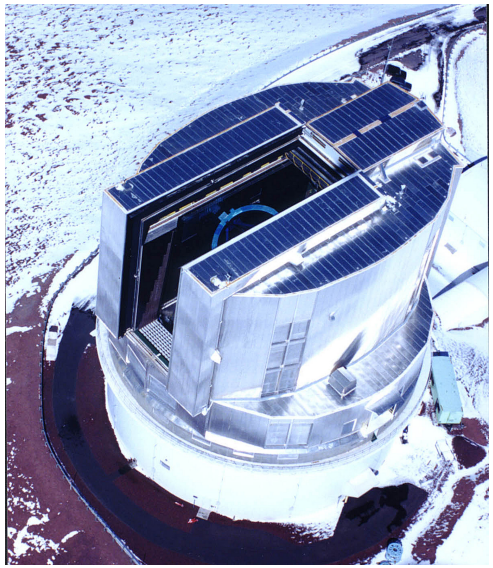
Conference Summary

Richard Ellis, ESO & UCL

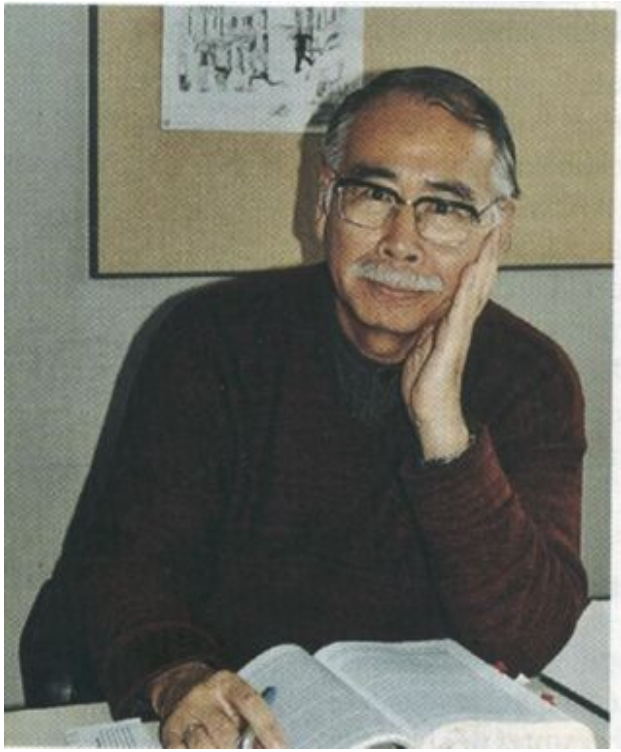
Hayama (2007)

Hiroshima (2016)



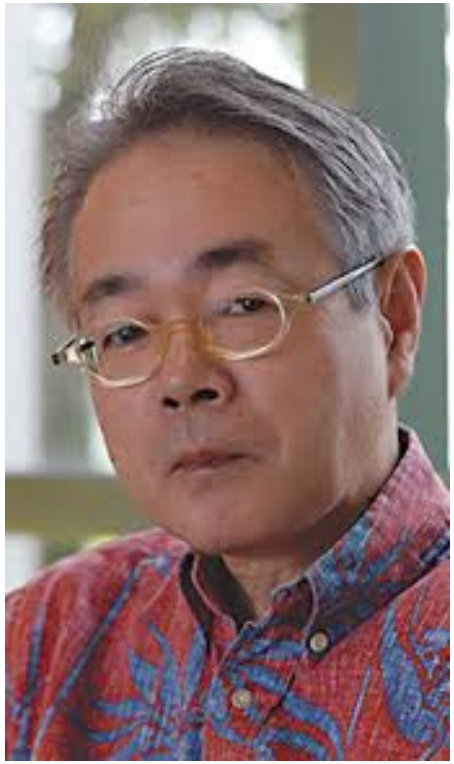
Celebrating Subaru's Pioneers

2007-2016



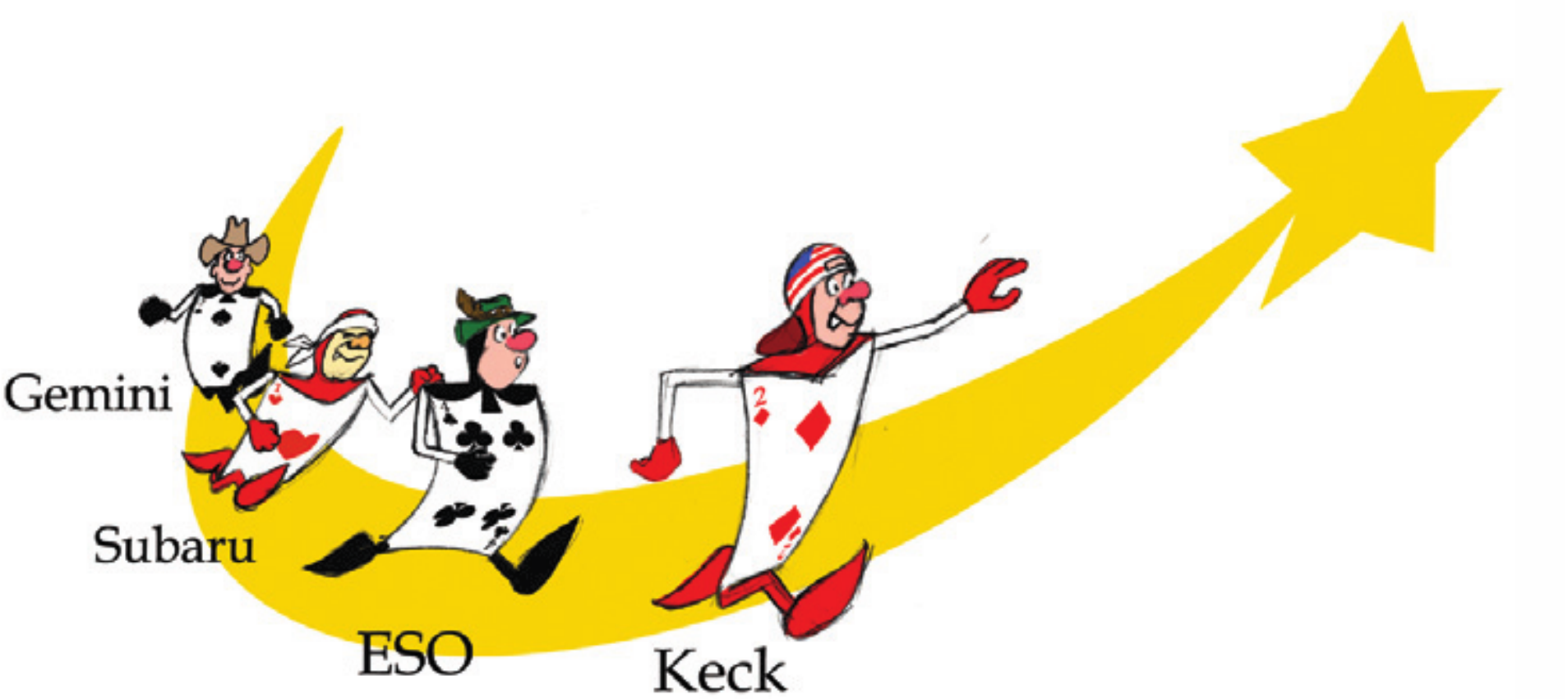
Kodaira-sama

Okamura-sama



Arimoto-sama

A Story of Large Telescope Supremacy..*

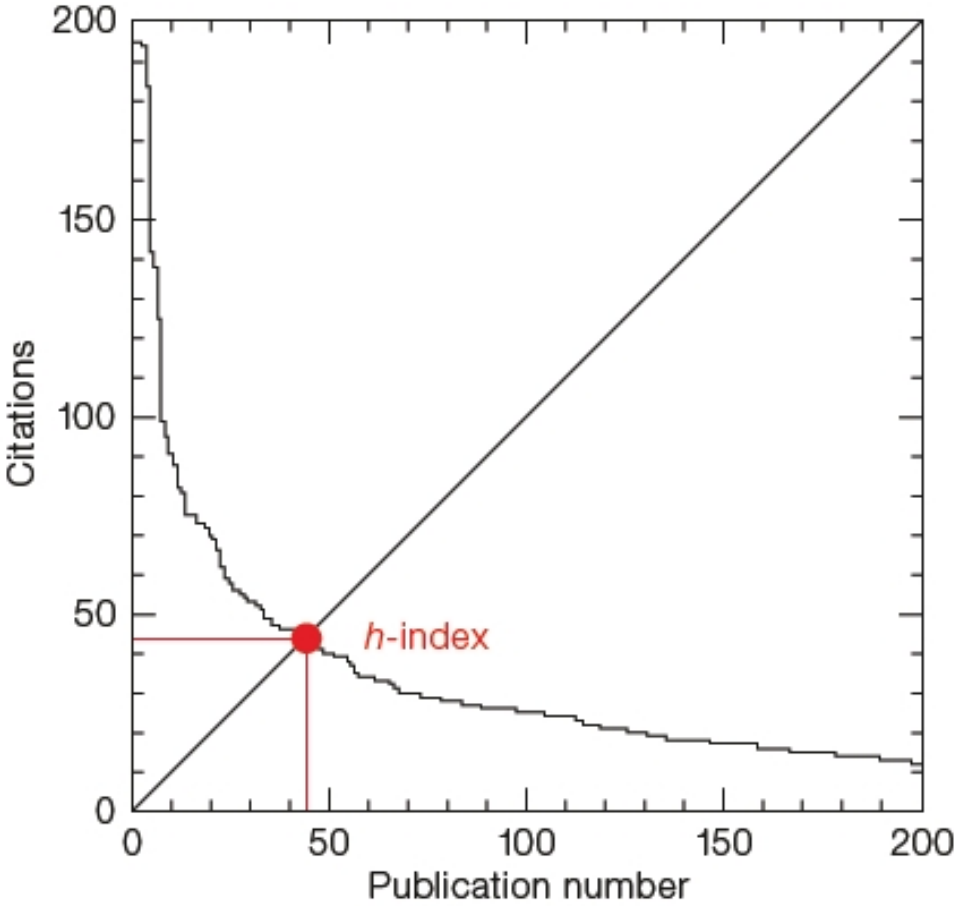


*The following story is with apologies to Dennis Crabtree & his comparative analyses

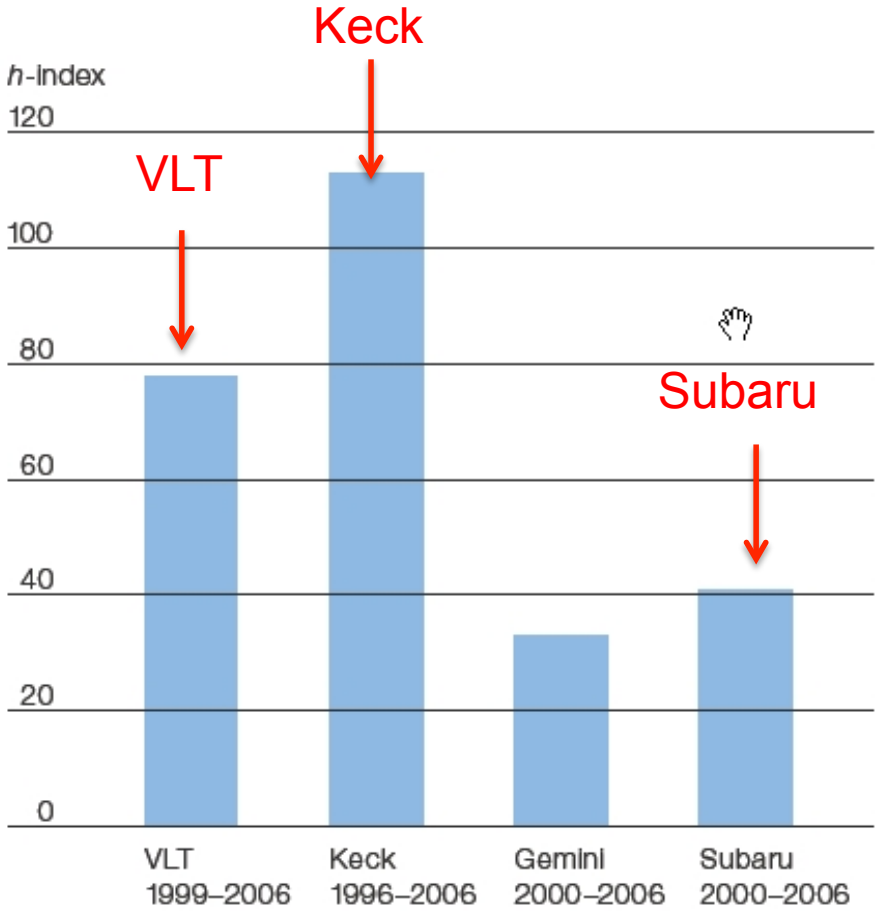
h - index of 8-10m Class Telescopes

The *h*-index is now a well-used statistic for individual researchers and so could be utilised to gauge the output of an observatory

h represents the number of publications with a citation rate ≥ *h*



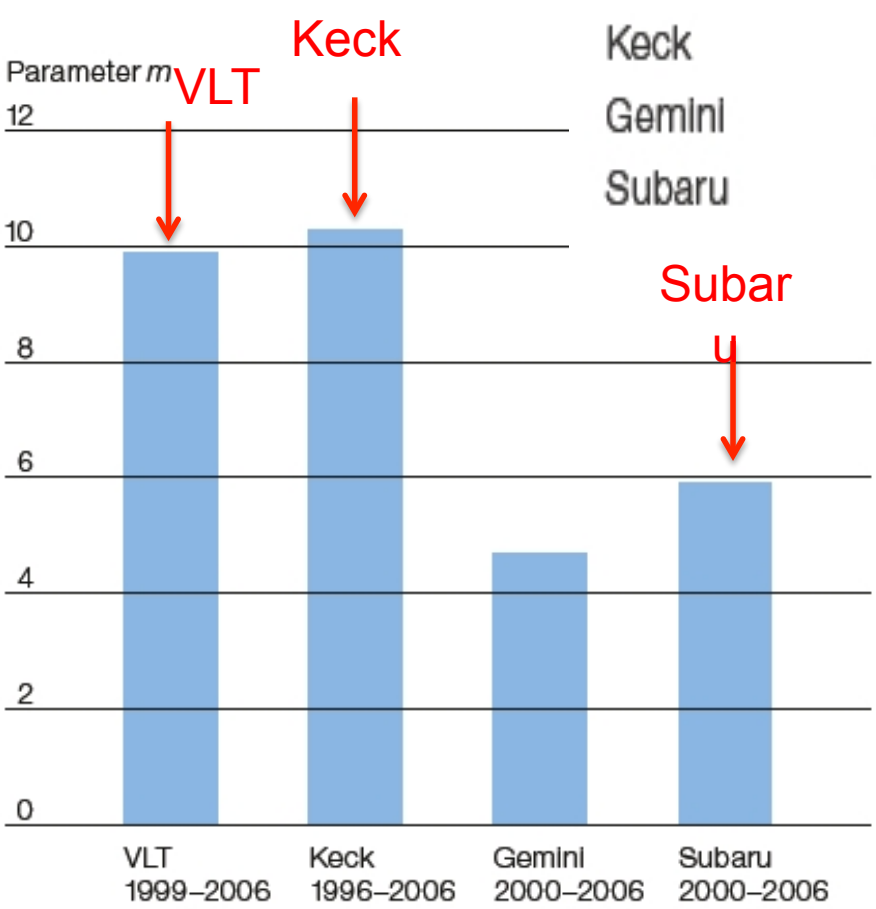
Hirsh Proc. NAS 102, 16569 (2005)



Grothkopf et al Messenger #128 (2007)

m - index:
(taking into account operational years)

Observatory	Range of years of publications	Years since first publication	*h*	*m*
VLT	1999–2006	8	79	9.9
Keck	1996–2005	11	113	10.3
Gemini	2000–2006	7	33	4.7
Subaru	2000–2006	7	41	5.9



Grothkopf et al. 2007

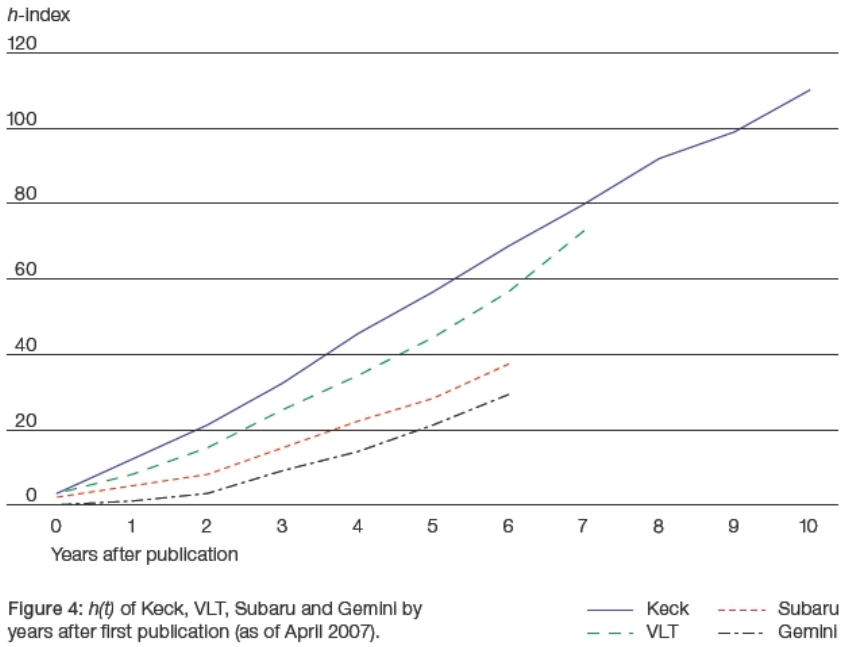
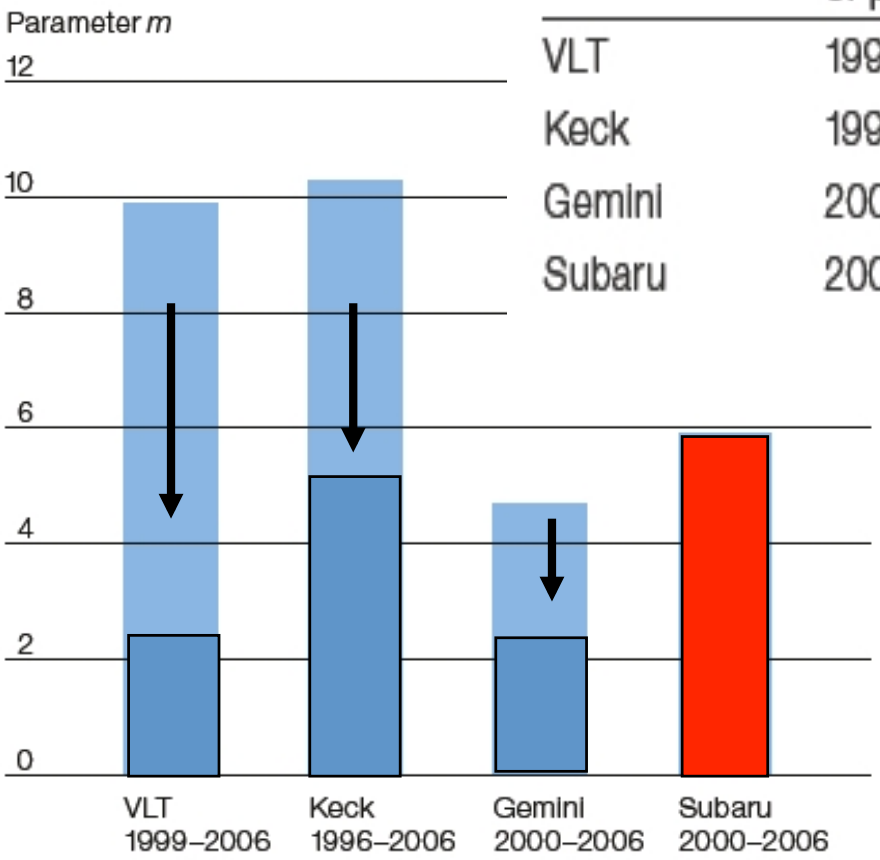


Figure 4: *h(t)* of Keck, VLT, Subaru and Gemini by years after first publication (as of April 2007).

i - index: taking account of number of telescopes

Observatory	Range of years of publications	Years since first publication	*h*	*m*	*i*
VLT	1999–2006	8	79	9.9	2.5
Keck	1996–2005	11	113	10.3	5.2
Gemini	2000–2006	7	33	4.7	2.4
Subaru	2000–2006	7	41	5.9	5.9



Simple division by the number of telescopes used (Iye 2007a)

Subaru rules!

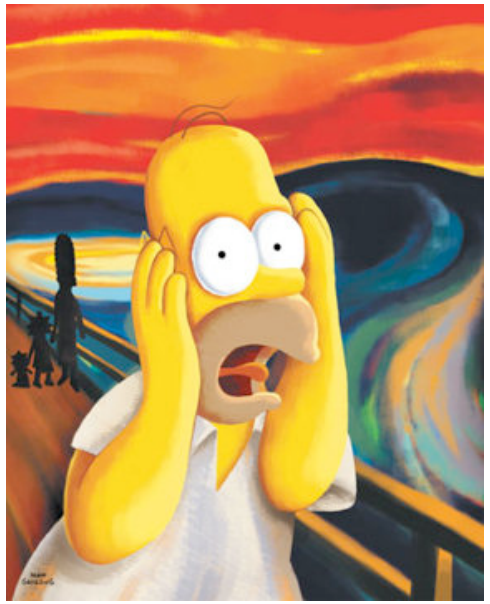
Courtesy of Masanori Iye

Disclaimer

60 talks × 20+ slides > 1200 slides

AND 47 posters

All carefully digested, rationalized, inter-compared with results in the literature to give a "lucid, crisp, holistic view of our present understanding of the Universe….."



What follows is a brief, personal, selection of key issues

Apologies if your talk/poster (or even entire field!) is not mentioned

Cosmic Dawn

The big questions

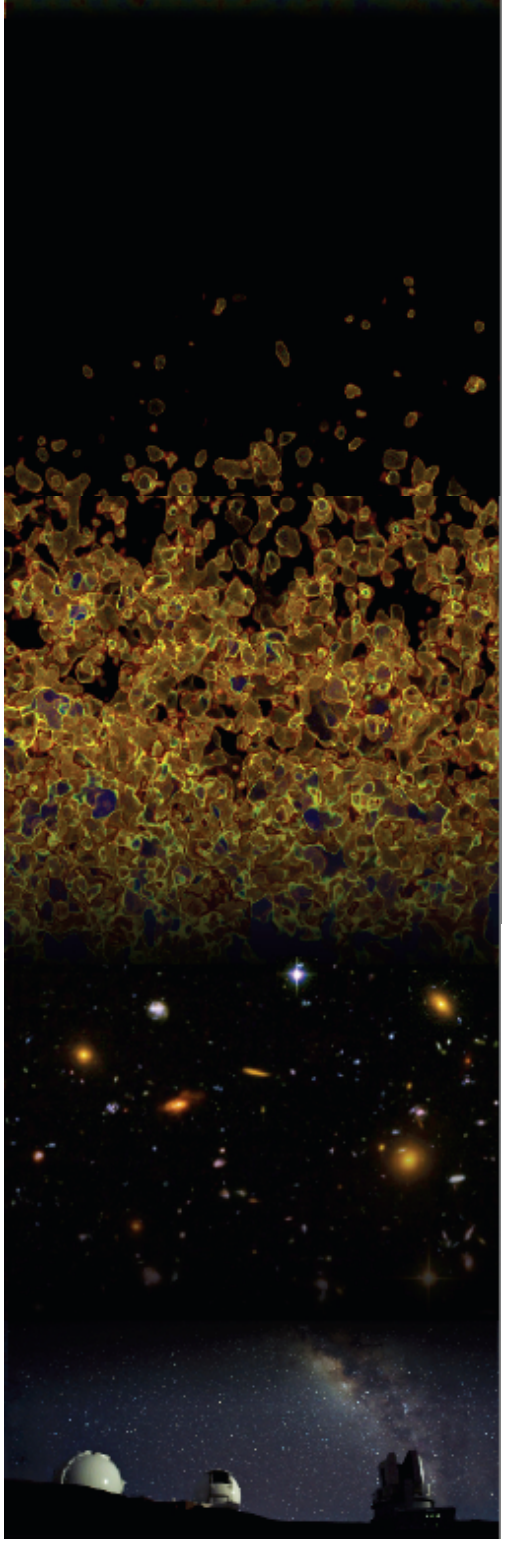
- When did reionisation begin and end?
- Is it a route to finding the first generation of galaxies?
- Contribution of stars and AGN – probably both!

The tools

- 21cm tomography and power spectra
- Luminosity function trends
- Spitzer: stellar masses and ages
- UV spectroscopy of HST-selected targets
- Demographics of LAEs
- Detailed studies of low z analogs

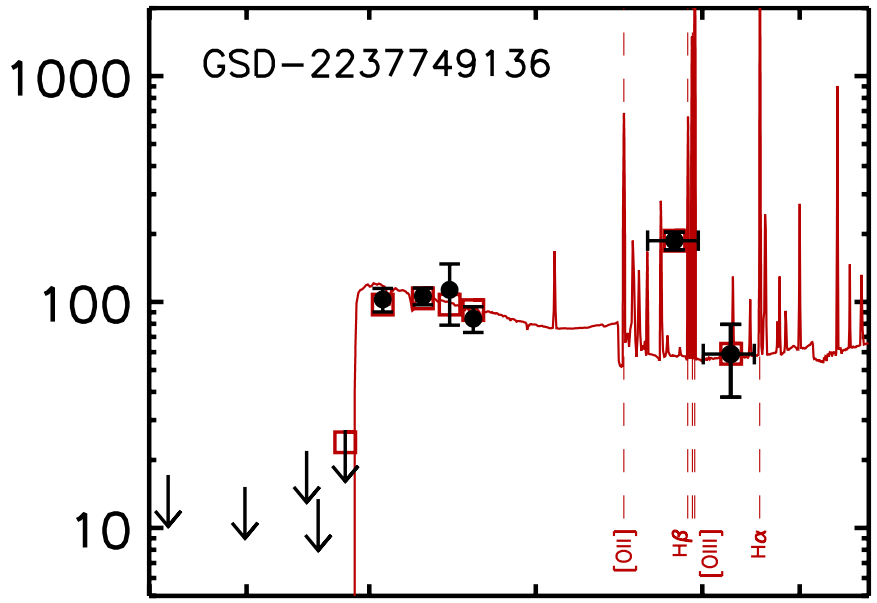
The major challenges

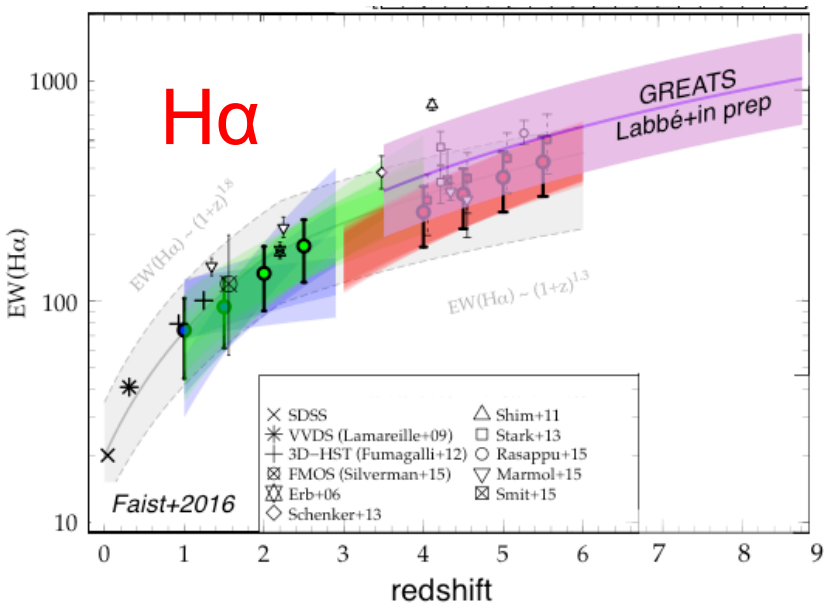
- Physical origin of intense [O III] emission
- Stars vs AGN??
- The dreaded escape fraction of ionizing photons
- How much SF beyond z~10?



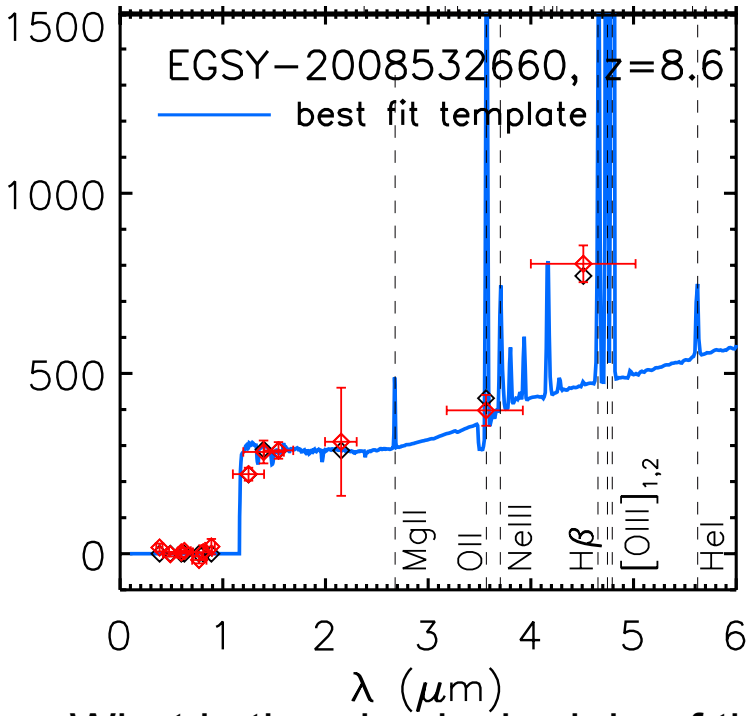
Extreme [O III] Emission at z > 6

Smit+15, ApJ, 801,122





Roberts-Borsani et al. 2016, ApJ, 823, 143



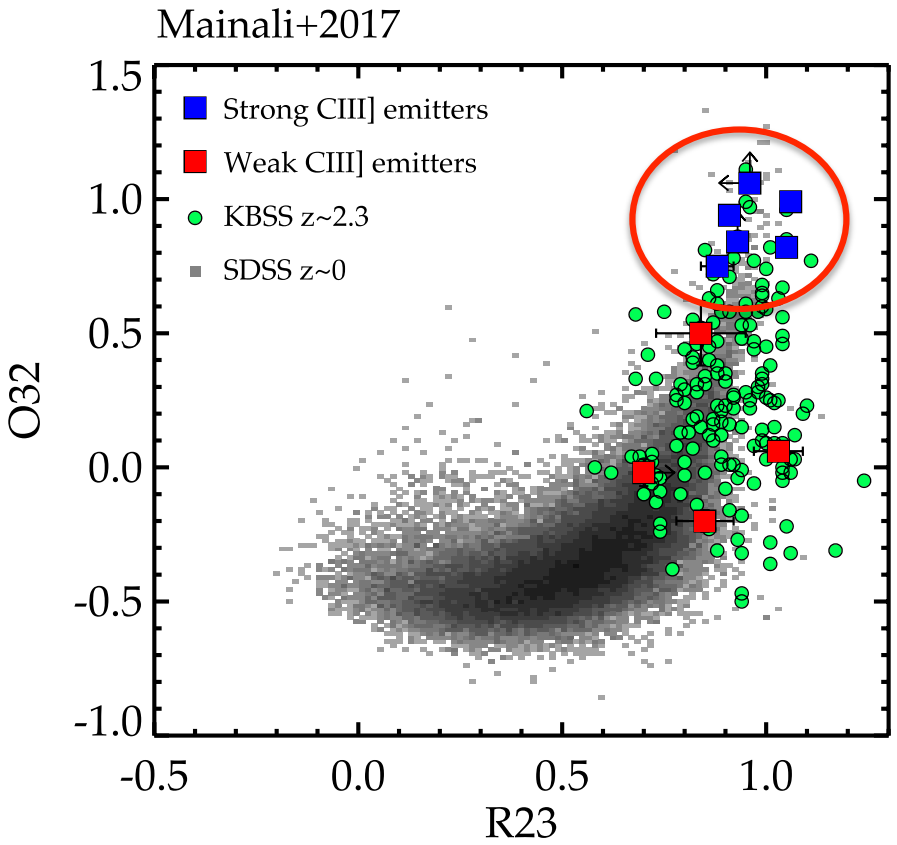
What is the physical origin of this remarkable intense [O III] emission at high z?

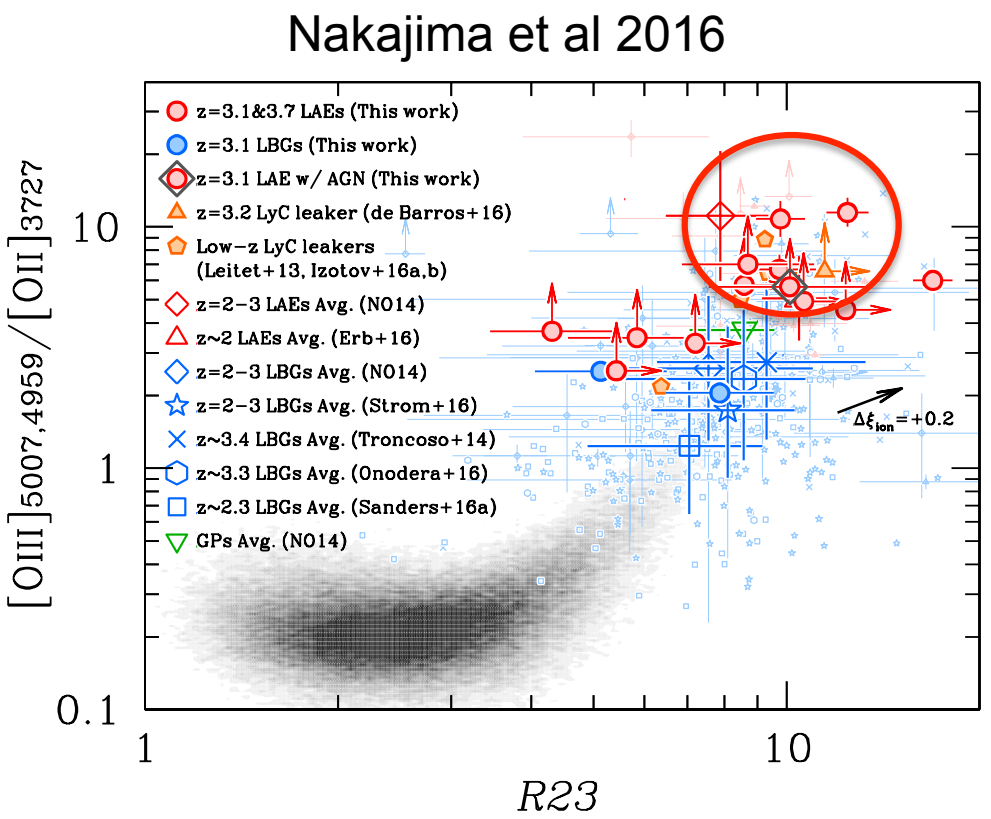
Harder ionizing spectra (UV metal lines) and unusual star-forming regions?

Detailed study of low z analogs may help

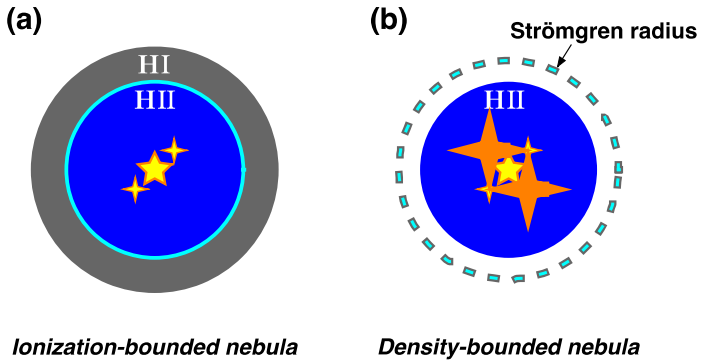
Stark, Labbé,

Low Redshift Analogs with Intense Emission



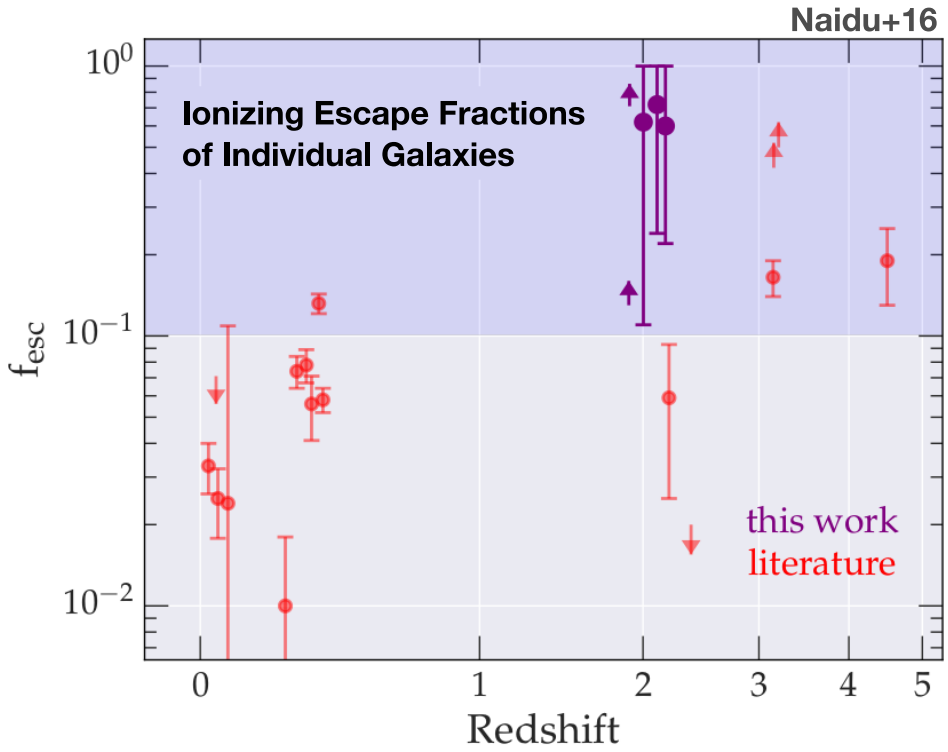


Photoionization models suggest high [O IIII]/[O II] ratios are linked to harder ionizing radiation AND perhaps high escape fractions reflecting density-bound H II regions which cannot form a complete Strömgren sphere (Nakajima & Ouchi 2014)



Stark, Kusakabe, Kojima

The Escape Fraction…



f_{esc} > 10% for reionisation

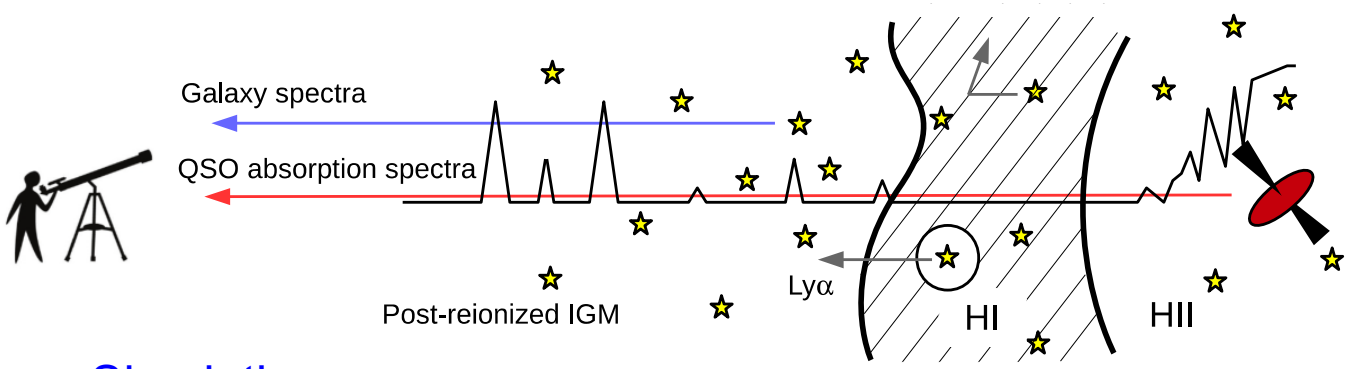
Simulations suggest young low mass galaxies are porous with high escape fractions (Wise+ 2014, Ma+ 2015, Sharma+2015) but hard to verify observationally

- Recombination lines provides joint constraint on ξ_{ion} and f_{esc} (Zakrisson+ 2016): *await James Webb Space Telescope*
- Covering fraction of low ionization gas via absorption line spectra (Jones +2013, Leethochawalit+ 2016)*: -assumes good proxy for HI (density & kinematics)*
- Statistical association between galaxy population and ionization state of IGM inferred from QSO spectra (Becker+ 2015, Kakiichi+ 2016): *spectroscopic at z~6*

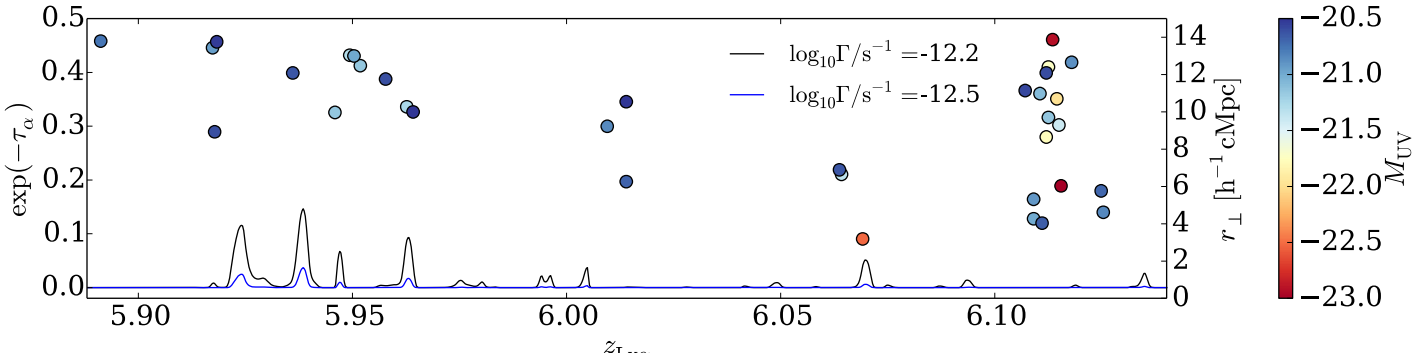
A New Route to the Escape Fraction?

Balance ionisation state of the IGM deduced from z>6 QSO spectra with contribution from galaxies of known luminosity, redshift and line-of-sight distance etc in the same cosmic volume

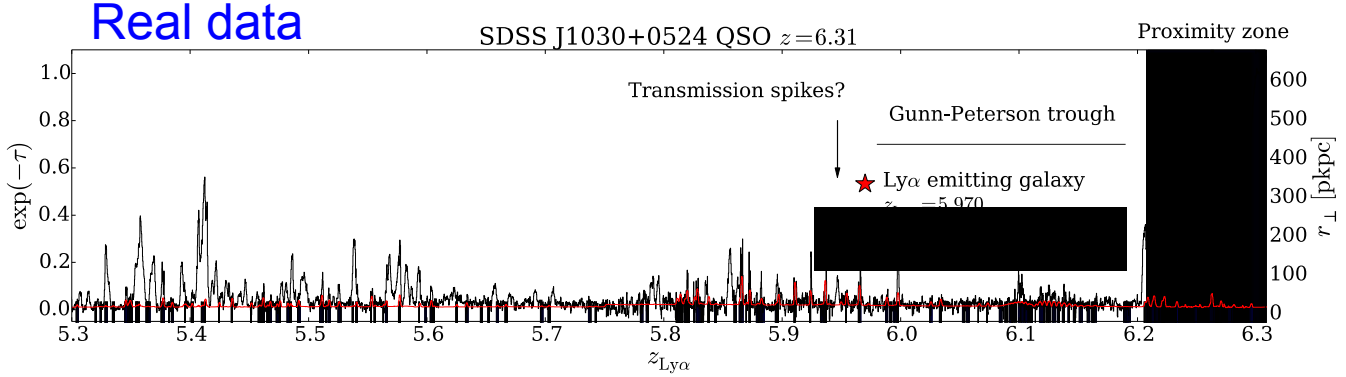
Need deep imaging and spectroscopy in fields of z~6 QSOs



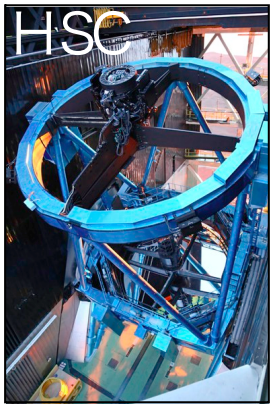
Simulation



Real data



Kakiichi (see earlier idea by Becker)



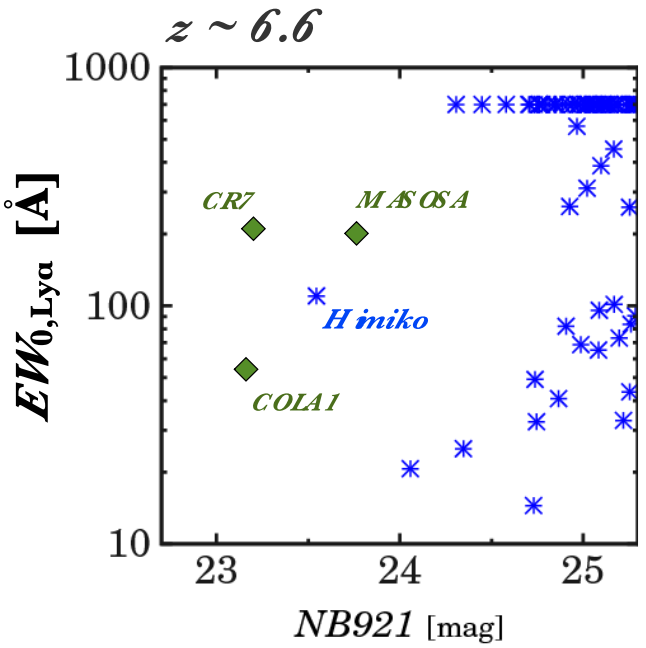
© NAOJ

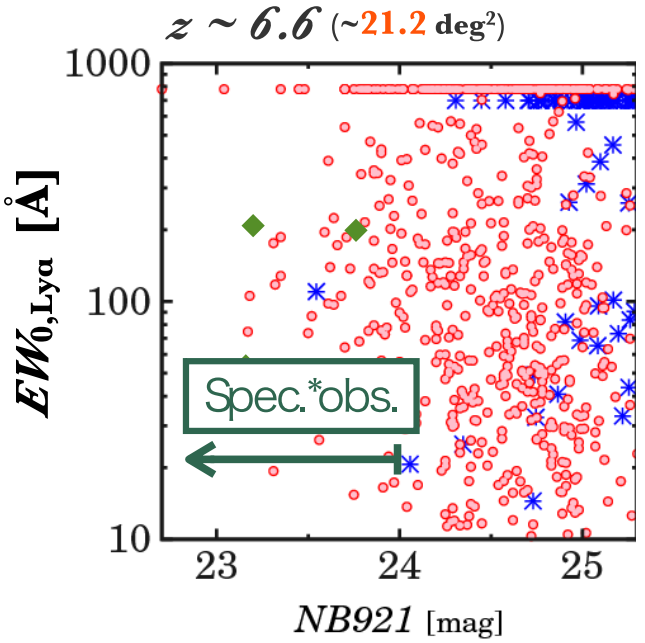
Progress: ~2400 LAEs 5.7 < z < 6.6 in HSC!

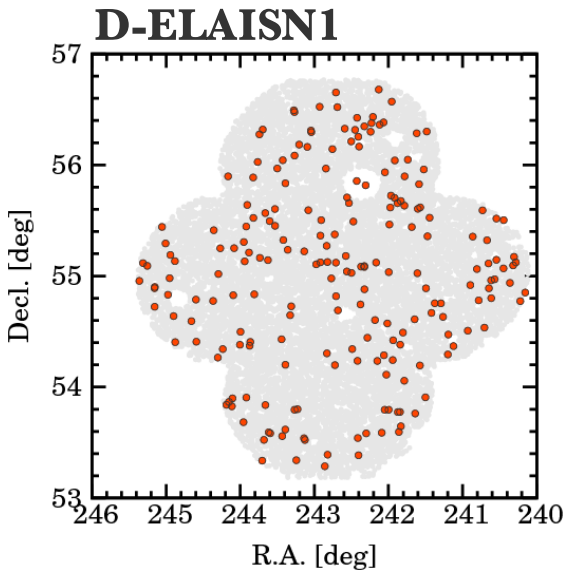
Enormous leap forward in number of luminous z~6.6 LAEs and z~6 LBGs

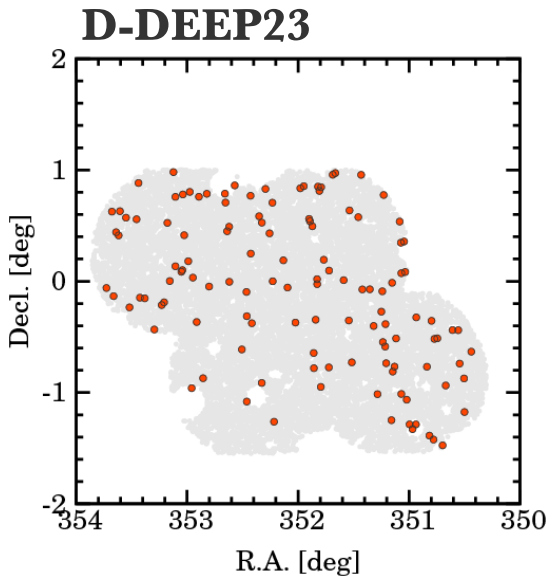
Offers exciting prospect of studies of spatial distribution of ionized bubbles and detailed spectra of galaxies at end of reionization!

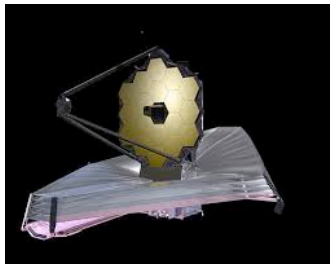
Shibuya, Konno...







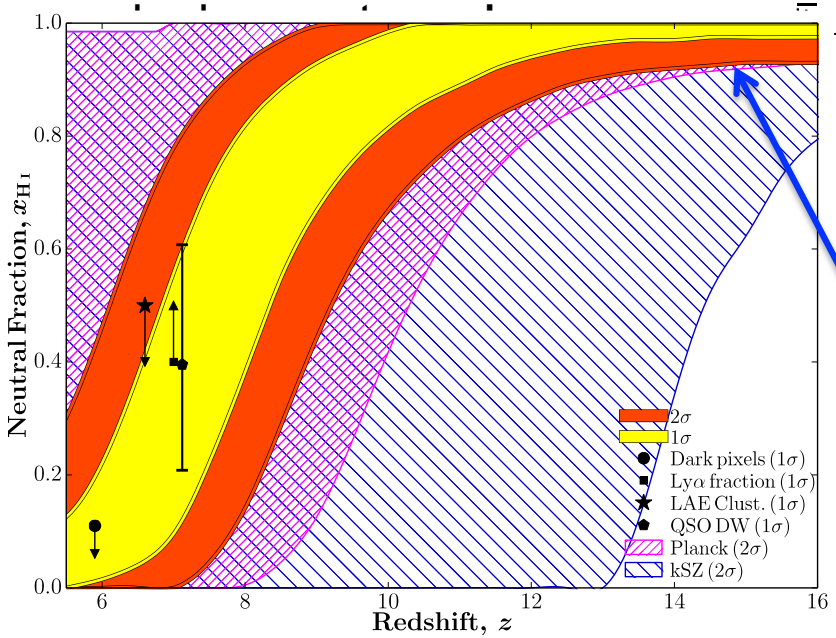




Coming Soon… JWST!

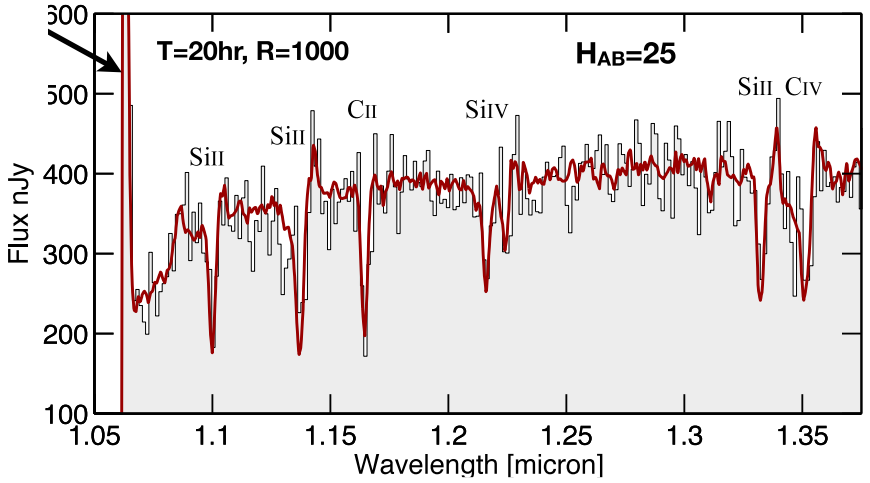
JWST offers space-based spectroscopy free from OH contamination and longward of 2 microns

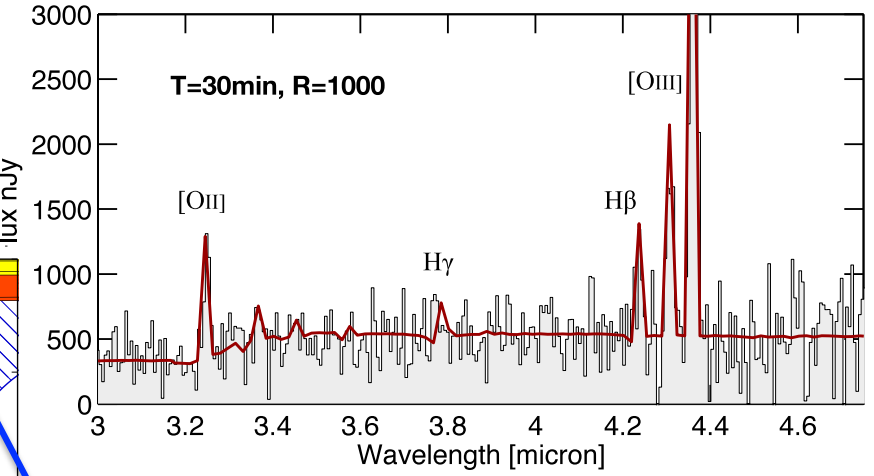
- Absorption line studies of stellar/ISM composition, low ionization gas
- Familiar nebular lines for gas-phase metallicity and AGN features
- There may be star formation beyond z~12
- ERS pr



Oesch

Simulation based on z=7.73 source from Oesch+15





Greig & Mesinger 2016 analysis of reionization history permits long tail of SF to z>12

Cosmic Afternoon

The big picture

- Stellar mass – halo mass relation: formation efficiency
- Disk formation and angular momentum evolution
- Feedback – flows in/out
- Quenching – environmental vs internal

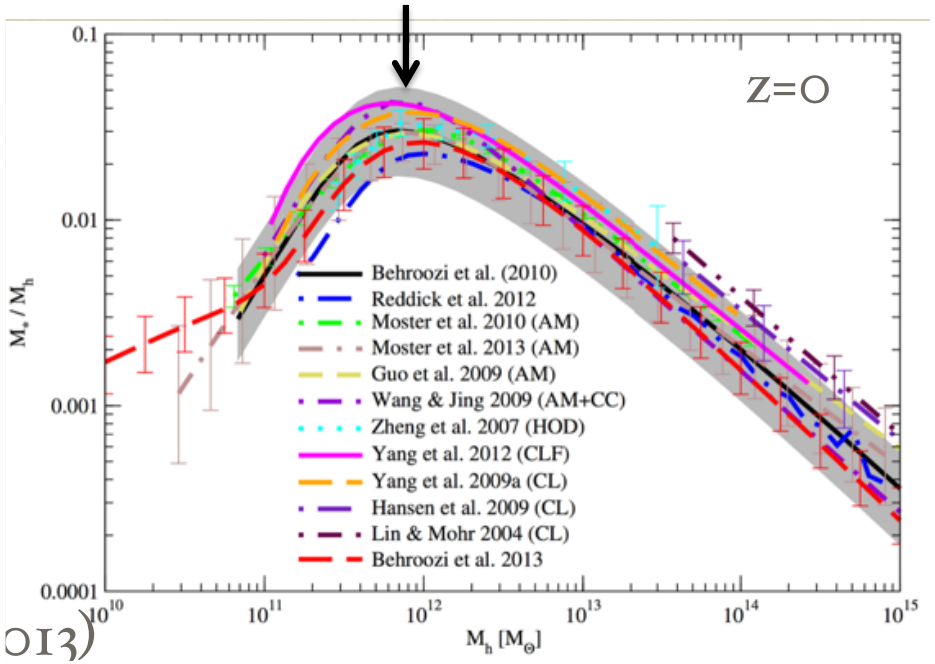
The tools

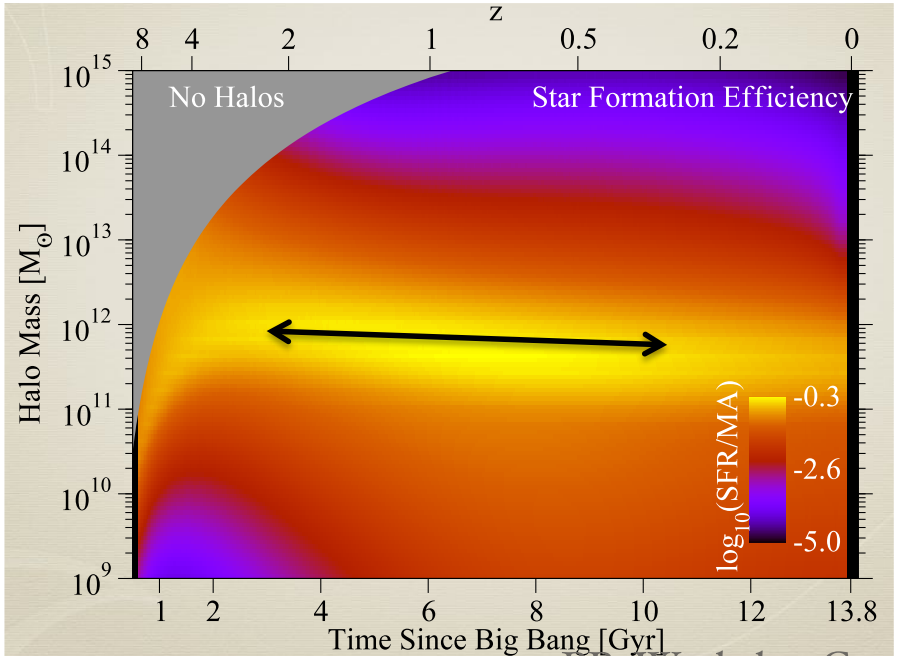
- Spectroscopy of galaxies and circumgalactic medium
- Resolved kinematics, chemistry etc from IFUs
- ALMA and molecular gas
- Hydrodynamical simulations

The issues:

- Do we understand stellar evolution (MS binaries, AGB)
- Role of Dust
- Early quiescent galaxies and implications
- Erratic star formation

The efficiency of galaxy formation



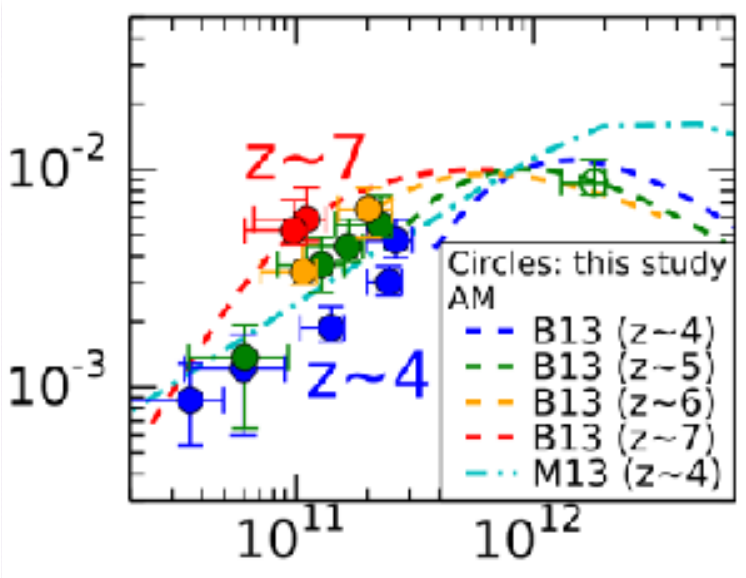


Efficiency of star formation probed by stellar mass/halo mass relation

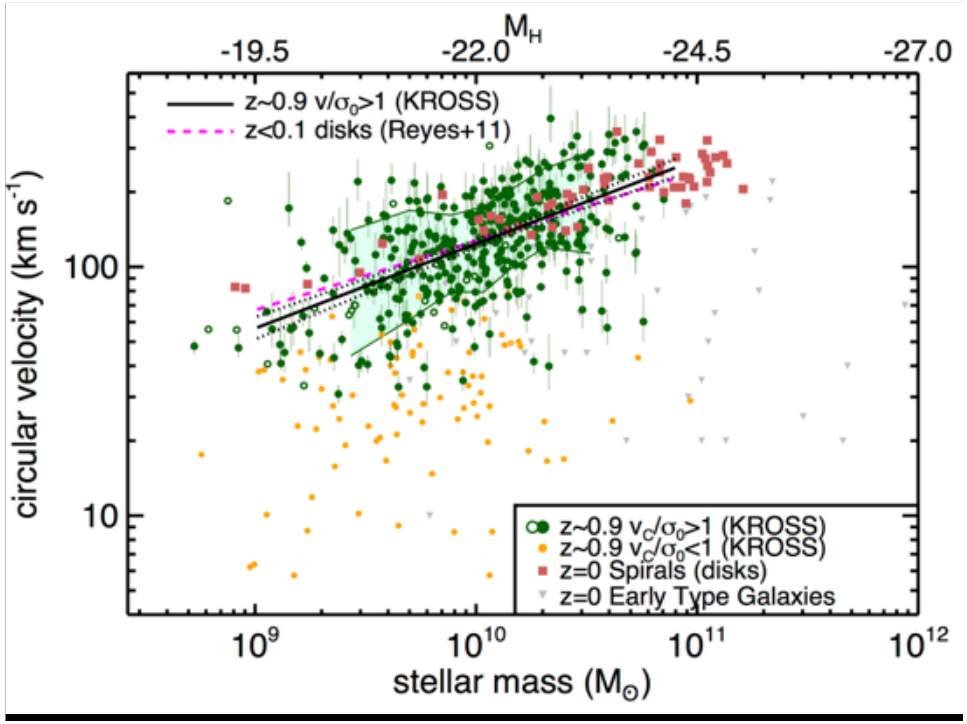
- Peaks at a halo mass of 10^{12} $M_\odot$
- Surprisingly constant over cosmic time?
- Tantalising evidence for higher efficiency z>4

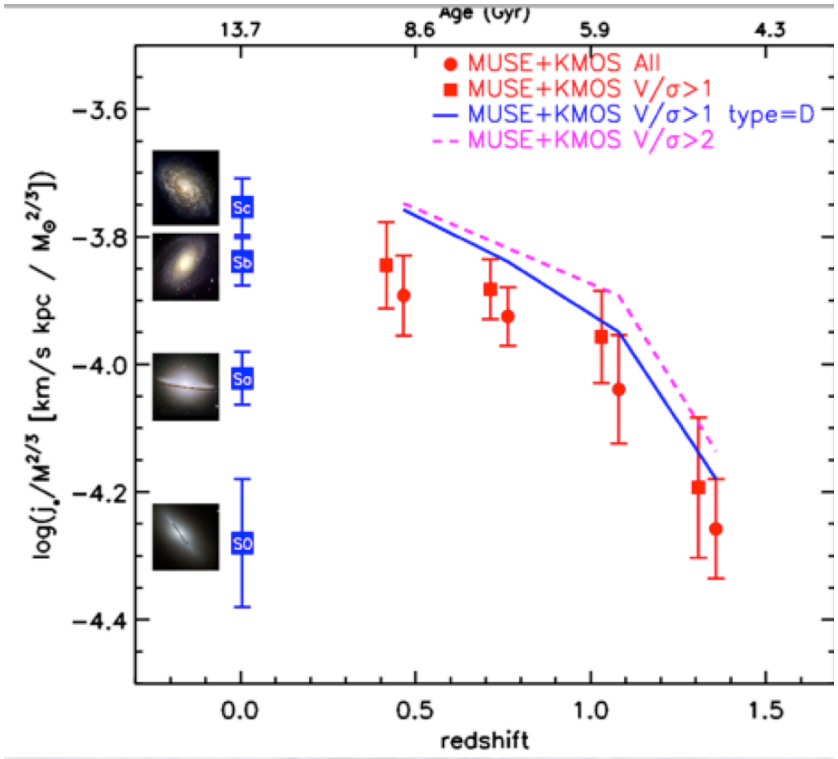
IF SO, WHY?

Behroozi, Harikane, Ferguson



Evolution of Angular Momentum





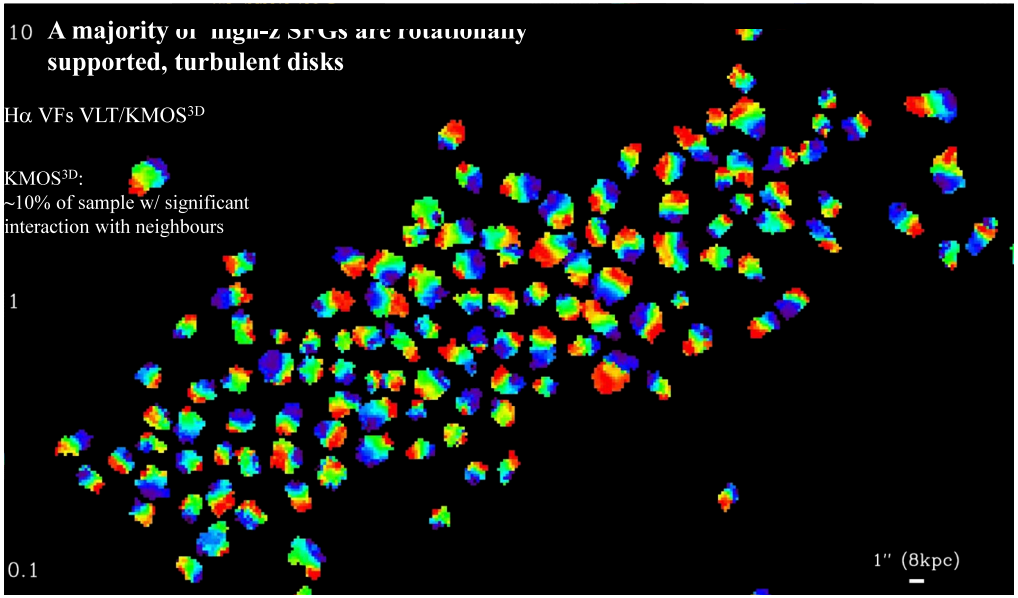
KMOS provides high quality IFU data for complete samples of 0.6 < z < 1 galaxies

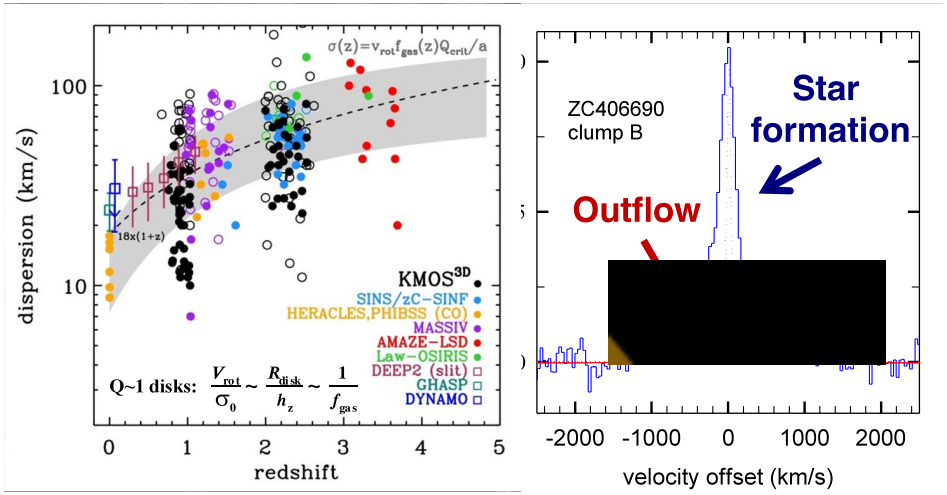
Wide scatter on TF relation – illustrates earlier results pre-selected “regular” systems

Although no broad evolution in TF relation – consistent with significant growth in a.m.

Bower

Extending Kinematics to z ~ 2

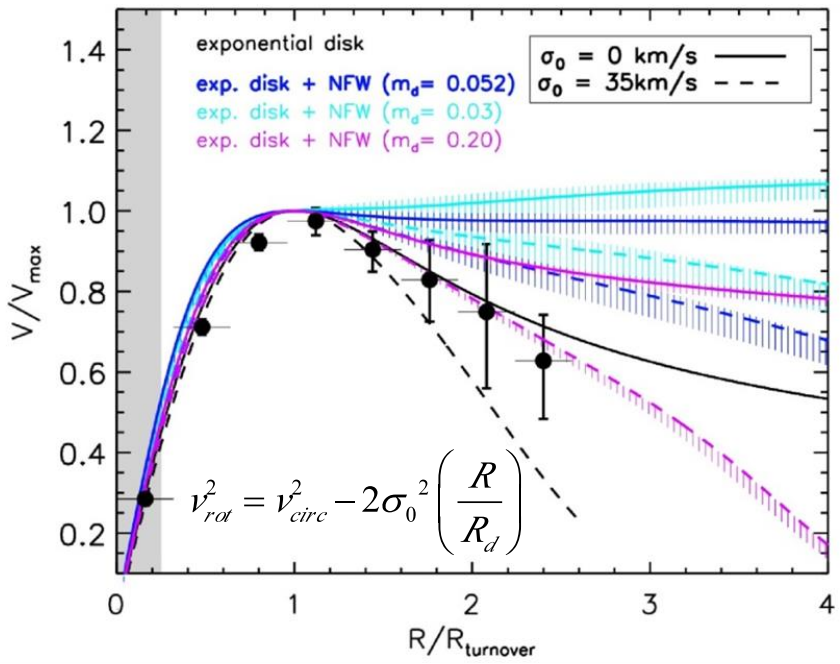




KMOS extends to higher redshift; seeing limited data checked with limited AO-based data – some differences in merger/clumpy statistics

Dispersion-dominated, strong outflows, falling rotation curves?

Flat metal gradients indicating strong feedback



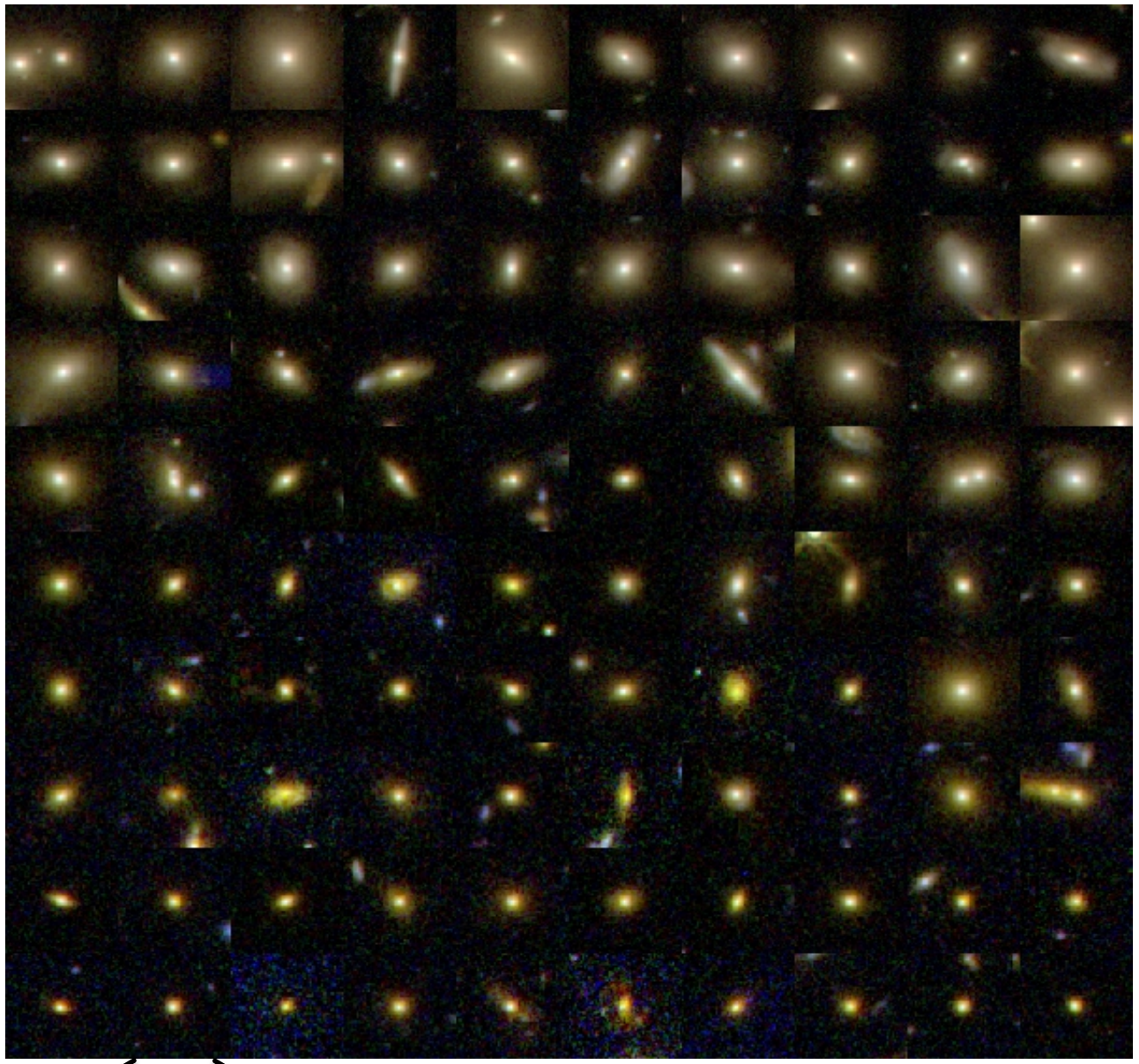
Förster-Schreiber, see also Jones, Leethochawalit

Assembly History of Spheroidals

z=0.4

Time

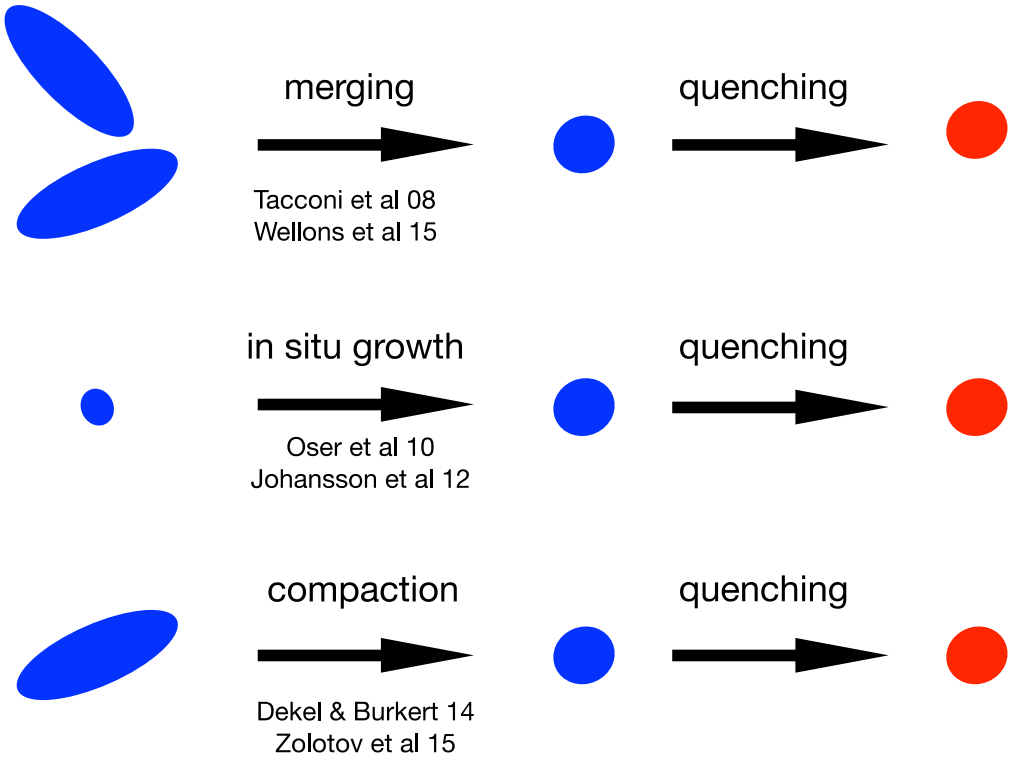
z=2



40 kpc

RED NUGGETS !

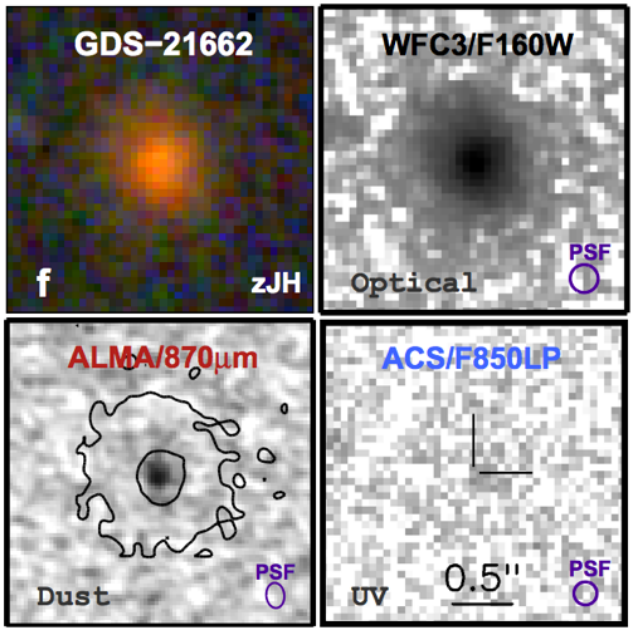
What were the pre-quenched progenitors?



Identifying earlier progenitors is tough, depending on numbers/quenching timescales

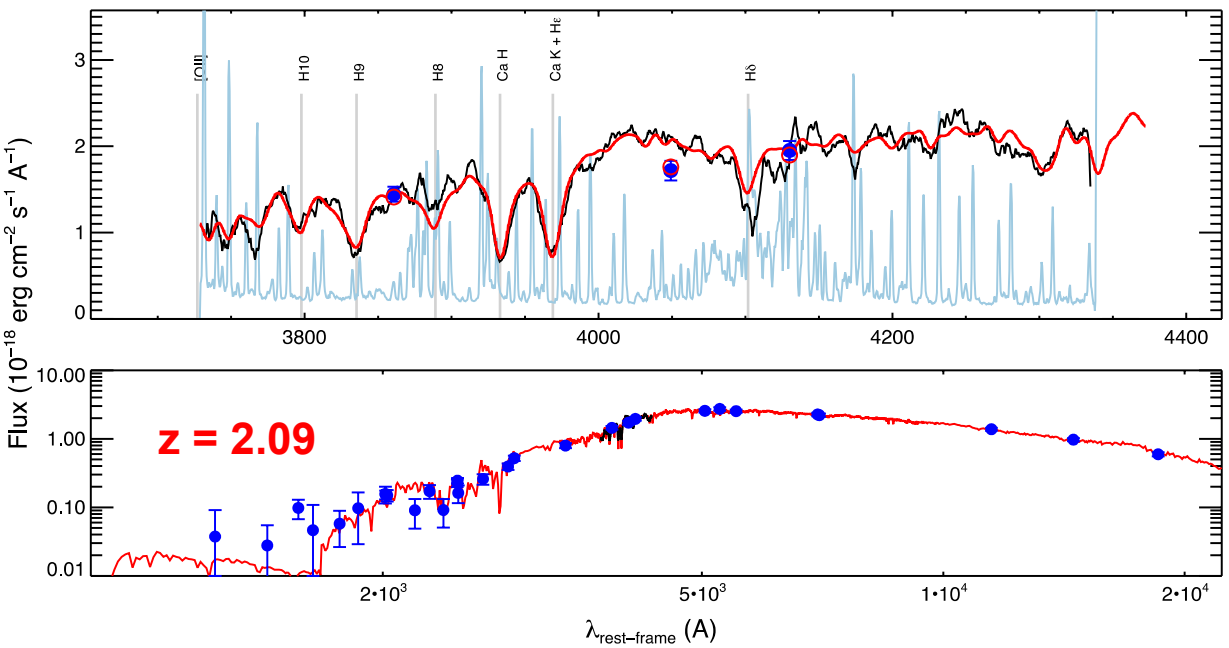
- compact dust-obscured sources (ALMA)

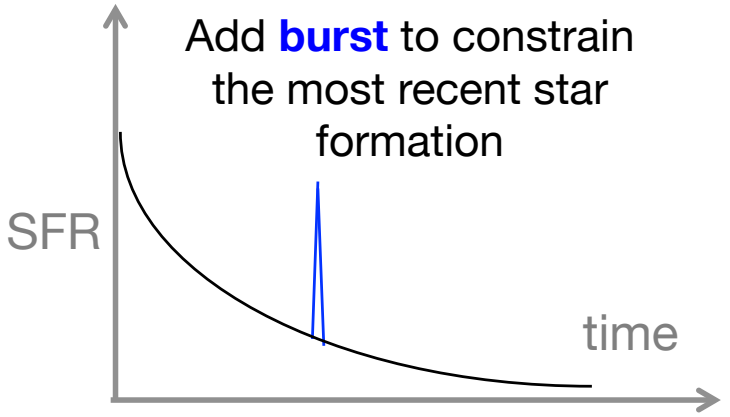
- compact star-forming systems (blue nuggets)



van Dokkum, Tadaki

Age Dating z~2 Compact Red Galaxies



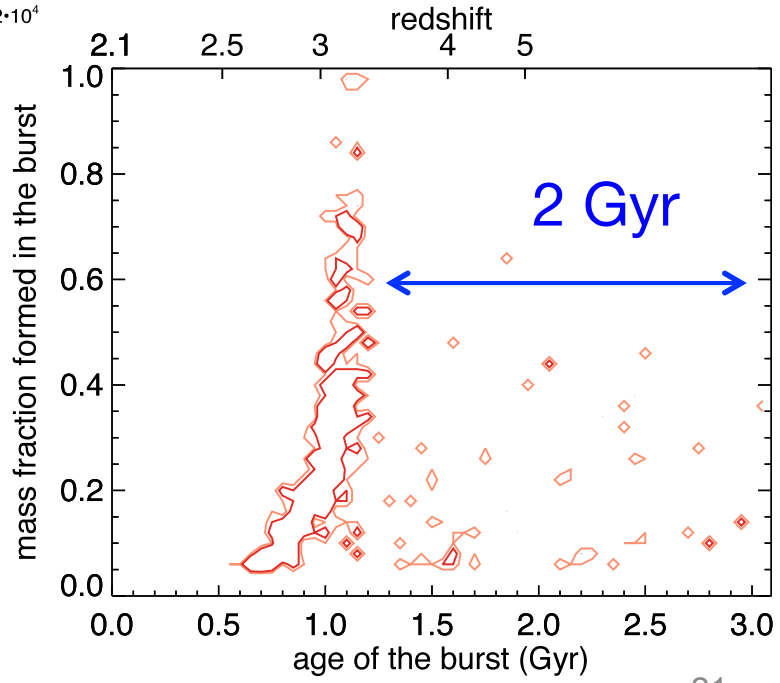


Combined MOSFIRE spectrum + CANDELS SED indicates $4 \cdot 10^{11}$ $M_\odot$ in stars was already in place at z > 3.5 when Universe was ~2 Gyr old

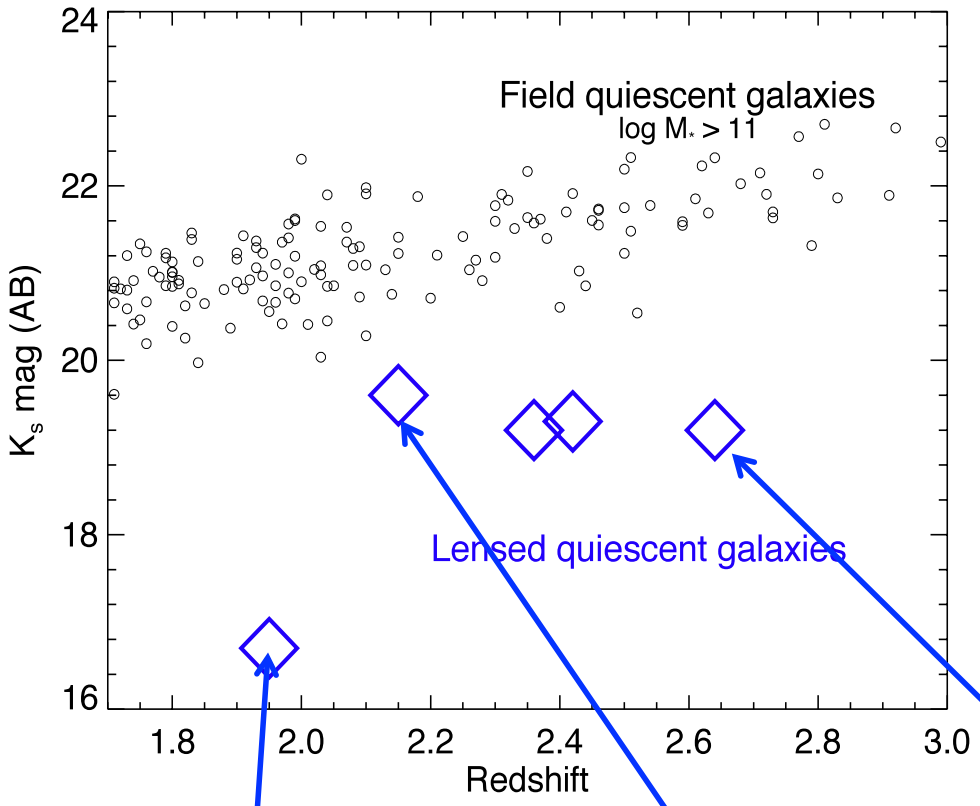
Implies progenitor SF rates comparable to those in sub-mm galaxies!

See also Glazebrook et al z~3.7 passive galaxy!

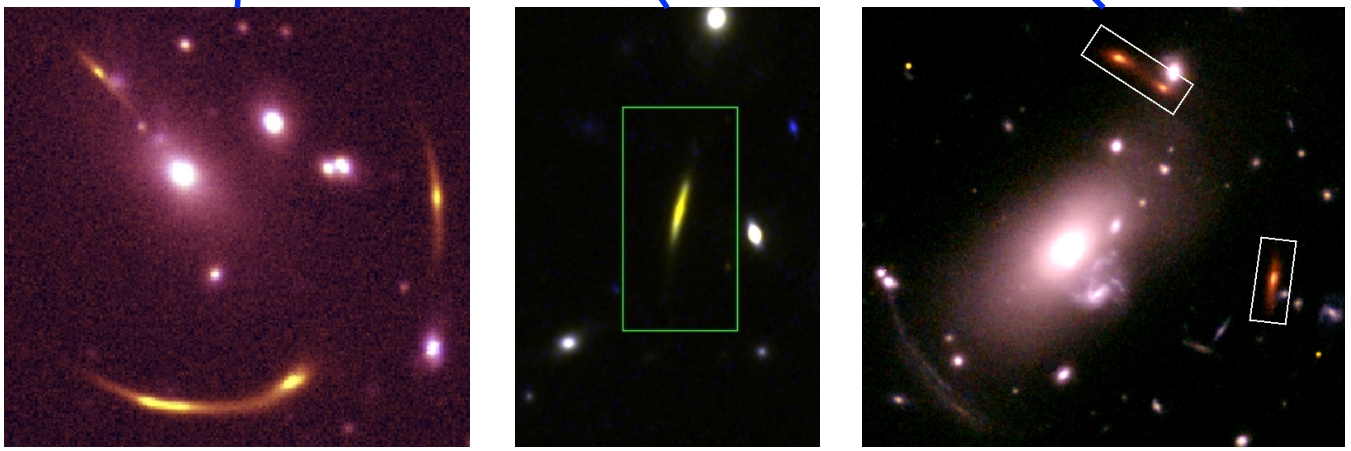
Belli, Newman + RSE



Gravitationally lensed quiescent galaxies

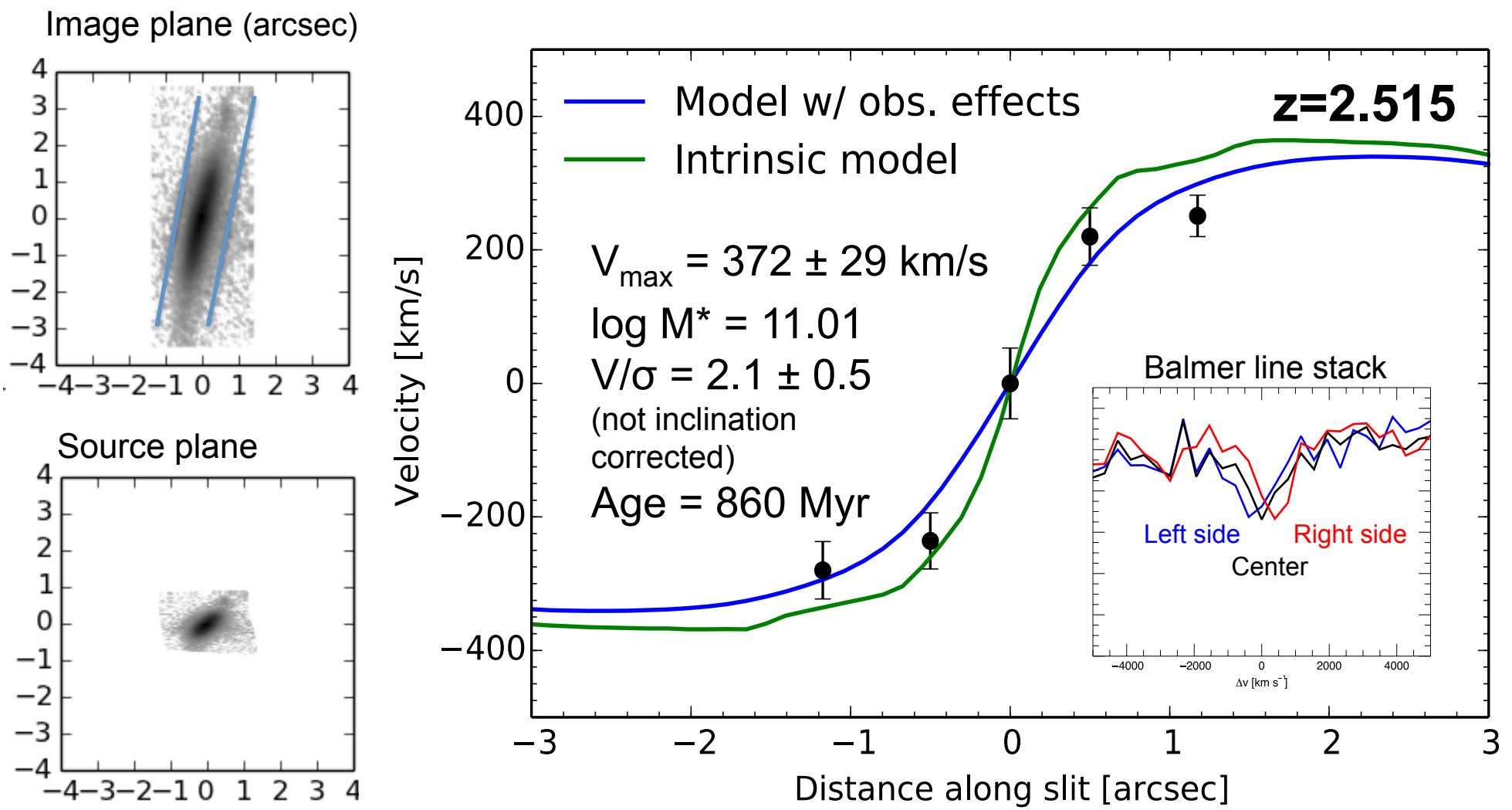


- 5 magnified and exceptionally bright quiescent galaxies at z = 2-2.6
- All spectroscopically confirmed
- MOSFIRE/FIRE spectra for them all



Newman, Belli & RSE in prep

Red Nuggets Have Rotating Stellar Disks!



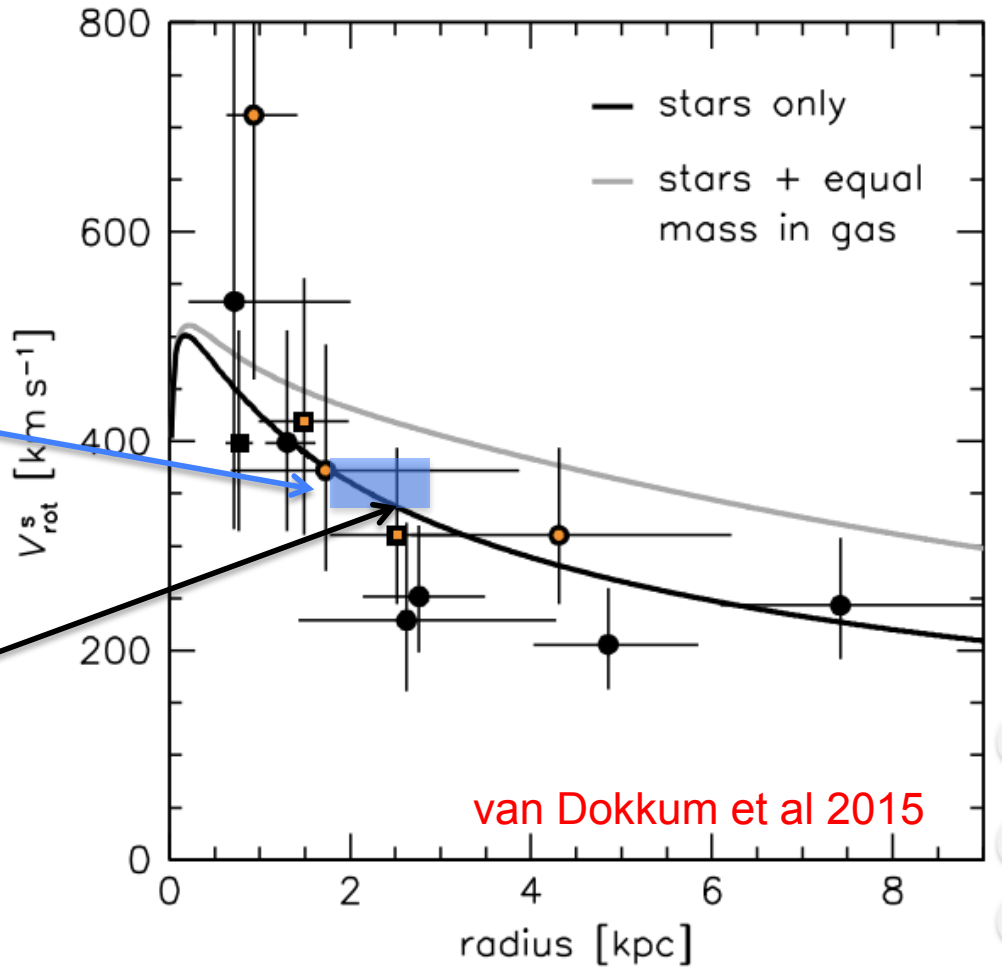
Similar data for 4 other cases!

Newman, Belli + RSE

Rotating gas disks in candidate progenitors

Estimated range for deprojected V_{max} for compact quiescent galaxies

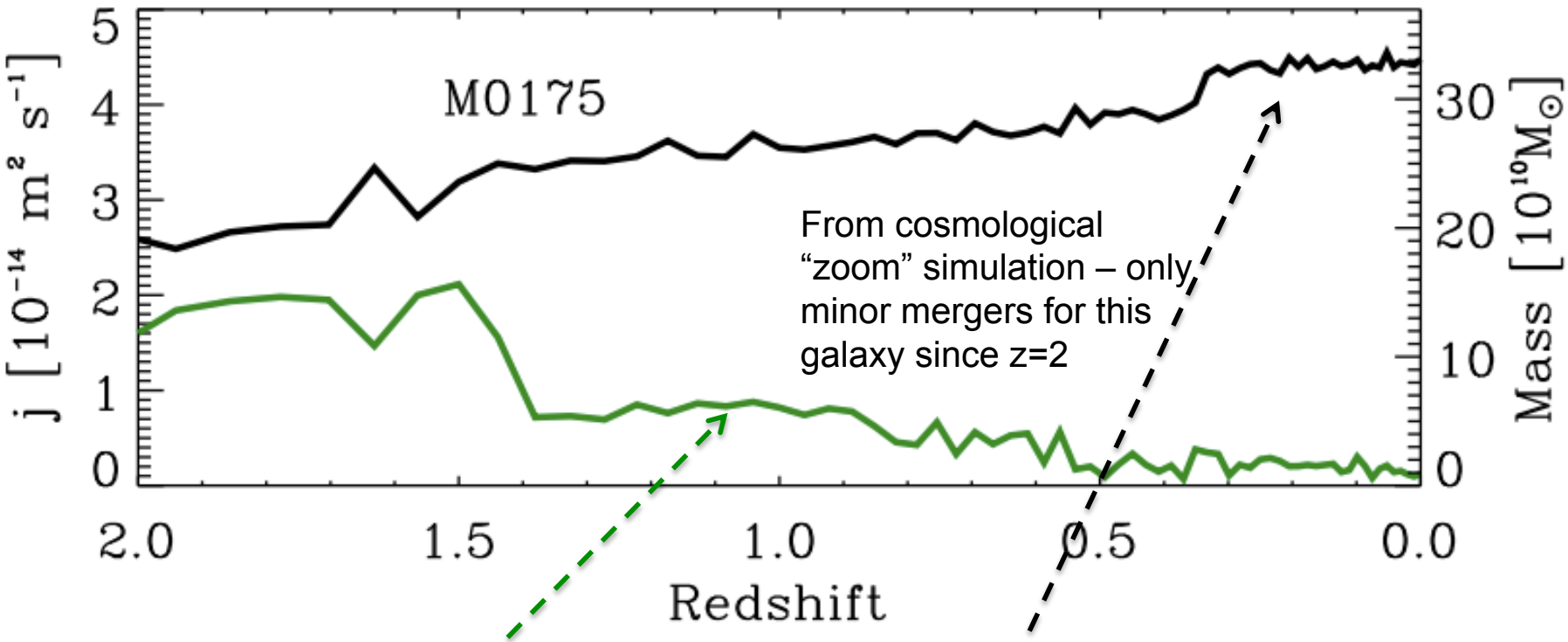
Inferred for compact star-forming galaxies a.k.a blue nuggets



Most likely quenching timescales vary – see Bello et al (in prep)

Barro et al 2014, 2016; Tadaki et al 2016

What happened to red nuggets?



Seems reasonable to assume many massive red nuggets have stellar disks with rapid rotation; they evolve to massive ellipticals that have no rotation. How did they lose their angular moment.

Repeated minor mergers (< 1:4) can **double mass**, increase the size and **reduce angular momentum** by 10x since z=2

Naab et al 2014

Dust Evolution?

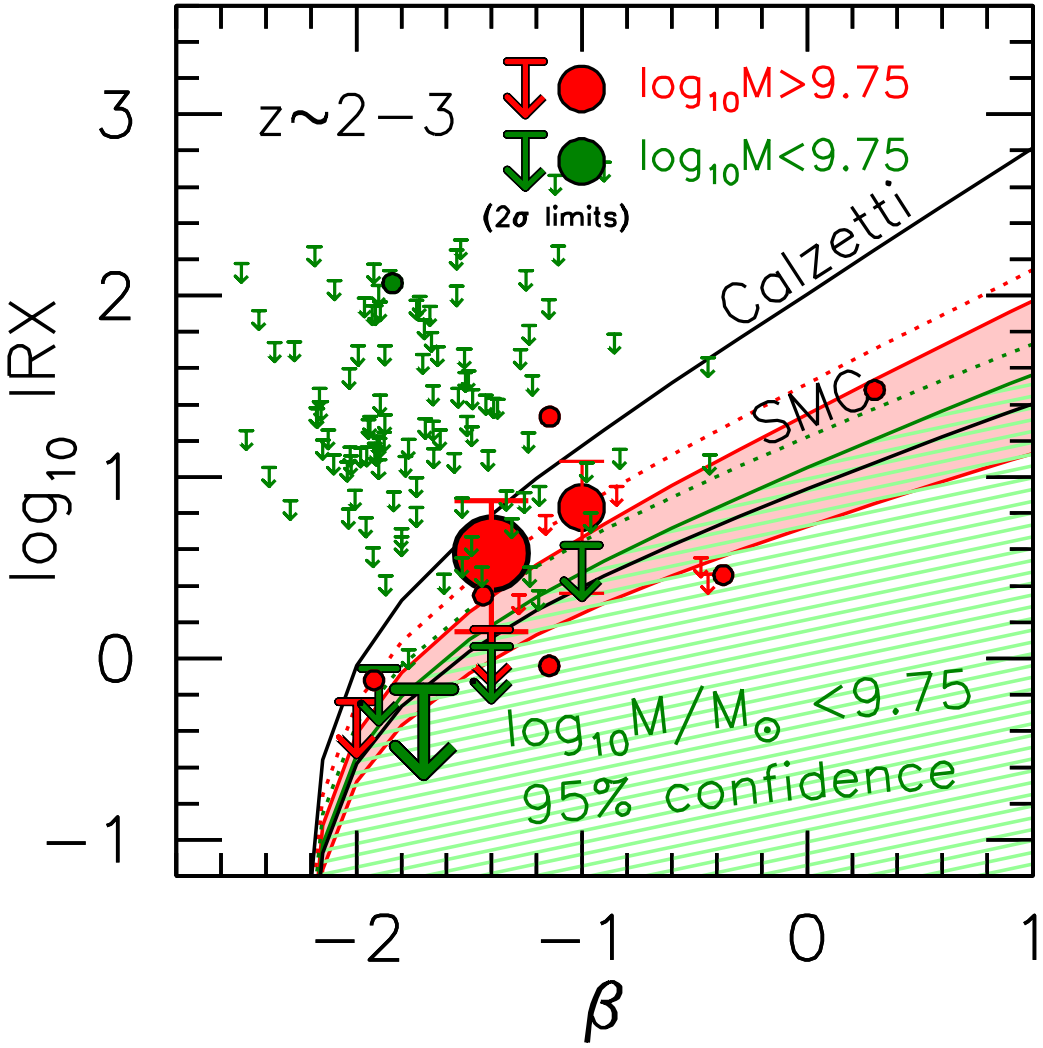
Empirical UV slope β-FIR flux relation predicts L(FIR)/L(UV) for simple dust-screen model

ALMA data suggests **less dust** than expected but why no shift in β? Maybe **different dust?**

NB: SMC is not a fully-fledged attenuation law (it does not include scattering into the beam so inapplicable to entire galaxy).

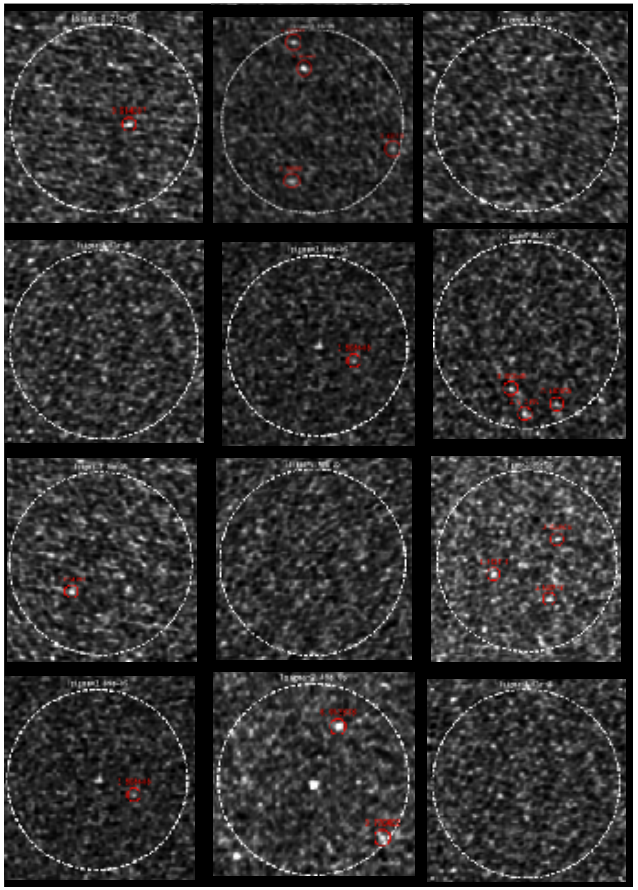
Pettini 1998 showed for LBGs that SMC "law" can be reconciled with Calzetti for the same dust.

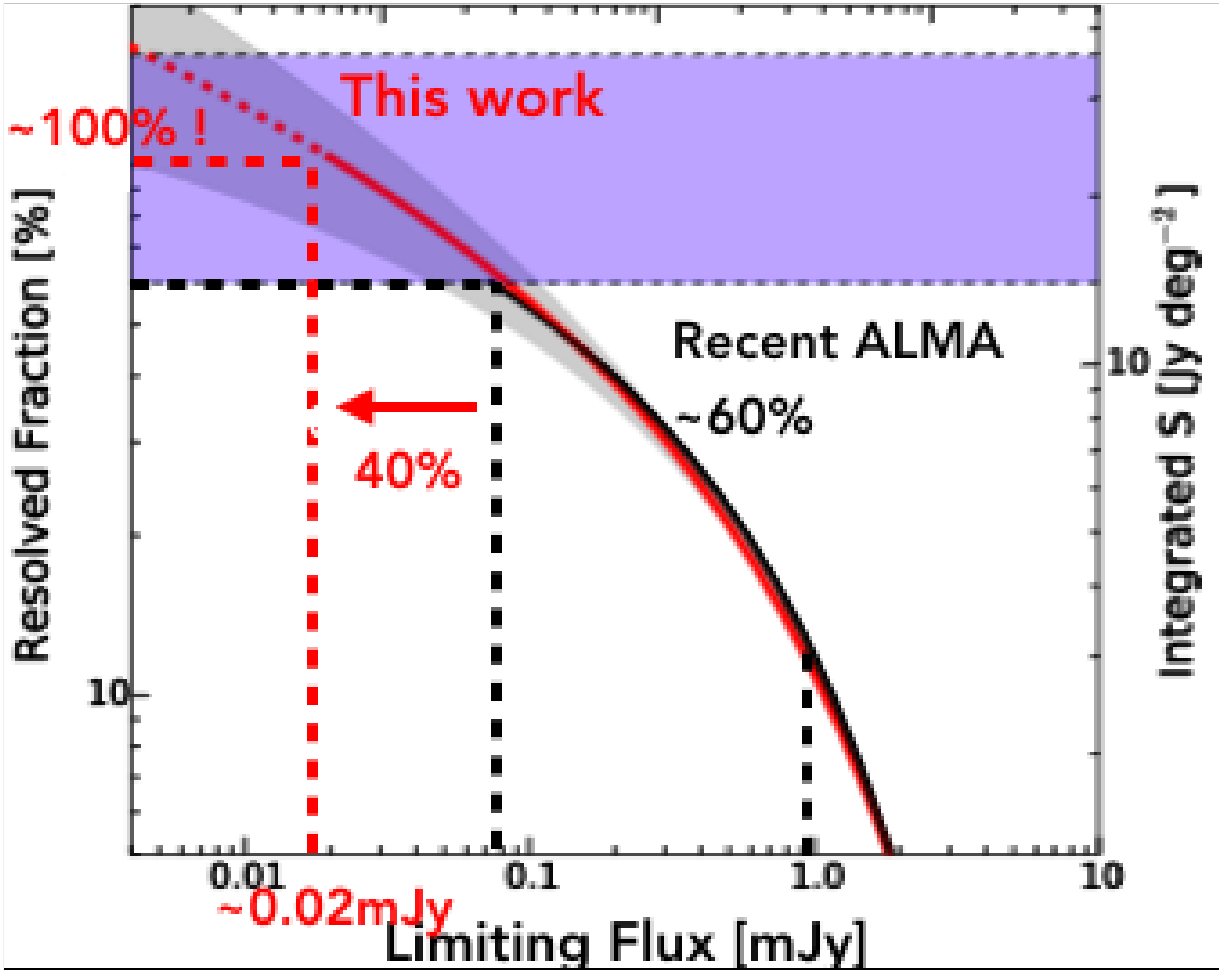
Da Cunha, Oesch



Bouwens et al 2016

Resolving the mm background



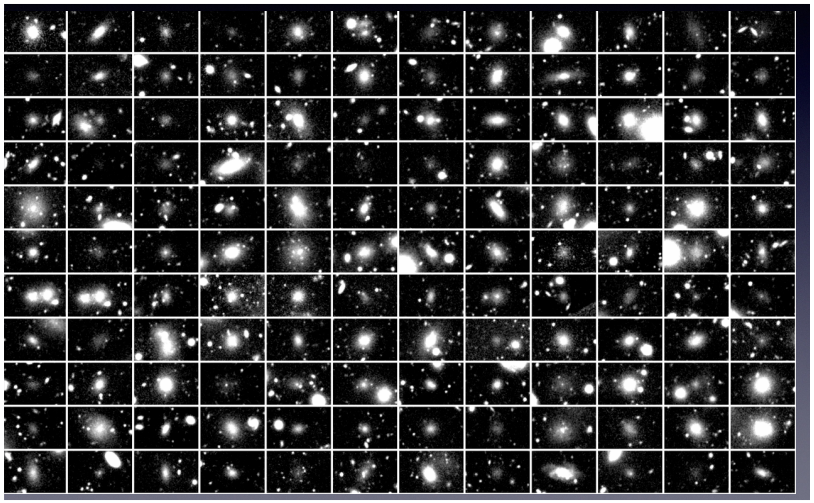


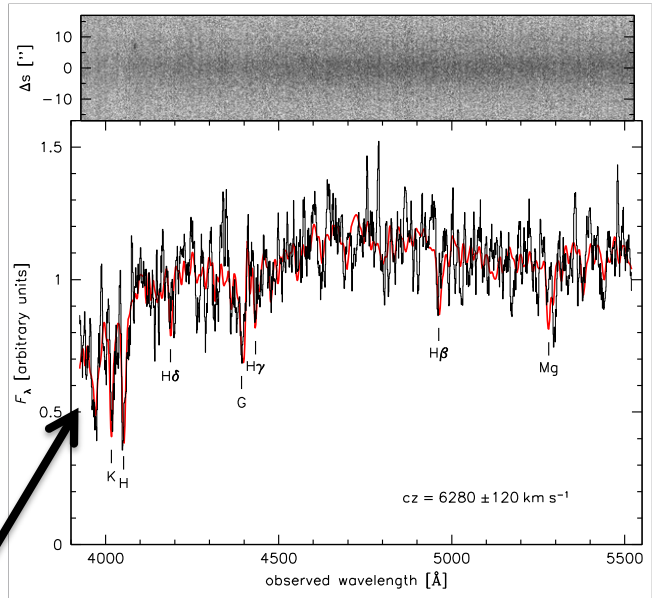
Millimeter background 80-100% resolved via deep ALMA fields including lensing cluster

60% of the faint sources appear to be star-forming LBGs at z~2-3

Fujimoto

Surprise #1: LSB Universe (again!)





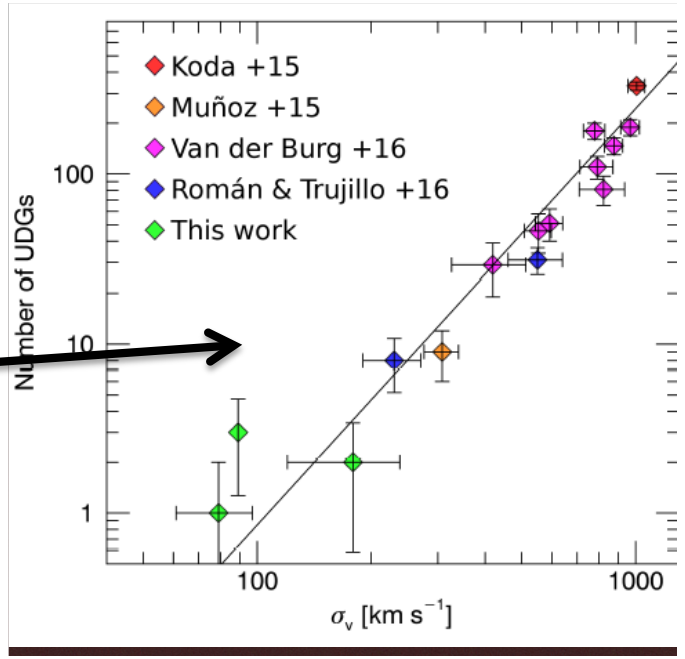
Passive and centrally concentrated in Coma

Heroic stellar velocity dispersion measurement

Surely environmentally driven..given correlation with cluster dispersion?

How did they survive? Are they important?!

Koda, van Dokkum



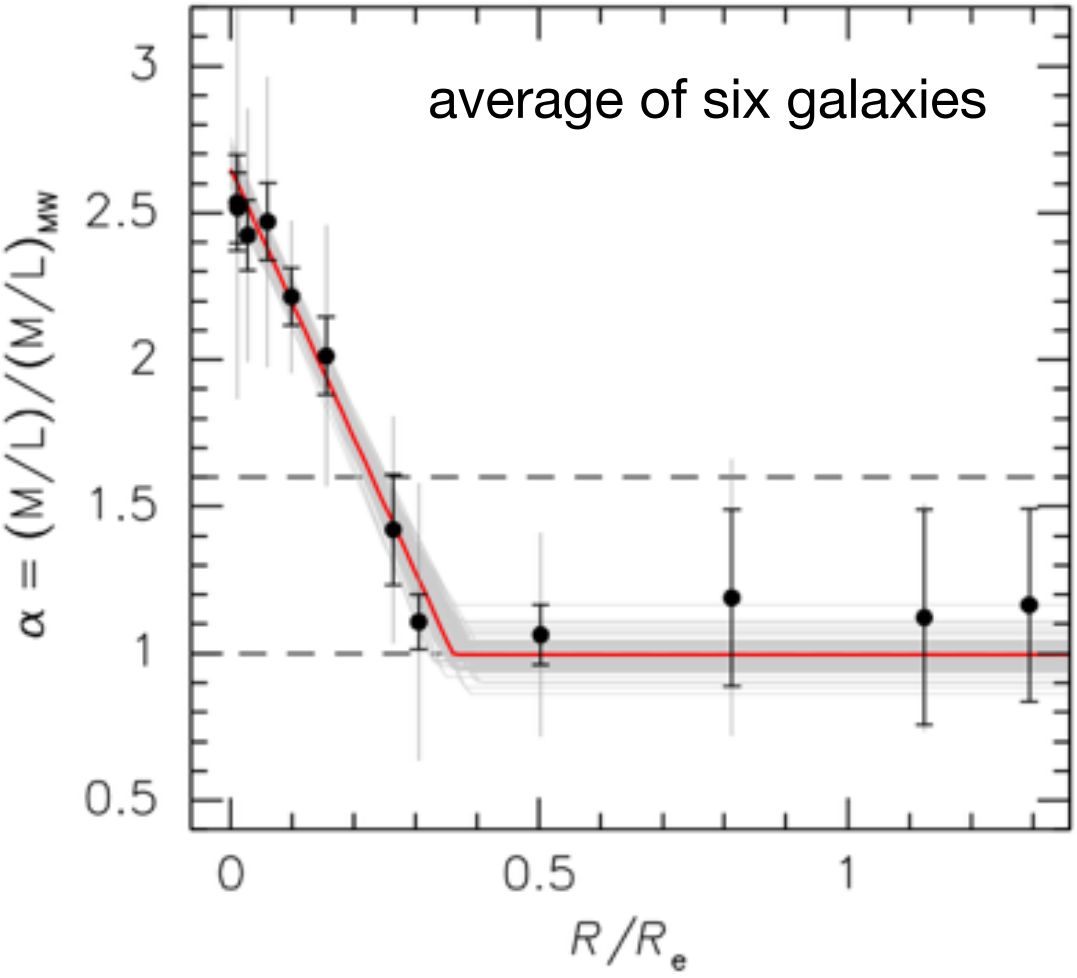
Surprise #2: Radially-dependent IMF

Stacking data from 6 galaxies can secure gravity-dependent indices as a function of radius

Contribution of low mass dwarfs to the main sequence

Claim is this can reconcile earlier controversies in IMF variations based on data taken with various apertures

OK – but what does it mean and how do such small compact cores with different IMFs retain their identity over long lifetimes?



van Dokkum et al, ApJ, submitted (astro-ph tomorrow!)

Reflections since 1988…

The big questions in galaxy evolution used to be attractively simple:

- Do galaxies evolve? counts, colours, redshift distributions (1980's)
- Nature versus nurture – the role of the environment e.g. in reproducing the morphology-density relation (1980's)
- Monolithic vs hierarchical assembly: the underpinning by dark matter assembly challenged by `downsizing' (1990's)
- Reconciling the cosmic star formation history with the redshift-dependent stellar mass density (2000's)
- Energetic feedback: reconciling the observed luminosity function with the DM halo mass function (2000's)

Now we are spoilt with rich datasets: stellar masses, SEDs, molecular gas fractions, resolved kinematics, metallicities over a wide range of sources to z~5!

And simulations which (as they always have!) reproduce most of these datasets

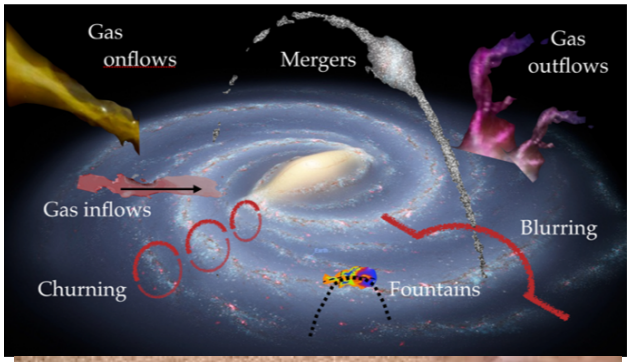
BUT..what are the big picture science questions in this new data-driven era?

Galactic Archeology

The big picture
- Assembly history of normal galaxies
- Stellar streams as probes of dark matter
- Dwarf galaxies as probes of reionisation era

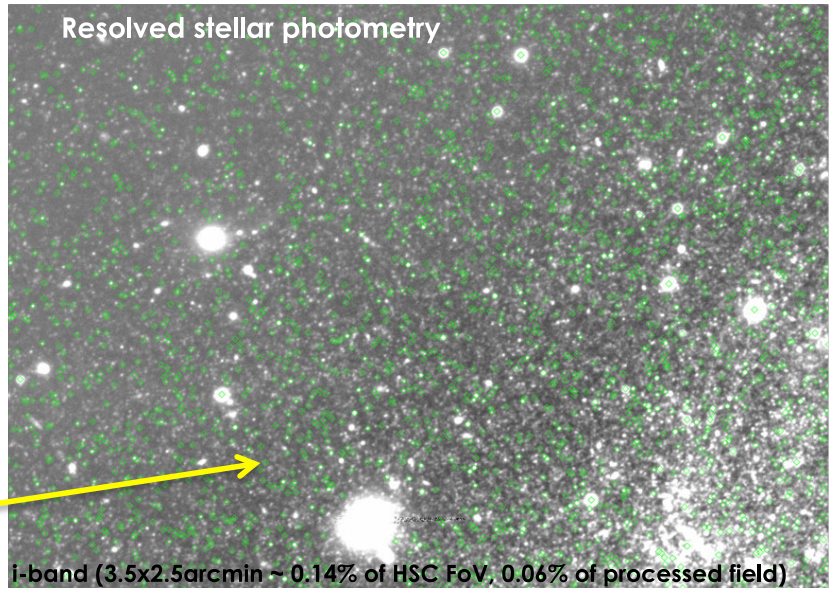
The tools
- The Gaia revolution
- Panoramic HST/HSC imaging of stellar halos
- Gas and stellar metallicity – mass relations
- Kinematics of stellar streams
- Abundance patterns in LG dwarfs

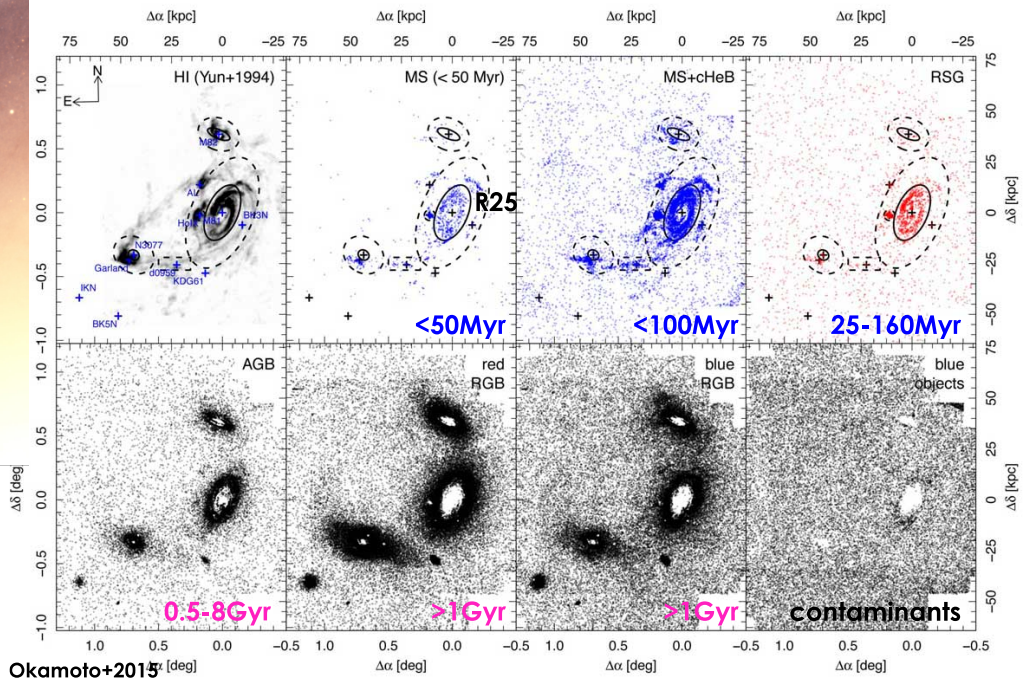
The issues/challenges:
- Thick disk and implications for z~2 galaxies
- Orbits and ages of stellar streams



I wish I hadn't volunteered to give the conference summary..

Demonstrating the Power of HSC: I – M81 Group

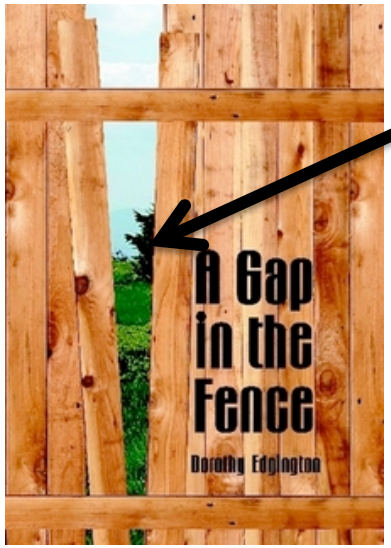




Spatial distribution of stellar ages across M81 group including dwarfs

Okamoto

Demonstrating the Power of HSC: II – M31 streams

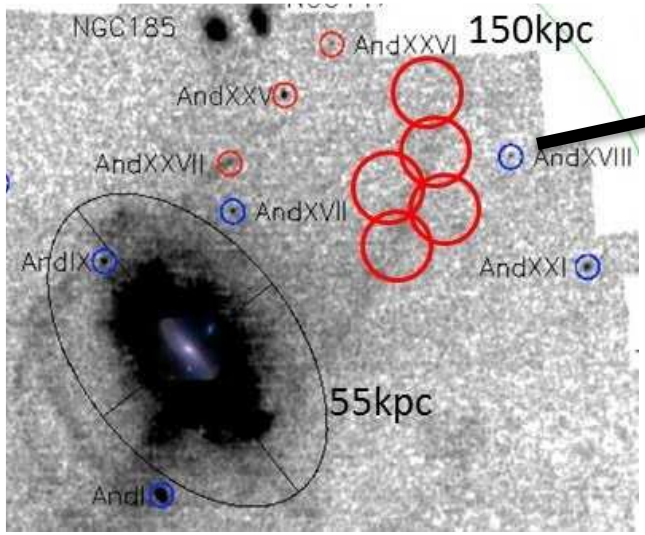


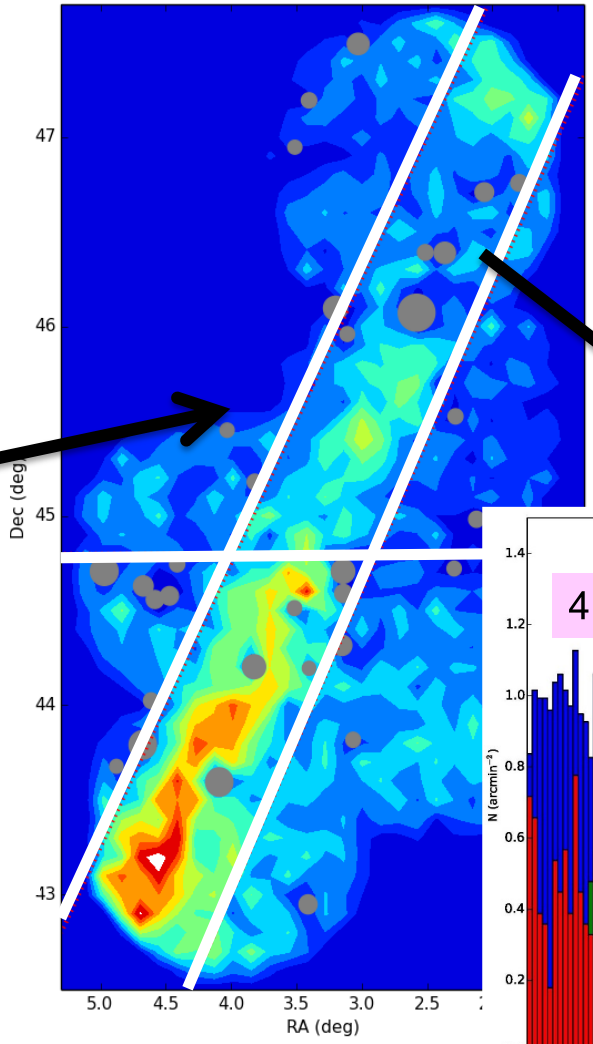
What happened?

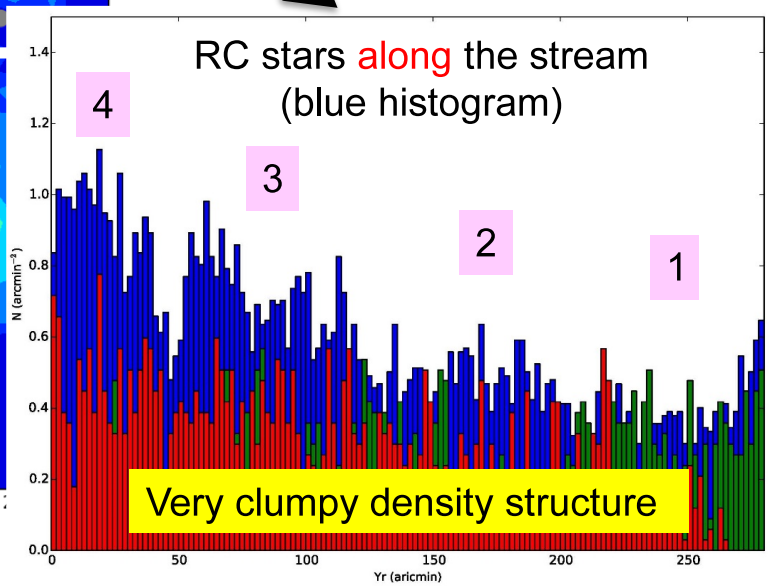
Gaps in stream due to perturbing DM halos

Free from foreground contamination in M31

Can the age/orbit be defined to test CDM?

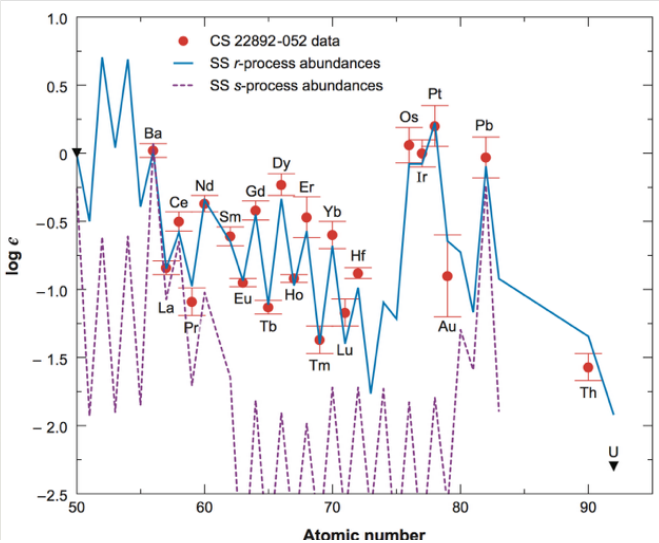






Chiba, Ishigaki

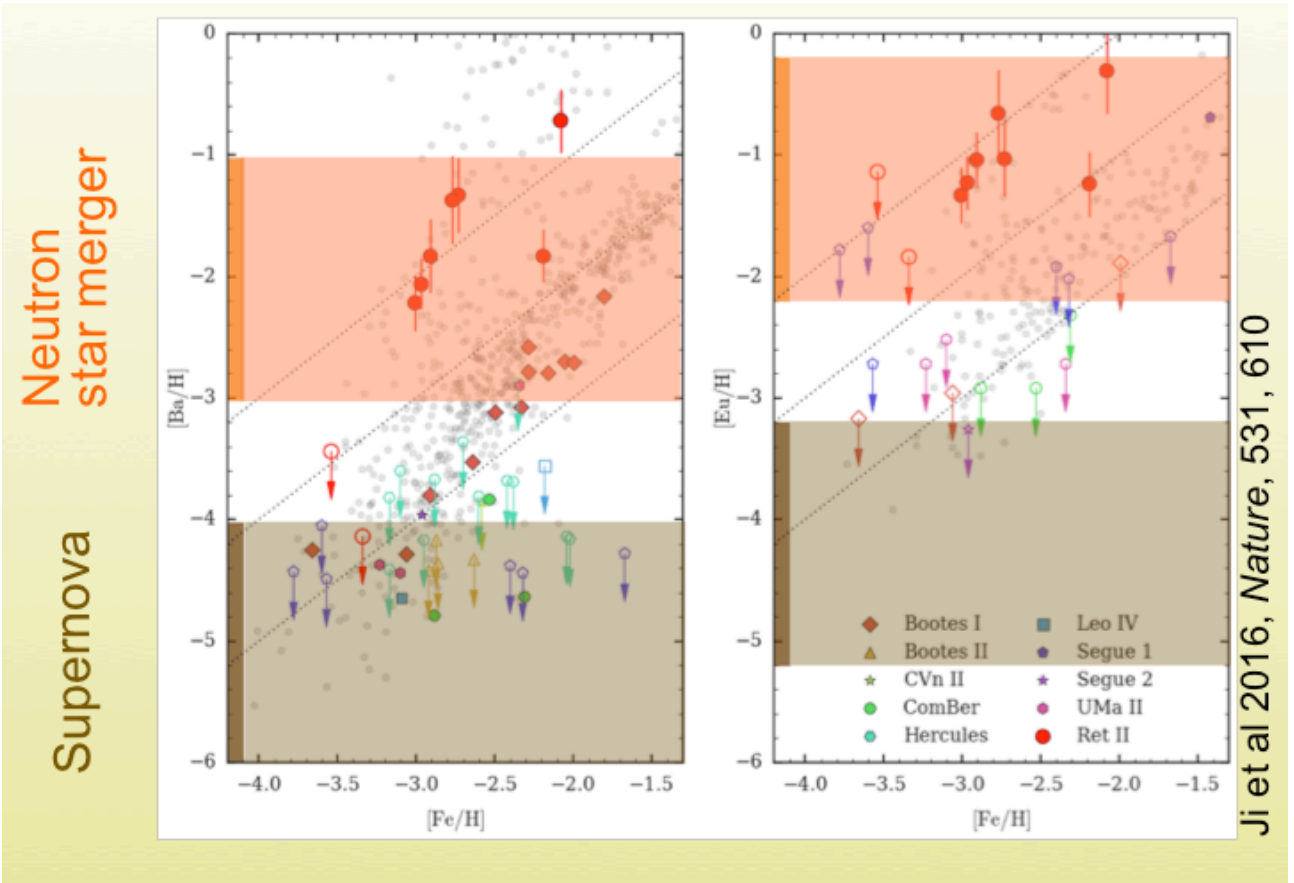
Origin of r-process Elements: Implications for First Generation Enrichment



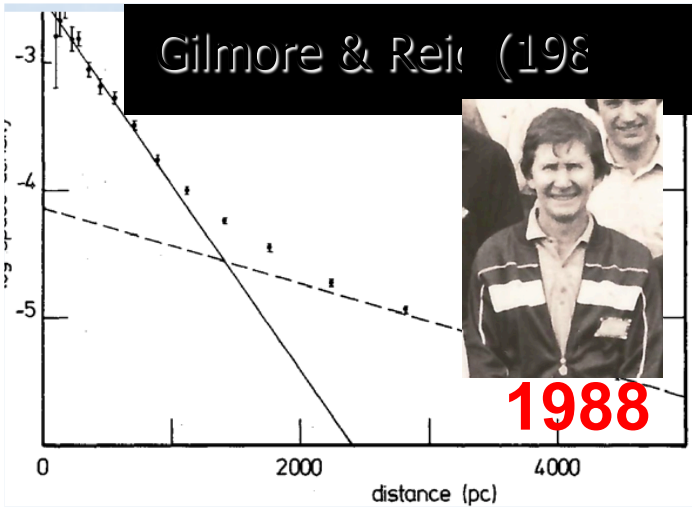
Spectra of Ba and Eu in 7/9 stars in Reticulum II super-abundant c.f. those in 10 other UFDs. Rarity consistent with neutron star mergers c.f. early SNe II

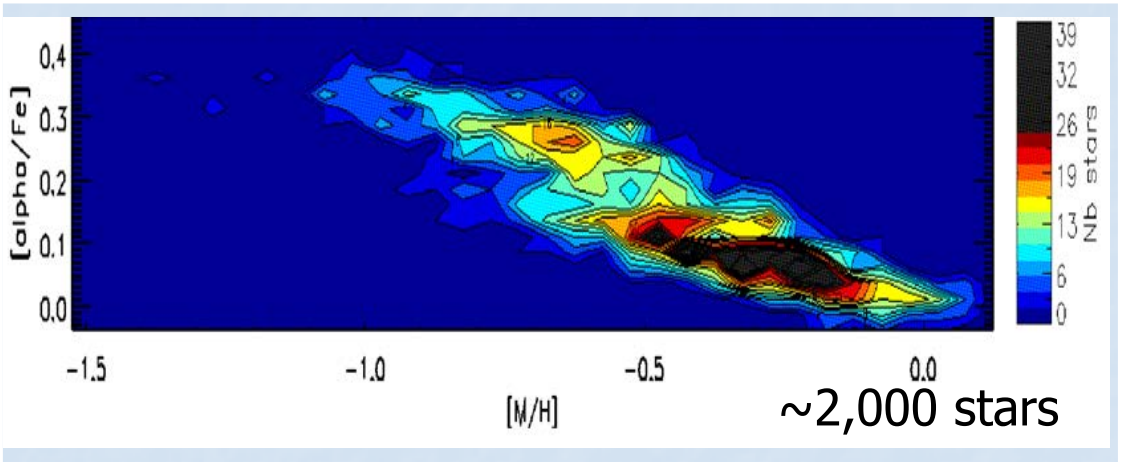
Could this signature and the rate of N star mergers (LIGO) be used, in conjunction with accurate stellar ages, to shed light on early formation history?

Frebel



Thick & Thin Disc: Continuity vs Distinct Entities?

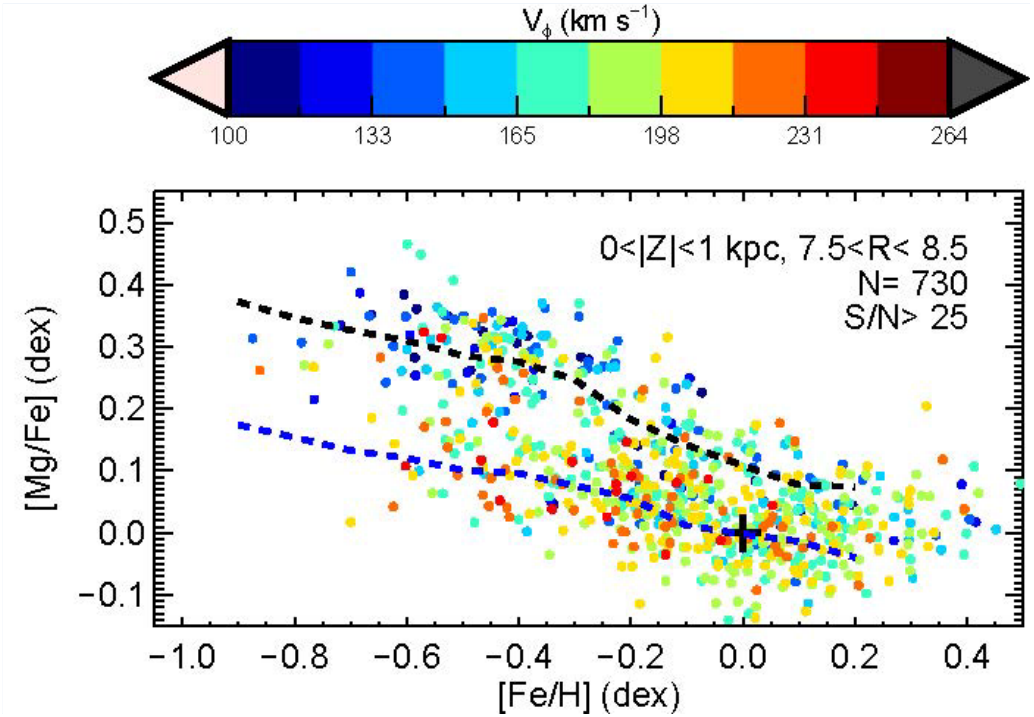




Kinematic and metallicity data have been used since 1983 to debate whether the thick disc is a distinct component. **It was controversial in 1988 (Norris!)**

Surely there's a definitive statistical test to reconcile these different views now the data is so extensive?

Connection to z~2 galaxies given quiescent history of Milky Way?



Wyse

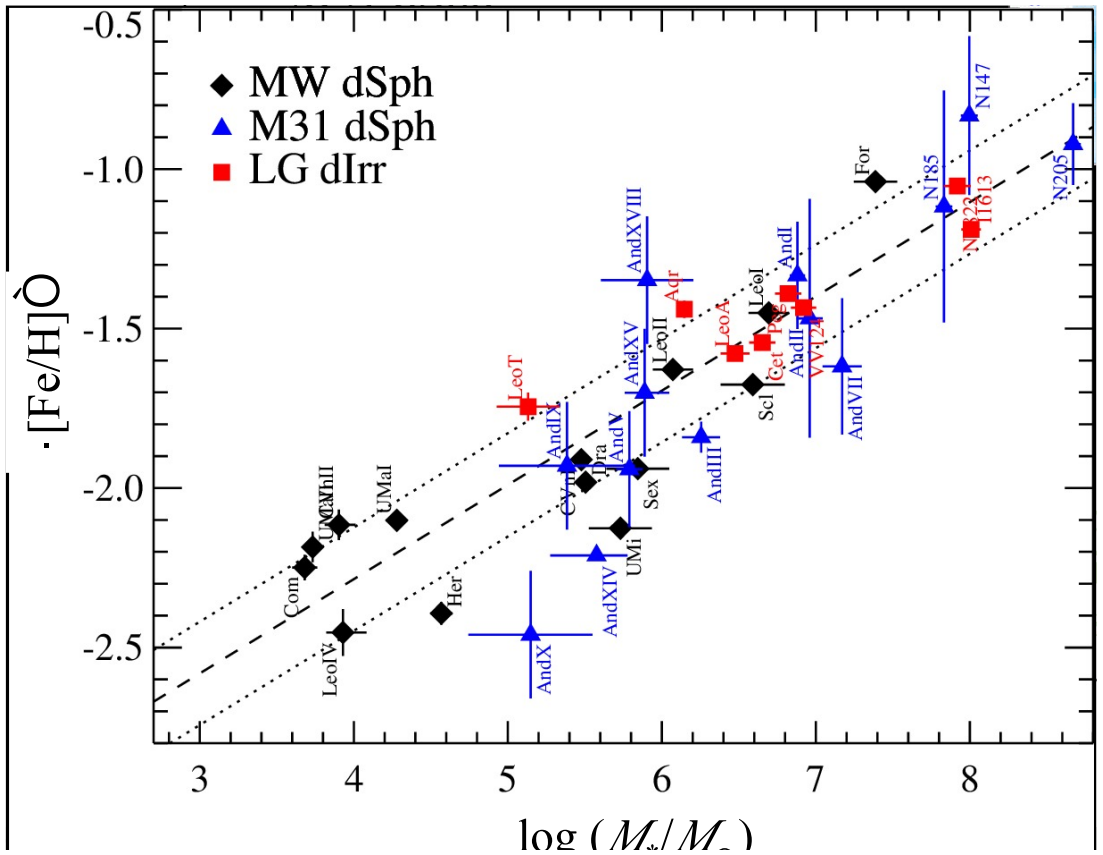
Stellar Metallicity as a Probe of Chemical History

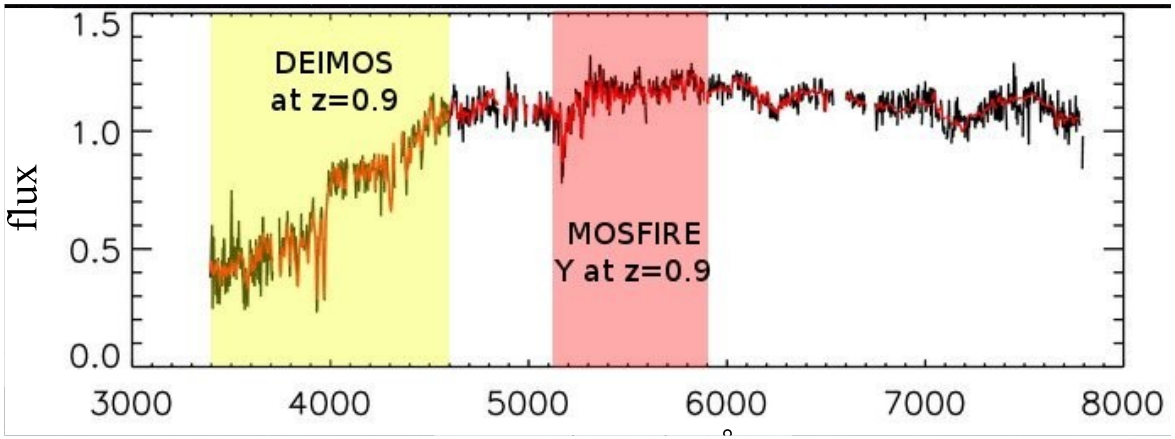
Tight stellar metallicity – mass relation over 8 dex including dIrr and DSph with very different SF histories

More robust indicator of chemical evolution if past SF is understood

Important future probe with ELTs – interesting to see what can be done with current 8-10m telescopes

Kirby





Cosmology

The big picture
- Nature of dark matter
- What is Dark Energy?
- Does Einstein GR need modification

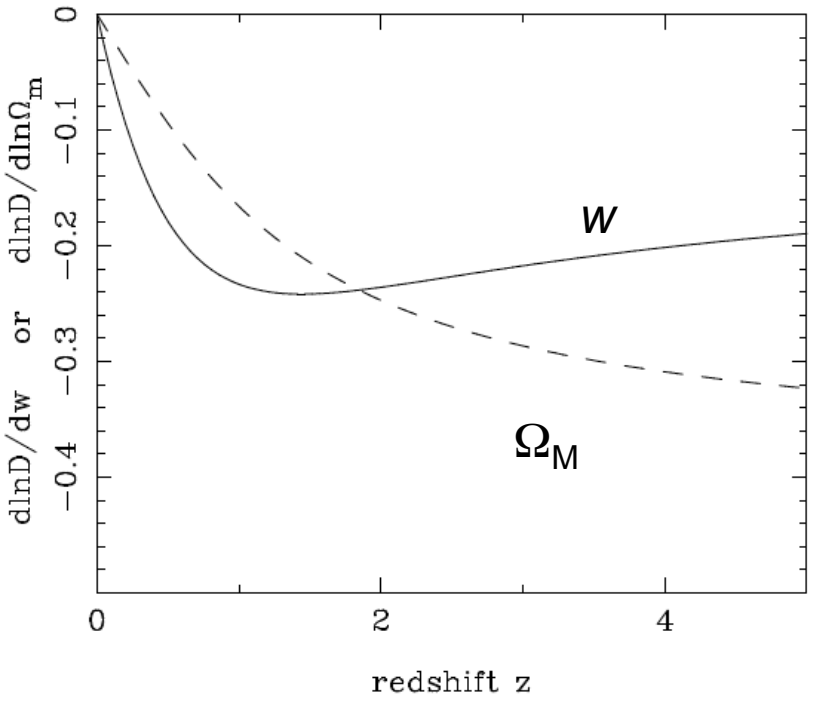
The tools
- Growth of structure (RSD, WL)
- Expansion history (BAO, SNe)

The projects: PFS + DESI ahead of Euclid
DES + KIDS + HSC

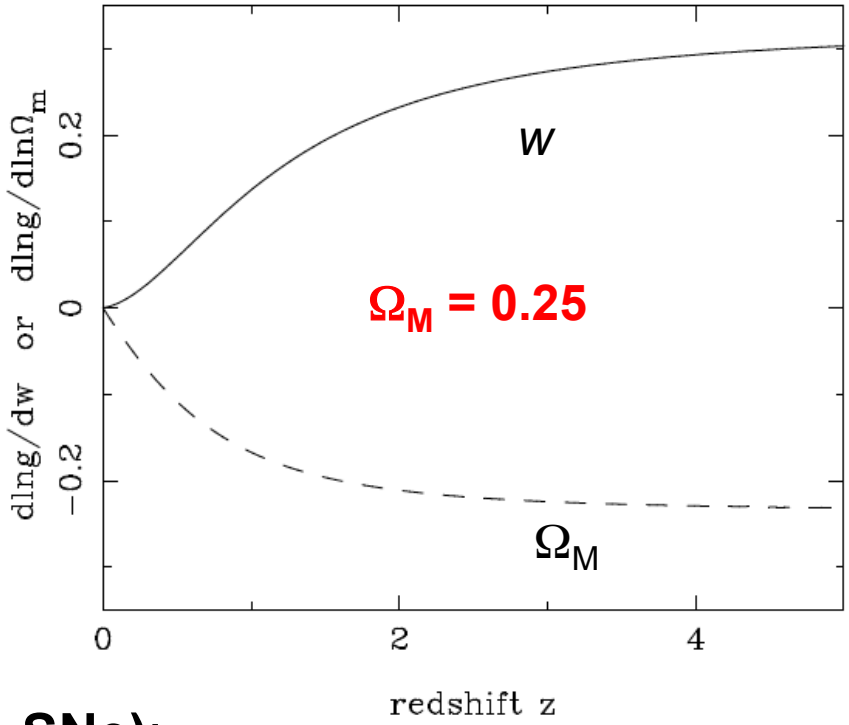
The issues/challenges:
- Velocity fields for RSD
- Systematics for WL
- Evolution/host properties for SNe
- Prejudice (Einstein can't be wrong etc)

Dark Energy: Distance & Growth-based Methods

dlnD/dw



dlng/dw



Distance – redshift relation (BAO, SNe):

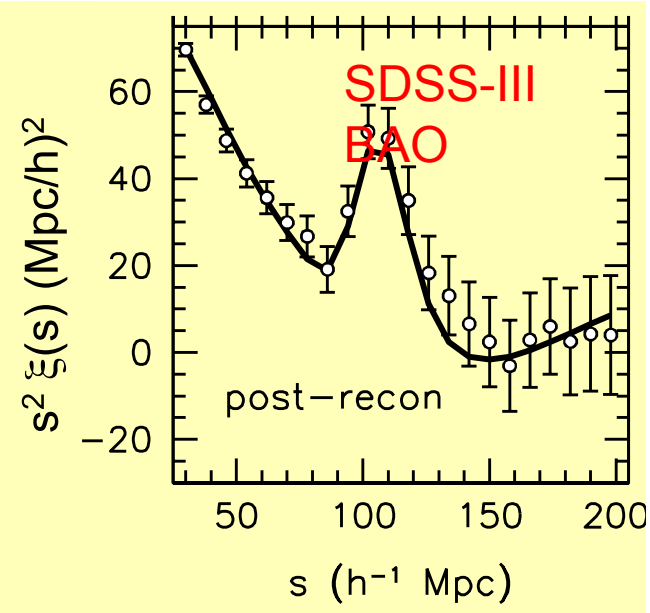
not v. sensitive to *w*: 1% precision requires D to 0.2%
w degenerate with changes in Ω_M

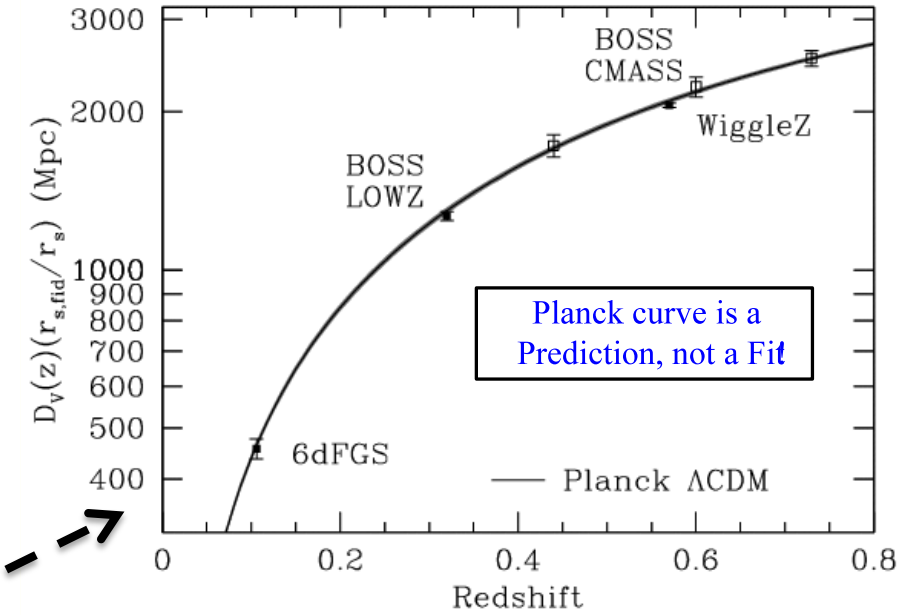
Growth – redshift relation (RSD, WL)

w has opposite effect to Ω_M with different systematic issues

Peacock

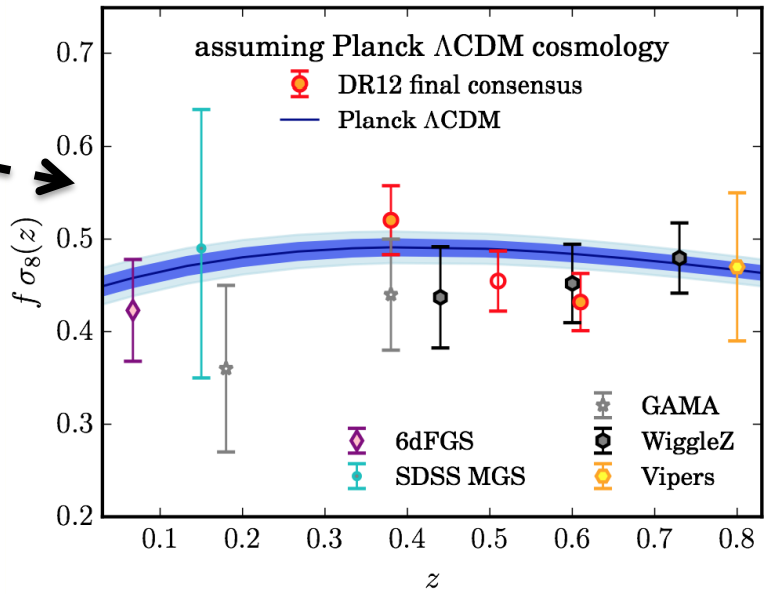
Large Scale Structure: State of the Art





Dark Energy is Λ to within 6% (if w not evolving)

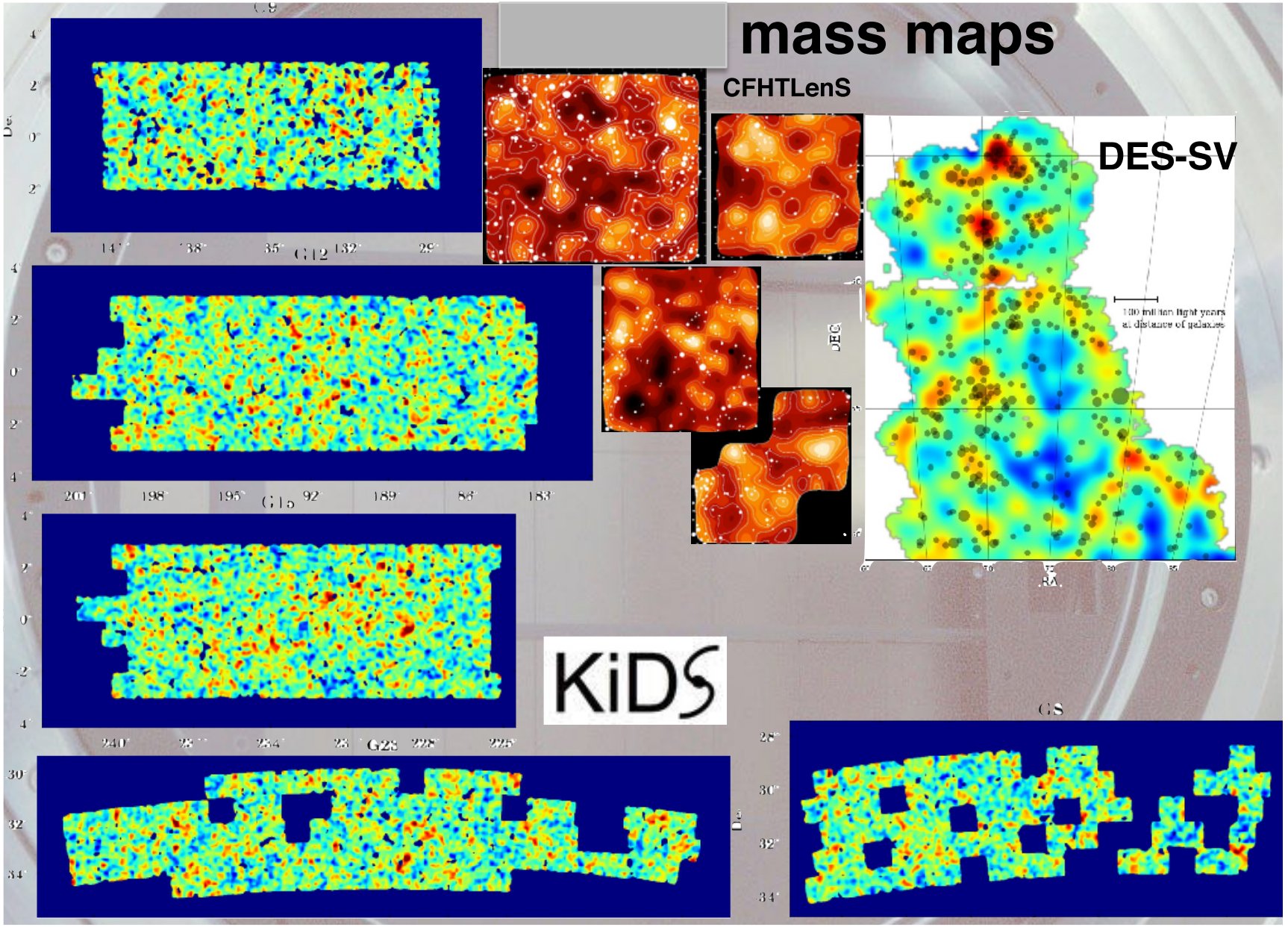
Redshift-space distortions:
Einstein GR is ok to 10%



Q: What would it take to convince to abandon status quo??

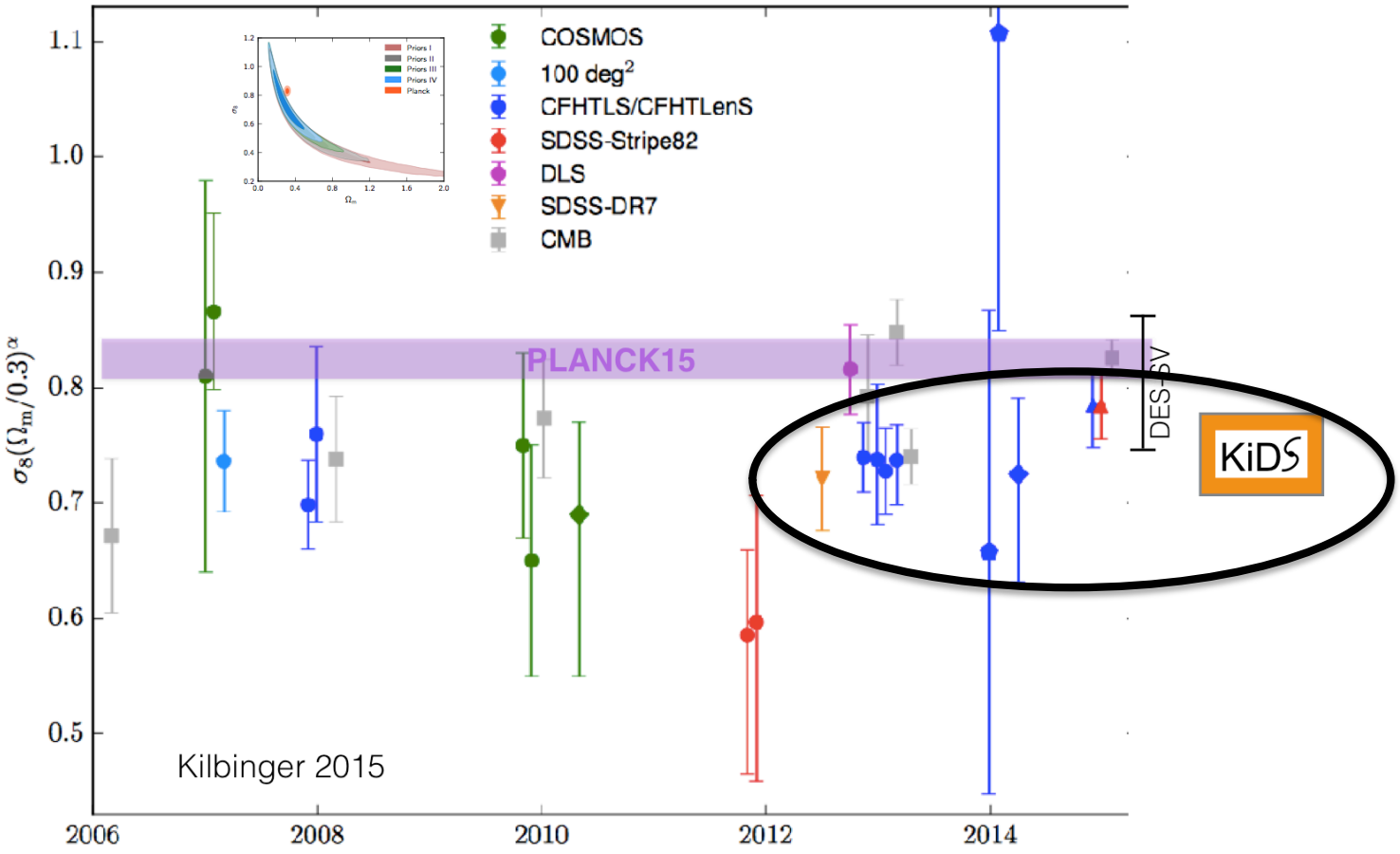
Peacock, Guzzo

Weak Lensing has Come of Age!



Frieman, Kuijken

Weak Lensing – Cosmic Shear & σ_8

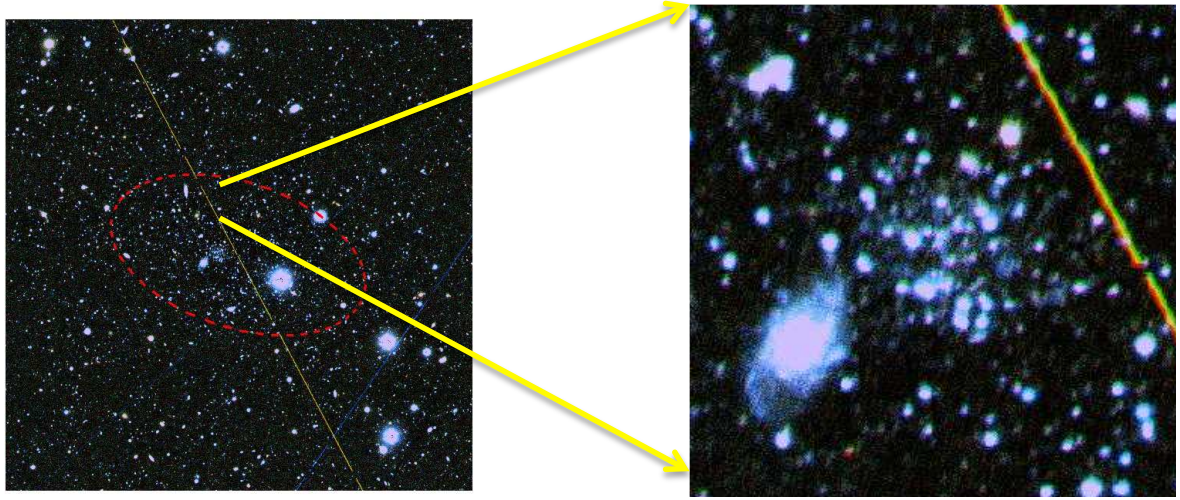


Tension with Planck?

- Examining data in overlapping areas from different instruments important to convince skeptics
- Where is the HSC data point??

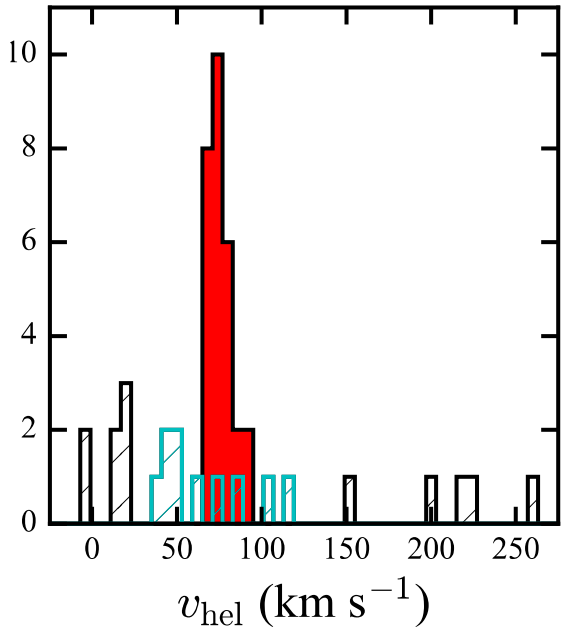
Frieman, Kuijken

After Masahiro's μlensing talk..another DM constraint

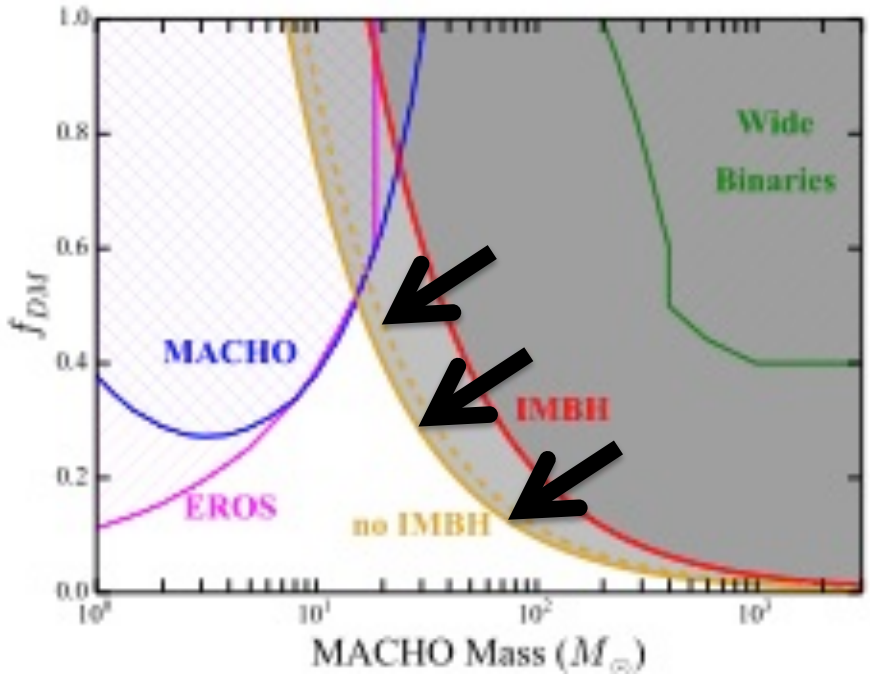


Eridanus II - a distant Ultra Faint Dwarf with a central star cluster

Li et al use 28 members to get a velocity dispersion of 6.9 km/s indicating a M/L~420 solar



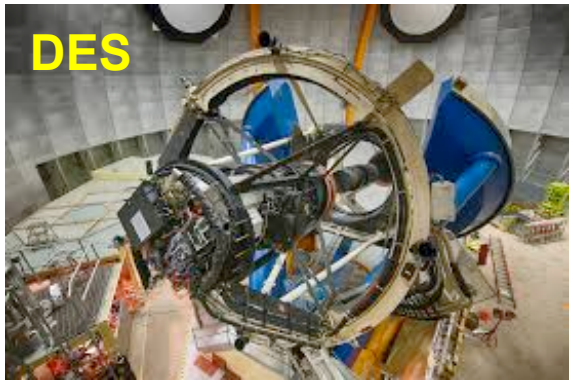
Frieman

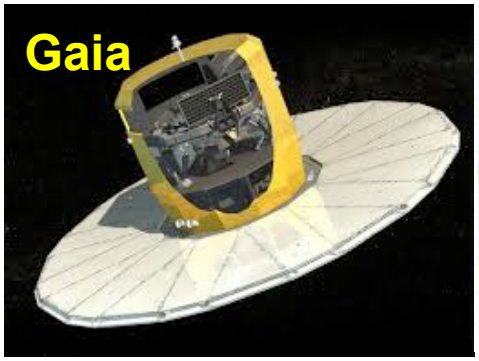


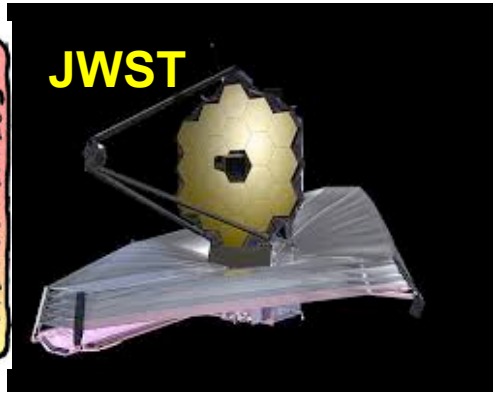
Survival of star cluster in sea of massive BHs constraints their abundance for various masses (Brandt 2016)

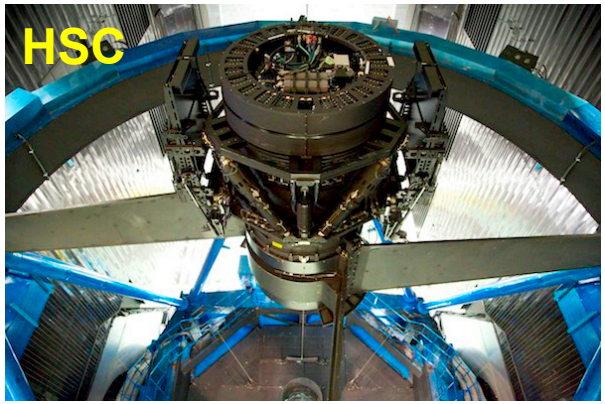
Crnojevic et al 2016, Brandt 2016, Li et al 2016

The Near Future is Exciting (and the present!)

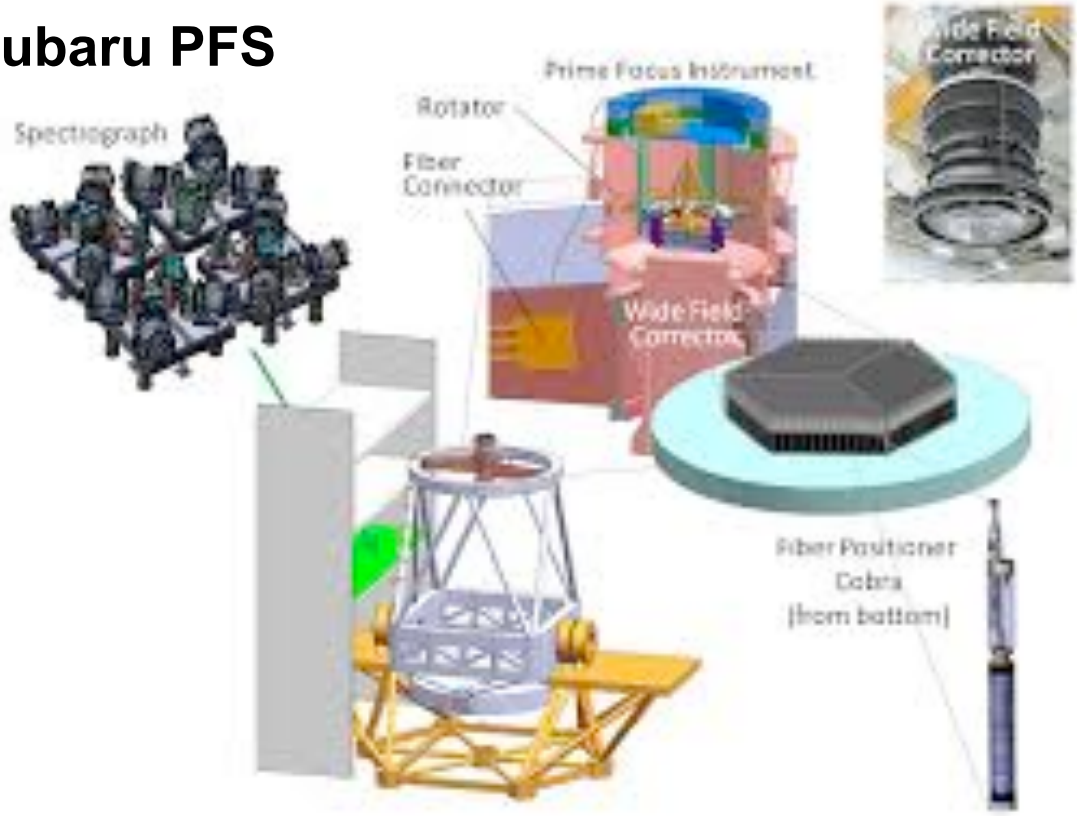








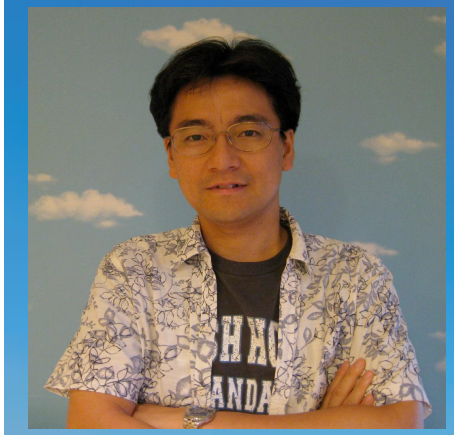
Subaru PFS



Understanding how to use these in a complementary way is important (Glazebrook)

Thanks to the SOC and LOC!

Taddy Kodama



Koji Kawabata

Michitoshi Yoshida