Science Analysis Group #6

Cosmic Origins Science Enabled by the Coronagraph Instrument on NASA's WFIRST/AFTA Mission

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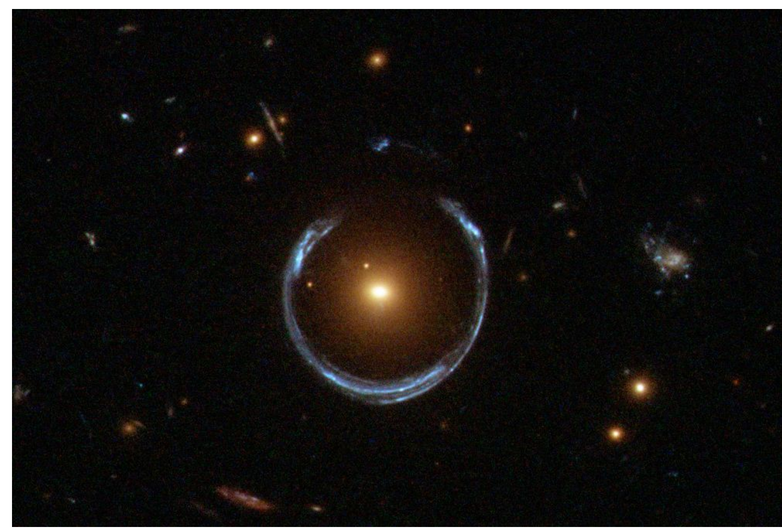


SAG 6 Charter

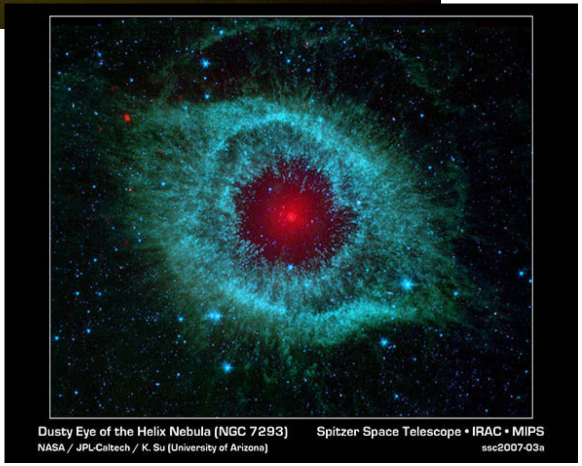
Here's what we were asked to think about.

The WFIRST-AFTA Science Definition Team solicits community input for potential WFIRST-AFTA coronagraphic science investigations related to NASA's Cosmic Origins (COR) or Physics of the Cosmos (PCOS) themes.

Such science investigations may further enhance the science case for the AFTA-study design that includes the coronagraph. While not a primary driver for coronagraph design, science investigations other than exoplanet and debris disk studies may provide helpful insight for future design choices.

COR science maps directly into the objectives of:
2010 Astrophysics Decadal Survey
2013 30 Year Roadmap

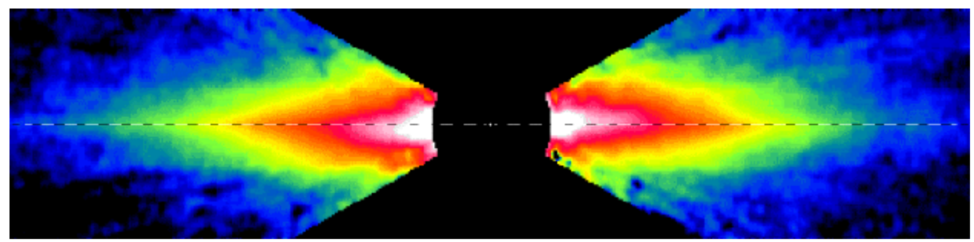
Supermassive Black Holes
Galaxy formation
Galaxy evolution
Starbirth
Protoplanetary systems
Stellar evolution



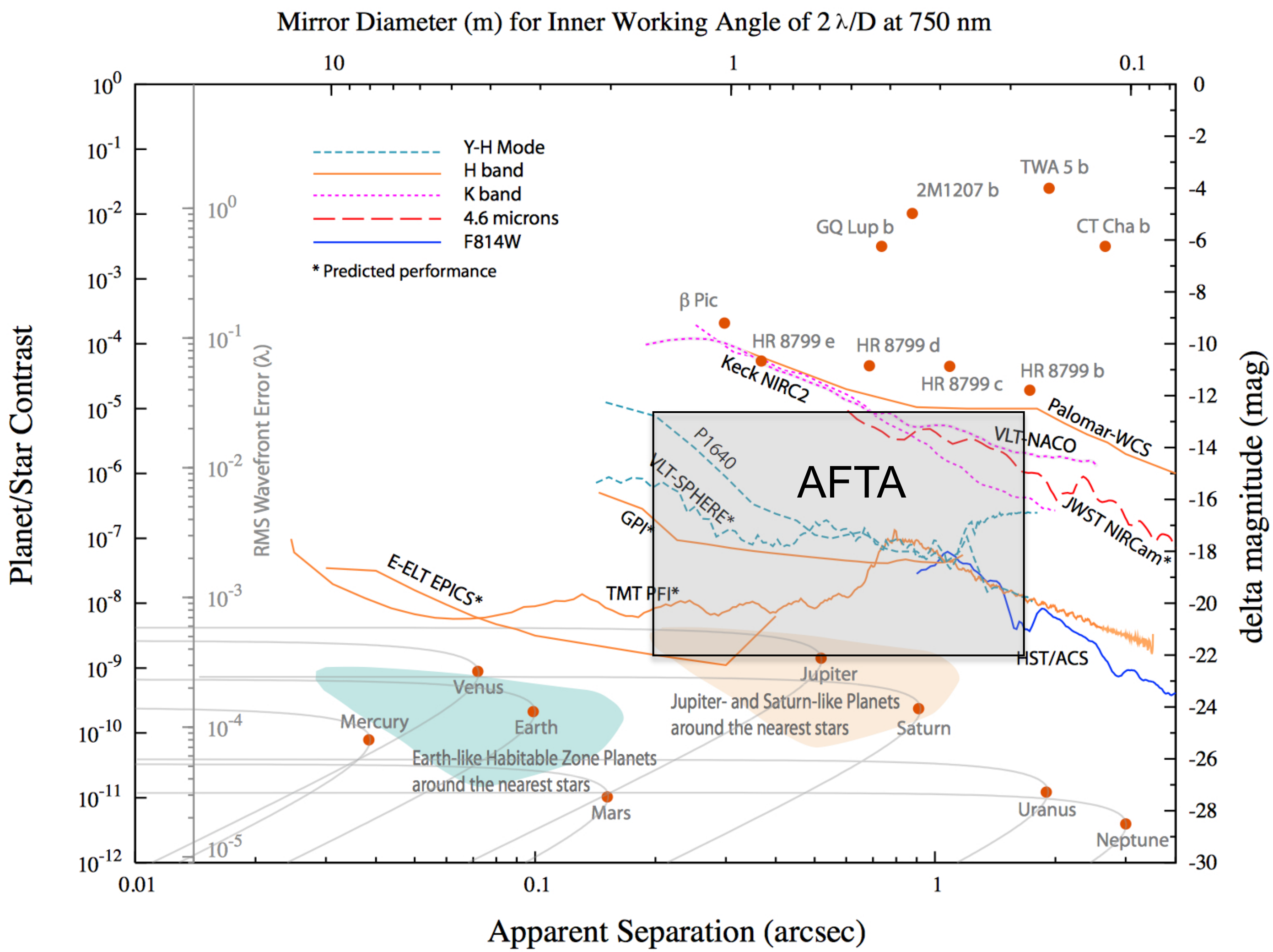
Potential COR Coronagraphic Investigations

- Quasars & AGN
  - Host galaxies
  - Central black holes
  - Accretion disks
  - Bulges, spiral arms etc.
  - Mergers
  - Jets
- Young stars
  - Accretion disks
  - Outflows, jets
  - Protoplanetary disks
- Evolved Stars
  - Debris disks
  - Ejecta, symmetries
  - LBVs - η Carinae
  - WR stars
  - Interactions with ISM

Interesting structures and processes may be hidden by a bright central object.



AFTA will explore a unique region of parameter space for a space observatory



Adapted from Mawet et al. 2012, Optical, Infrared, and Millimeter Wave Proceedings of the SPIE, Volume 8442, id. 844204

COR applications differ from exoplanet investigations in important ways

- In many cases the bright central object needing to be suppressed is not a point source.
- Contrasts as deep as 10^{-9} are not needed.
- The central objects will generally be much fainter than exoplanet host stars.
- In many cases the faint structures of interest emit in nebular emission lines, not scattered starlight continua.
- Extragalactic targets will be at a range of redshifts. The wavelengths of their important spectral features will differ from their rest-frame values.
- Spectroscopic diagnostics will require resolution of several hundred km s^{-1} to be of most value.

Baseline capabilities will be particularly useful for COR science.

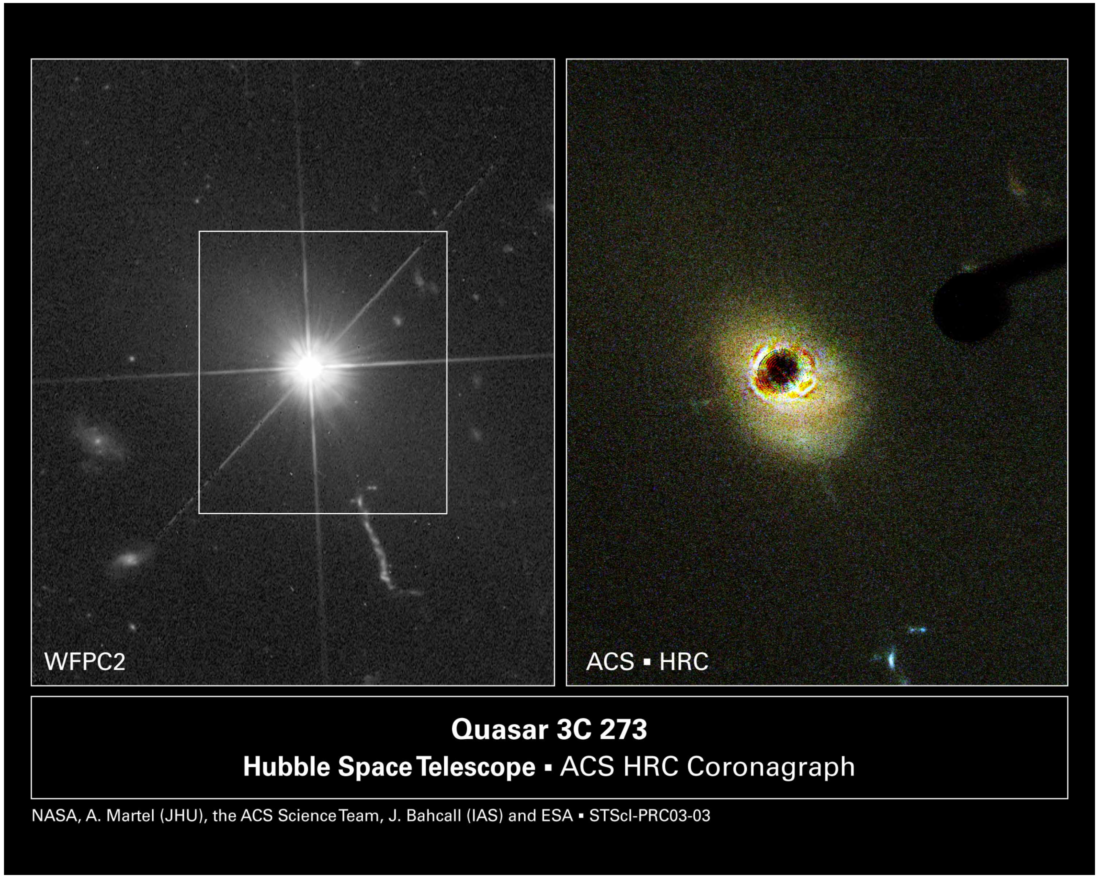
- Diffraction-limited angular resolution of a 2.4m telescope is better than 40 mas at the shortest wavelengths. Spatial sampling finer than 20 mas per pixel.
- Ability to observe full annular region around central object, either with annular format of HLC or sequence of separate masks in OMC
- Wide spectral bands for multi-color photometry
- Polarization capability
- IFS with spectral resolution R $\sim$70
- Range of contrasts, 10^{-9} not usually required for COR investigations
- "Straight through" mode with wider FOV

Additional Capabilities that could be useful

- Narrow-band filters, Hα, He, [O III], [N II], S etc. for nebular detection and diagnostics at zero redshift
- IFS with greater instantaneous wavelength coverage and higher spectral resolution, R=3000 ΔV=100 km s^{-1}
- Efficient means of providing contrasts of 10^{-6} to 10^{-7} when maximum contrast is not needed
- Efficient means of providing contrasts of 10^{-6} when the central bright object is not a point source. Image plane occulting spot or bar.

The host galaxies of quasars will be revealed

- Supermassive black holes in centers of most galaxies
- Galaxies are small and faint at redshifts of peak activity
- Limited success at detecting and characterizing galaxies, even with HST, even with nearest and brightest quasars.
- Nearly point source quasar well suited to coronagraph
- Broad band imaging will maximize sensitivity, measures colors, reveal morphology, star formation regions
- IFS spectroscopy can indicate signs of star formation, bulges



Dual nuclei AGN may be merging galaxies, or future merging SMBH

Recognized cases have nuclei separated by few tenths arc sec or more, and similar brightness.

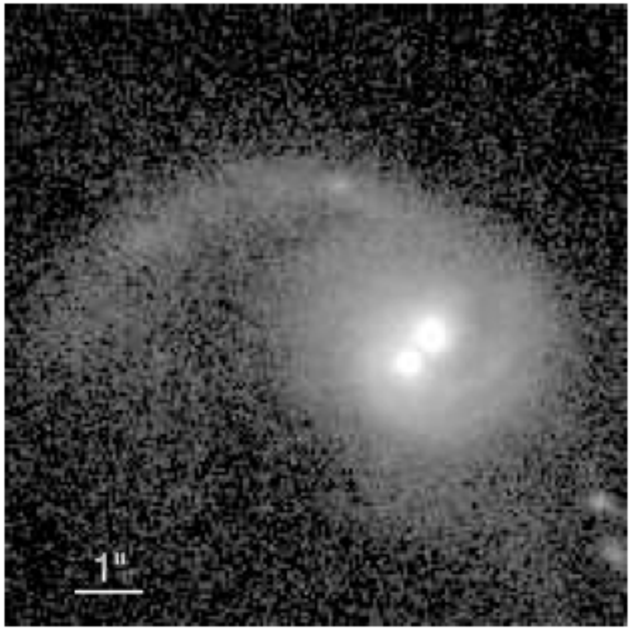
Suppression of apparently single nucleus could reveal fainter and/or closer second object.

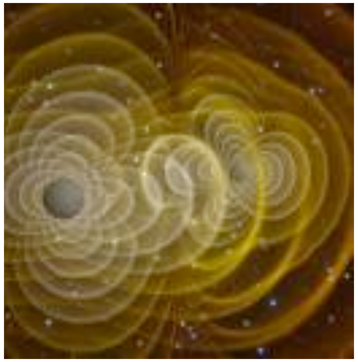
Broad band imaging with bright source suppressed could reveal vestiges of tidal interactions during merging.

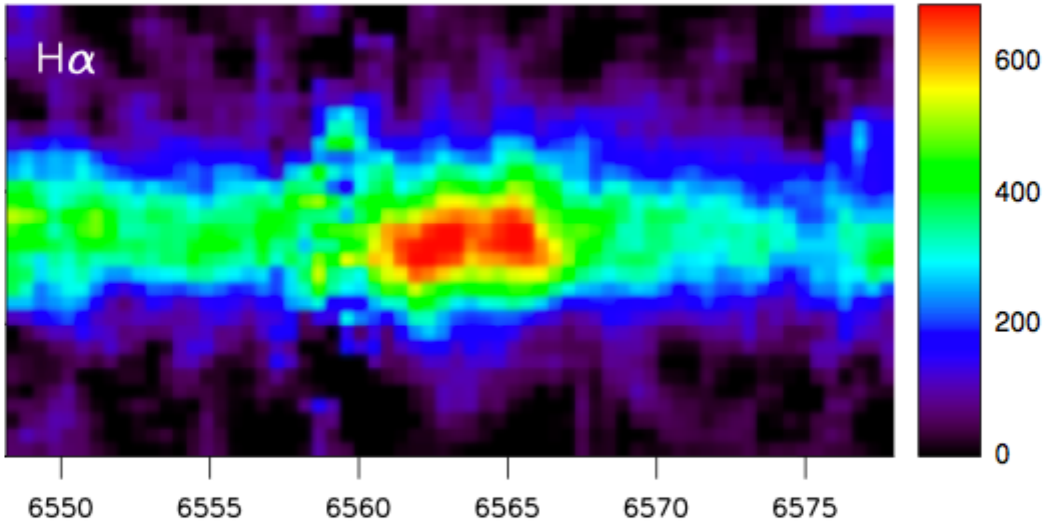
IFS could study double-peaked nebular emission lines, Hα, [O III], [N II] etc.

ΔV few hundred km s^{-1} typical

May inform understanding of SMBH merging for future GW detection missions (LISA)







The location of intergalactic matter that forms absorption lines in the spectra of Quasars

Gas clouds along line of sight to quasar

>50% of matter outside of galaxies

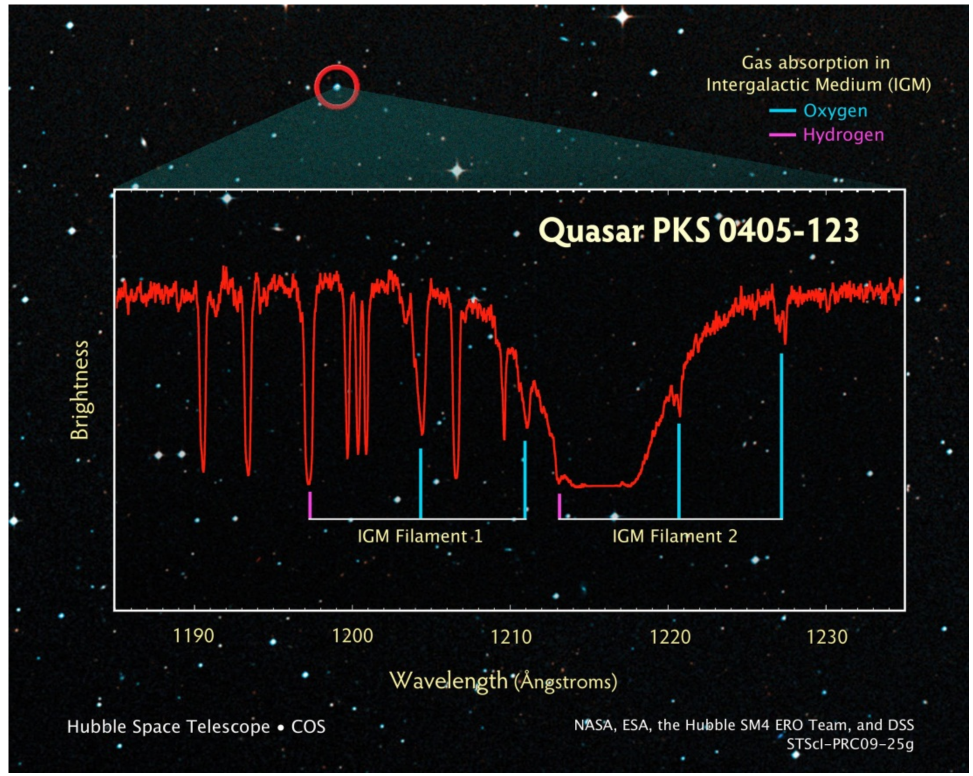
Cosmic Web?, filaments?

Complex structures and cycles of flow into filaments, into and out of galaxies

Few or no detections of source of gas producing absorption

Deep, broadband images with quasar light suppressed

Quasar effectively a point source. Well suited to coronagraph



Einstein Rings are gravitationally-lensed images of very distant galaxies

Lensed galaxies are at various distances, redshifts.

Multiple lensed galaxies

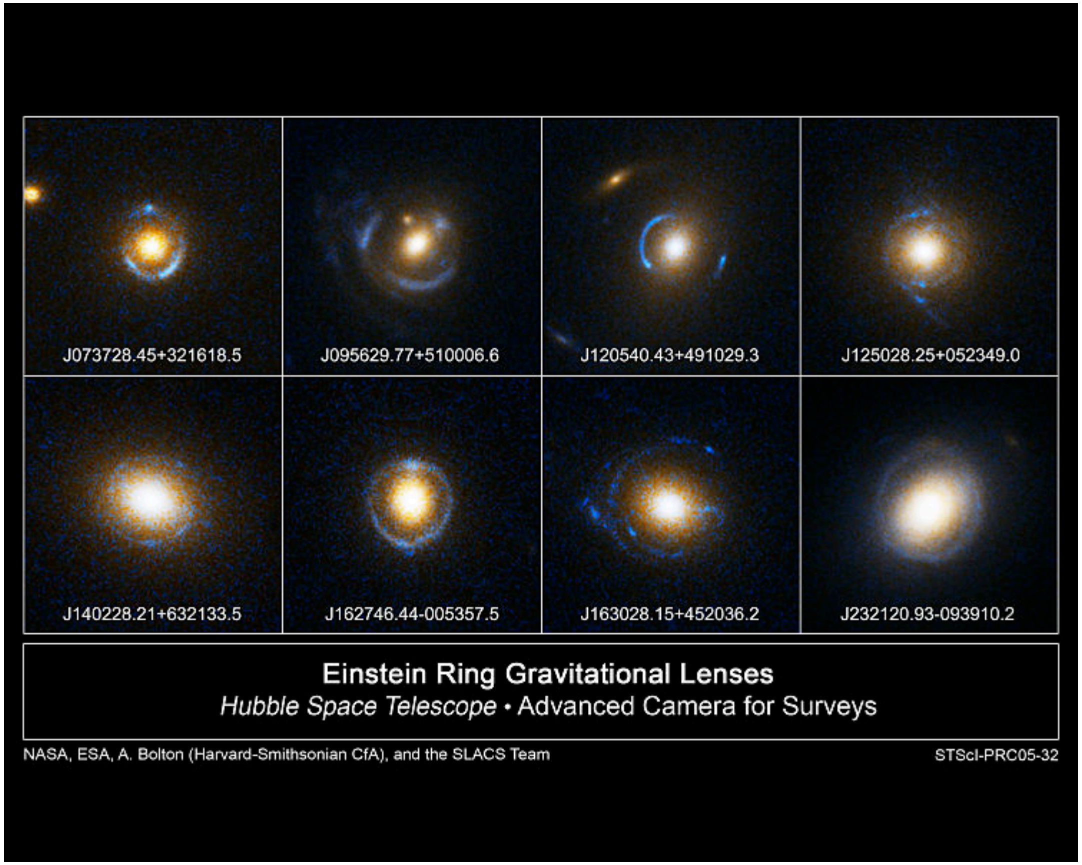
Well suited to broad band filter imaging.

Star formation regions in lensed galaxies

IFS spectra of knots in lensed galaxies

Mass distribution, including DM, in foreground lensing galaxy

Lensing galaxy is not a point source. Need an efficient way to suppress light from slightly extended object.



The core regions of AGN have accretion disks, and the origins of jets

Unobscured, high luminosity, actively accreting SMBH

Supermassive black hole having profound effects on surrounding galaxy

Traces of tidal tails of mergers?

Root of jets or bi-conical outflows

Accretion disks, torus

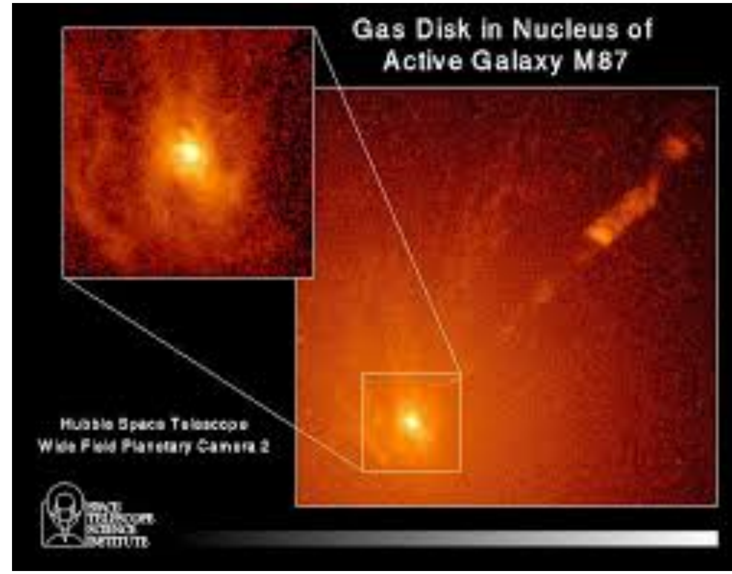
Intense star formation regions

Winds

Probably not point source. Contrast will not be maximum. That's OK

Multi-spectral images

Velocities few hundred km s^{-1}



Summary and conclusions

1. Many examples of important Cosmic Origins Science will be enabled. Investigations involving Quasars, Super Massive Black Holes and Gravitational Lenses may receive great benefits.
2. The AFTA coronagraph will be a very powerful instrument with its planned baseline capabilities . A few additional features would also be useful.
3. COR science targets and their measurement requirements differ in important respects from the host stars of exoplanets.
   - Many investigations will not require maximum contrast being implemented for exoplanet science. Efficient ways to achieve less extreme contrast would be valuable.
   - Not all targets will be point sources. Effective means of suppressing the glare of slightly extended objects would be useful.
   - Narrow-band filters would enhance observations of nebular emission features.
   - An Integral Field Spectrograph is a very powerful tool. Spectral resolution suitable for velocities of 100 km s^{-1} would be a very useful diagnostic.
4. Some of the most important objects of interest to COR are rare, in some cases with only a handful currently known. Surveys with the Wide Field Imager will discover many new examples.

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