SALT RSS-NIR
MID-TERM REVIEW
MAY 20 & 21, 2009

UW RSS SCIENCE:
THE PROCESSING OF BARYONS IN GALACTIC SYSTEMS

BARGER, BERSHADY, CHURCHWELL, GALLAGHER, NORDSIECK, SHEINIS, TREMONTI, WILCOTS, WOLF

DEPARTMENT OF ASTRONOMY

WHY RSS?

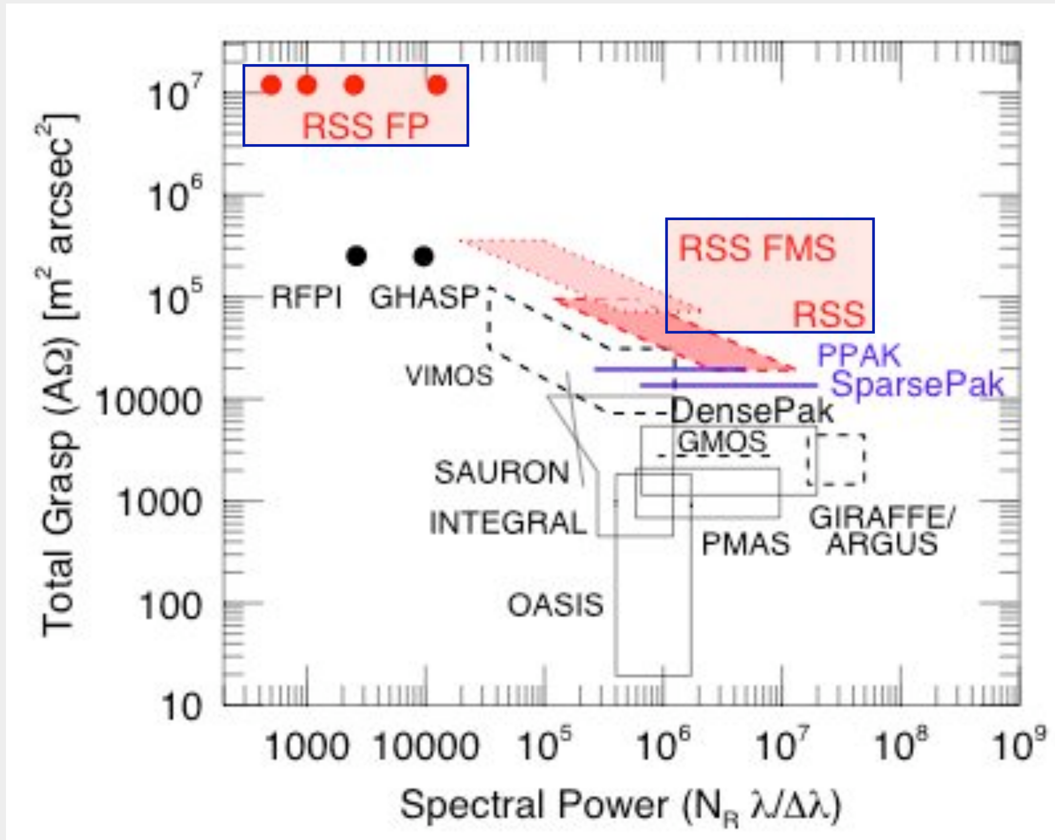
- **Nordsieck**: envisioned wide-field, high-etendue, medium-resolution NUV-VIS spectrograph with spectropolarimetric capabilities.
- **Buckley**: suggested use of VPH gratings
- **Williams**: realized Fabry-Perot and narrow-band imaging modes possible
- Nordsieck:
  - designed instrument capable of …
    - 8’ FoV, long-slit, multi-slit, imaging
    - 1000 < R < 6000 seeing-limited; R = 12000 Nyquist
    - 500 < R < 12500 FP imaging

❖ **wide-ranging, facility-class science programs for SALT consortium**
❖ **center-piece for SALT fore-front *survey* science mission**
❖ **development path to 2nd, simultaneous NIR beam**

- **Sheinis & RSS-NIR team**:
  - ➢ Conceptualized and crafted a workable design for NIR beam
  - ➢ Enables all NUV-VIS capabilities *but in the NIR*
  - ➢ Dramatically enhance wide-ranging facility-class science capabilities
  - ➢ Delivers optical-NIR *simultaneity*

SURVEY SCIENCE FIGURE OF MERIT
NUV-VIS BEAM

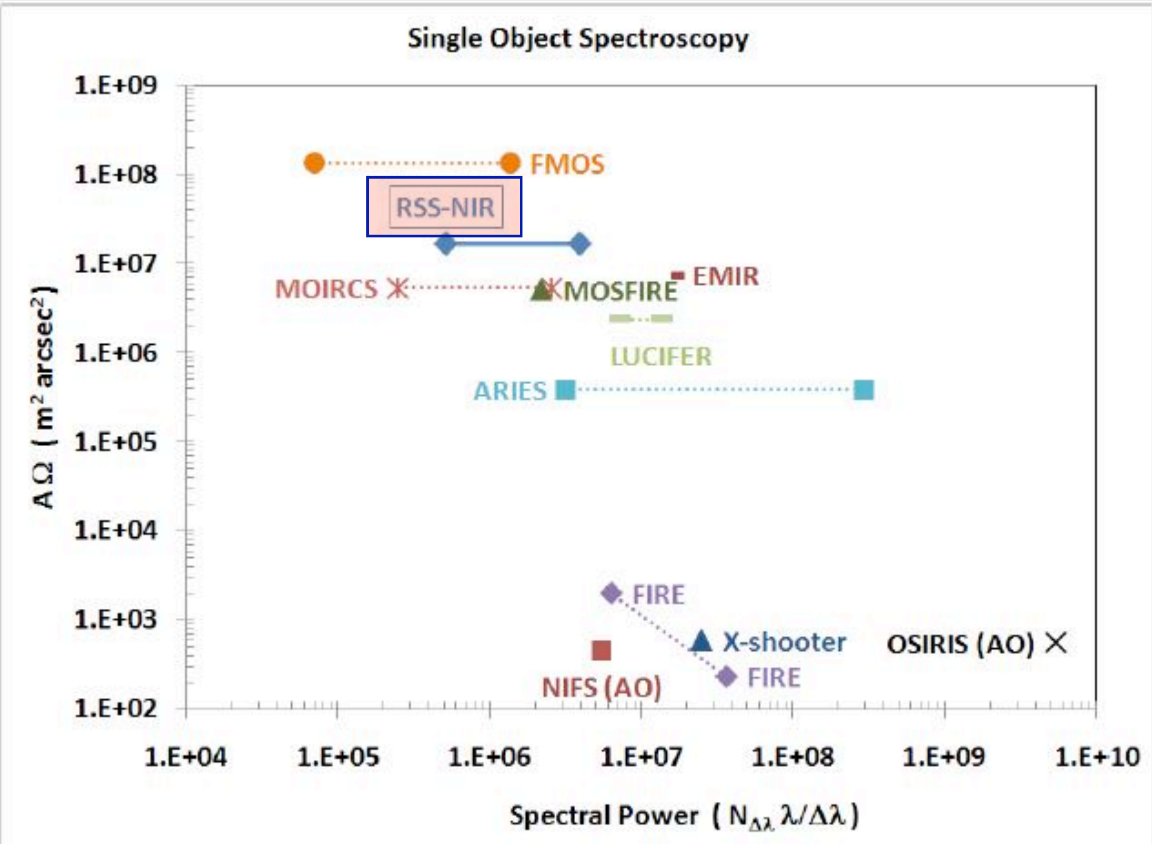
- Spatial vs spectral / coverage vs resolution
  - reliable, consistent ε measurements unavailable for most instruments
  - use grasp instead of etendue (warning: really want etendue)
  - many merit functions - grasp and spectral power fundamental



Bershady et al. '04 *(revised)*

SURVEY SCIENCE FIGURE OF MERIT
NIR BEAM

- Spatial vs spectral / coverage vs resolution
  - RSS-NIR is a highly competitive survey instrument with very large grasp.
  - Spectral power with simultaneous optical beam is also very high.

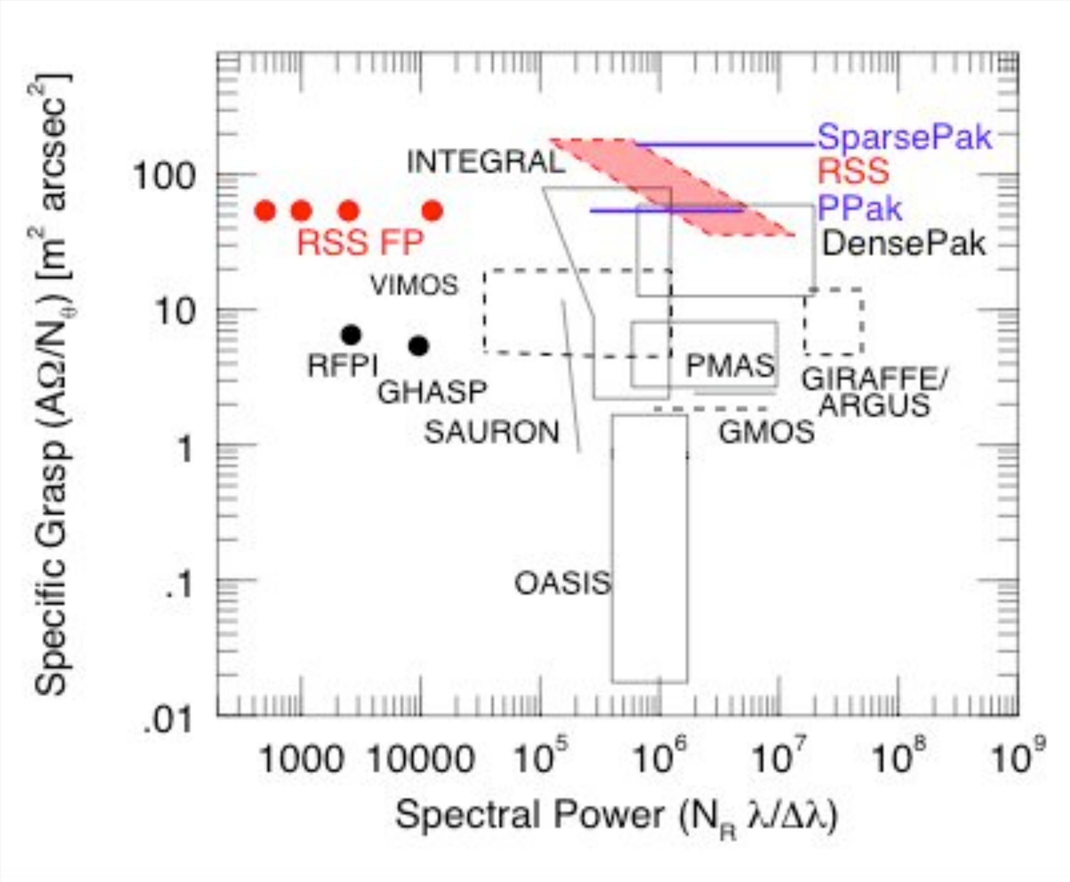


Nothing matches RSS for simulatneous VIS+NIR coverage

SURVEY SCIENCE FIGURE OF MERIT
VIS + NIR BEAM

- Specific grasp
  - RSS-NIR is a highly competitive survey instrument with very large *specific* grasp.

critical point for line-dominated foreground regimes where spectral resolution is critical. . .

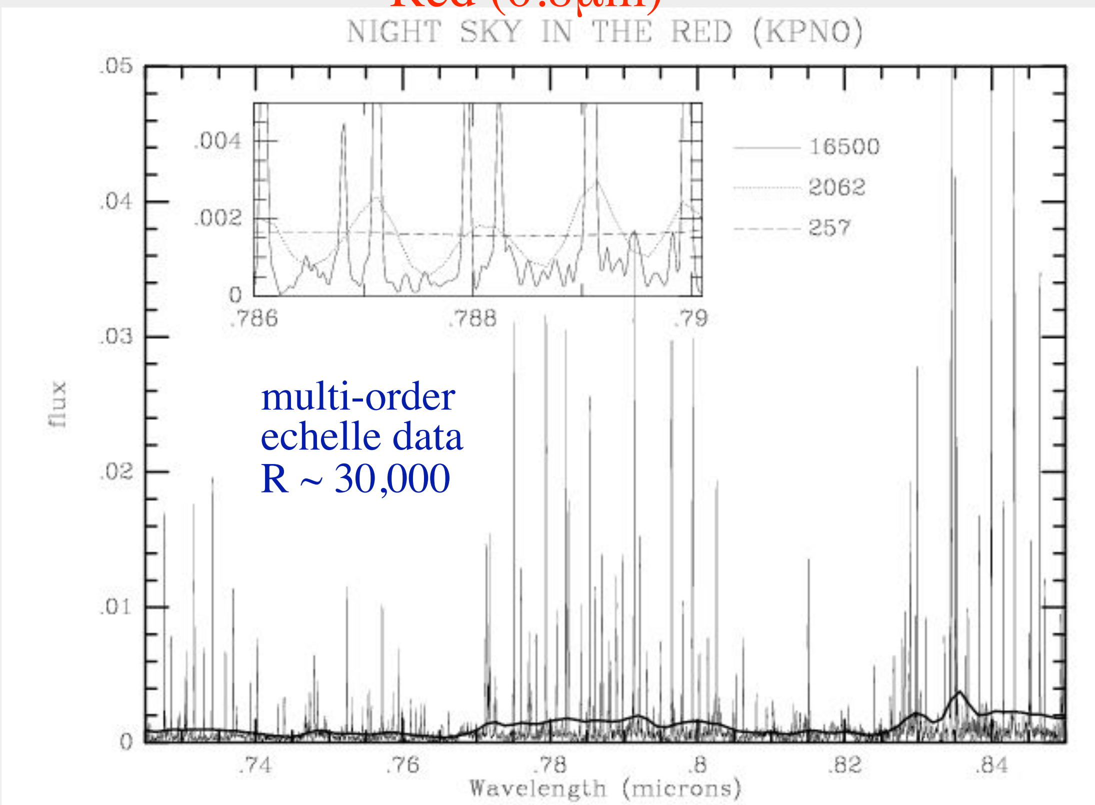


Bershady et al. ‘04 *(revised)*

WHY SPECTRAL RESOLUTION IS IMPORTANT

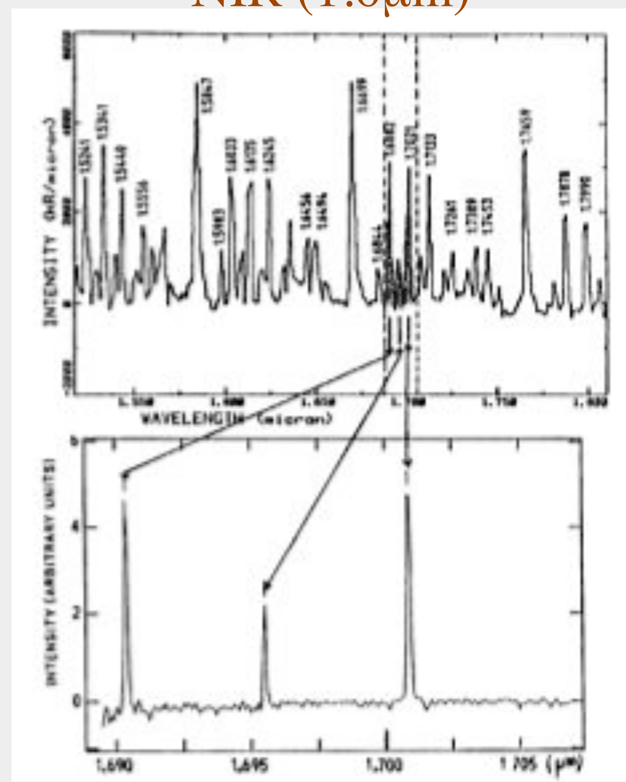
- Terrestrial foregrounds, sensitivity, and sky subtraction
- Situation similar from 0.7-2.2 microns: OH airglow dominates
- For faint sources under a bright sky line: *you are better off being read-noise limited and resolving out the sky line*

Red (0.8μm)



Bershady, using echelle data from York & Lauroesch

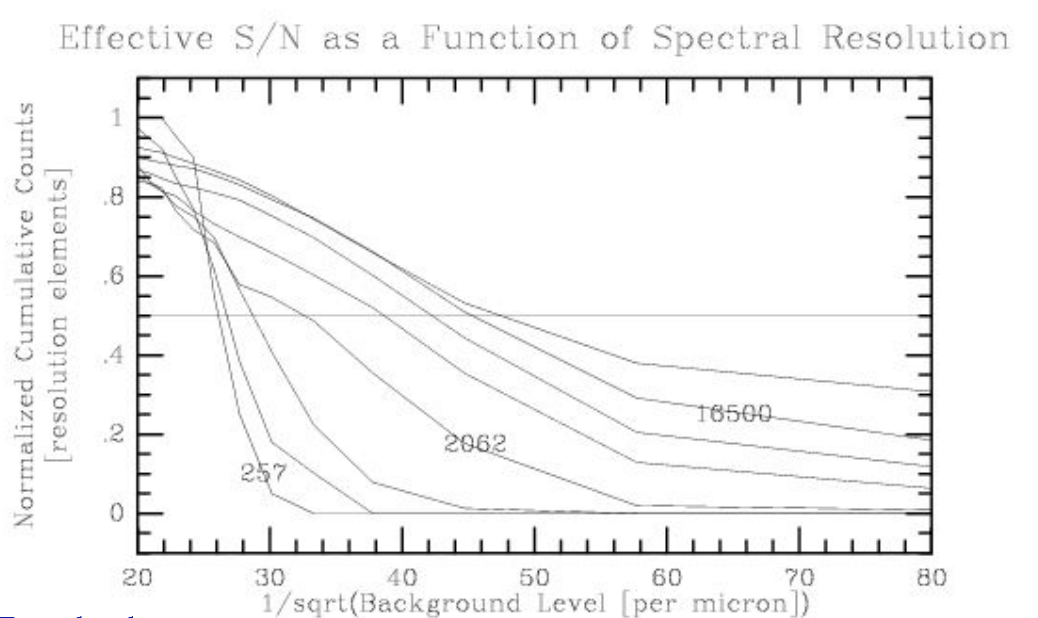
NIR (1.6μm)



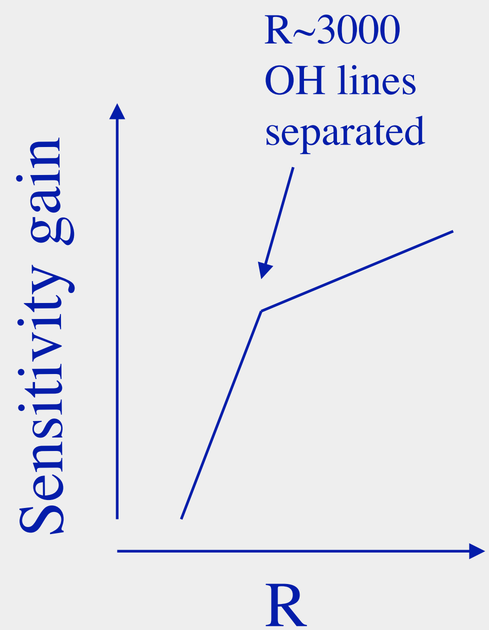
Maihara et al. '93

WHY SPECTRAL RESOLUTION IS IMPORTANT

- Sensitivity implications of increased spectral resolution
  - Significant gains up to R = 2000-4000 as OH lines are separated
  - ***BUT*** linear gains continue up to m/s resolution of atmospheric OH lines



Bershady

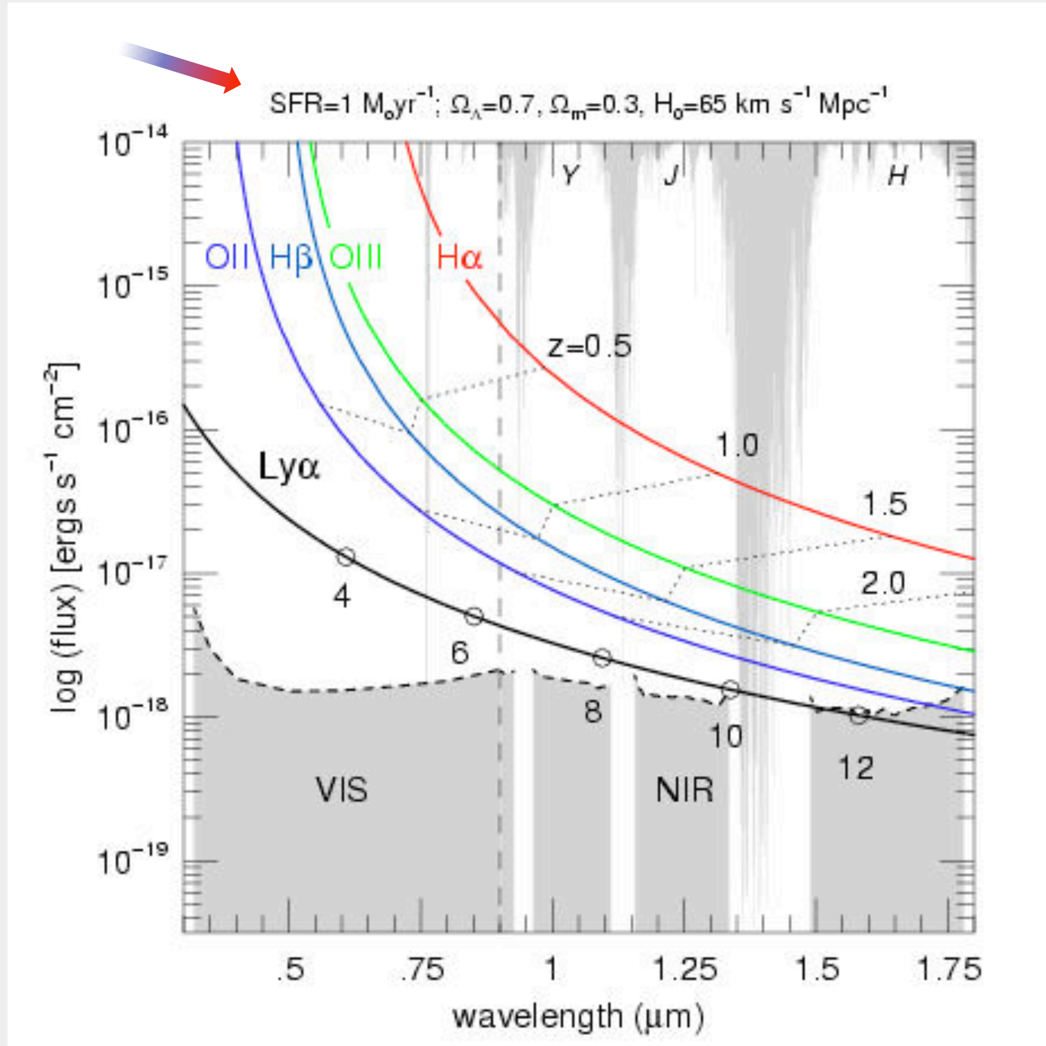


Fundamental science requirement to enable R>3000; push as hard as existing collimator, articulation and detector constraints allow.

SCIENCE THEMES

1. Discovering First Light
2. Star-Formation in the "Desert"
3. Baryon Processing in a Mature Universe
4. Star-formation at z = 0

We envision surveys generating consortium-wide collaboration



RSS Flux Limits

1. ULTRA-HIGH REDSHIFT UNIVERSE: FIRST LIGHT

Barger, Bershady et al.

- **Science Goal:**

  Discover when and how rapidly the first galaxies formed. When is reionization complete?

  The frontier is z>7. The achievable flux limit for SALT is about z=10.

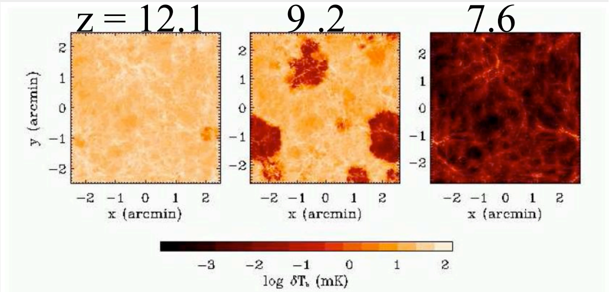
- **Instrument Requirements:**
  - FP imaging R=2500 to z=10 (1.35 μm).
  - At z=8 we expect > 30 sources in 12 hours
  - Z=9,10 expect ~30 sources in 53 and 1600 hours
  - Extension to 1.65 μm allows detection out to z=12-13, but SFR will have to be few Mo/yr -- unknown: *high-risk / high-return.*
  - Simultaneous optical FP to cull interlopers (tune to redshifted [OII]3727 if NIR-line is Hα).
  - *Immediate* follow-up optical-NIR MOS at R>4000 to eliminate remaining interlopers (split [OII]3727 doublet), determine kinematics to make dynamical mass estimates, constrain winds and outflows.

Unique in wide-field mode

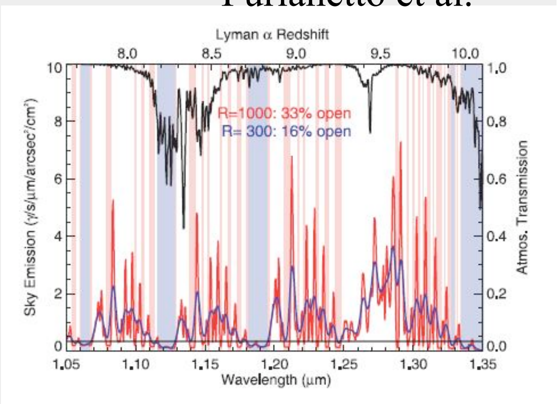
News-Flash: recent z=8.2 GRB started at J =19.3

Simulations

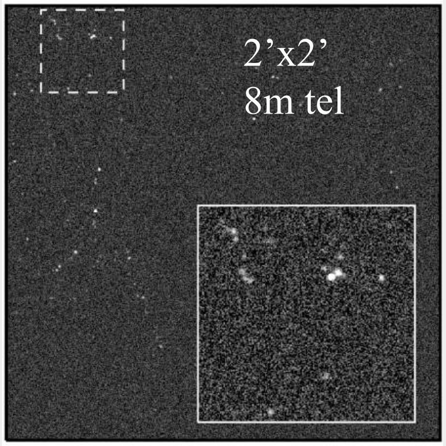
H I brightness temperature: Reionization



Furlanetto et al.



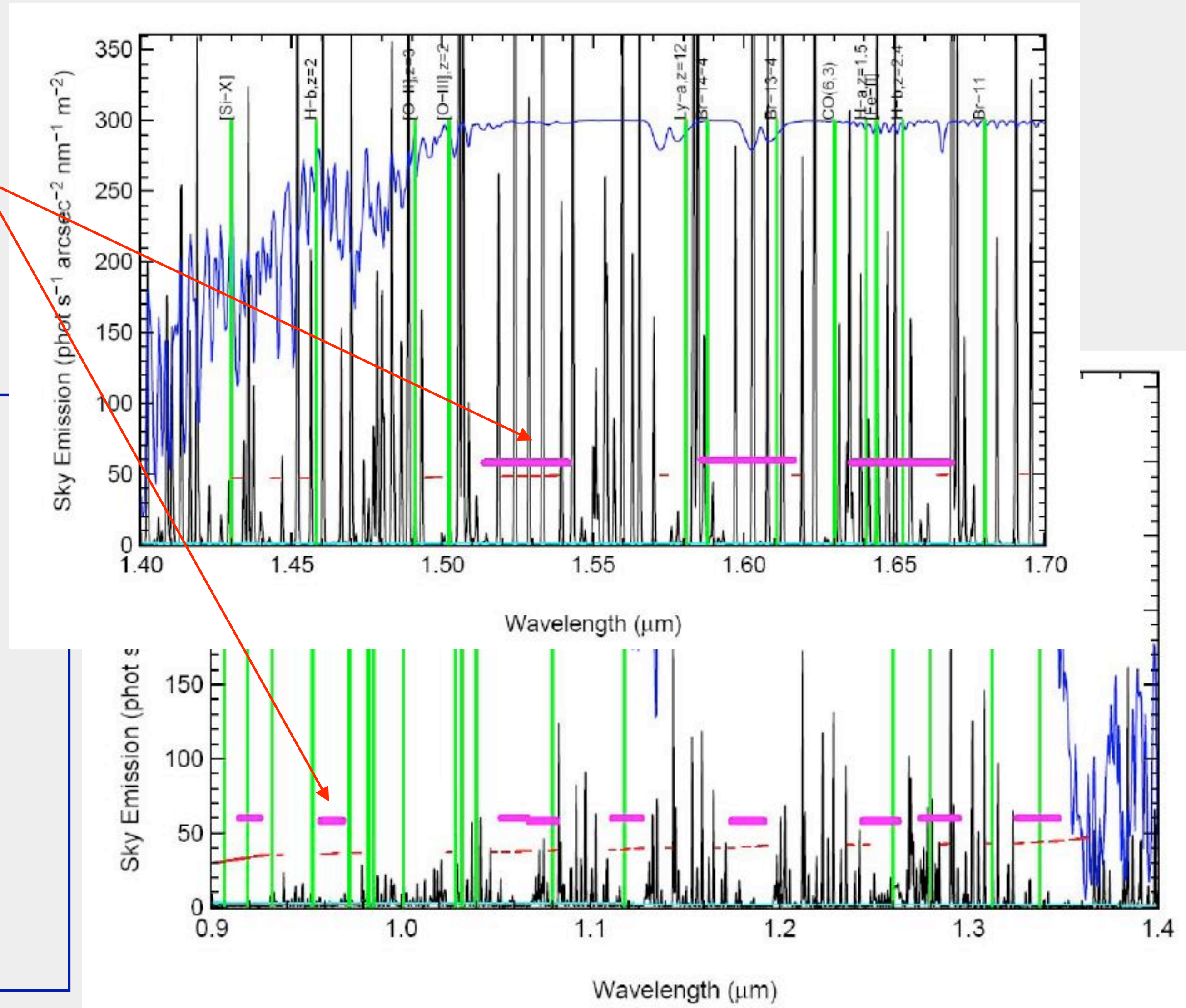
Lyα In the *J* band



Barton et al. '04

FP BLOCKING FILTERS:
ACCOMMODATE WIDE RANGE of SCIENCE

Filters



- Location chosen to minimize terrestrial foreground
- Optimize FIRST LIGHT detection in discovery mode
- …and hit key z=0 diagnostics

2. STAR-FORMATION IN THE DESERT: WHEN GALAXIES WERE YOUNG

- **Science Goal:**

  Map star-formation rate and dynamical masses using [OII]3727 in the 1.4<z<2.6 regime when most of the mass-assembly for massive galaxies is believed to have taken place.
- **Instrument Requirements:**
  - Simultaneous optical-NIR MOS at R>4000 out to 1.35 μm; resolution needed to optimize S/N, split [OII]3727 doublet, and estimate dynamical mass; OP/NIR needed to cull interlopers and acquire multiple lines for metallicity estimates and ISM diagnostics.
  - Extension to 1.65 μm allows detection in [OII]3727 out to z=3.4 at SFR≥1 Mo/yr - well-beyond peak in comoving SFR and AGN activity.

Credit: Hubble UDF

News-Flash: SPT SZE detections now underway.
High-z cluster tail ideal location for mass-assembly study w/ SALT.

BALANCINIG THE BARYON BUDGET

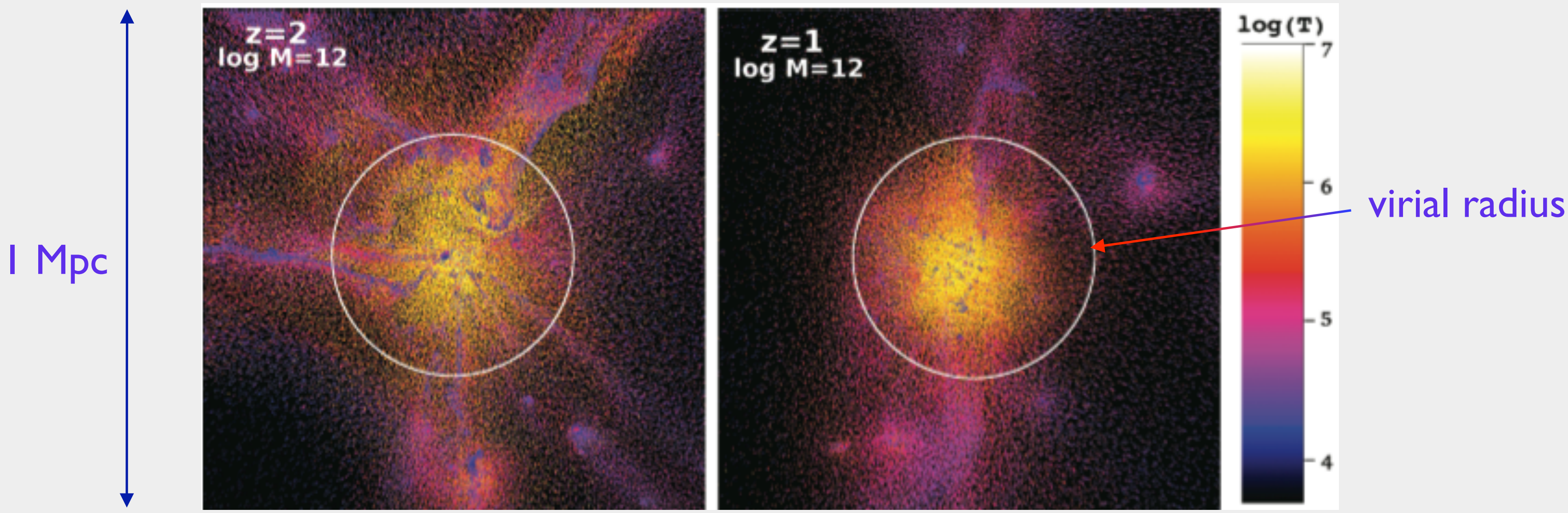
STAR FORMATION, GAS ACCRETION & FEEDBACK at Z=1.5

Tremonti et al.

Galaxy evolution: driven by **gas accretion, feedback, and merging**

-- many studies of galaxy mergers

-- important theoretical work on accretion & feedback, *but very few observations!*



Simulation of gas temperatures in Milky Way sized-halo at z=2 and z=1 (Keres et al. 2009).
Note the *coexistence* of hot and cold gas.

Baryon-to-dark matter ratio: isolated galaxies << galaxy clusters *WHY?*

Are "missing" baryons in hard-to-observe phases related to accretion & feedback?
e.g., small clumps of cold gas, diffuse hot gas

In the next few years several large NIR **photometric surveys** will document the stellar content of galaxies from z=1 to 6 . . .

The Spitzer Extragalactic Representative Volume Survey (SERVS)

- 1400 hour Spitzer warm mission survey (P.I. Mark Lacy)
- deep imaging at 3.6 an 4.5 um over 18 square degrees in 5 southern fields
- overlap with the VISTA-VIDEO near infrared and Herschel-HERMES and SCUBA2-S2CLS far-infrared surveys, ALMA coverage likely
- Goals:
  - photometric redshifts and stellar masses for galaxies at z=1 - 6
  - a census of dust and obscured star formation from Herschel & SCUBA2

NIR ***spectroscopy*** *is a crucial to understand the nature of the gas in and around these galaxies.*

RSS follow-up survey:

~100 galaxies at z=1.45 -- 1.65 selected to span a range of stellar mass, SFR, SFR/mass, and dust attenuation

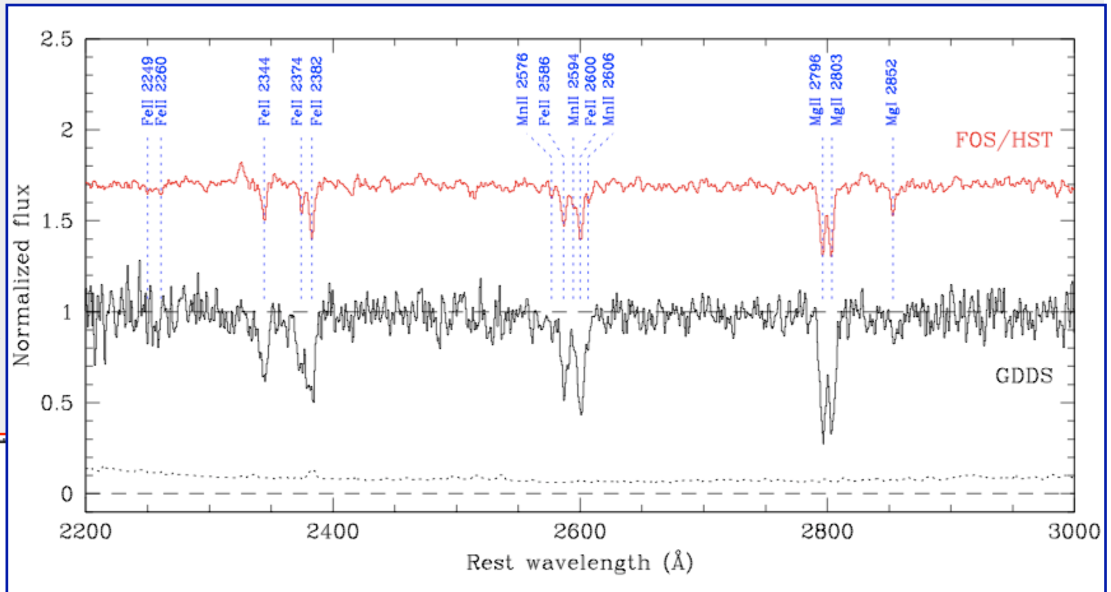
NIR & Optical MOS mode -- typically 3-10 targets per pointing

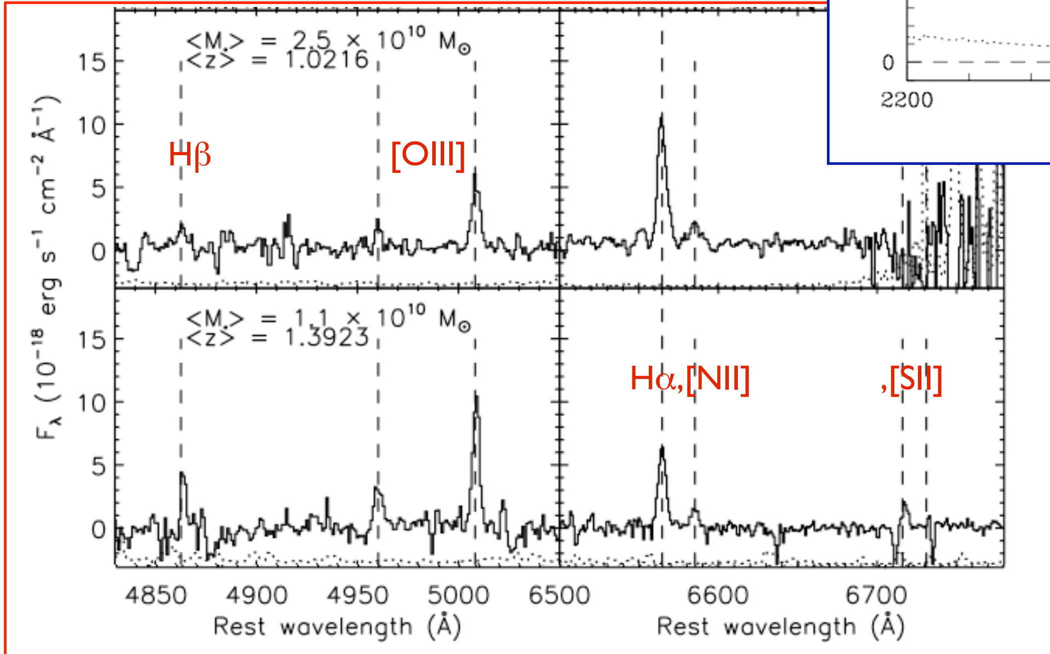
Probing star formation, gas accretion and feedback at z=1.5 with RSS

Optical light (5500 - 7500 A) traces rest-frame UV, interstellar medium absorption lines:

CIV, Fe II, Mn II, Mg II, Mg I

GDDS composite spectrum of 13 star forming galaxies at z=1.3 – 2 (Savaglio et al. 2004 - Gemini GMOS)





Composite restframe optical spectrum of 12 galaxies at z=1 - 1.5 (Liu et al. 2008 - Keck NIRSPEC)

Near-IR probes optical nebular lines
J-band: Hβ, [O III]
H-band: Hα, [NII], [SII]

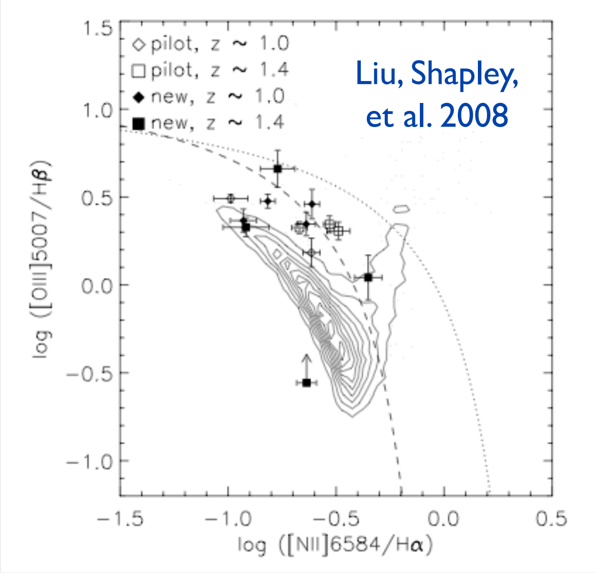
RSS VIS + NIR can do both simultaneously

Probing star formation, gas accretion and feedback at z=1.5 with RSS

Are the physical conditions in z=1.5 star-forming galaxies similar to those of local galaxies?

-Look for offsets in [NII]/Hα vs. [OIII]/Hβ diagram

- correlation with SFR, SF surface density, mass, etc?
- evidence for higher densities, pressures?



Does strong feedback drive gas outflows?

- Look for evidence of galactic winds
  - -measure relative velocity of the absorption and emission lines (emission lines trace gas in HII regions)
- Does outflow velocity depend on the ionization state of the gas?
  - -compare CIV, Mg II, Mg I velocities
- Does outflow velocity correlate with SFR, Mass, SFR/M, etc?

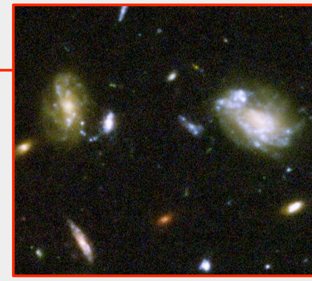
Are gas inflows required?

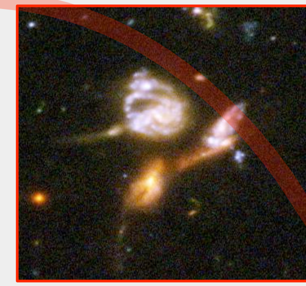
Following Erb et al. 2008:

- Compare SFR/M and galaxy age (from SED fitting) to simple models
  - > Infer ratio of inflow to "gas processing" (SFR+outflow)
- Compare gas fraction and metallicity
  - > Infer inflow and outflow rate relative to SFR

The galactic wind in M82

3. BARYON PROCESSING IN A MATURE UNIVERSE





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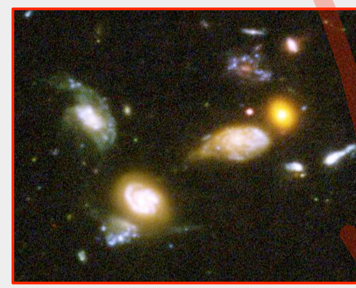


- **Science Goal:**

  Precision mapping of down-turn in co-moving SFR and chemical enrichment from 0<z<1 as function of dynamical mass using Hα and strong-line nebular diagnostics ([NII]/ Hα, [OIII]/ Hβ) and *stellar* kinematics.

- **Instrument Requirements:**
  - Simultaneous optical-NIR MOS at R>4000 out to 1.35 μm; split[OII]3727 doublet and cull interlopers; acquire multiple lines for metallicity estimates and ISM diagnostics.
  - R = 7000 for kinematics of narrow-lined (sigma<70 km/s) systems at the low-mass end.
  - Extension to 1.65 μm allows detection of Hα out to z=1.5, well into the youthful regime for massive galaxies.

BLUE CLOUD and RED SEQUENCE

growth and destruction

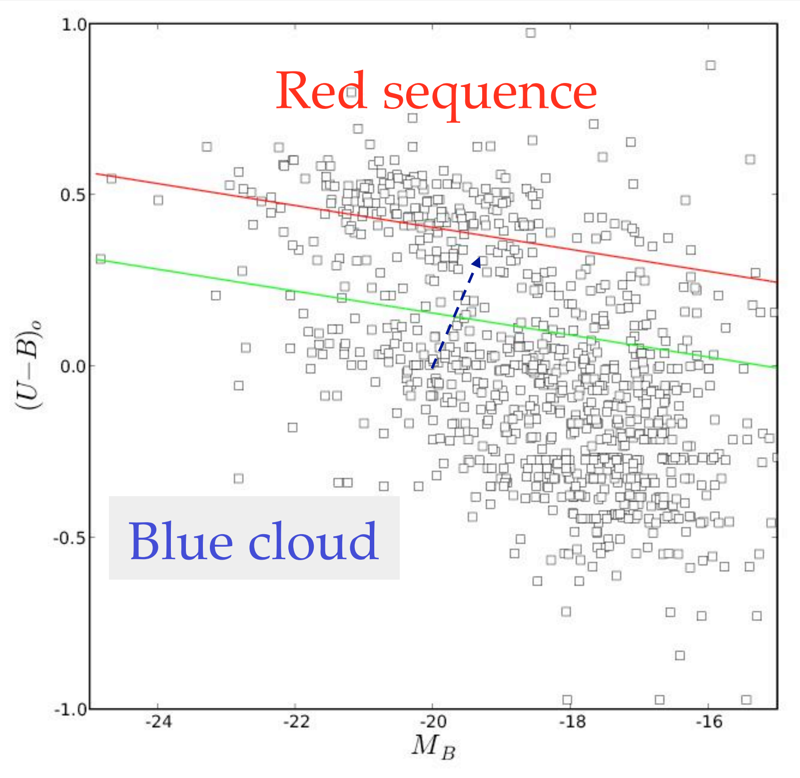
Bershady, Crawford et al.

- *Some* galaxies evolve from blue cloud to form the red sequence.
- *Most* stars are made in the blue cloud but end up in the red sequence.

e.g., Bell et al.'03,'07

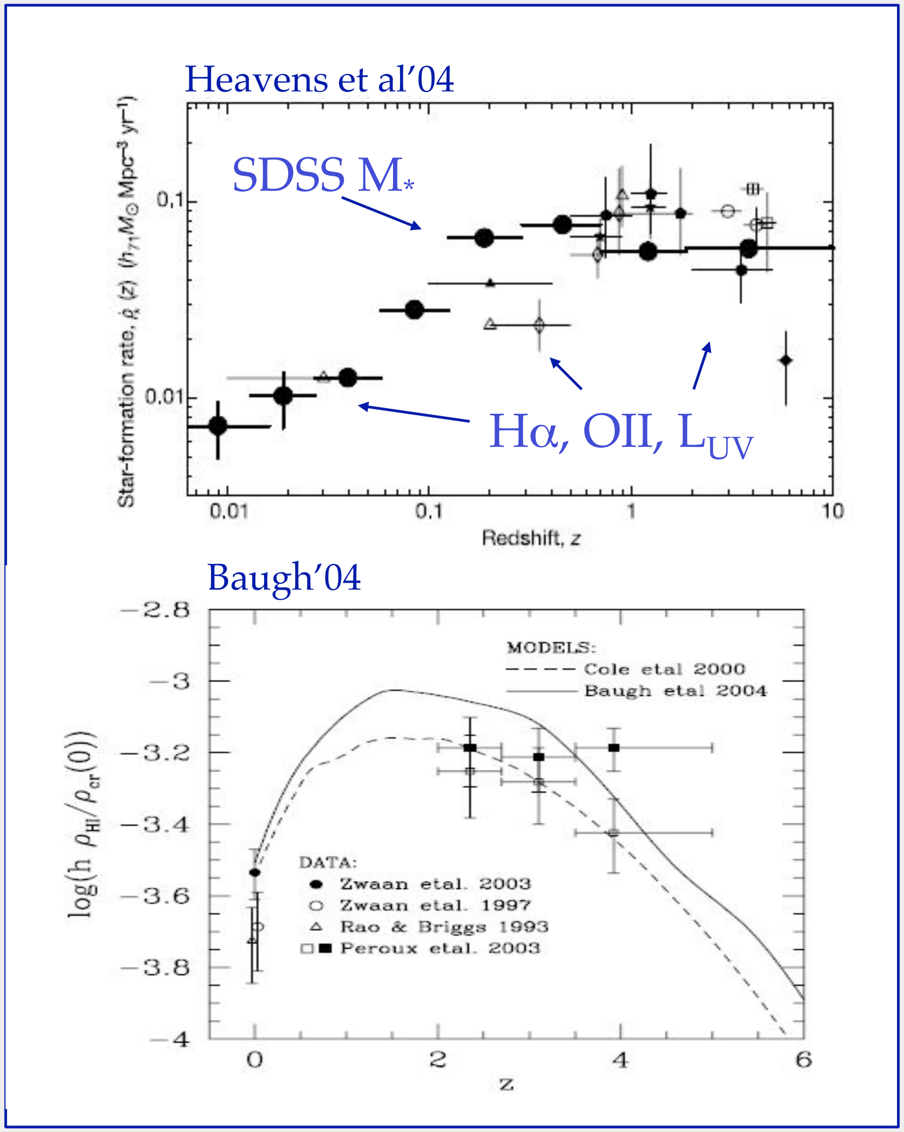
➢ Identify which are stirred, which are shaken:
  – Tag environment

➢ For those that are stirred:
  – Monitor smooth & continuous…
    ❖ accretion ⟶ *growth*
    ❖ star-formation
      ⟶ *gas consumption*



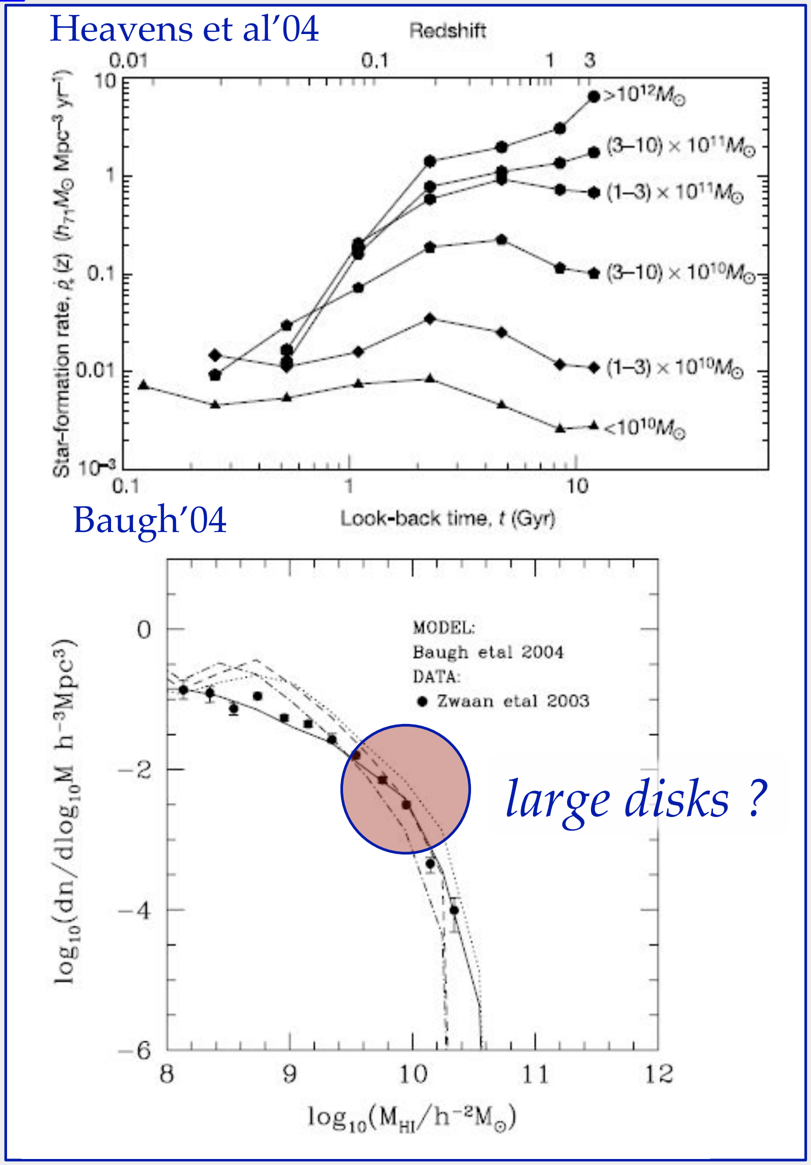
CONNECT OPTICAL AND HI VIEWS

ASKAP + MEERKAT *AND* SALT



- Are these two trends self-consistent?
- Confirm SFR with a single, direct measure from z = 0 to z = 1 and higher: **Hα**
- Measure $\Omega_{HI}(z)$ and HI mass-function directly
- Determine SFR as function of both dynamical and HI mass
- Identify the *individual* galaxies, e.g., at the knee of the HI mass-function

GO BEYOND THE CO-MOVING INTEGRAL . . .



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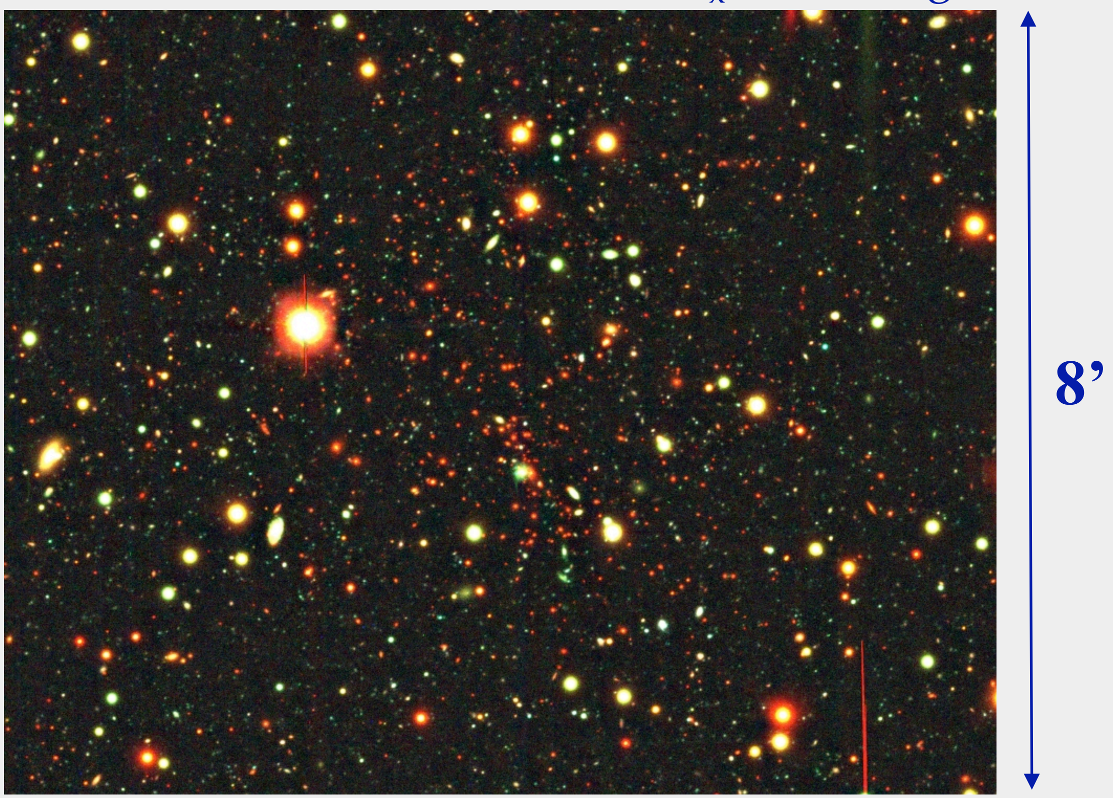
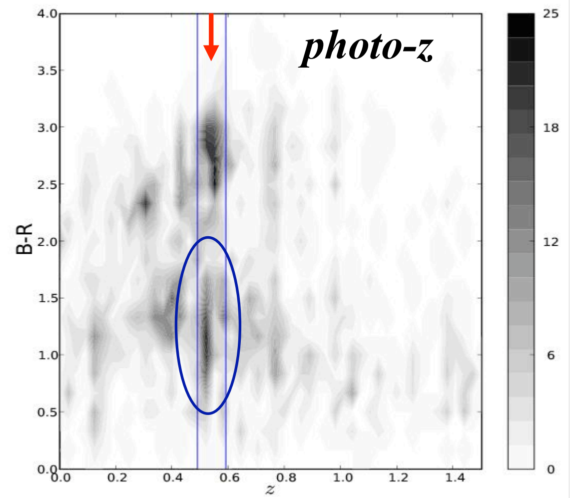
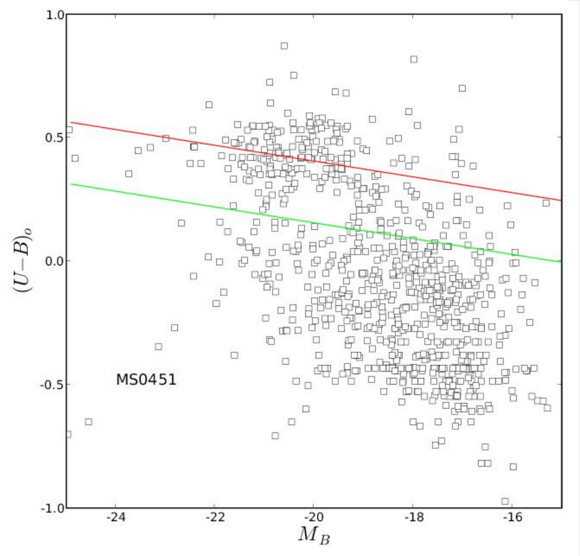
AT z=0.5 RED SEQUENCE APPEARS WELL FORMED in CLUSTER CORES…but

Spectroscopic redshifts, line-widths (masses), line-strengths (SFR) line-ratios (metals) needed to probe blue periphery and in-fall regions

MS0451: z=0.54, σ=1354 km/s, L_x=40e44 ergs/s







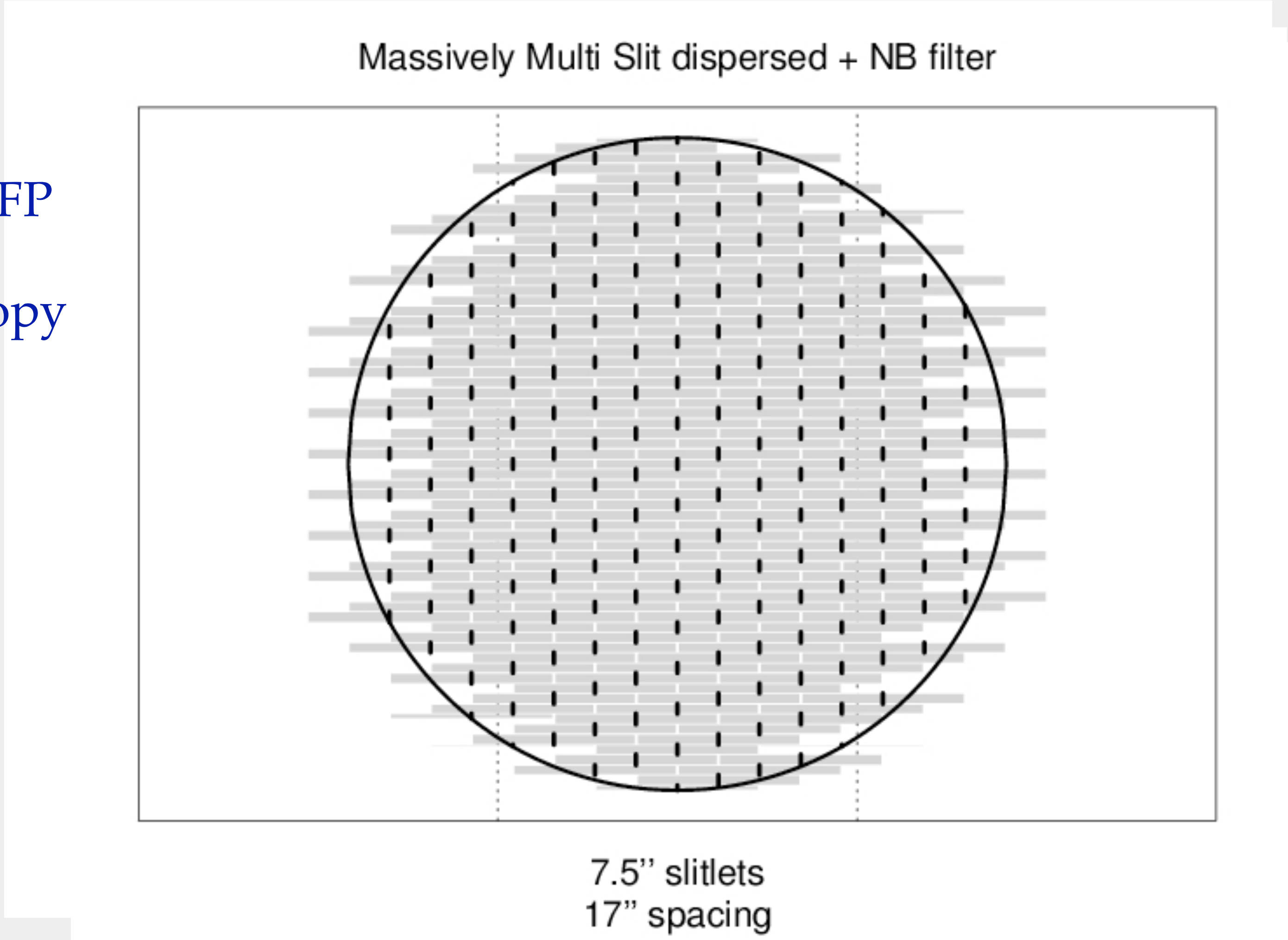
WIYN Long-Term Variability Survey
Crawford et al. 2006, 2009

NOVEL MODES for RSS

Tuning the trade-off between spatial and spectral multiplex

Imaging/FP

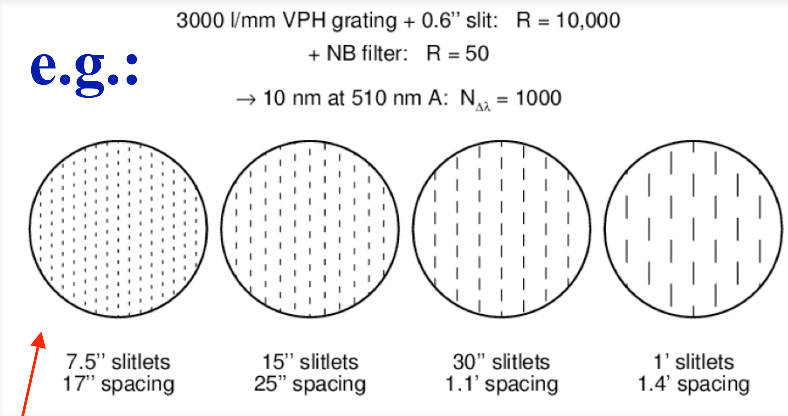
Spectroscopy

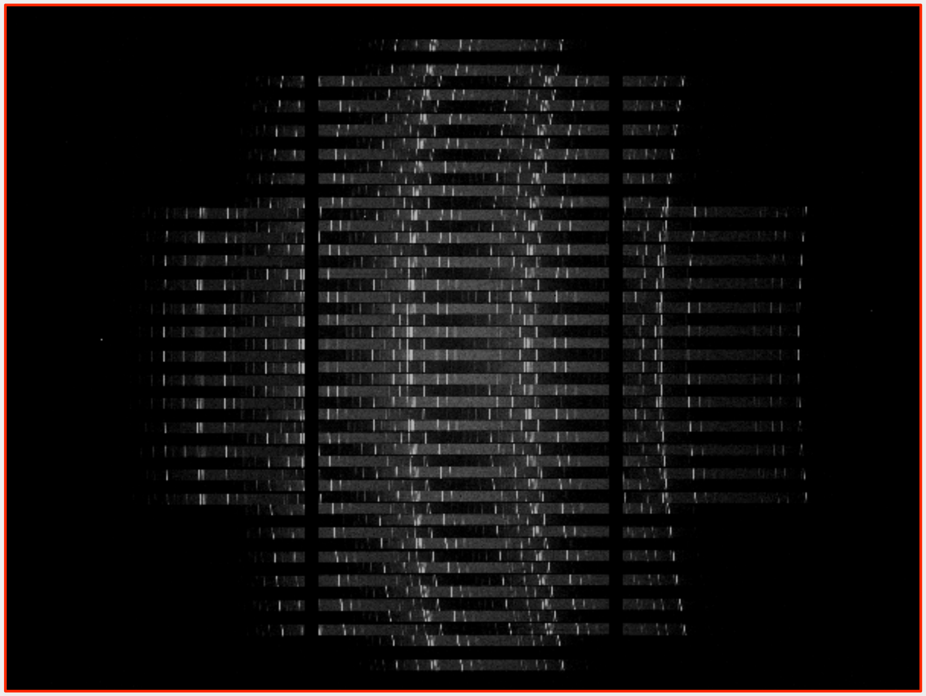


..taking advantage of NB filters in VIS and NIR beams

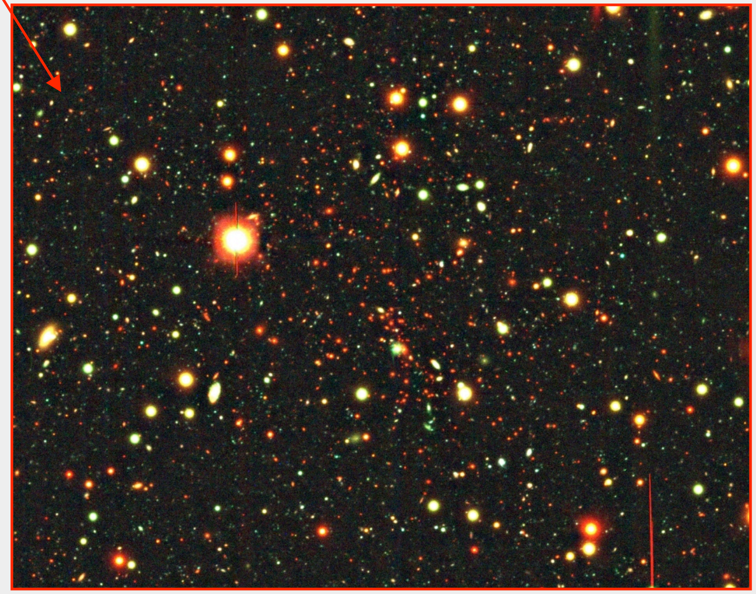
*F*ILTER *M*ULTIPLEXED *S*LITLETS

- Grating angles $\alpha \leq 50^o$
- NB filter R = 50
  - ➢ $R\,\phi \leq 6000$ arcsec
  - ➢ N_R=600 $(\phi/1\ \text{arcsec})^{-1}$
  - ➢ ΔV= 6000 km/s
  - ➢ 3x spatial multiplex for MOS

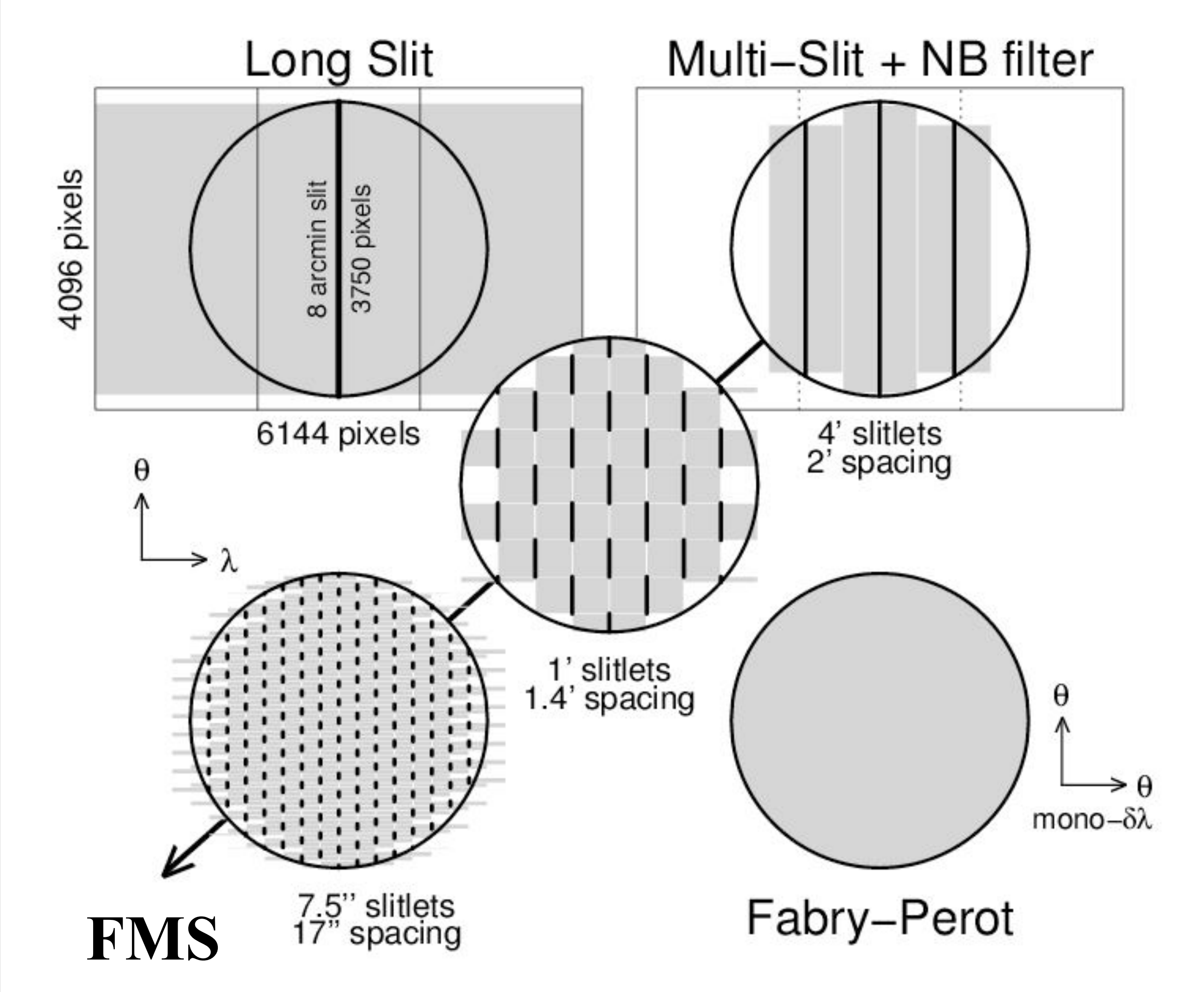




Tailor to irregular patterns for MOS



RSS SUMMARY OF MODES



SUMMARY REQUIREMENTS
Z>0 COSMOLOGICAL STUDIES

❖ Simultaneous VIS-NIR FP mode R~2500 essential

- data-cubes of 3000 km/s (cluster) volumes …
  → 10-20 nm pre-filtered bands
- … at 50 km/s (s) resolution
  → work between OH lines
  → optimize narrow emission-line detection.

❖ Simultaneous 4000 < R < 7000, $\lambda \leq 1.35$ μm MOS essential

- multi-object *nebular line-diagnostics* + *kinematics* (σ~25 km/s)
- foreground minimization (detection / redshift continuity)
- $\lambda \leq$ 1.65 μm desirable
- R = 12,500 desirable (σ = 10 km/s -- *disks are cold!*)

4. STAR-FORMATION AT Z=0

- **Science Goal:**

  Constrain theories of massive star-formation that link production of elements and luminosity, to the energetics of feedback mechanisms and chemical enrichment which drive the evolution of baryons in galactic systems. Hα/Paβ flux ratios in obscured, star-forming regions and linear spectropolarimetry of circumstellar regions in obscured sources are the primary measurements.

- **Instrument Requirements:**
  - Simultaneous optical-NIR longslit spectropolarimetry at R>4000 out to 1.35 μm to sample Hα and NIR line diagnostics.
  - Simultaneous optical-NIR MOS at R>4000 out to 1.35 microns to sample Hα and Paβ (1.28 μm).
  - Extension to 1.65 μm allows measurement of Paβ out to z=0.3, roughly the Sloan volume.

Spiterzer/IRAC
GLIMPSE view of RCW49
Credit: Churchwell et al.

…over the Jay…

SALT RSS-NIR
MID-TERM REVIEW
MAY 20 & 21, 2009

BARYONIC PROCESSING IN THE CURRENT UNIVERSE:
FROM STARS TO GALAXIES

JAY GALLAGHER
UNIVERSITY OF WISCONSIN-MADISON

Baryon Processing: Evolution of Stellar Populations – ISM – IGM

- Cool stellar photospheres
- Circumstellar disks
- Dust obscured sources
- SEDs & stellar populations
- NIR emission lines
- Chemical abundance patterns
- Galactic evolution
- Transients: novae, pre-MS, supernovae…
- …

SCIENCE REQUIREMENTS ARE ESSENTIAL FOR RSS-NIR DESIGN OF A VERSATILE INSTRUMENT

M17—Giant HII Major Galactic star formation event

GLIMPSE
SST
Image-
PAH +
Lines

IMF
Ages
Masses
….

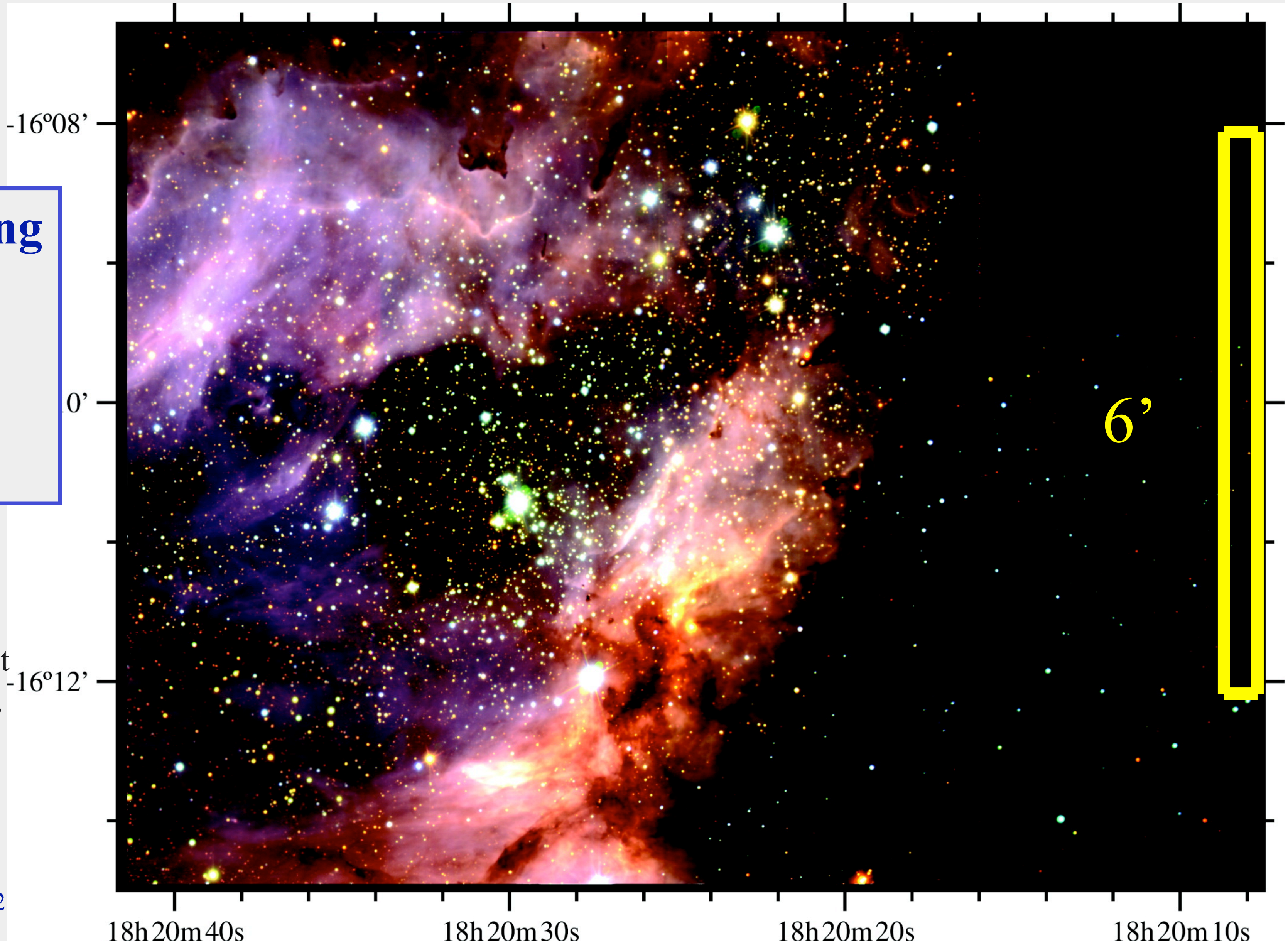
NIR-Ionized Gas & Young Stars

Clustering

MOS

FP

Hoffmeister et al. 2008, ApJ, 310

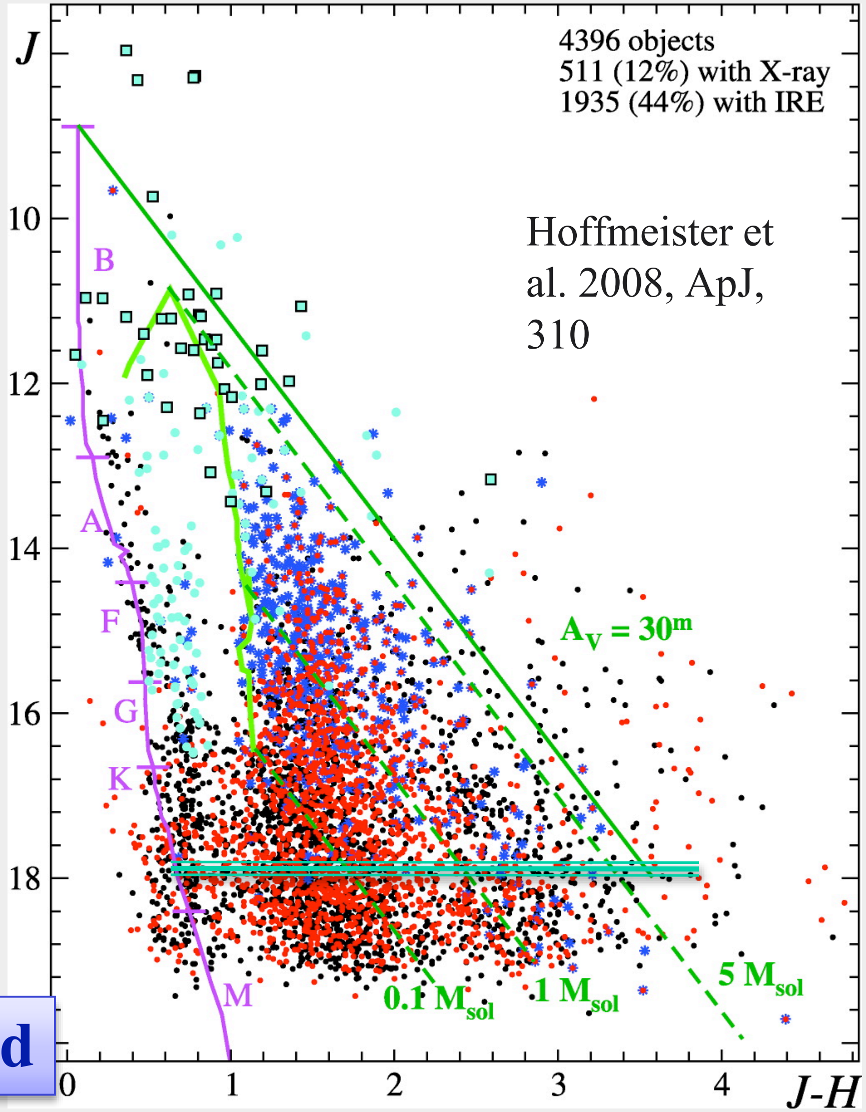


M17 NIR CMD

Galaxy: IMF + Star Formation Process Studies

From photometry to spectroscopy:
disks/ages, binarity

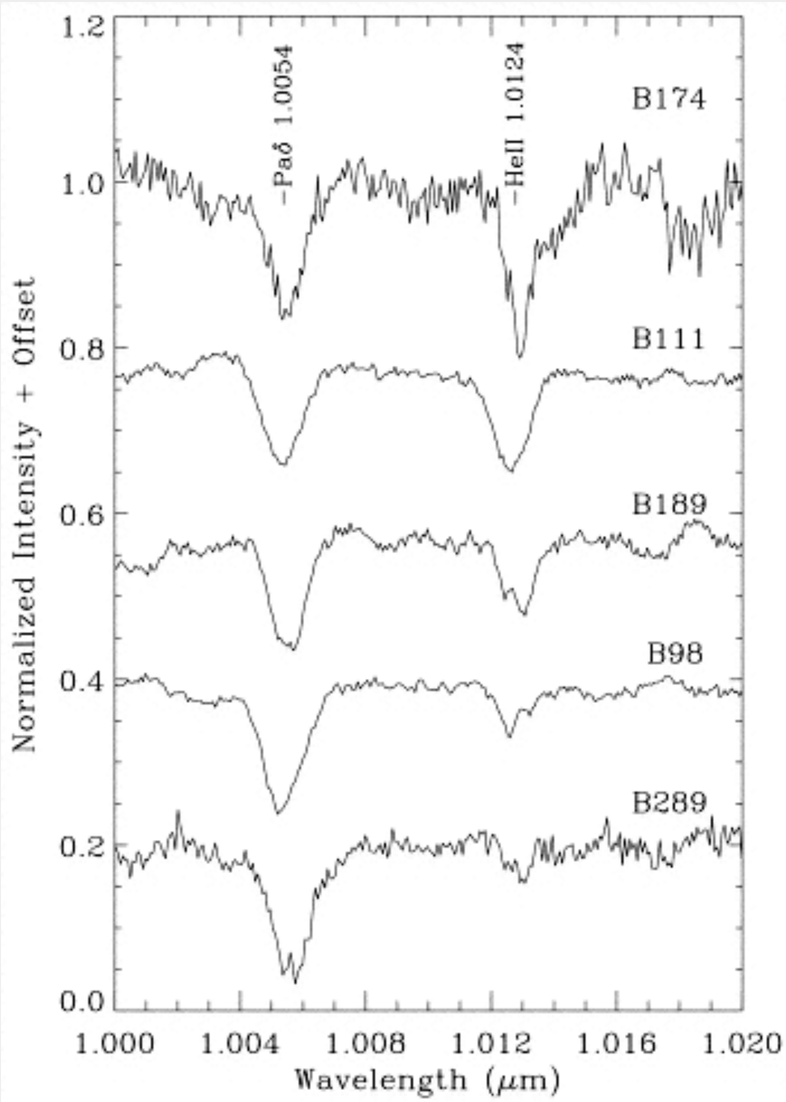
Inner Milky Way—multi-λ:
SST/GLIMPSE
ALMA

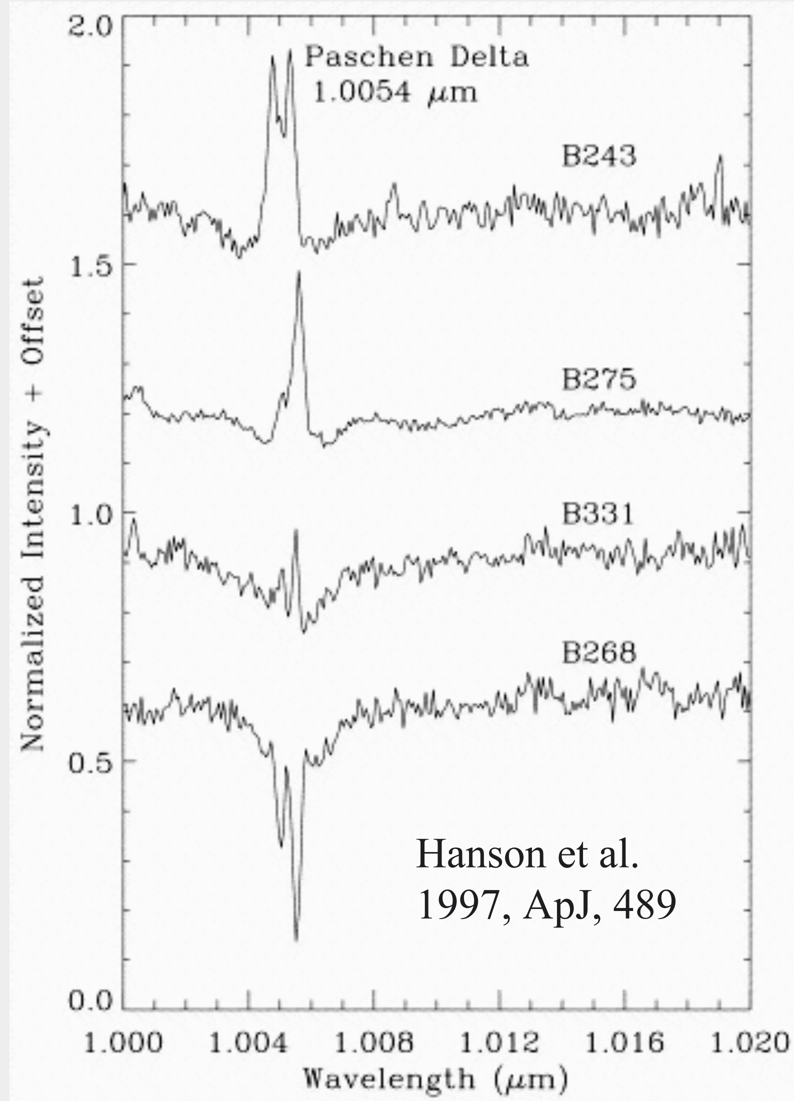


RSS-NIR J

J-band powerful from ground

Massive Stars Diagnostics—J Band

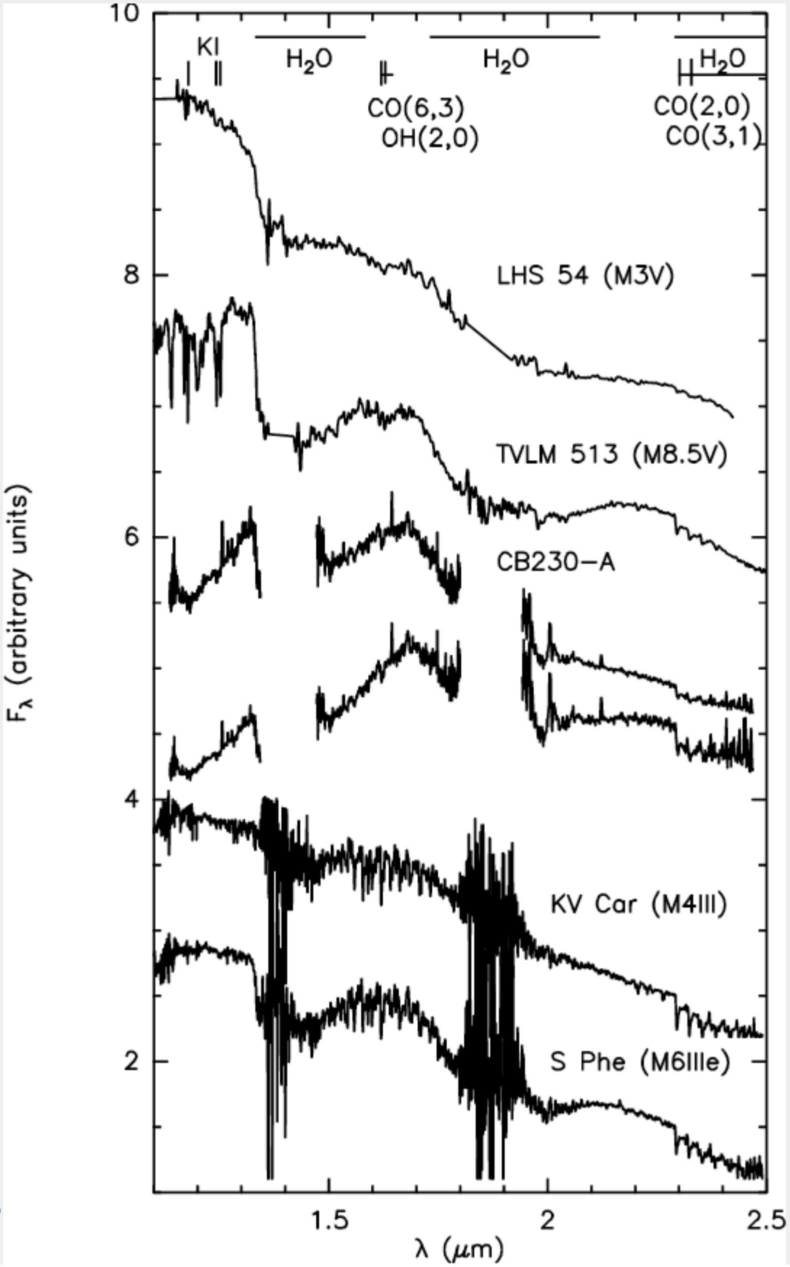




Hanson et al.
1997, ApJ, 489

Spectroscopic Characterization

CB230-A
Pre-MS

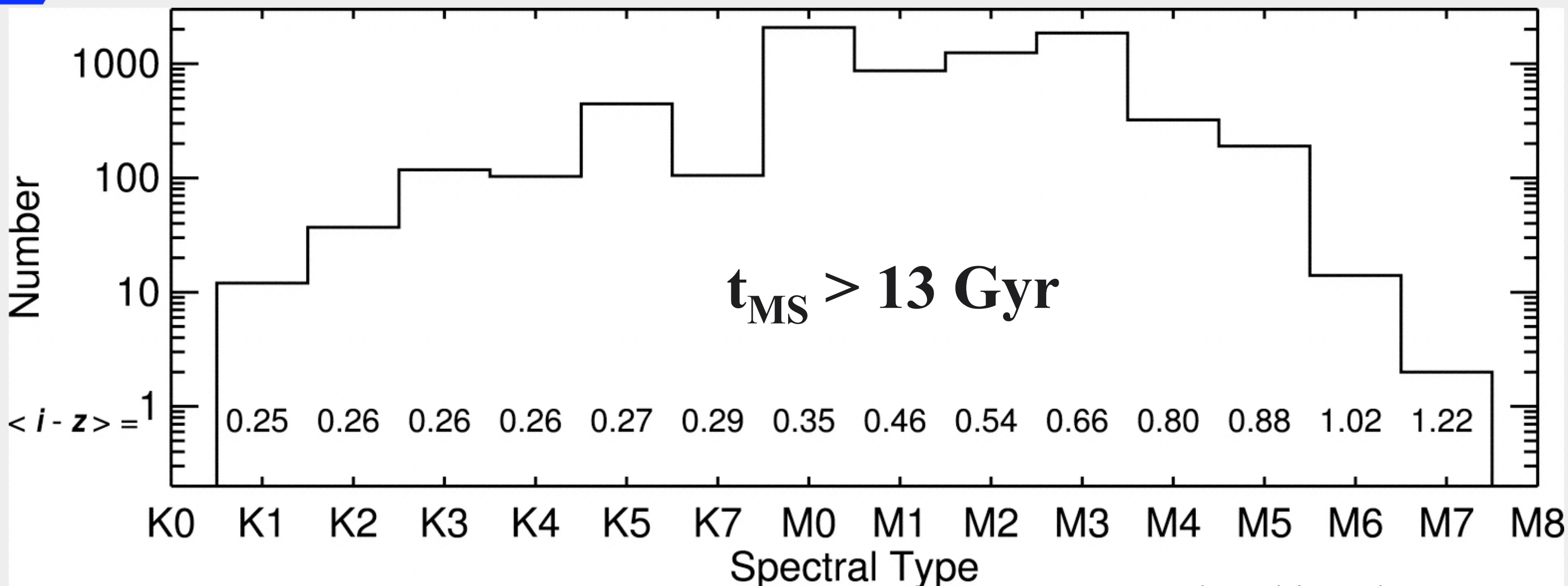


Distinguish:
Background RGB/RC
Foreground M dwarfs
Pre-MS Stars

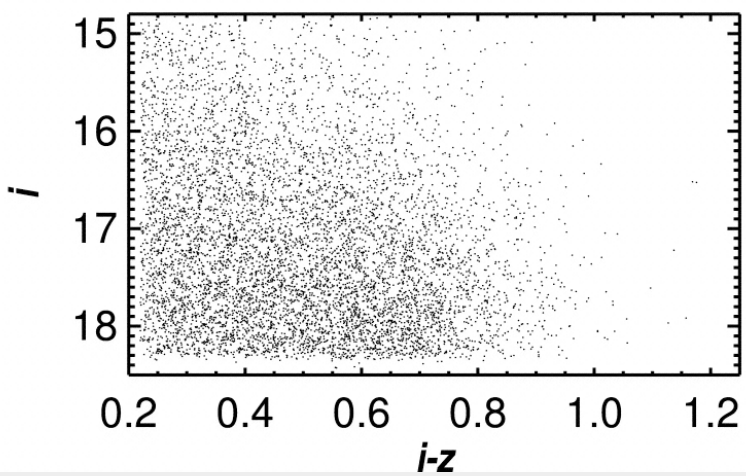
Characterize:
Pre-MS accretion
Photospheres

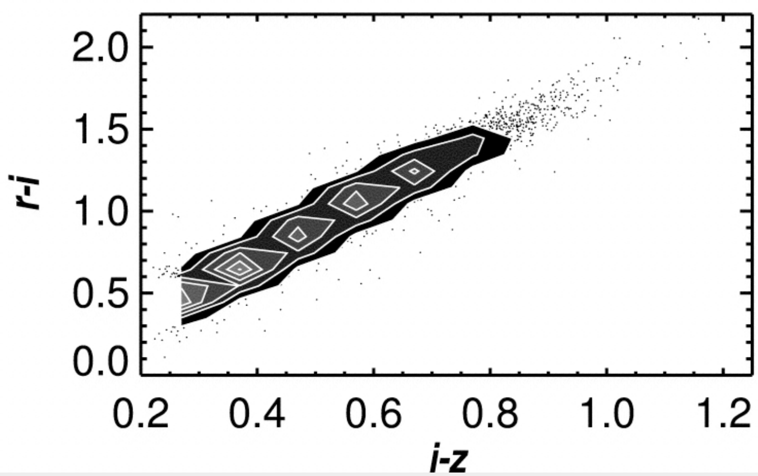
Massi et al. 2008, A&A, 490

Galactic K/M Dwarf Archaeology

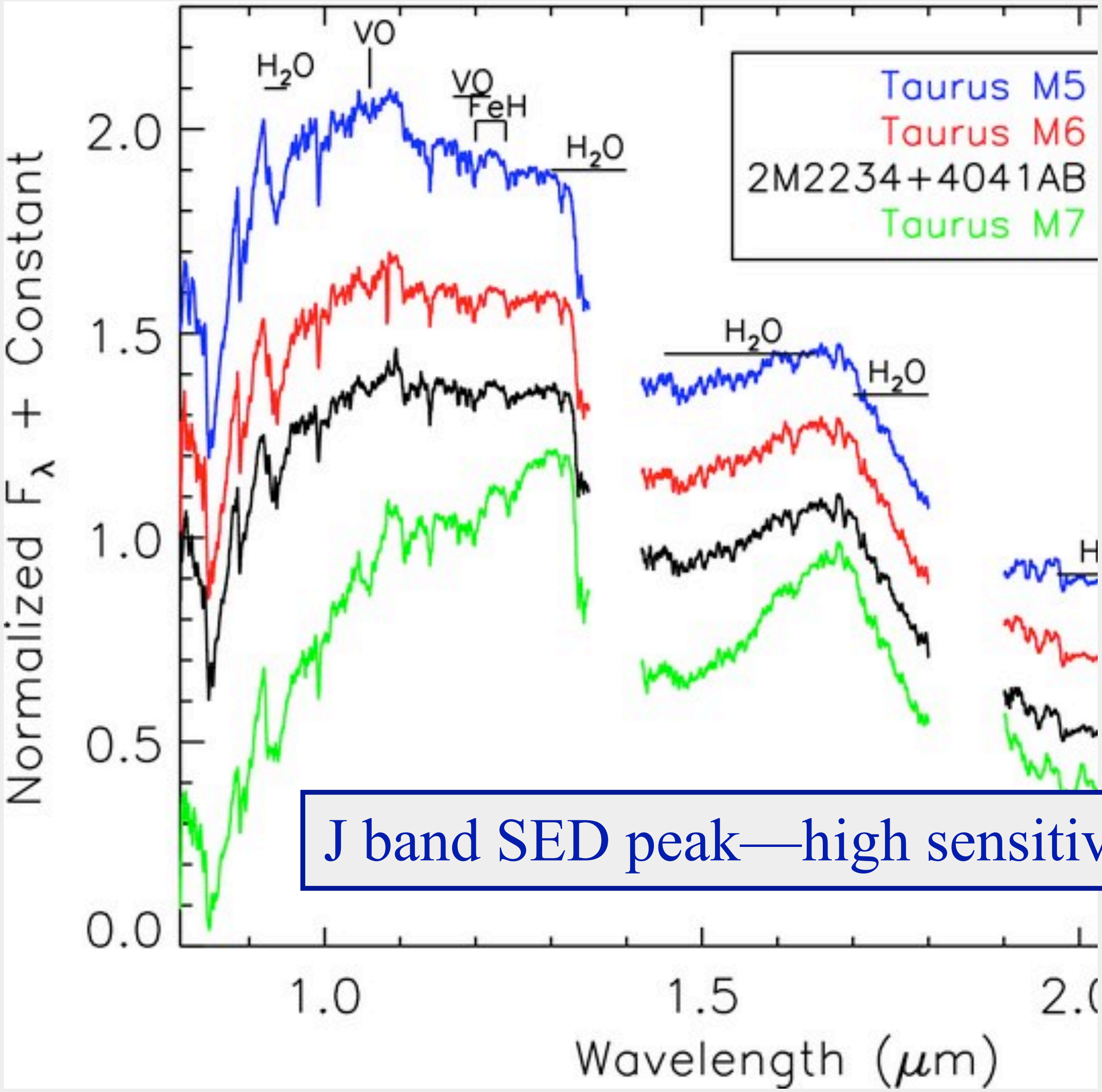


Bochanski et al. 2007, AJ, 134



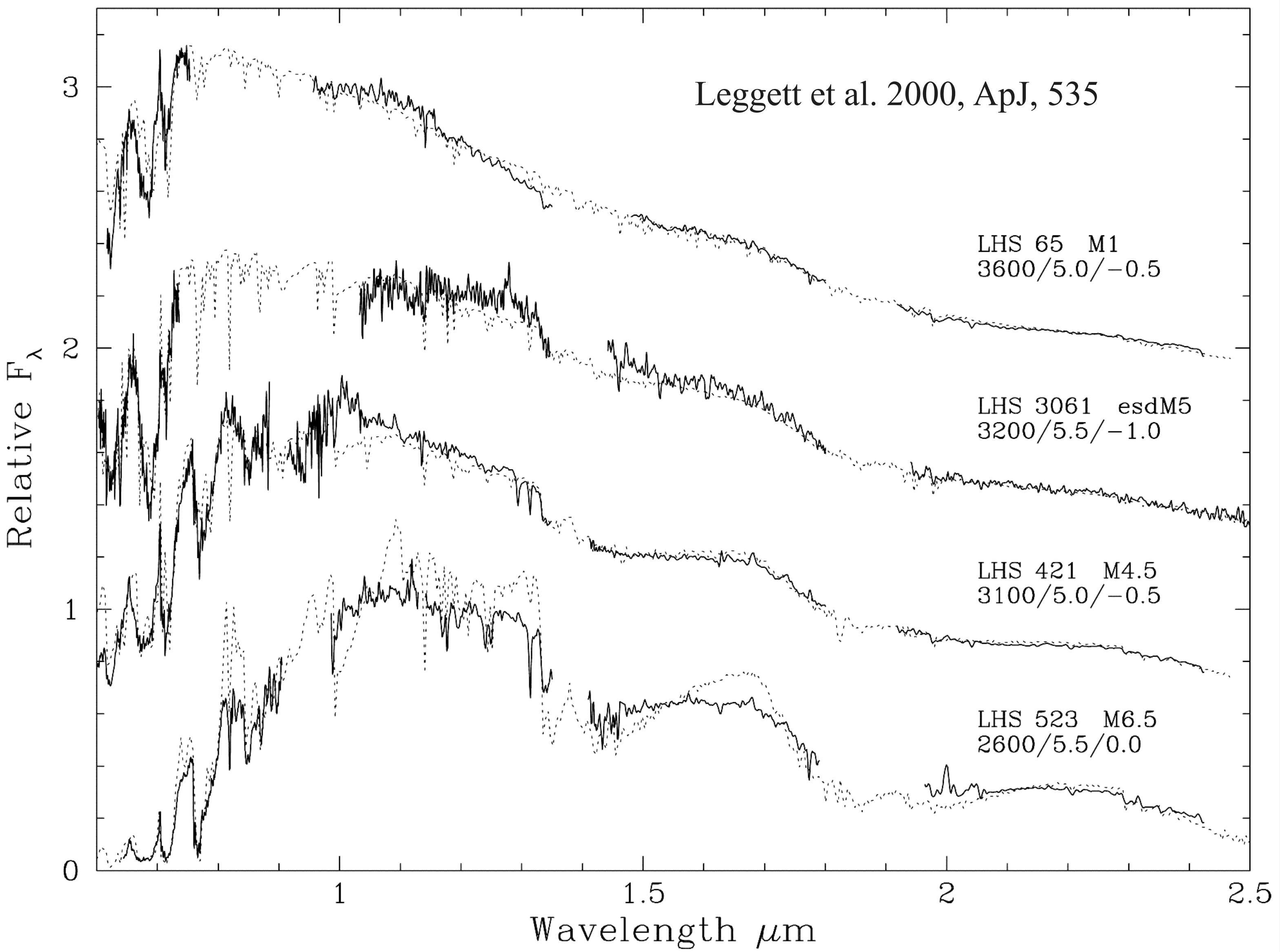


M V—SED Peak in J-Band



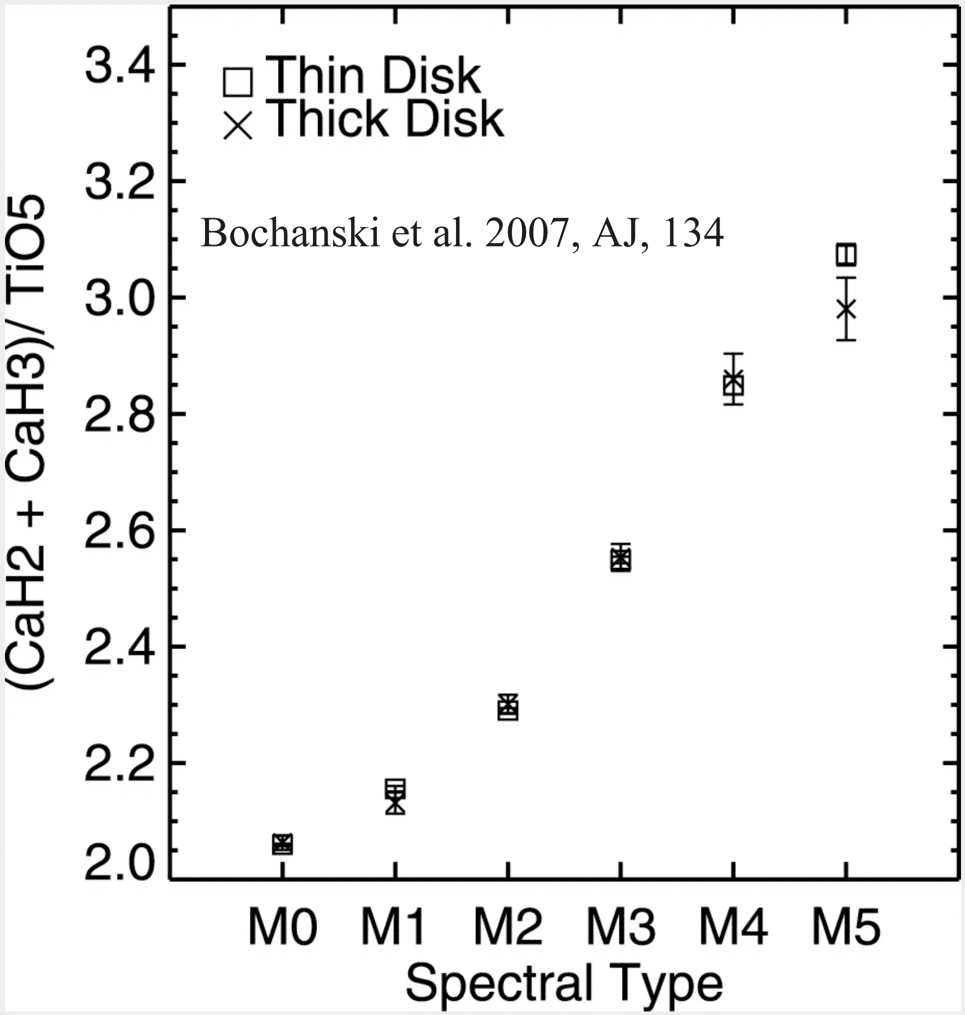
J band SED peak—high sensitivity from ground

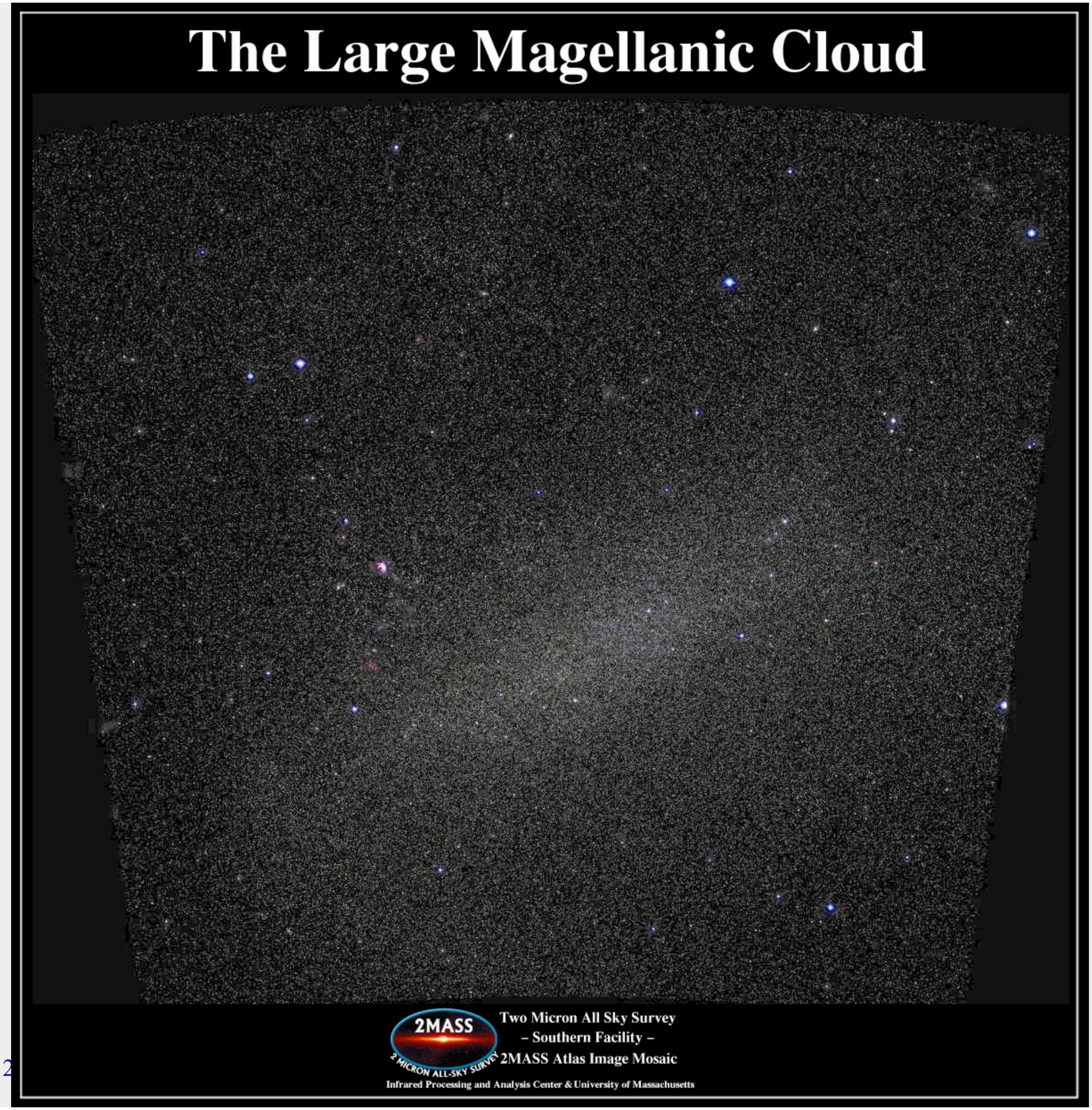
J-Band M Dwarf Metallicities



Existing Data—Subtle Abundance Gaactic Disk Trends?

Abundance Indicator




The Large Magellanic Cloud
2MASS
2 MICRON ALL-SKY SURVEY
Two Micron All Sky Survey
– Southern Facility –
2MASS Atlas Image Mosaic
Infrared Processing and Analysis Center & University of Massachusetts

NIR Stellar populations-
LMC
SMC
Fornax
Bulge…

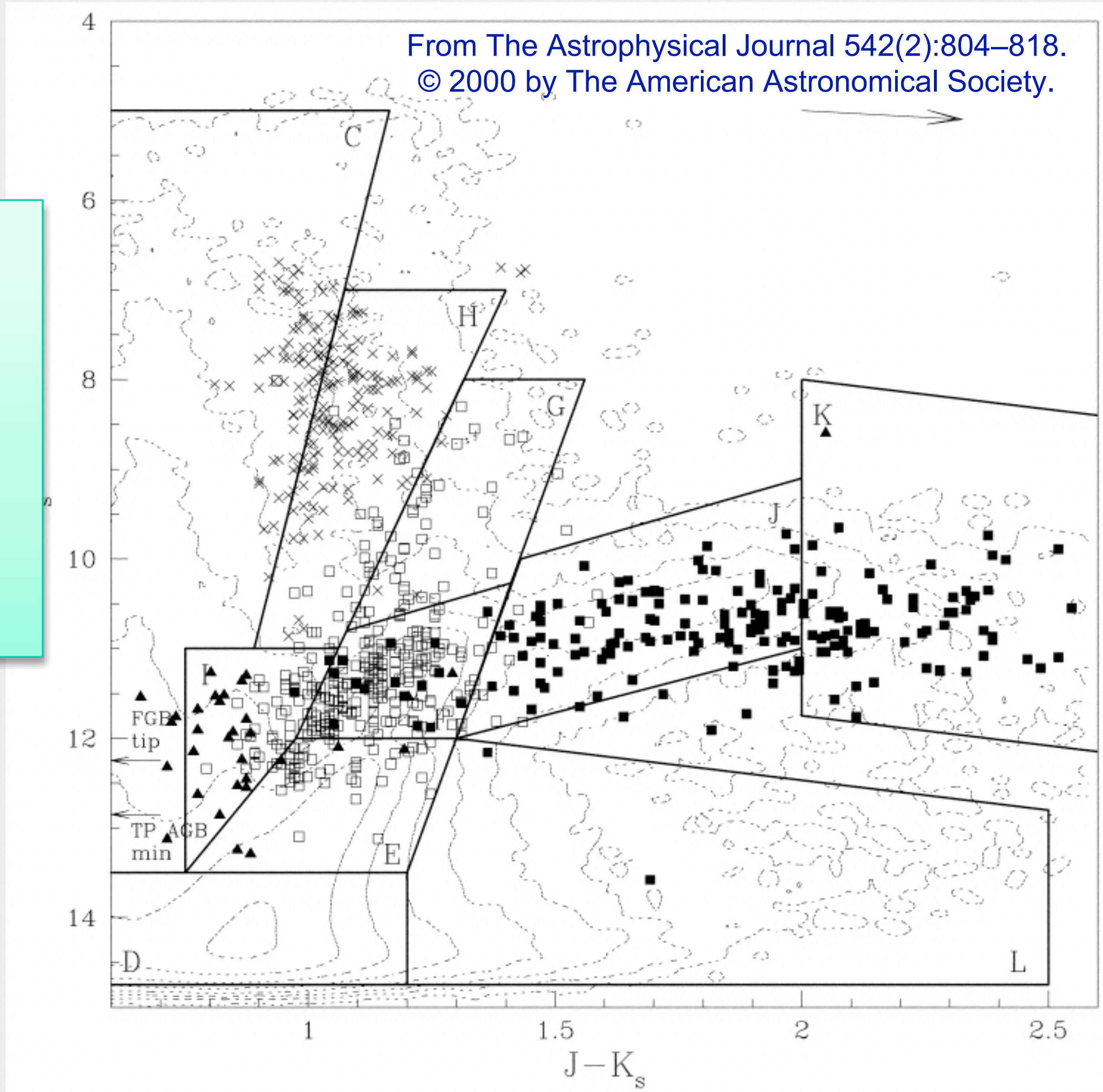
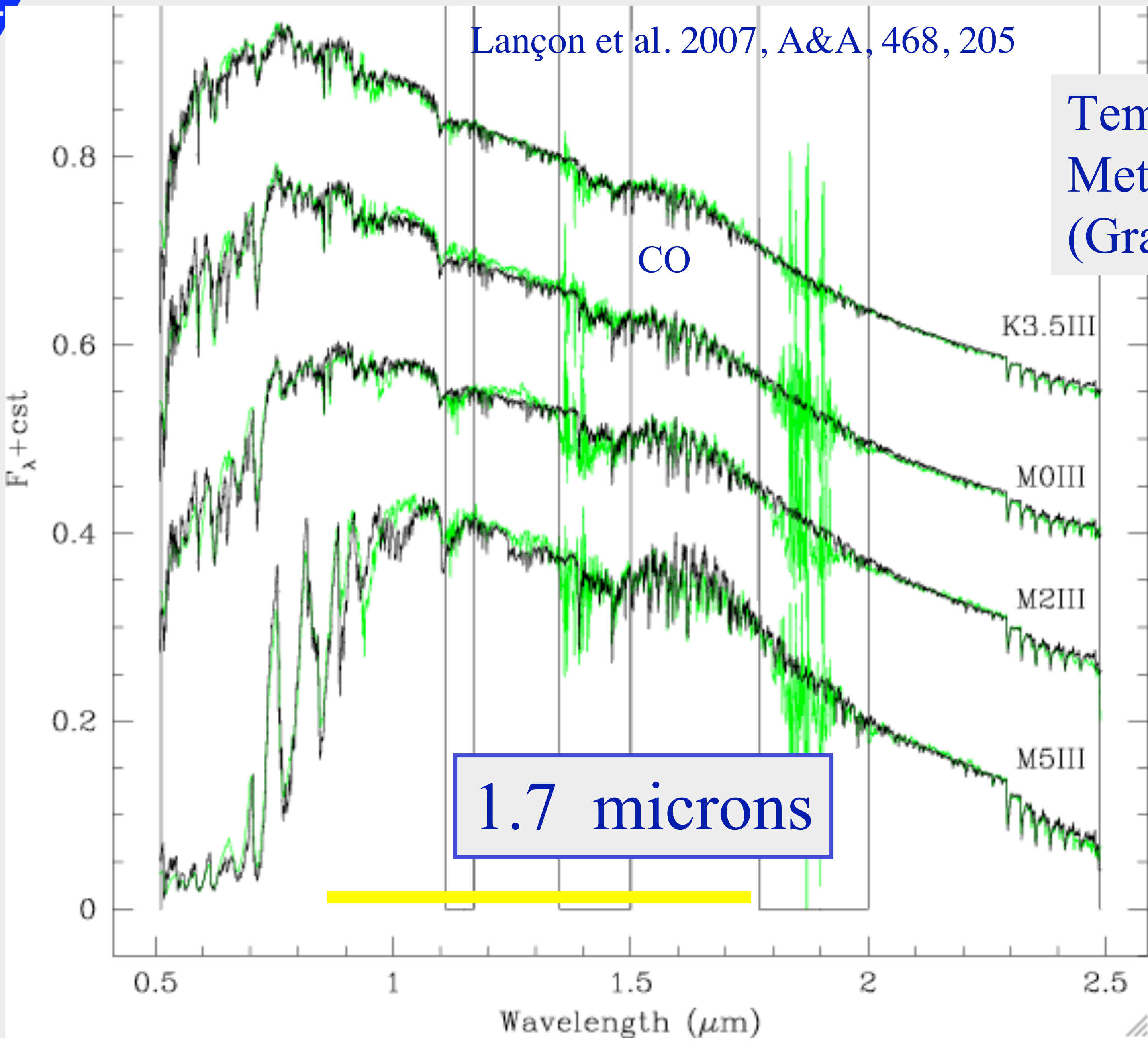


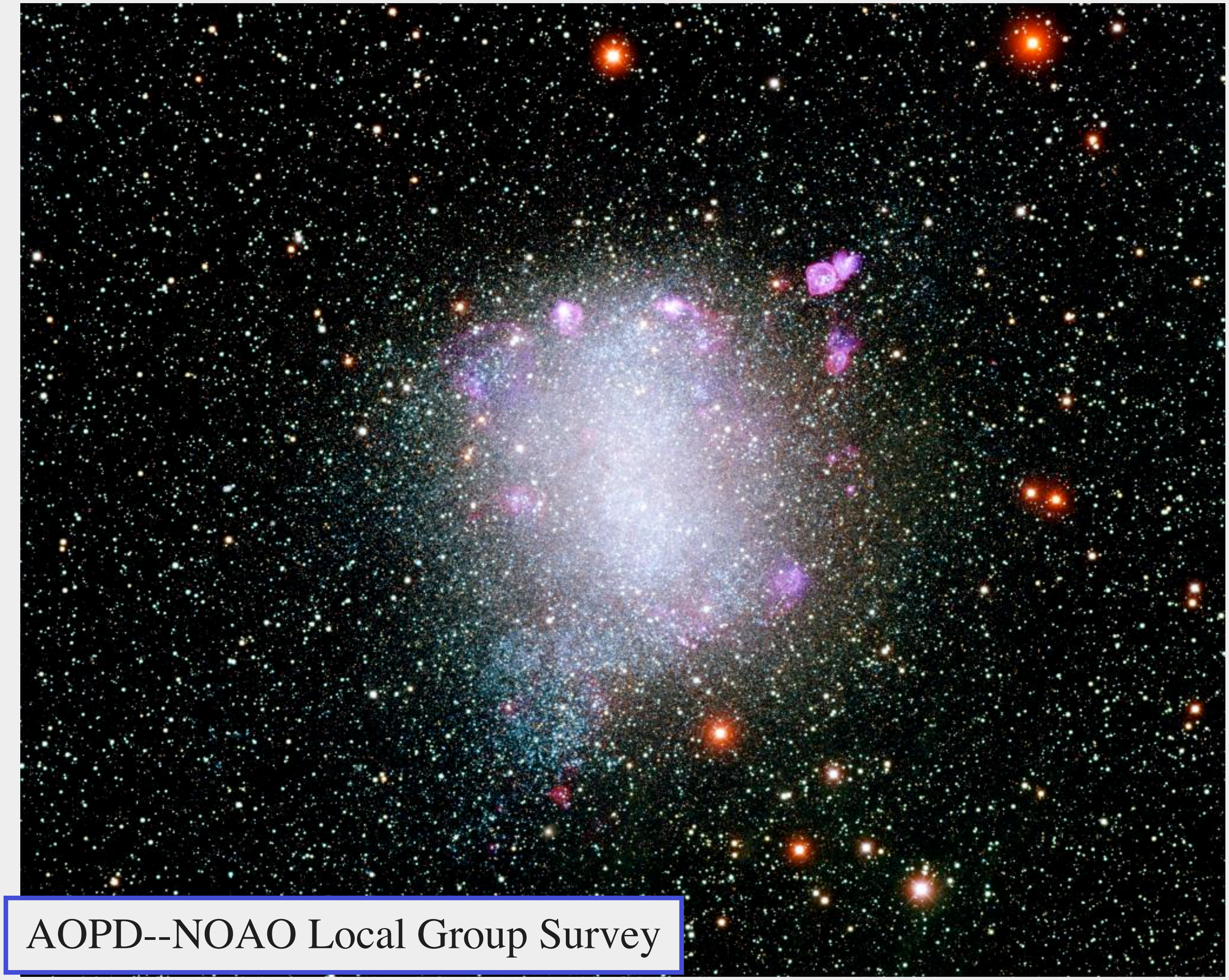
Fig. 8.— Portion of the CMD showing evolved stars. Crosses: M supergiants M1–M4 from Elias et al. (1985); solid triangles: K-type LPVs; open squares: M-type LPVs; solid squares: C-type LPVs from Hughes & Wood (1990). Arrows at left show the theoretical tip of the RGB stars and the lower luminosity limit for thermally pulsing AGBs. The reddening vector is for $E_{B-V}=0.5$.

Cool Giant NIR Spectra



Temperature
Metallicity
(Gravity?)

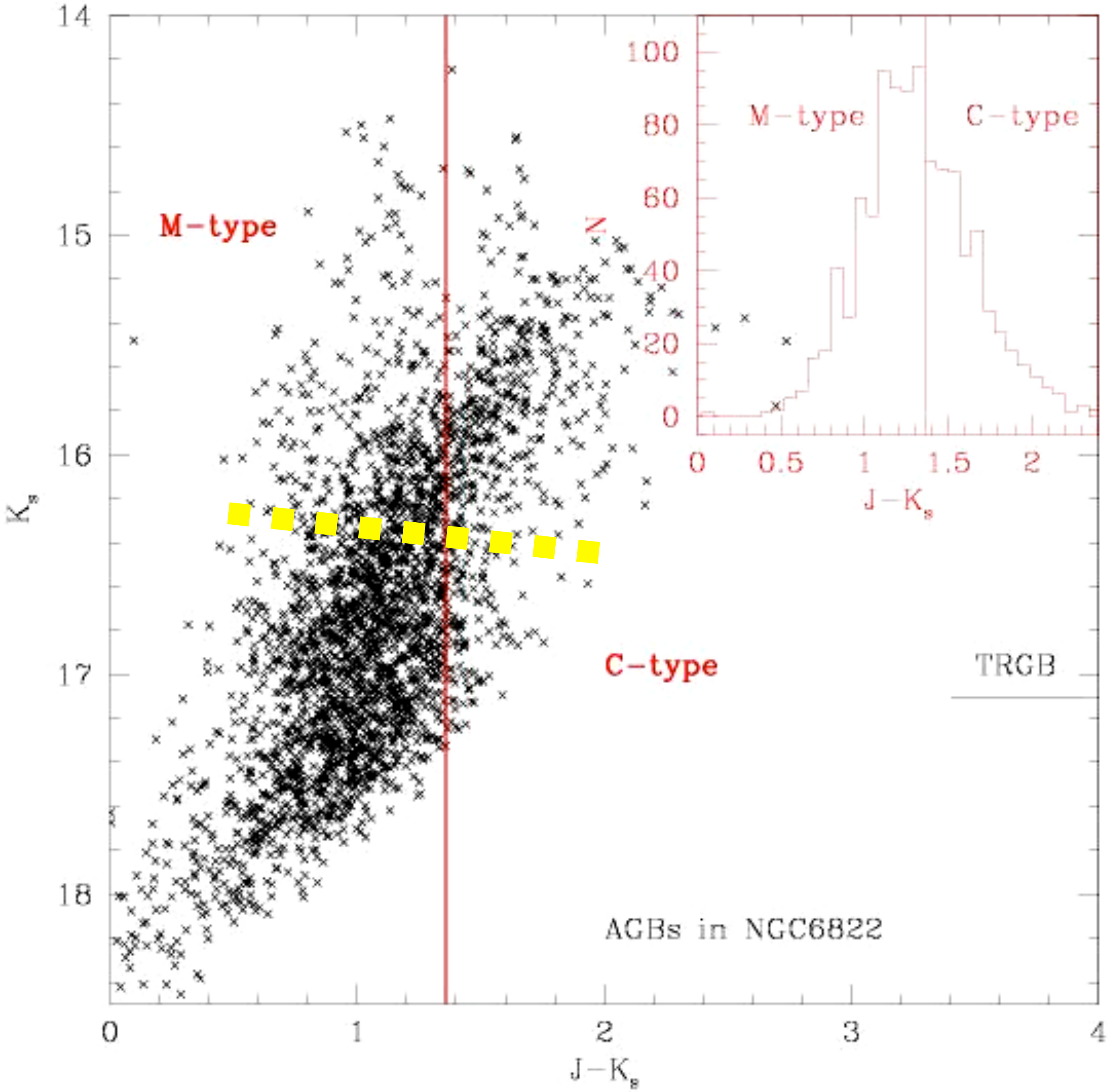
NGC 6822: Beyond the Milky Way
Magellanic Irregular at 0.4 Mpc



AOPD--NOAO Local Group Survey

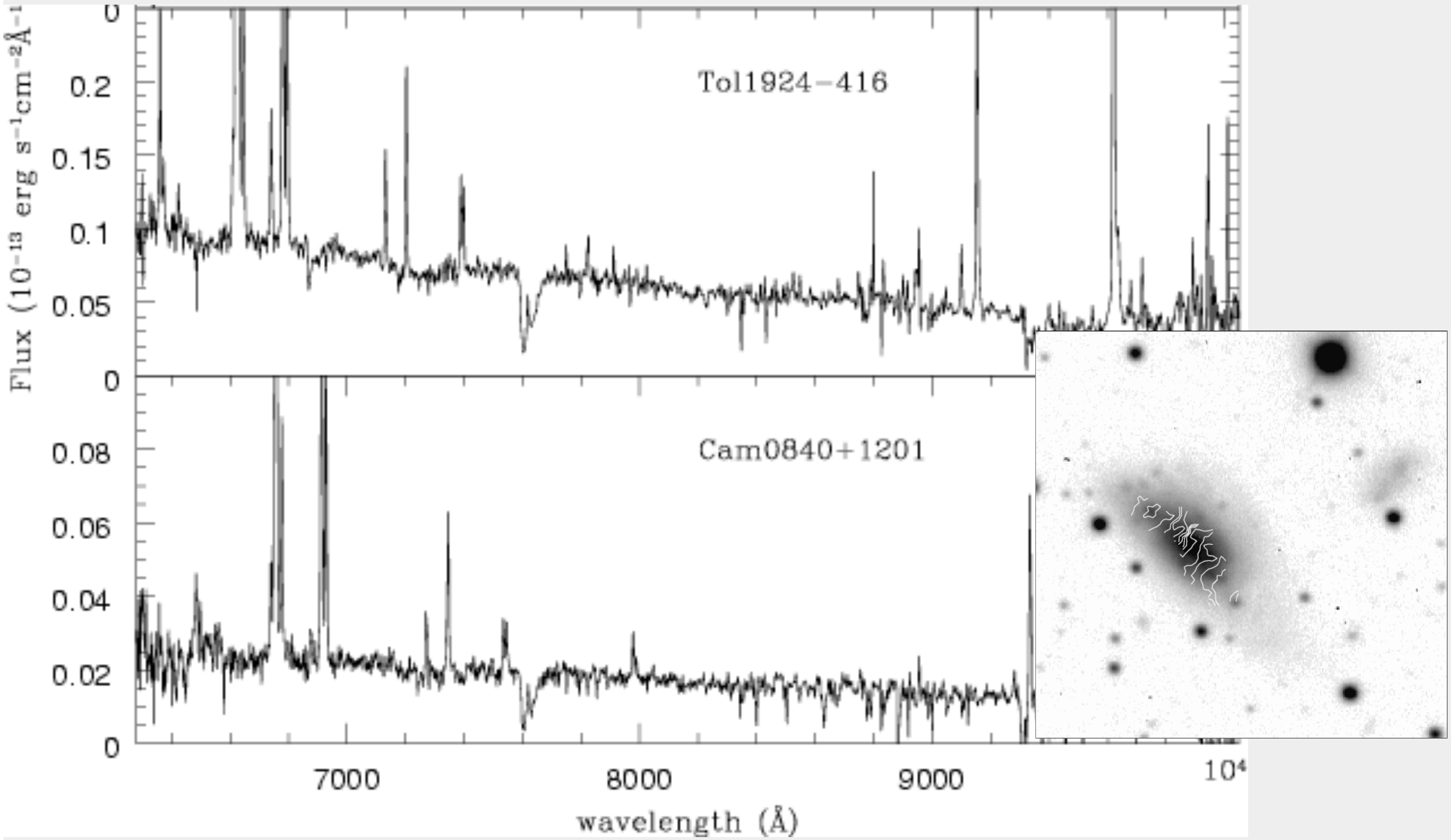
Access: NGC6822 AGB Exploring The Stellar Middle Ages

MOS Advantage!



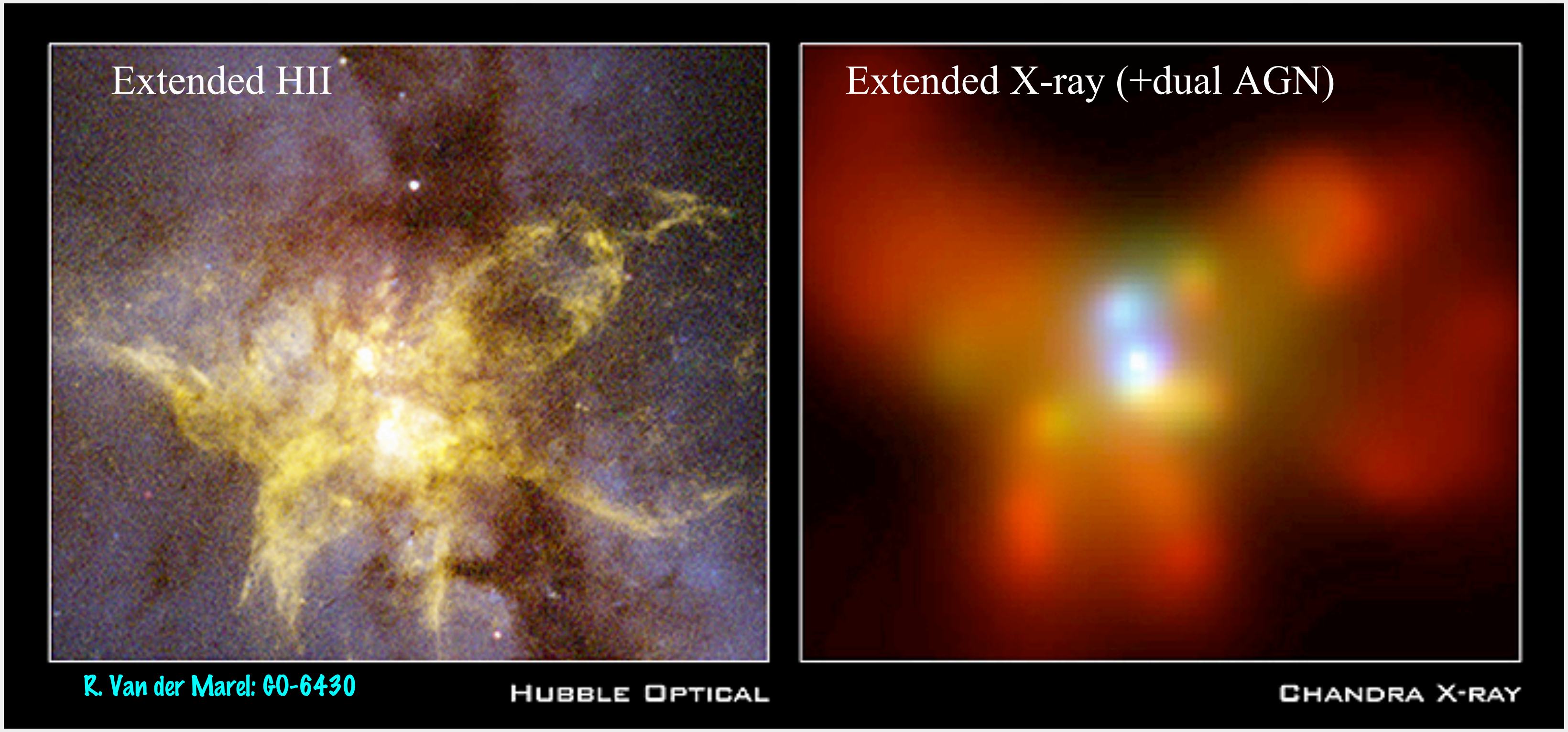
Cioni & Habing 2005, A&A, 429, 837

Galaxy HII Abundances--Extinction



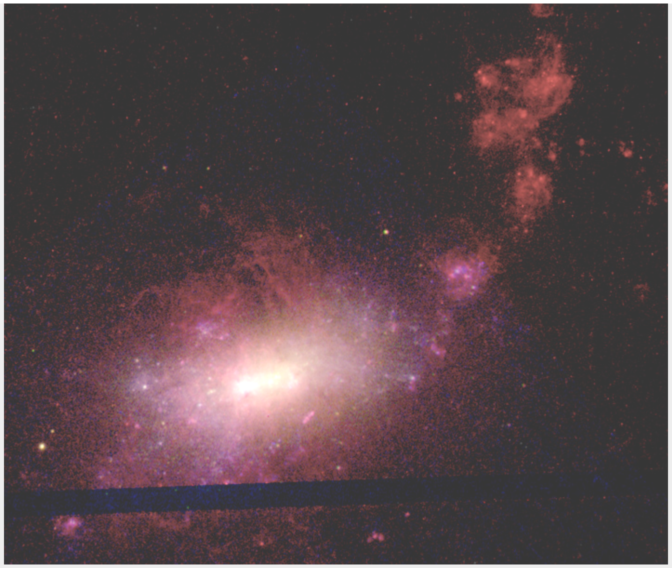
RSS/MOS: HII Region Abundance Surveys

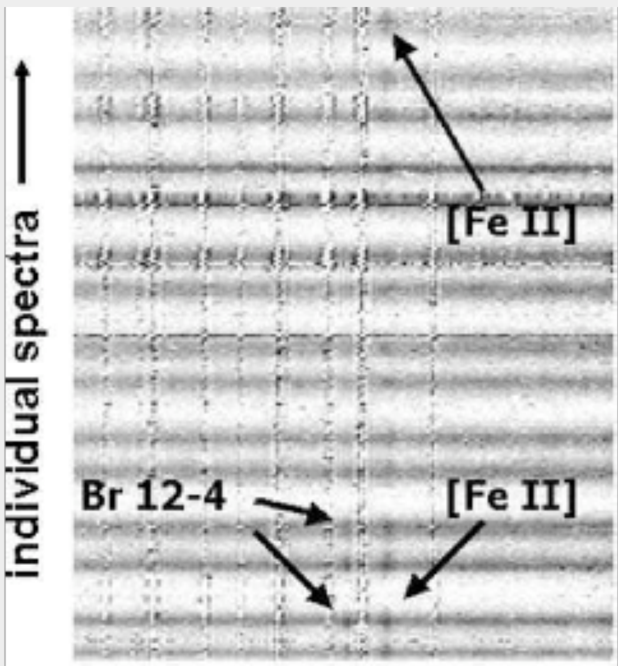
Galactic Starburst Winds: Stellar Powered Outflows: Wind Launching in Dense regions—NIR Access/Fabry-Perot



NGC6240--Ultraluminous merger

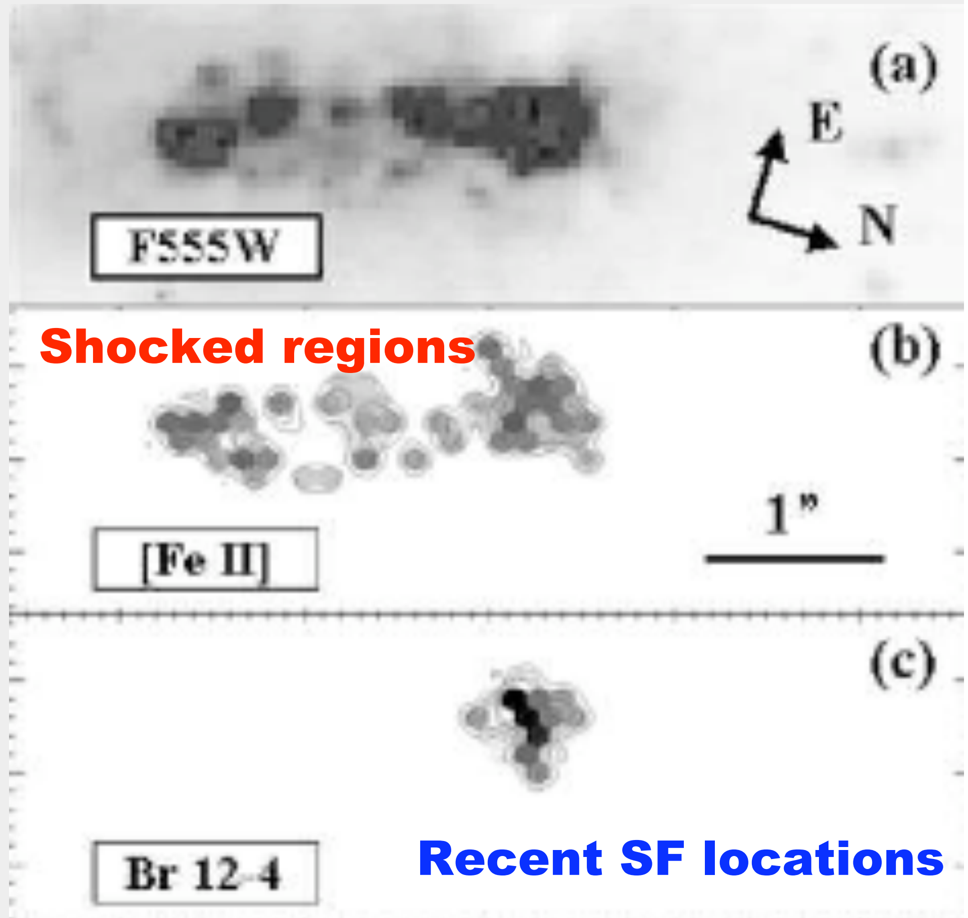
Tracing L(mech) in the NGC 1140: Merger/Starburst



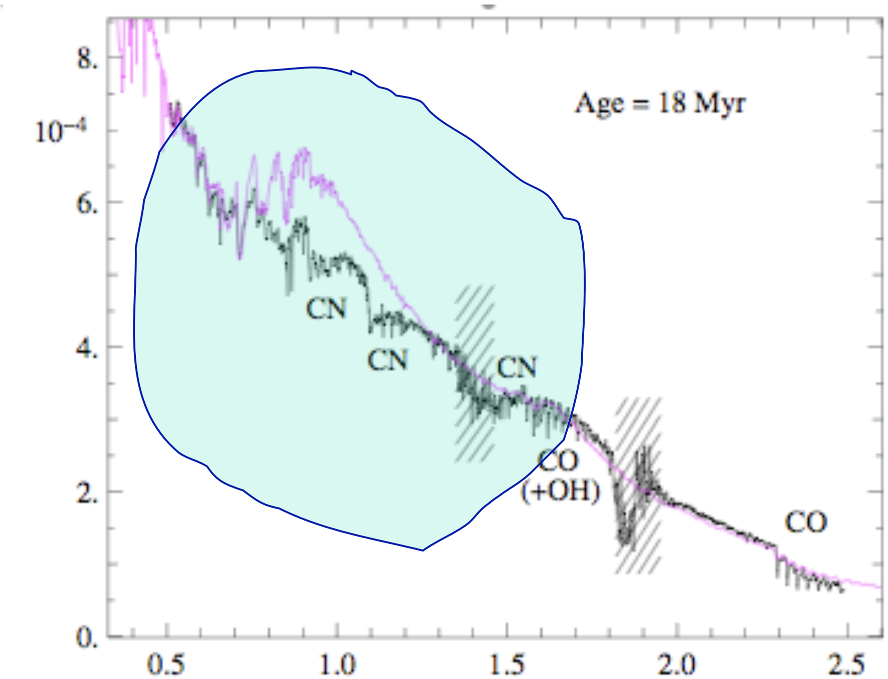


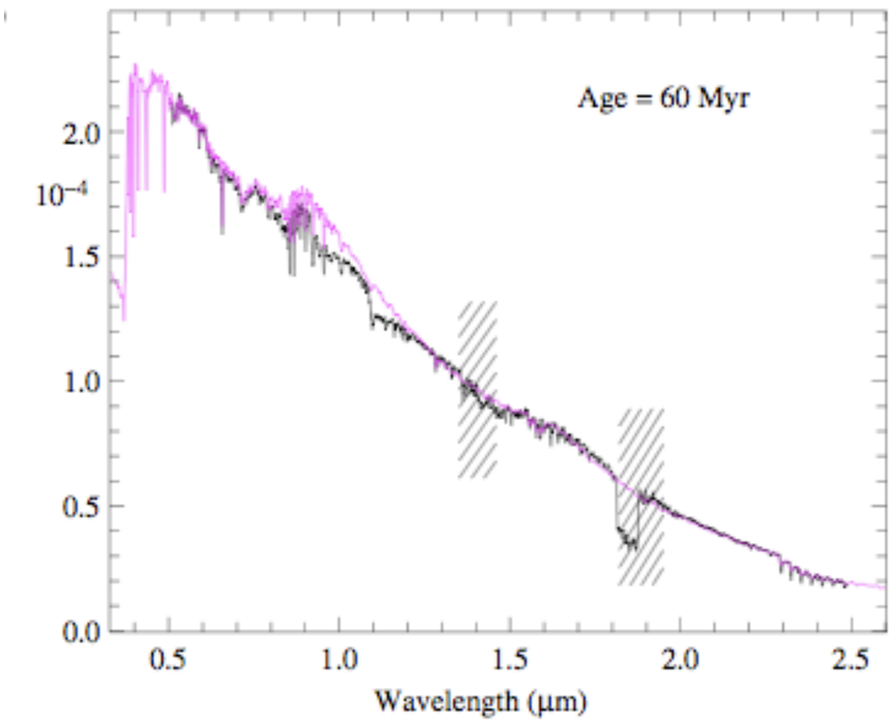
1.45-1.67 microns CIRPass/ Gemini—shock excitation—base of outflows.

de Grijs et al. 2004, MNRAS, 352, 263



Fabry-Perot!

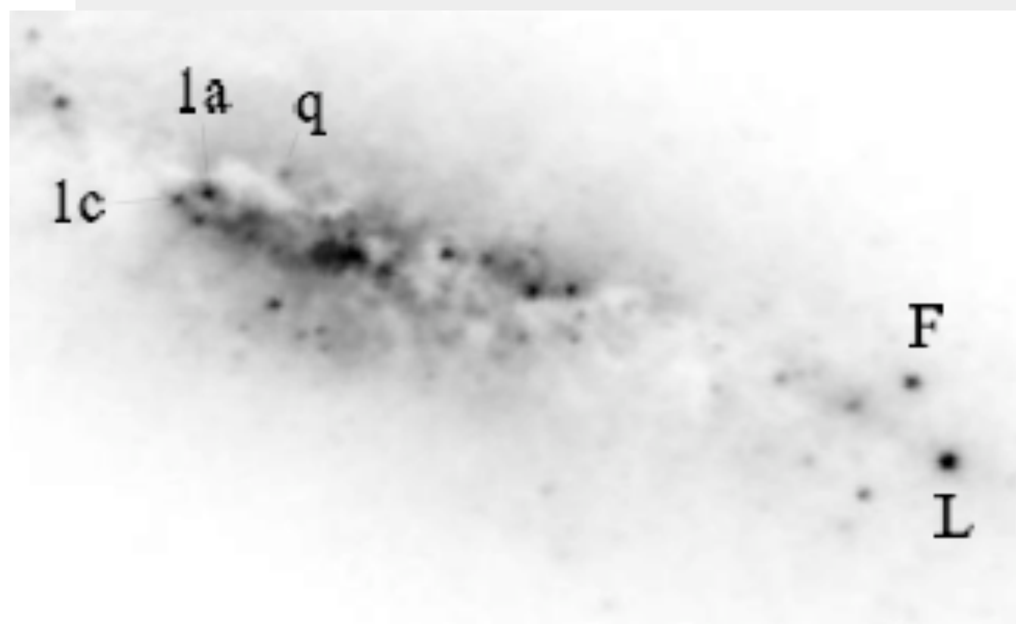




Learning from M82--
NIR IRTF SPEX study of SSCs

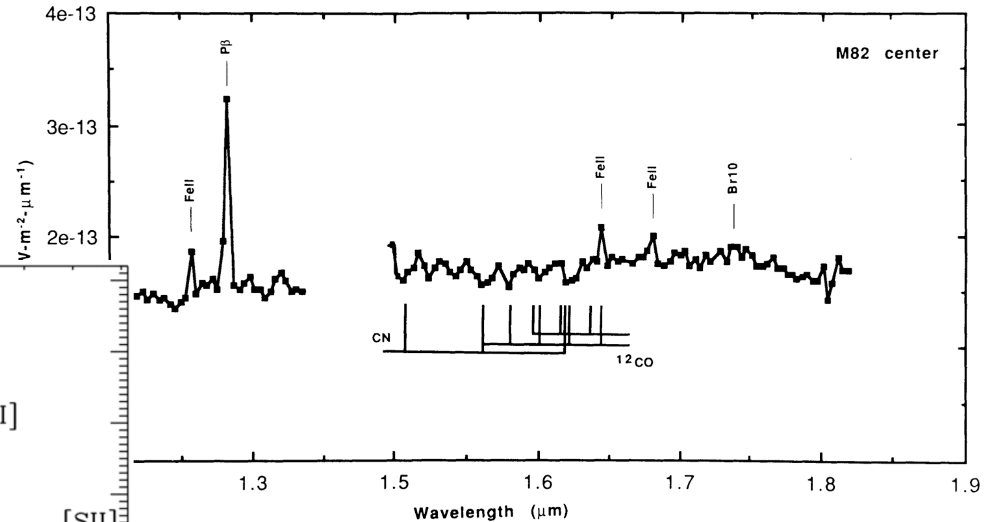
A. Lançon, JSG et al. 2008, A&A, 486, 165

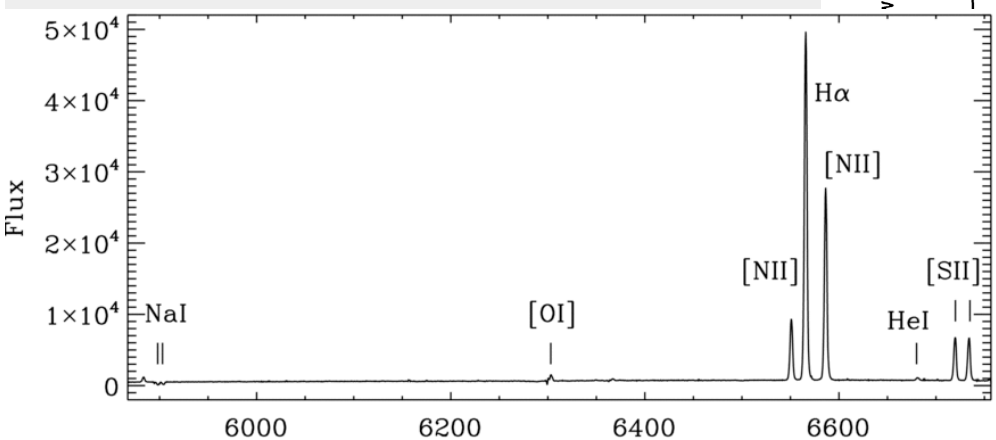
M82-NICMOS "H"

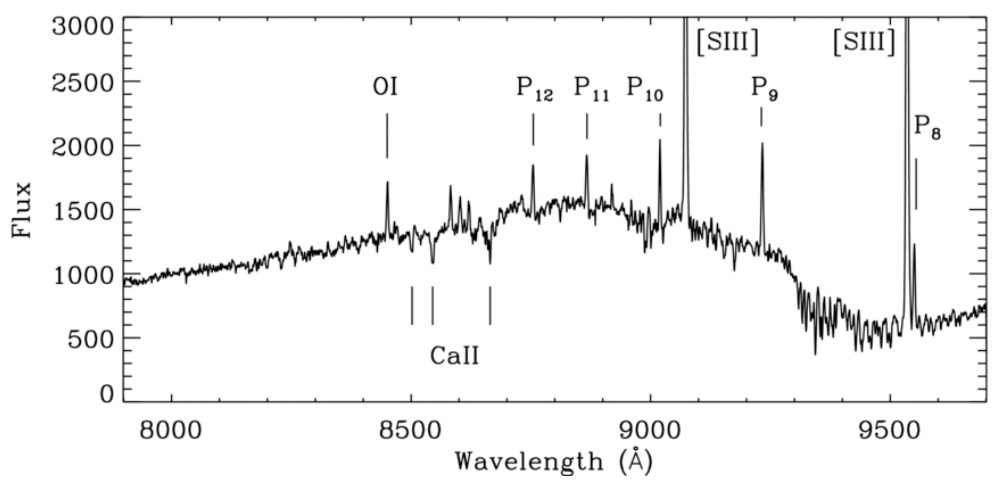


Starburst Diagnostics—SFR/Kinematics/Conditions—M82 Example

Larkin--NIR







WIYN CCD-Densepak

Westmoquette et al. 2009

Summary-
Sampler of Stellar Science & Requirements

PROJECT	Wavelength	Primary Mode
IMF Young Systems	0.5-≥1.5 microns	J= 12 to ≥18, R=4k MOS/Simul
Young OB Stars-MW/MC	~0.4-≥1.5 microns	J≥10 R>4k MOS/Simul
K/M Dwarf Galactic Tracers	0.6-≥1.6 microns	J≥18 R=4k Simul
Local Group AGB/M Ia/II	0.8-≥1.7 microns	J=10 – 18 R≥4k MOS/Simul
HII abundances	0.37-≥1.5 microns	(Emission) R>4k MOS/Simul
Starburst clusters/nuclei	0.35-≥1.7 microns	J≥15 R≥4k MOS/FP
Starburst/nuclear winds	0.6-1.7 microns	R≥4 k FP/MOS
Novae/CVs/GRB	0.3-≥1.7 microns	J>18 R≥1k Simul
AGB Stellar Pops	0.8≥1.7 microns	J>10,, R≥1.7 microns Simul

Summary

-- Access top “non-thermal” J+H =peak of cool stellar SEDs—abundances & kinematics; Local Group galactic archaeology => **≥1.7μ**

-- Ability to penetrate dust = access to young stars & disks

Hidden” intense mode star formation in starbursts.

-- Multi-object advantage: MOS/Fabry-Perot

--

SALT RSS-NIR
MID-TERM REVIEW
MAY 20 & 21, 2009

INSTRUMENT SCIENCE - POLARIMETRY

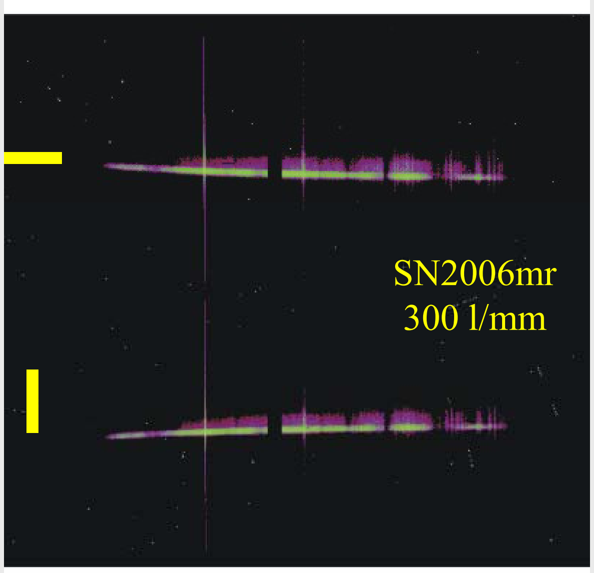
KENNETH NORDSIECK
UNIVERSITY OF WISCONSIN

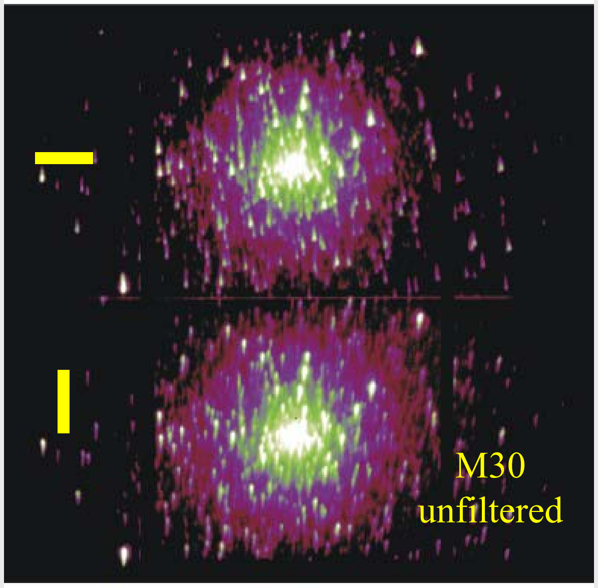
PROGRAM TABLE

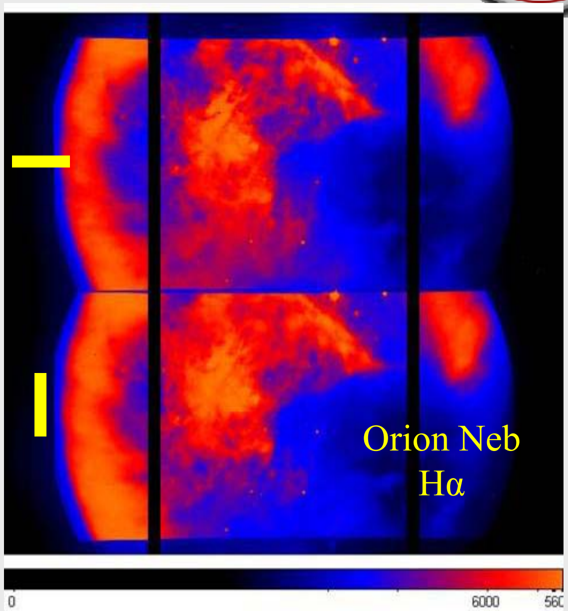
- Currently no NIR spectropolarimeter available on 10m-class telescope
- Projects suggested by consortium
  - Based on NIR spectropolarimetry on smaller telescopes
  - Based on 10m class Vis spectropolarimetry
  - Programs as yet unattempted

Program	Goal	Type	R	S/N	λ<	J_{lo}	J_{hi}	dual beam?	time resolved?	MOS?
GRB Polarization	detect jet-induced polarization, remove ISM	Grating	800 - 3000	100	1.55	15	18	Yes	Yes	no
AGN spectropolarimetry	Buried AGN, NIR reverberation mapping	Grating	4000	300	1.65			Yes	no	no
Supernova spectropolarimetry	sample full nuclear processing	Grating, Imaging	800	1000	1.65	11	15	Yes	Yes	no
Galaxy ejecta mapping	3D geometry of ejected matter	FP	2500	100	1.3	diffuse		helps	no	no
Atomic Fluorescence	New magnetic field mapping technique	Grating, FP	10000 2500	100 300	1.3	diffuse		helps	no	no
PreMS disks	study disks in embedded objects	Grating	4000	300	1.3	7	12	no	no	yes
Magnetic CV's	lower magnetic fields in polars	Grating all-Stokes	800	100	1.6	13	16	Yes	some	no

POLARIMETRIC MODES



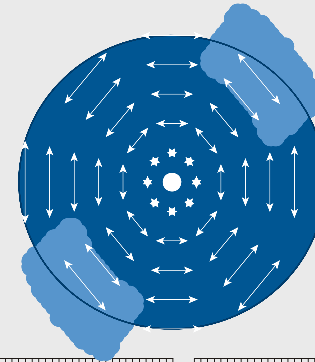


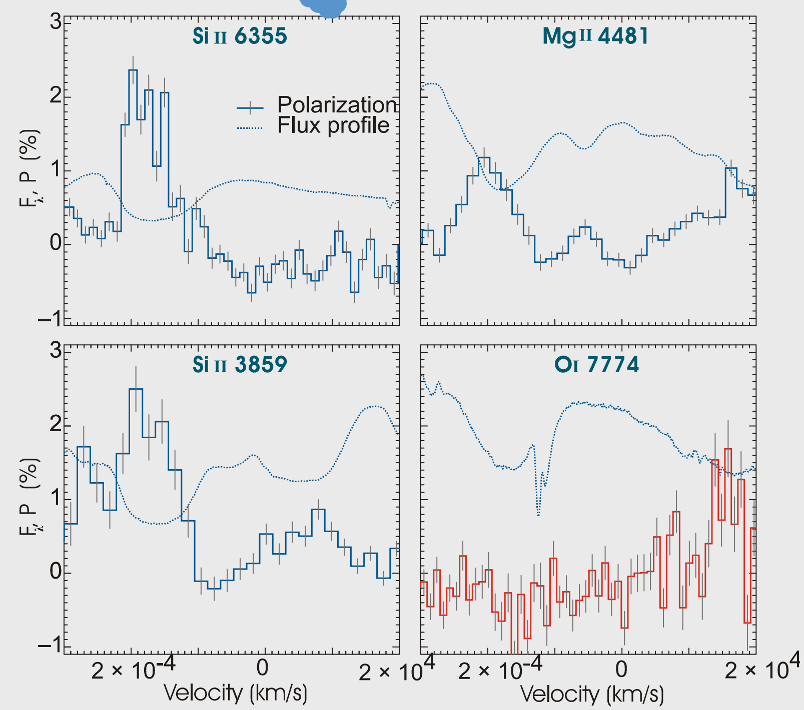


- Grating spectropolarimetry
  - Any grating setup
  - MOS possible with 4’ by 8’ slitmask
- Imaging polarimetry
  - Filterless: chromatic splitting makes 20” “objective prism” very low res spectro-polarimetry
  - MOS for faint objects
  - FP filters with or without FP for diffuse objects
- Fabry-Perot spectropolarimetry
  - Unique on any telescope; appropriate for big glass
  - Beamsplitter after FP guarantees λ match of FP wings

SUPERNOVA SPECTROPOLARIMETRY

- Successful spectropolarimetry of SNe only since introduction of 10m-class spectropolarimeters
- Continuum polarization from electron scattering in distorted pseudo-photosphere
  - SNIa: peaks ~0.3% at max, gone at +2 weeks:=> outer part asymmetric, core not
  - Core collapse: increases after max many %: core explosion asymmetric
- Line polarization from asymmetric blocking of photosphere
  - SNIa: different elements polarized differently => explosive nuclear processing introducing clumps

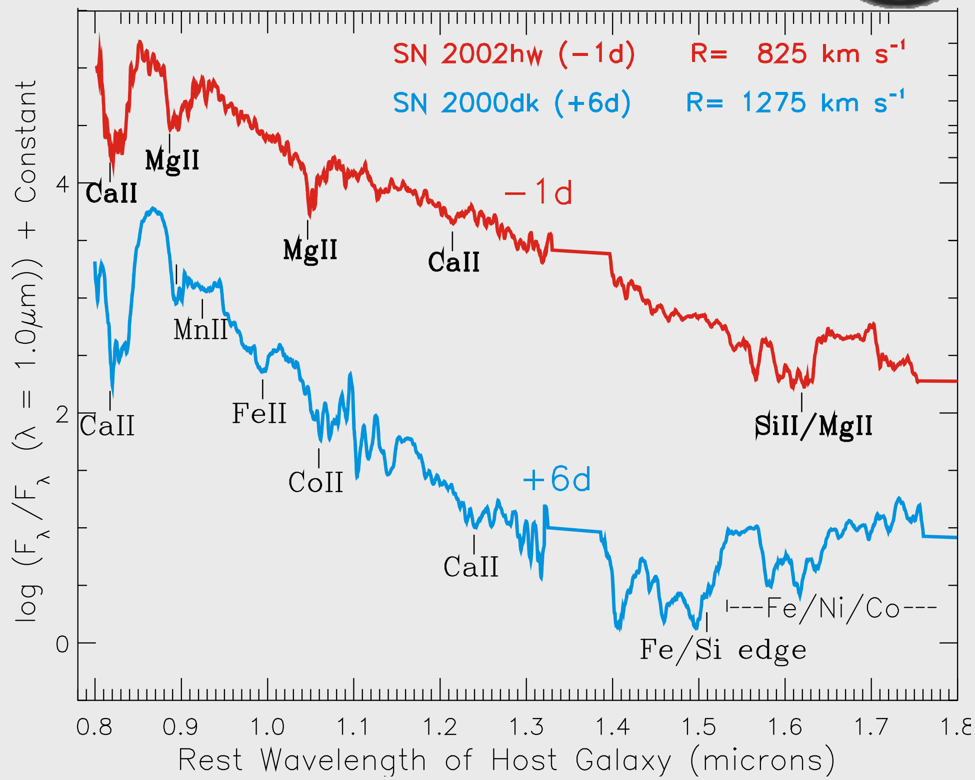


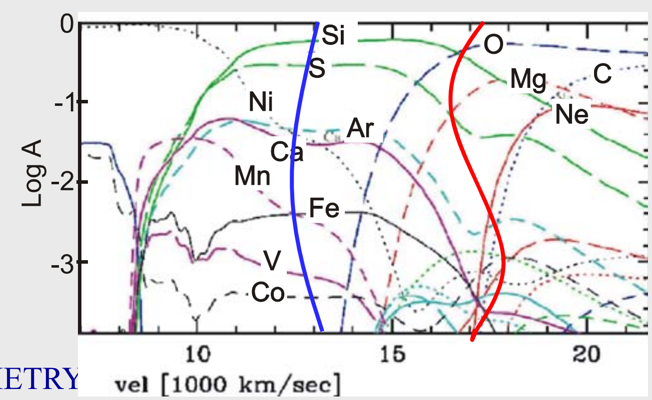


SNIa 2004dt (Wang & Wheeler 2008)

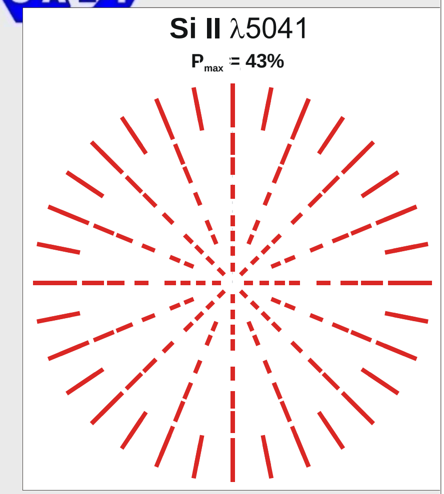
NIR SNIa Spectropolarimetry

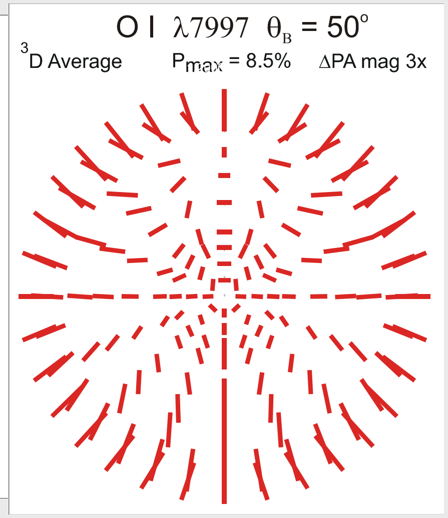
- Visible samples O, Mg, Si, Ca
- NIR also samples Fe-Peak: Fe, Ni, Co, Mn
- Vis + NIR line pol vs. time => geometry of explosion throughout explosion: compare with explosion codes, progenitor candidates
- Survey of dozens of different SNIa: difference between luminous & underluminous subtypes, possible existence of short-onset progenitors
- R = 800 grating spectropolarimetry, dual beam due to rapid development; imaging polarimetry Vis and NIR of field to get foreground interstellar polarization
- SALT queue mode allows for optimal scheduling of observations

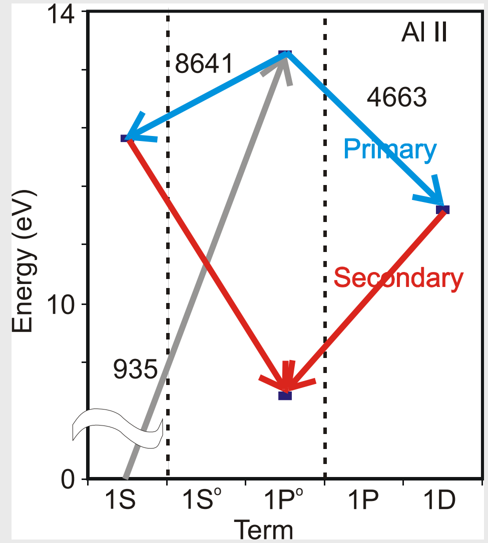


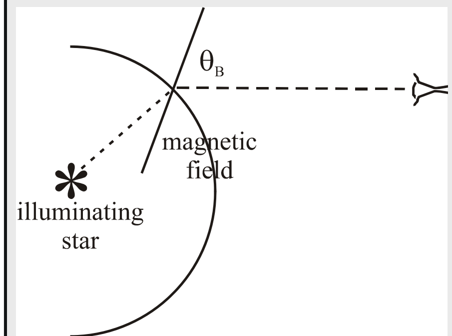


ATOMIC FLUORESCENCE







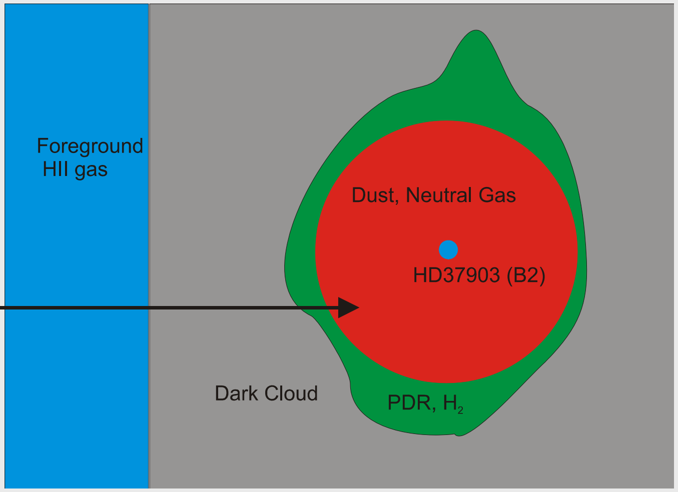


- Yan&Lazarian (2006 – 2008) suggest polarization of atomic scattering can be diagnostic of magnetic field
- In principle, a new magnetic field diagnostic for ISM, better than HI Zeeman
- “nonalignable” atom J(grnd) < 1
  - SiII, MgII
  - Primary fluorescence gives circumsymmetric pol => scattering angle
- “alignable” atom J(grnd) ≥ 1:
  - OI, NI, AlII, [FeII], [CrII], [NiII]
  - Illumination from one side pumps non-isotropic angular momentum distribution, realigned by Larmor precession in magnetic field < 1 μGauss in ISM
  - Primary fluorescence from aligned state is polarized, depends on scattering angle and 3D orientation of magnetic field
- Effect seen in Sun, not elsewhere due to lack of instrumentation

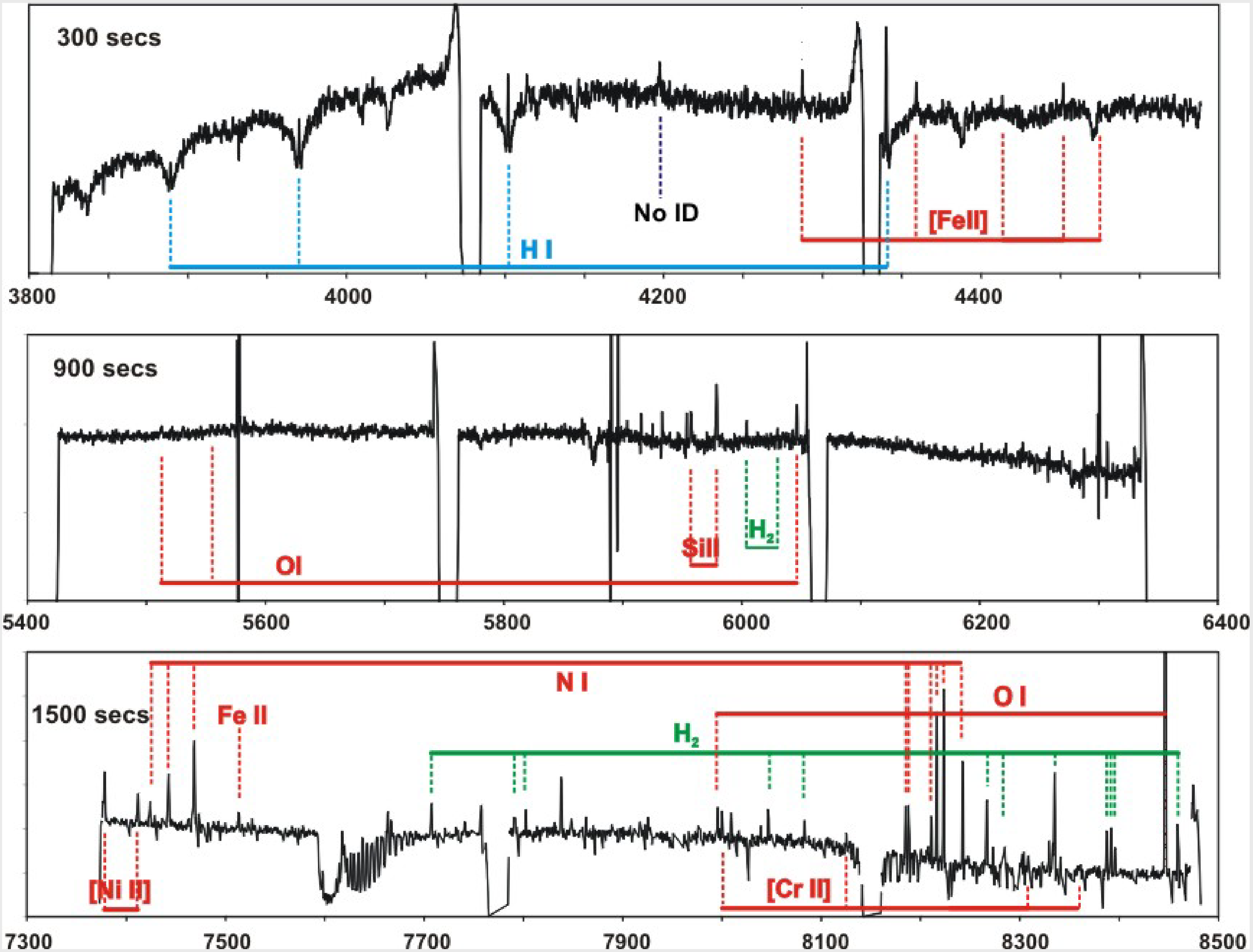
FLUORESCENCE TARGETS

- Observed in HII, but weak and confused by other excitation processes
- Should be sole emission lines in neutral gas, e.g. reflection nebulae (star form regions), extend later to other environments (e.g.circumstellar, circumgalactic)
- First verified by RSS-VIS "performance verification" observation of NGC2023
  - R ~ 9000, three colors, 8' x 0.6" slit, ~1000 secs
  - HI Balmer from foreground gas,
  - H_2 fluorescence in PDR (14 lines)
  - NI, OI, SiII, fluorescence (8 lines);
  - [FeII], [NiII], [CrII] (10 lines) metastable states pumped by fluorescence
  - Demonstrates RSS Grasp

Nonalignable | Alignable | Maybe

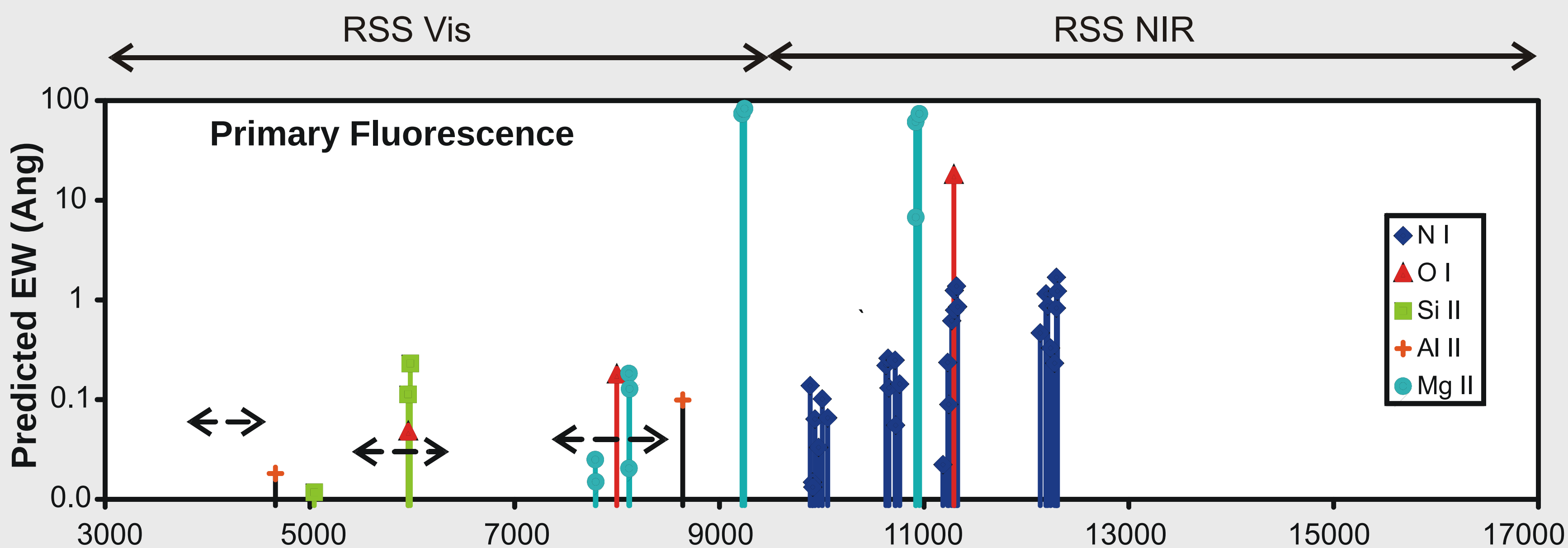


RSS-VIS NGC2023 SPECTRUM



VIS, NIR POLARIMETRY

- Predicted line equivalent widths
  - better for fainter reflection nebulae
  - NIR strong primary fluorescence from NI, OI (aligned), MgII (nonaligned): best place to look!
- Grating spectropolarimetry R=10,000 to verify best polarized lines. VIS: 1 Track SN <~ 100
- FP spectropolarimetry of
  - Unpolarized nonaligned line (ISPol map)
  - Polarized nonaligned atom => scattering map
  - Aligned atom => B-field 3D map
  - VIS: 30 spatial pixels SN > 100



SALT RSS-NIR MID-TERM REVIEW MAY 20 & 21, 2009

QSO Host Galaxies and E+A Galaxies: Phases of Galaxy Mergers?

ANDY SHEINIS & MARSHA WOLF
UNIVERSITY OF WISCONSIN

QSO Host Galaxies

Andy Sheinis, Marsha Wolf, Isak Wold, Corey Wood, Eric Hooper

Motivation

Big Questions

M-σ relation:

- Do galaxy mergers fuel AGN?(e.g. Hernquist 1989)
- Is M-σ due to AGN feedback?(e.g. Silk & Rees 1988)

Starbust-AGN connection

- Accretion and SF histories similar? (Boyle & Terlevich 1988)
- Star formation seen in local AGN (Cid-Fernandez et al. 1999)
- And also at high z? (Pageet al. 2001; Alexander et al. 2005)

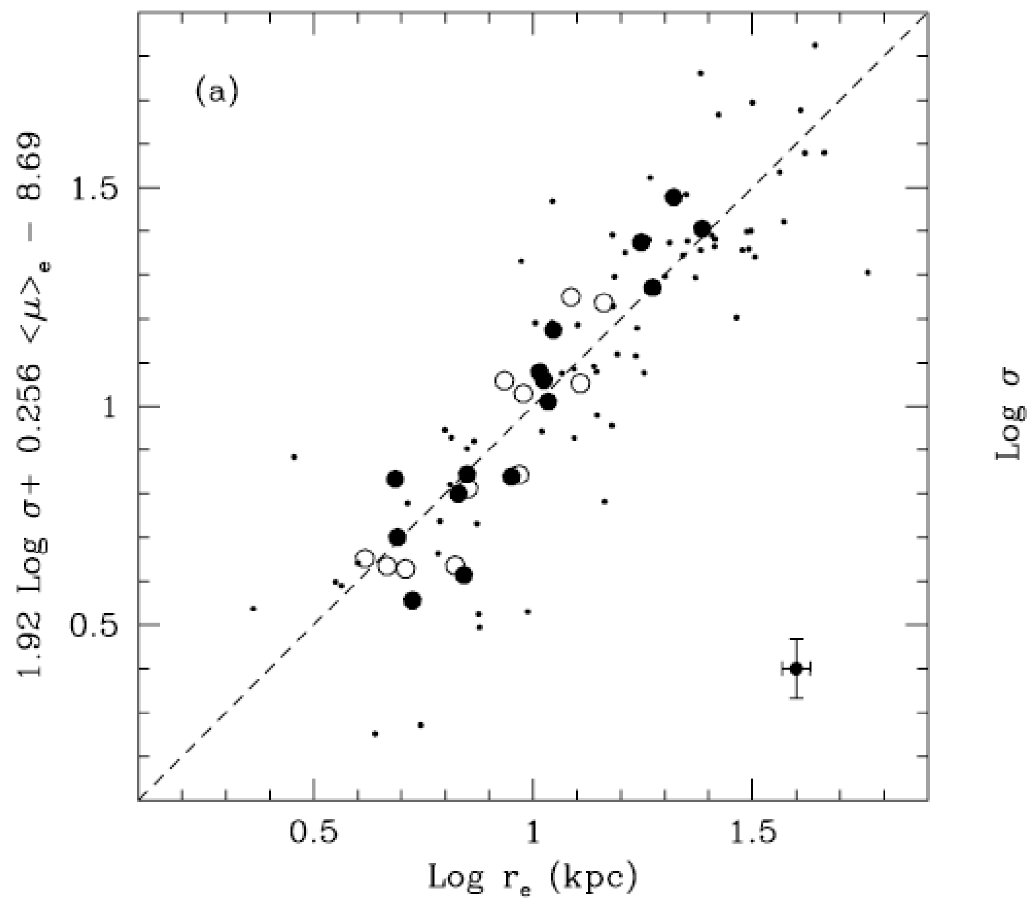
AGN-Galaxy co-evolution

- Need to look at properties of galaxies as well as AGN
- **QSO hosts are actively feeding their SMBH**
- **Nature of the hosts may give insight into the relationship between the host and it's SMBH as it is "caught in the act" of growth.**
- **Direct measure of host sigma* can calibrate MBH sigma* in massive luminous systems.**
- **Place limits on QSO lifetime, BH accretion using dynamical estimates and SFH estimates.**

Additional Issues

- Nearby low luminosity AGN show correlation of NLR LW with σ^* and MBH with BLR LW (Nelson and Whittle 1995). This has been extrapolated to high z high L high mass systems, but no direct measure of High L, high mass systems.
- Conclusions have been drawn about all AGN and their hosts based on hosts of low luminosity AGN, which may behave differently than those of bona fide quasars.
- Recent SDSS results show global SFR not well correlated with interaction. (Kauffmann et al)
- SDSS can be used only when integrated flux from host is close to or greater than AGN.
- *Very High L objects cannot be analyzed from SDSS.*

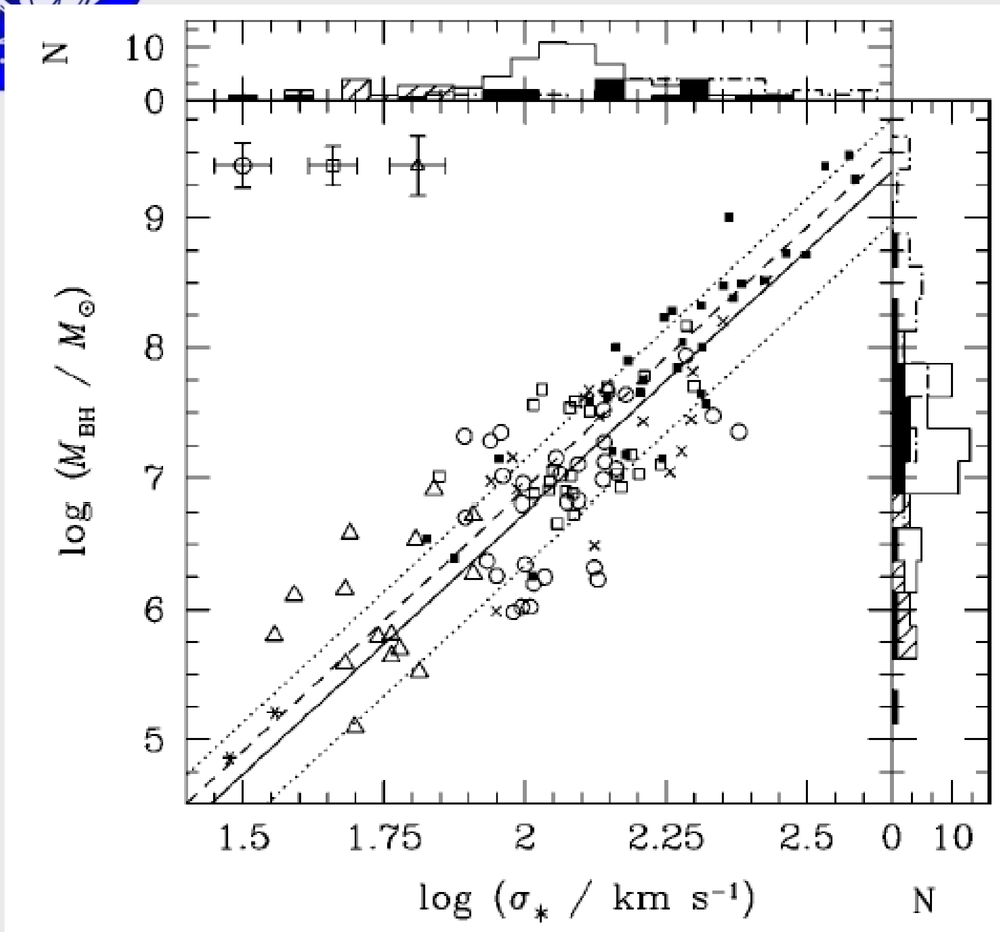
Woo et al 2004



- Lower luminosity AGN, BL-Lacs and radio galaxies
- Sigma* measured directly
- See FP agreement.
- Supports unification

FIG. 3.—Fundamental plane of AGN host galaxies. *Filled circles*: BL Lac object hosts and radio galaxies from spectroscopically observed sample. *Open circles*: BL Lac object hosts from Barth et al. (2002) and Falomo et al. (2003). *Small dots*: Radio galaxies from Bettoni et al. (2001). (*a*) Edge-on view of the fundamental plane for 26 AGN hosts showing a tight correlation among the three parameters with an rms scatter of 0.103 in log r_e. The dashed line is the fundamental plane relation defined by Bettoni et al. (2001), who used a 72 low-redshift ($\langle z \rangle \sim 0.04$) radio galaxy sample. The error bars on the lower right represent typical errors for our observed sample. (*b*) A different edge-on view of the fundamental plane. [*See the electronic edition of the Journal for a color version of this figure.*]

Greene and Ho 2006b

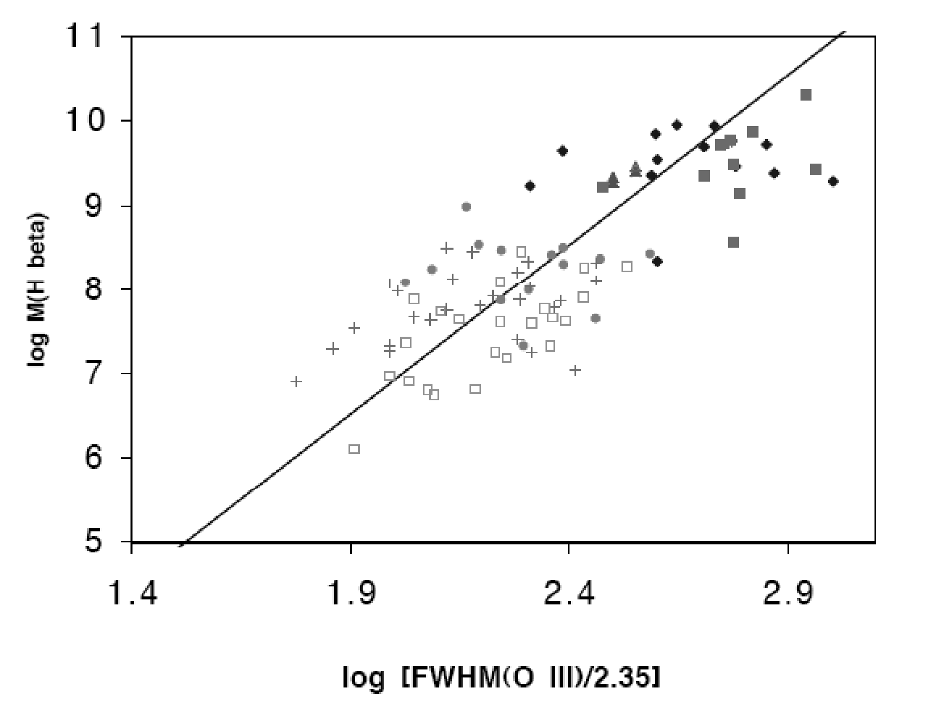


•Measured sigma* directly.

see good MBH/sigma* correlation with those of inactive galaxies.

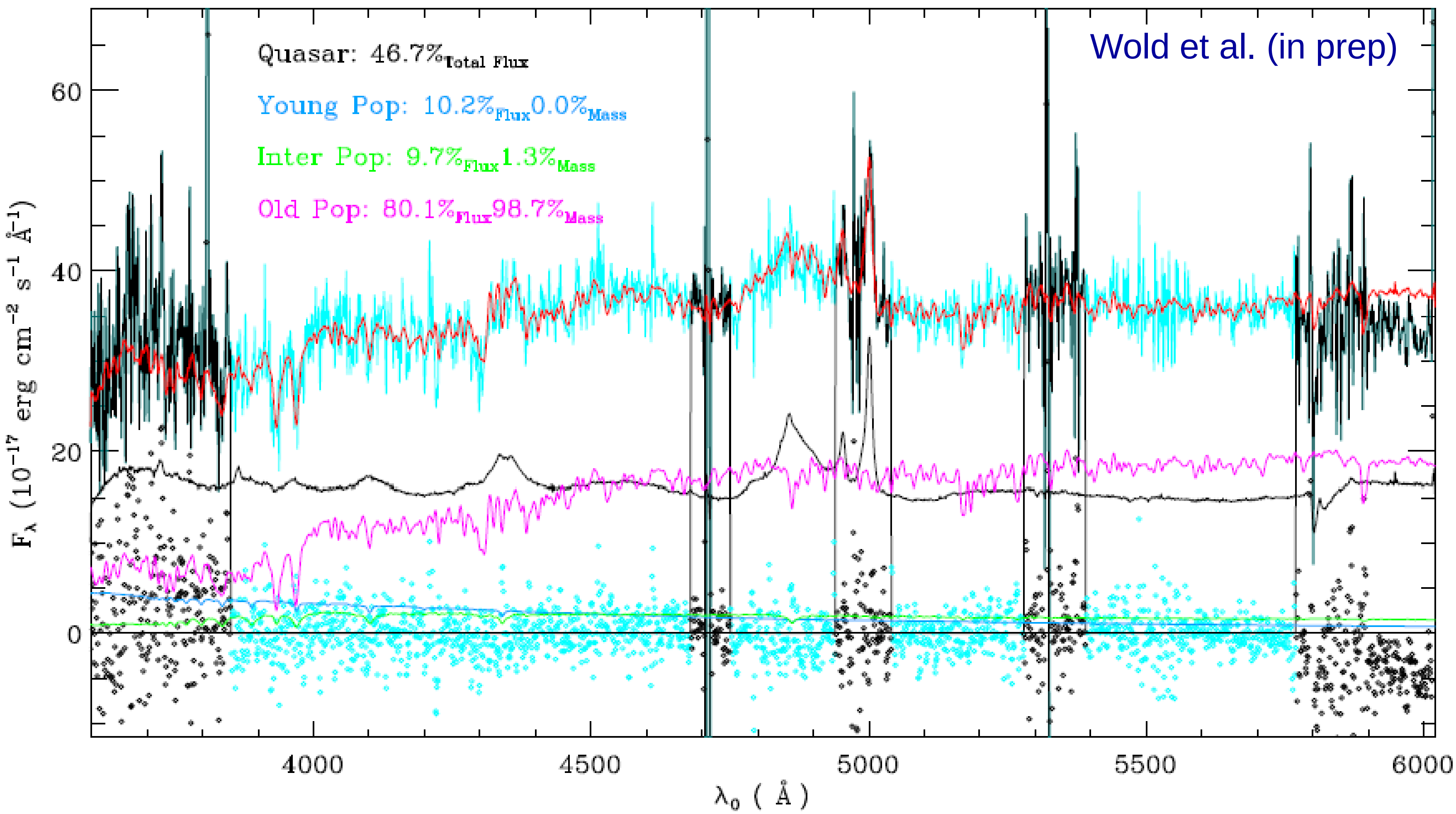
FIG. 1.—M_{BH}-σ_* relation for active and inactive galaxies. Open circles are measurements from this work using CaT, open squares are measurements using the 5250–5820 Å Fe region (see Greene & Ho 2005c), and open triangles represent the Keck data from Barth et al. (2005), but with M_{BH} recalculated using FWHM$_{H\alpha}$ values from DR3. Literature data include those of Onken et al. (2004) and Nelson et al. (2004; *crosses*; BH masses from Peterson et al. 2004), NGC 4395 and POX 52 (Filippenko & Ho 2003; Peterson et al. 2005;

MBH vs [OIII] fwhm (Shields 2003)



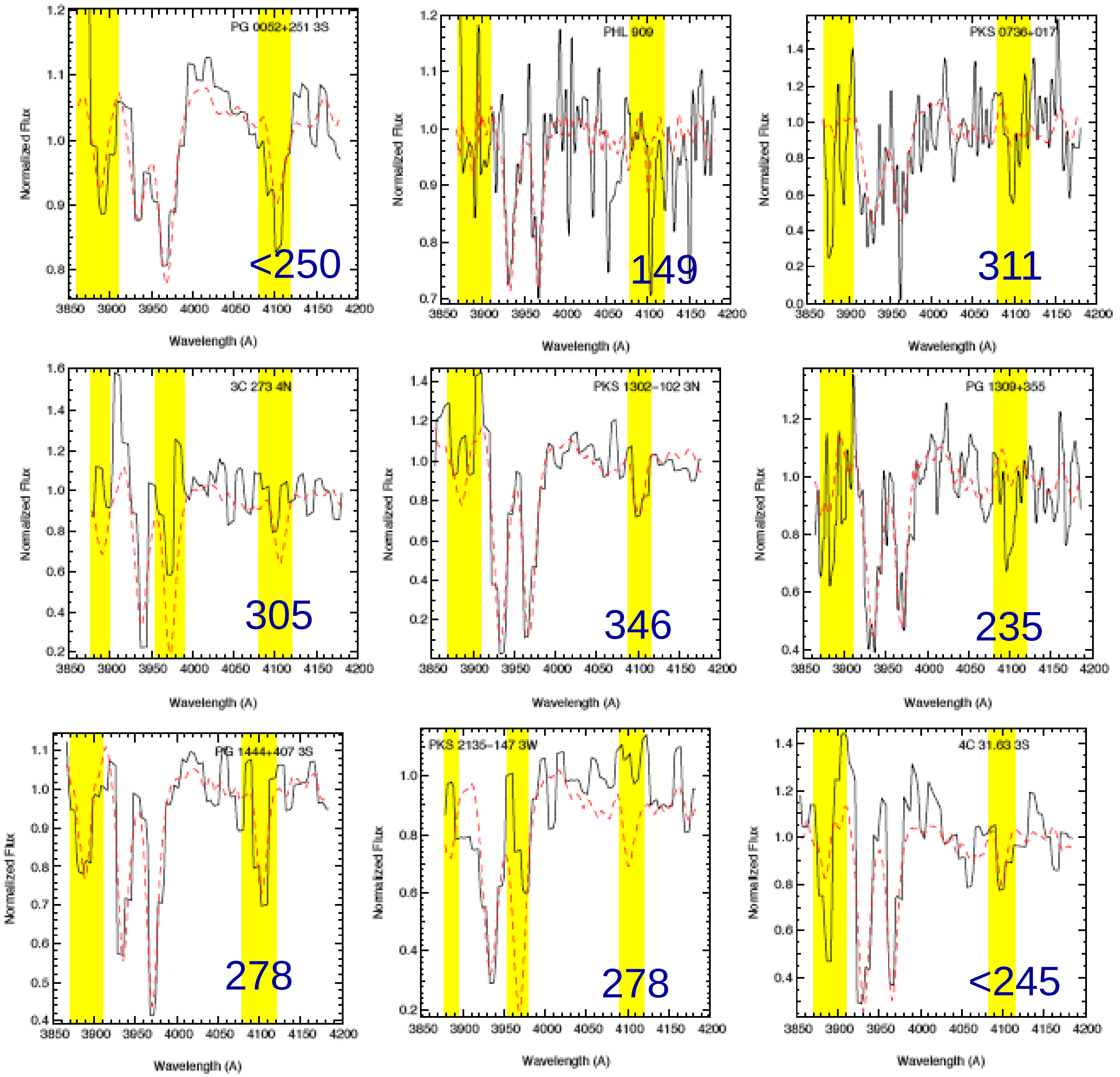
- Hbeta FWHM with L5100 to get MBH (Vestergaard & Peterson 2006)
- Use [OIII] fwhm to get sigma* (Nelson and Whittle 1995)
- Show good agreement with Tremaine 2002

FIG. 1.—Black hole mass derived from Hβ line width and continuum luminosity vs. width of the [O III] line for RQ AGNs (see text). The line shows the M_{BH}-σ_* relation from Tremaine et al. (2002), given by eq. (1); it is not a fit to the QSO data. Shown here are the " full " data sets from M99 and B96a, which include some highly uncertain values (see text) (*triangles*: D02; *diamonds*: M99; *squares*: B96a; *circles*: PG; *crosses*: G99). References are D02: Dietrich et al. 2002; M99: McIntosh et al. 1999; B96a: Brotherton 1996a; B96b: Brotherton 1996b; PG: this paper; G99: Grupe et al. 1999. Because of the scarcity of high-redshift points, we include as an open triangle the D02 object Q0256–0000, which barely exceeds the threshold to be classified radio loud. [*See the electronic edition of the Journal for a color version of this figure.*]



Stellar population fit to PG 1309+355 using data obtained on WIYN. The observed spectrum (blue line) with masked regions (black) is best fit by 47% scattered quasar light (black line). Of the remaining flux, approximately 80% is assigned to an 'old' (t > 109 yr) stellar population (pink line) with a relatively small contribution from an 'intermediate' (108 < t < 109 yr) stellar population (green line) and a 'young' (t < 108 yr) stellar population (blue line). The summation of these components (red line) and the residuals (diamond symbols) are also shown. The reliability of this fit is determined by Monte-Carlo simulations that indicate the stellar information (young, intermediate, and old percent) is accurate to within 15% for spectra with signal to noise and scattered light characteristics similar to the PG 1309+355 data.

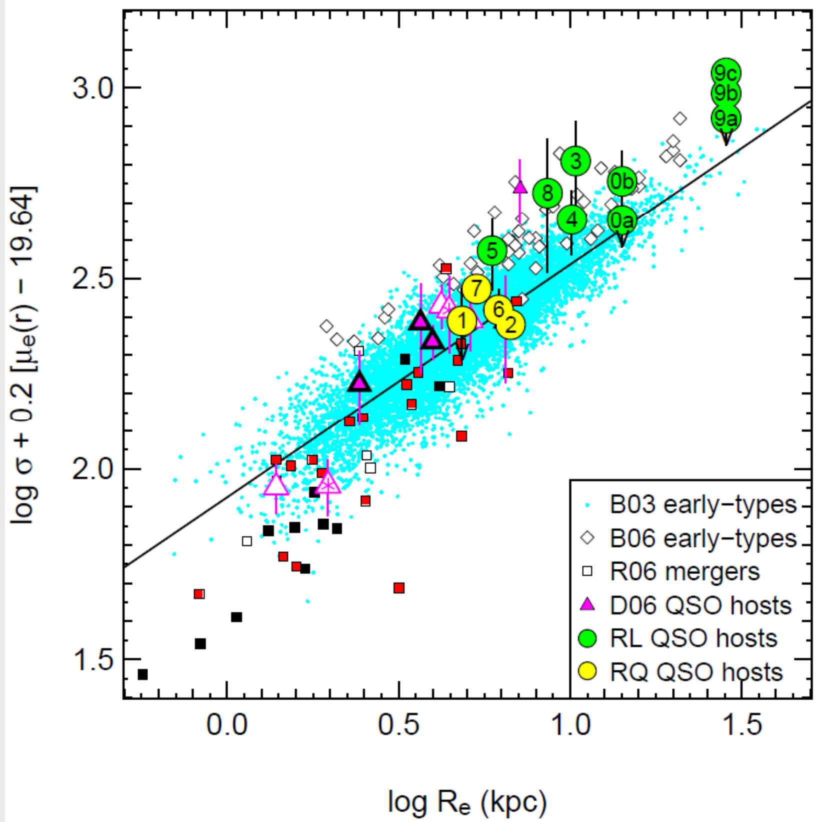
Host Galaxy Velocity Dispersions (km/sec)
Wolf & Sheinis, 2008, AJ, 136, 1587

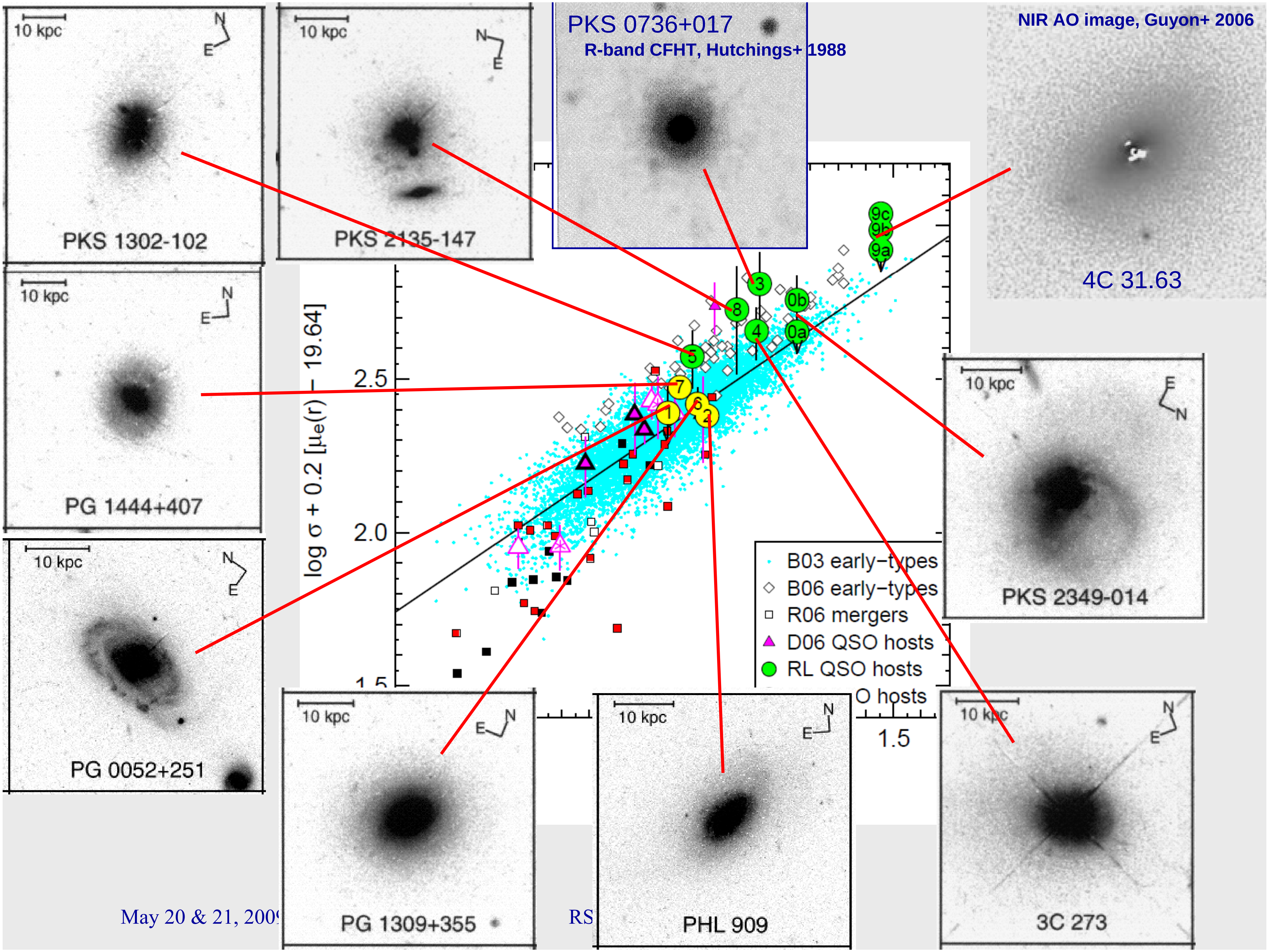


Comparison Data

- Normal early-type galaxies from SDSS (cyan dots)
  - Bernardi+ 2003
- Massive early-type galaxies ($\sigma_* > 350$ km s^{-1}) from SDSS (open diamonds)
  - Bernardi+ 2006
- Radio-quiet PG QSO hosts (magenta triangles)
  - Possible ULIRG counterparts
    - Merger of intermediate mass gas-rich galaxies
  - Dasyra+ 2007
- Merger remnants
  - Nuclei coalesced into one, starbursting phase
  - Rothberg & Joseph 2006
    - red squares - normal mergers
    - **black filled squares - LIRG/ULIRGs**
    - open squares - shell ellipticals

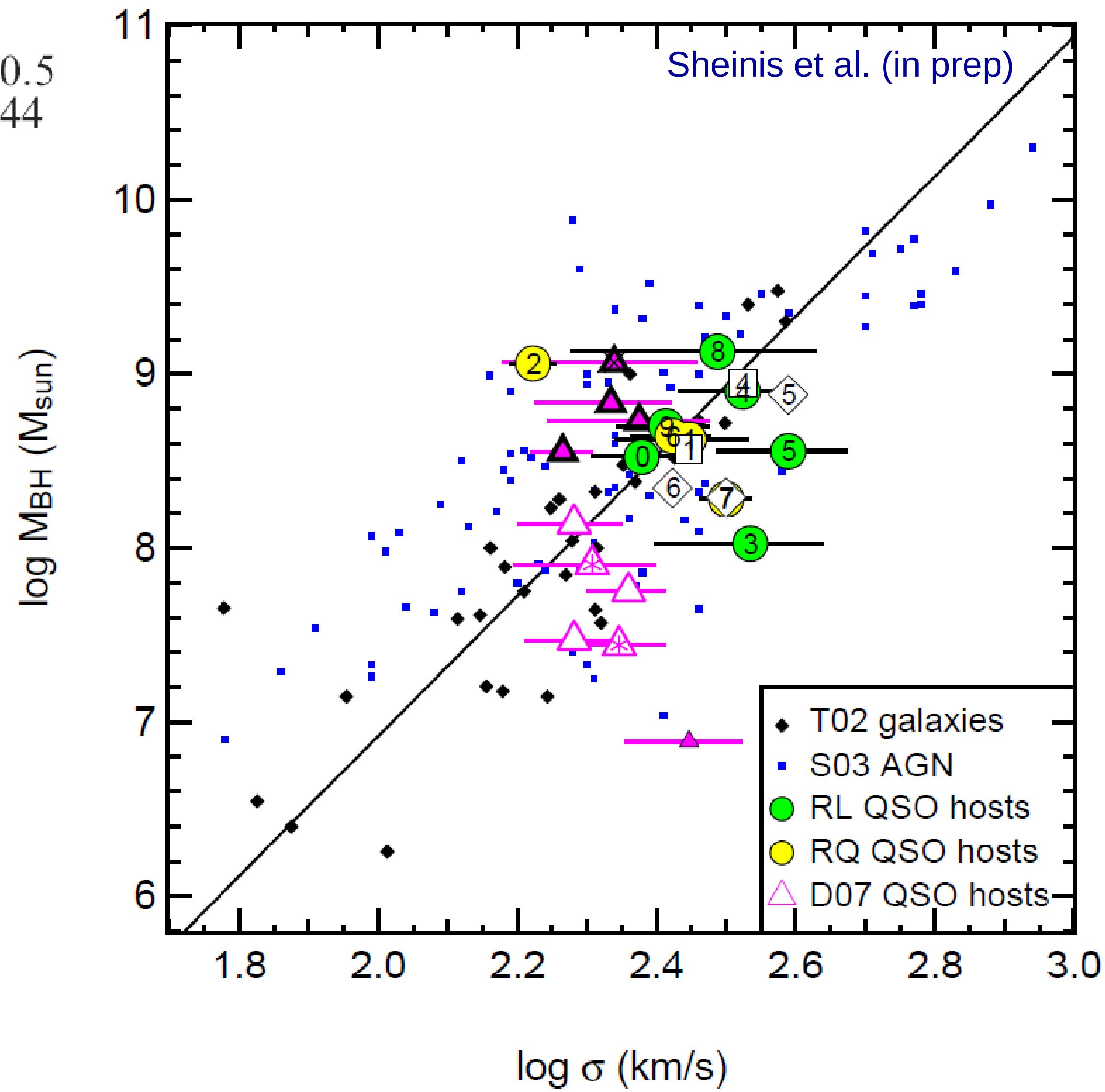
Wolf & Sheinis, 2008, AJ, 136, 1587





10 kpc
N
E
PKS 1302-102
PKS 2135-147
PKS 0736+017
R-band CFHT, Hutchings+ 1988
NIR AO image, Guyon+ 2006
4C 31.63
PG 1444+407
PG 0052+251
PKS 2349-014
PG 1309+355
PHL 909
3C 273
log σ + 0.2 [μe(r) − 19.64]
2.5
2.0
1.5
B03 early−types
B06 early−types
R06 mergers
D06 QSO hosts
RL QSO hosts
O hosts
May 20 & 21, 200
RS

$$M_{\rm BH} = (10^{7.69}\ M_{\odot}) v_{3000}^{2} L_{44}^{0.5}$$



The M_{BH}-σ_* relation. Our radio-loud QSOs are the large green circles and our radio-quiet QSOs are the large yellow circles. Their black hole masses are estimated from the Hβ FWHM and L(5100 Å) relation, and σ_* is the directly measured stellar velocity dispersion of the host galaxies. Error bars on black hole masses represent the 0.7 dex absolute accuracy of this technique statistically estimated by Vestergaard & Peterson 2006. The open squares are our objects with M_{BH} from reverberation mapping (Peterson et al 2004) and the open diamonds are our objects with M_{BH} estimated from the Hβ FWHM and L(5100 Å) by Vestergaard & Peterson 2006. Comparison objects: the radio-quiet QSOs from Dasyra et al 2007 are the triangles, quiescent galaxies from Tremaine et al 2002 are small black diamonds, AGN from Shields et al 2003, where the [OIII] emission linewidth has been used as a surrogate for stellar velocity dispersion, are small blue squares. The dashed line is the relation derived by Tremaine et al 2002.

□ M_{BH} from reverberation mapping (Peterson+ 2004)

◇ M_{BH} from L(5100Å)-FWHM(Hβ) (Vestergaard & Peterson 2006)

QSO Host Conclusions

- Ongoing Survey at UW
- Radio-loud QSO hosts lie at upper extreme of FP
  - properties similar to giant early-types in SDSS
  - large $<\sigma_*> = 351$ km s^{-1}
  - large $<R_e> = 11.6$ kpc
  - low $<\mu_e(r)> = 14.1$ mag $arcsec^{-2}$
- Radio-quiet QSO hosts lie on FP
  - $\sigma_* \sim 198$ km s^{-1}
  - R_e and $\mu_e(r)$ slightly higher than normal early-types in SDSS
- Distinction in galaxy properties, including radio-loudness, occurs at:
  - $\sigma_* \sim 300$ km s^{-1}
  - $M_* \sim 7 \times 10^{11} M_{sun}$
- Loose correlation between radio luminosity and σ_*
  - Tighter correlation with M_*
  - Most low-z QSO Hosts show recent or ongoing star formation.
- Need to extend to Ca triplet, higher SNR with RSS-NIR
- Need to extend to lower surface brightness with RSS-NIR

Future Work

- Why NIR?
  - Ca triplet
  - Scattered light ratios
- Why SALT?
  - Time variability
  - Polarization
  - Wide-field get environment and companions simultaneously
  - Fabry-Perot imaging of gas
- Where do we go from here?
  - IFU
    higher Z
  - Lower SB

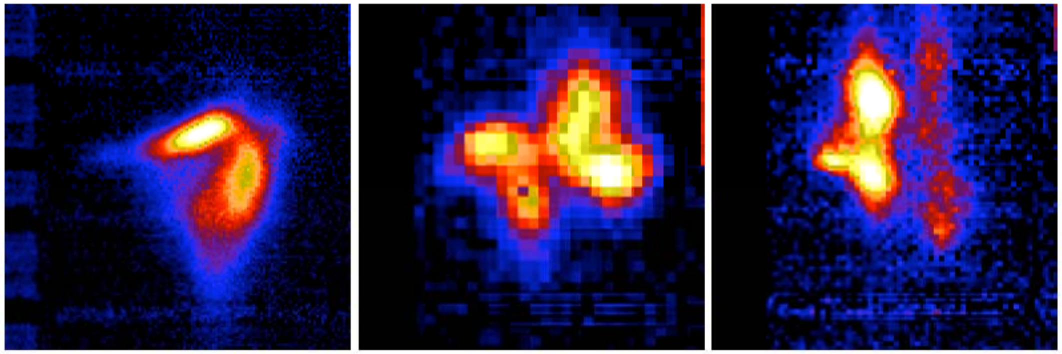


Figure 6.14: Two Dimensional extraction of the $\lambda = 5007\AA$ line for 3C 249.1 for three different slit positions: (a) 3 seconds east; (b) 3.5 seconds north; and (c) 3 seconds west . Dispersion is in the vertical direction and encompasses $\pm 787 kms^{-1}$. Slit runs along the horizontal dimension and encompasses $\pm 29.8 Kpc$.

Sheinis 2002

E+A GALAXIES WITH BURIED AGN

Marsha Wolf, Eric Hooper, Charles Liu

G515: an archetypal E+A galaxy

G515 is close to a neat well-ordered picture of E+A galaxies. Transition between merger & full formed elliptical. (Liu+2007; Oegerle+ 1991)

• Near end of Toomre merger sequence. See *Ks* image to right.

• Probably simple interaction history.

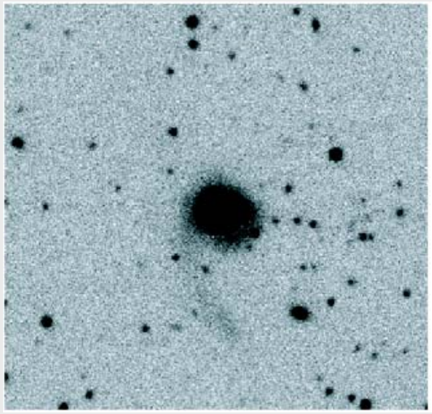
• Strong post-starburst & little or no optical star formation. See spectrum, with stellar population model, to right.

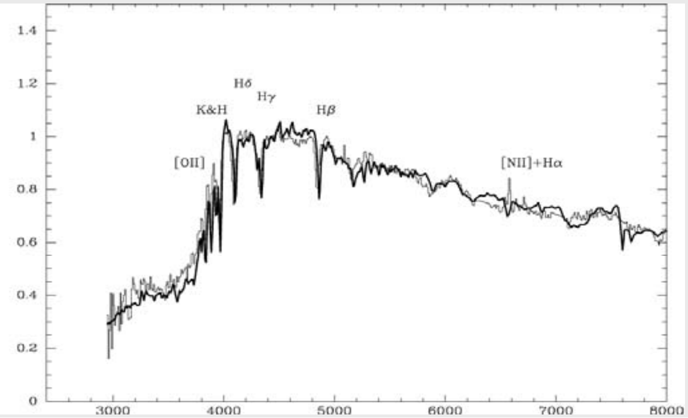
• HI mass < 1.5 x 10^9 solar masses.

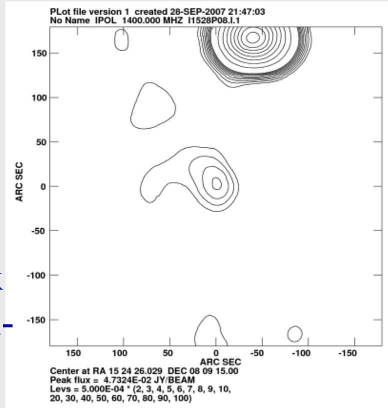
However, it is a radio source.

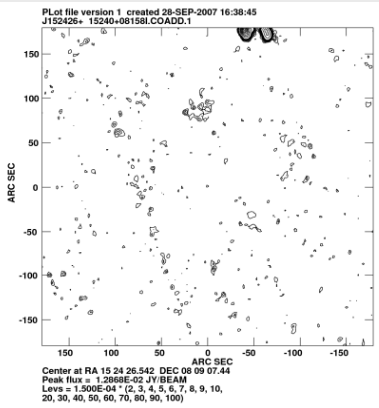
• Detected in NVSS, not in FIRST to lower flux limit. Re-observed as faint point source in high-res. VLA config. See contours right.

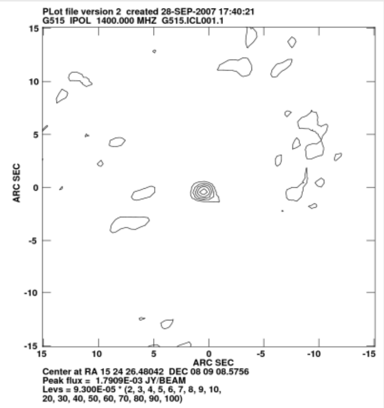
• Either variable point source (AGN) or extended emission lost in A and B arrays.











NVSS (D array) 1995 Feb 27

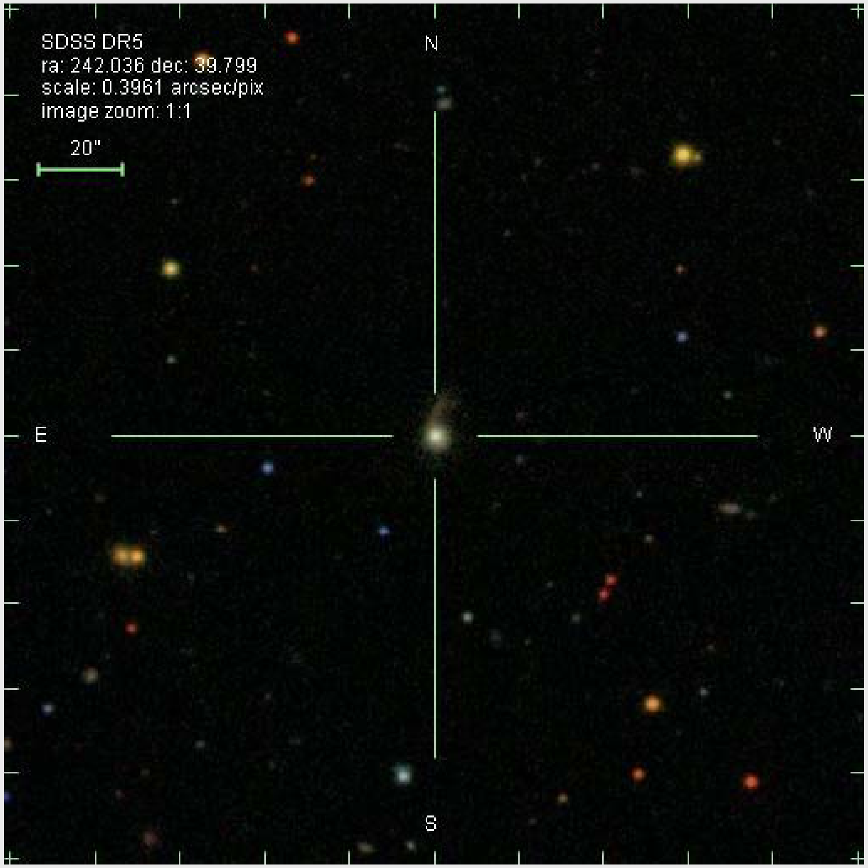
FIRST (B array) 2000 Jan 25

New data (A array) 2007 Jun 04

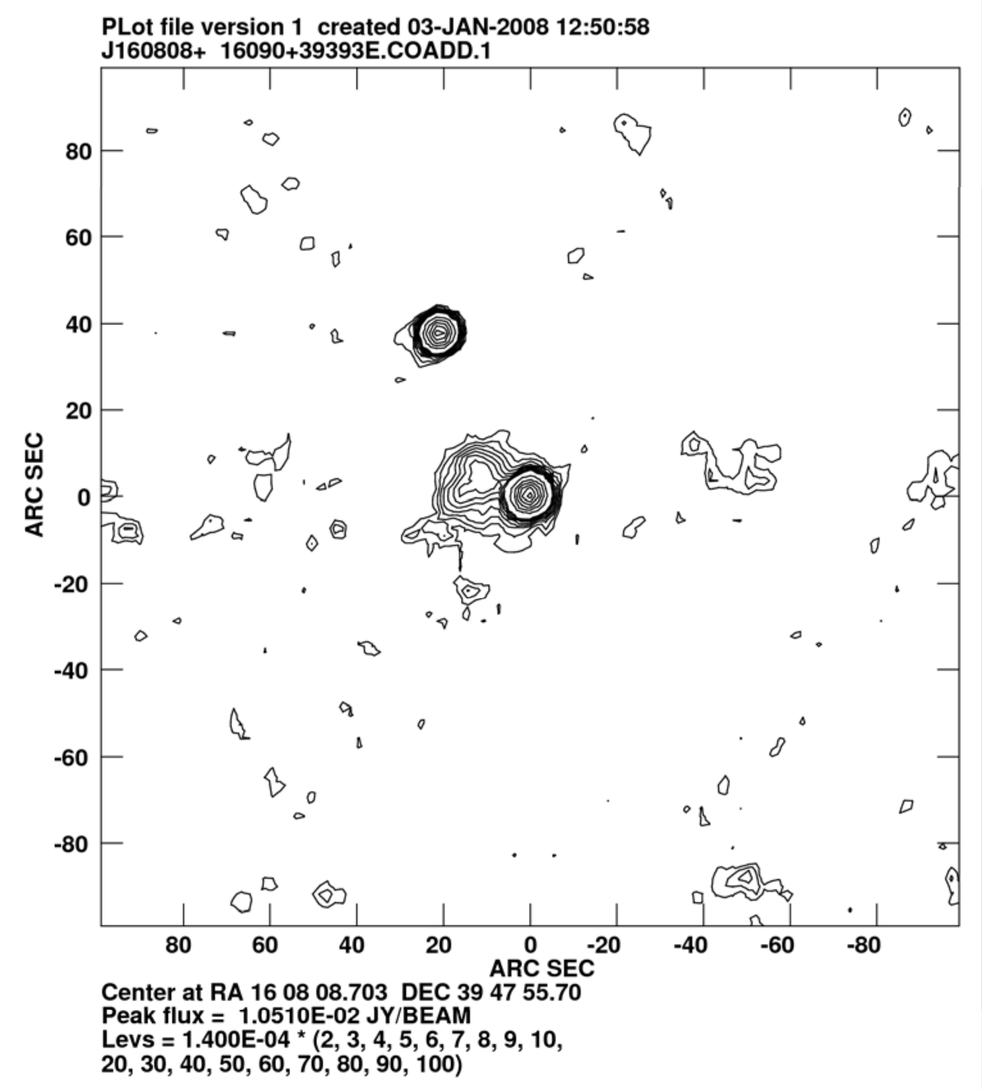
RADIO PROPERTIES OF E+A GALAXIES

(Hooper et al., 2007, BAAS, 39, 907)

- Following G515, we checked 1.4 GHz continuum fluxes for 564 E+A galaxies selected from SDSS to have *little or no star formation* (Goto 2007) using NVSS and FIRST surveys
  - FIRST goes deeper at higher spatial resolution than NVSS, but it can 'lose' large-scale extended emission to which NVSS is sensitive.
    - Hence, FIRST flux > NVSS flux → variability;
    - NVSS flux > FIRST flux → variability *and/or* lost extended emission
- A substantial fraction, possibly the majority, of radio detections in a sample of E+A galaxies selected to have little or no optical evidence of ongoing star formation have radio properties which indicate these galaxies have variable radio sources (i.e., AGN) and/or large-scale extended emission.
  - The latter would imply large-scale obscured star formation or radio lobes from an AGN
  - One source is clearly variable
  - Extended radio emission, some not coincident with the visible galaxy, is confirmed by direct imaging in some sources
- Further VLA data is being reduced to help distinguish variable components from extended emission for all sources in the sample
- Low level radio emission has been used to estimate the amount of obscured star formation in galaxies
  - The presence of hidden AGN in them complicates this estimate technique

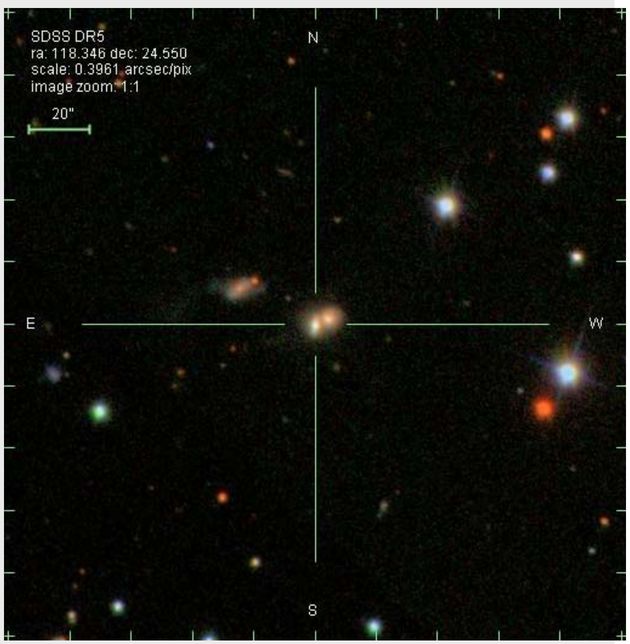


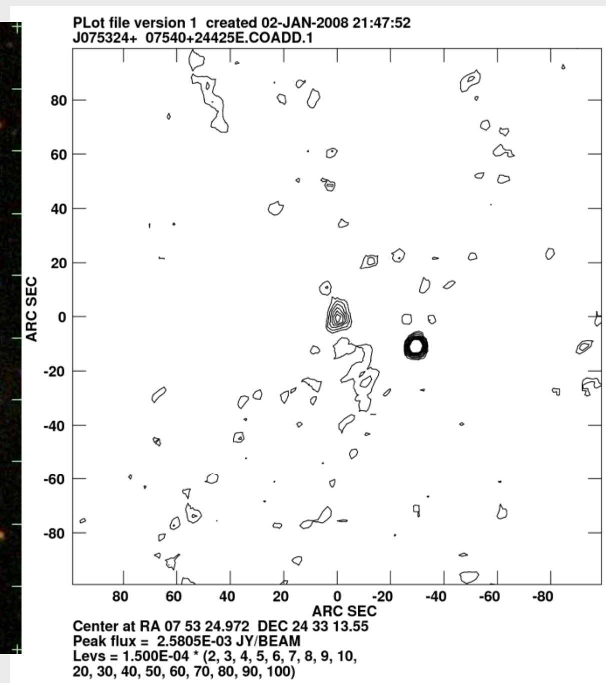
SDSS J160808.7+394755



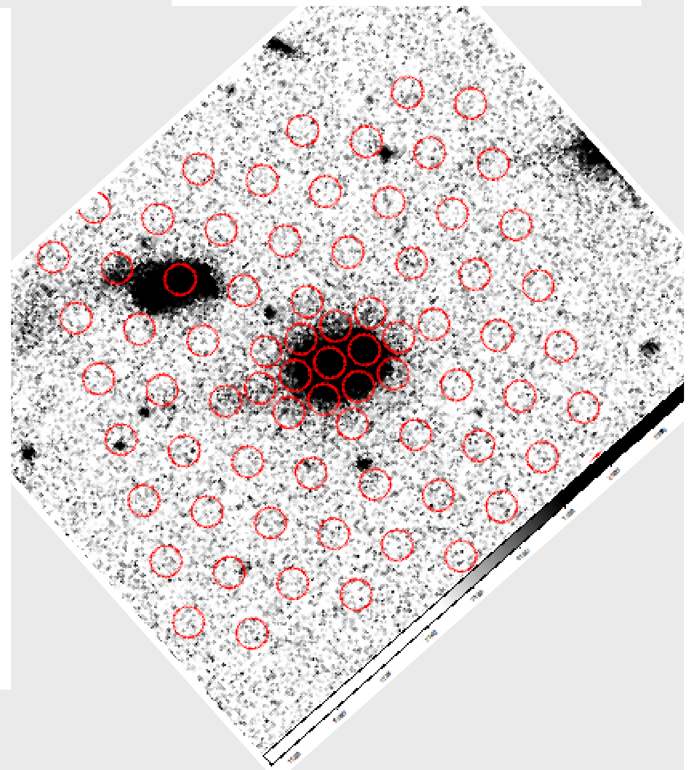
STELLAR POPULATIONS

- Ongoing IFU spectra with SparsePak on WIYN
  - Spatially distributed stellar populations
- J, H, K images with WHIRC on WIYN
  - To generate dust extinction maps

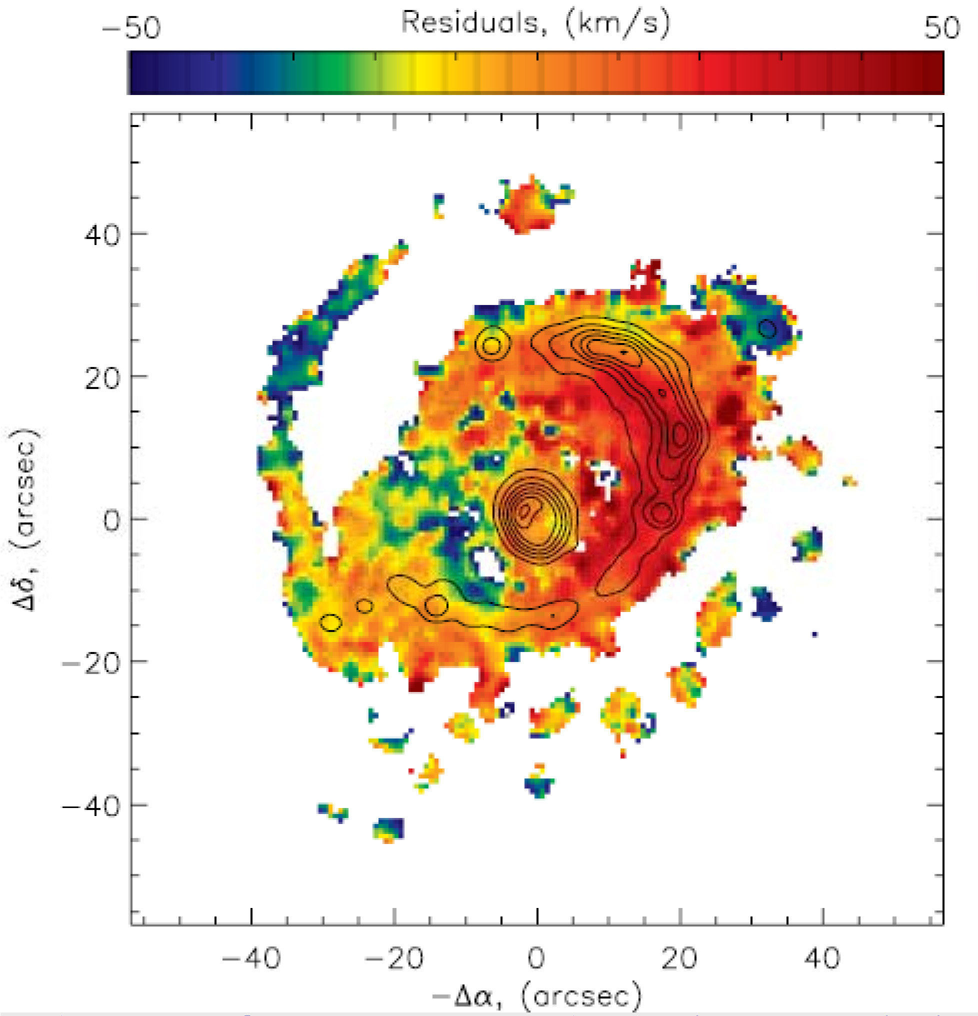




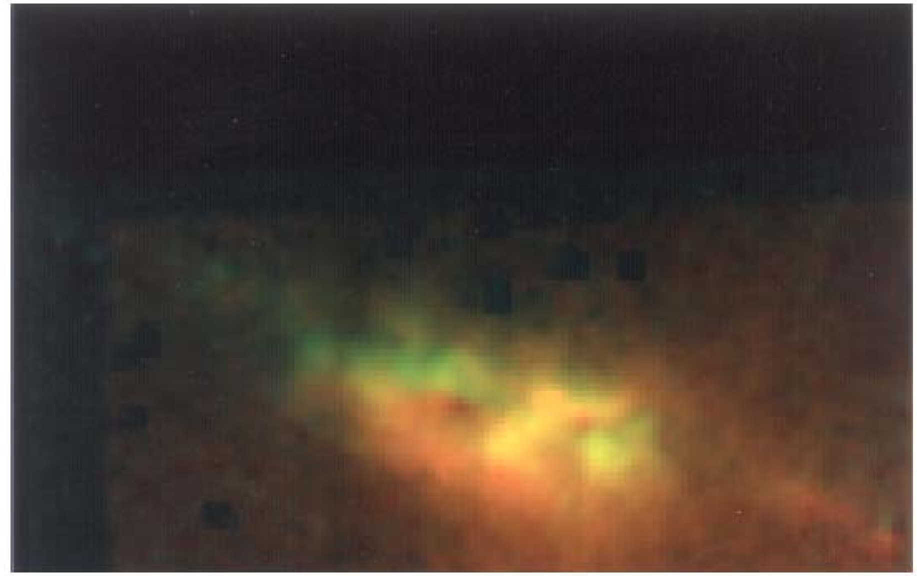
each fiber 5” diameter



THE FUTURE WITH SALT - FP



(Bizyaev et al, 2007, ApJ, 662, 304) Scanning FP at 40 km/s. Line-of-sight velocity residuals in Arp 10. A contour map of Hα emission is superimposed by thin black contours.

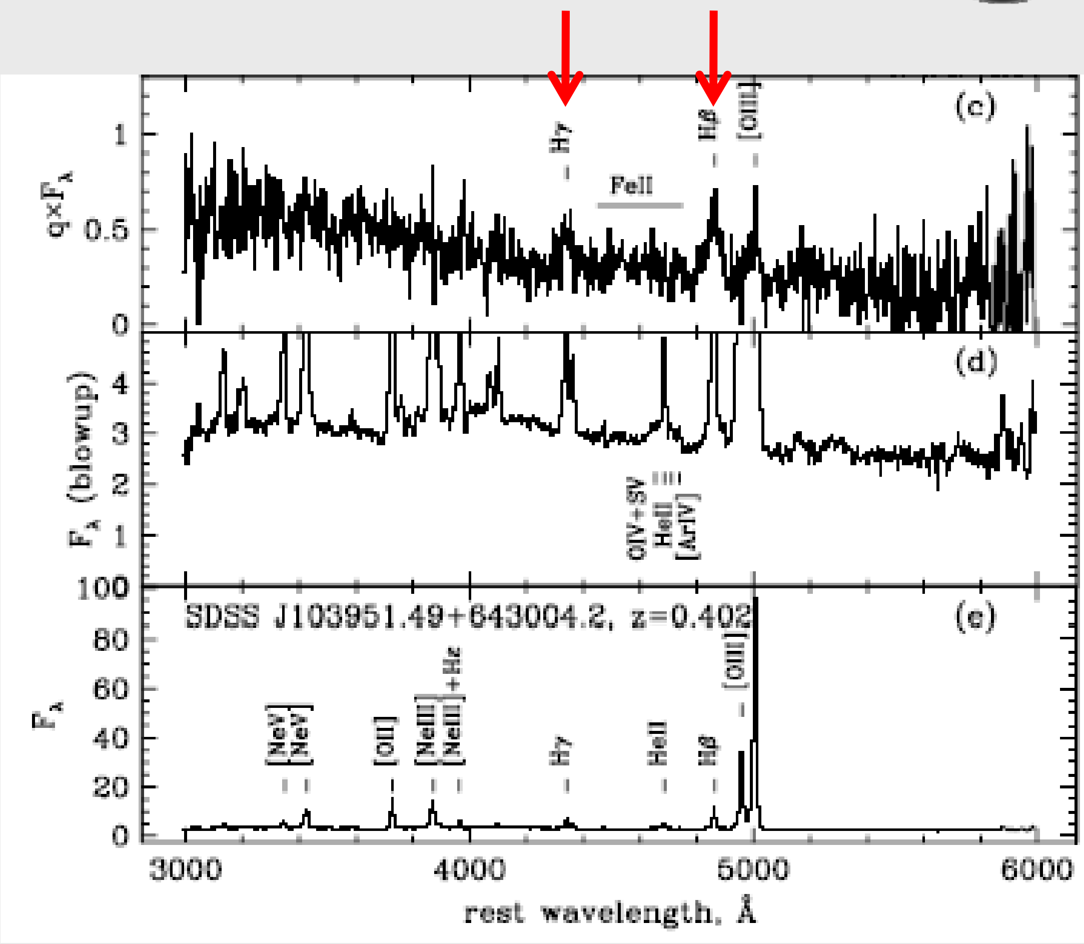


(Greenhouse et al.,1997, ApJ, 476, 105) FP observations of M82 at resolution of 375 km/s. A composite image of the [Fe II] (red) and Brγ (green) integrated line intensity. Yellow is a mixture of these components. The Brγ data are from Satyapal et al. (1995). [Fe II]/H II line ratios can yield a relative age-dating technique for starburst clusters

- Simultaneously map spatially distributed star formation (VIS) and shocks from SNe (NIR)
- Velocity maps to look for outflows and interactions

THE FUTURE WITH SALT - SPOL

- Confirm the existence of obscured AGN in the E+A galaxies?
- Distinguish AGN from liners, which can also be produced by shock ionization and photoionization
  - (Veilleux et al. 1995)



(Zakamska et al., 2005, AJ, 129, 1212) Spectropolarimetry of obscured quasars in SDSS. Broad lines show up in polarized spectrum: Hβ and Hγ. Same thing seen in Seyfert 2's *(Tran, 2003, ApJ, 583, 632)*.

ARE AGN A TYPICAL PHASE OF GALAXY MERGERS?

- IFU spectroscopy
  - Spatially distributed stellar populations
- NIR images
  - Map out dust extinction
- Fabry-Perot emission line images
  - Map out ongoing (Hα) or recent ([O II]) star formation
  - Map out shocks from supernova ([Fe II)
  - Create velocity maps
    - Look for outflows, kinematics of past interaction remnants (tidal tails)
- Spectropolarimetry
  - Confirm existence of hidden AGN with reflected light from obscured broad line regions
  - Learn about geometry of system

$\Rightarrow$Piece together timeline of the past interaction

$\Rightarrow$Tie into consolidated theme of AGN as phases of galaxy mergers?