Initial results of ALMA monitoring of the carbon star IRC +10216

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Outline

- Background: Mm line variation in AGB stars.
- Our ALMA/ACA monitoring of IRC +10216 & an overview of the results.
- Challenges in constraining flux uncertainties.
- First ALMA results: a qualitative presentation.
- Summary.

Millimeter line variations in AGB stars

Strong stellar winds & huge circumstellar envelope (CSE)

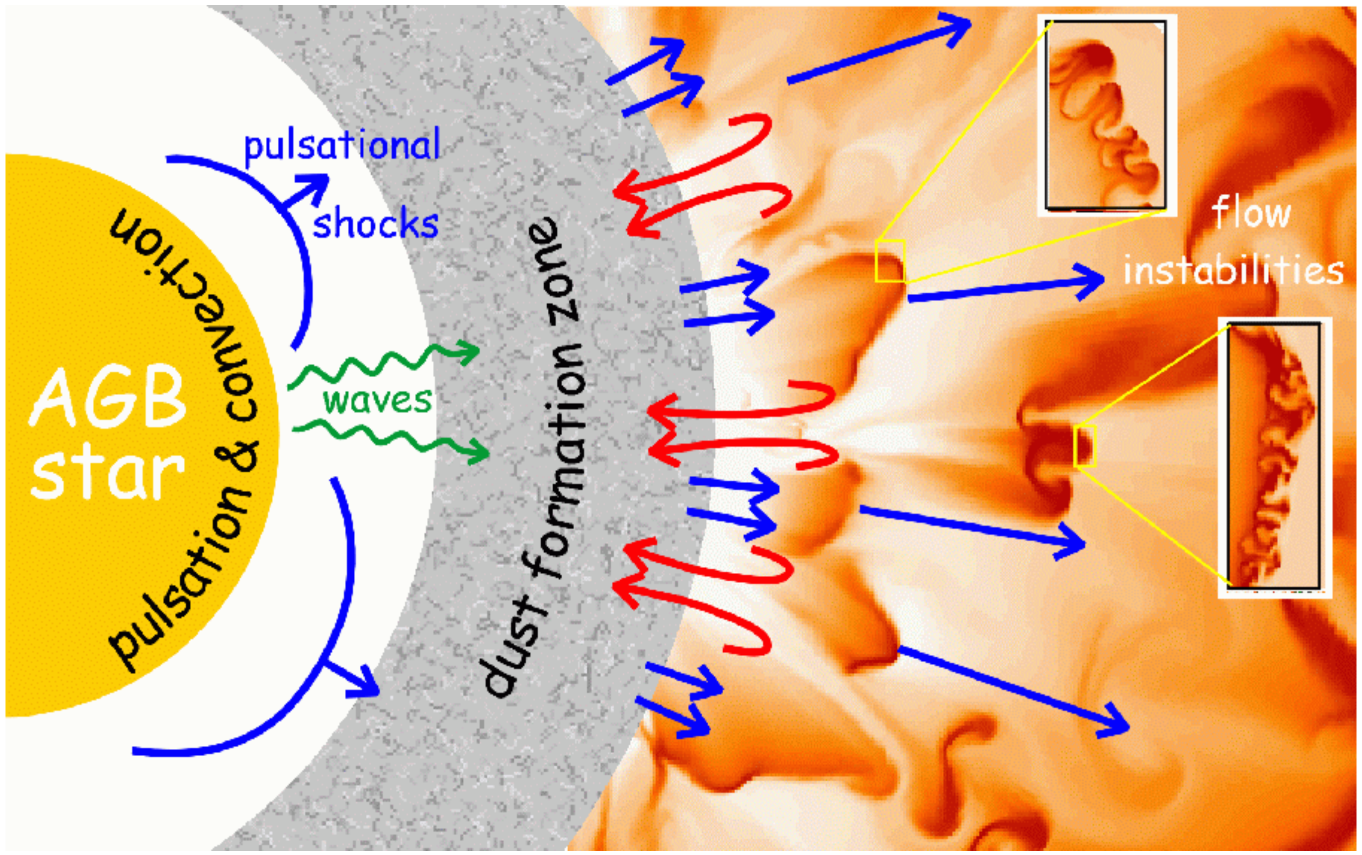
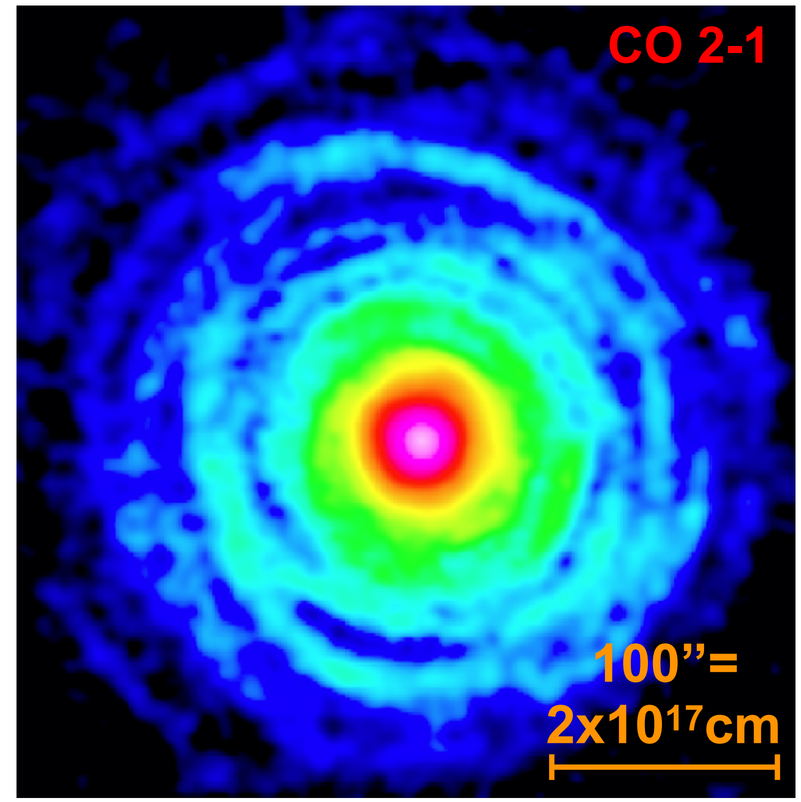


Figure from Internet.

IRC +10216



Cernicharo+ 2015A&A...575A..91C

Stellar radius: 0.02”

Are mm lines from such a huge CSE variables?

A bit of history

1990fmpn.coll..170C

Carlstrom+

a meeting paper

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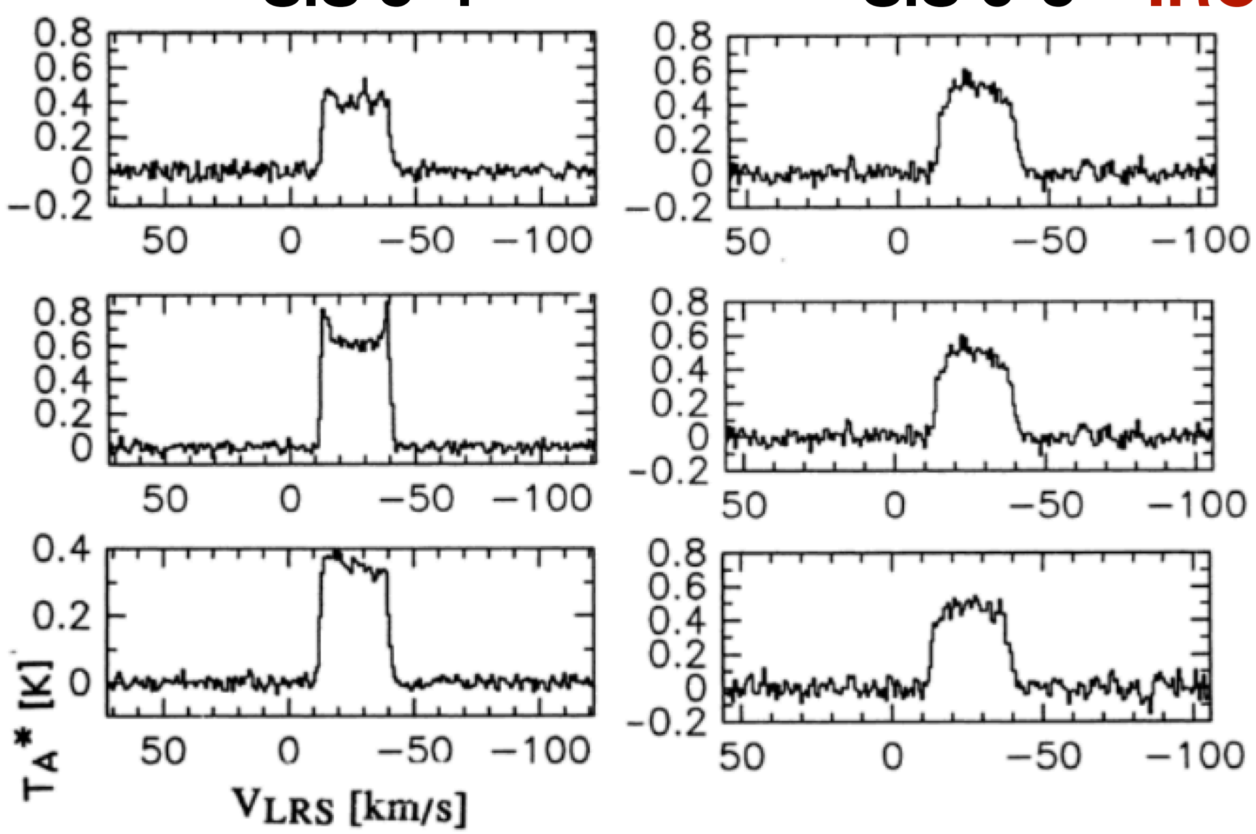
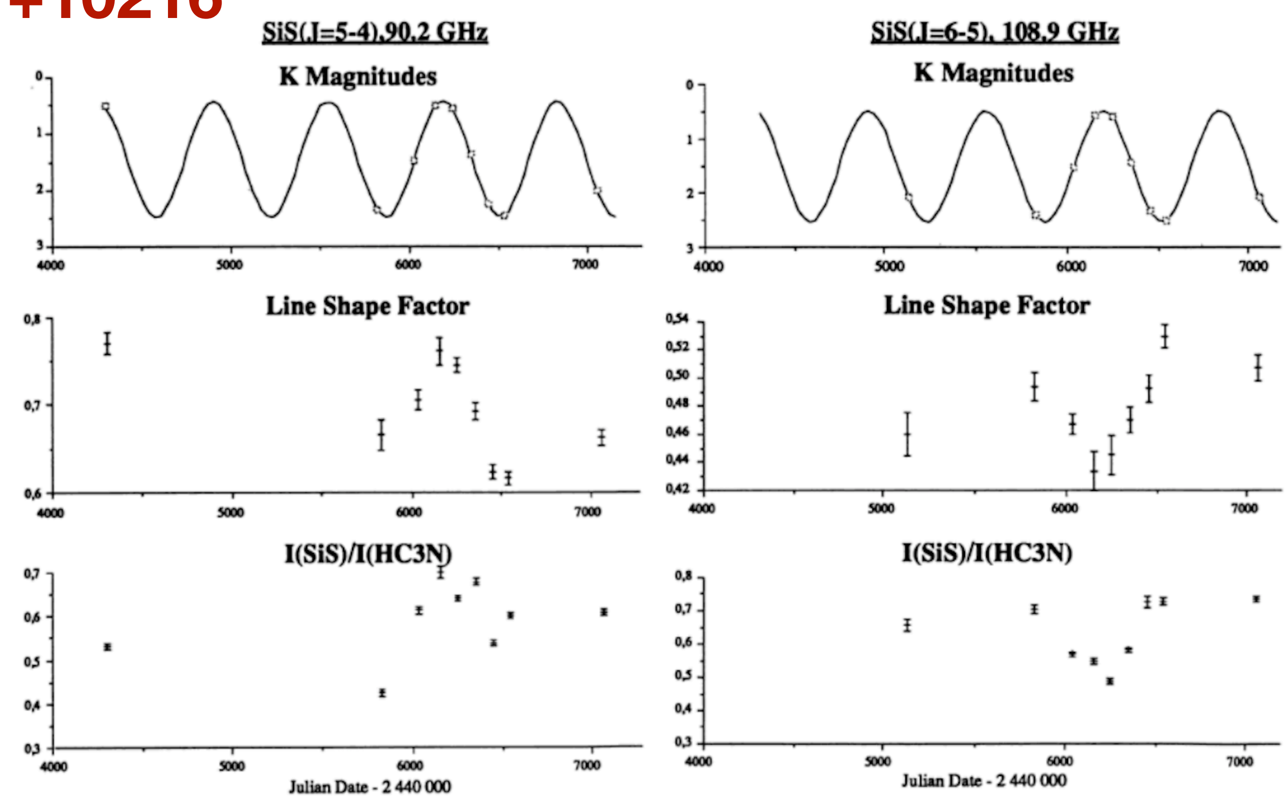
SiS 5-4 **SiS 6-5** **IRC +10216**

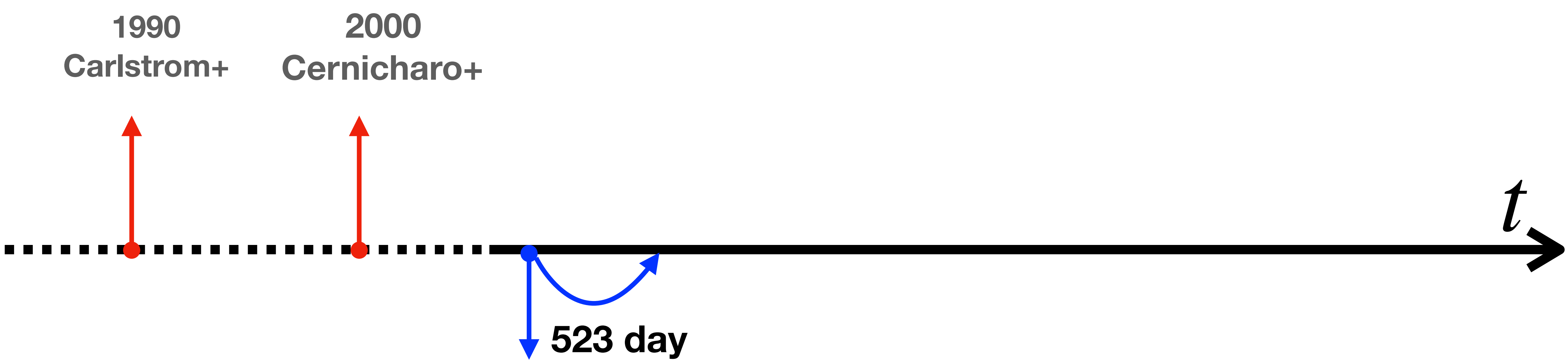




A bit of history

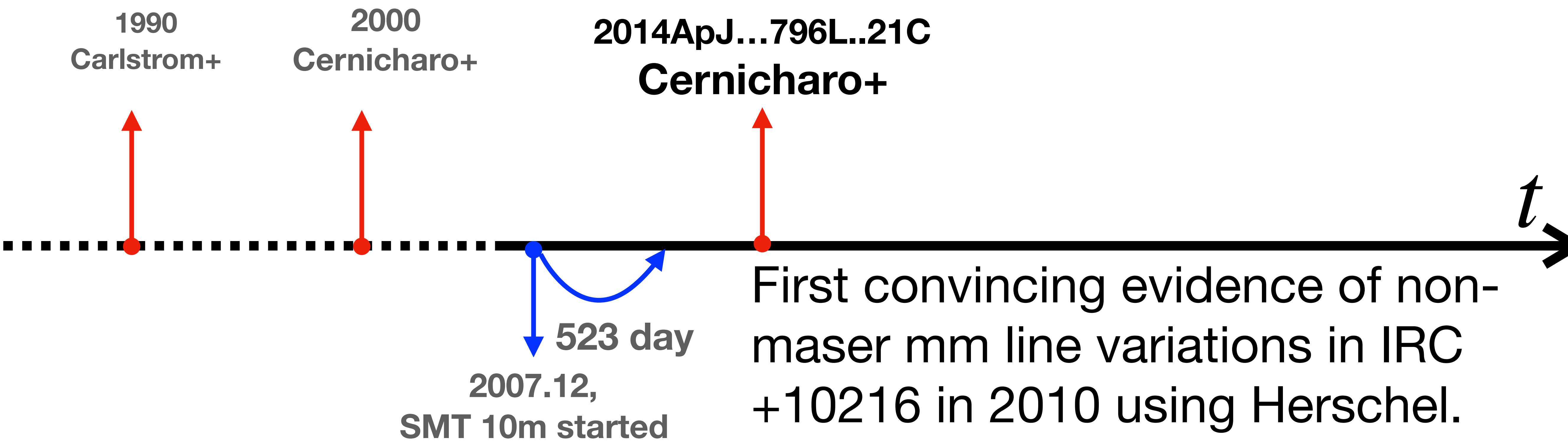
Repeated 2mm observations of IRC +10216 with IRAM30m only found variation in HCN $\nu_2 = 1$, J=2-1 maser line, but not in any other lines.

A bit of history

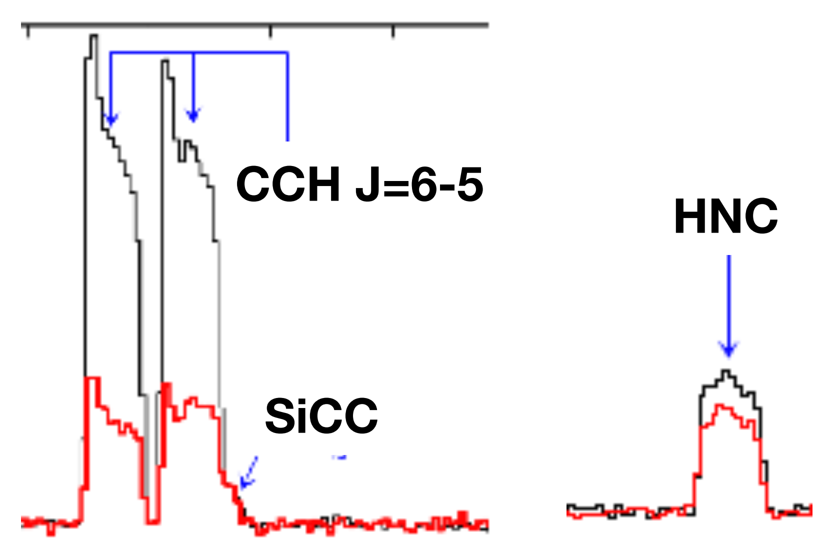


**December of 2007,
I started to monitor 1.1mm
line variation in IRC +10216
using SMT 10m
(ASIAA, Taiwan)**

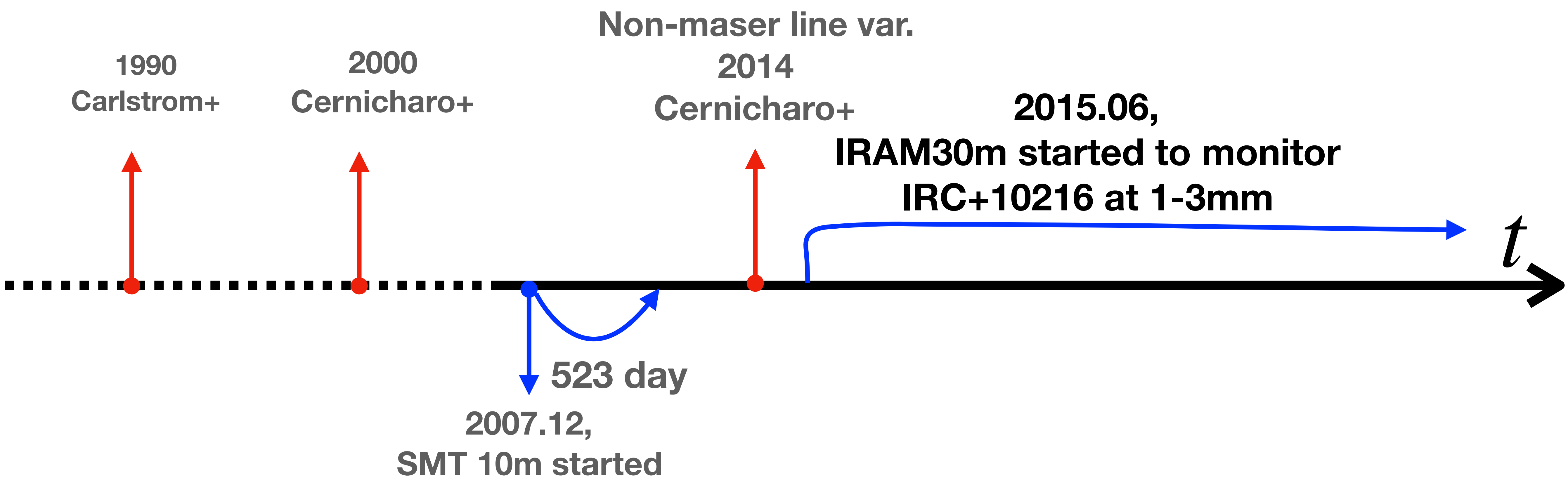
A bit of history



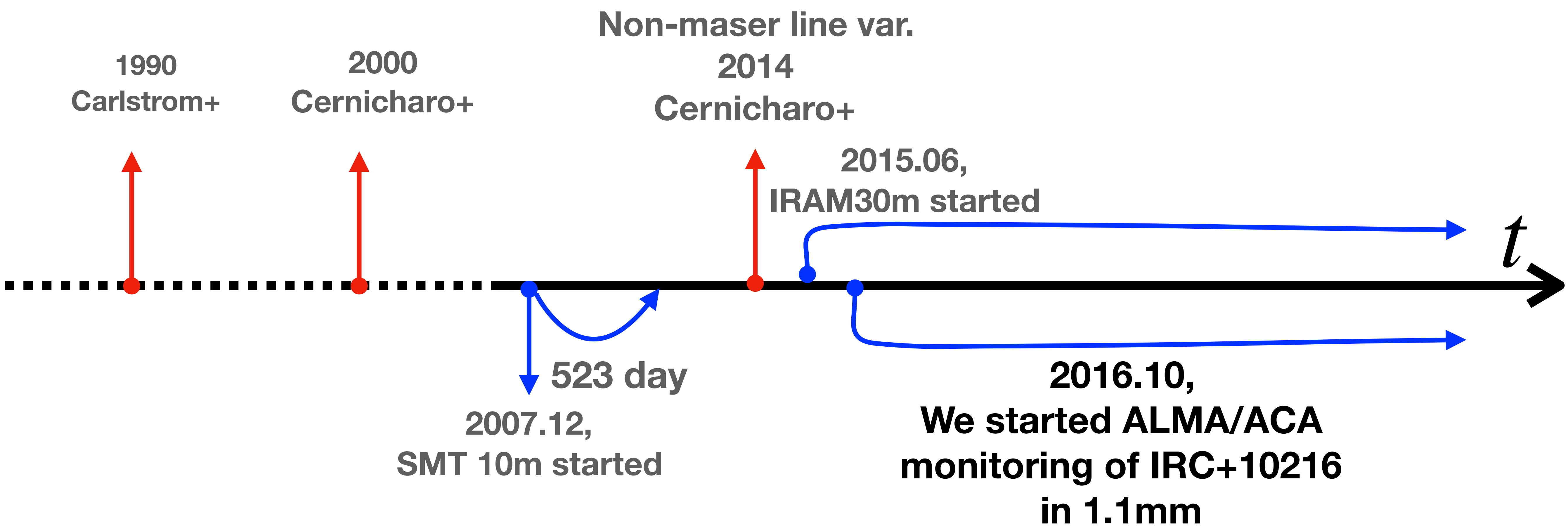
First convincing evidence of non-maser mm line variations in IRC +10216 in 2010 using Herschel.



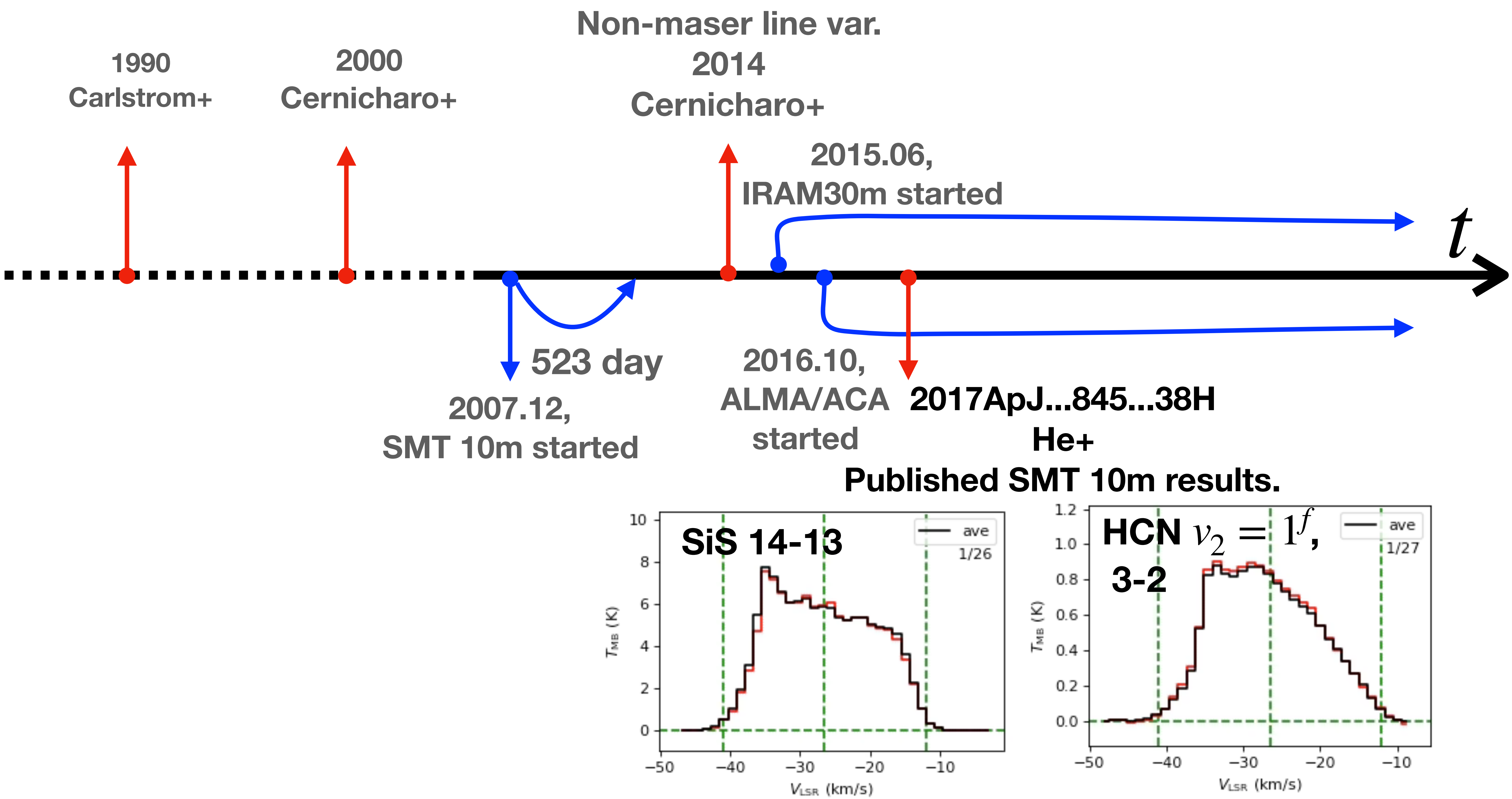
A bit of history



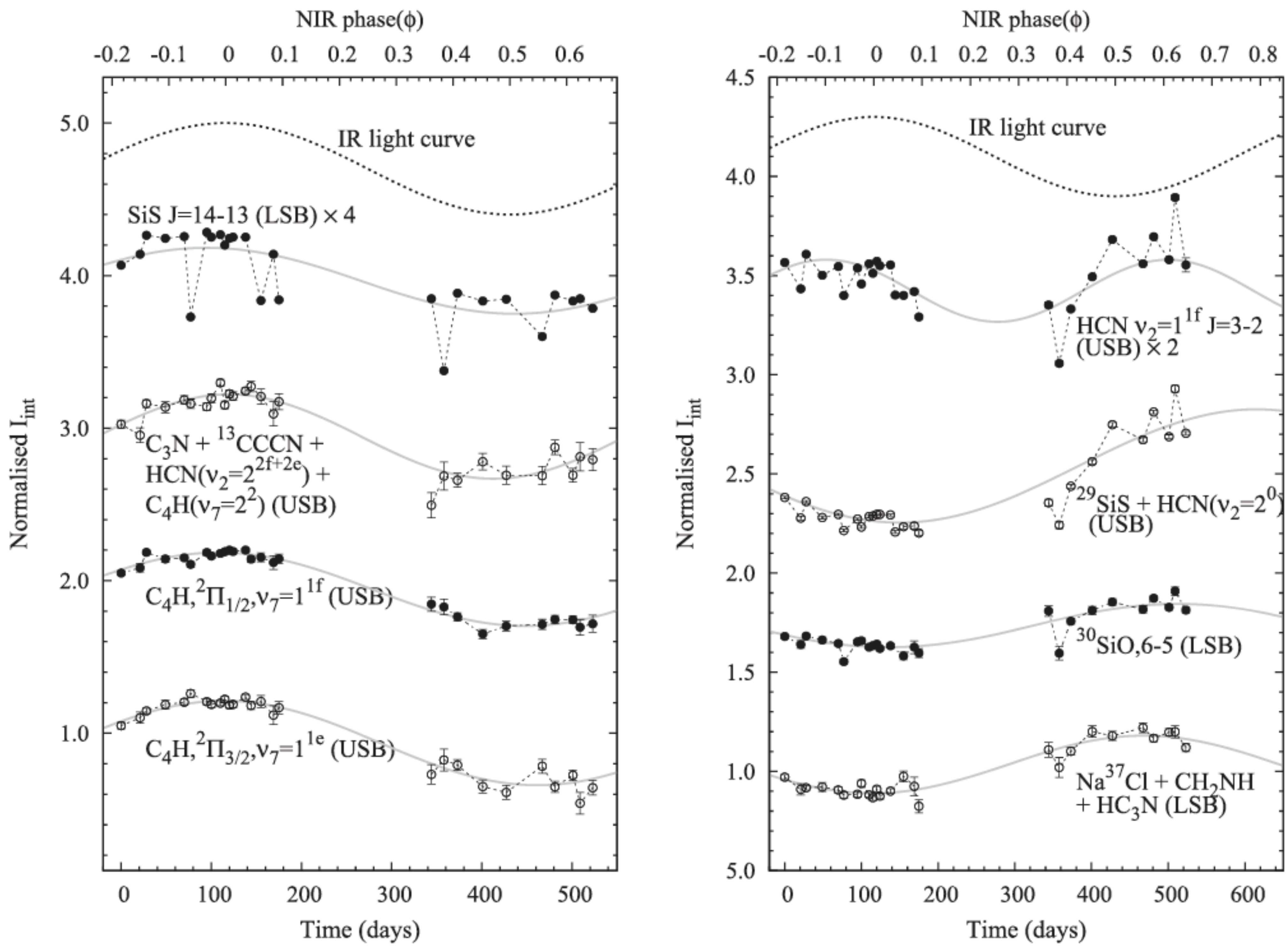
A bit of history



A bit of history



A bit of history



We also found different variation behaviors.

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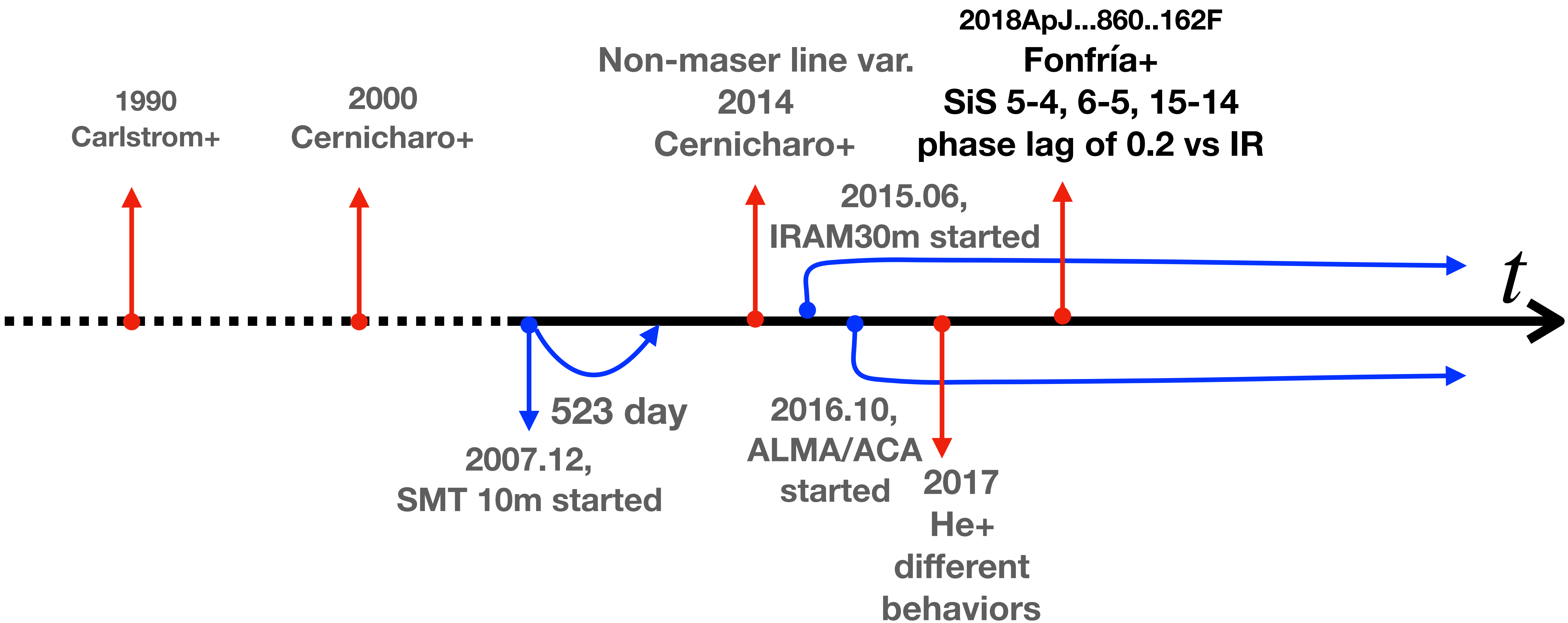
.38H

n results.

A bit of history



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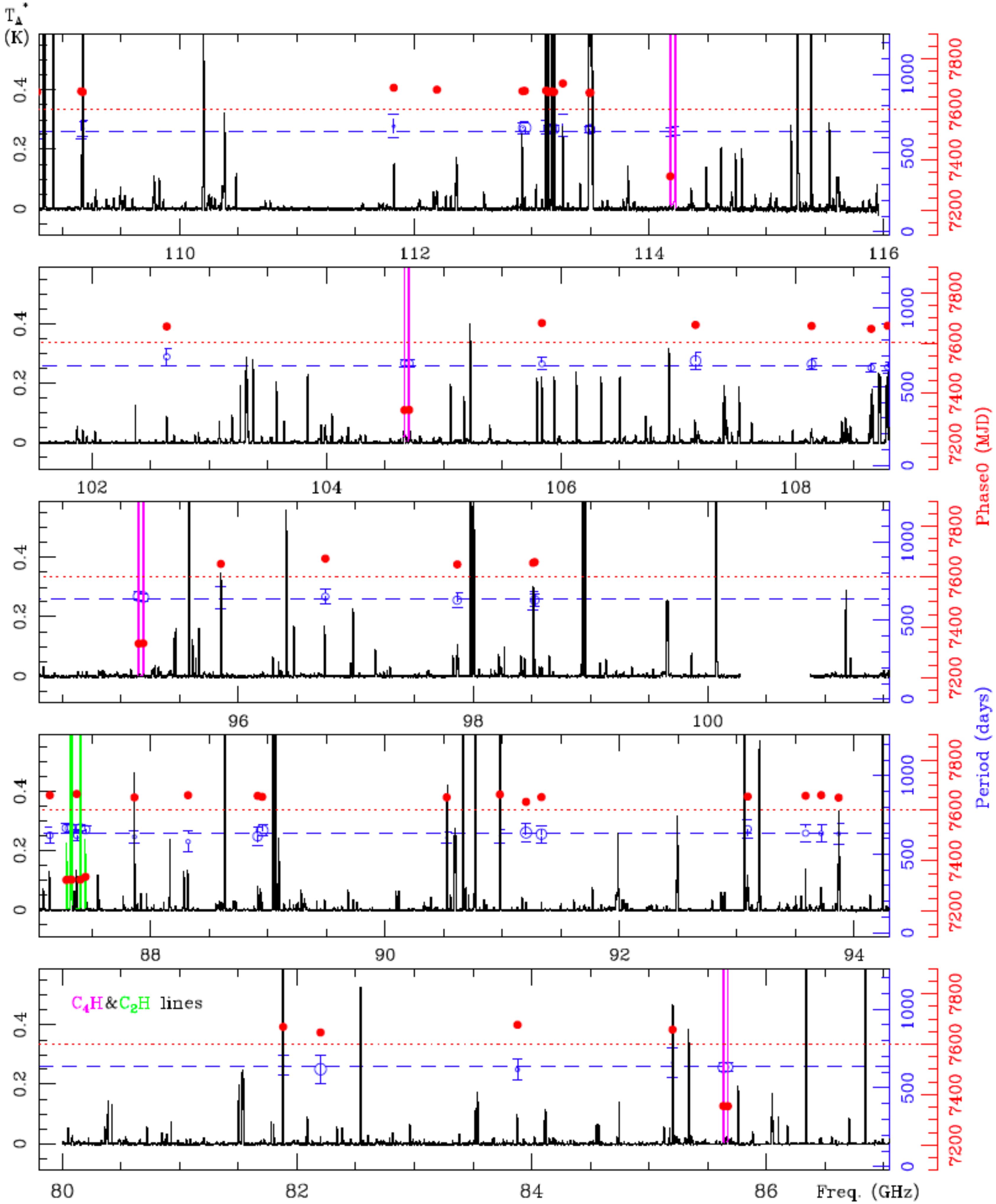

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2018

nfría+ 2018A&A...615L...4P

se lag Pardo+

0.2 3mm lines var

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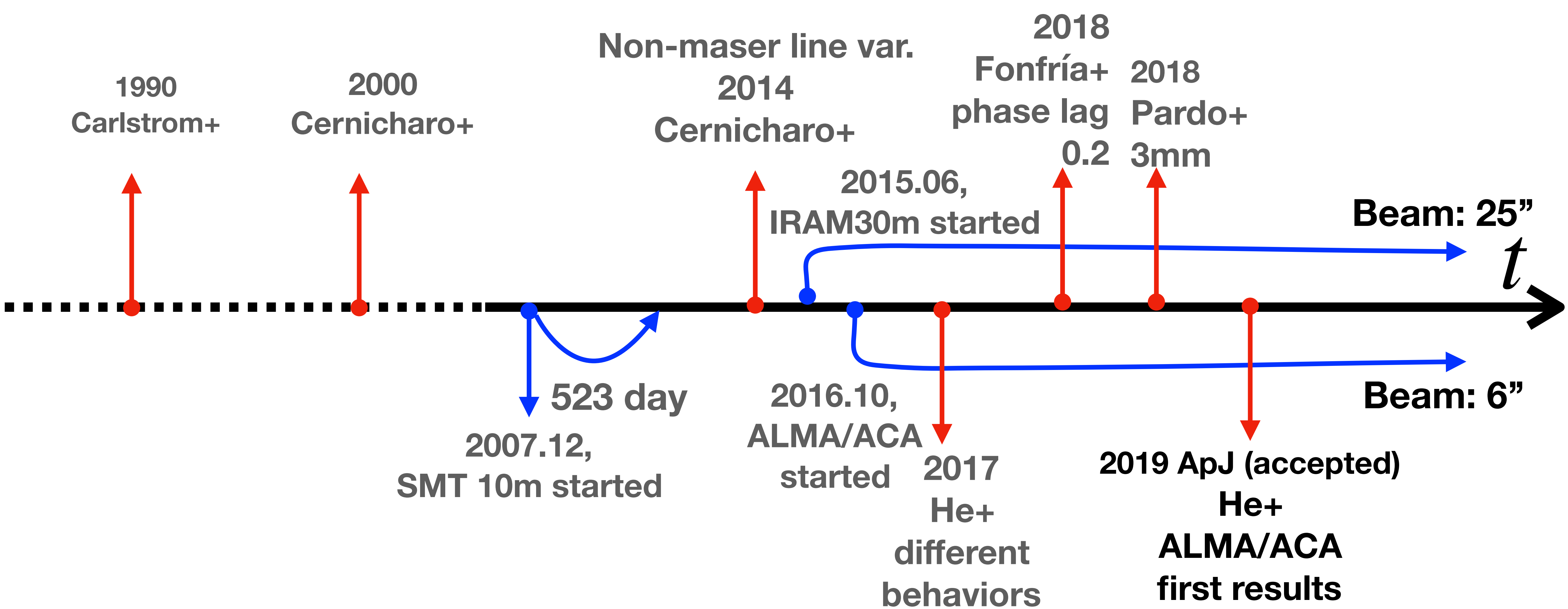
A bit of history



Why should we care mm line variations?

➡A new phenomenon. Need to understand how & why.

➡Can be new probes of AGB wind launching processes.

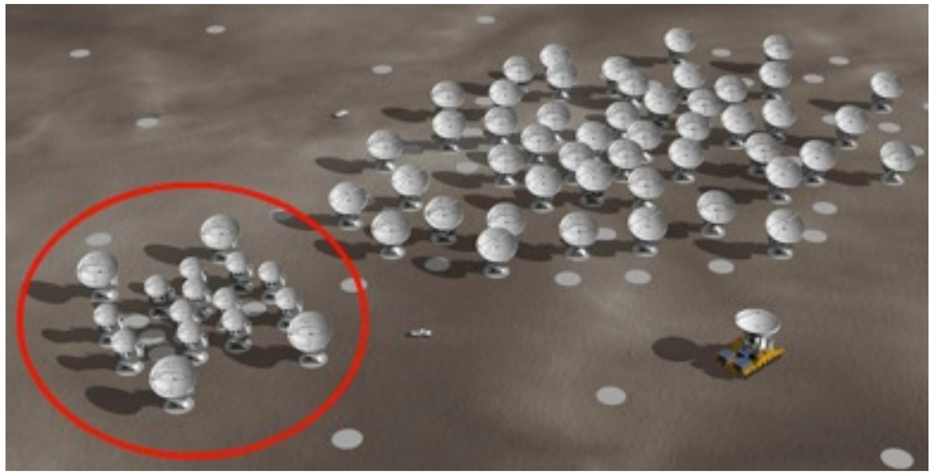
- ✴It involves pulsations, shocks, dust formation, chemistry, wind acceleration, etc.
- ✴The region is very small and lacking of exploration.
- ✴Some varying lines could come from this region.

ALMA/ACA monitoring of IRC +10216

The ALMA/ACA monitoring team

Universidad de Concepcion (Chile):
Ronald Mennickent
Baitian Tang

CASSACA (China):
Jinhua He
Wei Wang



Universidad de Chile (Chile):
Diego Mardones
Jixing Ge

CfA (USA):
Tomasz Kaminski

N. Copernicus Astronomical Center (Poland):
Miroslaw Schmidt
Ryszard Szczerba

Moscow State University (Russia):
Victor Shenavrin

ALMA/ACA monitoring of IRC +10216

The ALMA/ACA monitoring:

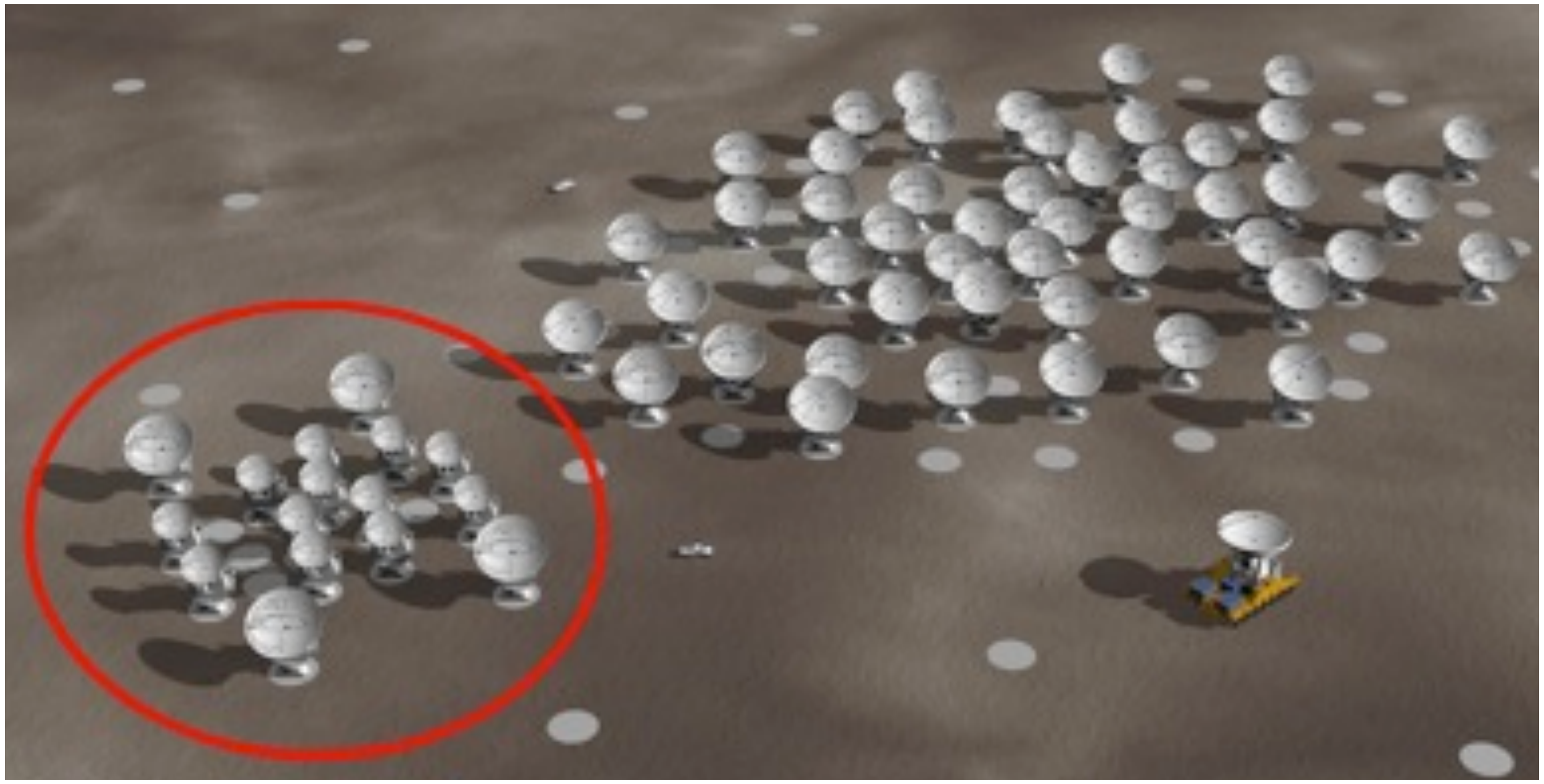
Goal: Explore mm line var. & search for tracers of AGB star wind launching dynamics.

Advantage of ACA: fixed baselines.

Freq band: 1.1mm (similar to but wider than our single dish work)

Cadence: once a month.

We have monitored IRC +10216 since Oct. 2016.
(ALMA Cycle 4, 5, 6 & 7). 4 yrs / 630 day = 2.3 pulsation periods.



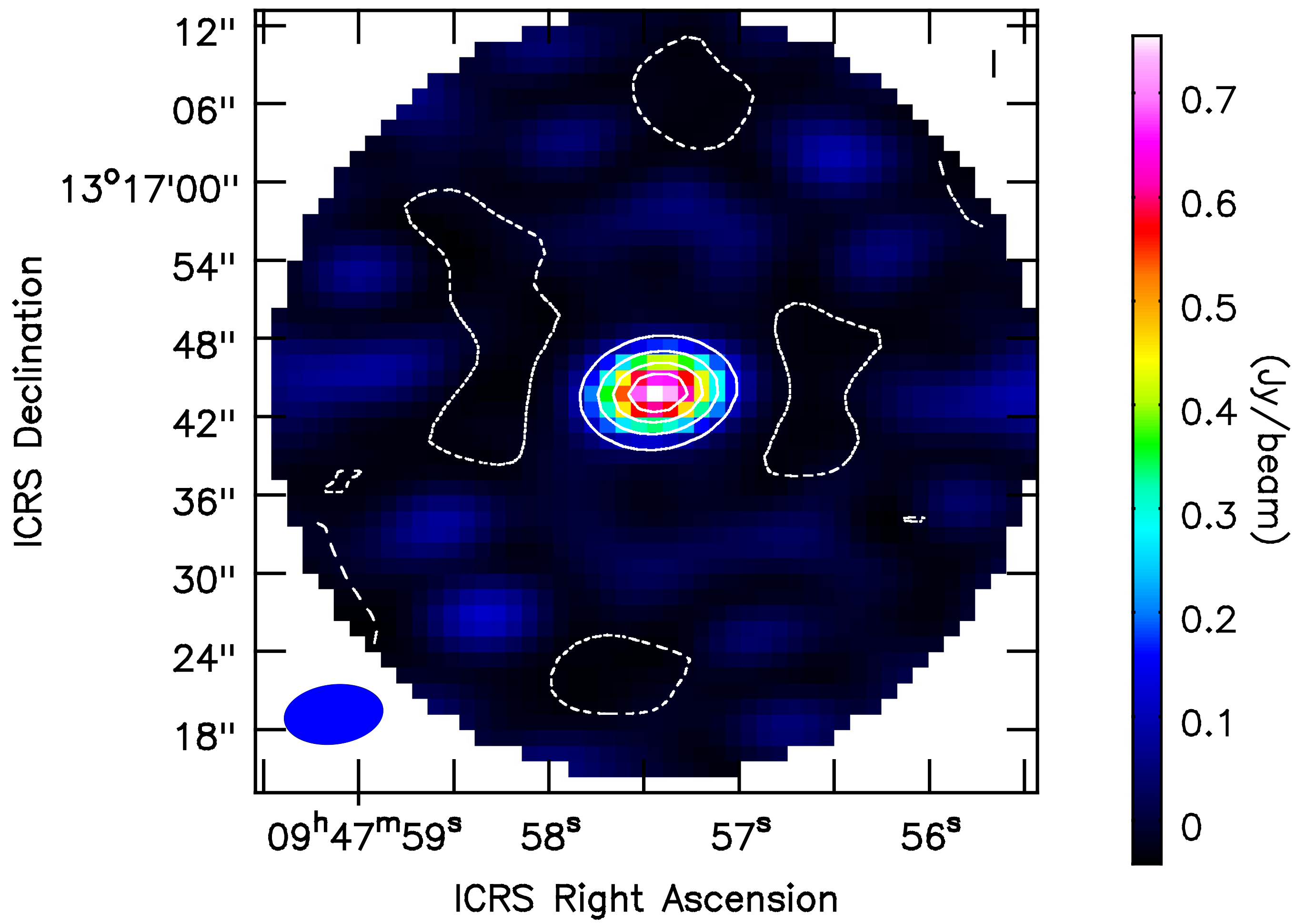
IR J,H,K,L,M monitoring:

Crimea 1.25m

Since Dec. 12, 2017

Overview of ALMA results

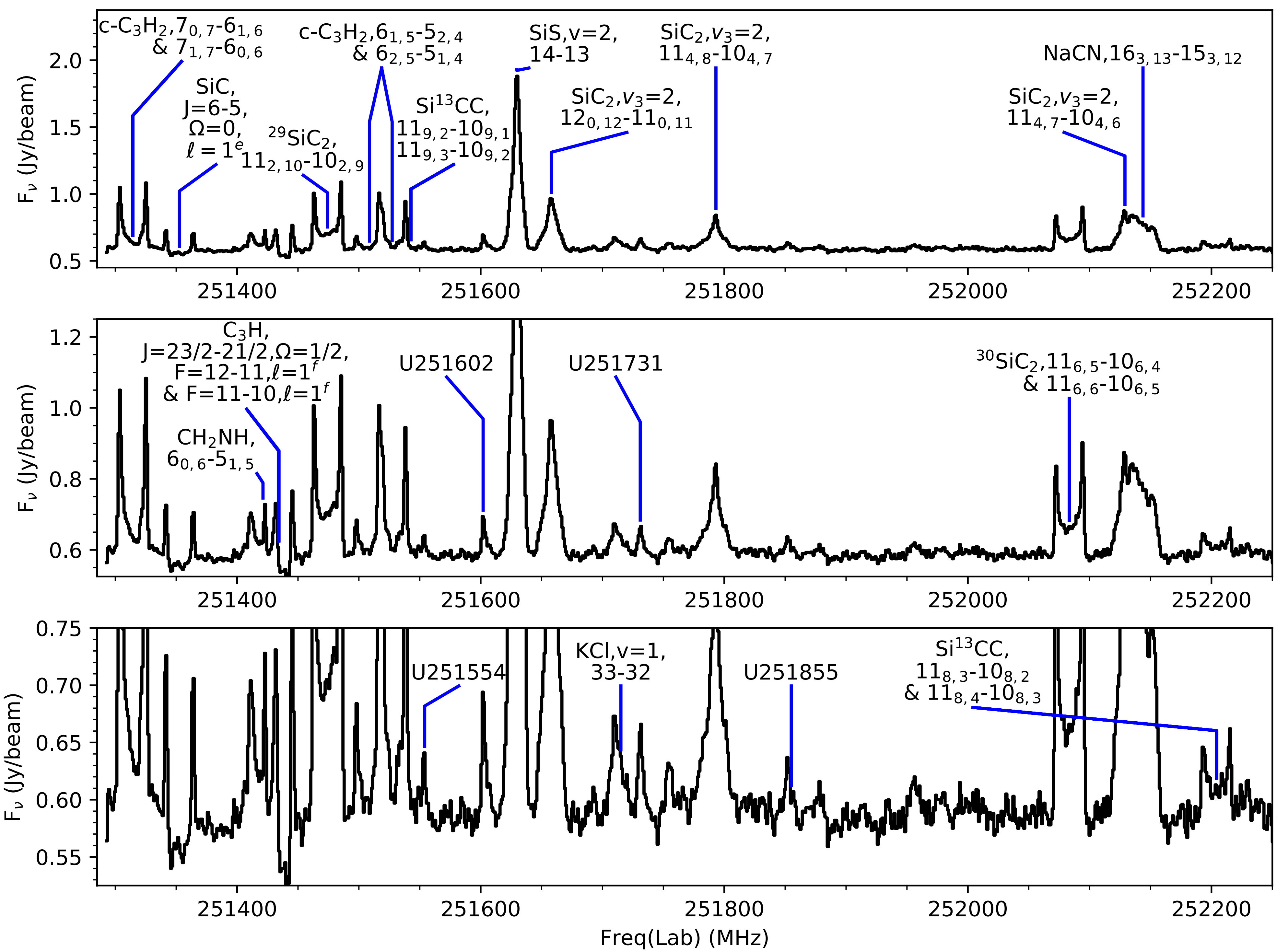
The field of view:



Color: 1.1mm continuum
Contours: Integrated SiS 14-13 line

Overview of ALMA results

Phase center spectra: 1/2 of one of the 4 line windows

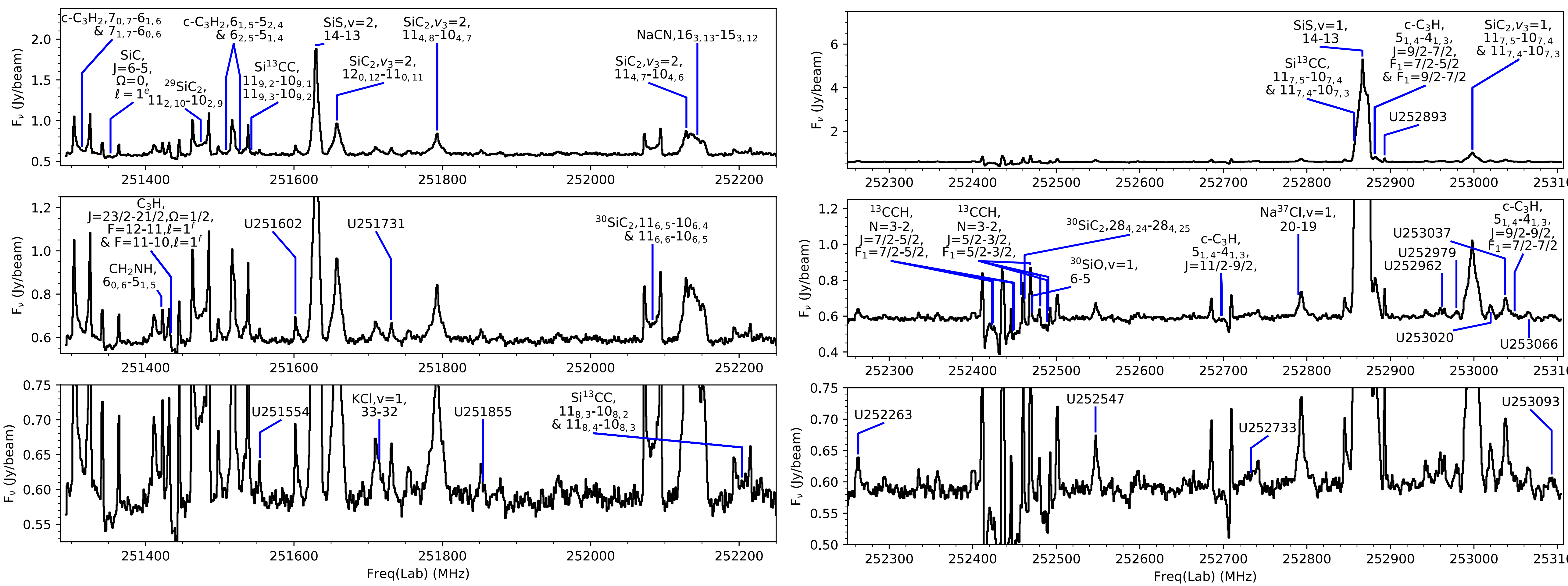


Averaged over 21 epochs, Baseline rms~10mK

Continuum

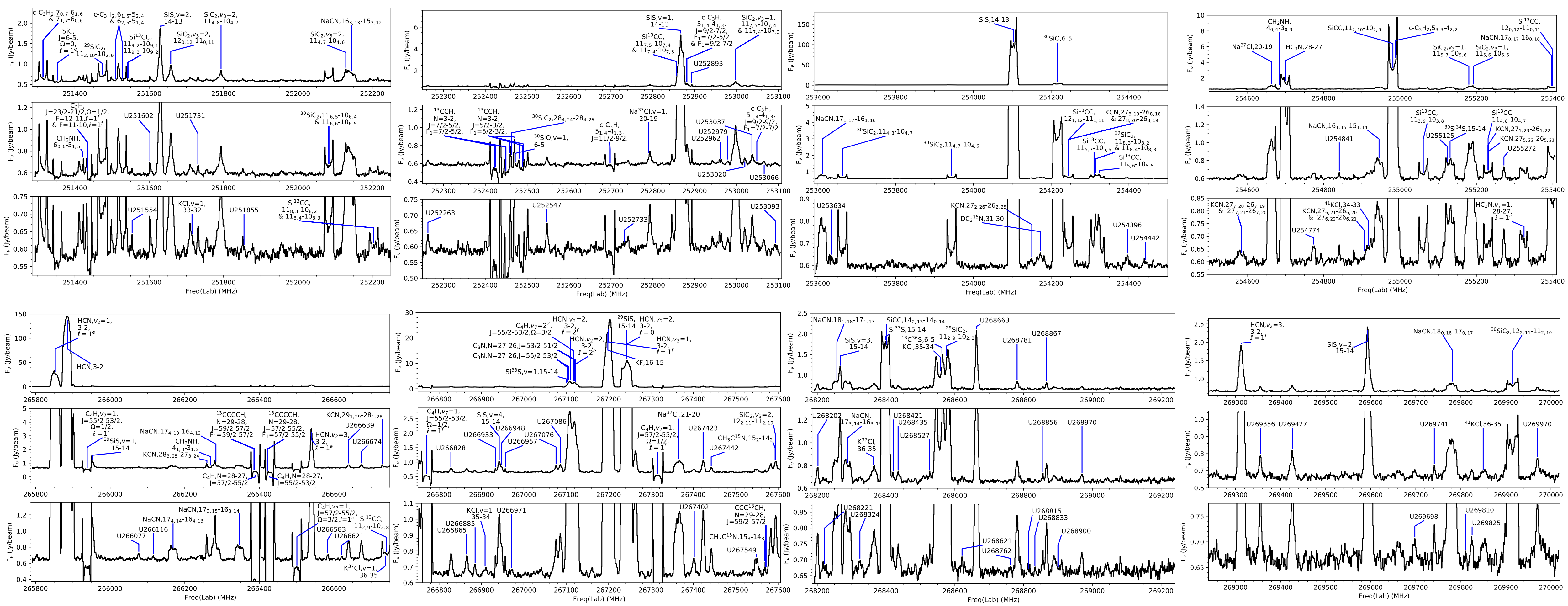
Overview of ALMA results

Phase center spectra: one of the 4 line windows



Overview of ALMA results

Phase center spectra: all 4 line windows



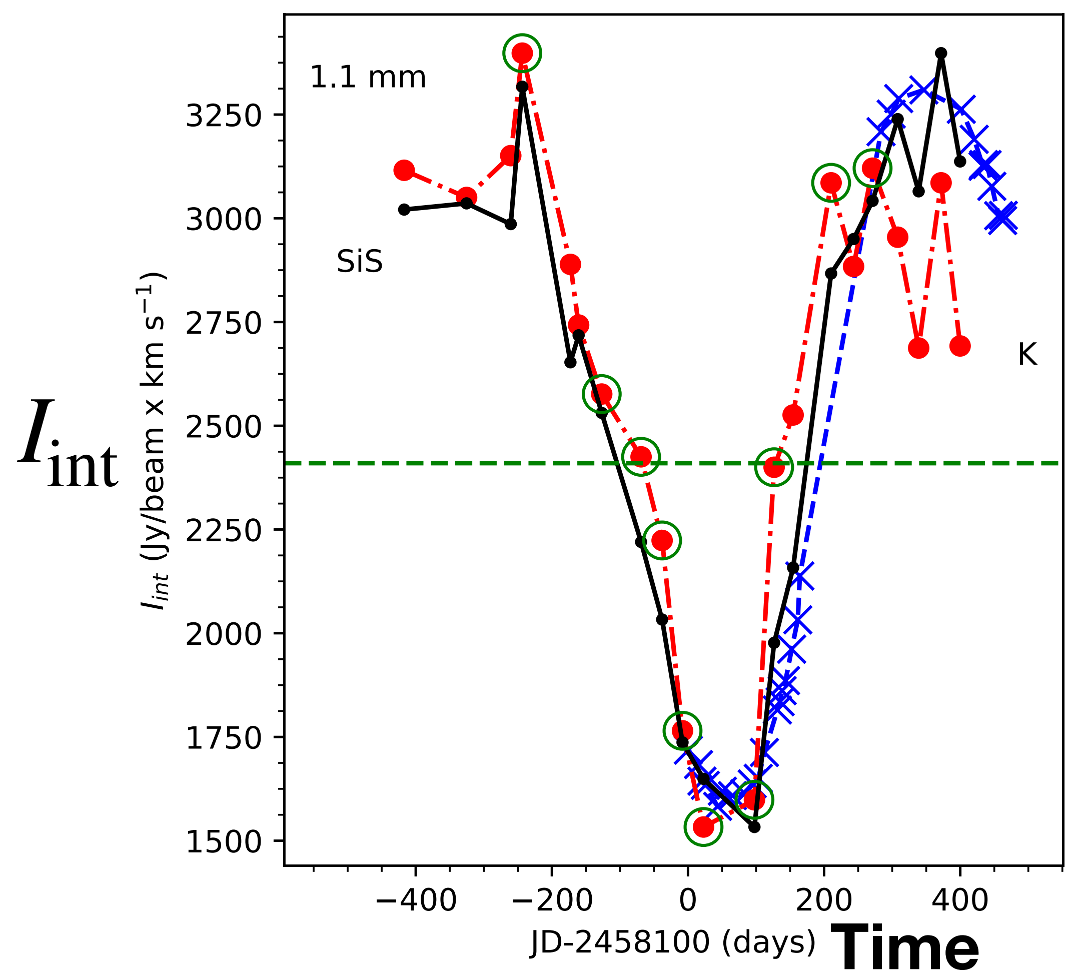
Identified 229 lines: 148 from 20 mols (and more isotopologues) + 81 unidentified lines. 125 line features.

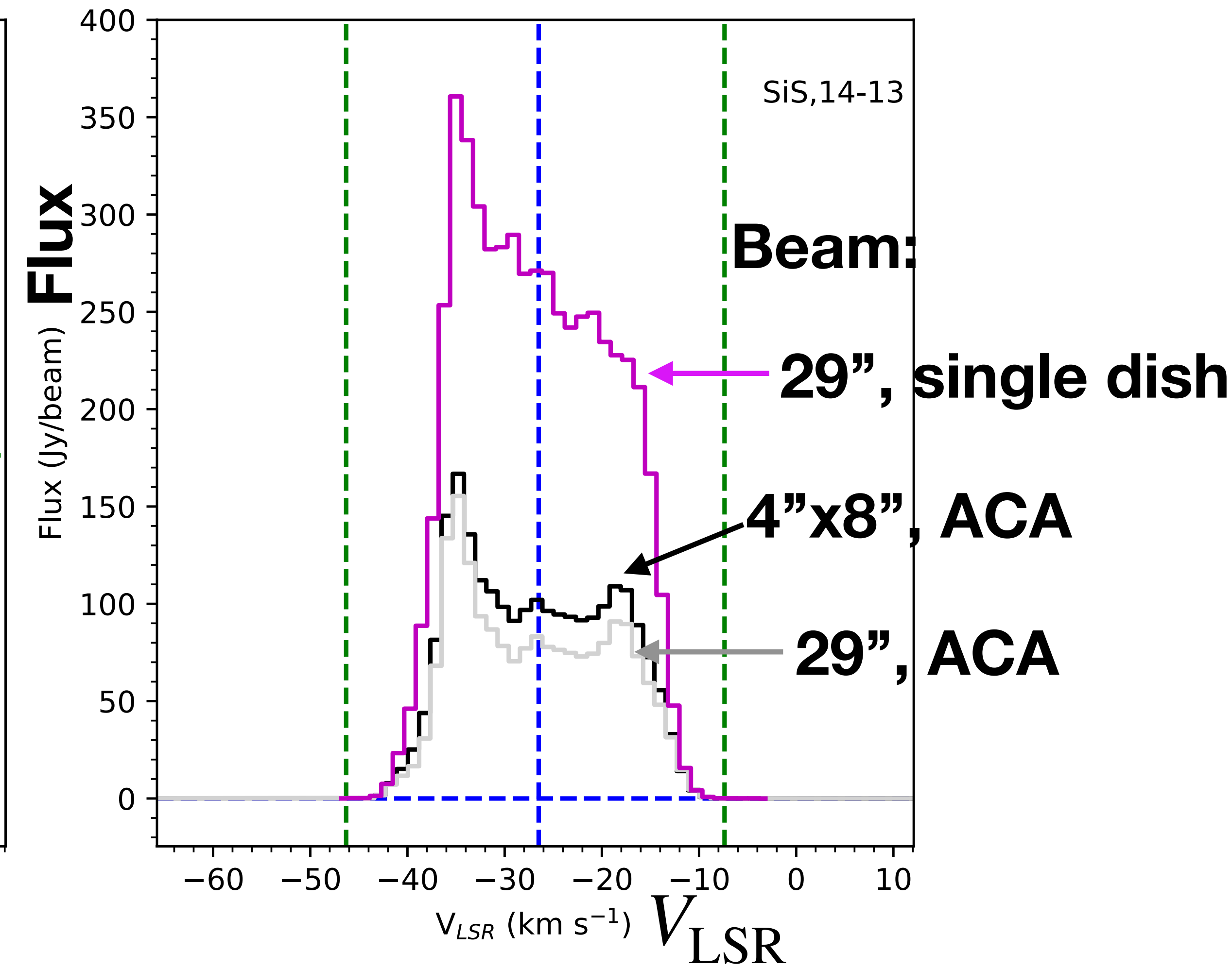
C_2H, C_3H, C_4H, c-C_3H, c-C_3H_2, HCN, C_3N, HC_3N, CH_2NH, CH_3CN,
KCl, KF, KCN, NaCN, NaCl,
SiS, SiC, SiCC, SiO,
CS.

Some lines from vibrational states:
SiS 14-13, v=0,1,2,3,4
HCN v_2= 0,1,2,3

Overview of ALMA results

Example light curves and average line profiles:

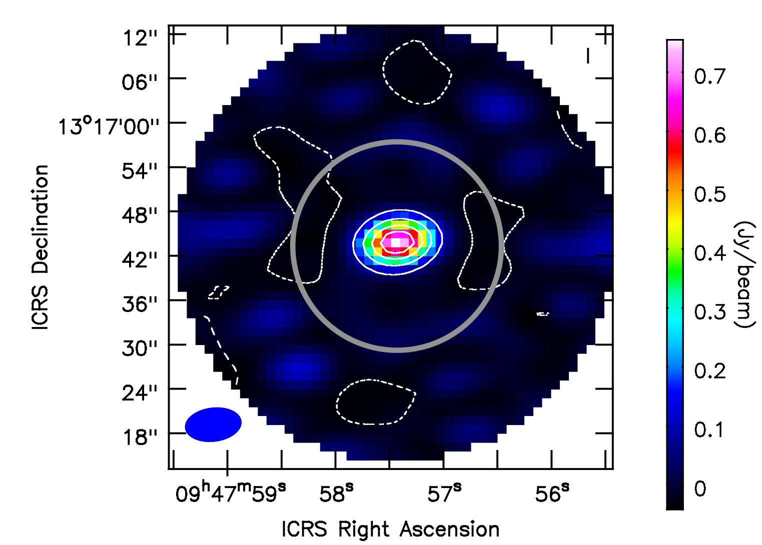




Red: 1.1mm continuum (normalized)

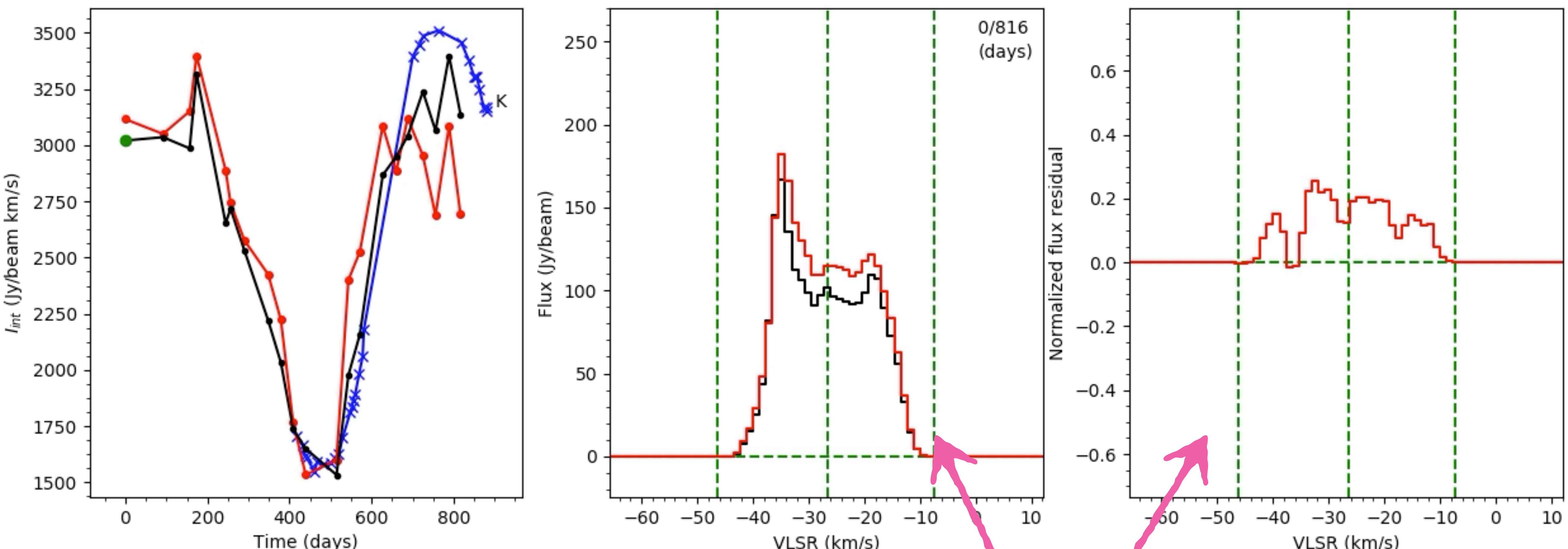
Blue: K-band (normalized)

Black: integrated SiS 14-13 line



Overview of ALMA results

SiS 14-13 light curve:

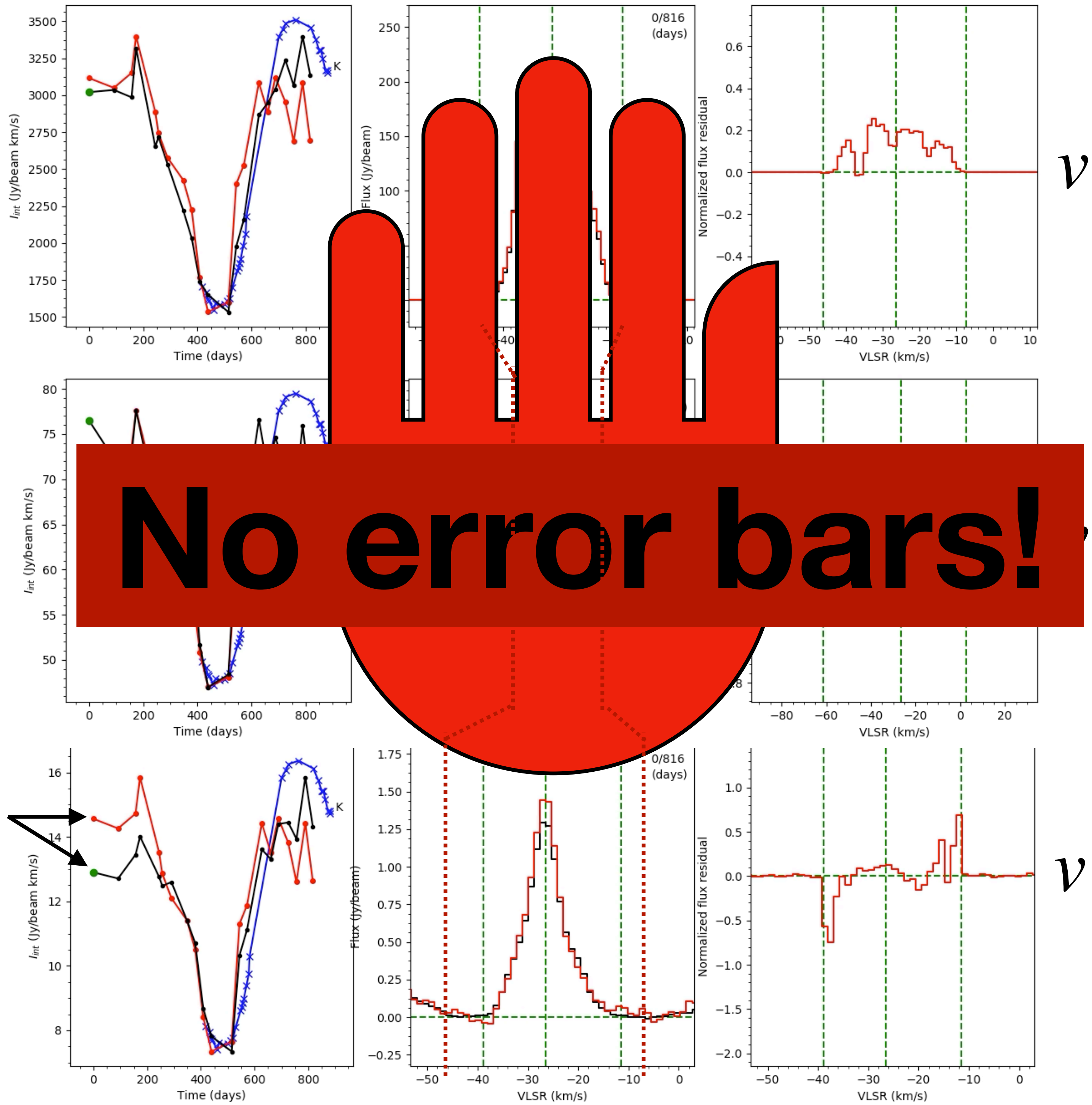


ying part of
ine profile

1) Variation of line profile shape.
2) The two maser peaks disappear at the minimum time.

Overview of ALMA results

SiS 14-13 light curves:



$v = 0$ **Var in shape**

$v = 1$ **Var in shape**

$v = 2$ **Non-var in shape**

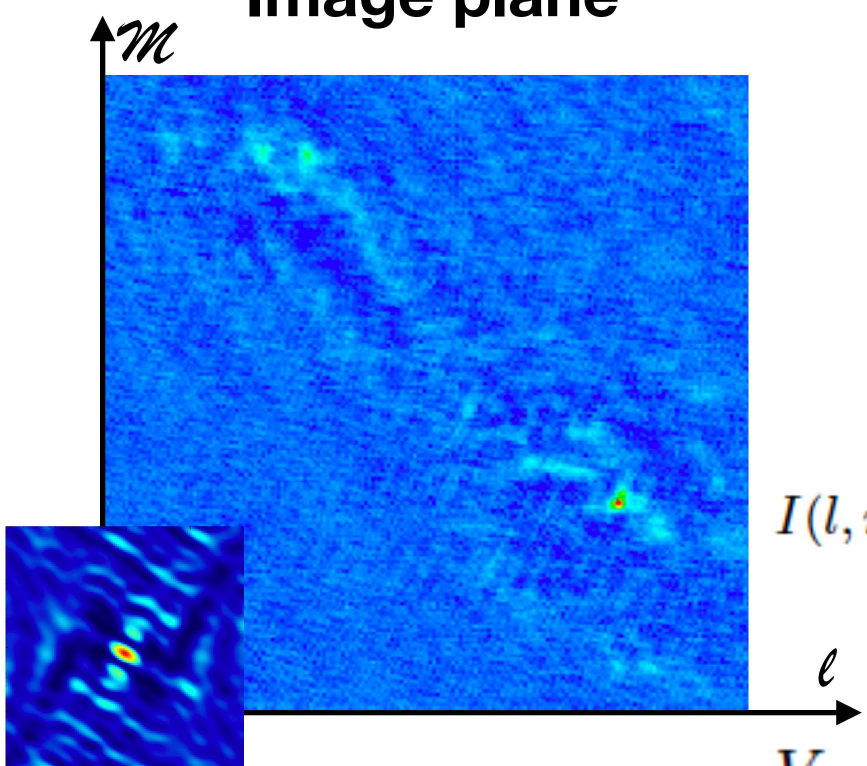
Difference in light curve

Challenges in constraining flux uncertainties.

Challenges in flux uncertainty handling

- The CLEAN method:

Image plane

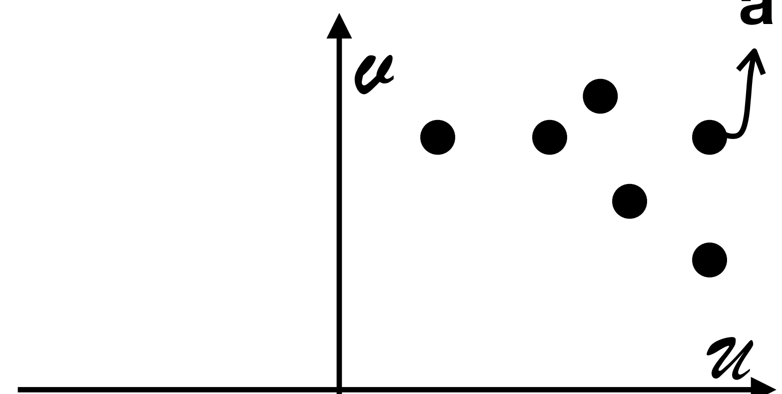


FT

$$I(l,m) = \sum_{j=1}^{M} w_j V_{0,j} e^{2\pi i (u_j l + v_j m)}$$

UV plane

A baseline: a visibility



$$V_{0,j} = p_0(u_j, v_j) e^{i\phi_0(u_j, v_j)} = x_0(u_j, v_j) + i y_0(u_j, v_j)$$

- **Major shortcomings of CLEAN:**
  - ✳ **Correlations of visibility are not included.**

Challenges in flux uncertainty handling

Astro targets

- The CLEAN method:

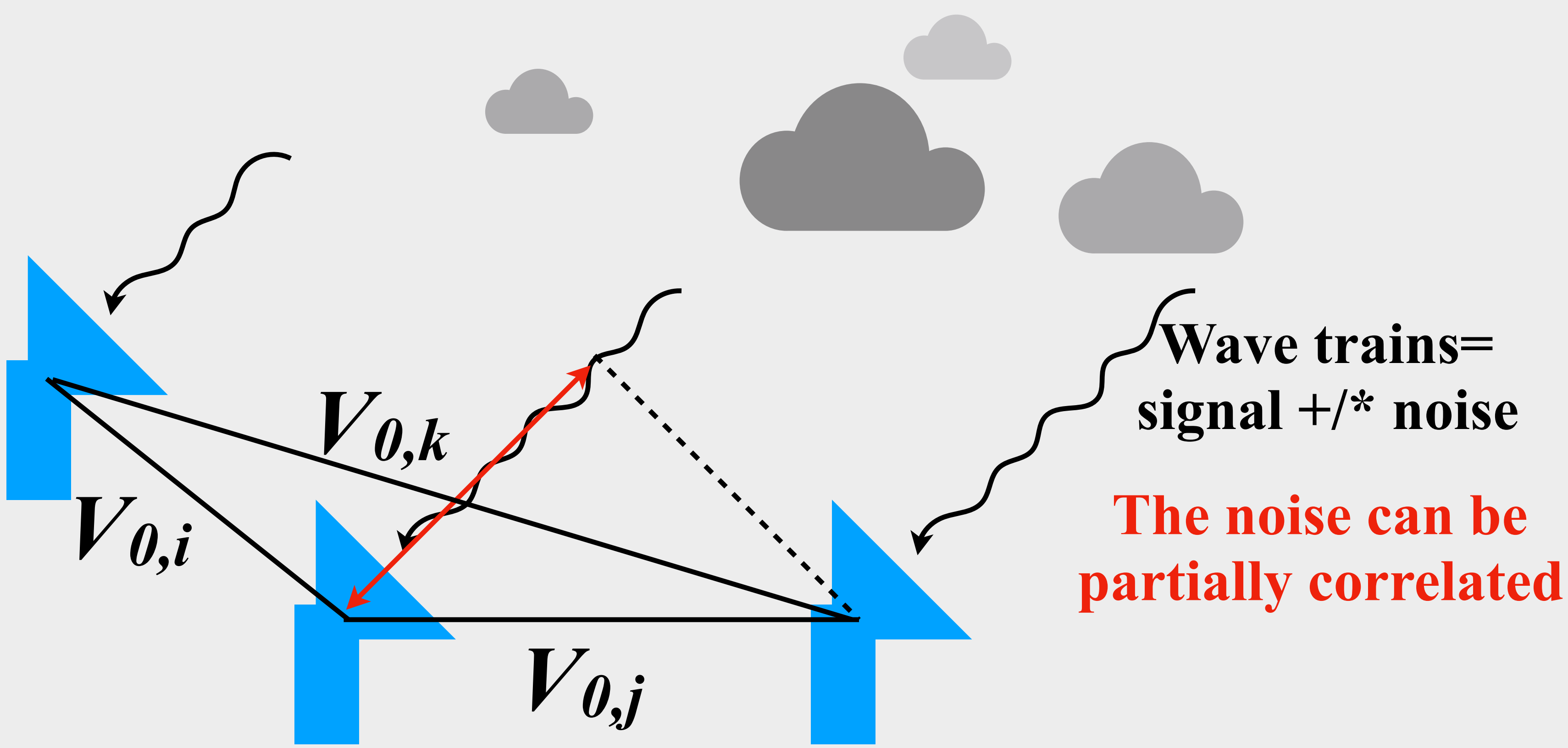
Visibility correlations.

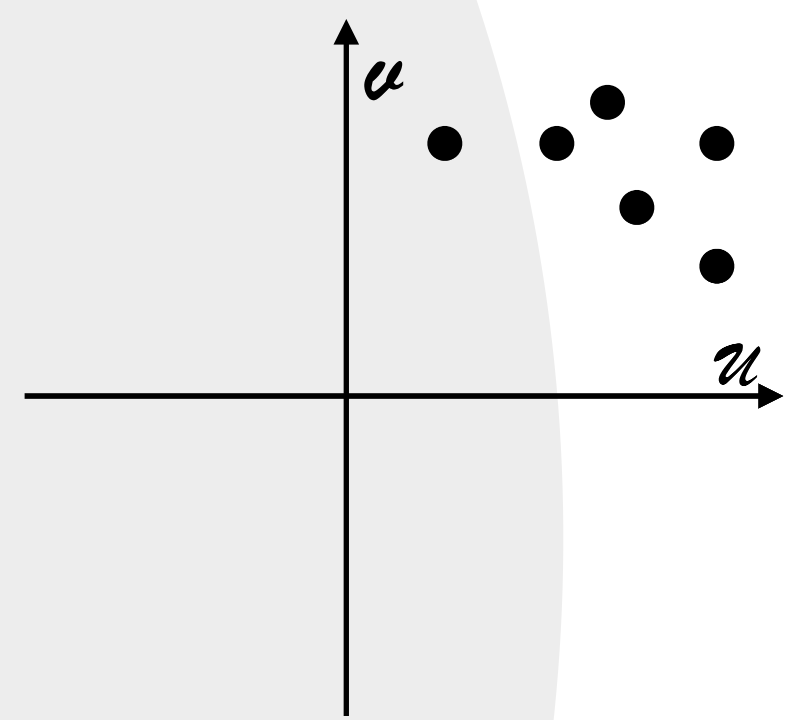
✦Share of atmosphere and ISM

✦Share of antennas

ISM = another random field
Correlation size scale
Correlation time
(scintillation)

Atmosphere = a random field
Correlation size scale
Correlation time

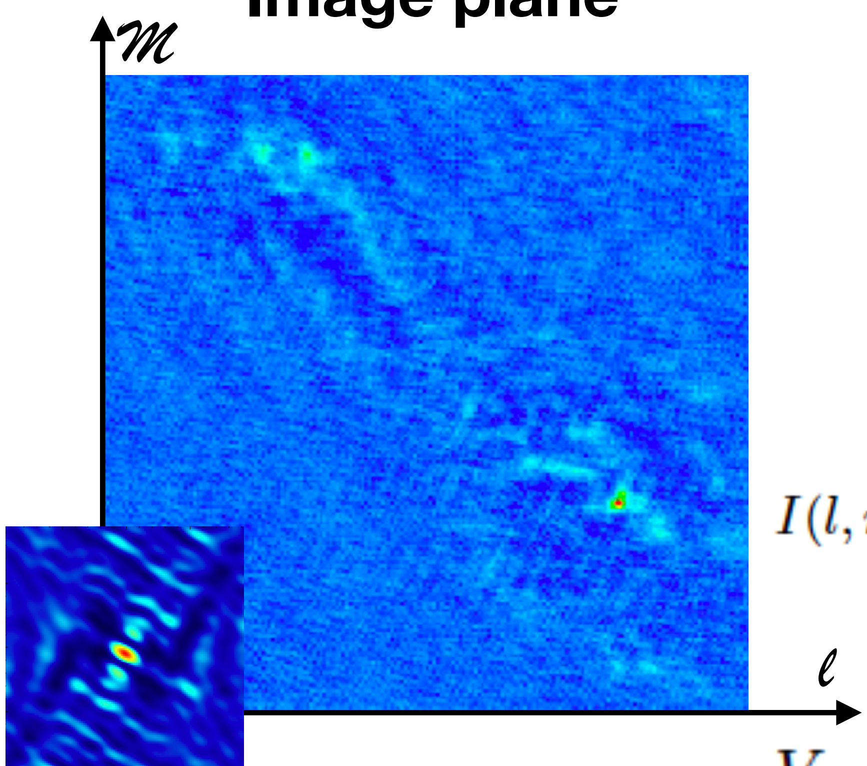




Challenges in flux uncertainty handling

- The CLEAN method:

Image plane

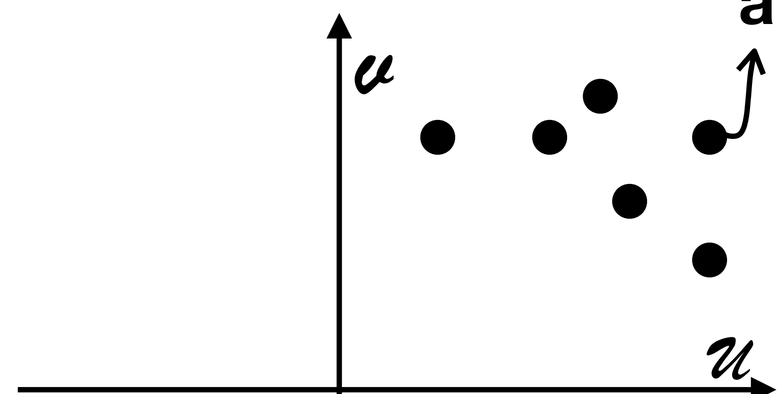


Dirty beam

FT

UV plane

A baseline:
a visibility



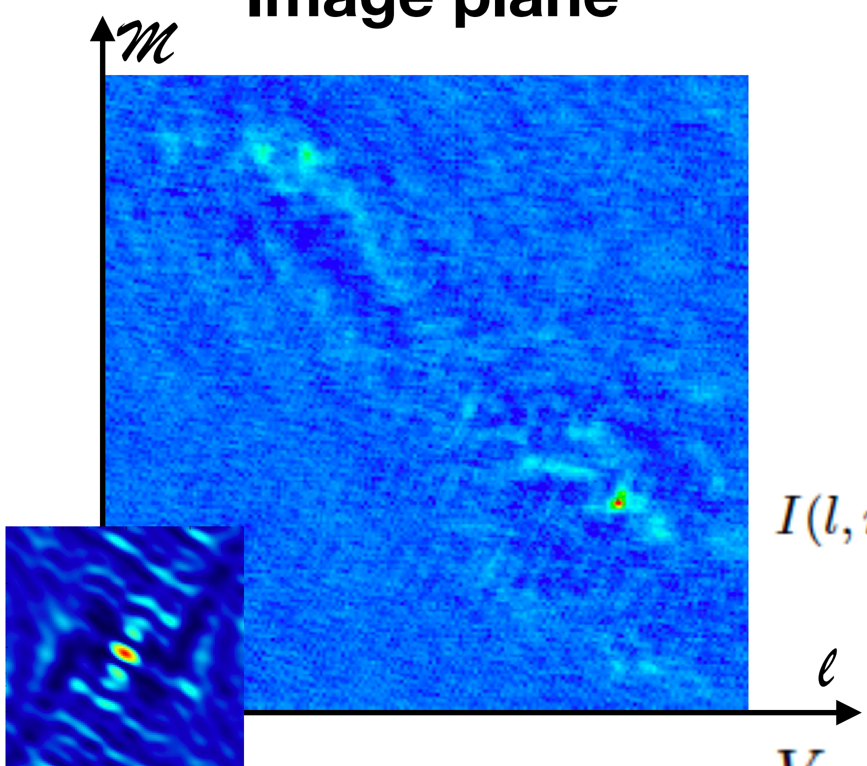
$$I(l,m) = \sum_{j=1}^{M} w_j V_{0,j} e^{2\pi i(u_j l + v_j m)}$$

$$V_{0,j} = p_0(u_j, v_j) e^{i\phi_0(u_j,v_j)} = x_0(u_j, v_j) + i y_0(u_j, v_j)$$

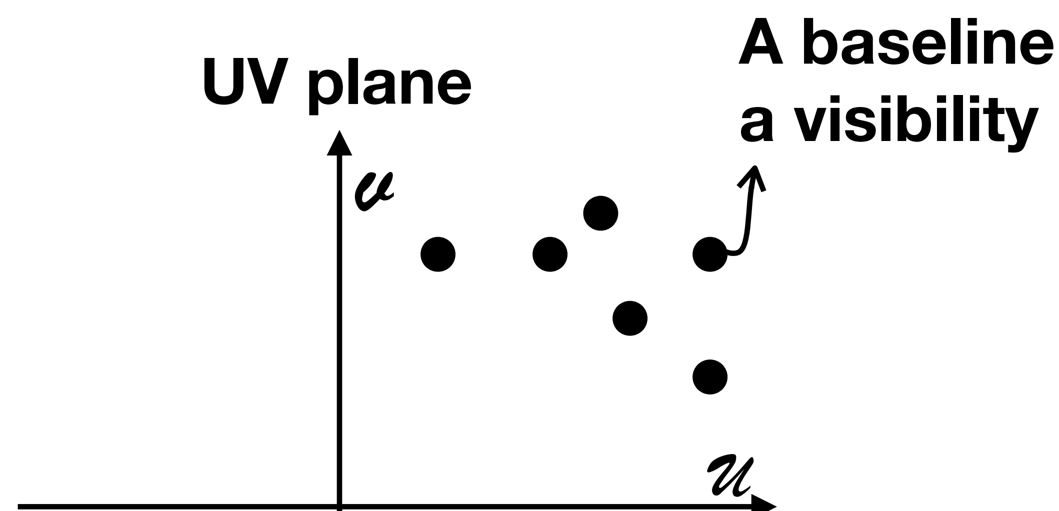
- **Major shortcomings of CLEAN:**
  - ✳**Correlations of visibility are not included.**
  - ✳**Transfer of observation error is not considered.**

Challenges in flux uncertainty handling

- The CLEAN method:



FT



$$I(l,m) = \sum_{j=1}^{M} w_j V_{0,j} e^{2\pi i(u_j l + v_j m)}$$

$$V_{0,j} = p_0(u_j, v_j) e^{i\phi_0(u_j,v_j)} = x_0(u_j, v_j) + i y_0(u_j, v_j)$$

- **Major shortcomings of CLEAN:**
  - ✳**Correlations of visibility are not included.**
  - ✳**Transfer of observation error is not considered.**
  - ✳**Pixel correlations are not considered adequately.**

Challenges in flux uncertainty handling

- For our ALMA monitoring project:

We hope to decently constrain
the flux uncertainties and their correlations
in both spatial and time dimensions.

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But, it is impossible with CLEAN

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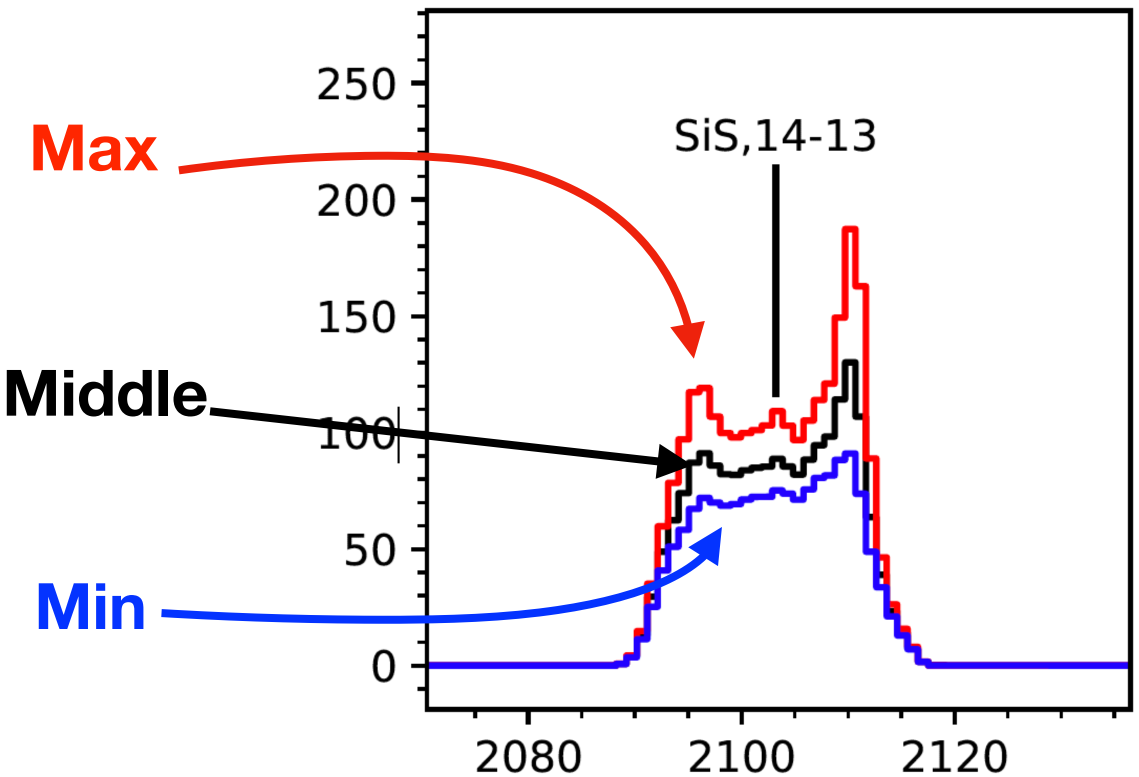
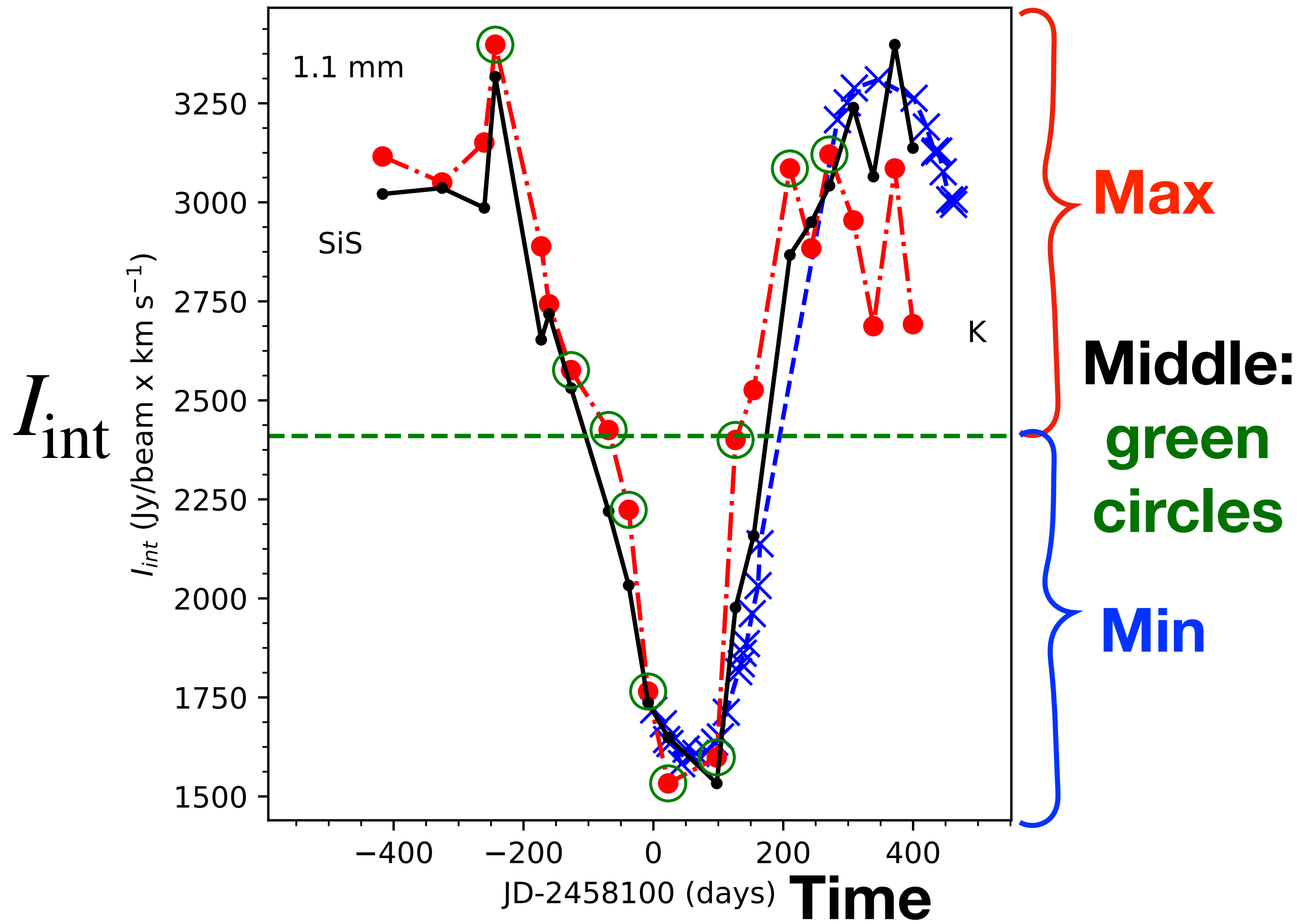
We are trying to make a new approach by ourselves!

First ALMA results:
a qualitative presentation

Qualitative ALMA results

Define three average spectra:





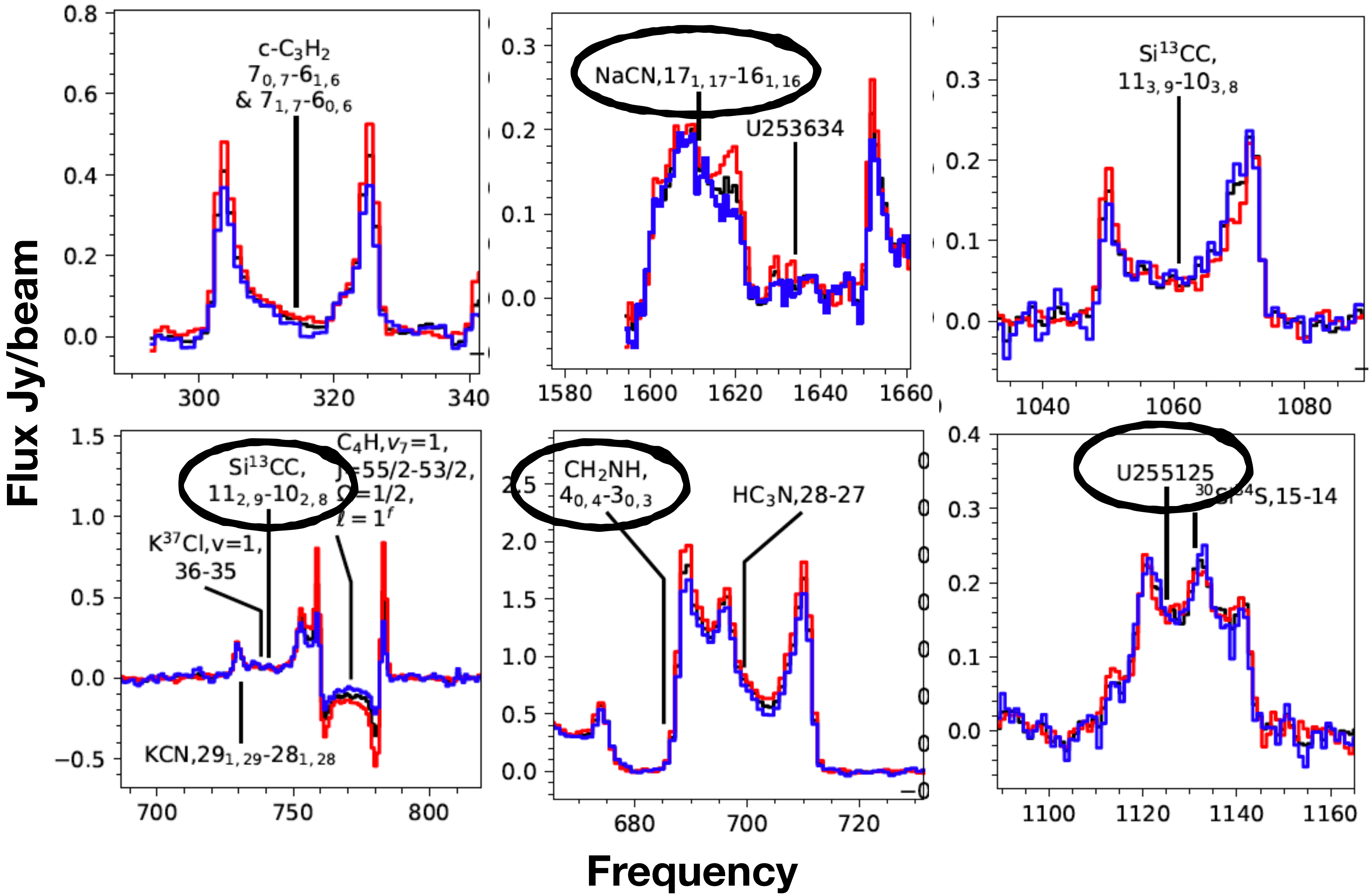
Red: 1.1mm continuum (normalized)
Blue: K-band (normalized)
Black: integrated SiS 14-13 line

Qualitative ALMA results

The line profiles can be divided into three groups:

1) stable lines;

Examples

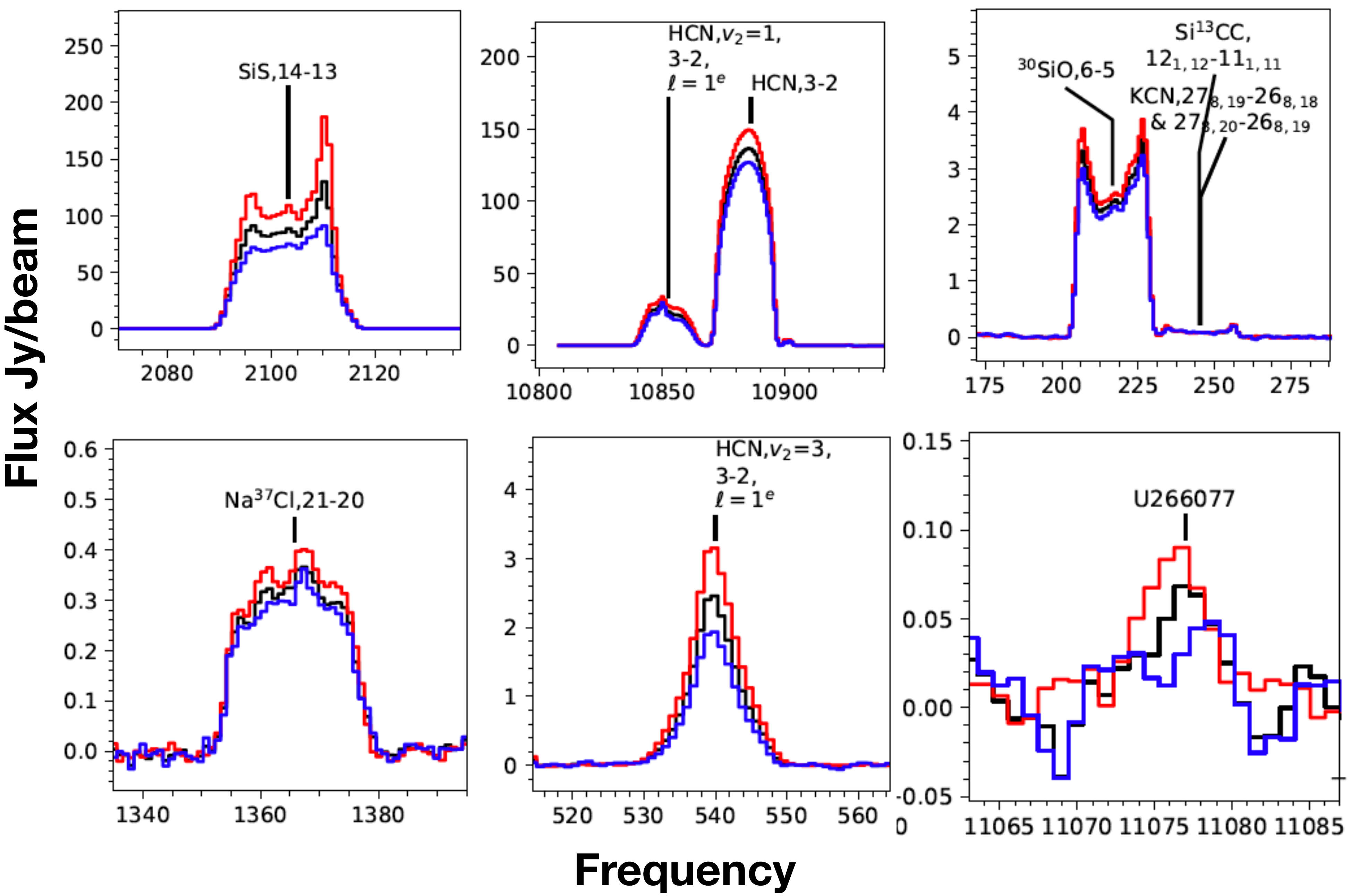


Qualitative ALMA results

The line profiles can be divided into three groups:

1) **stable lines;**
2) **those correlated with IR & mm cont.;**

Examples

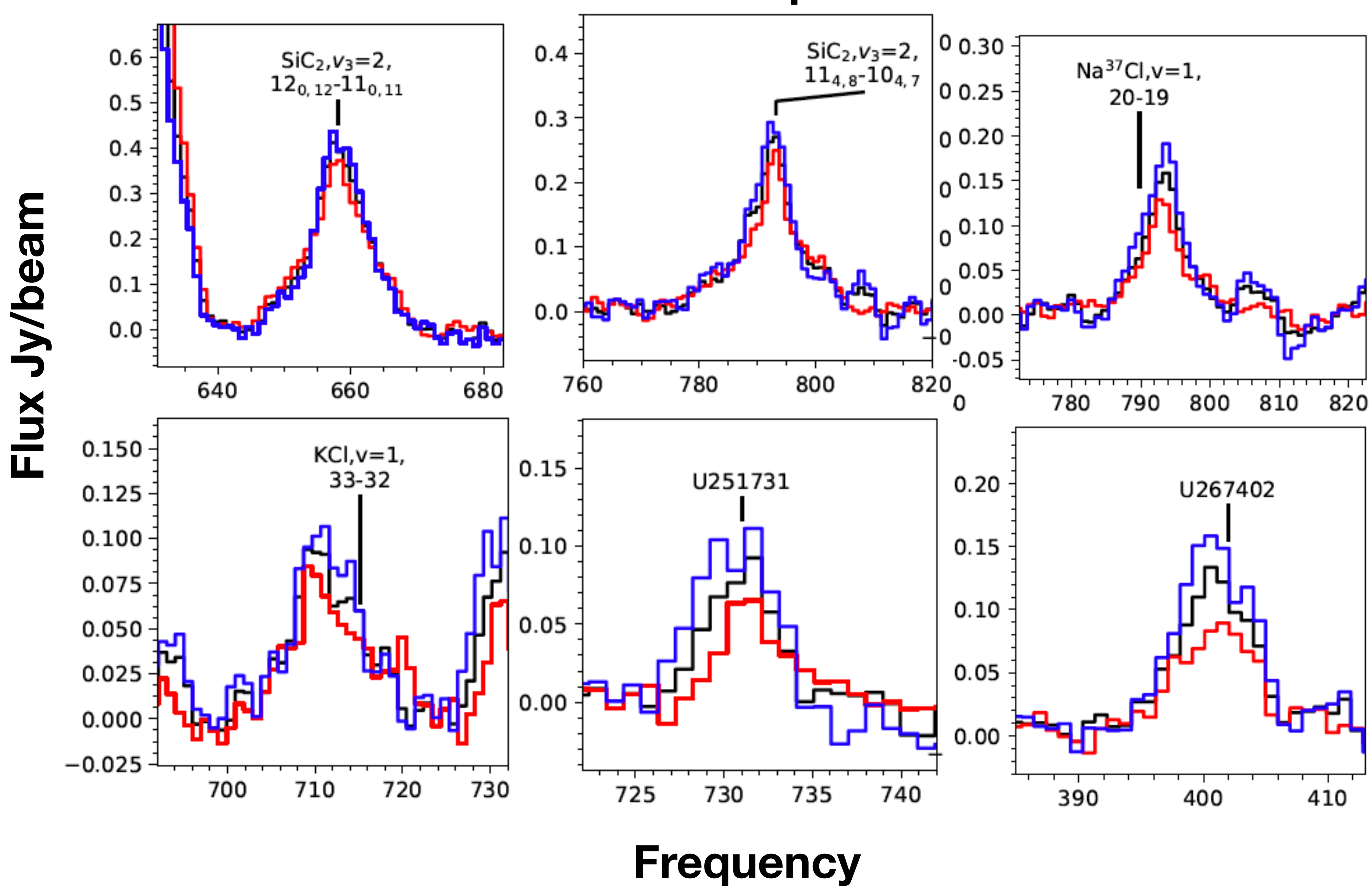


Qualitative ALMA results

The line profiles can be divided into three groups:

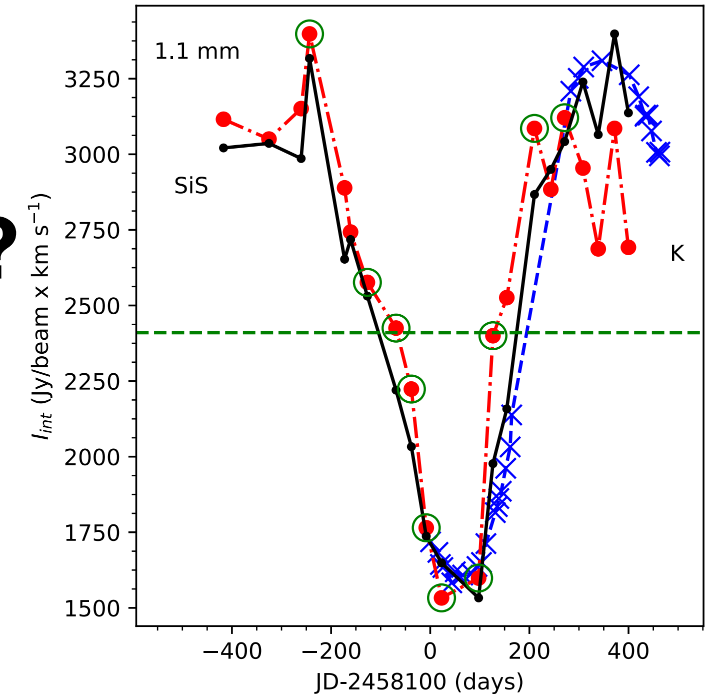
1) **stable lines;**
2) **those correlated with IR & mm cont.;**
3) **those anti-correlated with IR & mm cont.**

Examples



Qualitative ALMA results

Comments to the three types of behavior:



- **Stable lines: in-band calibration possible?**

- **Correlated lines: excited by IR light?**
  - **Speed up dust grains => couple to Tk**
  - **IR excitation of low lying vib. levels**
  - **IR pumping of mm masers (e.g., SiS 14-13)**

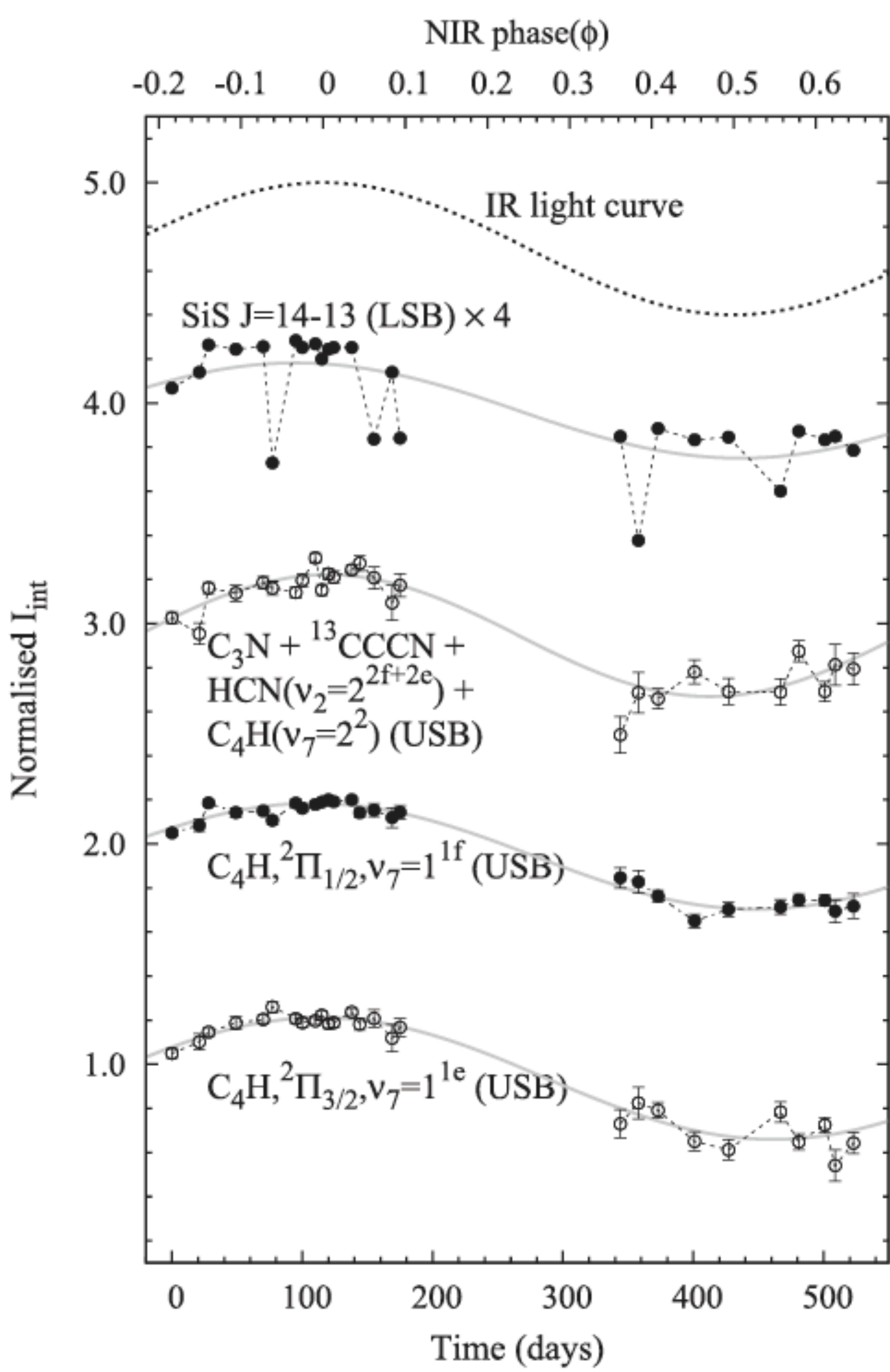
- **Anti-correlated lines:**
  - **Evacuation some levels and overpopulate some others by IR excitations (Cernicharo+ 2014).**

Eup: not correlated with the three behavior types.

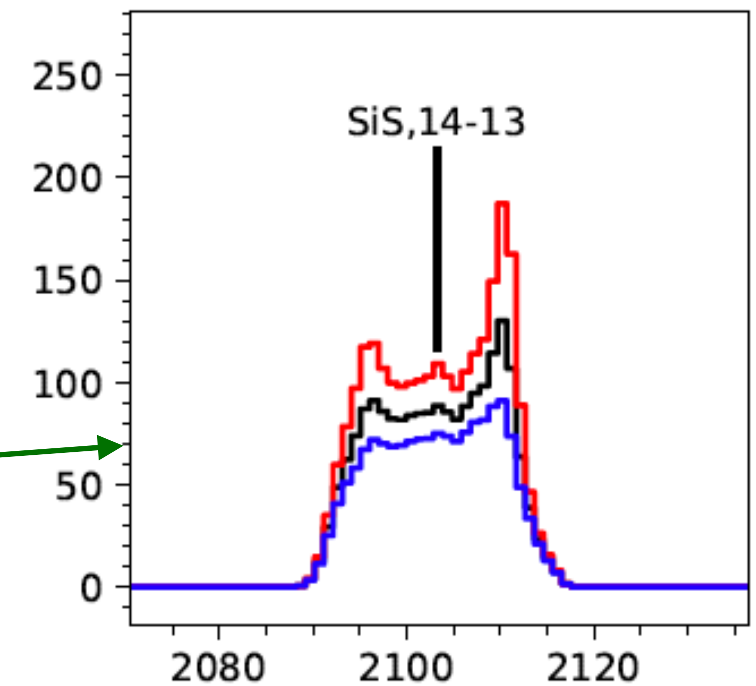
Qualitative ALMA results

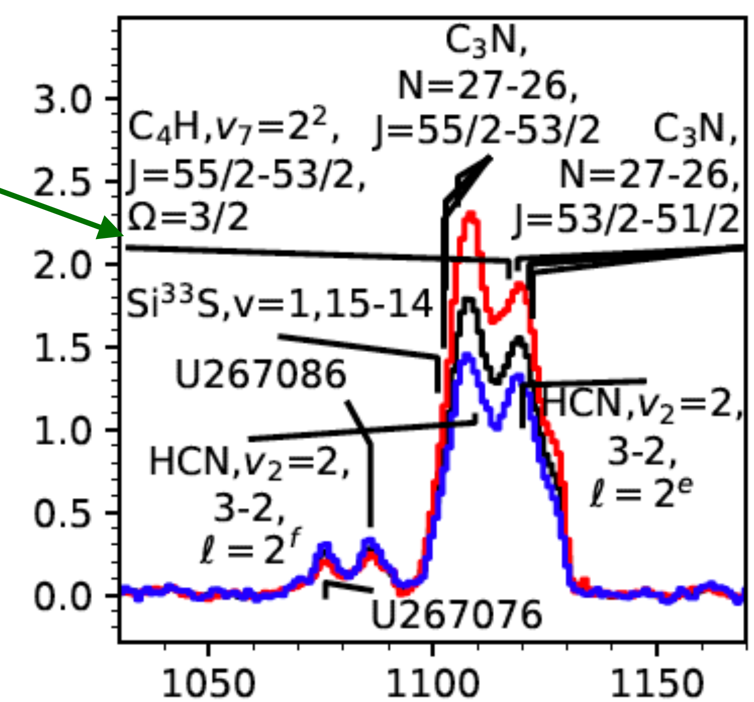
Qualitative comparison: ALMA vs single dish results:

Single dish	ALMA
In phase with IR	In phase with IR



Agree

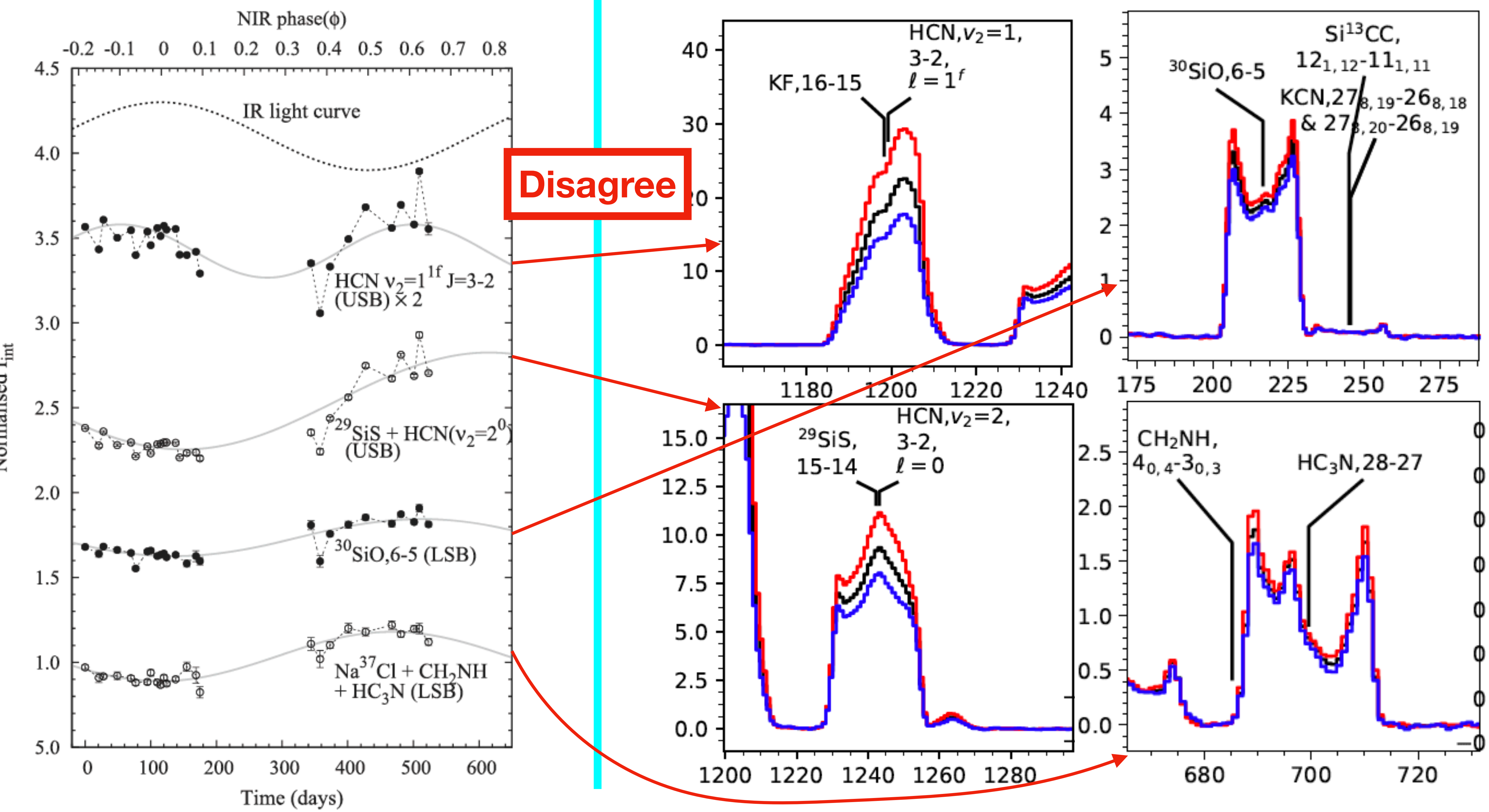




Qualitative ALMA results

Qualitative comparison: ALMA vs single dish results:

Single dish	ALMA
Out of phase with IR	In phase with IR



Qualitative ALMA results

Qualitative comparison: ALMA vs single dish results:

Why do some lines agree and some others disagree?

Missing flux of the ALMA data

Different beam sizes: 4”x8” vs 29”

Still need some mechanisms to operate in the CSE to differentiate the different lines.

Summary

- **Our ALMA/ACA monitoring of IRC +10216 has revealed rich varying 1.1mm lines (125 line features: 148 lines of 20 mols and their isotopologues + 81 U-lines).**
- **Still difficult to derive flux uncertainties with CLEAN. We are trying to improve it…**

Next step…

- **A qualitative presentation (max, middle, min spec.) has shown:**

  ★**Stable lines; lines correlated and anti-correlated with IR & 1.1mm cont. Interpretations need to be explored.**

  ★**ALMA vs single dish:**
  Variation behaviors are similar for two lines, but different for another four. The interpretation is an open question.

Fin.

¡Gracias!