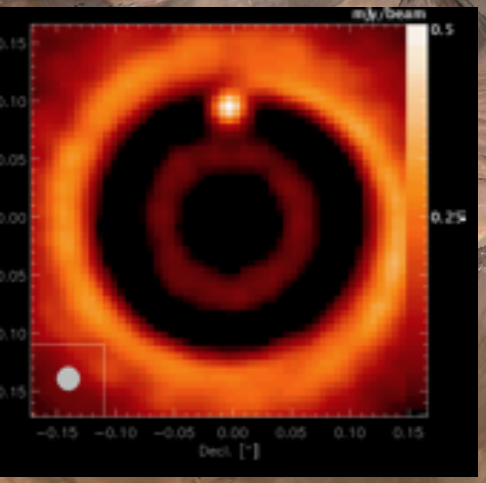
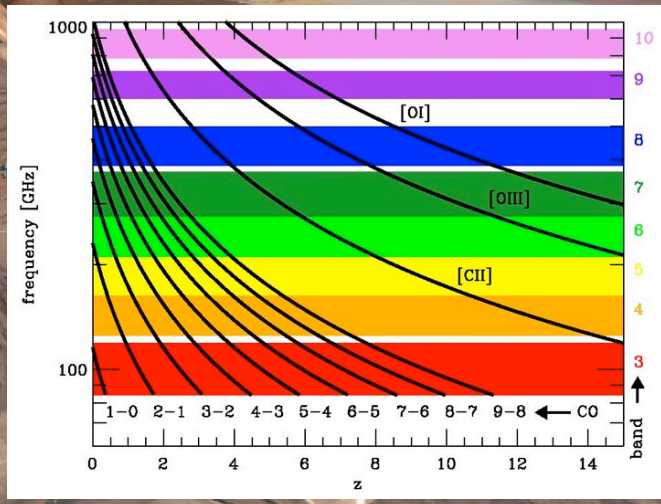
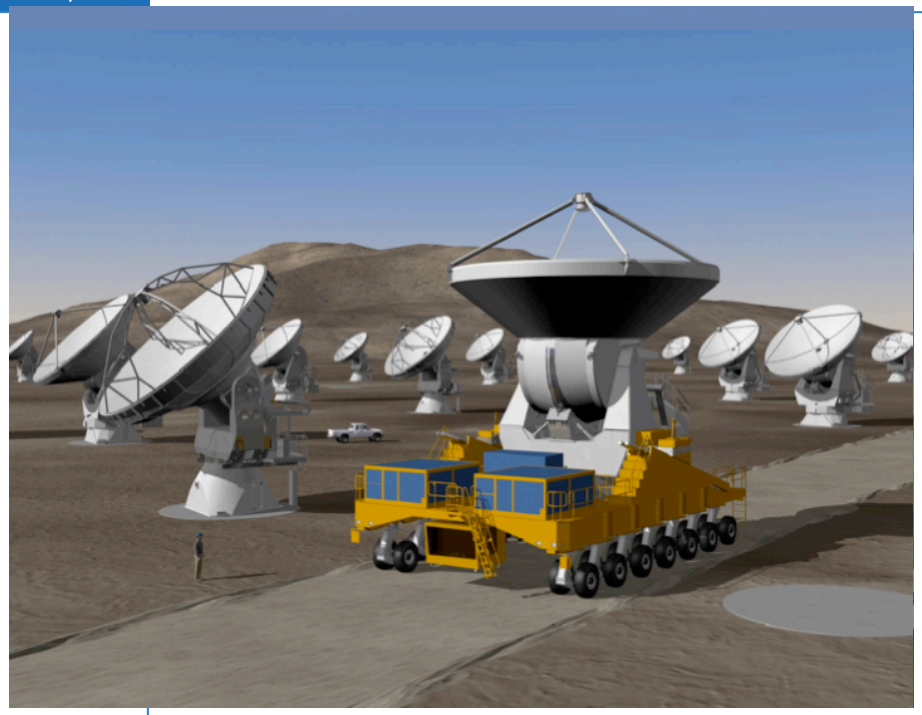
# ALMA: Science Highlights

*Leonardo Testi*
*ESO ALMA Programme Scientist*



# Atacama Large Millimeter Array



- At least 50x12m Antennas
- Frequency range 30-1000 GHz (0.3-10mm)
- 16km max baseline (<10mas)
- ALMA Compact Array (4x12m and 12x7m)

1. Detect and map CO and [C II] in a Milky Way galaxy at z=3 in less than 24 hours of observation
2. Map dust emission and gas kinematics in protoplanetary disks
3. Provide high fidelity imaging in the (sub)millimeter at 0.1 arcsec resolution

# ALMA Early Science

- ALMA Early Science C0 & C1
  - 30-70% of the total number of antennas
  - Maximum separation 1km (6% of final ALMA)
  - Already the most powerful submm observatory
- Enormous pressure to use ALMA worldwide
  - Requests for 9 times the available time
  - Top 8% science projects selected (ESO)

# ALMA Science Results

eso1325 — Science Release
eso1313 — Science
eso1334 — Science Release
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eso1301
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10 July 20
20 August 20

## ALMA Probes Mysteries of Jets from Giant Black Holes

16 October 2013

Click to Enlarge

**Two international teams of astronomers have used the power of the Atacama Large Millimeter/submillimeter Array (ALMA) to focus on jets from the huge black holes at the centres of galaxies and observe how they affect their surroundings. They have respectively obtained the best view yet of the molecular gas around a nearby, quiet black hole and caught an unexpected glimpse of the base of a powerful jet close to a distant black hole.**

eso131
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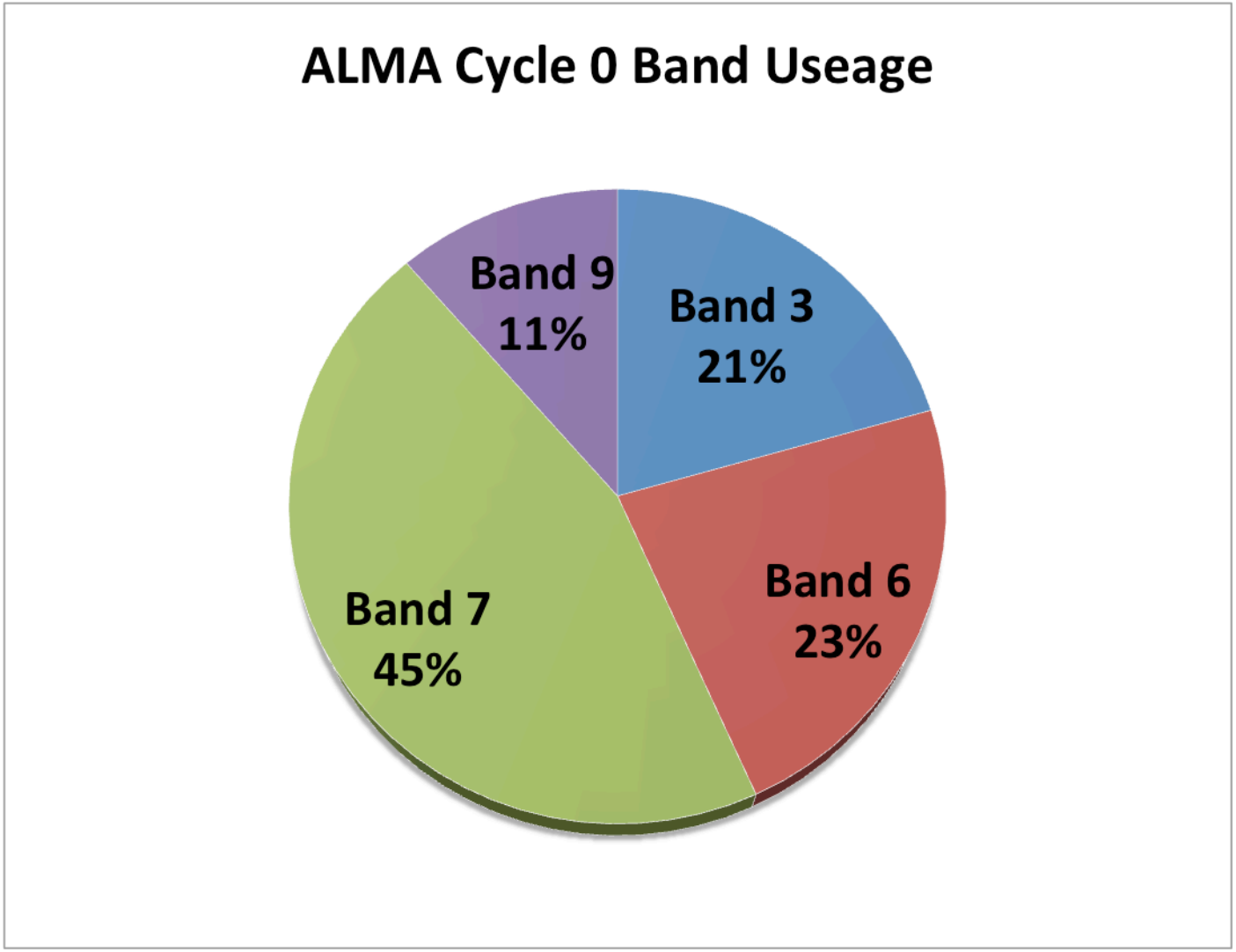
previously unknown jet pointing in a totally different
Nature on 25 July 2013.
are the first direct observations of such streams
gated by giant planets

# ALMA Bands Useage



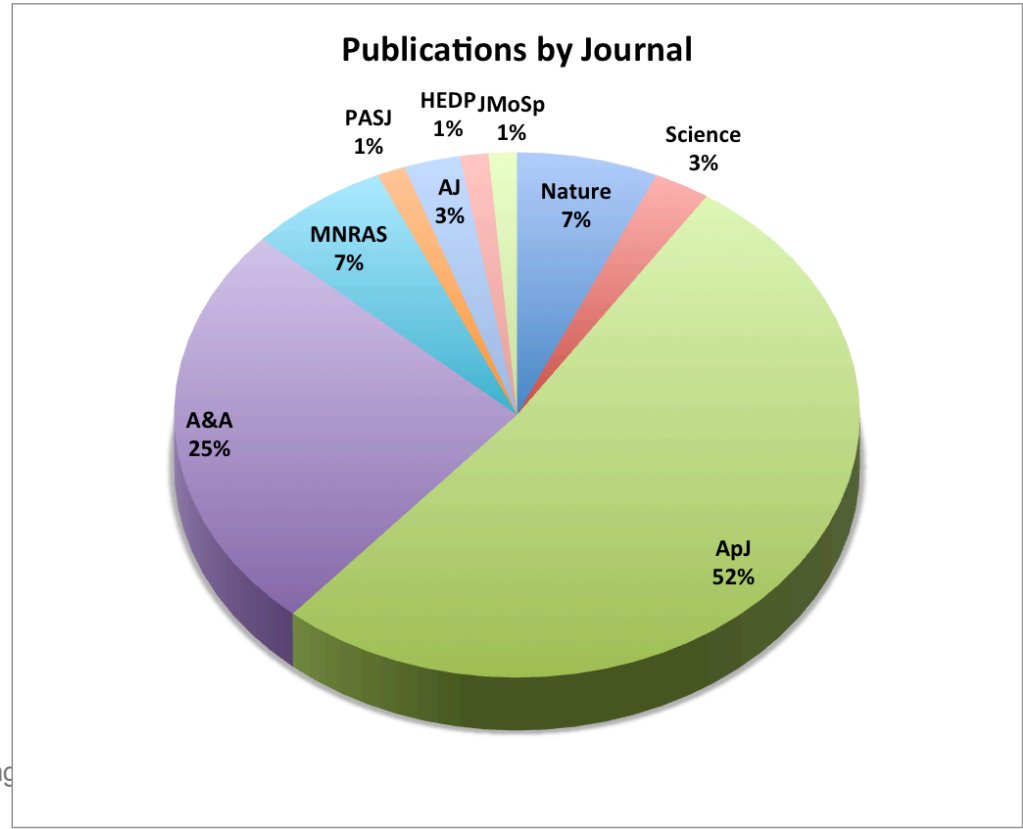
# ALMA SV+C0 Results

- Many results in published papers:
  - High-z, Disks, ISM, Star Formation, Local Universe, Solar System, Stellar Evolution, Supernovae, Cosmology, Fundamental Physics
  - For a sample, the First Year of ALMA Science Conference:
    - http://www.almasc.org/2012/
  - Planning for two major events next year:
    - Submm Astronomy Symposium at EWASS – Geneva, July 2014
    - ALMA Science Conference – Tokyo, December 2014

- ESO MS are very much engaged with ALMA Science
  - First authors of ~40% of papers so far
  - Involved in >75% of papers

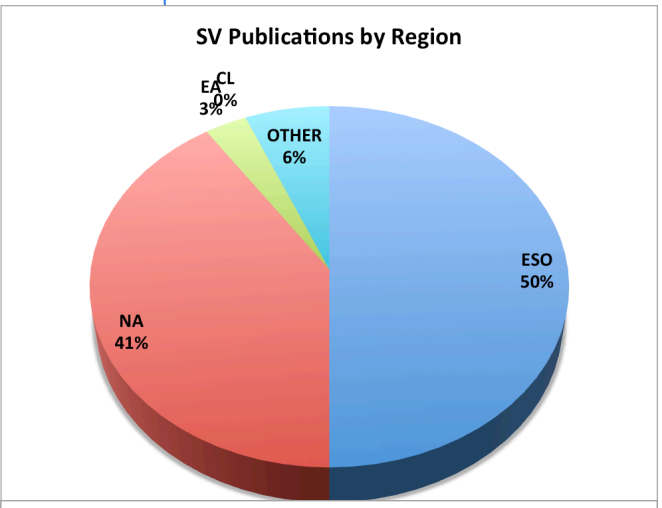
# ALMA Science Papers

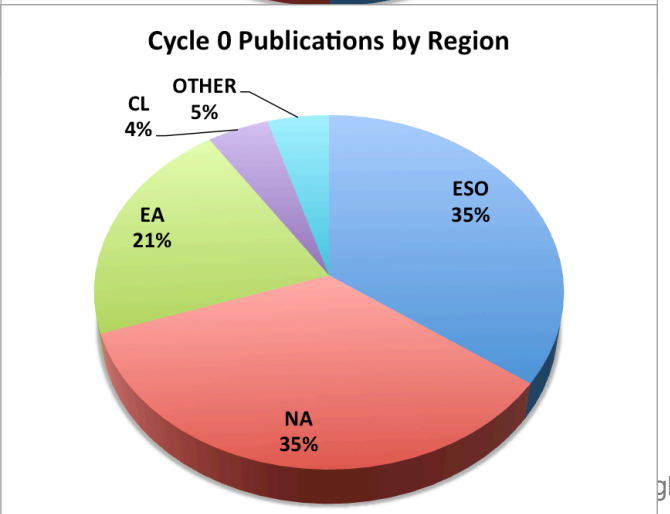
- Only refereed papers
  - Collected data as of **November 19, 2013** from telbib.eso.org (many, many thanks to Uta Grothkopf and Felix Stoehr, ++)
  - Only printed papers on refereed journals appear on the list
  - We know of more submitted/accepted papers, but we cannot be complete on those
- Database
  - 75 refereed publications
  - 32 based only on SV data
  - 43 used Cycle 0 data
  - **~10%** Nature/Science

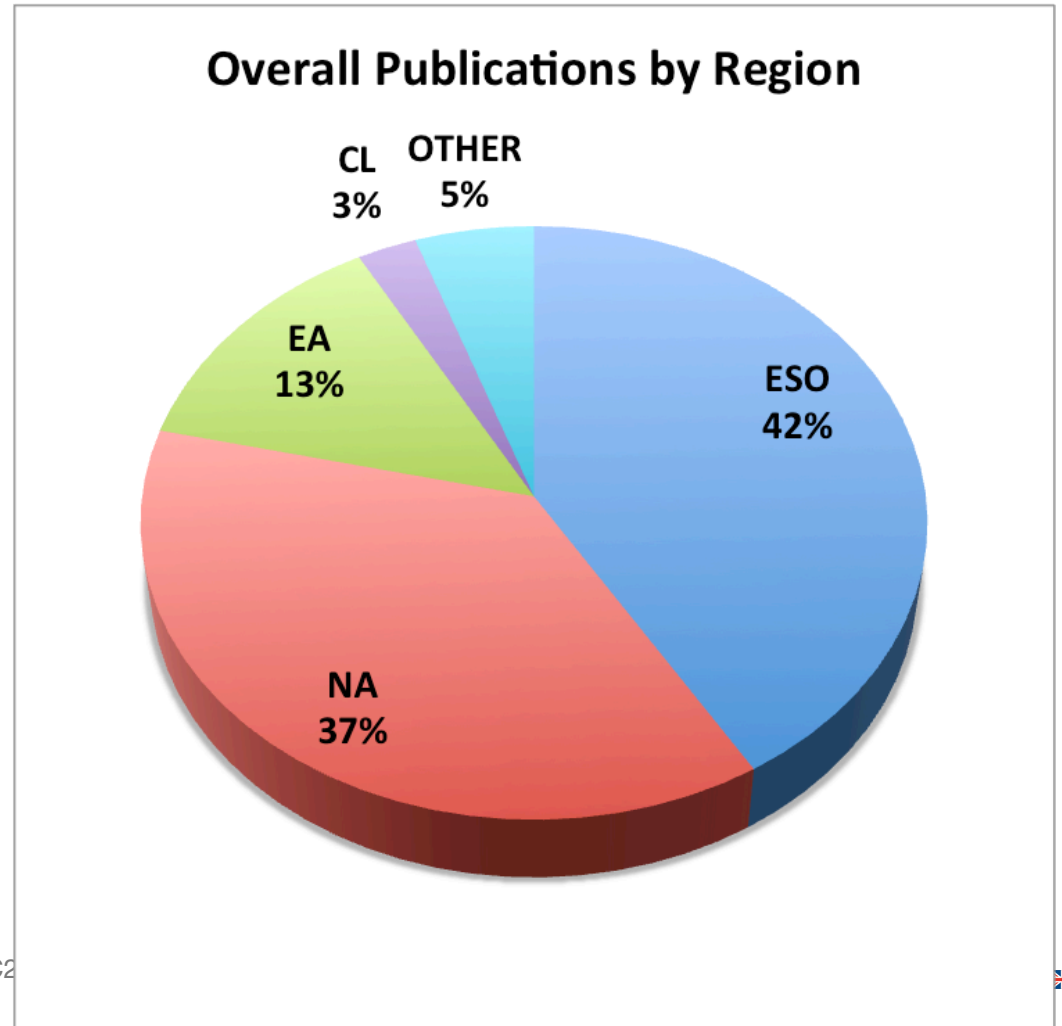


# Distribution by Region

- Very different use of SV data in the various regions
- Cycle 0 publications are well balanced

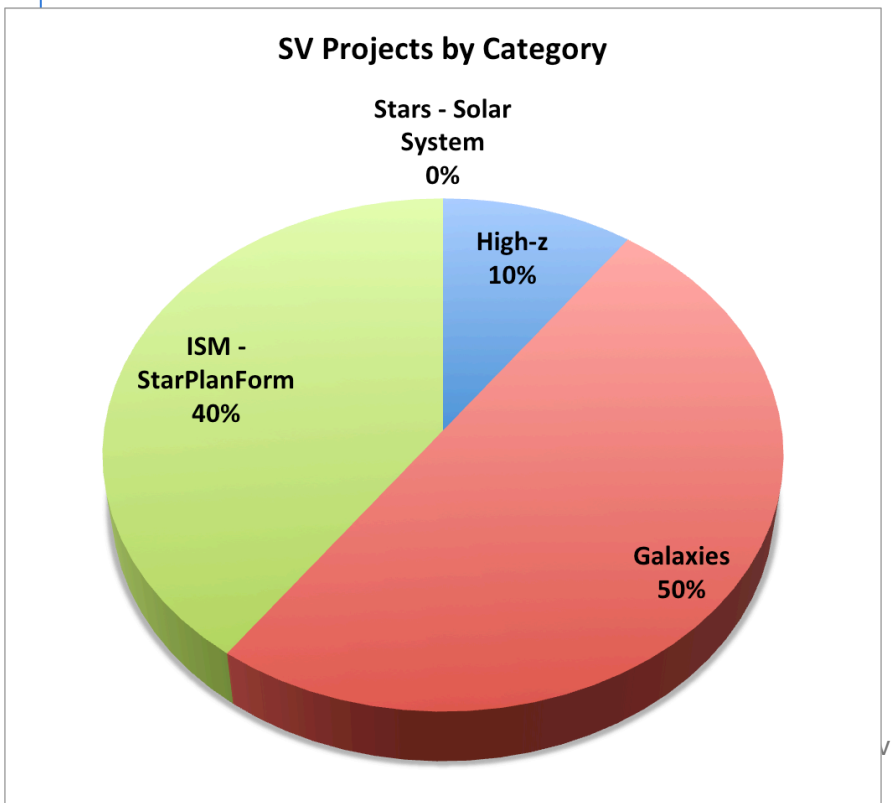


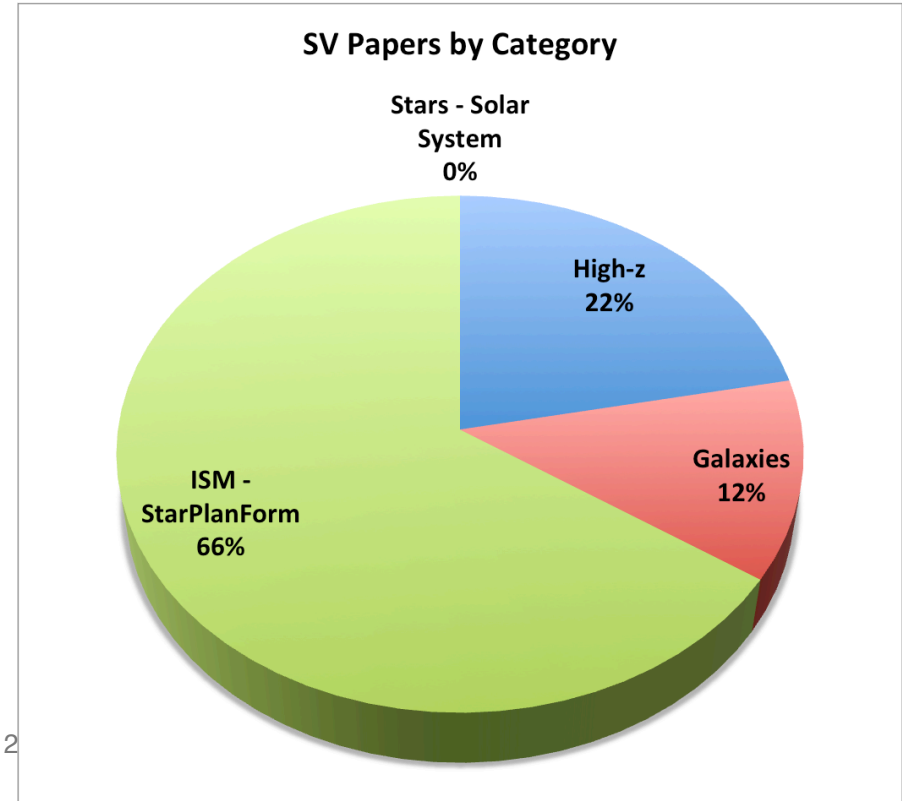



# Science Verification Publications

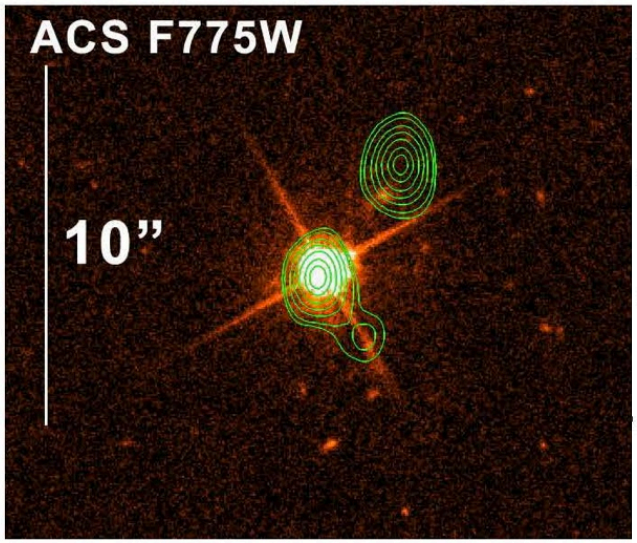
- Data was released for 10 SV projects
  - No Star/Solar System project so far
- Publications were produced for 7 projects (32 papers)
  - All high-z (1) and ISM-StarPlanForm (4) produced papers
- NB. Papers are not a goal of SV projects!!

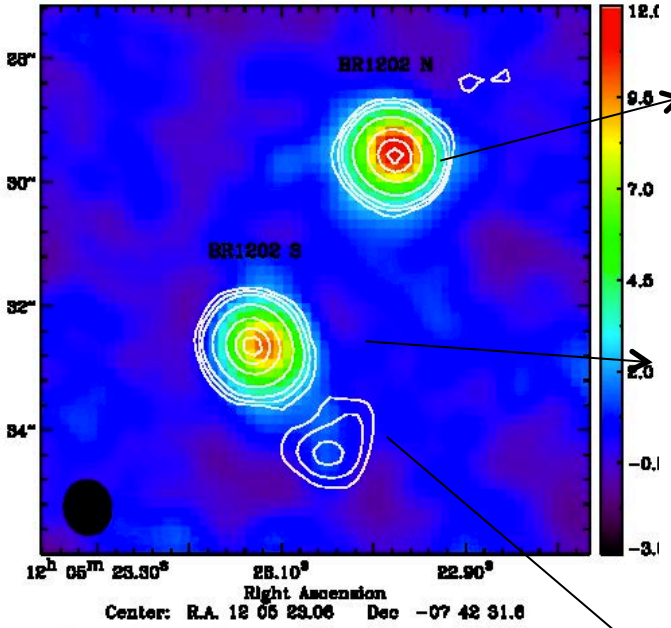


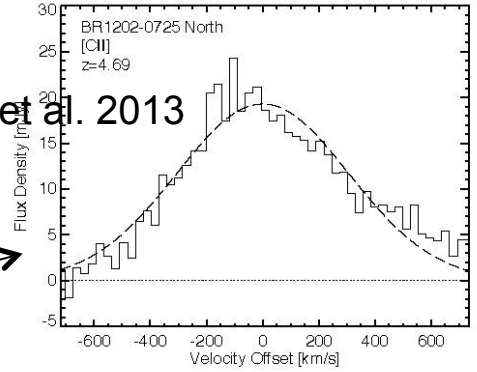



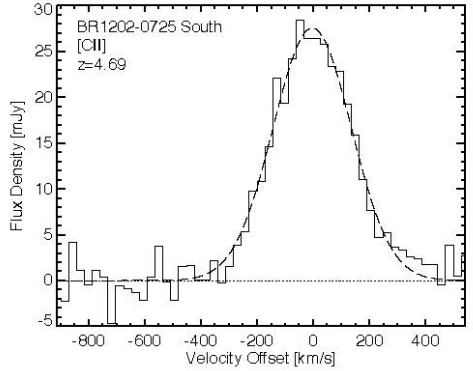
# ALMA SV Science Results

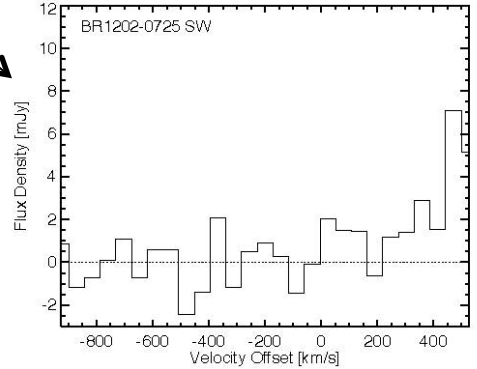
- Star formation in the Early Universe: [CII] at high z
  - Wagg et al. 2012; Carilli et al. 2012; Lentati et al. 2013; Carniani et al. 2013

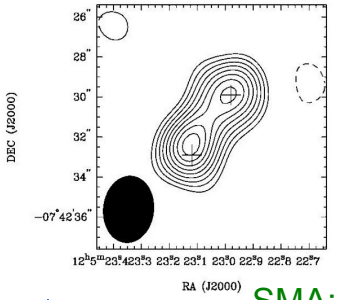


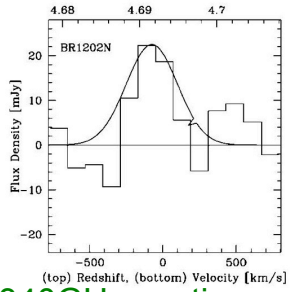



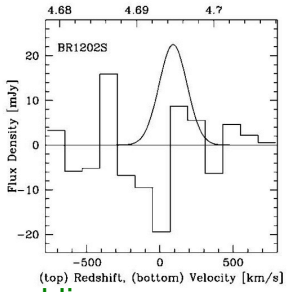



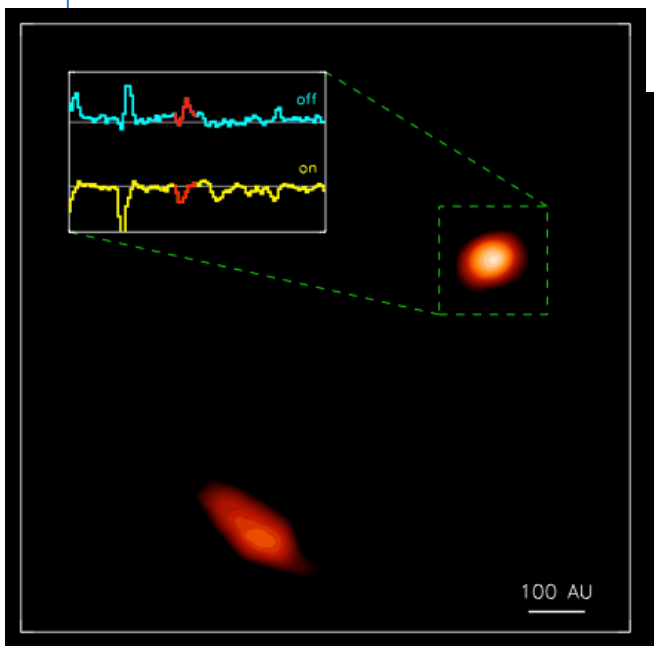



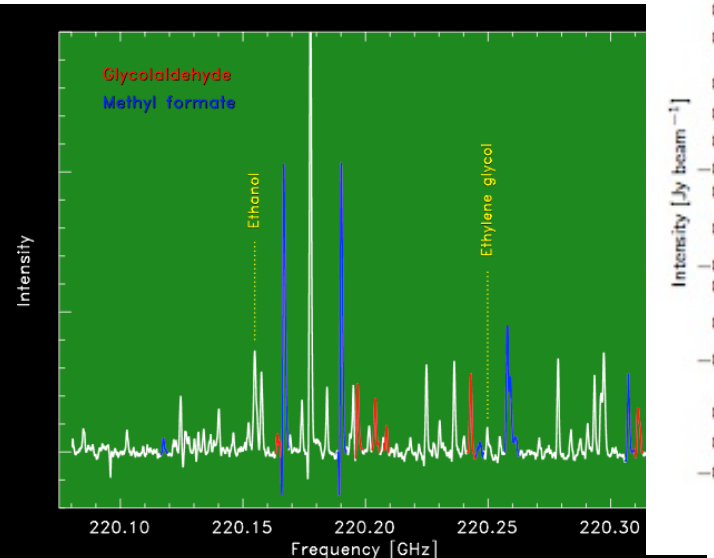

SMA: 340GHz continuum and line
Iono et al. (2006), [CII] (N only)+cont

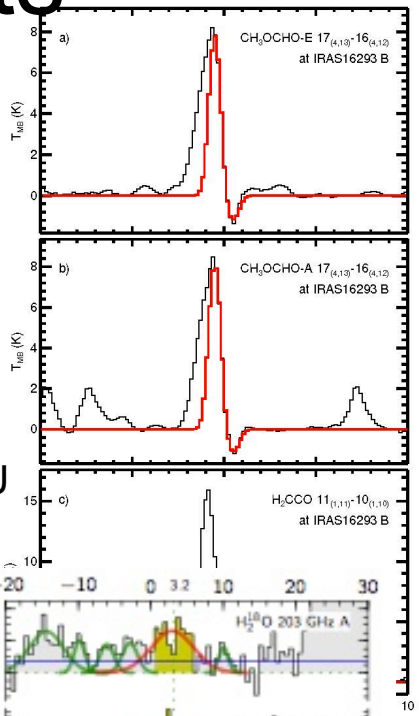
z=4.69

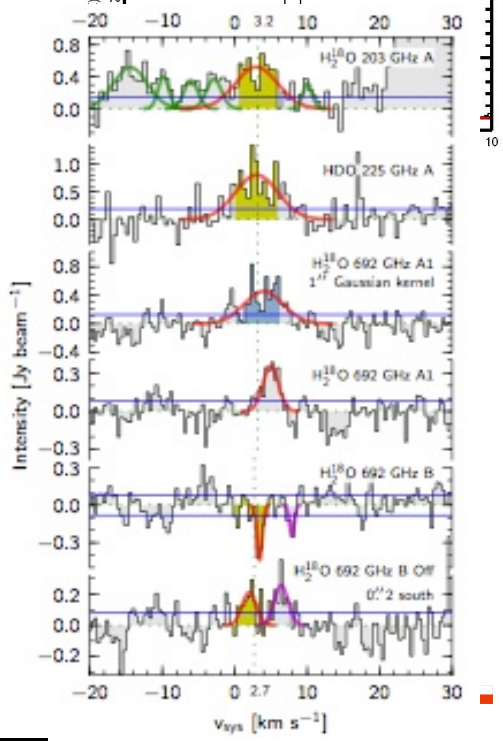
# ALMA SV Science Results

- Infall and pre-biotic molecules in IRAS16293
  - Jorgensen et al. 2012; Pineda et al. 2012; Persson et al. 2013
  - Kristensen et al. 2013; Zapata et al. 2013; Loinard et al. 2013
- First glycoaldeheyde detection in solar mass protostar
  - From B9 first released dataset. This simple sugar is found within ~25~AU from the central protostar and infalling into the inner regions of the disk.
  - Water isotopomers in Band 9



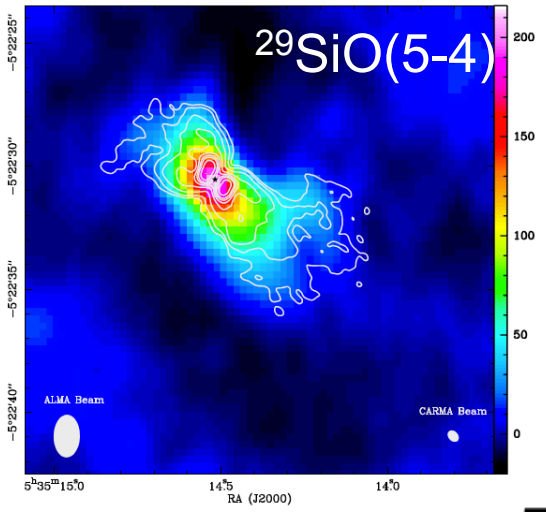



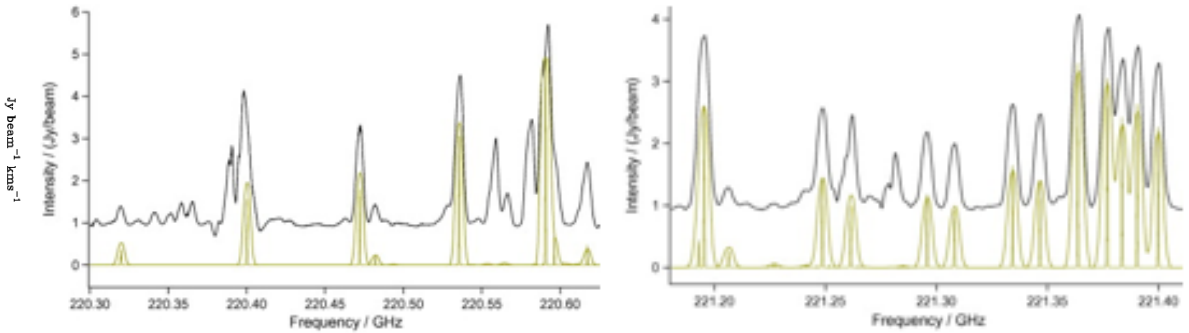
# ALMA SV Science Results

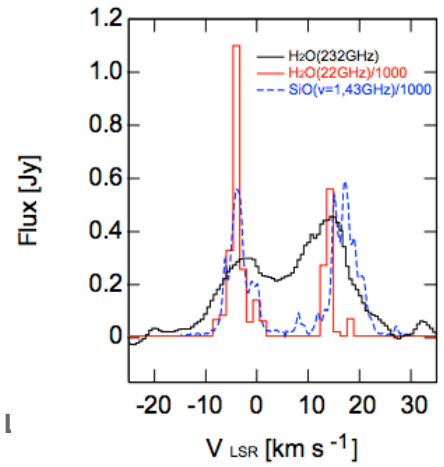
http://almascience.eso.org/alma-data/science-verification

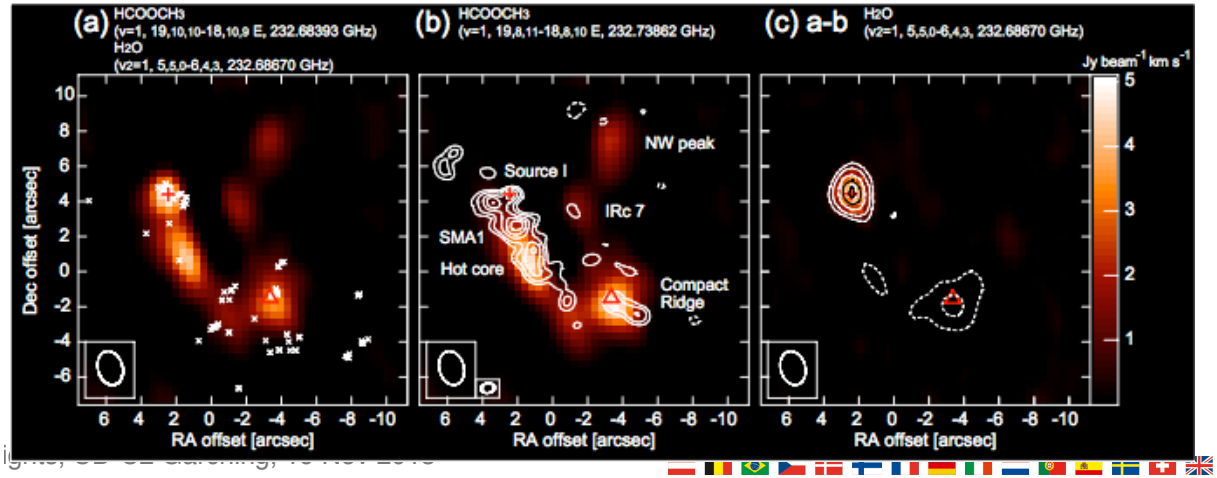
## Orion-KL Spectral Scan - Band 6

- Zapata et al. 2012; Hirota et al. 2012; Fortman et al. 2012; Chepherd et al. 2012; Niederhofer et al. 2012; Galvan-Madrid et al. 2012; Neill et al. 2013a & 2013b



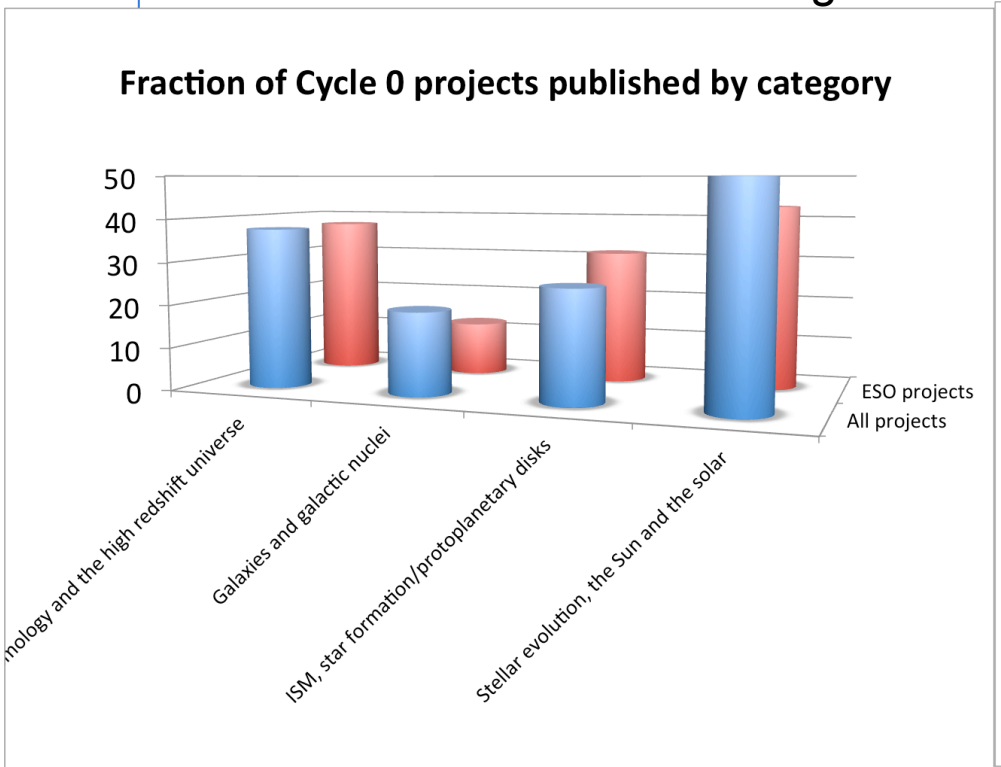



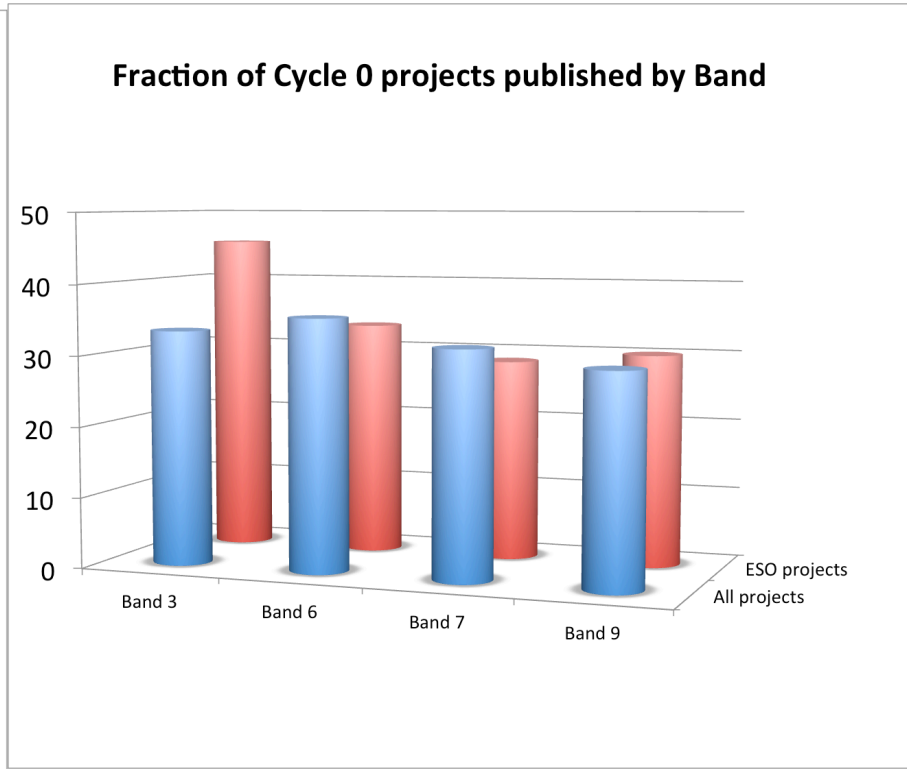



# Cycle 0 Publications

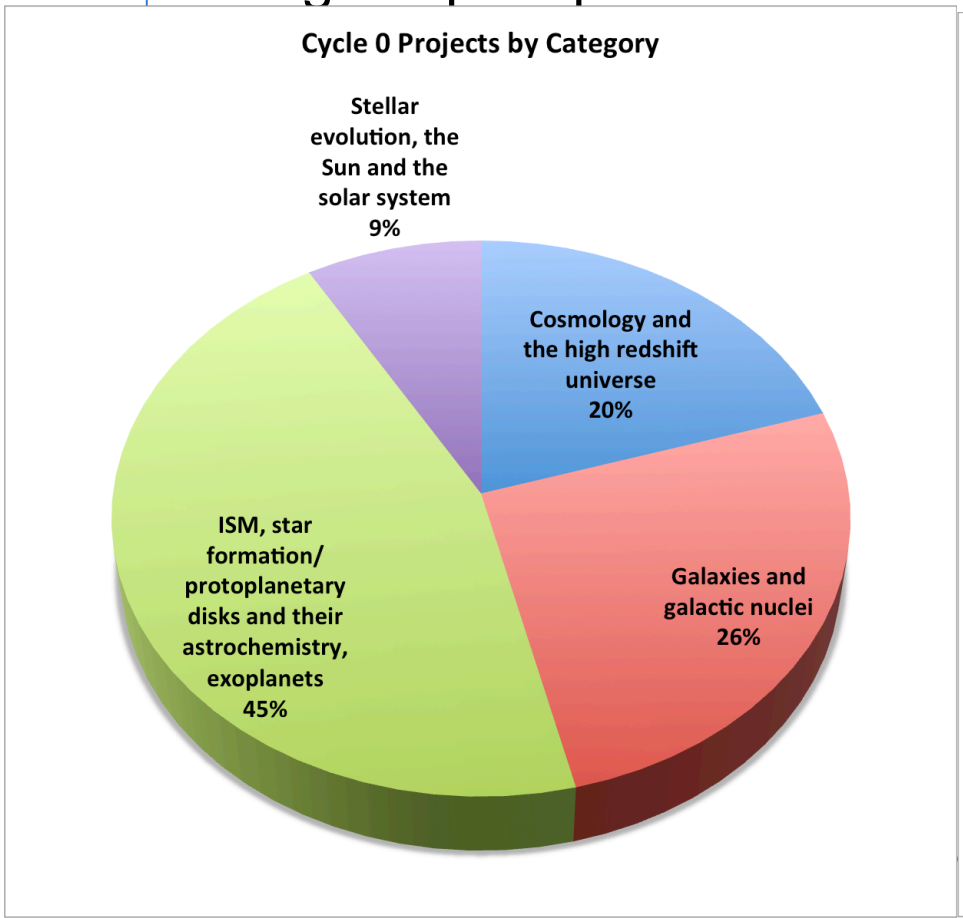
- Overall ~30% of the 119 projects for which data was delivered have resulted in a printed publication (43 papers)
  - No Solar System publication yet
  - Galaxies/AGN slightly lower than average (but coming up!)
- Publication fraction uniform across frequency band
  - Beware double counting. For ESO more B3.

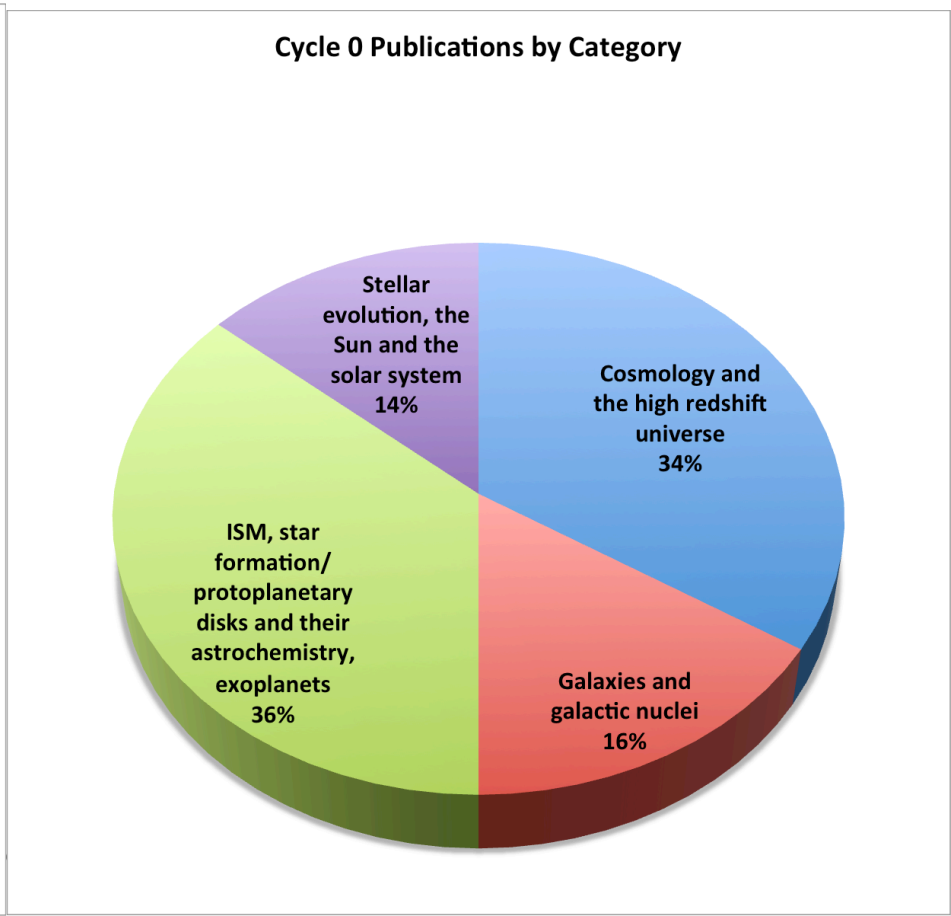


# Cycle 0 Publications

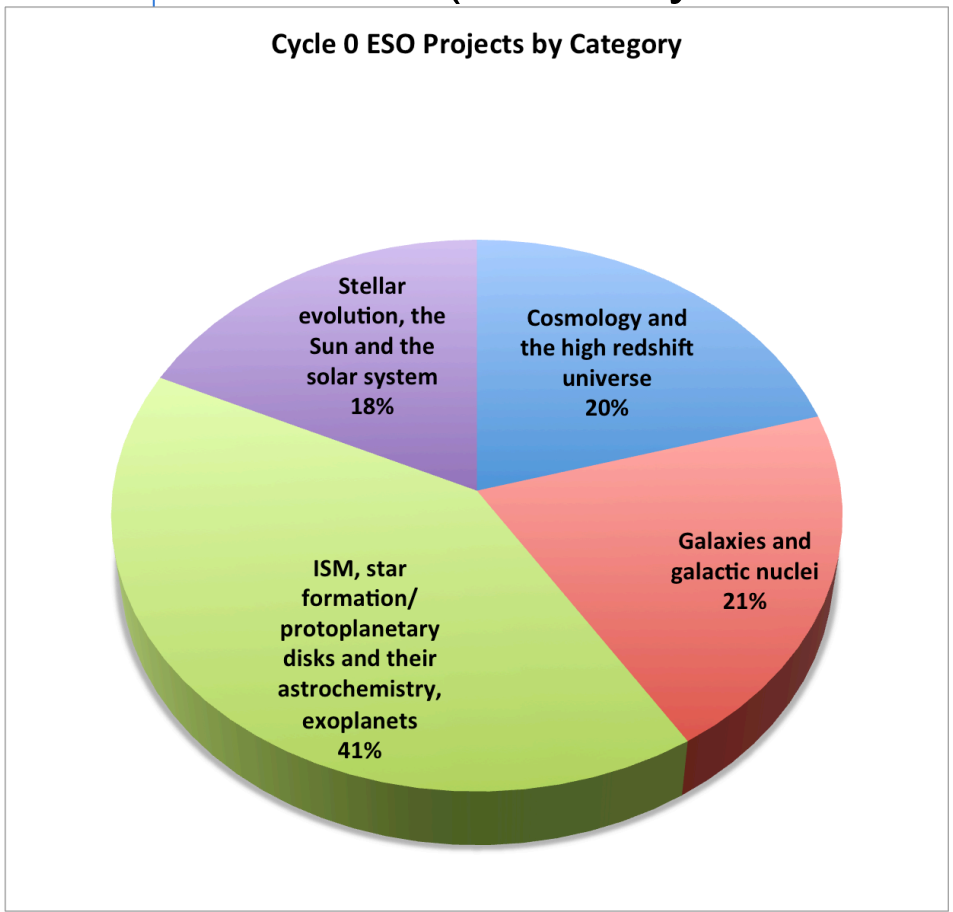
- Major impact so far in Cosmology/high-z and ISM/ StarPlanForm/Astrochemistry
  - No Solar System publication so far (CASA tasks available since May)
- High impact pubs in all four areas!

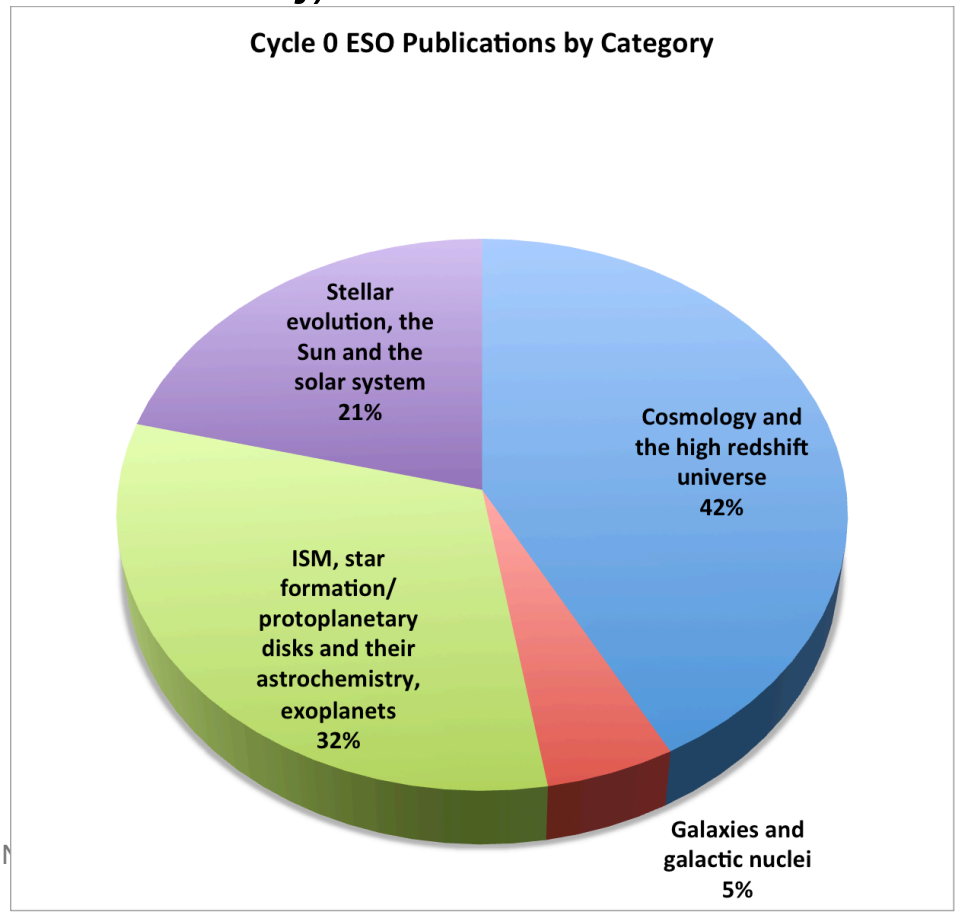


# Cycle 0 Publications

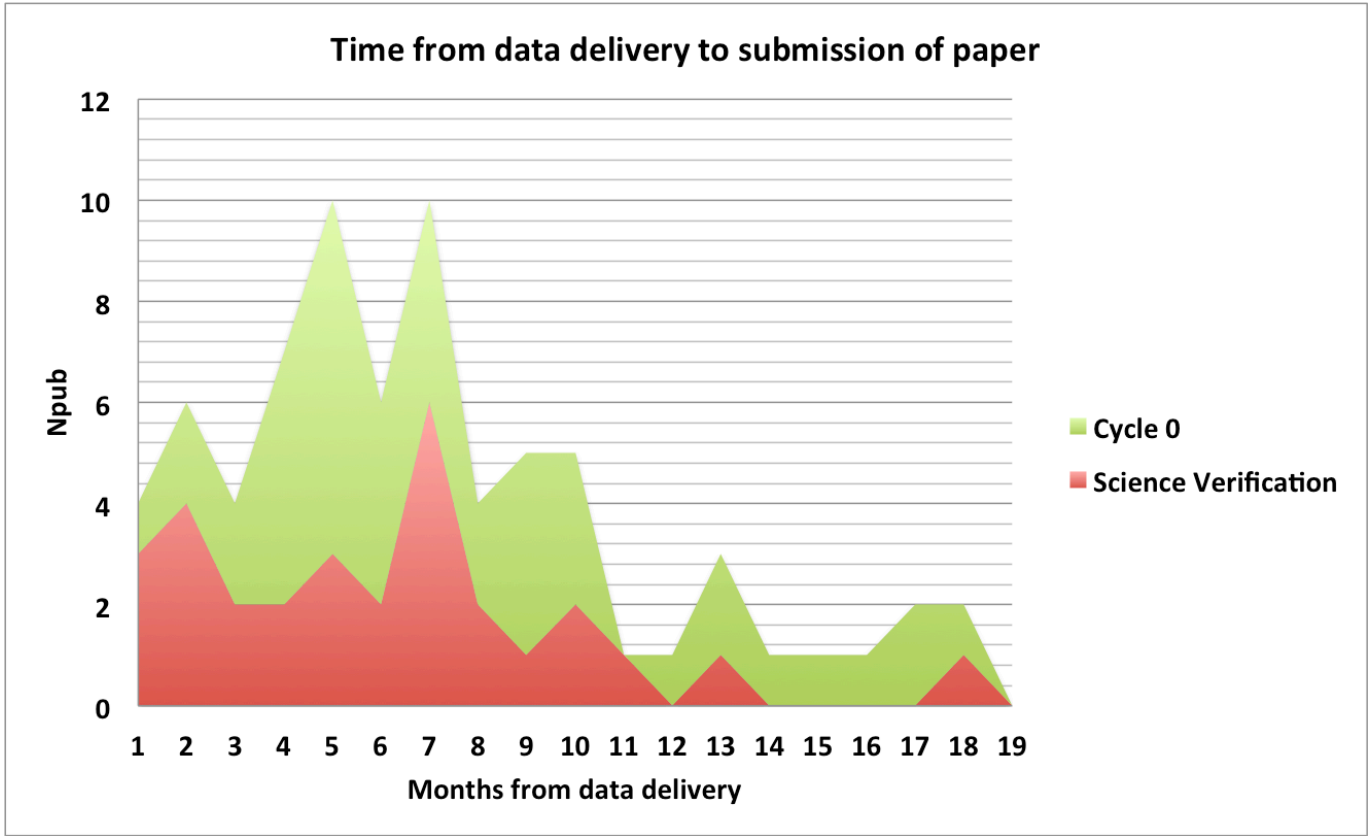
- Major impact so far in Cosmology/high-z and ISM/ StarPlanForm/Astrochemistry
  - No Solar System publication so far (CASA tasks available since May)
- ESO – (NB. Only 19 Pubs from 12 Proj)



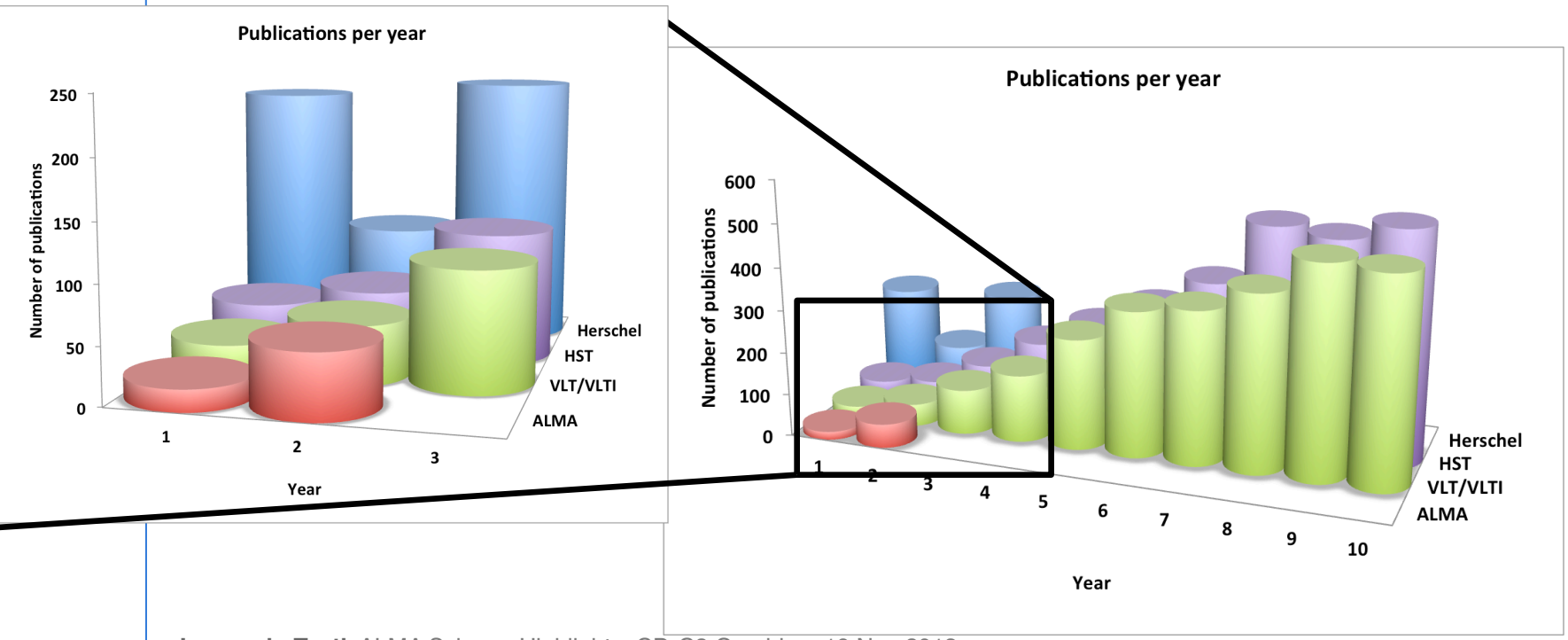
# Time from data delivery

- Time from data delivery to submission of paper
  - Note: this is very biased I have only “printed” papers and I am showing “submission” times (time difference can be several months)
- Most of C0 data delivered ~10-11 months ago



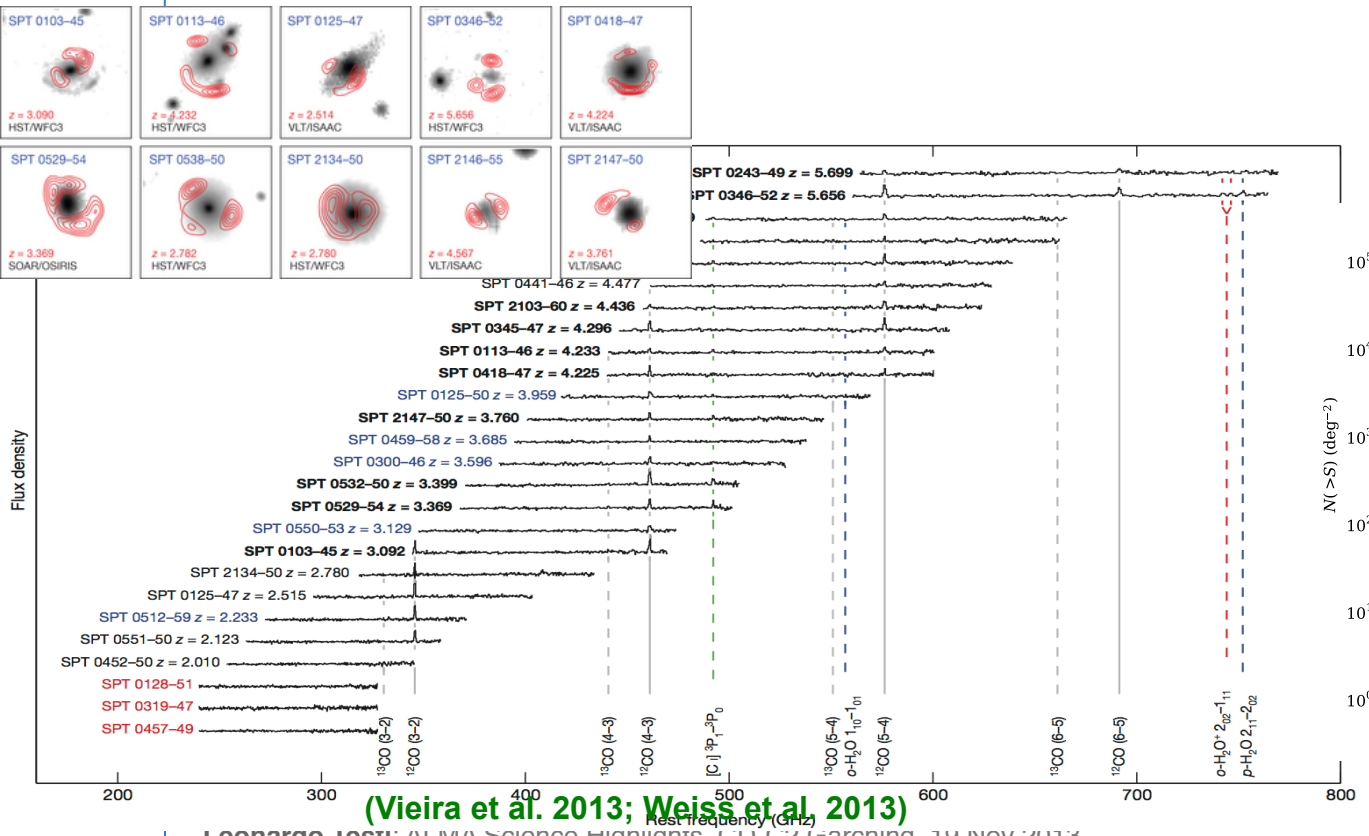
# Comparison with other facilities

- Data from ESO and HST databases
  - NB. Apai et al. (2010): HST database is incomplete for first 7yr (?)
- Year 2 of ALMA is still incomplete
- Nature/Science first two years (ALMA 7/75 ~10%):
  - Paranal: 1/81 ~1%; HST: 4/101 ~4%; Herschel: 6/327 ~2%

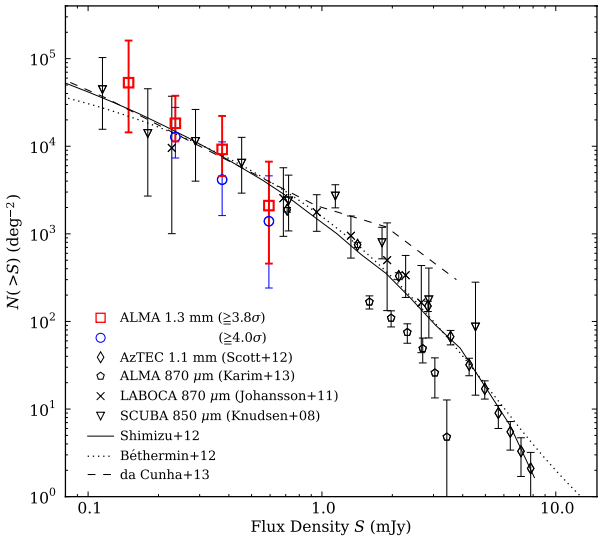


# Cosmology/High-z

- 1 Nature paper on the STP lensed SMGs
  - New redshift distribution
- Other results in many areas
  - Deep galaxy counts, GRBs, metals in QSOs and first galaxies



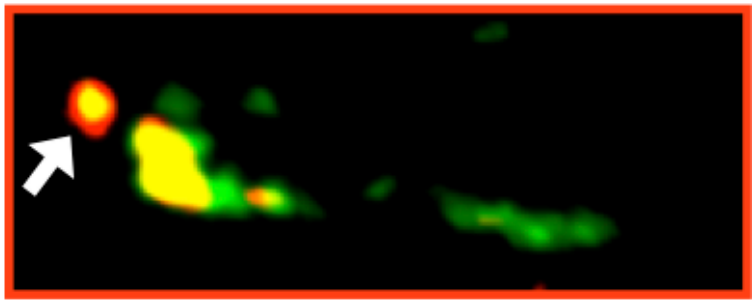

(Vieira et al. 2013; Weiss et al. 2013)



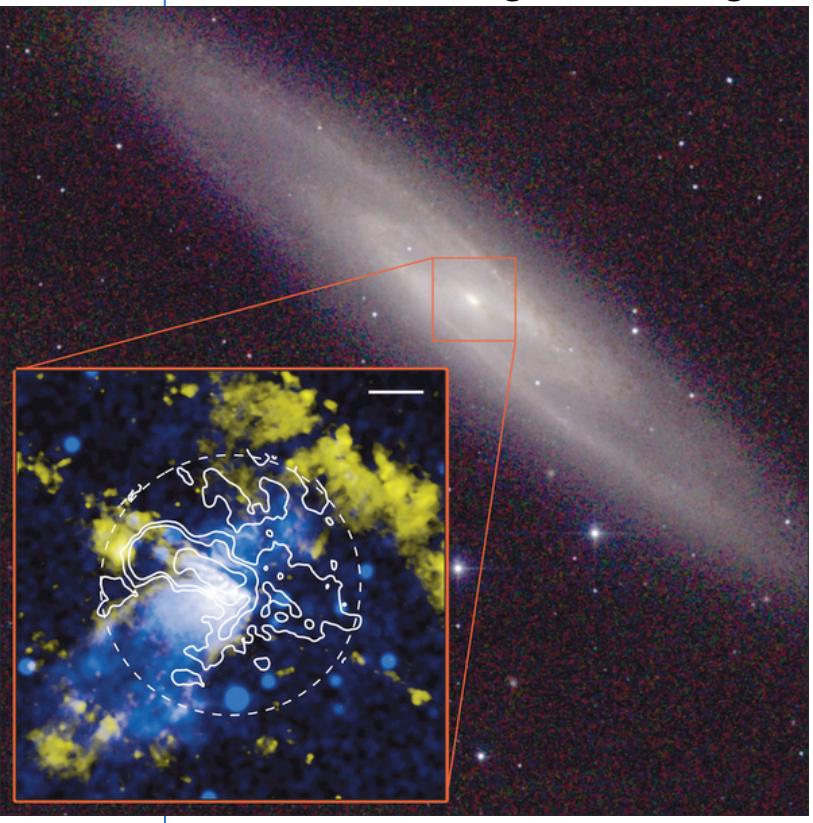

(Hatsukade et al. 2013)

# Galaxies/AGN

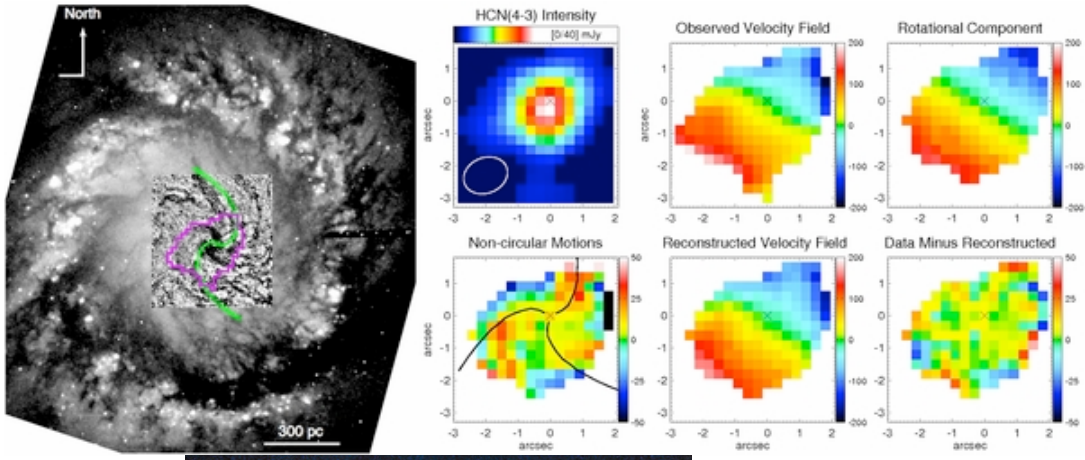
- 1 Nature paper on NGC 253
  - Molecular wind driven by starburst
- Other results
  - Dense gas feeding AGN nuclei



(Iono et al. 2013)



(Bolatto et al. 2013)

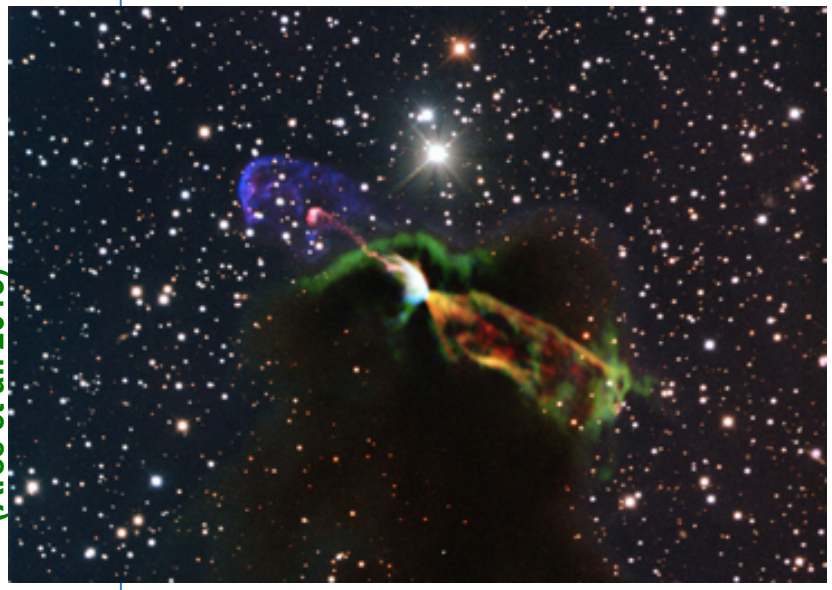



(Fathi et al. 2013)

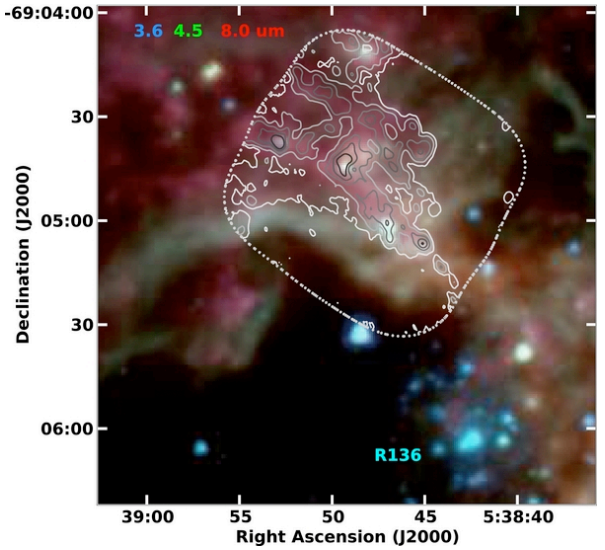
(Combes et al. 2013)

# ISM Star Formation

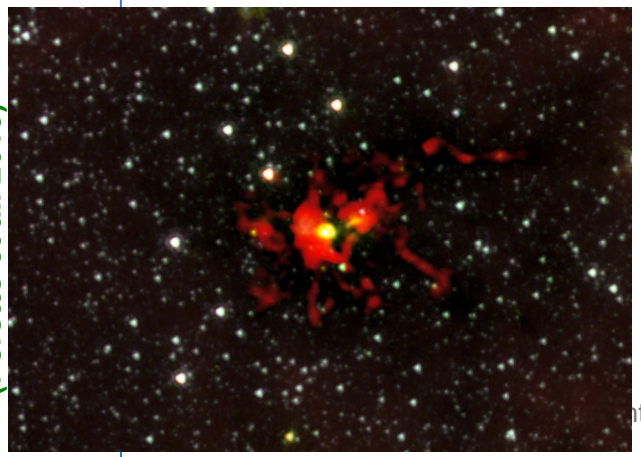
- Several important results
  - Molecular outflows, disks around high mass protostars, IRDCs



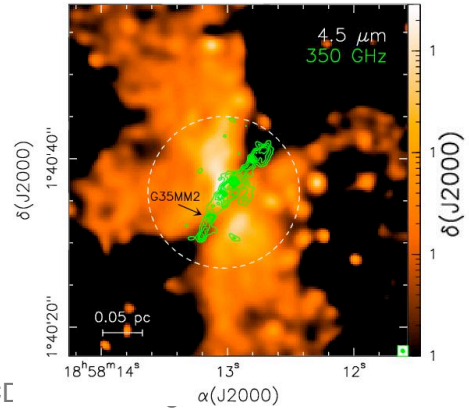
(Arce et al. 2013)

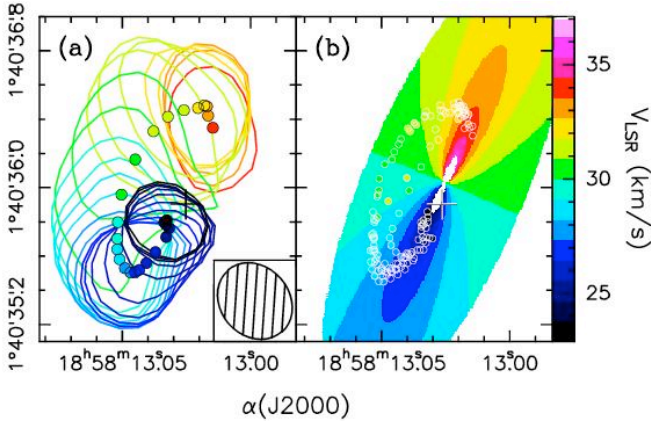



(Indebetouw et al. 2013)



(Peretto et al. 2013)

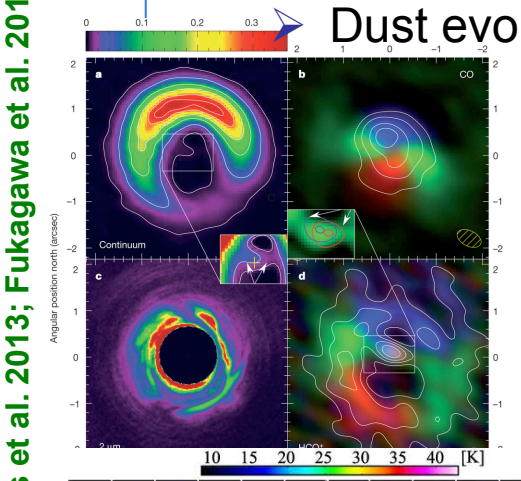


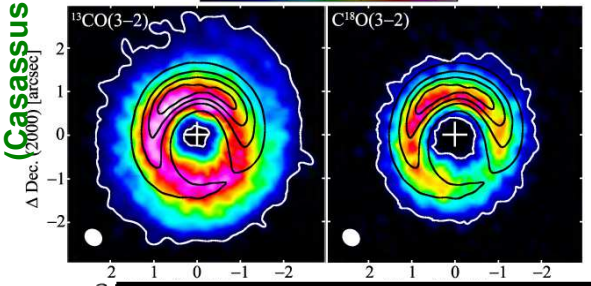

(Sanchez-Monge et al. 2013)

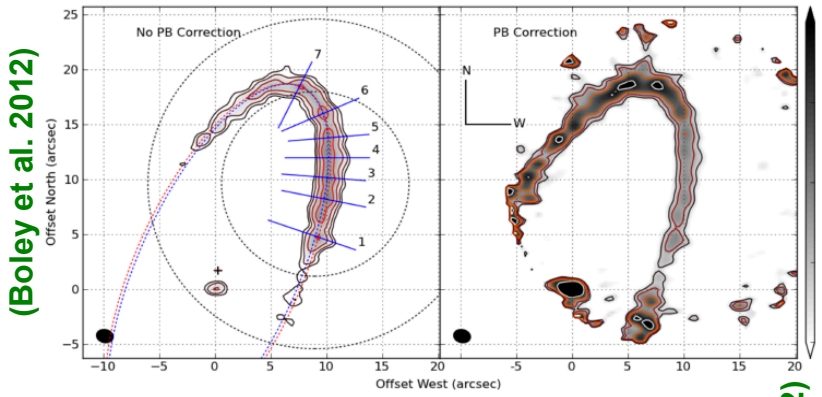
# Protoplanetary disks

- 2 Nature, 2 Science papers
  - Dust evolution, gaps, gas chemistry and snowlines

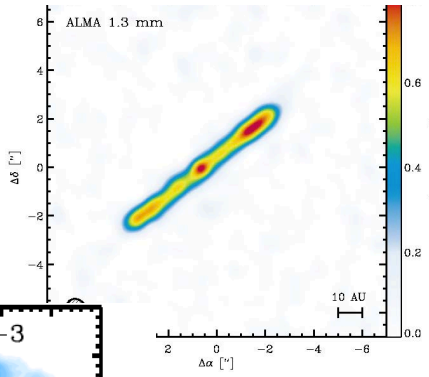



(Casassus et al. 2013; Fukagawa et al. 2013)

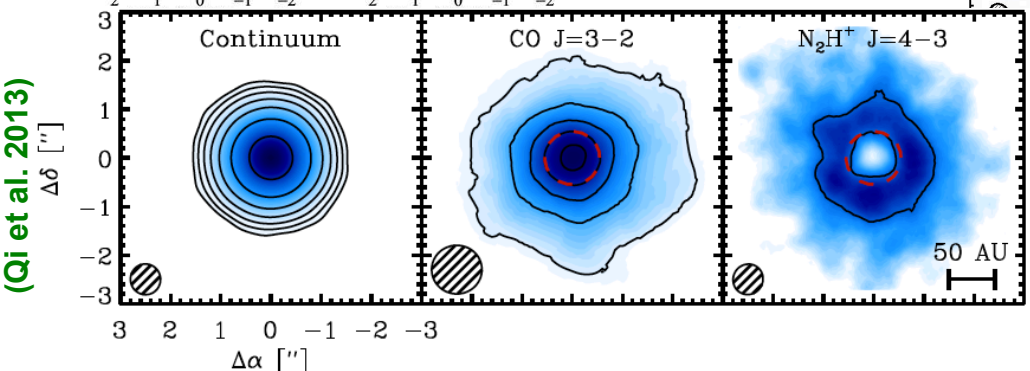


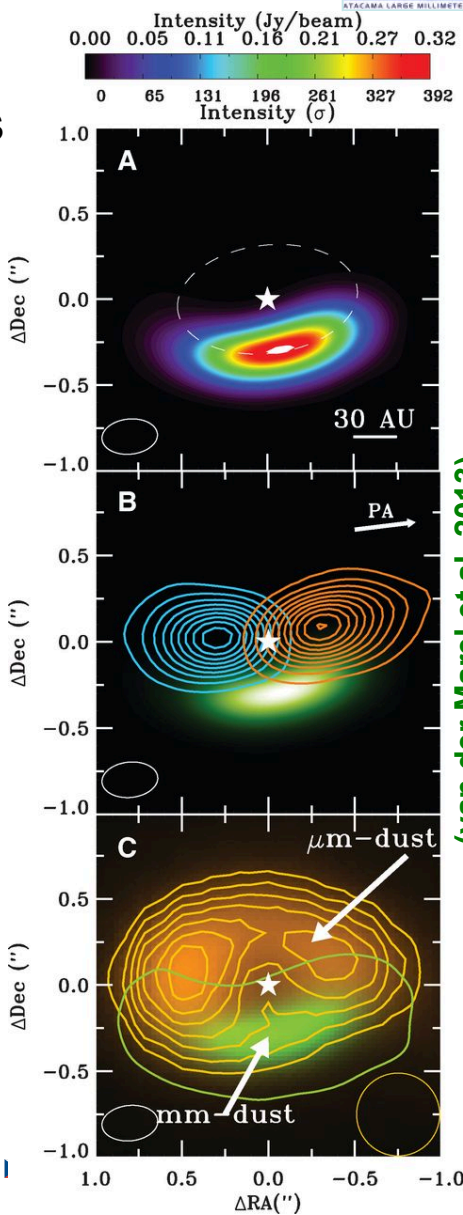

(Boley et al. 2012)




(McGregor et al. 2012)




(Qi et al. 2013)

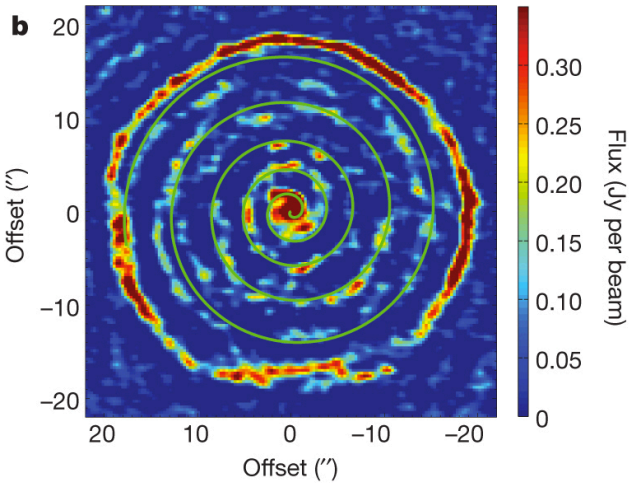



(van der Marel et al. 2013)

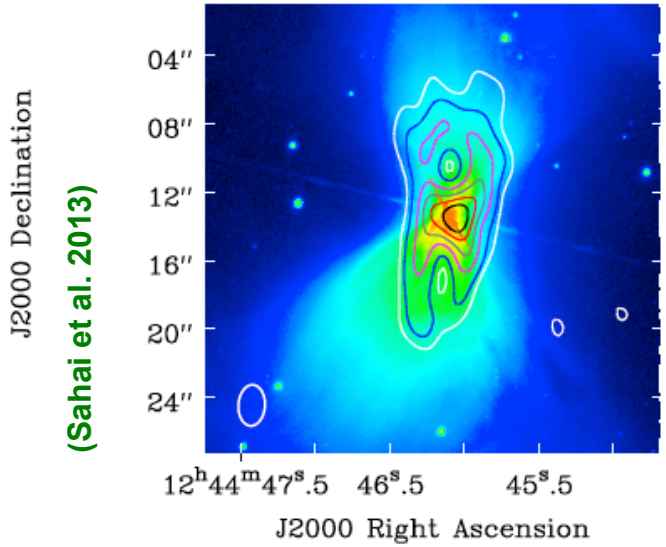
# Stellar evolution

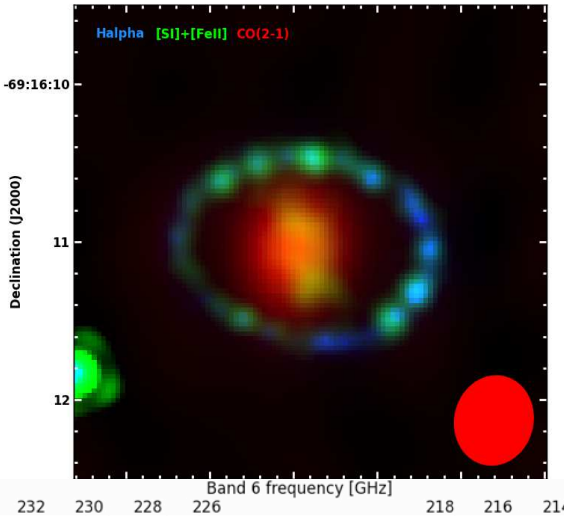
- 1 Nature paper
  - Post AGB stars, pre-planetary nebula, SN 1987

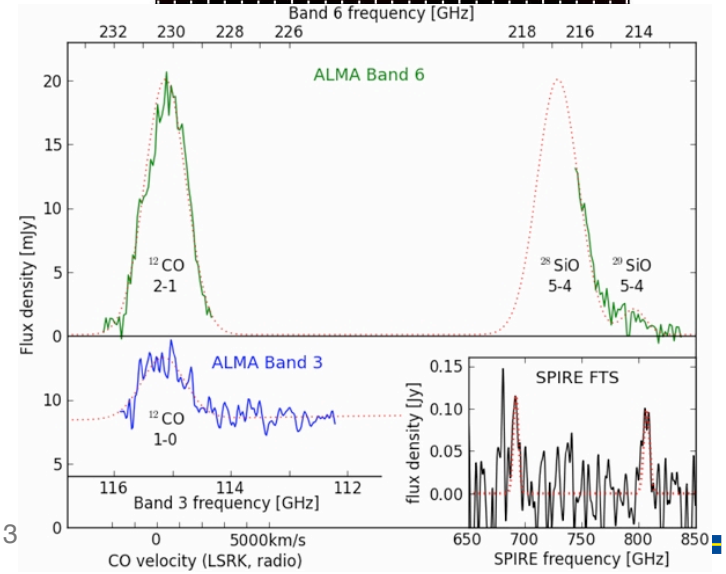
(Maercker et al. 2012)




(Sahai et al. 2013)




(Kamenetzky et al. 2013)

ov 2013

# Summary

- ALMA is producing transformational science!
  - Key role of the ARC Network in Europe (thanks!!)
  - The Archive is there for you to exploit!

- ALMA ES is just the beginning!
  - Cycle 2 – 5 Dec 2013 – additional capabilities and time (bands, pol, spectral scans)
  - Full Science Operations in 1-2yrs

- ALMA is a long lifetime observatory with a healthy Development Plan
  - Participation in the ALMA Upgrade Studies is important
  - New cycle of studies will start in early 2014