WE ARE ALL MADE OF STARS

WITHOUT STARS, WE WOULDN'T BE HERE. STARS PRODUCE BASIC ELEMENTS, LIKE CARBON, THE FOUNDATION OF THE COMPLEX MOLECULES WHICH MAKE UP LIFE.

AS • TRO • CHEM • IS • TRY

/ astrō'keməstrē /

(n) the study of molecules in space - where they are, how they got there, and what they are doing

THE BIG QUESTION

Where do we come from?

What is the interstellar molecular inventory?

How does chemistry evolve toward complexity?

How does physical environment impact chemical evolution?

THE BIG QUESTIONS

What is the interstellar molecular inventory?

How does chemistry evolve toward complexity?

How does physical environment impact chemical evolution?

What molecules are good tracers of astrophysical processes and properties?

THE BIG QUESTIONS

What is the interstellar molecular inventory?

How does chemistry evolve toward complexity?

How does physical environment impact chemical evolution?

~~What molecules are good tracers of astrophysical processes and properties?~~

GBO facilities are, and always have been, at the forefront of astrochemical discovery

‘Minor’ technical upgrades will enable significant new science

The upgrade we really need is political, not technical

VOLUME 22, NUMBER 13 PHYSICAL REVIEW LETTERS 31 MARCH 1969

MICROWAVE DETECTION OF INTERSTELLAR FORMALDEHYDE

Lewis E. Snyder and David Buhl
National Radio Astronomy Observatory,* Green Bank, West Virginia 22901

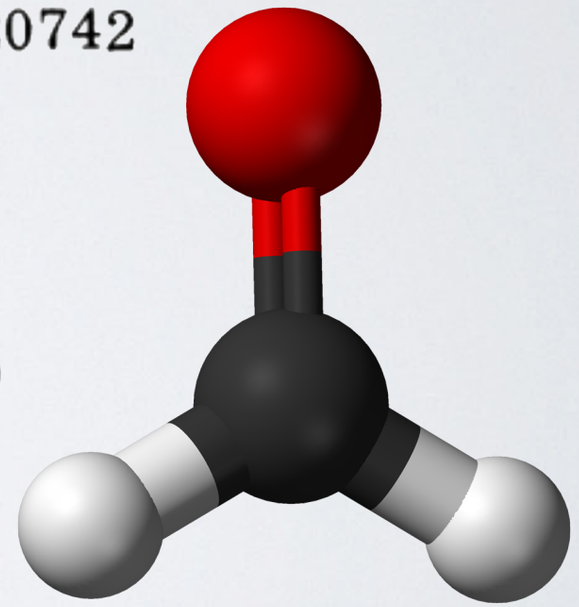
and

B. Zuckerman
University of Maryland, College Park, Maryland 20742

and

Patrick Palmer
University of Chicago, Chicago, Illinois 60680

(Received 17 March 1969)



THE ASTROPHYSICAL JOURNAL, 162:L203–L210, December 1970

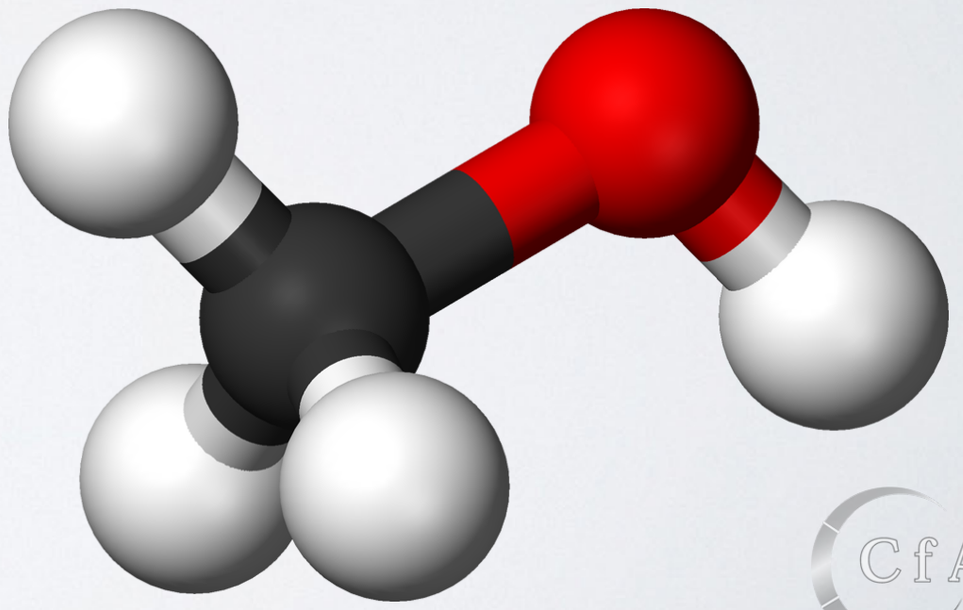
DETECTION OF METHYL ALCOHOL IN SAGITTARIUS

JOHN A. BALL, CARL A. GOTTLIEB, AND A. E. LILLEY
Harvard College Observatory, Cambridge, Massachusetts

AND

H. E. RADFORD
Smithsonian Astrophysical Observatory, Cambridge, Massachusetts

Received 1970 October 31



CfA

THE ASTROPHYSICAL JOURNAL, 163:L41–L45, 1971 January 15

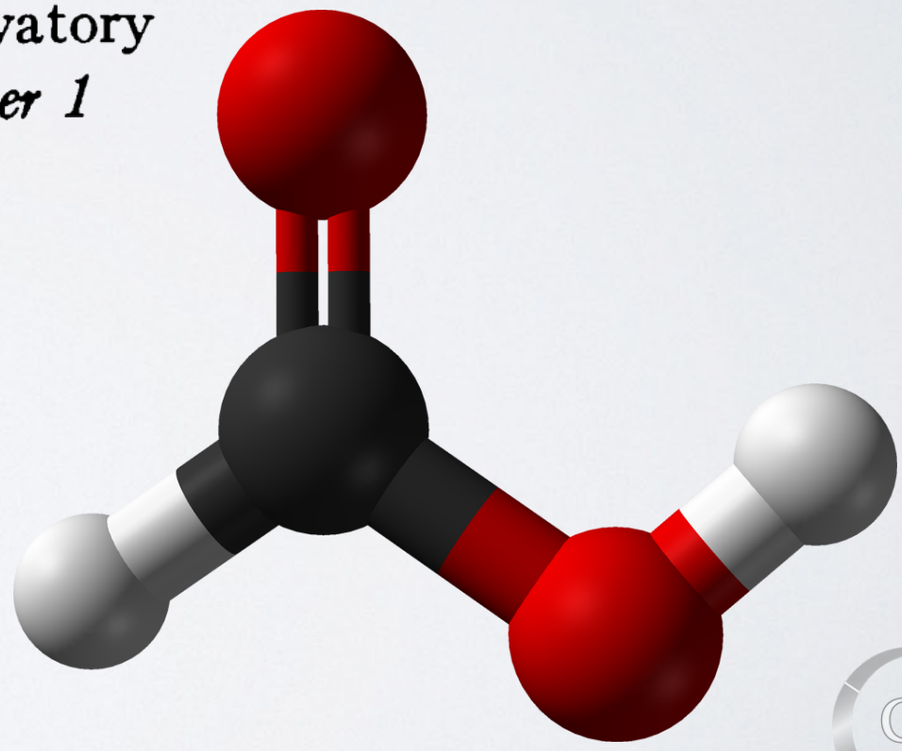
MICROWAVE DETECTION OF INTERSTELLAR FORMIC ACID

B. ZUCKERMAN
University of Maryland

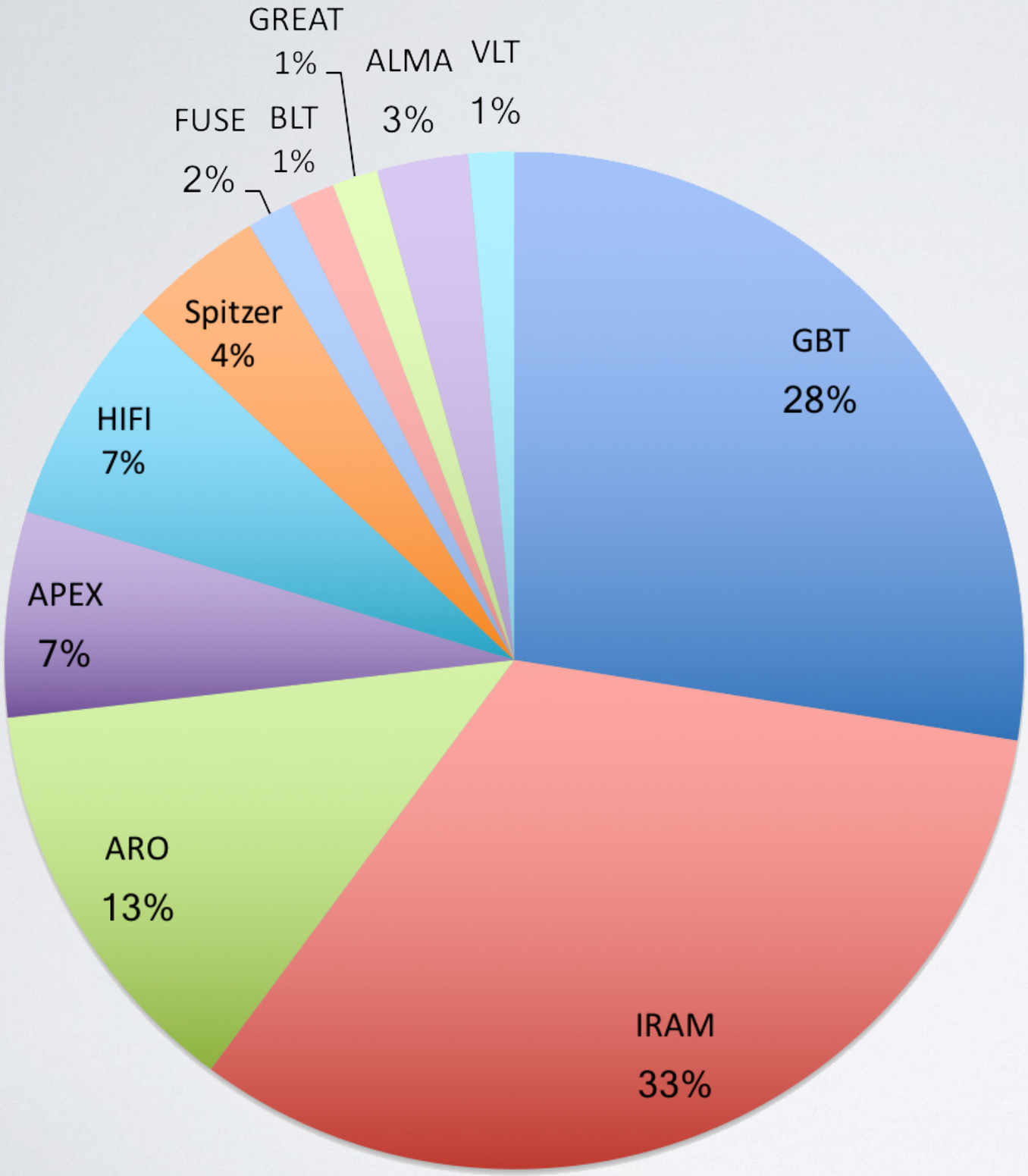
AND

JOHN A. BALL AND CARL A. GOTTLIEB
Harvard College Observatory

Received 1970 December 1

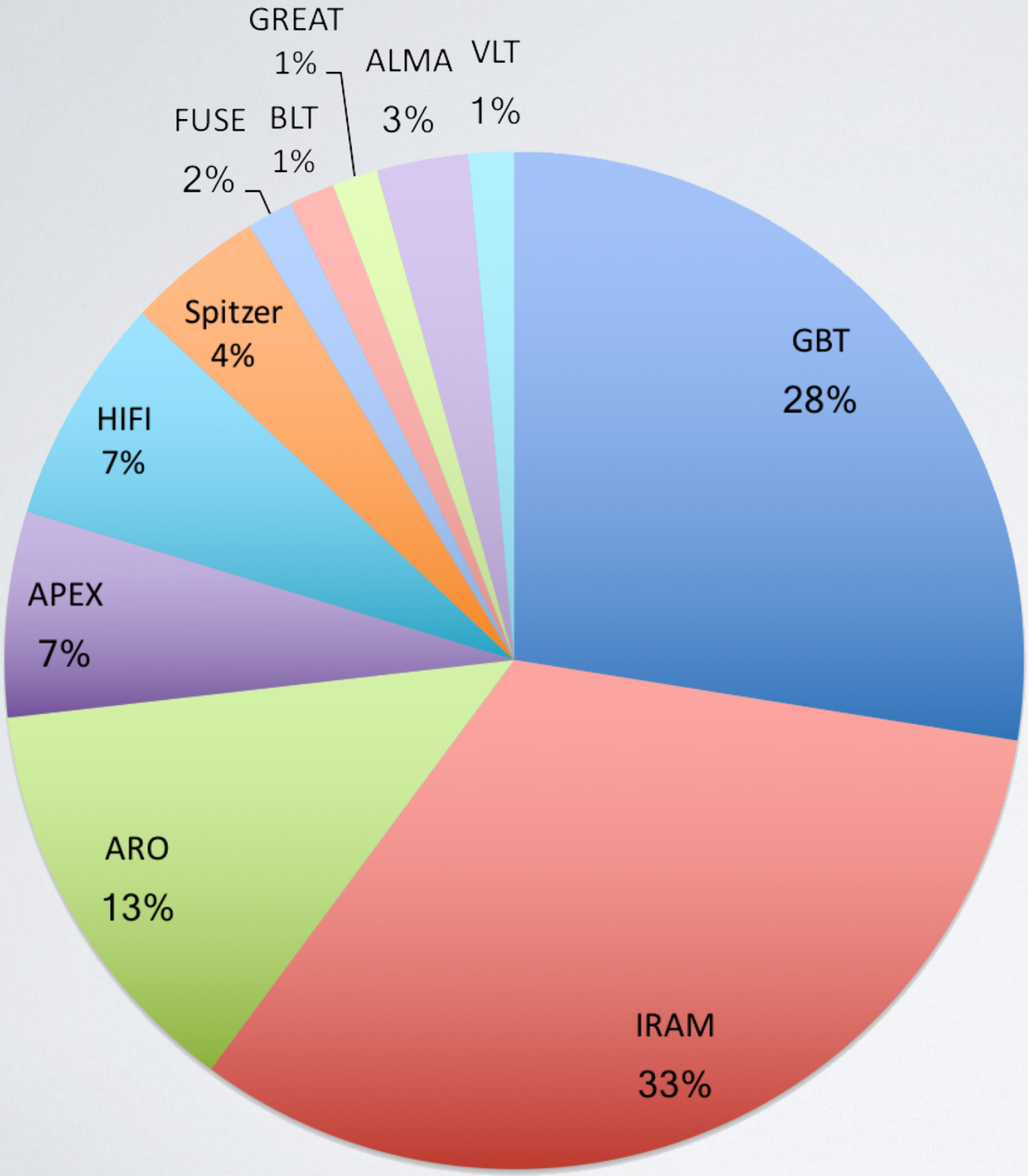


NEW MOLECULAR DETECTIONS SINCE 2004



CH_2CHCHO
CH_3CH_2CHO
CH_2CCHCN
c-H_2C_3O
CH_2CONH_2
CH_3C_6H
CH_2CNH
CH_3C_5N
C_6H^-
C_8H^-
$CNCHO$
$HNCNH$
CH_3CNHN
E-$HNCHCN$
CH_3CHCH_2O
HC_5O
HC_7O

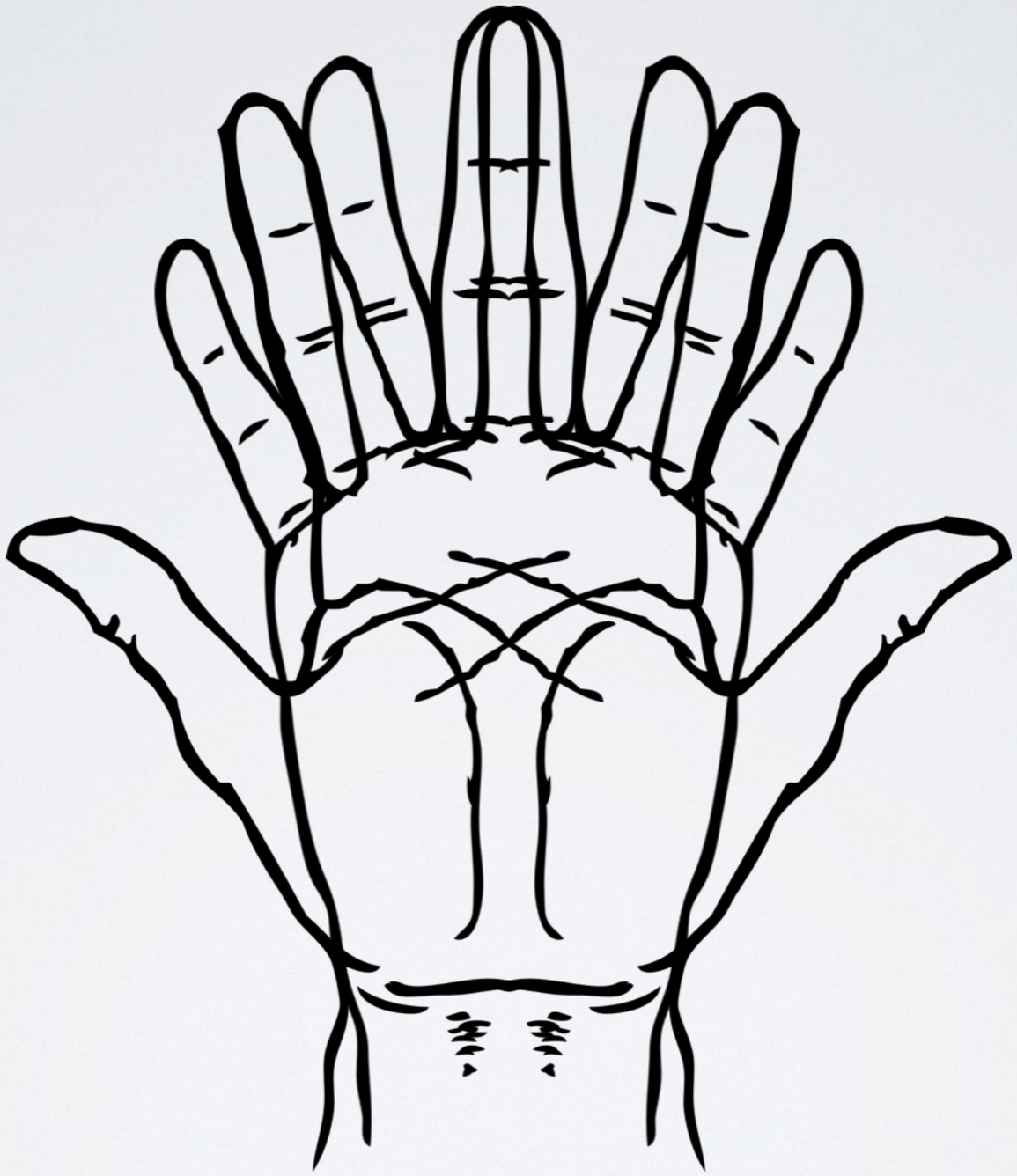
NEW MOLECULAR DETECTIONS SINCE 2004



CH_2CHCHO
CH_3CH_2CHO
CH_2CCHCN
c-H_2C_3O
CH_2CONH_2
CH_3C_6H
CH_2CNH
CH_3C_5N
C_6H^-
C_8H^-
$CNCHO$
$HNCNH$
CH_3CNHN
E-$HNCHCN$
CH_3CHCH_2O
HC_5O
HC_7O

THE SAME, BUT DIFFERENT

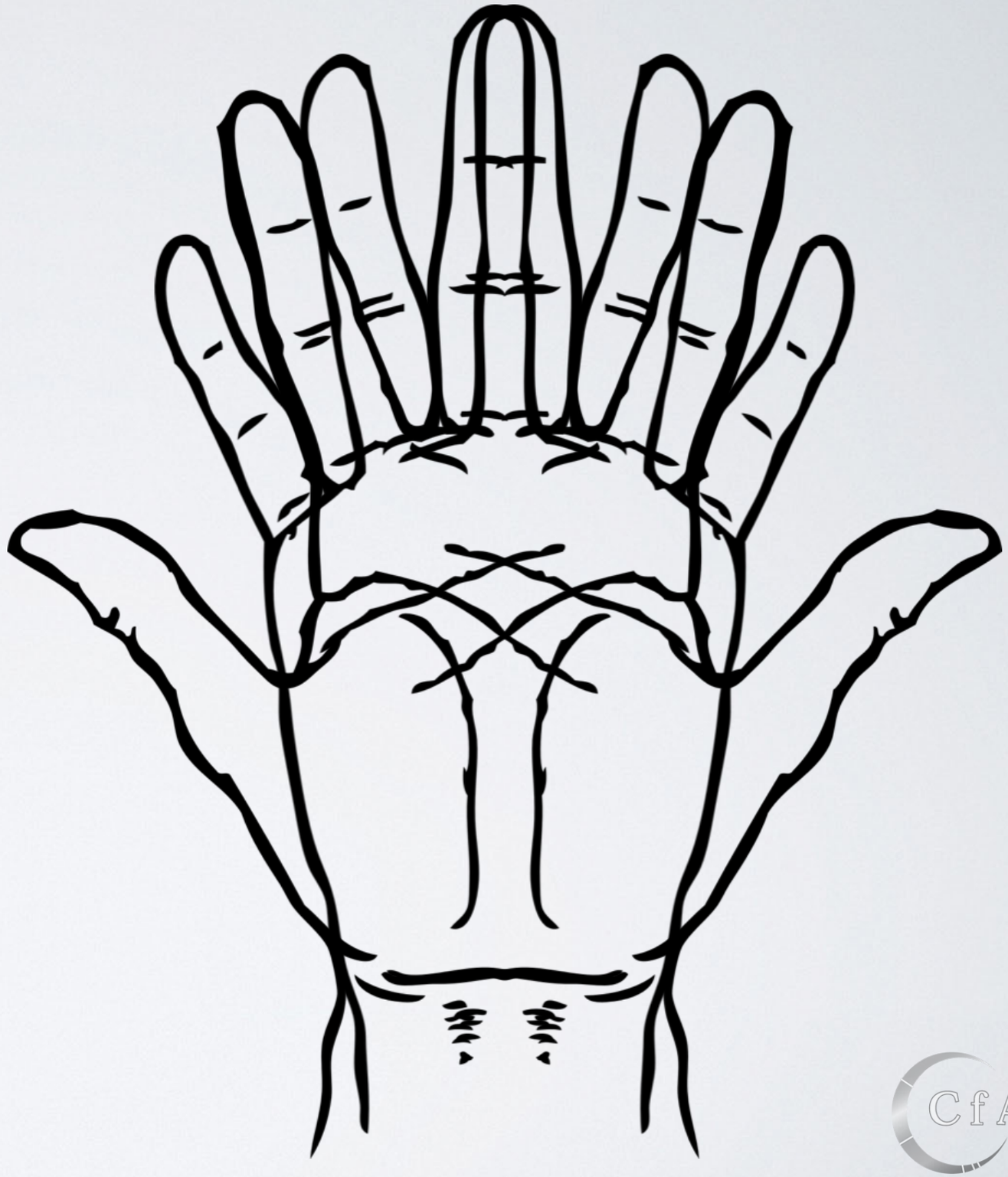
THE SAME, BUT DIFFERENT



Chirality

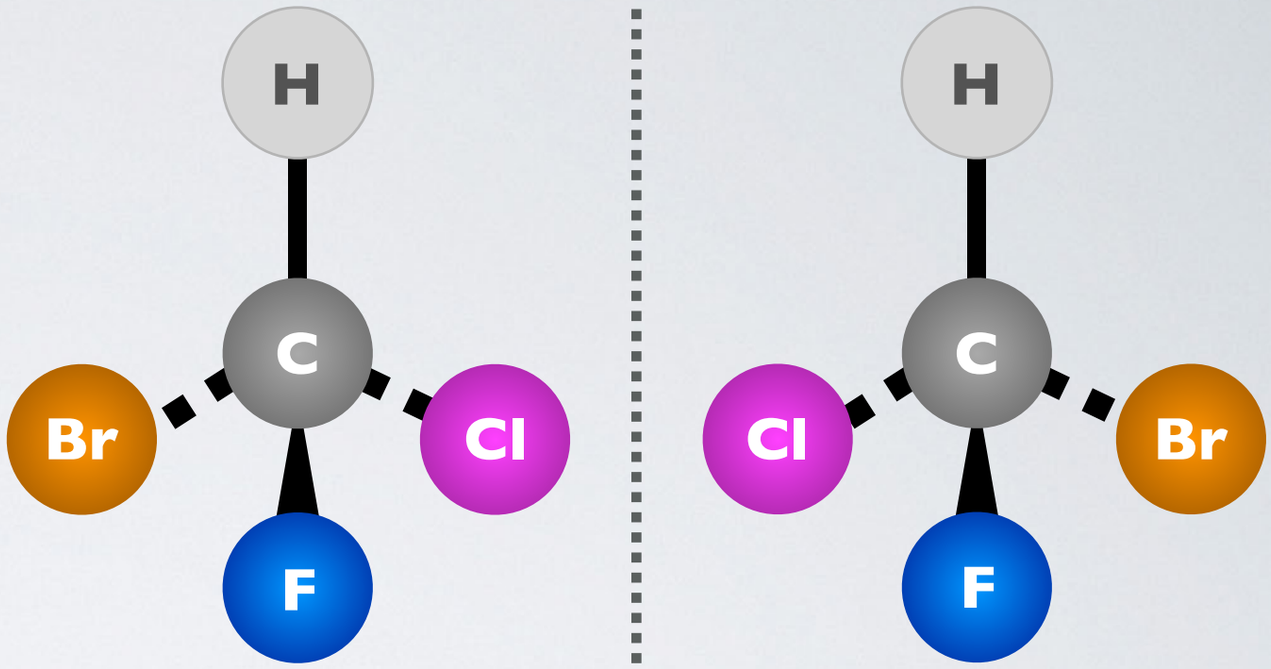
kaɪˈrælɪti

χειρ (kheir) - ‘hand’



Enantiomer

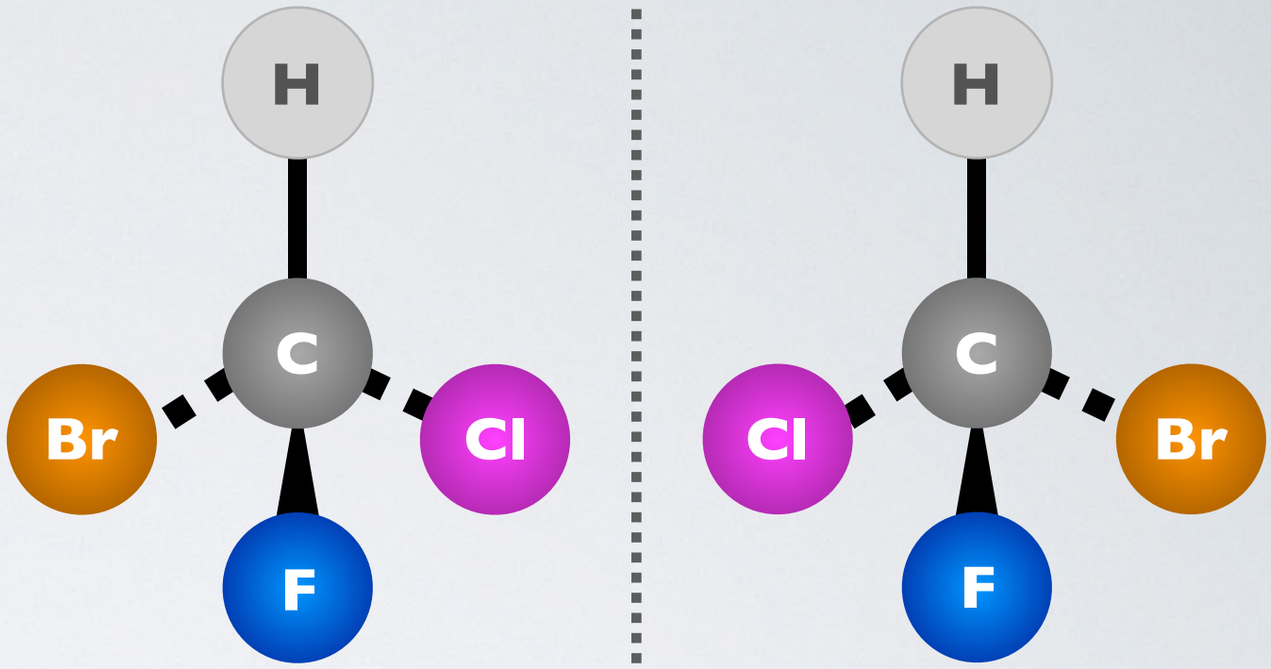
ə'nantēōmər



ἐνάντιος (enántios) - ‘opposite’
μέρος (méros) - ‘part’

Enantiomer

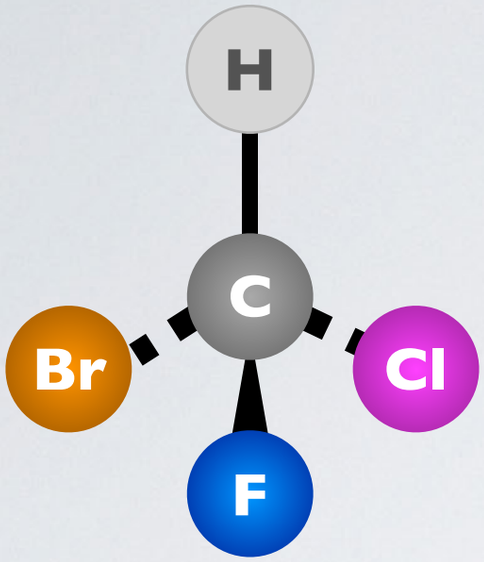
ə'nantēōmər

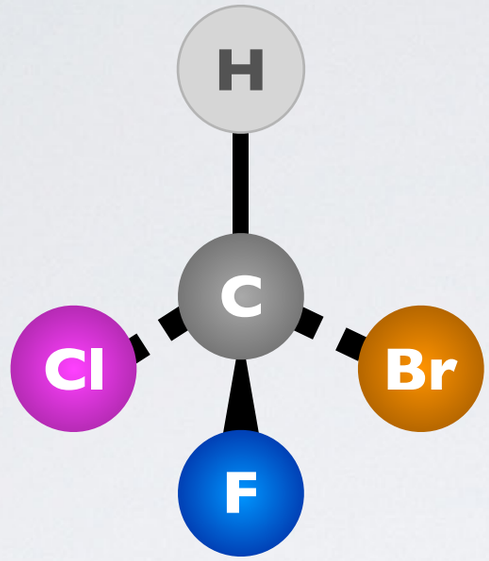


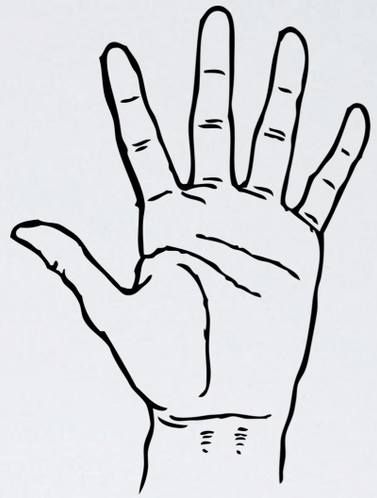
ἐνάντιος (enántios) - ‘opposite’
μέρος (méros) - ‘part’

Left			Right	
(*levorotory*)	L		D	(*dextrorotory*)
(*sinister*)	S		R	(*rectus*)

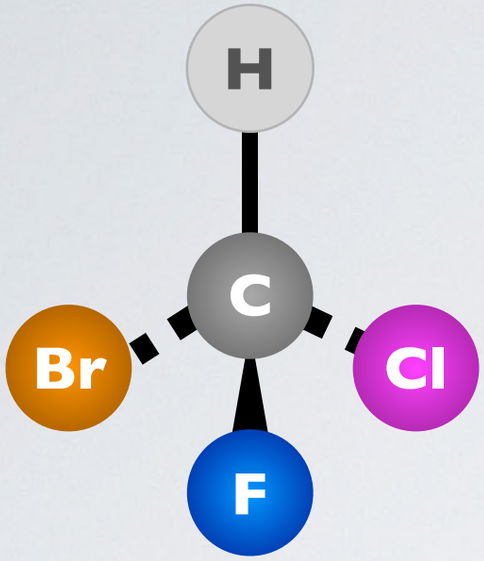
THE SAME

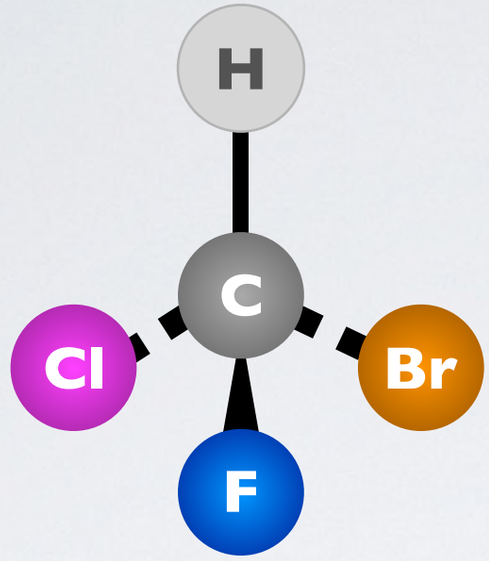


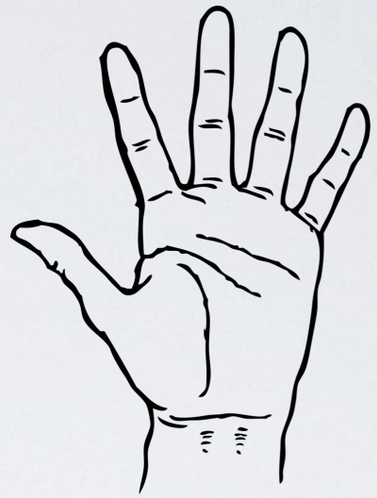




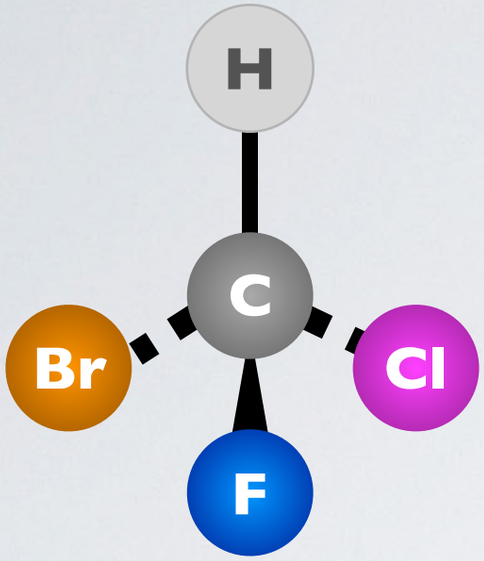
THE SAME

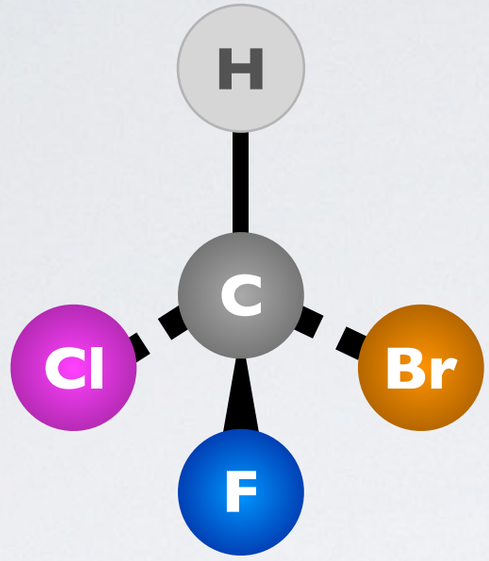


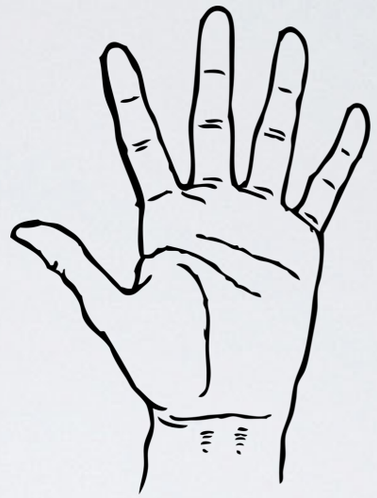




THE SAME

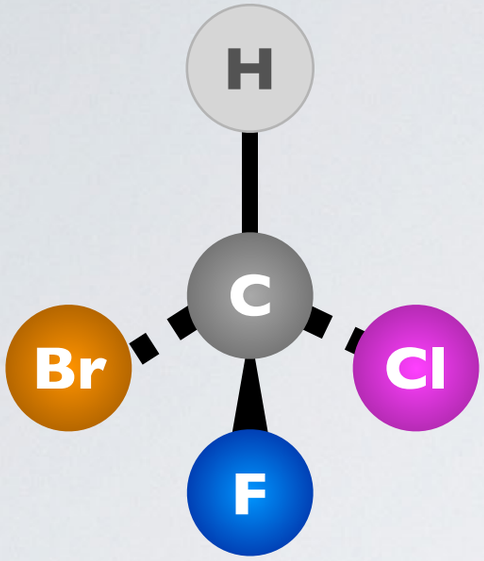


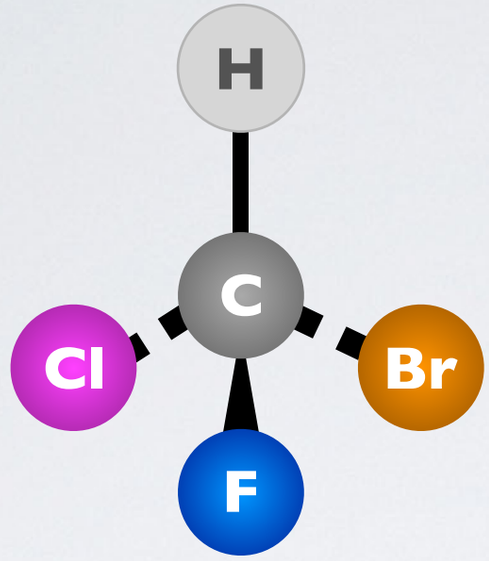


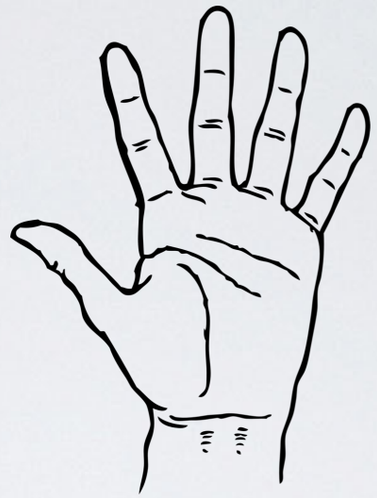


Same atoms, bonds

THE SAME



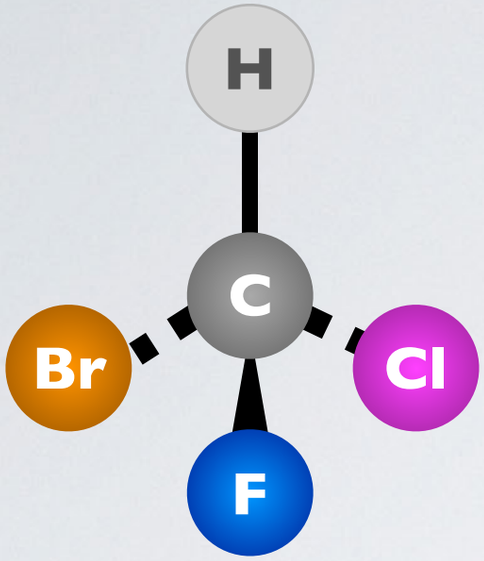


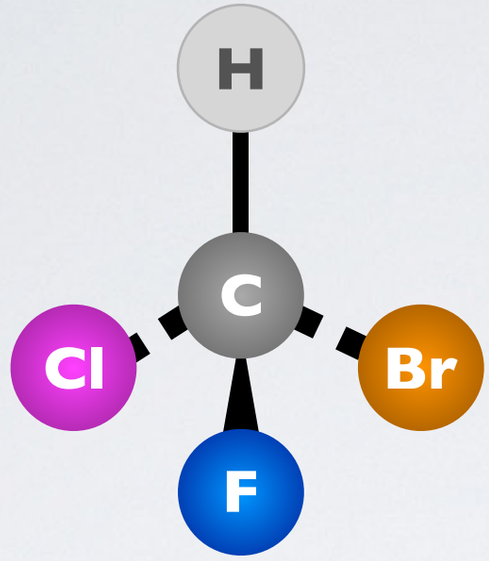


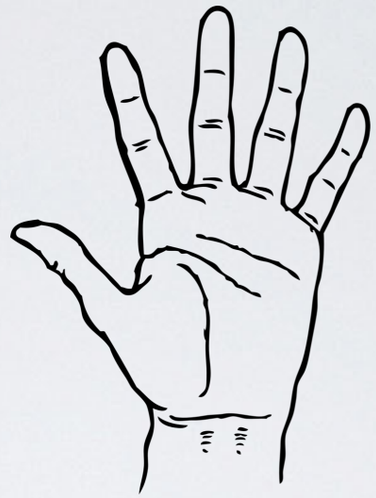
Same atoms, bonds

Same bones, tendons

THE SAME





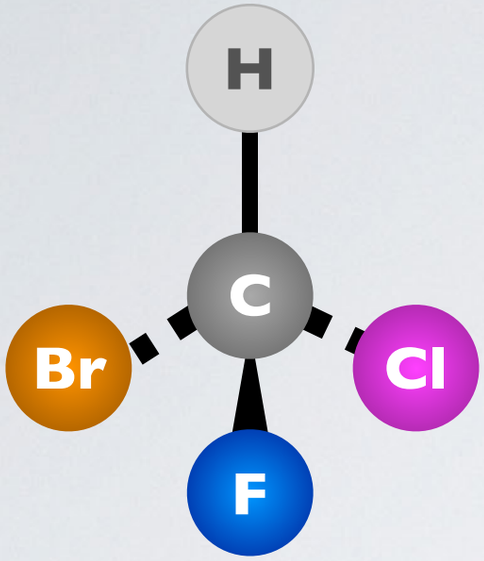


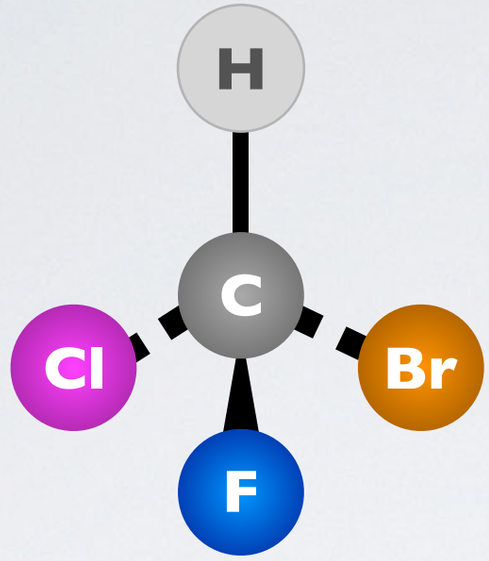
Same atoms, bonds

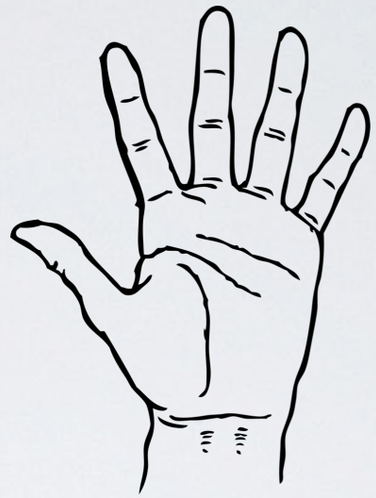
Same melting/boiling/freezing points

Same bones, tendons

THE SAME







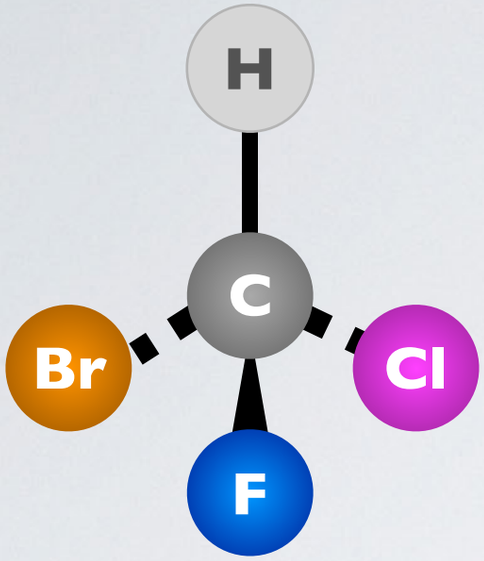
Same atoms, bonds

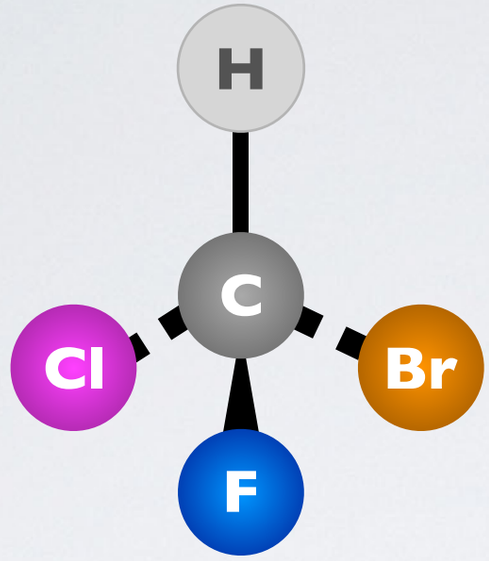
Same melting/boiling/freezing points

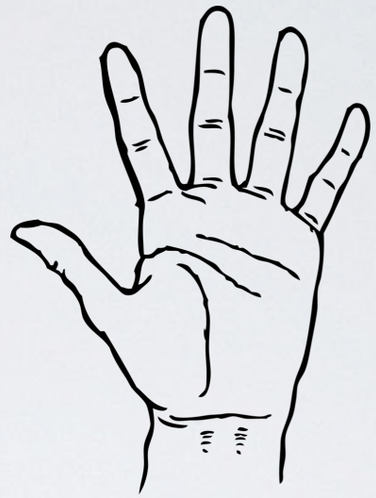
Same bones, tendons

Same melting/boiling/freezing points

THE SAME







Same atoms, bonds

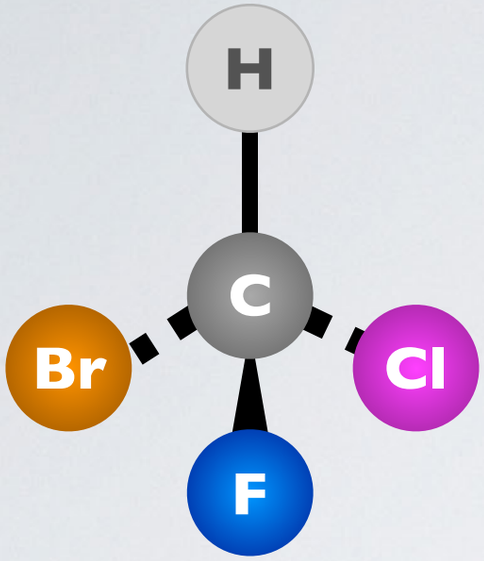
Same melting/boiling/freezing points

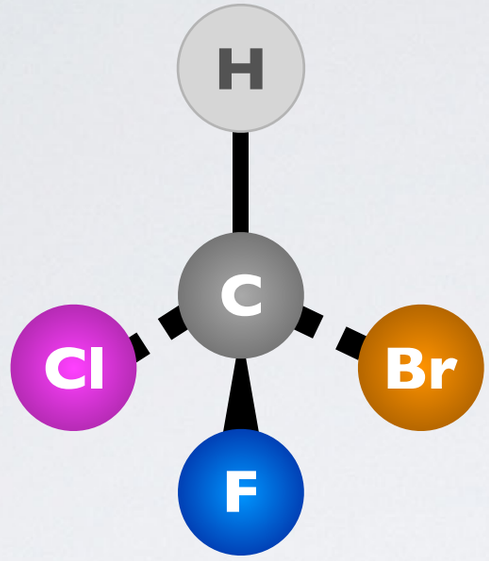
Same spectra

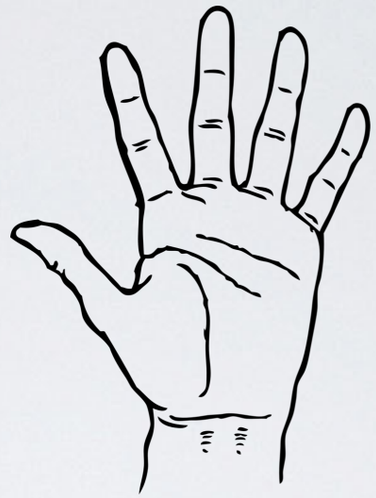
Same bones, tendons

Same melting/boiling/freezing points

THE SAME







Same atoms, bonds

Same melting/boiling/freezing points

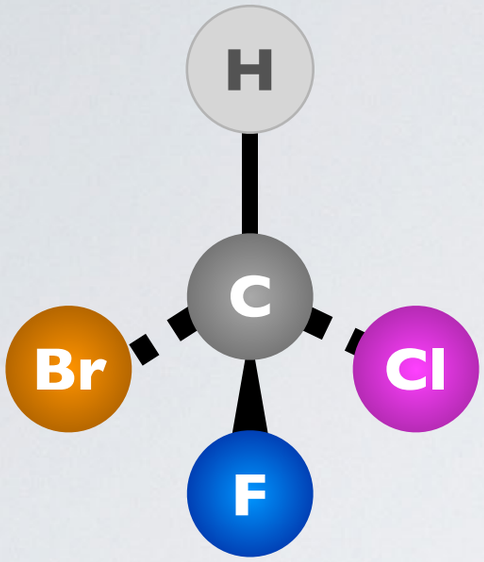
Same spectra

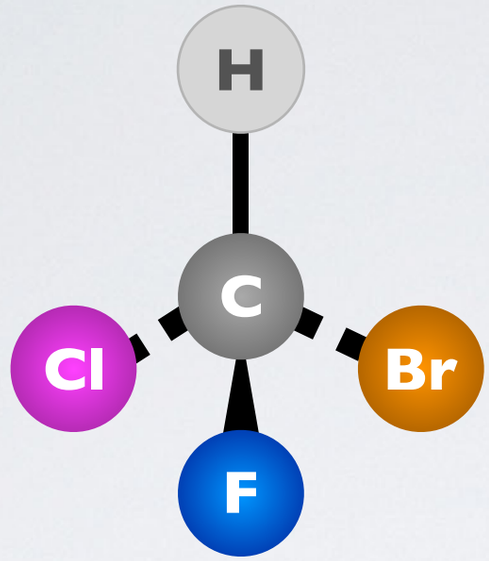
Same bones, tendons

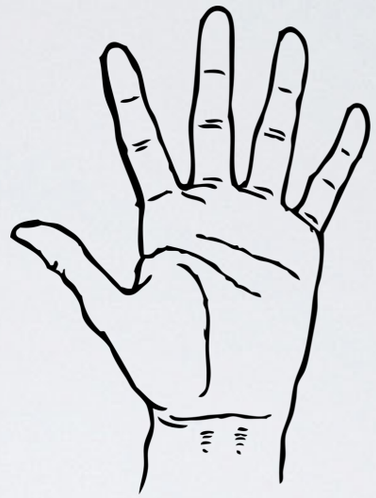
Same melting/boiling/freezing points

Same shadow

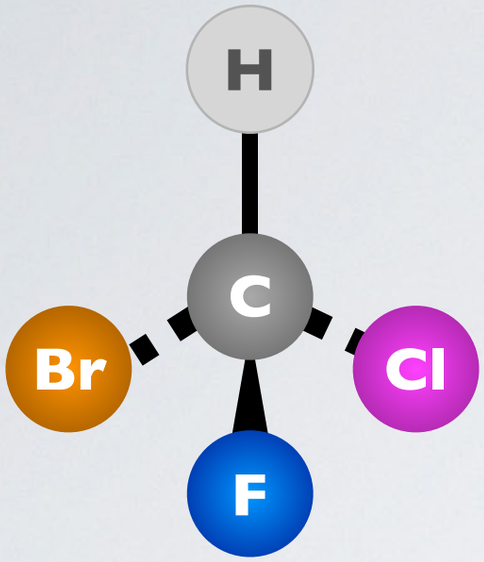
BUT DIFFERENT

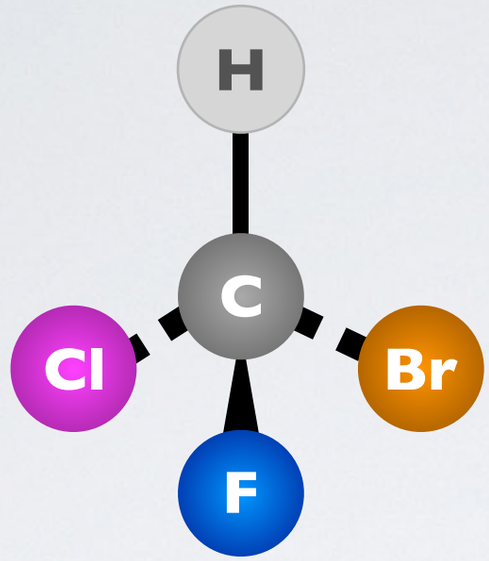


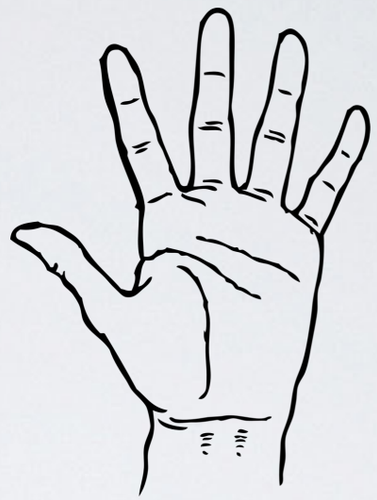




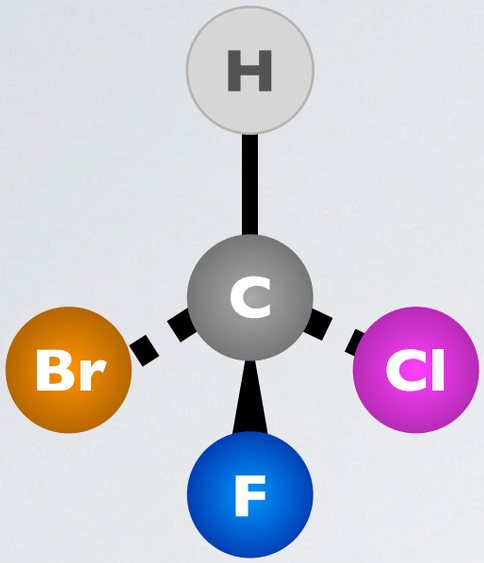
BUT DIFFERENT

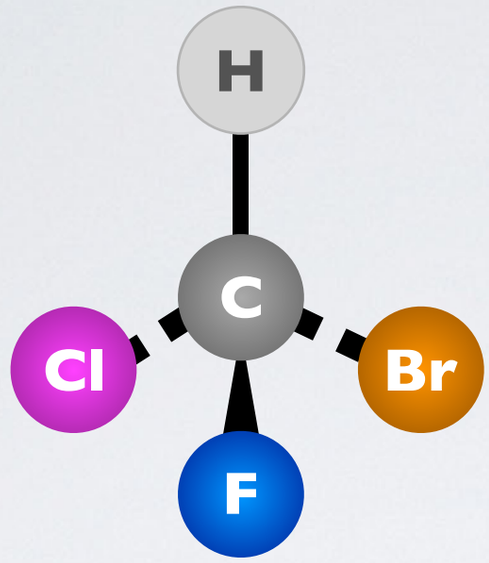


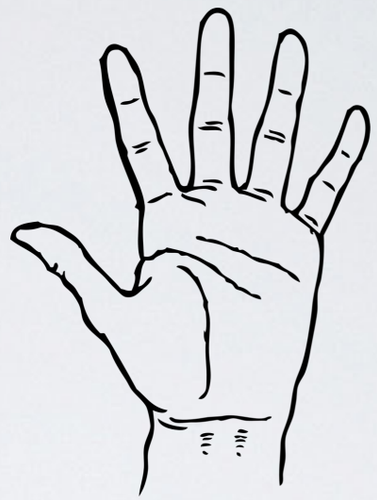


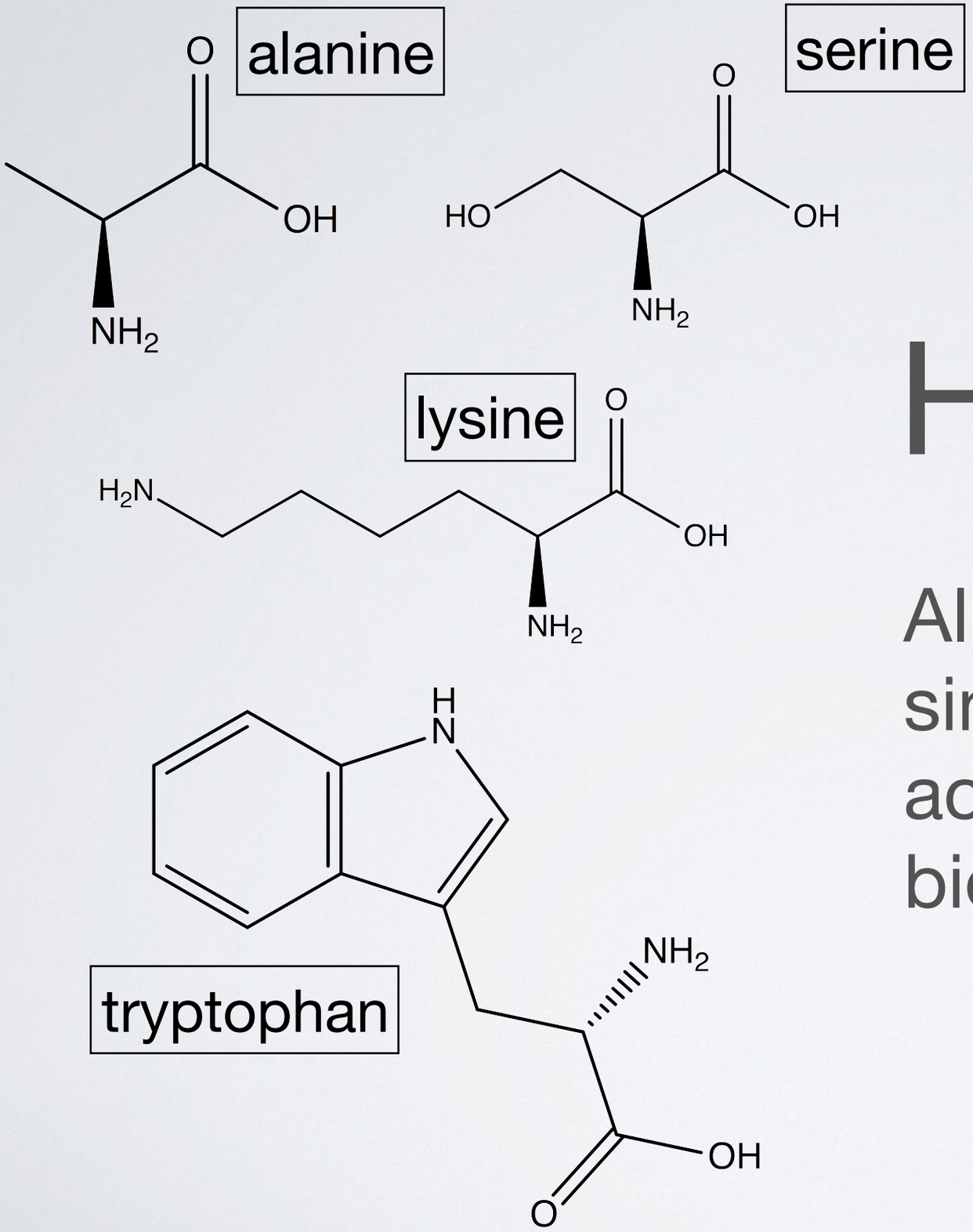


BUT DIFFERENT









Homochirality

All life on Earth uses only a single enantiomer of amino acids, sugars, and other biomolecules

Enantiomeric Excesses in Meteoritic Amino Acids

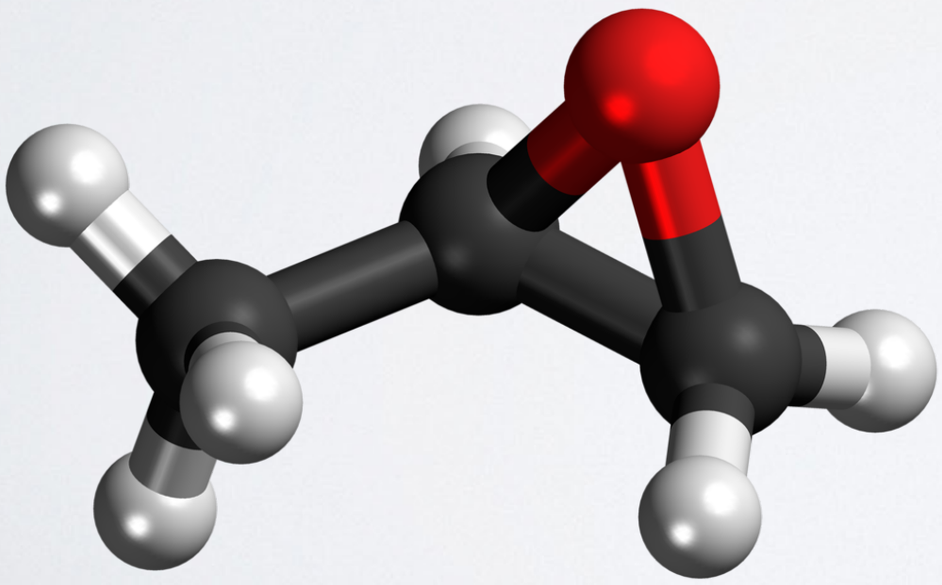
John R. Cronin and Sandra Pizzarello

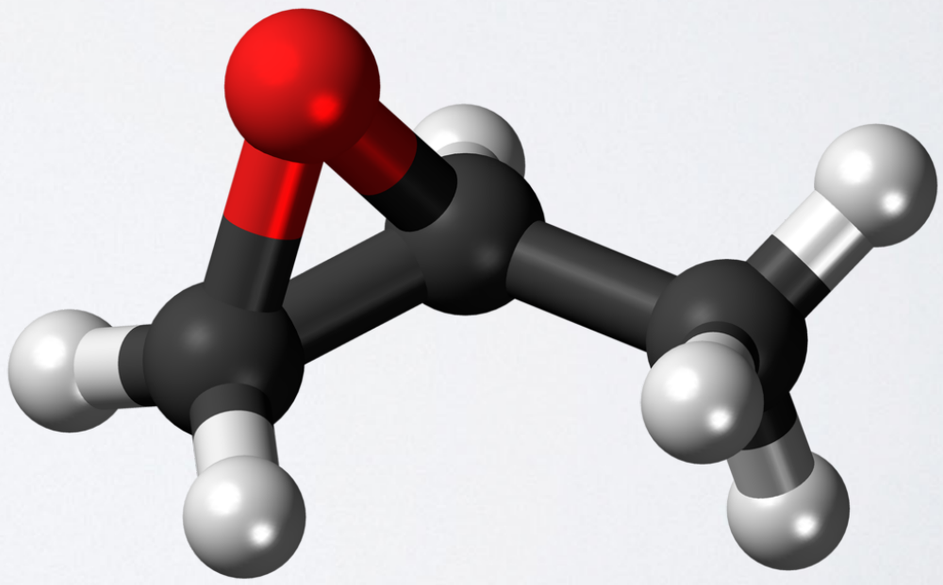
A few amino acids show excess of *L* by almost 10%

But where did it come from!?

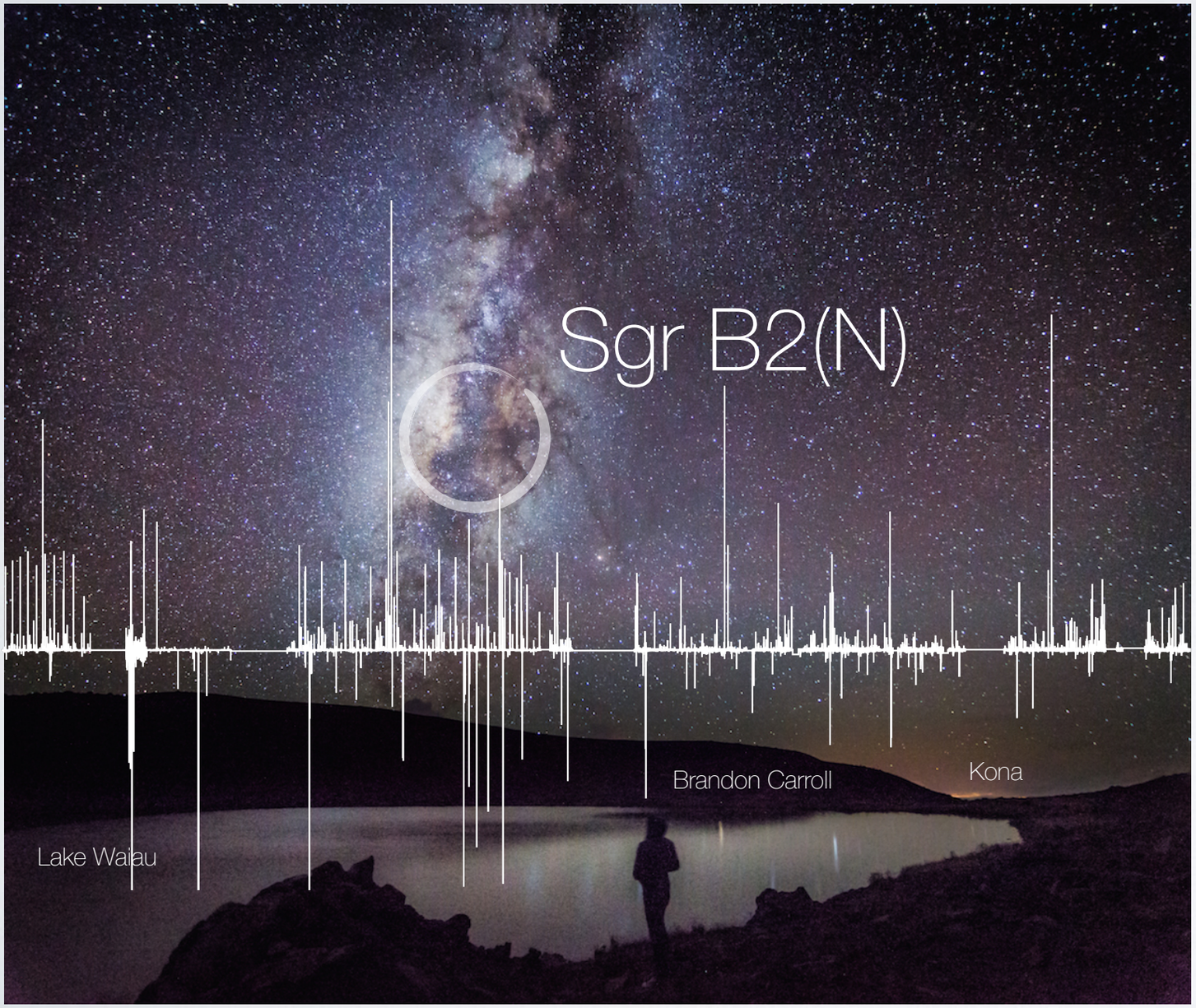
Discovery of the interstellar chiral molecule propylene oxide (CH_3CHCH_2O)

Brett A. McGuire,[1,2*†] P. Brandon Carroll,[2*†] Ryan A. Loomis,[3] Ian A. Finneran,[2] Philip R. Jewell,[1] Anthony J. Remijan,[1] Geoffrey A. Blake[2,4]





PRebiotic **I**nterstellar **MO**lecular **S**urvey



Coverage

0.5 - 50 GHz

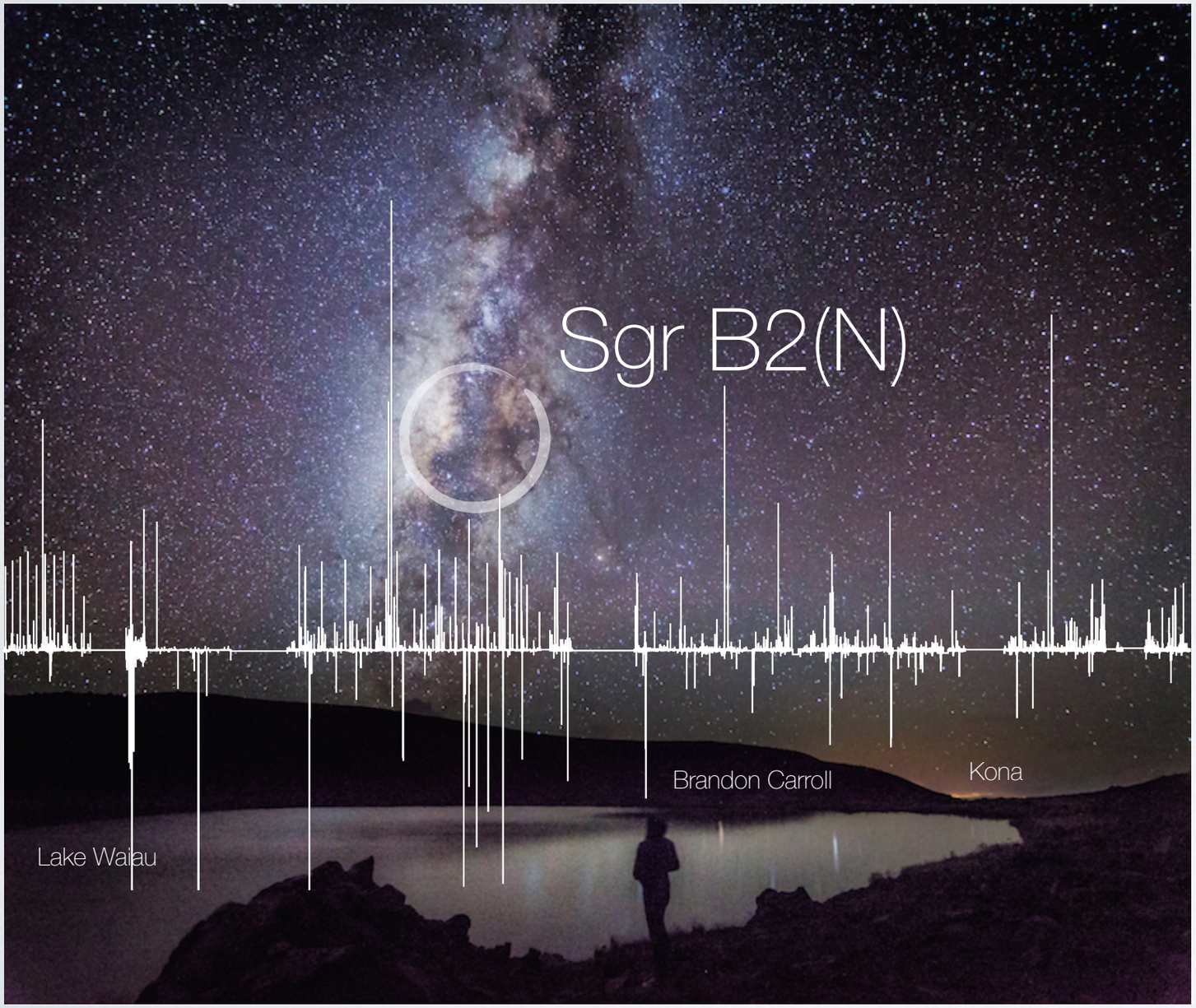
Resolution

24.4 kHz

15 km/s @ 0.5 GHz

0.15 km/s @ 50 GHz

PRebiotic **I**nterstellar **MO**lecular **S**urvey



Sensitivity @ 15 GHz

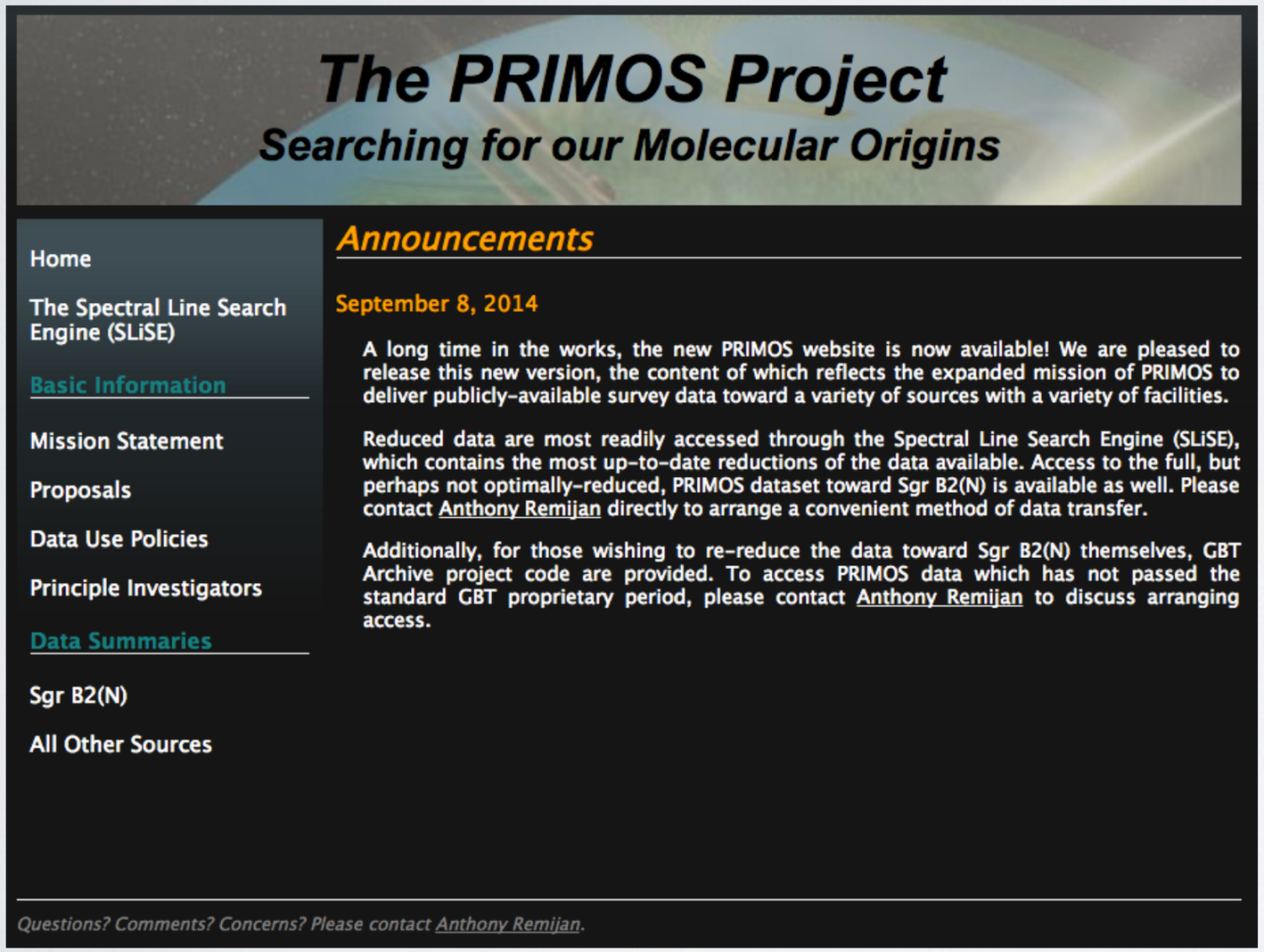
~ 3 mK RMS

Sensitivity @ 50 GHz

~ 10 mK RMS

PRebiotic **I**nterstellar **MO**lecular **S**urvey

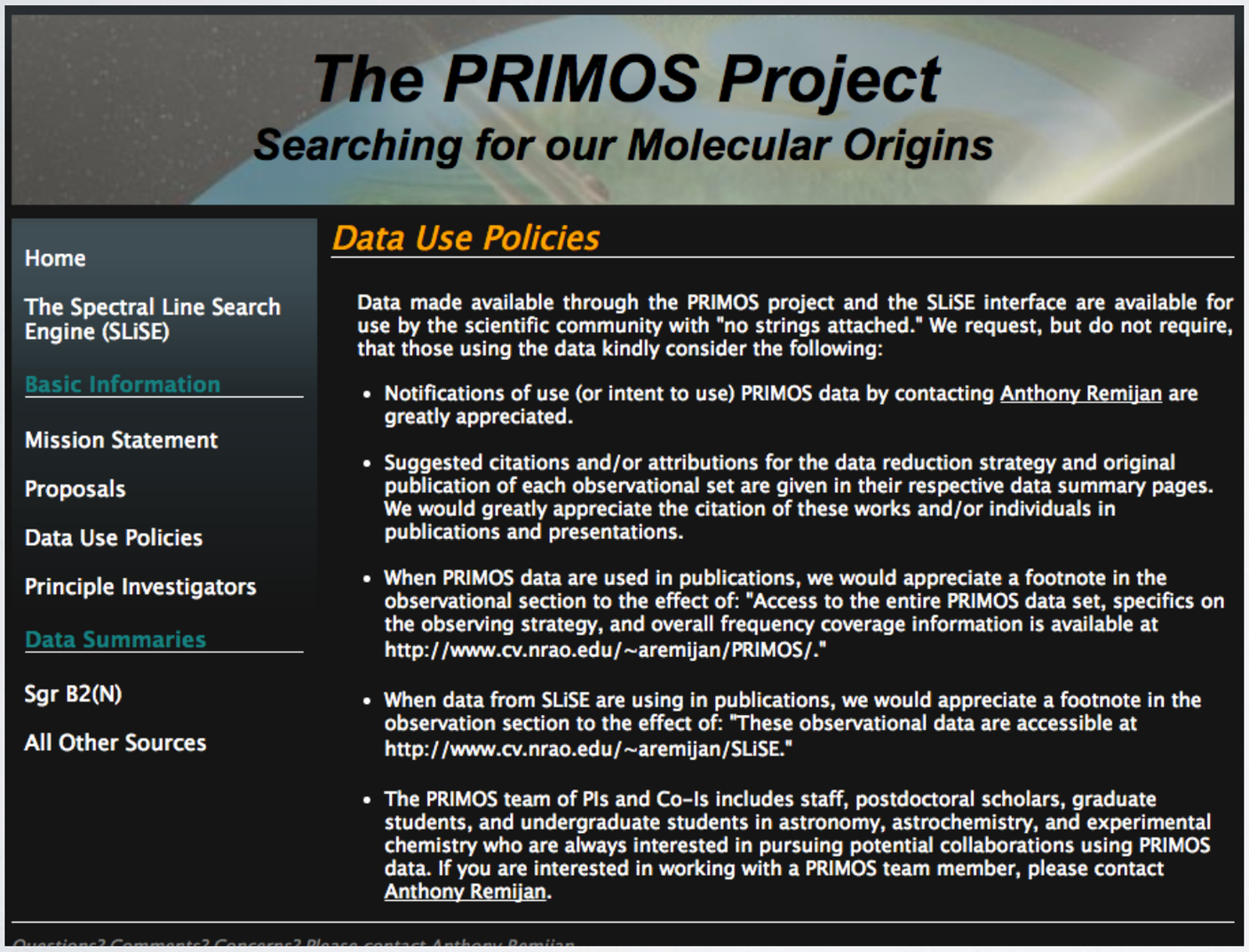
http://www.cv.nrao.edu/~aremijan/PRIMOS/



- ✓ Publicly Available
- ✓ Fully reduced
- ✓ Raw data

PRebiotic **I**nterstellar **MO**lecular **S**urvey

http://www.cv.nrao.edu/~aremijan/PRIMOS/



The PRIMOS Project

Searching for our Molecular Origins

Home

The Spectral Line Search Engine (SLiSE)

Basic Information

Mission Statement

Proposals

Data Use Policies

Principle Investigators

Data Summaries

Sgr B2(N)

All Other Sources

Data Use Policies

Data made available through the PRIMOS project and the SLiSE interface are available for use by the scientific community with "no strings attached." We request, but do not require, that those using the data kindly consider the following:

- Notifications of use (or intent to use) PRIMOS data by contacting Anthony Remijan are greatly appreciated.
- Suggested citations and/or attributions for the data reduction strategy and original publication of each observational set are given in their respective data summary pages. We would greatly appreciate the citation of these works and/or individuals in publications and presentations.
- When PRIMOS data are used in publications, we would appreciate a footnote in the observational section to the effect of: "Access to the entire PRIMOS data set, specifics on the observing strategy, and overall frequency coverage information is available at http://www.cv.nrao.edu/~aremijan/PRIMOS/."
- When data from SLiSE are using in publications, we would appreciate a footnote in the observation section to the effect of: "These observational data are accessible at http://www.cv.nrao.edu/~aremijan/SLiSE."
- The PRIMOS team of PIs and Co-Is includes staff, postdoctoral scholars, graduate students, and undergraduate students in astronomy, astrochemistry, and experimental chemistry who are always interested in pursuing potential collaborations using PRIMOS data. If you are interested in working with a PRIMOS team member, please contact Anthony Remijan.

Questions? Comments? Concerns? Please contact Anthony Remijan

Data made available through the PRIMOS project and the SLiSE interface are available for use by the scientific community with no strings attached.

Primary Science Result	Reference
Non-detection of propanimine (CH_3CNHCH_3)	Margulés et al. 2017 (in prep.)
Non-detection of thioacetaldehyde (CH_3CHS)	Margulés et al. 2017 (in prep.)
Detection of ubiquitous complex molecules in diffuse and translucent clouds	Corby et al. 2017 (in prep.)
[redacted]	
First discovery of ^{13}C isotopologues of HC_7N	Burkhardt et al. 2017
First discovery of HC_7O	McGuire et al. 2017ba
First discovery of HC_5O	McGuire et al. 2017a
Probing diffuse $\rightarrow$ translucent cloud transitions	Corby et al. 2017
Non-detection of 2-hydroxyacetonitrile ($HOCH_2CN$)	Margulès et al. (2017)
First discovery of propylene oxide ($CH_3CH(O)CH_2$)	McGuire et al. (2016b)
Search for vinyl formate ($CH_2CHOCHO$)	Alonso et al. (2016)
Investigations of the [H, N, C, S] isomeric family in the ISM	McGuire et al. (2016a)
Chemical simulations of prebiotic molecules	Quan et al. (2016)
Non-detection of HSO	Cazzoli et al. (2016)
Insights into cyanomethanimine isomers	Vazart et al. (2015)
Insights into kinetic vs thermodynamic-drive chemistry	Loomis et al. (2015)
Refuted detection of *trans*-ethyl methyl ether ($C_2H_5OCH_3$)	Carroll et al. (2015)
Identification of methyl formate masers in Sgr B2(N)	Faure et al. (2014)
Observational confirmation of identity of B11244 *l*-C_3H^+	McGuire et al. (2014)
Tentative first discovery of H_2NCO^+	Gupta et al. (2013)
Non-detection of allyl isocyanide (CH_2CHCH_2NC)	Haykal et al. (2013)
Detection of B11244 in Sgr B2(N)	McGuire et al. (2013)
First discovery of ethanimine (CH_3CHNH)	Loomis et al. (2013)
First discovery of *E*-cyanomethanimine (HNCHCN)	Zaleski et al. (2013)
First discovery of carbodiimide (HNCNH)	McGuire et al. (2012)
Tentative first discovery of trans-methyl formate	Neill et al. (2012)
Insights into spatial distributions and interstellar reactions	Neill et al. (2011)
Line profile analysis of hydrogen radio recombination lines	von Prochazka et al. (2010)
Non-detection of 1,2-propanediol ($CH_2OHCH_2CH_2OH$)	Plusquellic et al. (2009) Lovas et al. (2009)

29 Total

CfA

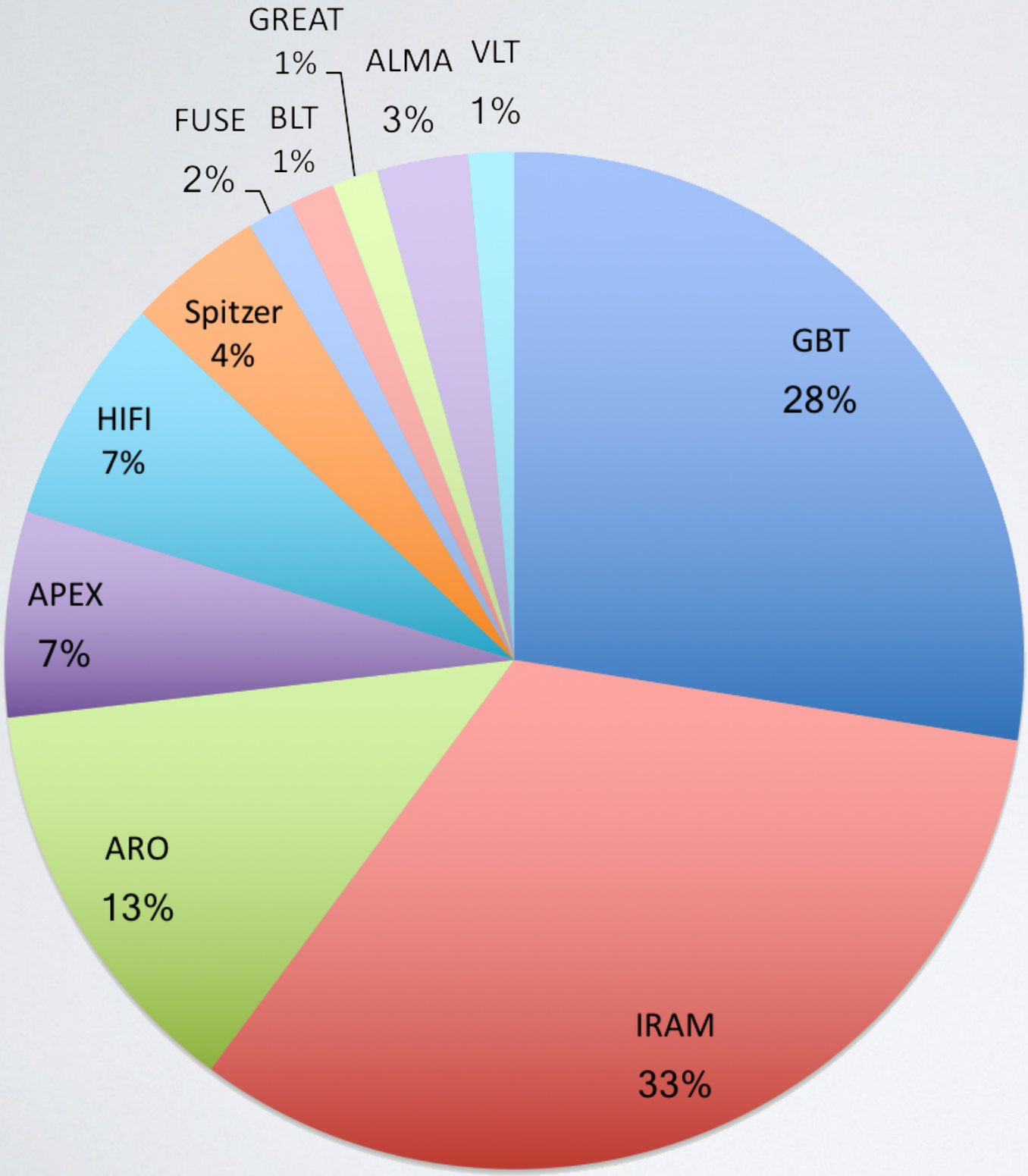
ALMA and other mm/sub-mm facilities have the monopoly on ‘traditional’ sources (hot cores, outflows, etc.)

ALMA and other mm/sub-mm facilities have the monopoly on ‘traditional’ sources (hot cores, outflows, etc.)

GBT excels at understanding the inventories and chemistry occurring BEFORE these later stages

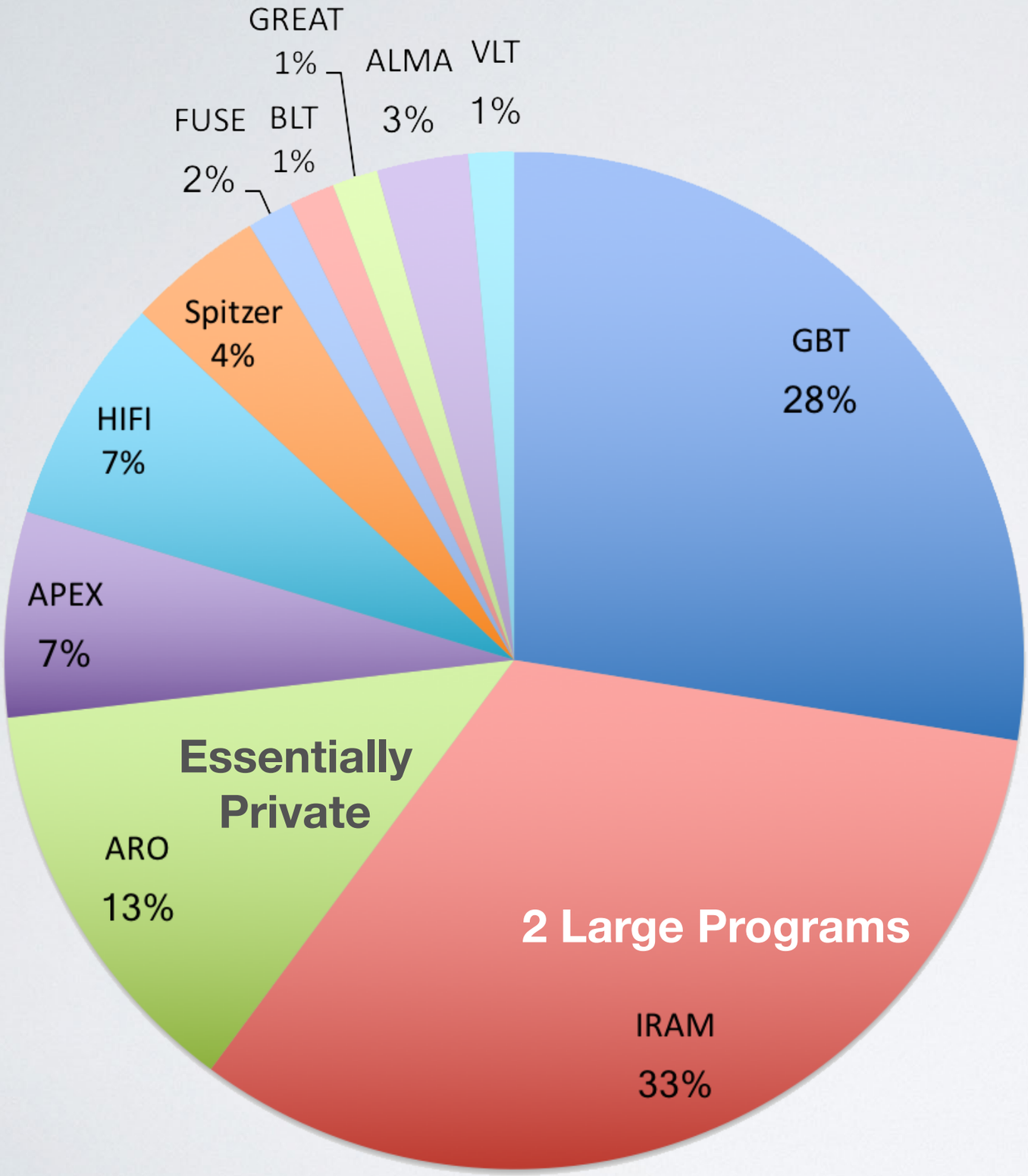
Absolutely essential; if you don’t have t = 0 correct, everything after that is hogwash and hand waving

NEW MOLECULAR DETECTIONS SINCE 2004



CH_2CHCHO
CH_3CH_2CHO
CH_2CCHCN
c-H_2C_3O
CH_2CONH_2
CH_3C_6H
CH_2CNH
CH_3C_5N
C_6H^-
C_8H^-
$CNCHO$
$HNCNH$
CH_3CNHN
E-$HNCHCN$
CH_3CHCH_2O
HC_5O
HC_7O

NEW MOLECULAR DETECTIONS SINCE 2004



CH_2CHCHO
CH_3CH_2CHO
CH_2CCHCN
c-H_2C_3O
CH_2CONH_2
CH_3C_6H
CH_2CNH
CH_3C_5N
C_6H^-
C_8H^-
$CNCHO$
$HNCNH$
CH_3CNHN
E-$HNCHCN$
CH_3CHCH_2O
HC_5O
HC_7O

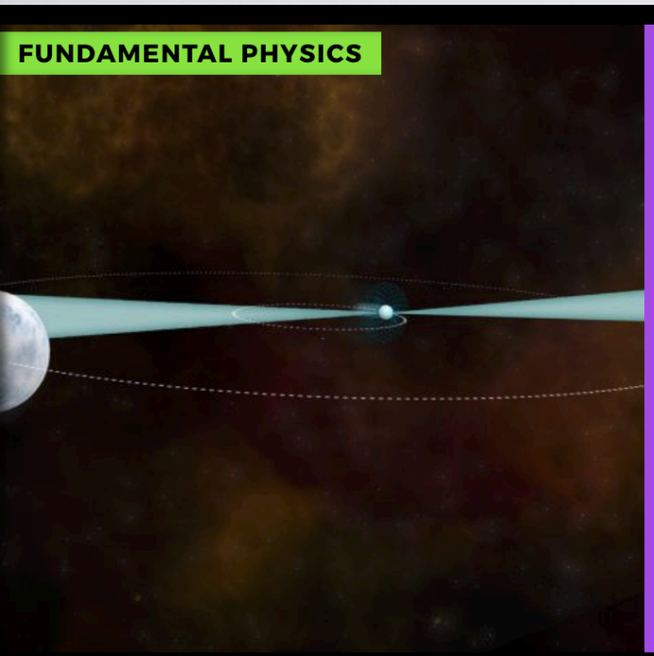
IRAM: Astrochemistry featured as ‘key science’ in every annual report since 2004

WE ARE ALL MADE OF STARS

WITHOUT STARS, WE WOULDN'T BE HERE. STARS PRODUCE BASIC ELEMENTS, LIKE CARBON, THE FOUNDATION OF THE COMPLEX MOLECULES WHICH MAKE UP LIFE.

ASTROCHEMISTRY @ GBO

FUNDAMENTAL PHYSICS

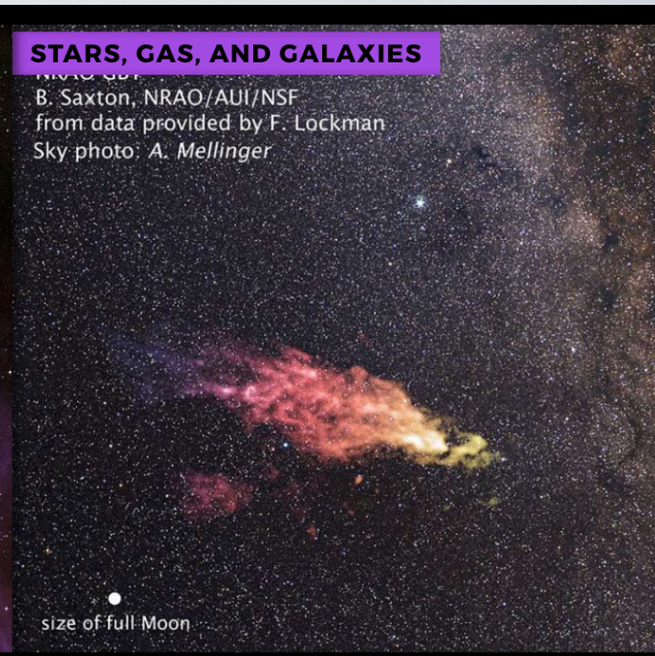


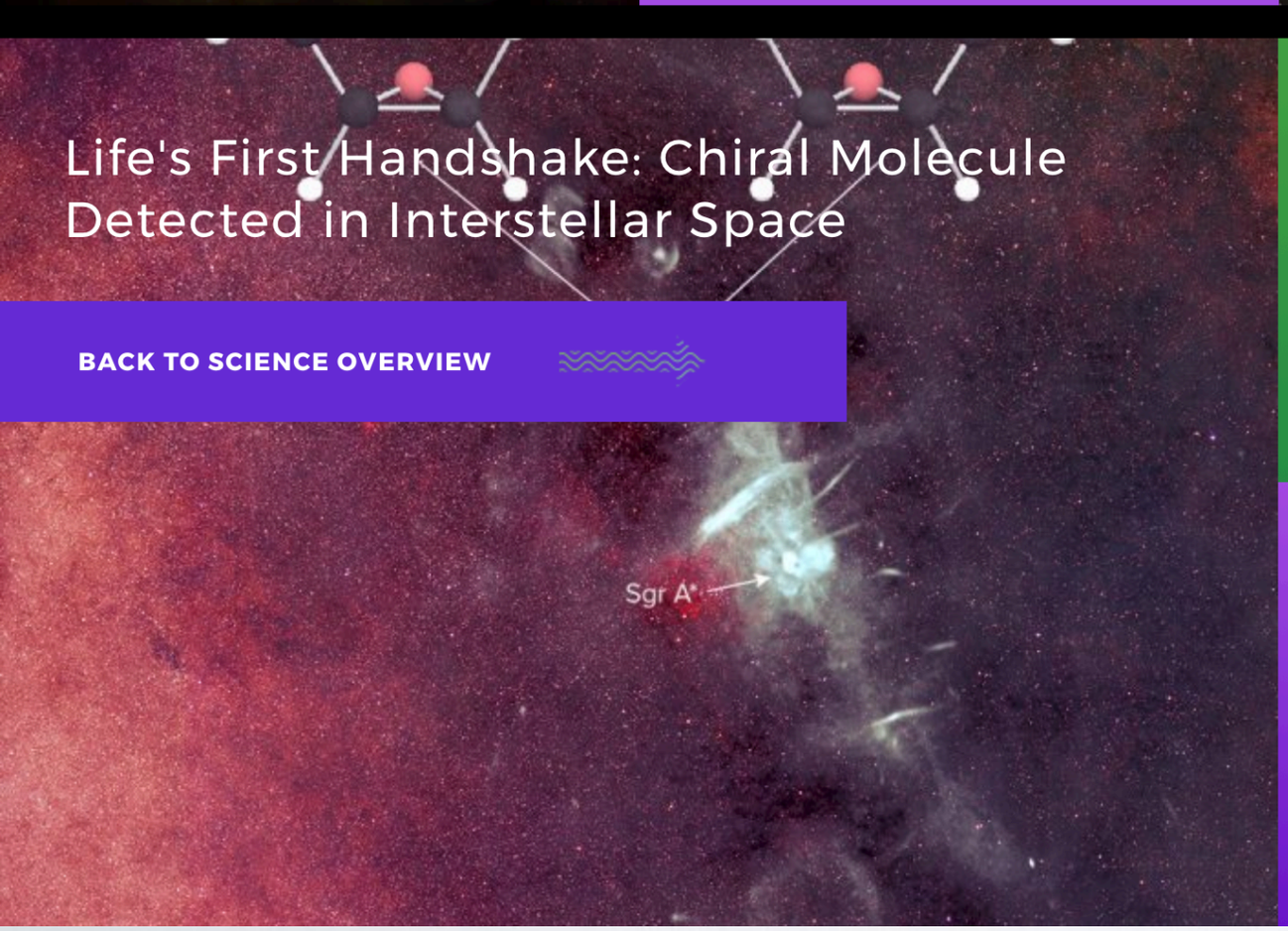
ORIGIN OF LIFE

Connect chemistry in space with life on Earth.

THE BIRTH OF PLANETS

STARS, GAS, AND GALAXIES





Life's First Handshake: Chiral Molecule Detected in Interstellar Space

BACK TO SCIENCE OVERVIEW

CONNECT ORGANIC CHEMISTRY IN SPACE WITH LIFE ON EARTH

HOW COMMON ARE THE BUILDING BLOCKS OF LIFE?

The GBT is used to discover and measure interstellar chemical processes to determine the characteristics of pre-biotic chemistry in star-forming regions

HOW DICONNECT ORGANIC CHEMISTRY IN SPACE WITH LIFE ON EARTHD LIFE ARRIVE ON EARTH?

HOW DID LIFE ARRIVE ON EARTH?

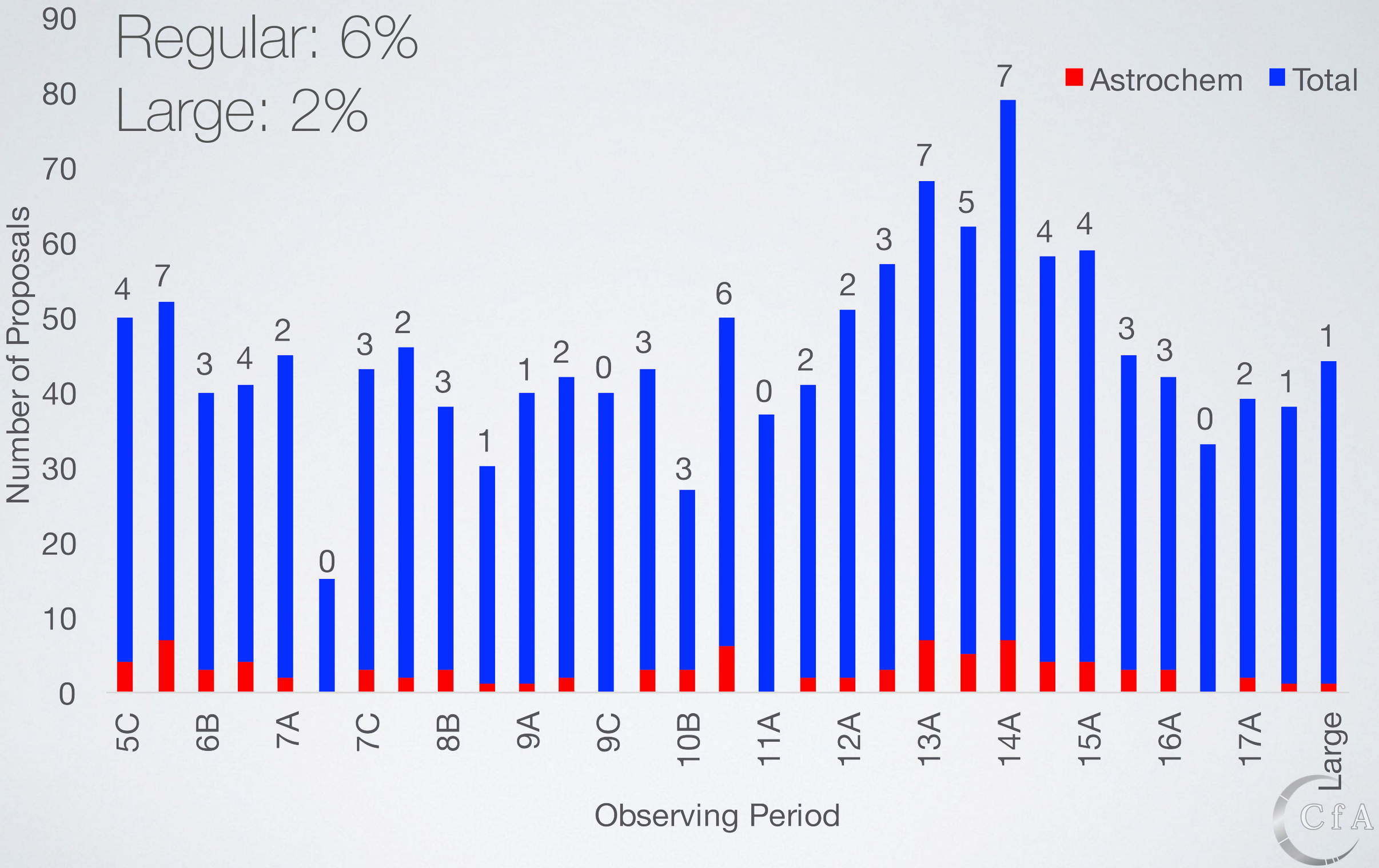
Rapid imaging of cometary molecules sets boundary conditions on solar system chemistry The GBT is the only telescope in the world which can provide the needed instantaneous sensitivity, resolution, and sky coverage

OOPS...

Science Category	
Active Galactic Nuclei	39
Astrometry/Geodesy	0
Energetic Transients and Pulsars	234
Extragalactic	263
Extragalactic Structure	139
Galactic	271
High Redshift and Source Surveys	62
Interstellar Medium	187
Normal Galaxies, Groups, and Clusters	49
Solar System	43
Solar System, Stars, Planetary Systems	77
Star Formation	70
Stellar	137

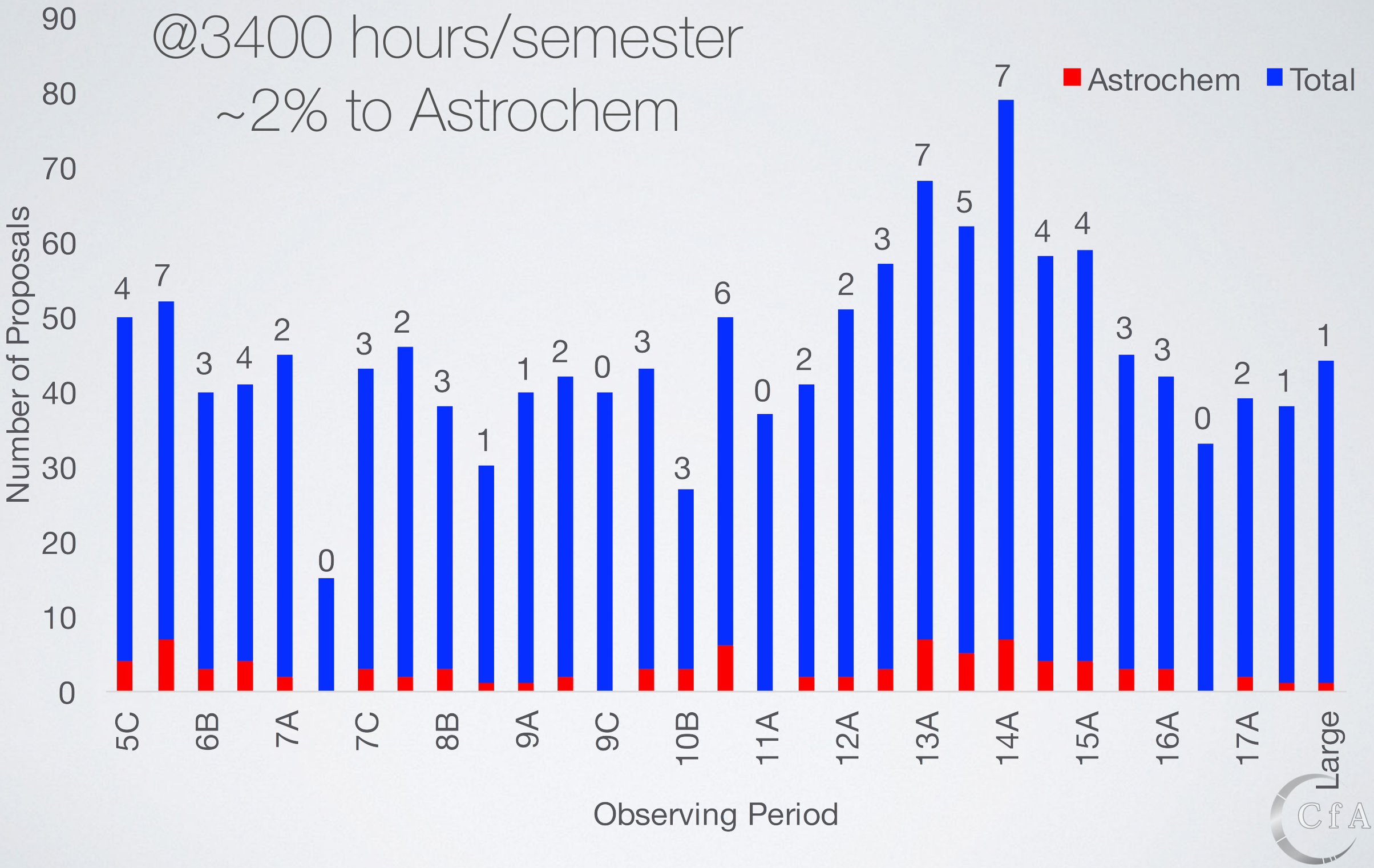
Astrochemistry is not a category in the proposal system…

FRACTION OF PROPOSALS

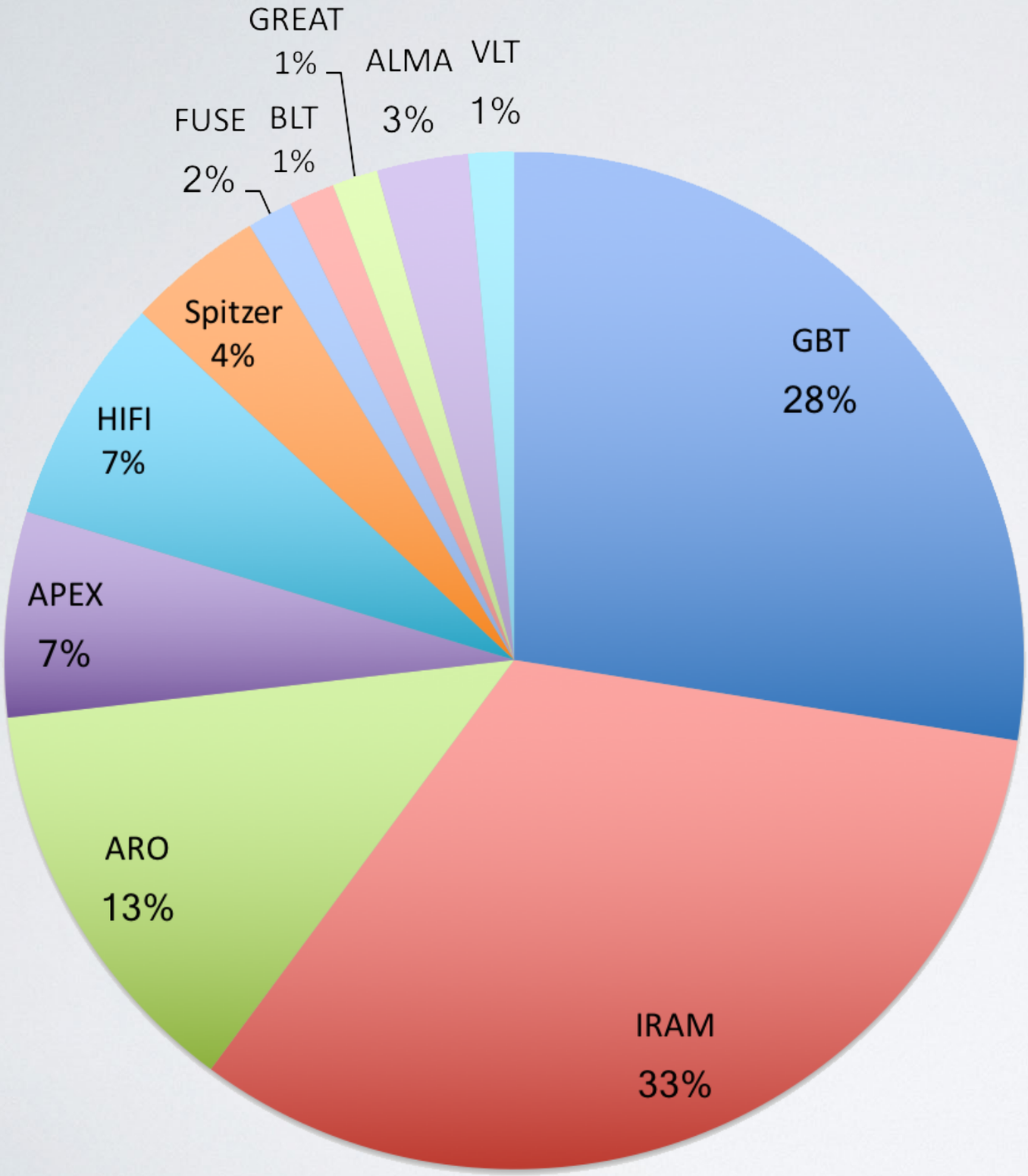


FRACTION OF PROPOSALS

@3400 hours/semester
~2% to Astrochem



NEW MOLECULAR DETECTIONS SINCE 2004



CH_2CHCHO
CH_3CH_2CHO
CH_2CCHCN
c-H_2C_3O
CH_2CONH_2
CH_3C_6H
CH_2CNH
CH_3C_5N
C_6H^-
C_8H^-
$CNCHO$
$HNCNH$
CH_3CNHN
E-$HNCHCN$
CH_3CHCH_2O
HC_5O
HC_7O

What's Next?

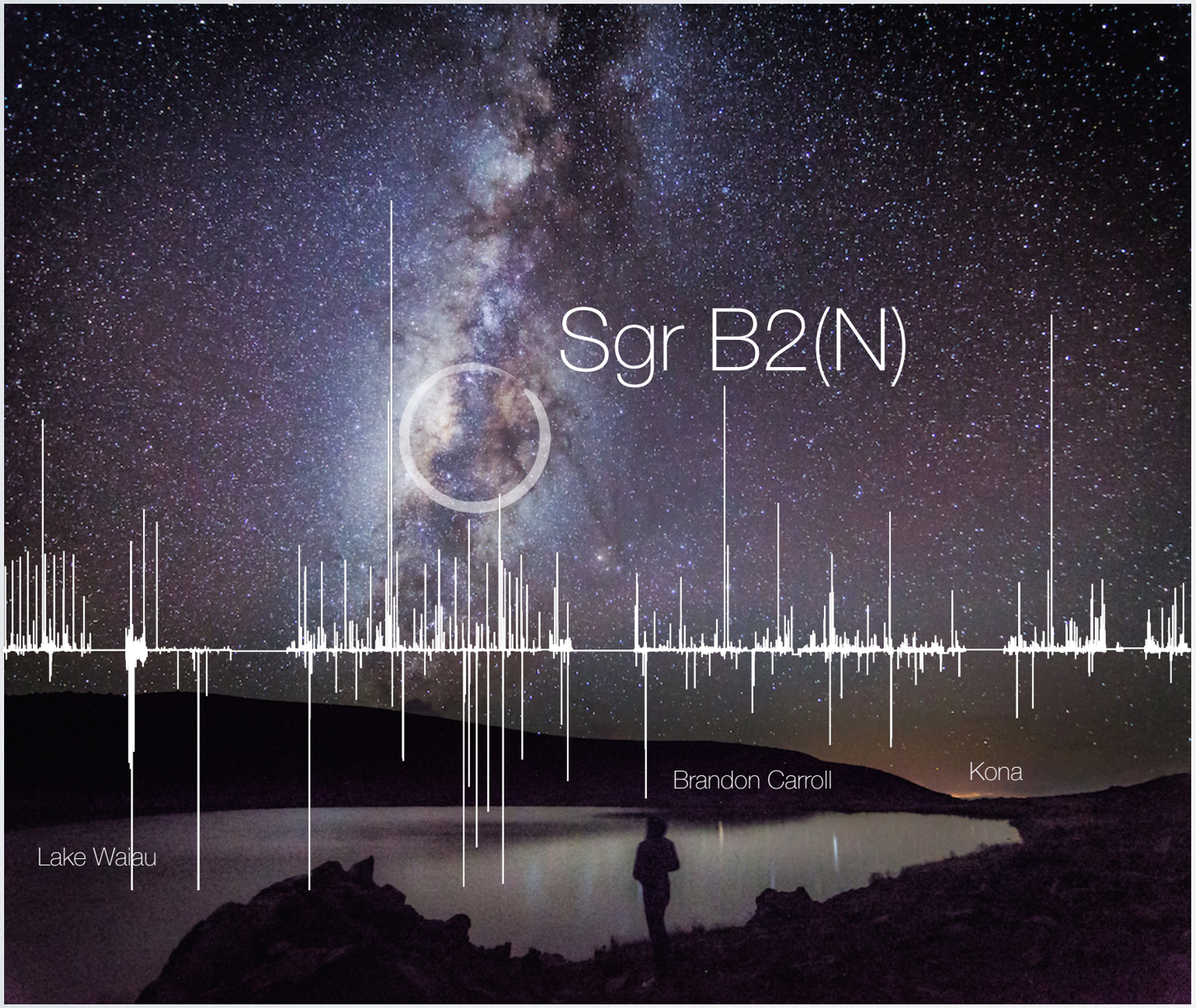
Sensitivity

Spectral Resolution / Bandwidth

~Beam Size

Unique Frequency Range

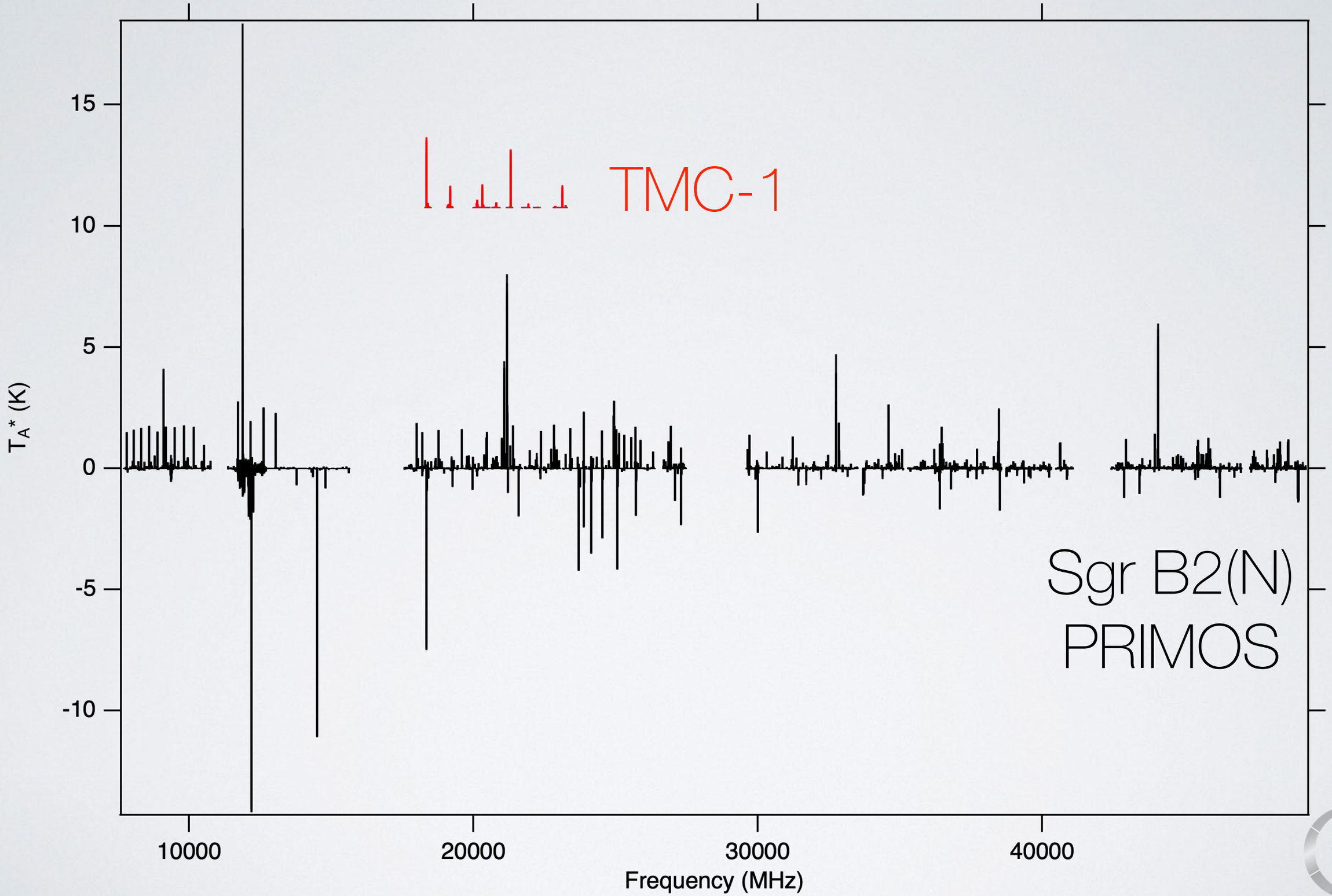
PRebiotic **I**nterstellar **MO**lecular **S**urvey



~1000 Hours w/
GBT Spectrometer

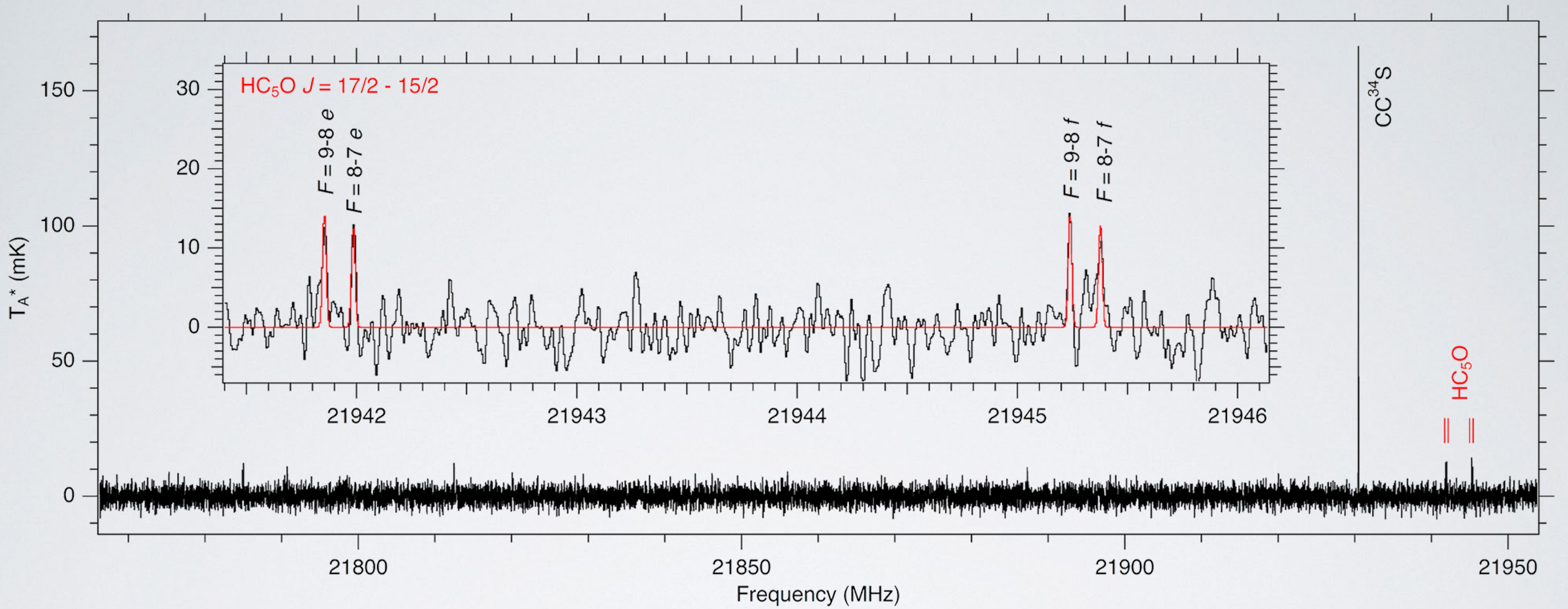
~300 Hours w/
VEGAS

~??? Hours w/
ATLANTIC CITY


TMC-1
Sgr B2(N)
PRIMOS
15
10
5
0
-5
-10
T_A^* (K)
10000
20000
30000
40000
Frequency (MHz)

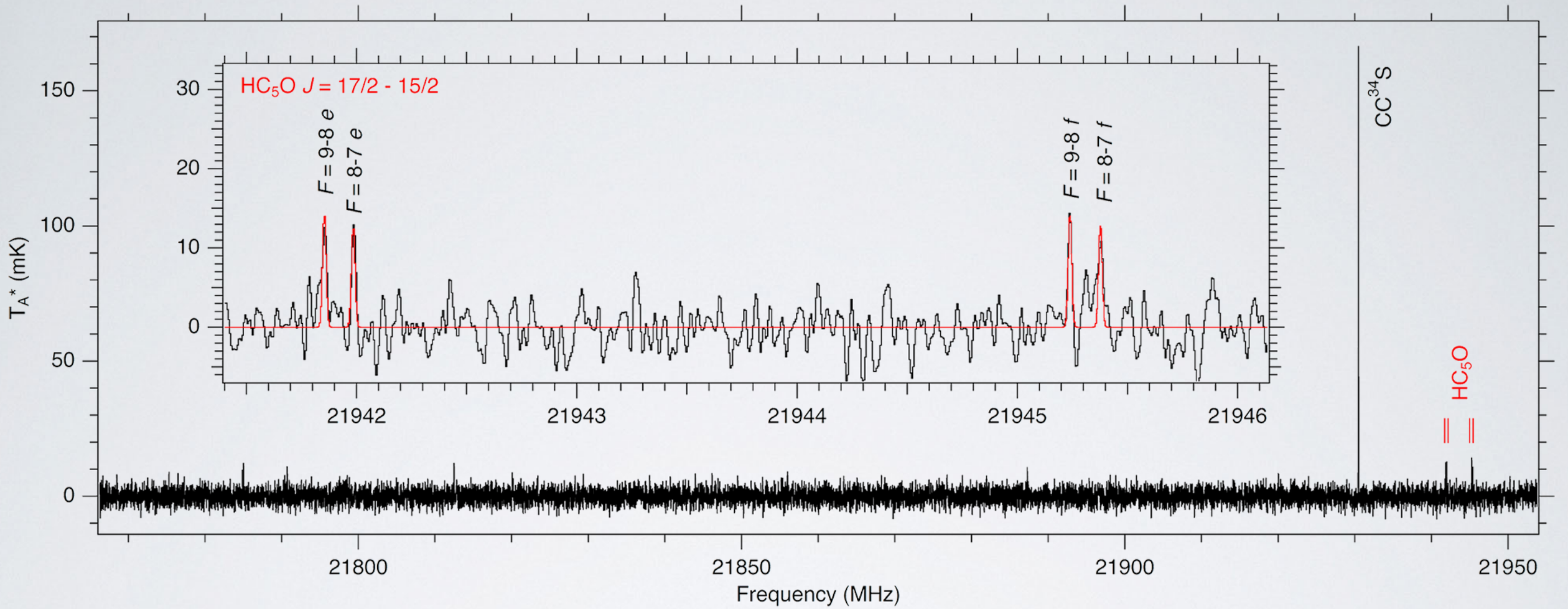
A BRIEF SIDE NOTE

McGuire et al. 2017 *ApJL* 843, L28
Burkhardt et al. 2017 *MNRAS* in revision



A BRIEF SIDE NOTE

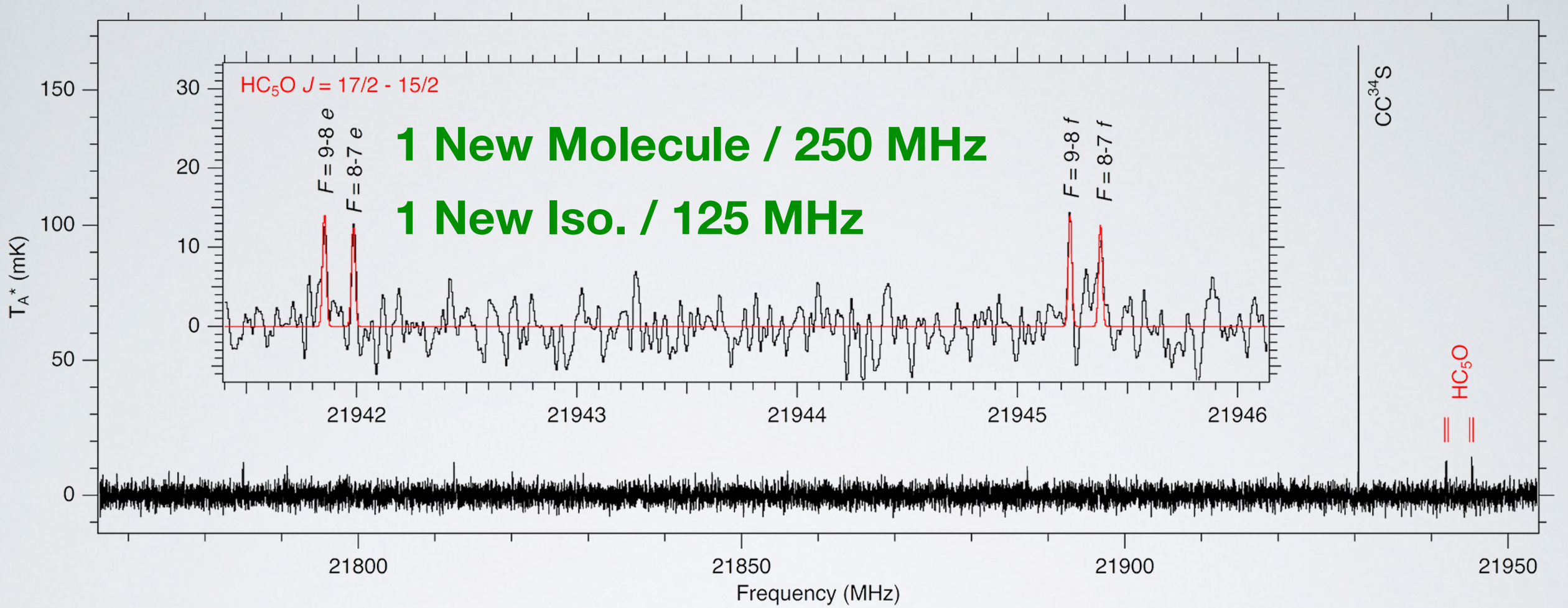
McGuire et al. 2017 *ApJL* 843, L28
Burkhardt et al. 2017 *MNRAS* in revision



$HC_5{}^{15}N$ $HC_6{}^{13}CN$ $HC_4{}^{13}CC_2N$ $HC_2{}^{13}CC_4N$

DC_7N $HC_5{}^{13}CCN$ $HC_3{}^{13}CC_3N$ $HC^{13}CC_5N$

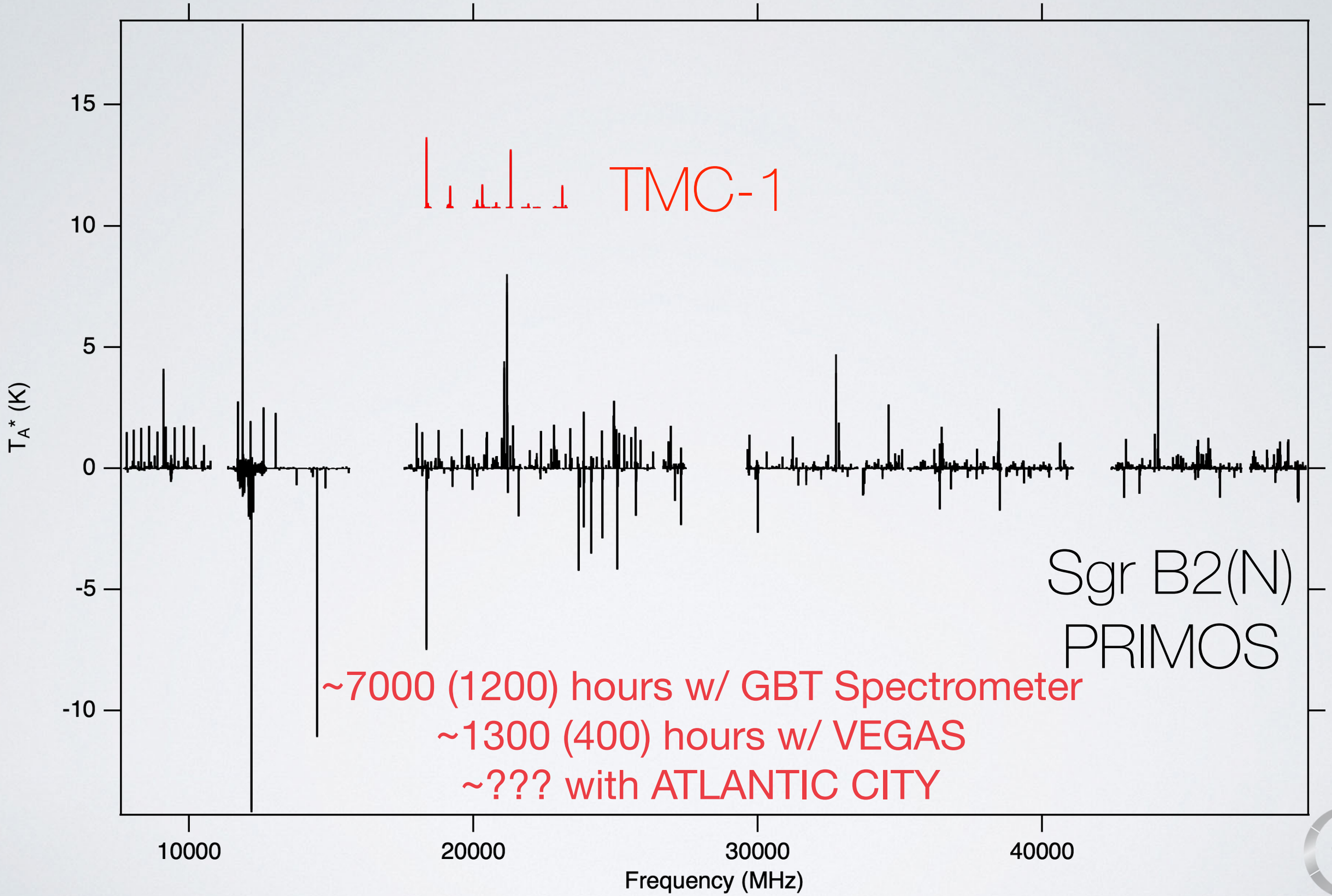
McGuire et al. 2017 *ApJL* 843, L28
Burkhardt et al. 2017 *MNRAS* in revision



$HC_5{}^{15}N$ $HC_6{}^{13}CN$ $HC_4{}^{13}CC_2N$ $HC_2{}^{13}CC_4N$

DC_7N $HC_5{}^{13}CCN$ $HC_3{}^{13}CC_3N$ $HC^{13}CC_5N$

WHERE DO WE GO FROM HERE?



What we really need:

A shift in the way we as a community view astrochemical research

What we really need:

A shift in the way we as a community view astrochemical research

The primary purpose of astrochemistry is to study *chemistry*

Actual *'weakness'* received on an astrochemistry proposal:

The proposal would benefit from a clearer description of the relation between the objectives [...] and studies of star formation on Galactic scales [...].

Could easily be recast for a star formation proposal:

The proposal would benefit from a clearer description of the relation between the objectives […] and studies of chemical evolution on Galactic scales […].

If both of these are not fair review criteria,

neither are

WE ARE ALL MADE OF STARS

WITHOUT STARS, WE WOULDN'T BE HERE. STARS PRODUCE BASIC ELEMENTS, LIKE CARBON, THE FOUNDATION OF THE COMPLEX MOLECULES WHICH MAKE UP LIFE.

ASTROCHEMISTRY @ GBT

Photo/Video | **Photo Album**

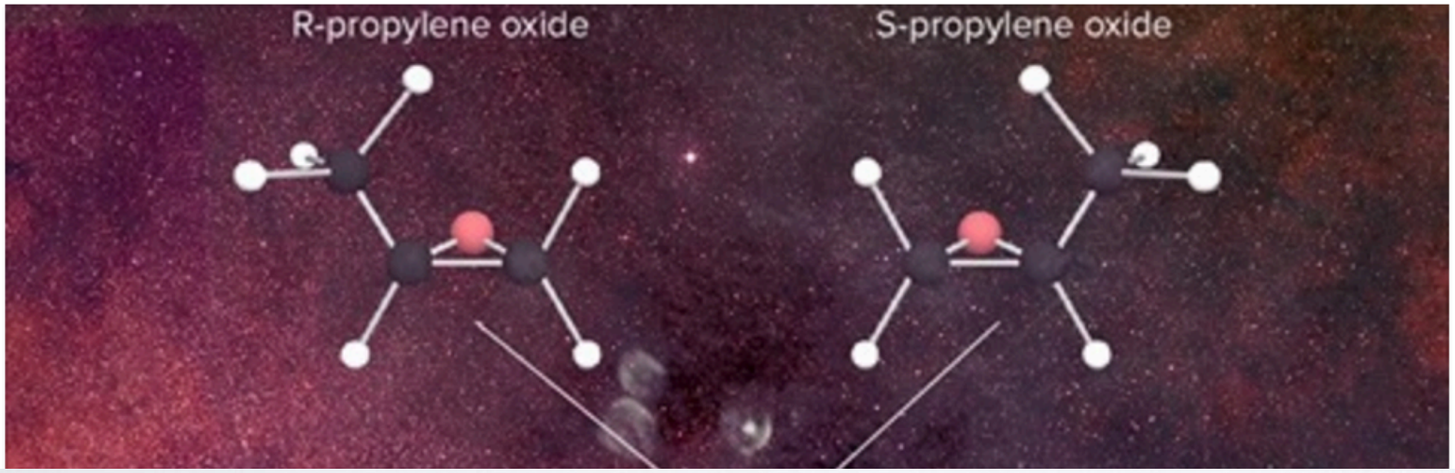
What's on your mind?

Friends **Post**

Geoffrey A. Blake commented on your post.

Brett McGuire with Ryan Loomis and 2 others.
11 hrs ·

Brandon and I did a thing with Geoff, Ryan, Ian, Phil, and Tony!!!



Annual Midsummer's P... on June 18

TODAY'S GAMES

TRENDING

- **Alexander Skarsgård**: Actor Says 'True Blood' Co-Star Ryan Kwanten Is a 'Good Kisser'
- **Donald Glover**: Actor in Talks to Join Cast of Upcoming 'Spider-Man: Homecoming' Film, Report Says
- **Mara Wilson**: Actress Says She Has 'Embraced the Bi/Queer Label Lately'
- **Yasmine Bleeth**: Former 'Baywatch' Actress Celebrates 48th Birthday on June 14
- **Jessie Graff**: Stuntwoman Competes in 'American Ninja Warrior' While Dressed as Wonder Woman
- **Game of Thrones**: HBO Releases Titles, No Descriptions for Final 2 Episodes of Season 6
- **Sniper Elite 4**: Tactical Shooter's Release Delayed Until February 2017
- **Chiral Molecules**: Scientists Discover Compounds Resembling Human Hands Outside Solar System

ASTROCHEMISTRY @ GBT

Photo/Video | Photo Album

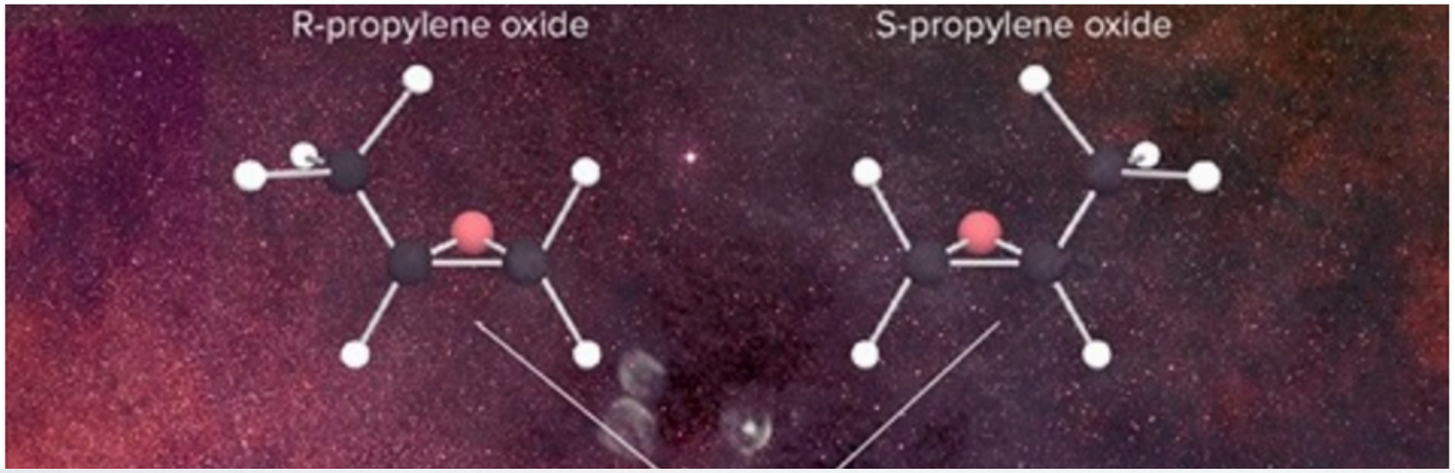
What's on your mind?

Friends | Post

Geoffrey A. Blake commented on your post.

Brett McGuire with Ryan Loomis and 2 others.
11 hrs ·

Brandon and I did a thing with Geoff, Ryan, Ian, Phil, and Tony!!!



Annual Midsummer's P... on June 18

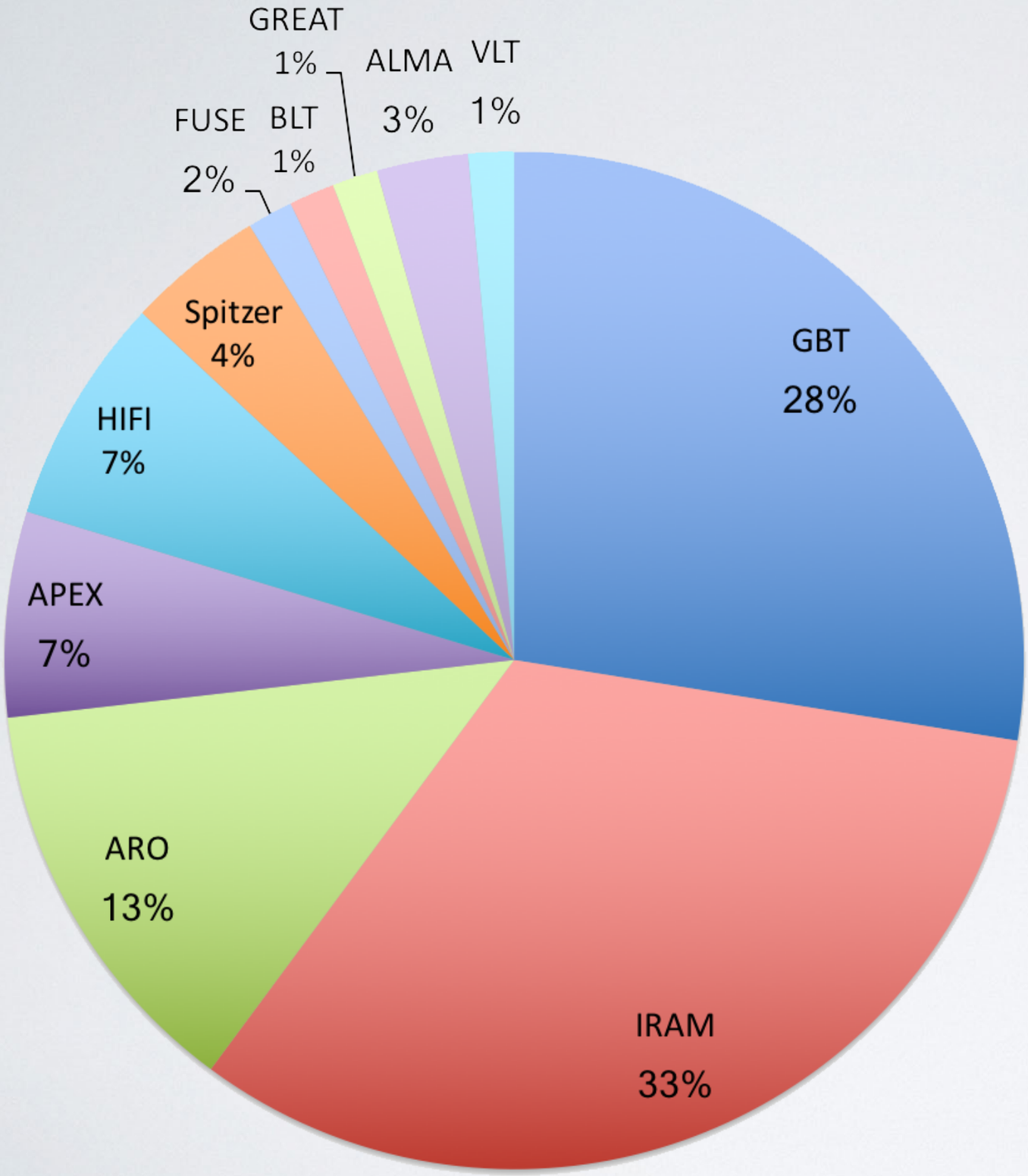
TODAY'S GAMES

TRENDING

- **Alexander Skarsgård**: Actor Says 'True Blood' Co-Star Ryan Kwanten Is a 'Good Kisser'
- **Donald Glover**: Actor in Talks to Join Cast of Upcoming 'Spider-Man: Homecoming' Film, Report Says
- **Mara Wilson**: Actress Says She Has 'Embraced the Bi/Queer Label Lately'
- **Yasmine Bleeth**: Former 'Baywatch' Actress Celebrates 48th Birthday on June 14
- **Jessie Graff**: Stuntwoman Competes in 'American Ninja Warrior' While Dressed as Wonder Woman
- **Game of Thrones**: HBO Releases Titles, No Descriptions for Final 2 Episodes of Season 6
- **Sniper Elite 4**: Tactical Shooter's Release Delayed Until February 2017
- **Chiral Molecules**: Scientists Discover Compounds Resembling Human Hands Outside Solar System

CfA

NEW MOLECULAR DETECTIONS SINCE 2004



CH_2CHCHO
CH_3CH_2CHO
CH_2CCHCN
c-H_2C_3O
CH_2CONH_2
CH_3C_6H
CH_2CNH
CH_3C_5N
C_6H^-
C_8H^-
$CNCHO$
$HNCNH$
CH_3CNHN
E-$HNCHCN$
CH_3CHCH_2O
HC_5O
HC_7O

GBO facilities are, and always have been, at the forefront of astrochemical discovery

‘Minor’ technical upgrades will enable significant new science

The upgrade we really need is political, not technical