Extended Emission-Line Regions: Remnants of Quasar Superwinds?

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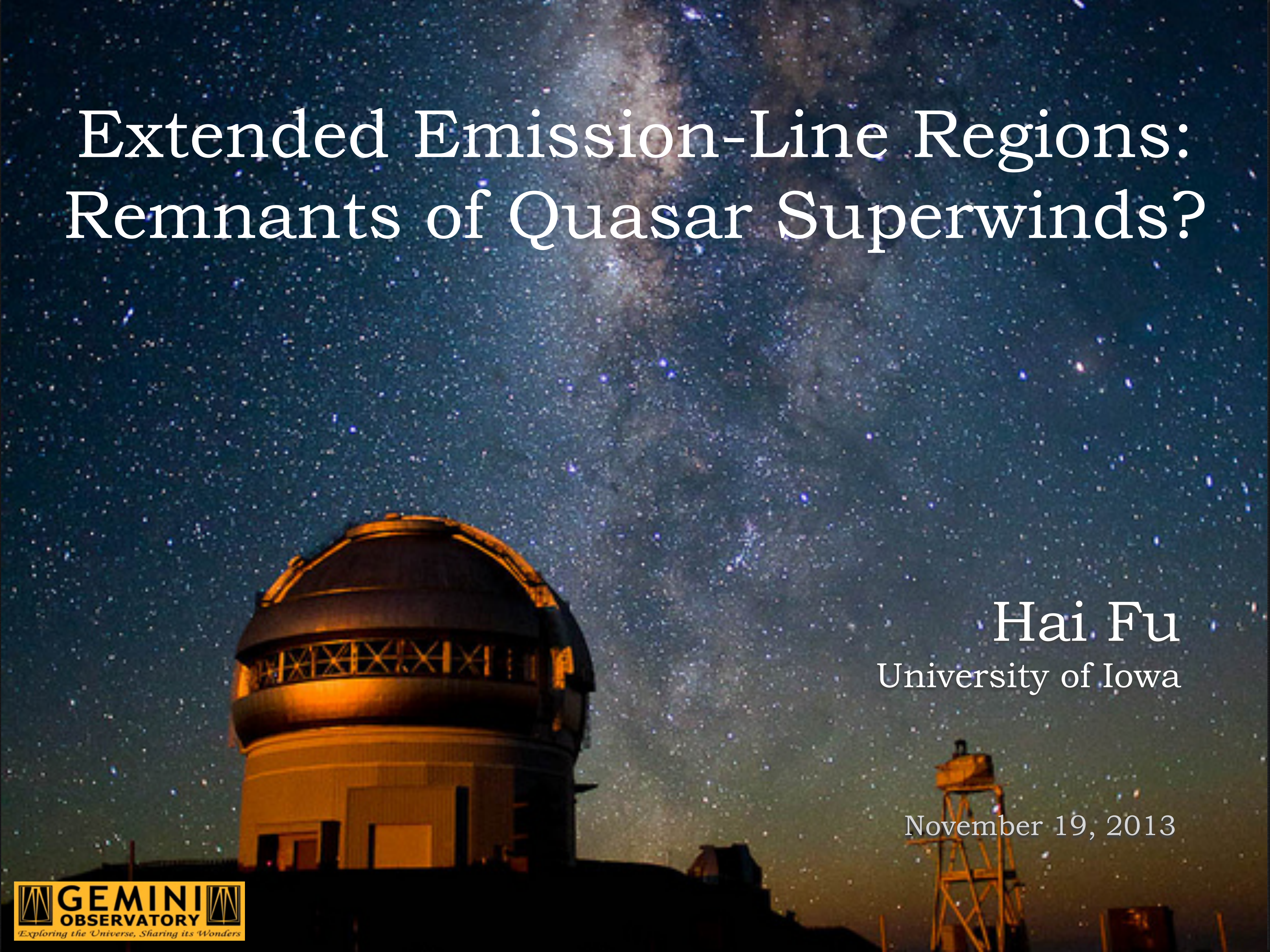
University of Iowa

November 19, 2013



Outline

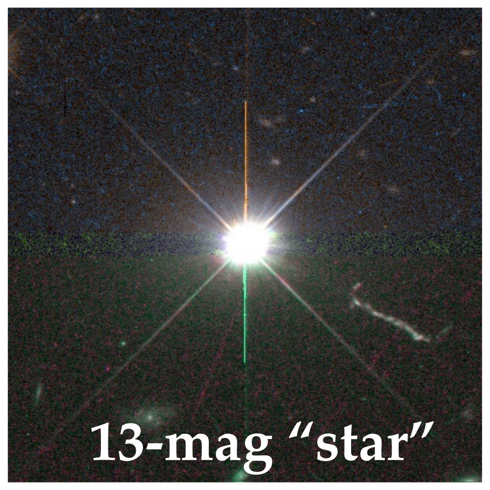
- History (1975–2005) and Motivation
- Integral Field Spectroscopy of Extended Emission-Line Regions (EELRs)
- EELR–Quasar Metallicity Relation
- Star Formation in the Host Galaxies
- Answers to Previous Questions

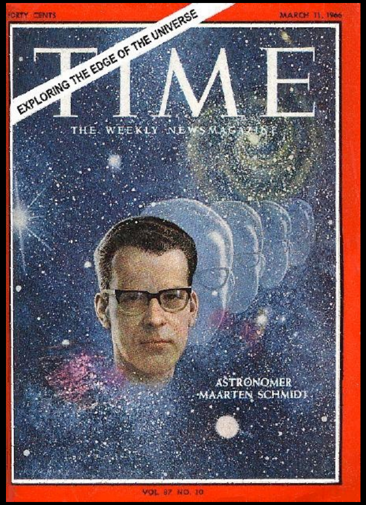
The Discovery of 3C 273: The First Quasar

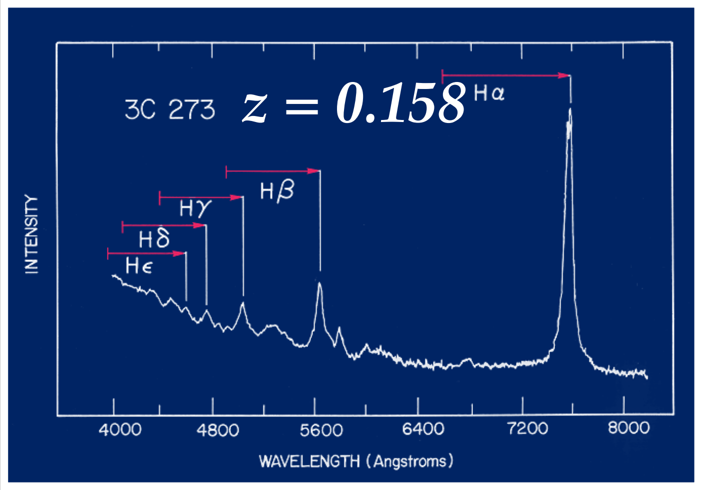
Edge *et al* (1959) - 1′

Hazard *et al* (1963) - Occultation, 1″

Schmidt (1963)

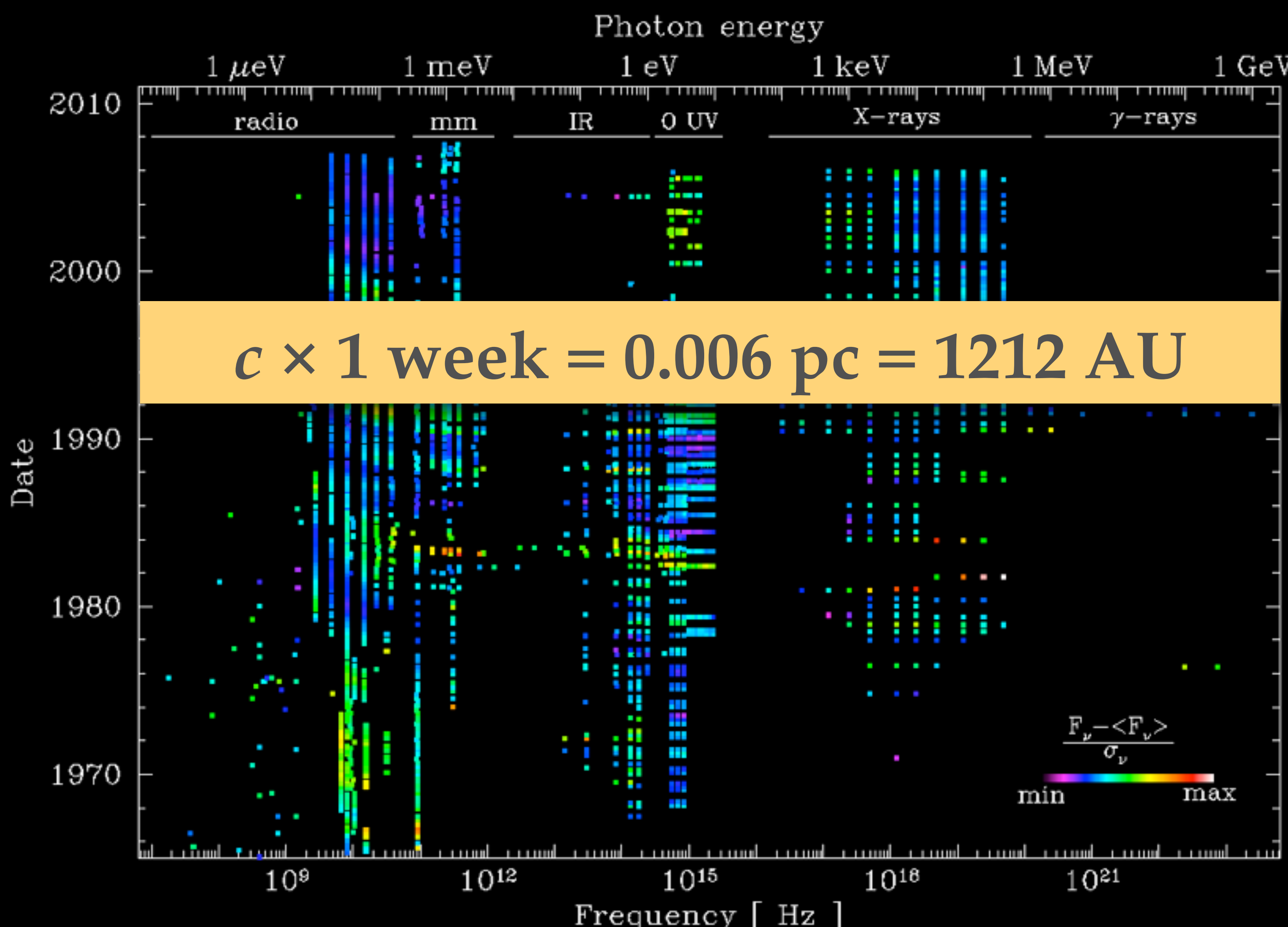






Quasar's Rapid Variation

Discovered by Smith & Hoffleit (1963)

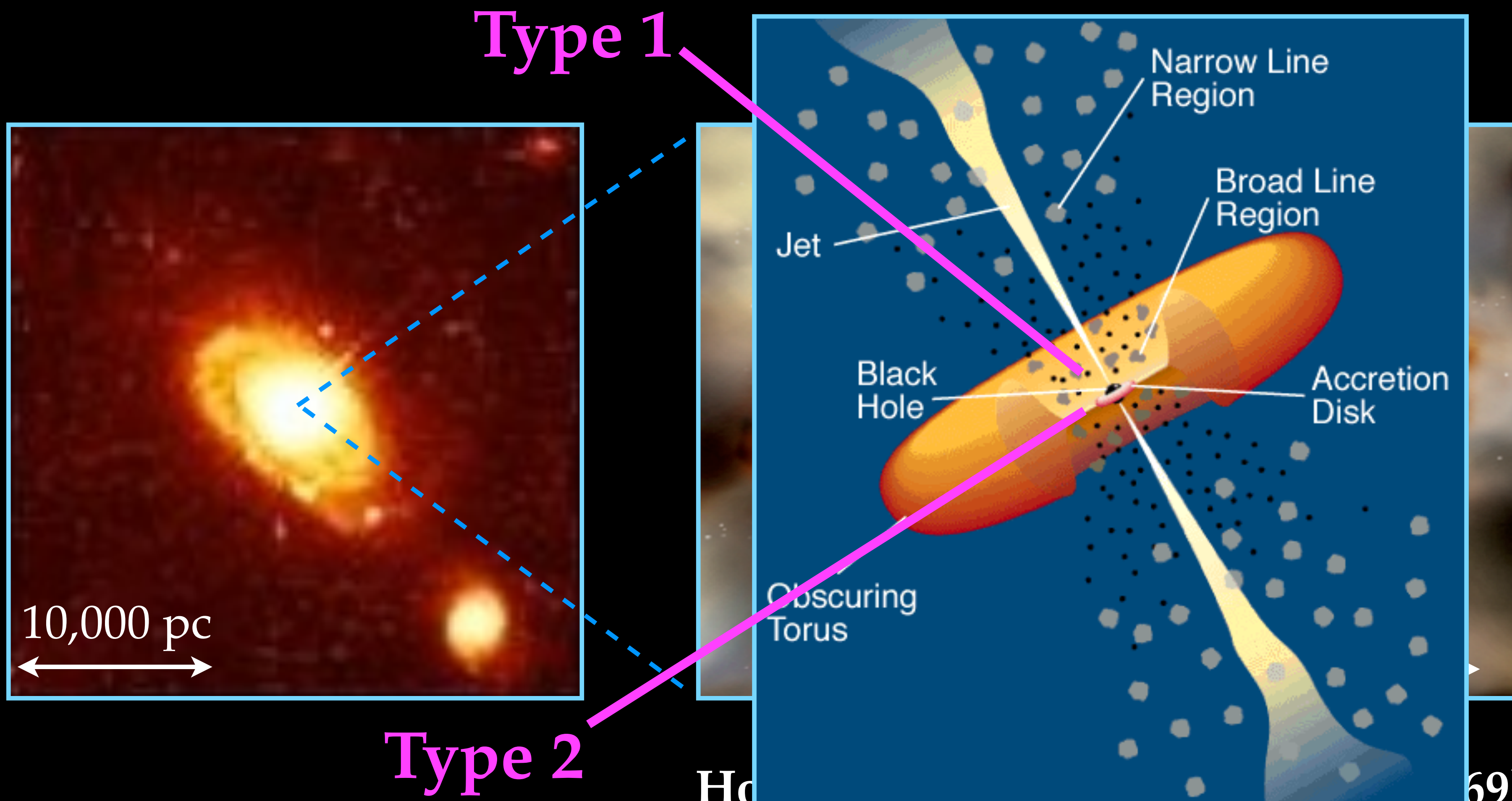


$c \times 1$ week = 0.006 pc = 1212 AU

3C 273 Light Curves from Radio to γ-ray, Soldi *et al* (2008)

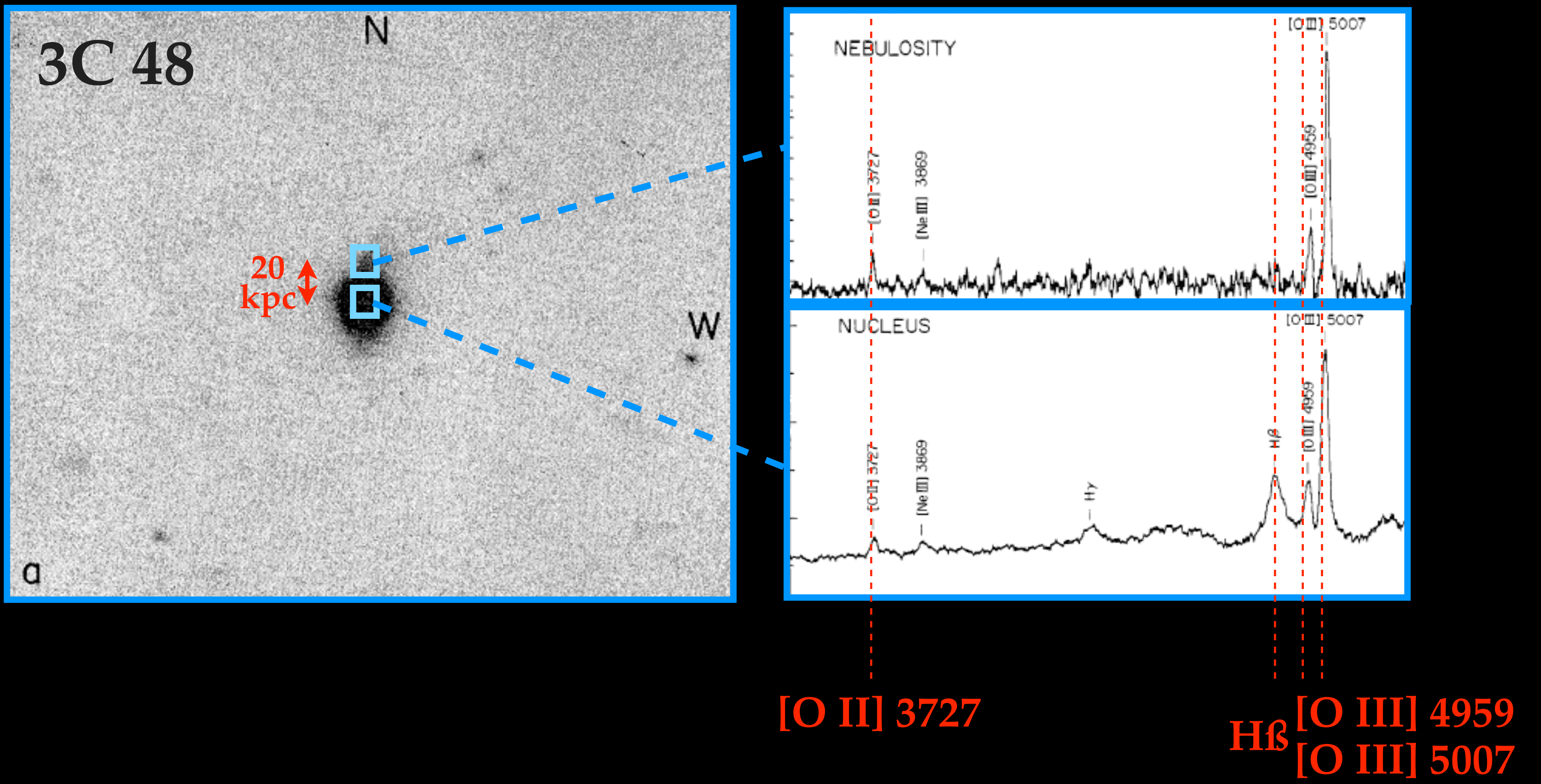
What Powers a Quasar?

Accreting black hole inside a giant galaxy



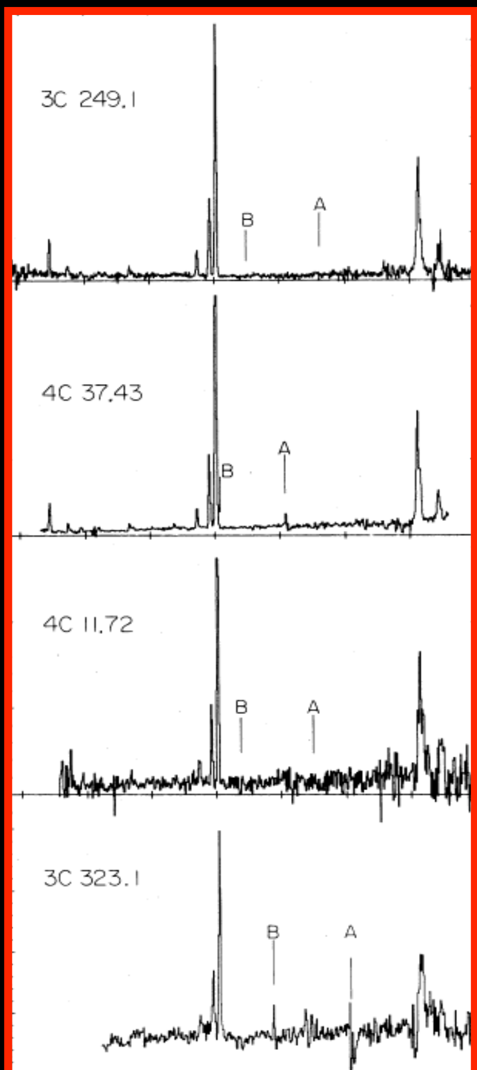
The Discovery of Extended Emission-Line Region (EELR)

Sandage & Miller (1966) Wampler et al (1975)

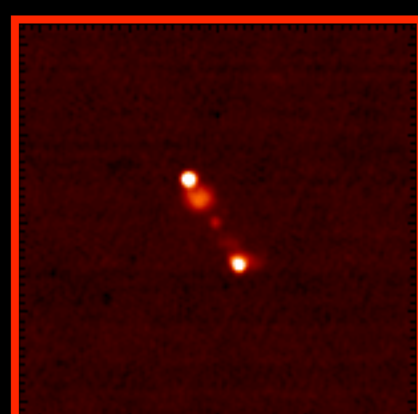


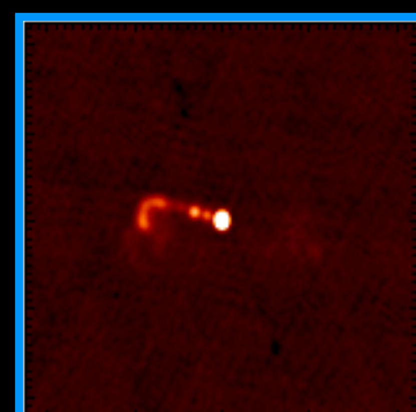
Which Quasars Have Extended Emission-Line Regions?

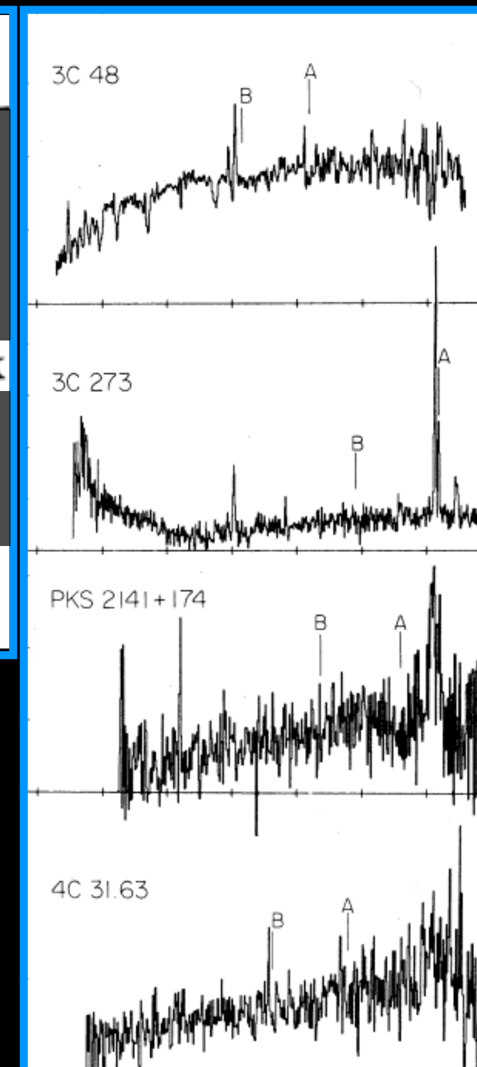
Boroson & Oke (1984) - A Spectroscopic Survey



Group 1	Group 2
Blue continuum	Red continuum
Strong emission lines	Weak or absent emission lines
No Fe II emission	Strong Fe II emission
Narrow lines are strong	Narrow lines are weak
Very broad, bumpy H lines	Less broad, smooth H lines
[O III]/Hβ large	[O III]/Hβ moderate
Steep spectral index	Flat spectral index
Double lobed structure	Compact structure





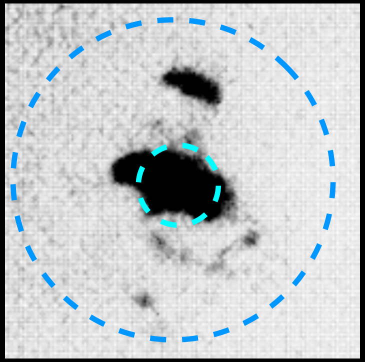


Which Quasars Have Extended Emission-Line Regions?

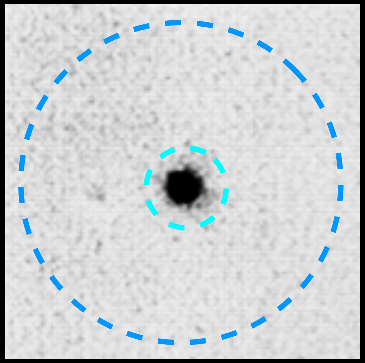
Stockton & MacKenty (1983,1987) - SM87 Sample

An [O III] Imaging Survey of 47 Quasars at z < 0.5

11 EELR Quasar **36 non-EELR Quasar**

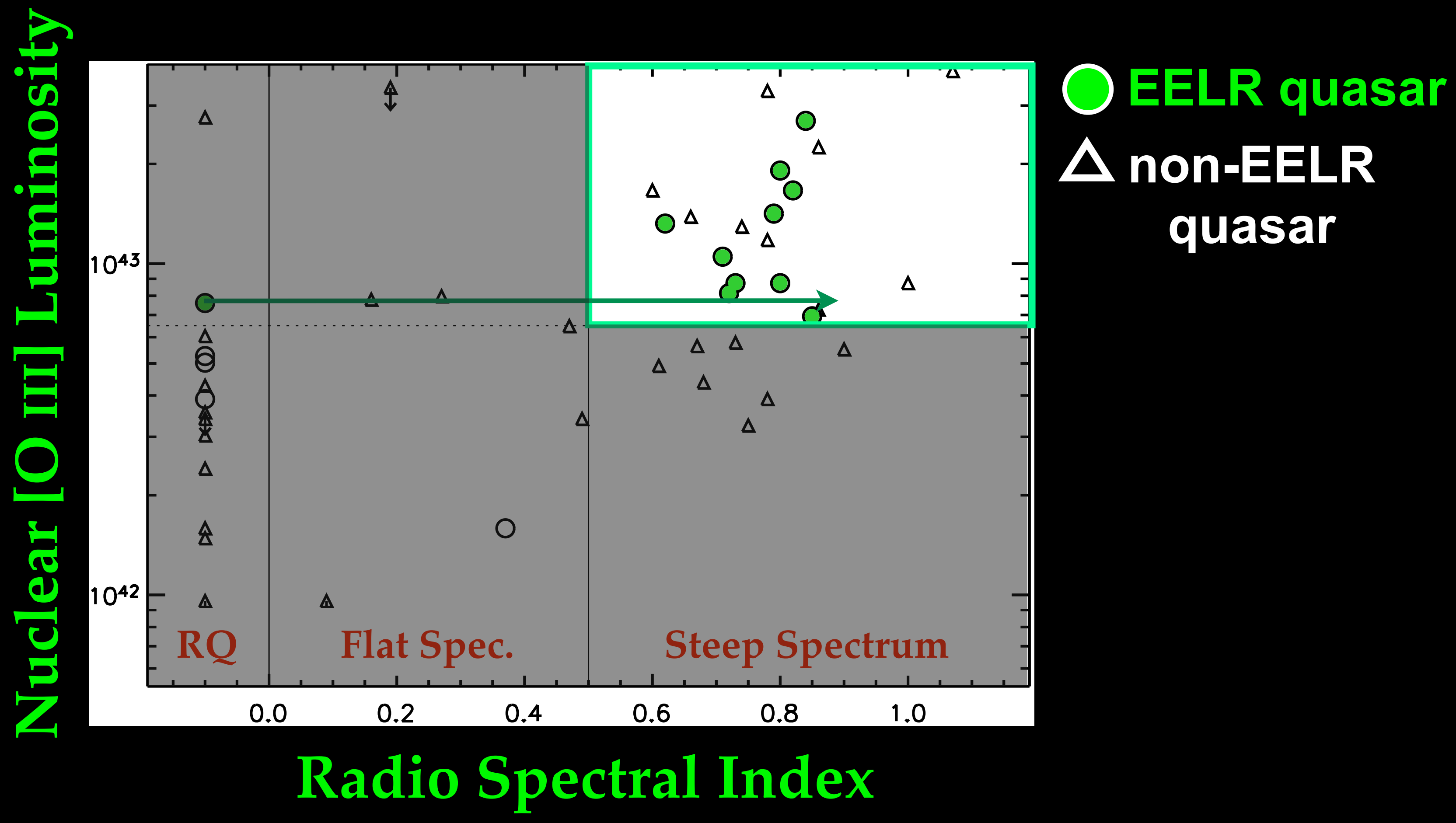


VS



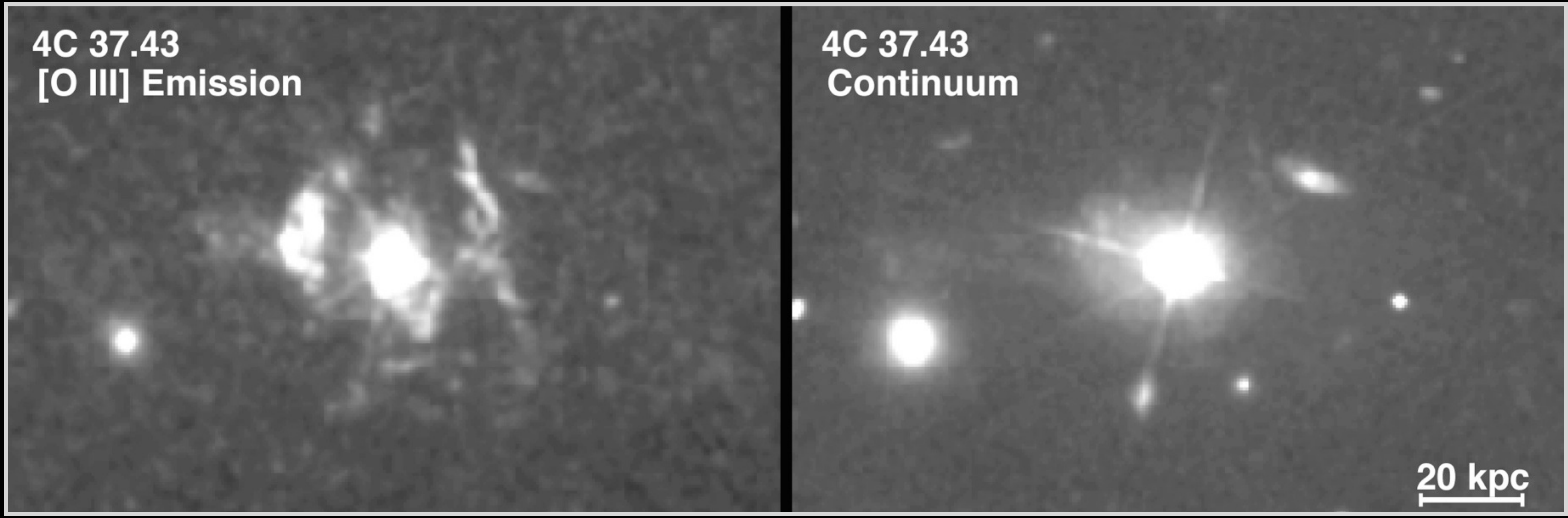
Which Quasars Have Extended Emission-Line Regions?

Stockton & MacKenty (1987)



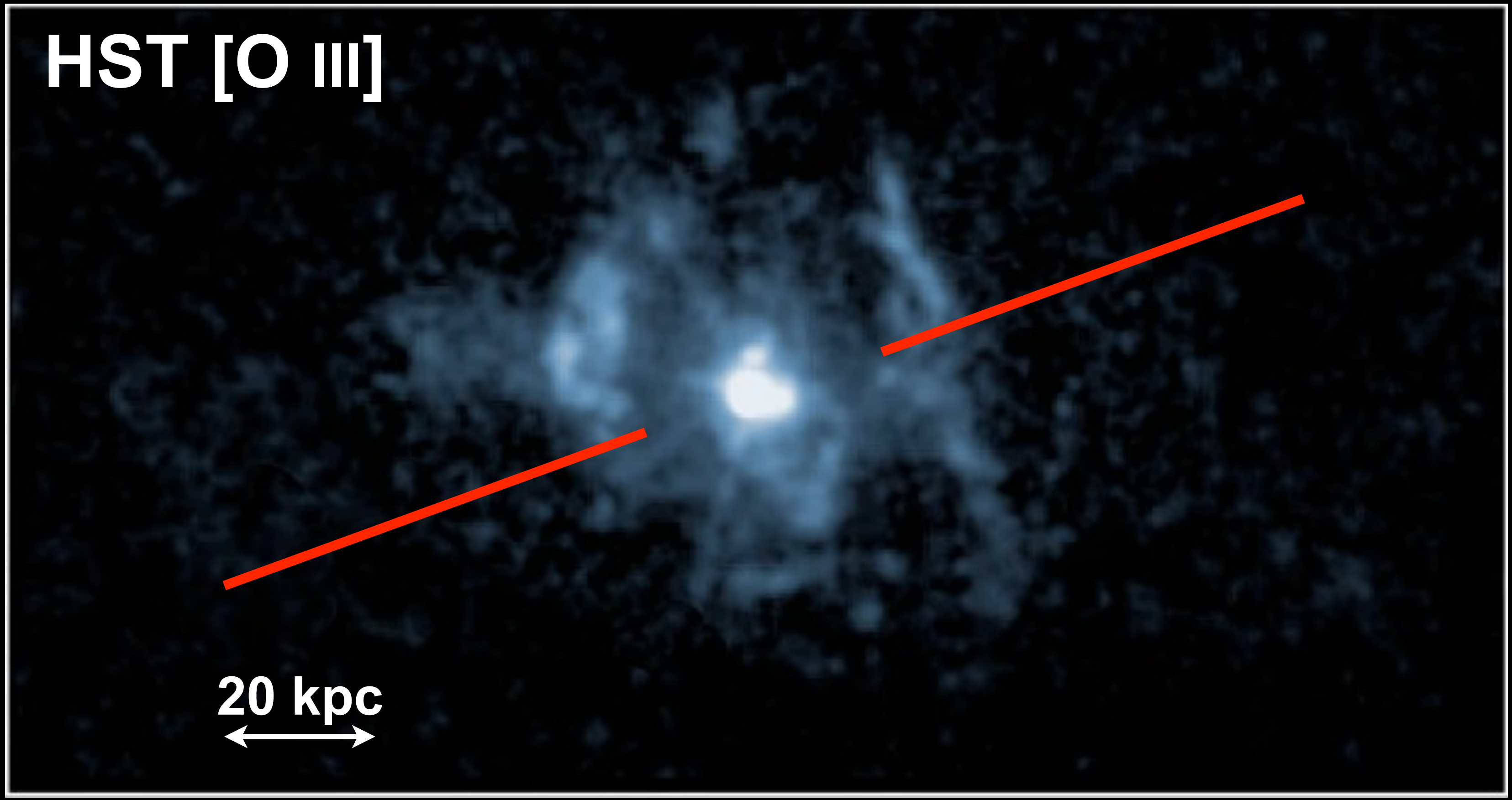
Morphology of EELRs

4C37.43 z=0.37



Stockton et al. (2002)

Morphology of EELRs



Summary & Questions

- EELR ~ $L_{[O\ III],nuclear}$ & Radio Morphology
- Independent Morphologies of EELRs
- Photoionization by the central source

? Are EELRs shock-ionized?

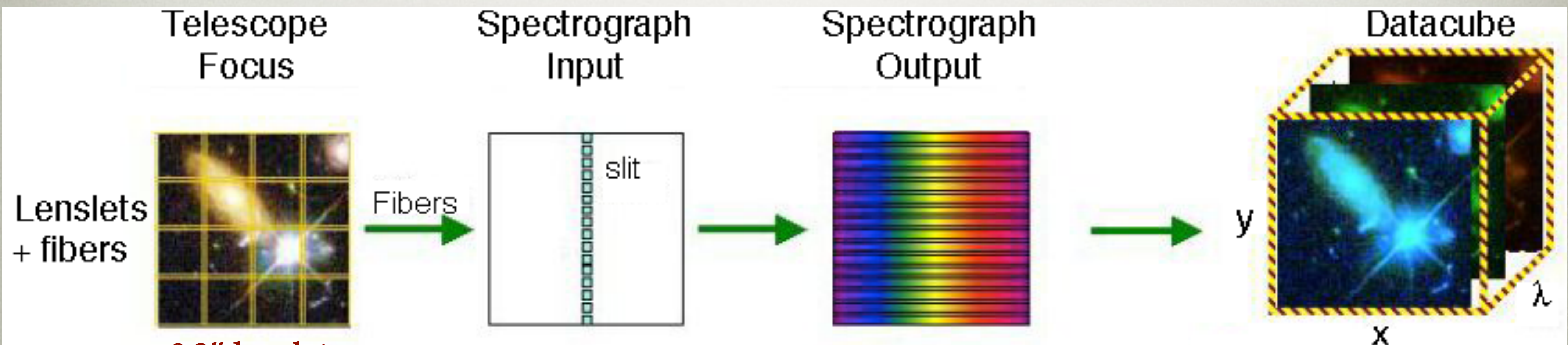
? What makes EELR quasars special?

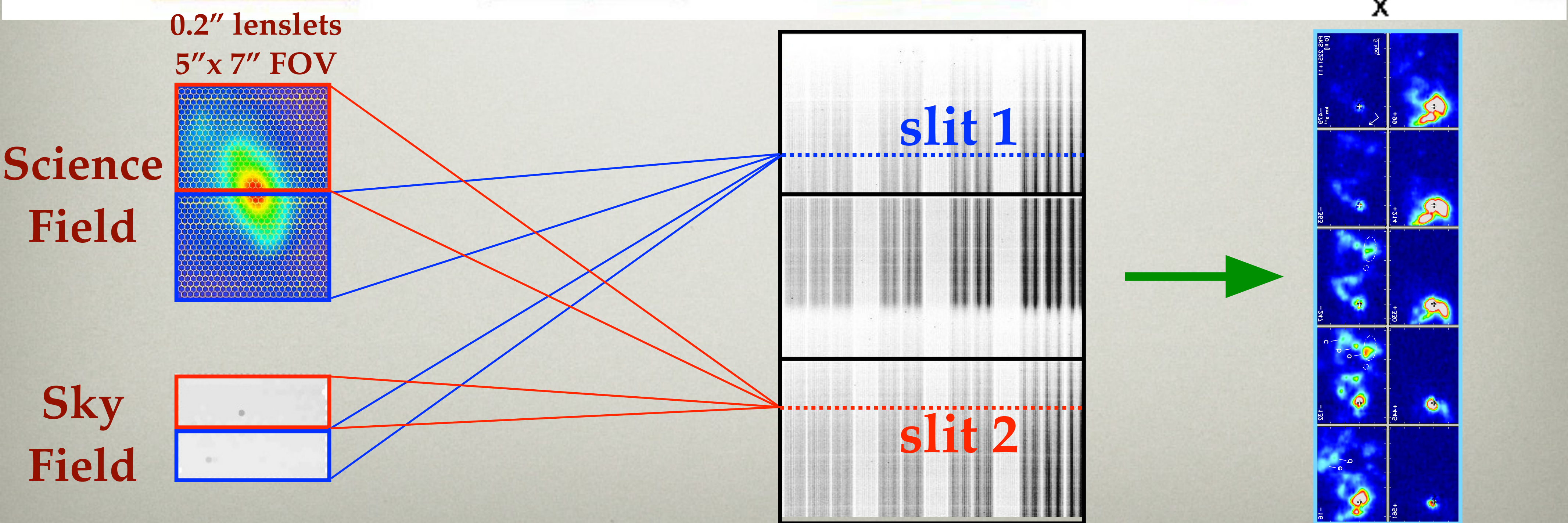
? Where did the gas come from?

? How were the EELRs formed?

Integral Field Spectroscopy of EELRs

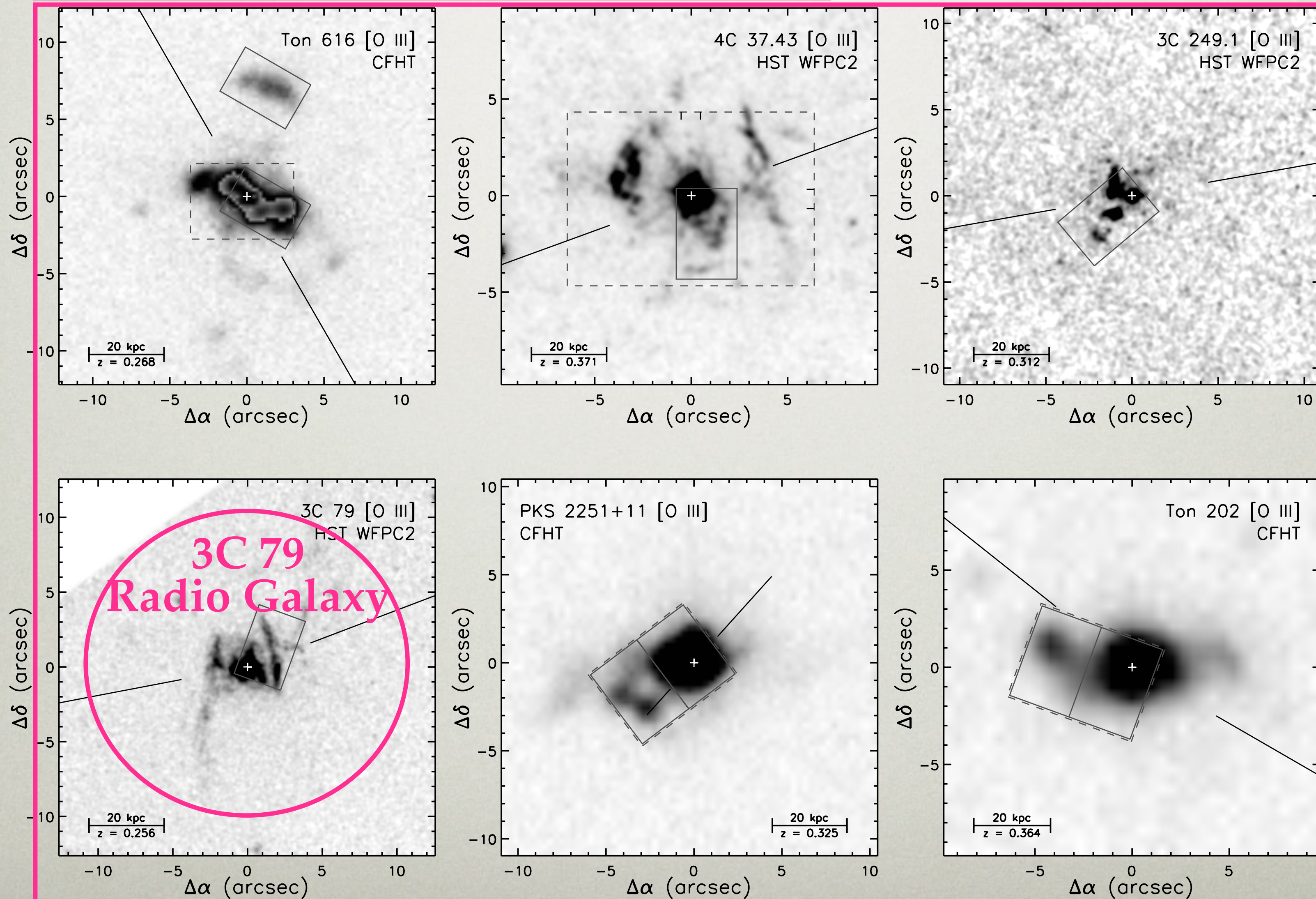
Sketch of Gemini GMOS/IFU (Alligton-Smith et al. 1998,2002)



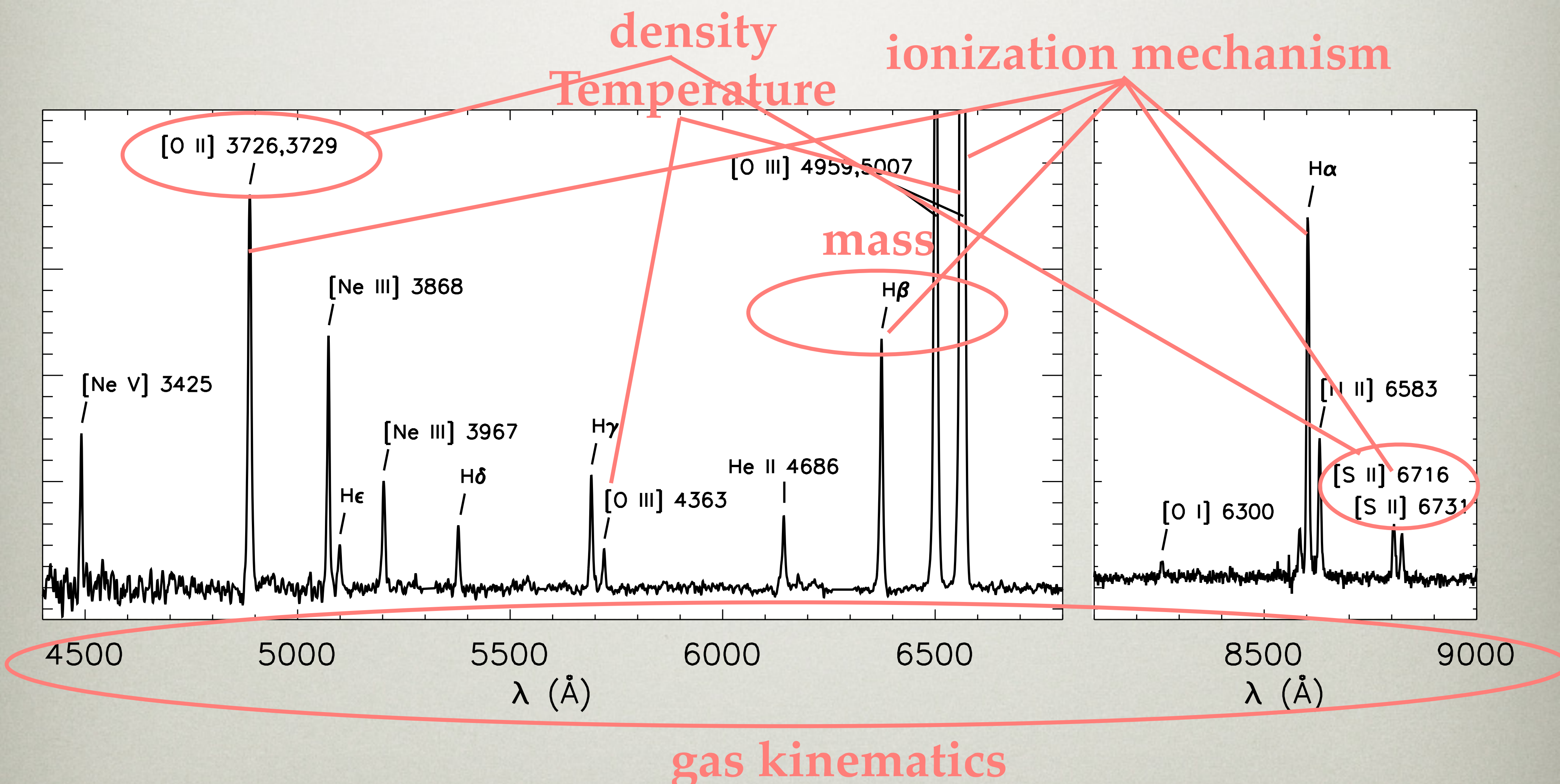


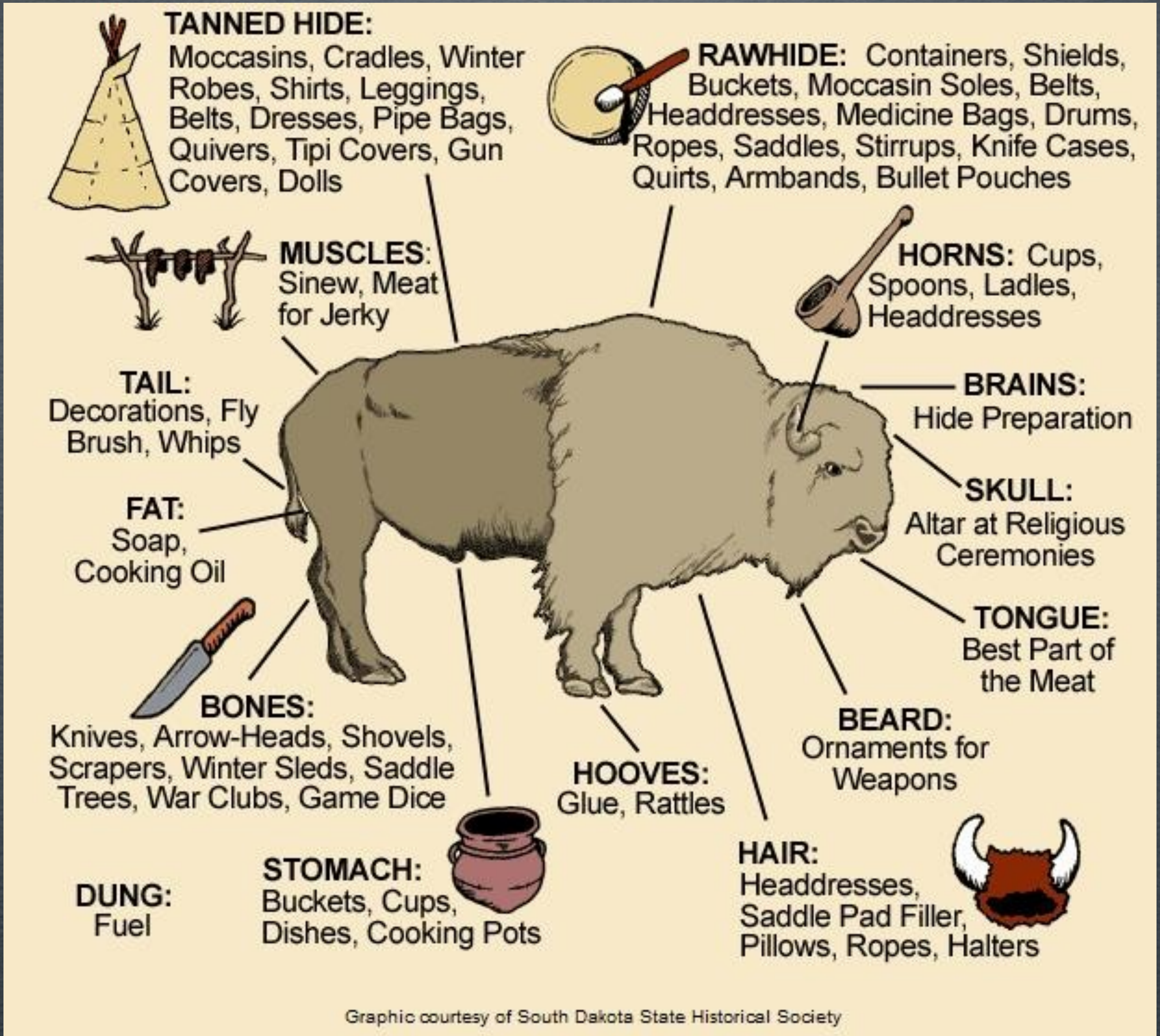
Integral Field Spectroscopy of Quasar EELRs

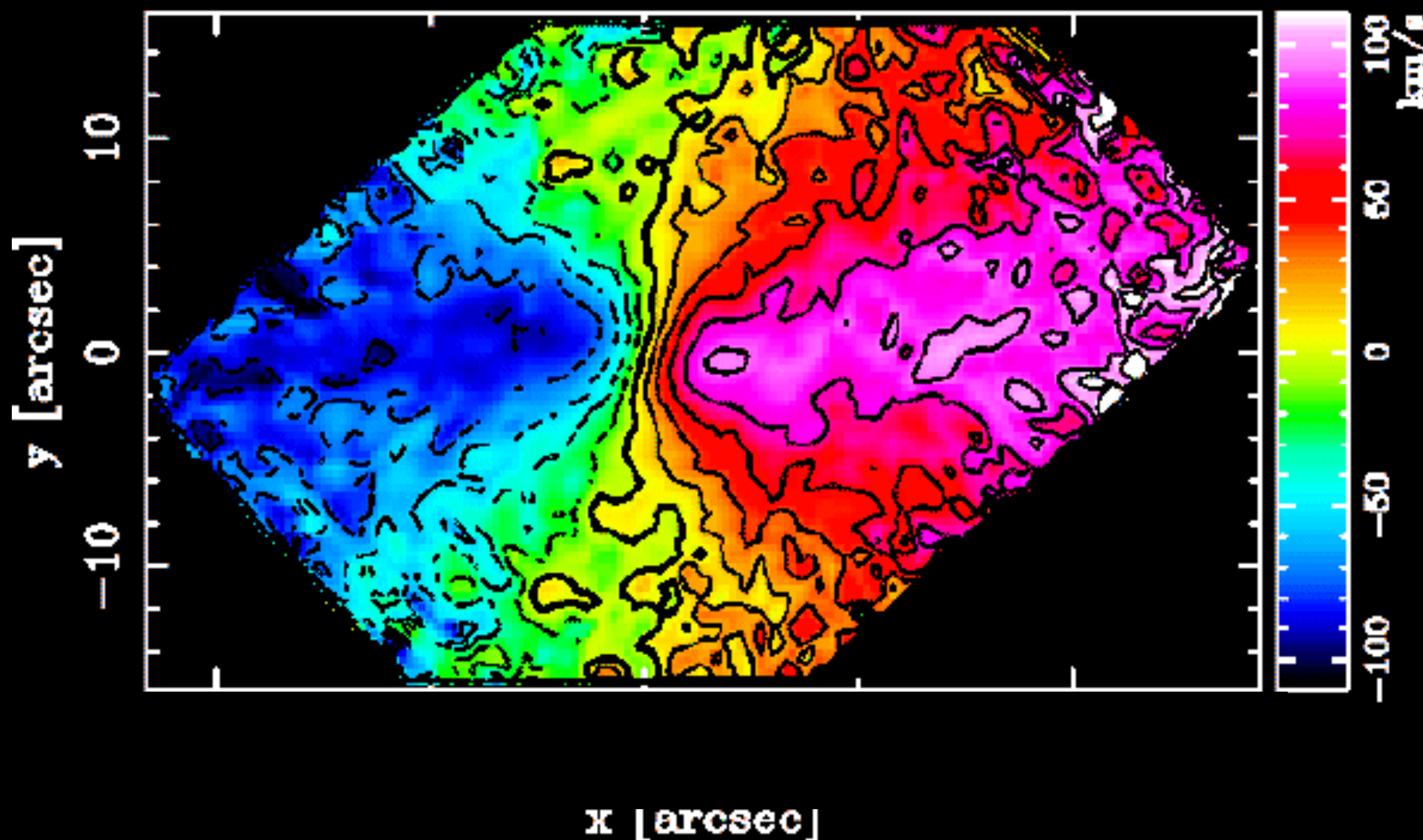
Large Radio Sources (0.25 ⩽ z ⩽ 0.37)



EELR Spectrum

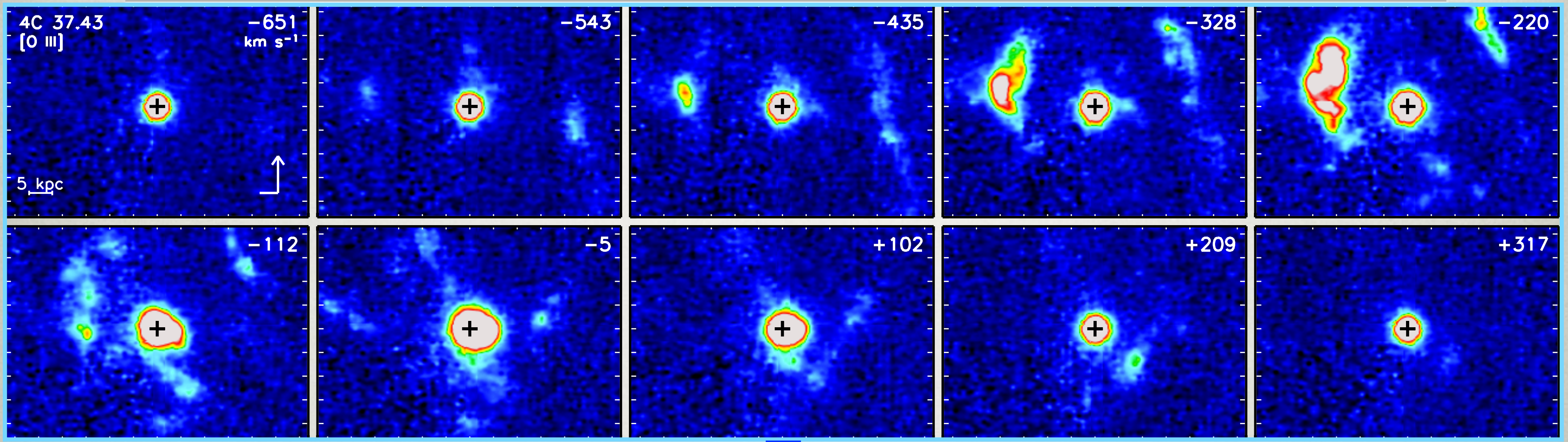


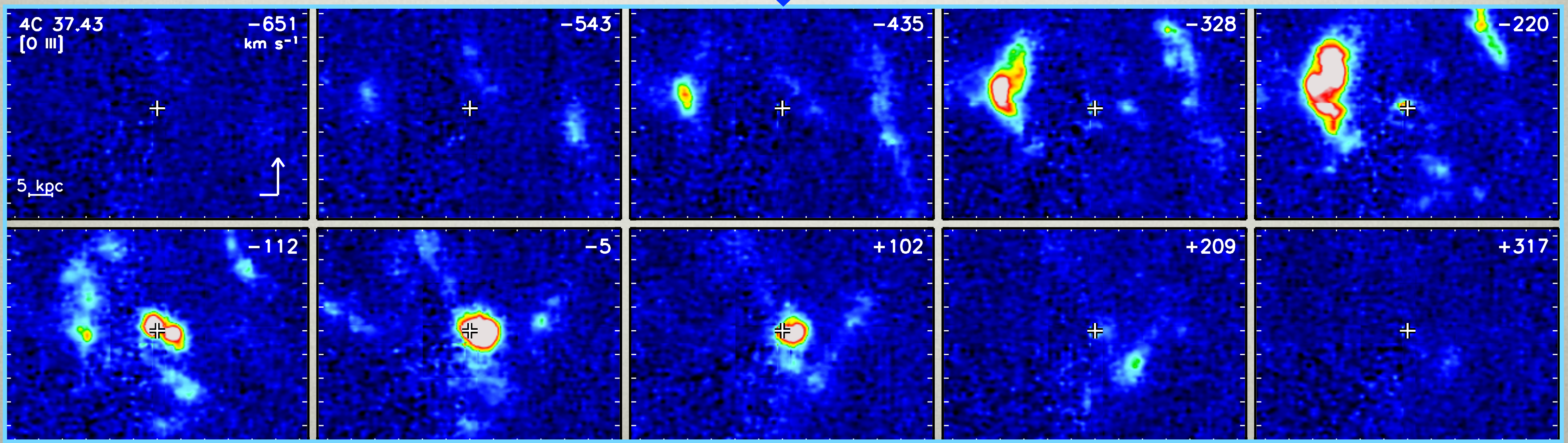

TANNED HIDE:
Moccasins, Cradles, Winter Robes, Shirts, Leggings, Belts, Dresses, Pipe Bags, Quivers, Tipi Covers, Gun Covers, Dolls
RAWHIDE: Containers, Shields, Buckets, Moccasin Soles, Belts, Headdresses, Medicine Bags, Drums, Ropes, Saddles, Stirrups, Knife Cases, Quirts, Armbands, Bullet Pouches
MUSCLES: Sinew, Meat for Jerky
HORNS: Cups, Spoons, Ladles, Headdresses
TAIL: Decorations, Fly Brush, Whips
BRAINS: Hide Preparation
SKULL: Altar at Religious Ceremonies
FAT: Soap, Cooking Oil
TONGUE: Best Part of the Meat
BONES: Knives, Arrow-Heads, Shovels, Scrapers, Winter Sleds, Saddle Trees, War Clubs, Game Dice
BEARD: Ornaments for Weapons
HOOVES: Glue, Rattles
HAIR: Headdresses, Saddle Pad Filler, Pillows, Ropes, Halters
STOMACH: Buckets, Cups, Dishes, Cooking Pots
DUNG: Fuel
Graphic courtesy of South Dakota State Historical Society



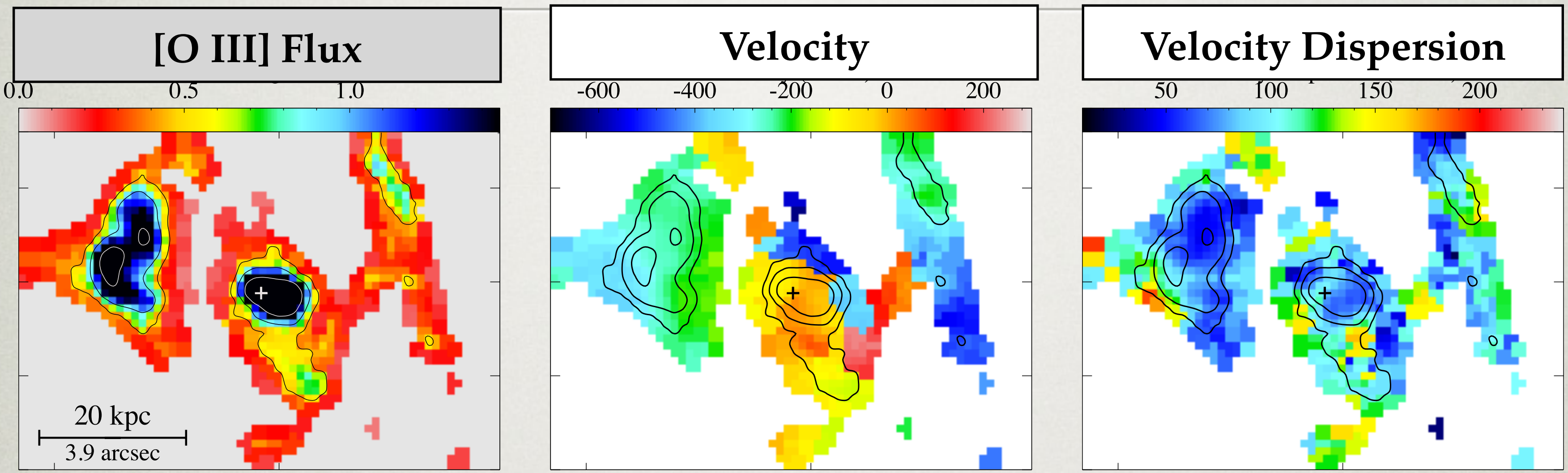
Gas Kinematics

Quasar Subtraction





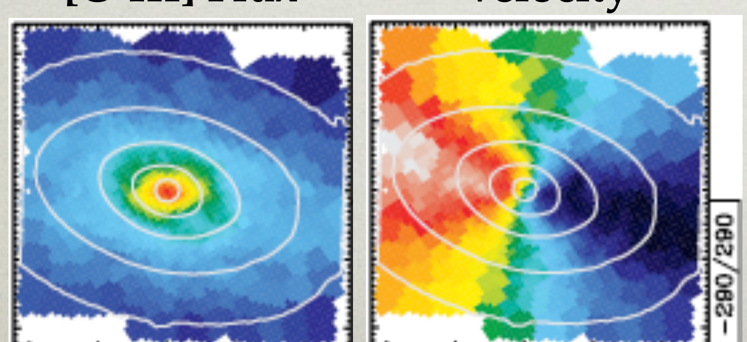
Velocity Structure



Fu & Stockton (2007a)

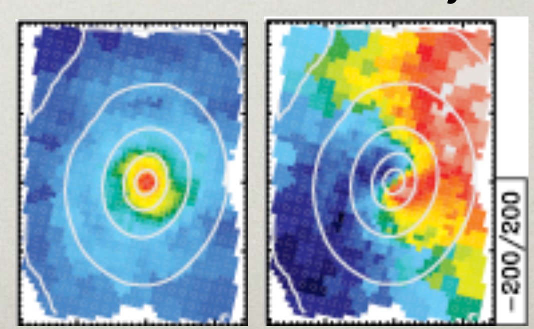
NGC 2974

[O III] Flux Velocity

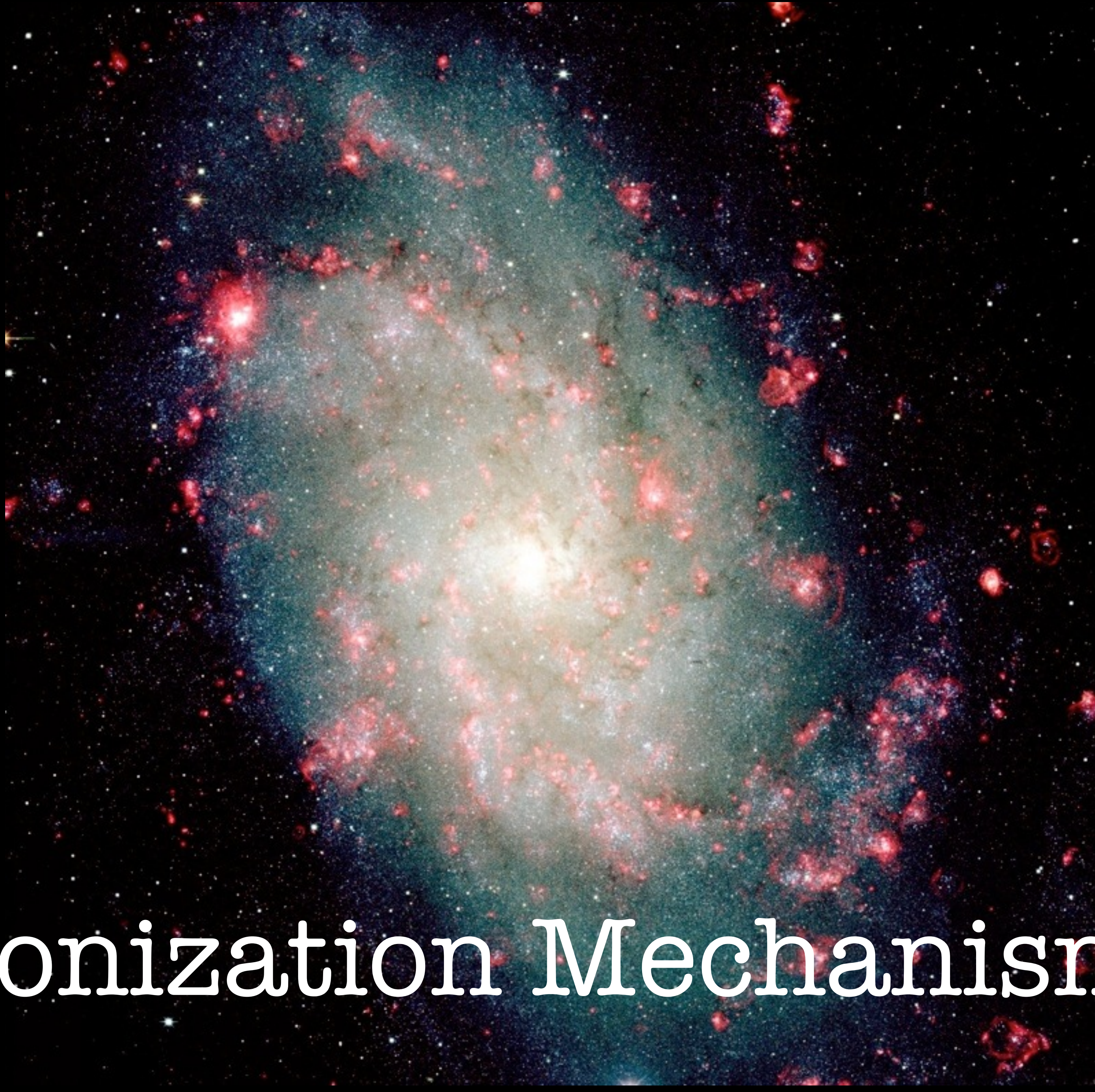


NGC 3414

[O III] Flux Velocity

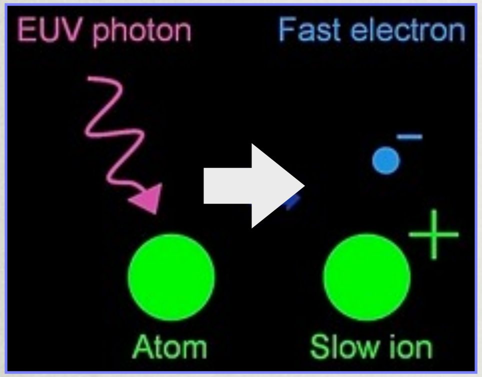


Sarzi et al. (2005)



Ionization Mechanism

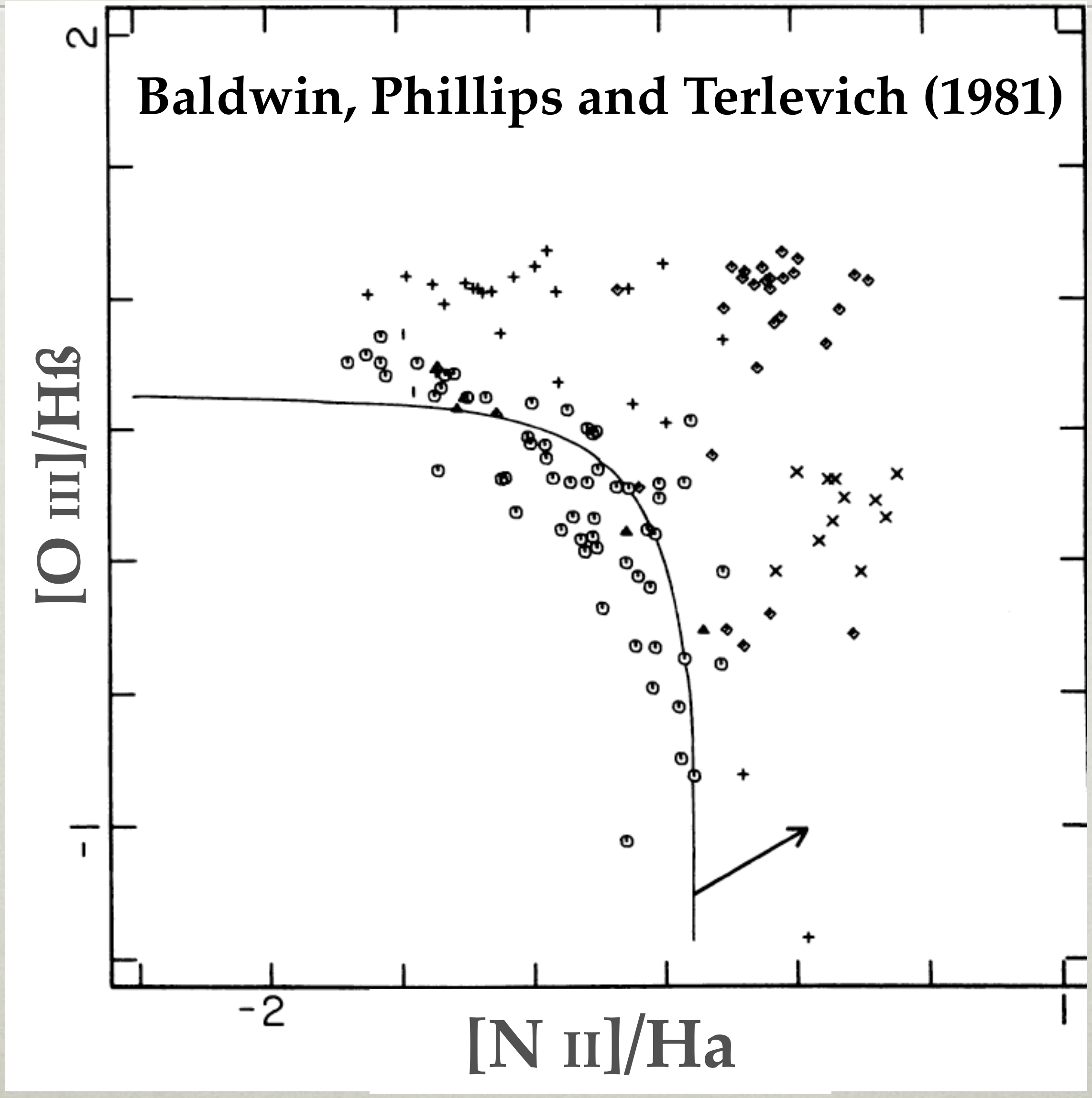
Ionization Mechanisms



Photoionizaton

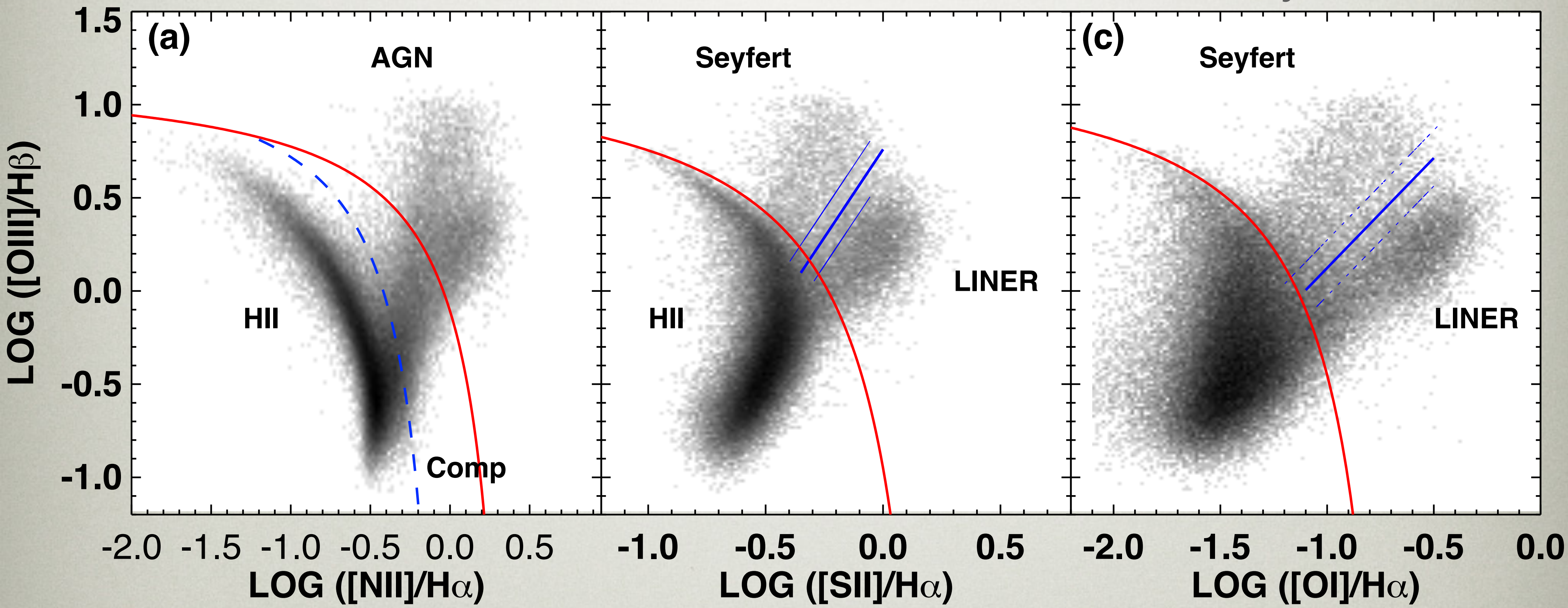
- ★ by massive stars (Kewley 2001)
- ★ by quasars (Groves et al. 2004)

Classification of Extragalactic Emission-Line Objects



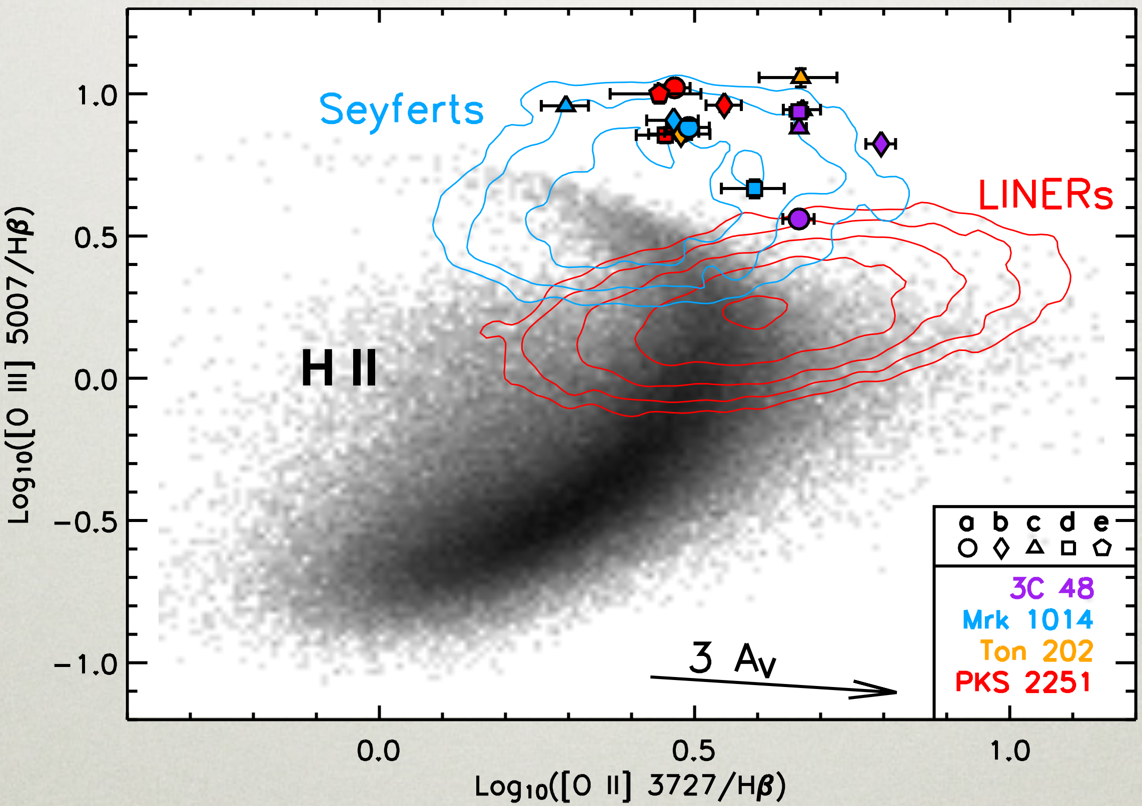
Classification of Extragalactic Emission-Line Objects

Kewley *et al* (2006)



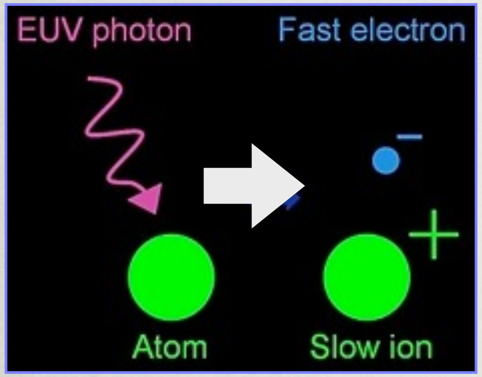
Photoionzed by Massive Stars? - No.

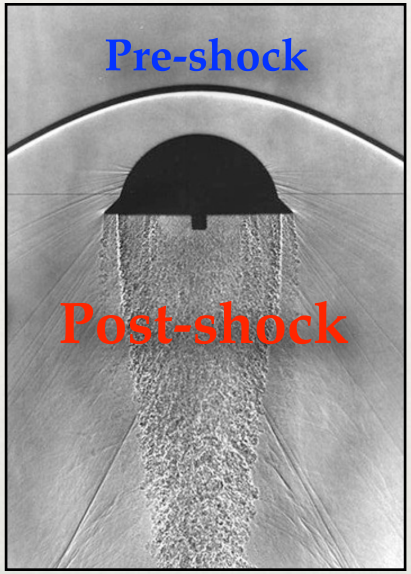
[O III]/Hß vs. [O II]/Hß

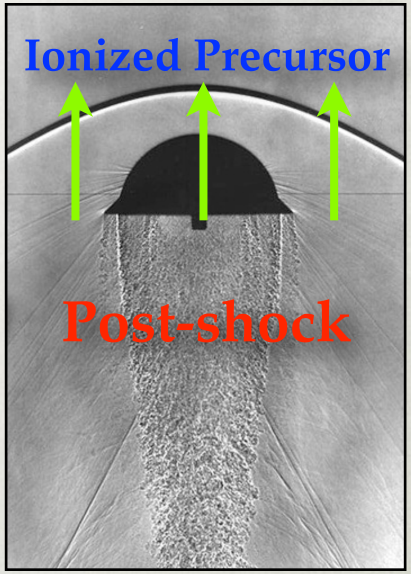


Fu & Stockton (2008b)

Ionization Mechanisms







Photoionizaton

- ★ by massive stars (Kewley 2001)
- ★ by quasars (Groves et al. 2004)

Shock

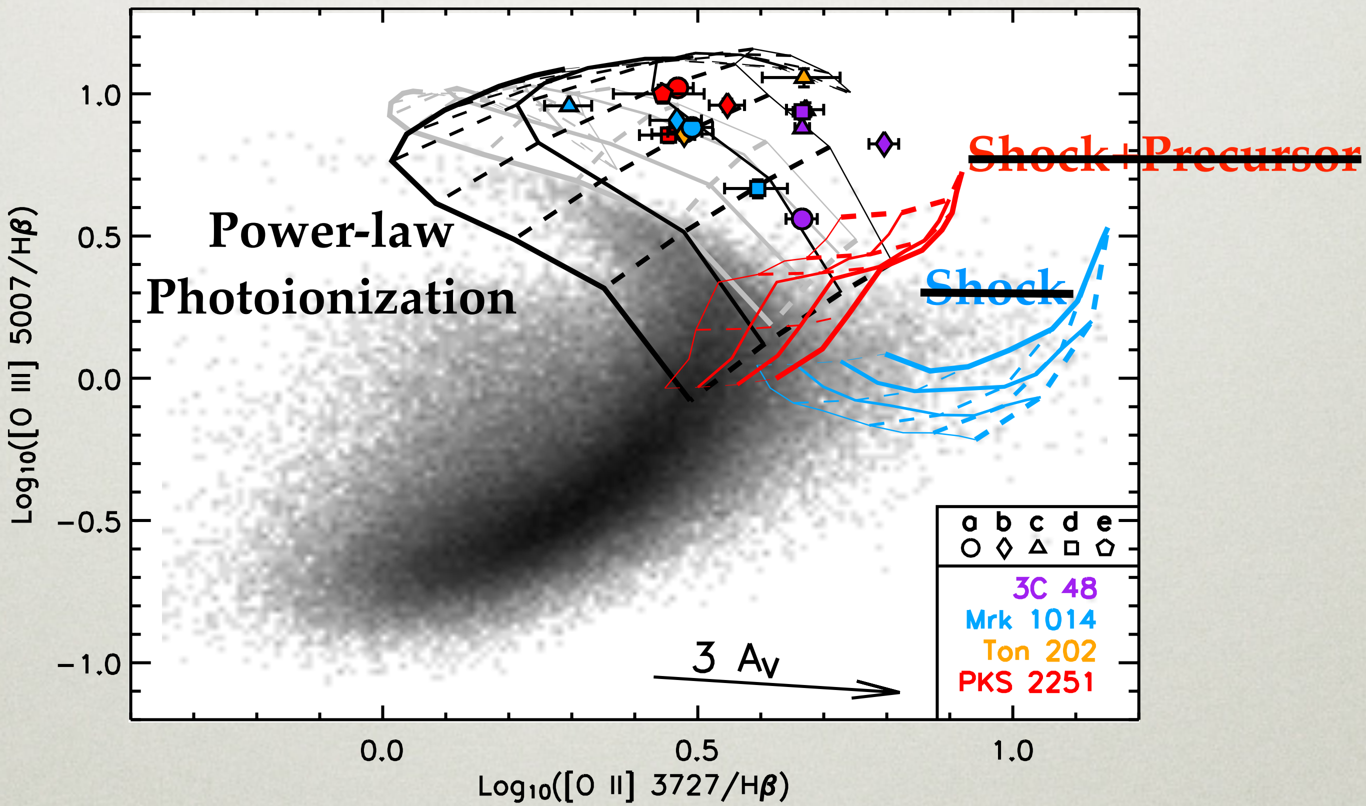
- ★ emission lines from cooling post-shock gas (Dopita & Sutherland 1996)

Shock+Precursor

- ★ emission lines from both post-shock and pre-shock gas

Shock Ionization? - No.

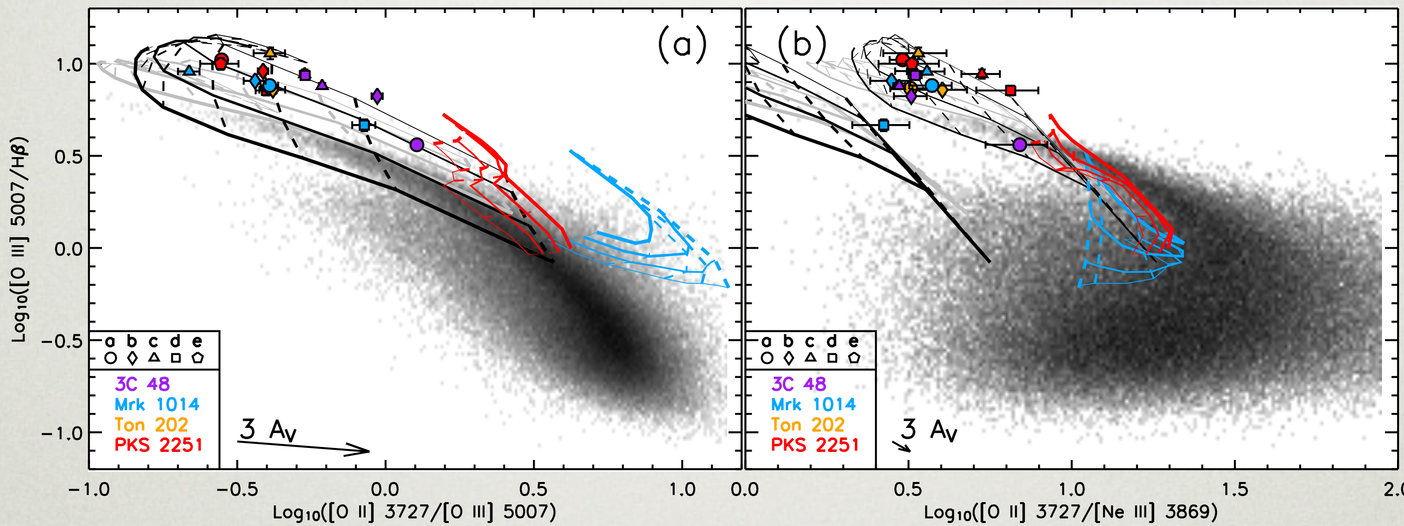
[O III]/Hß vs. [O II]/Hß



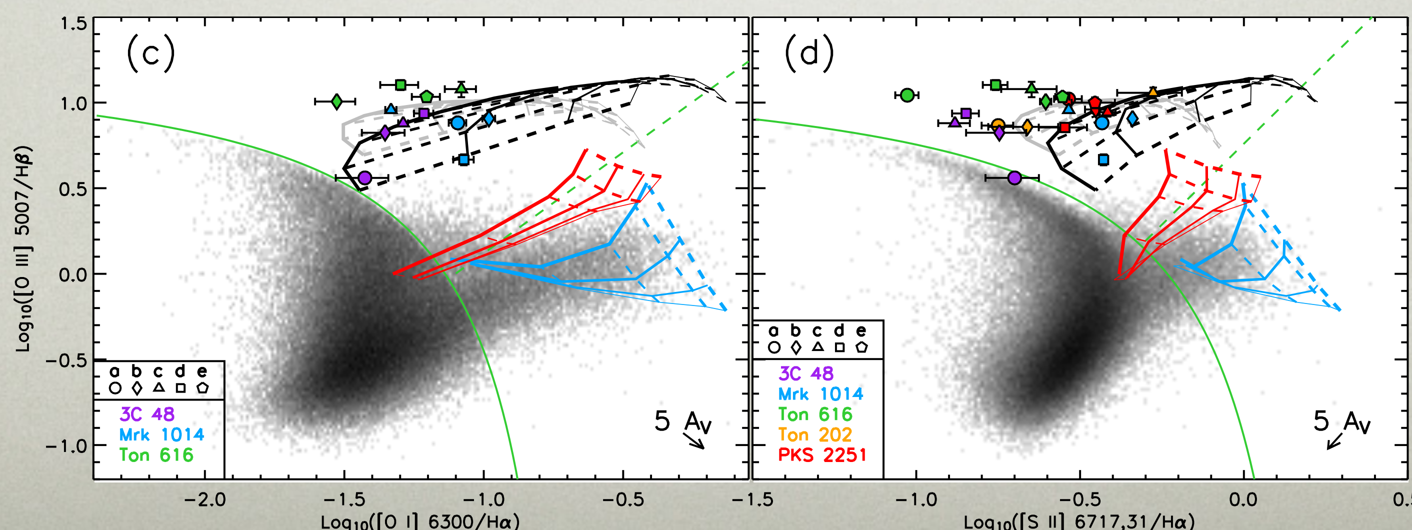
Fu & Stockton (2008b)

Photoionzed by Quasars

[O III]/Hß vs. [O II]/[O III] & [O II]/[Ne III]



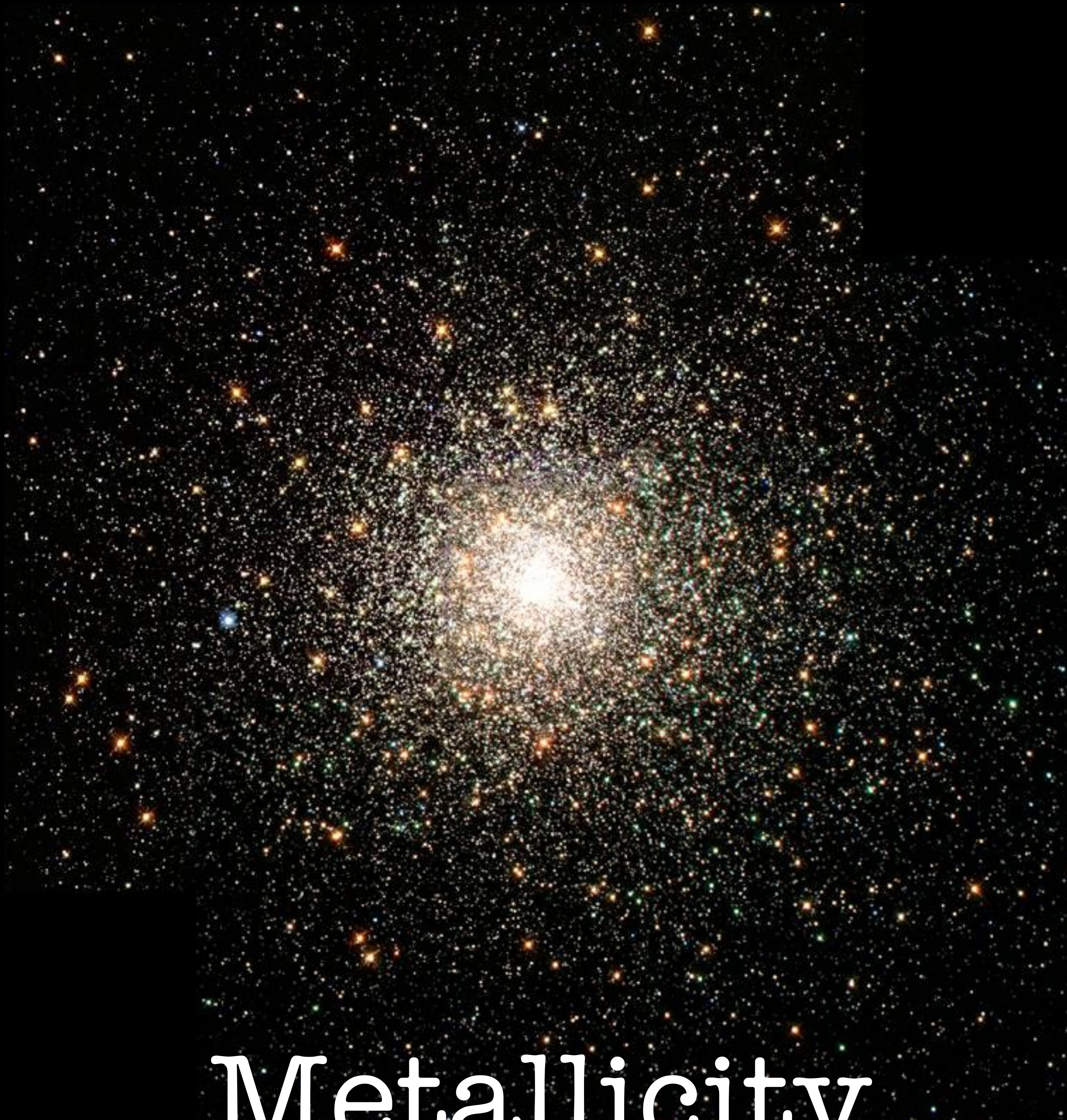
[O III]/Hß vs. [O I]/Hα & [S II]/Hα



Integral Field Spectroscopy of Quasar EELRs
Summary

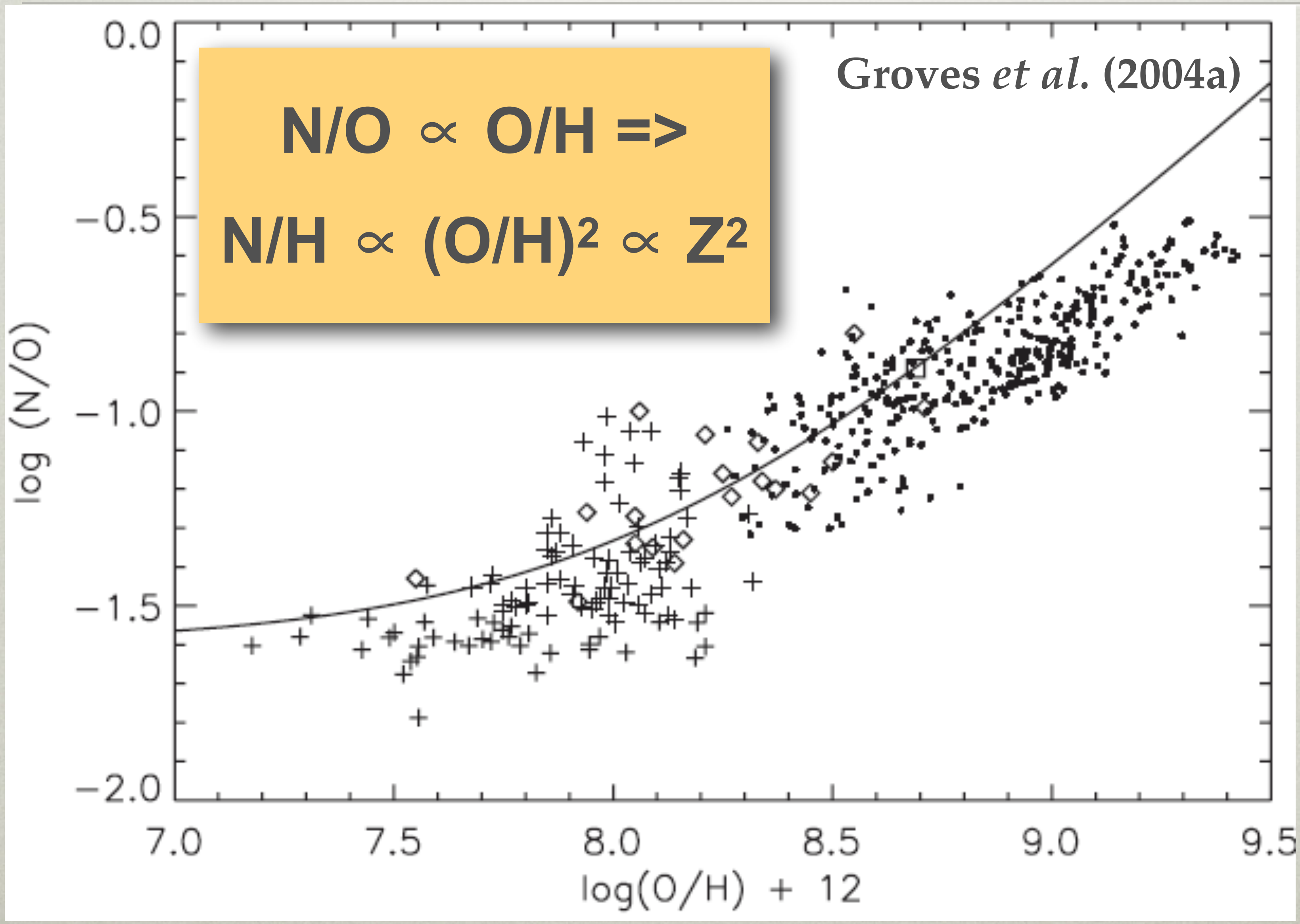
- Globally disordered kinematics
- Low velocity dispersions ~ 100 km/s
- Photoionized by quasar continuum

- Gas pressure ~ $10^4 – 10^6$ K cm^{-3}
- Ionized mass ~ 10^9 $M_\odot$



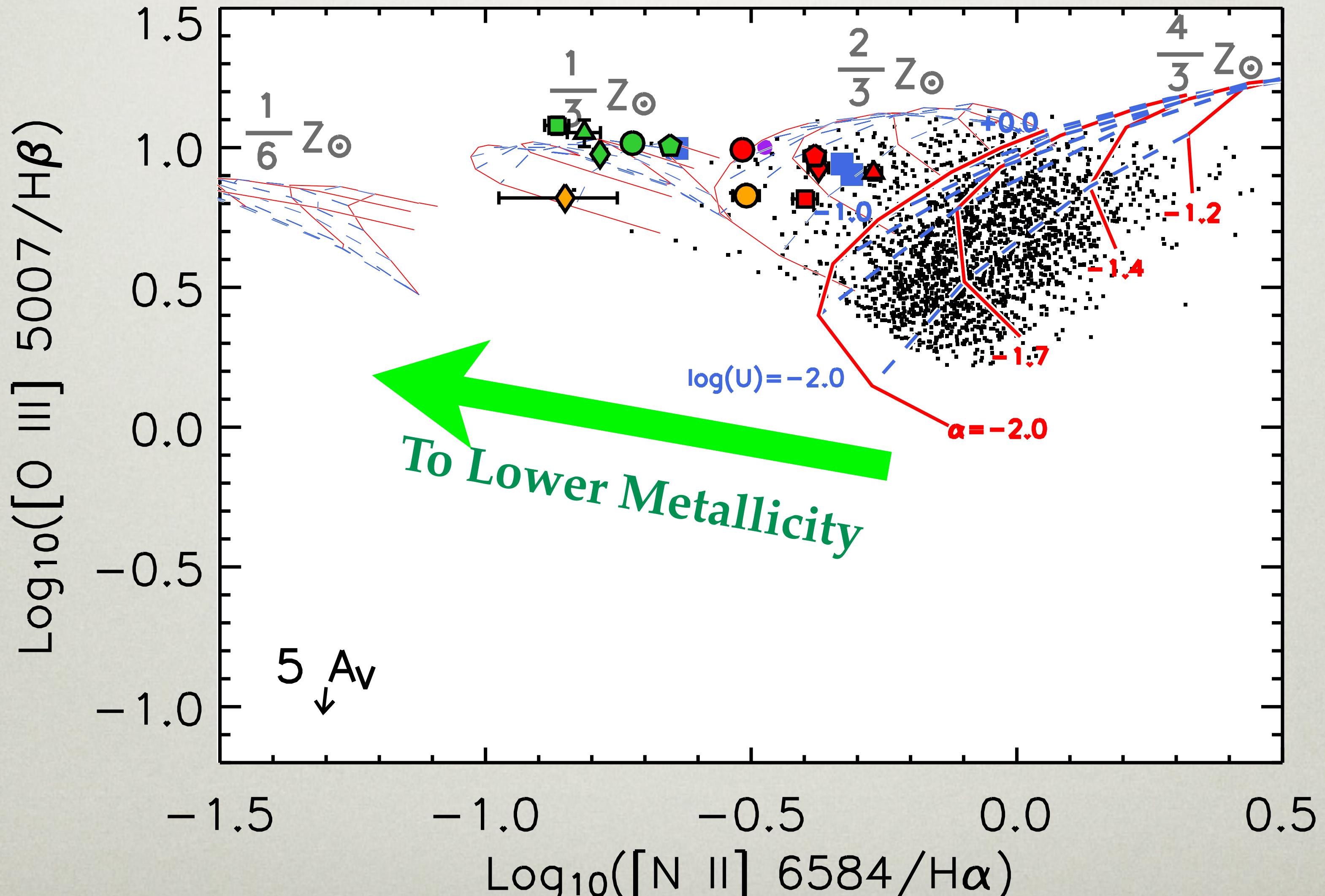
Metallicity

Secondary Production of Nitrogen

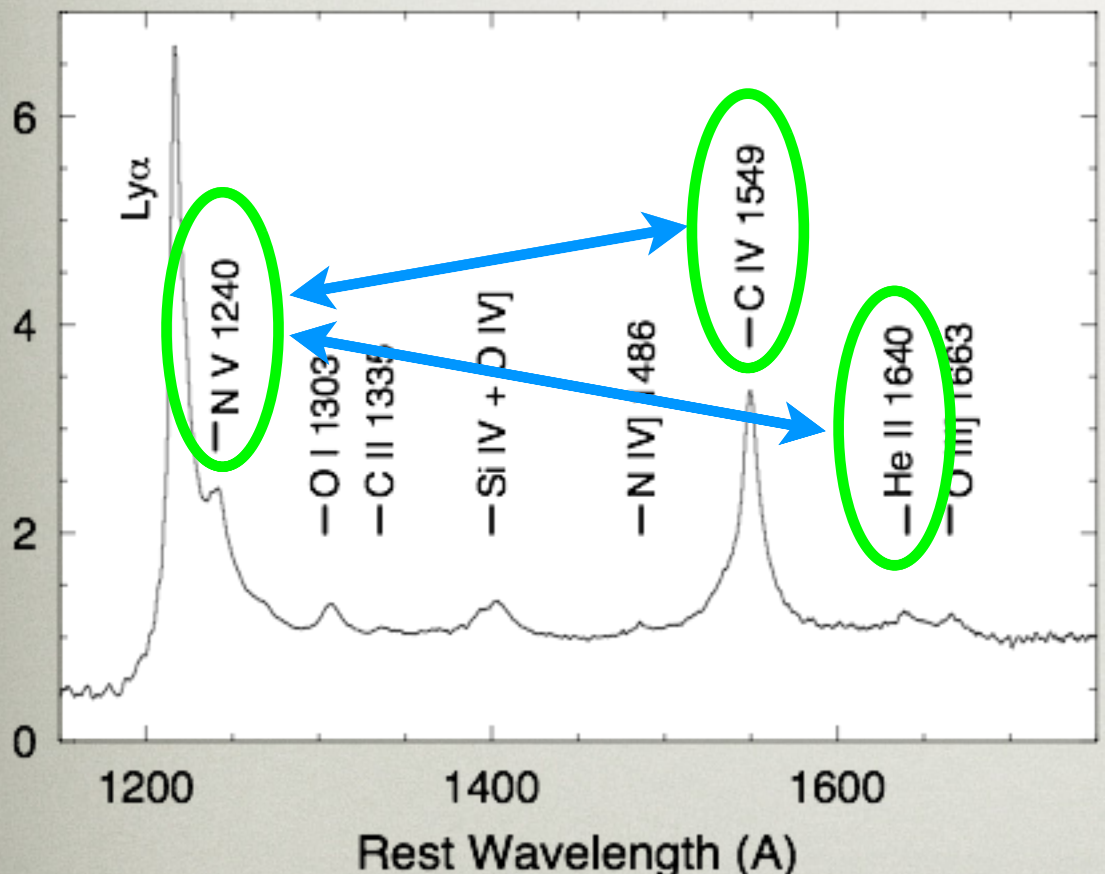


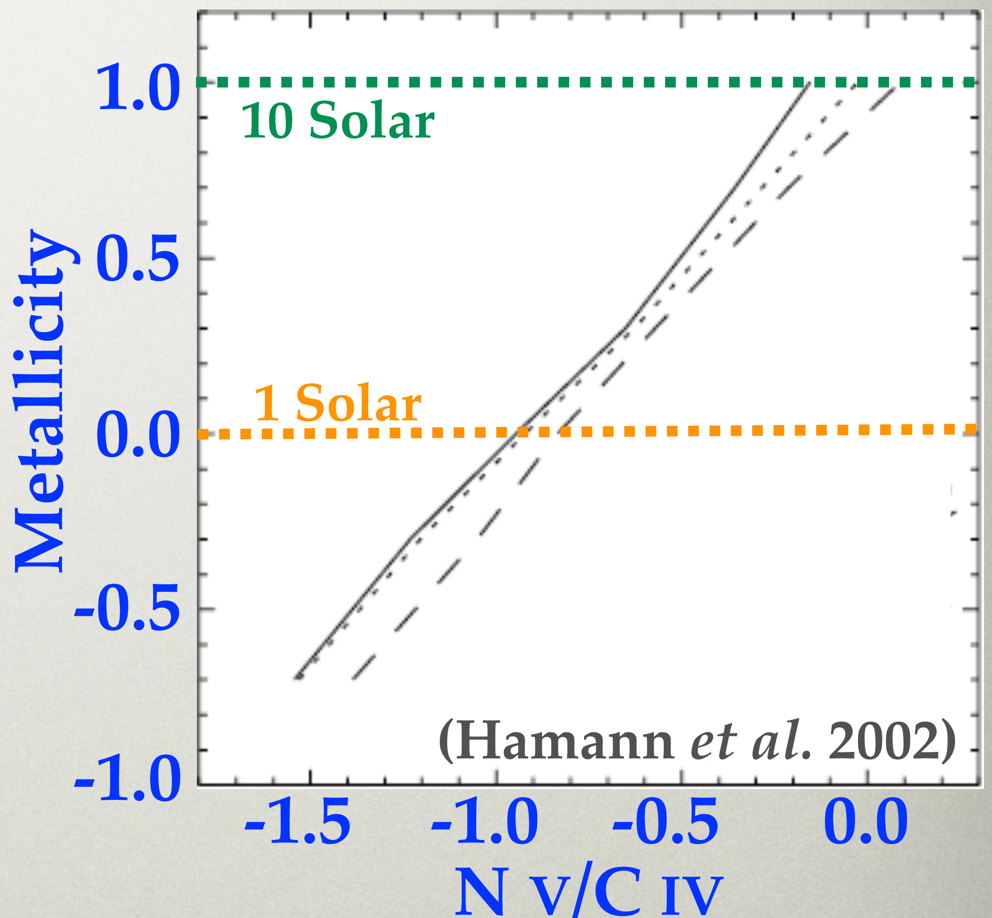
EELR Metallicity

Fu & Stockton (2006,2007a,2008b)



Quasar Metallicity from Broad-Line Region





EELR Quasars are Metal-Poor Quasars

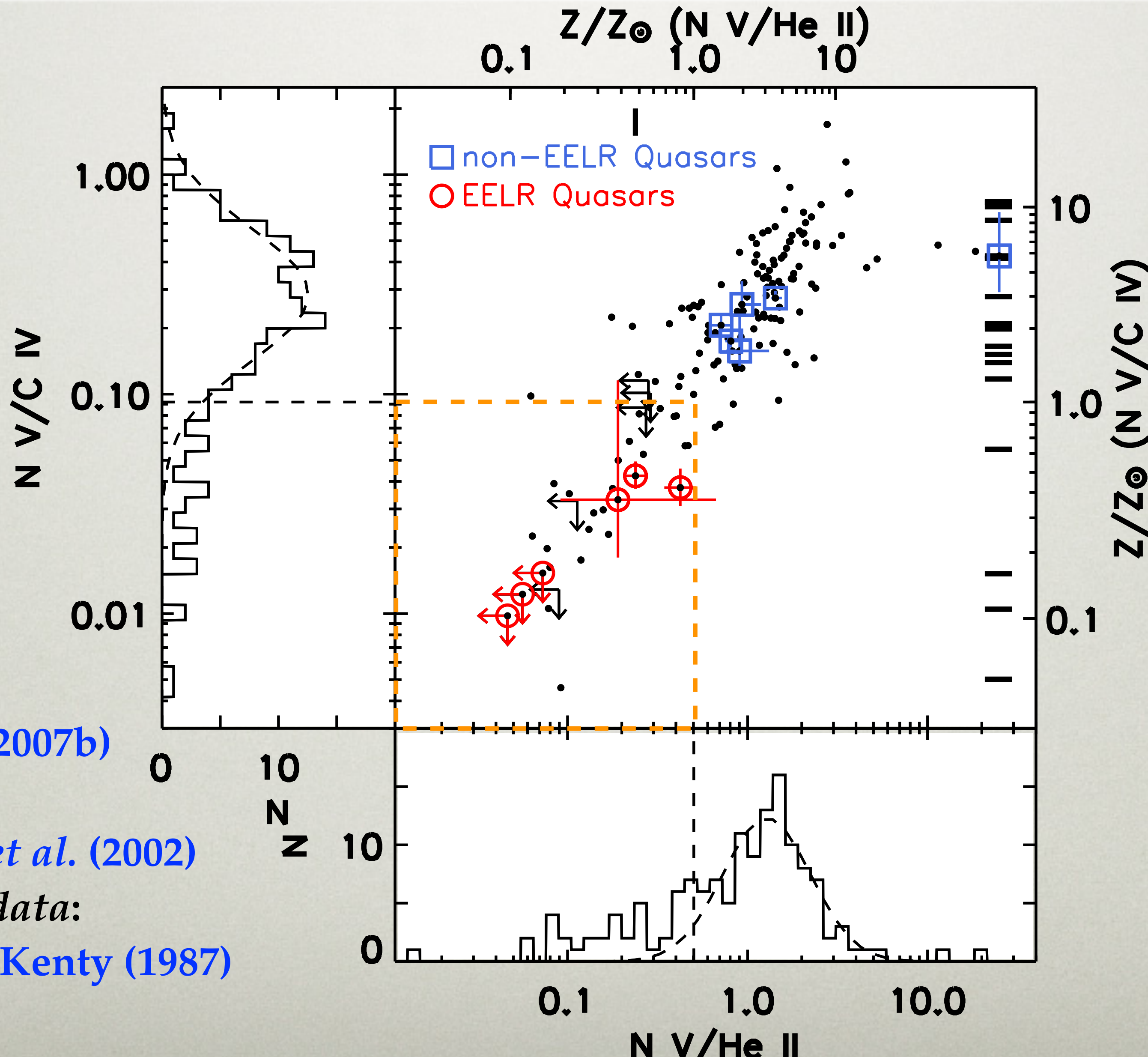


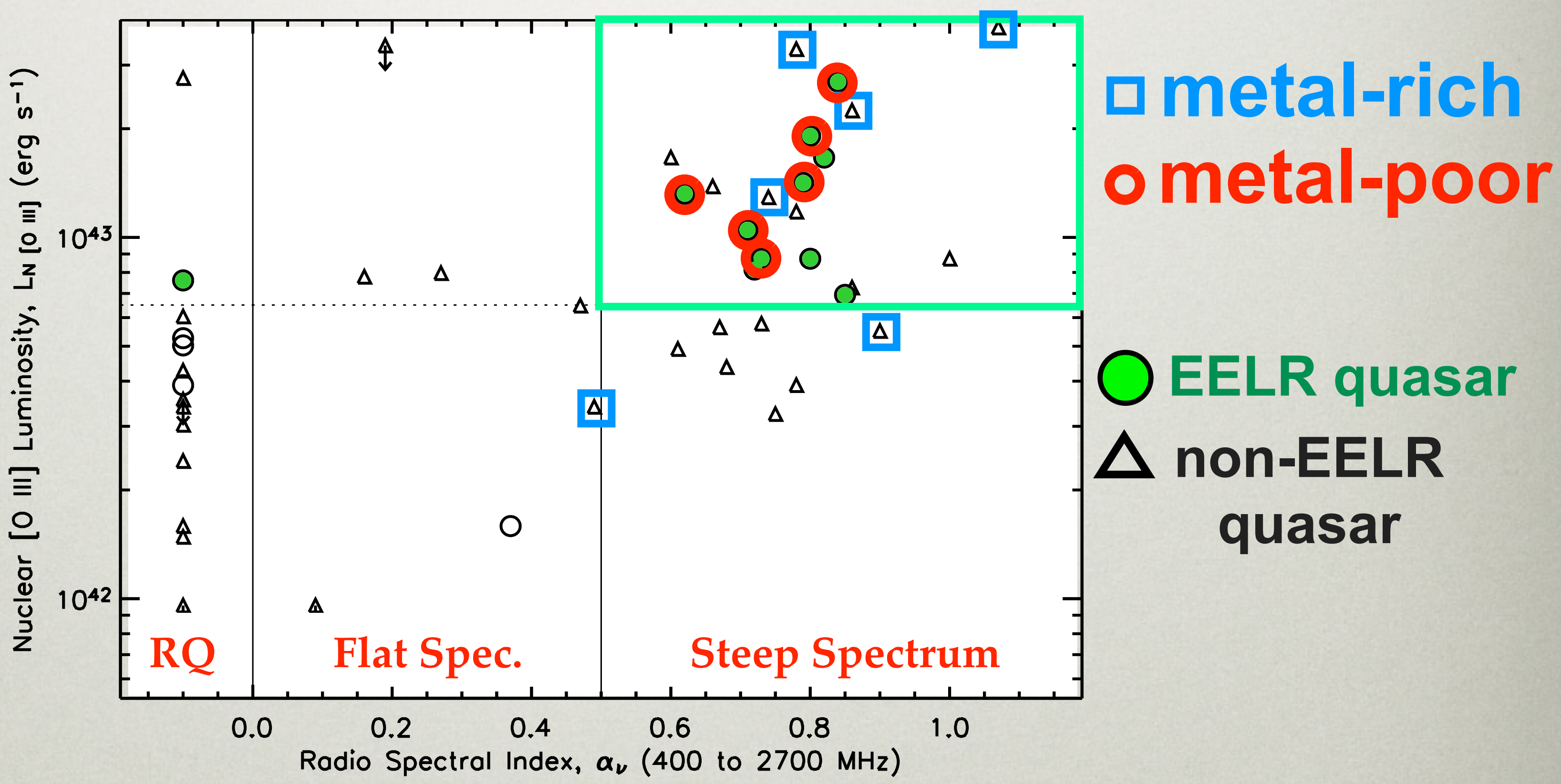
Figure: Fu & Stockton (2007b)

HST data: Kuraszkiewicz *et al.* (2002)

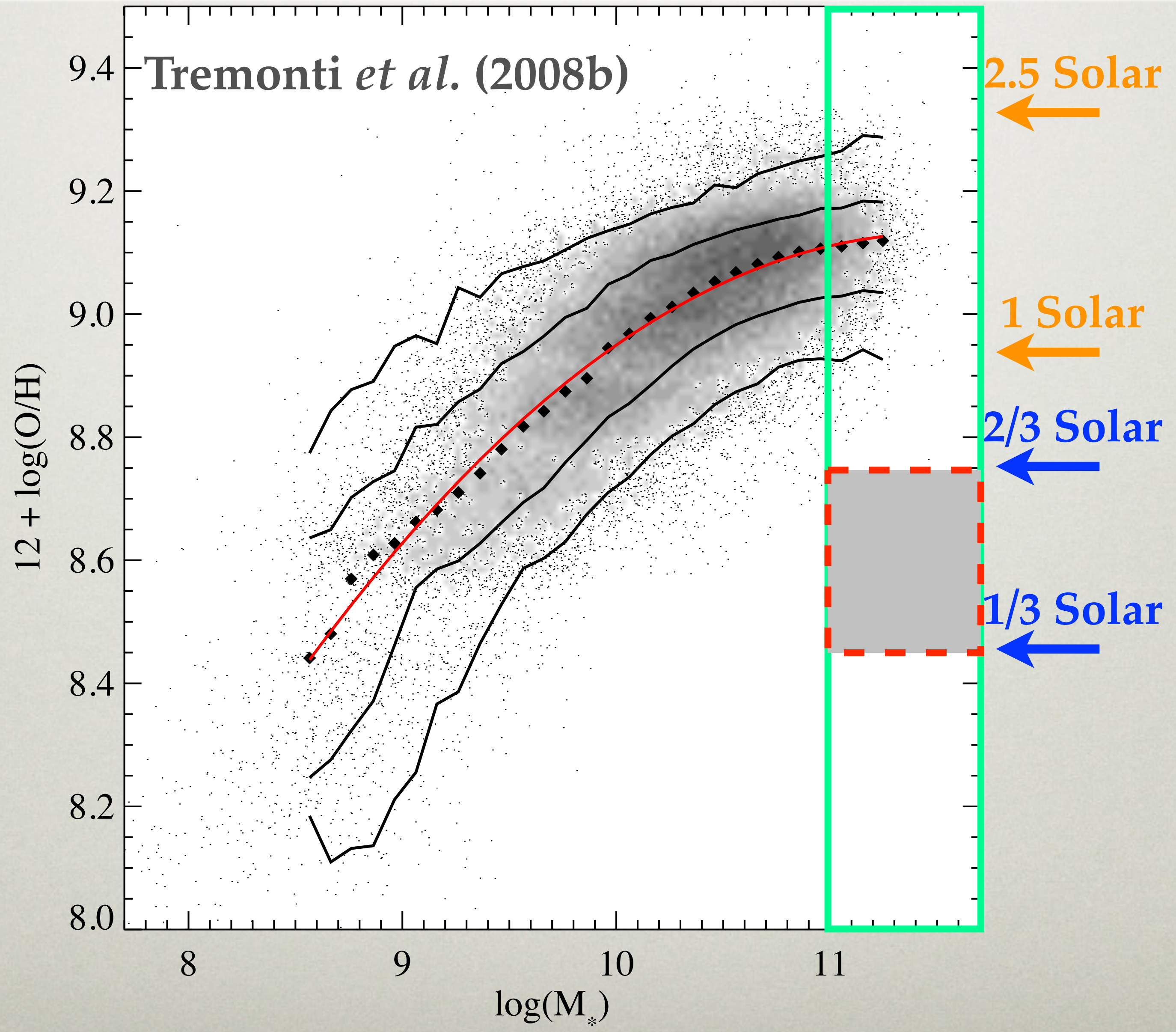
[O III] imaging data: Stockton & MacKenty (1987)

EELR quasars = Metal-poor quasars
+ lobe-dominated radio source
+ strong nuclear narrow-line emission

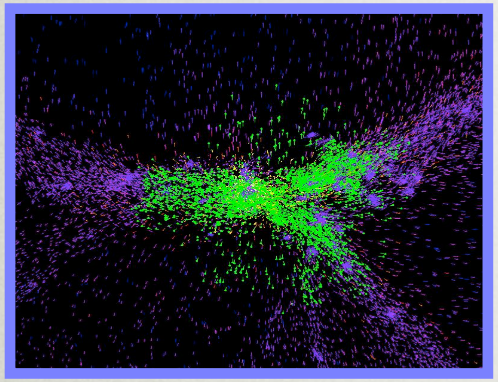
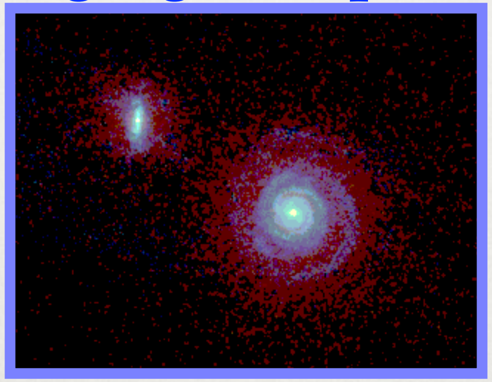
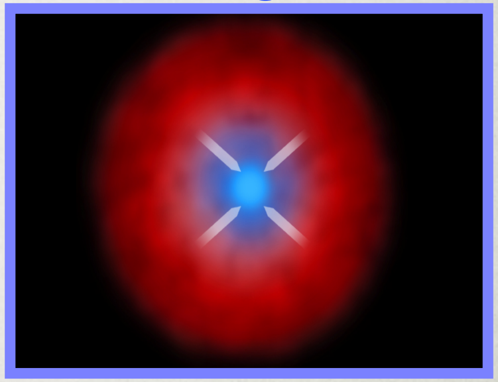
Nuclear $L_{[O\ III]}$ vs. Radio α_ν



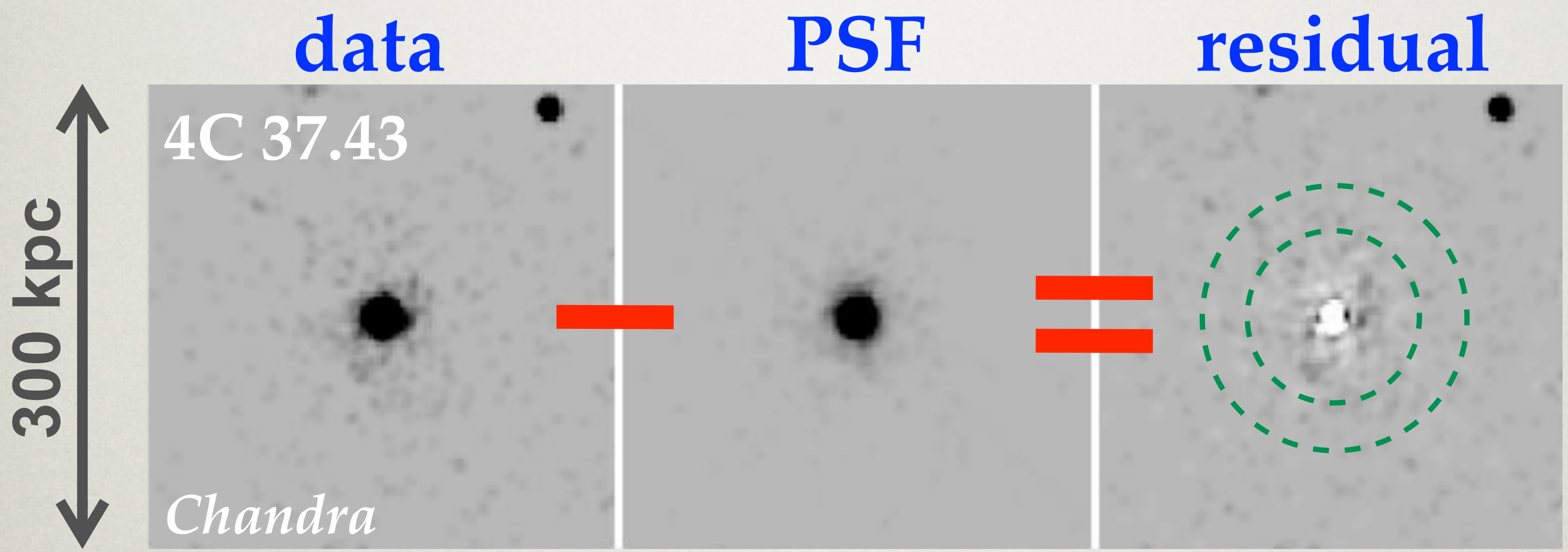
Mass—Metallicity Relation from SDSS



Origins of Metal-Poor Gas

Cold Accretion	Merging Companion	Cooling Flow
		
(Keres *et al.* 2005)	(Stockton *et al.* 1983)	(Fabian *et al.* 1987)
✓ metal-poor gas in extended nebulae	✓ metal-poor gas in extended nebulae	✓ metal-poor gas in extended nebulae
✤ metal-poor gas in nuclear region	✓ metal-poor gas in nuclear region	✓ metal-poor gas in nuclear region

X-ray Gas Cooling Rate



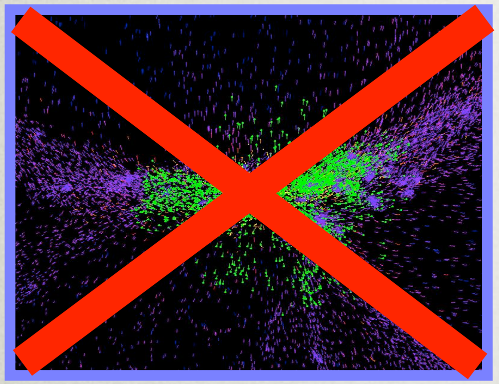
(Stockton, Fu *et al*. 2006)

Upper Limits on X-ray Luminosity

=> Cooling Rate < 0.7 $M_{\odot}$/yr (r < 20kpc)

The Origin of the Gas

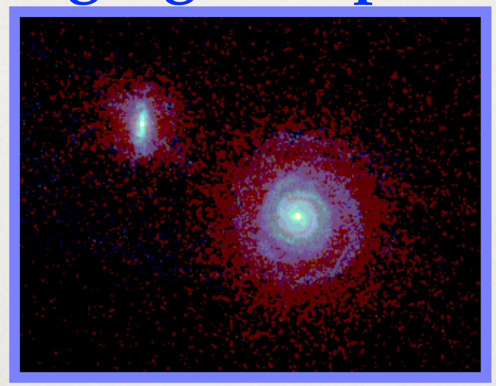
Cold Accretion



(Keres *et al.* 2005)

- ✓ metal-poor gas in extended nebulae
- ✤ metal-poor gas in nuclear region

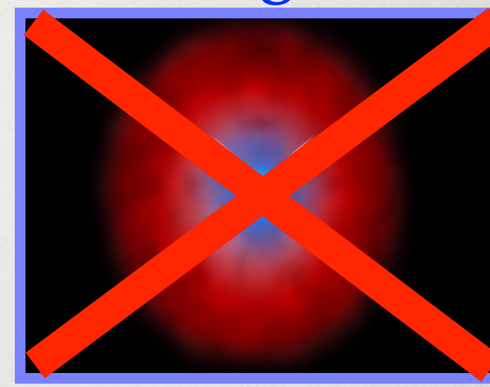
Merging Companion



(Stockton *et al.* 1983)

- ✓ metal-poor gas in extended nebulae
- ✓ metal-poor gas in nuclear region
- ✓ Low pressure in X-ray halo

Cooling Flow



(Fabian *et al.* 1987)

- ✓ metal-poor gas in extended nebulae
- ✓ metal-poor gas in nuclear region
- ✤ Low pressure in X-ray halo

The Formation of EELRs

Tidal Interactions

Stockton & MacKenty (1983)

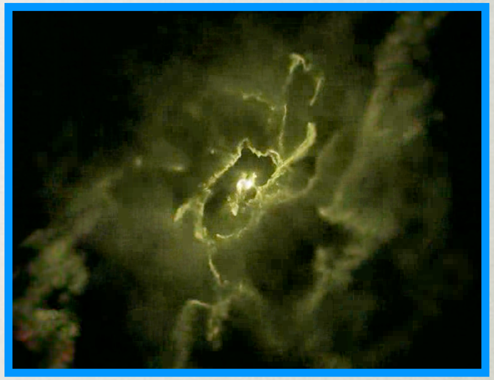
✓ disordered kinematics

Starburst Superwind

Stockton et al. (2002)

✓ disordered kinematics

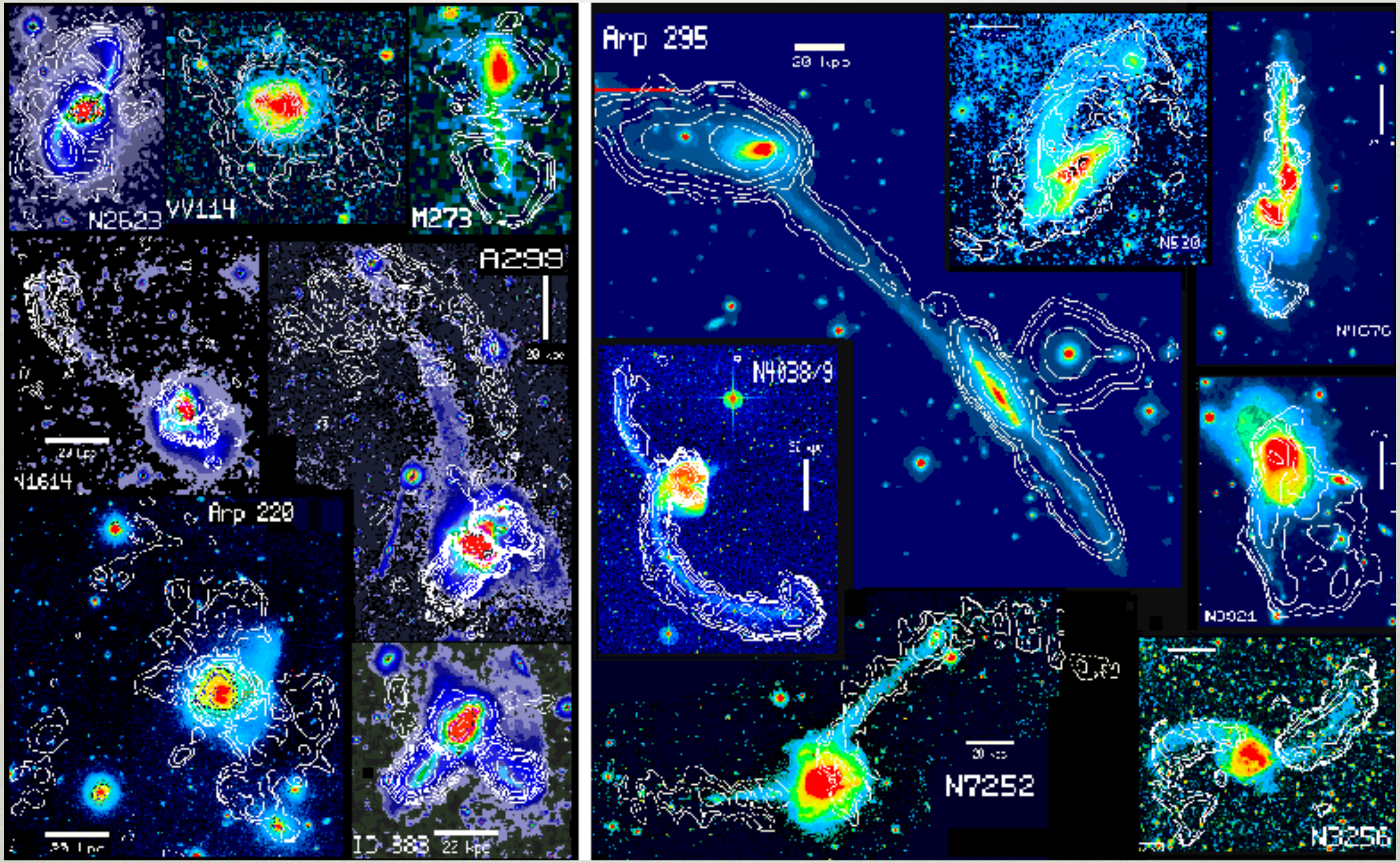
Quasar Superwind



Di Matteo et al. (2005)

✓ disordered kinematics

H I Gas in Interacting Galaxies



Hibbard *et al.* (1996-2001)

The Formation of EELRs

~~Tidal Interactions~~

Stockton & MacKenty (1983)

- ✓ disordered kinematics
- ✤ no underlying continuum
- ✤ high velocity clouds (v>500 km/s)

Starburst Superwind

Stockton et al. (2002)

- ✓ disordered kinematics
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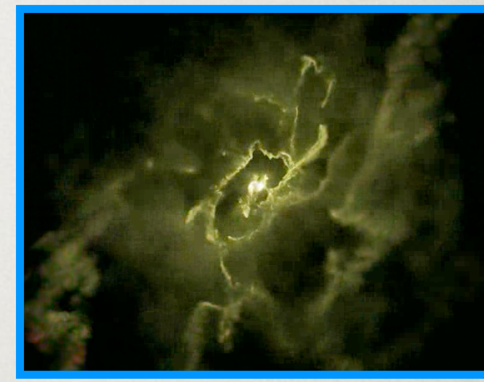
Quasar Superwind

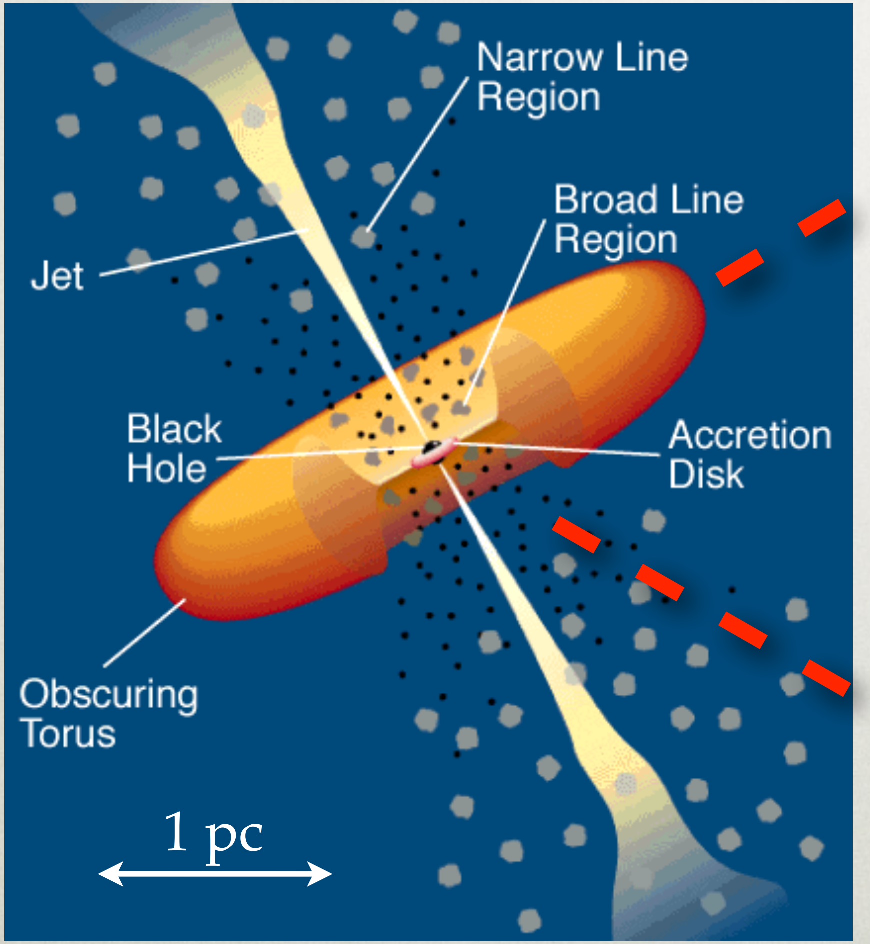


Di Matteo et al. (2005)

- ✓ disordered kinematics
- ✓ no underlying continuum
- ✓ high velocity clouds (v>500 km/s)

Unification of Quasars & Radio Galaxies

Barthel (1989)

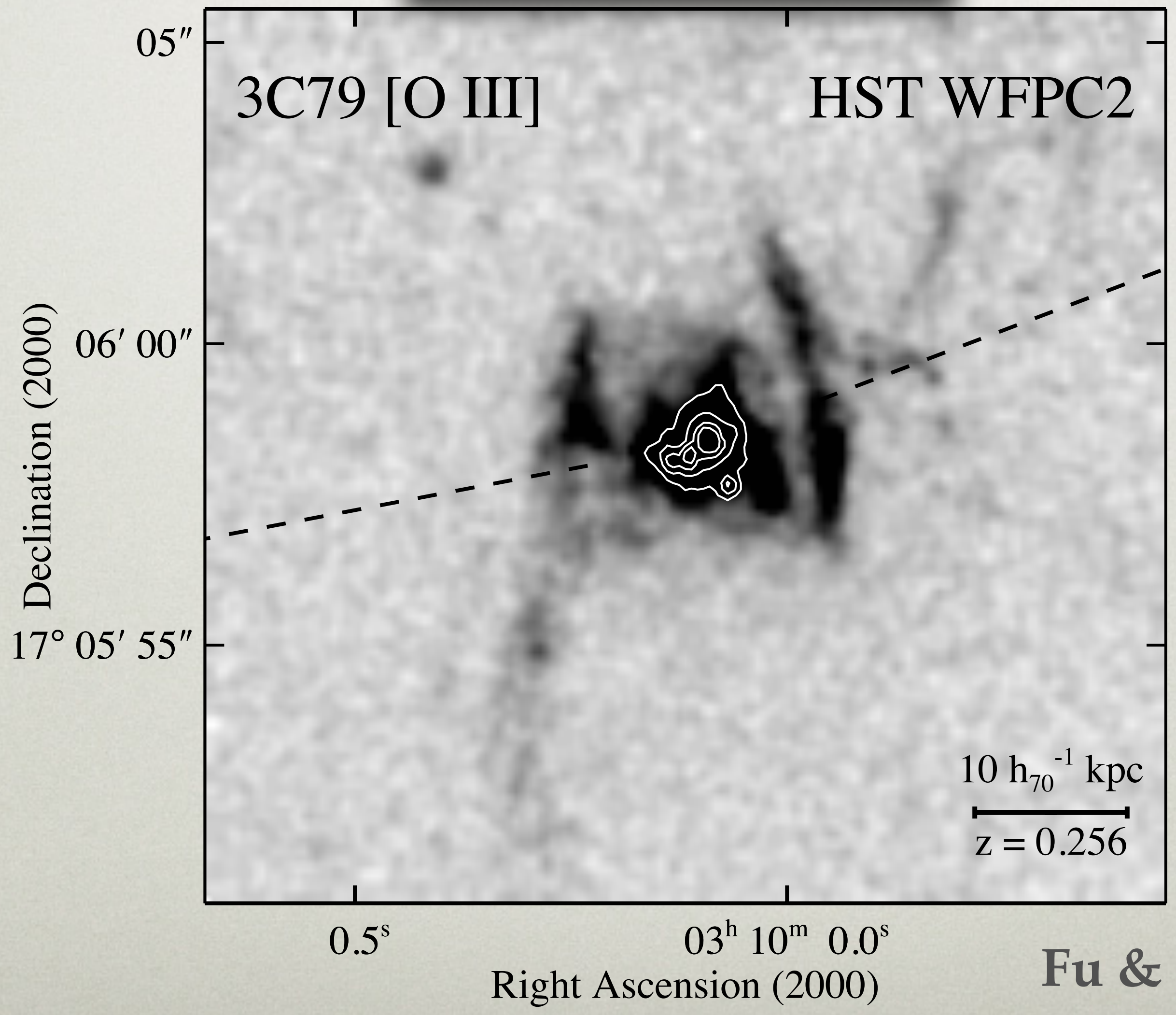


Radio Galaxy

Quasar

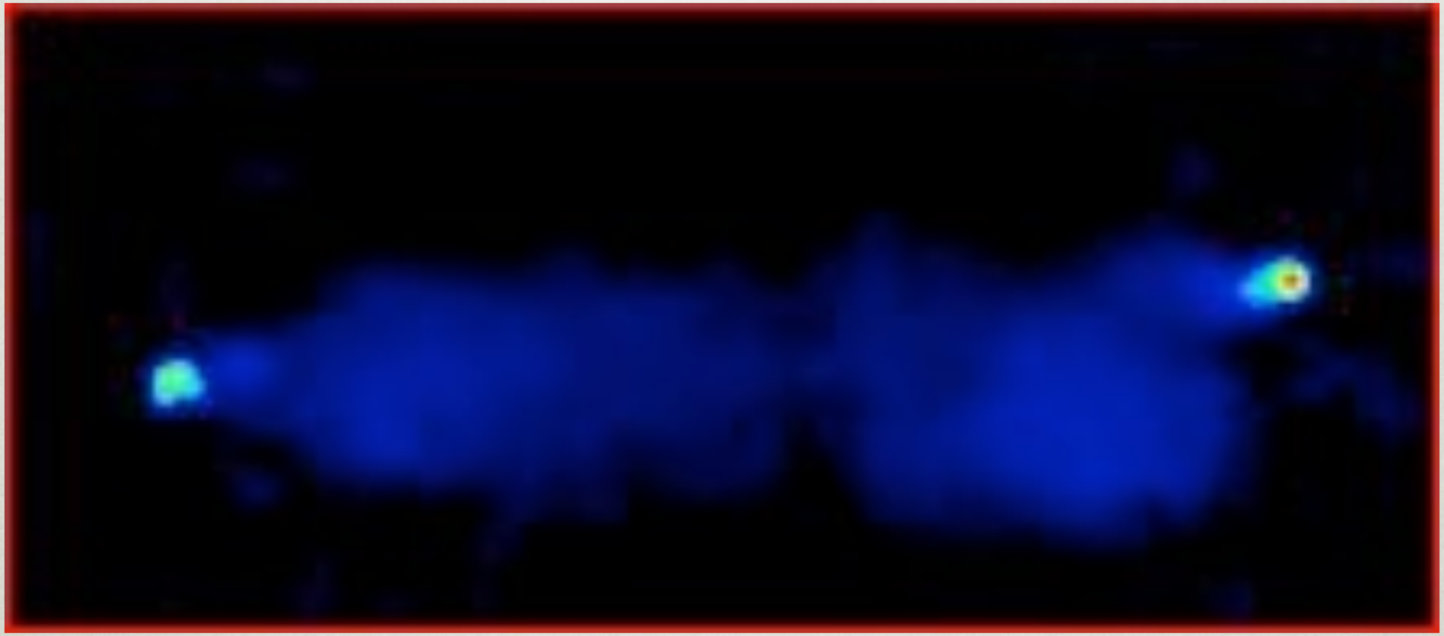
3C79: An EELR Radio Galaxy

redshift = 0.256

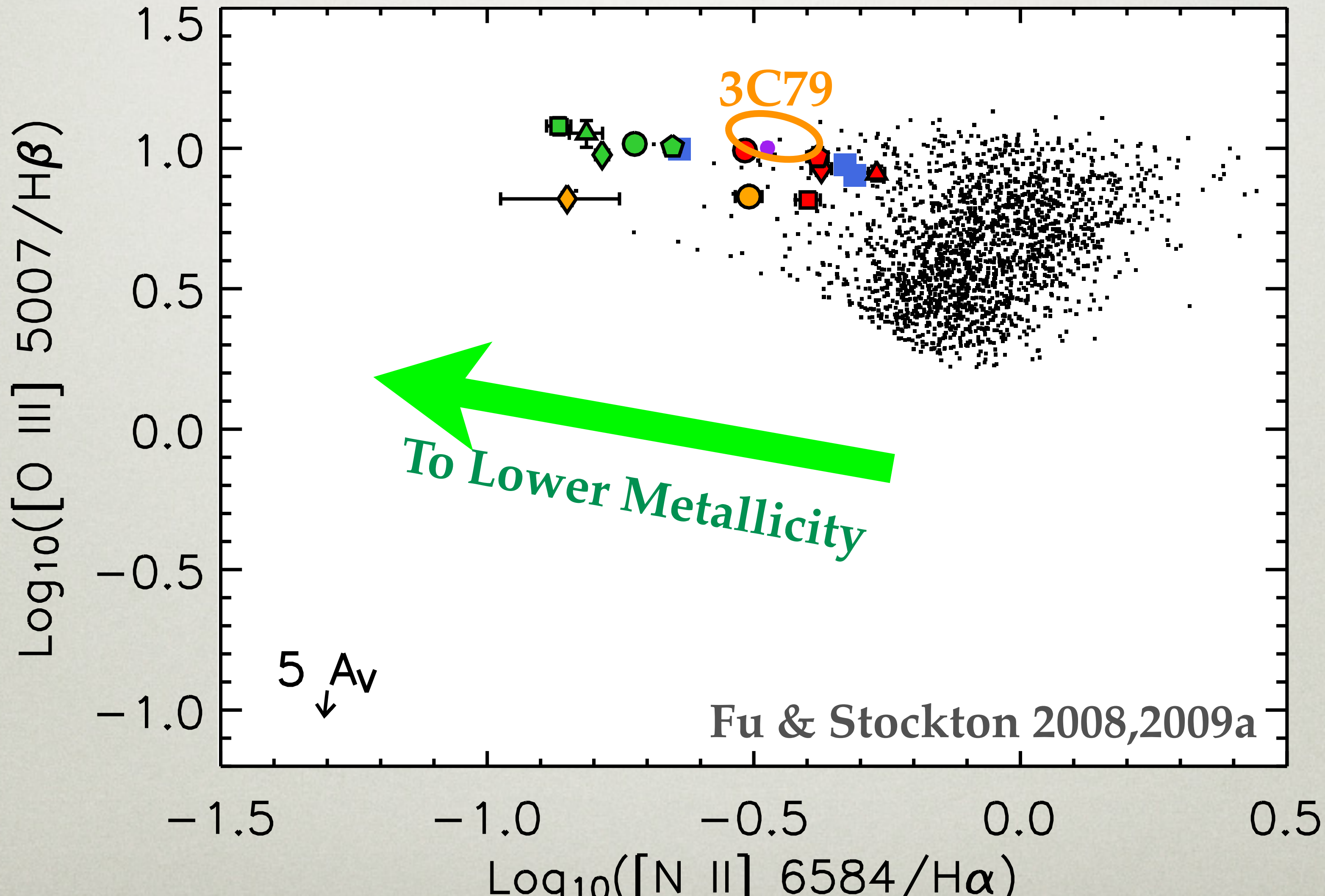


Fu & Stockton (2008)

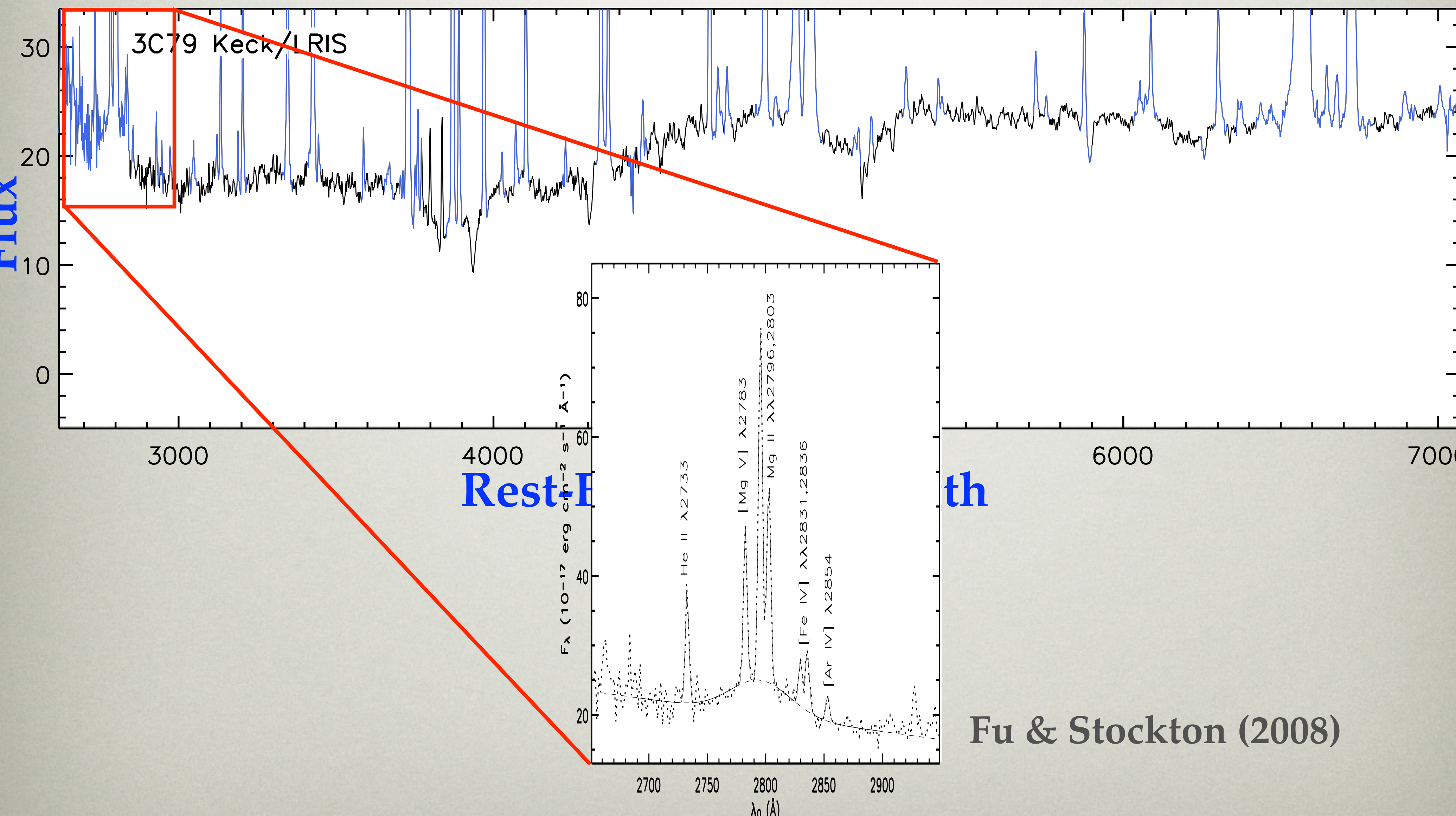
3C79: Radio Morphology



3C79: Low Metallicity



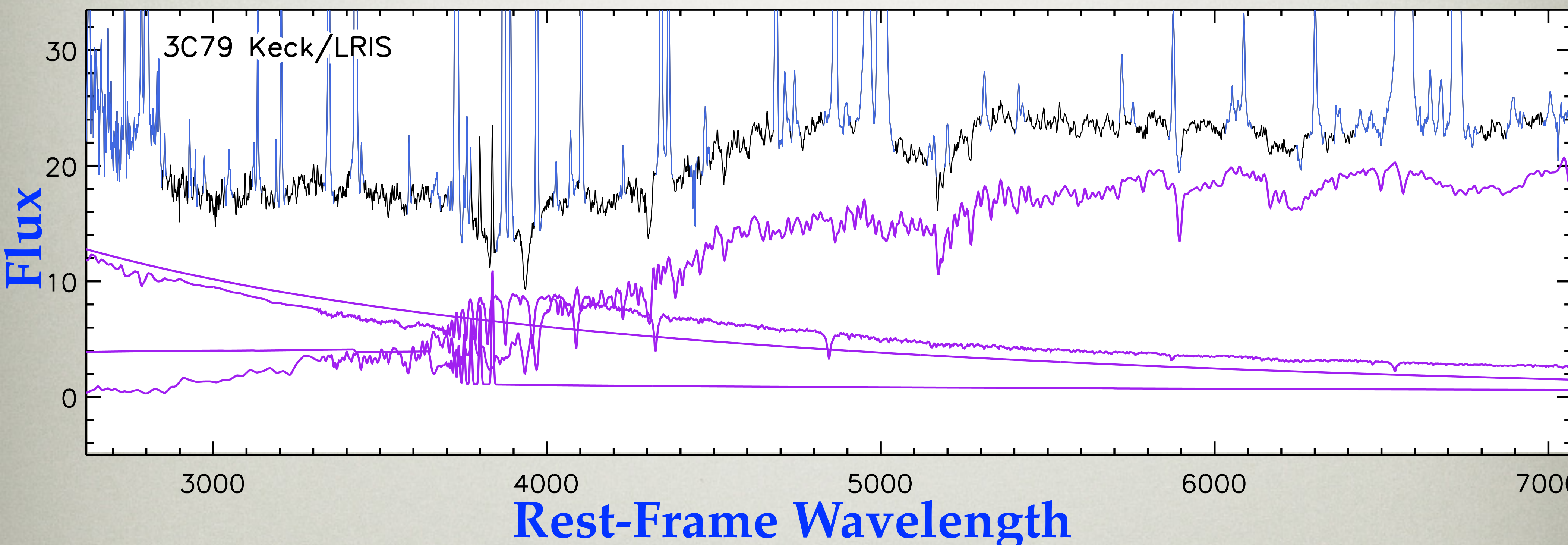
3C79: Broad Mg II Line



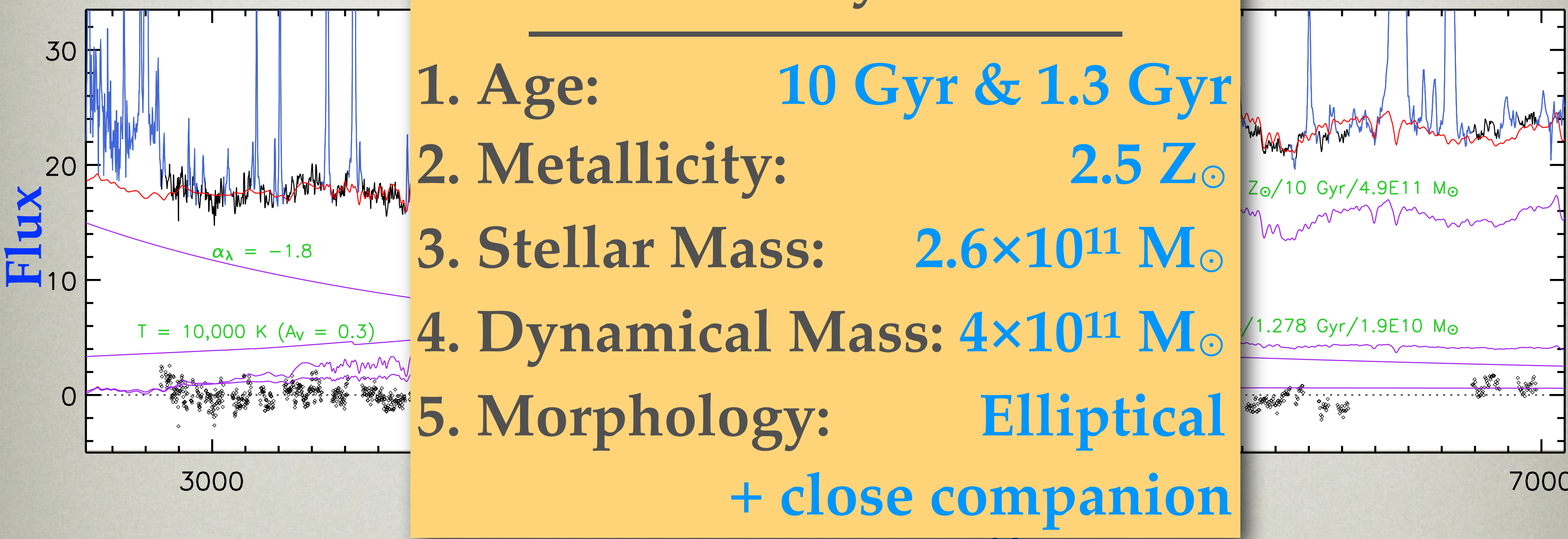
Fu & Stockton (2008)

3C79: Stellar Population

Fu & Stockton (2008)



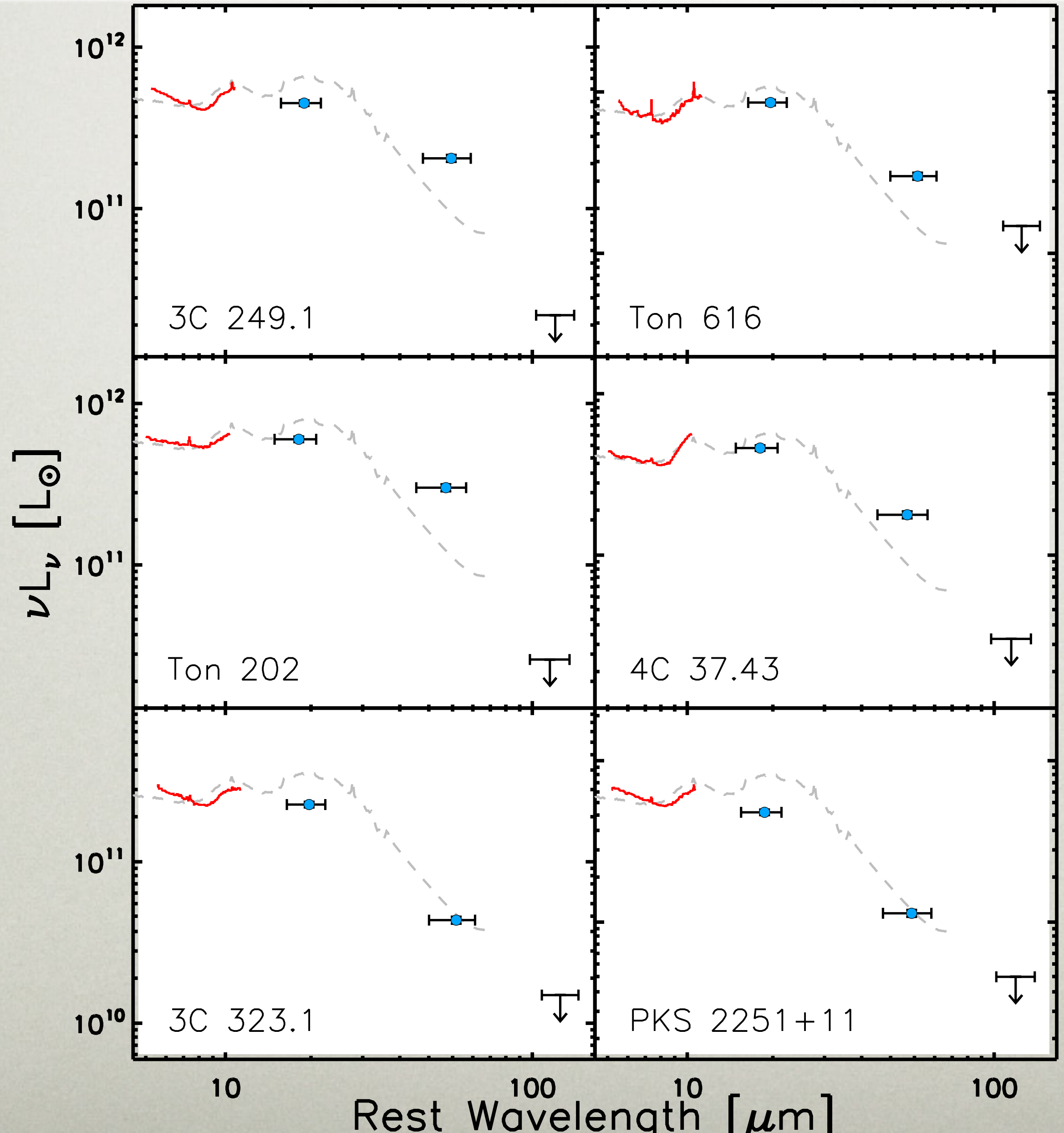
3C79: Stellar Population



Host Galaxy of 3C79

1. Age: 10 Gyr & 1.3 Gyr
2. Metallicity: 2.5 $Z_\odot$
3. Stellar Mass: 2.6×10^{11} $M_\odot$
4. Dynamical Mass: 4×10^{11} $M_\odot$
5. Morphology: Elliptical + close companion

Spitzer MIR-to-FIR SEDs of EELR Quasars



Spitzer IRS/MIPS

Fu *et al.* (2009b)

The Formation of EELRs

~~Tidal Interactions~~

Stockton & MacKenty (1983)

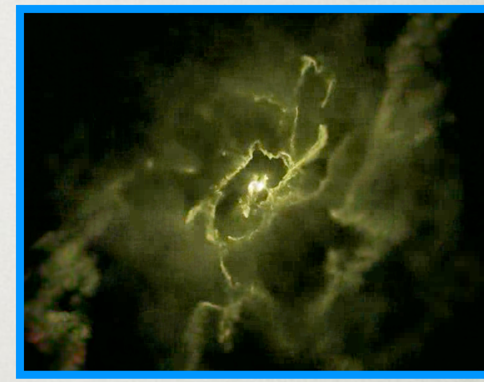
- ✓ disordered kinematics
- ✤ no underlying continuum
- ✤ high velocity clouds (v>500 km/s)

~~Starburst Superwind~~

Stockton et al. (2002)

- ✓ disordered kinematics
- ✓ no underlying continuum
- ✓ high velocity clouds (v>500 km/s)
- ✤ no significant young stellar pop.
- ✤ metal-poor gas in the nuclear BLR

Quasar Superwind



Di Matteo et al. (2005)

- ✓ disordered kinematics
- ✓ no underlying continuum
- ✓ high velocity clouds (v>500 km/s)
- ✓ no significant young stellar pop.
- ✓ metal-poor gas in the nuclear BLR

Summary

- GMOS Integral-Field Spectroscopy of 6 EELRs
- Disordered gas kinematics
- Quasar photoionization
- Gas (both nuclear & extended) in EELR quasars is metal-poor
- Stars in the host galaxy are *old* and metal-rich

Answers

- ? **Are EELRs shock-ionized?**
- **No. Quasar photoionization more likely.**
- ? **What makes EELR quasars special?**
- **Gas metallicity.**
- ? **Where does the gas come from?**
- **A merging gas-rich galaxy.**
- ? **How are the EELRs formed?**
- **Remnants of quasar superwinds.**