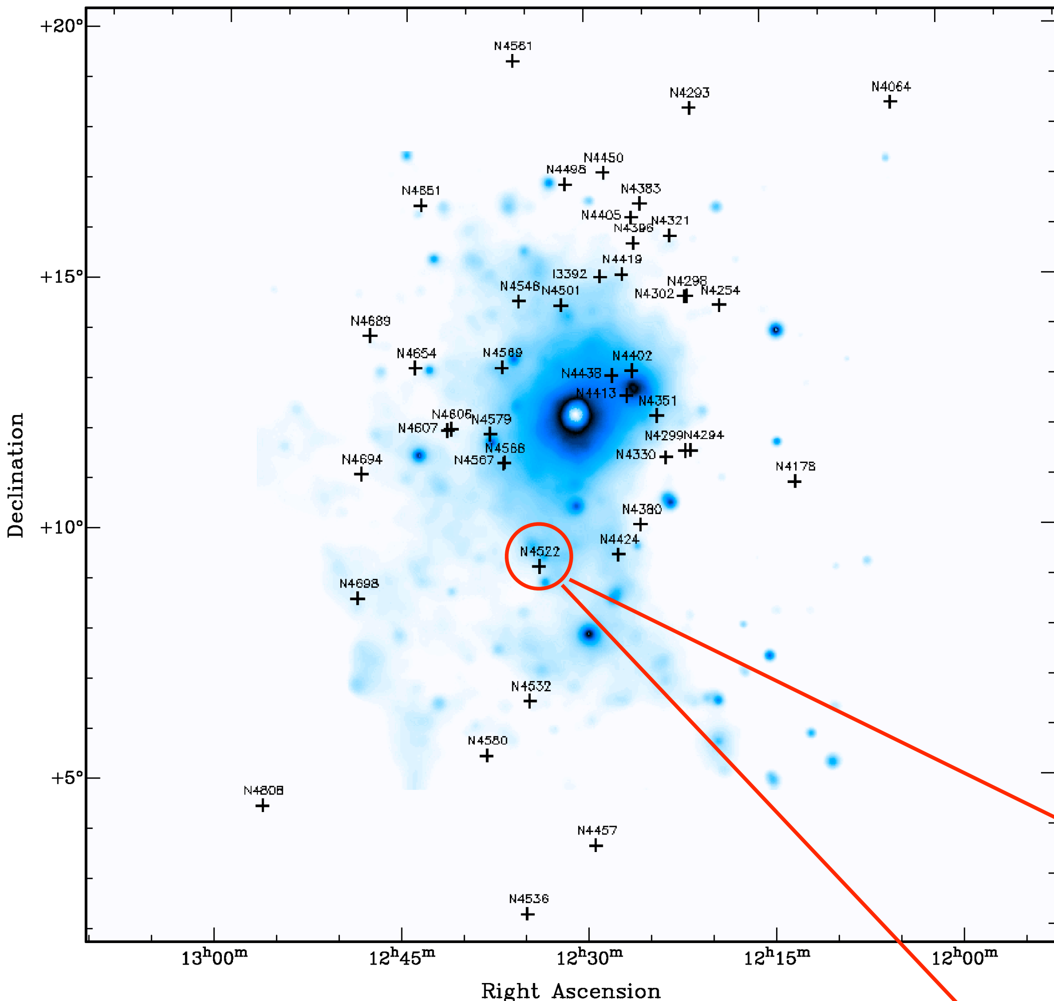
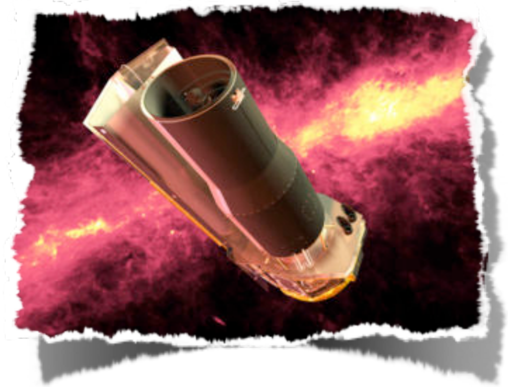
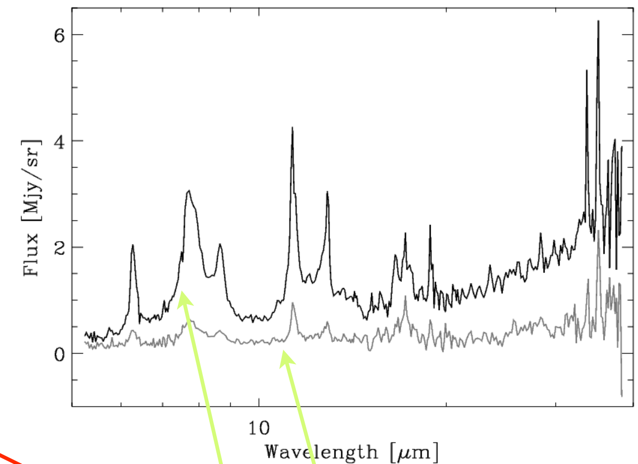
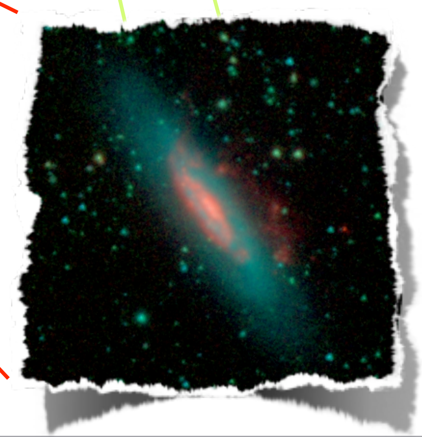








IRS spectroscopy

O. Ivy Wong

MOTIVATION

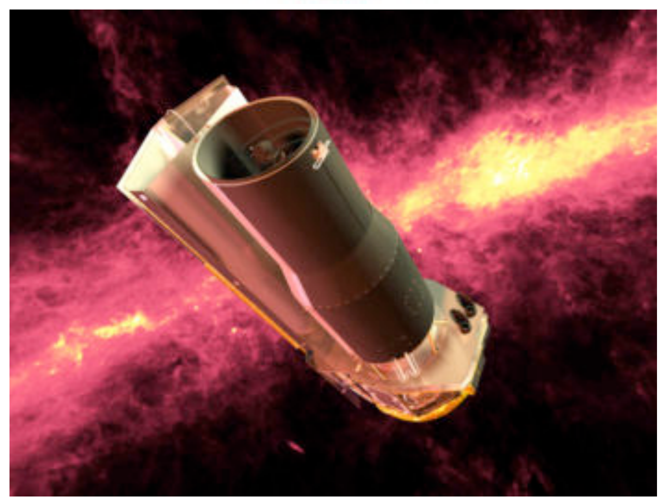
Galaxies with radio deficits appear to have enha
fluxes. Murphy proposed that the radio deficits a
ICM wind sweeping away the CR e- and their as

They also proposed that the CR e- are then reac
ICM-driven shocklets beyond the deficit region.
in an observed enhancement in radio brightness

- ☐ To determine if ISM shocking is a reasonable explanation for enhanced global radio-to-FIR ratios in galaxies experiencing strong pressure (cf. Eric's work)
- ☐ Roussel+ (2007) found that shocks may produce enhanced warm H_2/PAH fractions
- ☐ To investigate the warm H_2 properties of 4 Virgo galaxies (NGC 4330, NGC 4402, NGC 4501 & NGC 4522) known to be experiencing ram-pressure stripping

Spectral mapping with Spitzer's Infrared Spectrograph (IRS)

- Short-low (5.2 - 14.5 μm)
  - ➡ 1.8″ per pixel
  - ➡ 1σ line sensitivity ~ 0.06 mJy*
- Long-low (14.0 - 38.0 μm)
  - ➡ 5.1″ per pixel
  - ➡ 1σ line sensitivity ~ 0.4 mJy*



* in 512 seconds of integration

Excitation of H_2

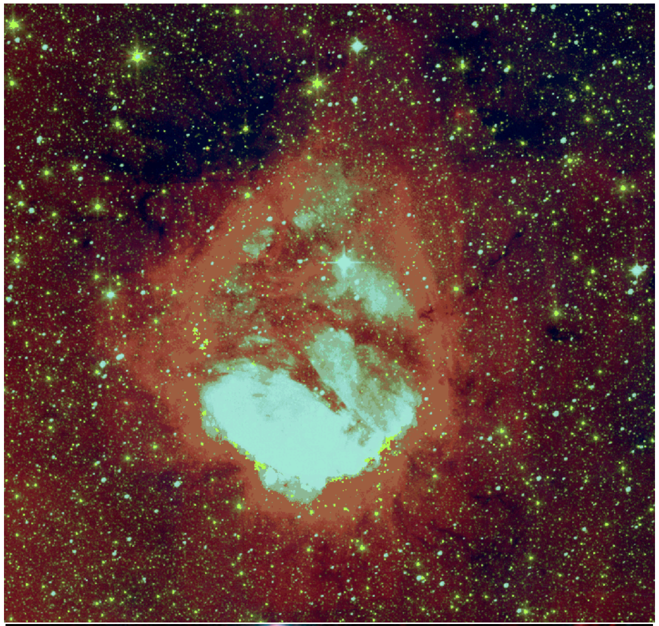
- MIR emission lines from rotational transitions of H_2 traces the bulk of the warm molecular gas phase at temperatures of 100-1000 K (Roussel+ 2007)
- Rotational lines can characterise the temp. & density conditions of a large mass fraction of the warm molecular ISM

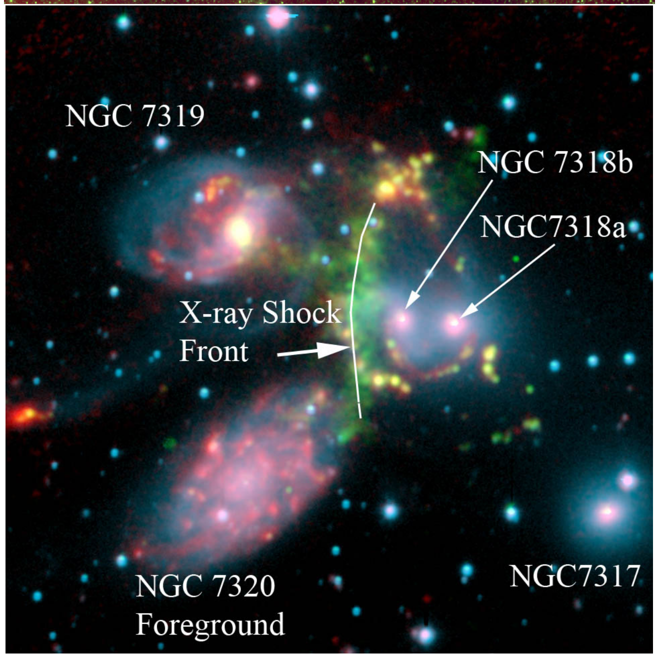
Typical heating sources of H_2

MOST LIKELY

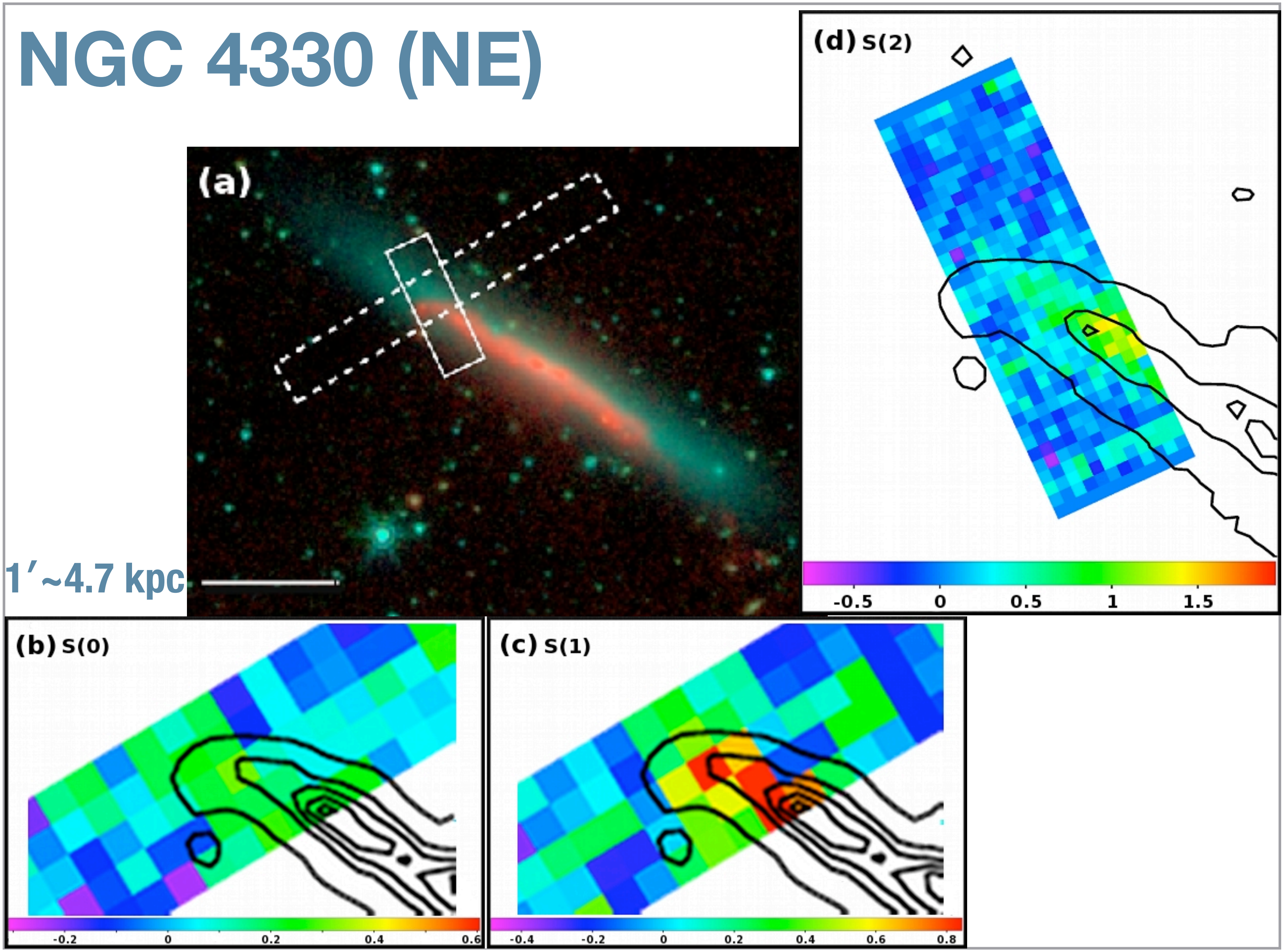
- ☑ FUV from massive stars (in photodissociation regions)
- ☑ Shocks (in molecular outflows, SNe remnants or cloud collisions in disturbed gravitational potentials)
- ☑ X-rays from AGN/SNe heats atomic and molecular H via collisional excitation

LEAST LIKELY

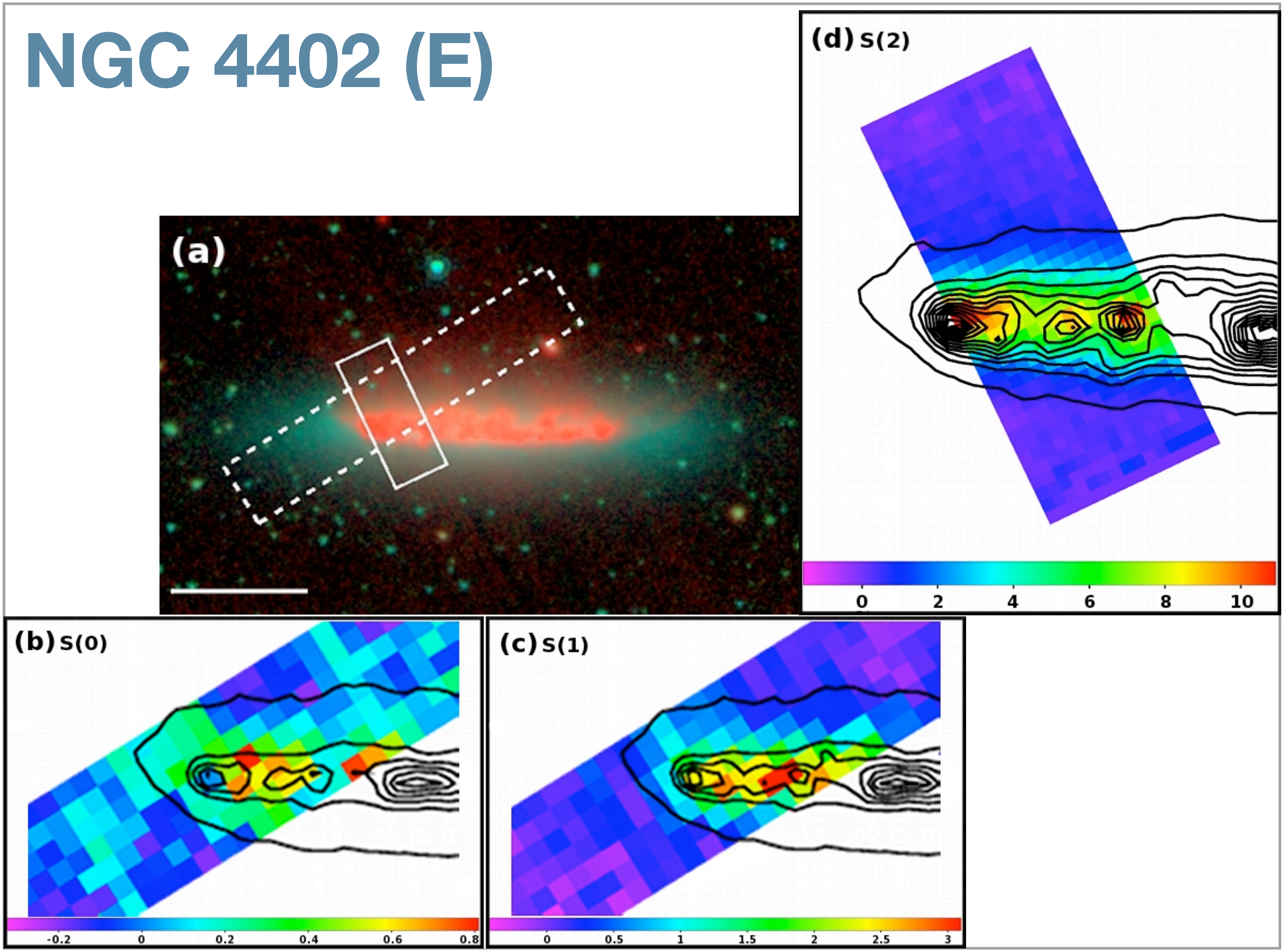




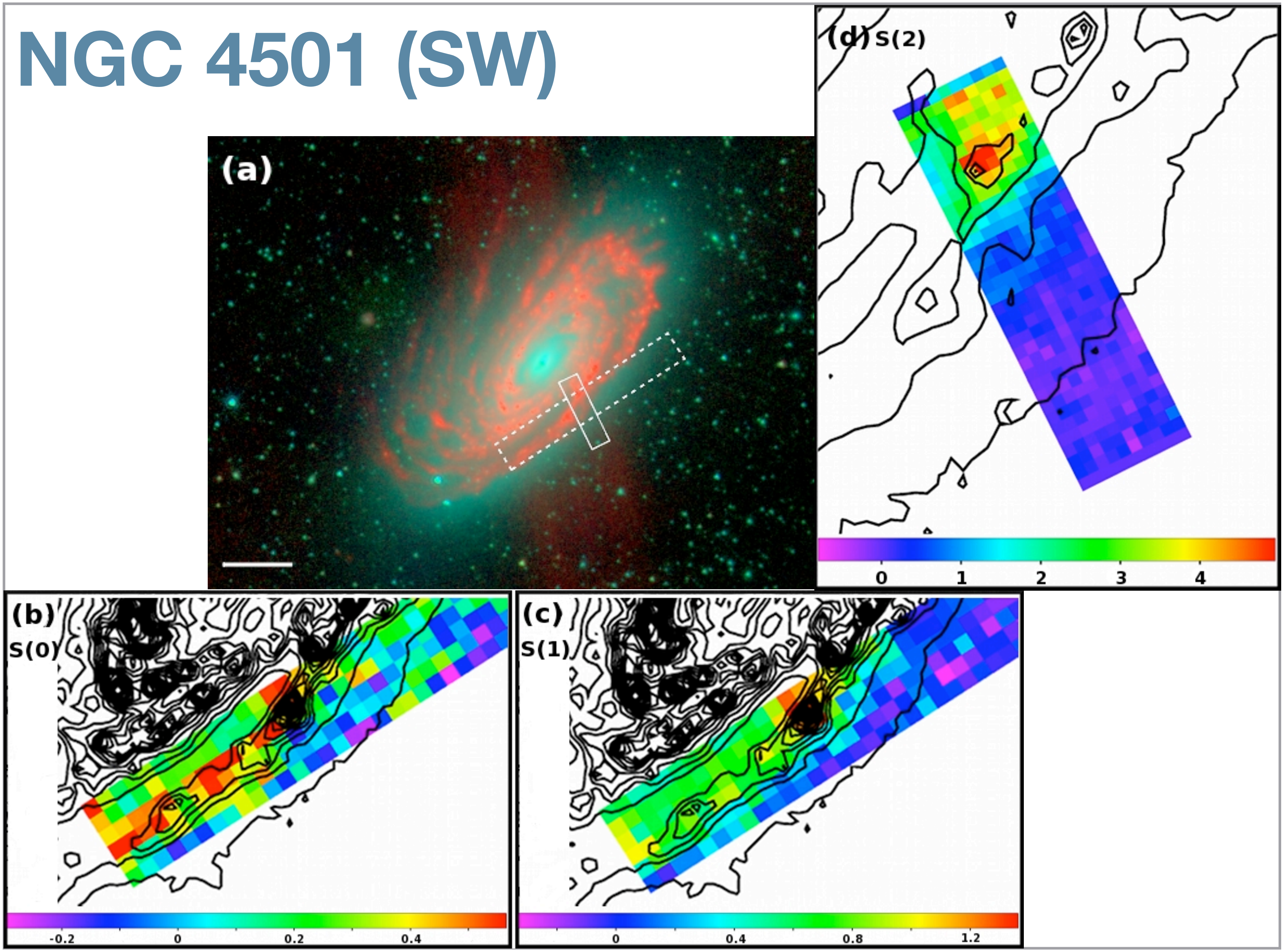
NGC 4330 (NE)



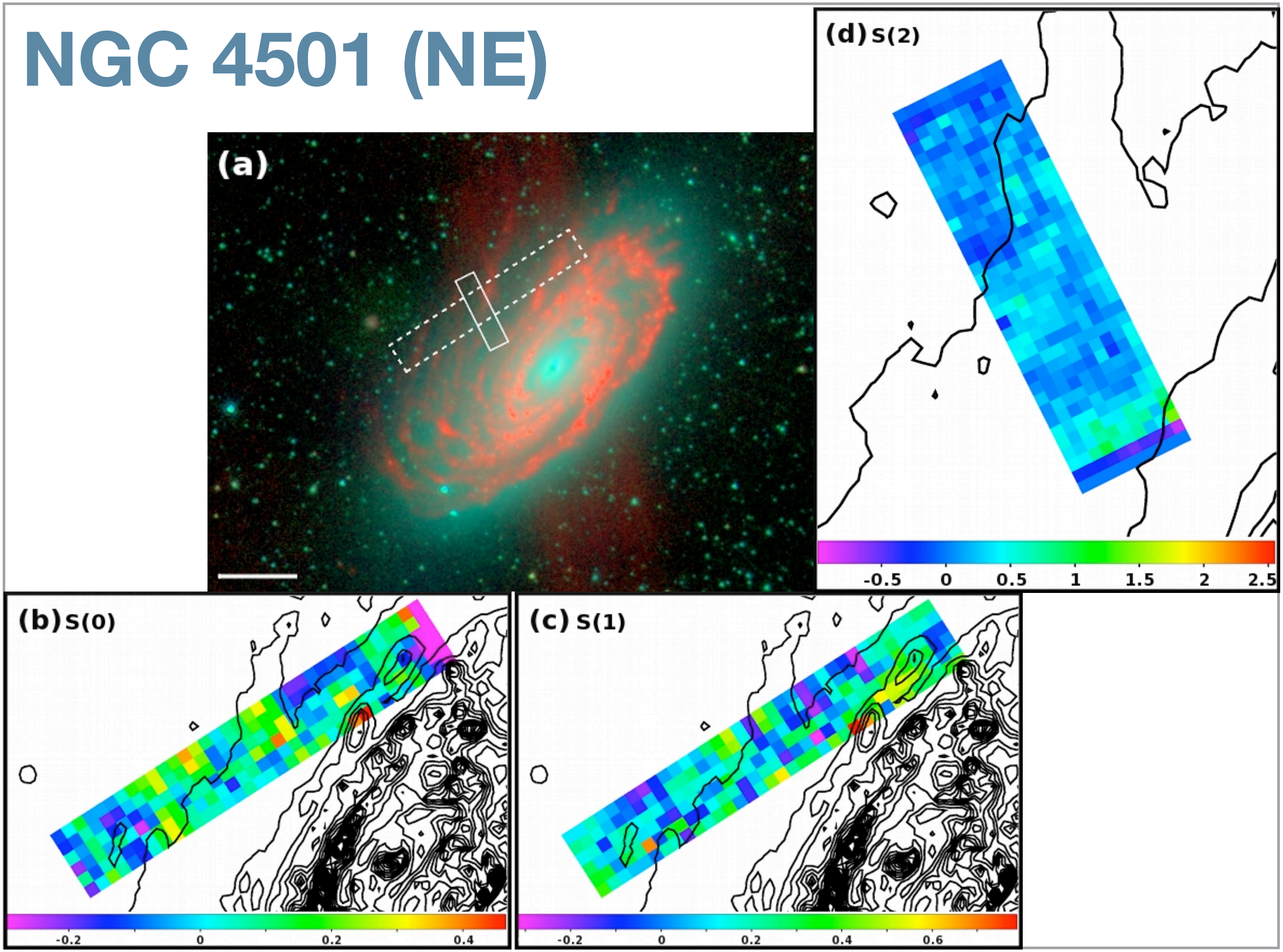
NGC 4402 (E)



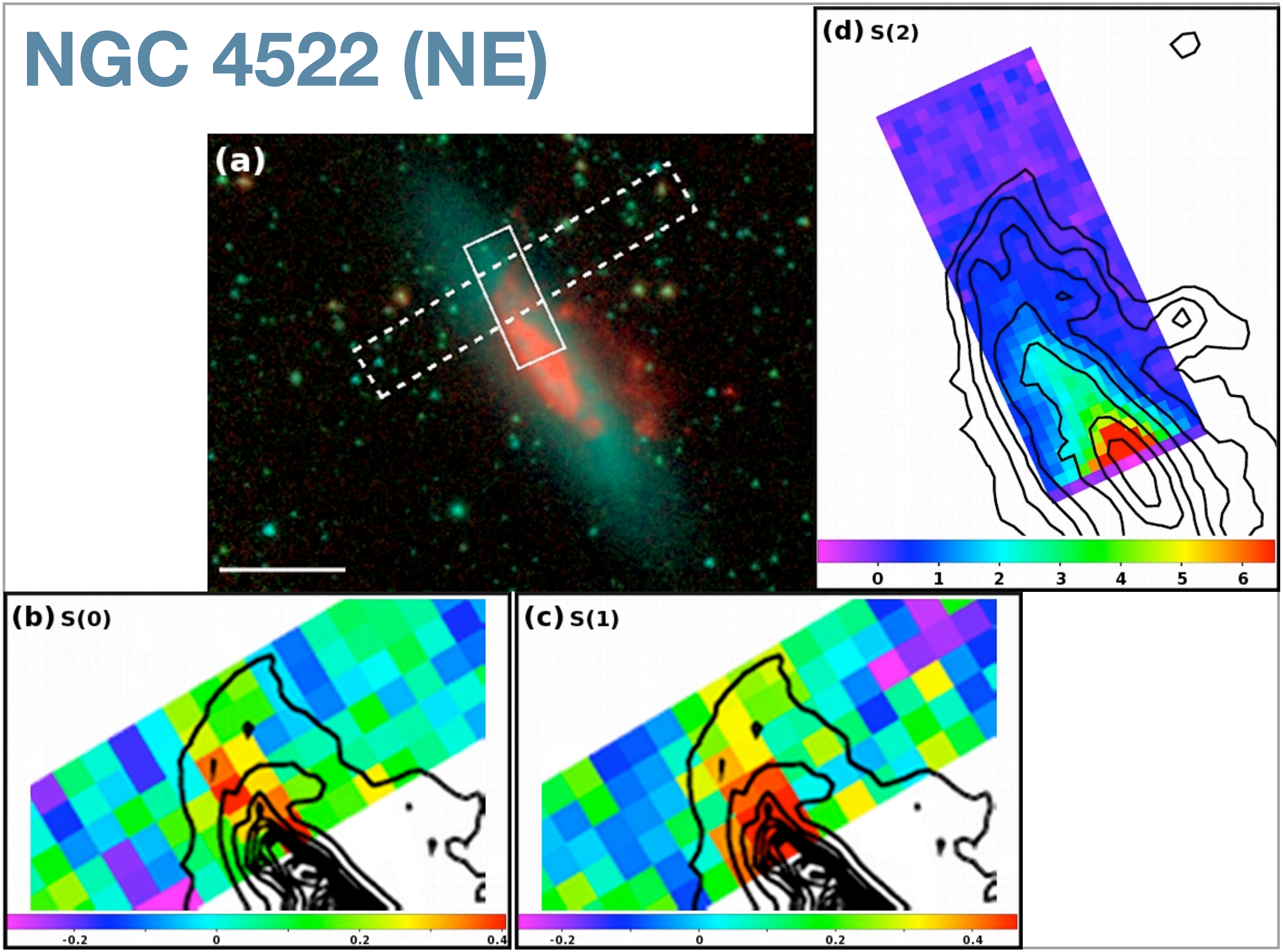
NGC 4501 (SW)



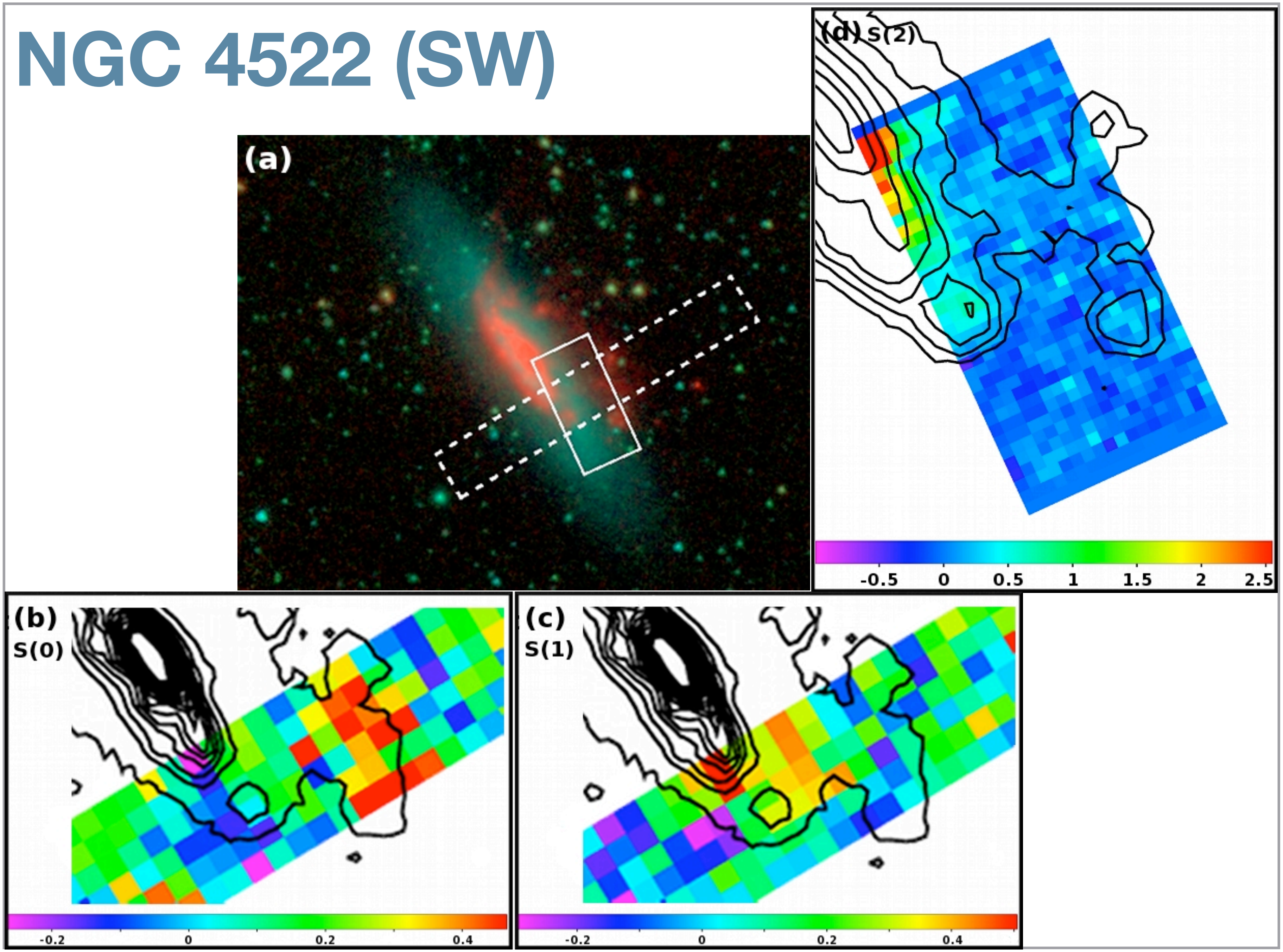
NGC 4501 (NE)



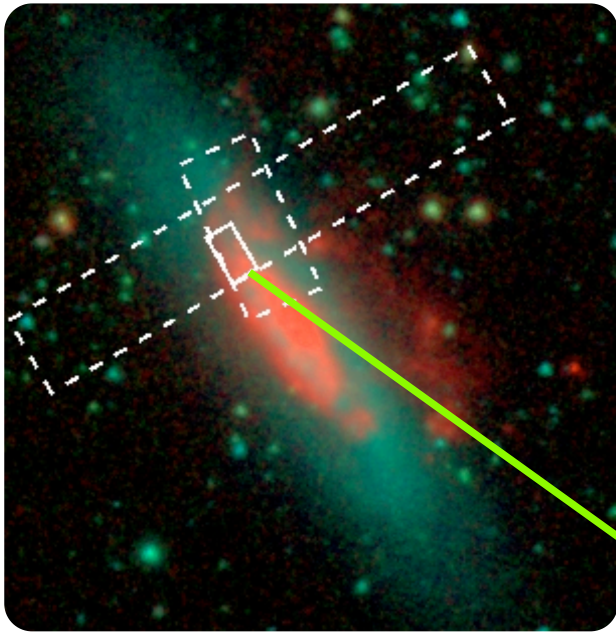
NGC 4522 (NE)

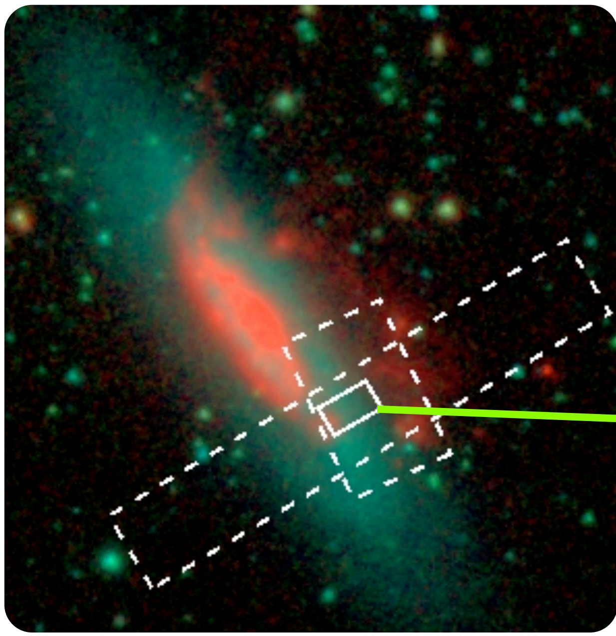


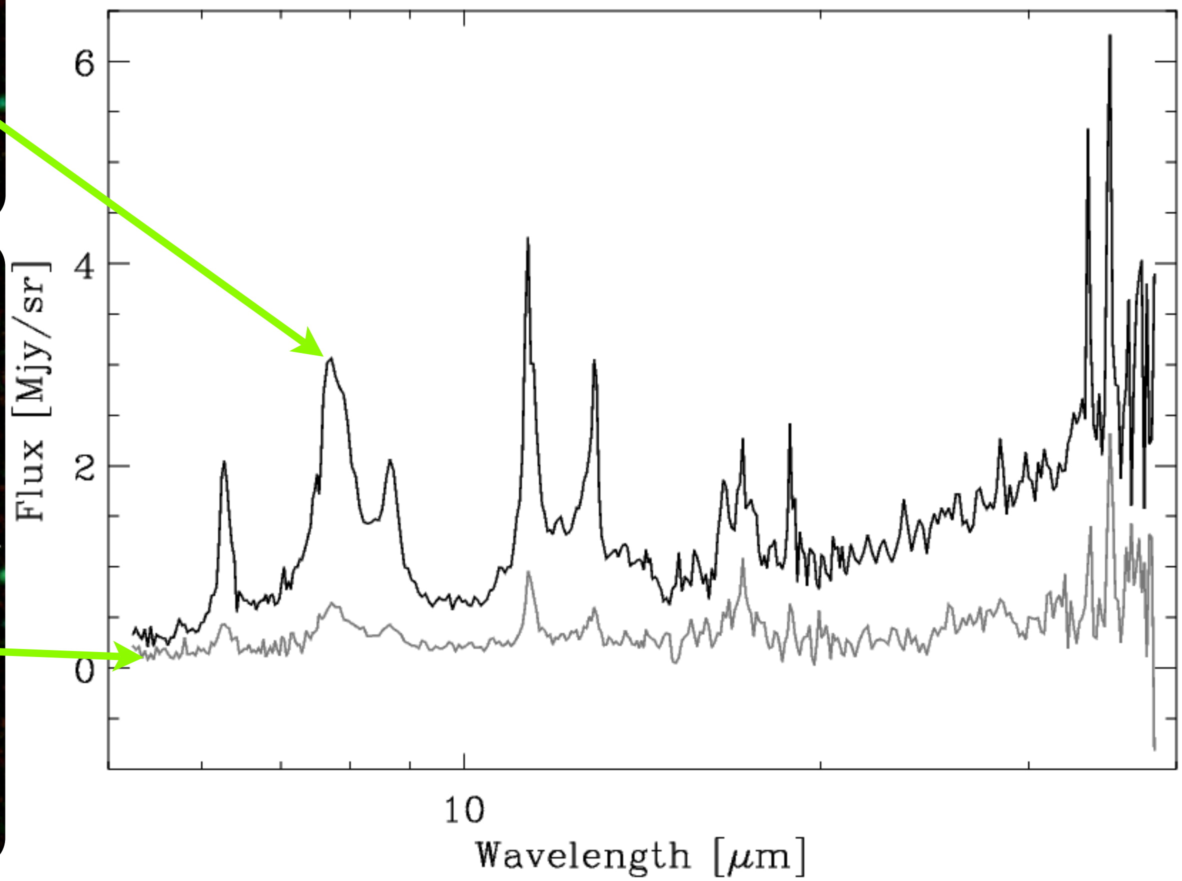
NGC 4522 (SW)



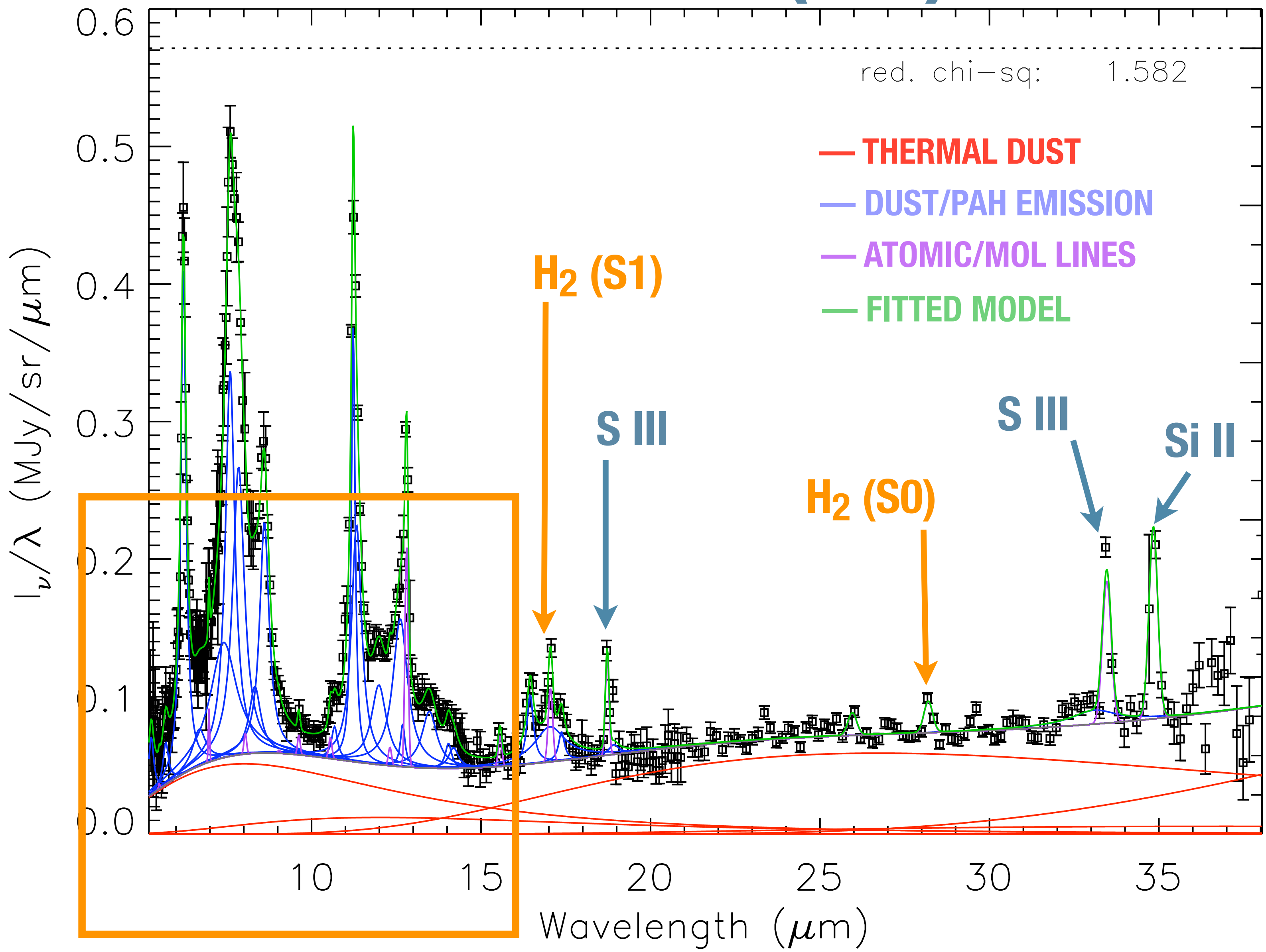
e.g. NGC 4522





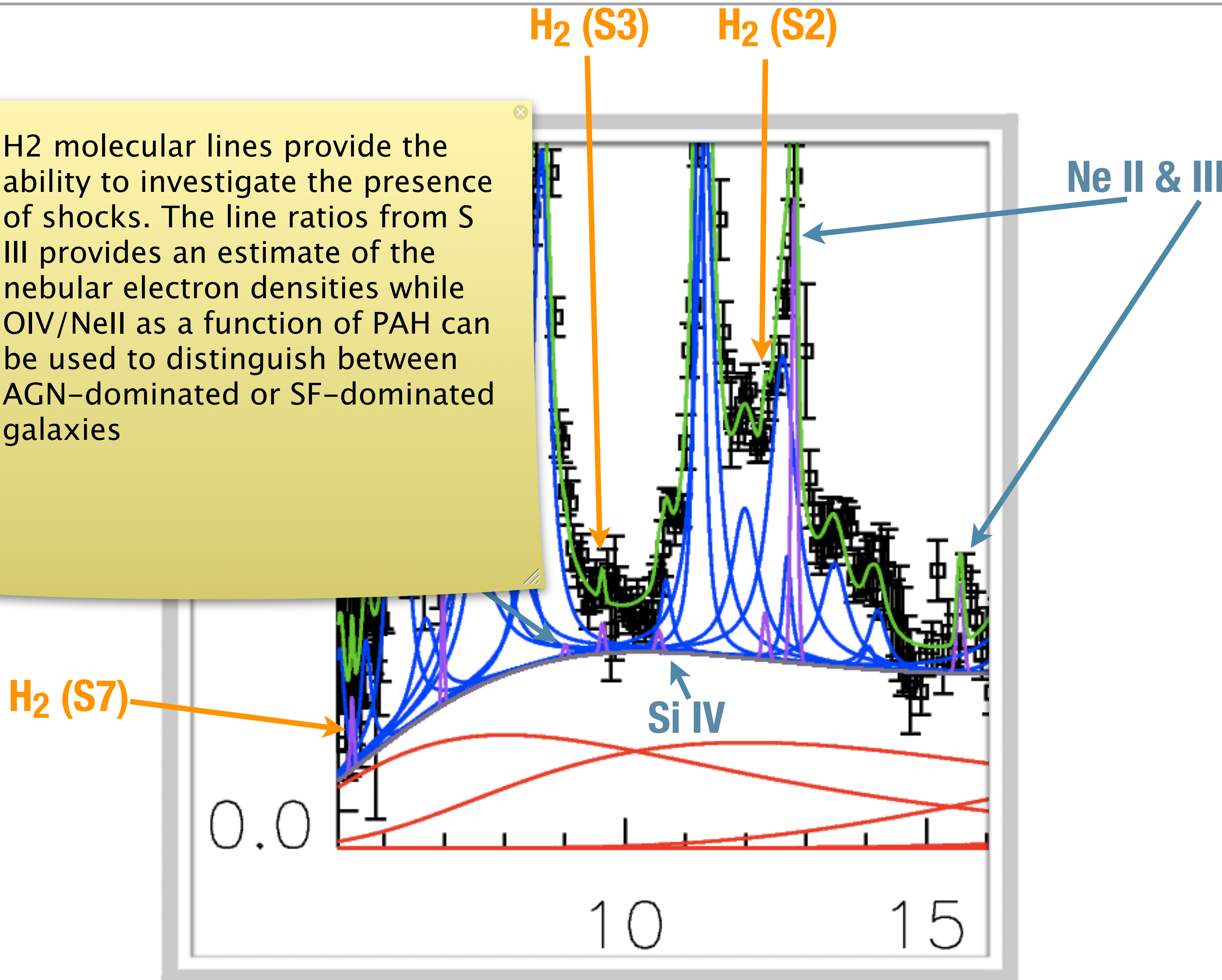


NGC 4522 (NE)



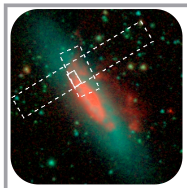
0.6
0.5
0.4
0.3
0.2
0.1
0.0
10
15
20
25
30
35
Wavelength (μm)
Iν/λ (MJy/sr/μm)
red. chi-sq: 1.582
THERMAL DUST
DUST/PAH EMISSION
ATOMIC/MOL LINES
FITTED MODEL
H2 (S1)
S III
H2 (S0)
S III
Si II

H2 molecular lines provide the ability to investigate the presence of shocks. The line ratios from S III provides an estimate of the nebular electron densities while OIV/NeII as a function of PAH can be used to distinguish between AGN-dominated or SF-dominated galaxies

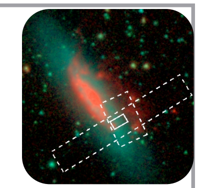


Excitation diagrams of H_2 (i)

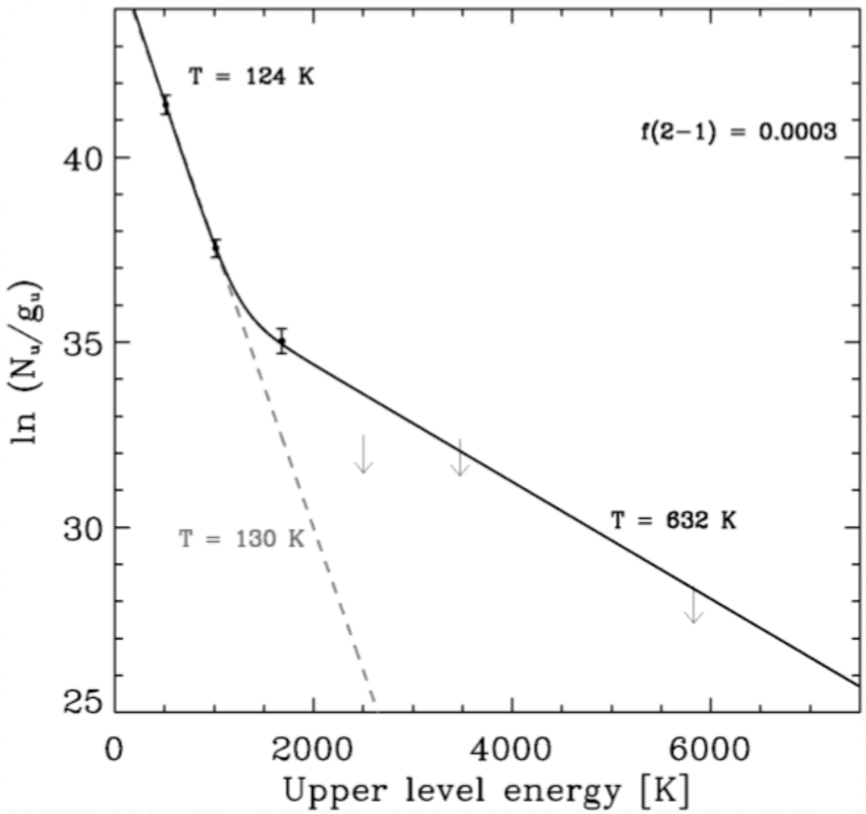
- Excitation diagrams show the weighted molecular column density (N_u/g_u) as a function of the upper level energy (E_u) of the transitions
- Used to constrain the temperatures and densities of the warm and hot H_2 components
- If our observations are in Local Thermodynamic Equilibrium (LTE) we can simply fit temperature models to get the temperatures and densities of the different T components



Excitation diagrams of H_2 (ii)

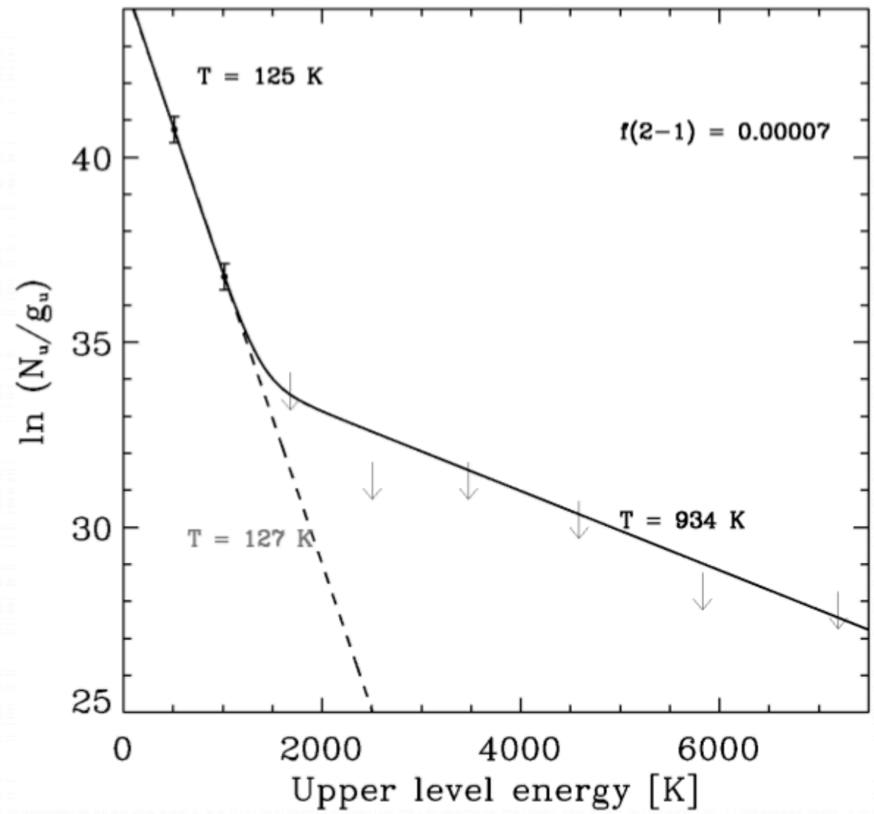


NGC 4522 (NE)



T(WARM) = 124 (+6/-5) K
T(HOT) ~ 632 (+796/-495) K
f(HOT-WARM) < 0.0003

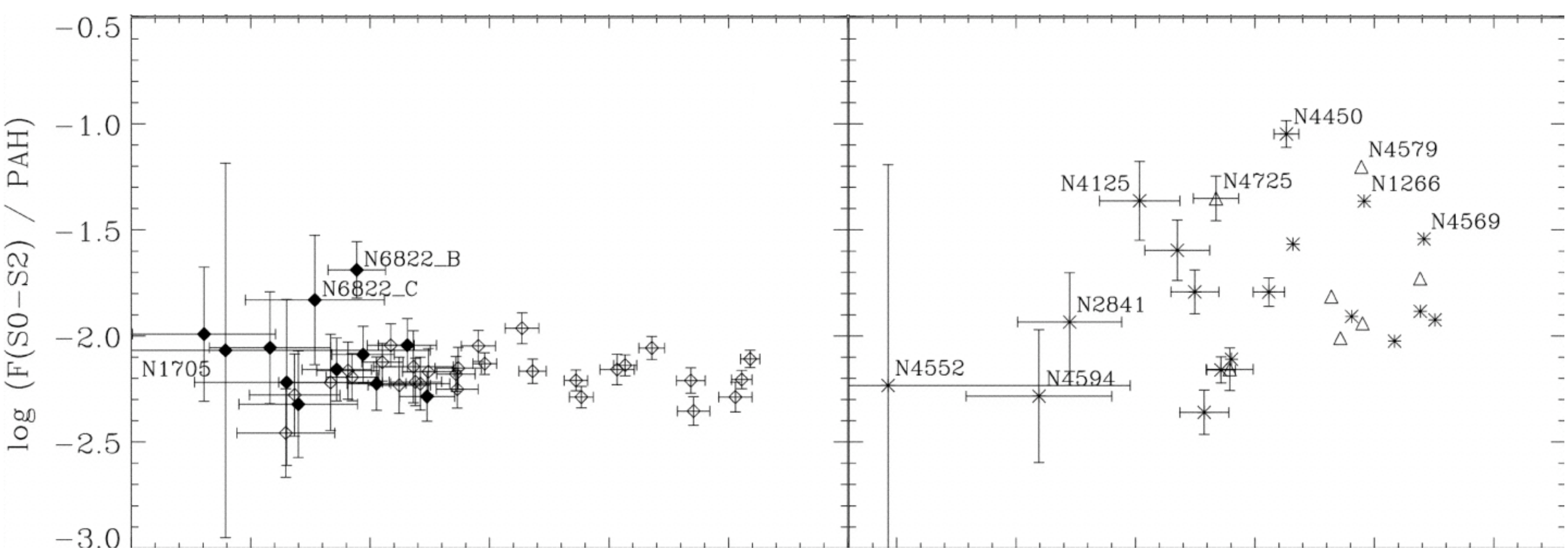
NGC 4522 (SW)



T(WARM) = 125 (+25/-16) K
T(HOT) ~ 934 (+494/-808) K
f(HOT-WARM) < 0.00007

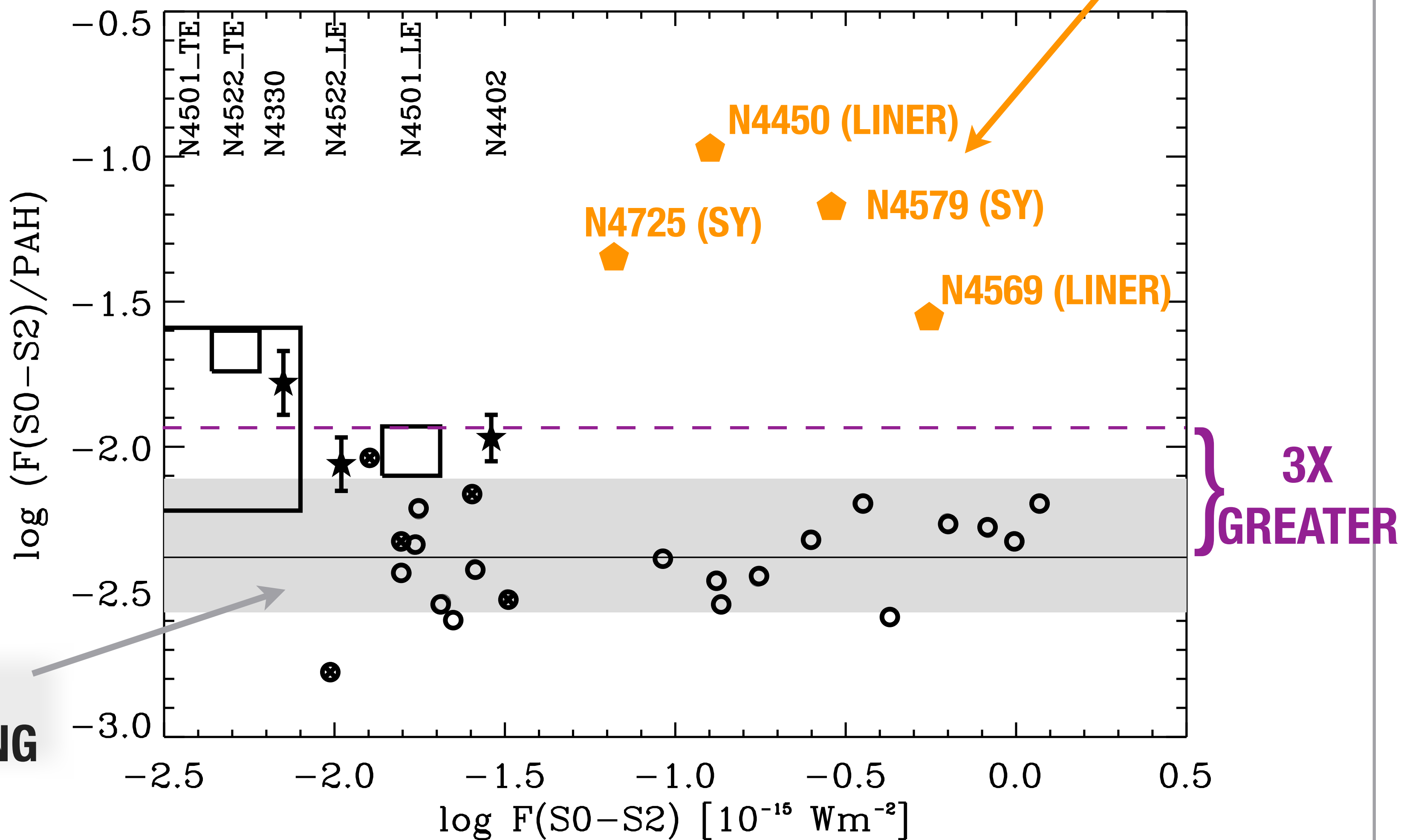
Shocks ?

- If the source of the warm MIR H_2 emission is mostly due to SF or PDR, the resulting H_2(S0+S1+S2)/PAH ratio is fairly uniform across these star-forming galaxies
- Shocks from SNe/AGN are the only reasonable explanation as collisional heating from X-rays do not provide enough energetics to produce such enhanced ratios of H_2



Warm H_2/PAH (i)

SHOCK HEATING



PDR HEATING

Warm H_2/PAH

- On average, our results appear to have H_2/PAH ratios 3 times greater than other nearby galaxies from the SINGS sample

- This suggests an enhancement of H_2/PAH possibly due to shocks triggered by interaction-induced cloud collisions (similar to shocks found in Stephan's Quintet; Appleton+2006)

Summary

- We detected warm H_2 emission in most of our regions using the IRS instrument and most of the warm H_2 emission coincide with the regions of PAH emission

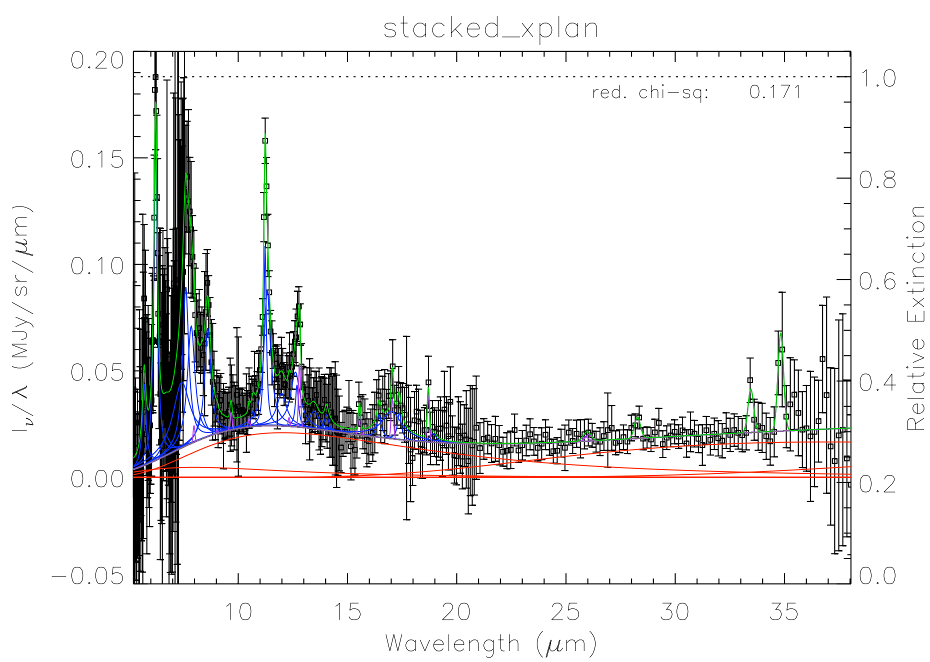
- Interesting to see that the concentration of S(0) & S(1) appears to be slightly different in N4522-SW (i.e. appear to have a larger concentration of lower energy transition further from the disk of the galaxy)

- Excitation diagrams & temperature modelling of 2 LTE regions show that a 1-temperature model is insufficient to model the warm gas within our regions and that a 2-temperature model shows that a very small fraction of the warm gas is in a much hotter phase

- Although our detections of warm H_2 emission are somewhat marginal, we see a suggestion that small amounts of shock may exist within the observed regions as shown by enhanced H_2 emission

STACKED EXTRAPLANAR REGIONS

- SF in stacked regions = SF in regions along leading edges
- Only upper limits were found for S(0), S(1), S(2) ... etc
- Stacked regions may be star-forming but our observations do not have enough S/N to detect warm H_2 transitions



NGC 4330 (ii)