Radio activity reloaded:

Young Stellar Objects as seen by VLA, VLBA, and ALMA

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A renaissance of **stellar radio astronomy**

New and newly upgraded facilities include

the Karl G. Jansky Very Large Array (**VLA**),
the Very Long Baseline Array (**VLBA**), and
the Atacama Large Millimeter Array (**ALMA**),

yielding **unprecedented continuum sensitivity** and **wavelength coverage**.

Great for Young Stellar Objects and nearby active stars in particular!

ngvla
Next Generation Very Large Array

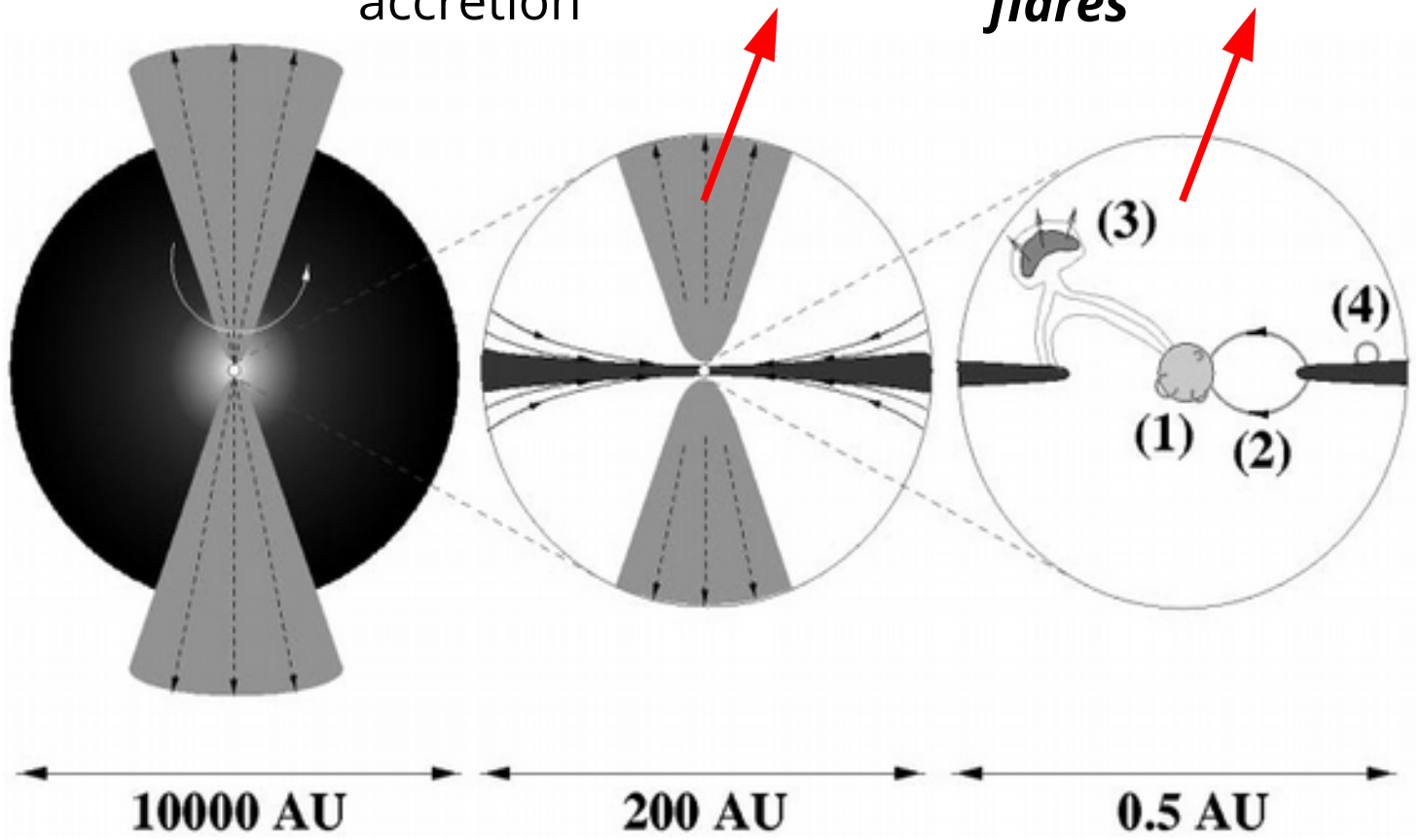
SKA
SQUARE KILOMETRE ARRAY

Forbrich

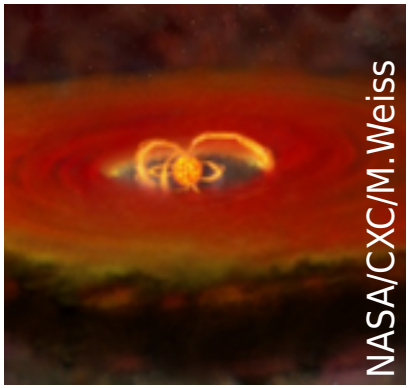
High-energy processes in Young Stellar Objects

Thermal radio emission, could fluctuate with accretion

Thermal X-ray emission, nonthermal radio emission, *flares*

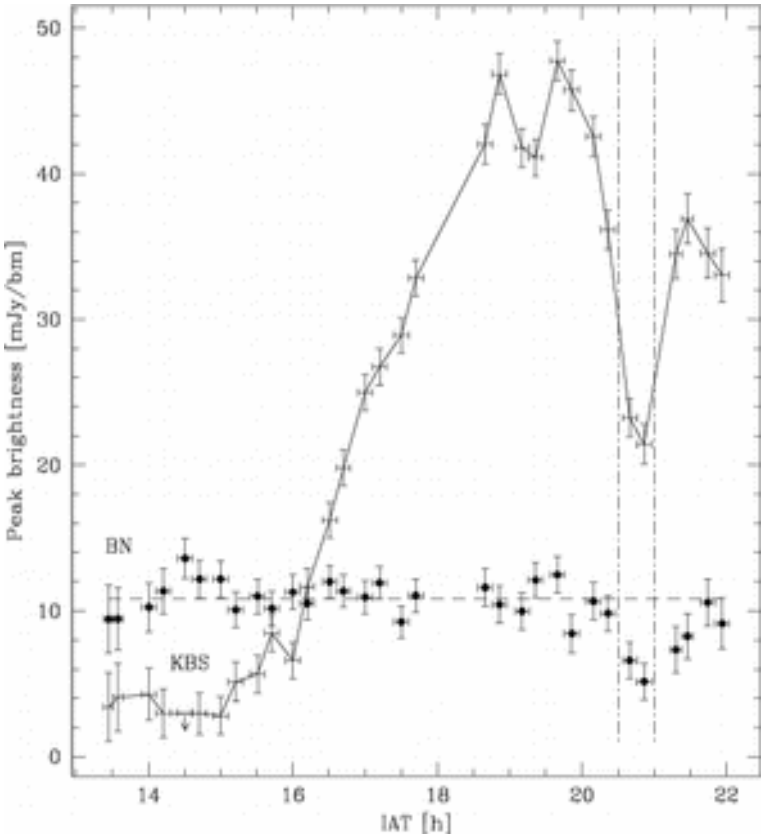


Feigelson & Montmerle (1999)



What about **radio flares**?

Forbrich, Menten, & Reid (2008)



Liebovich (1974): Single-event events (SEEs)

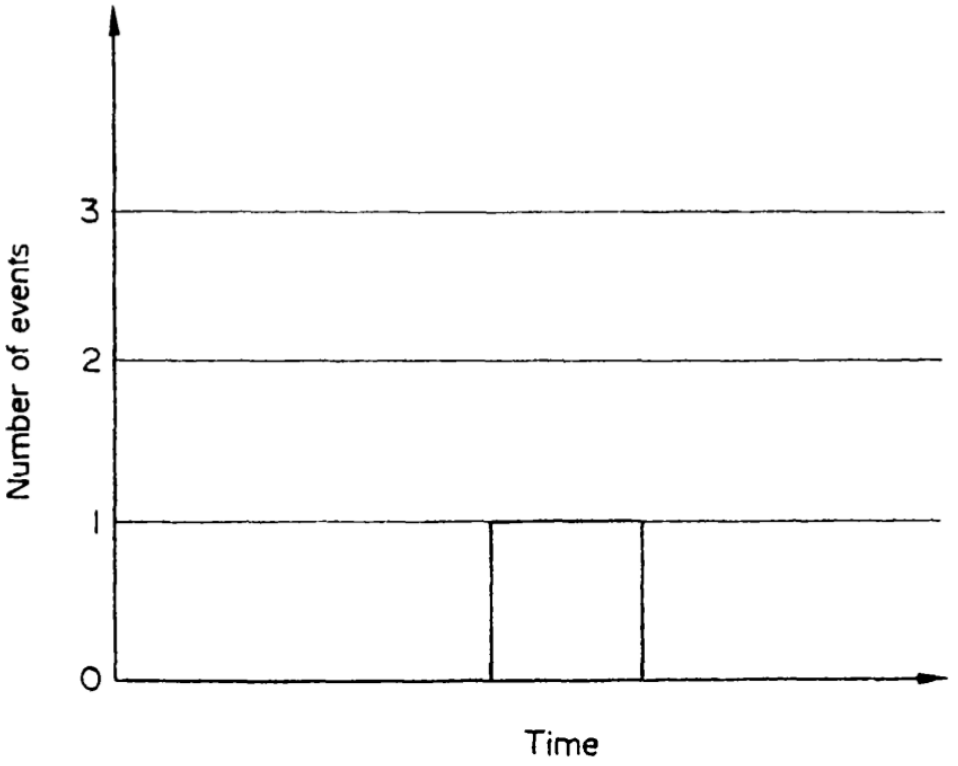


FIG. 1.

X-ray flares of YSOs are now relatively well characterized... but strong radio flares have remained single-event events so far. Do they occur in tandem?

THE ORION RADIO ALL STARS

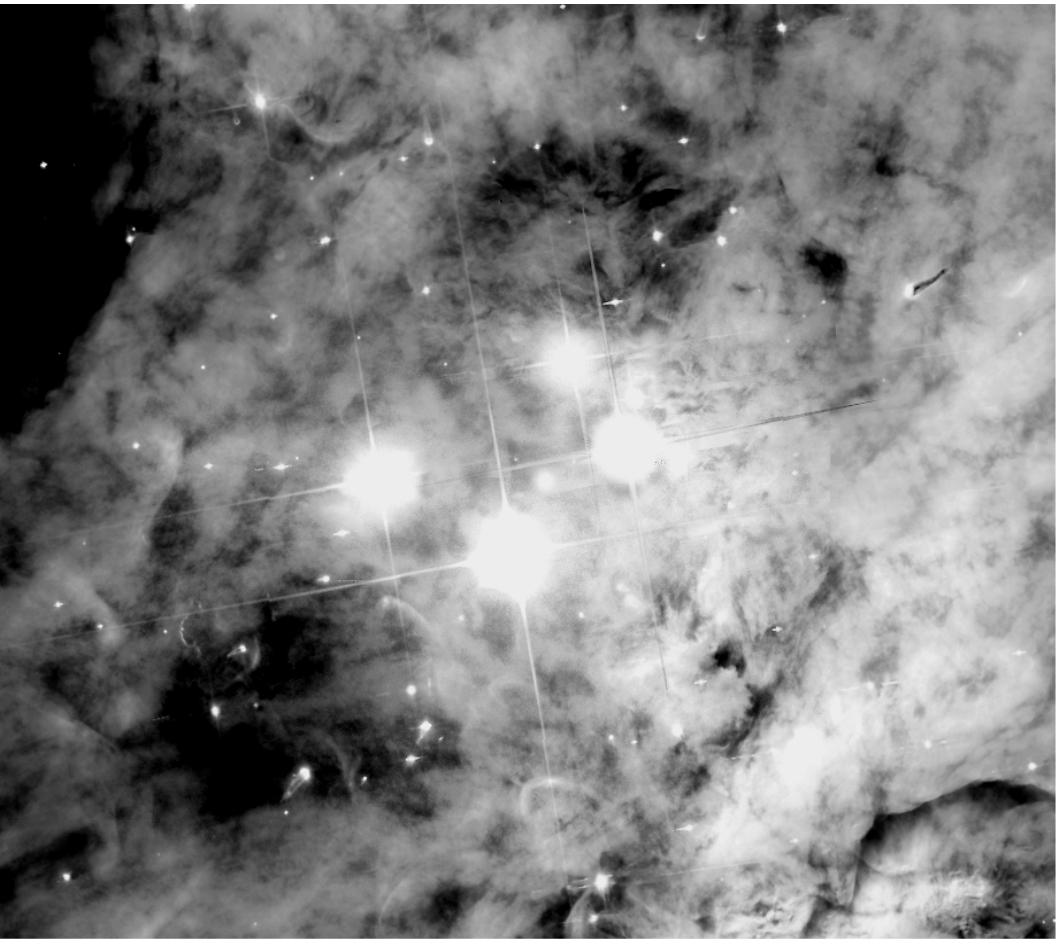
VLA data: 30h of C-band data (4-8 GHz) in a single deep pointing in the high-resolution A configuration, with simultaneous ***Chandra*** observations. Increased the number of known radio sources by 7x; first systematic time domain data set for YSOs. Surrounding fields.

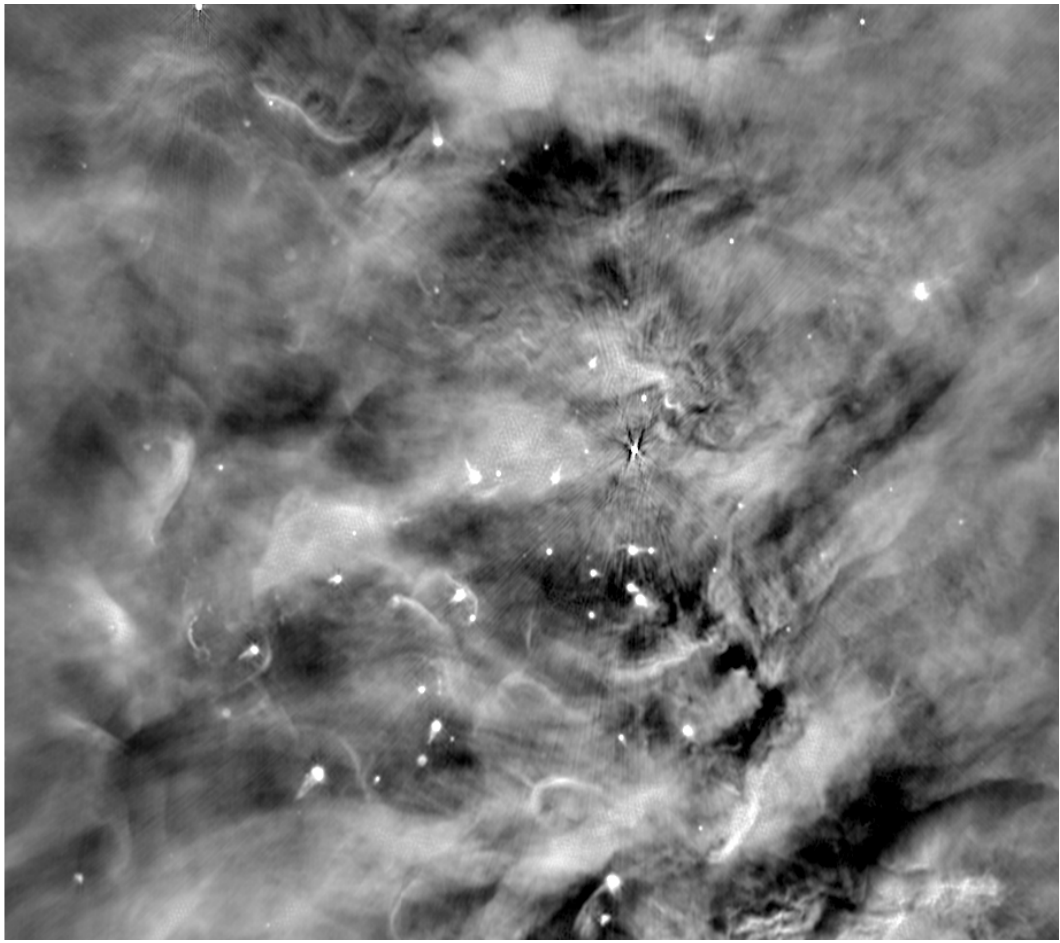
VLBA data: 4+ epochs of astrometric milli-arcsec follow-up of all 556 VLA sources!

ALMA data: pilot experiment to detect millimeter-wavelength variability (accretion/synchrotron)

NASA, ESA, M. Robberto (STScI/ESA) and the HST Orion Treasury Project Team

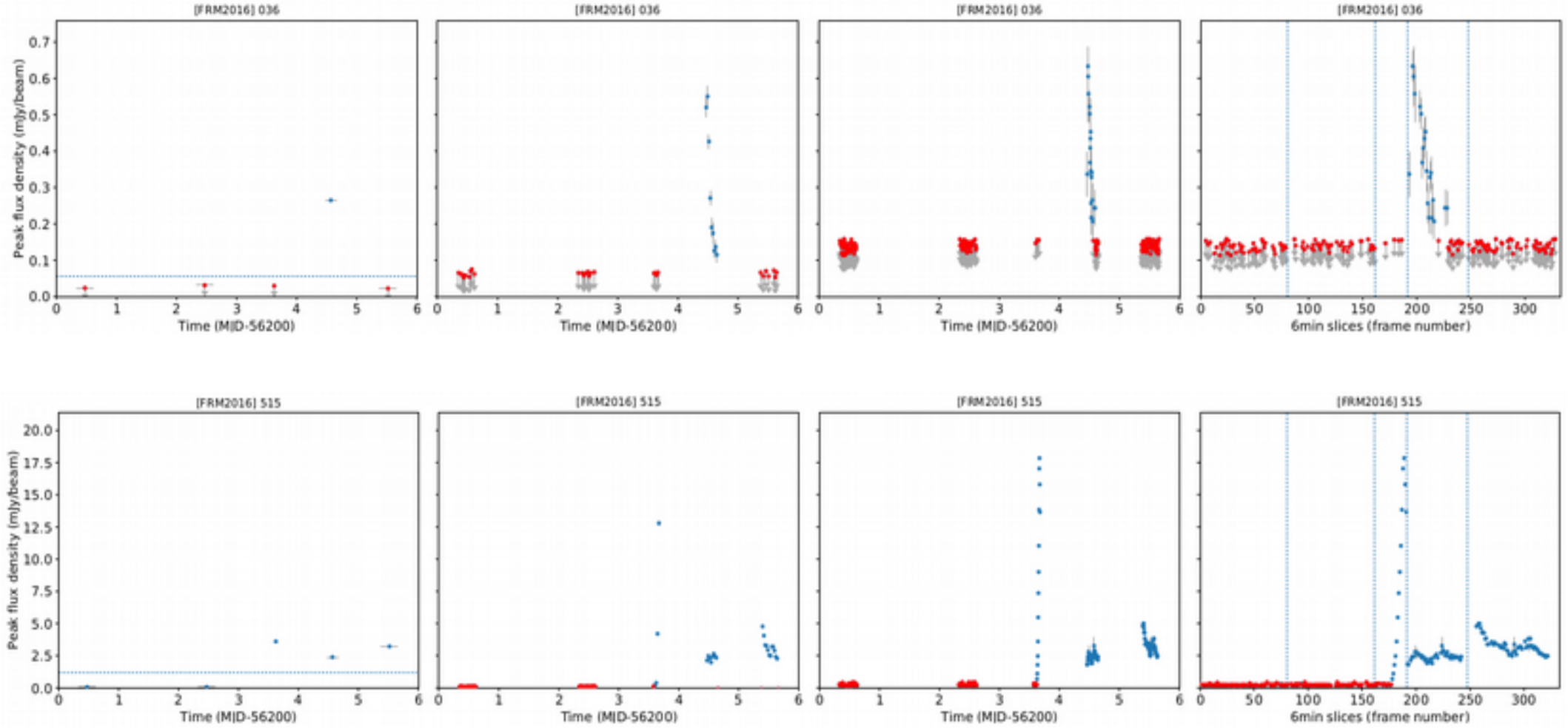
The **proplyds** (and more)





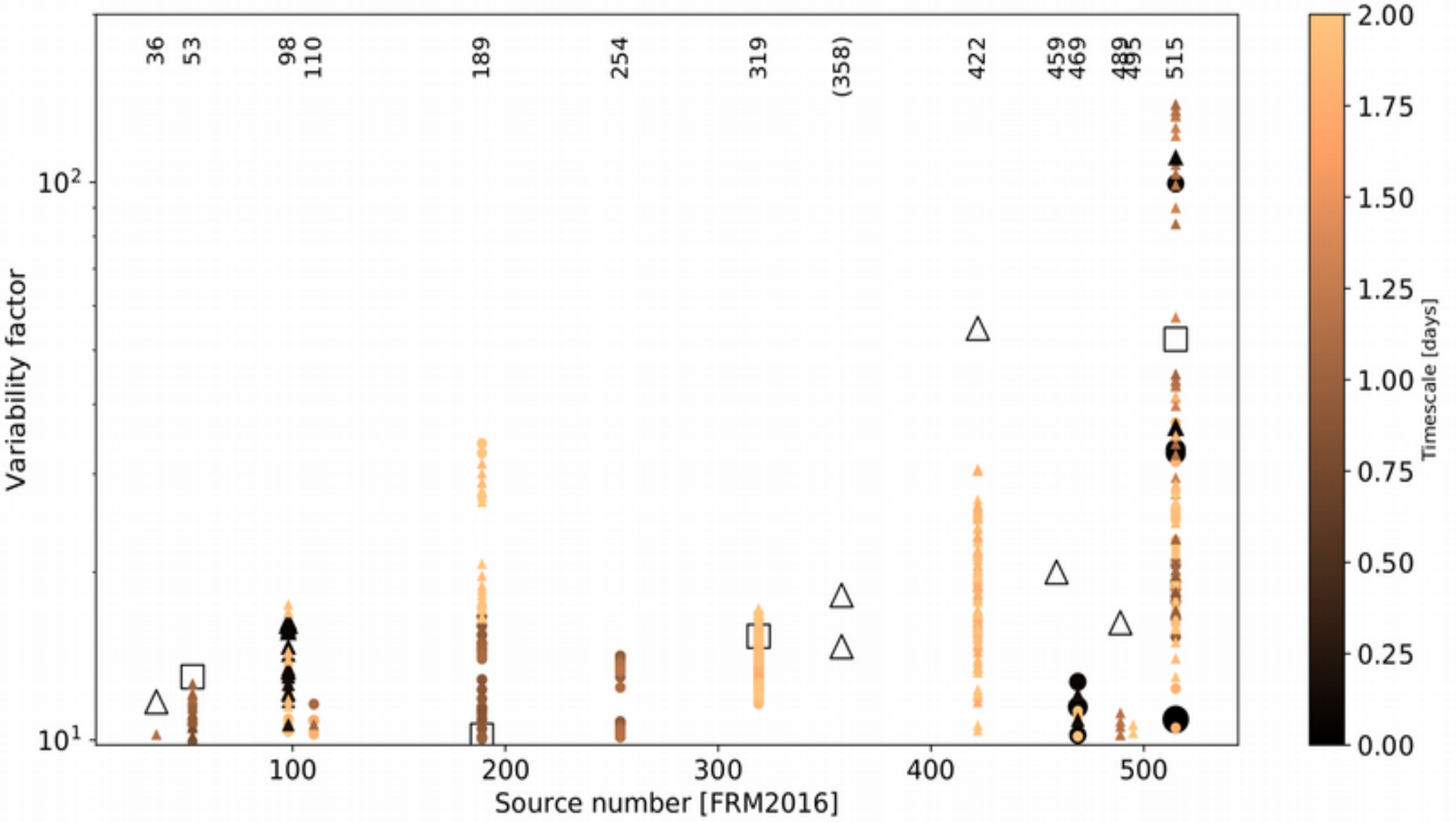
Forbrich et al. *in prep.*

Exploring YSOs in the radio **time domain**



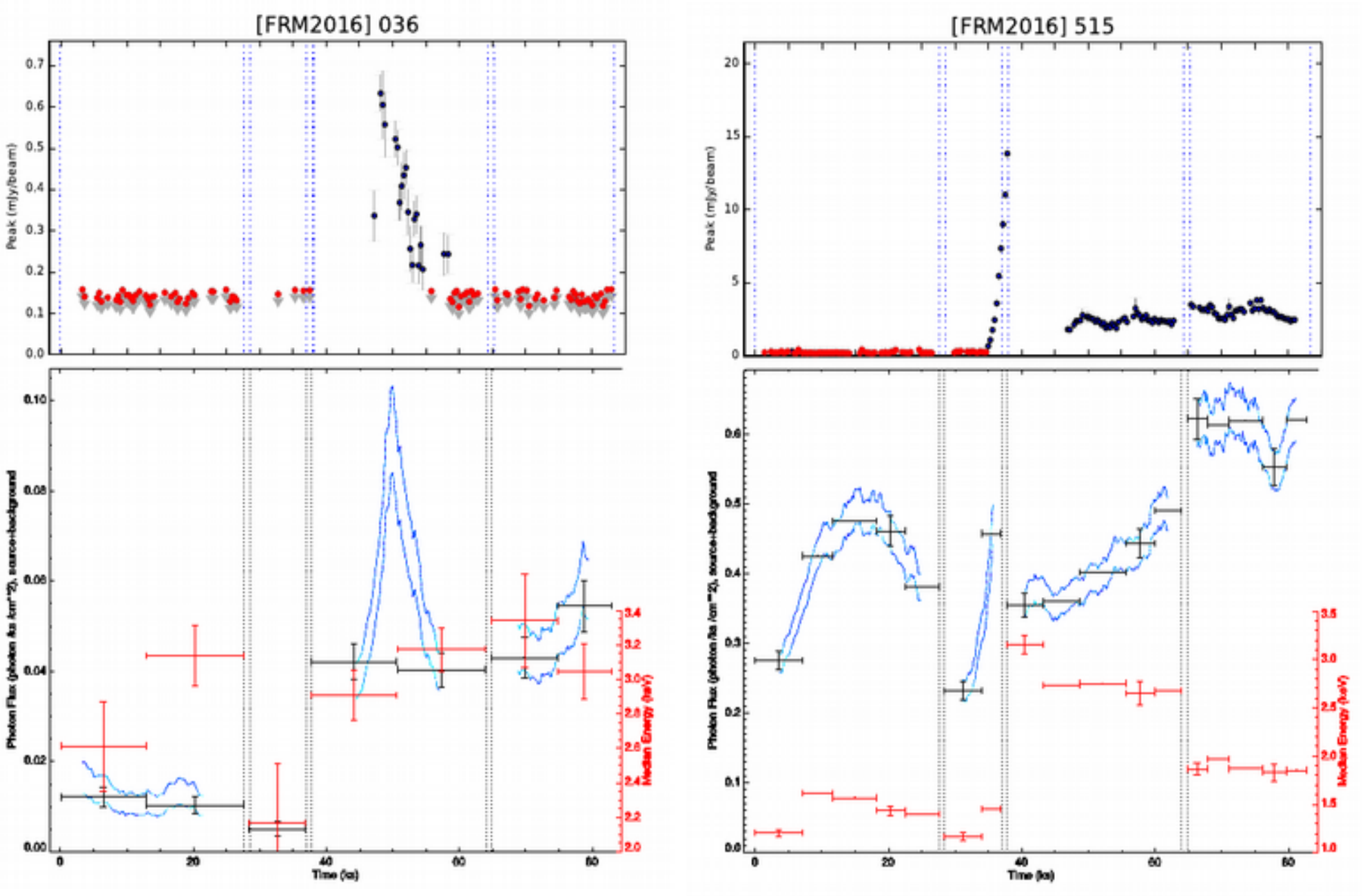
Forbrich et al. (2017)

Exploring YSOs in the radio **time domain**



Forbrich et al. (2017)

Exploring YSOs in the radio – X-ray **time domain**



Forbrich et al. (2017)

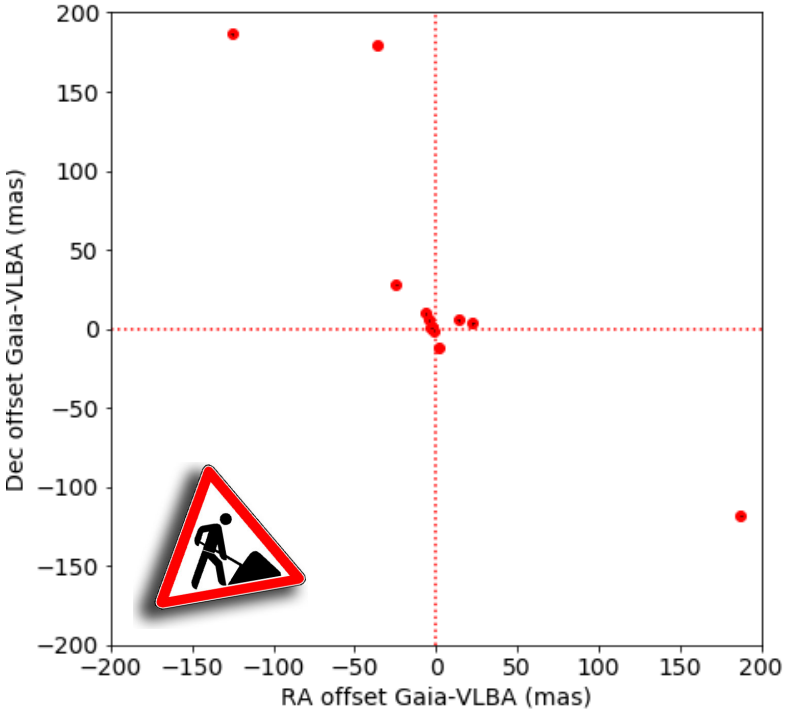
First lessons from ***Gaia*** **DR2 vs VLBA** comparison in ONC

Unbiased VLBA follow-up of all 556 VLA sources reveals flares from previously marginal sources. Ongoing program!

Angular resolution is 300x better than in VLA observations, with beam size 1 mas (0.4 AU). Large coronal features?

Often significant differences between *Gaia* and VLBA astrometry even though both have comparable uncertainties: multiple systems, nebulosity, unfair comparison?

Target uncertainty for absolute YSO proper motions: comparable to *Gaia* or better, but for embedded YSOs.



Forbrich et al. *in prep.*

Towards synchrotron emission with **ALMA**

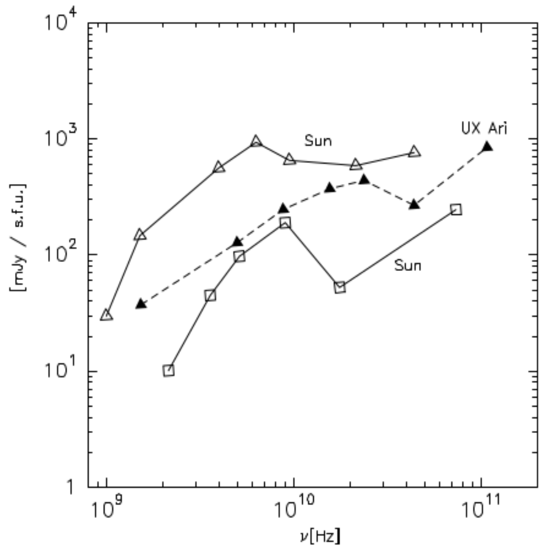
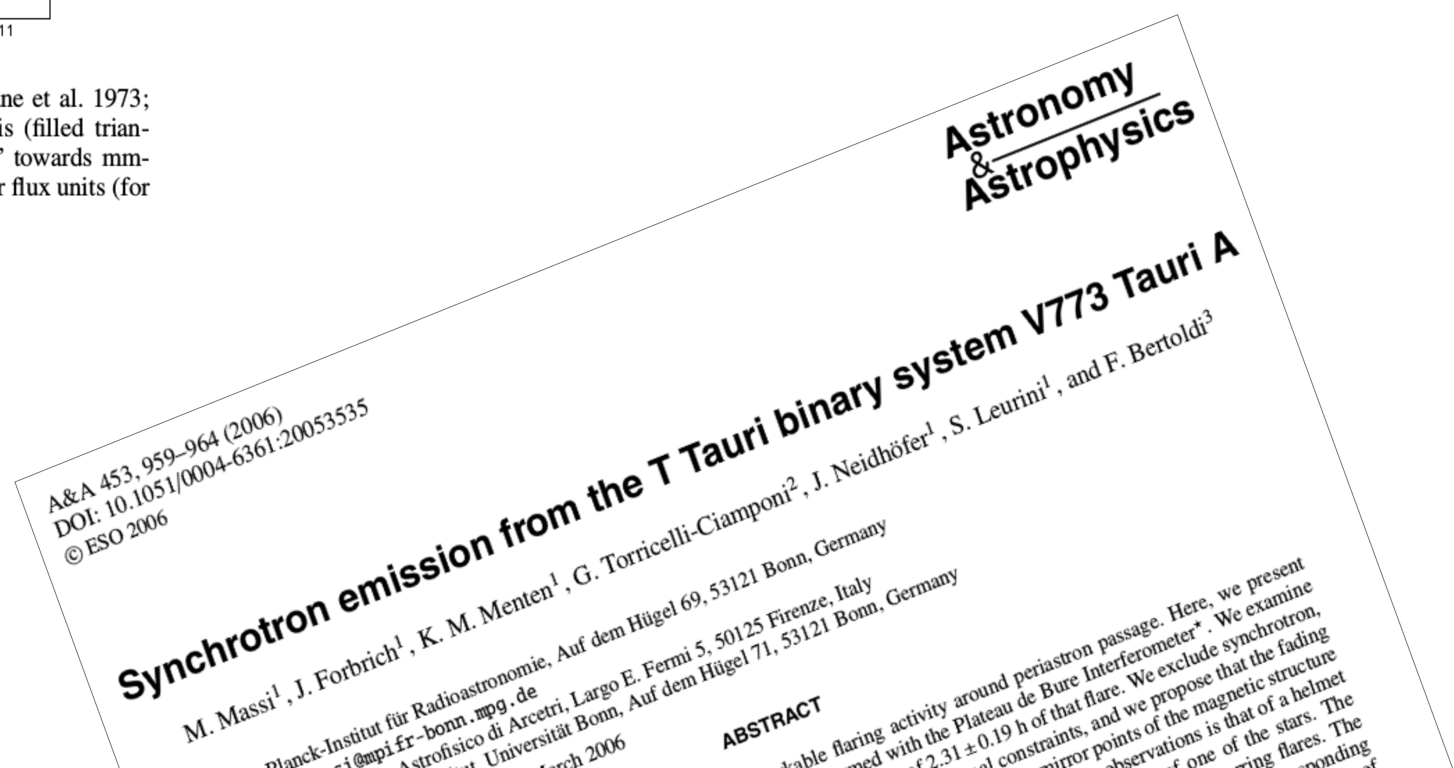


Fig. 1. Examples of spectra of the Sun (squares: Akabane et al. 1973; empty triangles: Zirin & Tanaka 1973) and UX Arietis (filled triangles: Beasley & Bastian 1998) exhibiting a "flattening" towards mm-wavelengths. Notice that the vertical scale is in both solar flux units (for the solar spectra) and mJy (for UX Arietis).

While we would typically trace gyrosynchrotron radiation at cm wavelengths, ALMA now allows us to systematically observe YSOs at mm wavelengths in the time domain to search for synchrotron radiation.



A&A 453, 959–964 (2006)
DOI: 10.1051/0004-6361:20053535

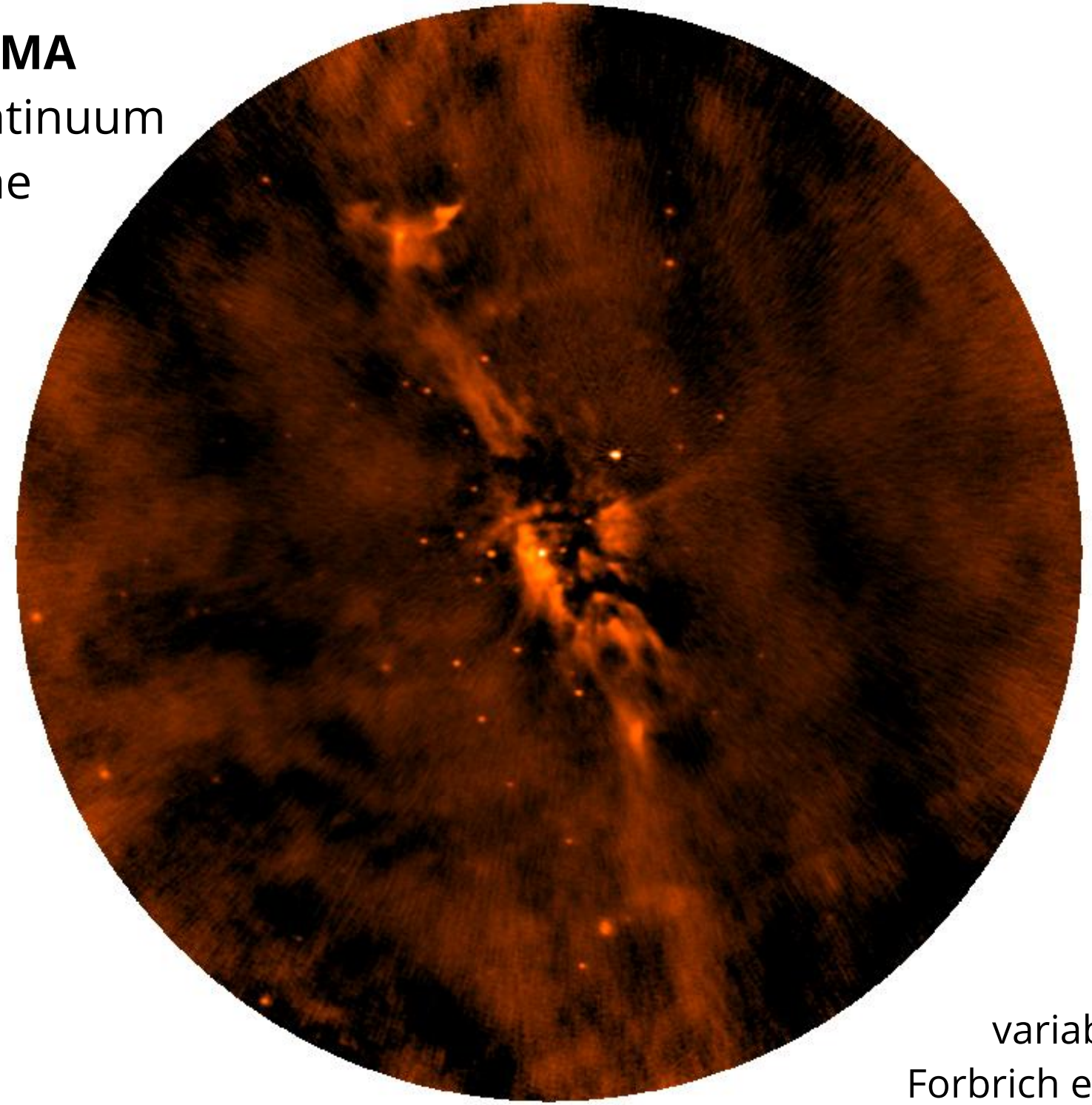
Astronomy & Astrophysics

Synchrotron emission from the T Tauri binary system V773 Tauri A

M. Massi[1], J. Forbrich[1], K. M. Menten[1], G. Torricelli-Ciamponi[2], J. Neidhöfer[1], S. Leurini[1], and F. Bertoldi[3]

ABSTRACT

A first **ALMA** 3mm continuum look at the ONC



0.18 pc

0.4” FWHM
variability search
Forbrich et al. *in prep.*

Summary

VLA & VLBA **upgrades** and ALMA are providing systematic access to the **time domain** in stellar radio astronomy. More to come!

The **Orion Nebula Cluster** provides us with a large sample of highly “radio-active” YSOs – and a wideband imaging testbed.

Only a small fraction of extreme YSO radio variability is correlated with X-ray variability and vice versa, providing us with a new perspective on **high-energy irradiation of YSO environments**, including protoplanetary disks and young planets. Needs sims!

The VLBA provides absolute YSO astrometry in both a cross-check with and a complement of ***Gaia***.