Continuum VLBI Science with SKA

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Paragi et al. (AASKA14.143)

Introduction: VLBI

- Very Long Baseline Interferometry in the SKA era:
  - Ultra-high angular resolution up to ~0.5 milli-arcseconds at μ-Jy levels
  - Astrometric precisions of ~few μ-arcseconds

Paragi et al. (AASKA14.143)

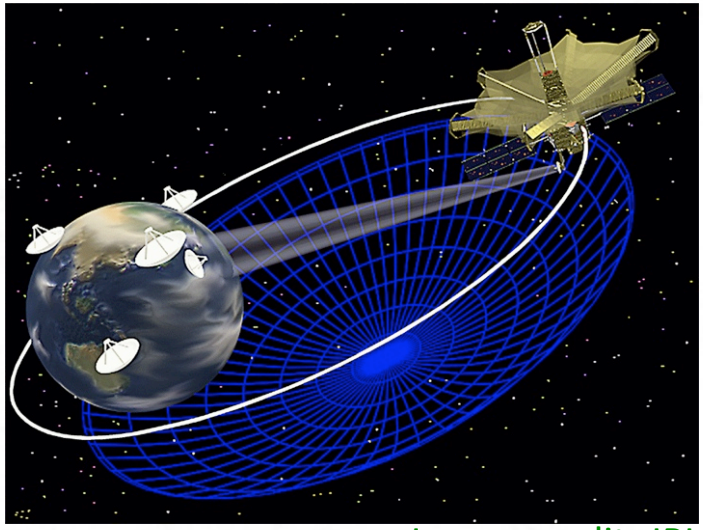
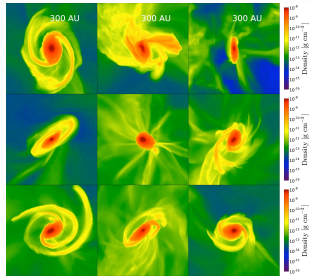
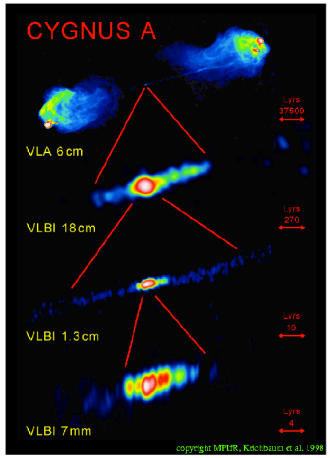


Image credit: JPL

- Extraordinary sensitivity provided by SKA would allow for studying a number of different astrophysical scenarios that were impossible to image before at broad redshift or luminosoty ranges with VLBI angular resolutions; or astrometric precisions (see below)

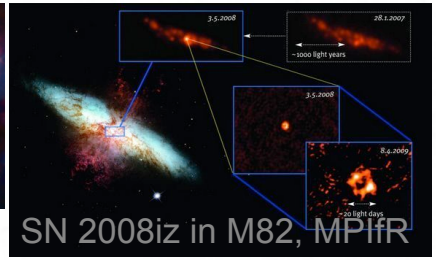


Latif et al. (2014)



- Low (essentially no) cost for SKA (beam-former required for pulsar community)

Image credit: M. A. Garlick, UW

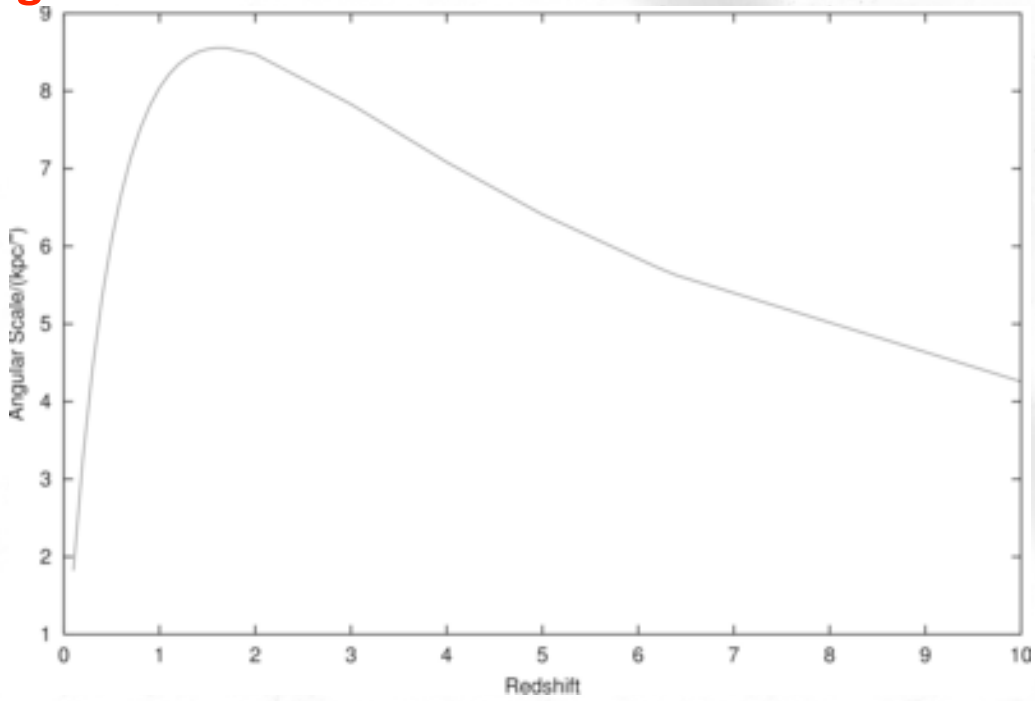


SN 2008iz in M82, MPIfR

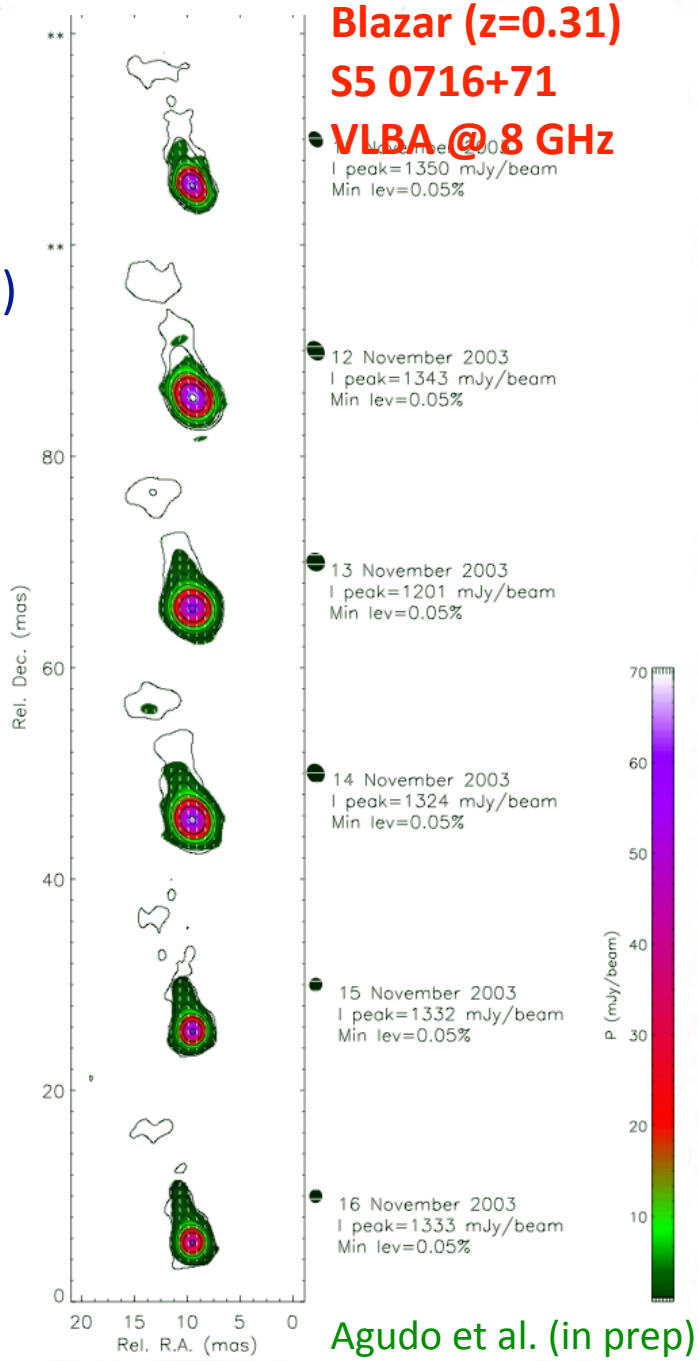
Introduction: VLBI

- At z=0.3, 1 arcsecond → 4.5 kpc
- At z=9.0, 1 arcsecond → 4.5 kpc (under λCDM cosm.)

Angular scale-redshift relation for λCDM cosmology



Blazar (z=0.31)
S5 0716+71
VLBA @ 8 GHz



Agudo et al. (in prep)

The big scientific questions to be studied with VLBI

- Rather than a research field, VLBI is a useful technique (complement to SKA alone)
- SKA-VLBI useful for a broad variety of astrophysical/astronomical scenarios:

(VLBI sensitive to compact sources only ⇒ targets for any SKA-VLBI=compact sources)

Ultra-high (sub-milli-arcsecond) resolution astronomy at micro-Jy sensitivity

- Identification of source populations through Tb & polarimetric observations
- AGN & environments of supermassive black holes
- Small and large scale extragalactic jets & star forming regions
- Tidal Disruption Events & intermediate mass black holes
- GRBs & SNE
- Microquasars
- Novae & cataclismic variables

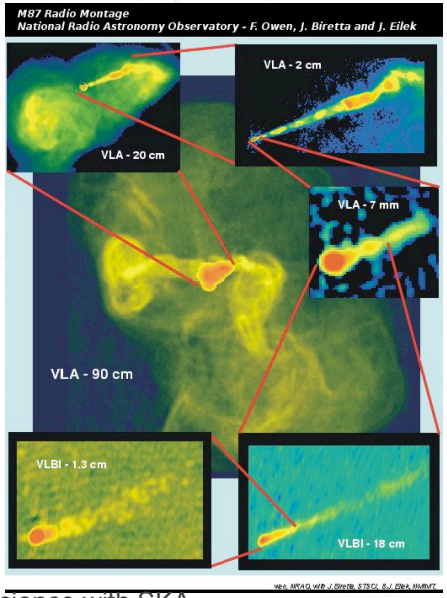
Ultra-precise astrometry at the micro-arcsecond level

- Pulsars
- Stars and protostelar objects
- Improvement of celestial reference frame and registration with opt one, Gaia

Ultra-high (sub-milli-arcsecond) resolution astronomy at micro-Jy sensitivity

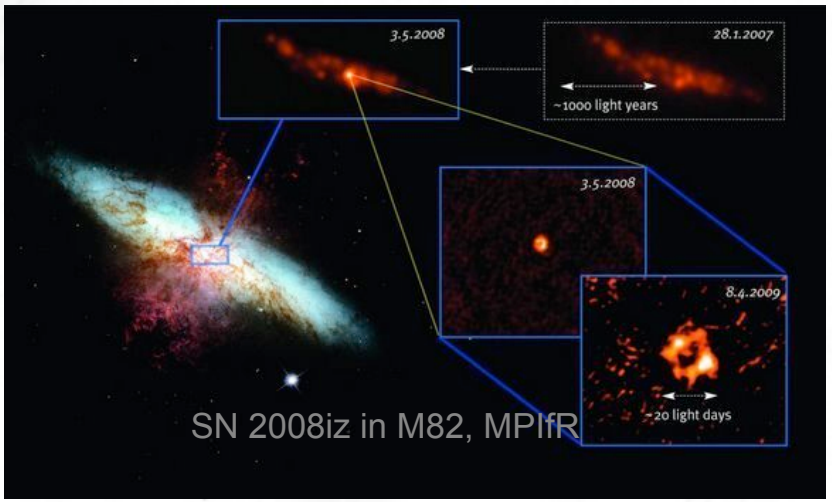
Identification of source populations from already observed SKA surveys

- To distinguish AGN jet emission from that of star-forming galaxies.
- Clearly, linear polarization and spectral index information from SKA1 will be a useful tool for that, as well as, optical data and photometric redshifts from LSST
- VLBI will be THE TOOL for confirmation of AGN nature of those sources with high Tb (perhaps at L-band to optimize UV coverage and sensitivity)
- Polarimetric measurements will also be critical in VLBI mode



VS.

Agudo et al. (AASKA14.093)

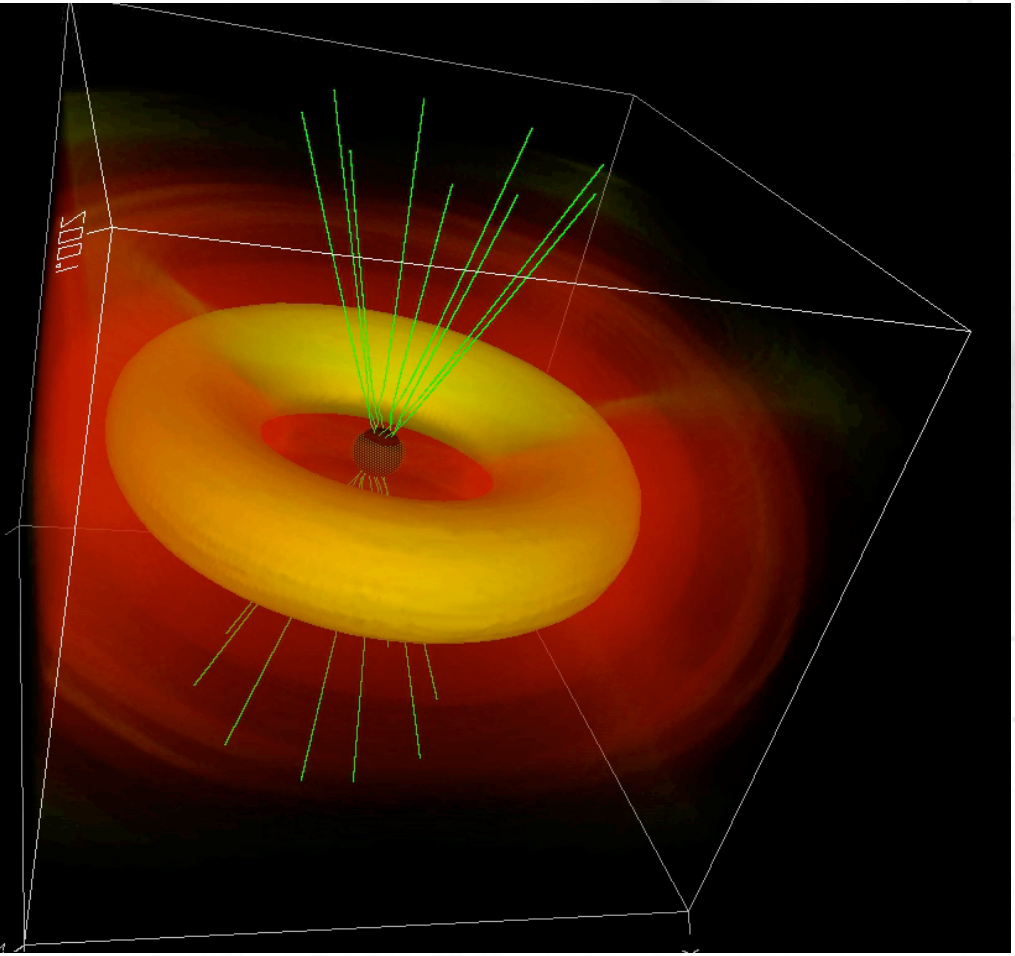


Ultra-high (sub-milli-arcsecond) resolution astronomy at micro-Jy sensitivity

Physics of AGN jet formation and its coupling to the accretion process and jet composition

Agudo et al. (AASKA14.093)

3D RMHD simulations of relativistic jet formation



McKinney & Blandford (2009)

- There are still relevant questions that remain to be answered, related to the innermost, less explored regions of AGN
- Starting to understand processes from simulations, but
- Confirmation will come from SKA multi frequency observations (up to 20 GHz or more), including VLBI
- And involving polarization observations (because of the prominent role of magnetic fields on jet formation processes)
- If precise (up to ~0.01%) circular polarization observations are included, unique information on jet and environment composition, B, e^- distrib will be obtained

Ultra-high (sub-milli-arcsecond) resolution astronomy at micro-Jy sensitivity

Tidal Disruption Events (TDEs)

- SKA will allow studying jet formation processes in dormant AGN in "real time" for 100's or 1000's of TDEs

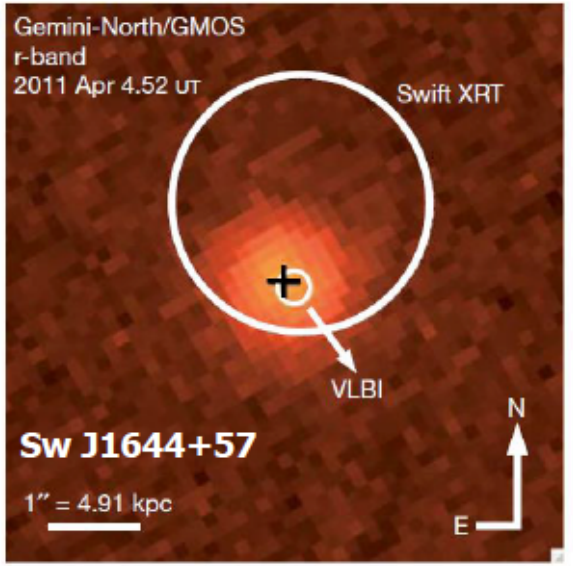
- SKA-VLBI will provide superior localization of events

- Sub-milliarcsecond resolution needed to measure source expansion/deceleration (will give clues on environment where the new jet is expanding)

- SKA-VLBI, -at ~5-8 GHz - will measure accurate sub-mas source sizes down to ~0.1 mJy level which is not possible today.

- SKA-VLBI will routinely provide astrometry accurate at the ≤10 μas level to measure jet ejecta proper motions

Image credit: M. A. Garlick, UW



Zauderer et al. (2011)

Donnarumma et al. (AASKA14.054)

Ultra-high (sub-milli-arcsecond) resolution astronomy at micro-Jy sensitivity

Cosmological studies of radio loud AGN

An almost entire field to explore!

Needs to answer questions as:

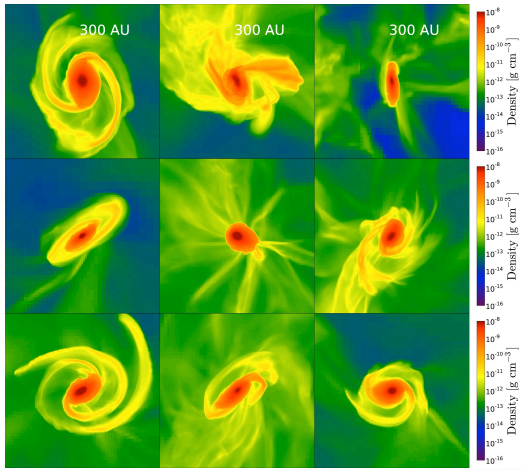
- When the first AGN were formed?
- How where they formed (properties of environments, SMBH and accretion systems)?
- How they evolved with time up to z~0.

Exciting science case for SKA through deep full Stokes (I, Q, U, V) surveys.

VLBI essential to characterize the sources (confirm their AGN nature) and study their small scale morphology.

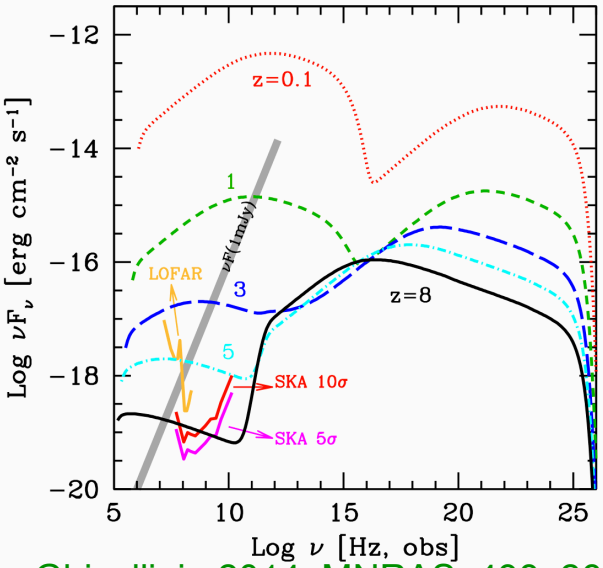
Agudo et al. (AASKA14.093)

Cosmological hydrodynamic simulations.



Latif et al. (2014)

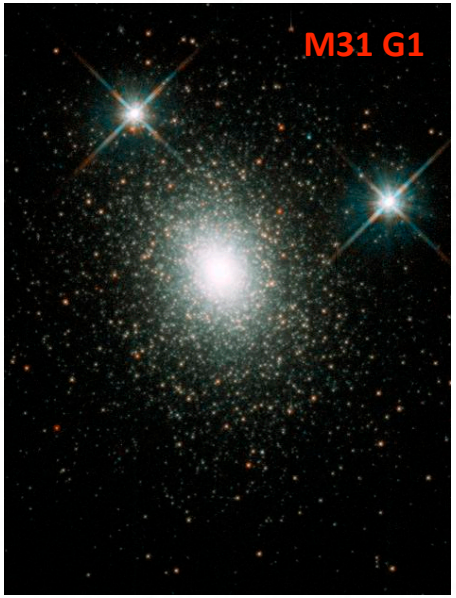
Importance of the CMB at high redshifts



Ghisellini+ 2014, MNRAS, 438, 2694

Ultra-high (sub-milli-arcsecond) resolution astronomy at micro-Jy sensitivity

Intermediate mass black holes

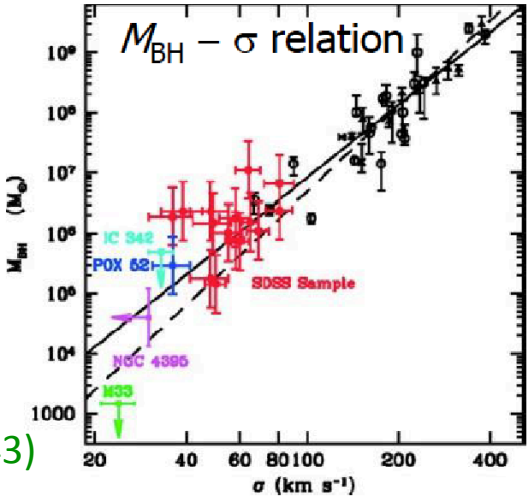


- Include low-power MBH in the centres of dwarf galaxies, off-centre intermediate-mass black holes and dual- or multiple supermassive black holes in advanced stages of mergers.

- Resolution well below arcsecond is needed to clarify the nature of radio emission in MBH at low accretion rates (simultaneous SKA-VLBI and local interferometer data!)

- The low-mass population of central SMBHs is little known (MBH, 10^4-10^5 M_{SUN})

- Where are the left-over seed BH required by structure formation models? How do they grow?



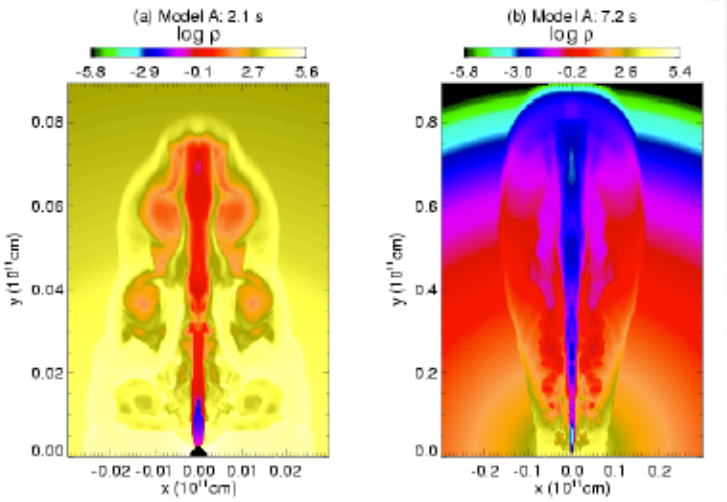
Paragi et al. (AASKA14.143)

Barth, Greene & Ho (2005)

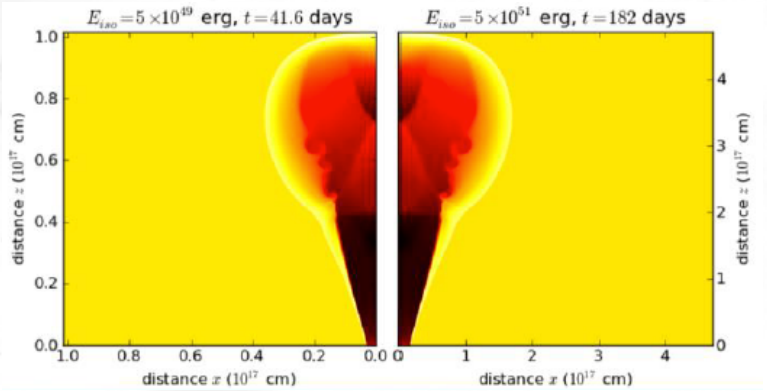
Other stellar-mass energetic/transient scenarios

- Gamma Ray Bursts, Radio Supernovae, and Supernova Remnants, Microquasars, Pulsars

- The excellent sensitivity of SKA-VLBI on very long baselines implies that extragalactic stellar explosions (e.g. supernovae and gamma-ray burst afterglows) will be imaged, in total intensity as well as in polarization, in more detail than is possible today.



Woosley (1993)
MacFadyen & Woosley (1999)



van Eerten, van der Horst & MacFadyen (2012)

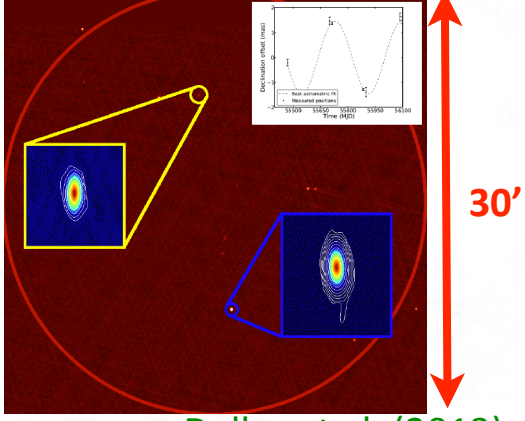
Ultra-precise astrometry at the micro-arcsecond level

- Distances and transverse velocities will be possible out to distances of tens of kpc via the measurement of proper motions and parallaxes of Galactic objects (in paricular for SKA pulsars)

- For radio-emitting stars, in addition to the distance via parallax, the presence of a planetary companion can be sought via the reflex motion of the star.

- Gaia astrometry can be improved using SKA-VLBI. These two facilities may open new fields, e.g.:

  -comparison of optical and radio positions of AGN
  -tie ICRF and the Gaia reference frames
  -through pulsar-WD binary systems: tie the radio, optical, and the Solar System dynamical frames
  -AGN *and* microquasar core-shifts (radio to optical): study accretion/magnetic fields/jets from stellar to supermassive BH



Deller et al. (2013)

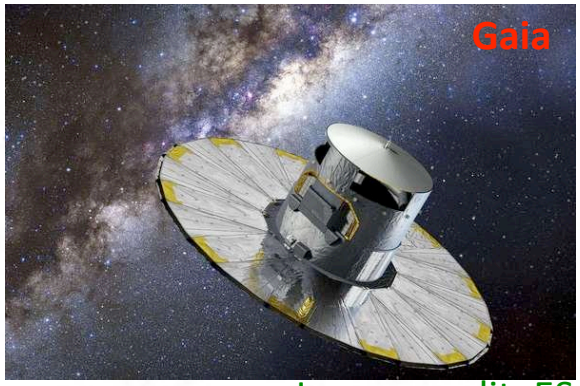
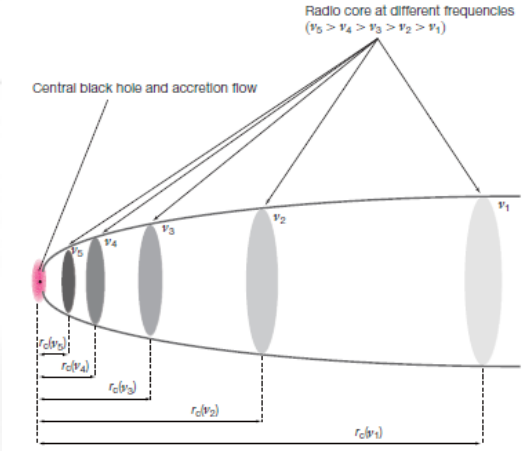


Image credit: ESA



Hada et al. (2011)

Notes on potential commensality & maximization of science return

- Every time that SKA is participating on a VLBI observation, the resulting SKA data may be treated in parallel following both the VLBI and SKA alone procedures (routinely done at VLA and WSRT)

- This implies that any VLBI observation might (in principle) provide SKA data both to the VLBI observer, and other scientific communities, and *vice-versa*

- This opens the possibility for all kinds of commensalities (specially with all-sky and deep surveys from 1 to 20 GHz, and follow up of transient objects and events).

- This implies synergies with all science cases covered by SKA-VLBI observations (essentially for all kinds of compact radio sources, see above)

- With any other science programs requiring big surveys and including compact sources