Synergy IR / radio interferometers

Observatorio Astronómico - Universidad de Valencia

Jose Carlos Guirado

8-11 October 2018 - Granada
14th EVN Symposium & Users Meeting
Why synergies?

Interferometer Facility Overview

![Graph showing wavelength coverage and maximum angular resolution available using radio and optical interferometers.]

Telescopes:
- CHARA: 6 x 1m
- VLTI: 4 x 8m + 4 x 1.8m
- VLBA: 10 x 25m
- ALMA: 64 x 12m
- VLA: 27 x 25m
- ALMA: 64 x 12m
- VLBI: 4 x 8m + 4 x 1.8m

Maximum Angular Resolution (arcseconds)

• VLTI, VLBA, and ALMA can observe the same targets in terms of angular resolution and sensitivity.
• They provide complementary information on different components and regions.

Table 5 for more information.

Fig. 14.— Graphical representation of the wavelength coverage and maximum angular resolution available using the radio and optical interferometers of the world.
Here are more realistic examples of long-baseline interferometers, both optical and radio, including the light collectors and delay line. Left panel: Optical interferometer, adapted from Monnier (2003). Right panel: Radio interferometer, adapted from Figure 2.3 in Thompson et al. (2001). See text for further discussion.
Table I. Some historically important astronomical results made possible by interferometry

<table>
<thead>
<tr>
<th>References</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Véron et al. (1979)</td>
<td>The first image of a galaxy, NGC 4258.</td>
</tr>
</tbody>
</table>

**Figure 1:** The image of the M87 galaxy, demonstrating the capabilities of interferometry in producing high-resolution images of distant objects.
The CHARA Array Science Meeting 2018

The near-IR/mid-IR gap

Dynamic range of a few $10^{-4}$ now at H/K and N bands

Thermal near-infrared (3-5 μm) not addressed

- Onset of thermal emission
- Sweet spot for imaging young planetary systems
- Many molecular species
- Less thermal background wrt KIN and LBTI — > potential for higher accuracy

Ertl et al. 2012

Instruments

<table>
<thead>
<tr>
<th>Gravity (K)</th>
<th>Gravity (K)</th>
<th>FINITO (H)</th>
<th>Fringe Tracker</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.5 / 9.0</td>
<td>8.0 / 8.0</td>
<td>8.5 / 10.5</td>
<td>AT/UT Mag. Lim</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>L+M+N</th>
<th>R=30,500</th>
<th>R=22,500,4000</th>
<th>R=5,30</th>
<th>H+K</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>35,1500,12000</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Commissioning in

Status

PrIMA also discontinued

Previous: MIDI, VINCI
a few, perhaps biased,

SCIENCE CASES
IR-interferometry from snapshot to imaging
Stellar surfaces

Scientific Goals
• From stellar properties to stellar processes
• CHARA Array: many and varied baselines make it ideal for imaging
• Need to define key science programs to guide designs

Zeta And (Roettenbacher et al. 2016)

Recent Stellar Images
Wittkowski+ 2017a
Wittkowski+ 2017b
Paladini+ 2018
Antares (AMBER) (Roettenbacher et al. 2016)
Synergies with VLA, eMERLIN, EVN

Stellar spots: RS Sculptoris (PIONIER)
Wittkowski et al. 2017

Companion to RSG V766 Cen

Imaging stellar surfaces
VLTI (AMBER & MIDI):
• Size and shape of IR and MIR photosphere.
• CLV, effects by molecular layers, inhomogeneities.
• Size, chemistry, shape of warm dust shell.

VLBA:
• SiO maser zone:
  • SiO maser.
  • The warm dust shell.
  • SiO, chemistry, shape of layers, inhomogeneities.
  • CLV (MIR) effects by molecular and MIR photosphere.
  • Size and shape of IR.

ALMA:
• At larger distances.
  • Water and OH maser.
  • Radio photosphere.
  • Size, shape, kinematics.
  • SiO maser zone.

VLTI (AMBER & MIDI):
• SiO maser bands / maser.
  • High-fidelity images.
  • Cool dust.
  • mm Photosphere.

Masers: joint VLBA/VLTI observations of Mira S Ori

Detailed structure of atmosphere and circumstellar envelope

Detailed physics of the mass-loss process
Maser: joint VLBA/VLTI observations of Mira S Ori

Detailed physics of the mass-loss process
Detailed structure of atmosphere and circumstellar envelope

Boboltz & Wittkowski 2005

VLTI (AMBER & MIDI):
• Size and shape of IR and MIR photosphere.
• CLV, effects by molecular layers, inhomogeneities.
• Size, chemistry, shape of the warm dust shell.

VLBA:
• SiO maser zone:
• Radio photosphere.
• Water and OH maser.
• SiO maser zone:

ALMA:
• SiO maser zone:
• Radio photosphere.
• SiO maser zone:
• Water and OH maser.
• SiO maser zone:

Detailed structure of atmosphere and circumstellar envelope
Detailed physics of the mass-loss process
More about Imaging:

**Binary**

VLTI/PIONIER: Image of the inner rim dust disk around a post-AGB
Disks around luminous post-AGB binaries are scaled-up, more irradiated versions of protoplanetary disks around YSOs. Complement to a larger gaseous disk as observed by ALMA (Bujarrabal et al. 2018).
Orbit from VLTI/AMBER/PIONIER/GRAVITY

Sánchez-Bernúdez et al. 2018. (VLBA)

Wind-wind collision. The triple system HD167971
Massive binary fraction: Multiple Star Systems in the Orion Nebula

VLTI/GRAVITY

Imaging and astrometric capabilities of GRAVITY
Massive binary fraction: Multiple Star Systems in the Orion Nebula

VLTI/GRAVITY
Low mass stars. AB Dor: LBA / VLTI

1. AB Dor A strong radio emitter
2. AB Dor C discovered by astrometric VLBI + dynamical mass
3. AB Dor C difficult to image in NIR (high contrast) – 10yr later
4. Important to calibrate stellar models
5. Radioemission discovered in AB Dor

LBA 1.4GHz

SDI / VLT

SINFONI / VLT
LBA 1.4GHz

AB Dor

C

Low mass stars. AB Dor: LBA / VLTI

1. AB Dor A strong radio emitter
2. AB Dor C discovered by astrometric VLBI + dynamical mass
3. AB Dor C difficult to image in NIR (high contrast) – 10yr later
4. Important to calibrate stellar models
5. AB Dor C found to be also radio emitter (see talk by Climent)
6. Non-standard VLTI/AMBER shows AB Dor C could be binary

LBA 1.4GHz
CSIzmadia + 2006

Peterson + 2010 (VLBA)

EVN + CHARA observations of Algol (coronal studies + astrometry)
The SS-433 System

- $M_{SWIR}=24\, M_{\odot}$
- $P=13.6\, \text{days}$
- $<300\, R_{\odot}$ (0.2 mas)
- $>160\, R_{\odot}$ (0.1 mas)
- GAS STREAM
- COMPACT OBJECT
- ACCRETION DISC
- COMPANION STAR
- CIRCUMBINARY DISC
- Jet approaching
- Jet receding
- 5 kpc
- Toward Earth
- and inclination ($\sim 56.5\, \text{days}$)
- Jet precession ($\sim 176\, \text{days}$)
- Orbit

Petrucci et al. 2017

Microquasar SS433

VLTI / GRAVITY
1. 90% of the infrared continuum comes from a central source of ~0.8 mas.

2. 10% IR from extended 1.5 mas structure.

3. Jet line mas along the jet.

4. Circumbinary disc.

Microquasar SS433

VLTI / GRAVITY:
VLTI/GRAVITY: SgrA*: Gravitational Redshift
Abuter et al. 2018

VLTI/GRAVITY: SgrA* Gravitational Redshift

Orbit of S2
VLTI/GRAVITY: SgrA* Gravitational Redshift

Abuter et al. 2018

Comparison of tests of General Relativity. Inspired by Faisal Shah.

Supernova ELA: SgrA* (4.5 Million Solar Masses) with VLTI.

Orbit: 120 x Earth-Sun

GRAVITY: SgrA*: Gravitational Redshift
The future of (NIR) interferometry

- Imaging capabilities
- Higher spectral resolution
- More sensitivity
- Wide-field astrometry
- Polarimetry
- Extending to the visible

But wait to ELT/SKA era...
Thanks!