High Redshift Galaxies
and
The Thirty Meter Telescope

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Outline

- The TMT
- High Redshift Galaxies
- Integral Field Spectrometry
- Data Reduction
- Results
- The Future (once we hit 88mph)

The Thirty Meter Telescope

Science Frontier Panels

- Planetary Systems and Star Formation (PSF)
- Stars and Stellar Evolution (SSE)
- The Galactic Neighborhood (GAN)
- Galaxies across Cosmic Time (GCT)
- Cosmology and Fundamental Physics (CFP)

GSMT - Overview

- Will transform a broad range of science including stellar astronomy, exoplanets, black holes:
  - Complements JWST, ALMA, LSST
  - High spatial resolution; high sensitivity spectroscopy
- Top ground-based recommendation in AANM
- Now two U.S. projects for 30m class optical-infrared telescopes under development:
  - Giant Magellan Telescope in Chile
  - Thirty Meter Telescope in Hawaii
- [Also ESO's E-ELT in Chile]

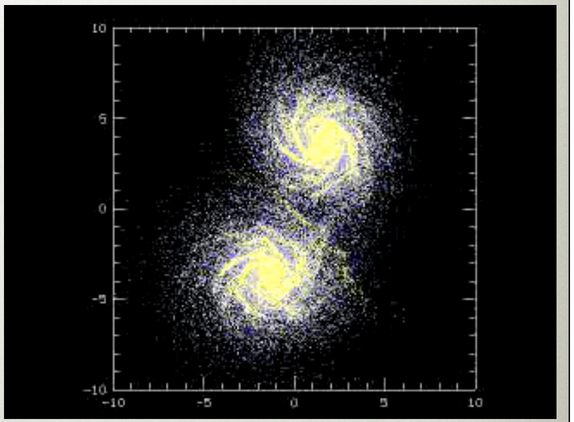
GSMT - Details

- GMT and TMT have each garnered private and international funding and made significant technical progress
- **RECOMMEND NSF choose one of the two U.S. projects and invest in a quarter share through some combination of construction, operations and instrumentation to provide access to the entire U.S. community**
- Total appraised cost of projects $1.1-1.4B
- Project estimate of total annual running costs $36M (GMT) and $55M (TMT)
- Expect science in mid 2020's; risk Medium to Medium-High
- LSST to be ahead of GSMT in MREFC queue

High Redshift Galaxies

High Redshift Galaxies

- Merging events
- Galaxy formation
- Morphology Evolution



High Redshift Galaxies

- Merging events
- Galaxy formation
- Morphology Evolution
- Star formation
- Can observe UV/optical/IR from ground

High Redshift Galaxies

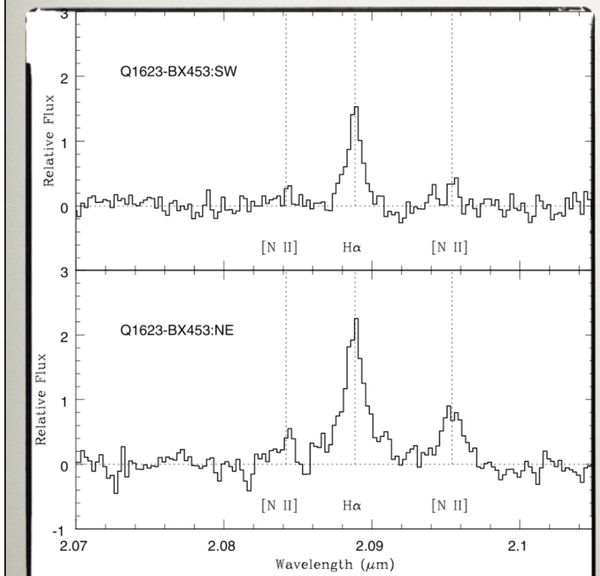
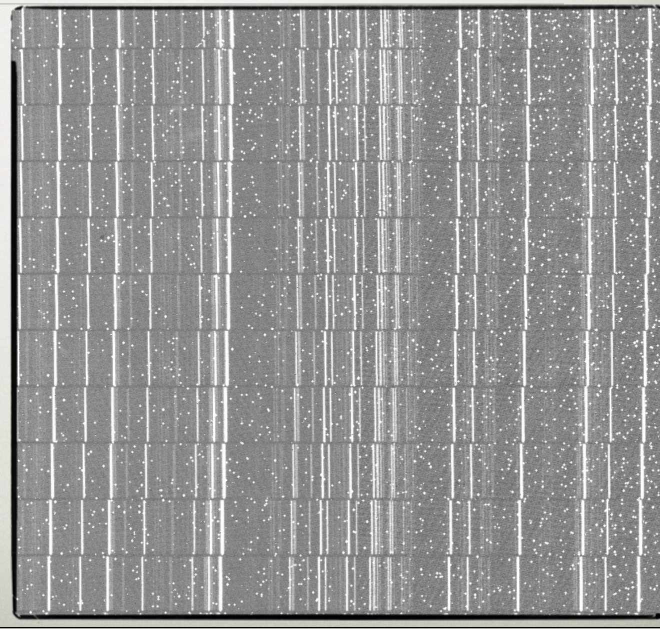


FIG. 3.—OSIRIS spectra of the northeastern (NE) and southwestern (SW) regions of Q1623-BX453. Vertical dotted lines denote the wavelengths of [N II] λ6550
Hα, and [N II] λ6585 emission.

- More information in spectral data: Kinematics & Abundances

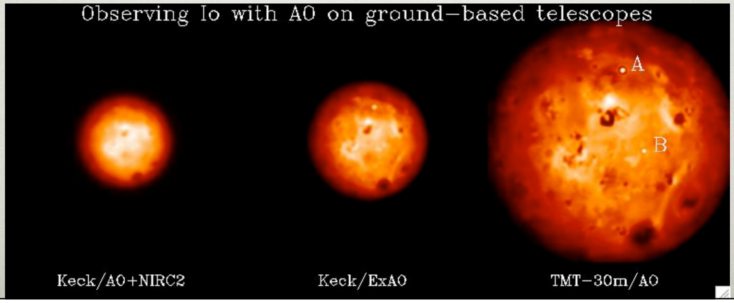
Integral Field Spectroscopy

- More familiar with slit spectroscopy
- Can only tell us about 1-D morphology
- IFU



TMT

- TMT will have an IFU in the IRIS instrument:
  - FoV = 3′
  - Possibility of 4-50mas / pixel
  - R ~ 4000



Sources

Table 1
Observing Details

Galaxy	z_{neb}[a]	R.A. (J2000.0)	Decl. (J2000.0)	Observing Run	Exposure Time[b] (s)	Filter	Em. Line[c]	Scale (mas)	θ_{PSF}[d] (mas)
Detections									
Q0449-BX93	2.0067	04:52:15.417	−16:40:56.88	2006 Oct	16200	Kn1	Hα	50	115/170
Q1217-BX95	2.4244	12:19:28.281	+49:41:25.90	2008 Jun	6300	Kn4	Hα	50	95/135
HDF-BX1564	2.2228	12:37:23.470	+62:17:20.00	2007 Jun	3600	Kn2	Hα	50	150/290
Q1623-BX453	2.1820	16:25:50.854	+26:49:31.28	2006 Jun	9000	Kn2	Hα	50	70/140
Q1623-BX502	2.1557	16:25:54.385	+26:44:09.30	2007 Jun	9900[e]	Kn2	Hα	50	195/220
Q1623-BX543	2.5211	16:25:57.707	+26:50:08.60	2008 Jun	11700	Hn5	[O III]	50	95/145
Q1700-BX490	2.3958	17:01:14.830	+64:09:51.69	2008 Jun	11700	Kn4	Hα	50	75/125
Q1700-BX710	2.2947	17:01:22.128	+64:12:19.21	2006 Jun	5400	Kn3	Hα	50	70/140
Q1700-BX763	2.2919	17:01:31.463	+64:12:57.67	2008 Jun	12600	Kn3	Hα	50	75/190
DSF2237a-C2	3.3172	22:40:08.298	+11:49:04.89	2006 Jun	5400	Kn3	[O III]	50	70/140
Q2343-BX418	2.3053	23:46:18.582	+12:47:47.77	2008 Jun	6300	Kn3	Hα	50	100/150
Q2343-BX513	2.1082	23:46:11.133	+12:48:32.54	2006 Oct	12600	Kn1	Hα	50	110/165
Q2343-BX660	2.1739	23:46:29.447	+12:49:45.93	2008 Sep	10800	Kn2	Hα	50	90/140
Nondetections									
Q0100-BX210	2.279[f]	01:03:11.996	+13:16:18.32	2006 Oct	1800[e]	Kn3	Hα	50	120
				2007 Sep	3600[e]	Hn3	[O III]	50	90
				2007 Sep	5400[e]	Kn3	Hα	50	120
HDF-BX1311	2.4843[f]	12:36:30.514	+62:16:26.00	2007 Jun	4500[e]	Kn4	Hα	50	140
HDF-BX1439	2.1865[f]	12:36:53.660	+62:17:24.00	2008 Jun	2700	Kn2	Hα	50	70
				2008 Jun	7200[e]	Kn2	Hα	100	80
Q1623-BX455[i]	2.4079	16:25:51.664	+26:46:54.60	2008 Jun	5400	Kn4	Hα	50	85
				2007 Sep	3600	Hn4	[O III]	50	70
Q1623-BX663	2.4333[f]	16:26:04.586	+26:47:59.80	2007 Jun	5400[e]	Kn4	Hα	50	100
Q1700-BX563	2.292[g]	17:01:15.875	+64:10:26.15	2007 Jun	1800[e]	Kn3	Hα	50	210
Q1700-BX691	2.1895[f]	17:01:06.117	+64:12:09.70	2006 Jun	10800[h]	Kn2	Hα	50	···
				2007 Jun	5400[e]	Kn2	Hα	50	200
Q2206-BX102	2.2104[f]	22:08:50.751	−19:44:08.24	2007 Sep	5400	Kn2	Hα	50	90
Q2343-BX389	2.1716[f]	23:46:28.911	+12:47:33.90	2007 Jun	8100[e]	Kn2	Hα	50	160
Q2343-BX442	2.1760[f]	23:46:19.362	+12:48:00.10	2007 Sep	9000[e]	Kn2	Hα	50	140
Q2343-BX587[i]	2.2429	23:46:29.192	+12:49:03.71	2006 Oct	5400	Kn3	Hα	50	105

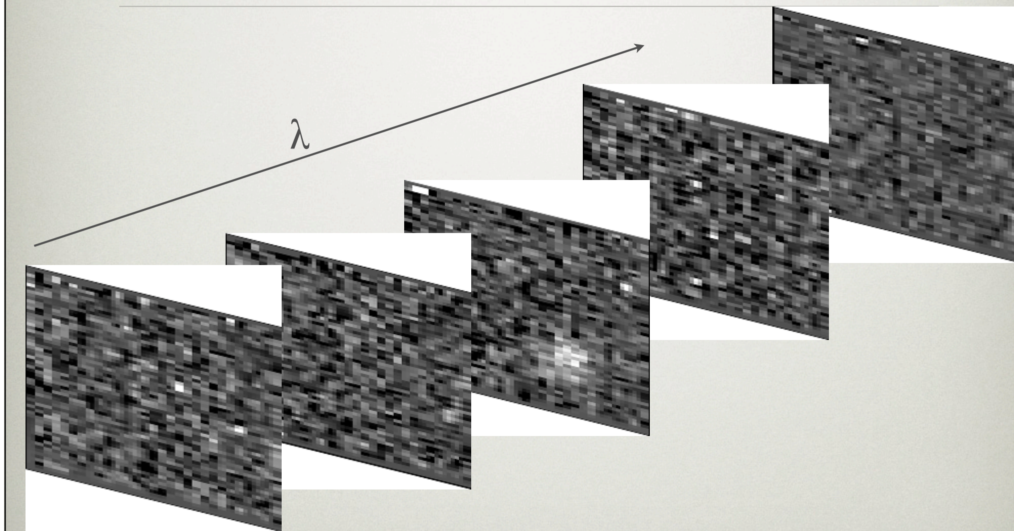
Notes.
[a] Vacuum heliocentric redshift of primary nebular emission line.
[b] Total observing time, mean value for detected sources was ~2 hr.
[c] Primary targeted emission line.
[d] FWHM of the *K*-band PSF (mas) during on-axis TT star observation (before/after spatial smoothing, respectively).
[e] Poor observing conditions.
[f] Redshifts estimated from NIRSPEC spectra.
[g] Redshift estimated from rest-UV spectrum.
[h] Individual exposures were each 300 s.
[i] Galaxy detected, but quality too poor for analysis.

- Photometric pre-selection - Un GR color selected (selects z 2-3 gals)
- UV follow-up work that found z - looked for young stellar pops, and old stellar pops
- multicomponent UV morphology - previous strong H-alpha detection
- Previous long-slit success - Bright star nearby for AO

Data Processing

Construct Datacube

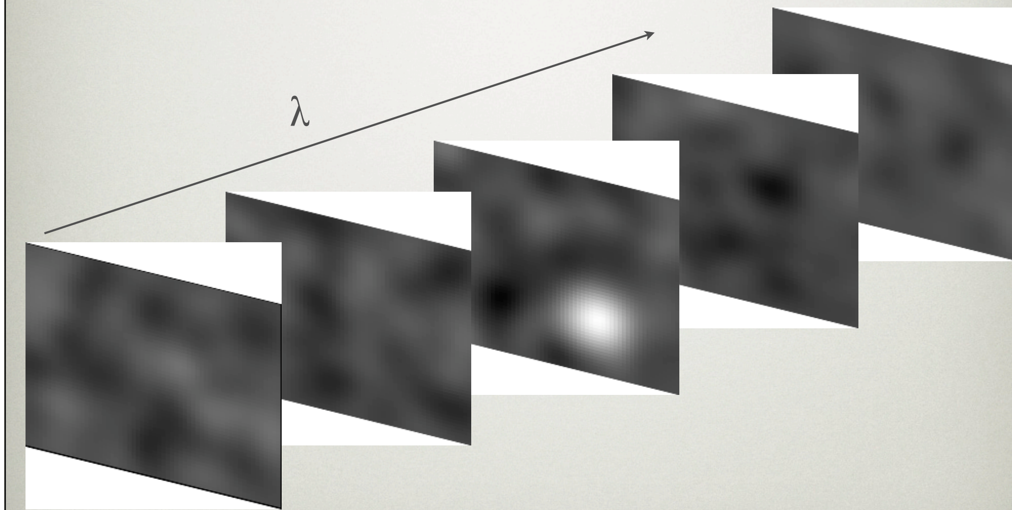
Data Processing



Data Processing

Smoothing

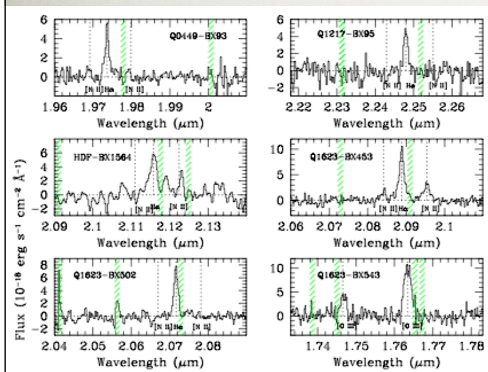
Data Processing

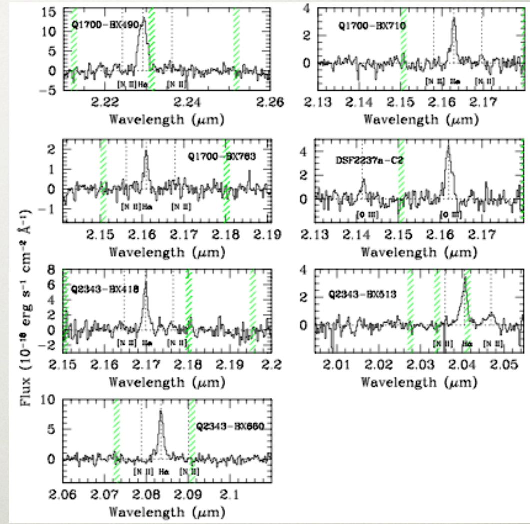


Data Processing

Getting 1D Spectrum

Data Processing





Data Processing

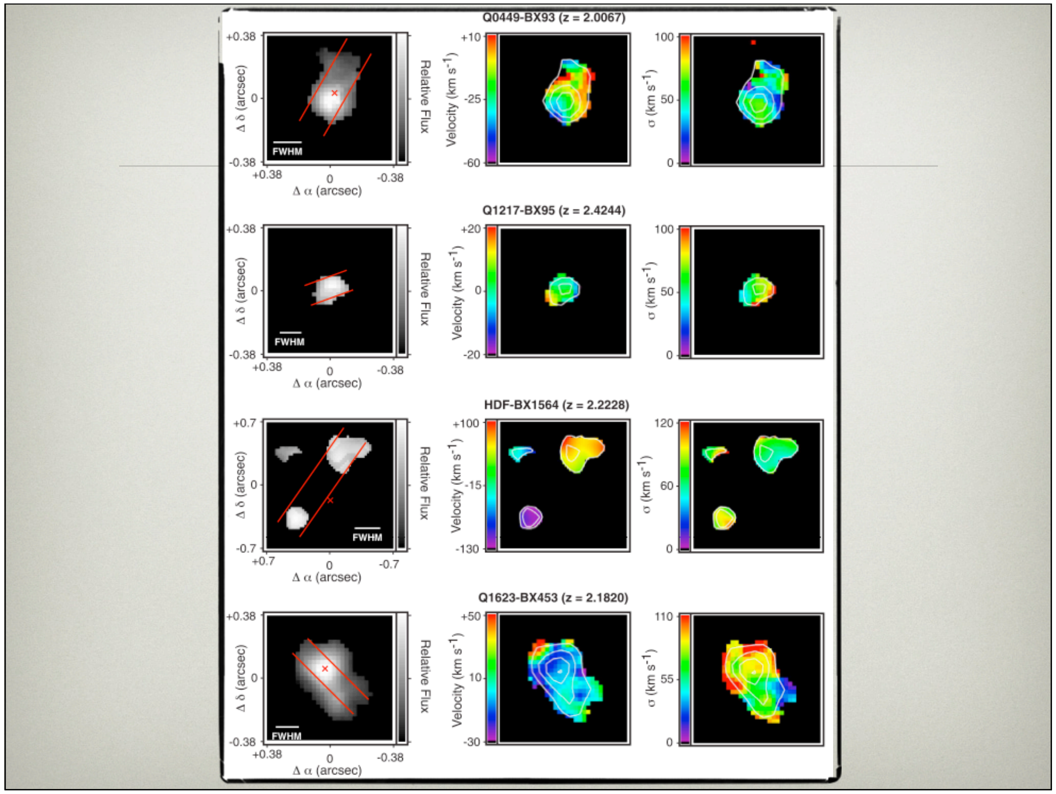
Construct Datacube

<u>Smoothing</u>

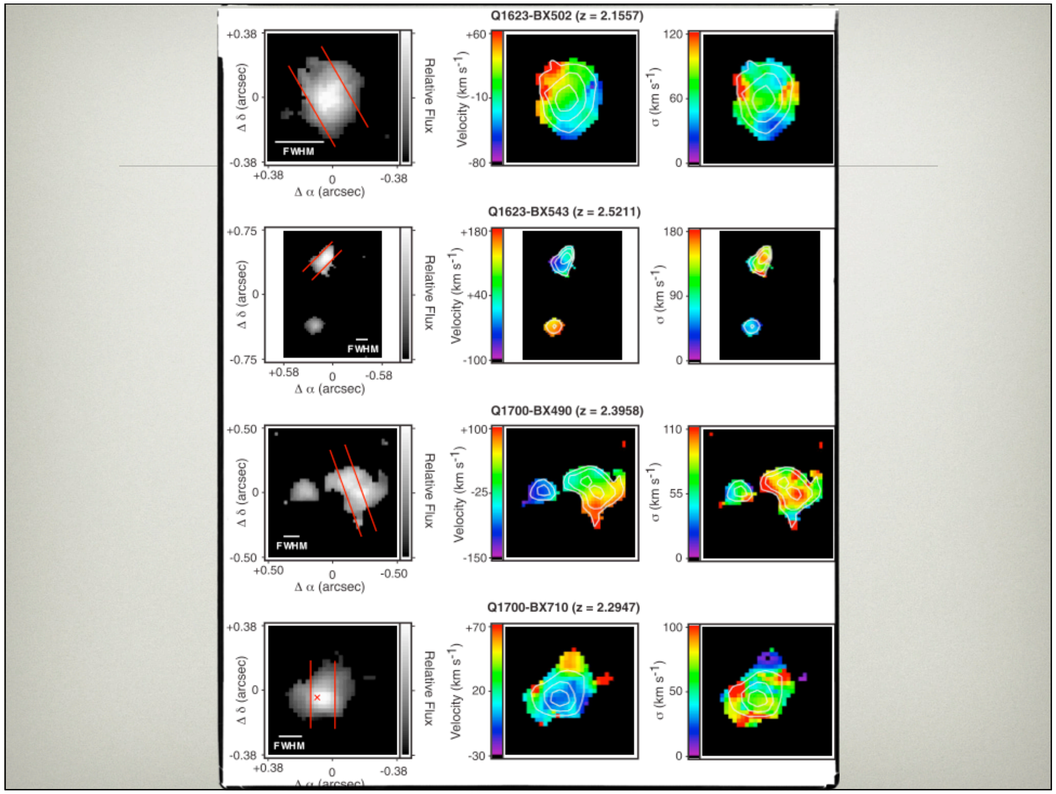
Getting 1D Spectrum

Getting 2D image

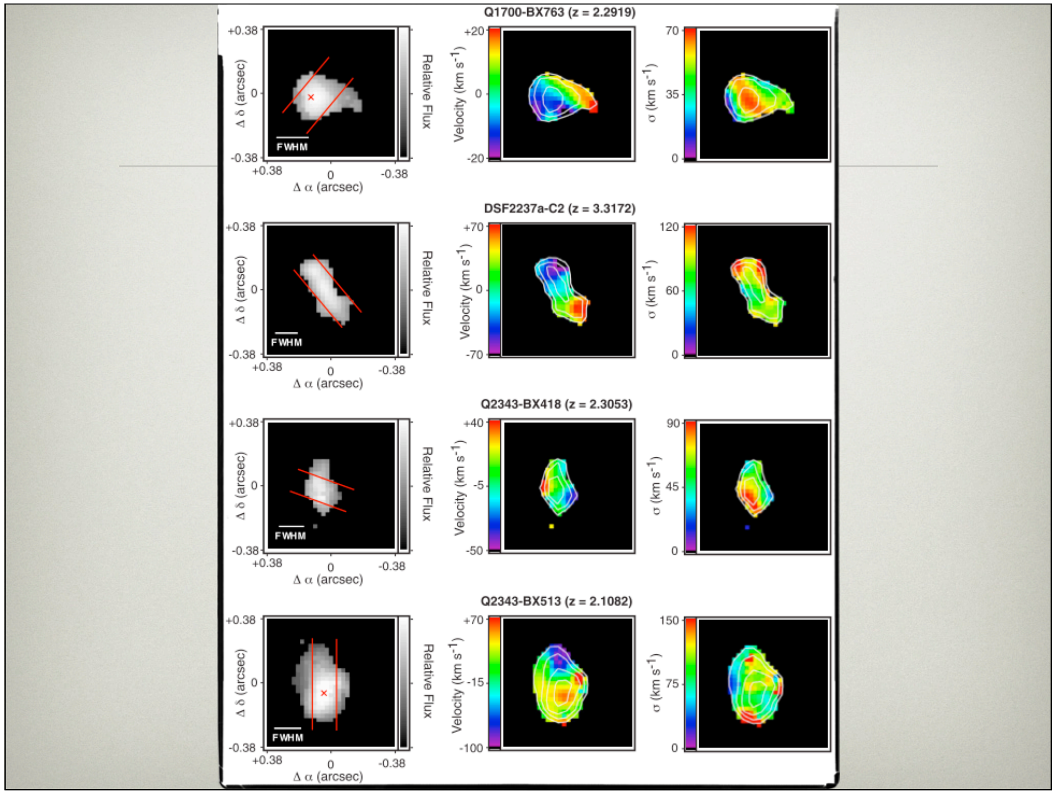
Get kinematic data



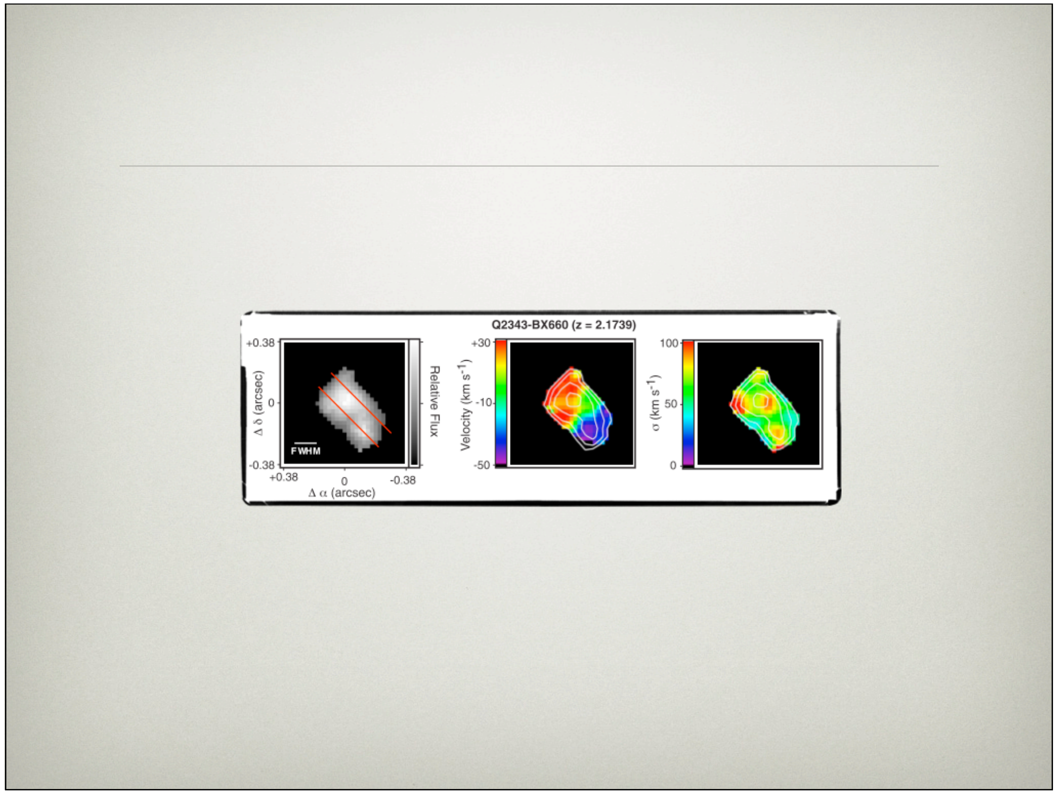
1) ~10^10Ms – Two v regions – Z ~ 0.5Zs
2) ~3 10^10Ms – similar to 1 – more compact – High Z
3) ~ Heavy smoothing – Delta-V 170km/s – Top left feature not real
4) Typical kinematics – ~3 10^10Ms – high Z



5) Low M: ~3 10^9 Ms – poor observing conditions – large PSF
6) d2c = 6.7kpc – if merger, M ~ 8 : 1
7) ~4 10^9 Ms – Z = 2/5 Ms
8) Nothing special



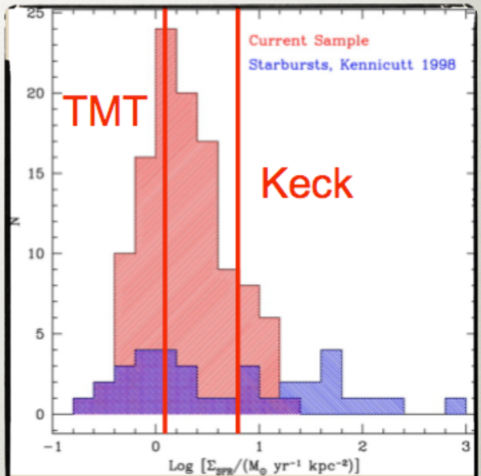
9)
10)
11) ~ 10^9 Ms - Little dust
12) Two v regions - Old - ~8 10^10Ms



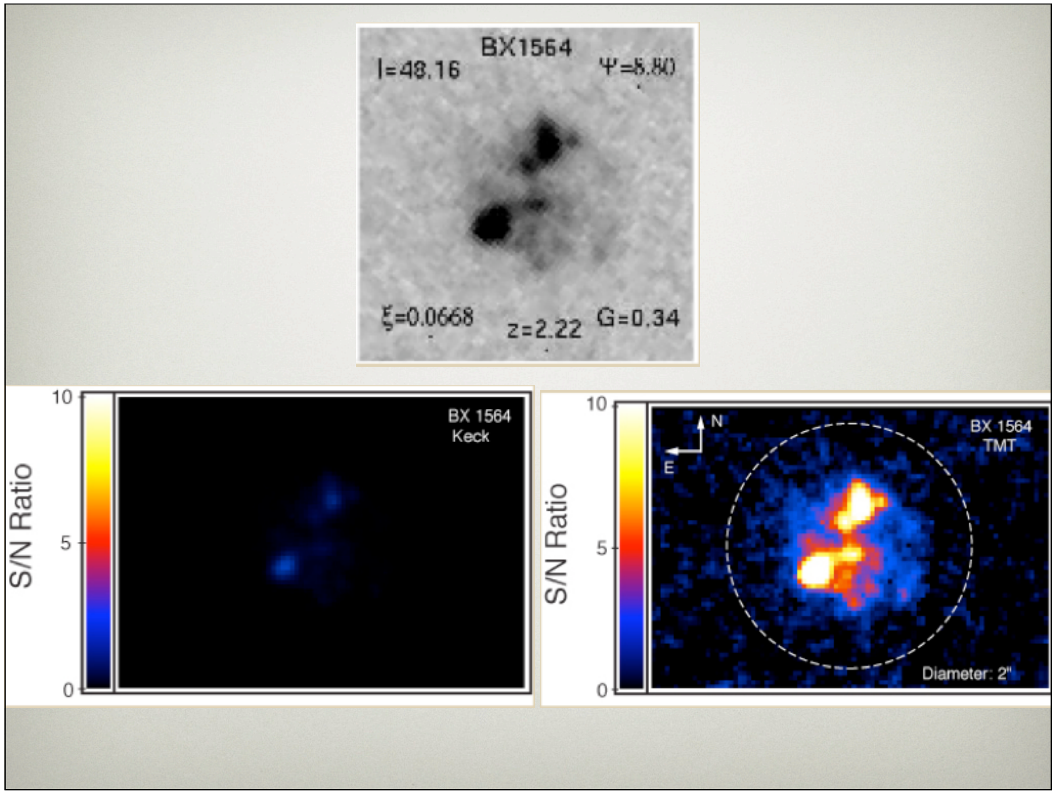
13) Two regions - 10^10 Ms

TMT

- How will TMT improve this science?
  - More collecting area
  - Better spectral resolution (3600 vs 4000)
  - Better AO
  - Lower IR background



SFR density of z ~ 2 galaxies (Erb et al. 2006)


BX1564
I=48.16
Ψ=5.80
ξ=0.0668
z=2.22
G=0.34
10
5
0
S/N Ratio
BX 1564
Keck
10
5
0
S/N Ratio
N
E
BX 1564
TMT
Diameter: 2"

Results

- Morphologies are highly irregular
- Stellar population & Formation modeling
- Kinematics indicative of some rotation (5/13), some small velocities (6/13), and some non-rotation (2/13).

- No consistent structure   - SFRs ~ 10s - 100s M/yr - Age ~ 10s - 1000s Myr - M* ~ 0.1s-1s 10^10

Summary

- Look at data collection and processing
- Random morphologies and kinematics
- TMT will expand this to fainter galaxies - the average guys
- NEED MORE SAMPLES!

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- The Galactic Neighborhood (GAN)
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Thanks! - Questions?

Resources

- David Law's Powerpoint: *TMT: Science Goals and Design Requirements for IFU Studies of High-Redshift Galaxies*
- HighZGal --> APOD: http://apod.nasa.gov/apod/ap040929.html
- Movies --> Chris Mihos: http://burro.cwru.edu/models/
- Star Formation --> http://www.profiledesigninc.com/OMOS-SO-Matrix-Reach4theStars-HR.html
- Law et al 2007, 2009