Radio stars are coming back, this time in color:

the VLBI perspective of young stars and ultracool dwarfs

*SS16: Registering the Universe at the **highest spatial accuracy***

Jan Forbrich

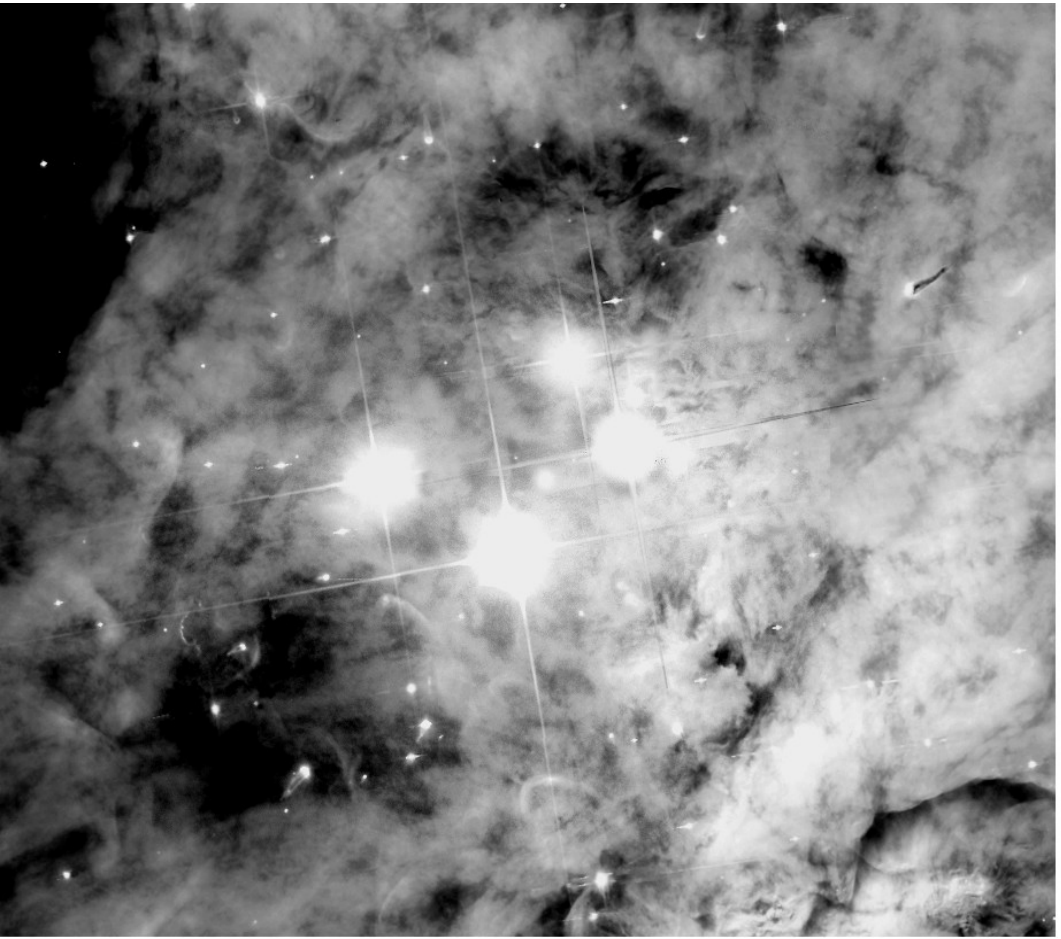
University of Hertfordshire UH

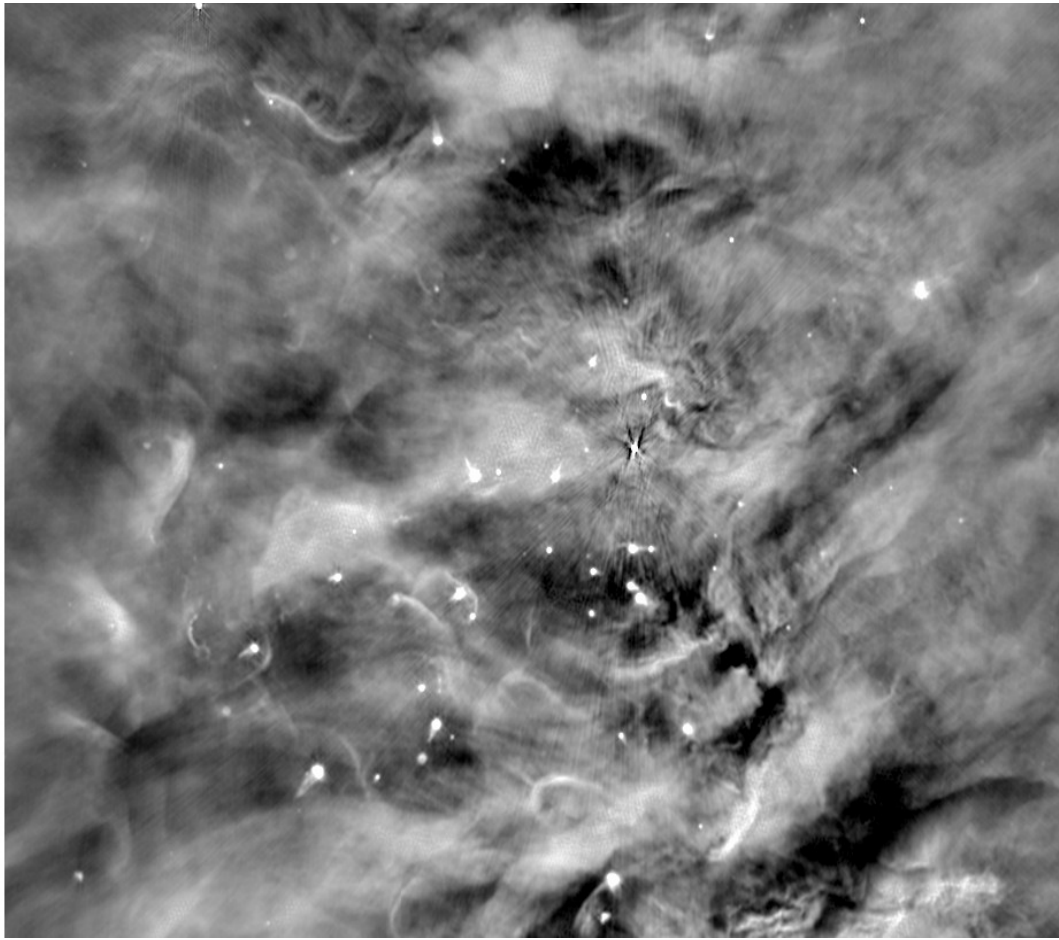
CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

This presentation has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 7308844 (JUMPING JIVE).

Forbrich et al. (2016)

The **proplyds** (and more)

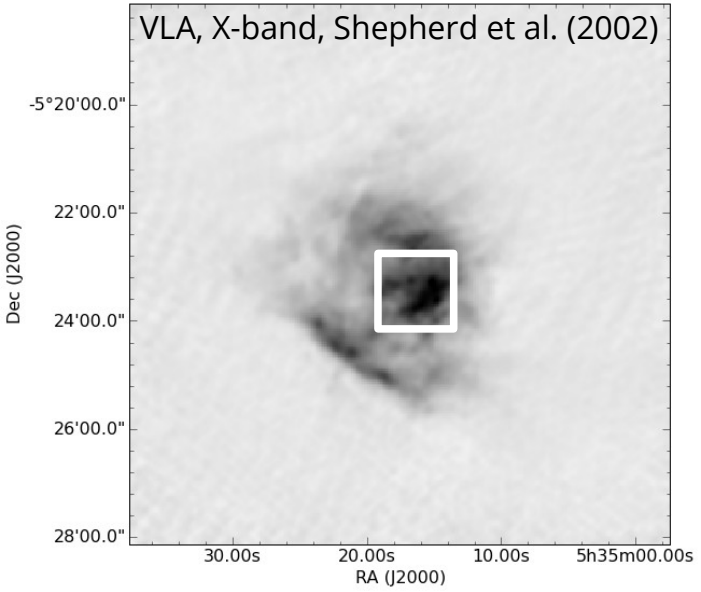


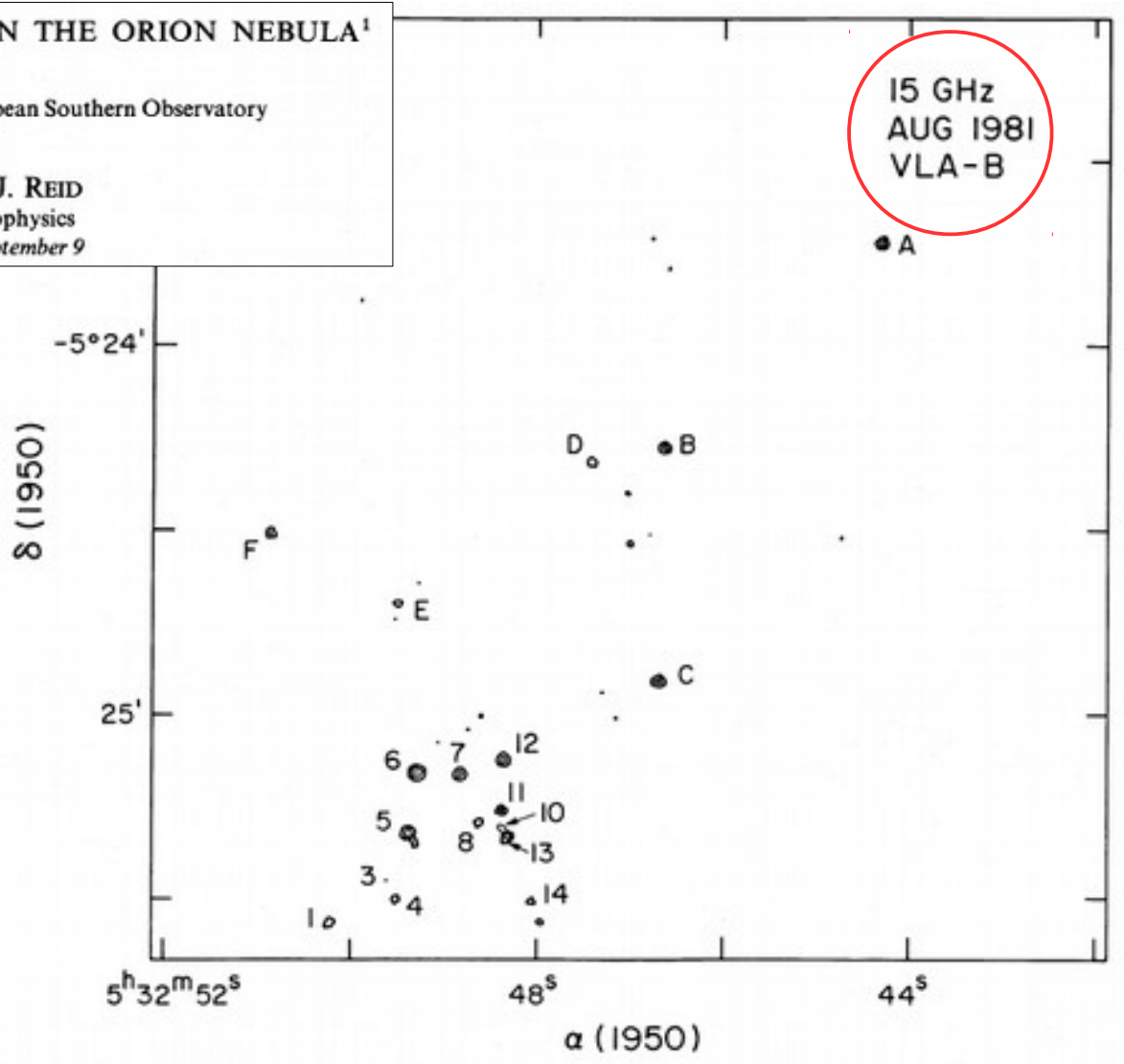


Vargaz Gonzalez et al., *in prep.*

COMPACT CONTINUUM RADIO SOURCES IN THE ORION NEBULA[1]

GUIDO GARAY
Harvard-Smithsonian Center for Astrophysics; and European Southern Observatory
AND
JAMES M. MORAN AND MARK J. REID
Harvard-Smithsonian Center for Astrophysics
Received 1986 July 7; accepted 1986 September 9

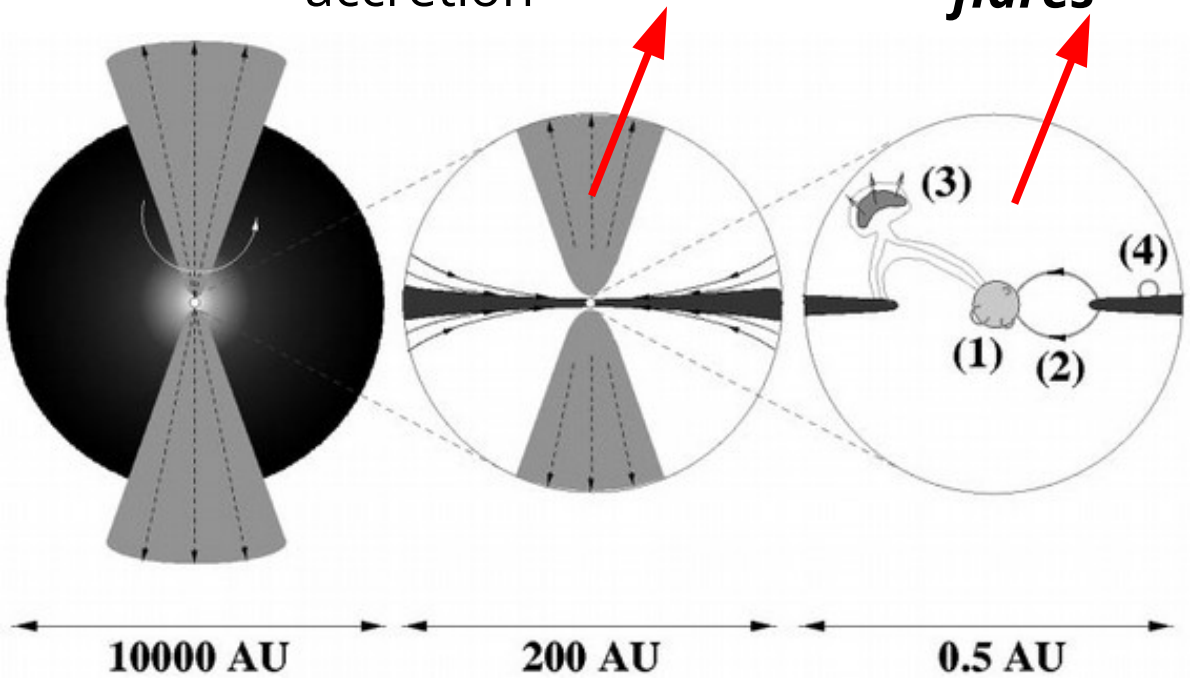




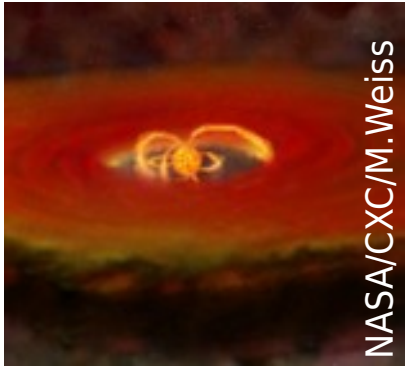
High-energy processes in Young Stellar Objects

Thermal radio emission, could fluctuate with accretion

Thermal X-ray emission, cm & mm nonthermal emission, *flares*

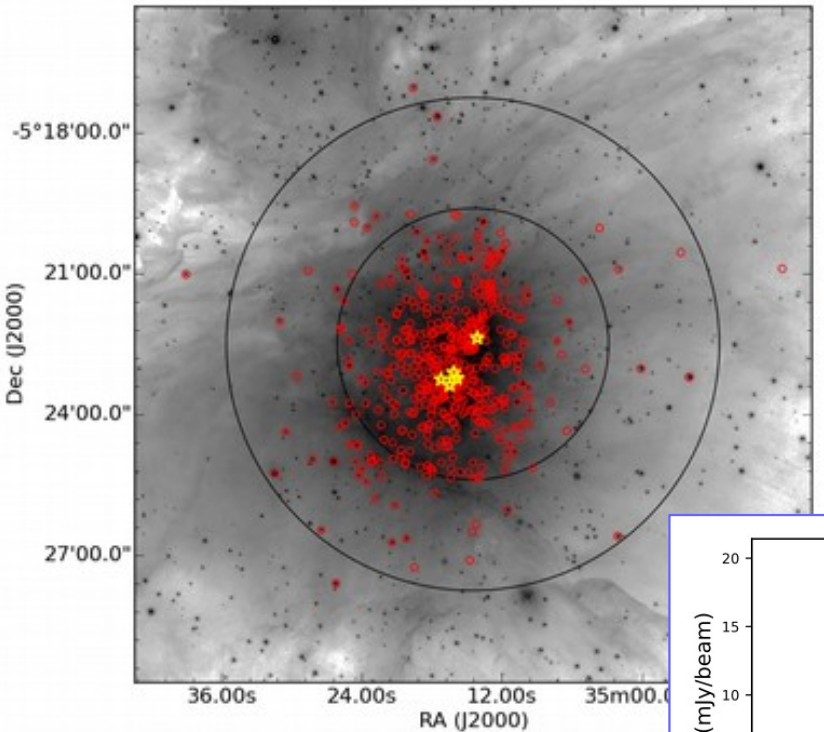


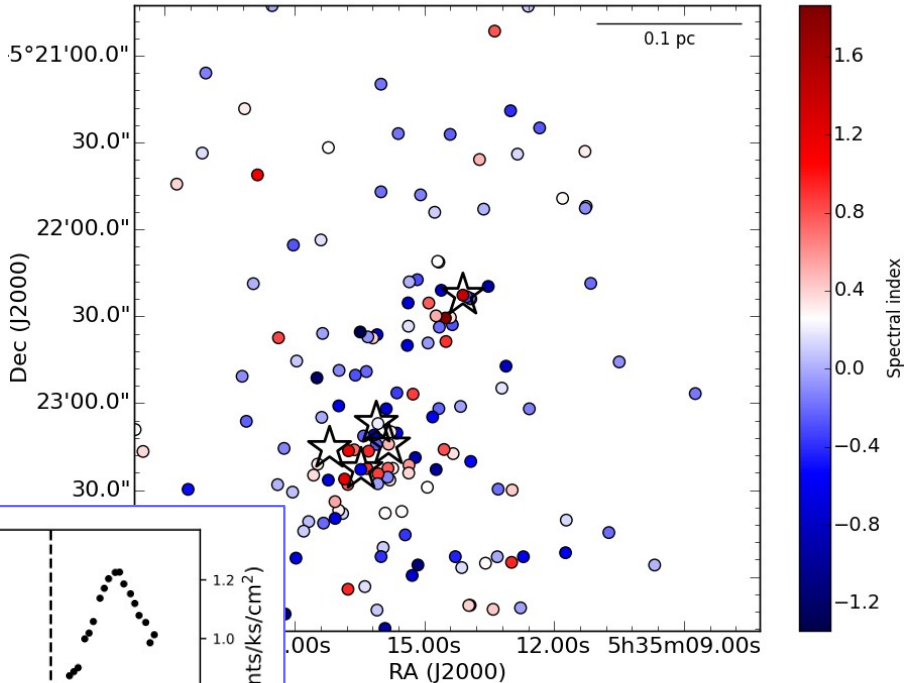
Feigelson & Montmerle (1999)

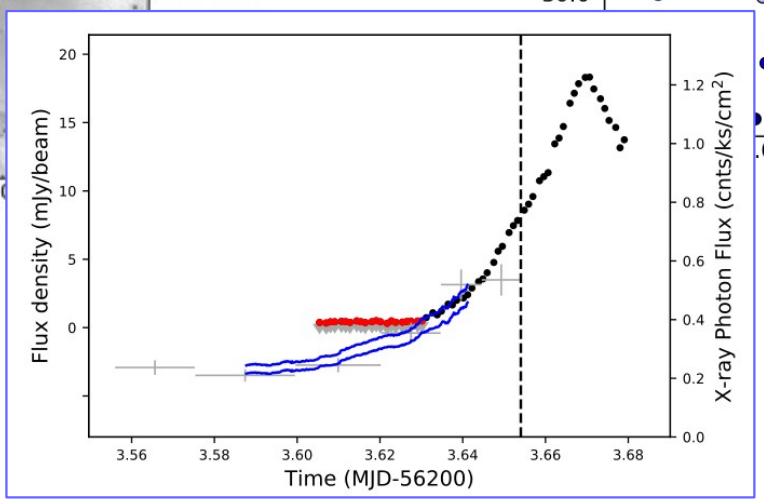


Both X-ray *and* nonthermal radio emission probe the ***innermost vicinities*** of protostars!

The VLA(!) **data**







The Orion Radio All Stars

VLA – VLBA – ALMA

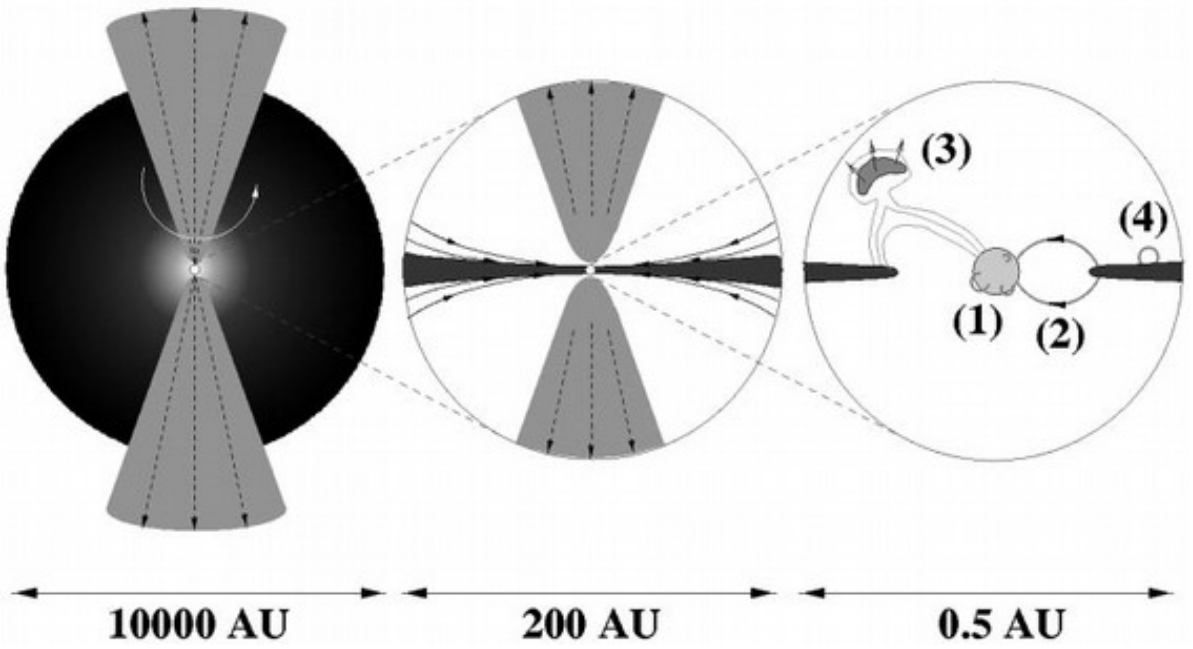
See also poster by Jaime Vargas Gonzalez!

Forbrich et al. (2016, 2017)

*SS16: Registering the Universe at the **highest spatial accuracy***

Mic Hartwich

*SS16: Registering the Universe at the **highest spatial accuracy***



Feigelson & Montmerle (1999)

Both X-ray *and* nonthermal radio emission probe the ***innermost vicinities*** of protostars!

Observing at 8 GHz

Beam sizes:
VLA (~0.2”, A config)
VLBA (~1 *mas*)

...in Orion:
VLA ~ 80 AU
VLBA ~ 0.4 AU

...factor of >100!

THE ASTROPHYSICAL JOURNAL, 706:L205–L209, 2009 December 1 doi:10.1088/0004-637X/706/2/L205
© 2009. The American Astronomical Society. All rights reserved. Printed in the U.S.A.

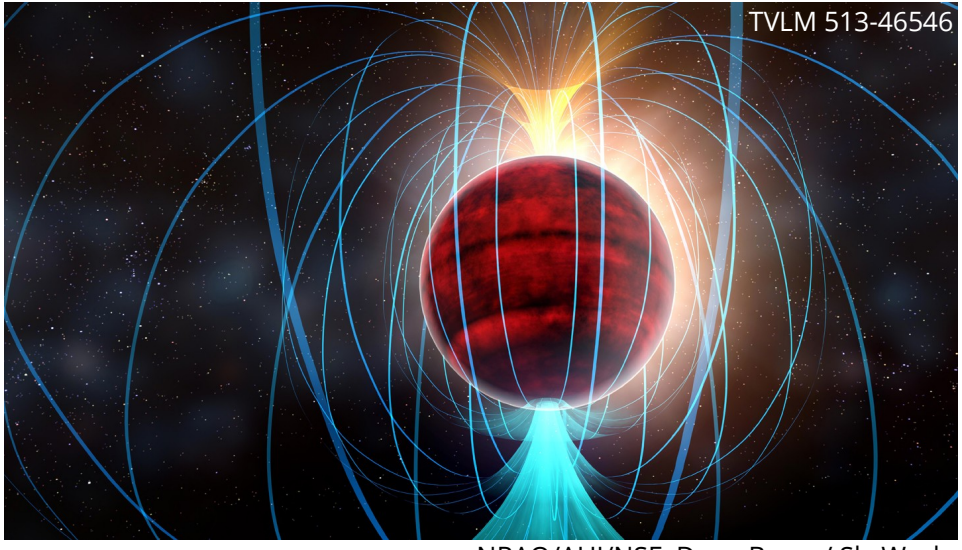
THE FIRST VLBI DETECTION OF AN ULTRACOOL DWARF: IMPLICATIONS FOR THE DETECTABILITY OF SUB-STELLAR COMPANIONS

JAN FORBRICH AND EDO BERGER
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA
Received 2009 September 28; accepted 2009 October 26; published 2009 November 10

VLBI observations of *nonthermal* stars also include **ultracool dwarfs** as a stepping stone between stellar and planetary radio emission.

Very nearby, sometimes significant motion in an observation due to parallax alone.

Interesting **physics**: electron cyclotron maser (ECM) emission.



NRAO/AUI/NSF; Dana Berry / SkyWorks

NB: Artist's impression, not a VLBI observation! :-)

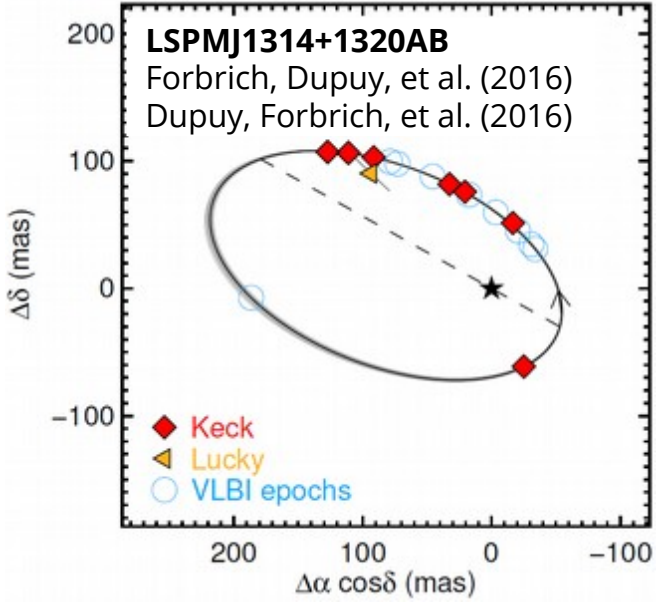
Applications in **precision astrometry**

VLBI observations of *nonthermal* stars and YSOs yield **near-absolute astrometry**, e.g., for parallax or (exoplanetary) reflex motion studies:

d(ONC) = 414 ± 7 pc
(Menten, Reid, Forbrich, & Brunthaler 2007, cf. Kounkel et al. 2017)

Using the benefits of **software correlation**, we are now monitoring all 556 VLA sources in the ONC (Forbrich, Dzib, et al. 2020, *subm.*)

Such YSO astrometry is **complementary to *Gaia* and LSST** programs.



Considerations for the **VLBA Orion Radio All-Stars**

- Unbiased VLBI follow-up of all 556 VLA detections in one pointing: non-thermal census, **10x deeper** (though not as deep as the VLA observations)**, 100x more sources**
- Focus on **absolute proper motions** with annual monitoring: sensitive to motions of 0.1 – 1 km/s, *everything moves!*
- Direct search for **binaries** and companions
- Search for **large magnetic structures**, for the first time in a large sample
- Small overlap with ***Gaia*** (bright nebula and embedded objects) offers an interesting astrometric **cross-check**
- Geodetic observing blocks for optimum astrometric calibration
- Epochs from 2015-2021+

VLBA Orion Radio All-Stars: first results

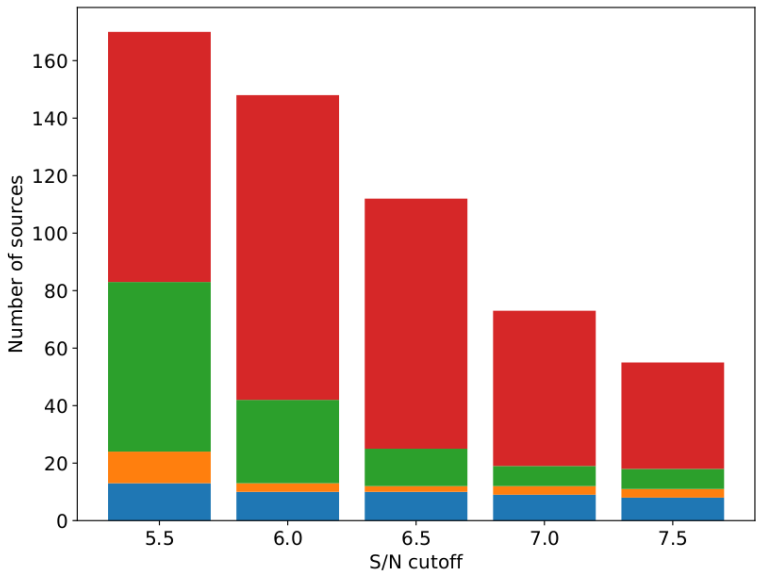
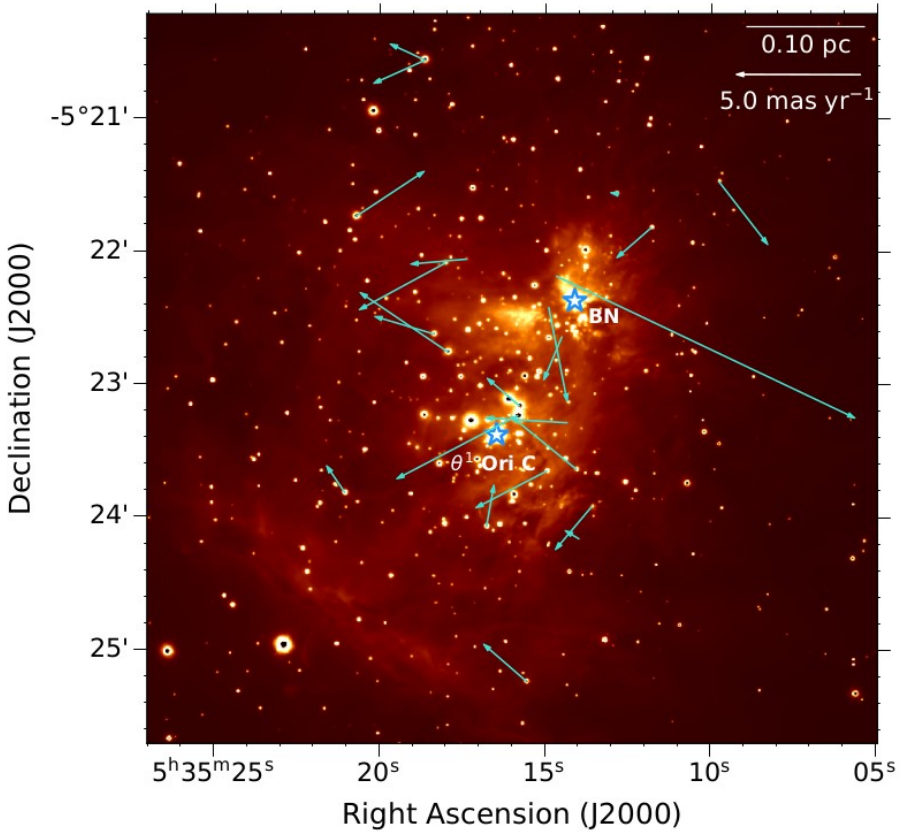


Figure 1. Number of sources detected above a given S/N threshold, color-coded by number of detections among four epochs (red=1, green=2, orange=3, blue=4).



123 nonthermal YSOs detected in inner ONC

Forbrich et al. (2020, *subm.*), Dzib et al. (2020, *subm.*)

VLBA Orion Radio All-Stars: first results

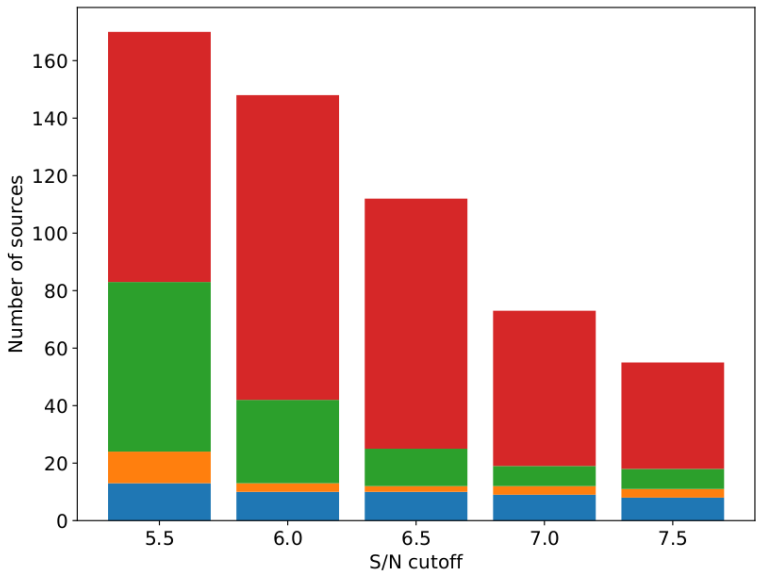


Figure 1. Number of sources detected above a given S/N threshold, color-coded by number of detections among four epochs (red=1, green=2, orange=3, blue=4).

123 nonthermal YSOs detected in inner ONC

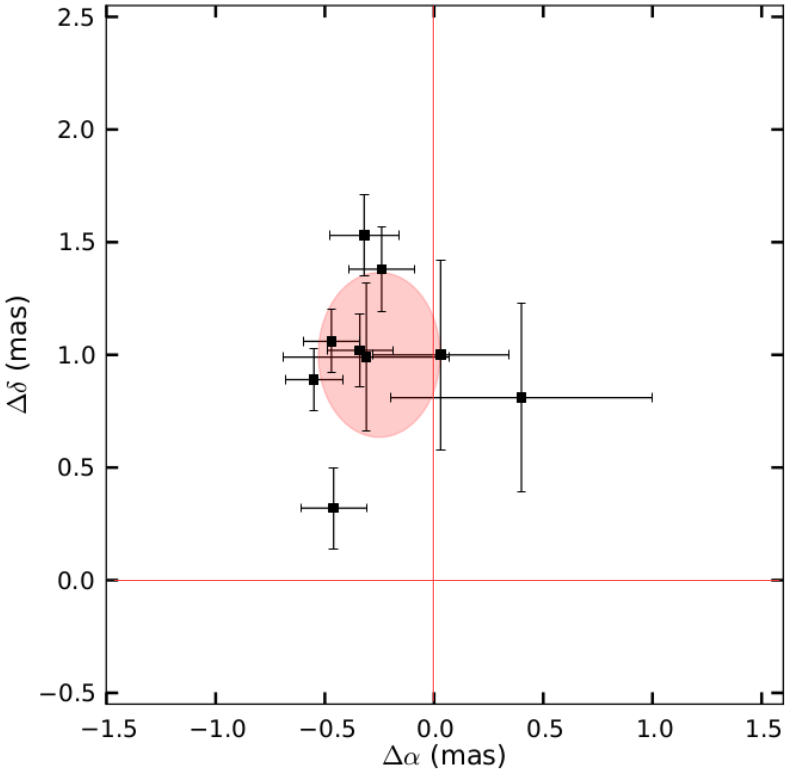


Figure 2. Comparison between VLBA and *Gaia* positions for the nine sources with total position separation < 1.5 mas. The pink ellipse is centered in mean separations and its size correspond to the standard deviation values.

Forbrich et al. (2020, *subm.*), Dzib et al. (2020, *subm.*)