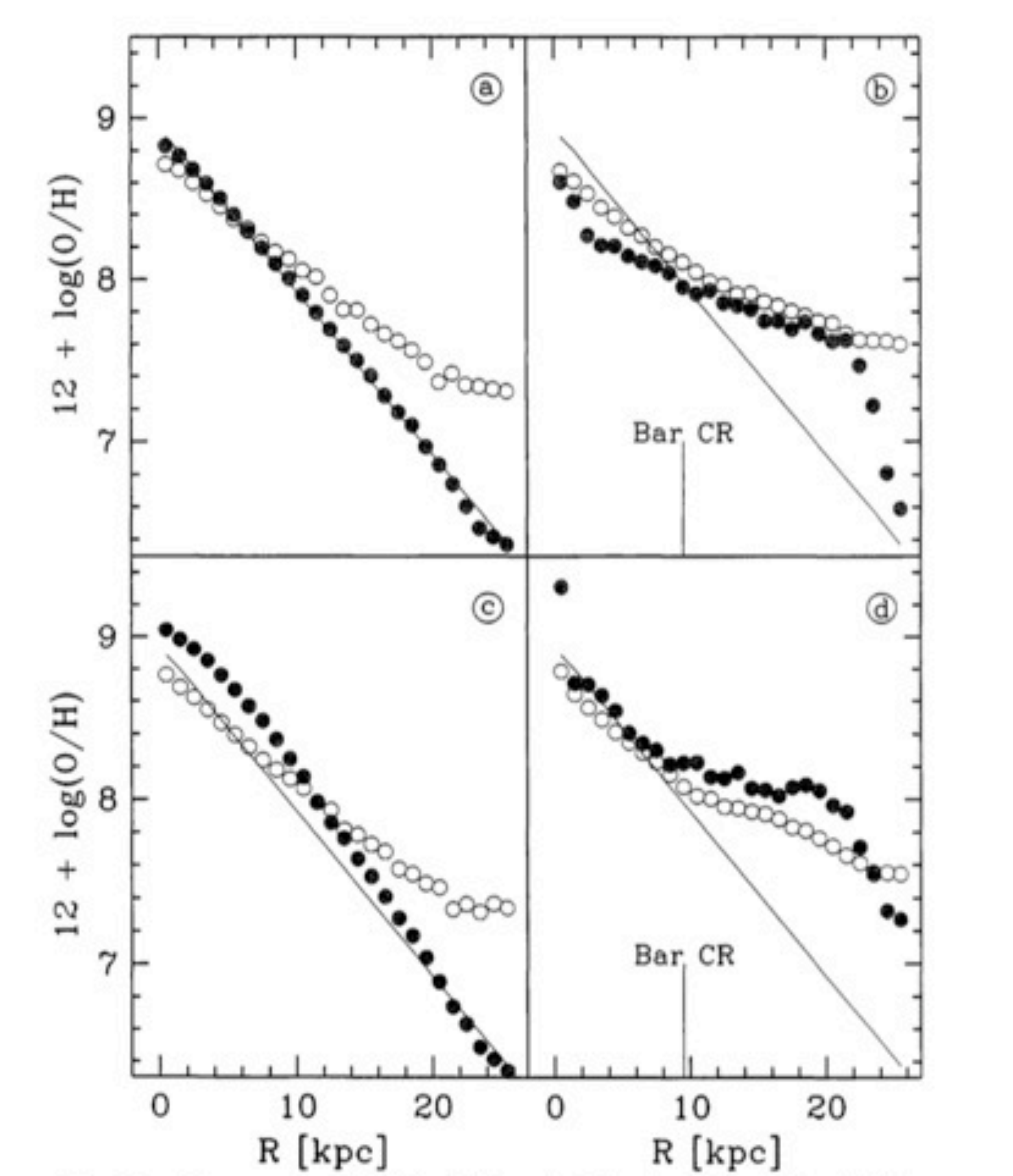


FIG. 1.—Mean gaseous (*solid cirles*) and stellar (*open circles*) radial abundance gradients after 1 Gyr. The solid line indicates the initial gradient. The CR of the bar is also indicated. (*a*) Model A_{no}. (*b*) Model B_{no}. (*c*) Model A_{sf}. (*d*) Model B_{sf}.

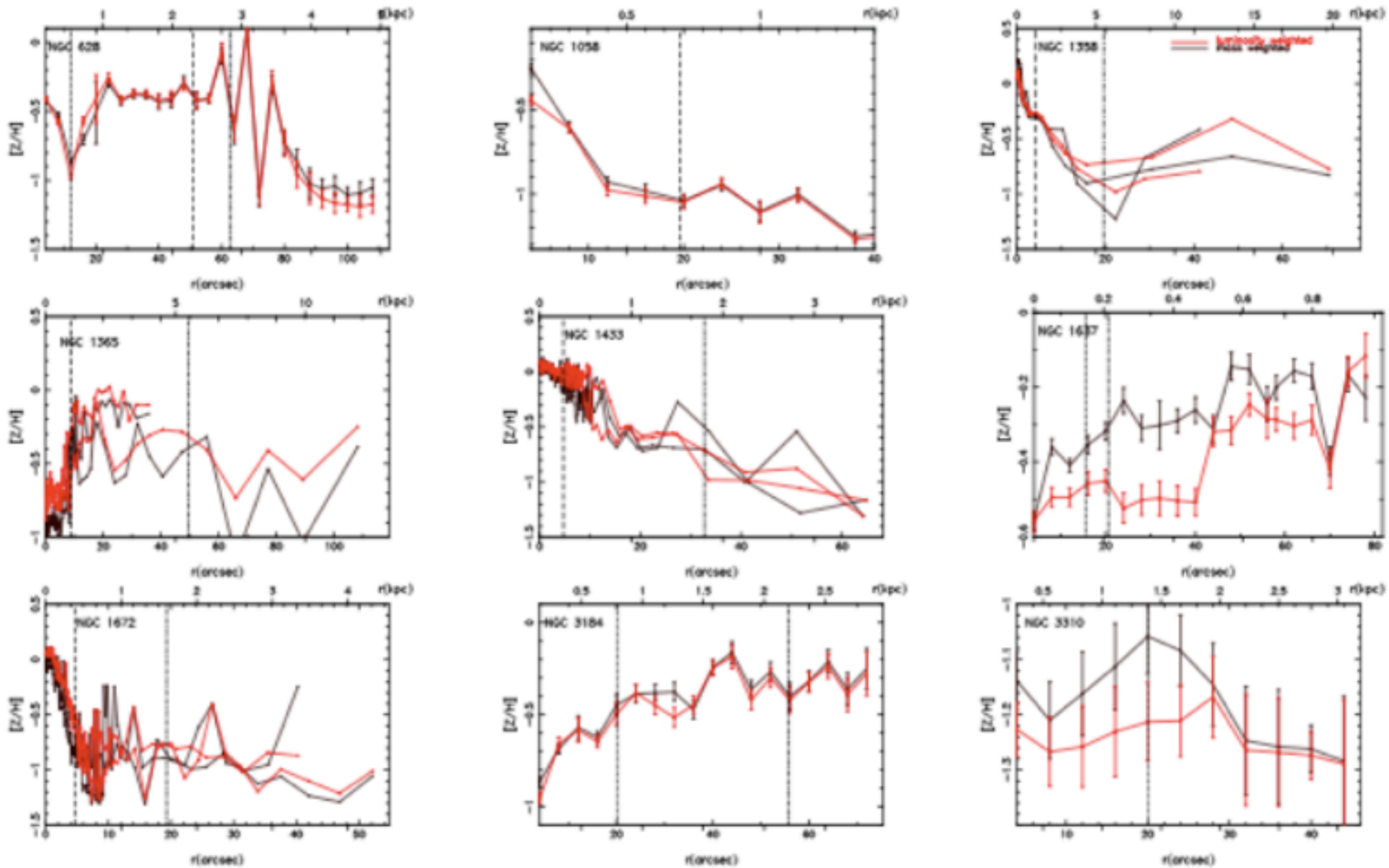
- Barred galaxies show a shallower gradient than un-barred galaxies.
- Central metallicities peak in star-forming barred galaxies.

Freidli et al. 1994

Metallicity gradients

[Z/H] gradients. First results

Luminosity weighted
Mass weighted



Large variety of metallicity gradients but very mild in the disk region

Patricia Sanchez-Blazquez 2011

Theory vs. Observations for bars

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- AGN triggers?

Why are bars important?

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  - Barred galaxies are "normal"
- How do bars form? Why don't all disk galaxies have bars?
- What is the role of dark matter?
- Evolution of Bar fractions with redshift.

The role of secular structures

1. Redistribute angular momentum between baryonic and dark matter components
2. Gas inflows
3. Build bulges - (pseudo-bulges)
4. Trigger AGN (?)
5. Metallicity gradients

- Triggered in unstable disks
- fractions (?)
- contribution to sfrd (?)
- timescales (?)
- destruction mechanisms? (?)

Results at z = 0
(SDSS)

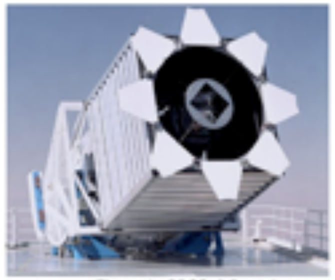
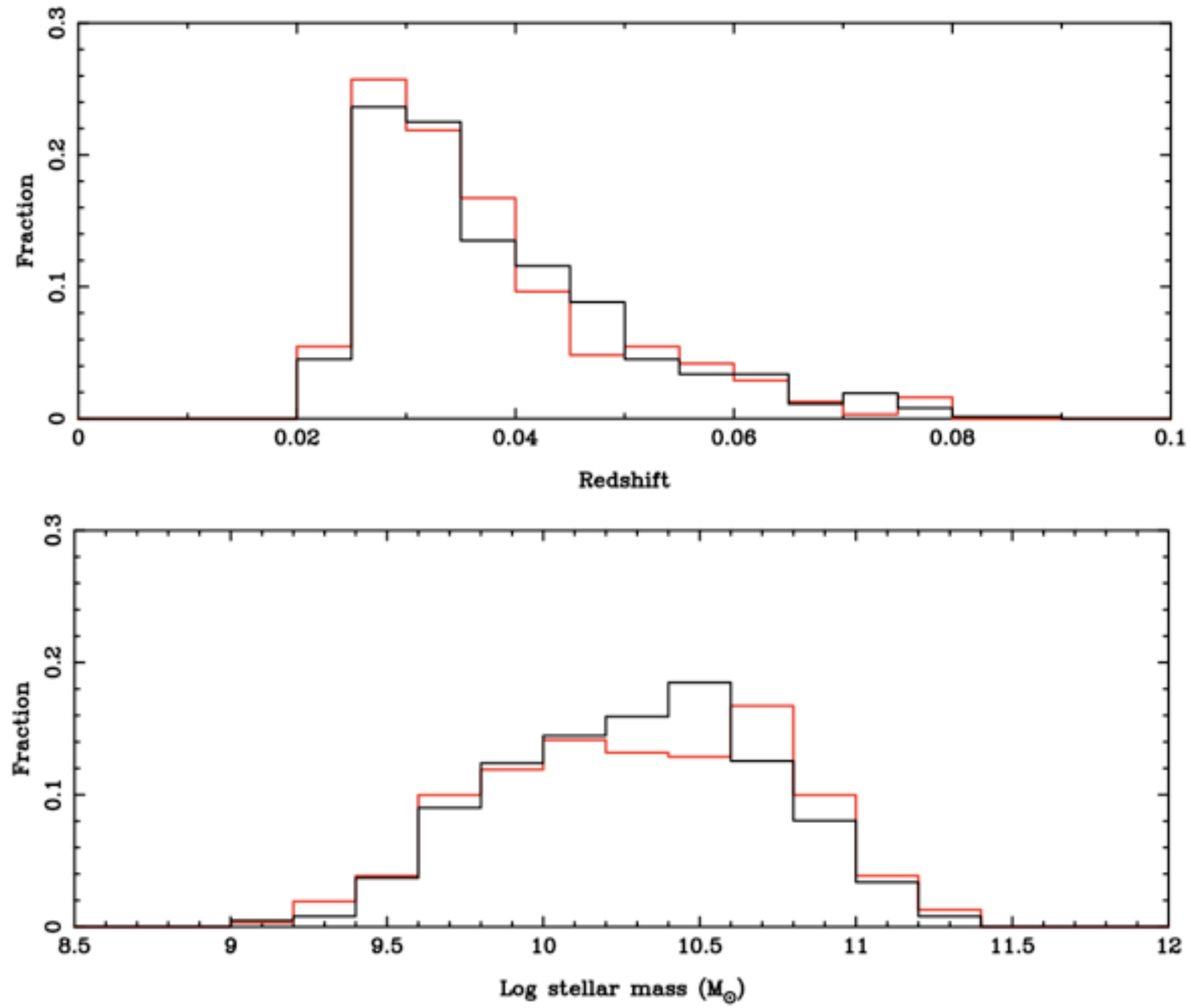


Figure 1 : SDSS 2.5m telescope
Image credit: Fermilab Visual Media Services

Sloan Digital Sky Survey
Mapping the Universe

- Visual catalog of Nair & Abraham 2010.
- 0.02 < z < 0.1
- S/N>5 in [OII], H_beta, [OIII], H_alpha, [NII]
- AGN are excluded.
- 311 barred galaxies and 806 unbarred galaxies.



Ellison et al. 2011

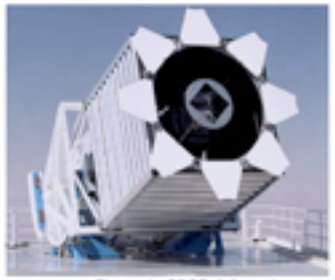


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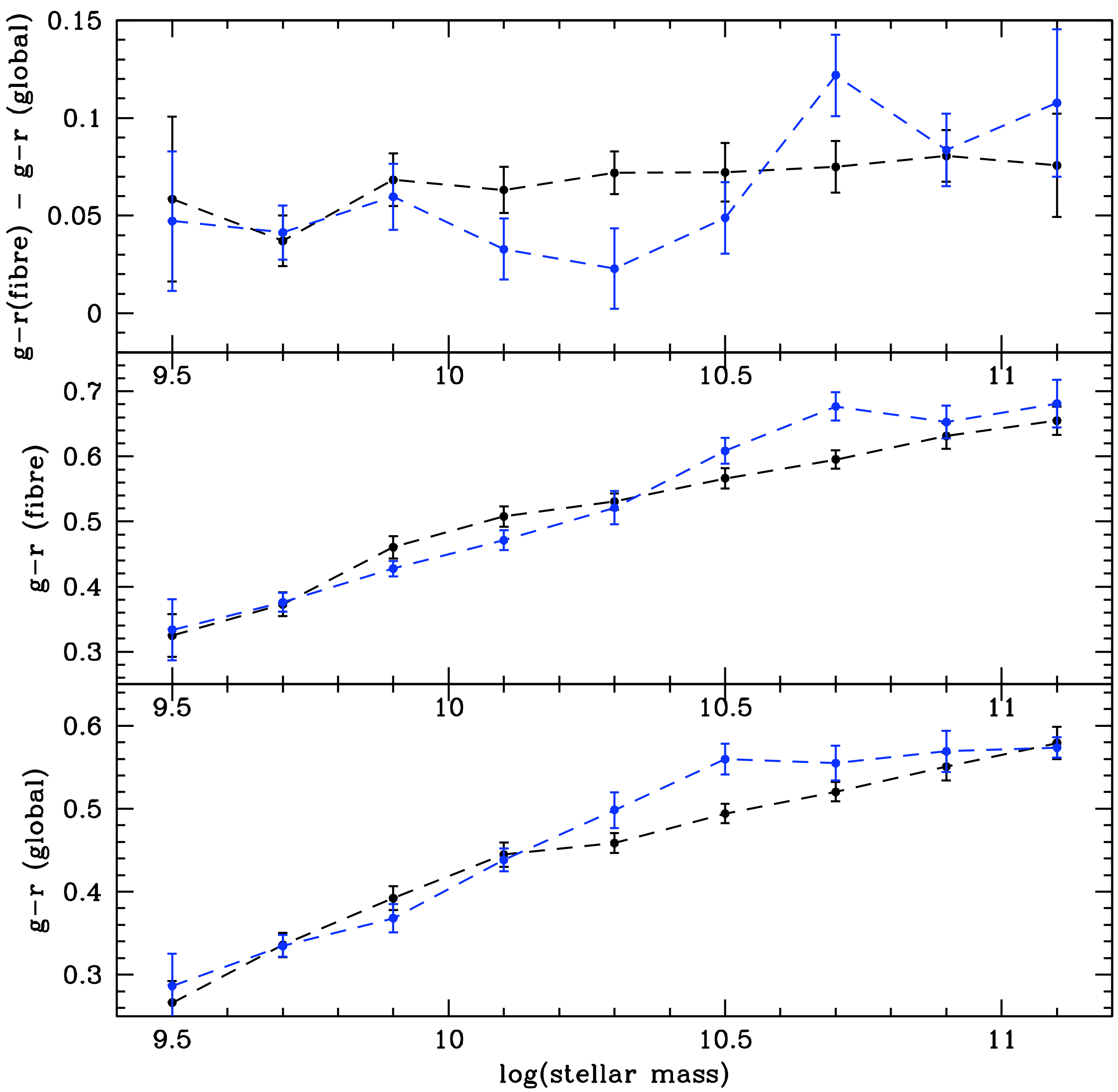
Image credit: Fermilab Visual Media Services

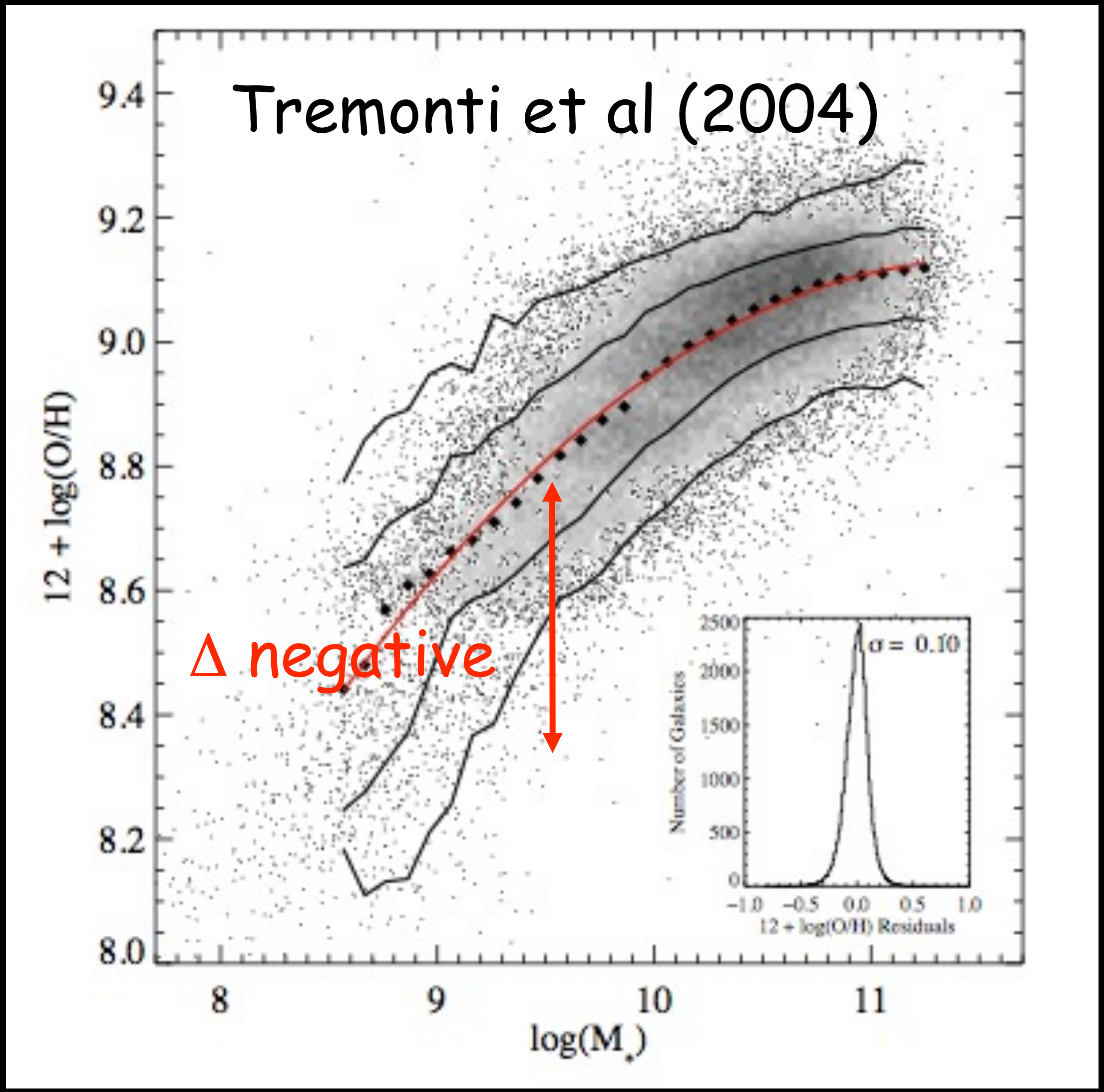
Properties of Barred Galaxies

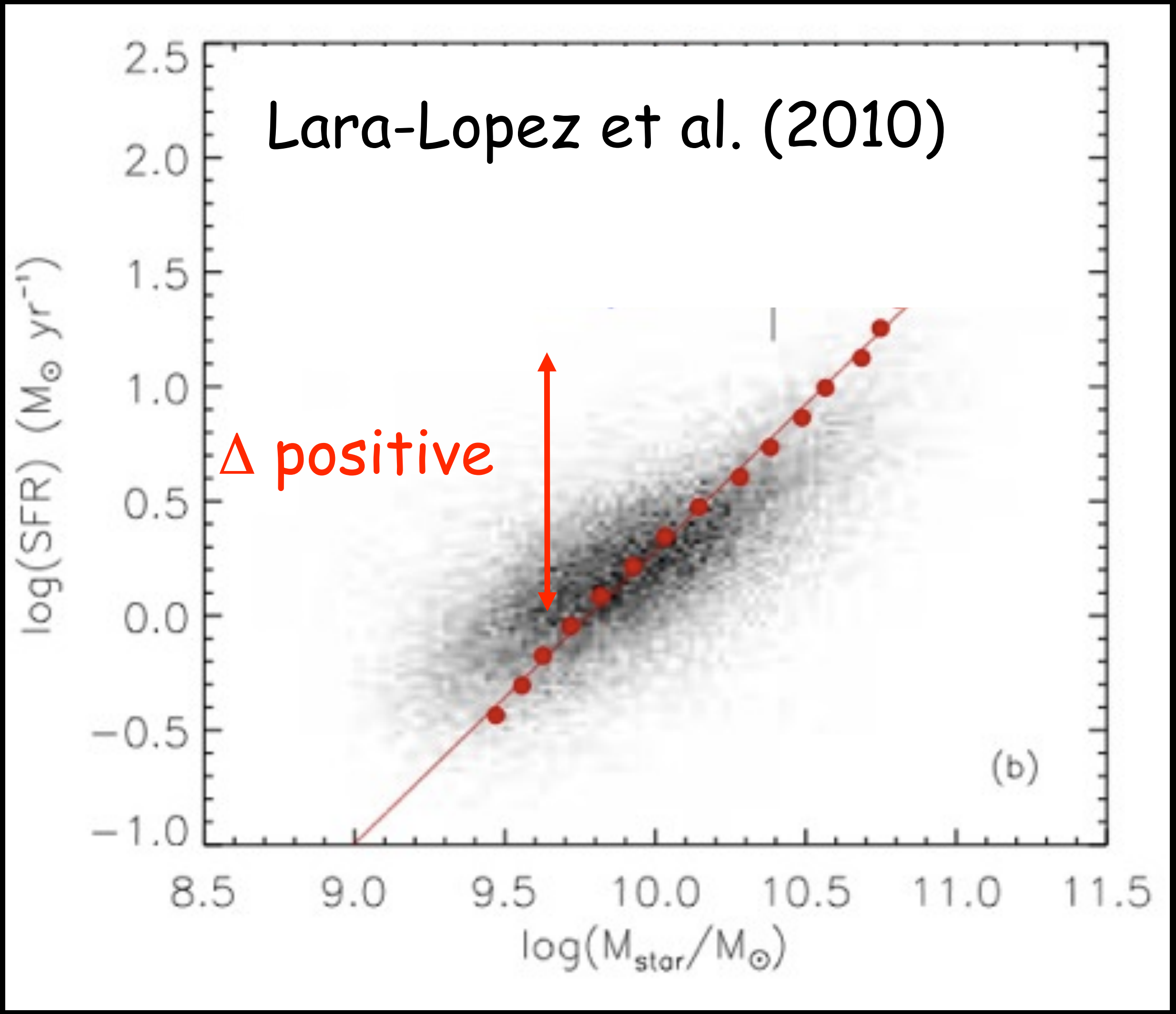
- Color Evolution



- Global colors shows a mass dependent offset where barred galaxies are redder than normal galaxies.
- Fiber colors are also redder in barred galaxies.

Quantify SFR and metallicity enhancements by looking for offsets from the mass-SFR and mass-metallicity relations of control galaxies.





Δ O/H = log O/H - log O/H$_{predict}$

Δ SFR = log SFR - log SFR$_{predict}$

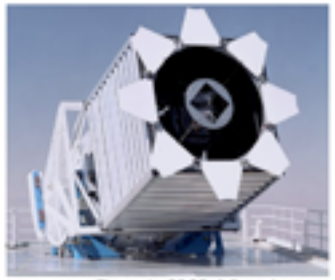
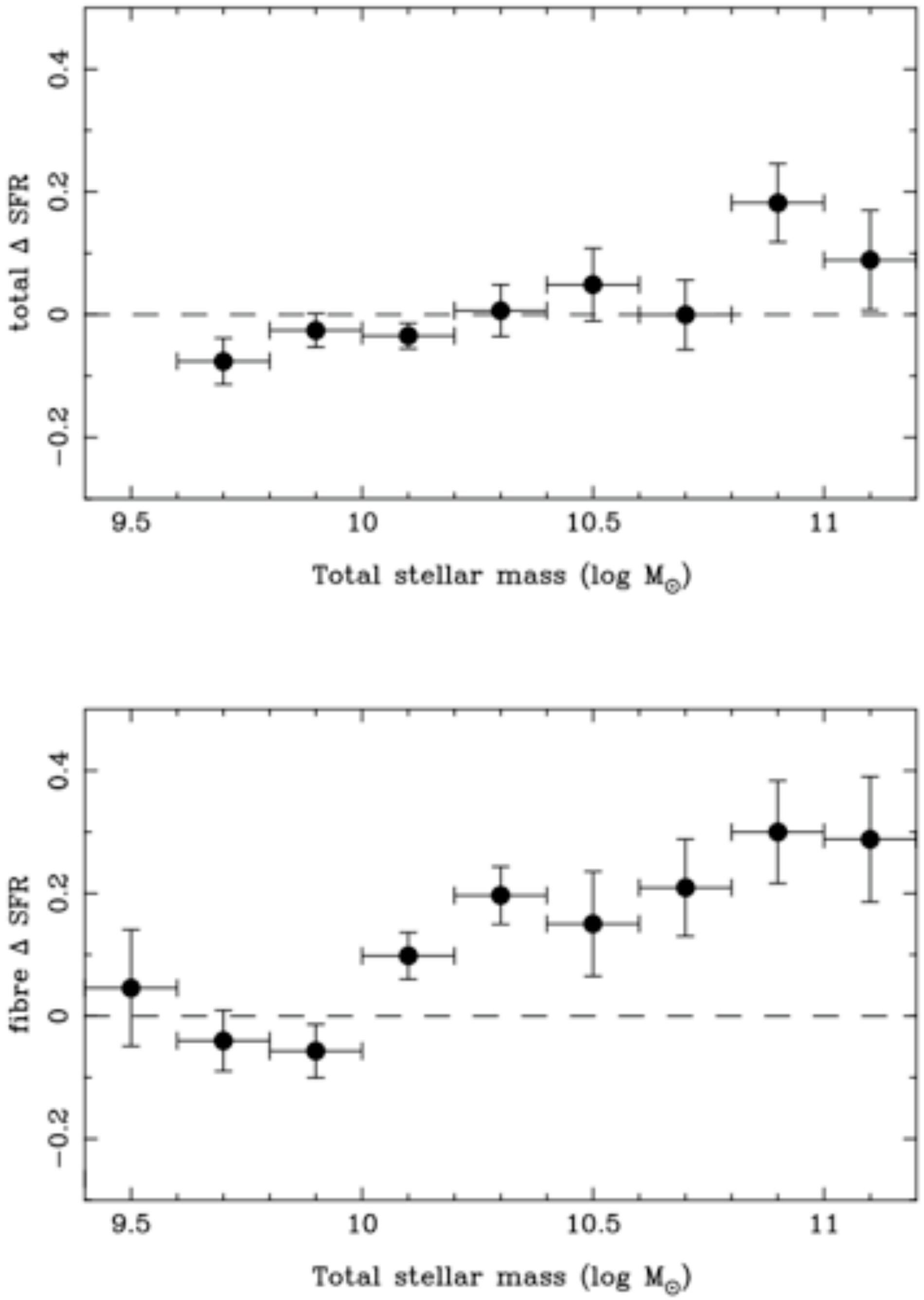


Figure 1 : SDSS 2.5m telescope
Image credit: Fermilab Visual Media Services

Properties of Barred Galaxies

- Star Formation Rates



- Figure shows offsets from the SFR-mass relation for non-barred galaxies .
- Radial gas flows triggered by bars do not affect the total star formation rates.
- They do cause an enhancement in fiber star-formation rates.

Ellison et al. 2011

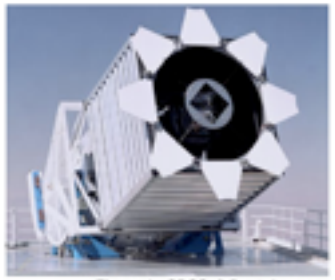
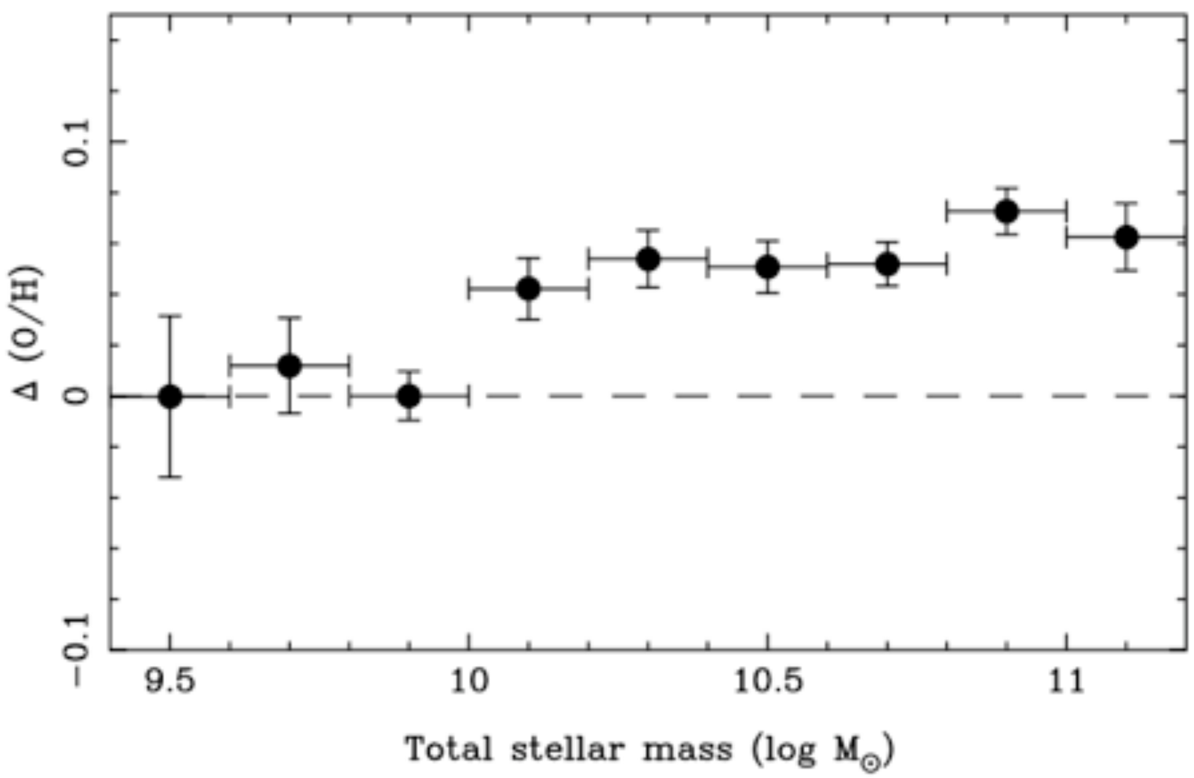


Figure 1 : SDSS 2.5m telescope
Image credit: Fermilab Visual Media Services

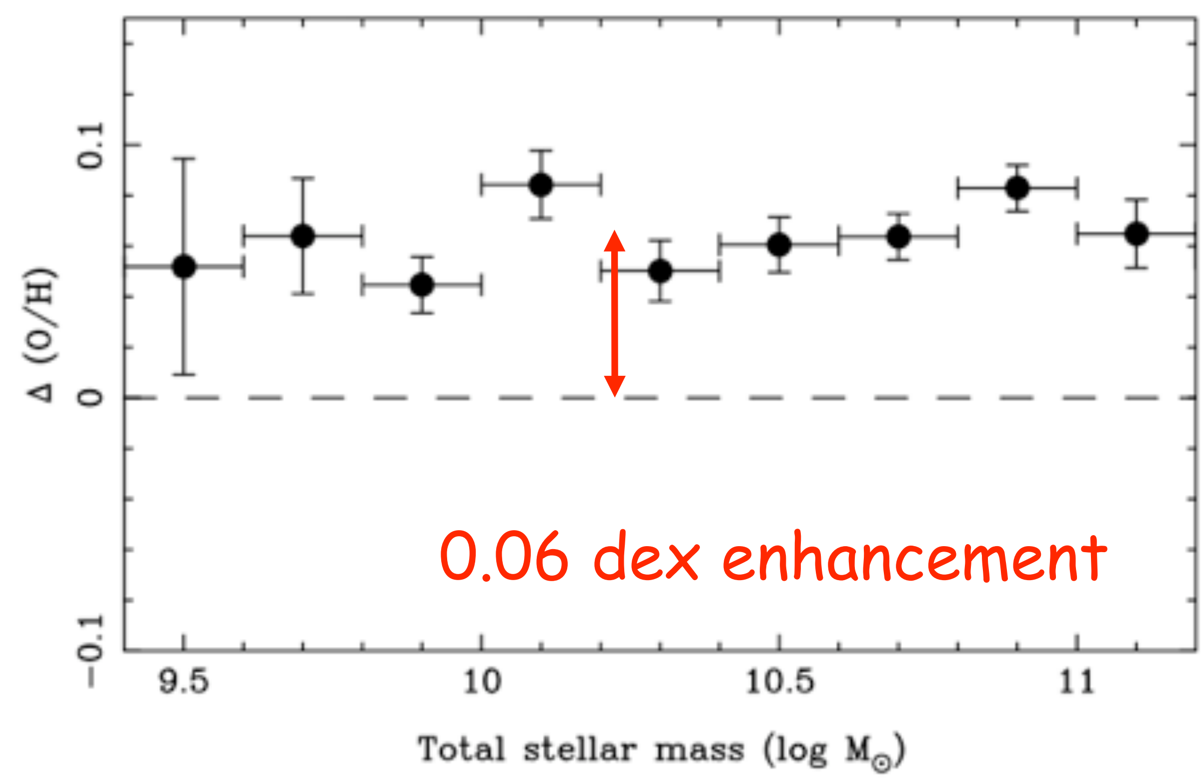
Properties of Barred Galaxies

- Metallicities

Metallicity vs. total stellar mass



Metallicity vs. fiber stellar mass



- Barred galaxies more metal-rich at all masses.

- Bars sufficiently long lived to show enrichment, even after SF.

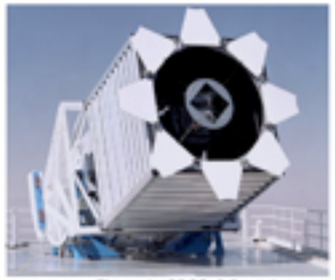


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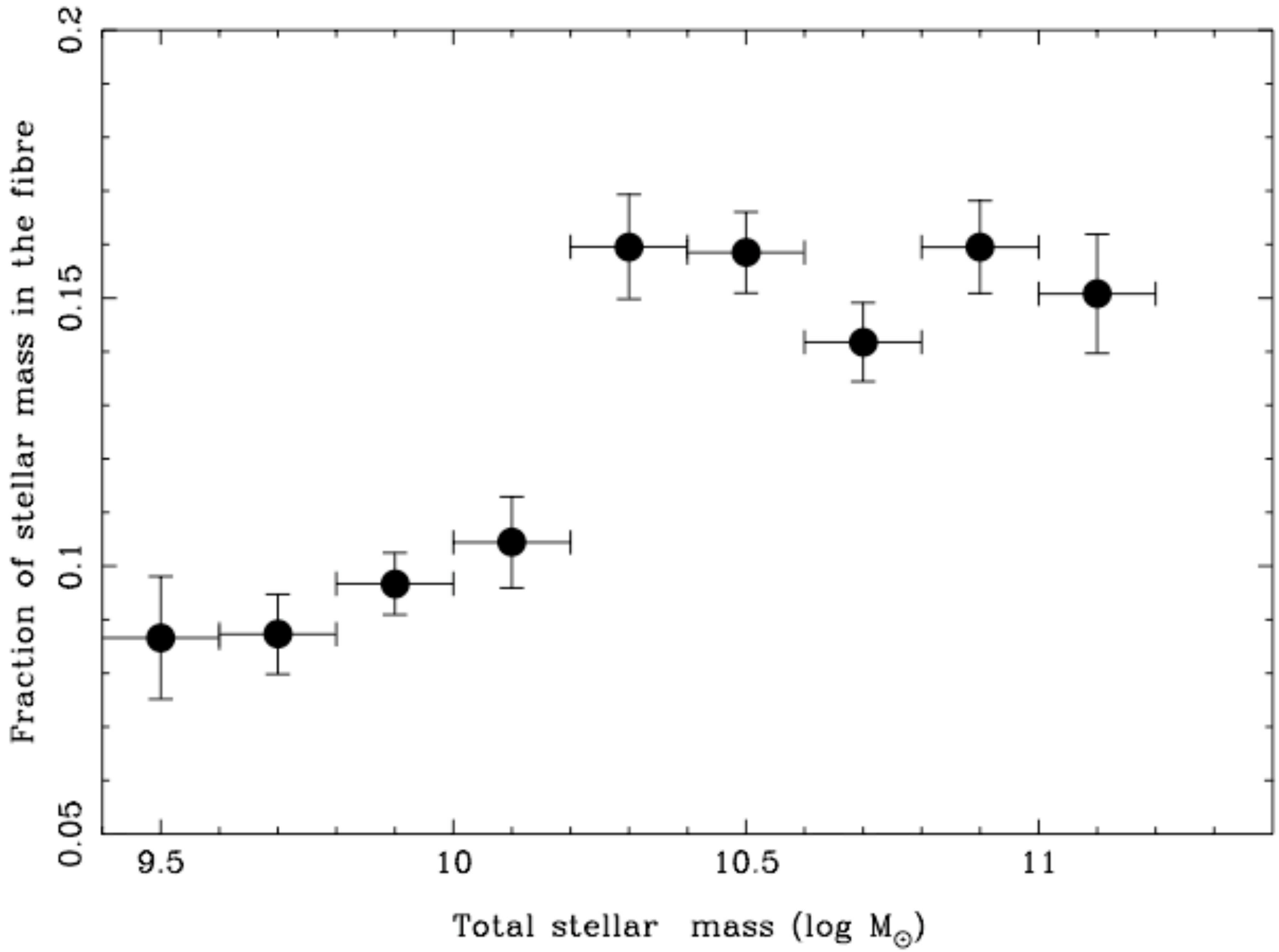
Image credit: Fermilab Visual Media Services

Properties of Barred Galaxies

- Metallicities aperture effects



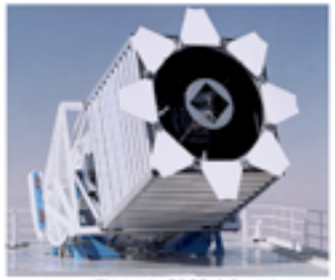

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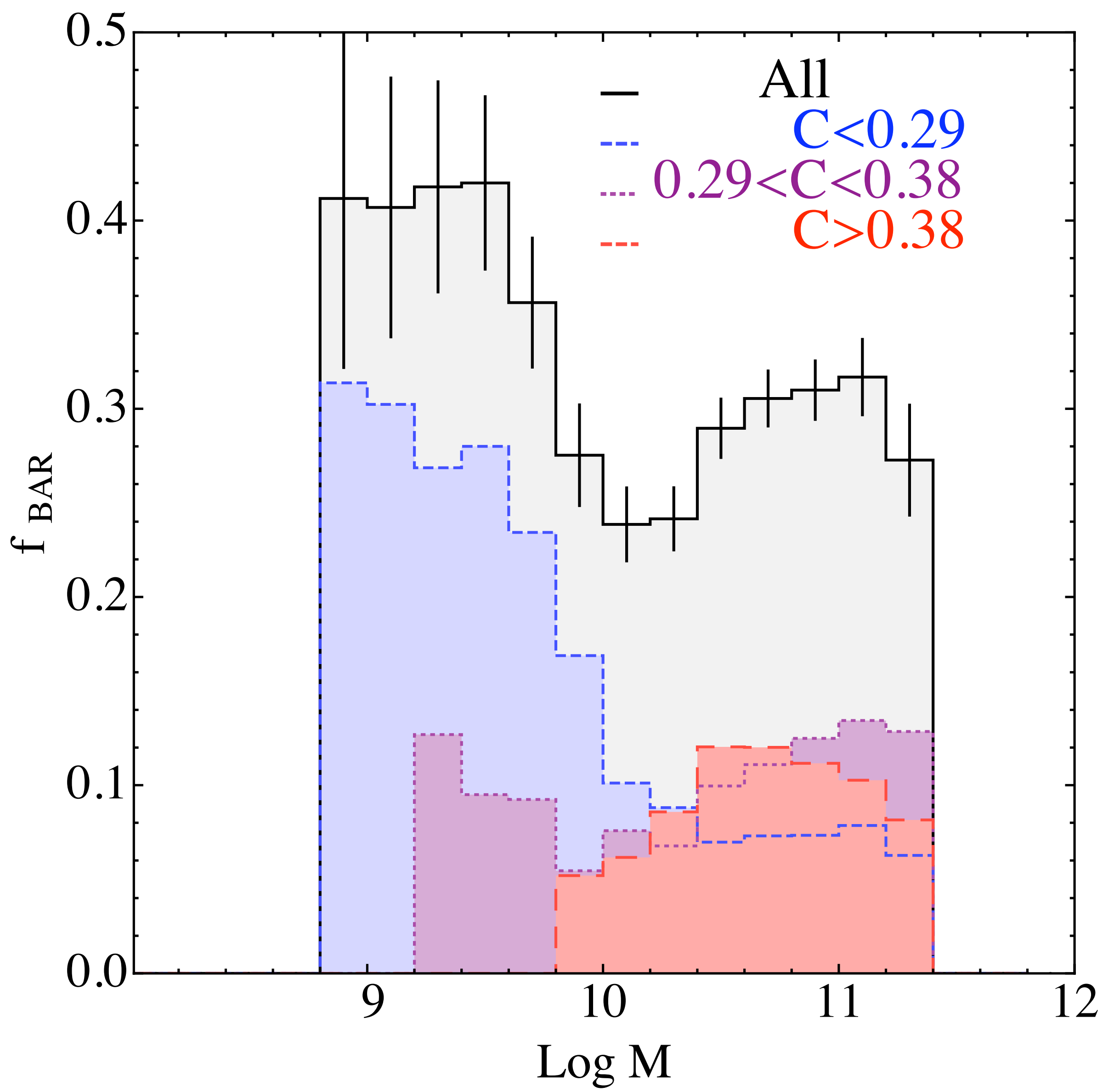
Image credit: Fermilab Visual Media Services

Properties of Barred Galaxies

- Bimodality in bar fractions



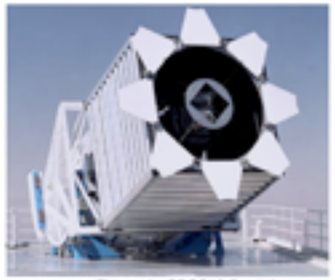
Nair & Abraham 2010

The Role of Secular Features

- Barred galaxies at masses >10^10 tend to have longer stronger bars in bulge dominated systems

- Barred galaxies below 10^10 tend to have shorter, weaker, exponential bars

- Simulations indicate that radial inflows depends on the length and strength of the bars.



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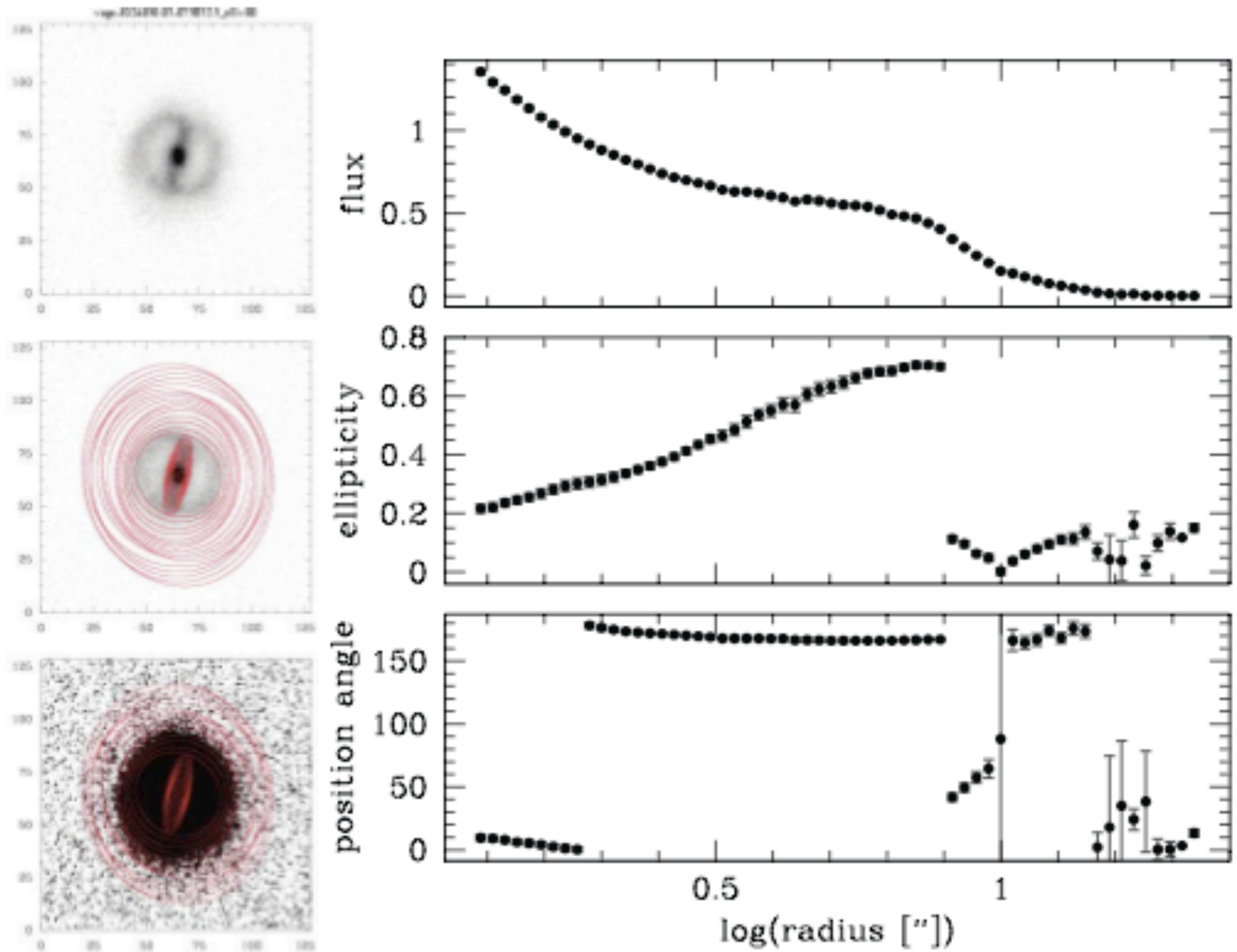
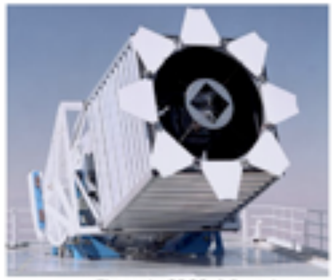
Properties of Barred Galaxies

- Bar Lengths



Barazza et al. 2008



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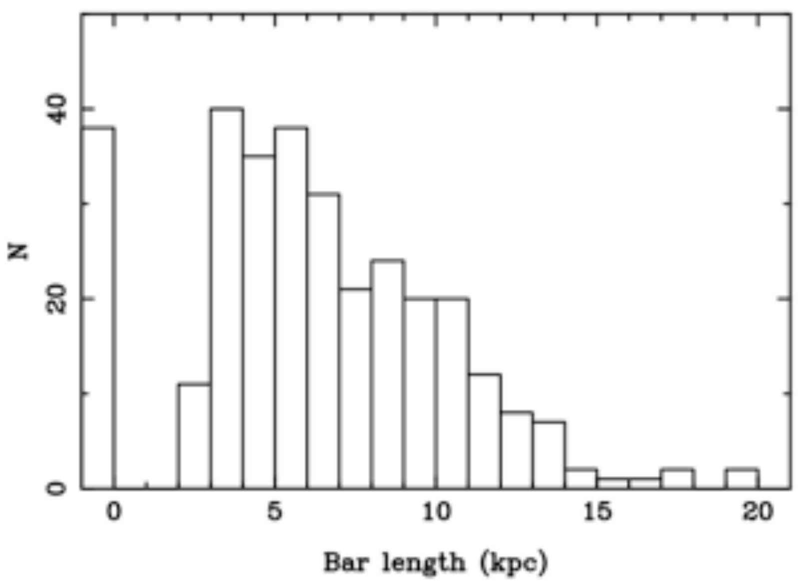
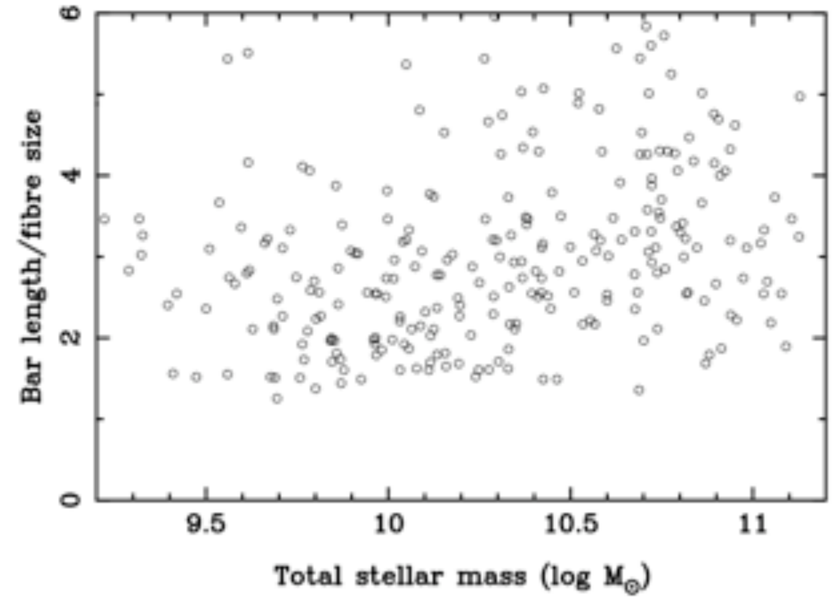
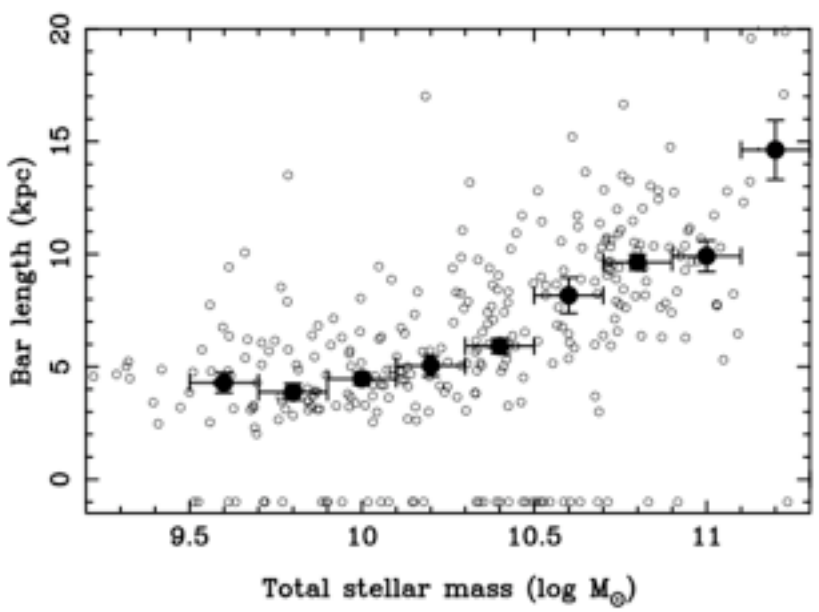
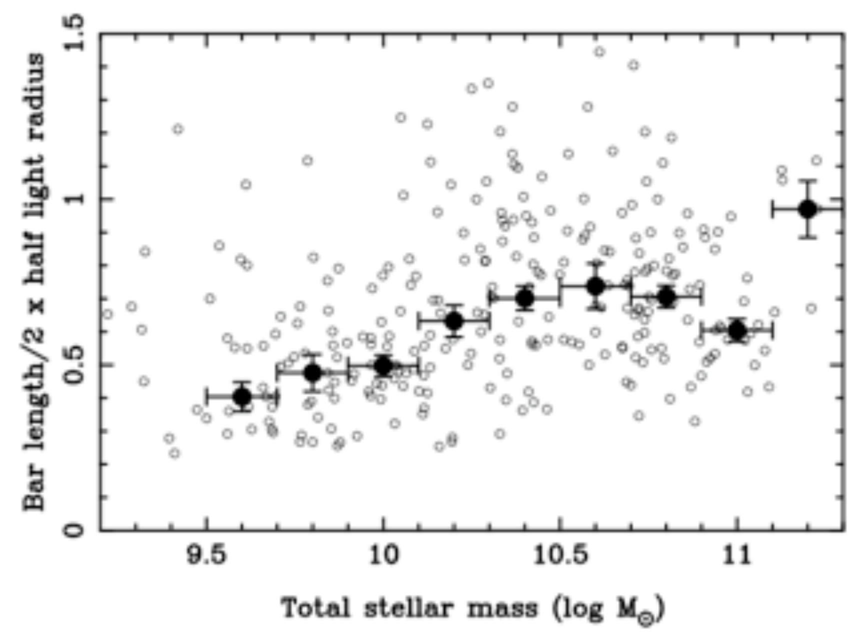








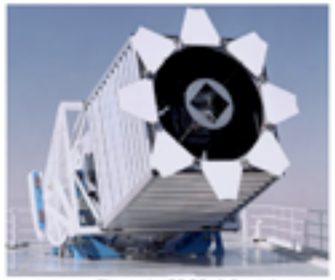
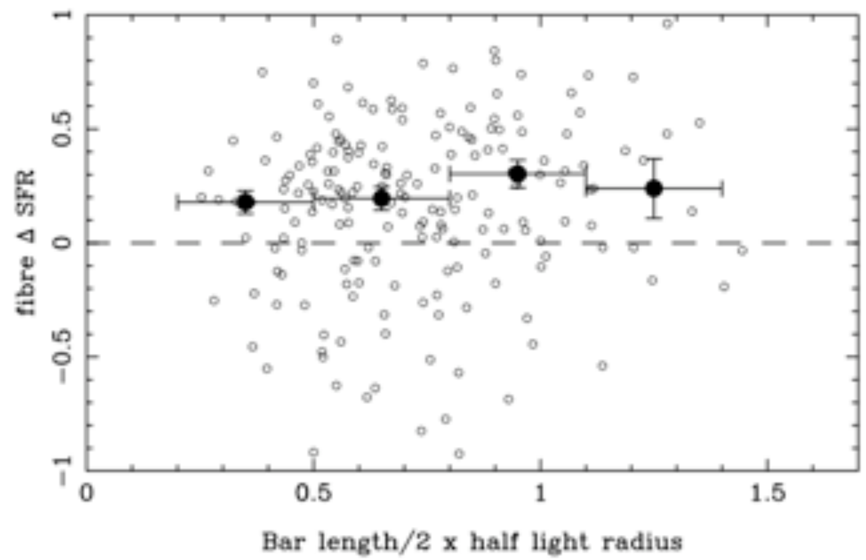
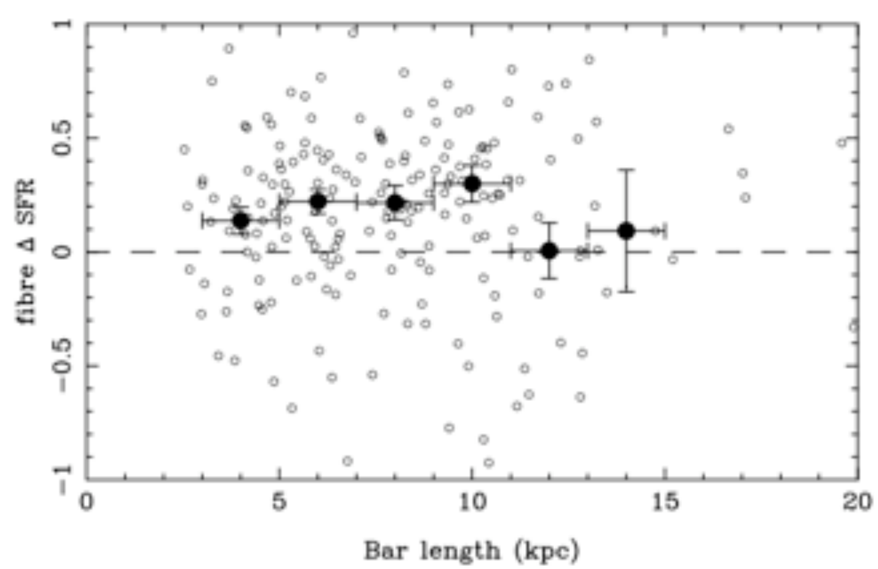


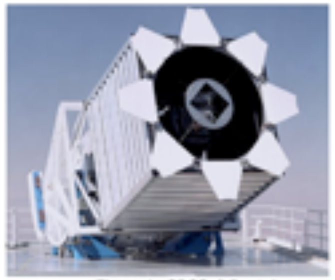
Figure 1 : SDSS 2.5m telescope
Image credit: Fermilab Visual Media Services

Properties of Barred Galaxies

- SFR vs. Bar Lengths







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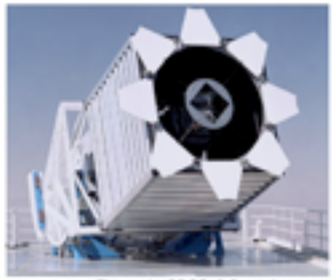

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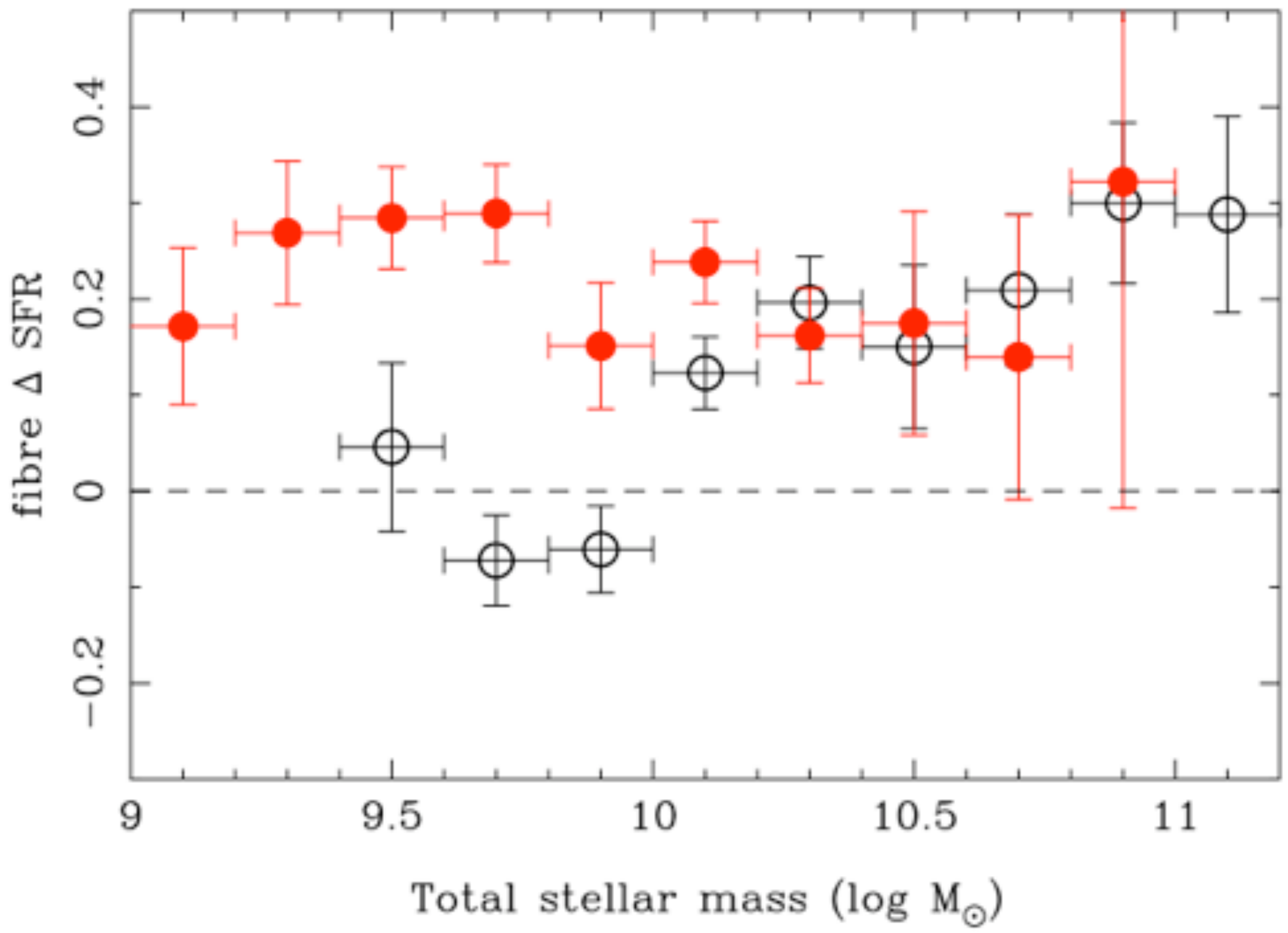

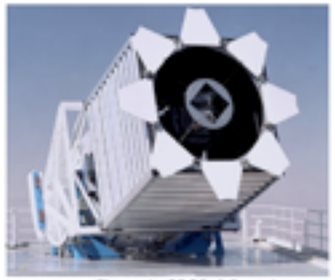

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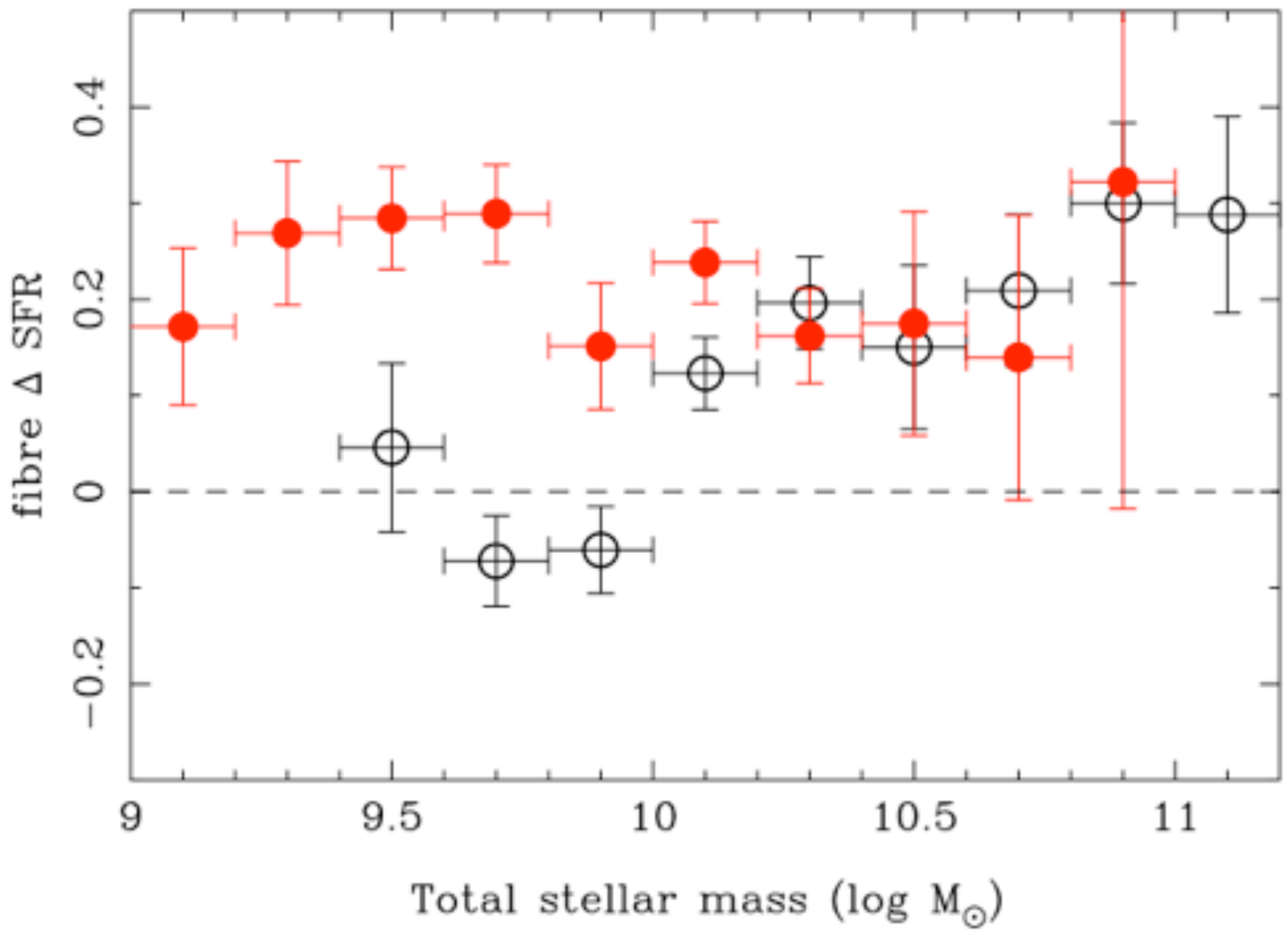
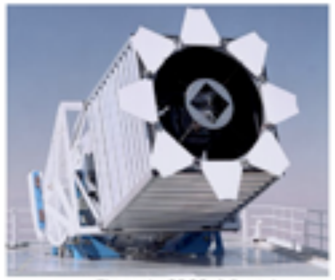


Ellison et al. 2011



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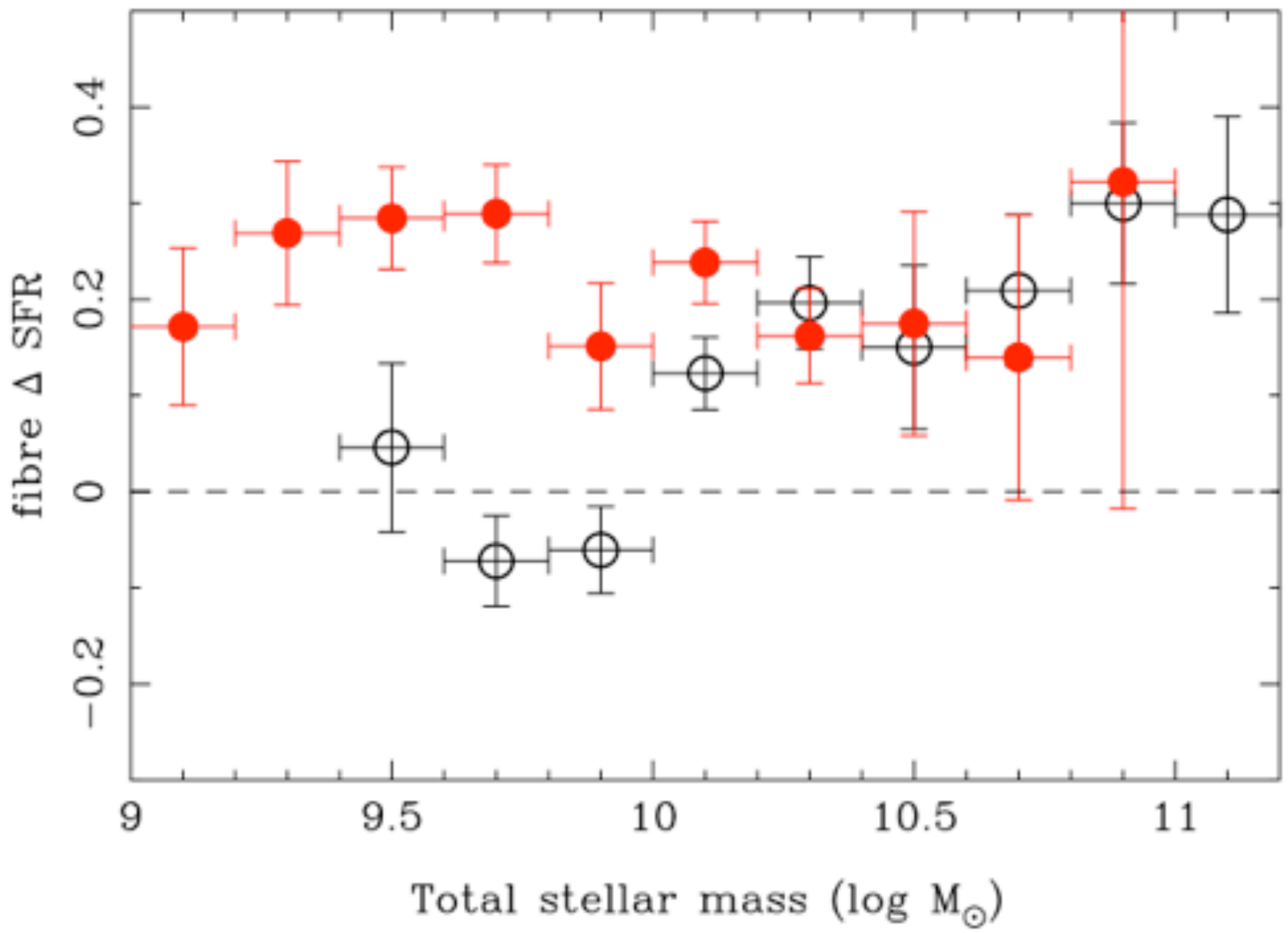

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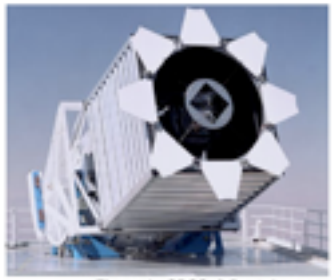

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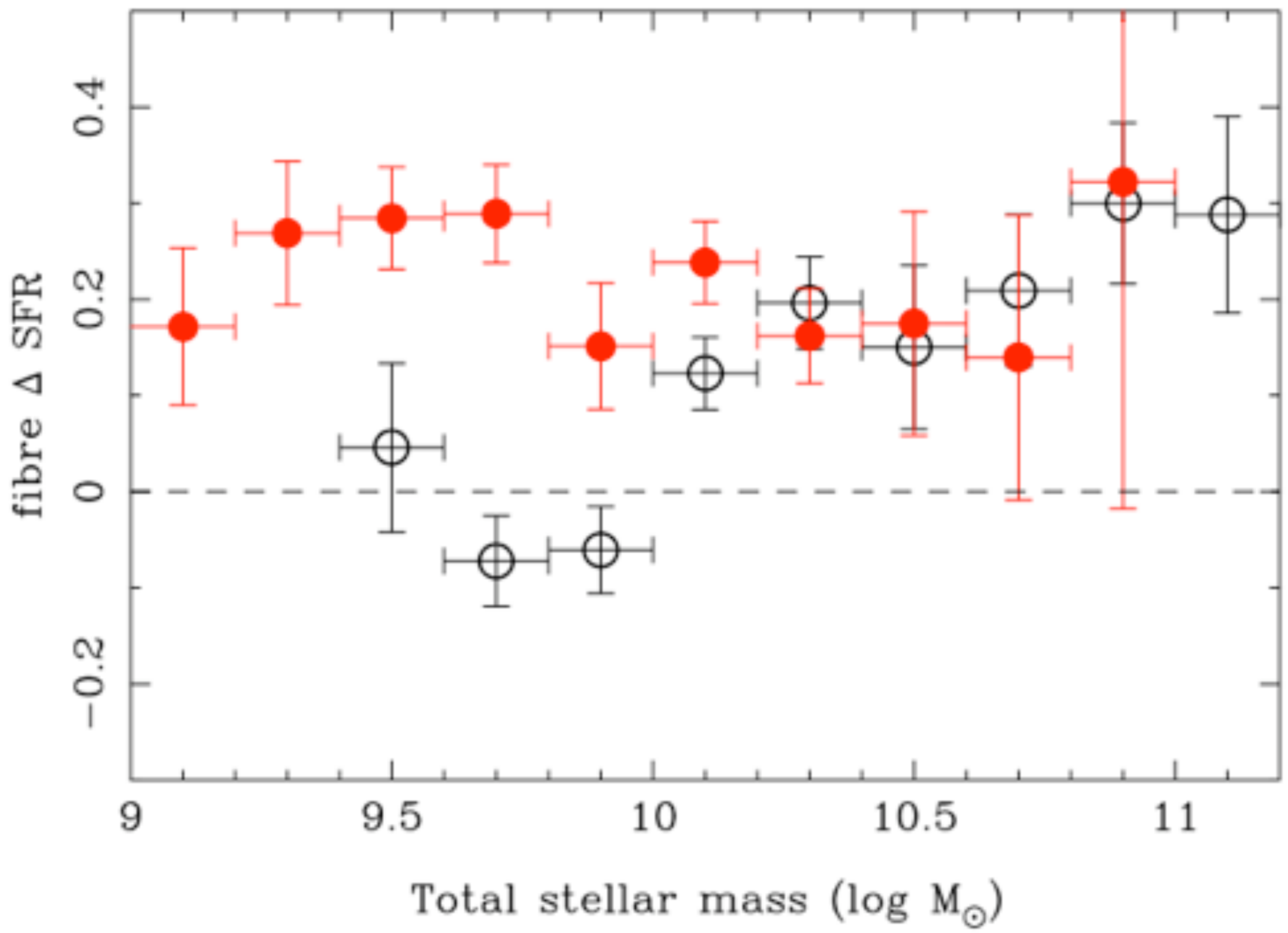

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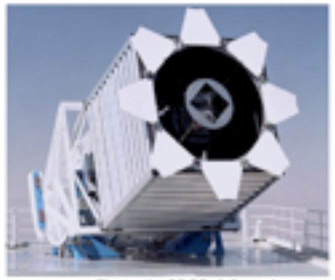

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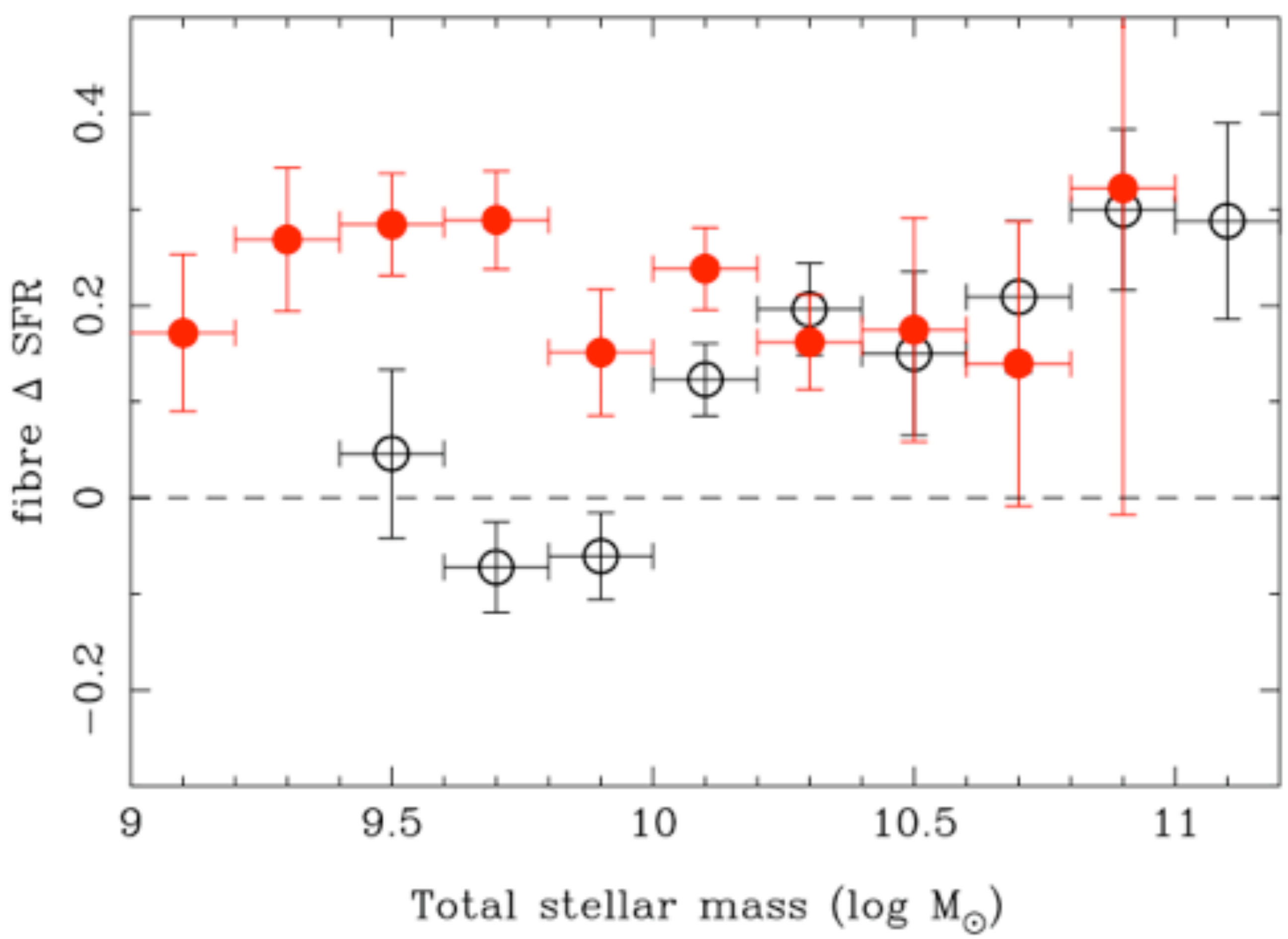

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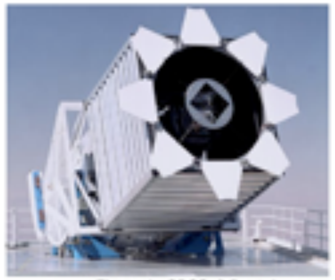

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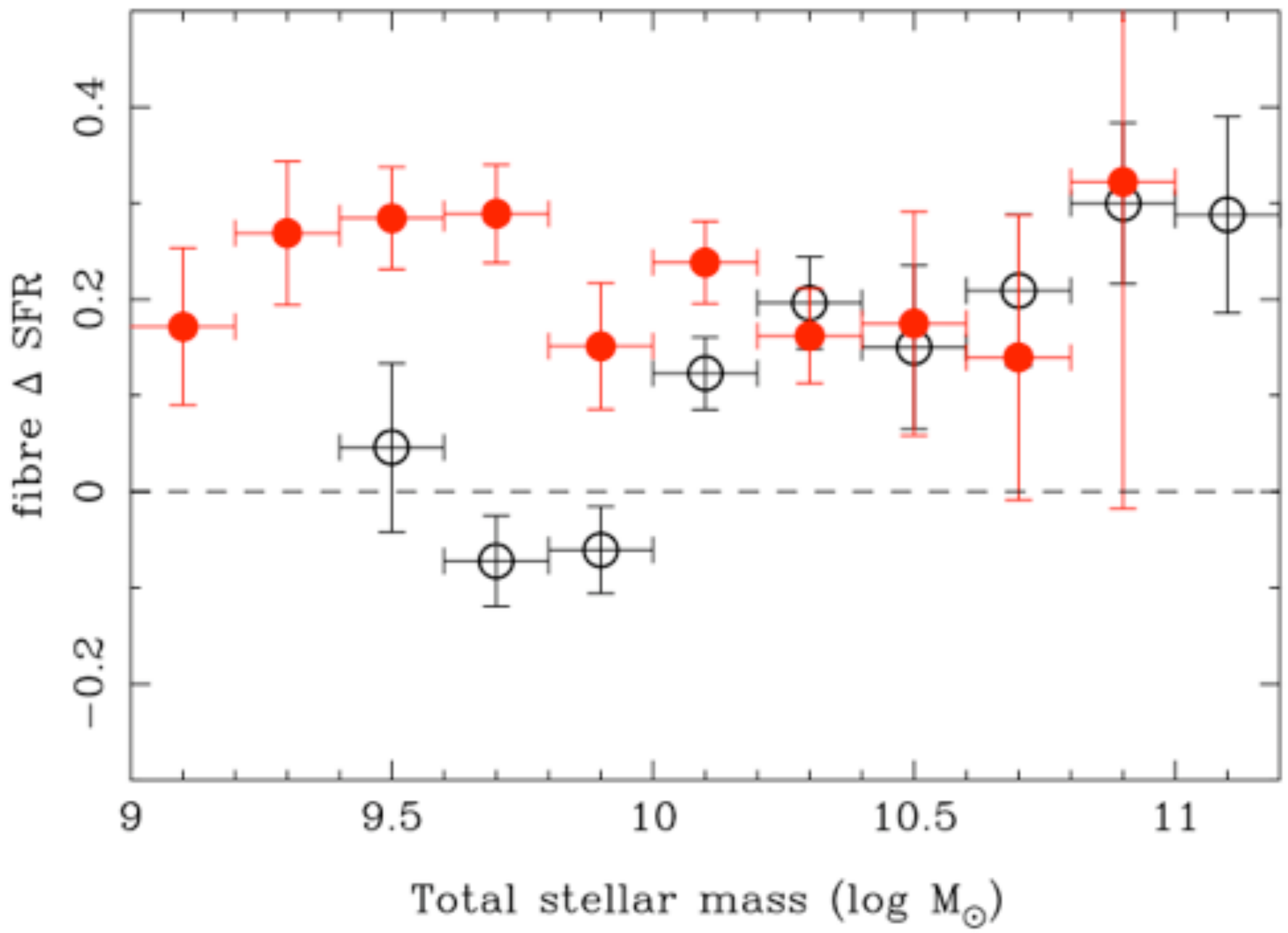

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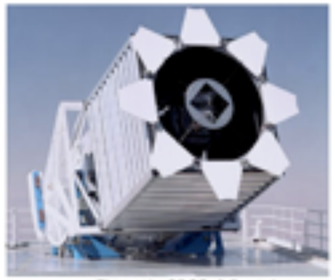

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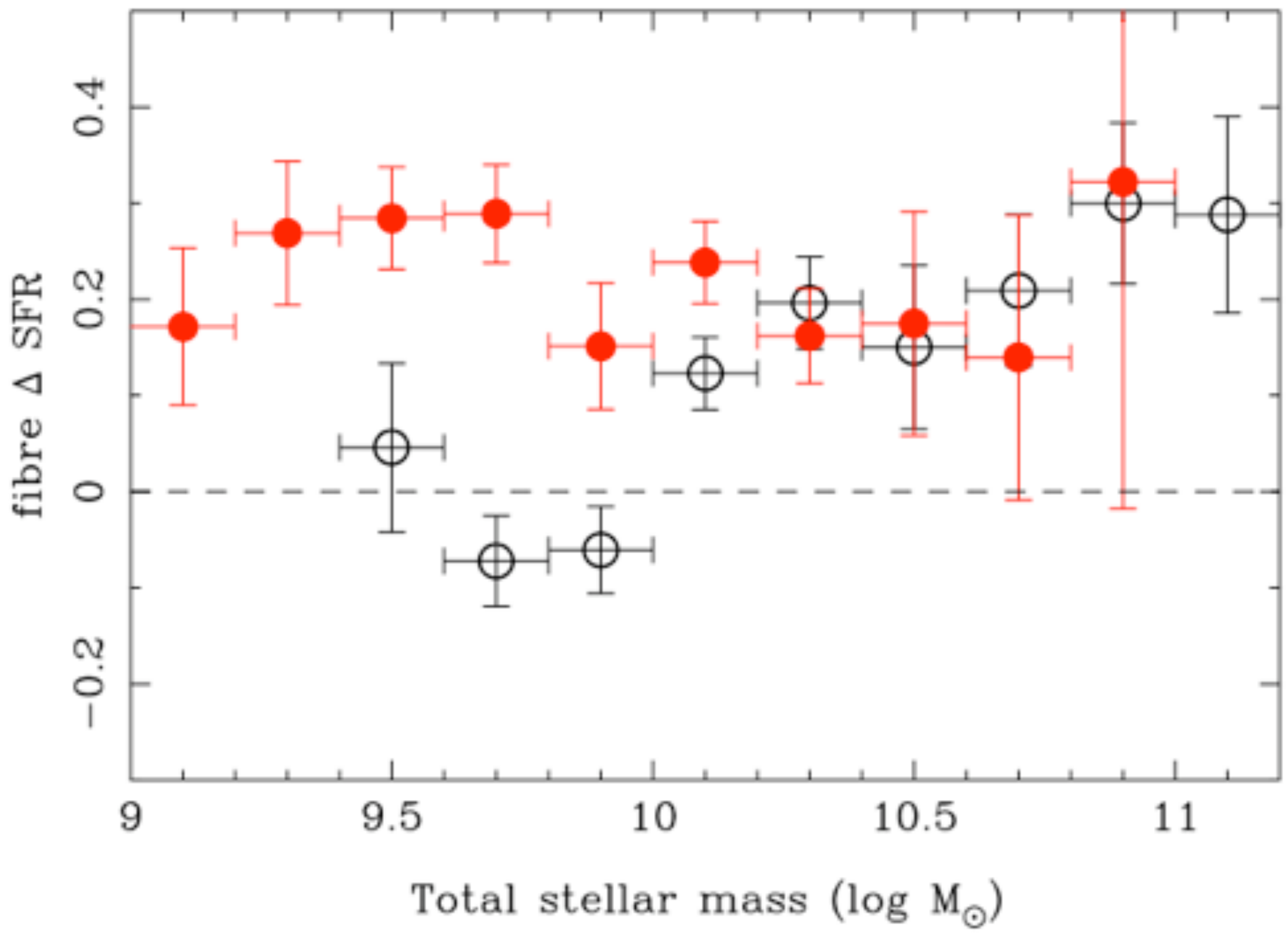

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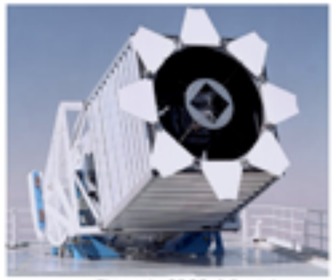
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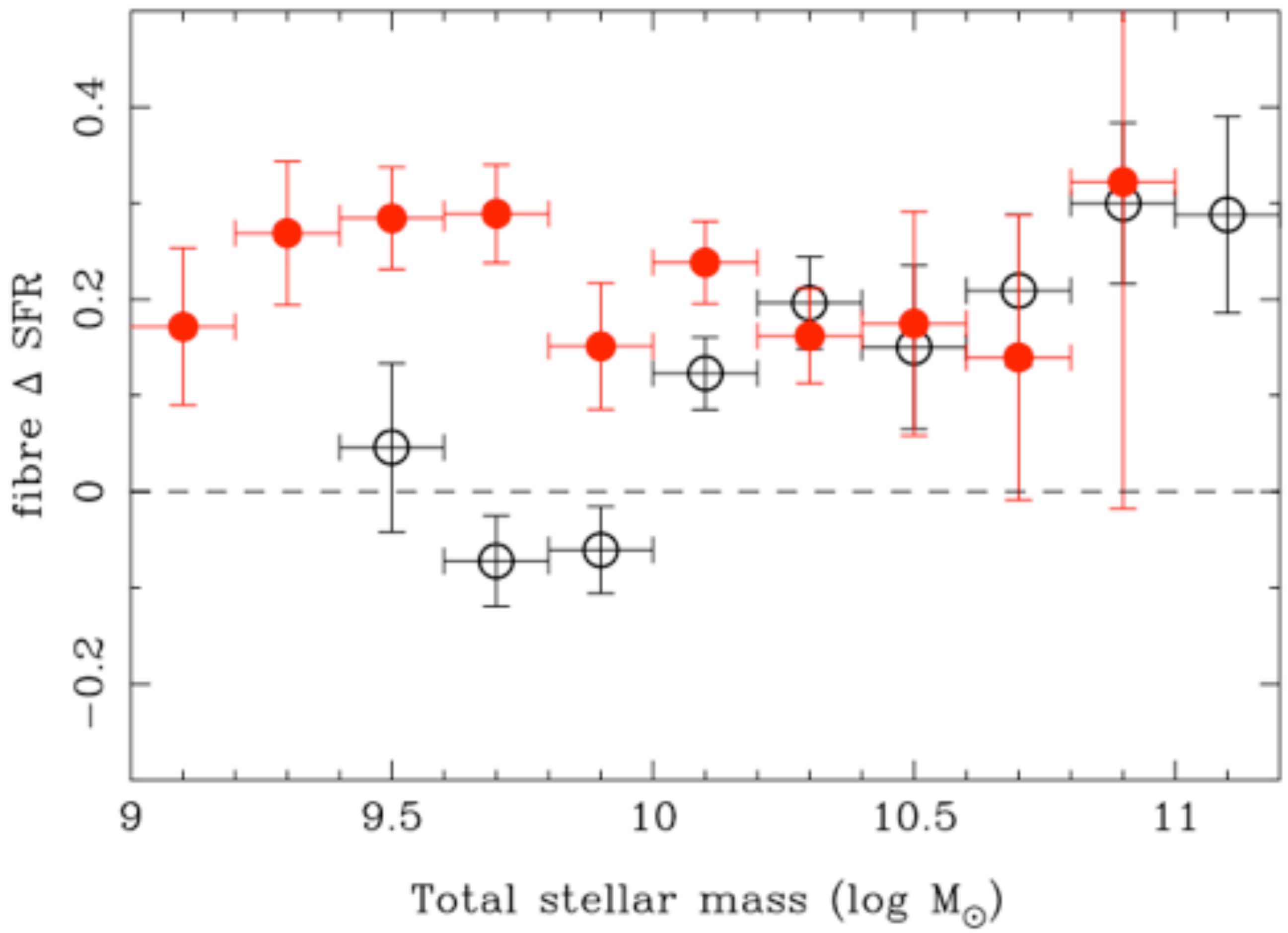

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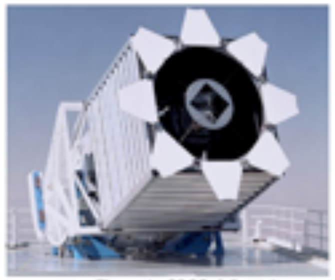

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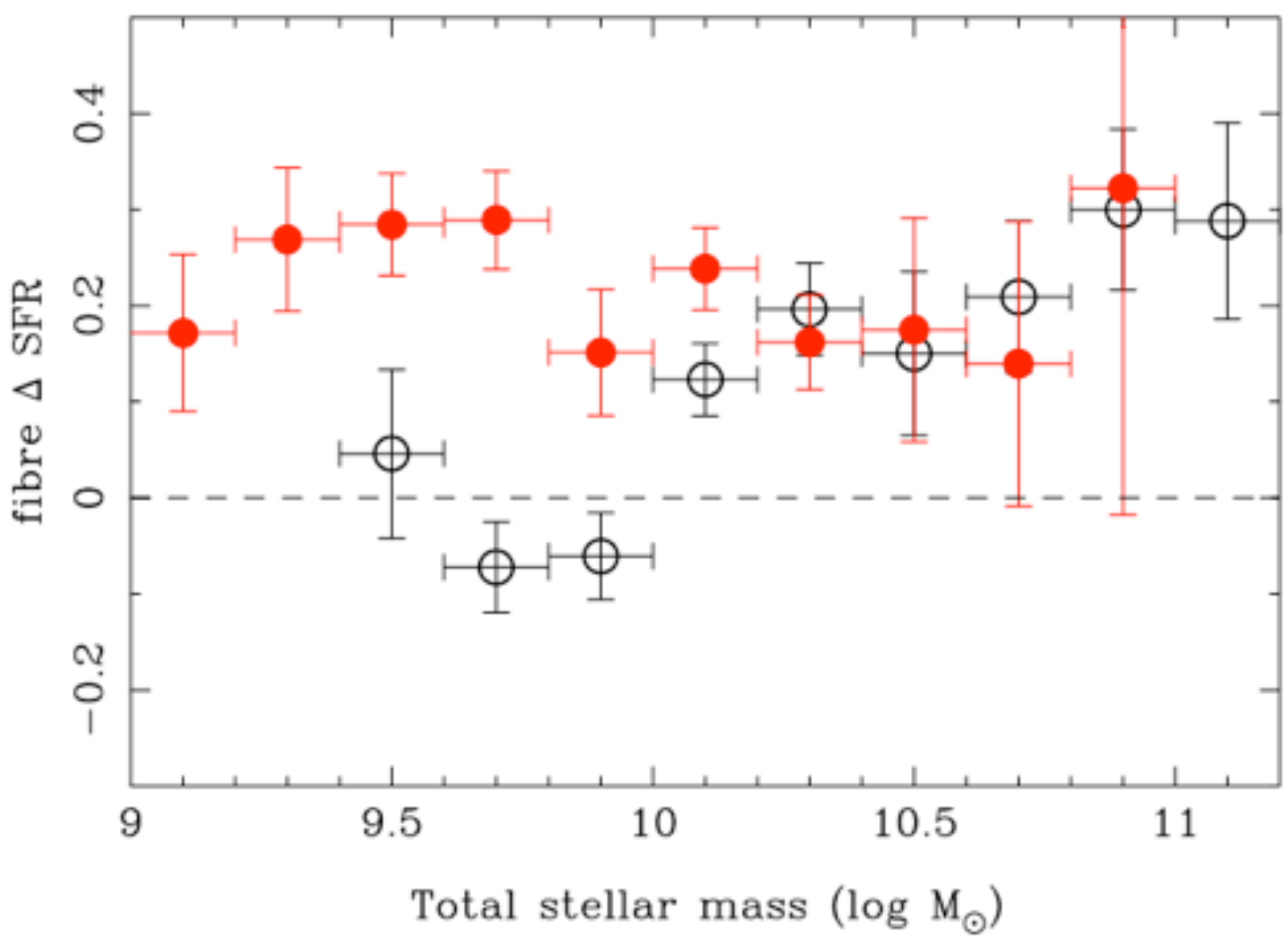

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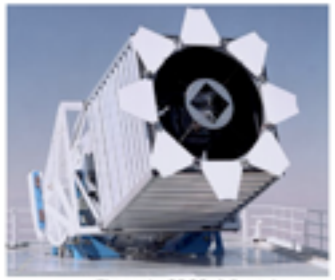

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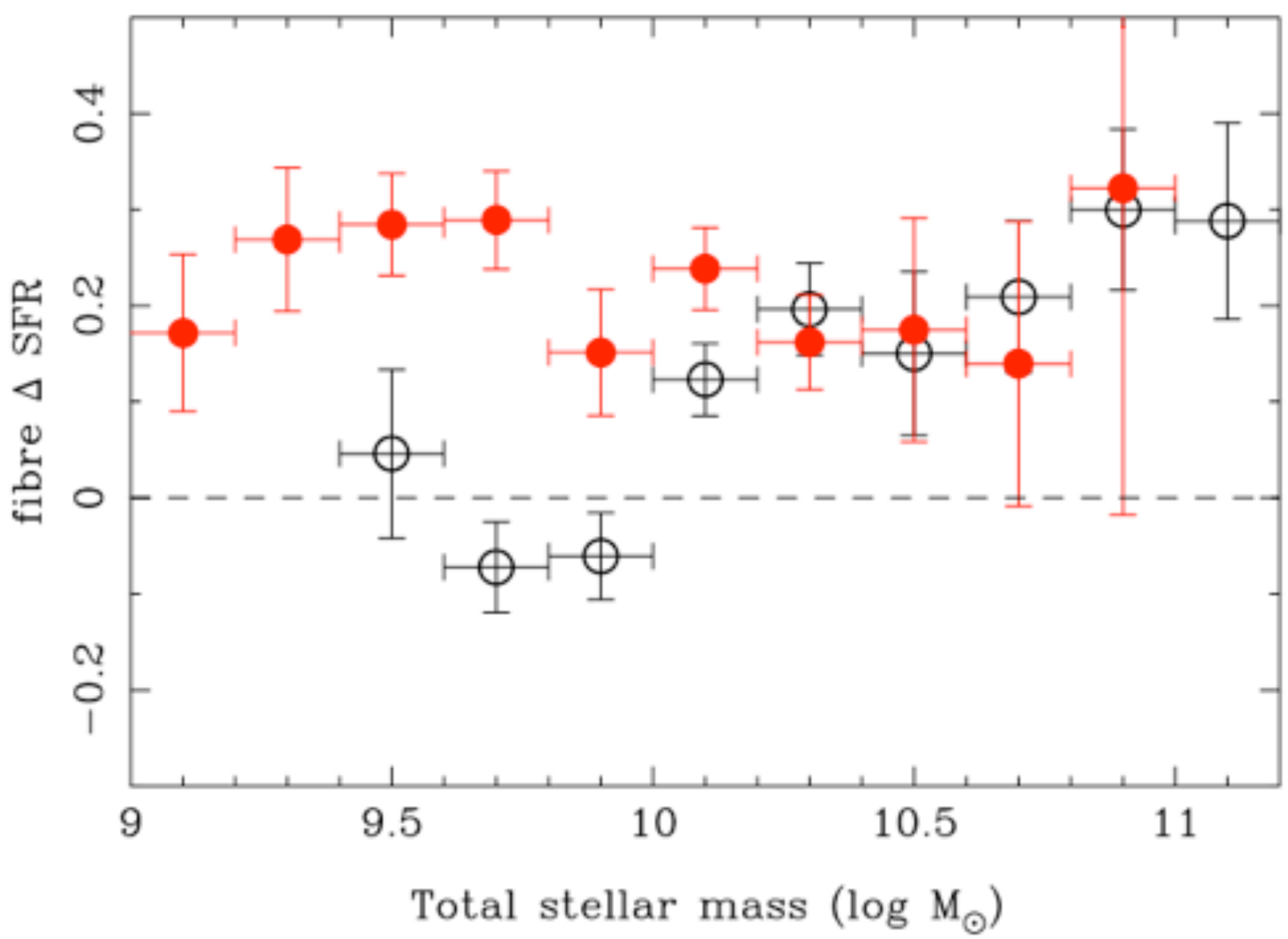

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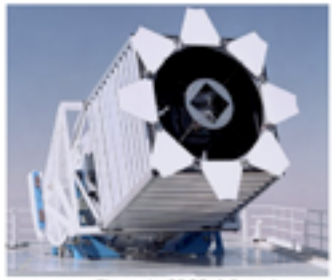

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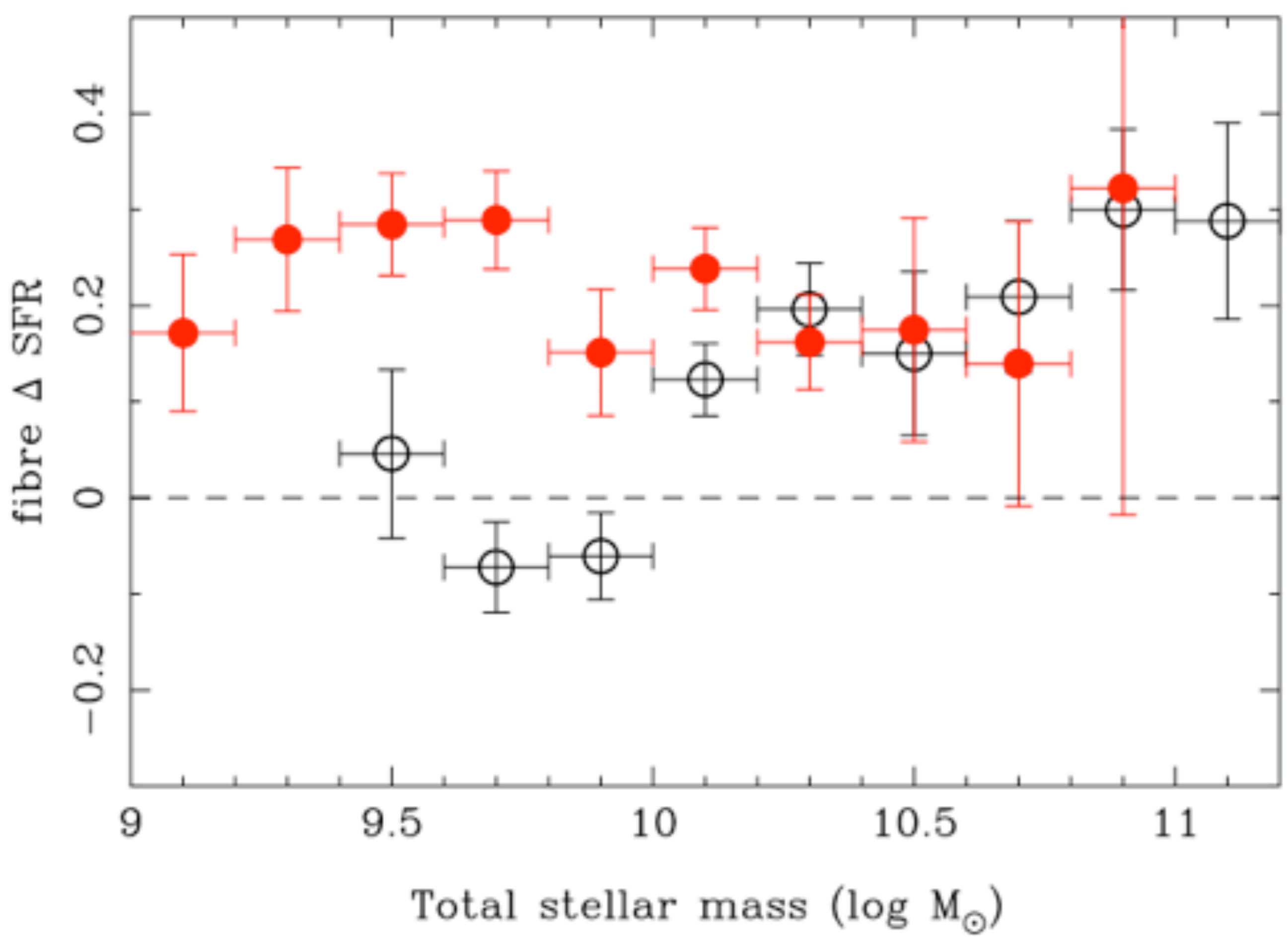

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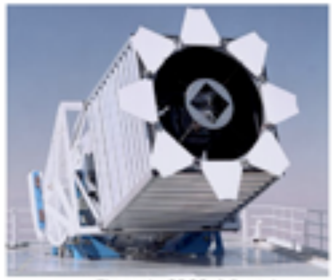

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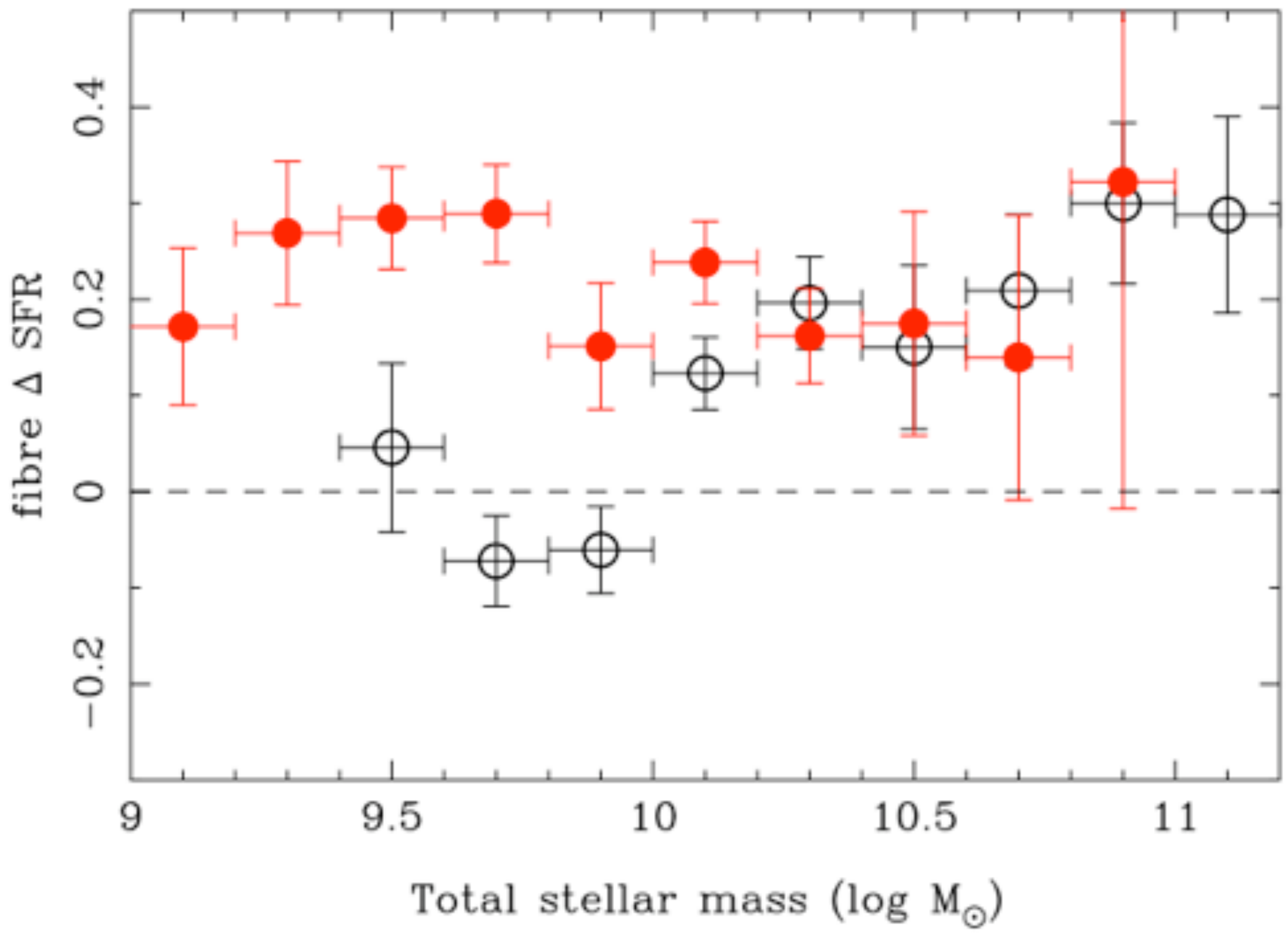

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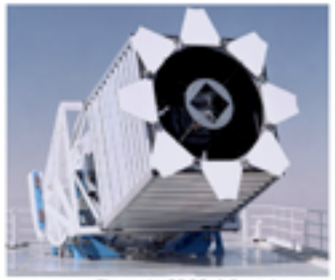

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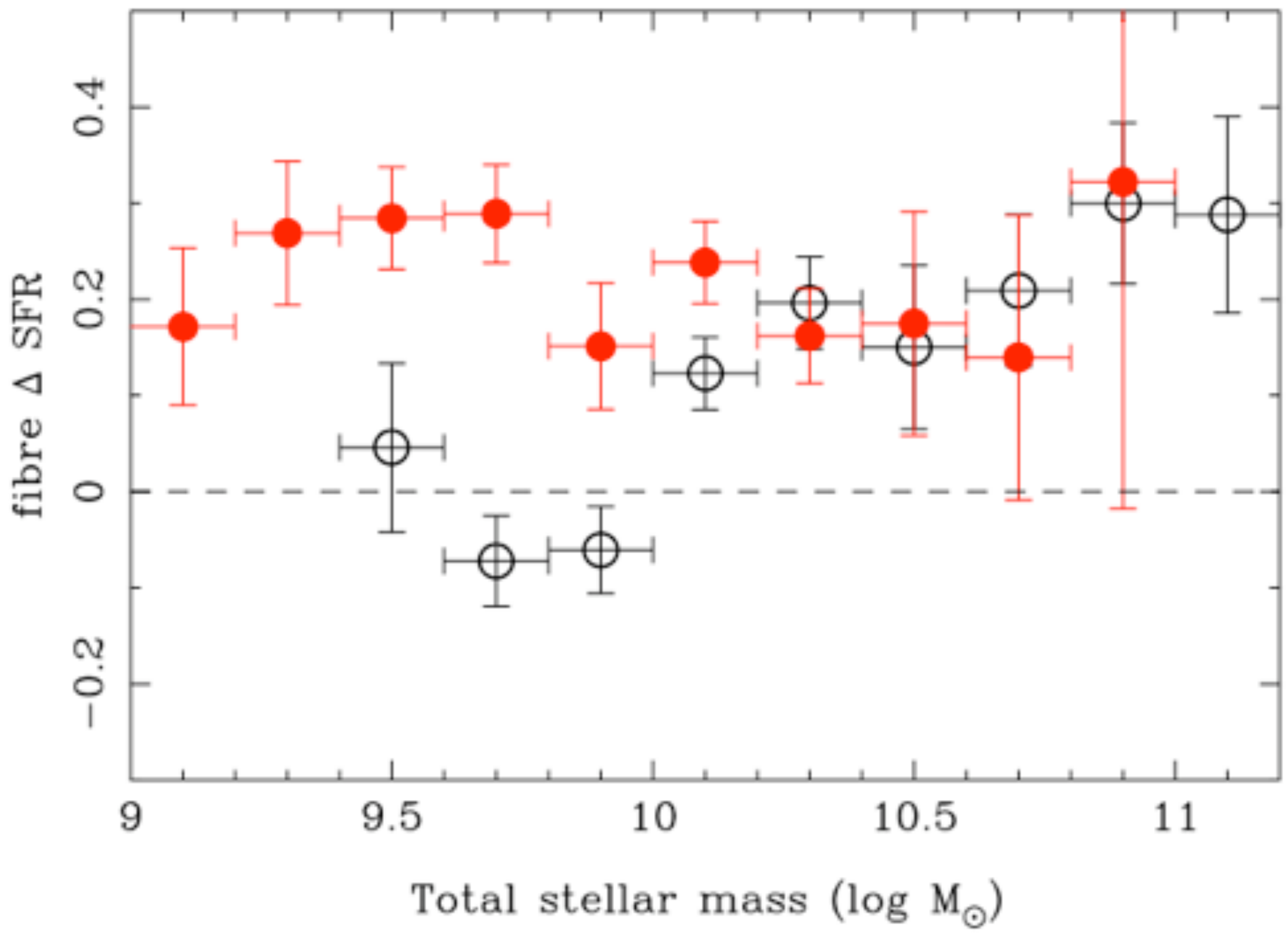

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$\epsilon_{b/p}$ >3, I.e. at least 3 times more central star formation comes from bars than pairs.

Theory vs. Observations for bars

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    - depends on length of bars?(Aguerri 1999)
    - Hubble type (Aguerri 1999 , Elmegreen et al.)
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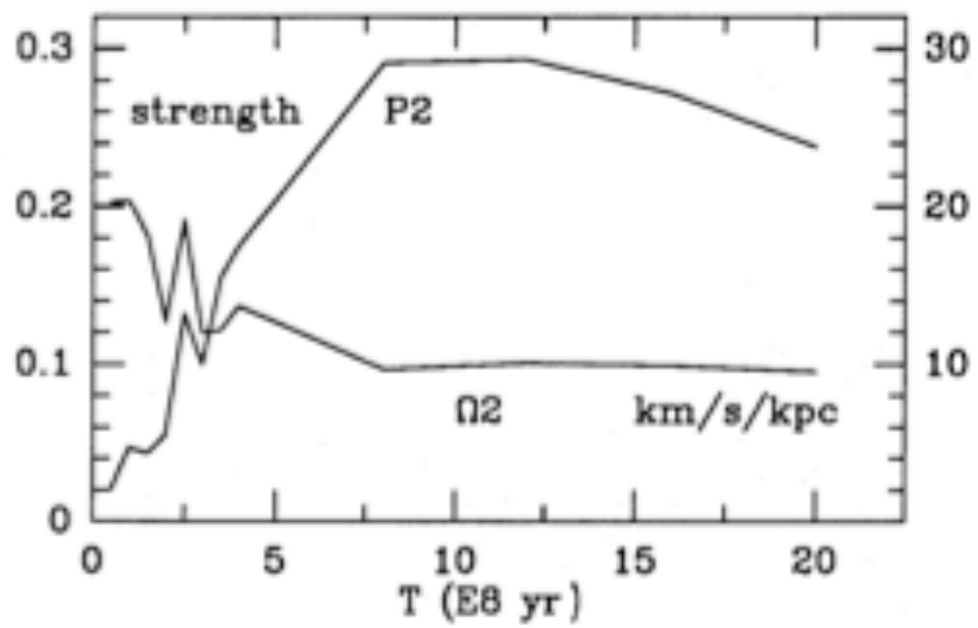
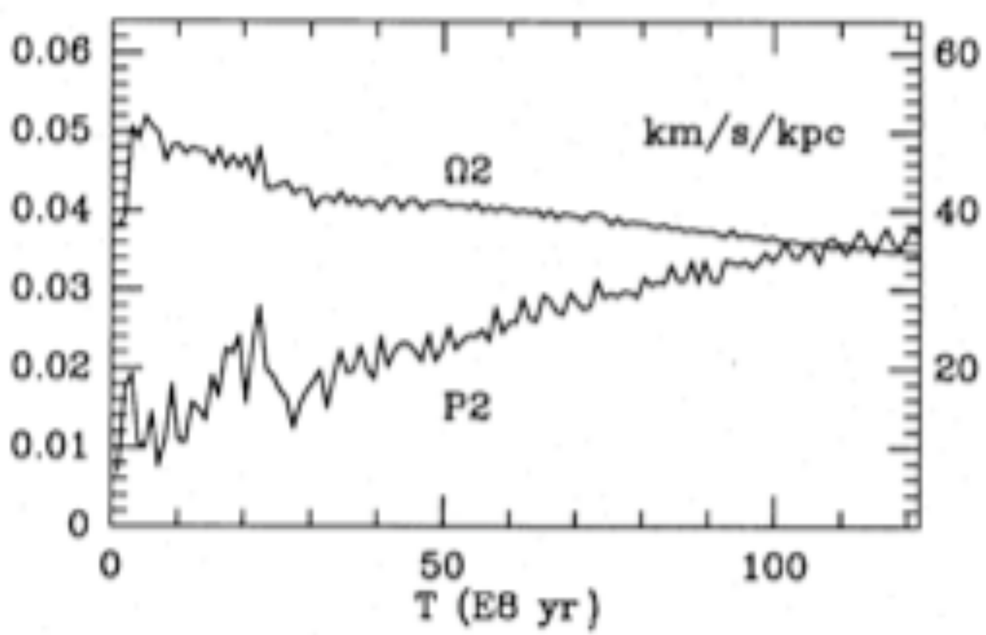
- AGN triggers?

Conclusions from SDSS

- Fiber metallicities of barred galaxies are uniformly higher by 0.06 dex.
- Fiber star-formation rates of barred galaxies are higher by 60%.
- Barred galaxies are redder at Log M > 10
- No correlation between bar length and star formation enhancement.
- Bars account for 3.5 times more triggered central star formation.

Theory vs. Observations for bars





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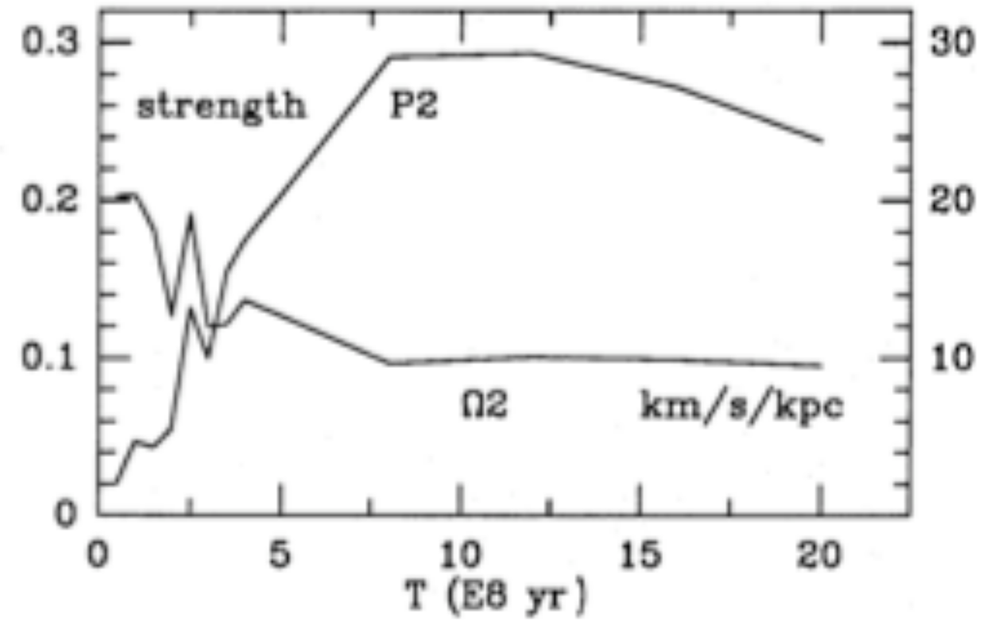
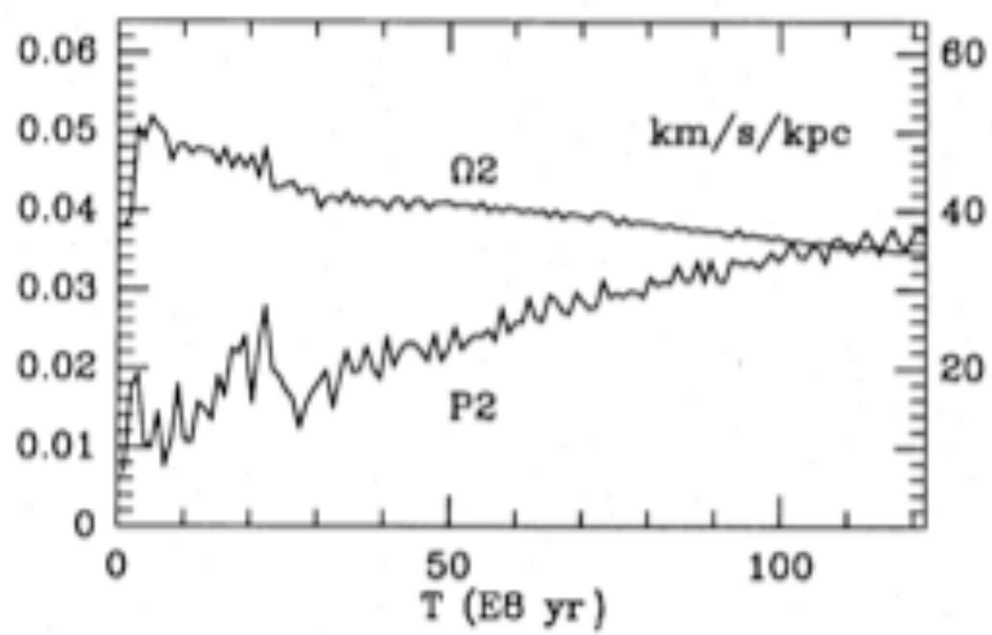
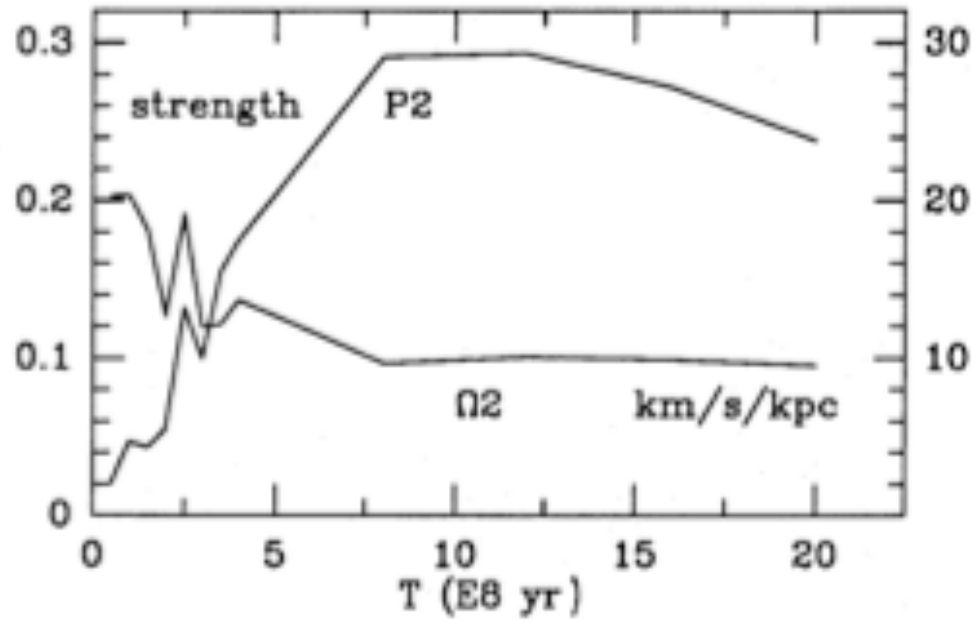


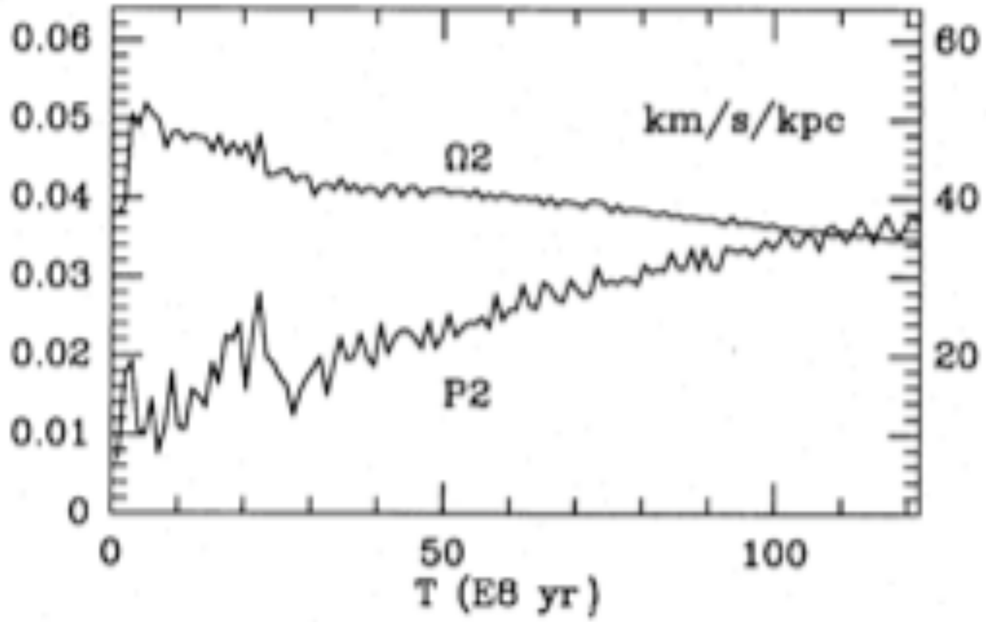


Combes & Elmegreen 1993

Theory vs. Observations for bars

Weak bars





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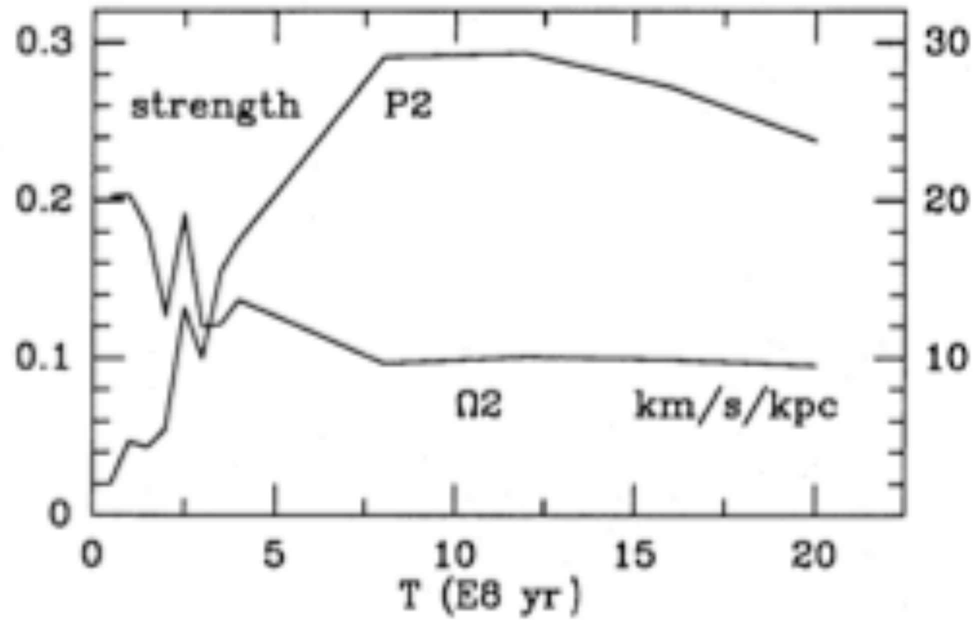

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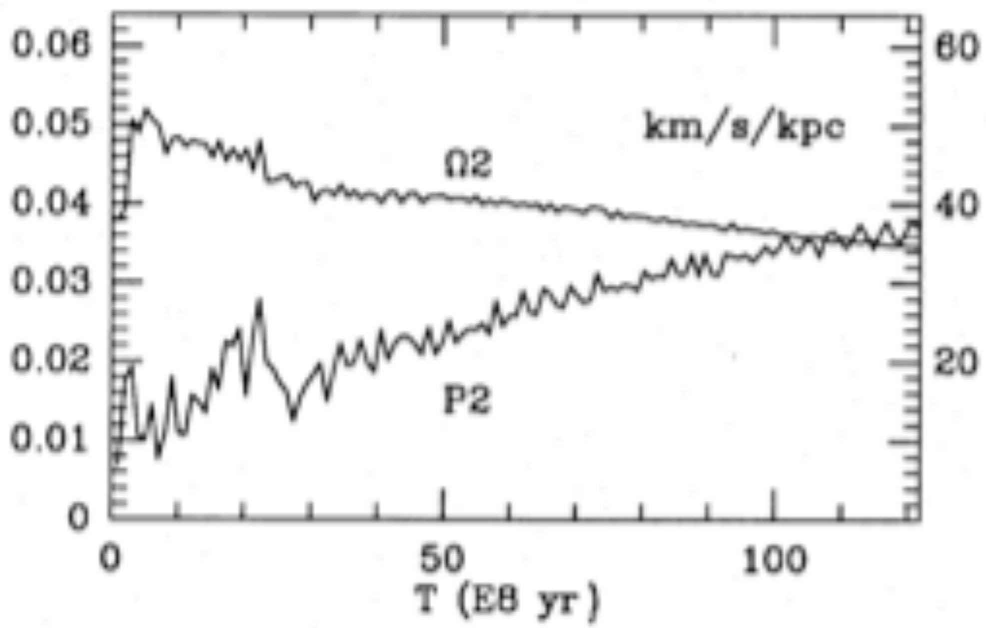

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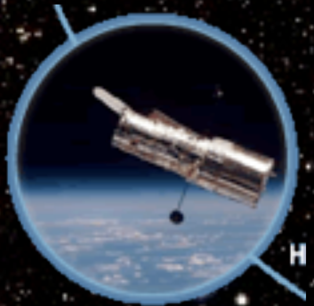
Cosmic Evolution Survey
cosmos



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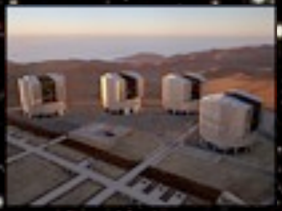

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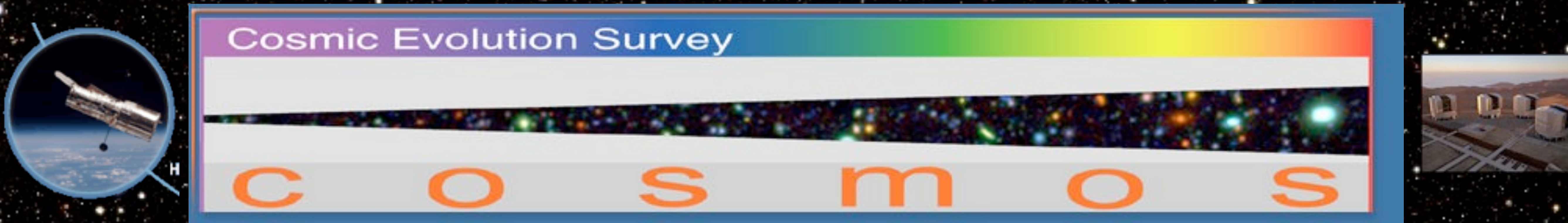

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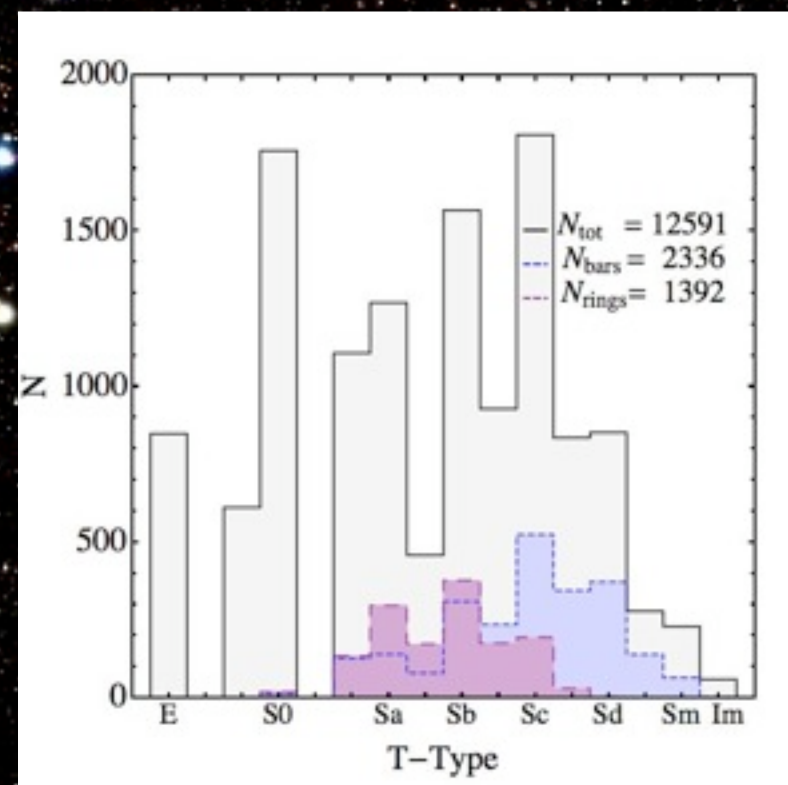

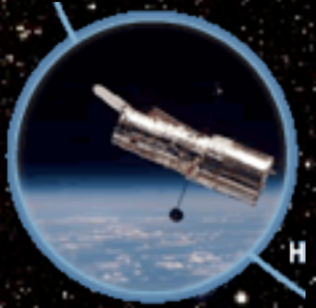

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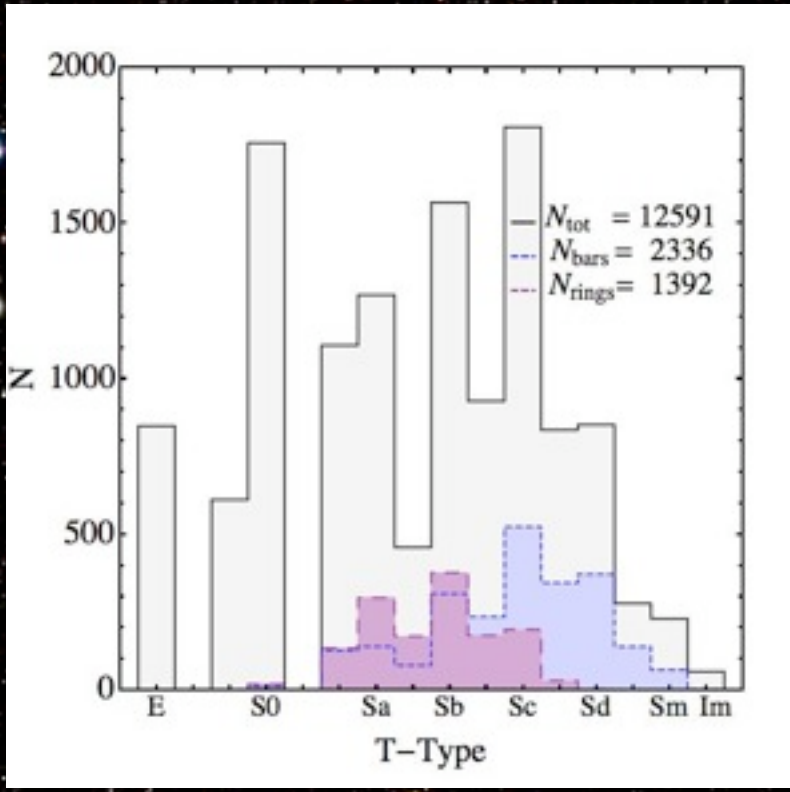

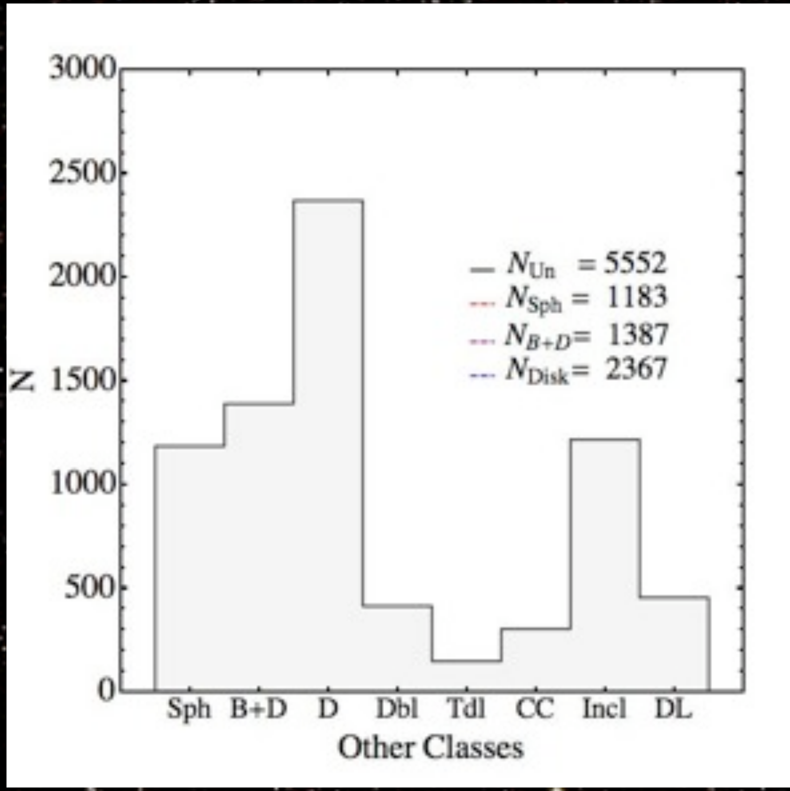

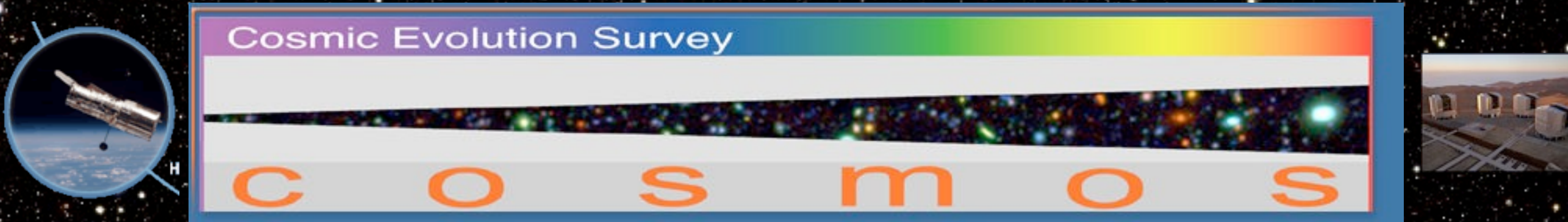

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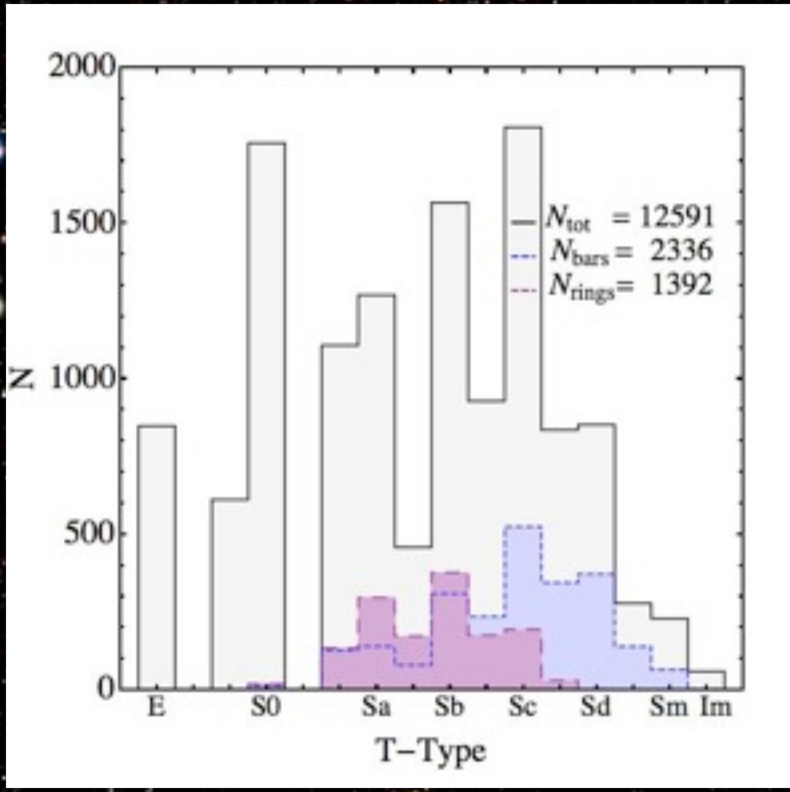

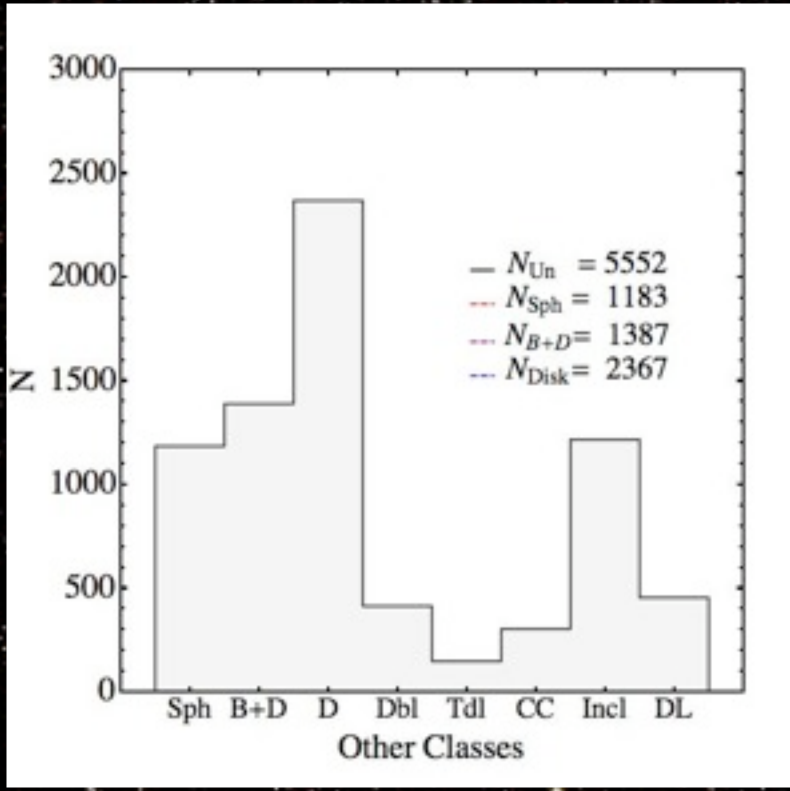

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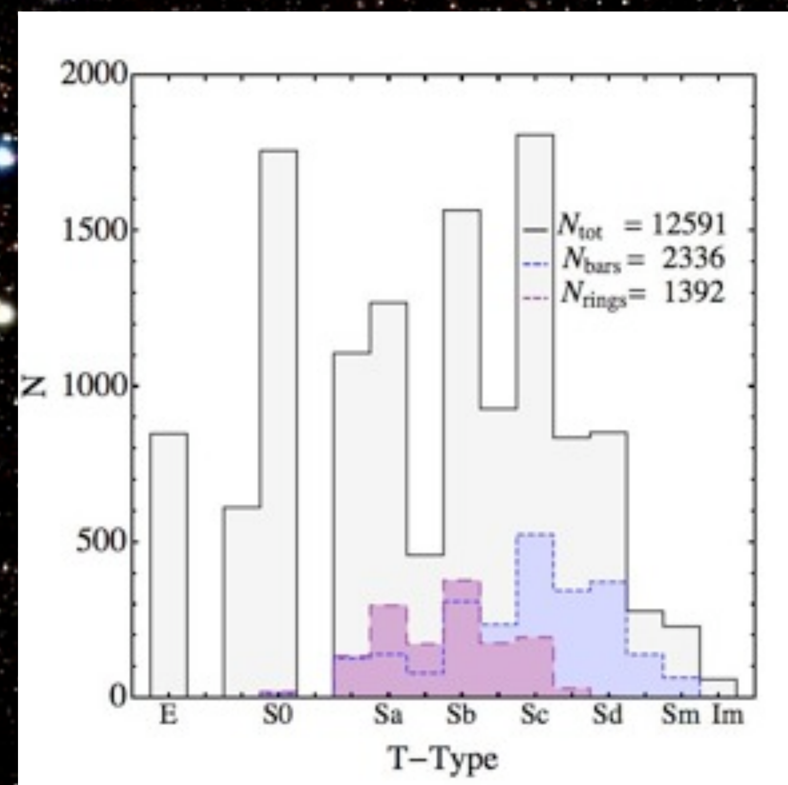

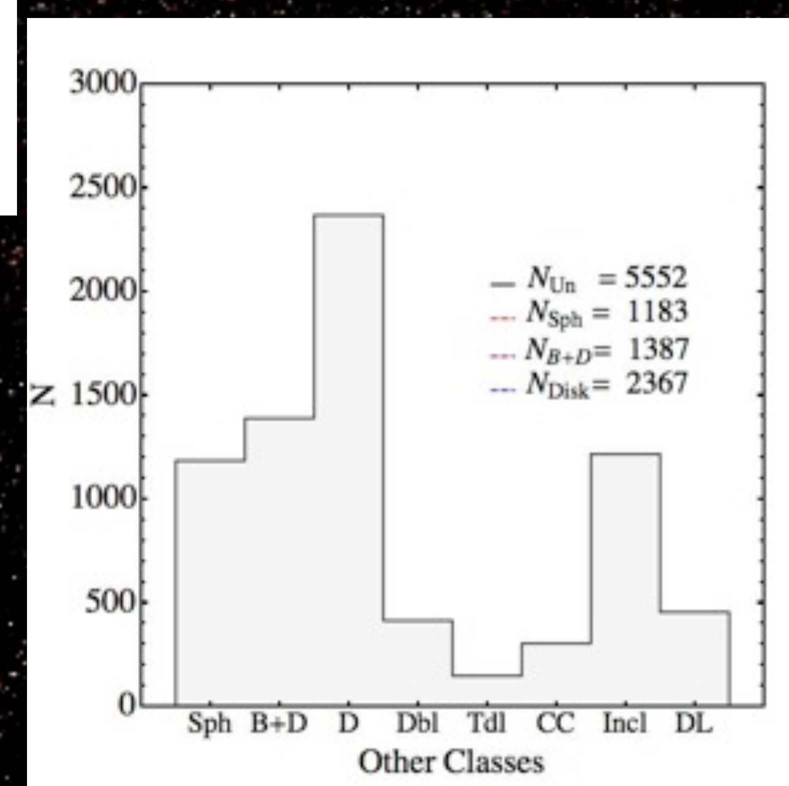

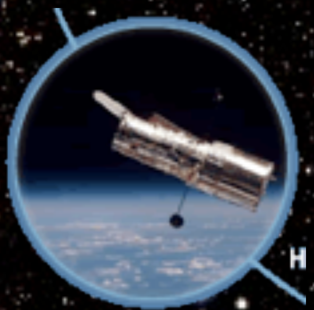

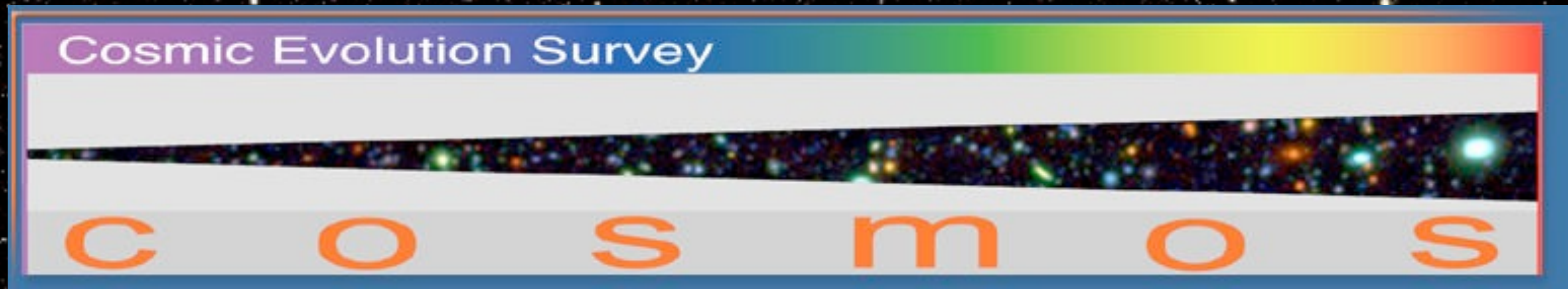

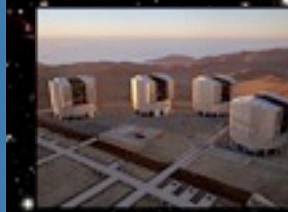

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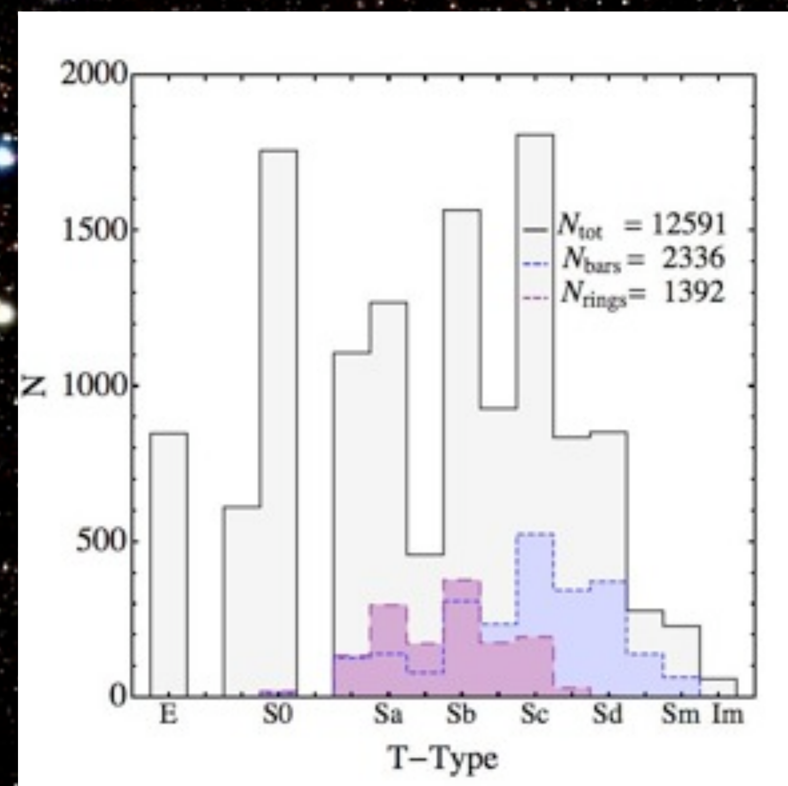

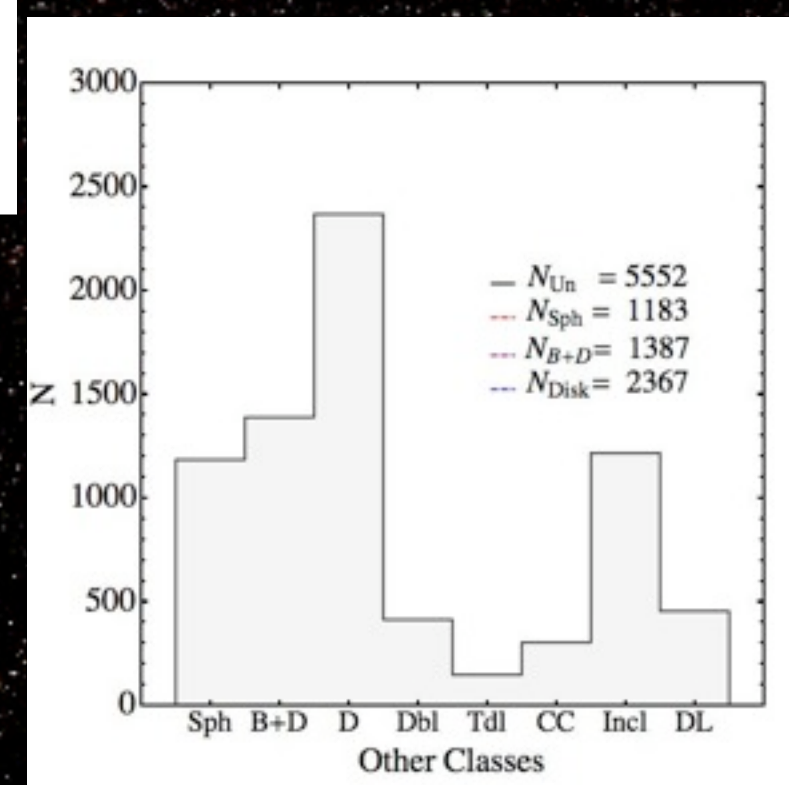

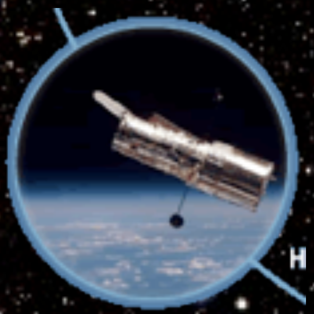

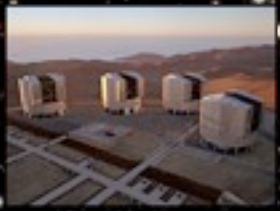

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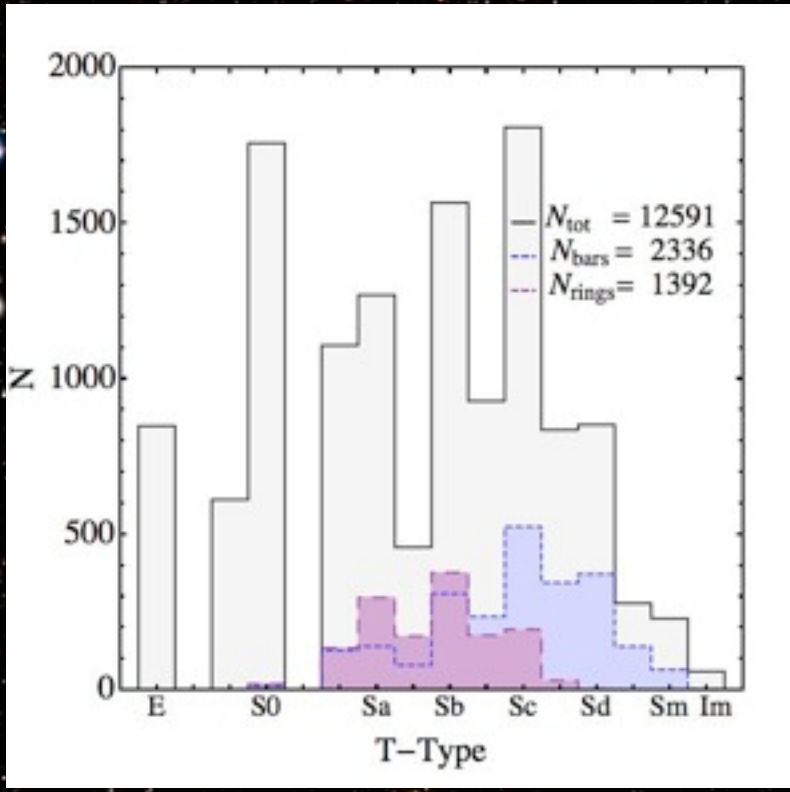

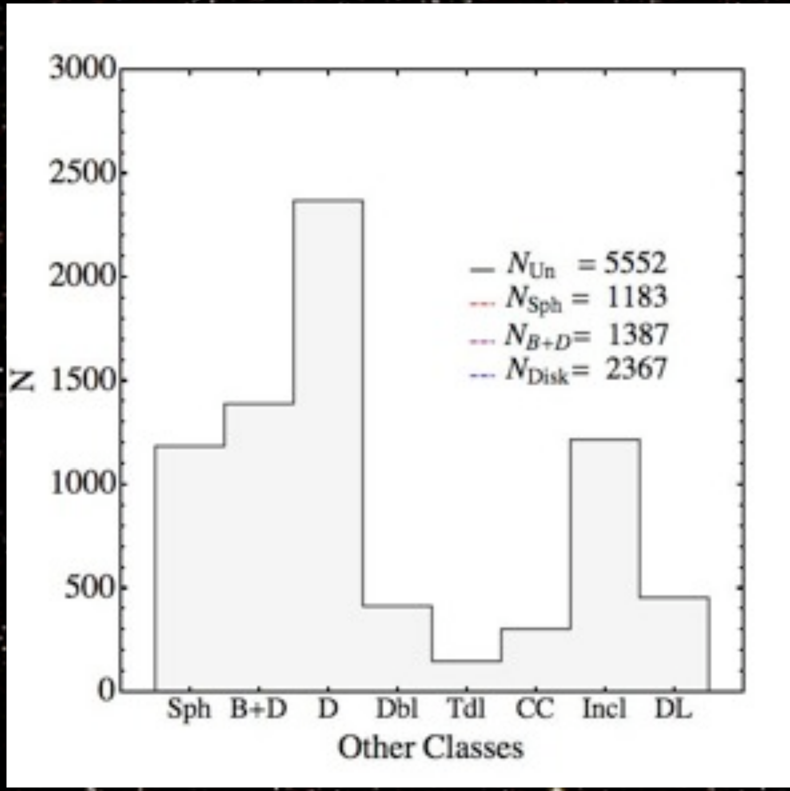

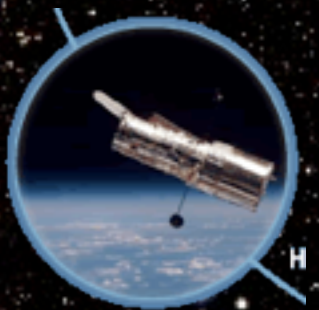

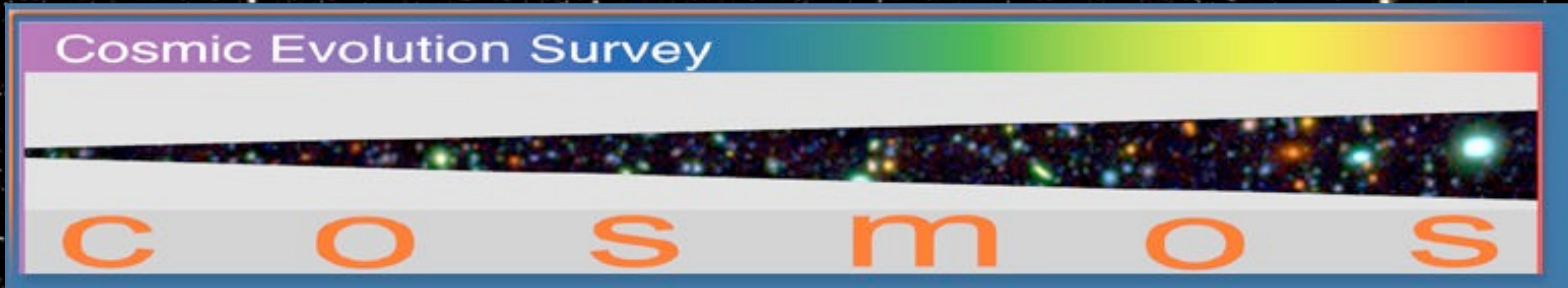

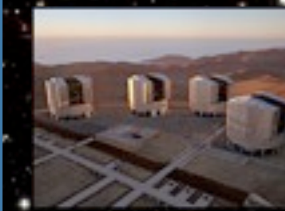

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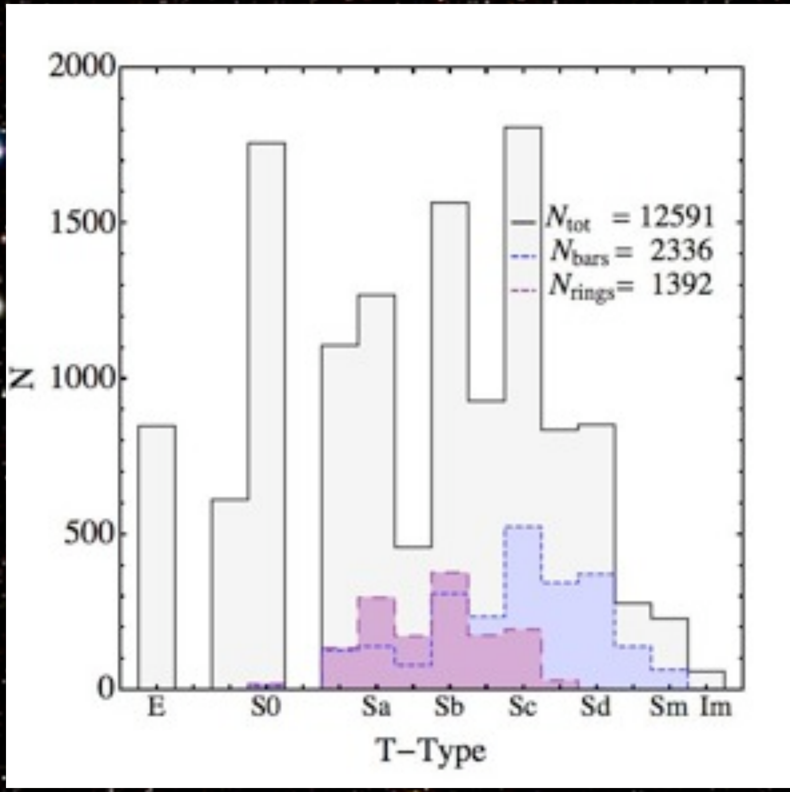

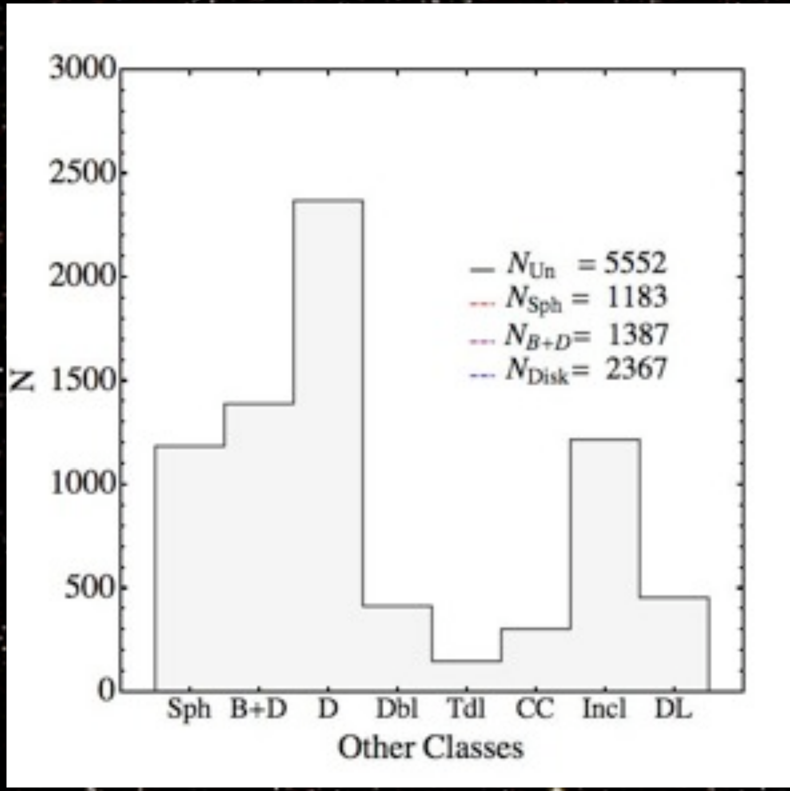

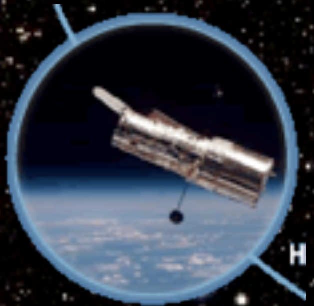

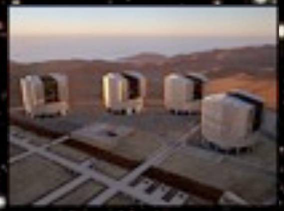

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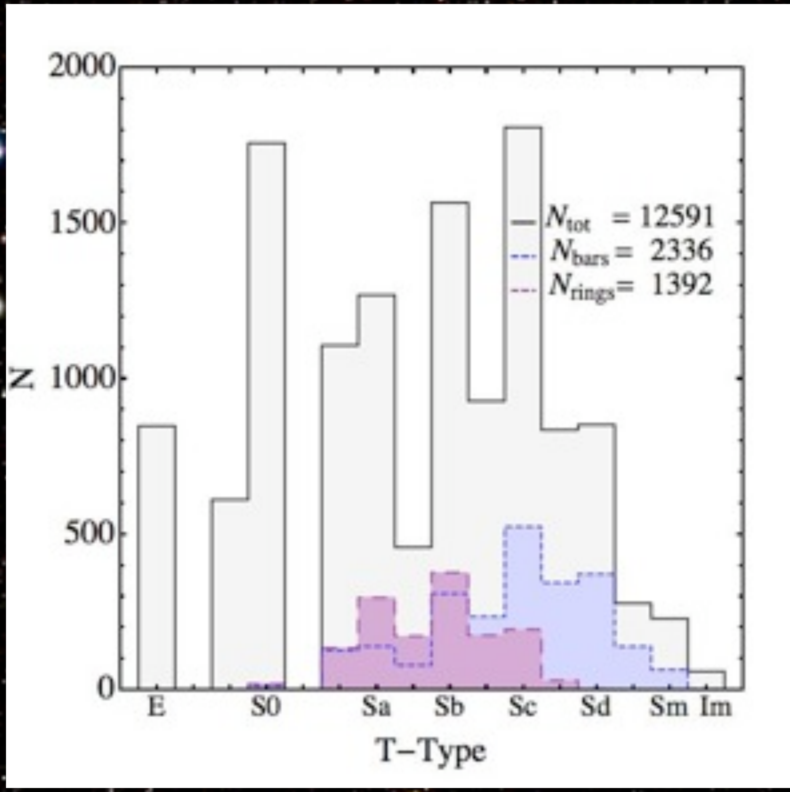

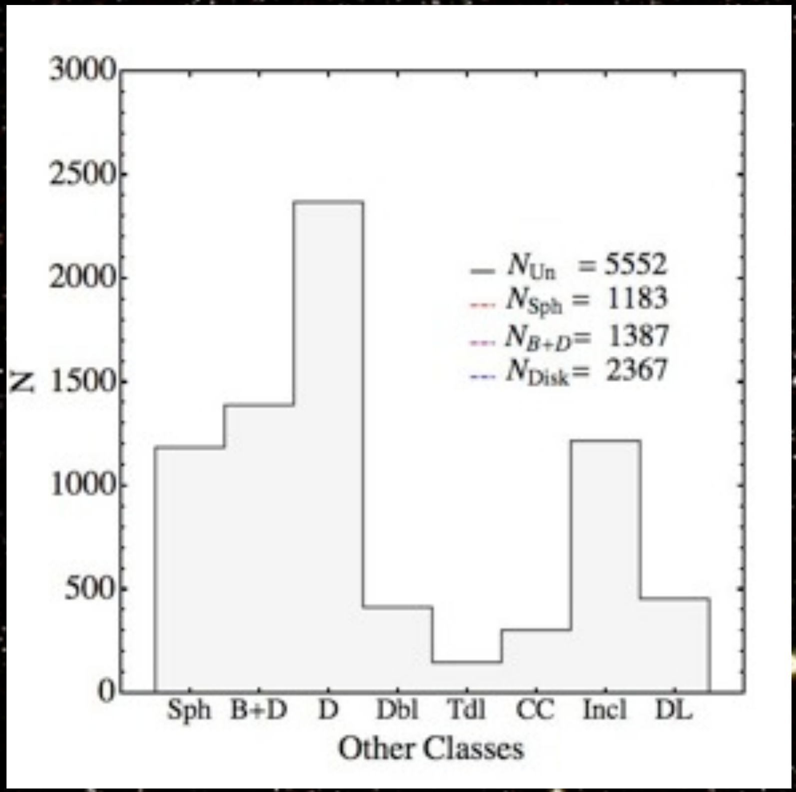

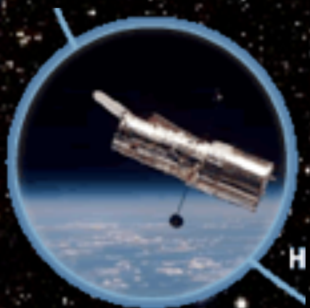

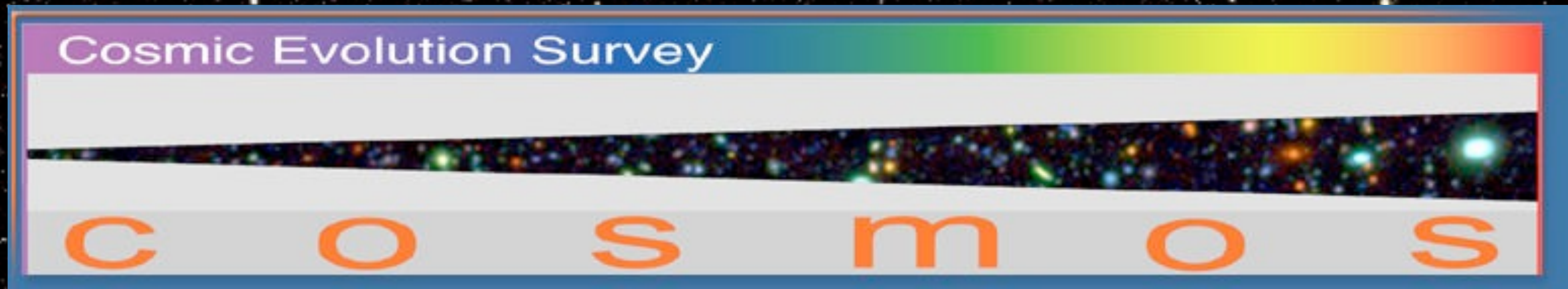

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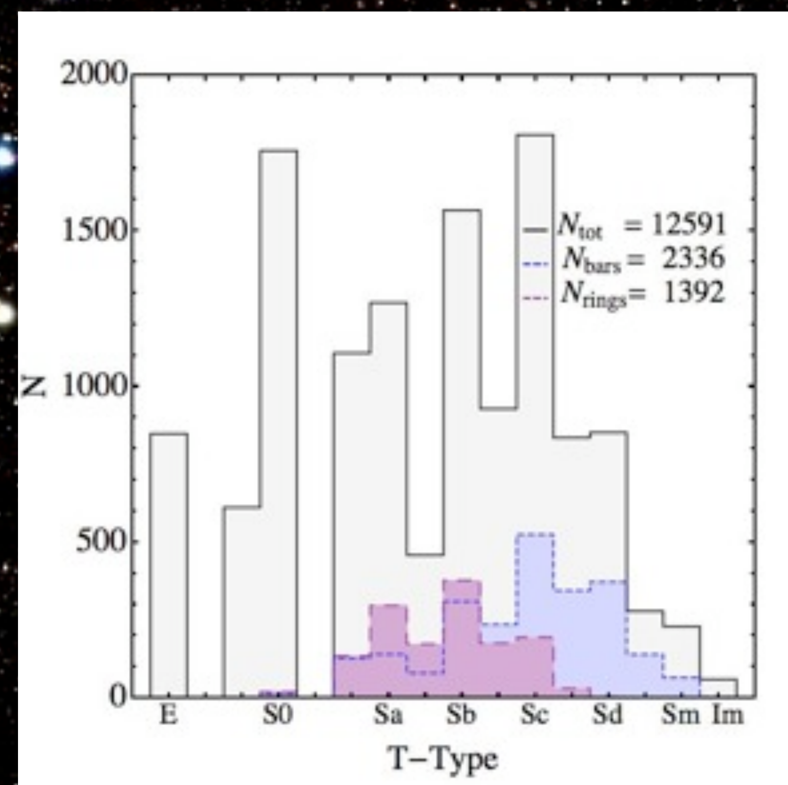

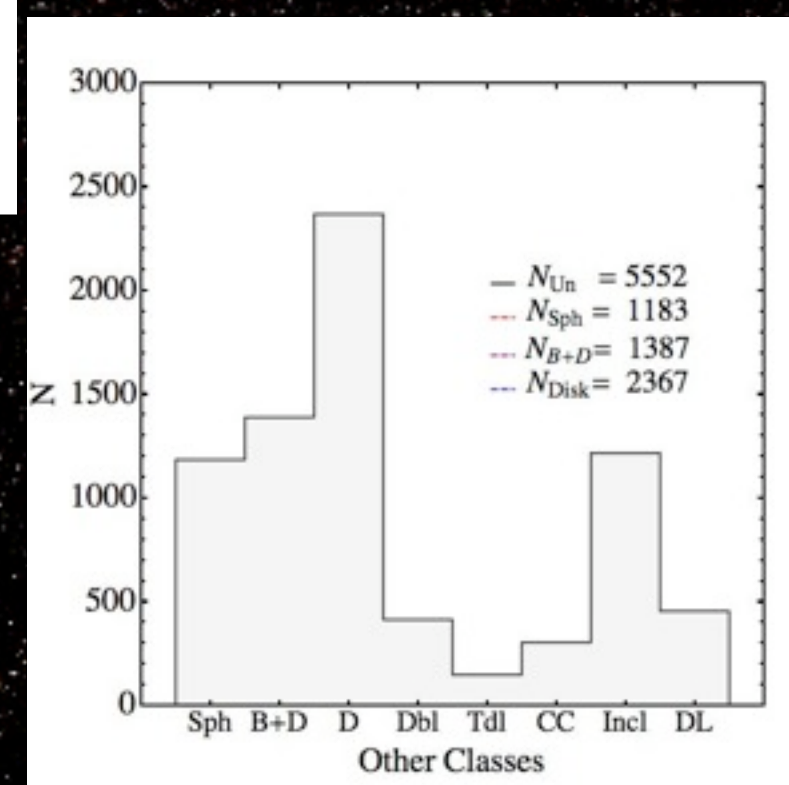

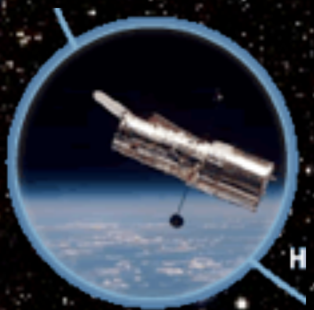

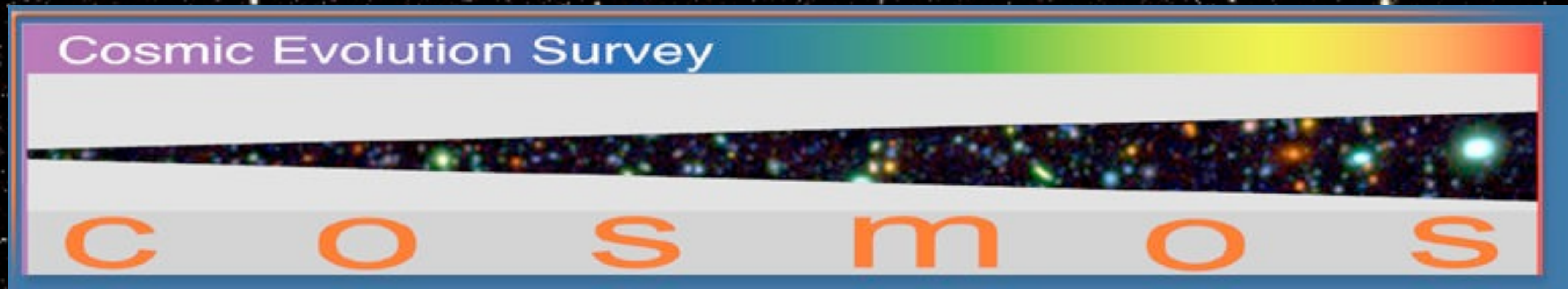

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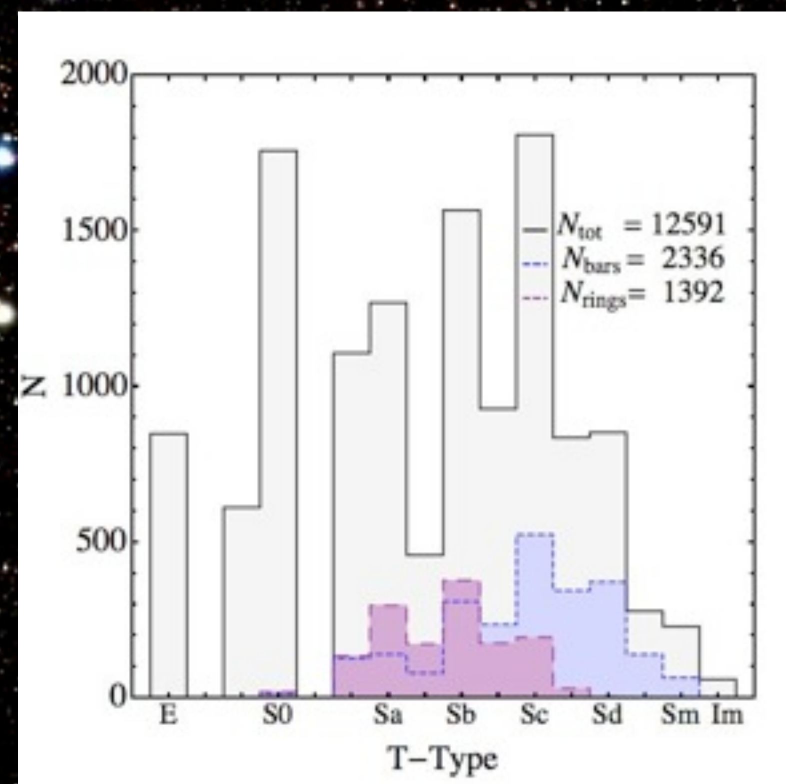
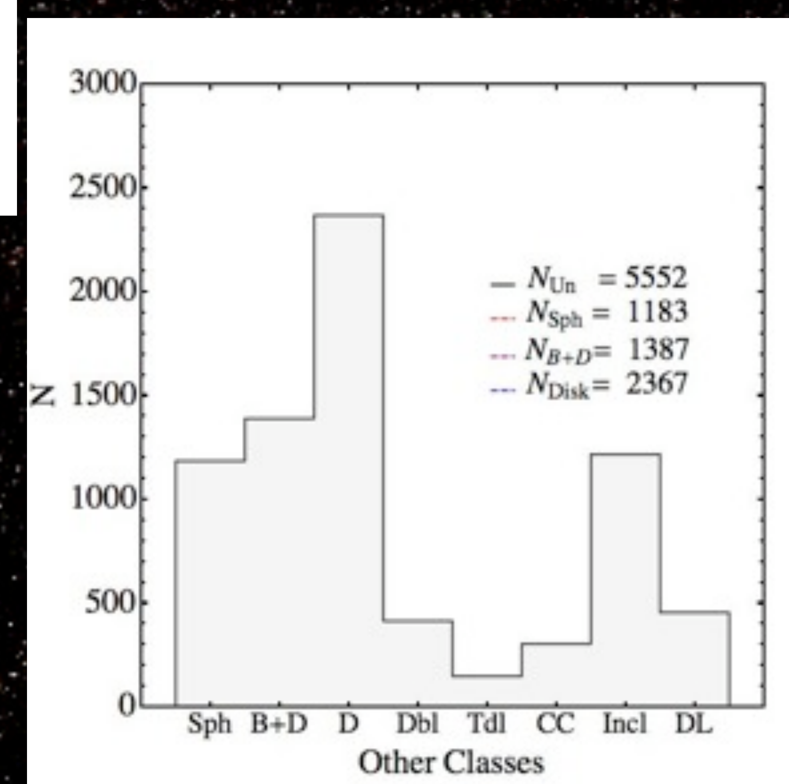
    - Additional flags: “Incl” corresponds to inclined or edge on galaxies and “DL” to galaxies with dust lanes.

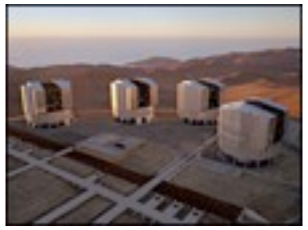




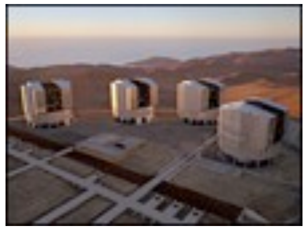
Quantity	$z < 0.45$	$0.45 < z < 0.9$	$0.9 < z < 1.4$
STB vs. AGN	Hα, [NII], [SII] [OIII], Hβ	[OIII],[OII],Hβ	[OII],[NeIII], Hδ
SFR	Hα	Hβ	[OII]
Reddening	Hα/Hβ	Hβ/Hγ	
Gas-phase Metallicity	N2=[NII]/Hα N2O3=[NII]/[OIII]	R_{23}	[OII],[NeIII], Hδ
Stellar mass	photometric SED +(D_{4000} + $H\delta_A$)($0.3 < z < 1.3$)		
Stellar mass, age metallicity & SFH	stellar cont. + abs. lines + photometry		

AGN diagnostics

- MEx diagram



COSMOS
z-COSMOS
40'000 VLT redshifts for COSMOS



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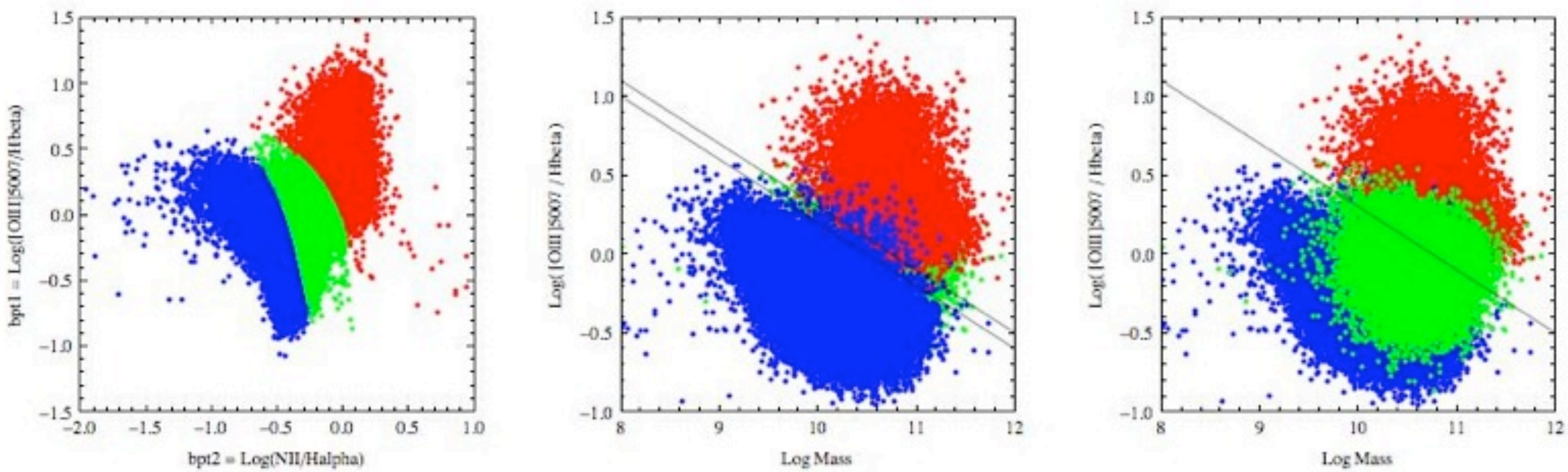

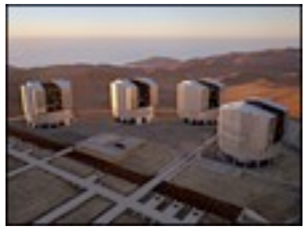

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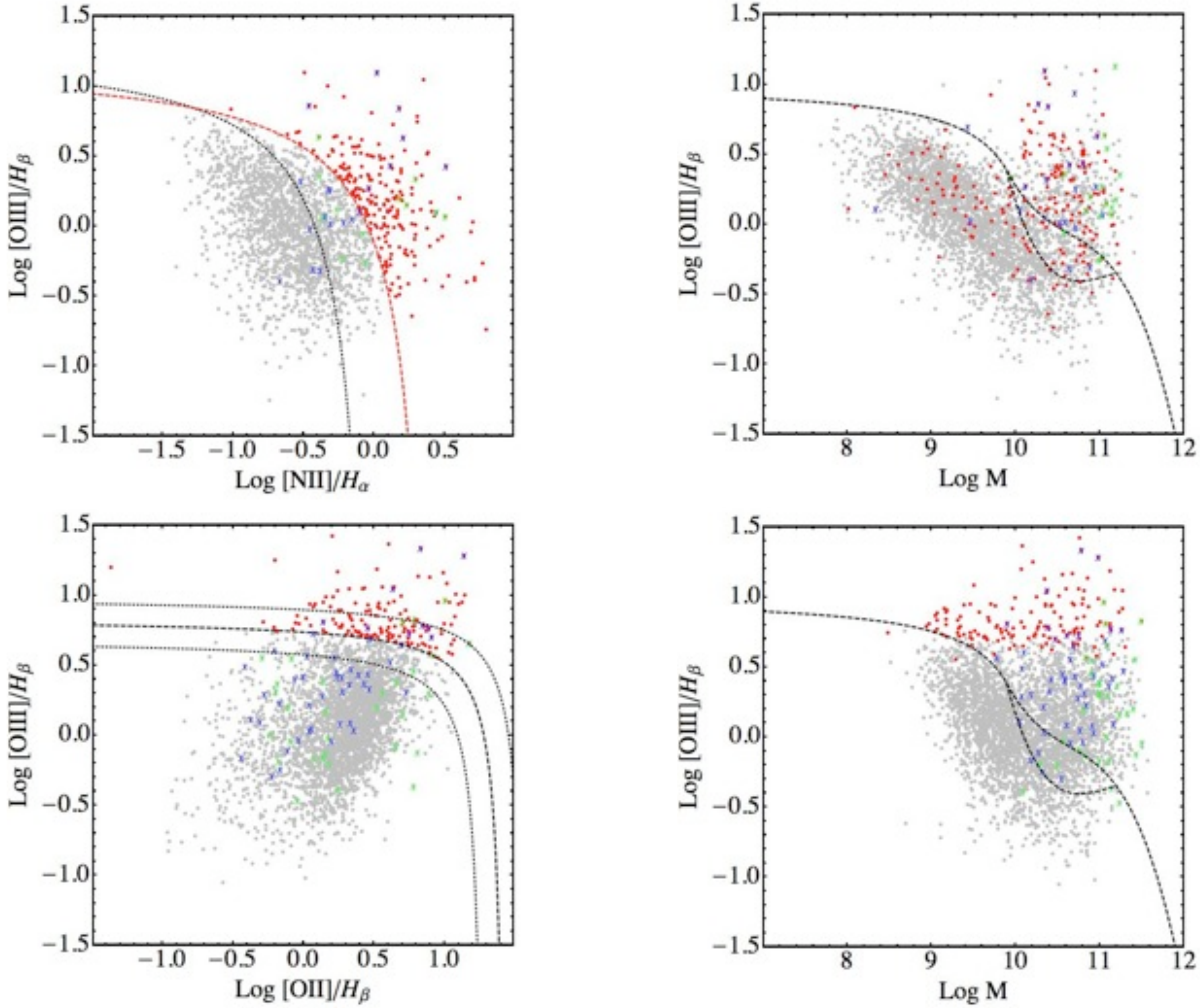
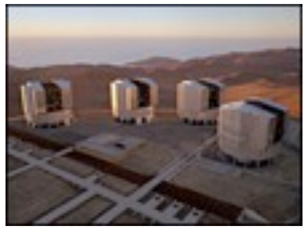
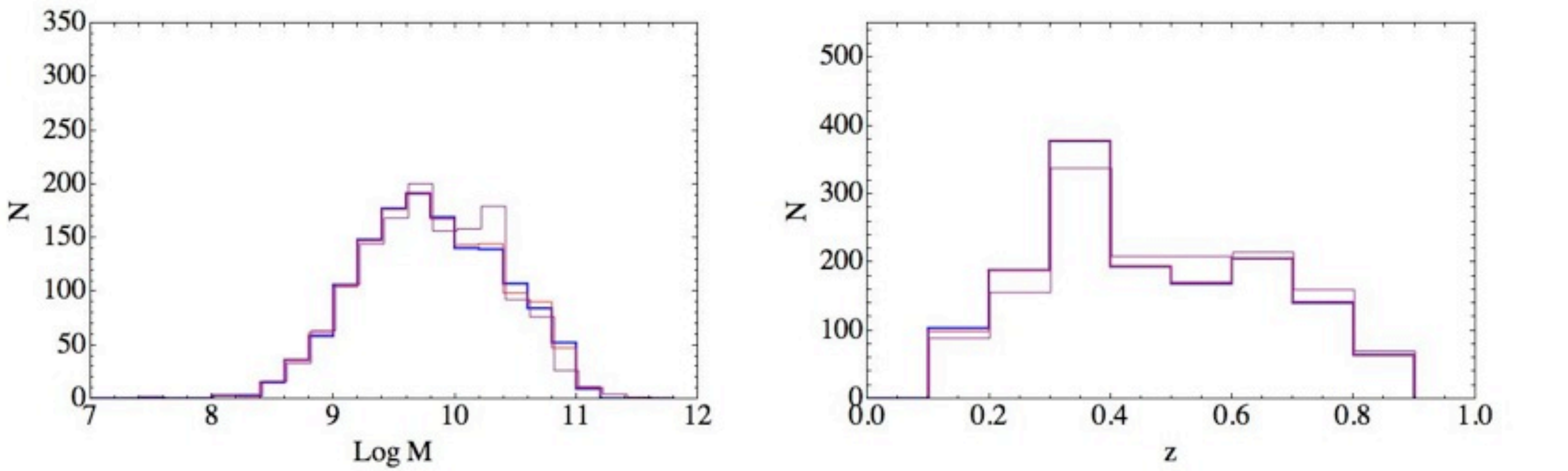


Sample size increases from ~1300 to 6200



Properties of high-z Barred Galaxies

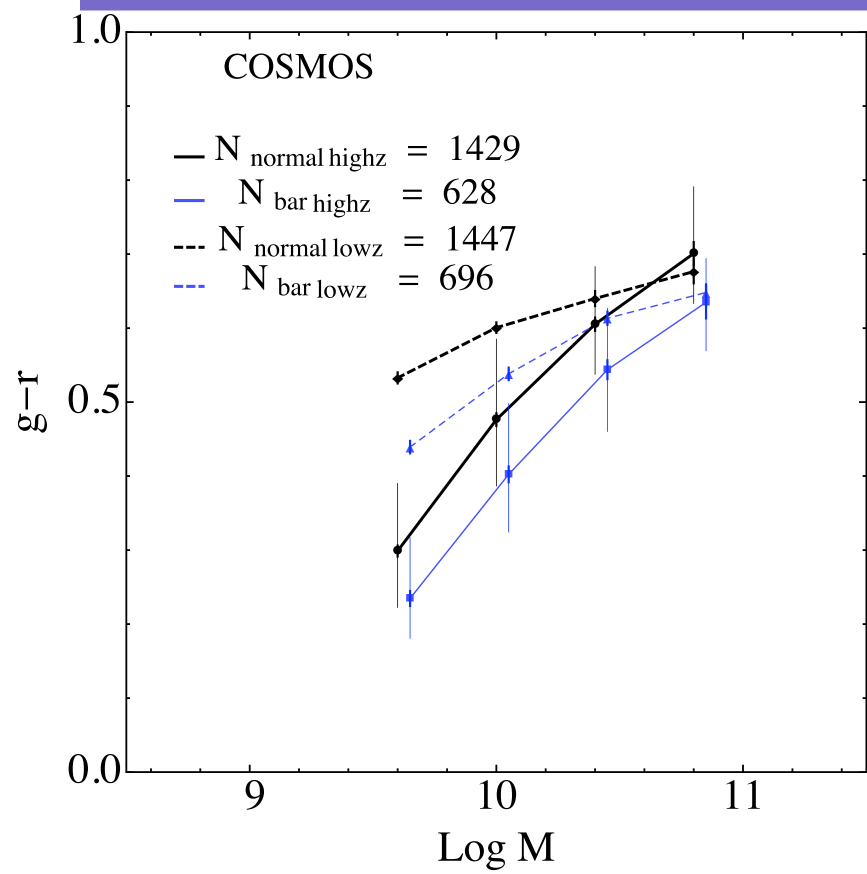
- sample selection

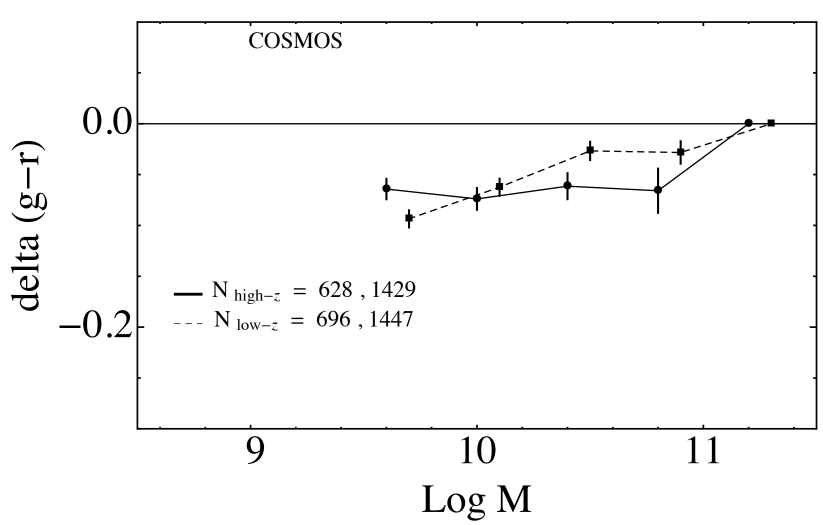


- Each barred galaxies is matched in mass and redshift to a control sample, where the control galaxies have no secular signatures (bars/rings/lenses).

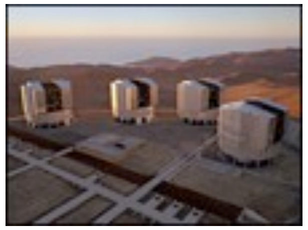
Properties of high-z Barred Galaxies

- Color Evolution





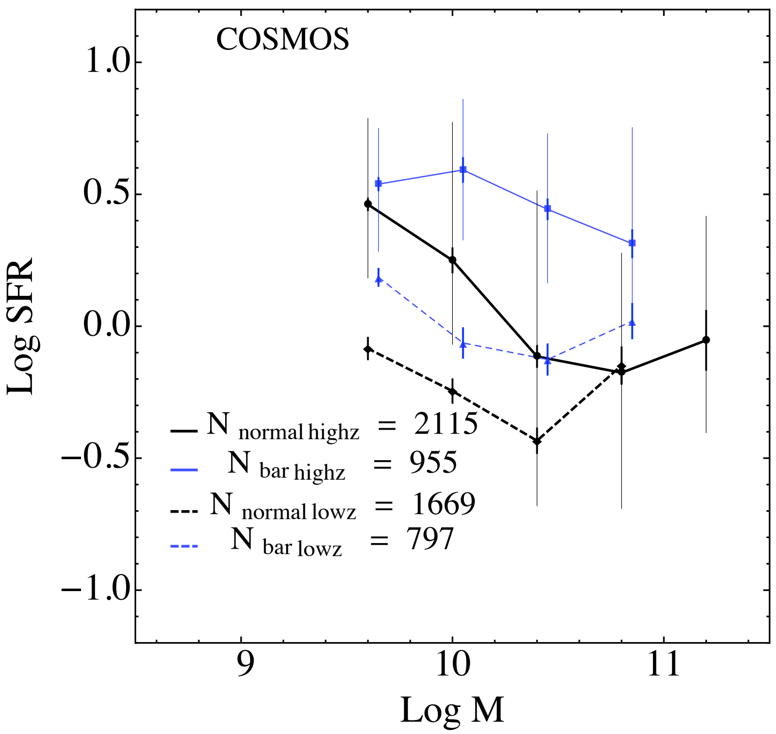
- Barred galaxies are bluer than control galaxies at all masses and at high and mid-z.
- The strength of the color offset decreases with redshift => barred galaxies are being quenched.
- Barred galaxies have to undergo 0.1 mag in color evolution since z~0.85



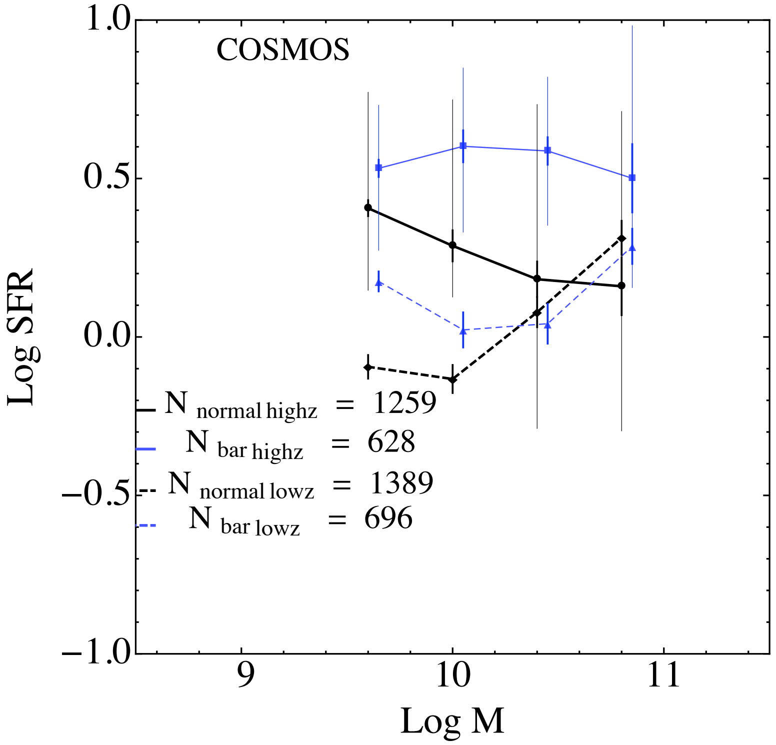
Properties of high-z Barred Galaxies

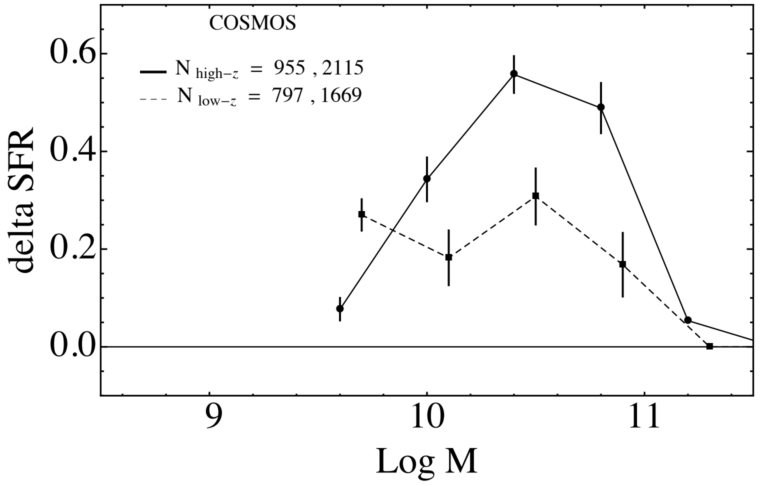
- Star Formation Rates

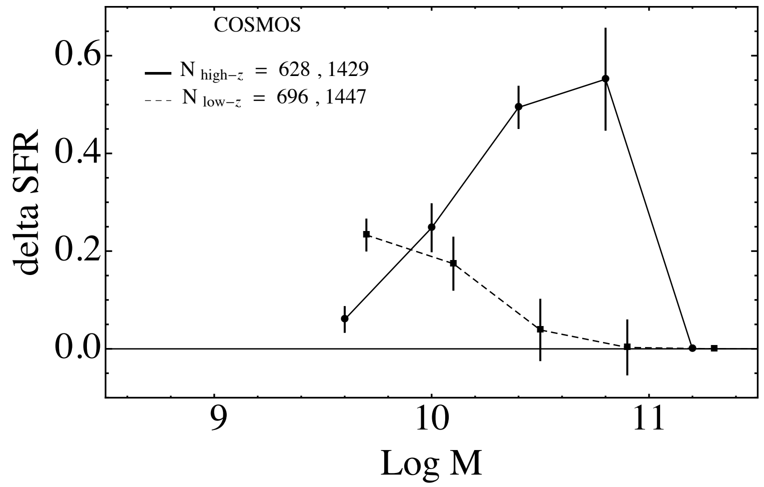
All



No MEx AGN



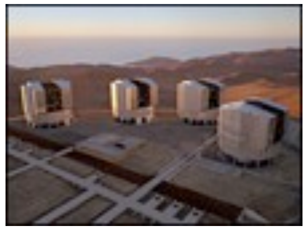




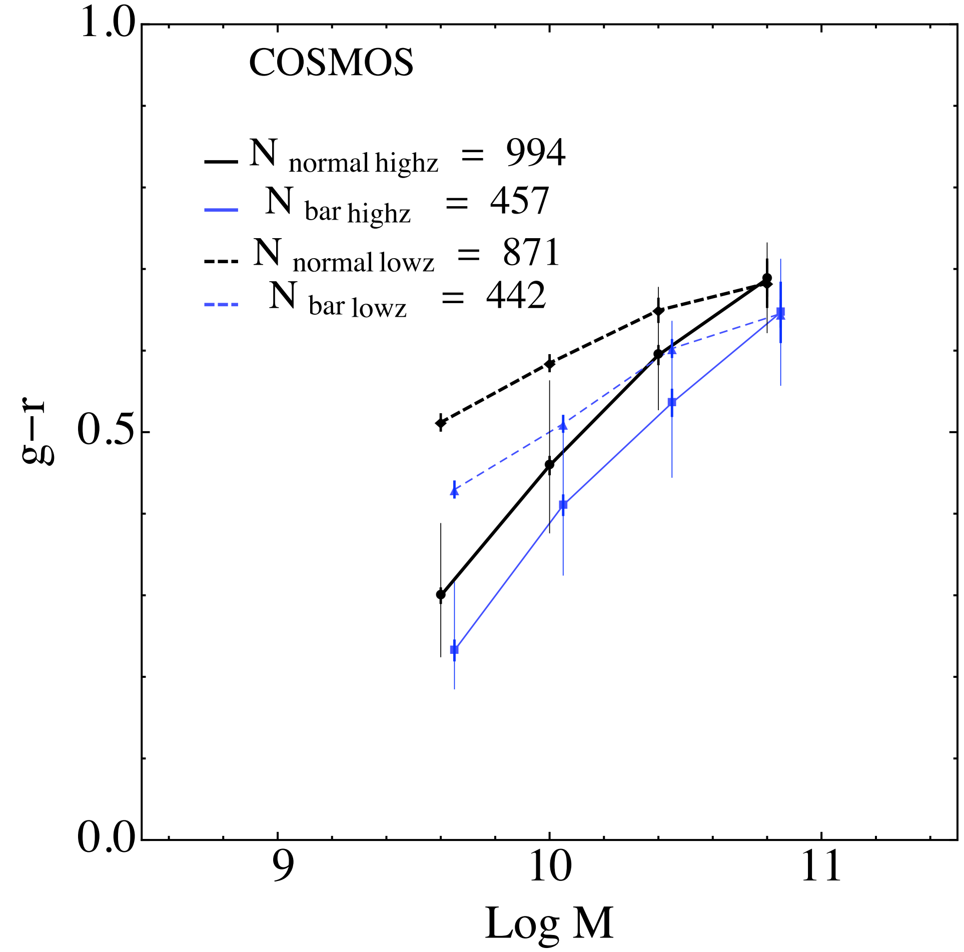
- Barred galaxies have a higher (mass dependent) star formation rate than control galaxies at all masses and at high and intermediate-z. (if AGN are ignored)
- Using MEx AGN, at intermediate redshifts, barred galaxies are quenched.

Properties of high-z Barred Galaxies

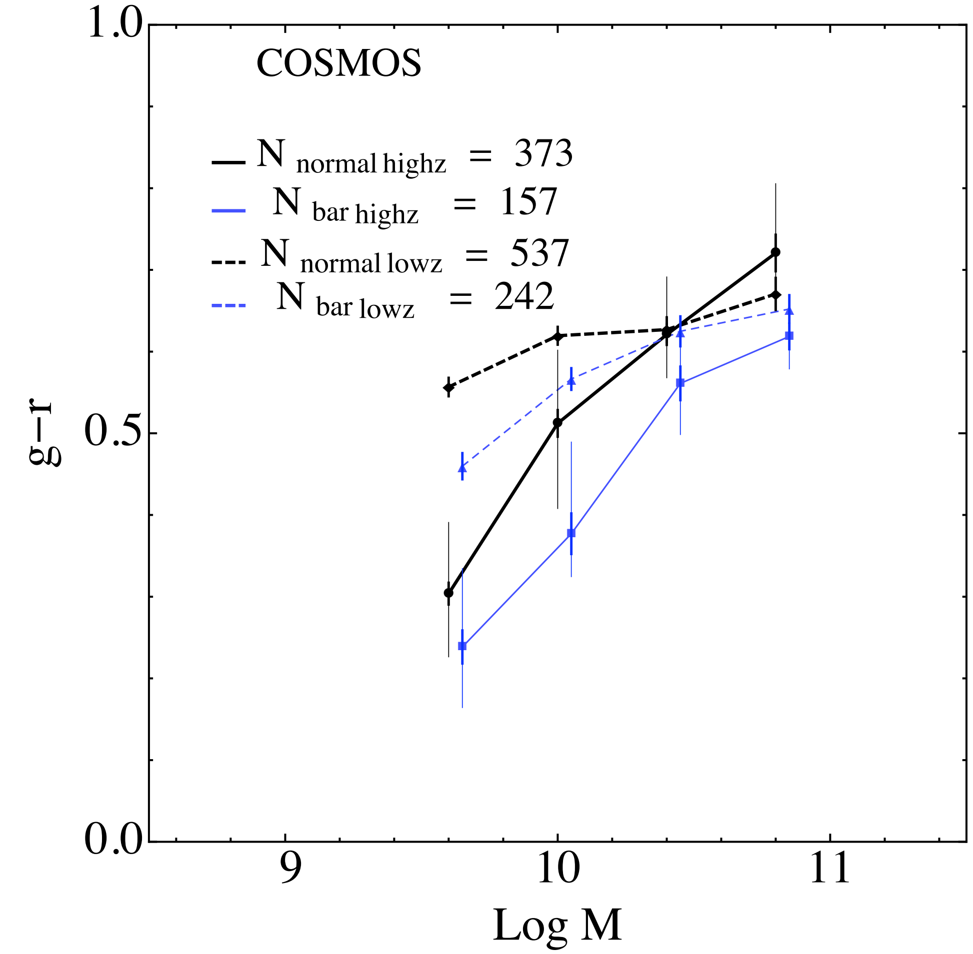
- Color/Environment



Sparse: N<2

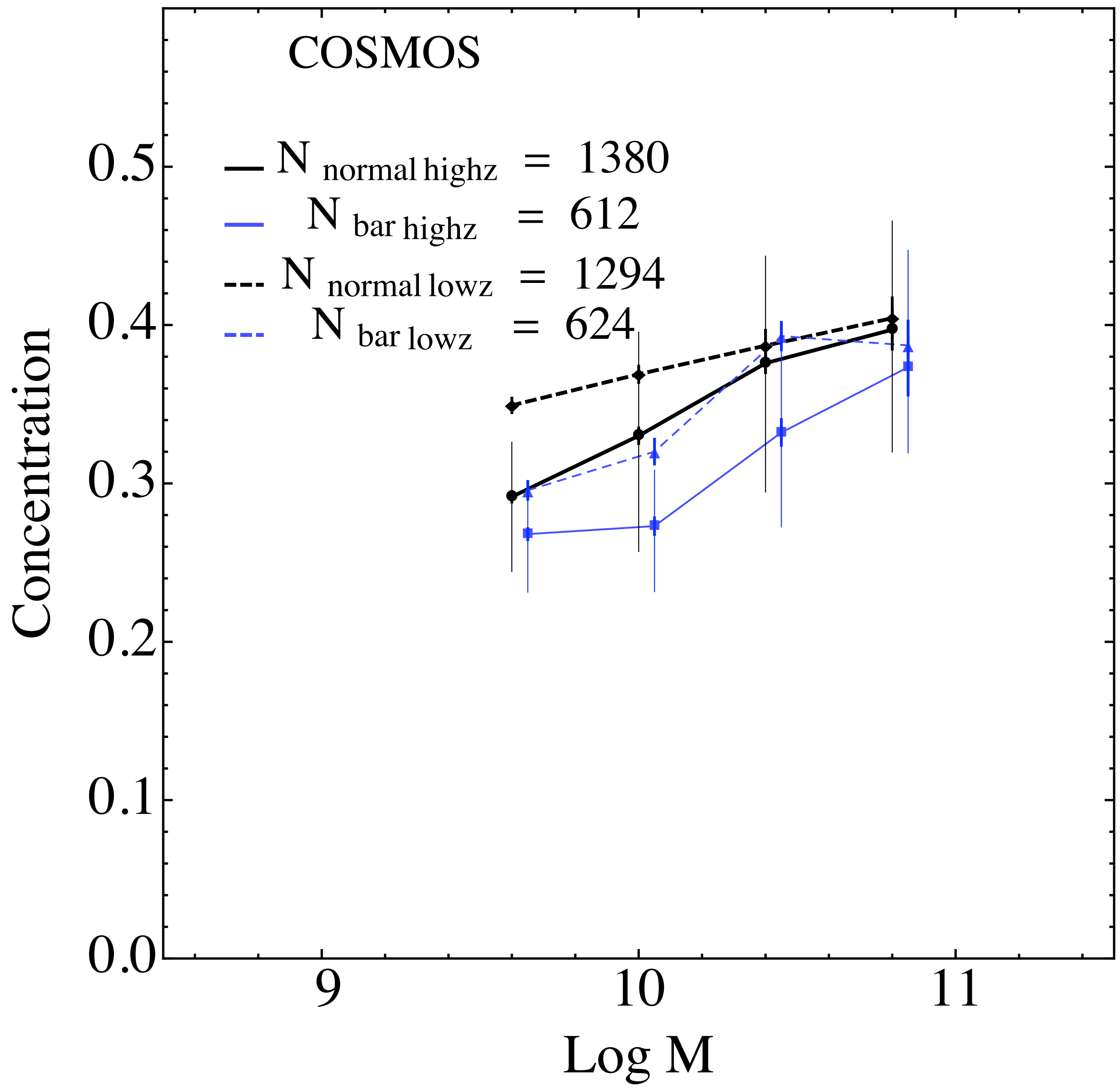


Rich: N>2



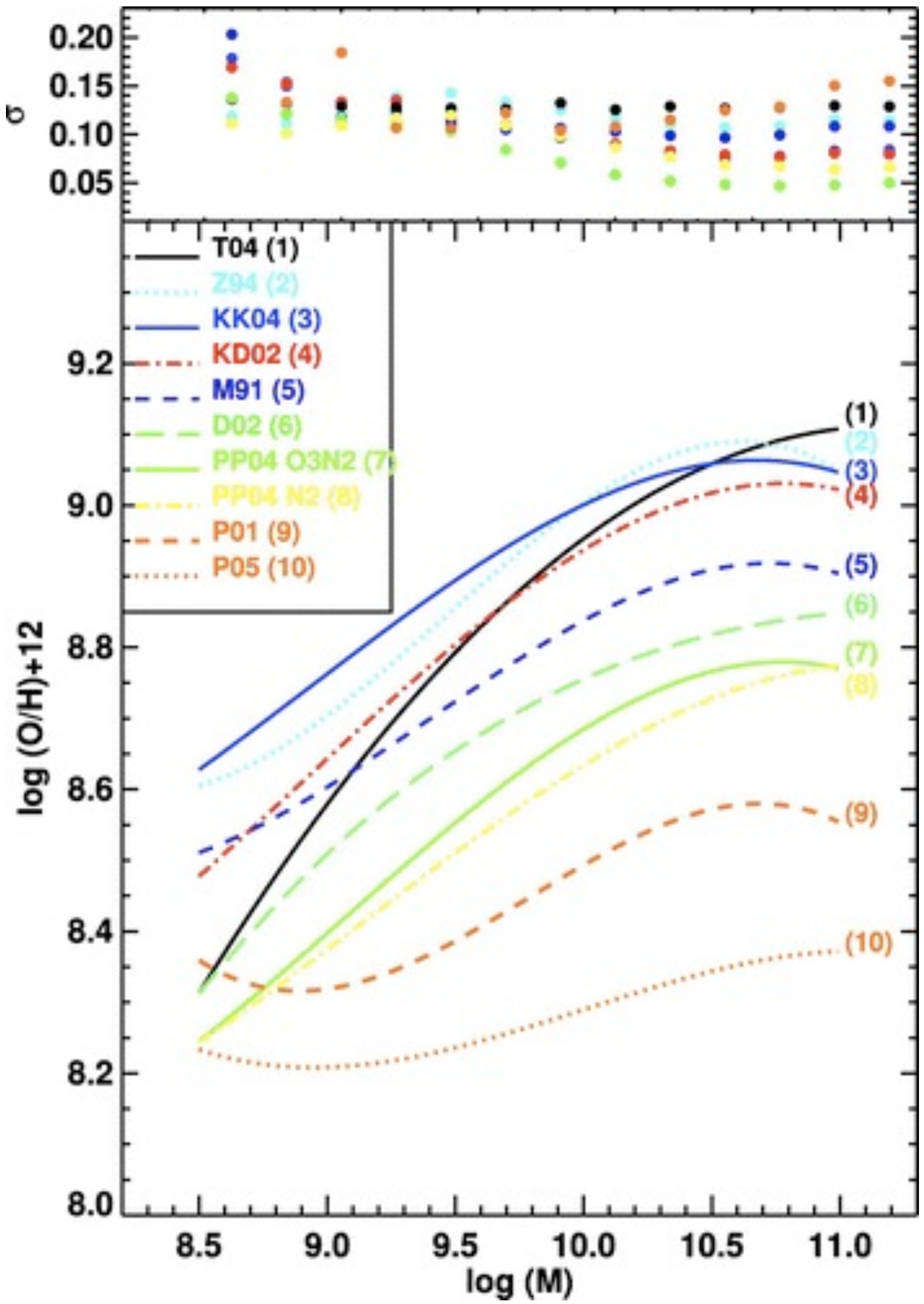
Properties of high-z Barred Galaxies

- Central concentration

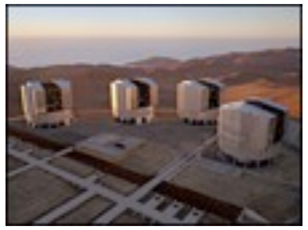


- Barred galaxies are less concentrated than the control sample at high redshifts.
- In the intermediate mass regime, barred galaxies are nearly the same concentrations as the control at high masses. Bulges are being built?

Metallicity Calibrators

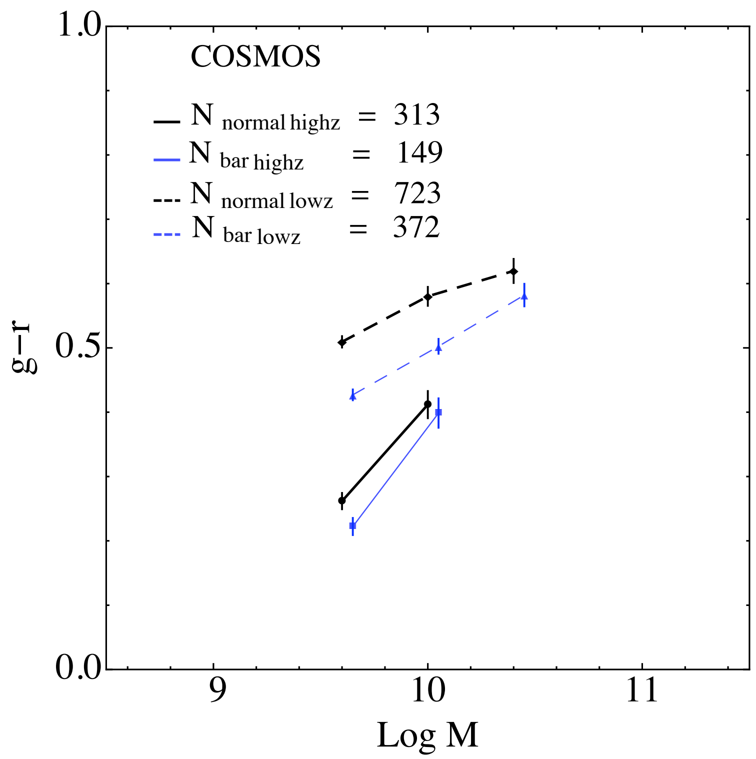


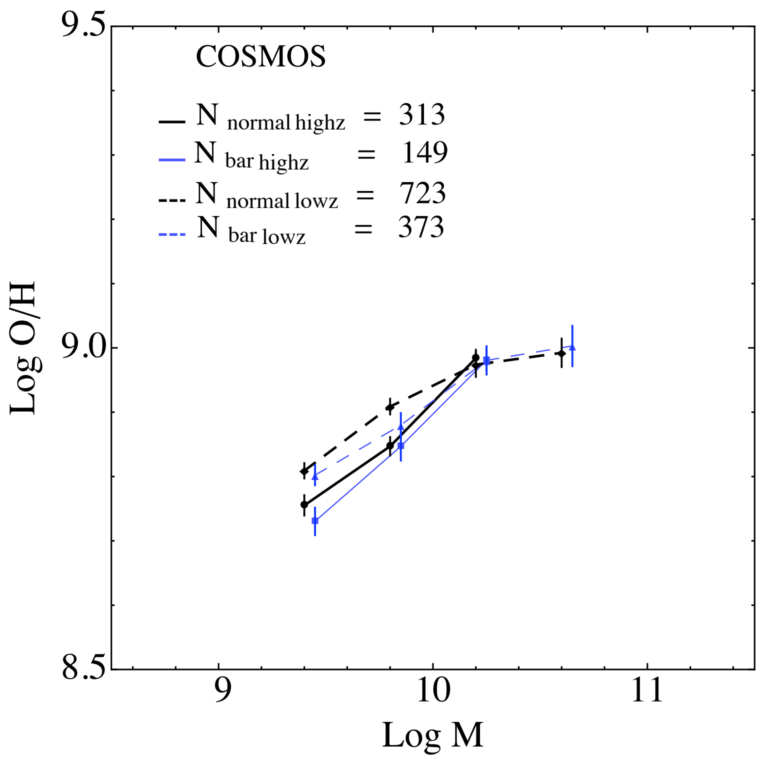
1. Tremonti 2004 - Theoretical estimator — [OII],Hβ,[OIII],Ha,[NII],[SII]
2. Zaritsky 1994 - Theoretical estimator — R_{23}
3. Kobulnicky & Kewley 2004 - Theoretical — R_{23}, [OIII]/O[II]
4. Kewley & Dopita 2002 - Theoretical — [NII]/[OII], R_{23}, [OIII]/O[II]
5. McGaugh 1991 - Theoretical — R_{23}, [OIII]/O[II]
6. Demicolo et al. 2002 - Combined — [NII]/Ha,
7. Pettini & Pagel 2004 -Empirical — [NII]/Ha, [OIII]/Hβ
8. Pettini & Pagel 2004 - Empirical — [NII]/Ha
9. Pilyugin 2001 - Empirical — R_{23}, [OIII]/O[II]
10. Pilyugin et al. 2005 - Direct — $[OIII]_{4363}$, $[OIII]_{4959,5007}$

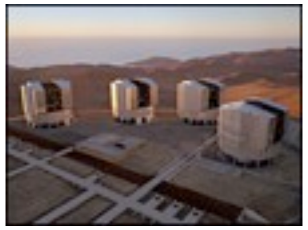


Properties of high-z Barred Galaxies

- Metallicities

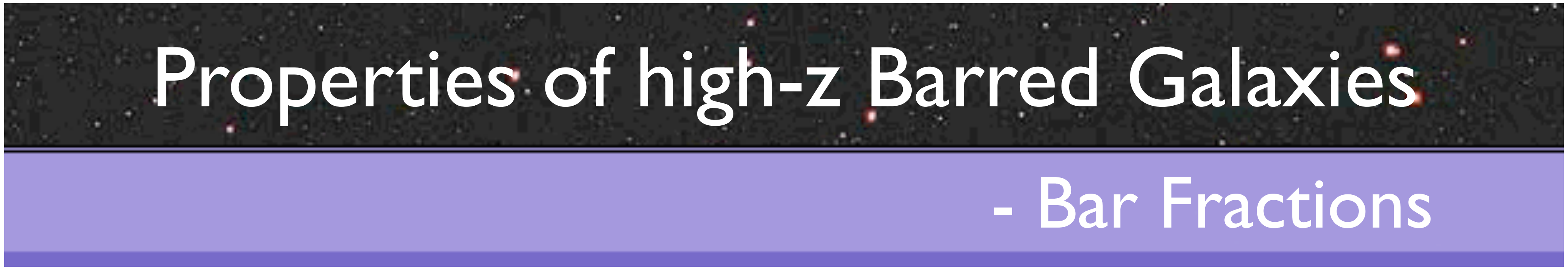




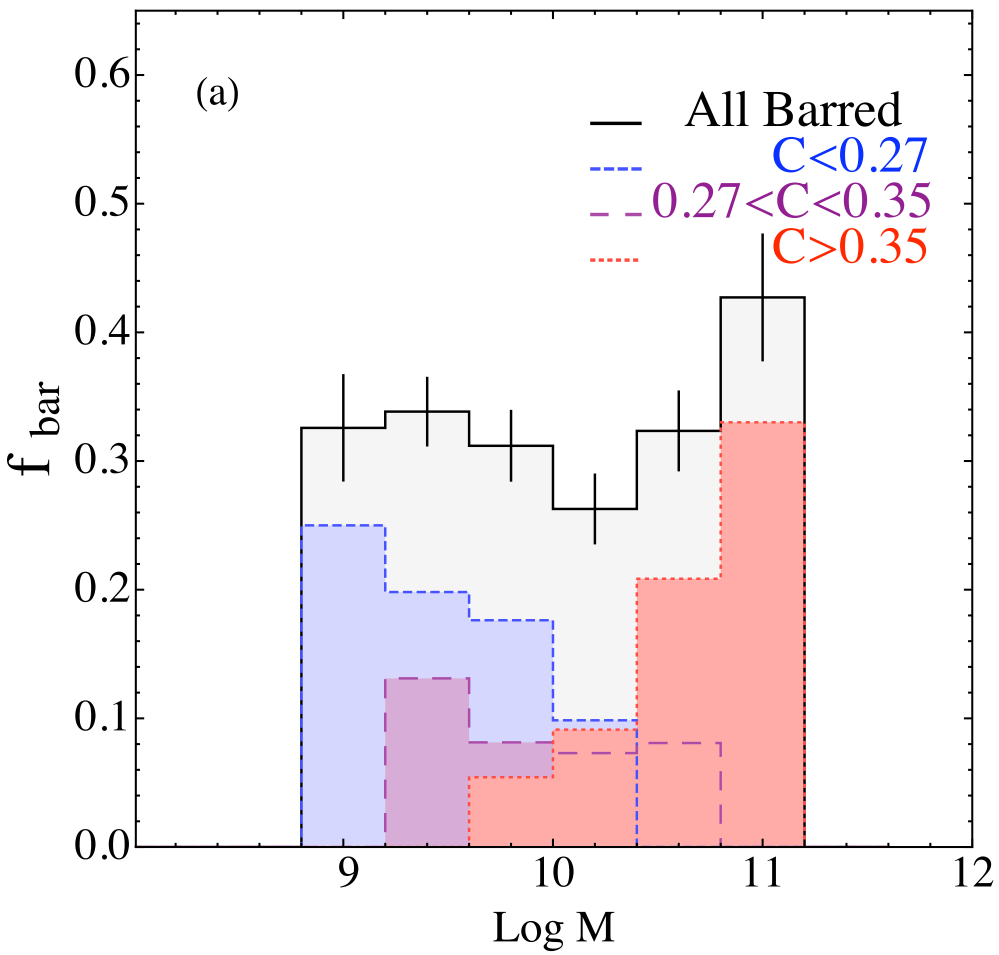


Properties of high-z Barred Galaxies

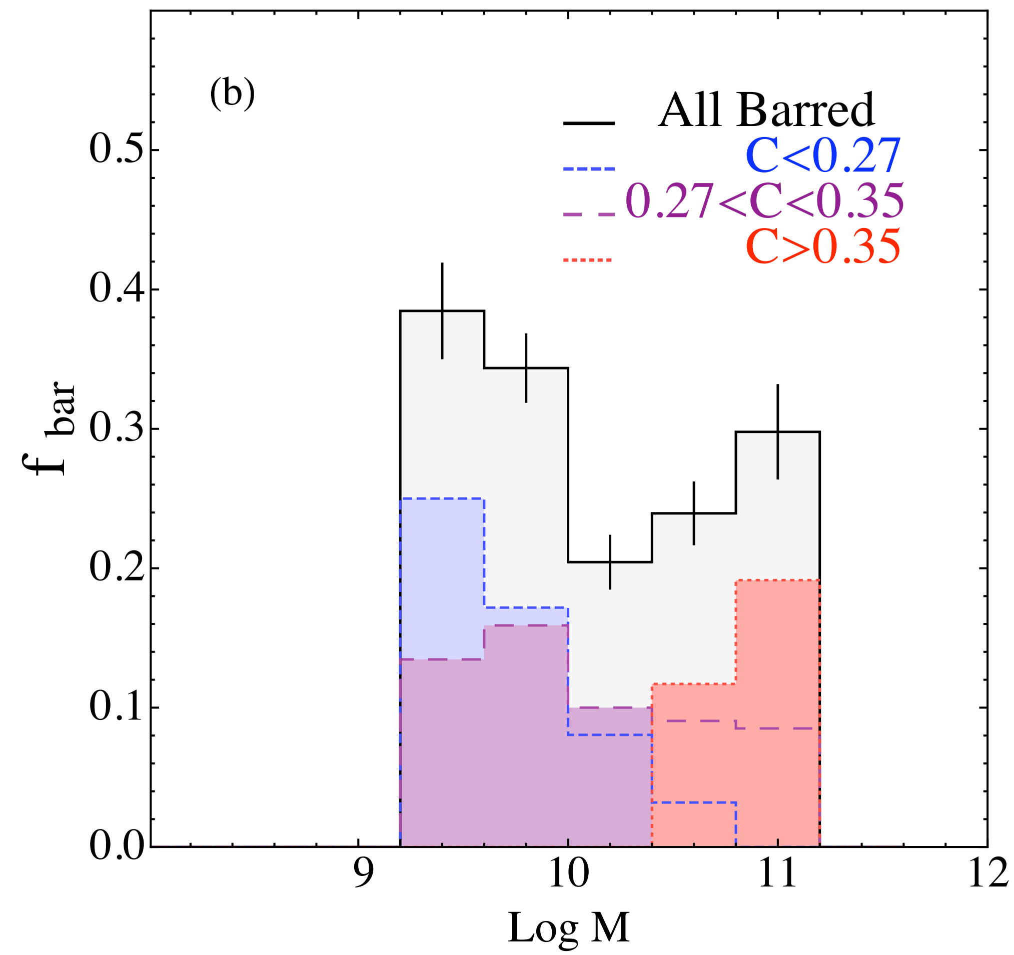
- Bar Fractions



$0.1 < z < 0.45$

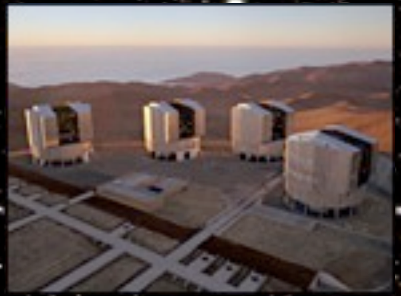


$0.45 < z < 0.85$

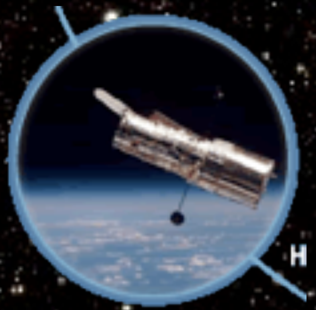


- Concentration dependence at low masses is similar at all redshift bins.
- Concentration dependence at high masses is not the same as at z~0
- There appears to be an evolution in the low mass bar fraction with redshift.

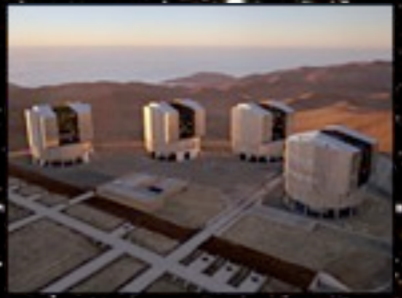
Conclusions



- High redshift barred galaxies show a strong global enhancement in star-formation rates compared to unbarred galaxies.
    - The enhancement is mass and redshift dependent such that it is higher at larger masses and at higher redshifts
- Barred galaxies are bluer at high redshifts at all masses.
- Group environments can quench barred galaxies.



Implications



- The interaction fraction increases from 6% locally to 15% by z ~1.
- While bar fractions for high mass galaxies (LogM>10) decreases with redshift, bar fractions are still ~20%.
- Bar fractions are still high for low mass (Log M <10) galaxies
- Barred galaxies account for a larger fraction of the star formation rate enhancement at high redshifts.
- Bars are just one of the axi-symmetric distortions which can cause gas inflow.

Questions

- What is the distribution of the enhanced star-formation within disk galaxies?
  - centrally concentrated or throughout the disk?
- What are the roles of AGN and environment in quenching star formation?
- Or is it some other bar destruction mechanism.