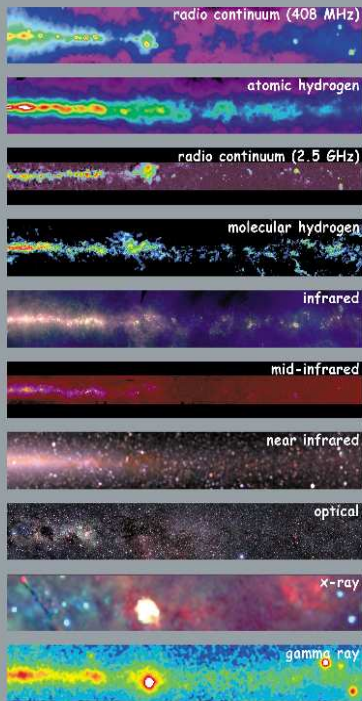


# Discovery of Carbon Radio Recombination Lines in M82

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Raymond Oonk, Francisco Salgado,  
Xander Tielens, Huub Röttgering,  
Carmen Toribio

April 8, 2014



# Overview

- Introduction to M82
- Recombination lines & Models
- Observations & Data Reduction
- Processing the spectra
- Cross-Correlation
- Preliminary Results
- Conclusions & Future Work

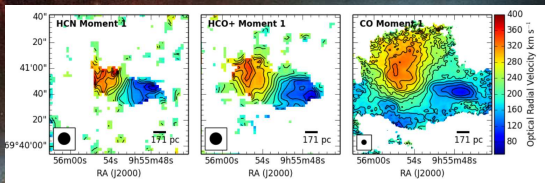
# Introduction to M82

- Nuclear starburst galaxy
- 3.6 Mpc distant
- Interacting with M81
- Filamentary streamers

Image credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

# Introduction to M82

Dense gas tracing SF  
Rotating Torus



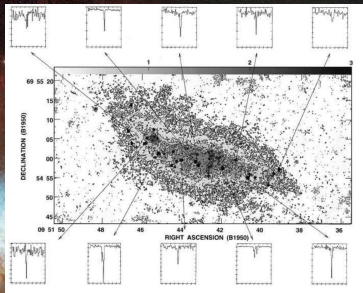
*Kepley et al. (2014)*

Image credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

# Introduction to M82

Dense gas tracing SF  
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Neutral Hydrogen  
Variable  $N_H$  across region



*Wills, Pedlar, & Muxlow (1998)*

Image credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

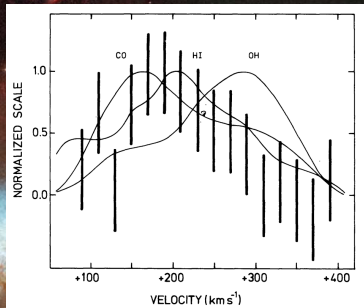
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Ionized Hydrogen (H166 $\alpha$ )  
HII regions

Stimulated by non-thermal  
background



*Shaver, Churchwell, & Rots (1977)*

Image credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

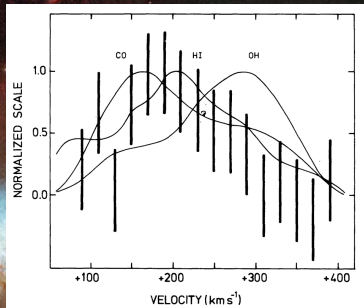
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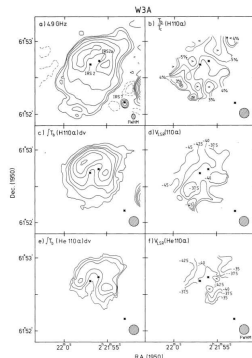
*Shaver, Churchwell, & Rots (1977)*

**What about cold, diffuse gas?**

# Radio Recombination Lines

## Classical RRLs (>1 GHz)

- H II Regions
- Extragalactic detections



*e.g., Roelfsema & Goss (1991)*



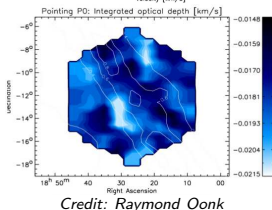
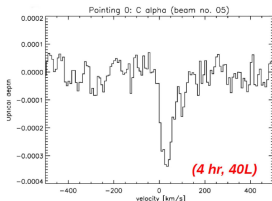
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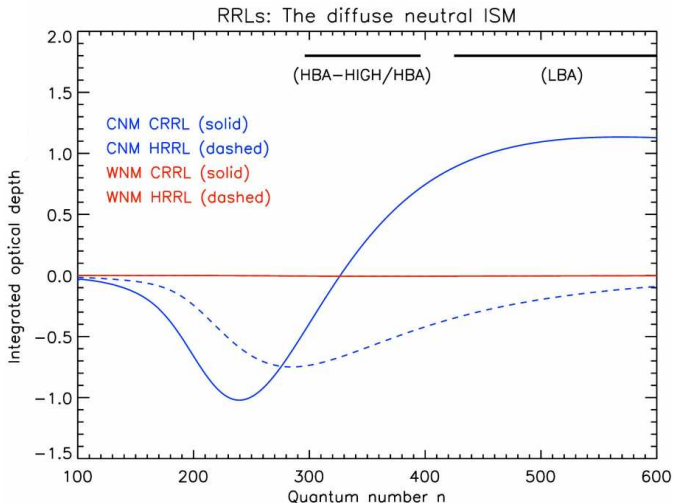
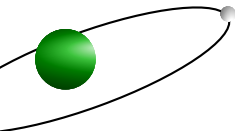
## Diffuse RRLs ( $<1$ GHz)

- Low ionization, C only
- Cold neutral medium (CNM)
  - $T_e \sim 10 - 300$  K
  - $n_e \sim 0.01 - 1.0 \text{ cm}^{-3}$
- No previous extragalactic detections!
- **This is what we want to probe in M82**

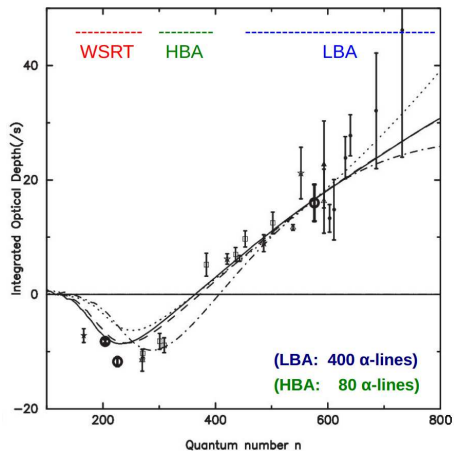


# Carbon Radio Recombination Lines

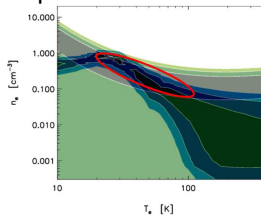
- Hydrogenic recombining C II
- Dielectronic-like processes



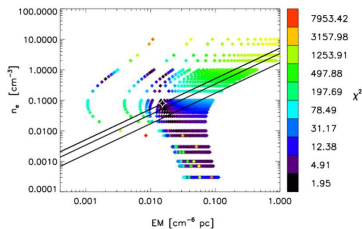
# Using the Models



## Temperature and Density



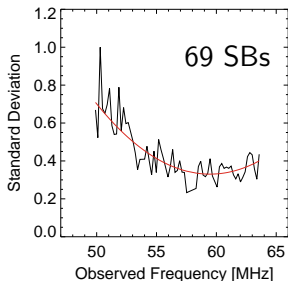
## C/H Ratio, column density



# Observations & Data Reduction

Project ID	LC0_043
Data ID	L96650
RA (J2000)	09h55m52.7s
DEC (J2000)	+69d40m46s
Observing date	2013 Feb 21
On-source time	5.0 h
Frequency range	30-78 MHz
No. SB	244
SB width	0.1953 MHz
Channels per SB	128
Velocity res.	6-16 km s <sup>-1</sup>
Simultaneous Cal.	3C196

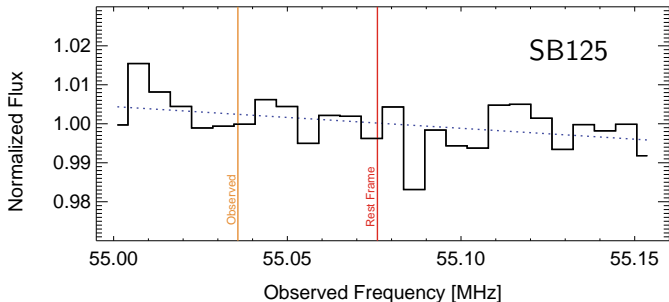
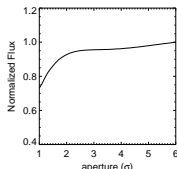
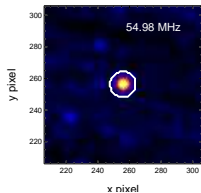
- Obs. processing for 3C196
- Solutions applied to M82
- Averaged to 32 ch/SB, 6 sec
- Channel images (AWimager)
  - convolved to 400x400 arcsec<sup>2</sup>



# Processing the Spectra

Each Subband is:

- Fitted with a Gaussian to M82
- Spatially integrated spectra extracted
- Checked for excess noise
- Visually inspected for lines



# Processing the Spectra

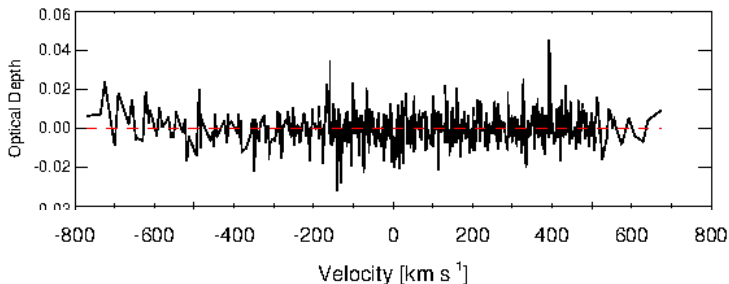
Each Subband is:

- Searched for  $\alpha$ -transitions  $\rightarrow$  22 Subbands
- Fitted with low-order polynomial  
(edges clipped,  $\pm 50 \text{ km s}^{-1}$  around line blanked)
- Transformed to velocity space (optical velocity)
- “Stacked” with other subbands

# Processing the Spectra

Each Subband is:

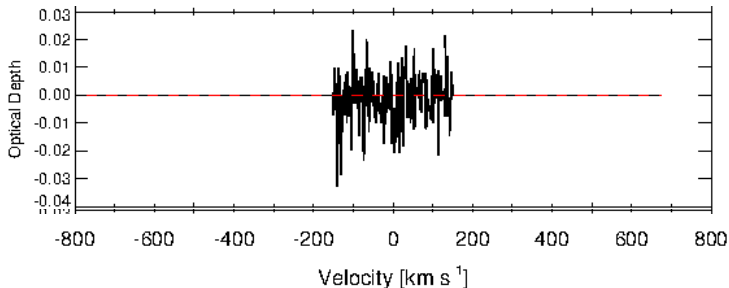
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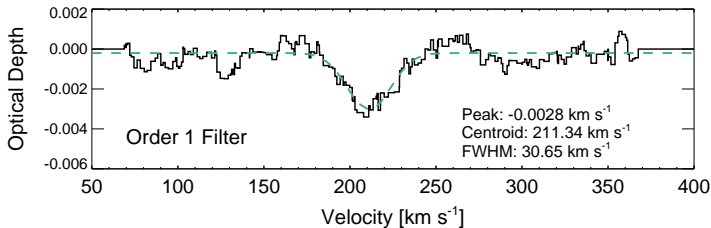
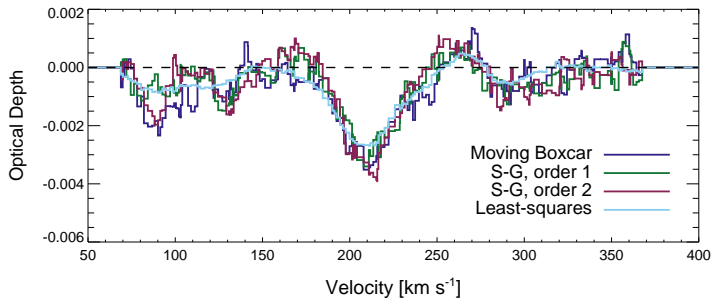
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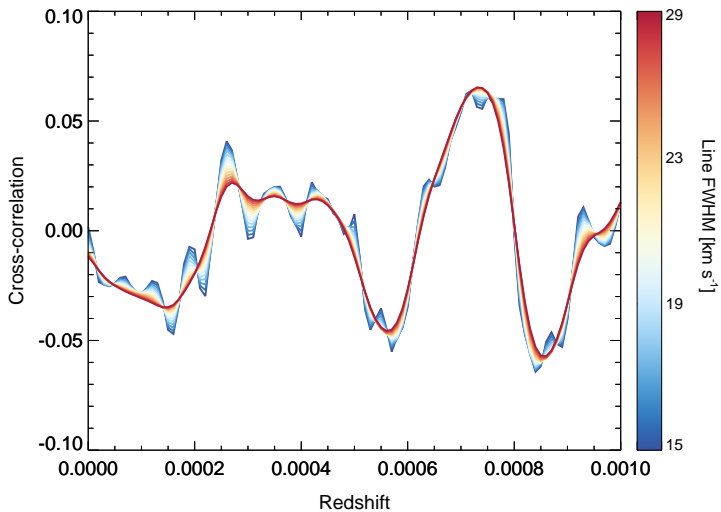




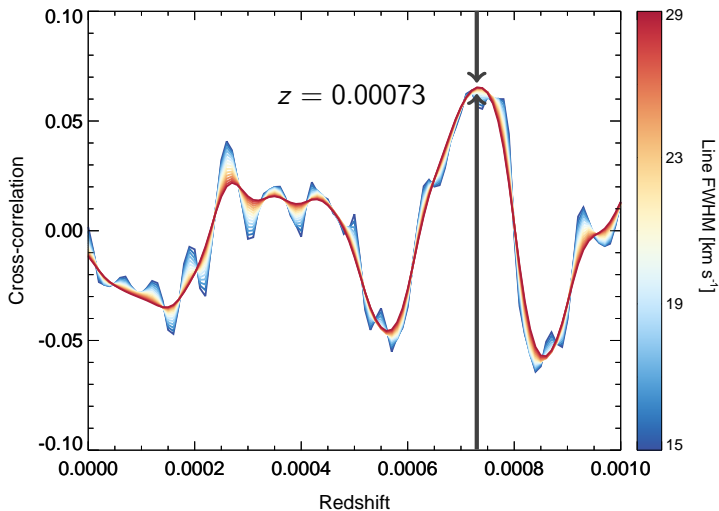
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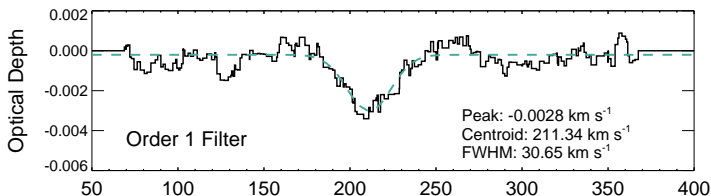
# Cross-Correlation



# Cross-Correlation



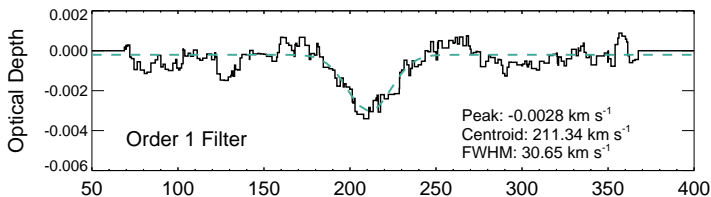
# Preliminary Results



What about ... ?

- 'Jack-knife' stacks show not dominated by one subband
- Random stacking shows no evidence of feature
- Sky background stack shows no evidence of feature
- Different noise filtering / smoothing methods all produce similar feature

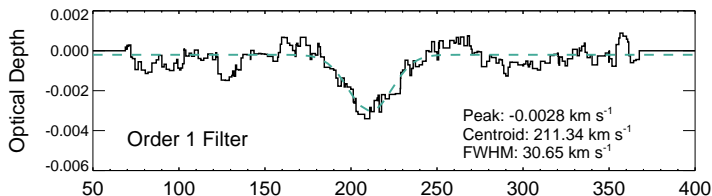
# Preliminary Results



Be careful!

- Sampling of individual line profiles makes recovery of peak unlikely
- Filtering to reduce the noise likely impacts line profile
- Continuum can be tricky to fit

# Preliminary Results

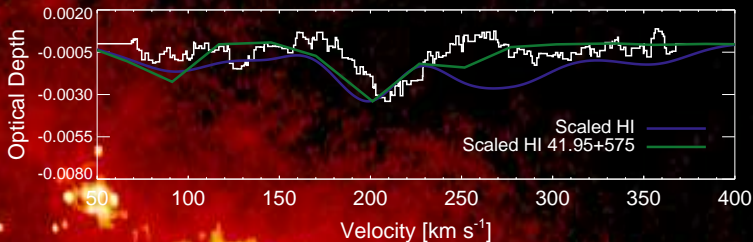


Be careful!

- Sampling of individual line profiles makes recovery of peak unlikely
- Filtering to reduce the noise likely impacts line profile
- Continuum can be tricky to fit

CONCLUSION: CRRL feature is present and detected, but line profile reconstruction with noisy data likely impacts measured parameters

# Preliminary Results



HI absorption features in direction of SNR  
*MERLIN*; Wills, Pedlar & Muxlow, 1998, *MNRAS*

SNR 41.95+575

*MERLIN + VLA L-band image: Muxlow, Pedlar, Sanders*

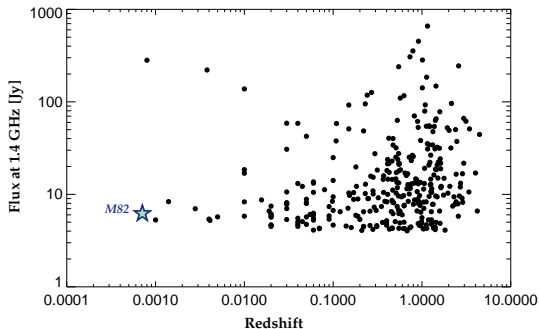
# Conclusions & Future Work

- First detection of CRRLs in extragalactic source!



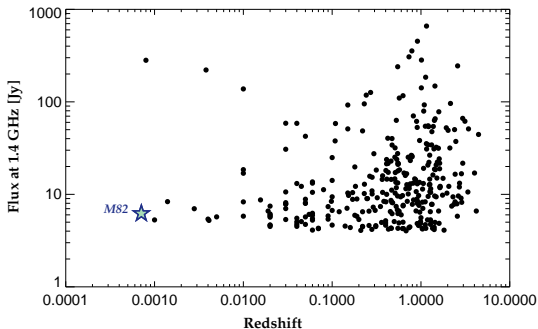
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# Conclusions & Future Work

- First detection of CRRLs in extragalactic source!



- Survey of CRRLs in other extragalactic sources
- Analysis of HBA observations (Carmen Toribio)