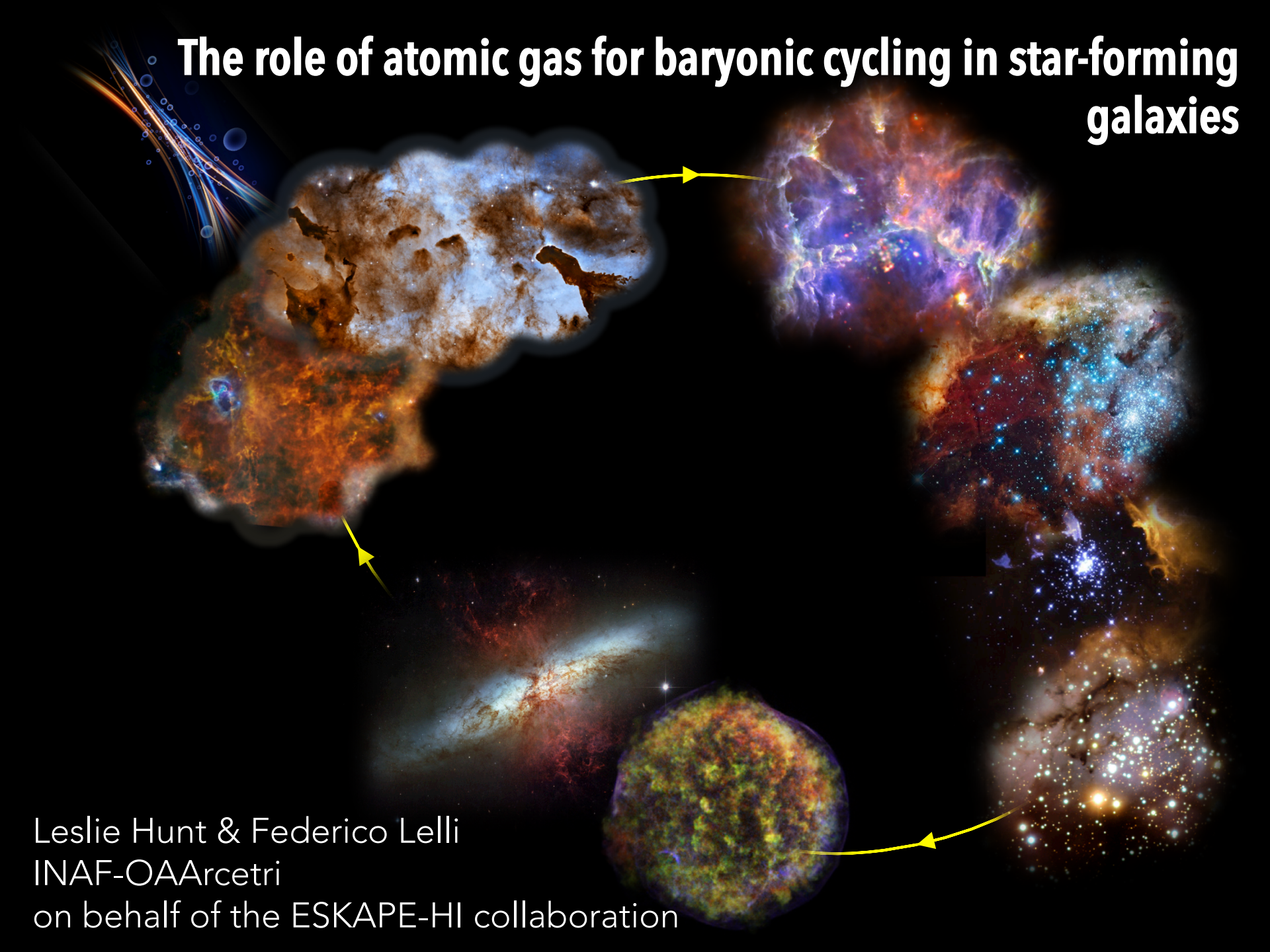
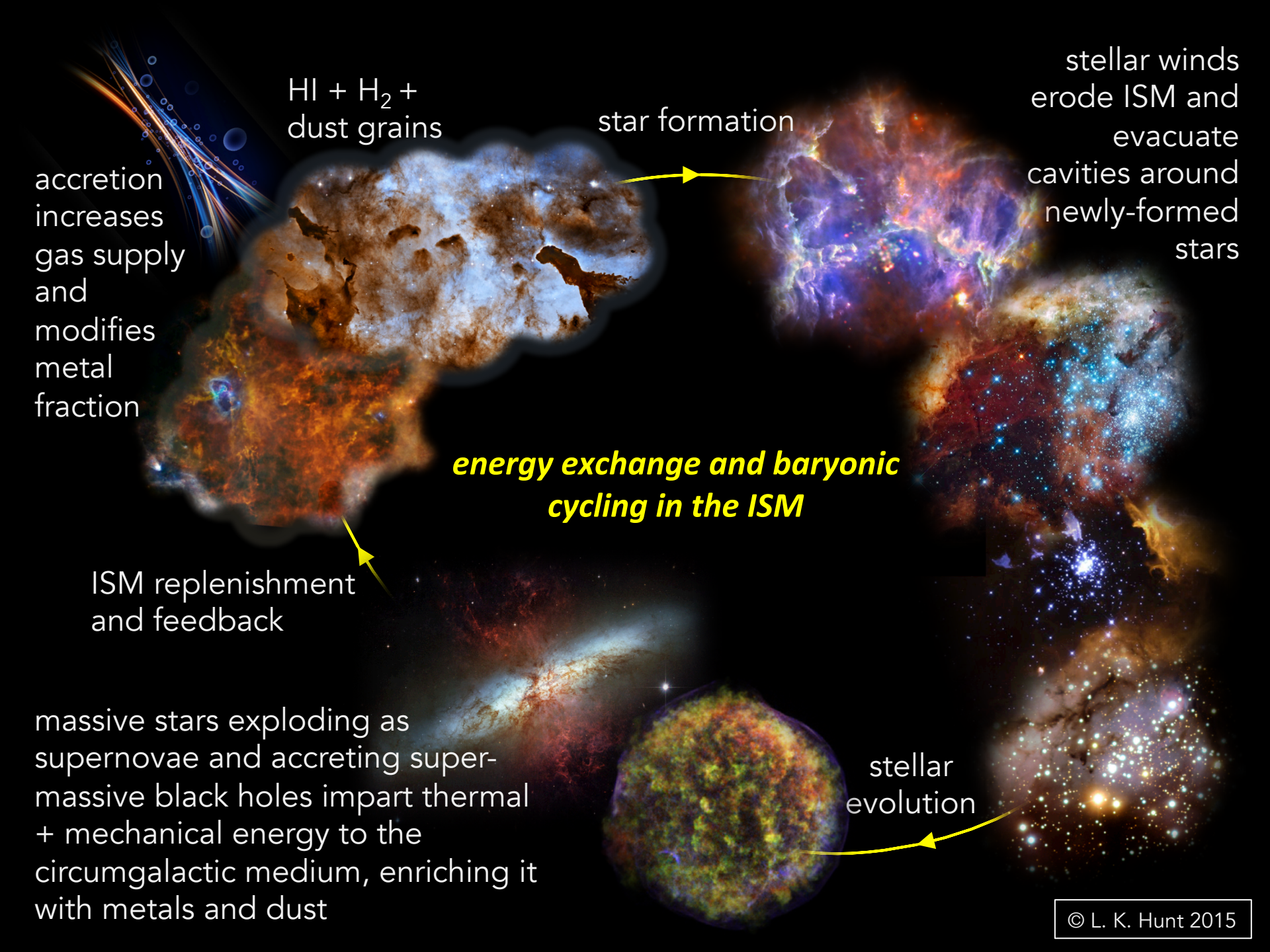
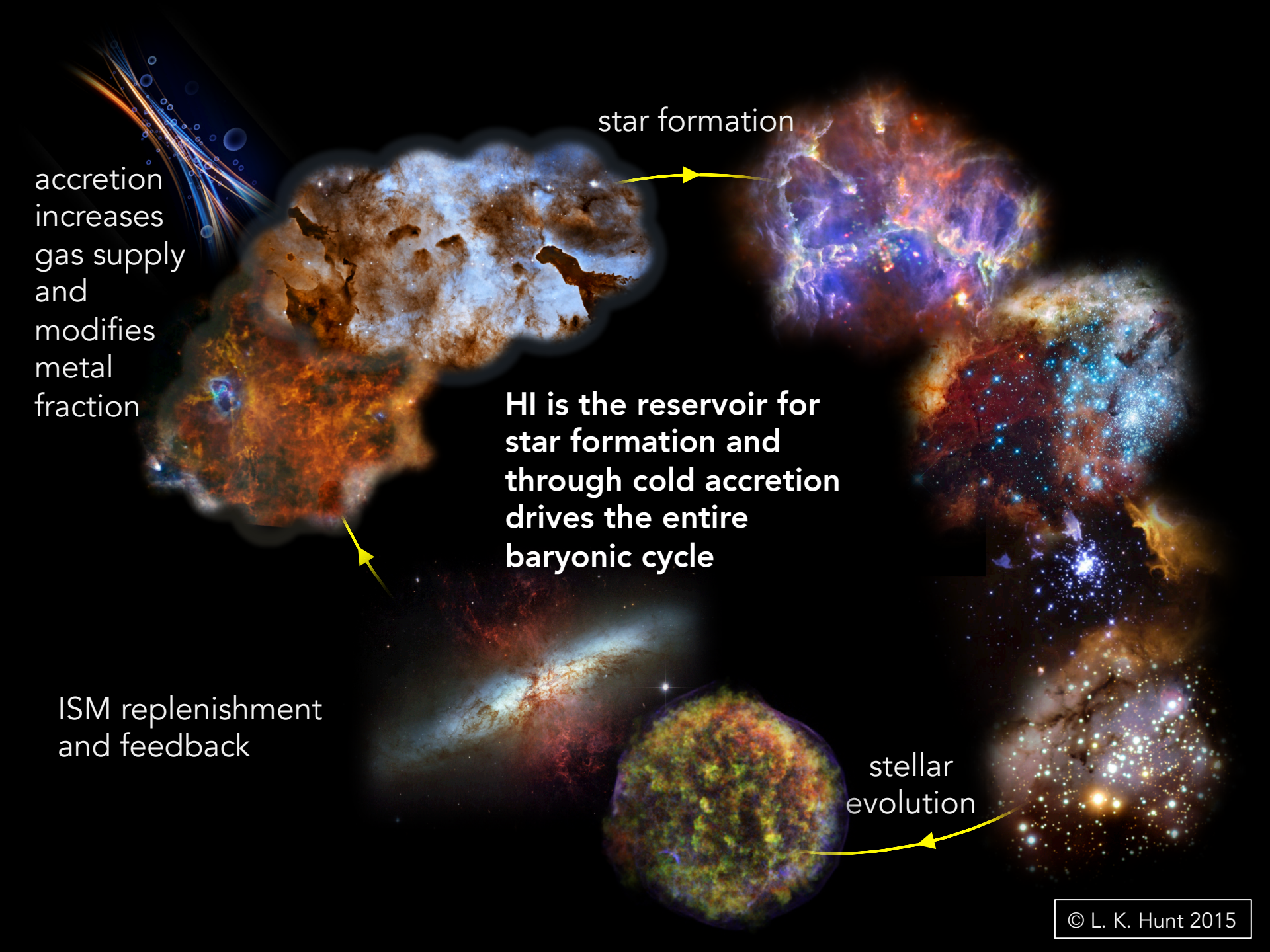
The role of atomic gas for baryonic cycling in star-forming galaxies



Leslie Hunt & Federico Lelli
INAF-OAArcetri
on behalf of the ESKAPE-HI collaboration


HI + H_2 + dust grains
star formation
stellar winds erode ISM and evacuate cavities around newly-formed stars
accretion increases gas supply and modifies metal fraction
energy exchange and baryonic cycling in the ISM
ISM replenishment and feedback
massive stars exploding as supernovae and accreting super-massive black holes impart thermal + mechanical energy to the circumgalactic medium, enriching it with metals and dust
stellar evolution


star formation
accretion increases gas supply and modifies metal fraction
HI is the reservoir for star formation and through cold accretion drives the entire baryonic cycle
ISM replenishment and feedback
stellar evolution
© L. K. Hunt 2015

PRIN-SKA 2016:
Empowering SKA as a probe of galaxy evolution with HI

Finanziamenti: 411 k€

National scientific coordinator:

Leslie Kipp Hunt
INAF-Osservatorio Astrofisico di Arcetri
Largo E. Fermi, 5
I-50122 Firenze, Italy
Phone: +39 055 2752296
Email: hunt@arcetri.inaf.it
http://www.arcetri.inaf.it

INAF nodes:

IASF-Milano
Osservatorio Astrofisico di Arcetri
Osservatorio Astronomico di Bologna
Osservatorio Astronomico di Brera
Osservatorio Astronomico di Capodimonte
Osservatorio Astronomico di Padova
Osservatorio Astronomico di Roma
Osservatorio Astronomico di Trieste

Other collaborating institutions:

University of Bologna
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OAS

WEAVE-APERTIF

+ INAF-IRA

Other collaborating institutions:

University of Bologna
University of Firenze
University of Padova

+ University of Roma Sapienza

SKAO consists of 2 telescopes over 2 continents

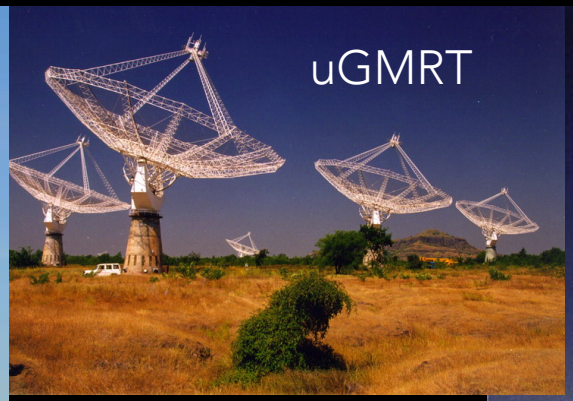
HI @ z≈0-1 with SKA-mid (0.35 – 15 GHz)

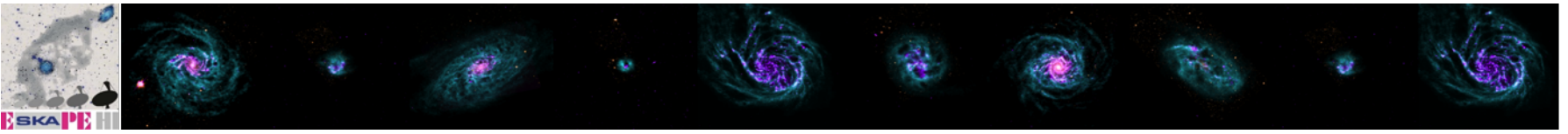
SKA-mid in South Africa (here MeerKAT precursor)

SKA-low (0.050 – 0.35 GHz)

SKA-low in Australia (here Murchison precursor)

Interferometers operating at SKA-mid frequencies



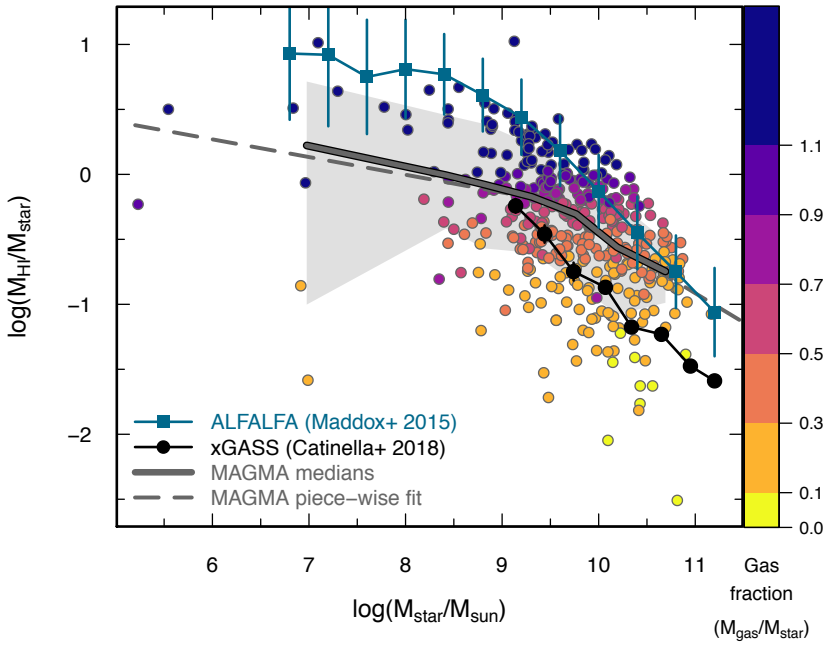


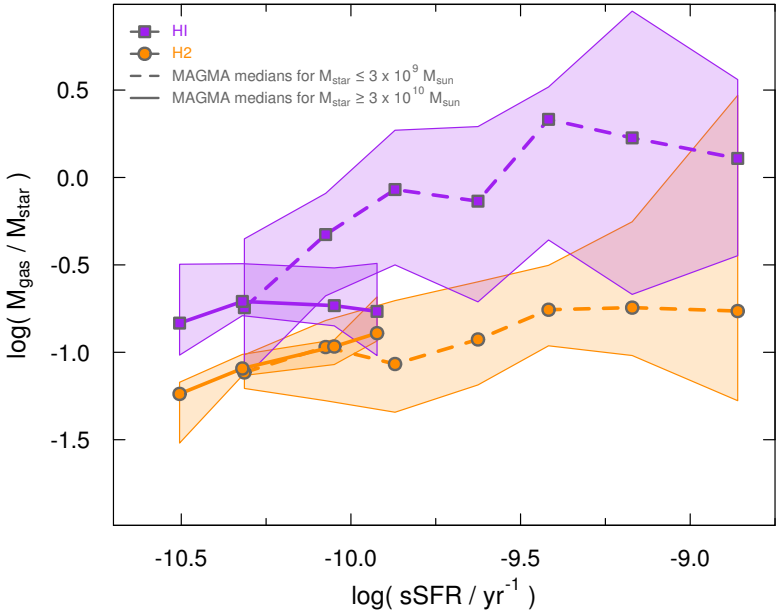
ESKAPE-HI, BaryonicCycling progress so far

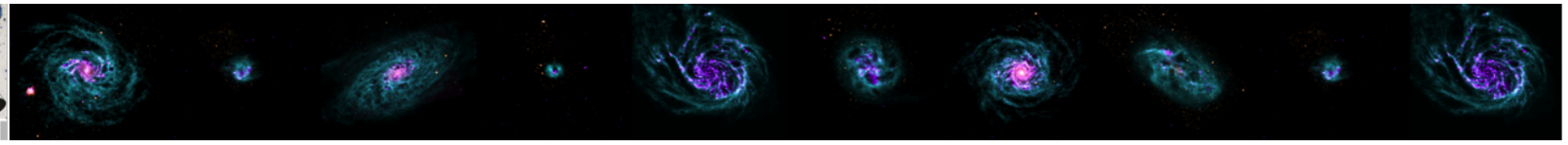
113 papers published in refereed journals in the context of ESKAPE-HI
(+1 currently under revision by A&A)

New sample of~400 galaxies (MAGMA) in the Local Universe and scaling relations linking stellar mass, star-formation rate, gas content (atomic + molecular) and metallicity (O/H) in the Local Universe (Ginolfi+ 2020, Hunt+ 2020, Tortora+ 2021)

At all stellar masses, gas budget dominated by atomic HI over molecular H_2

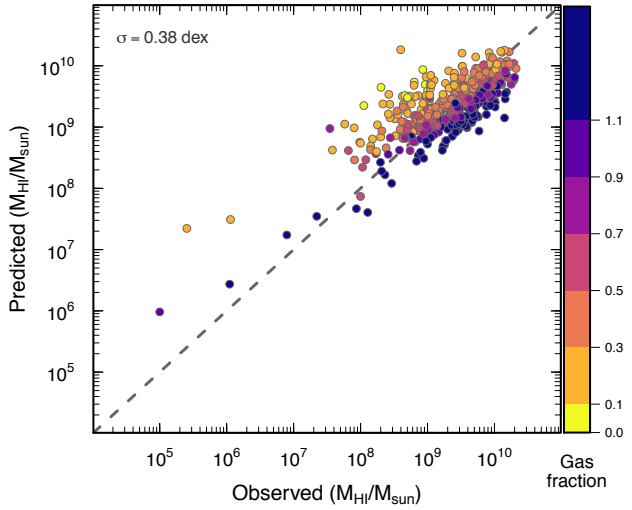






Scaling relations from MAGMA enable HI predictions

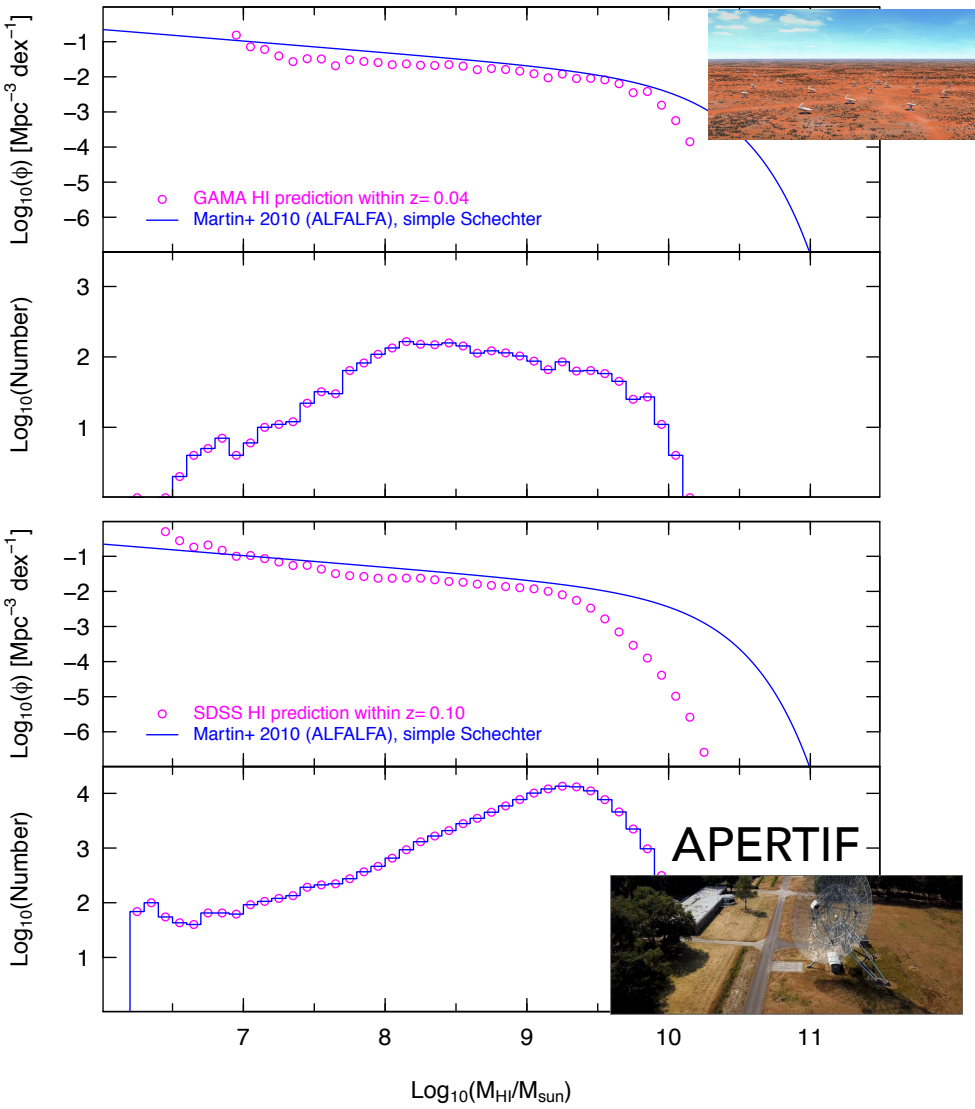
M_{HI} = fn(M_{star}, SFR) accurate to 0.38 dex.



Predict HI and check with HI mass functions for **ASKAP** and **APERTIF** surveys from M_{star}, SFR from Scodeggio + data base for SDSS (APERTIF) and GAMA (ASKAP), work in progress

High-M_{HI} discrepancy relative to ALFALFA HIMF stems from HI selection

ASKAP



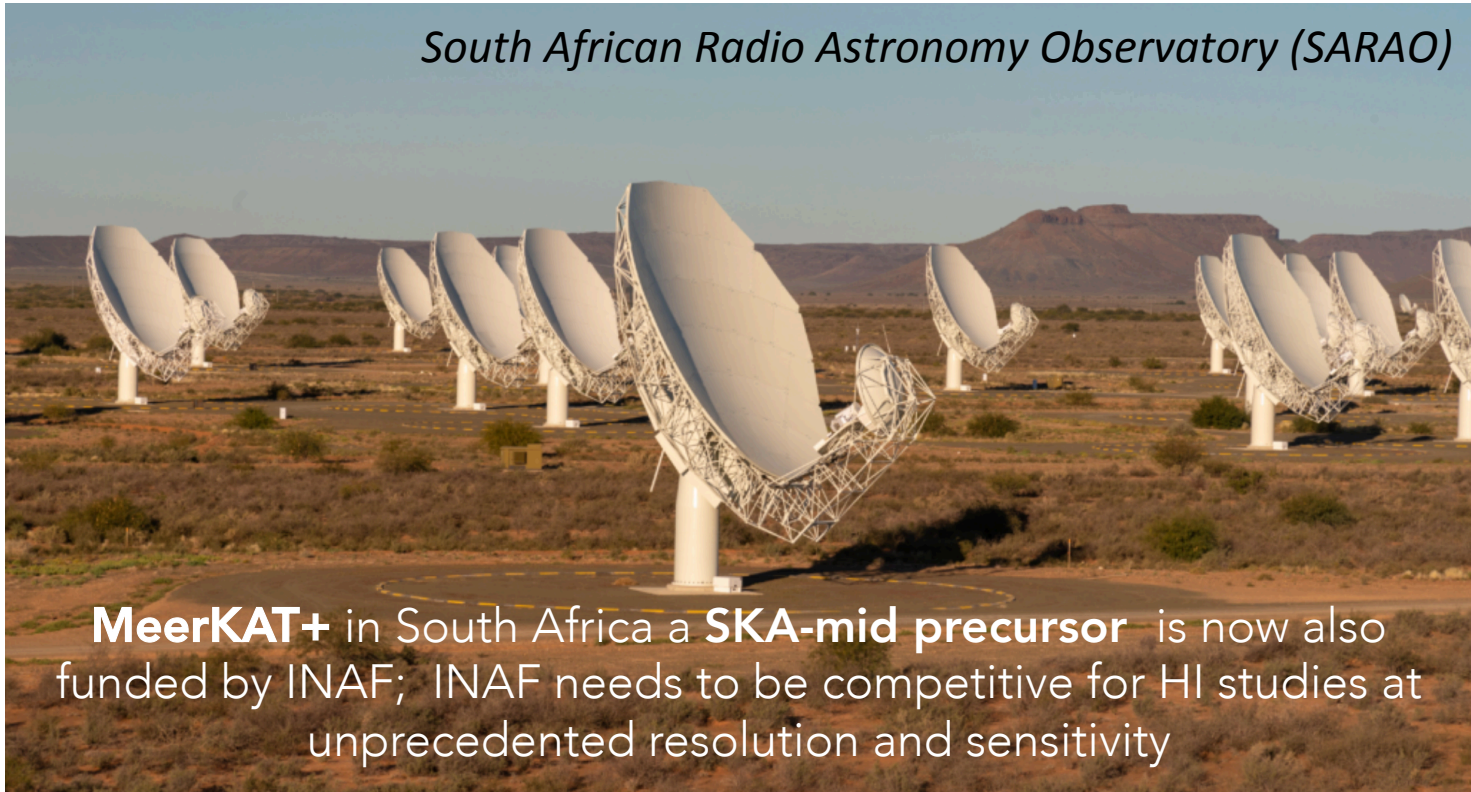
INAF leadership role for SKA

Heavy scientific and technological investment by INAF in SKA and precursors (see SKA infrastructure talk last week in May)

INAF expertise ➔ INAF's leadership role in the scientific exploitation of SKA:

- HI (GASP, Bianca Poggianti's talk; Fornax, see Paolo Serra's talk)
- HI from simulations (GAEA, Gabriella De Lucia's talk)
- radio continuum in galaxies (SKA_Galev, Isabella Prandoni's talk)

PRIN-SKA/CTA 2016 huge scientific investment! However, since then no funding opportunities targeted specifically at SKA



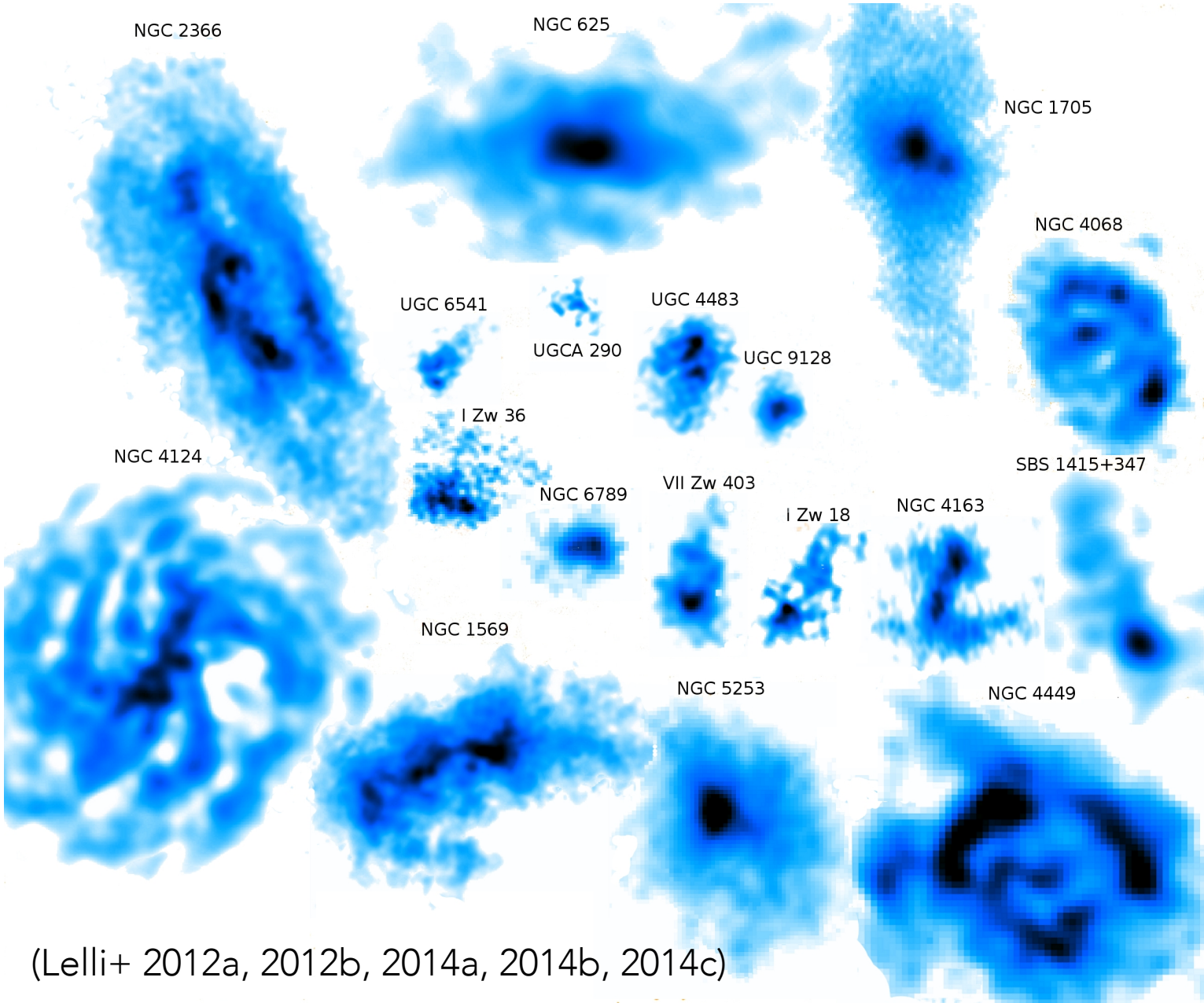
MeerKAT+ in South Africa a **SKA-mid precursor** is now also funded by INAF; INAF needs to be competitive for HI studies at unprecedented resolution and sensitivity

Where to go from here (evoluzione programmatica attività)

SKA-mid and precursor surveys will produce $10^4 - 10^5$ spatially-resolved HI cubes

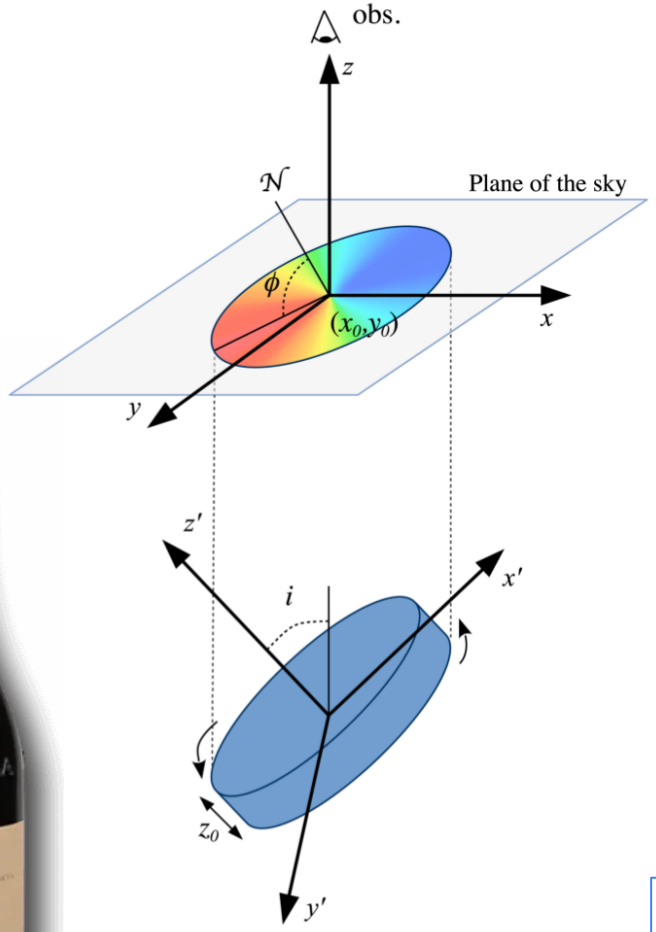
But in the meantime need to exploit existing spatially-resolved HI data

KEY to prepare for SKA HI science!



(Lelli+ 2012a, 2012b, 2014a, 2014b, 2014c)

Italian-manufactured software



rotating disk model projected on the sky

BHINGO! BAROLO HI Nearby Galaxies Overview (Di Teodoro, Lelli, et al., in prep.)

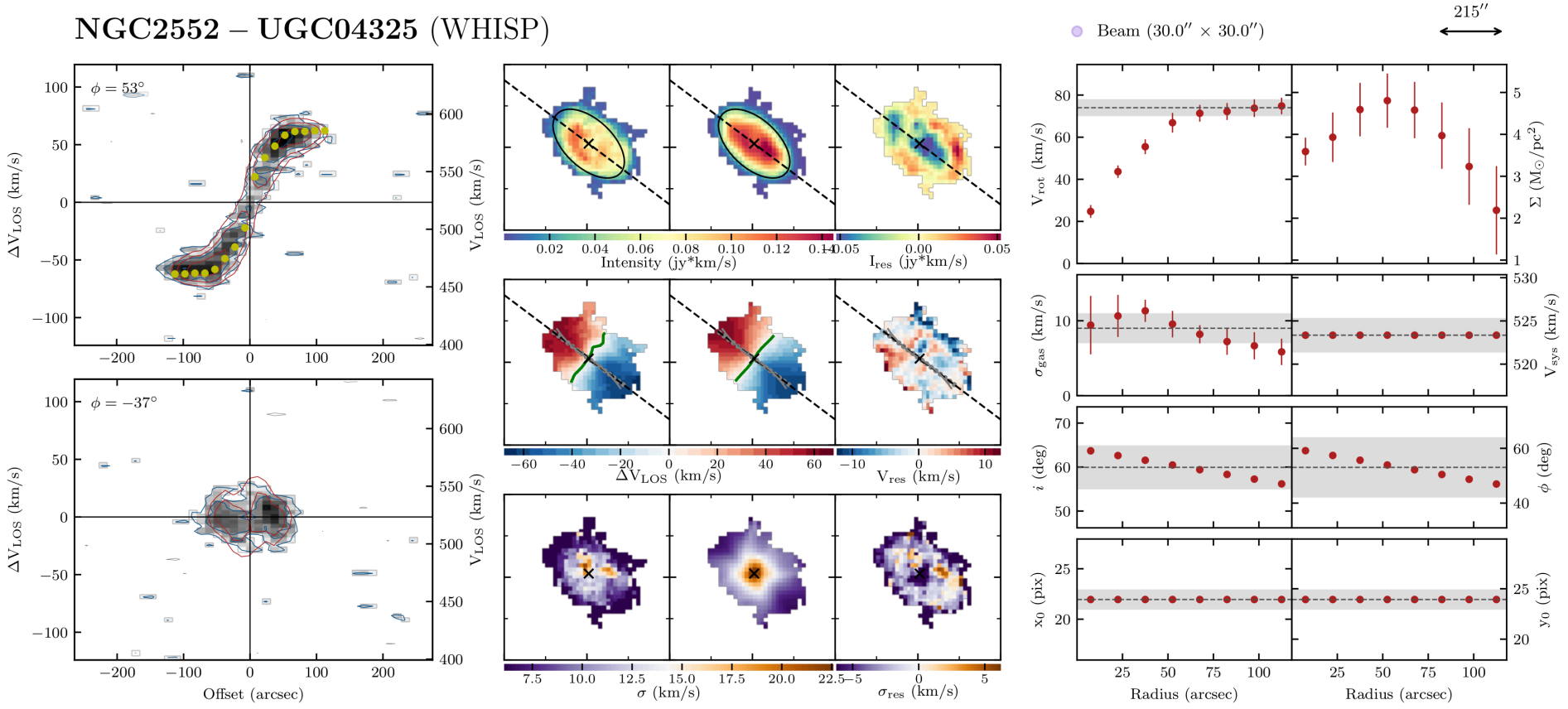
- homogeneous automated kinematic analysis applied to ~ 1000 HI cubes (largest HI sample to date)
- ^{3D}BAROLO = 3-dimensional modeling of HI cubes (Di Teodoro & Fraternali 2015) becomes more automated and realiable
- currently applied to ASKAP cubes as part of the WALLABY kinematic pipeline

GOAL: prepare the reference software for HI SKA science to reinforce INAF leadership in SKA scientific exploitation

Italian-manufactured software

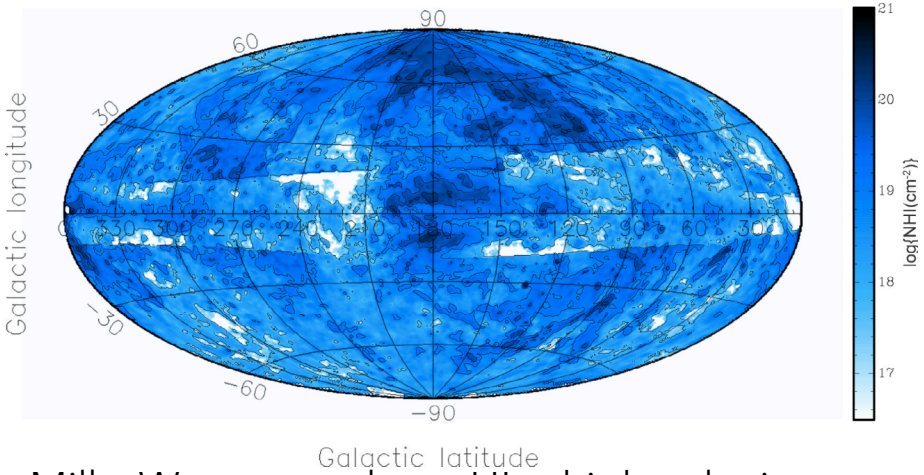
Examples of **high-level data products** from BHINGO including:

moment maps **+ easy-to-use tables** for immediate scientific use (geometric parameters, rotation curves, velocity dispersion profiles, gas surface-density profiles)



Contour levels at $2^n \times c_{min}$, where $c_{min} = 2.5\sigma_{rms} = 0.009422$ Jy/Beam and $n = 0, 1, ..., 8$

Hierarchical mass assembly: cold-gas accretion

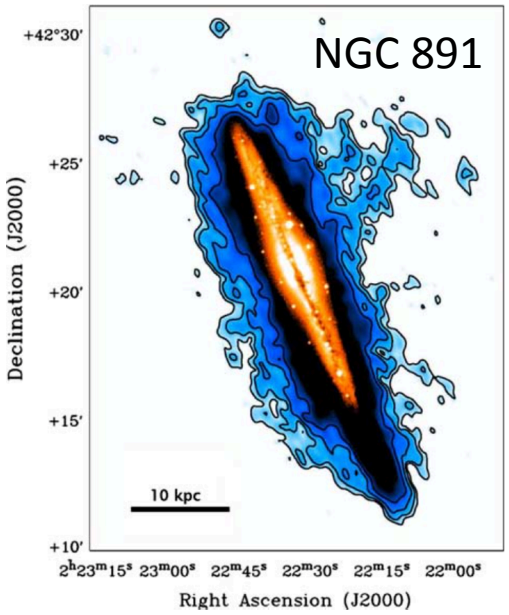


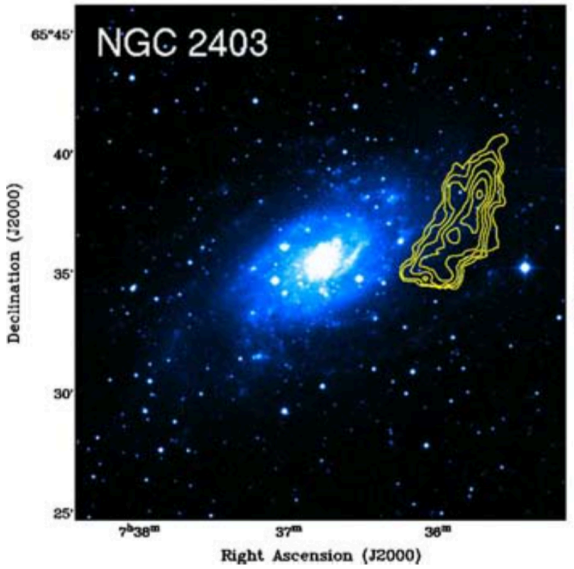
Milky Way extra-planar HI + high-velocity clouds (Marasco & Fraternali 2011)

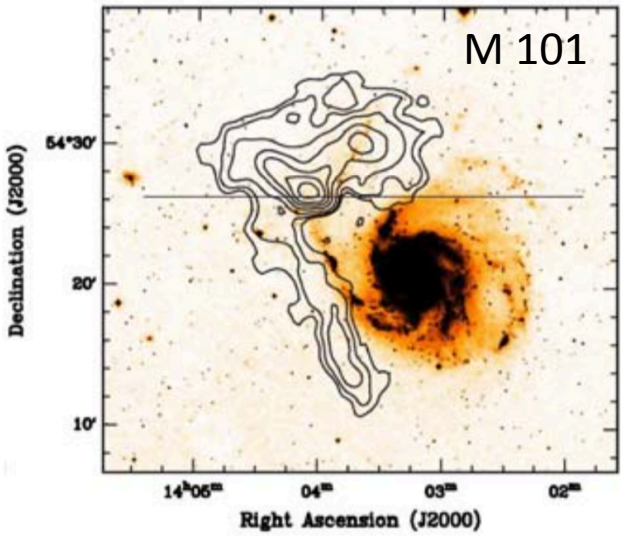
The "smoking gun" of hierarchical assembly is cold-gas accretion of low column density HI gas

Detecting this gas is one of the main goals of HI science with SKA and SKA precursors because of improved spatial resolution and sensitivity

Sancisi+ 2008 high-velocity HI clouds and extra-planar gas (see also Marasco+ 2019)



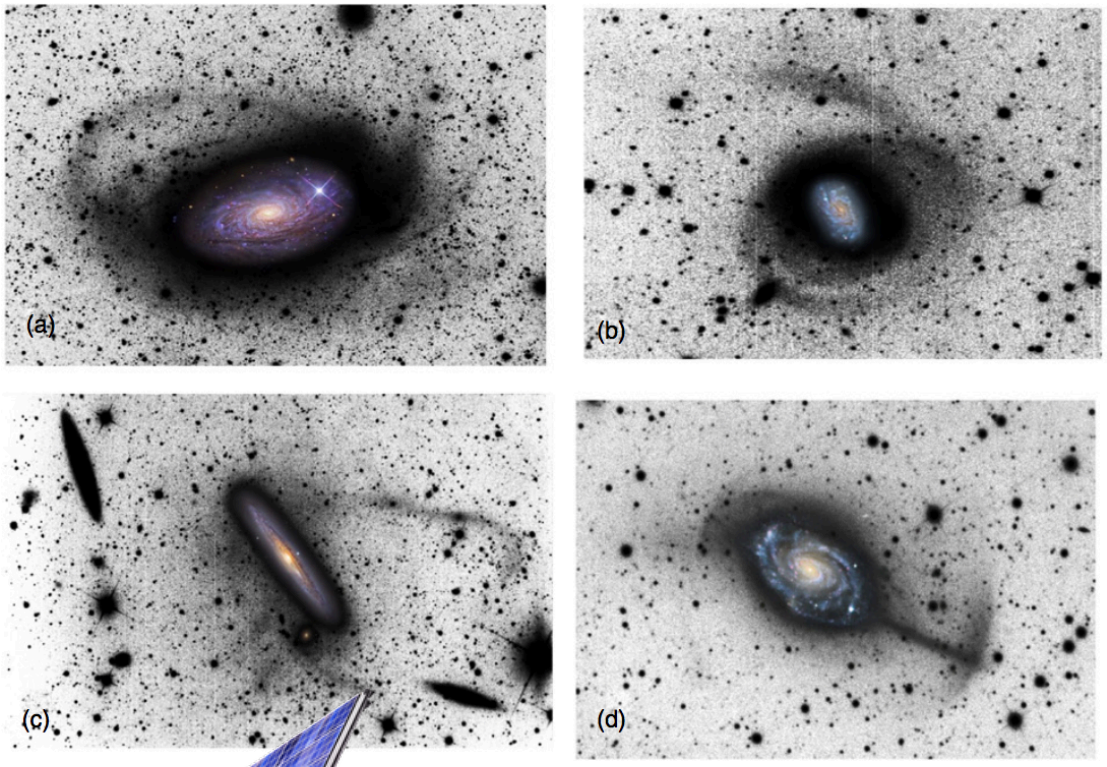




HI synergy at two mass scales with Euclid, LBT, VST

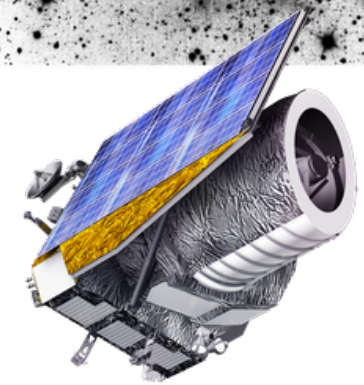
LBT large strategic program Smallest Scale of Hierarchy (SSH, Annibali+ 2019): dwarf galaxies

Low surface-brightness tidal features associated with HI?



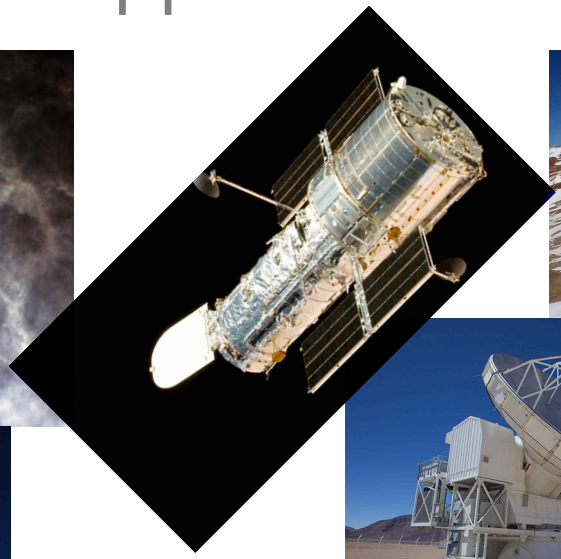
Martinez-Delgado+ 2010

VST Survey of Mass Assembly and Structural Hierarchy (VST-SMASH, Tortora & Hunt, VST call for ideas)



Euclid's sensitivity to low surface-brightness features even in the wide survey will be unprecedented! Mapping these is a main goal of the Euclid Local Universe SWG (co-led by INAF).

Multi-wavelength approach and international context



Over the last ten years, in addition to HI observations, our group has had PI proposals at many multi-wavelength facilities including ALMA, APEX, *Herschel*, *HST*, IRAM, *Spitzer*, VLA, VLT, and others. As PIs, we've recently (2021) submitted two Large Programs (ALMA, ESO/VLT).

We are PIs/coIs of several impactful international projects including WISDOM (PIs Davis, Bureau), WALLABY (PIs Koribalski, Staveley-Smith), SPARC (PIs Lelli, McGaugh, Schombert), PHANGS (PI Schinnerer), NUGA (PIs Combes, Garcia-Burillo), LEGUS (PI Calzetti), KINGFISH (PIs Kennicutt, Calzetti), ALFALFA (PIs Giovanelli, Haynes) and also collaborate with international experts of the ISM including Draine (Princeton), Elmegreen (IBM), Hunter (Arizona), Menten, Weiss, Henkel (Bonn), Rigopoulou (Oxford), …

maintain and consolidate INAF leadership for HI SKA science

- HI is the reservoir for star formation and through cold accretion drives the entire baryonic cycle
- INAF expertise in HI science (existing and potentially new staff) holds the key to fruitful scientific exploitation of SKA-mid
- Important to invest in the future for SKA HI science through periodic and continuous calls for funding, rather than sporadic funding efforts that are useful on the short term but do not guarantee long-term success