

S7 : The Siding Spring Southern Seyfert Spectroscopic Snapshot Survey

Probing the Physics of Seyfert Galaxies through their Extended Narrow Line Regions








Motivation:

- To constrain the chemical abundances in active galaxies with massive black holes.
- To use these to constrain the form of the ionising spectrum, delivering insights into the physics of accretion onto the black hole.
- To discover the relation of the radio jets with the optical emission from the nuclear environment.
- To understand the relationship between the central black hole, accretion rates, outflows, and the host galaxy.



S7: the Siding Spring Southern Seyfert Spectroscopic Snapshot Survey

- Started as an Indo-Australian Collaboration (PIs Mike Dopita & Prajval Shastri)
- Uses the Wide Field Spectrograph (WiFeS) on the ANU 2.3m telescope.
- S7 is an integral field survey of 132 active galaxies for which >40mJy radio emission has been detected.
- All objects are south of +10 degrees, and (in nearly all cases) more than 20 degrees out of the Galactic Plane
- Objects are chosen to be closer than *z=0.02*, so that the spatial resolution is better than 400 pc on the galaxy.



S7 : Project Personnel

AUSTRALIA:
Mike Dopita (ANU)

Julie Banfield (ANU)
Brent Groves (ANU)
I-Ting Ho (U Hawaii)
Bethan James (STSci)
Chichuan Jin (Durham U)
Darshan Kakkad (ESO)
Lisa Kewley (ANU)
Julia Scharwaechter (LERMA)
Ralph Sutherland (ANU)
Frederic Vogt (ESO)
Ingyin Zaw (NYU, Abu Dhabi)

Students:
Rebecca Davies (ANU)
Elise Hampton (ANU)
Adam Thomas (ANU)
Fergus Longbottom (ANU)
Ayush Patnaik (ANU)

INDIA:
Prajval Shastri (IIA)

Harish Bhatt (IIA)
Preeti Kharb (TIFR)
Shalima P. (RIE)
Lalitha Sairam (IIA)
Shweta Srivastava (PRL)

Students:
Chetna Duggal (DU)
Maitrayee Gupta (CAMK)
Debashish Jena (NISER)
Tanmaya Mishra (NISER)
Pavana Muralimohan (IIA)
Jaya Maithil (U Wyoming)
Swayamtrupta Panda (NIIT)
Vikram Radhakrishnan (Leiden U)
MN Sundar (Jain University)



















1. Data Products

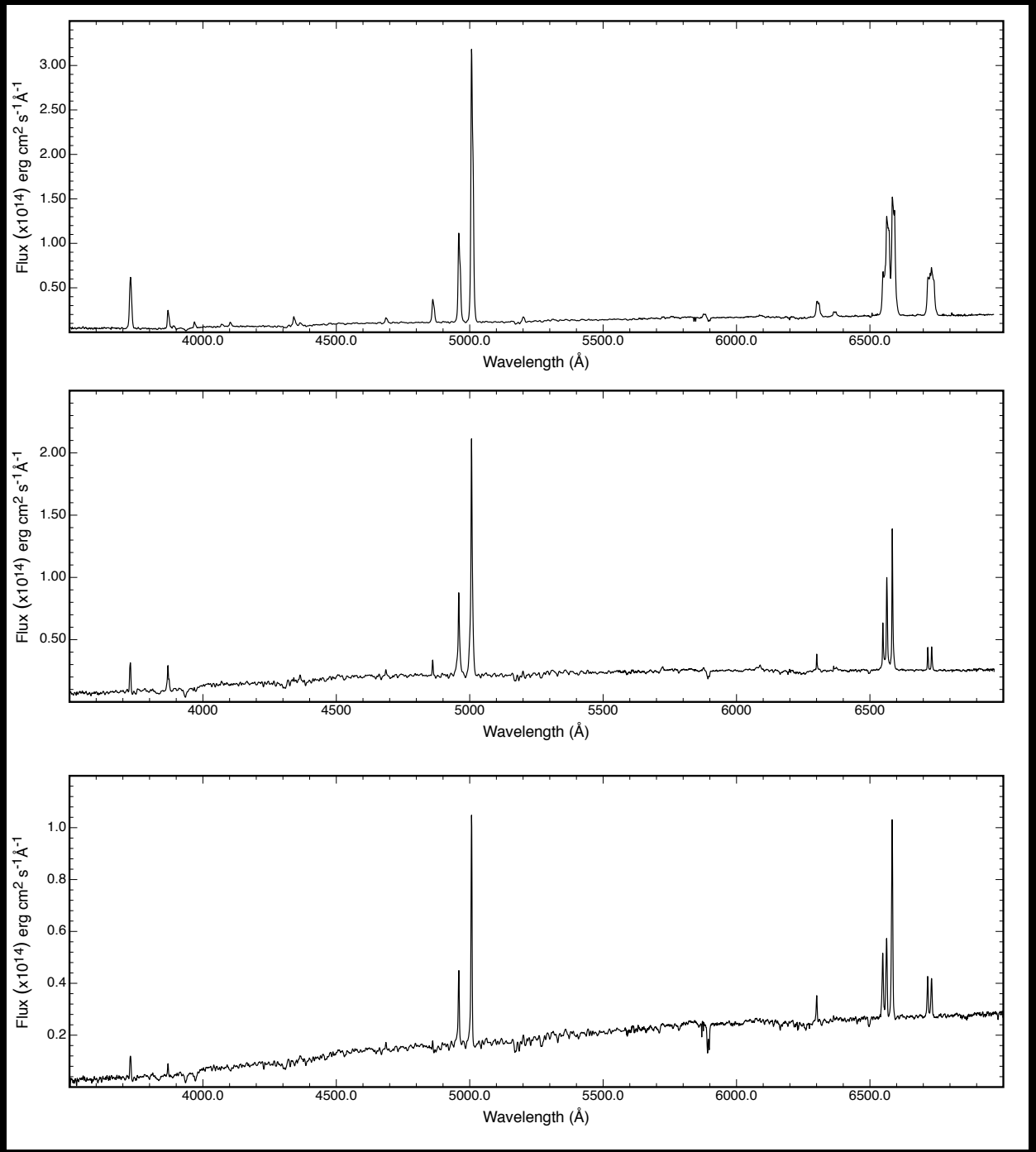
Full Data Release:
see: Thomas A. et al. 2017 arXiv 1708 02683

ANU

Australian Academy of Science

S7: Data Products: Nuclear Spectra

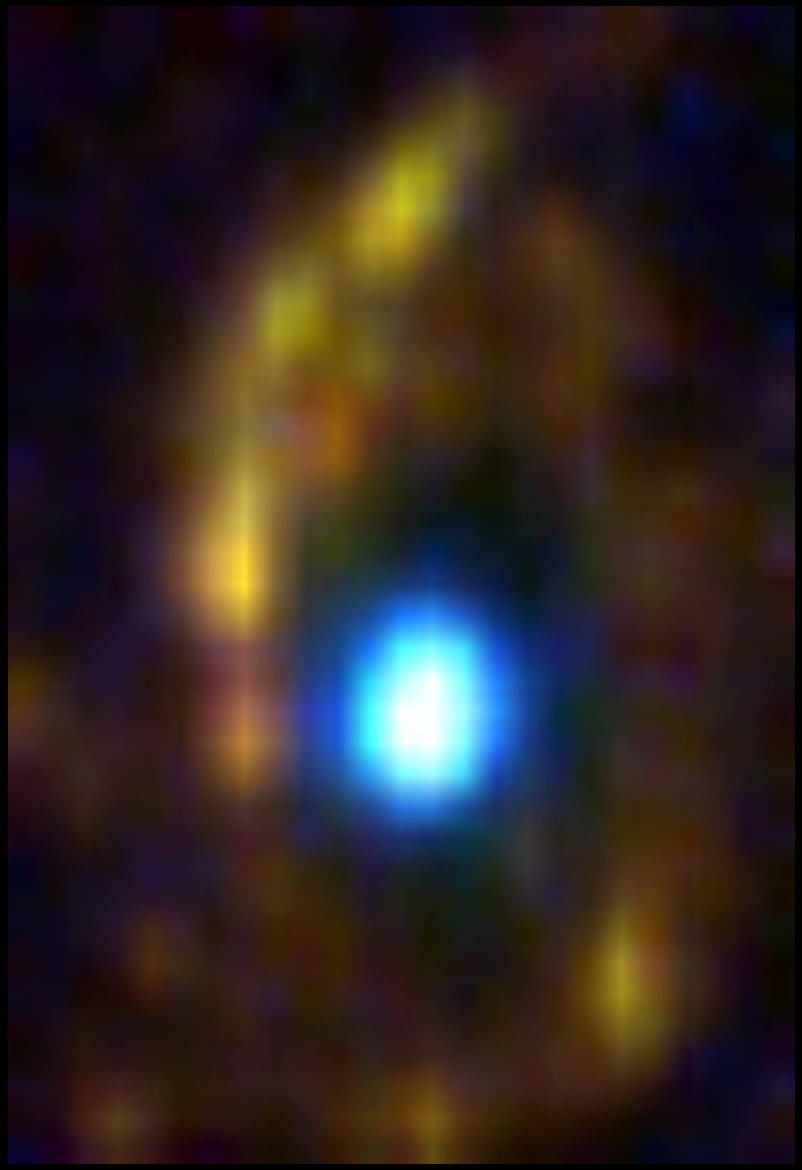
3300 - 5600Å
R=3000



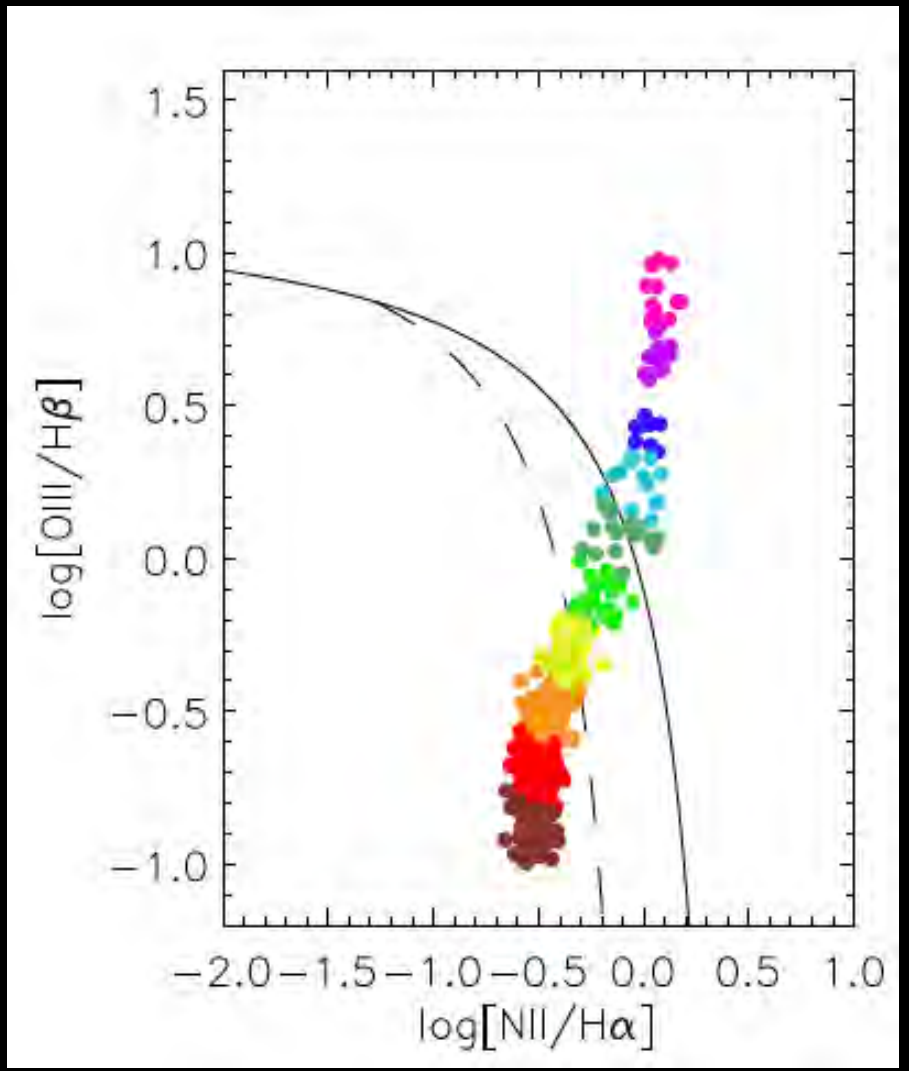
5400 - 7050Å
R=7000

S7: Data Products:

Colour Images: H-alpha, [NII], [OIII]



BPT Diagrams:





These images of Seyfert Galaxies courtesy of the *Siding Spring Southern Seyfert Spectroscopic Snapshot Survey* (S7)

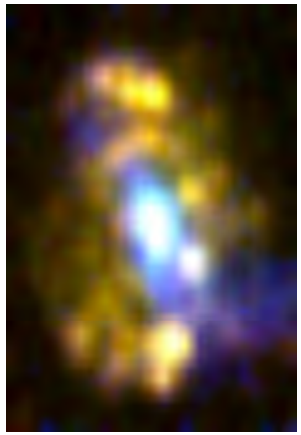
They are all obtained with the Wide Field Spectrograph (WiFeS) an integral field unit mounted on the ANU 2.3m telescope.
The field is 25x38 arc sec.

Blue represents emission in [O III], green [N II] and red, Hα emission. These distinguish the mode of excitation of the gas.

Star forming regions appear red, orange or yellow.

Regions ionised by the central Active Galactic Nucleus appear purple, blue turquoise or even green.
Here we map these Extended Narrow Line Regions (ENLR).

MCG-02-51-008



NGC 6860



NGC 2992



NGC 838



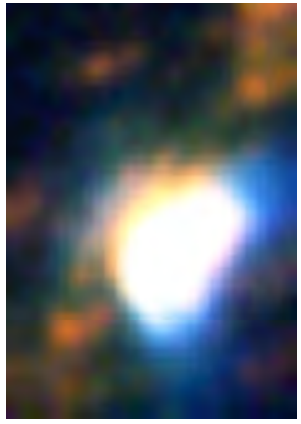
ESO137-G34



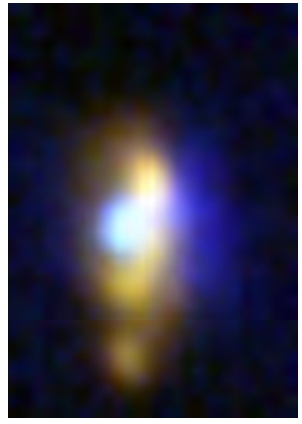
NGC 613



NGC 7582



NGC 5664



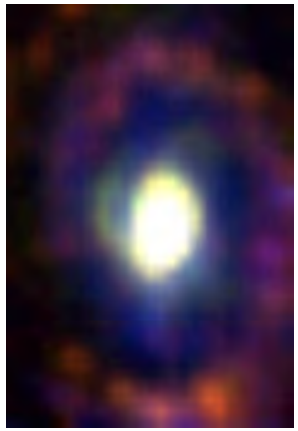
NGC 1125



IC5063



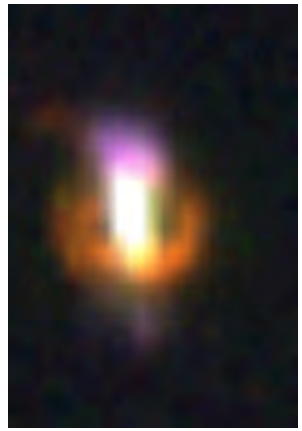
NGC 1068



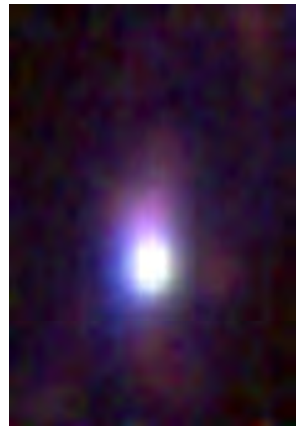
IC 1481



NGC 5728



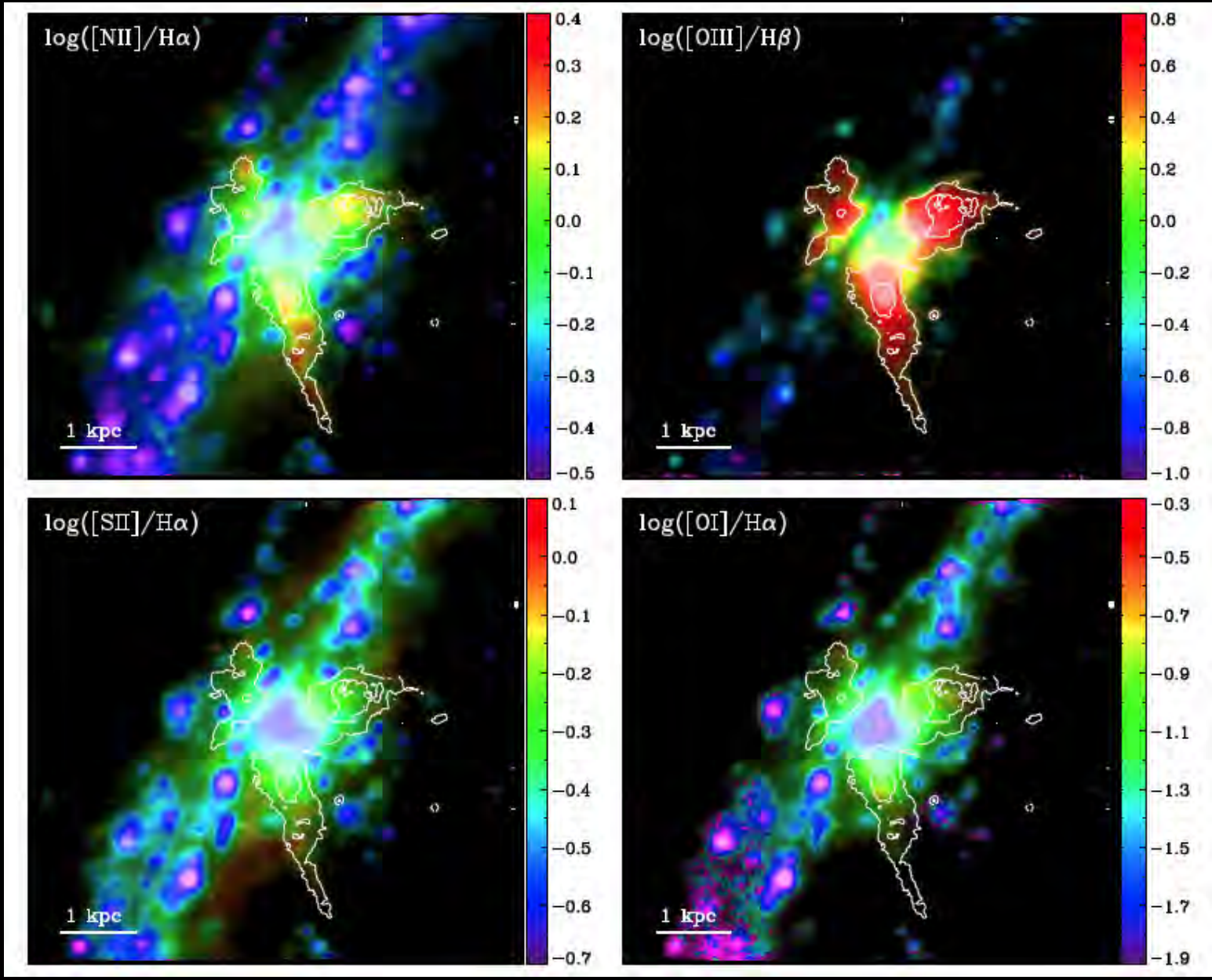
MCG-06-23-038



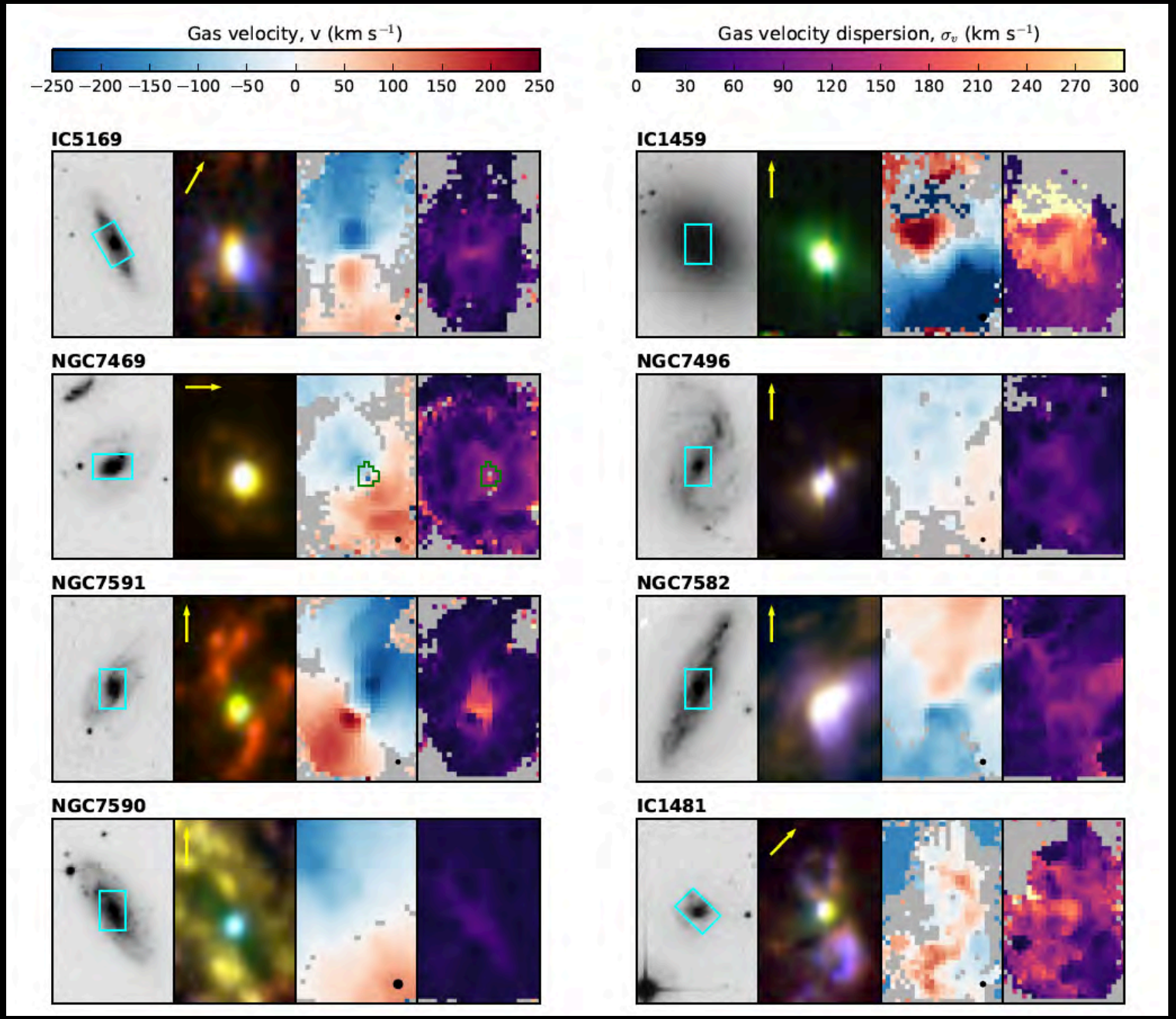
MARK 573



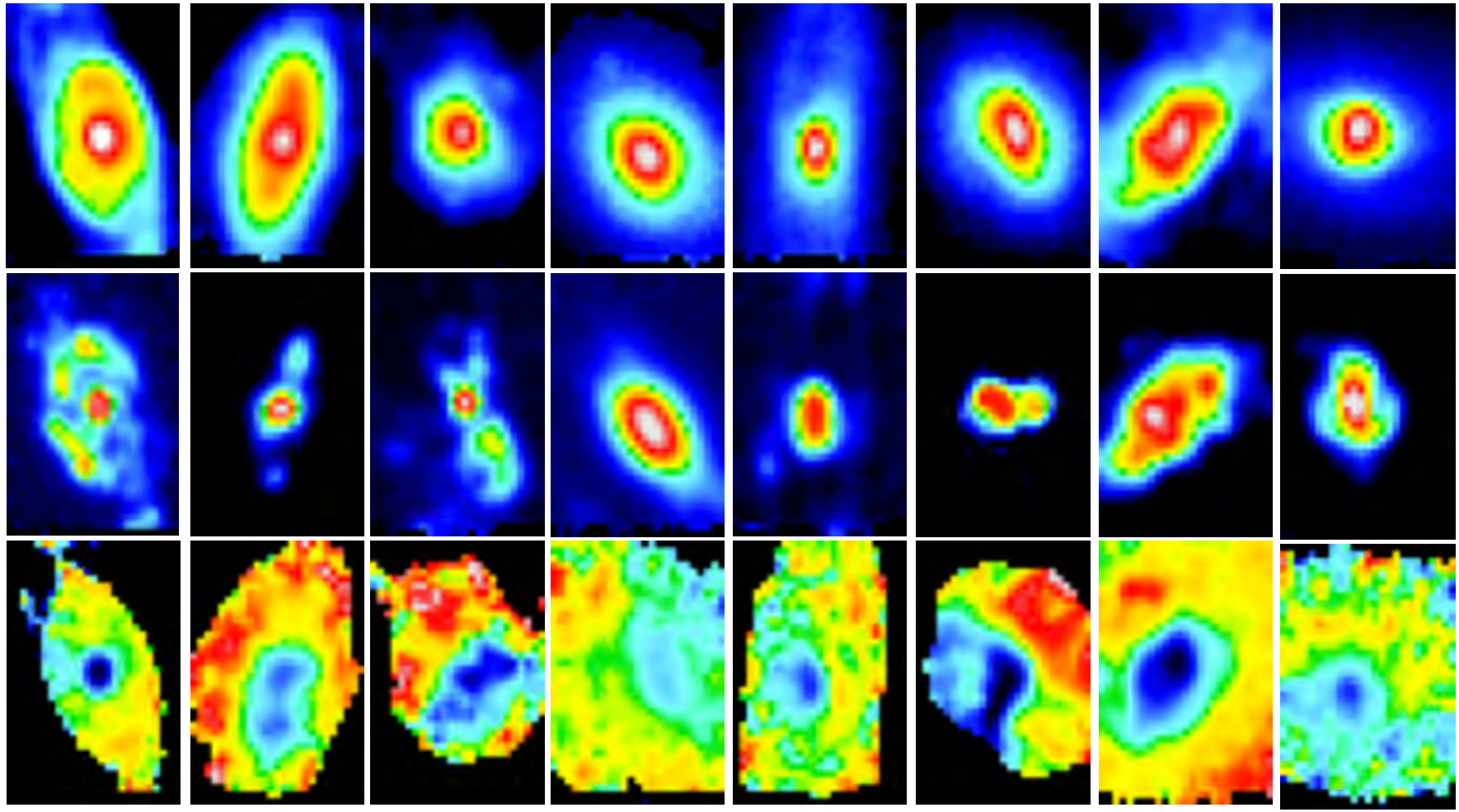
S7: Data Products
Line Flux Ratios (NGC 7582: MUSE data)



S7: Data Products
Kinematics



Atomic outflows seen in Na D Absorption



An Example ENLR: NGC 1125

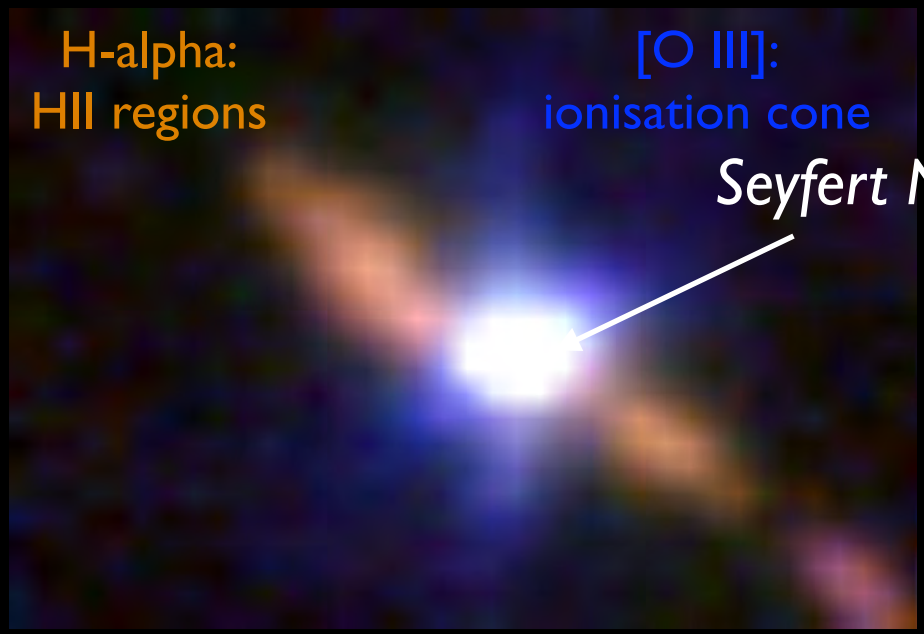


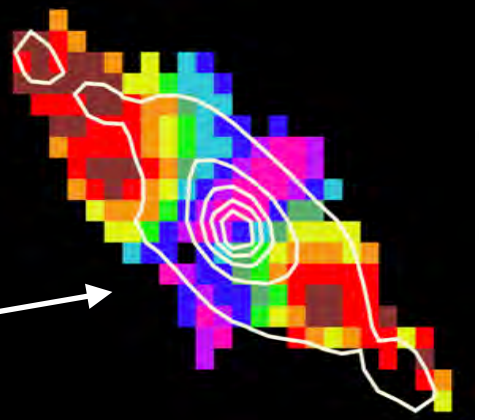
Image: *H-alpha*, *[NII]*, *[OIII]*

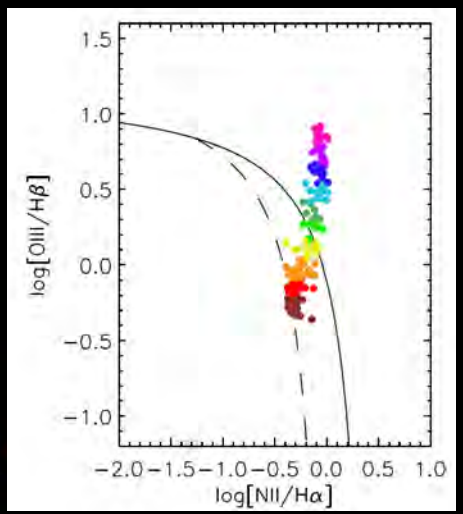


Radial Velocity

The ENLR in this galaxy is perpendicular to the plane and rotating with the galaxy.

The BPT diagram shows clear mixing between Seyfert and HII activity





BPT Diagram



2. Analysis & Modelling Tools

Modelling the AGN emission line spectrum

- We use the code MAPPINGS 5.0 (developed by Ralph Sutherland), which can make synthetic photoionisation, shock or cooling spectra in the spectral range ~1mm - 50keV.
- It includes all elements up to and including Zn.
- It includes full dust physics for Silicate, Carbonaceous and PAH grain types.
- It has an extensive library of EUV source spectra of OB stars, central stars of PNe, and AGN types.
- It is now available at: *miocene.anu.edu.au/mappings*

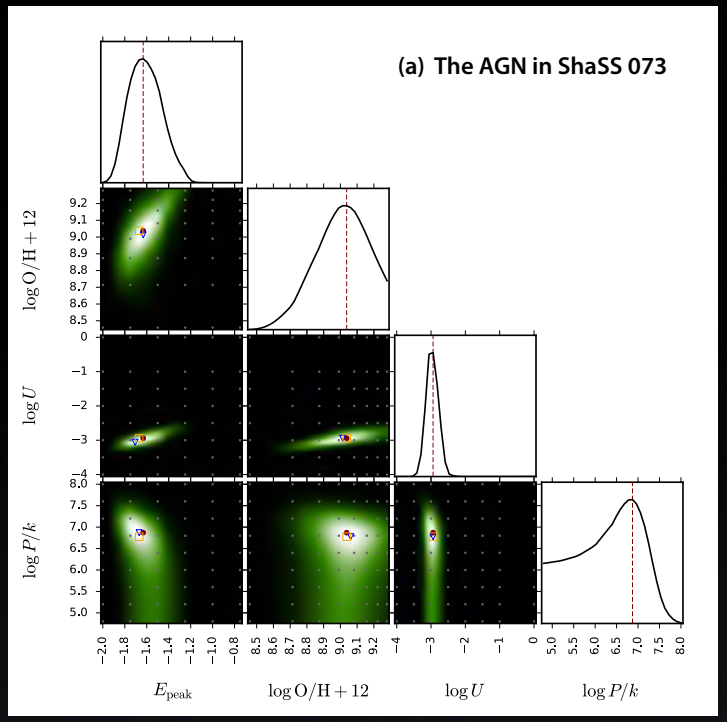
Models for the AGN spectrum
(Done & Jin, MNRAS, 2011-13)

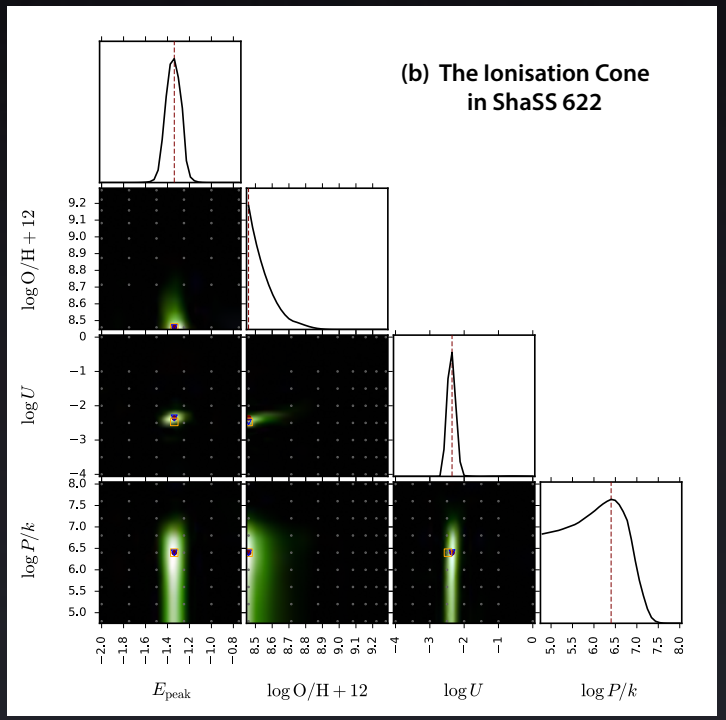
- Models solve for radiative transfer in inner accretion disk (gives hotter effective temperatures).
- They allow for a hard Compton heated component.
- They add a third intermediate Compton heated component to fit X-ray spectra of strong AGN.
- Models have been reduced in dimensionality and adapted to S7 galaxy fitting by Adam Thomas.
(OXAF: *2016, ApJ, 833, 266*).

ANU
Australian Academy of Science

Nebular Bayesian Fitting
(Thomas et al. 2017)

- *NebulaBayes* by Adam Thomas (this conference)
- Uses line fluxes and the OXAF AGN spectra to solve for the parameters : E_{peak}, log U, log P/k, and 12+log[O/H]
- Can also be used for HII region fitting.

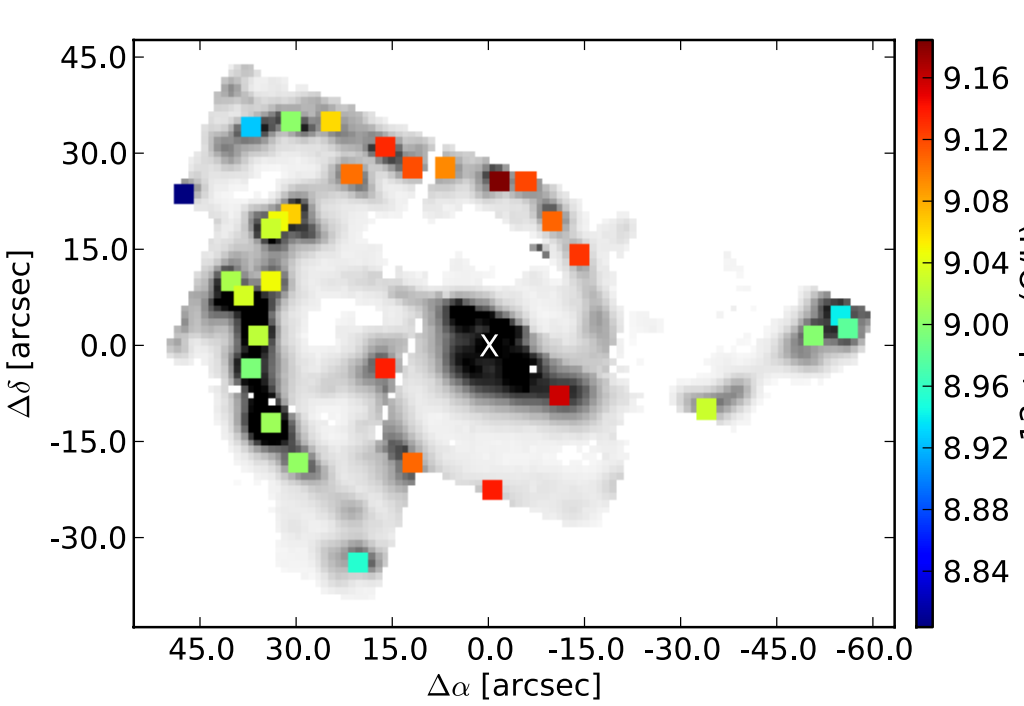


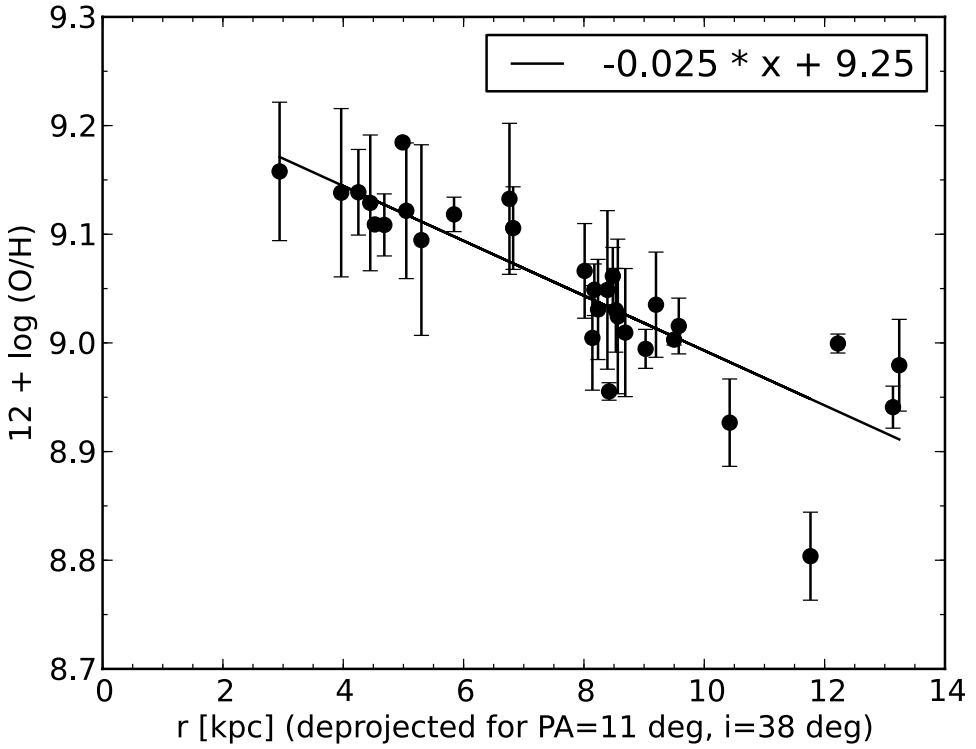


ANU

Australian Academy of Science

NGC5427: Constraining the Nuclear Abundance from HII region strong line spectra



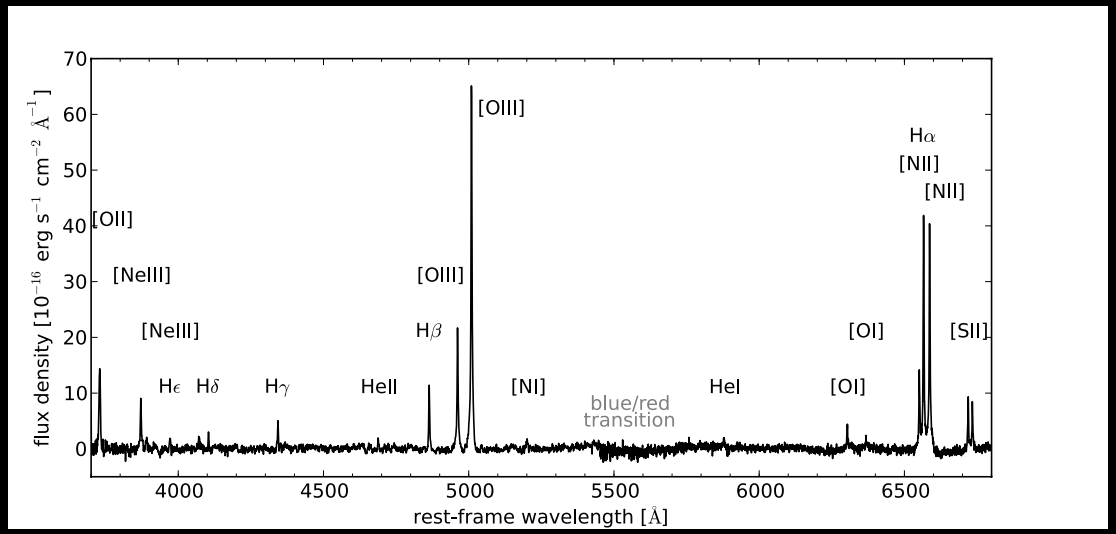


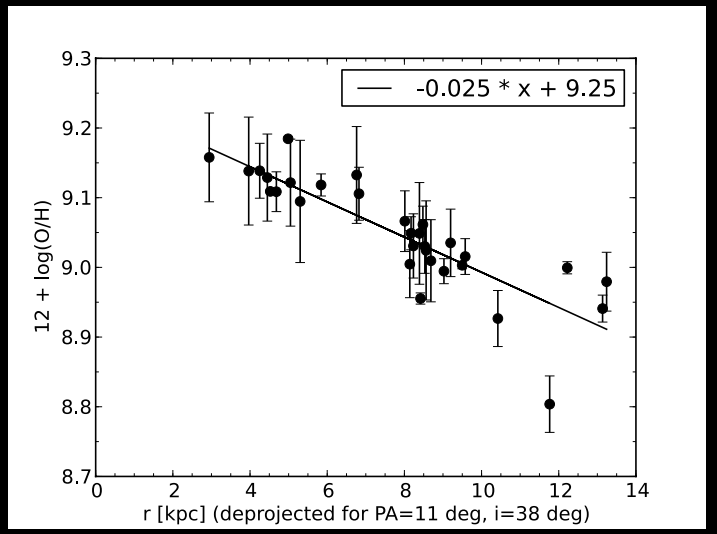
HII region chemical abundances (colour coded)

Inferred O/H abundance gradient

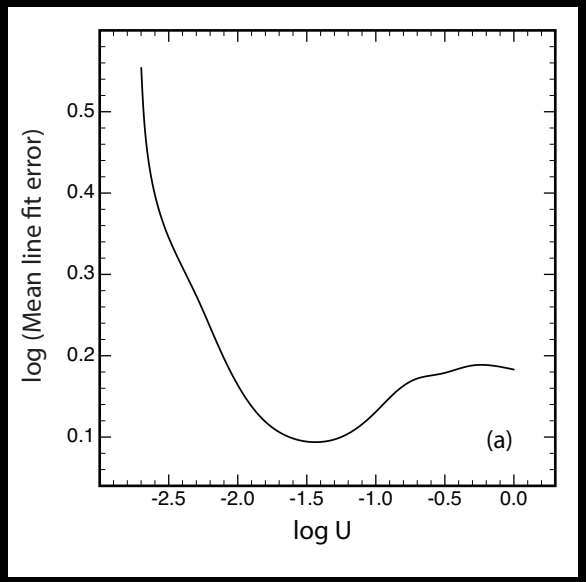
NGC5427: Constraining the EUV Spectrum

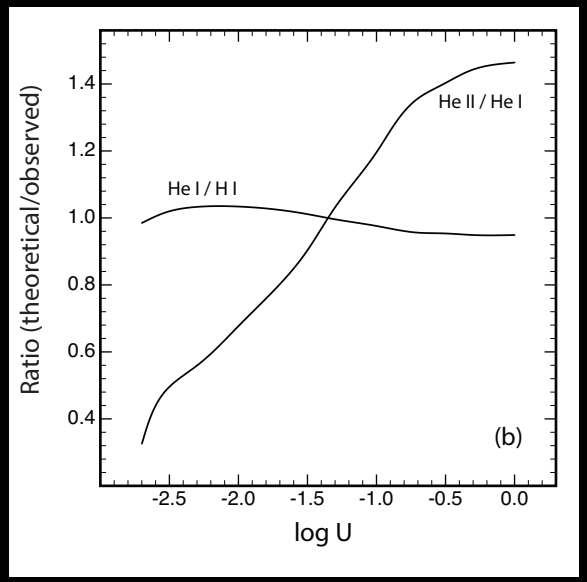
from the nuclear spectrum *and* *the chemical abundances*

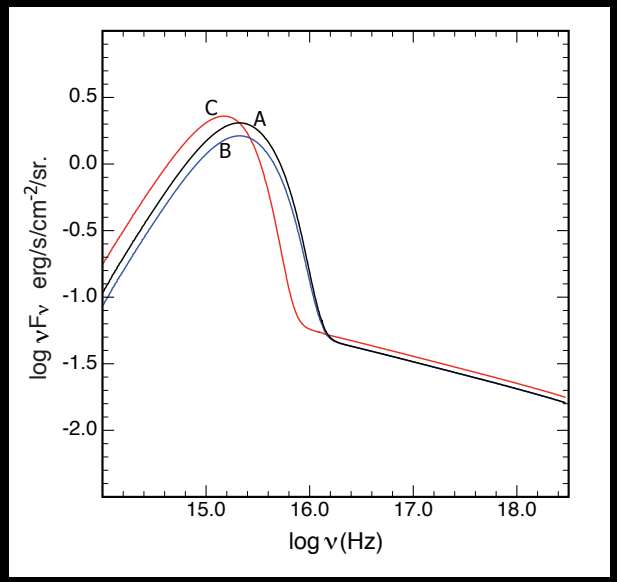




..we can infer the intensity and shape of the nuclear EUV spectrum









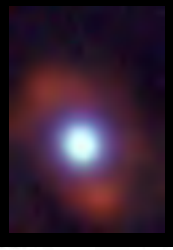
3. AGN / HII Mixing
on the BPT / V&O 87 diagrams

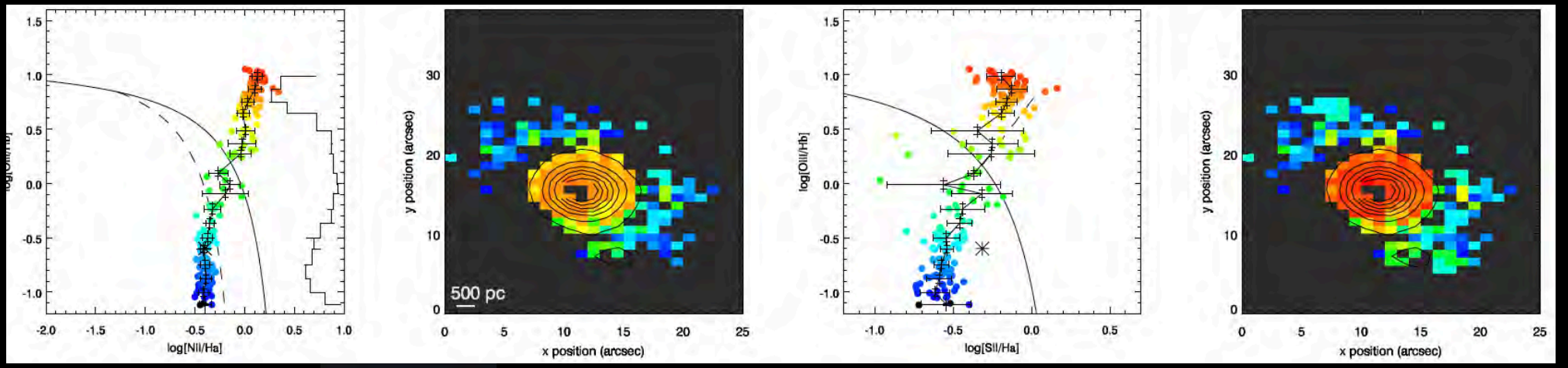
- *Rebecca Davies et al.*
  2014, MNRAS, 439, 3835
  2014, MNRAS, 444, 3961
  2016, ApJ, 824, 50
  2017, MNRAS, 470, 4674



Varieties of Mixing Curves : "Classical"

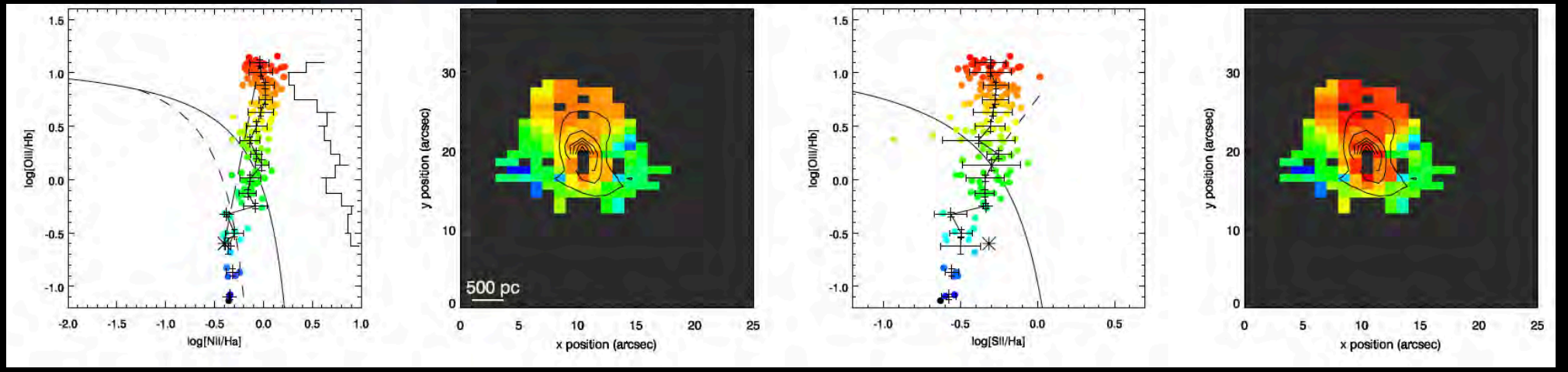
- **IC1816**



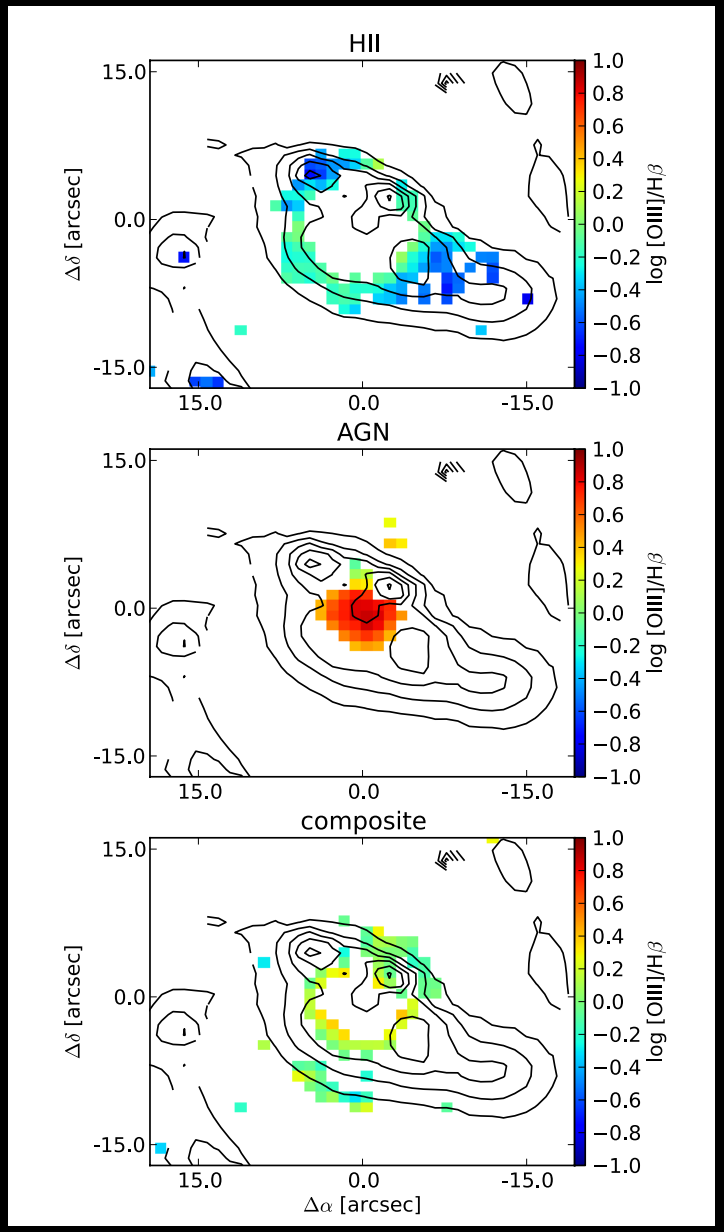


- **NGC7679**





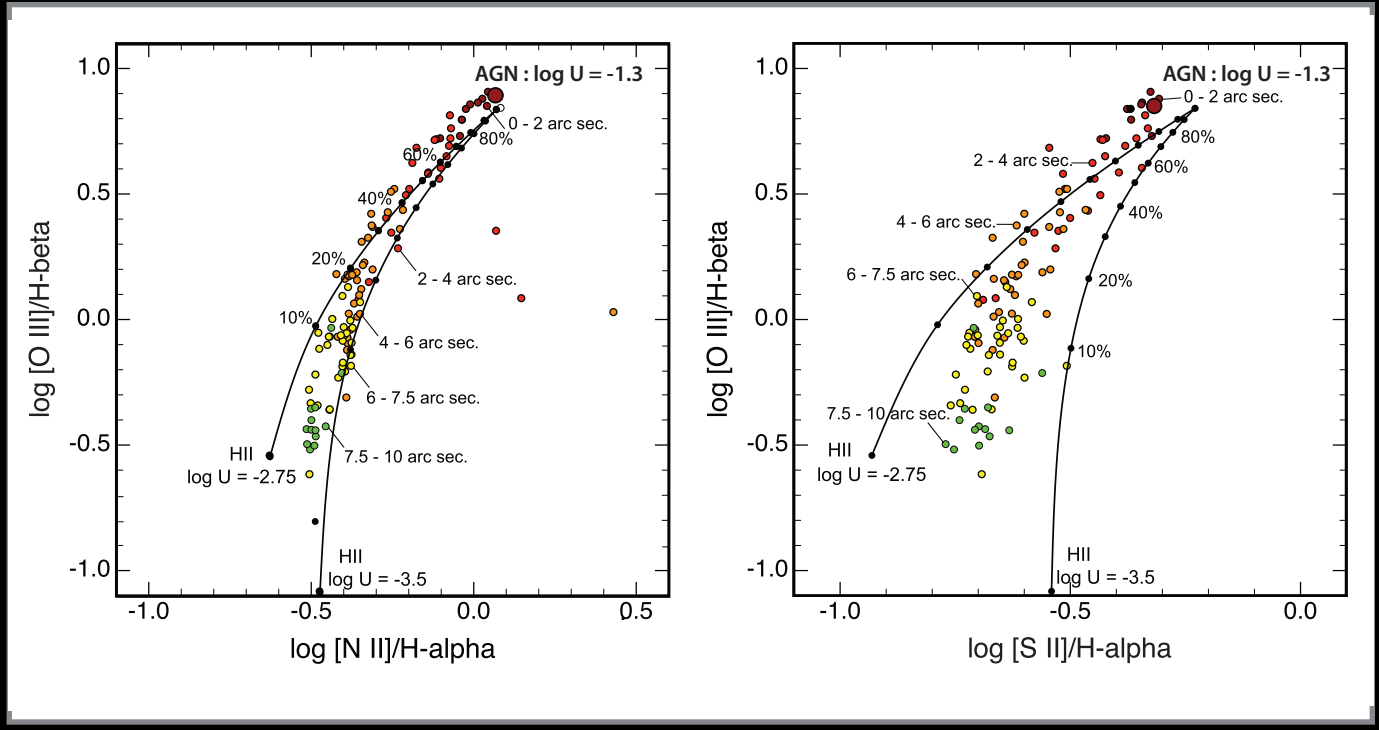
Classical Mixing in NGC5427



From the line ratios we can probe the extent of the ENLR

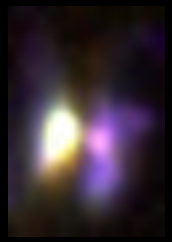
..and discover the mixing fraction between HII regions and ENLR

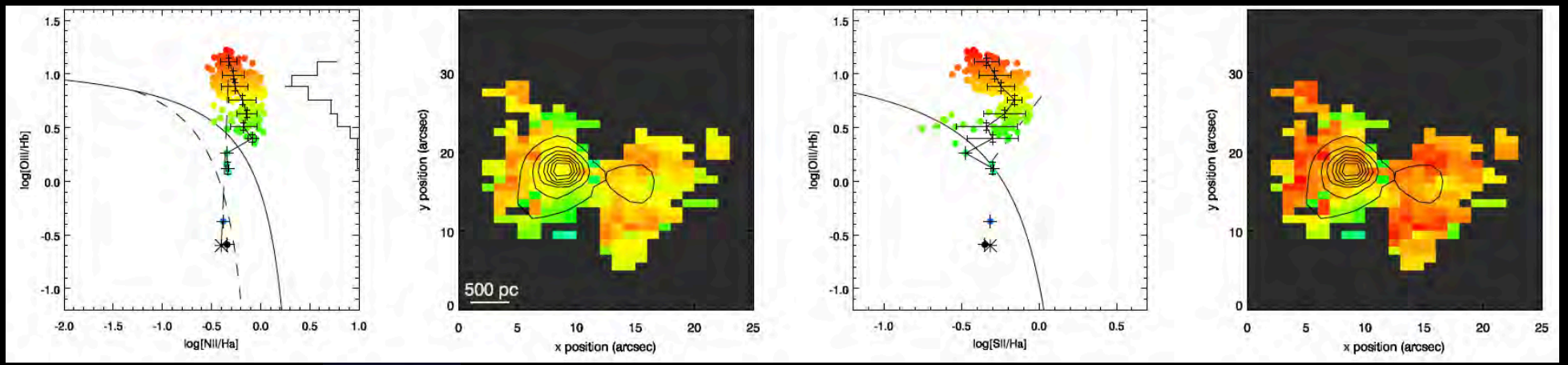
2014, A&A, 566, 41
Dopita, Scharwächter, Shastri, Kewley, Davies, Sutherland, Kharb, Jose, Hampton, Jin, Banfield, Basurah & Fischer



Varieties of Mixing Curves : "AGN Dominant"

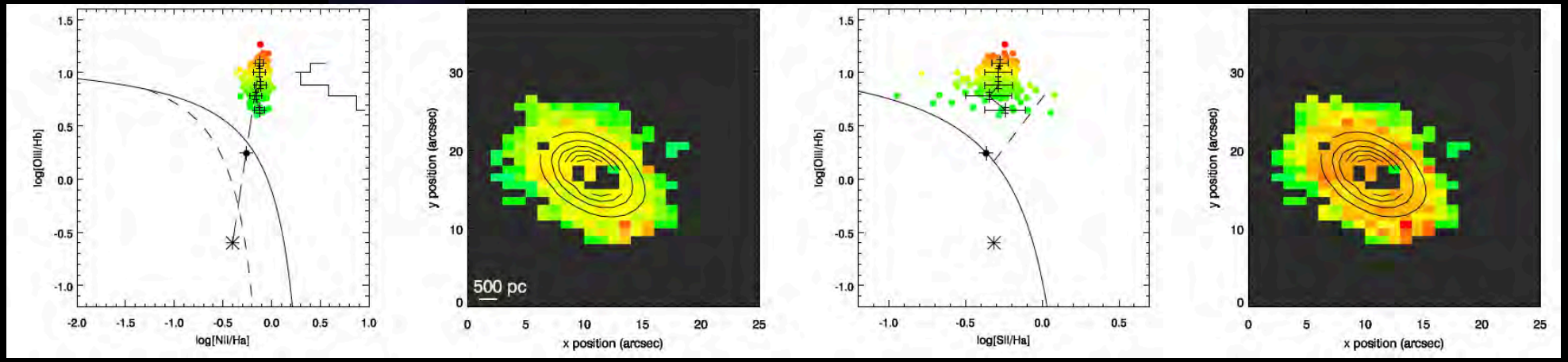
- **NGC 2992**





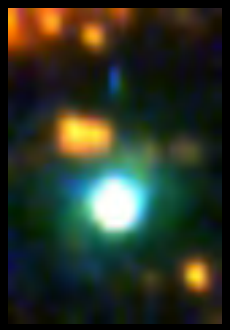
- **MARK 573**

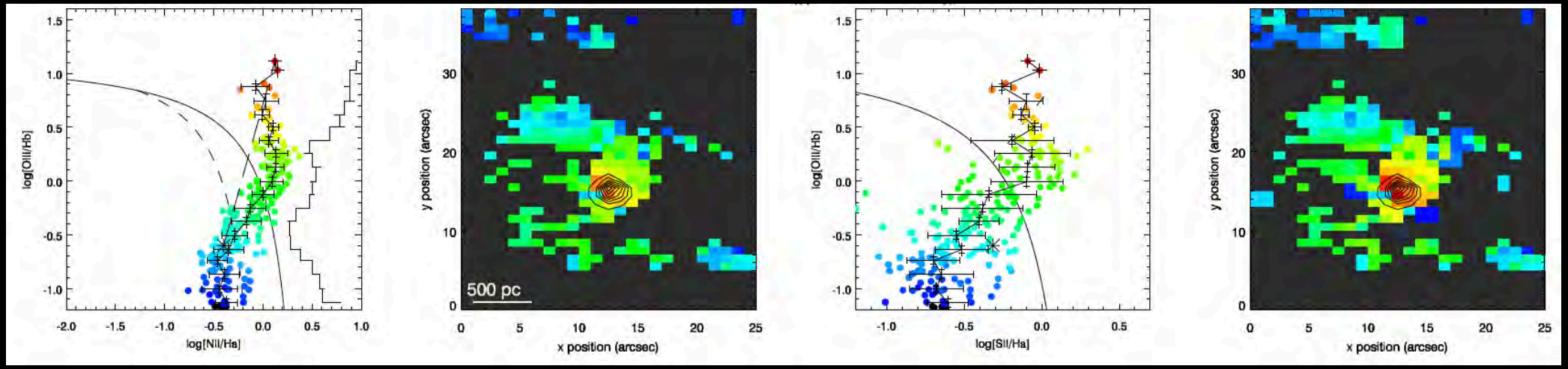




Varieties of Mixing Curves : "Mixed Mixing"

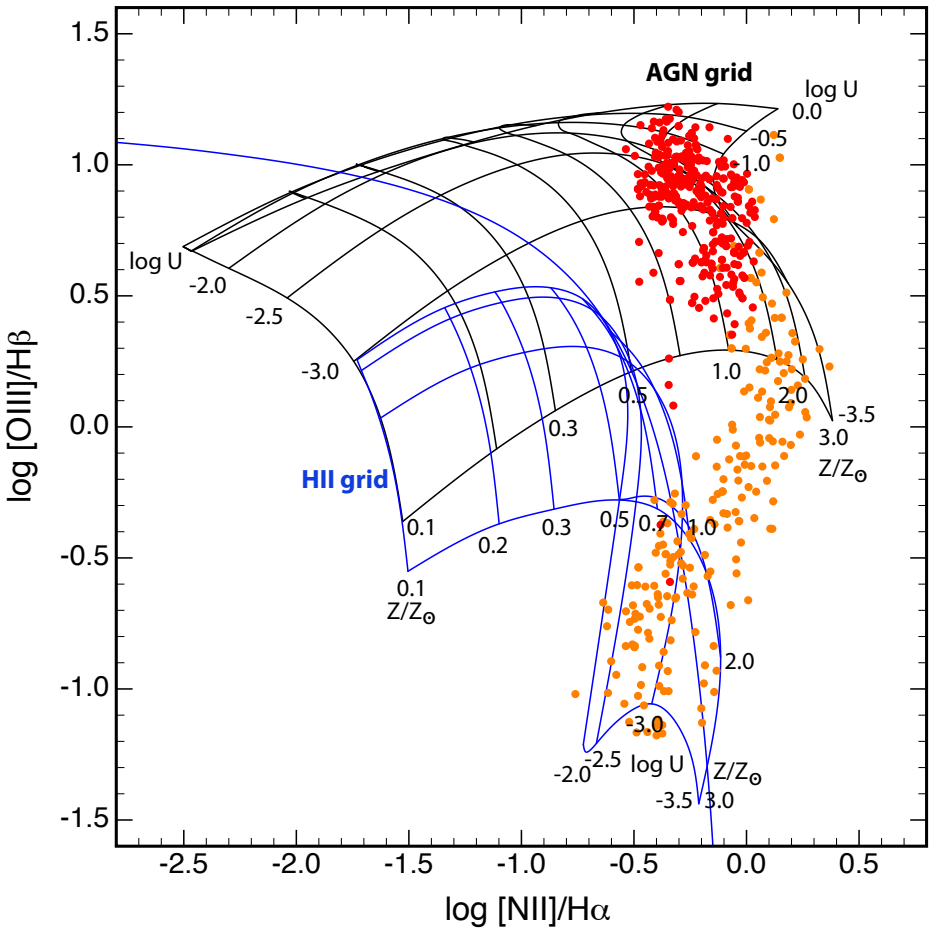
- **NGC 1566**

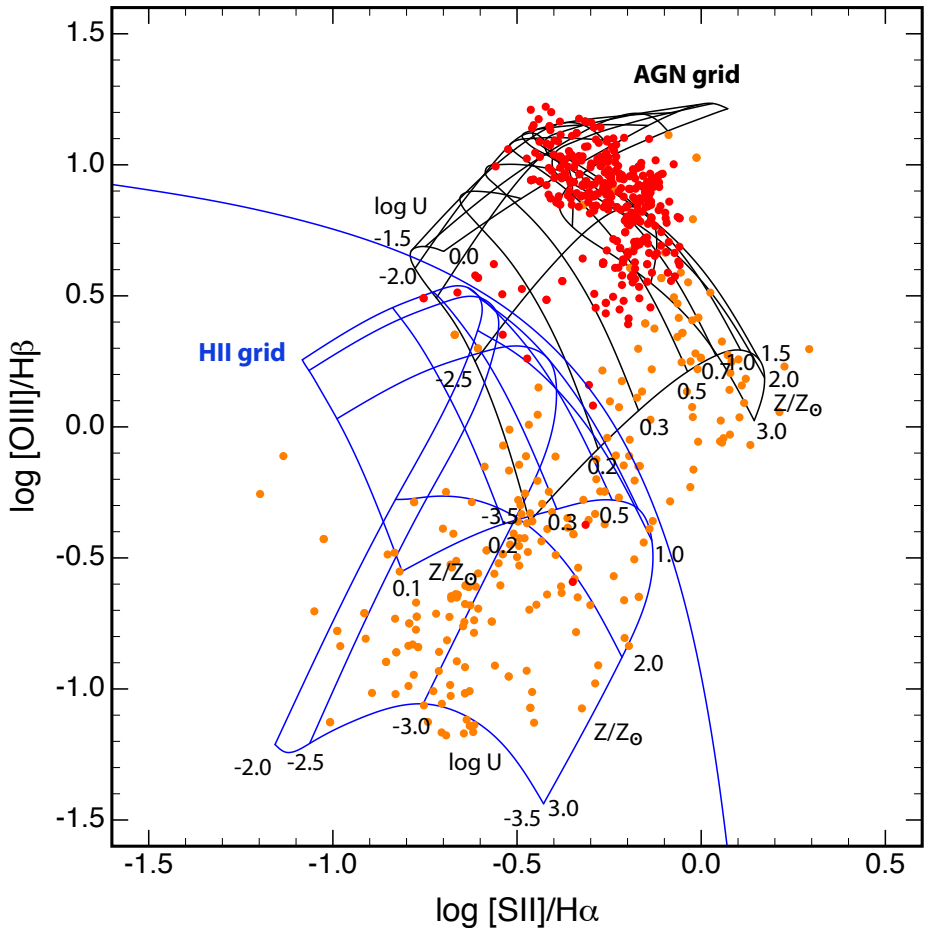




- this object has an "S" shaped mixing curve, with prominent HII regions (appearing blue in above diagram).
- …what do the orange, yellow and light green points represent?
- We hypothesise that these are due to dilution of the AGN radiation field.

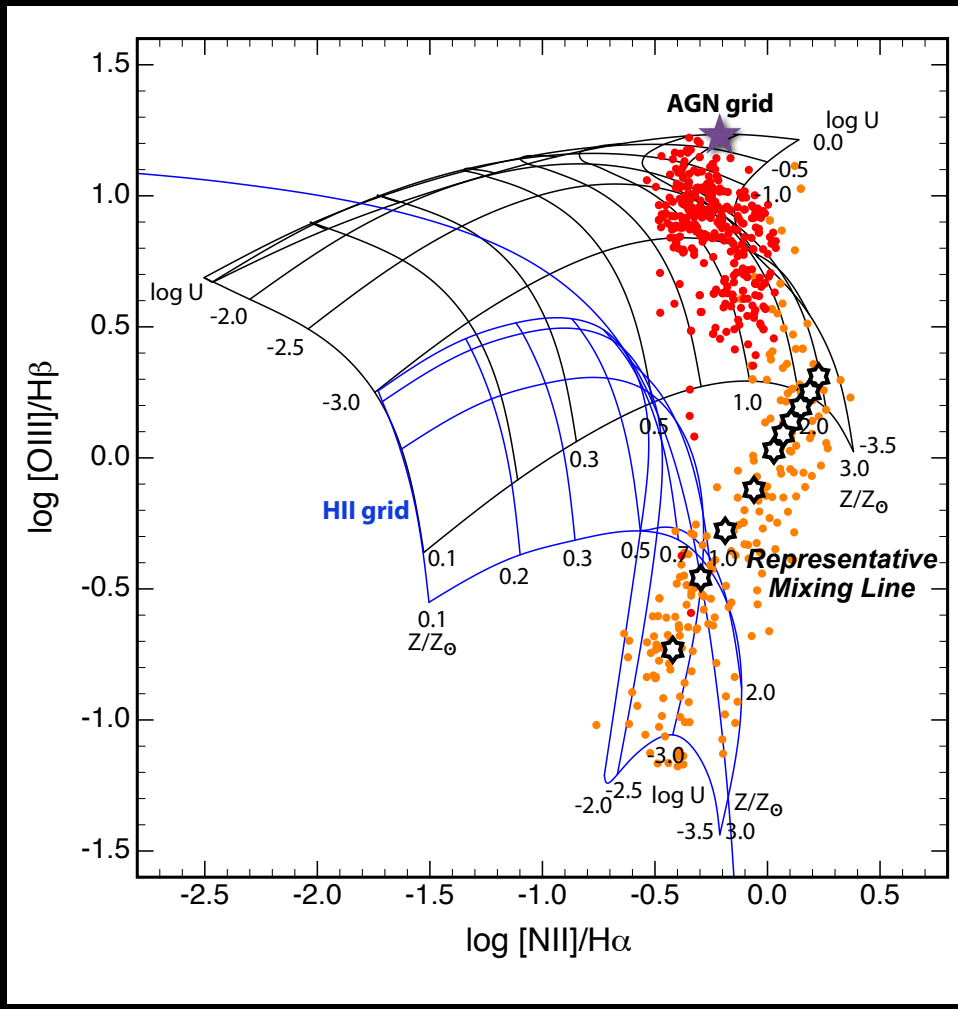
Theoretical Grids for "Mixed Mixing"

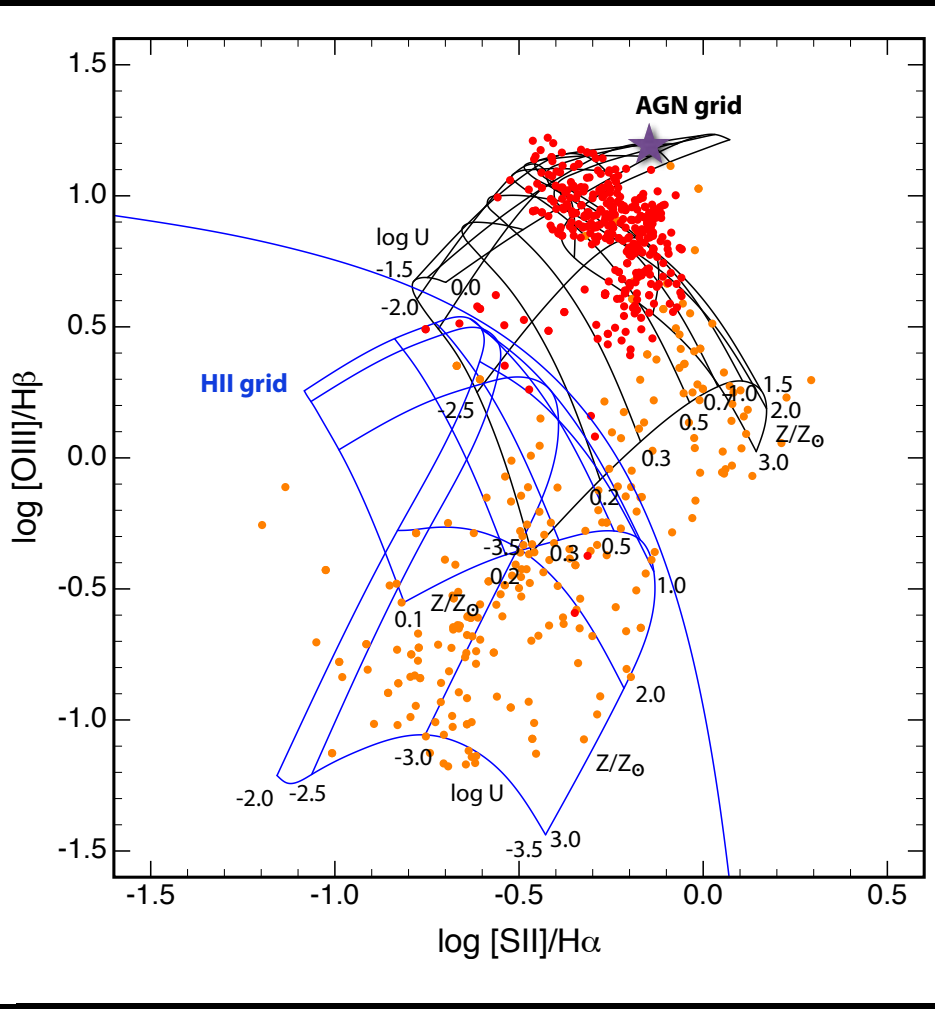




Red points: NGC 2992, *Orange points:* NGC 1566

Theoretical Grids for "Mixed Mixing"





Red points: NGC 2992, *Orange points:* NGC 1566

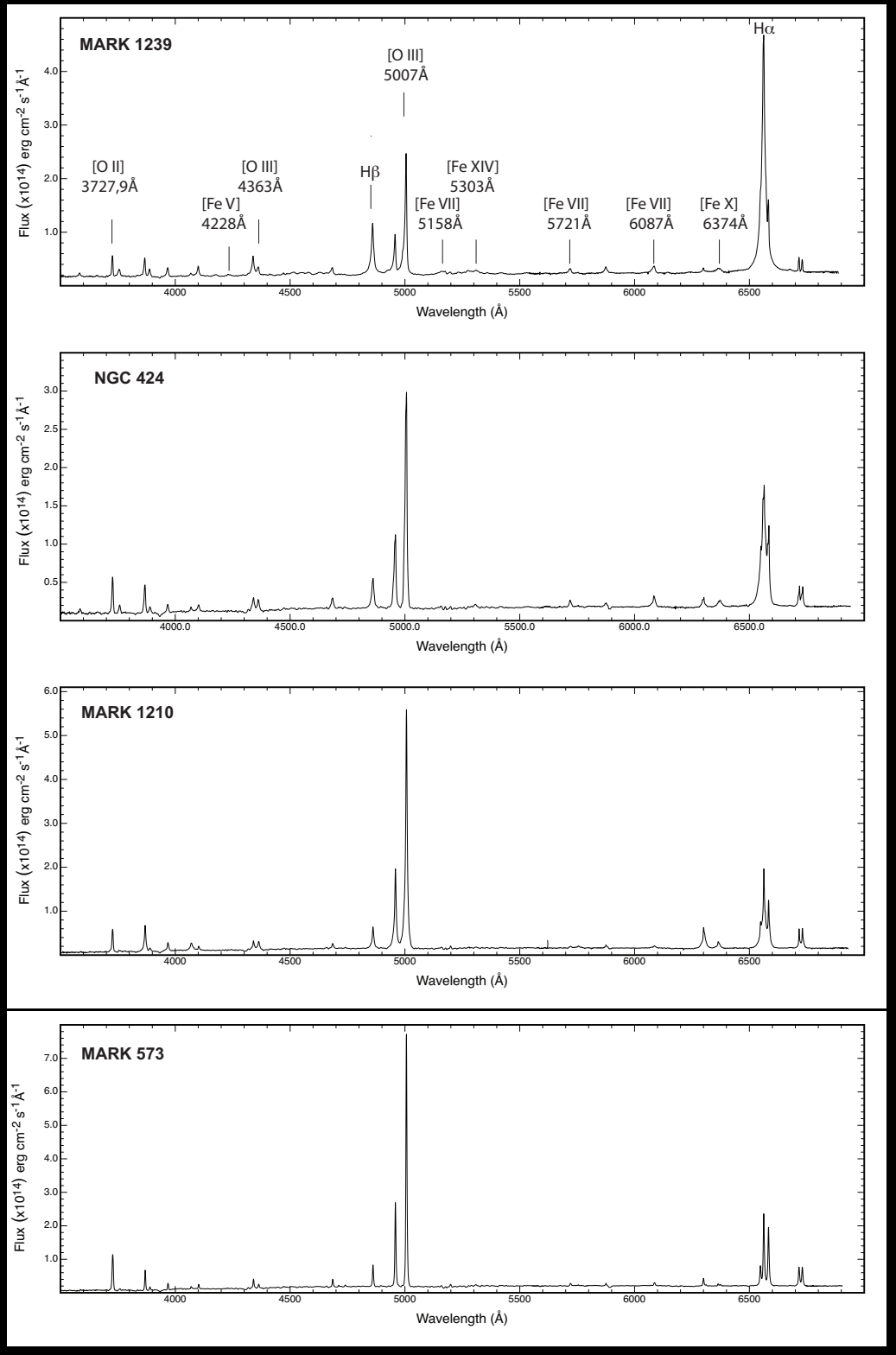


4. Coronal Line Emission



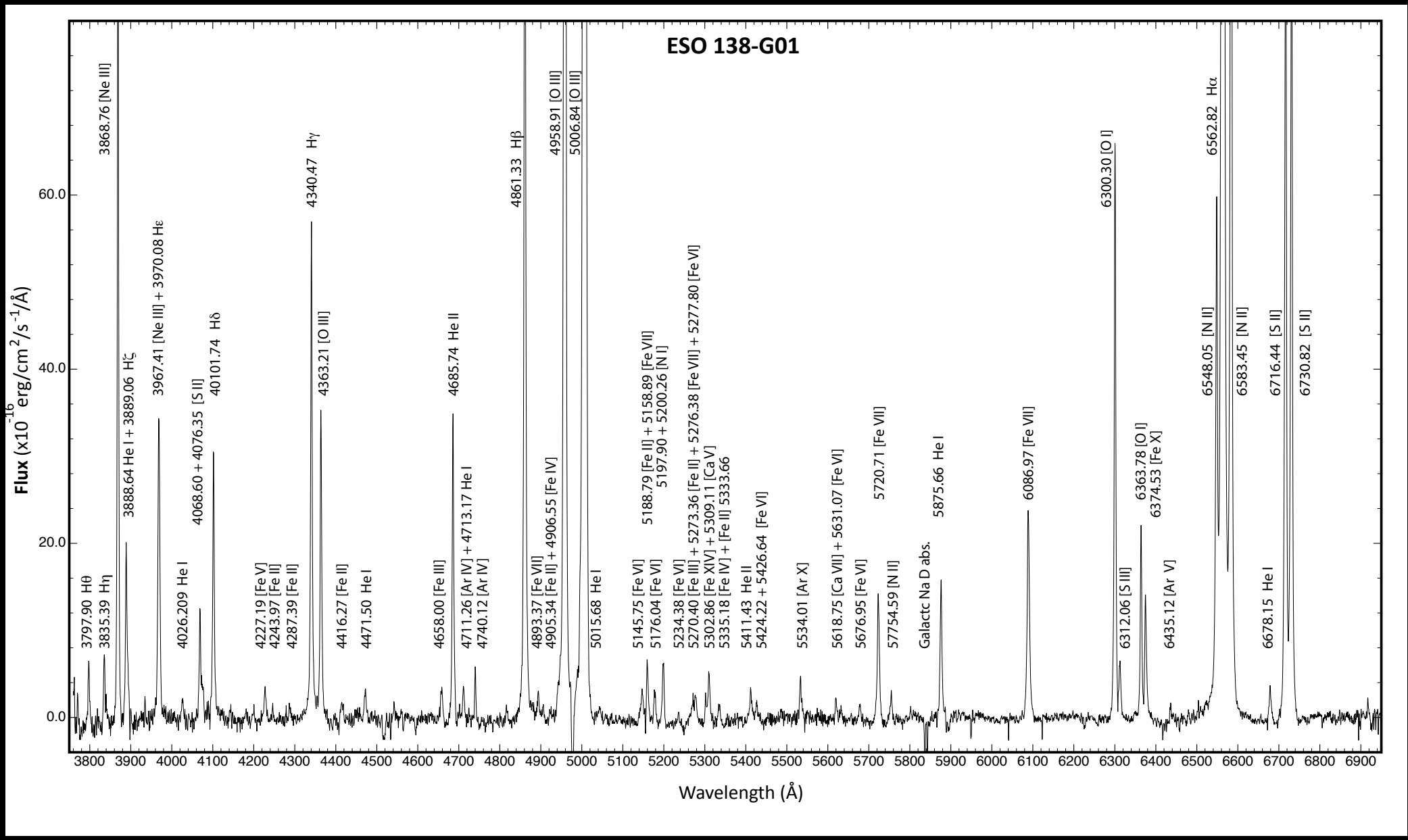



Examples of nuclear spectra of S7 galaxies showing strong coronal lines



The Coronal Spectrum of ESO 138-G01

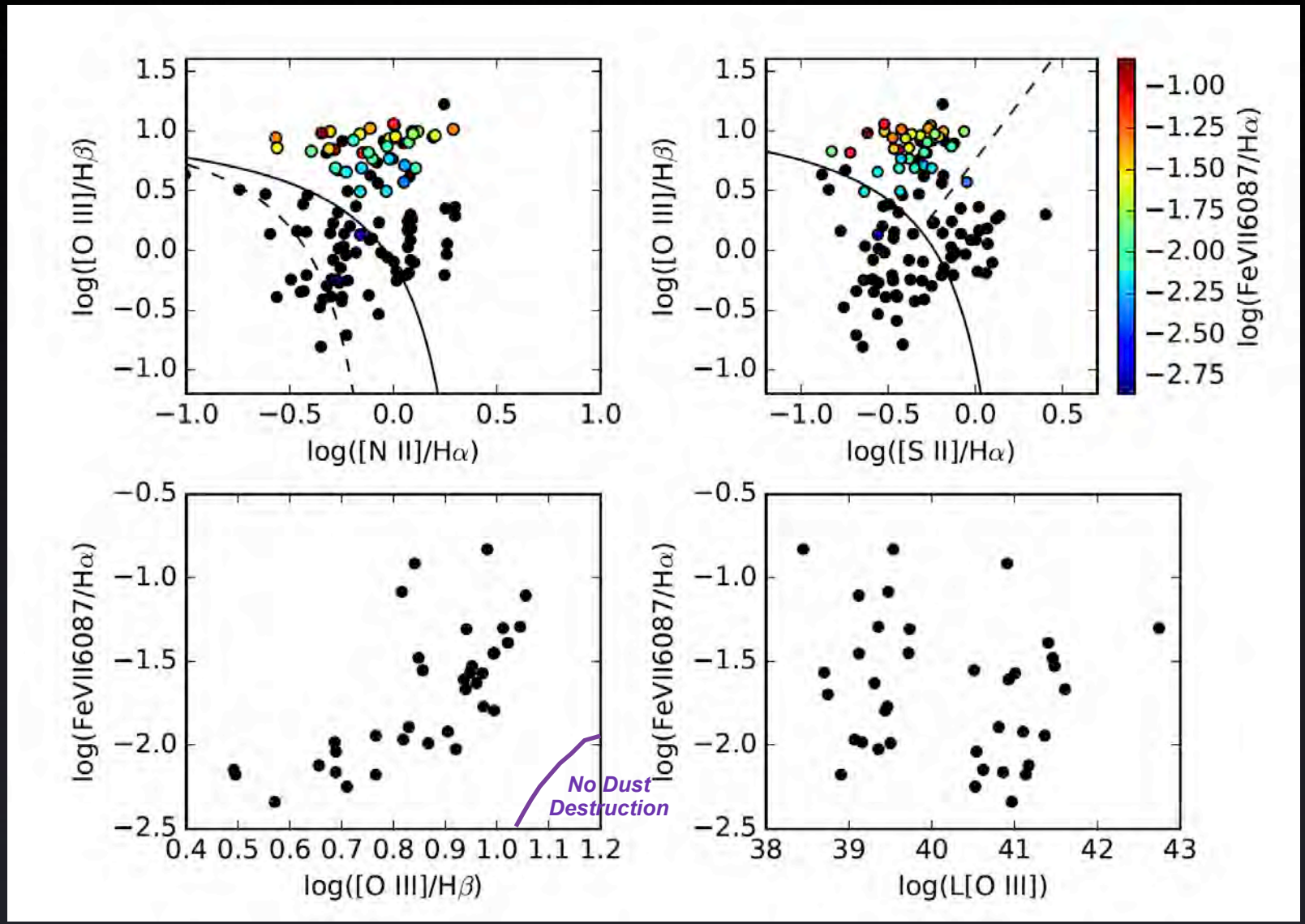
c.f. Alloin, Bica, Bonatto & Prugniel 1992, A&A, 266, 117



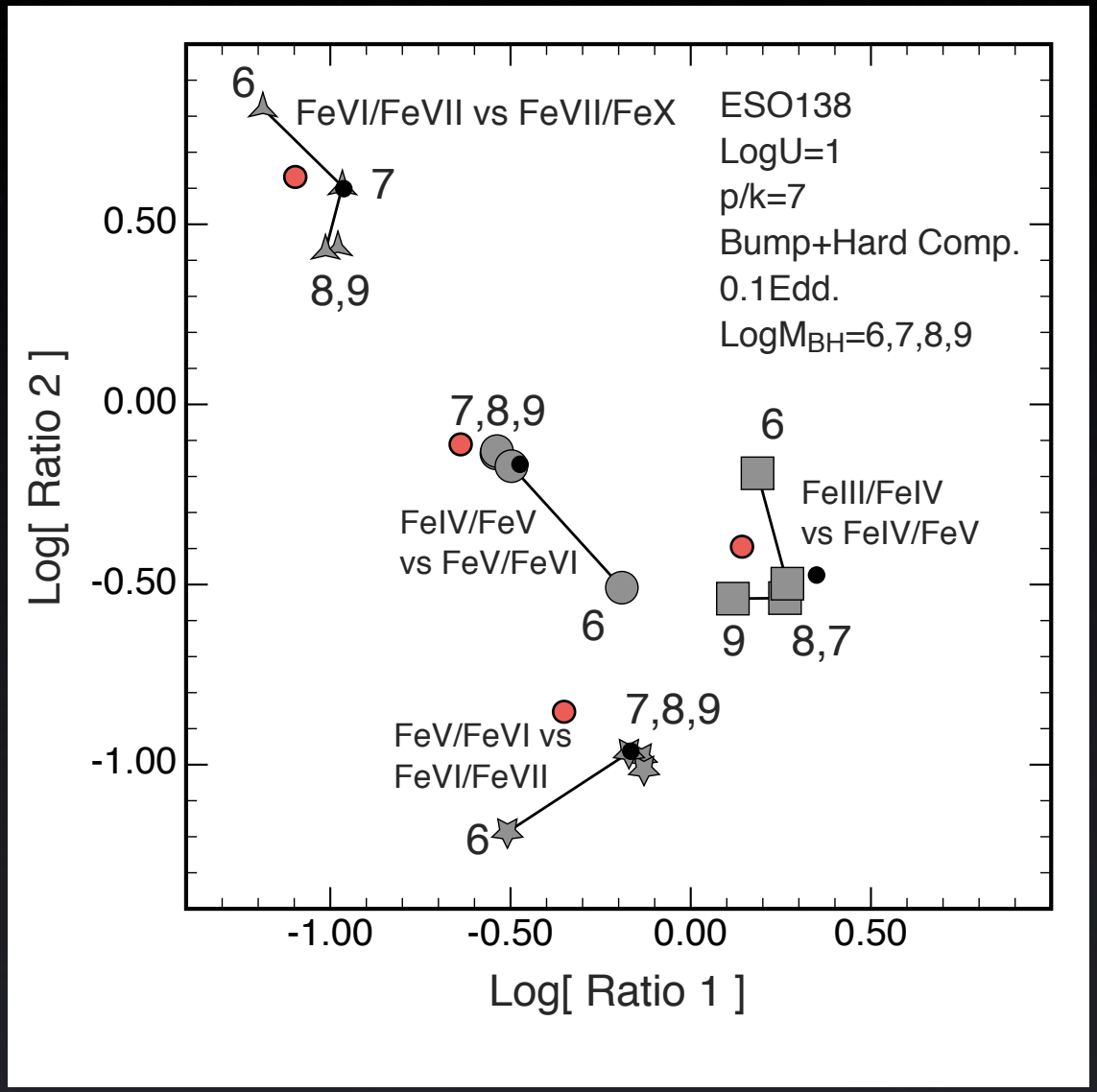
Strong [FeVII] is correlated with strong [O III]

— Extreme Ionisation Parameters are required

— Dust destruction is required for [Fe VII]



Ionisation-dependent Fe Line Ratios can constrain the shape of the soft X-ray spectrum



Results of Photoionisation Modelling

- M_{BH} ~ 1.0x10^7 solar, L/L_{edd} ~ 0.1.
- There are two pressure zones: log *P/k*~ 8.5 and log *P/k* ~ 5.5.
- The Coronal region has both a higher gas pressure and a higher ionisation parameter *U*.
- Abundances are sub-solar (Z~0.8 solar) suggesting that the NLR gas is a result of a minor merger.
- Dust is destroyed (or absent) when log *U* > -1.0, which raises the strength of the coronal lines, and weakens [N II], [S II] etc.

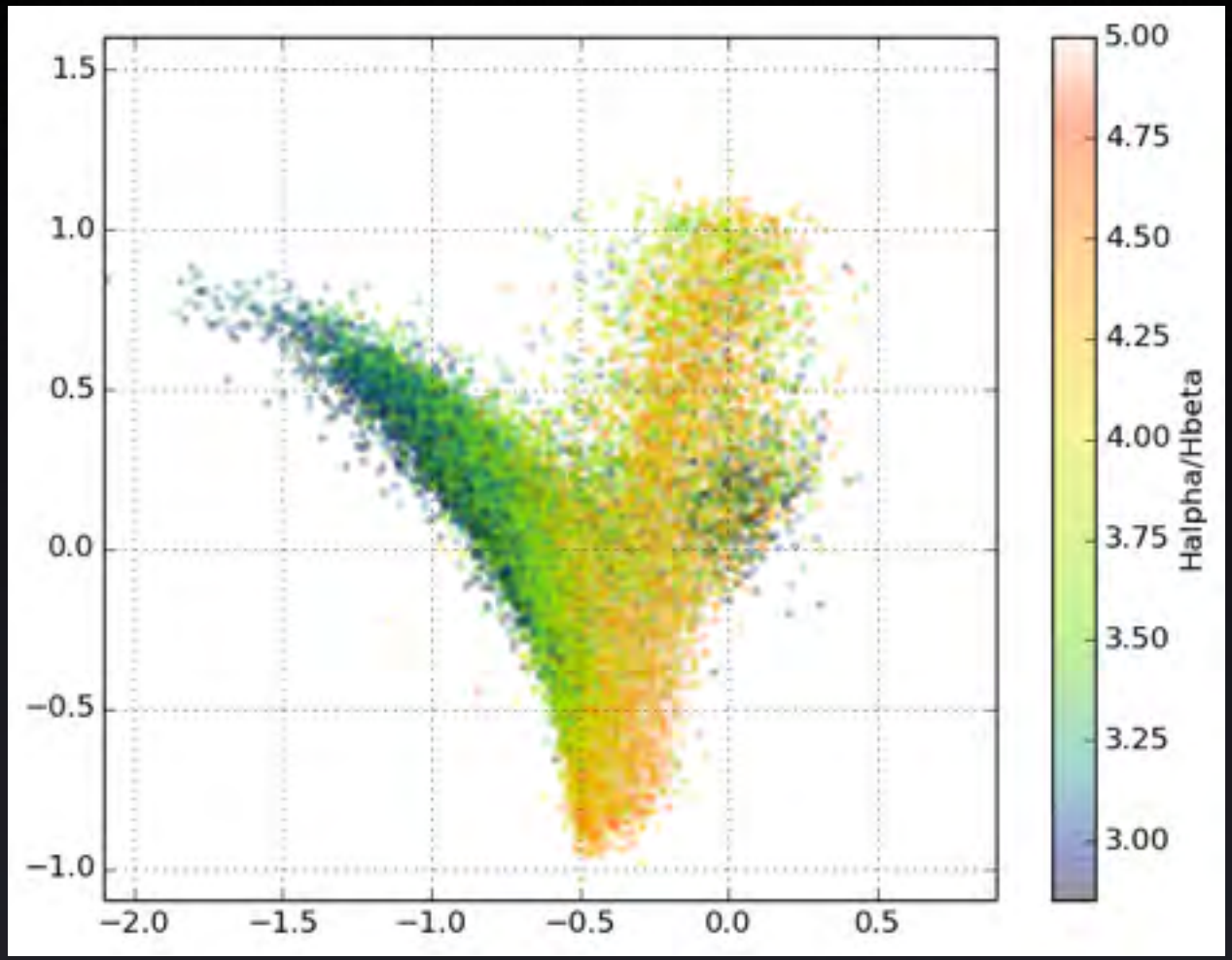


5. LINERS

(Low ionisation Nuclear Emission Line Regions)



LINERS have low reddening and occupy a distinct region in the BPT diagram



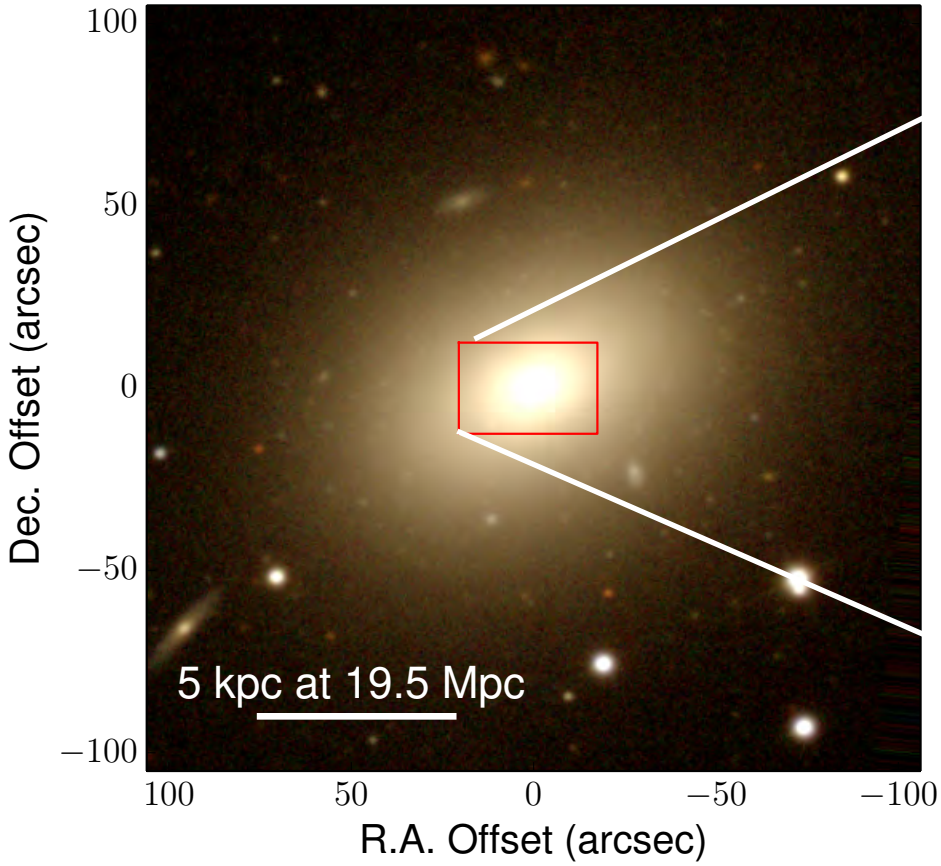
ANU

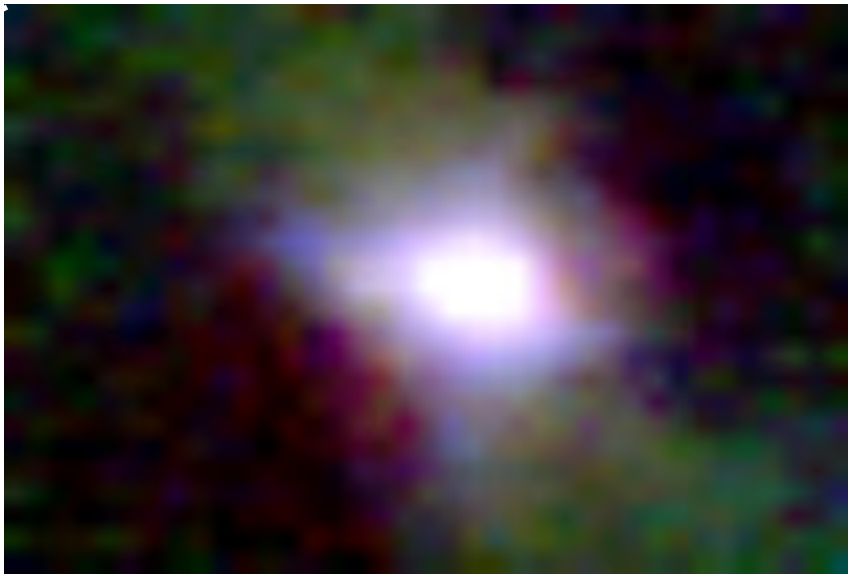
Australian Academy of Science

Physics of LINERS: The case of NGC 1052

Dopita et al 2015, ApJ, 801, 42

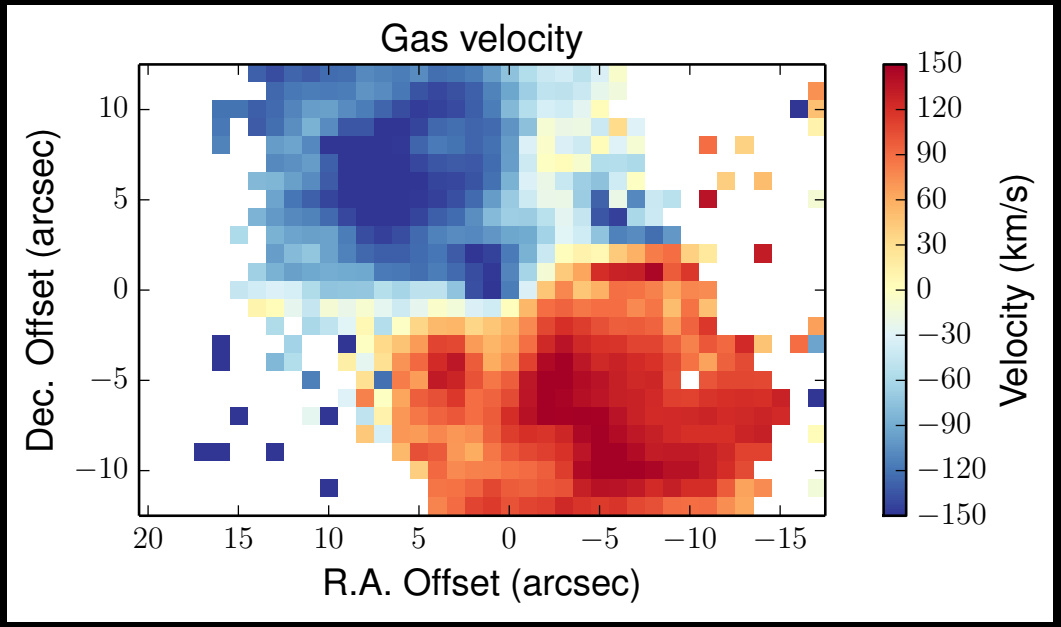
The Ionisation Cone of NGC 1052

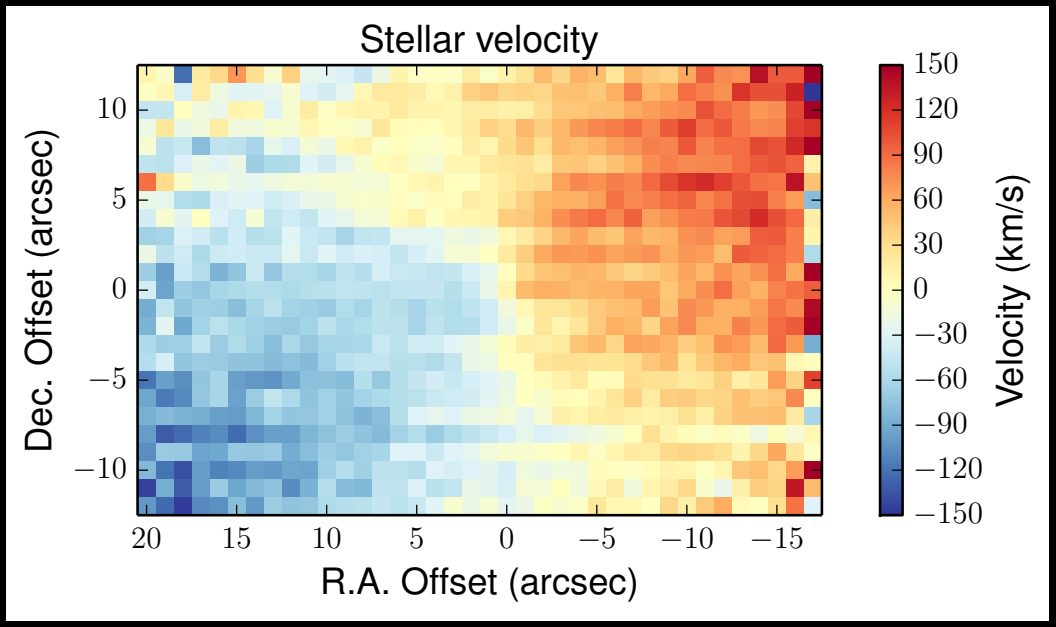


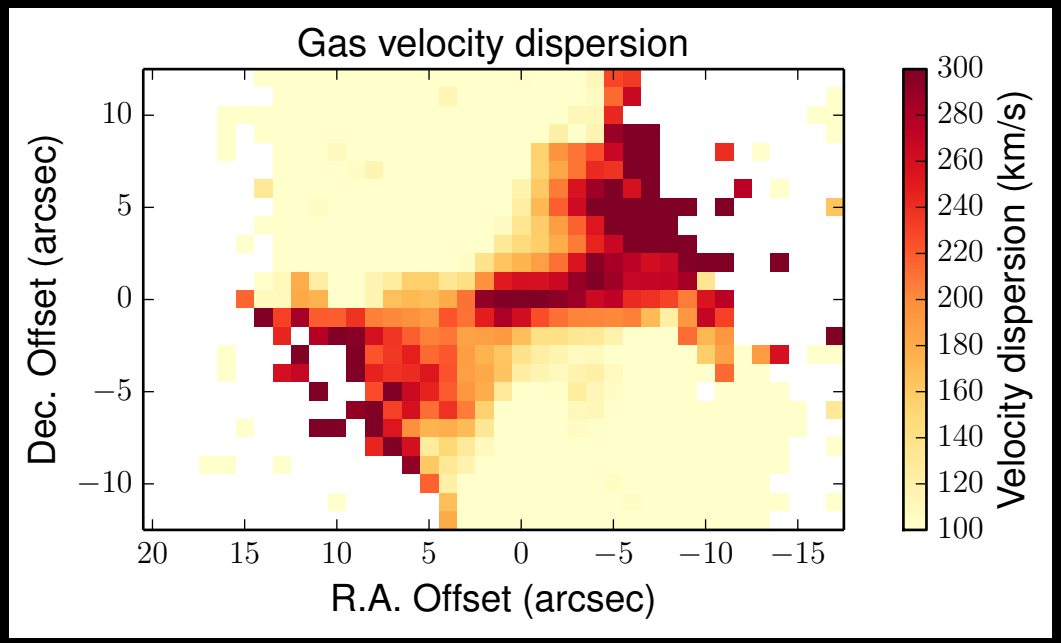


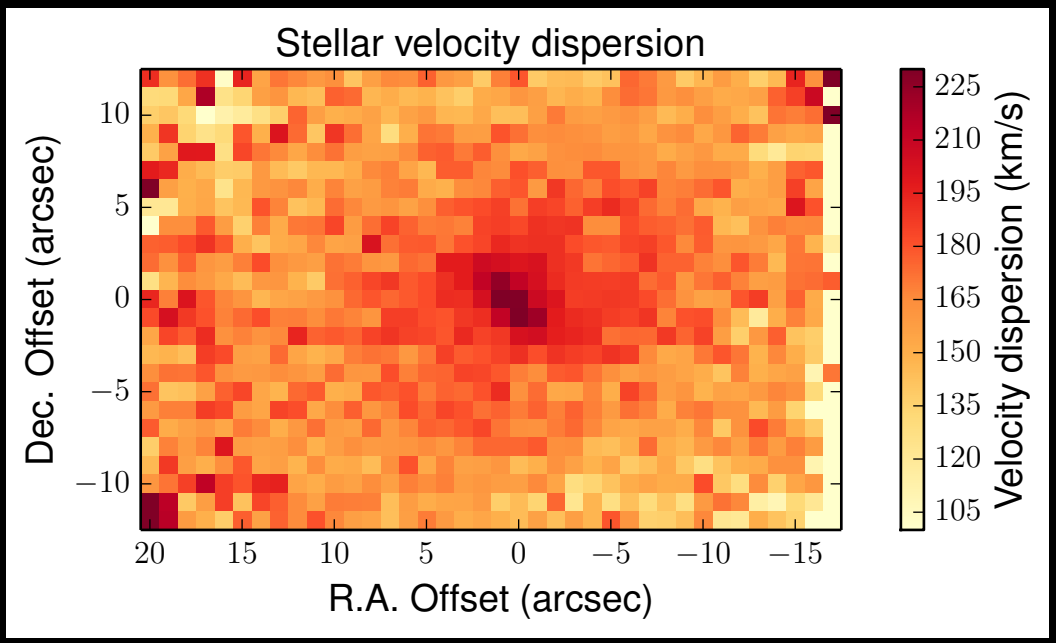
WiFeS Image: H-alpha, [NII], [OIII]

Jets & Accretion flow in NGC 1052



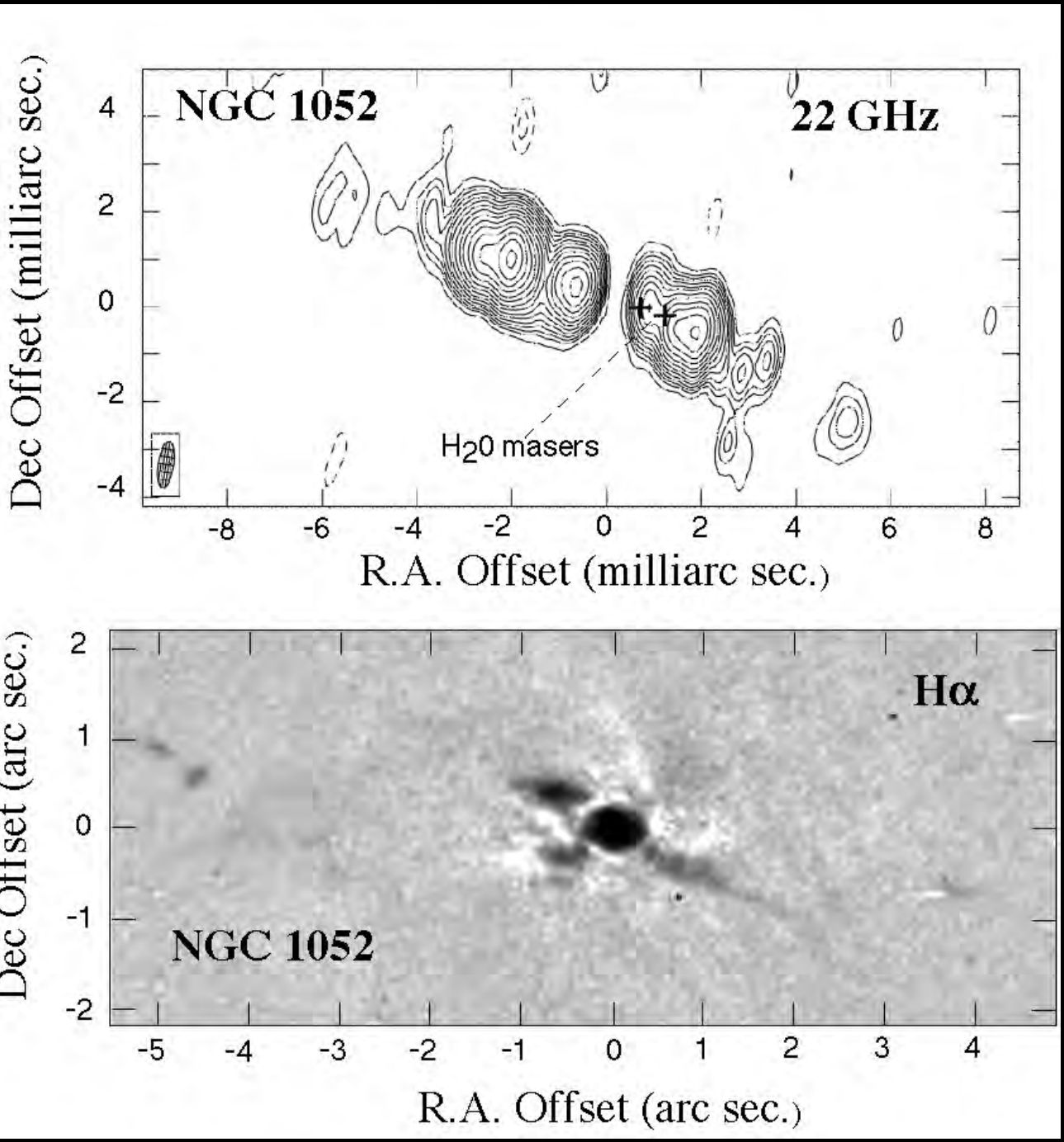






- *Jet directed along minor axis & rotation axes of galaxy.*
- *Accretion flow is towards plane of rotation of stars.*

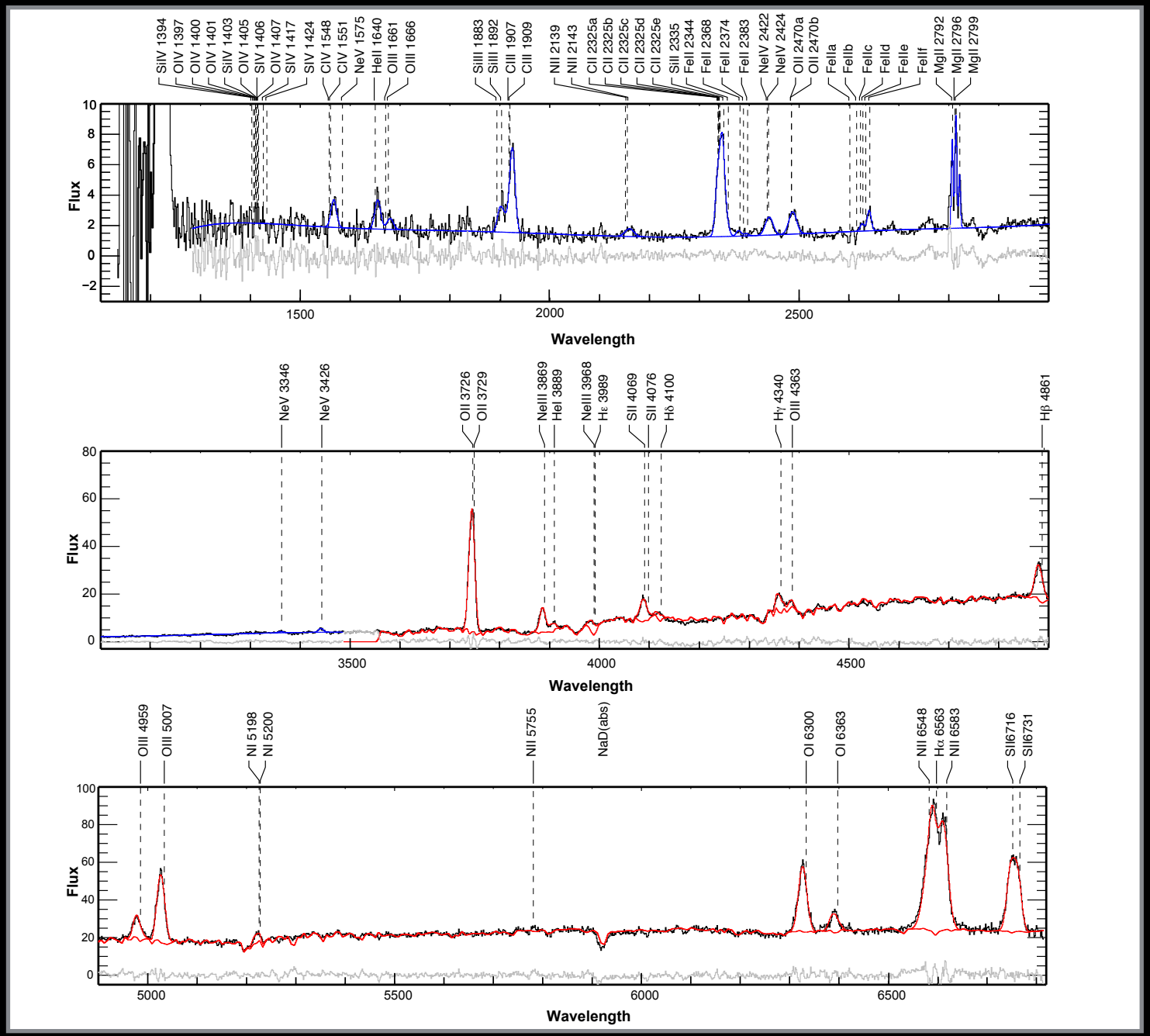
Inner Jet & Accretion Disk



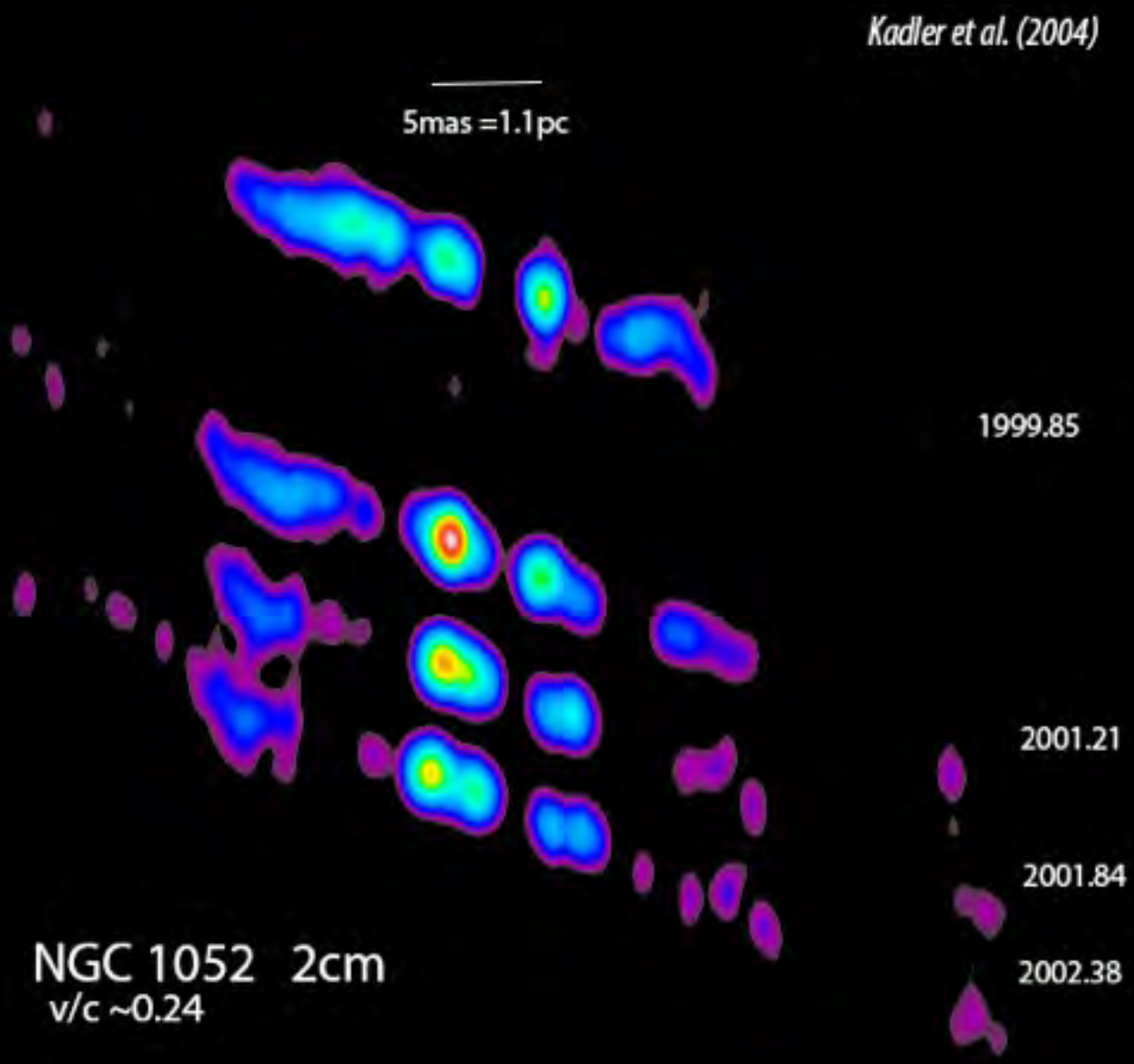
- **VLA** *Claussen 1998 ApJ 500.L129*
  R~0.1 pc

- **HST** *Pogge et al 2000, AJ 532, 323*
  R~35 pc

The HST FOS Spectrum:
Not so Low-Ionisation!



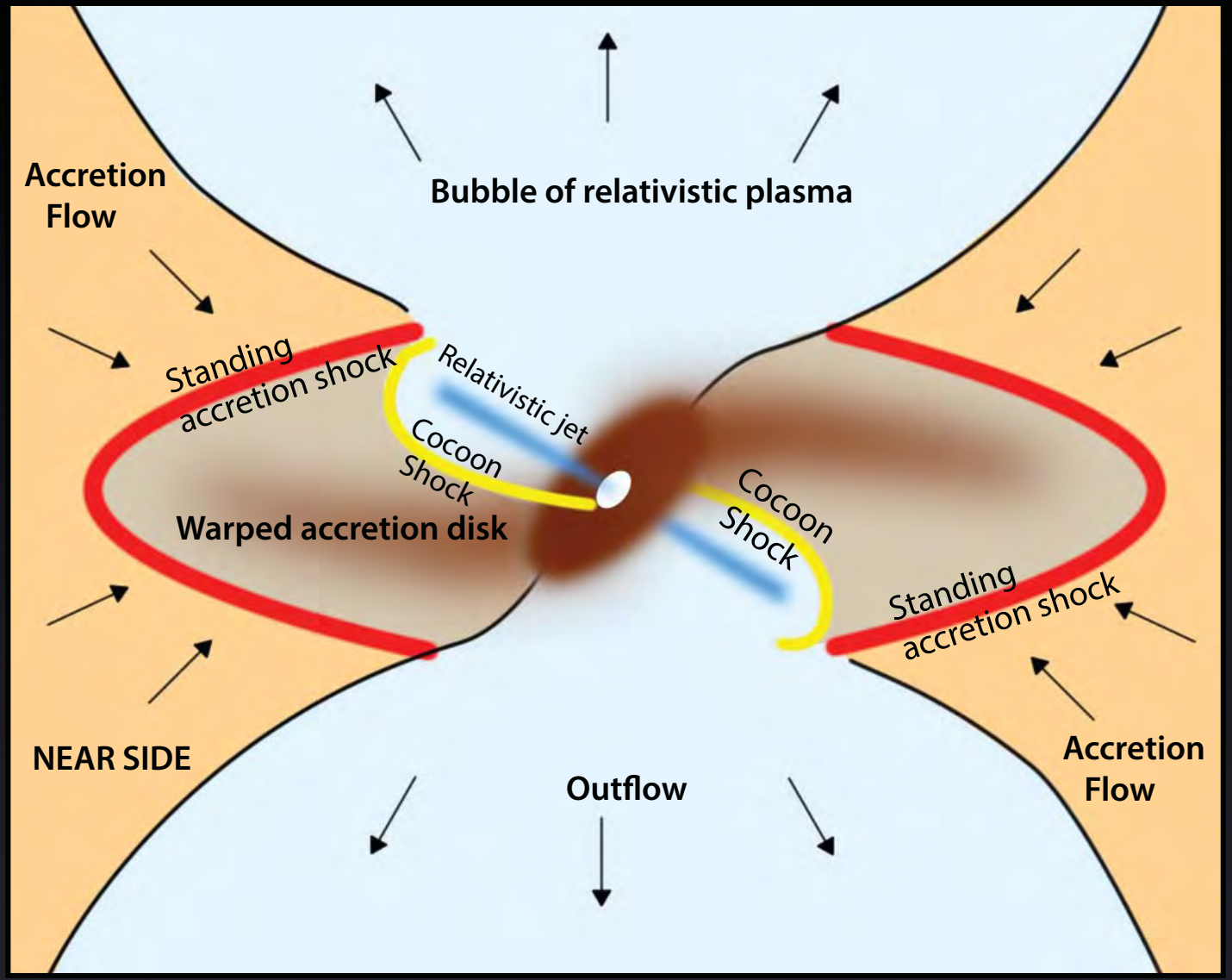
The inner jet of NGC 1052

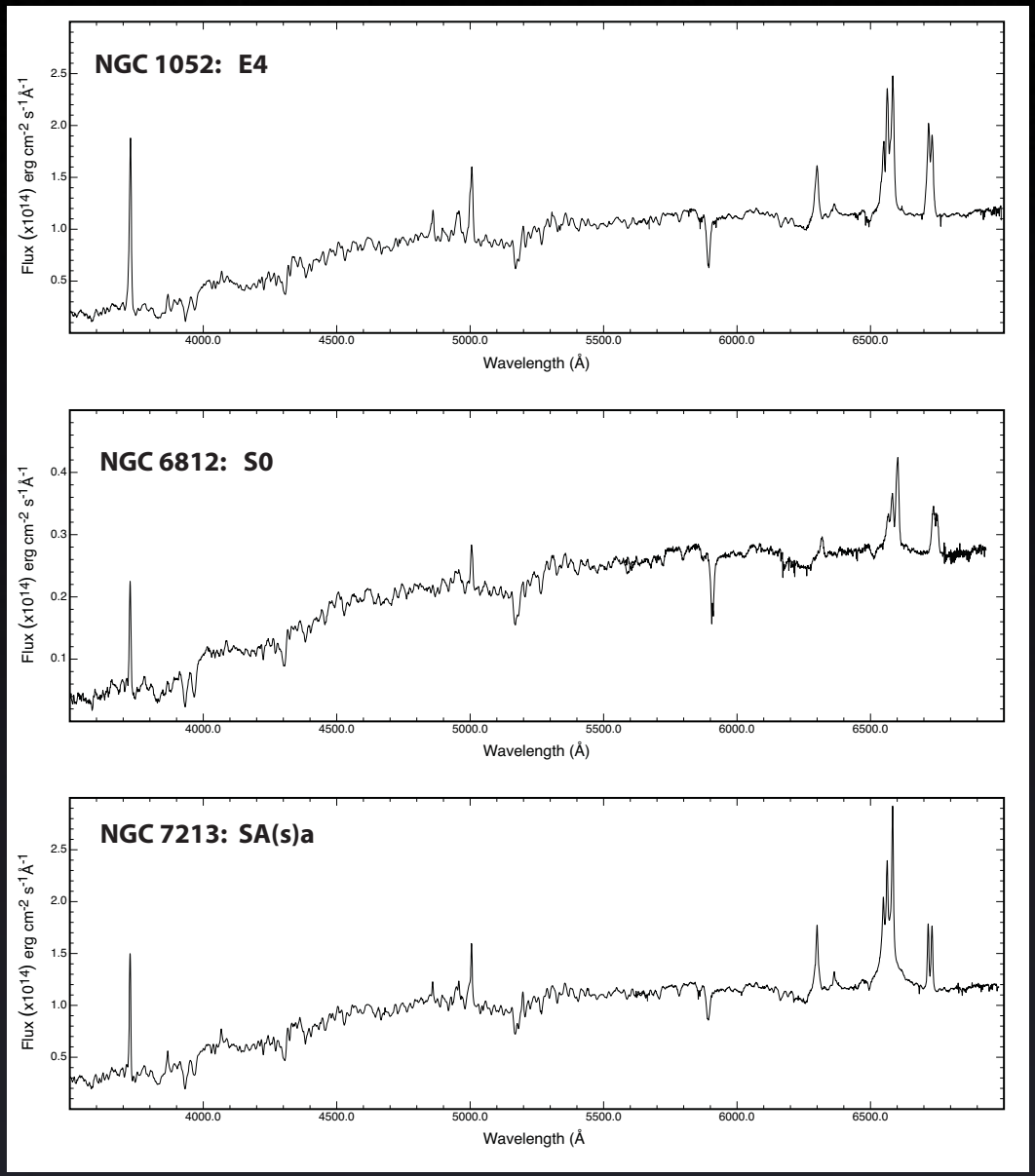


The Paradox of the LINER Spectrum

- The UV spectrum is very strong with high excitation lines, while the optical spectrum is of low excitation - incompatible with simple photoionisation models.
- Line ratios indicate the presence of both high- and low-density gas,
  e.g. [S II] 6717/6731 ratio gives $n \sim 10{,}000$ cm^{-3}
  while [SII] 6717,31/4068 ratio requires $n > 10^6$ cm^{-3}
- *A possible solution: Accretion shocks onto a dense accretion disk combined with Cocoon shocks resulting from the collision of a precessing jet with its own accretion disk.*
- *In this model:* Low-density phase comes from the accretion shocks & High-density phase comes from the cocoon shocks.
- A additional energetically-significant hard X-ray spectrum is needed (originating from the AGN) .

A physical model for the LINER structure





ANU

Australian Academy of Science

Conclusions

- From the S7 integral field study, we are gaining understanding into the fundamental physics of both Seyfert and LINER-type active galaxies.

Key results:

- **Seyfert** ionisation cones are consistent with radiative-pressure dominated photoionisation models
  - Many objects show “mixing” of both ENLR and HII region emission.
  - The bright HII regions constrain the nuclear abundance….
  - allowing good constraints to be placed on the EUV radiation field.
  - Massive atomic outflows in Na D absorption are seen in some objects.
  - Coronal emission regions are compact, have extreme ionisation parameters, and show clear evidence of dust destruction.
- **LINERS** can be understood as combined accretion and cocoon shocks excited in the presence of X-ray photoionisation.





That's All Folks!

