

An ESO/RadioNet Workshop
ESO Garching, 10–14 March 2014

3D2014

Gas and stars in galaxies:
A multi-wavelength 3D perspective

Highlight talk session 5 **Wednesday 10:05**

- **Privon**
- **Gallazzi**
- **Reeves**
- **James**
- **Kelz**
- **Kyoko**

Dynamical Models of Galaxy Mergers as a Tool to Constrain Star Formation Models

George Privon

University of Virginia

3D2014 Highlight Talk (& Poster #31)

A. Evans (UVa/NRAO), J. Barnes (IfA), J. Mazzeella (IPAC/Caltech), J. Hibbard (NRAO), L. Armus (IPAC/Caltech), and the GOALS collaboration

<http://goals.ipac.caltech.edu>

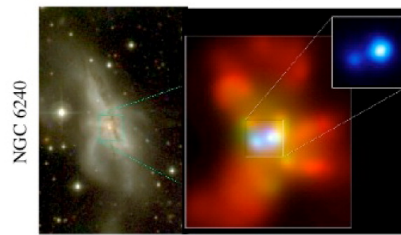
Merger Driven Activity

(c) Interaction/“Merger”



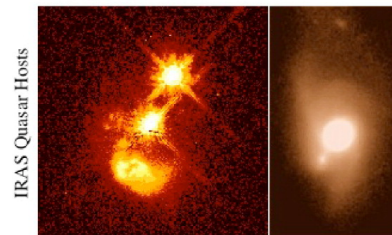
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

(d) Coalescence/(U)LIRG



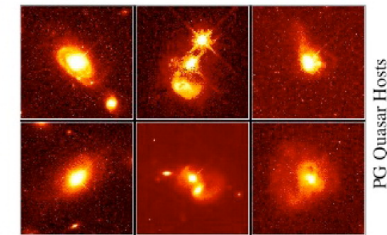
- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small

(e) “Blowout”



- BH grows rapidly: briefly dominates luminosity/feedback
- remaining dust/gas expelled
- get reddened (but not Type II) QSO: recent/ongoing SF in host
- high Eddington ratios
- merger signatures still visible

(f) Quasar



- dust removed: now a “traditional” QSO
- host morphology difficult to observe: tidal features fade rapidly
- characteristically blue/young spheroid

(b) “Small Group”

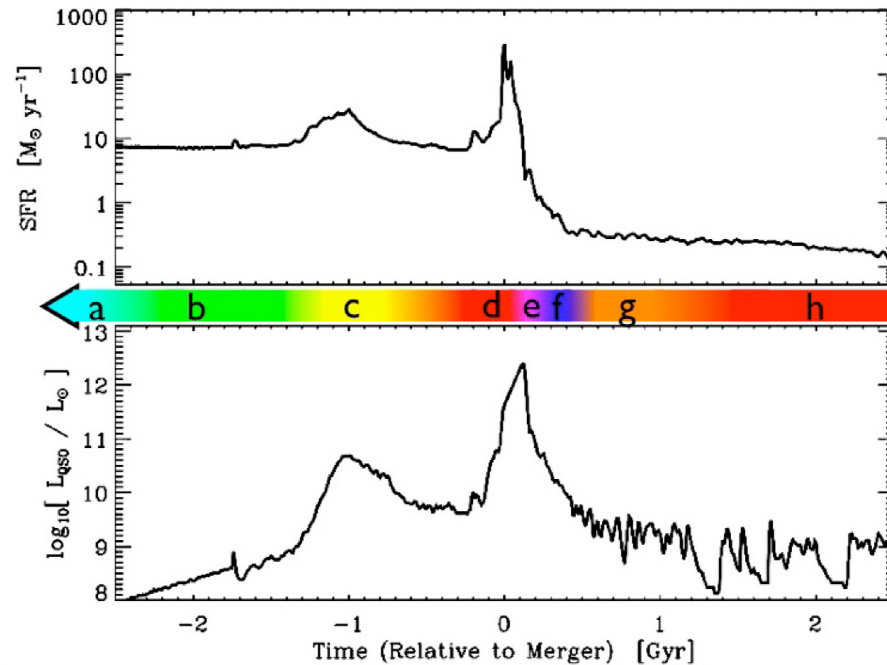


- halo accretes similar-mass companion(s)
- can occur over a wide mass range
- M_{halo} still similar to before: dynamical friction merges the subhalos efficiently

(a) Isolated Disk



- halo & disk grow, most stars formed
- secular growth builds bars & pseudobulges
- “Seyfert” fueling (AGN with $M_B > -23$)
- cannot redden to the red sequence



(g) Decay/K+A



- QSO luminosity fades rapidly
- tidal features visible only with very deep observations
- remnant reddens rapidly (E+A/K+A)
- “hot halo” from feedback
- sets up quasi-static cooling

(h) “Dead” Elliptical



- star formation terminated
- large BH/spheroid - efficient feedback
- halo grows to “large group” scales: mergers become inefficient
- growth by “dry” mergers

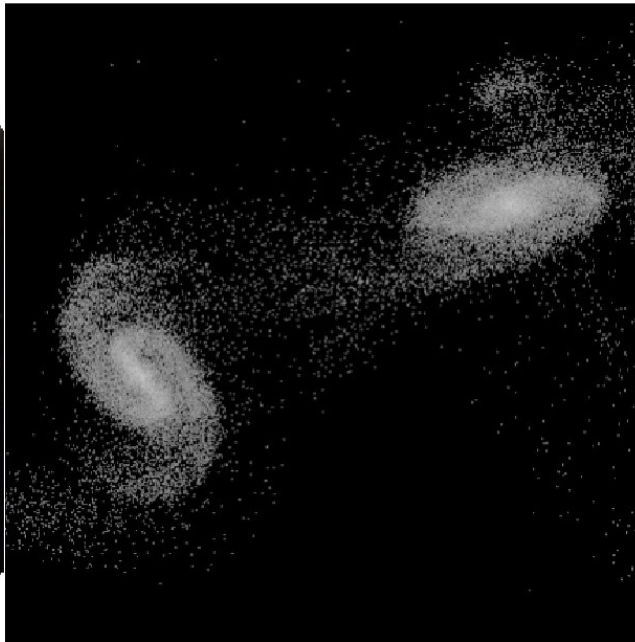
(e.g., Hopkins+ 2008, Sanders+ 1988)

Modeling Example: Arp 240

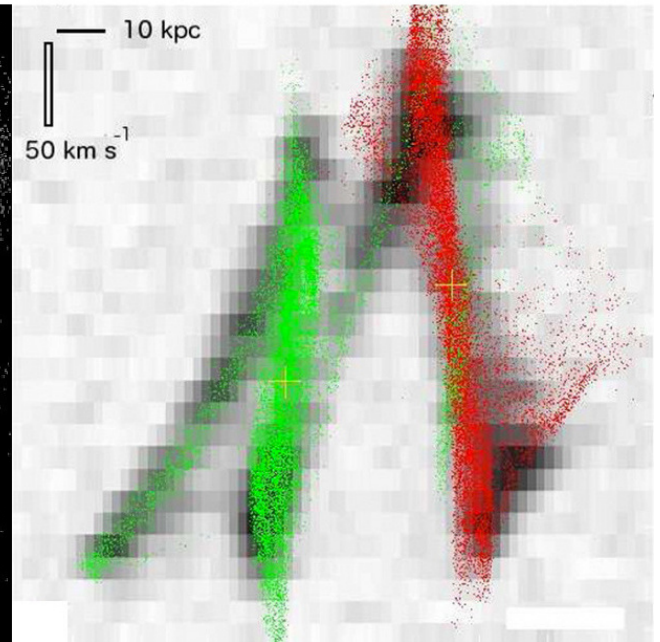
Arp 240 (HST/ACS)



Dynamical Model



Match to Kinematic Data

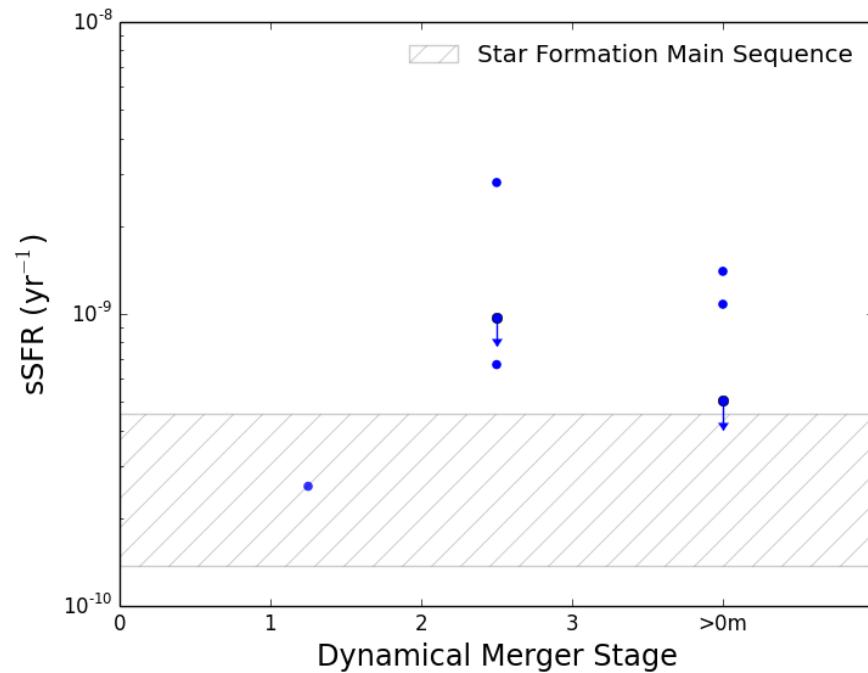


Early stage prograde-prograde encounter, wide pass (~ 7 disk scale lengths) of 2 roughly equal-mass galaxies. Viewed 230 Myr after first pass, merger in ~ 1.2 Gyr.

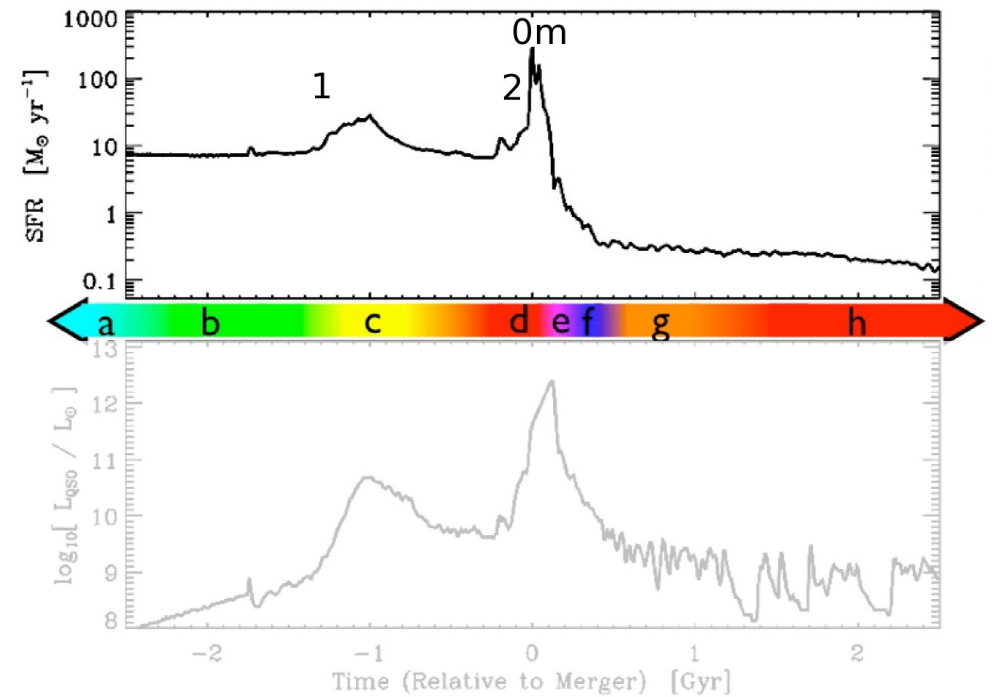
(Privon+ 2013)

Merger Driven Activity – Star Formation

With dynamical models for a *sample* of systems...



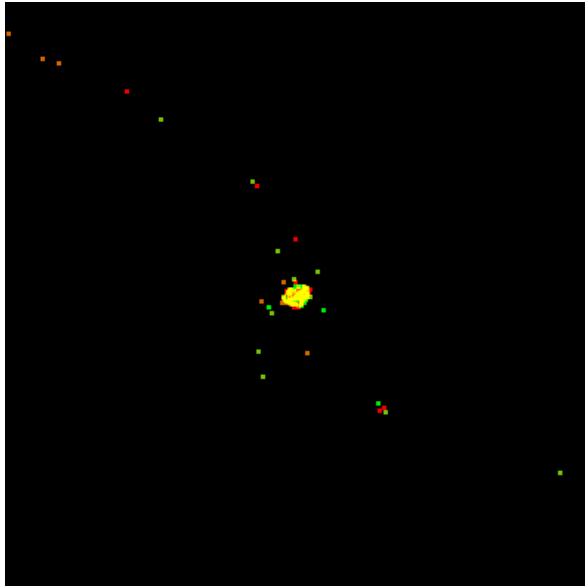
(Howell+ 2010, Elbaz+ 2011, Privon+ *in prep*)



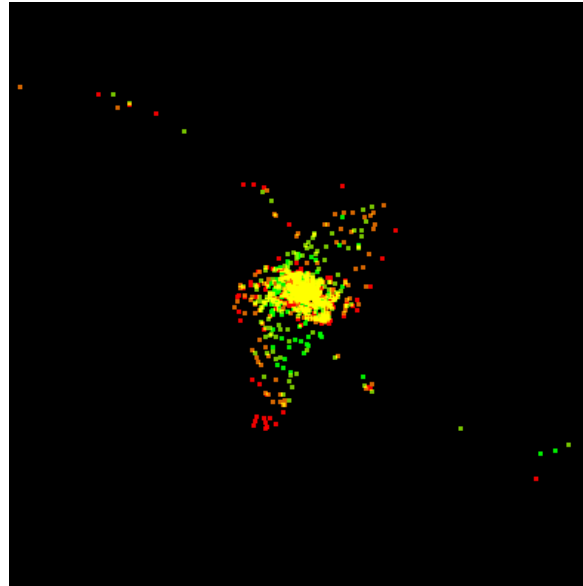
(Hopkins+ 2008)

Testing Star Formation Models – NGC 2623

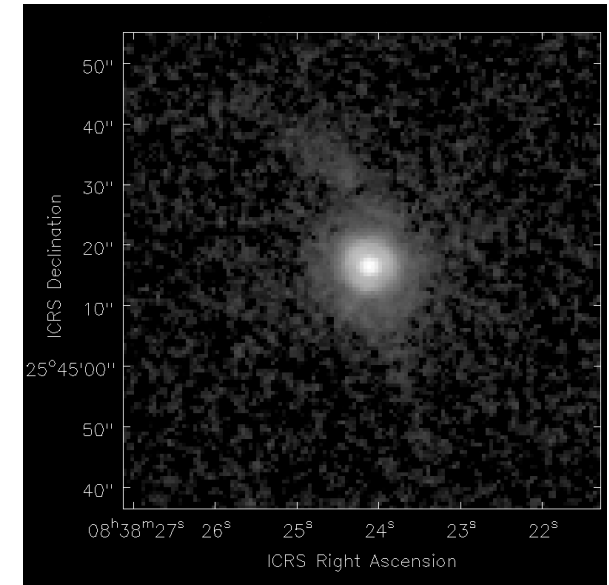
$\rho_{\text{sfr}} \propto \rho_{\text{gas}}^{1.5}$ – KS relation



$\rho_{\text{sfr}} \propto \dot{u}_{\text{int}}^{0.5}$ – shocks



IRAC ch4 ($8 \mu\text{m}$ PAH)



Simulated SF in the past 50 Myr (Red – older stars, green – younger).

(Privon+ *in prep*)

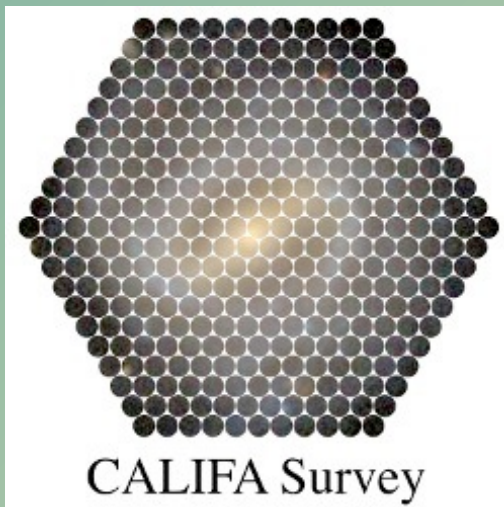
Stellar Populations and Mass Maps of nearby galaxies: toward an unbiased view with CALIFA

Anna Gallazzi

Stefano Zibetti, Elena Tundo

INAF - Osservatorio Astrofisico di Arcetri

and the CALIFA collaboration



PI: S.Sanchez, PS: J.Walcher
~400 galaxies observed so far
DR of 200-300 galaxies in
the Fall

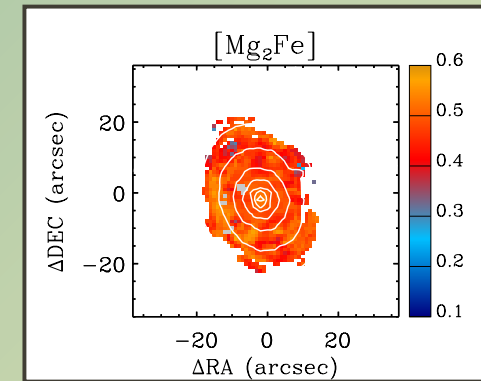
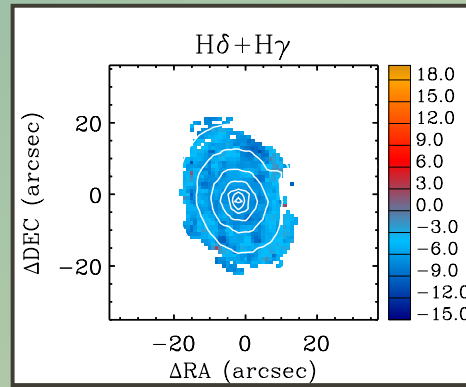
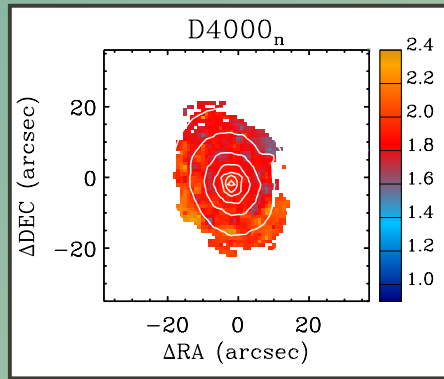
ESO 3D2014, 12/3/2014

- ★ The age and metal abundance of stellar populations are related to galaxy mass on a global scale
- ★ **Spatially resolved information** to 1) link these properties with galaxy structure **on local** (Gonzales-Delgado et al 2013, Sanchez et al 2013) and 2) **reassess global scaling relations**
- ★ **Correct for biases** in derived physical properties **due to incomplete and unresolved coverage**: affect comparison with galaxy formation models and assessment of redshift evolution
- ★ good leverage in galaxy morphological type and stellar mass

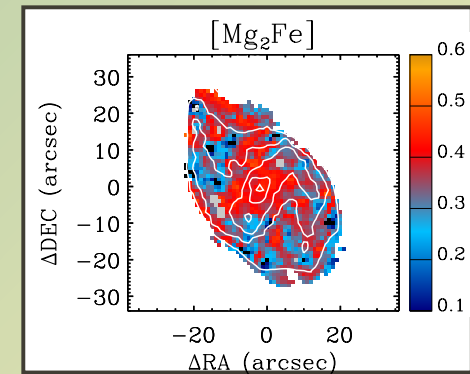
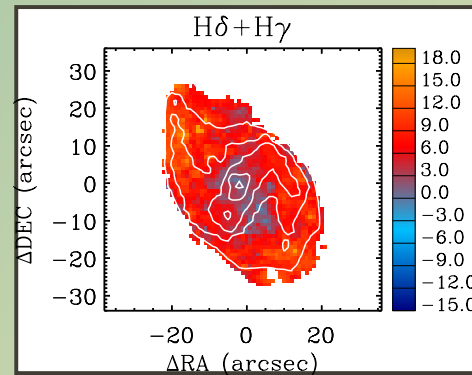
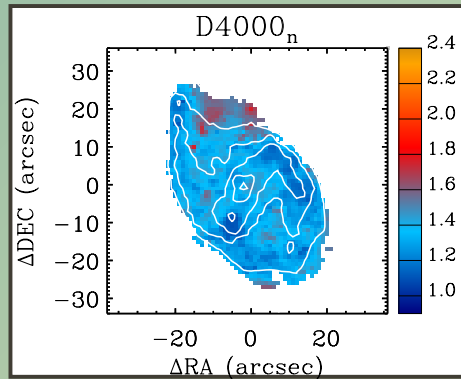
adaptive smoothing of cubes to ensure $S/N > 20$ out to $\sim 2R_e$ (see S. Zibetti's talk)

absorption features from individual spectra after continuum-emission line separation

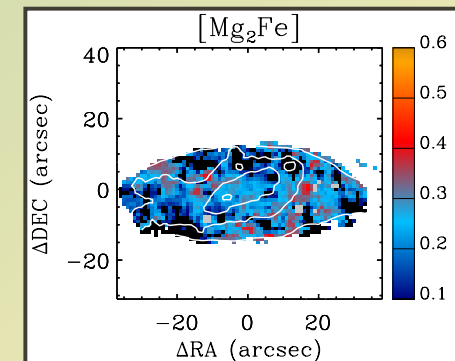
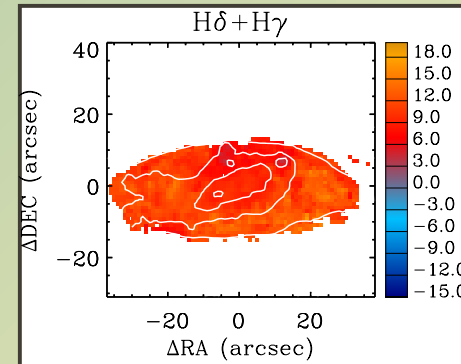
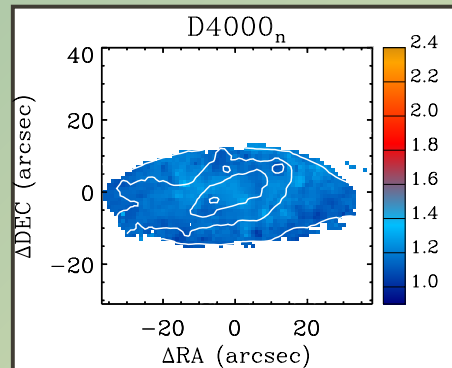
NGC 6515 - E
 $\log M^* = 10.72$



NGC 7549 - SB(s)cd pec
 $\log M^* = 10.70$

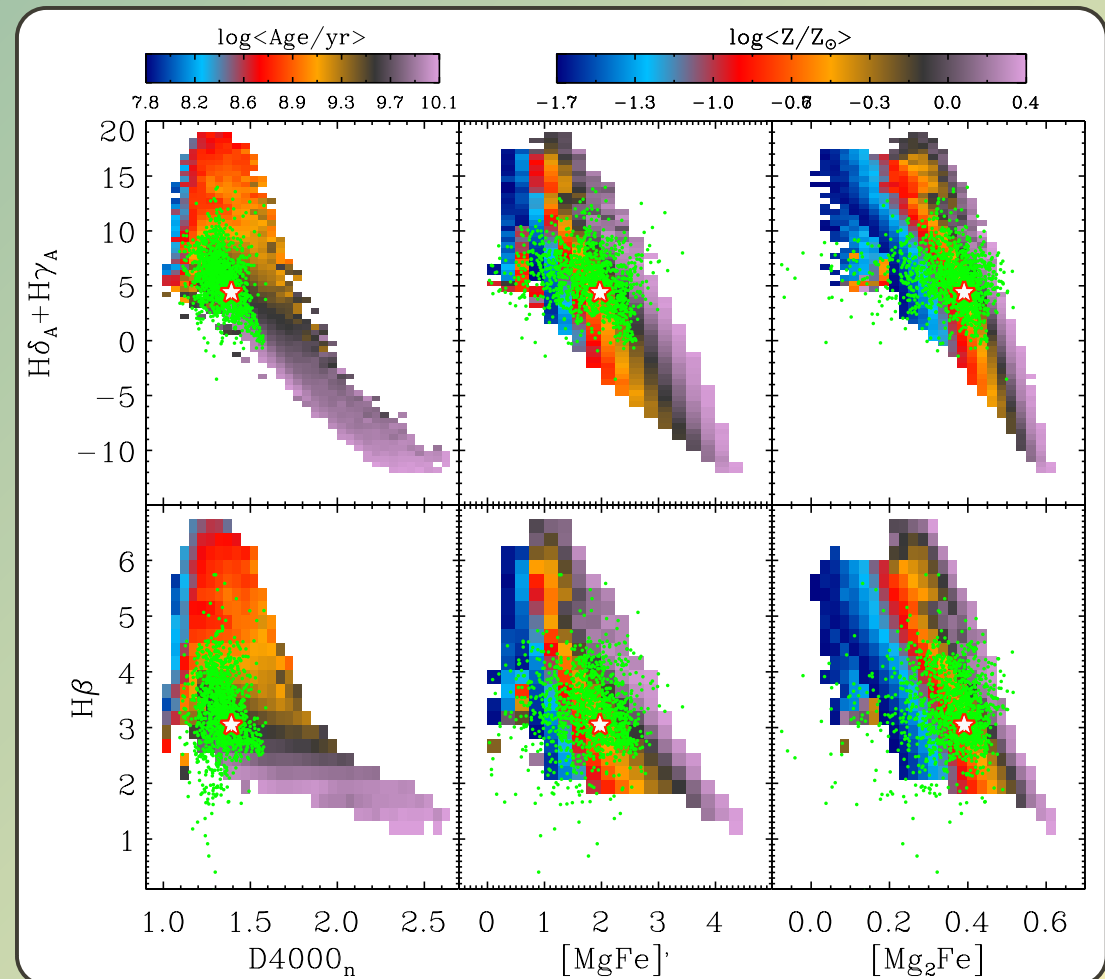


NGC 5630 - Sdm
 $\log M^* = 9.53$

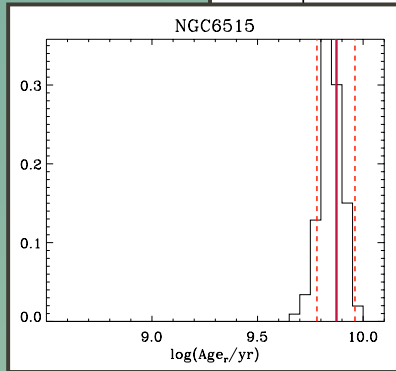
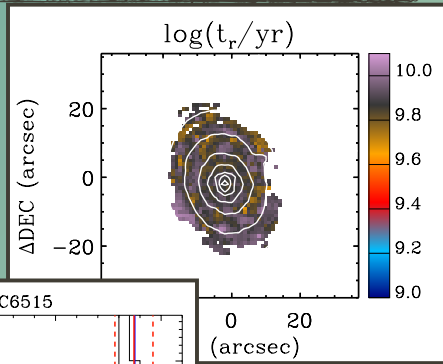


Age- and metallicity-sensitive absorption features Individual regions versus integrated value

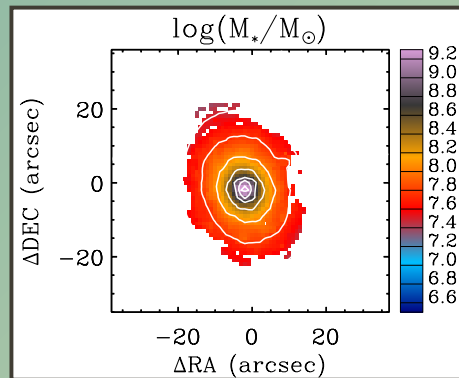
- ★ Optimal set of absorption features:
D4000, $H\beta$, $H\gamma+H\delta$, $[Mg_2Fe]$, $[MgFe]'$
- ★ g-i SDSS color to account for dust attenuation and constrain stellar mass
- ★ **MONTE CARLO LIBRARY OF COMPLEX SFH AND METALLICITIES:**
exponential SFH + random burst;
metallicity fixed for each model (i.e. no chemical evolution) - based on BC03; 2-parameter dust model a la Charlot&Fall2000
- ★ build **full probability density function** of **STELLAR MASS, LUMINOSITY- AND MASS-WEIGHTED AGE, STELLAR METALLICITY**



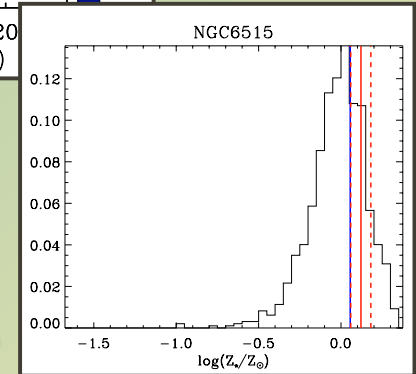
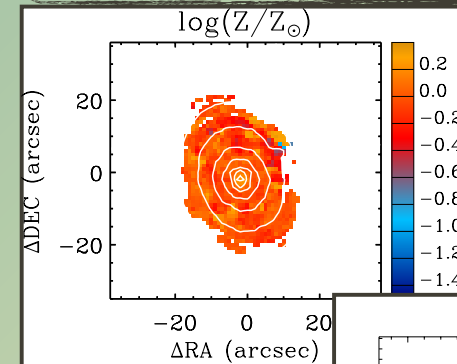
Light-weighted Age



Stellar Mass Map



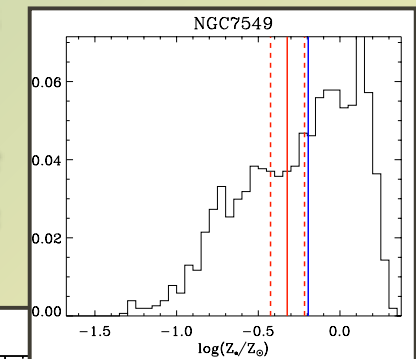
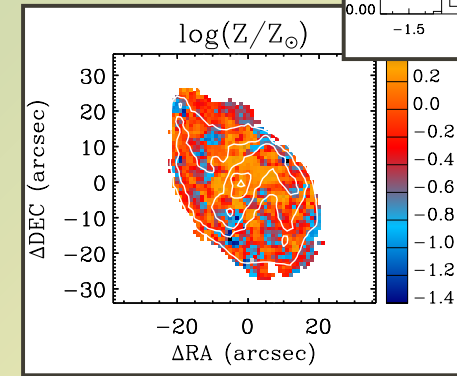
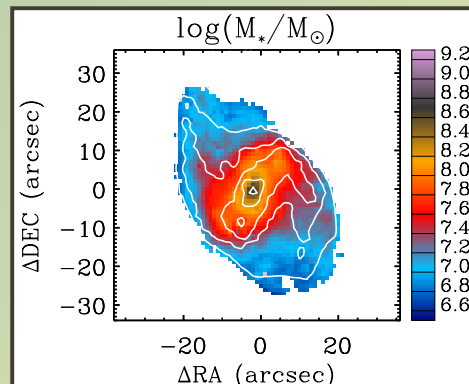
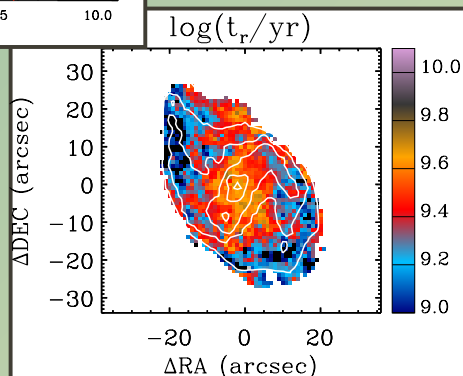
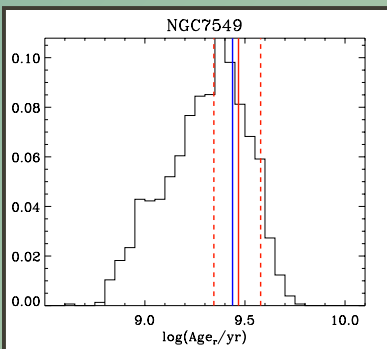
Stellar Metallicity



★ Global physical parameters and their spatial distribution depend on galaxy mass structure, even at similar total stellar mass

★ Stellar population parameters from **integrated spectra** compared to **resolved information**: **systematic differences in non-smooth galaxies and lower-mass galaxies**

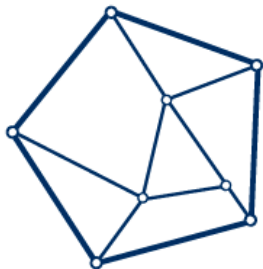
★ What are the effects on the zero-point and slope of galaxy scaling relations derived from fixed-aperture spectroscopy?



A search for HI absorption in nearby galaxies

Sarah Reeves

Elaine Sadler, James Allison,
Baerbel Koribalski,
Stephen Curran, Michael Pracy

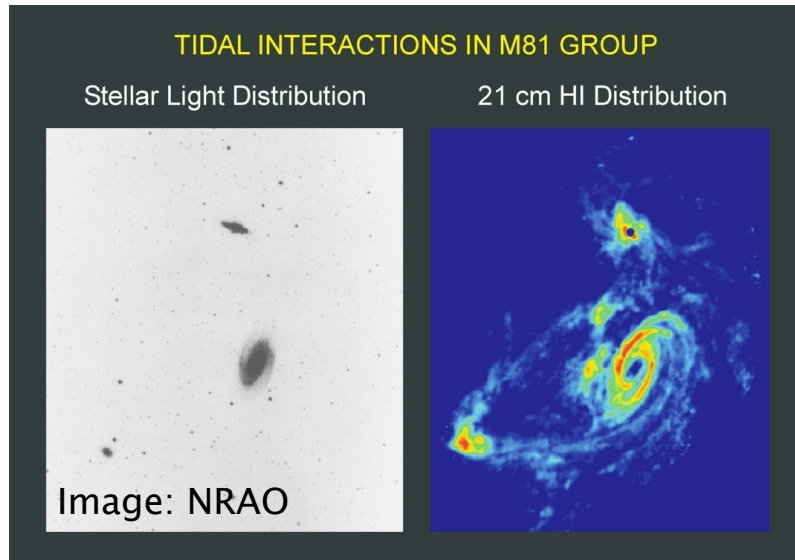


CAASTRO
ARC CENTRE OF EXCELLENCE
FOR ALL-SKY ASTROPHYSICS



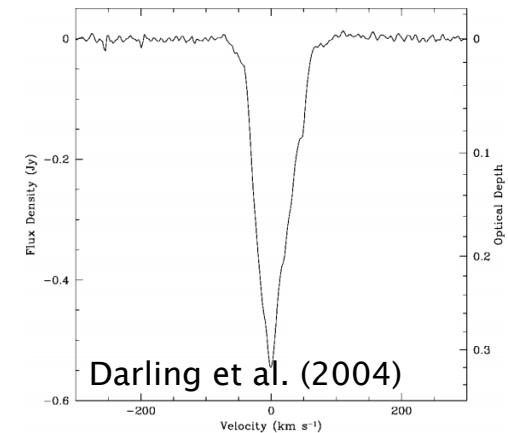
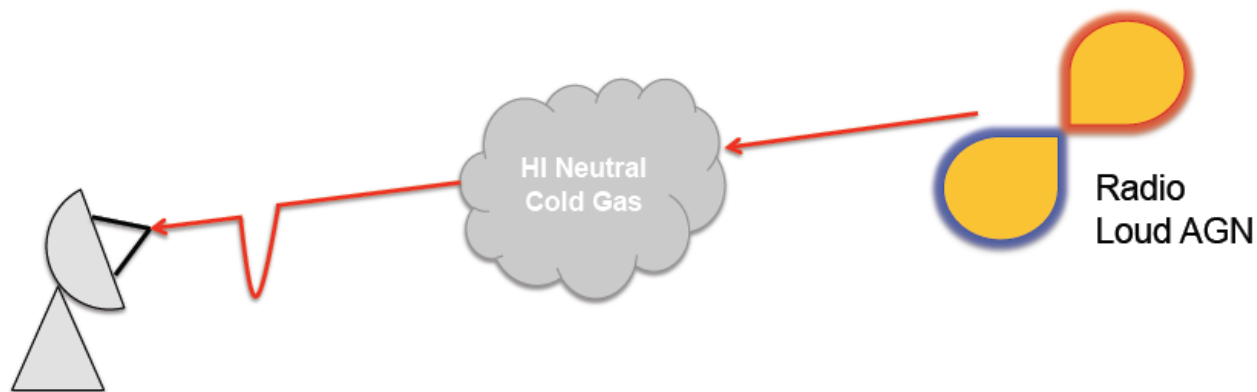
THE UNIVERSITY OF
SYDNEY



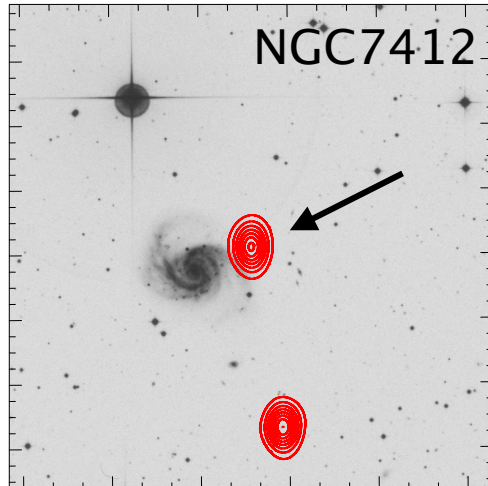


- HI absorption-line studies provide a **distance-independent** probe of the neutral gas in galaxies

$$N_{HI} \approx 1.823 \times 10^{18} \frac{T_S}{f} \int \tau_{obs}(v) dv$$

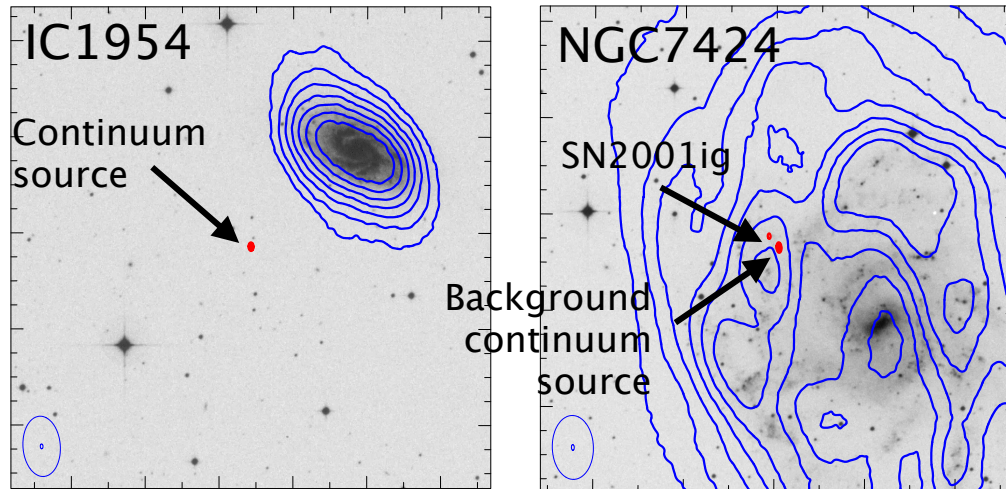


A search for intervening absorption in nearby galaxies

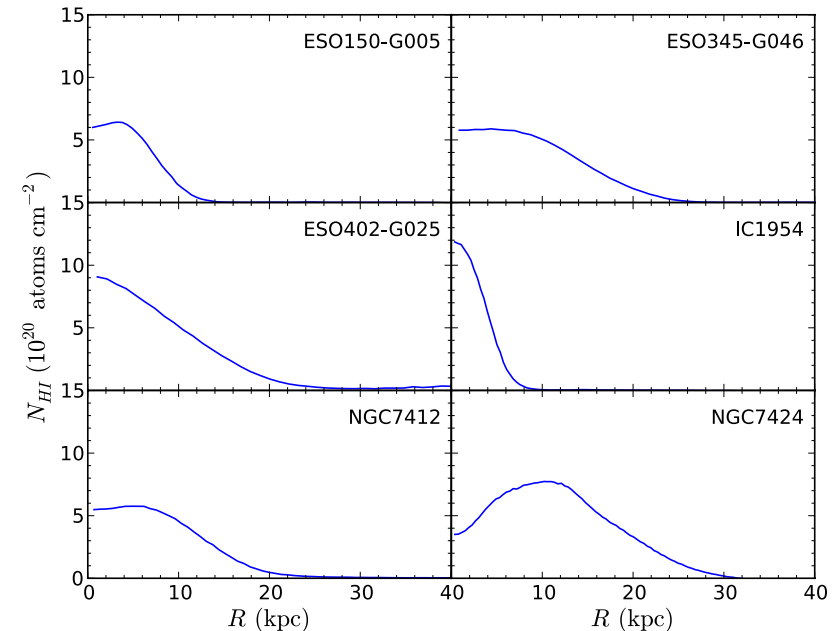


- Conducting a **targeted search** for intervening absorption with the ATCA
- Sample: **16 nearby, gas-rich galaxies** (selected from the HIPASS Bright Galaxy Catalogue; Koribalski et al. 2004)
- By targeting nearby galaxies we are able to simultaneously map the galaxies in HI - allows us to **directly relate gas distribution to the absorption-line detection rate**
- Investigate the detection rate of intervening absorption as a function of impact parameter
- Combined emission- and absorption-line data allows us to estimate the spin temperature of the gas

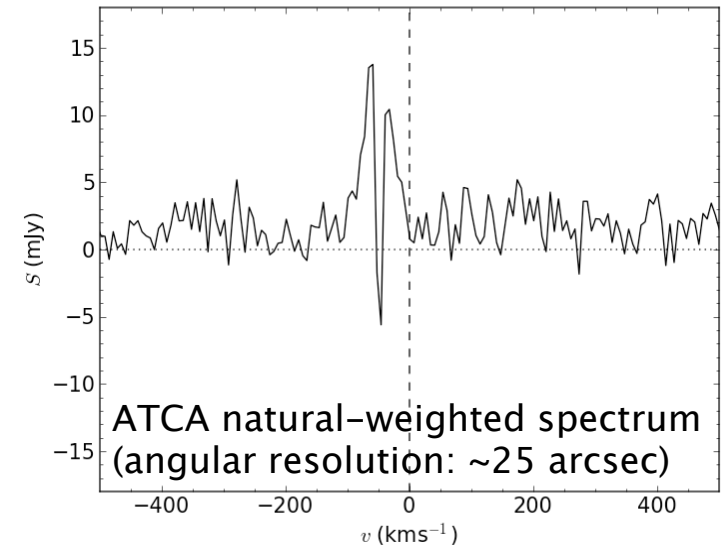
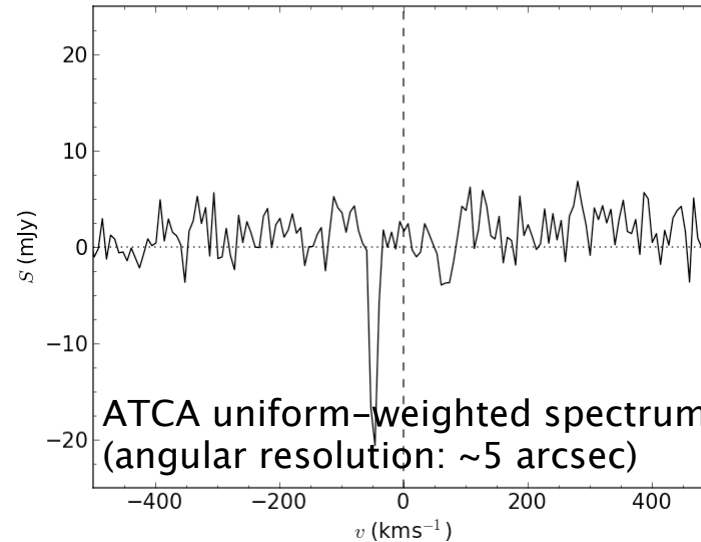
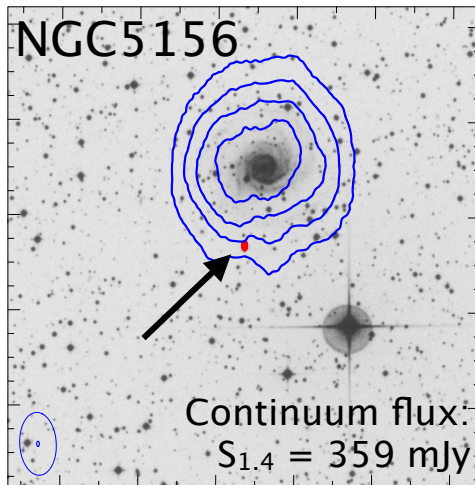




Blue contours: ATCA HI distribution
Greyscale: optical image (SuperCOSMOS)



- **7/15 sight-lines intersect the HI disk** of the foreground galaxy
- **One intervening absorption-line detection** (7% detection rate)
- Find low detection rate is largely due to the structure of the background sources
- This provides important information about the expected detection rate of future absorption-line surveys



- **Absorption-line:** optical depth $\tau_{\text{peak}} \sim 0.06$, line-width $\sim 13 \text{ km s}^{-1}$ (2 channels)
- **HI column density:** $N_{\text{HI}} \sim 1.1 \times 10^{21} \text{ cm}^{-2}$ (for $T_s/f = 100 \text{ K}$)
- **Spin temperature:** estimate $T_s/f \sim 160 \text{ K}$
- Currently conducting follow-up observations (high spectral resolution)

Further details:
POSTER 33

A spatially resolved chemodynamical analysis of Haro 11

B. James, Y. Tsamis, M. Barlow, J. Walsh & M. Westmoquette, 2013b, MNRAS

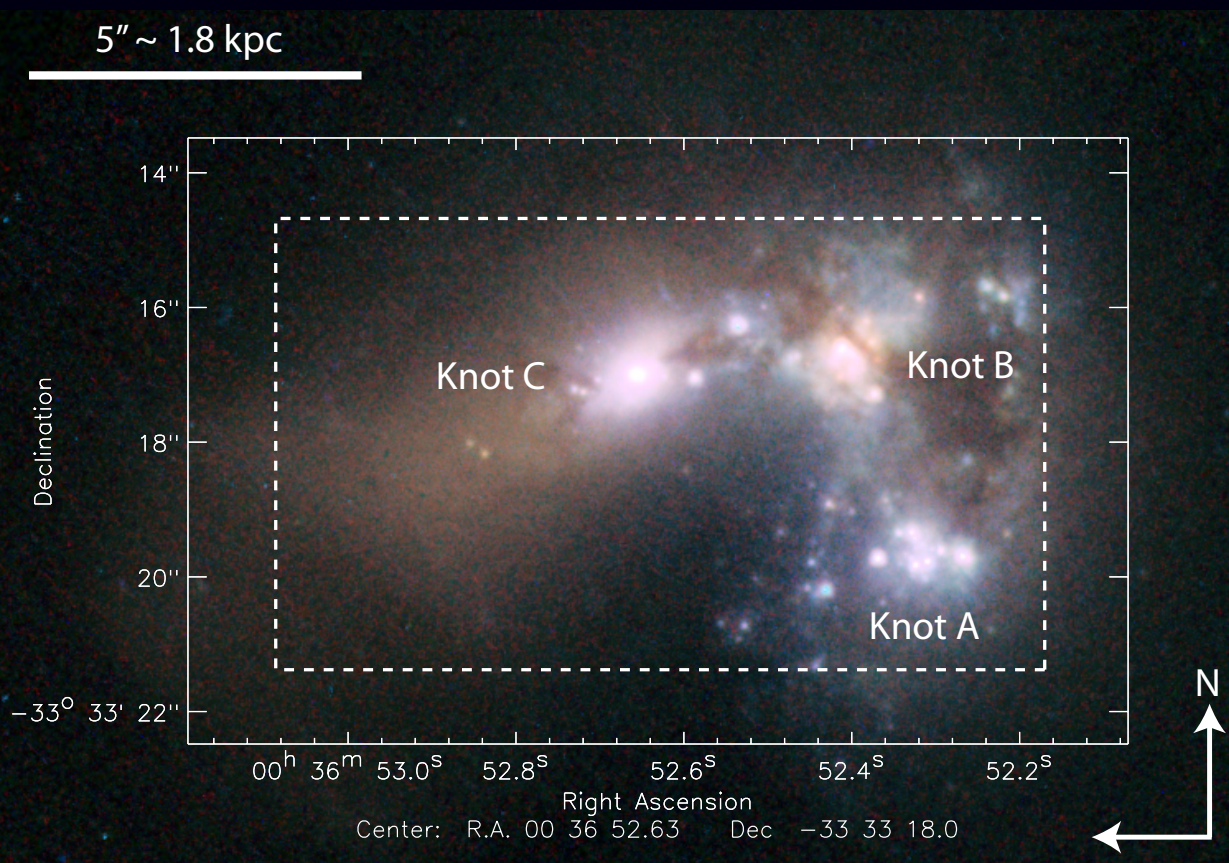
VLT-FLAMES IFU observations:

11.5" x 7.3" FoV

0.52" spaxels

3620Å → 7180Å

5" ~ 1.8 kpc



Property	Value	Reference
RA (J2000)	00h36'52.5"	NED ^a
Dec (J2000)	-33deg33'19"	NED ^a
z	0.020558	this work
Distance / Mpc	83.6	this work ^b
Velocity / km s ⁻¹	6146±17	this work
Stellar mass / M _⊙	~10 ¹⁰	Adamo et al. (2010)
Gas mass / M _⊙	2 × 10 ⁹	Bergvall et al. (2000)
Cluster masses / M _⊙	10 ³ -10 ⁶	Adamo et al. (2010)
Present SFR / M _⊙ yr ⁻¹	22±3	Adamo et al. (2010)
L_{IR} / L_{\odot}	1.9 × 10 ¹¹	Bergvall et al. (2000)

ACS-HRC F220W, F330W & F814W, with ACS-WFC F435W and F550W

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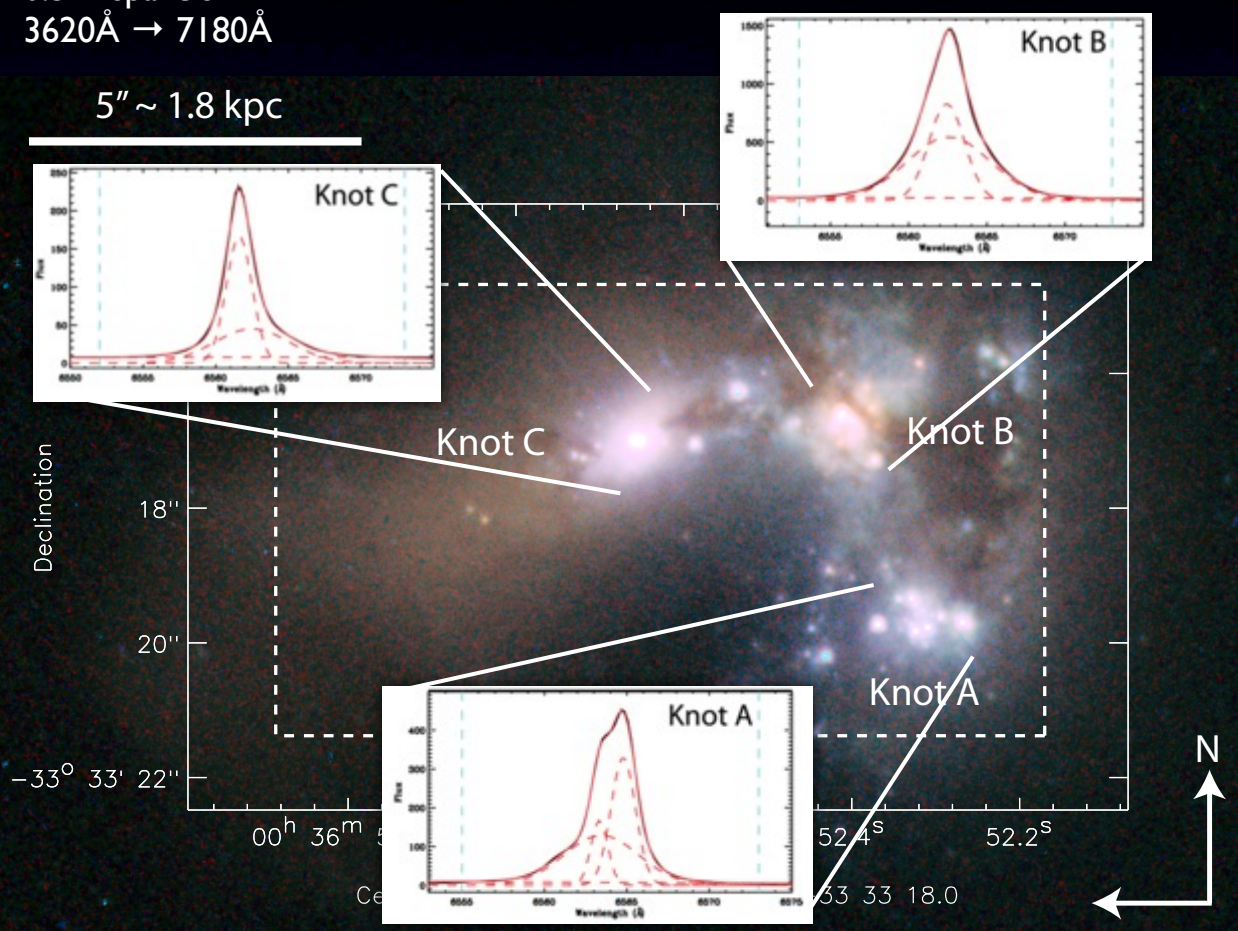
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Gas mass / M_{\odot}	2×10^9	Bergvall et al. (2000)
Cluster masses / M_{\odot}	$10^3 - 10^6$	Adamo et al. (2010)
Present SFR / $M_{\odot} \text{ yr}^{-1}$	22 ± 3	Adamo et al. (2010)
$L_{\text{IR}} / L_{\odot}$	1.9×10^{11}	Bergvall et al. (2000)

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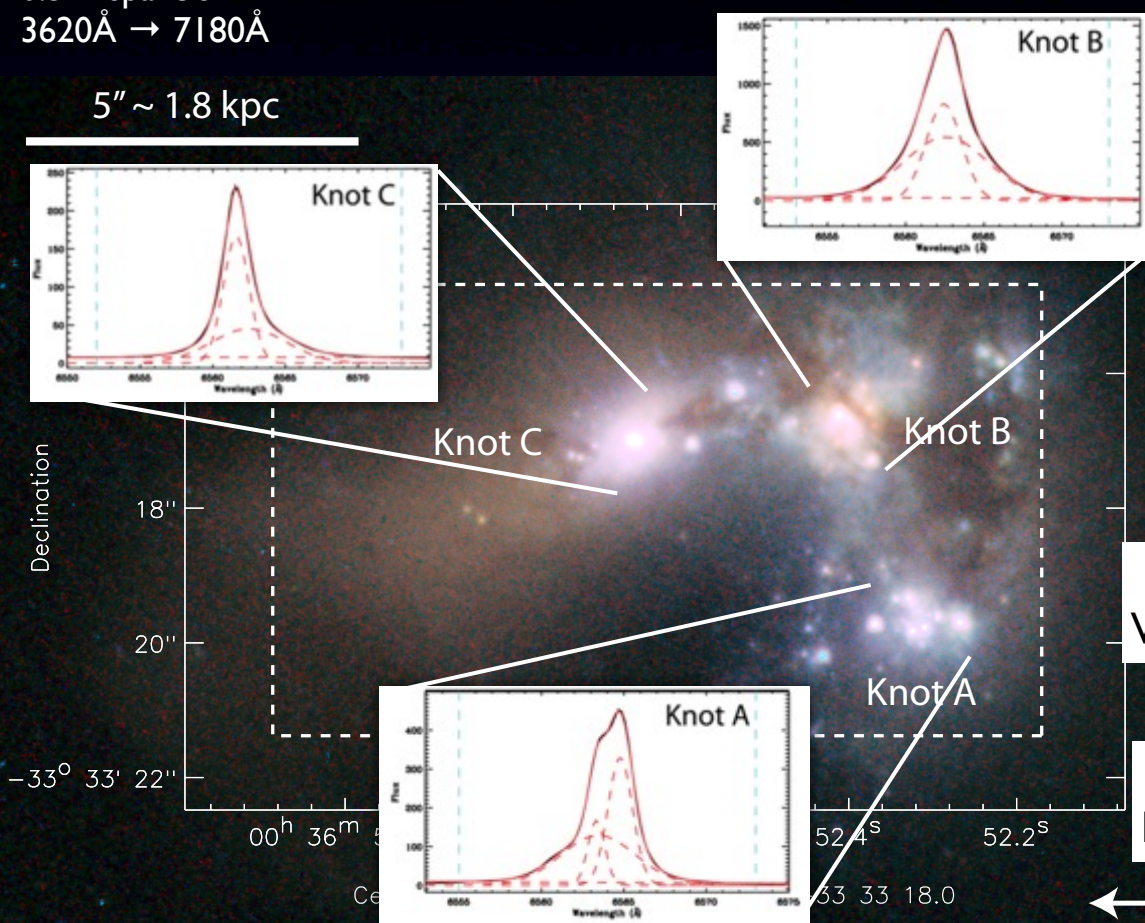
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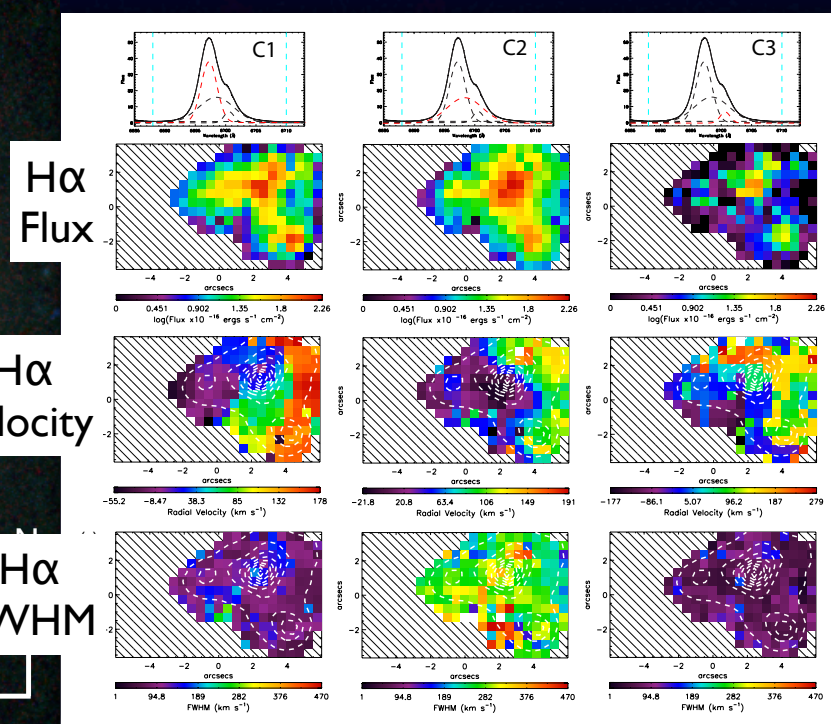
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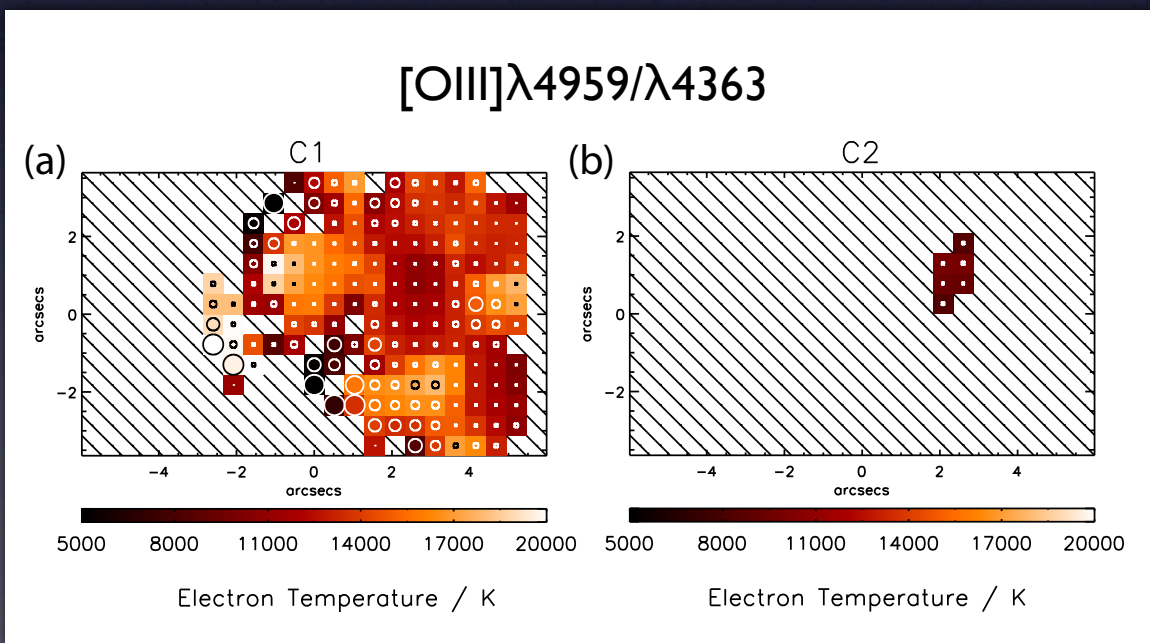
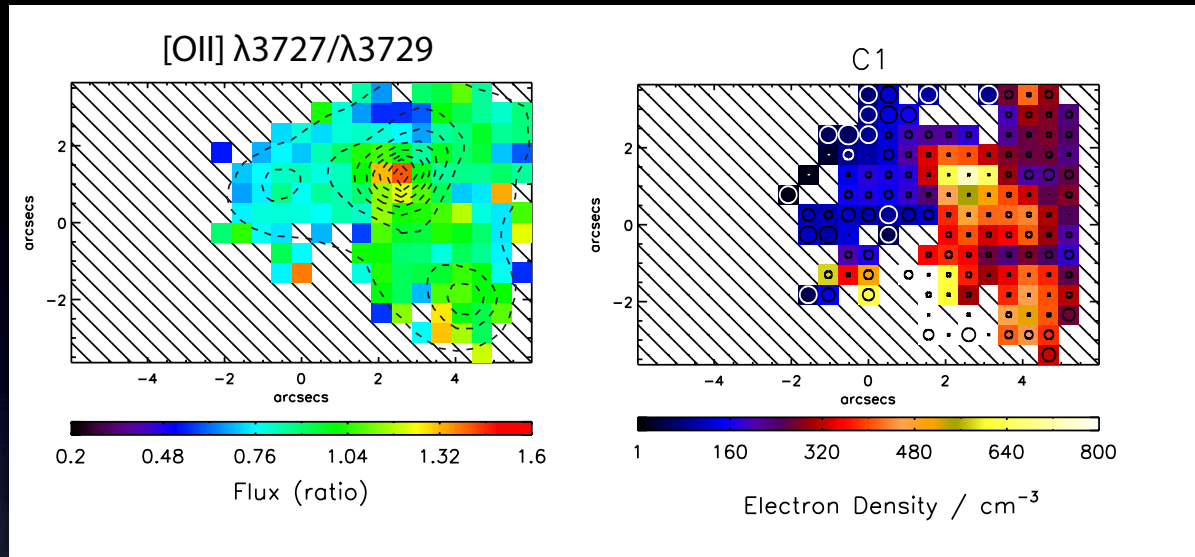
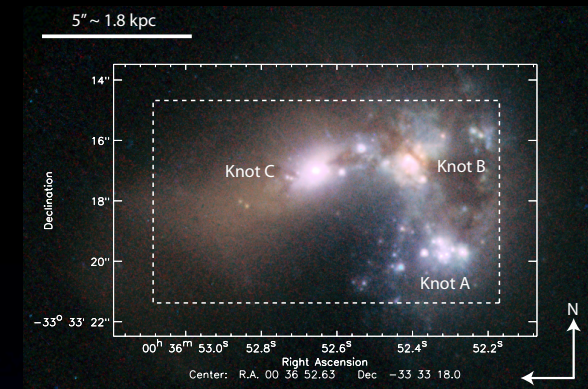


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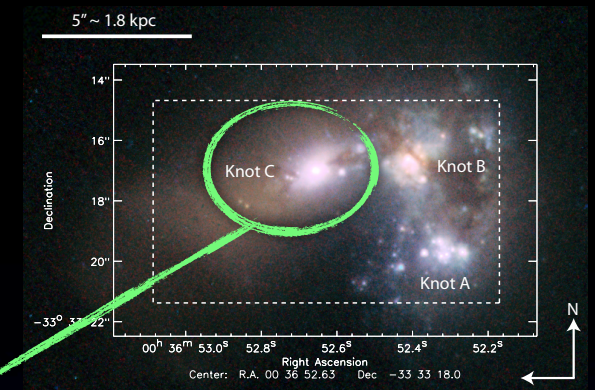
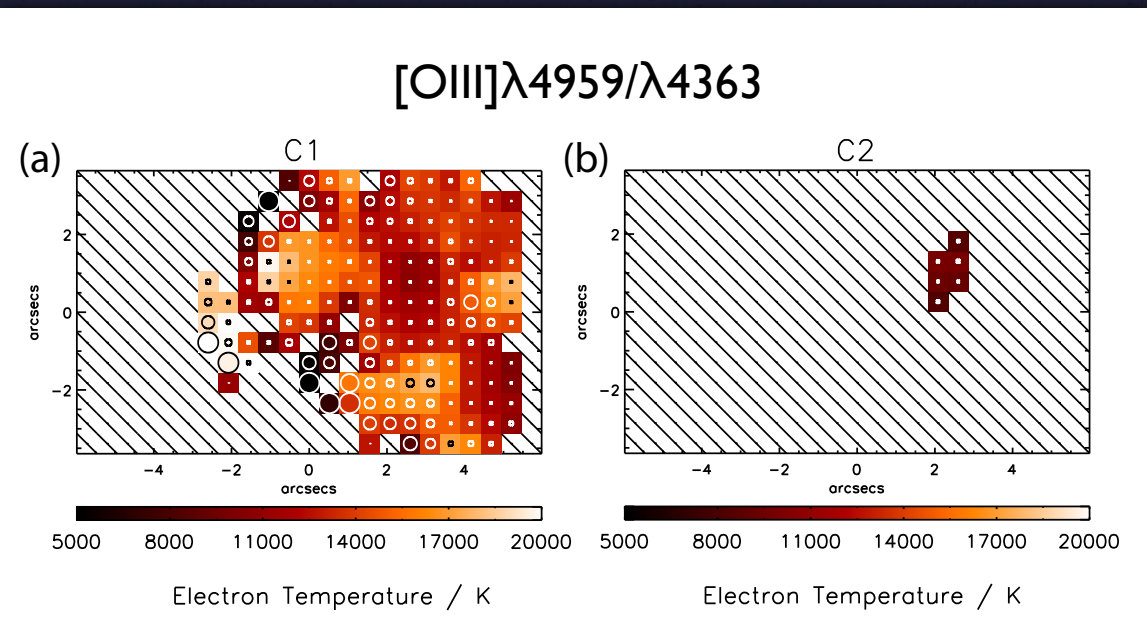
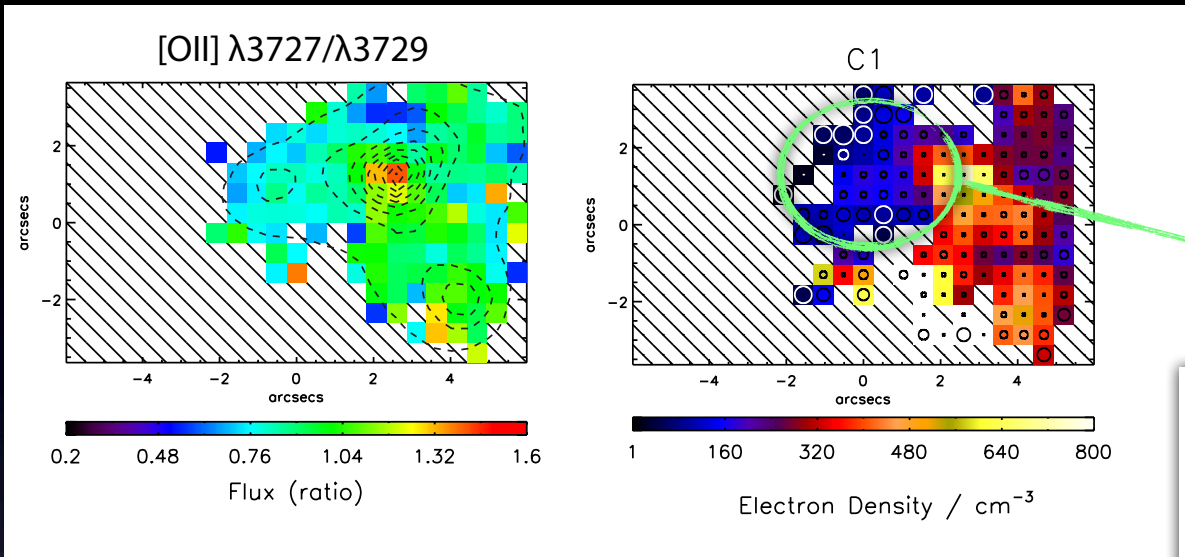


ACS-HRC F220W, F330W & F814W, with ACS-WFC F435W and F550W

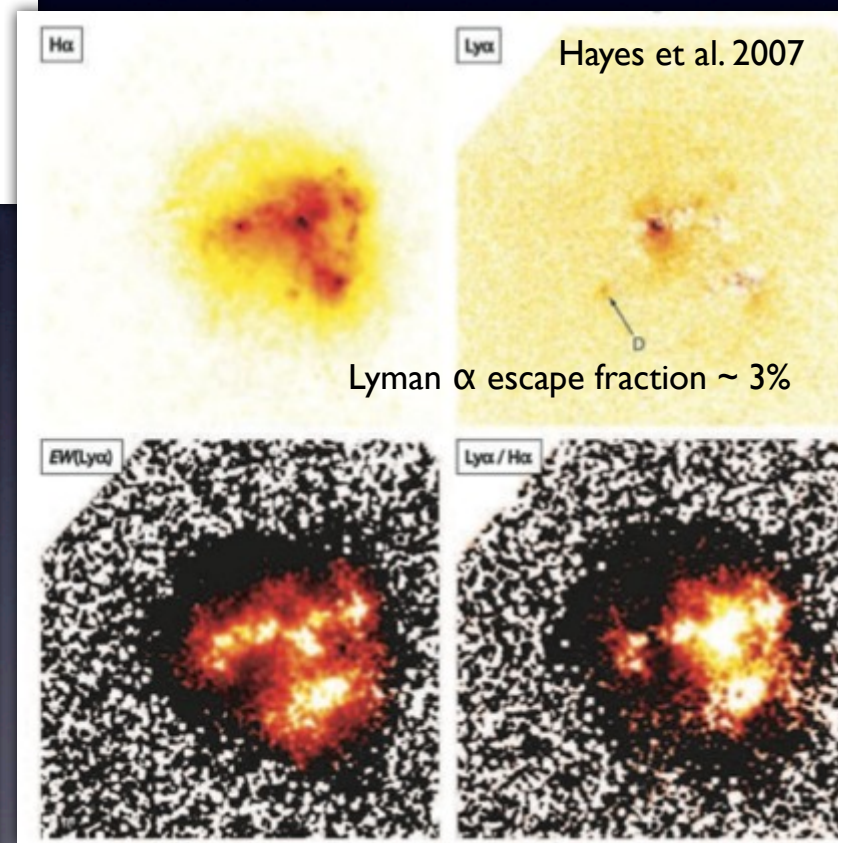
Haro 11: Electron Temperature and Density Maps



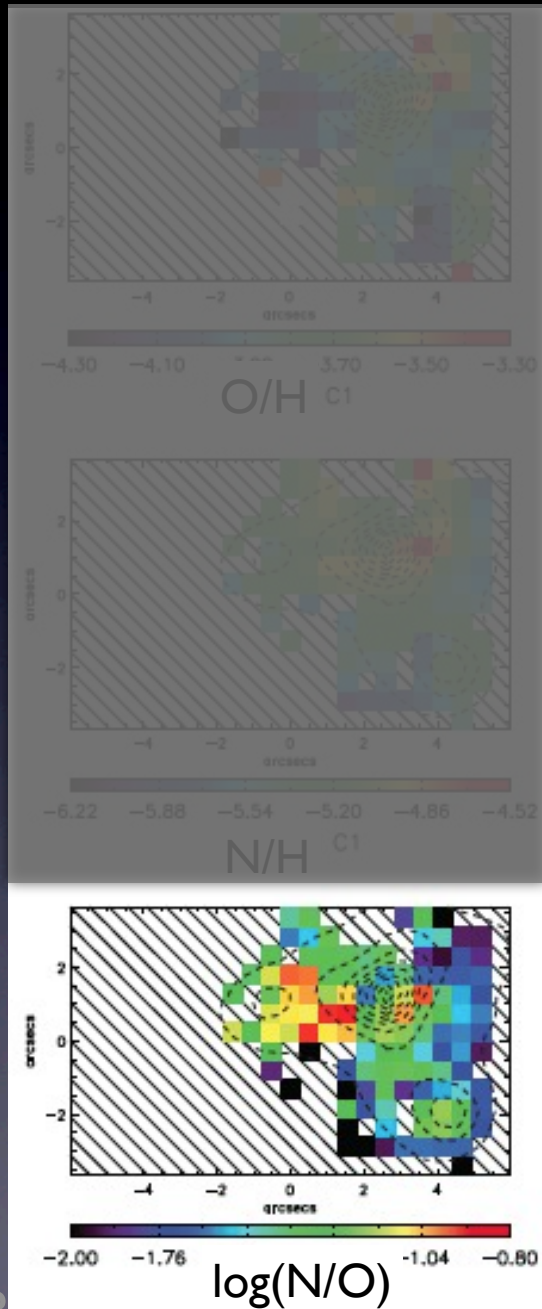
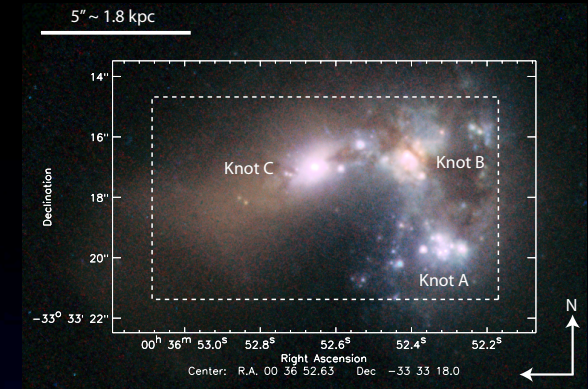
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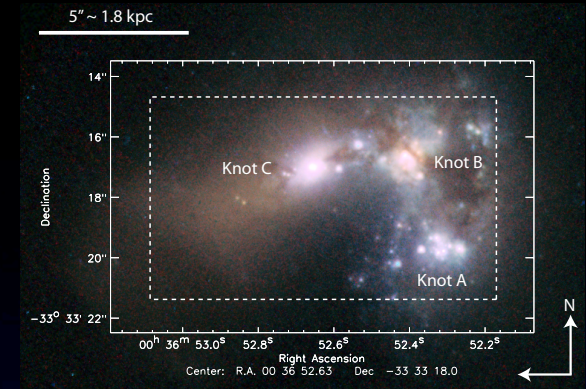
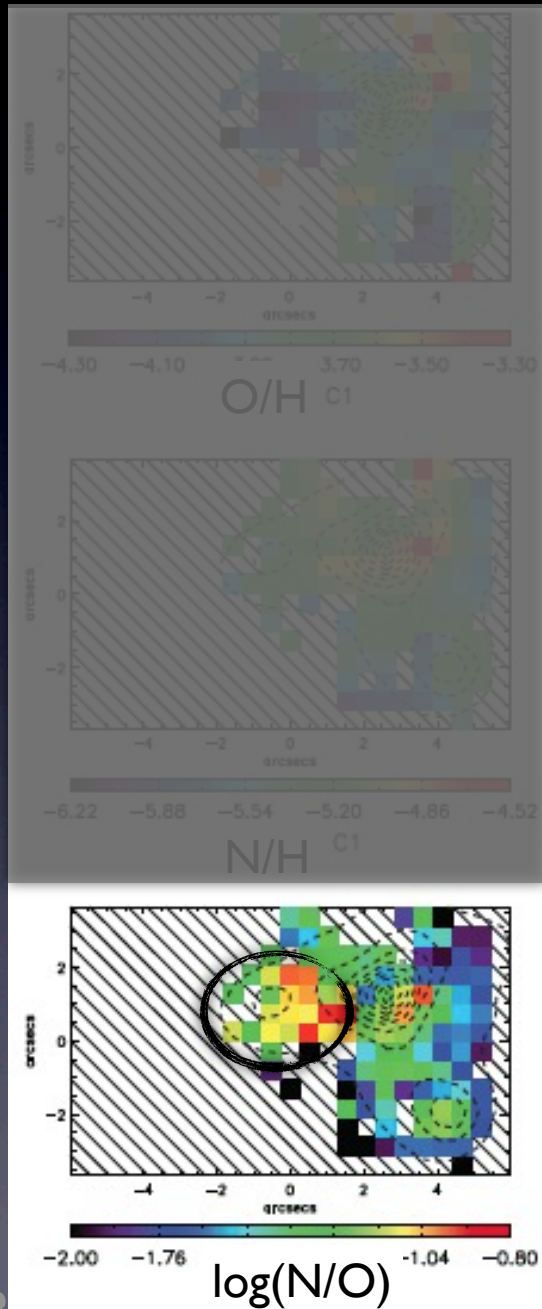
Escape of Ly α photons



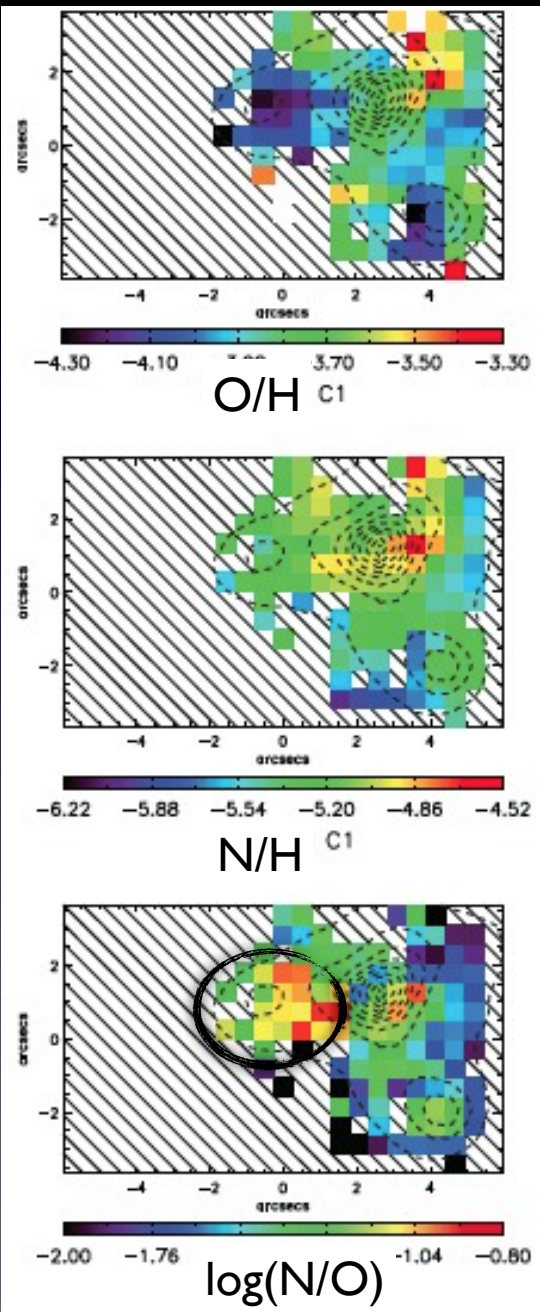
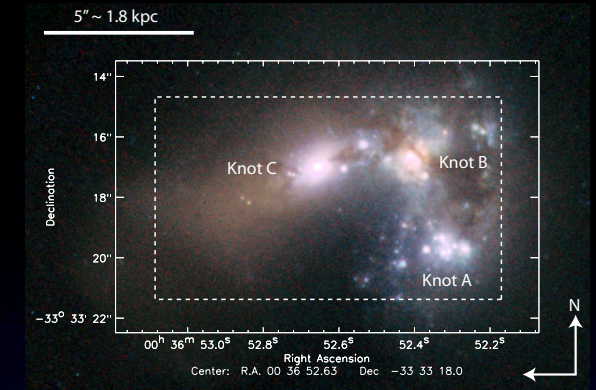
Haro I : N enrichment?



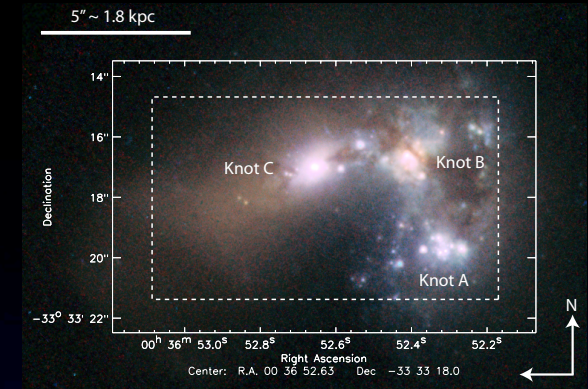
Haro I : N enrichment?



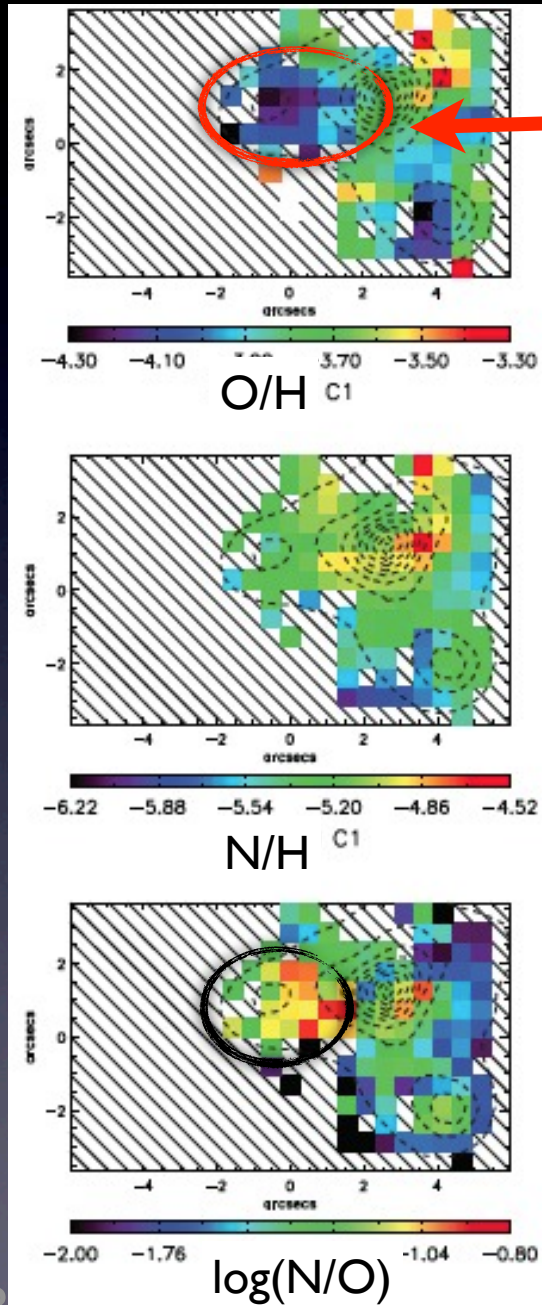
Haro 11: N enrichment?



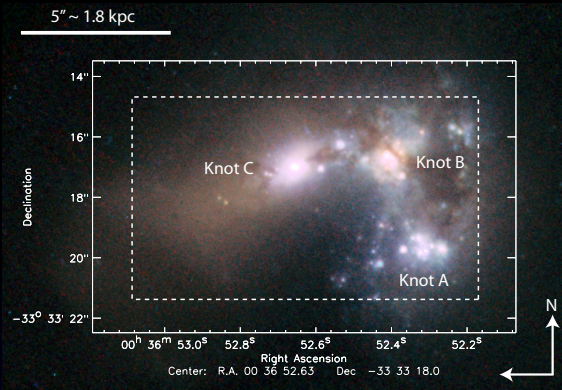
Haro 11: N enrichment?



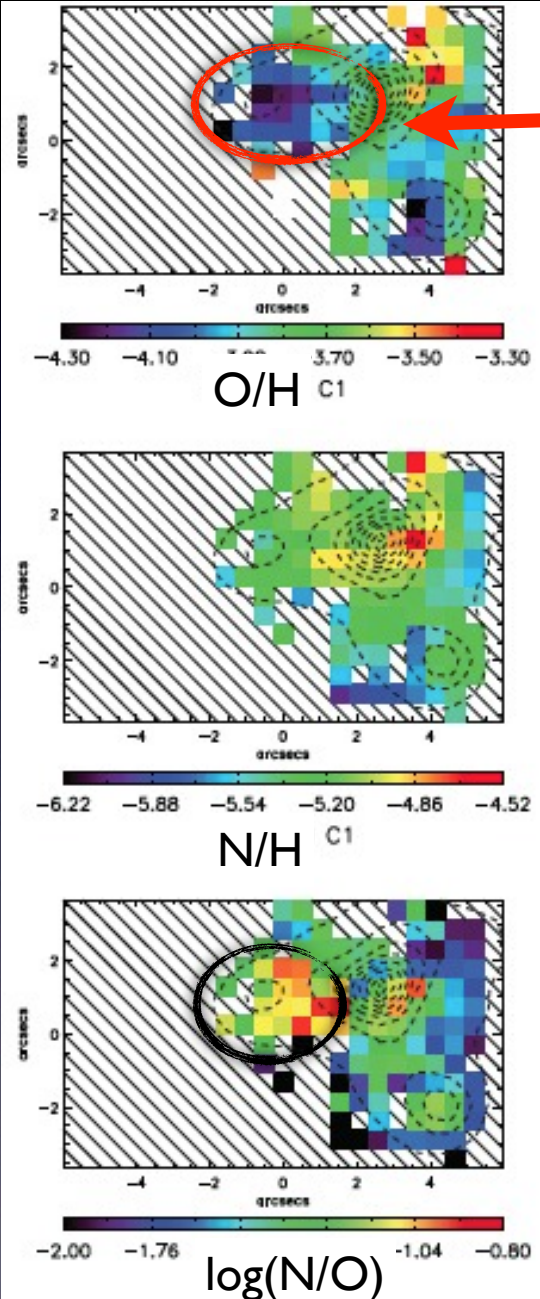
Accretion of metal-poor gas?
Outflow of O-enriched gas?



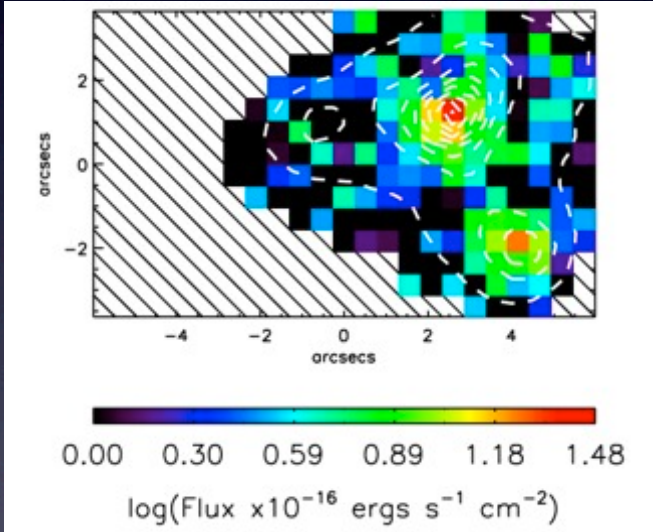
Haro I : N enrichment?



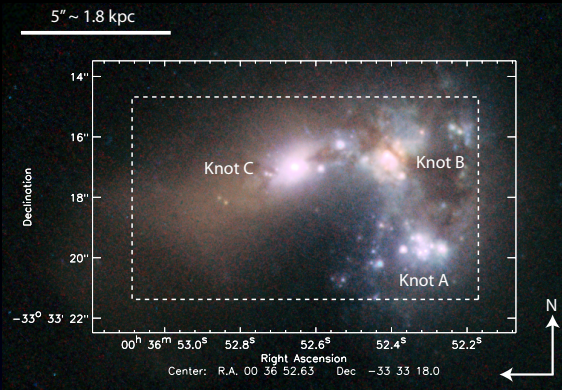
Accretion of metal-poor gas?
Outflow of O-enriched gas?



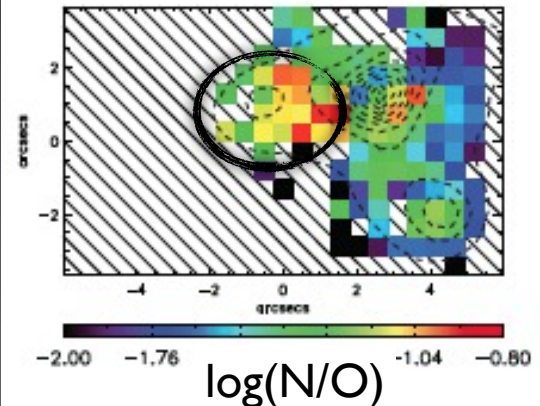
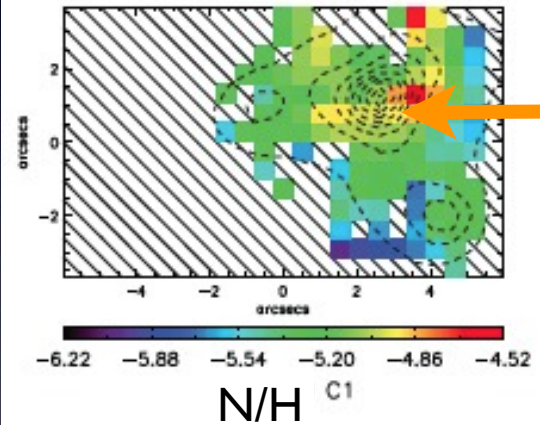
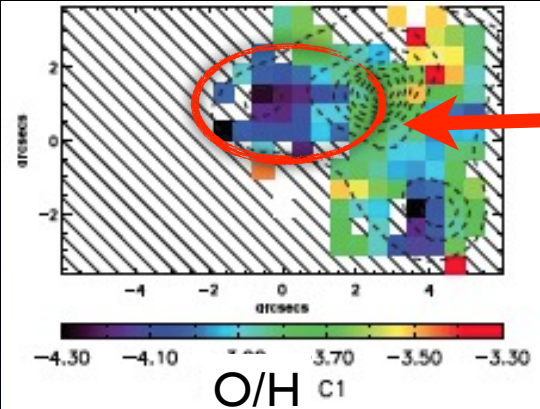
WR emission



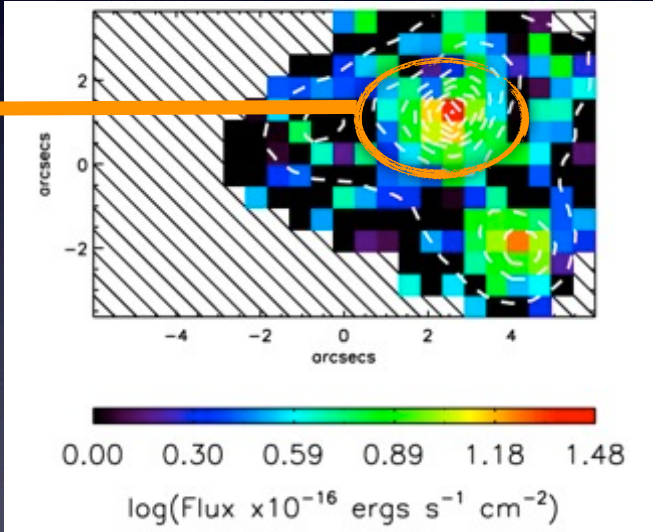
Haro 11: N enrichment?



Accretion of metal-poor gas?
Outflow of O-enriched gas?

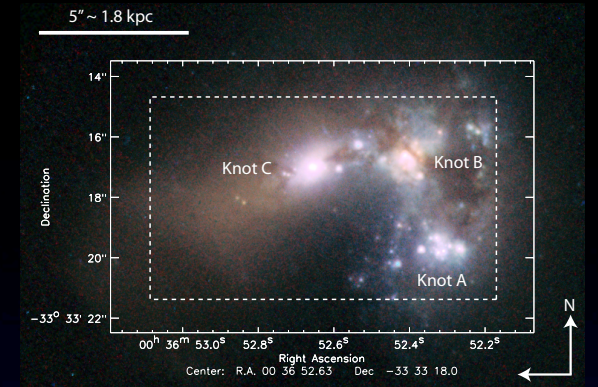


WR emission



Ejecta of WR stars haven't had time to cool/mix?
Spatial resⁿ not high enough to see N/O enhancement?

Haro 11: N enrichment?



Poster #14

ESO VLT-VIMOS & VLT-FLAMES present:
Spatially resolved chemodynamics of high N/O BCGs
 Bethan James, Yannis Tsanis, Jeremy Walsh, Mike Barlow & Mark Westmoquette

This poster summarises a series of publications concerning spatially resolved chemical abundances analyses of a sample of blue compact galaxies (BCGs), using VLT-FLAMES and VLT-VIMOS observations. Four galaxies were previously labelled as having enhanced N/O ratios for their metallicity. However, our analyses reveal regions of elevated N/O in only three of these galaxies. The VLT observations provide maps of the physical and chemical conditions within each system, along with maps of stellar population age, star-forming rate and Wolf-Rayet emission. By combining this plethora of information, we attempted to disentangle the relationship between N-enrichment and WR stars, and reveal that it is far from being one-to-one.

The sample: four BCGs for which our data reported high N/O: Mrk 996, UM 420, UM 448 & Haro 11

The Methodology:

- Local wavelength FUV data from VLT-FLAMES & VLT-VIMOS
- Stars with different physical properties were seen along each sight line → Physical model decomposed, and a separate chemical abundance analysis was performed on each velocity component → **chemodynamical** approach
- Electron temperature (T_e) and density (N_e) maps were used to create chemical abundance maps → each star/region has its own unique set of physical conditions.

1. Misdiagnosed high N/O status
 The widely quoted analysis revealed a normal N/O ratio for UM420 (or by mistake, by James et al. 2012). This is because observed features from emission lines can suffer from luminosity weighting. In fact, in each galaxy we found a significant difference in chemical abundances derived from spectra integrated over the entire galaxy and those derived from regional star ages across abundance maps.

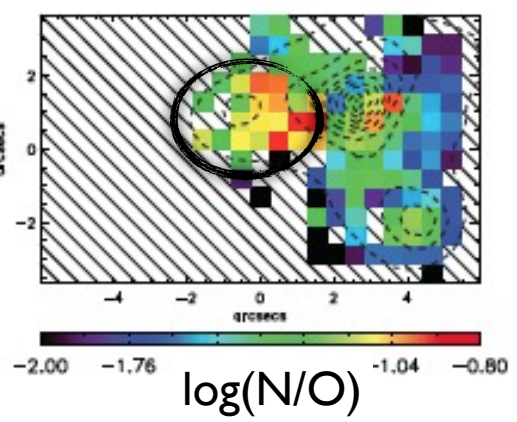
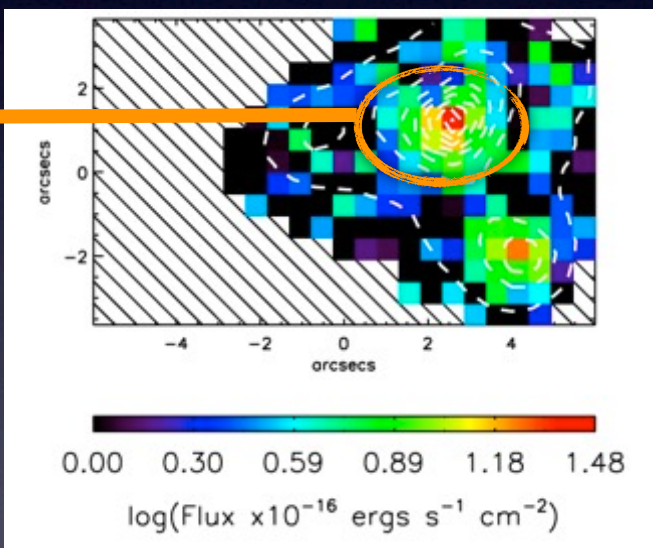
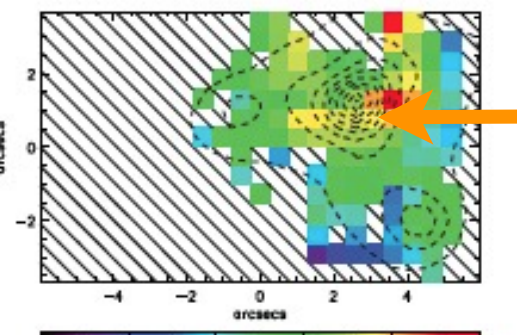
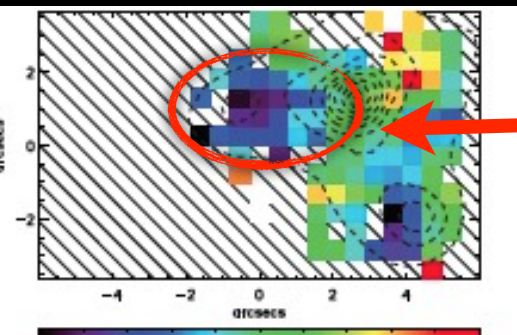
2. High N/O + WR stars
 We found that three scenarios were at play...
 • **Mrk996** - elevated N-enrichment to the broad component seen in the optical James et al. 2009. The elevated N/O in the WR stars is likely a result of a younger stellar population (WR stars are known to be located in environments of young stars).
 • **UM 448** - elevated N/O in the broad component. The elevated N/O in the WR stars is likely a result of a younger stellar population (WR stars are known to be located in environments of young stars).

3. Perturbed BCGs with & without WR stars
UM448: A region of increased N/O is located in a region of the galaxy that is not the broad component but no WR emission was detected (James et al. 2013b). The region of high N/O coincides with an area of lower C/H. Kinematical and stellar age maps suggest the observed C/H is due to accretion of metal-poor gas (flowing) from an interaction and/or merger between the two bodies.
Haro11: A region of elevated N/O is located in a region of the galaxy that is not the broad component and a lower C/H than the rest of the galaxy, along with an elevated N/O. However, WR stars are found in Knots A and B. The elevated N/O in the WR stars is likely a result of a younger stellar population (WR stars are known to be located in environments of young stars). The elevated N/O in the WR stars is likely a result of a younger stellar population (WR stars are known to be located in environments of young stars).

Spatially resolved chemodynamical analyses are essential in (i) deriving accurate chemical abundances and (ii) isolating regions of chemical enrichment. Detecting both WR features and enhanced N/O is a function of starburst age and the properties of the surrounding medium.

Accretion of metal-poor gas?
 Outflow of O-enriched gas?

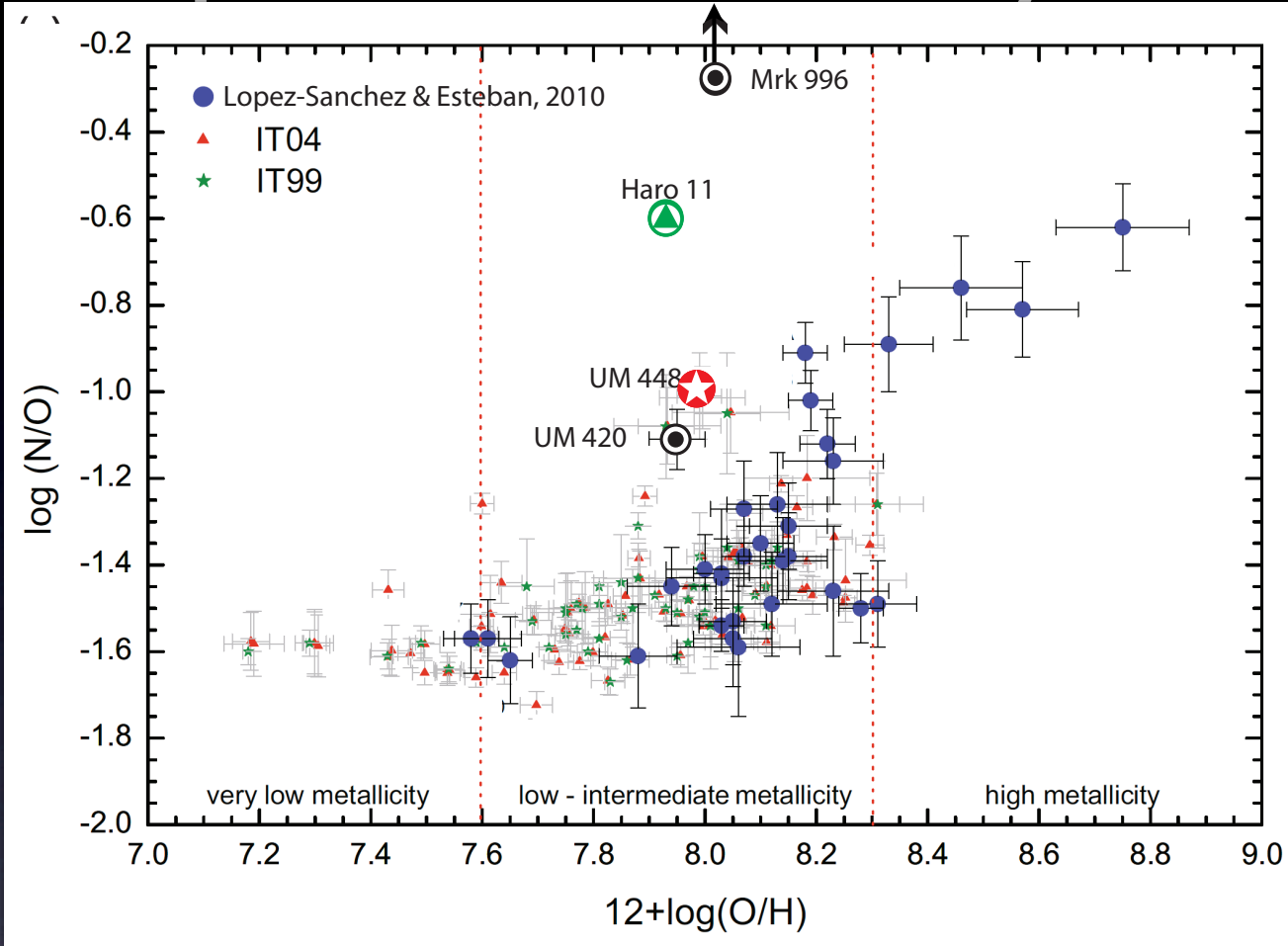
WR emission



Ejecta of WR stars haven't had time to cool/mix?
 Spatial resⁿ not high enough to see N/O enhancement?

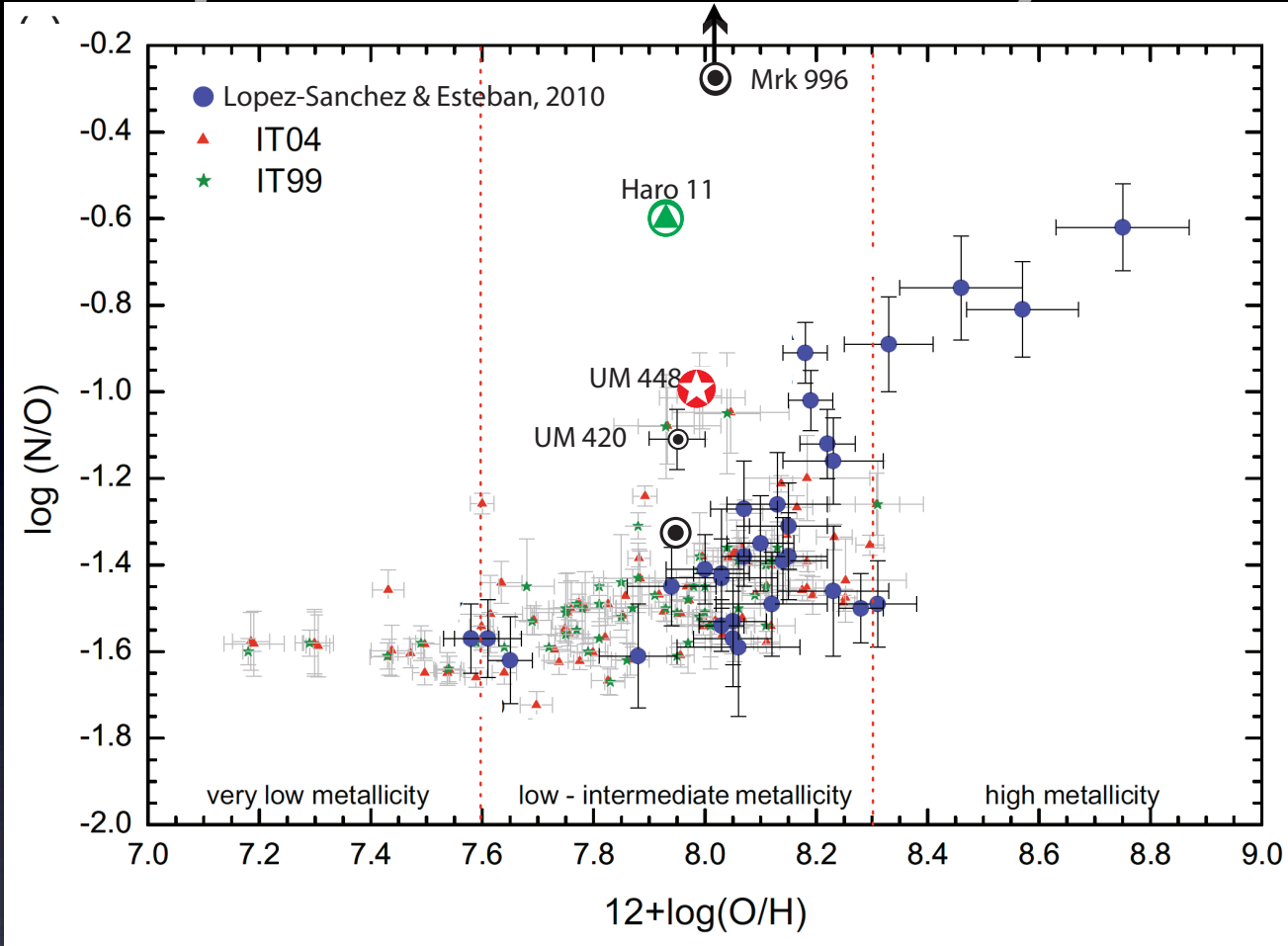
Poster #14

Impact of IFU Analysis



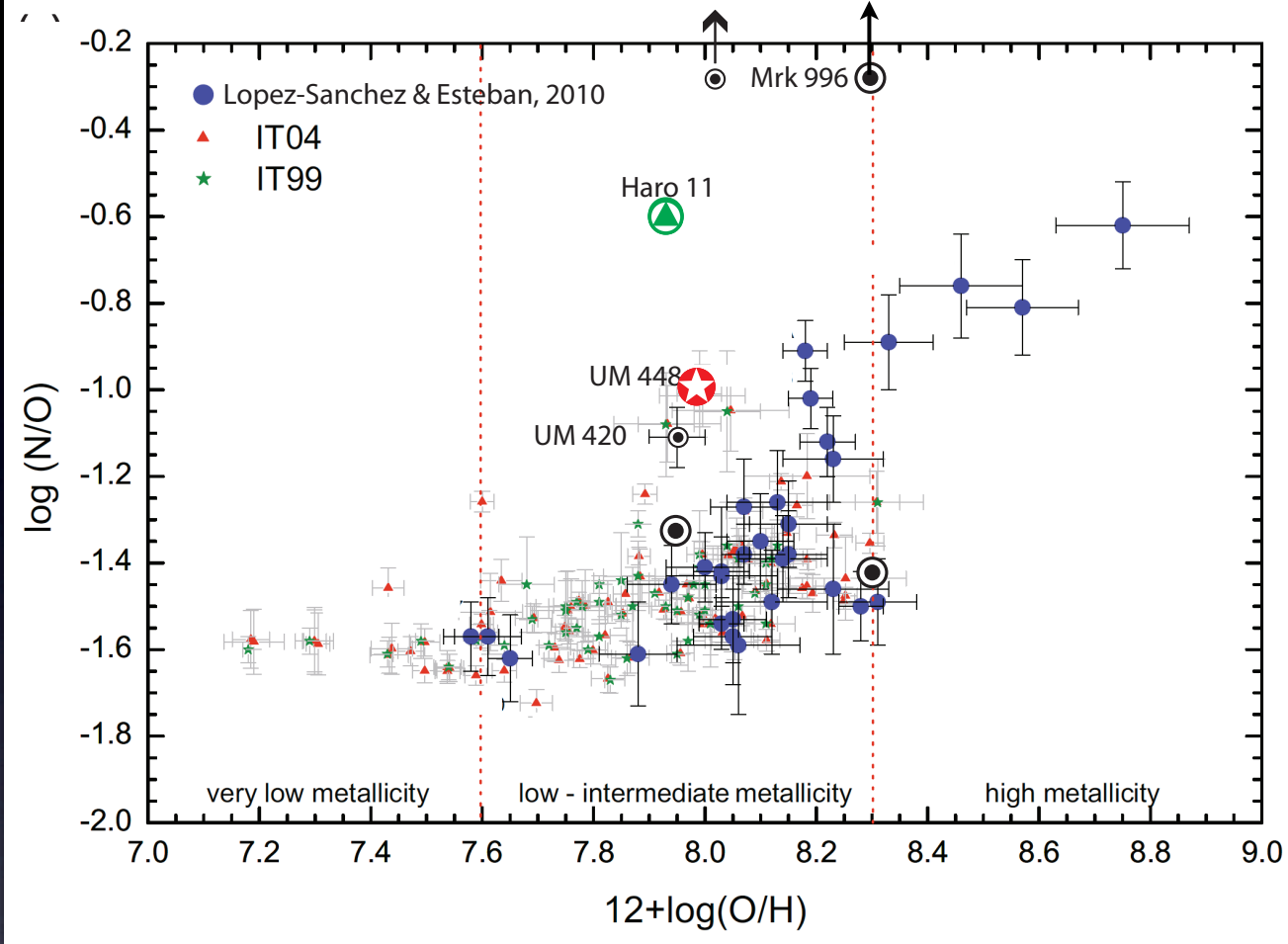
Poster #14

Impact of IFU Analysis



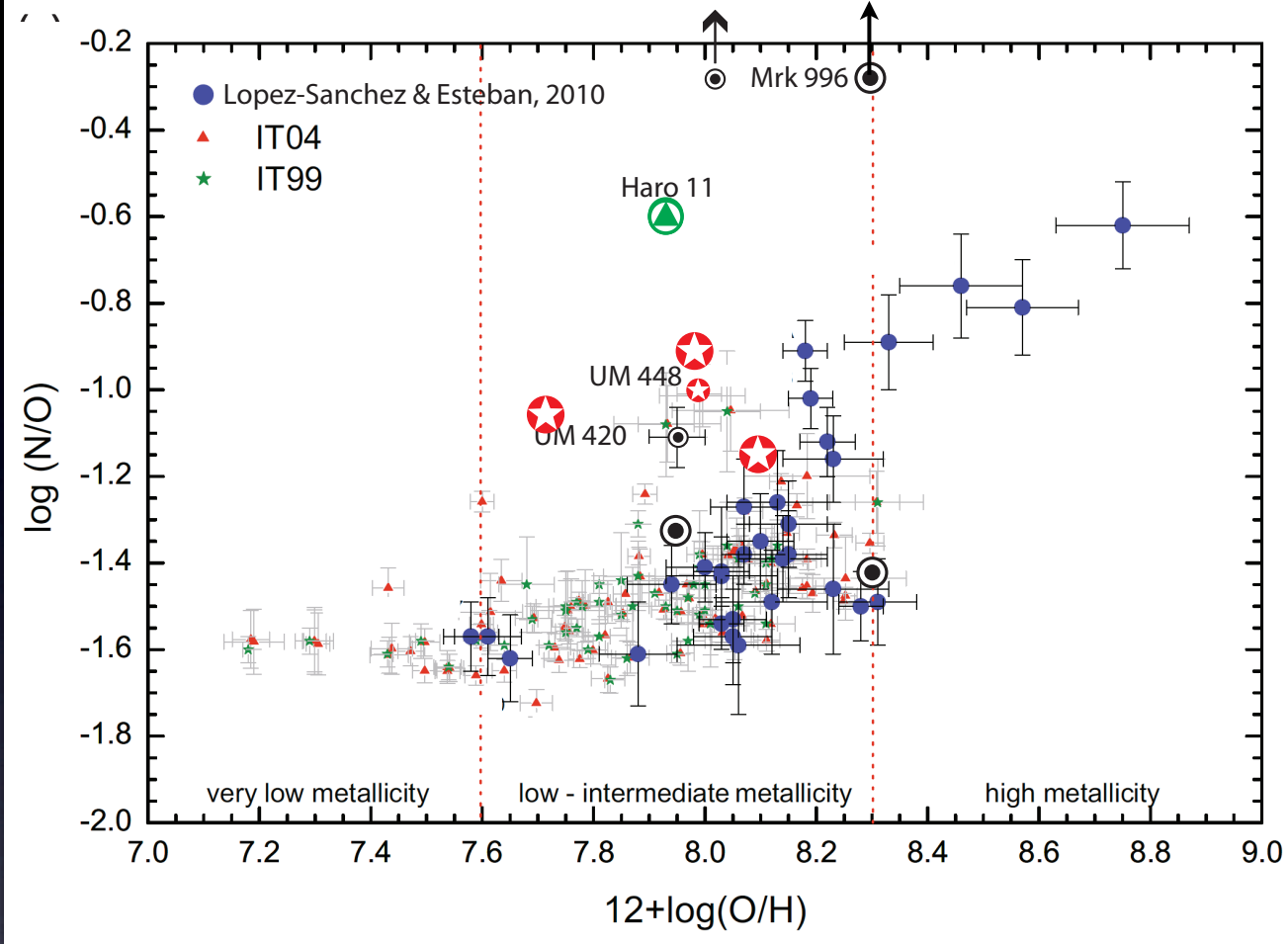
Poster #14

Impact of IFU Analysis



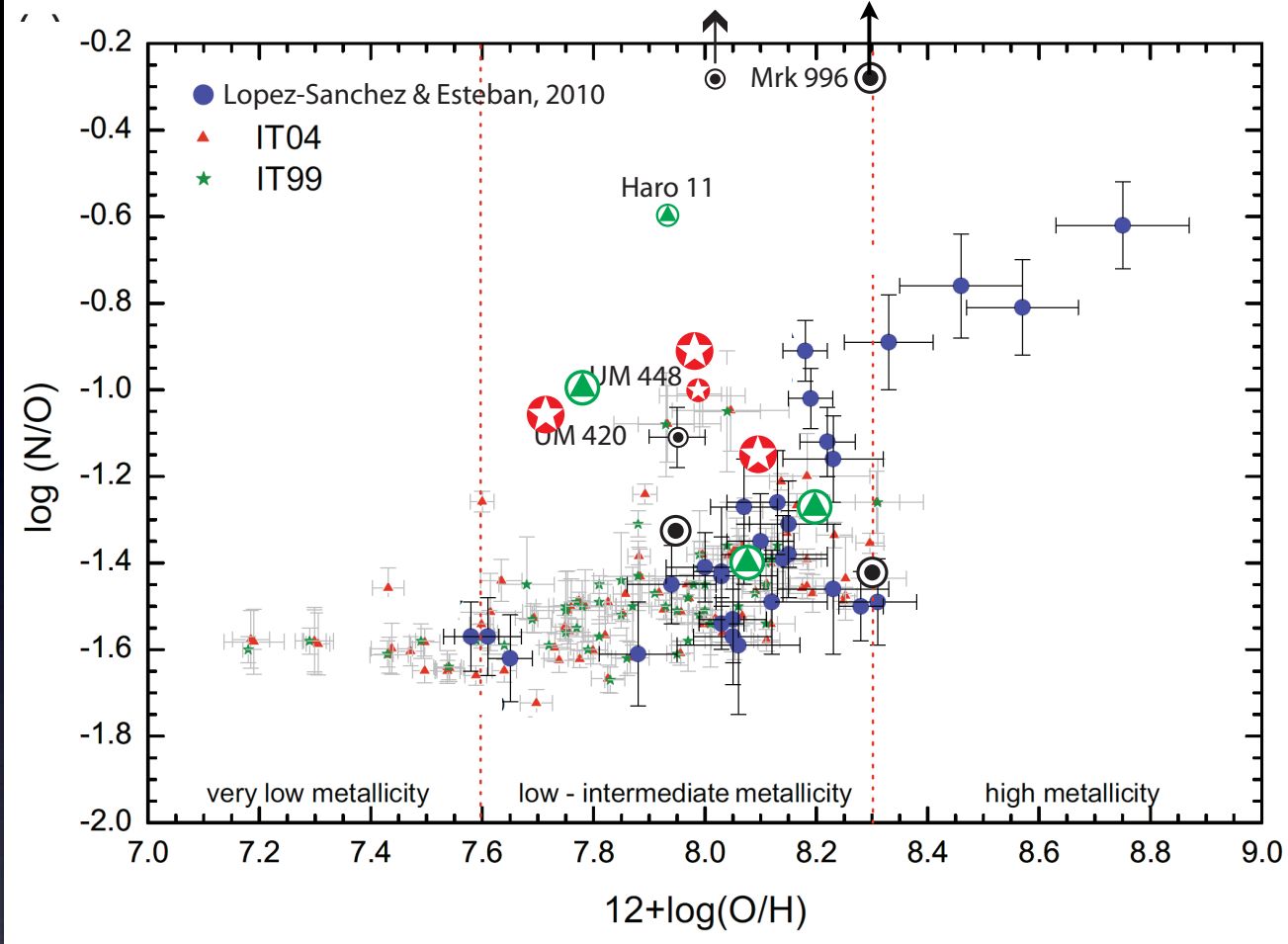
Poster #14

Impact of IFU Analysis



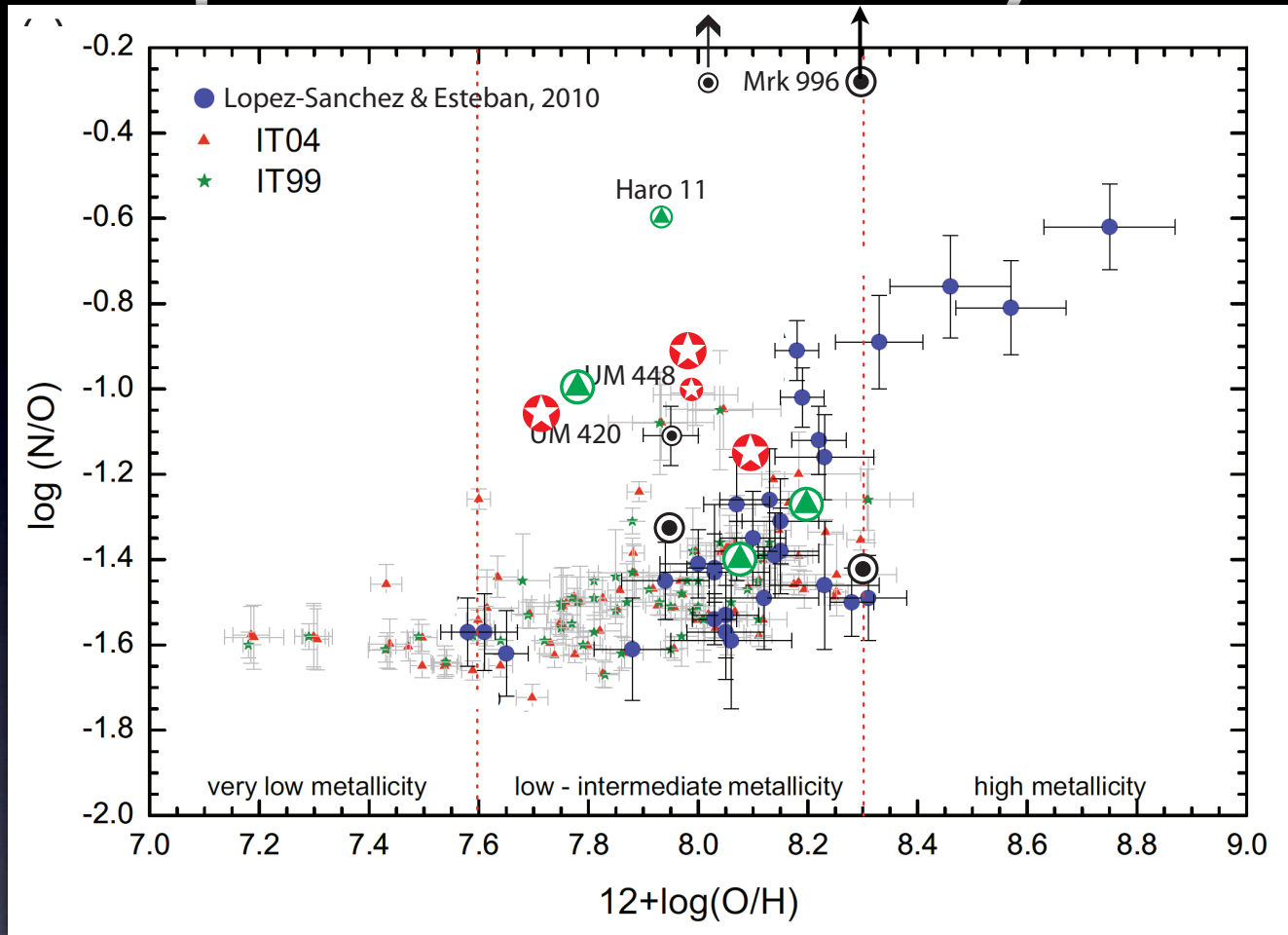
Poster #14

Impact of IFU Analysis



Poster #14

Impact of IFU Analysis



Spatially resolved, multi-component spectroscopic analyses
→ revised metallicities + isolate localised N-enrichment

Can we rely on luminosity-weighted measurements (i.e. long-slit, global spectra etc)
to reliably represent the physical properties of high-z galaxies?

See: e.g. Kobulnicky et al. 1999, Pilyugin et al. 2012, Perez-Montero et al. 2011.



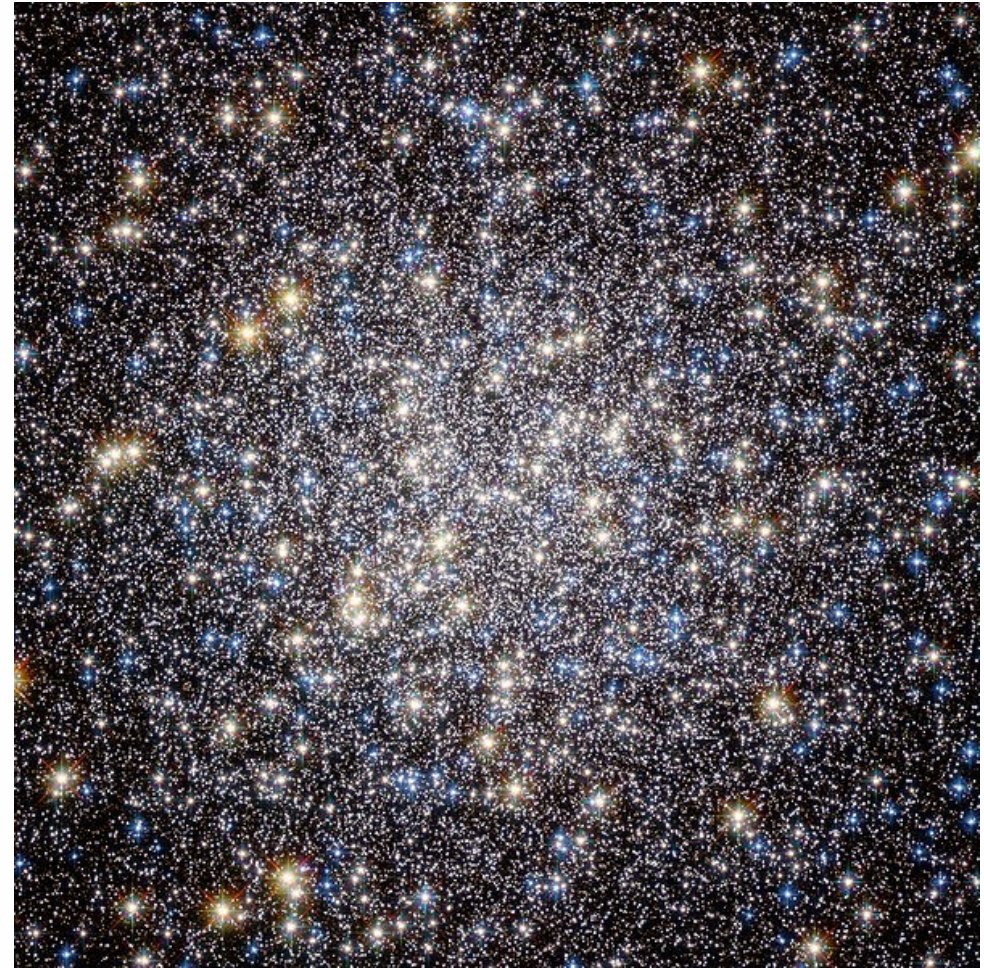
Crowded Field 3D Spectroscopy in Globular Clusters



Sebastian Kamann
Stefan Dreizler
Tim-Oliver Husser
Andreas Kelz
Martin Roth
Peter Weilbacher
Lutz Wisotzki

**Leibniz-Institut
für Astrophysik Potsdam (AIP)**

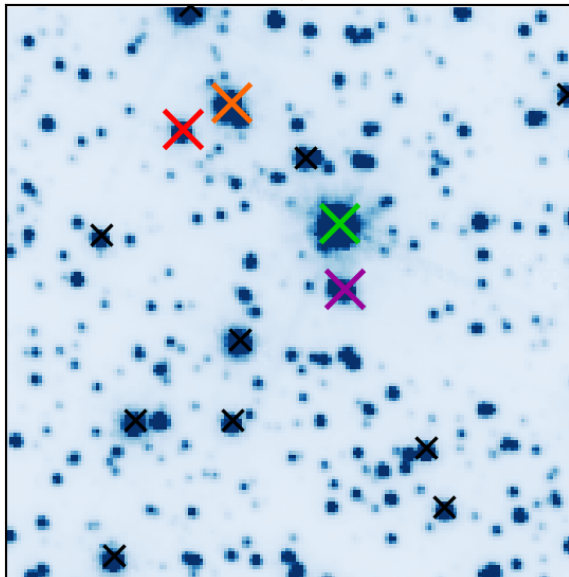
**Institut für Astrophysik,
Universität Göttingen (IAG)**



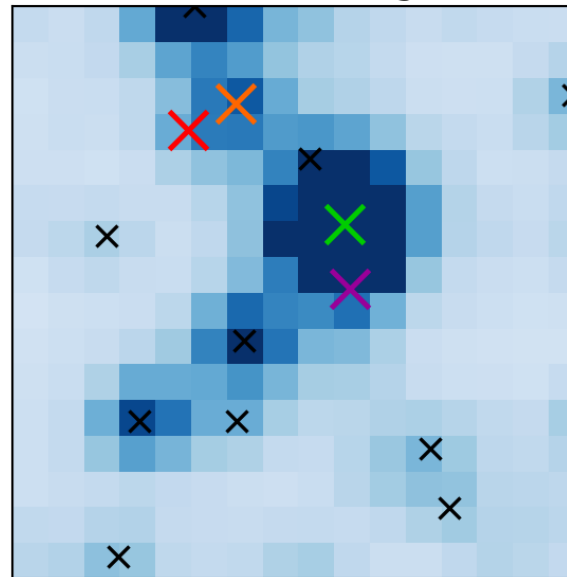
M13

3D spectroscopy in M13 with PMAS

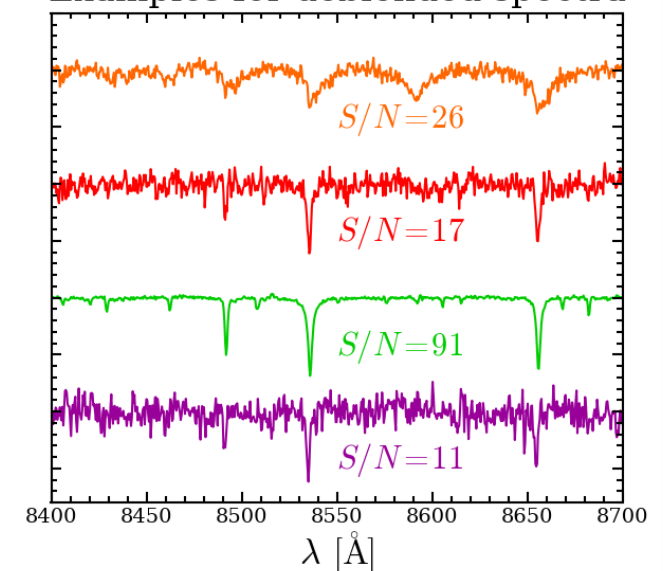
HST/ACS, F606W



PMAS, whitelight



Examples for deblended spectra

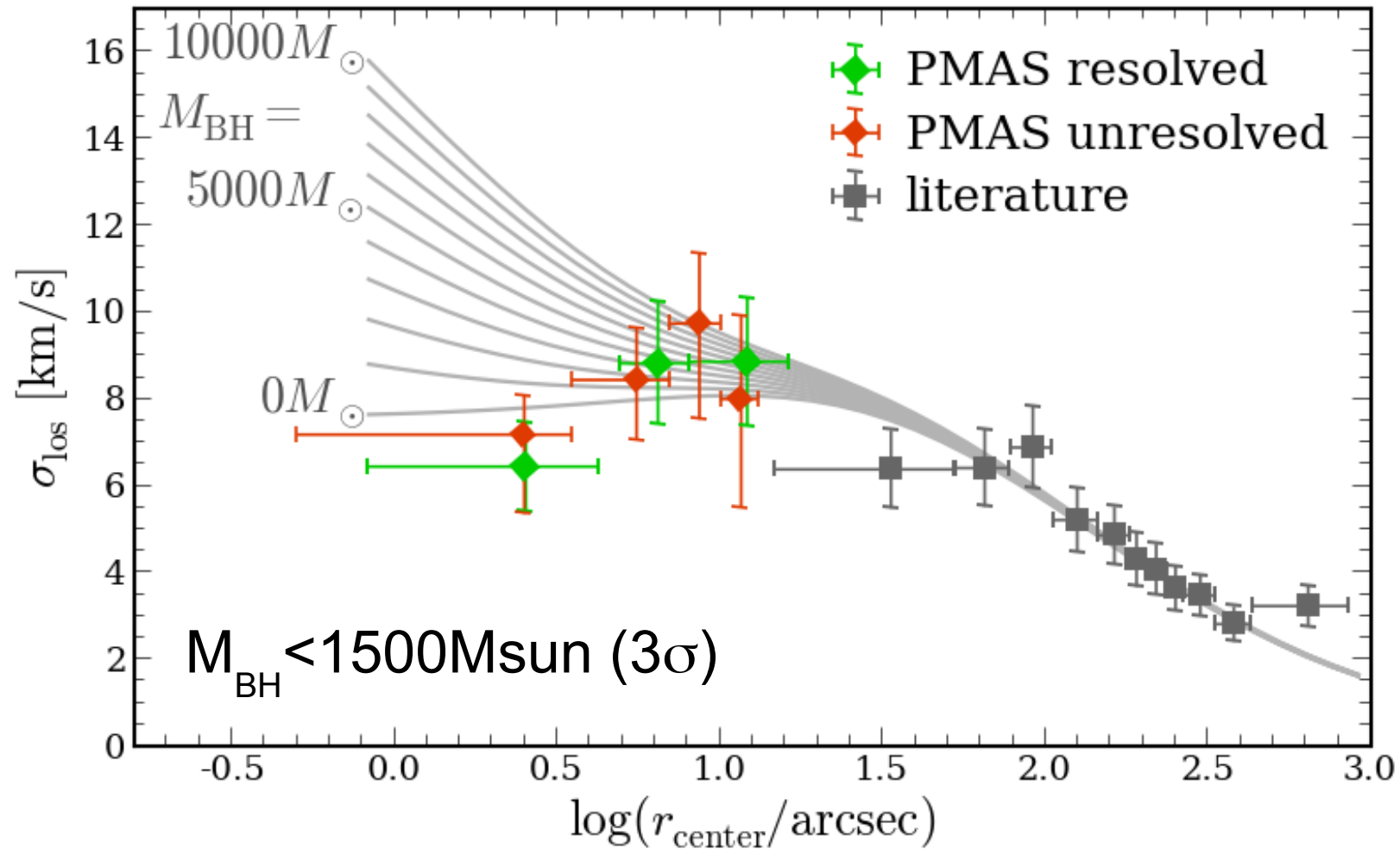


Kamann et al. (2014), A&A (submitted)

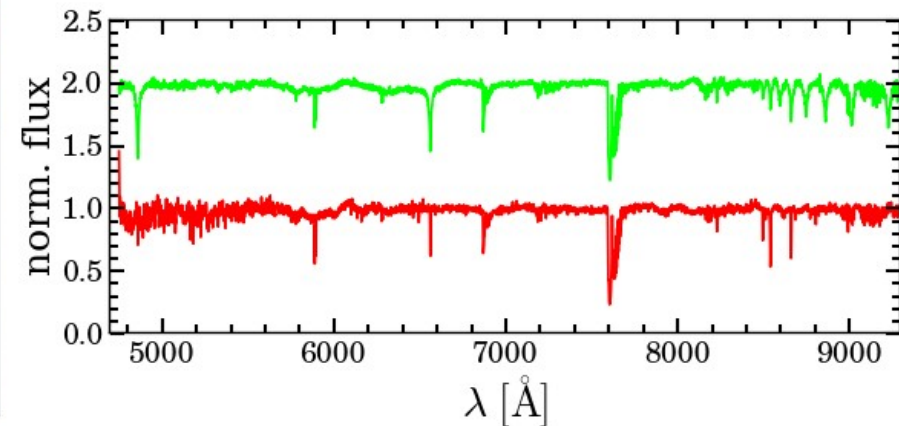
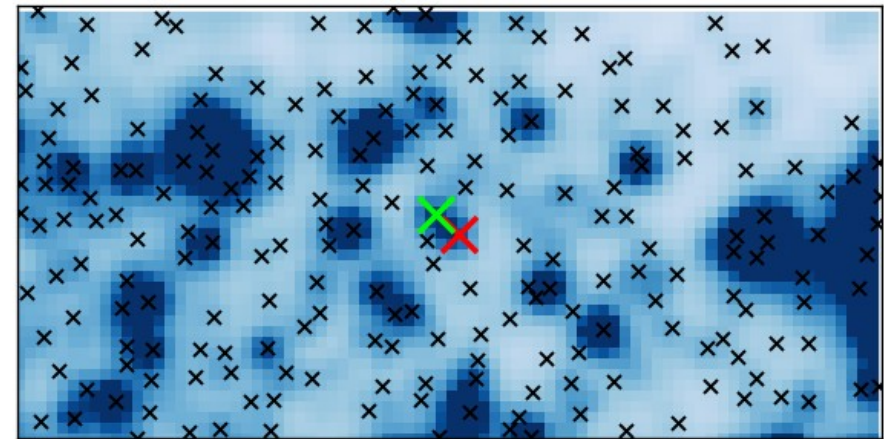
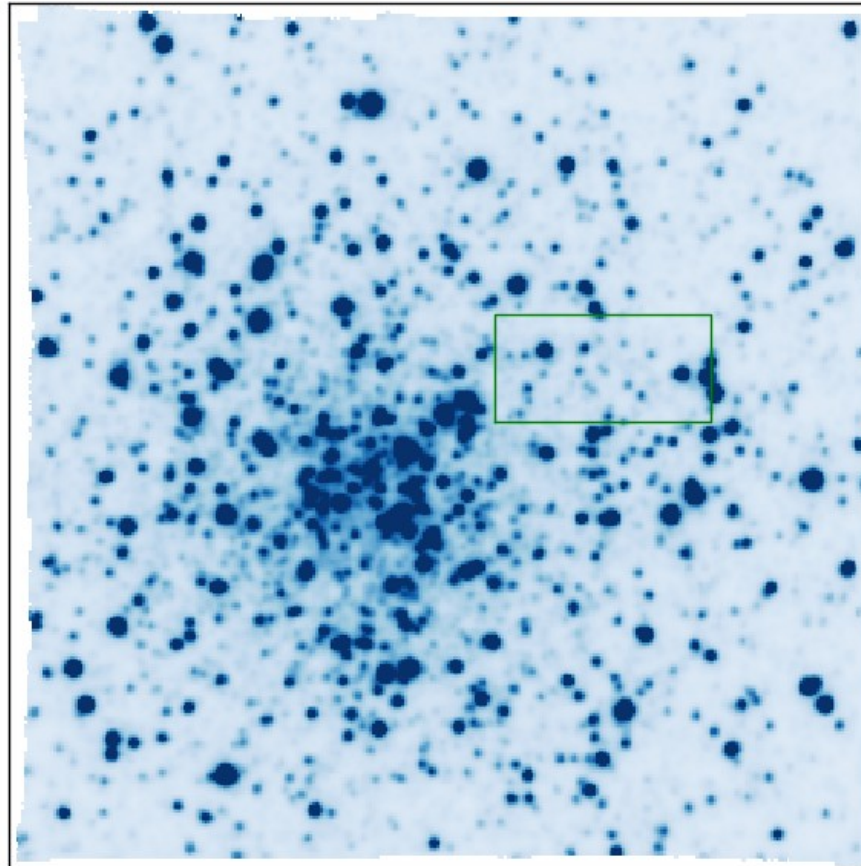
Advantages of using PSF fitting techniques

- S/N optimization
- Source deblending

Intermediate-mass black hole in M92?



3D spectroscopy with MUSE in NGC 6266



>5000 useful spectra, most of them not accessible via traditional spectroscopic techniques!

see Poster #15

Black-hole mass estimation of NGC 1097 with ALMA Cycle 0 Data

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S. IGUCHI^{1,2}, K. SHETH³, K. KOHNO⁴

²National Astronomical Observatory of Japan (NAOJ)

³National Radio Astronomy Observatory (NRAO)

⁴The University of Tokyo

BH plays an important role in galaxy evolution

- **(BH mass) – (host galaxy properties) relation**

suggests the coevolution process of galaxy and BH.

e.g., BH mass- host galaxy bulge luminosity, bulge mass,
stellar velocity dispersion

- what kind of coevolution process they indicate?
- AGN feedback process? (DiMatteo et al. 2005; Sijacki et al. 2007)
- redshift dependence? (Peng et al. 2006; Sijacki et al. 2007)
- dependence on galaxy type? (McConnell & Ma 2013)
- no correlation for pseudobulge hosts? (Kormendy & Ho 2013)

BH plays an important role in galaxy evolution?

We need more samples to discuss on a couple of problems...

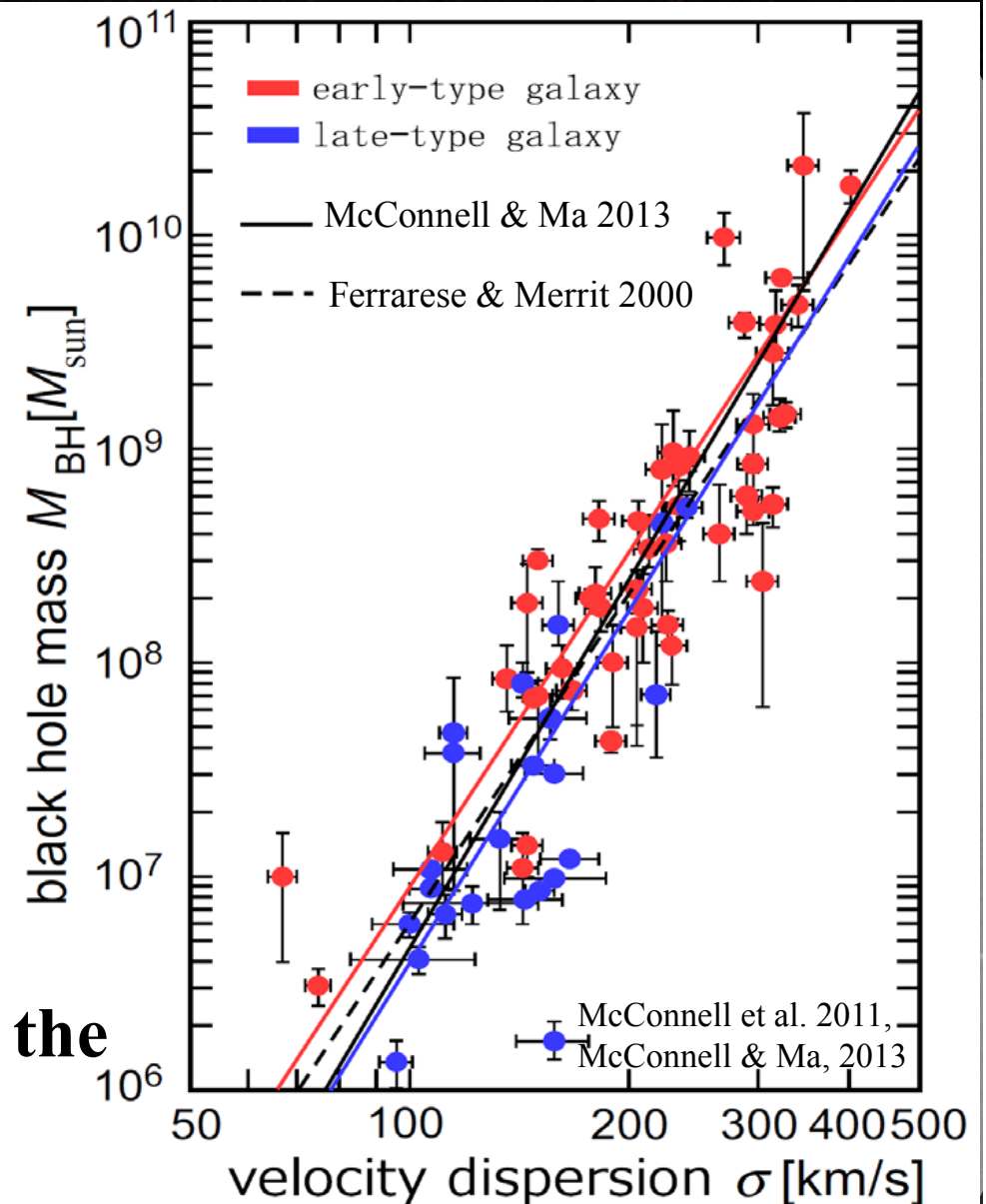
▪ $M_{\text{BH}}-\sigma$ relation

- the tightest correlation
- indicates the coevolution process?
- different trend with galaxy types?
McConnell & Ma 2013
- do not arise in pseudobulge hosts?
Kormendy & Ho 2013

Need more samples!

Increasing the number of galaxy samples is not straightforward. Using molecular gas dynamics is the most possible method!

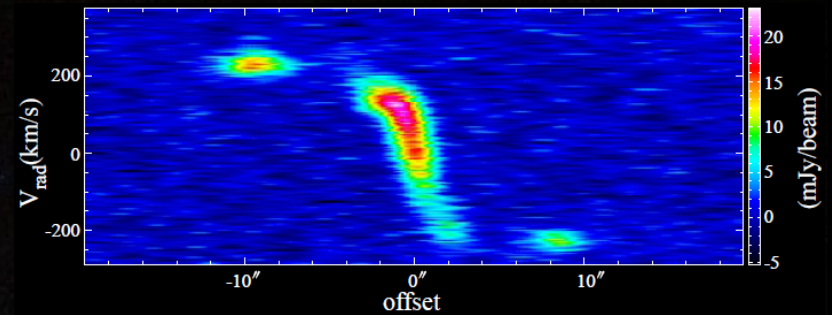
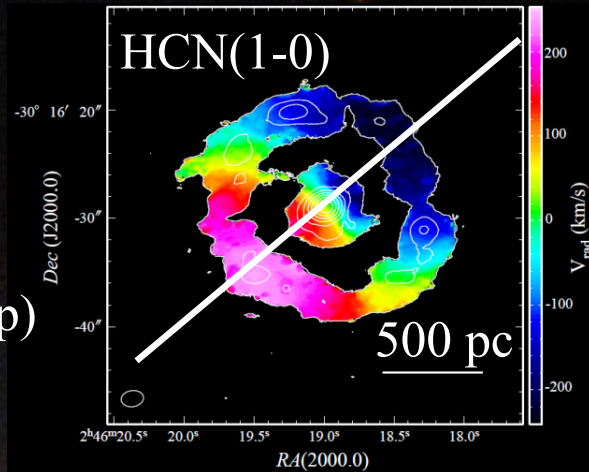
(see **Davis's talk on session 3!**)



We used molecular gas dynamics to estimate the BH mass in NGC 1097

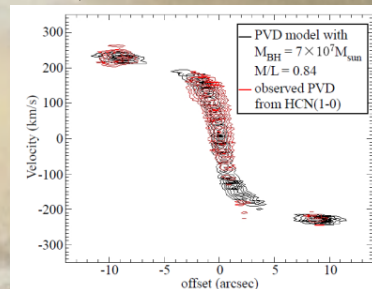
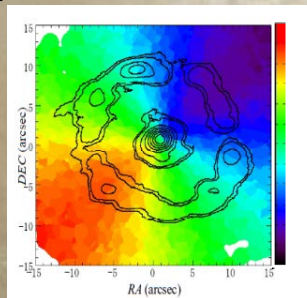
Observation :

ALMA Cycle0
Band3
(Kohno et al. in prep)

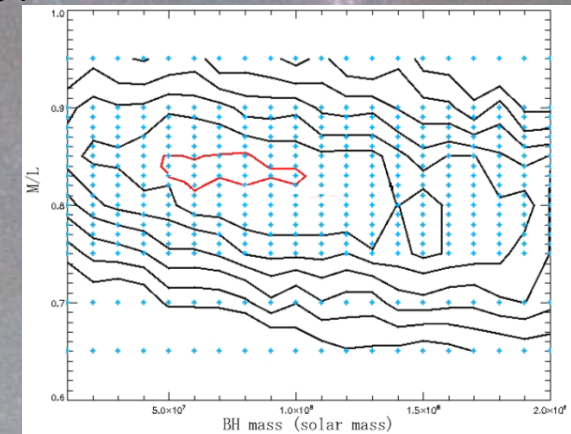
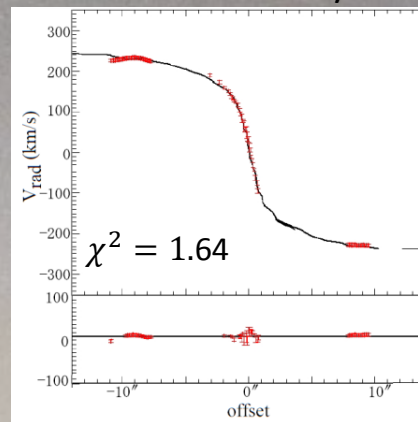


Model:

- mass profile (stellar mass + BH mass)
- velocity field (JAM, Cappellari 2008)
- observational effects (KinMS, Davis+ 2013)
- parameters: M/L ratio, BH mass



Fitting: BH mass = $0.7^{+0.3}_{-0.2} \times 10^8 M_{\odot}$
M/L=0.84



See Poster No. 28!

To summarize...

- BH plays an important role in galaxy evolution
- We need more samples to discuss on a couple of problems
- Increasing the number of galaxy samples is not straightforward
- Using the dynamics of molecular gas is the most possible method to increase the sample of measurable BH mass
- We estimated the BH mass of NGC 1097 with ALMA Cycle 0 data
 - HCN(1-0) and HCO⁺(1-0) line was used to trace the velocity
 - derived BH mass is $0.7^{+0.3}_{-0.2} \times 10^8 M_{\odot}$
- Please come and see my **poster No. 28!**
- see also Dr. Timothy Davis's talk on session 3!

