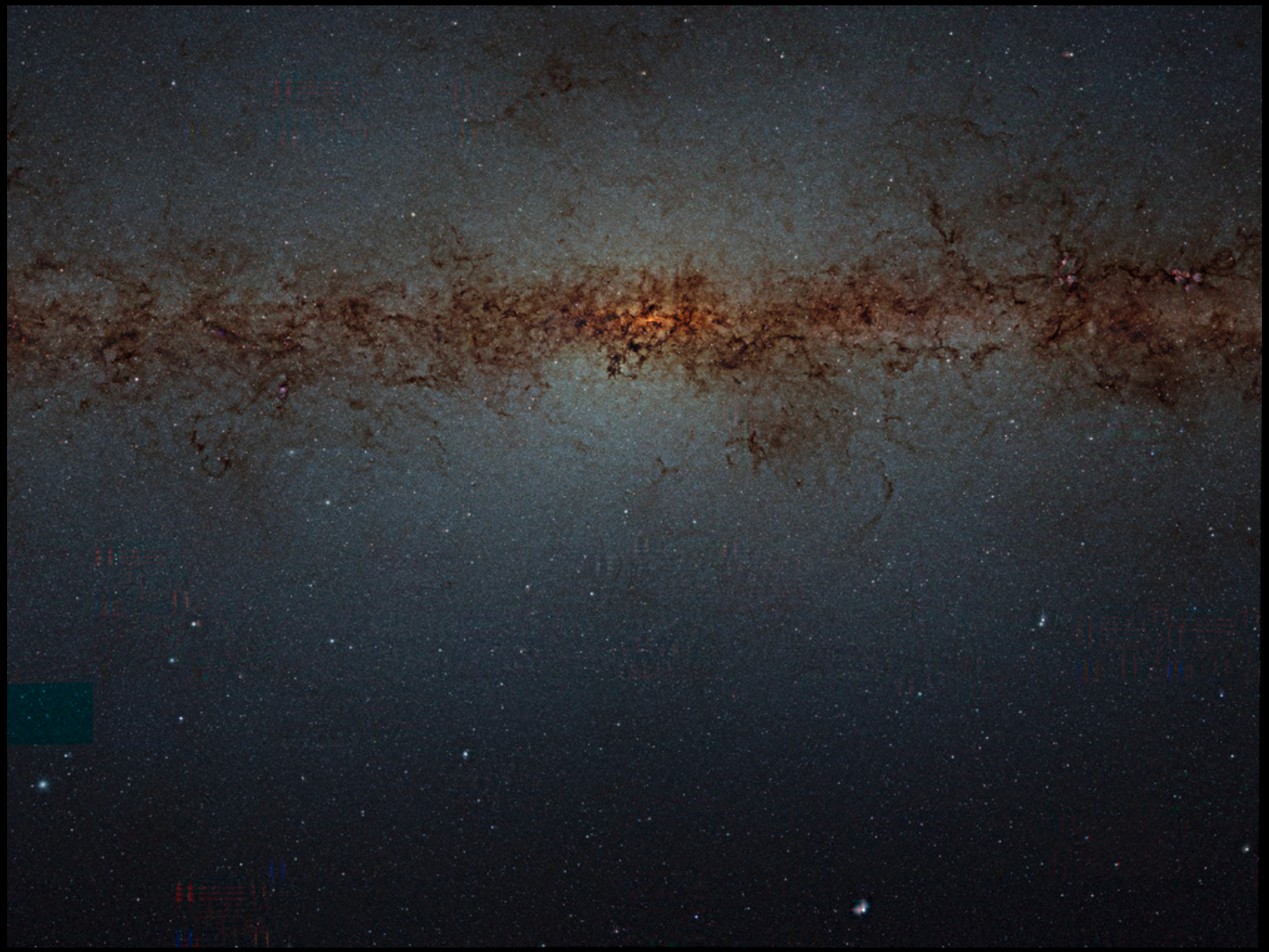
# Synergies between ground- and space-based observatories

Bruno Leibundgut
(ESO)

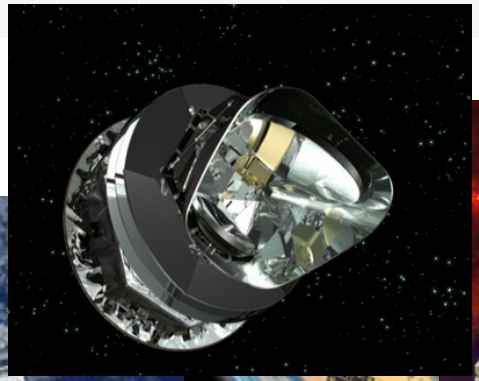
# VISTA Variables in the Via Lactea VVV



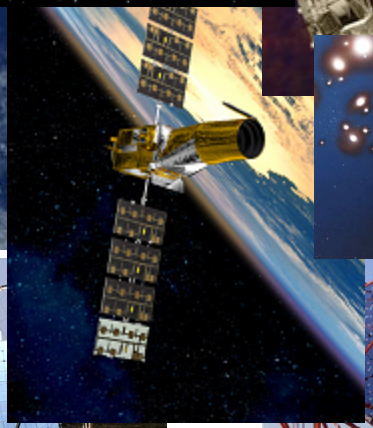
# Outline

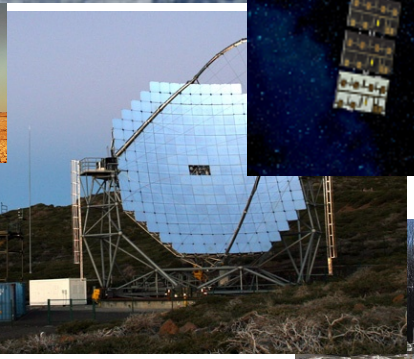
- Ground vs. Space
  - multi-wavelength astronomy
- Science topics
- *Poster Child*
- ESO-ESA coordination

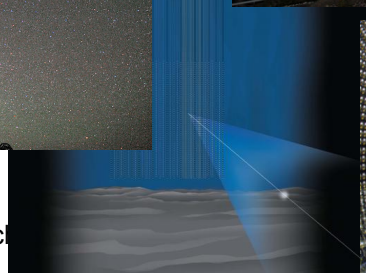
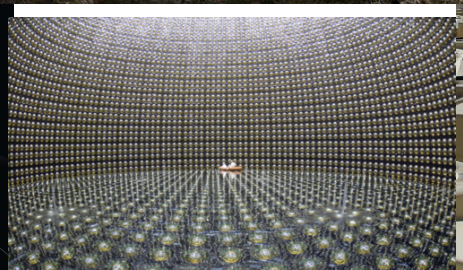
# Current facilities








# Why would you not use all resources?

- Full coverage of electro-magnetic spectrum
  - 19 orders of magnitude in wavelength or frequency
    - meter to attometer ($10^{-18}$) or MHz to YHZ (yotta – $10^{25}$)

| Electro-magnetic radiation | Current facilities | Future facilities |
|---|---|---|
| UHE | MAGIC, HESS, VERITAS | CTA |
| γ-rays | INTEGRAL, FERMI | |
| X-rays | XMM-Newton, Chandra, Swift, Rossi/XTE, Suzaku | eROSITA, ASTRO-H |
| UV | GALEX | |
| optical | ground-based observatories, HST, CoRoT, Kepler | ELTs, Gaia |
| IR | ground-based observatories | ELTs, JWST, Euclid |
| mid-IR | ISO, SPITZER, AKARI | |
| 100μm | HERSCHEL, PLANCK, SOFIA | |
| sub-mm/mm | IRAM, APEX, CARMA, JCMT, SMA, ALMA | ALMA, CCAT |
| cm/m | radio observatories, LOFAR | SKA |

- "Messengers"

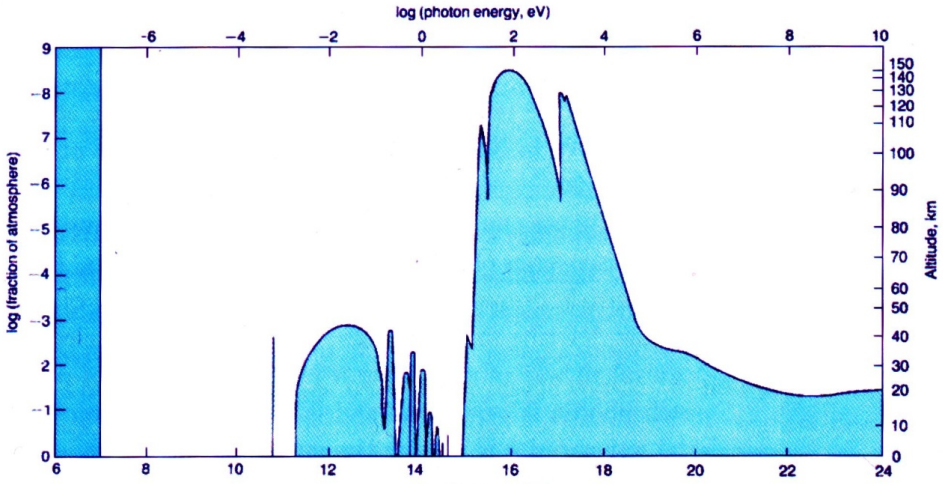
| non-EM observatories | Current facilities | Future facilities |
|---|---|---|
| cosmic rays | Auger | |
| neutrinos | IceCube | KM3NET |

# Exploring synergies

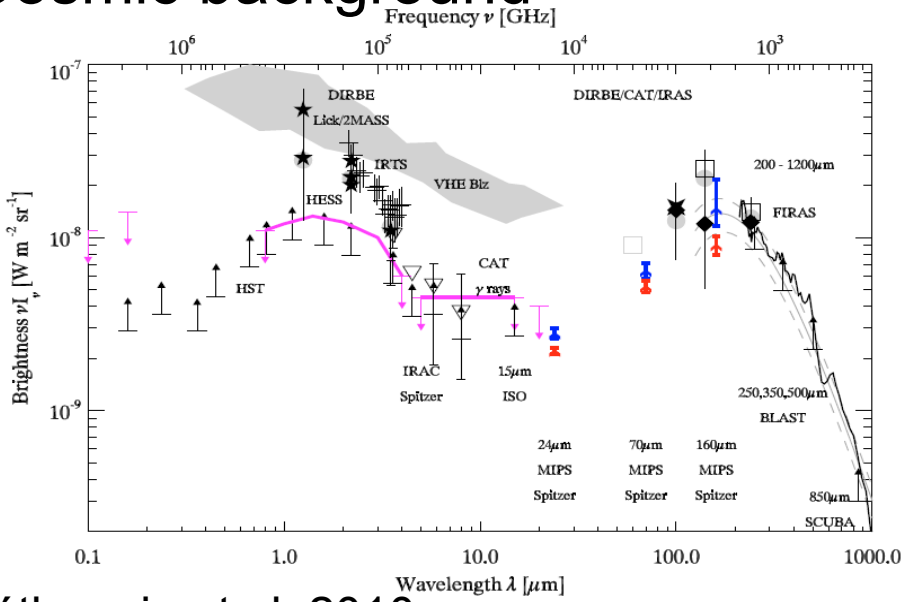
- Astronet Science Vision and Roadmap
- ESA Cosmic Vision initiative
- Special publicati[illegible]
  - ESA-E[illegible]oup reports

# Ground vs. Space

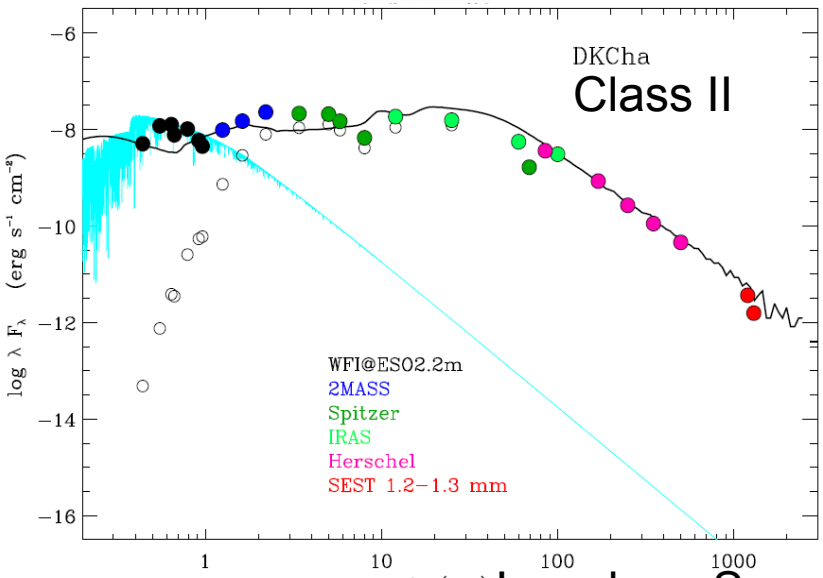
- sensitivity, wavelength access
  - ➡ talks by *Testi, van Dishoeck, Preibisch*




Cosmic background




Béthermin et al. 2010




Loredana Spezzi

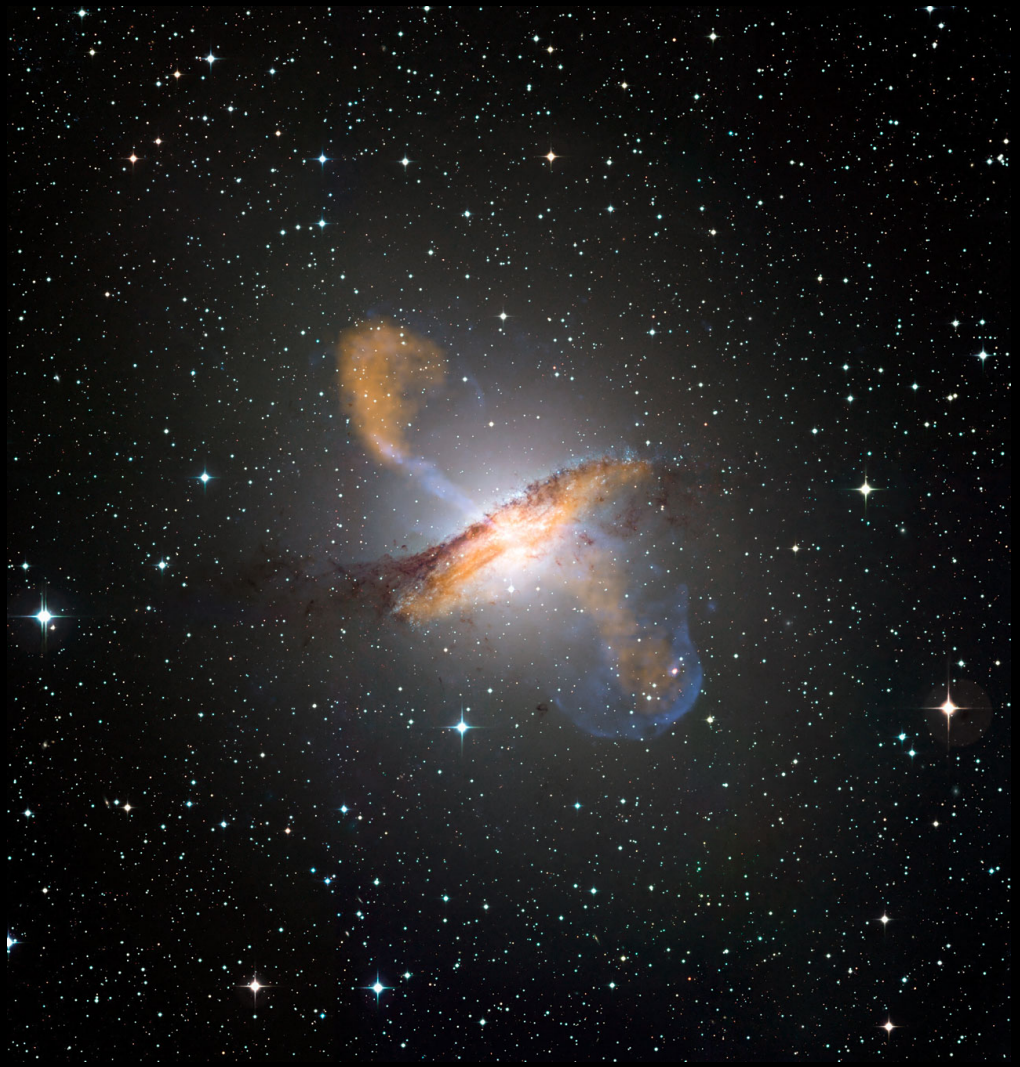
# Ground vs. Space

- stability
  - ➡ talks by *Udry, Bouchy*
  - ➢ photometric
    - CoRoT, Kepler
  - ➢ spectroscopic
    - HARPS
- sky coverage
  - ➢ all sky
    - COBE, WMAP, Planck, Gaia
- accessibility
  - ➢ repairs, upgrades
- image quality, confusion
  - ➢ talks by *Genzel, Rejkuba, Piotto, Tolstoy, Neumayer*
  - ➢ HST *vs.* optical ground
  - ➢ longer wavelengths *vs.* optical ground

# Ground vs. Space

- spectroscopic redshifts, internal dynamics
  - mostly optical domain, but ALMA!
  - multiplex
  - ➡ talks by *Fynbo, Combes, Lilly, Tacconi, De Breuck, Föster Schreiber, Mellier, Franx, Hammer, Petitjean, Murphy, Cristiani*
- positional accuracy
  - atmospheric issues
- direct access
  - solar system missions
  - ➡ talks by *Sicardy, Vernazza*
- cost

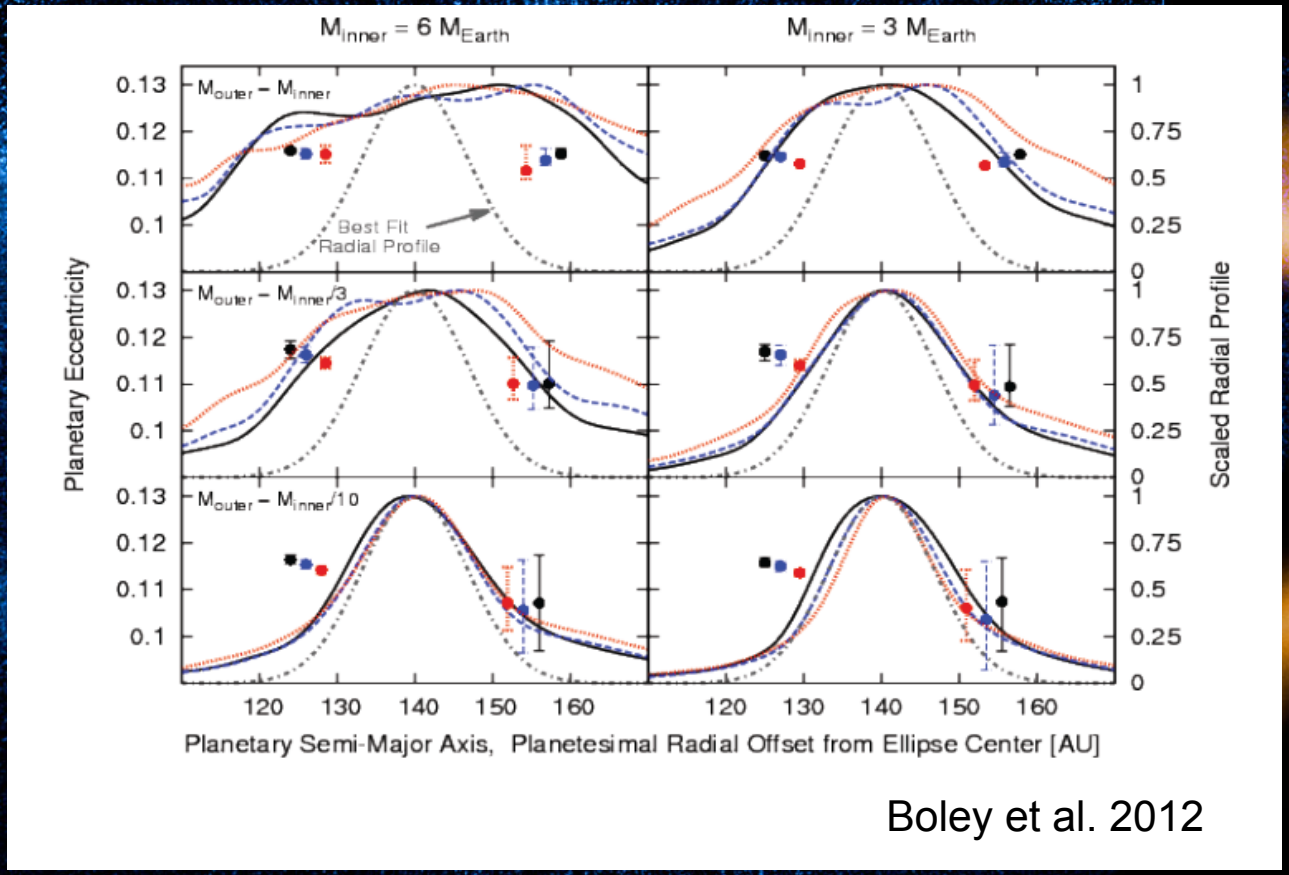
# Multi-wavelength



X-rays – Chandra
sub-mm APEX
optical 2.2m

# HST/ALMA/Spitzer/ATCA

- Dust ring around Fomalhaut
- Hints for two planets → a few Earth masses



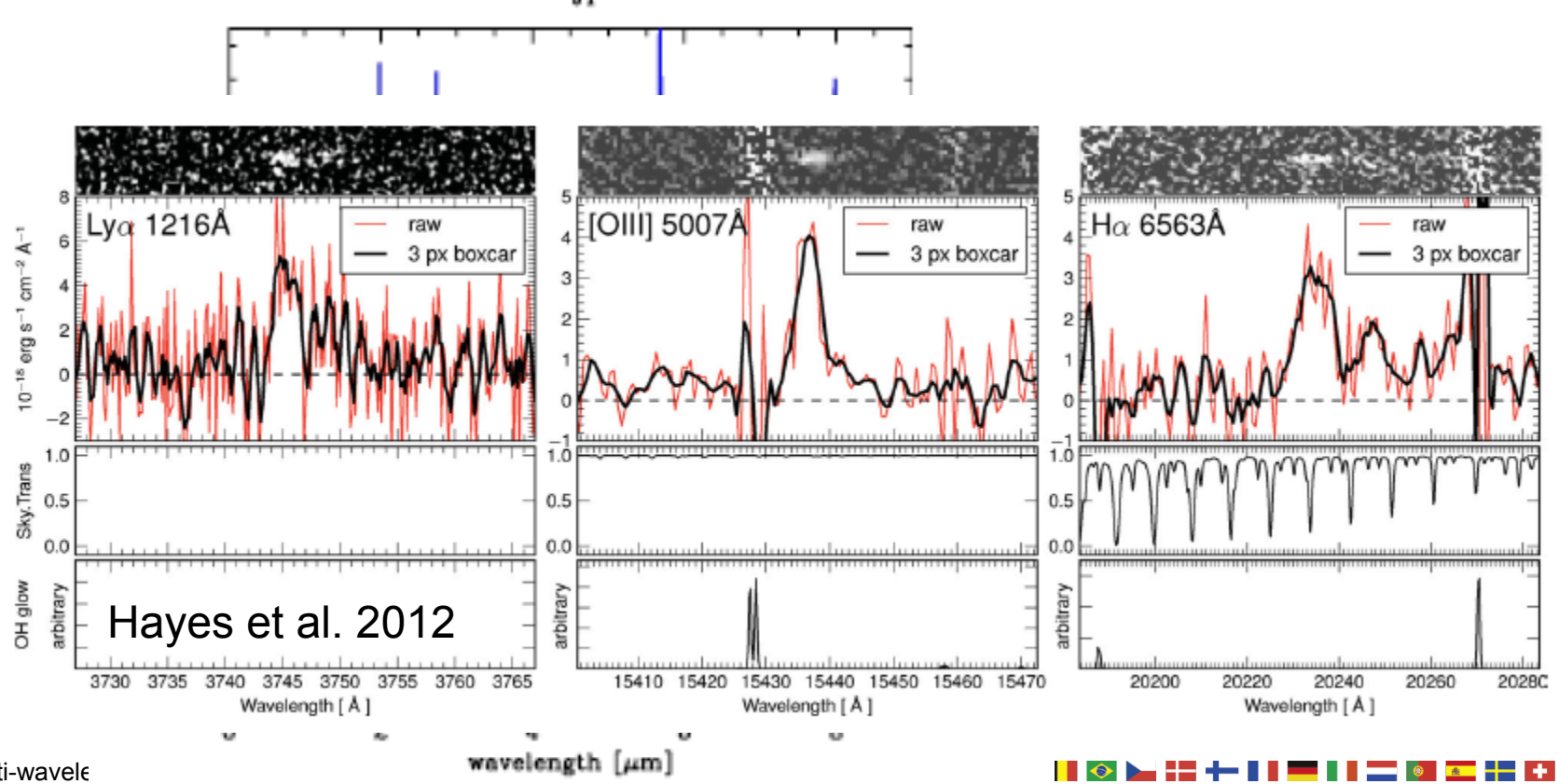

Boley et al. 2012

# High-redshift galaxies

- GOODS/CDF/COSMOS
  - redshift pushes relevant optical features into the IR → HST imaging required for photometric redshifts
  - follow-up with VLT/Keck spectroscopy
    - spectroscopic redshifts, spectral analyses
  - CO and [C I] detections with mm telescopes (APEX, JCMT, IRAM, ALMA)

# High-redshift galaxies

- Importance of spectroscopy
  - galaxy with photometric redshift 9.6<z<12
  - X-shooter spectrum: z=2.08

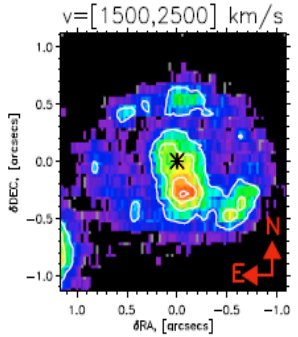


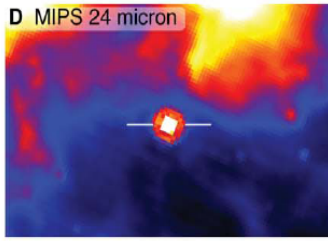
# Other topics

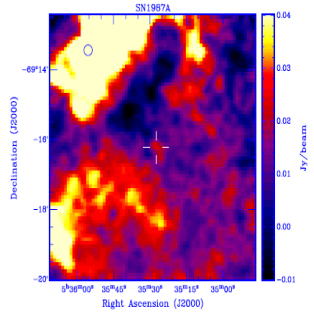
- CoRoT, Kepler, Cheops
  - use photometric stability for transiting planets
  - follow-up with radial velocity curves to characterise the planets (or vice versa with CHEOPS)
- XMM-Newton Cluster search
  - redshift determinations with ESO telescopes
- GRBs
  - detection in γ-rays, localization with X-rays, follow-up/ characterisation with optical telescopes (redshifts!)
- Distant supernovae
  - regular observing pattern with HST (light curves), (galaxy) redshifts with 8m telescopes

# SN 1987A

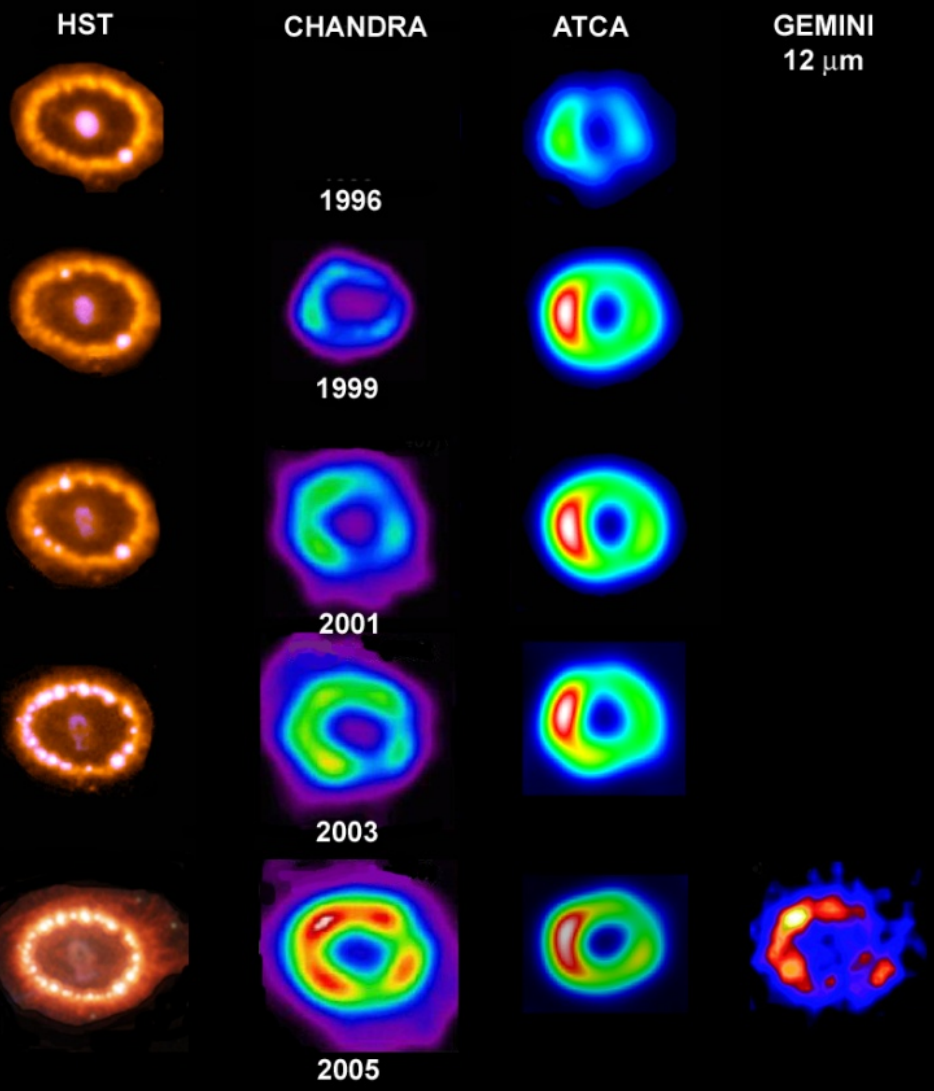
- Gift for ESO's 25th anniversary
- Observed at all wavelengths
  - HST
    - COS, STIS, WFPC1/2, NICMOS, WFC3, ACS, FOC
  - VLT
    - ISAAC, FORS, UVES, SINFONI, NACO, VISIR
  - Rosat, Chandra, XMM-Newton
  - Spitzer, Herschel
  - APEX, ALMA, ATCA



# Optical, X-rays and Radio

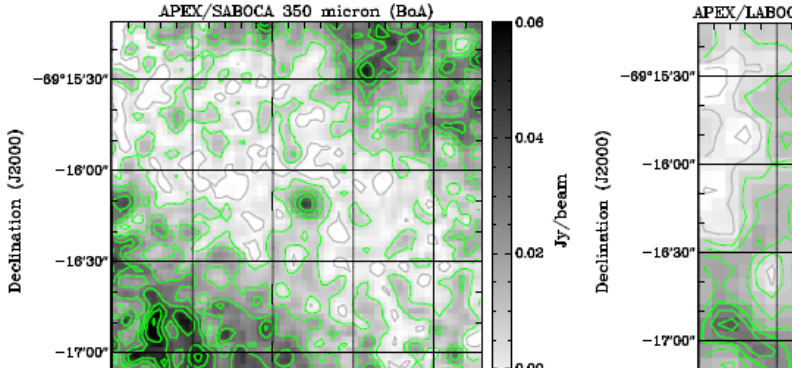


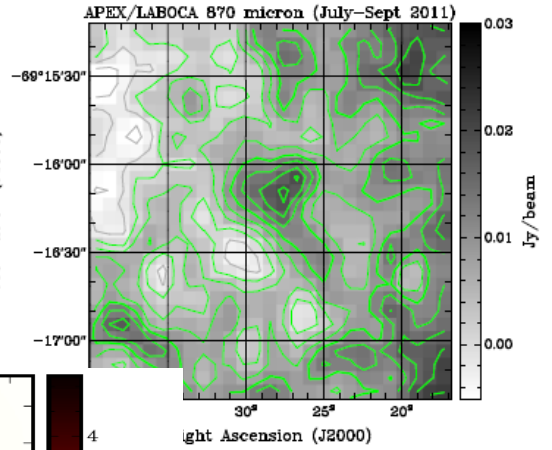

NACO H-band
Danziger & Bouchet 2007

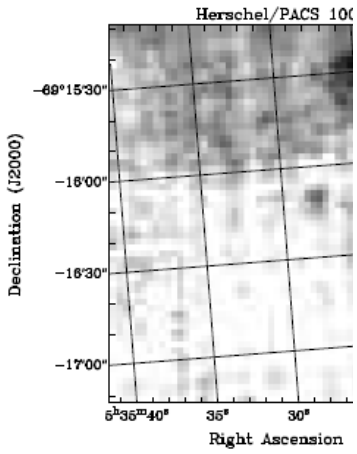
Park et al
Manchester et al

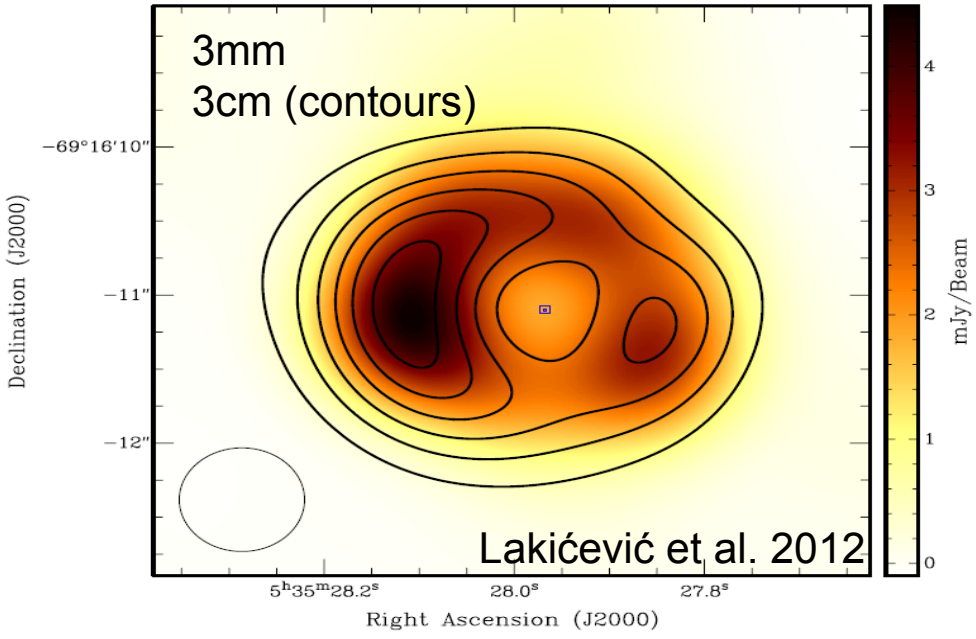
# Exciting developments 2011/12

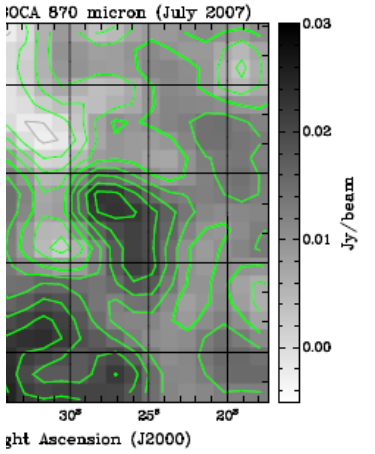
Lakićević et al. 2012




Matsuura et al. 2011

I Background subtracted

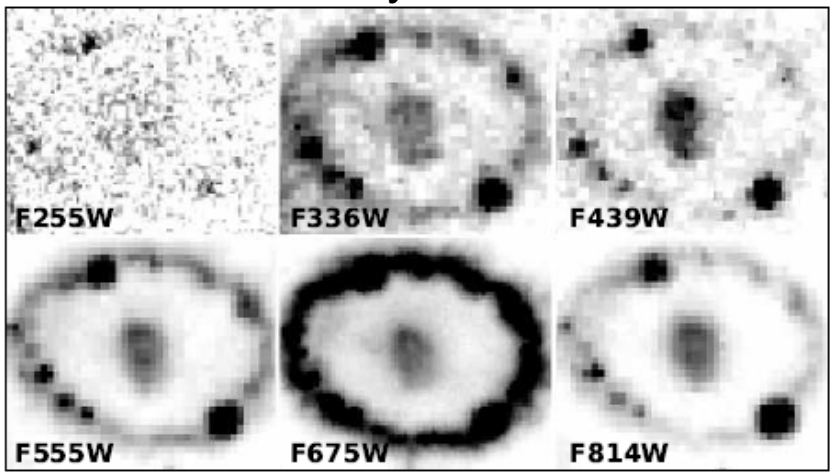
# Space and ground synergy

## Different morphologies

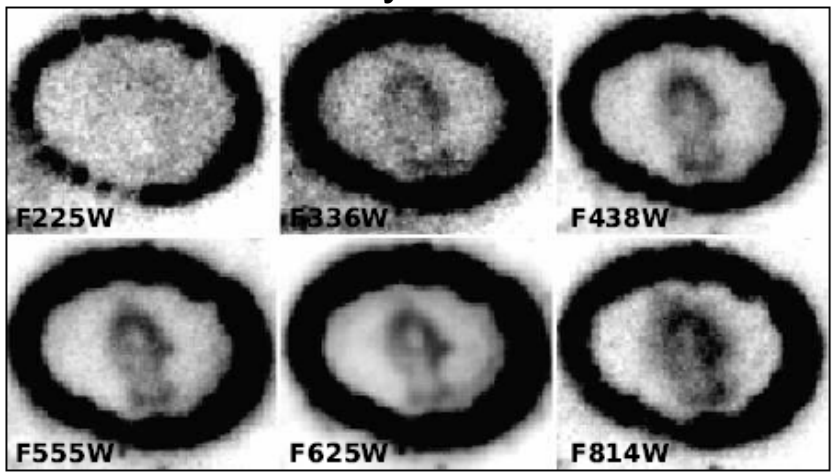
Optical: X-ray heating from ring collision

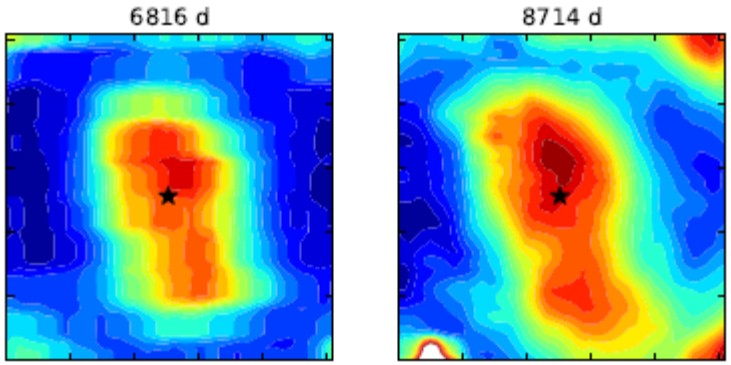
IR: mostly still radioactive heating

Day 5012




Day 8328



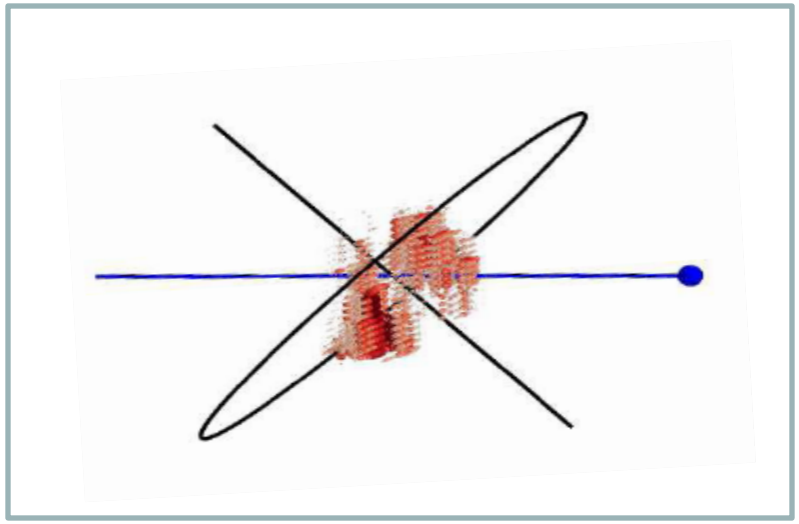




SINFONI – 1.644μm [Si I] and [Fe II]

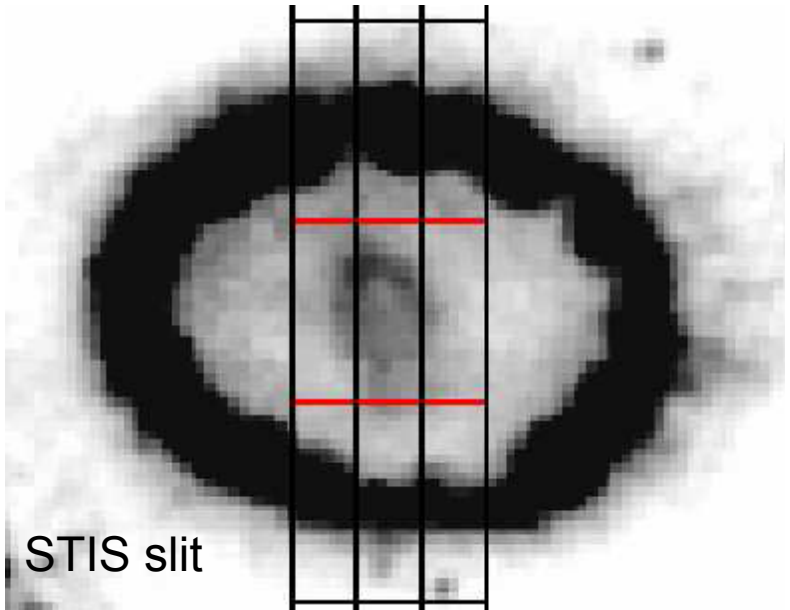
Larsson et al. 2013

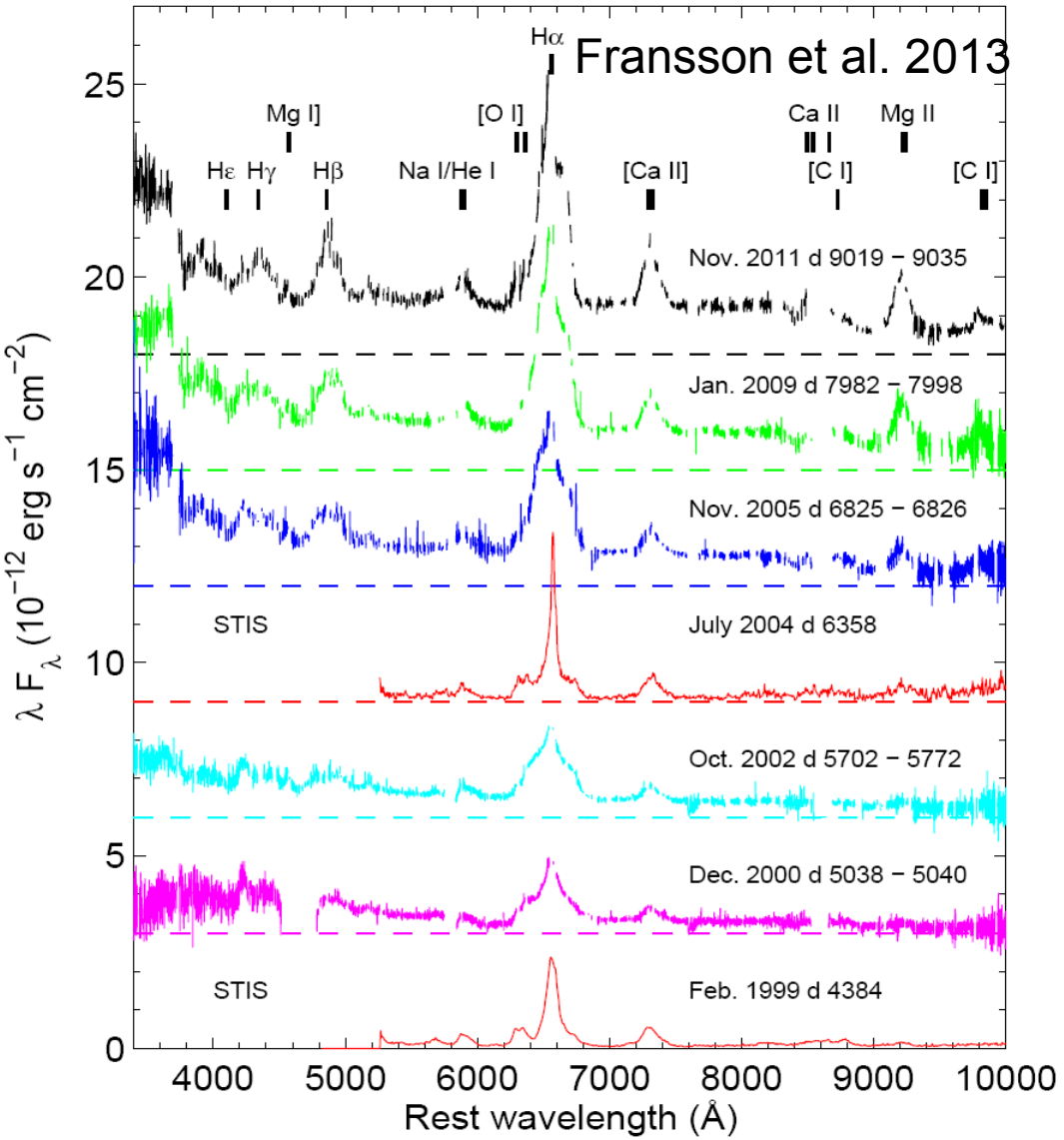
# Distribution of the inner ejecta

- Clumpy distribution of the inner ejecta
- Inner ejecta is increasing in brightness since day 5000
- Emissivity is not directly linked to matter distribution any longer
  - different heating mechanisms

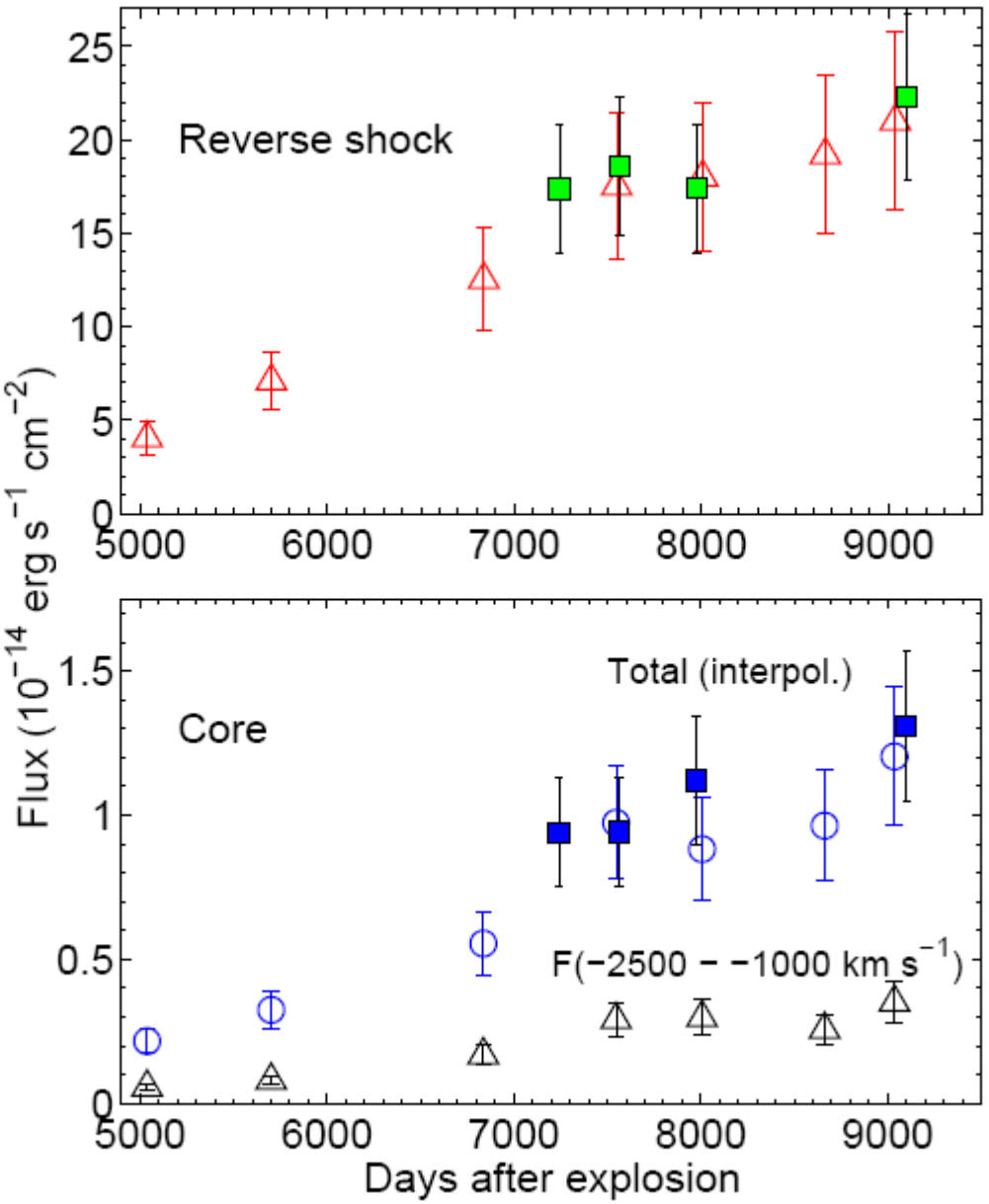


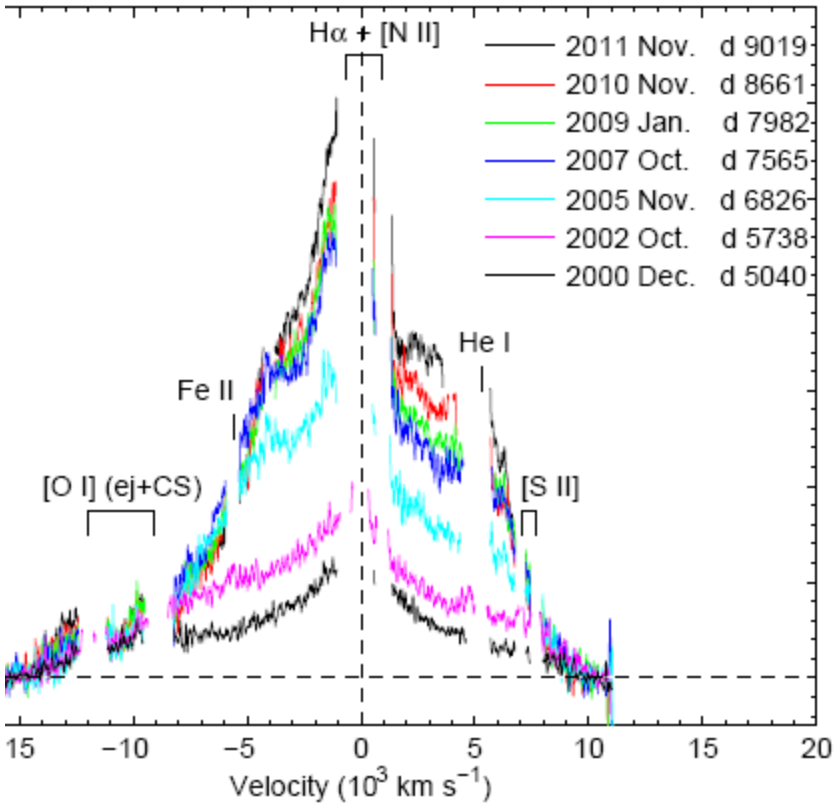
# Combined analysis

# Brightening ejecta



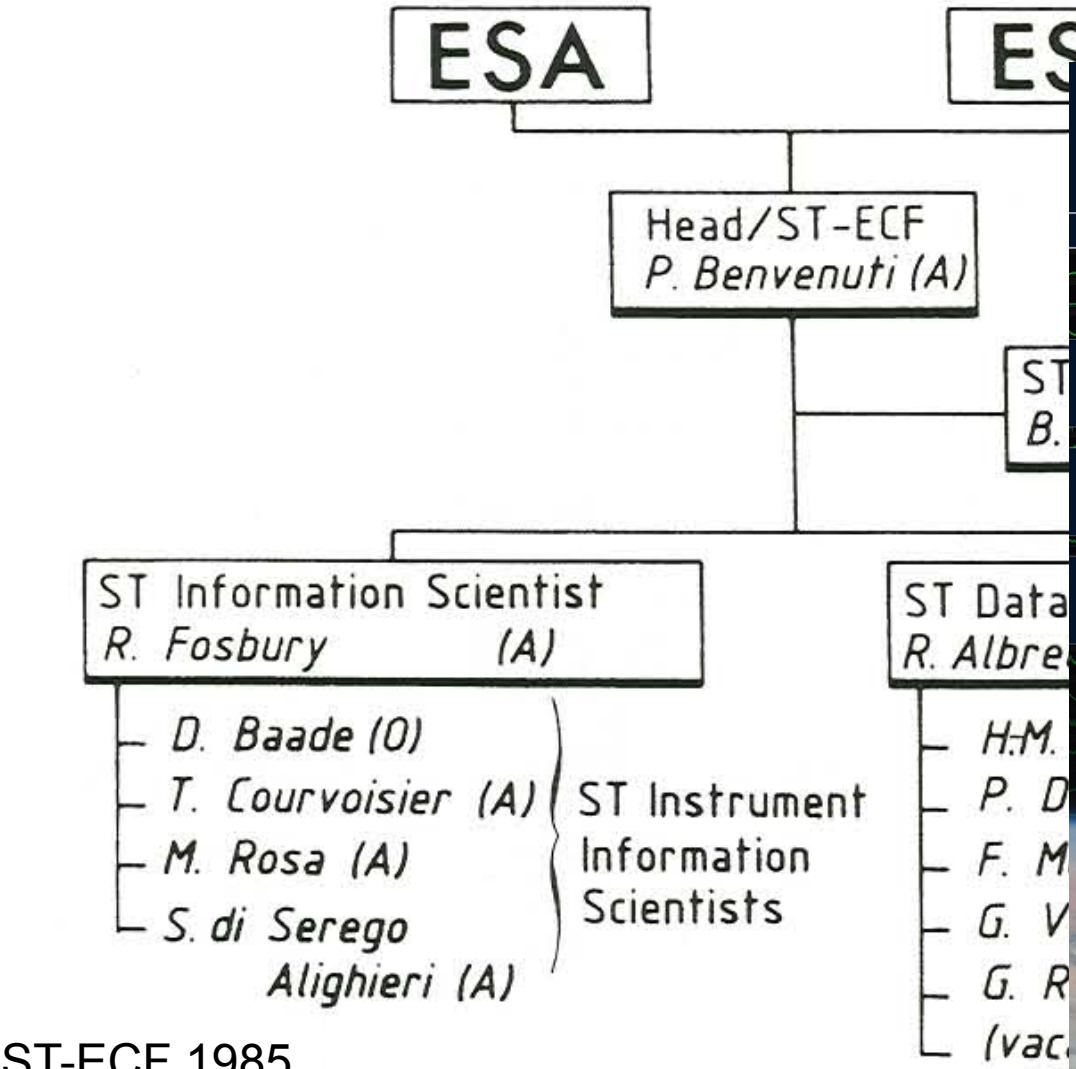
# The complex SN 1987A

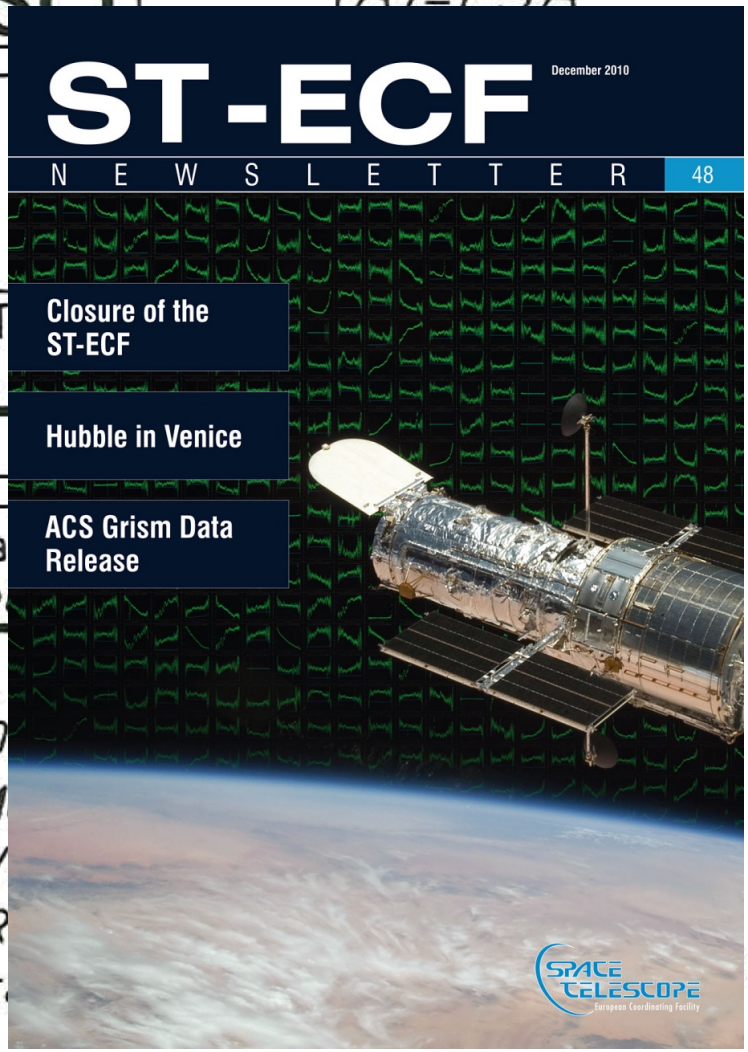
- Inner ejecta
  - now heated by X-rays from the reverse shock
- reverse shock
- shocked ring gas
- recombining ring
- dust
  - location unclear
    - inner ejecta? ring? reverse shock?

# ESO-ESA coordination

- ST-ECF
  - 26 years (1984-2010) of daily interaction between ground and space (HST)
  - direct link to the HST project
  - strong impact on VLT operations model
    - lessons learnt, good practices
  - instrument modelling and calibration
    - e.g. UVES wavelength calibration
    - evaluation of the slitless spectroscopy capabilities for EUCLID
  - Science Archive
  - Coordination activities
    - GOODS
  - Outreach activities

# ST-ECF

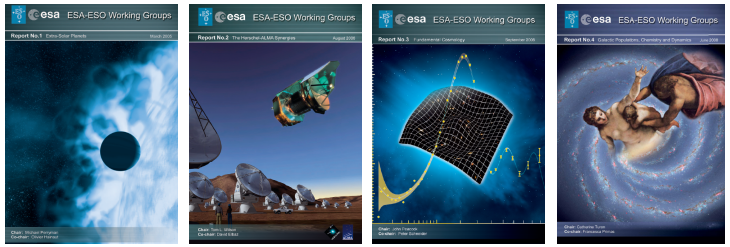



ST-ECF 1985

# ESO-ESA collaboration

- Regular (bi-annual) meetings
- Information exchange
- Commissioned the working group reports
  - coordinated by the ST-ECF




- Continue European HST outreach at ESO
- XMM-Newton/VLT joint observing programmes (e.g. CfP 91)

# Support of ESA missions

- Hipparcos

Messenger 56, June 1989

PROFILE OF TWO KEY PROGRAMMES

## Complementary Astrophysical Data for Hipparcos Stars

### (1) Astrophysical Fundamental Parameters of Early-type Hipparcos Stars

*M. GERBALDI, Institut d'Astrophysique, Paris, France*
*A. GÓMEZ, S. GRENIER, C. TURON, Observatoire de Paris, Meudon, France*
*R. FARAGGIANA, Università di Trieste, Italy*

ESO 1.5m

### (2) Radial Velocities of Southern Late-type Hipparcos Stars

*M. MAYOR, A. DUQUENNOY, M. GRENON, Observatoire de Genève, Switzerland*
*C. TURON, F. CRIFO, Observatoire de Paris, Meudon, France*
*M. IMBERT, E. MAURICE, L. PREVOT, Observatoire de Marseille, France*
*J. ANDERSEN, B. NORDSTRÖM, Copenhagen University, Denmark*
*H. LINDGREN, ESO*

Danish 1.54m

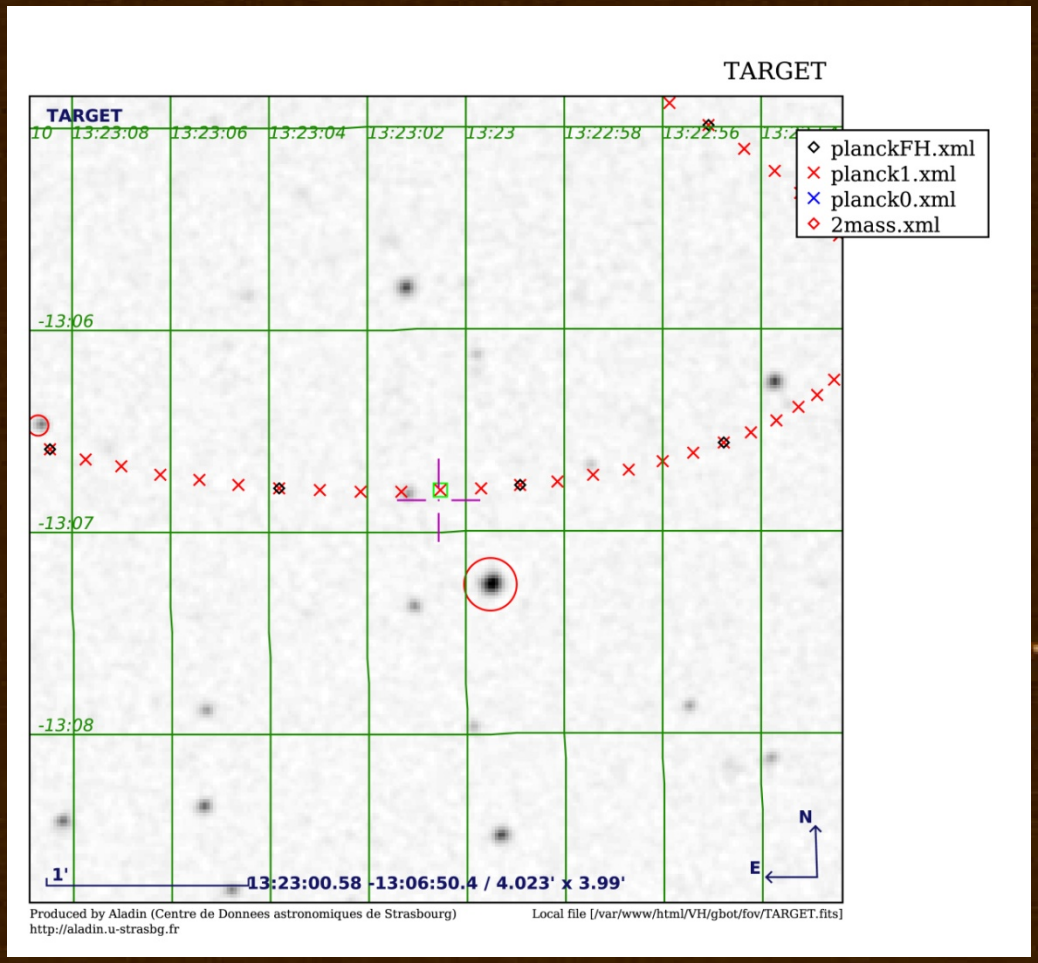
# Ground-based support for Gaia

- Calibration observations obtained with ESO telescopes over the years through regular proposals
  - most data received and analysed
- Gaia alerts for transient objects
  - PESSTO public spectroscopic survey
- Accurate satellite position required for astrometric goals
  - explore whether ESO telescopes could support this activity
  - test observations of Planck have been taken (VST)

# CHIP 12 eso ccd #84

*OMEGA.2012-04-04T05:41:47.818*

PLANCK

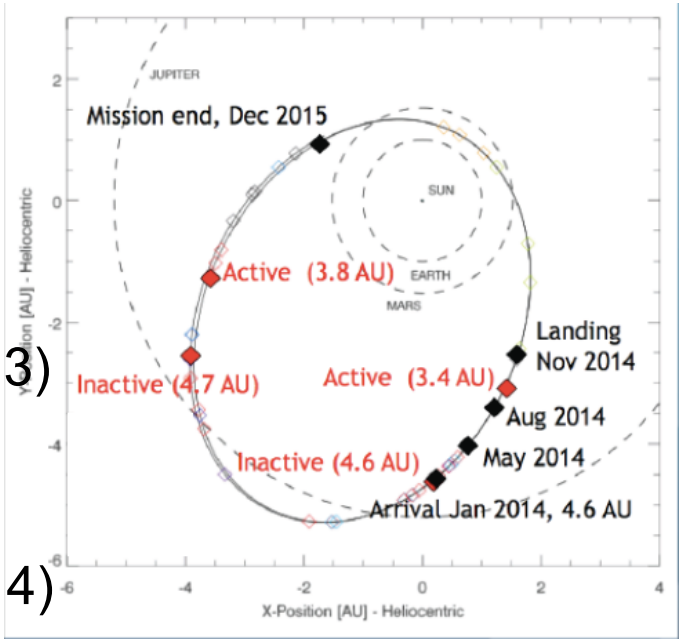


# Ground-based support for Gaia

- Spectroscopic follow-up
  - already started with Gaia-ESO public spectroscopic survey
  - MOS science cases have a focus on Gaia follow-up
- Agreed that this should be driven by the scientific community

# Ground-based support for Rosetta

- Important observations required for the approach of satellite to 67P/Churyumov-Gerasimenko
  - ESO telescopes ideally placed
  - could include nightly monitoring for activity
  - 'Wish list':
    - astrometric observations (starting in 2013)
    - photometric and spectroscopic monitoring (through 2014)
    - IR observations during landing (Nov 2014)
    - follow-up during perihelion (until April 2015



# Ground-based support for Euclid

- Photometry
  - mostly covered by DES, PanSTARRS-2 and KIDS
  - some 2500 □° remain
- Spectroscopy
  - needed for calibration of photo-z's
- ESA and ESO should consider organising a joint workshop to explore the synergies and needs

# ESO-ESA coordination

- Near-Earth objects
  - characterisation of potentially hazardous near-Earth objects
  - part of UN activity (within the UN Committee for Peaceful Uses of Outer Space)
  - coordinate the activities between ESA and ESO
    - establish relevant groups within both organisations

# ESO-ESA coordination

- Driven by the community
  - workshops
  - working groups
  - proposals
    - missions, instruments
    - observing projects

# Summary

- Astrophysics is happening everywhere
- Currently access to essentially the full electro-magnetic spectrum
- Wavelength chauvinism is on the decline
- Other messengers are catching up
- Experiments are now covering all bases from the design phase
  - GOODS, COSMOS, EUCLID, CHEOPS
- Observatories must see themselves as partners providing unique instruments in an orchestra – the individual astronomer is the conductor and chooses the tune