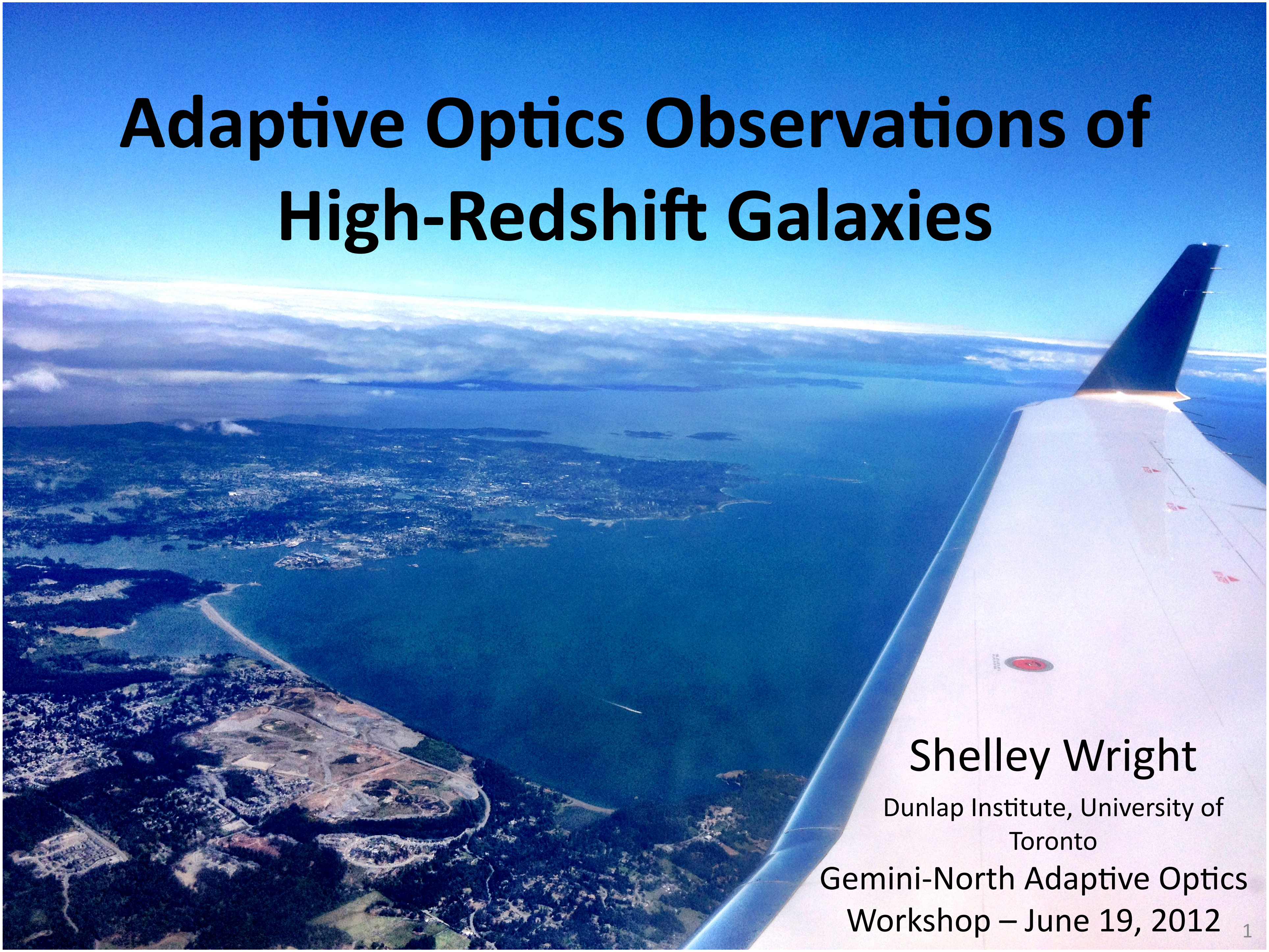
Adaptive Optics Observations of High-Redshift Galaxies



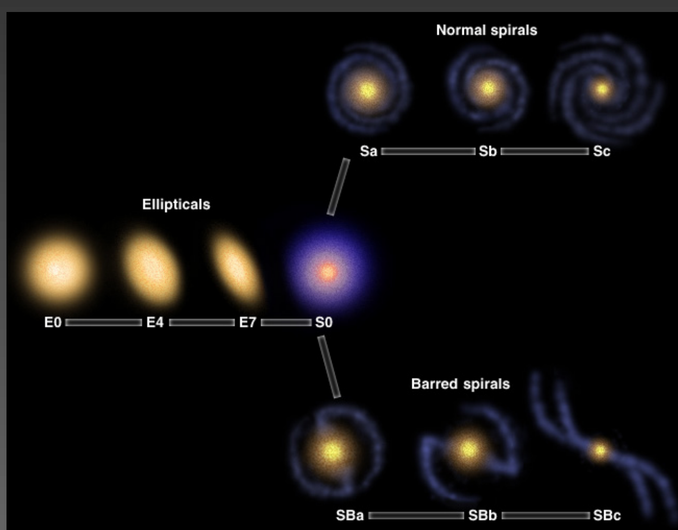
Shelley Wright

Dunlap Institute, University of Toronto

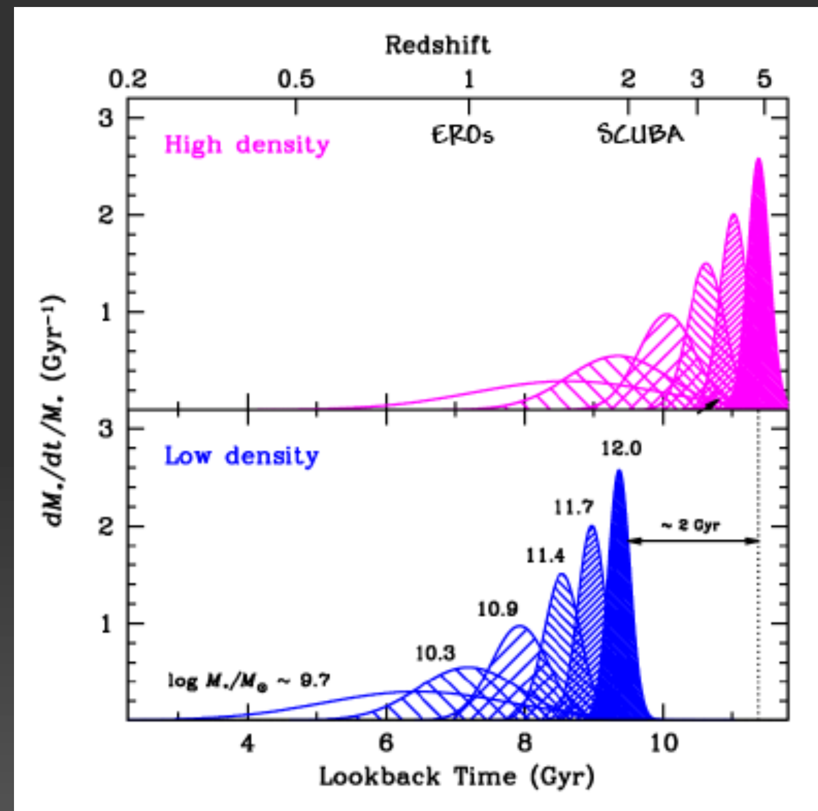
Gemini-North Adaptive Optics Workshop – June 19, 2012

Formation era of galaxies is likely a function of Hubble type

- Determining the formation epoch of galaxies is not certain
- Galaxies in clusters form earlier than field galaxies
- More massive galaxies assembled at higher redshifts



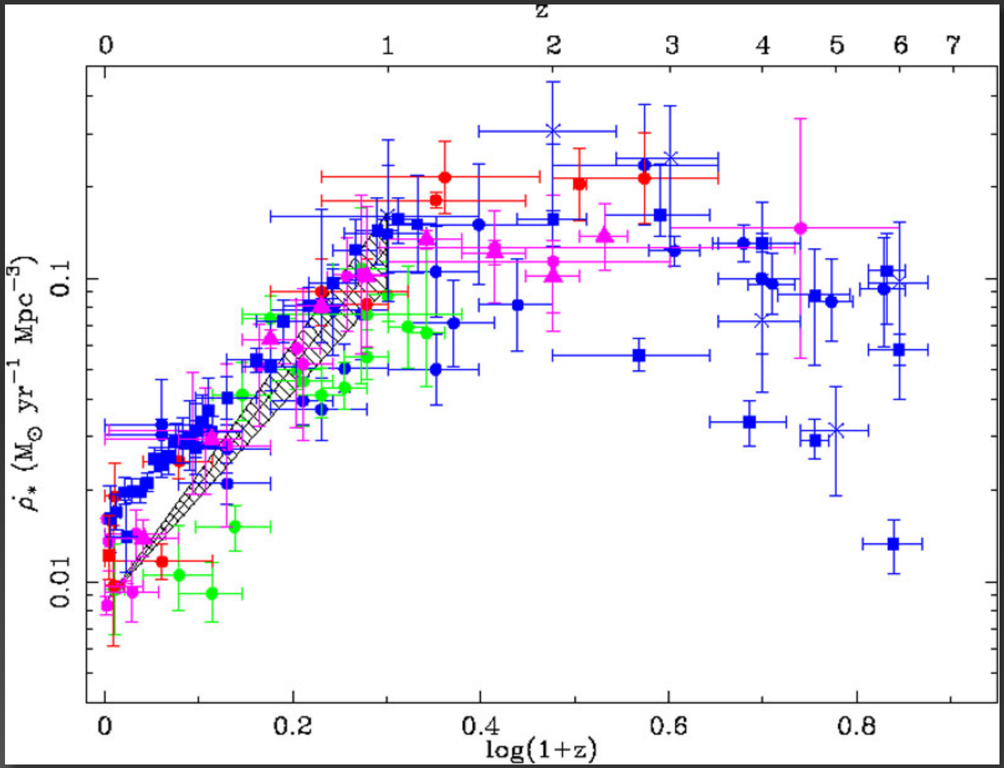
Total Galaxy Mass and Age



Thomas et al. 2005

Large statistical samples have shown rapid evolution observed at 1 < z < 3

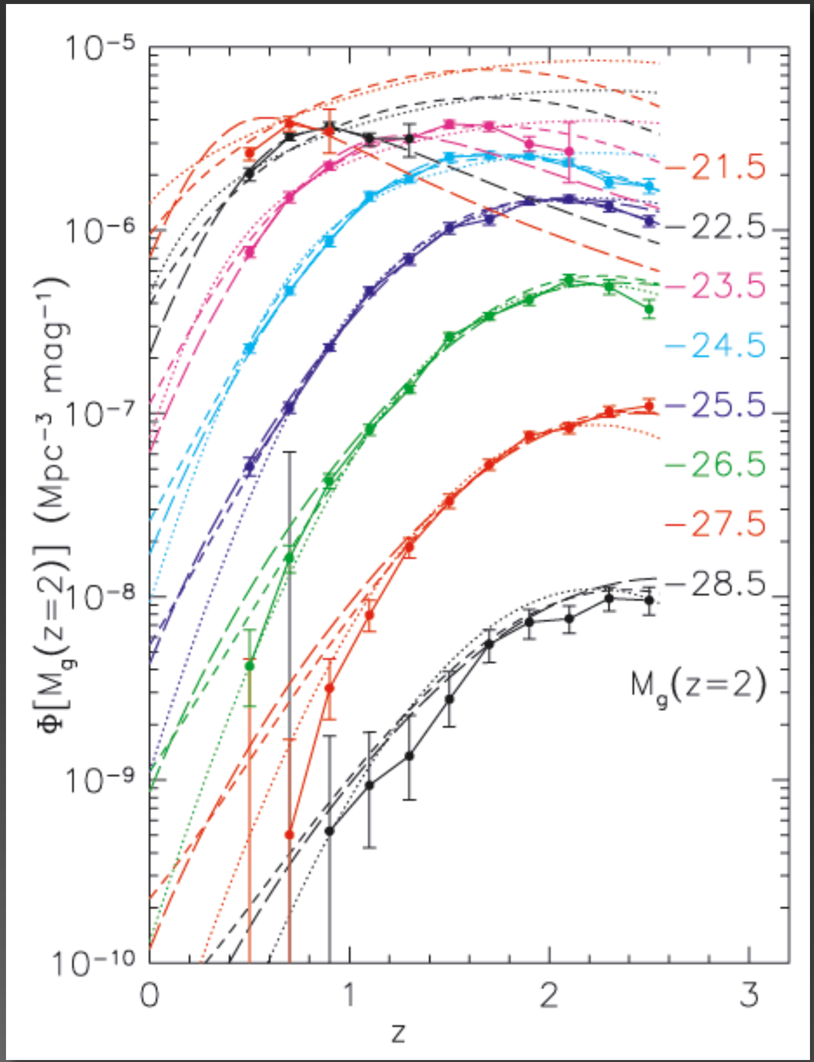
- Cosmic SFR density peaks at z~1-3



Hopkins & Beacom 2006

Large statistical samples have shown rapid evolution observed at 1 < z < 3

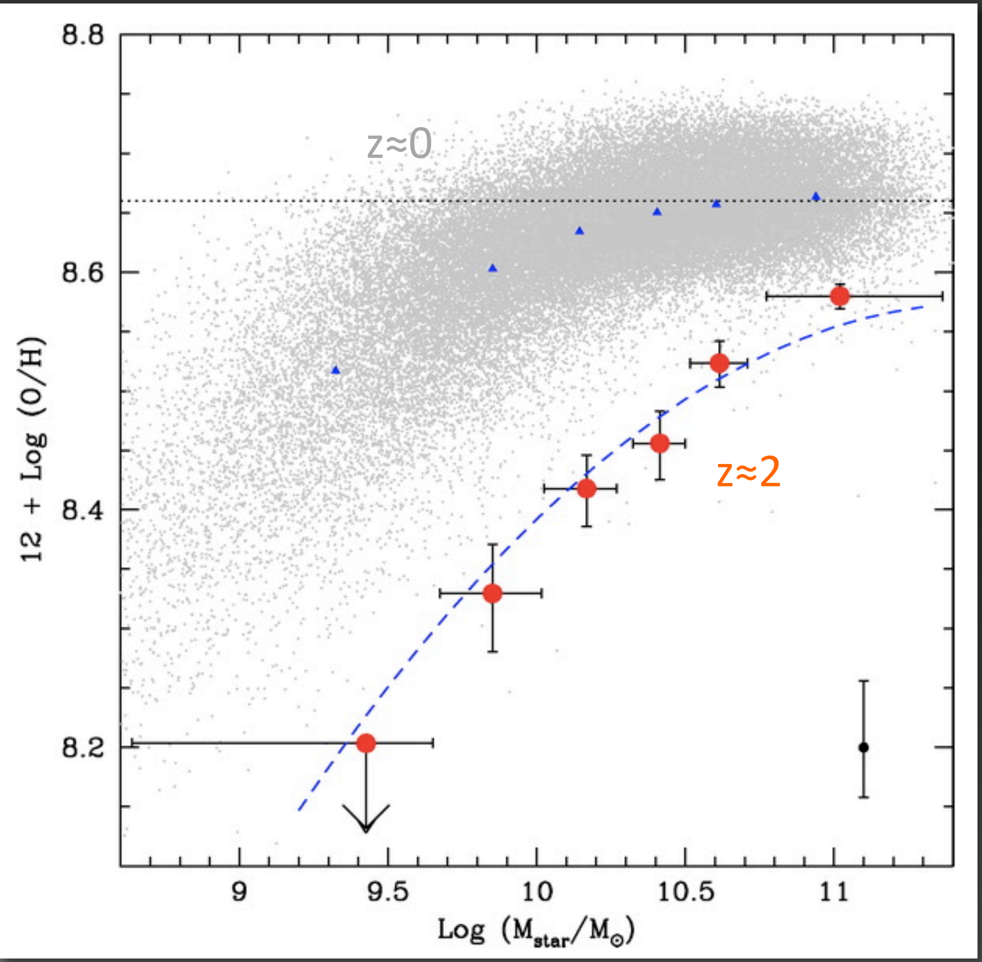
- Cosmic SFR density peaks at z~1-3
- Quasars peak at similar epochs at z~2-3



Croom et al. 2010

Large statistical samples have shown rapid evolution observed at 1 < z < 3

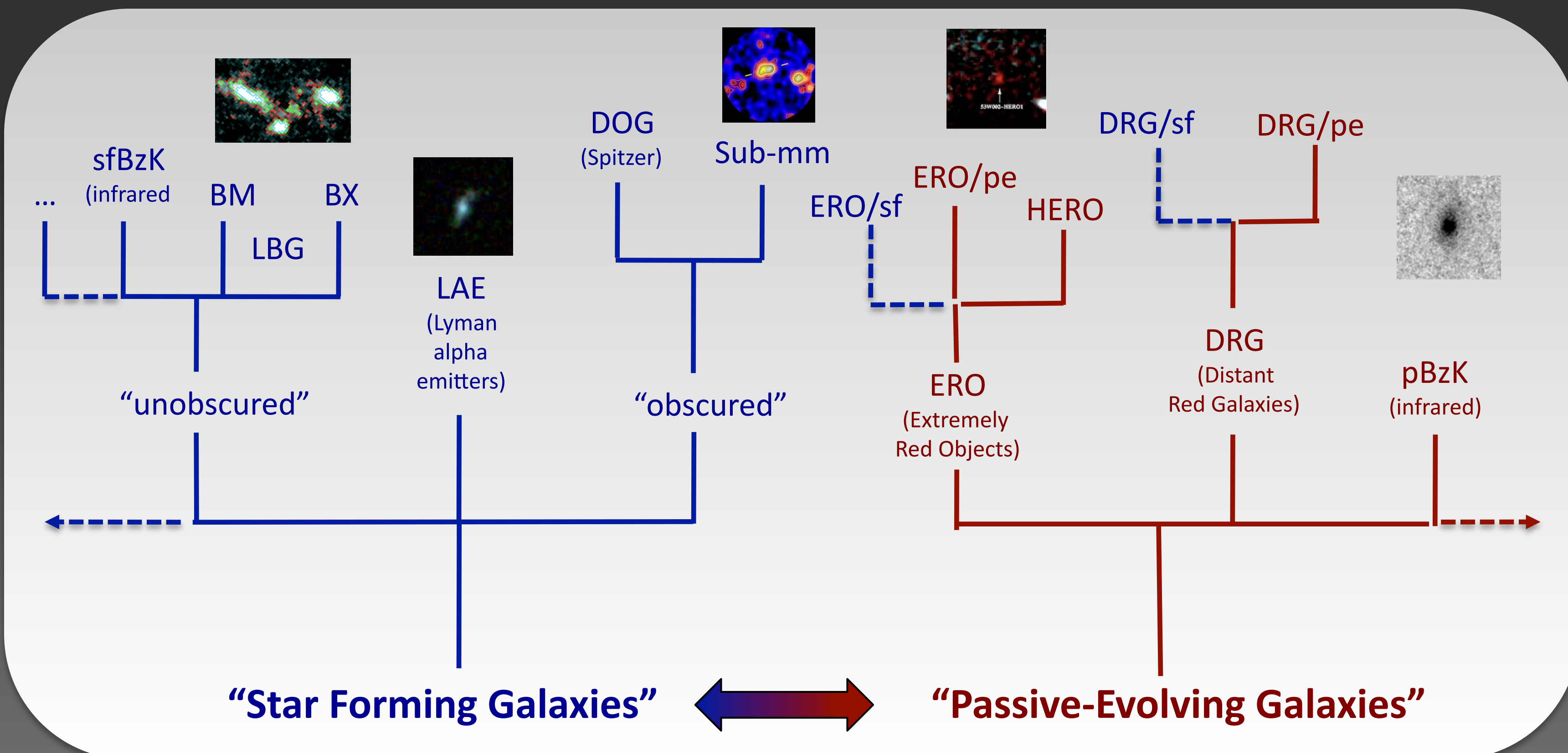
- Cosmic SFR density peaks at z~1-3
- Quasars peak at similar epochs at z~2-3
- Mass-Metallicity relationship in place at high-z



Erb et al. 2006

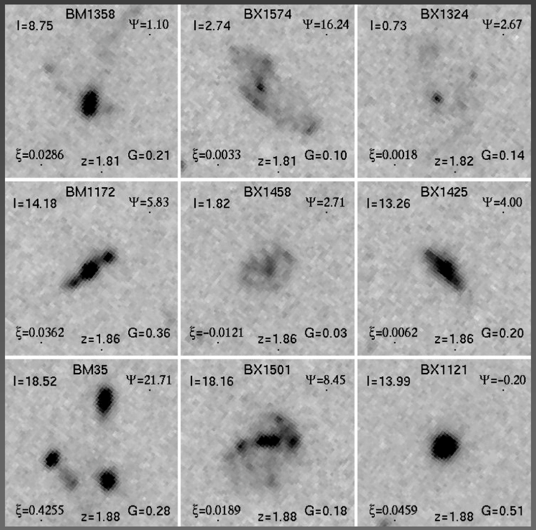
"Zoology" of high-redshift galaxies

- Determined by Wavelength Selection and redshift
  - Color-color selection (Optical and NIR, varying methods) produce differing types
  - Sub-mm (Scuba, 850 um, dust obscured)
  - Infrared selection
- Parameter space : M_*, SFR, extinction, ages, clustering

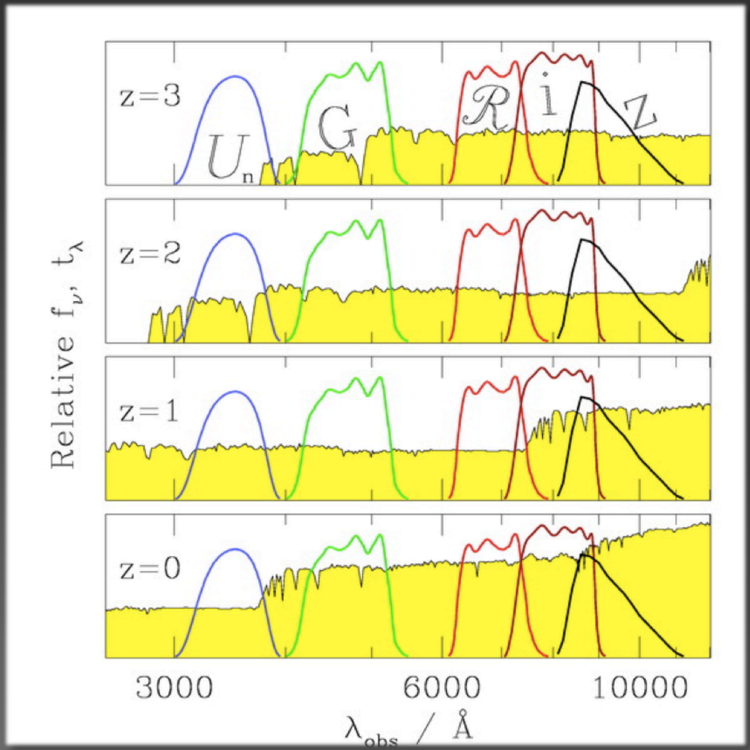


High-z Star forming galaxies

- Color selection techniques generate 1 < z < 3 galaxy samples (e.g., using Lyman/Balmer break)
- >2,000 spectroscopically confirmed redshifts
- Typical properties:
  - High SFR 5 - 100 M⊙/yr
  - Stellar mass $10^{9\text{-}11}$ M⊙
  - Halo masses $10^{11\text{-}12}$ M⊙
  - Angular Size ~ 1” , (Re~1-3 kpc)

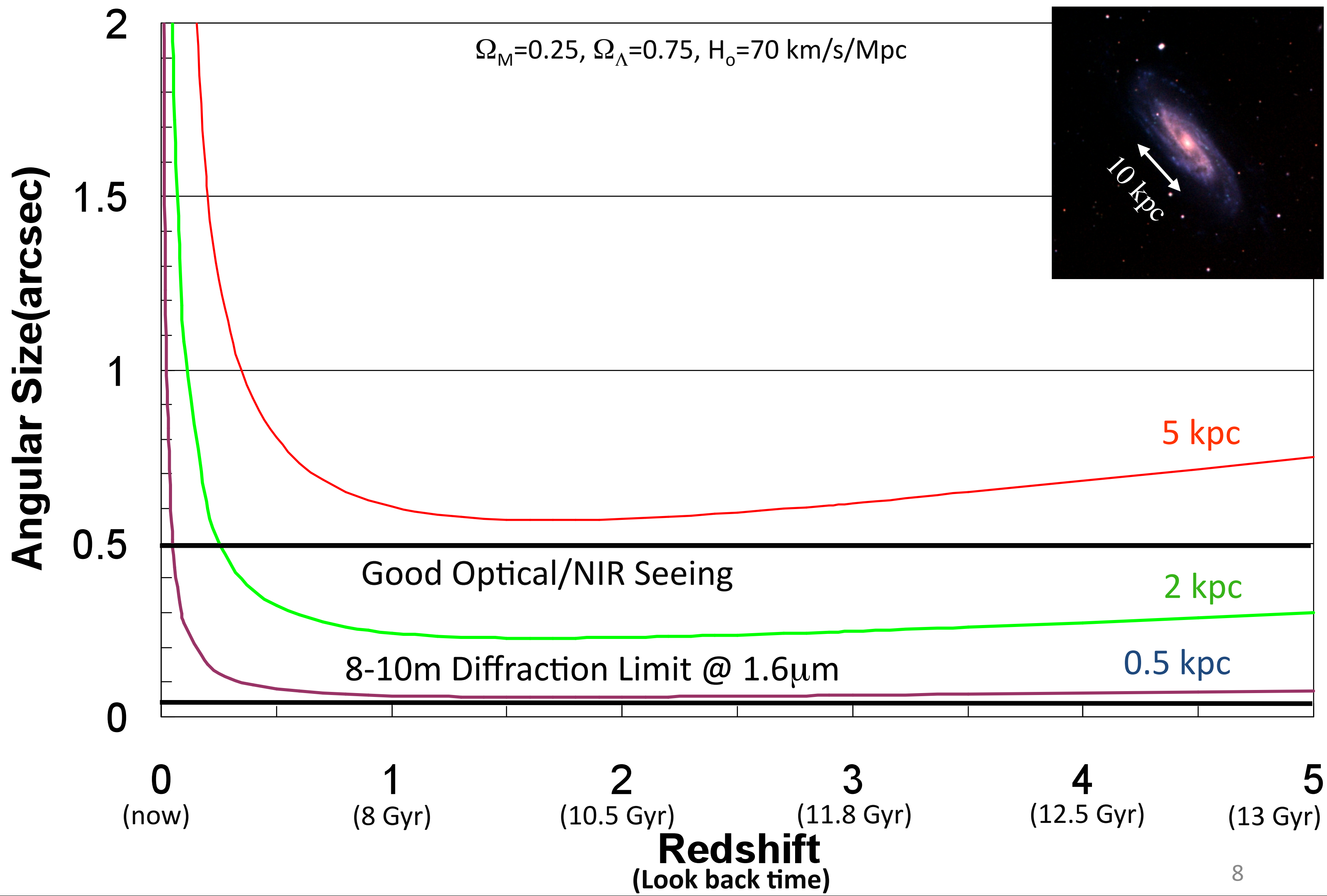


Law et al. 2007



Adelberger et al. 2004

High-z galactic substructure is challenging to observe

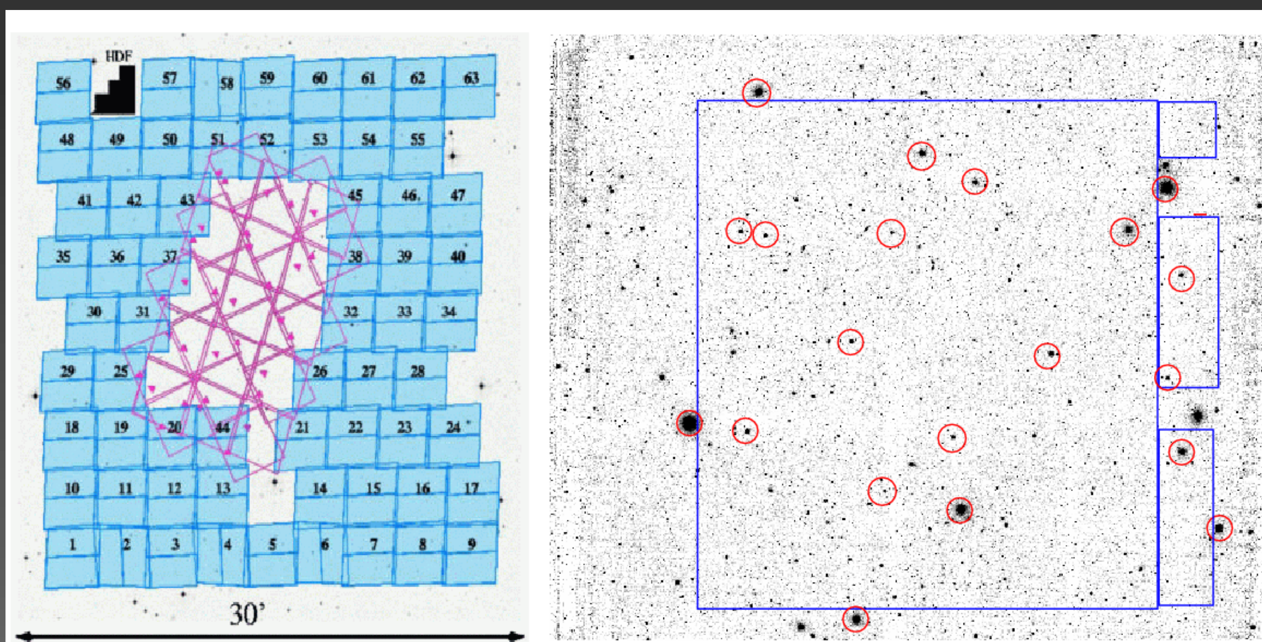


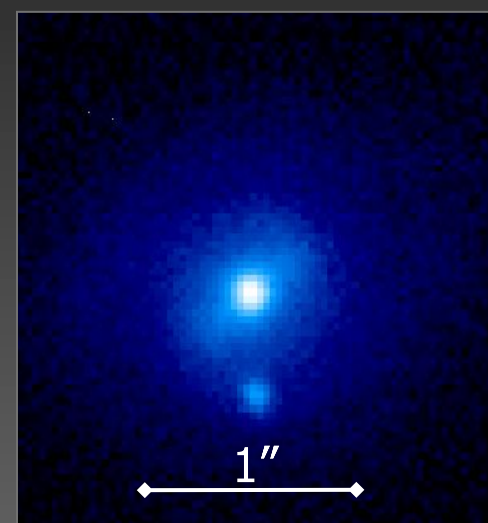
AO Selection Criteria of High-z Galaxies

- Using LGS, ***suitable tip/tilt star*** (R<18 mag, < 50”) yields about ~10% high-z galaxies (dependent on elevation coverage and poles)
- For spectroscopy targeting optical emission lines ([OII], [OIII], Hβ, Hα, [NII]) redshifted into NIR atmospheric windows
- Ensure prime emission line does not fall on OH sky line, ***has dependency on R***
- Estimate SNR based on surface brightness profile, SFR, other indicators and ***sensitivity of instrument and Strehl ratio***

First NGS AO imaging programs of high-redshift galaxies

- Limited to only small regions (<40”) of the field where bright stars were available for the AO system
- NIRC2 at Keck used for original NGS lamppost survey of galaxies around bright stars and later LGS



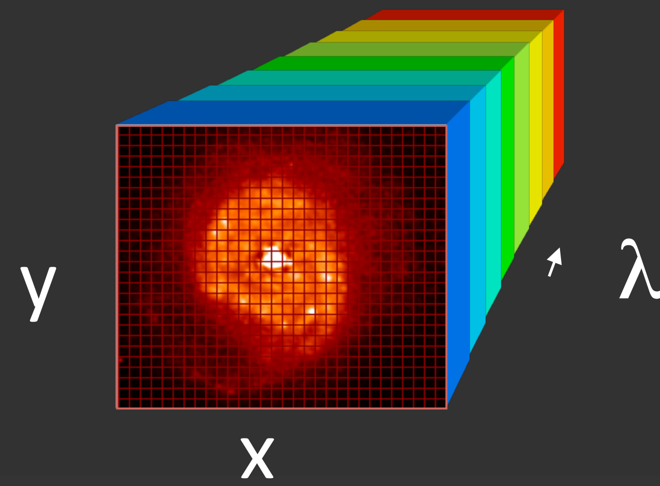


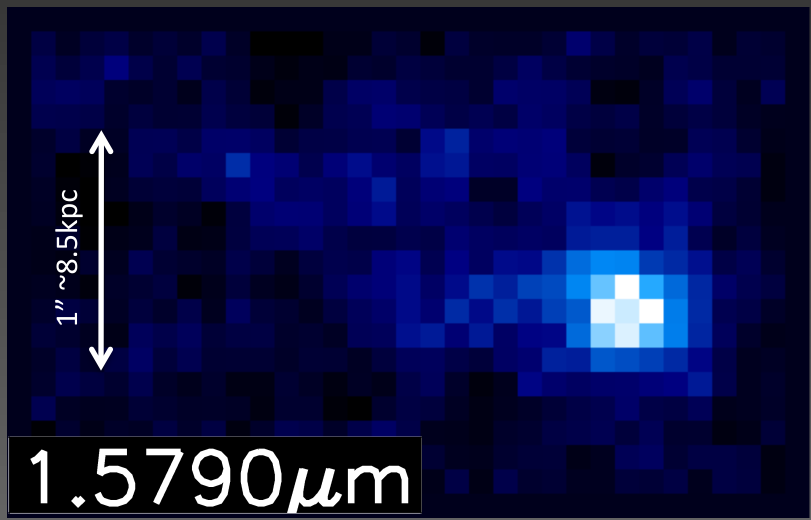
NIRC2

~30’x30’ Field, to V~27 mag with deep CHANDRA, ACS images

Integral field spectrographs behind AO

- NIFS at Gemini
  - Near-IR (Y, J, H, K)
  - R ~ 5000
  - 0.1" /w AO
  - Image Slicer
- SINFONI at VLT
  - Near-IR (Y, J, H, K)
  - R ~ 1500 – 4000
  - 0.25", 0.1", 0.025"
  - Image Slicer /w multiple gratings
- OSIRIS at Keck
  - Near-IR (Y, J, H, K)
  - 0.02", 0.035", 0.05", 0.1"
  - R ~ 3200 – 4000
  - Lenslet Array /w single fixed grating



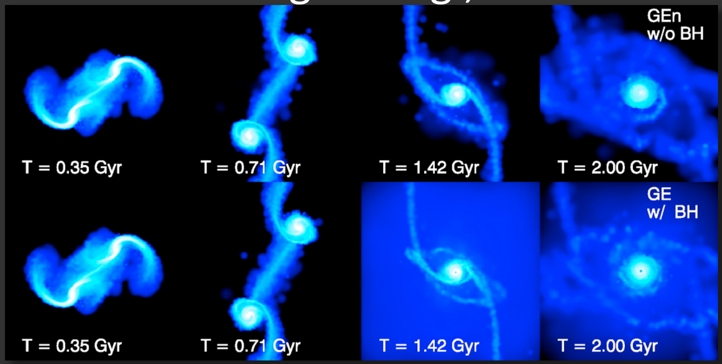


OSIRIS data cube – Hα from z~1.4

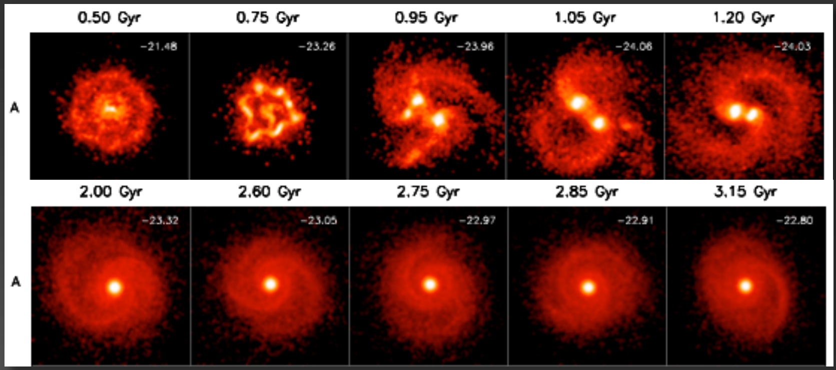
Some IFS + AO Key Science Goals

- Disk formation via secular evolution and mergers?
- Bulge vs. Disk formation?
- Feedback mechanisms and impacts via star formation and AGN?
- Timescale of disk formation & baryonic mass fraction growth?
- Metal production and locations? Inside-out disk formation?
- Merger rates?
- Black hole growth?

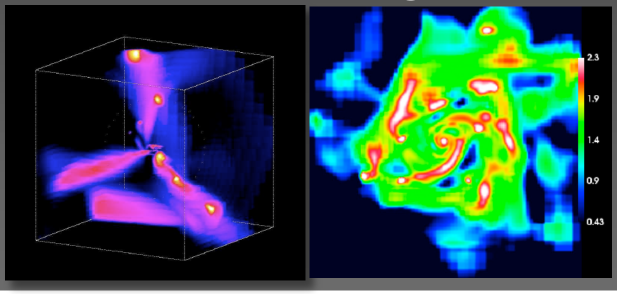
Gas-rich mergers: e.g., Robertson+2006



Dissipational collapse: e.g., Immeli+2004



Cold flow filaments: e.g., Dekel+2009



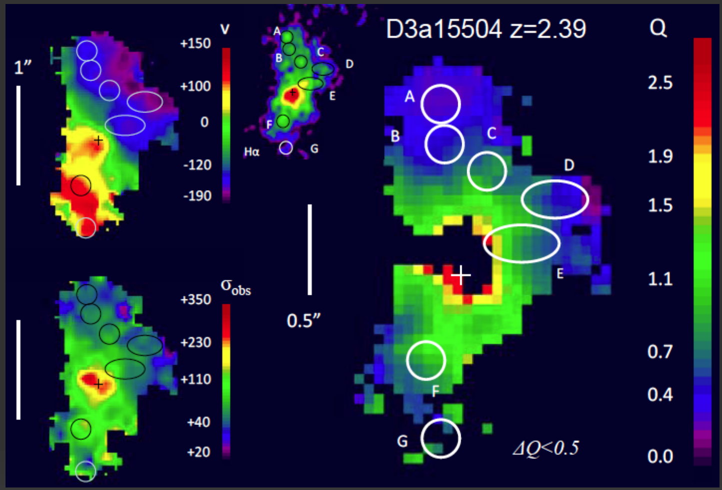
A boom of IFS high-z SFG studies using integral field spectrographs

- SINS survey (SINFONI/VLT) - seeing-limited & AO observations with a range of target selections (e.g., Forster-Schreiber et al. 2006/2009; Genzel et al. 2006, Bouche et al. 2007, Shapiro et al. 2008, Cresci et al. 2009, Genzel et al. 2011)

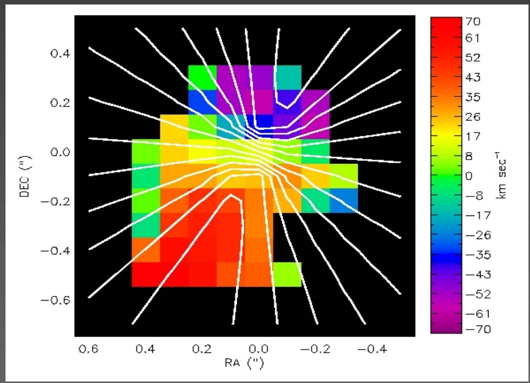
- Other SINFONI/VLT observations e.g., Epinat et al. 2009 (I-band, [OII] selection), van Starkenberg et al. 2009 (MIPS selection, single galaxy), Nesvadba et al. 2008 (BX, single galaxy), Kriek et al. 2007 (K< 20 sample)

- NIFS/Gemini - Seeing-limited & AO observations Alexander et al. 2010 (single galaxy, sub-mm), Swinbank et al. 2009 (z~4.9 lensed)

- OSIRIS/Keck uses LGS-AO system, Law et al. 2007/2009/2012, Wright et al. 2007/2009/2010, Jones et al. 2010 (lensed), Wisnioski et al. 2011, 2012



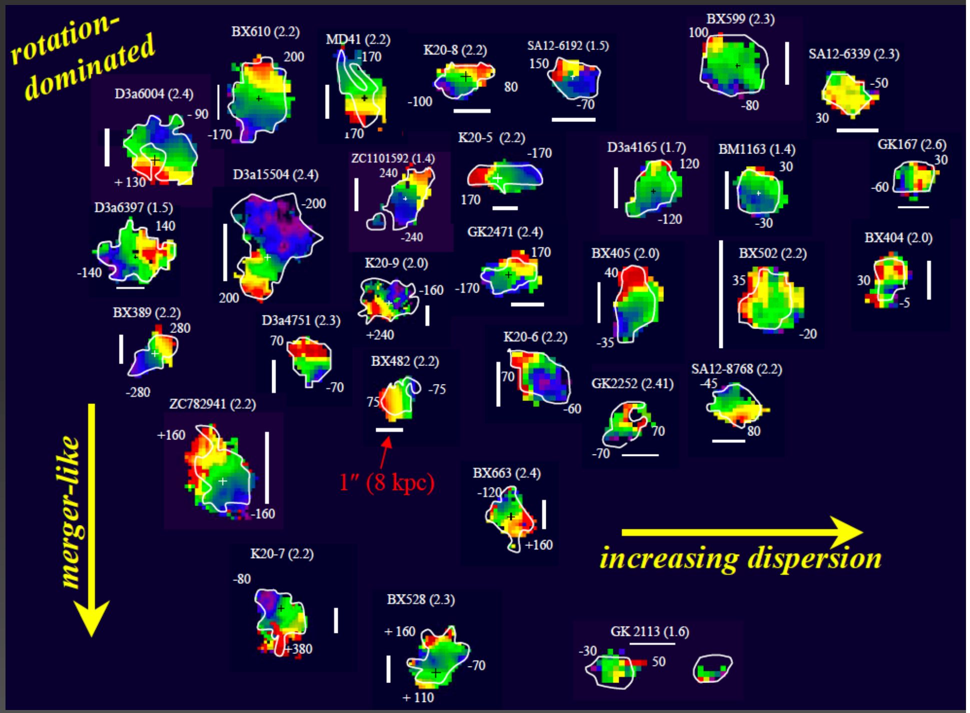
Genzel et al. 2011



Disk candidate z~1.5, Wright et al. 2007

SINS survey of 62 galaxies show diverse kinematics

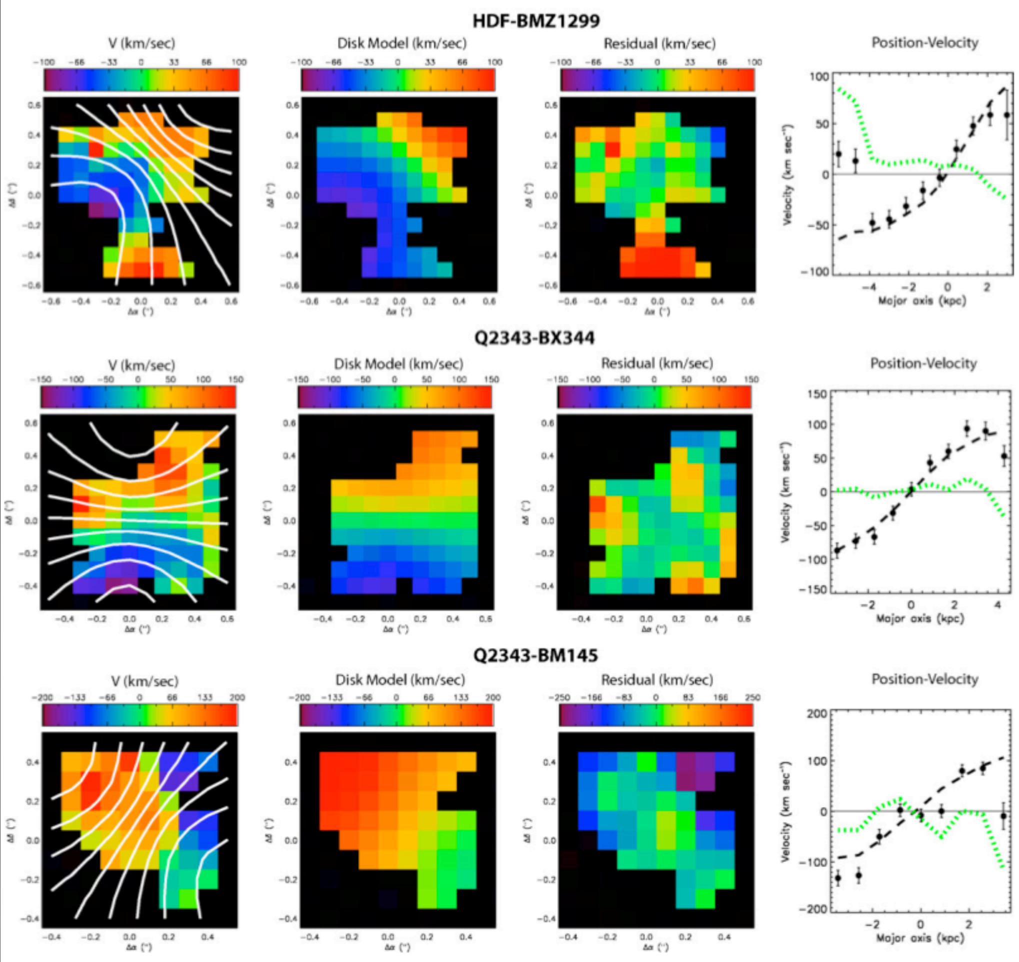
- SINFONI targeting primarily z~2 galaxies where Hα falls in K-band, only 12 galaxies with AO on VLT
- Found diverse kinematics of star forming galaxies:
  - Dispersion-dominated galaxies, v/σ ~ 1
  - Rotational-dominated galaxies, large velocity gradients
  - Irregular kinematics or "mergers"



Forster-Schreiber et al. 2009

Disk candidates at z~1.5, less turbulent than the z~2 counterparts

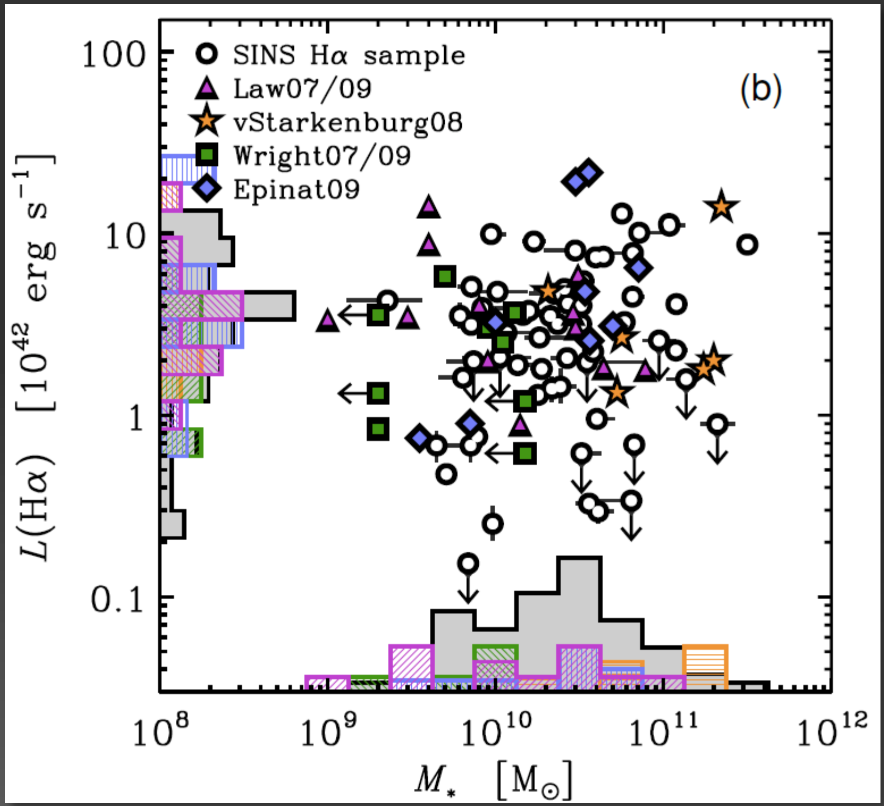
- Inclined disk models
- Convolve each model with estimated observed PSF
- Exhaustive grid search to compare to observed kinematics
- Plateau velocities of 185 km/s
- Residuals are low (20 km/s) compared to disk fits at higher z>2



Wright et al. 2009

Comparison of z~1.5 & 2 sources and SINFONI/OSIRIS sample

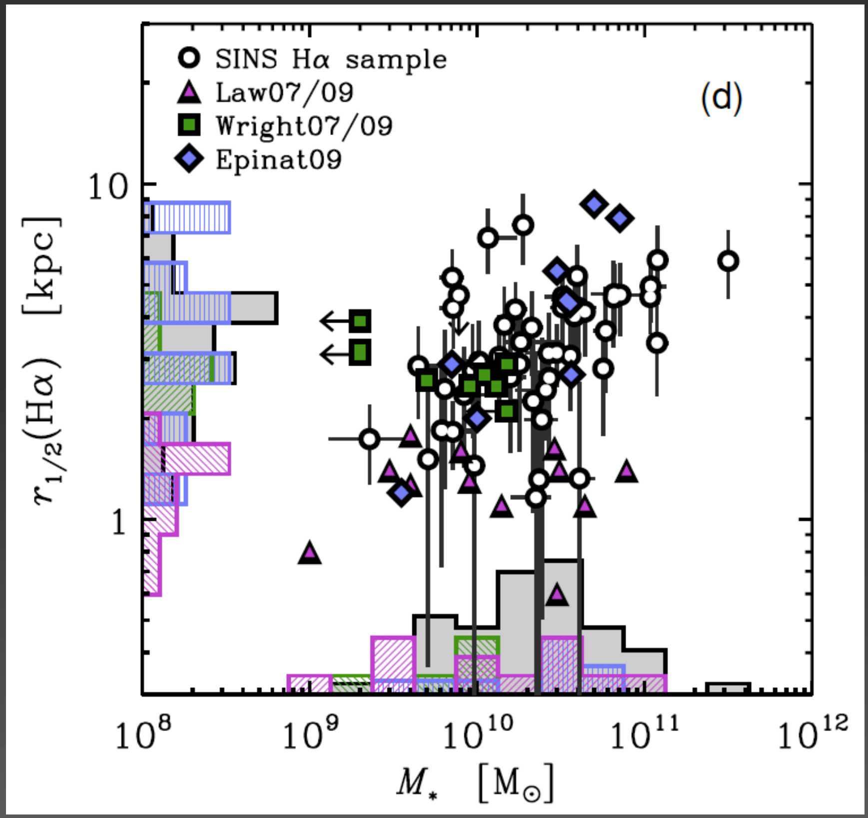
- Dynamics mass estimates
  - Virial masses - M_{vir} ~ $3x10^{10}$ M⊙
  - Enclosed masses - M_{enc} ~ $3x10^{10}$ M⊙
  - Halo masses - M_{halo} ~ $1x10^{12}$ M⊙
- Gas mass and star formation surface densities
  – M_* ~ $0.2\text{-}1.3x10^{10}$ M⊙
- Stellar mass from SED fits
  – Mgas ~ $3x10^{10}$ M⊙ and μ~70%



Förster-Schreiber et al. 2009

Comparison of z~1.5 & 2 sources and SINFONI/OSIRIS sample

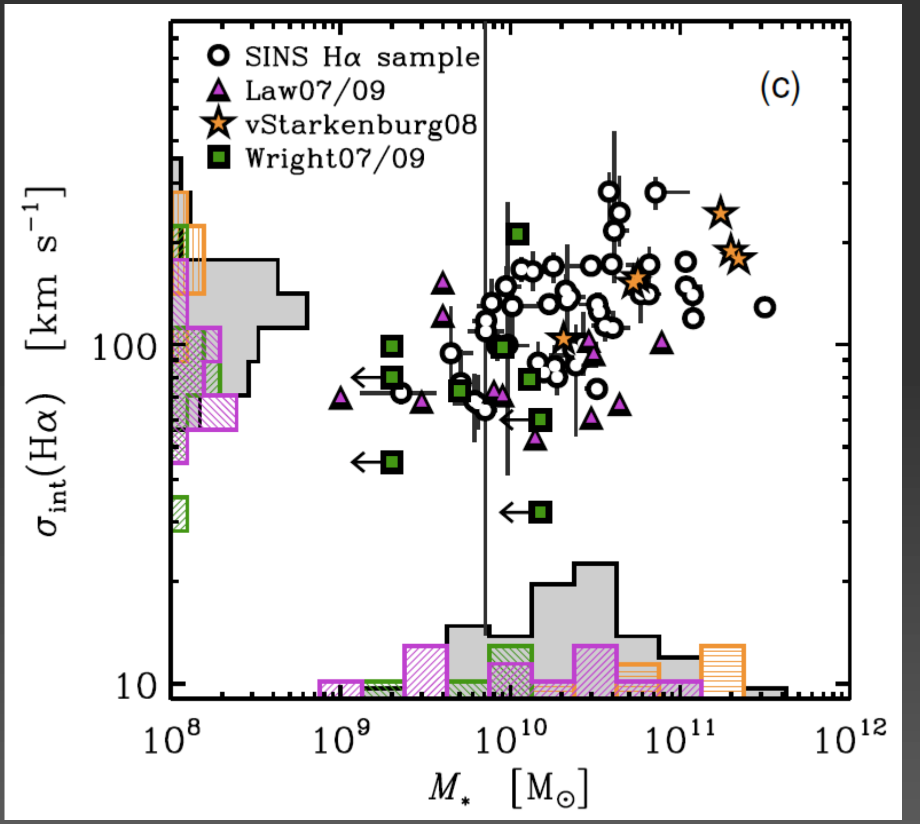
- Dynamics mass estimates
  - Virial masses - $M_{vir} \sim 3 \times 10^{10}$ M⊙
  - Enclosed masses - $M_{enc} \sim 3 \times 10^{10}$ M⊙
  - Halo masses - $M_{halo} \sim 1 \times 10^{12}$ M⊙
- Gas mass and star formation surface densities
  - $M_* \sim 0.2\text{-}1.3 \times 10^{10}$ M⊙
- Stellar mass from SED fits
  - Mgas ~ 3×10^{10} M⊙ and μ~70%



Förster-Schreiber et al. 2009

Comparison of z~1.5 & 2 sources and SINFONI/OSIRIS sample

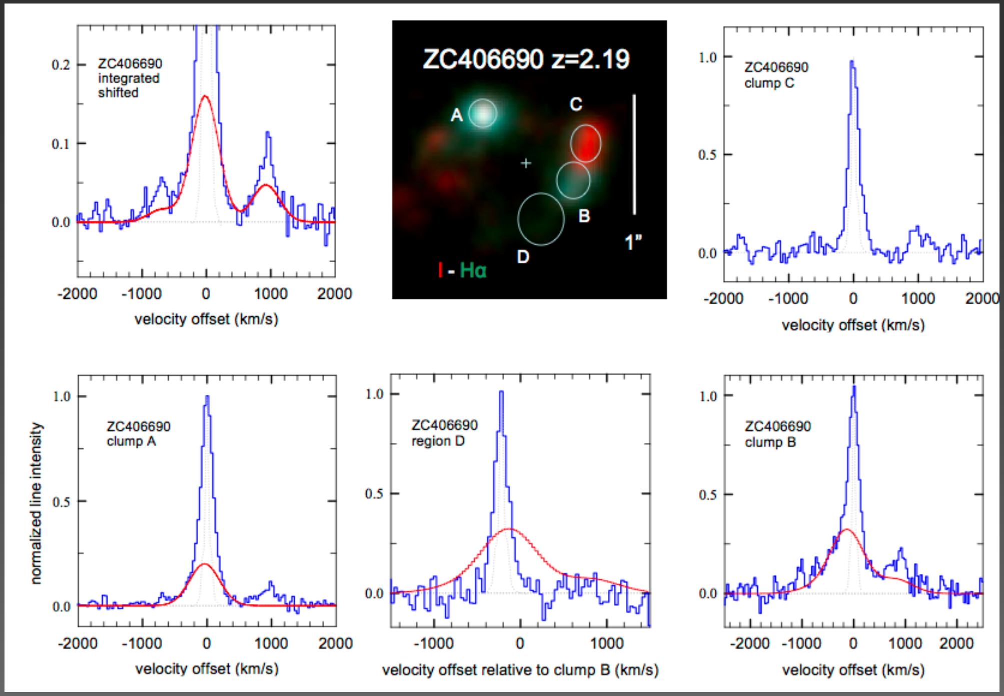
- Dynamics mass estimates
  - Virial masses - M_{vir} ~ $3x10^{10}$ M⊙
  - Enclosed masses - M_{enc} ~ $3x10^{10}$ M⊙
  - Halo masses - M_{halo} ~ $1x10^{12}$ M⊙
- Gas mass and star formation surface densities
  - M_* ~ 0.2-1.3$x10^{10}$ M⊙
- Stellar mass from SED fits
  - Mgas ~ $3x10^{10}$ M⊙ and μ~70%



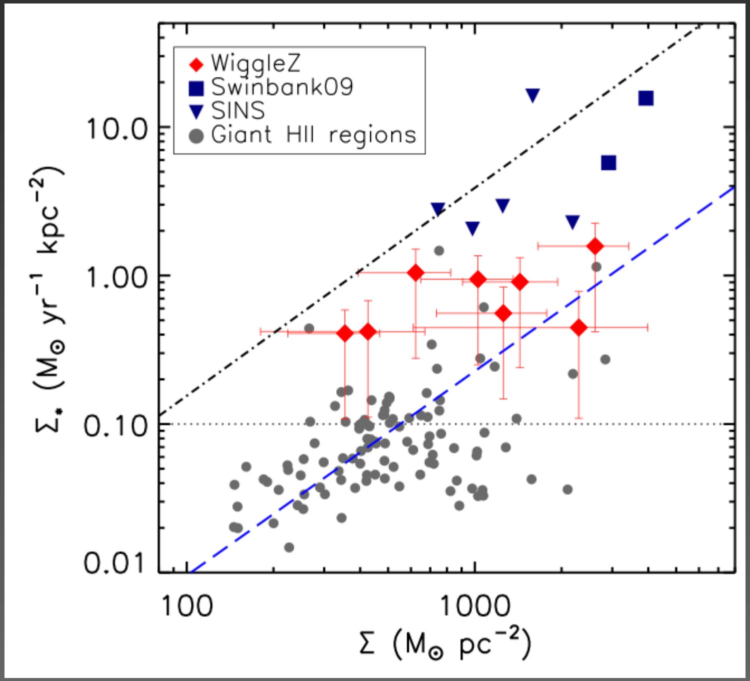
Förster-Schreiber et al. 2009

"Clumps" in high-z galaxies

- Five z~2 galaxies with SINFONI + AO (some have total integrations > 12 hours!) and OSIRIS at z~1.5
- Clumps found in "disk" galaxies with high velocity dispersions – inferred outflows with intense SF



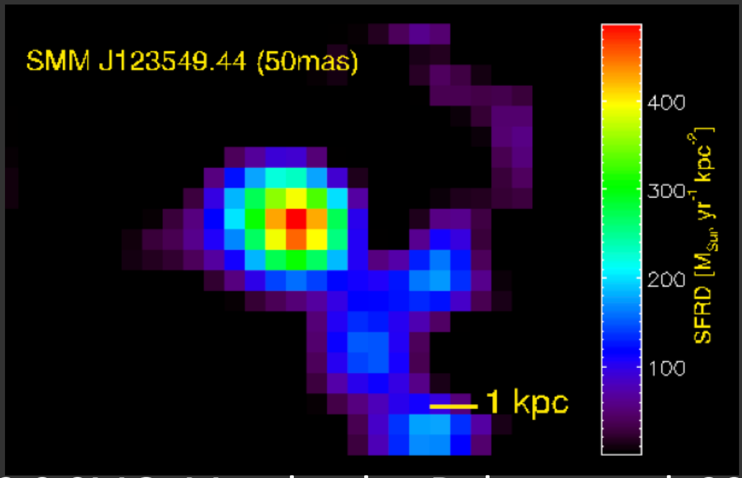
Genzel et al. 2012



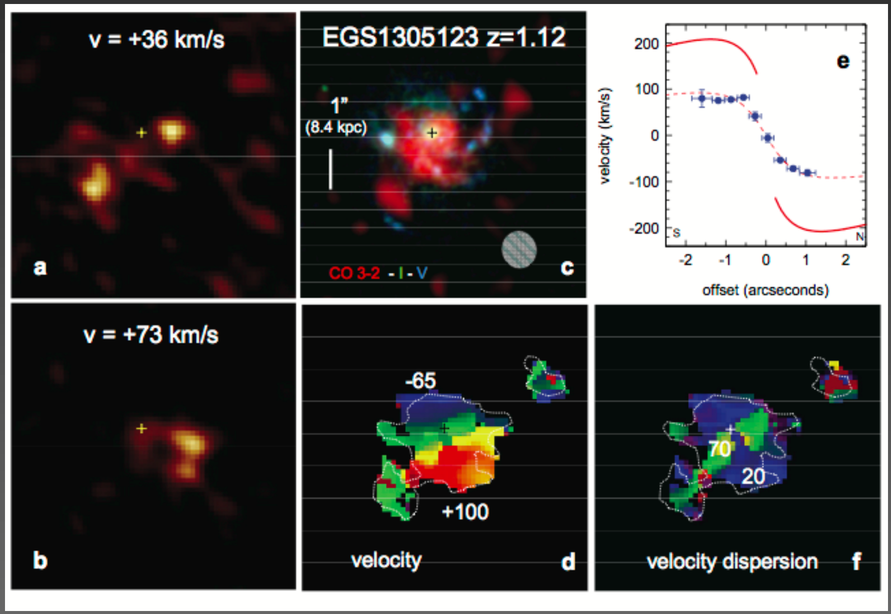
Wisnioski et al. 2012

AO observations of sub-mm galaxies

- OSIRIS on SMGs separate broad, nuclear Hα emission and extended SF regions (Menendez-Delmestre + 2011) – difficult with previous non-AO observations
- CO interferometry have shown high-z galaxies to be gas rich (~>50% gas fractions) in both optically selected galaxies and massive sub-mm galaxies (Tacconi+2008, 2010)



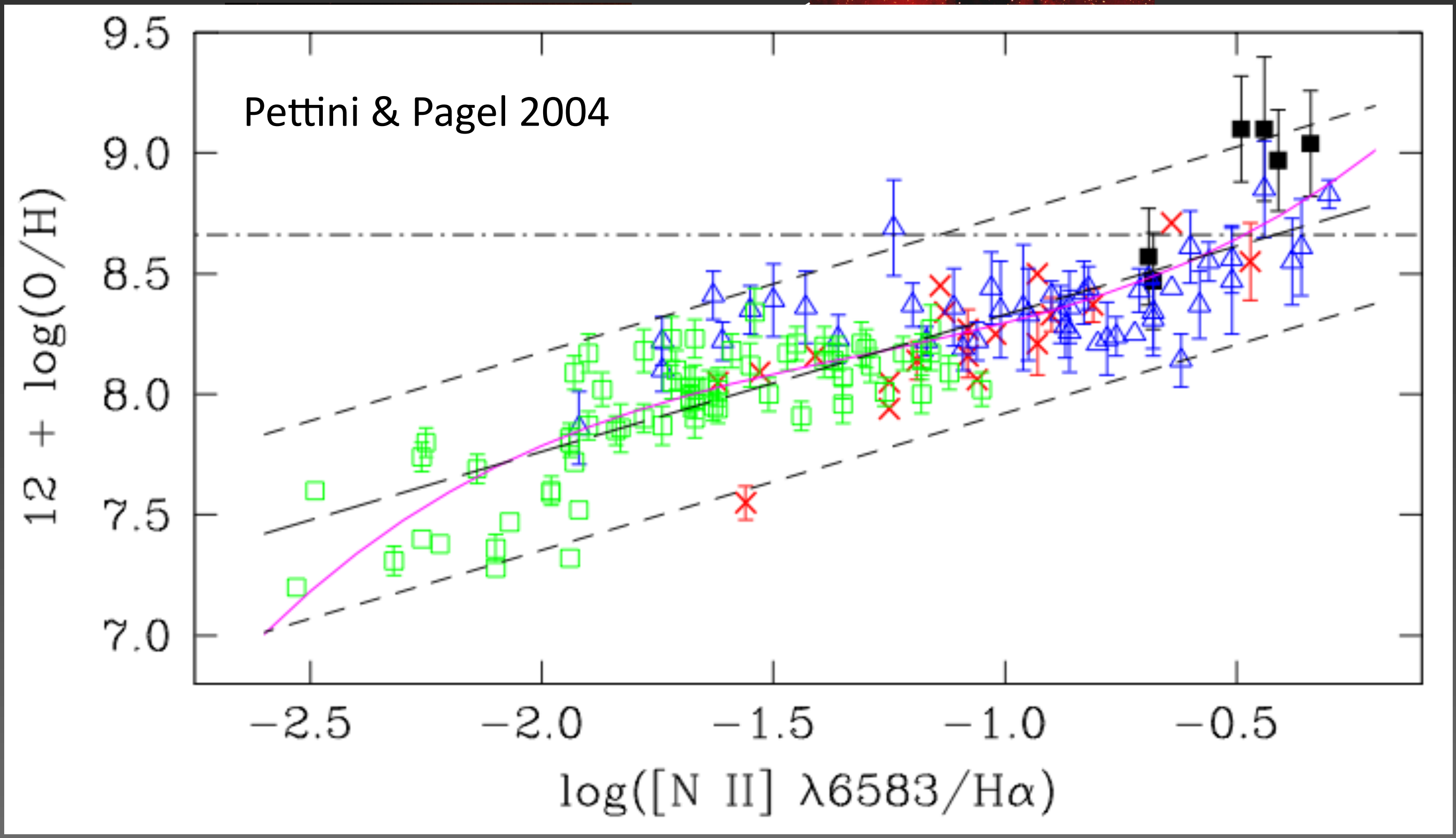
Z~2.2 SMG, Mendendez-Delmestre al. 2011



CO, PdBI, Tacconi et al. 2010

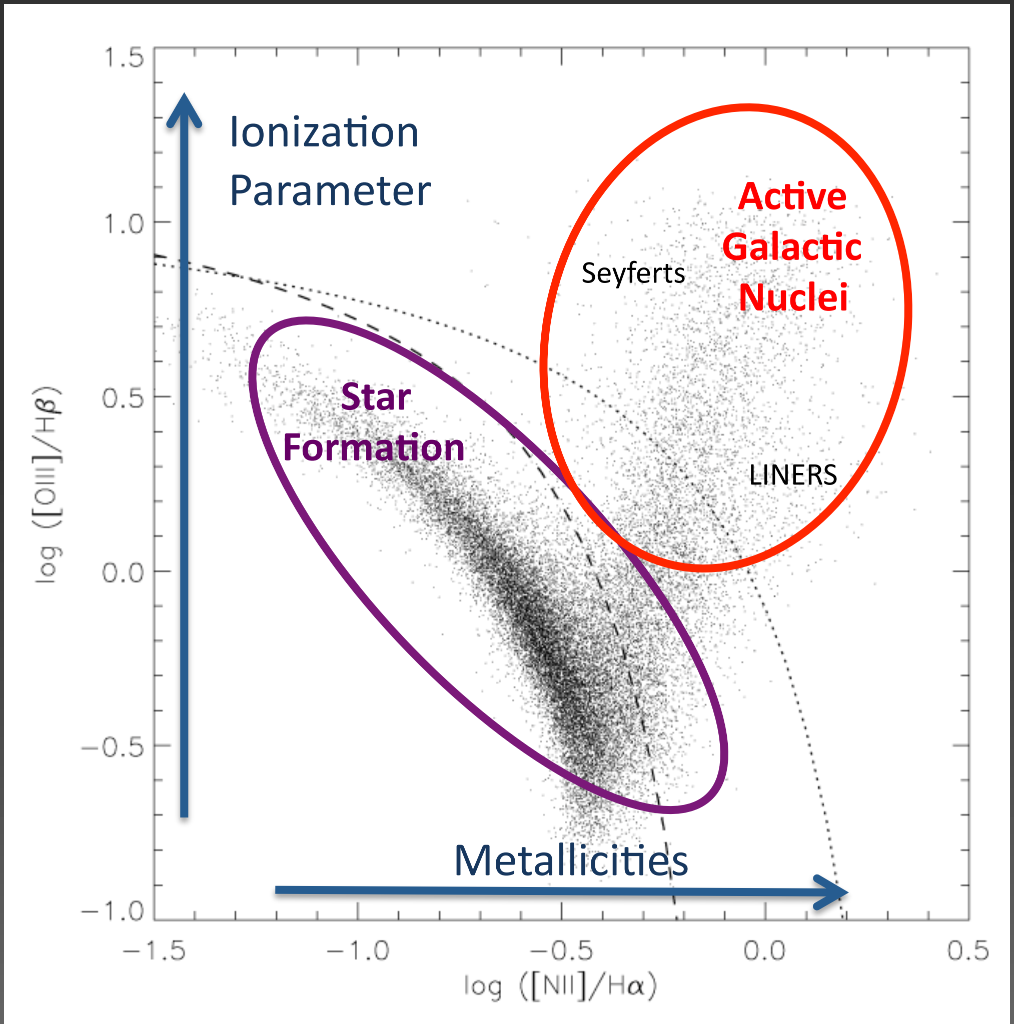
High-z metallicity studies use optical emission lines

- A range of studies have targeted (1 < z < 3) star forming galaxies (e.g., Shapley et al. 2005, Erb et al. 2006, Maier et al. 2006, Kriek et al. 2006, Liu et al. 2008, Maiolino et al. 2008)



Distinguishing between star formation and AGN activity

- Based on rest frame UV spectroscopy and SEDs, all high-z galaxies used to study metallicity are selected to <u>not</u> have AGN activity

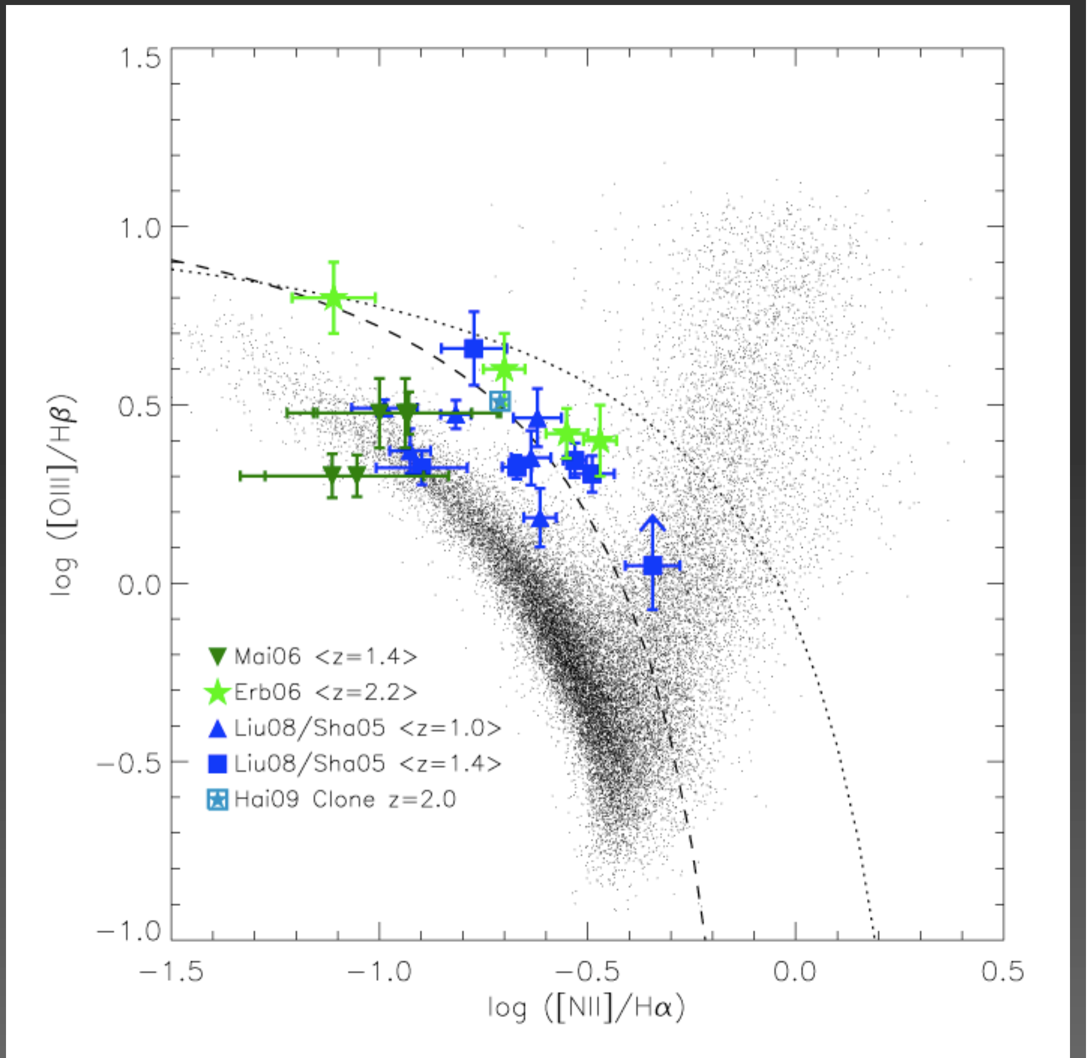


SDSS (z<0.35) 99,000 galaxies

Distinguishing between star formation and AGN activity

- Based on rest frame UV spectroscopy and SEDs, all high-z galaxies used to study metallicity are selected to not have AGN activity

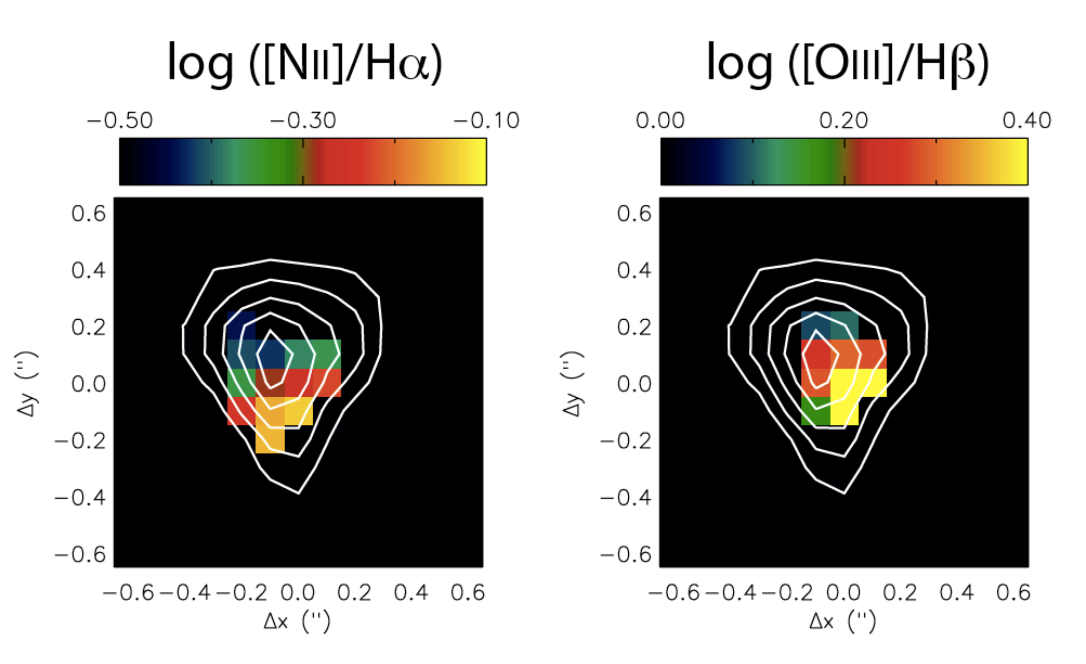
- Previous high-z studies have found elevated ratios above local excitation sequence of star forming galaxies



SDSS compared to high-z studies

OSIRIS LGSAO nebular ratio maps indicate AGN

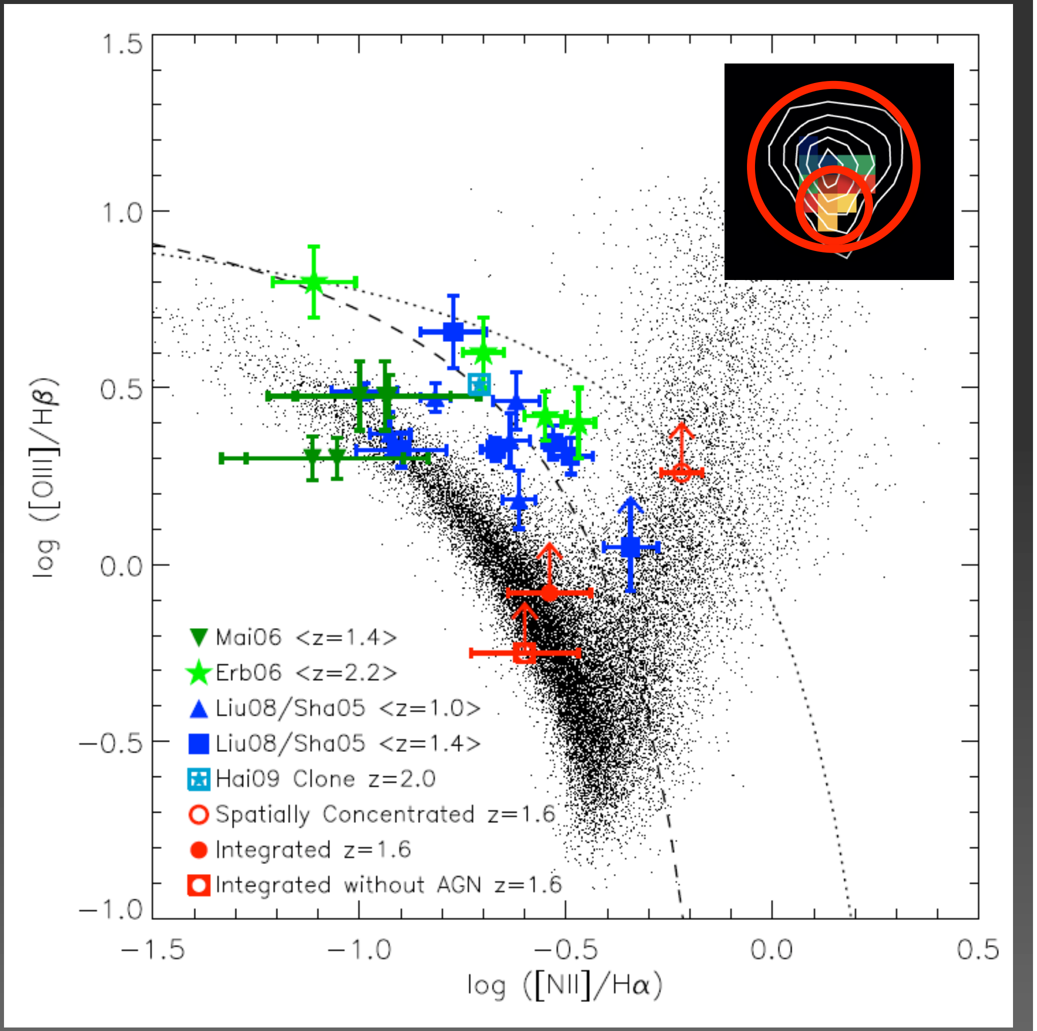
- [NII]/Hα peaks with high ratios ~1 indicating presence of AGN
- But galaxy showed **<u>NO</u>** signs of AGN activity in SEDs or rest-frame UV spectra



Wright et al. 2010

OSIRIS distinguishes AGN missed by seeing-limited observations

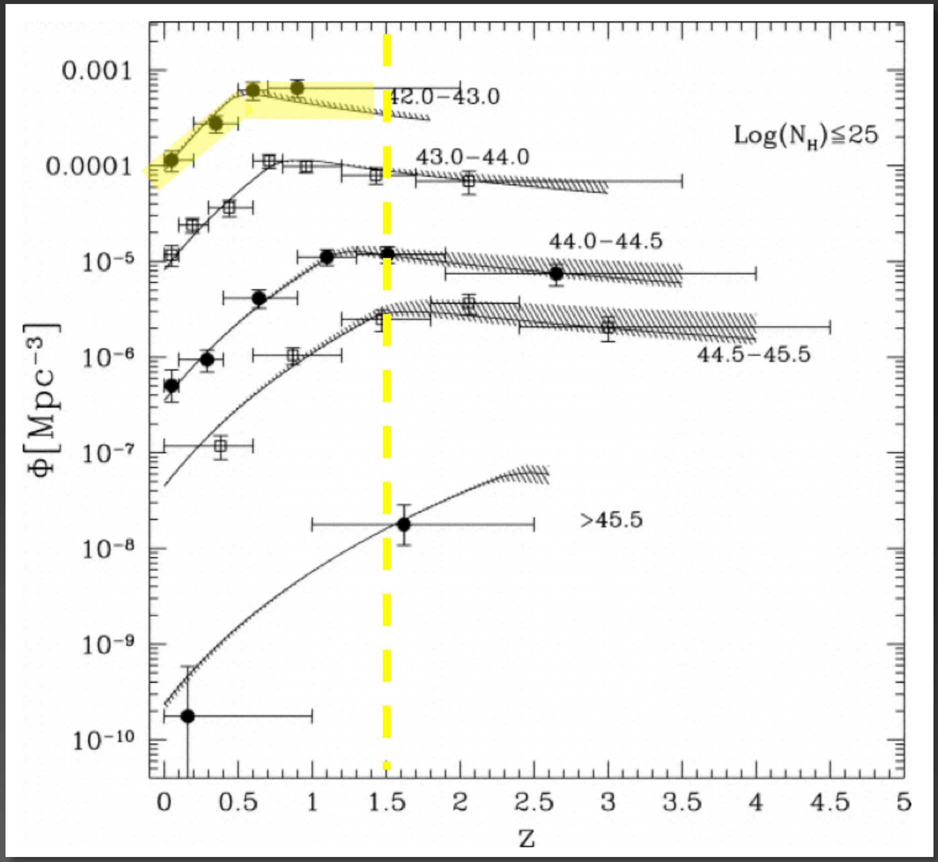
- Spatially concentrated ratios fall within the AGN distribution
- Seeing-limited observations would see composite of star formation and AGN
- NEED higher spatial resolution and IFS to detect weak AGN



Wright et al. 2010

Probing the high-z AGN luminosity function

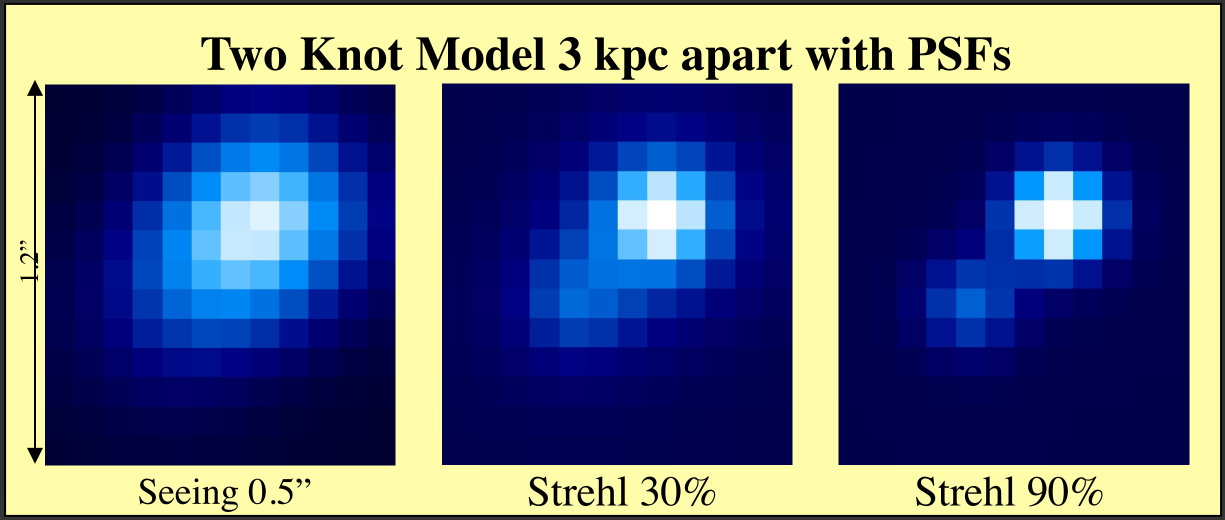
- Hα and [OIII] luminosity of high-z AGN ~2×10^{41} erg s^{-1}
  - Local Seyfert population (10^{40-42} erg s^{-1})
- Chandra observations show 3σ limit, Lx(2-8 keV) < 2×10^{42} erg s^{-1}
- If these AGN reside in BM/BX galaxies then 10-40% of SFGs at z=1.5 would host an AGN of similar Hα and [OIII] luminosity

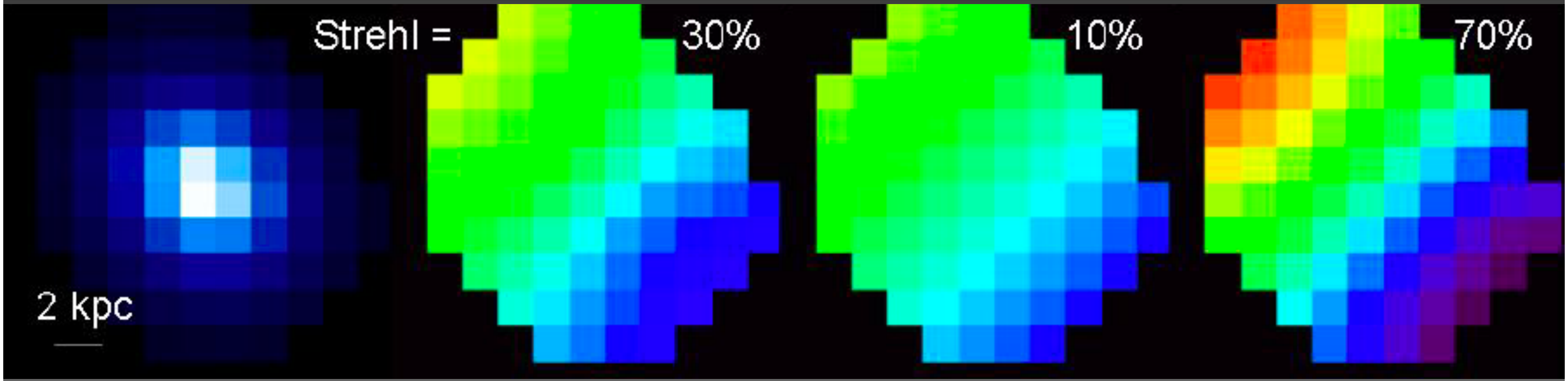


High-z AGN X-ray Luminosity Function
La Franca et al. 2005

PSF knowledge for disentangling intrinsic velocities and morphologies

- Understanding "smearing" is essential for morphological & kinematic classification and inferred dynamics





Improvements to IFS sensitivities, and improved AO performance

- Current IFS+AO observations probing the "tip of iceberg" of massive galaxies with typically high SFR
- Limited by both instrumental sensitivity and AO performance – Strehl can greatly effect detection
  - Limitation to current NIFS + Altair system compared to OSIRIS and SINFONI?
  - It would be great to get an apples-to-apple comparison between NIFS, SINFONI, and OSIRIS with LGS-AO
  - Large overhead per source – typical integration time of 2-3 hours
  - Currently upgrading OSIRIS grating and investigating new detector

Reasons for improved sensitivity and performance…

- Extend to less massive systems, lower surface brightness sources
- Detect fainter emission lines for HII region photoionization diagnostics, metallicity gradients, AGN, shocks
- Probe lower surface brightness regions at larger radii – essentially sampling < 10 kpc of high-z galaxies
- Would love to eventually target passive galaxies and absorption line systems at rest-frame optical
- Would love to target rest-frame UV (e.g., Ly-α) at high-z – optical AO with IFU

Limited by selection and small number of sources – need multiplexing!!!

- IFS+AO observations is limited to small number statistics – this is in the realm of large statistical surveys
- Near-infrared multi-object spectrographs are now coming on-line
- Ultimate would be multi-object integral field spectrograph behind MCAO
  - E.g., Conceptual designs with E-ELT's EAGLE

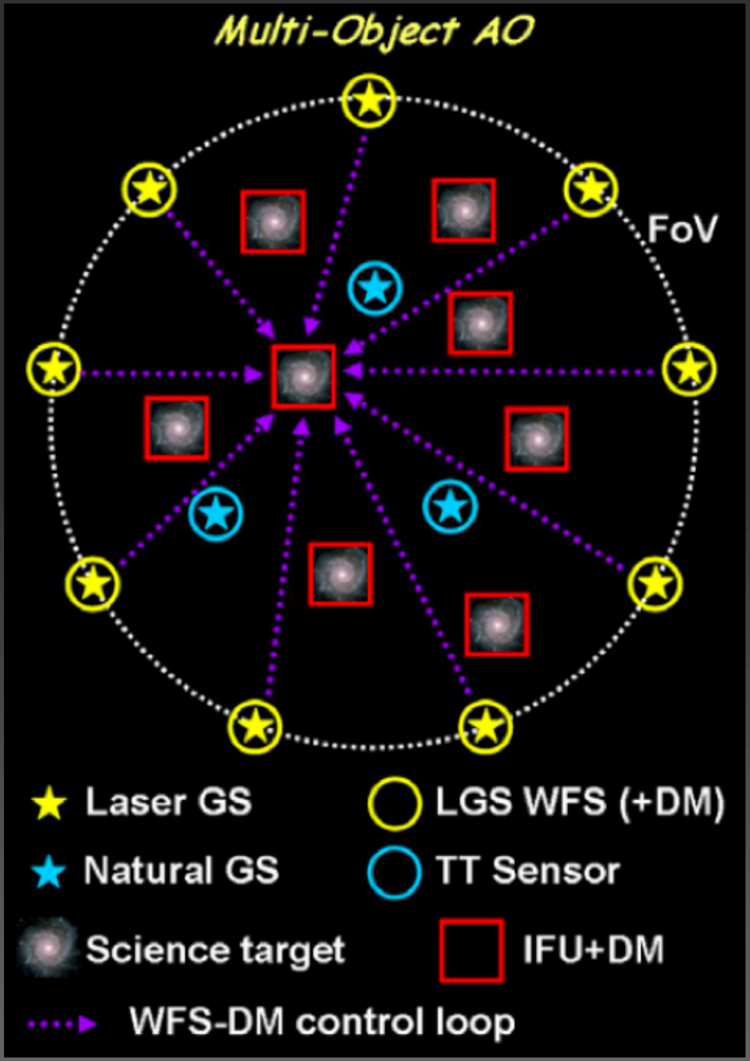
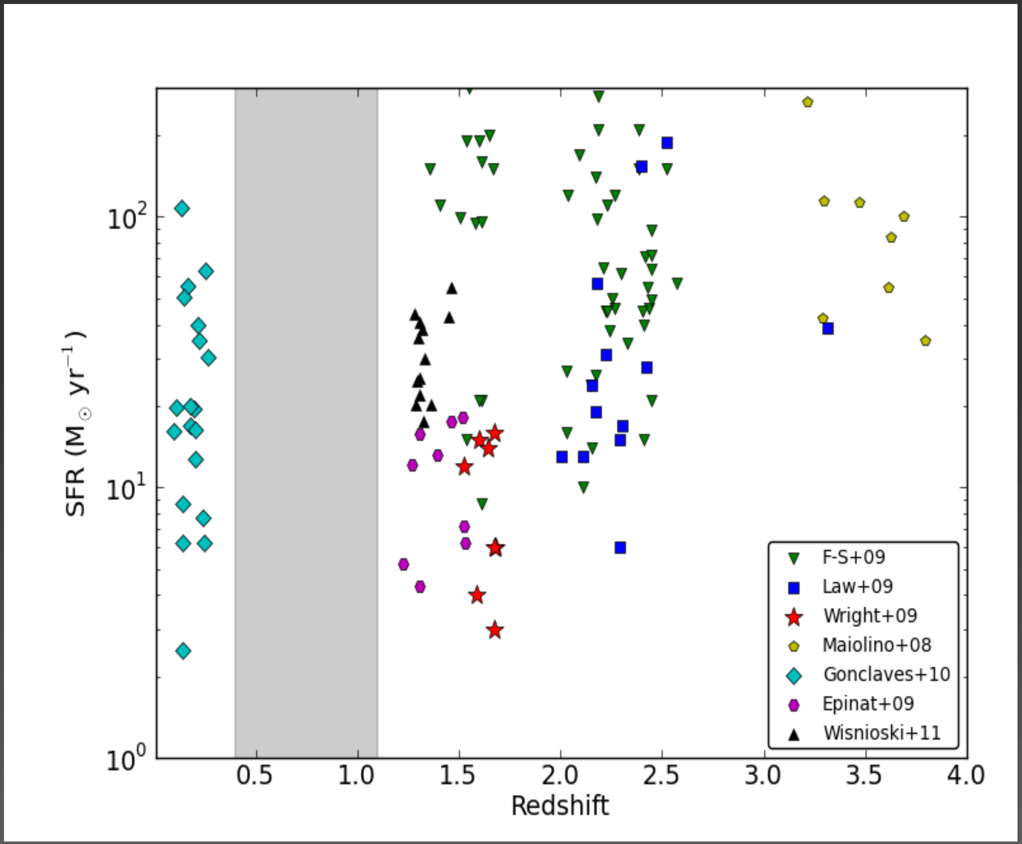


Image Credit, Simon Morris (Durham)

AO with Integral Field Spectrographs have had a large impact

- NIFS 2005 commissioned
- SINFONI 2004 commissioned
- OSIRIS 2005 commissioned
- Over 150 galaxies observed with IFS, likely 50+ high redshift galaxies with AO
- Continuing observations at lower surface brightnesses and extending to other redshift regimes and selections



c’est tout