The Starburst-AGN Connection:
Integral Field Spectroscopy of Merging and Seyfert 2 Galaxies

Sarah A. Jaeggli
Robert D. Joseph, project mentor

Activity in Galaxies

In the course of their evolution, galactic nuclei occasionally light up

Energy from a galactic nucleus may come from two sources

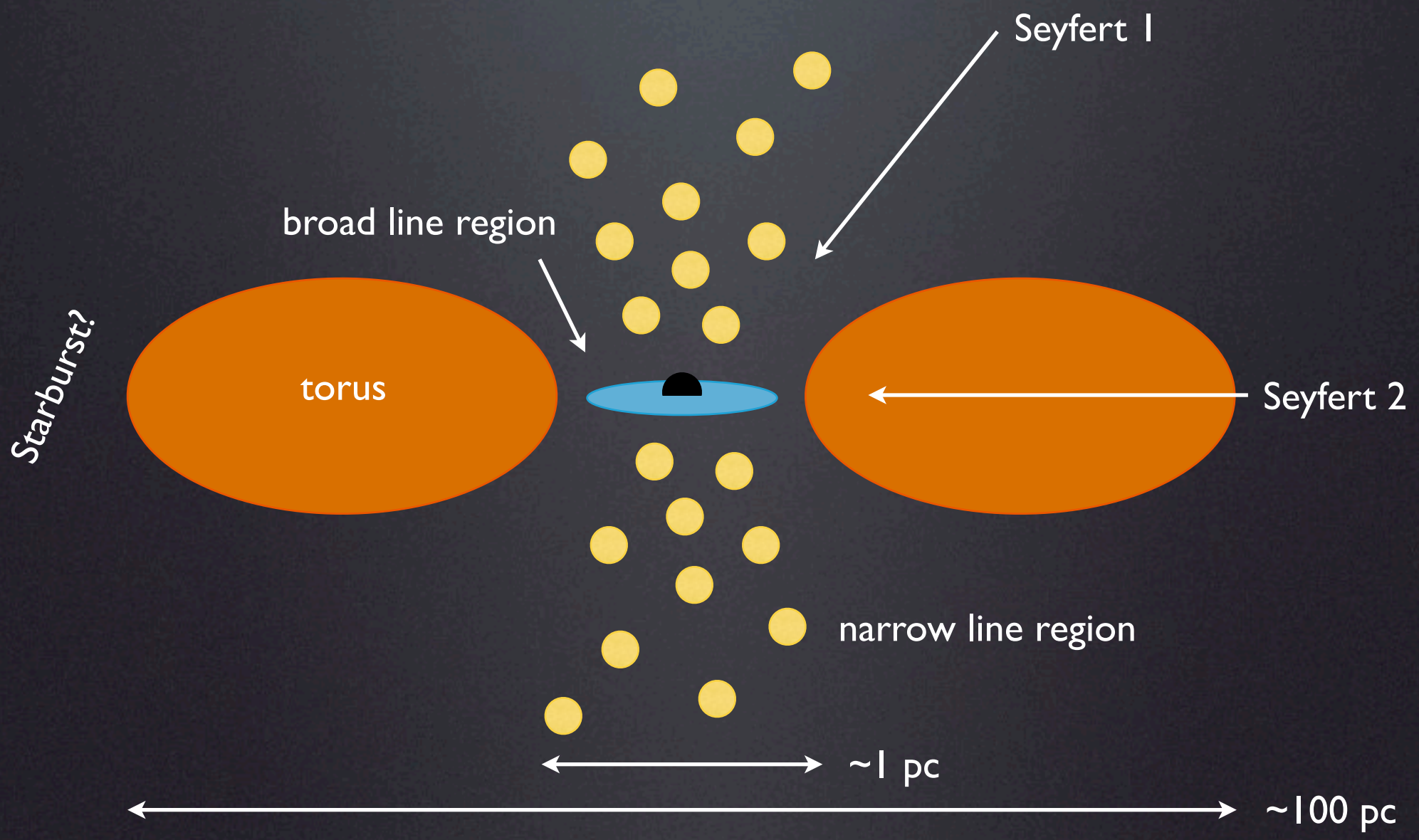
- Accretion of matter onto a massive compact object (Active Galactic Nuclei or AGN)
- The sudden onset of star formation, a Starburst

Both occur within a large amount of dust

A Starburst/AGN Connection?

- Conservation of angular momentum makes it difficult to feed an AGN directly (Gunn 1977)
- A little accreted mass turns into a large amount of spectral energy
- Nuclear starbursts may be the answer
  - Supernovae and outflows from giants and super giants may provide the necessary material

Active Galactic Nuclei



Project Goals

- Using integral field spectroscopy in the infrared determine the presence of a nuclear Starburst/AGN
- Estimate the strength of a possible Starburst based on infrared spectral diagnostics and stellar synthesis models
- Look for connections between the possible Starburst and AGN

Observations

- Observations of 20 merging and/or Seyfert 2 galaxies taken by R. Joseph on April 19-23, 2003
  - 15 have the S/N needed for these measurements
  - 4 of these 15 are presented
- UK Infrared Telescope Imager-Spectrometer (UIST) integral field unit
  - 1.4 - 2.4 μm
  - 6 x 3.3 arcsec^2
  - R~900

H & K-band Spectral Diagnostics

Diagnostic	Physics
[Fe II]	Produced in supernova remnants, lasts for 10^4 years
Paschen α, Brackett γ	O & B main sequence stars, broad and narrow line regions of AGN
[Si VI]	Very high ionization potential(~200eV), only produced in AGN
H_2 (1-0)	Shocked neutral medium, AGN, SN, mergers
He I	Windy O & B main sequence stars
CO (2-0) band	Red giant stars

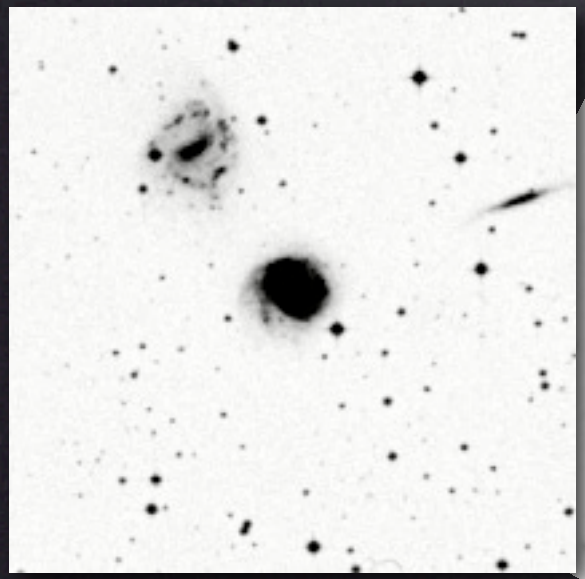
IC 3639

Type: SBbc

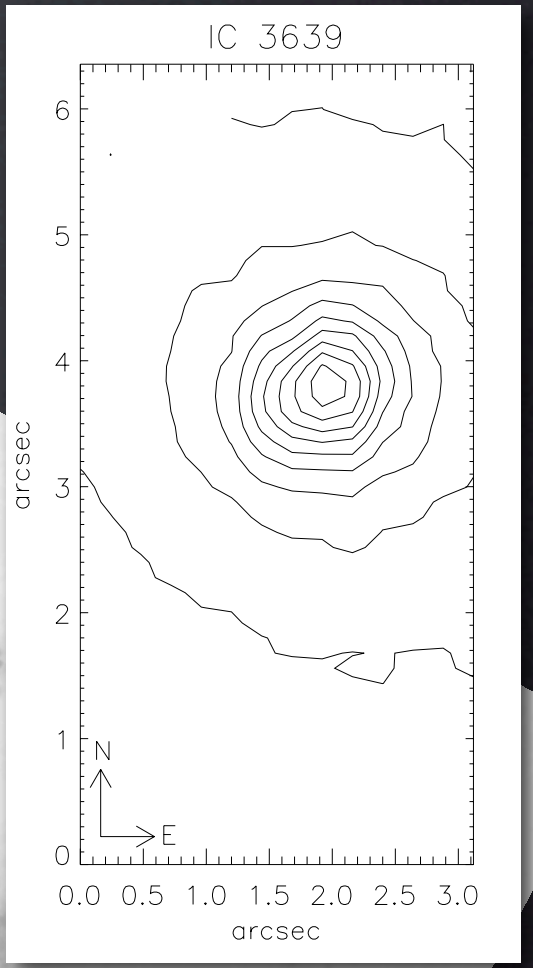
Nuclear Activity: Seyfert 2

Distance: 49.6 Mpc

2 companion galaxies

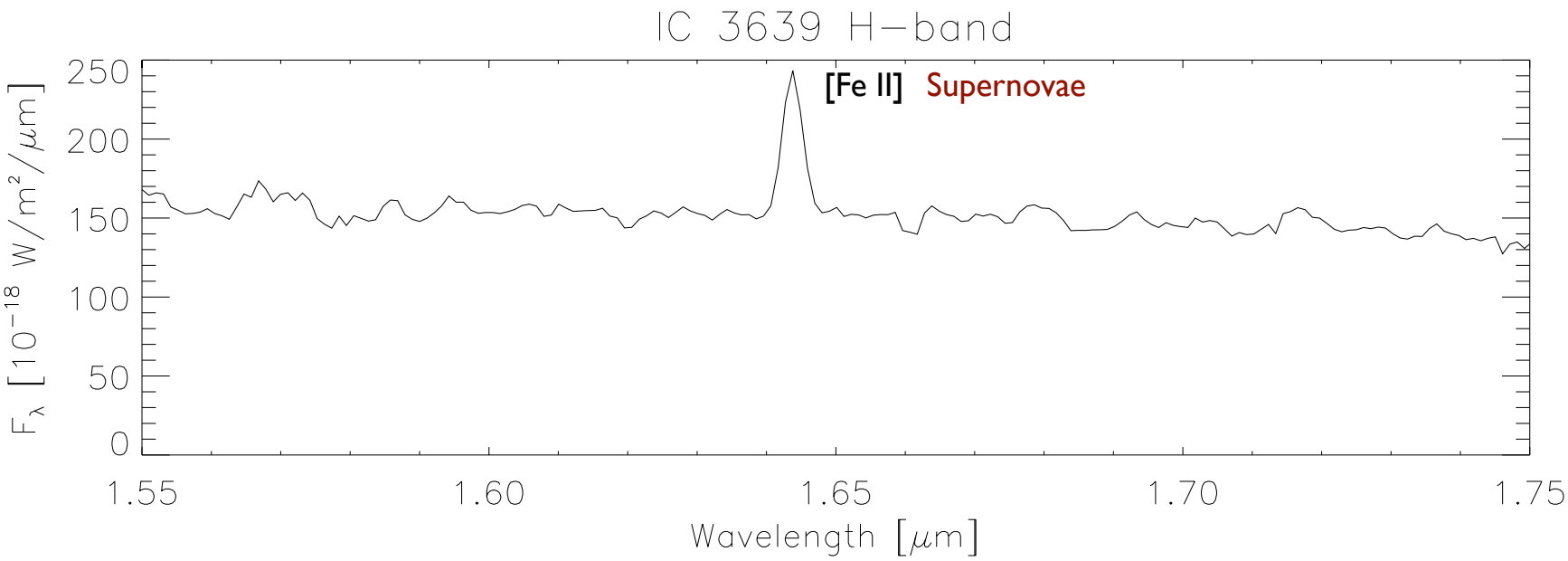


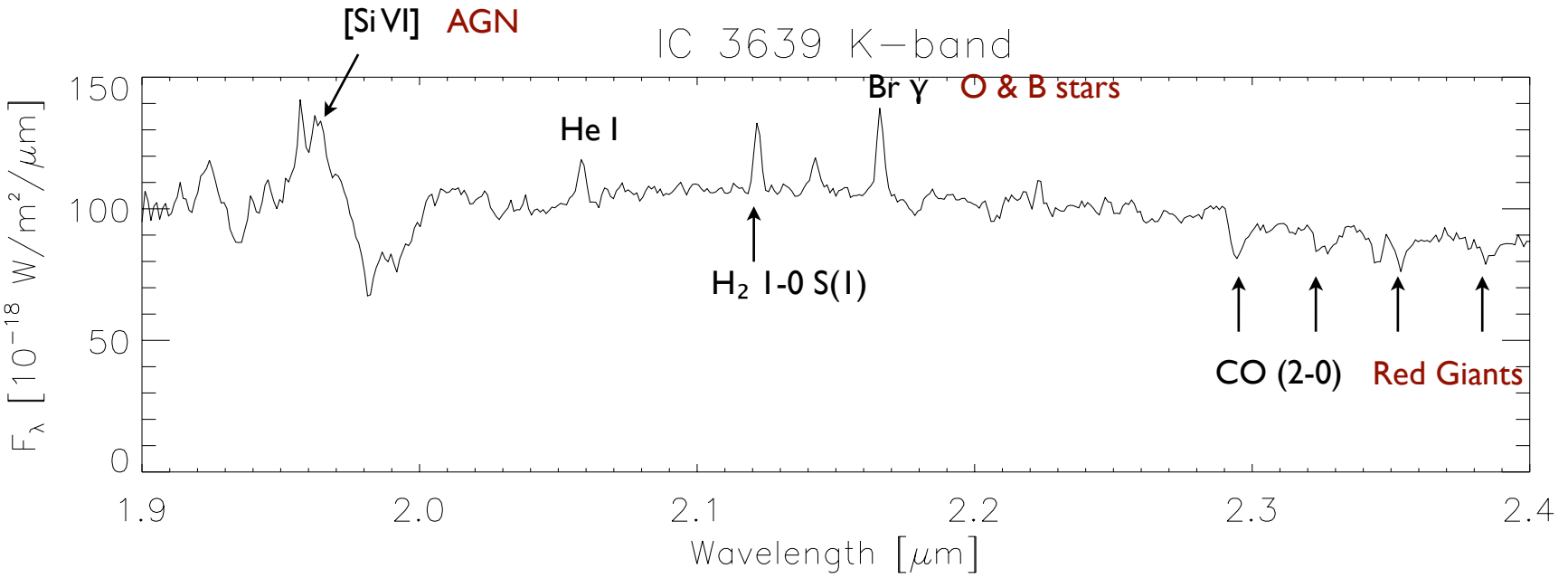
DSS1 4680A
6 arcmin



HST 6030A
0.6 arcmin

IC 3639


IC 3639 H−band
[Fe II] Supernovae
F_λ [10^{-18} W/m^2/μm]
250
200
150
100
50
0
1.55
1.60
1.65
1.70
1.75
Wavelength [μm]


[Si VI] AGN
IC 3639 K−band
Br γ O & B stars
He I
H_2 1-0 S(1)
CO (2-0) Red Giants
F_λ [10^{-18} W/m^2/μm]
150
100
50
0
1.9
2.0
2.1
2.2
2.3
2.4
Wavelength [μm]

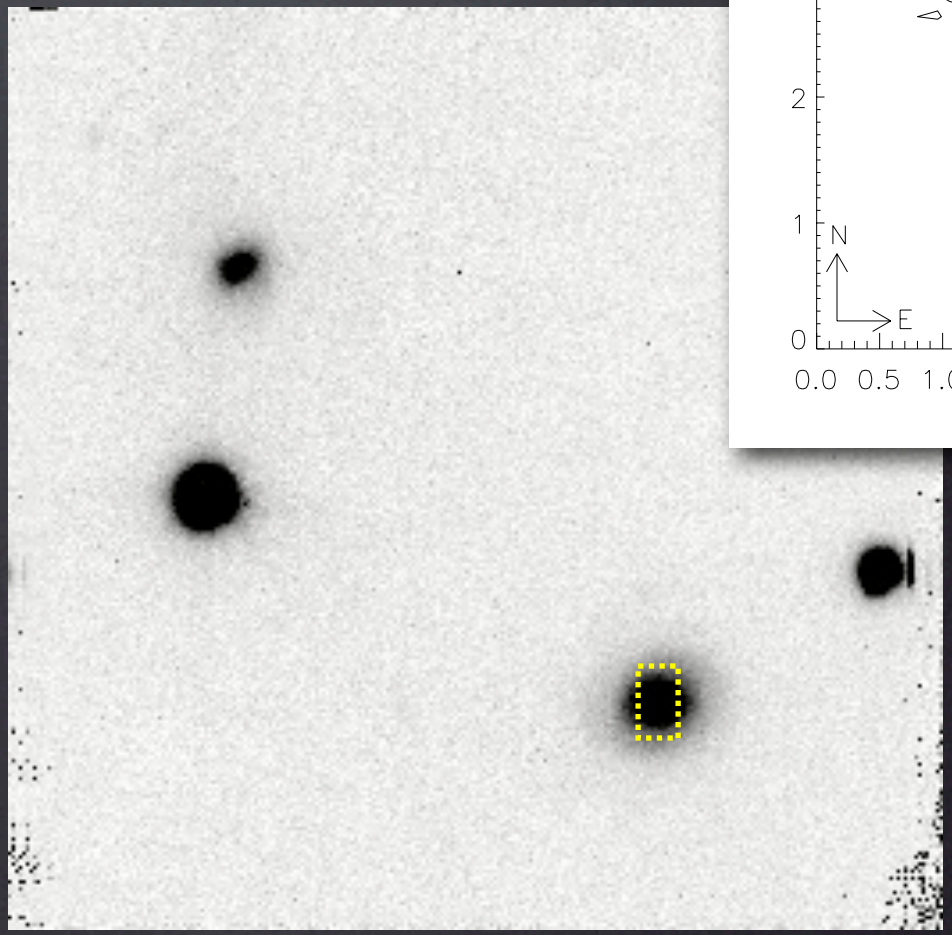
MRK 477

Type: Compact

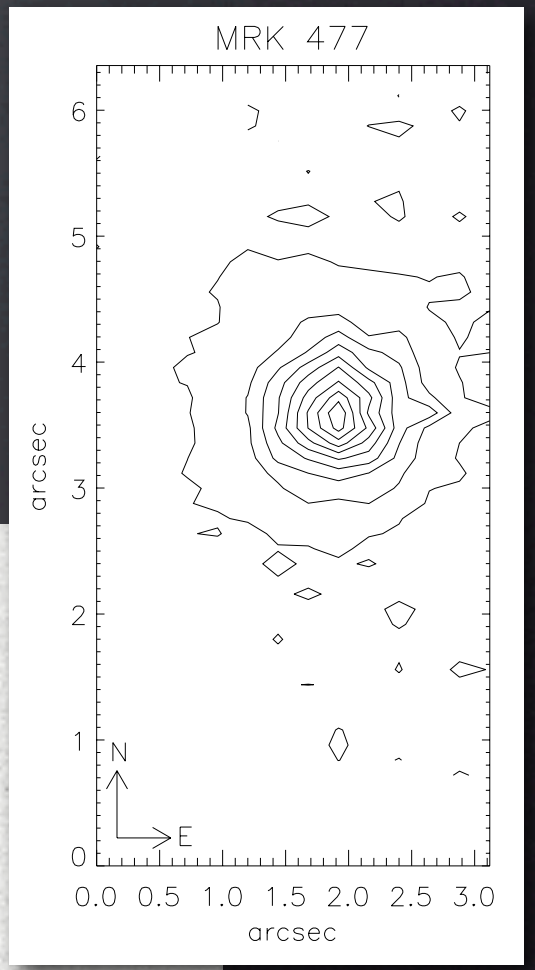
Nuclear Activity: Seyfert 2

Distance: 158.1 Mpc

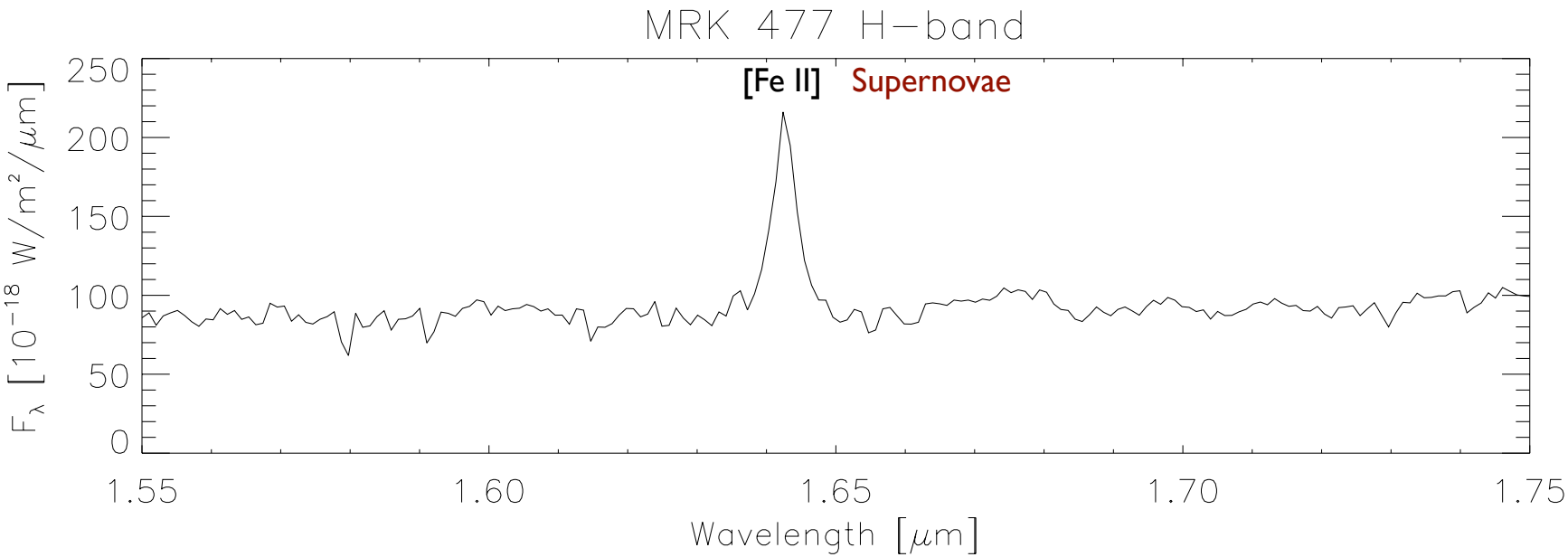
Interacting with companion galaxy



IRTF H-band
1.3 arcmin



MRK 477


MRK 477 H−band
[Fe II]
Supernovae
F_λ [10^{-18} W/m^2/μm]
250
200
150
100
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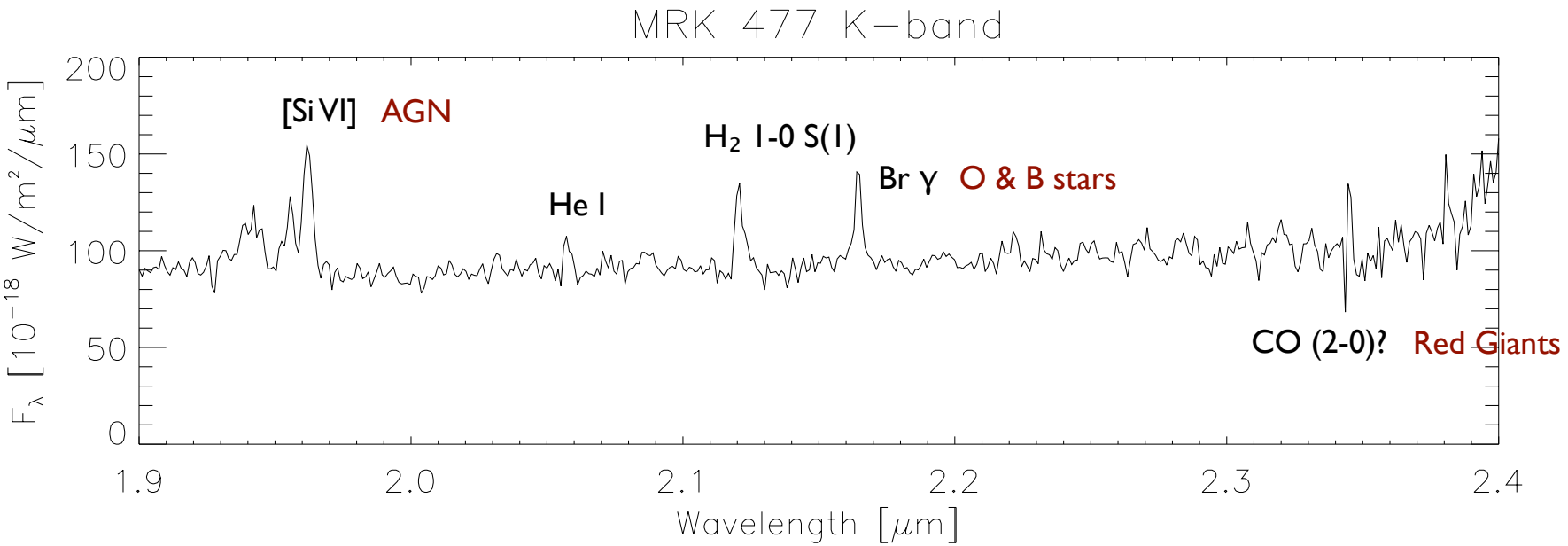
0
1.55
1.60
1.65
1.70
1.75
Wavelength [μm]


MRK 477 K−band
[Si VI]
AGN
H_2 1-0 S(1)
He I
Br γ
O & B stars
CO (2-0)?
Red Giants
F_λ [10^{-18} W/m^2/μm]
200
150
100
50
0
1.9
2.0
2.1
2.2
2.3
2.4
Wavelength [μm]

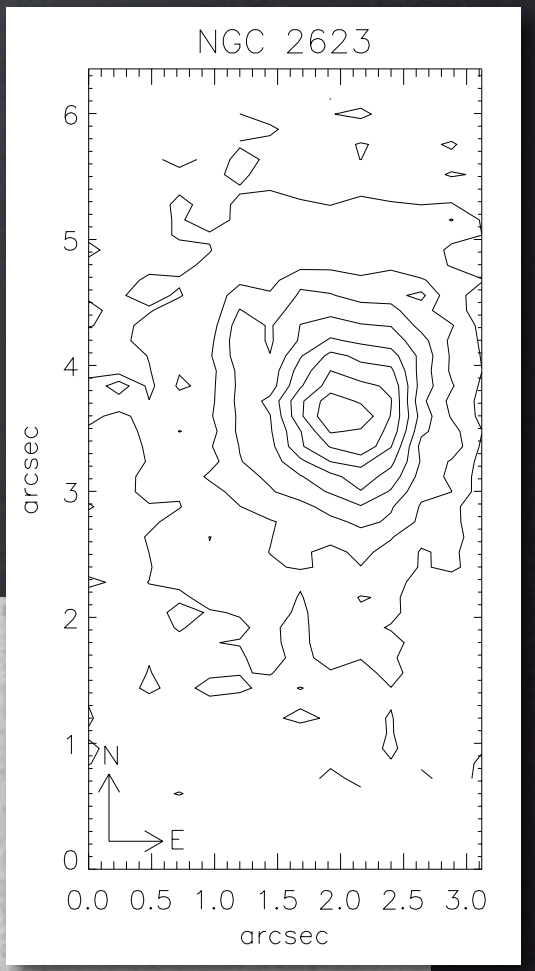
NGC 2623

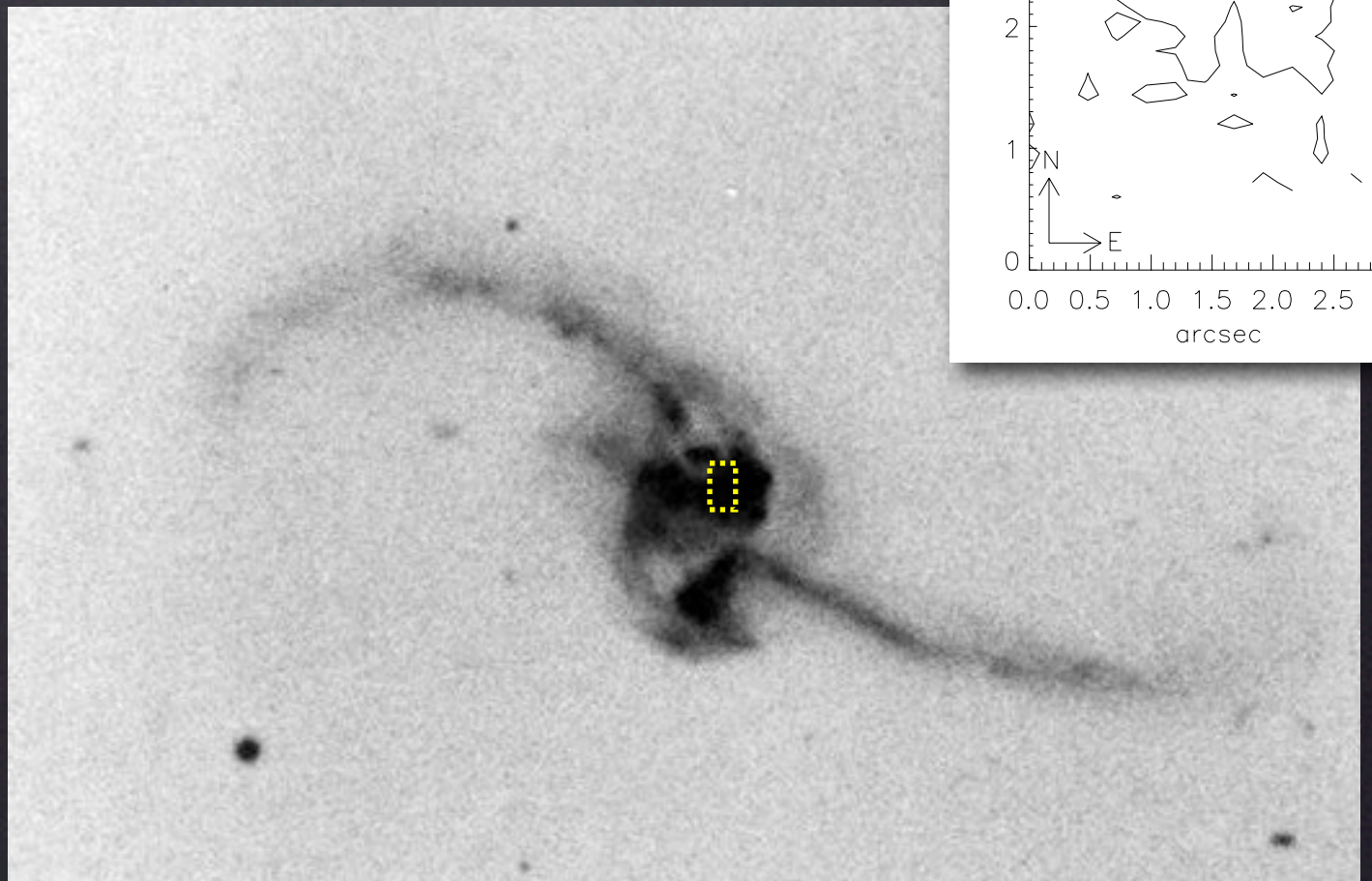
Type: Peculiar

Nuclear Activity: Seyfert 2

Distance: 75.9 Mpc

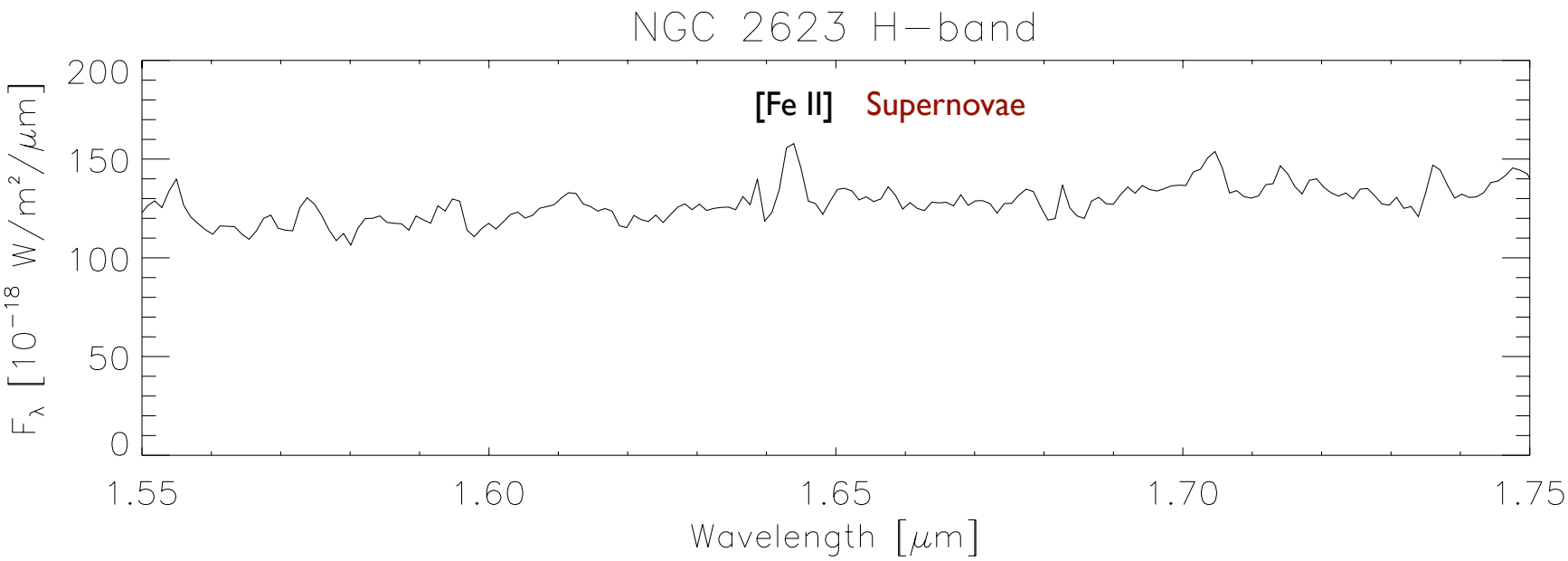
Merger

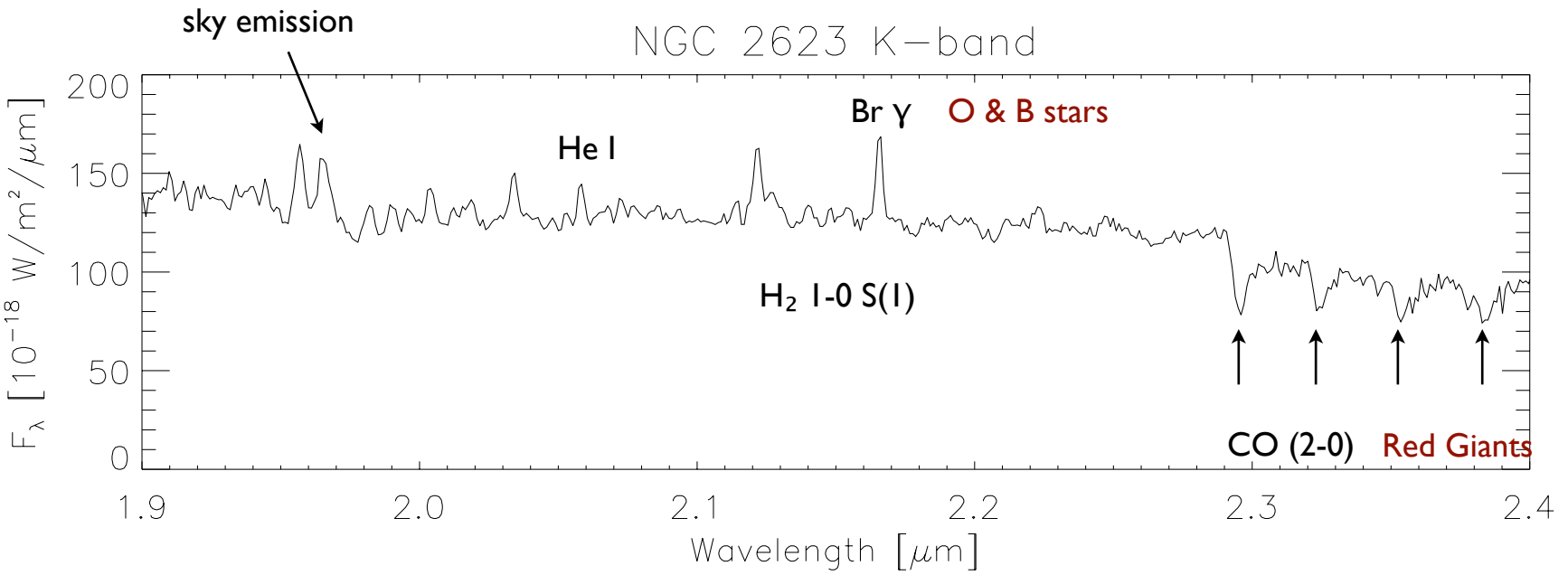




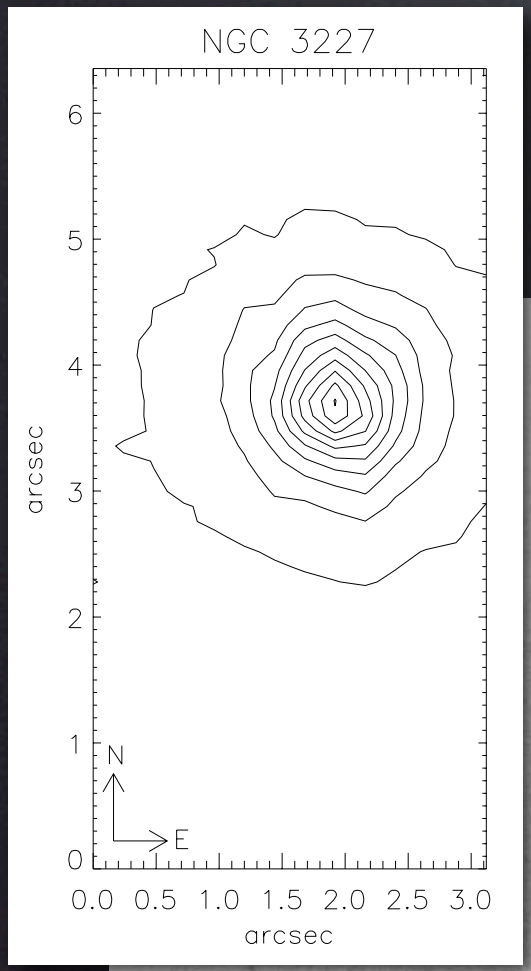
Palomar 5m 4050A
2.8x2.2 arcmin

NGC 2623


NGC 2623 H−band
[Fe II]
Supernovae
F_λ [10^{-18} W/m^2/μm]
200
150
100
50
0
1.55
1.60
1.65
1.70
1.75
Wavelength [μm]


sky emission
NGC 2623 K−band
He I
Br γ
O & B stars
H_2 1-0 S(1)
CO (2-0)
Red Giants
F_λ [10^{-18} W/m^2/μm]
200
150
100
50
0
1.9
2.0
2.1
2.2
2.3
2.4
Wavelength [μm]

NGC 3227



Type: SAB peculiar

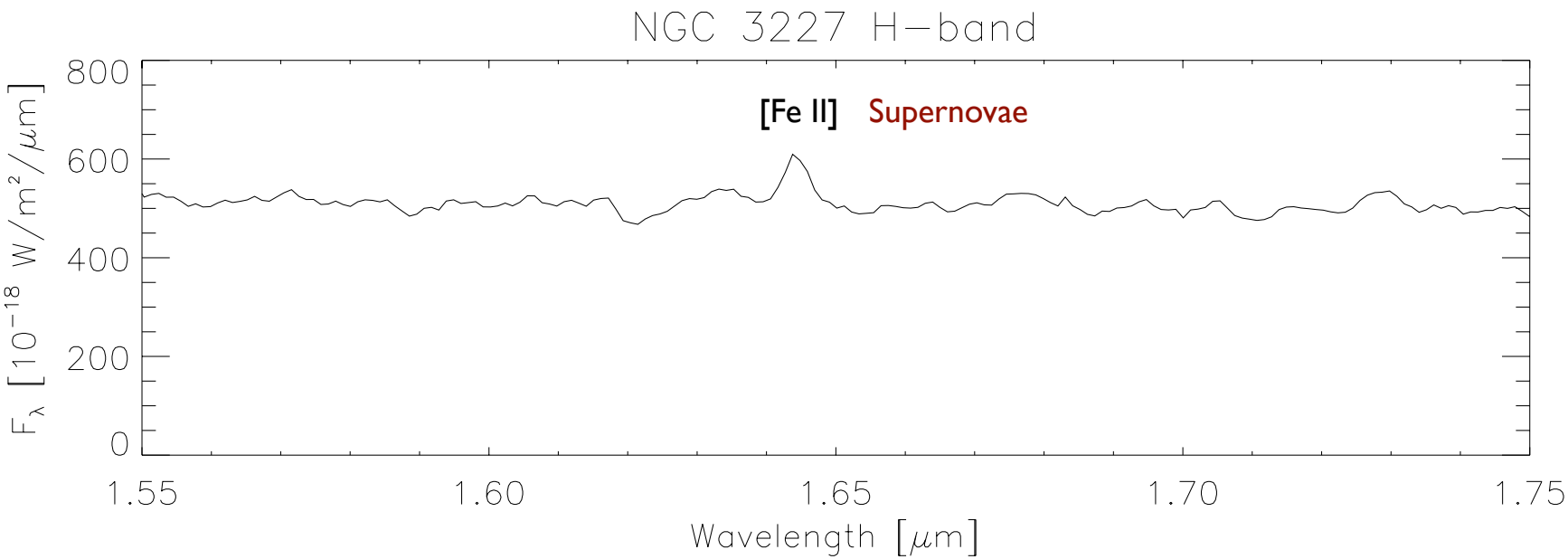
Nuclear Acticity: Seyfert 1.5

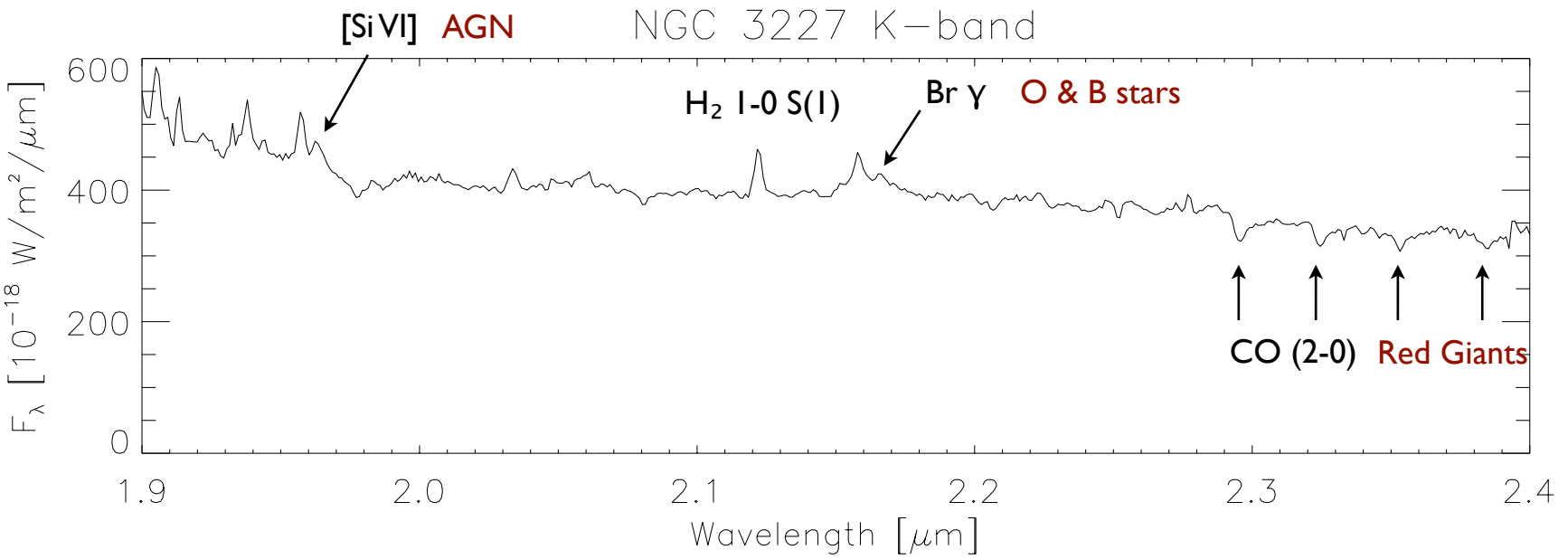
Distance: 18.3 Mpc

Possible companion, within a group of 13 galaxies

Palomar 200in 4050A
~9 arcmin

NGC 3227


NGC 3227 H−band
[Fe II]
Supernovae
800
600
400
200
0
1.55
1.60
1.65
1.70
1.75
Wavelength [μm]
F_λ [10^-18 W/m²/μm]


[Si VI]
AGN
NGC 3227 K−band
H2 1-0 S(1)
Br γ
O & B stars
CO (2-0)
Red Giants
600
400
200
0
1.9
2.0
2.1
2.2
2.3
2.4
Wavelength [μm]
F_λ [10^-18 W/m²/μm]

Starburst Stellar Synthesis

Starburst99

Predictions of the spectral properties of a stellar population based on age

-Continuous and instantaneous star formation

-Initial mass function:

-Salpeter (-2.35, 1-100 M_{sun})

-Steeper power law (-3.3, 1-100 M_{sun})

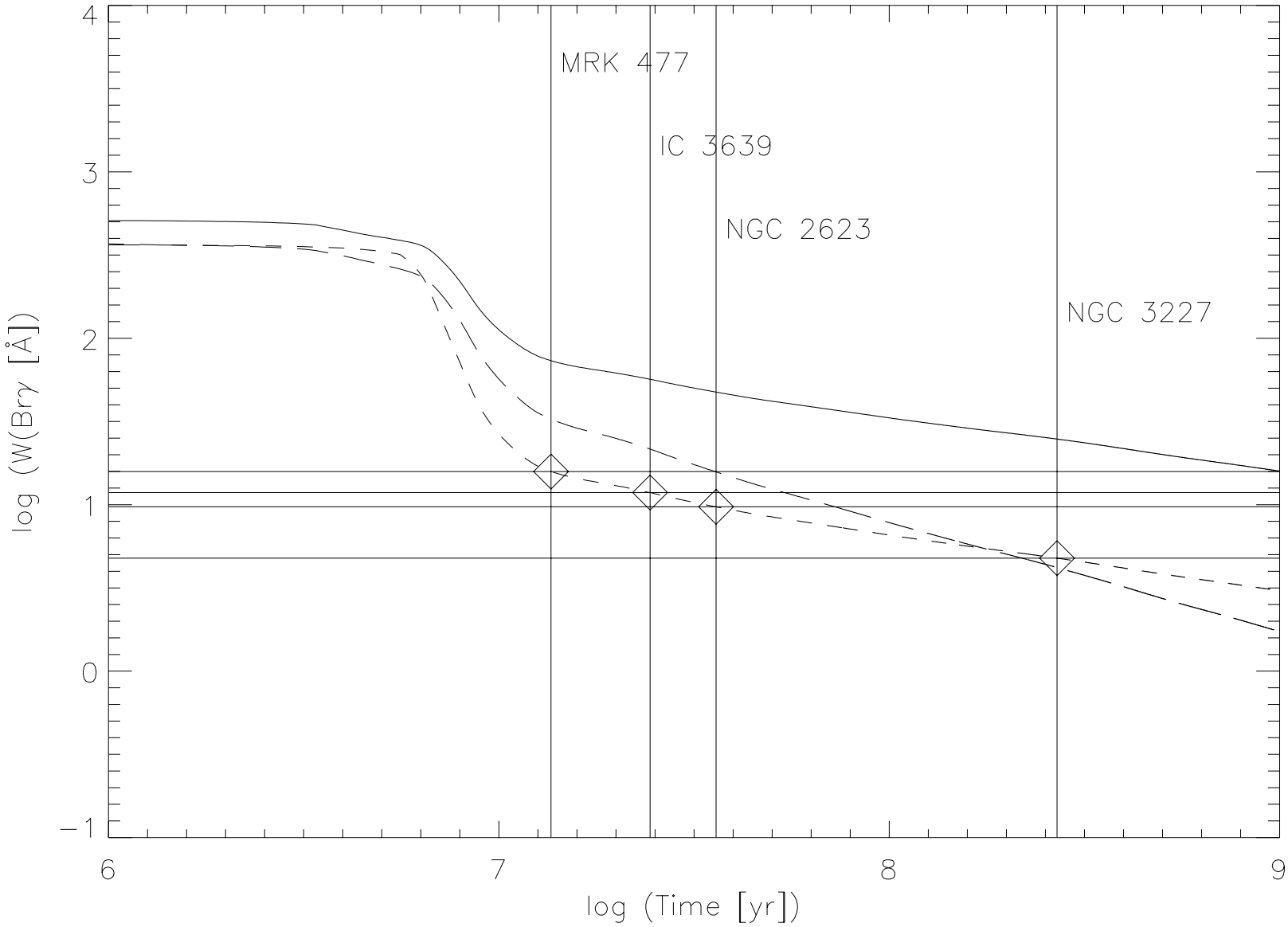
-Lower mass cutoff (-2.35, 1-30 M_{sun})

Using Starburst99

- Assuming:
  - The starburst is the major source of the luminosity from the nucleus
  - Star formation is continuous and ongoing
- Procedure:
  - Use Br γ to find the starburst age
  - Use [Fe II] luminosity to estimate the supernova rate
  - Use the SNR and the model to find the star formation rate
  - Find Starburst99 M_K and compare with measured M_K

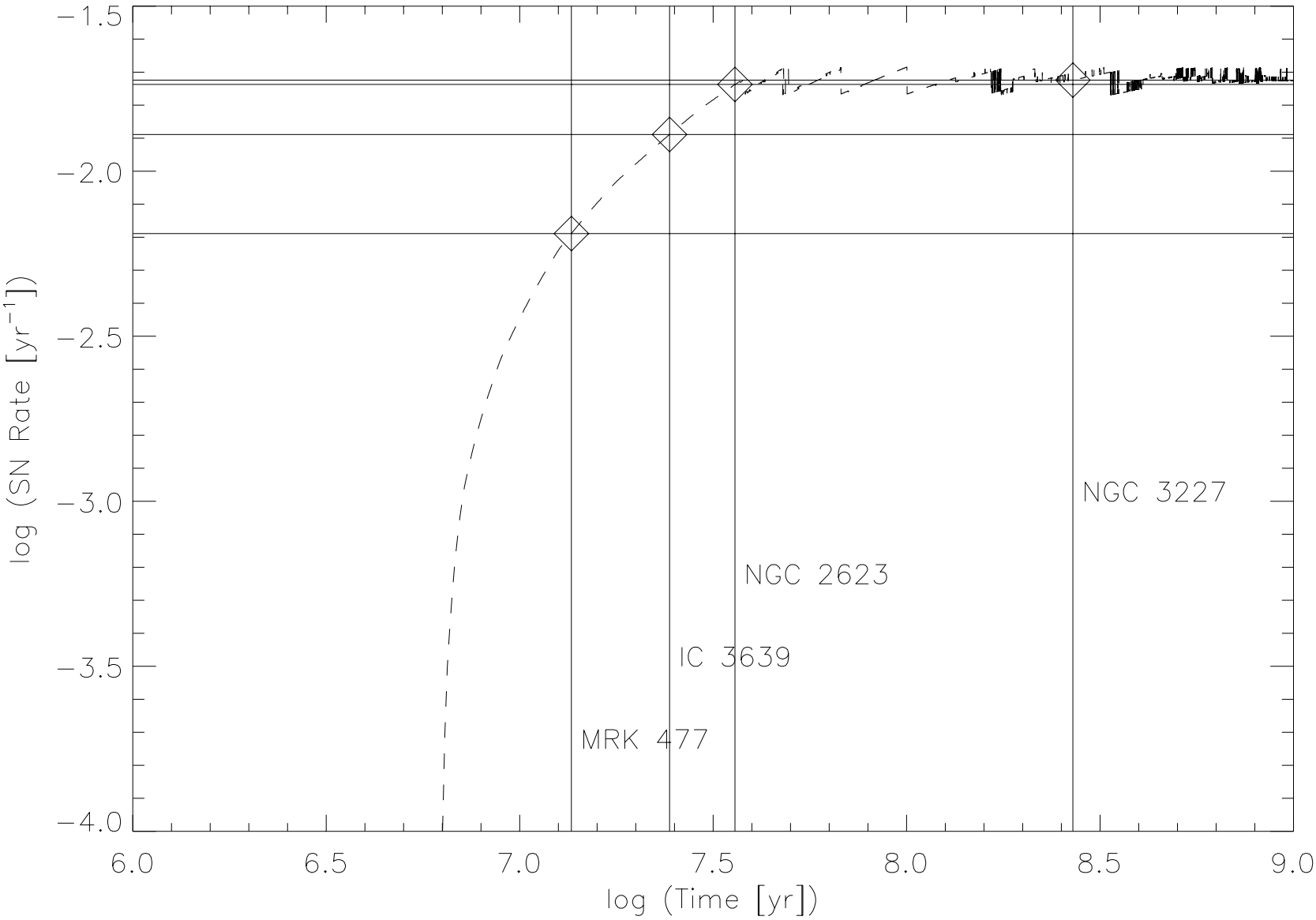
Age from the Equivalent Width of Brackett γ

Galaxy	log(W(Brγ)[Å])	Age[Myr]
IC 3639	1.07 ± 0.02	24 ± 2
MRK 477	1.20 ± 0.05	14 ± 3
NGC 2623	0.99 ± 0.02	36 ± 4
NGC 3227	0.68 ± 0.05	270 ± 10



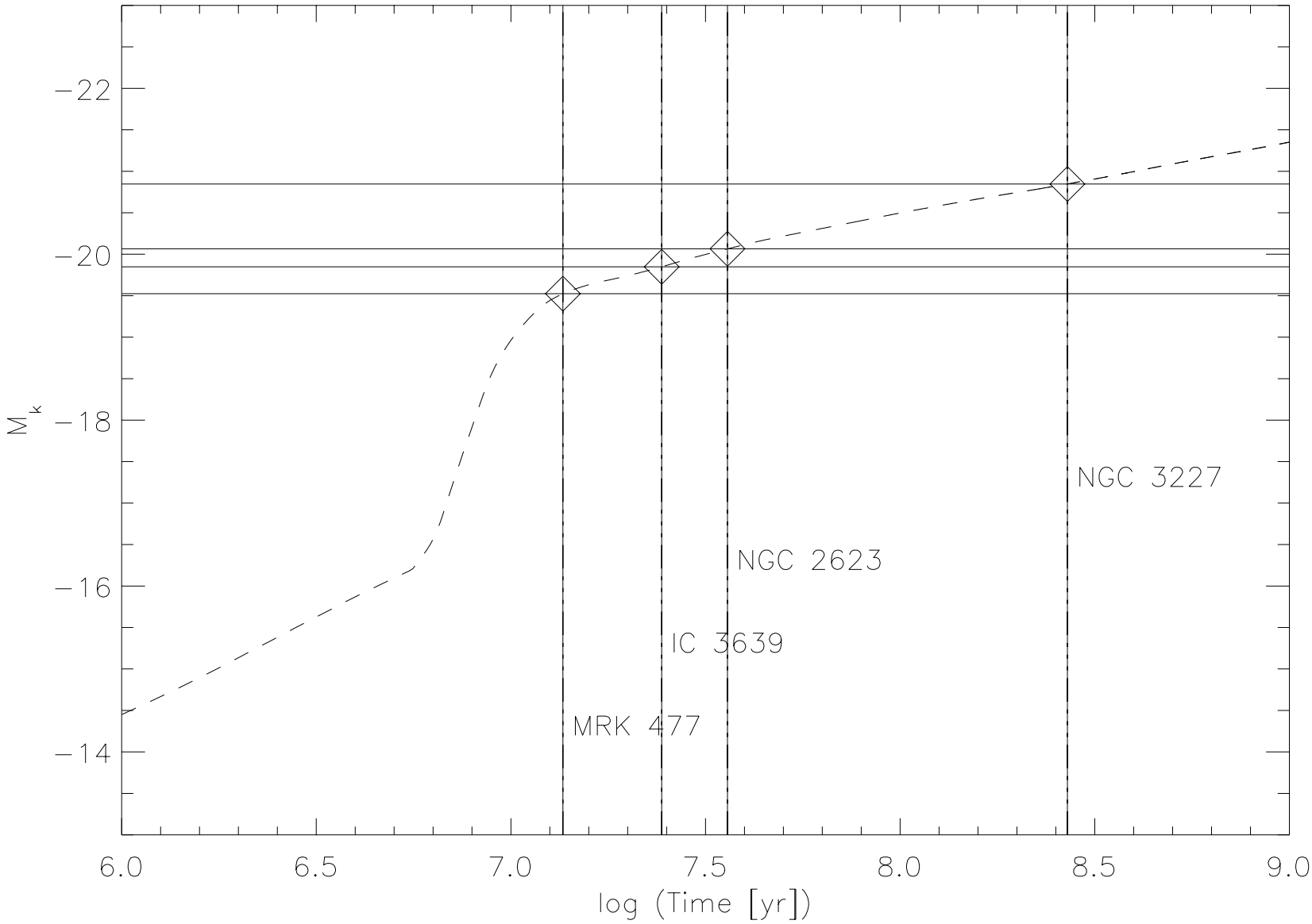
Scaling from the Supernova rate

Galaxy	Measured SNR[yr^{-1}]	SFR[yr^{-1}]
IC 3639	0.045 ± 0.004	3.45 ± 0.40
MRK 477	1.03 ± 0.08	159 ± 5.0
NGC 2623	0.080 ± 0.03	4.36 ± 1.5
NGC 3227	0.014 ± 0.002	0.75 ± 0.11



Comparison through M_K

Galaxy	measured M_K	predicted M_K	% K-band flux
IC 3639	-22.7 ± 0.2	-21.2 ± 0.1	30%
MRK 477	-24.8 ± 0.2	-25.0 ± 0.1	120%
NGC 2623	-23.9 ± 0.2	-21.7 ± 0.4	10%
NGC 3227	-21.6 ± 0.2	-20.5 ± 0.2	40%



Conclusions

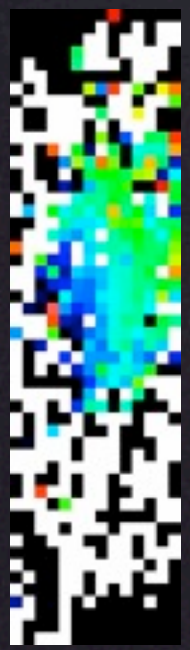
- Three galaxies have a confirmed Seyfert nucleus (IC 3639, MRK 477, NGC 3227)
- Consistent starburst models are found for IC 3639, NGC 2623, and NGC 3227
- Observations with the IFU confirm previous results from long slit spectroscopy that the IMF is bottom-heavy

Future Work

IC 3639

NGC 2623

- Improve the Starburst 99 age estimation
  - Characterize the continuum emission from other sources: AGN, old stellar population
  - Use an iterative method to determine the relative contributions
- Mass estimation from velocity
- Statistics with 11 more galaxies



MRK 477

NGC 3227