SPIDER: CMB Polarimetry from the Edge of Space

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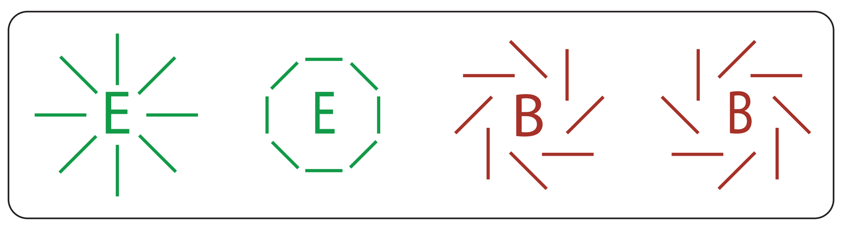
for the SPIDER collaboration

Poster PE-4

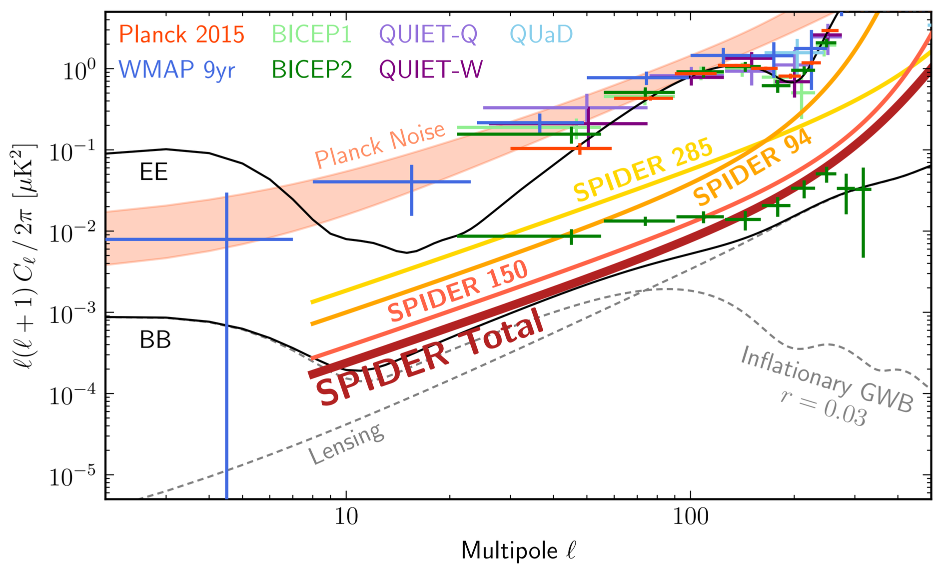
The SPIDER Program

SPIDER is a **balloon-borne** millimeter-wave polarimeter designed to measure or constrain the **B-mode polarization** of the CMB at **large angular scales** in the presence of **galactic foregrounds**. Such B-modes are expected to be sourced by primordial gravitational waves generated during the inflationary epoch. The **tensor-to-scalar ratio (r)** is a key parameter for distinguishing among inflationary models.



SPIDER's near-space (**36 km**) observing platform provides low photon noise and atmospheric fluctuations and a wide range of accessible frequencies. SPIDER takes advantage of this to map a large area (**~10% of the sky**) with high fidelity over a wide range of angular scales (**10<l<300**) at multiple frequencies (**90-280 GHz**). This will allow it to characterize the BB spectrum, verify signal isotropy, and better distinguish CMB signal from galactic foregrounds.

The plot below shows the expected sensitivity of SPIDER after two flights. We expect to be able to constrain **r<0.03** (3 sigma) in the absence of detection. Current constraints (BICEP/Keck + Planck) indicate that r<0.07 (95% CL).

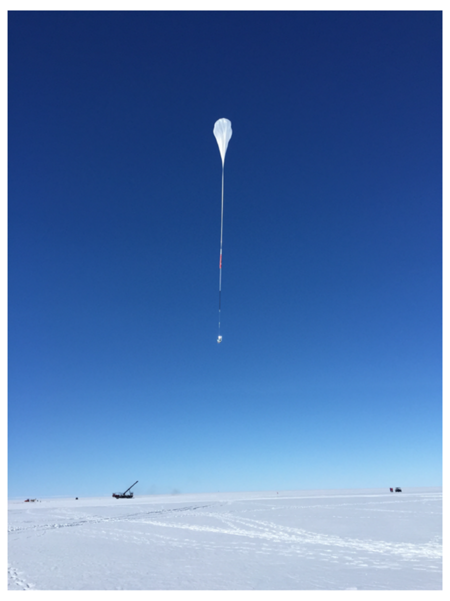


SPIDER's **second flight** is targeted for **Dec. 2018 - Jan. 2019**, and will incorporate an upgraded cryogenic system and three new higher-frequency (**280 GHz**) receivers to characterize galactic dust emission.

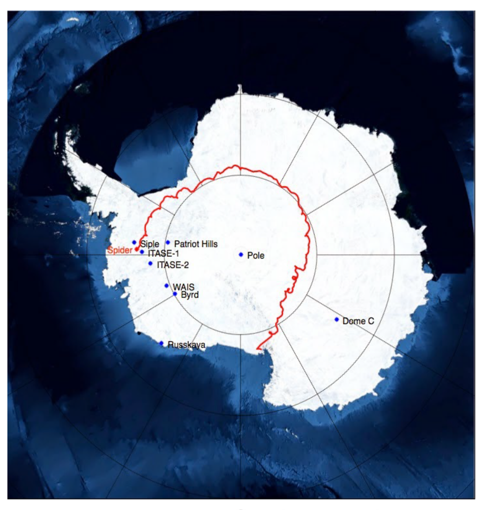
2014-15 Antarctic Campaign

SPIDER took to the air on a NASA long-duration balloon (LDB) from McMurdo Station, Antarctica on **January 1, 2015**. The flight lasted **16 days** and mapped **~10% of the sky** at **90 /150 GHz**. The flight terminated successfully in West Antarctica, 2270km from the launch point.

SPIDER's recovery was supported by the **British Antarctic Survey**: data disks in February 2015, full payload in November 2015. Hardware condition is very good, and much will be flown again in 2018.



Launch day!



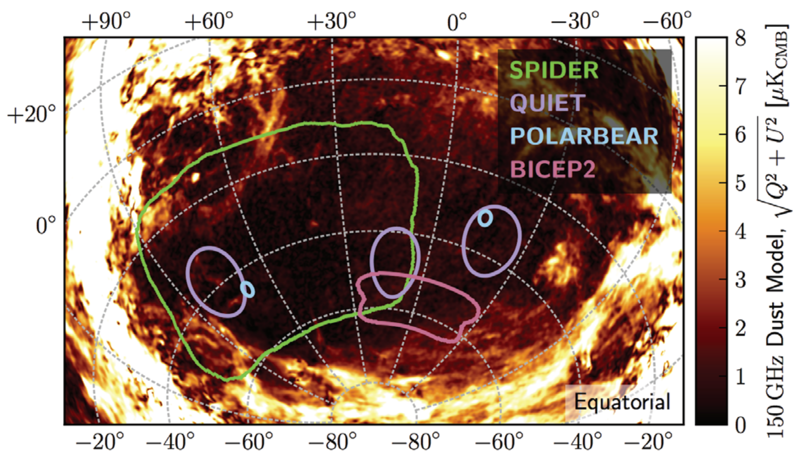
SPIDER's flight path

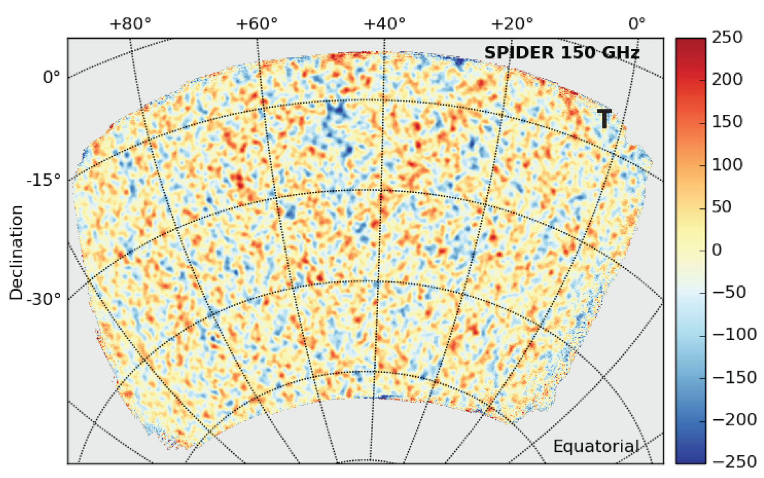
SPIDER landing site, Feb. 2015

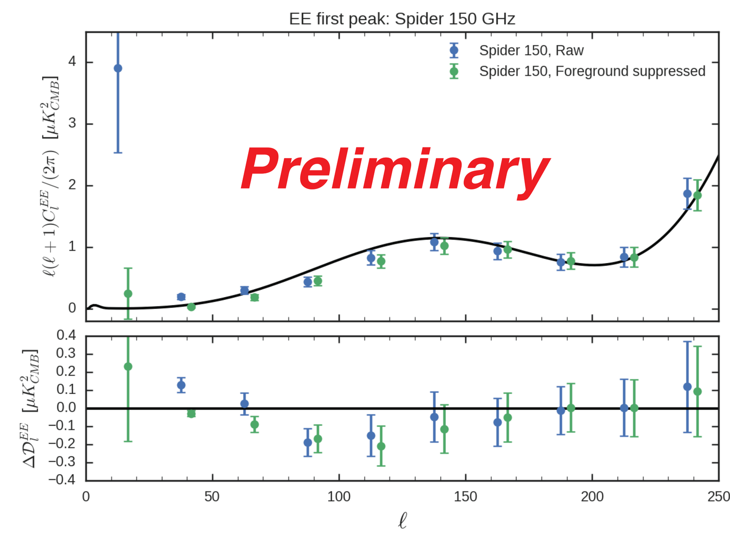
Flight Data Analysis

SPIDER's data analysis is well underway.

- All flight systems functioned nominally (*except redundant dGPS*)
- Total in-band loading: ≤ **0.35 (0.25) pW** at 150 (95) GHz
- Significant data flagging due to **RFI**; **cosmic rays** insignificant
- Sky coverage: **12.3% geometric (6.3% hit-weighted)**







Preliminary EE auto spectra from Xfaster pipeline

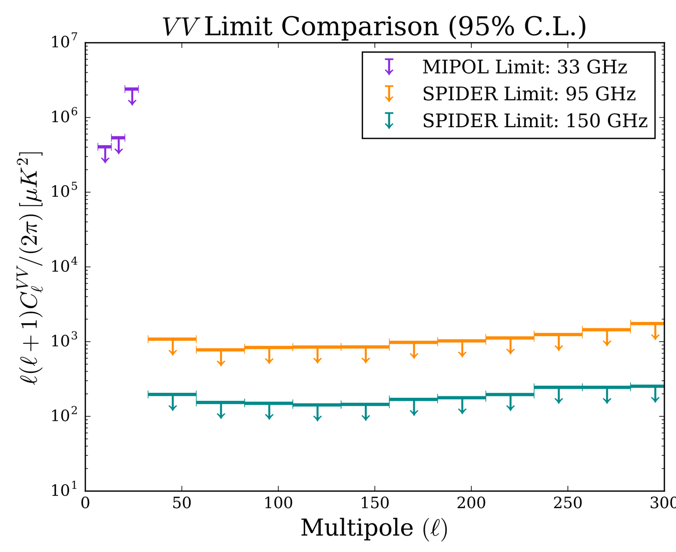
Dust subtraction with single template (Planck 353-100), free fit to scaling coefficient

Proof-of-principle: more advanced foreground cleaning in development

First science result: a new world-leading constraint on CMB circular polarization

SPIDER is sensitive to circular polarization (Stokes V) due to wave plate non-idealities that mix circular and linear polarization

J.M. Nagy et al., Astrophys. J. **844**, *151 (2017)*
arXiv:1704.00215



The SPIDER 2015 Payload

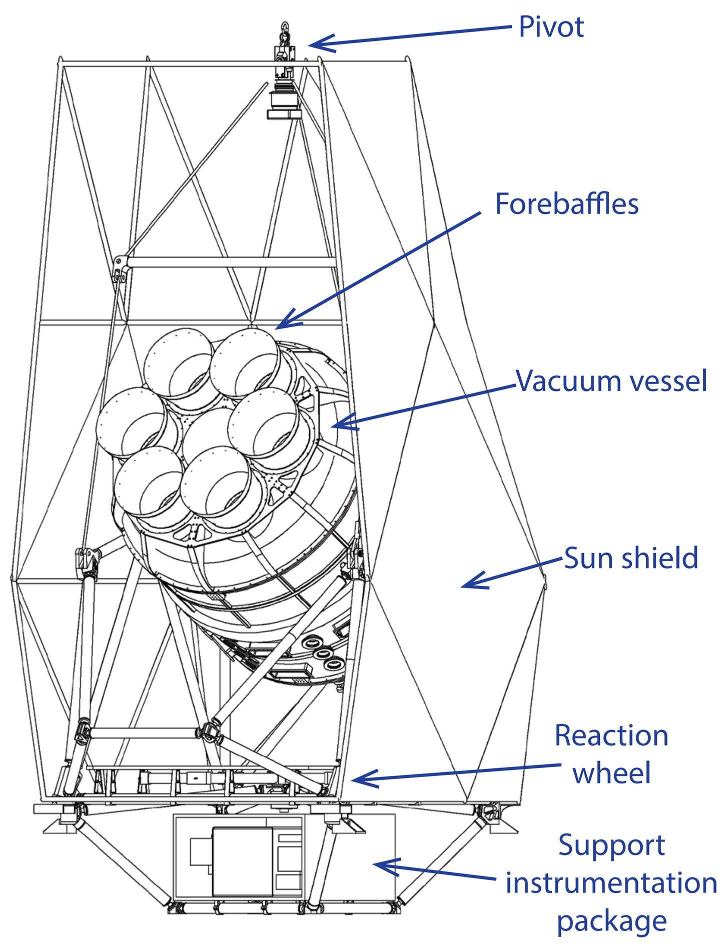
Shared **1284L LHe cryostat** (4K + 1.6K), largest yet deployed on an LDB (*Gudmundsson et al. 2015*)

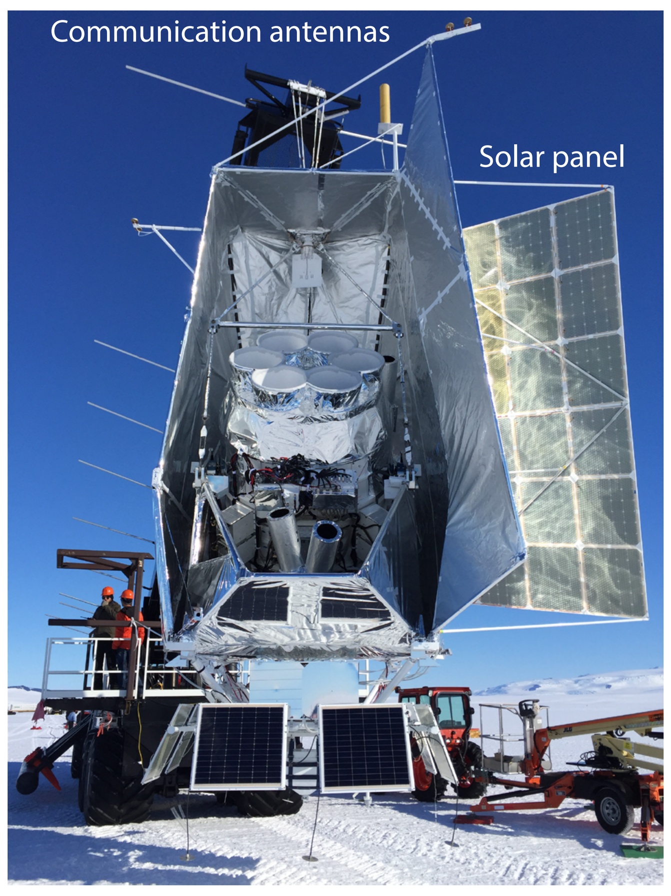
Six monochromatic two-lens **refractors**, with metal mesh filters and cold (<2K) optical path baffling (*Runyan et al. 2010*)

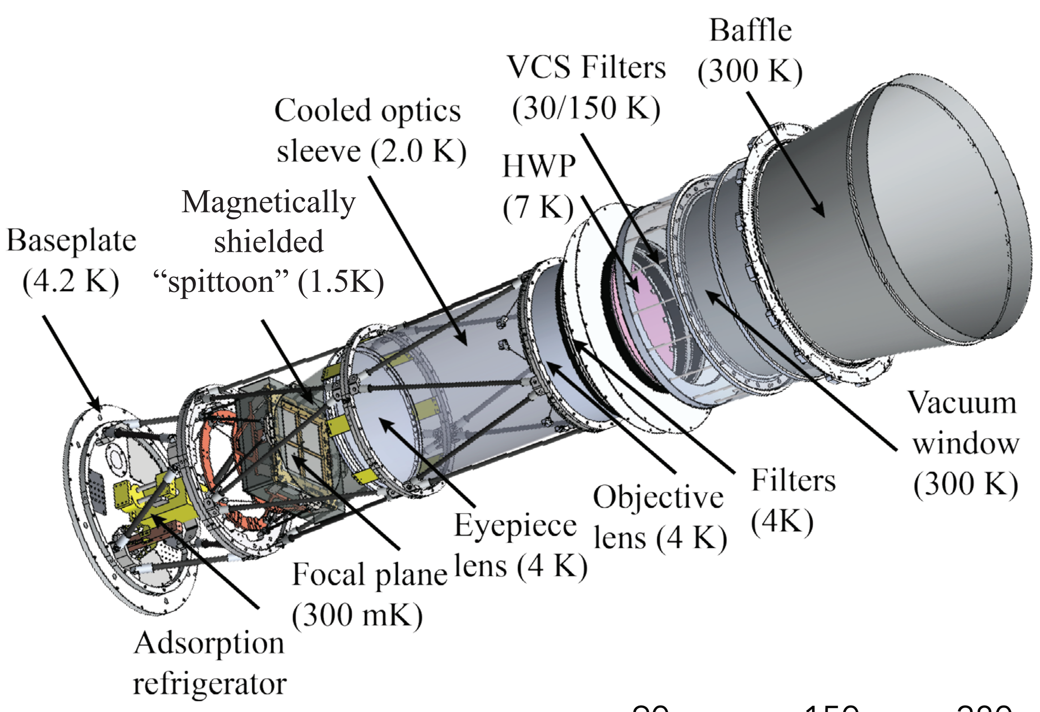
An AR-coated sapphire **half-wave plate** for each receiver, stepped in orientation twice daily, modulates the sky polarization to control systematics. (*Bryan et al. 2015*)

Lightweight **carbon fiber gondola** scans payload in azimuth (4 deg/s), elevation. (*Soler et al. 2014*)

Solar power, pointing sensors (~6" reconstruction), satellite communications.







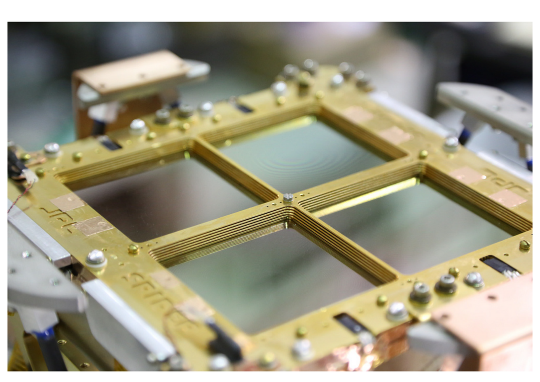
Each **focal plane** consists of planar arrays of dual-polarization antenna-coupled transition edge sensors, developed at Caltech/JPL (Ade et al. 2015, 1502.00619). Light is collected by photolithographically-patterned antennas, passes through on-chip band-defining filters, and is detected by **TES bolometers** (300 mK) read out using the NIST/UBC time-division SQUID multiplexer system. SPIDER's first flight totaled **2400 TESs**, optimized for high sensitivity using low-conductance meandered support legs

Extensive **passive magnetic shielding** protects the TESs and SQUIDs from scan-synchronous and location-dependent pickup from Earth's magnetic field

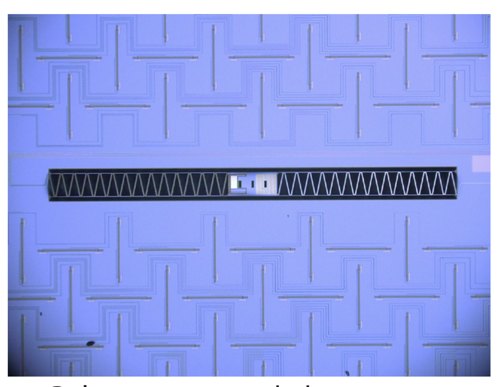
SPIDER-2's 280 GHz receivers will employ NIST feedhorn-coupled arrays of Al-Mn TESs. (*Hubmayr et al. 2016*)
See **A.S. Bergman, talk O-71, Thursday**.

	90 GHz	150 GHz	280 GHz
Bandwidth [GHz]	21	33	67
Beam FWHM [arcmin]	42	30	17
Number of FPUs, 1st (2nd) flight	3 (1)	3 (2)	0 (3)
Number of detectors per FPU	288	512	512
Detector sensitivity [$\mu K_{CMB} s^{1/2}$]*	166 (150)	164 (150)	(335)
Instrument sensitivity [$\mu K_{CMB} s^{1/2}$]§	7.1 (10)	5.3 (7)	(15)

* *Estimated from 2015 flight, pre-flight estimates in parentheses.*
§ *Estimated in 2015 flight, with strict data cuts (80.8% detector yield). Estimates in parentheses based on 85% detector yield*



SPIDER focal plane, showing 4 silicon detector tiles under quartz AR coats



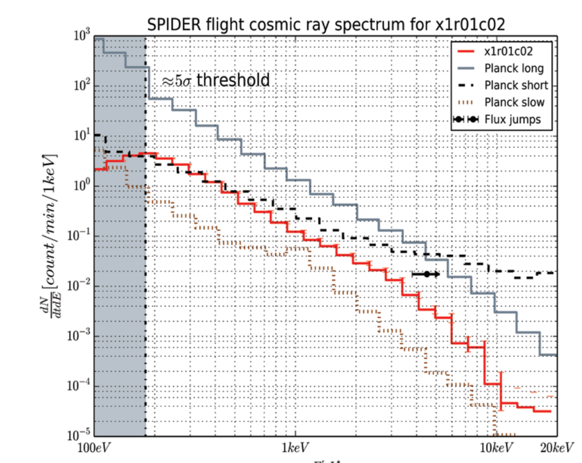
Bolometer suspended on meandered SiN legs, surrounded by slot antenna array

Cosmic Ray Response

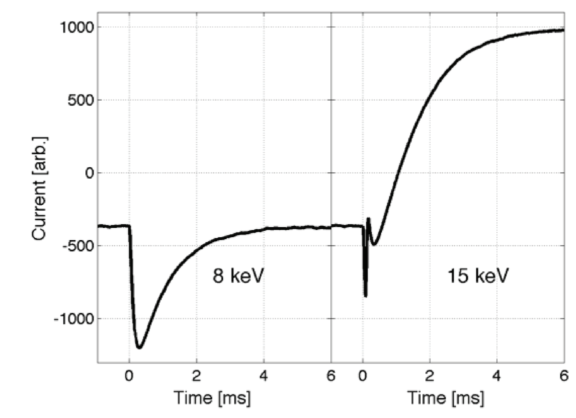
Cosmic ray-induced glitches are seen in SPIDER 2015 data every **~2 minutes** in each detector. These glitches are flagged and removed, with negligible effect on our science analysis.

- Glitch rates are 10-100x lower than in Planck/HFI, consistent with hits to the bolometer island (not the shared silicon tile)
- Coincidence rates are low (~0.03%), suggesting little long-distance energy propagation through the silicon tile
- Depositions above a few keV often induce flux jumps in the SQUID amplifier, yielding step discontinuities in the data
- No "long tails" are seen in laboratory tests with beta sources. Flight glitches consistent with expected MCE filter response

Laboratory tests with alpha sources in progress (*Ben Osherson, UIUC*) to better mimic cosmic ray energy depositions in the silicon tile (*supported by NASA Strategic Astrophysics Technology program*)



Observed glitch spectrum in a representative SPIDER detector, plotted against Planck glitch rates. Energy calibration is approximate from power integral. Plot by Robert Gramillano (UIUC)



Glitches induced by an S-35 beta source in a non-SPIDER JPL detector, sampled at 104 kHz to illustrate the appearance of flux jump discontinuities. SPIDER's lower G pushes the typical flux jump threshold to lower energies than shown here.

The SPIDER Collaboration