High Resolution Mapping of the Narrow Spectral Lines in IRC+10216

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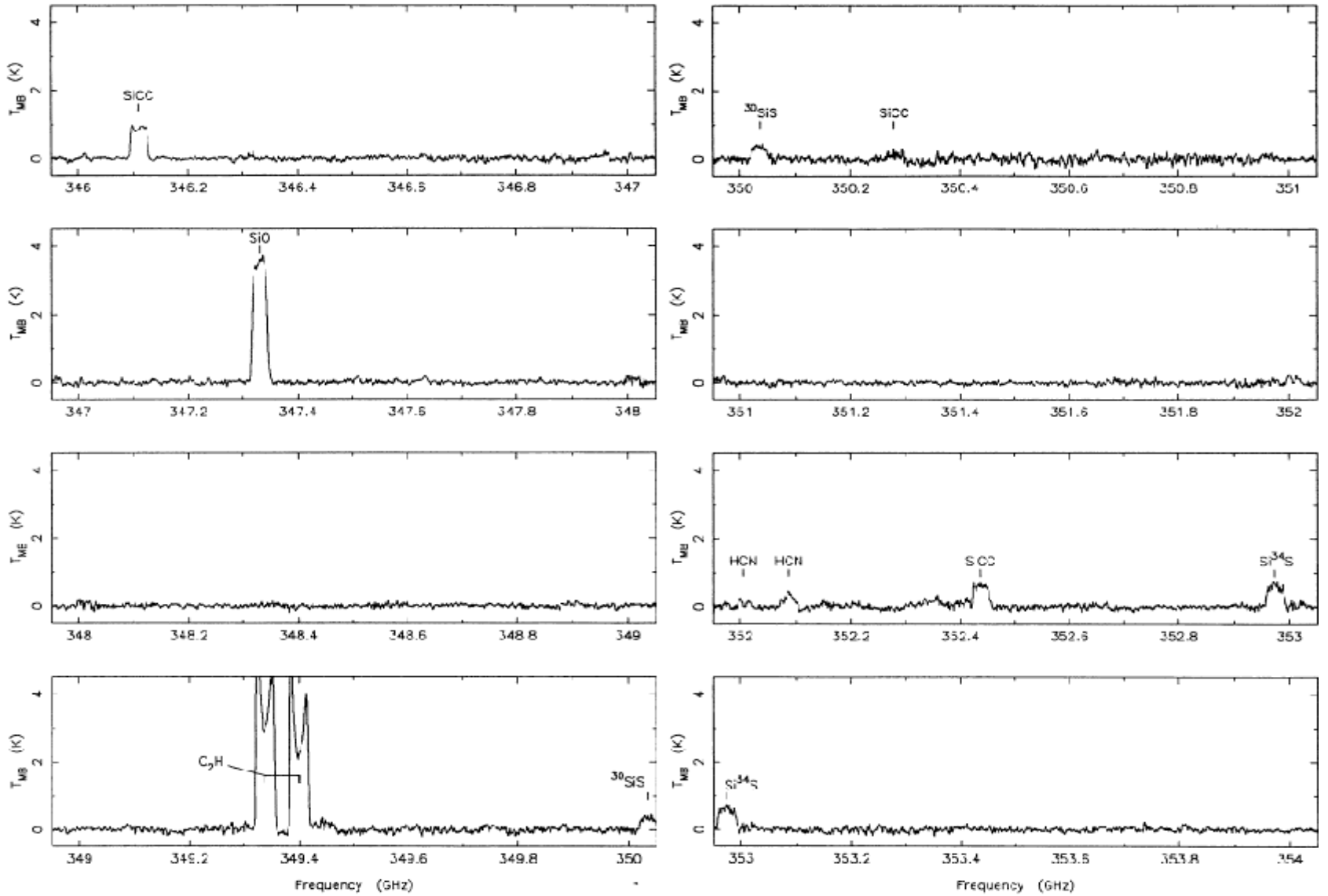
- **JCMT:** Rimo Tilanus
- **CSO:** Hiroko Shinaga, Richard Chamberlin

Spectral Line Surveys of IRC+10216 usually show a very consistent line width of ~ 30 km/sec



Groesbeck *et al*. 1994, ApJS, **94**, 147 (CSO)

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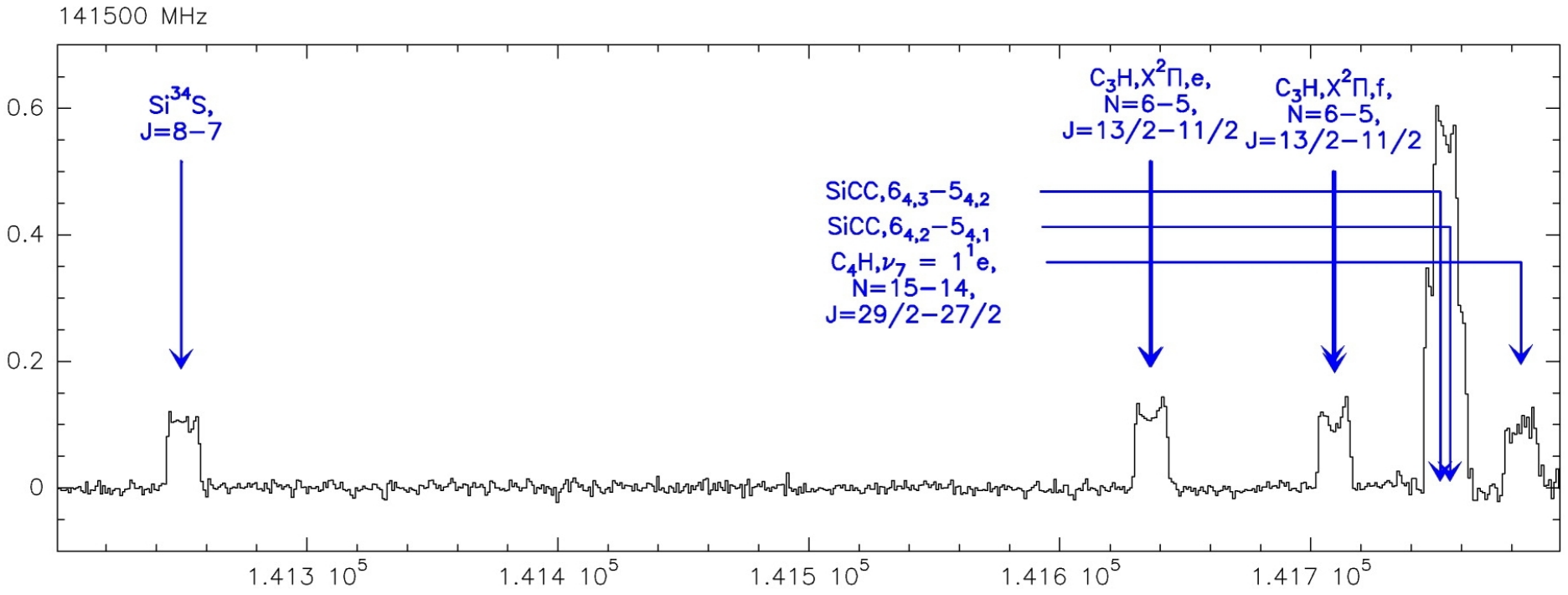
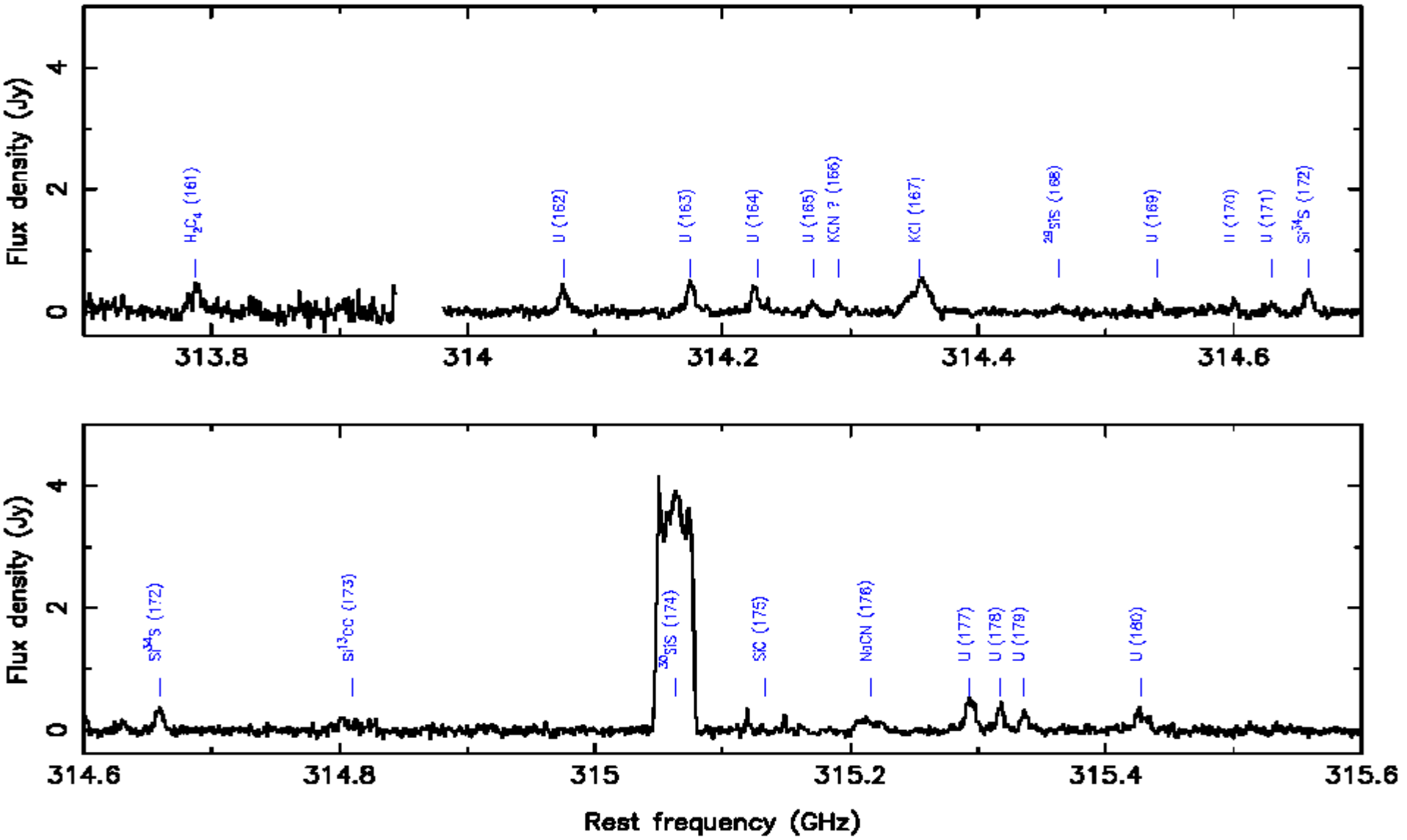


He *et al.* 2008 ApJS **177**, 275

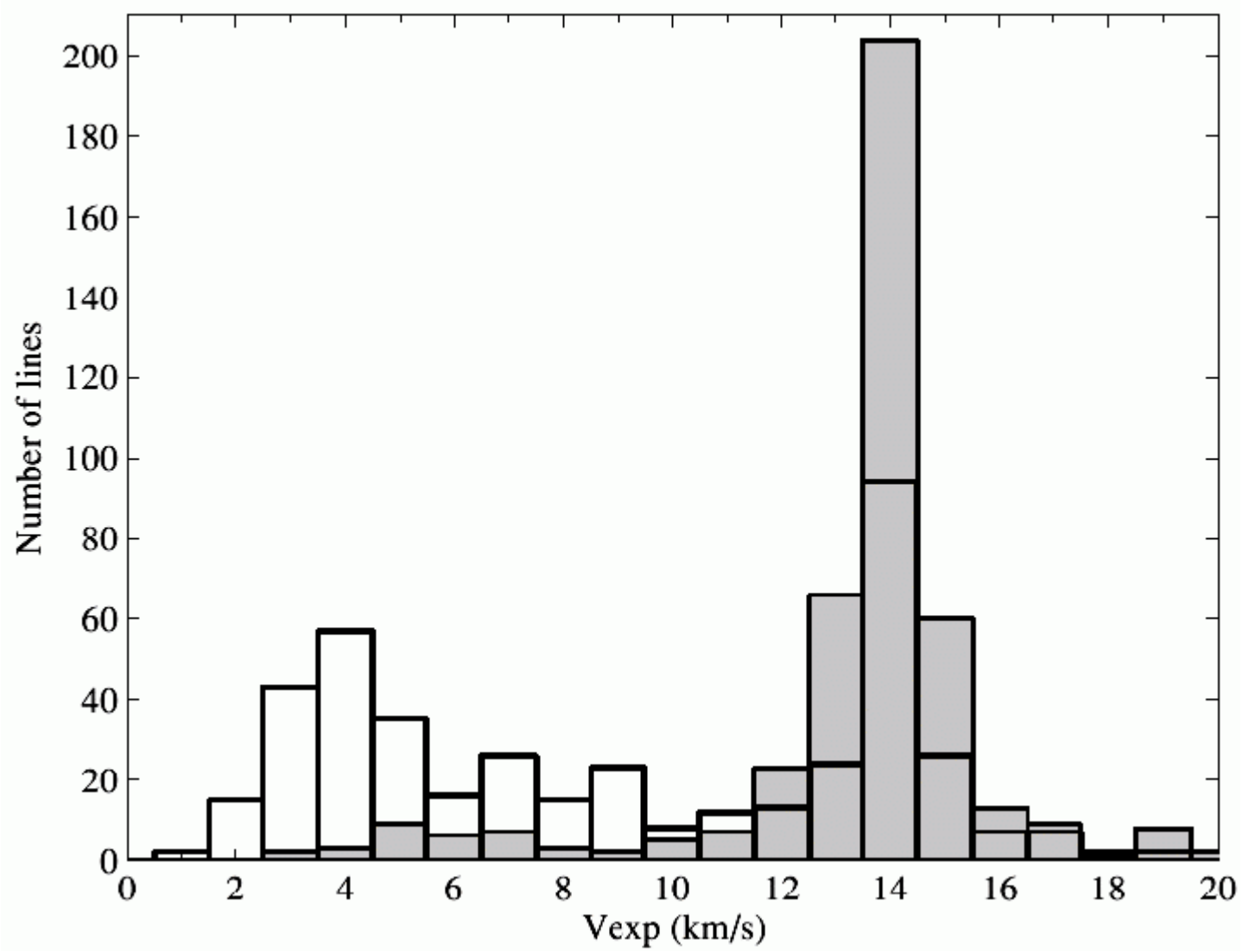
(12m and SMT)

The 2009 Patel Survey showed many much more narrow lines

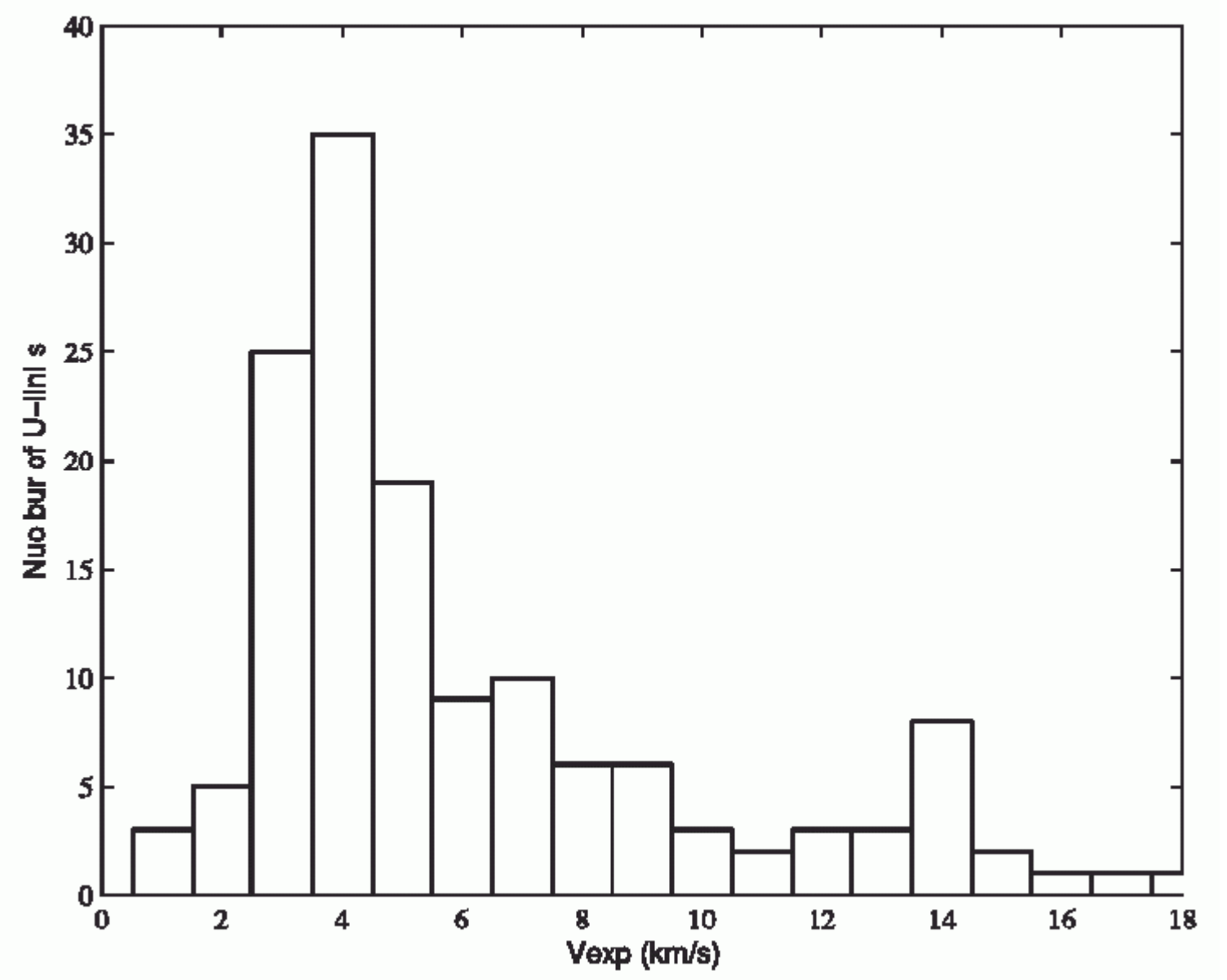


Patel *et al.* 2011, ApJS, **192**, 17 (SMA)

The narrow lines form a distinct set, with fulls widths of ~8 km/sec

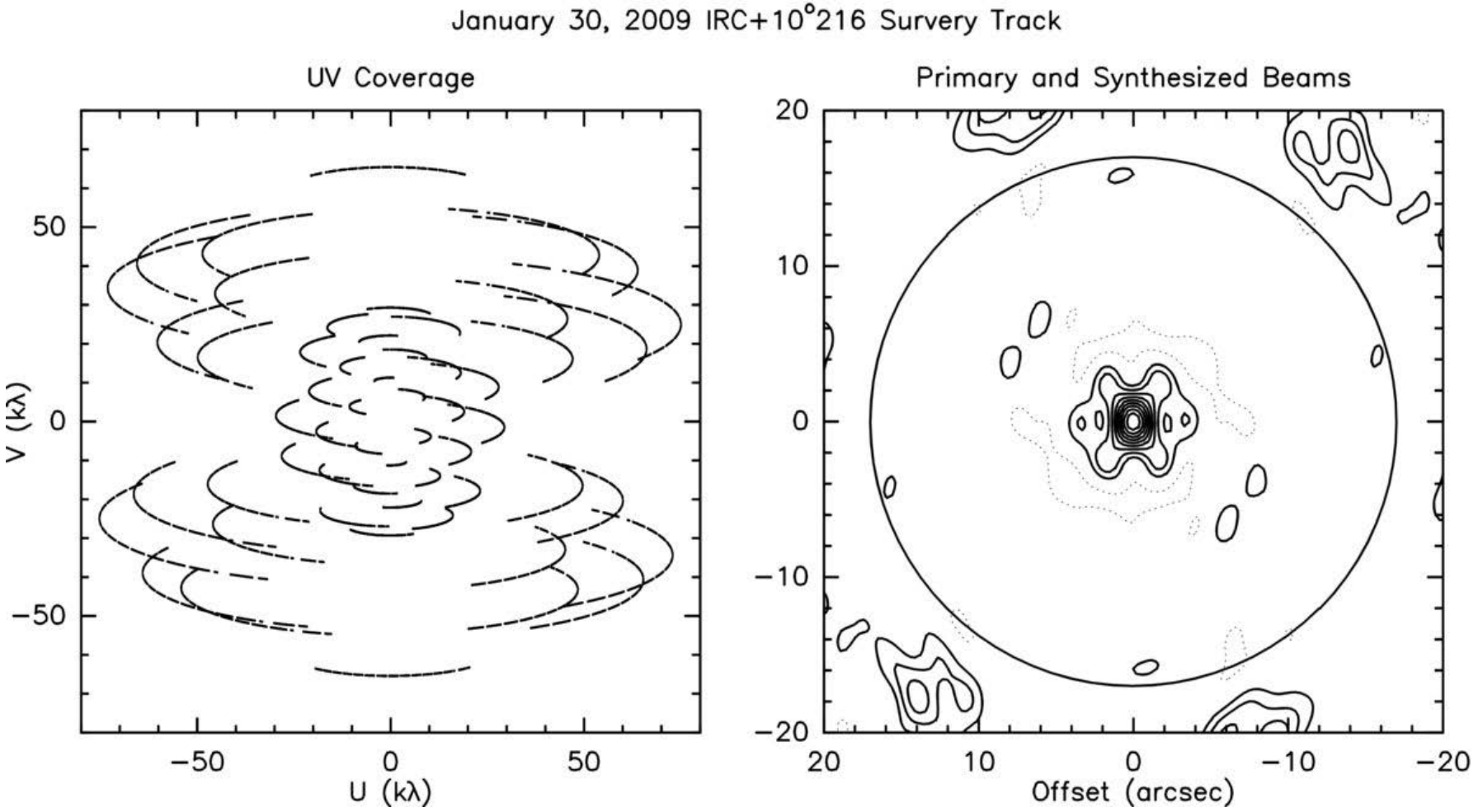


A very large fraction of the “U Lines” are narrow



The Patel Survey used the SMA “Subcompact” configuration

The Patel Survey had a synthesized beam about 3” in diameter

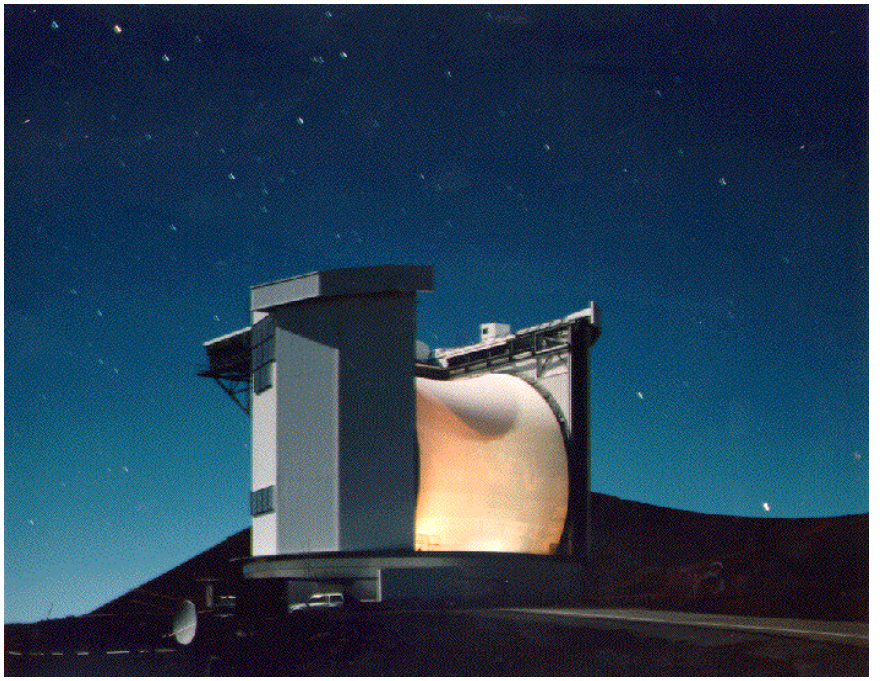


Why do a higher resolution follow-up?

- The narrow lines have triangular profiles, indicating acceleration (Bujarrabal *et al*. 1986).
- Many of the narrow lines arise from high energy, vibrationally excited transitions.
- The Patel Survey did not resolve the narrow lines.
- Stellar photosphere has a radius of ~40 mas, acceleration may take place at several stellar radii.
- Modeling infrared C_2H_2 and HCN spectra gives a radius of 400 mas for the outer dust formation zone (Fonfría et al. 2008).
- mm/submm interferometers now can achieve resolutions of a few hundred mas. They might be able to see the acceleration taking place.
- IRC+10216 lacks SiO, H_2O, OH masers to probe the innermost envelope.

The SMA has friendly neighbors who can improve our resolution

CSO (10.4 meter)

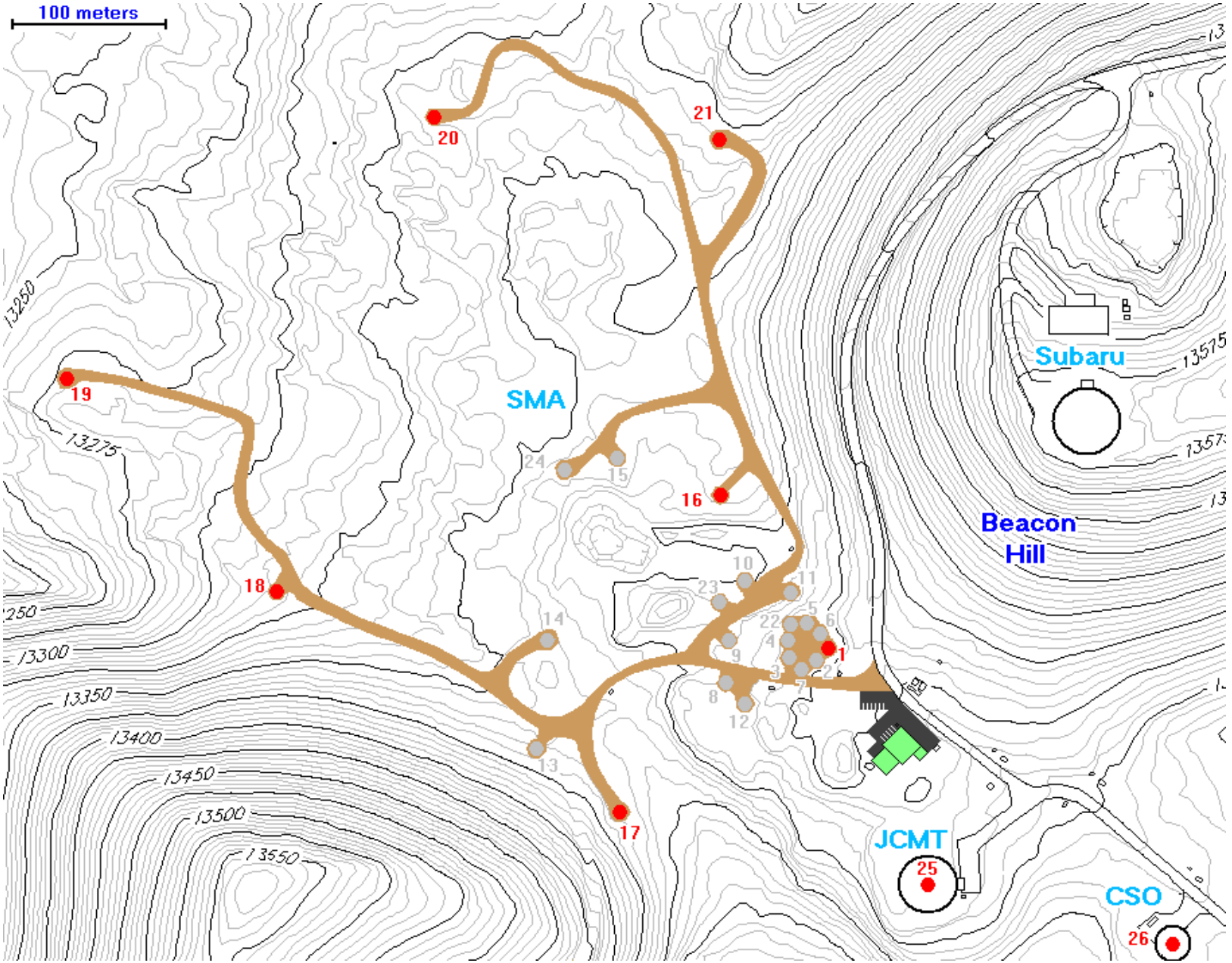


JCMT (15 meter)

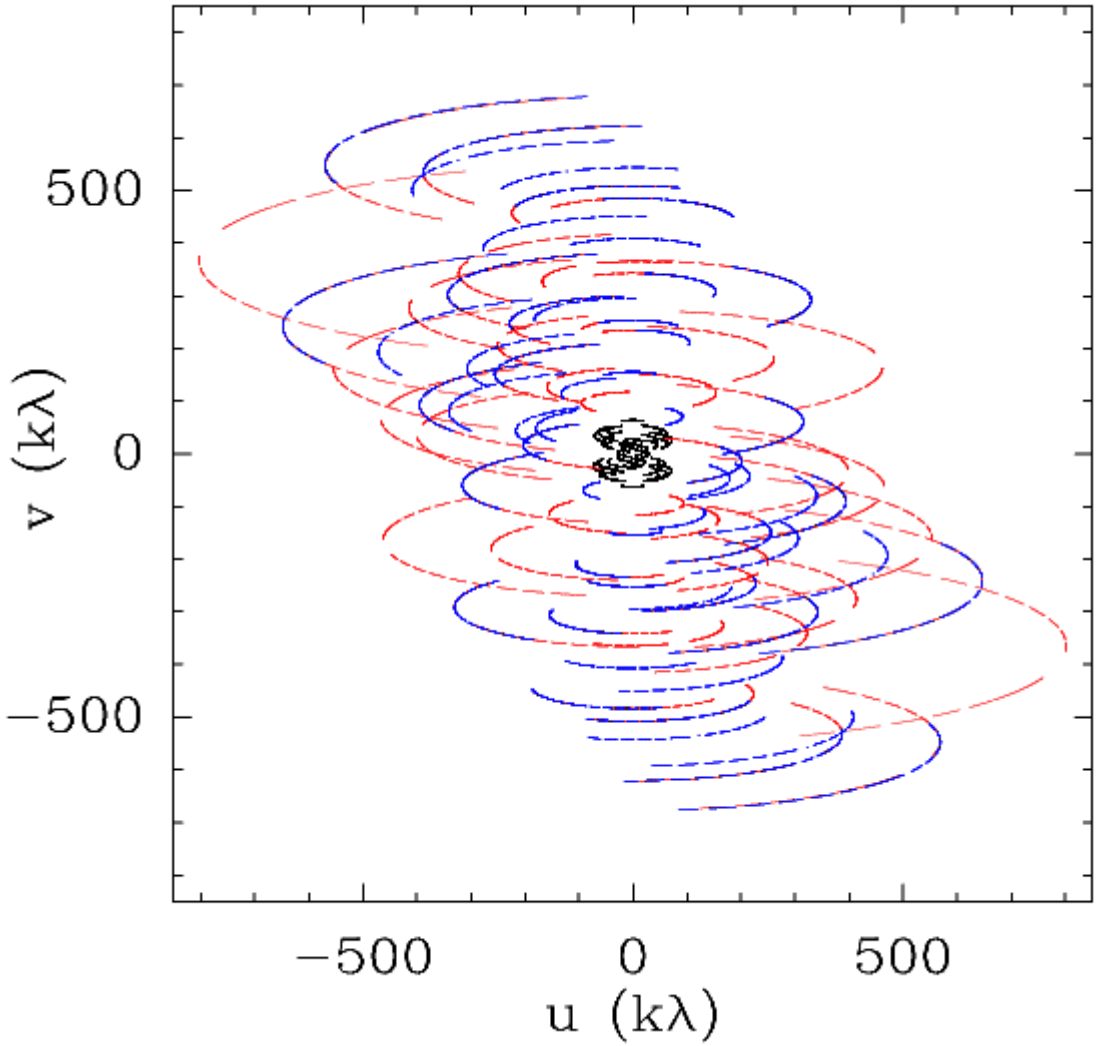
The SMA+JCMT+CSO forms the eSMA

Connecting infrastructure can enable eSMA and EHT

The SMA+JCMT+CSO forms the eSMA



The SMA+JCMT+CSO forms the eSMA



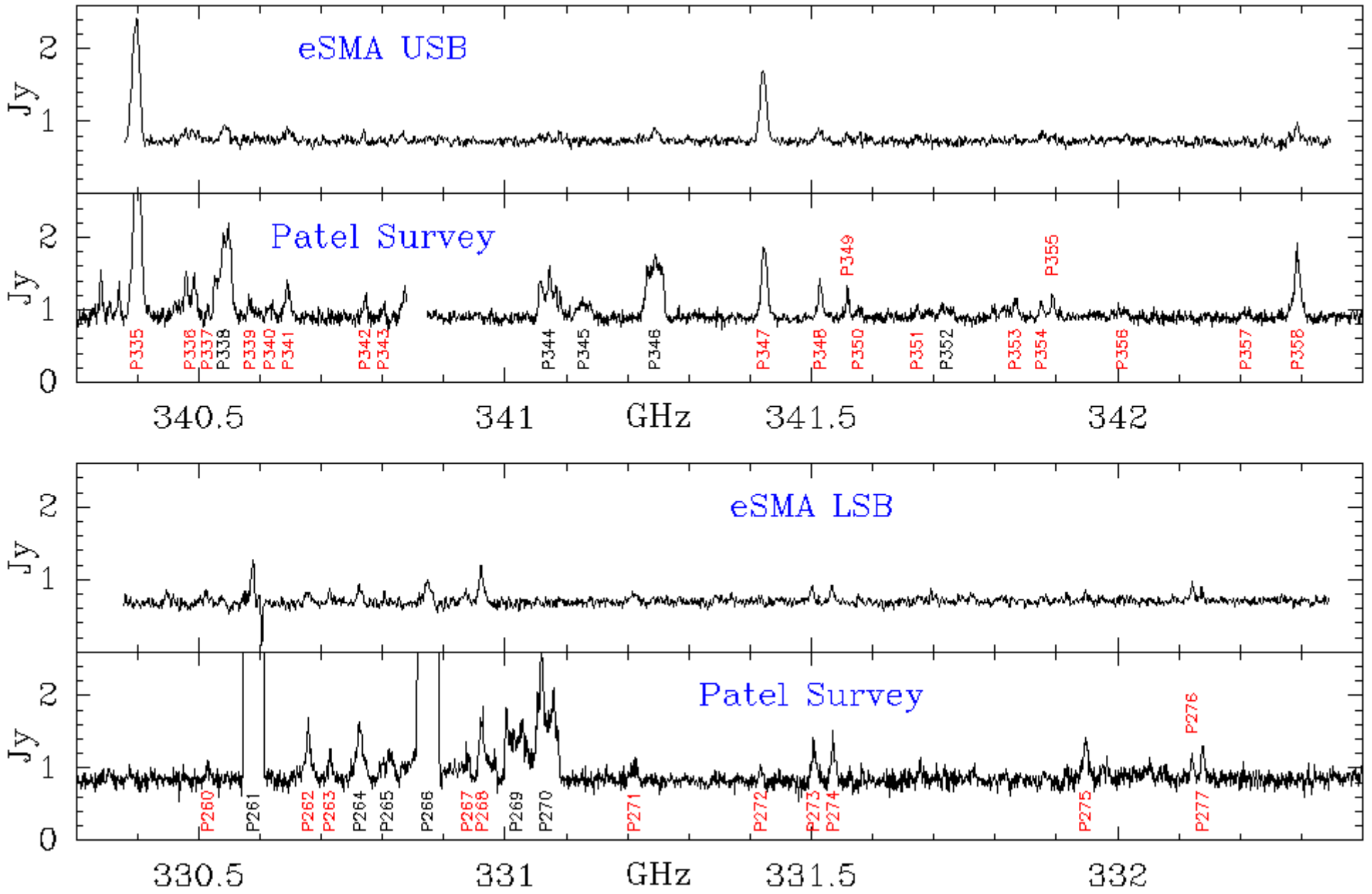
eSMA Narrow Line Observations

- Covered 330.392 $\rightarrow$ 332.360 GHz (LSB)
  340.392 $\rightarrow$ 343.360 GHz (USB)
- 31 narrow lines (V_{exp} < 10 km/sec) from Patel Survey covered
- Observed twice, 04/01/2010 and 01/16/2011
- Obtained a matching CSO single dish spectrum

eSMA Results

- Detected on baselines up to 890 kλ
- Continuum flux matches what was seen in Patel Survey
- 10 of the 31 narrow lines were not detected in the eSMA dataset alone
- Almost all the spectral lines, including the narrow lines, appear to have been resolved by the eSMA
- The eSMA and Patel Survey data sets were combined to produce maps, giving roughly 20 hours of on-source time.

The Patel Survey and eSMA spectra look very different



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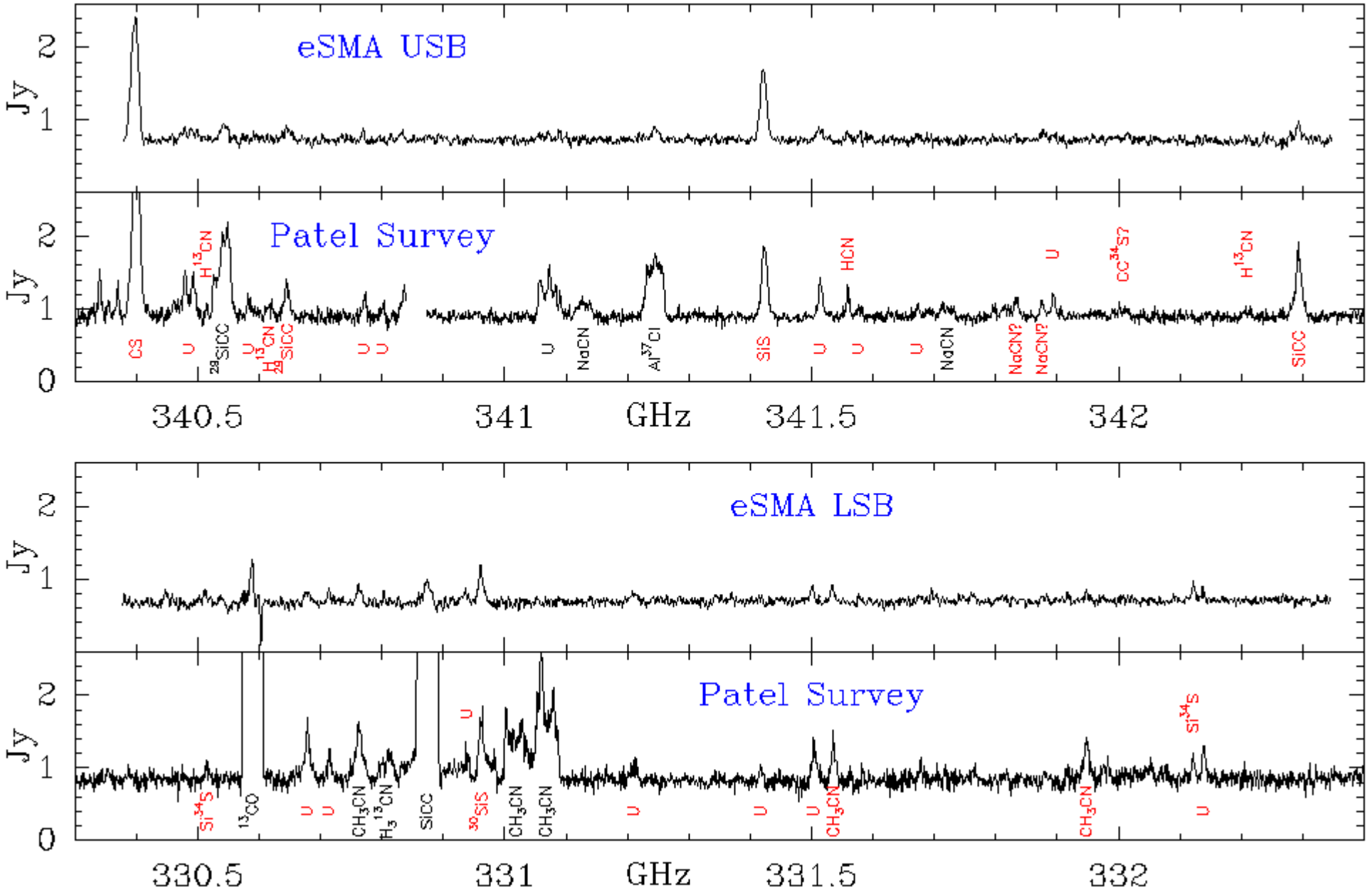
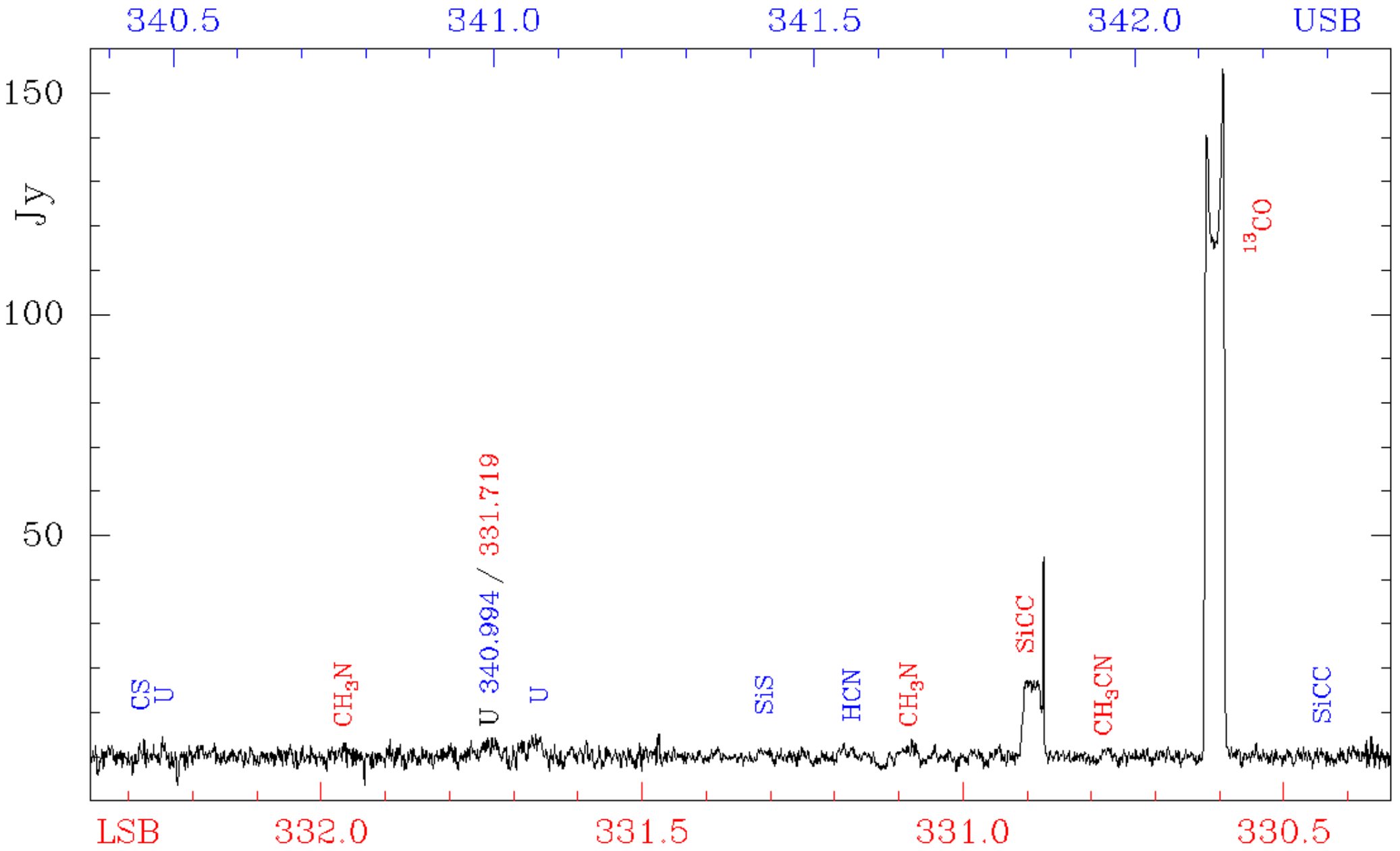
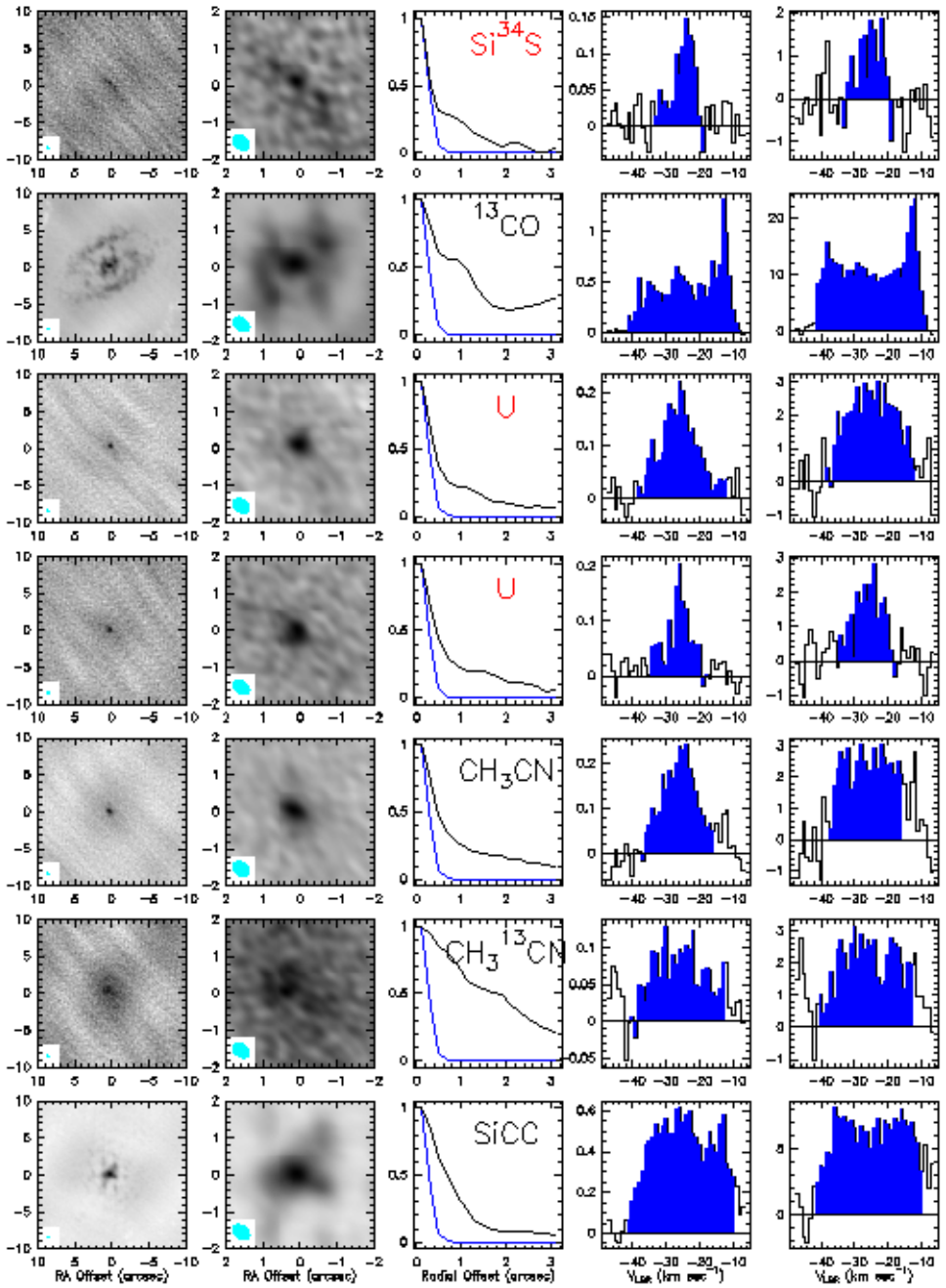
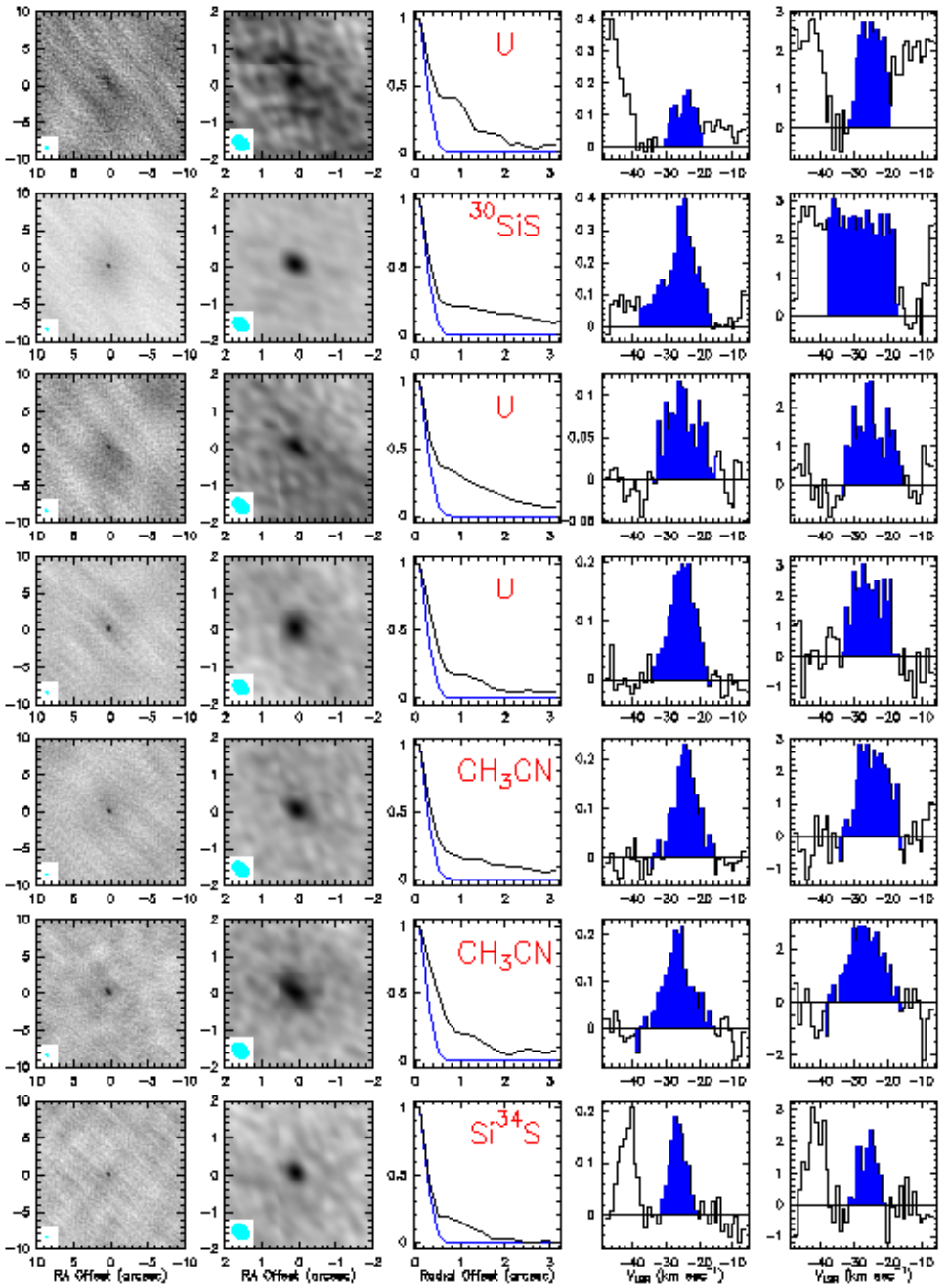
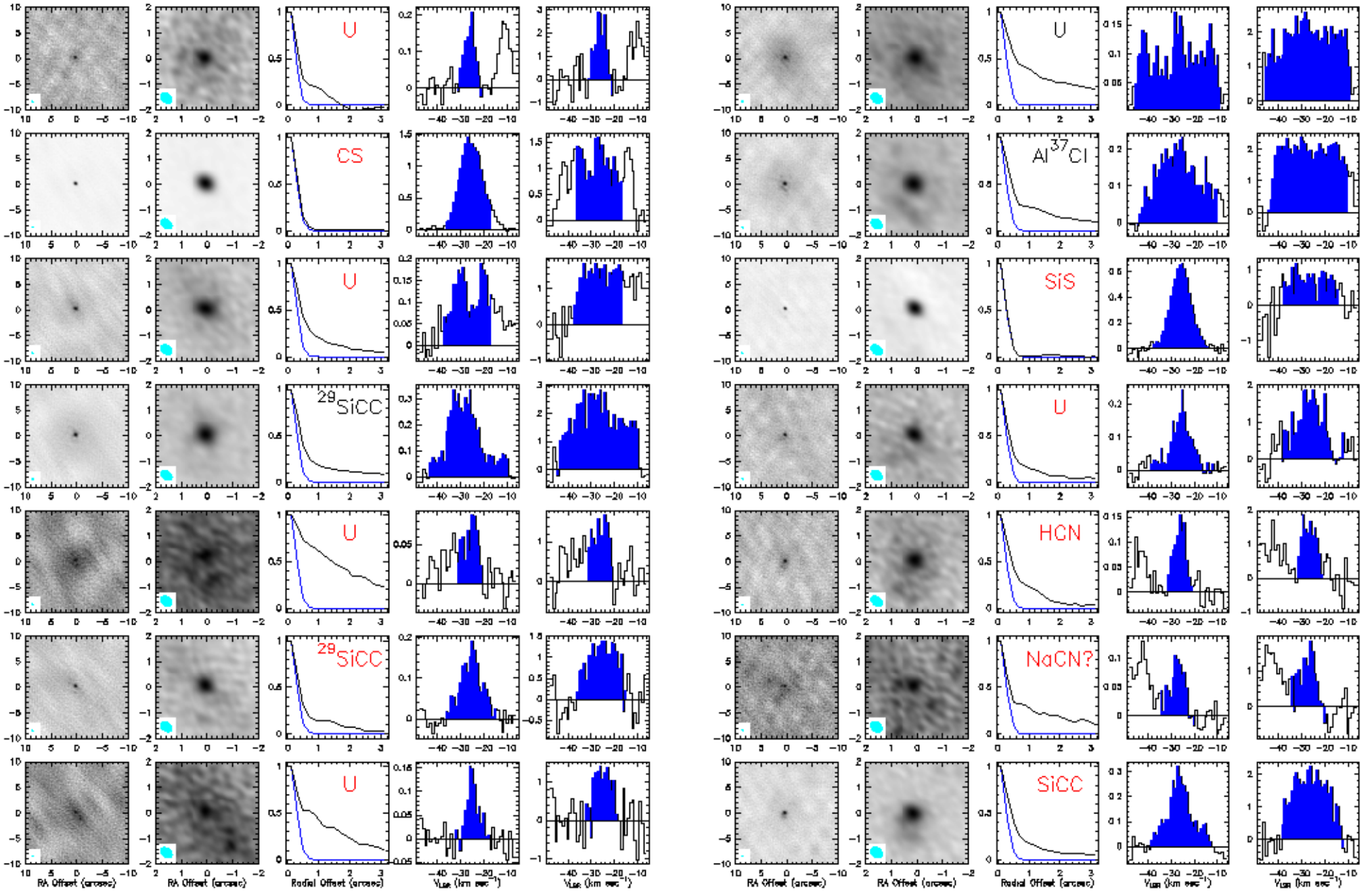


We obtained a CSO spectrum of the same frequency interval

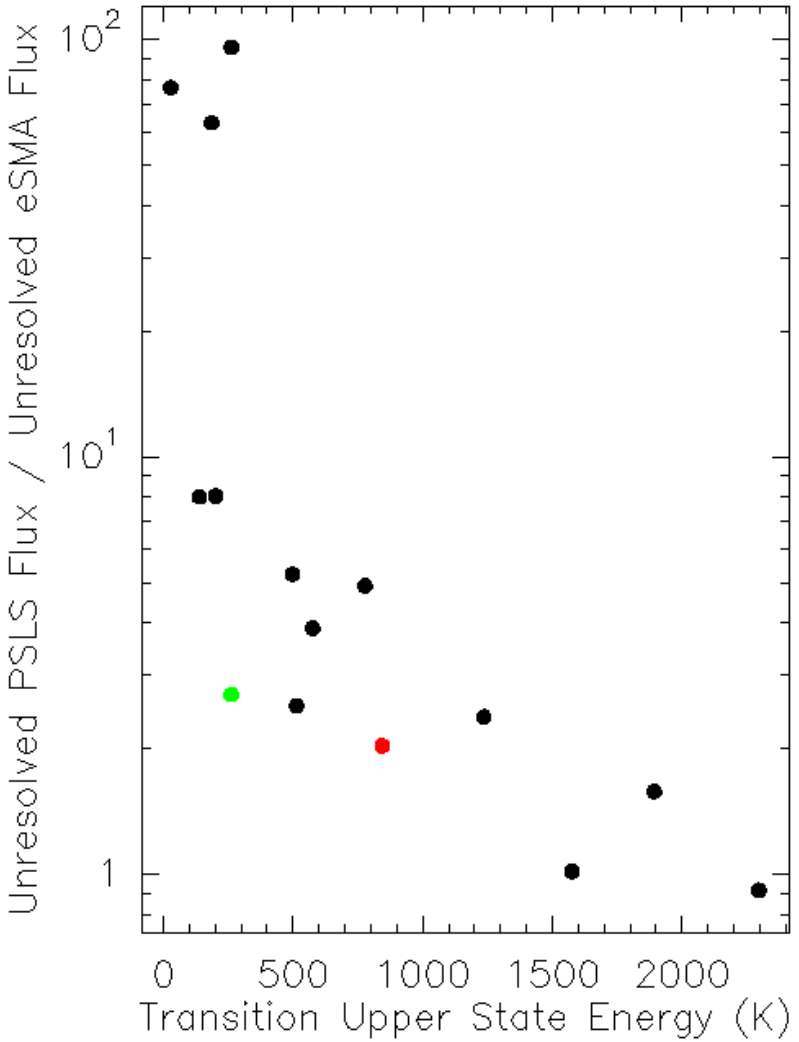



Si34S
13CO
U
U
CH3CN
CH313CN
SiCC
RA Offset (arcsec)
RA Offset (arcsec)
Radial Offset (arcsec)
VLSR (km sec-1)
VLSR (km sec-1)


U
30SiS
U
U
CH3CN
CH3CN
Si34S
RA Offset (arcsec)
RA Offset (arcsec)
Radial Offset (arcsec)
VLSR (km sec-1)
VLSR (km sec-1)

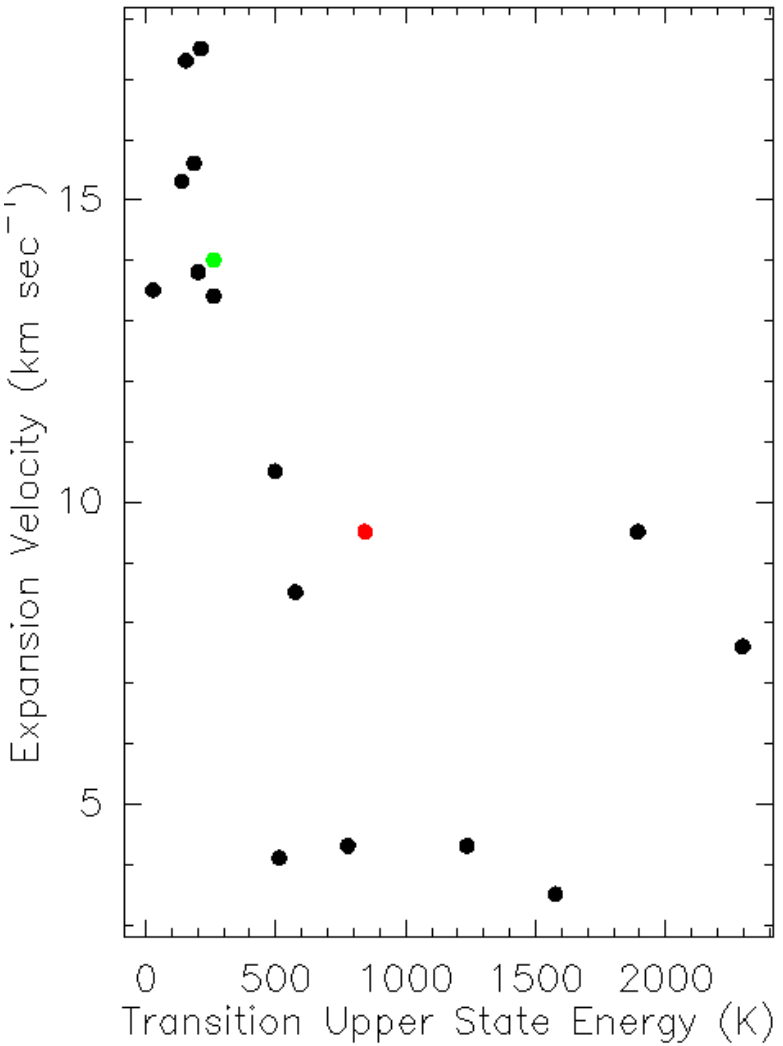

U
CS
U
29SiCC
U
29SiCC
U
U
Al37Cl
SiS
U
HCN
NaCN?
SiCC
RA Offset (arcsec)
Radial Offset (arcsec)
VLSR (km sec-1)

Of the identified narrow lines, which ones are resolved?



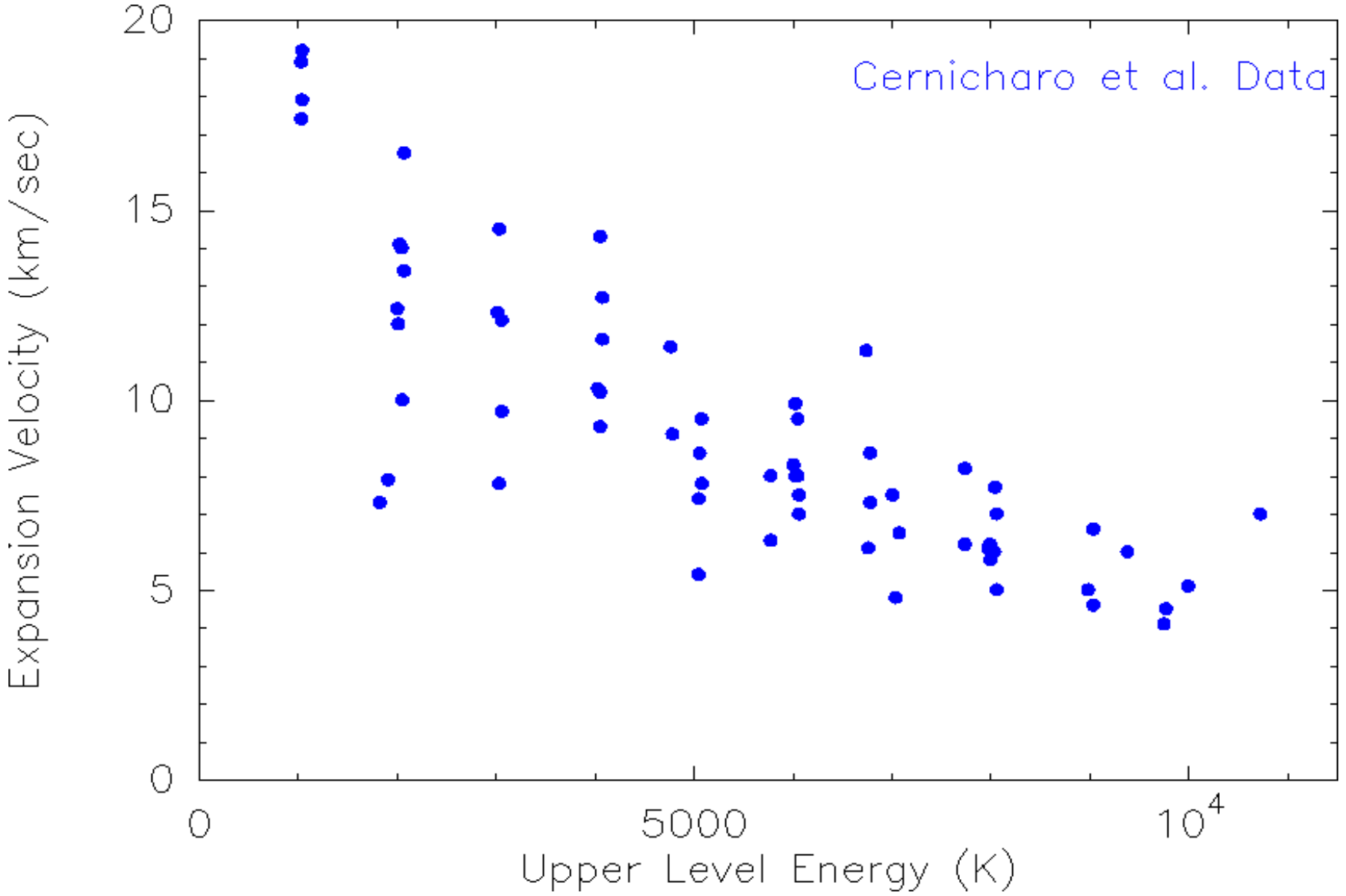
- All the very low energy narrow lines are highly resolved by the eSMA.
- The highest energy narrow lines are unresolved.

Are the narrow lines the highest energy lines?



- All of the lines with the canonical ~ 30 km/sec width are highly resolved.
- For the narrow lines, there is no correlation between the line width and transition energy.

Cernicharo *et al*. saw an HCN energy-V_{exp} correlation



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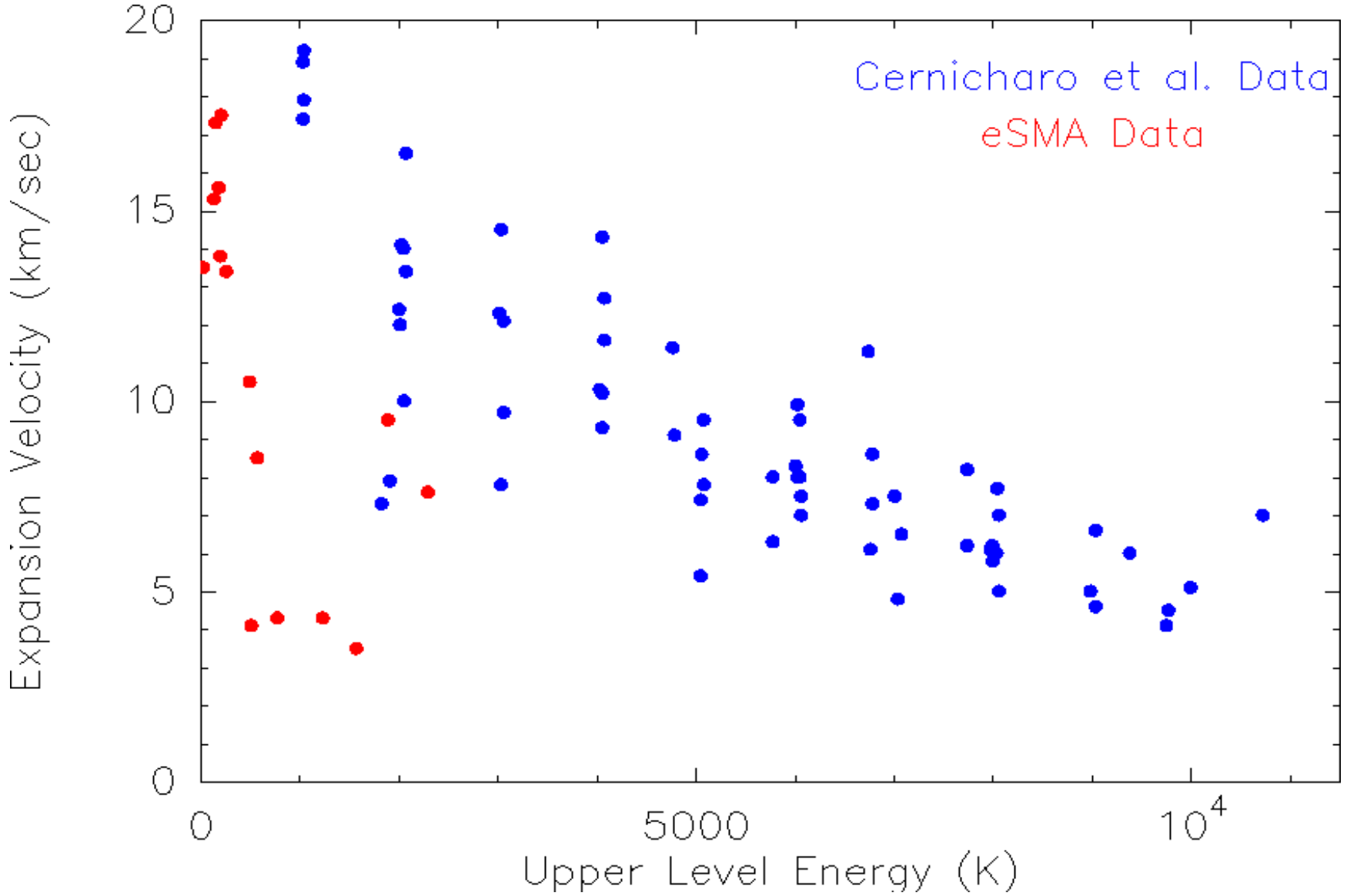
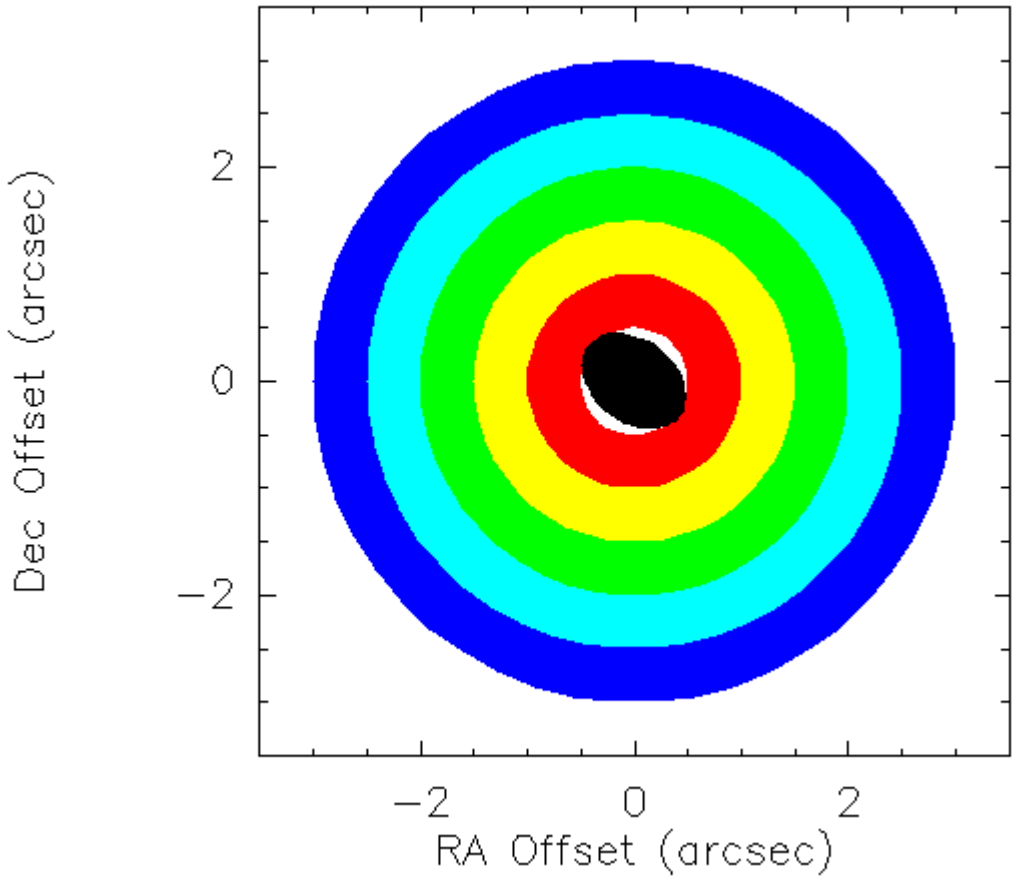
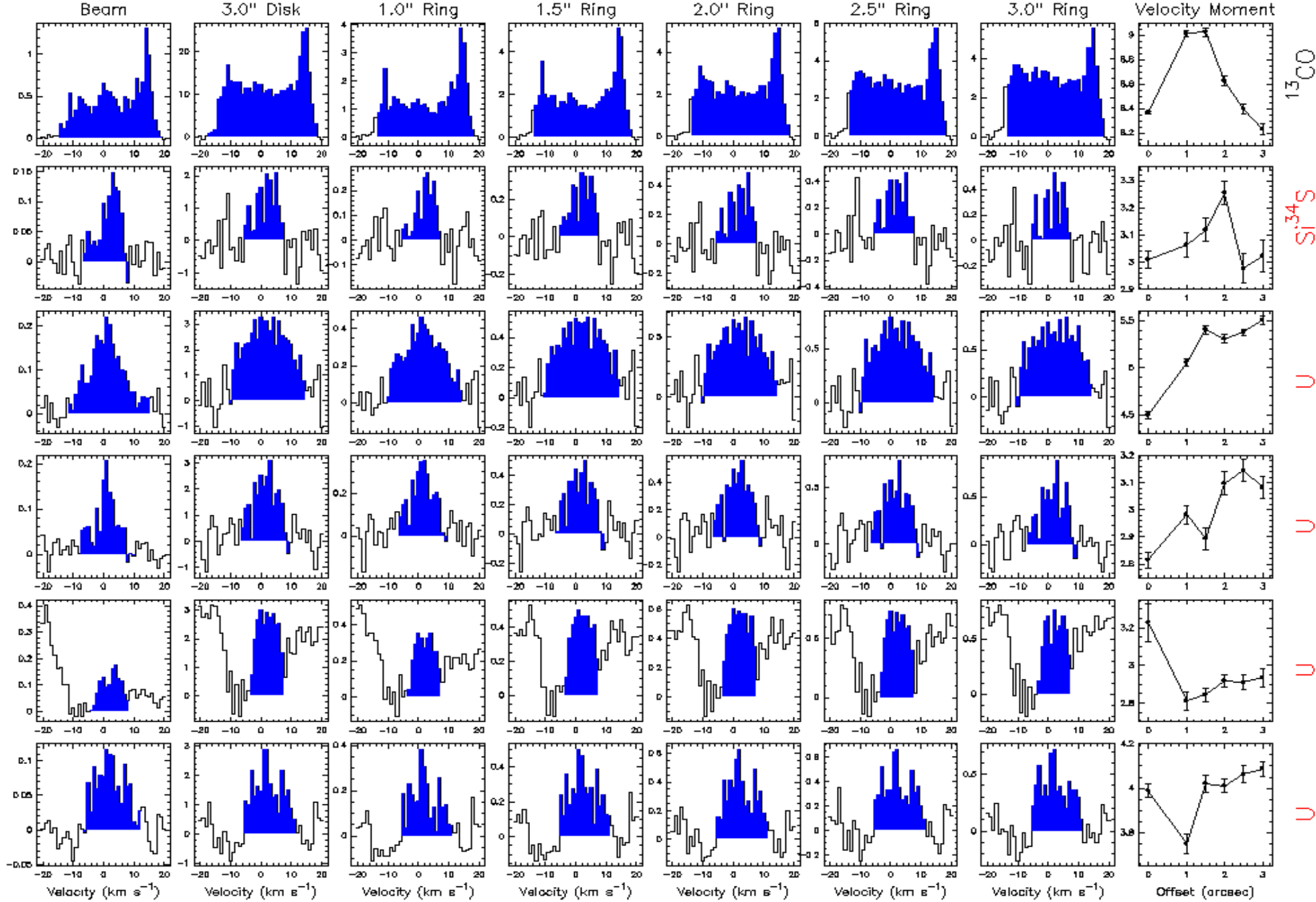
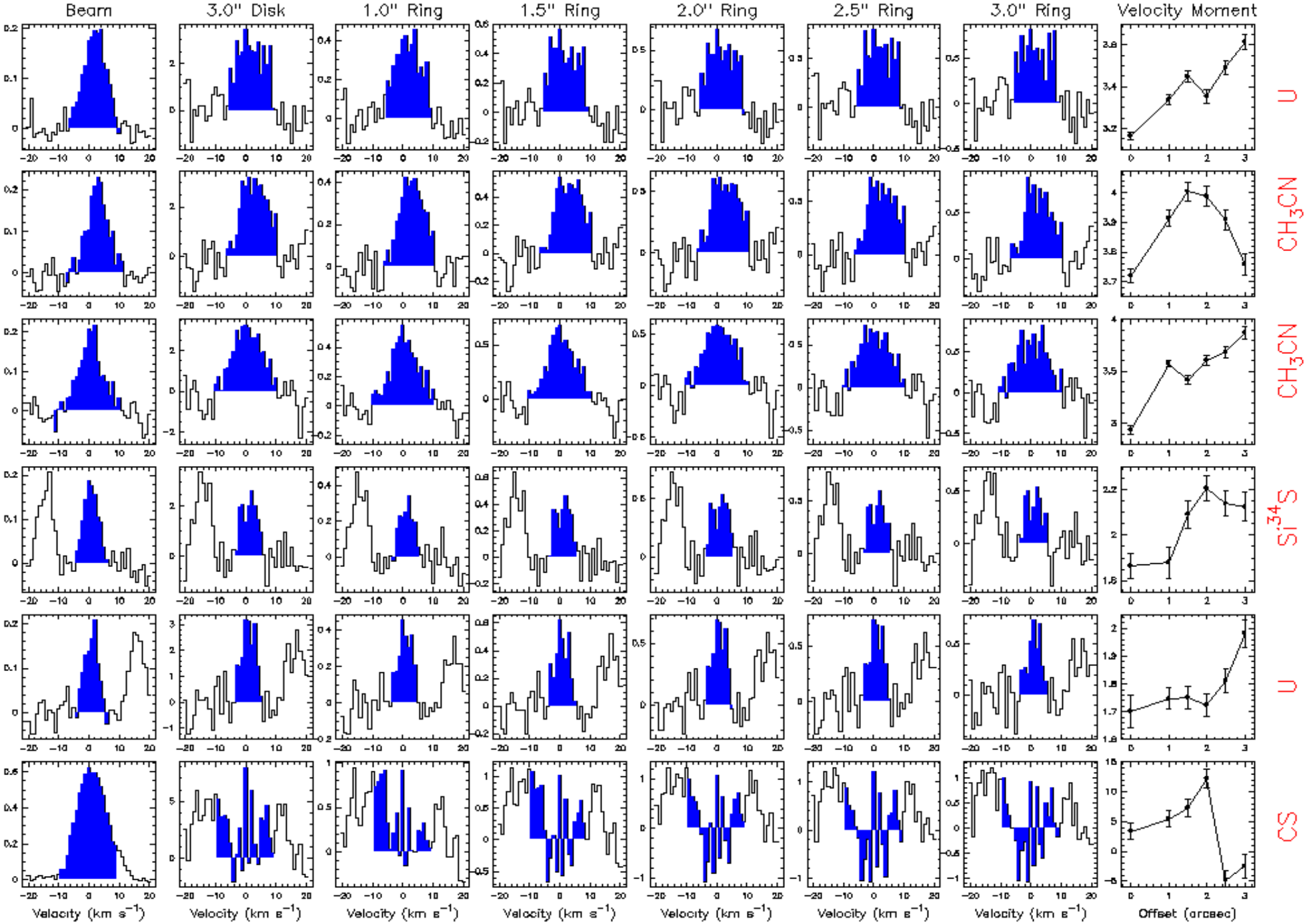


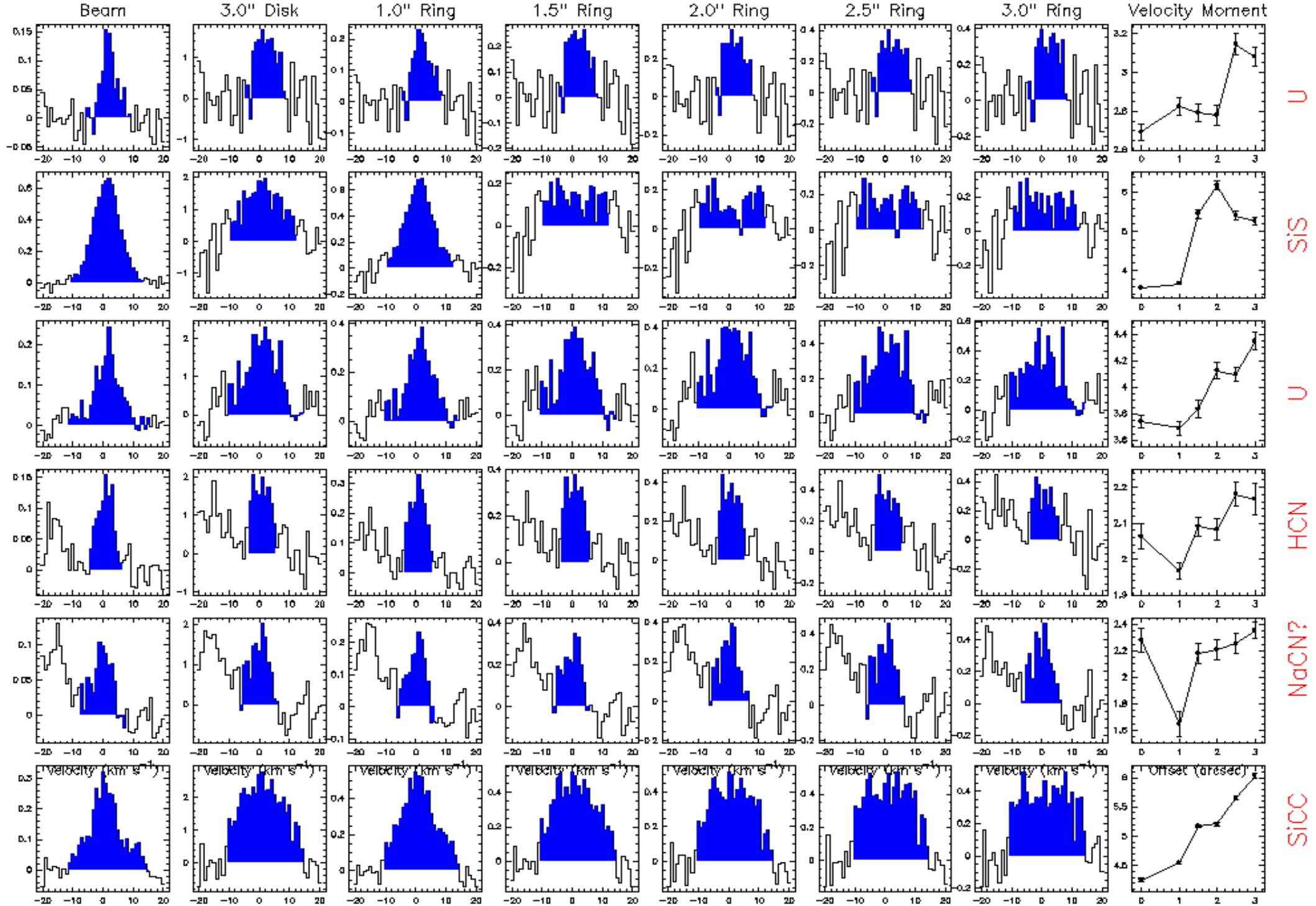
We made masked spectra, and calculated a velocity moment



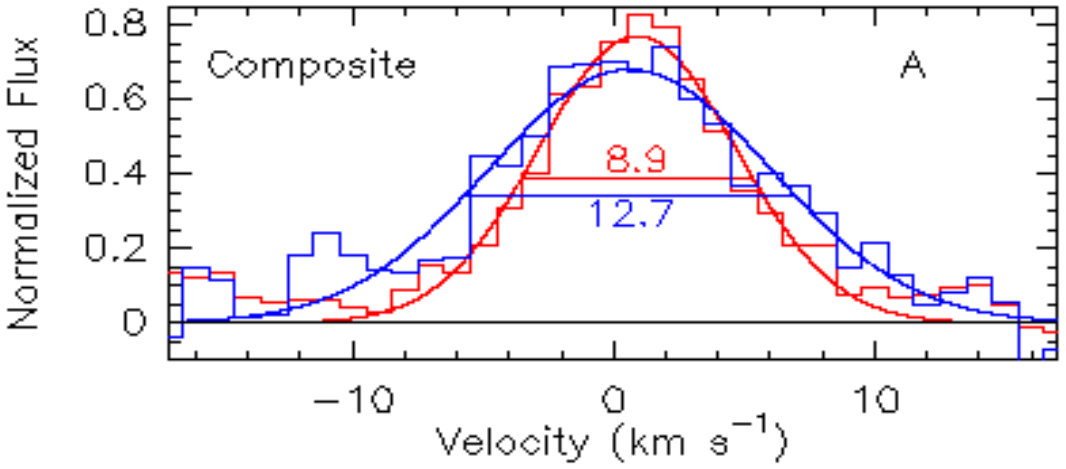
$$M = \frac{\sum^{Line} |V(i)| \times F(i)}{\sum^{Line} F(i)}$$


Beam
3.0" Disk
1.0" Ring
1.5" Ring
2.0" Ring
2.5" Ring
3.0" Ring
Velocity Moment
^{13}CO
Si^{34}S
U
U
U
U
Velocity (km s^{-1})
Velocity (km s^{-1})
Velocity (km s^{-1})
Velocity (km s^{-1})
Velocity (km s^{-1})
Velocity (km s^{-1})
Velocity (km s^{-1})
Offset (arcsec)


Beam
3.0" Disk
1.0" Ring
1.5" Ring
2.0" Ring
2.5" Ring
3.0" Ring
Velocity Moment
U
CH3CN
CH3CN
Si34S
U
CS
Velocity (km s−1)
Offset (arcsec)


Beam
3.0" Disk
1.0" Ring
1.5" Ring
2.0" Ring
2.5" Ring
3.0" Ring
Velocity Moment
U
SiS
U
HCN
NaCN?
SiCC
Velocity (km s-1)
Offset (arcsec)

Composite spectrum compared with acceleration models

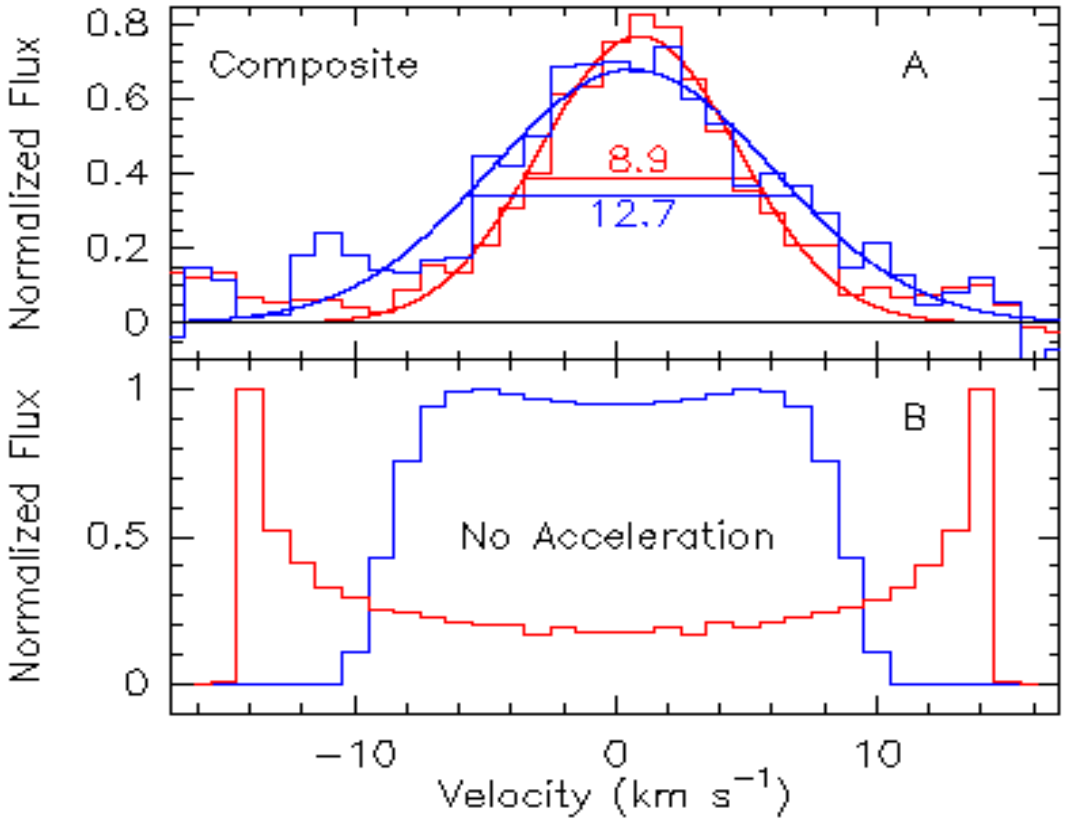


Beam Mask Spectrum

Annular Mask Spectrum

The composite spectrum made with the largest annular mask is 40% larger then the spectrum made with the beam mask.

Composite spectrum compared with acceleration models

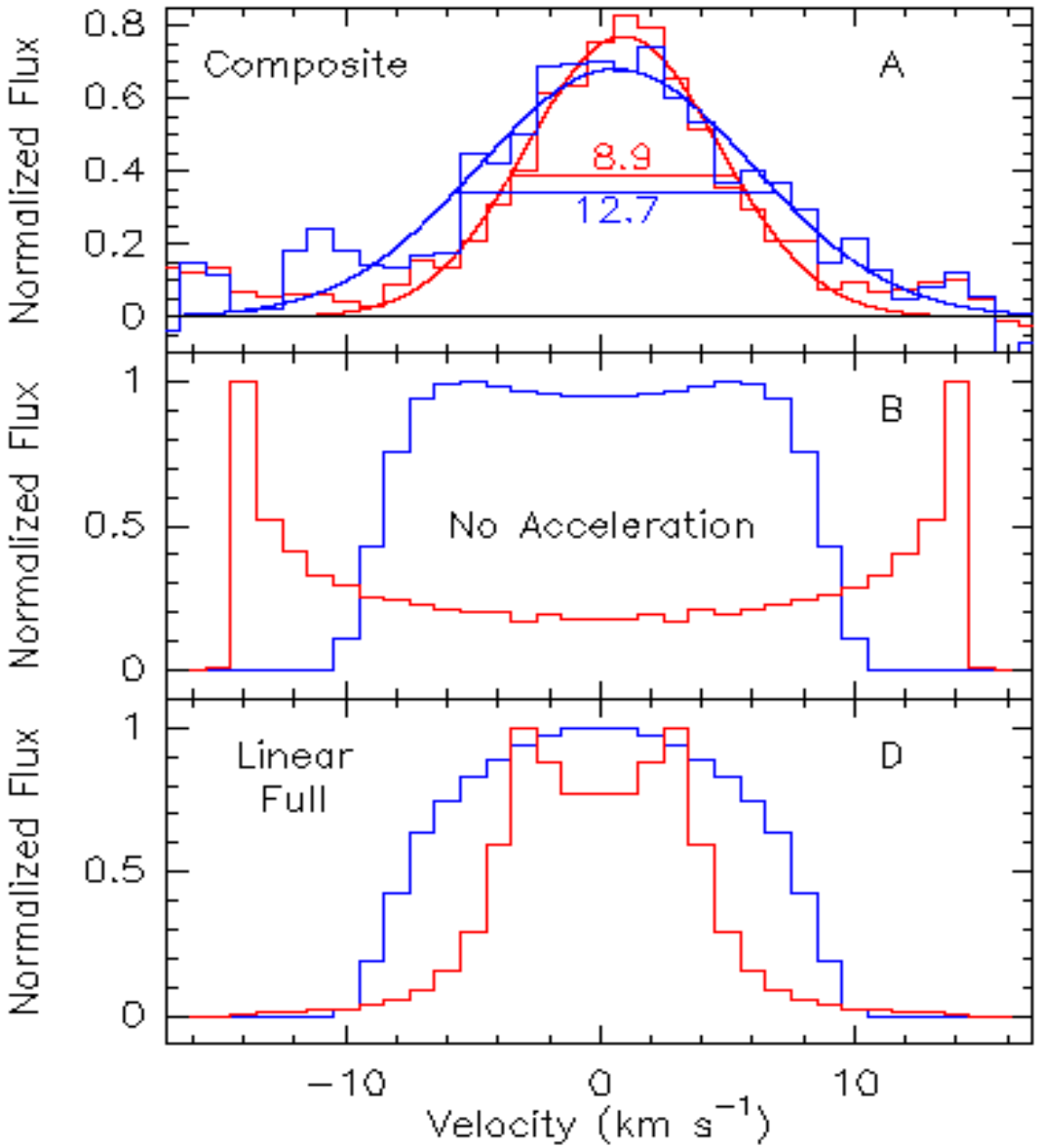


Beam Mask Spectrum

Annular Mask Spectrum

Constant outflow velocity

Composite spectrum compared with acceleration models

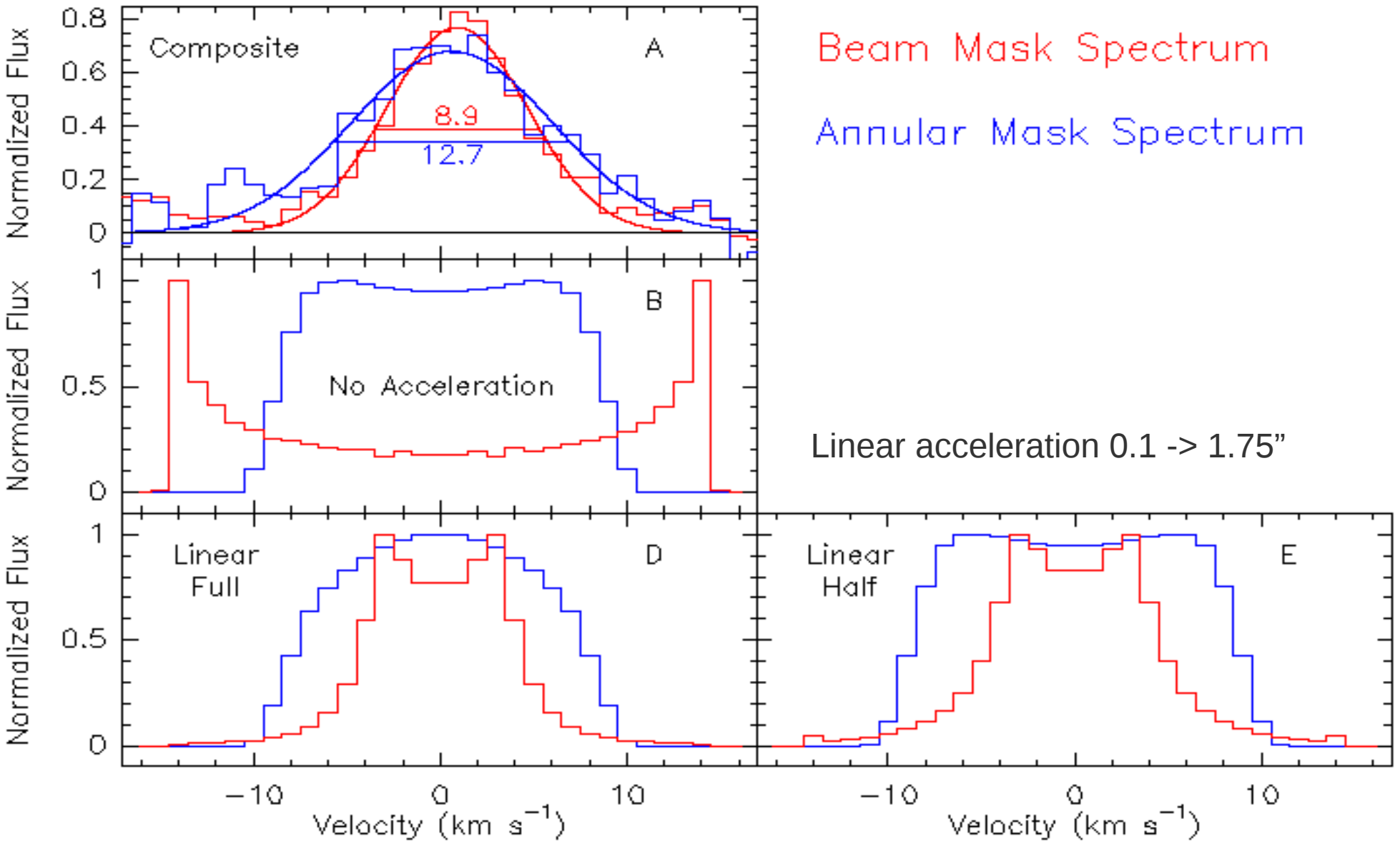


Beam Mask Spectrum

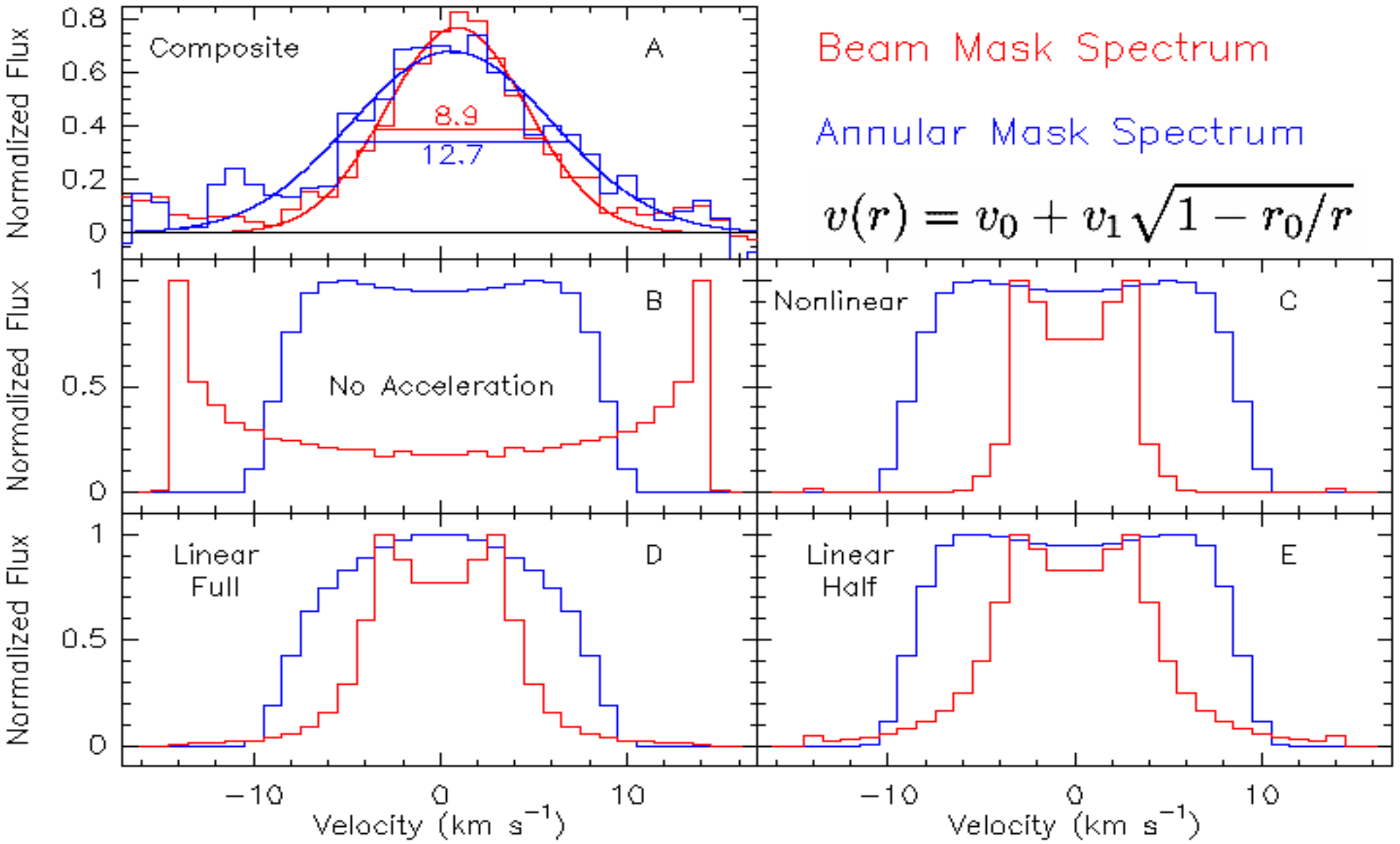
Annular Mask Spectrum

Linear acceleration
V = 3.7 @ 0.1”
V = 15.0 @ 3.5”

Composite spectrum compared with acceleration models



Composite spectrum compared with acceleration models



Conclusions

- We resolved nearly all of the narrow lines with our ~0.3” synthesized beam.
- The only lines unresolved by the eSMA have upper state energies above 1500 K.
- Many of the narrow lines show a change in line width when spectra are produced from different regions. In most cases the line widths increase as you examine material further from the star.
- The change in profile shape as a function of radius differs dramatically from what one would expect from a uniformly expanding shell.
- The signal/noise of the derived spectra are too low for distinguishing between different acceleration profiles.